CONFERENCE SUMMARY AND ABSTRACT BOOK:
FROM STARS TO PLANETS - CONNECTING OUR UNDERSTANDING OF STAR AND PLANET FORMATION
Jonathan C. Tan (Dept. of Astronomy, University of Florida) on behalf of the SOC and LOC

Abstract:
This document summarizes the conference “From Stars to Planets - Connecting Our Understanding of Star and Planet Formation” that took place from 11th-14th April 2007 at the University of Florida. We list a number of open science questions in the topics of star formation, circumstellar disks and planet formation, followed by one sentence summaries of the talk presentations. Finally we provide the full science program, including all talk and poster abstracts. Talk presentations and poster summary slides are available online (http://conference.astro.ufl.edu/STARSTOPLANETS/).

Open Questions:
The SOC (Fred Adams, Stan Dermott, Eric B. Ford, Jian Ge, Lynne Hillenbrand, Elizabeth Lada, Doug Lin, Jonathan C. Tan, Charles Telesco, Jonathan Williams, Andrew Youdin) identified key open questions in the fields of star formation, circumstellar disks, and planet formation.

Star Formation: Why do certain regions of giant molecular clouds (GMCs) form stars at relatively high efficiency, while most parts are quiescent? What is the relative importance of external triggering and spontaneous gravitational instability? How close to equilibrium are the initial conditions for star cluster formation (i.e. gas clumps) and individual (or close binary) star formation (i.e. gas cores)? Is the stellar initial mass function (IMF) set during the core formation process or by competitive accretion of protostars? How do brown dwarfs form given their mass is small compared to the expected thermal Jeans mass?

Circumstellar Disks: How relevant is disk fragmentation for binary star and giant planet formation? How important are magnetic fields, including global magnetic fields, in protoplanetary disk dynamics? What role do dead zones play in planet formation? How do chemical and dust grain evolution affect the initial conditions for planet formation? How important is the disk dispersal process for planet formation?

Planet Formation: How do large (~m sized planetesimals) grow given difficulties of coagulation? How important and general is planetary migration? What is the frequency of planets for different stellar masses and different orbital periods? What are the mechanisms for halting migration of close in planets? What is the origin of planetary eccentricity? How do terrestrial planets form in the face of drastic dynamical evolution of giant planets, and how contingent is this process on the final arrangement of the giants? How do we reconcile our solar system with systems containing hot Jupiters?

Talk summaries: (talk and poster titles (p5) and abstracts (p15) are listed below)

Day 1:
Novak presented observational results on magnetic field strengths in GMCs that suggest the magnetic energy density is comparable to the turbulent kinetic energy, and that there is evidence for continuity between large scale Galactic fields and GMC fields.
Tasker presented global numerical simulations of GMC formation in disk galaxies that reproduce several properties of observed GMC populations, including mass functions and angular momentum distributions.
Bate presented results of a high resolution star cluster formation SPH simulation that reproduces the observed IMF and binary properties of stars and brown dwarfs via a combination of Jeans mass fragmentation, competitive accretion and stellar ejections.

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Lada, C. presented observational evidence that the core mass function is similar in shape to the stellar IMF, and that the IMF can be understood as a result of thermal fragmentation.

Rathborne discussed properties of Infrared Dark Clouds, showing they contain massive starless cores and that they are undergoing a process of hierarchical fragmentation as the initial stages of star cluster formation.

Goodman discussed several comparisons of observational star formation data sets with numerical simulations, including different methods of measuring column density distributions and new methods to describe clumpy structure.

Myers presented a model for star cluster formation from virialized filamentary layers, relevant to groups, sparse clusters, and the first stars to form in rich clusters.

Lada, E. presented results from multi-object NIR spectroscopic surveys of star-forming regions, showing most stars form in clusters, the IR excess fraction can be used as an age indicator, and that there is tentative evidence for an environmental dependence on the ratio of brown dwarfs to stars.

Gutermuth presented results on cluster structure (e.g. asymmetry) and substructure from a Spitzer survey of nearby clusters, finding, for example, young ages compared to relaxation times.

Ferreira examined core structure (circularity, central concentration, core size) and its evolution using NIR data.

Meyer discussed the IMF in star clusters, including super star clusters, concluding, based on integrated spectroscopy, the IMF is similar to the field star IMF.

Stassun presented empirical constraints on the masses and radii (∼1% accuracy) of young low-mass stars and brown dwarfs and evidence for magnetically suppressed convection.

Frank presented numerical simulations of protostellar jet interactions and cavities as a source of turbulence in star-forming gas.

Alves discussed the formation of Galactic massive star clusters.

Eikenberry presented evidence for multi-epoch massive star formation in cluster 1806-20.

Fuller presented observational constraints on the structure and dynamics of massive star-forming cores.

Krumholz discussed several theoretical issues associated with high-mass star formation, including suppression of fragmentation by radiative heating, formation of massive binary twins and the inability of radiation pressure to halt disk accretion.

Day 2:

Evans presented Spitzer data showing low/high star formation efficiencies in clouds/dense cores, a core mass function similar to the stellar IMF, and new statistics for Class 0, I, II, III populations and lifetimes.

Muench derived a relatively constant and prolonged star formation history for IC348, and discussed the cluster’s circumstellar disk population.

Stahler presented a model for accelerating star formation in clusters controlled by the dissipation of turbulent motions.

Haisch discussed the multiplicity of young stars finding similar properties to field stars, as well as many examples of mixed pairings of SED types.

Jayawardhana discussed multiplicity and presence of disks for young brown dwarfs.

Allers described the NIR spectral properties of brown dwarfs, including measuring gravity with Na and K lines and spectral type from the 1.45 μm steam absorption feature.

Luhman discussed brown dwarf formation, arguing that the similar spatial distributions and disk fractions of BDs and stars, continuity in their
accretion rates, and (some) relatively large BD disks imply a similar formation mechanism (although ejection scenarios are not necessarily ruled out).

Martin described substellar mass objects in $\sigma$ Ori, including a smooth IMF from stars down to planetary masses ($\sim 5M_{Jup}$), as well as the presence of disks around very low mass objects.

Shu discussed the dynamical effects of magnetic fields in several examples of different types of star formation, including induced deviations from Keplerian orbits and the confinement of planetesimal formation to dead zones.

Day 3:
Matzner discussed protostellar disk fragmentation, arguing it tends to be stabilized by irradiation for low-mass protostars, but becomes more important for high-mass protostars, perhaps influencing the upper mass limit of the IMF.

Mayer presented numerical simulations of disk fragmentation: fragmentation is suppressed when simulations account for radiative diffusion; fragmentation requires large disk masses and/or an efficient cooling mechanism (perhaps convective).

Rafikov considered fragmentation of protoplanetary disks, including effects due to convective cooling, irradiation and opacity gaps, concluding fragmentation does not occur in realistic disks.

Feigelson presented X-ray observations of young stars: the X-ray activity is dominated by flares that are unrelated to accretion or presence of a disk; X-ray ionization dominates CR ionization by factors of $\sim 10^8$, and thus controls the extent of the dead zone.

Pudritz discussed planet formation in dead zones, emphasizing gap opening as a mechanism to set planetary masses and influence migration.

Matsumura described models for planet formation in dead zones, including the expected rapid evolution of the dead zone.

van Dishoeck discussed evidence for grain growth and settling, chemistry in the surface PDR layers of disks, and effects of disk evolution, including chemistry of transitional disks.

Andrews presented sub-mm observations of disk density and temperature structure, including comparison of disks in Taurus and Orion.

Monnier described IR interferometry as a probe of inner ($\sim AU$) disk structure.

Chiang presented a model for the inner dust-free part of a transitional disk, fed by a MRI acting in the surface layers of the puffed-up inner rim.

Liu described the forthcoming Gemini NICI Planet-Finding Campaign to directly image Jupiter-mass planets around other stars.

Hollenbach discussed disk photoevaporation models, expecting this to be the dominant dispersal mechanism for the disk beyond several AU.

Bally discussed how photoevaporation enhances the metallicity of disks with important implications for planetesimal formation.

Garaud presented a model for dust grain evolution in protoplanetary disks evolving under the influence of viscosity and photoevaporation.

Youdin discussed formation of km-sized planetesimals, emphasizing the role of the linear streaming instability induced by aerodynamic drag feedback in producing particle clumping.

Johansen presented simulations of planetesimal formation via gravitationally instability in clumps formed via this streaming instability.

Day 4:
Henning discussed properties of dust across a range of environments from the diffuse ISM to protoplanetary disks, raising questions about the production of crystalline silicates, the structure of agglomerates, the importance of destruction processes and the fate of 0.1m sized “particles”.

Rice presented models for planetesimal growth in self-gravitating accretion disks in which solid particles are concentrated in the centers of spiral
arms.

Blum described a range of laboratory experiments investigating particle-particle interactions including, fractal growth, restructuring/compaction, aggregation, bouncing, fragmentation and erosion.

Gustafson discussed polarimetric color differences between cometary and zodical dust (including scaled-up laboratory experiments) as evidence for different aggregation processes.

Lin talked about several different physical processes involved in the sequential accretion scenario for planet formation, in which gas giants form first and then dynamically influence the formation of the terrestrial planets.

Klahr presented theoretical/numerical work on planet formation, particularly planetary accretion of material from a gas disk to form “hot bubbles”, which influence migration and detectability.

Wyatt discussed debris disk evolution, including steady-state and stochastic processes.

Telesco discussed how mid-IR observations can probe catastrophic planetesimal collisions in debris disks.

Moro-Martín searched for a correlation between the presence of planets (from RV surveys) and presence of debris disks (Spitzer FEPS) and did not find a significant correlation.

Bergin discussed how oxygen isotope ratios can be changed by selective photoevaporation in a disk that is exposed to intense UV radiation, and that the solar system data can be explained by having the Sun form near an O star, presumably in a rich star cluster.

Gaidos discussed how evidence for enrichment of the early solar nebula with $^{26}$Al (from WR winds) indicates the Sun formed near a massive star, presumably in a rich star cluster.

Zinnecker discussed the frequency of planets in binary and multiple systems, and implications for formation scenarios.

Adams described a set of N-body simulations of clusters to derive statistics on UV exposure (for photoevaporation models) and scattering encounters, finding the typical cluster environment has a relatively modest effect on star and planet formation compared to isolated star formation environments.

Ge described the planned MARVELS search of $\sim$ 40,000 FGK stars for exoplanets.

Ford discussed how observed properties of exoplanet systems can constrain models of planet formation and dynamical evolution, and in particular the different mechanisms for exciting eccentricity.

Veras discussed predicted correlations between giant planets and terrestrial planets, emphasizing an expected deficit of terrestrial planets in systems with eccentric giant planets produced by gravitational scattering.

Murray-Clay discussed photoevaporative mass loss from Hot Jupiters, including stellar wind interaction and predictions for Ly-\(\alpha\) observations.

Harrington presented Spitzer observations of Hot Jupiters that can help constrain day-night contrasts and atmosphere models.
FROM STARS TO PLANETS: CONNECTING OUR UNDERSTANDING OF STAR AND PLANET FORMATION
Sponsored by UF Dept. of Astronomy, UF Research & Graduate Programs, NSF, Alachua County Visitors & Convention Bureau
SOC: Elizabeth Lada (co-chair, UF), Jonathan Tan (co-chair, UF), Fred Adams (Michigan), Stan Dermott (UF), Eric B. Ford (CfA), Jian Ge (UF), Lynne Hillenbrand (Caltech), Doug Lin (UCSC), Charles Telesco (UF), Jonathan Williams (Hawaii), Andrew Youdin (CITA)

Tuesday 10th April 2007 5pm-7.30pm Welcome Reception and Registration, Arredondo Room, 4th Floor, Reitz Union.

Wednesday 11th April 2007 Session 1 - Star Formation: Formation of GMCs and star clusters; The stellar initial mass function; Influence of feedback - protostellar outflows, massive stars; Properties of binary and multiple systems; Formation of brown dwarfs

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<th>Speaker</th>
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<tr>
<td>8.30am</td>
<td>Registration</td>
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<tr>
<td>8.45am</td>
<td>Dermott, S. &amp; Glover, J. (UF)</td>
<td>Welcome</td>
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<tr>
<td>9.00am</td>
<td>SOC</td>
<td>From Stars to Planets: Open Questions</td>
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<tr>
<td>9.15am</td>
<td>Novak, G. (Northwestern)</td>
<td>GMC formation and magnetic fields: results from the SPARO 2003 survey</td>
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<tr>
<td>9.35am</td>
<td>Tasker, E. (UF)</td>
<td>Cloud Formation and Star Formation in Global Simulations of Disk Galaxies</td>
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<tr>
<td>9.50am</td>
<td>Bate, M. (Exeter)</td>
<td>Numerical Simulations of Star Cluster Formation</td>
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<tr>
<td>10.10pm</td>
<td>Lada, C. (CfA)</td>
<td>The Mass Function of Dense Cores and the Origin of the IMF</td>
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<tr>
<td>10.30am</td>
<td>Coffee Break and Posters</td>
<td>Cluster Formation in Infrared Dark Clouds: The Detection of Multiple Protostars in IRDC Cores</td>
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<tr>
<td>11.00am</td>
<td>Rathborne, J. (CfA)</td>
<td>Star Formation Taste Tests</td>
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<tr>
<td>11.15am</td>
<td>Goodman, A. (CfA)</td>
<td>Formation of an IMF-Cluster in a Filamentary Layer</td>
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<tr>
<td>11.35am</td>
<td>Myers, P. (CfA)</td>
<td>A FLAMINGOS View of Star Formation</td>
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<tr>
<td>11.55am</td>
<td>Lada, E. (UF)</td>
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<tr>
<td>12.15pm</td>
<td>Poster Overview 1</td>
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<tr>
<td>12.35pm</td>
<td>Lunch and Posters</td>
<td>Characterizing the Structure of Embedded Clusters with the Spitzer Young Stellar Clusters Survey</td>
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<tr>
<td>2.00pm</td>
<td>Gutermuth, R. (CfA-SAO)</td>
<td>Probing the Structure of Nearby Embedded Clusters</td>
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<tr>
<td>2.15pm</td>
<td>Ferreira, B. (UF)</td>
<td>Two Tails of a Distribution Function: The Initial Mass Functions of Extreme Star Formation</td>
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<tr>
<td>2.30pm</td>
<td>Meyer, M. (U. Arizona)</td>
<td>Empirical constraints on physical properties of young stars and brown dwarfs</td>
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<tr>
<td>2.50pm</td>
<td>Stassun, K. (Vanderbilt)</td>
<td>Huerta, M.; Deshpande, R.; Montgomery, M.; Tata, R.; Phan-Bao, N.</td>
</tr>
<tr>
<td>3.10pm</td>
<td>Poster Overview 2</td>
<td>Dunham, M.; Steckhum, B.; Padgett, D.; Guedel, M.; Townsley, L.; Li, Z-Y.</td>
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<tr>
<td>3.30pm</td>
<td>Coffee Break and Posters</td>
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<td>Time</td>
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<tr>
<td>4.00pm</td>
<td>Frank, A. (U. Rochester)</td>
<td>Feedback: Protostellar Outflows on Meso and Macroscales</td>
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<tr>
<td>4.20pm</td>
<td>Alves, J. (Calar Alto Obs.)</td>
<td>Galactic massive stellar clusters</td>
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<tr>
<td>4.40pm</td>
<td>Eikenberry, S. (UF)</td>
<td>Multi-epoch Star Formation in Cluster 1806-20</td>
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<tr>
<td>4.55pm</td>
<td>Fuller, G. (U. Manchester)</td>
<td>The Evolution of Massive Dense Cores</td>
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<tr>
<td>5.10pm</td>
<td>Krumholz, M. (Princeton)</td>
<td>From Massive Cores to Massive Stars</td>
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<td>5.30pm</td>
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<td>Reception &amp; Posters (Room 284)</td>
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**Posters 1:**

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<tr>
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<tr>
<td>P1-1 Jackson, J. (BU)</td>
<td>The Galactic Distribution of Infrared Dark Clouds</td>
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<tr>
<td>P1-2 Butler, M. (UF)</td>
<td>Extinction Mapping of Infrared Dark Clouds</td>
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<tr>
<td>P1-3 Hernandez, A. (UF)</td>
<td>Dynamical Properties of Infrared Dark Clouds</td>
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<tr>
<td>P1-4 Ragan, S. (U. Michigan)</td>
<td>Peering into the Heart of Galactic Star Formation</td>
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<tr>
<td>P1-5 Greissl, J. (U. Arizona)</td>
<td>IMF in Extreme Environments: Direct Detection of Young Low Mass Stars in Unresolved Starbursts</td>
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<tr>
<td>P1-7 Roman-Zuniga, C. (CfA)</td>
<td>The Structure of Dense Cores in the Pipe Nebula</td>
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<tr>
<td>P1-8 Robitaille, T. (St. Andrews)</td>
<td>Results from fitting pre-computed model SEDs to YSOs in Spitzer IRAC and MIPS surveys</td>
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<tr>
<td>P1-9 Gorlova, N. (UF)</td>
<td>FLAMINGOS NIR Survey of Serpens Clouds</td>
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<tr>
<td>P1-10 Rashkind, N. (UF)</td>
<td>FLAMINGOS Spectroscopy of Low Mass Stars and Brown Dwarfs in Orion</td>
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**Posters 2:**

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<tr>
<th>Presenter</th>
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<tbody>
<tr>
<td>P2-1 Huerta, M. (UF)</td>
<td>A New Effective Temperatures Scale for T-Tauri Stars</td>
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<tr>
<td>P2-2 Deshpande, R. (UCF)</td>
<td>Spectroscopic follow-up of Brown Dwarf Candidates in the Sigma Orionis Cluster</td>
</tr>
<tr>
<td>P2-4 Tata, R. (UCF)</td>
<td>The low-mass population of the young open cluster NGC6823</td>
</tr>
<tr>
<td>P2-6 Dunham, M. (U. Texas)</td>
<td>Observations of Very Low Luminosity Objects Discovered with the Spitzer Space Telescope</td>
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<tr>
<td>P2-7 Stecklum, B. (Thueringer L. T.)</td>
<td>Herbig-Haro flows from young brown dwarfs</td>
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<tr>
<td>P2-8 Padgett, D. (Spitzer SC/Caltech)</td>
<td>Spitzer Legacy Survey of the Taurus Molecular Cloud</td>
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<tr>
<td>P2-9 Guedel, M. (ETH Zürich &amp; PSI)</td>
<td>An X-Ray Survey of the Taurus Star Formation Region</td>
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<tr>
<td>P2-10 Townsley, L. (PSU)</td>
<td>Chandra’s X-ray View of Massive Star-forming Regions</td>
</tr>
<tr>
<td>P2-11 Li, Z-Y. (U. Virginia)</td>
<td>Cluster Formation in Protostellar Turbulence Driven by Collimated Outflows</td>
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### Thursday 12th April 2007

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<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
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<tbody>
<tr>
<td>9.00am</td>
<td>Evans, N. (U. Texas)</td>
<td>Star Formation: From Cores to Disks</td>
</tr>
<tr>
<td>9.20am</td>
<td>Muench, A. (CfA)</td>
<td>A Spitzer view of the IC 348 nebula</td>
</tr>
<tr>
<td>9.40am</td>
<td>Stahler, S. (UC Berkeley)</td>
<td>From Clouds to Clusters: A Tale of Orion</td>
</tr>
<tr>
<td>9.55am</td>
<td>Haisch, K. (Utah Valley SC)</td>
<td>Observational Frontiers in the Multiplicity of Young Stars</td>
</tr>
<tr>
<td>10.15am</td>
<td>Jayawardhana, R. (U. Toronto)</td>
<td>Multiplicity Among Young Stars and Brown Dwarfs</td>
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<tr>
<td>10.35am</td>
<td><strong>Coffee Break and Posters</strong></td>
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<tr>
<td>11.00am</td>
<td>Allers, K. (U. Hawaii/IfA)</td>
<td>Near-IR Spectral Properties of Young Brown Dwarfs</td>
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<tr>
<td>11.15am</td>
<td>Luhman, K. (PSU)</td>
<td>The Origin of Brown Dwarfs</td>
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<tr>
<td>11.35am</td>
<td>Martin, E. (IAC/UCF)</td>
<td>Observational constraints on the formation of very low-mass objects</td>
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<tr>
<td>11.55am</td>
<td>Shu, F. (UCSD)</td>
<td>Magnetic Fields in Star and Planet Formation</td>
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<td>12.15pm</td>
<td><strong>Excursion to Lake Wauburg and Paynes Prairie, including lunch</strong></td>
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<td>5.00pm</td>
<td><strong>Start of Starry Night: The Birth of the Stars and Planets, Florida Museum of Natural History</strong></td>
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<tr>
<td>6.00pm</td>
<td>Kane, S. (UF)</td>
<td>Family-Oriented Lecture: Wanderers in the Celestial Sphere and Beyond</td>
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<tr>
<td>7.00pm</td>
<td>Lada, C. (CfA)</td>
<td>Public Lecture: The Search for Stellar Origins from Antiquity to the 21st Century</td>
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### Friday 13th April 2007

#### Session 2 - Circumstellar Disks and Planet Formation:  
*Gravitational instability and fragmentation; Theoretical models of disk structure; Basic observed properties: protostellar to debris disks, evolution and lifetimes; Star-disk-outflow interaction; Chemistry and grain evolution; Planetesimal formation; Terrestrial and Giant planet formation; Planet-disk interaction, migration; Planets and Debris Disks; Observational constraints from the Solar System; Observational constraints from exoplanet surveys; Planet-planet interactions; Planet formation and the star-forming environment*

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<tr>
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<tbody>
<tr>
<td>9.00am</td>
<td>Matzner, C. (U. Toronto)</td>
<td>Disk fragmentation, the brown dwarf desert, and the stellar upper mass limit</td>
</tr>
<tr>
<td>9.20am</td>
<td>Mayer, L. (U. Zürich/ETH Zürich)</td>
<td>Fragmentation of protoplanetary disks into giant planets</td>
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<tr>
<td>9.40am</td>
<td>Rafikov, R. (CITA)</td>
<td>Can giant planets form by gravitational instability?</td>
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<tr>
<td>10.30am</td>
<td><strong>Coffee Break and Posters</strong></td>
<td>X-rays and Planet Formation</td>
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<tr>
<td>11.00am</td>
<td>Feigelson, E. (PSU)</td>
<td>Dead zones and the growth of giant planets</td>
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<tr>
<td>11.35am</td>
<td>Matsumura, S. (Northwestern)</td>
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</tbody>
</table>
11.55am  van Dishoeck, E. (Leiden)  Chemistry in evolving protoplanetary disks
12.15pm  Andrews, S. (IfA/Hawaii)  A Submillimeter View of Protoplanetary Disks

12.35pm  Lunch and Posters
2.00pm  Carpenter, J. (Caltech)  Spitzer Constraints on Primordial and Debris Disk Evolution
2.20pm  Monnier, J. (U. Michigan)  High-Resolution Observations of YSO Disks using Optical Interferometry
2.35pm  Chiang, E. (UC Berkeley)  Inside-Out Evacuation of Transitional T Tauri Disks
2.55pm  Liu, M. (IfA/Hawaii)  Direct Imaging of Extrasolar Planets: The Gemini NICI Planet-Finding Campaign
3.15pm  Poster Overview 4
3.35pm  Coffee Break and Posters
4.00pm  Hollenbach, D. (NASA Ames)  Photoevaporation of Disks Around Young Stars
4.20pm  Bally, J. (U. Colorado)  Prompt UV-induced Planetesimal Formation in Disks
4.40pm  Garaud, P. (UCSC)  Modeling the dust size distribution in evolving disks
5.00pm  Youdin, A. (CITA)  Aerodynamic Processes in Planetesimal Formation
5.20pm  Johansen, A. (MPIA)  Planetesimal formation in turbulent traffic jams

5.35pm  End of Day 3 Science Program
6.45-7pm  Buses leave for conference dinner

Posters 3:  Presenter  Title
P3-1  Cai, K. (McMaster)  3D Hydrodynamics Simulations of Gravitational Instabilities in Irradiated Protoplanetary Disks
P3-2  Stamatellos, D. (Cardiff)  Disc fragmentation forms brown dwarfs not planets
P3-3  Turner, N. (JPL/Caltech)  Turbulence and the Dead Zones in Protostellar Disks
P3-4  Brown, J. (Caltech)  High Resolution SMA Imaging of the LkH-alpha 330 Transitional Disk
P3-5  Bitner, M. (U. Texas)  The TEXES/Gemini Survey of H2 in Protoplanetary Disks
P3-6  Knez, C. (U. Maryland)  TEXES detection of water in a disk around RW Aur
P3-7  Salyk, C. (Caltech)  Investigating Inner Disk Structure with High Resolution Molecular Spectroscopy
P3-8  Zhu, Z. (U. Michigan)  The hot inner disk of FU Ori
P3-9  Kamp, I. (ESA/STScI)  Probing Protoplanetary Disk Evolution with the HI 21cm Line
P3-10  Oliveira, I. (Leiden/Caltech)  Studies of Protoplanetary Disk Evolution in the Serpens Molecular Cloud
P3-11  Espaillat, C. (U. Michigan)  Disks in Transition Around Pre-Main Sequence Stars
P3-12  Alexander, R. (U. Colorado)  Dust dynamics during protoplanetary disc clearing
P3-13  Padgett, D. (Spitzer SC/Caltech)  Multiwavelength Imaging of Edge-on Circumstellar Disks
P3-14  Tannirkulam, A. (U. Michigan)  The inner dust rim of Herbig Ae star - MWC275: A view into the gas to dust transition region
**Posters 4:**

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<td>Gomez de Castro, A. (Madrid)</td>
<td>The influence of the jet engine on the evolution of the inner disk: an ultraviolet view</td>
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<tr>
<td>Bary, J. (U. Virginia)</td>
<td>The Physical Conditions of Accreting Gas in T Tauri Systems</td>
</tr>
<tr>
<td>Cieza, L. (U. Texas)</td>
<td>Angular Momentum Regulation Through Star-Disk Interaction in NGC 2264 and the Orion Nebula</td>
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<td>Disk Evolution &amp; Planet Formation at 10-20 Myr: Observations of h &amp; chi Persei</td>
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<td>Kalas, P. (UC Berkeley)</td>
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**Saturday 14th April 2007**

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<td>11.55am</td>
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<td>12.15pm</td>
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<td>2.55pm</td>
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<td>4.50pm</td>
<td>Harrington, J. (UCF)</td>
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<td>5.10pm</td>
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<td>5.10pm</td>
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**5.30pm** End of Day 4 Science Program

~6.00pm Farewell Event: TBD

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<td>P5-4 Gonzalez, J-F. (Lyon)</td>
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<td>P5-5 Murray-Clay, R. (UC Berkeley)</td>
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<td>P5-7 Kitiashvili, I. (Kazan SU)</td>
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Gomez de Castro, Ana  U. C. Madrid  aig@mat.ucm.es  The Initial Mass Function of NGC1333: Brown Dwarfs and Low Mass Stars
Gomez Martin, Cynthia  U. Florida  gomez@astro.ufl.edu  Star Formation Taste Tests
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Gorlova, Nadya  U. Florida  ngorlova@astro.ufl.edu  Infrared Dark Clouds: Initial Conditions for Massive Star and Star Cluster Formation
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Guedel, Manuel  ETHZ & PSI  guedel@astro.phys.ethz.ch  The Galactic Distribution of Infrared Dark Clouds
Gustafson, Bo  U. Florida  gustaf@astro.ufl.edu  A New Effective Temperatures Scale for T-Tauri Stars
Gutermuth, Robert  SAO  rgutermuth@cfa.harvard.edu  A blue needle pointing west: Extreme asymmetry in the HD 15115 debris disk
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Kane, Stephen  U. Florida  skane@astro.ufl.edu  Planetary bodies formation in turbulent traffic jams
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Krumholz, Mark  Princeton  krumholz@astro.princeton.edu  From Massive Cores to Massive Stars
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<td><a href="mailto:jrathborne@cfa.harvard.edu">jrathborne@cfa.harvard.edu</a></td>
<td>Cluster Formation in IR Dark Clouds: The Detection of Multiple Protostars in IRDC Cores</td>
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<td>Rice, Ken</td>
<td>U. Edinburgh</td>
<td><a href="mailto:wkmr@roe.ac.uk">wkmr@roe.ac.uk</a></td>
<td>Planetesimal formation in self-gravitating accretion discs</td>
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<td>Robitaille, Thomas</td>
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<td><a href="mailto:tr9@st-andrews.ac.uk">tr9@st-andrews.ac.uk</a></td>
<td>Results from fitting pre-computed model SEDs to YSOs in Spitzer IRAC and MIPS surveys</td>
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<td><a href="mailto:cromanzu@cfa.harvard.edu">cromanzu@cfa.harvard.edu</a></td>
<td>The Structure of Dense Cores in the Pipe Nebula</td>
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<td>Microgravity Experiments Probing Collision Processes in Protoplanetary Disks</td>
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Salyk, Colette Caltech csalyk@gps.caltech.edu Investigating Inner Disk Structure with High Resolution Molecular Spectroscopy

Shu, Frank UC San Diego fhshu@ucsd.edu Magnetic Fields in Star and Planet Formation

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Stassun, Keivan Vanderbilt keivan.stassun@vanderbilt.edu Empirical constraints on physical properties of young stars and brown dwarfs

Stecklum, Bringfried TL Tautenburg stecklum@tls-tautenburg.de Herbig-Haro flows from young brown dwarfs

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Telesco, Charles U. Florida telesco@astro.ufl.edu The low-mass population of the young open cluster NGC6823

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Williams, Darren Penn State Erie dmw145@psu.edu Stability of satellite systems during close interplanetary encounters

Wiseman, Jennifer NASA Goddard jennifer.wiseman@nasa.gov A Planetary System Around HD 155358: The Lowest Metallicity Planet Host Star

Wittenmyer, Rob U. Texas at Austin robw@astro.as.utexas.edu Debris disk evolution

Wyatt, Mark IoA, Cambridge wyatt@ast.cam.ac.uk Aerodynamic Processes in Planetesimal Formation

Youdin, Andrew CITA youdin@gmail.com The hot inner disk of FU Ori

Zhu, Zhaohuan U. Michigan zhuzh@umich.edu Formation of planets in binary/multiple star systems
Most stars are born in Giant Molecular Clouds (GMCs). The process by which the GMCs themselves are formed is not well understood; factors that may be important include gravitational, thermal, and magnetic instabilities, as well as turbulent fluctuations. In order to constrain the role that magnetic fields may play in the formation and evolution of GMCs, we have carried out a survey of the global magnetic fields of GMCs, using our submillimeter polarimeter, SPARO, at South Pole station. We draw two conclusions from our results: (1) Based on the observed degree of order in the GMC fields, we argue that the magnetic energy density is comparable to the turbulent kinetic energy density. (2) Based on the observed correlation between the mean direction of the GMC fields and the orientation of the Galactic plane, we argue that the field direction tends to be preserved during the process of GMC formation.

Due to the number of factors governing star formation, modeling it on a galactic scale poses many challenges. In addition to the complex nature of the interstellar medium, star formation is additionally affected by global galaxy properties such as its structure and rotation. That such effects play a strong role in star formation is evident from the range of rates and star formation histories we observe in other galaxies. In this work we consider the formation of star forming clusters in an isolated galaxy disc, looking at the star formation properties of the disk and the structure of the interstellar medium. We use the adaptive mesh-refinement code, Enzo, to model the gas and star particles and include feedback from type II supernovae.

I will present results from numerical simulations of star cluster formation, the most recent of which now form clusters of hundreds of stars and brown dwarfs and, thus, provide statistics of unprecedented precision. I will discuss the origins and properties of the stars and brown dwarfs, including their mass function, multiplicity, disc properties, and velocity dispersion, and how the numerical results compare with observations.
Lada, Charles Harvard-Smithsonian CfA clada@cfa.harvard.edu

The Mass Function of Dense Cores and the Origin of the IMF

The stellar IMF is one of the most fundamental distributions in astrophysics and its origin one of the most important problems for star formation research. In this talk I will discuss how infrared observations of young embedded clusters have enabled the extension of the IMF well into the substellar mass regime and revealed the existence of a characteristic mass for star formation. I will then describe the results of very recent measurements of infrared extinction in a dark cloud complex that have enabled the determination of the mass function of dense cloud cores in that cloud. The infrared extinction measurements permit the extension of the core mass function to lower masses than previously possible. The derived core mass function is found to be surprisingly similar in shape to the stellar IMF but scaled to higher mass by a factor of about 3. I will argue that this suggests that the stellar IMF directly originates from the core mass function and that the form of the stellar IMF is a direct product of the form of the core mass function and a constant star formation efficiency of roughly 30%. Finally I will explore the possibility that the core mass function itself has its origins in a process of simple thermal fragmentation.

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Cluster Formation in Infrared Dark Clouds: The Detection of Multiple Protostars in IRDC Cores

Infrared Dark Clouds (IRDCs) are cold, dense molecular clouds identified as extinction features against the bright mid-IR Galactic background. Our recent 1.2 mm continuum emission survey of IRDCs reveal many compact (< 0.5 pc) and massive (10-2100 M⊙) cores within them. Here we present high-angular resolution spectral line and mm/sub-mm continuum images obtained with the IRAM Plateau de Bure Interferometer and the Sub-millimeter Array toward six high-mass IRDC cores. Toward these six cores, we detect a total of sixteen compact (< 0.024 pc) protostellar condensations. Four of the cores are resolved into multiple protostellar condensations. The remaining two cores contain single, compact protostellar condensations with a very rich molecular spectrum; these two IRDC cores are hot molecular cores. Gradients in the velocities of molecular lines suggest that two protostars may be surrounded by circumstellar disks. The derived gas masses for the protostellar condensations suggest that each core is forming at least one high-mass protostar (~10 Msun) and four cores are also forming lower-mass protostars (~few Msun). The close proximity of multiple protostars of disparate mass indicates that these IRDCs are in the earliest evolutionary states in the formation of stellar clusters.

Goodman, Alyssa Harvard-Smithsonian Center for Astrophysics agoodman@cfa.harvard.edu

Star Formation Taste Tests

By analogy to the iterative taste tests carried out by brave chefs trying to replicate a dish for which they have no recipe, I will argue that we need to “taste” simulations of star-forming regions in the same way we “taste” real regions: by subjecting them to a host of observations, each type of which probes a unique set of physical properties. The talk will cover: 1) a summary of recent large surveys of star-forming regions (e.g. COMPLETE, c2d, etc.); 2) an overview of existing simulations and their properties; 3) a categorization of techniques for “observing” simulations; and 4) new results stemming from the application of the “taste-based” statistics (e.g. dendrograms) we are developing to real observations and simulations. I will
conclude with a demonstration of the "Star Formation Taste Tests" online collaboratory we have established, and with a discussion about the future.

Myers, Phil Smithsonian Astrophysical Observatory pmyers@cfa.harvard.edu

Formation of an IMF-Cluster in a Filamentary Layer
We present a cloud model which forms an IMF-cluster in ∼1 pc in ∼1 Myr. The cloud is a self-gravitating layer of finite horizontal extent, probably swept up by fast flows from OB stars or supernovae. The local Jeans length sets the spacing of star-forming cores, and the local pressure sets their mass. Each core is a critically stable Bonnor-Ebert sphere, forming a stellar mass with constant efficiency. The cloud surface density profile yields a stellar IMF if its slope is shallow inside and steep outside, or if the cloud has a central "hub" surrounded by tapering filaments. The model matches observed properties (1) line width increasing as a power of cloud size, and mean column density nearly constant, as in Larson’s Laws, (2) centrally maximal values of stellar mass, stellar surface density, and gas surface density within a radius ∼1 pc, (3) global star formation efficiency > 1% and core mass fraction > 3%, and (4) ∼100 stars following the IMF from brown dwarfs to late B stars. The cloud contracts radially due to self-gravity, and the free-fall time ∼1 Myr is likely a lower limit to its star-forming life.

Lada, Elizabeth University of Florida lada@astro.ufl.edu

A FLAMINGOS View of Star Formation
Embedded clusters are the fundamental units of star formation in our Galaxy therefore studying their properties is critical for understanding how star formation proceeds on both the local and Galactic scale. I will discuss recent results from our FLAMINGOS Star Formation Survey. FLAMINGOS, the FLoridA Multi-Object Imaging Near-Infrared Grism Observational Spectrometer, is a wide field NIR imager and the world’s first fully cryogenic NIR multi-object spectrometer, offering an unparalleled opportunity to study young embedded clusters. We have surveyed embedded clusters in local molecular clouds with FLAMINGOS and are investigating the star forming histories, IMF, structure and evolution of these young clusters. In this presentation, I will focus on our results for the clusters in the Rosette and Orion star forming complexes where we find evidence for the evolution of cluster structure, sequential star formation and variations in the low mass IMF.

Jackson, James Boston University jackson@bu.edu

The Galactic Distribution of Infrared Dark Clouds
Using the 13CO 1-0 and CS 2-1 lines, we have measured the radial velocities of over 500 infrared dark clouds. With these velocities we have derived their kinematic distances. IRDCs have sizes ∼5 pc and masses of a few 1000 M☉, similar to cluster forming molecular clumps. They are located preferentially in the Galaxy’s 5 kpc molecular ring. IRDCs probably represent the earliest stages in the formation of star clusters.
Butler, Michael J. U. Florida butler85@astro.ufl.edu

Extinction Mapping of Infrared Dark Clouds

Infrared Dark Clouds (IRDCs) are cold, dense regions of giant molecular clouds that are opaque at wavelengths $\sim 10\,\mu m$ or more and thus appear dark against the diffuse Galactic background emission. They are thought to be the progenitors of star clusters. We use 8 $\mu$m imaging data from SPITZER-IRAC (GLIMPSE) to make extinction maps of 10 infrared dark clouds (IRDCs), selected to be relatively nearby and massive. The extinction mapping technique requires construction of a model of Galactic IR background intensity behind the cloud, which is achieved by interpolation from the surrounding regions. We investigate three different methods for this interpolation, finding that systematic differences are at about the 20% level. For standard dust opacities and dust to gas ratios, such an uncertainty corresponds to a column density of about 0.04 g cm$^{-2}$, above which we conclude this extinction mapping technique attains validity. Within the clouds, cores have been identified via mm emission by Rathborne et al. (2006). For about 40 cores, we compare the masses derived from mm emission with those derived from extinction mapping, finding general agreement at the level of a factor of $\sim 2 - 3$, and with a systematic offset of $< 25\%$. We discuss possible causes of this scatter and systematic difference. We conclude with a discussion of the implications of these results for star cluster formation theories, including comparison of probability distribution functions of mass surface density with various theoretical models.

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Dynamical Properties of Infrared Dark Clouds

Massive stars and star clusters are important throughout astrophysics due to their effects on many systems, from galaxy evolution to planetary formation. Galactic massive stars and star clusters form from the densest gas clumps within Giant Molecular Clouds. These clumps reveal themselves by IR extinction and are known as Infrared Dark Clouds (IRDCs). The McKee & Tan (2003) and Tan et al. (2006) models for massive star and star cluster formation assume that IRDCs are near virial equilibrium. To test this, we use 13CO Galactic Ring Survey (GRS) data to determine kinematic distances and dynamical masses of a sample of 9 IRDCs and their embedded cores. First we employ a simple virial relation, ignoring external pressure, to derive cloud masses and compare those with the extinction mass results of Butler et al. (2007). We find that the cloud masses derived from the average 13CO line width are within a factor of about three of the extinction masses. Cloud masses derived from the dispersion of the peak velocities of embedded cores are much smaller. This may be explained by the spatial concentration of dense cores in the centers of the clouds or by optical depth effects in the 13CO spectra so that they fail to accurately trace the dense core velocity structure. We have also derived pressure-bounded virial masses of cores by assuming the density and pressure are power-laws in radius, and the external pressure is related to the mass surface density of the surrounding cloud material. These core masses are also compared with the core extinction masses of Butler et al. (2007).

Ragan, Sarah University of Michigan seragan@umich.edu

Peering into the Heart of Galactic Star Formation

To date, most star formation studies have focused on nearby regions forming low-mass stars, but the local environment may not be representative
of typical star formation regions in the Galaxy. Most stars are known to form in clusters in the vicinity of high-mass stars, most of which reside in the molecular ring of the Galaxy. To overcome the distance barrier to these more typical star-forming clusters, we have isolated a unique sample of high-mass pre-stellar cores and performed deep Spitzer observations, resolving dense, absorbing structures at multiple infrared wavelengths. They correspond very well to molecular emission by tracers of dense gas, and we therefore view these objects as pre-stellar, cluster-forming clouds undergoing fragmentation. The addition of high-resolution velocity data for these cores will allow for a more detailed study of typical star formation in the Galaxy and a direct comparison with local star formation.

Greissl, Julia University of Arizona jgreissl@as.arizona.edu

**Constraining the IMF in Extreme Environments: Direct Detection of Young Low Mass Stars in Unresolved Starbursts**

We demonstrate the feasibility of detecting directly low mass stars in unresolved super-star clusters with ages $\leq$ 10 Myr using near-infrared spectroscopy. Such measurements could constrain the ratio of high to low mass stars in these extreme star-forming events, providing a direct test on the universal nature of the IMF compared to the disk of the Milky Way. Using a combination of results from Starburst99 for main sequence and post-main sequence evolution and pre-main sequence evolutionary models, we show that $\sim 4 - 12\%$ of the integrated light at 2.2 microns comes from low mass PMS stars with late-type stellar absorption features. This light is discernible using high signal-to-noise spectra ($> 100$) at modest resolution ($R=1000$) placing constraints on the ratio of high to low mass stars contributing to the integrated light of the cluster. In addition we present results analyzing a high signal-to-noise H and K-band spectrum of a young cluster in the Antennae and place constraints on the IMF in the cluster.

Dib, Sami Korea Astronomy and Space Science Institute dib@kasi.re.kr

**The Mass Spectra and Scaling Relations of Cores in Turbulent, Magnetized, Self-Gravitating Molecular Clouds**

We discuss the properties and time evolution of the mass spectra of cores formed in a set of 3D, isothermal, magnetized, self-gravitating and driven molecular clouds. The simulations, which have a resolution of $512^3$ grid cells, vary by the strength of the magnetic field ranging from subcritical to strongly supercritical. We also investigate the scaling relations of the cores, such as the mass-, average density-, velocity dispersion-, and specific angular momentum-radius relationships and their time evolution in the models from the early stage of roundish cores to the protostellar disk phase.

Roman-Zuniga, Carlos Harvard-Smithsonian Center for Astrophysics cromanzu@cfa.harvard.edu

**The Structure of Dense Cores in the Pipe Nebula**

We present our preliminary results of deep, high resolution near-infrared observations of a collection of dense pre-stellar cores in the Pipe Nebula. Our observations allowed us to construct detailed extinction maps for the cores, revealing their internal structure and physical properties. Our observations are part of a large scale program, where near and mid-infrared, and radio observations are combined to shed light on the initial conditions that prevail before or at the very early stages of star formation.
Robitaille, Thomas University of St Andrews tr9@st-andrews.ac.uk

Results from fitting pre-computed model SEDs to YSOs in Spitzer IRAC and MIPS surveys

We have developed a large grid of radiation transfer models of axisymmetric young stellar objects (YSOs), covering a wide range of stellar masses and evolutionary stages (Robitaille et al. 2006), and have taken the approach of fitting the resulting model SEDs to multi-wavelength data, in order to determine what can be learned about the physical conditions in YSOs (Robitaille et al. 2007, in preparation). In this poster we present results from analyzing Spitzer data, in particular using data from the GLIMPSE and MIPSGAL surveys. We show results for individual sources and regions, and we also attempt to characterize the physical conditions in YSOs in the entire galactic mid-plane covered by these surveys. Our aim is to improve our understanding of the physical conditions in young protostars and protoplanetary disks throughout the Galaxy.

Gorlova, Nadya and FLAMINGOS team Univ. of Florida ngorlova@astro.ufl.edu

FLAMINGOS NIR Survey of Serpens Cloud

We present preliminary results of the JHK imaging and multi-object JH spectroscopy of the cluster of young stellar objects (YSOs) in the Main Core of Serpens Cloud. Because of the high extinction in the region, the majority of protostars have been previously identified and characterized through the mid-IR emission of their circumstellar material. Going 1-2 mag deeper than 2MASS and obtaining low-resolution spectra of both known and new candidates in the field, we aim to investigate the stellar properties of these YSOs. The survey is part of the larger ongoing survey of the nearby giant molecular clouds with FLAMINGOS instrument, based on 2m and 4m telescopes at KPNO.

Rashkind, Noah UF nrashkind@astro.ufl.edu

FLAMINGOS Spectroscopy of Low Mass Stars and Brown Dwarfs in Orion

In this poster we present results from a near-infrared spectroscopic survey of young embedded clusters in the Orion molecular cloud complex. These data were obtained as part of the FLAMINGOS/NOAO survey of the star forming content of the five nearest giant molecular clouds. All data were obtained using FLAMINGOS the KPNO 2.1m and 4m telescopes. We use spectra to determine effective temperatures for a magnitude-limited sample of cluster sources. These data were then combined with FLAMINGOS J, H, and K-band photometry to determine bolometric luminosities and then place all objects on the H-R diagram. The data are then compared to current pre-main sequence evolutionary models and we estimate masses and ages for all objects. Finally, we examine the star forming history of the region and investigate the significance of the brown dwarf population.
The Initial Mass Function of NGC1333: Brown Dwarfs and Low Mass Stars

We present results from a near-infrared spectroscopic study of candidate brown dwarfs & low mass stars in the young cluster NGC1333. Using FLAMINGOS on the Kitt Peak National Observatory 4-m telescope, we have obtained spectra of ~172 members of the cluster & classified them via the prominent J & H band magnesium & water absorption features. We derived spectral ranges between ~M1 to M8.5 for 40 objects, with typical classification errors of 0.5 - 1 subclasses. The remainder of the objects fall in three categories: 1) too noisy to be classified, 2) hotter stars, i.e. earlier than M1, and 3) 1 possible giant. Combining these spectral types with JHK photometry, we are able to place the objects on the H-R diagram & use theoretical pre-main sequence evolutionary models to determine their masses & ages. Out of the 40 classified objects, 41% of them exhibit infrared excess, and ~25% are brown dwarfs. We determined a median age of $2.3 \times 10^5$ yr for this low mass population.

Characterizing the Structure of Embedded Clusters with the Spitzer Young Stellar Clusters Survey

I will present a summary of the now-complete Spitzer Young Clusters Survey, a 1-24 micron imaging survey of over 30 young and embedded clusters within the nearest 1 kpc. With these data, we have achieved a near-complete census of both protostars and pre-main sequence stars with disks down to the hydrogen-burning mass limit. These sources dominate the total membership of very young clusters. As such, they can be used to characterize stellar surface density structure with high confidence, as they are free of the hindrance of field star contamination. We have uniformly described the clusters in terms of their number of members, their size, their population of protostars, the structure of their surface density maps, their relation to molecular gas, their filamentary nature. On the basis of these factors, the clusters can be classified into several categories, each containing similar members. I will present a brief overview of this empirical classification scheme.

Probing the Structure of Nearby Embedded Clusters

We have studied the morphologies of 62 young embedded clusters, thus obtaining results which suggest the division of clusters into two categories: flat-type density profiles and centrally-condensed profiles. We used young-cluster catalogs present in the literature to build our sample of cluster fields. Clusters in those fields were then detected using a nearest-neighbor-based detection algorithm on surface density mapping of 2MASS data. Aside from the morphology we also measure the mass, the number of members, the core and total radii, the extinction, the infrared excess fraction, and the maximum density for each cluster. With this study we aimed to find out whether young cluster have a preferential density distribution as well as furthering our understanding of the connection between the density structure of the host molecular cloud to that of the resultant cluster.
Meyer, Michael  The University of Arizona mmeyer@as.arizona.edu

Two Tails of a Distribution Function: The Initial Mass Functions of Extreme Star Formation

"It was the best of times, it was the worst of times..." Considerable progress has been made over the past decade in characterizing the shape of the stellar and sub-stellar initial mass function in regions of nearby star formation (e.g. Meyer et al. 2000; Luhman et al. 2006). However, fundamental questions remain unanswered. Does the ratio of stars to sub-stellar objects vary as a function of initial condition in molecular clouds? Is there an "end" to the IMF set by the opacity-limit for fragmentation? Does the ratio of high to low mass stars vary as a function of metallicity, ambient gas pressure, and/or magnetic field strength throughout the Milky Way, local group galaxies, and beyond? I will summarize recent results from our group that offer answers to these questions focusing on studies concerning: i) the sub-stellar IMF down to 30 Mjupiter in nearby star-forming regions (Andersen et al. 2006; Greissl et al. 2007; Meyer et al. 2007); ii) the ratio of high to low mass stars in luminous HII regions such as W51 and R 136 (Andersen et al. 2005; 2007; and iii) the promise of constraining the ratio of high to low mass stars in unresolved super-star clusters found in starburst galaxies using observations of their integrated near-infrared spectra (Meyer and Greissl, 2005; Greissl et al. 2007). Our goal is to use observations of the shape of the IMF to reveal characteristic physical scales (e.g. mean mass, variance, departures from the log-normal form) and correlate any observed variations with initial conditions in order to constrain predictive theories of star formation.

Stassun, Keivan  Vanderbilt University keivan.stassun@vanderbilt.edu

Empirical constraints on physical properties of young stars and brown dwarfs

We discuss efforts to directly and accurately measure the fundamental physical properties (masses, radii, luminosities) of young low-mass stars and brown dwarfs as critical tests of theoretical models of star formation and evolution. We highlight a few recently discovered young eclipsing binaries as exemplars, including the first brown-dwarf eclipsing binary, to illustrate some of the physical insights that are emerging about (a) the interior structures of young stars, and (b) the possible dynamical origin of brown-dwarf binaries.

Huerta, Marcos  University of Florida marcosh@astro.ufl.edu

A New Effective Temperatures Scale for T-Tauri Stars

Many studies of T Tauri Stars rely on placing the stars on HR diagrams and using pre-main-sequence tracks to determine properties such as age and mass. The determination of effective temperature is usually done through a spectral type to effective temperature scale, either using a dwarf scale or a giant scale or some combination. I present new temperature determinations of T Tauri stars from direct fitting of the TiO band head near 7000 angstroms to NextGen synthetic spectra. The temperatures are as much as 400K warmer than previous SpT-Teff scales. This produces higher masses using the pre-main-sequence evolutionary tracks - potentially eliminating discrepancies between masses based on spectra and known dynamical masses in T Tauri binary systems.
We have identified several brown dwarf and planetary mass object candidates from ground-based, deep imaging in the young Sigma Orionis Cluster. We have obtained near-infrared and optical, low-resolution spectra for them. We discuss their spectroscopic properties and their cluster membership status.

Montgomery, Michele University of Central Florida montgomery@physics.ucf.edu

Infrared Spectroscopic Characterization of Field Brown Dwarf Candidates in the Trapezium Cluster
with Rohit Deshpande, Eduardo Martin, Ramarao Tata, Richard Wainscoat

We present preliminary results of low-resolution, near-infrared spectra obtained with NIRSPEC on the Keck II telescope for brown dwarf candidates that were previously identified in the IFA Subaru/Suprimecam deep survey. The photometric identification was made on the basis of extremely red optical colors. The NIRSPEC spectrum allows us to derive the spectral classification. We present their spectroscopic properties.

Tata, Ramarao University of Central Florida tata@physics.ucf.edu

The low-mass population of the young open cluster NGC6823

We present preliminary results of our near infrared imaging study of the young (2-7 Myr) open cluster NGC6823. The open cluster was observed using the CTIO 4m Blanco Telescope in J, H and K bands. This work is part of a larger survey to characterize the low-mass population of several open clusters with different initial conditions.

Phan-Bao, Ngoc UCF pngoc@physics.ucf.edu

Wide Very Low Mass Binaries: A Test for the Ejection Models of Brown Dwarf Formation

We review some recent detections of wide very low mass binary systems. We also present our discovery of the triple system LP 714-37 that consists of three very low mass components. We discuss the implications of this finding for brown dwarf formation.
Observations of Very Low Luminosity Objects Discovered with the Spitzer Space Telescope

Recent observations of low-mass star-forming regions obtained in the Spitzer Space Telescope c2d Legacy Project show that some cores without embedded sources detected by IRAS in fact harbor low-luminosity, embedded protostars. This has given rise to a new class of Very Low Luminosity Objects (VeLLOs) with internal luminosities less than or equal to 0.1 solar luminosities (the internal luminosity is the total luminosity of the central protostar and circumstellar disk, if present) and embedded in dense cores. VeLLOs are difficult to explain in the standard model of star formation, which instead predicts that an accreting object on the stellar/substellar boundary will have an accretion luminosity of about 1 solar luminosity. One possible explanation for the very low luminosities of these objects is episodic rather than constant mass accretion, and indeed observational evidence for one VeLLO supports this possibility. However, only three VeLLOs have been studied in detail, leaving many important questions unanswered: How common are VeLLOs? How many show evidence for episodic mass accretion? What are the properties of their parent cores? We present the results of a search for VeLLOs in the c2d data that forms a complete sample and thus begin to address some of these fundamental questions.

Herbig-Haro flows from young brown dwarfs

There is mounting evidence that brown dwarfs grow like stars, i.e. be accretion from disks. Since this process is generally accompanied by outflow activity, young brown dwarfs should possess jets and Herbig-Haro flows as well. We report on the detection of a of Herbig-Haro flow from L1014-IRS, the lowest luminosity object known to date which drives a molecular outflow. The flow consists of three knots. The brightest one is located ~8' north of L1014-IRS, exactly aligned with the symmetry axis of the bipolar nebula associated with the young object. The variation in position angle of the HHOs with radial distance is similar to that of the molecular outflow, and suggests a precession of the flow axis. Properties of the HHOs and implications of their detection will be discussed.

Spitzer Legacy Survey of the Taurus Molecular Cloud

Lacking young stellar clusters and luminous OB stars, Taurus hosts a distributed mode of low-mass star formation that has proven particularly amenable to observational and theoretical study. In 2005, the Taurus Spitzer Legacy team mapped the central 30 square degrees of the main Taurus cloud using the IRAC and MIPS cameras on the Spitzer Space Telescope. In Feb/March 2007, we will map an additional 14 square degrees of Taurus with Spitzer. Together, these images will form the largest contiguous Spitzer map of a single star-forming region (and any region outside the galactic plane). Our Legacy team is currently generating re-reduced mosaics and source catalogs, which become available to the community beginning in December 2006. The Spitzer Taurus survey is a central and crucial part of a multiwavelength study of the Taurus cloud complex that we have performed in collaboration with survey teams using XMM, CFHT, and the SDSS. The photometric data points from Spitzer will allow us to characterize the circumstellar environment of each object, and, in conjunction with optical and NIR photometry, construct a complete luminosity
function for the cloud members that will place constraints on the initial mass function. We present results drawing upon our preliminary Taurus catalog of several hundred thousand IRAC and thousands of MIPS sources. Initial results from our study of the Taurus clouds include new examples of disks around brown dwarfs, low luminosity YSO candidates, and Herbig-Haro objects seen in the thermal IR.

Guedel, Manuel ETH Zuerich & Paul Scherrer Inst. guedel@astro.phys.ethz.ch

An X-Ray Survey of the Taurus Star Formation Region

We present an overview of results from the "XMM-Newton Extended Survey of the Taurus Molecular Cloud [TMC]" (XEST). XEST is a large X-ray (and U band) survey designed to study the generation of high-energy radiation in forming stars, its interaction with the surrounding molecular gas, and its potential impact on disks and forming planets. Stars in TMC form in relative isolation, high-mass stars being entirely absent. Strong mutual influence due to outflows, jets, winds, or UV radiation is therefore minimized. XEST thus ideally complements X-ray studies of clustered star formation regions such as Orion. It systematically surveys, for the first time, TMC protostars and substellar objects in X-rays. We report the discovery of a new spectral component in accreting T Tau stars, a "soft excess" that is probably induced by accretion processes and that adds a hitherto neglected X-ray component. We discuss a new type of X-ray source related to jet-driving T Tau stars that may be important for the ionization of the stellar environment. XEST is, in combination with a large Spitzer TMC survey, also the basis for studies of the gas-to-dust mass ratio around T Tauri stars and in their disks, relevant for our understanding of dust evolution.

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Chandra’s X-ray View of Massive Star-forming Regions

Chandra is providing remarkable new views of massive star-forming regions, revealing the effects of massive stars on their surroundings. We will explore the latest data on several such regions, highlighting physical processes that characterize the life of a massive stellar cluster, from deeply-embedded cores too young to have established an HII region to superbubbles so large that they shape our views of galaxies. X-ray observations reveal hundreds of pre-main sequence stars accompanying the massive stars that power these great HII region complexes; this X-ray selected sample of young stars can be used to study disk frequency and evolution in the proximity of massive stars. The most massive stars themselves are often anomalously hard X-ray emitters; this may be a new indicator of close binarity. These complexes are sometimes suffused by diffuse X-ray structures, signatures of multi-million-degree plasmas created by fast O-star winds. In older regions we see the X-ray remains of the deaths of massive stars that stayed close to their birthplaces, exploding as cavity supernovae within the superbubbles that these clusters created.

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Cluster Formation in Protostellar Turbulence Driven by Collimated Outflows

The majority of stars are thought to form in clusters. Cluster formation in dense clumps of molecular clouds is strongly influenced, perhaps controlled,
by supersonic turbulence. We show that the initial turbulence in regions of active cluster formation is quickly transformed by the forming stars through protostellar outflows, and that the outflow-driven protostellar turbulence is the environment in which most of the cluster members form. We quantify the global properties of the protostellar turbulence through 3D MHD simulations. We find that collimated outflows are more efficient in driving turbulence than spherical outflows that carry the same amounts of momentum. This is because collimated outflows can propagate farther away from their sources, effectively increasing the turbulence driving length; turbulence driven on a larger scale is known to decay more slowly. Gravity plays an important role, generating infall motions in the cluster forming region that more or less balance the outward motions driven by outflows. The resulting quasi-equilibrium state is maintained through a slow rate of star formation, with a fraction of the total mass converted into stars per free fall time as low as a few percent. Magnetic fields are dynamically important even in magnetically supercritical clumps, provided that their initial strengths are not far below the critical value for static cloud support. We find a prominent break in the velocity power spectrum of the protostellar turbulence, which may provide a way to distinguish it from other types of turbulence. Results on the properties of the dense cores and stars formed in the protostellar turbulence will also be presented.

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Feedback: Protostellar Outflows on Meso and Macroscales

Protostellar outflows can extend across parsecs. Their large extent may allow them to exert significant feedback on large scale regions of a molecular cloud from which they formed. In this talk we will review recent computational results examining issues of feedback by protostellar outflows. Our emphasis will be on the resupply of turbulence to cluster-size regions but will also touch on the generation of cavities and the role of inhomogeneous regions in the cloud. Finally we will also present new laboratory astrophysics experiments which are relevant to protostellar outflows.

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Galactic massive stellar clusters

Most stars form in the Galaxy were formed in massive clusters. Perhaps more important, essentially all of the massive stars in the Galaxy were also formed in massive clusters. Understanding the basic properties of these clusters is then essential to understand Galactic evolution, from the production of heavy elements to the survival of proto-planetary disks. In this talk I will present our latest NTT and VLT-Adaptive Optics results on the characterization of the massive clusters W49A (1e5 Msun), Gum 29 (few 1e4 Msun), and Trumpler 14 (few 1e4 Msun). I will also discuss the difficulties and limits in these kind of studies and present general thoughts on how similar studies of these type of clusters in nearby galaxies will bring precious missing links in the understanding of massive cluster formation.
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Multi-epoch Star Formation in Cluster 1806-20

The Galactic star cluster 1806-20 contains one of the strangest assortments of massive stars and stellar remnants in the Galaxy. Cluster members include one LBV, several WC and WN Wolf-Rayet stars, a highly-magnetized neutron star, and a host of "normal" OB supergiant stars. This menagerie already creates some problems for "single-epoch" star formation models in the cluster. In addition, I will present new mid-IR observations revealing an embedded massive protostar near the cluster core, indicating that massive star formation continues in this cluster, over a time span of several million years.

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The Evolution of Massive Dense Cores

The results of two recent studies probing the evolution of massive cores will be presented. A single position survey recently demonstrated a statistical excess of blue-asymmetry line profiles consistent with the presence of infall towards a sample of massive dense cores. On the basis of multiple blue-asymmetric spectral lines observed towards each source, 21 sources were identified as good candidates for the presence of infall. Detailed follow-up studies of these infall candidates are now being undertaken and the first results from this work will be discussed. A comparison of the column density of CO and dust towards a sample of massive HMPOs has also been recently completed. This shows a range of depletion of CO towards the objects suggesting that the gas in these regions remains cold and dense for \( \sim 2 - 4 \times 10^5 \) years. The sources divide into two groups. Those with the largest line-widths have the lowest CO abundances. They also show evidence of heating by the central young star, have steep density profiles and high mass to luminosity ratios. The remaining sources show less evidence of heating, have shallower density profiles and smaller \( M/L \) ratios. It is proposed that these two groups of sources represent an evolutionary sequence in the properties of these massive cores and the stars they are forming.

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From Massive Cores to Massive Stars

In the last few years, millimeter interferometers have revealed a population of compact, massive gas cores that could be the direct progenitors of massive stars. I discuss the evolution of these objects, focusing on the questions of whether and how massive cores fragment, whether stars formed in this process undergo a phase of competitive accretion that determines the stellar IMF, and whether radiation pressure from newly formed stars is able to halt accretion. Based on a combination of analytic modeling and simulations, I argue that massive cores are indeed the precursors of massive stars, and that many of the observed properties of young star clusters, including the IMF, can be understood as direct imprints of the properties of their gas phase progenitors.
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Star Formation: From Cores to Disks
I will highlight recent developments in the early stages of star formation. Observations with the Spitzer Space Telescope and complementary data at other wavelengths have provided more complete samples of star-forming regions. These provide constraints on theoretical models of the origin of the initial mass function and evolutionary stages. The early stages of star formation include the separation of dense cores from the background molecular cloud, the evolution before point source formation, the infall onto the central source, and the formation of the disk. These events are usually associated with changes in the SED associated with the Class System. The large sample available from the Cores to Disks (c2d) program provides good statistics on the numbers of objects in various stages, and these can be used to estimate timescales.

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A Spitzer view of the IC 348 nebula
The IC 348 nebula is the best studied star formation site in the local Galaxy. I present the results of a Spitzer survey of the IC 348 nebula, including the disk properties of 300 known members and the identification of ~60 new disk bearing sources. The disk properties of the known members suggest that the inner disks of young stars evolve on a timescale that correlates with the central star’s mass. New sources identified with Spitzer include a population of protostellar objects that are distributed in a long filament along the nebula’s southern border and that are spatially anti-correlated with the centrally condensed cluster of class II and III members. I show that the existence of this protostellar population yields an integrated star forming history of the IC 348 nebula that began about 3-5 My ago and continues to the present at a roughly constant rate. Star formation in this corner of the Perseus molecular cloud has been ongoing for 3-5 crossing times, a timescale that will only increase given the large number of starless sub-mm cores in and around the nebula. The implications of such a long duration of star formation are discussed.

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From Clouds to Clusters: A Tale of Orion
Stars are born into three types of groups - T associations, bound clusters, and OB associations. What circumstances determine which group is formed? I propose that the critical factor is the mass of the progenitor cloud. This cloud slowly contracts, while being partially supported against gravity by turbulent pressure. I illustrate this general picture by modeling the star formation history of the Orion Nebula Cluster, a young OB association. Here, the cloud contraction is very deep, leading to the birth of massive stars. In T associations and bound clusters, the contracting cloud is also eroded by winds from low-mass stars. This erosion slows down or reverses the contraction process.
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Observational Frontiers in the Multiplicity of Young Stars

It has now been known for over a decade that low-mass stars located in star-forming regions are very frequently members of binary and multiple systems, even more so than main sequence stars located in the solar neighborhood. This high multiplicity rate has been interpreted as the consequence of the fragmentation of small molecular cores into a few seed objects that accrete to their final mass from the remaining material and dynamically evolve into stable multiple systems, possibly producing a few ejecta in the process. Analyzing the statistical properties of young multiple systems in a variety of environments therefore represents a powerful approach to place stringent constraints on star formation theories. In this contribution, I first review a number of recent results related to the multiplicity of T Tauri stars. I then present a series of studies focusing on the multiplicity and properties of optically undetected, heavily embedded protostars. These objects are much younger than the previously studied pre-main-sequence stars, and they therefore offer a closer look at the primordial population of multiple systems.

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Multiplicity Among Young Stars and Brown Dwarfs

Multiple systems are a common outcome and an important diagnostic of the star and brown dwarf formation processes. Here I will report the results of sensitive adaptive optics imaging and radial velocity surveys of large target samples in nearby young regions, and discuss their implications.

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Near-IR Spectral Properties of Young Brown Dwarfs

Determining accurate masses of young brown dwarfs, as found by placing them on an H-R diagram, has proven a difficult task. Not only are the evolutionary models untested in the low temperature/low gravity regime, but the derived temperatures (from either model fits or from the spectral types) of an object can vary by ~500 K depending on the method used (e.g., recent papers on Oph1622-2405AB). Clearly, tighter constraints on the gravities and temperatures of young brown dwarfs are necessary to determine accurate masses. We present moderate resolution (R=1200-1800) near-IR spectra of a sample of ~50 young brown dwarfs and low mass stars. The strength of the alkali metal features in the near-IR spectra of late-M/early-L type objects is known to be very sensitive to surface gravity, and hence age. Using gravities determined from the alkali metal features, we examine the gravity sensitivity of the H-band continuum shape. For the subset of our sample having circumstellar disks, we compare the surface gravity and accretion indicators in their near-IR spectra with their disk properties as determined from Spitzer IRS, IRAC and MIPS data.
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The Origin of Brown Dwarfs

I propose to review the current state of observational and theoretical work on the formation of brown dwarfs. I will begin by describing the latest measurements of various properties of brown dwarfs, including their initial mass function, binarity, circumstellar environment (disks, accretion, envelopes), and spatial and velocity distributions at birth. These observational constraints will be compared to similar measurements for stars, and then compared to the predictions of theories for the formation of brown dwarfs, such as embryo ejection, turbulent fragmentation, and photo-evaporation.

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Observational constraints on the formation of very low-mass objects

Observational results relevant for understanding the formation of very low-mass stars, brown dwarfs, and planetary-mass objects are summarized. New observational results that constrain scenarios for the formation of very low-mass objects are presented. These results include: a) A new estimate of the mass function down to 6 Jupiter masses in the Sigma Orionis cluster b) Spitzer detection of infrared excess in Sigma Orionis cluster planets c) Additional evidence for cluster membership of the 3 Jupiter mass object SOri70 d) An Halpha emission search for a widely distributed population of substellar T Tauri analogs

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Magnetic Fields in Star and Planet Formation

We present self-consistent models of disk accretion driven by the magneto-rotational instability associated with magnetic fields dragged in by a process of gravitational collapse from rotating, magnetized, molecular cloud cores. We compare such star-formation models with constraints from astronomical observations, meteoritic investigations, and comet sample returns. We show that previous theoretical studies have missed two crucial effects: (1) the fact that diffusion is occurring not only via a "viscous" redistribution of angular momentum but also by a non-ideal drift of inwardly moving matter across magnetic field lines that thread vertically through the disk, and (2) that realistic circumstances may result in magnetically pinched disks which rotate at substantially sub-Keplerian speeds. We also argue that the complete data set cannot be understood for sun-like stars without incorporating the interaction of the inner edge of the accretion disk with the magnetosphere of the central star that results in X-winds and funnel flows, with important, incompletely examined, consequences for the processes of planet formation.
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Disk fragmentation, the brown dwarf desert, and the stellar upper mass limit

All stars form through disks, and some are proposed to form within disks around other protostars. The success or failure of disk accretion therefore leaves its mark on the distribution of stellar masses. Protostellar accretion disks fragment, thanks to self-gravity, wherever the temperature falls below a threshold value set by the mass supply rate. Once created, fragments might remain as low-mass companions or grow to rival their central star, which can itself be starved of gas if fragmentation is rapid enough. Fragmentation is strongly suppressed around low-mass stars, because of heating by stellar irradiation and viscosity. This provides an explanation for the brown dwarf desert and a suppression of the brown dwarf population (compared to isothermal simulations). More massive protostars are increasingly susceptible to disk fragmentation, however – most dramatically for accretion rapid enough to reach the stellar upper mass limit. I discuss the physics underlying this trend, and comment on the implications for the two ends of the stellar initial mass function.

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Fragmentation of protoplanetary disks into giant planets

In the gravitational instability model Jupiter-size clumps form as a result of fragmentation of a massive gaseous protoplanetary disk. The ability of the disk to cool fast is essential for fragmentation to happen. I will review the results of SPH simulations of disk instability with various treatments of radiation physics, including radiative transfer with the diffusion approximation. I will then discuss the conditions required for fragmentation in the broader context of protostellar disk formation. Finally, I will show the results of a code comparison project in which grid-based and particle-based simulations are performed starting from the same initial model of a massive protoplanetary disk.

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Can giant planets form by gravitational instability?

Gravitational instability has been proposed as a possible mechanism of rapid formation of gas giant planets. In this talk I will revise the viability of this avenue of planet genesis by investigating the conditions under which gravitationally unstable disks can fragment into bound objects (to become protoplanets later on). Strong analytical constraints on the properties of disks in which planets can form by gravitational instability will be presented. I will show that planet formation in a typical protoplanetary disk (consistent with the observed properties of both disks and planets) is not very likely.
It is generally thought that protoplanetary disks embedded in envelopes are more massive and thus are more susceptible to gravitational instabilities (GIs). We present three-dimensional radiative hydrodynamics simulations of protoplanetary disks in the presence of envelope irradiation. We find that, for a disk with a moderate mass around a young star of 0.5 Msun, envelope irradiation tends to weaken and even suppress GIs as the irradiating flux is increased. The global mass transport induced by GIs is dominated by the low-order modes, and mild irradiation preferentially suppresses higher-order modes. As a result, gravitational torques and mass inflows are actually enhanced by mild irradiation. None of the simulations produce dense clumps or rapid cooling by convection, arguing against direct formation of giant planets by disk instability in irradiated disks. We also report results from a preliminary simulation with $\text{Tirr}(r) \sim r^{-1/2}$ to mimic the surface temperature distribution of a stellar irradiated disk and interesting comparisons with $\text{Tirr}(r) = \text{constant}$ cases can be made.

Disc fragmentation has been proposed as a possible mechanism for the formation of planets around young stars. This mechanism works only if the disc can cool efficiently enough to allow for proto-condensations to grow. Disc simulations have produced contradictory results about whether this is feasible or not (e.g. Durisen et al., Boss et al.). We will present radiative-hydrodynamic (RT-SPH) simulations of discs, using a newly developed method that accounts for the radiative transfer within proto-condensations. The effects (i) of the rotational and vibrational degrees of freedom of H2, H2 dissociation, (ii) opacity changes due to e.g. the melting of dust ices and the sublimation of dust, and (iii) thermal inertia, can all be captured at minimal computational cost. Our simulations suggest that discs cannot fragment within $\sim 100$ AU from the central star. However, massive discs can fragment at distances larger than $\sim 100$ AU to produce brown dwarfs, and possibly planets and low-mass hydrogen-burning stars. This result agrees with recent analytic calculations (Whitworth & Stamatellos 2006).

Turbulence plays a central role in protostellar disks as it controls accretion, brings grains together to build larger bodies and modifies the orbital migration of protoplanets. Turbulence is driven by magnetorotational instability if the gas is sufficiently ionized to couple to magnetic fields. Cosmic rays and X-rays ionize only the surface layers of the terrestrial planet formation region, possibly leaving the midplane as a quiescent "dead zone". We have explored whether the dead zone is eliminated under favorable conditions leaving the whole disk turbulent. We used 3-D resistive-MHD
computer calculations including a simplified time-dependent ionization and recombination reaction network. If gas-phase metal atoms are present while sub-micron grains are absent, the timescales for recombination and turbulent mixing are similar, and ionized material from the surface layers reaches the midplane fast enough for weak coupling of the gas to the magnetic fields. Although the midplane remains non-turbulent, the magnetic stresses average just a few times less than in the active layers. The dead zone is effectively eliminated and accretion proceeds throughout. However the midplane flow is fundamentally different from the surface layers as it is driven by smooth large-scale magnetic fields, providing a novel environment for planet formation.

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High Resolution SMA Imaging of the LkH-alpha 330 Transitional Disk
The evolutionary processes transforming massive, gas-rich circumstellar disks into tenuous, gas-poor debris disks are still not well understood. During this crucial interval, planet(esimal)s form and the remaining disk material is accreted or dispersed. Mid-infrared spectrophotometry of proto-planetary disks have revealed a small sub-class of objects with spectral energy distributions (SEDs) that suggest the presence of large inner gaps with low dust content, often interpreted as a signature of young planets. However, SEDs are notoriously difficult to interpret as multiple physical scenarios can result in the same SED. We present some of the first direct evidence supporting the gap hypothesis in the form of a SMA 340 GHz continuum map resolving the inner disk hole in the disk around pre-main sequence star LkH-alpha 330. The hole, first discovered through mid-IR spectroscopy, has a diameter 0.35 arcseconds, corresponding to 80 AU at the distance of the Perseus molecular cloud, in excellent agreement with predictions from SED modeling. Because these observations trace optically thin emission in the Rayleigh-Jeans regime, the data are exquisitely sensitive to the mass surface density profile in the disk. In combination with modeling, these data constrain the gap properties and help determine the most likely evolutionary processes active in this young disk.

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The TEXES/Gemini Survey of H2 in Protoplanetary Disks
In July and November 2006, we searched for mid-infrared pure rotational H2 emission from young stellar objects with disks using TEXES, the Texas Echelon-cross-Echelle Spectrograph on Gemini-North. TEXES is a high spectral resolution, mid-infrared spectrograph available to the astronomical community on both the NASA IRTF and Gemini-North telescopes. We gave highest priority to observations of each target at the J=3-1 (17.035 microns) and J=4-2 (12.279 microns) settings. Sources with a detection at either setting were followed up with observations at the J=6-4 (8.026 microns) setting to constrain the temperature of the emitting gas. Flux ratios of the three lines are sensitive to gas temperatures between 200 and 800 K. We have observed 20 sources in at least one line. Our sample includes 5 class I sources, 7 class II/III sources, 2 FU Ori stars, 5 Herbig Ae/Be stars, and 1 debris disk. We have detected all three lines in four sources. Most of the lines we detect are narrow, FWHM \(< 10 \text{ km/s, and have small equivalent width. In these cases, ground-based high spectral resolution observations are more sensitive than observations with the Spitzer Space Telescope. The high spectral resolution available with TEXES, R~60,000 for J=3-1 and R~80,000 for J=4-2 and J=6-4, coupled with knowledge of\)
the disk inclination by other means, allows us to determine the radial location of the emitting gas. Non-detections provide limits on the amount of warm gas in regions where the dust is optically thin. Observations with TEXES are supported by NSF grant AST-0607312.

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**TEXES detection of water in a disk around RW Aur**

We present mid-infrared spectroscopy of water emission lines originating from the disk around the T Tauri star RW Aur A. The observations were made with TEXES on Gemini North with ~4 km/s spectral resolution in the 12-13 micron region. The line profiles are double peaked with a central velocity that is consistent with both the radial velocity of the star and the double-peaked CO spectrum at mm wavelengths (Cabrit et al. 2006). The velocity extent of the profiles shows that the water emission is tracing the disk near 1 AU, at radial distances that correspond to the terrestrial planets in our Solar System. The temperature of the gas traced by the water is about 500 K.

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**Investigating Inner Disk Structure with High Resolution Molecular Spectroscopy**

Observations of the inner regions of circumstellar disks are essential for obtaining a complete understanding of star and planet formation, but are difficult to obtain with conventional imaging techniques. High-resolution infrared molecular spectroscopy has recently emerged as a key technique for studying these complex regions, as molecular rovibrational emission specifically probes the temperatures and densities of inner disk surfaces. Additionally, high spectral resolution can provide spatial information since the emission arises from a differentially rotating Keplerian disk. We have undertaken an extensive M-band survey of T Tauri and HAe/Be disks with NIRSPEC, a high-resolution echelle spectrograph on the Keck II telescope, with the goal of understanding inner disk structure and evolution. We present results from an analysis of emission line shapes, which imply inner disk structure consistent with results from IR interferometry, but suggest differences between disks around high mass and low mass stars, and between classical and transitional disks. We also discuss preliminary analyses of inner disk temperatures and densities, with the ultimate goal of integrating spectroscopy with spectral energy distributions to constrain radiative transfer models.

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**The hot inner disk of FU Ori**

We have constructed a detailed radiative transfer disk model which reproduces the main features of the spectrum of the outbursting young stellar object FU Orionis from ~4000 angstrom, to ~8 micron. Using an estimated visual extinction $A_V \sim 1.5$, a steady disk model with a central star mass 0.3 solar mass and a mass accretion rate around $2\times10^{-4}$ solar mass per year can reproduce the spectral energy distribution of FU Ori. The spectrum with this lower extinction value than previous analysis is well fitted by the steady disk model, which requires less extra energy dissipation of the boundary layer in the inner disk. Using the mid-infrared spectrum obtained by the Infrared Spectrograph (IRS) on board the Spitzer Space Telescope,
we estimate that the outer radius of the hot, rapidly accreting inner disk is around 1 AU, and if the irradiation of this hot inner disk to the outer cool disk is considered, the outer radius of this inner disk may be reduced by a factor of up to two in order to fit the overall IRS spectrum. In either case, the radius is inconsistent with a pure thermal instability model for the outburst. Our radiative transfer model implies that the central disk temperature $>1000$ K out to $\sim 1$ AU, suggesting that the magnetorotational instability can be supported out to that radius. Assuming that the $\sim 100$yr decay timescale in brightness of FU Ori represents the viscous timescale of the hot inner disk, we estimate the viscosity parameter to be $\alpha \sim 0.1 - 0.01$ in the outburst state, consistent with numerical simulations of the magnetorotational instability in disks. The radial extent of the high mass accretion region is inconsistent with the model of Bell & Lin, but may be consistent with theories incorporating both gravitational and magnetorotational instabilities.

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**Probing Protoplanetary Disk Evolution with the HI 21cm Line**

Little is known about the gas disk dispersal timescales in the planet formation process. Disks have a complex chemical structure and wide range of excitation conditions, making the interpretation of line observations difficult. Detailed chemo-physical disk models are used to predict the HI abundance for a wide range of disk evolutionary stages. HI traces the surface layers and the HI line, if detected, can be used to study the effects of UV, X-ray irradiation and evaporation in addition to the disk kinematics. We use a simple radiative transfer approach to convert the model disk parameters into predicted HI 21cm line maps and spectral profiles. These are compared to upper limits on the 21cm emission from the Australia Telescope Compact Array and Giant Meterwave Radio Telescope to obtain limits on the total disk mass for Herbig Ae, T Tauri and debris disk stars. We also discuss more recent VLA observations of the protoplanetary disks in Orion, where we looked for the HI 21cm line in absorption against the bright nebula background. As an outlook, we briefly address the capabilities of the planned Square Kilometer Array for imaging the surfaces of disks during the entire planet forming stage.

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**Studies of Protoplanetary Disk Evolution in the Serpens Molecular Cloud**

We are conducting an optical spectroscopic survey designed to confirm the youth and determine spectral types of young stellar objects candidates (YSOc) with infrared excess, belonging to a new young stellar population in the Serpens Molecular Cloud, discovered by the Spitzer Legacy program "From Molecular Cores to Planet-Forming Disks" (c2d). The optical spectra cover the Halpha line, used to characterize accretion and distinguish classical T Tauri stars (CTTS) from weak T Tauri stars (WTTS). Spectral types are use to constrain the modeling of spectral energy distributions (SED) for the sources, together with 2MASS and infrared photometry points from the c2d catalog. We discuss disk evolution and the possibility of multiple paths from thick to thin disks, through grain growth or gap opening, in the evolution from class II to class III sources.
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Disks in Transition Around Pre-Main Sequence Stars

Circumstellar disks are essential in the evolution of stars and planets. It is believed that the formation of these disks is a natural outcome of the star formation process and that with time the disk becomes the principle supplier of the material that eventually makes up a star as well as the solids that eventually coalesce into planetary systems, much like our own solar system. The finer details of how circumstellar disks evolve are still debated. The way in which the disk material dissipates is not well understood, specifically with regard to the physical processes which lead to the disappearance of the inner regions of a disk, a characteristic observed in transition disks. Transition disks have characteristics that fall between those objects that have clear evidence for disks and those objects with no disk material. Given that circumstellar disks are most easily detected in the infrared, the Spitzer Space Telescope has dramatically improved the ability to identify and study these objects by giving us detailed spectral energy distributions (SEDs) for pre-main sequence stars in the wavelength range 3.6-35 microns, corresponding to regions ∼0.1-5 AU from the central star. With our disk modeling codes, we can model the SEDs of these objects, providing important constraints on disk evolution and here we will present our results.

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Dust dynamics during protoplanetary disc clearing

We consider the dynamics of dust and gas during the clearing of protoplanetary discs. We work within the context of a photoevaporation/viscous model for the evolution of the gas disc, and use a two-fluid model to study the dynamics of dust grains as the gas disc is cleared. Micron-sized grains remain well-coupled to the gas, but larger (mm-sized) grains are subject to inward migration from large radii (∼50AU), suggesting that the timescale for grain growth in the outer disc is ∼10^4 − 10^5 yr. We describe in detail the observable appearance of discs during clearing, and find that pressure gradients in the gas disc result in a strong enhancement of the local dust-to-gas ratio in a ring near to the inner disc edge. We suggest that observations of disc masses and accretion rates provide a straightforward means of discriminating between different models of disc clearing, and compare our results with recent observations of "transitional" discs.

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Multiwavelength Imaging of Edge-on Circumstellar Disks

We present the first results from a Hubble Space Telescope imaging study of 14 edge-on young stellar object disks. The target objects all have pre-existing Hubble or adaptive optics imaging in either the optical or near-infrared, but not at both wavelengths. The new observations extend the observed wavelength baseline to 0.6-2.0 microns in 12 of these objects. These data allow us to characterize changes in the structure of the reflection nebulosity with wavelength, changes which should be diagnostic of the grain properties in these systems. We will present the optical and near-IR images, and initial scattered light models for a few of the objects.
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The inner dust rim of Herbig Ae star - MWC275: A view into the gas to dust transition region
with John Monnier, Tim Harries, Rafael Millan-Gabet & Theo ten Brummelaar

We have used the CHARA interferometer array to completely resolve out the the dust evaporation front in Herbig Ae star - MWC 275. Model fits to the data suggest that we have detected gas emission in the near infrared from within the dust destruction radius. We also present theoretical results showing that dust grain growth and settling will have dramatic effects on the structure of the inner rim in YSOs and these effects must be included to fully understand the near & mid-IR SEDS and high resolution interferometry data.

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X-rays and Planet Formation

X-ray studies have established that low-mass stars exhibit their highest levels of magnetic activity during their pre-main sequence phases when planet formation occurs. Our understanding of this activity, and particularly violent magnetic reconnection flares, has been greatly advanced by recent studies such as the Chandra Orion Ultradeep Project (COUP). COUP spectroscopy provides two lines of evidence that X-rays efficiently illuminate and ionize the protoplanetary disks. This may have dramatically affect disk gases: induction of MHD turbulence via the MRI instability with subsequent suppression of protoplanetary migration, heating of disk outer layers, catalysis of nonequilibrium chemistry, and so forth. Flare effects on disk solids may address long-standing meteoritic issues such as the production of short-lived radionuclides and the flash melting of chondrules. We conclude that solar systems form in cool dark disks which are likely irradiated by millions of violent magnetic reconnection flare events.

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Dead zones and the growth of giant planets

Dead zones (DZs) are dense regions in the interiors of protoplanetary disks that are too poorly ionized to support MRI instabilities and turbulence. The gap opening masses of planets are therefore very different within and outside DZs and we have shown (Matsumura & Pudritz 2006) that this can account for low versus high mass planets. In this talk, we also present new numerical simulations of planetary-disk interaction over the lifetime of disks, that follow the formation of massive planets as they accrete and migrate in disks with evolving dead zones.

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Saving Planetary Systems: Dead Zones & Planetary Migration

The timescale for planetary migration in protoplanetary disks is a couple of orders of magnitude shorter than the disk lifetime. This discrepancy implies the existence of some mechanism to stop or slow down planet migration effectively. Assuming that the primary source of the disk’s viscosity is
the magneto-rotational instability (MRI) turbulence, we show that the low viscosity region in a disk called a "dead zone" can offer a possible solution to this problem. Using a hybrid numerical code which combines a symplectic N-body integrator SyMBA and a one-dimensional disk model, we show that both type I and type II migration will be strongly affected by dead zones. Type II migrators are slowed in the dead zone due to the lower viscosity there. Planets which execute type I migration in a standard disk, on the other hand, tend to open a gap inside the dead zone due to the lower gap-opening mass there. As a result, even the migration of an Earth mass planet is slowed inside the dead zone. We will also show that this mechanism can account for hot Jupiters.

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Chemistry in evolving protoplanetary disks  
This talk presents an overview of recent work by our group on observations and models of protoplanetary disks in various stages of evolution. Observationally, recent spectroscopic data on ices, silicates, PAHs and hot organic gases obtained in the context of the Spitzer Space Telescope ‘Cores to Disks’ (c2d) Legacy program will be presented, complemented by ground-based infrared and submillimeter data. The results will be discussed in the context of physical and chemical models of flared and non-flared disks and their evolution from protostellar regions to the debris disk phase. Special attention will put on the importance of an accurate description of the photoprocesses as grains grow and disks evolve from the gas-rich to the gas-poor phase.

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A Submillimeter View of Protoplanetary Disks  
I will present both single-dish and high resolution submillimeter observations of circumstellar disks in the Tau-Aur and Oph-Sco regions, as well as the Trapezium Cluster in Orion. Resolved observations of the former allow us to measure disk sizes and surface density profiles. The results are compared to models of viscous evolution. The latter study includes the first mass measurements of the Orion proplyds. That initial Orion survey is being extended to include disks outside the cluster center. As we build up statistics, we aim to measure and compare the disk mass function in the two very different star forming environments.

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Spitzer Constraints on Primordial and Debris Disk Evolution  
I will summarize results from two Spitzer programs designed to measure the evolution of primordial and debris disks. I will first examine disk properties as a function of stellar mass at a fixed age of \( \sim 5 \) Myr through a Spitzer photometric study of the Upper Sco OB Association. Primordial, optically thick disks at this age are preferentially found K- and M-stars, while disks around massive stars are more similar to debris systems. These results suggest that the mechanisms for dispersing primordial optically thick disks operate less efficiently on average for stars with masses <1 Msun.
I will also present results from the FEPS Legacy program designed to measure the evolution of debris disks as a function of time at a fixed stellar mass of about 1 Msun. Preliminary results suggest a nearly constant 24$\mu$m debris disk fraction for ages between 10 and 300 Myr, and a rapid decline in the 24 $\mu$m excess fraction at older ages.

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High-Resolution Observations of YSO Disks using Optical Interferometry

Newly-commissioned long-baseline interferometers can scrutinize galactic (and extragalactic) objects with nano-radian angular resolution. This incredible resolution allows us look into the inner accretion disks of young stellar objects (YSOs) in nearby star forming regions. The inner AU of these "protoplanetary" disks plays host to a variety of important and fascinating phenomena: it is the site of magnetospheric accretion lifting material off the disk, the disk material here mediates the orbital migration of newly formed "Hot Jupiter" exoplanets, and, of course, terrestrial planet building occurs in the the inner AU. Near-infrared observations can isolate the hot dust (and molecular) emission arising from the inner disk, while mid-IR data probe the cooler, outer dust. Here, I will give an overview of recent work in this field, results which have directly challenged existing paradigms of the inner accretion disk and the star-disk connection. Lastly, I will discuss new studies on the horizon, highlighting the possibility of direct imaging of the inner disk using the CHARA interferometer.

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Inside-Out Evacuation of Transitional T Tauri Disks

How protoplanetary disk matter loses angular momentum to accrete onto T Tauri stars is an unsolved problem. The magneto-rotational instability (MRI) supplies a powerful means of transport, but its application to protoplanetary disks, which are considered too poorly ionized to couple well to magnetic fields, is uncertain. We show that the MRI readily explains the observed accretion rates of newly discovered transitional disks, which are swept clean of micron-sized dust inside rim radii of 1-25 AU. The MRI drains gas from the vertically extended disk rim, which is directly exposed to ionizing stellar X-rays. The accretion rate is limited by the depth to which X-rays ionize the rim wall. In contrast to previous models of surface layer accretion, the entire disk inside the rim is MRI-active and accretes at a steady rate that is entirely set by conditions at the rim. Blown out by radiation pressure, dust largely fails to accrete with gas. Our picture defines a robust setting for theories of how planets grow and have their orbits shaped in viscous gas, and when combined with studies of photo-evaporative disk winds, provides a general framework for understanding how disks dissipate.

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Direct Imaging of Extrasolar Planets: The Gemini NICI Planet-Finding Campaign

Direct imaging is one of the most compelling (and thus far unachieved) methods for studying the properties and origin of extrasolar planets. NICI
(the Near-Infrared Coronagraphic Imager) is the new high contrast adaptive optics imager for the Gemini-South 8.1-meter telescope, tailored to direct detection of extrasolar planets through dual-channel methane-band coronagraphic imaging. Our team has been selected to carry out an extensive multi-year observing program beginning this year with NICI. Our Gemini NICI Planet-Finding Campaign is expected to be the largest and most sensitive imaging survey to date for massive (∼1 \textit{M}_\textit{jup}) planets around other stars.

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(1) University of Herfordshire (2) University of Hawaii (3) Penn State University (4) Astronomical Technology Centre

The Precision Radial Velocity Spectrometer (PRVS) is designed to provide high throughput Doppler reflex measurements. PRVS is designed to always be available and provide 1.0 to 1.8 micron high-resolution spectroscopy with very high stability over several years. It should thus provide for the detection of terrestrial-mass extra-solar planets in the habitable zones of low-mass stars. It should also be suitable for a wide range of other applications including studies of magnetic fields, young stellar objects, brown dwarfs, high redshift quasars and gamma-ray bursts. PRVS is scheduled to be the next Aspen-process instrument for the Gemini 8-meter telescopes and be available in 2010. http://www.roe.ac.uk/ukate/projects/prvs/

**Gomez de Castro, Ana, I.** Universidad Complutense de Madrid aig@mat.ucm.es

The influence of the jet engine on the evolution of the inner disk: an ultraviolet view

Young stellar objects are an excellent laboratory to study the physics of accretion and outflow. The impact of this physics on the evolution of the constituents of pre-main sequence systems (star, disk) and the relevance of ultraviolet instrumentation to study this process are outlined. Special emphasis is made on the spectral characterization of the gravito-magnetic engine as well as on the role of the engine on the evolution of the inner disk.

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The Physical Conditions of Accreting Gas in T Tauri Systems

We present a result from a multi-epoch low resolution near-infrared spectroscopic survey of actively accreting T Tauri stars in the Taurus-Auriga star forming region. Using CorMaSS, a cross-dispersed spectrograph with excellent wavelength coverage, we simultaneously observed multiple HI recombination lines of the Paschen and Brackett series transitions between 0.8 and 2.5 \textmu m. We compare our observed decrements to those predicted by hydrogen ion recombination line theory, Case B, and find a best fit to the models with 500 < T < 3000K and an electron density of $10^{10}$cm$^{-3}$. 

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Angular Momentum Regulation Through Star-Disk Interaction in NGC 2264 and the Orion Nebula

According to current evolutionary models, pre-main-sequence (PMS) stars contract by a factor of \( \sim 5 \) in radius during their PMS evolution. Were PMS stars to conserve their angular momentum, they would spin up by a factor of \( \sim 25 \) before arriving on the main-sequence. However, observations reveal slow rotators in young clusters of various ages, indicating that angular momentum is somehow removed from these objects. The mechanism by which spin-up is regulated as young stars contract is one of the longest-standing problems in star formation. Attempts to observationally confirm the prevailing theory that circumstellar disks regulate these rotation periods have produced mixed results. Using Spitzer data from NGC 2264 and the Orion Nebula Cluster (ONC), we show that a dramatic correlation between period and the presence of a disk can be seen once mass effects and sensitivity biases are removed from the sample. Our results represent the strongest evidence to date that star-disk interaction regulates the angular momentum of PMS stars. We use Monte Carlo simulations to reproduce the period distributions of stars with and without a disk in NGC 2264 and the ONC and to constrain disk-regulation parameters. Our models use the evolution of stellar radii predicted by theoretical tracks to evolve the periods of unregulated stars and to calculate the amount of angular momentum drained as a function of time from stars regulated by disks.

A Search for Disk-Locking in the Chamaeleon I and Taurus-Auriga Star Forming Regions

We investigated the connection between the presence of disks and stellar rotation. Disk-locking theory predicts that accreting stars are preferentially slow rotators compared to their peers. If true, classical T Tauri stars (CTTS), which are accreting, should have observably lower \( v \sin i \) values compared to weak-lined T Tauri stars (WTTS), which are not accreting based on weak H-alpha emission. We present our findings from high-resolution optical spectra taken with the Magellan Inamori Kyocera Echelle (MIKE) spectrograph on the Magellan Clay 6.5-m telescope located at the Las Campanas Observatory of 207 T Tauri stars in the Chamaeleon I and Taurus-Auriga star forming regions.

Disk Evolution & Planet Formation at 10-20 Myr: Observations of h & chi Persei

I shall discuss results from a recent Spitzer/IRAC and Hectospec survey of \( \sim 13 \) Myr h & chi Persei, the most massive, evolved open cluster within 2.5 kpc of the Sun. The goal of this study is to constrain circumstellar disk evolution and planet formation theories at ages of 10-20 Myr. I find evidence for a mass/spectral type-dependent and (stellocentric) distance-dependent evolution of (presumably) 2nd-generation circumstellar disks for sources more massive than the Sun. SED modeling of these disks reveals that their emission likely results from collisionally-produced debris from planet formation occurring on \( \sim \)AU scales. I also find preliminary evidence for a mass/spectral type-dependence on gas accretion signatures.
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A blue needle pointing west: Extreme asymmetry in the HD 15115 debris disk
with Michael P., Fitzgerald and James R. Graham

We present the first scattered light images of an edge-on dust disk surrounding the F2V star HD 15115 using the Hubble Space Telescope in the optical, and Keck adaptive optics in the near-infrared. With a needle-like morphology, HD 15115 represents the most asymmetric debris disk observed to date. The east side of the disk is detected to $\sim 315$ AU radius, whereas the west side of the disk has radius $> 550$ AU. We find a blue optical to near-infrared scattered light color relative to the star that indicates grain scattering properties similar to the AU Mic debris disk. The existence of a large debris disk surrounding HD 15115 adds further evidence for membership in the Beta Pic Moving Group. We hypothesize that the extreme disk asymmetry is due to dynamical perturbations from HIP 12545, another Beta Pic Moving Group member 0.38 pc east of HD 15115 that shares a common proper motion vector, heliocentric distance, Galactic space velocity, and age.

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Exploring the Geometry of Herbig Ae/Be Protoplanetary Disks in the Mid-Infrared

We have imaged the circumstellar environments of 20 Herbig Ae/Be stars at 12 and 18 microns using Michelle on Gemini North and T-ReCS on Gemini South. Five sources are clearly spatially resolved at both wavelengths with disks radius in the range of 50 to 200 AU. Another four sources are marginally resolved at least at one wavelength. The remaining 11 sources have compact unresolved mid-infrared emission. There is a strong correlation between the spatially resolved sources and their mid-IR colors, where all the resolved sources are brighter at 18 microns than at 12 microns. We also find that mid-infrared disk sizes decrease with stellar age. Our results are well explained by a passively irradiated disk model with a puffed-up inner rim. In this scenario, mid-infrared emitting dust grains are located in the spatially unresolved inner rim and on the flaring surface of the disk. Younger systems will have large flaring disks, as these systems evolve, an increase in grain sizes causes the disks to gradually collapse behind the shadow of the inner rim, decreasing the size of the mid-infrared emission. Eventually, disks become self-shadowed, very cold at larger radii and mid-infrared emission is limited to the unresolved inner rim.

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HD 32297: Another Beta Pic?

We have recently resolved the debris disk of the A star HD 32297 with subarcsecond-resolution imaging at 11 and 18 microns, adding another resolved source to the current handful of disks that have been resolved in the mid-IR. This result follows the resolution of the source in scattered light at optical and near-IR wavelengths (Schneider et al. 2005, Kalas 2005). In both optical and mid-IR images, the disk spans $\sim 100$ AU in radius, while in near-IR images the disk radius extends beyond 1400 AU. These measurements are all comparable to those made from images of the archetypal debris disk of Beta Pic. In this work, we compare characteristics such as fractional IR luminosity, age, and morphology of these two sources, and consider the significance of any similarities.
Dust Dynamics, Surface Brightness Profiles, and Thermal Spectra of Debris Disks: The Case of AU Mic

AU Microscopii is a 12 Myr old M dwarf that harbors an optically thin, edge-on disk of dust. The scattered light surface brightness falls with projected distance $b$ from the star as $b^{-a}$; within $b = 43$ AU, $a = 1-2$, while outside 43 AU, $a = 4-5$. We devise a theory to explain this profile. At a stellocentric distance $r = r_{BR} = 43$ AU, we posit a ring of parent bodies on circular orbits: the "birth ring," wherein micron-sized grains are born from the collisional attrition of parent bodies. The "inner disk" at $r < r_{BR}$ contains grains that migrate inward by corpuscular and Poynting-Robertson (CPR) drag. The "outer disk" at $r > r_{BR}$ comprises grains just large enough to remain bound to the star, on orbits rendered highly eccentric by stellar wind and radiation pressure. How the vertical optical depth $\tau$ scales with $r$ depends on the fraction of grains that migrate inward by CPR drag without suffering a collision. If this fraction is large, the inner disk and birth ring share the same optical depth, and $\tau$ scales as $r^{-5/2}$ in the outer disk. By contrast, under collision-dominated conditions, the inner disk is empty, and $\tau$ scales as $r^{-3/2}$ outside. These scaling relations, which we derive analytically and confirm numerically, are robust against uncertainties in the grain size distribution. By simultaneously modeling the surface brightness and thermal spectrum, we break model degeneracies to establish that the AU Mic system is collision-dominated, and that its narrow birth ring contains a lunar mass of decimeter-sized bodies. The inner disk is devoid of micron-sized grains; the surface brightness at $b < 43$ AU, the disk’s V-H color should not vary with $b$; outside, the disk must become bluer as ever smaller grains are probed.

The Dust and Gas Around beta Pictoris

We have obtained Spitzer IRS 5.5 - 35 micron spectroscopy of the debris disk around beta Pictoris. In addition to the 10 micron silicate emission feature originally observed from the ground, we for the first time also detect the silicate emission bands at longer wavelengths. The IRS dust emission spectrum is well reproduced by a dust model consisting of fluffy cometary and crystalline olivine aggregates, with an additional population of warm dust to account for the emission at $\lambda < 15$ micron. We searched for line emission from molecular hydrogen and atomic S I, Fe II, and Si II gas but detected none. We place a 3 sigma upper limit of $< 17 M_{\text{earth}}$ on the H2 S(1) gas mass, assuming an excitation temperature of $T_{ex} = 100$ K, suggesting that there is less gas in this system than is required to form the envelope of Jupiter. We hypothesize that the atomic Na I gas observed in Keplerian rotation around beta Pictoris may be produced by photon-stimulated desorption from circumstellar dust grains.

A Search for Warm Dust in the Habitable Zones

As part of a program to search for and characterize the presence of warm dust in the habitable zones around nearby solar like stars, we have search
for dust within a few AU of the central stars. We have observed 146 FGKM stars with the Spitzer short-low and long-low IRS modules, and using the FLUOR instrument on the CHARA interferometer, we have observed the main sequence A star beta Leo, which is known to have a debris disk. We present the initial findings of the Spitzer and interferometry programs.

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Toward understanding the long-term decay of debris disks  
with Loehne, T. and Rodmann, J.

Infrared surveys indicate a tendency of debris disks to gradually decline with the stellar age over timescales of hundreds of Myr. Furthermore, it was found that the decay is an inside-out process, in which outer parts of the disks survive longer than the inner ones. One possible explanation is that collisional depletion of planetesimals that act as sources of visible dust is faster in the inner regions, due to higher collisional rates and velocities there. Using our collisional code, we simulated the long-term evolution of debris disks with various initial masses and distributions of material around G stars over a Gyr timescale and computed the resulted decay of fluxes at 24 and 70 µm. We will present the simulation results and compare them with the Spitzer data for a selection of G stars from the Spitzer/FEPS Legacy program and some other surveys.

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Photoevaporation of Disks Around Young Stars

We focus on the photoevaporation of young, planet-forming disks by the radiation from the central star. We contrast the effects of far ultraviolet FUV (photon energies less than 13.6 eV), extreme ultraviolet EUV (between 13.6 and 100 eV), and X-ray photons on the photoevaporation process. EUV photons have been treated previously. They have little effect until the disk accretion rate drops below a critical value, which is about $10^{-9}$ solar masses per year for a typical solar mass star. They then create a gap at a few AU, the inner disk rapidly accretes onto the star, and the EUV then evaporates the outer disk from inside out. We mainly discuss the effects of FUV and X-ray photons, and will report on ongoing work as a function of stellar mass, the surface density distribution of the disk, and the dust properties in the disk. Photoevaporation timescales are short and, in conjunction with viscous accretion and spreading, are compatible with the observed dispersal of disks on Myr timescales. We conclude by discussing effects on planet formation.

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Prompt UV-induced Planetesimal Formation in Disks

All proto-planetary disks are irradiated by strong UV radiation fields generated by their central stars (“self-irradiation”); some are illuminated by nearby massive stars in the parent cluster (“external irradiation”). I will review recent observations of photo-evaporating systems and discuss the consequences of UV-induced mass-loss for viscous disks in which grains have grown and started settled into the disk mid-plane. Because photo-ablation...
occurs at the disk surface, the UV-induced wind tends to be metal-depleted. Thus, the surviving disk becomes metal-enriched. The metallicity of the disk mid-plane can increase to the point where gravitational instabilities can rapidly form kilometer-sized planetesimals, thereby bypassing the thorny problems associated with grain growth from micron-sized dust to large bodies. X-ray and infrared observations of Orion’s proplyds provide evidence that some photo-ablation flows are indeed metal-depleted.

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**Modeling the dust size distribution in evolving disks**

We propose a new set of simplified evolution equations to model the growth and migration of grains in a protostellar disk. Starting from the assumption that the grain size distribution function always maintains a power-law structure approximating the average outcome of the exact collision/destruction equation, the model can focus on the calculation of the growth rate of the largest grains only. The coupled evolution equations for the maximum grain size, surface density and gas surface density are then presented and solved self-consistently using a simple one-dimensional disk model. The corresponding disk SEDs are then estimated. Various simulations are presented for various stellar types (from brown dwarves to HAeBe stars) and various initial conditions (smaller/larger initial disk radii, smaller/larger initial disk masses, smaller/larger metallicity). In each case, the model is evolved until total dispersion of the gas by photoevaporation or accretion, yielding predictions for the amount and location of the remaining planetary building blocks (in the form of proto-planetary embryos). The SED predictions are studied in the light of recent observations of transition disks, and in particular those presenting evidence for inner holes together with ongoing gas accretion.

**Youdin, Andrew** CITA, U. of Toronto youdin@gmail.com

**Aerodynamic Processes in Planetesimal Formation**

I will briefly review the proposed formation mechanisms for km-sized planetesimals from dust grains: collisional coagulation and gravitational instability of solid particles. The diffusion of particles in a turbulent gas disk has been identified as the main obstacle to gravitational collapse. I will present recent calculations of turbulent particle stirring that include orbital dynamics (Youdin & Lithwick, submitted). This work yields a new result for particle diffusion, and hence the Schmidt number (ratio of gas to particle diffusion coefficients). Finally I will emphasize the importance of aerodynamic feedback effects, i.e. when particle inertia influences gas dynamics through drag forces. Drag feedback generally produces particle clumping. The basic mechanism is the linear streaming instability, which arises from aerodynamic feedback in idealized unstratified disks (Youdin & Goodman 2005, Youdin & Johansen 2007). Recent simulations show that the non-linear saturation of the streaming instability naturally produces particle overdensities of several hundred (Johansen & Youdin 2007). The gravitational collapse of such dense particle clumps into planetesimals will be addressed in the talk by Anders Johansen.
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**Planetesimal formation in turbulent traffic jams**

We investigate the gravitational attraction between dust particles embedded in the turbulent flow of a protoplanetary disk. The drag force between the gas and the dust causes meter-sized dust boulders to be concentrated in regions of the turbulent flow that are slightly overdense, either in gas, where the particles tend towards local pressure maxima, or in dust, due to the clumping effect of the streaming instability. We have developed a fully parallel numerical solver for the gravitational interaction between the boulders. The overdense regions are found to undergo gravitational fragmentation in disks that are similar in mass to the minimum mass solar nebula, forming a few gravitationally bound clumps with masses comparable to 1000-km solid bodies.

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**Henning, Thomas** MPI for Astronomy (MPIA) henning@mpia.de

**From molecular cloud dust to planetesimals**

An important link between star formation in molecular cloud cores, protoplanetary disk evolution, and extrasolar planets is provided by grain growth from submicron sizes to planetesimals. I will provide a theoretical framework for this process and discuss the major challenges to grow tiny particles to planetesimal sizes. In the second part of the talk I will present observational evidence for this process, mainly based on infrared spectroscopy and millimeter continuum data. I also intend to connect mineralogy data for protoplanetary disks to what we know from primitive material in the solar system.

**Rice, Ken** University of Edinburgh wkmr@roe.ac.uk

**Planetesimal formation in self-gravitating accretion discs**

One of the unsolved problems in the standard core accretion model for planet formation is how kilometer-sized planetesimals form from initially micron-sized dust grains. We consider here how solid particles evolve in a marginally stable, self-gravitating accretion disk. We find that the influence of gas drag causes solid particles to collect along the self-gravitating spiral structures, with the effect being most significant for those particles that have the largest drift velocities. These particles achieve densities that not only enhance their collisions rates, but that are potentially also high enough for further growth through direct gravitational collapse.
Blum, Jürgen Institute for Geophysics and Extraterrestrial Physics, TU Braunschweig j.blum@tu-bs.de

The Formation of Planetesimals - The Laboratory Perspective

Laboratory experiments on the formation of planetesimals have revealed interesting aspects about particle sticking, coagulation and the morphology of growing pre-planetesimal dust aggregates. They have, however, also set constraints to the formation scenarios for planetesimals by showing under which conditions collisions among dust aggregates do not lead to sticking. I will review the findings from the laboratory experiments and the implications for our understanding of planetesimal formation.

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From Star Dust to Interplanetary Dust

Presented here is a modern and expanded version of the original "Bird’s-Nest" paradigm by Greenberg and Gustafson (1981) that probably was the first to propose a model for comet dust based on a its evolution from interstellar grains. Even in its original form it presented a consistent physical model of comet dust as uniquely defined aggregate structures down to the level of chemical composition, size, core-mantle structure and shape of individual grains inside the aggregates. Variables was the alignment or lack thereof of grains within the aggregates, the overall aggregate size and indirectly the shape supported by astronomical observations and a combination of theoretical light scattering calculations with results from laboratory simulations. I will summarize a quarter century of laboratory data and key astronomical observations that have helped refine this model. The proposed expansion of the model to asteroid fragment grains will be presented along with a discussion of key processes in the accretion disk affecting the final dust aggregation geometry. Finally a set of recent laboratory data sets will be used to show how this evidence for the key processes may be observable in the scattered light or thermal emission from dust grains resulting from the breakup of planetesimals. The paradigm should be equally valid for exosolar planet systems as for our own and might help reveal differences in the dust accretion and early planet formation.

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Microgravity Experiments Probing Collision Processes in Protoplanetary Disks

with Daniel Heißelmann (TU Braunschweig), Germán Chaparro (Leiden), Guido van der Wolk (Groningen), Philipp Reißaus (Kayser-Threde GmbH), Helen J. Fraser (Strathclyde), and Jürgen Blum (TU Braunschweig)

We present results from our microgravity experiment to study particle collisions in the solar nebula during ESA’s 45th Parabolic Flight Campaign. Specifically, we investigate the impact behavior at ambient temperatures of dust aggregates (assembled from 1.5 μm SiO₂ spheres) that measure 0.2-6 mm across, are 85% porous, and possess velocities of 12-18 cm/s. These properties roughly simulate grains in protoplanetary disks that are initially supported by turbulent gas, but as they grow to centimeter sizes begin to settle to the midplane. Throughout this period, the play between sticking probability, fragmentation efficiency, mass exchange, and compaction behavior during encounters will help shape disk lifetime and the effectiveness of planet formation via grain growth. Using a vacuum chamber setup during parabolic flight, we began by firing individual agglomerates at a large target of similar, but denser dust structure. We followed with individual aggregate to aggregate collisions. We recorded over 100 separate impacts at
107 frames per second during 33 minutes of combined weightlessness. In this initial run, we observed a very low sticking probability (∼10%), only for very small agglomerates against a larger target. Semi-elastic collisions appear to dominate all encounters (∼80-90%) with occasional fragmentation observed.

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The Effect of Gas-Density Enhanced Regions on the Formation of Planetesimals via Gravitational Instability
The model of the formation of planetesimals through gravitational instability requires the density of solid particles in the central plane of the solar nebula to reach a critical value. As suggested by Youdin and Shu (2002), this density enhancement is due to the radial drift of small objects subject to gas-drag. Numerical simulations by Weidenschilling (2003) have shown that the collective motion resulted from turbulent stress on particles may inhibit their accumulation and prevent the disk to reach its critical density. The effect of turbulence may, however, be avoided, noting that during the evolution of a nebula, regions may appear where the density of the gas is locally enhanced. The combined effect of gas-drag and pressure gradient causes small objects, in the vicinity of such gas-density enhanced regions, to migrate towards and accumulate at the locations of the maximum gas pressure. Since the pressure gradient is non-existence at these locations, small particles accumulate at these regions and increase the local density of the disk’s solids. In a gas-density enhanced region with a long lifetime, the accumulation of particles may reach the critical value necessary to trigger gravitational instability. I will present the results of the simulations of the formation of such solid-density enhanced regions, and discuss the conditions for which the local disk-density is massive enough to start gravitational instability.

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Effect of the equation of state on the planet migration
Planet migration has been extensively studied analytically and numerically under the two assumptions of an infinitely thin and vertically isothermal disk. These two hypotheses deserve to be questioned. We perform 3D SPH simulations of a protoplanetary disk with a 1 Jupiter mass embedded planet initially located at 5 AU and free to move in response to the disk torques. We use the code GASOLINE with either a vertically isothermal equation of state or an adiabatic one but with including shock heating. Then we perform new simulations in the flux limited diffusion approximation. We find that the planet migrates much more slowly inwards in the adiabatic case than in the isothermal one. We conclude that a more realistic treatment of the energy equation is required in order to properly describe the planet migration and this could be part of the solution to the too high migration rate problem for planet formation.

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Gap formation in the dust layer of a protoplanetary disk (presented by Fouchet, Laure)
Planet-disk interactions have been mostly studied in the gas phase but the building of a gap in the settled dust layer is expected to show different
properties. Using a two-fluid, gas+dust SPH code, we investigate the gap formation by a planet fixed at 5 AU in the dust layer and find the gap to be cleaner than in the gas phase. We also find that there is a range of masses where a planet can open a gap in the dust layer when it doesn’t open one in the gas phase. This gives tighter constraints on the planet masses and dust grain sizes that will be inferred from future ALMA observations. We also discuss implications of the gap formation on planetesimal growth.

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Brownian Motion in Planetary Migration

A residual planetesimal disk of mass 10-100 Earth masses remained in the outer solar system following the birth of the giant planets, as implied by the existence of the Oort cloud, coagulation requirements for Pluto, and inefficiencies in planet formation. Upon gravitationally scattering planetesimal debris, planets migrate. Orbital migration can lead to resonance capture, as evidenced here in the Kuiper and asteroid belts, and abroad in extra-solar systems. Finite sizes of planetesimals render migration stochastic (“noisy”). At fixed disk mass, larger (fewer) planetesimals generate more noise. Extreme noise defeats resonance capture. We employ order-of-magnitude physics to construct an analytic theory for how a planet’s orbital semi-major axis fluctuates in response to random planetesimal scatterings. To retain a body in resonance, the planet’s semi-major axis must not random walk a distance greater than the resonant libration width. We translate this criterion into an analytic formula for the retention efficiency of the resonance as a function of system parameters, including planetesimal size. We verify our results with tailored numerical simulations. Application of our theory reveals that capture of Resonant Kuiper belt objects by a migrating Neptune remains effective if the bulk of the primordial disk was locked in bodies having sizes <O(100) km and if the fraction of disk mass in objects with sizes >1000 km was less than a few percent. Coagulation simulations produce a size distribution of primordial planetesimals that easily satisfies these constraints. We conclude that stochasticity did not interfere with, nor modify in any substantive way, Neptune’s ability to capture and retain Resonant Kuiper belt objects during its migration.

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A Magnetic Mechanism for Outward Planet Migration

We calculate the torque of a pre-main-sequence (PMS), solar-type star on a magnetically-linked orbiting gaseous protoplanet. This torque results from a toroidal magnetic field generated from the star’s poloidal (dipole) field by the twisting differential motion between the star’s rotation and the protoplanet’s revolution. Outside the corotation radius, where a protoplanet orbits slower than its host star spins, this torque transfers angular momentum from the star to the planet, halting inward migration and pushing the protoplanet away from the star. Necessary conditions for angular momentum transfer include the requirement that the Alfvén speed $v_A$ in the region magnetically linking a protoplanet to its host star exceeds the planet’s orbital speed $v_K$. In addition, the timescale for ohmic dissipation $\tau_D$ must exceed the protoplanet’s orbital period $P$ to ensure that the planet is magnetically coupled to its host star. For a typical protoplanet-star system, $v_A > v_K$ and $\tau_D > P$ only for giant gaseous protoplanets orbiting within about 0.05 AU ($P \simeq 3 – 4$ days) of an evolved PMS star. The observed “pile-up” of extrasolar planets having orbital periods of 3-4 days may be a signature of magnetic torques halting inwardly migrating protoplanets at the Alfvén radius where $v_A \simeq v_K$. A calculation of the time-dependent
semimajor axis of a magnetically-torqued protoplanet confirms that very little outward migration occurs beyond a few tenths of an AU, primarily because of the rapid drop in the strength of the magnetic field (and hence $v_A$ and the associated magnetic torque) with increasing distance from the central star.

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**Spin Evolution of Extra-Solar planets on Close Orbits by Tidal Interaction from Parents Stars**

Among detected exoplanets, we can select the class of planets, which move on close orbits. For rotational evolution of the planets, basic role has tidal and gravitational perturbations from a parent star. Known that a structure of planetary systems depends from effects of their own rotation. We consider rotary evolution of exoplanets at close orbits under action of tidal and gravitational perturbations. During investigation, we found evolutional trajectories of kinetic momentum vector for some exoplanets with circular orbits: TrES-2 ($a = 0.037$, $P = 2.5d$), OGLE-TR-56 ($a = 0.02$, $P = 1.2d$), OGLE-TR-113 b ($a = 0.02$, $P = 1.4$) and others; and with quasi-circular orbits. We are analyzed speed of planets evolution and probability of capture in resonant motion.

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**Axis rotation evolution of exoplanet in disk**

On early stage forming planetary system the gravitational and tidal interaction of a planet and disk are essential. The process of planetary formation significantly determine by the orbital-rotational characteristics of the planet. The rotation of the extra-solar planet characterizes by the position of the kinetic momentum vector in space and determines by gravitational, tidal and magnetic interactions of an exoplanet and protoplanetary disk. We model evolution of the vector kinetic momentum of exoplanets on early stage of formation planetary system under action tidal and gravitational interaction between gaseous exoplanet and disk. We have received various regimes of axis rotation evolution of planets for different values of parameters. The gallery of phase portraits shows the scenarios of cosmogonical evolution of the young exoplanet.

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**Extrasolar giant planet formation: Monte Carlo simulations**

The characteristics of the now over 200 known extrasolar planets begin to provide a database with which current planet formation theories can be put to the test. We use our core-accretion model that includes concurrent migration and disk evolution to perform Monte Carlo simulations of extrasolar giant planet formation. With probability distributions for the initial conditions derived from observations we thus generate populations of synthetic planets. We then determine the subset of synthetic planets that could actually be detected with current radial velocity or transit techniques. The properties of this subset are then compared in statistical tests with the observed extrasolar planets. We find that we can reproduce with high statistical significance the most important observed properties and correlations, per example the observed mass distribution, or the correlation of metallicity

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Stability of satellite systems during close interplanetary encounters

Satellite systems of EGPs may experience dynamical erosion either through planet-disk interactions or chance encounters with other planet-sized objects. The inner satellites of Jupiter and Saturn show strong resistance to erosion from encounters because of their close proximity to their parent planets (Beauge et al. 2002. Icarus 158, 483). Satellites of EGPs orbiting within a few AU of their stars will be affected more severely, both because their planet’s protective Hill spheres are smaller and because the chance of encountering Mars- or Earth-sized objects is greater. Here we revisit the result of Raymond et al. (2006. Science 313, 1413) in which a Jupiter migrates through a swarm of proto-Earths within the Habitable Zone of a Sun-like star and determine the fraction of encounters between a Jupiter and a proto-Earth that result in dynamical erosion of otherwise stable satellite systems.

An Unseen Companion for BD+201790?

with Hernán-Obispo M., De Castro E. & Cornide M.

The detailed analysis of spectra with high S/N can be used to detect the presence of active regions in different layers of active stars: spots on photosphere, plages and prominences on chromosphere and flares. We included BD +201790 in a comprehensive study of late type active stars to obtain high temporal and spectroscopic resolution spectra and analyse variations on equivalent width and line profile asymmetry of different magnetic indicators (mainly Ha (6562.9 Angstroms) and H? (4861 Angstroms) ). As part of the study, using cross-correlation techniques, we measured accurate heliocentric radial velocity, finding significant variations in short time period. We present here the study of the sources of these radial velocity variations, taking into account that several explanations should be analyse: activity features evolution, stellar companion light reflection and sub-stellar companion presence.

Status of the Keck ET Exoplanet Survey

The W. M. Keck Exoplanet Tracker (Keck ET) is a precision Doppler radial velocity instrument based on dispersed fixed-delay interferometry, a new technique that allows for multi-object RV surveying for extrasolar planets. Installed at the 2.5m Sloan telescope at Apache Point Observatory, the combination of Michelson interferometer and medium resolution spectrograph is designed for simultaneous precision Doppler measurements of up to 60 targets. Using the same technique, the single-object prototype ET installed at the KPNO 2.1m telescope was previously used to discover a new 0.49MJup (m sin i) planet, HD 102195b (ET-1). The Keck Exoplanet Tracker now yields 59 usable simultaneous fringing stellar spectra, of a quality
sufficient to attempt to detect short period hot-Jupiter type planets. Although systematic errors remain to be ironed out, typical photon limits for stellar data are now around the 30m/s level for magnitude V around 10.5 (best 6.9m/s at V=7.6). Further modifications are planned to try and improve this, and a number of targets showing interesting RV variability are also under investigation. Here we present updates from the most recent observing and engineering runs.

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Planet Detection and Simulations from Multi-Object Spectrograph Surveys
with Donald P. Schneider, Jian Ge
The development of multi-object spectrographs for use in radial velocity surveys is expected to increase the detection rate of extra-solar planets by at least an order of magnitude. The dramatic increase in data acquisition requires that a robust method be developed which is able to adequately screen the data for planet candidates. We present simulations of the expected results from a generic multi-object survey based on calculated noise models and sensitivity for the instrument and the known distribution of exoplanetary system parameters. This is applied to a survey of several fields using the W.M. Keck Exoplanet Tracker instrument, the design of which utilises a dispersed fixed-delay interferometer, which is currently being used on the Sloan Digital Sky Survey 2.5m telescope. We have developed code for automatically sifting and fitting the planet candidates produced by the survey to allow for fast follow-up observations to be conducted. The techniques presented here may be applied to a wide range of multi-object planet surveys.

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Detectability in radial velocity surveys and the distribution of extrasolar planet orbital parameters
The distribution of extrasolar planet masses, orbital periods and eccentricities contains important clues to the planet formation process and environment. Understanding these distributions requires a careful accounting of selection effects. We discuss the main selection effects in radial velocity surveys for planets, concentrating on the incompleteness for low masses and large eccentricities.

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A Planetary System Around HD 155358: The Lowest Metallicity Planet Host Star
We report the detection of two planetary mass companions to the solar-type star HD 155358. The two planets have orbital periods of 195.0 and 530.3 days, with eccentricities of 0.11 and 0.18. The minimum masses for these planets are 0.89 and 0.50 $M_{\text{Jup}}$, respectively. The orbits are close enough to each other, and the planets are sufficiently massive, that the planets are gravitationally interacting with each other, with their eccentricities and arguments of periastron varying with periods of 2300-2700 years. While large uncertainties remain in the determined orbital eccentricities, our orbital integration calculations indicate that our derived orbits would be dynamically stable for at least $10^8$ years. With a metallicity [Fe/H] of -0.68, HD
155358 is tied with the K1III giant planet host star HD 47536 for the lowest metallicity of any planet host star yet found. Thus, a star with only 21% of the heavy-element content of our Sun was still able to form a system of at least two Jovian-mass planets and have their orbits evolve to semi-major axes of 0.6–1.2 AU.

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Statistics from the EXPLORE/OC Planet Transit Search

We have conducted a photometric variable star search campaign, EXPLORE/OC, in pursuit of transiting extrasolar planets in southern open clusters. This massive and precise variability survey searched eight open clusters, and yielded ∼32000 light curves with 2-10 mmag photometric precision (rms) at typically 1000-2000 epochs per light curve, with magnitudes of 14<1<17. Our search yielded a handful of as yet unverified planet transit candidates. Also, our large yield of eclipsing binary stars (∼300) is allowing us to investigate distributions of binary star properties, and also evolution of the binary fraction as a function of cluster age.

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High-Contrast Imaging with Extreme AO and a Band-limited Mask

We have built a band-limited image mask for the AO-fed near-IR instrument, PHARO, at the Palomar Hale 200” telescope. We will use this technology in concert with an off-axis optical configuration that can deliver K-band Strehl ratios as high as 94%. We present here our predictions for performance and the first results using a fiber-coupled white light source. Observations commence in April, 2007. We will observe young and nearby stars, members of the TPF-C Top 100 list, known planet-bearing stars, and - since the mask has a linear geometry - visual binary stars.

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Planet-formation efficiency and time scales

According to the recently-updated core-accretion model, terrestrial planet formation is a robust process despite many growth barriers and disruptive obstacles. We show that, after the disk’s metallicity is enriched by photo-evaporation, grains readily form planetesimals which are effectively retained at the grains’ sublimation fronts. Through cohesive collisions, planetesimals grow into dynamically isolated embryos. Due to their tidal interaction with their nascent disks, the first-generation embryos migrated into their host stars. But, massive embryos are preserved and can grow into the cores of emerging proto gas giant planets during the transition between protostellar to debris disks. In competition with the declining gas supply, the formation probability of gas giant planets depends sensitively on the structure and evolution of their nascent disks.
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Hot gas bubbles around nascent planets: Influence on migration, accretion and detectability

We perform 3D radiation hydro simulations of Planet-Disk interaction including accretion of gas onto the planets and irradiation from the central star. As a follow up on previous work (Klahr & Kley 2006) we now study systematically the effects of radiation transport for lower mass planets (1-100 $M_{\text{earth}}$). We discuss the influence of proper thermodynamics on the migration rates and the possibilities to observe the planetary embryos early on in the womb of their mother disk.

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Debris disk evolution

Debris disks provide a unique insight into the evolution of extrasolar planetary systems, since by observing the dust content of many stars of different ages we are able to infer how individual disks must have evolved. However, while numerous surveys have been performed, there is no consensus as to how these disks evolve, and it is still not known whether the disks that can be detected are evolving in steady-state, or whether they are seen during a period of extreme dustiness, perhaps following a recent collision between massive planetesimals. Here I will present the results of a new model for the steady-state evolution of planetesimal belts. Application to the recent Spitzer surveys of A stars shows that it reproduces all the available statistics very well. Thus there is no need to invoke stochastic evolution to explain the majority of these systems. In contrast, application to sun-like stars shows that the disks at a few AU found around 2% of these stars cannot be evolving in steady-state. Rather this dust must be transient, and it is inferred that these systems may be undergoing epochs akin to the Late Heavy Bombardment in the solar system.

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Can We Detect Catastrophic Planetesimal Collisions in Debris Disks?

The birth of the Moon, thought to have resulted from the collision of a Mars-sized body with the proto-Earth, must have been a truly spectacular event. Would the occurrence of such a catastrophic collision in another planetary system be observable directly? If so, then we could begin to make a more concrete connection between important phases of the planet building process in our own and other planetary systems. I will highlight the best current evidence that for some disks we may indeed be seeing the aftermath of such catastrophic collisions. The key conclusions are that: 1. for the youngest debris disks, detailed images, particularly in the mid-IR, can distinguish clumps and asymmetries associated with catastrophic collisions from the very bright integrated emission associated with the more frequent background collisions of small planetesimals, and 2. for somewhat older disks, single catastrophic collisions may cause a flaring in the disk brightness that can substantially exceed the integrated background disk brightness.
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Are Debris Disks and Massive Planets Correlated?

Using data from the Spitzer Legacy FEPS we have searched for debris disks around 9 FGK stars (2–10 Gyr), known from radial velocity studies to have one or more massive planets. Only one of the sources, HD 38529, has excess emission above the stellar photosphere. Applying survival tests to the FEPS sample and the results for the FGK survey published in Bryden et al. (2006), we do not find a significant correlation between the frequency and properties of debris disks and the presence of close-in planets. We discuss possible reasons for the lack of a correlation.

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The Fossil History of the Solar System: Links to Interstellar Chemistry

In a few key instances the chemical composition of meteorites and comets provides a fossil record of the physical conditions present at their creation. In this talk I will explore lines of evidence that link the chemistry of the solar nebula to that seen in the interstellar medium today. In particular, I will present results that address a long-standing question in solar system chemistry: the origin of oxygen isotopic anomalies seen in primitive meteorites. I will show how an answer to this question implies the birth of the Sun in a large star cluster.

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Short-lived radioisotopes: Cosmochemical connections between star and planet formation

Our Solar System still serves as ground truth for theories of star and planet formation. Isotopic evidence for short-lived radioisotopes in the parent bodies of some meteorites requires or at least suggests a nearby massive star in early Solar System history, a scenario probable only in an early stellar cluster. We compare the inferred initial solar system abundance of Fe-60 with calculations that combine an n-body dynamical model of a stellar cluster environment with a model of disk evolution. These calculations show that the minimal scenario of a 60 solar mass star in a 500-star cluster was very unlikely to be the birthplace of the Sun; a much more massive cluster is required. We also estimate the inventory of Al-26 that would have been deposited in the protosolar cloud using both this model as well as a model of HII bubble-triggered star formation in which the Al-26 is carried by the winds of a massive star and injected into a shell of collapsing, star-forming gas. We calculate the distribution of initial Al-26 in planetary systems in such a cluster. Al-26 was the dominant source of heat in the Solar System and responsible for early planetesimal differentiation; we speculate on some possible effects of its variation in abundance.

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Formation of planets in binary/multiple star systems

A fair number (30) of planets are now known in solar-type visual binary systems and a few (3) even in triple systems. At least 20% of the planet
hosting star have a visual companion (for a compilation see Raghavan et al. 2006). However, exoplanet hosts seem to be deficient in having stellar companions when compared to field stars (ca. 50%). Does this mean planet formation is reduced in binary star systems or is this a selection effect? Relevant to this question is the fact that consistently only one of the two binary components hosts a short period Jupiter-like planet, and we can ask: why not the other?

Also very relevant to the formation issue is the fact that circumstellar disks have been detected around the individual components of young wide binary systems, such as the L1551-IRS5 system (separation 0.3 arcsec = 45 AU, resolved in the dust continuum at 7mm with the VLA by Rodriguez et al. 1998); Lim & Takakuwa (2005) even claim the system to be a hierarchical triple. If true, this suggests a break of symmetry and a reason why only one of two main components will form a planet, i.e. planet formation is inhibited near the component with the close pair of a hierarchical triple.

In an attempt to further discuss these questions, we refer to our recent paper (Correia et al. 2006 A&A 459, 909) in which we present a survey of multiple systems among visual pre-main sequence binaries and conclude that some 30% of our young wide pairs are actually triple and quadruple systems, the majority in a hierarchical configuration. The individual components of our multiple systems tend to favor "mixed pairs" (i.e. systems including components of wTTS and cTTS type), which is in general agreement with previous studies of disks in binaries (see Monin et al. 2006, PPV-review), except in Taurus where one finds a preponderance of similar types. Here planets around each binary component may be formed. However, since most young stars are born in OB associations and not in T associations like Taurus, Taurus may not be a representative region for supplying stellar binaries to the general field star population.

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Influence of the star forming environment on planet formation

This talk outlines possible effects of the cluster environment on solar systems forming within them. We first consider the dynamical evolution of clusters themselves, including the pre-cluster initial conditions, star formation efficiency, and gas removal. For clusters of intermediate size, N = 100 - 3000, the dynamics are highly chaotic and multiple realizations of equivalent cases must be carried out to build up a robust statistical description of the results, e.g., the probability distribution of closest approaches, the mass profiles, and the distribution for the radial locations of cluster members. These results provide a framework from which to assess the effects of groups/clusters on star and planet formation. The distributions of radial positions can be used in conjunction with the probability distributions of the expected FUV luminosities to determine the radiation exposure of circumstellar disks. These radiation levels can then be used in conjunction with photoevaporation models to assess the damage inflicted on circumstellar disks. The distributions of closest approaches can be used in conjunction with scattering cross sections to determine the probability of disruption for newly formed solar systems. This talk discusses how the interaction rates, radiation levels, and corresponding odds of disruption vary with cluster membership N.

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The Multi-object APO Radial-Velocity Exoplanet Large-area Survey (MARVELS)

The Multi-object APO Radial-Velocity Exoplanet Large-area Survey (MARVELS) aims to use the ARC 2.5m wide field telescope to detect ~500
extrasolar planets orbiting 40,000 relatively bright stars within 1000 light years in 2008-2014. The survey will systematically assemble a well-defined sample of planets with a wide range of masses and orbits; the planets will be drawn from a set of stars with a diverse set of compositions, ages, and rotational velocities. The survey's main scientific objectives are to study the diversity of extrasolar planets; to investigate the correlations between planets and host star properties; to measure the distribution of planet masses and orbital parameters; to constrain theoretical models of planet formation, migration and evolution; to discover a few dozen transiting planets around relatively bright stars for detailed studies of planet properties; to identify candidates for multiple planet systems or additional lower mass planet companions; and to detect rare planets or rare objects. The MARVELS survey has the capability to accommodate one red-sensitive multi-object Doppler survey instrument, called Red ET, and one optical extremely high precision (∼15-object) optical Doppler instrument, called EXPERT. Red ET could enable a survey of cool, low mass stars with the goal of identifying short-period super-Earth mass planets, possibly including some in the habitable zones around these low mass stars. EXPERT will simultaneously search bright solar type stars in each survey field to detect and characterize short-period planets in the mass range of Uranus and Neptune.

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Testing Theories of Planet Formation and Evolution of Planetary Systems using the Orbital Properties of Extrasolar Planets

The first discoveries of extrasolar planets demonstrated that nature produces a much greater diversity of planetary systems than astronomers had anticipated. In an attempt to explain these surprises, theorists have proposed numerous generalizations to the classical model of planet formation. Recently, researchers have begun to tests some of these theories using the observed orbital properties of extrasolar planets. These tests can be broadly divided into two categories: First, analyzing the orbital interactions of specific multiple planet systems can reveal remnant scars that were imprinted during earlier stages of planet formation. This has become a powerful tool for testing models of planet formation thanks to the increasing number, temporal baseline, and precision of observations. I will discuss the implications of a few particularly interesting multiple planet systems. A second method for testing planet formation models is based on comparing the predicted distributions of planet periods, eccentricities, and masses to those of the observed population of extrasolar planets. This approach is becoming increasingly powerful thanks to the increasing number of planet discoveries and improving capability to control for detection biases. I will summarize the orbital properties of the extrasolar planet population based on a systematic analysis of radial velocity planets and discuss implications for planet formation theory.

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Predictions for the Correlation between Giant and Terrestrial Extrasolar Planets

Our mounting knowledge of extrasolar planetary systems showcases an increasing need to explain their formation and subsequent evolution. Gravitational scattering simulations have produced a quantitative match to the distribution of known extrasolar planet eccentricities, and may represent the dominant eccentricity driver in initially crowded systems. In most extrasolar planetary systems, the present orbits of known giant planets admit the existence of stable terrestrial planets. Because gravitational scattering is likely to produce multiple rearrangements of the terrestrial and giant
planets prior to stabilization, during such transient periods giant planets can temporarily encroach the terrestrial planet zone, both physically and with resonant perturbations. We use marginally stable systems of giant planets, with a realistic planetary mass range, to demonstrate the signatures such planets leave in the terrestrial zone. We derive the distribution of orbital radii across which strong perturbations are likely to affect the survival of habitable planets, and demonstrate that the domain of influence of the scattering massive planets increases as the mass differential between the massive planets decreases. We find that sufficiently active and/or long periods of gravitational scattering amongst giant planets largely prohibit terrestrial material from surviving long enough in the habitable zone to become habitable planets.

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Atmospheric Escape from Hot Jupiters

Photoionization heating from UV radiation incident on the atmospheres of hot Jupiters drives planetary mass loss in the form of hydrodynamic winds. Observations of HD 209458b, the first hot Jupiter discovered on an orbit transiting its host star, have confirmed that the planet is losing atomic hydrogen. These observations do not necessarily imply loss of gas at a rate large enough to significantly reduce the mass of the planet. We construct a model of mass loss from the atmospheres of hot Jupiters, including realistic heating and cooling, ionization balance, and boundary conditions. We find that hot Jupiters lose less than 1 percent of their mass over their lifetimes. We predict that during transit, neutral hydrogen in a wind escaping from HD 209458b completely obscures Lyman-alpha and Lyman-beta emission from the planet’s host star at line center. Lyman-alpha absorption has been observed at wavelengths offset from line center, indicating the presence of neutral hydrogen moving at speeds near 100 km/s. This high velocity gas may originate in a turbulent bow shock where winds from the planet and its host star collide.

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Spitzer Observations of Extrasolar Planets

The Spitzer Space Telescope is the only instrument to have measured photons originating from extrasolar planets. Measurements of secondary-eclipse flux decrements, when combined with a planetary radius measured in transit, give the brightness temperature for a planet in that waveband, which approximates the physical temperature of its photosphere. Since the stellar flux at the planet is known, one can also solve for an albedo. Measurements in multiple bandpasses yield information about departures from black-body behavior and constrain models of chemistry, atmospheric dynamics, and cloud microphysics. For nearby non-transiting planets, although the radius and therefore the precise temperature are unknown, we can still measure the day-night contrast, and indeed the overall phase lag or lead of the surface brightness distribution relative to the orbital phase. Reasonable assumptions regarding the radius yield temperature ranges for the day-night contrast, which together with the phase offset strongly constrains atmospheric models. All of these goals have been achieved, and measurements of many planets are now in hand. Several groups are now pursuing the spectra of several transiting planets in eclipse, as well as their surface brightness distributions, and some of these results should be available at the conference.