Conference Summary

Jonathan C. Tan (UF)

The process of star formation (SF) is fundamental for the formation and evolution of galaxies. It occurs mostly in giant molecular clouds (GMCs) and is highly clustered. Star clusters appear to be the basic building blocks of galactic stellar populations. The processes that shape the stellar initial mass function operate on these scales. Massive stars seem to form almost exclusively in star clusters. These massive stars regulate the heating and cooling of the interstellar medium, produce heavy elements, and may regulate the global and local rates of star formation. The rate of star formation also depends on large-scale properties of galaxies, especially gas content. It may also be affected by orbital dynamics, spiral density waves, pressure, metallicity, and, in certain circumstances feedback from active galactic nuclei.

Some open questions to be addressed are:

What controls the rate and clustering of star formation in GMCs?

What sets the stellar initial mass function and binary properties, and do these vary with environment?

How does massive star formation differ from low-mass star formation?

What is the timescale of star cluster formation?

What is the lifetime of GMCs?

What sets the initial cluster mass function and does this vary with environment?

What sets the rate and efficiency of kpc-scale star formation in different environments?

How does global galactic star formation activity vary with gas content, orbital shear, amplitude of spiral density waves, pressure, metallicity, and feedback environment?

What processes influenced the cosmic evolution of star formation?

Thus for a more complete understanding of star formation and galaxy formation and evolution, this conference covered the topics of:

A Internal Properties of GMCs: Gravity, Turbulence, Magnetic Fields

We heard from Basu about turbulent ambipolar diffusion and the possibility of long-lived tension mode oscillations. Crutcher told us there are no magnetically subcritical GMCs or cores – they are all supercritical, although only by typically factors of a few. On the other hand the atomic gas appears to be mostly subcritical. I would suggest this transition is important for GMC formation. Padoan argued that the mean field in GMCs is relatively weak, so that the turbulence is super-Alfvenic. Nordlund then showed how models of such turbulence can be used to estimate the star formation rate (SFR). Brunt told us how to probe the Mach number from the density variance. We heard arguments for stronger magnetic fields from Tassis, Mouschovias and Kunz, and how they may play a more controlling role in setting the SFR and core mass function (CMF). Hansen told us how anisotropic turbulence decays more slowly than
isotropic. Pineda showed us evidence the decay of nonthermal support is observed across the boundary of a dense core. Glover set the stage for how we can infer the properties of molecular hydrogen gas from observations of CO. C. Lada argued for the importance of column density threshold effects in setting the SFR from observations of some nearby GMCs.

B Initial Conditions of Massive Star and Star Cluster Formation

Jackson showed a very large linear infrared dark cloud (IRDC) filament. It would be interesting to see if such structures are seen in numerical models of star formation in galaxies. Krause showed us results from Herschel, including its view of IRDCs in emission. Caselli overviewed chemical diagnostics, including the level of deuteration in starless cores. Jimenez-Serra presented evidence for large-scale SiO emission in a filamentary IRDC, perhaps associated with formation-related shocks and/or widespread early star formation. Hernandez discussed formation of IRDCs, including an analysis of the properties of their surrounding GMCs. Ragan found flat temperature profiles in IRDCs. Fontani compared starless cores in clustered, high-mass star-forming regions with those in isolated, low-mass star-forming regions finding similar chemistry in spite of higher temperatures and more turbulent conditions.

C Massive Star Formation (and comparison with low-mass star formation)

Beuther and Fallscheer discussed massive star formation – rotating structures are present, although there is no good case of Keplerian rotation seen so far, probably because the scale have not yet been resolved. Csengeri search for massive pre-stellar cores find a few examples (although there is always the issue of whether they will be seen to fragment at higher angular resolution) and studied their internal kinematics. Goddi presented high angular resolution SiO maser data on the Orion source I protostar. I would argue, and I think Goddi and other would agree, that there are still many aspects of this system that we do not understand clearly. De Buizer emphasized the role outflows play in shaping the mid-IR appearance of massive YSOs. Klein showed how difficult it is stop accretion to massive protostars with radiation pressure.

D Star Cluster Formation and the Stellar Initial Mass Function

Li presented numerical simulations demonstrating the importance of outflow-driven turbulence in star cluster forming gas, and with some potential implications for massive star formation. Brogan presented observational data on such regions with crowded, multiple outflows. Bik found multiple generations of star formation in young clusters from near-IR spectroscopy. Myers presented a model for the creation of the initial mass function (IMF) starting from thermal cores embedded in a turbulent medium. Offner predicted protostellar mass and luminosity functions for several different star formation theories. Bate showed how the IMF results from simulations of star cluster formation depended strongly on the inclusion of radiation pressure and magnetic fields. Gutermuth and Bressert used Spitzer data to show most stars form in clusters, though with relatively low densities, and that there is a continuum in star formation efficiencies (SFEs) between distributed and clustered extremes. Hartmann argued it is difficult to create quasi-virial equilibrium initial conditions for star cluster formation based on observational evidence that star formation proceeds rapidly and thus an expectation that the gas must be concentrated quickly. Clark numerically simulated the initial conditions for star cluster formation with a new thermodynamic and chemistry model. On the disruption of star clusters, E. Lada discussed the structure of young, embedded star clusters and how it evolves as gas is removed, while Stahler discussed the role of binary heating and tidal disruption at later stages as illustrated in the Pleides. Krumholz calculated the effects of feedback on star cluster formation, finding it suppresses fragmentation and caps star formation efficiency at ~1/3 independent of cluster mass. Covey reviewed evidence for IMF variations in the Galaxy and found very little evidence for variation as a function of environment.
Heitsch argued for a rapid onset of star formation in GMCs and presented a model of GMC formation from colliding atomic flows. Tasker presented galaxy-scale simulations that track the formation and evolution of clouds equivalent to GMCs, finding high rates of interactions between GMCs. Van Loo discussed the kinds of structures that can form when warm, magnetized atomic gas is swept-up by shock waves. Ballesteros-Paredes presented Vasquez-Semadeni’s talk presenting simulations of GMC evolution that find continuous accretion and processing of material is important for massive clouds. We heard about ionization feedback from Gritschneder, who also presented some results from Ercolano. Pillar-like structures form naturally when turbulent gas is ionized. We then heard a series of observational talks: Di Francesco presented results from the JCMT Gould Belt survey; Bally discussed Bolocam Galactic Plane Survey results and how star formation varies in the local neighborhood compared to the Galactic center; Barnes presented results from the CHaMP survey of a complete census of dense gas clumps in the southern Milky Way; Hoare presented results from a Galaxy-wide survey of massive YSOs that constrain various accretion theories; Robitaille demonstrated a method of estimating the Galactic SFR from Spitzer-GLIMPSE data; and Molinari presented early results from the Herschel-HiGAL survey of the Galactic plane. Evans derived SFR-gas surface density relations in Galactic GMCs and found a much higher SFR compared to extragalactic relations.

Lu described adaptive optics studies of young stellar systems in the Galactic center and Galactic disk, emphasizing the role of precision relative astrometry. Larsen compared star cluster formation in different environments, fitting initial cluster mass functions (ICMFs) with Schechter functions and predicting there should be at least ~20 clusters with masses >10^5 solar masses and ages <200Myr, which have not been seen yet due to incompleteness of current surveys. Konstantopoulos studied cluster disruption in a steady SFR system, finding evidence for mass-dependent disruption rates. Johnson discussed extreme star formation in super star clusters, arguing that at least some are special in the sense of requiring unusual conditions for their formation, and perhaps can be viewed as a distinct population from normal galactic clusters. Testi presented SMA CO(2-1) observations of the initial conditions of super star clusters, but argued that observations with ALMA of higher density tracers are needed for useful constraints on the gas that will undergo efficient star formation. Bastian’s talk was unfortunately not presented, but his submitted PDF file reviews evidence for IMF variations in extreme and extragalactic environments, finding little evidence for variations. Scoville reviewed star formation in the high gas density environments of galactic nuclei, noting the Galactic circumnuclear disk clumps have extreme gas densities but little evidence for star formation, and arguing that extreme starbursts have their SFRs limited by radiation pressure feedback. Tacconi described gas-rich systems at z~1-3, showing they follow a similar dynamical (“Elmegreen-Silk”) star formation relation as normal galaxies. Narayanan argued the standard Kennicutt-Schmidt relation, \( \Sigma_{SFR} \propto \Sigma_{gas}^{1.5} \), may apply to these z~2 systems and that excitation conditions of the CO emitting gas need to be accounted for. Casey discussed Ultra Luminous IR Galaxies and emphasized the need to find a complete sample at high z. Murray talked about stellar feedback and galaxy formation, emphasizing the importance in the Milky Way of the most massive clusters.

Calzetti discussed measures of SFRs, highlighting uncertainties introduced by possible high-mass end IMF variations and describing the use of 70 micron emission as an indicator. Leroy presented results on how the molecular to atomic gas mass ratio varies with galactic physical properties, finding correlations with ISM conditions but only weak or nonexistent correlations with dynamical properties. Bigiel considered star formation relations on sub-kpc scales, arguing for 3 regimes: outer disks/dwarfs;
normal galactic disks; and starbursts. Sandstrom presented observational results on dust-to-gas ratios and $X_{\text{CO}}$ in nearby galaxies finding the former is proportional to (O/H) and the latter shows its highest value in an Irr galaxy and lowest value in a starburst. Blanc described the spatially-resolved star formation law as revealed from integral field spectroscopy, which can help make more accurate measurements of SFRs. Koda presented results from CARMA/Nobeyama surveys of CO(1-0) in nearby galaxies finding larger and massive GMCs and GMAs in arm regions compared to interarm and arguing for relatively long (~100Myr), dynamically-driven GMC lifetimes. Grosbol studied young star clusters in grand design spirals, finding that while arms concentrate star formation in a galaxy and may allow for the birth of more massive clusters, they do not appear to enhance the overall SFR in a galaxy. Blitz discussed atomic and molecular gas and star formation in early type galaxies, finding surprising amounts of cold gas and evidence for a molecular galactic outflow in one system. Mac Low argued the star formation relation is controlled by gravitational instability that creates cold neutral medium (atomic gas) that then quickly forms molecules and stars. E. Ostriker presented a model for SFR in galaxies that is set by thermal and dynamical equilibrium of midplane gas that controls the fraction that forms gravitationally bound clouds. Dobbs presented results from simulations of gas orbiting in galactic potentials with spiral arms, finding no dependence of the SFR with the spiral shock strength.

I Star Formation in Low-Metallicity Environments of Outer Disks and Dwarf Galaxies

Bolatto discussed GMCs in low metallicity systems and the method of using dust, rather than CO, emission to trace the full extent of the clouds. Hughes described properties of GMCs in the LMC, finding diverse properties, no variation of $X_{\text{CO}}$ with radiation field strength and no clear correlation of SFR with $\Sigma_{\text{H}_2}$. Lamb studied SMC field OB stars finding no evidence for IMF variation and no evidence for dependence of the maximum stellar mass with cluster mass. Bush discussed star formation in outer disks, finding extended faint star-forming disks can be created with standard star formation relations and a gas surface density threshold if there is an extended gas disk subject to spiral wave instabilities.

J Cosmic Evolution of Star & Galaxy Formation

Kravtsov presented cosmological simulations of galaxy formation that include $\text{H}_2$ formation physics – low SFE is predicted in dwarfs (as traced by high z damped Lyman alpha galaxies) that can help explain the observed low-end of the galaxy luminosity function. Agertz showed he was able to form large galactic disks by including inefficient (slow) star formation rate relations in his cosmological simulations. Skillman discussed resolved star formation histories, especially in dwarf galaxies, to test the impact of feedback on star formation activity. Moustakas described how the IMF can be constrained over cosmic time by comparing the cosmic SFR history with the build up of cosmic stellar mass density. O’Shea discussed how the Galactic star formation history as measured from the properties of old stars can constrain evolution of the star formation process. Boley discussed the connection between globular cluster formation and the formation of the Galactic halo. O. Gnedin proposed globular cluster formation is triggered by gas-rich mergers and thus was a more dominant component of Galactic star formation >10Gyr ago. The distinction between red and blue globular cluster populations is due to a few late massive mergers.