Clarifying our View of Star Formation in Massive Young Clusters and the Galactic Center with Adaptive Optics

Jessica Lu
California Institute of Technology
April 9, 2010

Collaborators:
Andrea Ghez, Mark Morris, Will Clarkson, Nate McCrady, Sylvana Yelda, Andrea Stolte, Keith Matthews

Funding:
Caltech Millikan Postdoctoral Fellowship
We can bridge the gap between nearby star forming regions and extragalactic starbursts.

Best studied star forming regions
- Taurus (140 pc, ~100 M_{sun})
- Orion (410 pc, ~2000 M_{sun})

Extreme Star Formation
- M82 super star clusters (3.3 Mpc, ~10^6 M_{sun})
For detailed studies, we need to resolve individual stars.

Galactic:
Can resolve individual stars, but less varied environments

Extragalactic:
Study integrated cluster light, but more varied environments
The Galactic Center hosts a supermassive black hole and a massive young nuclear cluster.

**Black Hole**

Ghez et al. (2005)

**Young Stars**
Ages of 4-8 Myr

**Paradox of Youth:**

Black hole generates strong tidal forces:
- Required gas densities are $\sim 10^{10} \text{ cm}^{-3} \times [R_{\text{GC}}/5'']^{-3}$
- orders of magnitude above what is observed today.
Fundamental Question: Did the young stars form near the supermassive black hole?

1. Stars formed *in situ* (where we see them today) in a disk around the black hole.

2. Stars formed far from the black hole in a large cluster which then spiraled in towards the black hole.

Test with kinematic measurements.

[Source](chandra.harvard.edu/resources/illustrations/blackholes.html)
We used astrometry + radial velocities to constrain stellar orbits of the young stars.

- 11 years of data
- 1 mas centroid errors
- 2 km/s proper motion errors
- 3 km/s/yr acceleration errors
We find that 50% of the young stars are in a thin disk, with a steep radial profile and eccentric orbits.

Lu et al. (2009)
We find that 50% of the young stars are in a thin disk, with a steep radial profile and eccentric orbits.

Lu et al. (2009)
We find that 50% of the young stars are in a thin disk, with a steep radial profile and eccentric orbits.
We find that 50% of the young stars are in a thin disk, with a steep radial profile and eccentric orbits.

Lu et al. (2009)
The kinematics of the young stars suggest they may have formed when two molecular clouds collided.

Simulating Cloud-Cloud Collisions

1. Two molecular clouds of $10^4 \, M_{\text{sun}}$
2. Clouds spiral in and collide
3. Tidal shear creates disks and streams
4. Disk is unstable due to self-gravity
5. Star formation occurs
6. Stellar kinematics today still trace origins.

Hobbs & Nayakshin (2009)
Young stars in the central 1” may be an older generation.
Young stars in the central 1” may be an older generation.

Lu, Yelda, Do, Ghez et al. in prep

Bartko et al. 2010
Massive young stars are distributed throughout the Galactic Center region.

Massive Post-Main Sequence Stars Identified Via X-rays

Mauerhan et al. 2010
Studies of the Arches cluster have been limited by field contamination.
Proper motions are a powerful tool for distinguishing between cluster members and contaminating field stars.

- commonly used on globular clusters
- high spatial resolution optical capabilities of HST
- massive young clusters require better astrometric precision
- massive young clusters require infrared astrometry

Anderson et al. 2006
Adaptive optics provides infrared astrometry with an accuracy of ~0.2 milli-arcseconds over many years.

**Keck AO Relative Astrometry**

Astrometry is repeatable over years at the 0.1 – 0.2 mas level.

**Palomar AO Relative Astrometry**

Lu et al., Yelda et al. (in prep)

Cameron et al. (2009)
With our multi-year observing campaign, we can measure proper motions with high precision.

Clarkson, Lu, Ghez, Morris, McCrady, & Yelda, in preparation; See also Stolte et al. 2008
We can distinguish cluster from field AND measure the internal velocity dispersion of the cluster.

Clarkson, Lu, Ghez, Morris, McCrady, & Yelda, in preparation; See also Stolte et al. 2008

Arches Cluster Intrinsic Dispersion ~12 km/s

Field Velocity Ellipsoid
The dynamically estimated mass enclosed within 0.5 pc is consistent with photometric estimates.

- JHK photometry
- Salpeter IMF
- within 0.4 pc

$M = 20,000 M_{\text{sun}}$

$30,000 M_{\text{sun}}$
With our multi-year observing campaign, we will derive a precise stellar IMF.

McCready, Lu, Clarkson, Ghez, Morris, & Yelda. in preparation
With 0.2 mas astrometry, motions and internal dispersions can be measured in 1 and 3 years for many clusters.
So all we have to do is wait…

See posters DP9 (Kudryavtseva) and DP8 (Rochau)
Goal:
- comparative IMF studies and
- observed vs. simulated internal kinematics

Bastian et al. 2010

Bate et al.
Studies of the Galactic center require high spatial resolution at infrared wavelengths.

Image courtesy of Claire E. Max, UCSC
Photometry isn’t too bad either…

Lu et al. (in prep.)
With improvements, relative astrometry below 100 micro-arcseconds is possible.

- correct differential atmospheric refraction
- improve distortion solution
- high quality data (Strehl > 0.3)
- spatially dependent PSFs
Studies of Milky Way massive young clusters requires high spatial resolution at infrared wavelengths.
Past infrared studies of Milky Way starburst clusters cannot identify individual cluster members.
Statistical corrections are applied to estimate the cluster initial mass function, age, distance, and structure.

Westerlund 1 Cluster

Off-Cluster Control

Brandner et al. 2008
Variable extinction is problematic both in the cluster and in selecting the control fields.

W51 Giant Molecular Cloud

Clark et al. 2009