Star Formation Near Supermassive Black Holes

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June 8, 2009

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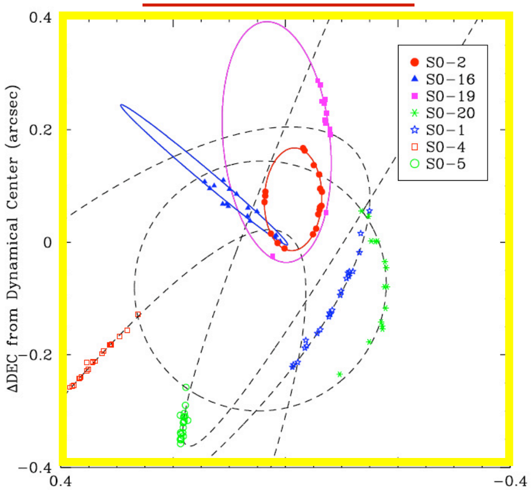
Funding:

NSF Graduate Research Fellowship,

Caltech Millikan Postdoctoral Fellowship

The existence of massive young stars near a supermassive black hole gave rise to the "paradox of youth".

Black Hole



Ghez et al. (2005)

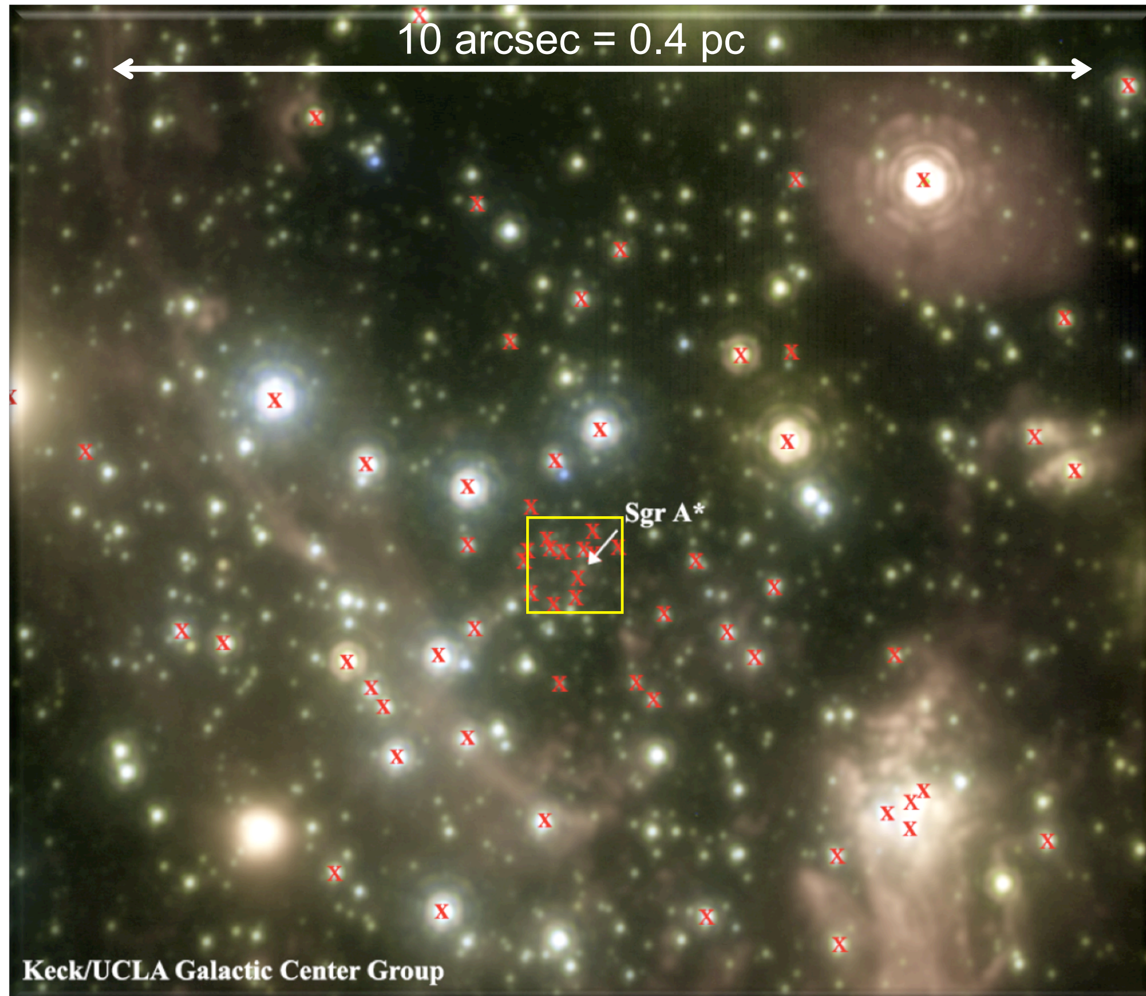
+

Young Stars

Ages of 4-8 Myr

↓

Paradox of Youth:

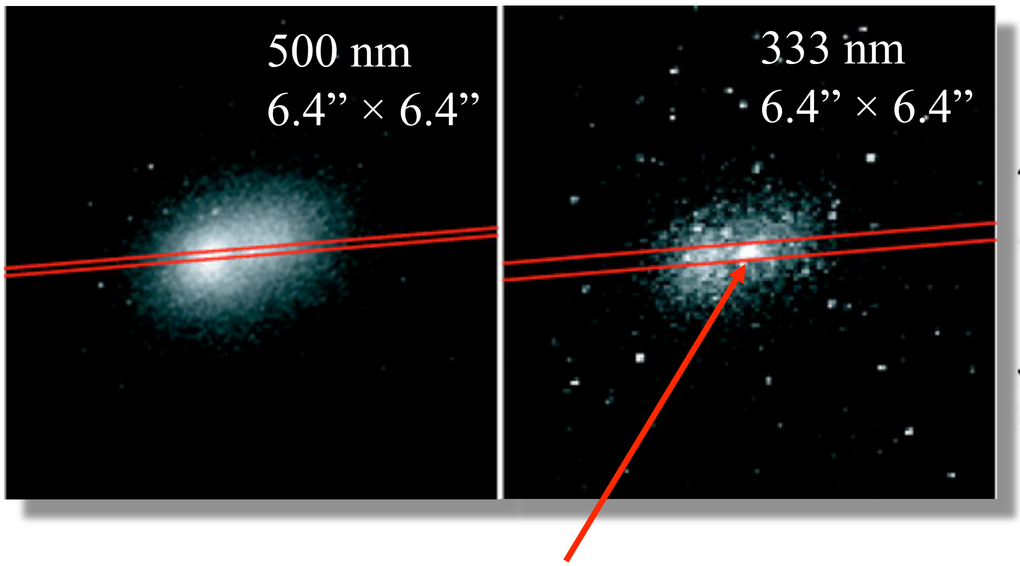


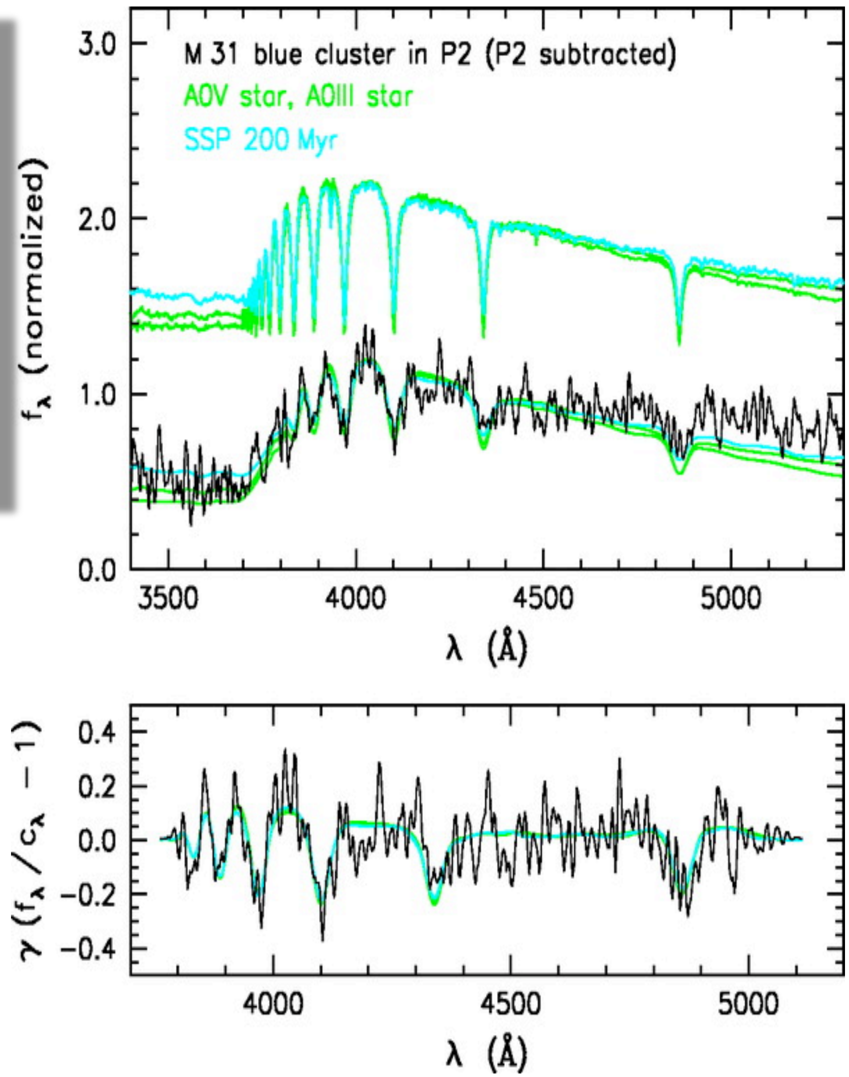
Black hole generates strong tidal forces:

- Required gas densities are ~10^{10} cm^{-3}*$[R_{GC}/5'']^{-3}$
- orders of magnitude above what is observed today.

Young stars have also been detected near SMBHs in other galaxies.

Bender et al. (2005)

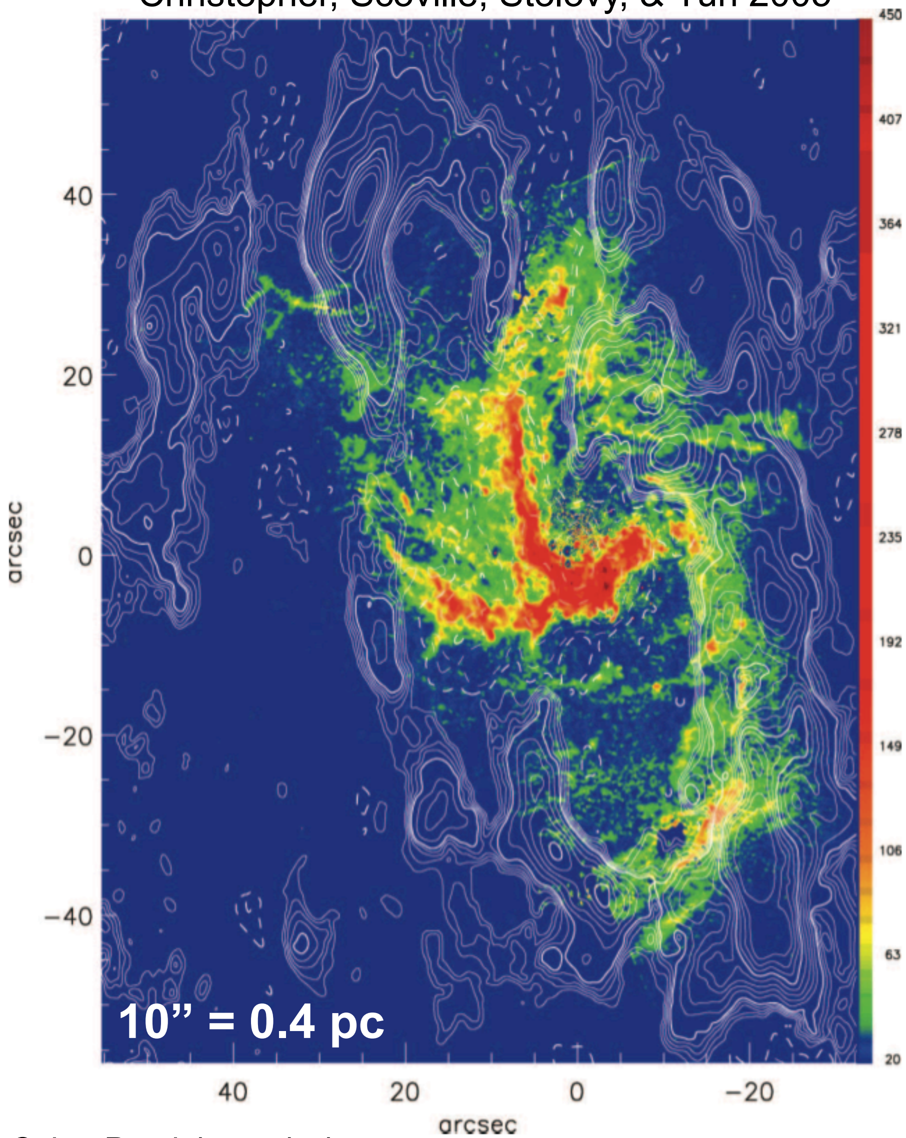




- Compact blue source around M31 SBH
- Spectrum consistent with A-star
- Age ~ 200 Myr

Observed gas densities in the Galactic center and in M31 are insufficient to form stars.

Christopher, Scoville, Stolovy, & Yun 2005



Color: Pa-alpha emission
White Contours: HCN

Need $\rho > 10^{10}$ cm^{-3}*$[R_{GC}/5'']^{-3}$ for gravitational collapse.

Gas in the GC

- Circum-Nuclear Disk (CND)
  $\rho \sim 10^3 - 10^7$ cm^{-3}

- Ionized Mini-Spiral
  $\rho < 10^3$ cm^{-3}

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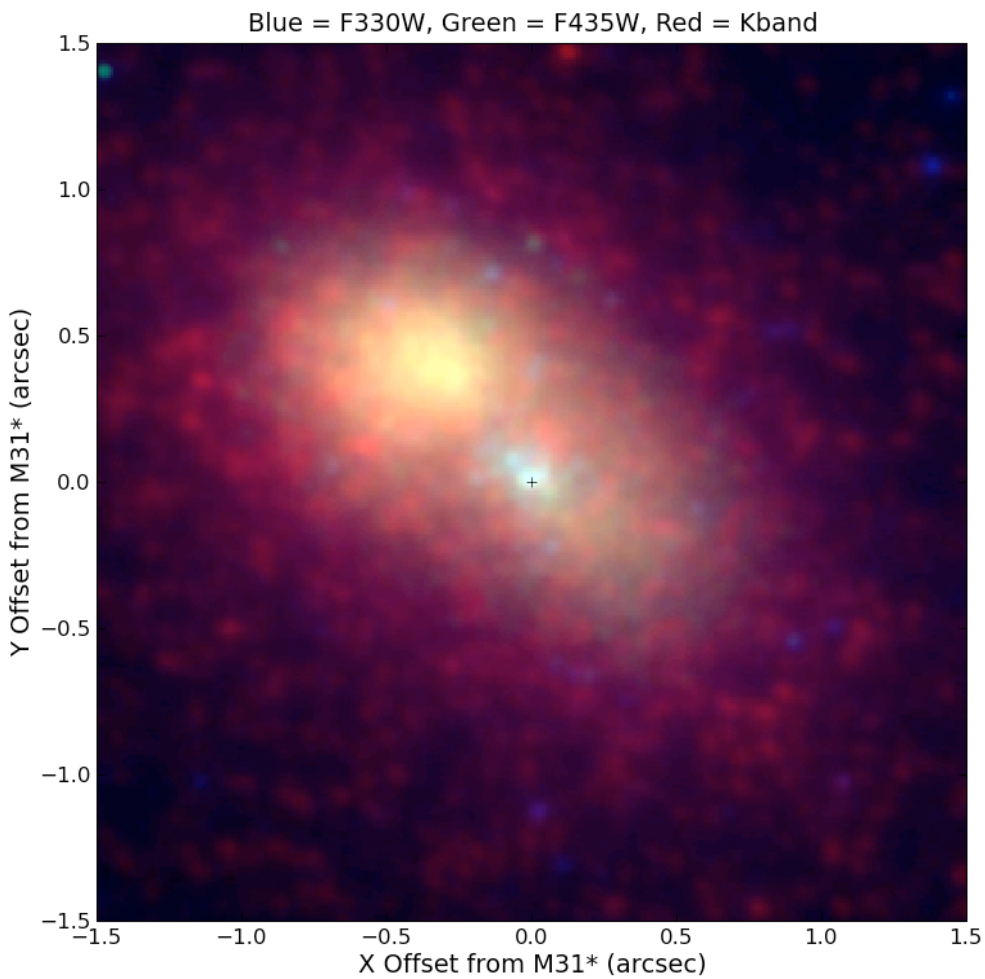


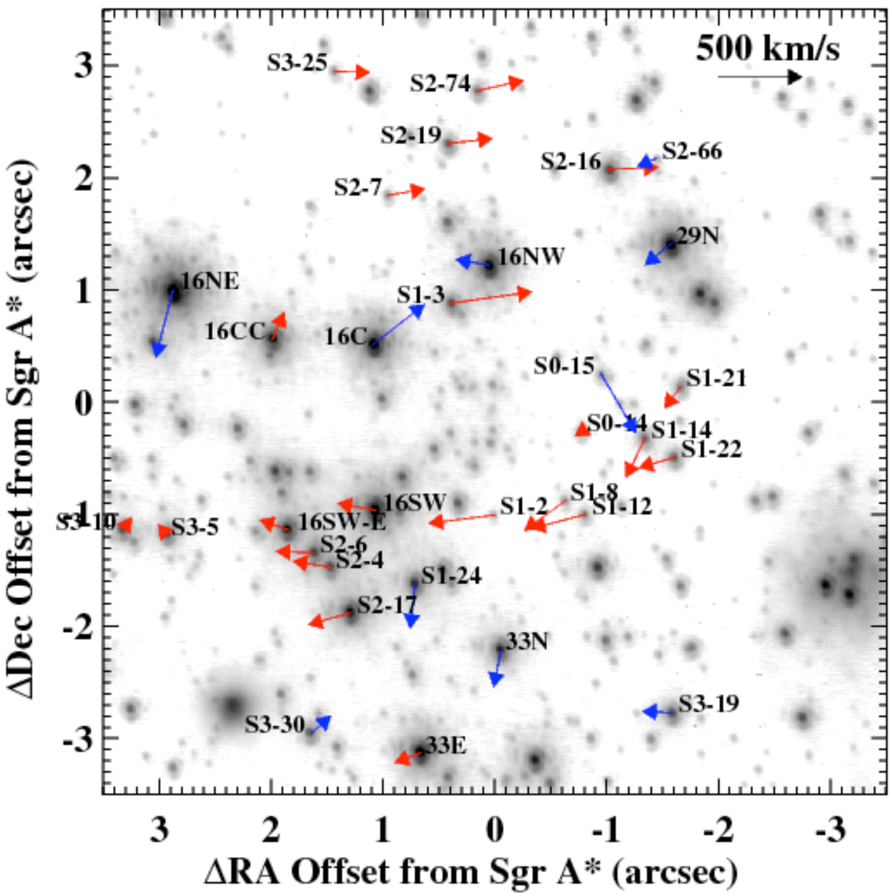
Gas in M31

None detected in CO or optical extinction maps.

In the GC, we use AO to measure 3D kinematics of individual young stars in order to constrain their orbits.

Proper Motions:
- >12 years of <1 mas astrometry
- measured to 1-2 km/s
- some accelerations measured

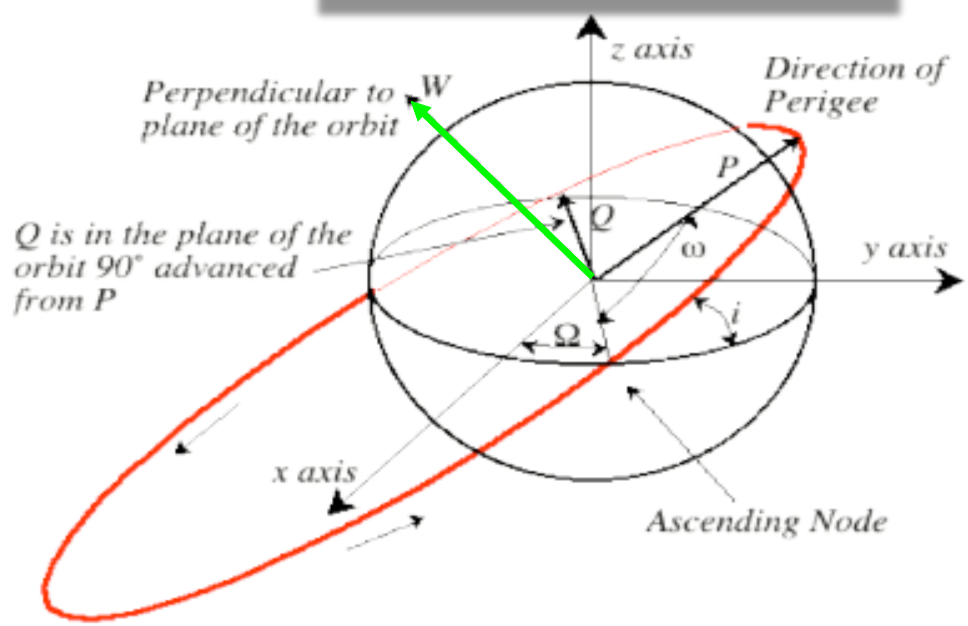
Radial Velocities:
- spectroscopy IDs young stars
- 1-2 measurements each
- measured to 10-30 km/s



Orbital Parameters

e, i, Ω, ω, P, T_0

(shape, orientation)



Our observations and analysis are designed to maximize our relative astrometric accuracy.

Observations:

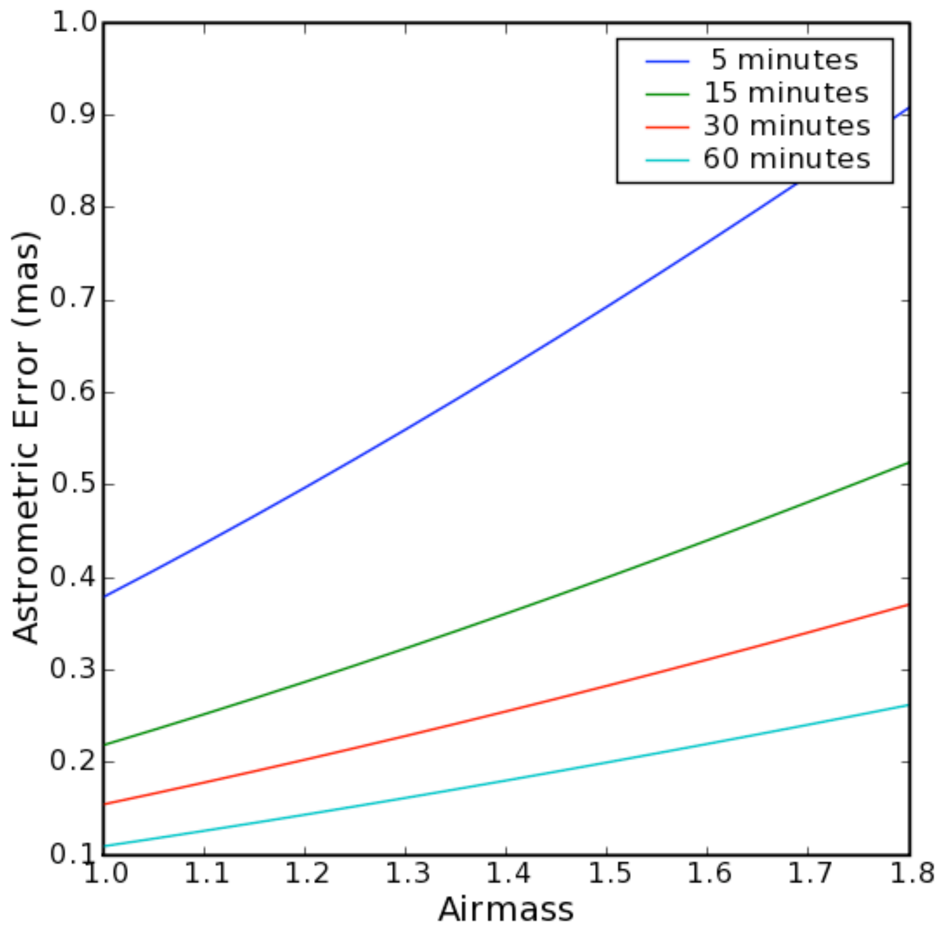
1. Position field at same detector position.

2. Dither often by small (<0.7" x box for 10" FOV).

3. Use finest plate scale to improve PSF sampling.

4. Don't saturate any stars.

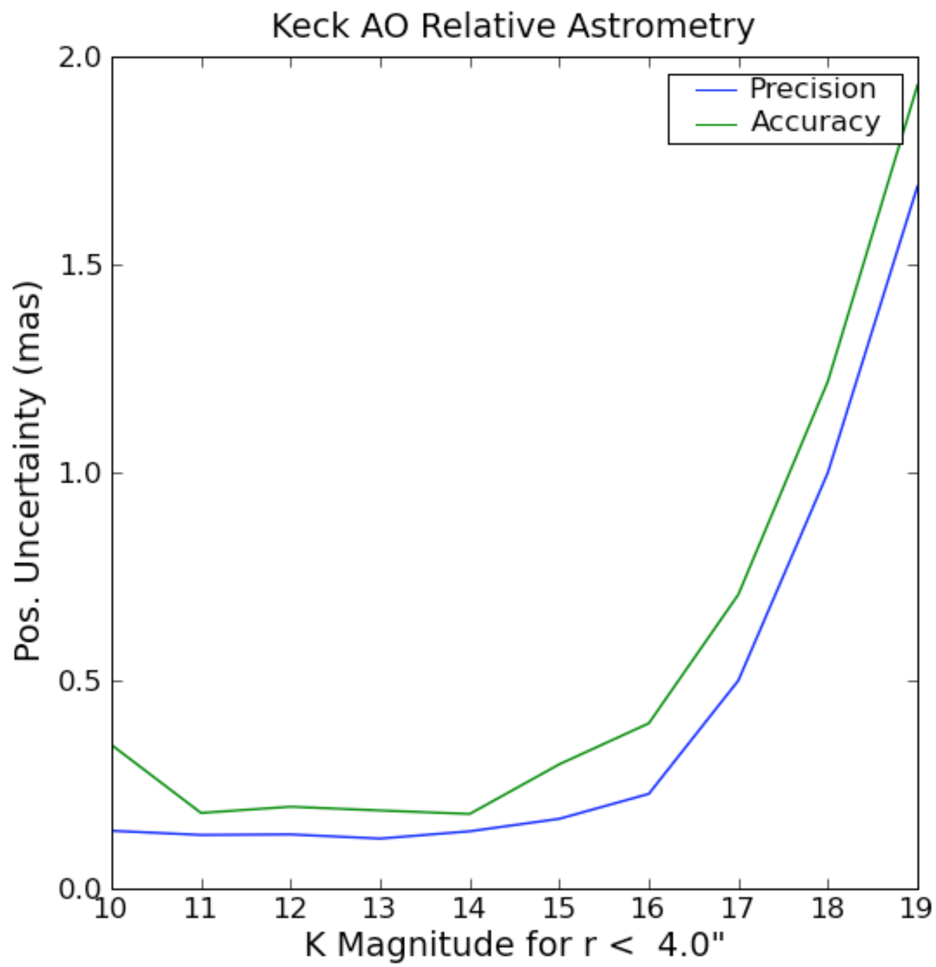
5. Build up integration time to reduce differential tip-tilt jitter [scales as $1/\mathrm{sqrt}(t_{int})$].



Our observations and analysis are designed to maximize our relative astrometric accuracy.

Analysis:

1. Correct images for distortion and differential atmospheric refraction.
2. Combine images after rejecting lowest Strehl (or highest FWHM) frames.
3. Use StarFinder (*Diolatti et al.*) to extract positions and fluxes.
4. Use 3 independent subsets of the data to estimate errors.

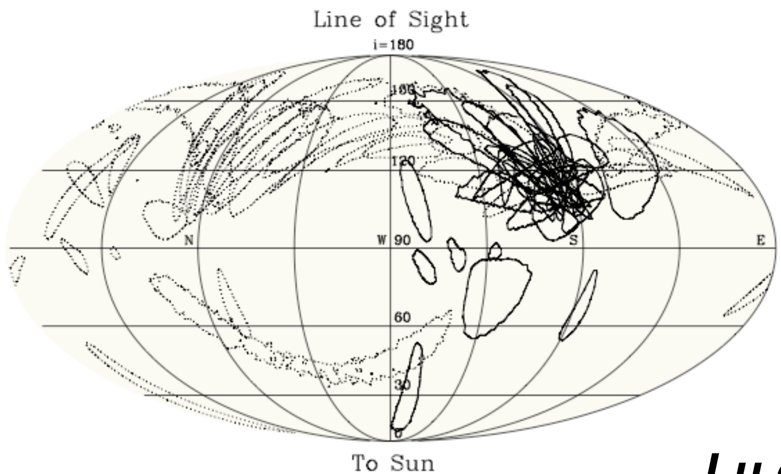


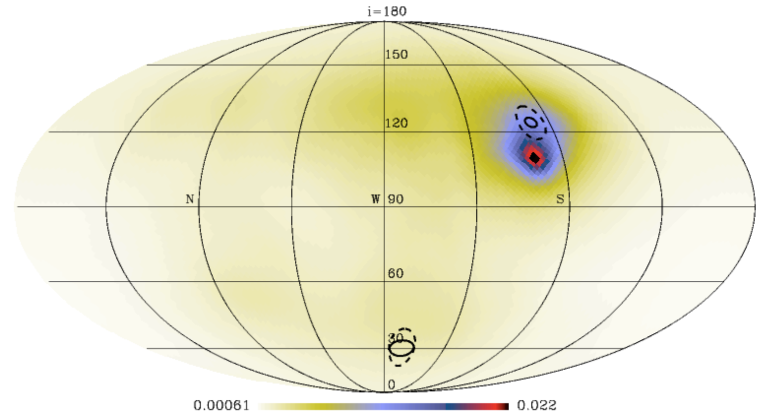
Resulting Astrometry:

- ***Average Precision: 0.12 mas***
- ***Average Accuracy: 0.18 mas***

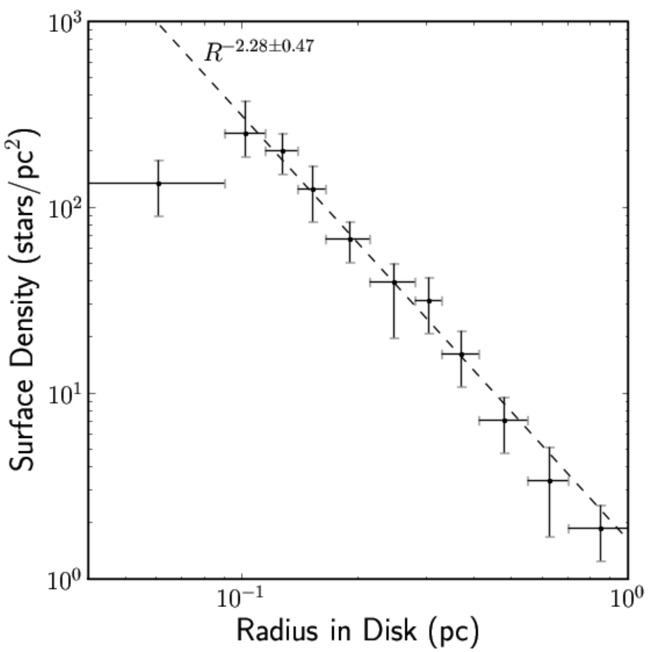
0.18 mas/yr = 7 km/s * [D / 8 kpc]

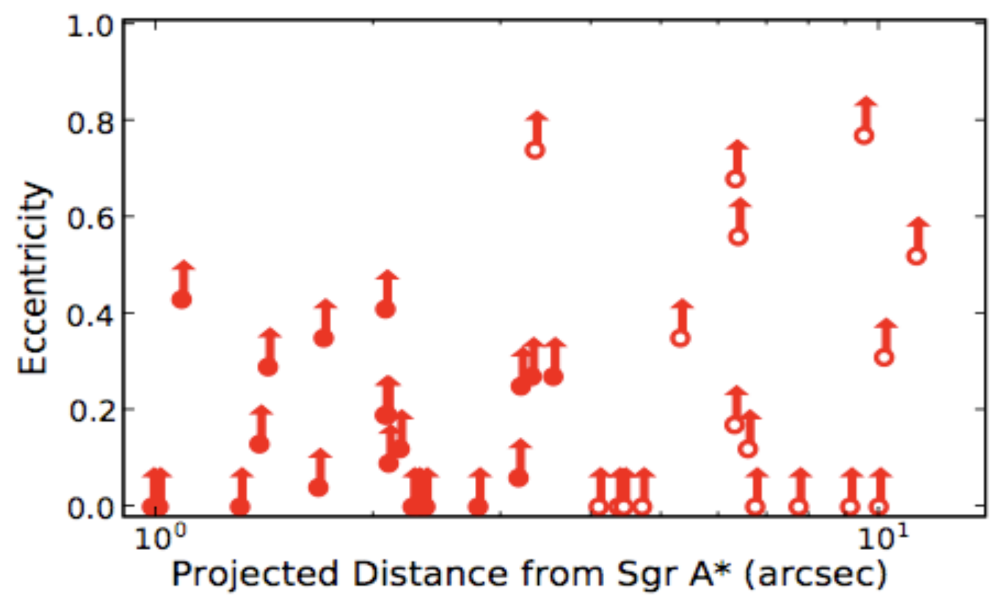
We find that 50% of the young stars are in a thin disk, with a steep radial profile and eccentric orbits.



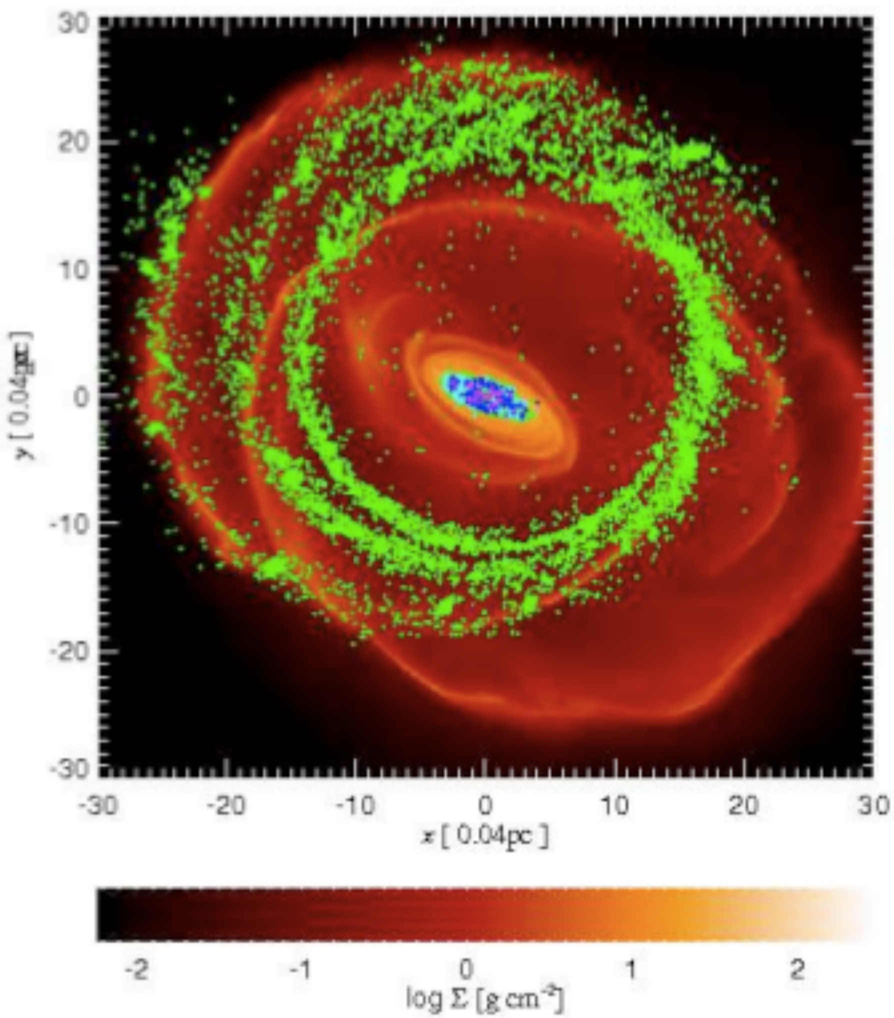


Lu et al. (2009)





The kinematics of the young stars suggest they may have formed when two molecular clouds collided.



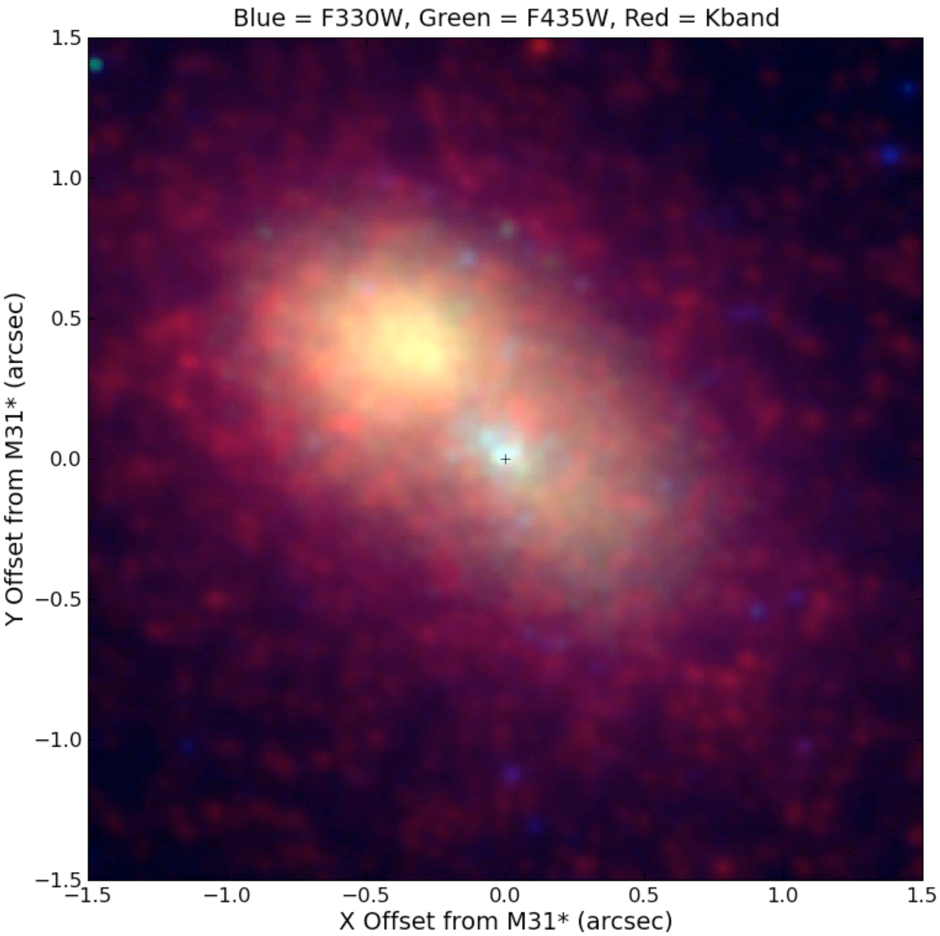
Hobbs & Nayakshin (2009)

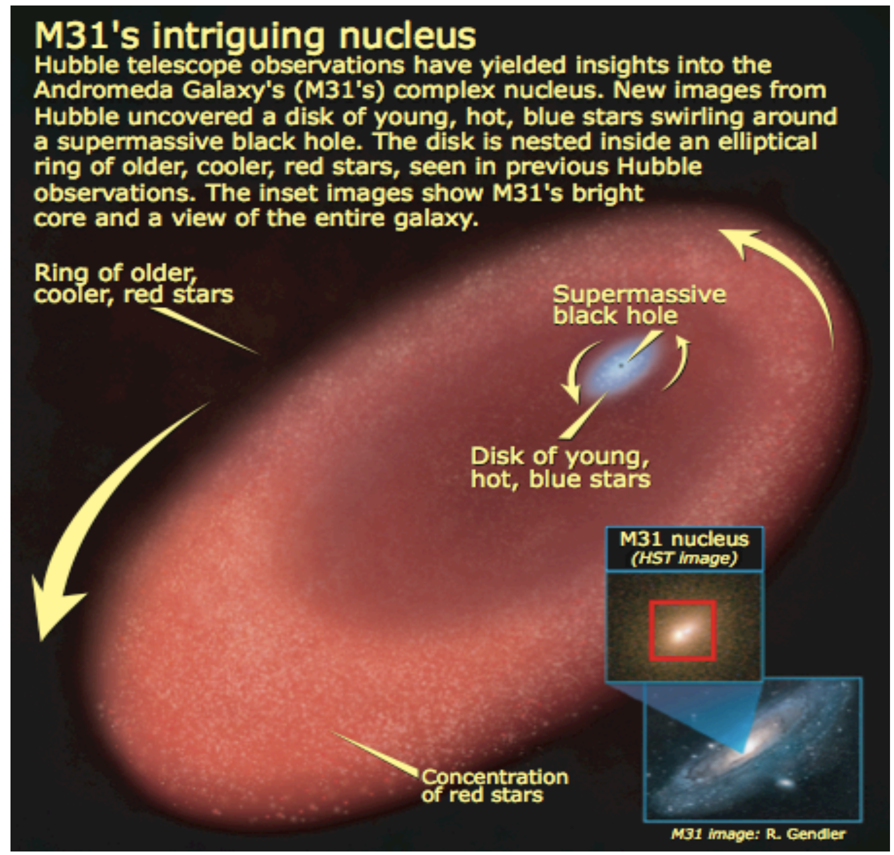
<u>Simulating Cloud-Cloud Collisions</u>

1. Two molecular clouds of 10^4 M_{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.

GC has molecular clouds, M31 does not??

The source of the molecular gas in M31 may be the winds from AGB stars in an eccentric disk *(Chang et al. 2007)*.



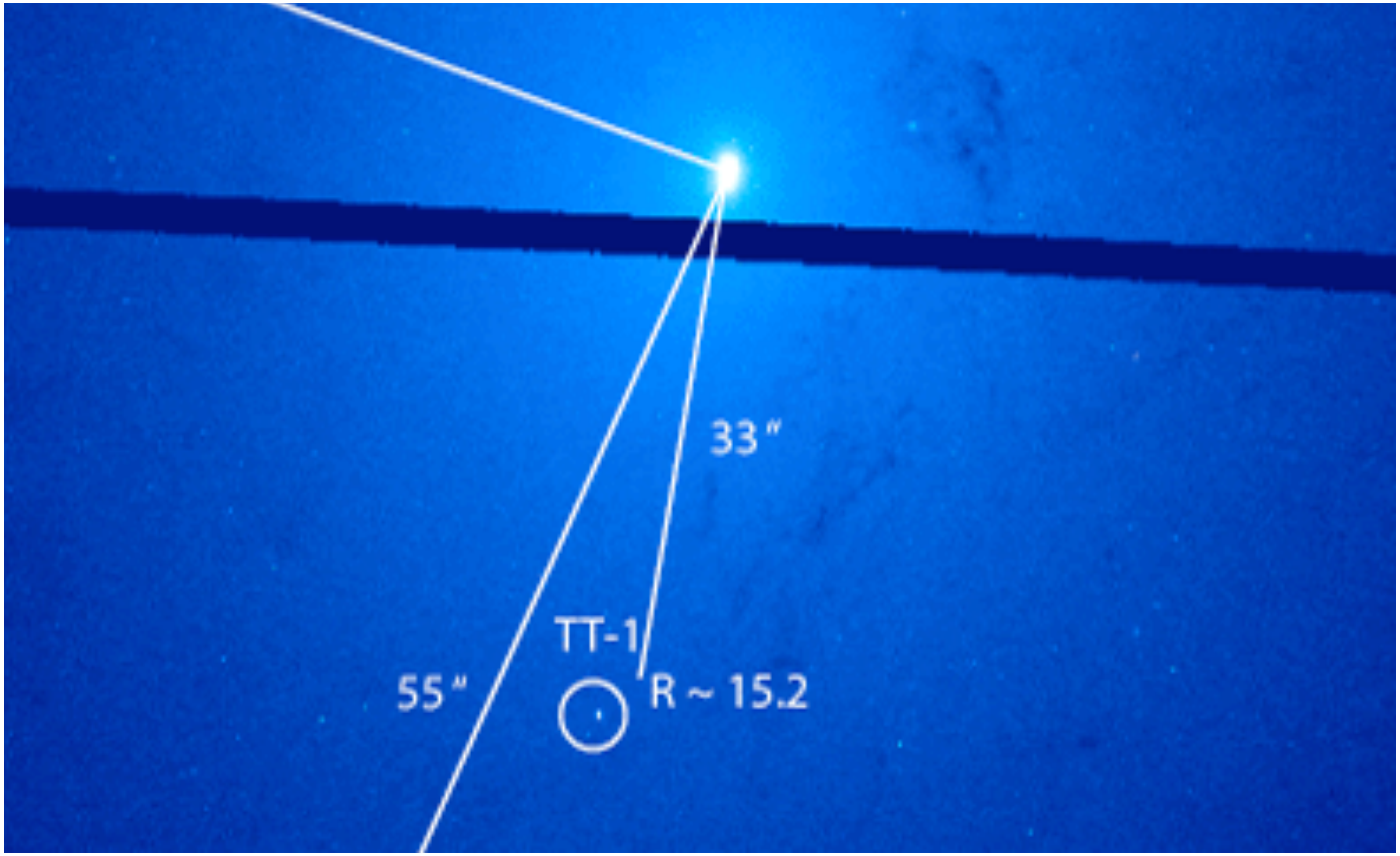


NASA, ESA, R. Bender (MPE), T. Lauer (NOAO), J. Kormendy (UT)

Gas only reaches the central parsec efficiently if the eccentric disk precesses slowly (<10 km/s/pc)

We have begun an IFU spectroscopy study with OSIRIS and Keck LGS AO to obtain spatially resolved kinematics.

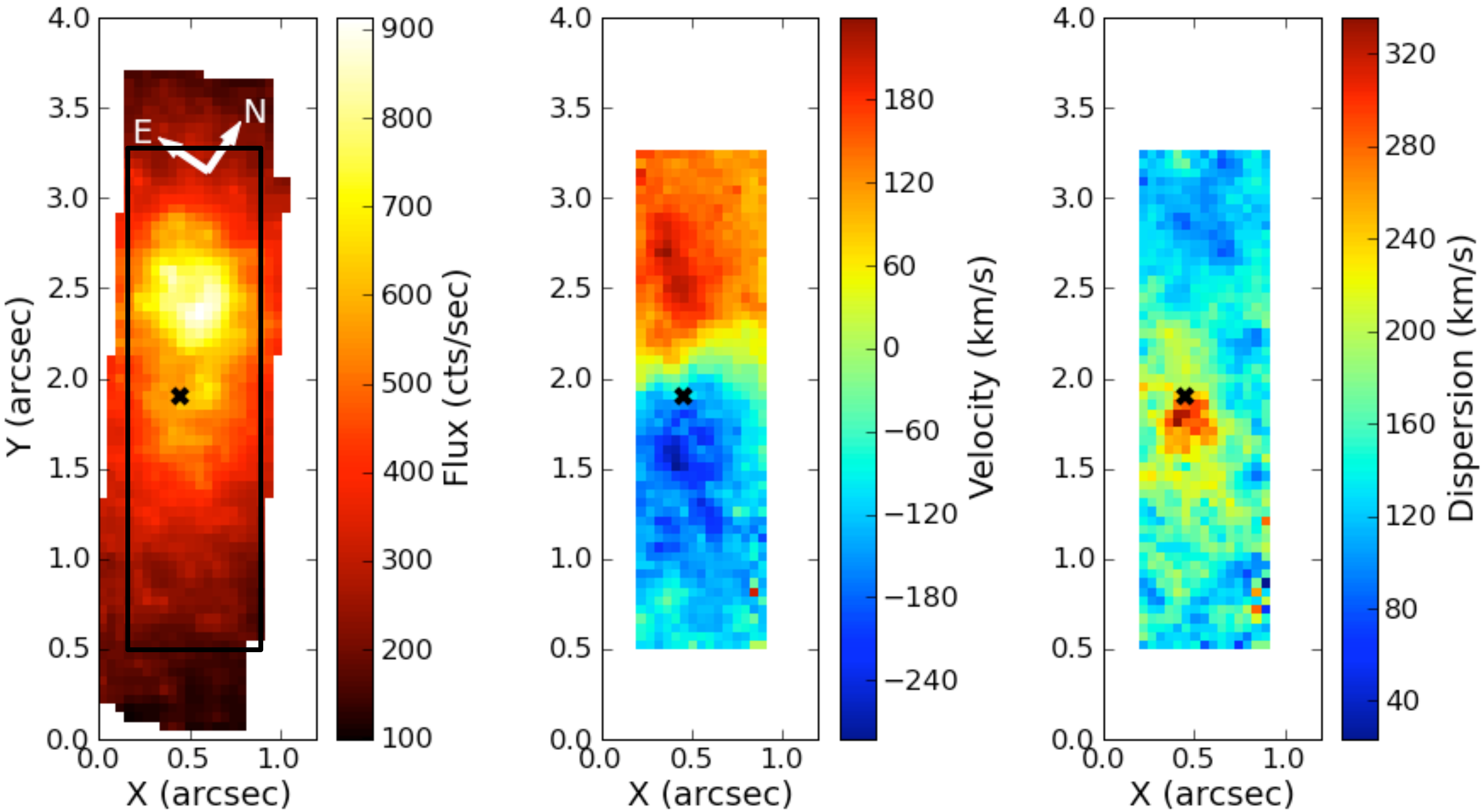
AO observations of nearby Galactic nuclei are complicated by strong light gradients at tip-tilt stars.



In Progress: High spatial-resolution 2D kinematic maps will allow us to model black hole + old eccentric disk.

15 mag/sq. arcsec
S/N ~ 60 per pixel
T_{int} ~ 3 hours

Radial Velocity Errors ~ 15 km/s



Conclusions

- Young nuclear star clusters are interesting as they are born of gas that would otherwise accrete onto the SMBH.

- Young stars in the Galactic Center may have formed from infalling molecular cloud or cloud-cloud collision.

- Young stars in M31 (in progress) may have formed from gas expelled by AGB stars in an eccentric disk.

- AO observations are an excellent tool for proper motion and radial velocity studies in crowded or extended regions.