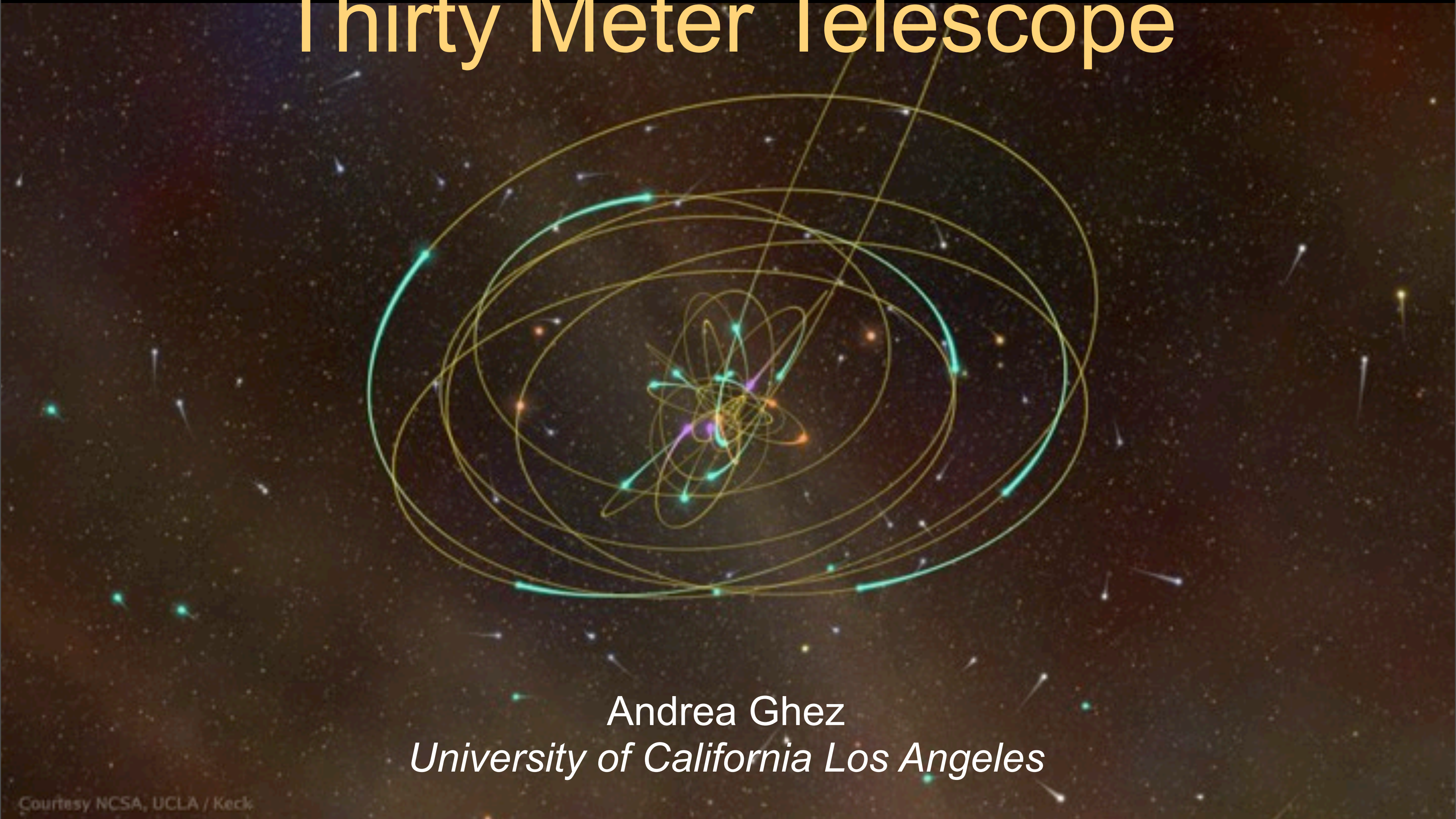
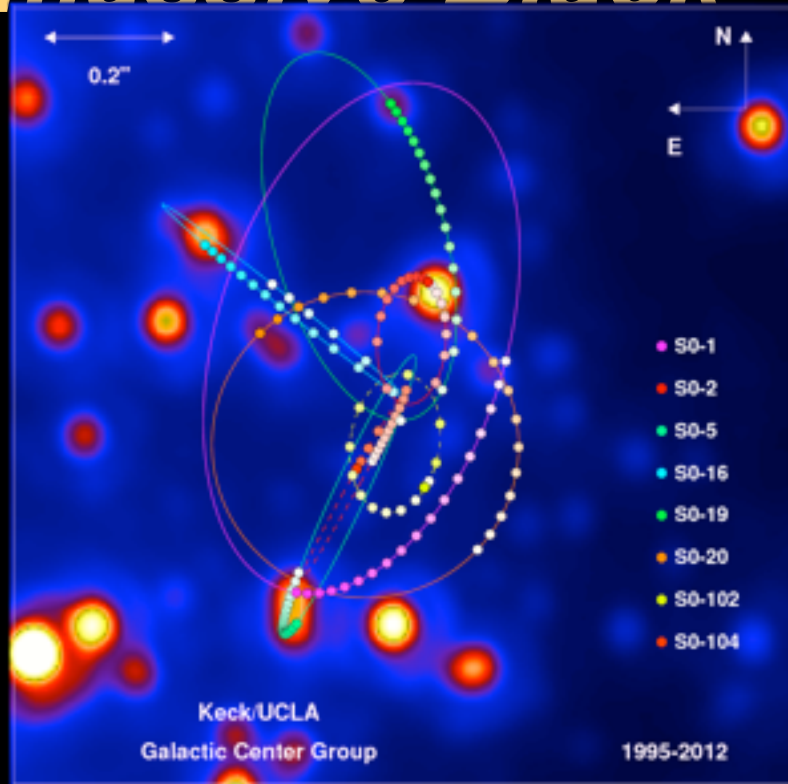
Galactic Center Science with the Thirty Meter Telescope



Andrea Ghez
University of California Los Angeles

Eric Becklin, Mark Morris, Anna Boehle, Tuan Do, Jessica Lu, Keith Matthews, Leo Meyer, Kim Phifer, Gunther Witzel, Sylvana Yelda

The Galactic Center is a Unique Lab for Studying a Supermassive Black



10" = 0.4 pc

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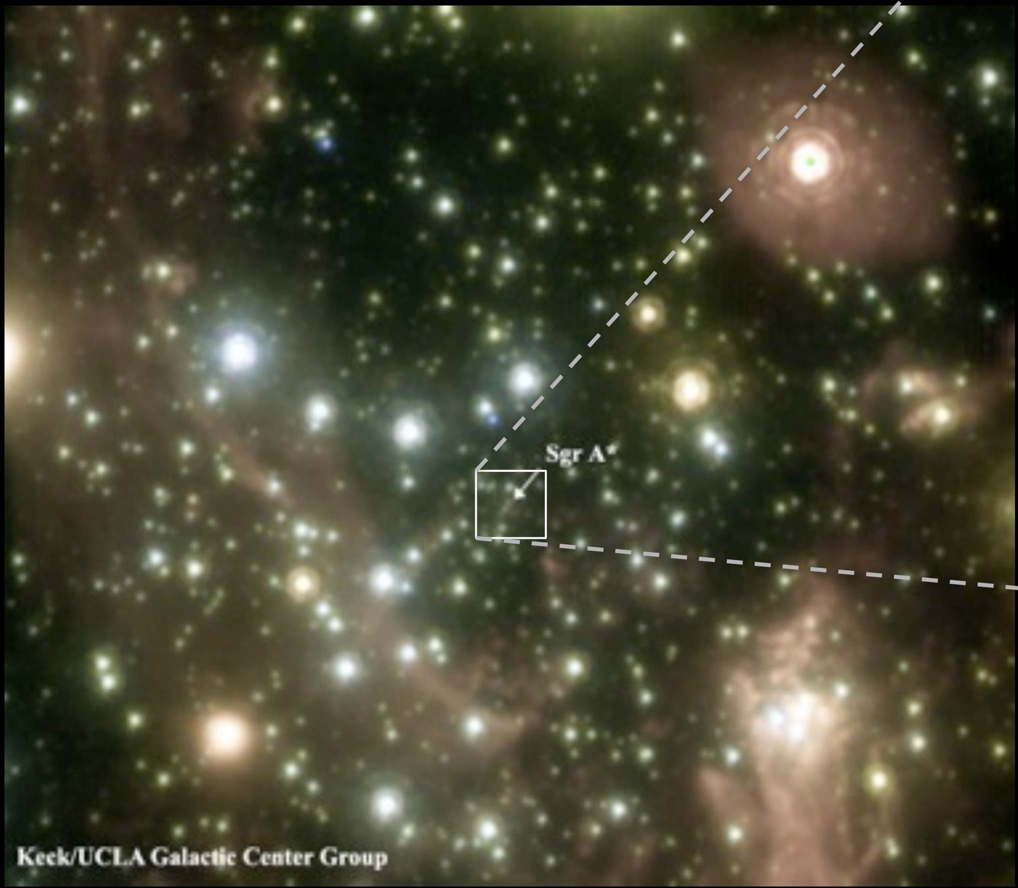

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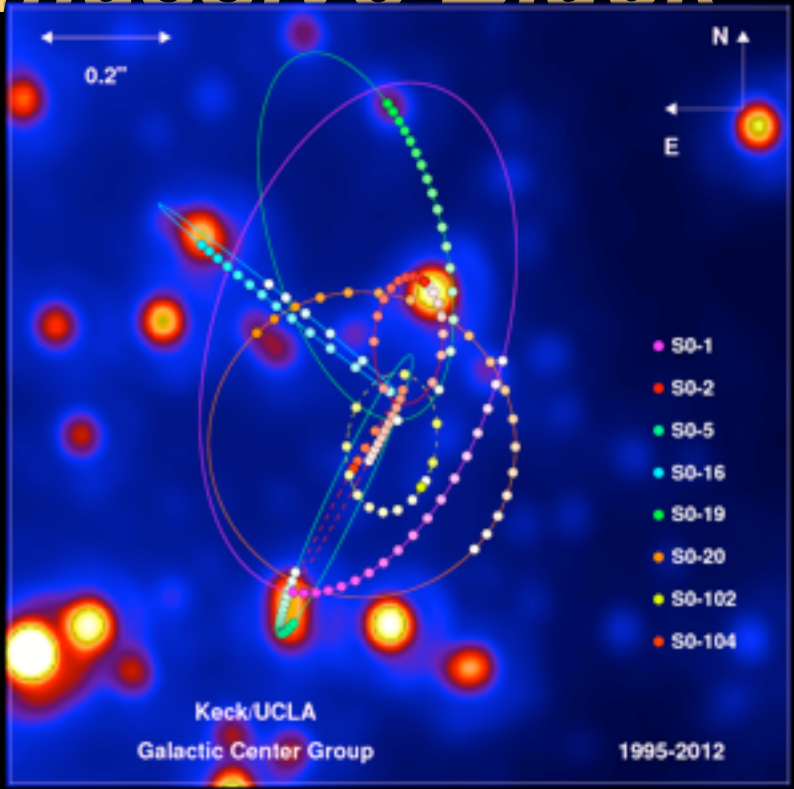
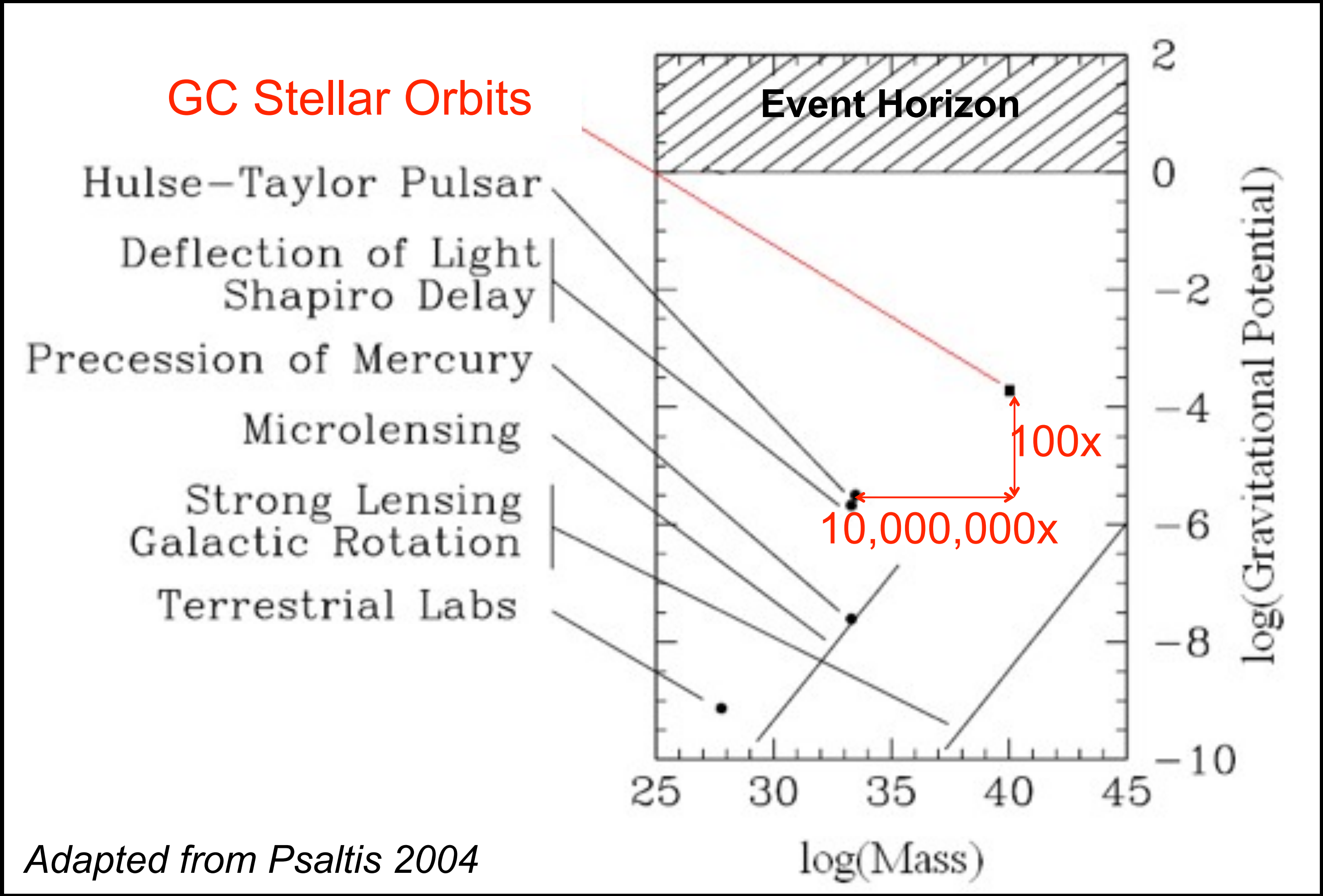


The only galactic nucleus with measured stellar orbits

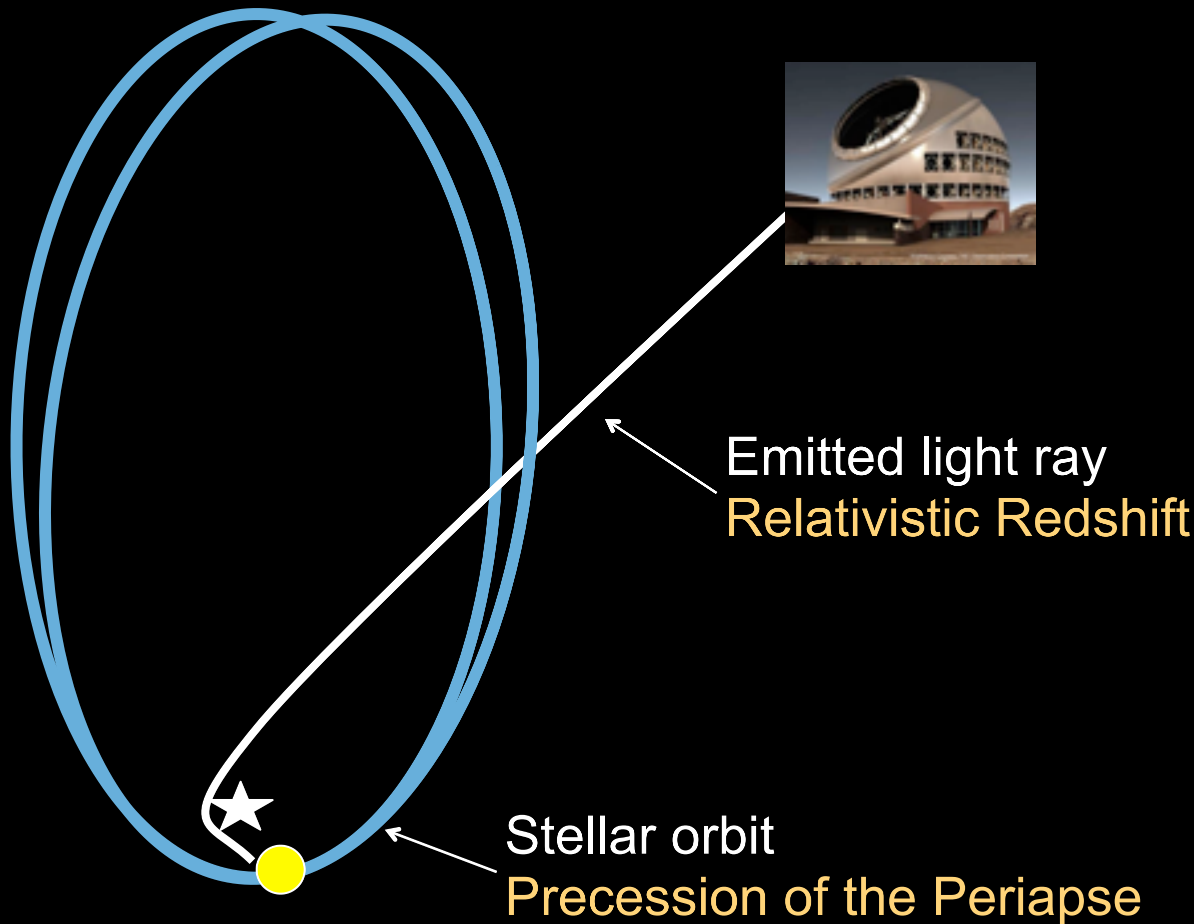
Two Big Picture Perspectives

- **Physics:** Do black hole exist? Testing General Relativity.
- **Astronomy:** What role do black holes play in the formation & evolution of galaxies?

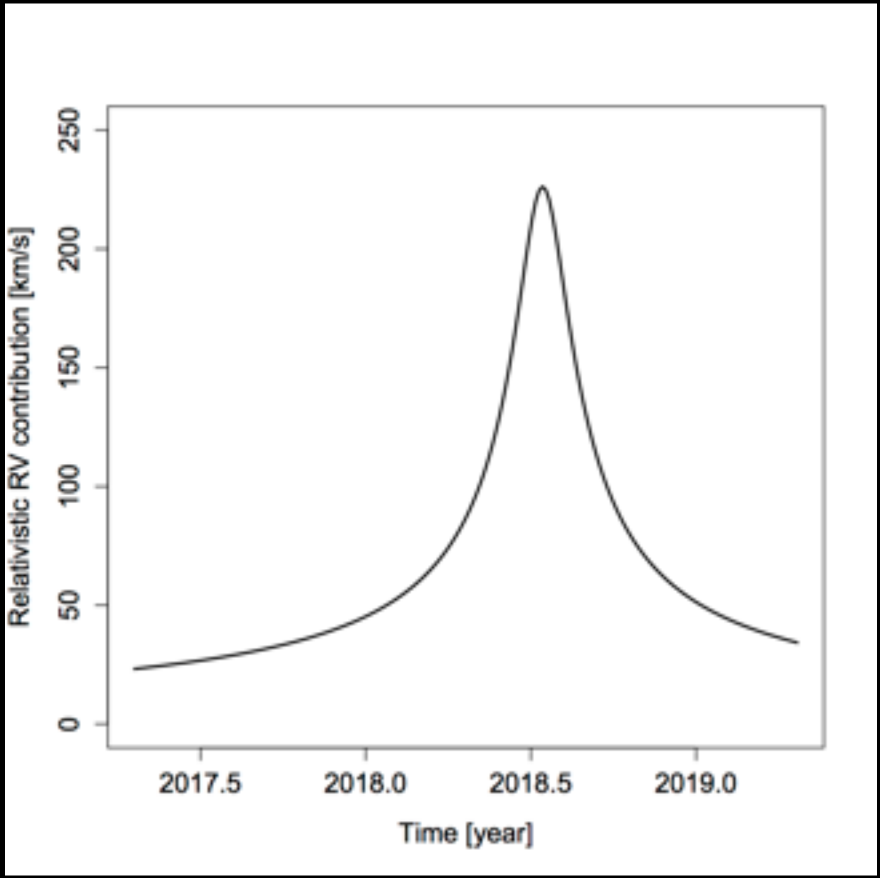
Galactic Center Stellar Orbits Test Einstein's Theory of General Relativity in Unexplored Regime



Orbits Provide Two Tests of Einstein's Theory of General Relativity



Only First Step Potentially Possible with Today's Telescopes



Relativistic Redshift During S0-2's Next Closest Approach (Periapse) in 2018
Keck & VLT expected to make a 5-σ measurement

Zucker et al. 2006; Angelil & Saha 2011

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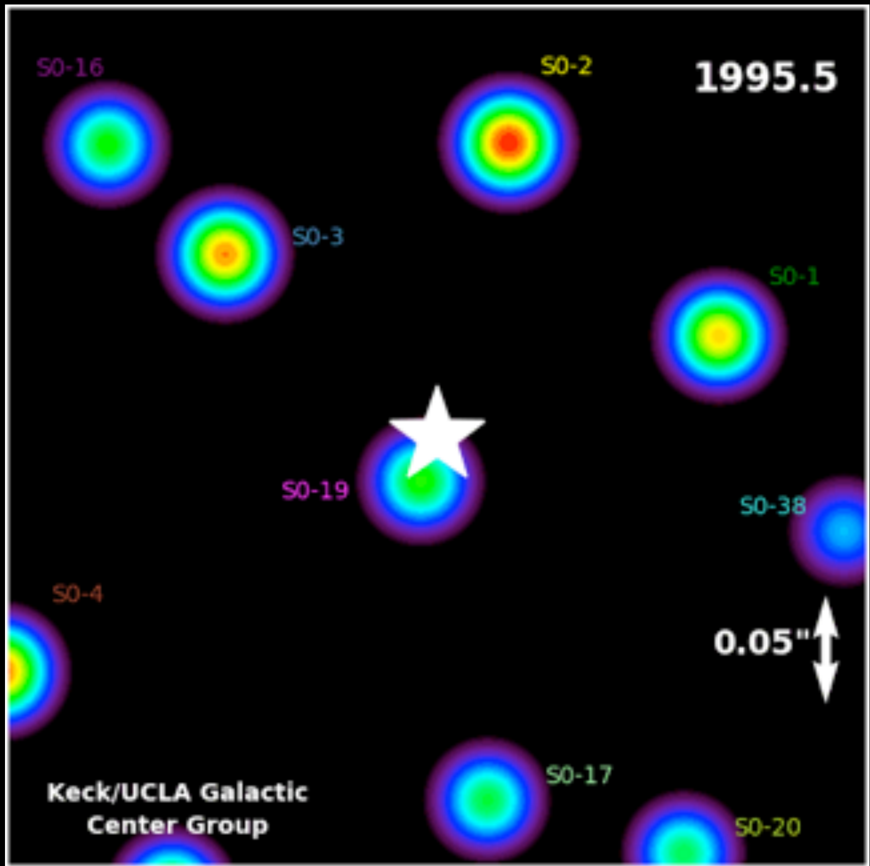

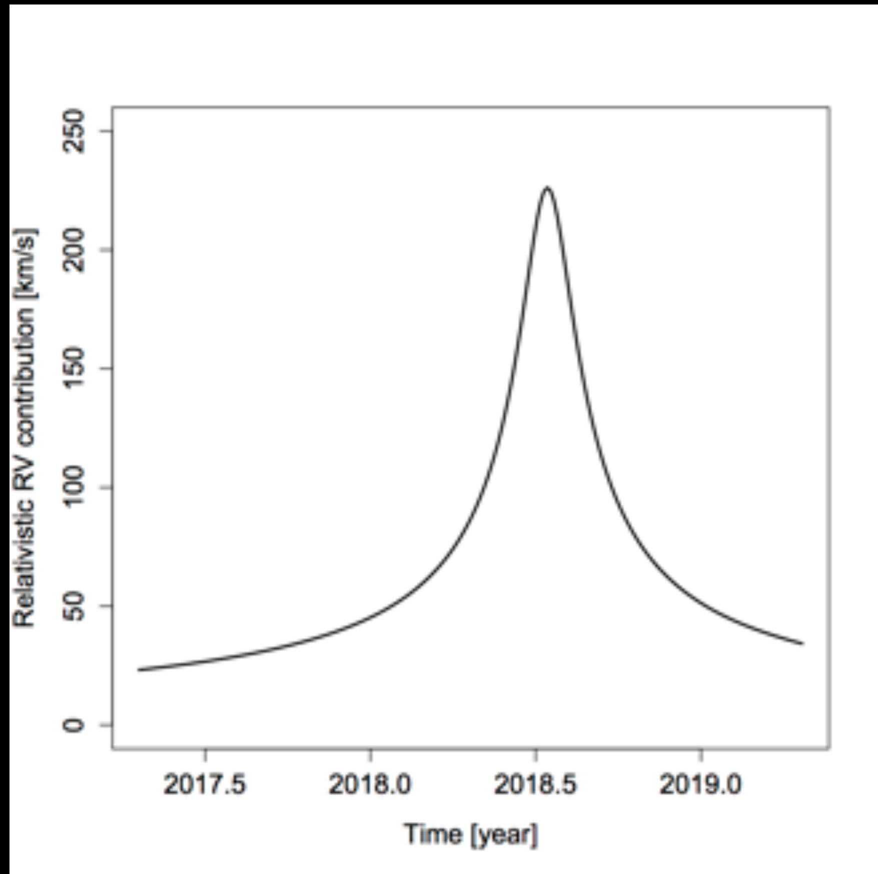

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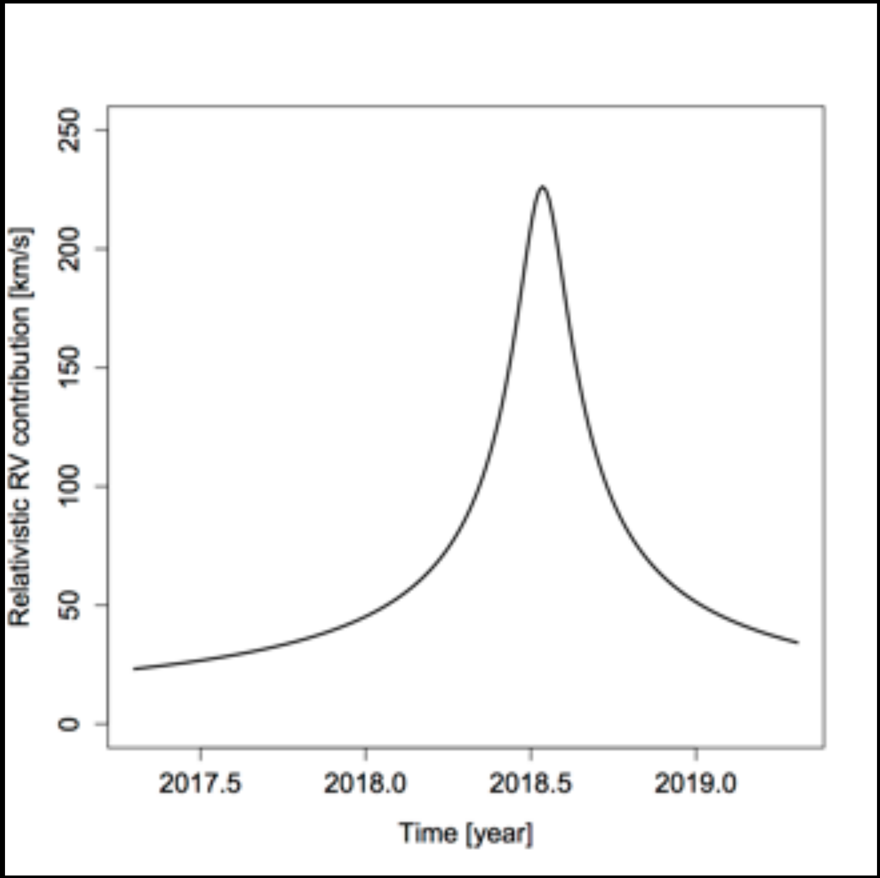

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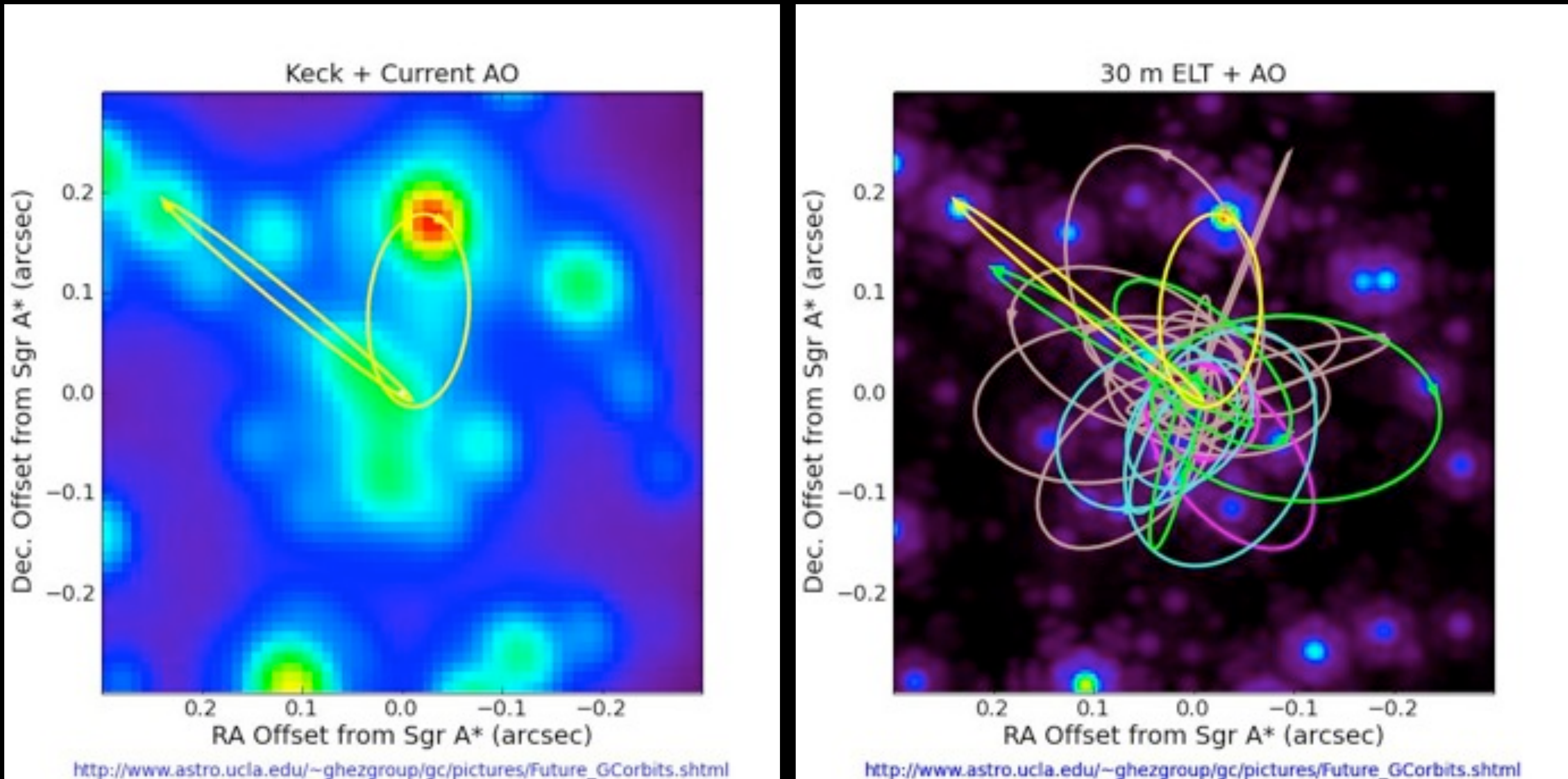
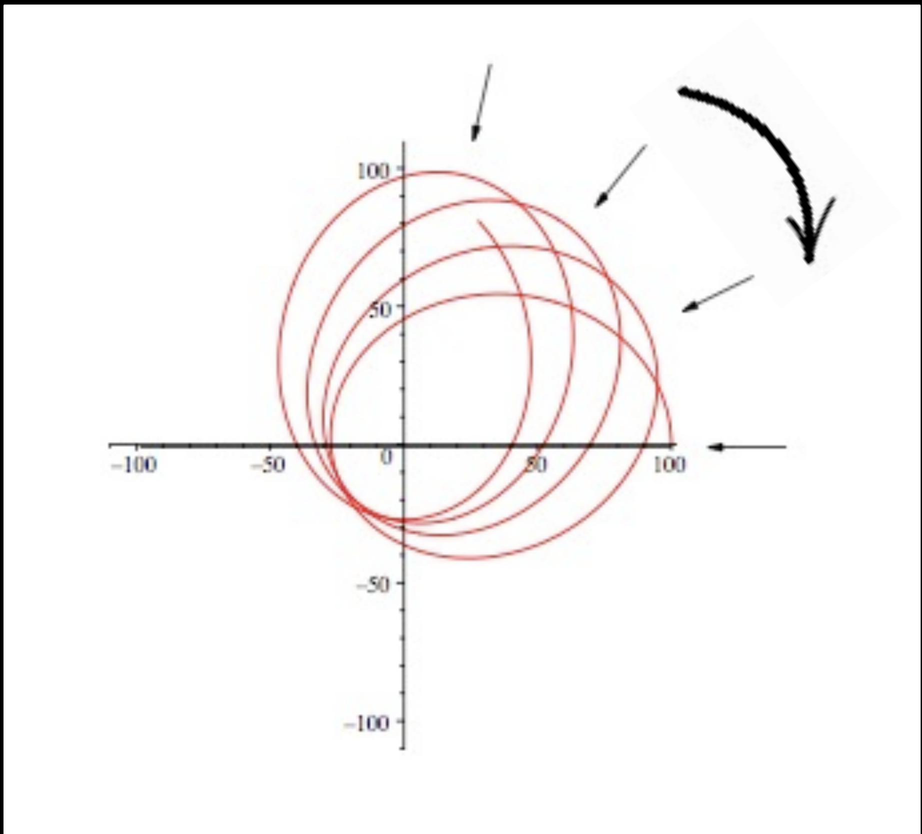
TMT will Detect an Order of Magnitude More Short-Period Stars



Should find stars with orbital periods as short as 2 years vs. current limit of 11.5 years

Weinberg et al. 2005; Yelda et al. 2013 Meyer et al. 2013

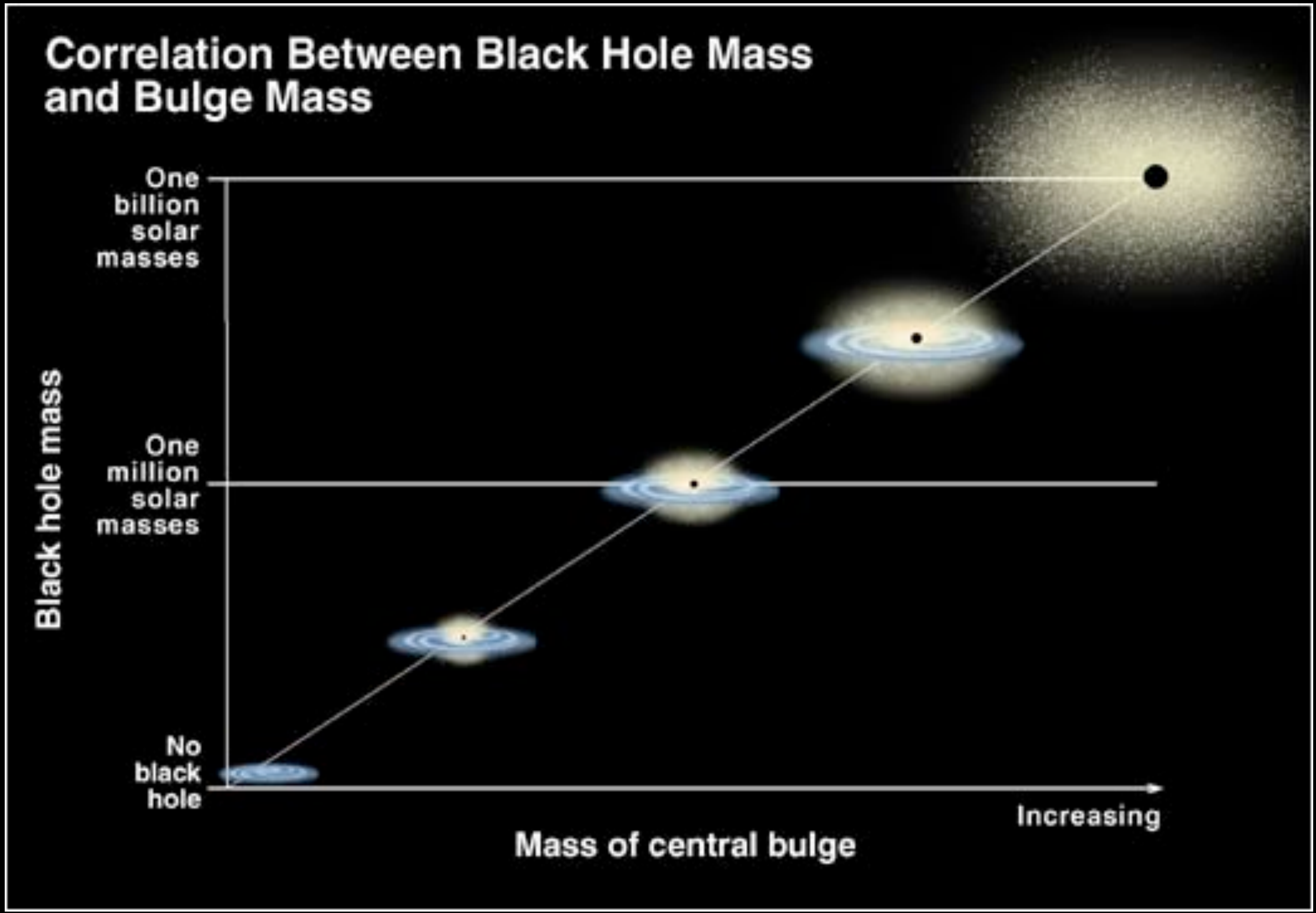
TMT will Enable Measurement of Precession of Periapse



- **General Relativity**
  - **Prograde precession**
    - $\Delta s \sim a(1-e)\Delta\phi$
      $= 6\pi GM/[c^2 (1-e)]$
    - $\Delta s = 0.8$ mas for S0-2
  - Current Limitations:
    - Reference frame stability
    - Source confusion
    - Degeneracy with extended mass (need more than one star!)

Munyaneza et al. 1998; Jaroszynski 1998; Fragile & Mathews (2000), Rubilar & Eckart 2001 (shown), Weinberg et al. 2005, Will 2008

What Role Do Supermassive Black Holes Play in the Formation and Evolution of Galaxies?



Unique Ability to Study Radiatively Inefficient Accretion Flow

Sgr A* is radiative source associated with black hole

Accretion Flow ($L \sim 10^{-8}\, L_{Ed}$)

- Highly variable!
- Possible variation on very short time scales that are not explained by current statistical models
- Possible time lag in IR

- Most of time suffers significant source confusion

Genzel et al. 2003; Ghez et al. 2004, 2005; Eckart et al.2004, 2006; Hornstein et al. 2006; Meyer et al. 2008, 2009; Do et al. 2009; Dodds-Eden et al. 2011; Wtizel et al., in prep

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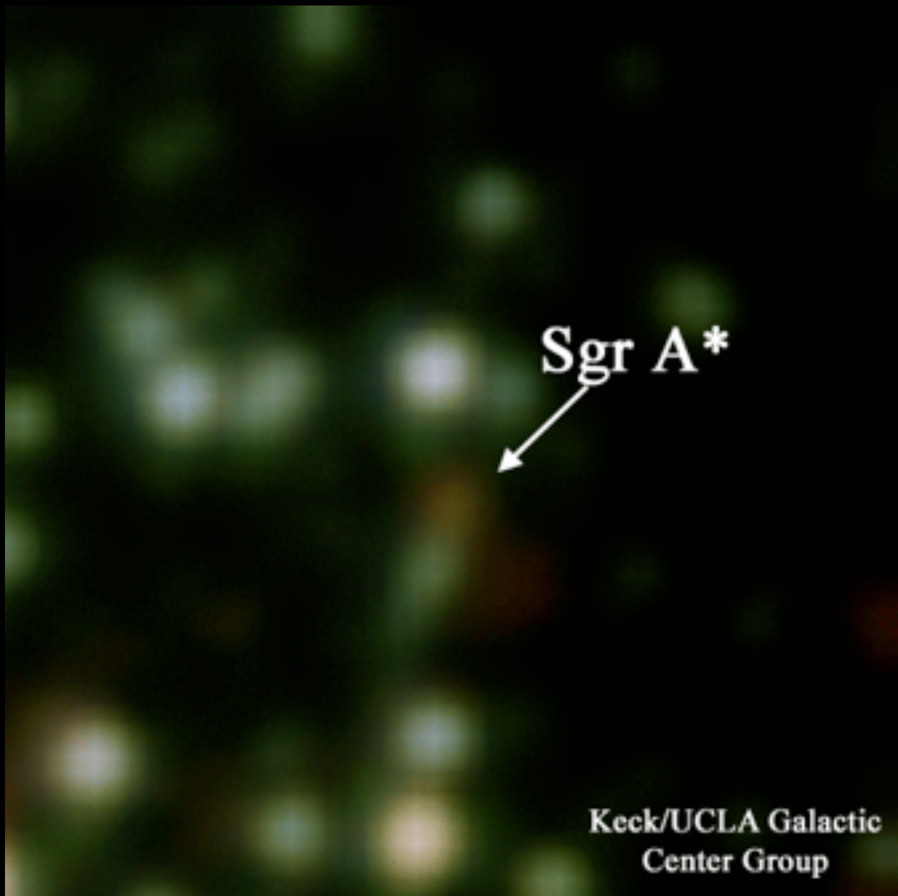

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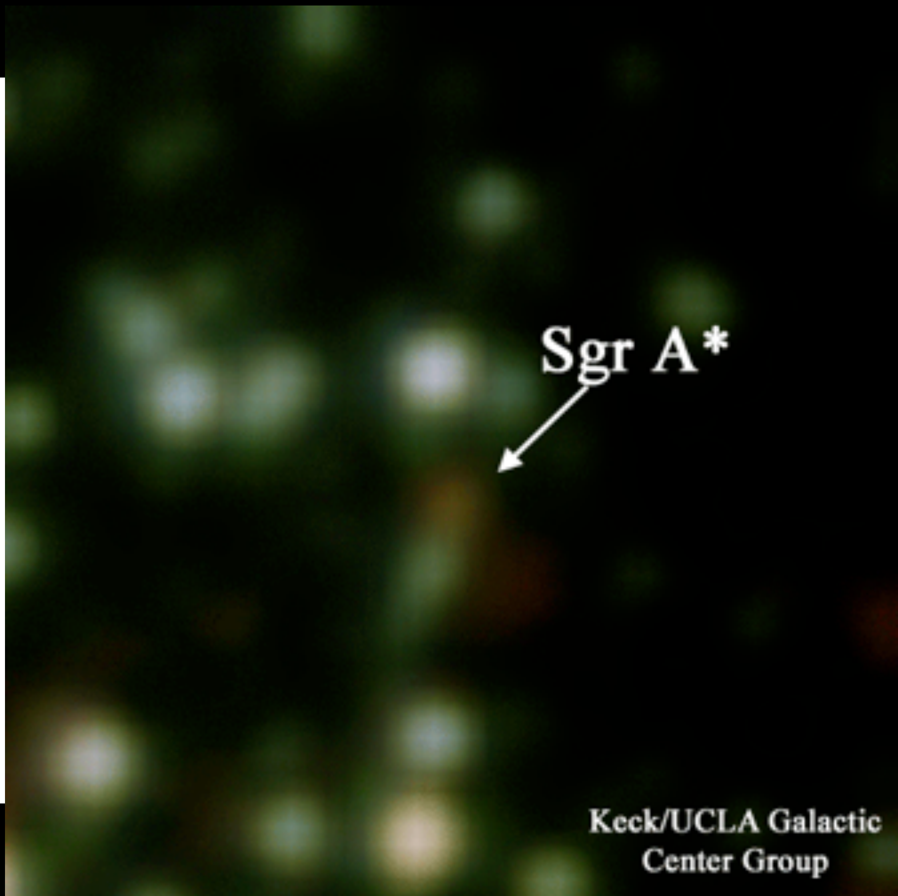

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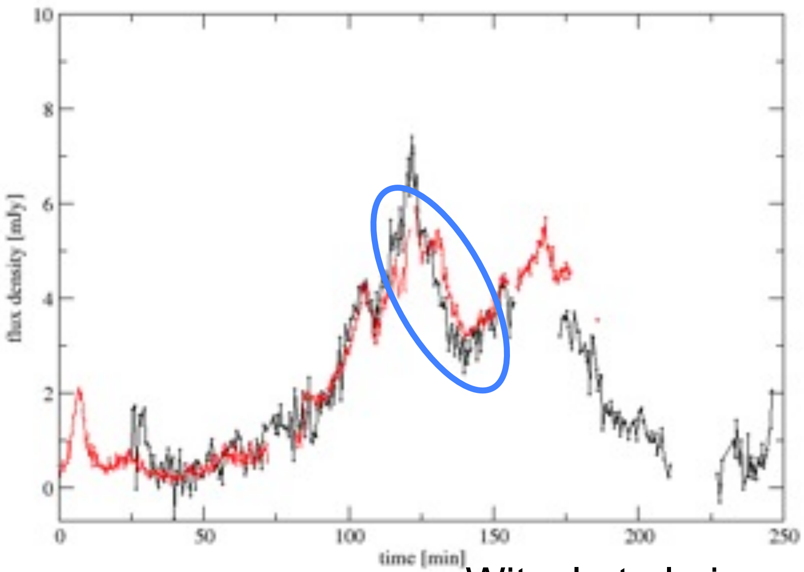

Witzel et al., in prep

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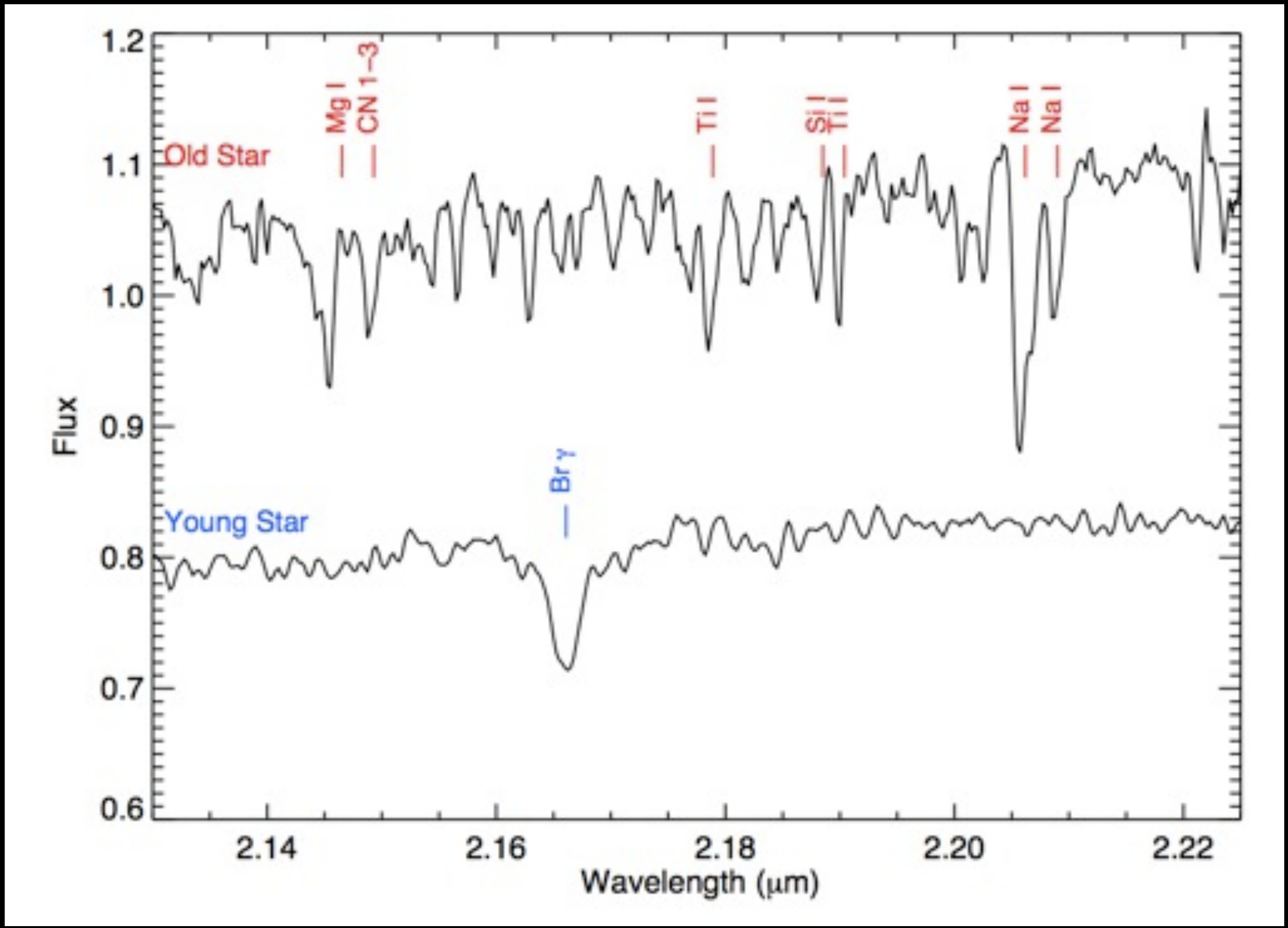
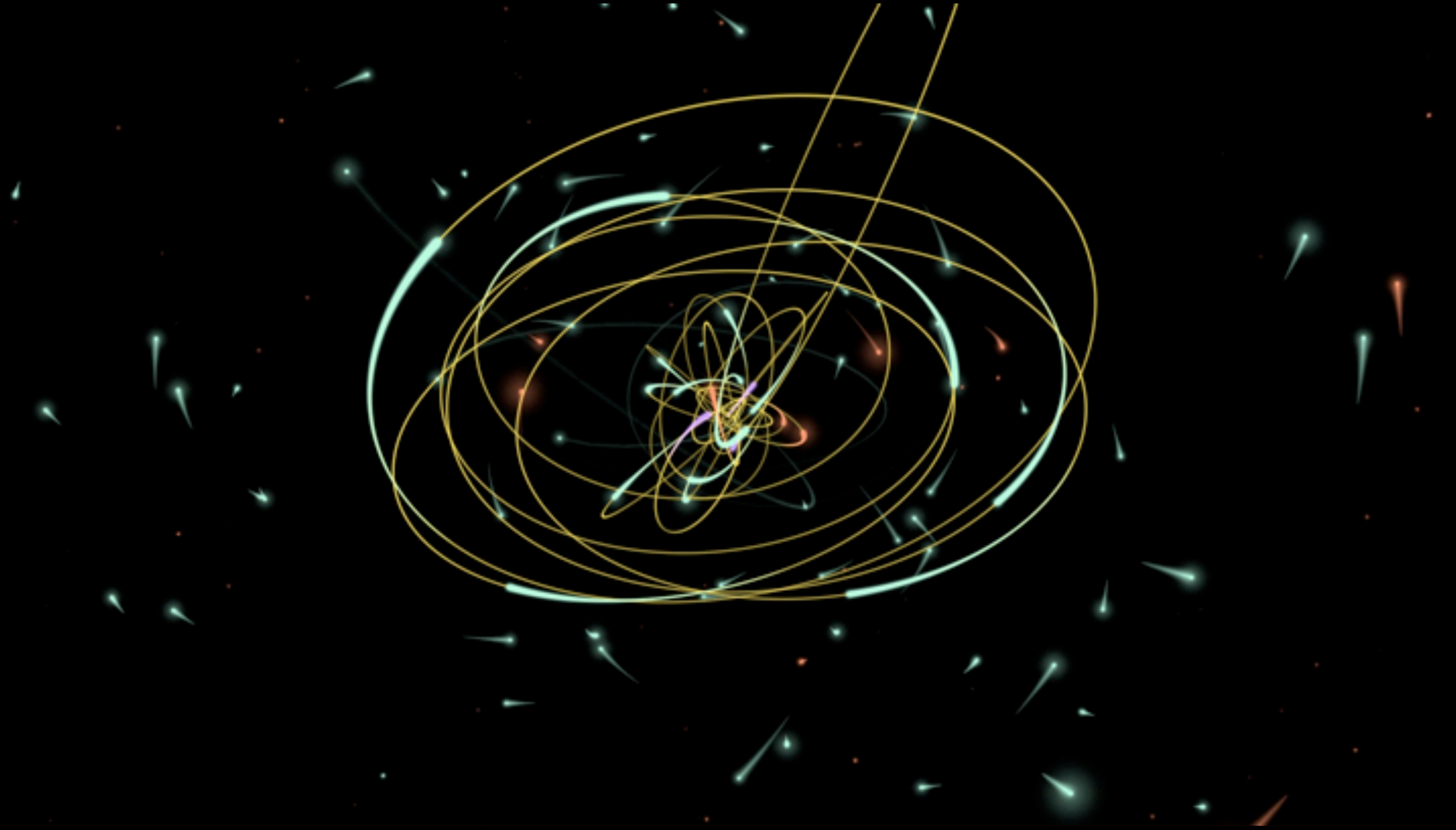
New Insight into Stellar Populations



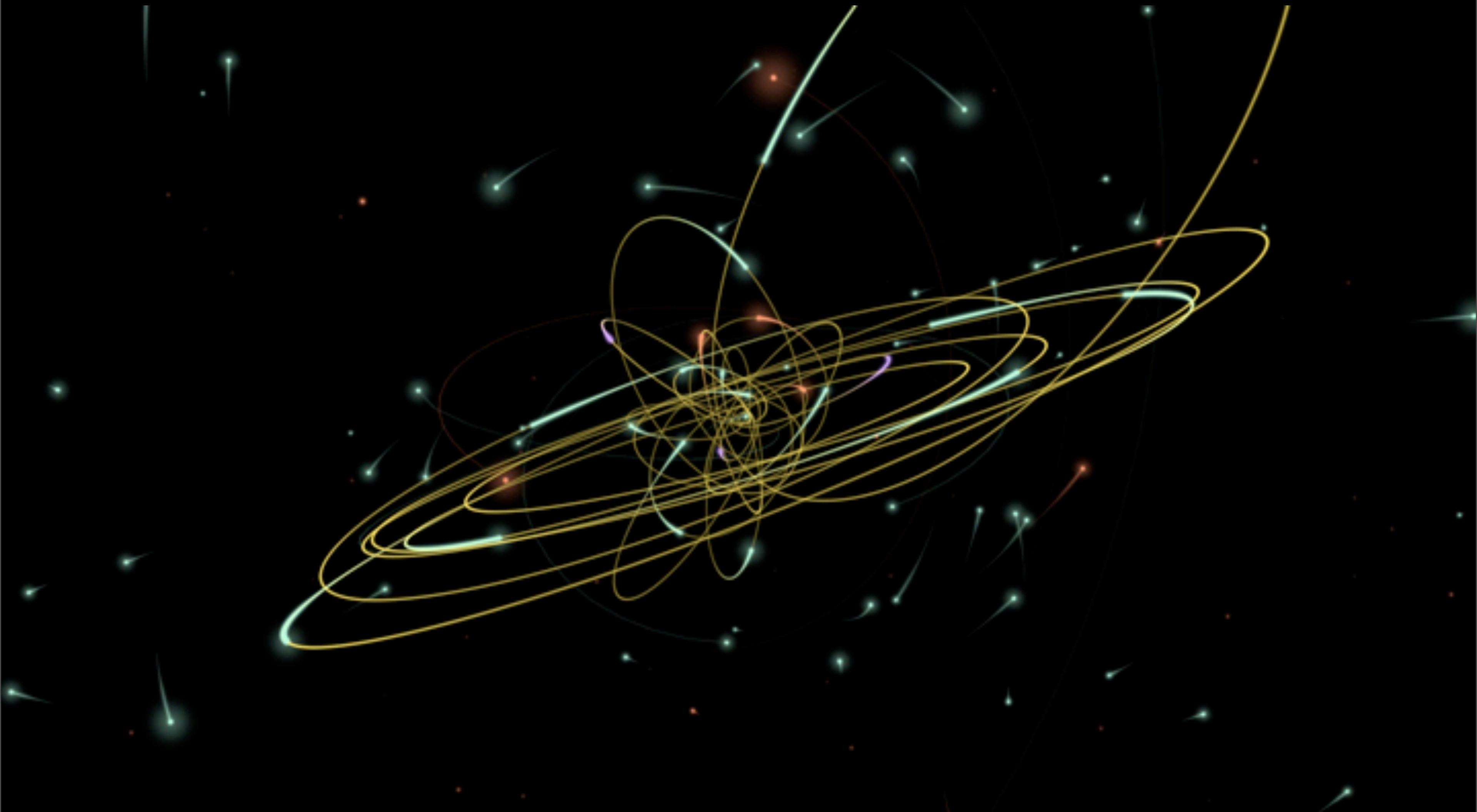
Do et al. (2013)

Unexpected Stellar Populations

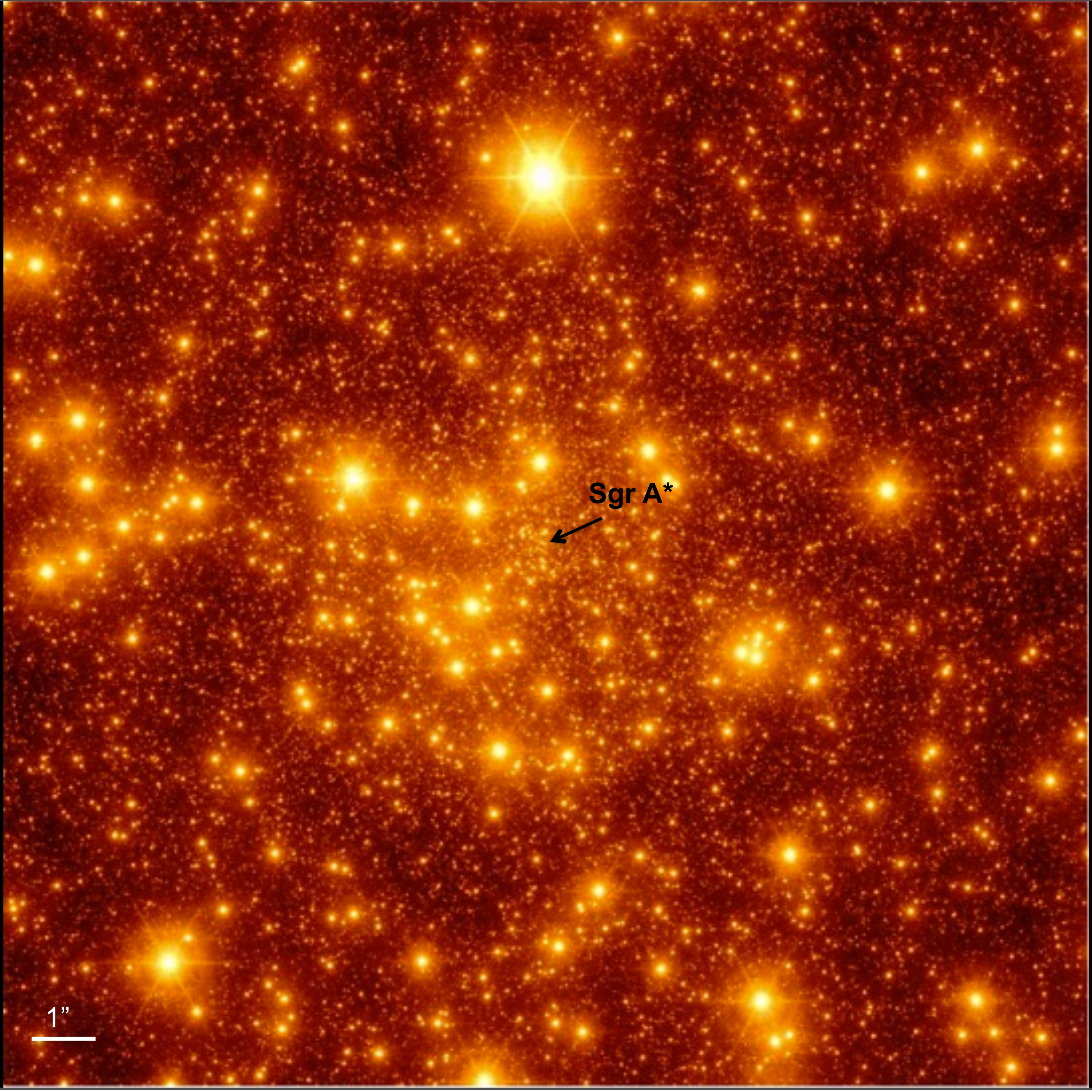


Visualization by Stuart Levy & Robert Patterson, NCSA, University of Illinois

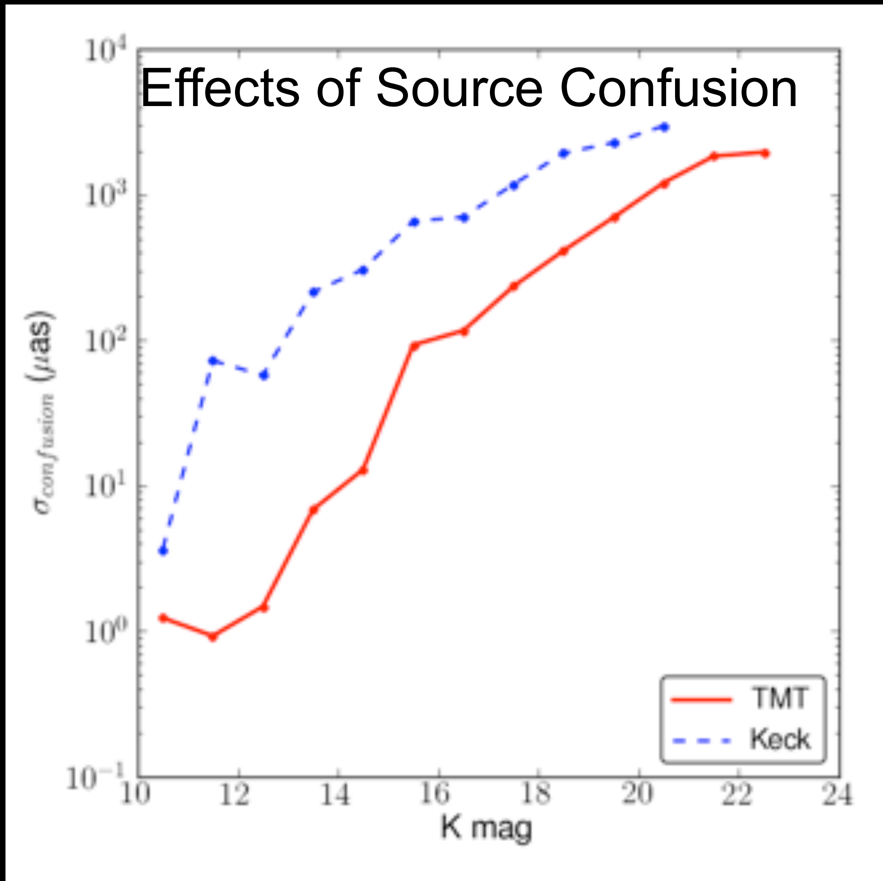
Unexpected Stellar Populations



- Today: Young Stars – 20% in stellar; Observable old stars – no cusp…
- Need TMT to understand structure of 80% of young stars and late-type stars (need accelerations at larger radii)

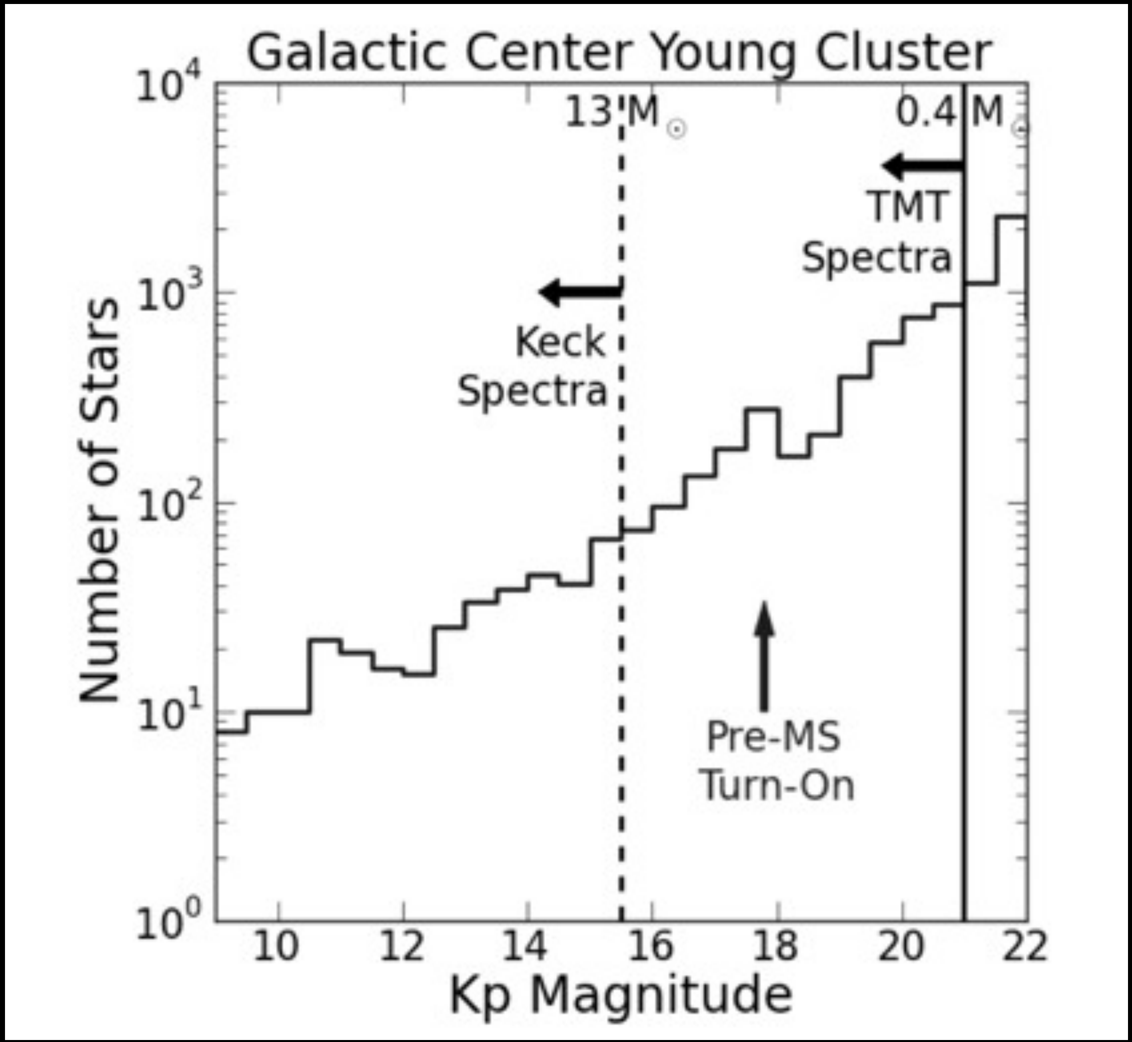

Sgr A*
1”

TMT Dramatically Reduces Current Limitation for Probing Long Orbital Periods



Yelda, Meyer & Ghez (2013) TMT Project Report

Today We Only See Tip of Ice Berg



Lu et al. (2013)

Expect the Unexpected!

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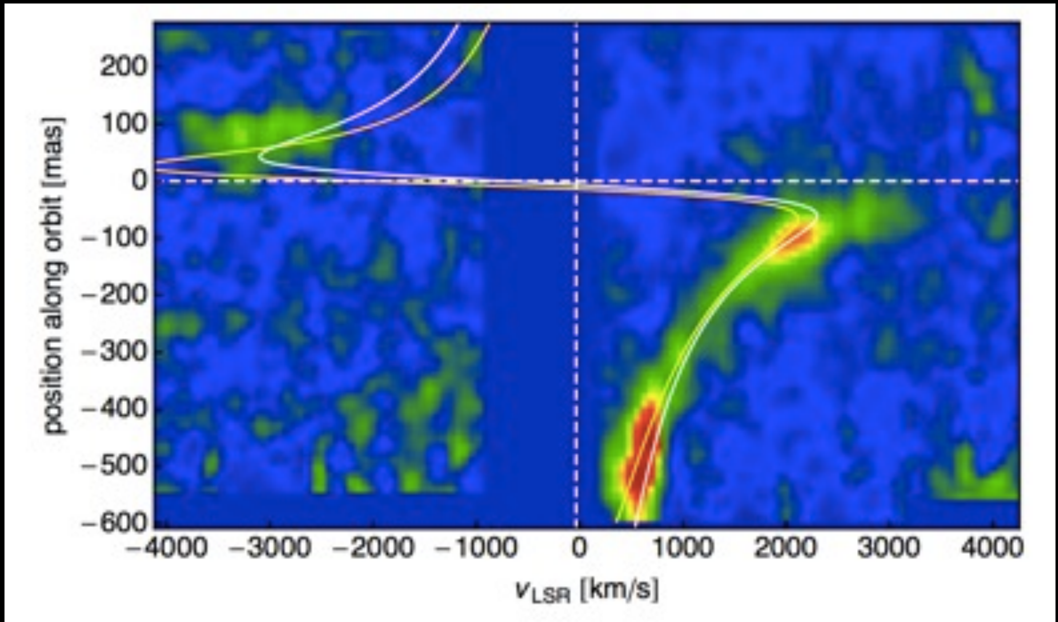
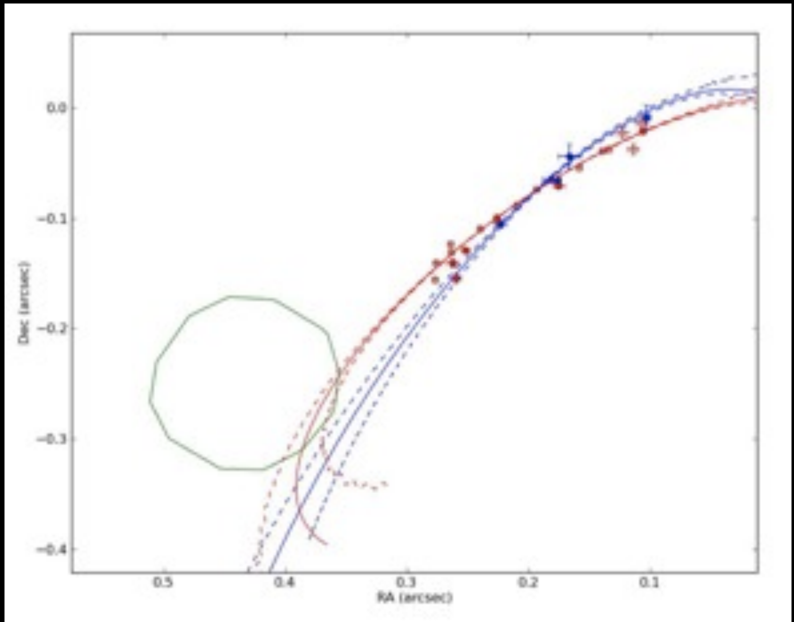
G2 – tidal disruption of an infalling gas cloud?





Gillessen et al. 2013

Phifer et al. 2013

Observations: Gillessen et al. 2012,2013; Phifer et al. 2013

Theory: Burkert et al. 2012, Miralda-Escude 2012, Schartmann et al. 2012, Murray-Clay & Loeb 2012, Schoville & Burkert 2013

Conclusions

Exciting future in story for Galactic Center science with TMT

- testing Einstein's theory of General Relativity in an important & unexplored regime
- Exploring black hole accretion physics
- Understanding star formation in the extreme environment of a black hole
- Solving the mystery of the missing cusp

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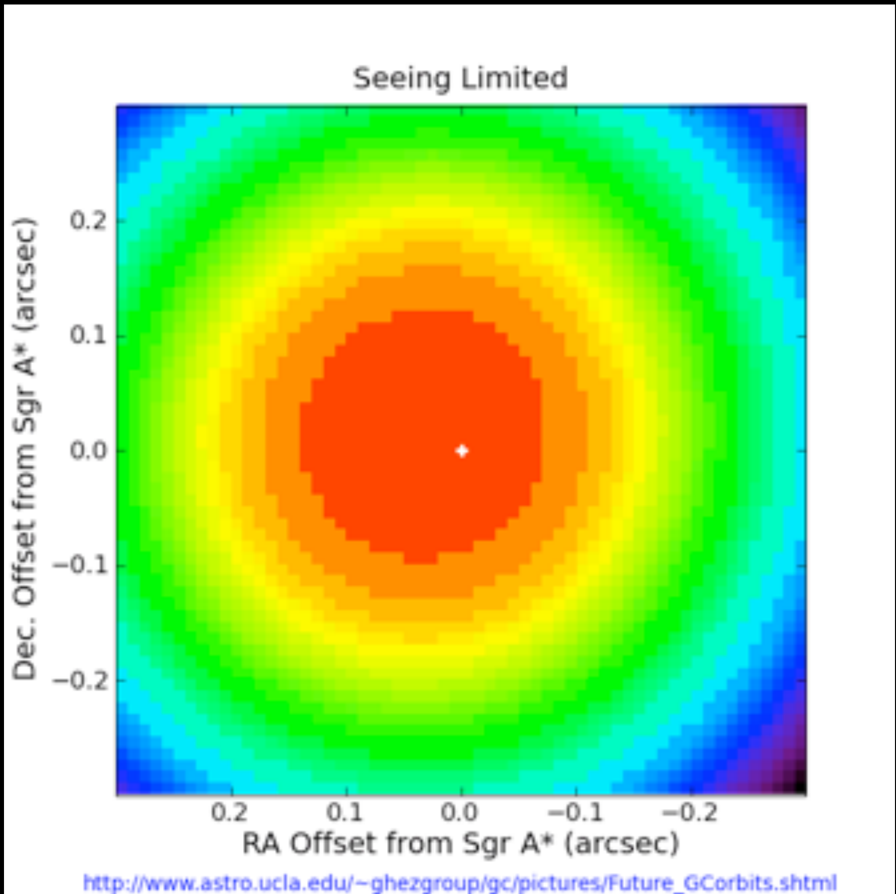

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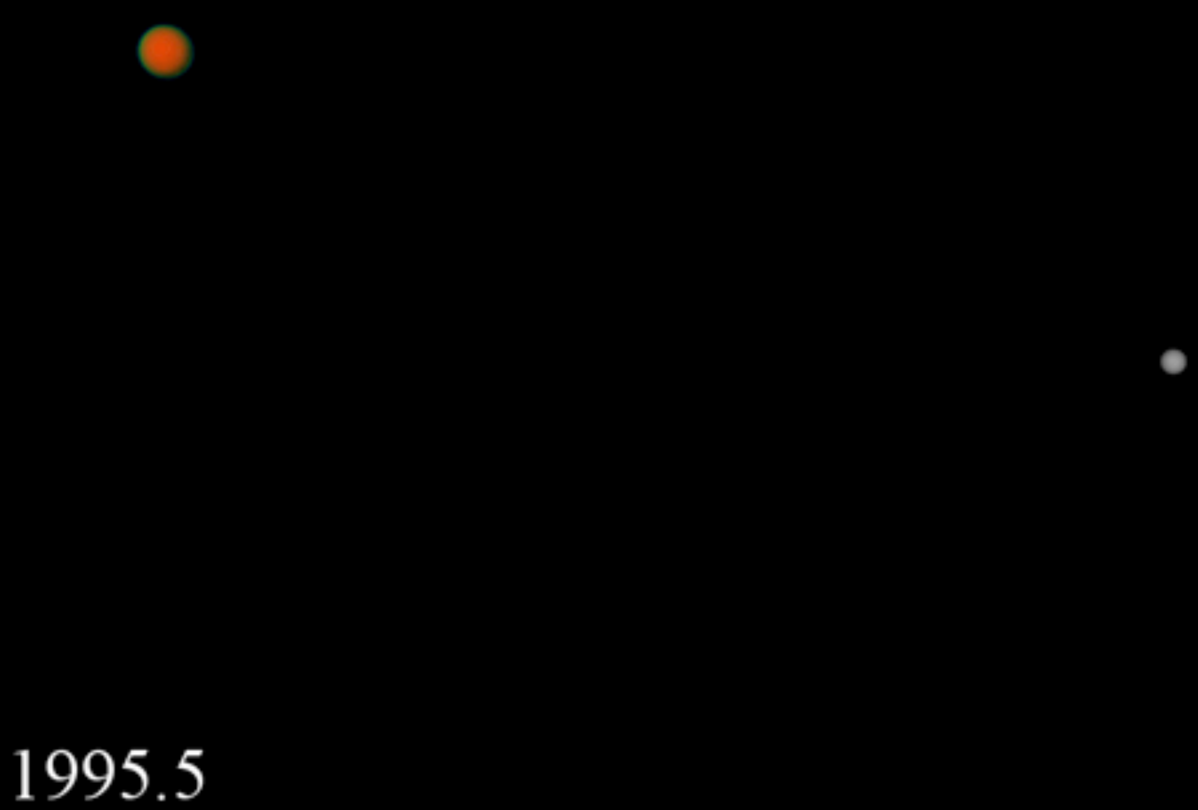
Visualization by Stuart Levy & Robert Patterson, NCSA, University of Illinois

An Incoming Gas Cloud?

Simulation by Anninos, Fragile et al.

An Incoming Gas Cloud?



Simulation by Anninos, Fragile et al.

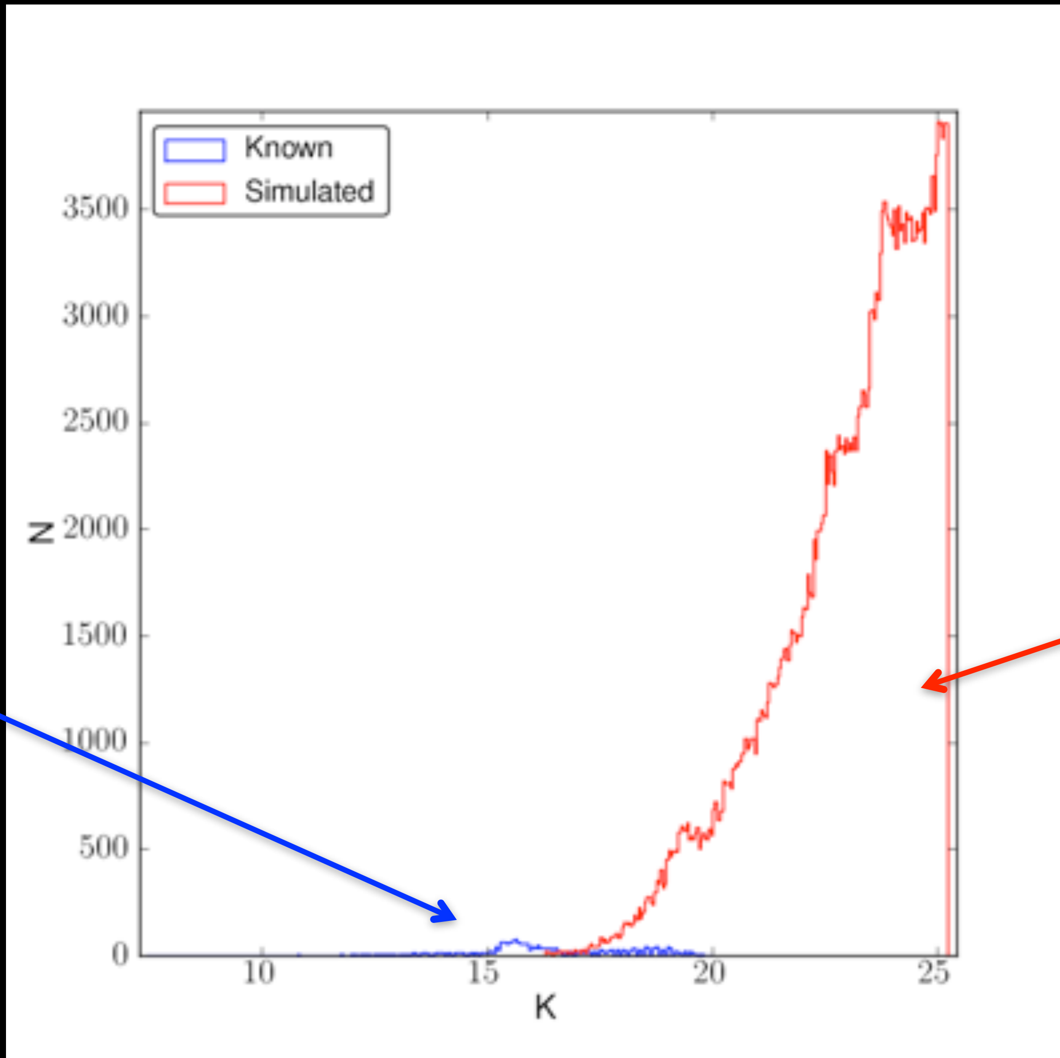
An Incoming Gas Cloud?

Simulation by Anninos, Fragile et al.

The Galactic center astrometric error budget so far looks promising…

Effect	Error
Photon, detector, thermal noise	4.2 μas
Differential TT jitter	$1/\sqrt{t_{int}}$
PSF estimation error in crowded field w/o anisoplanatism	3.9 μas
Guide probe positioning	<0.2 μas
Static distortion	8.5 μas
(Grid interpolation: 4.2 μas)	
(Distortion modeling error: 5.7 μas)	

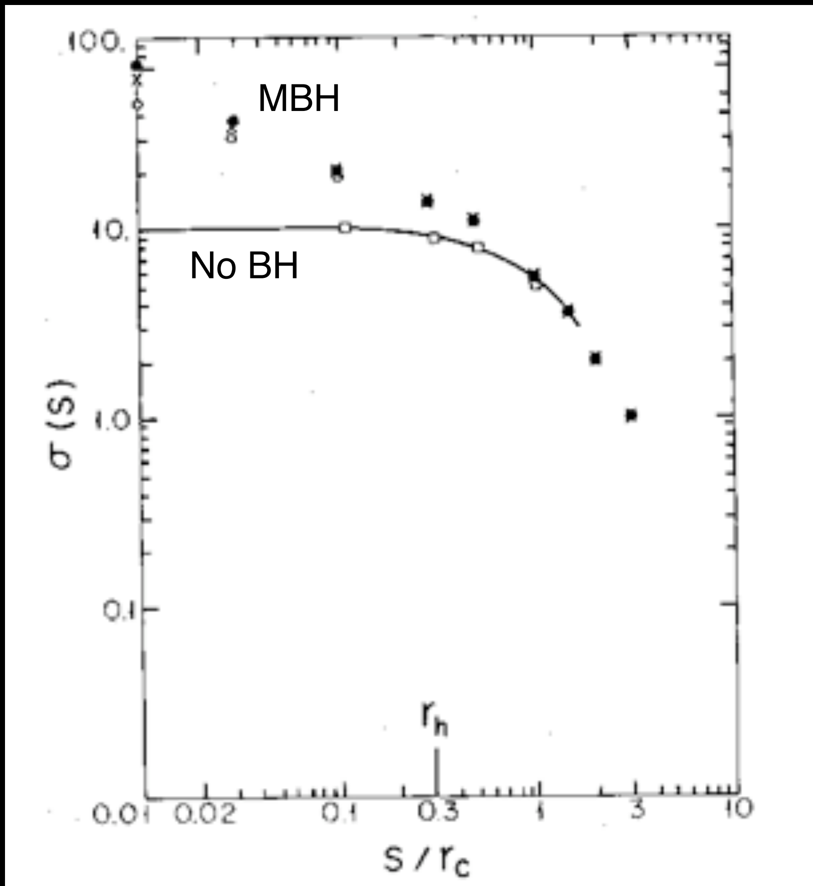
Fainter stars included to test effects of confusion.



~3000 stars

~300,000 stars

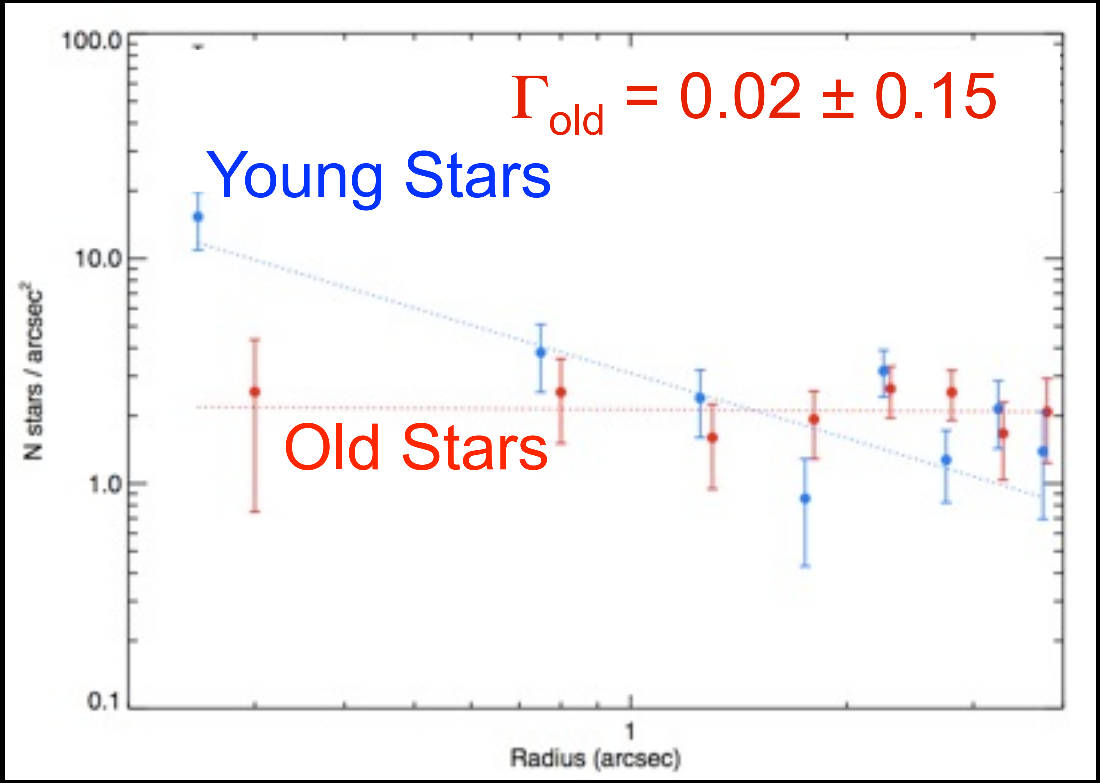
Dearth of Old Stars Not Understood



- **Key prediction for**
  - Understanding evolution of galactic nuclei (e.g black hole merger rates)
  - Finding black holes in other galaxies
- **To test possible need individual orbital parameters at larger radii**

GC Observations: Do et al. 2009, 2013; Schoedel et al. 2009; Bartko et al. (2010)
Solutions: Murphy et al. (1991), Alexander (2005), Merritt & Szell (2006), Alexander & Hopman (2008), Davies et al. (2010), Murphy (2010), Merritt (2010)

The Observed Profile of Old Stars is Flatter Than Expected for a Cusp



The Observed Profile of Old Stars is Flatter Than Expected for a Cusp

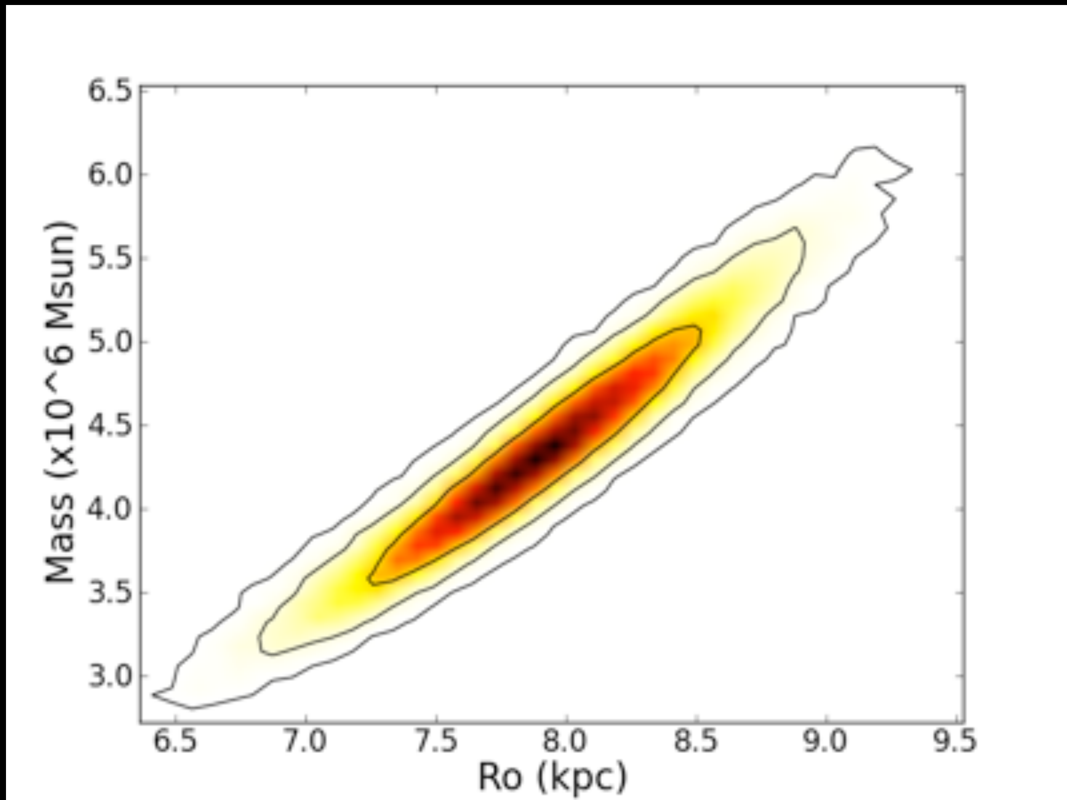
Theory: $3/2 < \gamma < 7/4$

Observed Star Counts: $\gamma < 1$

+ 3-D kinematics: $\gamma = 0.6 \pm 0.2$

Schoedel et al. (2009); Do et al. 2009 & in prep (shown); Bartko et al. (2010)

Central Mass of 4 x 10^6 M_{sun} is Confined to within 1,200 R_s



- BH Mass = 4.1 ± 0.4 x10^6 M_{sun}
- Distance =7.7 ± 0.4 kpc
- Velocity at periapse ~ 8,500 km/s (0.03c)
- Period = 16.2 ± 0.2 yr

- Periapse dist. = 0.52 ± 0.03 mpc (~1,200 R_S)