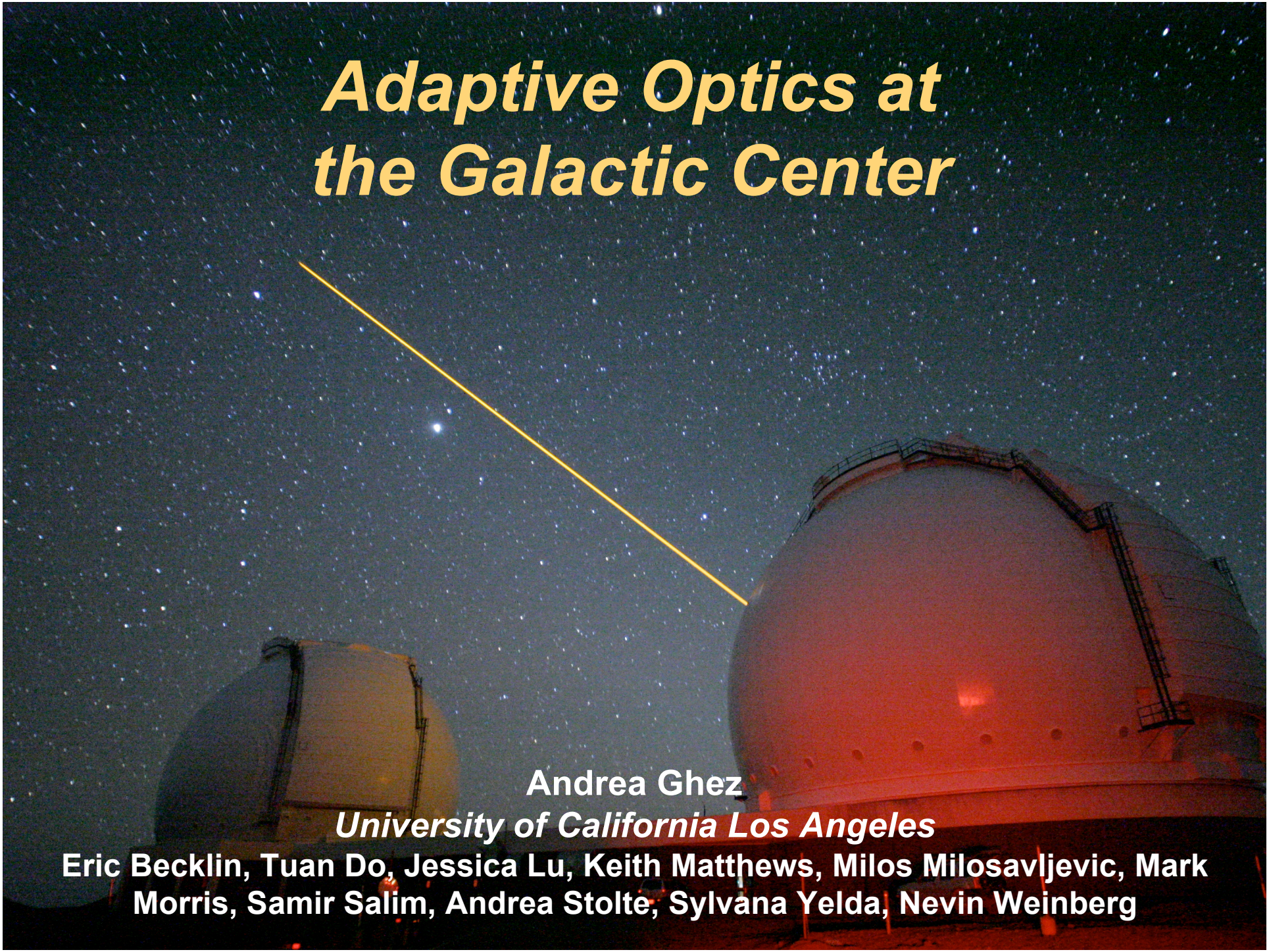
Adaptive Optics at the Galactic Center



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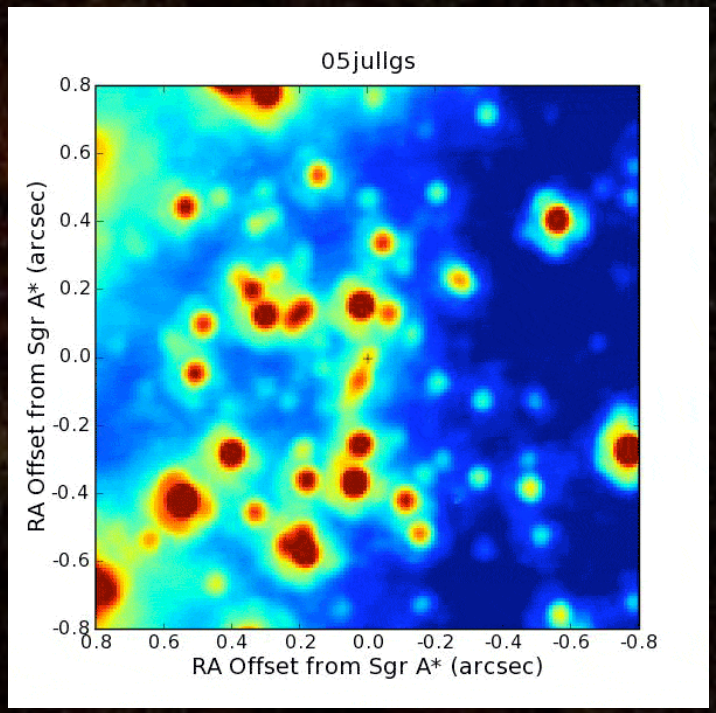
Diffraction-Limited Data on the Galactic Center Offer Insight into a Number of Questions

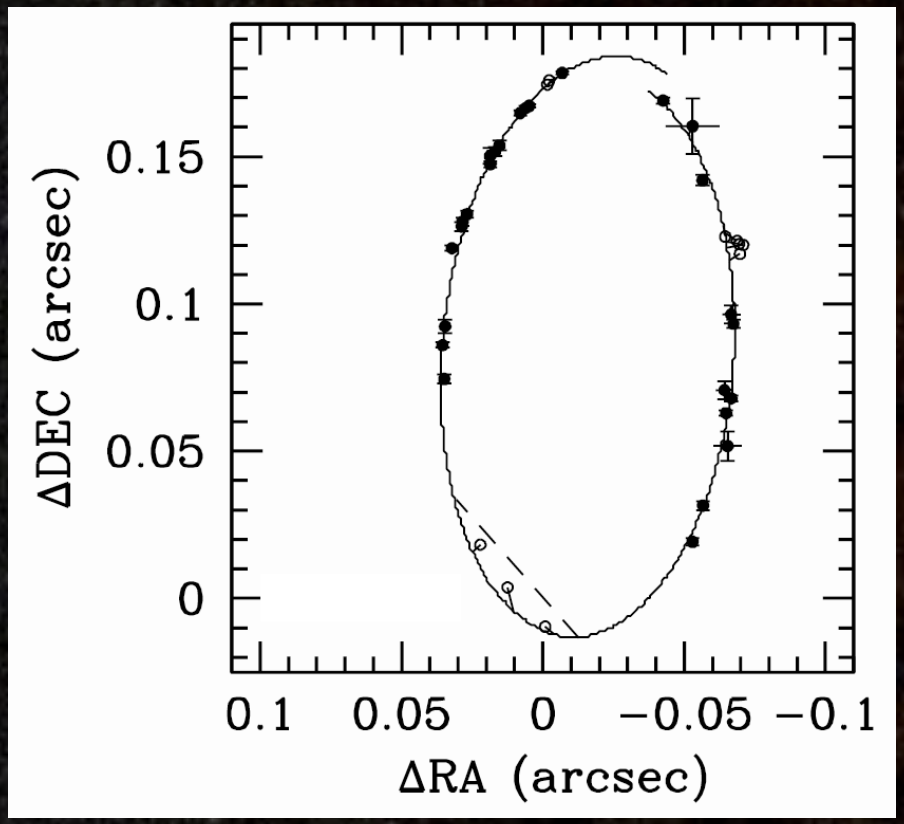
- **What are detailed properties of our Galaxy's supermassive black hole?**
  - *Position (association with SgrA*)*
  - *Mass (M_{bh} vs σ)*
  - *Distance (Galactic Structure)*
  - *Companions or extended dark mass?*
  - *Future (GR, spin?)*
- **How do young stars come to reside in its vicinity?**
- **What is the structure of the surrounding stellar cusp?**
- **What are the properties of the accretion flow and why is it so under-luminous (10^{-9} L_{Ed})?**

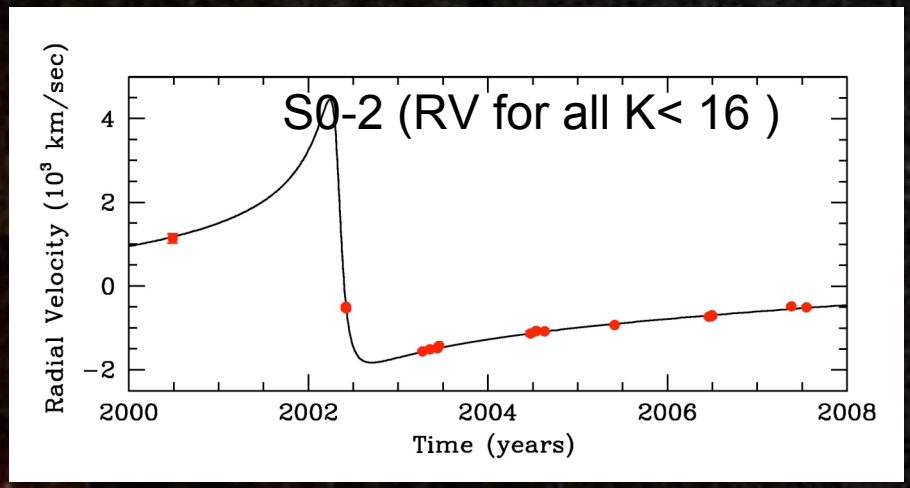
Speckle (1995-2005) →

LGSAO (2004-) ↓



Stellar Orbits at GC Provide the Strongest Cases for a Supermassive Black Hole in a Normal Galaxy

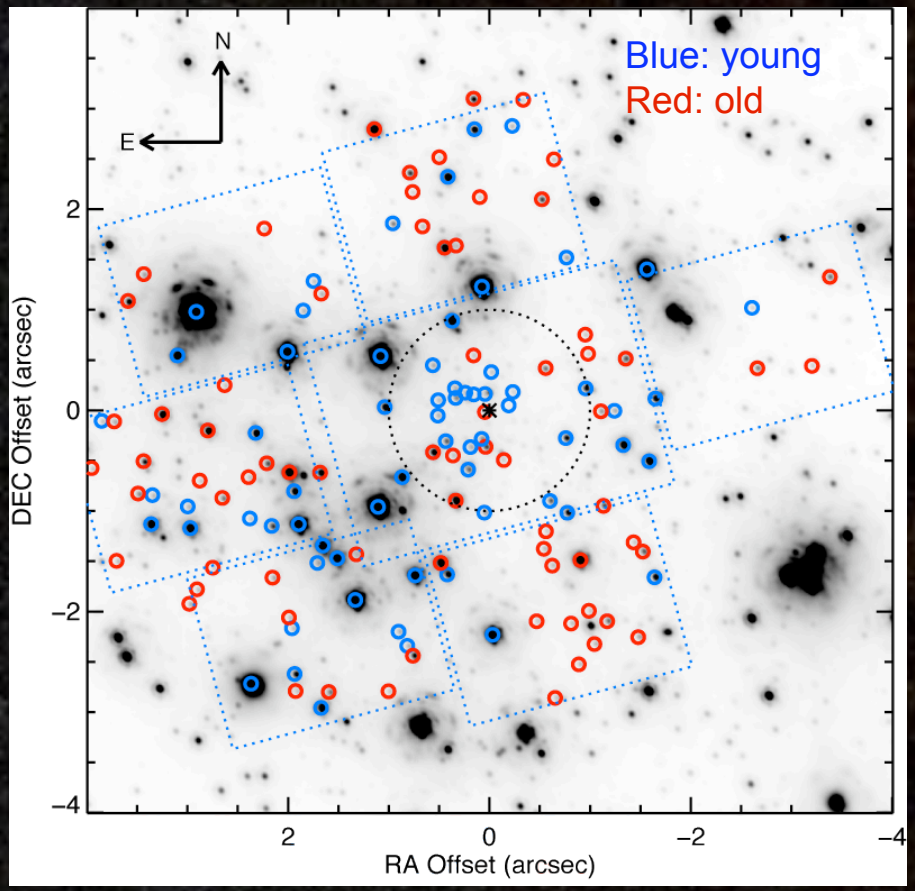




- **S0-2 dominates our knowledge of the central potential**
  - **Bright (K = 14 mag)**
  - **Shortest known period (15 yr)**
- **Orbital Parameters Imply**
  - $\rho_{dark\ matter} = 6 \times 10^{15}\ M_o/pc^3$
  - $Mass_{BH} = 4.1 \pm 0.6 \times 10^6\ M_o$
  - Rel. motion = 0.4 ± 0.1 mas/yr

Ghez et al. 2003, 2005, 2008 (shown); Eisenhauer et al. 2003, 2005; Gillissen et al. 2009

Now Possible to Investigate Surrounding Stellar Population that Surrounds SMBH

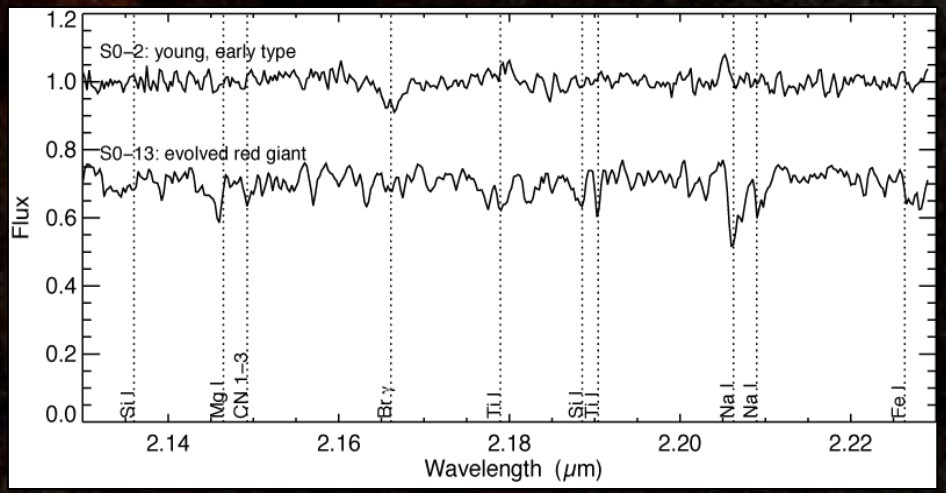


Due to spatially variable extinction

* IR color can not separate populations
* Need spectra!

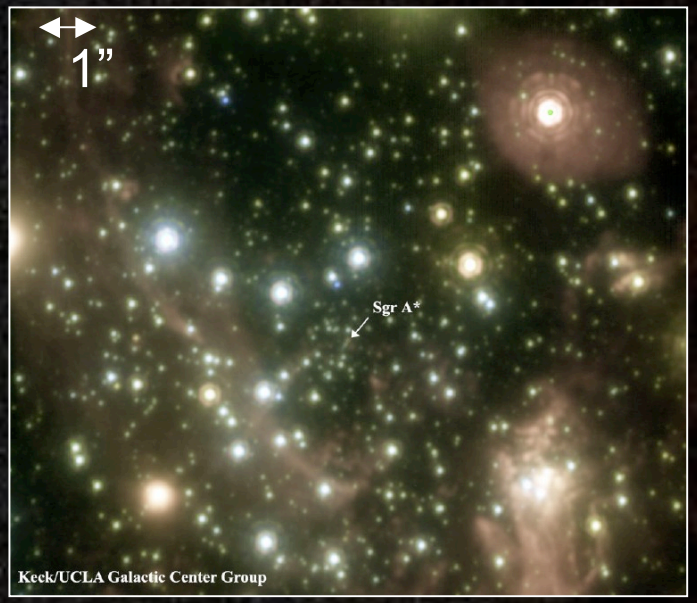
  Br γ = early type / young

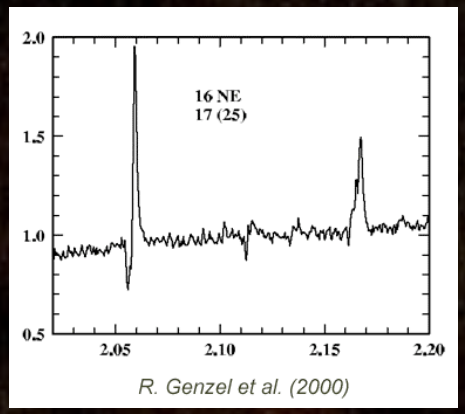
  Na I = late type / old



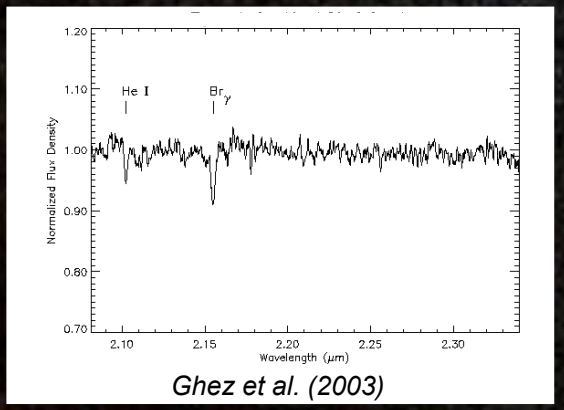
Paumard et al. (2006) Do et al. (2009; shown), Trippe et al. (2009)

AO Reveal an Unexpected Population of Young Stars at the Galactic Center





R. Genzel et al. (2000)



Ghez et al. (2003)

- Wolf-Rayet stars
- Progenitors were > 20 M_o
- Ages of 5-7 Myr
- Between 1 - 10”

- OB Main-Sequence stars
- Masses < 15 M_o
- Ages < 20 Myr
- Between 0.”1 - 10”

Blue stars are massive (short lifetimes)

Forrest et al. 1987; Allen et al. 1990; Krabbe et al. 1991, 1995; Blum et al. 1995; Tamblyn et al. 1996; Paumard et al. 2001, 2006; Ghez et al. 2003, Eisenhauer et al. 2005, Martins et al. 2008

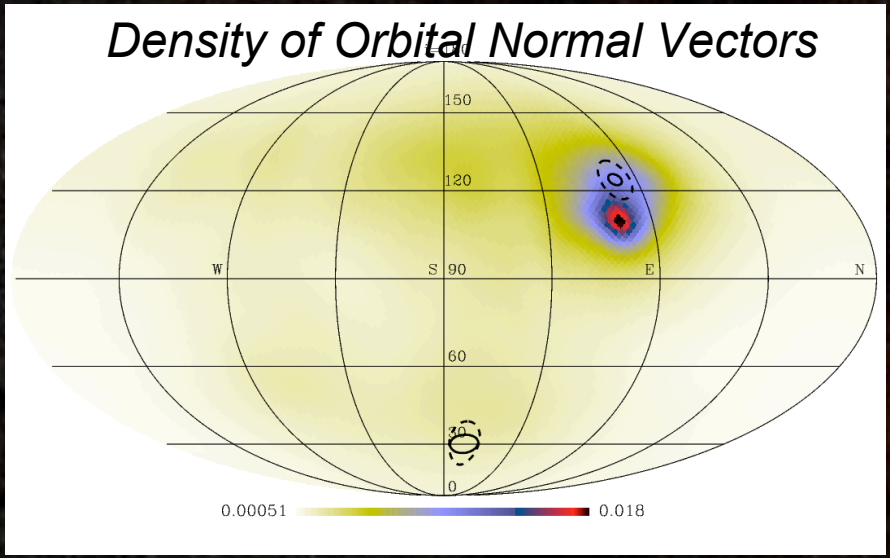
Many Solutions Have Been Proposed to Solve the "Paradox of Youth"

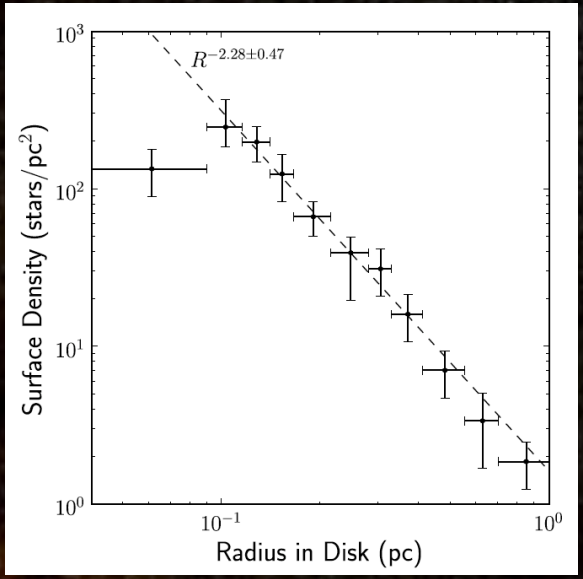
- **Old Stars Masquerading as Youths**
  (e.g., Morris 1993, Lee 1994, Davies et al. 1998, Genzel et al. 2003, Alexander & Morris 2003)

- **Young Stars that Formed at Larger Radii ("cluster or binary infall")**
  (e.g., Gerhard et al. 2000, Kim & Morris 2003, Portegies-Zwart et al 2003 Hansen & Milosavljevic 2003, Gould & Quillen 2003, Perets & Alexander 2007, Perets et al. 2008)

- **Young Stars that Formed In-Situ**
  (e.g., *Morris et al. 1993, Sanders 1998, Levin & Belobordov 2003; Nyakshin & Cuadra 2005; Nayakshin et al. 2007; Levin 2007, Bonnell & Rice 2008)*

Stellar Dynamics Point to in-situ Formation in a Pre-existing Disk



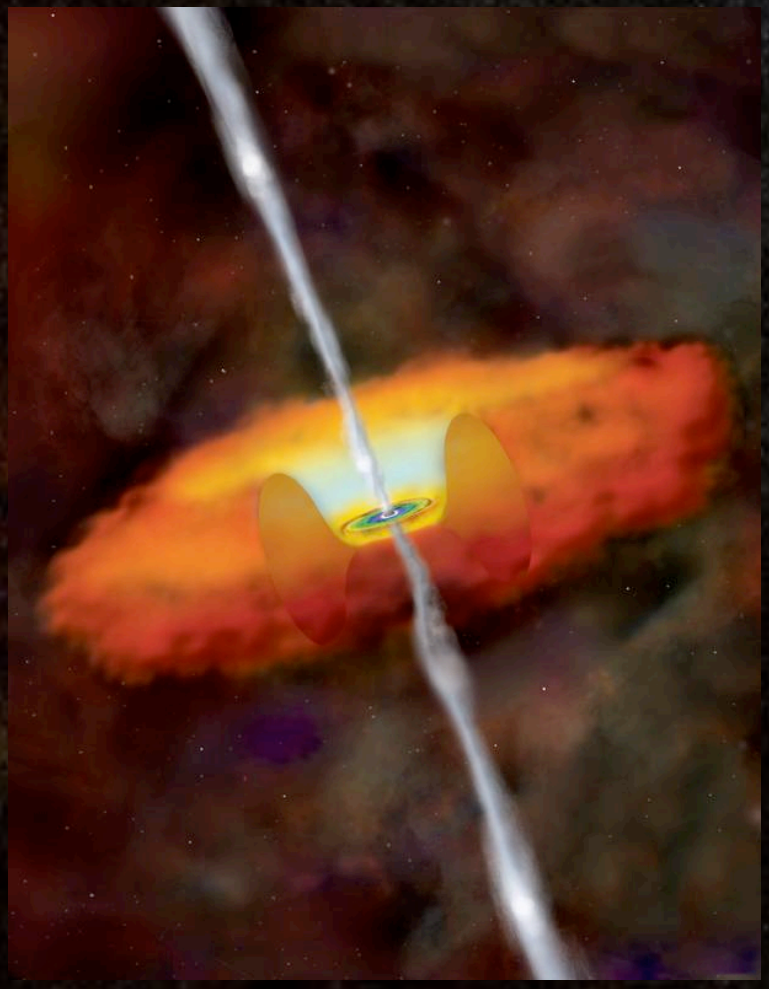


Individual stellar orbits provides direct evidence for a single, nearly edge-on stellar disk with r^{-2} surface density

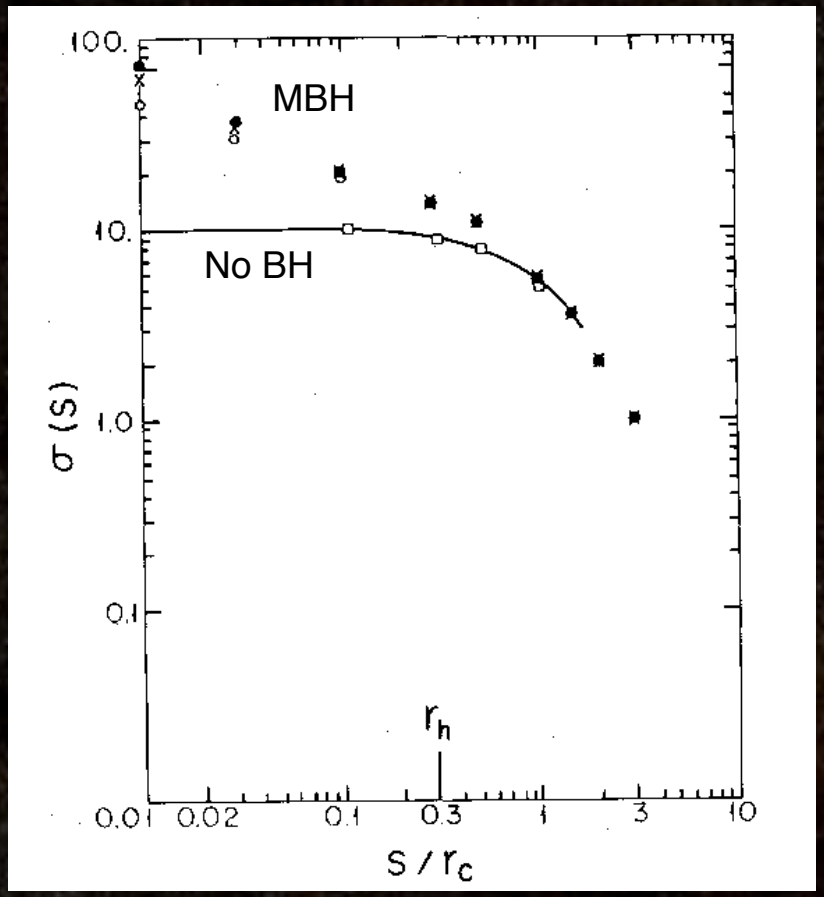
Levin & Beloborodov 2003, Genzel et al. 2003, Paumard et al. 2006, Lu et al. 2008 (shown, next talk)

Gas That Fueled Star Formation Also Likely to Have Fed the Central Black Hole

- **Our central supermassive black hole may have been much more active in its youth**
- **Hyper-velocity stars in the halo provide evidence for previous star formation events**
  (e.g., Brown et al. 2007; O'Leary& Loeb 2007)



Can Now Test Theories of How Black Hole Alters the Structure of a Stellar Cluster



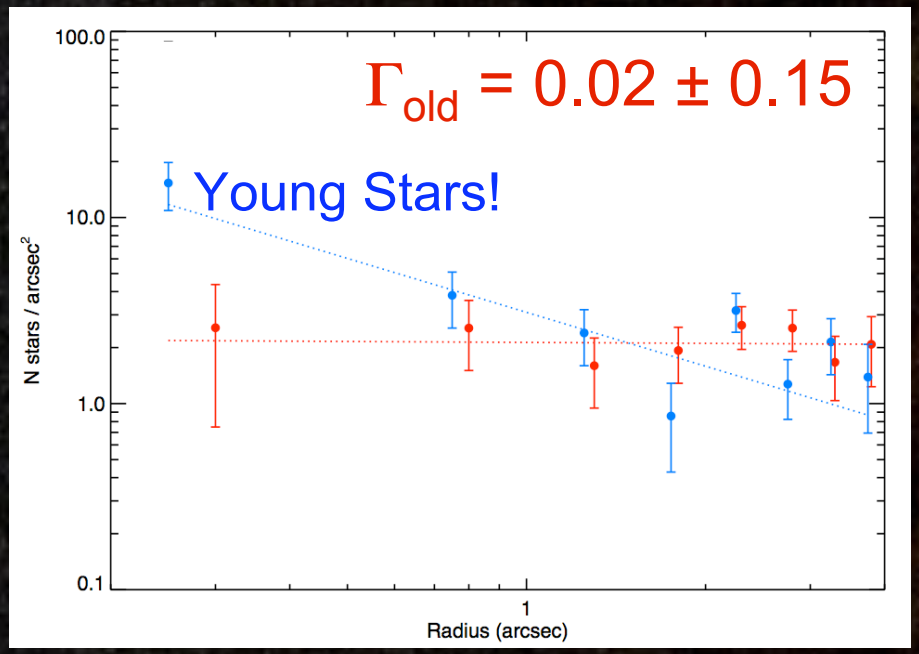
$\rho \alpha r^{-\gamma}$
or
$\sigma \alpha r^{-\Gamma}$

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

Original Prediction for stellar surface density profile

Bahcall & Wolf 1977 (shown), Young 1980, Lee & Goodman 1989, Quinlan et al. 1995

The Stellar Profile is Flatter Than Than Theoretical Predictions



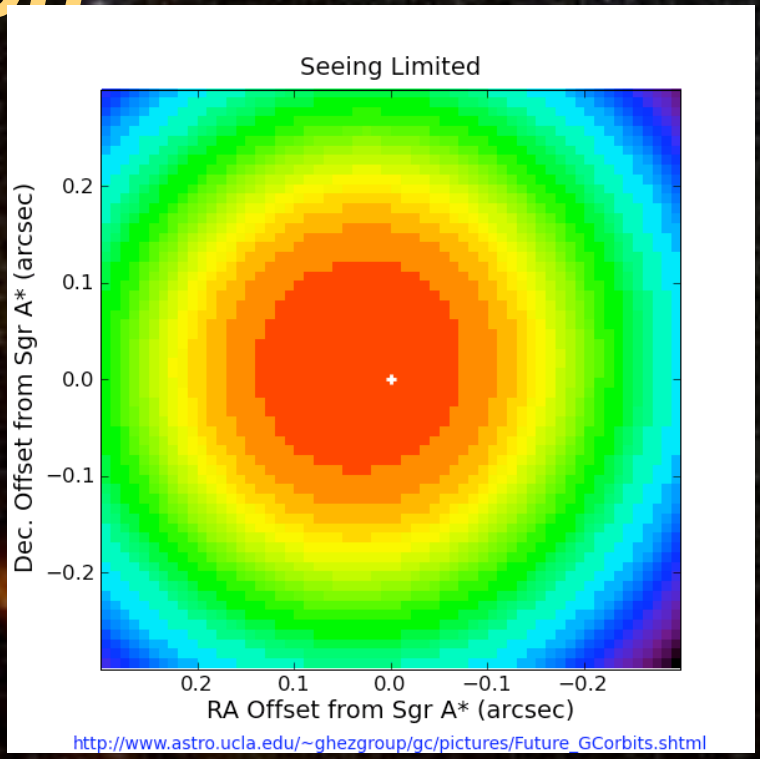
Shoedel et al. 2009; Do et al. 2009 (shown)

- **Rule out $\gamma > 1$ at the 99.7% confidence level**
- **Many Possible Solutions**
  Murphy et al. (1991), Alexander (2005), Merritt & Szell (2006), Alexander & Hopman (2008)
  - **Mass segregation with stellar remnants**
  - **Tidal stripping of these giant stars IMBH in-spiral**
  - **Most recent merger event too recent for a cusp to re-form**
- **Next Step**
  - **Use stellar orbits to place stronger constraints on profile**

AO with GSMT Will Significantly Expand Scientific Reach of GC Research

- **Measure Ro to <1% accuracy**
- **Detect GR Precision**
- **Detect Extended Dark Matter Distribution**
  - **Stellar remnants (~1000 M_o)**
  - **Cold dark matter particles (~1000 M_o)**

Weinberg, Milosavljevic, & Ghez (2005)



- Order of magnitude more detections
- P_{min} = 2.5 yr (instead of 15 years)
- Over come stellar confusion (150 μ–arcsec vs. 500 μ–arcsec

Conclusions

- **Dramatically improved case for black hole.** The Milky Way is now the best example of a normal galaxy containing a supermassive black hole.

- **Stellar Dynamics Offer Powerful Probe**
  - Old stars

    Compared to theory, deficit in central ~6". Possibly due to stripping of envelopes by unseen stellar remnant population.
  - Young stars

    Roughly 1/2 of known young stars reside in a relatively thin, nearly edge-on disk (0.04 - 0.4 pc). In-situ star formation

- **Exciting Future: possibility of deviations from Keplerian orbits (GR test, extended mass, spin?)**