Title: Stellar Orbits at the Galactic Center

Date: Nov 10, 2014 10:45 AM

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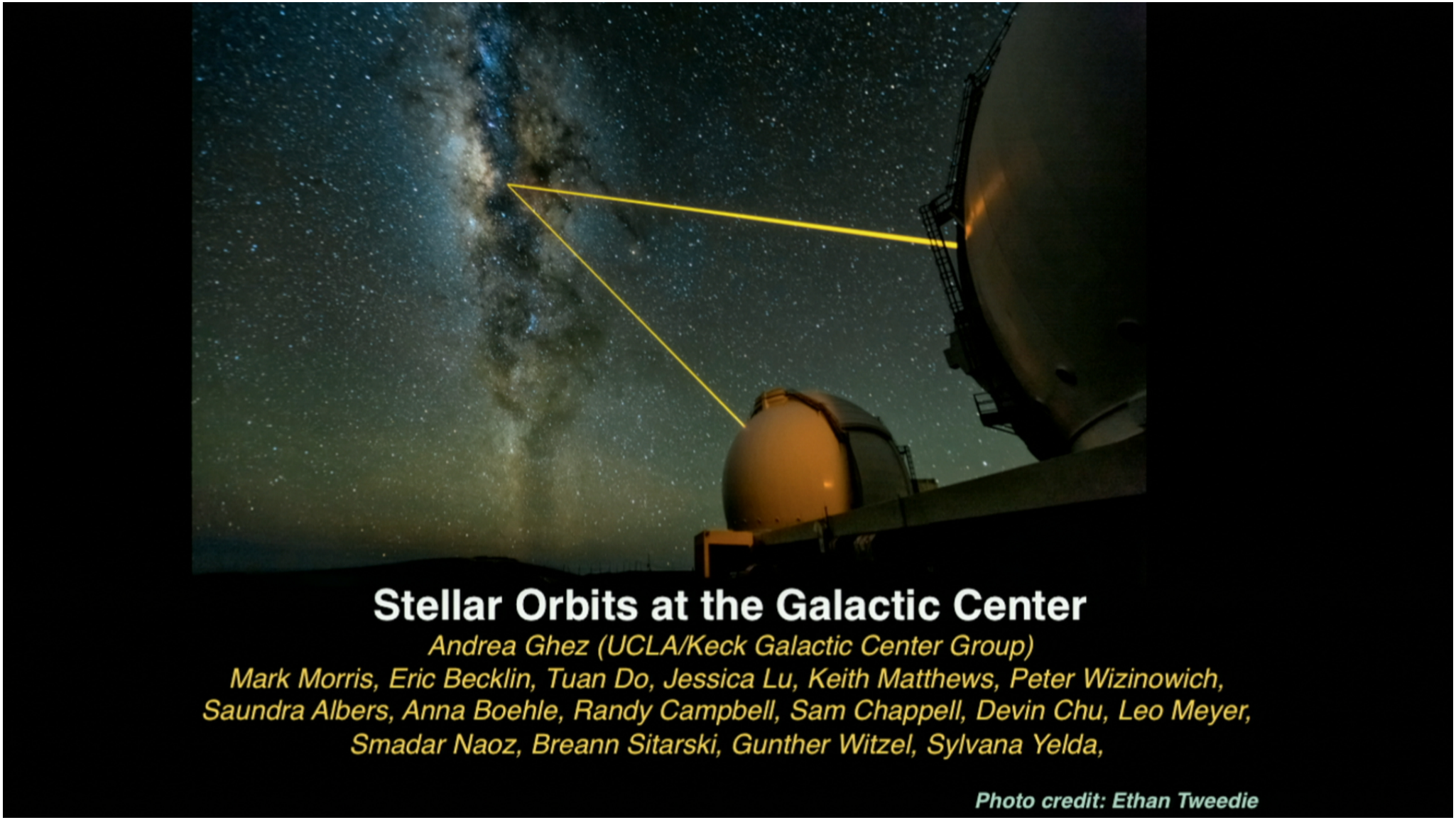
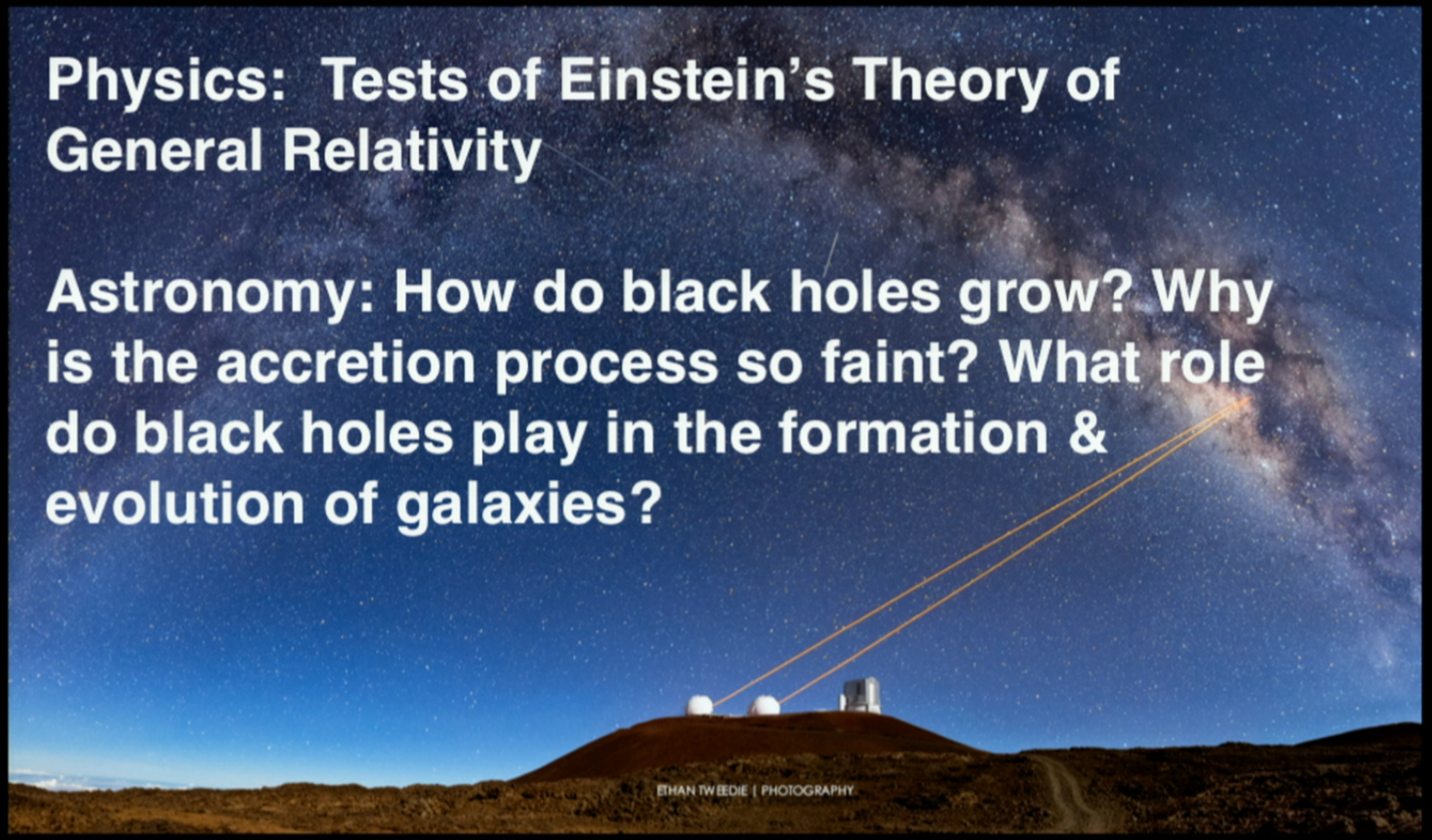
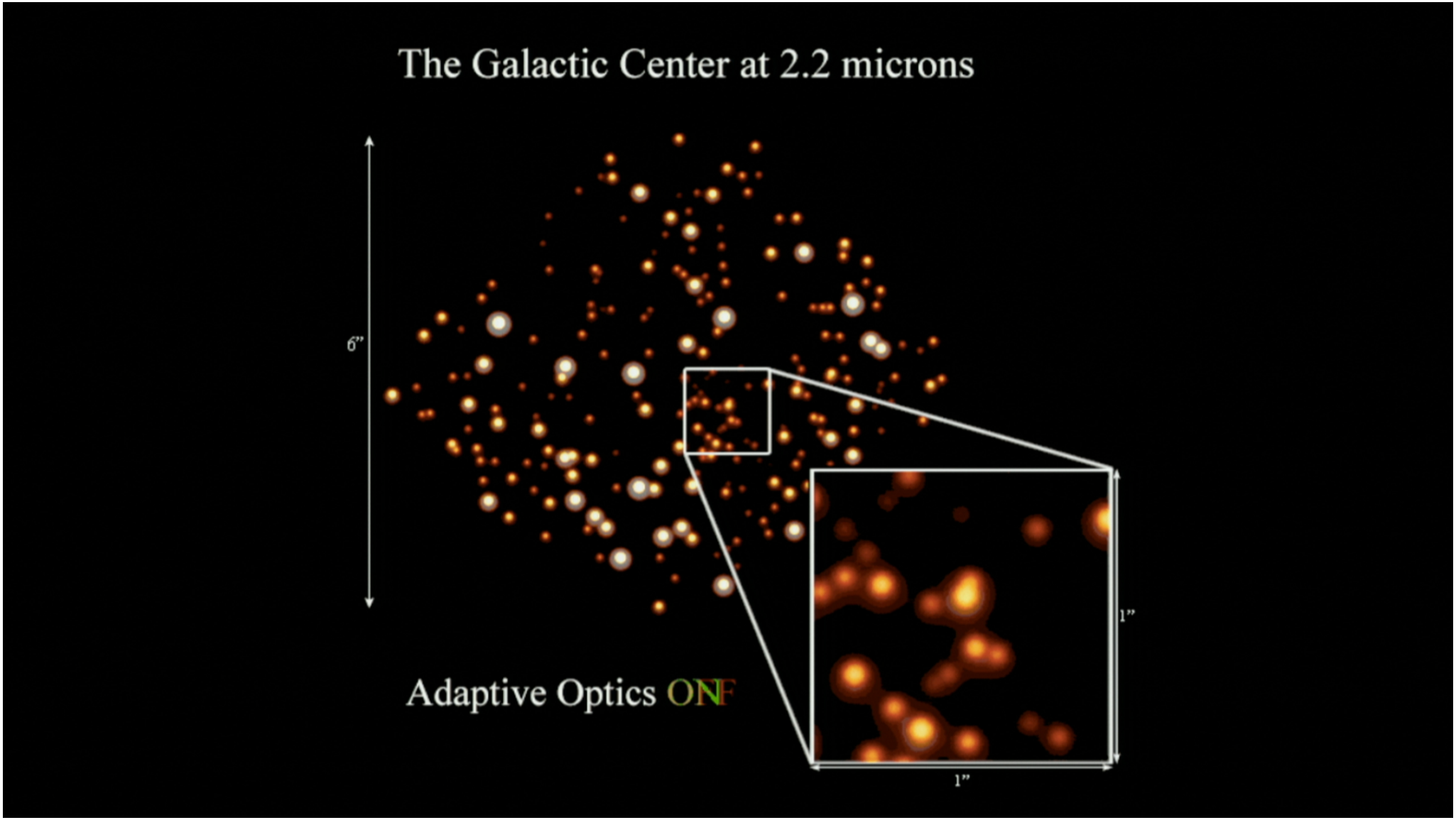
Abstract: Over the last 20 years, advances in high angular resolution imaging technology has enabled the motions of individual stars to be tracked at the Galactic Center.
This has provided the best evidence to date not only for the presence of a supermassive black hole at the center of our Galaxy, but for the existence of black holes in general. These high resolution measurements have also revealed an environment surrounding the black hole that is quite unexpected in a number of ways, challenging our understanding of the physical processes between black holes and their surround stars and gas. As the only galactic nucleus in which individual stellar orbits can be measured, the Galactic Center is now offering new insights into the fundamental physics of black holes, with unique tests of Einstein's theory of General Relativity on the horizon, and the astrophysics processes between black holes and their host galaxies that are thought to shape the co-evolution of central black holes and their host galaxies.

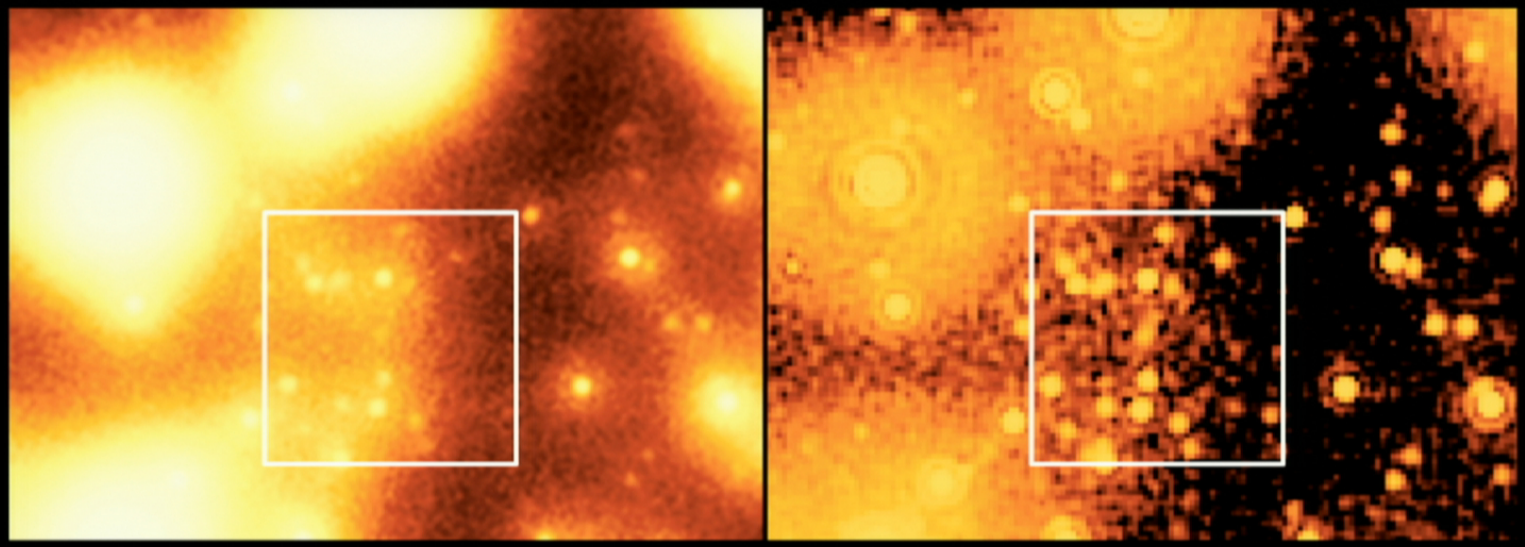
I will review the work done by the UCLA Galactic Center Group and others on measuring stellar orbits, with an emphasis on (1) our recent model for G2 as a binary star that has been driven to merge through three-body interactions with the central black hole, (2) precision measurements of the distance to the black hole (R0), which is a fundamental constant for many astrophysical studies (e.g., galactic structure), and the mass of the black hole (Mbh), which as a ratio with R0 (Mbh/R0) is a key ingredient for interpreting future EHT measurements of the black hole's shadow, and (3) upcoming tests of General Relativity that are within reach through precision measurements of stellar orbits.


Stellar Orbits at the Galactic Center
Andrea Ghez (UCLA/Keck Galactic Center Group)
Mark Morris, Eric Becklin, Tuan Do, Jessica Lu, Keith Matthews, Peter Wizinowich,
Saundra Albers, Anna Boehle, Randy Campbell, Sam Chappell, Devin Chu, Leo Meyer,
Smadar Naoz, Breann Sitarski, Gunther Witzel, Sylvana Yelda,
Photo credit: Ethan Tweedie


Physics: Tests of Einstein's Theory of General Relativity
Astronomy: How do black holes grow? Why is the accretion process so faint? What role do black holes play in the formation & evolution of galaxies?
ETHAN TWEEDIE | PHOTOGRAPHY


The Galactic Center at 2.2 microns
6”
1”
1”
Adaptive Optics ON

Improved Methodologies: Increased Science Return of Earlier Data Sets



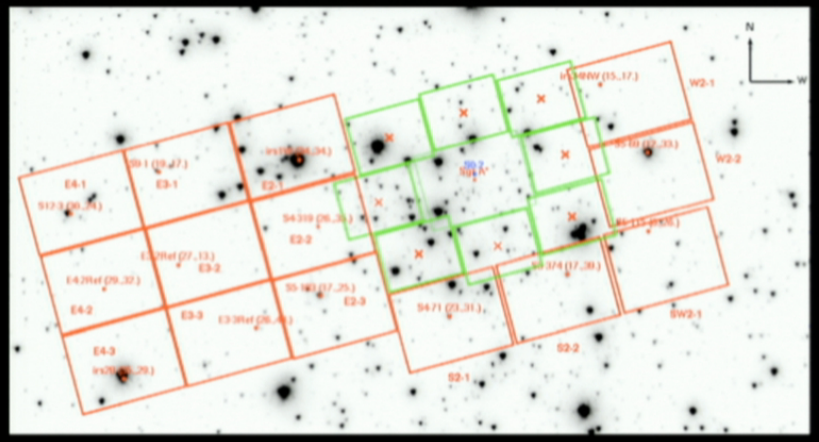
Previous Analysis
Shift-and-Add

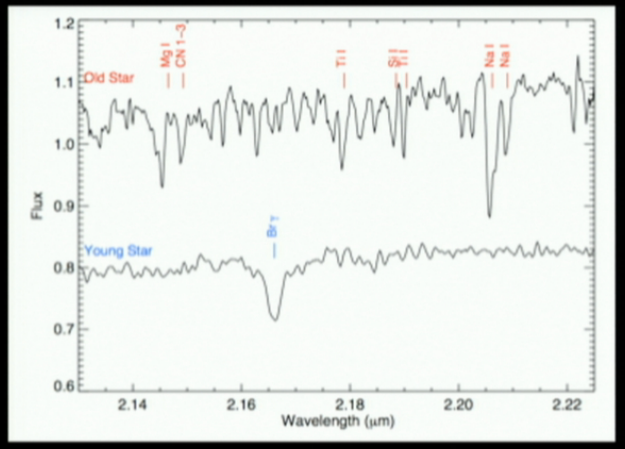
New Analysis
Speckle Holography

Additional Work: Priors & AO PSF modeling

Schoedel, Yelda, AMG et al. 2012; Boehle, AMG, Meyer et al. 2014

Improved Technology Introduced Spectroscopy





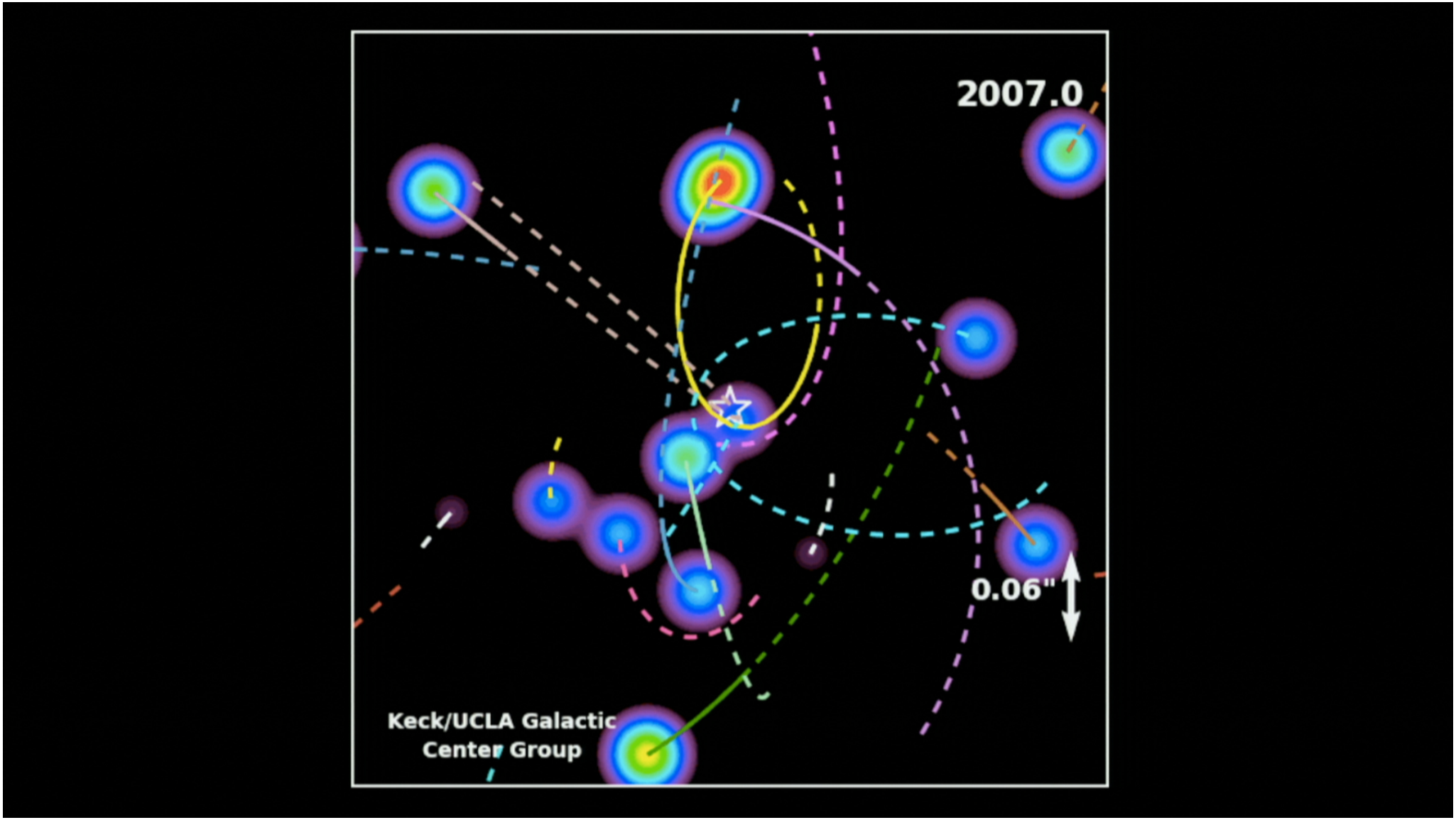
Physics

– Measures missing third dimension of motion

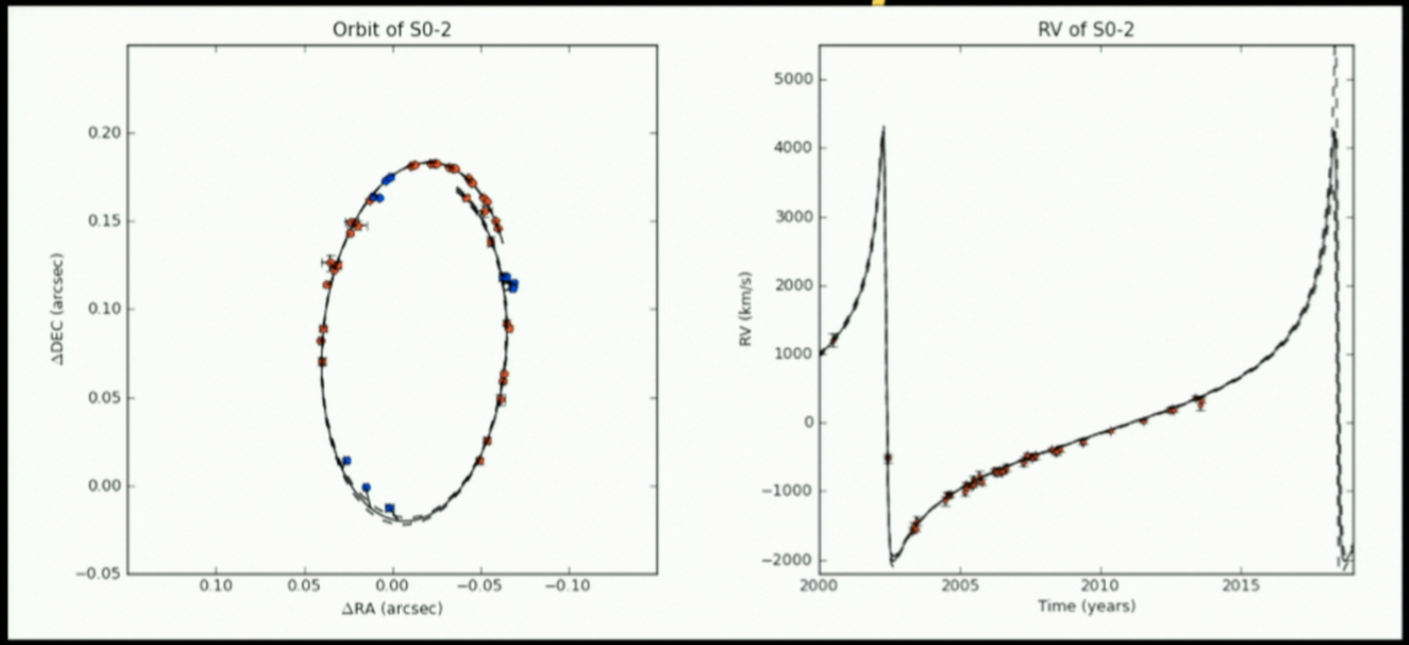
Astronomy

– Astrophysical nature of sources

– Reveals many surprises!!


2007.0
0.06"
Keck/UCLA Galactic
Center Group

Today S0-2 Offers Strongest Case for Existence of Black holes & MW Black Hole Properties



Mass = = 3.9 ± 0.3 x10^6 M_{sun}

Periaspe = = 0.52 ± 0.02 mpc (~1,200 R_S~100 AU)

ρ = 6.3 ± 0.8 x 10^{15} M_o/pc^3

10,000x larger than in any other galaxy

Eisenhauer et al. 2003, 2005;
Ghez et al. 2003, 2005, 2008;
Gillessen et al. 2009a,b;
Yelda 2012; Meyer et al. 20012;
Boehle et al. 2014

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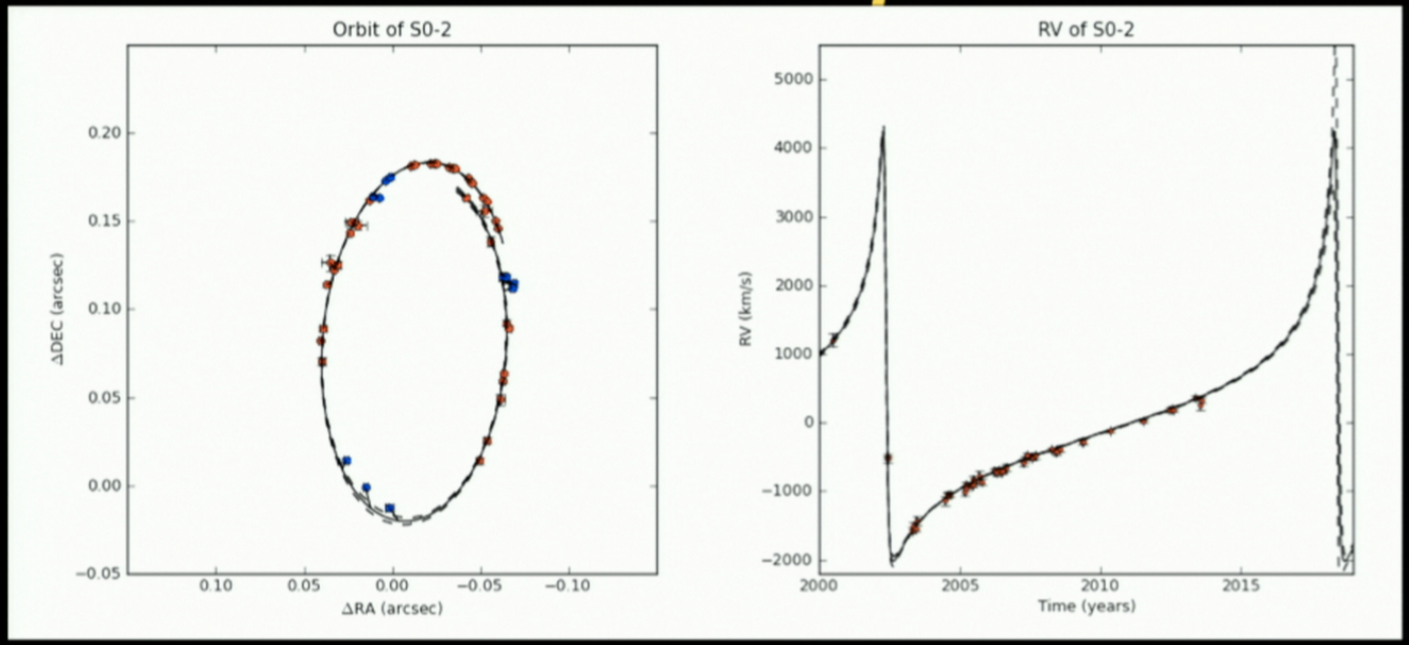

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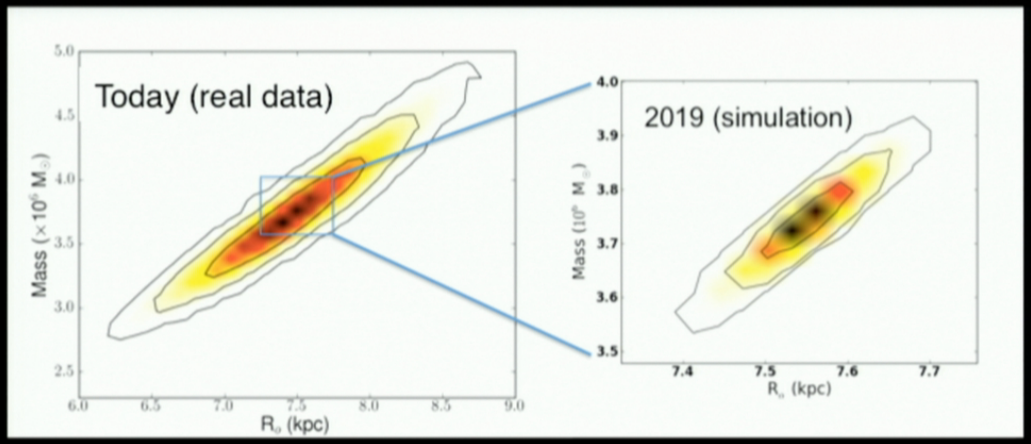
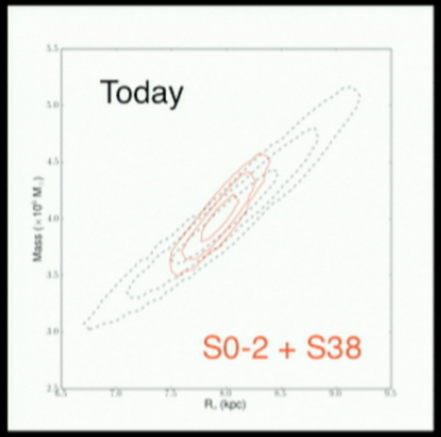
More Precision in Black Hole Properties from Stellar Orbits Needed for EHT and is Possible



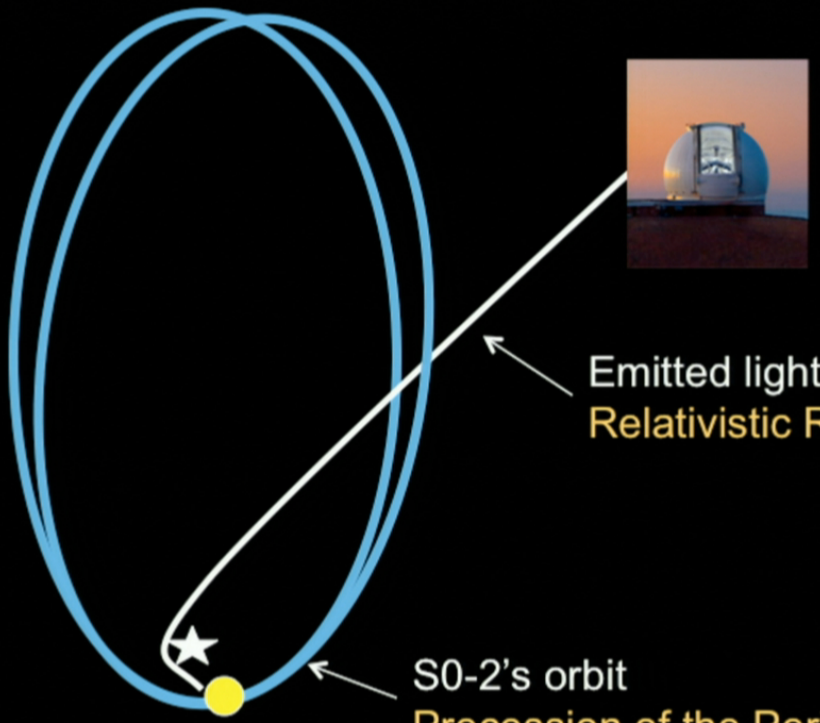
(1) More time

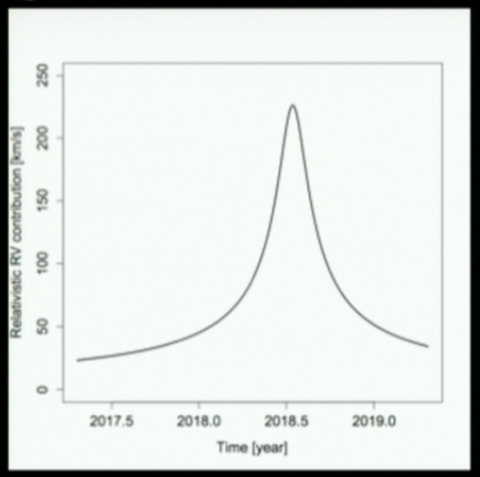


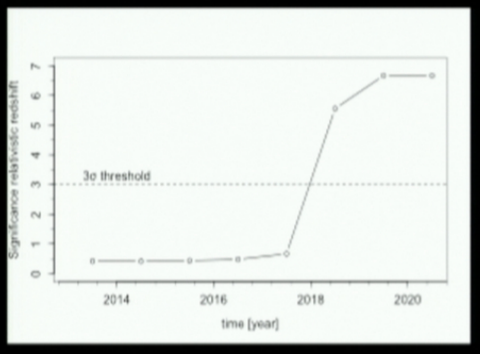
(2) More stars

Location of ring set by M/R_o

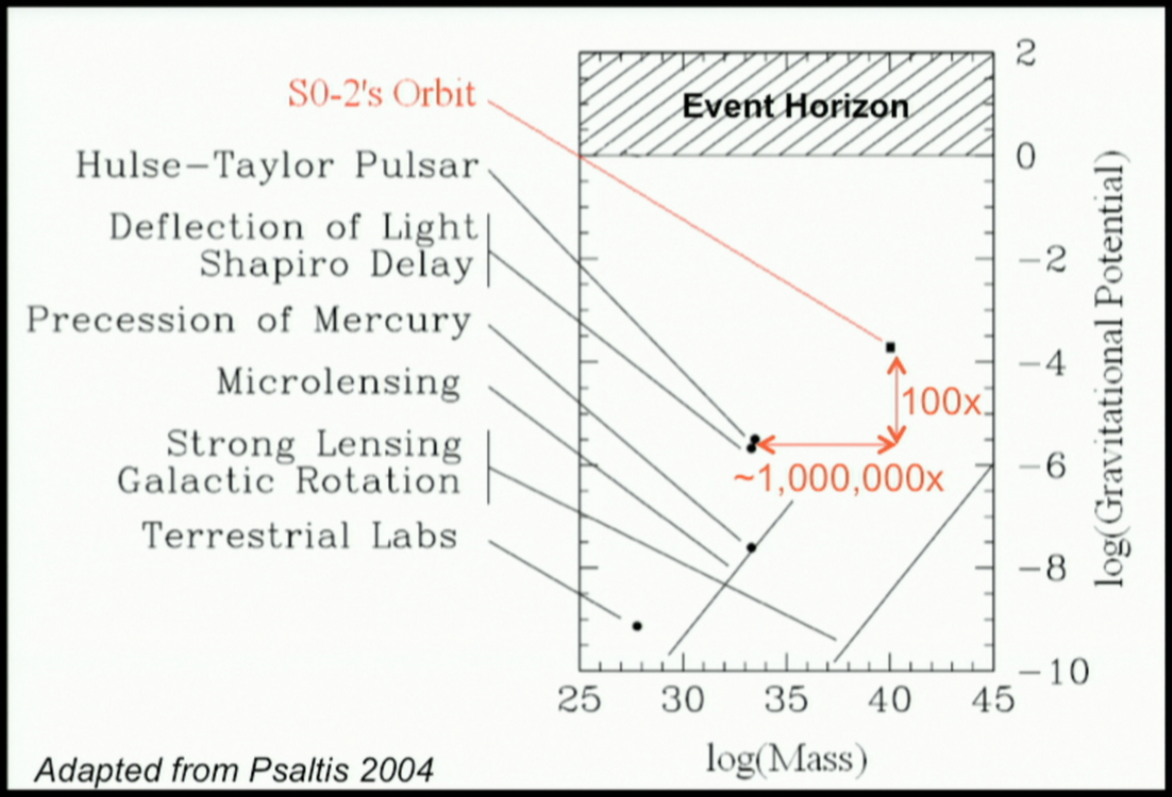
This Will Also Allow Orbits to Test Einstein's Theory of General Relativity



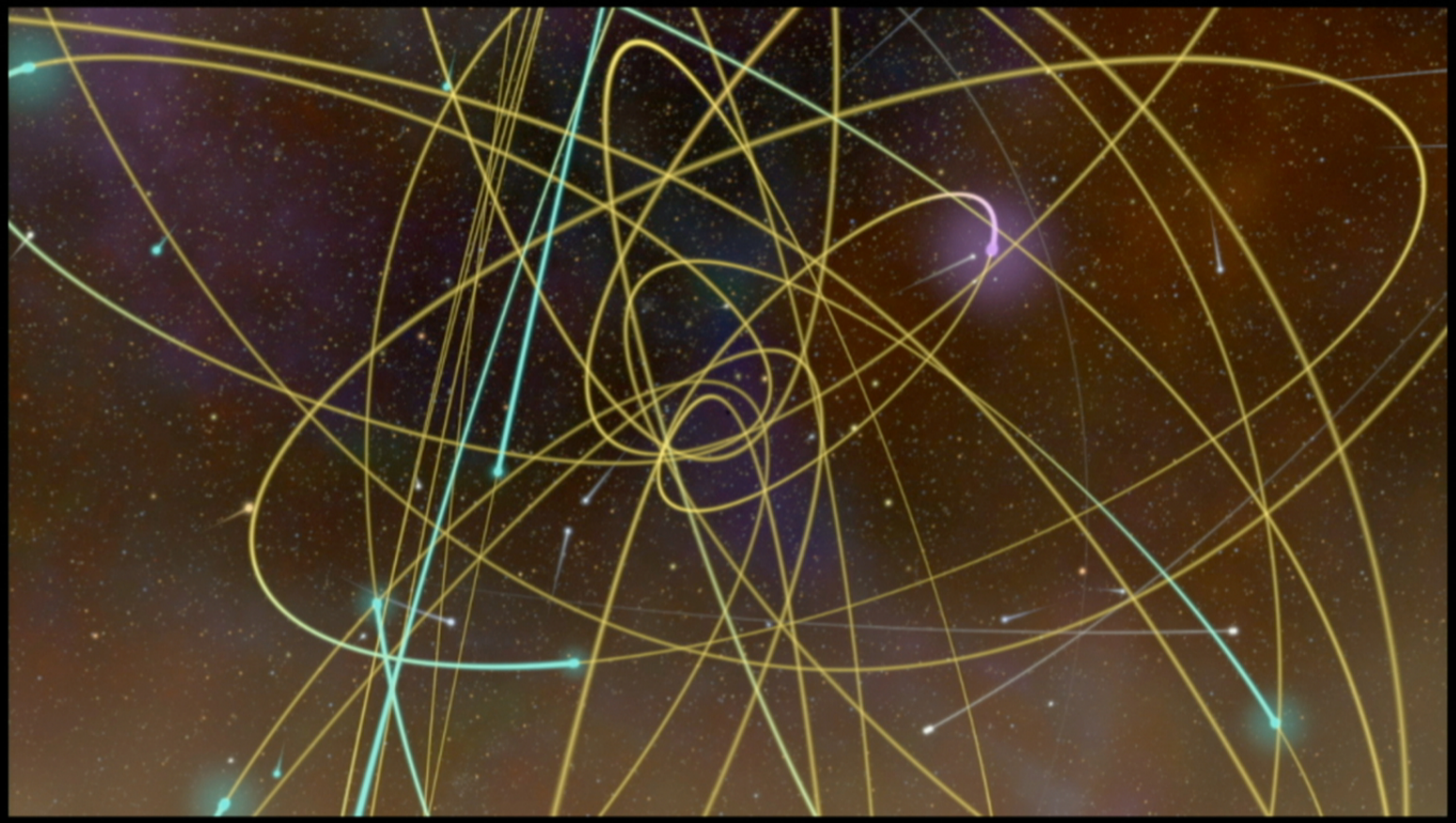




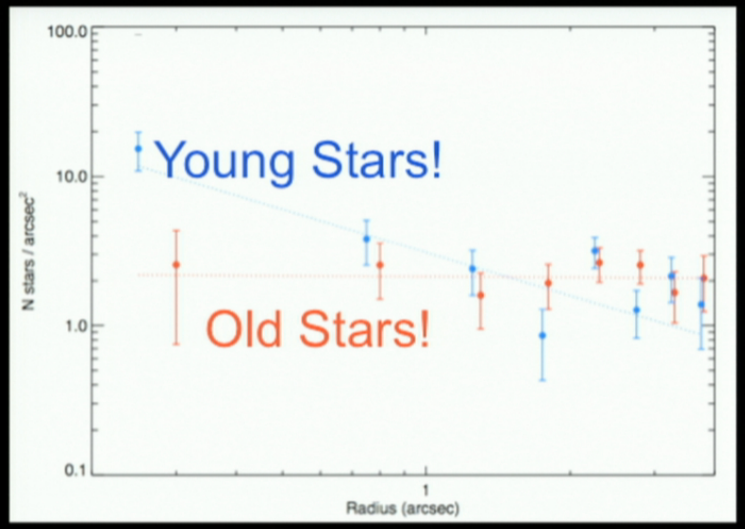
Orbits Offer a Different Probe General Relativity than the EHT



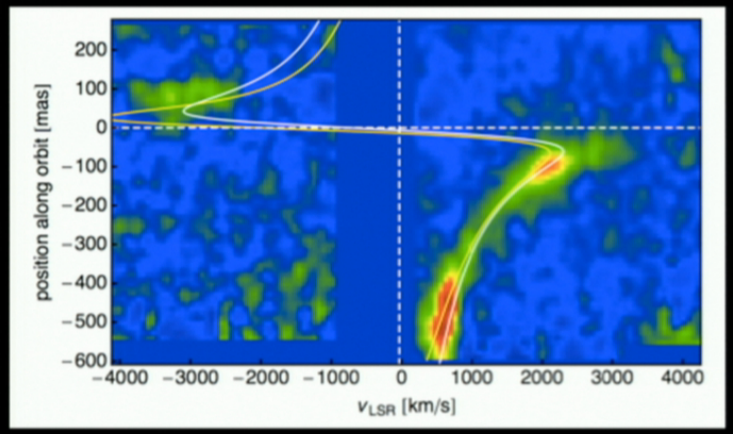
PROBING THE BLACK HOLE ENVIRONS



Many Unexpected Results



Do et al. 2009, 2013; Shoedel et al. (2009); Bartko et al. 2010; Gezari et al. 2002; Ghez et al. 2003; Eisenhauer et al. 2005

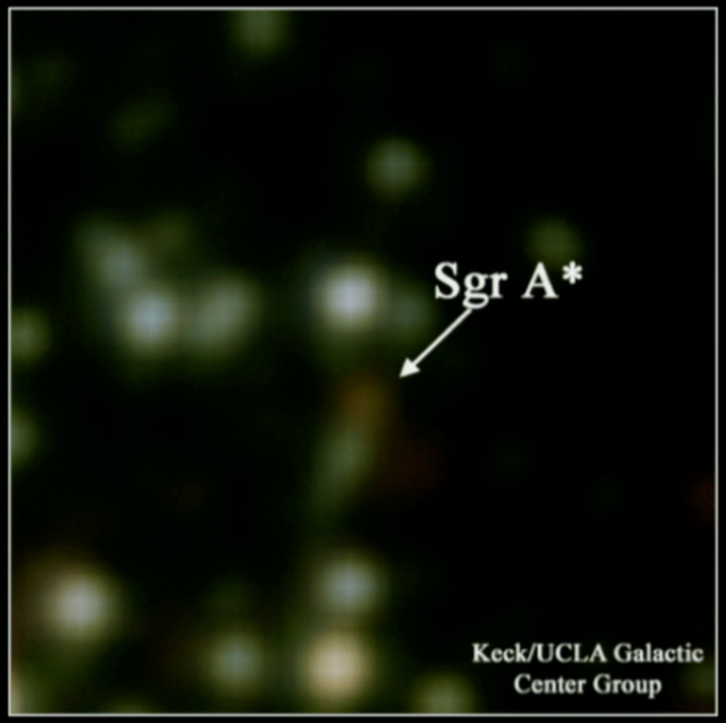


Gillessen et al. 2012, 2013ab; Phifer et al. 2013; Pfuhl et al. 2014; Witzel et al. 2014

- Lots of young stars where none expected
- A dearth of giant stars in lieu of a cusp
- G2! A tidally interacting object at

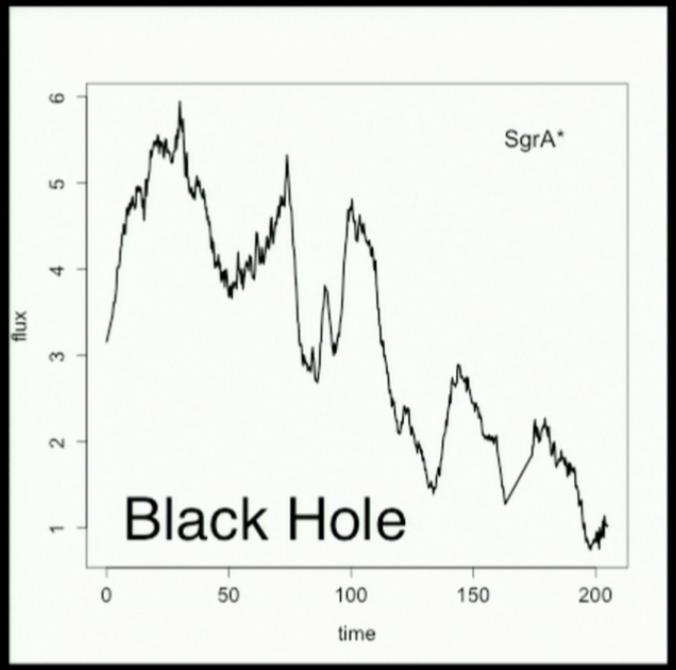
G2 - An Incoming 3 M_{Earth} Gas Cloud?

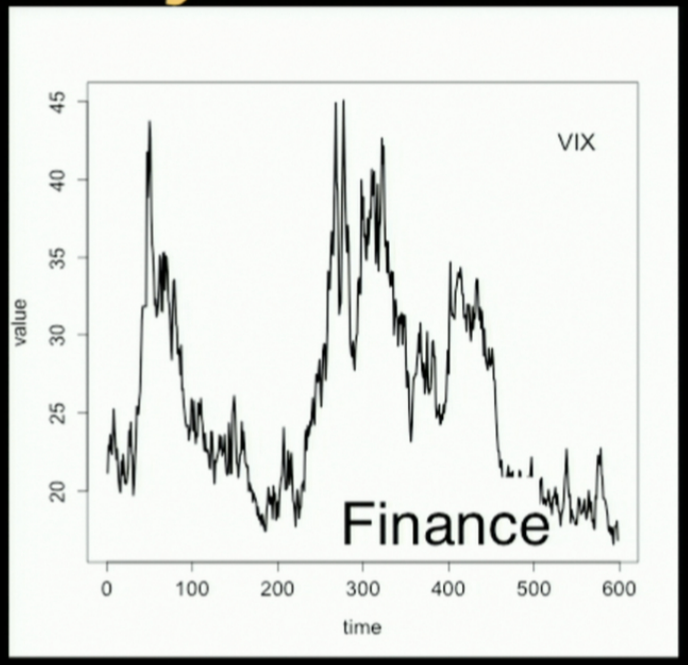
Simulation by Anninos, Fragile et al.



- Unique opportunity to observe a predicted accretion event?
- Closest approach Spring/Summer 2014

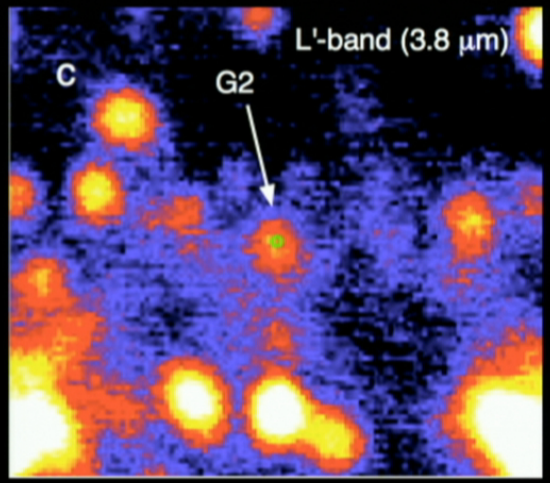
Need a Discriminating Tool To Assess Possible Changes in SgrA*'s Variability

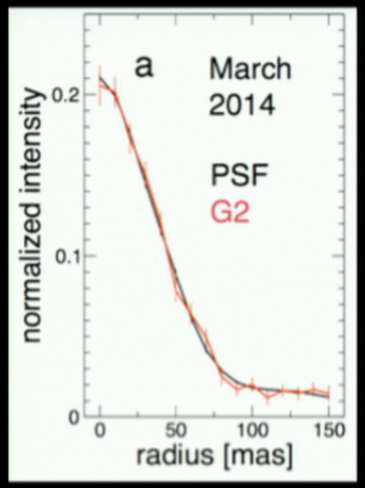


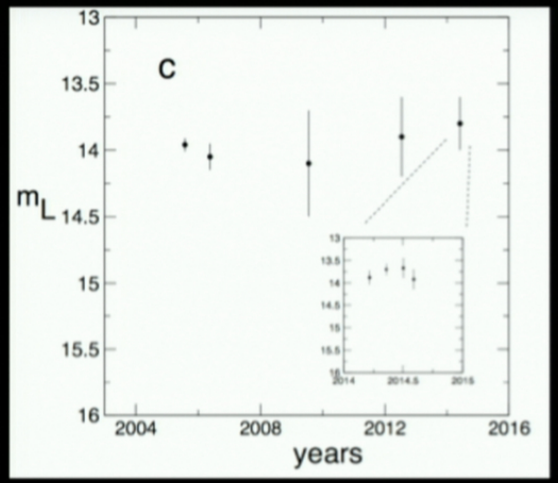


Developed a new method that fully incorporates timing information!
Hidden Markov Model (used for financial market analysis)
Meyer, Longstaff, Witzel, Ghez 2014, ApJ, 791, 24

But G2 Survived Periapse Intact as a Compact Constant Brightness L' source….

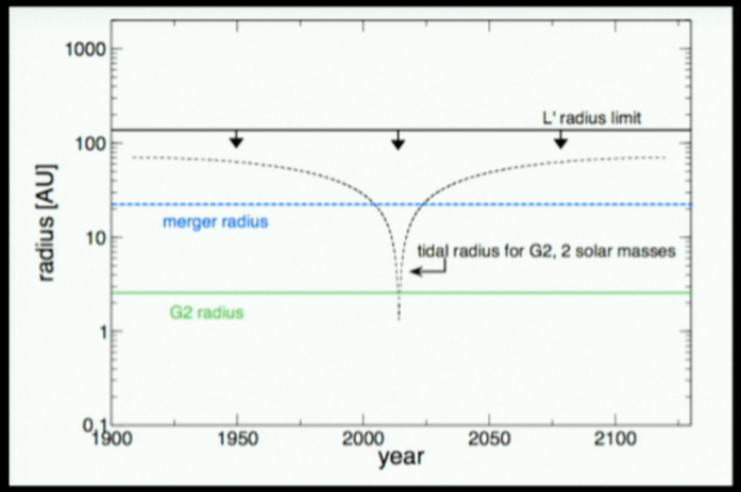


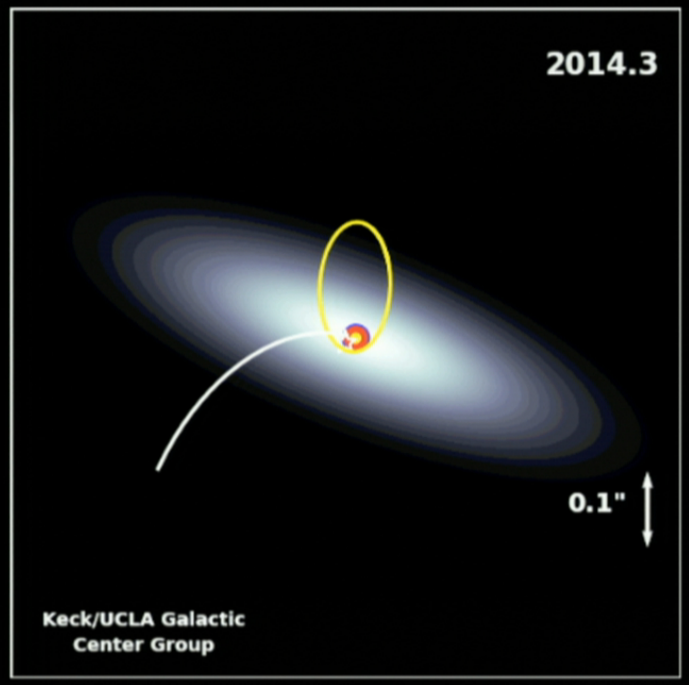




G2 is not a simple gas cloud….

G2 May be a Binary Star Merger





Black hole can drive binary to merge via Kozai-Lidov effect

Red: optically thick 3 μm (internally heated)
White: optically thin Br-γ (externally heated)

Pfuhl et al. 2014; Witzel et al. 2014; Prodan et al. 2014; Zajacek et al. 2014
Lots of other models have been proposed: Burkert et al. 2012, Miralda-Escude 2012, Schartmann et al. 2012, Murray-Clay & Loeb 2012, Schoville & Burkert 2013

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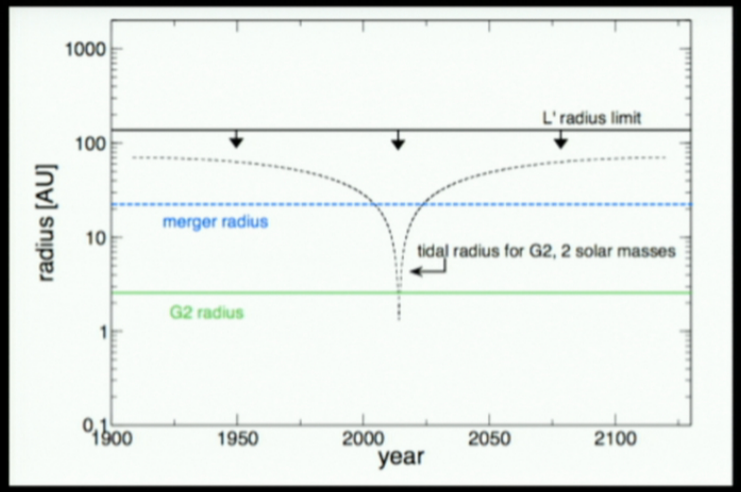

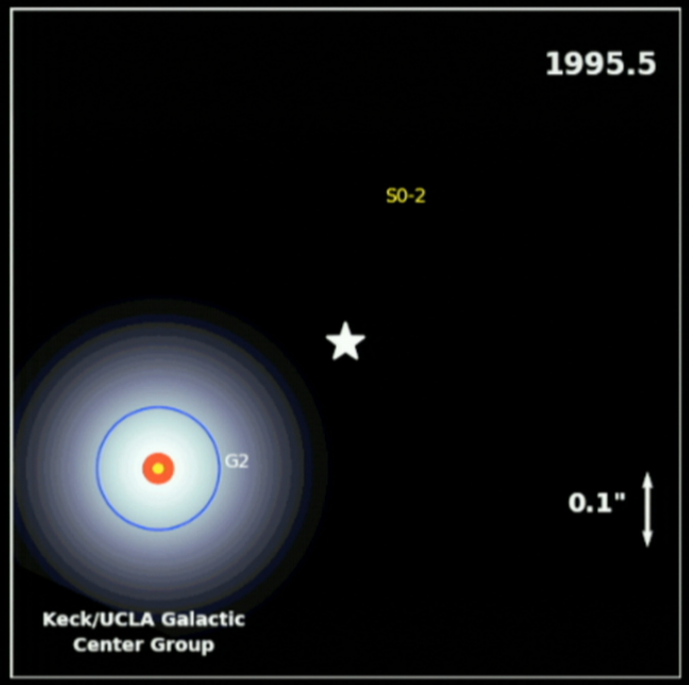

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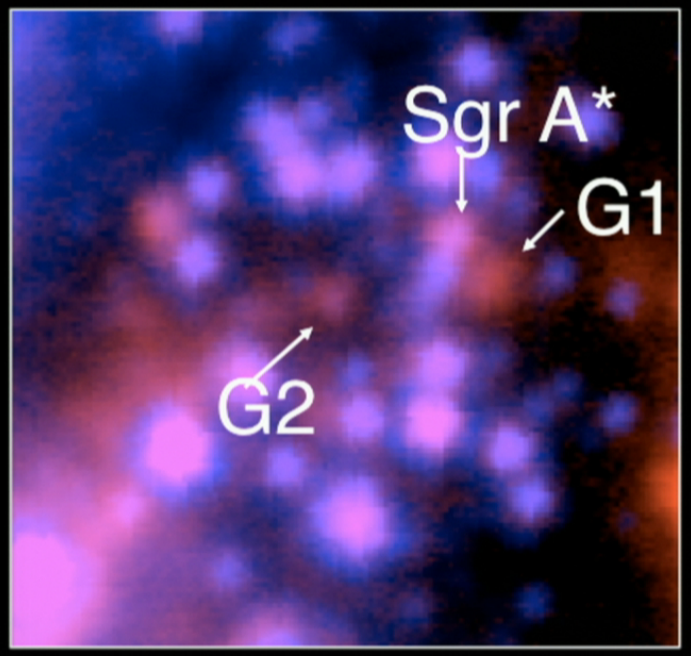
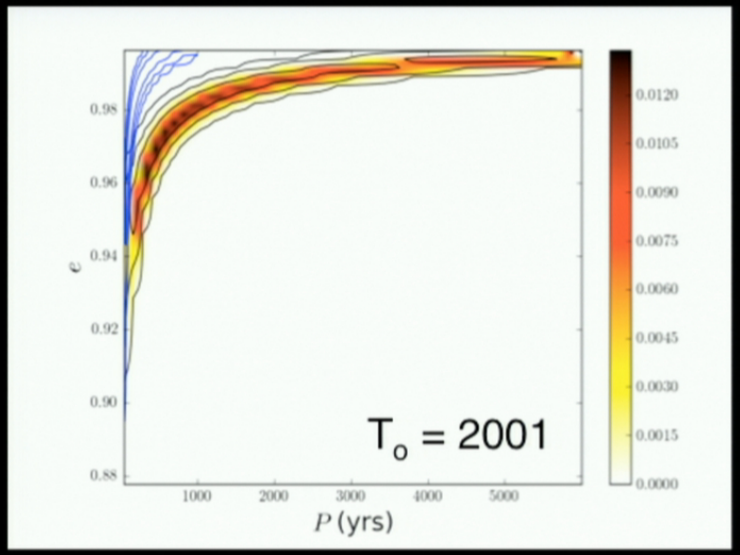
G2 is not Unique!





Sitarski, Witzel, Ghez et al. 2014

G1 Appears to Have Had a Similar Tidal Interaction 13 Years Ago