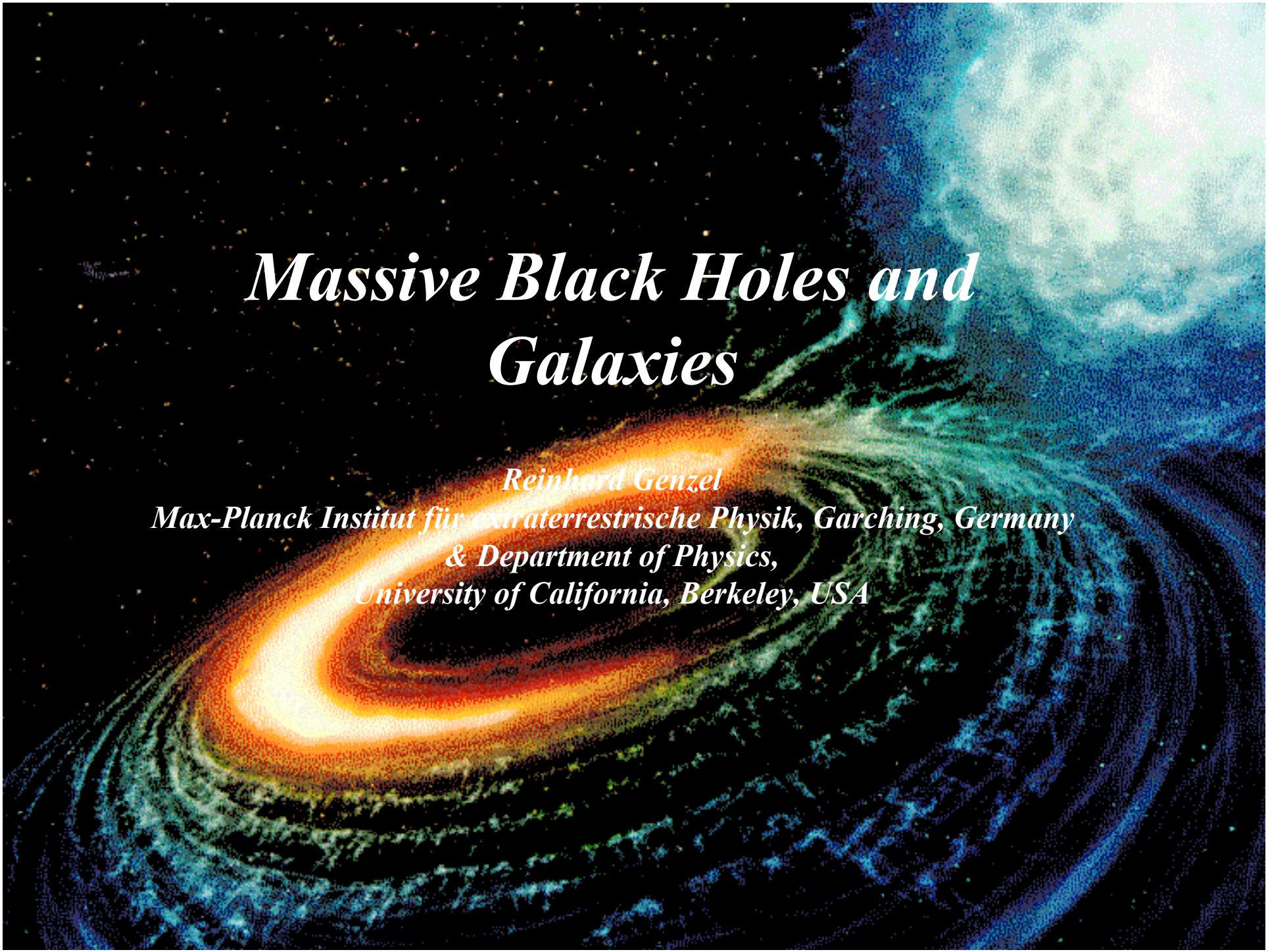
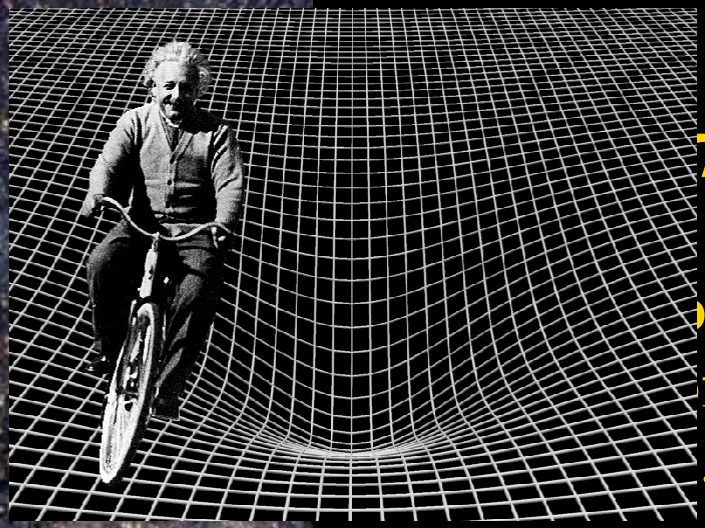


Massive Black Holes and Galaxies

Reinhard Genzel
Max-Planck Institut für extraterrestrische Physik, Garching, Germany
& Department of Physics,
University of California, Berkeley, USA

Journey from the Milky Way, Brent Tully, U Hawaii

Black Holes



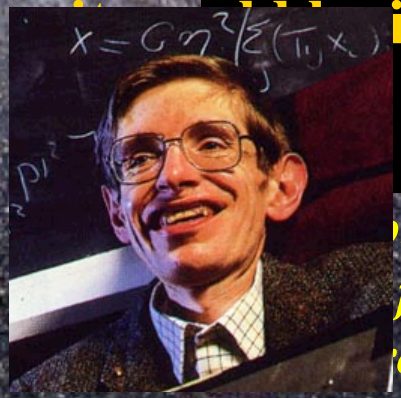
Albert Einstein 1915/16

783)

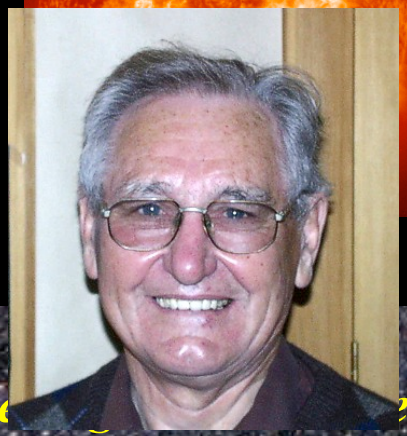
perty
f the
3km ?

invisible!

Karl Schwarzschild 1916



Stephen Hawking 1973

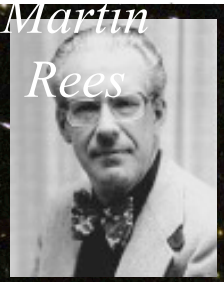


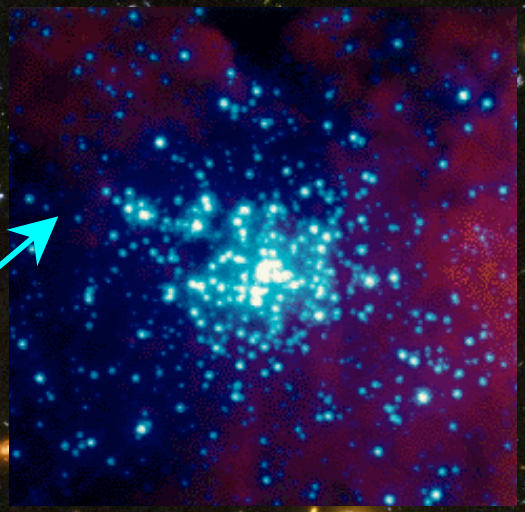
Roy Kerr 1953

lose the Hawking ne other
falls into it and conve energy
e the matter disappears behind the horizon

Quasars

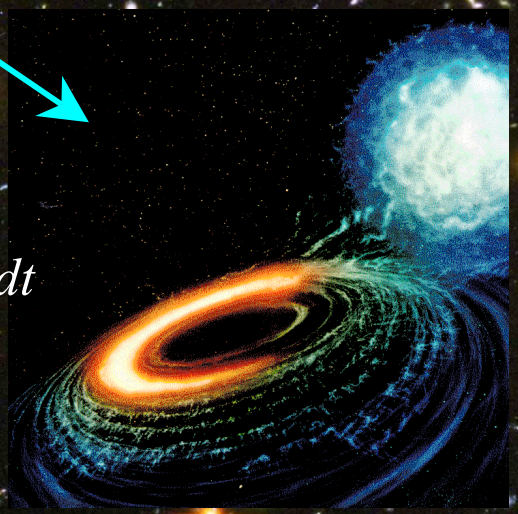
Martin Rees





$E < 0.005\ Mc^2$

mass distribution

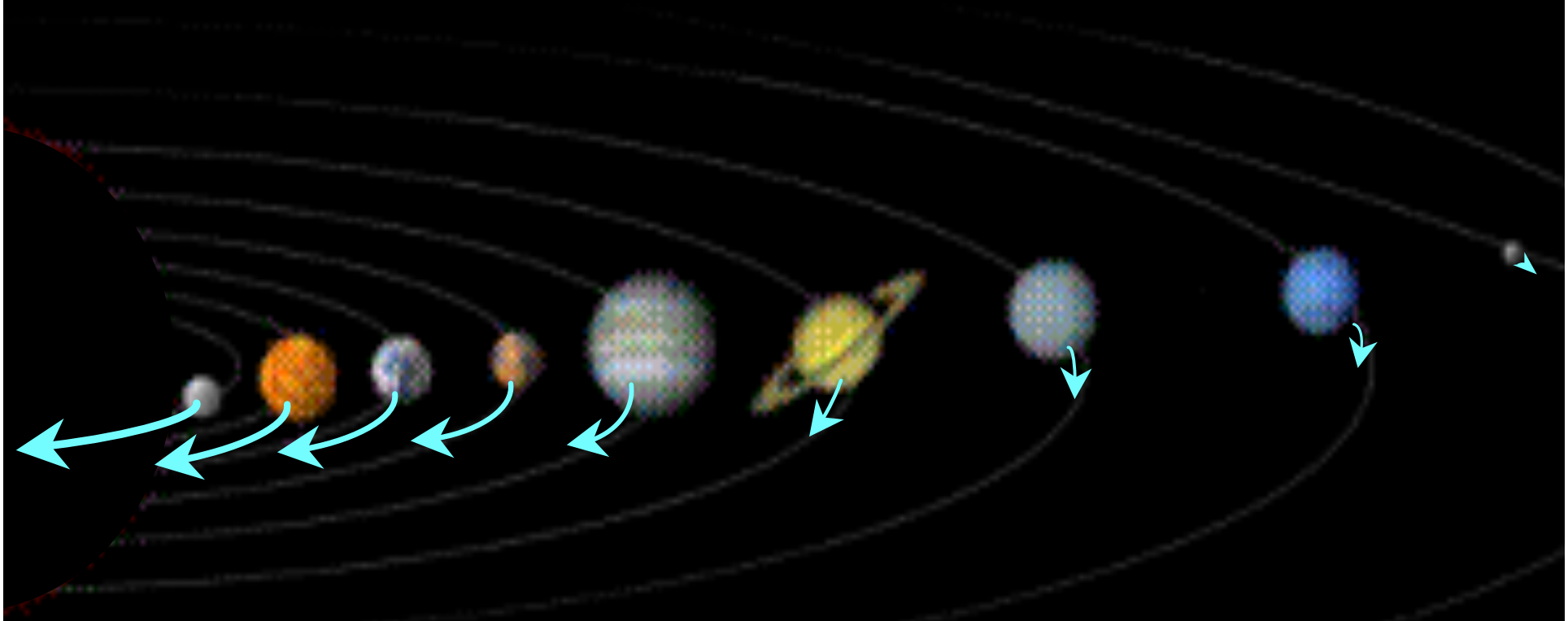


$E < 0.4\ Mc^2$

variable X- and γ-radiation

relativistic radio jets

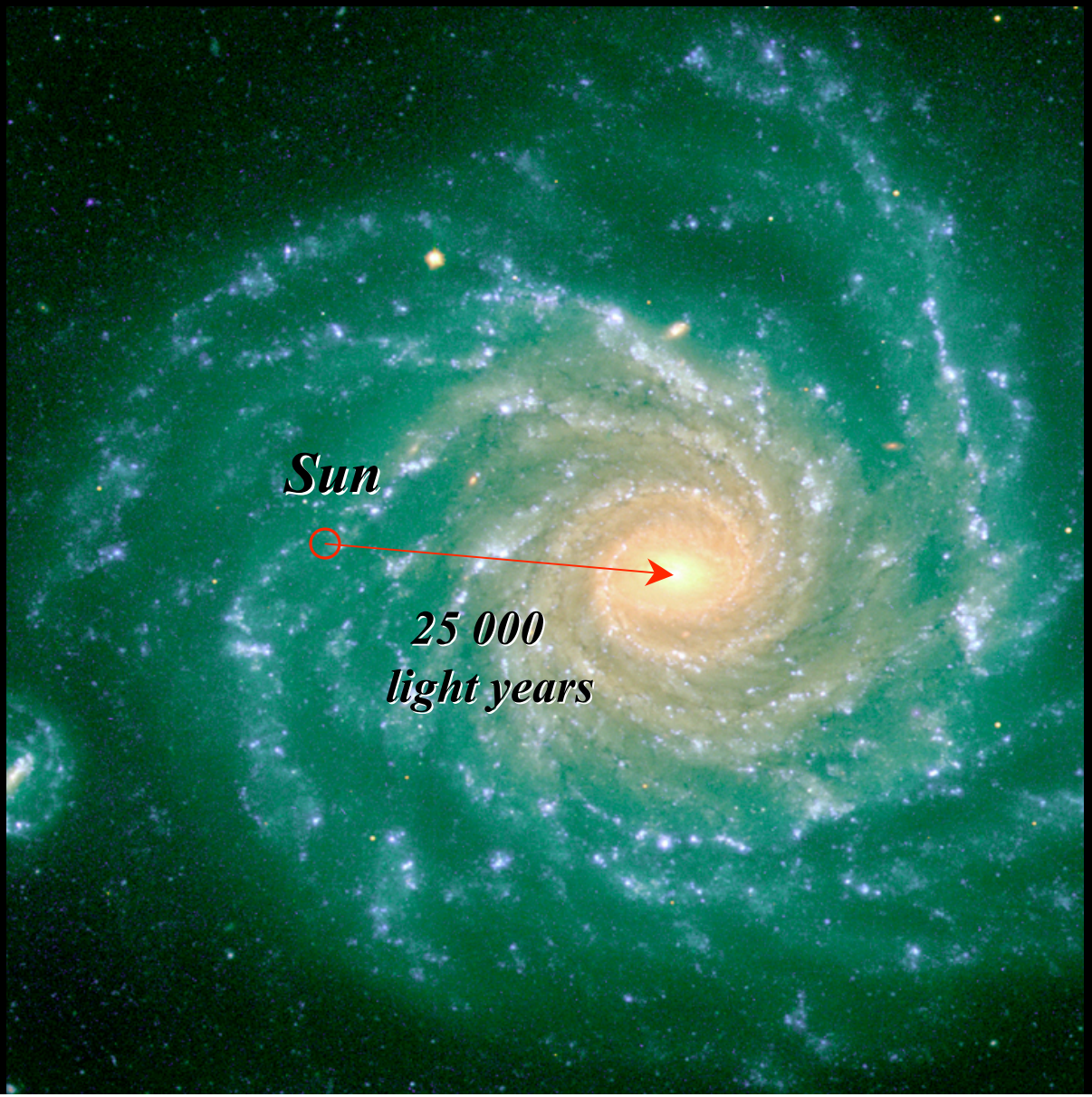
How does one determine gravity ?



$v \sim R^{-1/2}$

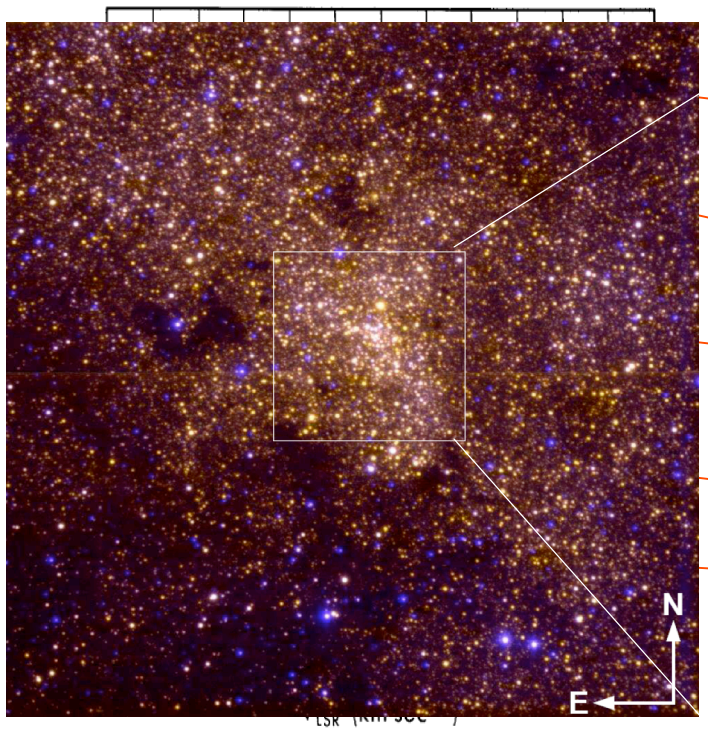
(Kepler)

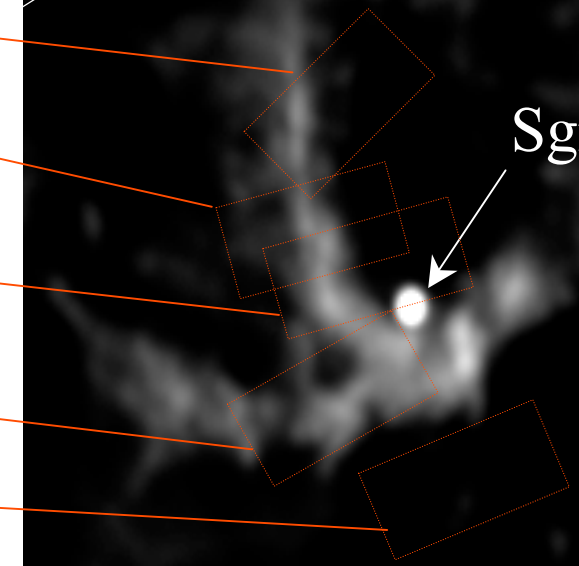
The Milky Way



early evidence for a central mass concentration

near-infrared image



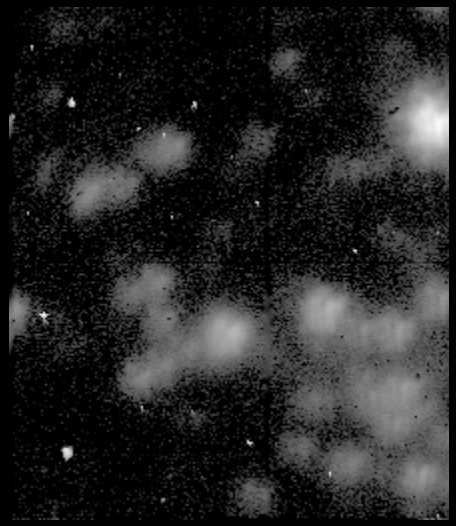


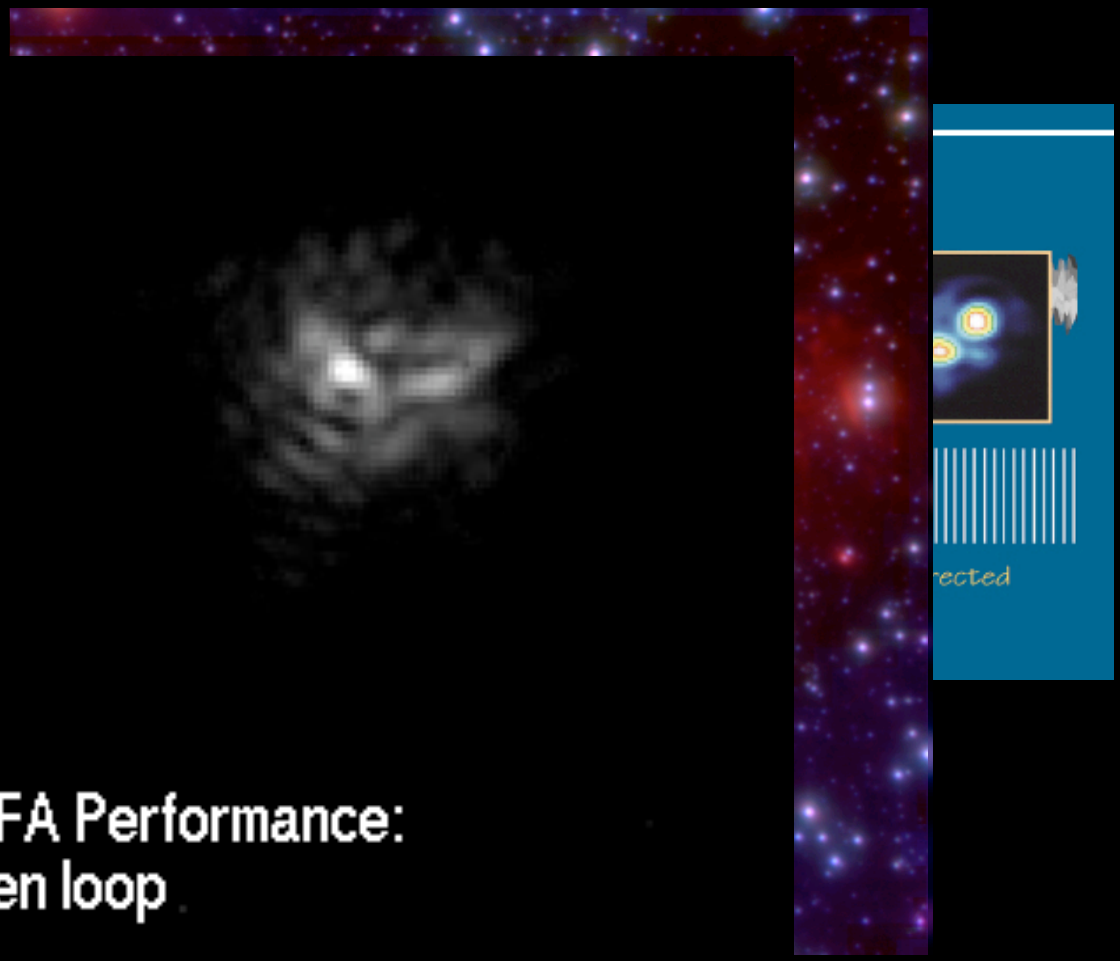
radio image of central
few light years of the Milky Way
(NRAO VLA)

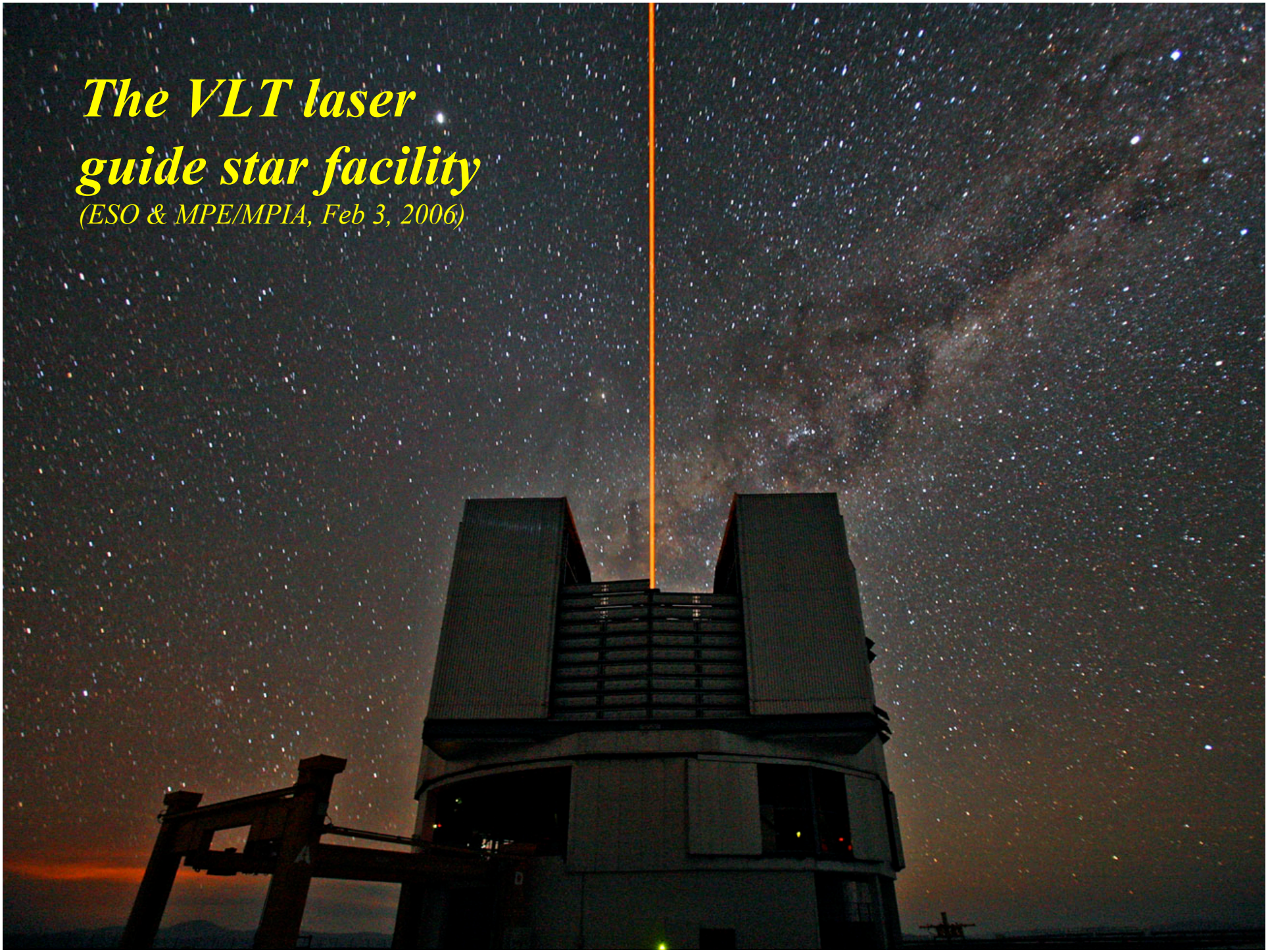
10” (1 light year)

C.H.Townes

Adaptive Optics



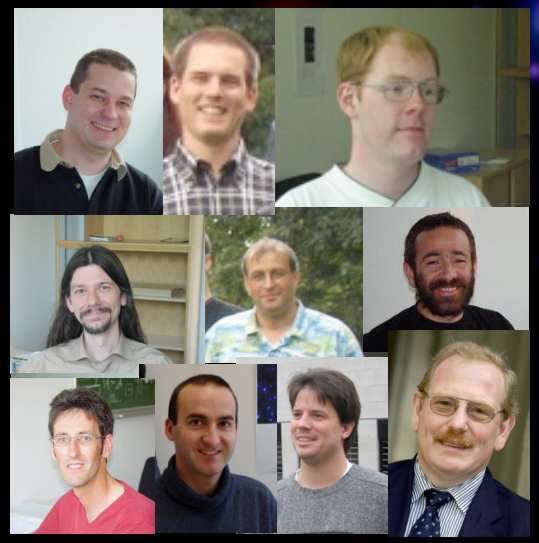



The VLT laser
guide star facility
(ESO & MPE/MPIA, Feb 3, 2006)

In search of the black hole ……..

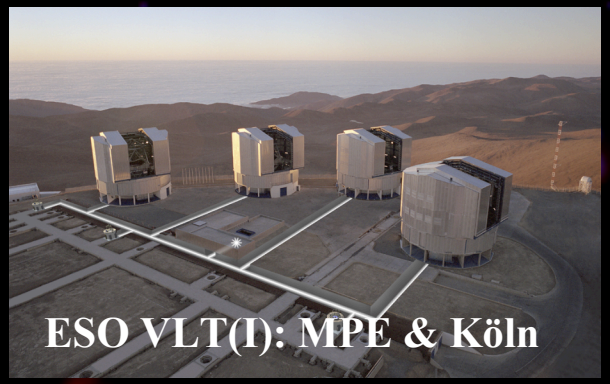
(1992……..)

Galactic Center teams,
MPE & Univ. Köln (VLT)
Univ. California Los Angeles (Keck)



MPE & Köln teams

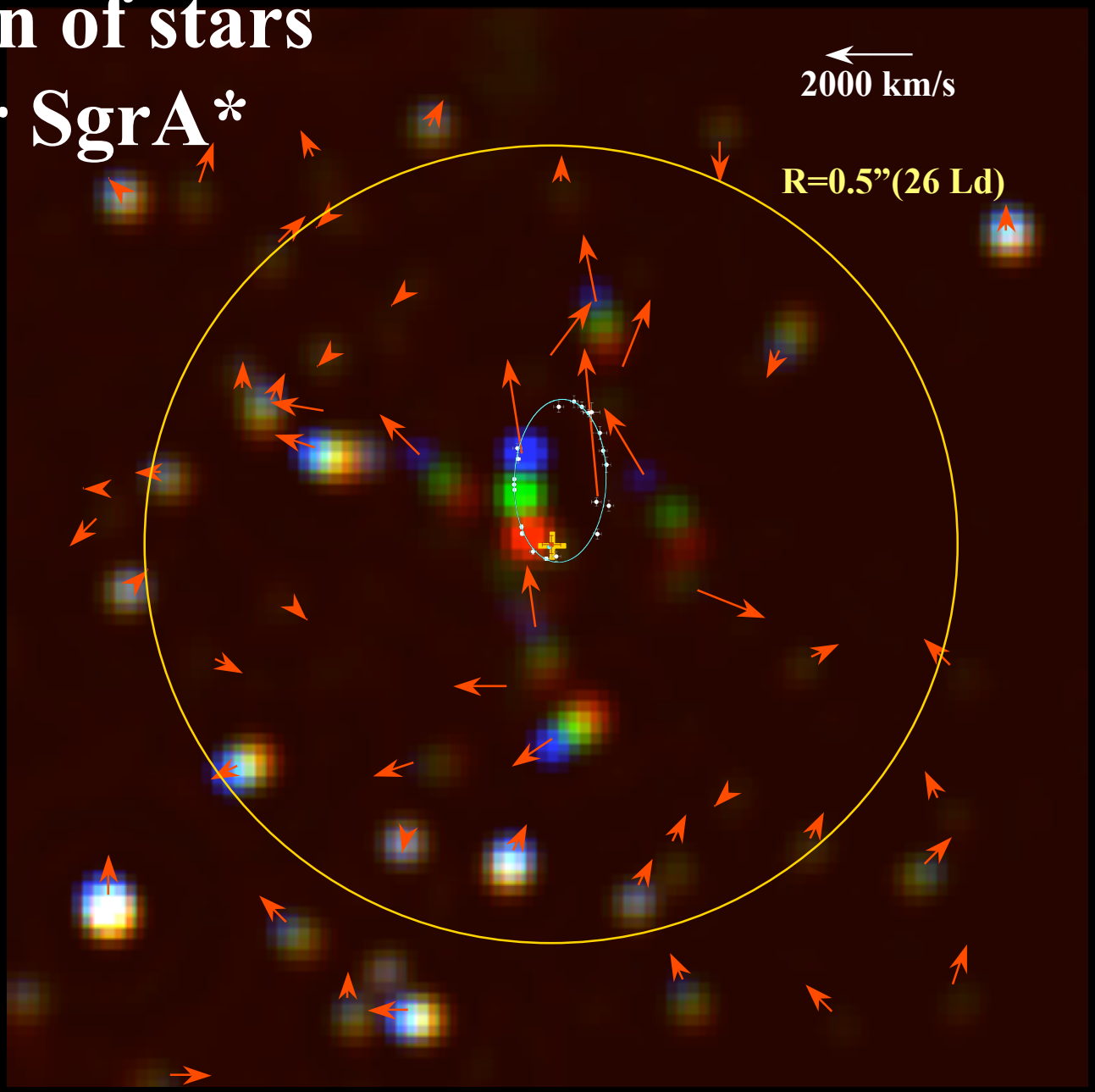
UCLA team



ESO VLT(I): MPE & Köln

Keck: UCLA group

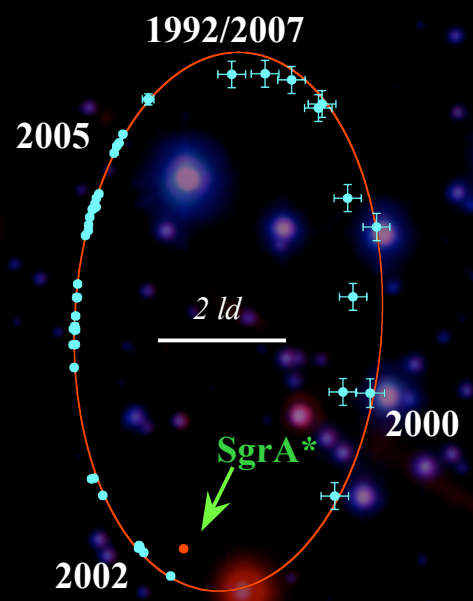
Motion of stars near SgrA*

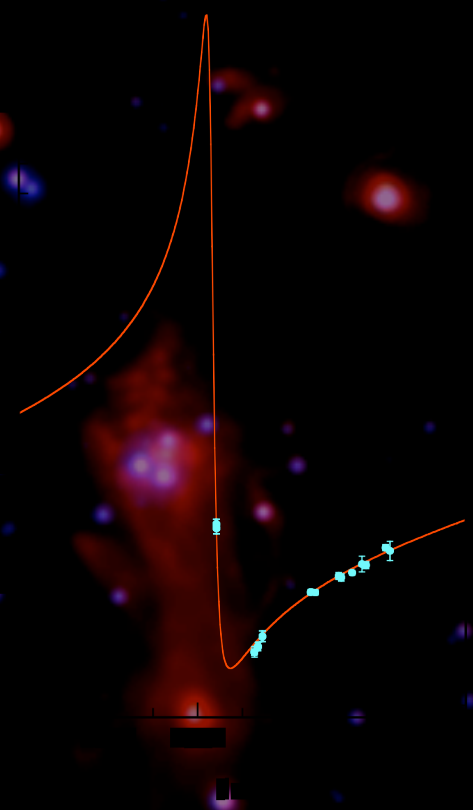


precision measurements of stellar orbits

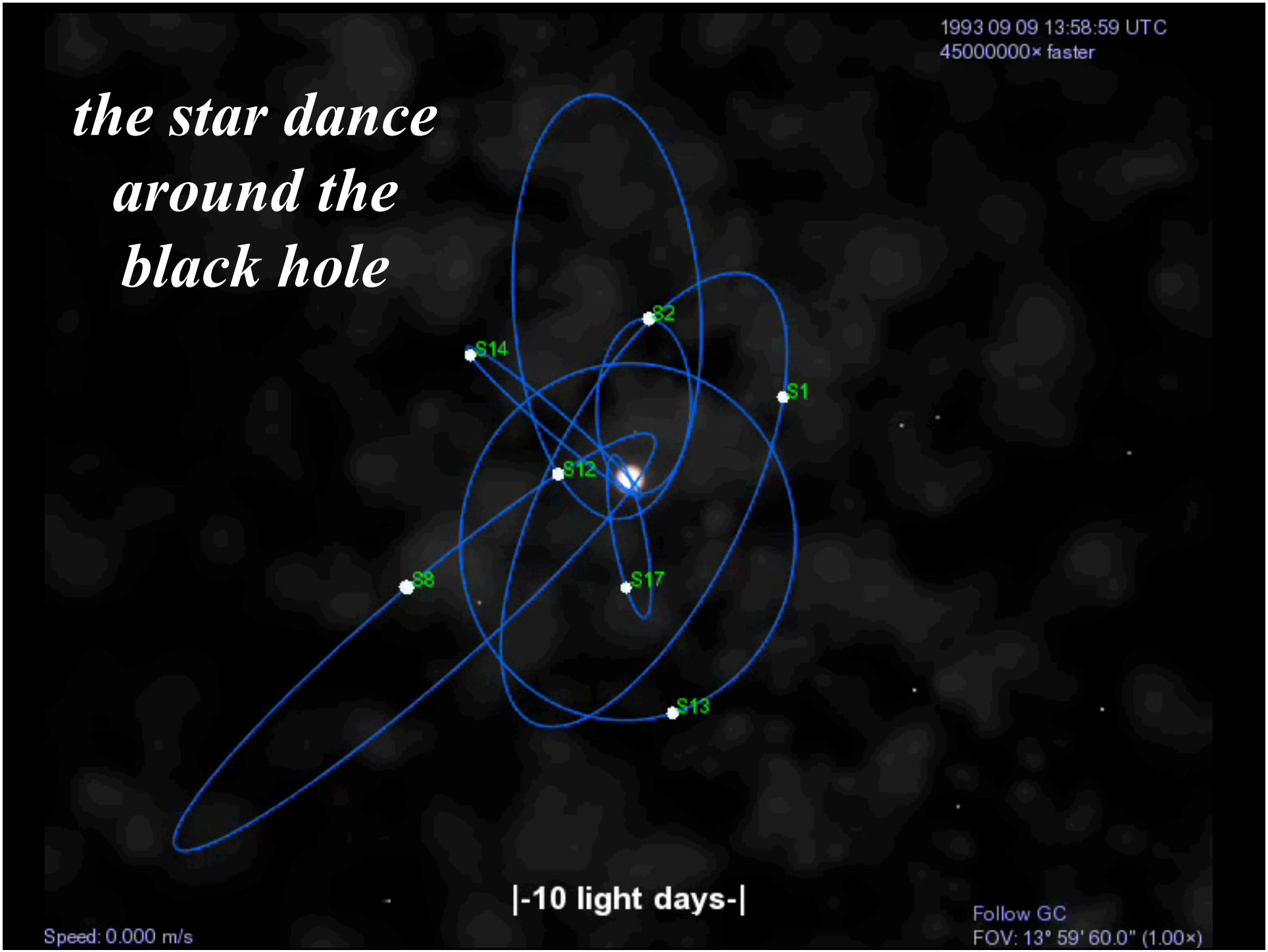
R_o (ly)	25400±1300
M_o ($M_\odot$)	$3.6\pm0.3\times10^6$

Galactic Center teams at
MPE & Univ. Cologne (VLT)
Univ. California Los Angeles (Keck)

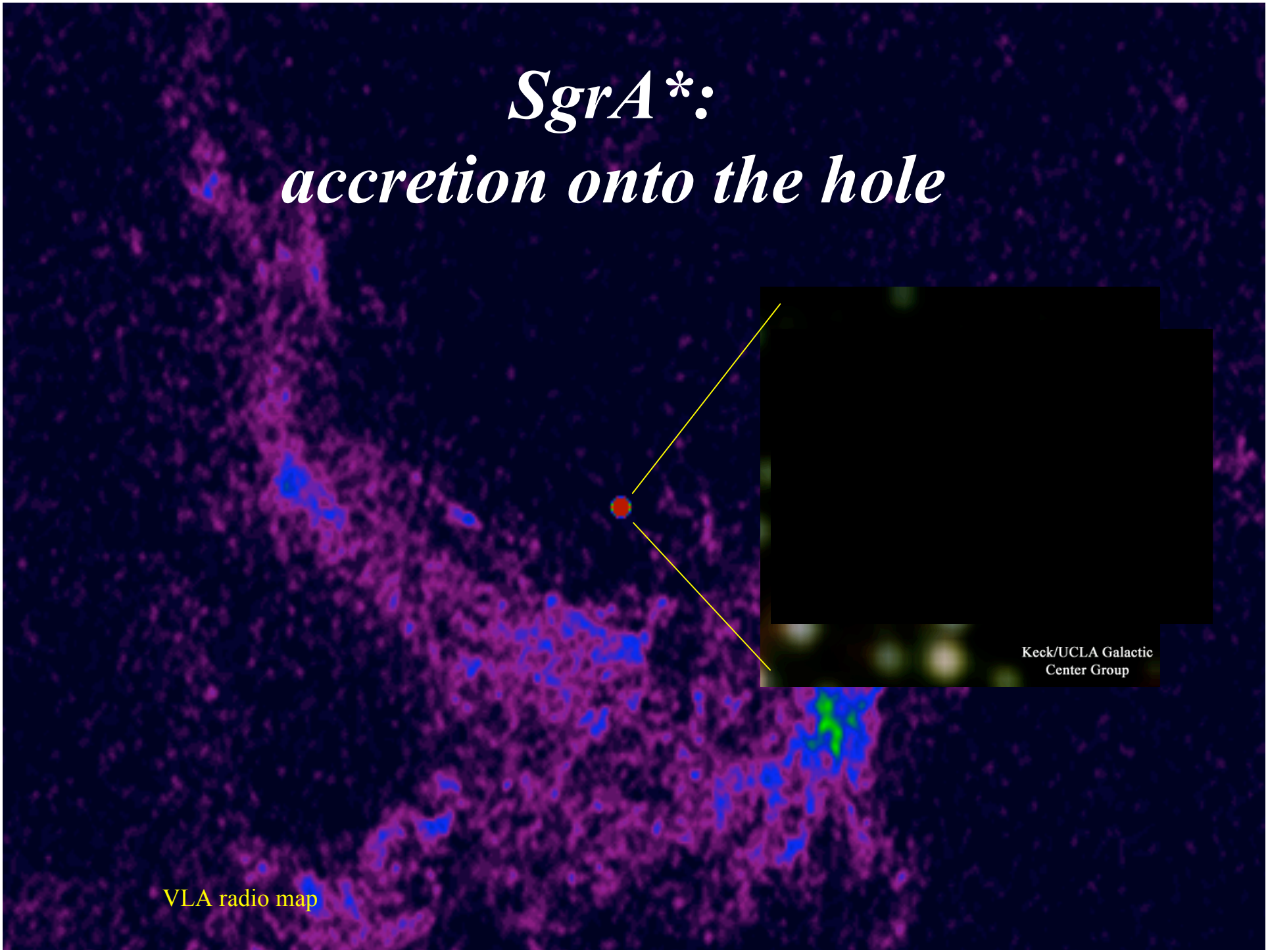




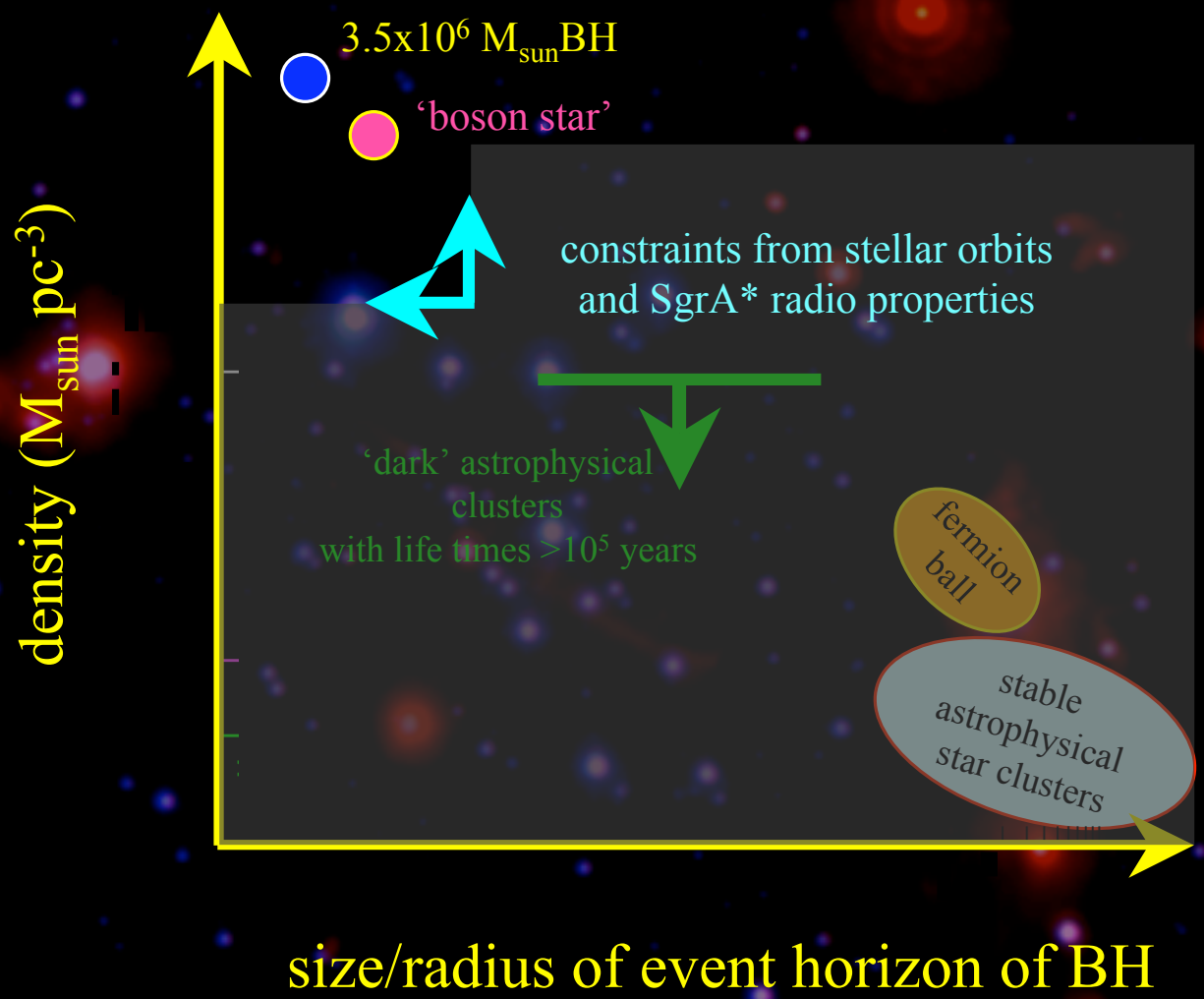
extended mass < a few % of the point mass (<10^5 $M_\odot$)
effects of Special and General Relativity will be detectable over the next few years


the star dance
around the
black hole
1993 09 09 13:58:59 UTC
45000000× faster
S2
S14
S1
S12
S8
S17
S13
|-10 light days-|
Speed: 0.000 m/s
Follow GC
FOV: 13° 59' 60.0" (1.00×)

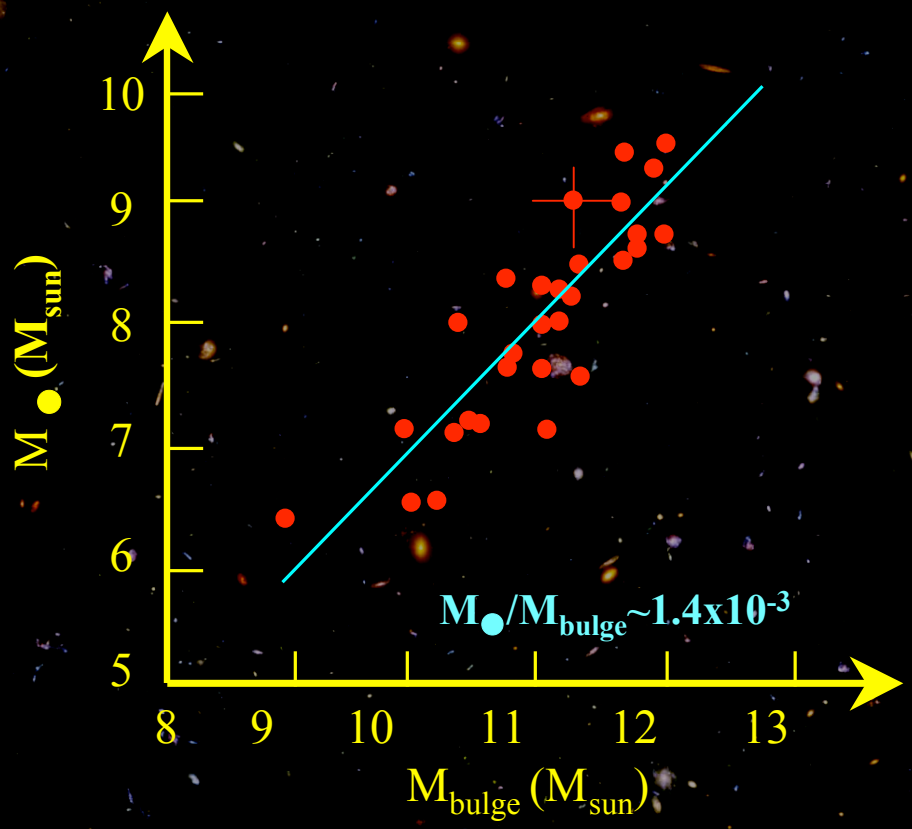
SgrA: accretion onto the hole*

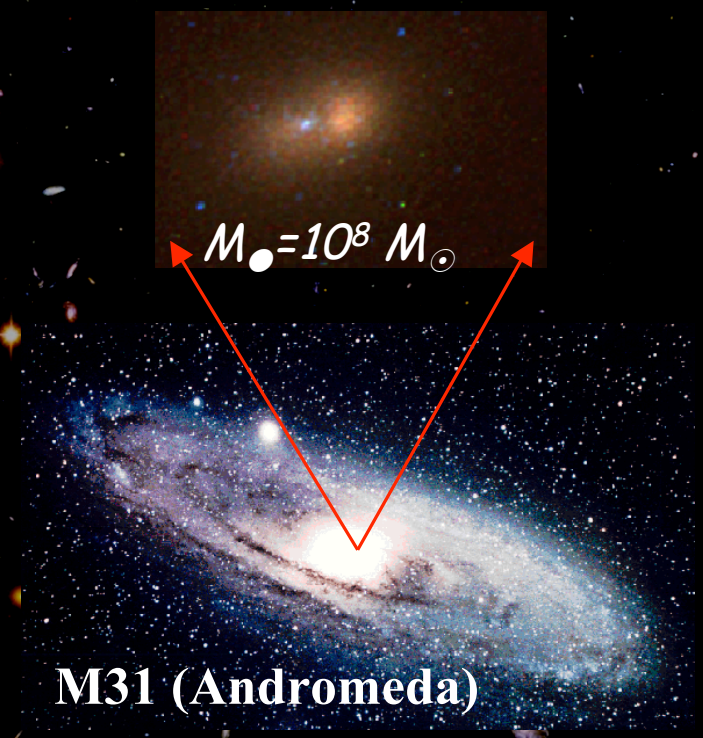


Is SgrA a black hole ?*

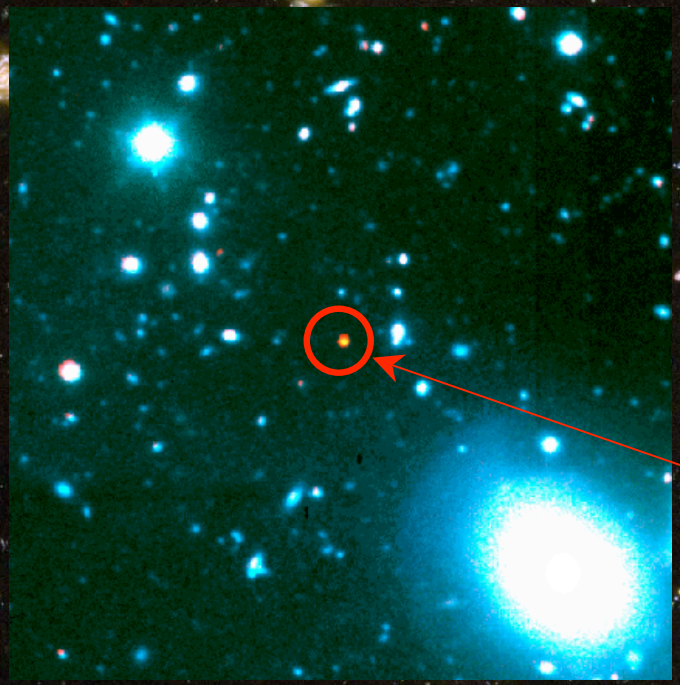


massive black holes in nearby galaxies

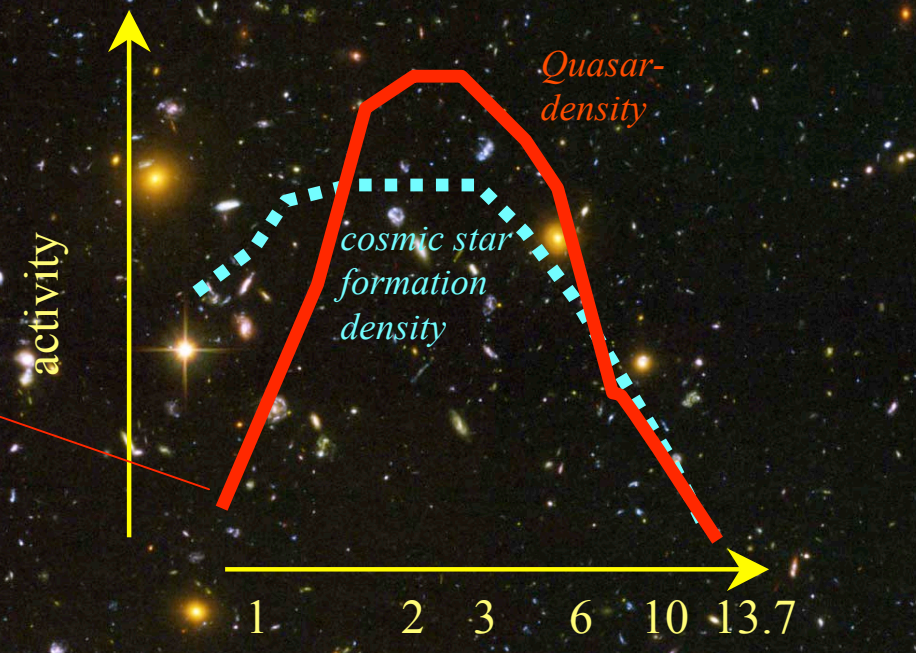




galaxies and massive black holes in the young Universe



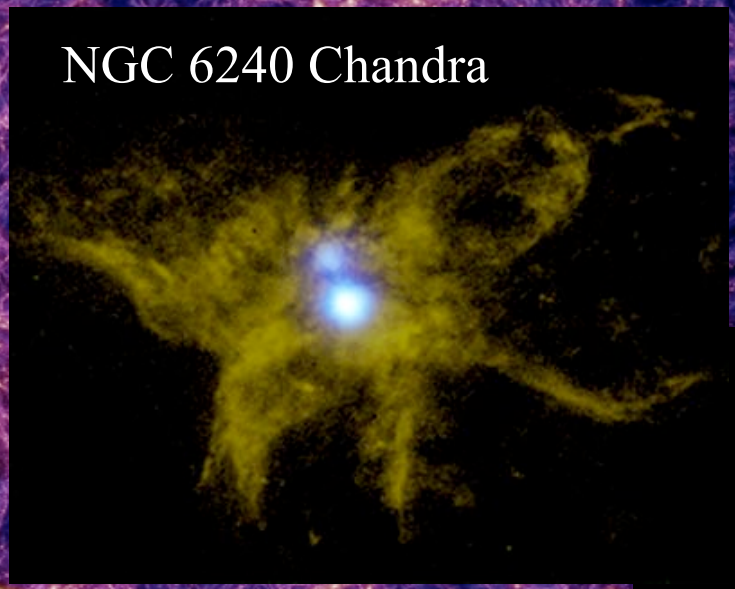
a 3 billion solar mass black hole 800 million years after the Big Bang!

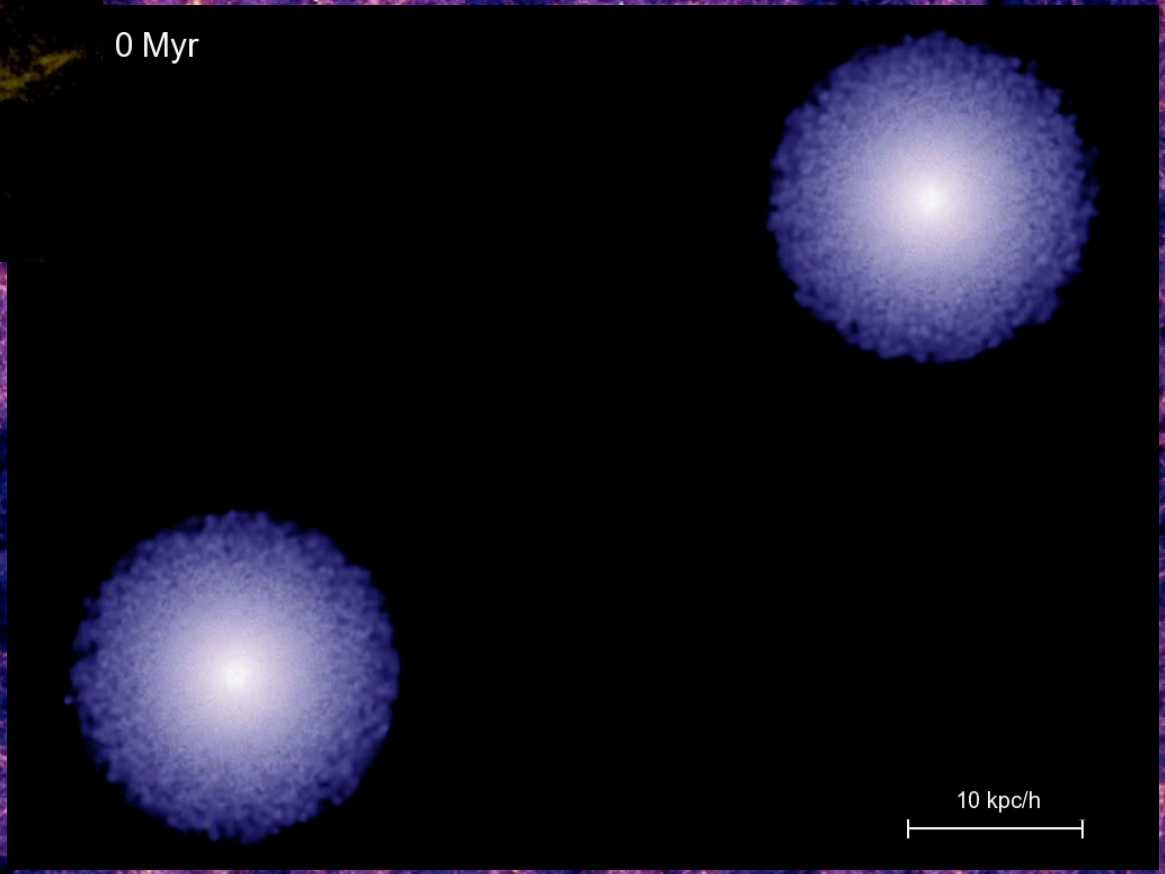


formation of galaxies

Computer simulations: MPA (Garching), Durham University

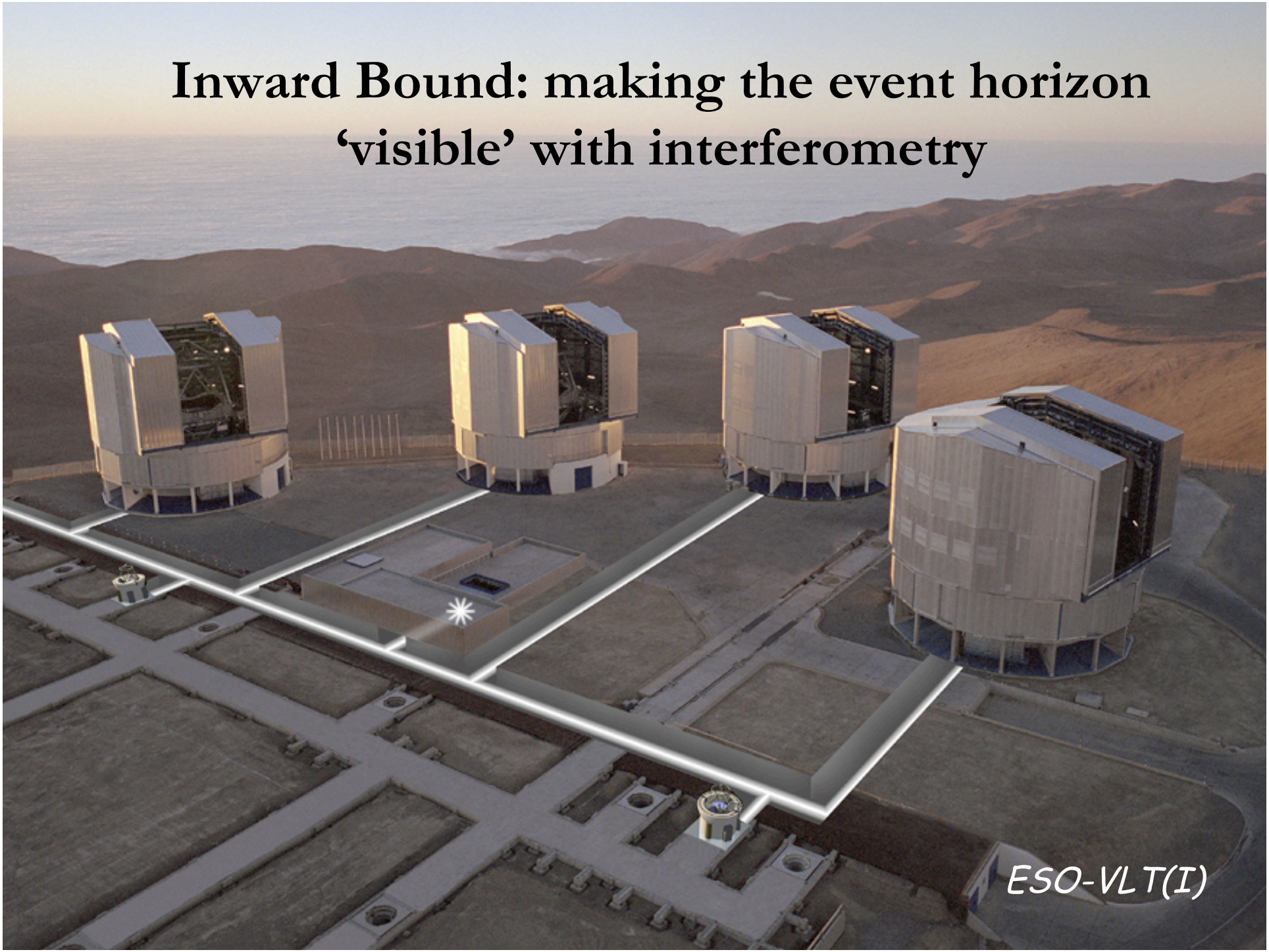
formation of quasars



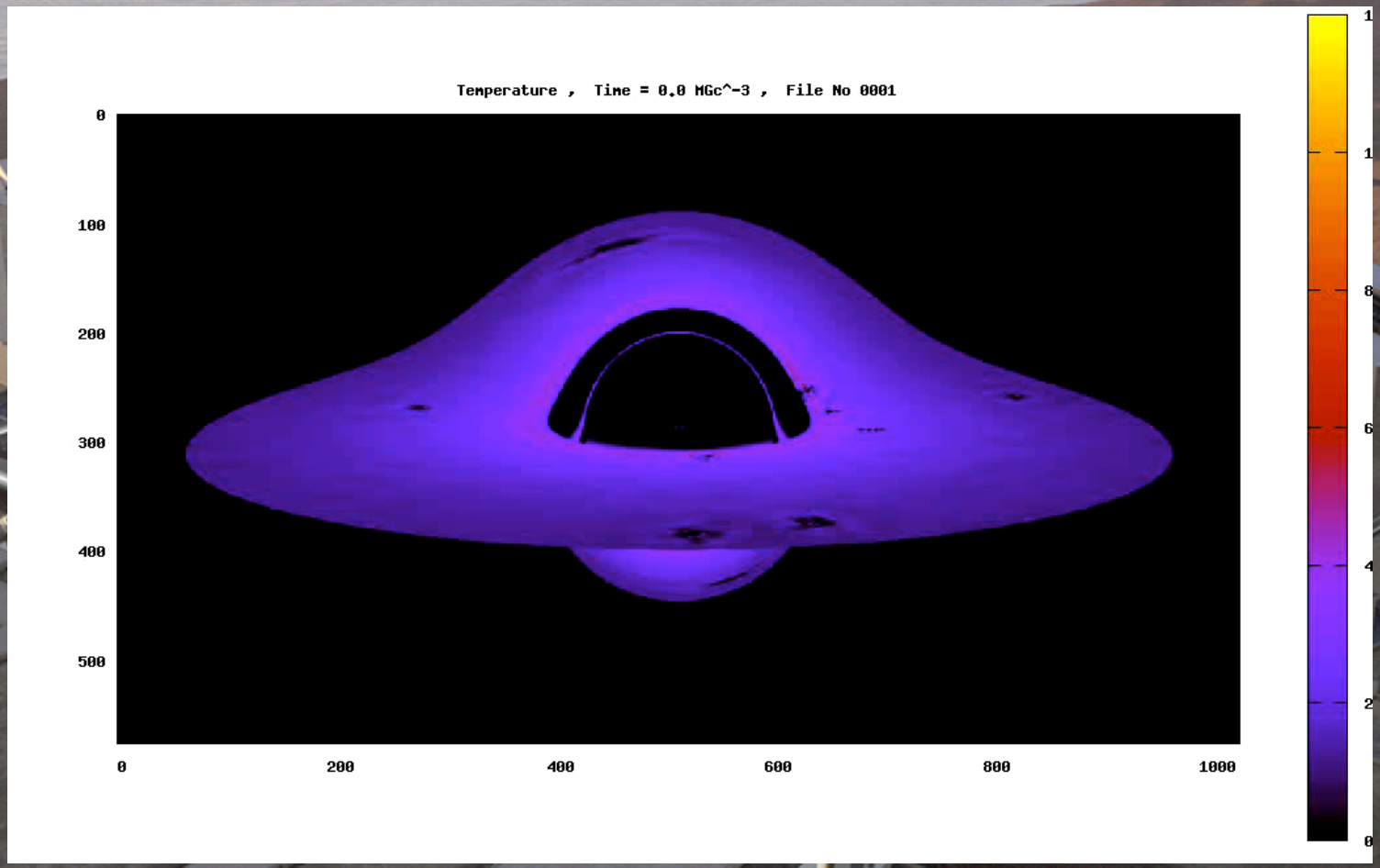


Computer simulations: MPA (Garching), Carnegie-Mellon University, Harvard University

Inward Bound: making the event horizon 'visible' with interferometry



Inward Bound: making the event horizon 'visible' with interferometry



ESO-VLT(I)

Massive Black Holes & Galaxies

Reinhard Genzel

2007