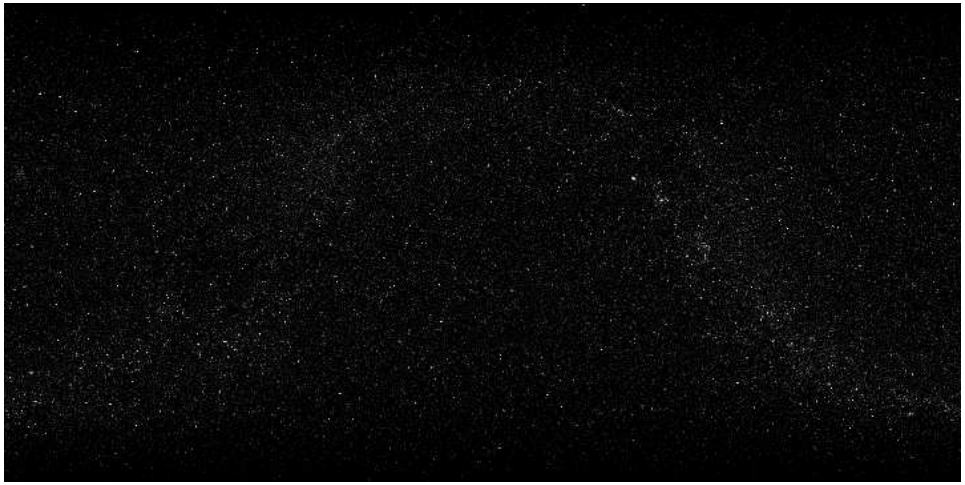
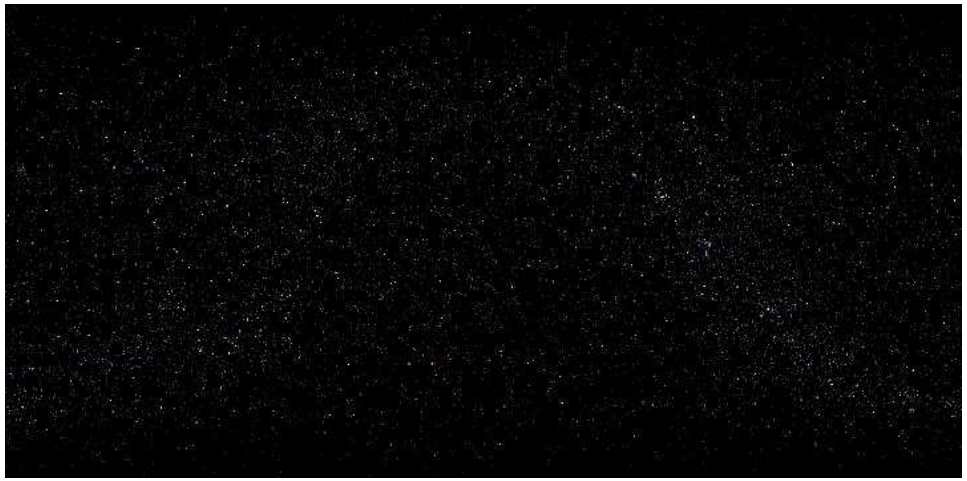
The Galactic Center



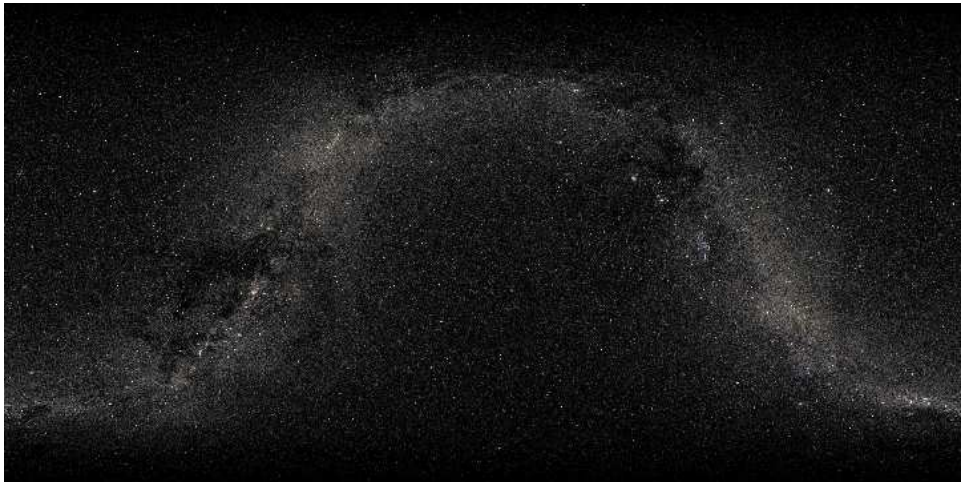
D.Seal/JPL

The Hipparcos Catalogue (118000 stars)



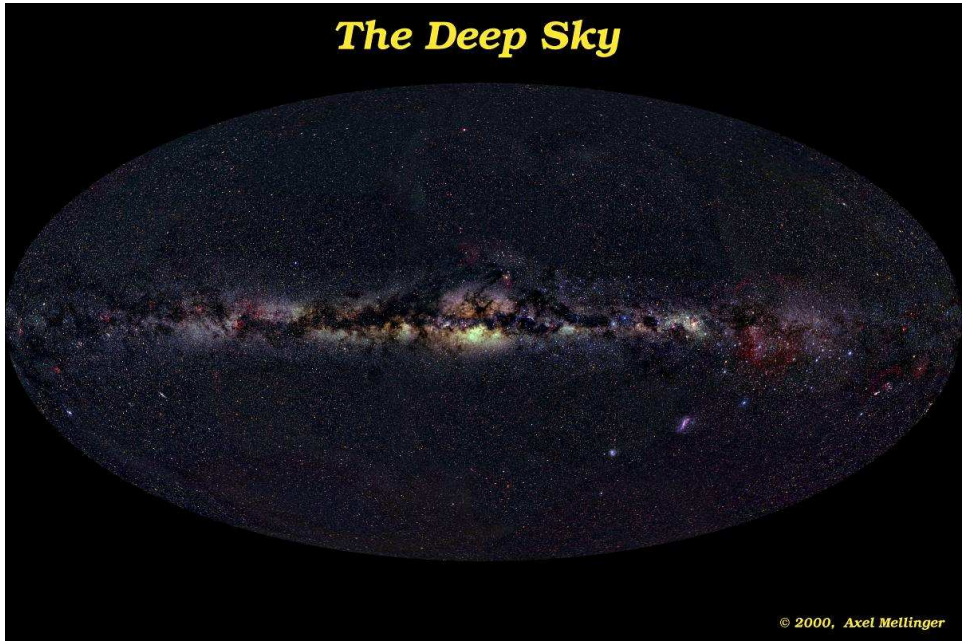
D.Seal/JPL

The Yale Bright Star Catalogue (9110 brightest stars)

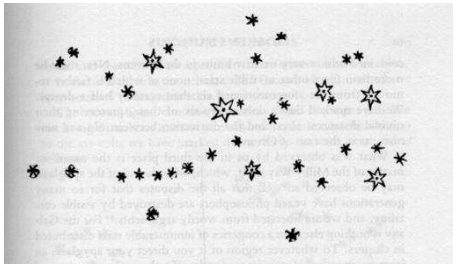


D.Seal/JPL

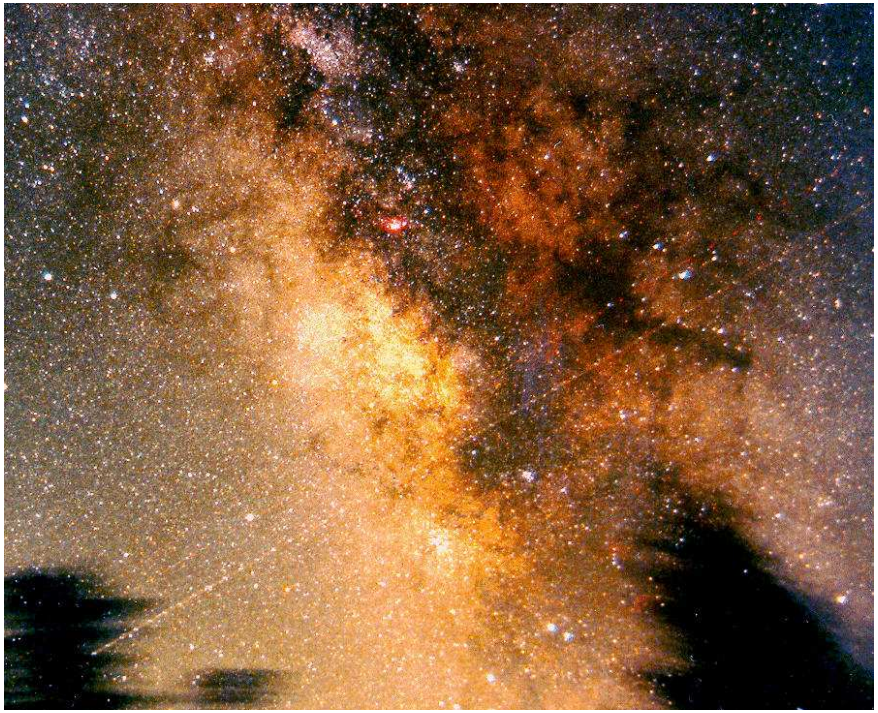
The second Tycho Catalogue (2.5 million stars)



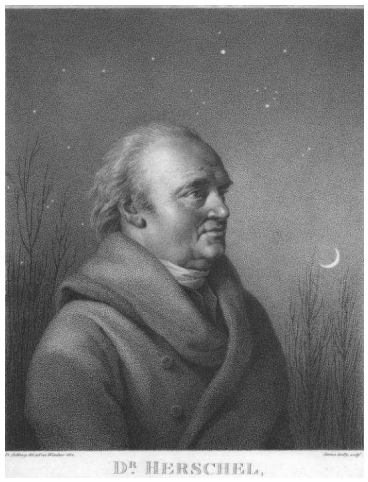
The Night Sky, VI

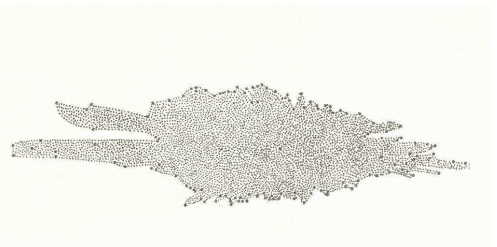


Galileo Galilei (1564–1642; Sidereus Nuncius): Telescopes resolves (part of) the milky way in stars, discovers new stars $\Longrightarrow$ Milky way is not “milky”!



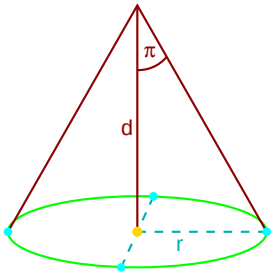
The Night Sky, VII

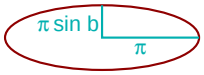




William Herschel (1738–1822): First attempts to determine morphology of the Galaxy.
Note: heliocentric!

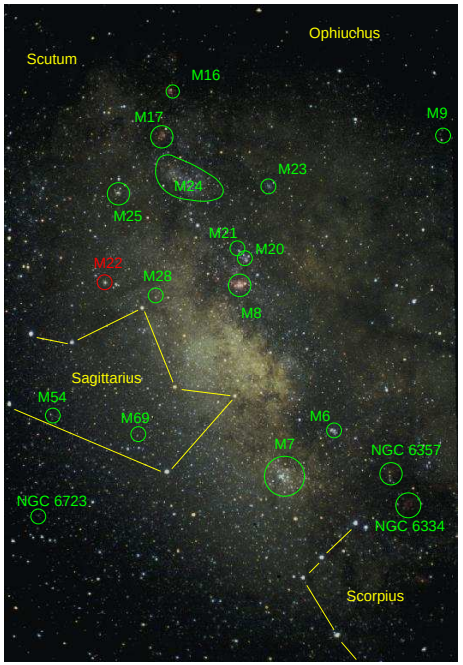
The Night Sky, VIII





Wilhelm Bessel (1784–1846): First determination of a stellar parallax

reminder:
1 parsec = 3.26 Lj = 3×10^{13} km



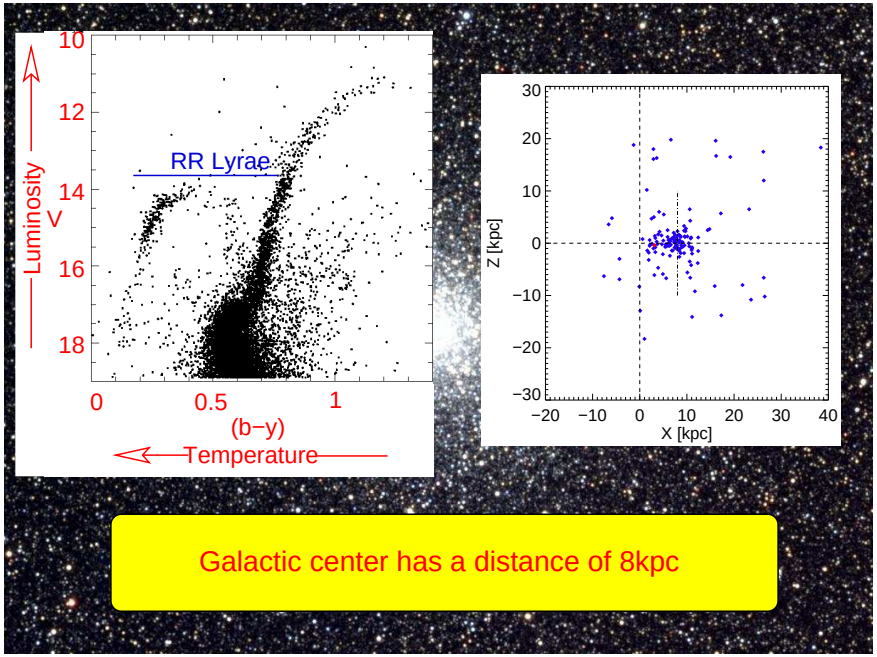
Milky way in Sagittarius
$27^\circ \times 40^\circ$

W. Keel (U Alabama)

Milky way in Sagittarius
$27^\circ \times 40^\circ$

W. Keel (U Alabama)

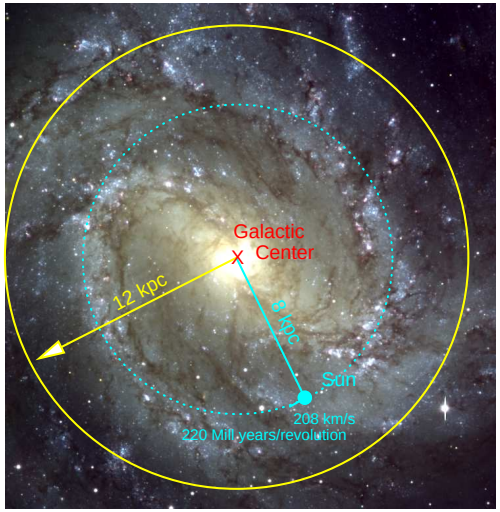
M22, KPNO (N.A.Sharp, REU program/NOAO/AURA/NSF)



Richter et al., 1999, A&A 350, 476

M22, KPNO (N.A.Sharp, REU program/NOAO/AURA/NSF)

Milky way as a Galaxy



M83: ESO [VLT ANTU+FORS1]

Luminosity: $\sim 2 \times 10^{10}\, L_\odot$

Mass: $\sim 10^{11}\, M_\odot$ (radiating)

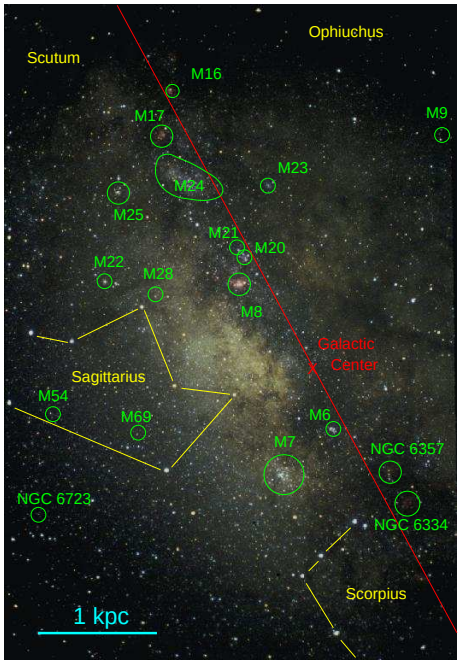
$\sim 10^{12}\, M_\odot$ (total)

Stellar density:

$\sim 0.3\, M_\odot\,\mathrm{pc}^{-3}$

$1\, M_\odot = 2 \times 10^{33}\,\mathrm{g} = 2 \times 10^{30}\,\mathrm{kg}$,

$1\, L_\odot = 4 \times 10^{33}\,\mathrm{erg\,s}^{-1} = 4 \times 10^{26}\,\mathrm{W}$



W. Keel (U Alabama)

Milky way in Saggitarius

$27^\circ \times 40^\circ$

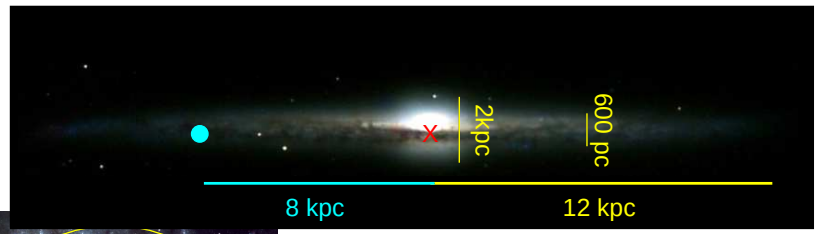
Distance: 8 kpc

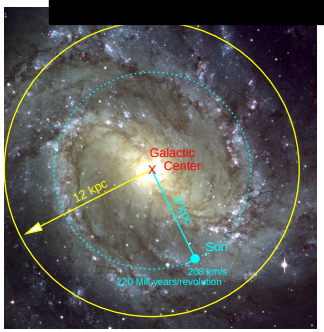
$\Longrightarrow 1^\circ \sim 140\,\mathrm{pc}$

$\Longrightarrow 1' \sim 2\,\mathrm{pc}$

$\Longrightarrow 1'' \sim 0.3\,\mathrm{pc}$

Milky way as a Galaxy





NGC 4565: W. McLaughlin

Luminosity: $\sim 2 \times 10^{10}\, L_\odot$

Mass: $\sim 10^{11}\, M_\odot$ (radiating)

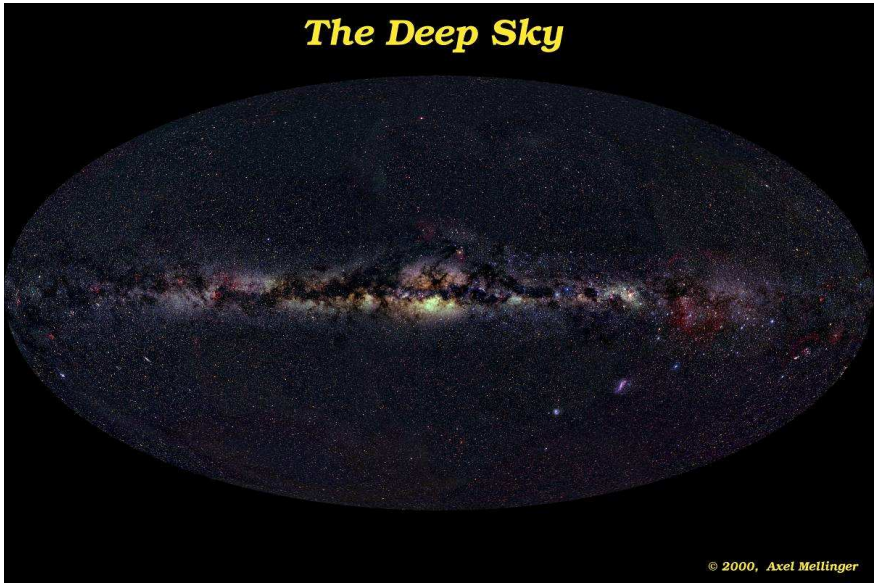
$\sim 10^{12}\, M_\odot$ (total)

Stellar density:

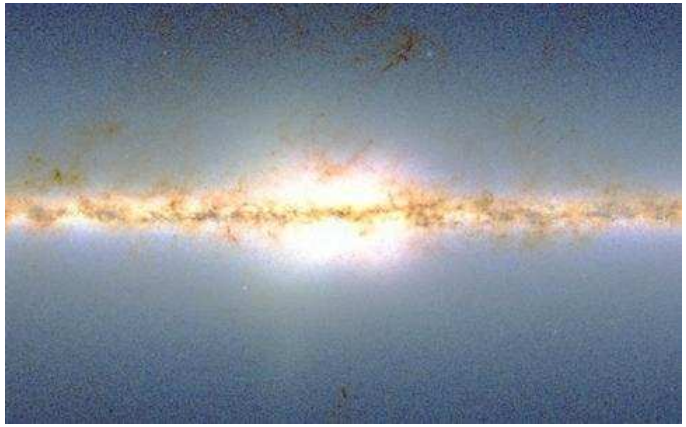
$\sim 0.3\, M_\odot\,\mathrm{pc}^{-3}$

$1\, M_\odot = 2 \times 10^{33}\,\mathrm{g} = 2 \times 10^{30}\,\mathrm{kg}$,

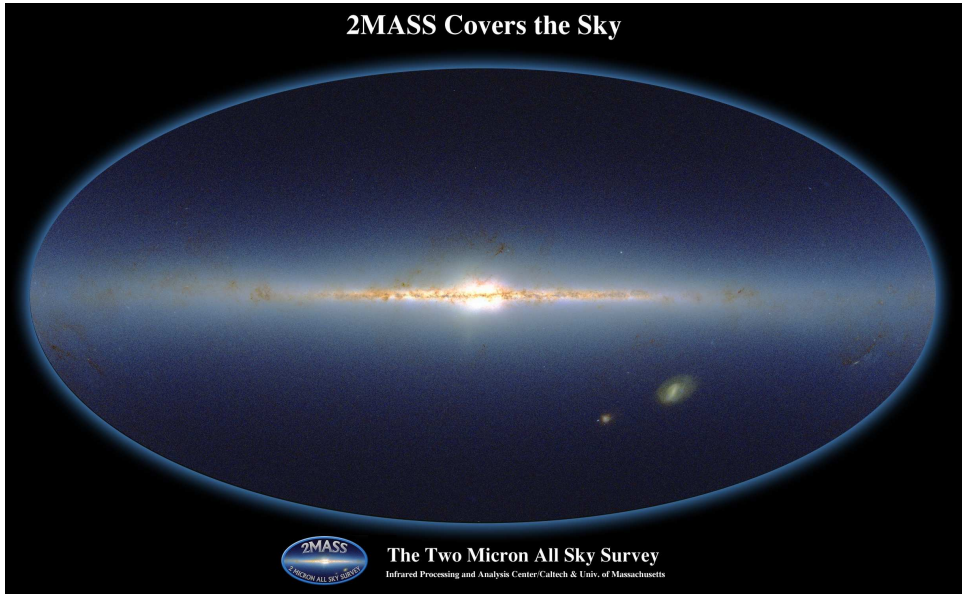
$1\, L_\odot = 4 \times 10^{33}\,\mathrm{erg\,s}^{-1} = 4 \times 10^{26}\,\mathrm{W}$



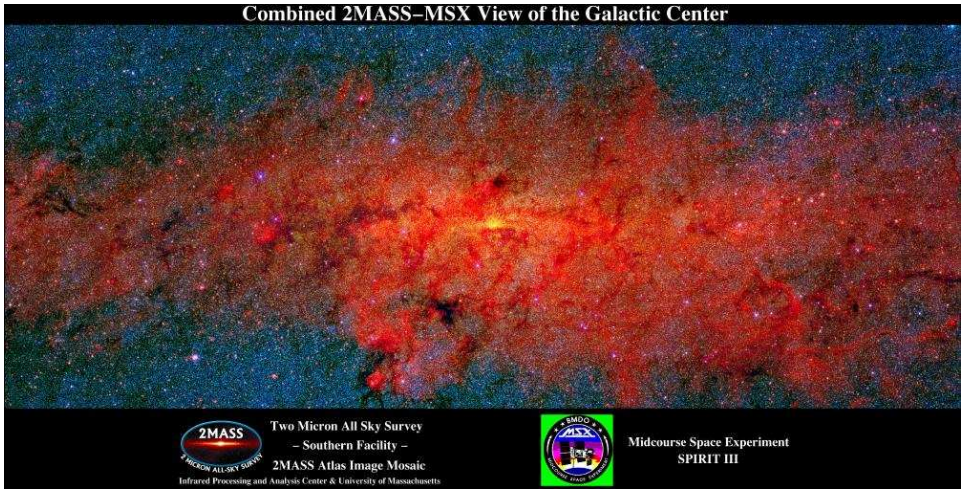
Problem: strong extinction due to dust
($A_V \sim 30$ mag: 10^{12} times reduction in the optical!)
$\Longrightarrow$ Multiwavelength astronomy!



2MASS: inner $60^\circ \times 45^\circ$

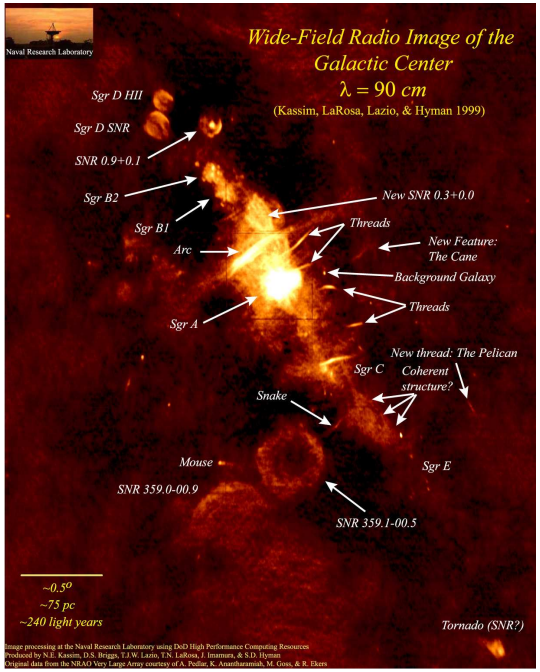


Infra red: Dust becomes transparent!
2MASS: 3 IR Bänder: J (1.25 μm), H (1.65 μm), K_s (2.17μm)

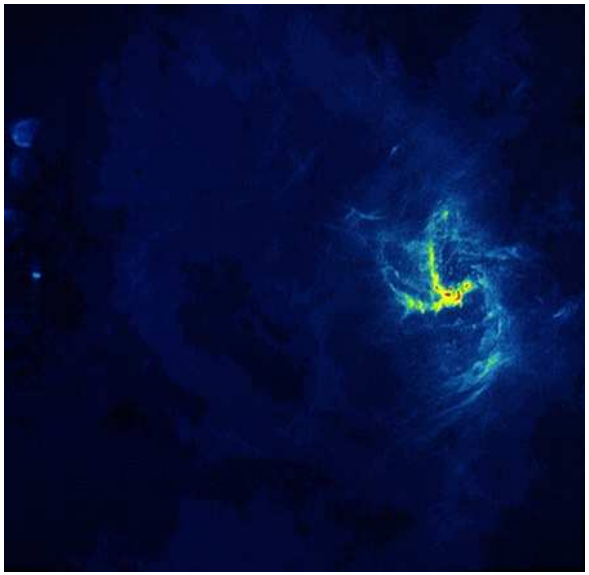


2MASS/MSX: Inner $4^\circ \times 2^\circ$

2MASS (J [1.25 μm], red), (K [2.17 μm], green), MSX (A [6–11 μm], blue)



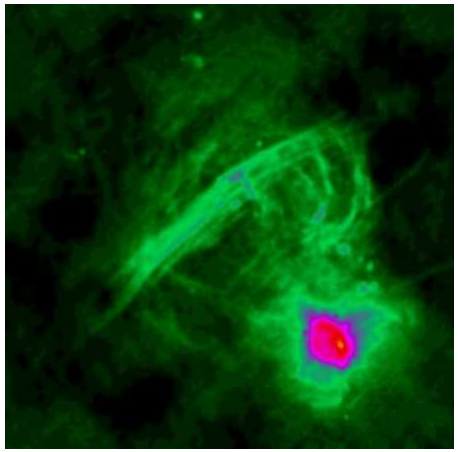
X



Sgr A (3.6 cm, courtesy K.Y. Lo/NRAO/AUI)

Sgr A West (“spiral”):
2 pc diameter,
$\sim 60\, M_\odot$ ionized gas, shaped by tidal forces
(probably influence of mG B-field),
northern arm falls on center, east and south arms rotate.
around Sgr A West: circumnuclear disk of molecular gas, ($r \sim 2$ pc).
total mass accretion rate onto Sgr A*:
$\sim 0.03\, M_\odot$ yr^{-1}

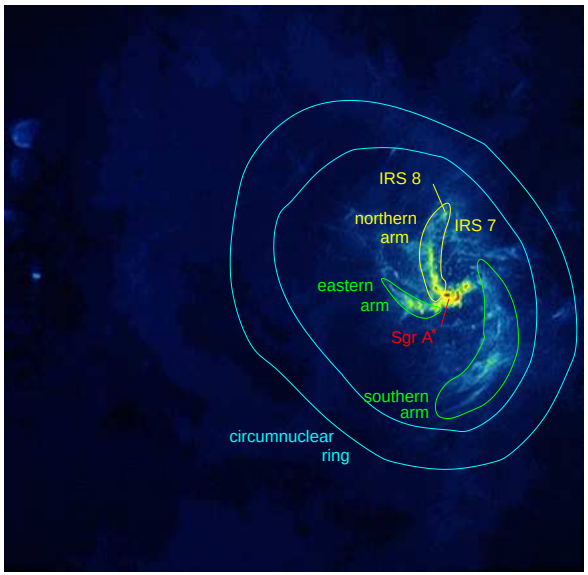
The Inner kpc



70 pc × 70 pc, VLA (F. Yusef-Zadeh et al., 1982–1984)
©NRAO/AUI

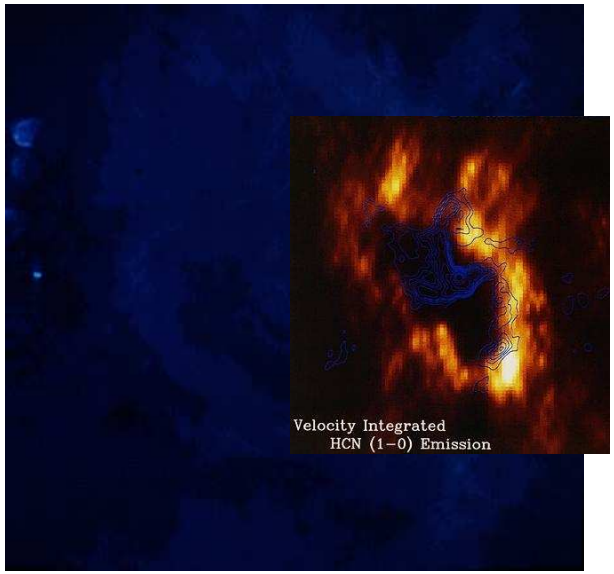
Radio source Sgr A:
Sgr A (West) (Arc): 5″ (=0.2 pc) broad radio filaments, part of a much larger Ω-shaped structure $\perp$ galactic plane.

polarized, steep radio spectrum $\Longrightarrow$ synchrotron radiation (nonthermal electrons; $n_e(E) \propto E^{-p}$)!
caused by shocks from supernovae?



Sgr A (3.6 cm, courtesy K.Y. Lo/NRAO/AUI)

Sgr A West (“spiral”):
2 pc diameter,
$\sim 60\, M_\odot$ ionized gas, shaped by tidal forces
(probably influence of mG B-field),
northern arm falls on center, east and south arms rotate.
around Sgr A West: circumnuclear disk of molecular gas, ($r \sim 2$ pc).
total mass accretion rate onto Sgr A*:
$\sim 0.03\, M_\odot$ yr^{-1}



Sgr A (3.6 cm, courtesy K.Y. Lo/NRAO/AUI)

Sgr A West (“spiral”):
2 pc diameter,
$\sim 60\, M_\odot$ ionized gas, shaped by tidal forces
(probably influence of mG B-field),
northern arm falls on center, east and south arms rotate.
around Sgr A West: circumnuclear disk of molecular gas, ($r \sim 2$ pc).
total mass accretion rate onto Sgr A*:
$\sim 0.03\, M_\odot\,\mathrm{yr}^{-1}$

The Inner Parsec: Central Cluster, I

Center of Sgr A contains massive and dense cluster
($> 10^6\, M_\odot\,\mathrm{pc}^{-3}$, compare solar neighborhood: $0.1\, M_\odot\,\mathrm{pc}^{-3}$)
Spectroscopy: Stars are rich in Helium, early type (=massive), strong winds
($v_{\mathrm{Wind}} \sim 1000\,\mathrm{km\,s}^{-1}$).

The Inner Parsec: Central Cluster, II

Gemini North/AURA

Observations are difficult because of astronomical seeing
($\sim 0.7''$=0.2 pc)

The Inner Parsec: Central Cluster, III

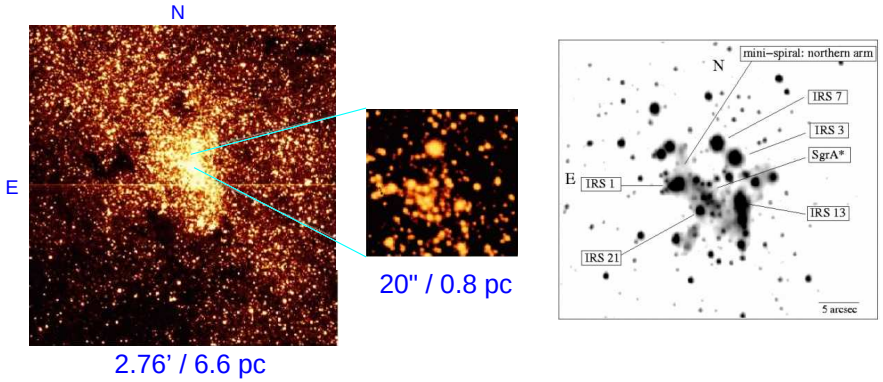
Gemini North/AURA

Observations are difficult because of astronomical seeing
($\sim 0.7''$=0.2 pc)
. . . which can be corrected by adaptive optics
$\Longrightarrow$ resolution: diffraction limit!

$$\theta = 1.22\,\mathrm{rad} \cdot \lambda/d \sim 1\,\mathrm{mas}$$

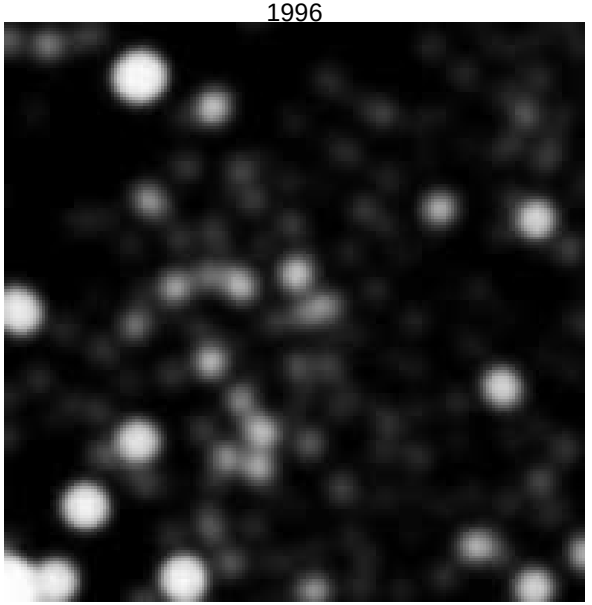
(for $d = 8$ m, $\lambda = 2.2\,\mu$m)
$\Longrightarrow$ 140 AU for gal. center!

The Inner Parsec: Central Cluster, IV



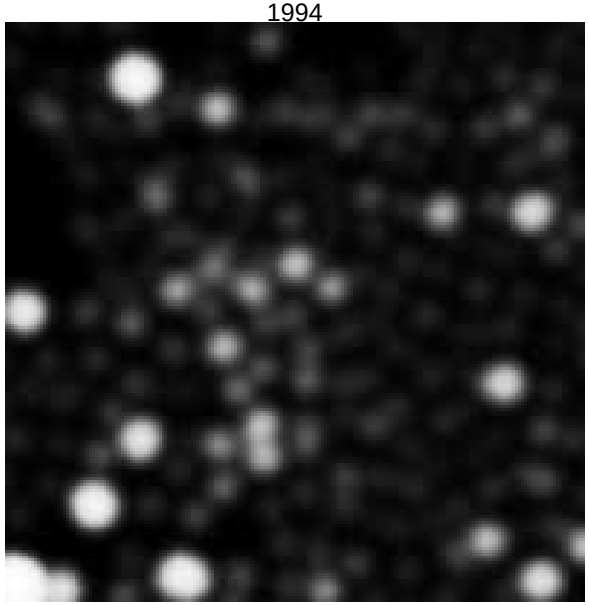
VLT ISAAC K-Band (2.2 μm) (Genzel/Eckart)

1996



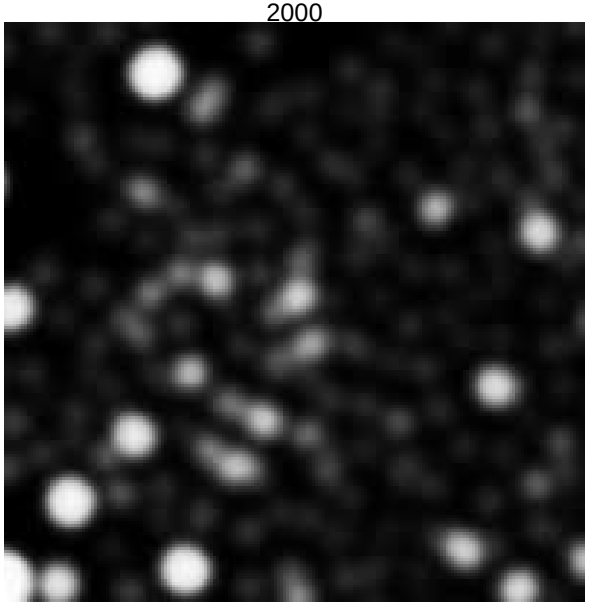
Genzel/Eckart

1994

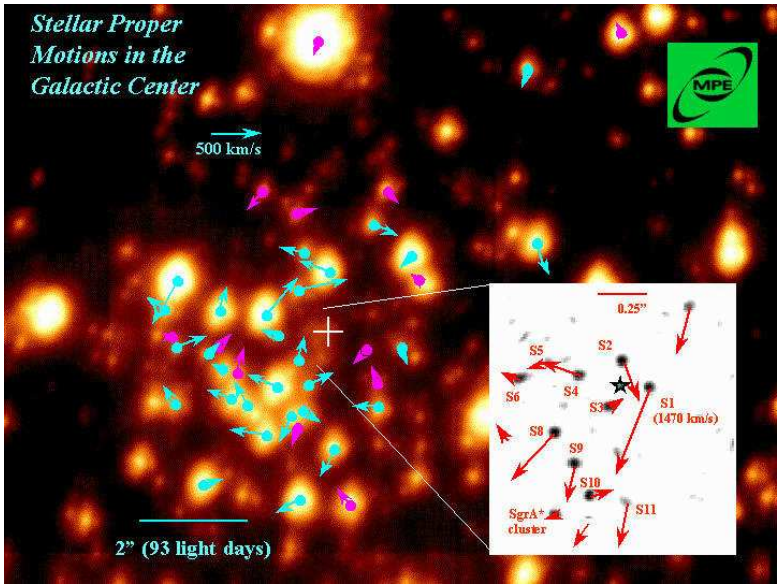


Genzel/Eckart

2000

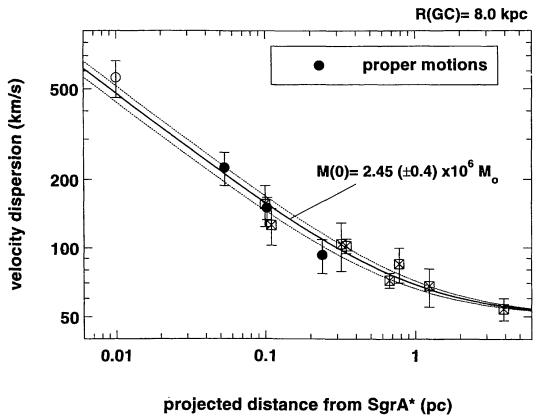


Genzel/Eckart



Genzel et al. (MPE)/Ghez et al. (UCLA): dynamical mass determination by measuring the proper motion of $\sim$ 40 stars of the central cluster (Fig.: MPE results 1991–2000).

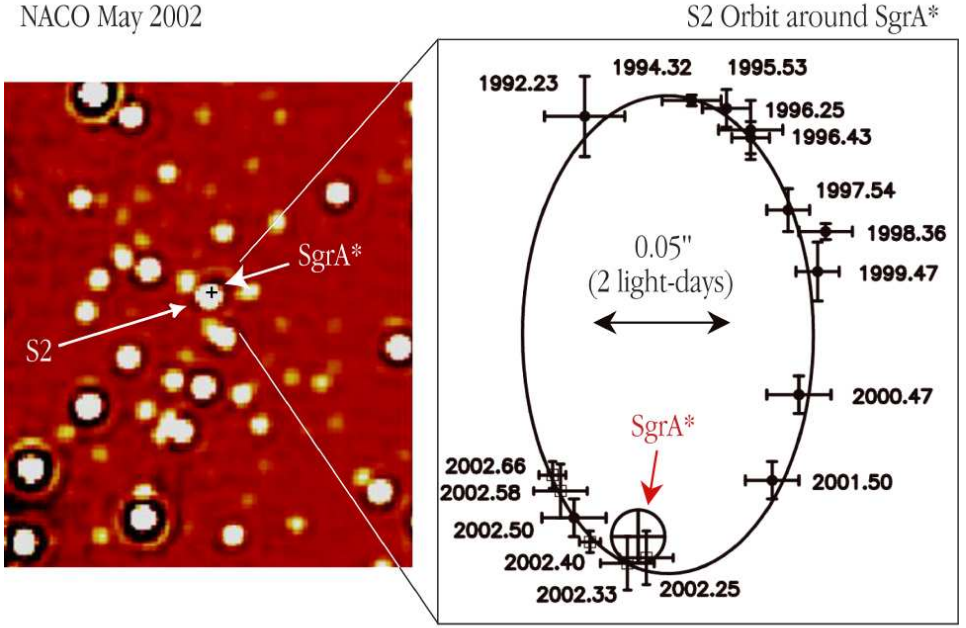
The inner parsec: mass determination



Velocity dispersion in the center

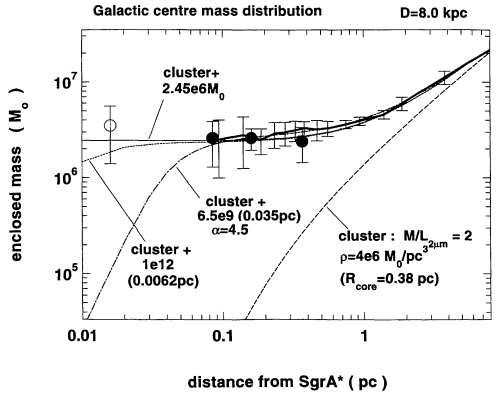
For $r \geq 0.057$ pc: Keplerian velocity profile ($\sigma_v \propto v^{-1/2}$), influenced by cluster at smaller distances

Eckart & Genzel, 1997, MNRAS, 284, 576



ESO, Oct 2002

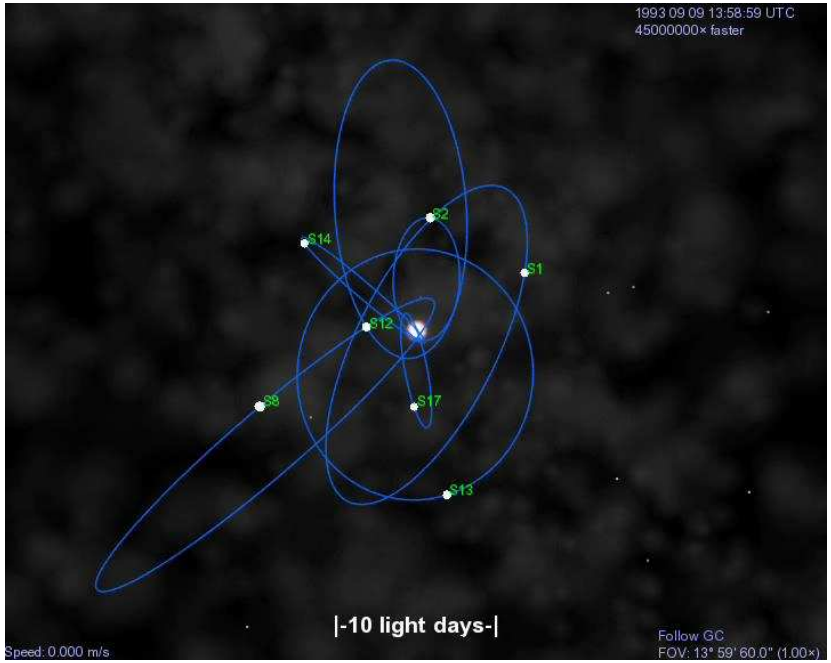
The inner parsec: mass determination



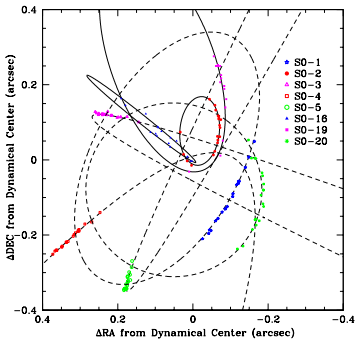
Model: point source plus cluster with a velocity dispersion of 50 km s^{-1} $\Longrightarrow$ central mass: 2.4 $\times$ 10^6 $M_\odot$.

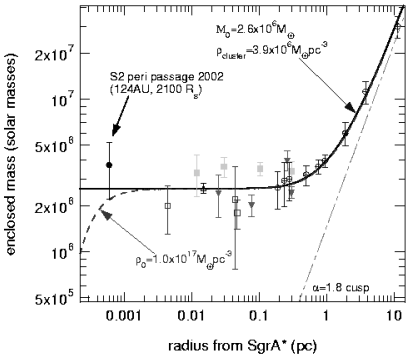
Eckart & Genzel, 1997, MNRAS, 284, 576

Evidence for a very massive compact object in the Galactic center $\Longrightarrow$ Black Hole?



The inner parsec: mass determination



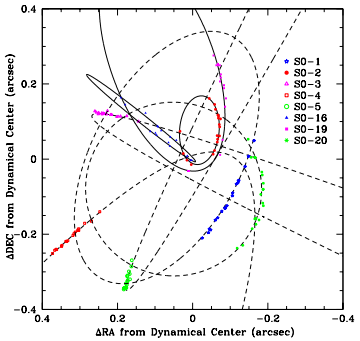


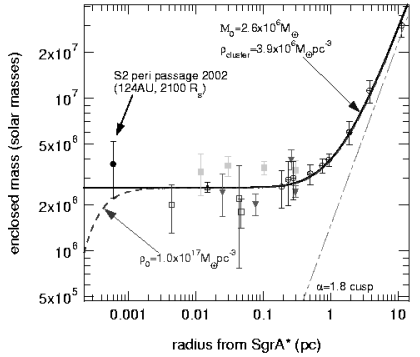
Ghez et al. (2003) Schödel et al. (2002)

Mass determination: 3. Kepler

$$a = 5.5\,\text{light days} \qquad P = 15.2\,\text{years} \qquad \Longrightarrow \qquad \frac{P^2}{a^3} = \frac{4\pi^2}{G(m_* + M_{\text{BH}})}$$

The inner parsec: mass determination





Ghez et al. (2003) Schödel et al. (2002)

The center of the Galaxy harbors a black hole with
$M_{\text{BH}} = (3.7 \pm 1.0) \times 10^6\, M_\odot$