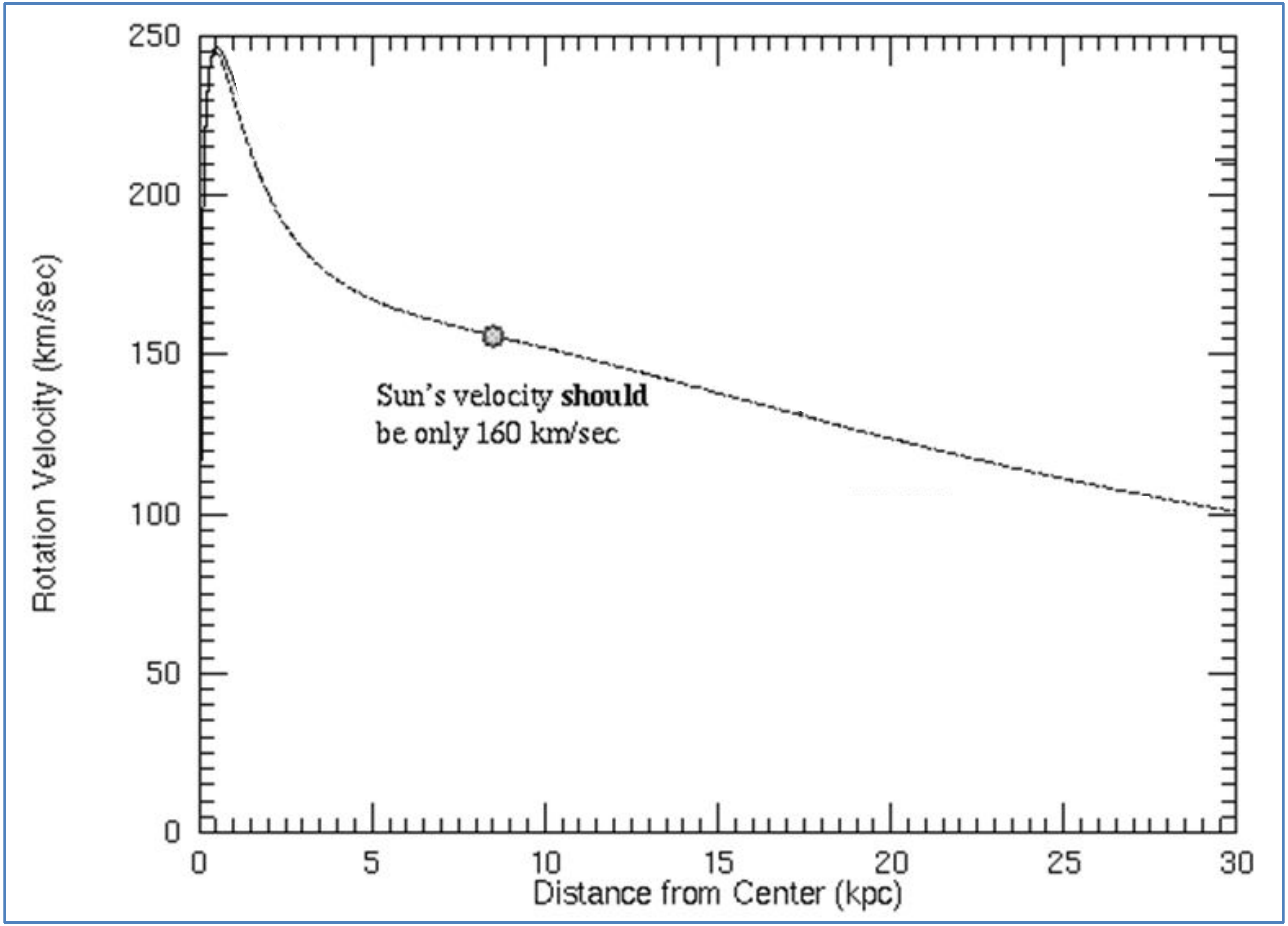
Week 10: Milky Way Center & Active Galaxies

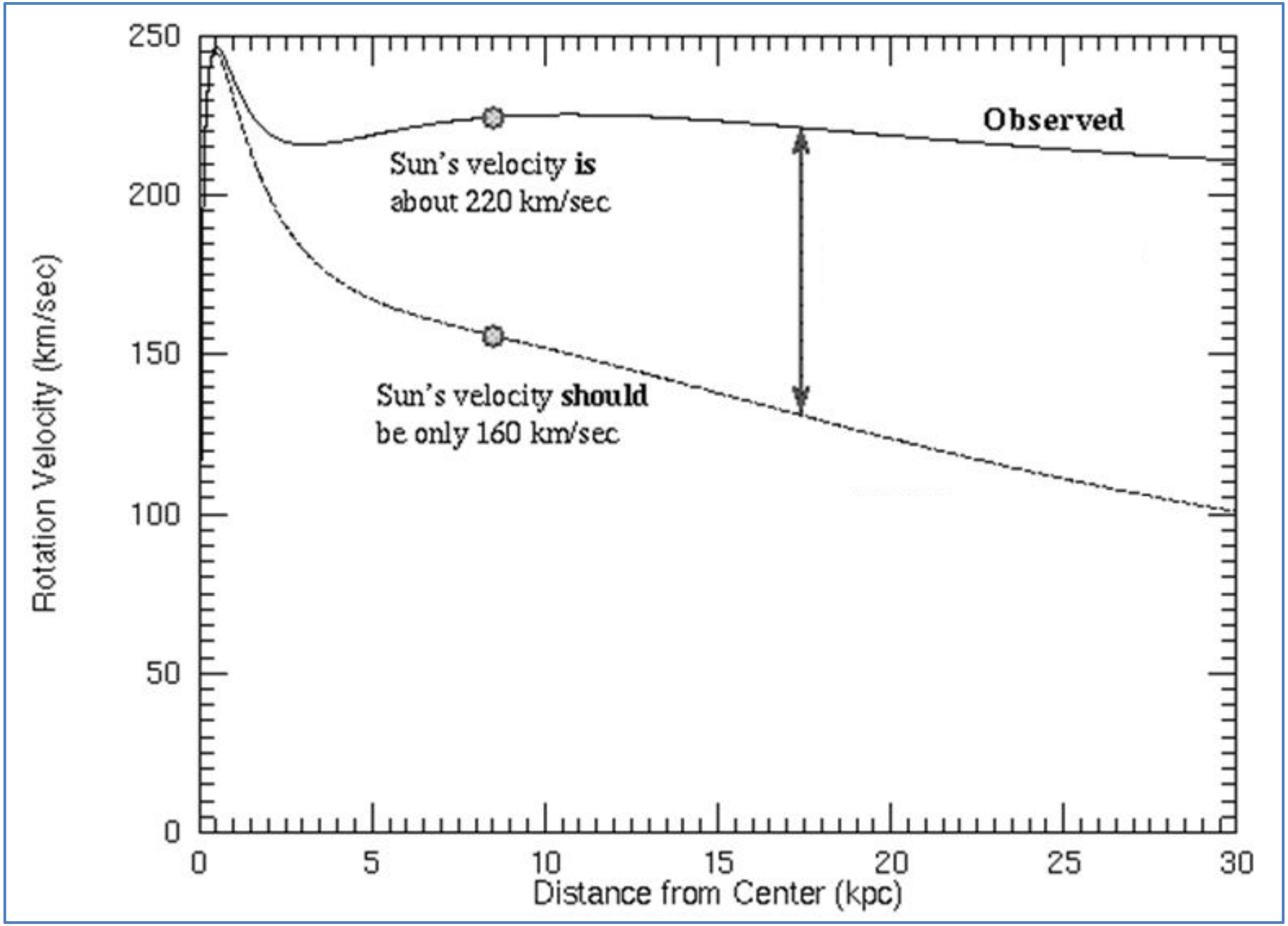
HW9 due now (HW10 available next week)

Ch. 19.7, 21.0-3 today, Ch. 20 for Tuesday

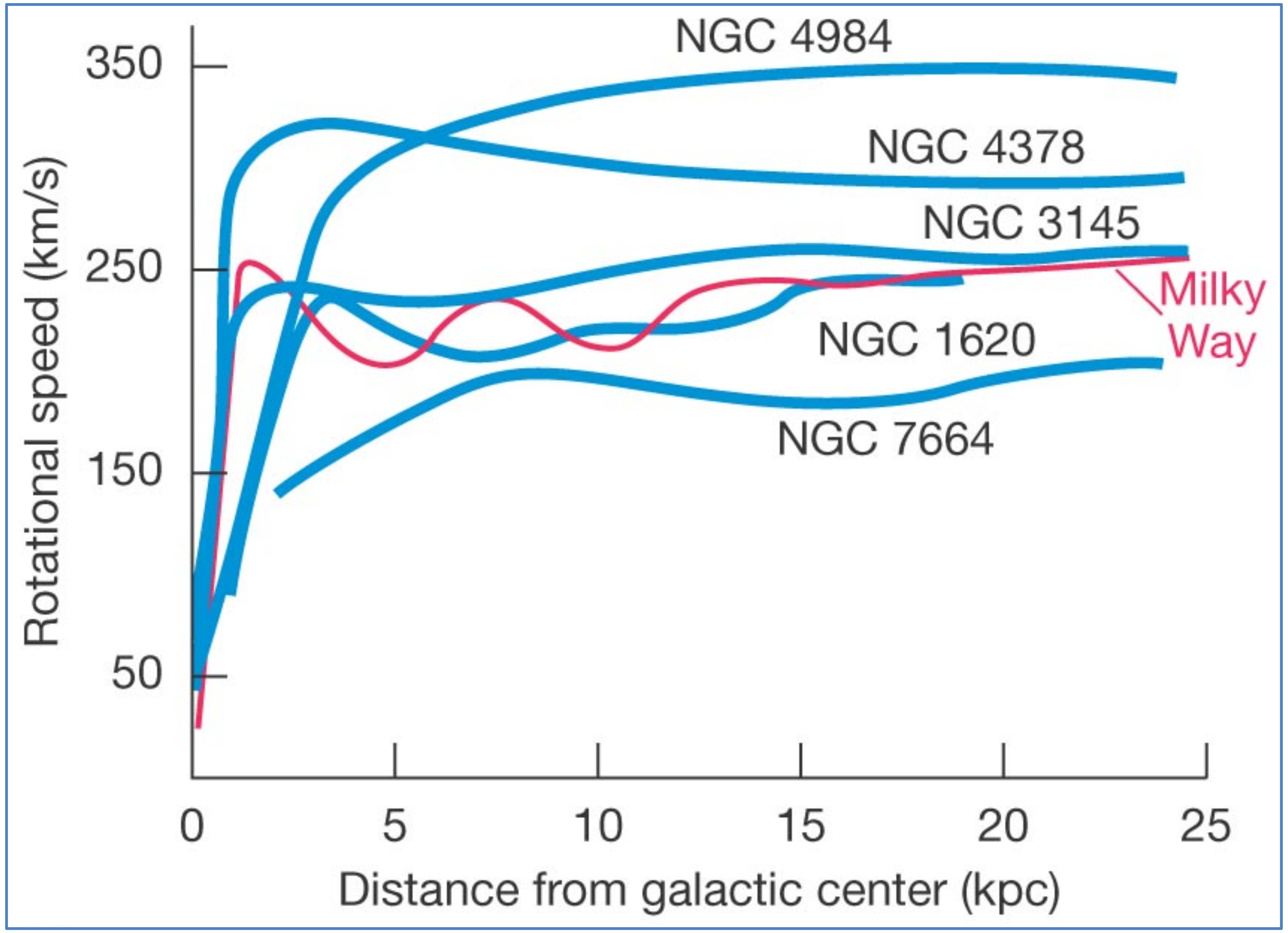
Midterm 2 next Thursday

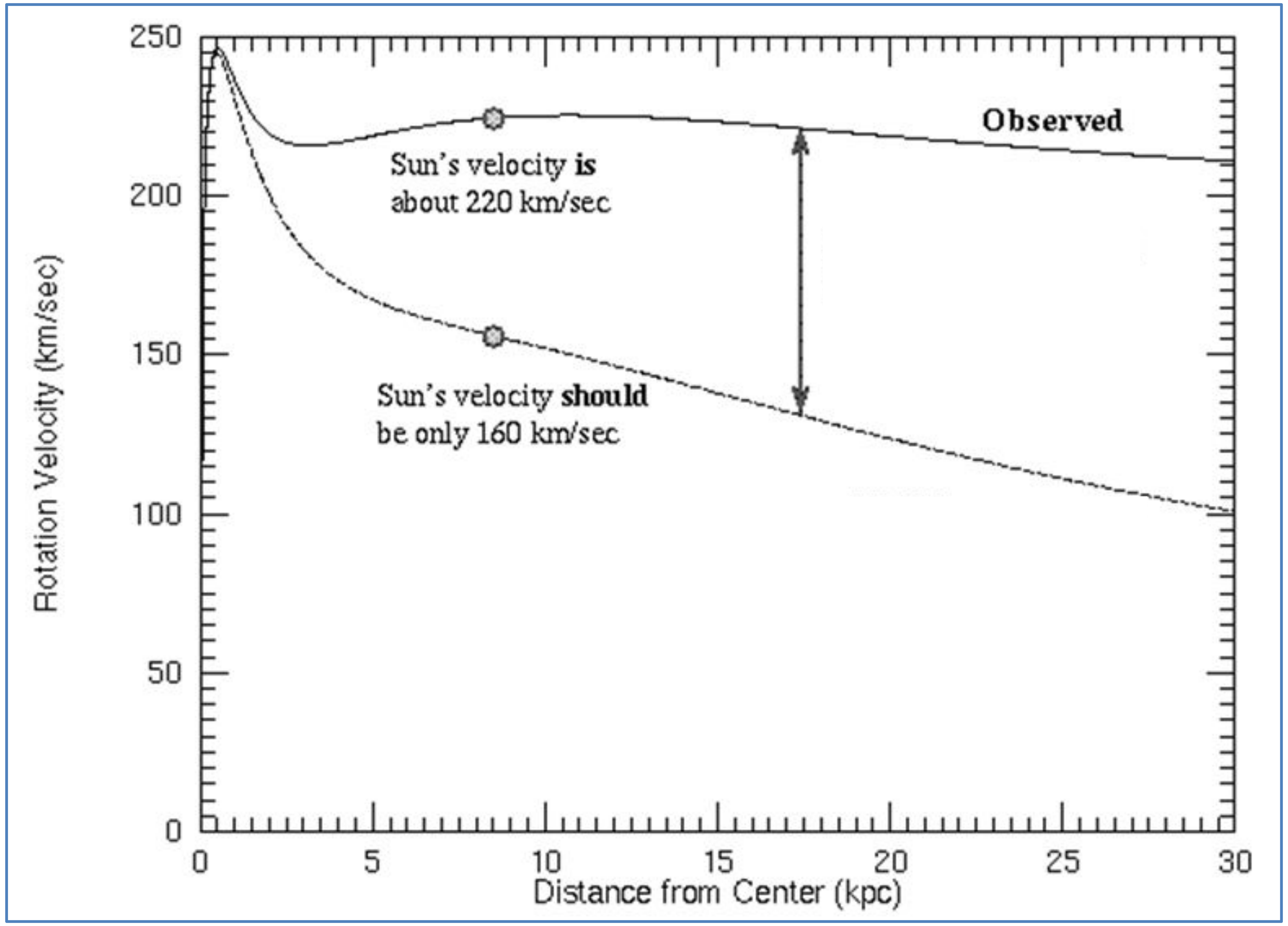


250
200
150
100
50
0
Rotation Velocity (km/sec)
Sun's velocity **should**
be only 160 km/sec
0
5
10
15
20
25
30
Distance from Center (kpc)


Observed
Sun's velocity **is** about 220 km/sec
Sun's velocity **should** be only 160 km/sec
Rotation Velocity (km/sec)
Distance from Center (kpc)
250
200
150
100
50
0
0
5
10
15
20
25
30

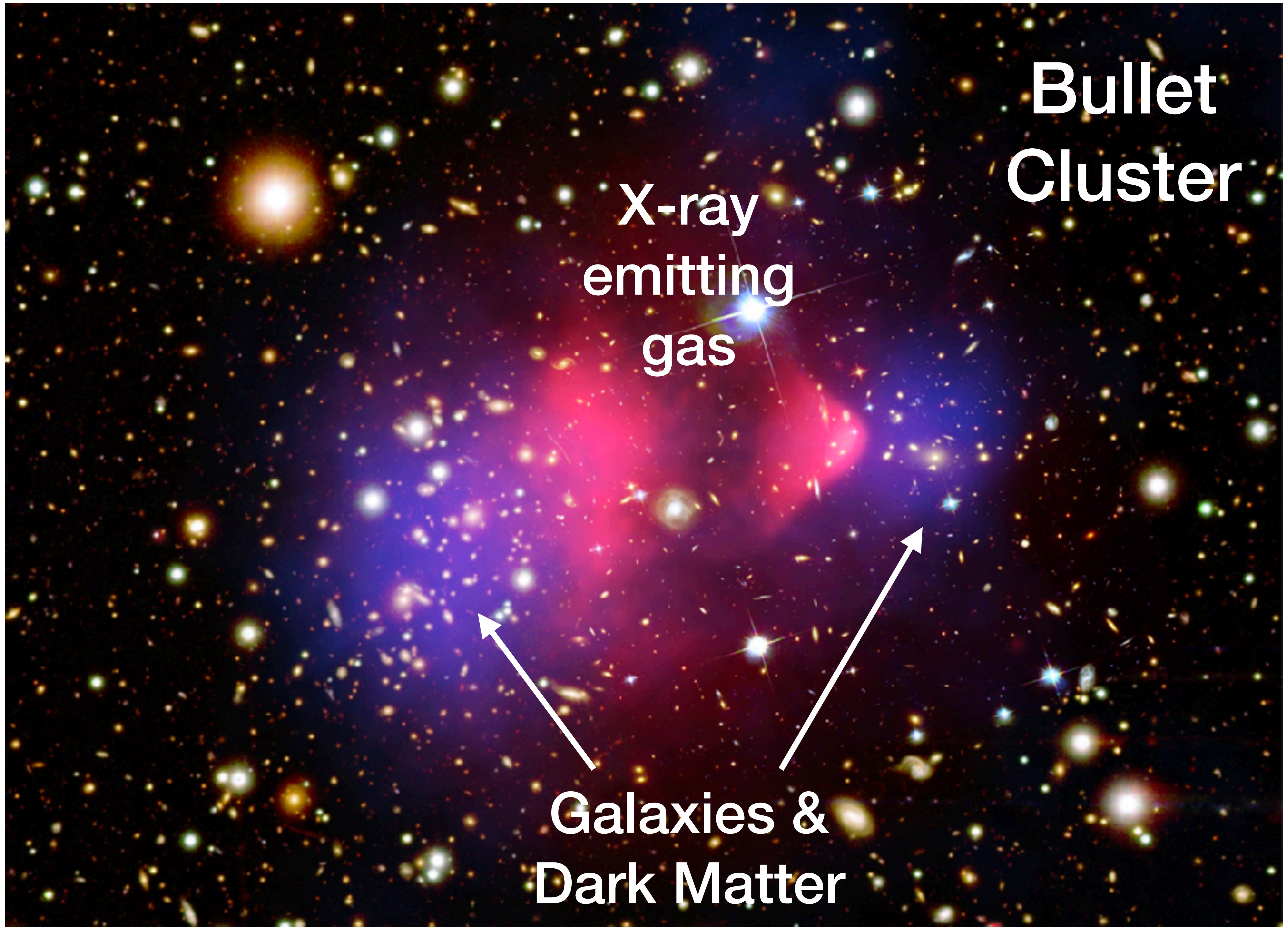
Milky Way is not alone — there is extra, non-luminous matter in galaxies: "dark matter"





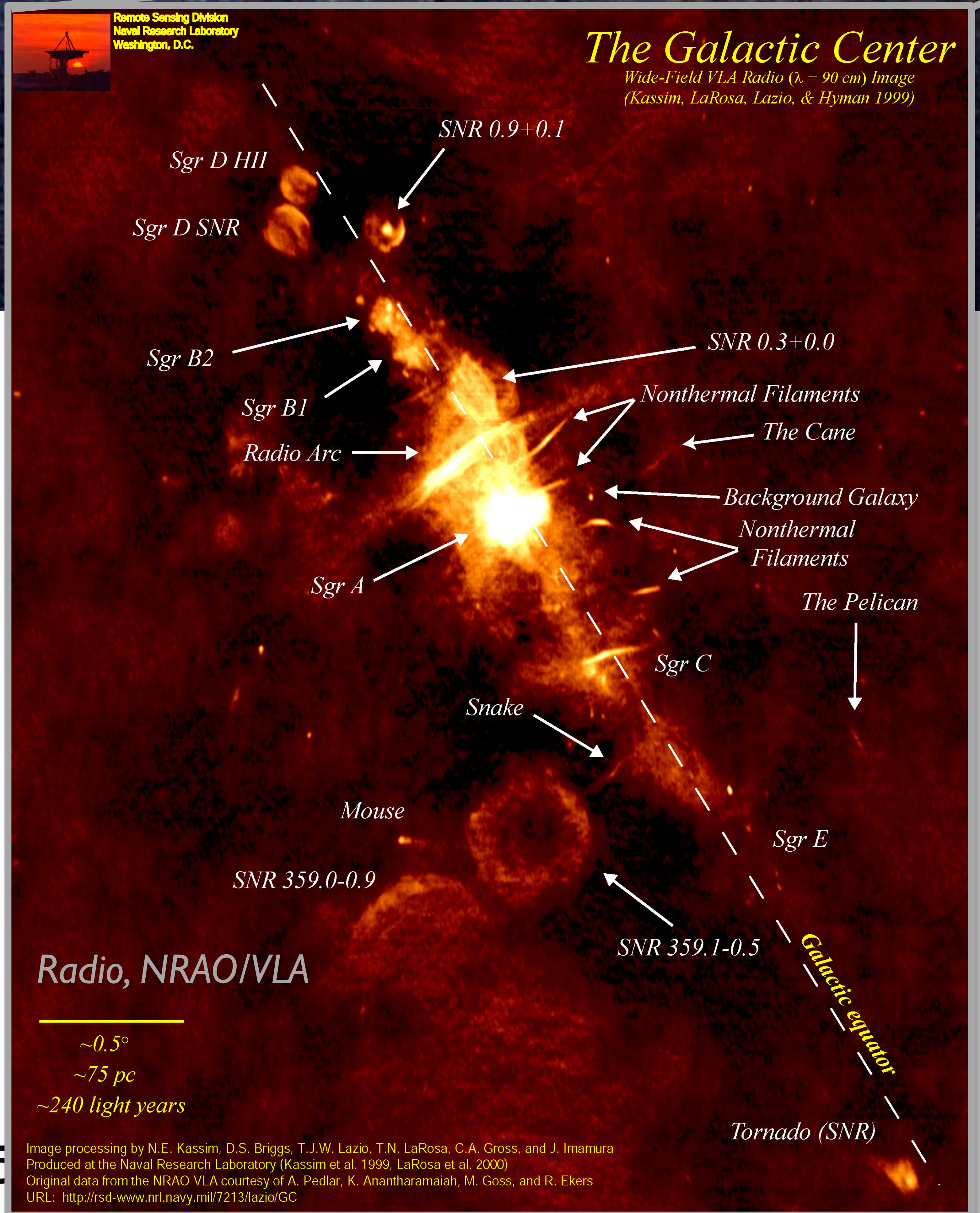

Expected rotation
Observed rotation

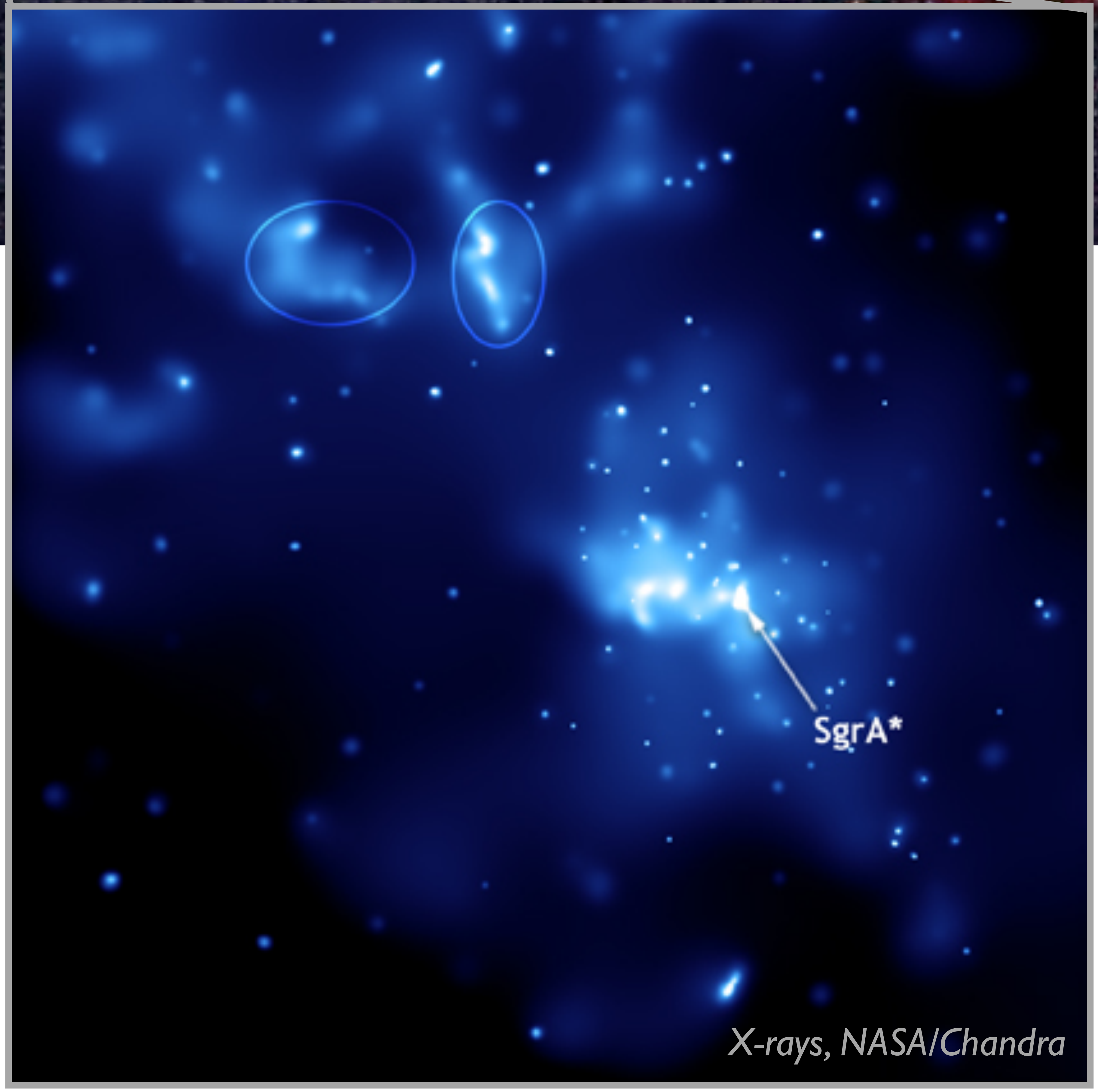
Dark Matter: what is it?



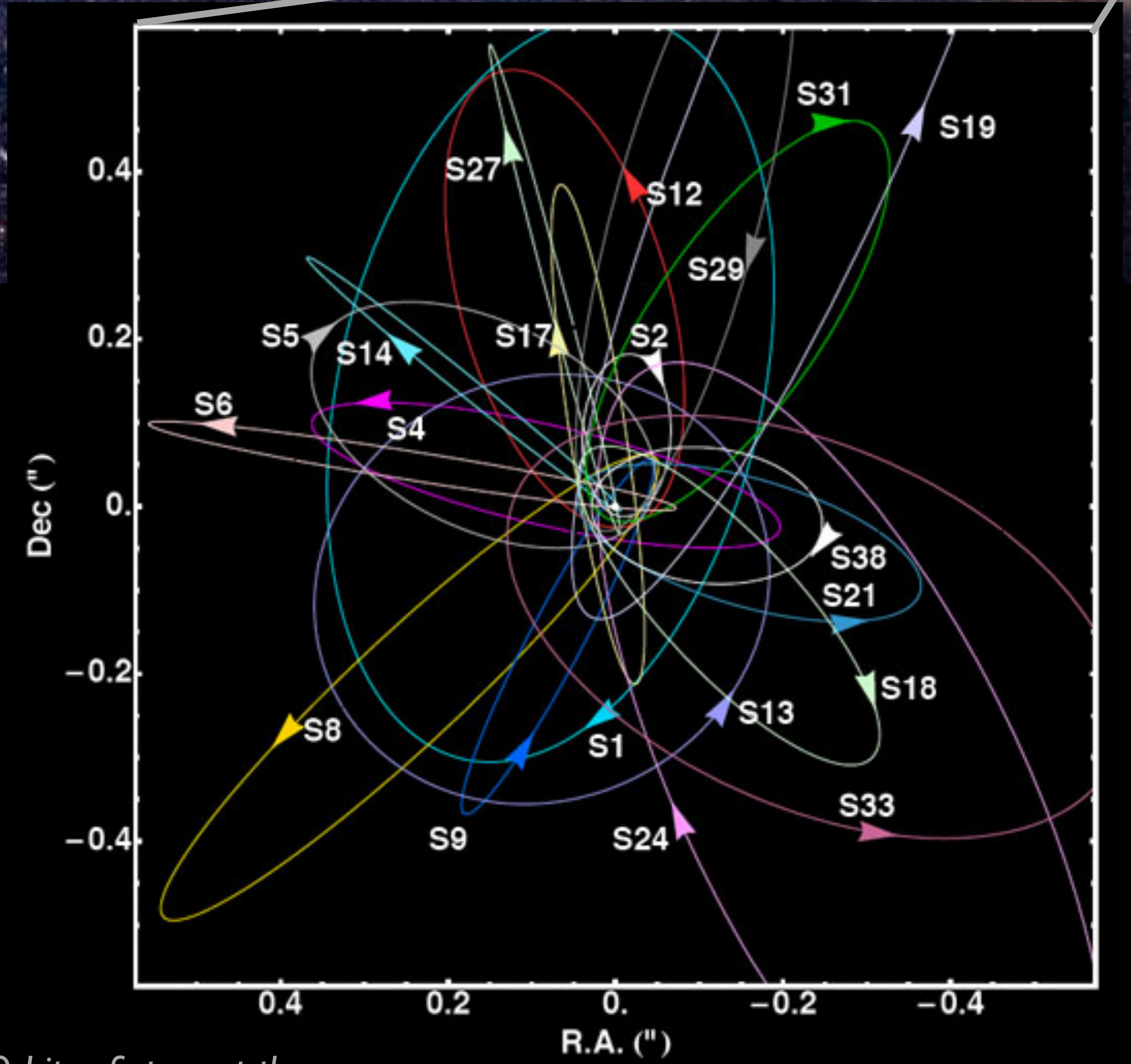
- Neutrinos (like those produced in fusion
    - Have mass, but not enough
    - New kind? Sterile Neutrino
- WIMP (Weakly Interacting Massive Particle)
    - Direct detection searches have failed
    - “WIMP miracle” not miraculous
- MACHO (MAssive Compact Halo Object)
    - WDs, NSs, BHs roaming around
    - Can detect via gravitational lensing - ruled out
- Theorists are clever - can invent other options!
- Modified Gravity (explains galaxy rotation, but…)

The Milky Way's Center

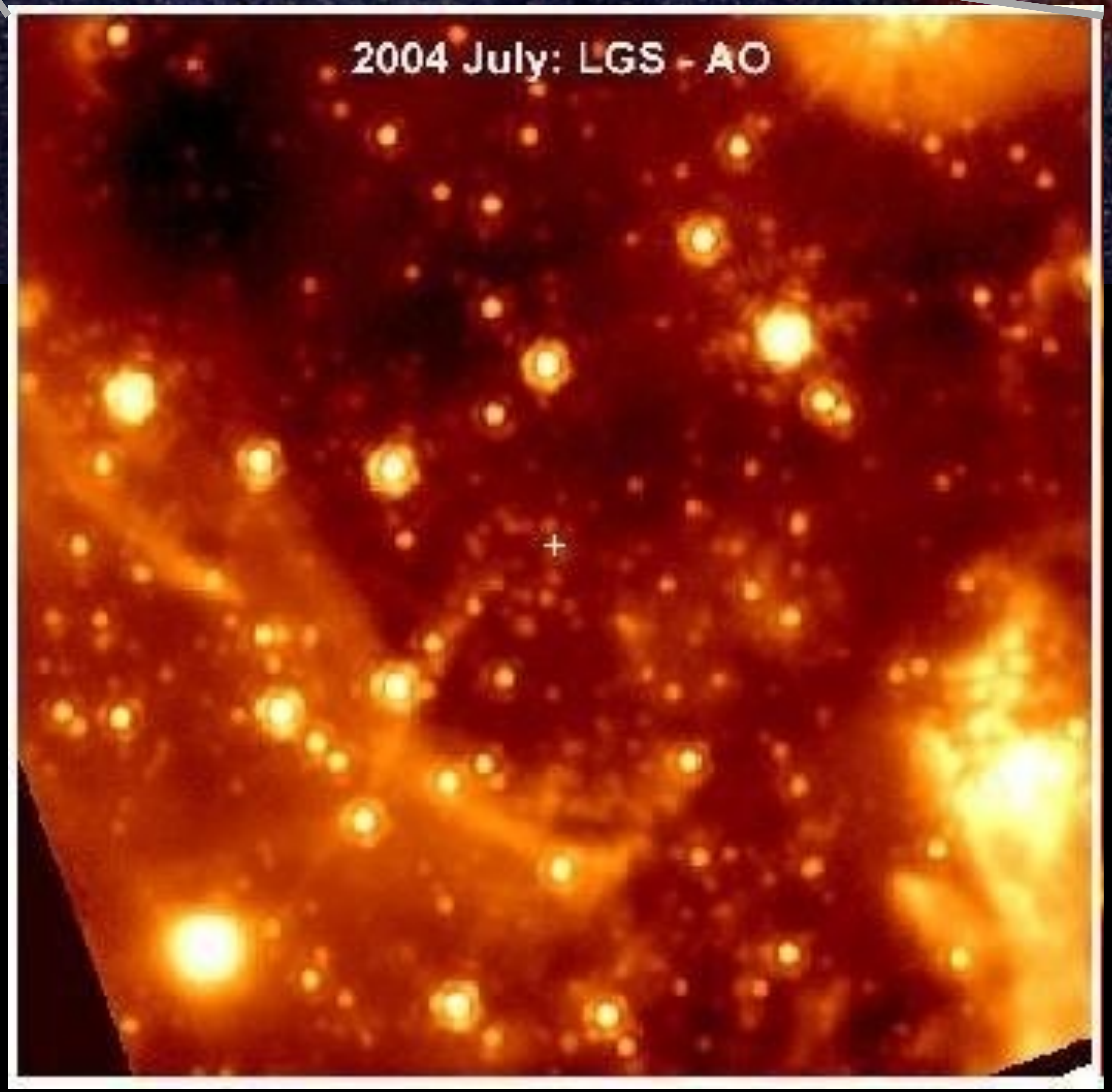




The Milky Way's Center

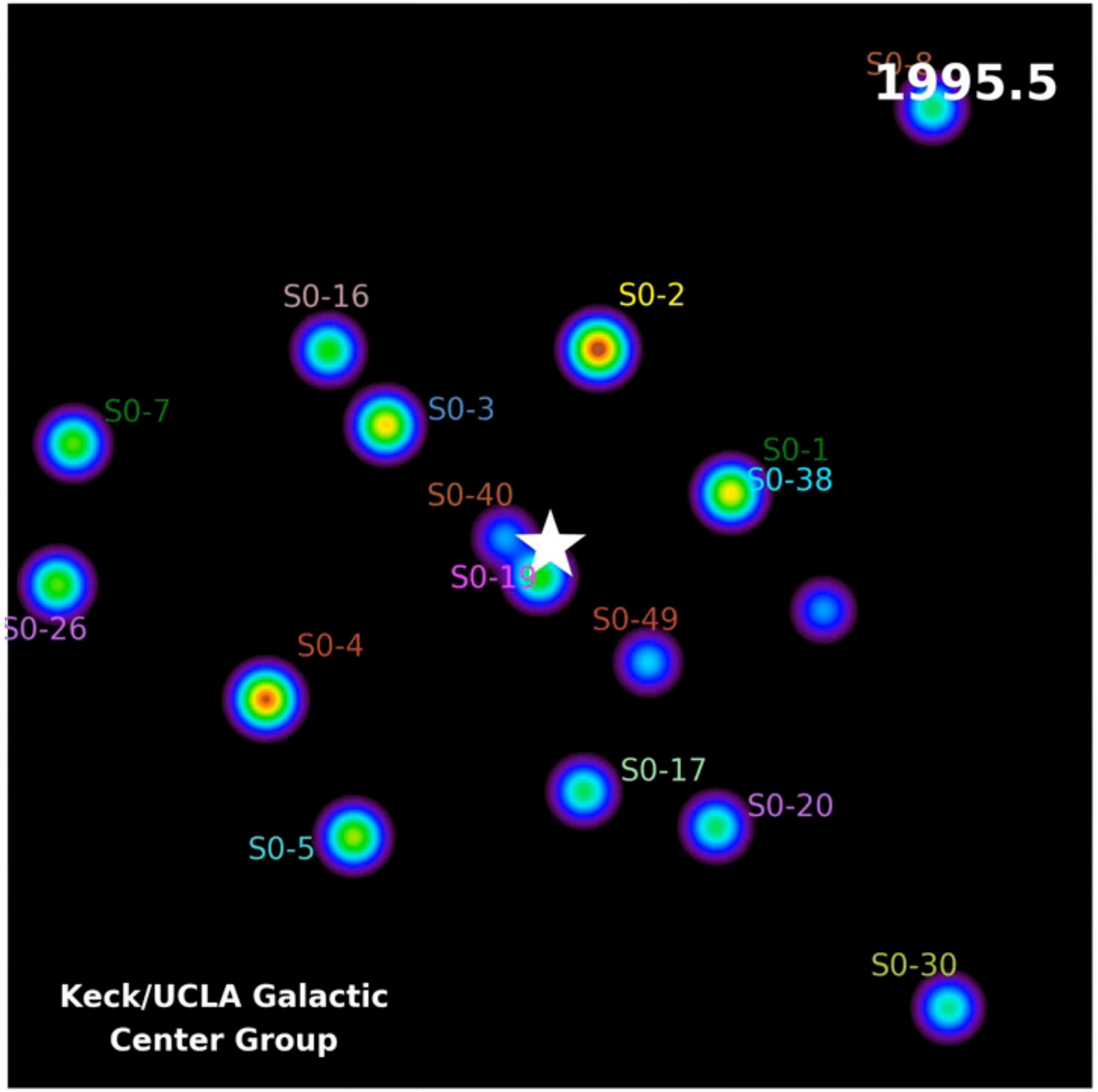


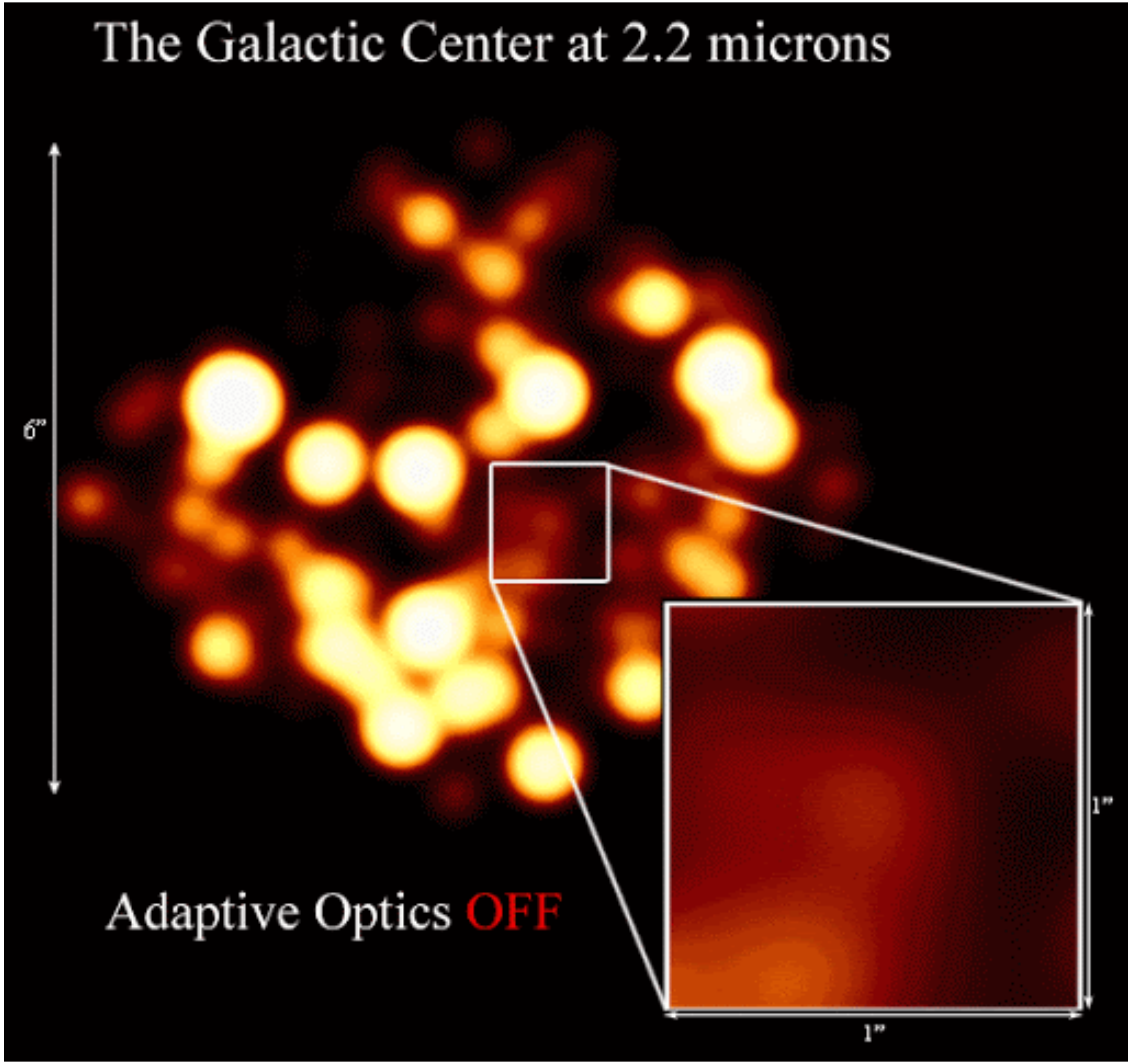
Orbits of stars at the very center of the Galaxy



Infrared image of the central stars (Keck telescope)

2020 Physics Nobel Prize-winning work





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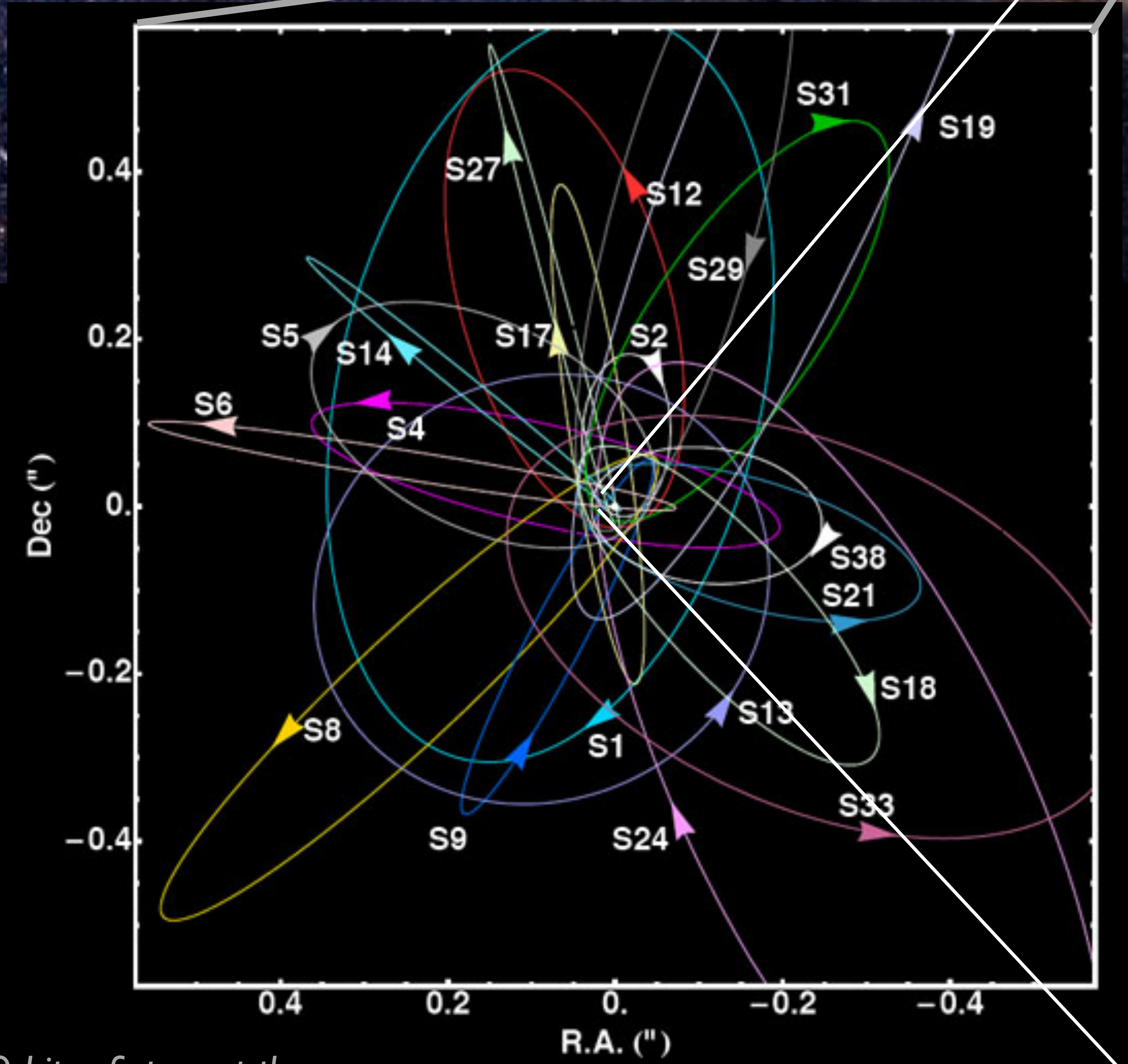
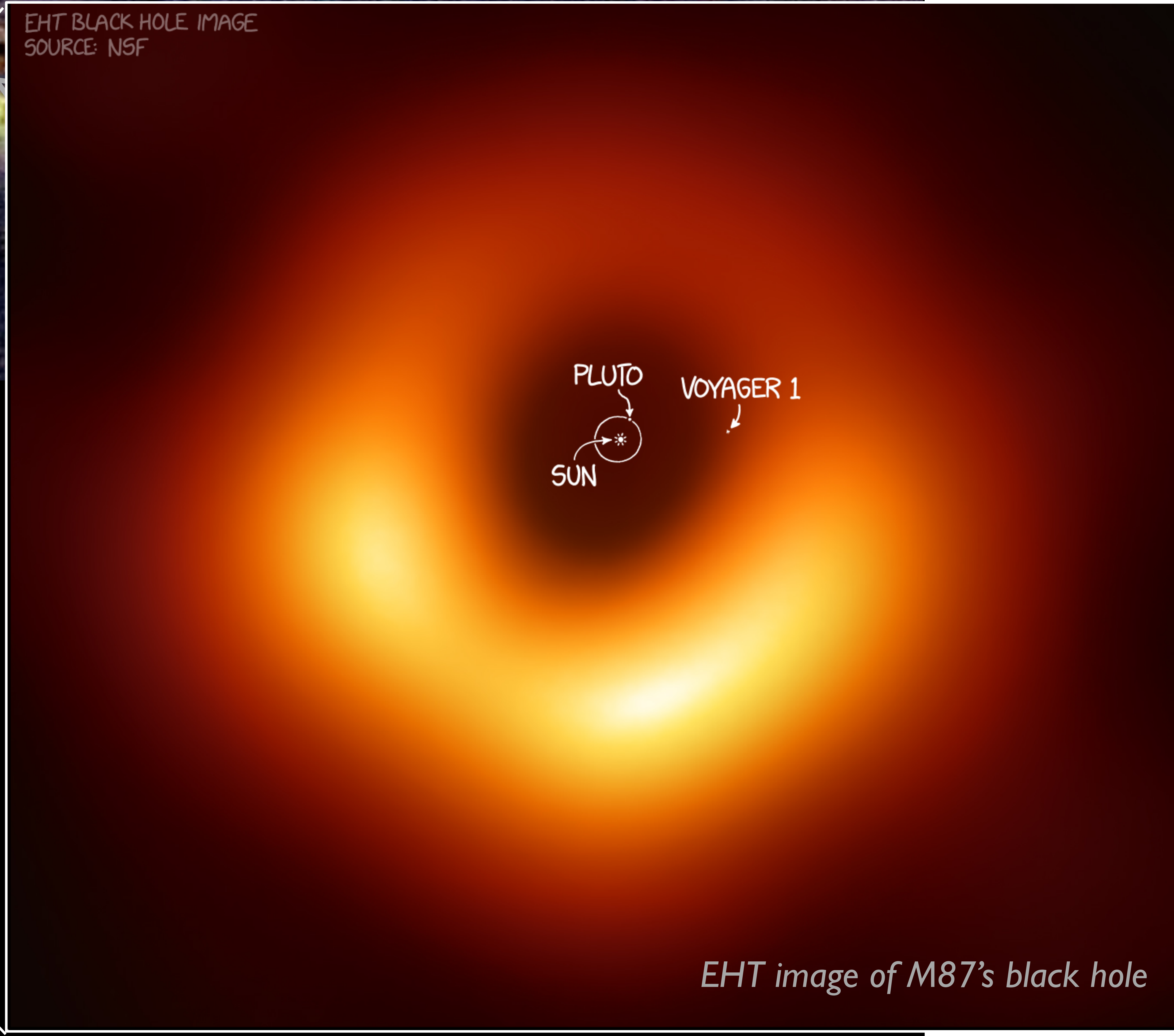
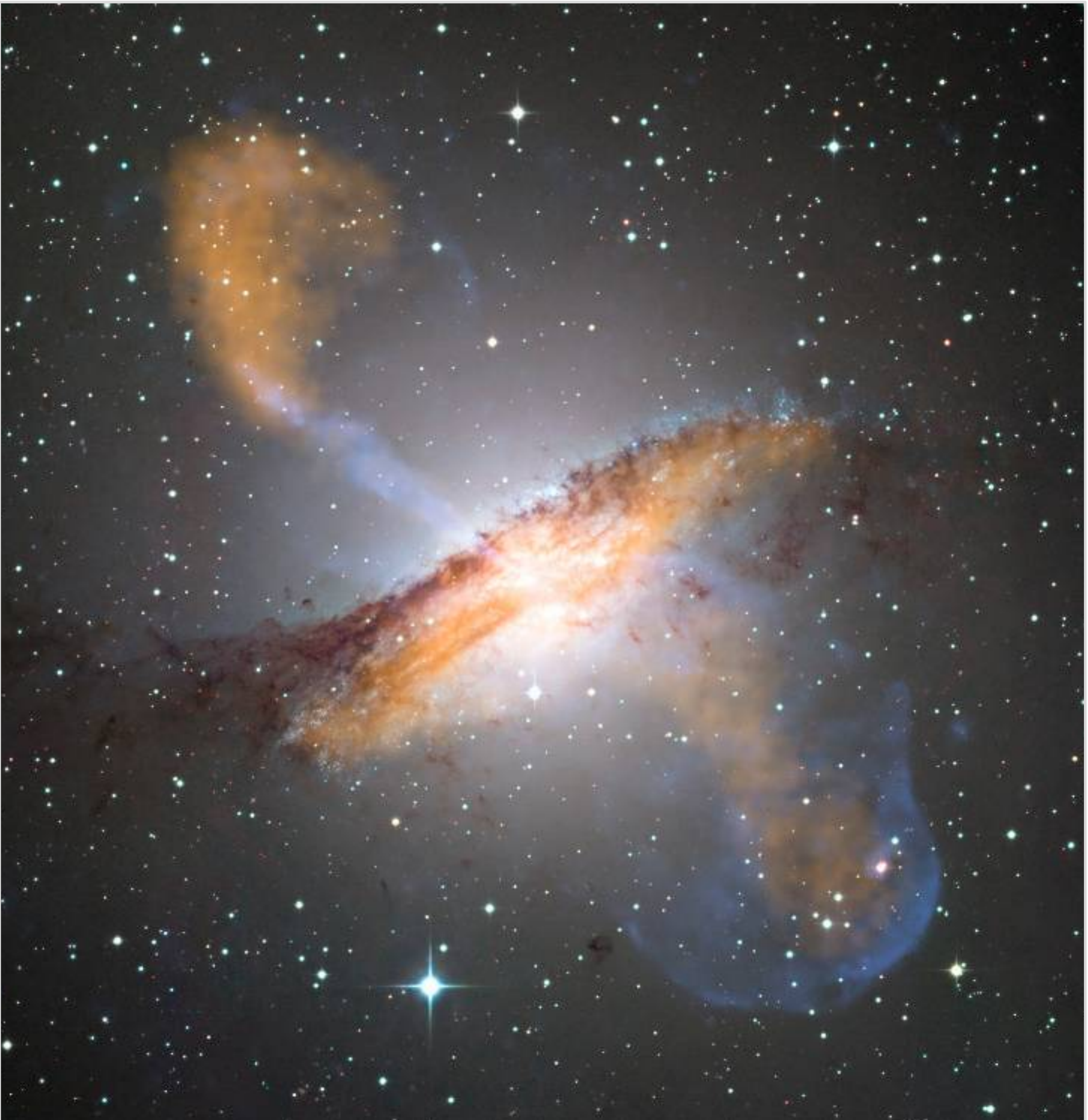


Orbits of stars at the very center of the Galaxy



EHT image of M87's black hole



Active Galaxies

Centaurus A galaxy, in radio / optical / X-ray

What is an “active” galaxy?

In short, it means the galaxy has a lot “nonstellar” emission emanating from its center, which usually dominates the emission in at least one wavelength regime (i.e., radio, optical, X-ray, etc.)

The action occurs within an Active Galactic Nucleus, or AGN.

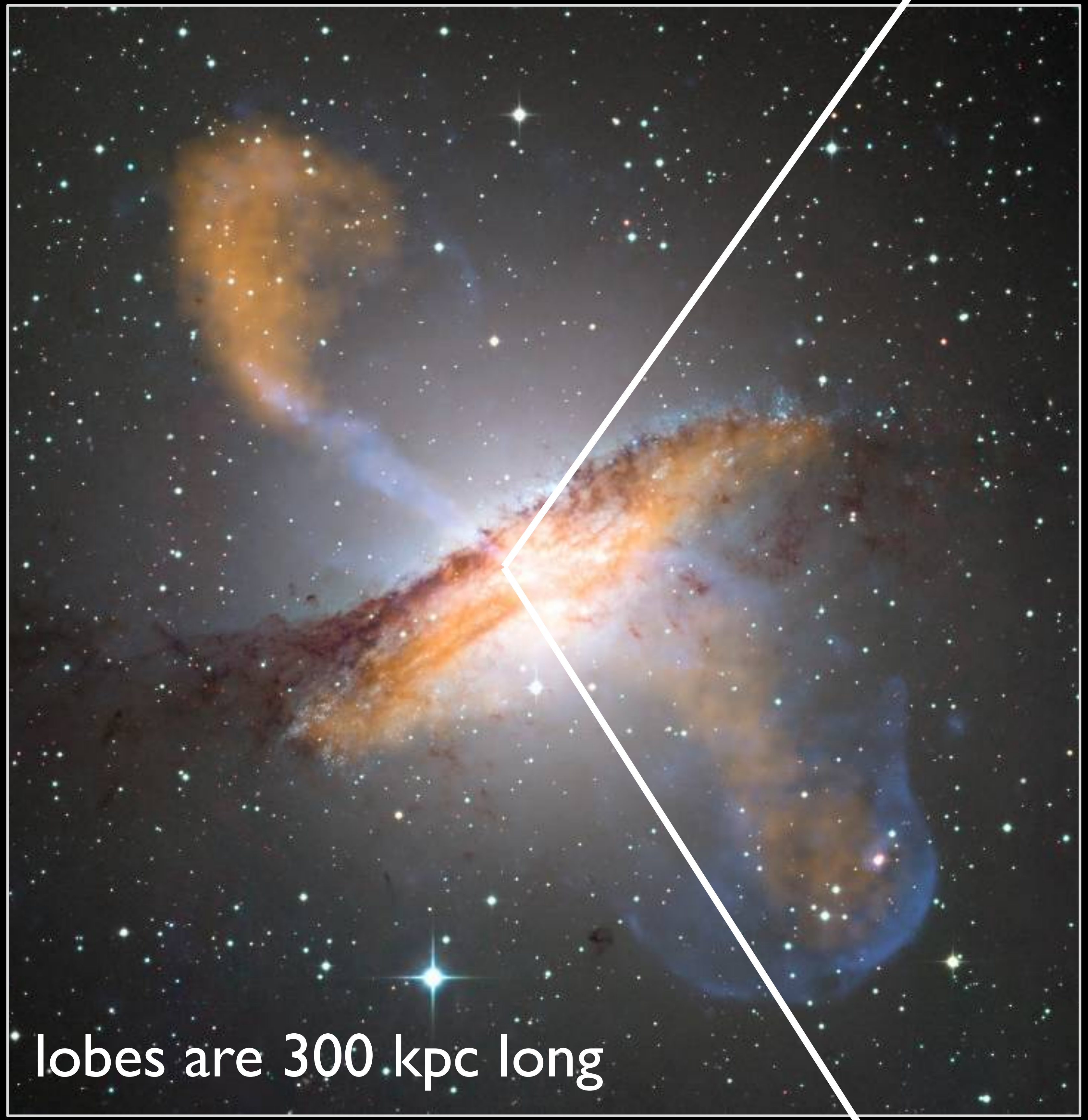
AGN are supermassive (million to billion solar mass) BHs in the centers of galaxies. All massive galaxies have supermassive BHs (SMBHs), whether or not they have AGN.

AGN light at any wavelength is variable on short timescales (minutes to months).

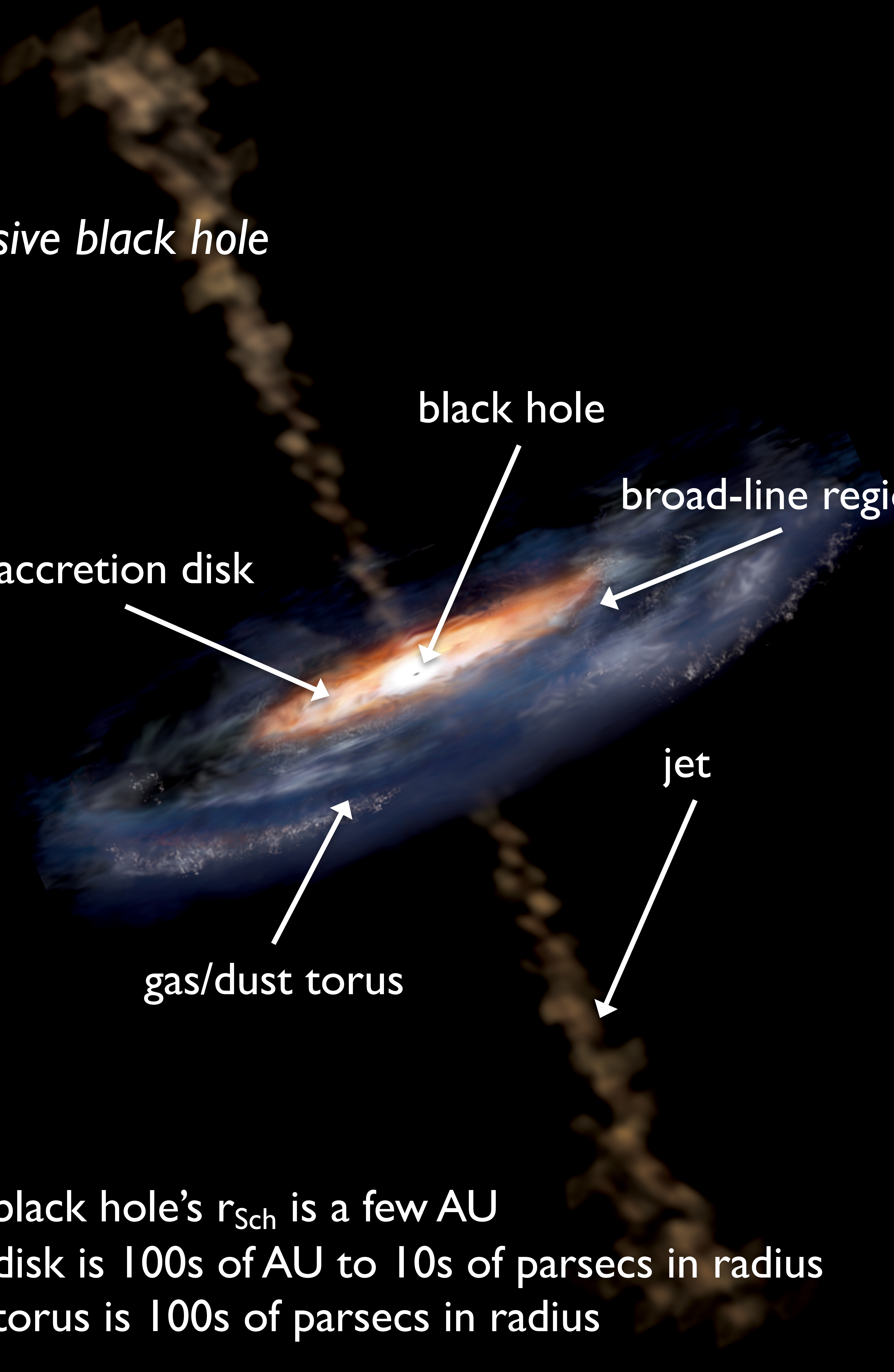
Some AGN have jets that can extend 100s of kpc, even though it originates from a region the size of the solar system.

Active Galaxies

Galaxies with a rapidly accreting supermassive black hole



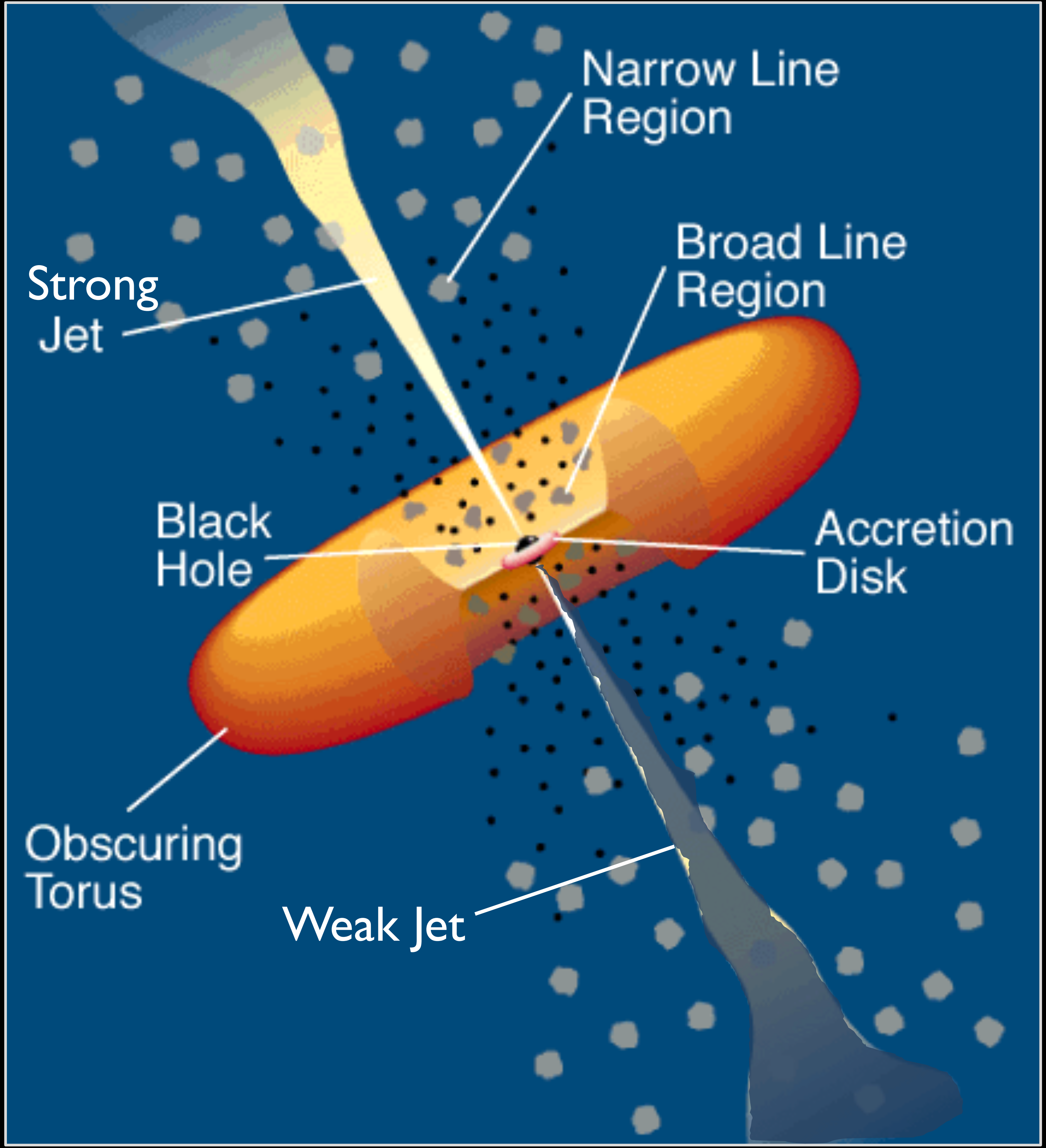
Centaurus A, in optical and radio light



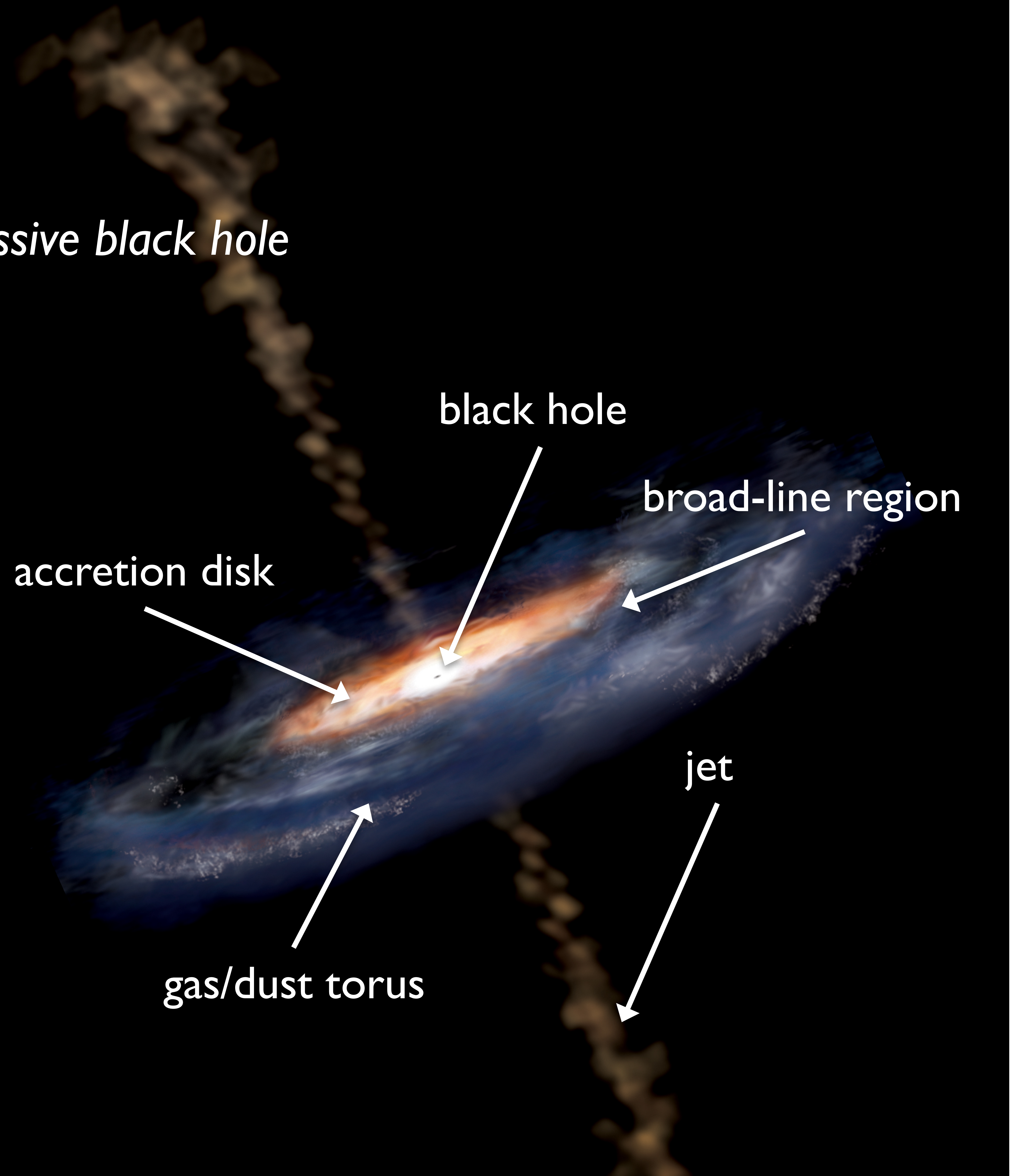
black hole's r_{Sch} is a few AU
disk is 100s of AU to 10s of parsecs in radius
torus is 100s of parsecs in radius

Active Galaxies

Galaxies with a rapidly accreting supermassive black hole



AGN schematic



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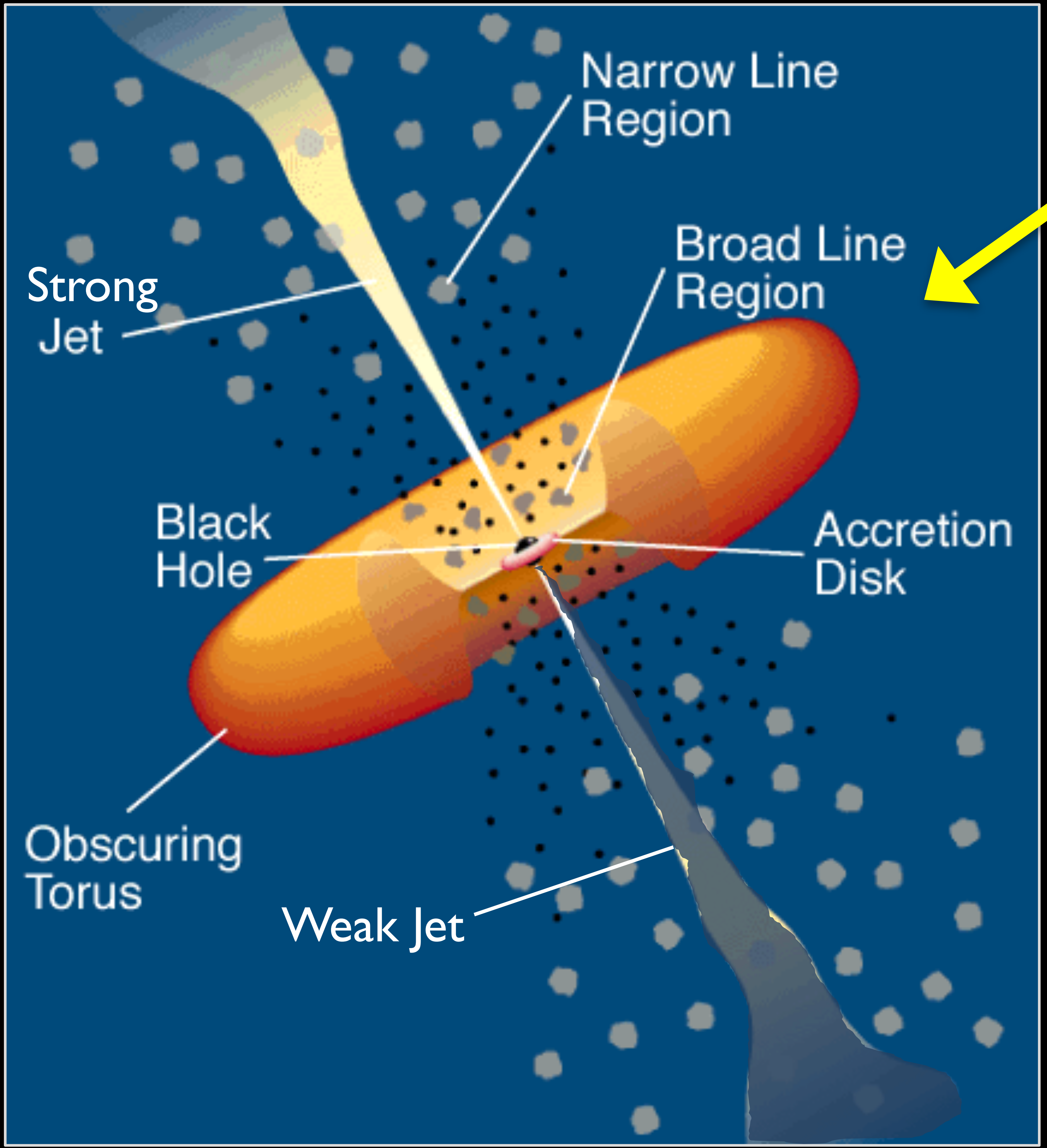
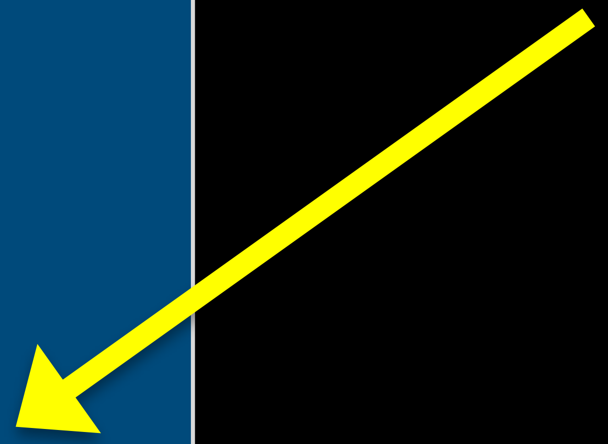
Active Galaxy Classification

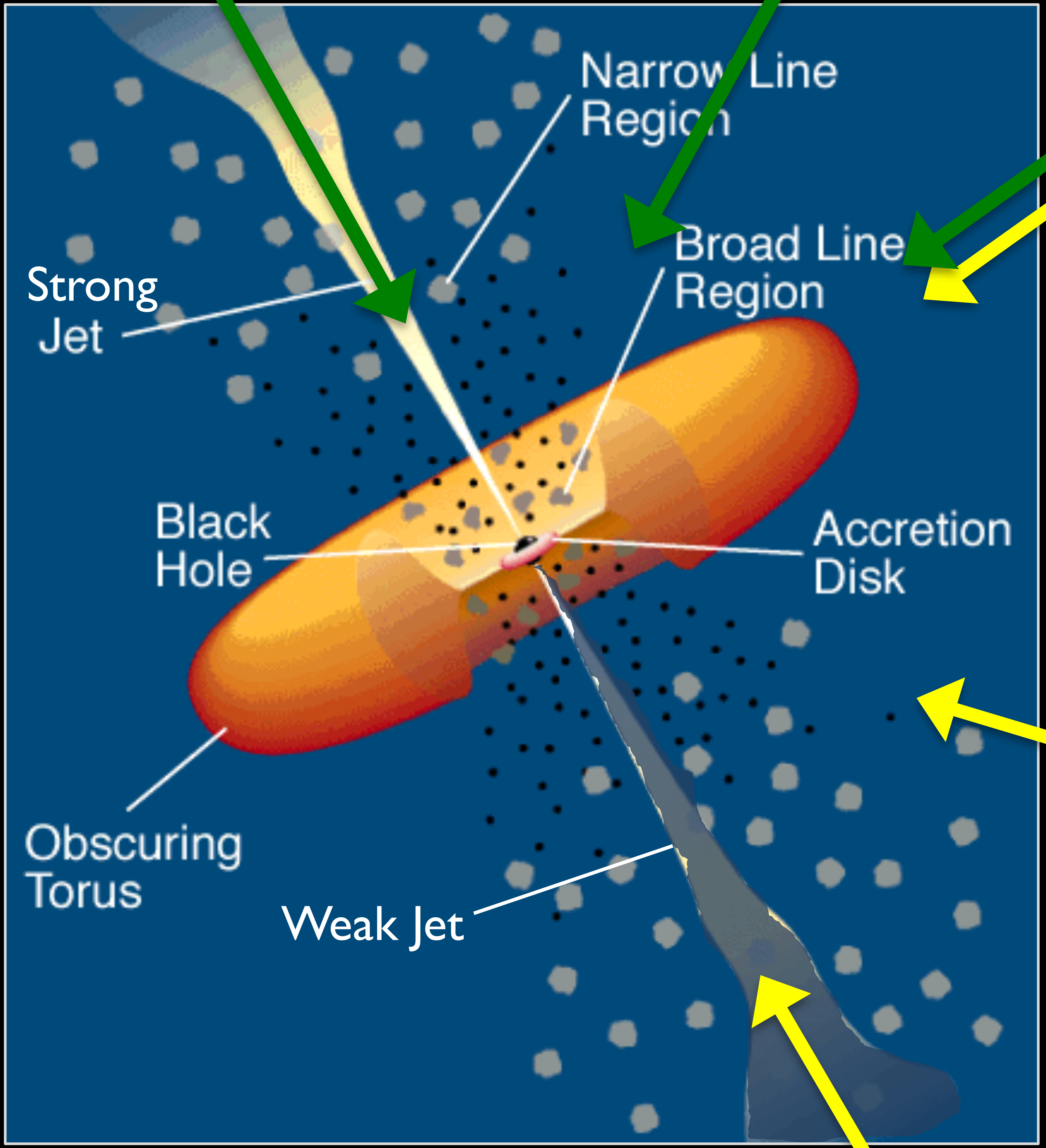


AGN schematic



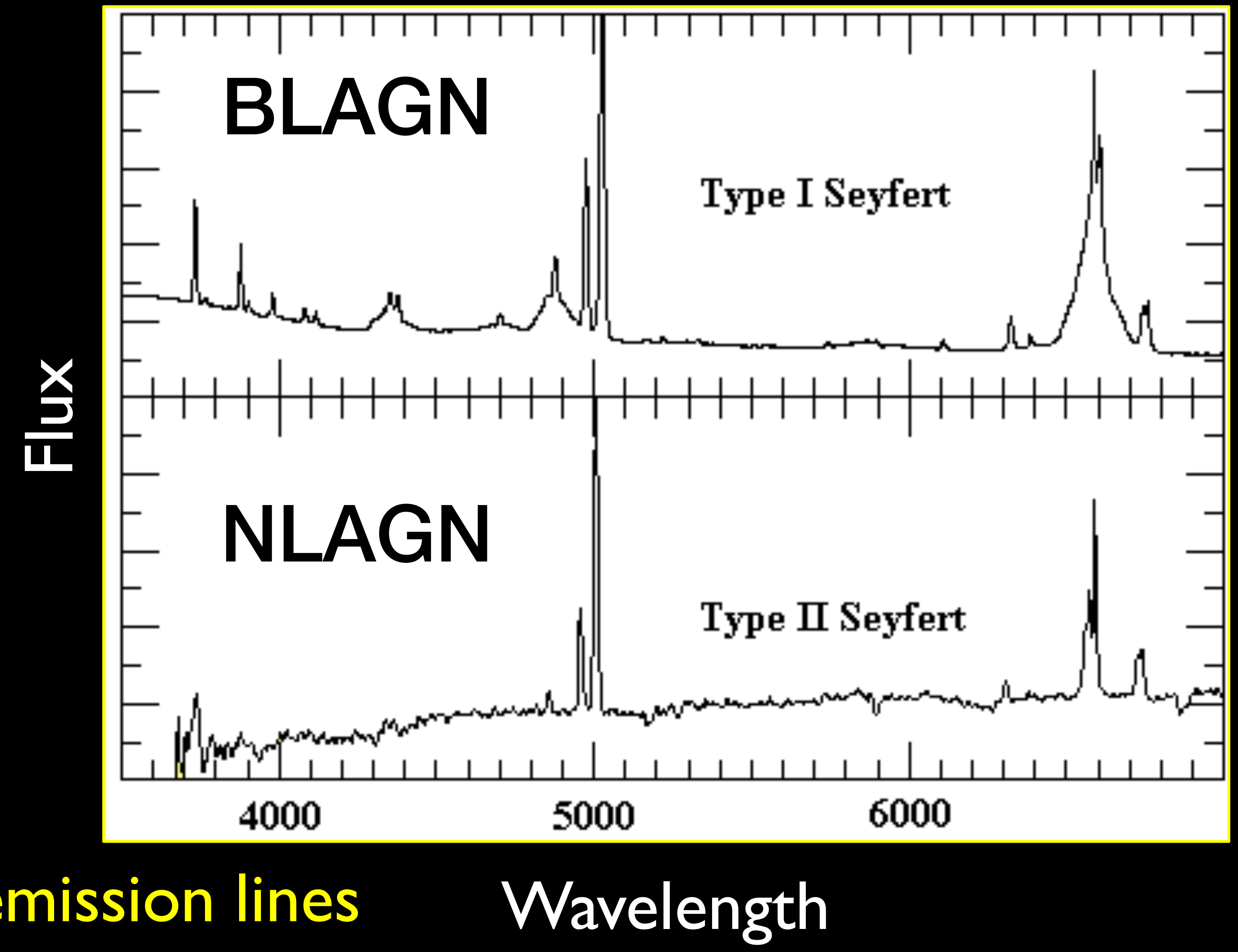
Active Galaxy Classification

"Radio-loud" versions of Seyferts and BL Lac objects



AGN schematic

Seyfert 2
- narrow emission lines



Seyfert 1
- broad emission lines
- narrow emission lines

BL Lac
- strong continuum
- few (or zero) emission lines

Quasar: high-luminosity version of a Seyfert

How can something so small outshine an entire galaxy?

$$\Delta E = U_0 - U_f = -\frac{GM_{\rm BH}m}{r} + \frac{GM_{\rm BH}m}{r_{\rm Sch}} = KE$$

Since $r_{\rm Sch} = \frac{2GM_{\rm BH}}{c^2}$, $KE \approx \frac{1}{2}mc^2$

If a particle falls straight into a BH from a large distance, this *KE* adds to its mass.
Is that what typically happens?

In general, much of this energy is radiated away in an accretion disk as the particle converts its change in potential energy into light.

$$\Delta E_{\rm phot} = \eta mc^2$$

↑ efficiency, ~0.1

$$L = \eta \dot{M} c^2$$

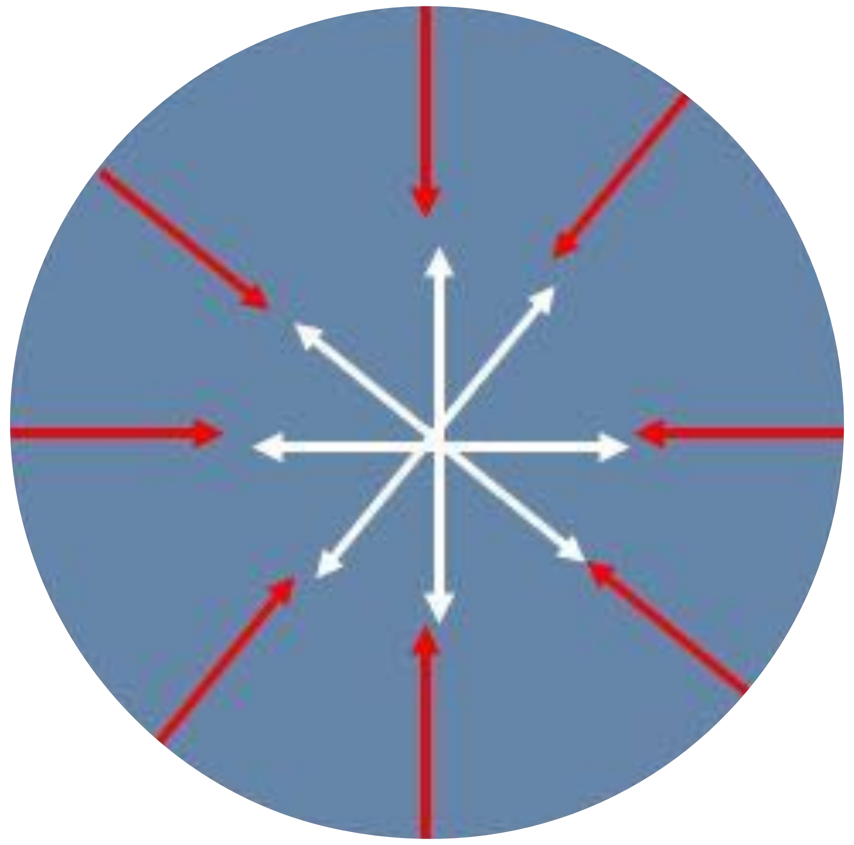
↑ Mass accretion rate

But, there's a limit to how bright (or how quickly material is accreted) an AGN can be.

Consider a proton and an electron

Radiative Force

$$F_{\rm rad} = \sigma_e F_p$$
$$= \sigma_e \frac{F}{c} = \frac{\sigma_e}{c} \frac{L}{4\pi r^2}$$



Gravitational Force

$$F_g = -\frac{G M_{\rm BH}(m_p + m_e)}{r^2}$$
$$\approx -\frac{G M_{\rm BH} m_p}{r^2}$$

Light carries momentum: $p = \frac{E}{c}$

Transfers momentum to electron when they collide — #photons intersecting electron given by the flux *F*

When forces equal, accretion stops, luminosity stops

$$L_E = \frac{4\pi G m_p c}{\sigma_e} M_{\rm BH}$$
$$= 3.3 \times 10^{12}\ L_\odot \left(\frac{M_{\rm BH}}{10^8\ M_\odot}\right)$$

Eddington Luminosity