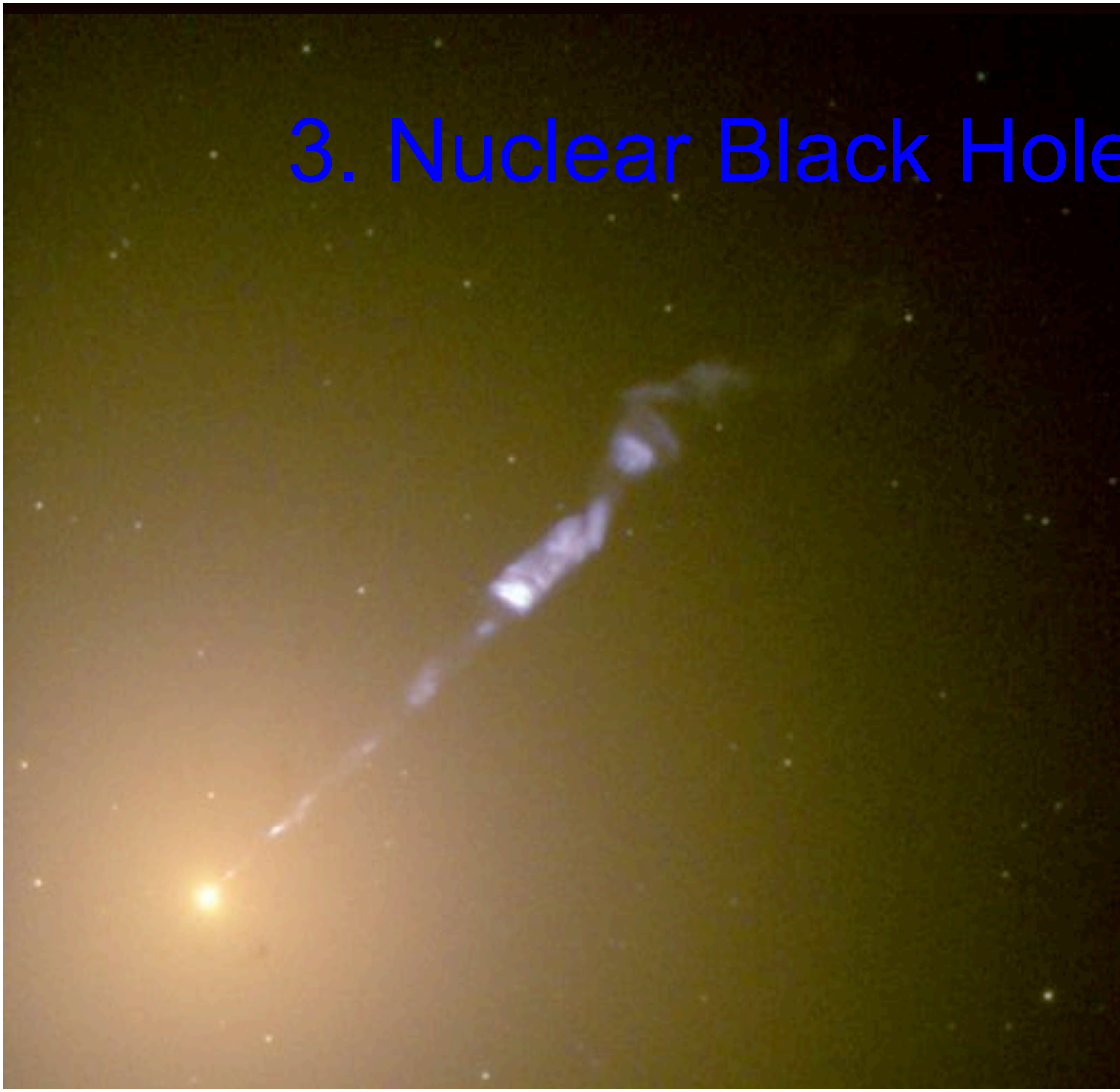
3. Nuclear Black Holes



Some Background [AT 16.2]

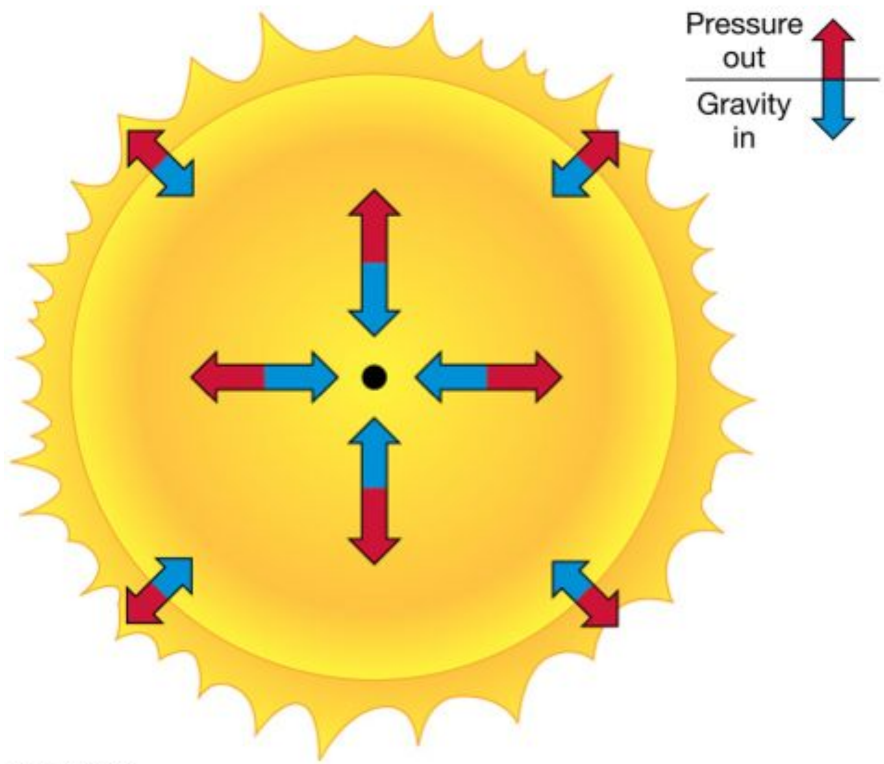
- Why does sun not collapse under its own gravity?

Some Background [AT 16.2]

- Why does sun not collapse under its own gravity?

In equilibrium, inward gravitational force must be balanced by outward pressure from heat generated by nuclear reactions.

"Hydrostatic Equilibrium"



Star runs out of fuel – what happens?

Star runs out of fuel – what happens?

Mass of core	Outcome	Size

Mass of core	Outcome	Size
$< 1.4\ M_\odot$	White Dwarf	10^4 km
$1.4\text{-}3\ M_\odot$	Neutron Star	10 km
$> 3\ M_\odot$	Black Hole	A few km

N.B. This refers to core mass of star – the envelope is usually blown off!

N.B. So far as we know, the star will stay in this end state forever!

AT 22.5-22.8

Three Properties of a Black Hole

1. Mass
2. Charge
3. Spin

"A black hole grows no hair."
John Wheeler

Inside a Black Hole

?

Schwarzschild Radius

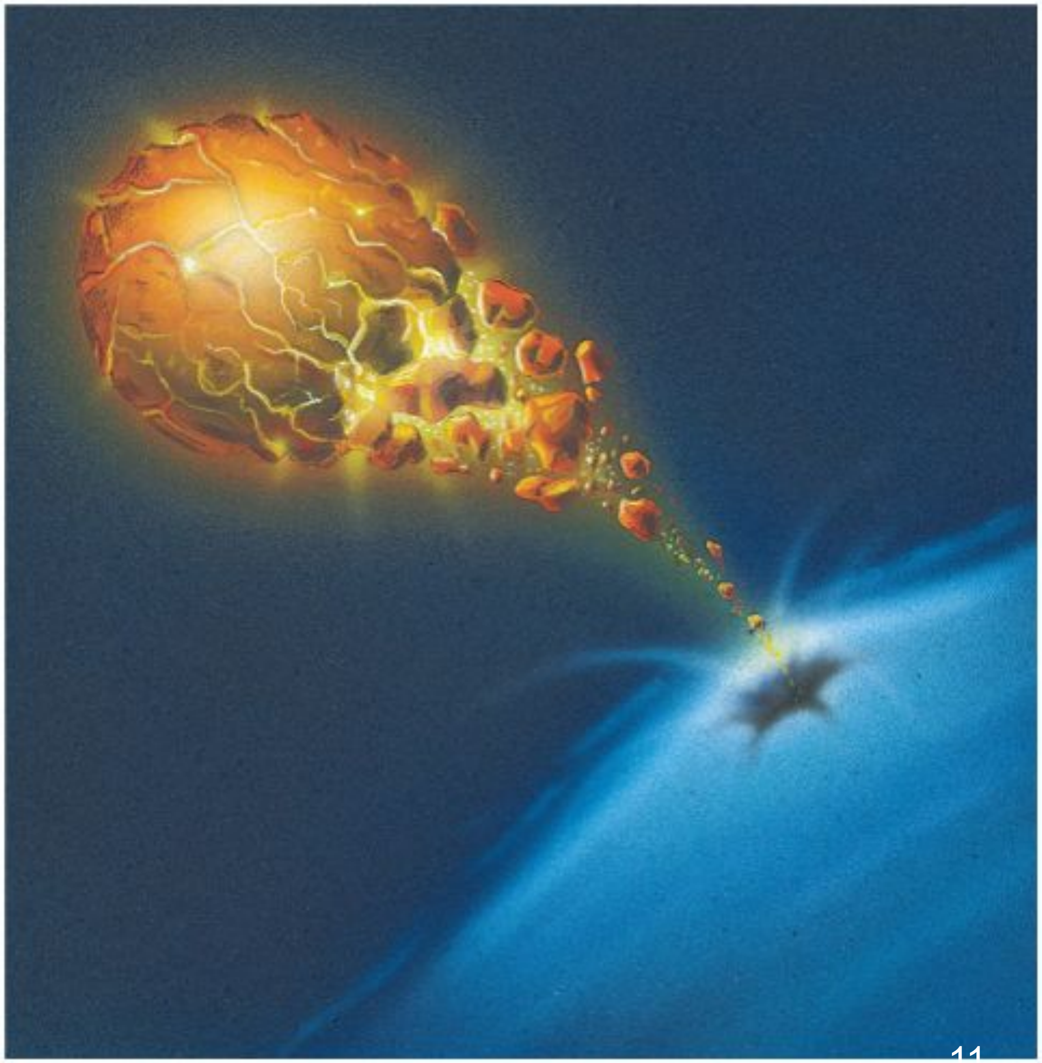
- Radius of the “event horizon”, within which nothing can escape the black hole, not even light.

$$\mathbf{R_{\text{schwarz}} = 3\ M}$$

[R in km] [M in $M_\odot$]

- The Earth’s Schwarzschild radius is about a centimeter; the Sun’s is about 3 km.

Effects Near Black Holes

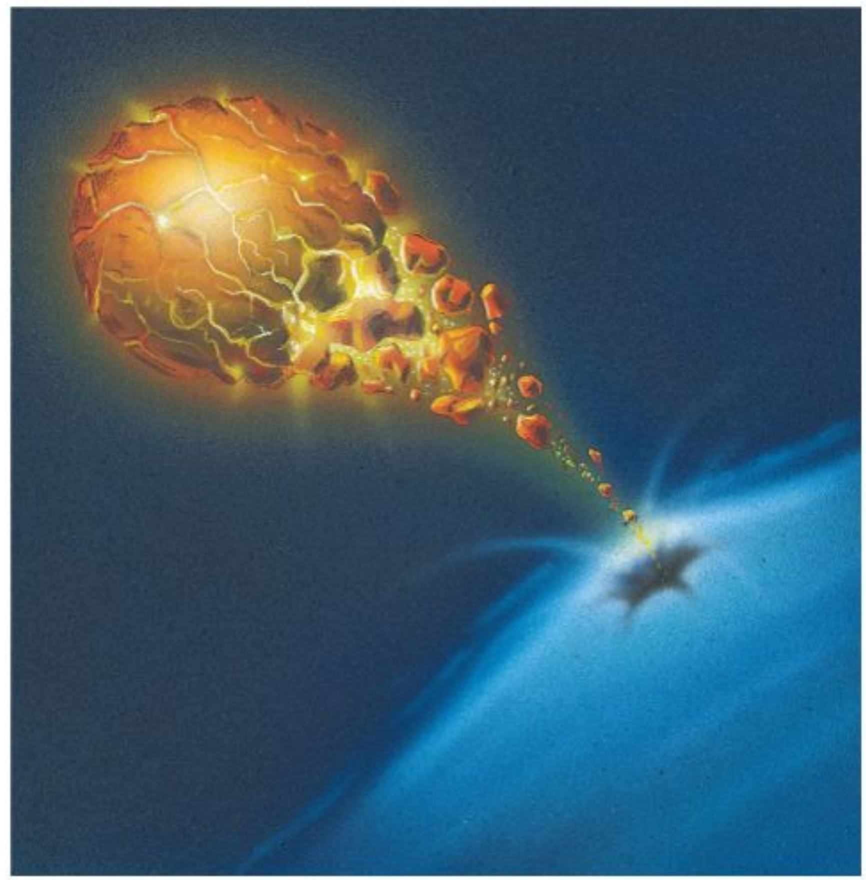


Effects Near Black Holes

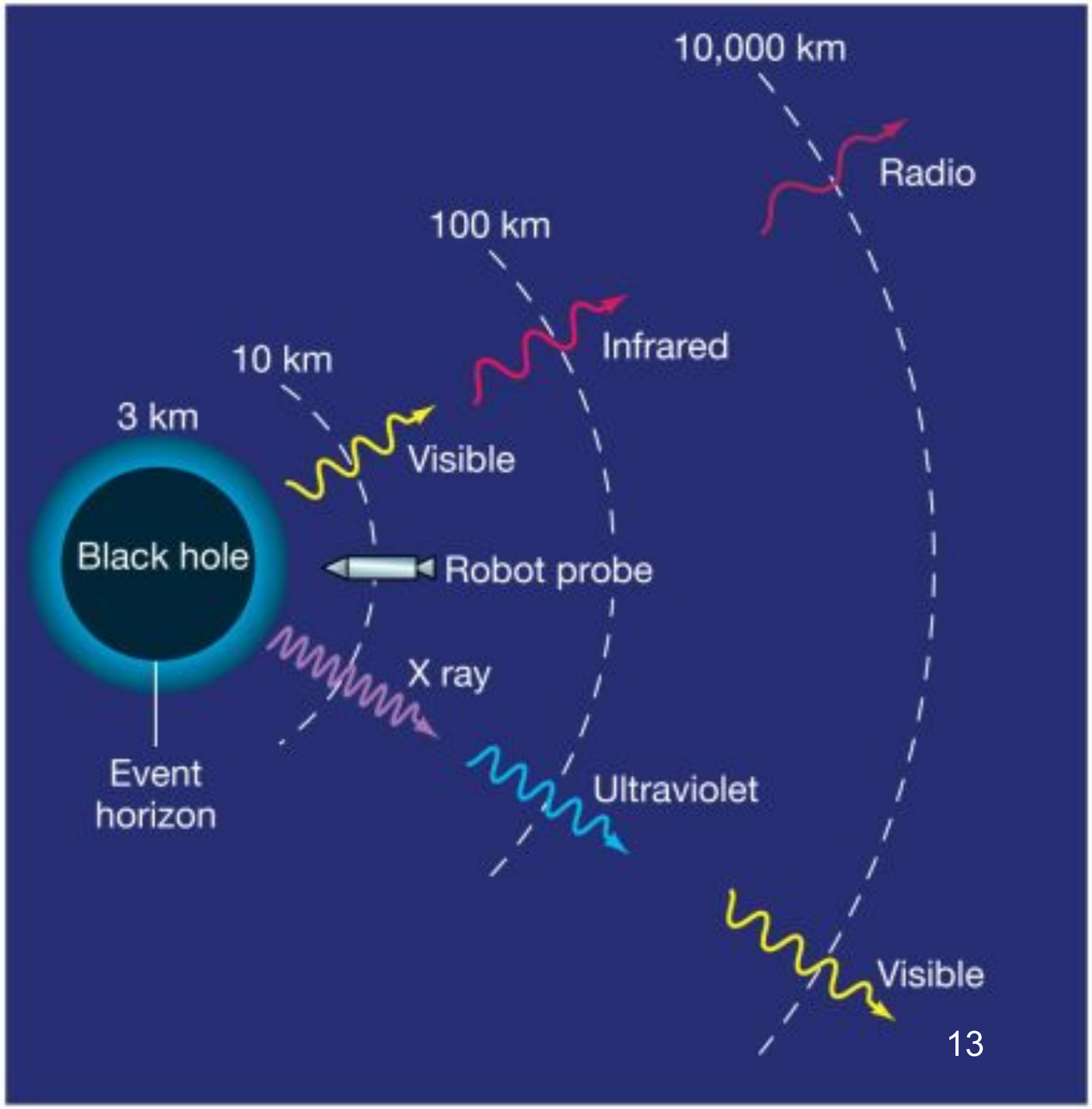
- Matter falling into a black hole reaches the speed of light – why?

- Matter falling into a black hole gets extremely hot – why?

- Matter encountering a black hole will experience enormous tidal forces that will both heat it enough to radiate, and tear it apart – why?



Effects Near Black Holes

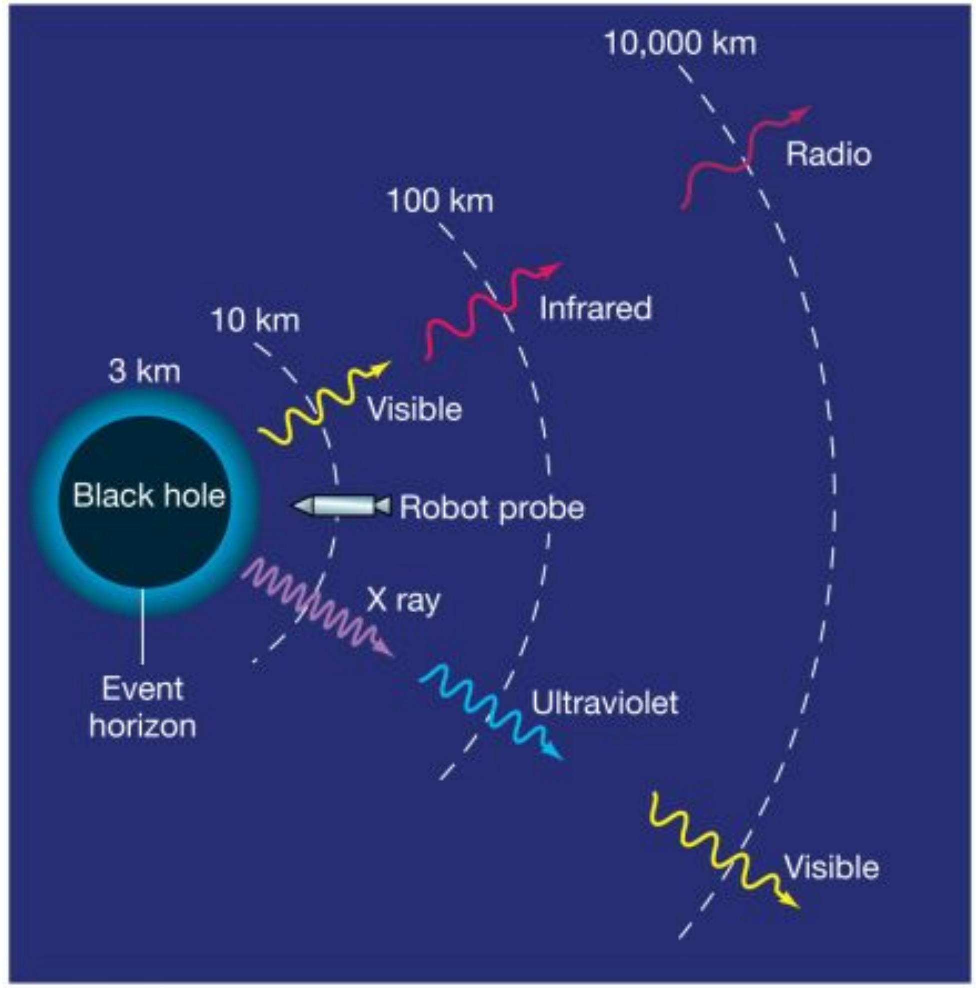


Effects Near Black Holes

Photon escaping from the vicinity of a black hole:

- wavelength gets longer and longer due to "gravitational redshift"

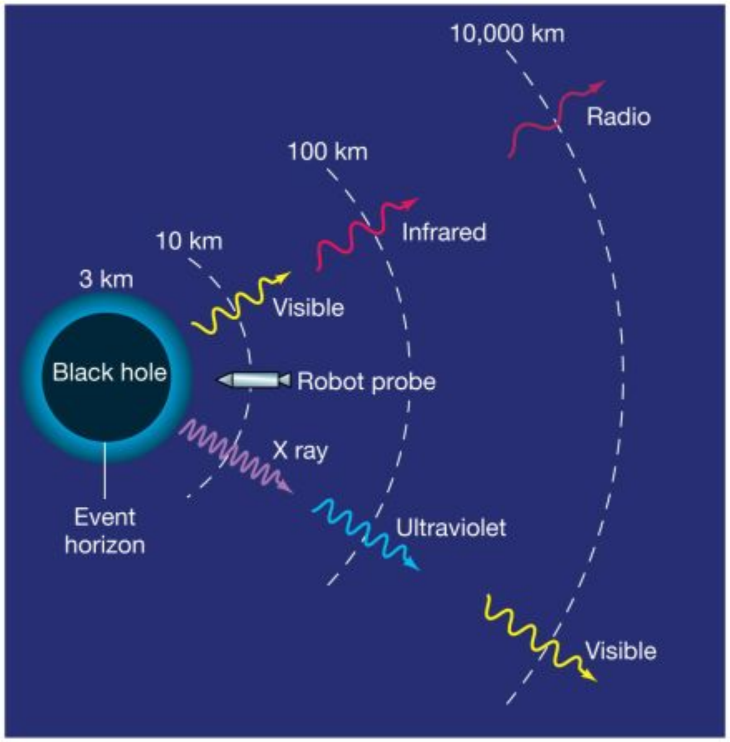
- Speed of light does NOT change



Effects Near Black Holes

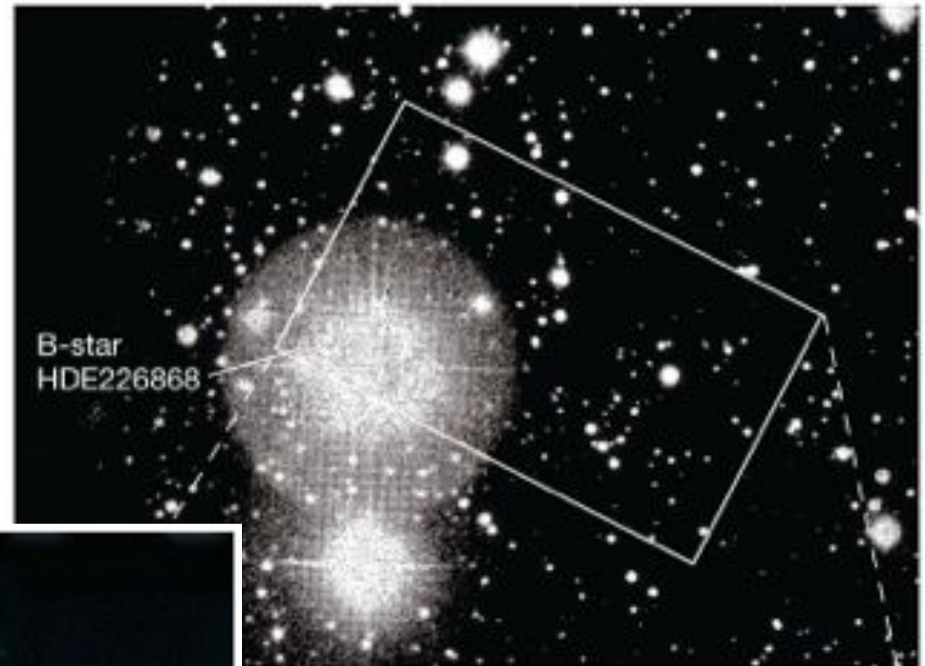
- Imagine a probe nearing the event horizon of a black hole. As seen by outside observers:

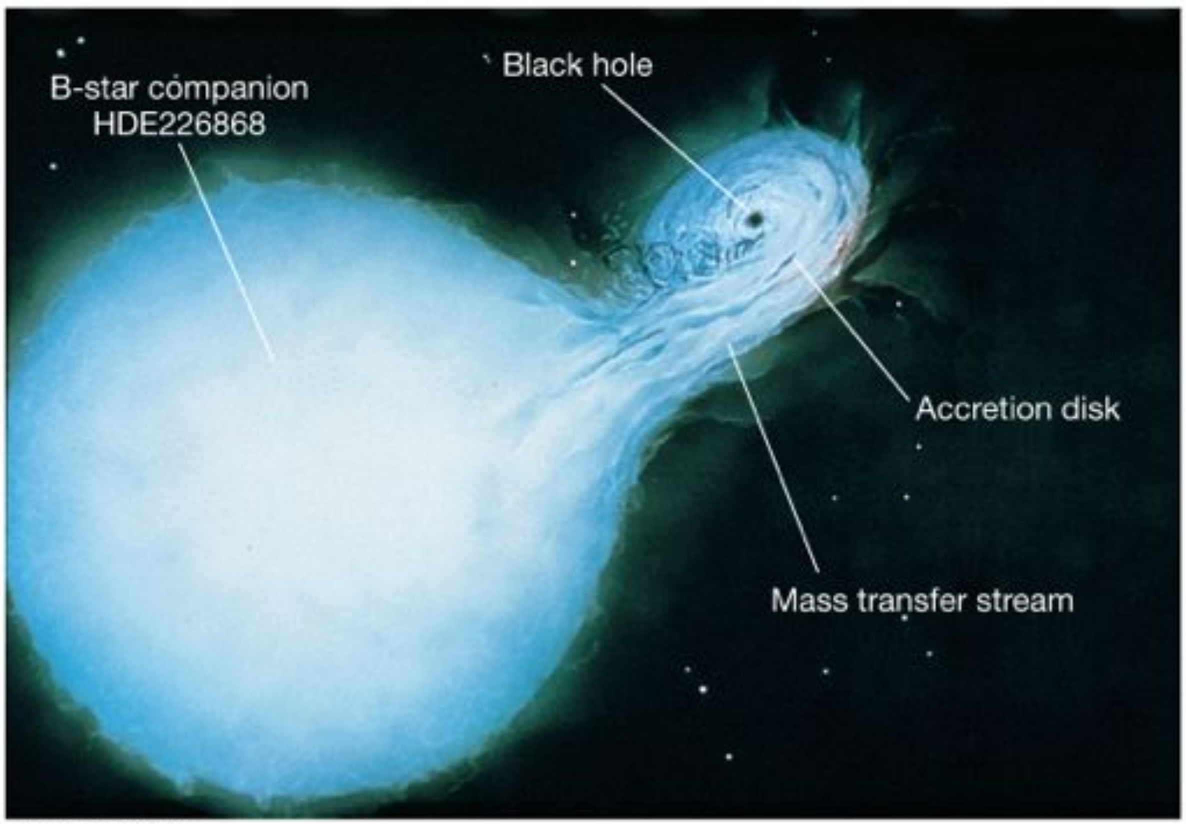
  - a dramatic redshift as it gets closer – the gravitational redshift, due not to motion, but to the large gravitational fields present.
  - time appears to be going more and more slowly as probe approaches the event horizon



- Inside the probe, however, time and everything else would appear normal

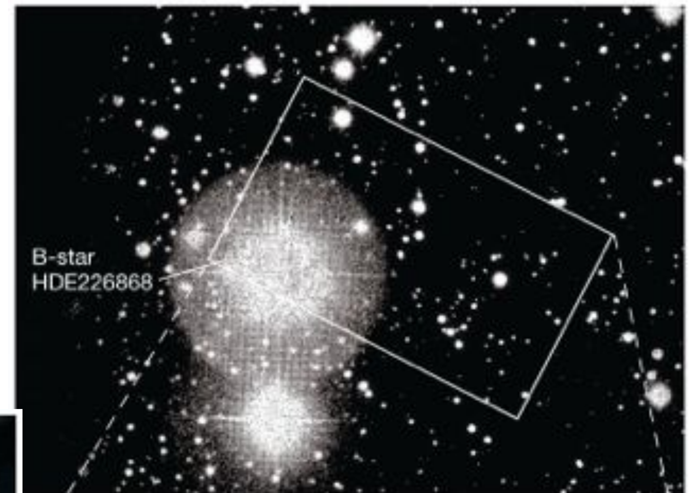
Observational Evidence for Black Holes

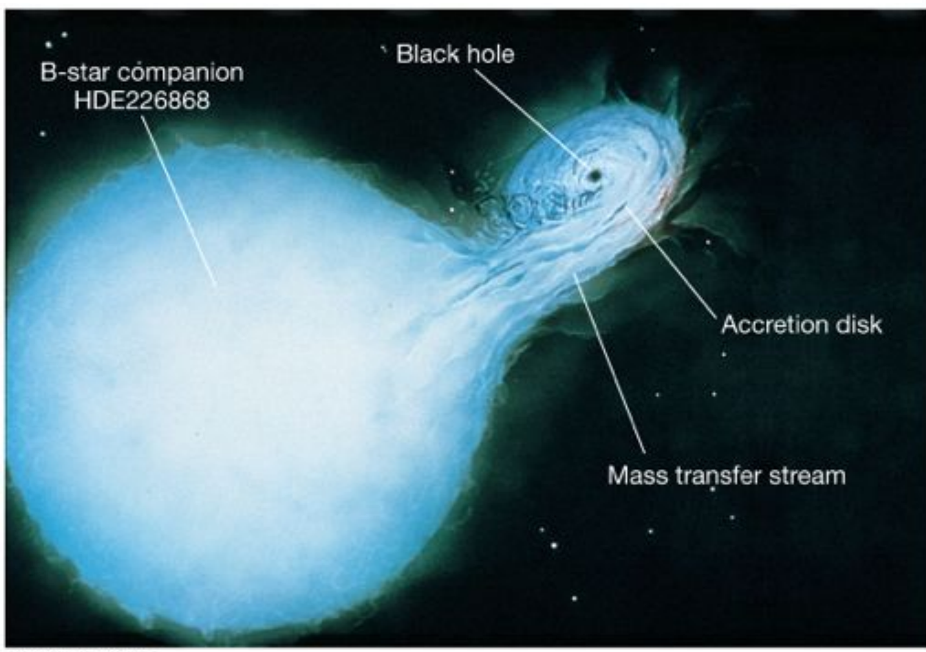




Observational Evidence for Black Holes

strong X-ray emitter Cygnus X-1 = HDE 226868





- unseen, massive, compact companion
- hot gas falling in
- **Accretion disk**
- discovered by a Canadian 1972

Supermassive Black Holes – the Milky Way [AT23.7]

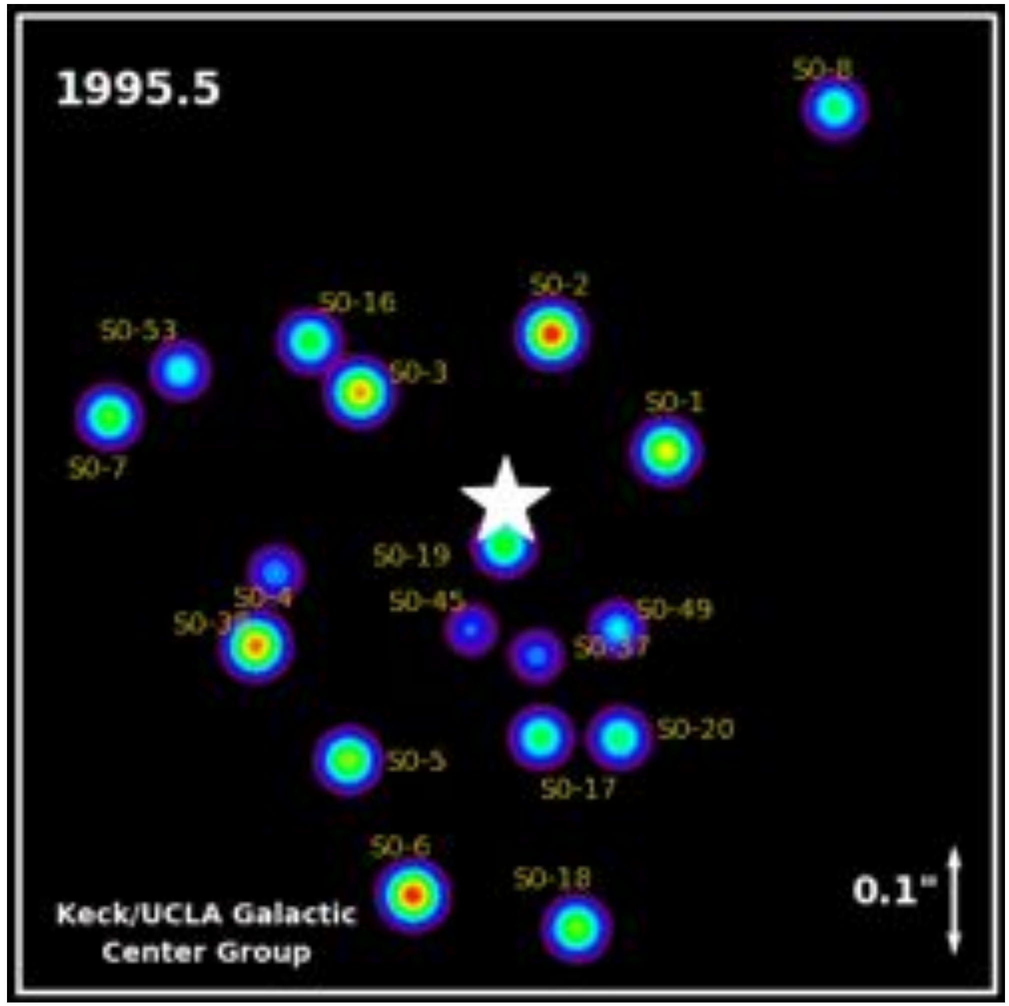
The centres of most galaxies contain super-massive black holes.

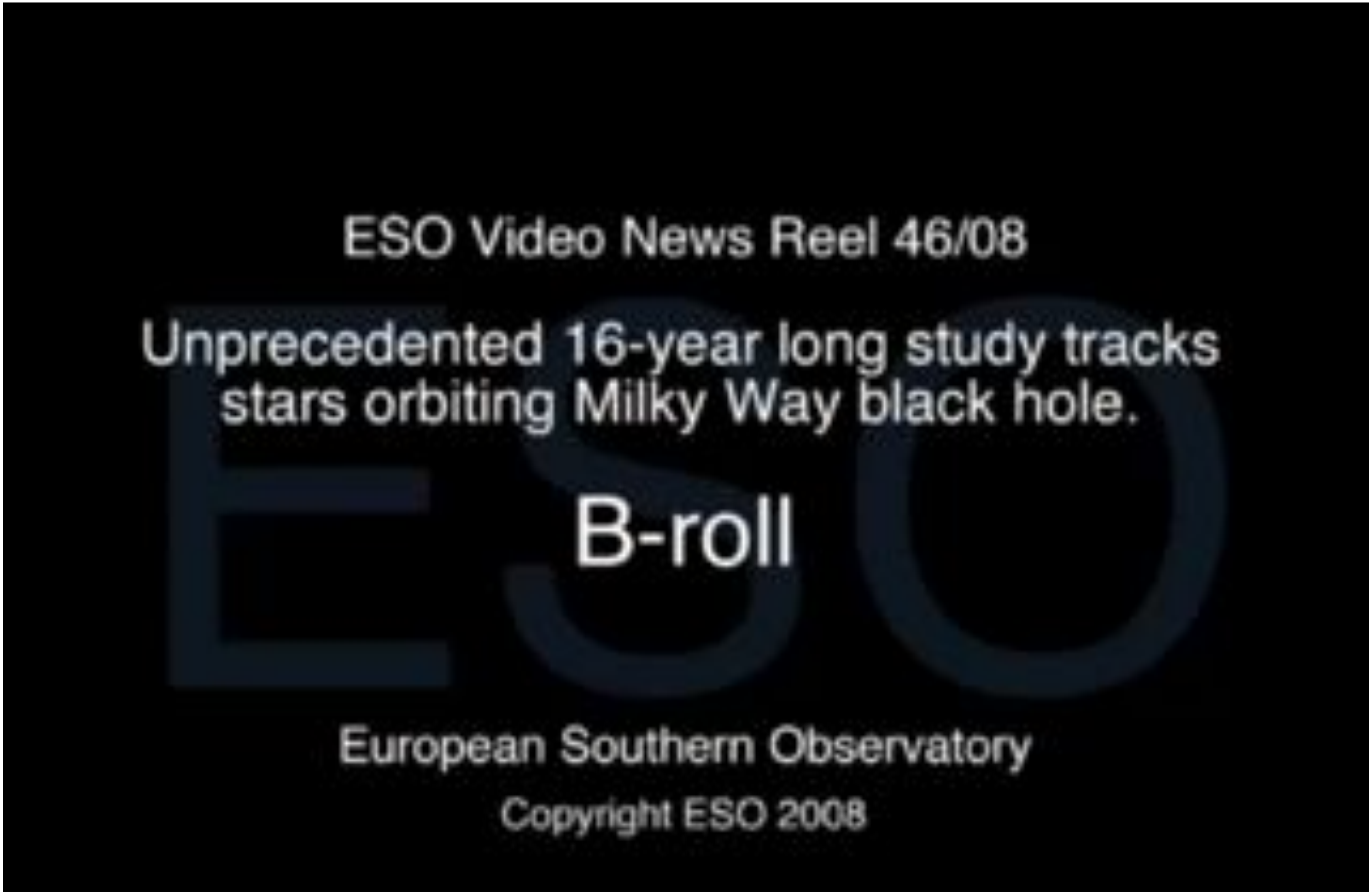
Supermassive Black Holes – the Milky Way [AT23.7]

The centres of most galaxies contain supermassive black holes.

Centre of Milky Way infrared - $4 \times 10^6\ M_\odot$!

largest known is $3 \times 10^9\ M_\odot$ or more!





http://www.youtube.com/watch?v=36xZsgZ0oSo

What is the Schwarzschild radius of the black hole found in the centre of the Milky Way?

A. 1.2×10^7 km
B. 1.2×10^7 m
C. 4×10^6 km
D. 4×10^6 m
E. Need more information

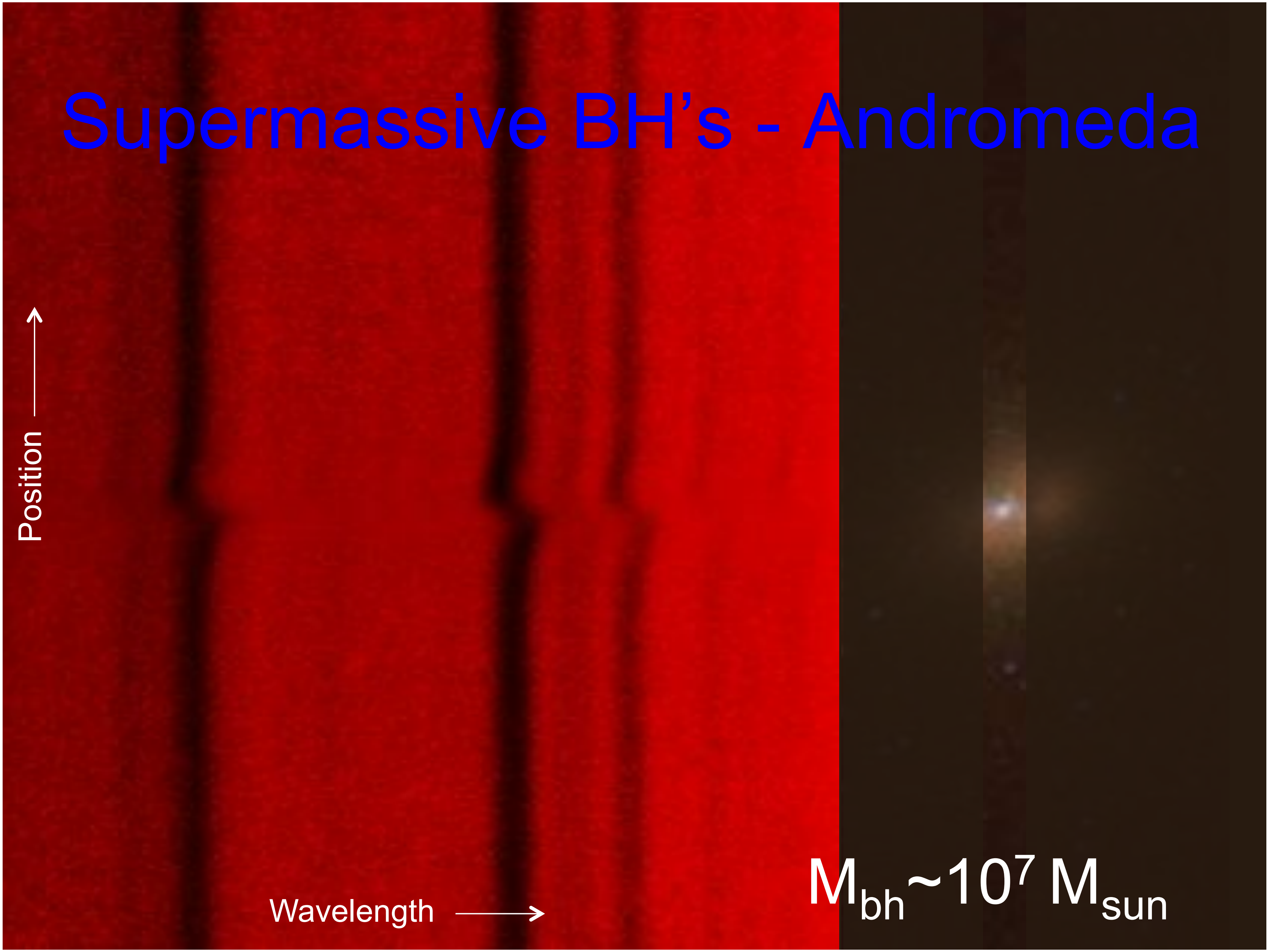
Supermassive Black Holes [AT25.4]

- First Detection:
  - M87 – Virgo cluster
  - $M_{bh} \sim 10^9\ M_{sun}$
  - Young et al 1979

Supermassive BH’s - Andromeda

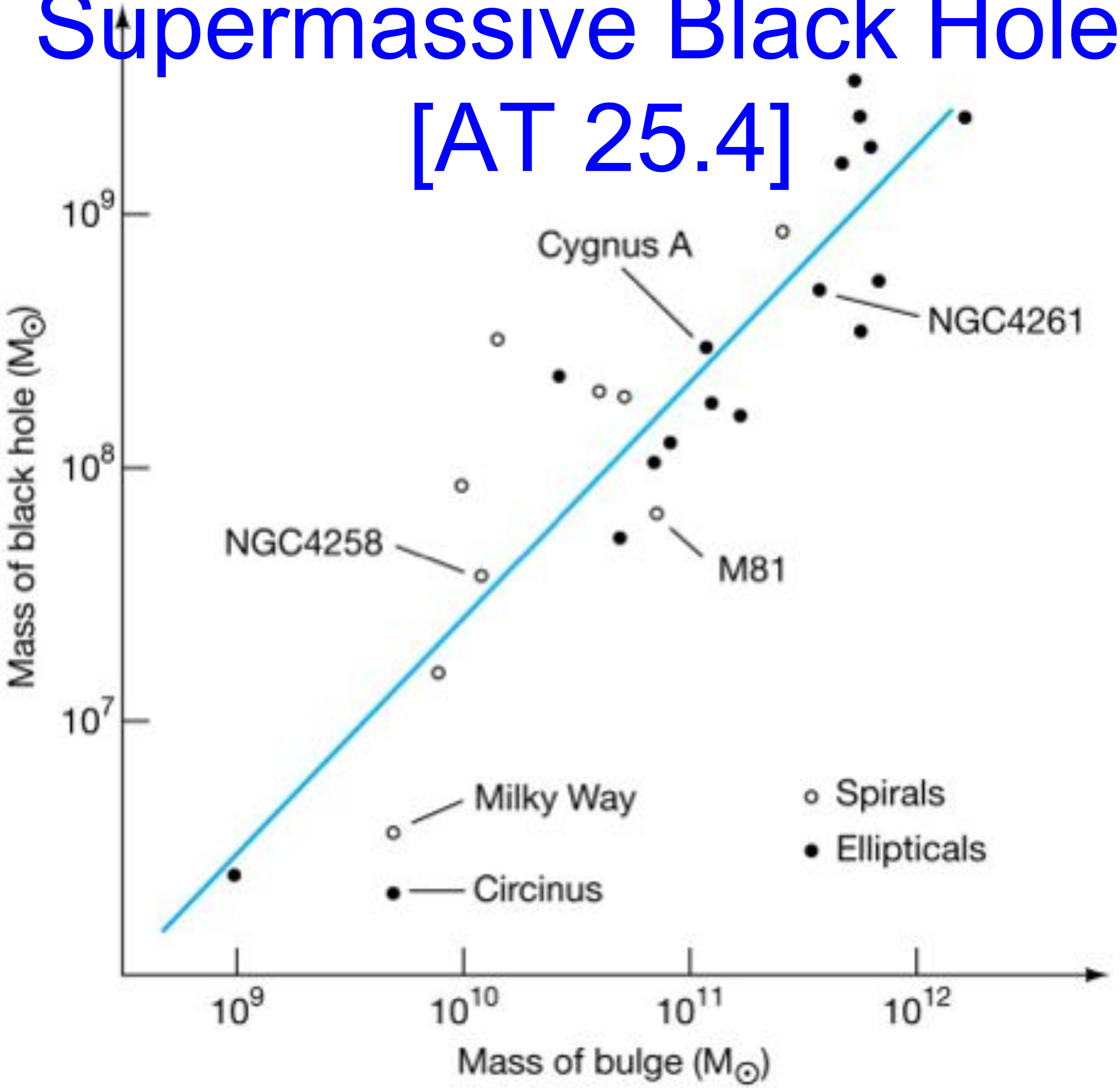
$M_{bh} \sim 10^7\ M_{sun}$

Supermassive BH's - Andromeda



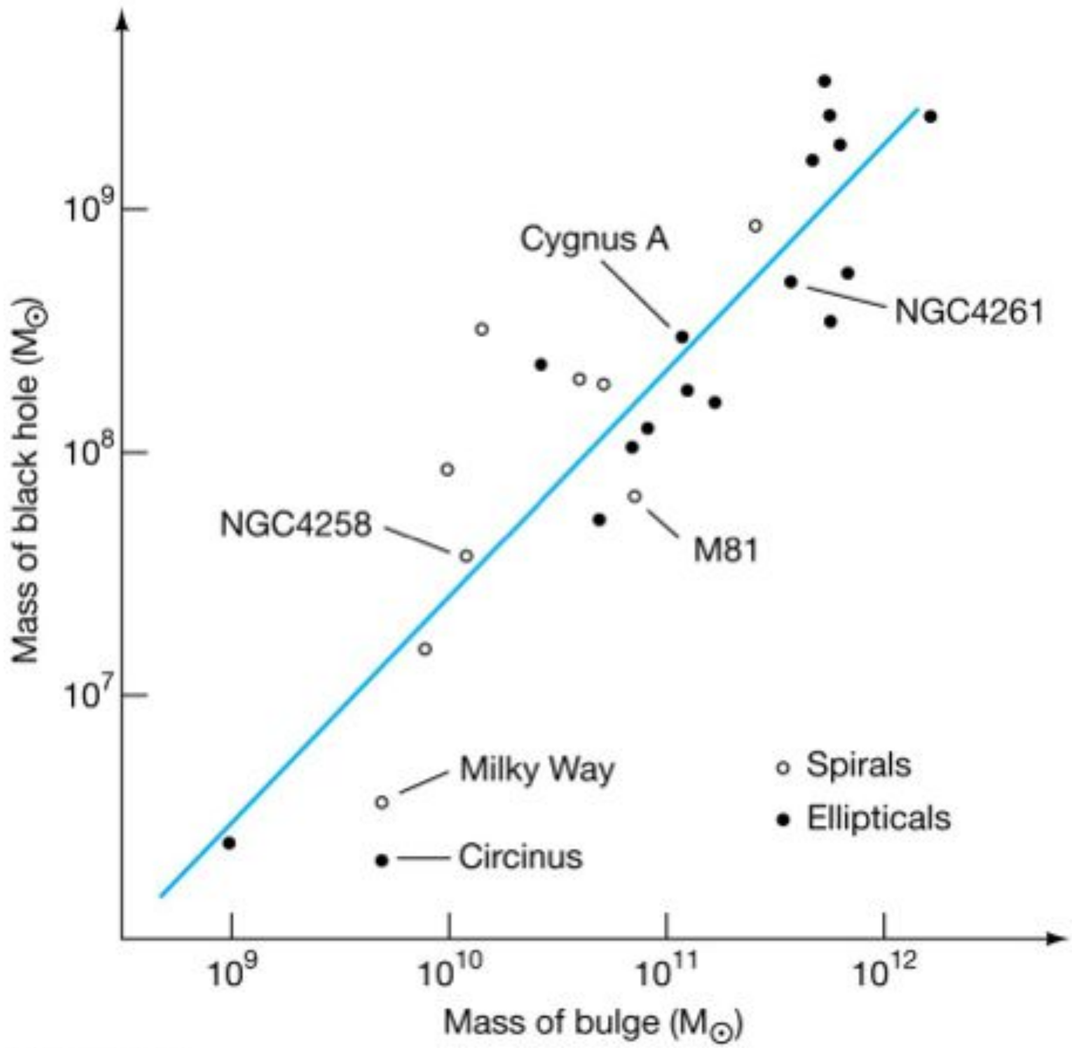
$M_{bh} \sim 10^7\, M_{sun}$

Supermassive Black Holes [AT 25.4]



Supermassive Black Holes [AT 25.4]

The mass of the central black hole is well correlated with the mass of the galactic bulge, for those galaxies where both have been measured.



Supermassive Black Holes

$$M_{bh} \sim 0.001\ M_{gal}$$

- M_{gal} refers to stellar component (not dark matter)
- M_{gal} refers to mass of bulge or elliptical component only

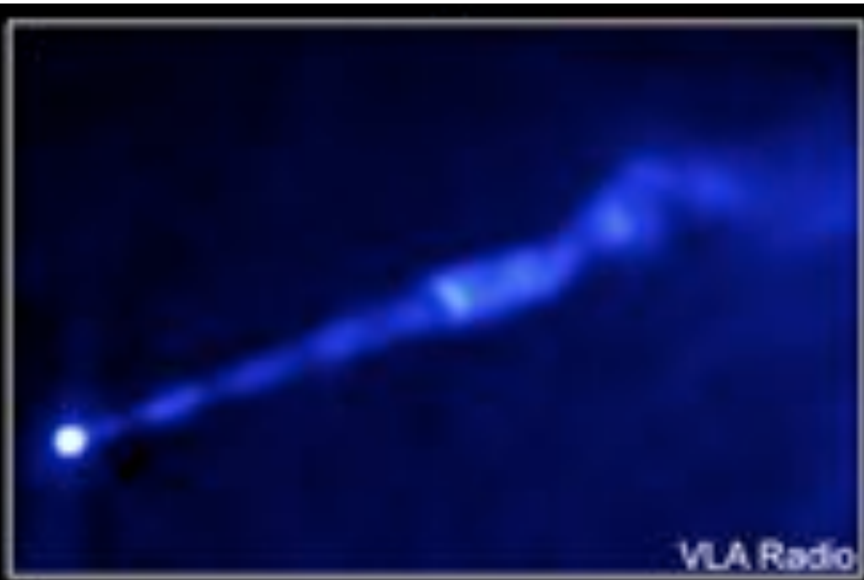
- Another piece of evidence for central black holes is …

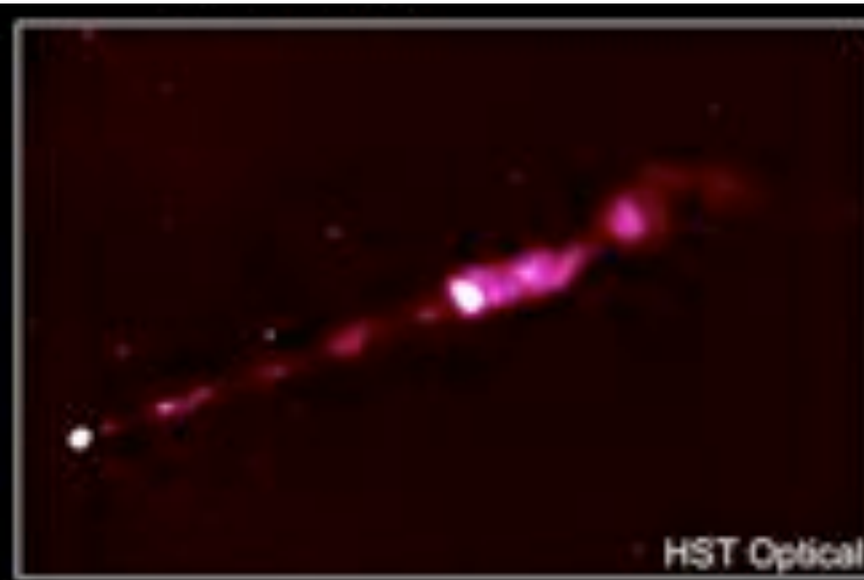
Tidal flares – more obs evidence

1 per 1000 yr per Milky Way-like galaxy
more obs evidence for black holes!

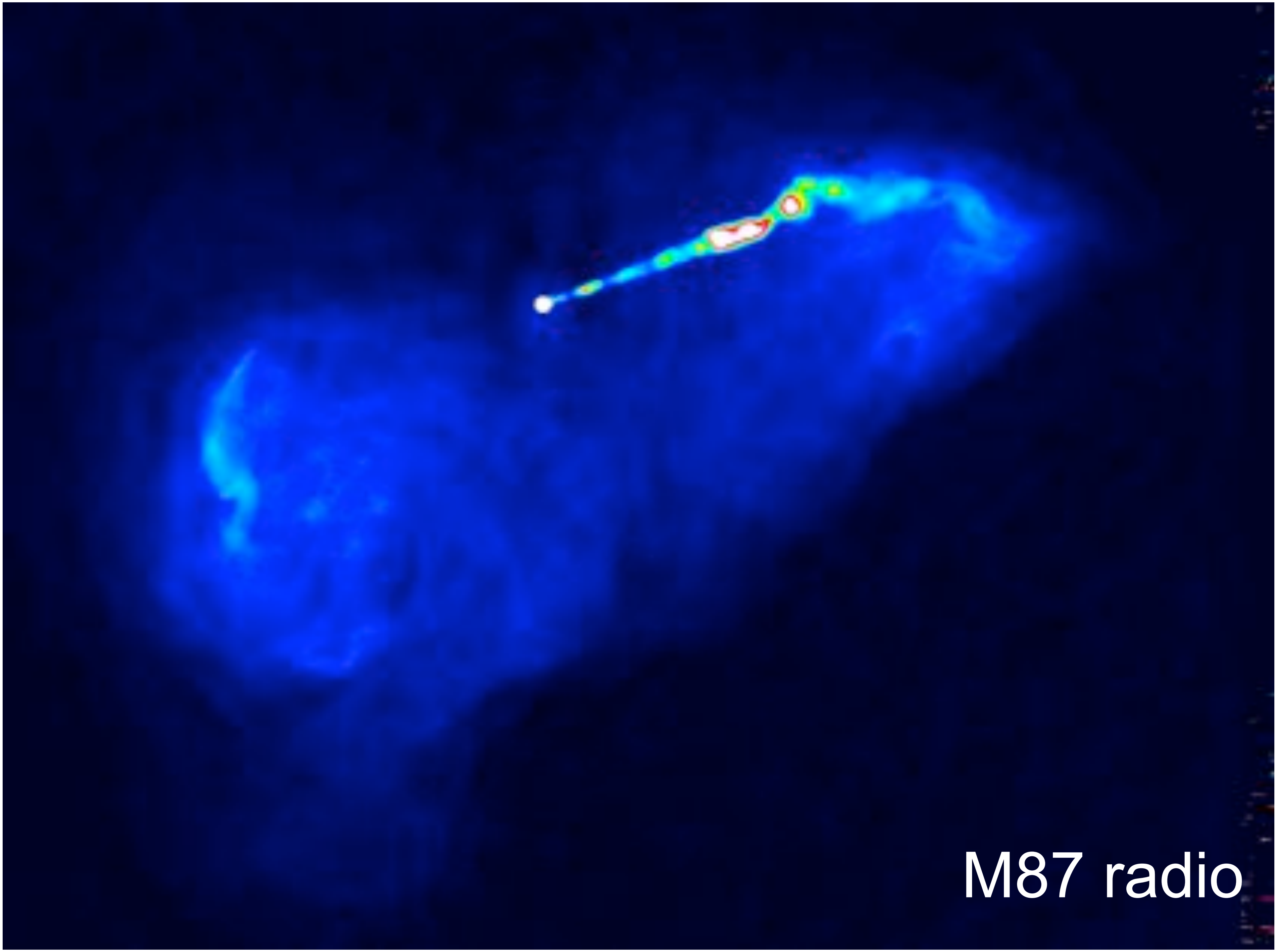
4. Radio Galaxies and Active Galactic Nuclei [AT 24.5, 25.4]

M87 and its jet



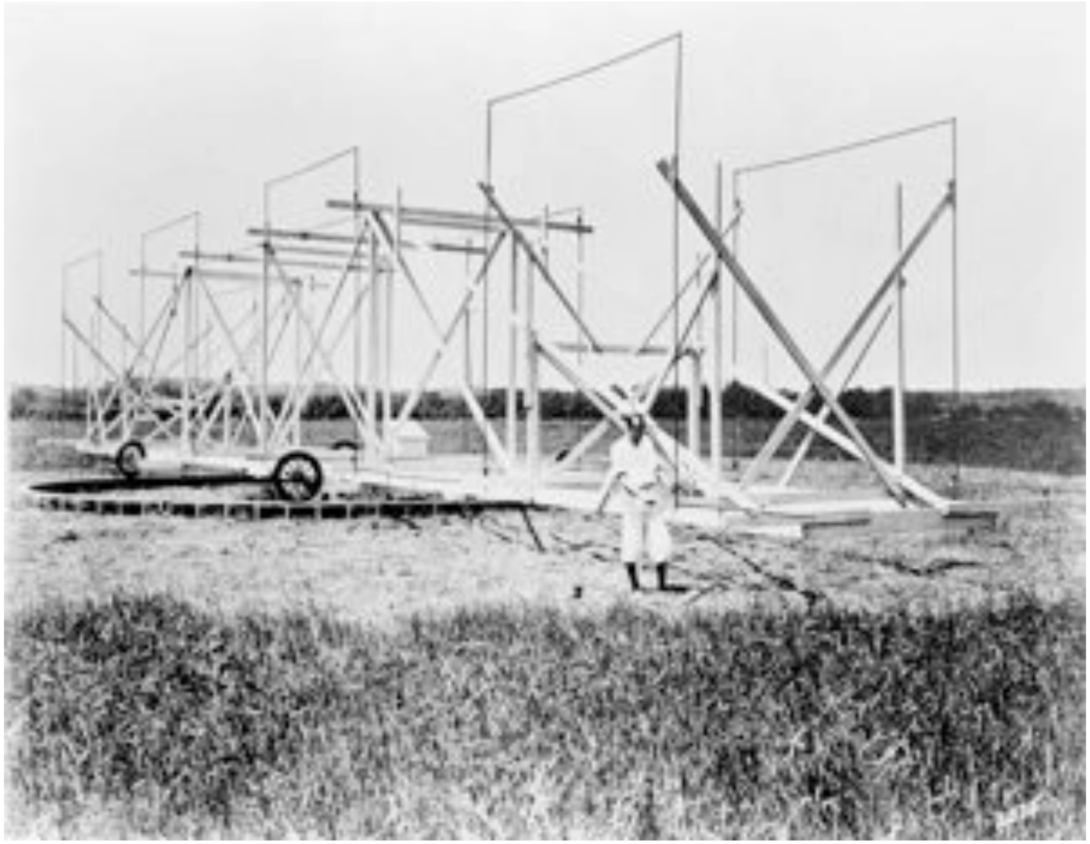


An energetic jet from the core of giant elliptical galaxy M87 stretches outward for 5,000 light-years. This monstrous jet appears in the panels above to be a knotted and irregular structure, detected across the spectrum, from x-ray to optical to radio wavelengths. In all these bands, the observed emission is likely created as high energy electrons spiral along magnetic field lines, so called synchrotron radiation. But what powers this cosmic blowtorch? Ultimately, the jet is thought to be produced as matter near the center of M87 swirls toward a spinning, supermassive black hole. Strong electromagnetic forces are generated and eject material away from the black hole along the axis of rotation in a narrow jet. Galaxy M87 is about 50 million light-years away and reigns as the large central elliptical galaxy in the Virgo cluster.


M87 radio

Radio Astronomy

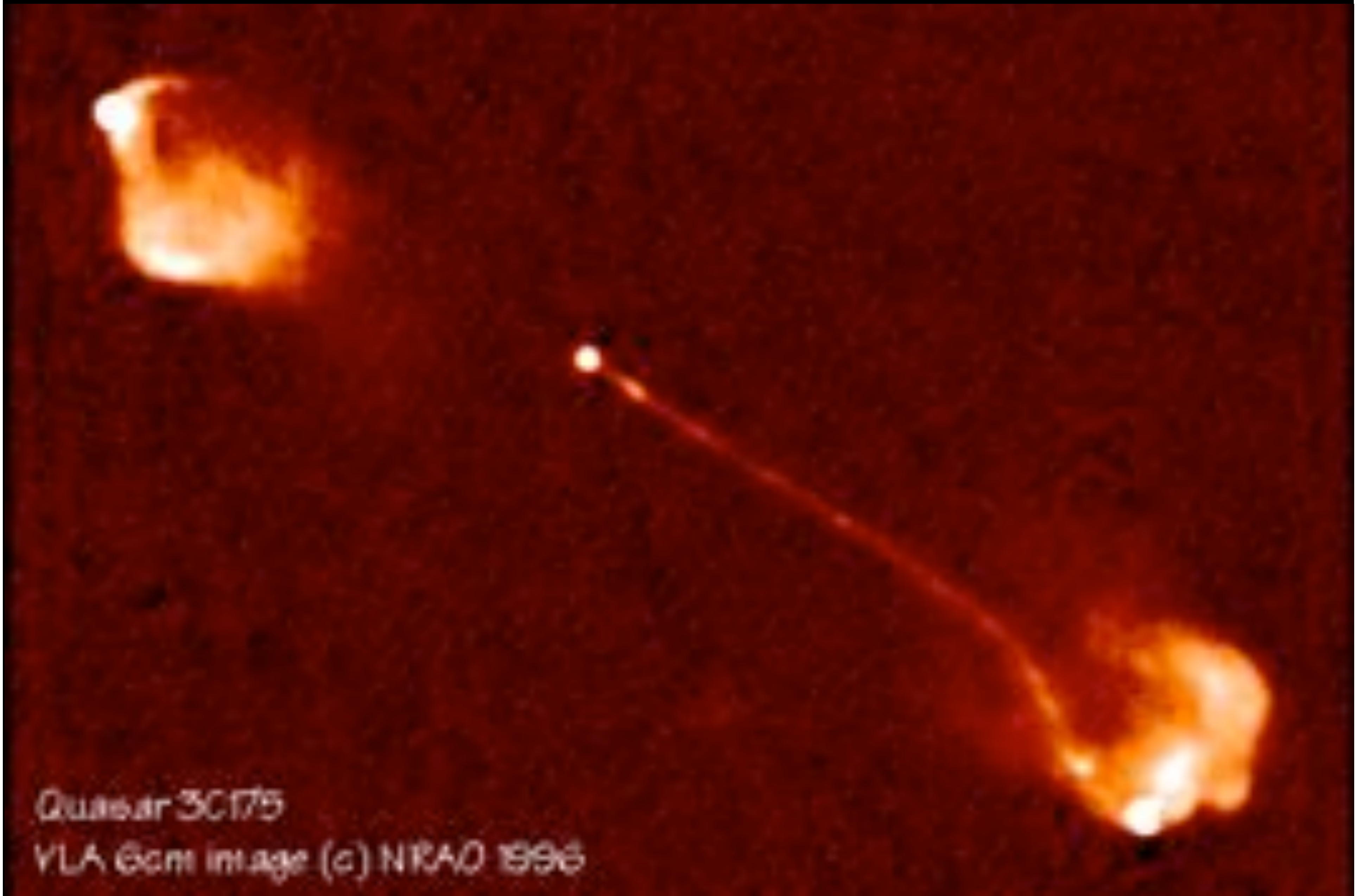
Karl Jansky 1905-1950



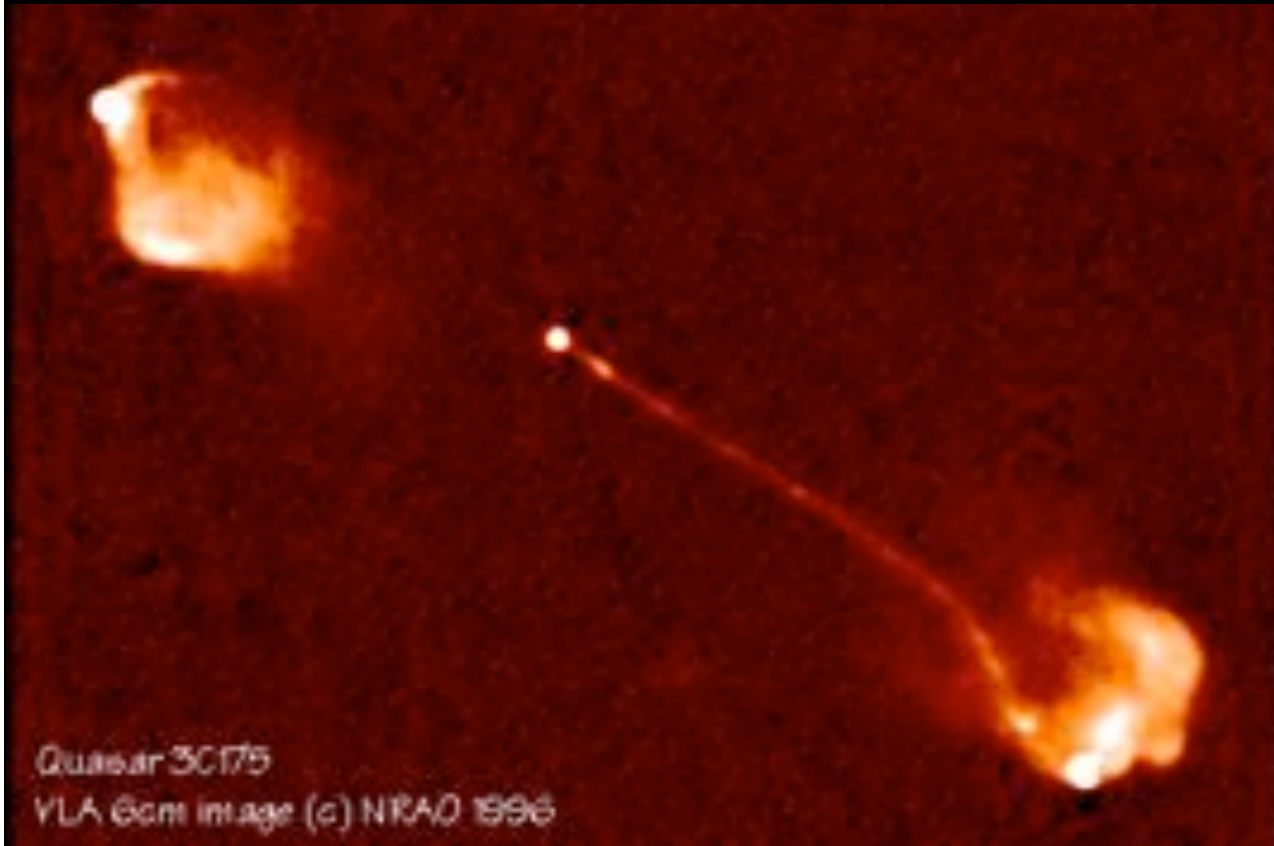
- discovered radio emission from the Milky Way in 1931

Jansky VLA New Mexico

Square Kilometre Array

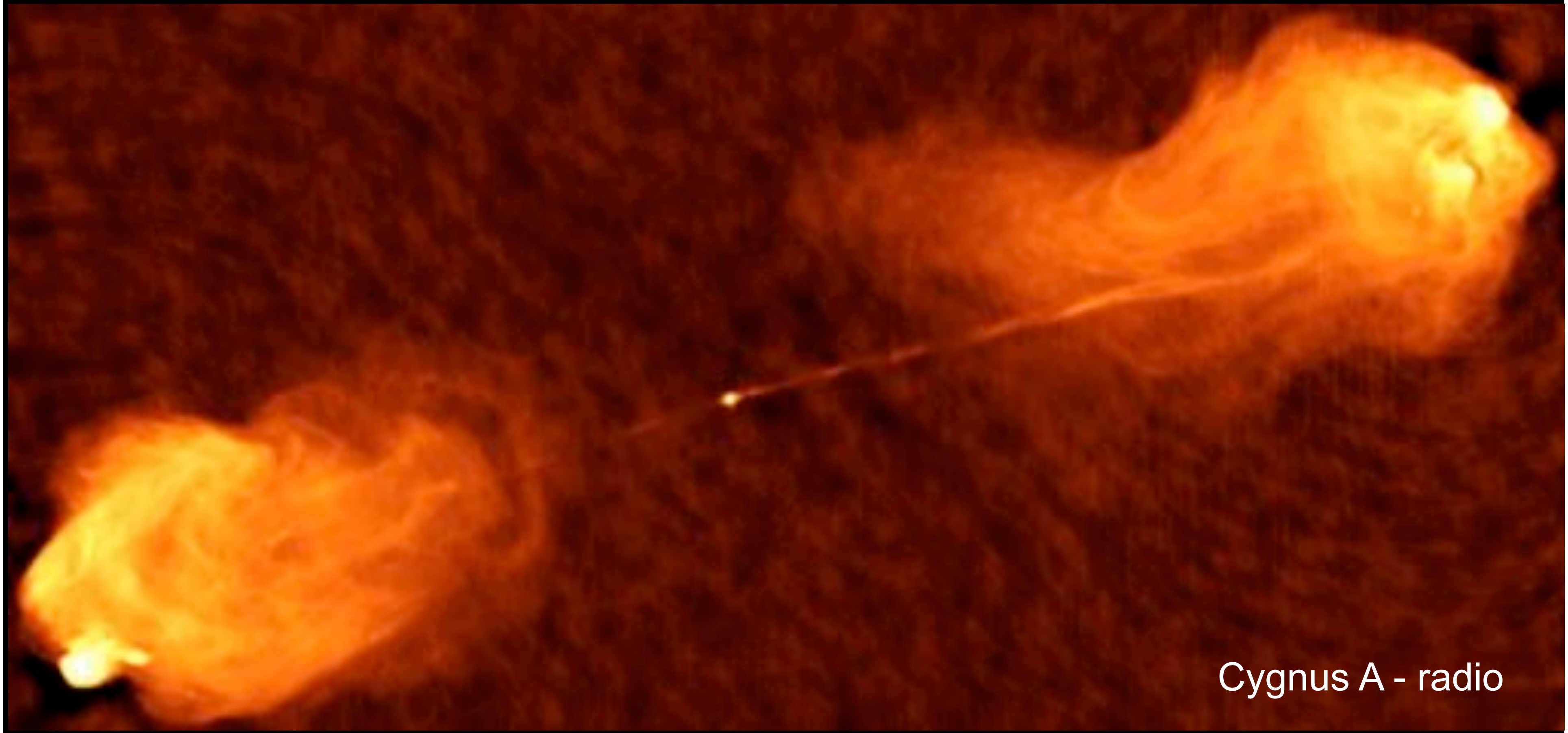


3C175, redshift z=0.77



This image shows the radio emission from relativistic streams of high energy particles generated by the quasar. This is a classic double-lobed radio source. Astronomers believe that the jets are fueled by material accreting onto a super-massive black hole at the center of the host galaxy (not shown in this image). The high energy particles are confined to remarkably well collimated jets, and are shot into extragalactic space at speeds approaching the speed of light, where they eventually balloon into massive radio lobes. The overall linear size is of the radio structure is 212 kpc (for a Hubble constant of 100 km/s/Mpc), which can be compared to a typical galaxy diameter of about 30 kpc. The quasar has double lobes with prominent hot spots, and has a narrow jet, but no counter-jet. Its possible that we only see the jet that is pointing toward us, which may be "Doppler boosted" in brightness when the particles emitting the radio radiation are moving toward us at close to the speed of light. The counter-jet would be moving away from us, and would thus not experience Doppler boosting. The jet brightens and bends as it enters its lobe.

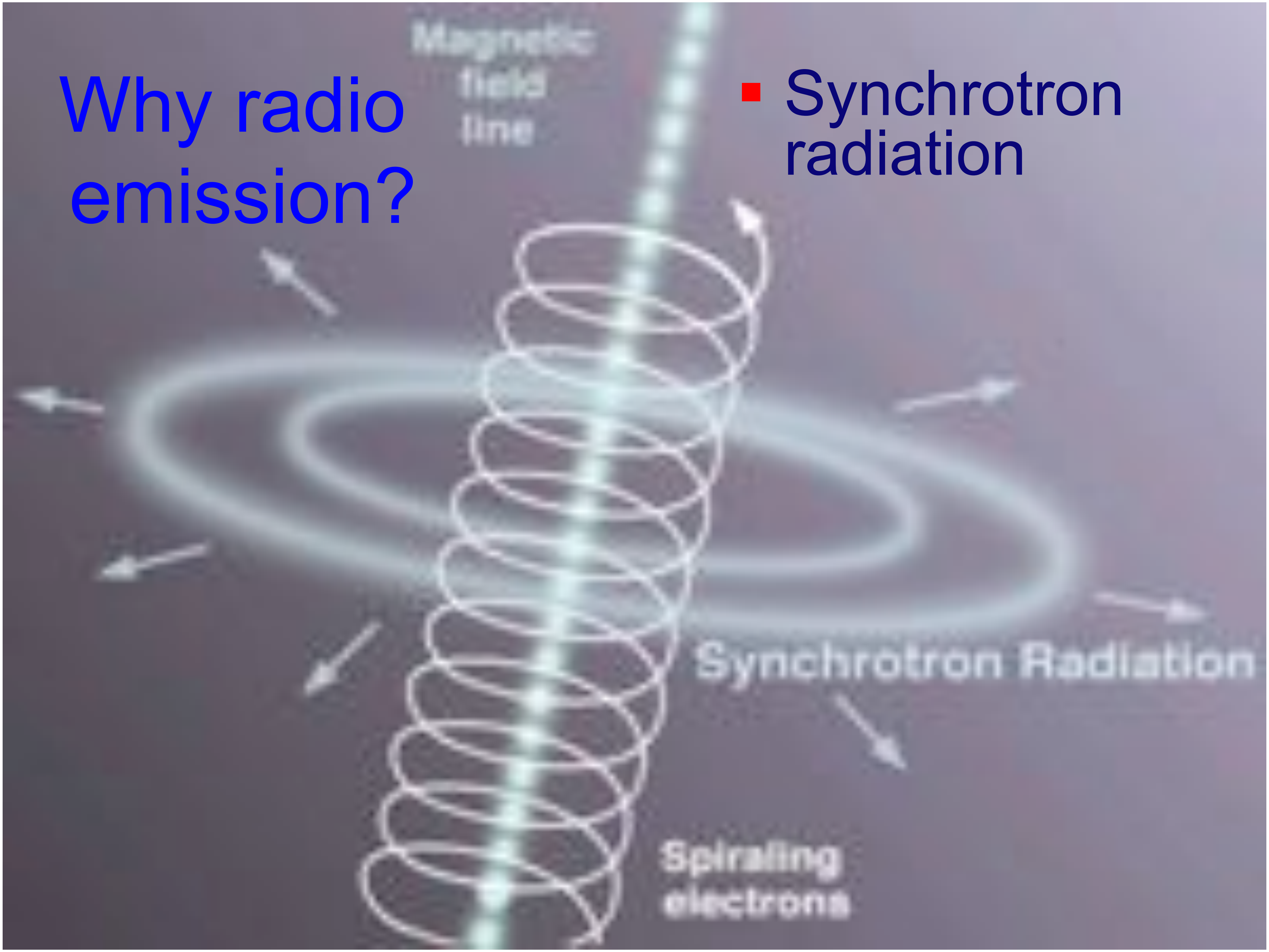
3C175, redshift z=0.77



Cygnus A is the most powerful radio galaxy in our corner of the Universe. It is at a redshift z = 0.0565 (distance of about 700 million light-years). The jets are generated by a supermassive black hole at the galaxy's core—a black hole with 2.5 billion Solar masses. Compare these jets with the jet from galaxy M87, which harbors a black hole of similar mass.

Why radio emission?

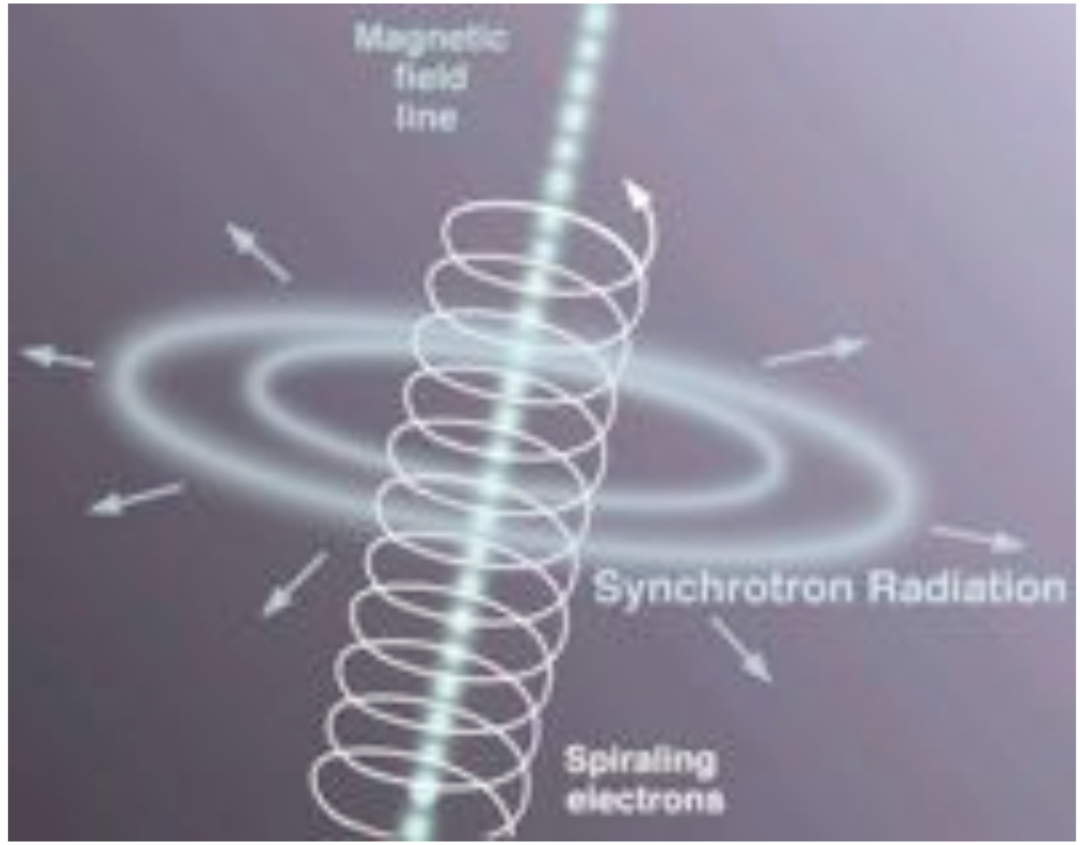
- Synchrotron radiation



Why radio emission?

- Synchrotron radiation

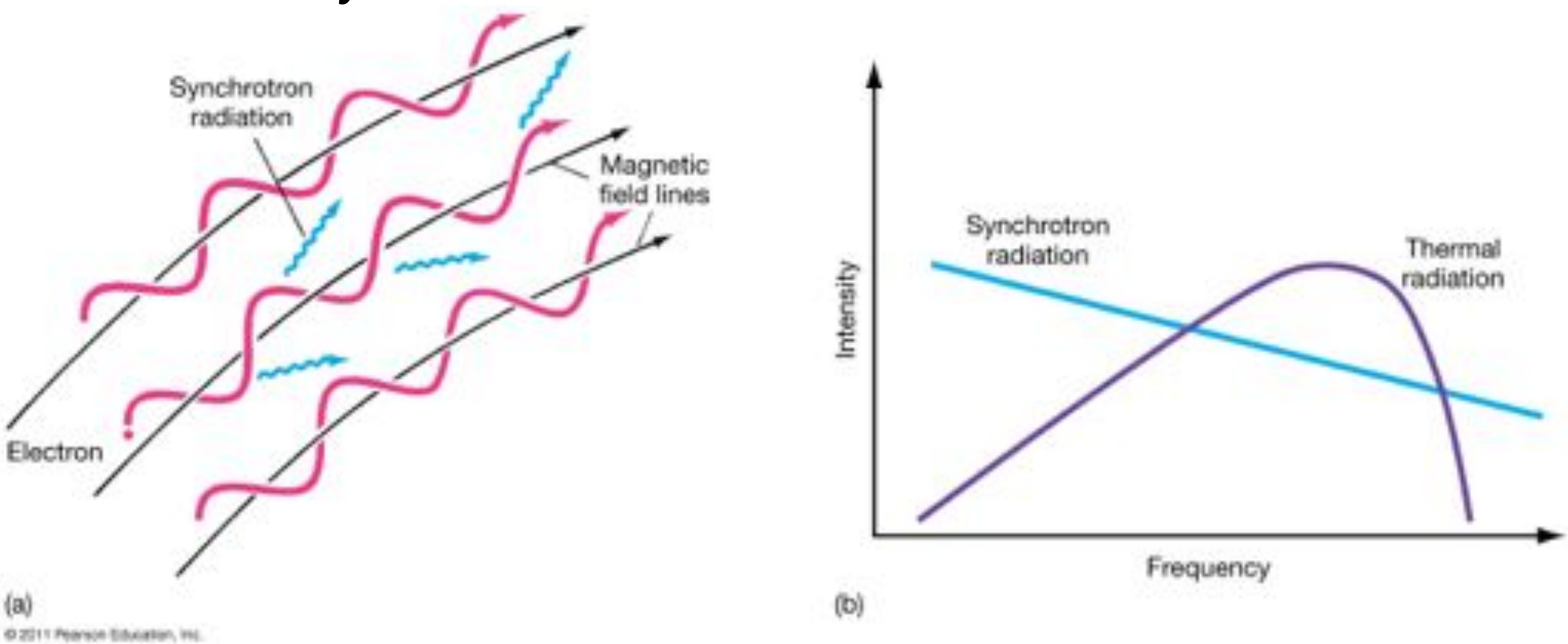
  Relativistic electrons spiraling around magnetic fields



Electromagnetic radiation emitted by electrons that are spiralling along, and therefore being constantly accelerated, in a magnetic field at a rate great enough for relativistic effects to be important. Predicted long ago, much of the radiation observed by radio astronomers originates in this fashion. Synchrotron radiation from cosmic sources has a distinctive spectrum, or distribution of photons with energy. When synchrotron radiation is observed in supernova remnants, cosmic jets, or other sources, it reveals information about the high-energy electrons and magnetic fields that are present.

24.5 The Central Engine of an Active Galaxy

Particles will emit synchrotron radiation as they spiral along the magnetic field lines; *this radiation is decidedly non-stellar and non-blackbody.*



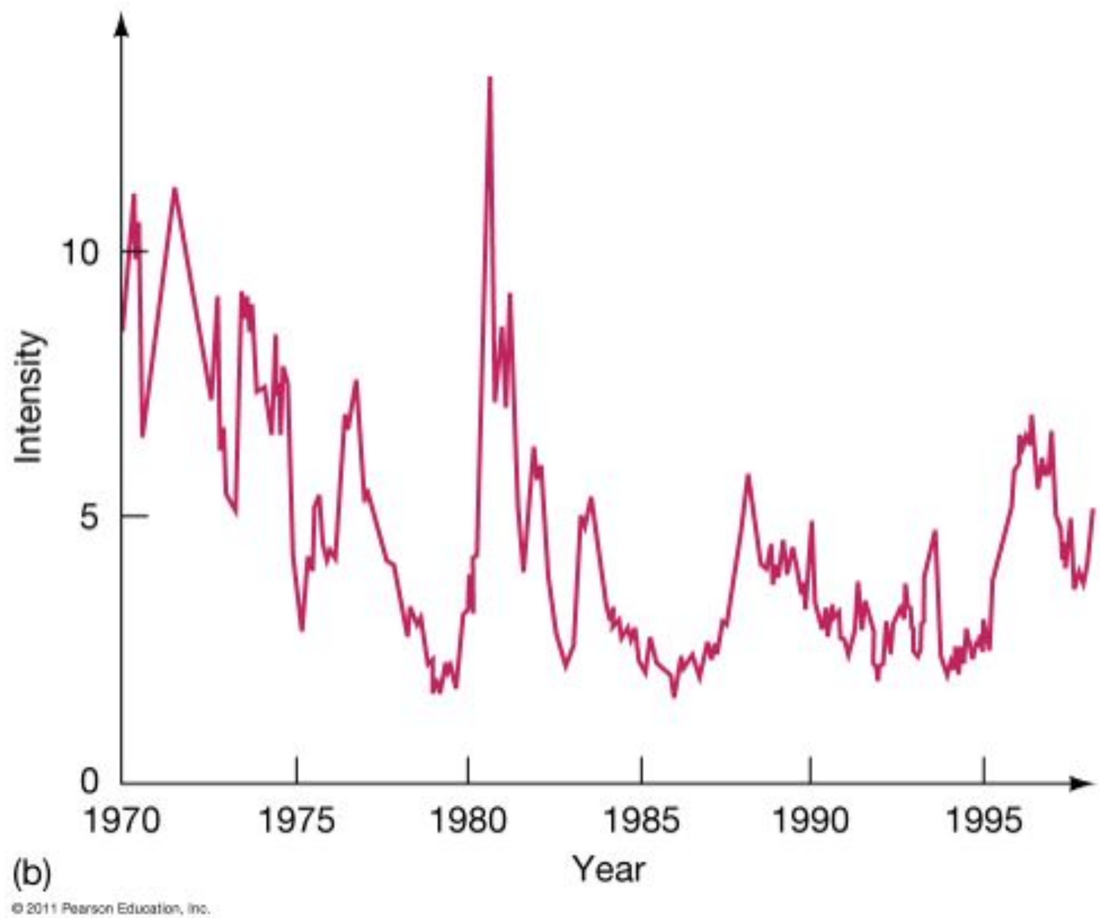
Active Galactic Nuclei – Optical

- Quasi-stellar objects (quasars)
- Seyfert galaxies (not as bright)

- Seyfert galaxies resemble normal spiral galaxies, but their cores are thousands of times more luminous.

Active Galactic Nuclei

The rapid variations in the luminosity of Seyfert galaxies and quasars indicate that the core must be extremely compact



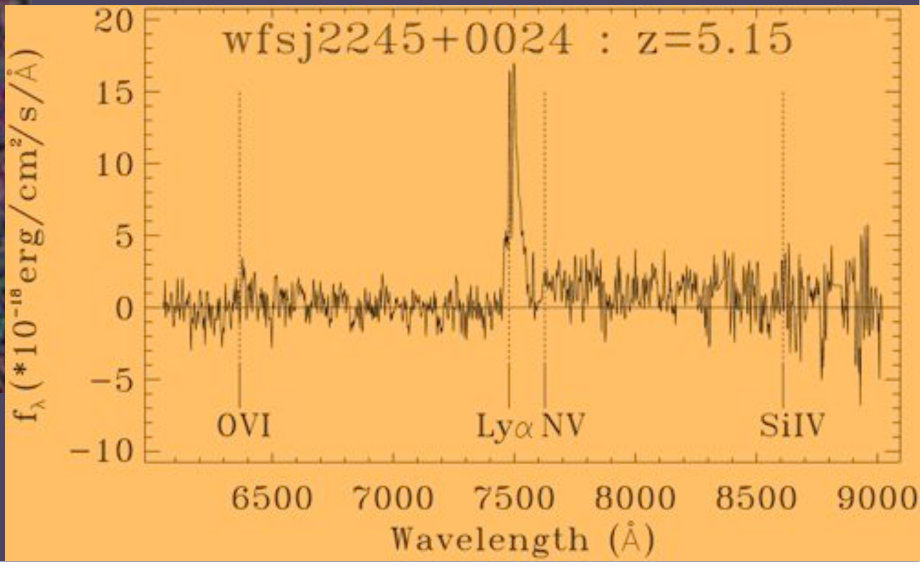
Quasar 3C273

- z=0.16
- m=12.9
- Lum=400 x Milky Way (in nucleus alone!)
- Note optical jet

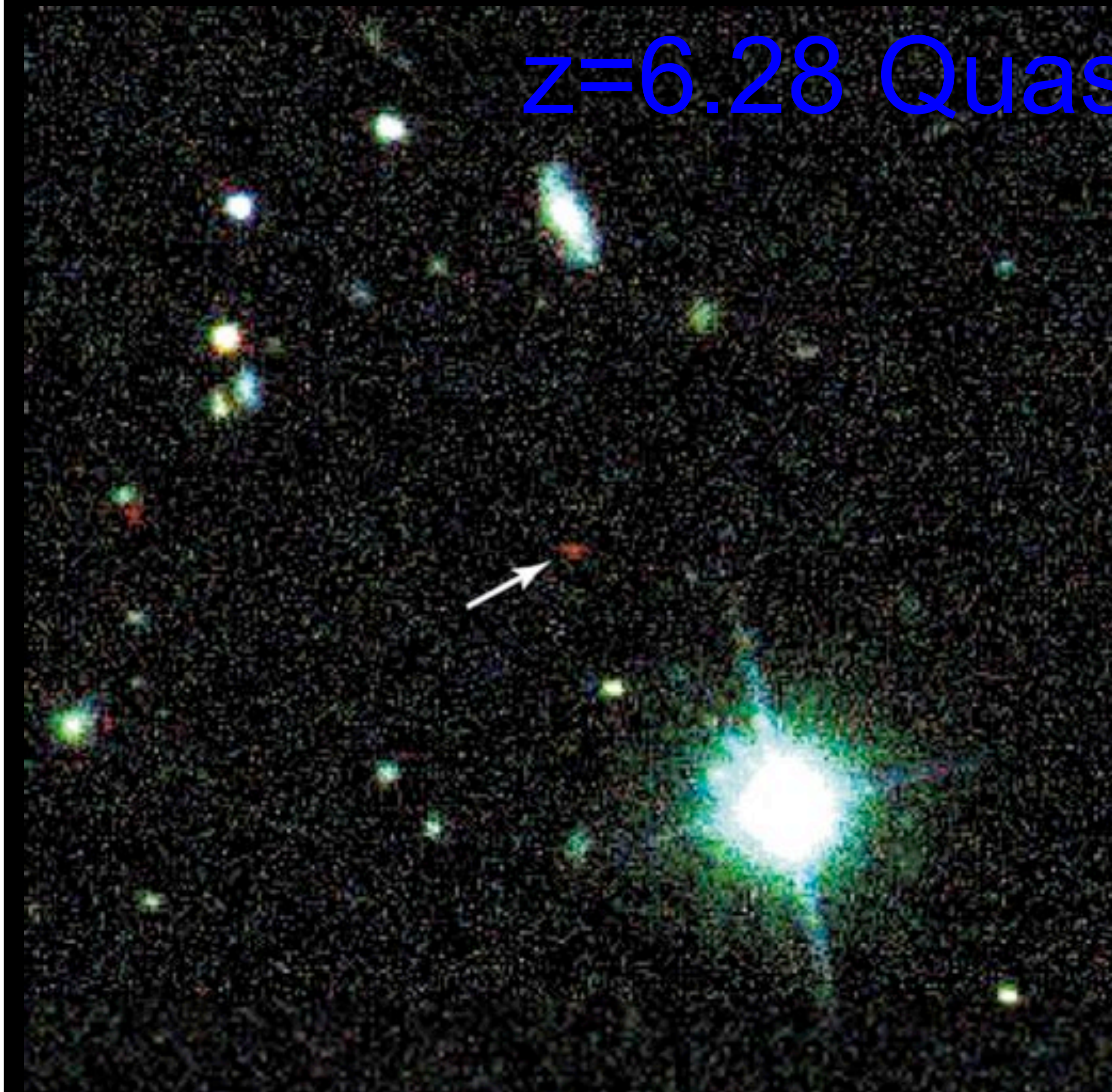
http://en.wikipedia.org/wiki/3C273

High Redshift Quasars

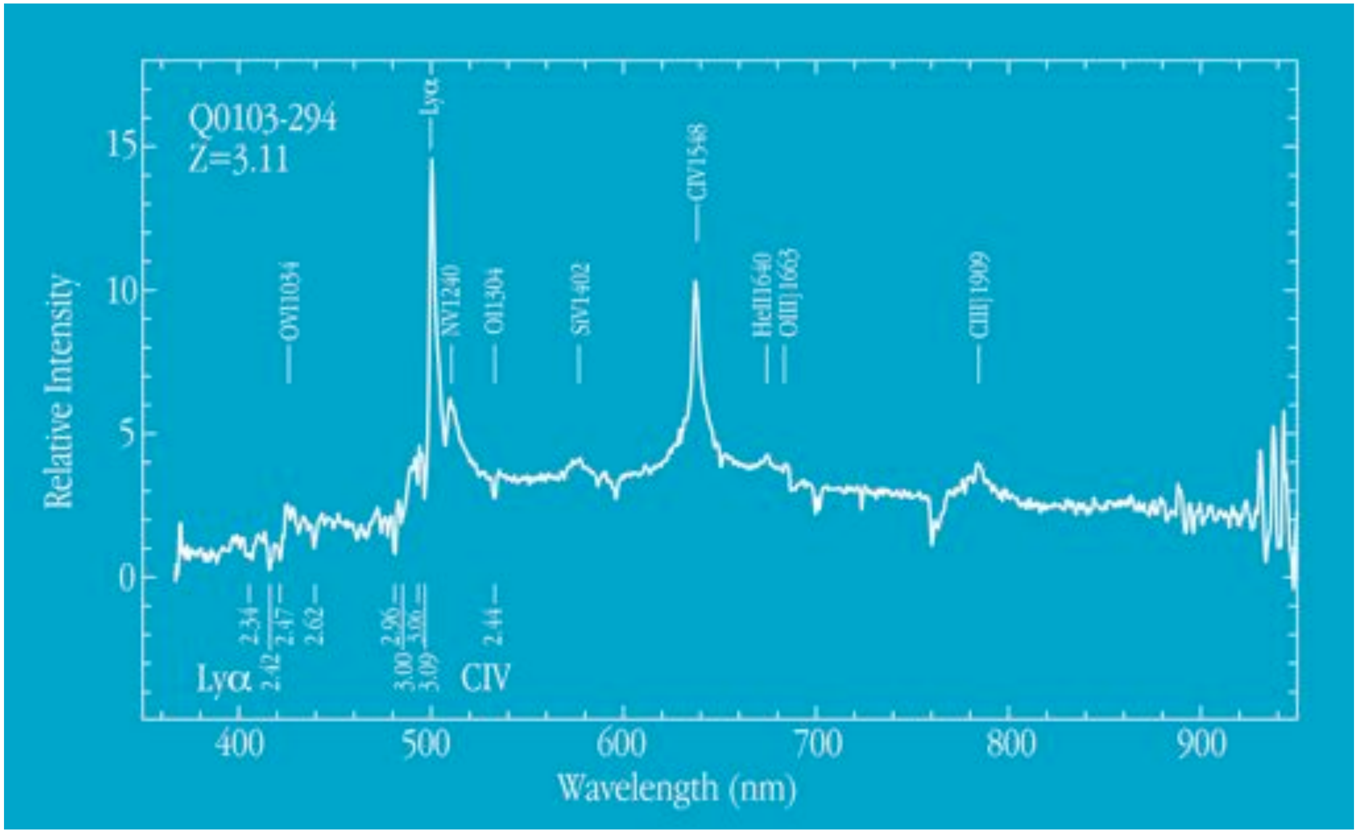
- Many! This one at z=5.15
- Peak in quasars numbers at z=2



z=6.28 Quasar



The high redshift of quasar SDSS 1030+0524 implies that this object emitted its light when the Universe had an age of only 6% of its present-day age. This corresponds to 700 million years after the Big Bang, which according to cosmological models occurred some 15 billion years ago. The mere existence of a quasar at such an early time has interesting consequences for the early evolution of the Universe and for the time scales on which galaxies formed.

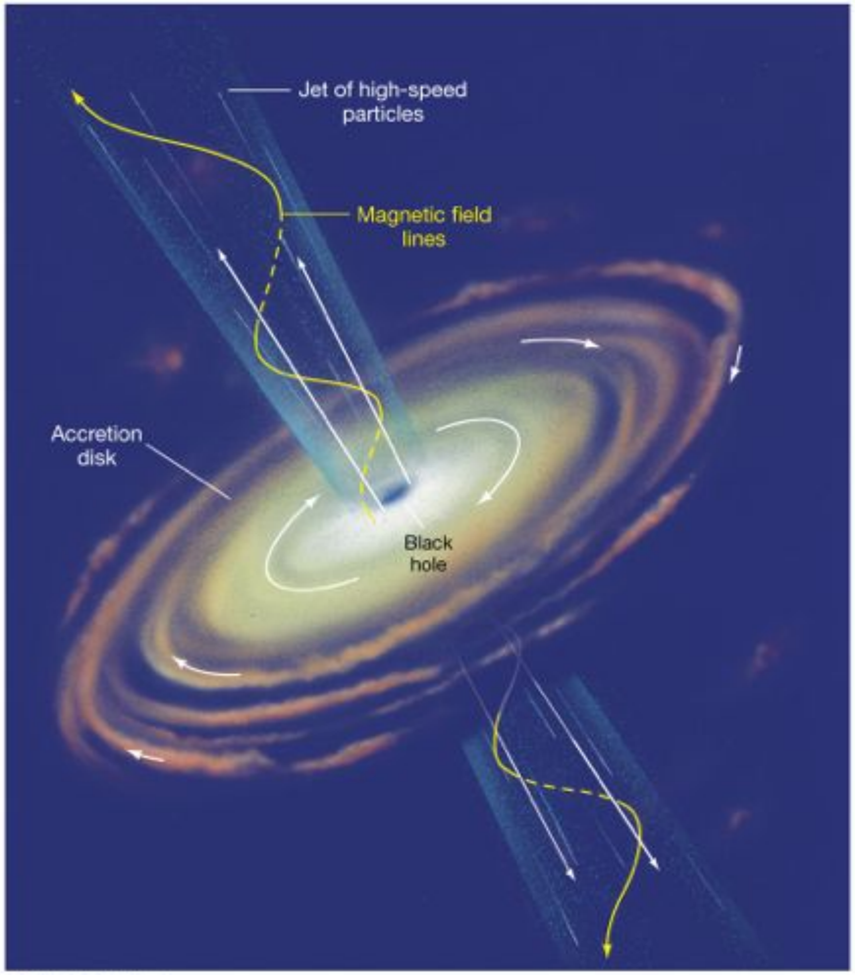


Quasars

- Incredibly luminous nuclei of galaxies
- Most abundant at z=2, known to z>7
- Spectra weird – high velocities (rapid rotation)

The Central Engine of an Active Galactic Nucleus [AT24.5]

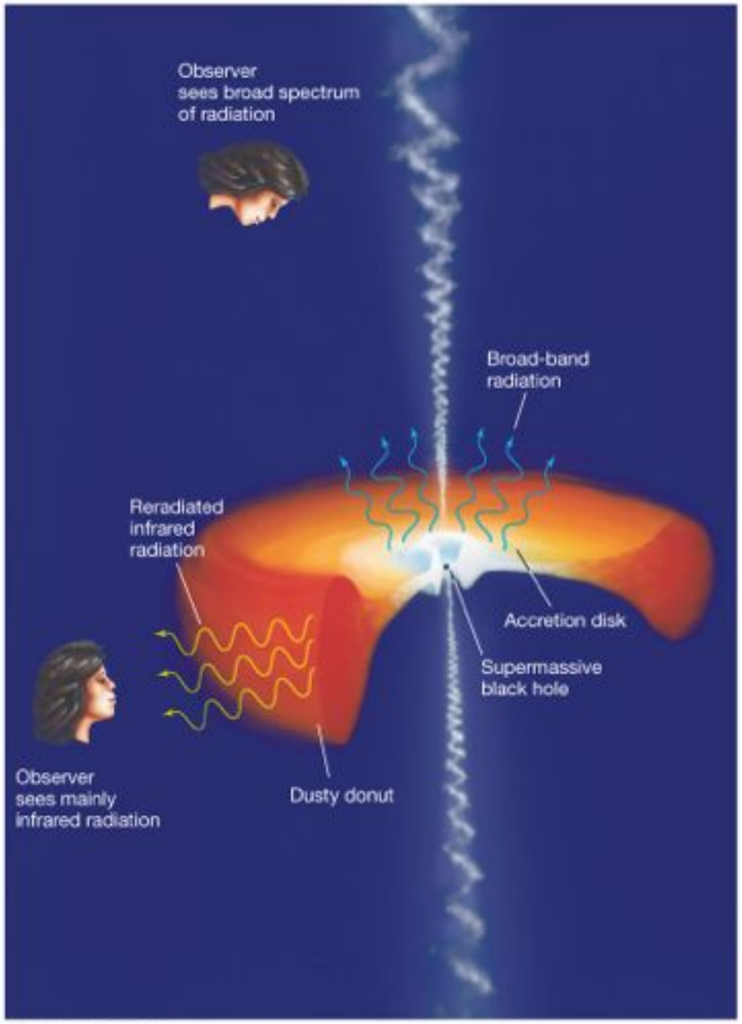
A black hole, surrounded by an accretion disk. The strong magnetic field lines around the black hole channel particles into jets perpendicular to the magnetic axis.



The Central Engine of an Active Galactic Nucleus [AT 24.5]

One might expect the radiation to be mostly X and gamma-rays. Why?

- apparently it is often "reprocessed" in the dense clouds around the black hole and reemitted at longer wavelengths.



Active Galactic Nuclei - Summary

Active galactic nuclei have some or all of the following properties:

- high luminosity
- nonstellar synchrotron energy emission
- variable energy output, indicating small nucleus
- jets and other signs of explosive activity
- broad emission lines, indicating rapid rotation

Energy comes from material accreting onto a supermassive black hole.

Q: **most** massive galaxies harbour a supermassive black hole in their core. So, why aren’t all galaxies quasars?

The Milky Way has a supermassive black hole in its core. Is the Milky Way an AGN?

A. Yes, always.
B. No, never – its black hole isn't massive enough
C. Possibly at some time in the past, but not at the present time.
D. No, never – spiral galaxies never become AGN's.