Active Galaxies

- Colliding galaxies and mergers
- Starburst galaxies
- Active Galactic Nuclei
- Super-massive black holes

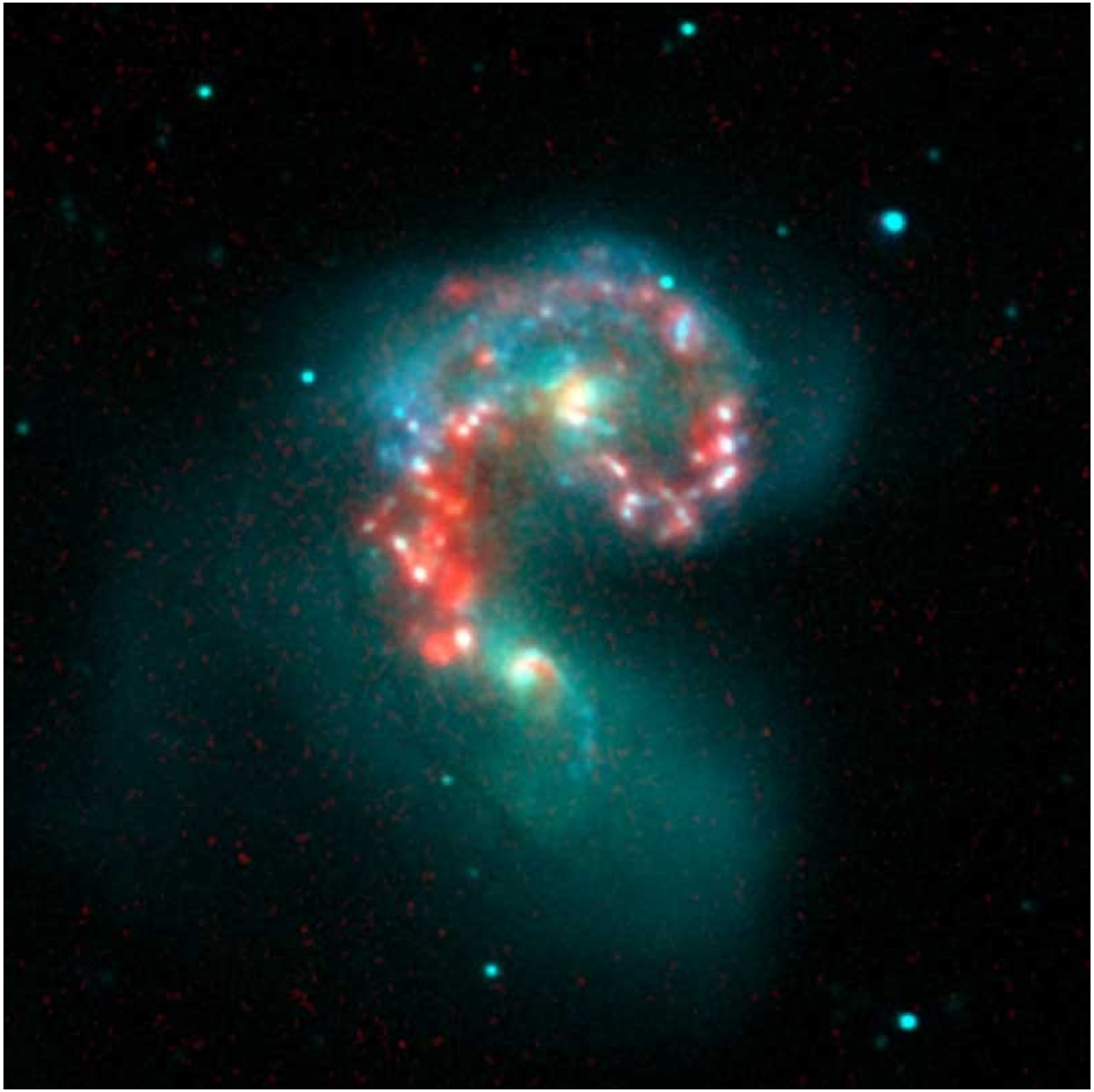
Colliding Galaxies

- When two large galaxies collide they get completely disrupted
- Large tidal tails can develop as the galaxies orbit each other in close proximity
- If both galaxies contain gas then this gets shocked and compressed
- This results in a burst of star formation – can result in a so-called starburst

Antennae galaxies

Optical

Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration



Antennae

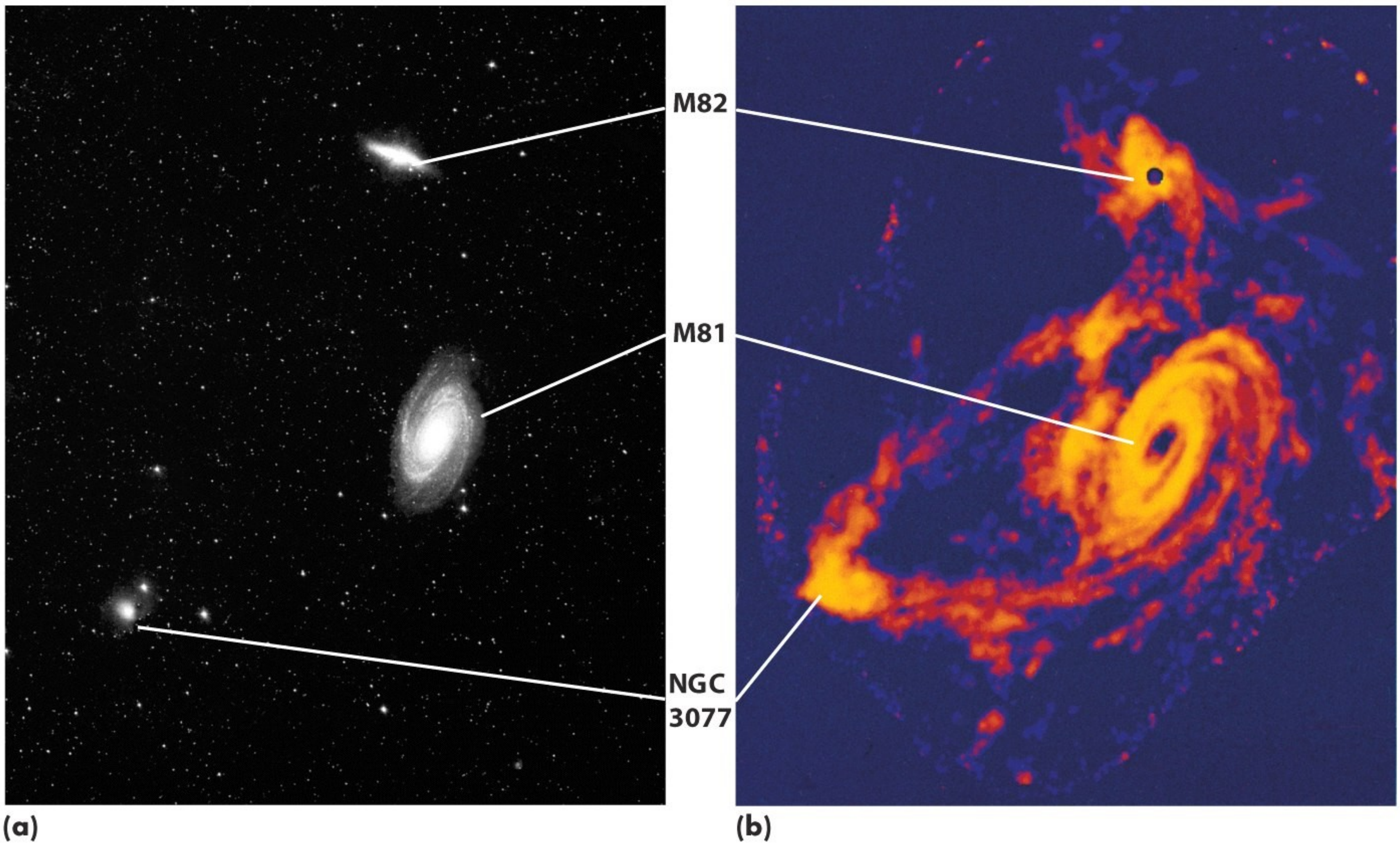
Mid-infrared

Credit: NASA/JPL-Caltech/Z. Wang (Harvard-Smithsonian CfA); Visible: M. Rushing/NOAO

Credit: NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA

The Tadpole Galaxy

Radio images reveal interaction where none is obvious

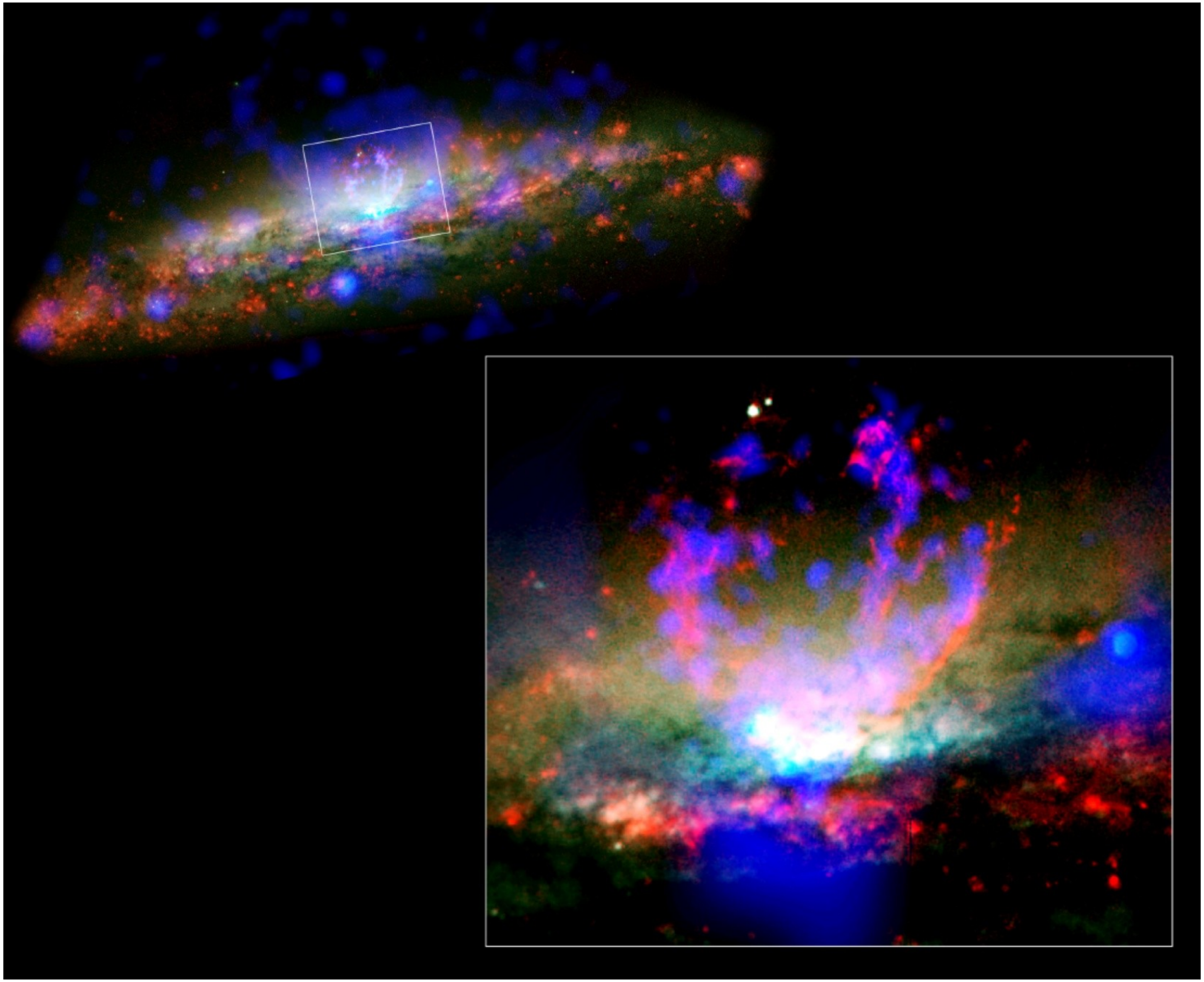


Optical: no obvious signs of interaction

H I: Tidal tails of atomic gas connecting the galaxies

Starburst galaxies/Super winds/

- The large numbers of massive stars and their supernovae in starbursts blows gas out of the galaxy → starburst galaxies
- This action can remove all gas from a galaxy, stopping all subsequent star formation, leading to the formation of an elliptical galaxy



NGC 3079

Optical: red, green (HST)

X-ray: blue

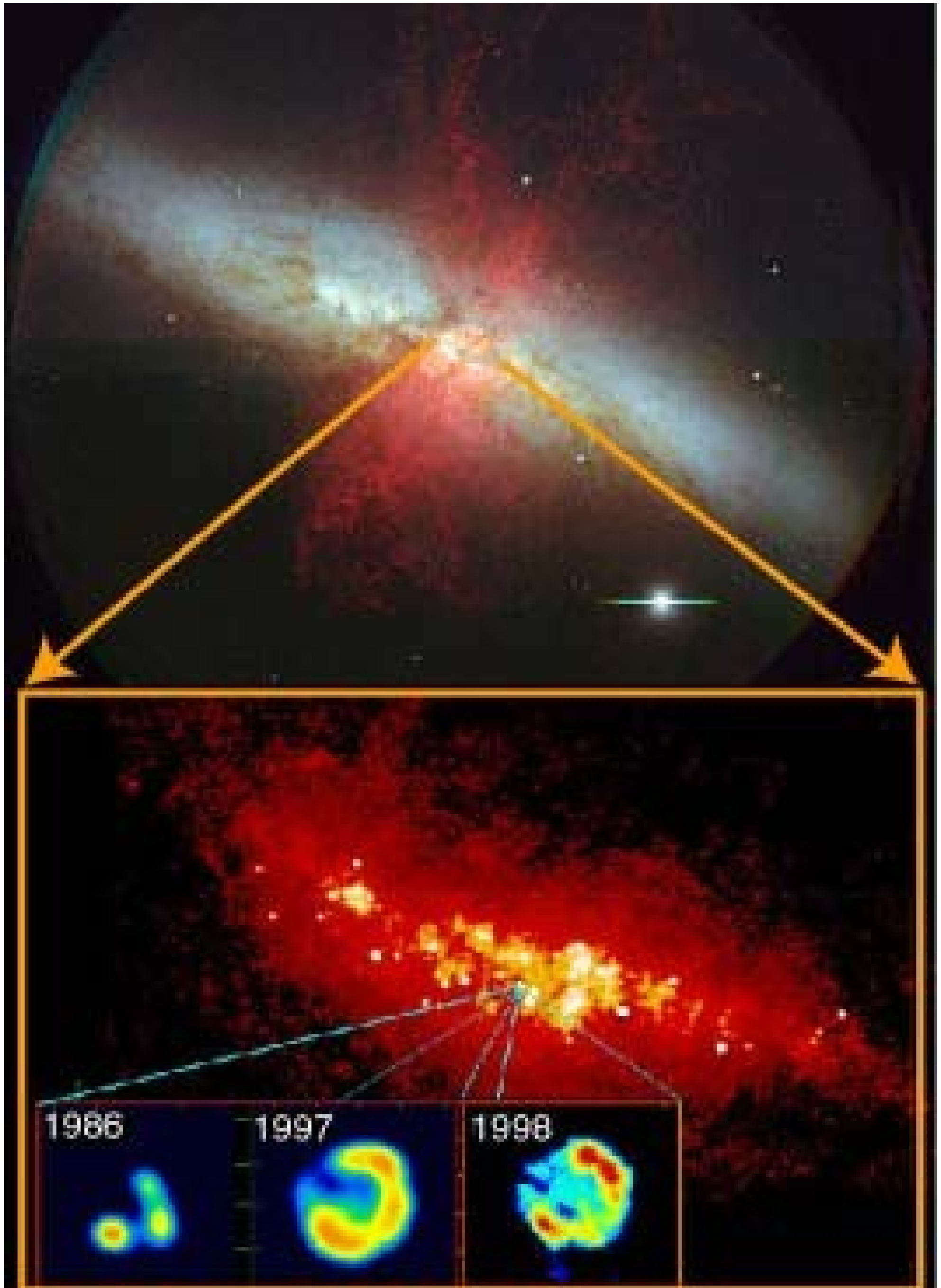
(Chandra)

Credit: NASA/CXC/STScI/U.North Carolina/G.Cecil

M82 Optical: yellow/green, Hα: red (HST)

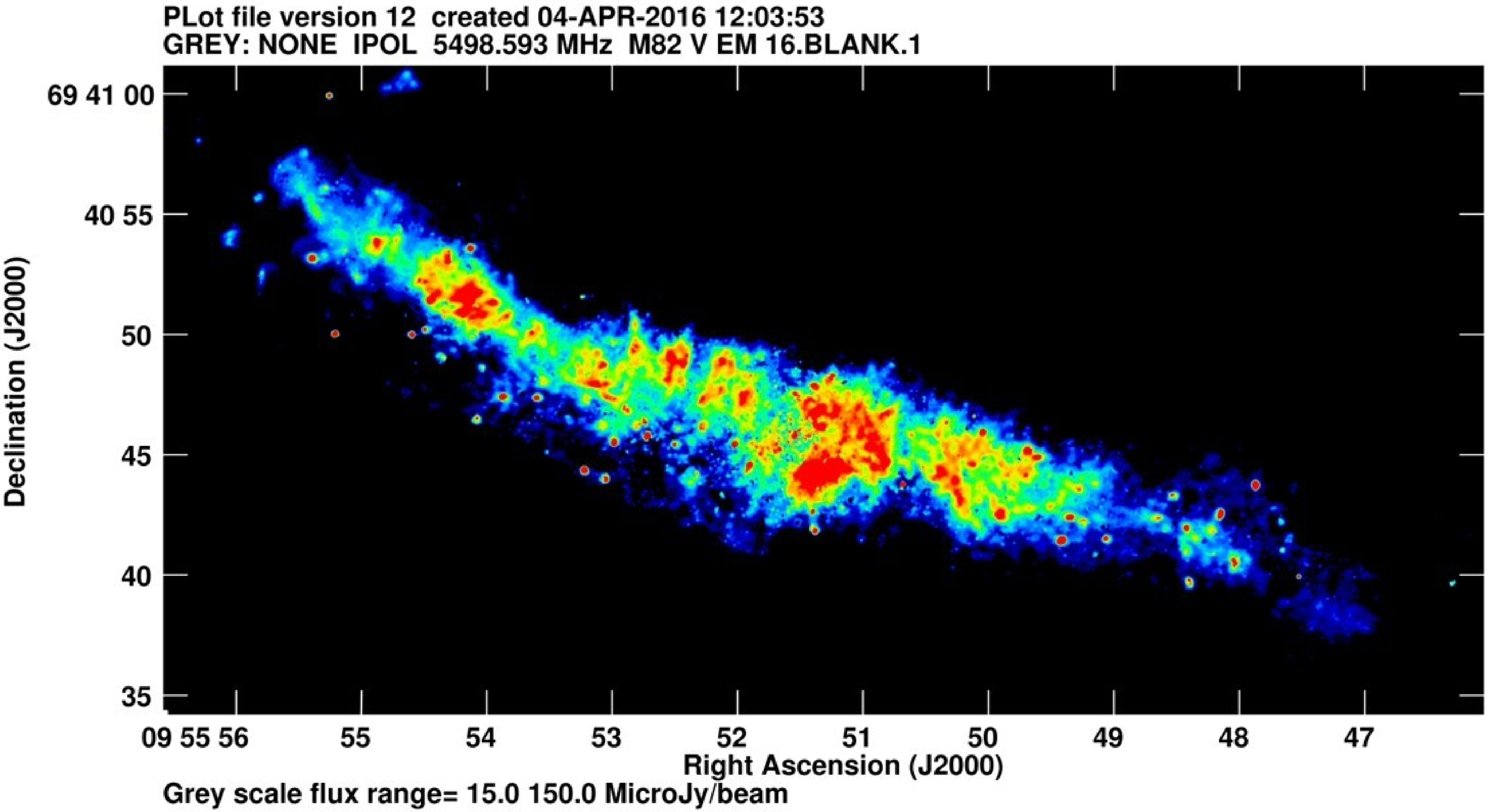
X-ray: blue (Chandra)

Credit: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht



M82 optical

M82 central region; radio showing supernova remnants



M82 central region; radio image showing supernova remnants in more detail

Active Galactic Nuclei

- Active galaxies have a luminous point-like nucleus (hence AGN)
- If the very luminous nuclei dominates the galaxy – quasi-stellar objects or quasars

Active galaxies and active galactic nuclei (AGN)

- These kinds of galaxies have **active nuclei**:
  - Quasars: in elliptical galaxies
  - Radio galaxies: in elliptical galaxies
    - Both discovered originally by radio astronomers. Thousands of each are now known.
  - Seyfert galaxies: spirals with weak central AGN activity
  - "Blazars": radio galaxies and quasar jets pointing at us
    - Both discovered originally by visible-light astronomers. Hundreds of each also now known.
- We know thousands of them, but active galaxies are rare (~1% powerful to 10% weak) → they are greatly outnumbered by normal galaxies.

What makes AGN so special?

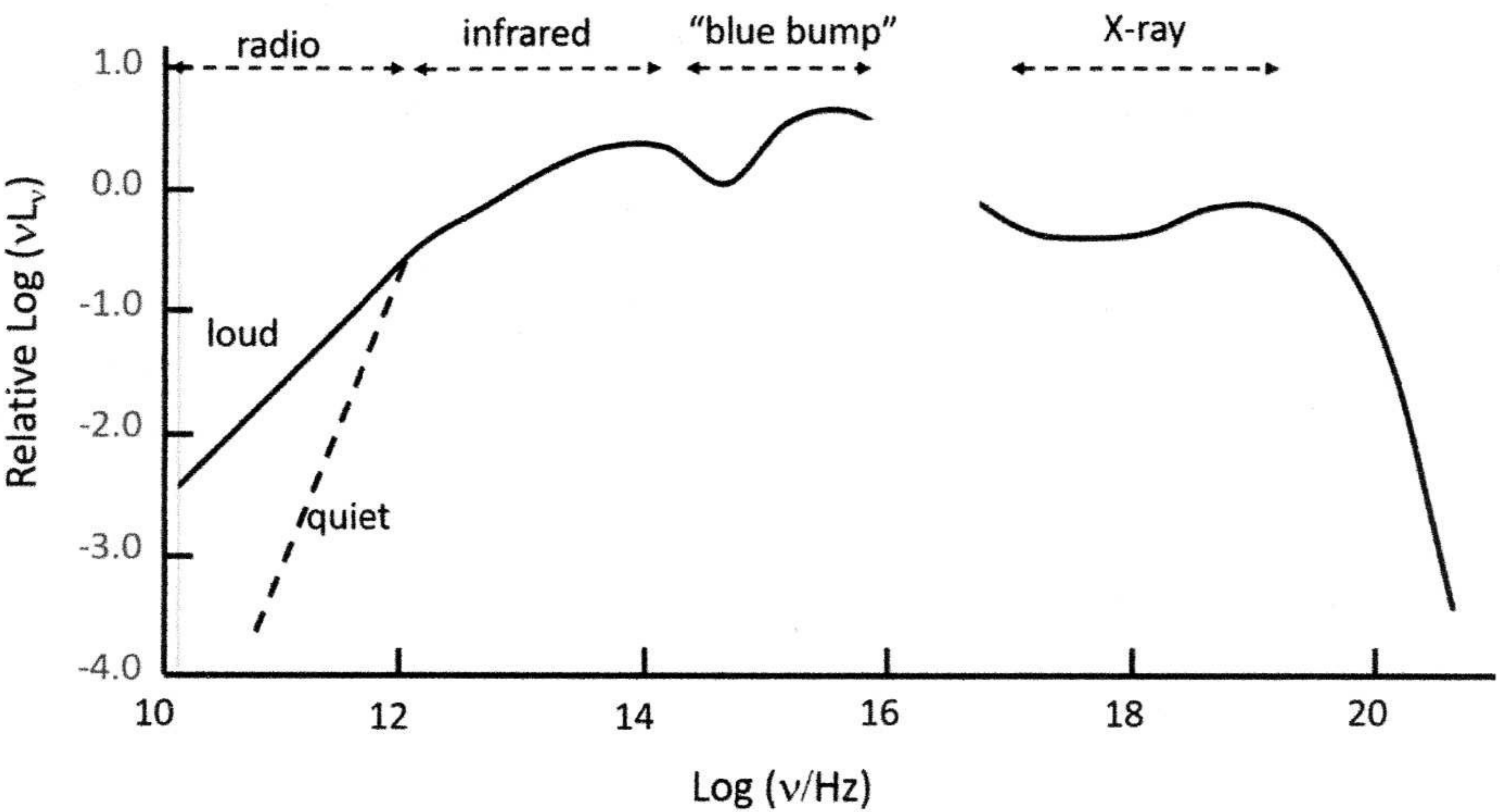
- Very large luminosities are possible (up to 10,000 times a typical galaxy)
- The emission spans a huge range of photon energy (radio to gamma-rays)
- The source of energy generation is very compact (< size of the solar system)
- In some cases, there is significant energy transported in relativistic jets → radio loud AGN

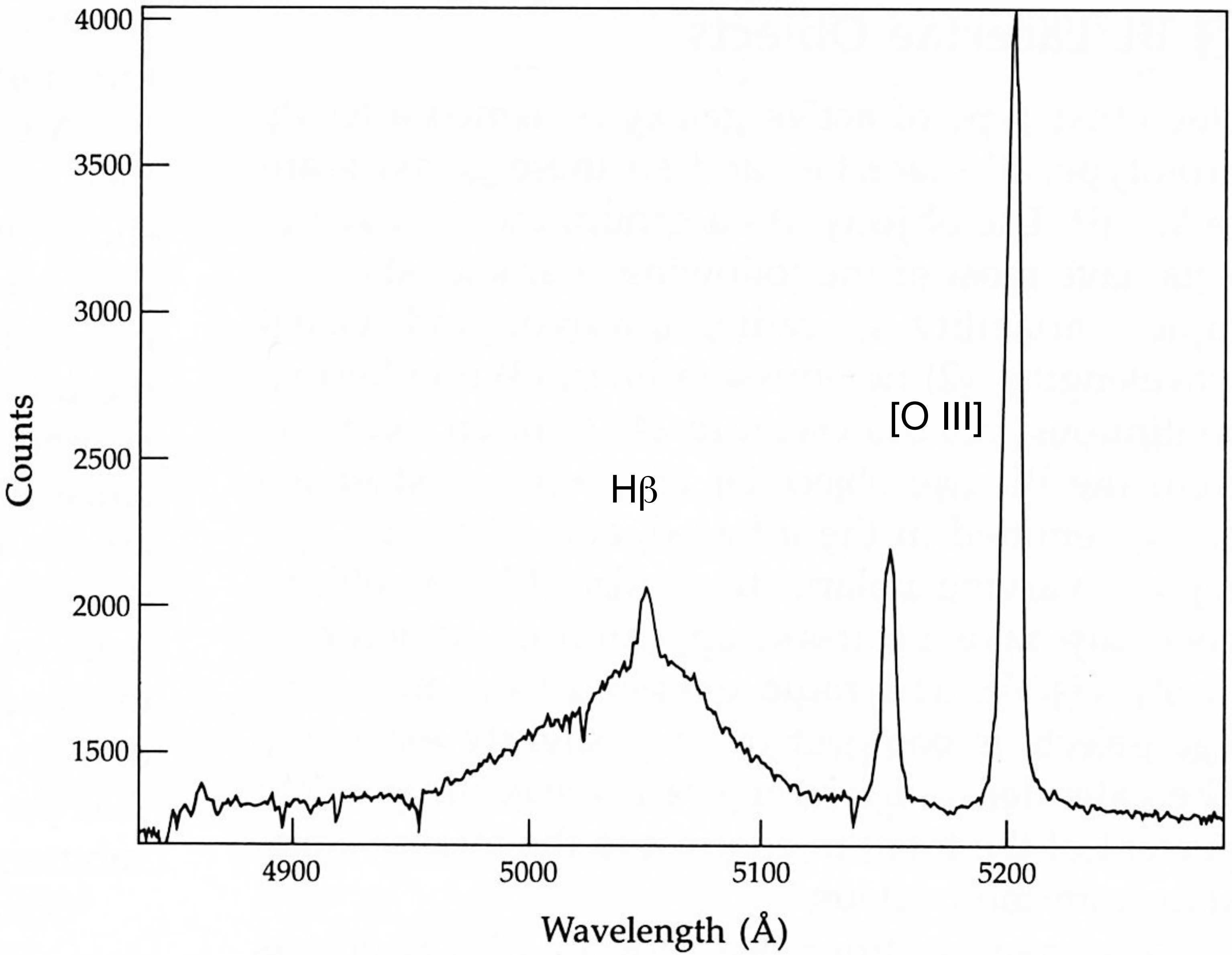
- An AGN nucleus has a non-thermal continuum spectrum that extends from radio to X-rays and γ–rays
  - Very much broader than the integrated light of stars (sum of “black bodies” with temperature range of ~10)

- Also has an emission line spectrum where the Balmer lines are often seen to be very broad → Doppler shifts → high velocities
of gas in the nuclear regions

AGN emit over a very broad frequency range

(Totally unlike stars which are quasi-black bodies)





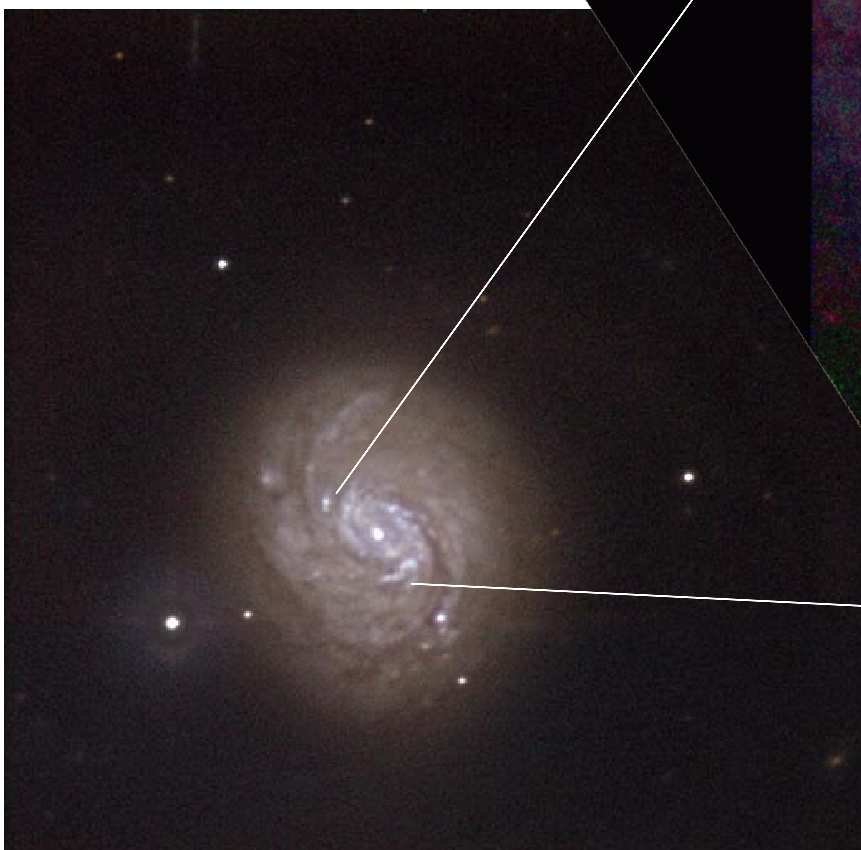
Active galaxy optical spectrum showing broad emission line (Zeilik Fig 24-2)

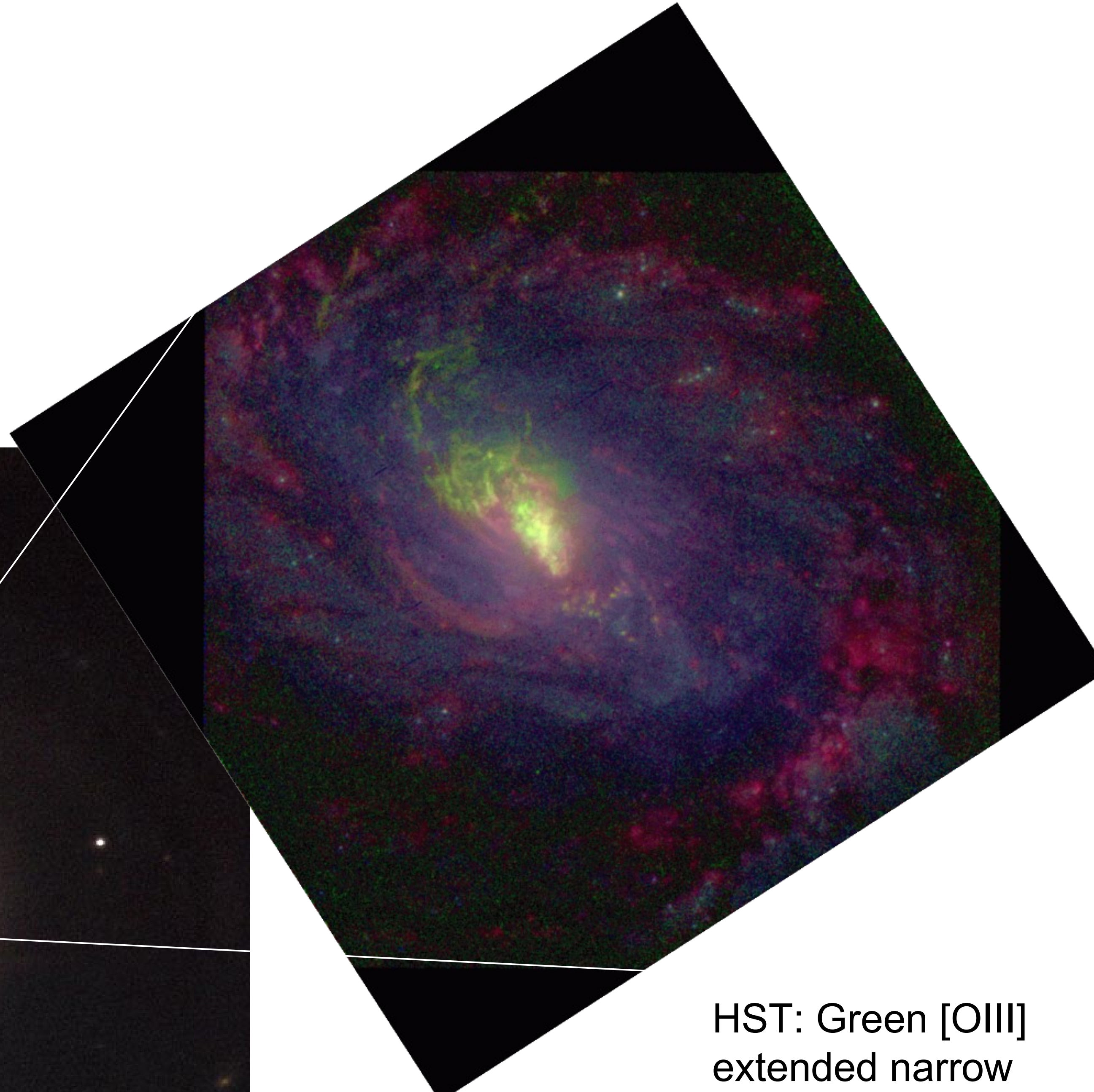
- Active galaxies have a luminous point-like nucleus (hence AGN)
- If the very luminous nucleus dominates the galaxy – quasi-stellar object or quasar
- The high redshift quasar host galaxies show signs of interaction
- In low redshift *spiral* galaxies the nuclear activity is much weaker – Seyfert Galaxies

Active Galaxy (Seyfert) NGC 4051 Image Credit: George Seitz/Adam Block/NOAO/AURA/NSF

NGC 1068

Seyfert 2

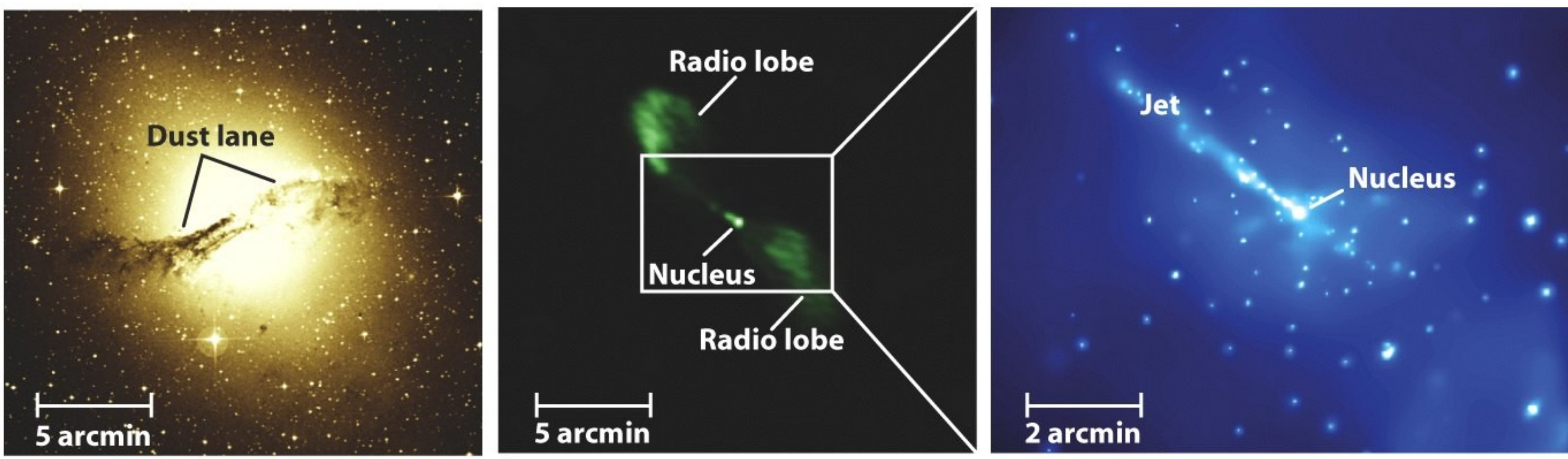




HST: Green [OIII] extended narrow line region

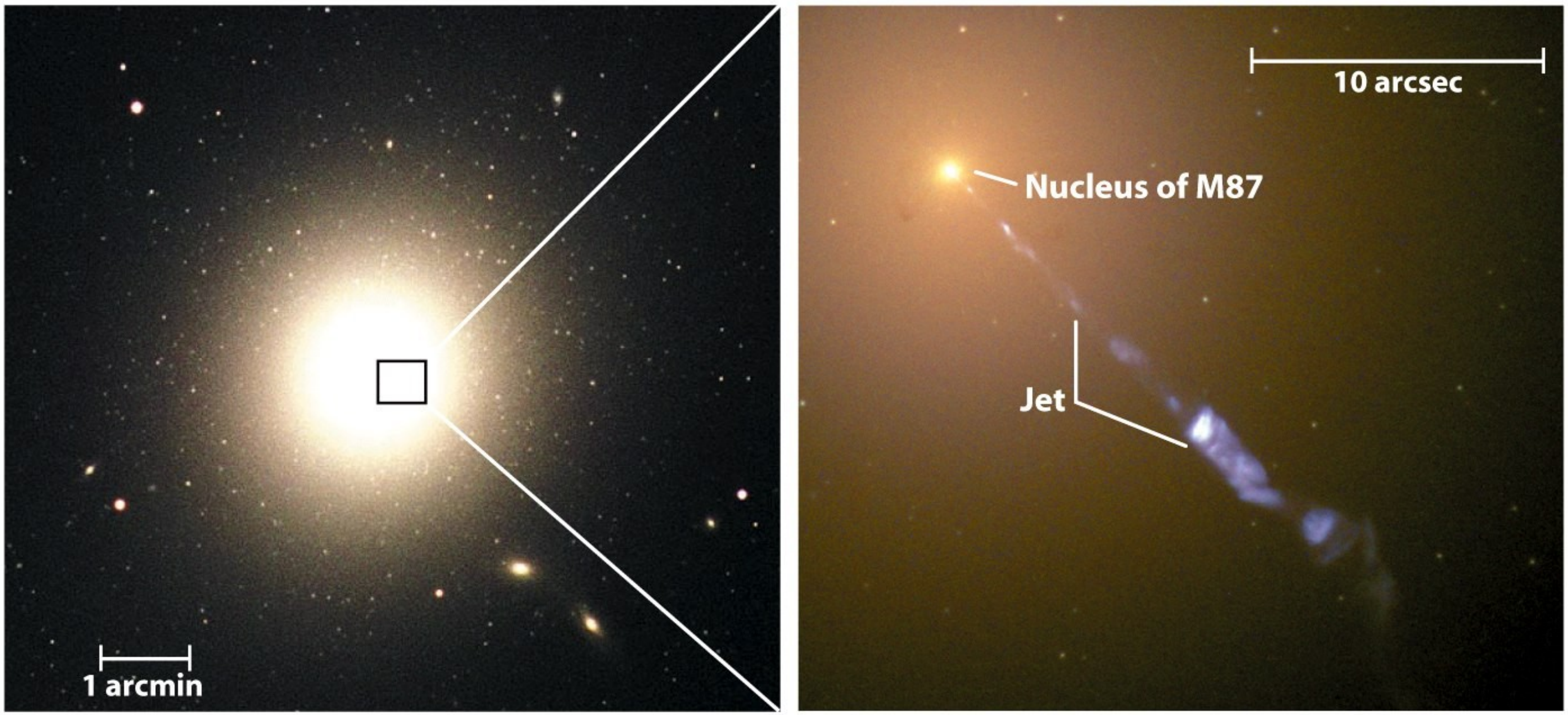
Radio galaxies

are *elliptical* galaxies located midway between the lobes of a double radio source – much more luminous than Seyferts



(a) Centaurus A: light from stars **(b)** Centaurus A: radio lobes **(c)** An X-ray-emitting jet emanates from the nucleus

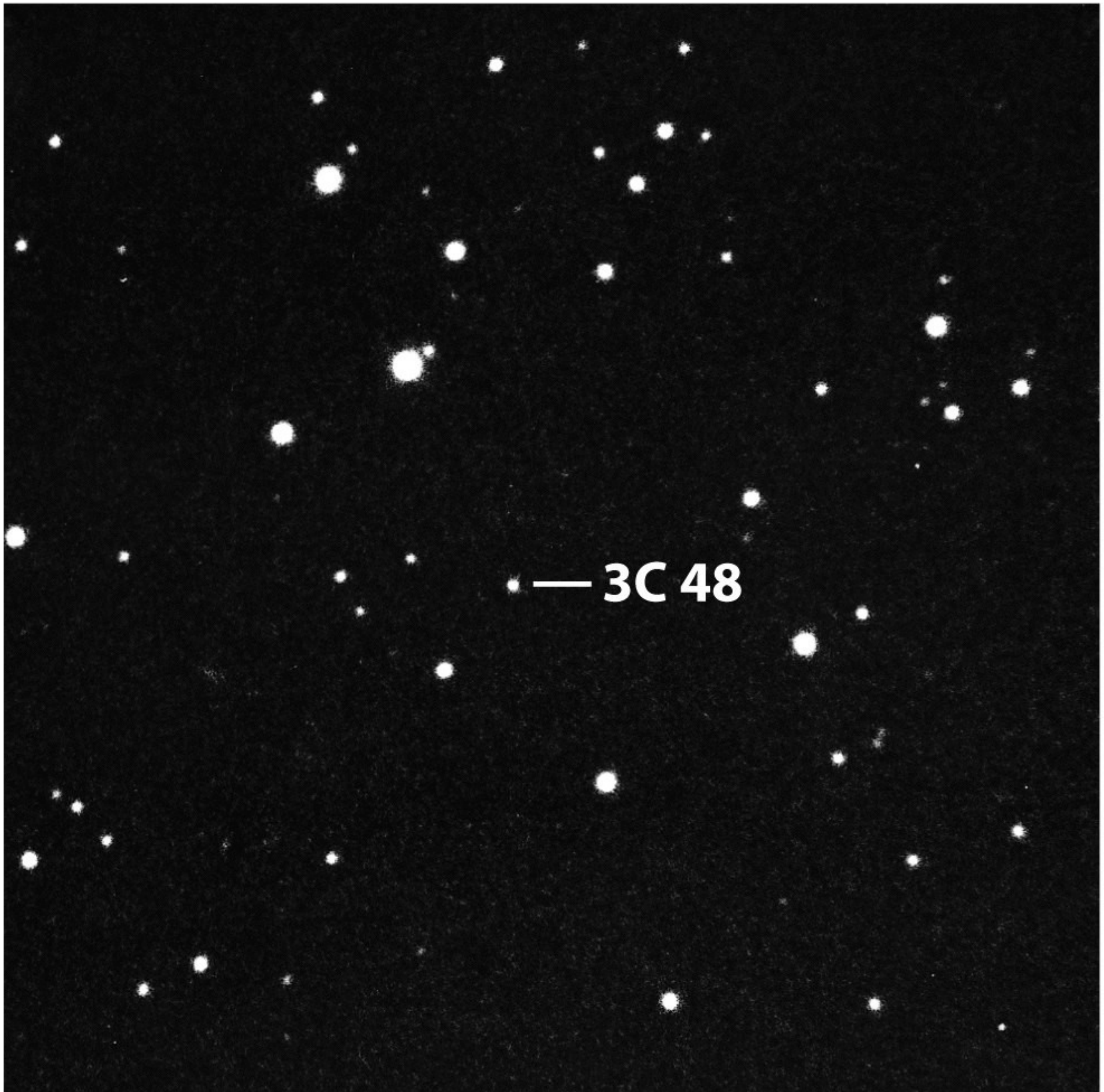
Relativistic particles are ejected from the nucleus of a radio galaxy along two oppositely directed beams



(a) The giant elliptical galaxy M87

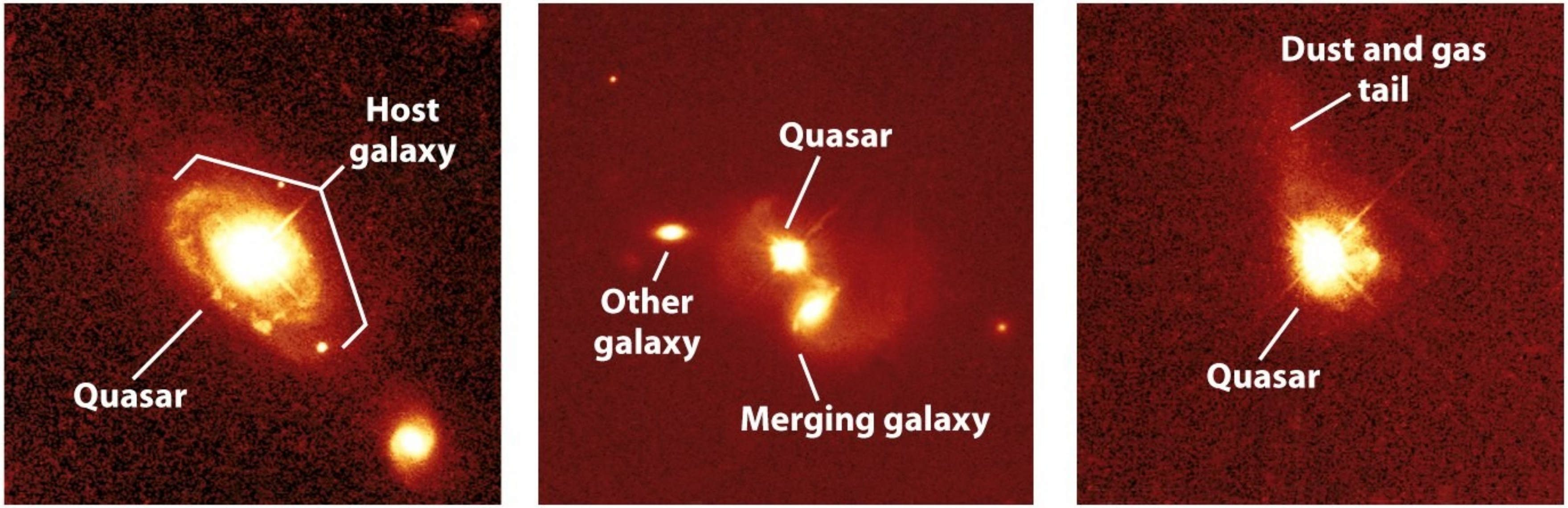
(b) A shorter exposure reveals M87's jet

Quasars



Optical image of quasar

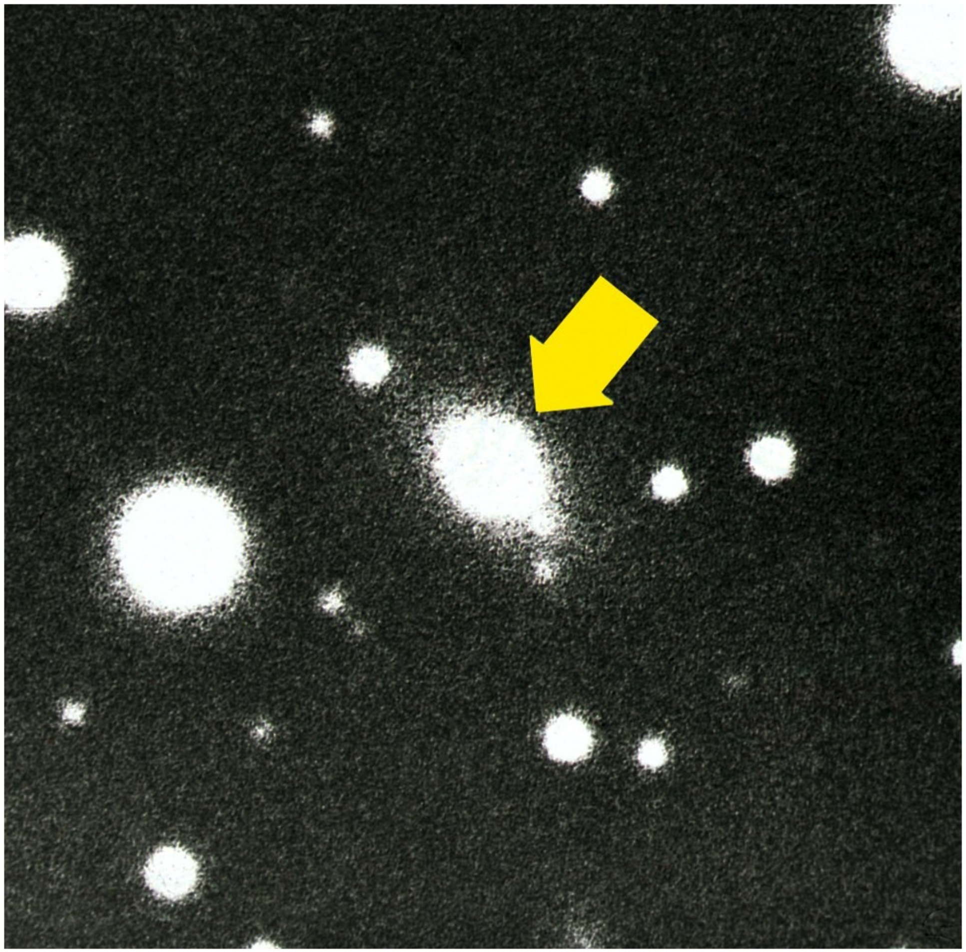
Quasars



(a) (b) (c)

- Quasars are the ultraluminous centers of distant galaxies
- HST has revealed the host galaxies of some quasars
- Most show signs of interaction – trigger the activity

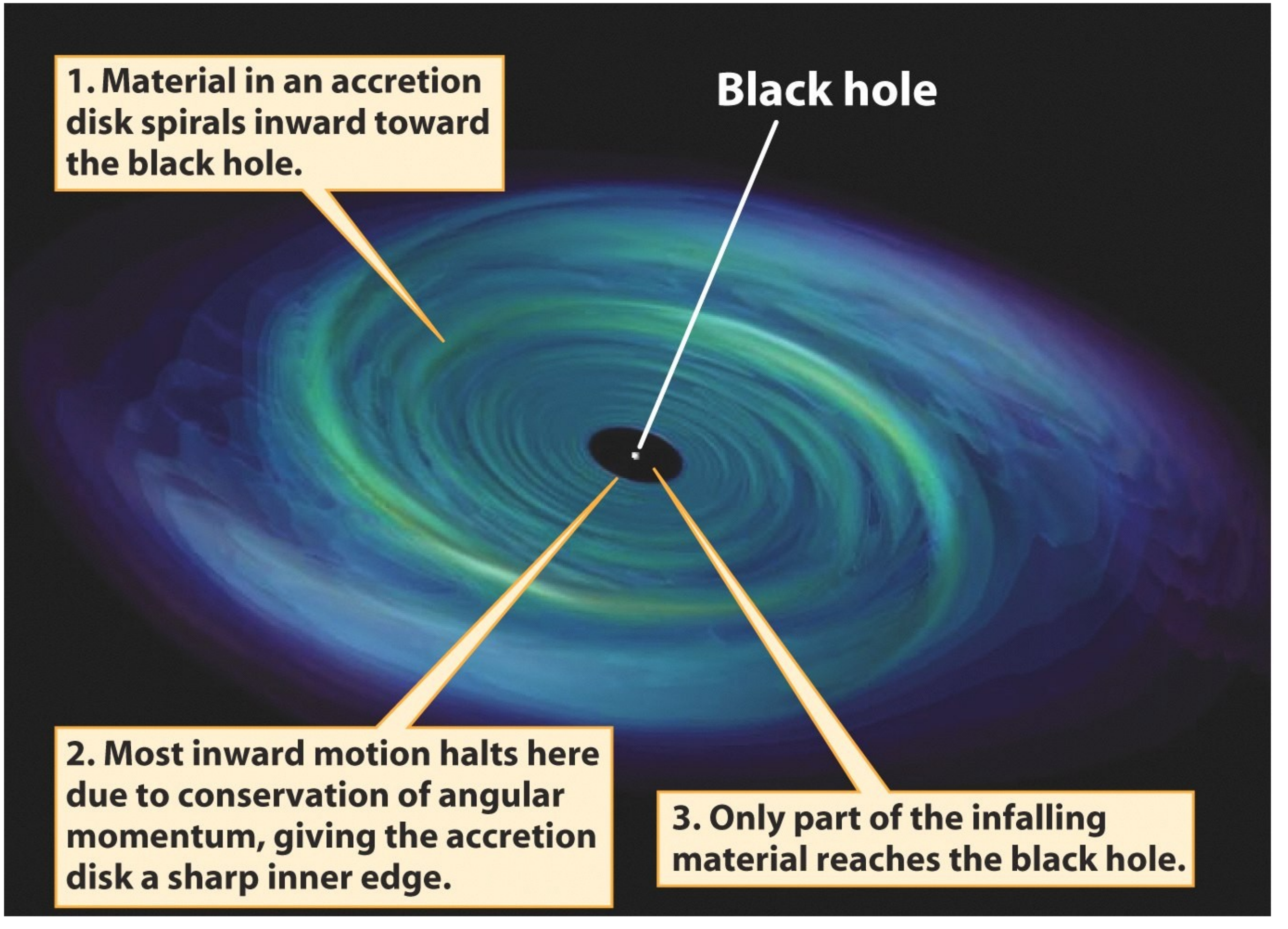
Blazars



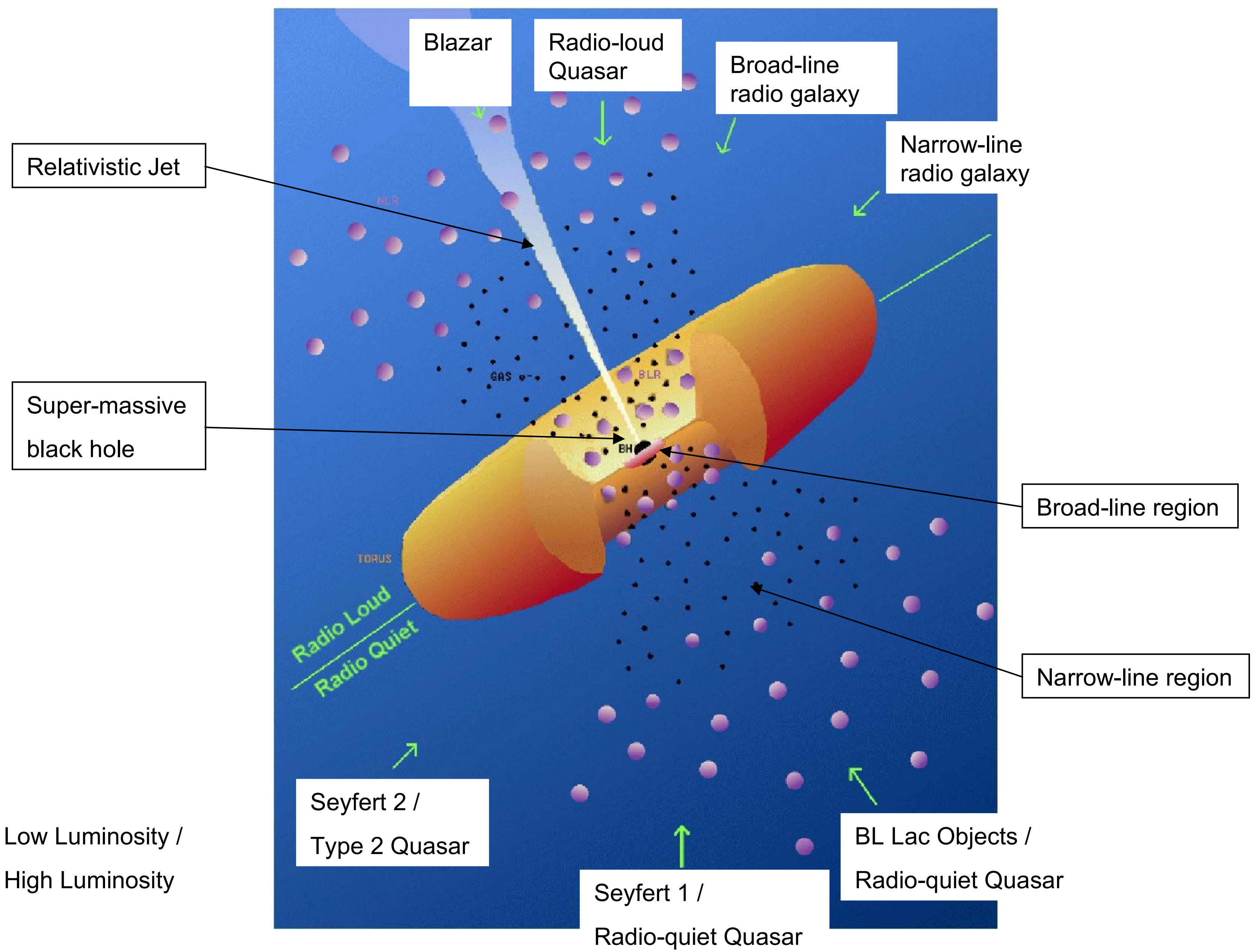
- Blazars are bright, starlike objects that can vary rapidly in their luminosity
- They are radio galaxies or quasars seen end-on, with a jet of relativistic particles aimed toward the Earth

Accretion Discs

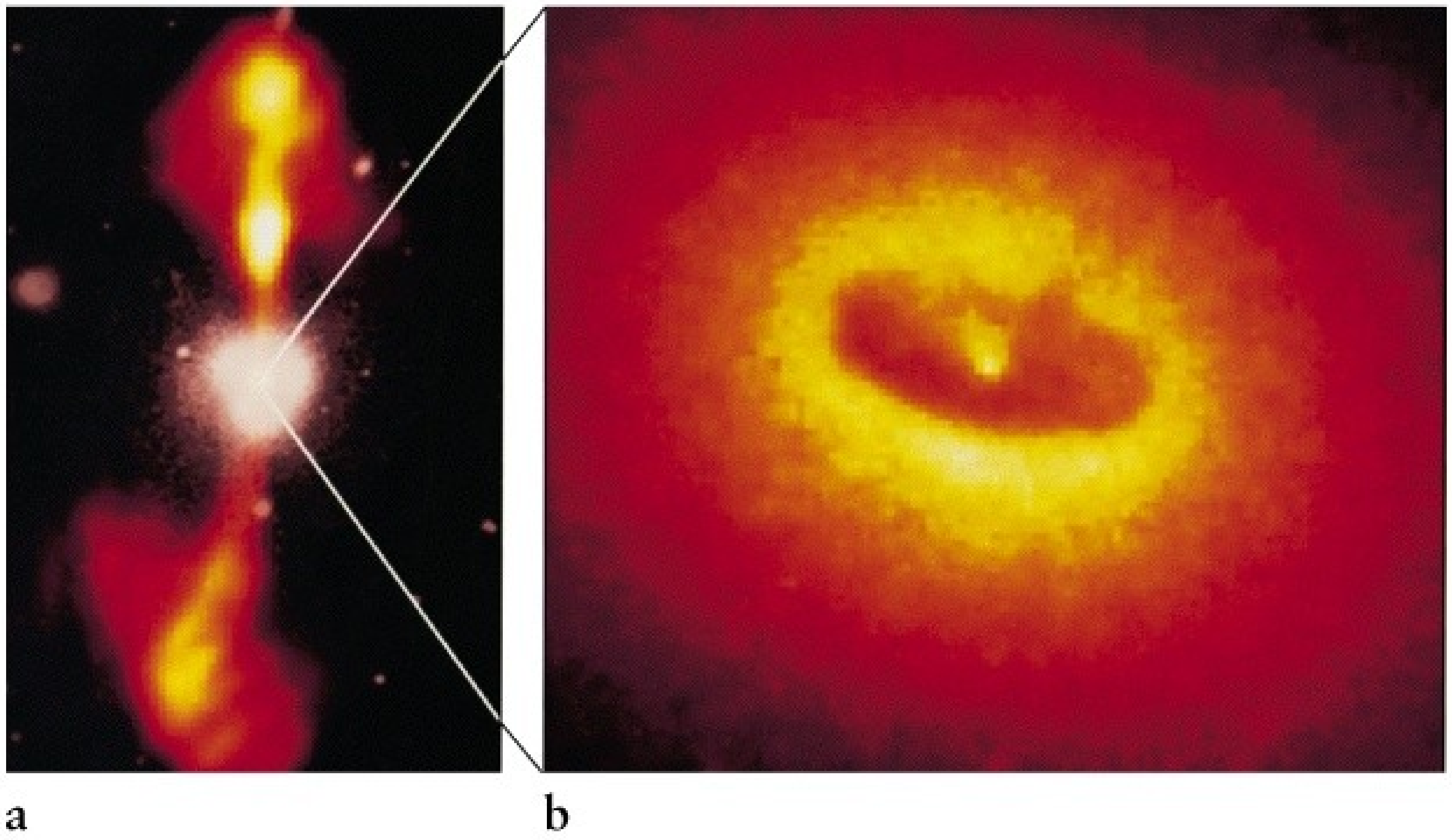
- The broad lines seen in AGN spectra can be explained by rotation of material around the super-massive black hole in a rotating accretion disc – also associated with the "broad line region"
- Rotating, magnetic disc drives a jet
- Hot gas in evacuated cavities gives rise to the narrow emission lines – called the "narrow line region"



Remind you about the star formation scenario?



Blazar
Radio-loud Quasar
Broad-line radio galaxy
Narrow-line radio galaxy
Relativistic Jet
Super-massive black hole
Broad-line region
Narrow-line region
NLR
GAS e-
BLR
BH
TORUS
Radio Loud
Radio Quiet
Seyfert 2 / Type 2 Quasar
Seyfert 1 / Radio-quiet Quasar
BL Lac Objects / Radio-quiet Quasar
Low Luminosity / High Luminosity



NGC 4261 Radio and Optical

NGC 4261 HST image of disc around the nucleus

Credit: National Radio Astronomy Observatory, California Institute of Technology
Credit: Walter Jaffe/Leiden Observatory, Holland Ford/JHU/STScI, and NASA

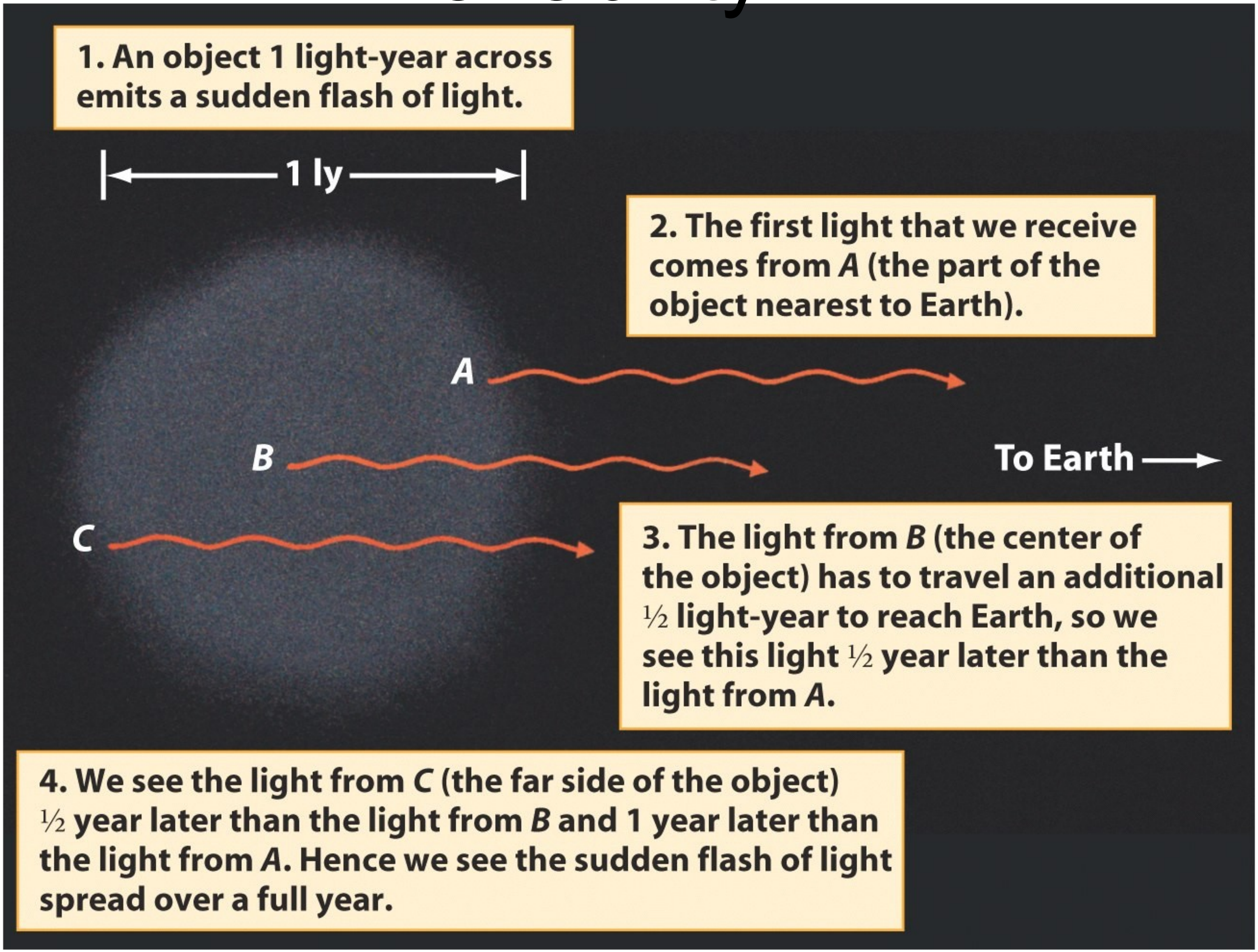
Variability

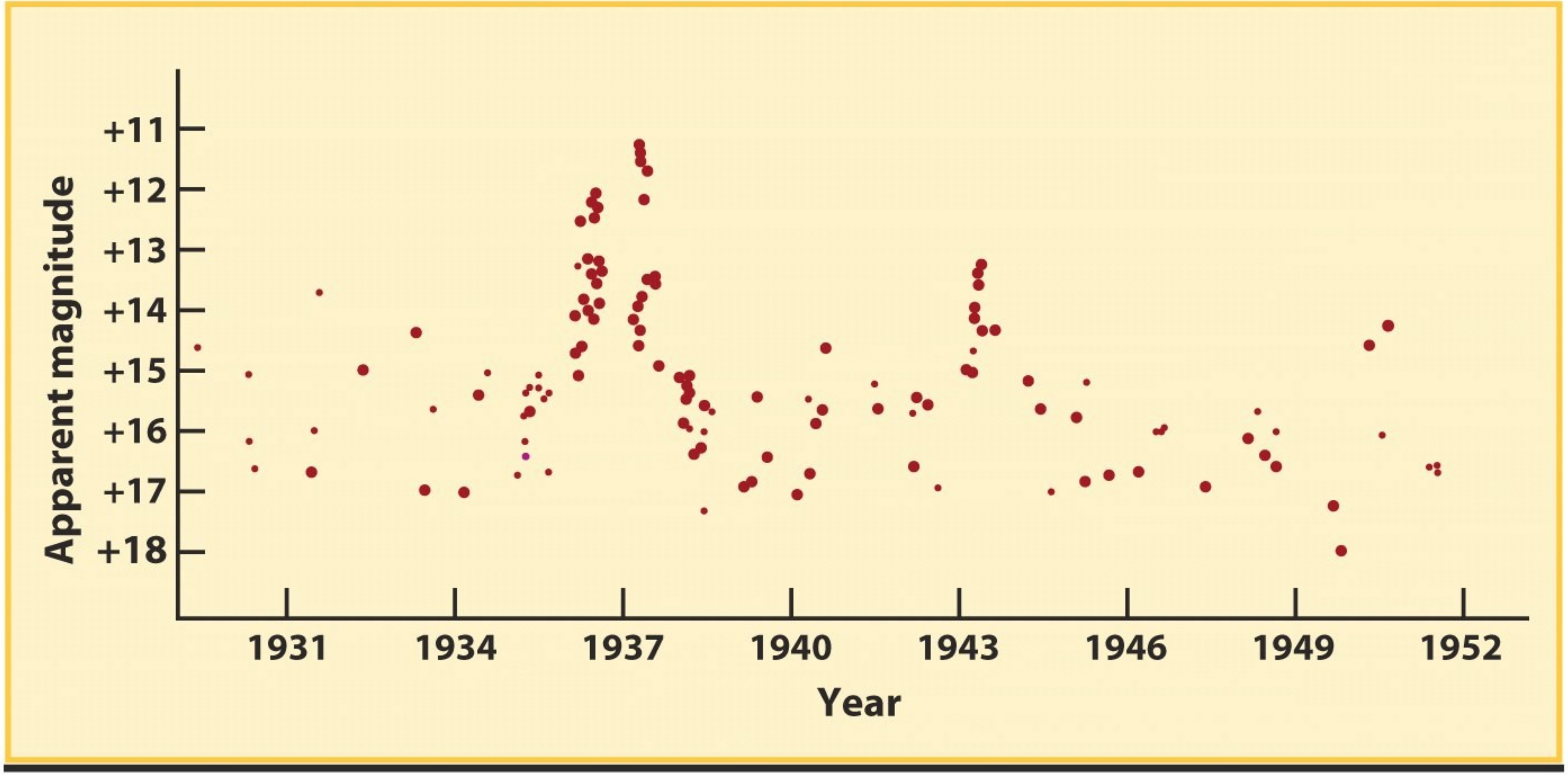
- Most AGN show variability in their brightness on timescales of months
- The variability timescale allows an upper limit to be placed on the size of the emitting region

$$l \leq ct$$

where l is the size of the region and t is the variability timescale

Variability





Light curve showing the variability of the continuum for an AGN

Super-massive Black Holes

- The high luminosity from such a small region can only be explained by the release of gravitational potential energy of material falling onto a very massive, compact object – a super-massive black hole

AGN Luminosity

- The total amount of energy available from letting an amount of material with mass *m*, fall onto an object of mass *M*, size *R* is

$$E = \frac{GMm}{R}$$

- If material is falling at a rate

$$\dot{m} = \frac{dm}{dt}$$

- And some fraction ε is turned into radiation the luminosity is

$$L = \varepsilon \frac{GM\dot{m}}{R}$$

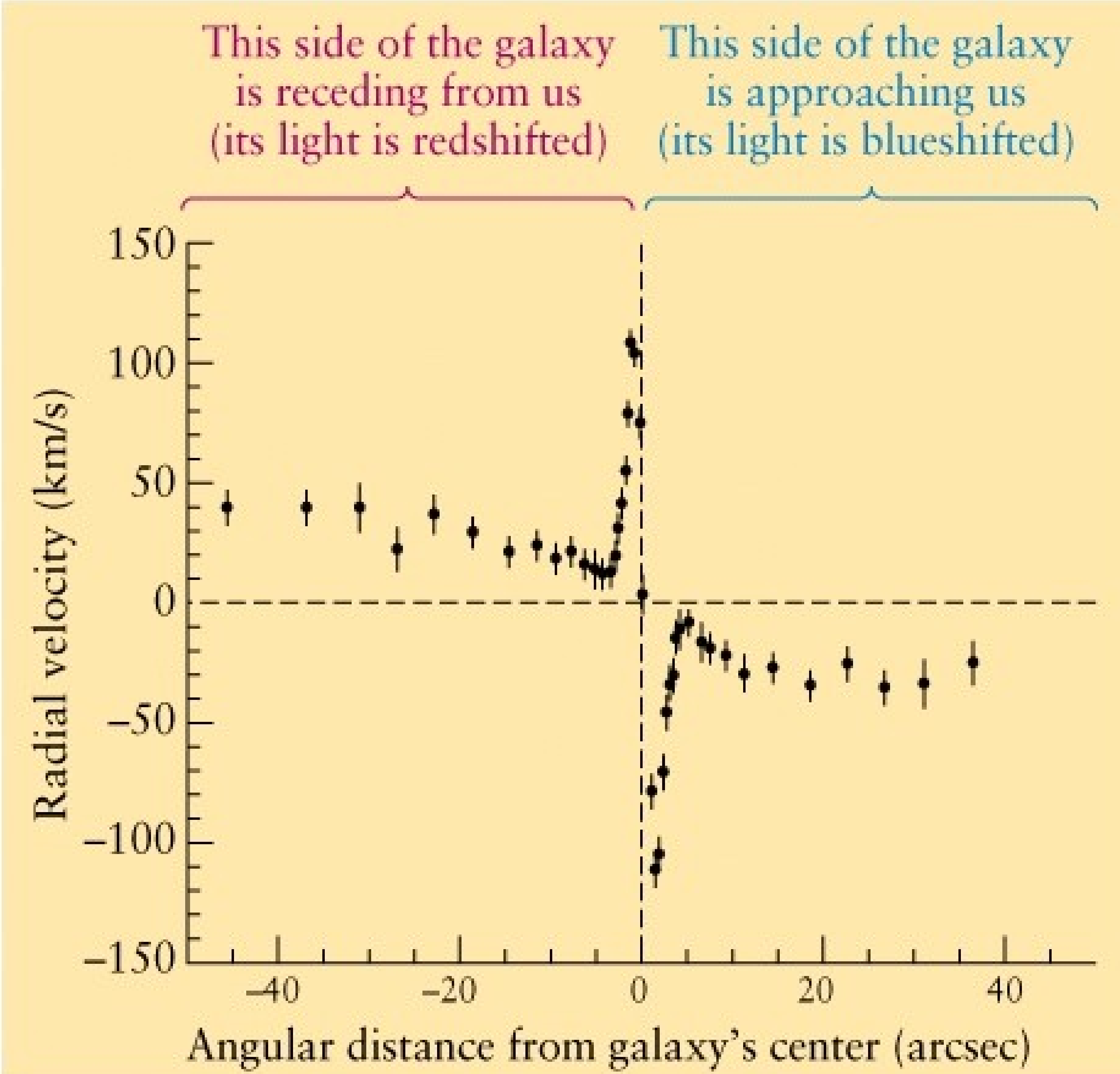
- If material gets to the Schwarzschild radius

$$L = \varepsilon \frac{1}{2}\dot{m}c^2$$

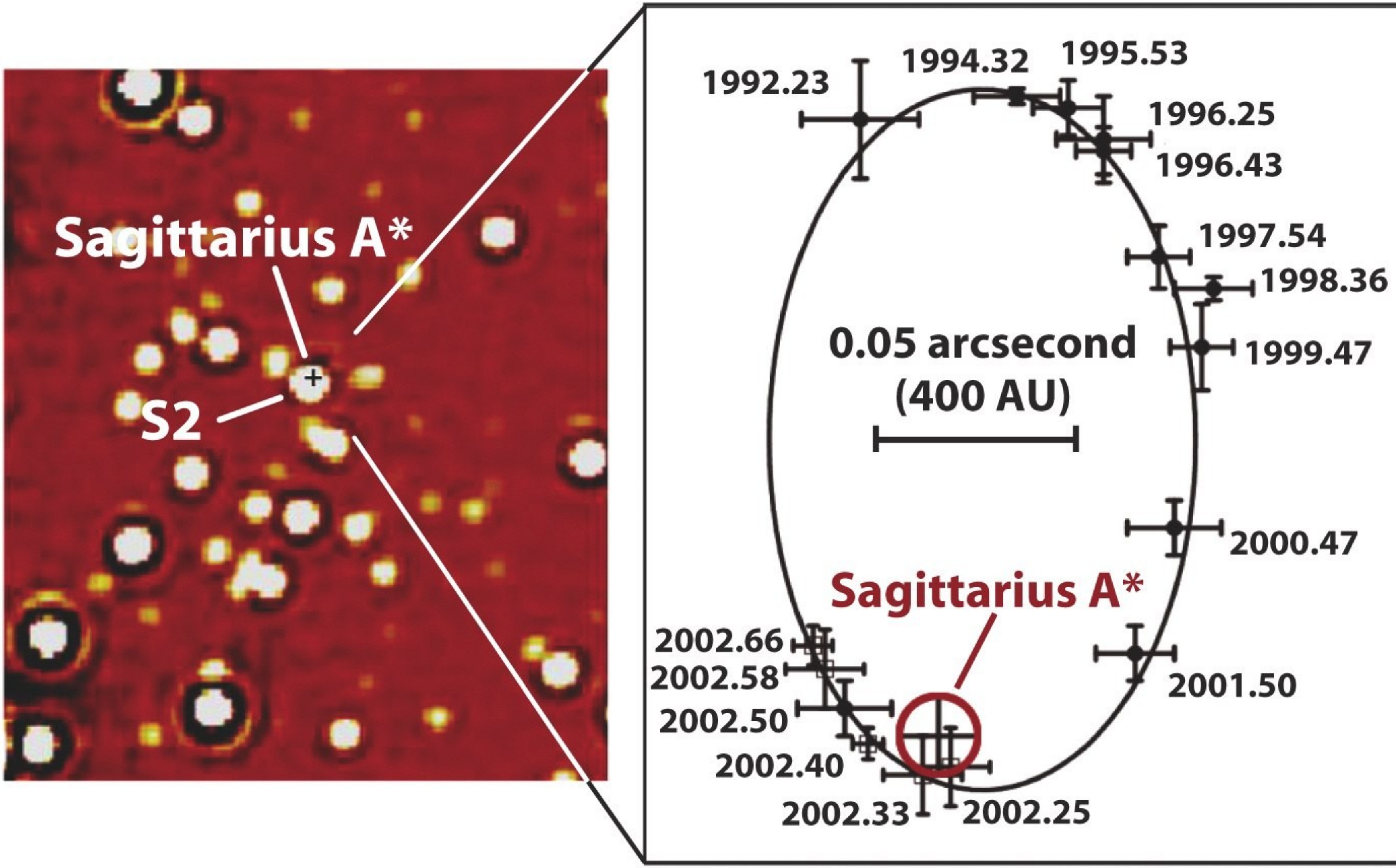
- The efficiency, ε, is thought to be about 10%

Black Hole Masses

- Super-massive black holes are revealed by the fast motion of stars near the centres of nearby galaxies
- The Doppler effect used to measure the mass
- Millions to billions of solar masses
- All galaxies posses central black holes, not just active ones, even our own

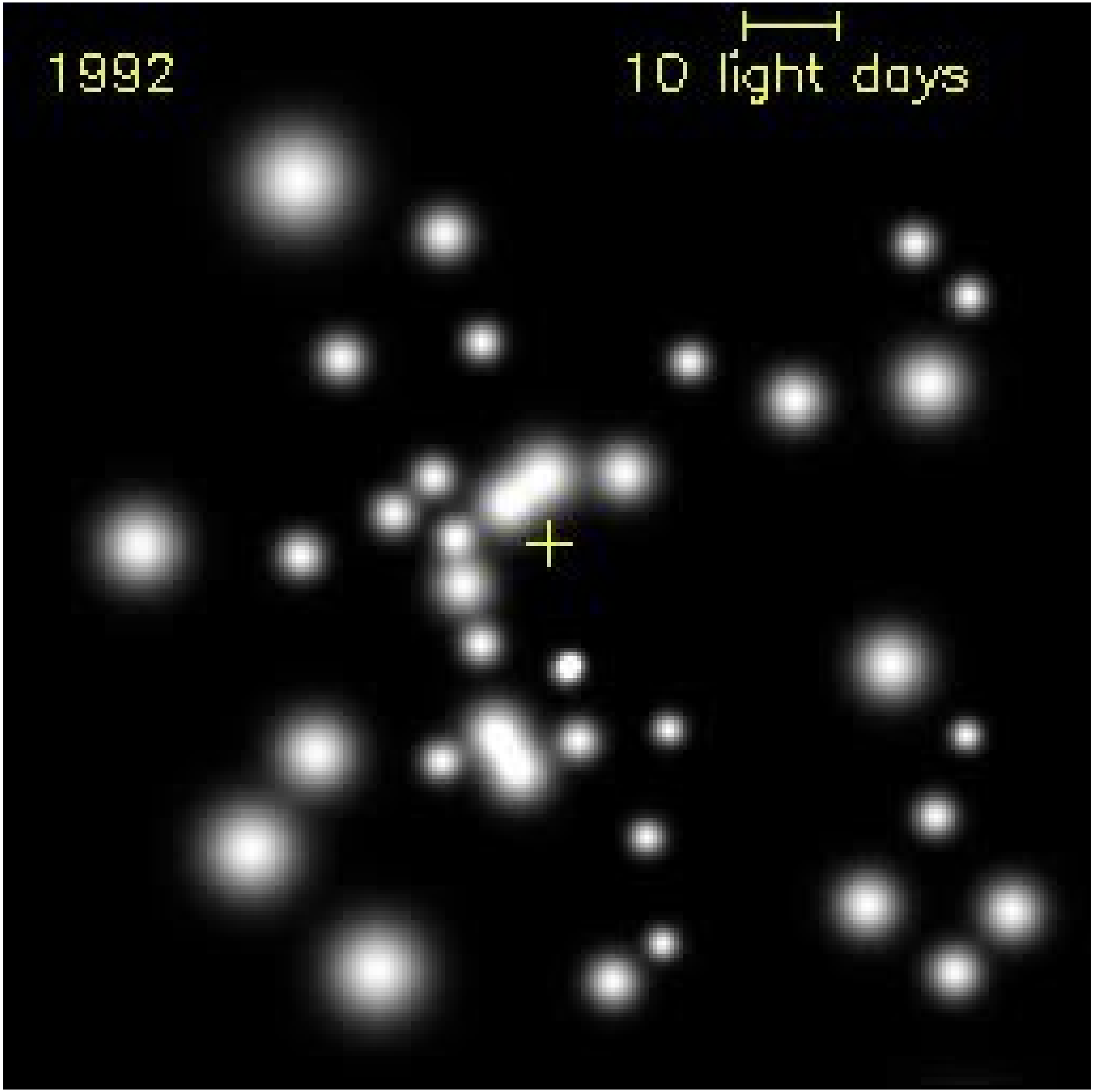


Stellar radial velocities in the core of M31

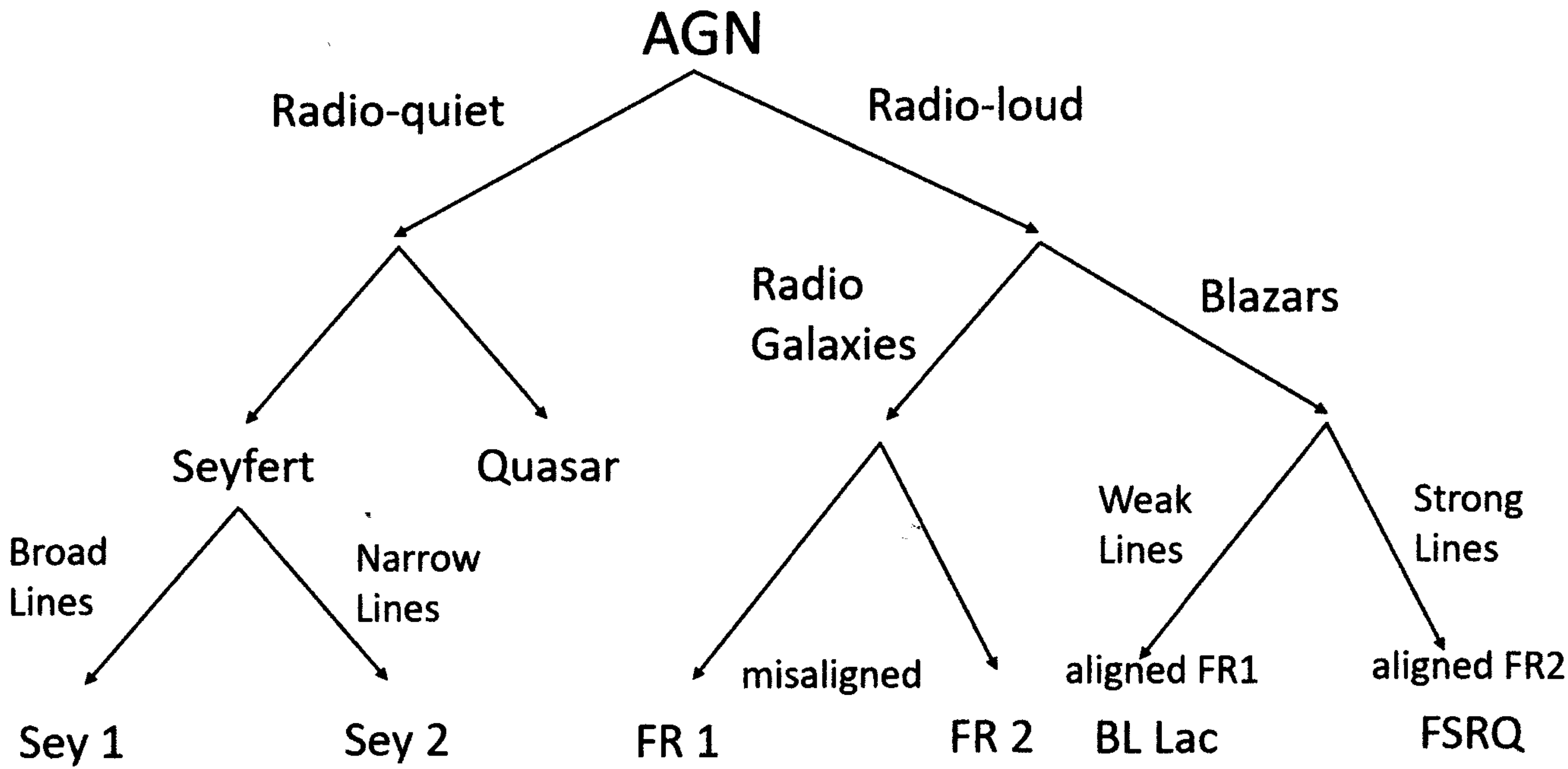


- Stellar orbits prove our Galaxy has a $4x10^6$ $M_\odot$ black hole at the centre

Genzel MPE, Garching


1992
10 light days

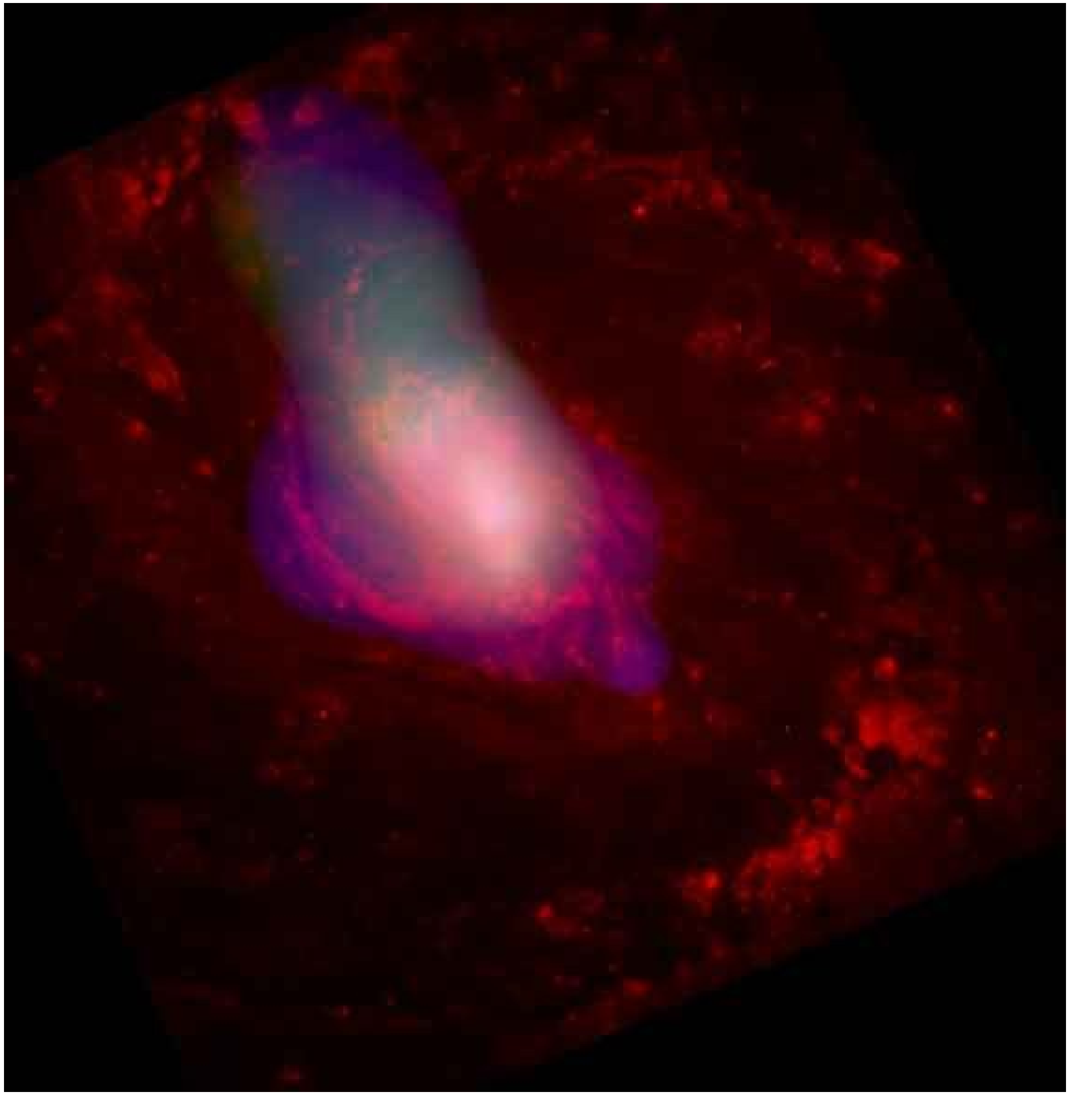
Summary - 1



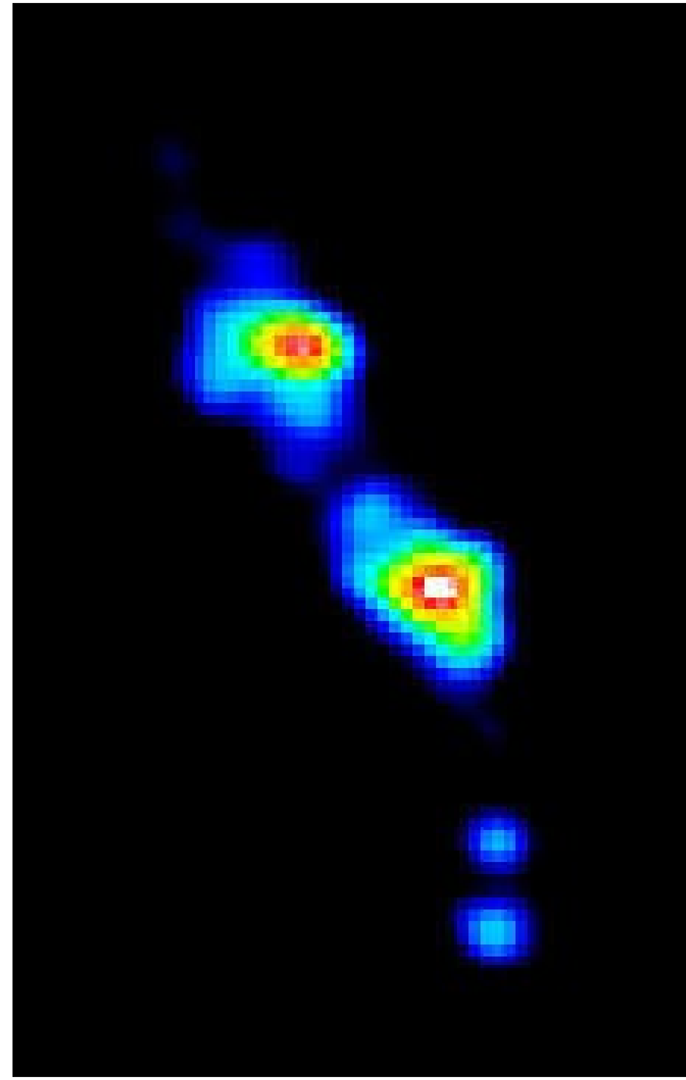
AGN
Radio-quiet
Radio-loud
Radio Galaxies
Blazars
Seyfert
Quasar
Broad Lines
Narrow Lines
Weak Lines
Strong Lines
misaligned
aligned FR1
aligned FR2
Sey 1
Sey 2
FR 1
FR 2
BL Lac
FSRQ

Summary- 2

- Galaxy interactions and mergers can result in a starbursts and superwinds
- Could also fuel accretion on to supermassive black hole at centre resulting in AGN activity.
- One of the main causes of evolution in the galaxy population over time



Chandra X-ray (green & blue) HST (red) 2 arcmin



Radio: MERLIN 2 arcsec