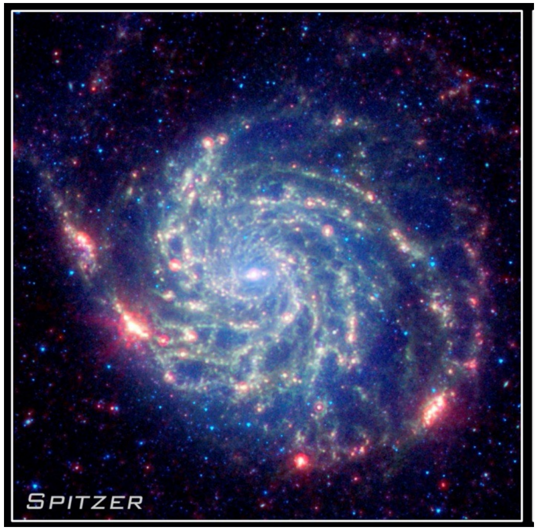
Multi-Wavelength Views



Interacting and Active Galaxies

- Colliding galaxies
- Active galaxies
- Super-massive black holes

Colliding Galaxies

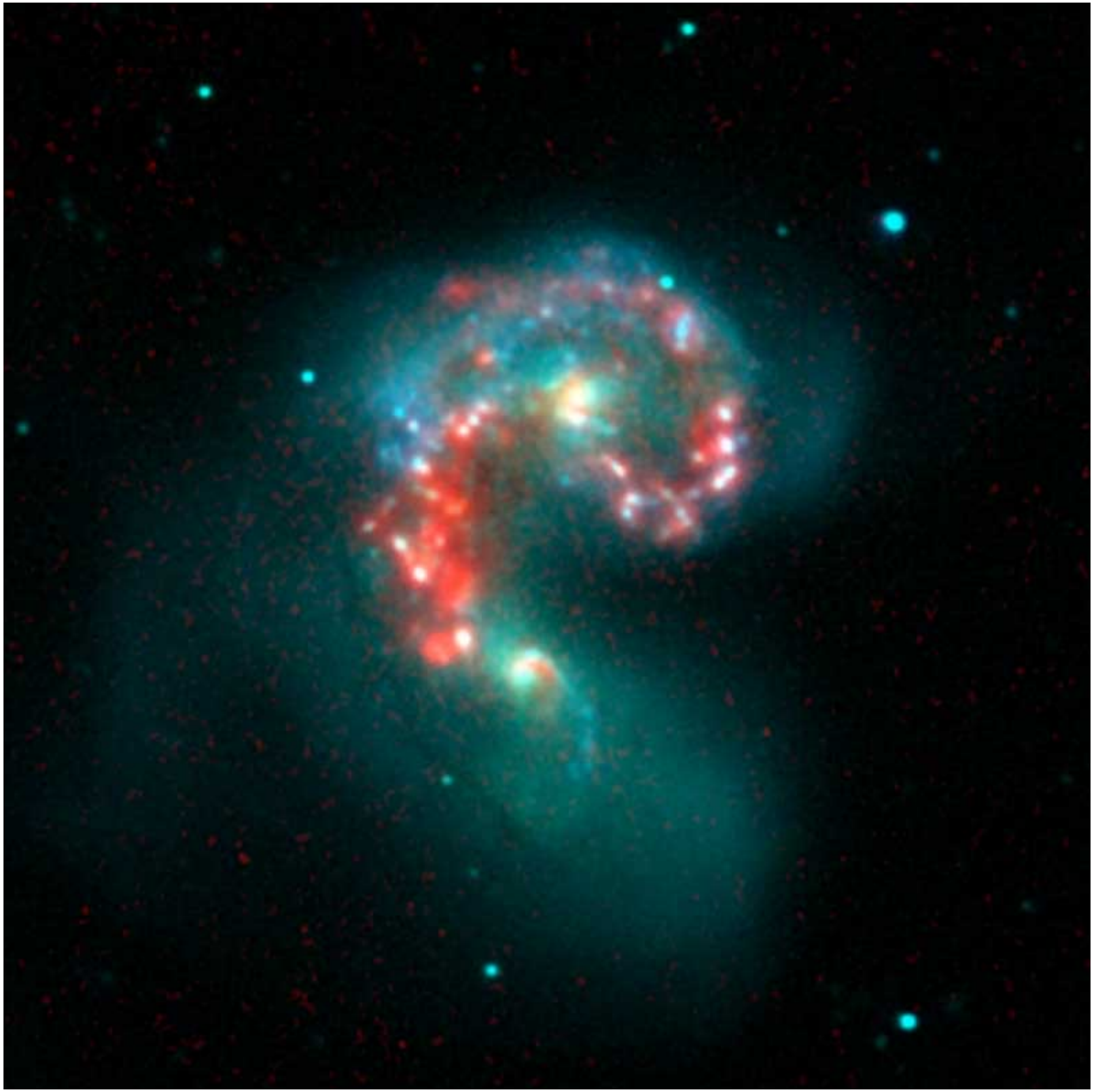
- When two large galaxies collide they get completely disrupted
- Large tidal tails can develop as the galaxies orbit each other in close proximity
- If both galaxies contain gas then this gets shocked and compressed
- This results in a burst of star formation – can result in a so-called starburst

ESA/Hubble Credit: Robert Gendler

Antennae galaxies

Optical

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



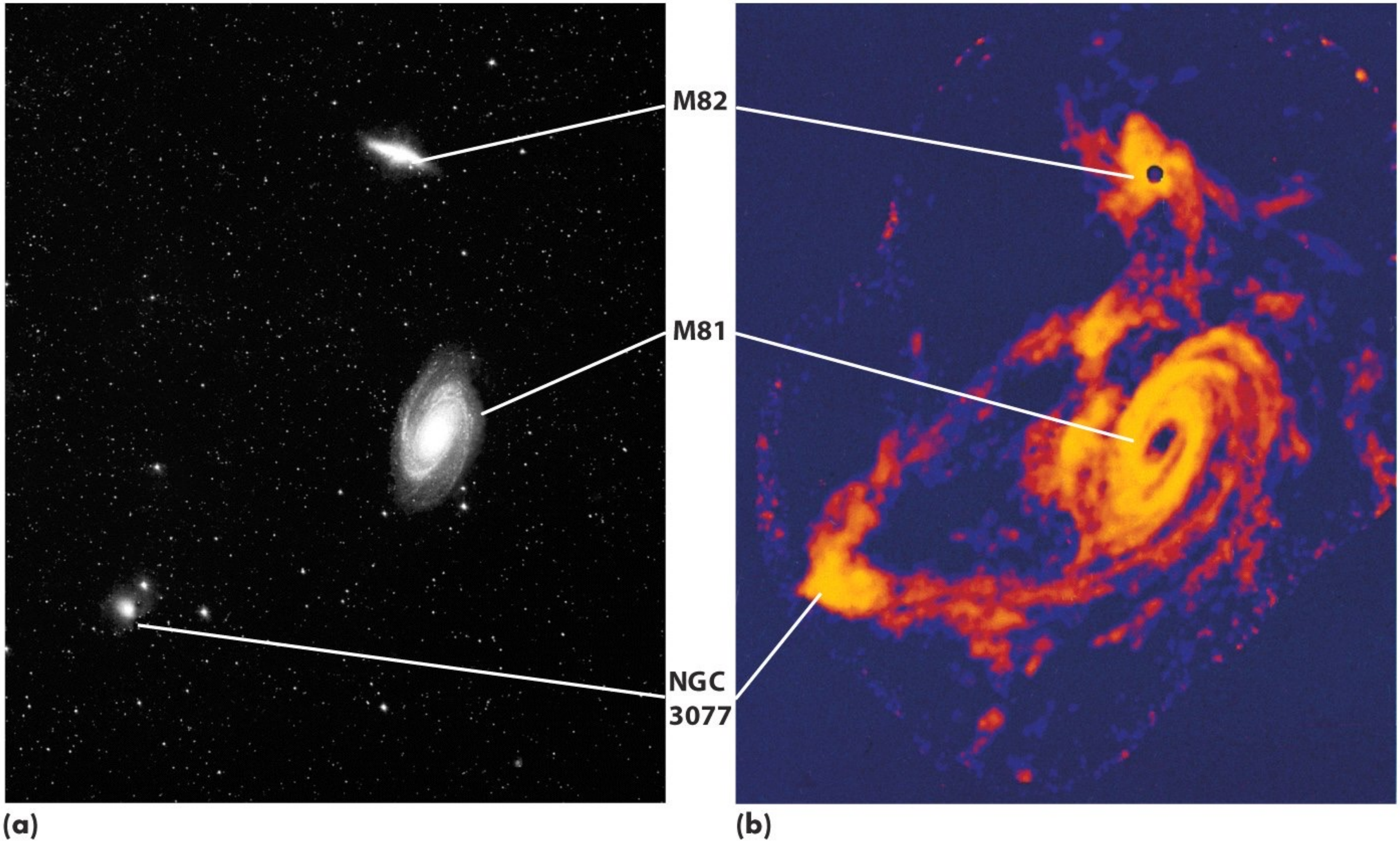
Antennae

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



Optical: no obvious signs of interaction

H I: Tidal tails of atomic gas connecting the galaxies

From Universe textbook

Starburst galaxy

NGC 1961

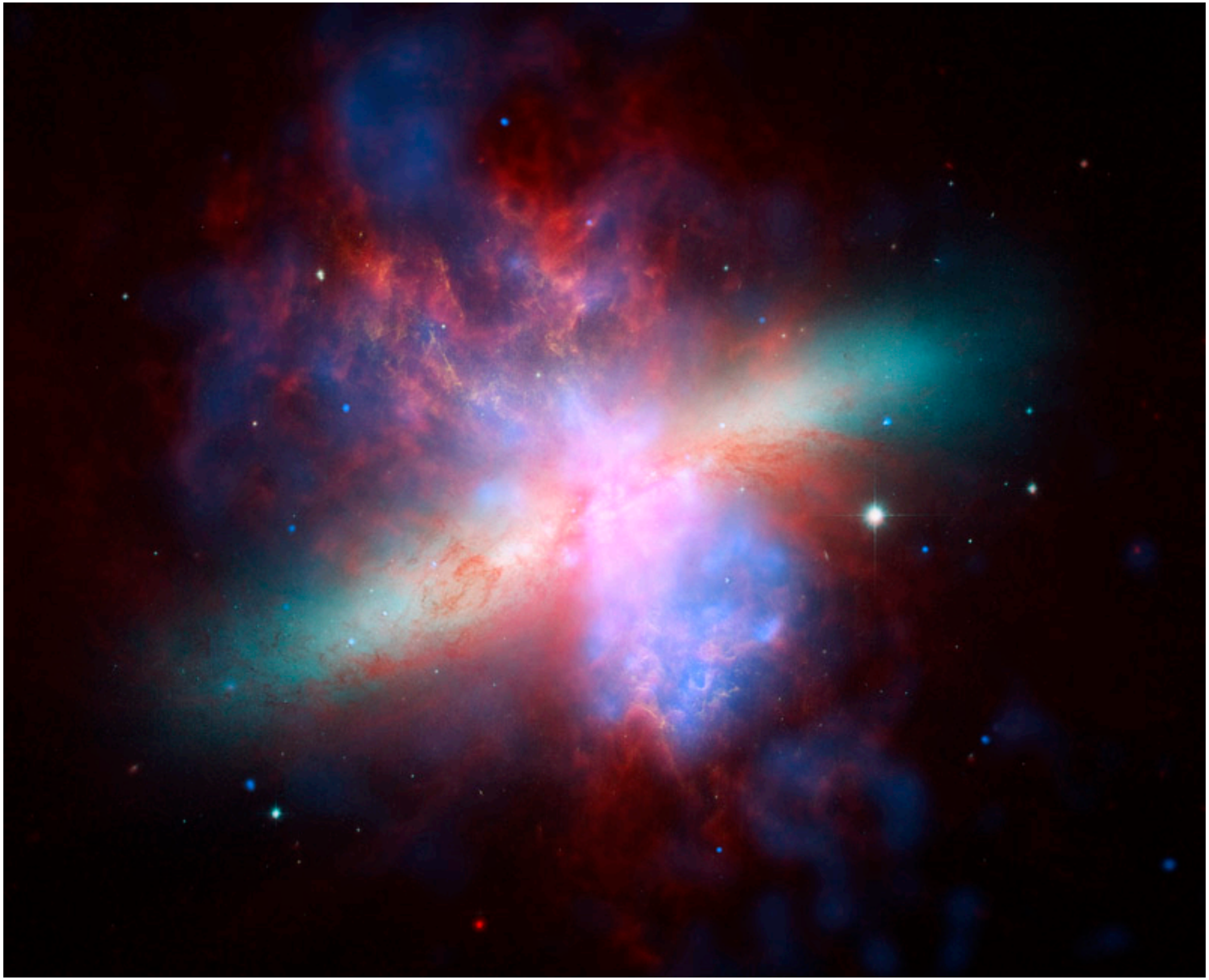
Mid-IR

NASA Spitzer

http://spaceflightnow.com/news/n0406/14spitzer/

Superwinds

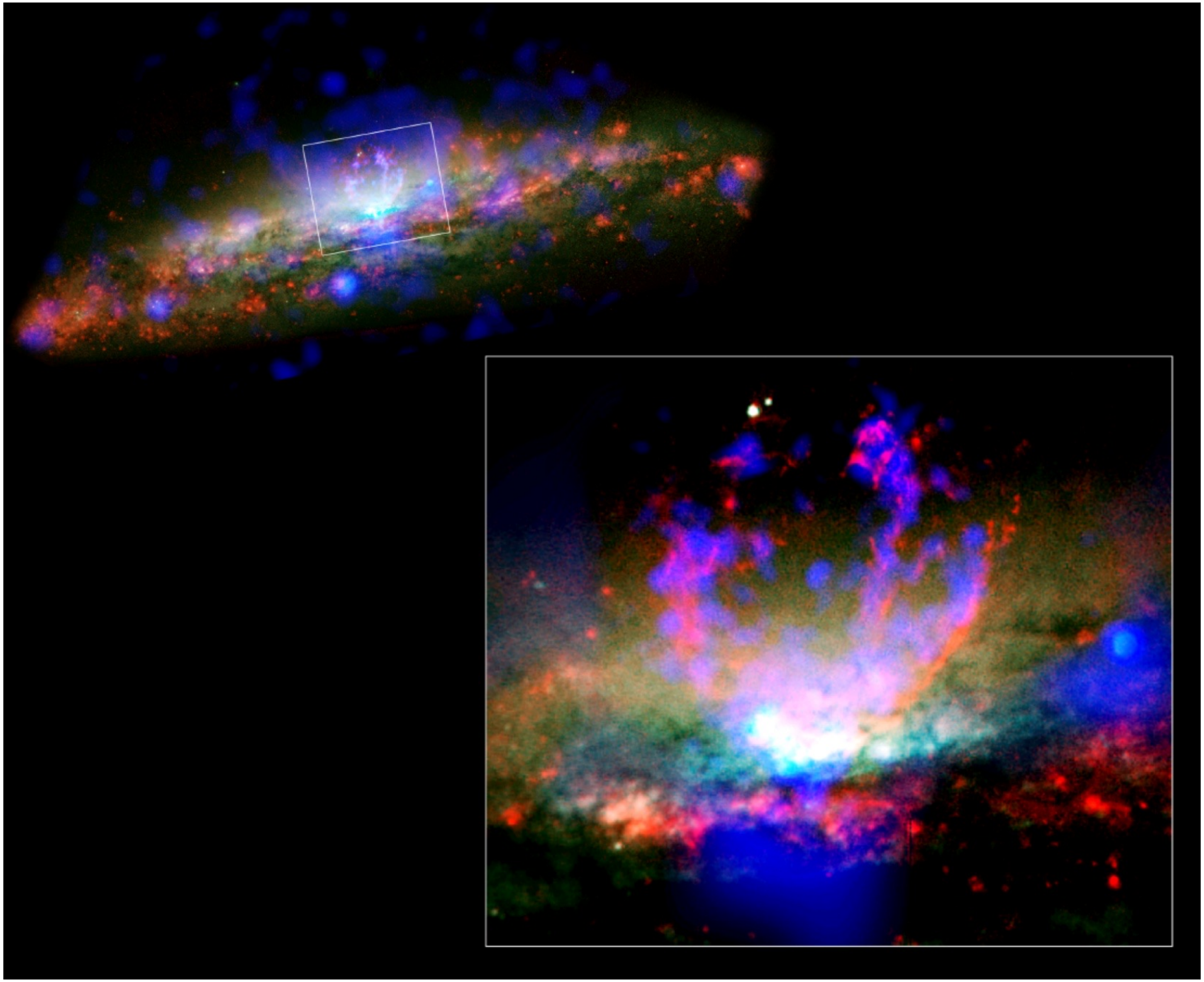
- Starburst galaxies often have galactic superwinds where the action of large numbers of massive stars and supernovae blows gas out of the galaxy
- This action can remove all gas from a galaxy, stopping all subsequent star formation, leading to the formation of an elliptical galaxy



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



NGC 3079

Optical: red, green (HST)

X-ray: blue

(Chandra)

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

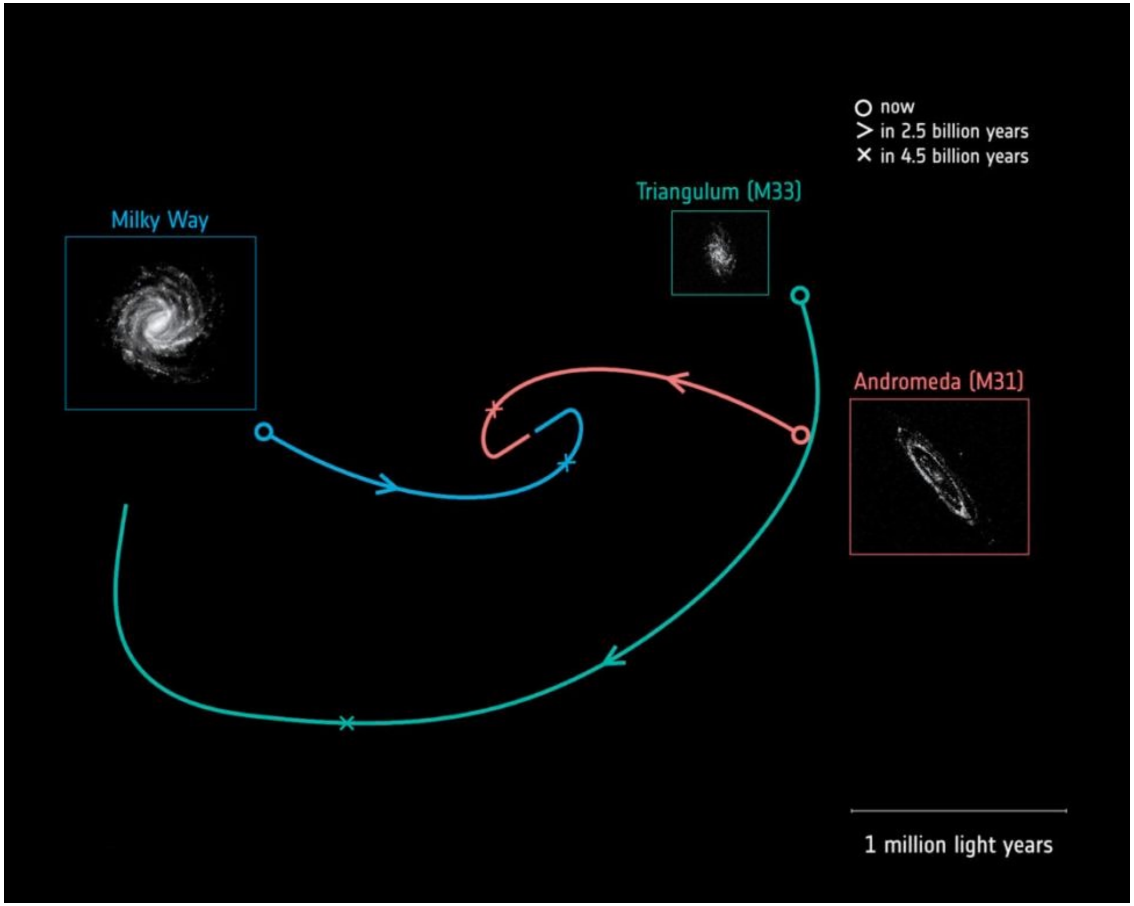
Class Example

- The Andromeda galaxy at at distance of 0.9 Mpc has a radial velocity relative to the Milky Way of -300 kms^{-1}. If it is heading straight for us how long before it collides?

$$t = \frac{d}{v} = \frac{0.9\times10^{6}\times3.1\times10^{16}}{300\times10^{3}}$$

$$= 9\times10^{16}\ \text{s}$$

$$= 3\times10^{9}\ \text{years}$$

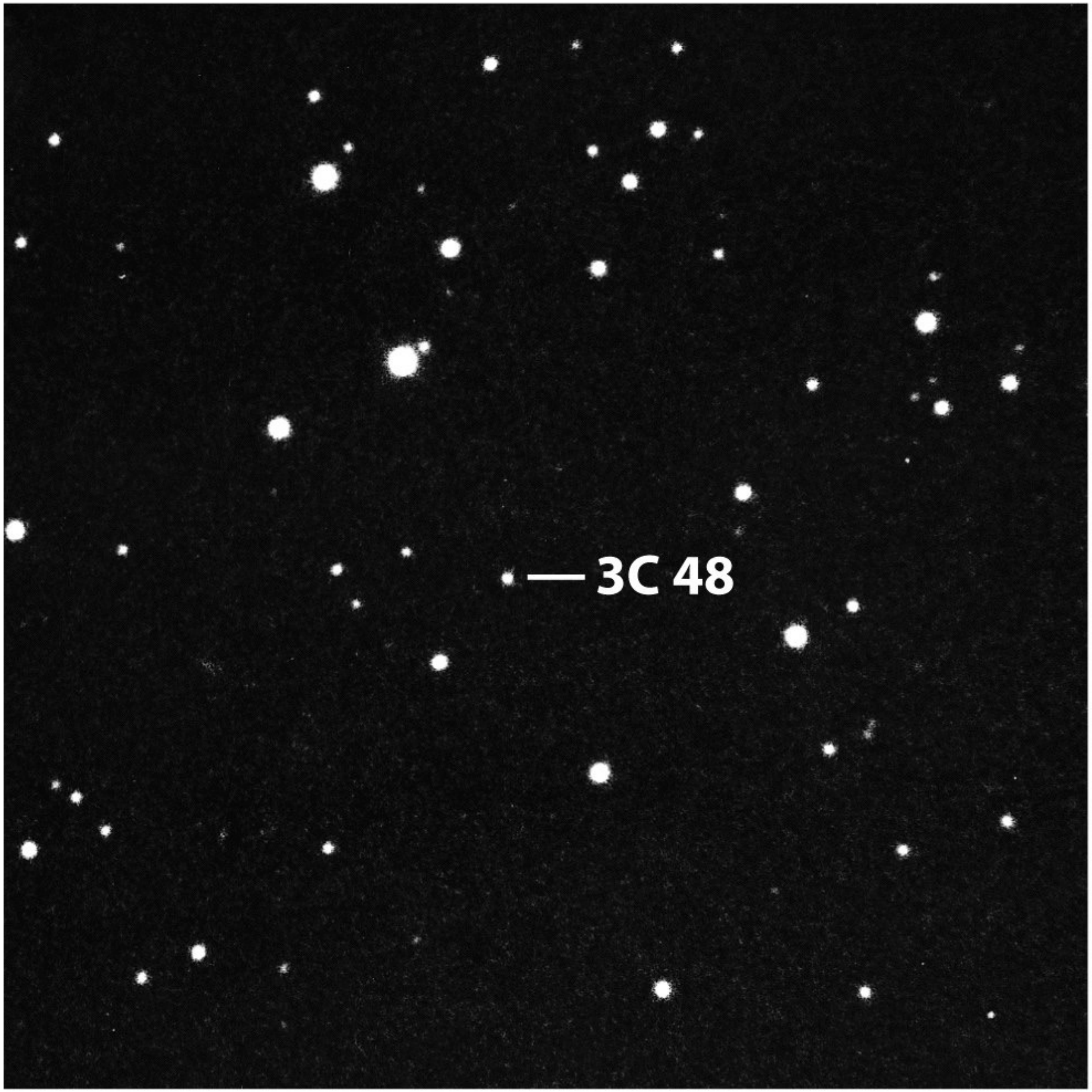


https://videos.space.com/m/OaN3fwM4/milky-way-and-andromeda-galaxies-collision-simulated-video?list=9wzCTV4g

Active Galaxies

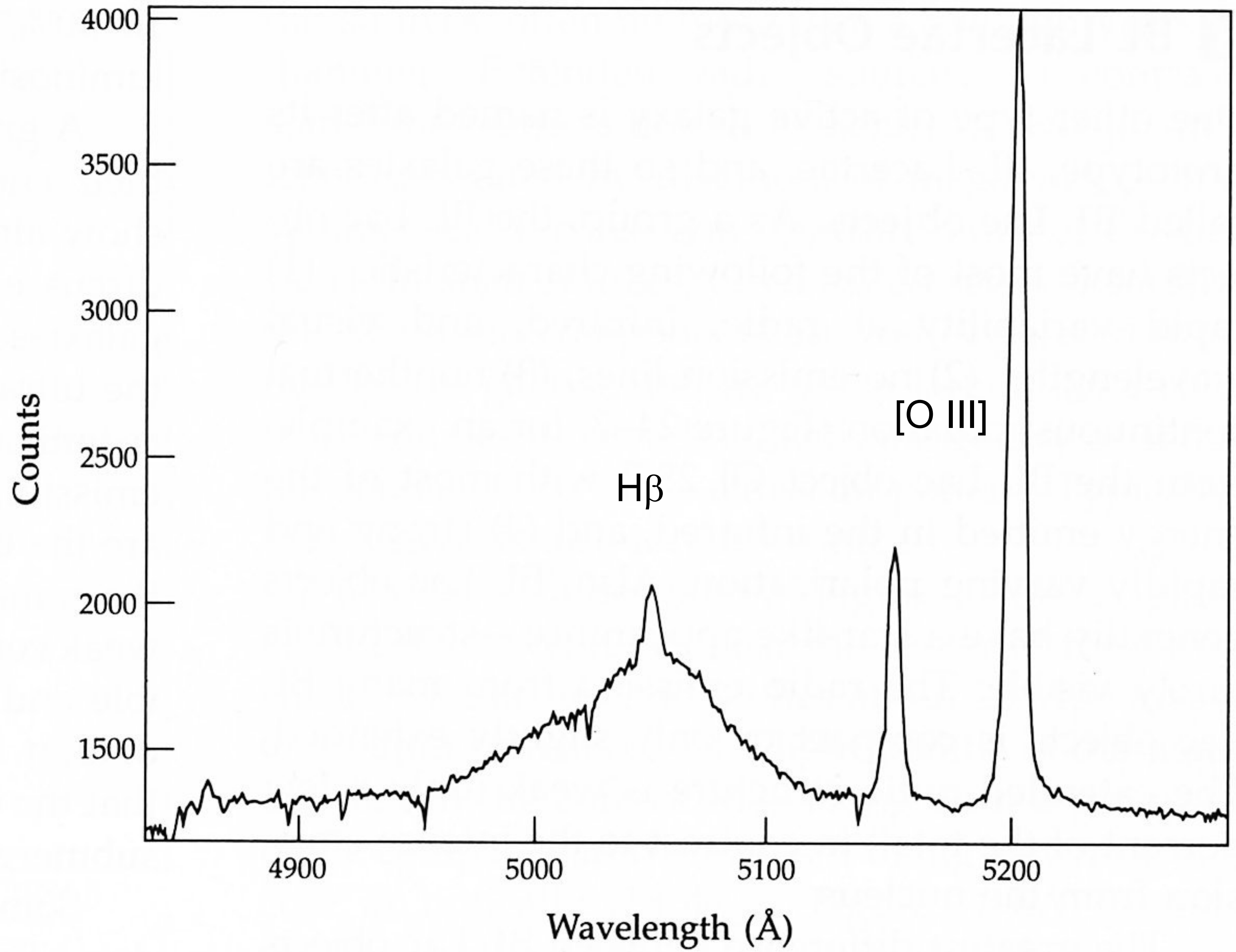
- Active galaxies have a luminous point-like nucleus (hence AGN)
- In the most luminous types (quasars) the nucleus completely outshines the galaxy
- The nucleus has a non-thermal continuum spectrum and emission lines
- Some emission lines are very broad due to fast Doppler motion

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

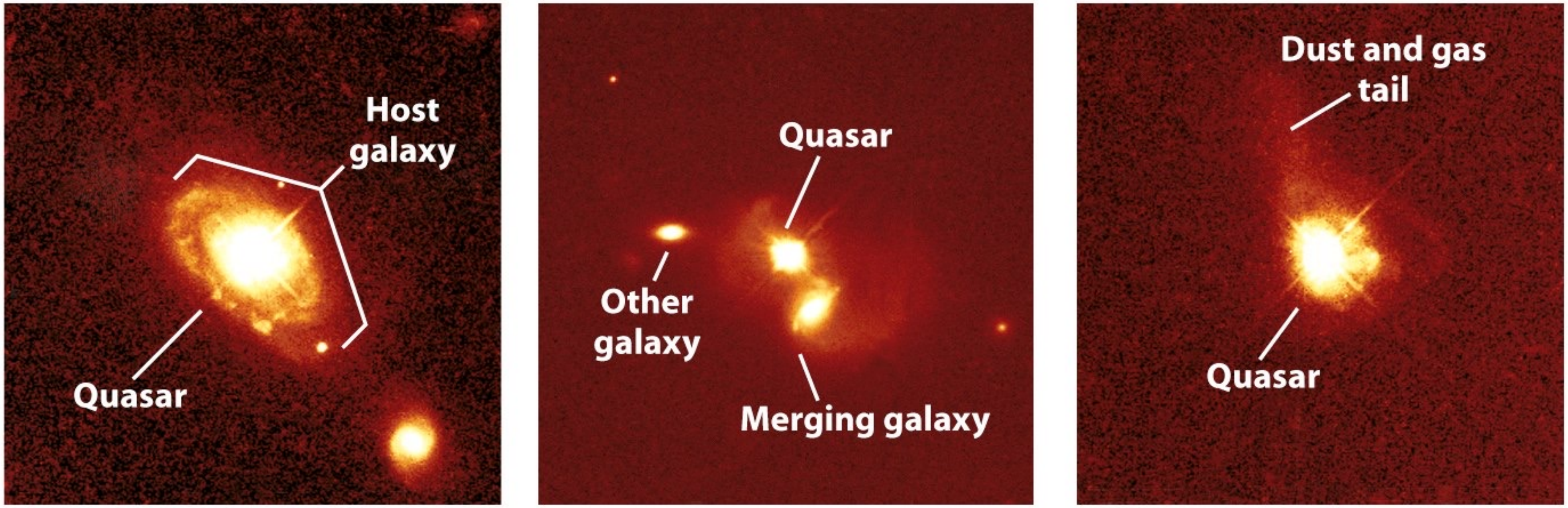


Optical image of quasar

From Universe textbook



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



(a) (b) (c)

From Universe textbook

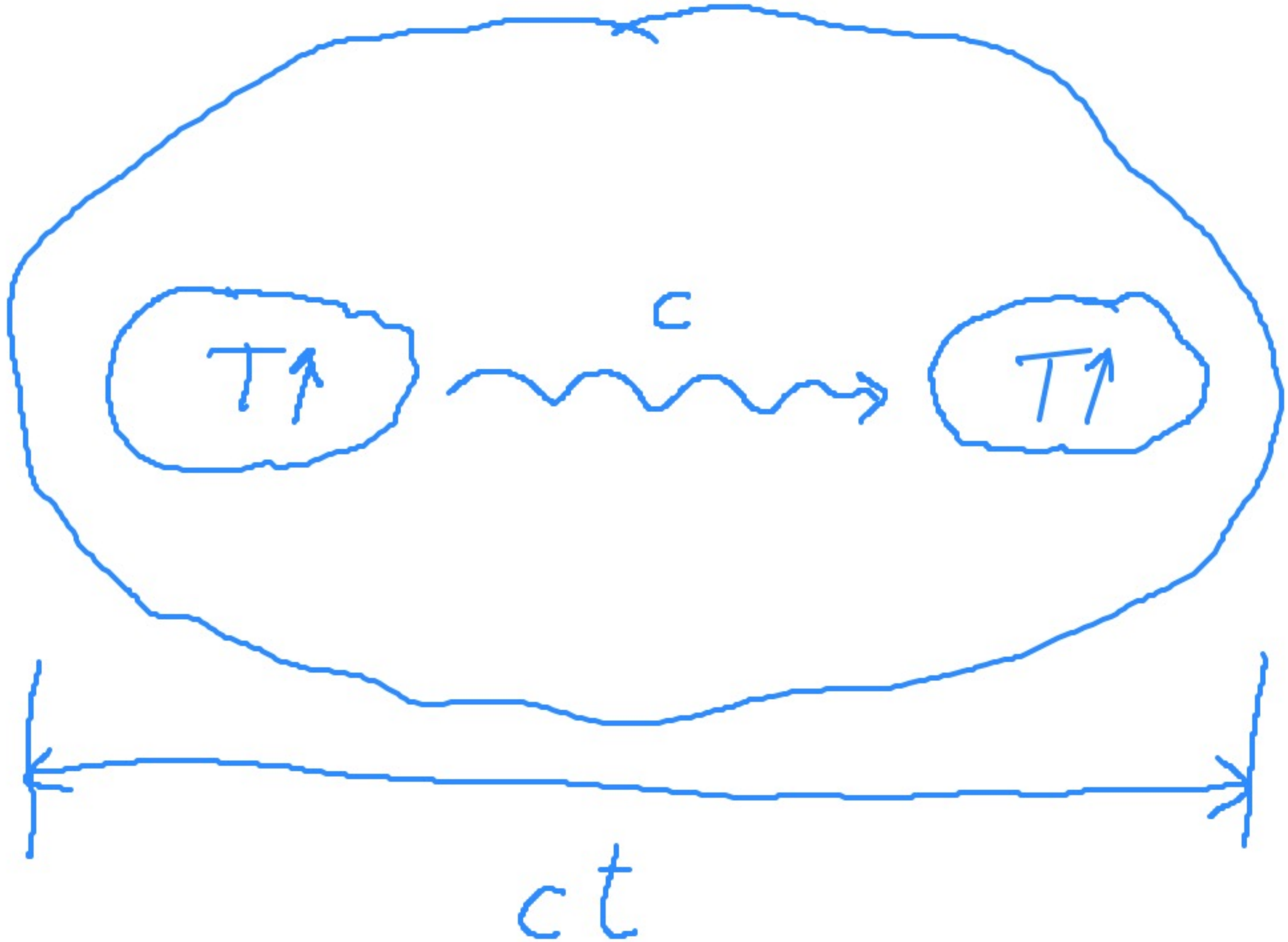
- HST has revealed the host galaxies of some quasars
- Most show signs of interaction

Variability

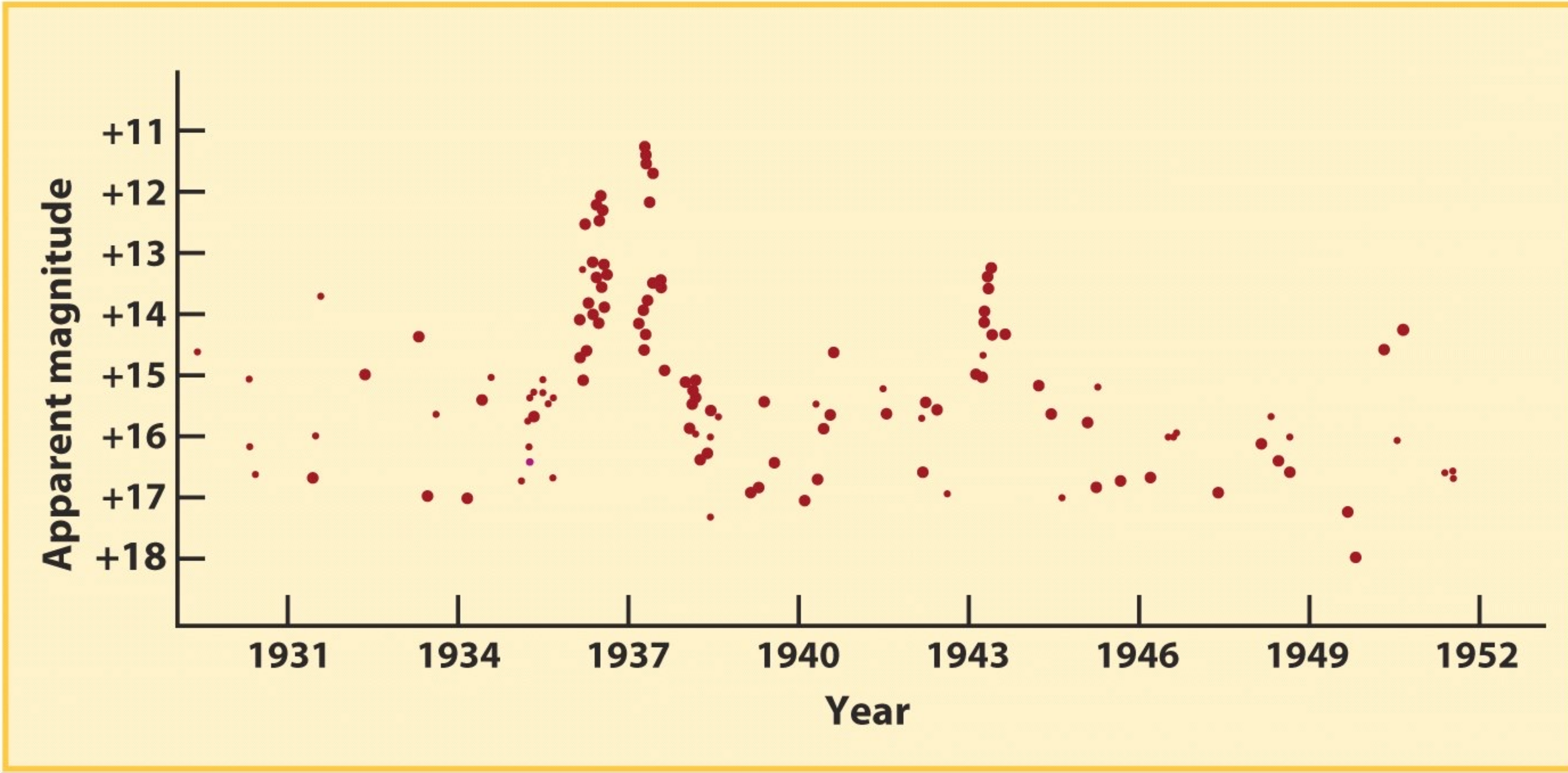
- Most AGN show variability in their brightness on timescales of months
- The variability timescale allows an upper limit to be placed on the size of the emitting region

$$l \leq ct$$

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



T↑
c
T↑
ct



Light curve showing the variability of the continuum for an AGN

From Universe textbook

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

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

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

- Effective ‘size’ of black hole is given by the Schwarzschild radius

$$R_S = \frac{2GM}{c^2}$$

- Is where escape speed equals the speed of light
- Therefore for material falling in to a black hole

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

Class Example

- Estimate how many solar masses of material must fall on to a super-massive black hole per year to explain the most luminous objects in the Universe that have a luminosity of $\sim 10^{13}\ L_{\odot}$.

- Infall rate for most luminous objects

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

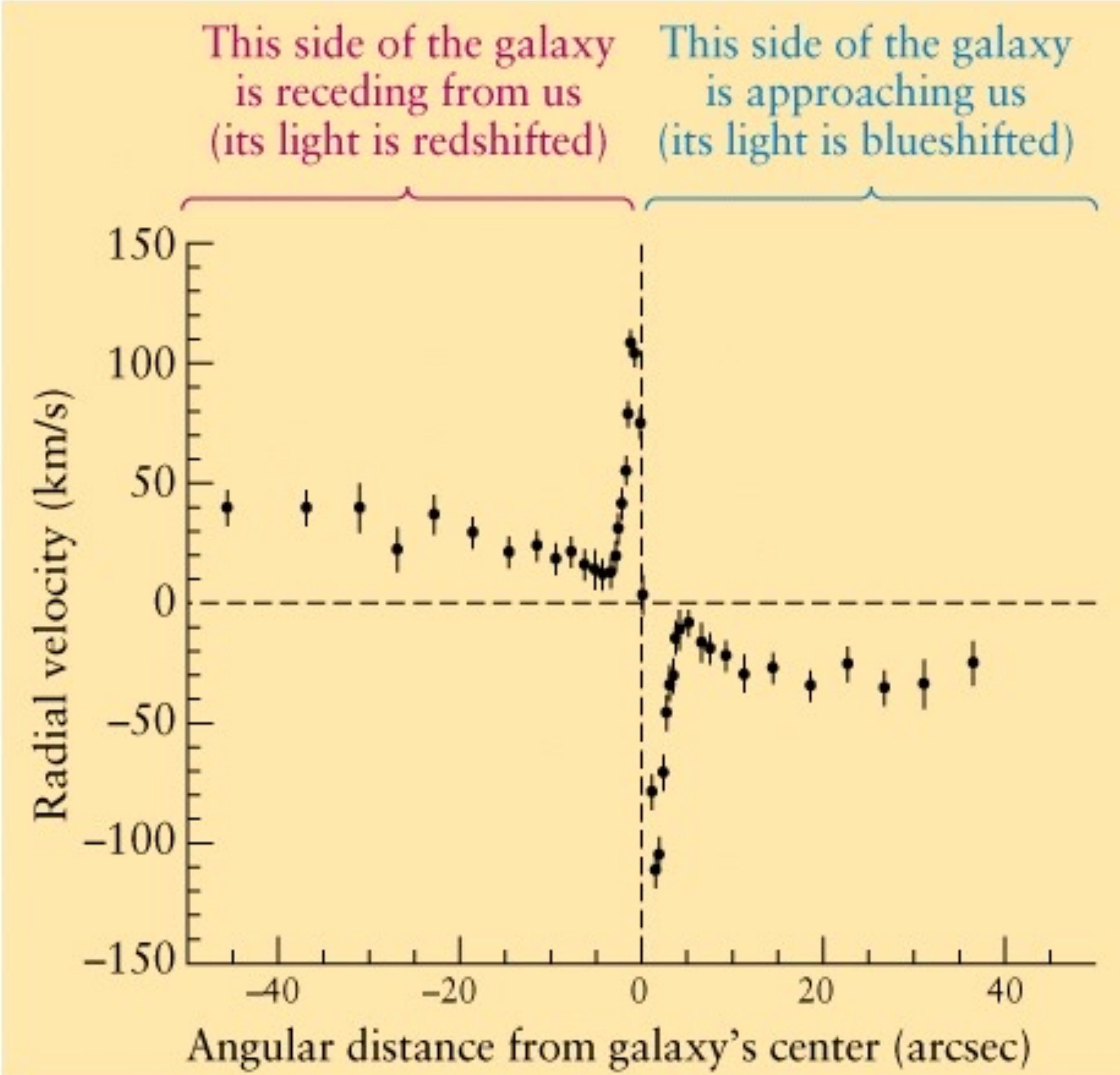
$$\dot{m} = \frac{2L}{\varepsilon c^2} = \frac{2(10^{13} \times 4 \times 10^{26})}{0.1\left(3 \times 10^8\right)^2} = 9 \times 10^{23} \text{ kg s}^{-1}$$

$$\dot{m} = 9 \times 10^{23} \times \frac{3 \times 10^7}{2 \times 10^{30}}$$

$\approx$ 10 solar masses per year

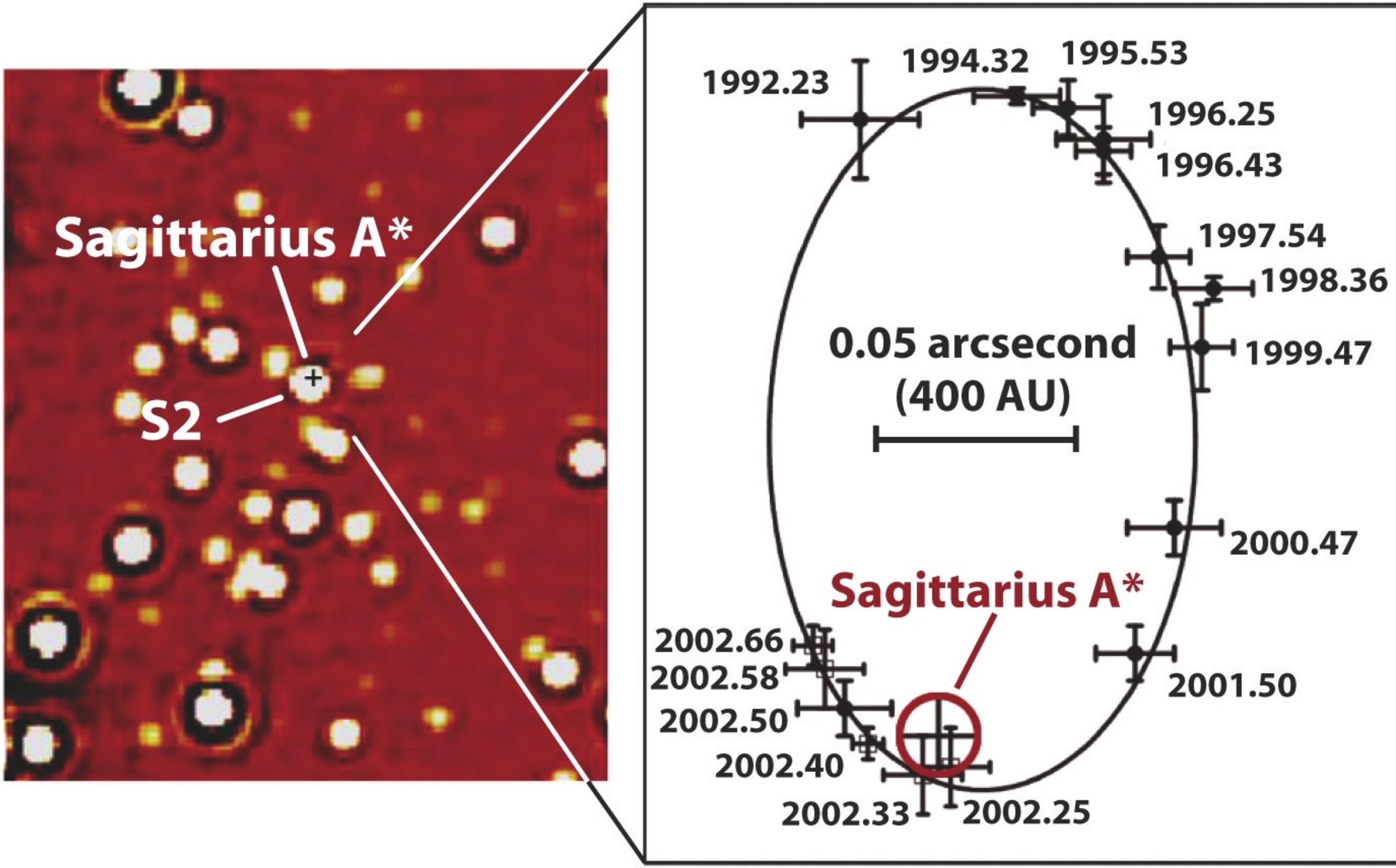
Black Hole Masses

- 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



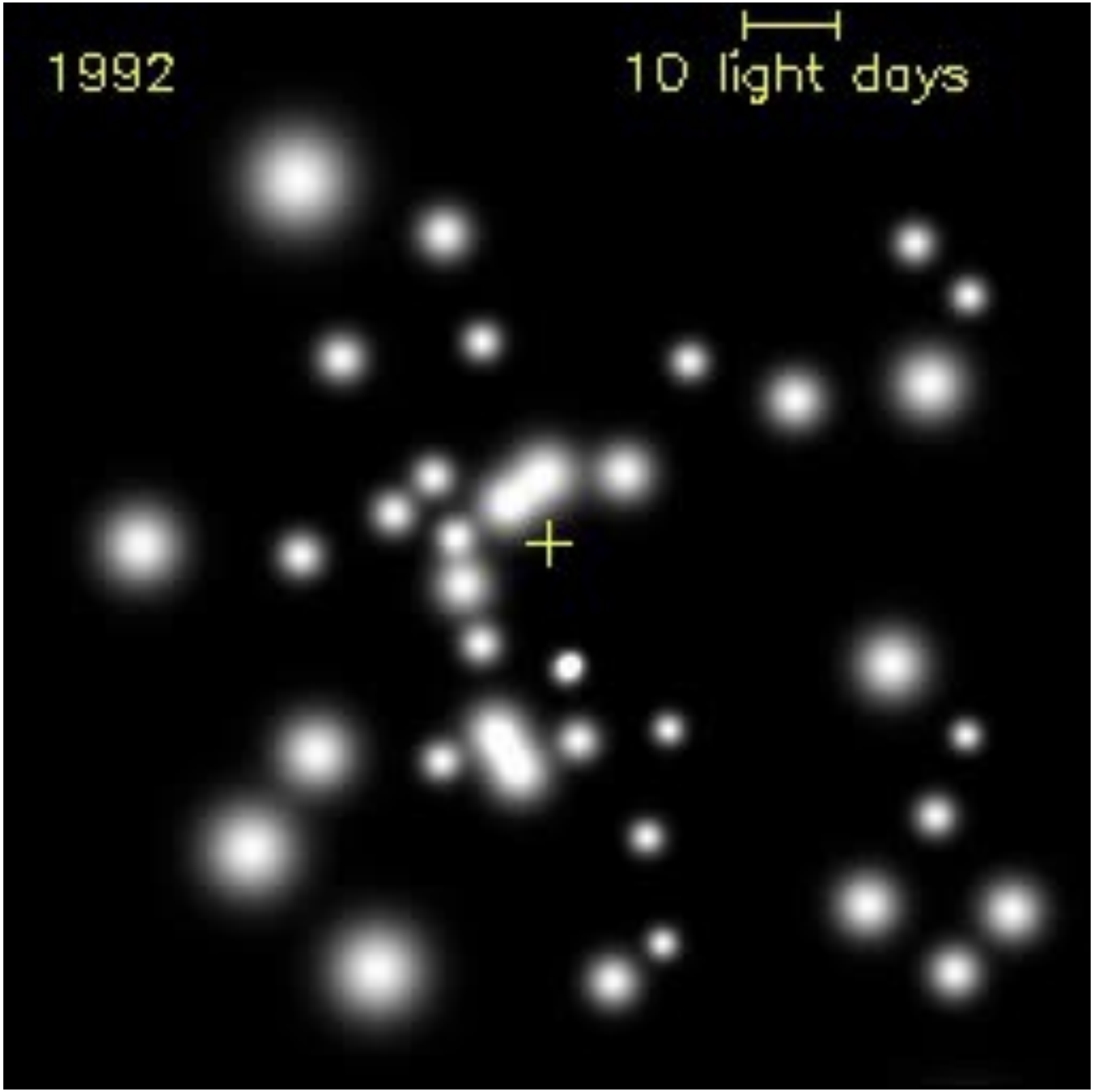
Stellar radial velocities in the core of M31

From Universe textbook

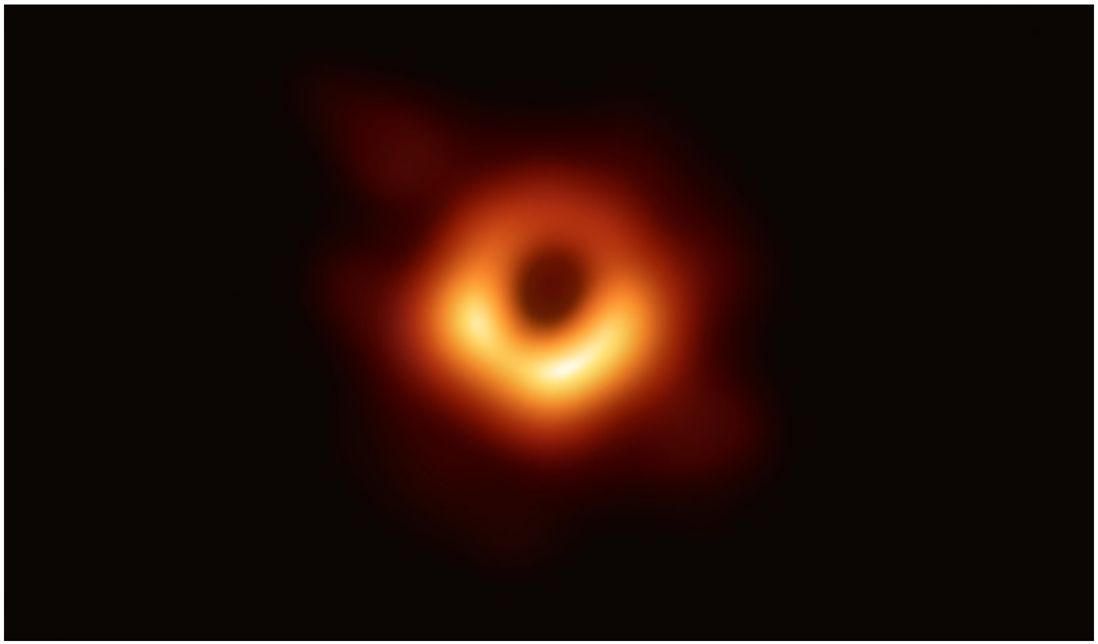


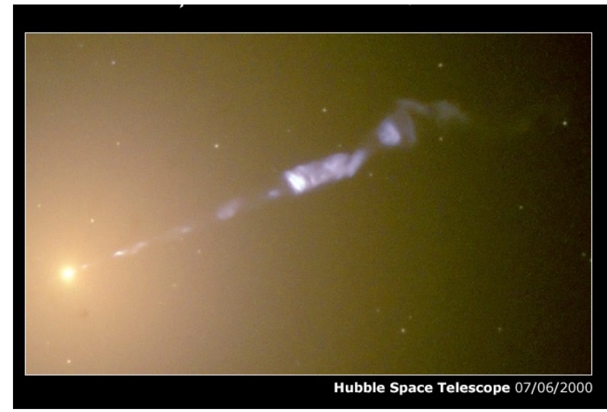
- Stellar orbits prove our Galaxy has a $4x10^6$ $M_\odot$ black hole at the centre

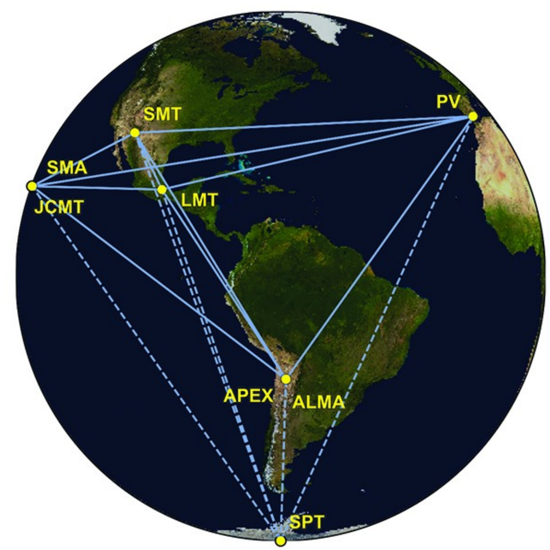
Genzel MPE, Garching


1992
10 light days

First Image of Black Hole

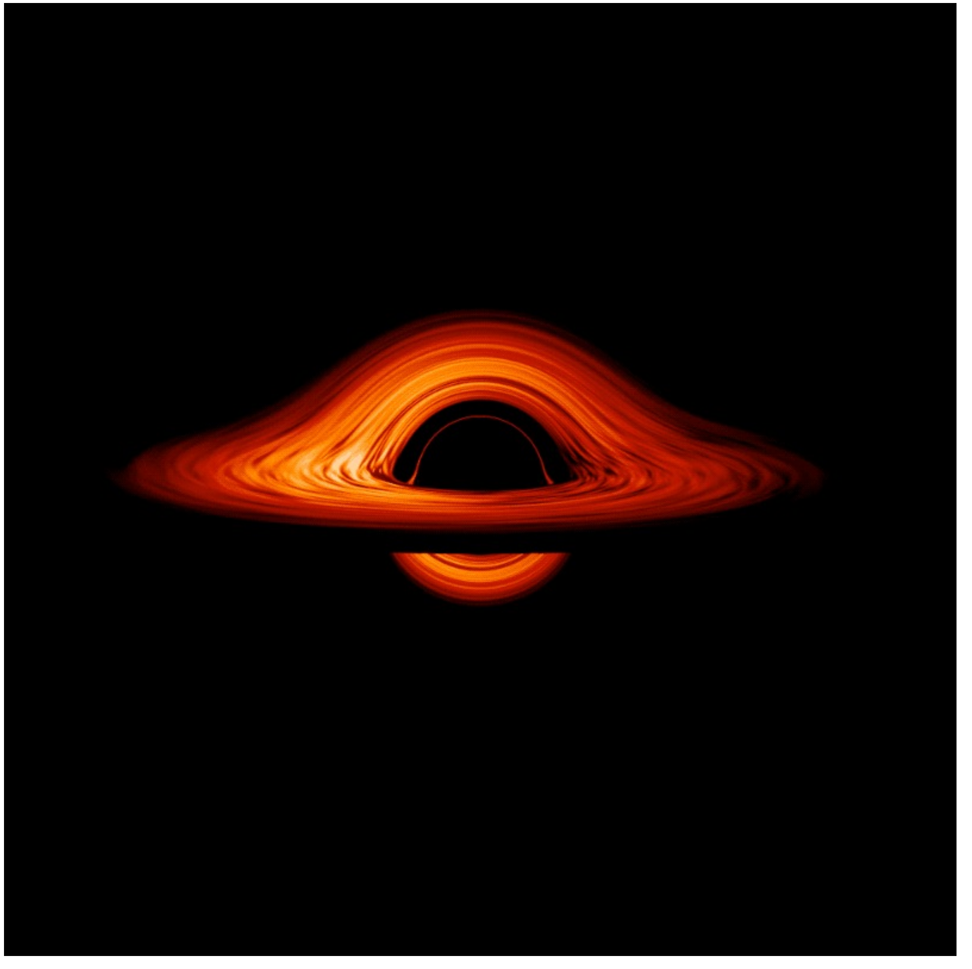






- Global array of telescopes at 1 mm giving 20 micro-arcsecond resolution

Accretion on to black hole



Varying viewing angle

https://svs.gsfc.nasa.gov/13326

Summary

- Galaxy interactions, collisions and mergers can result in a starburst and superwind
- 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

Class Example

- The M87 galaxy is 16.4 Mpc away and its super-massive black hole is $2.4 \times 10^9\ M_\odot$. What is the angular size of the black hole?