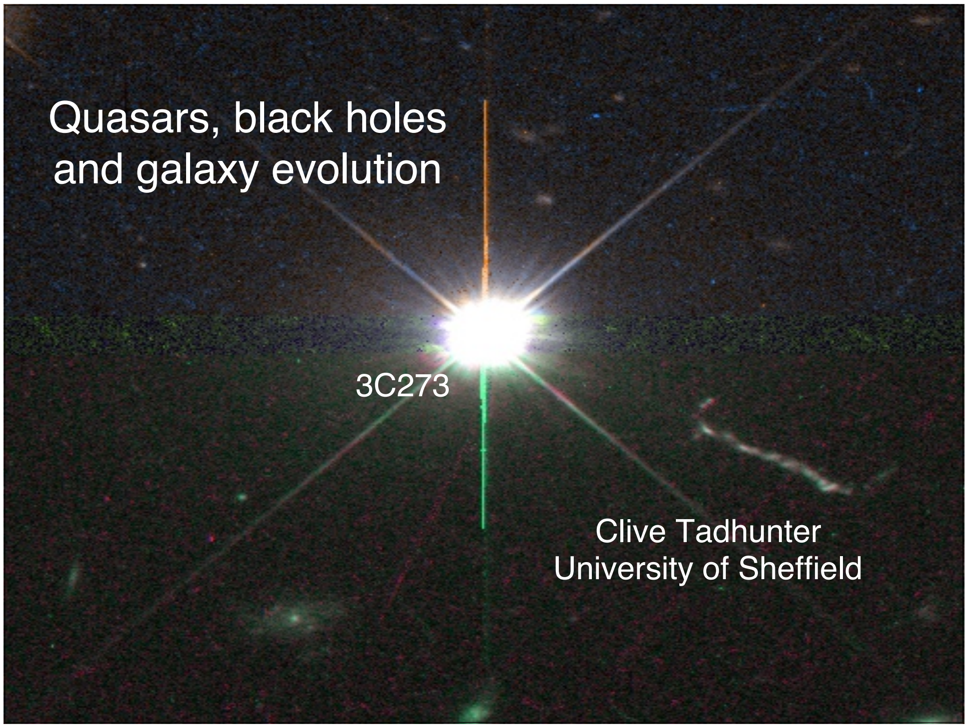
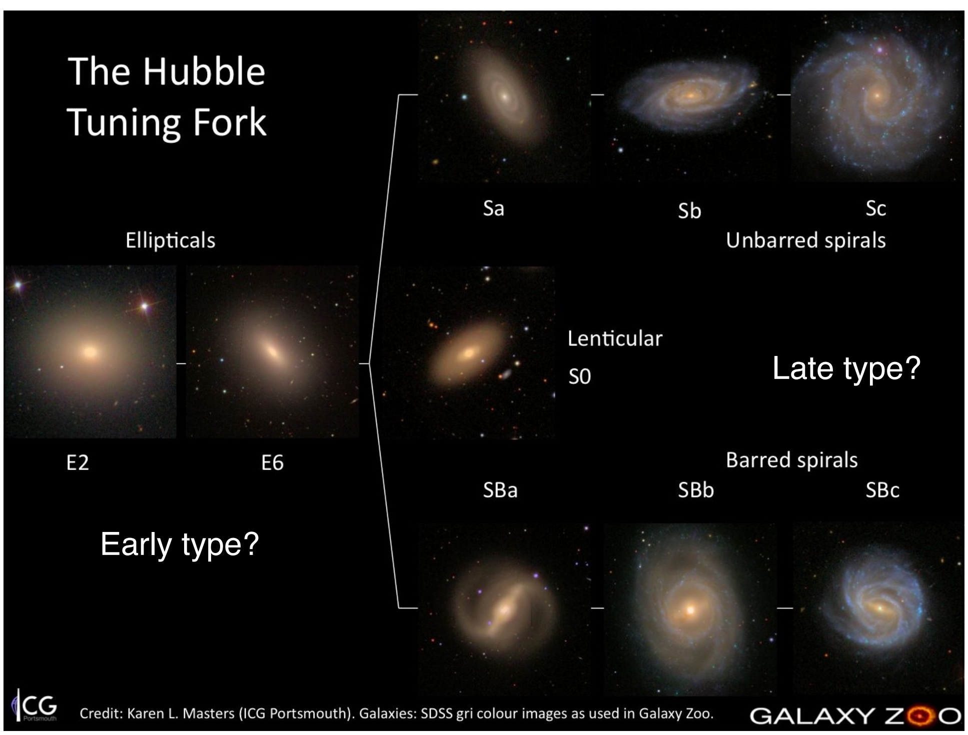
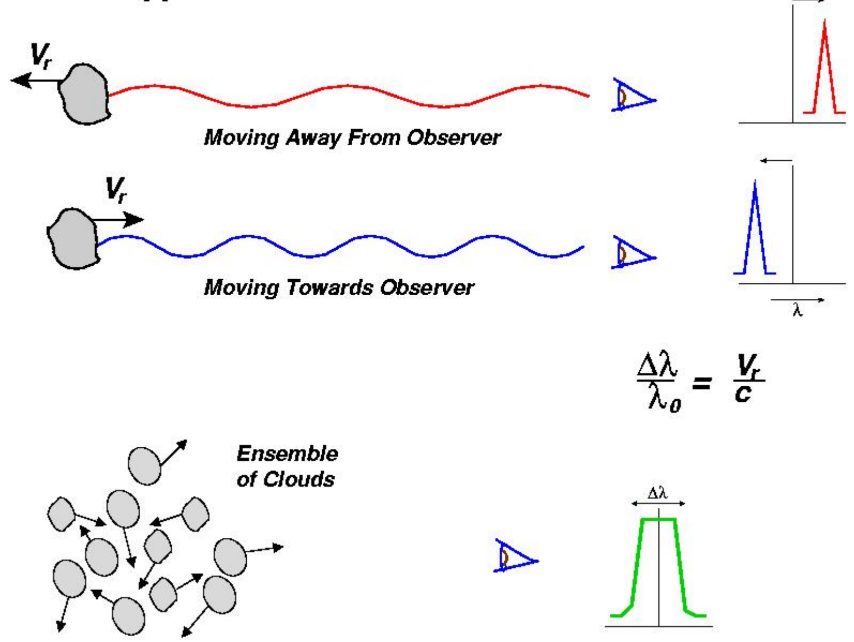

Quasars, black holes
and galaxy evolution
3C273
Clive Tadhunter
University of Sheffield

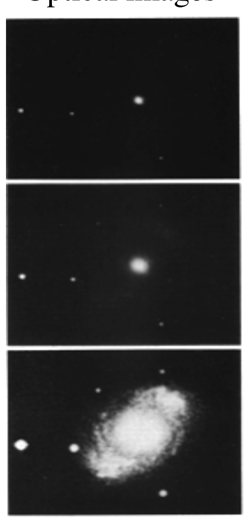

The Hubble
Tuning Fork
Ellipticals
E2
E6
Early type?
Sa
Sb
Sc
Unbarred spirals
Lenticular
S0
Late type?
Barred spirals
SBa
SBb
SBc
ICG
Credit: Karen L. Masters (ICG Portsmouth). Galaxies: SDSS gri colour images as used in Galaxy Zoo.
GALAXY ZOO

The Doppler Effect

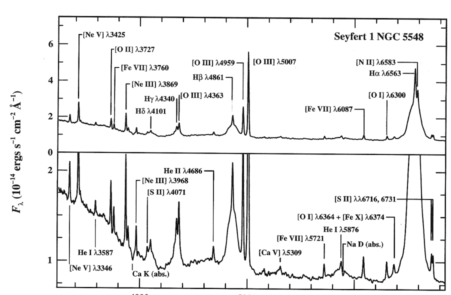


Seyfert Galaxies

Optical images



Optical spectra

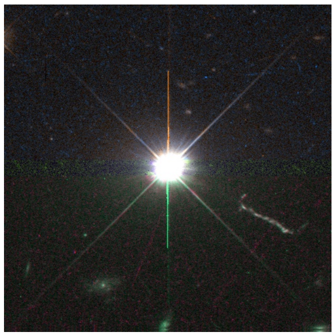


Seyfert (1943)

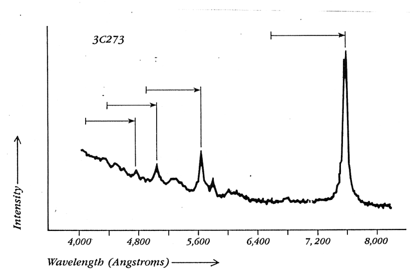
The discovery of the quasar 3C273

(Schmidt 1963)

Optical image



Optical spectrum z=0.158



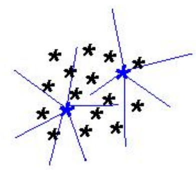
At the distances estimated from the redshifts of the emission lines, quasars have a luminosity 10 - 10,000x the integrated light of all the stars in the Milky Way.

Active nuclei: key characteristics

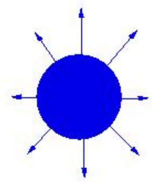
- Large luminosities (1 - 10,000 galaxies)
- Small size of emitting region (< 1 light year)
- Large lifetimes (1 - 100 million years)
- Ability to produce highly collimated jets

Energy Sources for AGN/Quasars

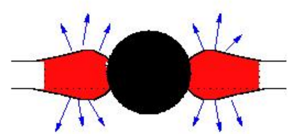
1. Central cluster of massive ($M^*>20xM_{sun}$) stars which explode as supernovae.



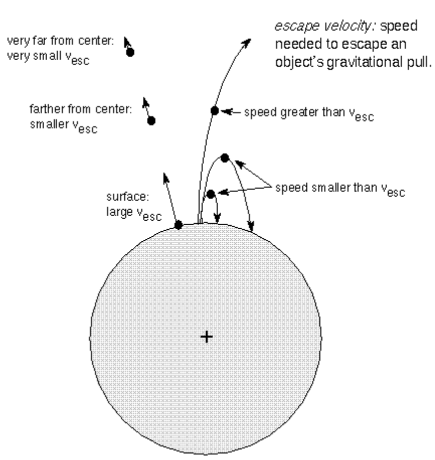
2. Central supermassive star ($M^*>10^6xM_{sun}$)



3. Central super–massive black hole ($10^6< M_{bh}< 10^{10}M_{sun}$)



Escape velocity

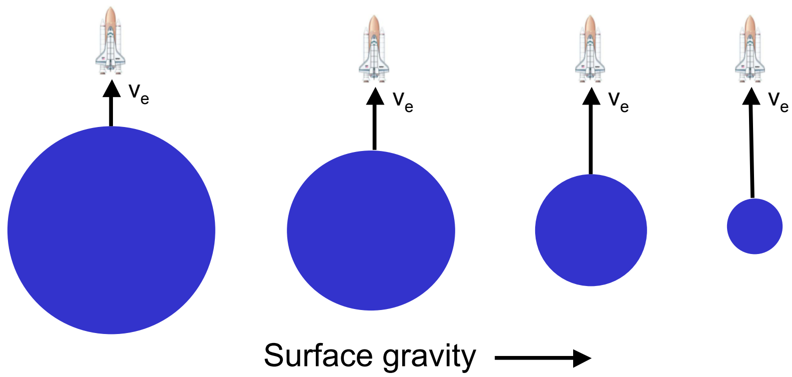


The escape velocity is the velocity you would need to give an object for it to have enough energy to escape the planet/star.

The escape velocity increases as the body becomes smaller and/or more massive.

The escape velocity from the surface of the Earth is ~11 km/s

The escape velocity increases as planet or star gets smaller

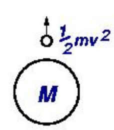


If we were to shrink the Earth keeping its mass fixed, its surface gravity and escape velocity would increase…

What are black holes?

Black holes are objects in which the gravitational field is so strong that nothing can escape, not even light.

Michell (1783)
Laplace (1796)



Simple Newtonian approximation

For escape:

Particle kinetic energy > |Grav. potential energy|

Limit: $\frac{1}{2}mv_e^2 = \frac{GMm}{r}$

$\Rightarrow \quad r = \frac{2GM}{v_e^2}$

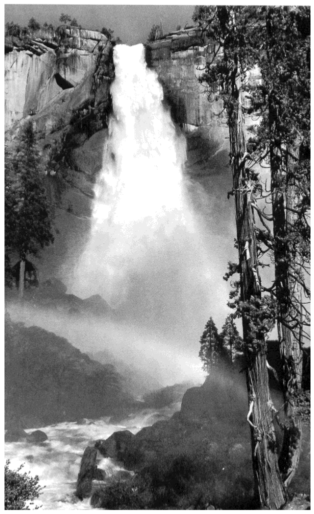
Set $v_e = c \quad \Rightarrow \quad \boxed{r_s = \frac{2GM}{c^2}}$

Schwarzschild Radius: the radius of the event horizon of a black hole of mass M.

e.g. M(Earth) $\Rightarrow \quad r_s = 1$ cm

M(Sun) $\Rightarrow \quad r_s = 3$ km

Gravitational energy generation around black holes

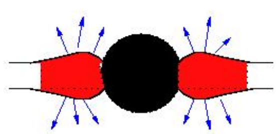


The release of gravitational energy when material falls close to the event horizon of a super-massive black hole is equivalent to 10 - 30% of the rest mass energy (0.1 - 0.3xMc^2).

This is ~10x more efficient than nuclear fusion (0.007xMc^2)!

Black Holes: how do we detect them?

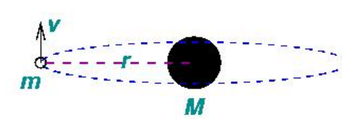
1. Heating effect



2. Motions of test particles

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

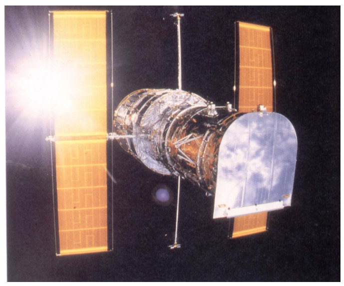
$$\Rightarrow \boxed{M_{bh} = \frac{v^2 r}{G}}$$



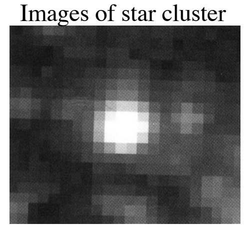
Test particles can be used to "weigh" the black hole if v. r are known.

Hubble Space Telescope Capabilities

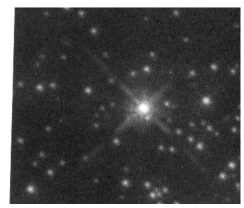
Images of star cluster



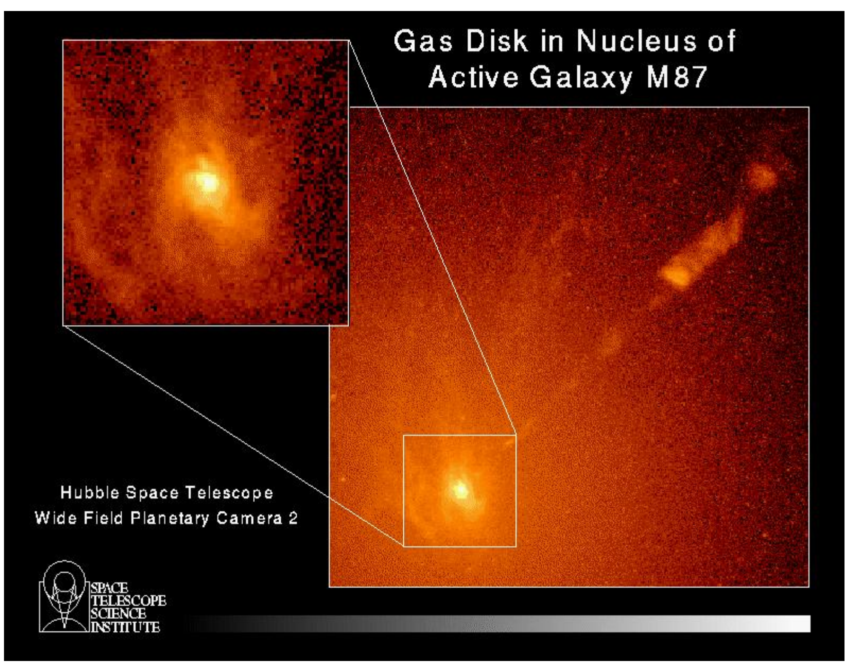
HST in orbit



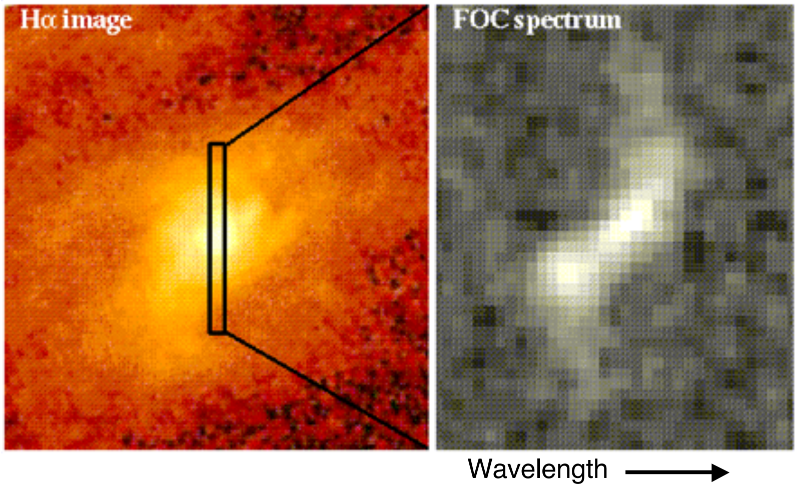
From ground



From HST

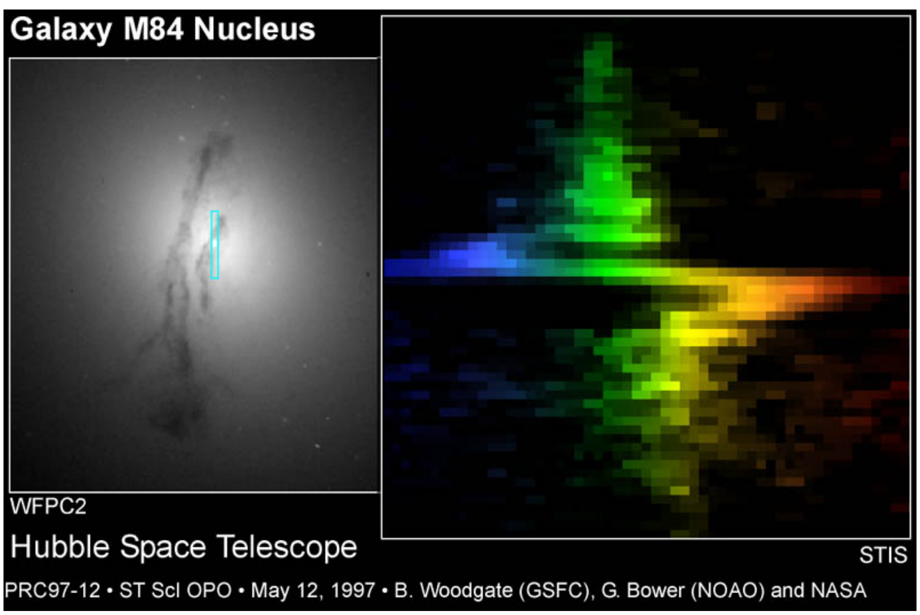


HST observes of the high speed disk in M87



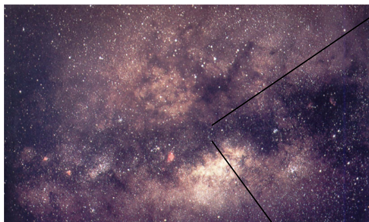
$M_{bh} = 3x10^9 M_{sun}$

(Central mass ~30x greater than be accounted for by the visible stars and gas)



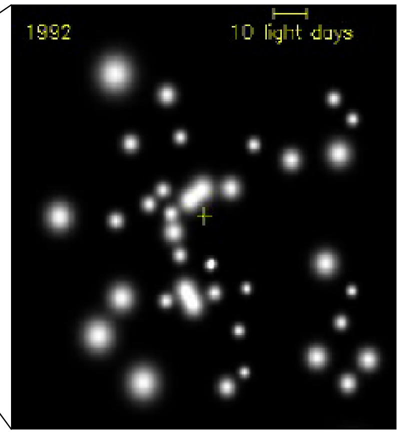
$M_{bh} = 1.5x10^9 M_{sun}$

Observations of the centre of the Milky Way

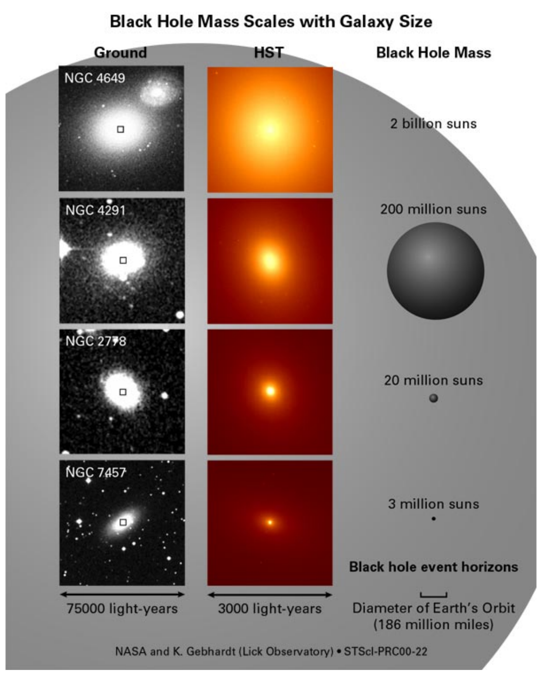


Wide field optical image of the Galactic Centre

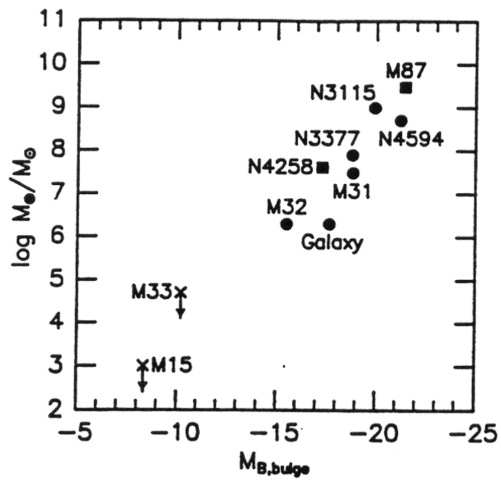
$M_{bh} = (4.1+/-0.4)x10^6 M_{sun}$



High resolution infrared image
Genzel et al. (2003)



Correlation between black hole mass and galaxy bulge mass/luminosity

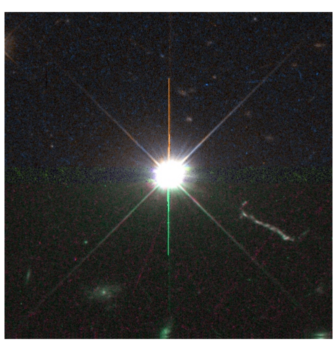


Kormendy & Richstone (1995)

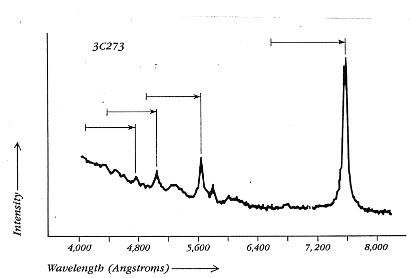
The discovery of the quasar 3C273

(Schmidt 1963)

Optical image

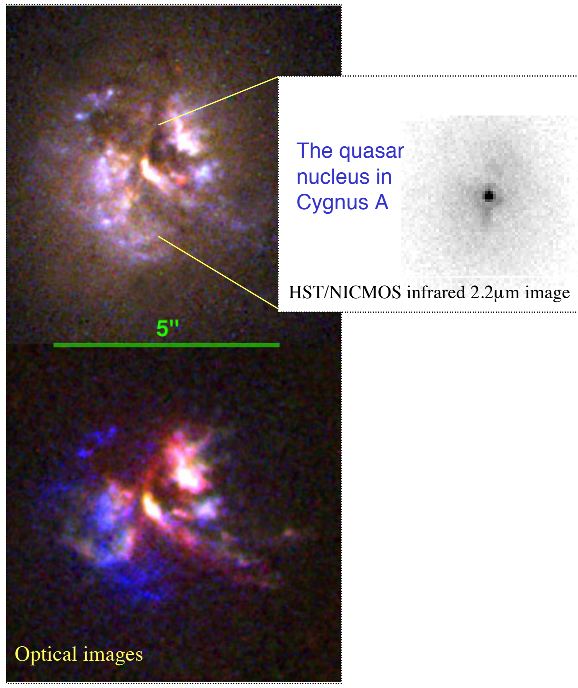


Optical spectrum z=0.158

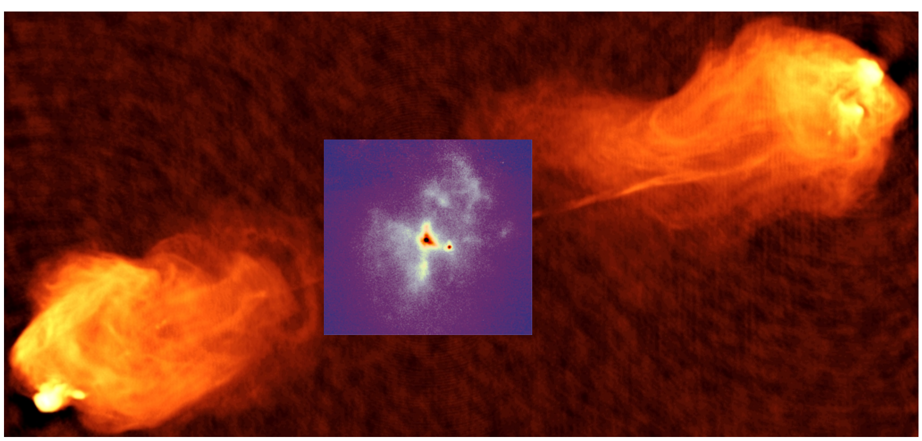


At the distances estimated from the redshifts of the emission lines, quasars have a luminosity 10 - 10,000x the integrated light of all the stars in the Milky Way.

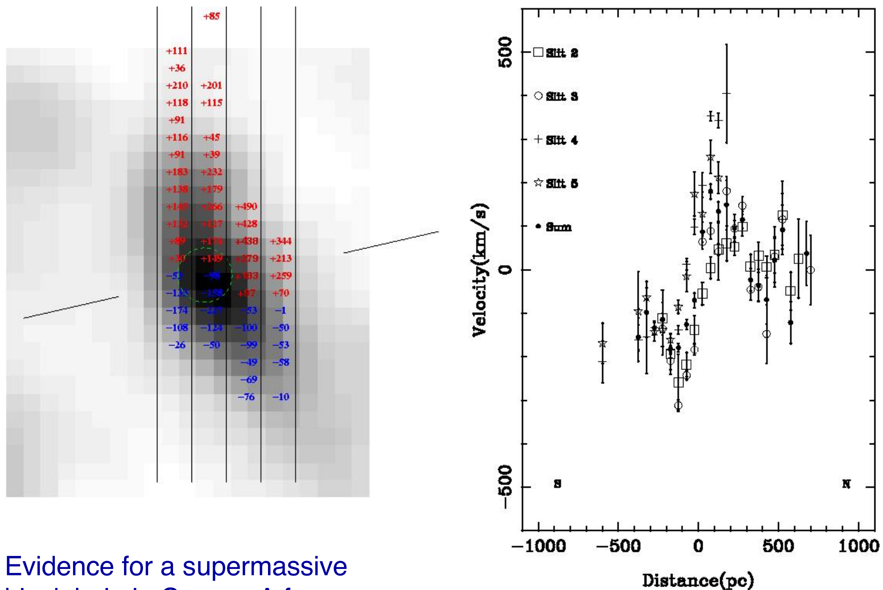
Cygnus A viewed by HST



The jets in Cygnus A



Some quasars emit powerful jets of particles that are moving at close to the speed of light. In the case of Cygnus A the quasar nucleus itself is hidden by dust.

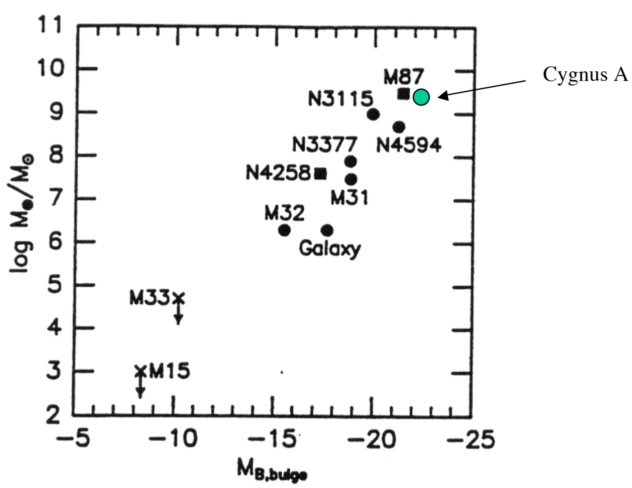


Evidence for a supermassive black hole in Cygnus A from HST/STIS data

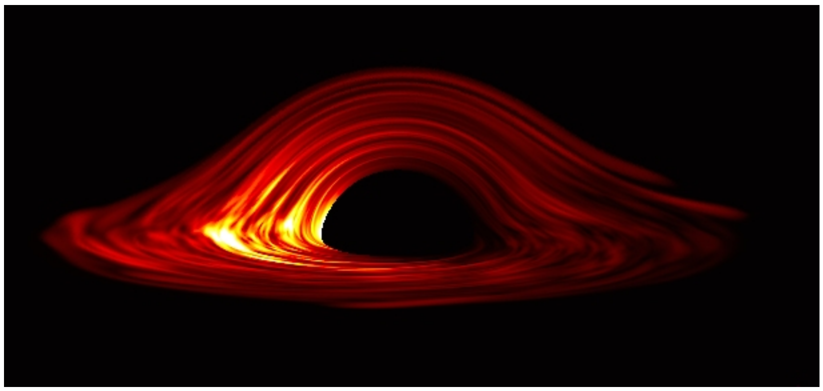
Tadhunter et al. (2003)

$M_{bh} = (2.5+/-0.5)x10^9 \ M_{sun}$

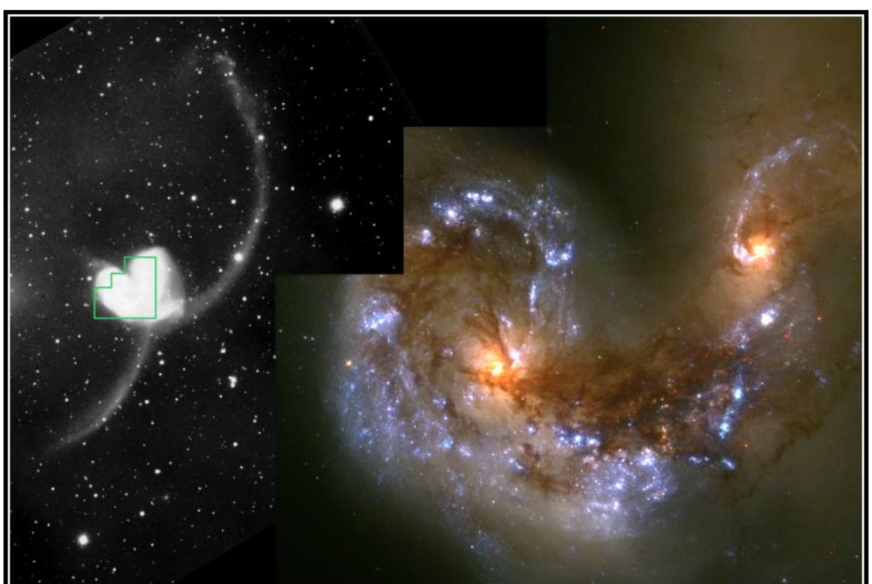
Correlation between black hole mass and galaxy bulge mass/luminosity



Supermassive black holes: the energy source for active galactic nuclei

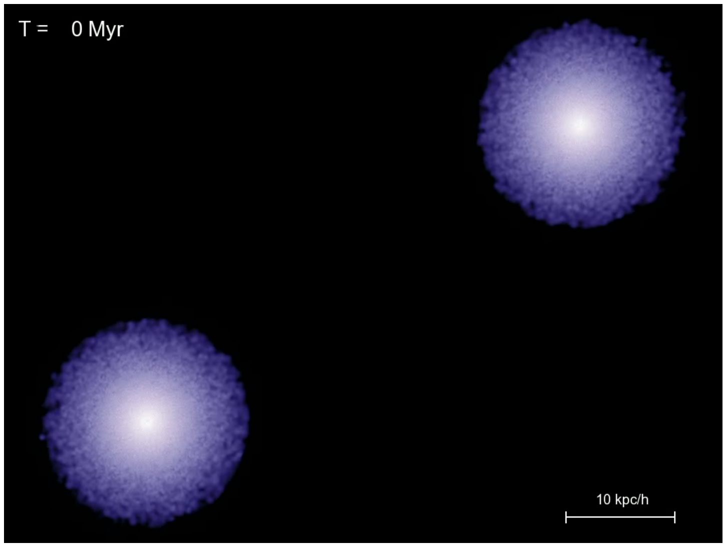


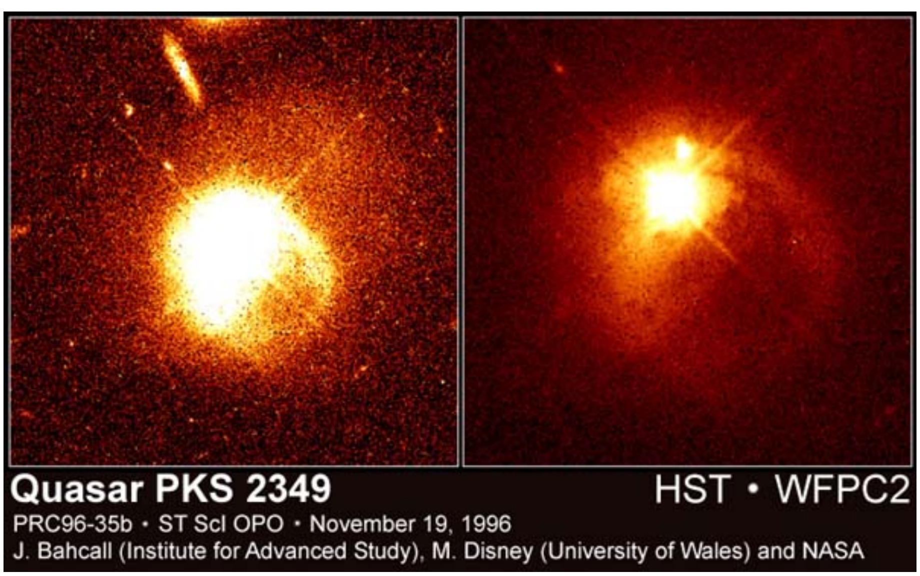
Armitage and Reynolds (2003)



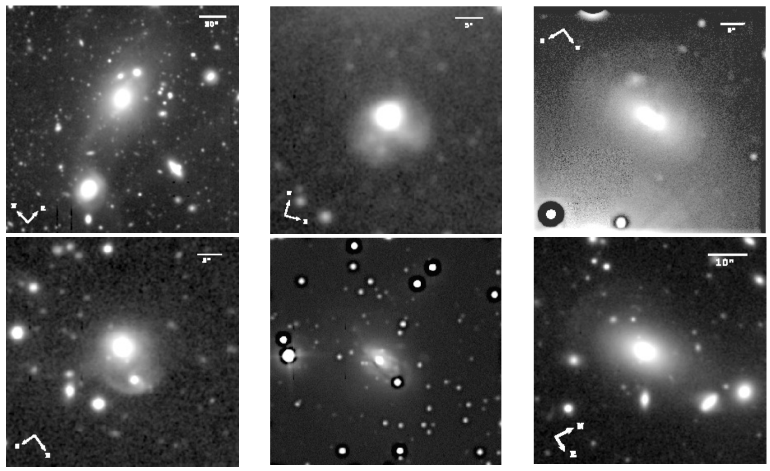
Colliding Galaxies NGC 4038 and NGC 4039 HST • WFPC2
PRC97-34a • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

Galaxy Mergers



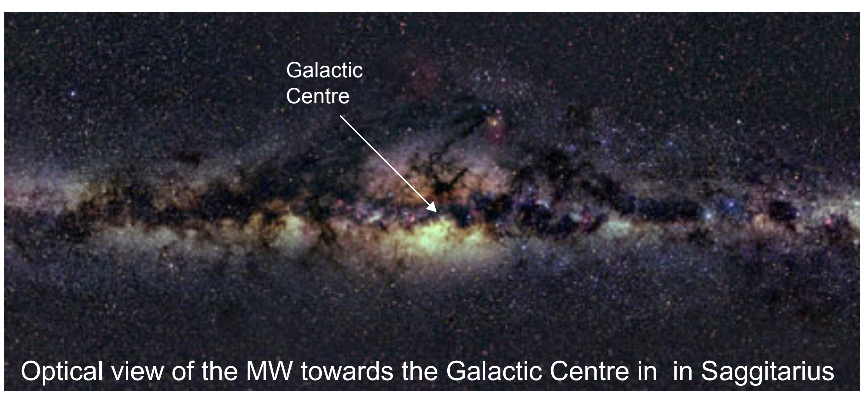


Deep Gemini imaging of the radio galaxies



95% of nearby radio galaxies with hidden quasar nuclei show signs of recent mergers

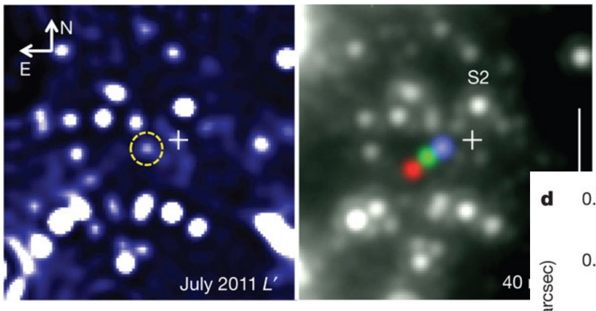
Why no quasar in the Milky Way?

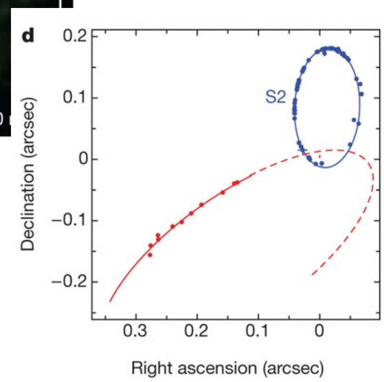


Optical view of the MW towards the Galactic Centre in in Saggitarius

There is currently no quasar in the centre of the Milky Way because there is insufficient gas “fuel” being accreted by its super-massive black holes. But there may be minor flare-ups from time-to-time as as small gas clouds pass close to the centre…

A gas cloud falling towards the Milky Way black hole…





Gillessen et al. (2011)

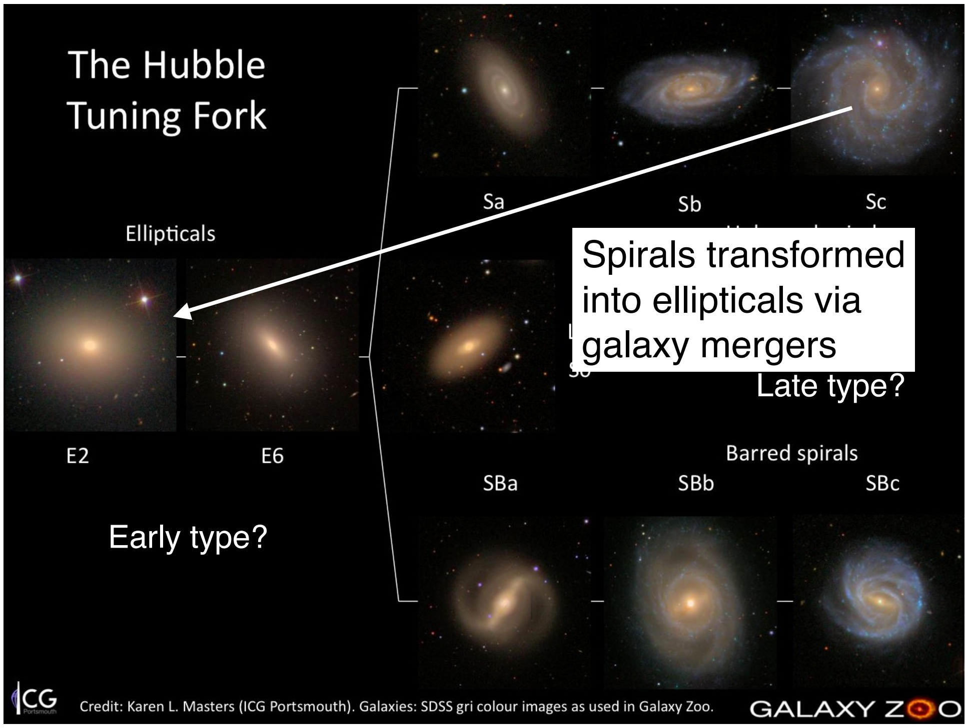
The 3 Earth mass gas cloud will pass close to the black hole in 2013. If the cloud is disrupted, the resultant gas accretion will lead to a "flare" of radiation.

The Andromeda spiral galaxy (M31)

The Andromeda spiral galaxy is the nearest large galaxy to the Milky Way. *It is moving towards us at 300 km/s and will collide with the Milky Way in ~6 billion years…*

The ultimate fate of the Milky Way

The future…



Conclusions

- Most nearby galaxies have evidence for super-massive black holes in their cores, but the black holes are quiescent because of a lack of gas fuel
- Quasars are triggered when gas is accreted close to super-massive black holes
- As galaxies evolve by merging, gas is funnelled into the nuclear regions and triggers quasars
- Quasars drive massive outflows that eject the gas from galaxies and halt star formation