Introduction to Astronomy

Lecture 8:

Galaxies

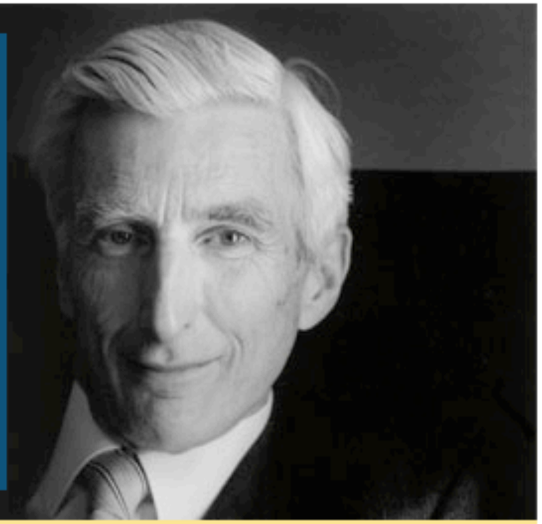
normal galaxies to quasars

University of Sydney
Centre for Continuing Education
Spring 2012

WE INVITE YOU TO

A SYDNEY IDEAS DISTINGUISHED GUEST LECTURE

THE UNIVERSITY OF SYDNEY



BIG BANGS, BIOSPHERES AND THE LIMITS OF SCIENCE

PROFESSOR MARTIN REES, 9 NOVEMBER 2012

CO-PRESENTED WITH THE FACULTY OF SCIENCE

Astronomers have made astonishing progress in probing our cosmic environment. We can trace cosmic history from some mysterious 'beginning' nearly 14 billion years ago, and understand in outline the emergence of atoms, galaxies, stars and planets - and how, on at least one planet, life emerged and developed a complex biosphere of which we are part. We have recently learnt, moreover, that many other stars are orbited by retinues of planets - some resembling our Earth, and perhaps harbouring alien life. Telescopes have revealed billions of galaxies, each containing billions of stars. But there are intimations that physical reality is hugely more extensive than the domain our telescopes can probe. Indeed we may inhabit a 'multiverse' - living in the aftermath of one among an infinity of 'big bangs'.

But these advances pose new questions: How 'special' is our Earth, and the time in which we are living? Are there aspect of science that human brains will never grasp? What does the long-range future hold, for our cosmos and for 'post-human' evolution? This illustrated lecture will attempt to address such issues.

FRIDAY 9 NOVEMBER
6.30 to 8.00pm
The Great Hall
The Quadrangle
The University of Sydney, Camperdown
(click here for campus maps)

RSVP
Please register online to attend this event.
Click here

Event is now full, but places will probably be available at the door

The trip to Mount Wilson is on this coming Saturday.

Make sure you have a handout, which includes how to get there, and a contact number in case the weather looks bad.

Several people have indicated they would like lifts; if you can help, please get phone numbers from the list down the front.

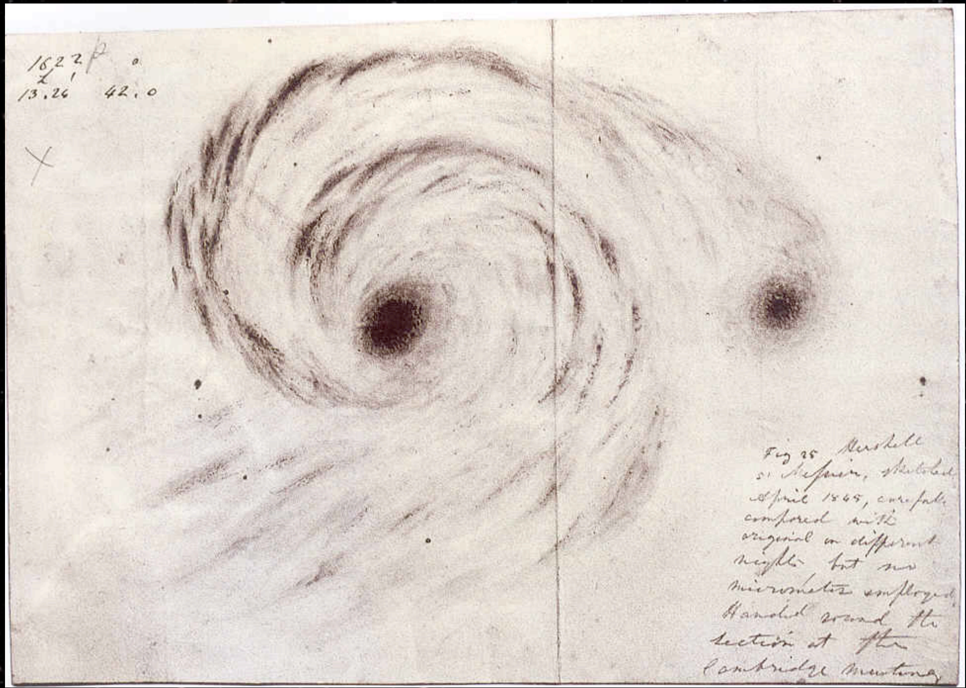
Outline

- The discovery of galaxies
  - *how we worked out there are other systems of stars*
- Types of galaxies
  - *how we classify galaxies*
- The monster within: active galaxies
  - *the weird world of supermassive black holes*

The discovery of galaxies

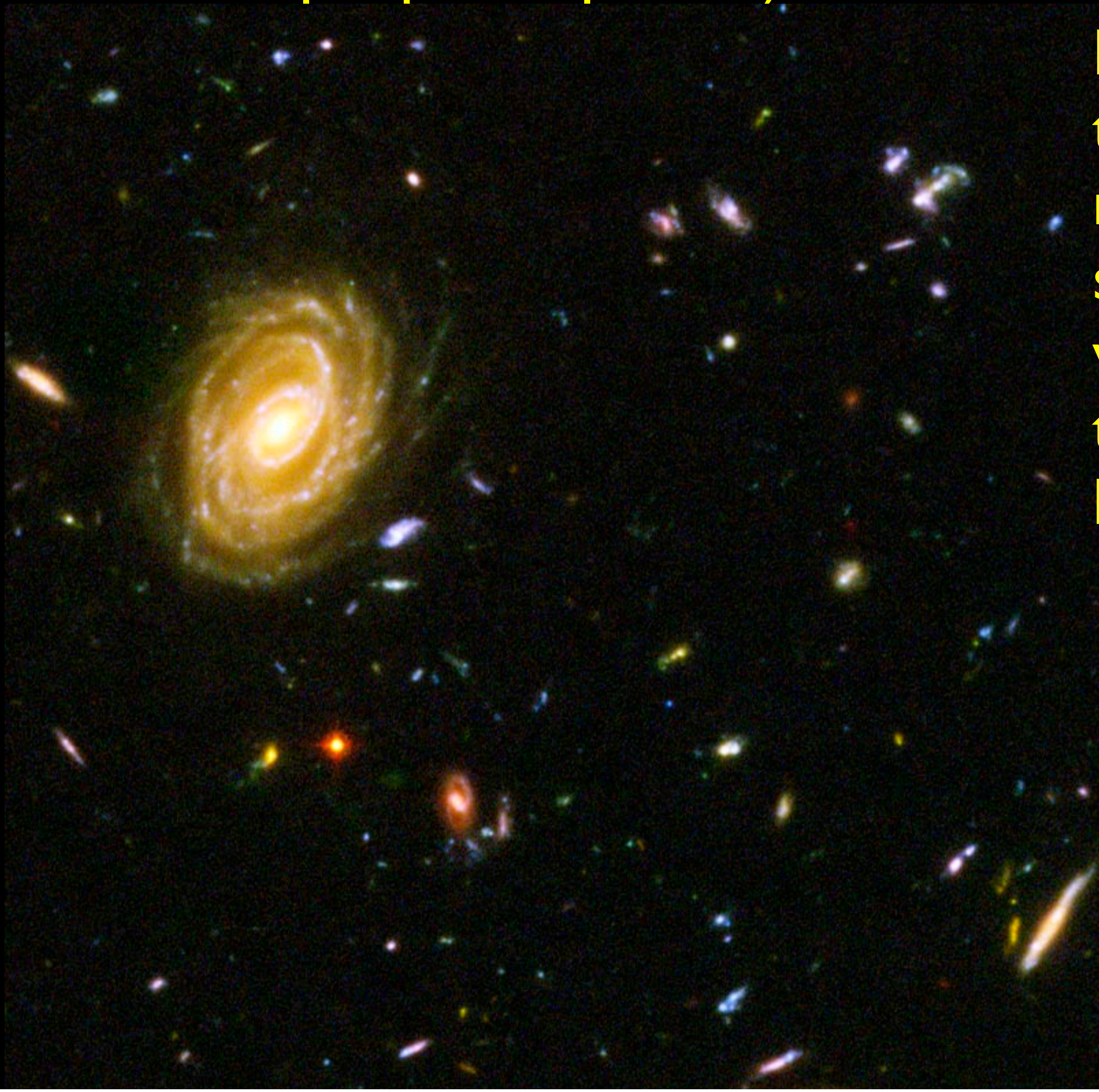
Edwin Hubble at the eye-piece of the Palomar 48" Schmidt telescope

In 1845, William Parsons, the third Earl of Rosse, discovered that some nebulae are spiral in shape.



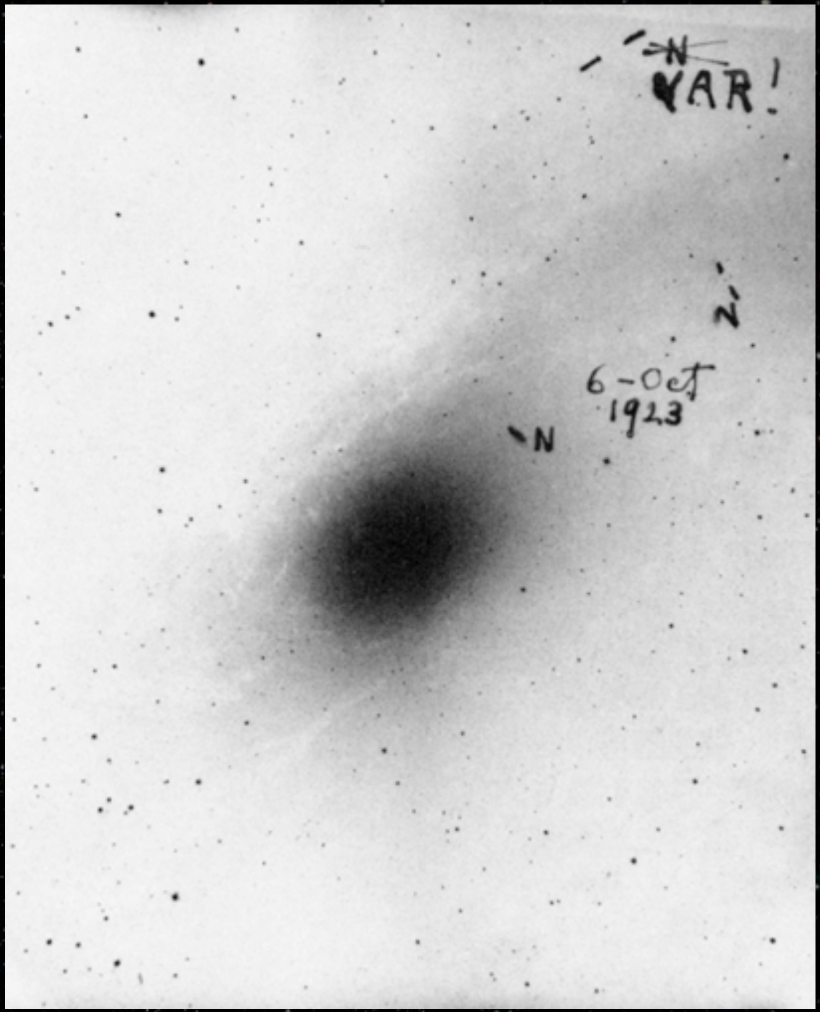
Parson's drawing of the Whirlpool Galaxy M51, compared to the Hubble picture

The nature of these spiral nebulae was debated for many years. Were they part of the Milky Way, or were they (as some people suspected) entire "island universes" like the Milky Way, so far away that their stars were not resolved into point sources of light but were instead blurred together so they looked like a nebula.

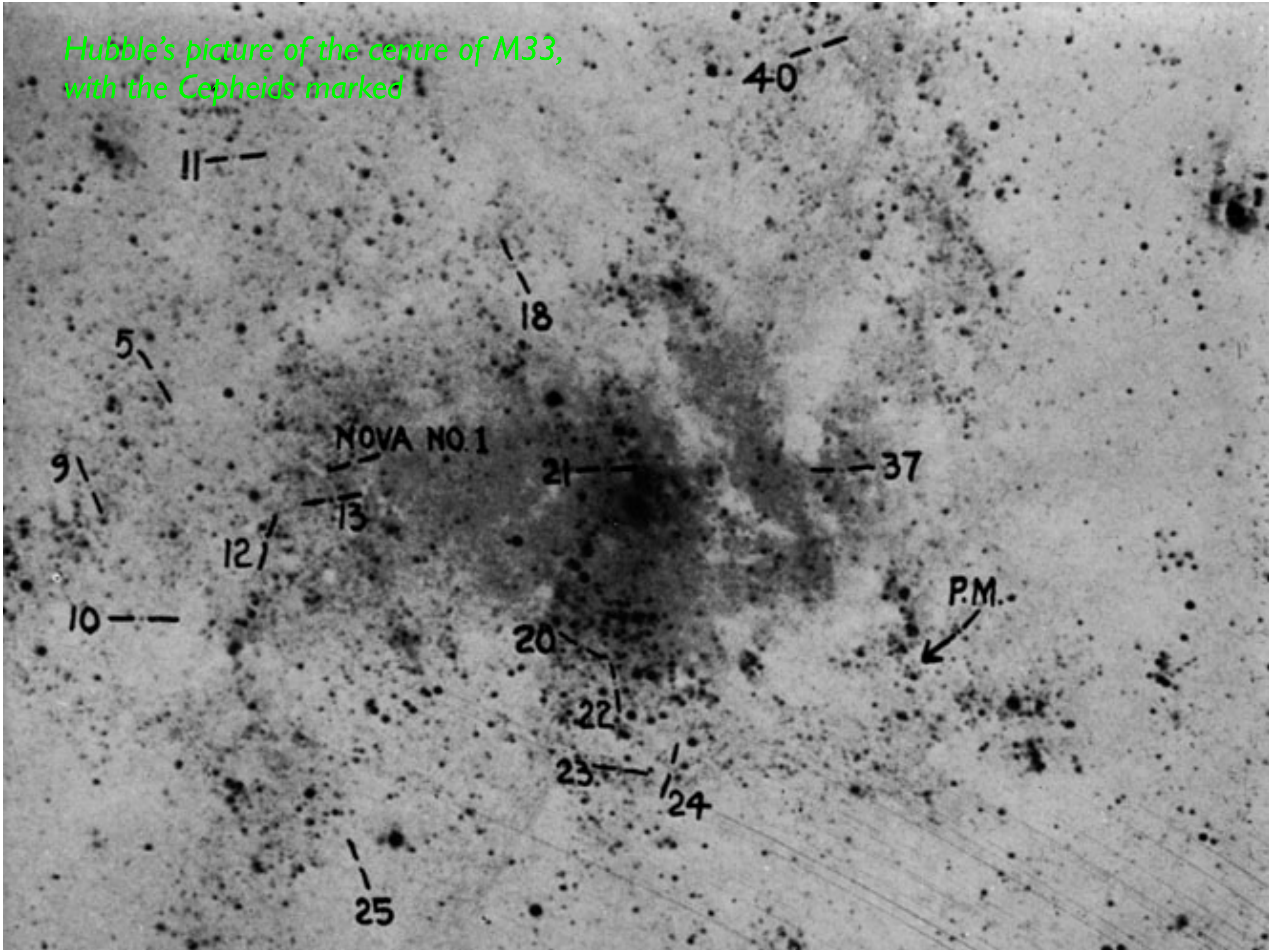


Galaxies from the Hubble Ultra-Deep Field.

In 1924, Hubble used the 100-inch telescope at Mt Wilson to resolve some of the spiral nebulae into stars. Further, he found several Cepheid variables in M31, and concluded that it lay at a distance of 300,000 parsecs, or more than a million light years. This was well outside the limits of Shapley's estimate for the size of the Milky Way.



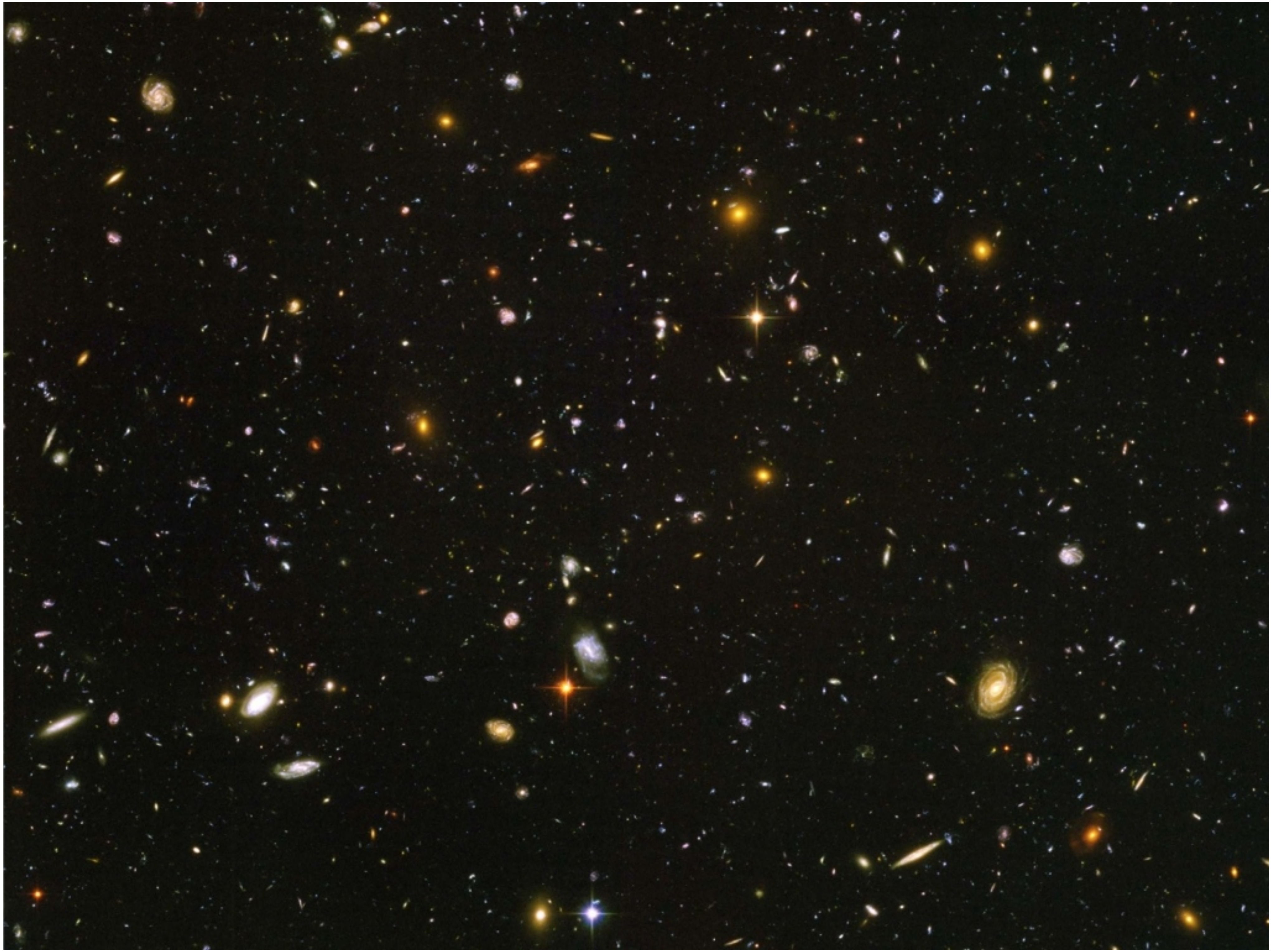
"The great spirals … apparently lie outside our stellar system."
—Edwin Hubble



Hubble's picture of the centre of M33, with the Cepheids marked

Hubble suggested that these systems should be called *external galaxies*, to distinguish them from "the Galaxy", a synonym for the Milky Way.

> "Some astronomers consider that since nebulae are now known to be stellar systems they should be designated by some other name, which does not carry the connotation of clouds or mist... The proposal most frequently discussed is a revival of the term *external galaxies*... The term *nebulae* offers the values of tradition; the term *galaxies*, the glamour of romance."
>
> – Edwin Hubble, *The Realm of the Nebulae*



Types of galaxies

We now recognise that all galaxies are collections of stars, gas and dust, bound together by their own gravitational pull.

Hubble pointed out that galaxies fall into three major types, based on their appearance on photographic plates: ellipticals, spirals, and irregulars.

Hubble's "tuning fork" diagram of galaxy types.

Elliptical galaxies appear oval in shape, with lines of equal brightness made up of concentric and similar ellipses. They can have shapes ranging from circular (E0) to highly flattened (E7).

The giant elliptical galaxy NGC 1316 in the Fornax Cluster

Elliptical galaxies have smoothly varying brightnesses, steadily decreasing outward from the center. These galaxies are nearly all of the same colour: they are somewhat redder than the Sun. Ellipticals are also devoid of gas or dust and contain just old stars.

The elliptical galaxy M60 is noticeably different in colour than the neighbouring blue spiral NGC 4647

All ellipticals look pretty much the same.

The elliptical galaxy M87, together with other ellipticals NGC 4478 and 4476

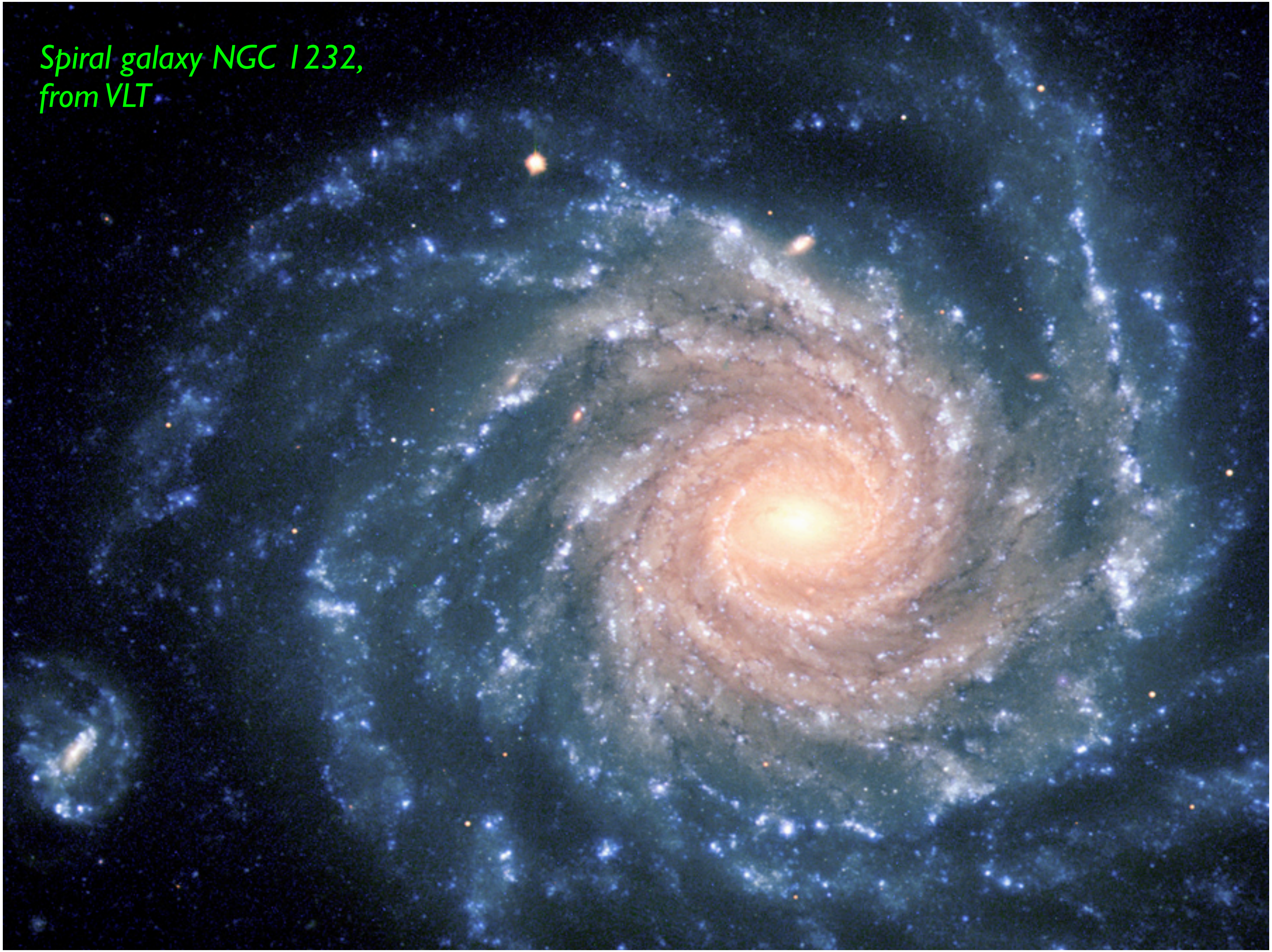
Spiral galaxies have two or more spiral-shaped arms, which begin from or near the nucleus and gradually wind outward to the edge.

Spiral galaxy M74, from Hubble

The nucleus of a spiral galaxy is a bright distinct region, which can be quite small or, in some cases, can make up the bulk of the galaxy. The arms are embedded in a thin disk of stars. Both the arms and the disk of a spiral system are blue in colour, whereas its central areas are red like an elliptical galaxy.

Spiral galaxy NGC 5033

Spiral galaxy NGC 2841
close-up, from Hubble


Spiral galaxy NGC 1232,
from VLT

The 'Sombrero Galaxy', M104, shows a large bulge and a nearly edge-on disk with dust lanes.

Spiral galaxies can be tightly wound (type Sa) or more open spirals (Sc).

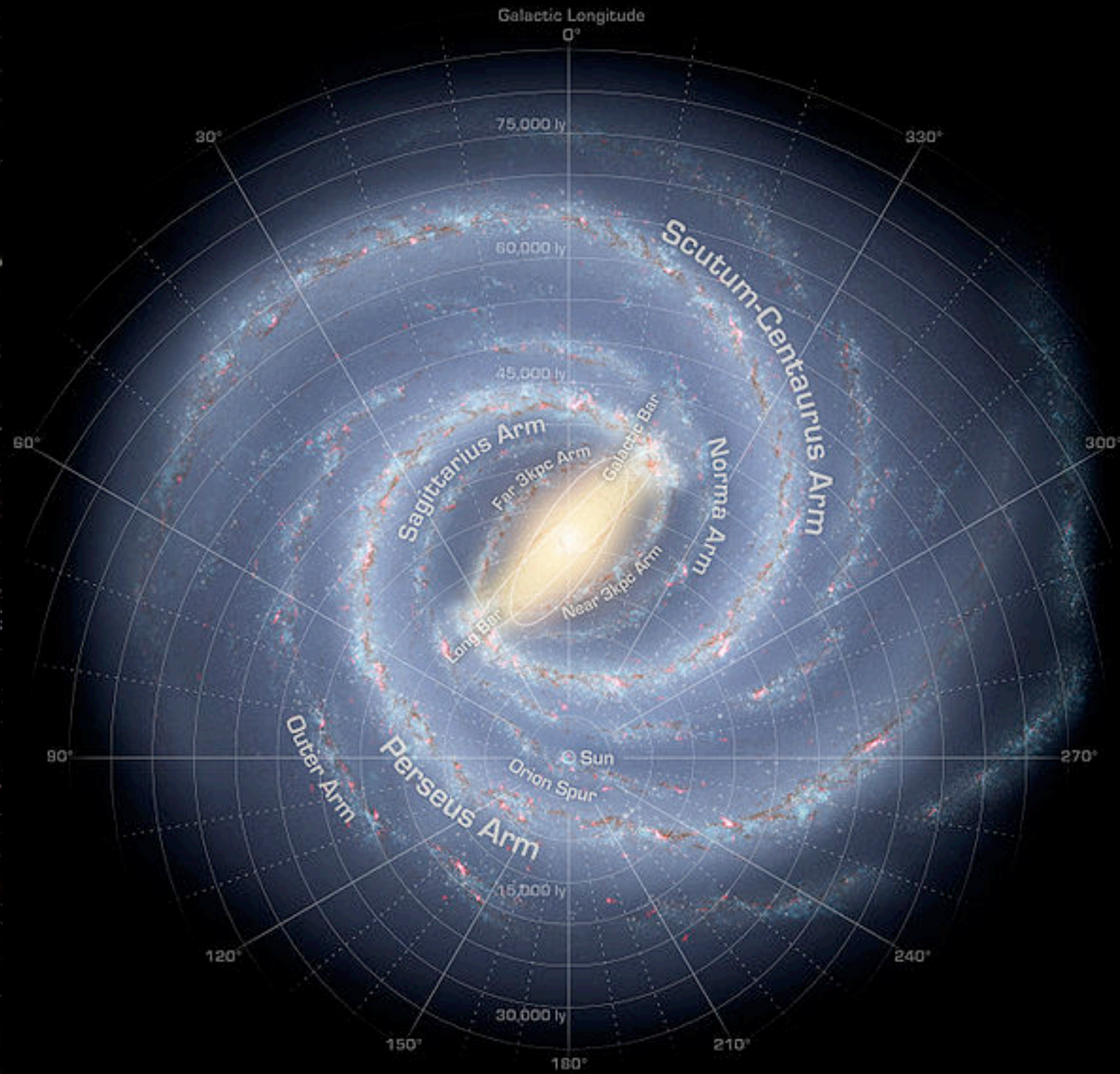
M81 (type Sa) and M51 (type Sc)

Some spirals are called *barred spirals*, where the arms emerge from a bar-shaped bulge in the centre of the Galaxy.

Barred spiral NGC 1300, from Hubble


NGC 1365

The Milky Way is actually a barred spiral.



Irregular galaxies have no noticeable symmetry nor obvious central nucleus. They are generally bluer in colour than are the arms and disks of spiral galaxies.

The Large Magellanic Cloud

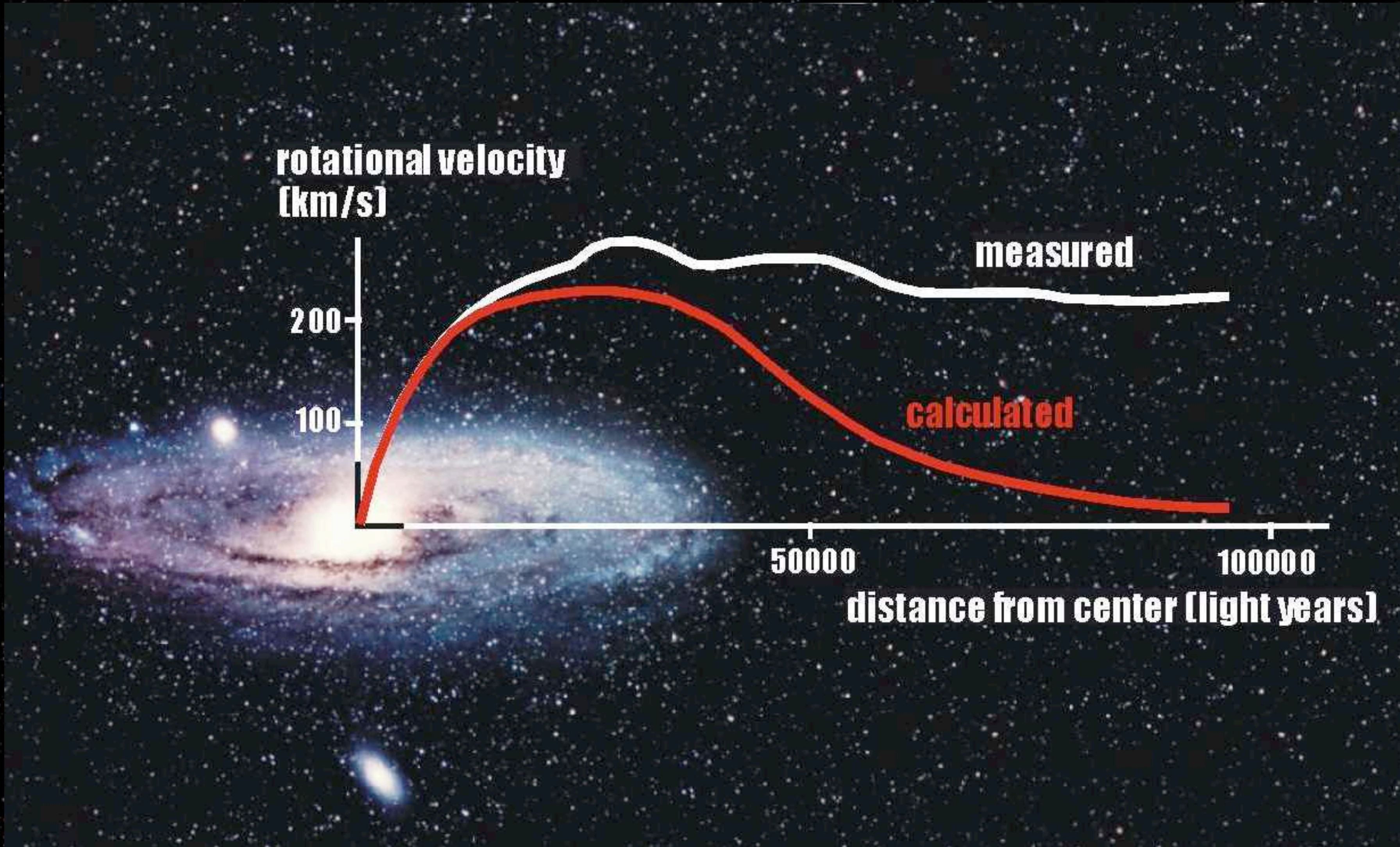
The irregular galaxy NGC 4449, from Hubble

Irregular galaxies tend to be small, 1–25% of the size of our Galaxy.

Our Galaxy is large compared to most spirals, though there are some larger.

Elliptical galaxies cover a range of sizes. Giant ellipticals are the largest galaxies, up to 5 times the diameter and 50 times the mass of the Milky Way.

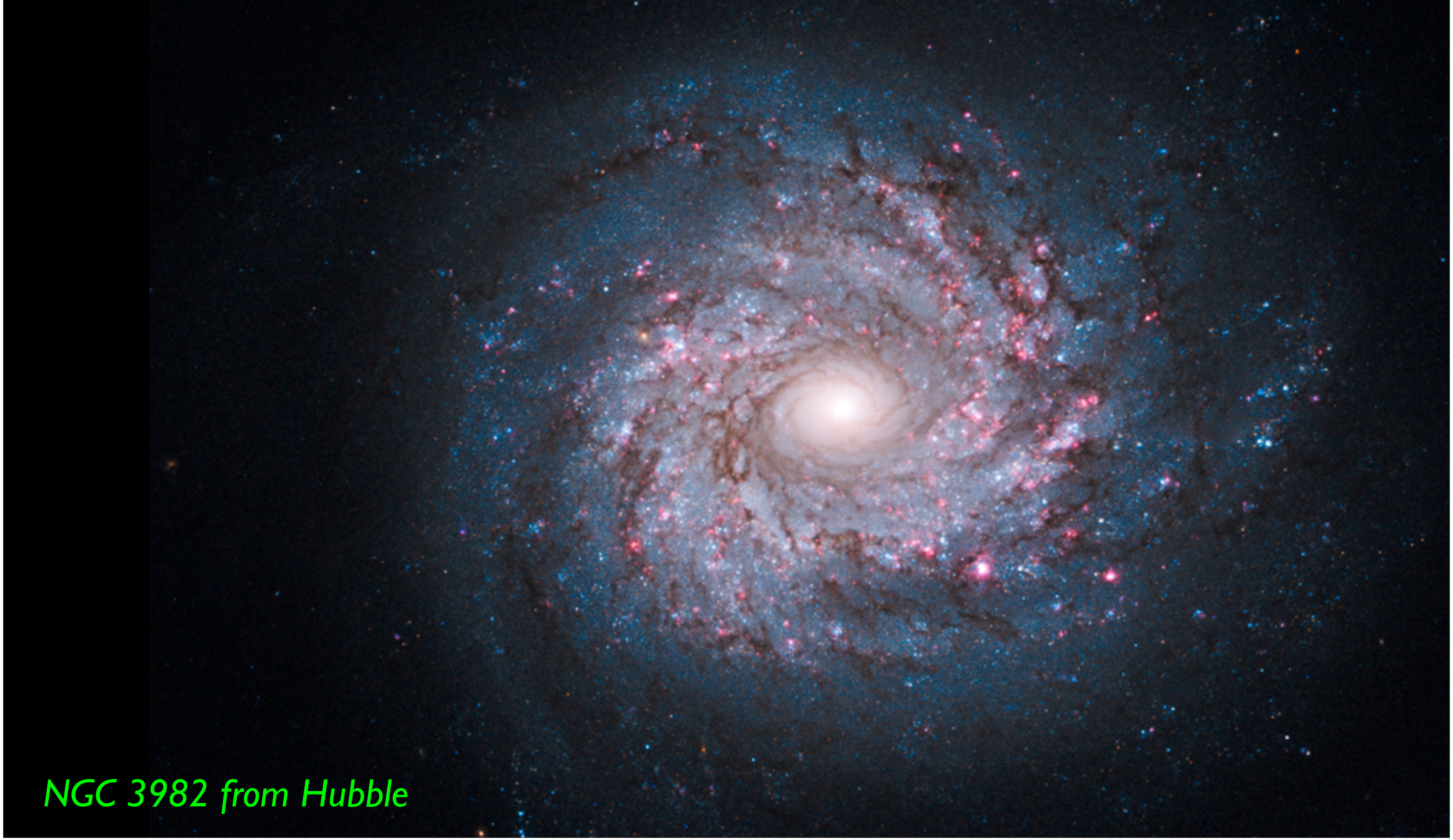
Like the Milky Way, other galaxies all show evidence that most of their mass is not in the form of visible stars: they too are dominated by *dark matter*.



Most of the mass of a galaxy is in dark matter and stellar remnants, but almost all of the light is due to photons emitted from normal stars. Thus, a study of the appearance and total luminosity of galaxies with time is a question of the behaviour of the stellar population of which they are composed.

What colour a galaxy appears depends mostly on how much gas and dust it contains.

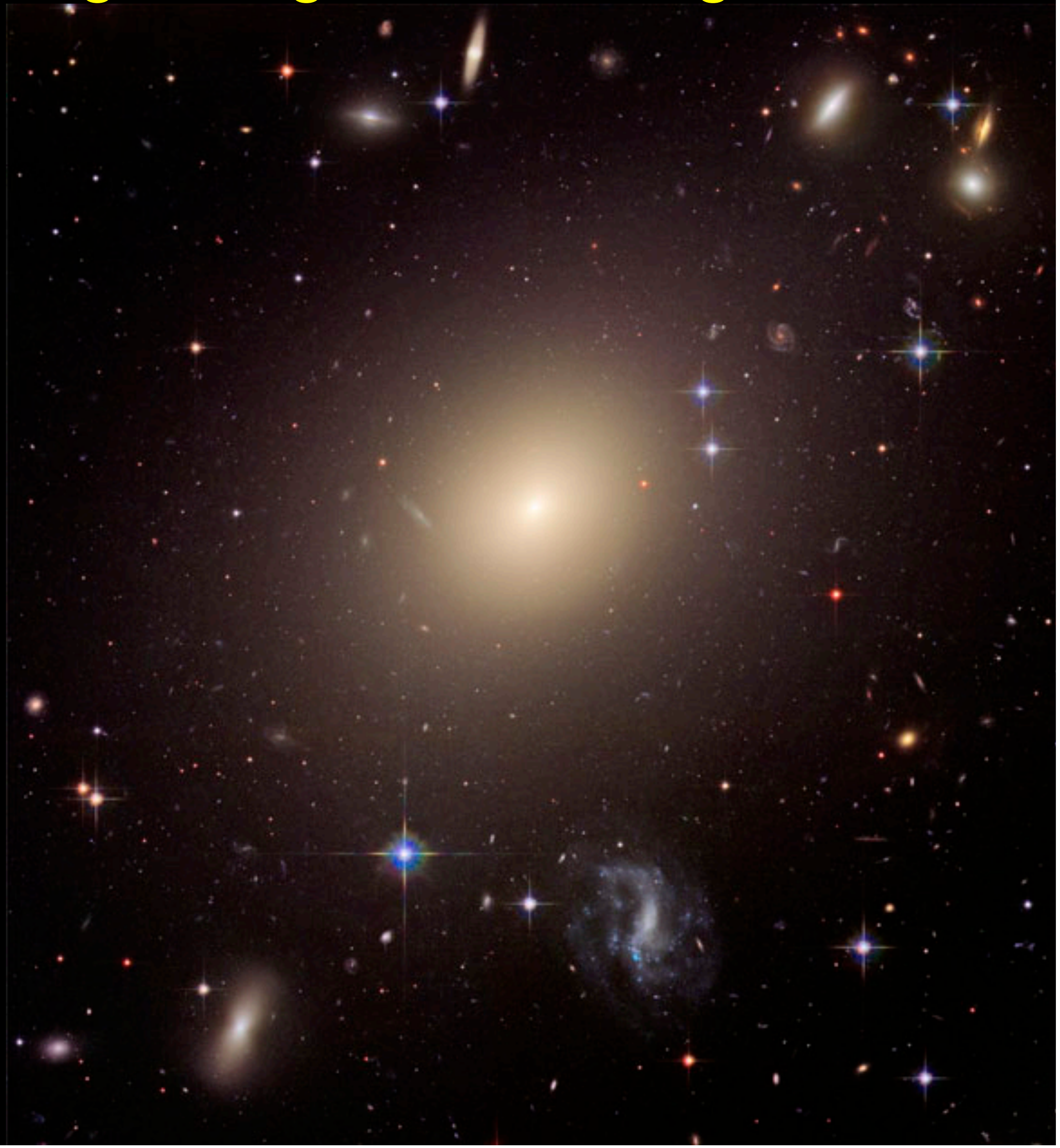
Spiral galaxies contain large amounts of gas and dust, which means they produce lots of young stars. The hot, blue O and B stars in these galaxies give them a distinct blue colour.



NGC 3982 from Hubble

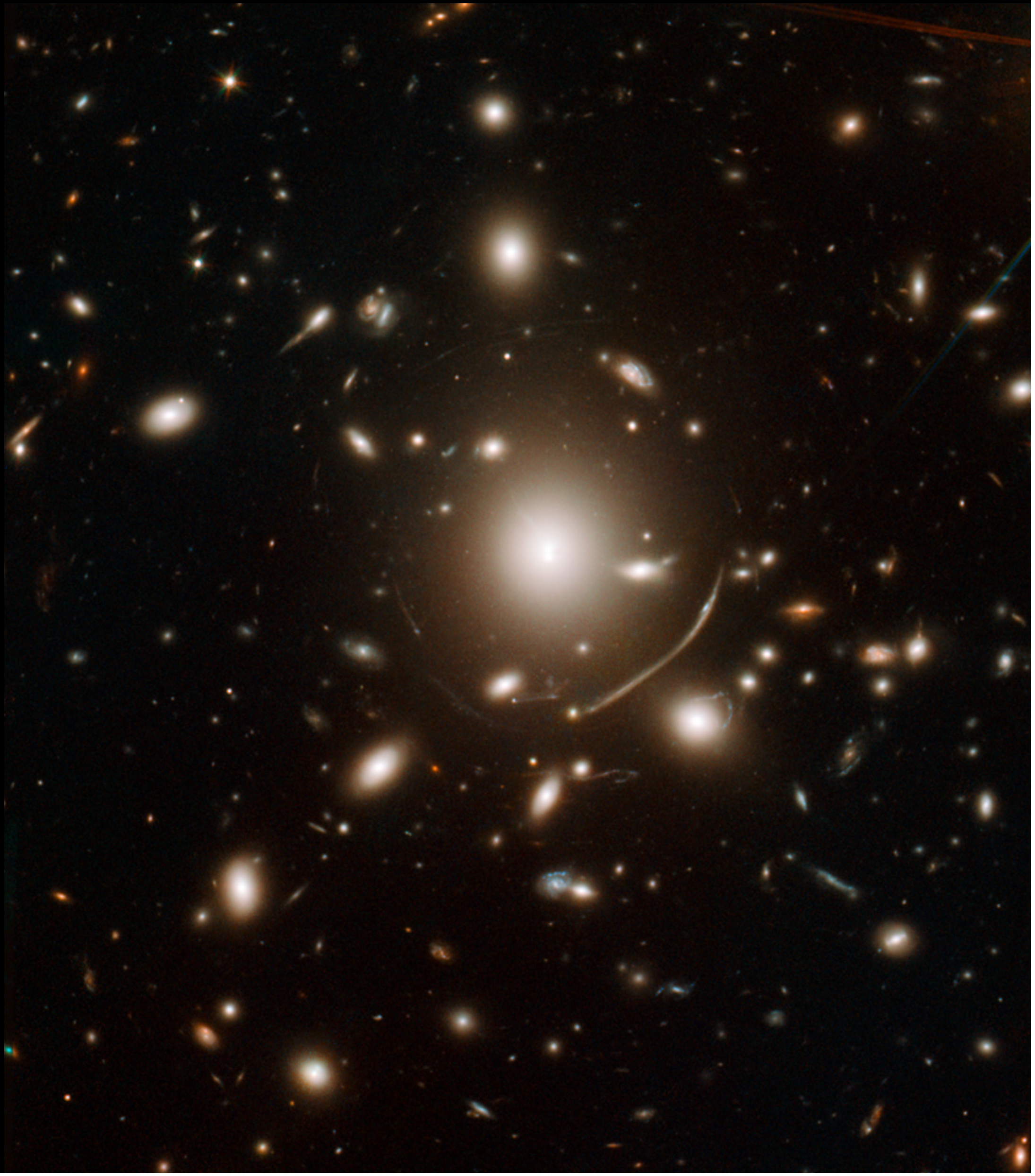

NGC 1309 from Hubble

Elliptical galaxies contain very little gas and dust, so they stopped making stars a long time ago. The hot, bright blue stars have all died, so the remaining stars are all red. Thus the light from the galaxy, which is just the sum of the light from the stars, is also red.

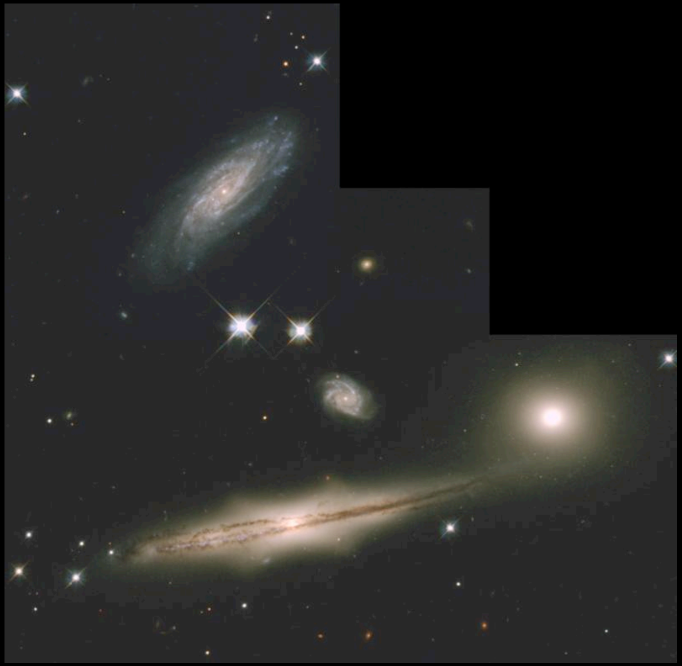


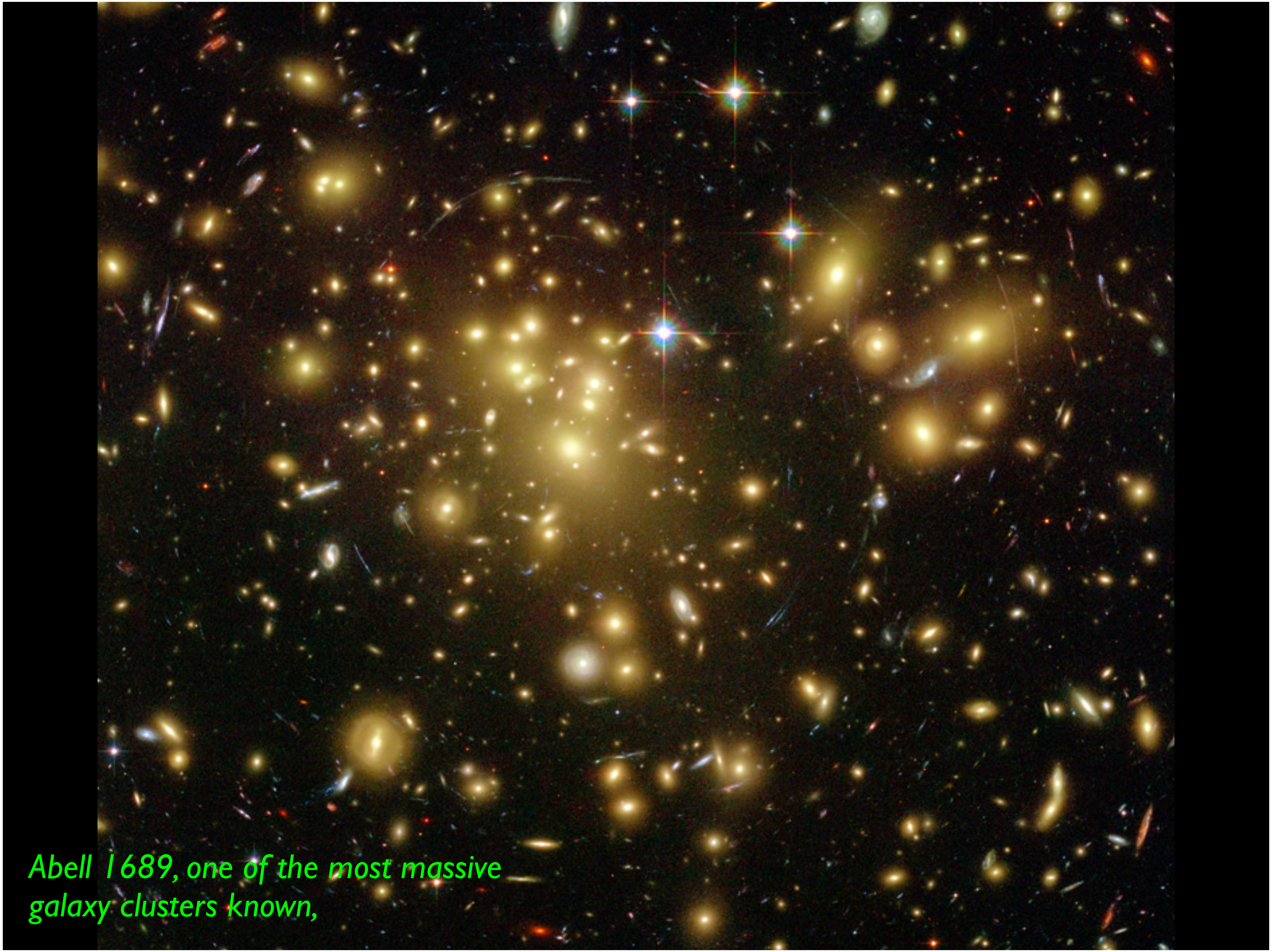
Elliptical galaxy ESO 325-G004 in the centre of the cluster Abell S0740

Galaxies lives in groups (~20 members) or clusters (up to 1000s of members). Many clusters have a giant elliptical galaxy at their centre.

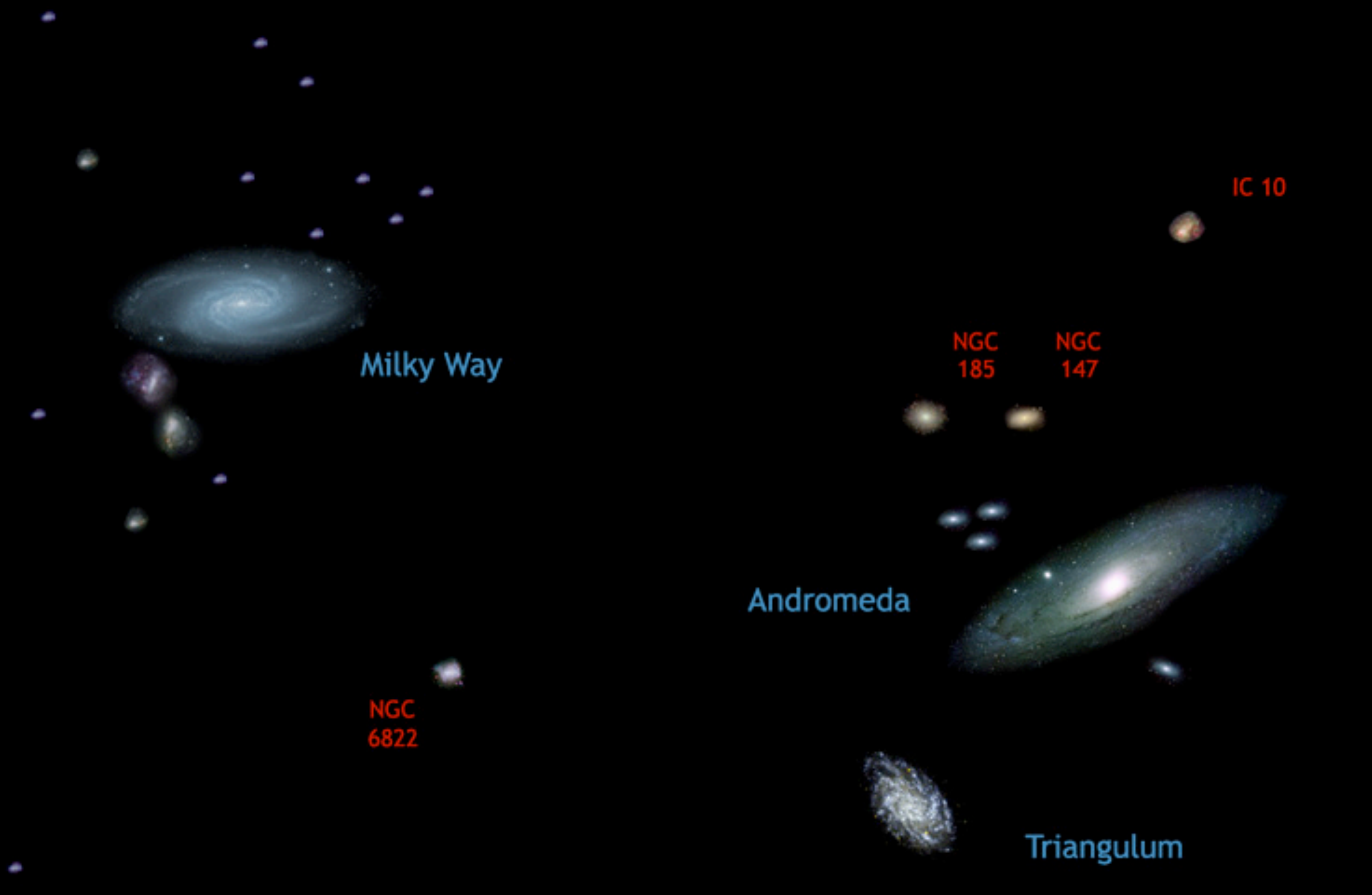


A group of galaxies (below) and a cluster, Abell 383 (right)

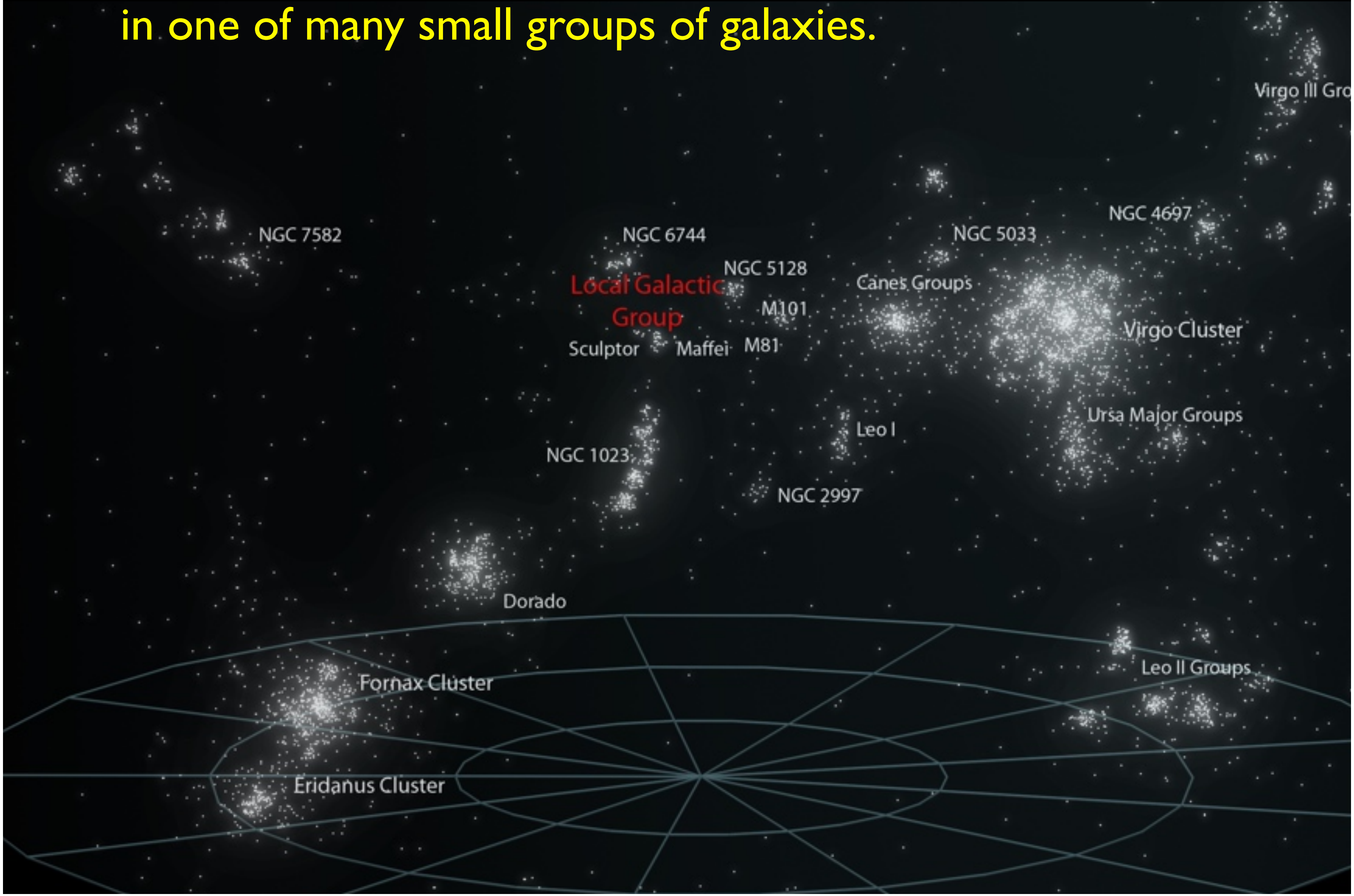



Abell 1689, one of the most massive
galaxy clusters known,

The Milky Way lives in a small group of galaxies called the *Local Group*. It consists of 54 galaxies: two large spirals – the Milky Way and the Andromeda galaxy – and a host of smaller spirals and irregular galaxies.



The Local Group is at the outskirts of the *Virgo supercluster*, in one of many small groups of galaxies.




Deep image of the Virgo cluster
by Fabian Neyer

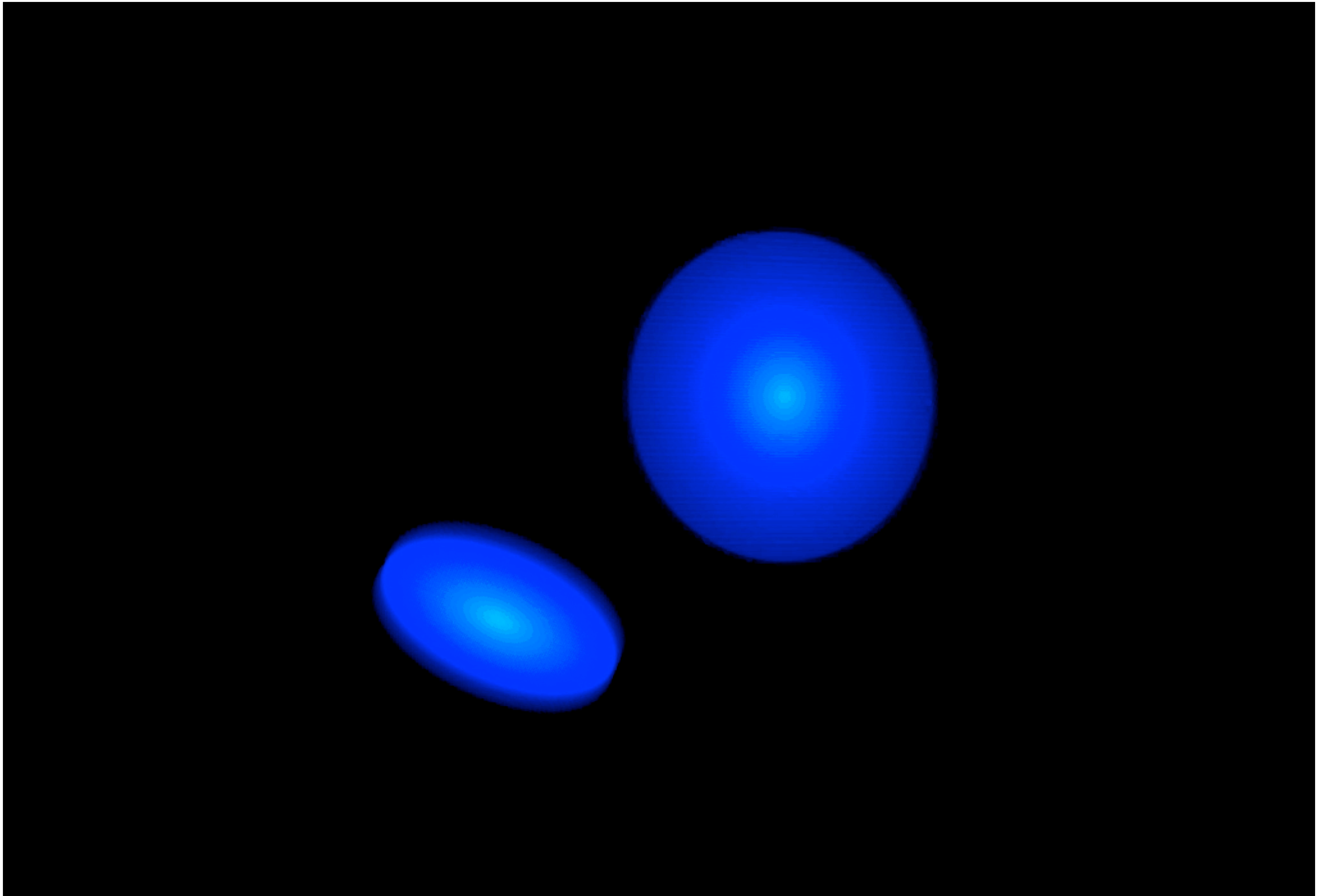
Galaxies can collide, particularly in clusters. The stars themselves rarely collide, but the mutual gravity can distort both galaxies, often throwing long tails of stars and gas out of the system entirely.

Pair of interacting galaxies NGC 4767 "The Mice"


Giant galaxy NGC 6872, winner of the
Australian Gemini School Astronomy
Contest,2010

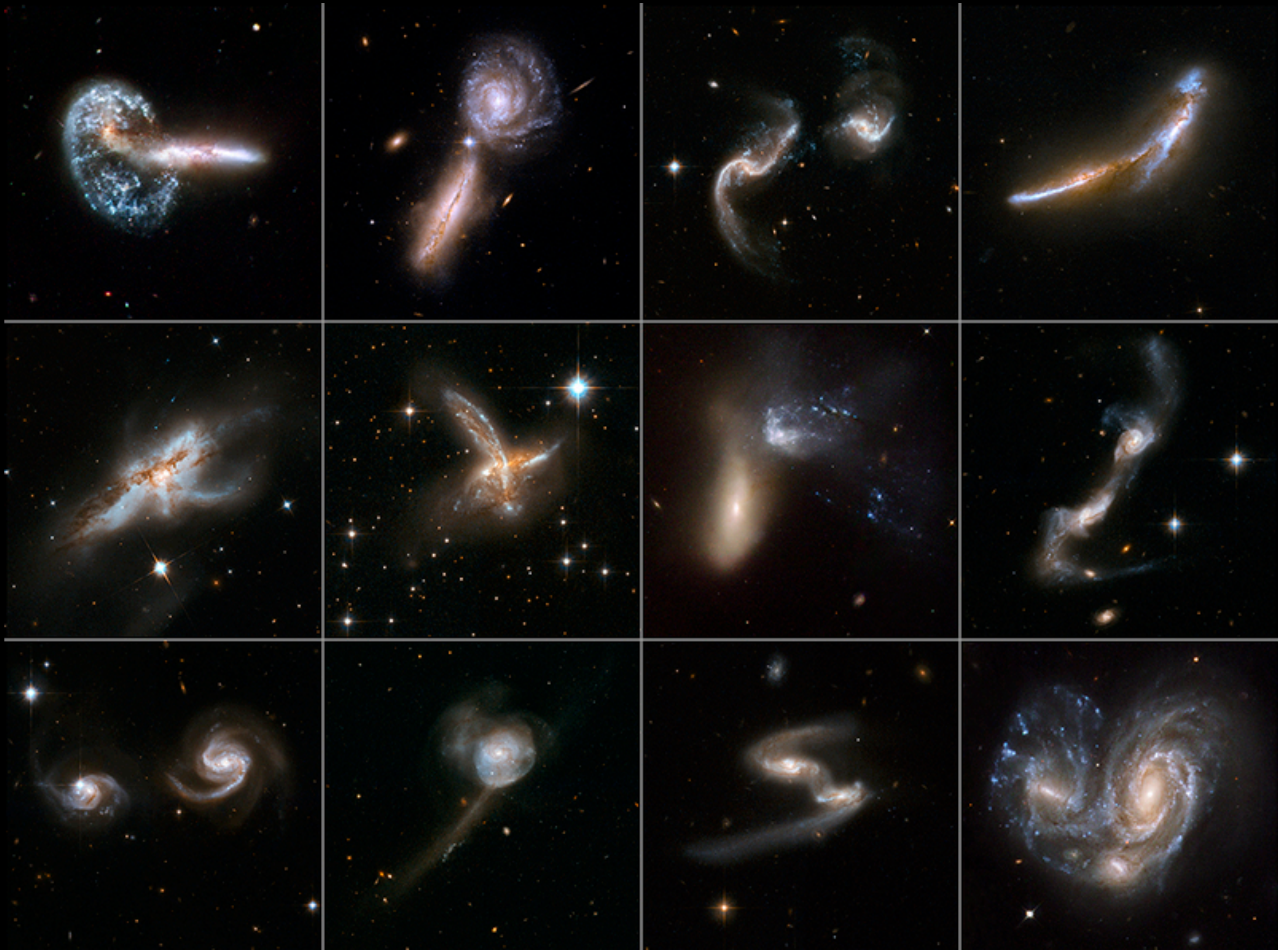
Pair of interacting galaxies
NGC 4038/4039
"The Antennae"

Gas clouds within the galaxies get compressed in the collision, which often triggers huge bursts of star formation.



Simulation of the Antennae galaxies interaction

Hubble has imaged many of these cosmic collisions



The Milky Way has devoured several small companions in the past.

Artist's impression of the Sagittarius Tidal Stream, a loose filament of stars and gas, the remains of a dwarf companion galaxy.

In about four billion years, the Milky Way and Andromeda will collide. It will take about 2 billion years for the combined remnant to settle down into an elliptical galaxy; the Solar System will probably be tossed further from the centre than it is now.

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The monster within

– active galaxies

Some galaxies show evidence that there are extremely violent processes taking place within them.

This can include

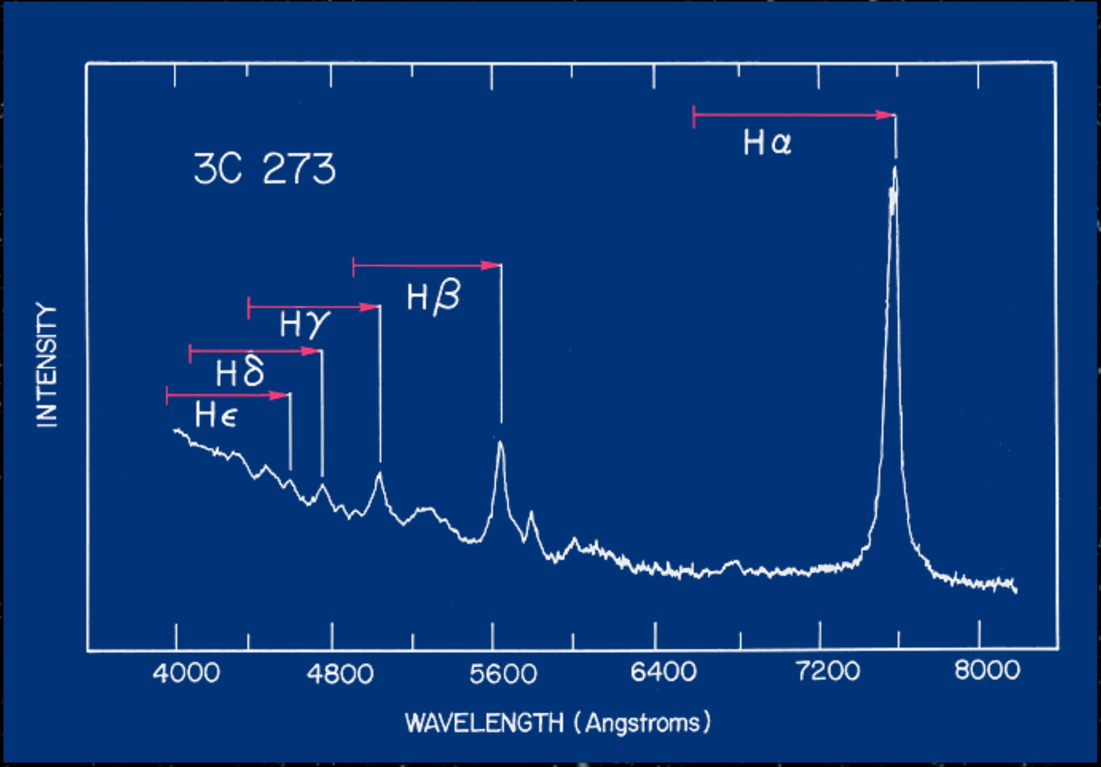
- jets emanating from the nucleus
- excess X-ray, UV or radio emission
- high luminosity
- rapid variability of the nucleus

Such galaxies are referred to as *active galaxies*. We now believe that all active galaxies are powered by rotating supermassive black holes at their centres.

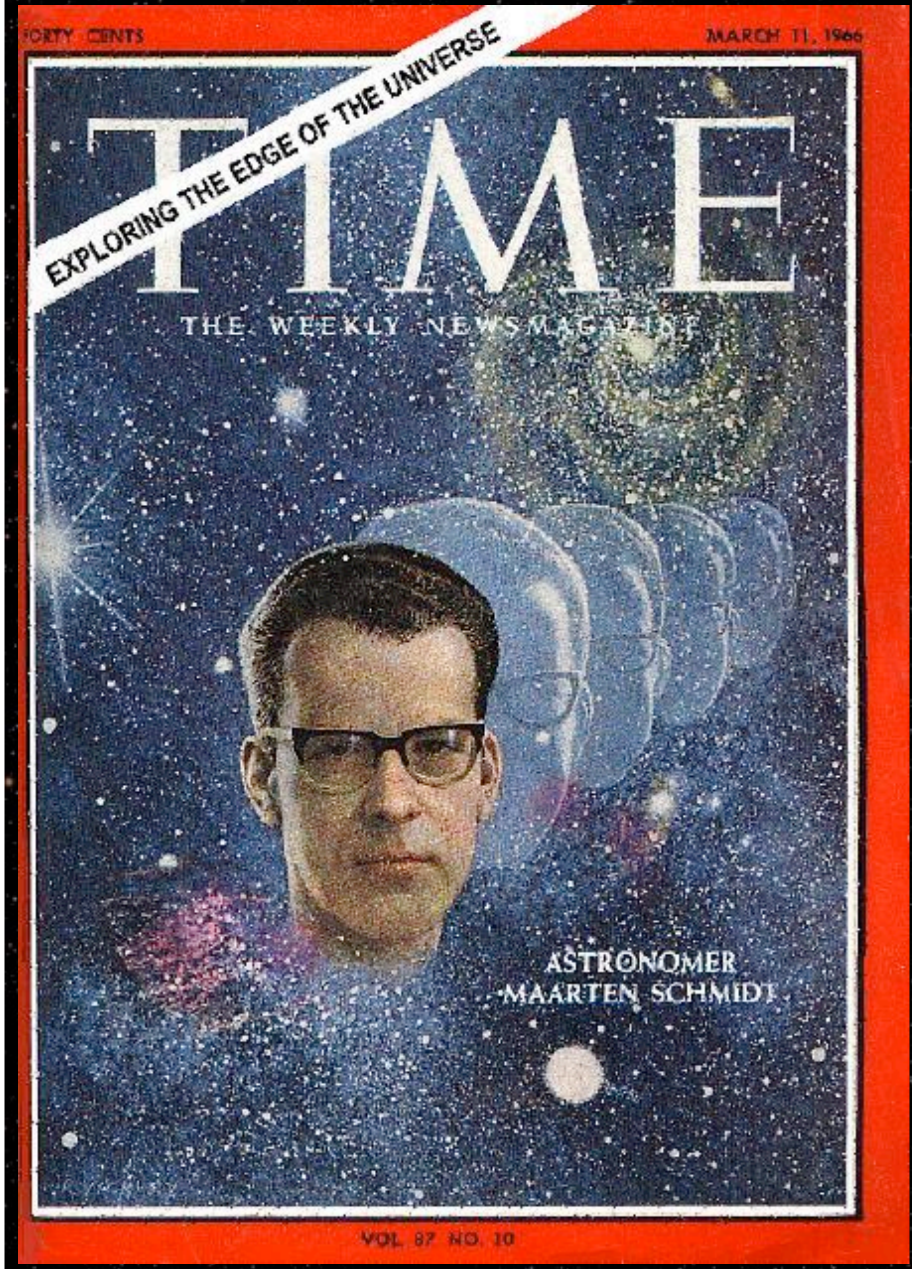
Quasars were discovered in the 1960s. They looked like stars, but emitted radio waves, and had extremely peculiar optical spectra.

The Dutch/American astronomer Maarten Schmidt realised that the broad emission lines were the ordinary hydrogen lines, but redshifted by 15%.

This suggested it was extremely bright, a thousand times brighter than the brightest galaxy.



The spectrum of the first quasar, 3C 273, showing the redshifted hydrogen lines

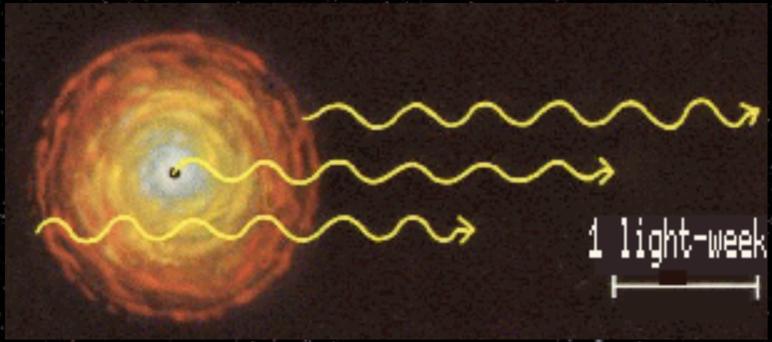


Twinkle, twinkle, quasi-star,
Biggest puzzle from afar.
How unlike the other ones,
Brighter than a trillion Suns.
Twinkle, twinkle, quasi-star,
How I wonder what you are!

– George Gamow

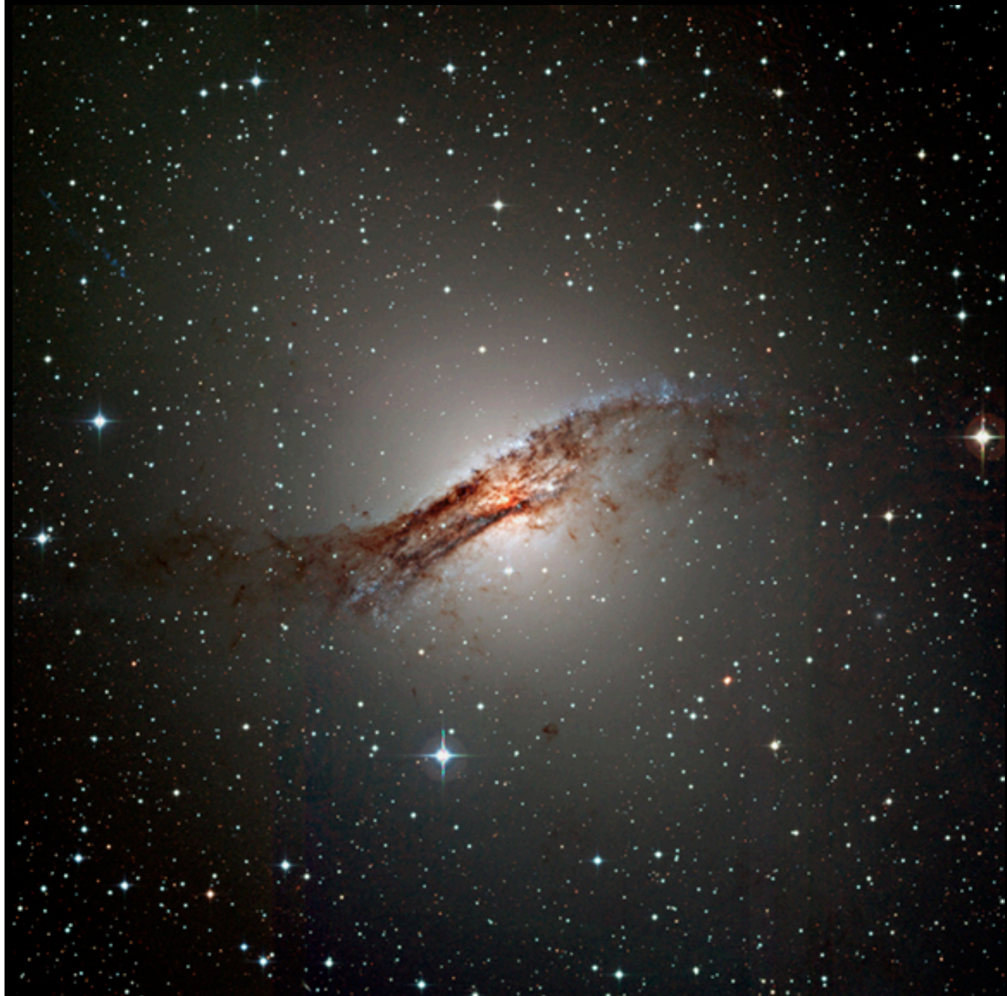
Quasars were also found to be highly variable, varying by huge amounts in times as small as a week or so. This means they must be *small* – smaller than about a light-week.

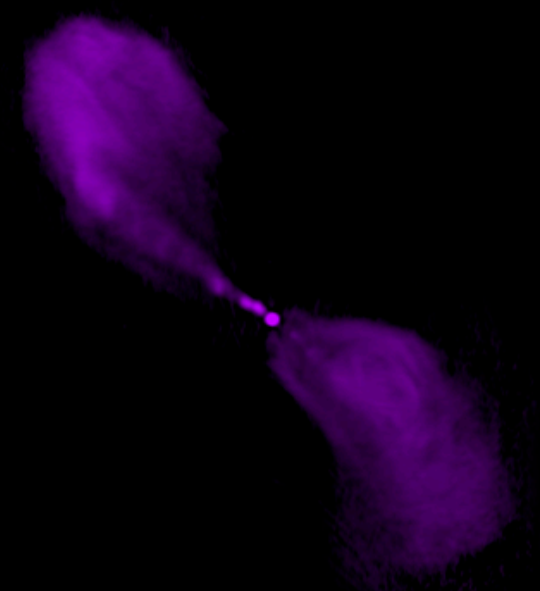
So we have an object brighter than a thousand galaxies, inside a region the size of the Solar System!



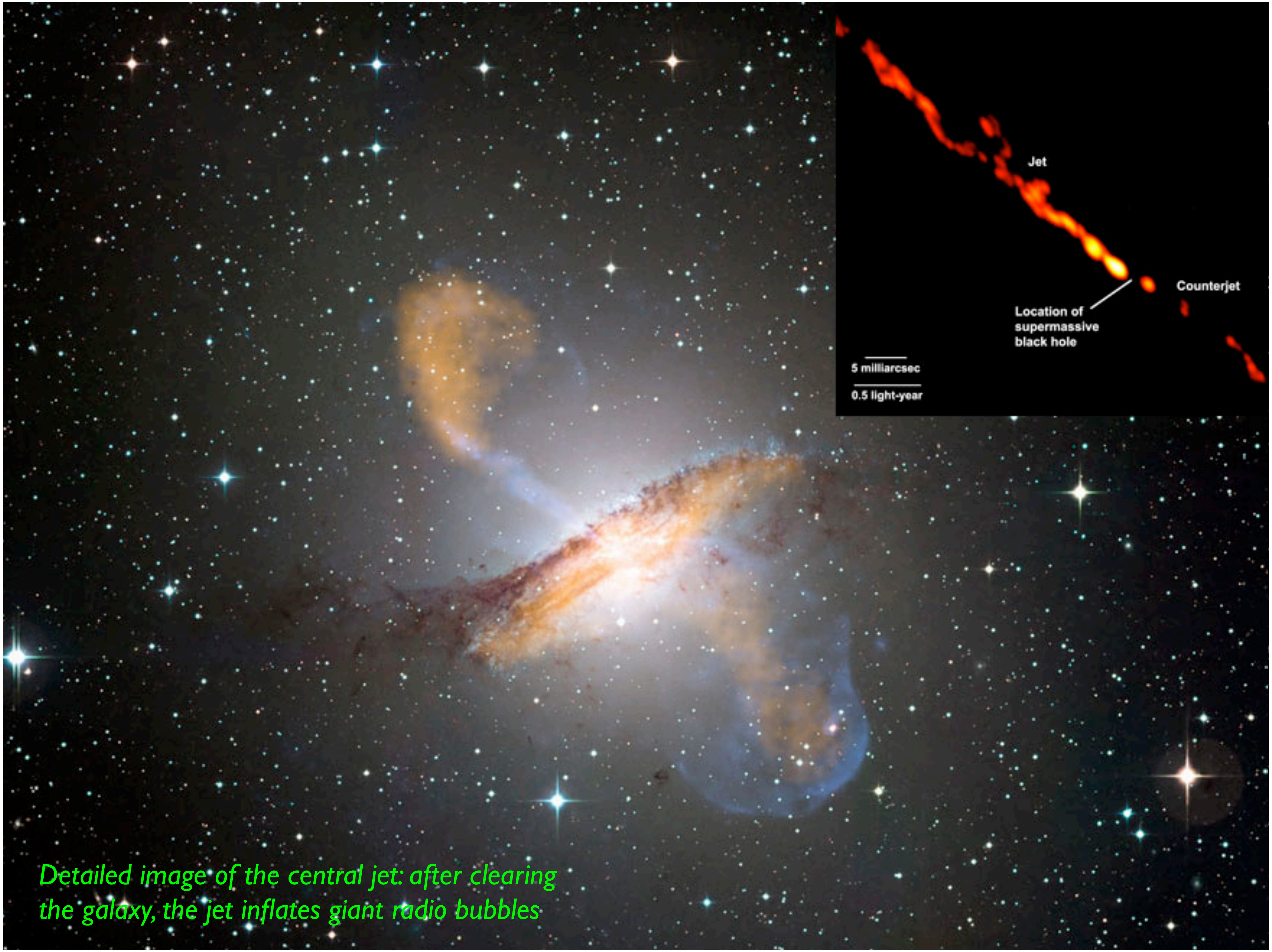
If a quasar changed its brightness all at once, like a flash, then the light from the centre of the quasar would always be behind the light from the front, so would reach the observer later. If the quasar is two light-weeks across, then the light would rise and fall over two weeks.

Meanwhile, the new science of radio astronomy had found that the radio sky looks very different to the optical sky. Radio telescopes see jets being shot from the centres of some large elliptical galaxies.





The galaxy Centaurus A and its radio jets.

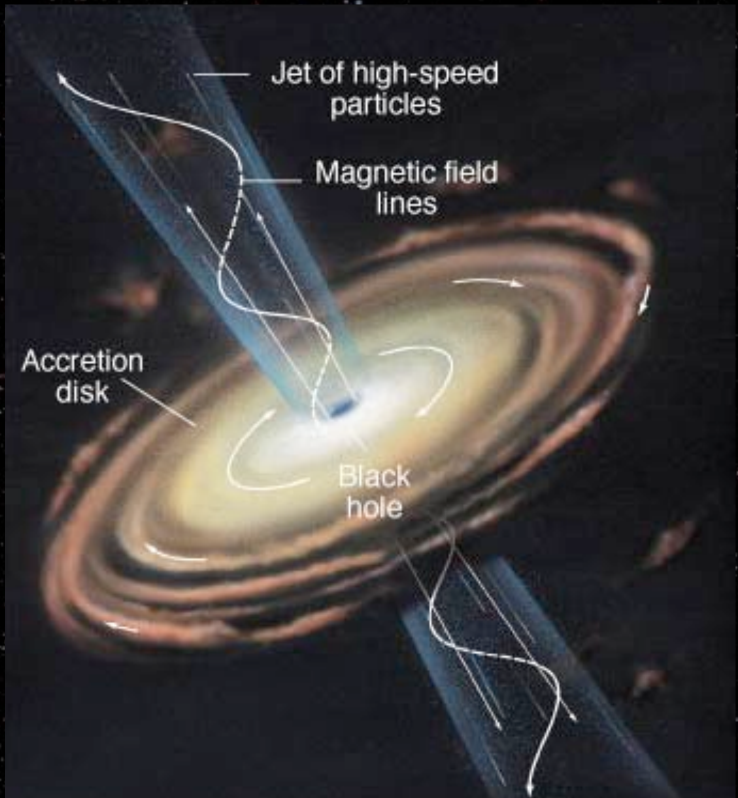


Detailed image of the central jet: after clearing the galaxy, the jet inflates giant radio bubbles

Often these jets are many times larger than the host galaxy.

Fornax A: the radio lobes (orange) span over a million light years, well outside the host galaxy, NGC 1316

We now believe that all active galaxies contain a supermassive black hole at their core. Material flowing into the black hole forms an accretion disk around the black hole. Somehow, magnetic fields in the disk get warped and tangled, and a jet forms which ejects high temperature gas at right-angles to the disk, often at nearly the speed of light.

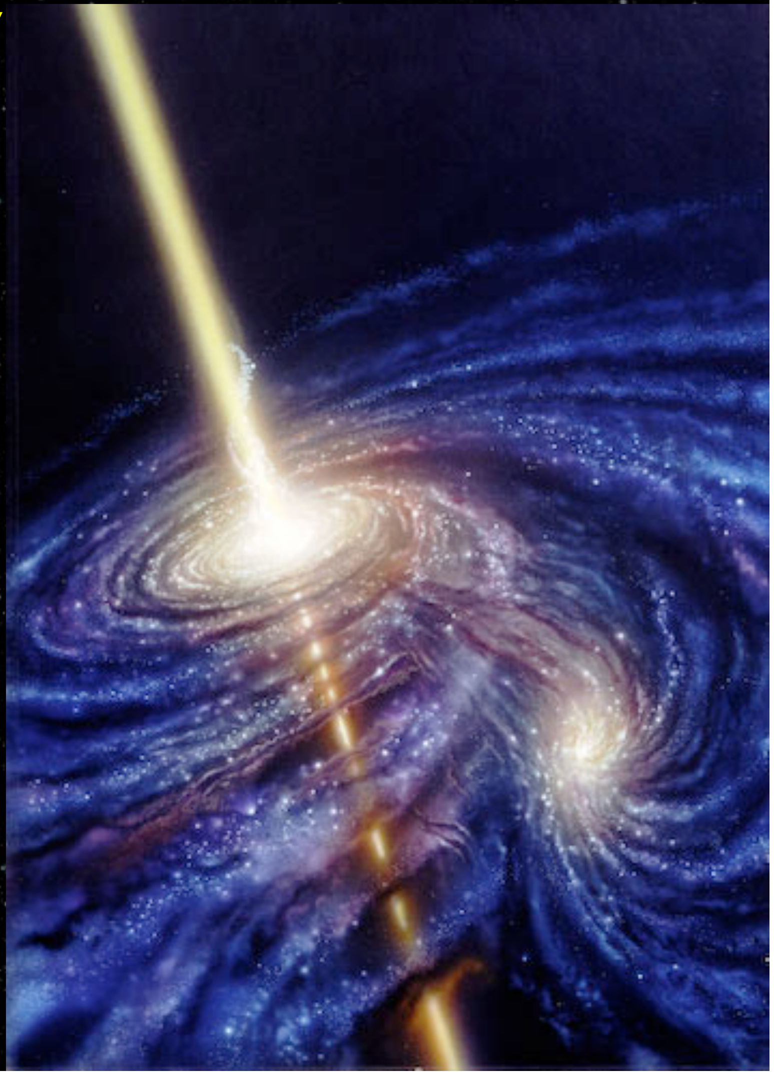


If the jet is pointed side-on to us, we see the jets and the lobes formed where the jets are slowed down.

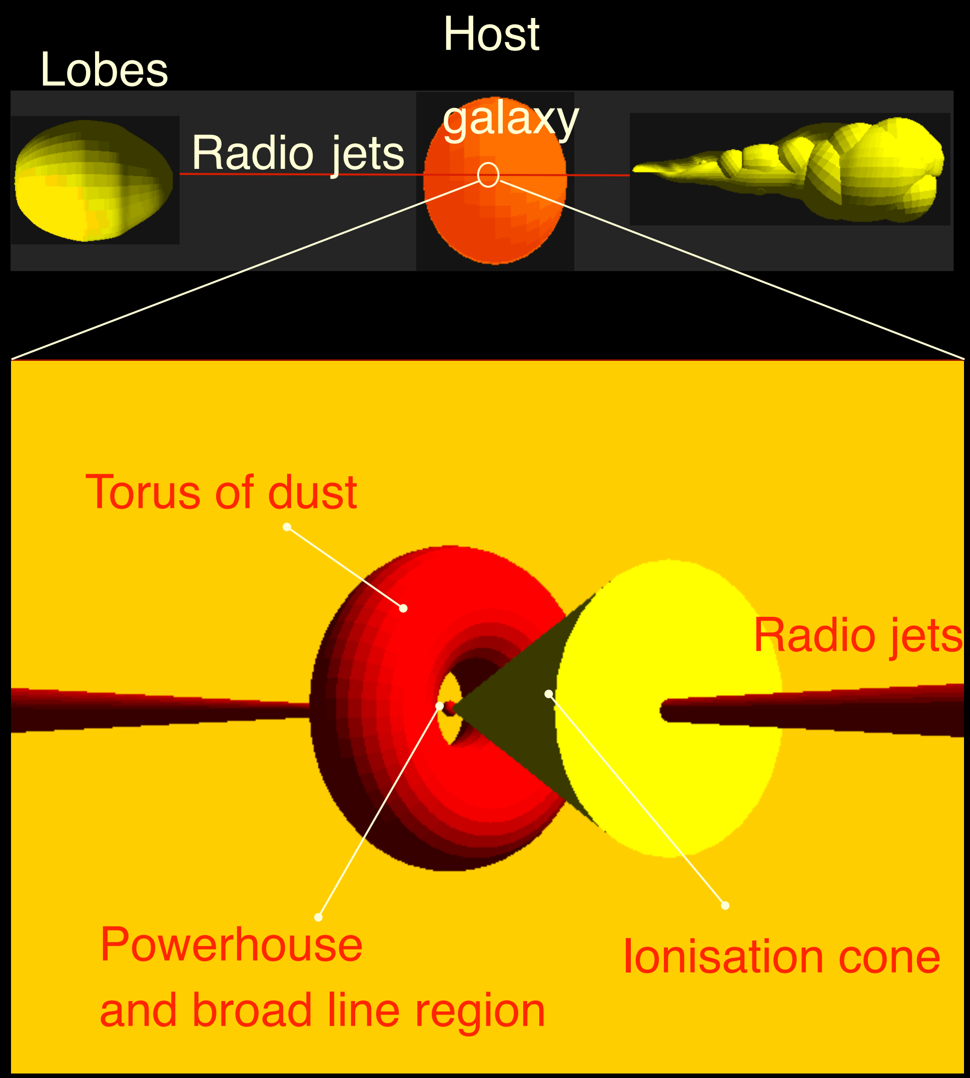
We don't see the central black hole, because it is hidden from us by a torus of gas and dust that blocks the central region from us, so we see a *radio galaxy*.

If the jet is pointed straight towards us, all we see is the bright jet, so we see a *quasar*.

Both are an explosive result of the overfeeding of the black holes at their centres.

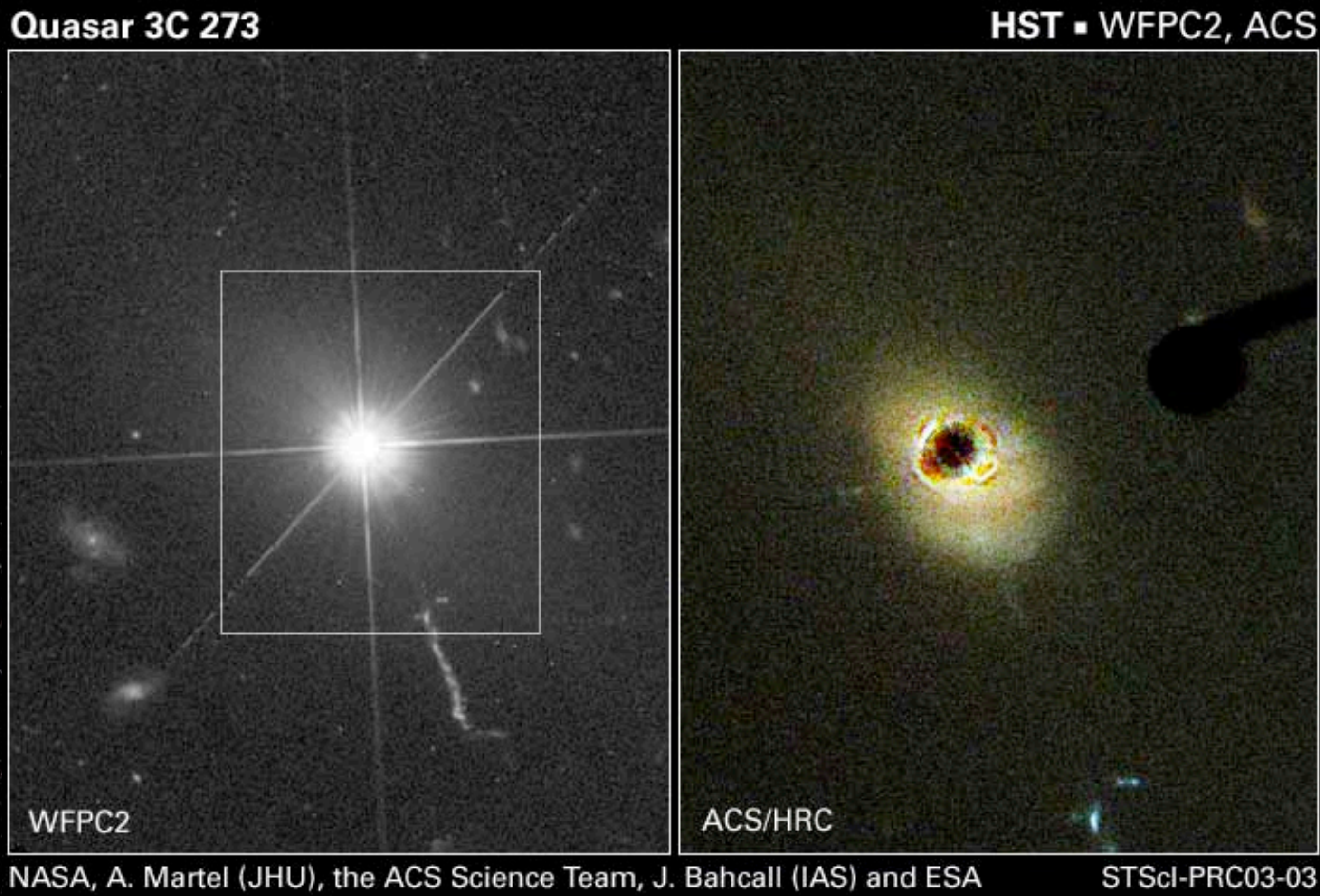


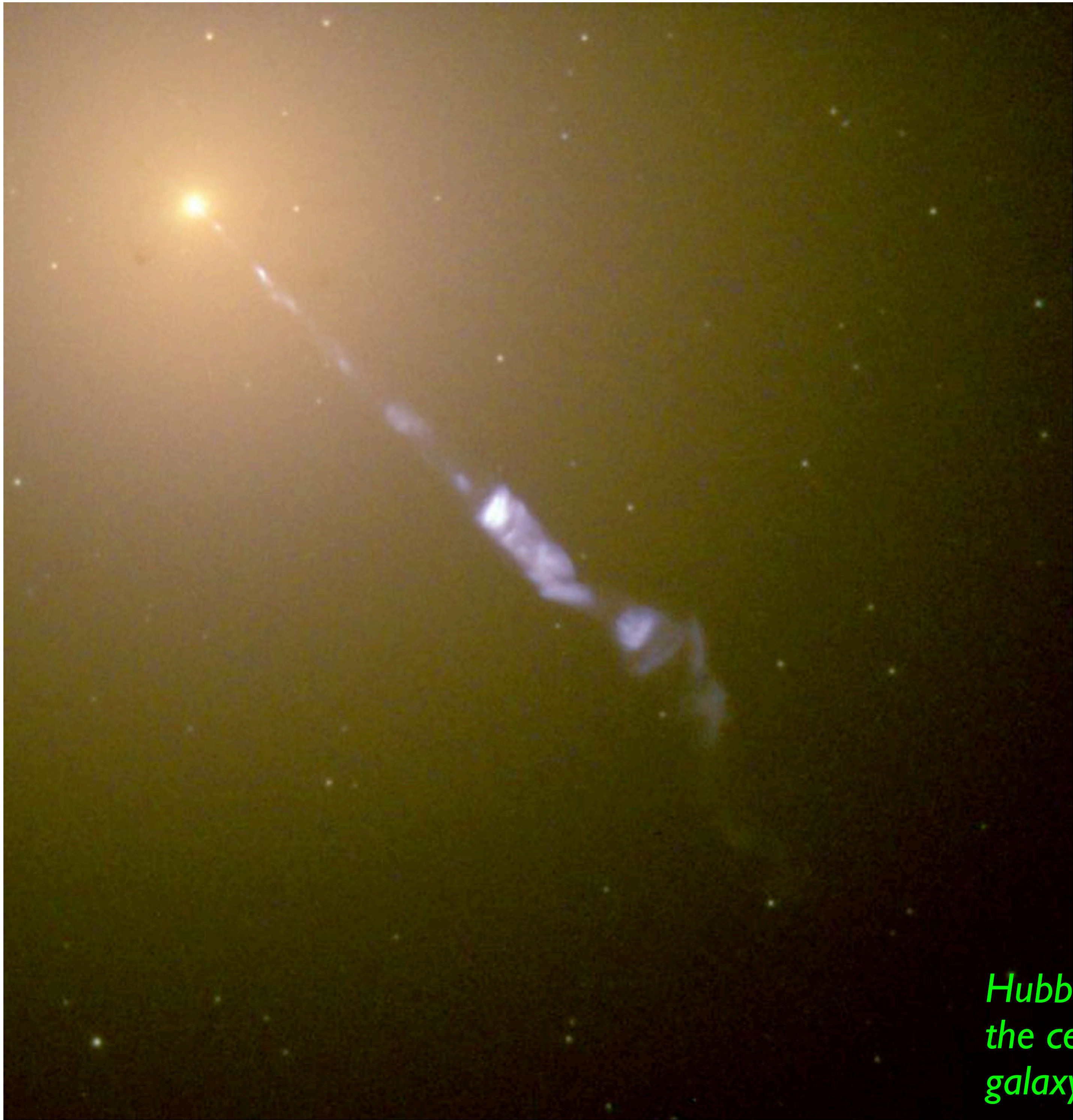
painting by Don Dixon



Host
Lobes
galaxy
Radio jets
Torus of dust
Radio jets
Powerhouse
and broad line region
Ionisation cone

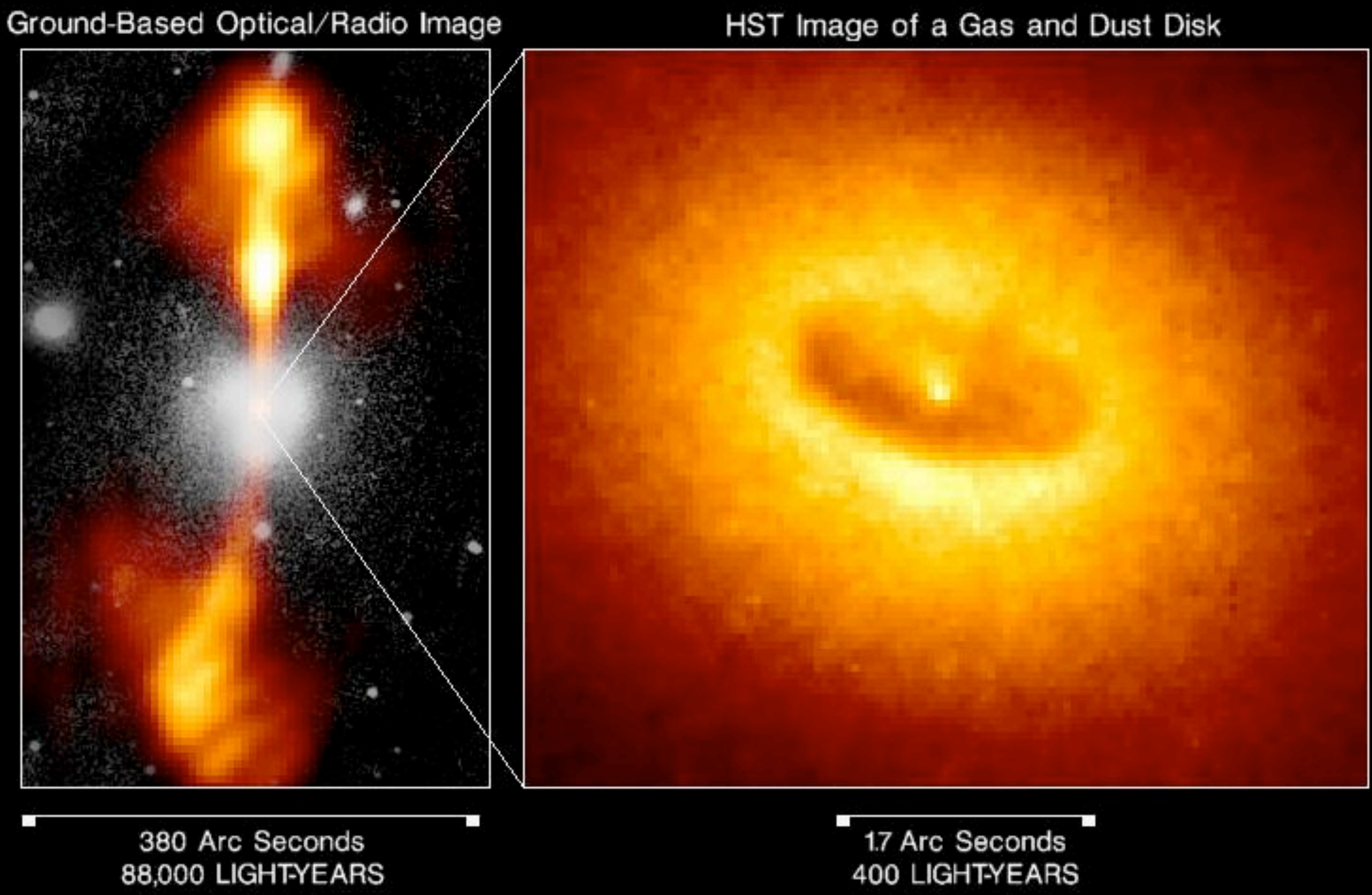
By blocking out the light from the quasar, HST was able to see the host galaxy for 3C 273.



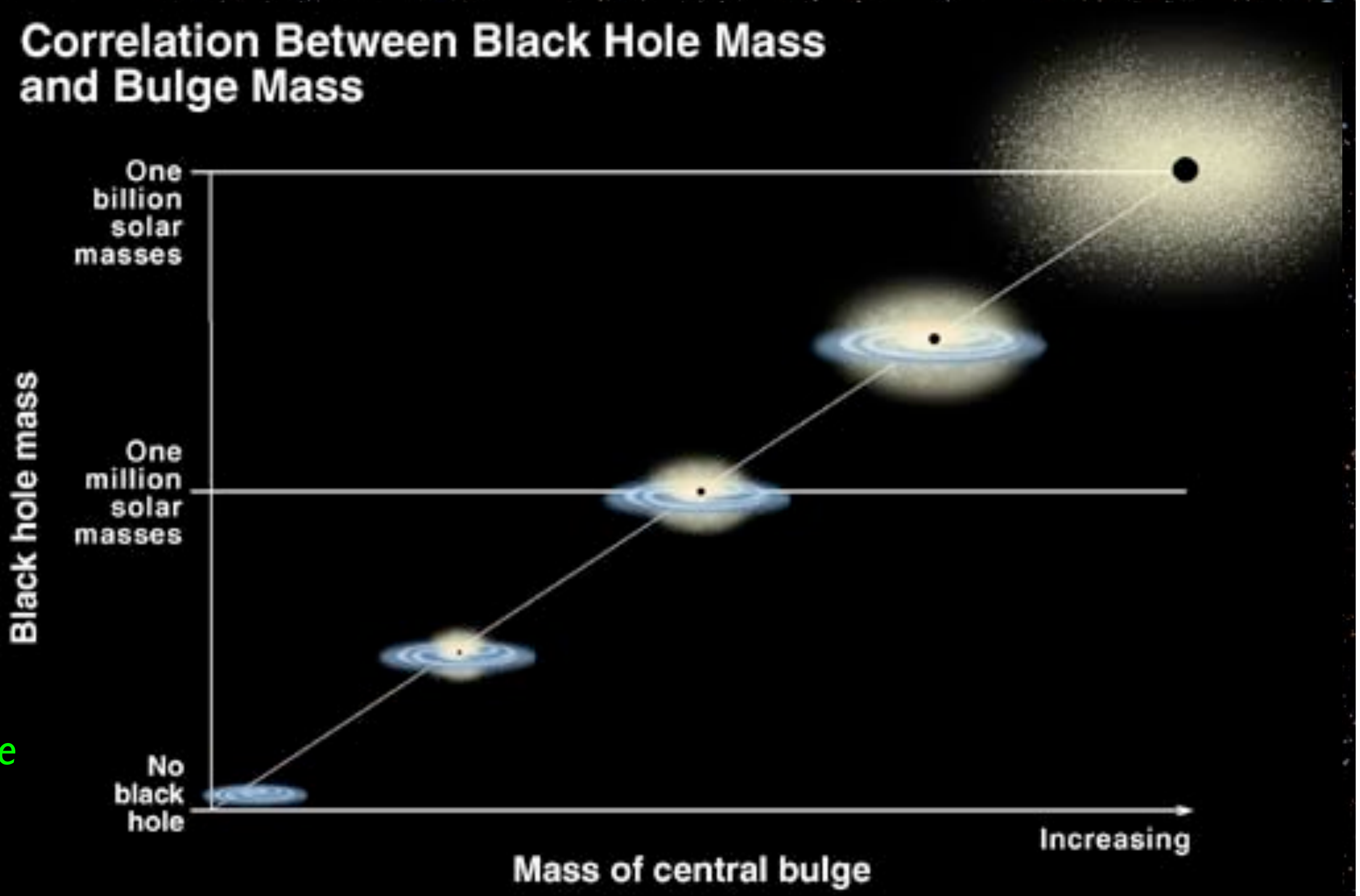


Hubble image of the jet from the centre of the giant elliptical galaxy M87

HST can actually show us the central regions of active galaxies.



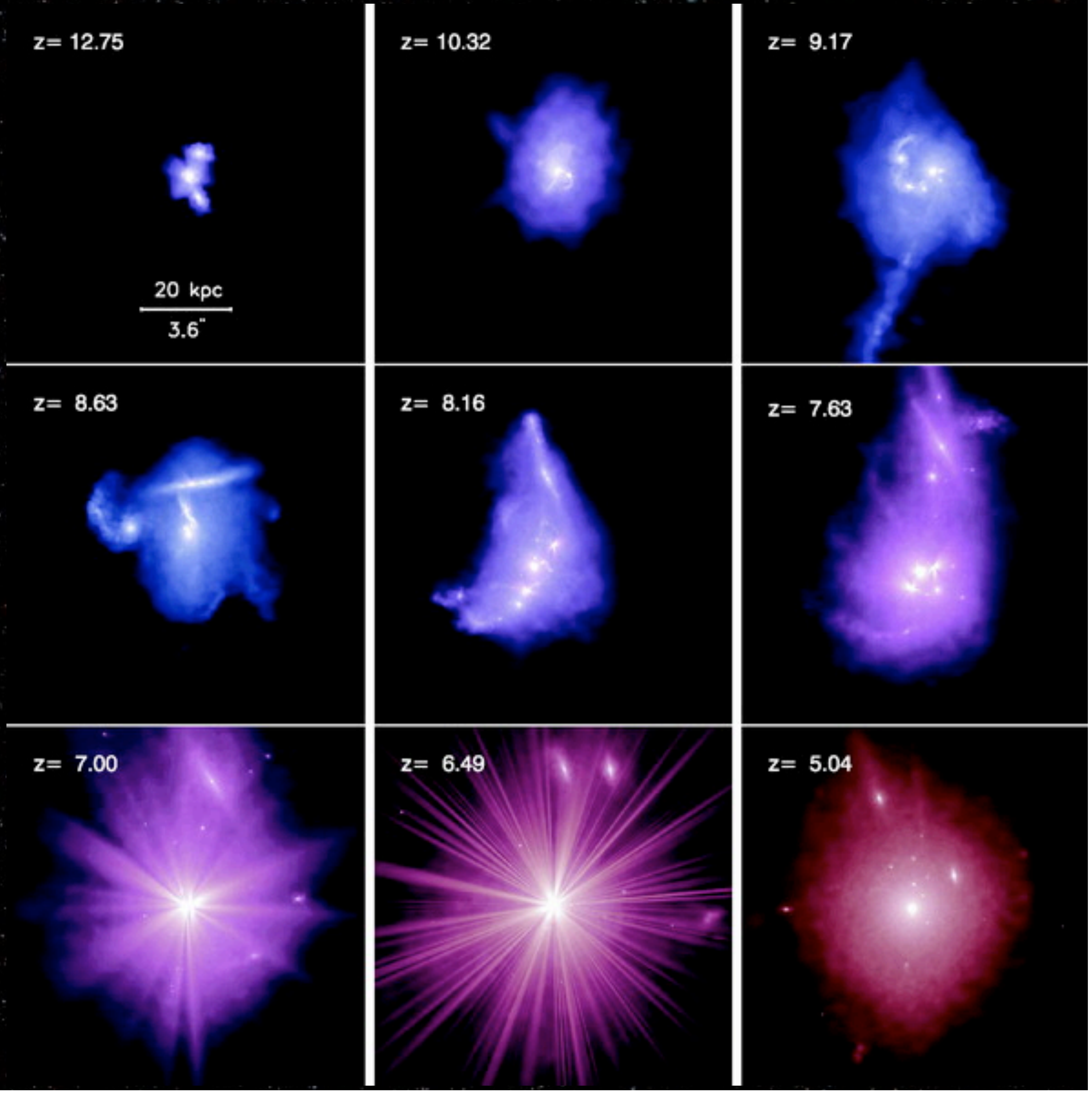
What's more, we are now finding that almost every galaxy has a massive black hole at its heart, and that the bigger the galaxy, the bigger the black hole. This suggests that the growth of the galaxy and the black hole are somehow intimately linked.



The size of the black hole in the centre of galaxies is related to the size of the galaxy itself.

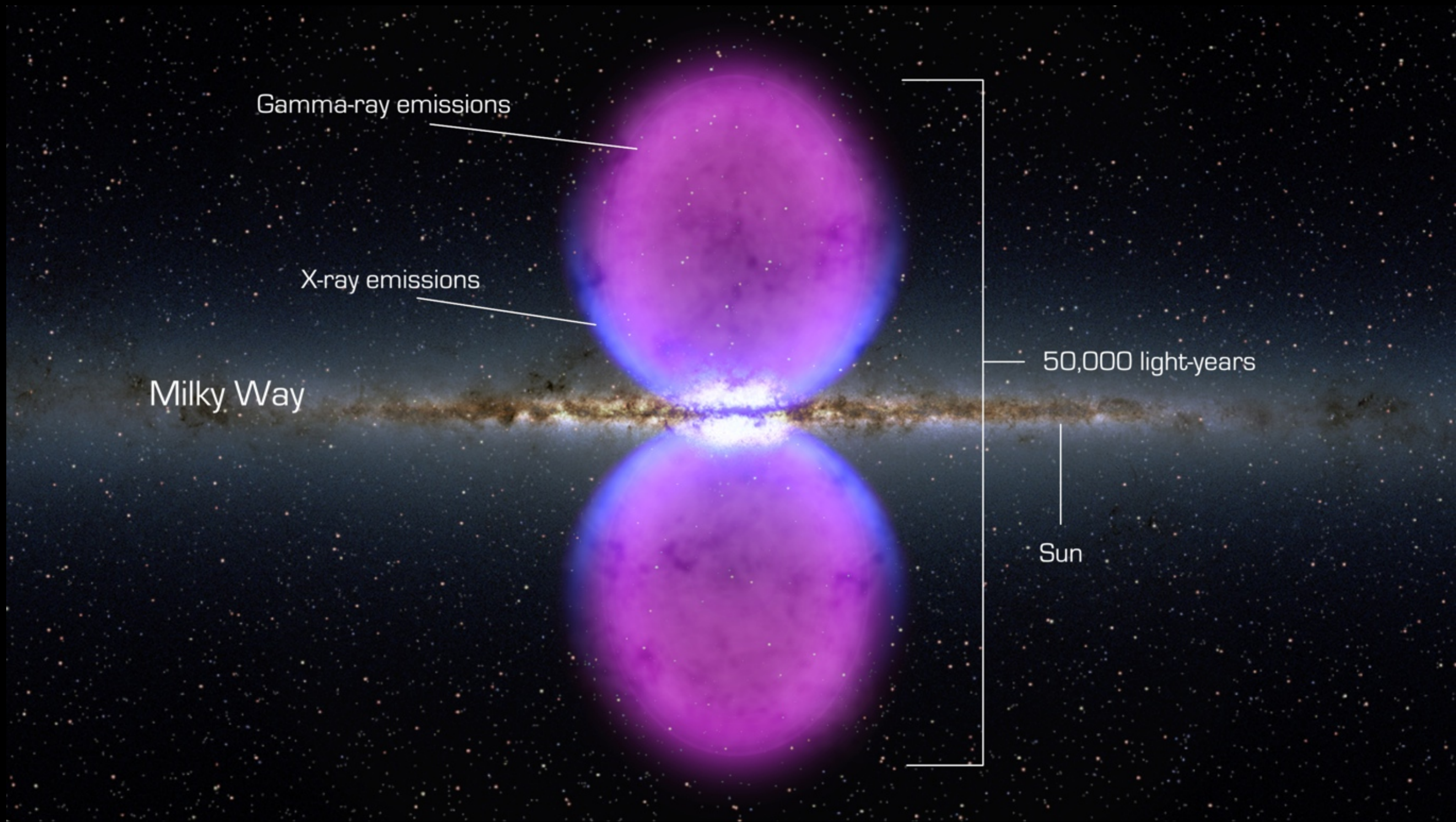
We think that the link is that both galaxies and black holes grow through the merging of galaxies. The same collisions that help galaxies grow can also feed the black hole at the centre. As gas falls in to build the galaxy, at the same time some gets funnelled in to the black hole.

It is possible that a quasar is just a particularly violent stage in the life of a galaxy, one that many (most?) galaxies have gone through.



Simulation of the history of a quasar host galaxy as it undergoes several mergers. When the gas from the merger reaches the central black hole, it "switches on" as a quasar.

Perhaps those gamma-ray bubbles around the centre of the Milky Way are the remnant of a quasar phase, some time in the past few million years.



An artist's conception showing the approximate scale of the newfound Fermi bubbles above and below the Milky Way.

Next week...

... we put it all together, and look at how the universe changes and evolves.

Further reading

- The American Institute of Physics has an excellent website called "Cosmic Journey: A History of Scientific Cosmology" at http://www.aip.org/history/cosmology/index.htm. The page called "Island Universes" discusses the discovery of galaxies in lots of detail.
- There's a good description of the different types of active galaxies at "Astronomy 162: Stars, Galaxies, and Cosmology" http://csep10.phys.utk.edu/astr162/lect/active/active.html
- There's another nice page at "Gene Smith's Astronomy Tutorial: Quasars and Active Galaxies" http://casswww.ucsd.edu/archive/public/tutorial/Quasars.html. This has lots of good information about the different types of active galaxies.

Sources for images used:

- Hubble at the 48" Palomar Schmidt: from Edwin Powell Hubble quest.nasa.gov/hst/about/edwin.html
- Stephan's Quintet, from http://hubblesite.org/newscenter/archive/releases/2001/22/
- Rosse's drawing of M51: from "Telescopes from the ground up" http://amazing-space.stsci.edu/resources/explorations/groundup/lesson/basics/g44/. Hubble picture: from Hubble Heritage http://heritage.stsci.edu/2005/12a/index.html
- Galaxies in the HUDF: from HubbleSite http://hubblesite.org/newscenter/archive/releases/2007/21/image/a/
- Hubble's photo of variable in M31: from http://www.aip.org/history/cosmology/ideas/island.htm
- Hubble's photo of M33: from "Discovery of Galaxies" by George Rieke http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/galaxies.htm
- Hubble tuning fork diagram: from John Kormendy http://chandra.as.utexas.edu/~kormendy/a301-2010-spring.html
- M60 and NGC4647: from HubbleSite http://hubblesite.org/newscenter/archive/releases/2012/38/image/a/
- M87 and friends: from APOD http://apod.nasa.gov/apod/ap100520.html
- Spiral galaxy M74: from APOD http://apod.nasa.gov/apod/ap071201.html
- Spiral galaxy NGC 1232: from APOD http://apod.nasa.gov/apod/ap120107.html
- 'Sombrero galaxy' M104, from APOD http://apod.nasa.gov/apod/ap110515.html
- Barred spiral galaxy NGC 1300: from HubbleSite http://hubblesite.org/newscenter/archive/releases/2005/01/image/a/
- Barred spiral galaxy NGC 1365: from APOD http://apod.nasa.gov/apod/ap070328.html
- Overview of Milky Way: from A. Finkbeiner, "Galaxy formation: The new Milky Way", Nature 490 News Feature
- LMC: image by Wei-Hao Wang, from APOD http://apod.nasa.gov/apod/ap060510.html
- NGC 4449: from APOD http://apod.nasa.gov/apod/ap110225.html
- Galaxy rotation curve: from http://asterisk.apod.com/viewtopic.php?f=31&t=26118
- NGC 3982: from HubbleSite http://www.hubblesite.org/newscenter/archive/releases/galaxy/2010/36/
- NGC 1309: from HubbleSite http://hubblesite.org/newscenter/archive/releases/2006/07/
- Elliptical galaxy : from HubbleSite http://www.hubblesite.org/newscenter/archive/releases/galaxy/elliptical/2007/08/
- Virgo cluster: image by Fabian Neyer, from http://www.starpointing.com/ccd/virgodeep.html
- Abell 1689: from http://hubblesite.org/newscenter/archive/releases/2008/08/
- Local Group: from Chris Mihos: ASTR 222 Galaxies and Cosmology http://burro.astr.cwru.edu/Academics/Astr222/Galaxy/Environ/localgroup.html
- Virgo supercluster: from Wikimedia Commons, http://en.wikipedia.org/wiki/File:Earth%27s_Location_in_the_Universe_%28JPEG%29.jpg

- "The Mice" NGC 4676: from HubbleSite http://hubblesite.org/newscenter/archive/releases/2002/11/image/h/
- NGC 6872: from Australian Gemini School Astronomy Contest: 2010 http://ausgo.aao.gov.au/contest2010/
- "The Antennae" http://hubblesite.org/newscenter/archive/releases/2006/46/
- Antennae formation simulation: from http://irfu.cea.fr/Projets/COAST/movies_galaxies_formation.htm
- Galaxy collision montage: from Hubblesite http://hubblesite.org/gallery/album/galaxy/interacting/pr2008016a/
- Milky Way/Andromeda collision: from http://hubblesite.org/newscenter/archive/releases/2012/20/
- The Sagittarius Dwarf Tidal Stream: image by David Martinez-Delgado, from APOD http://apod.nasa.gov/apod/ap050529.html
- Dragon: from www.webweaver.nu/clipart/dragons.shtml
- Spectrum of 3C273 and image of Maarten Schmidt: from Gene Smith's Astronomy Tutorial: Quasars & Active Galaxies: http://casswww.ucsd.edu/archive/public/tutorial/Quasars.html
- Radio galaxy Centaurus A: from Chandra site chandra.harvard.edu/photo/2008/cena/index.html
- Details of radio jet: from APOD apod.nasa.gov/ap110531.html
- Quasar: painting by Don Dixon http://cosmographica.com/gallery/portfolio/portfolio301/pages/326-QuasarB.htm . Artwork copyright 2003 by Don Dixon/cosmographica.com, used with permission.
- Model for active galaxies: courtesy of Julia Bryant
- 3C 273: from Hubblesite http://hubblesite.org/newscenter/archive/releases/galaxy/quasar_active-nucleus/2003/03/
- Jet from M87: from Hubblesite http://hubblesite.org/newscenter/archive/releases/galaxy/quasar_active-nucleus/2000/20/
- Gas disk in NGC 4261: from Hubblesite hubblesite.org/newscenter/archive/releases/1992/27/
- Black hole-galaxy mass correlation: from "Correlation of Black Hole Mass and Bulge Mass/Brightness", http://www.spacetelescope.org/images/opo0022b/
- Quasar episode: from Li et al. 2007, "Formation of z~6 Quasars from Hierarchical Galaxy Mergers", ApJ, 665, 187 http://adsabs.harvard.edu/abs/2007ApJ...665..187L
- Fermi bubble: from NASA, "NASA's Fermi Telescope Finds Giant Structure in our Galaxy" http://www.nasa.gov/mission_pages/GLAST/news/new-structure.html