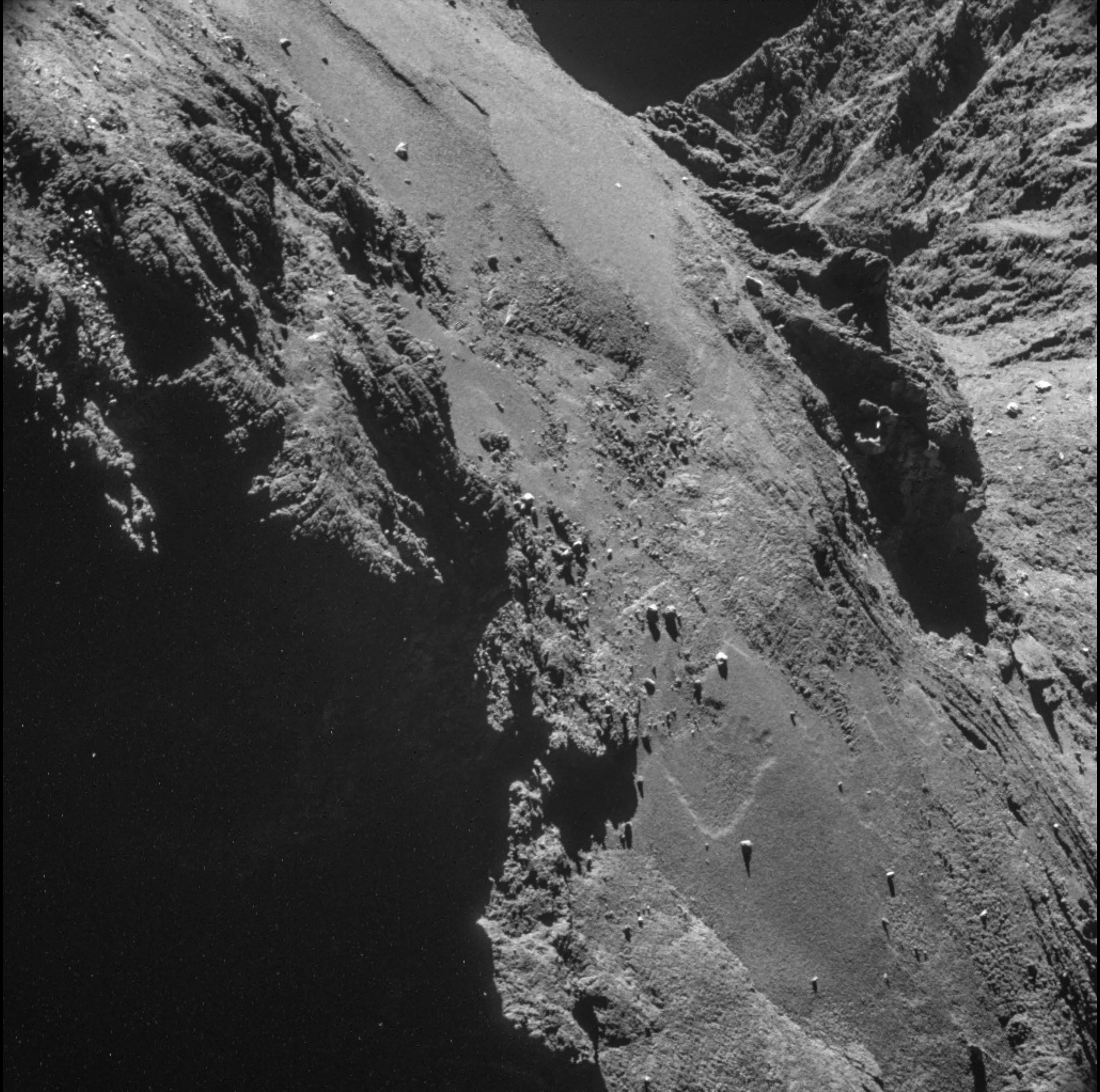
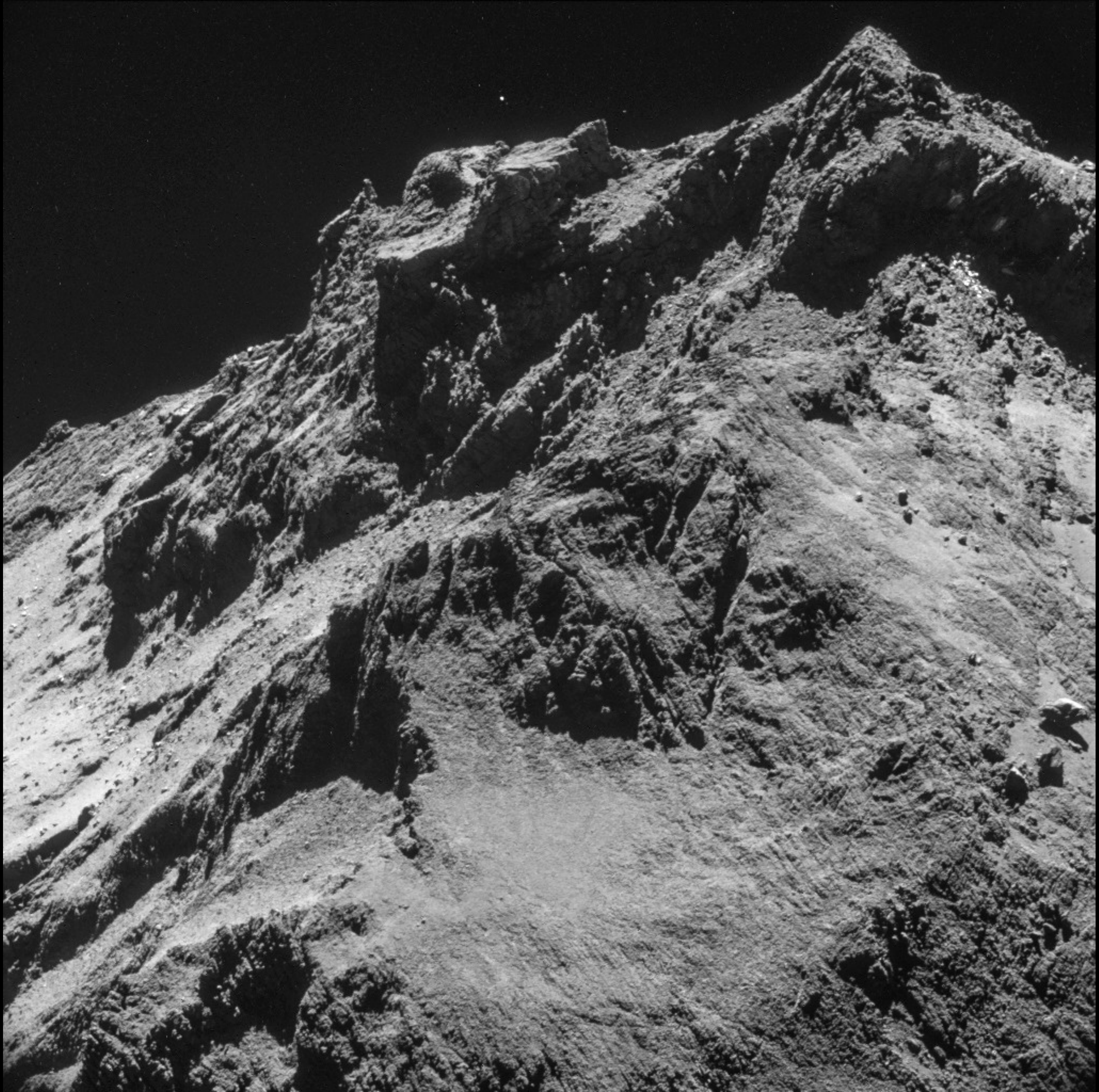
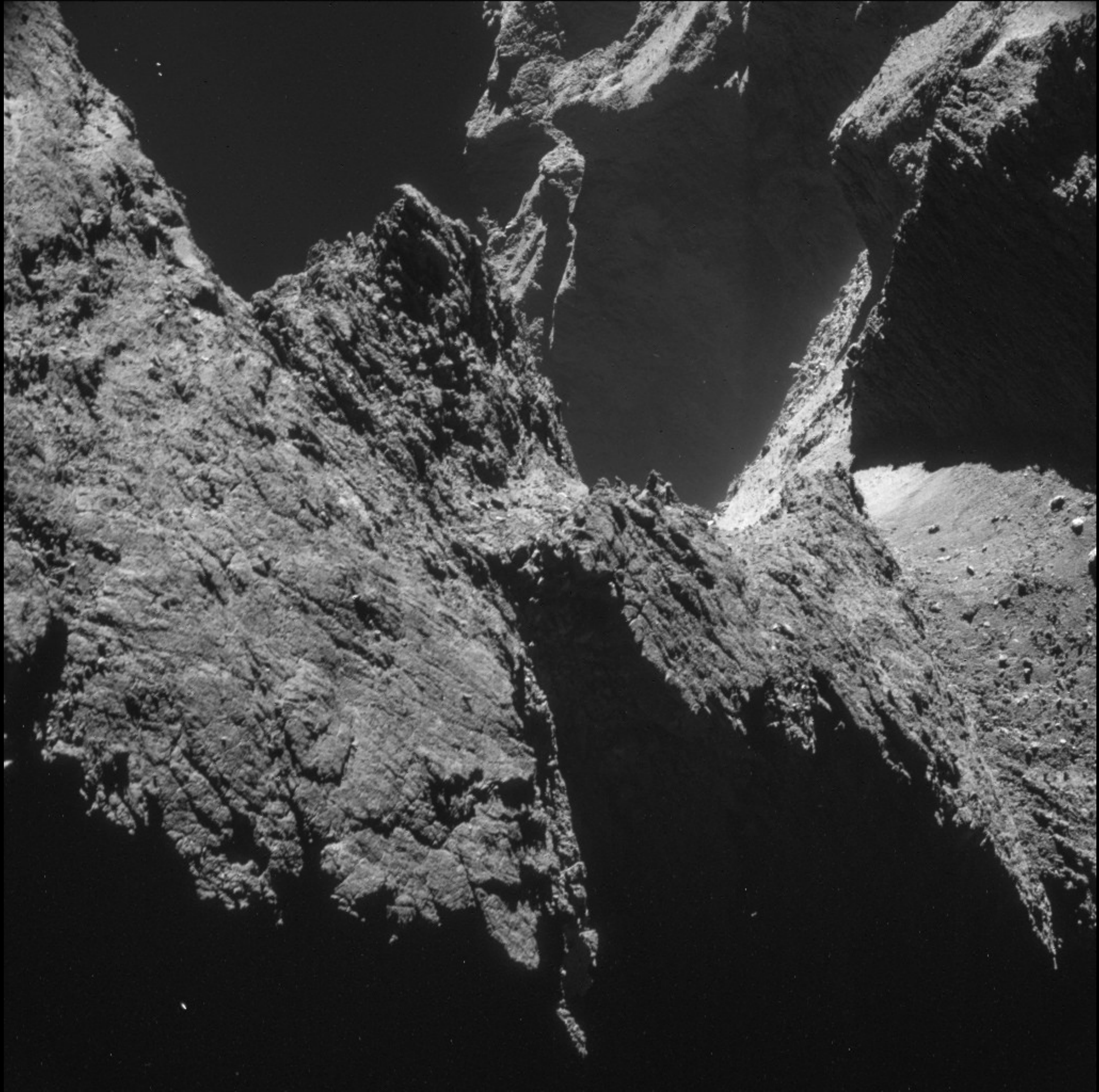
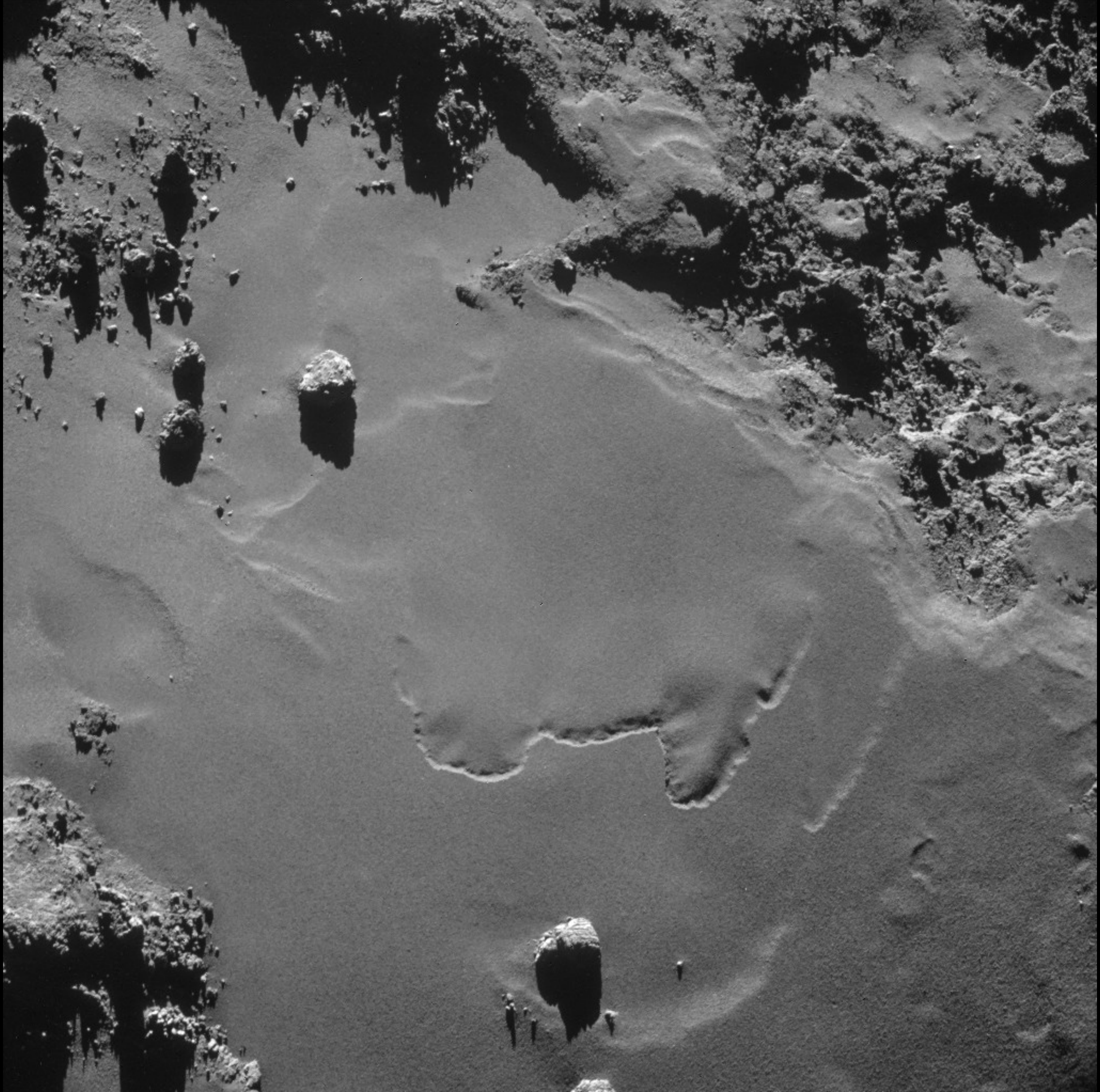
News flash

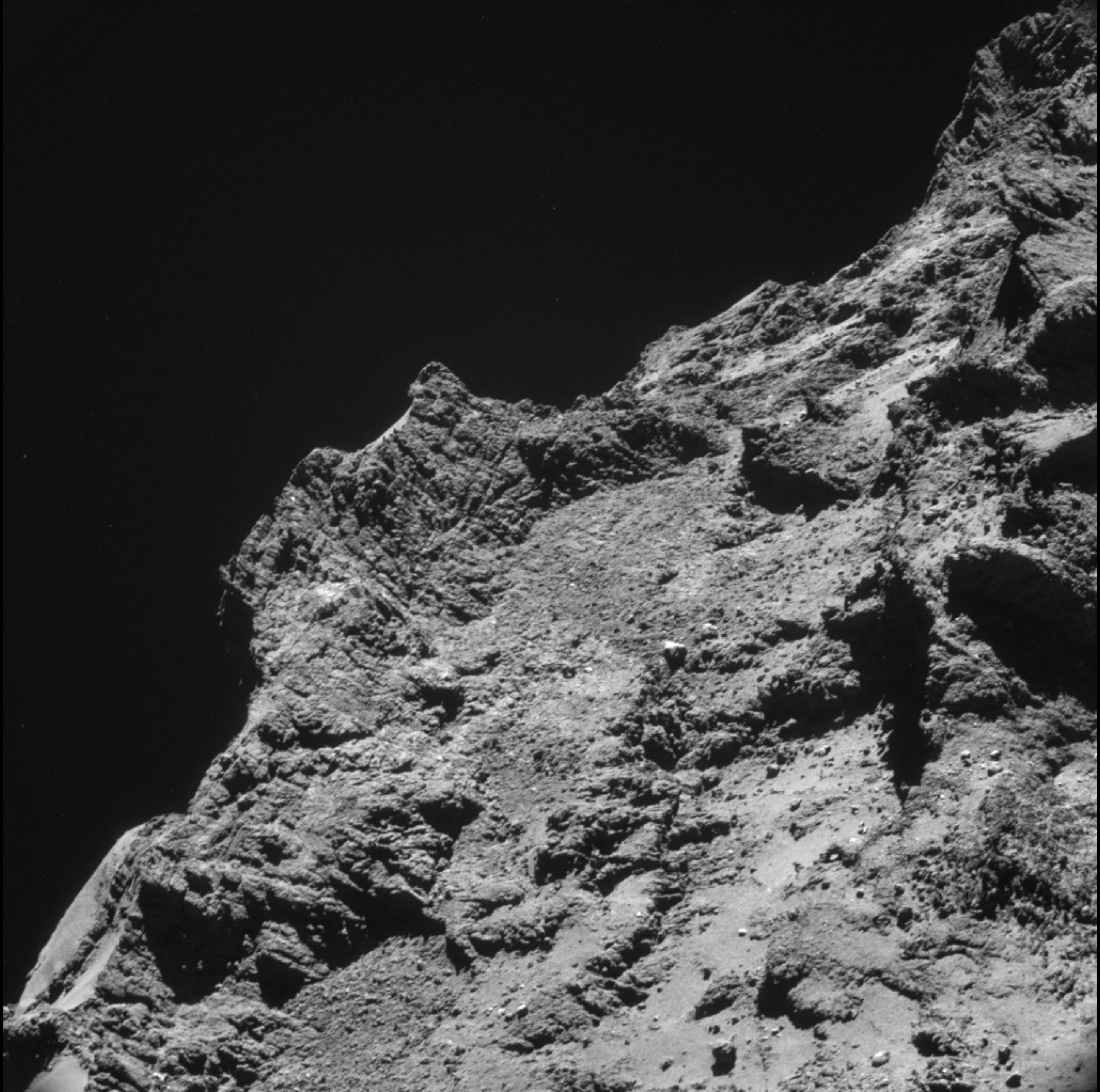
- Philae landed on Rosetta
  First touchdown as expected at ~10.02 am !!!
- Some technical problems:
  Harpoons did not fire and cold-gas thrusters did not work either
- Philae bounced off the surface to altitude of ~ 1 km, landed again, bounced off again, and landed again → 3 landings on a comet ;)
- Worries: Philae is partially in the shade, so might not receive enough solar power

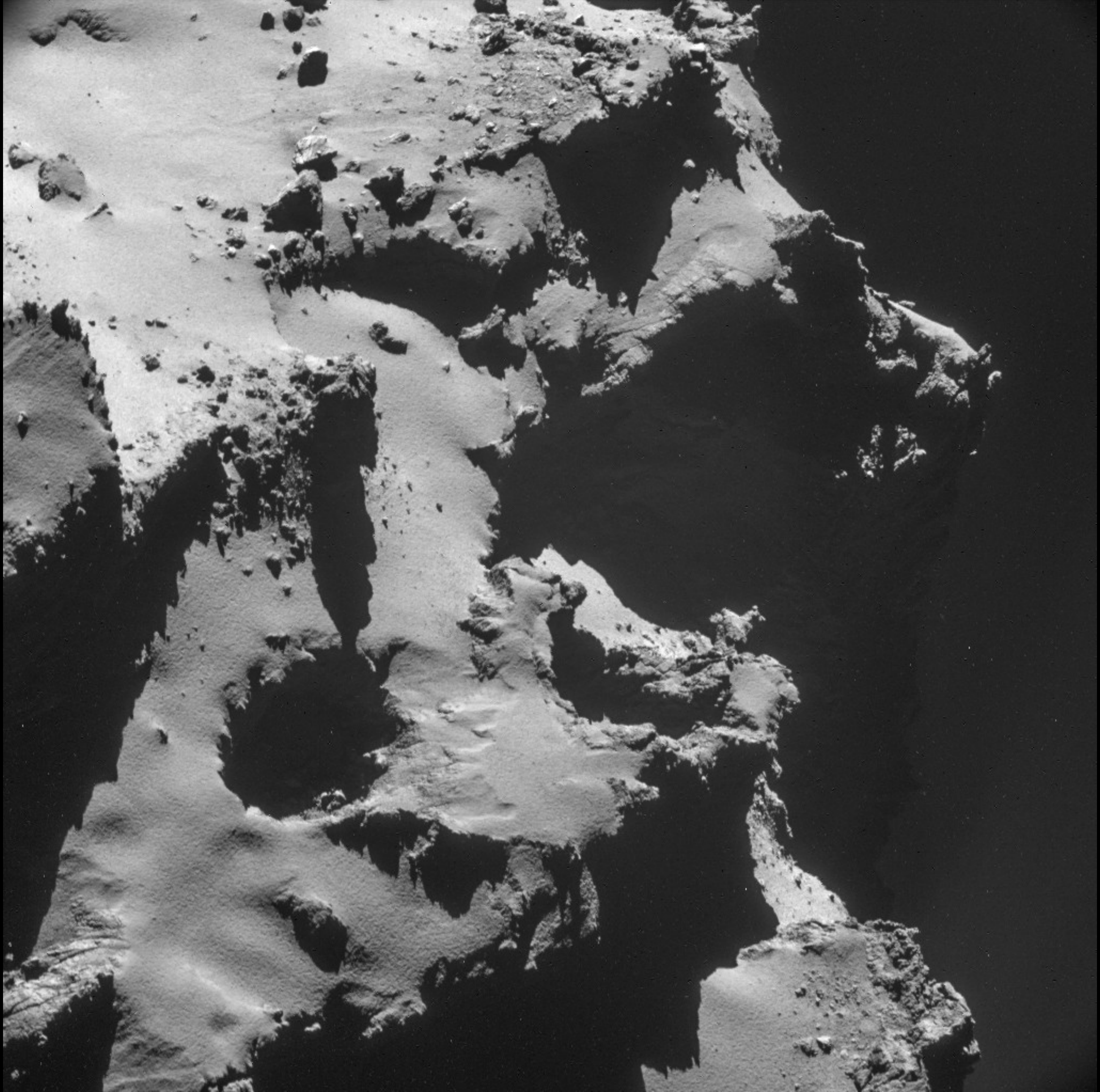


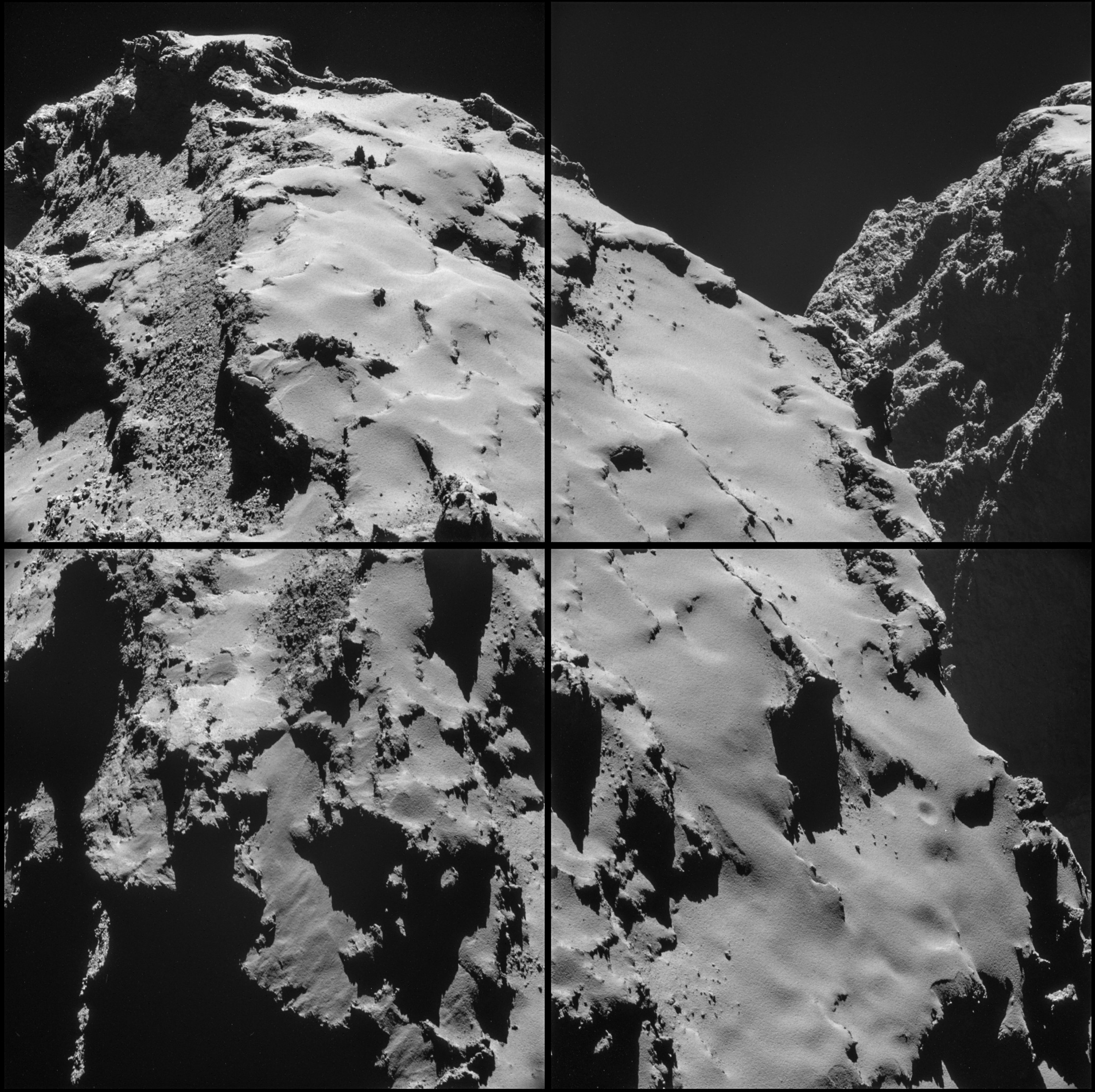


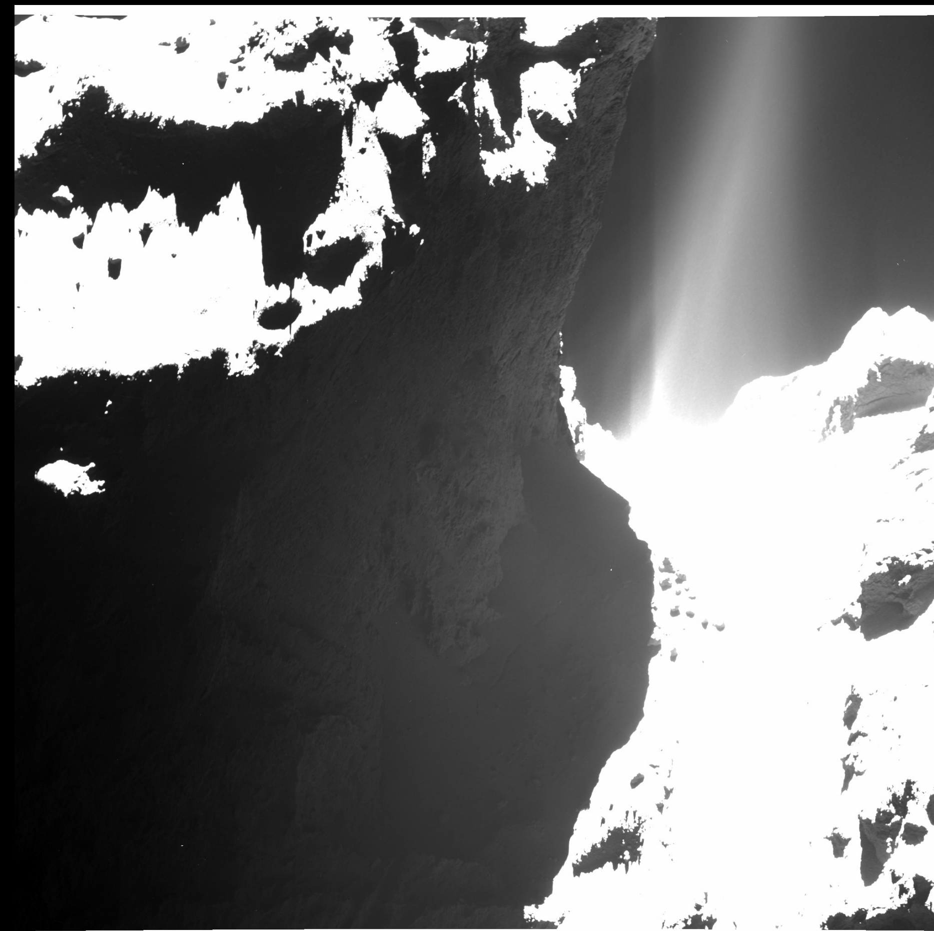


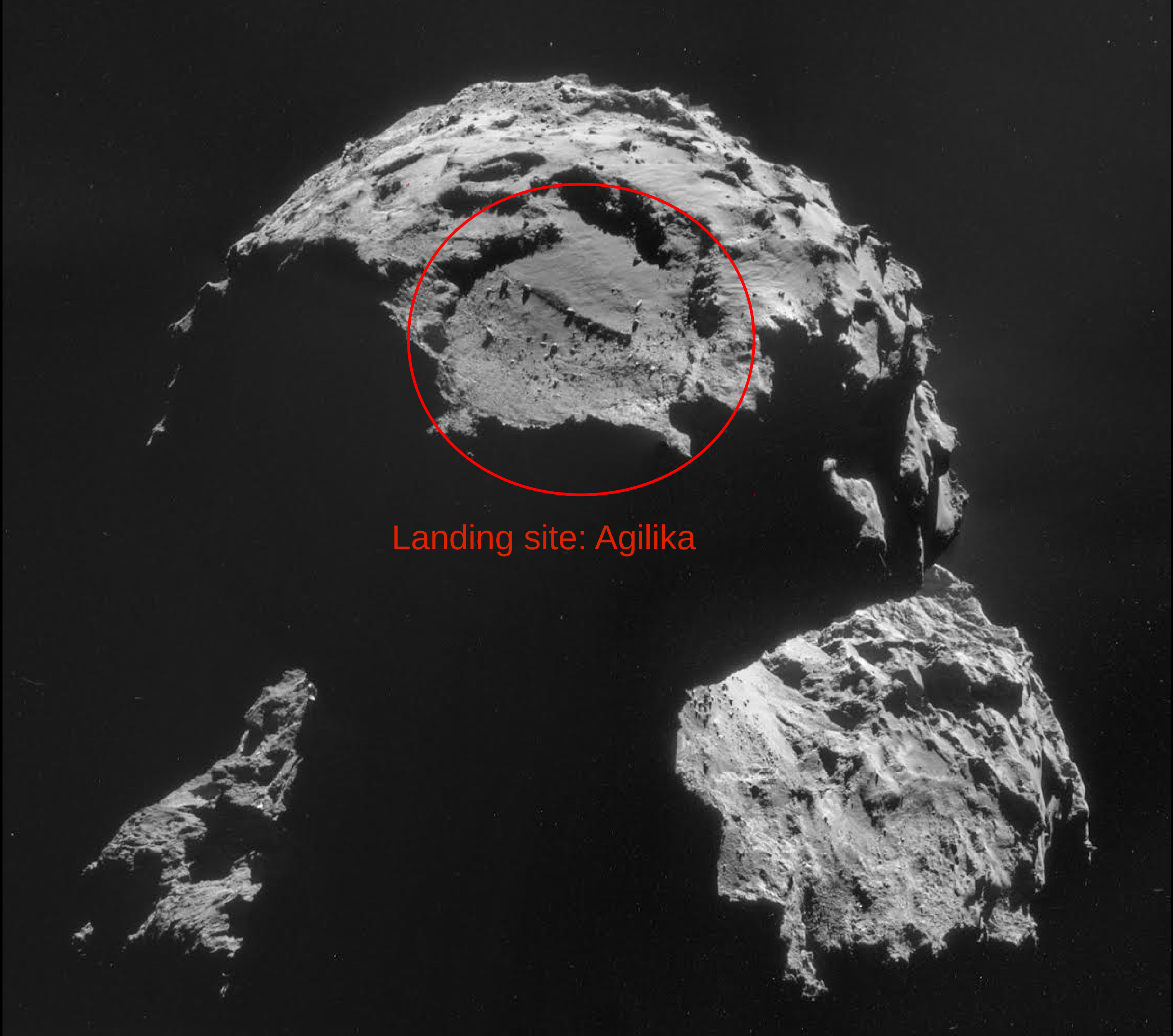


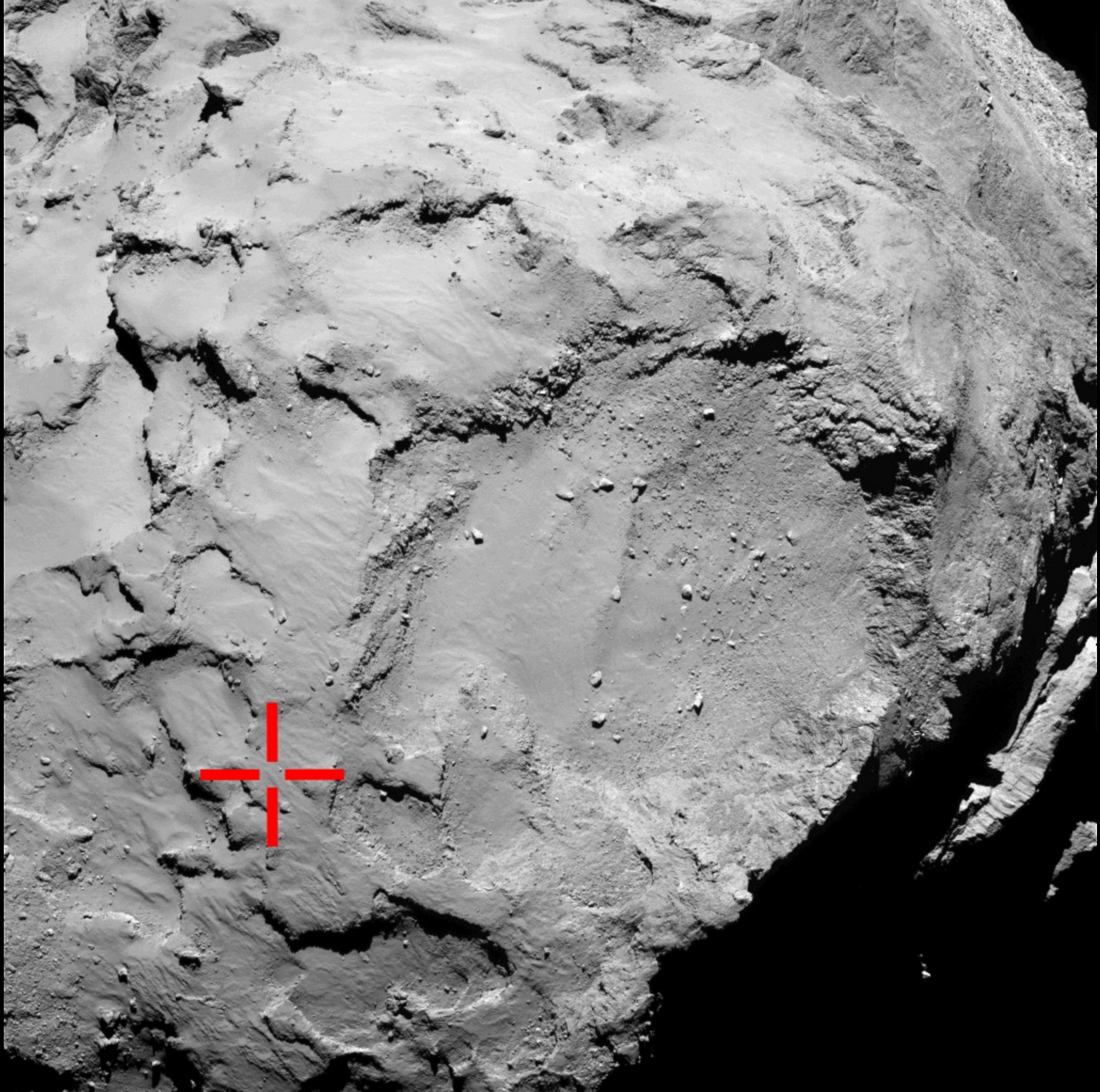


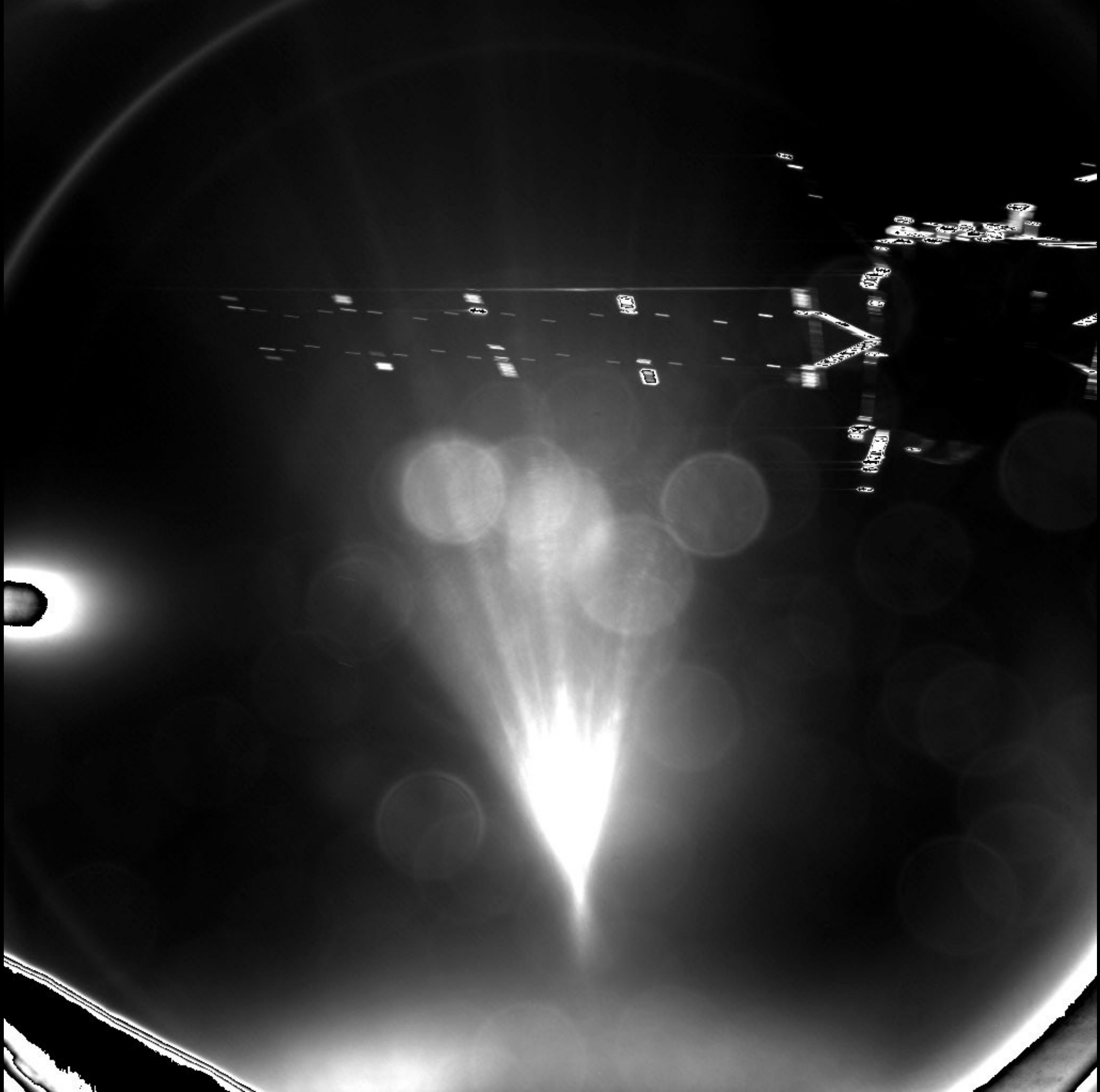


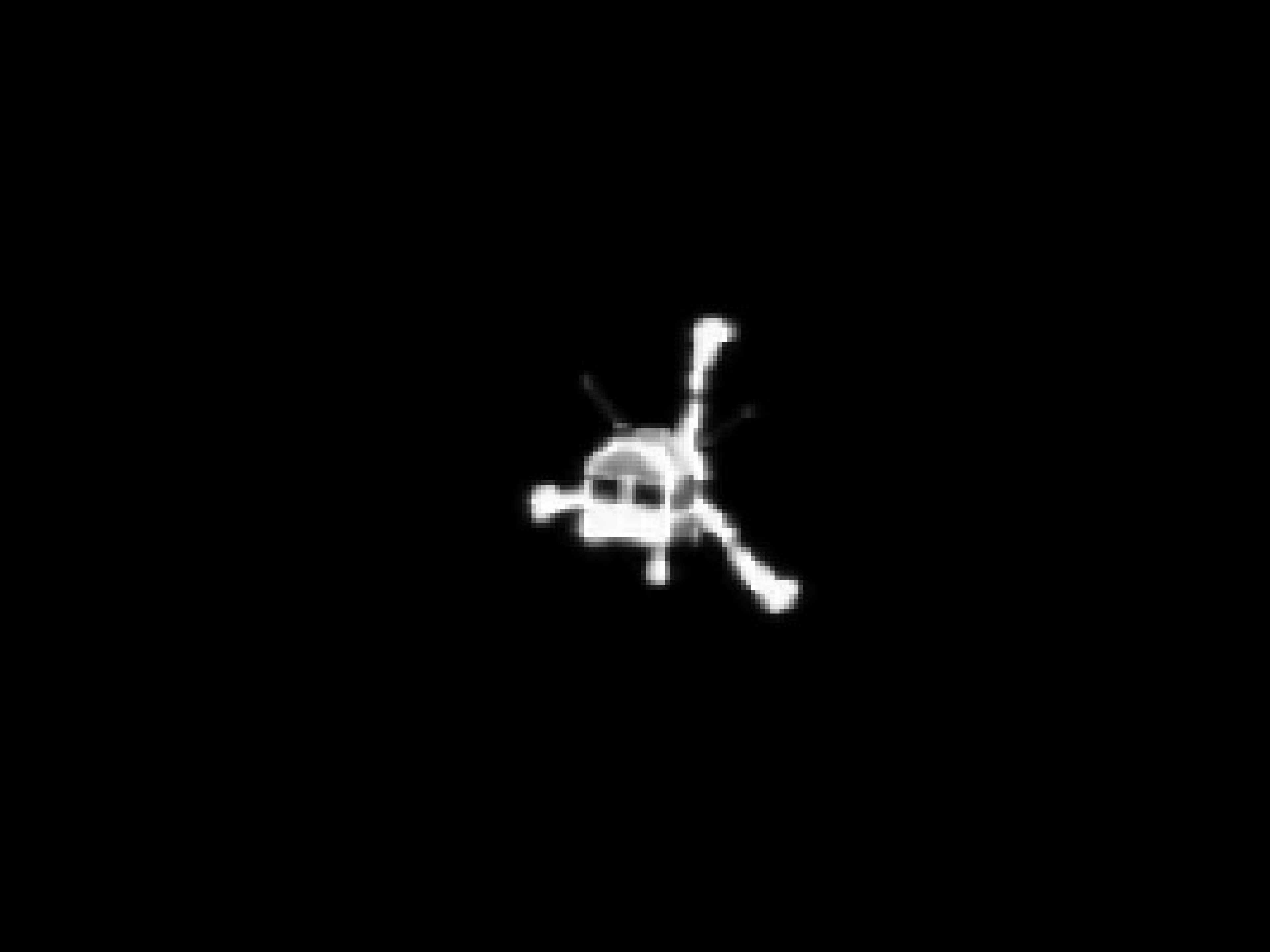


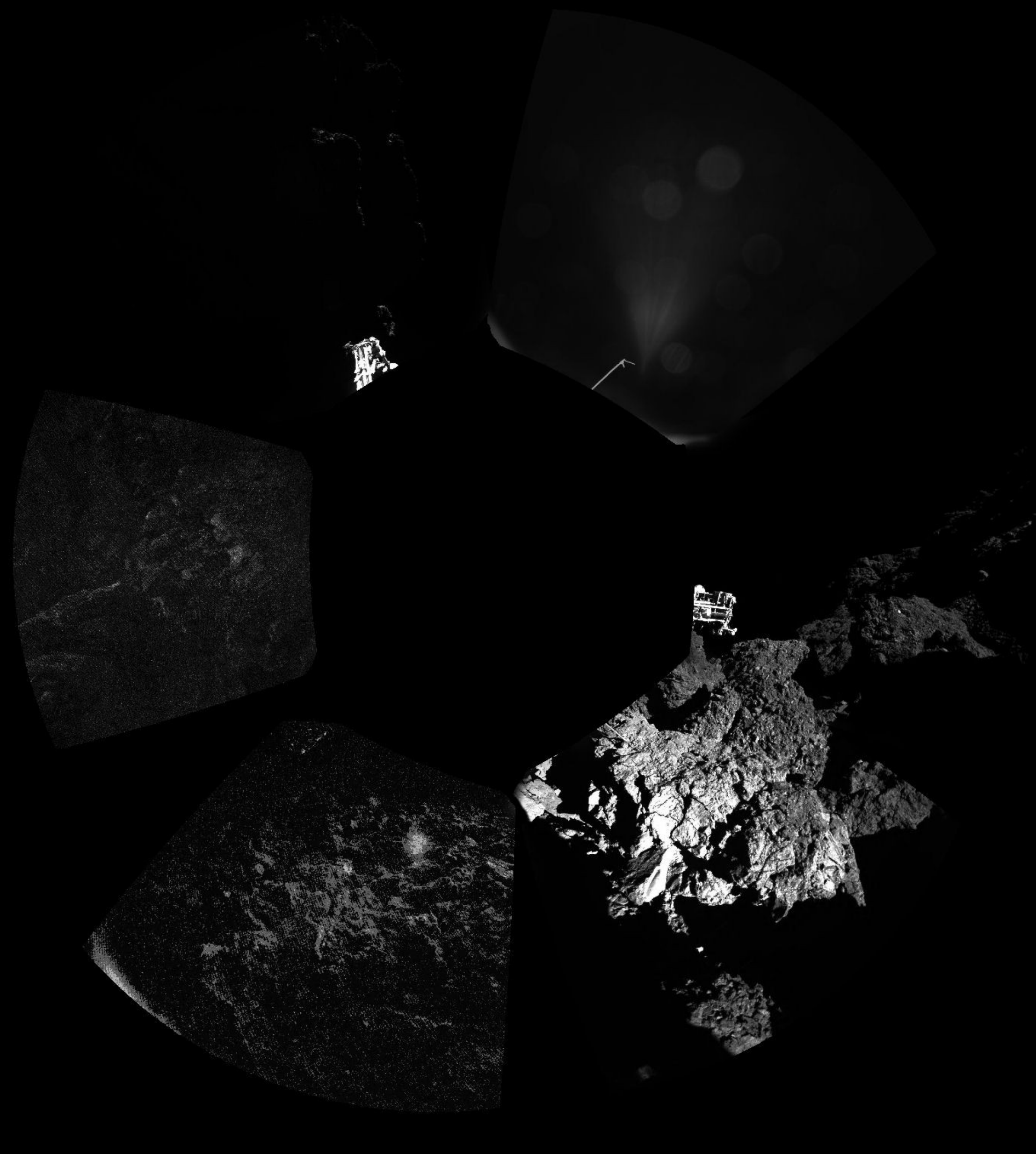


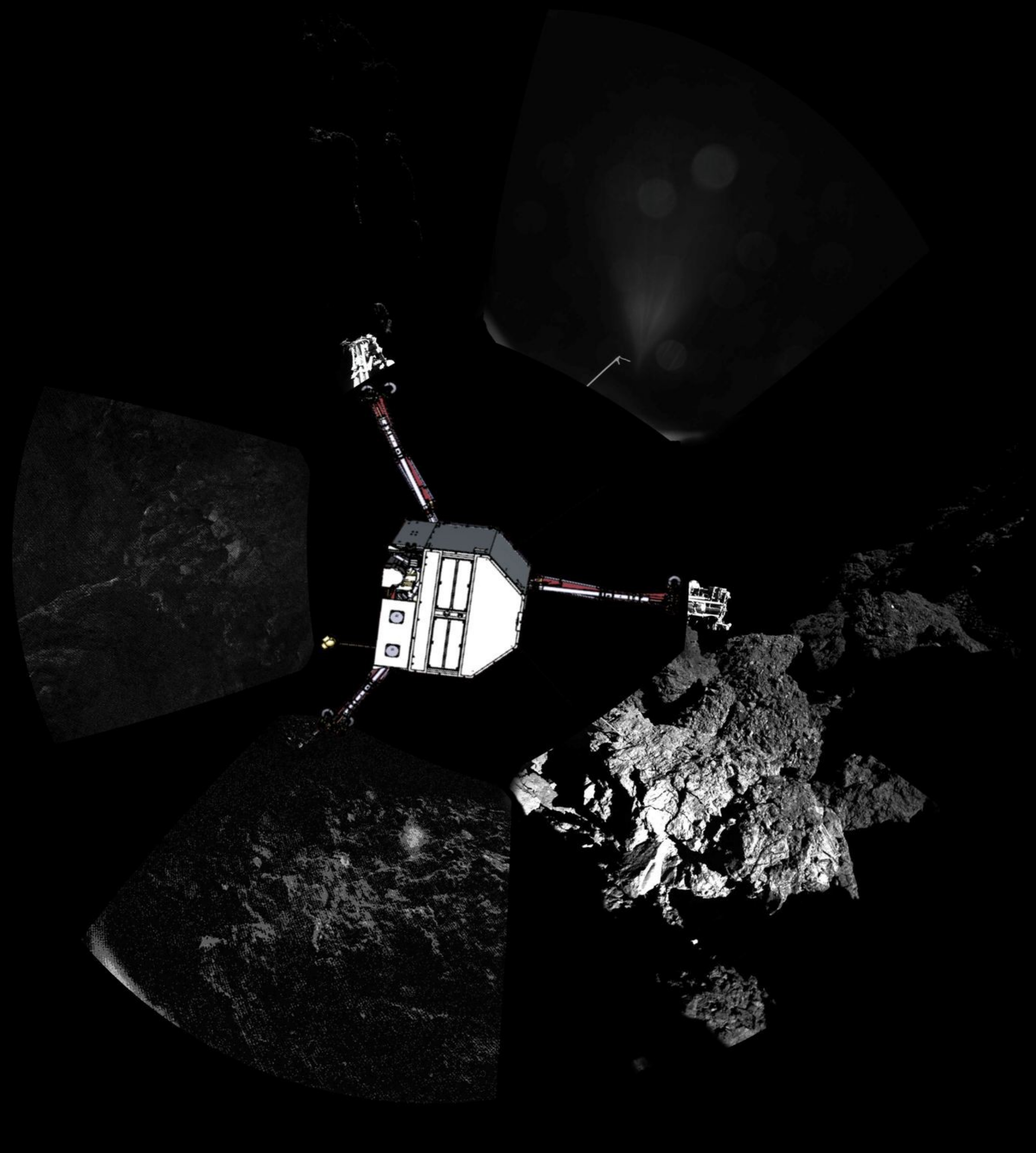

Landing site: Agilika











Philae's weight on 67P/

Compute the weight of Philae on the comet:

Comet: radius ~ 3 km, density ~ 1000 kg/m^3

→ V = 4/3 * pi * r^3 ~ 1 x 10^{11} m^3

→ mass = volume * density

= 10^{11} m^3 * 1^3 kg/m^3 = 10^{14} kg

~ 2 x 10^{-11} M_{earth}

Philae's weight on 67P/

Mass = $2 \times 10^{-11}\ M_{earth}$

Radius of comet: 3 km ~ $5 \times 10^{-4}\ r_{earth}$

Weight = $(G\ M\ m) / r^2$

Mass on Earth: ~ 100 kg → weight ~ 200 lbs

On the comet:

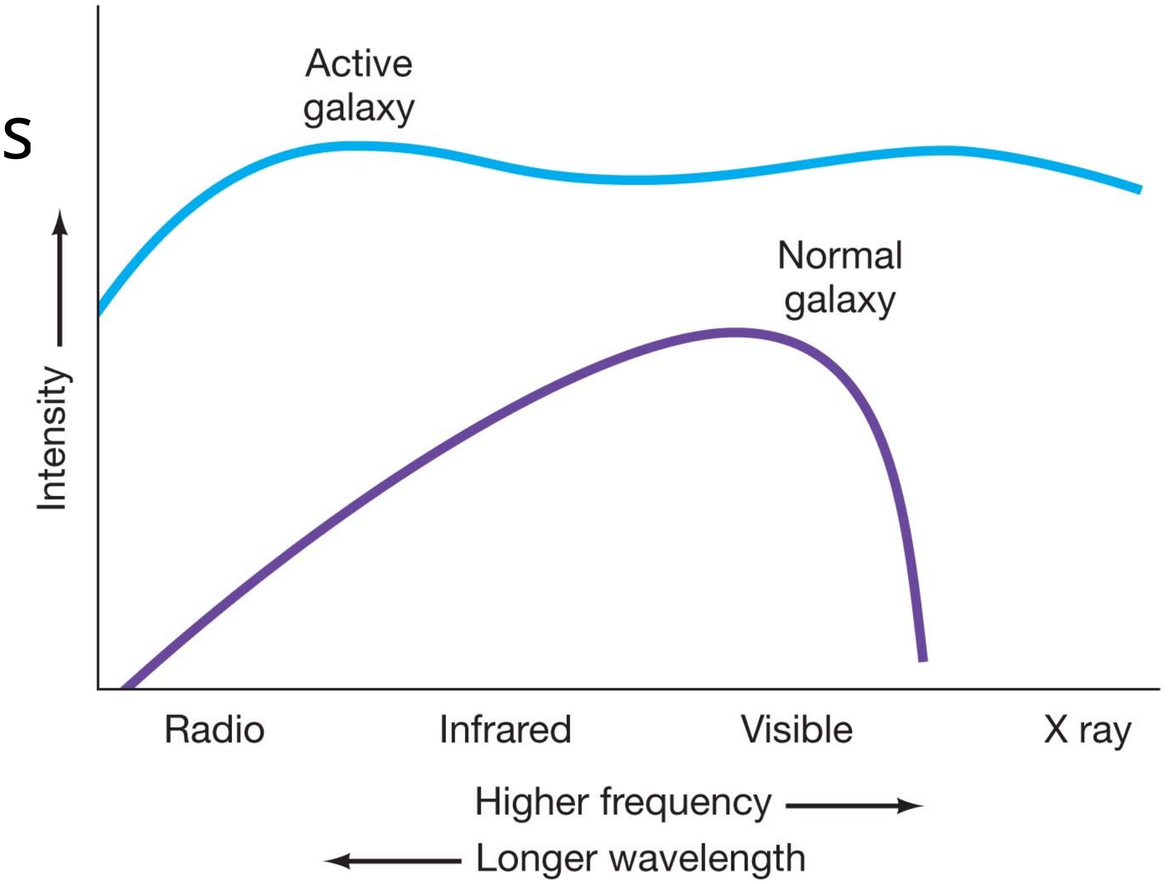
$W_{comet} = W_{earth} * (M_{comet}/M_{earth}) / (r_{comet}/r_{Earth})^2$

$= 200\ \text{lbs} * 2\text{x}10^{-11} / (5\text{x}10^{-4})^2 = 0.016\ \text{lbs} \sim ¼\ \text{oz}$

Active Galaxies

About 20–25 percent of galaxies don't fit well into the Hubble scheme – they are far too luminous.

Such galaxies are called active galaxies They differ from normal galaxies in both their luminosity and in the type of radiation they emit.



Active Galaxies

The radiation from these galaxies is called **nonstellar** radiation, meaning that it is not produced by stars.

Many luminous galaxies are experiencing an outburst of star formation, probably due to interactions with a neighbor. These galaxies are called starburst galaxies, and we will discuss them later.

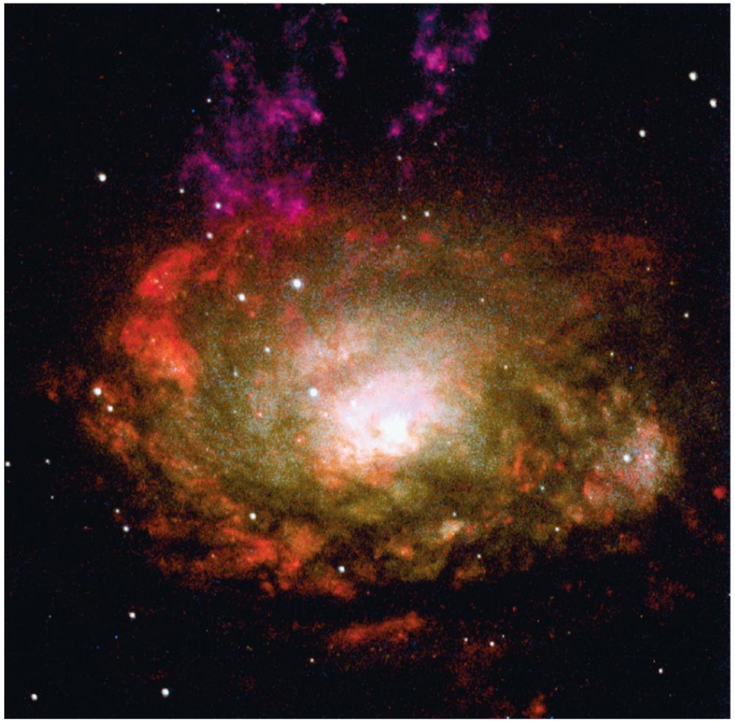
The galaxies we will discuss now are those whose activity is due to events occurring in and around the galactic center. For this reason they are called **active galactic nuclei** or **AGN**.

Active Galaxies

Active galaxies are much more luminous than normal galaxies and have nonstellar spectra, emitting most of their energy outside the visible part of the electromagnetic spectrum.

Active galaxies are classified into three types:

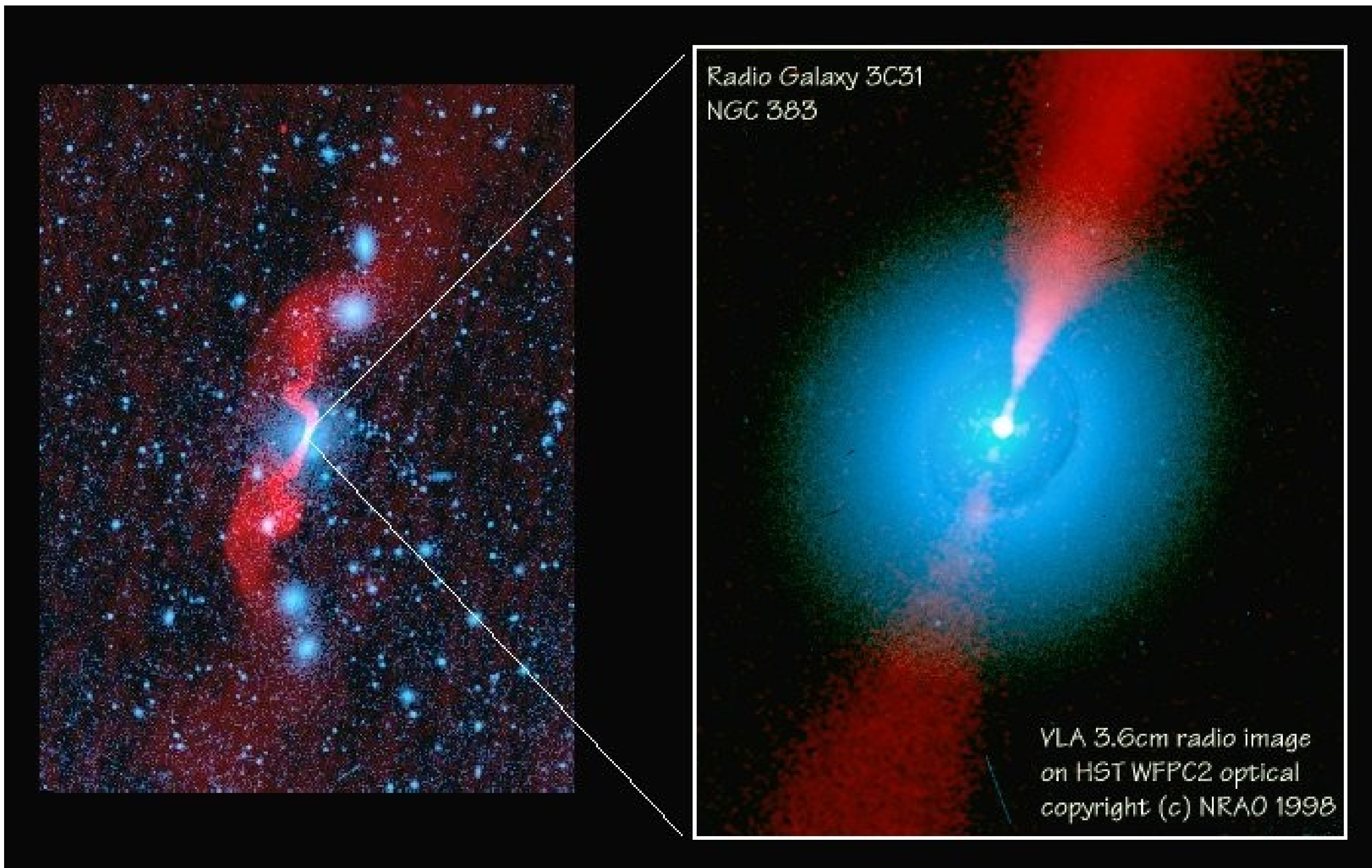
- Seyfert galaxies
- radio galaxies
- quasars.



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

Radio galaxies

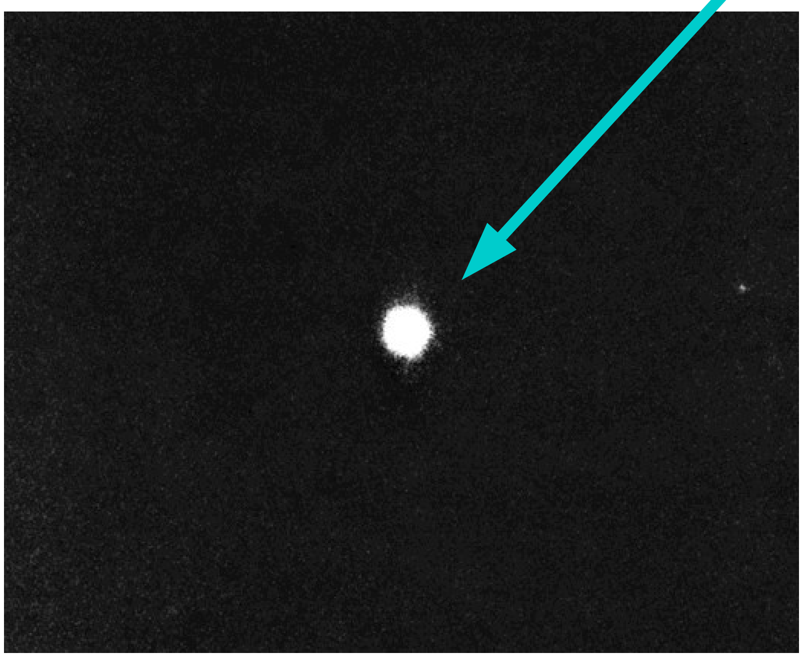
Radio galaxies emit large amounts of energy in the radio part of the spectrum. The corresponding visible galaxy is usually **elliptical**.

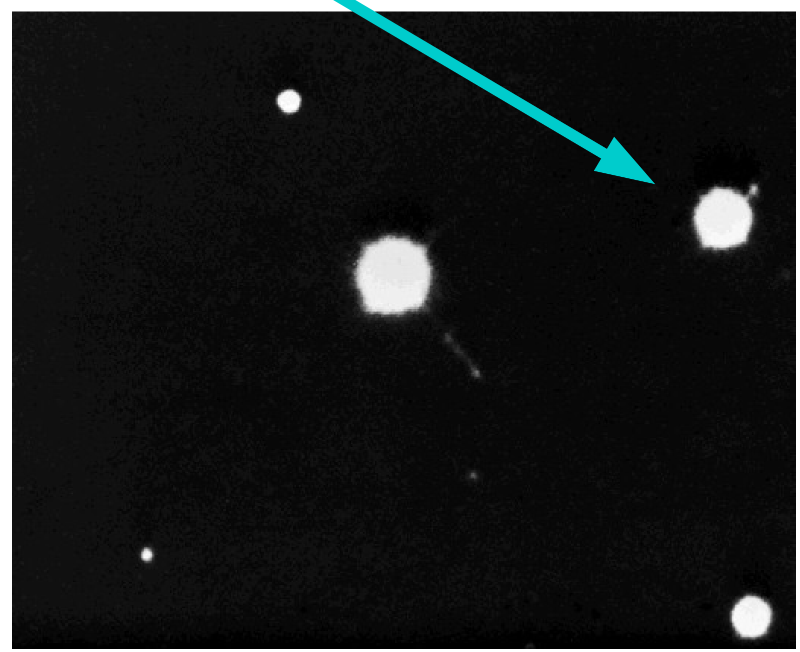


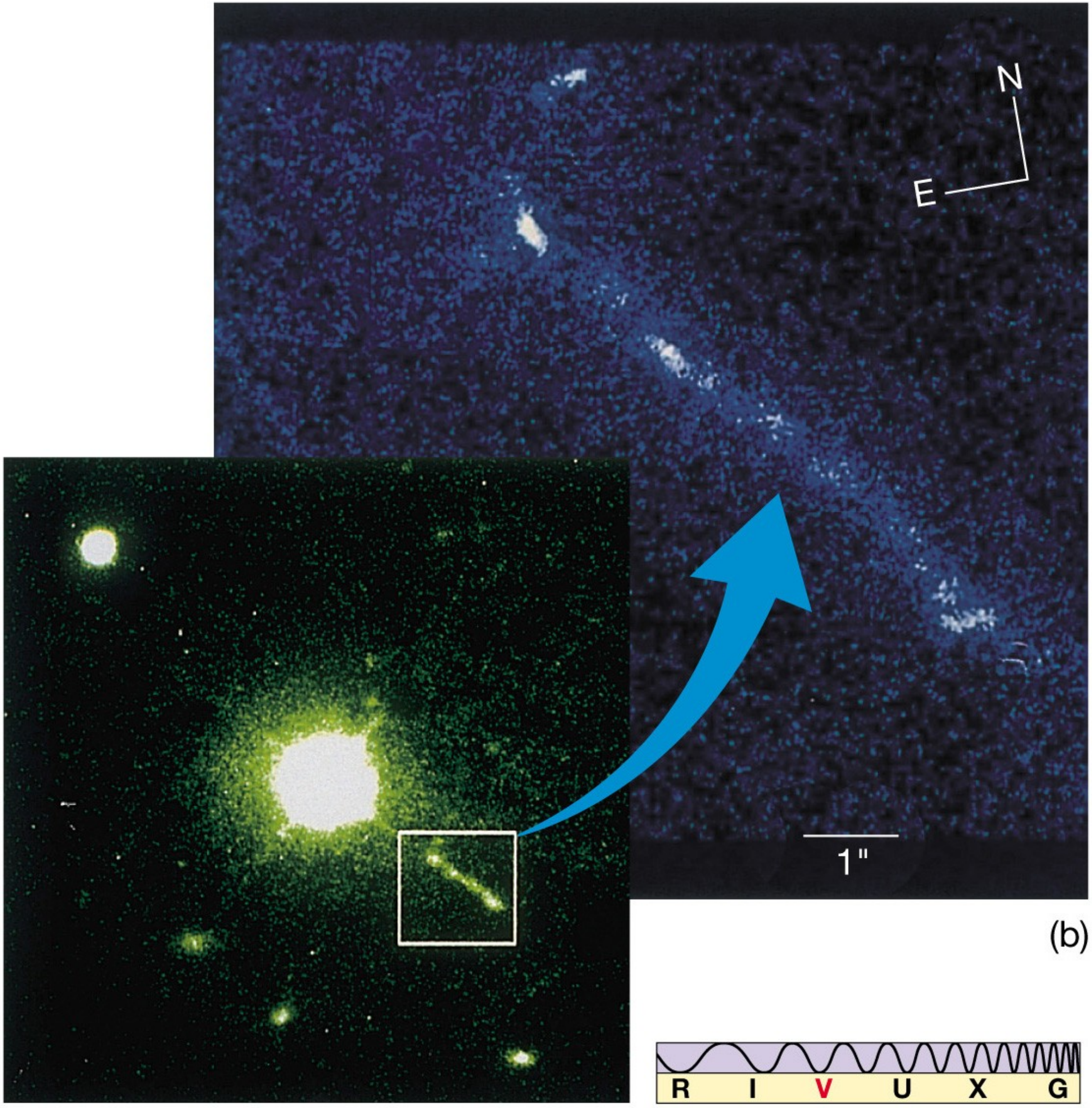
Quasars

Some active galaxies are strong radio sources.

Several of the strongest radio sources seemed to be identified with funny-looking stars: They were called quasi-stellar objects, or **quasars** for short, because they looked like stars





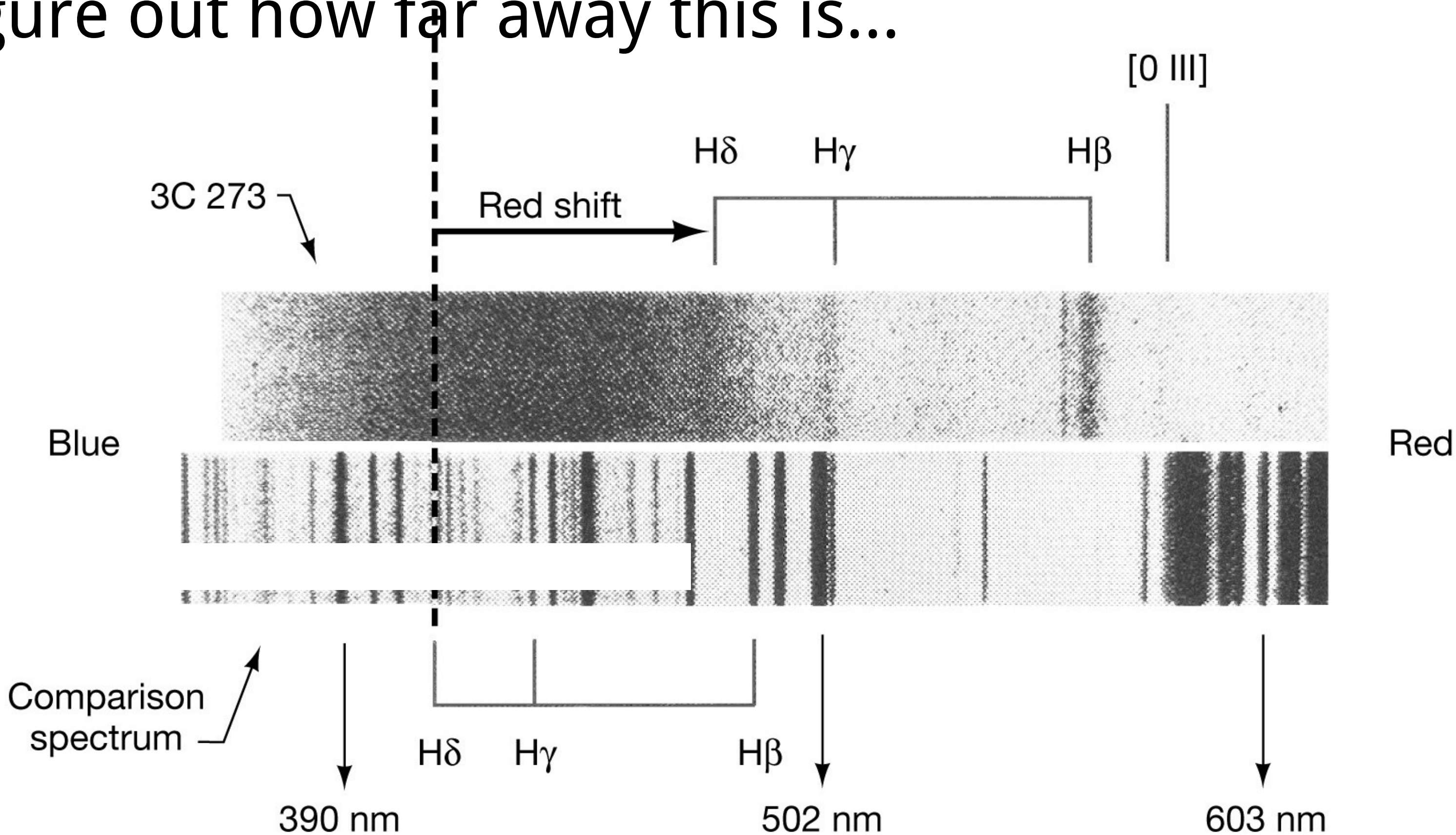


(b)
(a)

Quasars can emit thousands of times more energy than normal galaxies.

Quasars

For a long time, it wasn't clear how far away these quasars were until Maarten Schmidt finally identified the spectrum of one of the brightest as simply hydrogen redshifted by a velocity 15% of the speed of light! From Hubble's law, we can figure out how far away this is...



Quasar Distances

Marten Schmidt saw that the quasar is moving away from us at 15% of the speed of light or 48,000 km/s

Remember Hubble's Law: v = H x d

And H is 70 km/s/Mpc

So this gives: 48,000 = 70 x d or d = 642 Mpc away, or almost 2 billion light years away!

Quasar Distances

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Finding the distance introduces a new problem: quasars must be among the most luminous objects in the universe, since they appear so bright and are so far away. What's the source of all that energy?

What powers active galaxies?

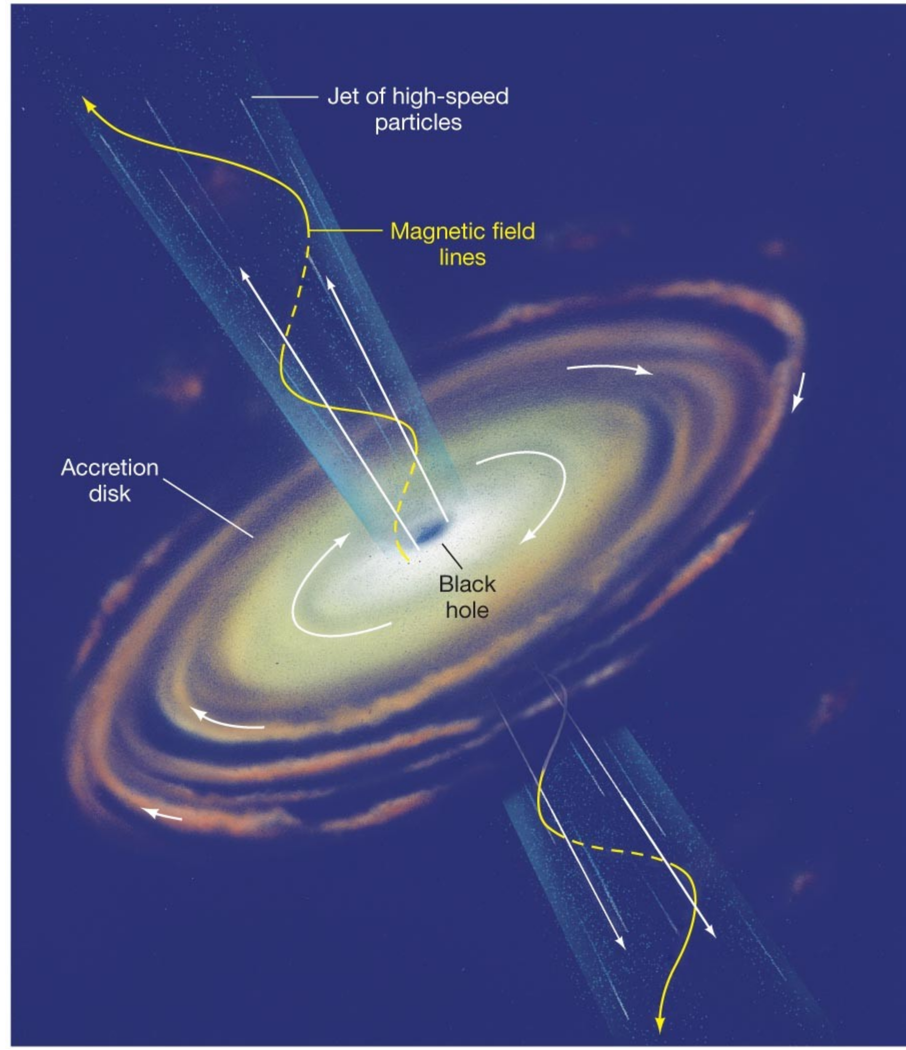
The power source for active galaxies must be phenomenal

- They are bright. They are typically brighter than normal galaxies by a factor of 10^6-10^8
- They are compact – they vary on short (1 week – years) timescales, so they can be at most 1 light-week to light-years in size
- Doppler shifts of spectral lines show evidence of motion with velocities of ~ 10,000 km/s: very fast!

The only power source that can explain all of this is a **supermassive black hole**.

The Central Engine of an Active Galaxy

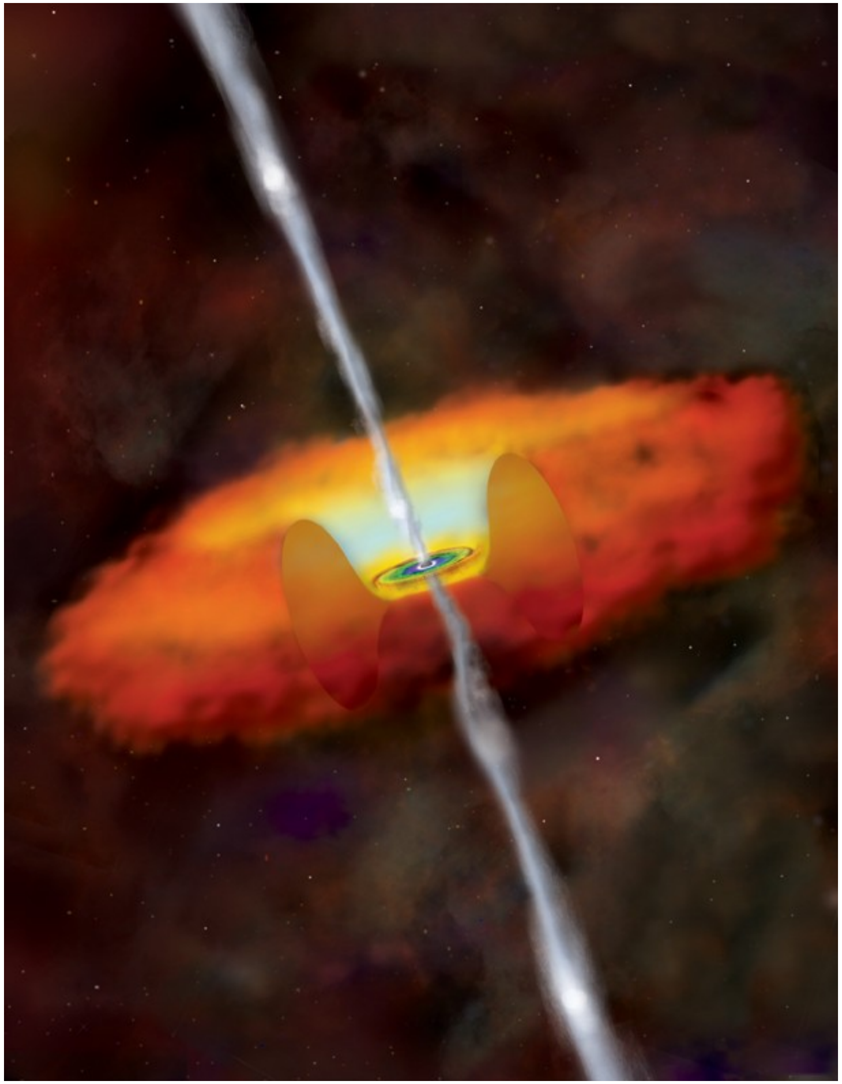
This is the leading theory for the energy source in an active galactic nucleus: a black hole, surrounded by an accretion disk. The strong magnetic field lines around the black hole channel particles into jets perpendicular to the magnetic axis.



The Central Engine of an Active Galaxy

In an active galaxy, the central black hole may be billions of solar masses.

The accretion disk consists of clouds of interstellar gas and dust. As the gas and dust spirals into the central black hole, friction heats the accretion disk to high temperatures. It may radiate away as much as 10–20 percent of its mass before disappearing.

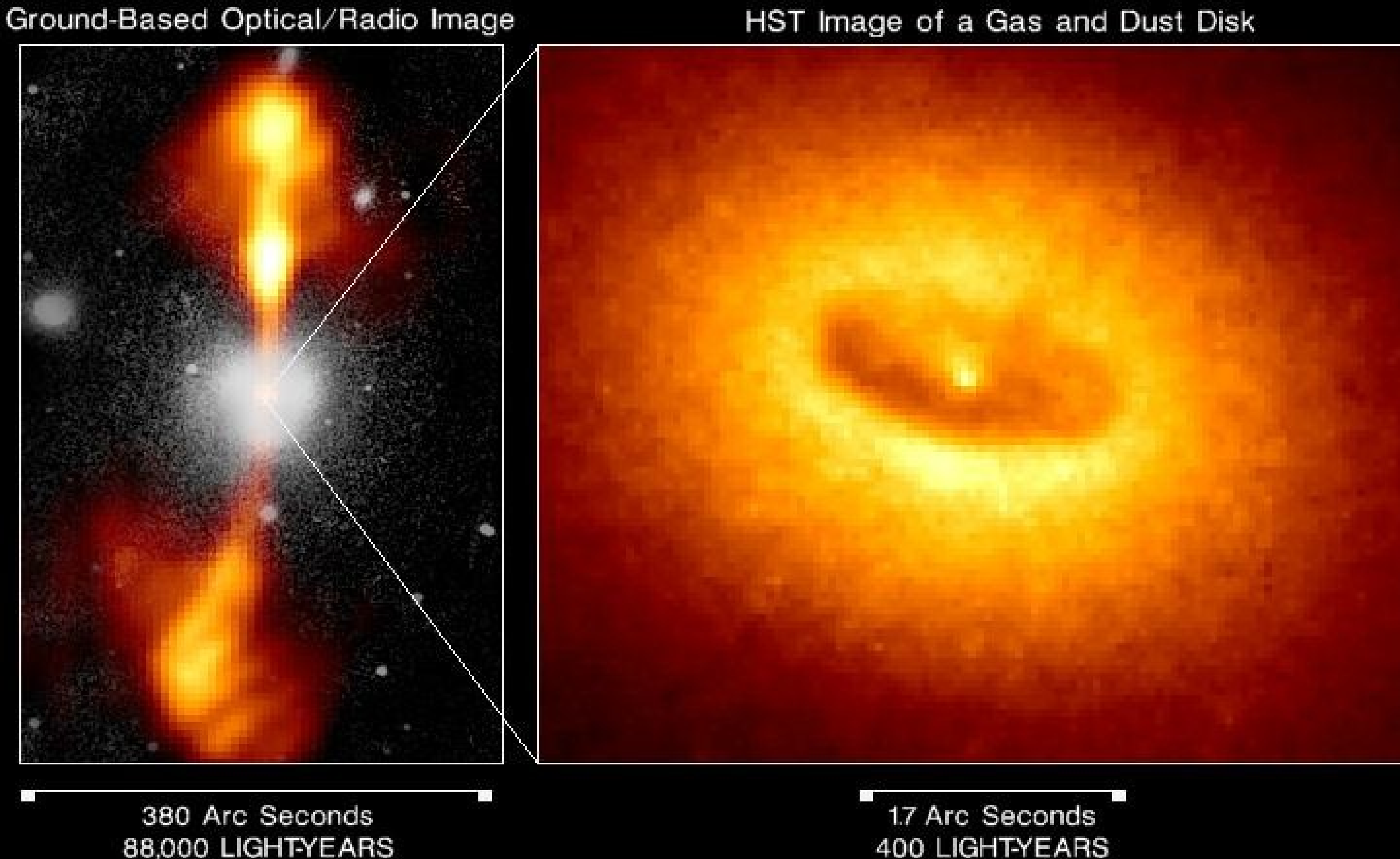


Artist’s conception of an AGN

Core of Galaxy NGC 4261

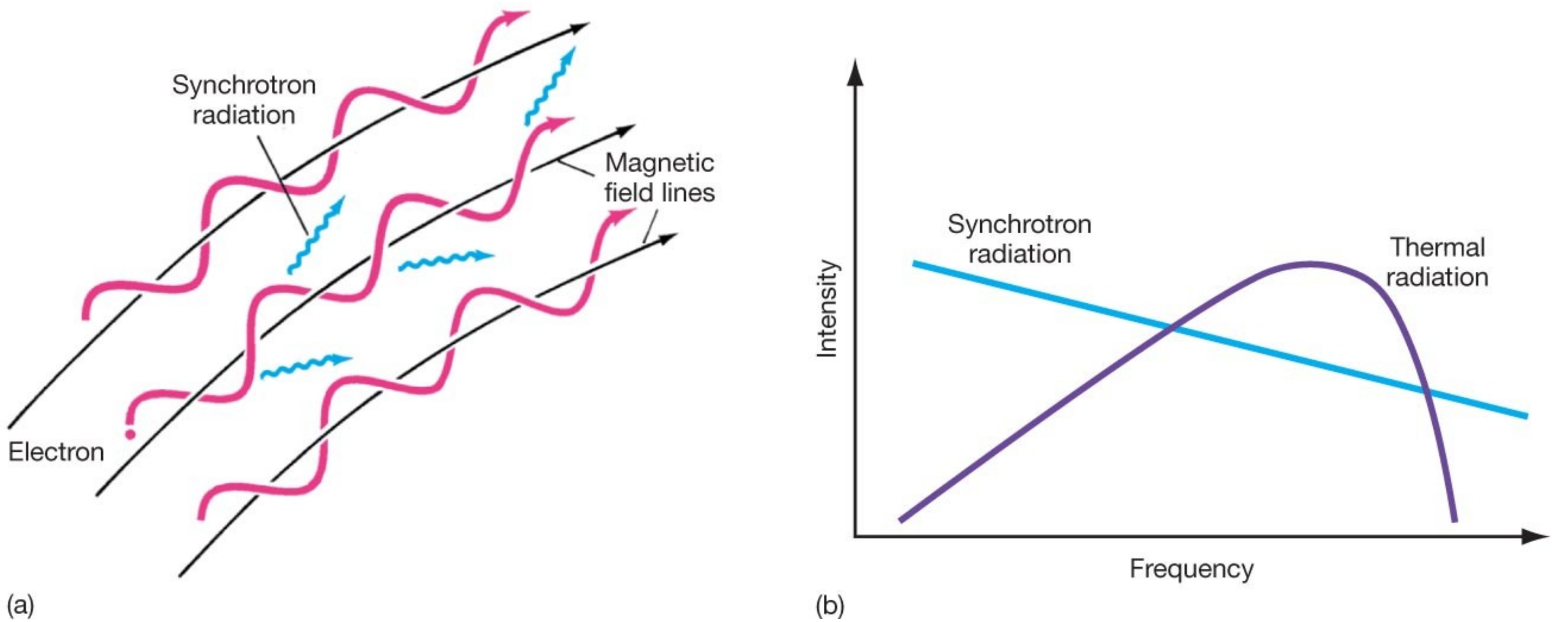
Hubble Space Telescope

Wide Field / Planetary Camera



The Central Engine of an Active Galaxy

Particles will emit **synchrotron radiation** as they spiral along the magnetic field lines; this is nonstellar radiation we see at radio wavelengths.



Why a Black Hole?

Because these active galaxies can be extremely luminous, they must have an extremely efficient power source

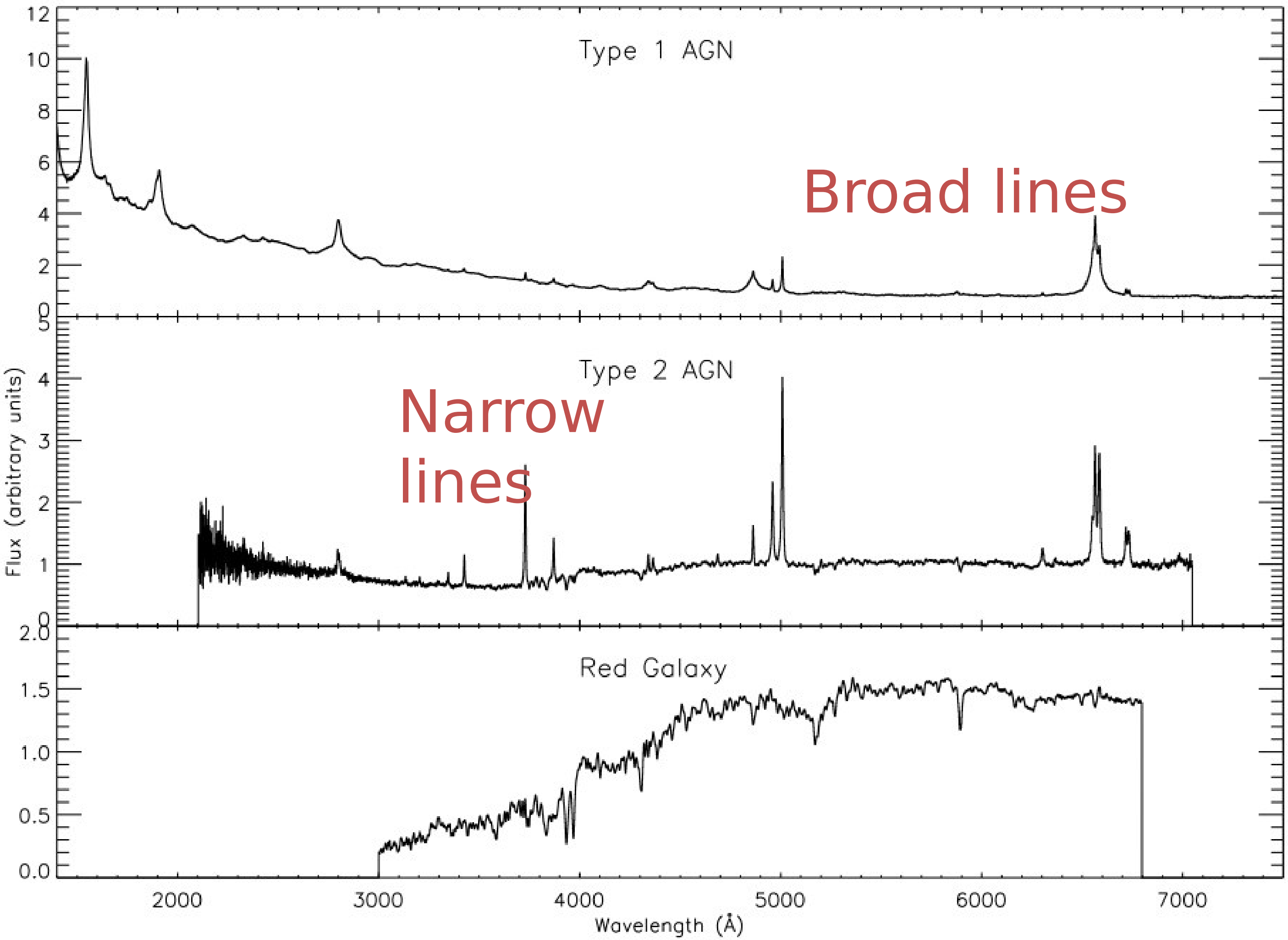
Black holes can convert about 10% of mass into energy ($E=mc^2$). Compare this to hydrogen fusion, which converts 0.7%

They are also compact. Most of the energy is emitted close to the black hole, where the size is a few light-seconds to 1 light minute across

Stuff orbits around a black hole very fast – explains why we see evidence for rapid motion

Spectra of Active Galaxies

Active galaxies show two components to their spectra: a narrow component and a broad component.

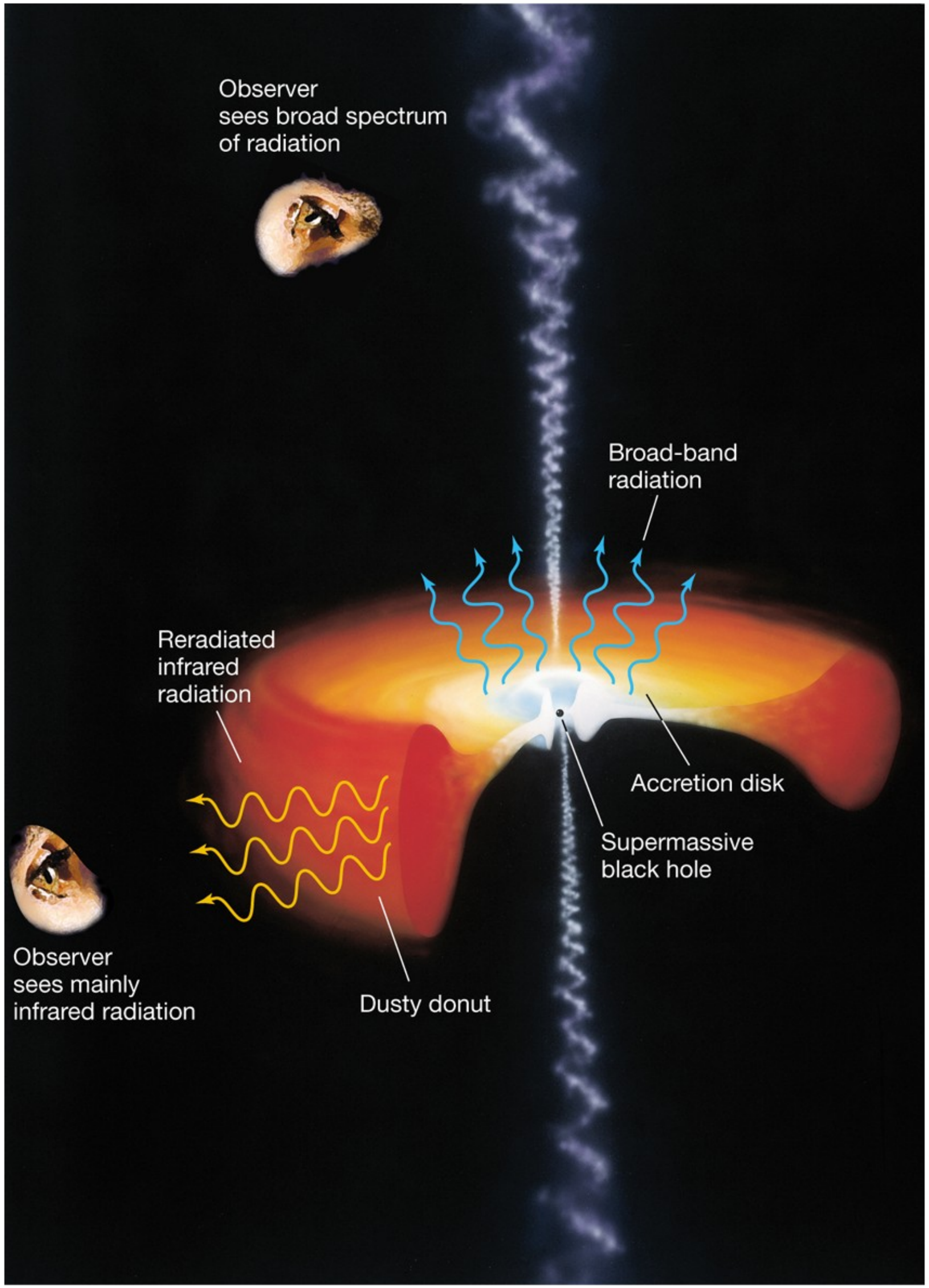


Doppler shifts of the broad component show high velocities – this is why the lines are broad.

But not all active galaxies have broad lines: we don't always see evidence for fast motion.

To explain this, astronomers think there is a dusty torus (a donut-shaped ring) that surrounds the black hole.

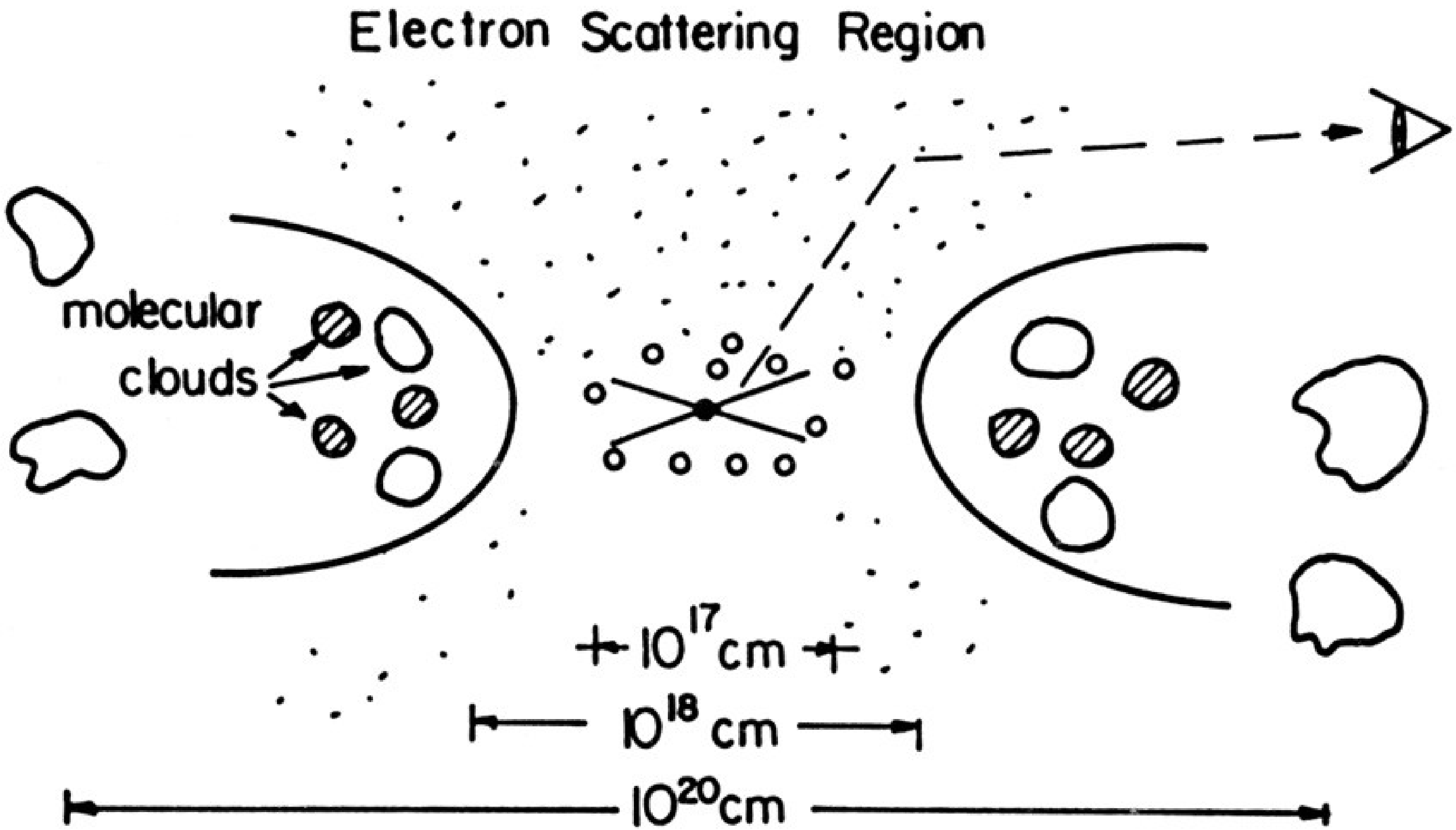
Only from certain angles can we see the central accretion disk. Otherwise we only see the narrow lines.



The Dusty Donut

There is some evidence that this model is correct. If we can look at the same galaxy from multiple angles, we can test this idea.

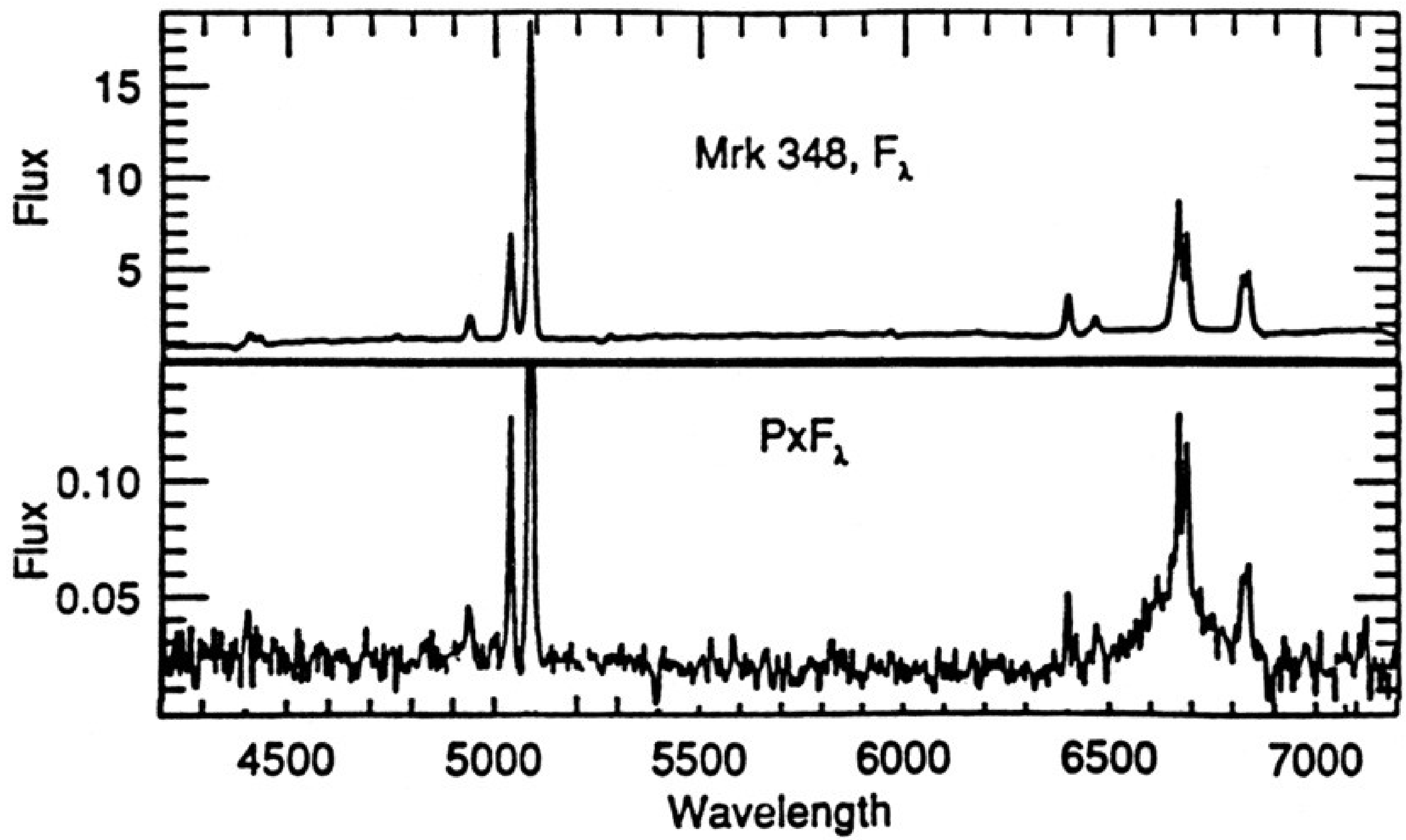
We can do this if we look at the scattered light.



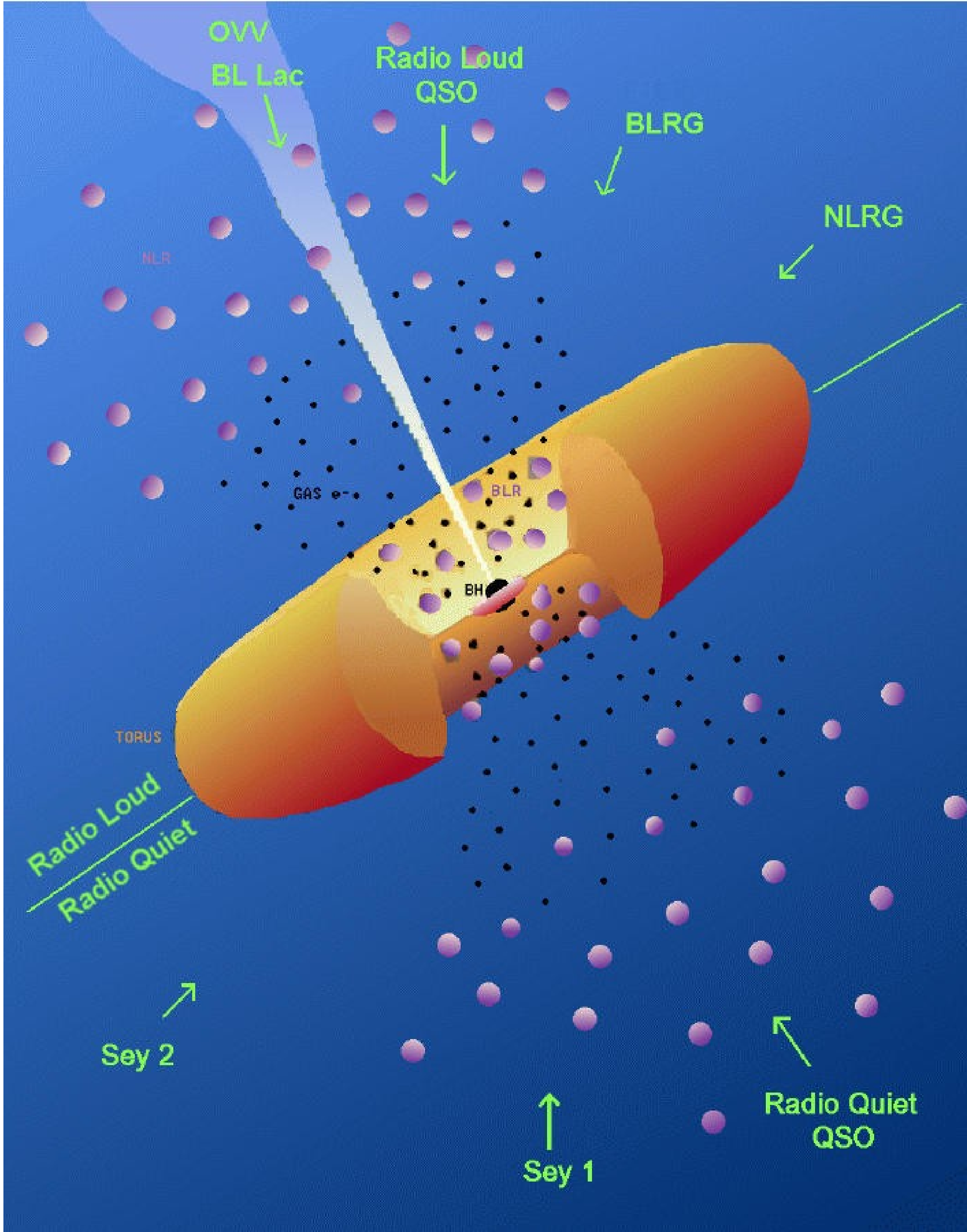
Light from the central accretion disk is blocked by the torus, but some of it is scattered in our direction.

The Dusty Donut

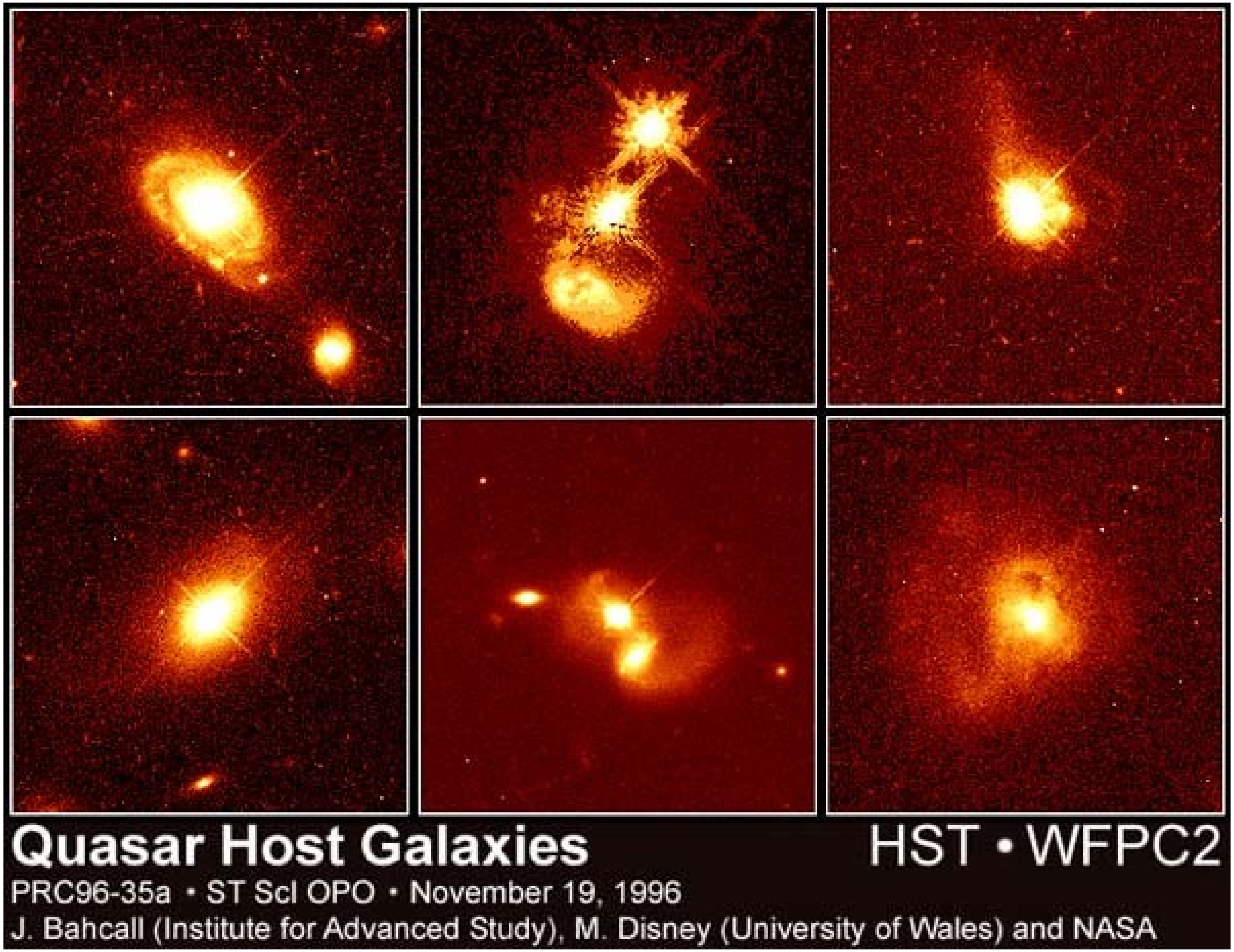
In this system, Mrk 348, we can look for the scattered light and see that it has broad lines. So this broad line is completely scattered light – coming from the central accretion disk!



So… active galaxies are all basically the same beast, but they appear different because they are viewed from different angles!

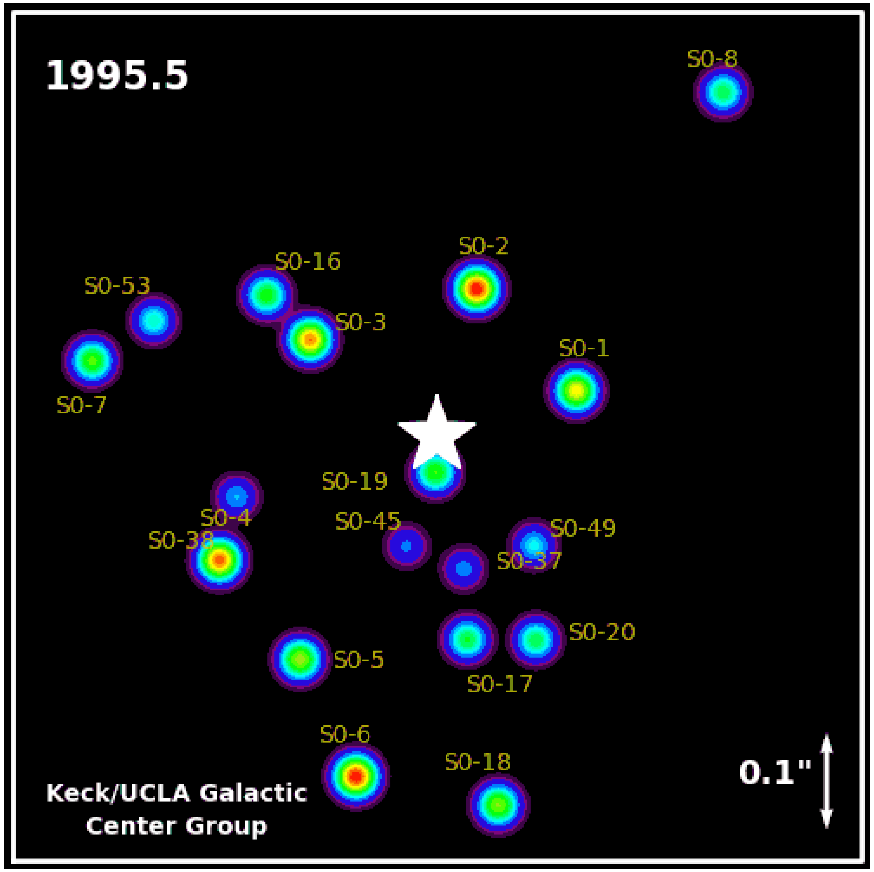


We can now image the host galaxies of quasars with the Hubble Space Telescope.



What about black holes in regular galaxies?

- We think most moderately large galaxies, including the Milky Way, have supermassive black holes at their centers
- So why aren't most galaxies active galaxies?
- They aren't accreting as much stuff onto their black holes
- Many of them were probably more active in the past



Orbits of stars at the center of the Milky Way indicate the presence of a supermassive black hole.

Quasars are called "quasi-stellar" because

- **A** they generate energy partly through H to He fusion like stars
- **B** they show spectra similar to extremely bright O stars
- **C** in short exposures photographs, their images appear stellar
- **D** they are dense concentrations of millions of stars

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Galaxies and Active Galaxies: Summary

- The Hubble sequence organizes galaxies according to their shapes
- Galaxy types include spiral, barred spiral, elliptical, and irregular
- Objects of relatively uniform luminosities are called **"standard candles"**; examples include Cepheid variable stars and Type I supernovae. We use them to find distances to other galaxies.
- The Milky Way lies within a small cluster of galaxies called the Local Group
- Other galaxy clusters may contain thousands of galaxies

Galaxies and Active Galaxies: Summary

- **Hubble's law**: Galaxies are receding from us, and the farther away they are the faster they recede
- **Active galaxies** are far more luminous than normal galaxies, and their radiation is nonstellar
- Seyfert galaxies, radio galaxies, and quasars all have very small cores; many emit high-speed jets.
- Active galaxies are thought to contain **supermassive black holes** in their centers; infalling matter is converted to energy, powering the galaxy
- Most normal galaxies probably contain black holes, but they aren't accreting enough gas to be brighter than the stars in the galaxy