Estimating galaxy shape and flux with CNNs

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Overall task

- A galaxy image can be described by a simple model with 5 parameters (a brightness and 4 shape parameters).
- We want to estimate those parameters, given an image (or millions of them).
- We can generate mock images as a function of the 5 parameters to produce a training set.

Your task is to make a training set, train a CNN to do this regression, and then assess its performance on a sample of mock images.

Image noise

Real astronomical images have a lot of imperfections that make them different from a theoretical model.

- Noise: There is noise in the readout electronics of a CCD (charge-coupled device, the sensor used in most telescopes).

- Sky background: The night sky is not “dark” — there are many sources of light (reflected city light, airglow, moonlight, …)

- Photon counting is a Poisson process anyway.

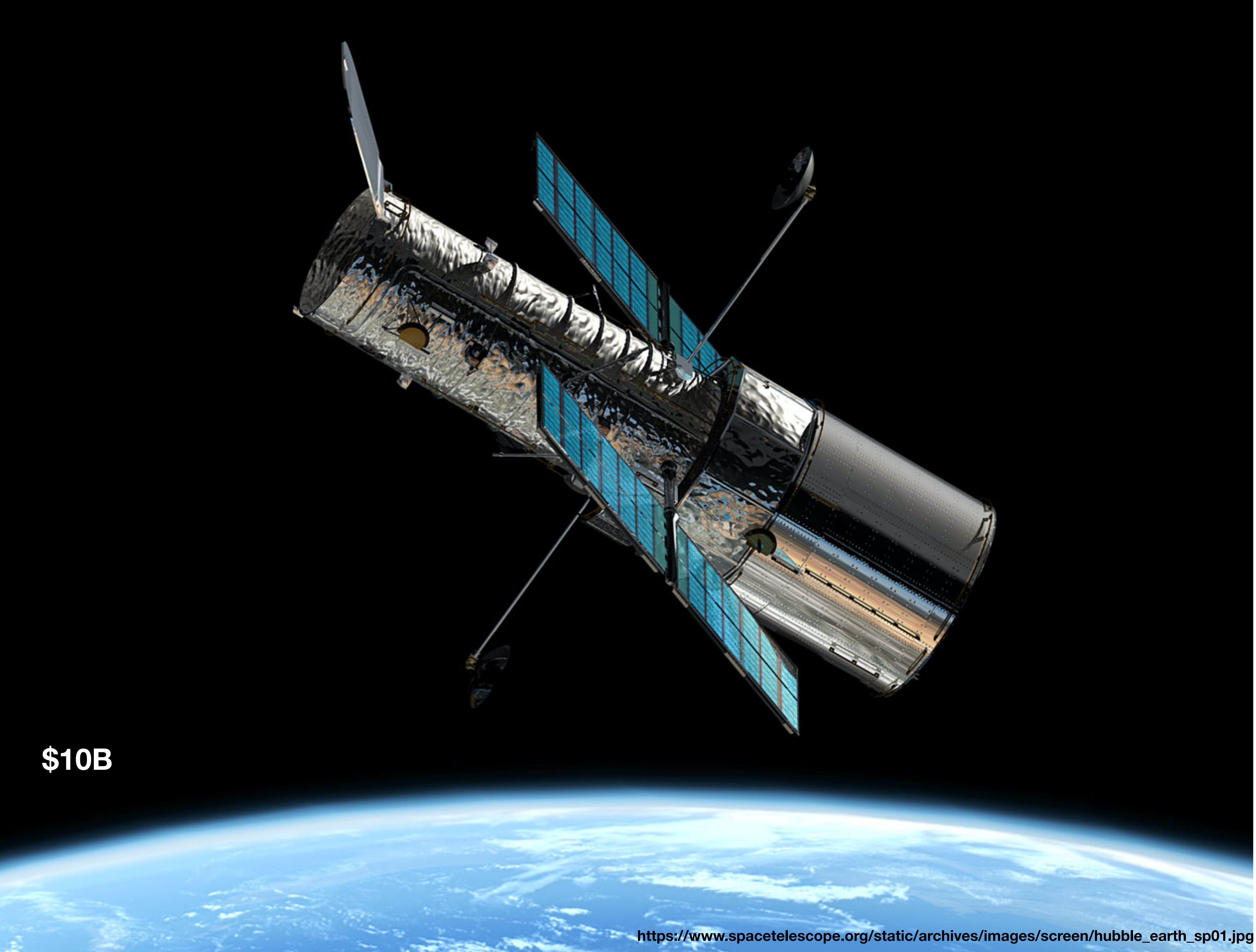
Point-spread function

The telescope optics are partly responsible, and dominate in a space telescope. For a ground-based telescope, the atmospheric turbulence usually dominates (i.e. it is *much worse* than the blurring from the telescope itself).

The diffraction limit is 1.22 wavelength / diameter.
For the Hubble Space telescope in greenish light that is about 0.05 arcsecond.   (3600 arcsec = 1 degree)

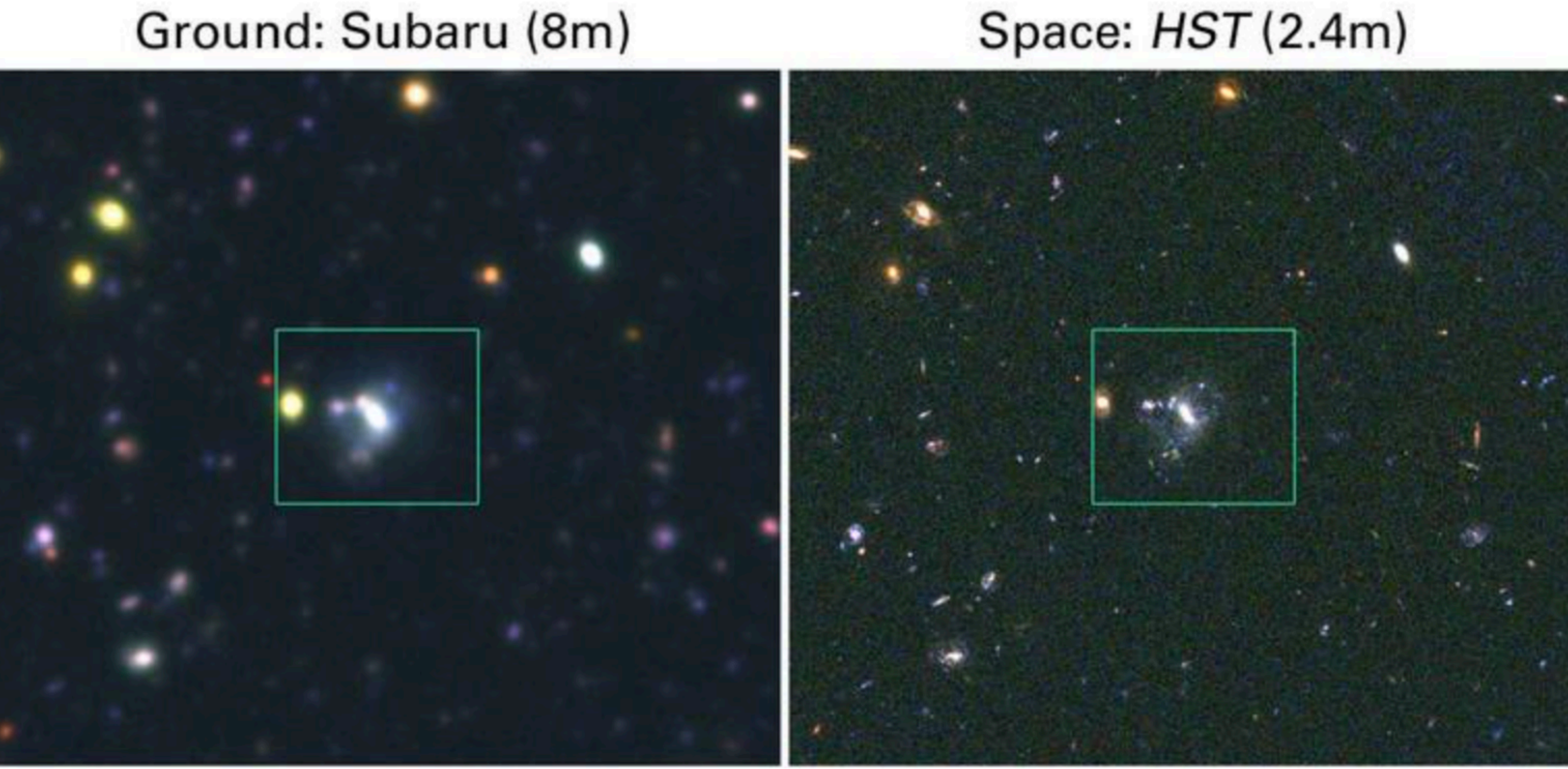
$$\delta\theta = \frac{1.22\lambda}{d} = \frac{1.22(0.5\mu\mathrm{m})}{2.4\mathrm{m}} \approx 2.5 \times 10^{-7}\mathrm{rad}$$

https://www.hawaiimagazine.com/content/get-out-world-view-tour-big-islands-subaru-telescope



https://www.spacetelescope.org/static/archives/images/screen/hubble_earth_sp01.jpg

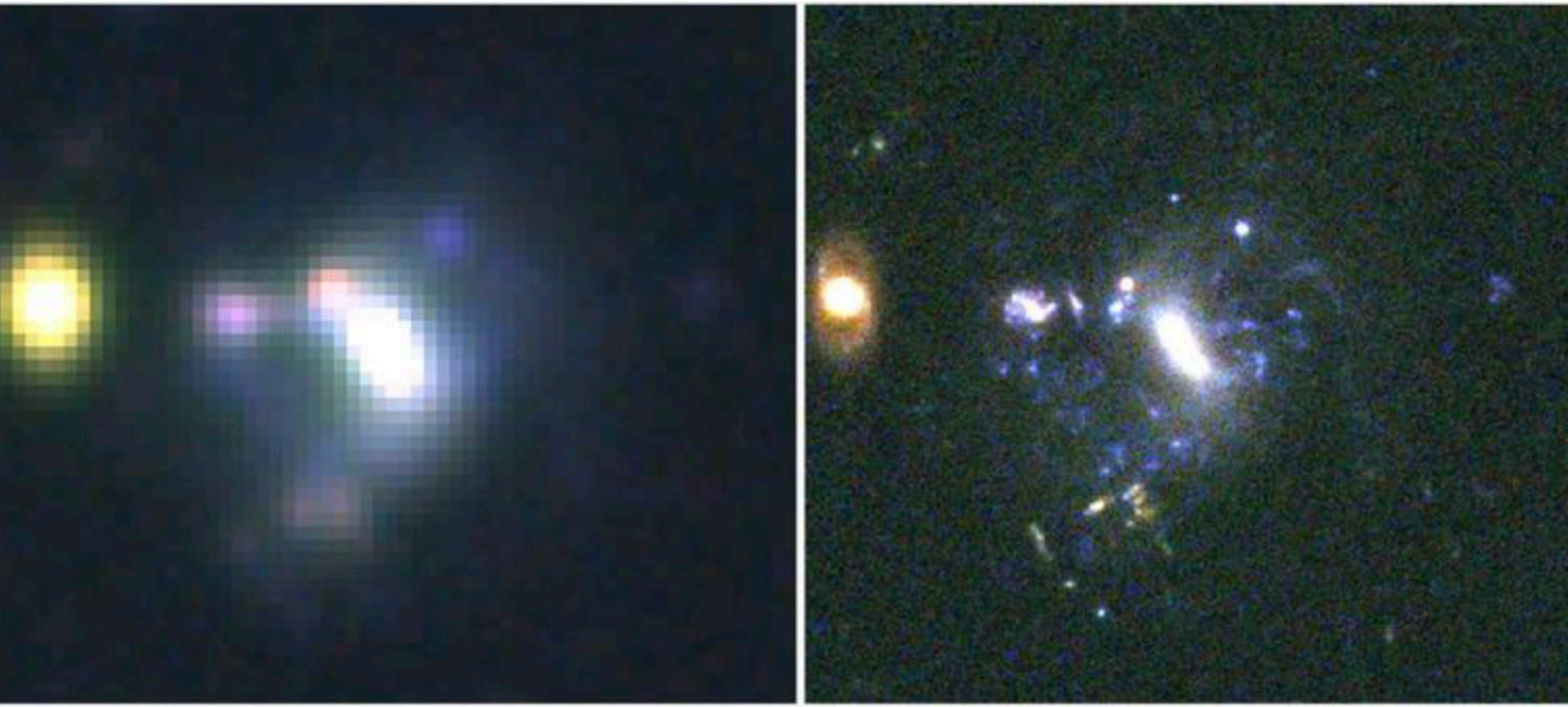
PSF is better (smaller) in space



https://hubblesite.org/contents/media/images/2004/07/1461-Image.html

Point-spread function

Ground: Subaru (8m) — Space: *HST* (2.4m)



Mock images must include Noise and PSF smoothing

But don't worry, we'll show you how to do it with a python package called "galsim"

Motivation for looking at galaxies

- It’s cool that it is even possible to study things that are millions (or billions!) of light years away.

- Galaxy “counts” to a certain brightness or distance, along with redshifts, teach us about the origin and evolution of the Universe.

- Galaxy shapes, via “**gravitational lensing**” can be used to tell us about the mass distribution in the Universe. Even matter we cannot see directly!

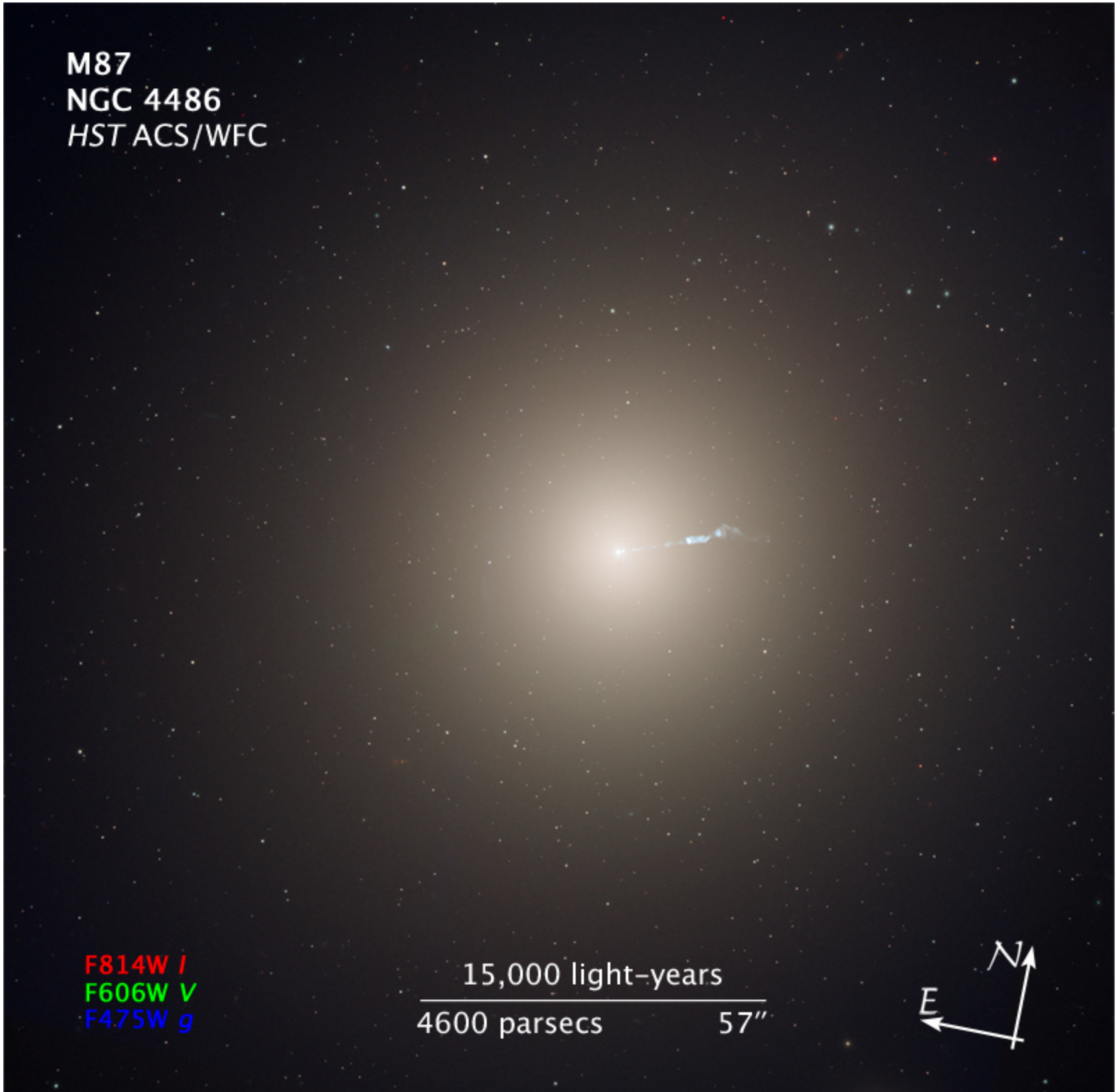
I’ll tell you more about galaxies in a second, but first…

Let’s talk about how big things are

The Universe is 10^{27} x bigger than you

Thing	Length-scale	Speed	Time-scale
You	1m	1m/s (running speed)	1 s
Earth	10^4 km	300 m/s (soundspeed; Rotation speed)	1 day
Earth-Sun	10^8 km	30 km/s (orbital speed)	1 yr
Earth to Nearby star	1 pc = 3×10^{13} km	30 km/s (random speed w.r.t. neighbors)	300,000 yr
Earth to Galactic center	10^4 pc = 3×10^{17} km	300 km/s (orbital speed around Milky Way)	3×10^8 yr

A galaxy is a bunch of stars -



The Galaxy is the *Milky Way*
(The one we live in)

360 deg panorama assembled by ESO (Wikipedia)

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Galaxy cluster	10^6 pc = 3×10^{19} km	1000 km/s (galaxy relative velocities)	10^9 yr
Universe	10^{10} pc = 3×10^{23} km	~ 300,000 km/s (Hubble flow)	1.37×10^{10} yr

The bigger something is

- The higher the typical speed, and
- The longer the characteristic timescale

Amazingly, we can study things that are enormously bigger, older, and faster than we are (or the Earth!)

That is the field of “Physical Cosmology”

(Astronomy 130 will be offered next semester!)

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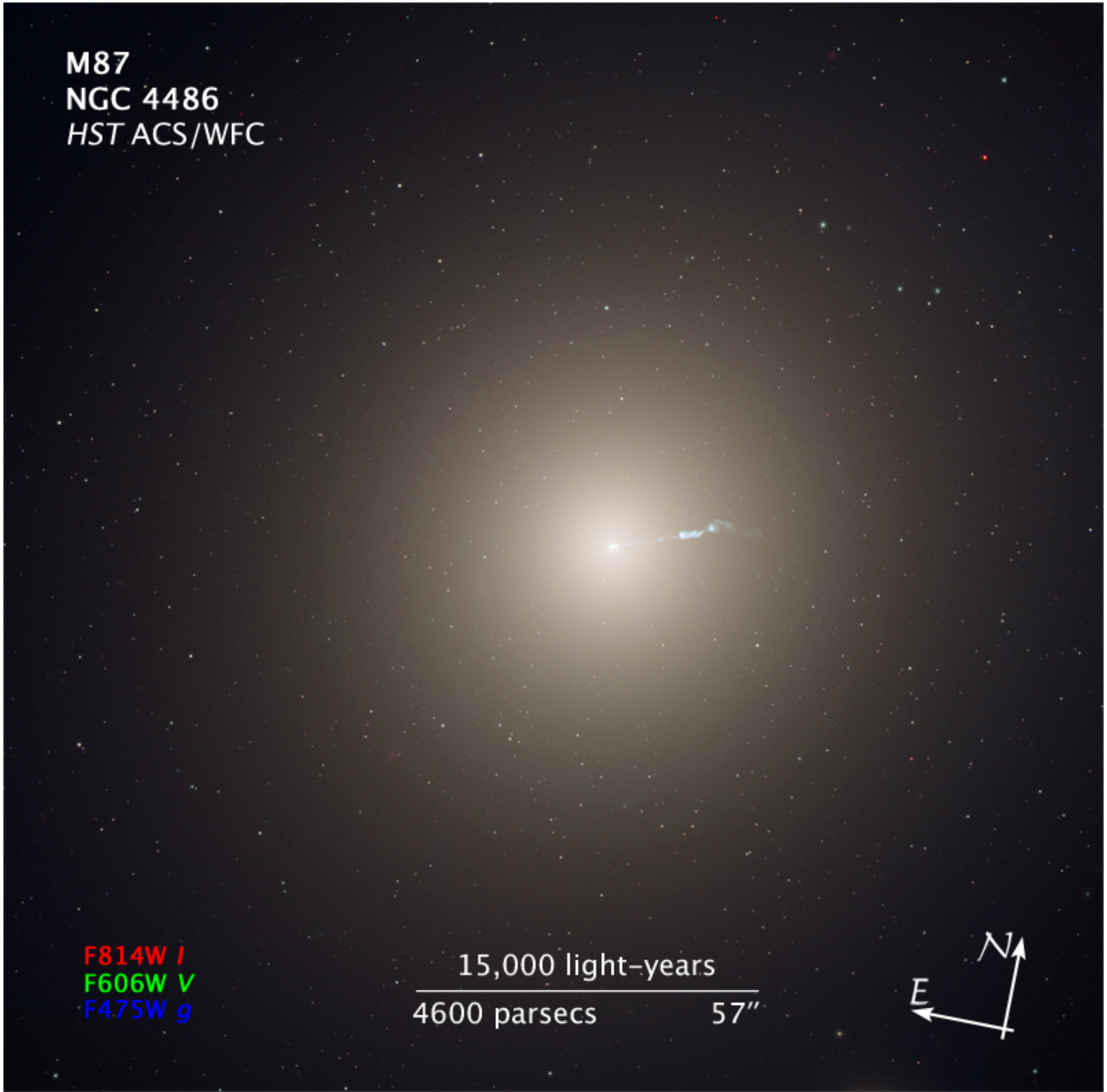
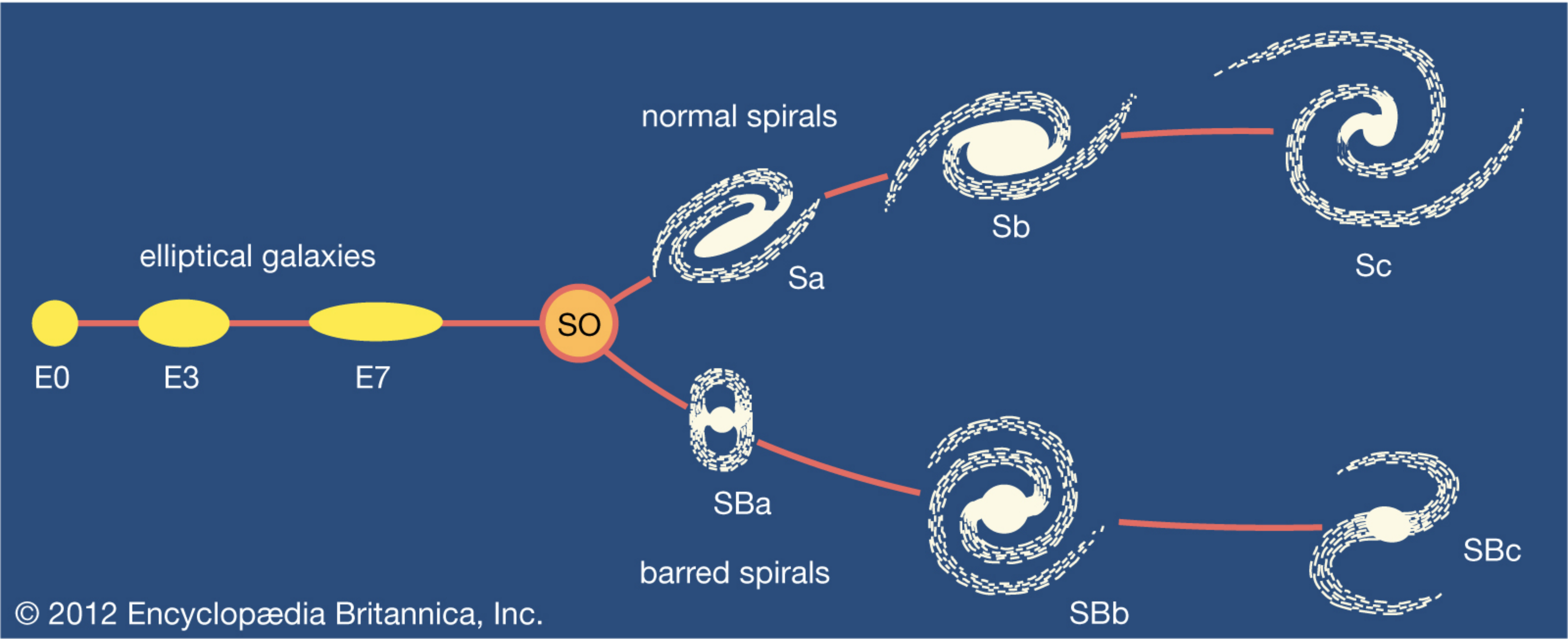
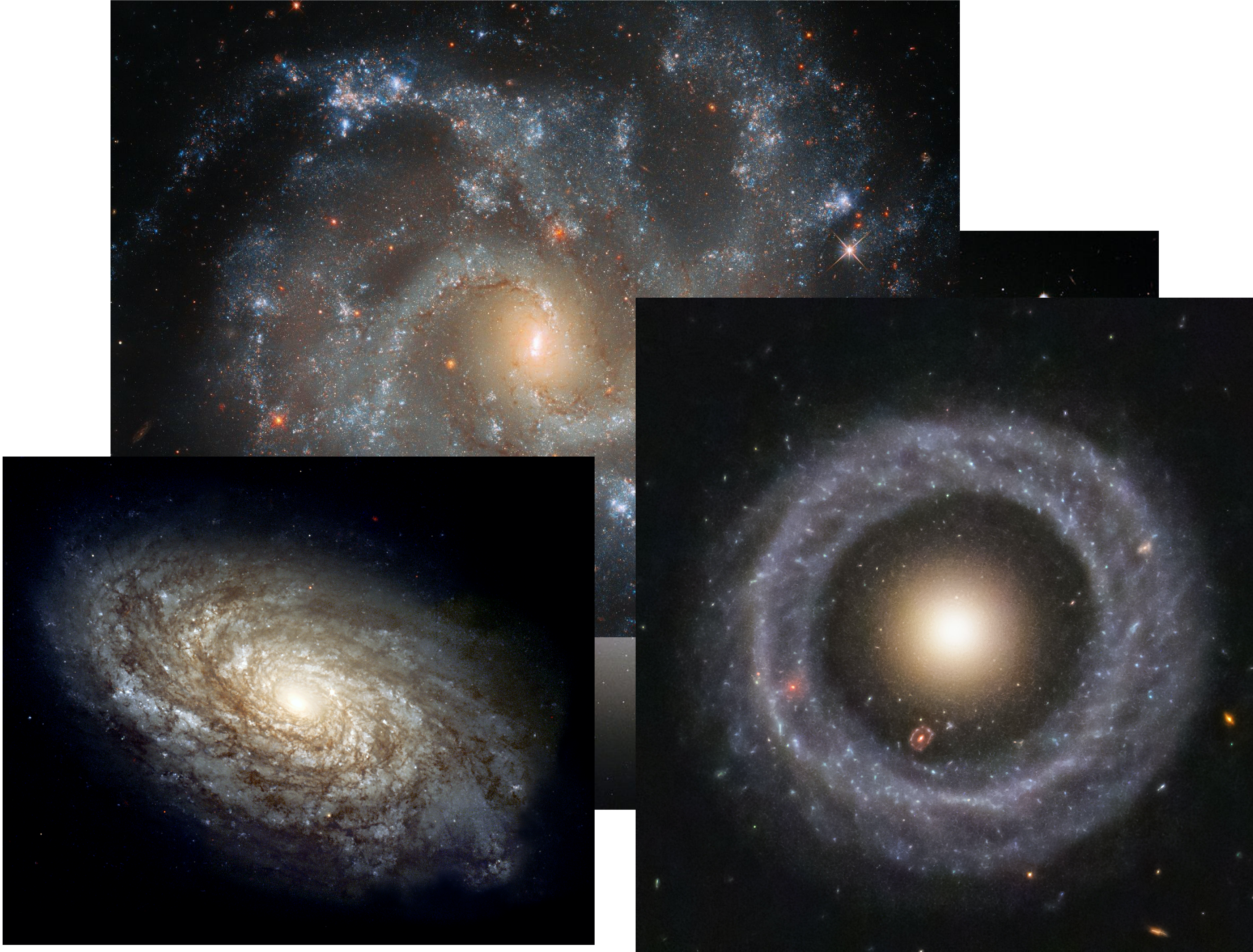


… and sometimes much more (gas, dust, ionized nebulae, jets…)

Most galaxies are roughly “spiral” or “elliptical”

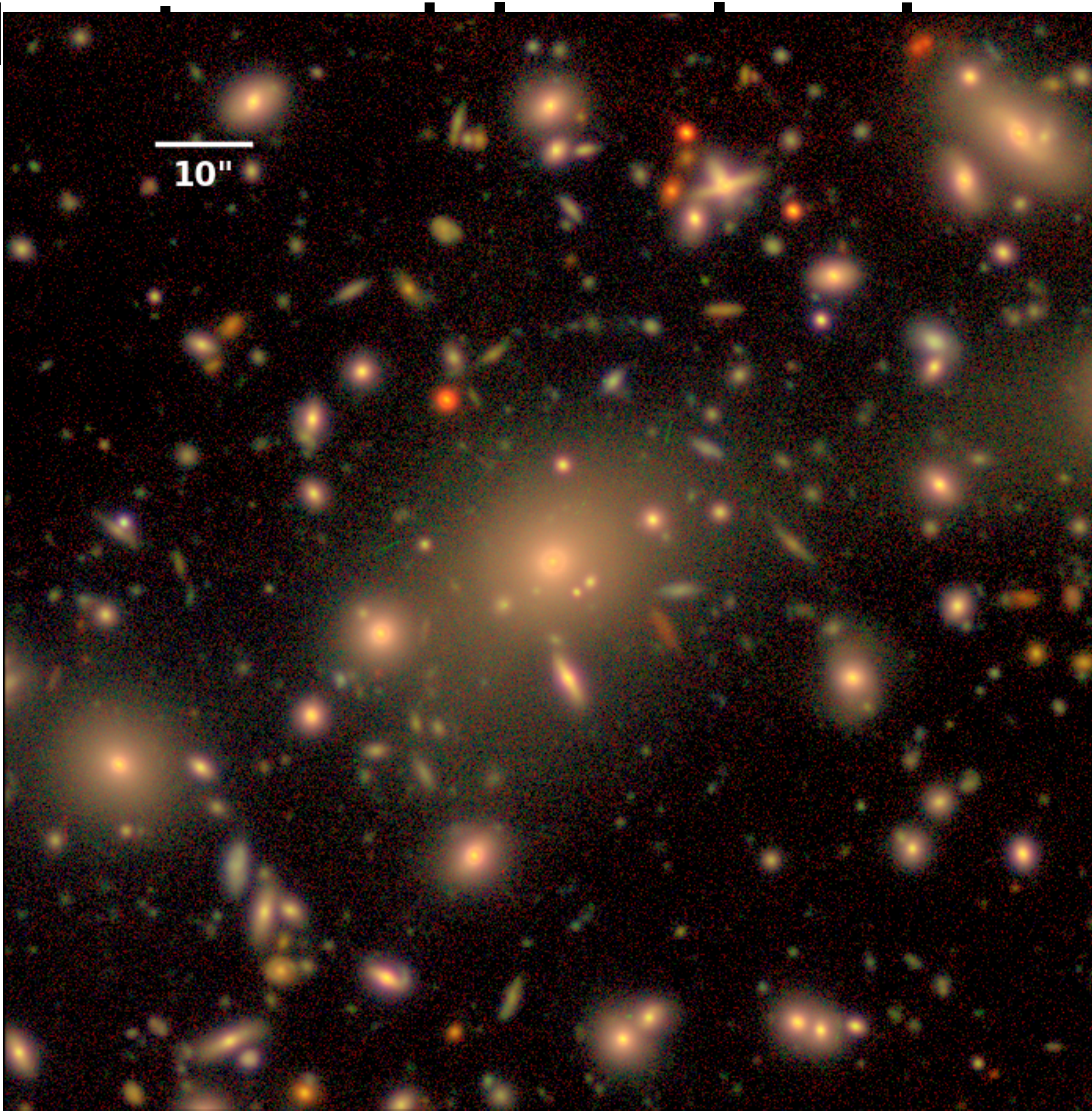


Hubble’s tuning fork



How to model a galaxy image?

H e?



How to model a galaxy image?

- Most galaxies can be ~ adequately modeled as a fuzzy blob at some position with some size, shape, brightness.

- We use the Sérsic model. (José Luis Sérsic was an Argentine astronomer) See https://arxiv.org/pdf/astro-ph/0503176.pdf

Sérsic's (1963; 1968) $R^{1/n}$ model is most commonly expressed as an intensity profile, such that

$$I(R) = I_{\mathrm{e}} \exp\left\{-b_n\left[\left(\frac{R}{R_{\mathrm{e}}}\right)^{1/n} - 1\right]\right\}, \qquad (1)$$

where I_{e} is the intensity at the effective radius R_{e} that encloses half of the total light from the model (Caon et al. 1993; see also Ciotti 1991, his Equation 1). The constant b_n is defined in terms of the third and final parameter n which describes the 'shape' of the light–profile, and is given below.[2]

$b_4 = 7.669$ and $b_1 = 1.678.$

Typical spiral or elliptical galaxies

- For n=1 this is an “exponential” profile, appropriate for many spiral galaxies.

- For n=4, it is a de Vaucouleurs profile, useful for elliptical galaxies. N can go from 0.75 to 6 or 7.

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