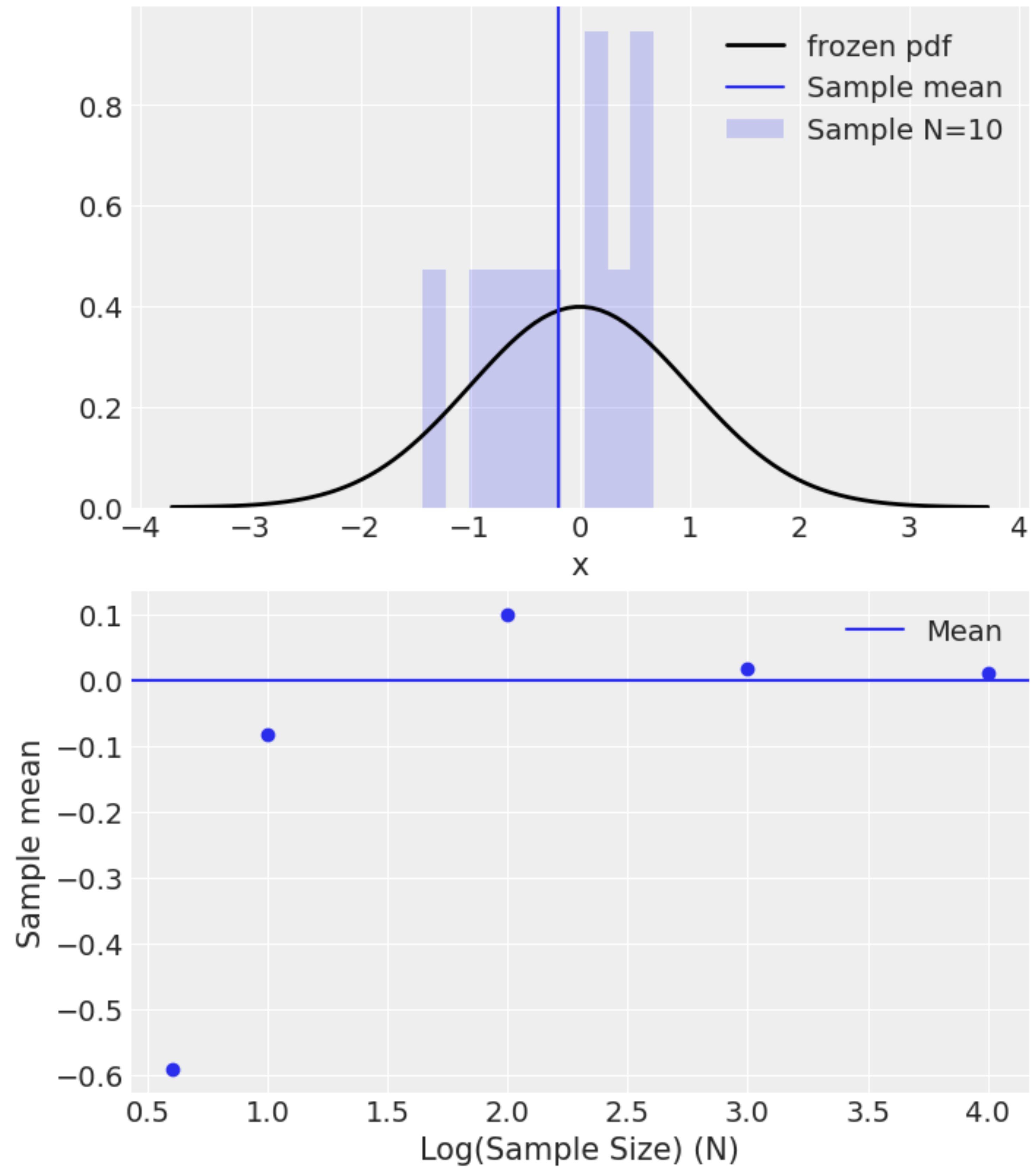
Notes on activity

- The variance of the probability of observing the data given the flux of the star could be estimated from the provided data
- The mean and variance of the prior should NOT have been estimated from the data!
- Why sampling from the posterior?

$$q(\mu \mid x_i) \propto \boxed{p(x_i \mid \mu)\nu(\mu)}$$

You won't always know how to compute this function but there are techniques to sample from it.



Binomial random variables

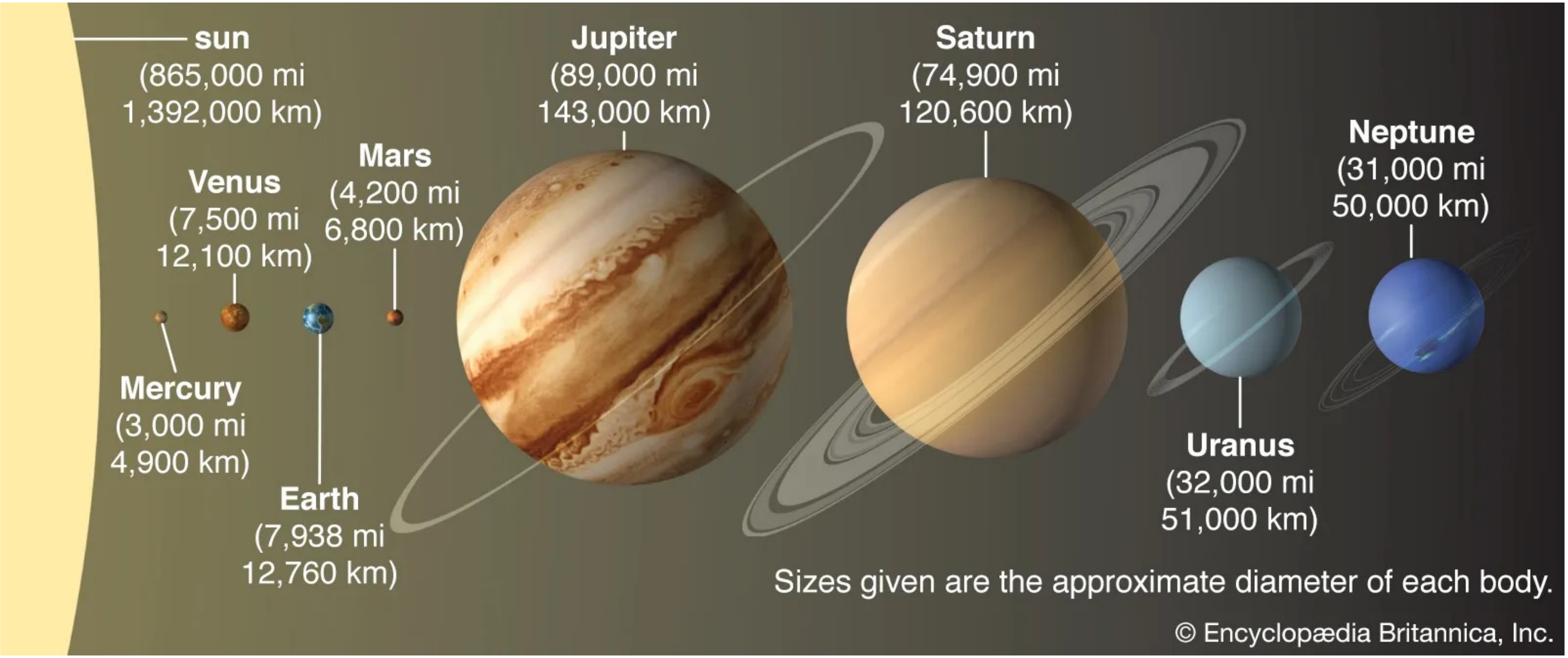
A binomial random variable, X, counts how often a particular event, with probability θ of success, occurs in N independent trials.
When X is the total number of successes that occur in N trials, X is a binomial random variable with parameters θ and N.

Binomial random variables

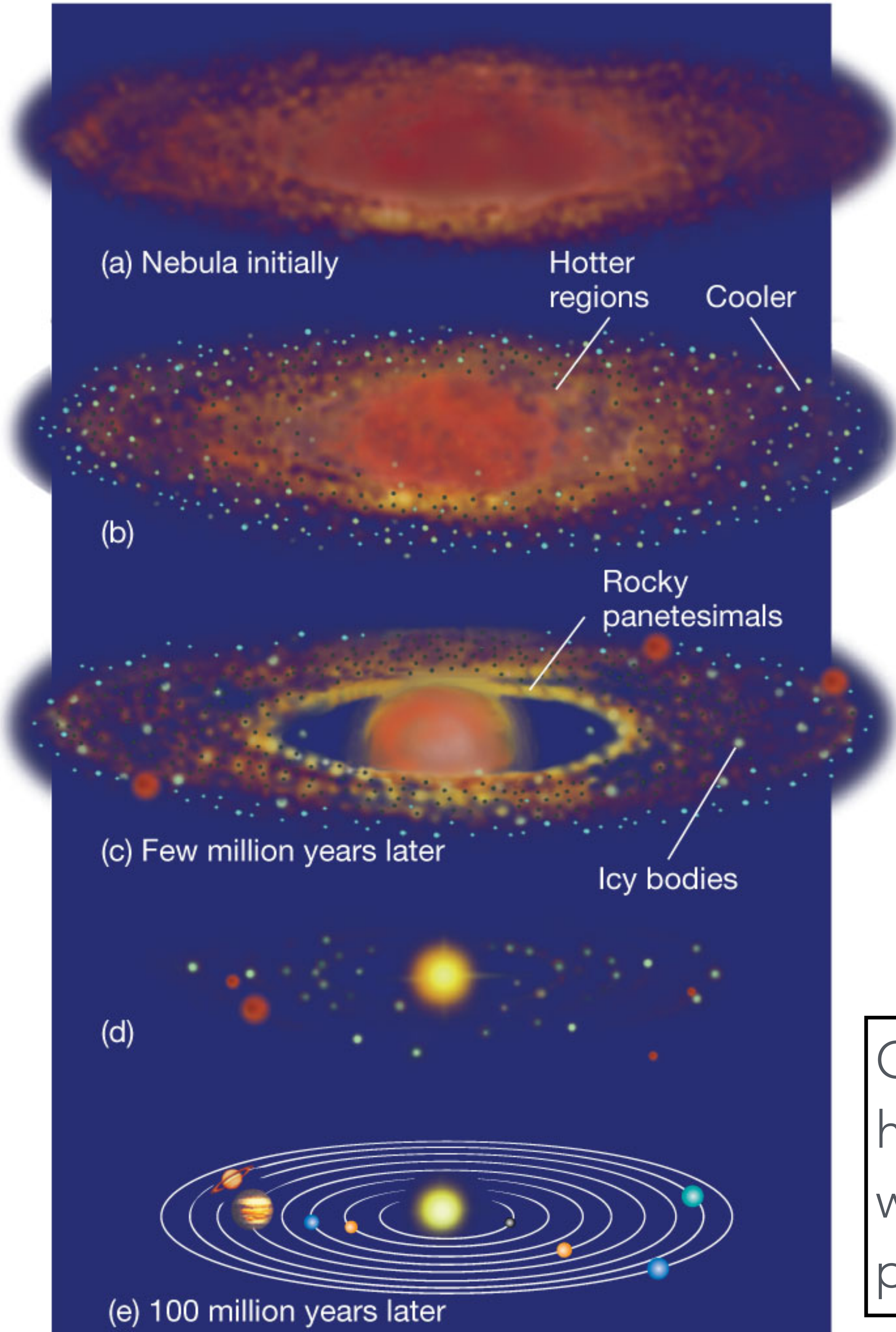
Examples:

1. Number of solar-type stars, out of a sample of N stars, with an Earth-like planet orbiting around them [or any kind of stars/planet combination],
2. Number of galaxies, out of a sample of N objects, that host an active galactic nucleus (AGN),
3. Number of galaxies, out of a sample of N objects, with a very bright background AGN within a certain distance,
4. Number of elliptical galaxies, out of a sample of N ellipticals, that magnify a background object.
5. …

Example of Binomial distribution:
Number of stars with an Earth-like planet



This is our solar system. Planets' sizes are roughly to scale, distances are not. Orbiting around the Sun, there are two main types of planets: rocky and Jovian planets. Earth is rocky planet.



We have a good understanding of how the solar system formed (Nebular Theory of solar system formation):

- start from a gaseous nebula
- contracts into a spinning disk hot at the center (conservation of energy and angular momentum)
- Sun form at the center. Planets form from an accretion onto the first solid planetesimals.
- Rocks/metals solidify at higher temperatures, so rocky planets form closer to the Sun.
- Formation halts when the Solar wind clears residual gas from the solar system.

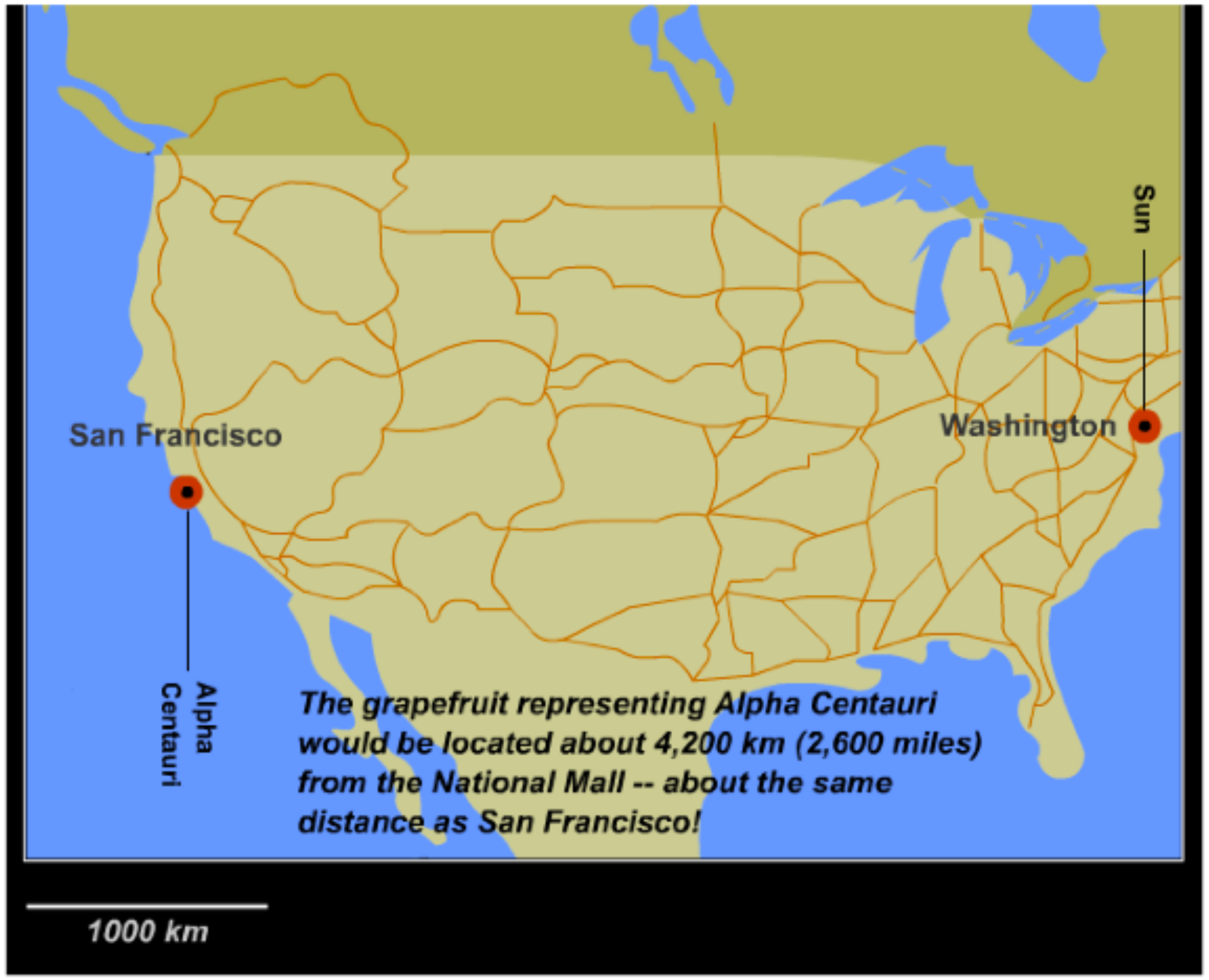
One of the questions that has fascinated humans since the beginning of time is whether or not there are other Earth-like planets that can host life.

Most stars should have planets orbiting around them, with the details of Rocky vs. Jovian planets likely depending on the details of the star we are considering.

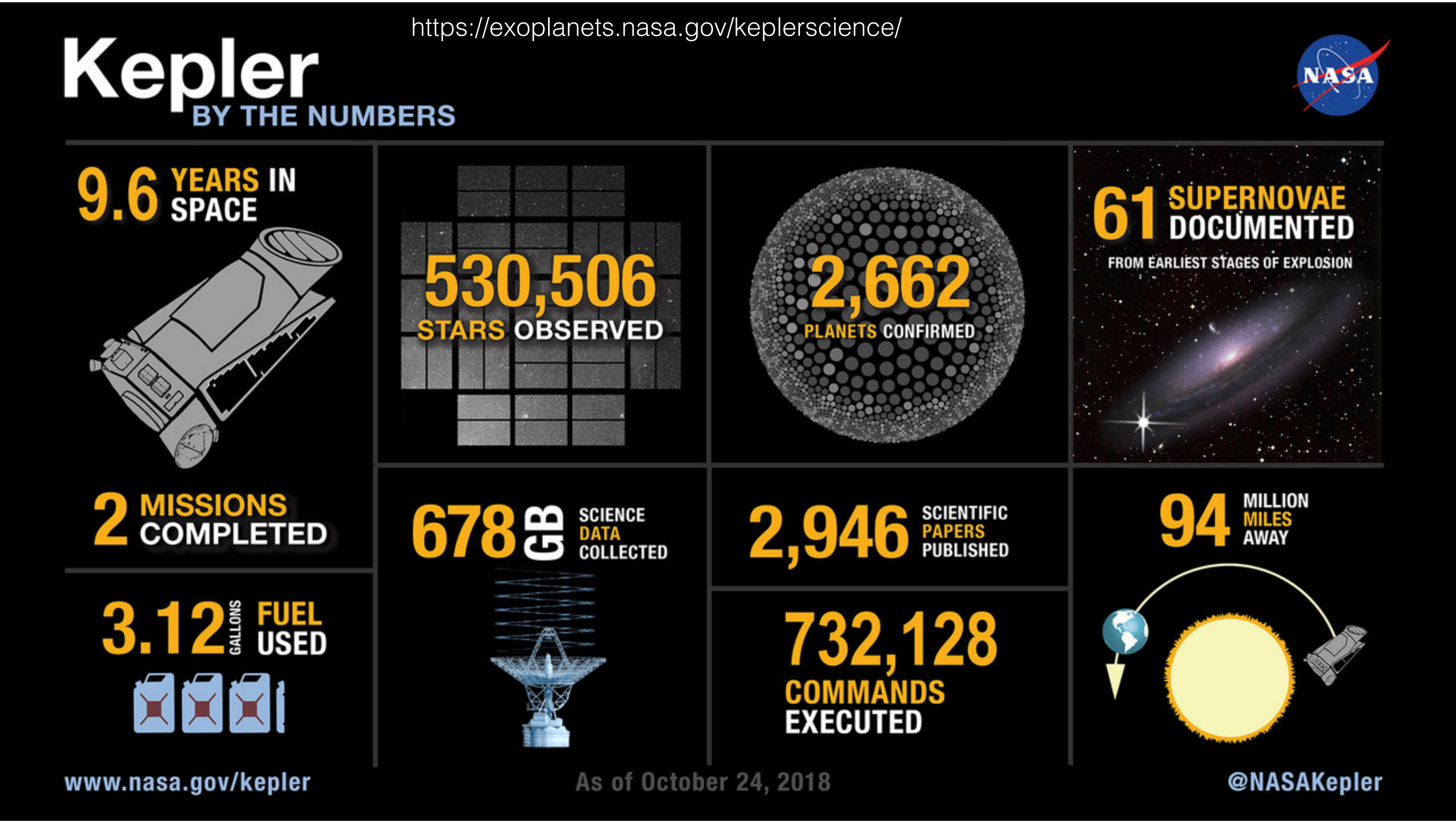
Detecting extrasolar planets is hard:

1. A Sun-like star is about a billion times brighter than the light reflected from its planets.

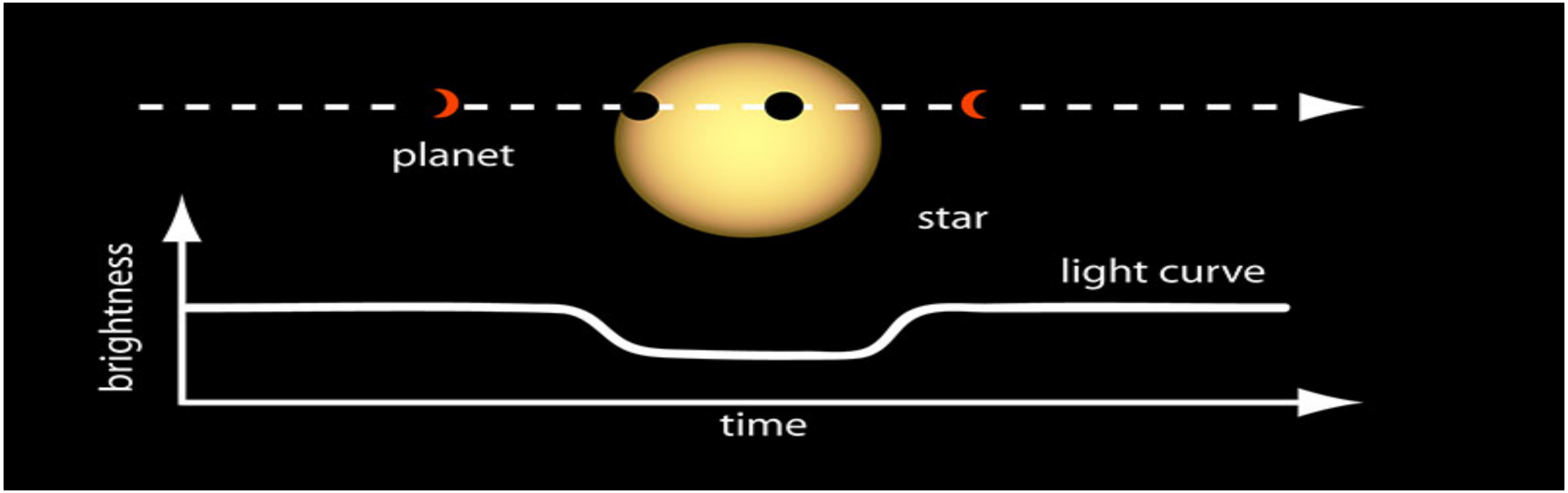
2. Planets are close to their stars, relative to the distance from us to the star.



Detecting extrasolar planets is like being in San Francisco and trying to see a dim pinhead 15 meters away from and in the glare of a very bright grapefruit in Washington, D.C.



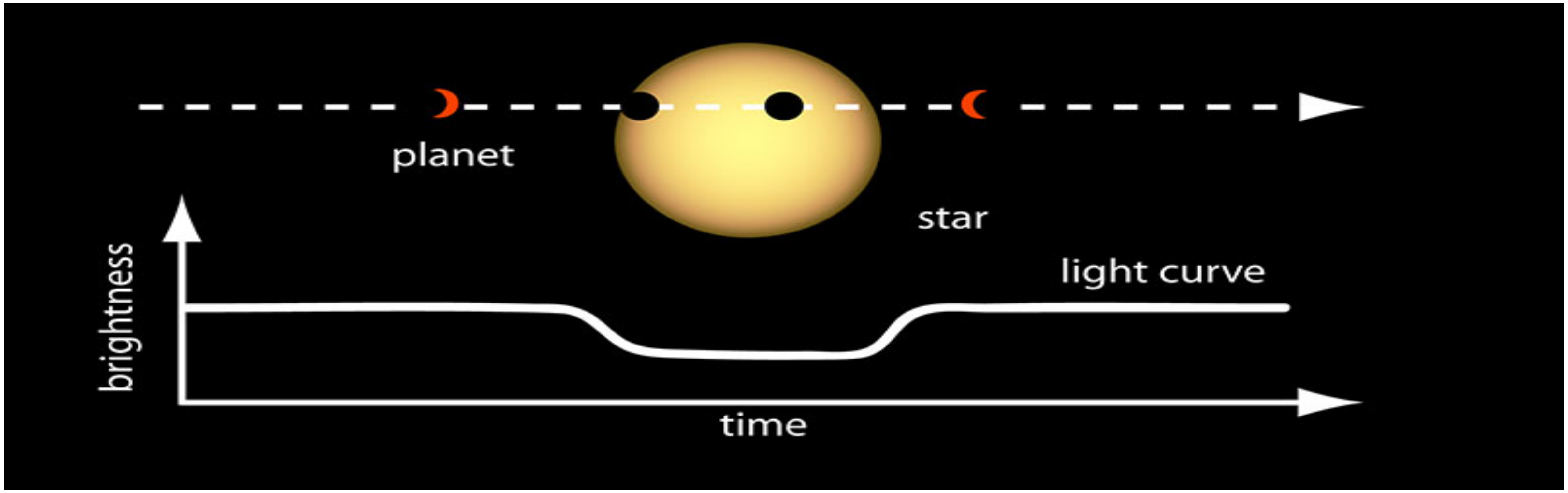
Kepler used transit technique to identify planets orbiting around stars. When seen by a distant observer the earth dims the Sun by ~100 parts per million, lasting 12h every 365d.



Astronomers have used Kepler data to count the number of Sun-like star being orbited by an Earth-like planet. These data were used to estimate ($\eta_\oplus$) the frequency of Earth-like planets around Sun-like stars.

Petigura et al. (2013) searched 42,557 Sun-like stars for Earth-like transits.

The total number of successes among the *N= 42,557* trials is a binomial random variable with parameters $\eta_\oplus$ and *N*, ($\eta_\oplus$ =is the probability that observing a Sun-like star returns an Earth-like planet — the number we don't know.)



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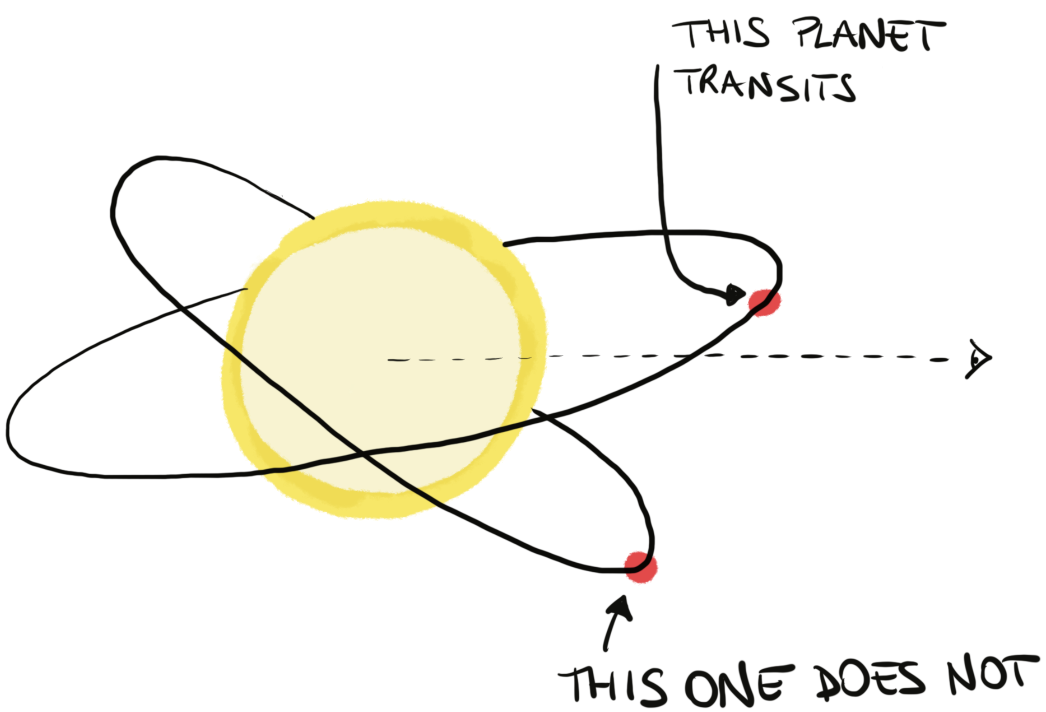
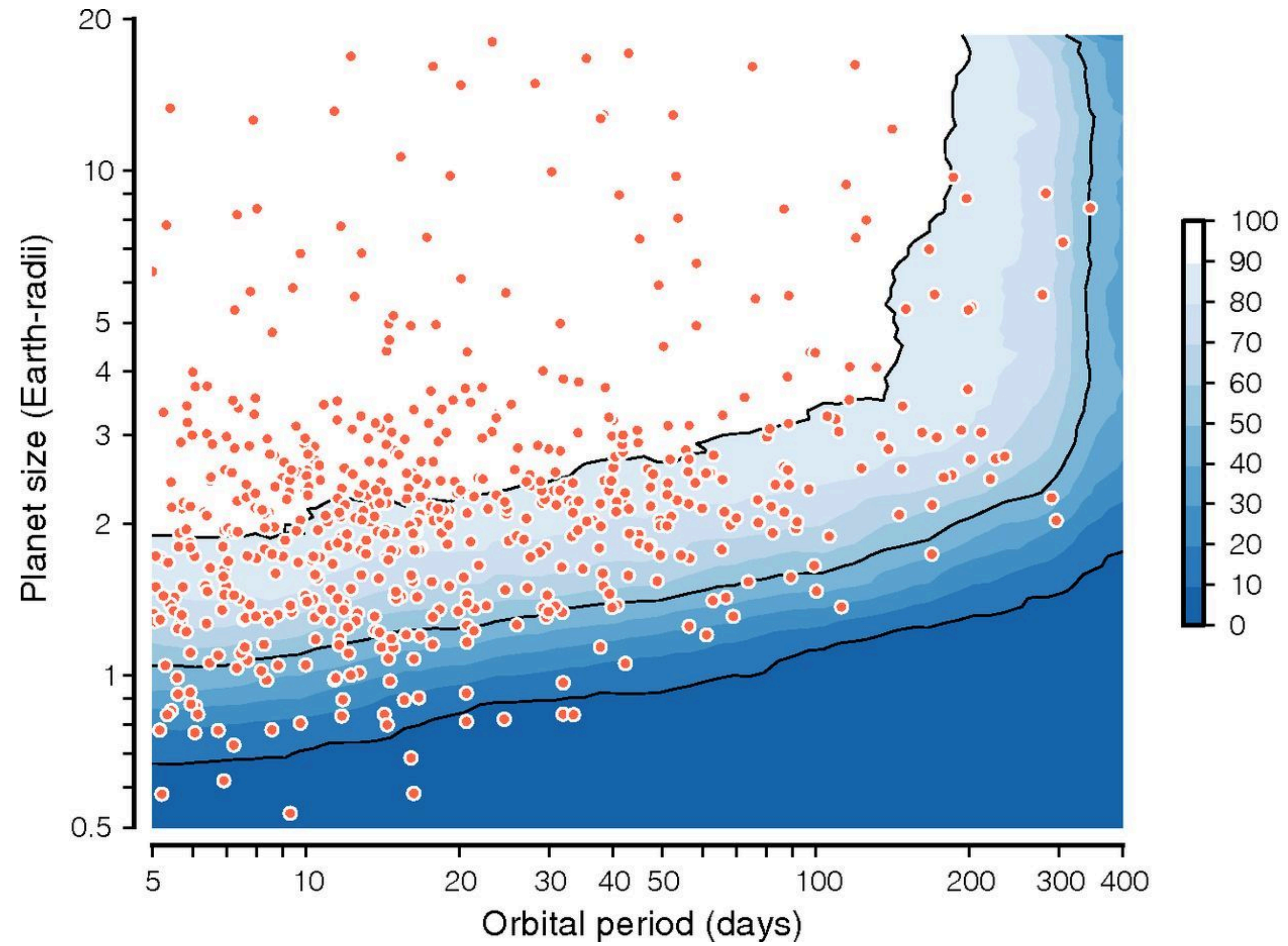
Petigura et al. (2013) identified a total of 10 Earth-like planets in the N= *42,557 Sun-like stars*, and estimated the frequency of potentially habitable Earths to be $\eta_{\oplus} = 22 \pm 8\%$.

Where does 22% come from? It's certainly not equal to 10/42500!

Two corrections need to be applied to the counted planets:

- geometric correction
- detection correction





These corrections are estimated with simulations of the datasets.

If the probability that a Sun like star has an Earth-like planet is $\eta_\oplus$ — then the probability that an observation of that star returns a Earth-like planet will be

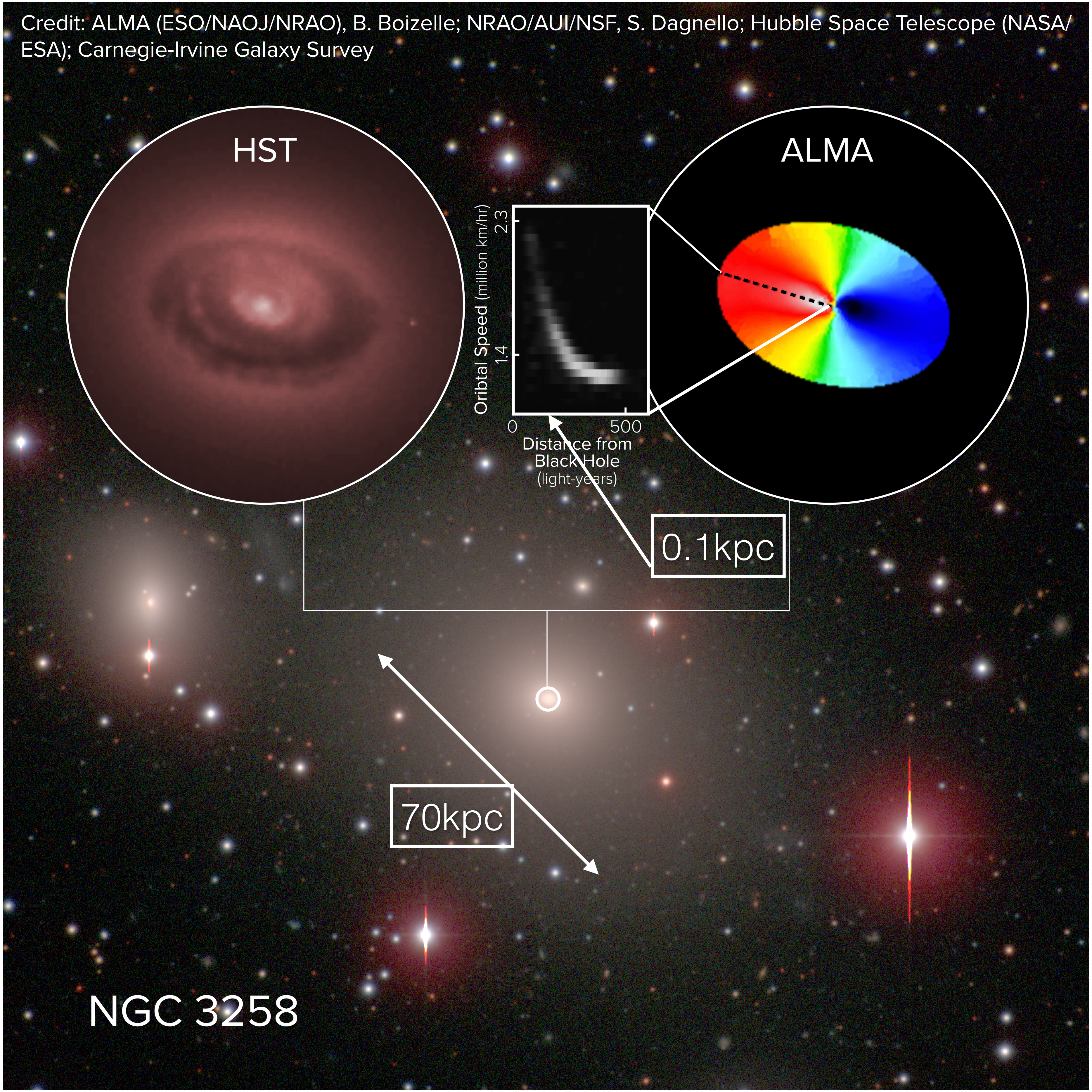
$$\theta = \eta_\oplus P_T P_D$$

Where P_T and P_D are the probability of transit (geometric correction) and the detection probability (detection correction).

Example of Binomial distribution:
Number of galaxies hosting an active nucleus

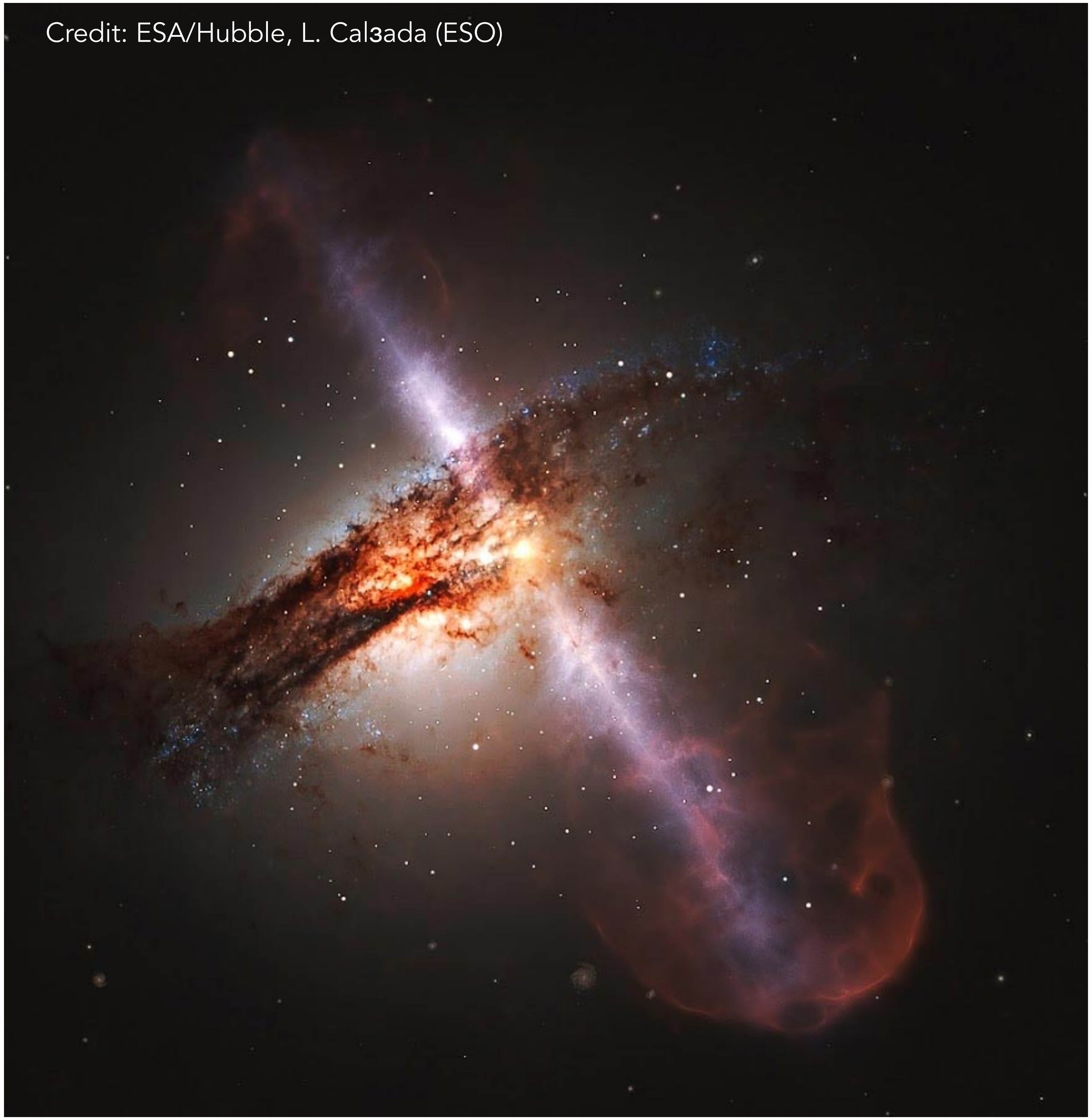
Super Massive Black Holes are black holes with $>10^9 M_{sun}$ and are found in the center of "all" massive galaxies. These are huge monsters, whose presence can only be inferred indirectly (i.e., light does not escape a BH, so we cannot "see them").

We can identify them either in very nearby galaxies, where we can see their gravitational sphere of influence, or when they are in an active accretion phase.



0.1kpc or ~700 times smaller than the galaxy

The velocity of the gas in the center tells us that there must be a mass $\sim 10^9 M_{sun}$ in a very small area. Only a BH can have that density, When gas is falling on the BH, then we can see it. In this phase we say the galaxy is active and we call it an Active Galactic Nucleus.



A powerful AGN can produce more energy than its entire host galaxy.
AGN are so bright because of the release of gravitational potential energy: **inflowing gas forms an accretion disk around a black hole, that** heats up and starts emitting light.

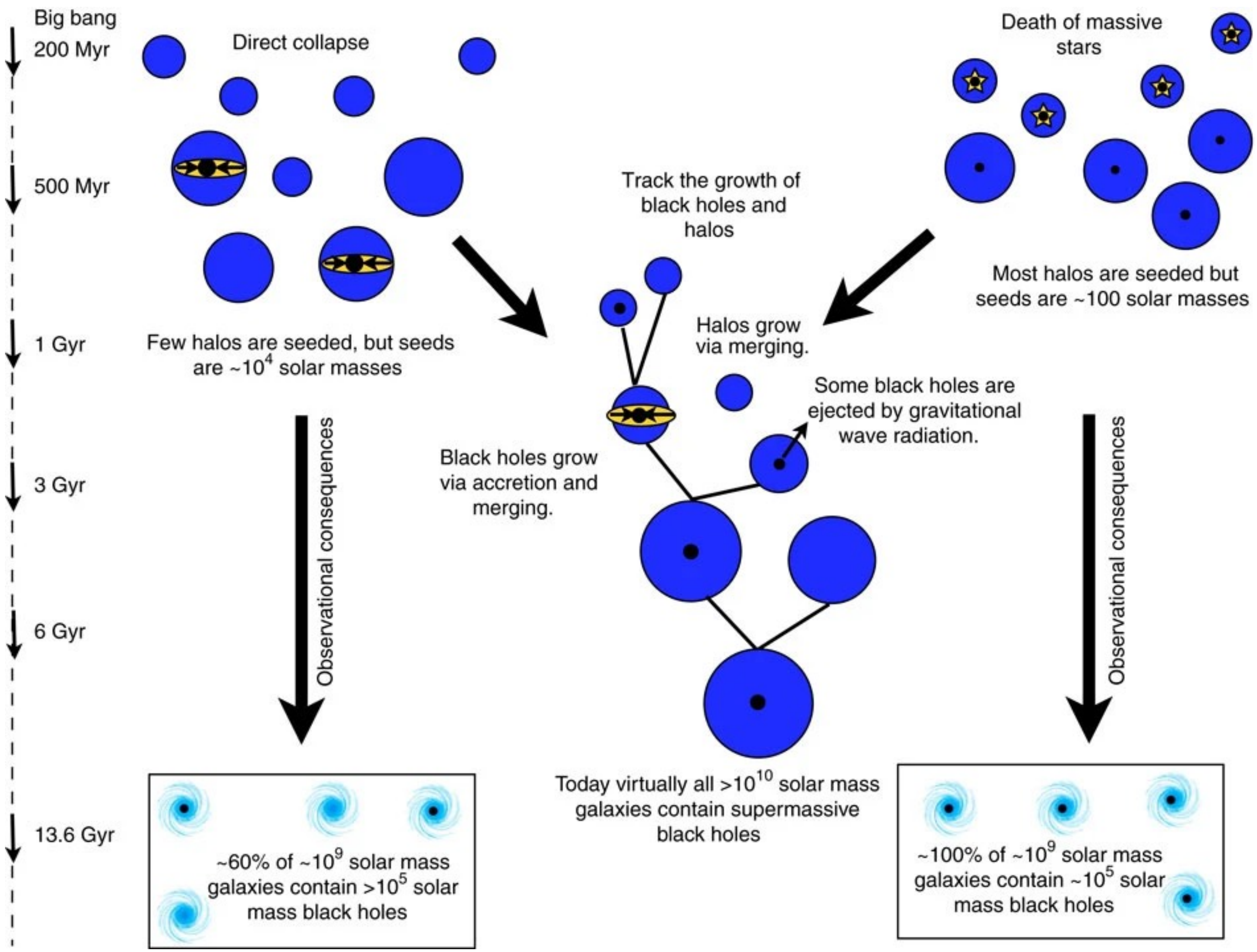
The brightest AGN are also called QSO (for historical reasons — they looked like stars)

The problem :
is there enough time to form the monsters we see?

We observe SMBHs in the very distant* Universe, when the Universe was only a few hundred million years old.
This is a problem — a BH needs time to grow, and there is an upper limit on how fast a BH can grow by accretion.

Two theories have been proposed to explain these distant SMBHs. They make different predictions on the probability that a low mass (small) galaxy hosts a SMBH.

*the further a galaxy the younger the Universe seed black holes



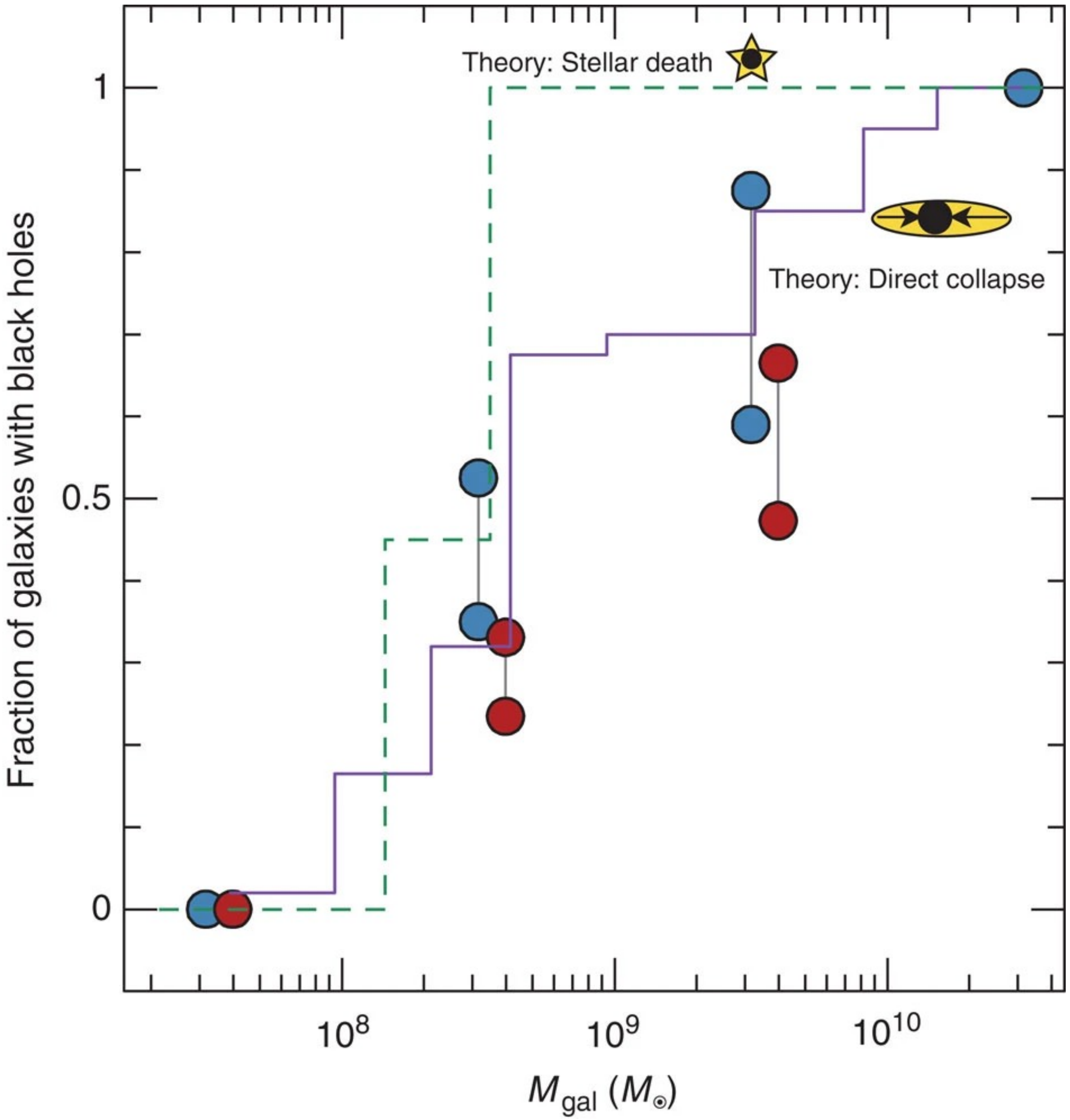
Two different formation mechanisms:

- the death of the first generation of massive stars
- the direct collapse of gas into a black hole.

Black holes grow both via merging and by accreting gas.

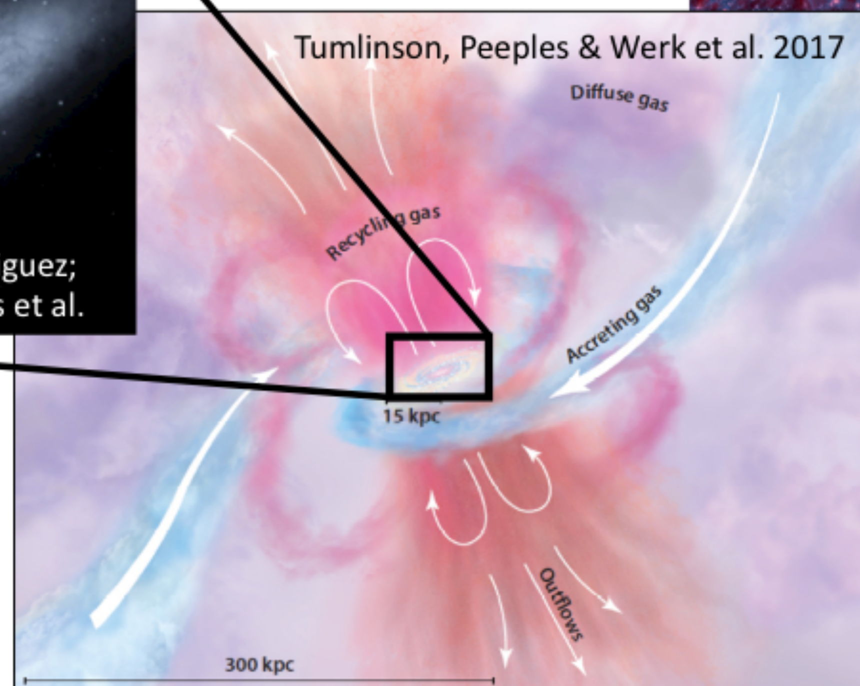
We can distinguish between the two scenarios based on the fraction of small galaxies that contain massive black holes.

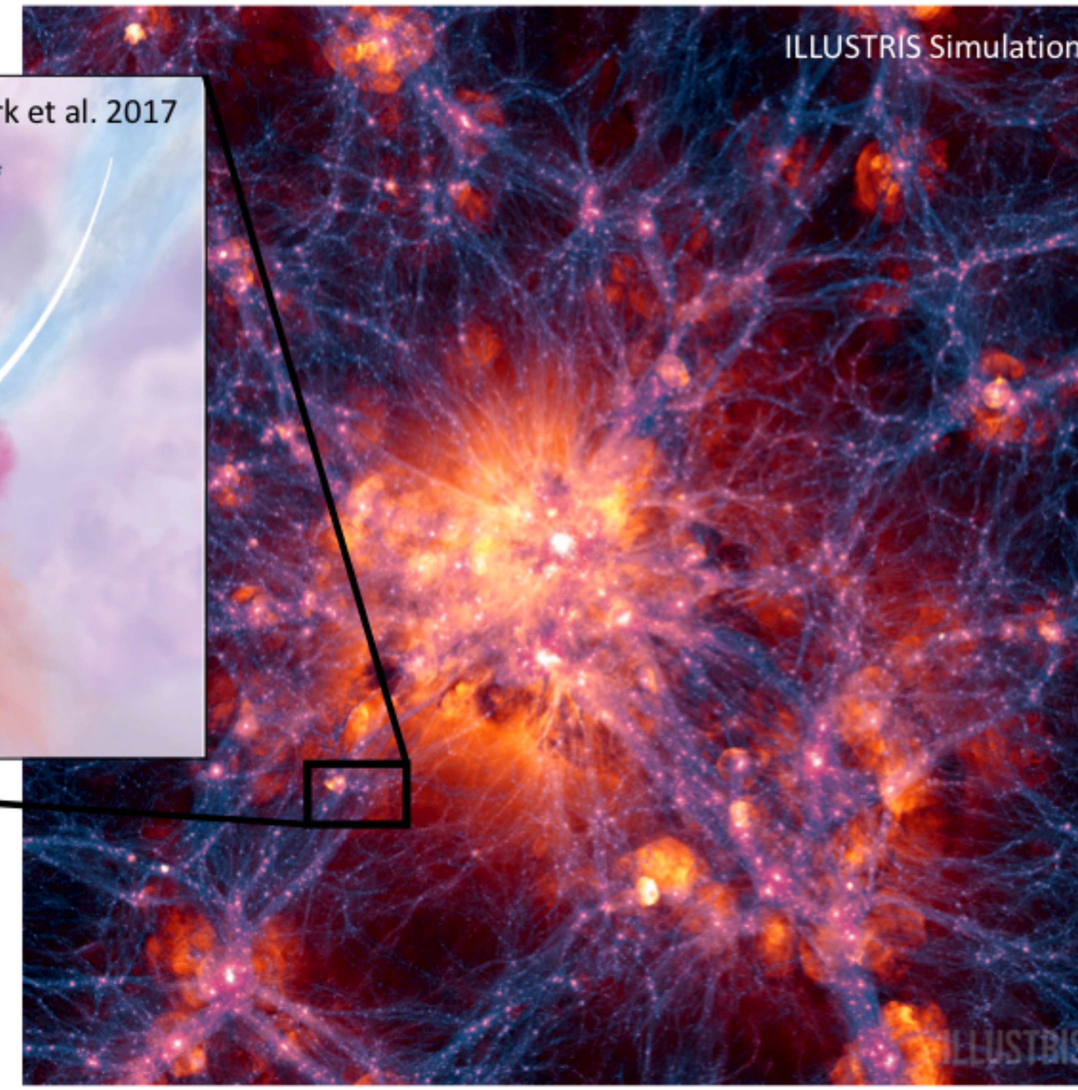
The total number of dwarf galaxies that host a BH at their center among a sample of *N* objects is a binomial random variable with parameters η and *N*.



Expected fraction of galaxies with $M_{gal} \lesssim 10^{10}$ $M_\odot$ that contain black holes with $M_{BH} \gtrsim 3 \times 10^5$ $M_\odot$, for high efficiency massive seed formation (solid purple line), as well as stellar deaths (green dashed line).
Data from literature: large circles show the fraction of galaxies containing black holes greater than 10^6 $M_\odot$ (lower points) and greater than 3×10^5 $M_\odot$ (higher points) based on Desroches *et al.* (blue) and Gallo *et al.* (red).

Example of Binomial distribution: Number of galaxies with a background bright AGN





ISM = Interstellar Medium, **CGM** = Circum galactic Medium, **IGM** = Inter-galactic Medium, **SMBH** = Super Massive Black Hole

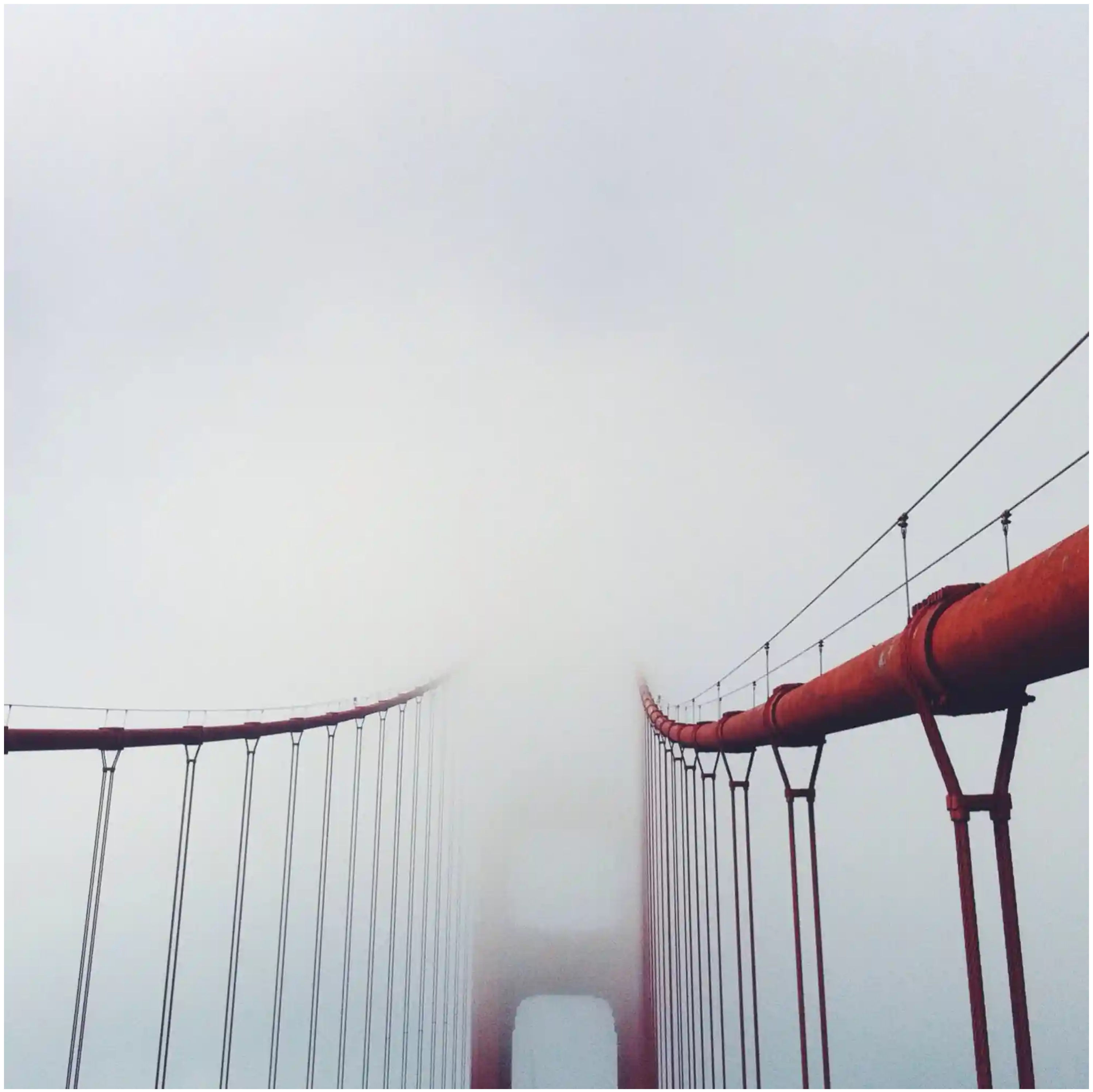
Quiescent ISM
- Star formation
- SMBH accretion

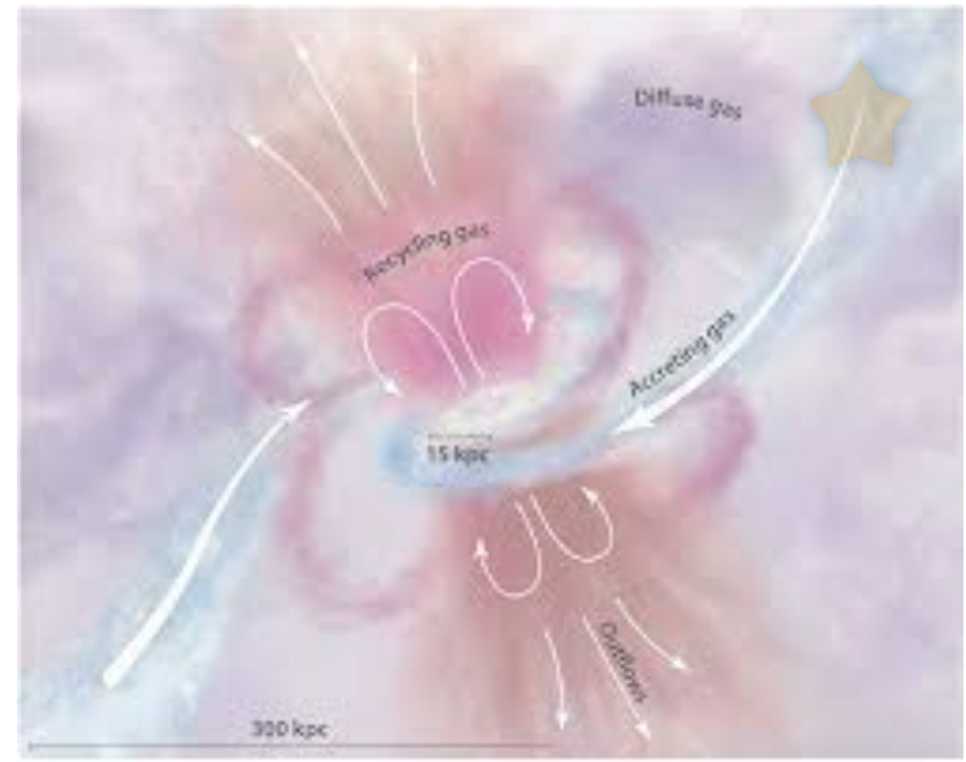
Outflowing ISM
- Links ISM to larger-scale environment
- Feeds the CGM: role in both feedback and feeding processes

The interplay between the reservoir of gas around galaxies and the galaxies themself is a fundamental process for galaxy growth but it's quite difficult to study.

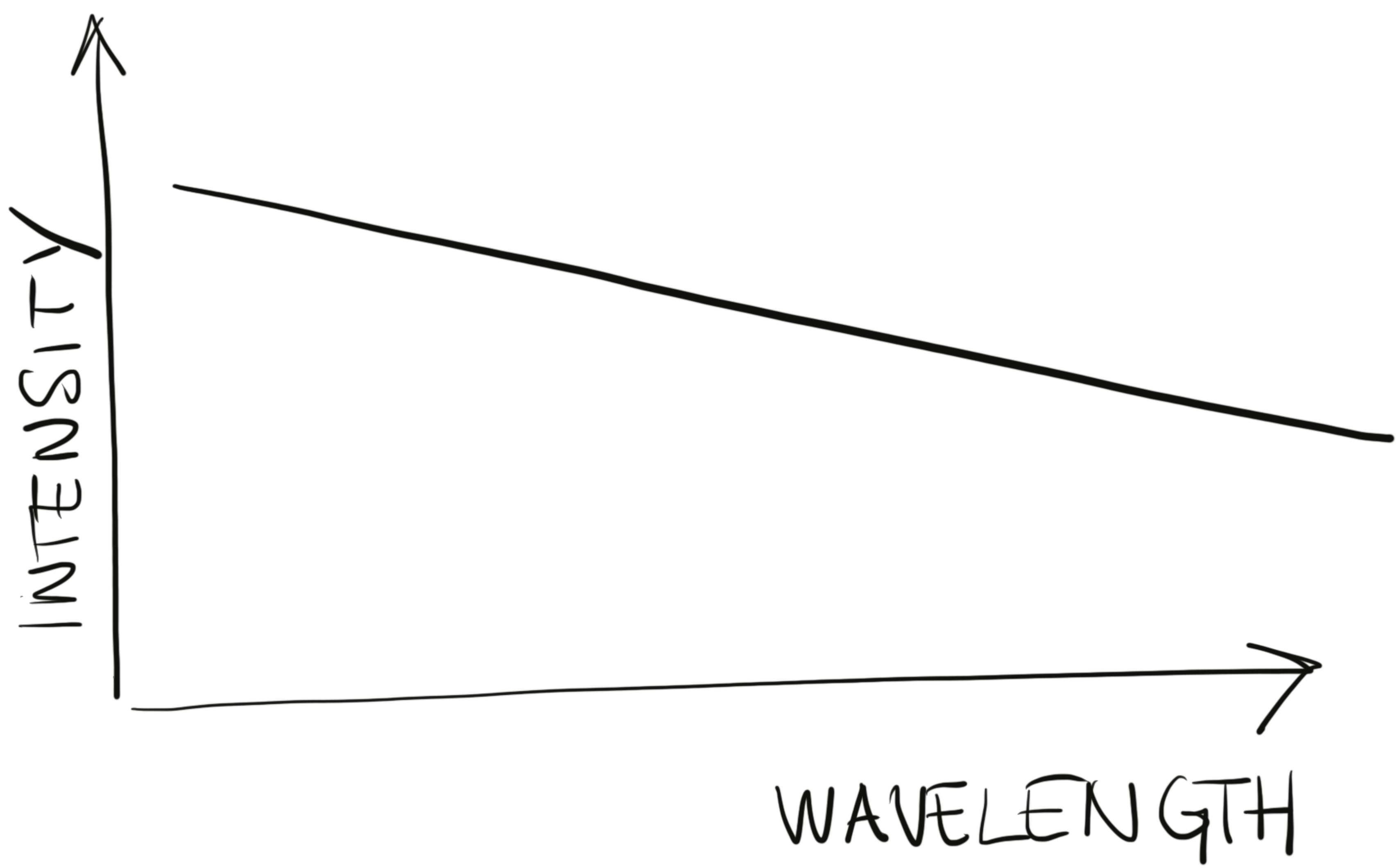
This gas is very diffuse and emits very few photons (i.e., is faint!).

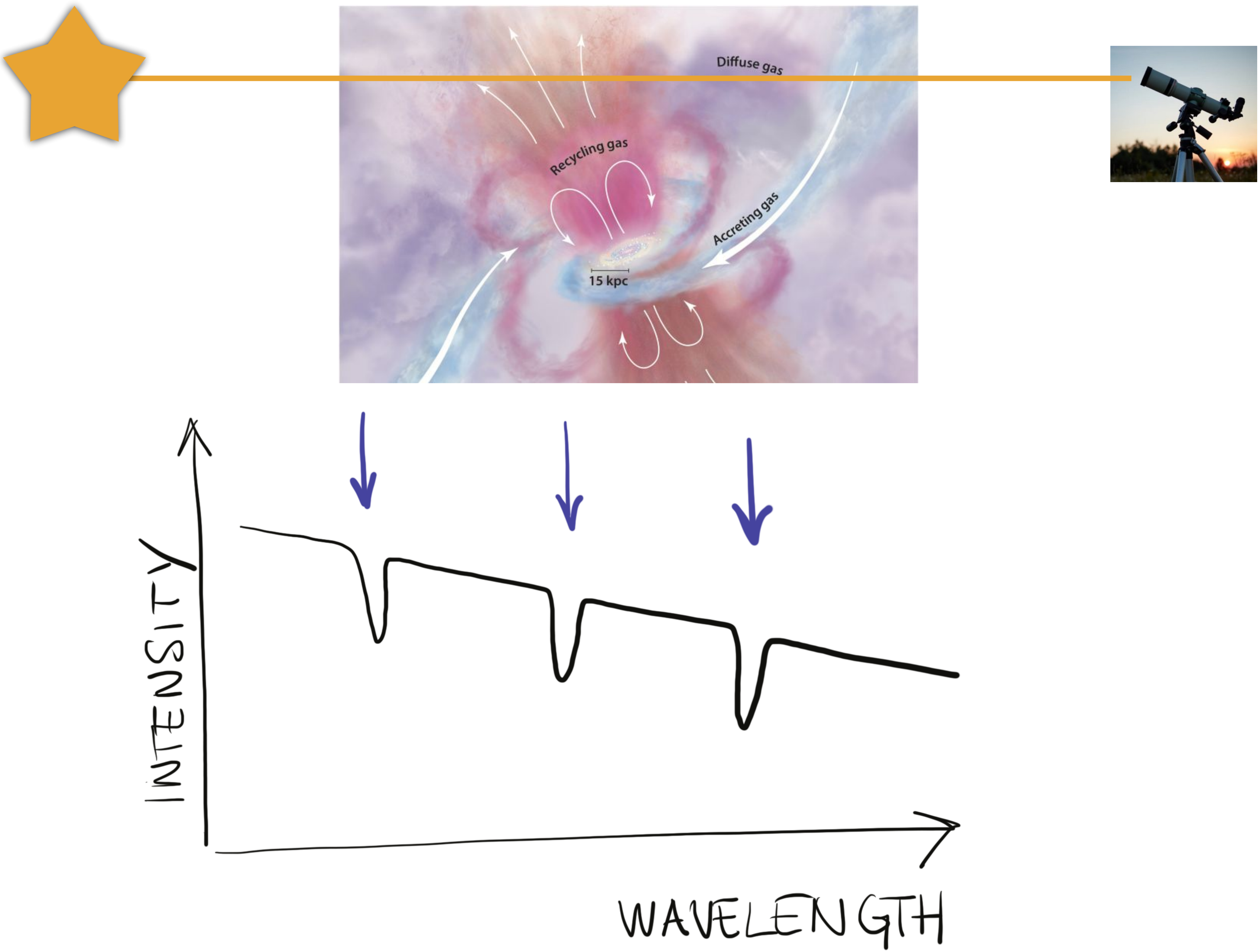
Even though we cannot see this gas directly, we can still see its effect on background sources.





Astronomers are interested in the interested in how common galaxy with background sources are.
The number of galaxies, out of a sample of N objects, with a bright background QSO (within a certain distance) is a **binomial random variable**


INTENSITY
WAVELENGTH


Diffuse gas
Recycling gas
Accreting gas
15 kpc
INTENSITY
WAVELENGTH