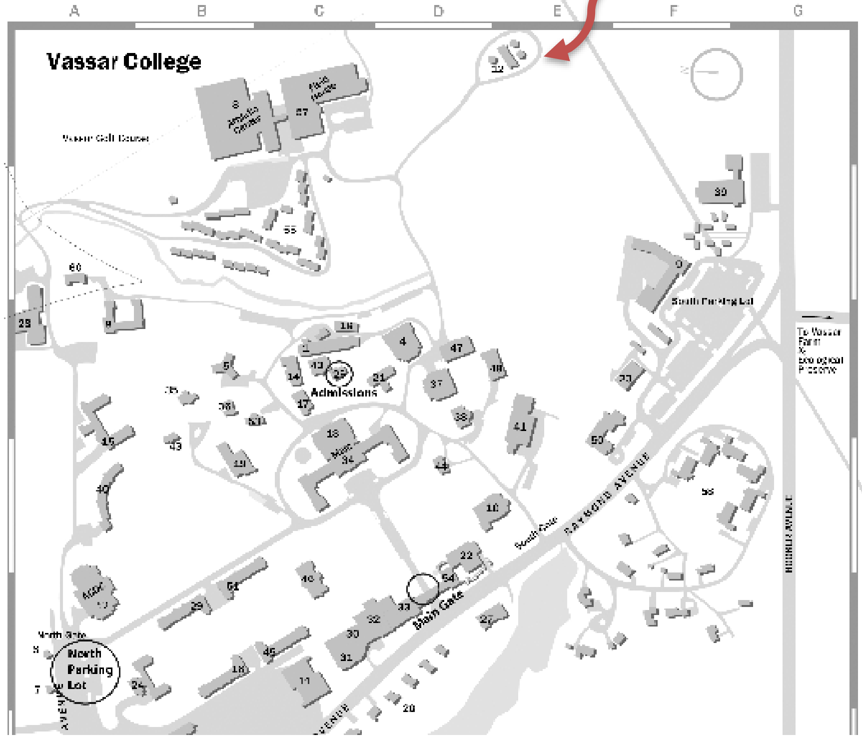
Visit to the Vassar College Observatory

Class of '51
Observatory



The Class of 1951 Observatory is open to our class and other visitors

This Wednesday Nov 13 at 9 PM, weather permitting.

If it is clear, I will be there at 9, but I will depend on the student interns to run the observing session.

Park on the side of the road at the observatory.
This is a public open night, so all are welcome.
However, I have alerted the students that our class has priority at the beginning of the session.

In general, the observatory is open to the public every Wednesday 9-11 pm when classes are in session.

Astronomy Update

Recent advances and research priorities

Lectures for the
Lifelong Learning Institute
Fall 2024
Session 3

Fred Chromey

Professor Emeritus of Astronomy and
Former Director, Vassar College Observatory

Prospectus: Astronomy Update

Introduction: Sources of astronomical news

Part 1. Solar system news

Part 2. Exoplanetary frontiers

Part 3. Mapping galaxies, making galaxies.

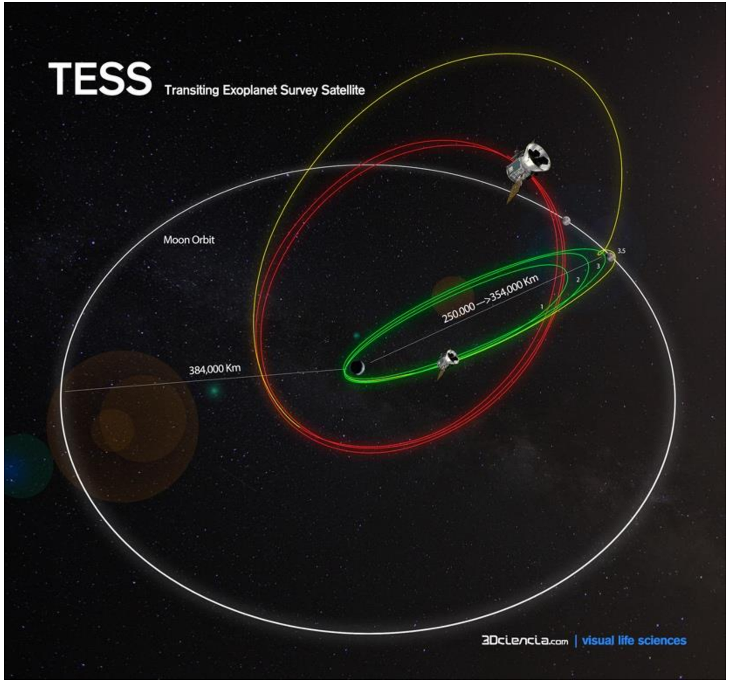
Part 4. The universe and the biggest questions

TESS

(Transiting Exoplanet Survey Satellite)

Observations began 25 July 2018,

Extended mission 2020-2025



TESS

Strategy:

Four small telescopes —>
Wide Field (24° x 96°) —> 200,000 Bright stars – complete sky coverage

Bright stars —> Easy follow-up by ground-based telescopes and JWST
Bright stars —> Nearby stars
Nearby stars—> Red/Orange dwarves —> many planets
data stream —> 251 terabytes (=streaming 167,000 movies in full HD)

Detections:

Currently: 7341 candidates (October 30, 2024)
568 confirmed planets

Predicted: around 12,000 confirmed planets
20 "Earths" in habitable zone

Other TESS results:

Three Earth-sized planets in their star’s habitable zone

Hundreds of supernovae and thousands of other candidate short-lived events.

Star about to explode (nova)

Delta Scuti stars spin so rapidly they flatten into ovals, which jumbles pulsation signals and makes them harder to decode.

One stable Six-star system

Star being torn apart by a supermassive black hole

Exoplanet current topics:

Extreme Exoplanets:
Hot Jupiters (planet migration only explanation?)
Hot Earths (Lava worlds, sand rain)
Ice Worlds (Like Europa, but bigger)
Water Worlds
Popcorn planets

Flares from red dwarf stars: they tend to be polar, also weaker than expected (lower chance of atmospheric stripping)

Composition of exoplanet atmospheres – are there biomarkers, technomarkers?

Recent exoplanet results

Brown Dwarf revisited mass – Gliese 229 B has a companion

JWST confirms stellar winds in four protoplanetary disks

A planet around Barnards Star, the closest single star to the Sun — and there are probably more worlds in this system. The find settles years of controversy.

New analysis reveals evidence of a super-Earth-mass exoplanet forming in the disk surrounding the star TW Hydrae.

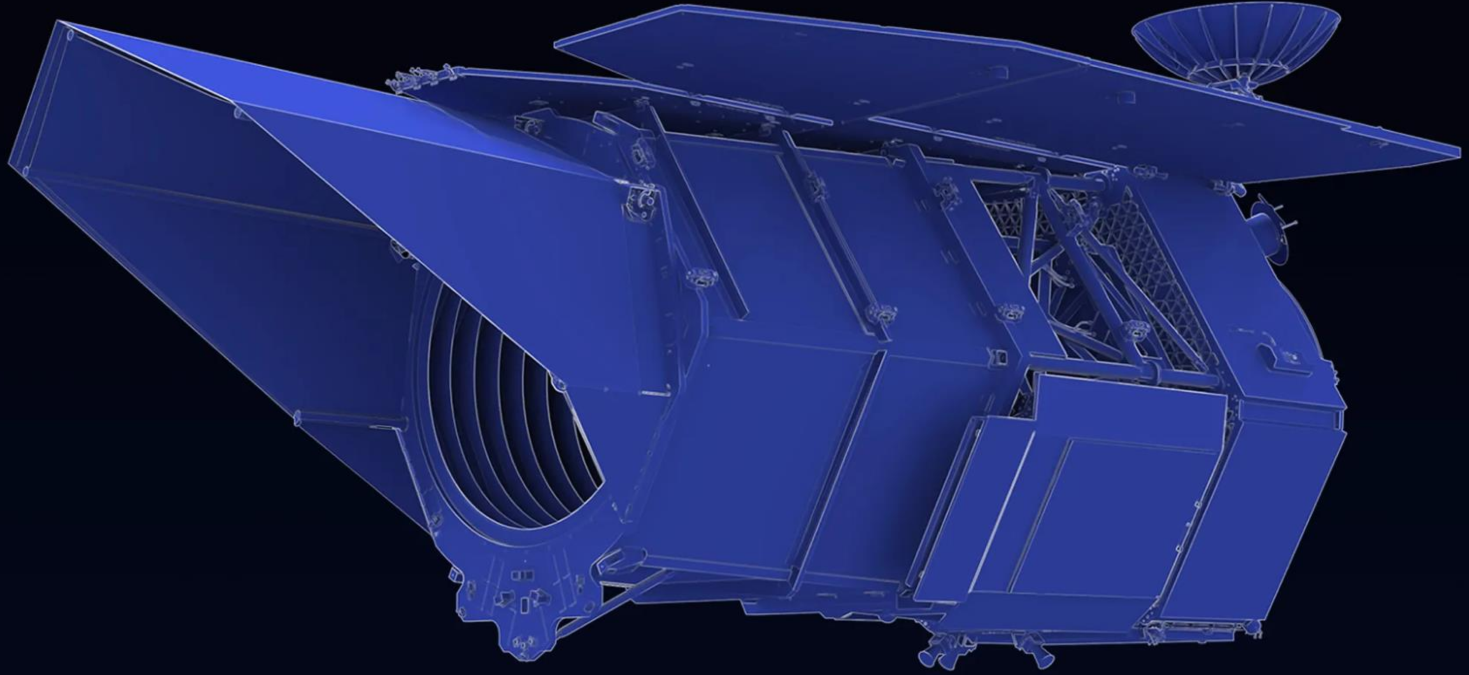
New James Webb Space Telescope observations of LHS 1140b hint at a temperate water world with a nitrogen-rich atmosphere.

Gliese 12b orbits a cool red dwarf star around 40 light-years away — a period of 12.8 days.
that its surface might be temperate (107°F = 42°C) enough for life.

AI assisted search for Dyson spheres in data for 5 million stars

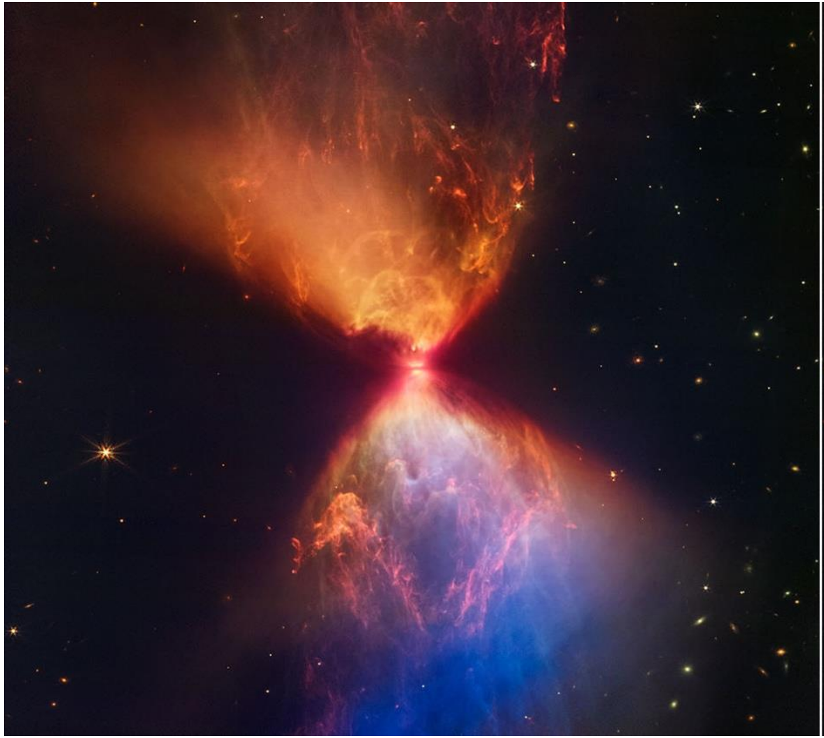
Nancy Roman Space Telescope

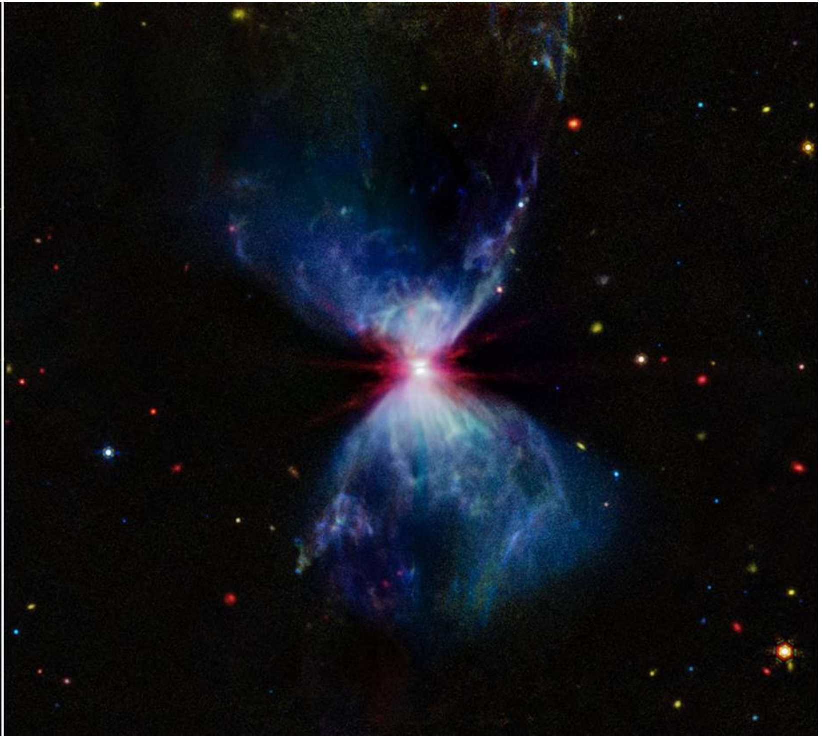
–follow up observations of known exoplanets



Protoplanetary Disks

Star formation and planet formation occur simultaneously -



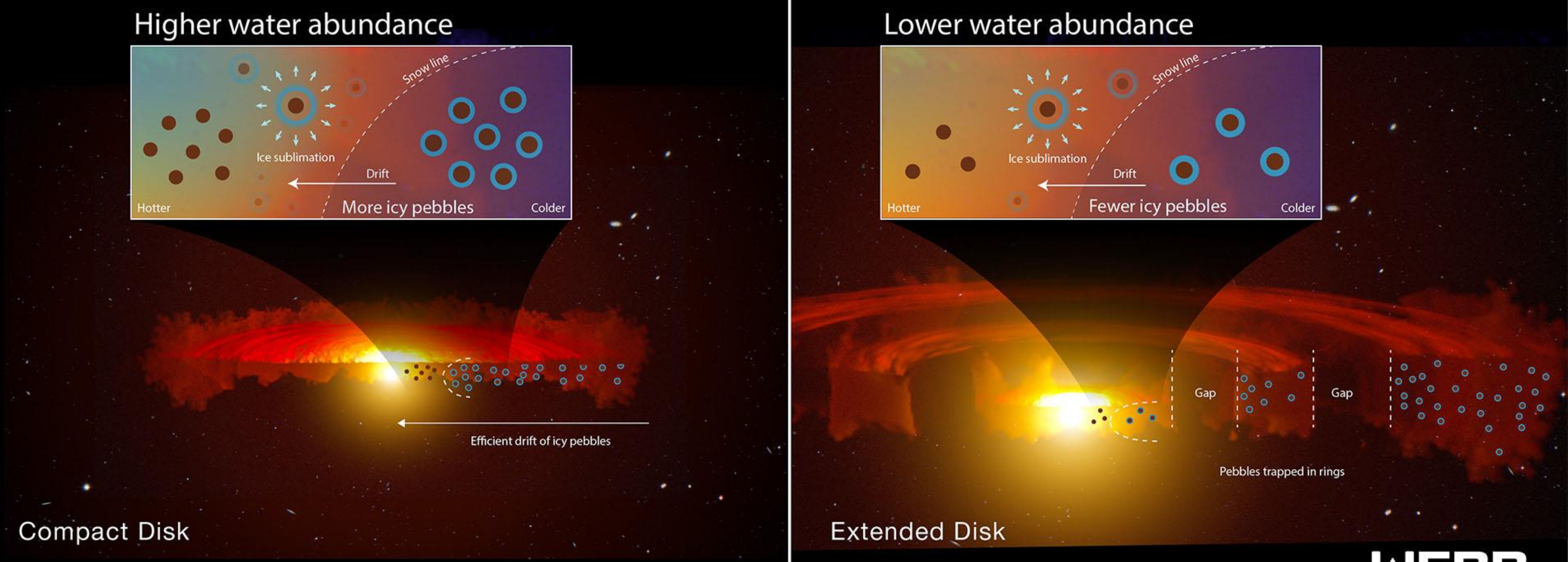


ALMA Image of evolving disk HL Tau

PROTOPLANETARY DISKS

ICY PEBBLE DRIFT

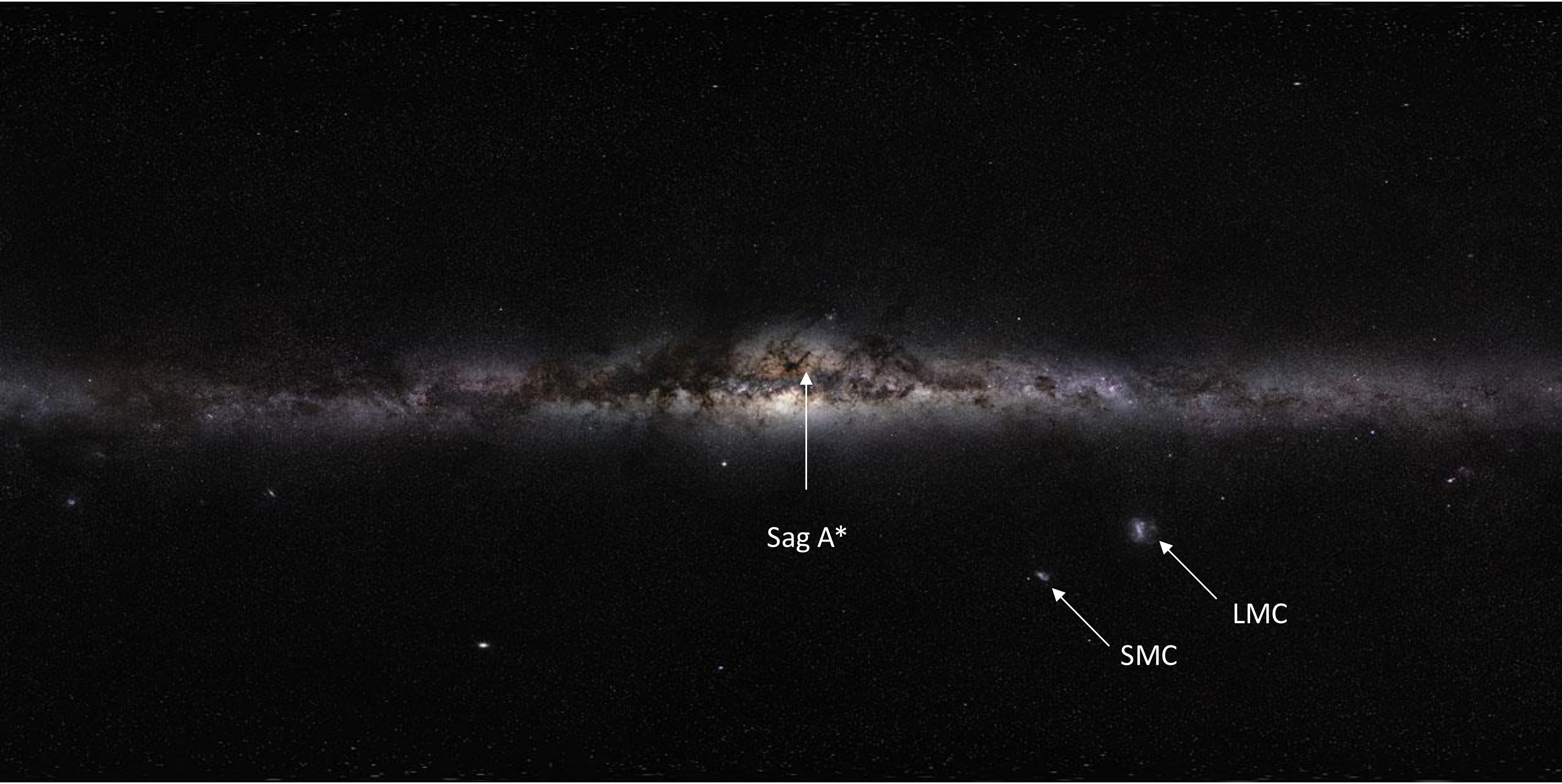
MIRI | Medium Resolution Spectroscopy

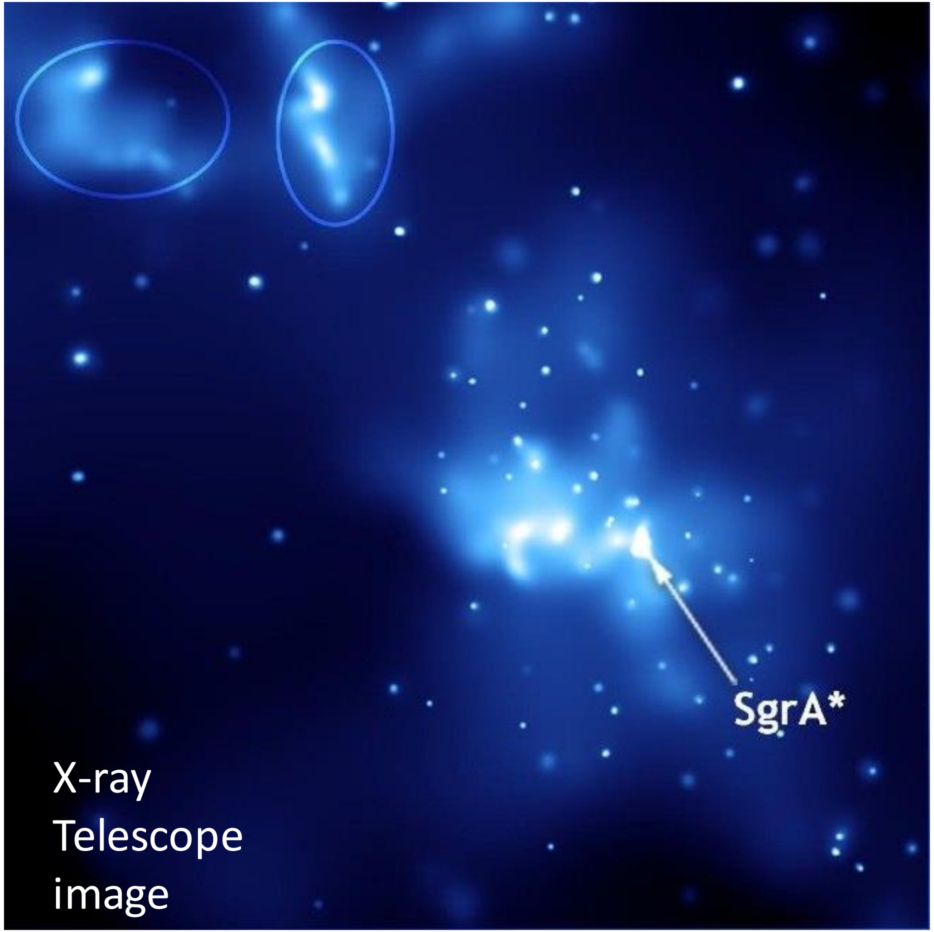


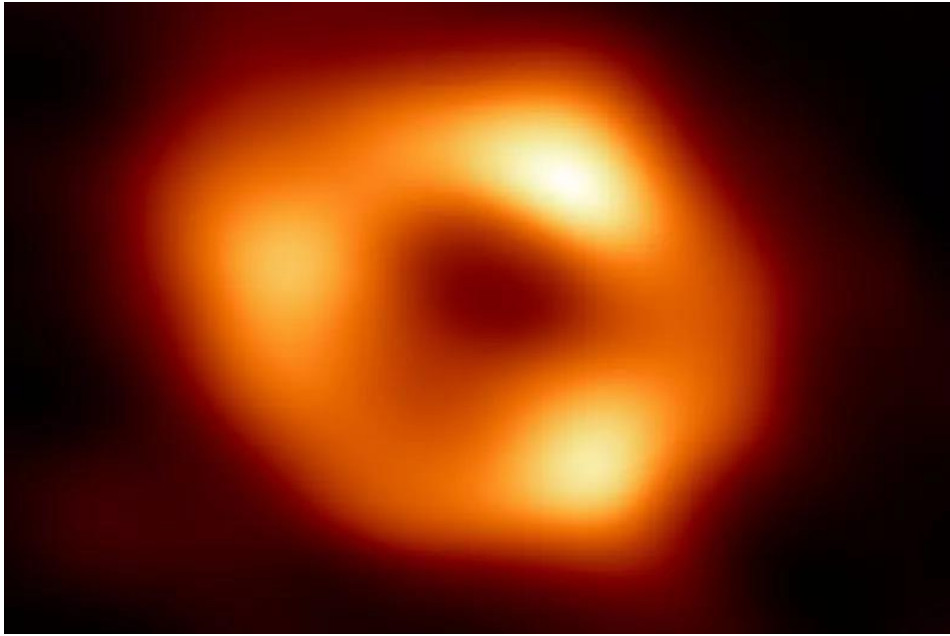
WEBB SPACE TELESCOPE

Mapping Galaxies, Making Galaxies

The Milky Way Galaxy


Sag A*
LMC
SMC





Supermassive (4 million solar masses)
Black Hole at Sgr A*

Image by the Event Horizon Radio Telescope shows emission from infalling gas in accretion disk of BH

How big is it?
What does it look like from outside?
Where are we in it?

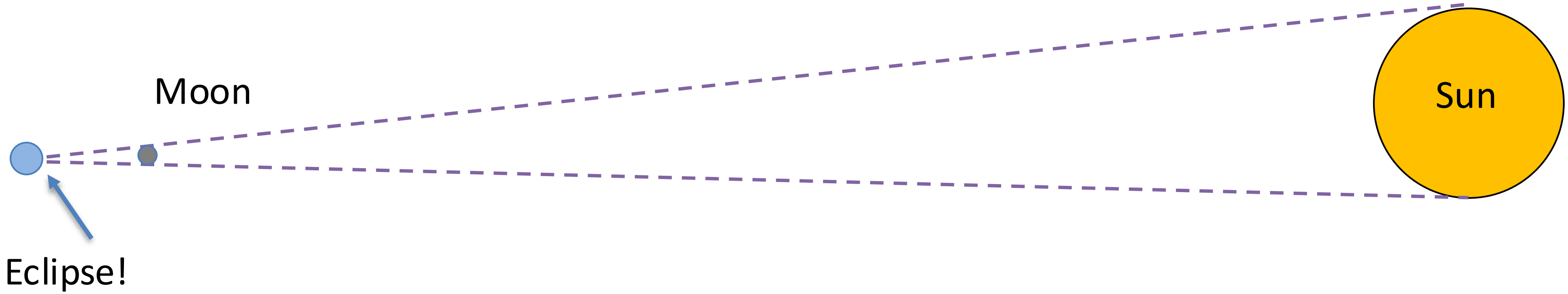
Astronomy's fundamental mapping problem:

Easy to measure a 2-D image

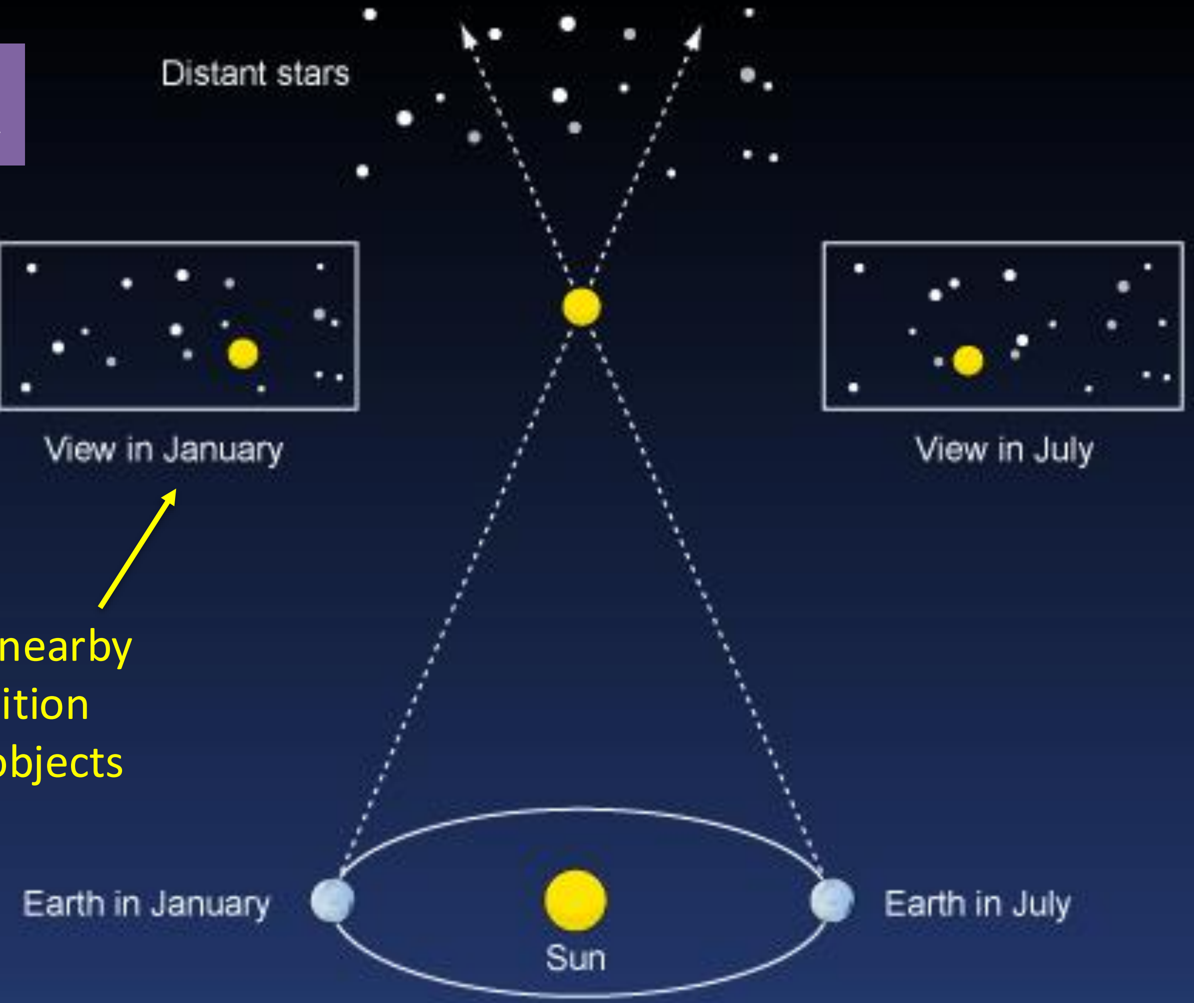
No obvious way to way to measure the third dimension

For example, Sun and Moon are the same
ANGULAR size (0.5° = 30 arcmin = 1800 arcsec)

But we now know the sun is 60 times further away



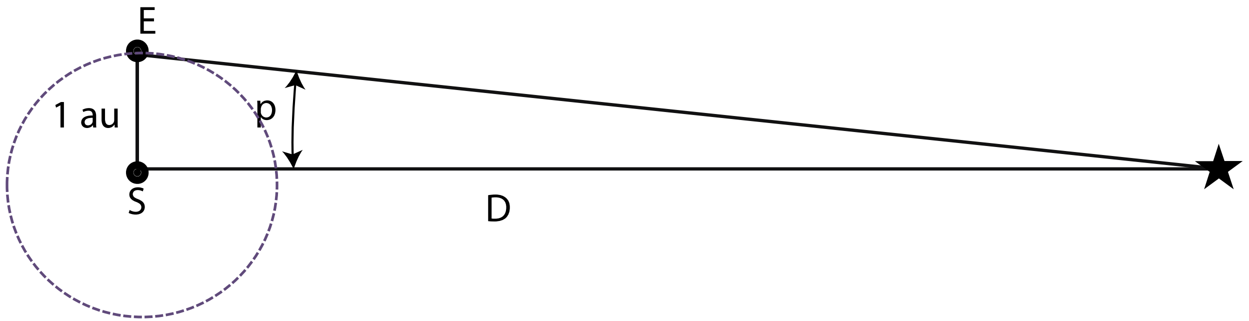
Stellar Parallax



As Earth orbits the sun, nearby star appears to shift position relative to background objects

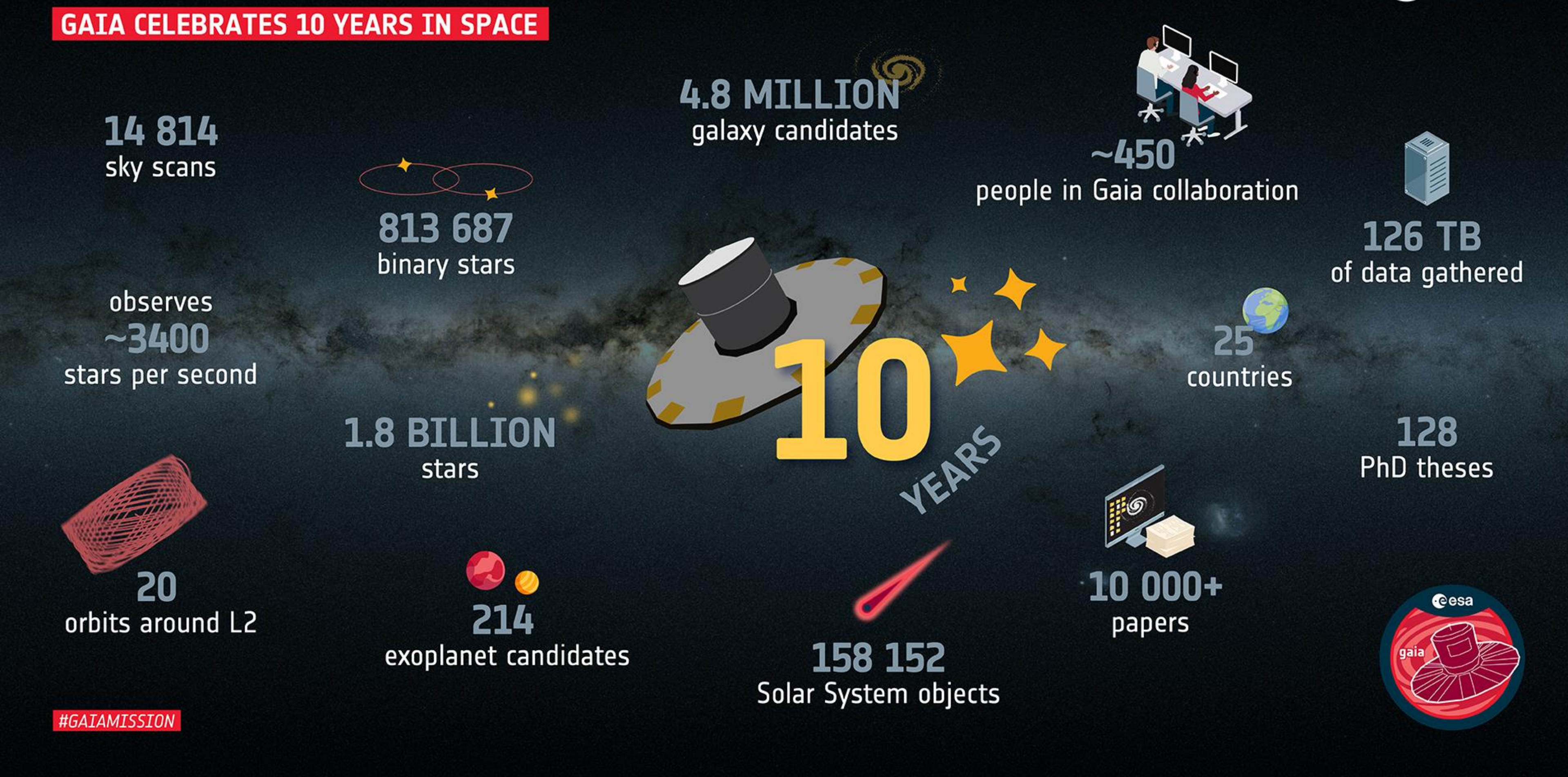
1 parsec = 206,265 au

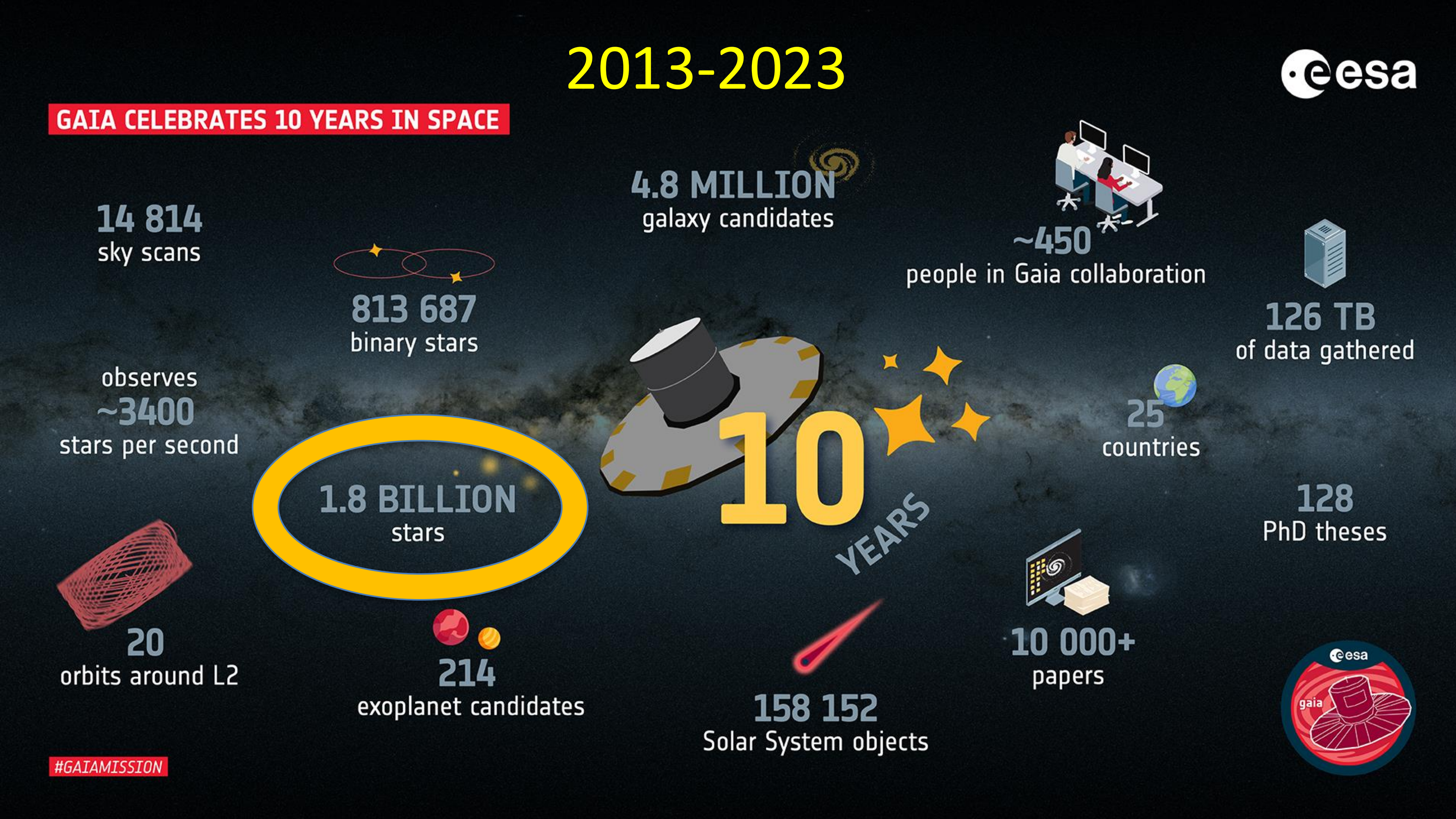
$$D[\text{parsecs}] = \frac{1}{p[\text{arcsec}]}$$



Prior to space-based telescopes, precise distances from parallax were limited to stars within 20 parsecs (parallax >.05 arcsec = 50 milliarcsec = 50,000 microarcsec), about 1000 stars

2013-2023


esa
GAIA CELEBRATES 10 YEARS IN SPACE
4.8 MILLION
galaxy candidates
14 814
sky scans
813 687
binary stars
~450
people in Gaia collaboration
126 TB
of data gathered
observes
~3400
stars per second
10
YEARS
25
countries
1.8 BILLION
stars
128
PhD theses
20
orbits around L2
214
exoplanet candidates
158 152
Solar System objects
10 000+
papers
esa
gaia
#GAIAMISSION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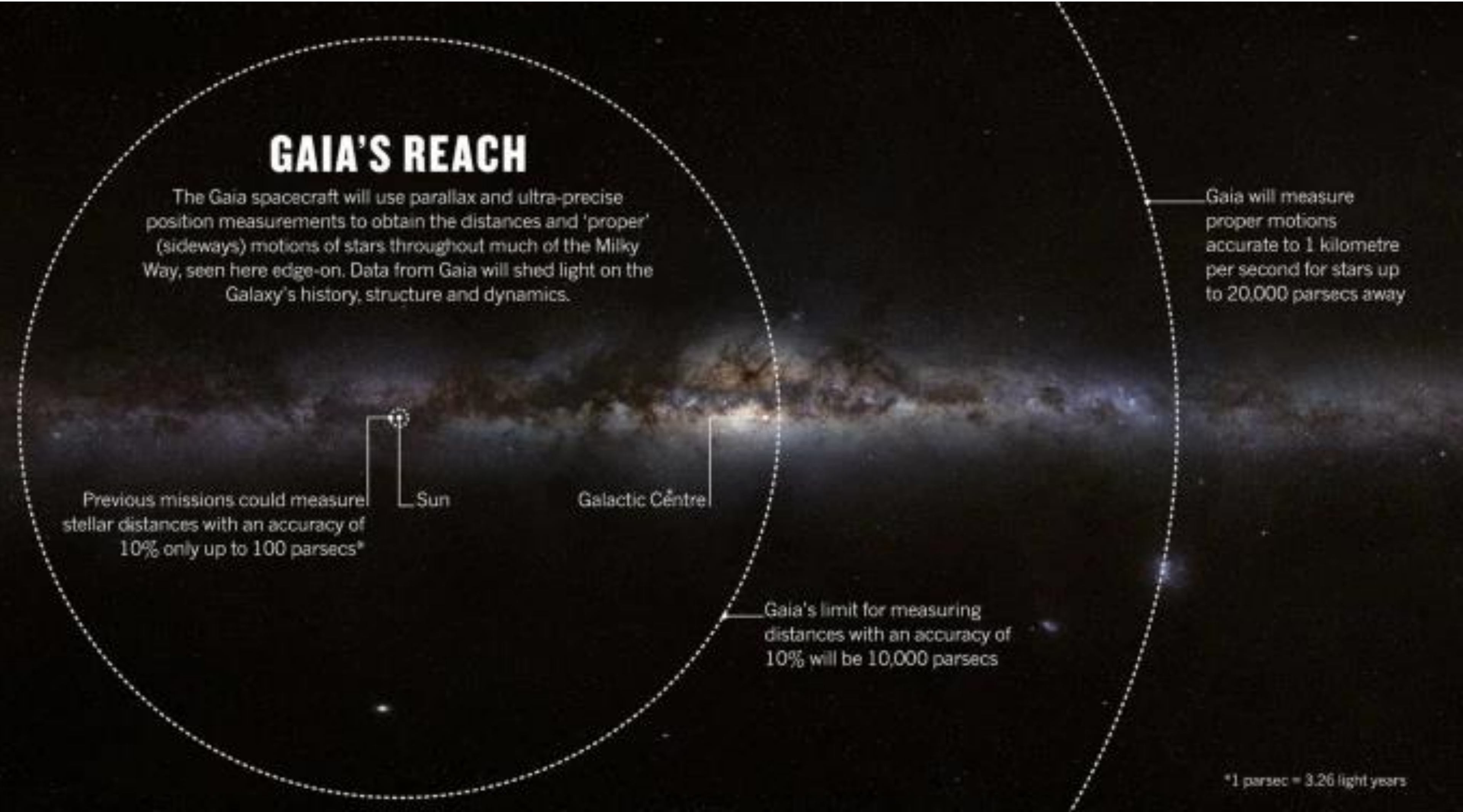
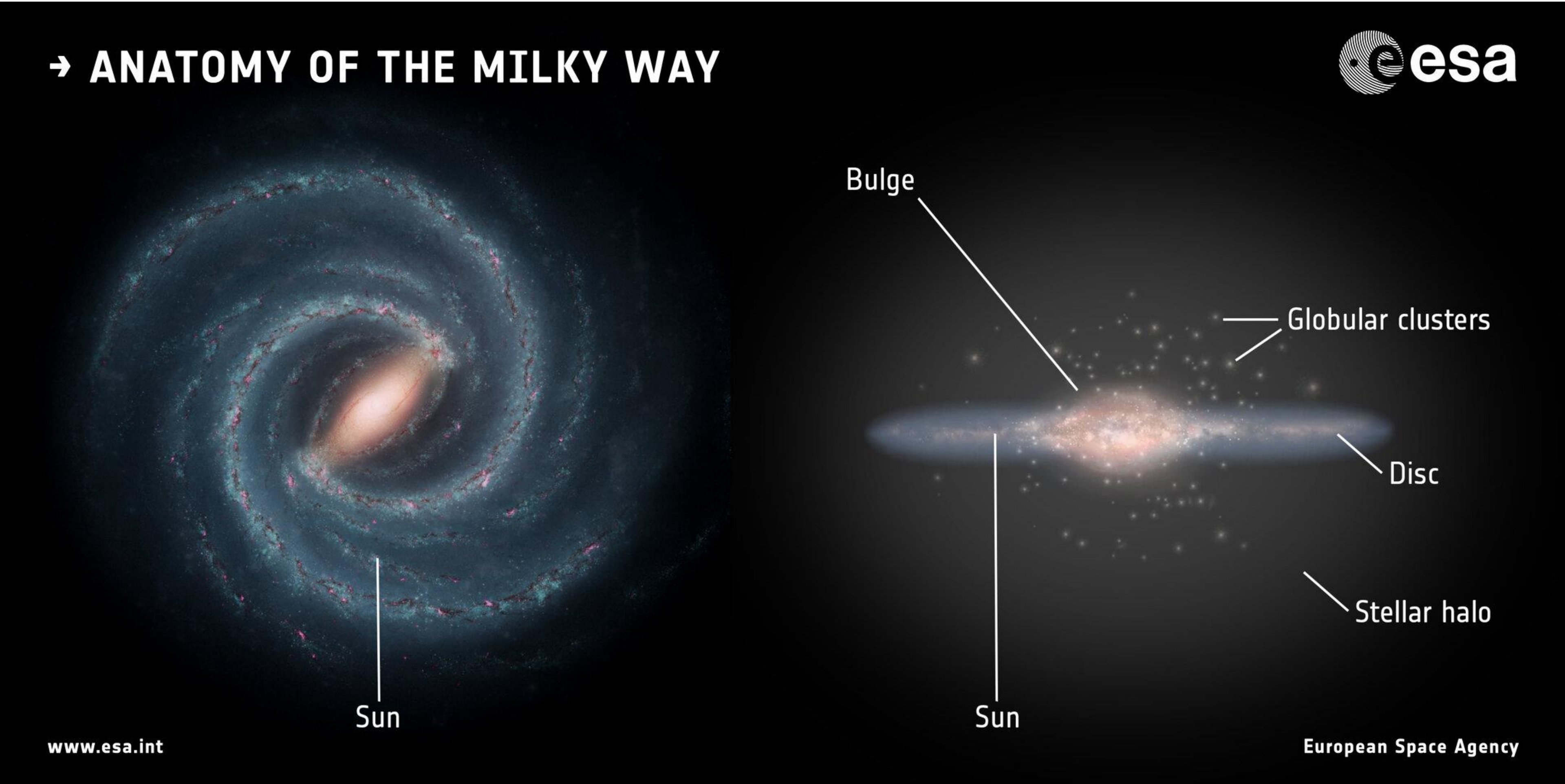
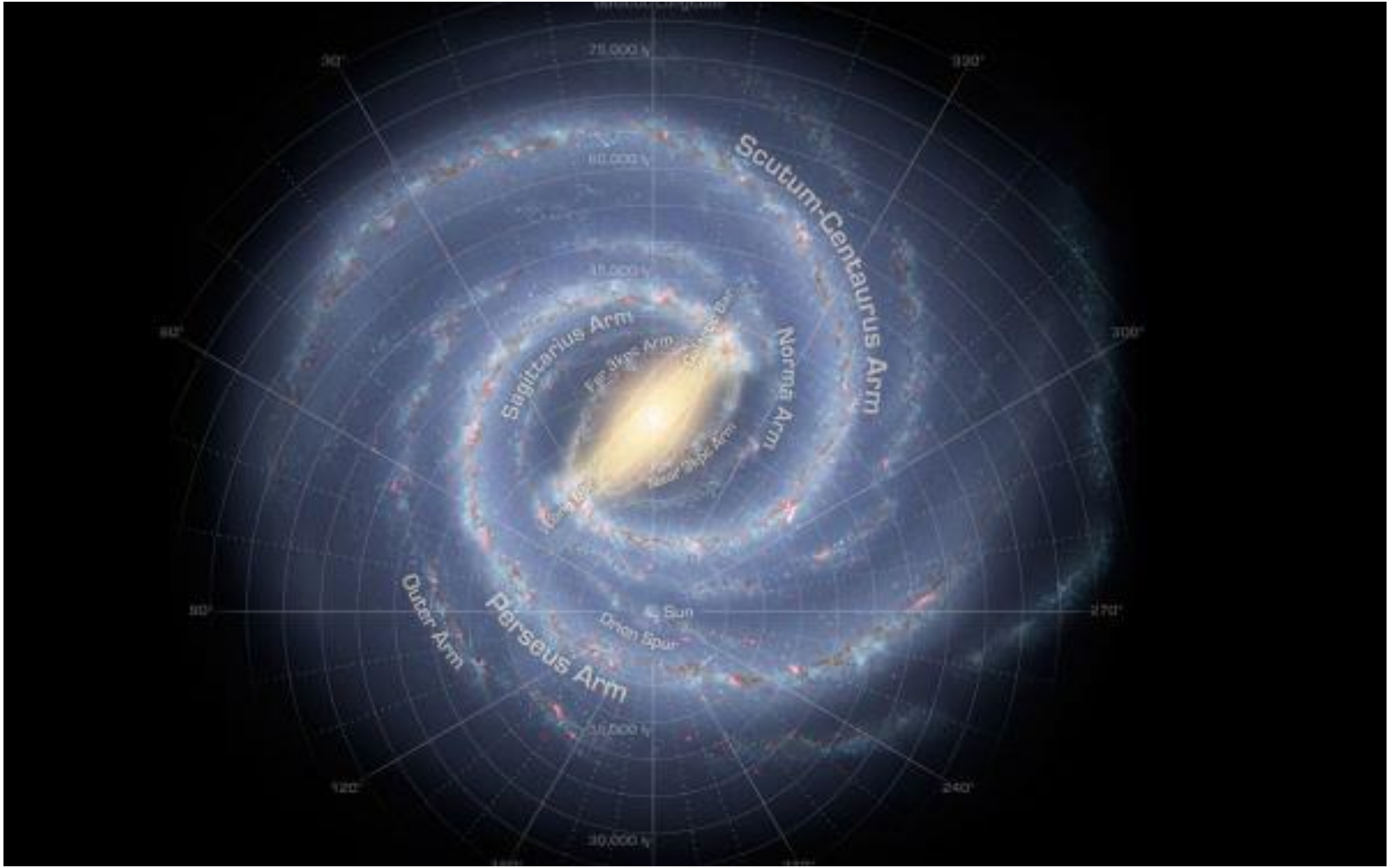
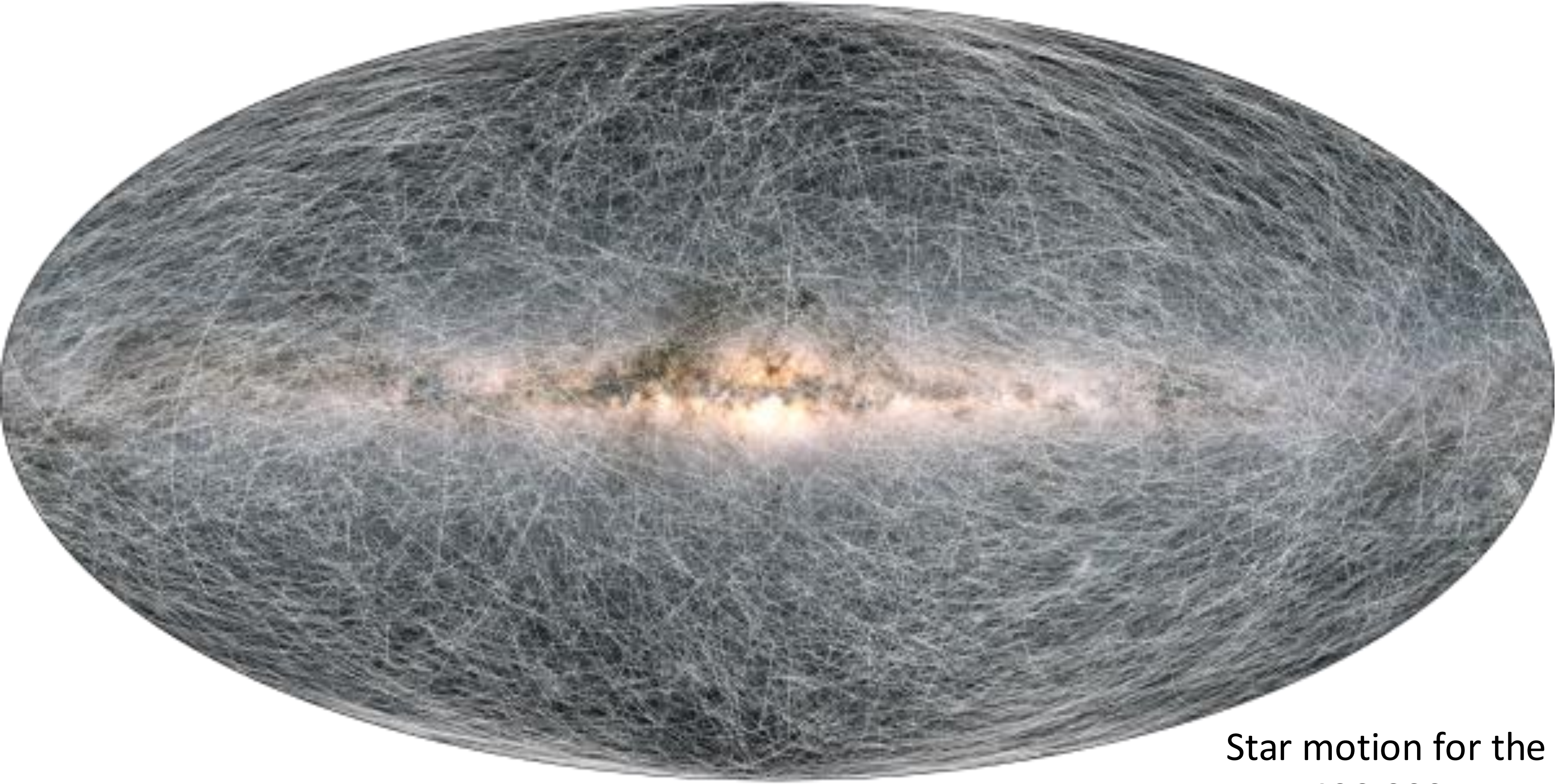

GAIA'S REACH
The Gaia spacecraft will use parallax and ultra-precise position measurements to obtain the distances and 'proper' (sideways) motions of stars throughout much of the Milky Way, seen here edge-on. Data from Gaia will shed light on the Galaxy's history, structure and dynamics.
Gaia will measure proper motions accurate to 1 kilometre per second for stars up to 20,000 parsecs away
Previous missions could measure stellar distances with an accuracy of 10% only up to 100 parsecs*
Sun
Galactic Centre
Gaia's limit for measuring distances with an accuracy of 10% will be 10,000 parsecs
*1 parsec = 3.26 light years

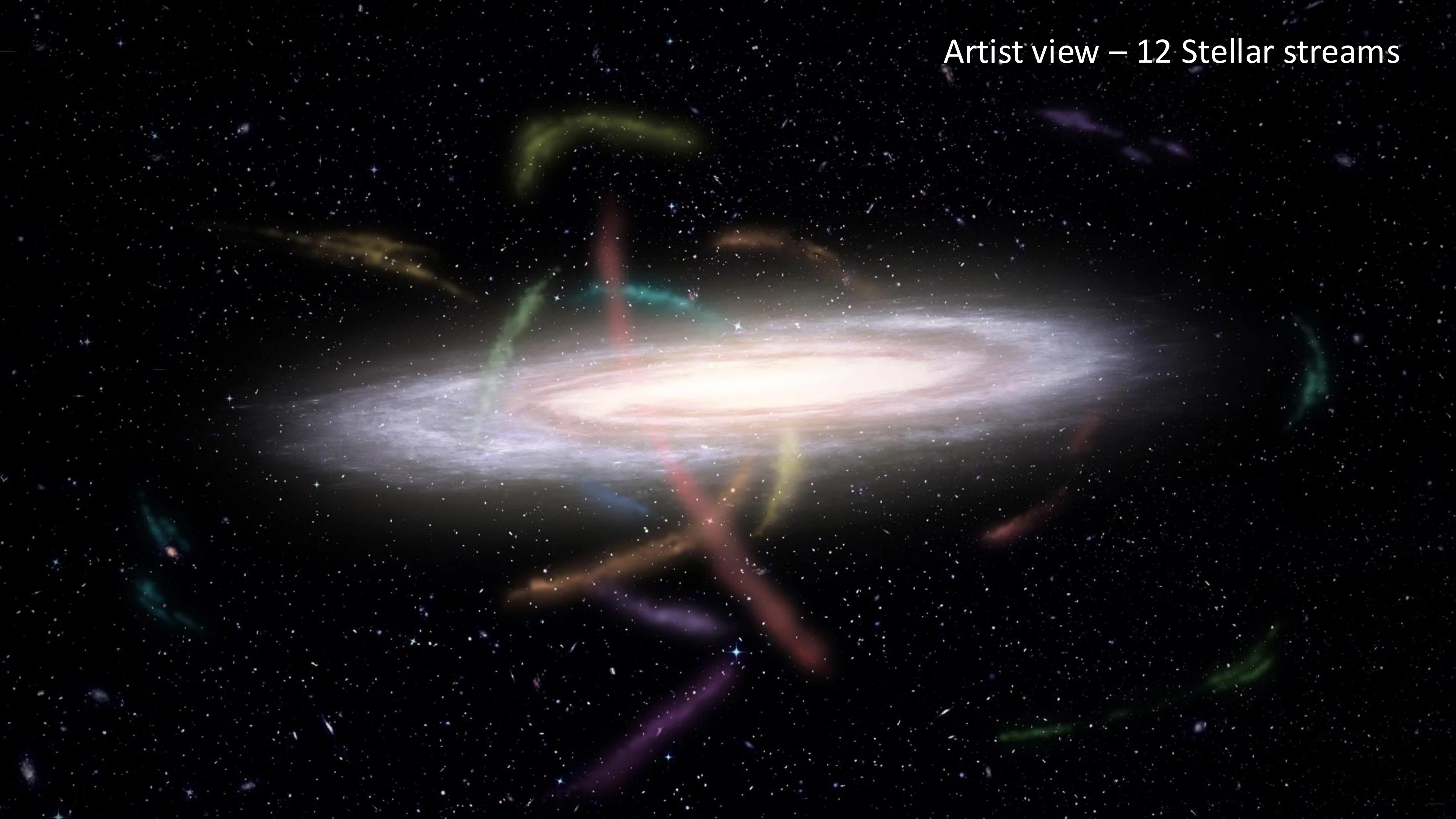

ANATOMY OF THE MILKY WAY
esa
Bulge
Globular clusters
Disc
Stellar halo
Sun
Sun
www.esa.int
European Space Agency


Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Orion Spur
Sun
30°
330°
60°
300°
90°
270°
120°
240°

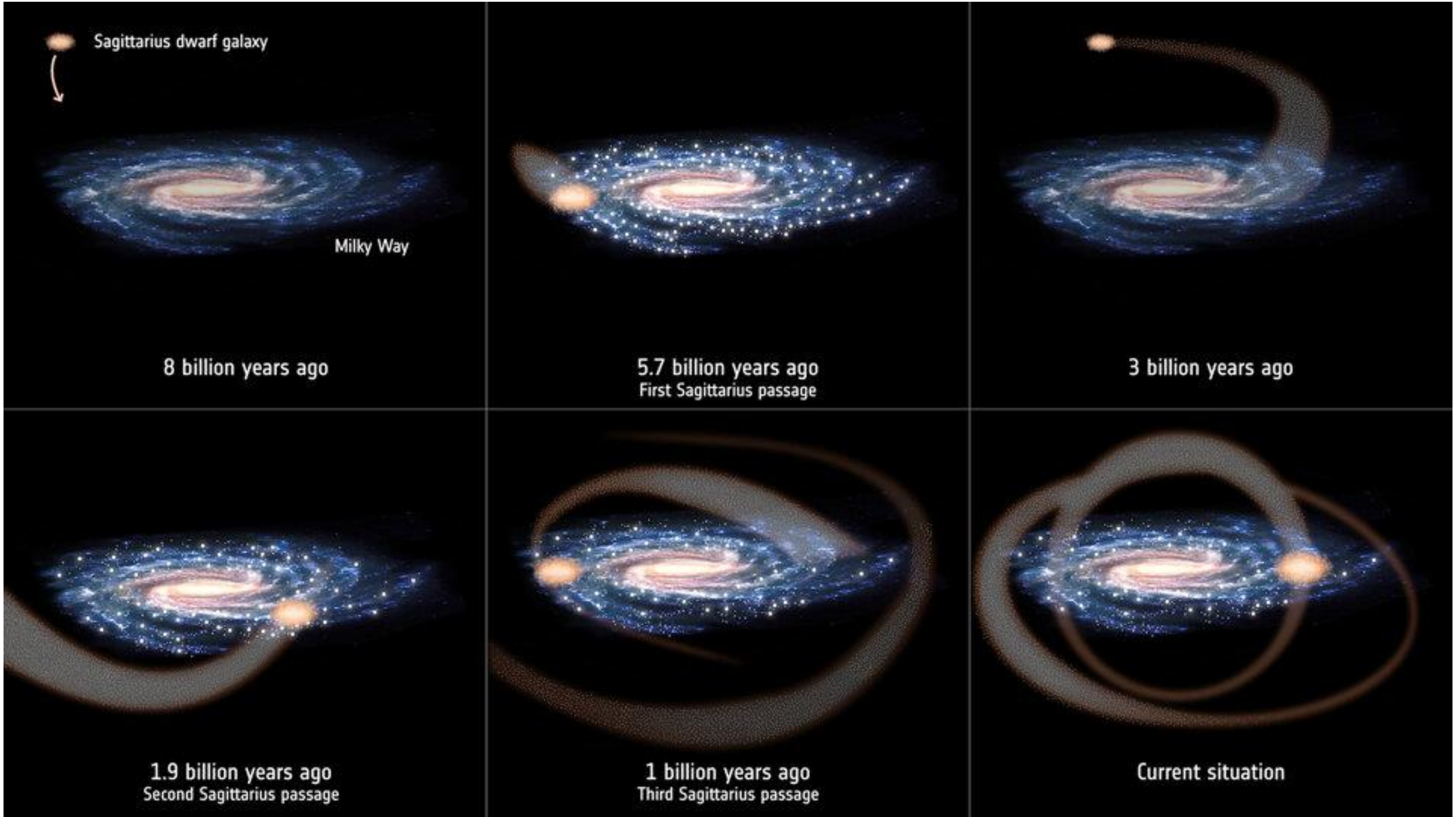


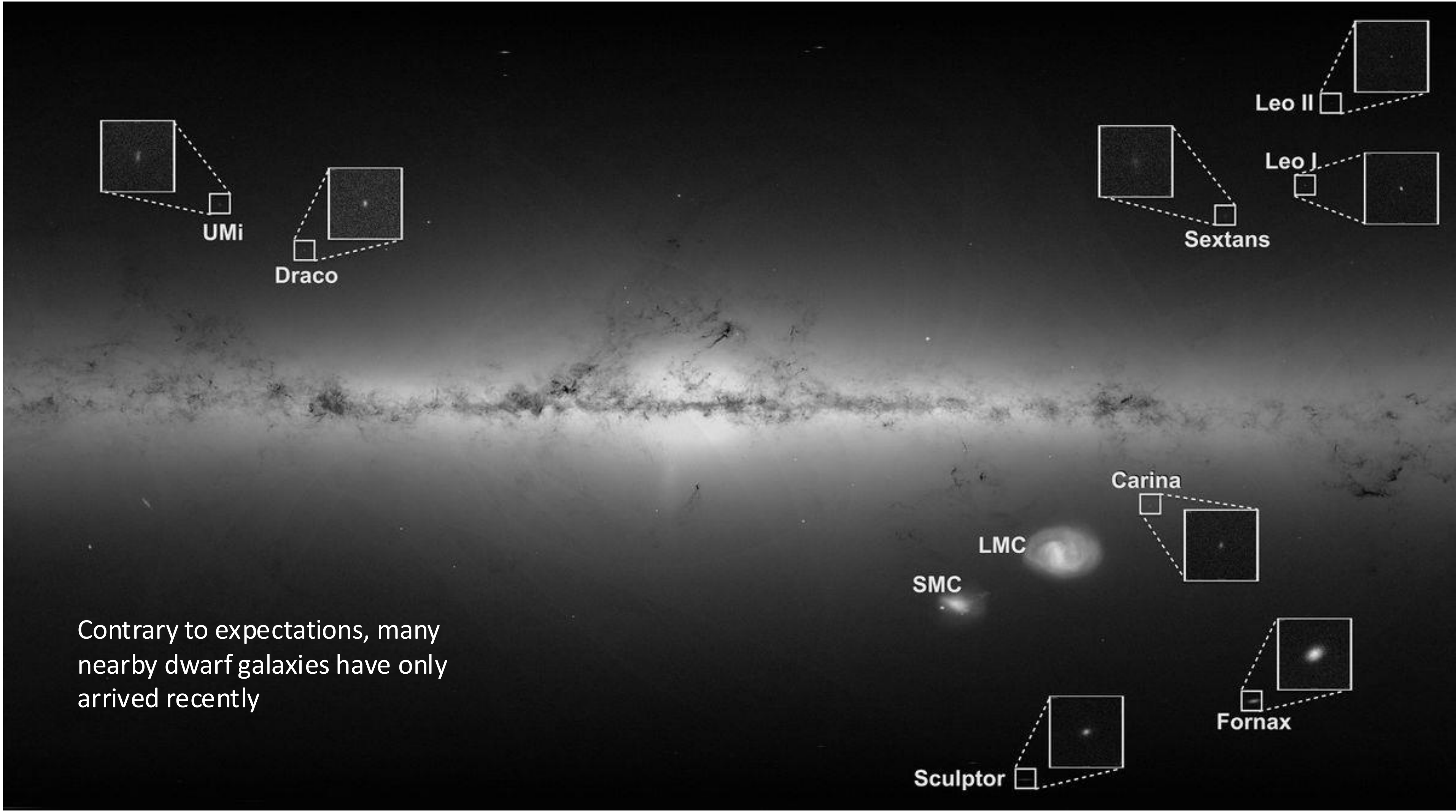
Star motion for the
next 400,000 years

Artist view – 12 Stellar streams



Stellar streams are remains of other galaxies largely destroyed by collision with the MWG





Contrary to expectations, many nearby dwarf galaxies have only arrived recently

APPROXIMATE TIMELINE FOR THE FORMATION OF

THE MILKY WAY

0 YEARS
Big Bang

~250 MILLION YEARS OLD
Clouds of gas and dark matter begin to collapse under their own gravity, forming protogalaxies.

~1 BILLION YEARS OLD
The inner halo and bulge of the Milky Way begin to form from a gas cloud with low angular momentum.

~2.8 BILLION YEARS OLD
The Milky Way merges with the so-called Kraken galaxy. This collision is considered the largest galactic collision that the Milky Way ever experienced and likely drastically transformed the appearance of the Milky Way.

~3.8 BILLION YEARS OLD
The Milky Way experiences a stellar 'baby boom' whereby stars were produced 30 times faster than today.

~4.8 BILLION YEARS OLD
The Milky Way merges with the Gaia-Enceladus galaxy. This is thought to be the last big merger even experienced by our Galaxy.

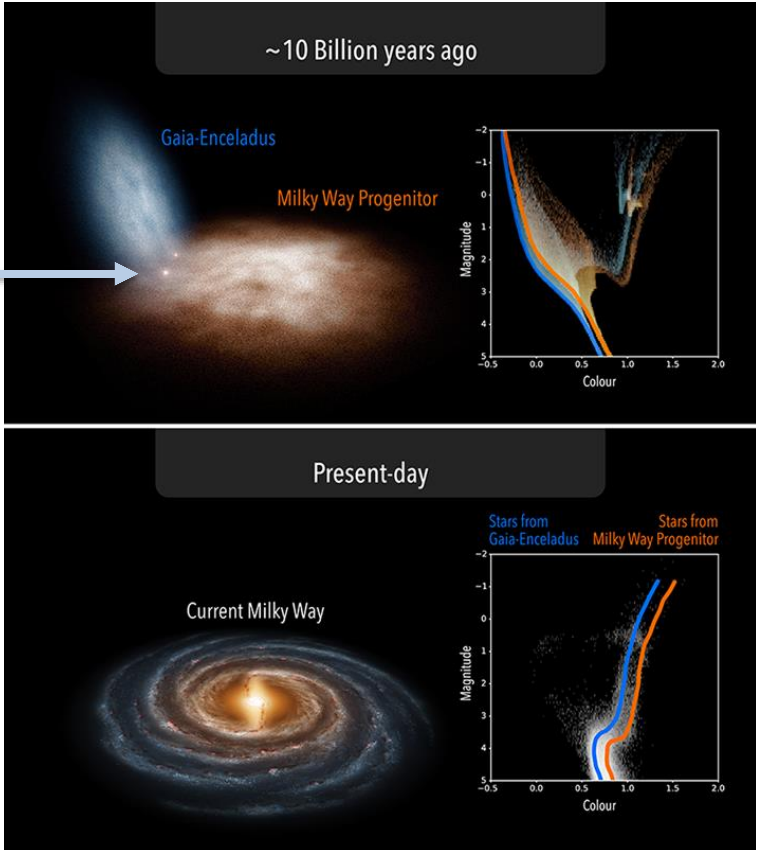
~5 BILLION YEARS OLD
The formation of a small disk stretches out from the central bulge of the Milky Way. The disk begins to grow 'inside out' with the central-most region forming first. The rotation of the disk increases in momentum causing the gas clouds to collapse along the rotational axis and forming the relatively flat disk we recognize today.

~9 BILLION YEARS OLD
The Milky Way disk begins to grow and the outer regions of the disk continue to form.

~9.3 BILLION YEARS OLD
Our sun and solar system begin to form from a dense cloud of interstellar gas and dust.

~10 BILLION YEARS OLD
Life on Earth begins, shortly after the late heavy bombardment.

13.6 BILLION YEARS OLD - PRESENT DAY
Outer regions of the galactic disk continue to form and It is currently not fully understood why stellar formation in the disk is still in an active phase



How to tell when a star was formed?

Metals

Massive stars make energy by converting H → He → C →O->->->Fe

and then ejecting some of their interiors back into the interstellar medium

First stars formed (oldest stars) have no metals in their atmospheres

Most recently formed stars have the most metals

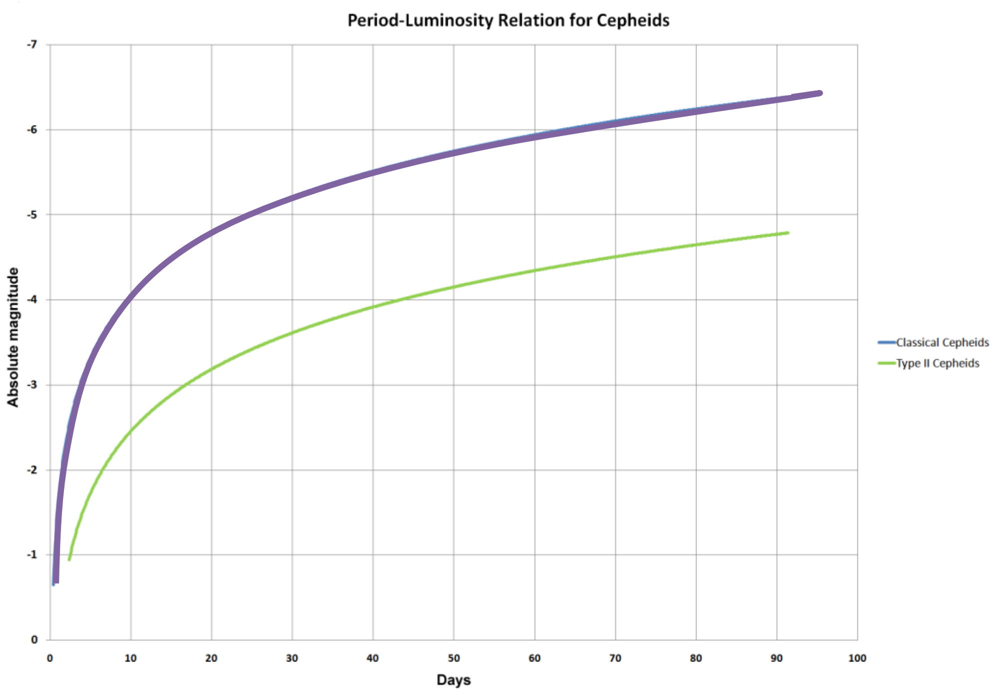
Other Galaxies

Mapping other galaxies:

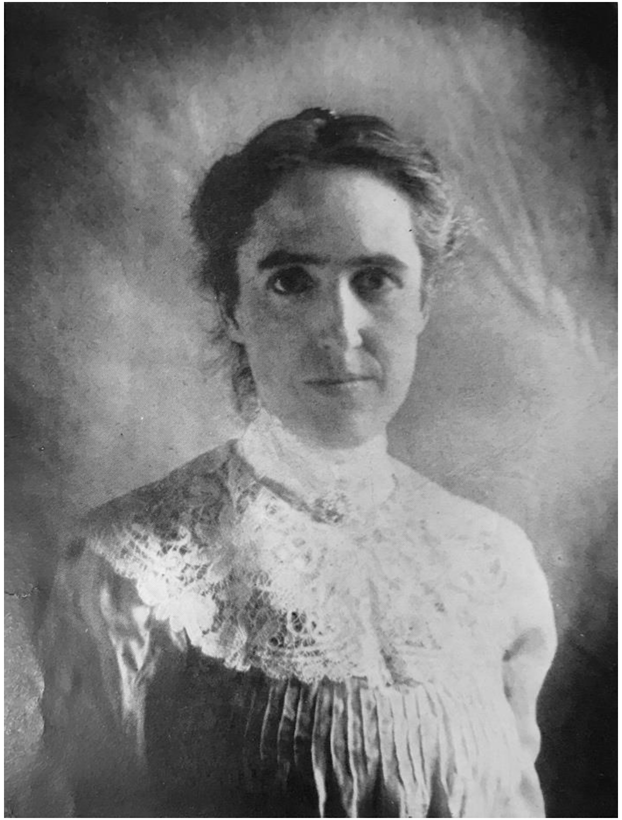
Parallax does not reach even the nearest galaxies

Cepheid Variables as Standard Candles

More
Luminous



Longer Pulsation Period



Henrietta Swan Leavitt 1868-1921
Period-Luminosity Law (1908-1912)

The cosmic distance ladder:

Distance to the Sun (1 au)

Parallax – Distance to stars in MWG (10 kpc)

Standard Candles:

- Cepheid Variable (40 Mpc)
- Tip of the Red Giant Branch (15 Mpc)
- Spiral galaxy luminosity: Tully-Fisher relation-- TFR (100 MPC)
- Type Ia Supernova ($z < 2.26$)

Hubble flow (all “observable” galaxies)

The cosmic distance ladder:

Distance to the Sun (1 au)

Parallax – Distance to stars in MWG (10 kpc)

Calibrate

Standard Candles:

Calibrate

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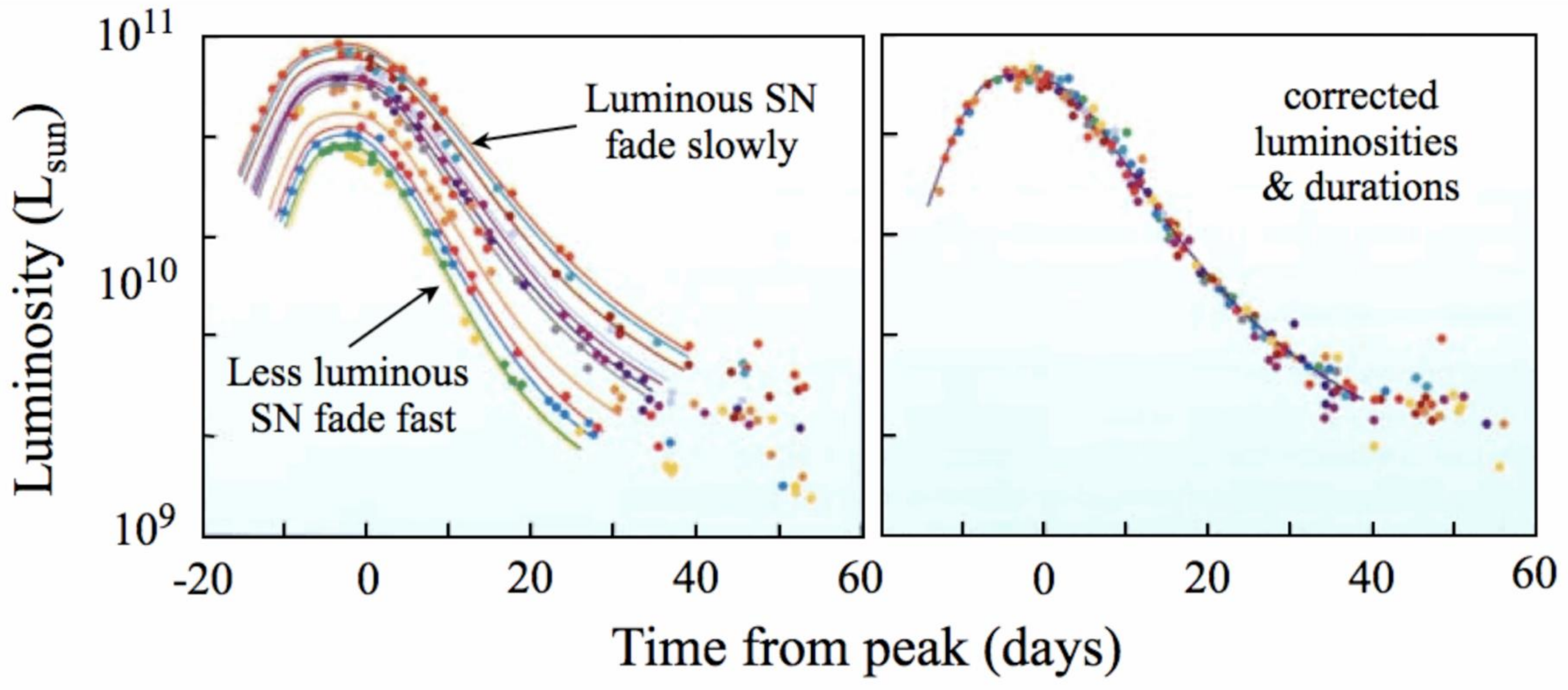
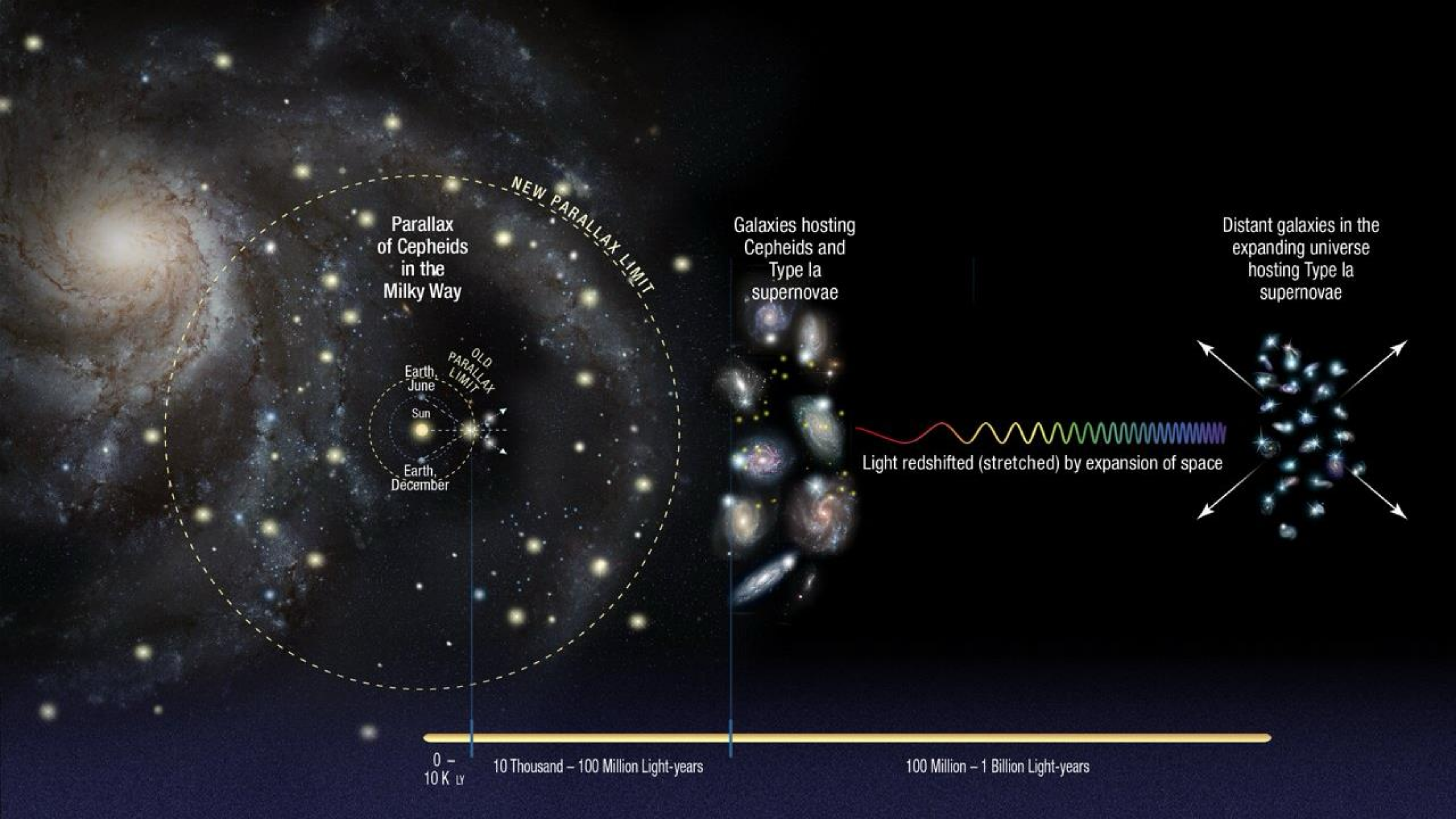
Calibrate

Hubble flow (all “observable” galaxies)

Type Ia Supernovae all reach a peak luminosity that can be determined by the rate at which they fade.

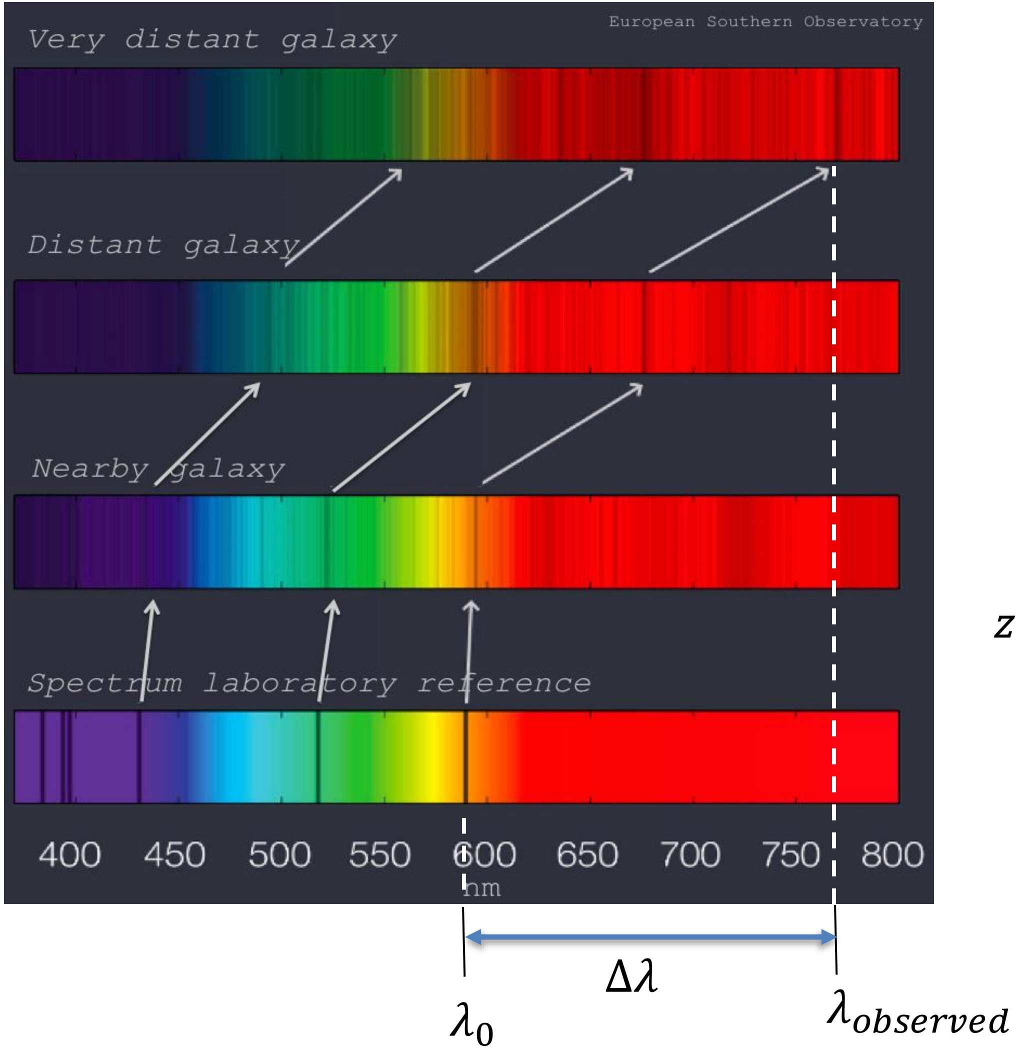


NGC 5468 (JWST image) —
At 40 Mpc, the most distant galaxy in which a Cepheid and a type Ia SN have both been observed



Parallax of Cepheids in the Milky Way
NEW PARALLAX LIMIT
OLD PARALLAX LIMIT
Earth, June
Sun
Earth, December
Galaxies hosting Cepheids and Type Ia supernovae
Distant galaxies in the expanding universe hosting Type Ia supernovae
Light redshifted (stretched) by expansion of space
0 – 10 K LY
10 Thousand – 100 Million Light-years
100 Million – 1 Billion Light-years

The Hubble Flow



The redshift parameter

For any nearby object moving with low velocity, the Doppler Effect means:

V_r= Radial velocity

$$z = \frac{\lambda_{observed} - \lambda_0}{\lambda_0} \equiv \frac{\Delta\lambda}{\lambda_0} \cong \frac{V_r}{c} \equiv \beta$$

$$V_r = Hd$$

Ay large velocities the redshift parameter depends on velocity in a more complex way, so z can be greater than 1

$$z = \frac{\Delta\lambda}{\lambda_0} = \sqrt[2]{\left(\frac{1+\beta}{1-\beta}\right)} - 1$$

The Hubble Law

For distant galaxies

The further away an object is, the faster it is moving away from us. (Except for local objects)

$$V_r = Hd$$

This is interpreted as an expansion of space.

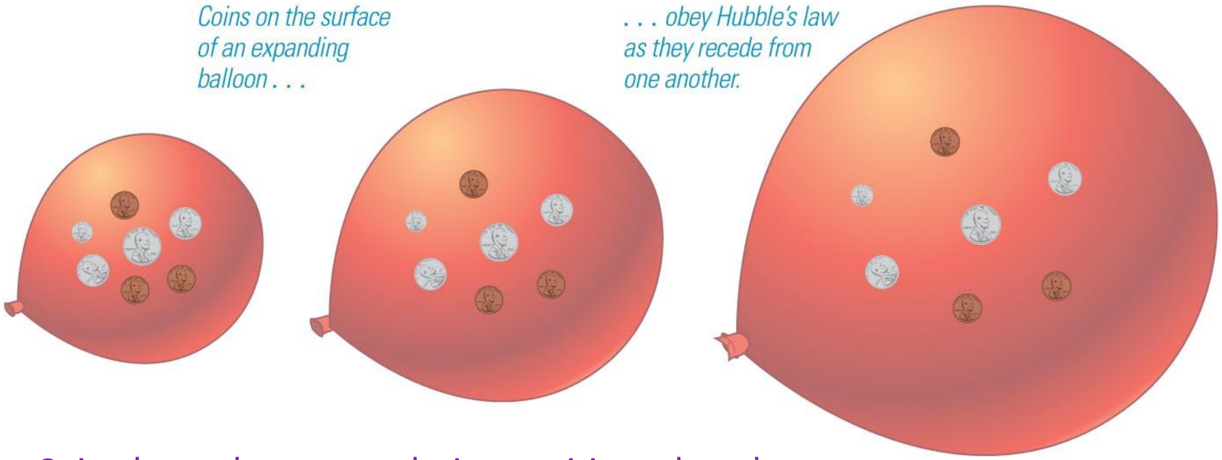
Strong local interactions can cause local objects (e.g. Andromeda and MWG) to move through in this expanding space, but they are still carried along by the expansion.

The Hubble Law means that the distance to an object can be determined by measuring its redshift

(provided the value of H is known)

The Expanding Universe

Two dimensional analog: Imagine a balloon with coins stuck to it. If the balloon expands, the coins all move farther and farther apart. There is, on the surface of the balloon, no “center” of expansion.

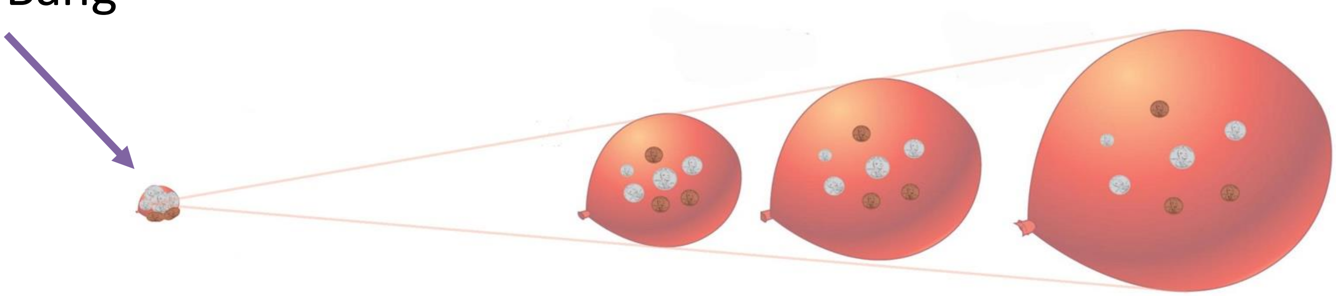


Coins keep the same relative positions, but the SCALE FACTOR of their universe increases with time

If we know the speed of the expansion, we can run it backwards in time until all galaxies were together. So, the expansion started

13.8 ± .04 Gyr ago

The Big Bang



What was the Big Bang?

The event 13.8 billion years ago wherein the distance between every two objects in the Universe was zero,.

Where was the Big Bang?

Everywhere

Was the expansion uniform after the Big Bang?

No