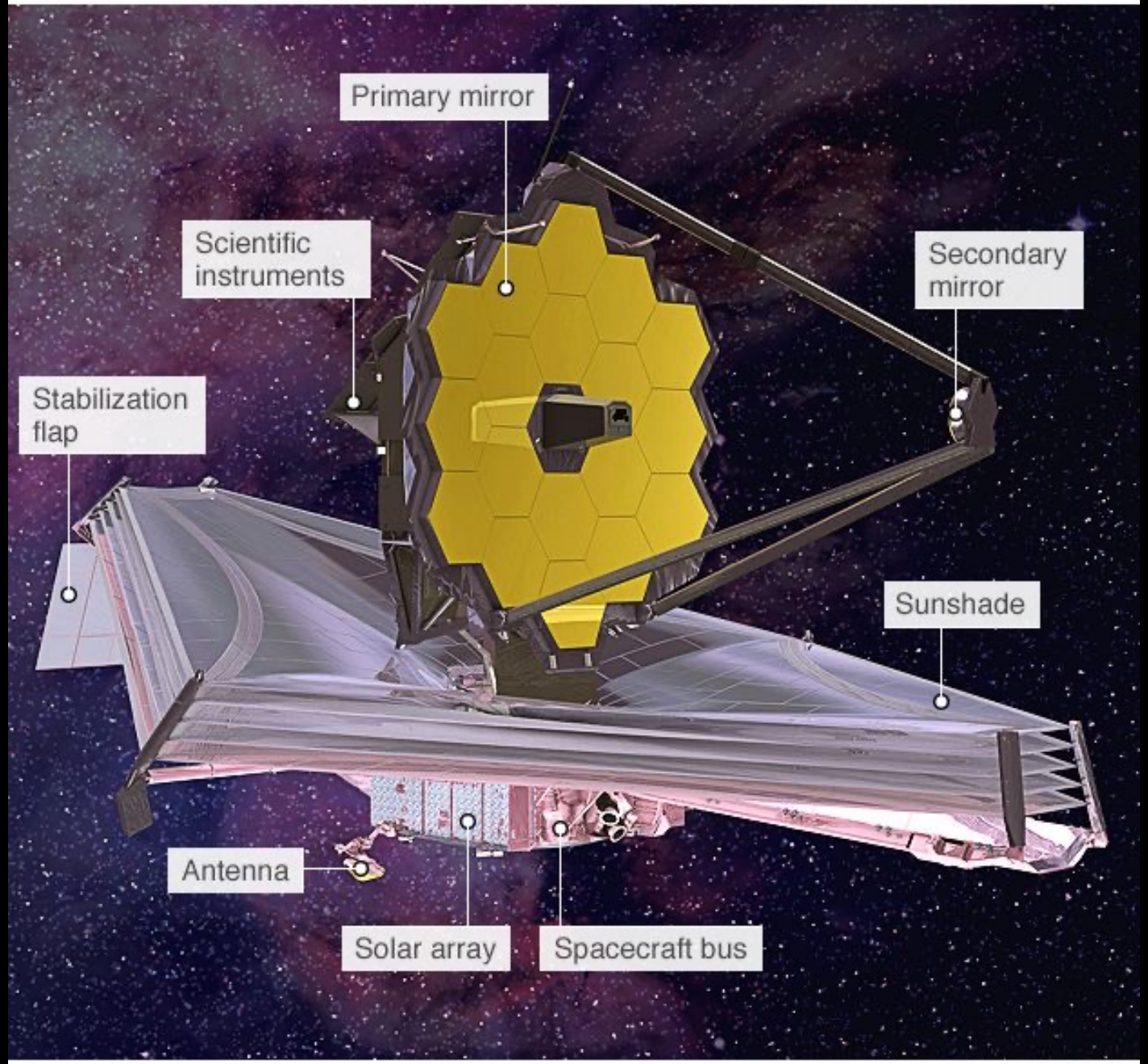
Diving deeper with the James Webb Space Telescope

Megan Reiter
Assistant Professor
Physics and Astronomy
Rice University

The *James Webb Space Telescope:* the best Christmas present ever.

NASA

James Webb Space Telescope



Source: NASA

BBC

Bigger is better (at least for telescopes).

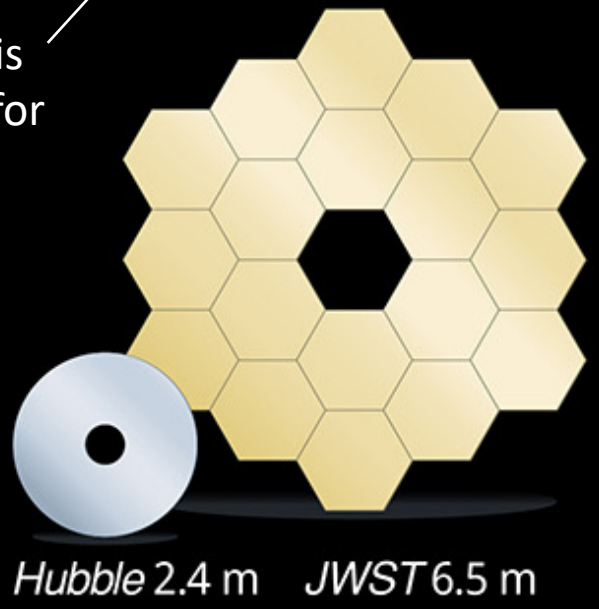
resolution

$$\theta \sim \frac{\lambda}{D}$$

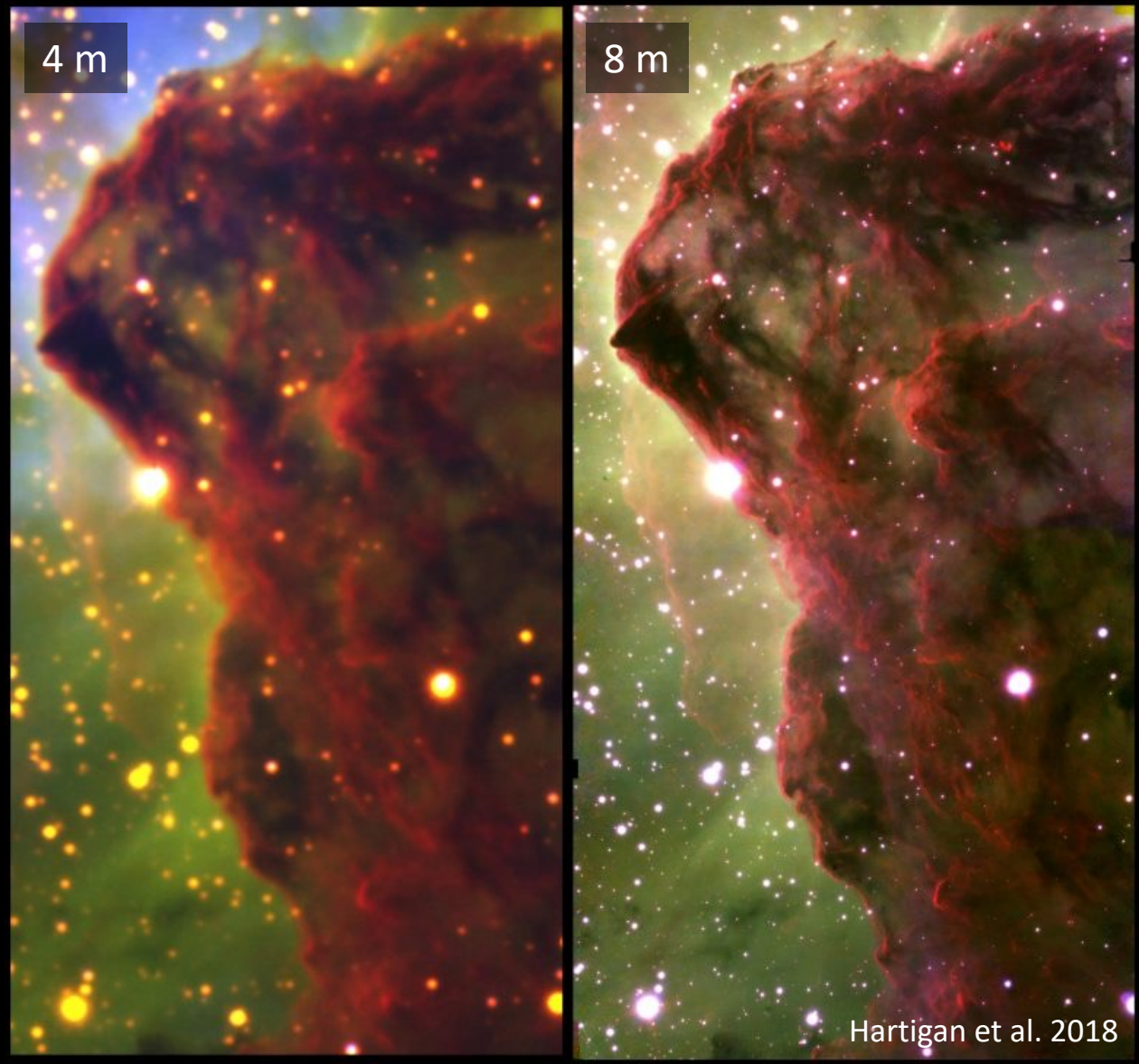
wavelength

telescope diameter

make this smaller for sharper images



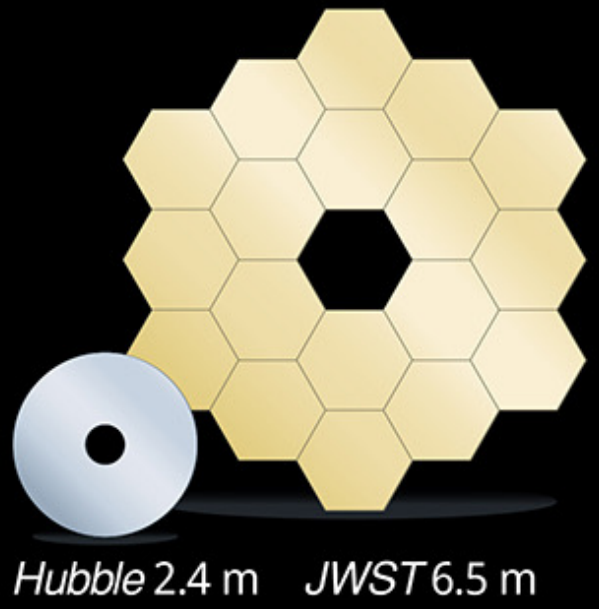
exoplanets.nasa.gov



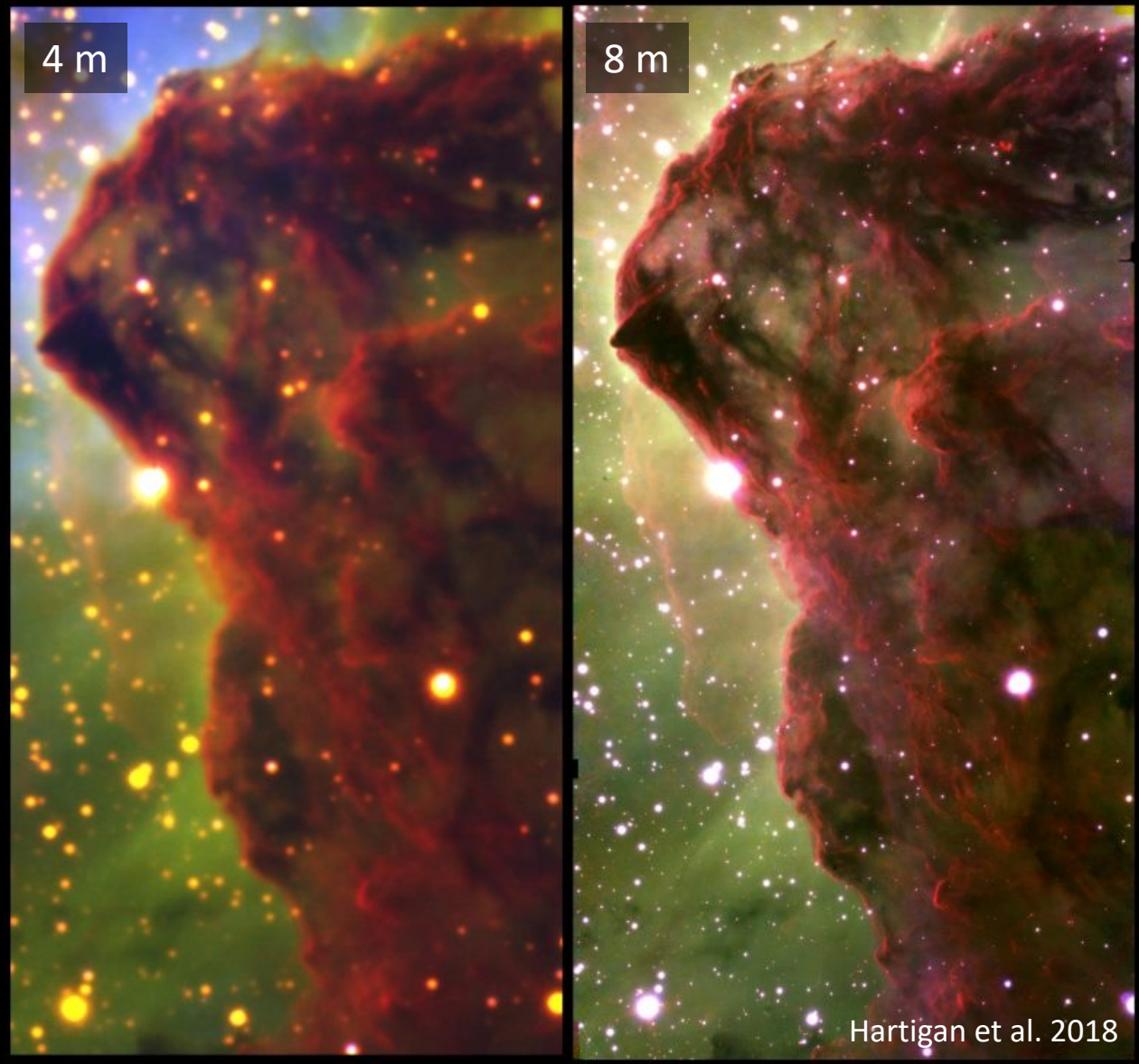
Hartigan et al. 2018

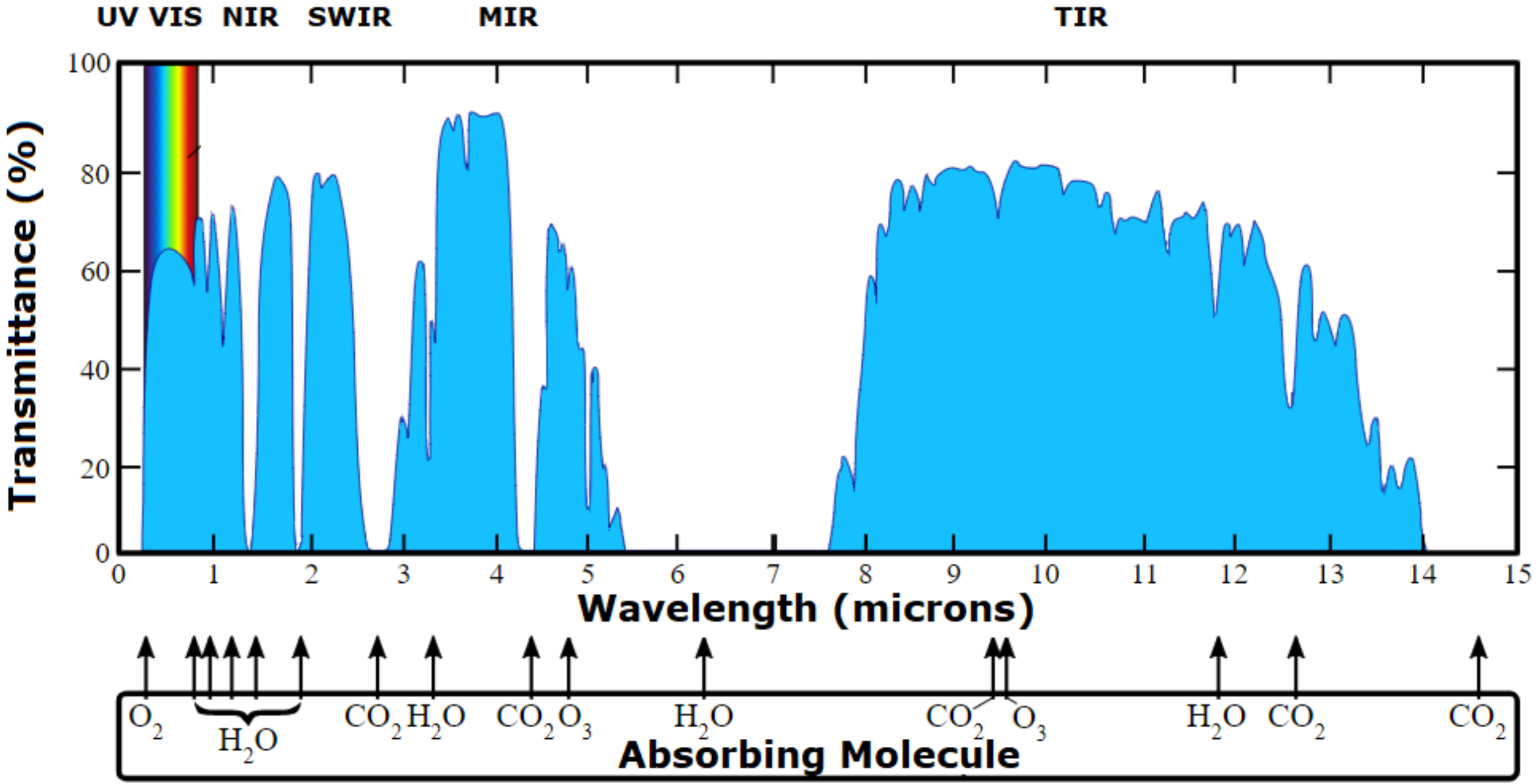
Bigger telescopes collect more light.

$D^2_{8m} / D^2_{eye} \sim 1{,}000{,}000$



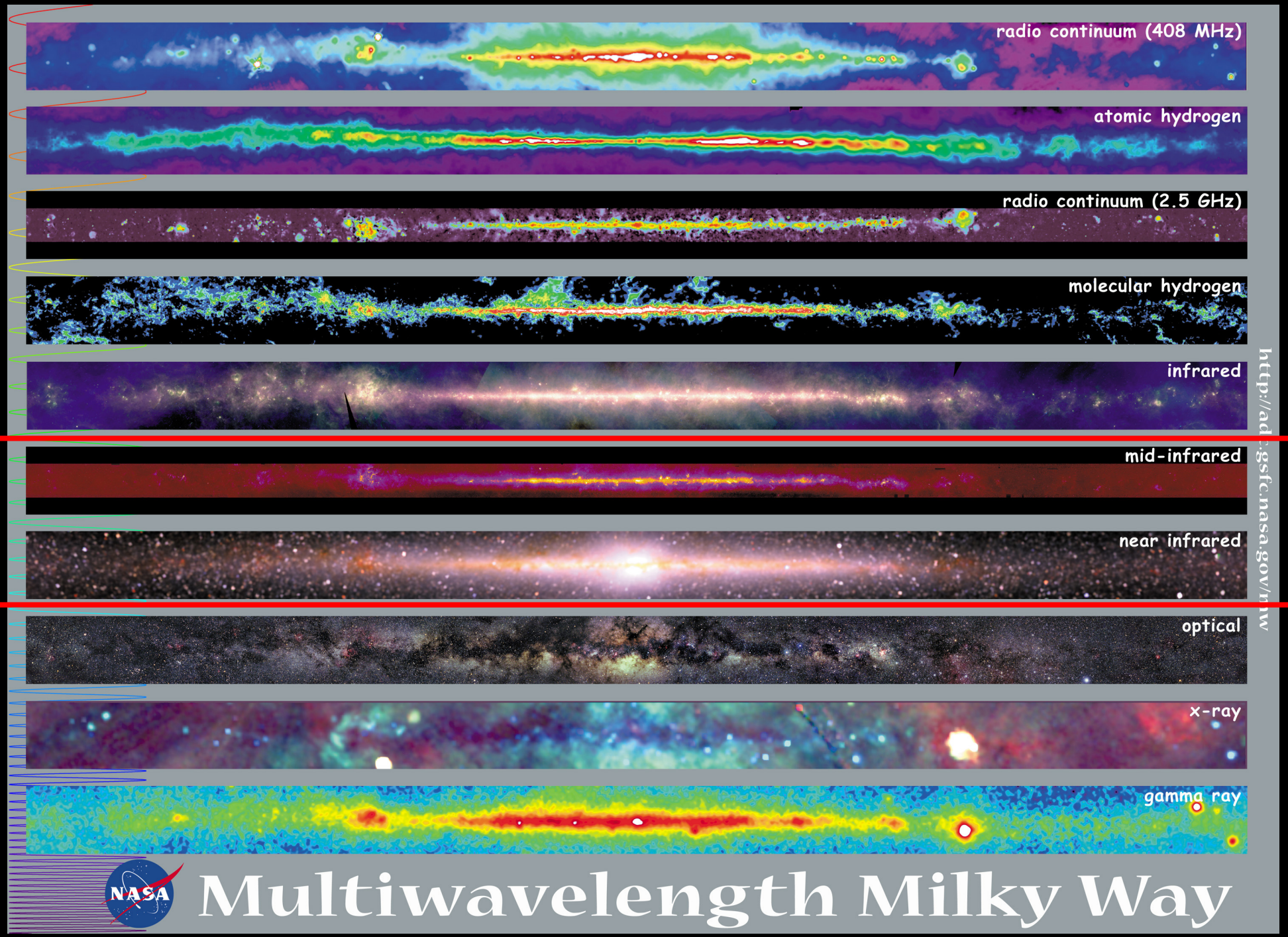
exoplanets.nasa.gov

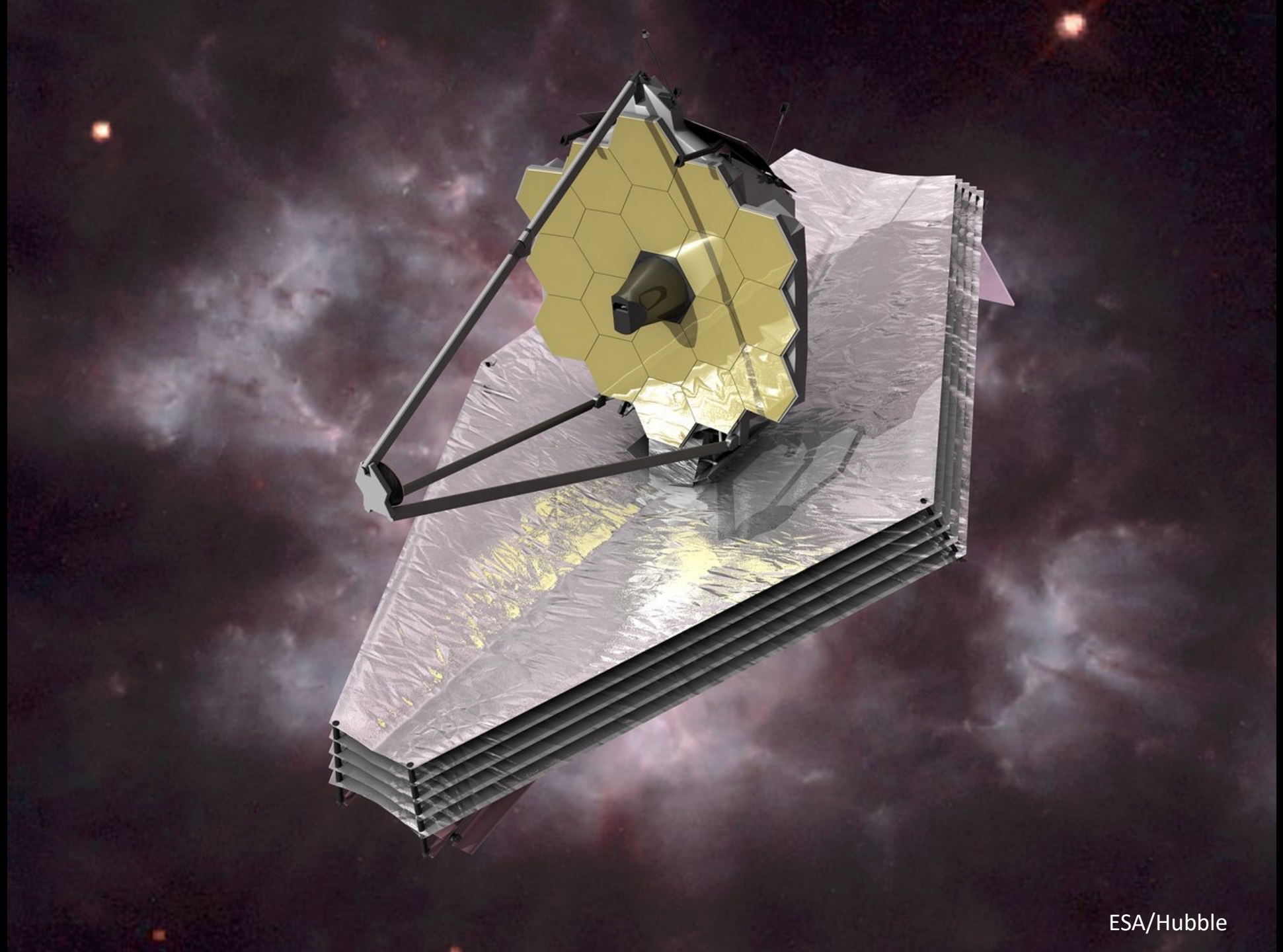



UV VIS NIR SWIR MIR TIR
Transmittance (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Wavelength (microns)
O2
H2O
CO2 H2O
CO2 O3
H2O
CO2 O3
H2O CO2
CO2
Absorbing Molecule

X-ray

Infrared

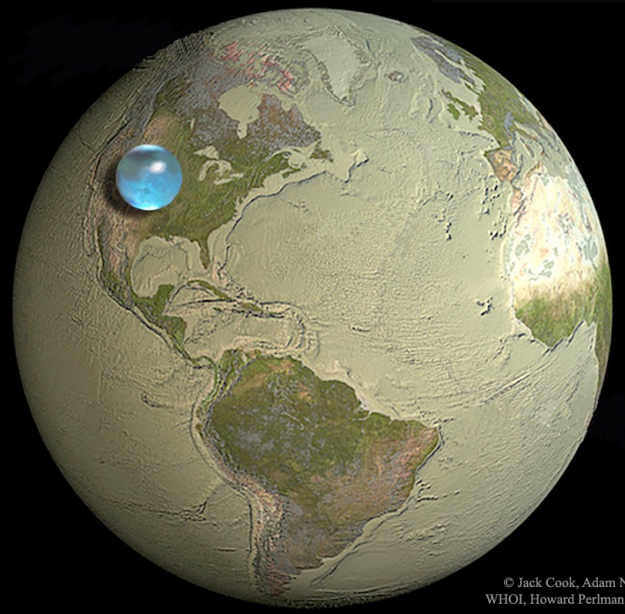

radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way



ESA/Hubble

Are we alone?

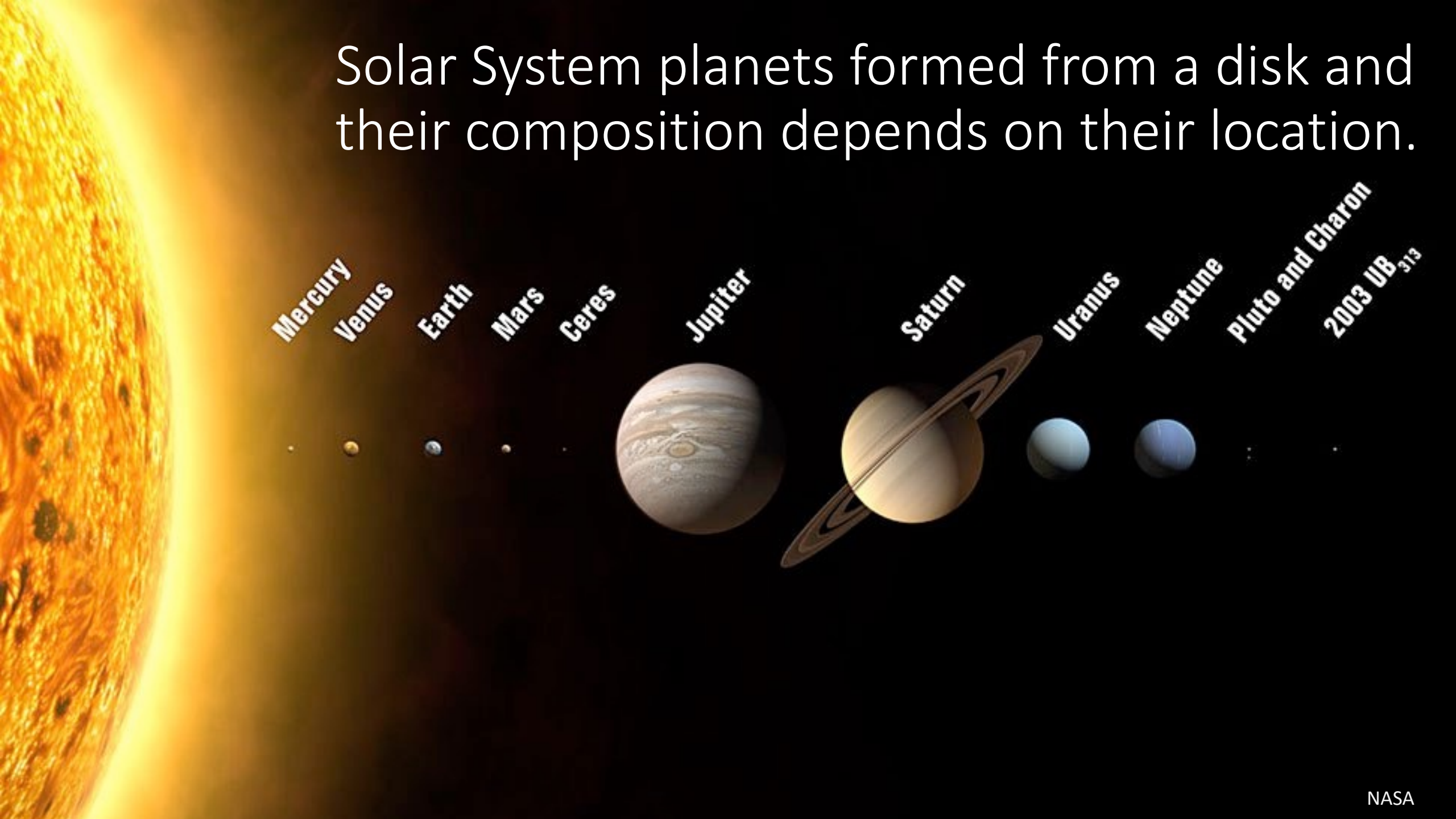
All the water on Earth!



© Jack Cook, Adam Nieman, WHOI, Howard Perlman, USGS

ESA

Solar System planets formed from a disk and their composition depends on their location.



NASA

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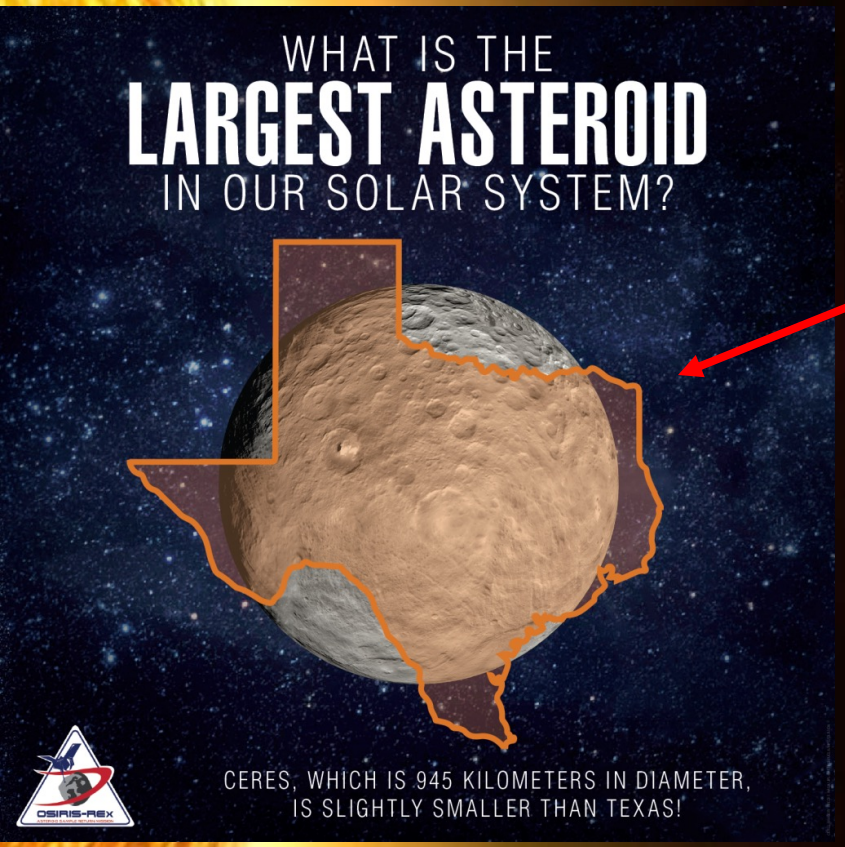
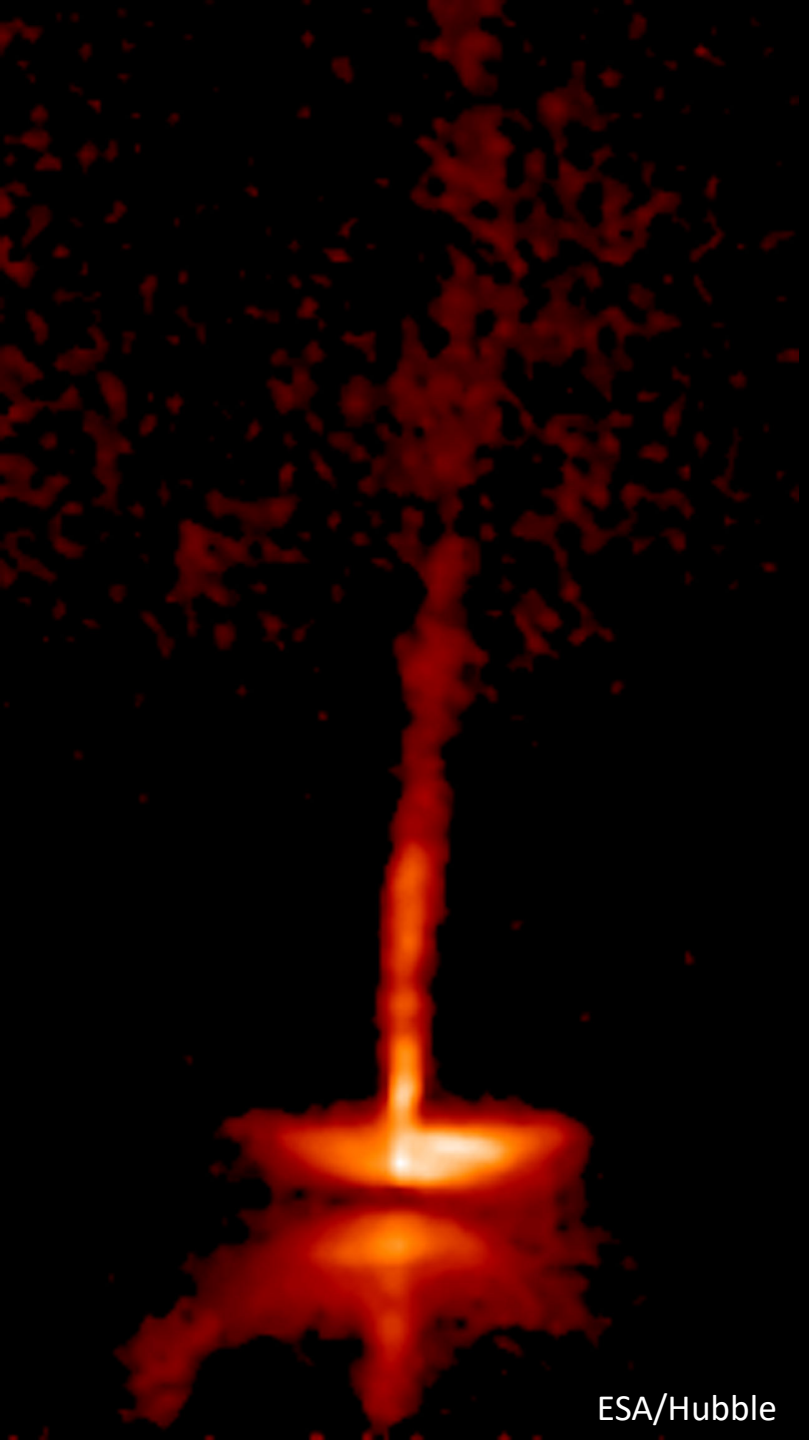


NASA

Planets form in disks around young (mostly) Sun-like stars.



ESA/Hubble

ALMA partnership

Stars form from clouds of cold gas and dust.

Embedded Outflow in HH 46/47

Spitzer Space Telescope • IRAC

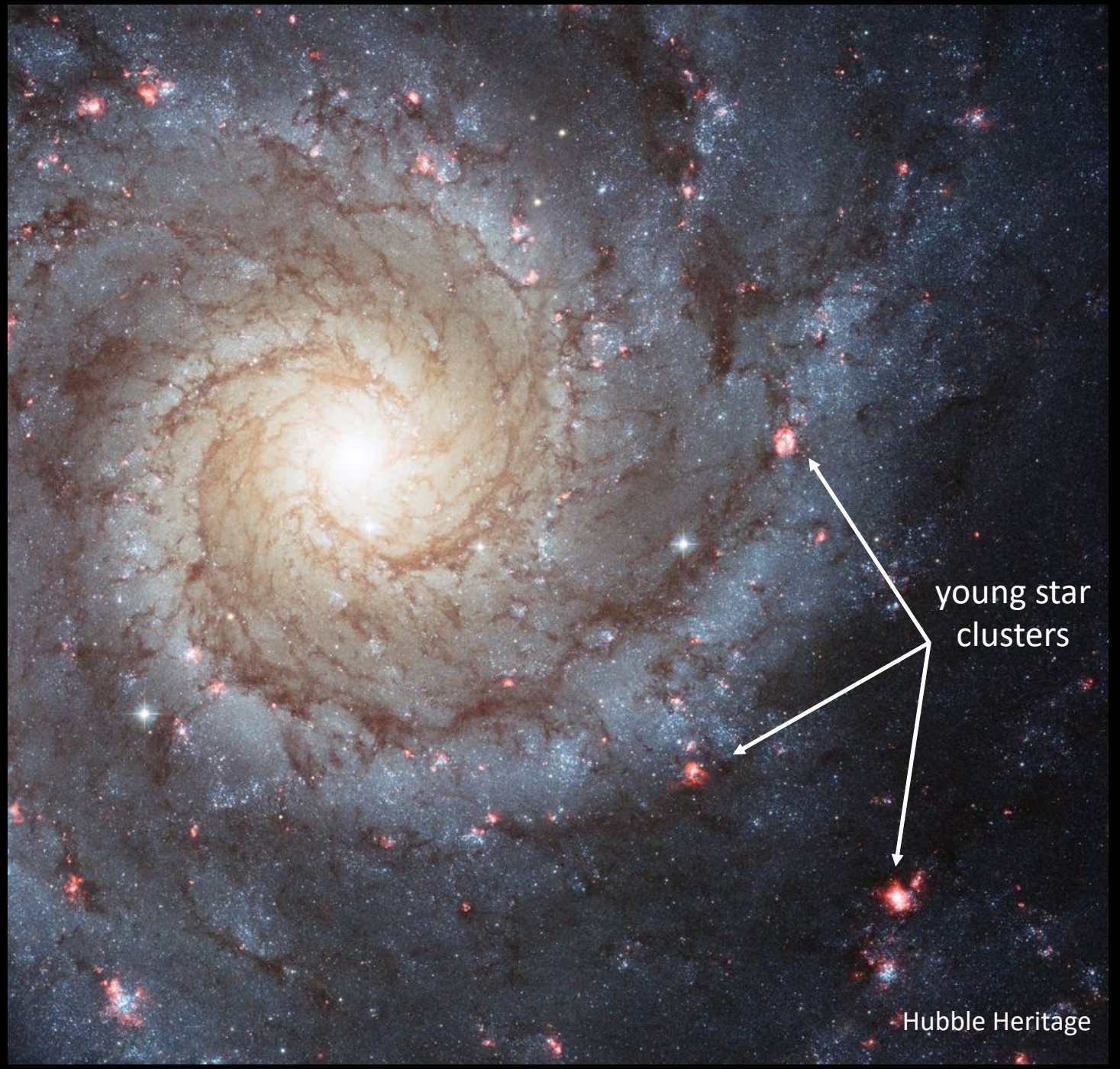
Inset: visible light (DSS)

NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)

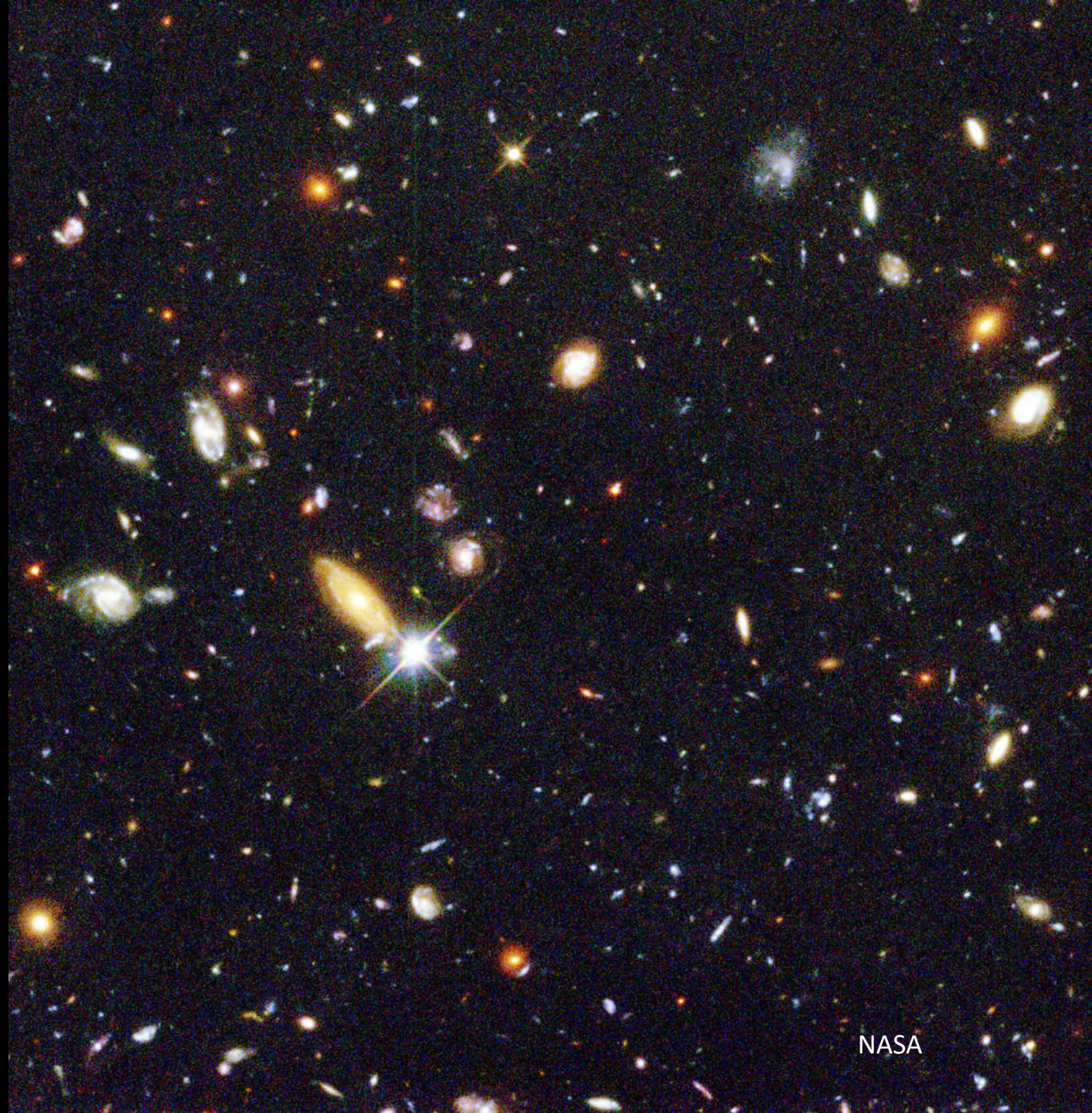
ssc2003-06f

Stars form in family groups in large clouds of cold gas and dust.

Stars are born, live, and die in galaxies.

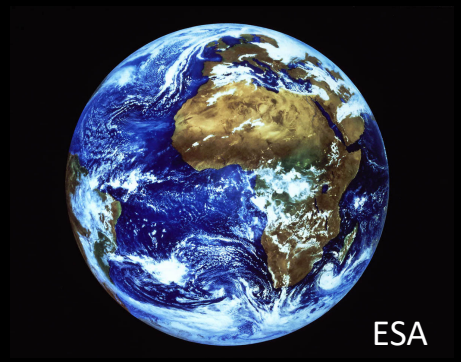


Galaxies provide the best view of how stars form across cosmic time.

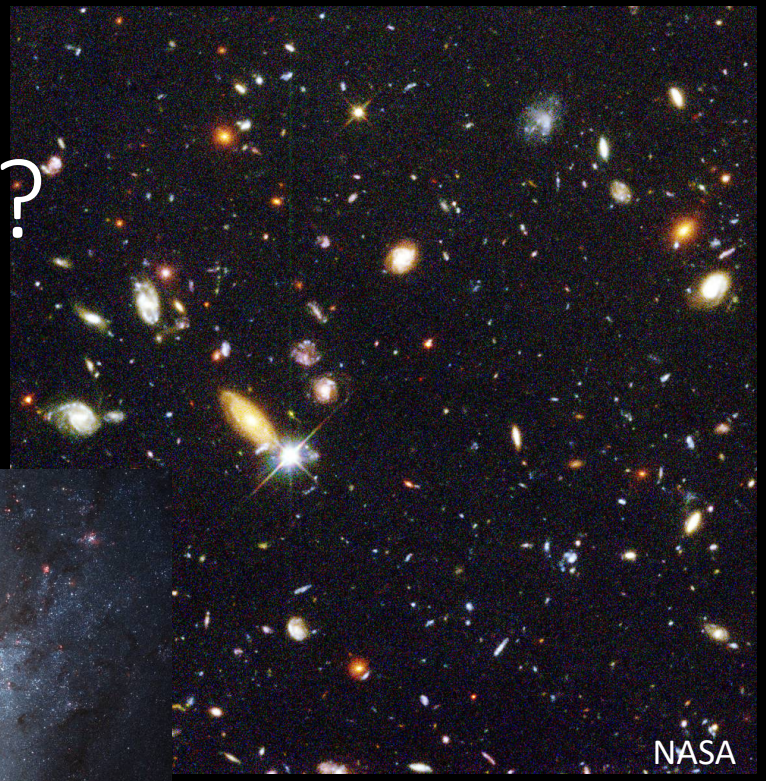


How did we get here? Are we alone?

(these are BIG questions)



ESA



NASA

Hubble Heritage

ALMA partnership

ESA/NASA

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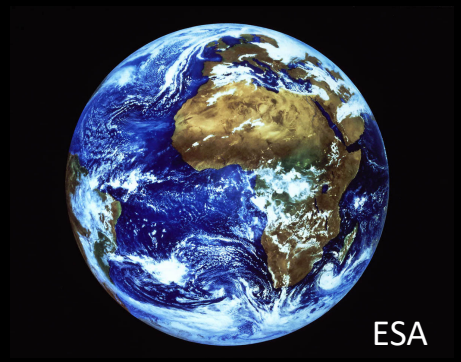
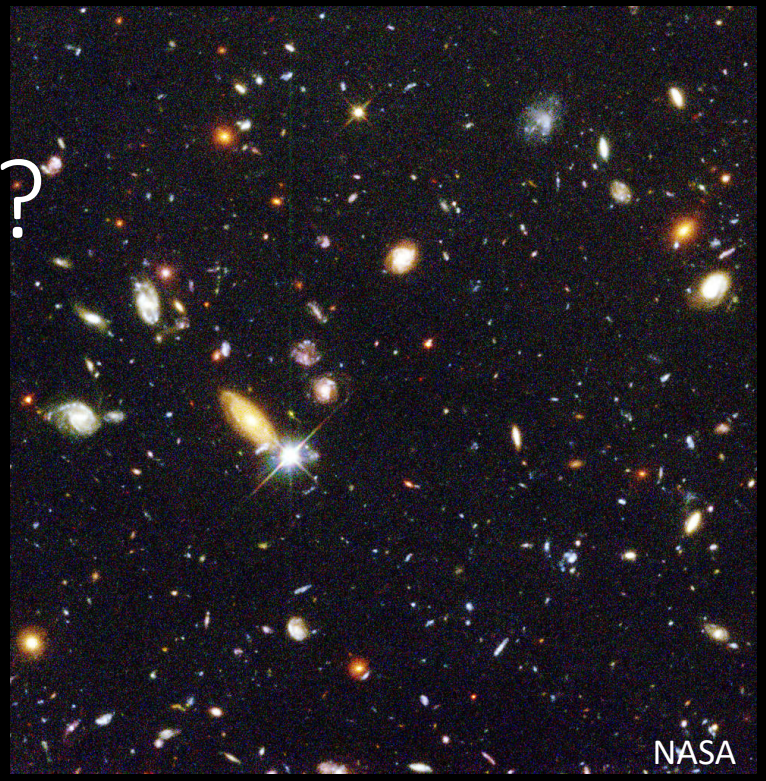
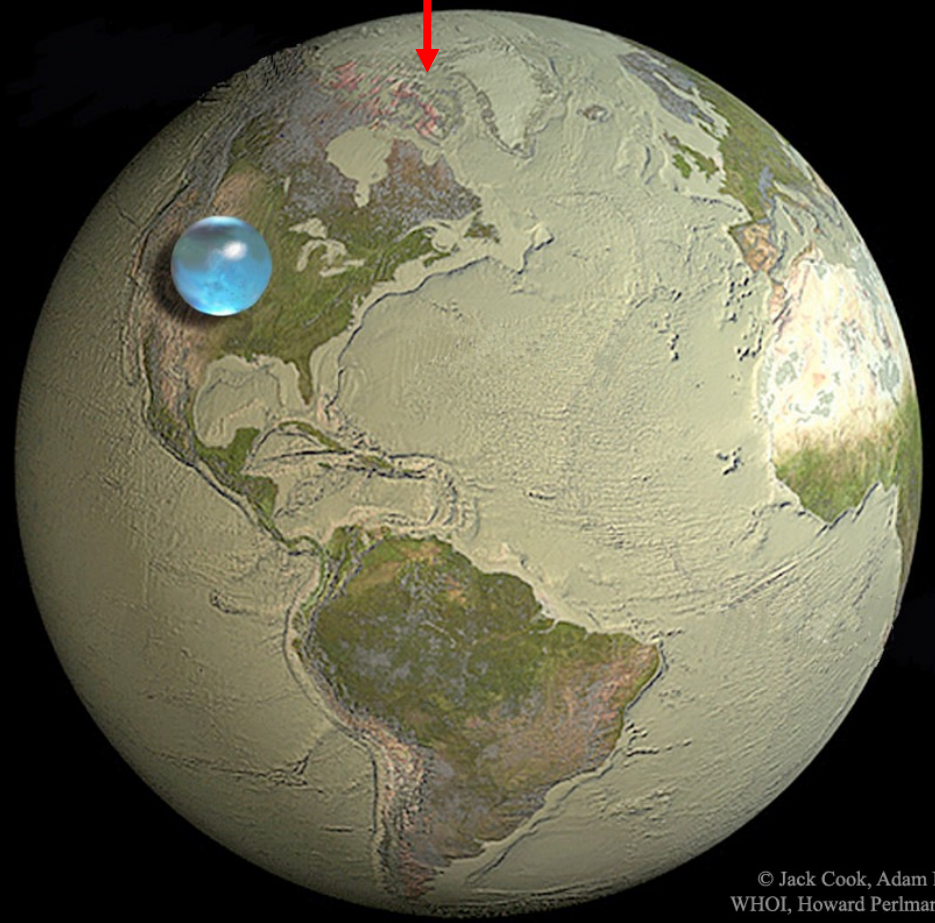


(these are BIG questions)
(let's just tackle 2 parts)
(we only have an hour)

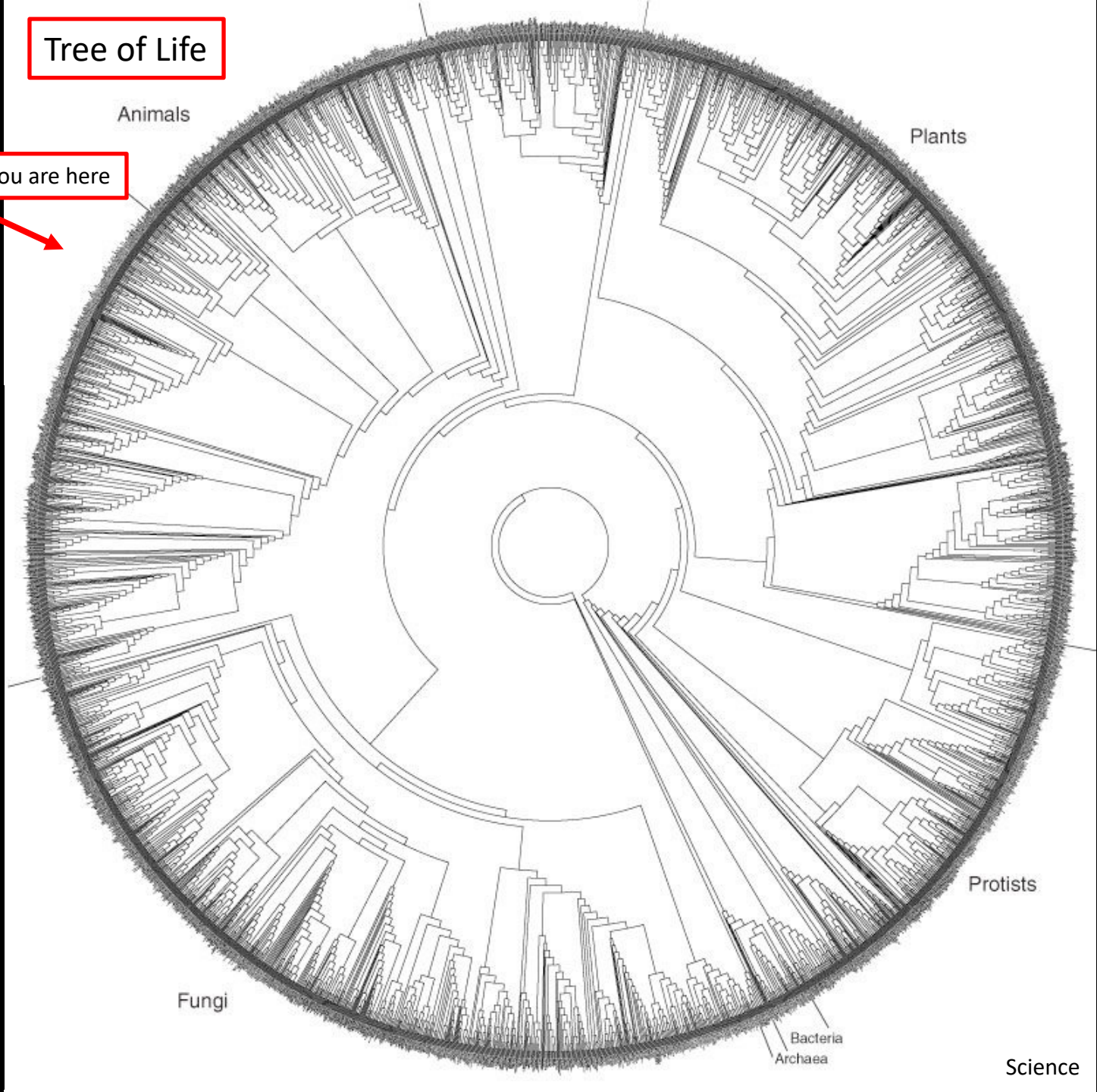


1. ingredients
2. timescale

All the life on Earth.
All the water on Earth.



Tree of Life

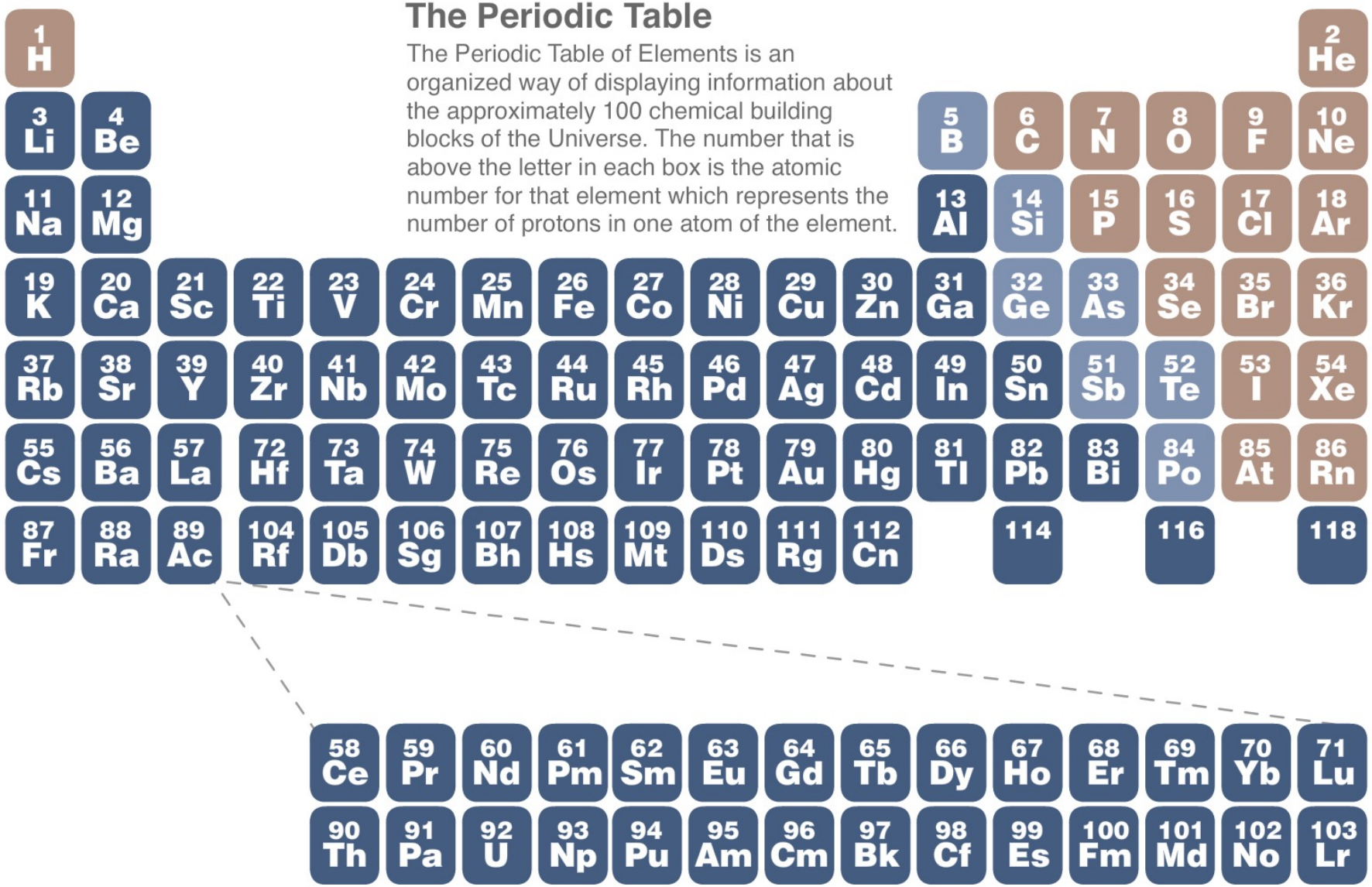


Science

The Chemical Universe

The Periodic Table

The Periodic Table of Elements is an organized way of displaying information about the approximately 100 chemical building blocks of the Universe. The number that is above the letter in each box is the atomic number for that element which represents the number of protons in one atom of the element.

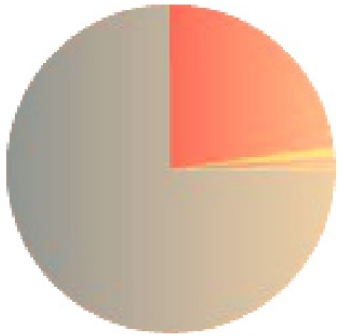


NASA / Chandra

The Chemical Universe

The Periodic Table for Astronomy

In this version of the periodic table, the average abundance by mass of the various elements in the universe (called cosmic abundances) relative to hydrogen is shown by the size of the square for each element. Each pixel corresponds to 0.01 % relative abundance by weight. As illustrated by the size of the squares (rollover to see the actual size) and the pie chart, hydrogen and helium are far and away the most abundant elements in the universe. All the other elements combined would fit inside one pixel, so amount to less than .01 % of the total.



SEE DETAILS

Rollover elements to learn their names and their mass sizes.

NASA / Chandra

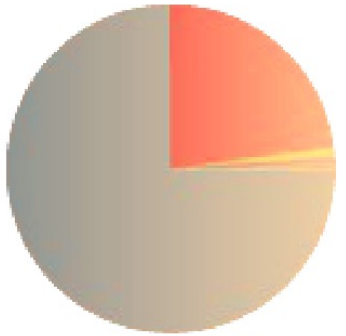
In the beginning…

The Chemical Universe

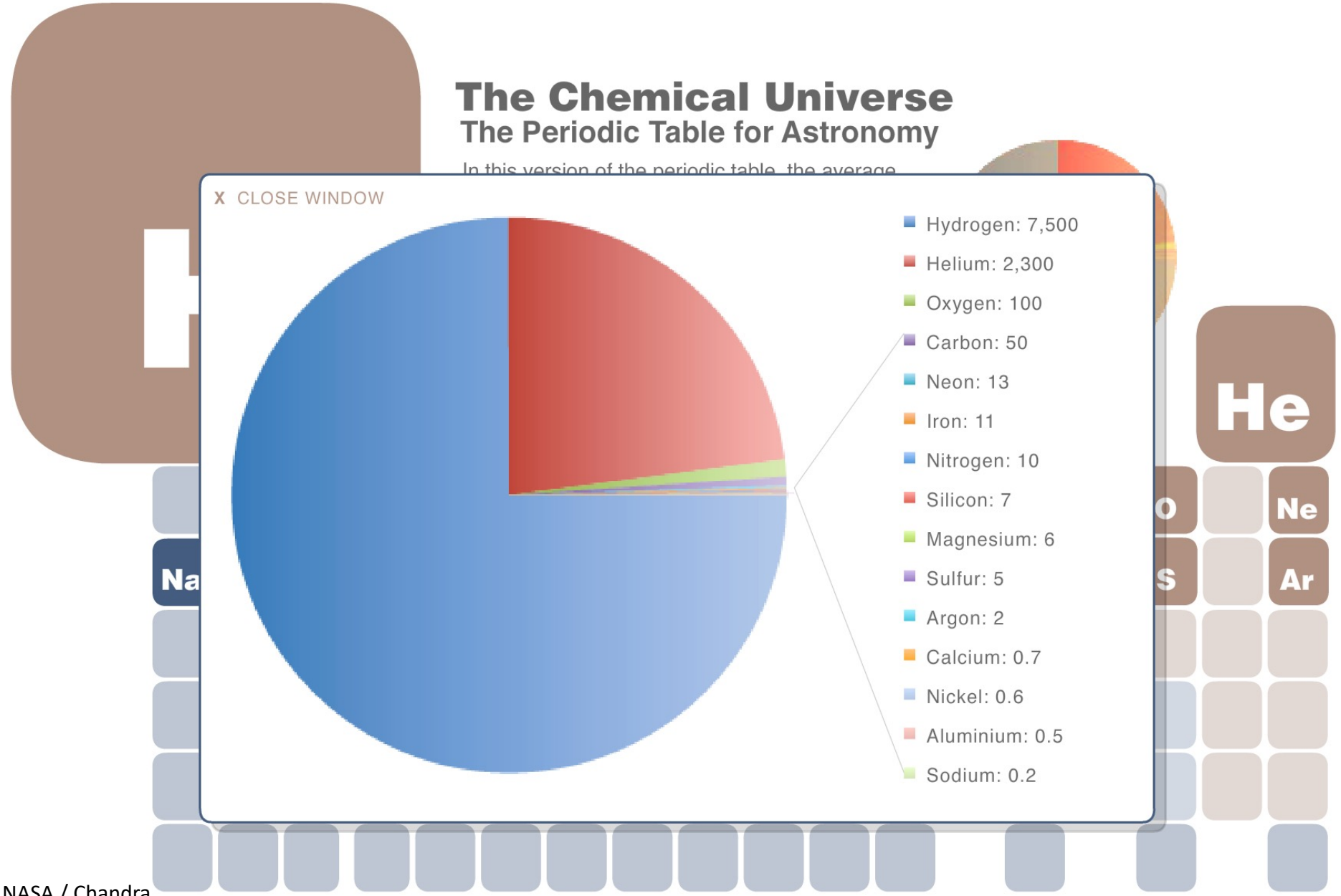
The Periodic Table for Astronomy

In this version of the periodic table, the average abundance by mass of the various elements in the universe (called cosmic abundances) relative to hydrogen is shown by the size of the square for each element. Each pixel corresponds to 0.01 % relative abundance by weight. As illustrated by the size of the squares (rollover to see the actual size) and the pie chart, hydrogen and helium are far and away the most abundant elements in the universe. All the other elements combined would fit inside one pixel, so amount to less than .01 % of the total.

Rollover elements to learn their names and their mass sizes.

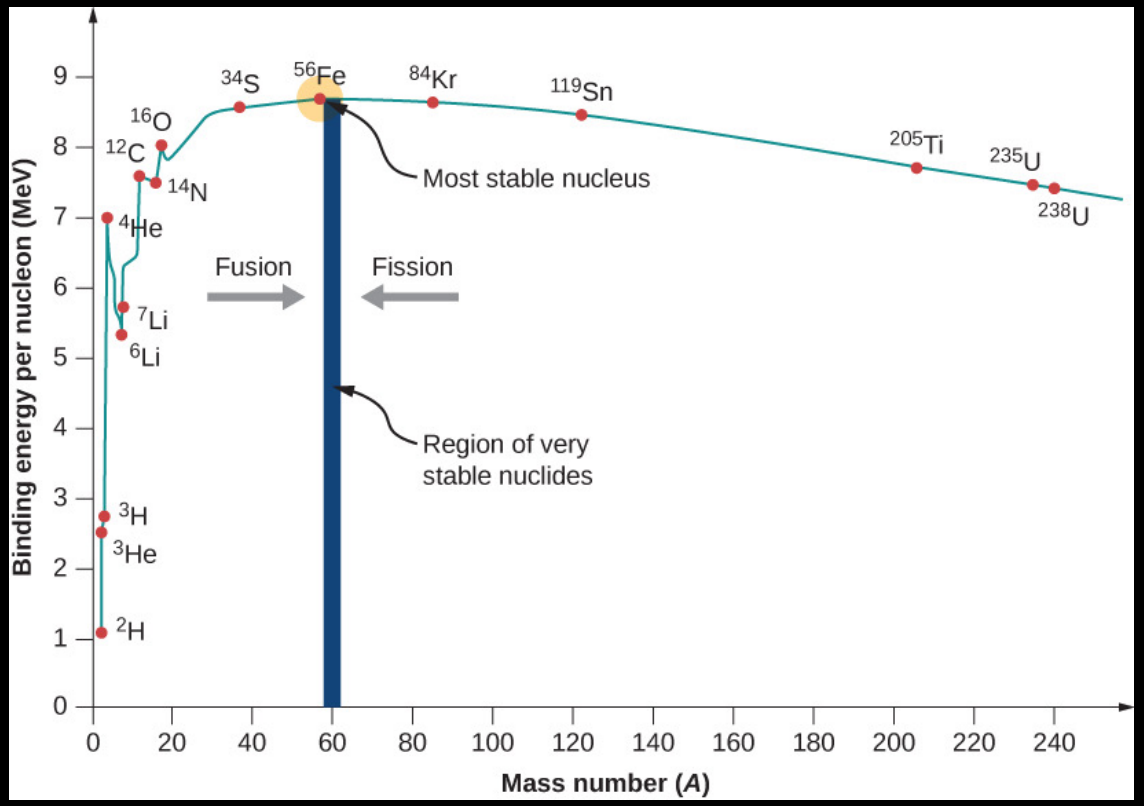


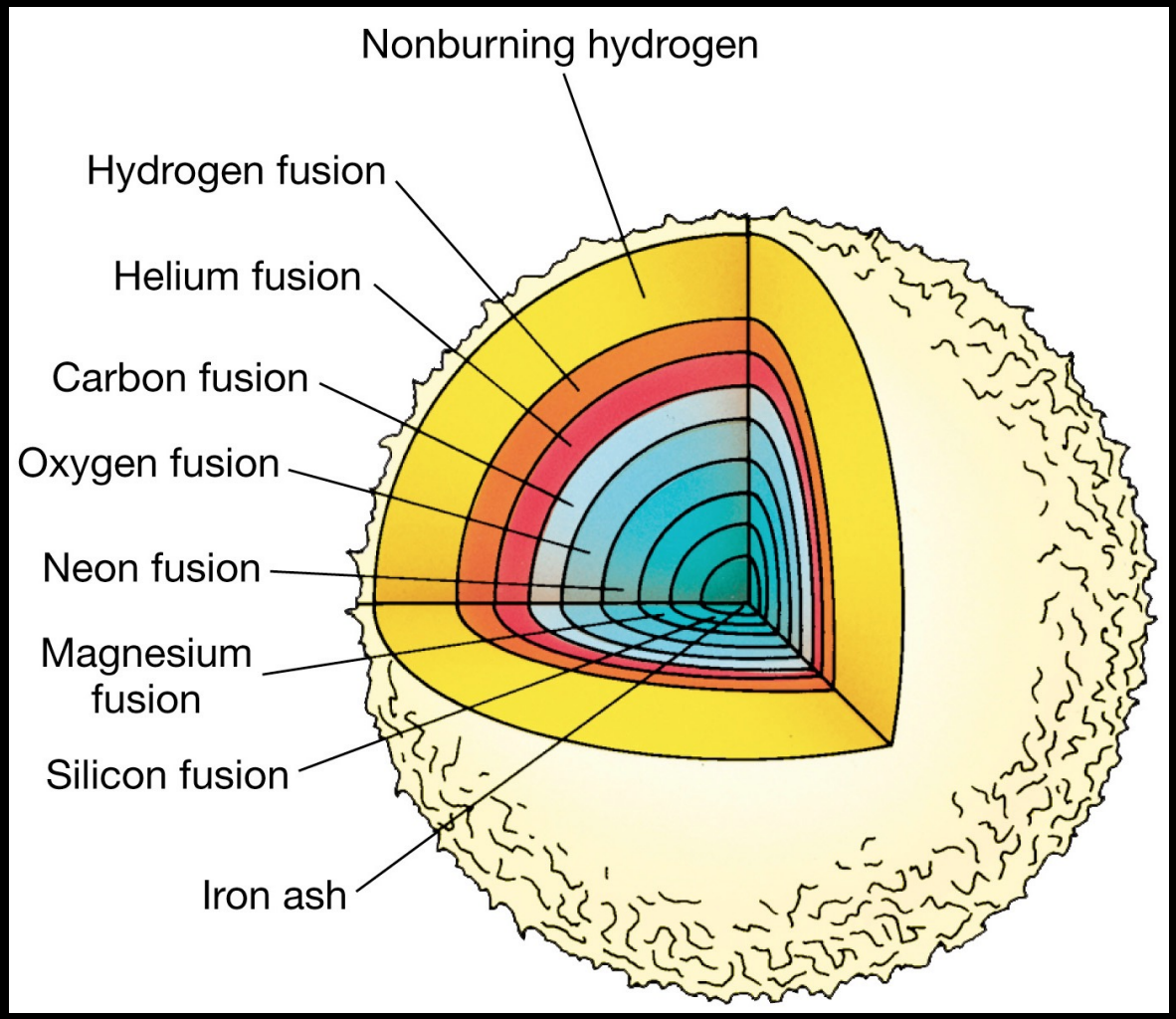
NASA / Chandra



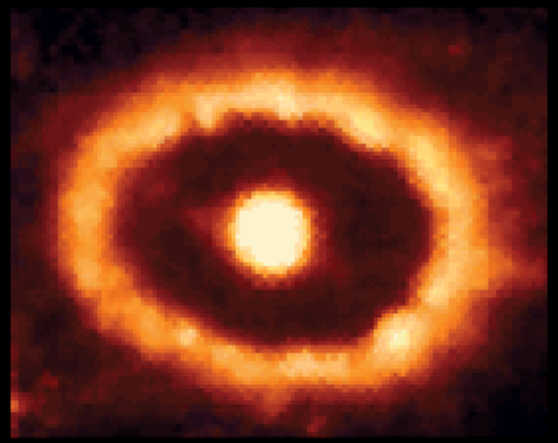
NASA / Chandra

We are all made of star stuff – the result of a battle between gravity and whatever the star can come up with.





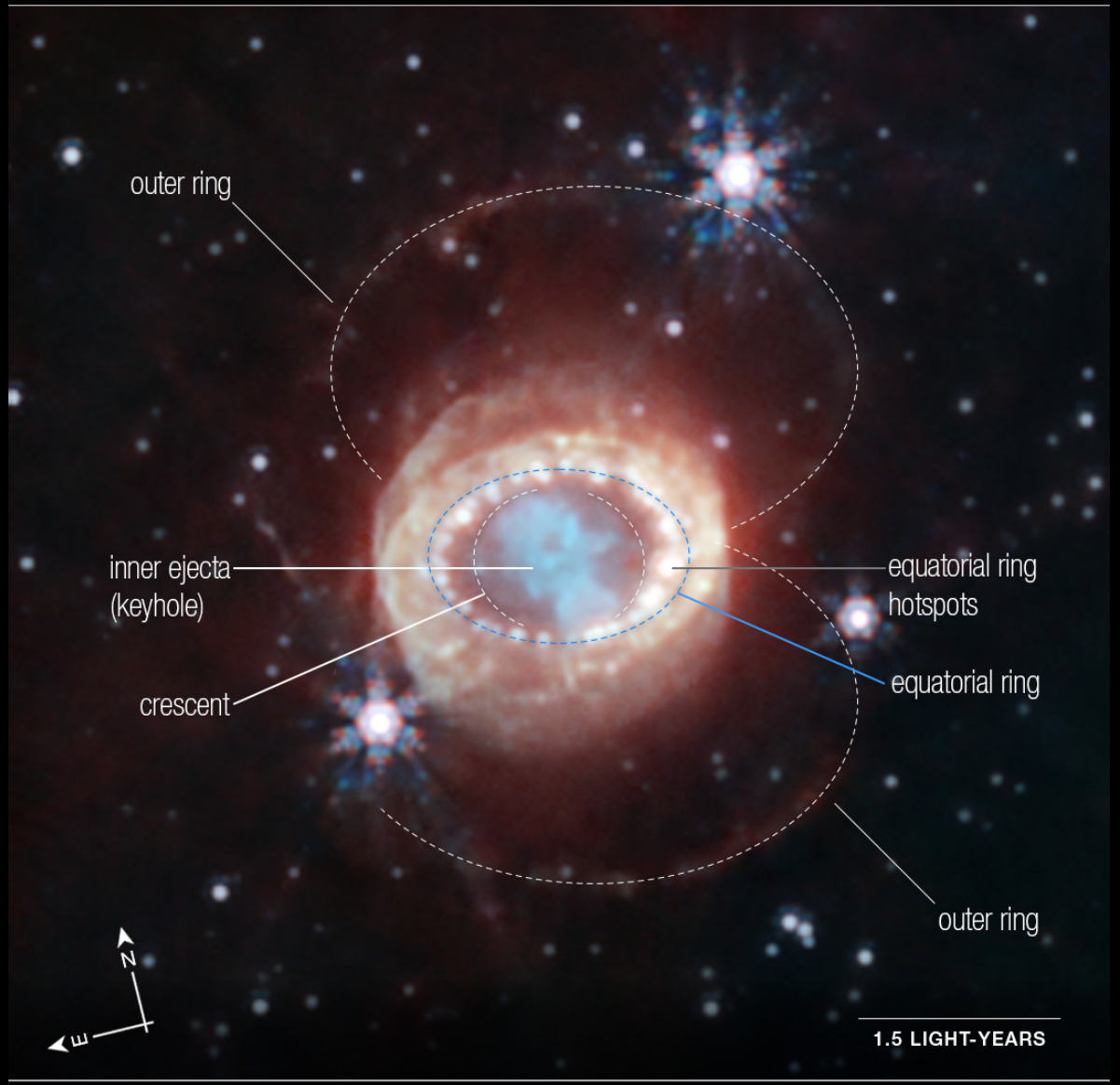
SN1987A (HST/ACS – Peter Challis)



09/1994

JAMES WEBB SPACE TELESCOPE

SUPERNOVA 1987A



NIRCam Filters | F150W F164N F200W F322N F405N F444W

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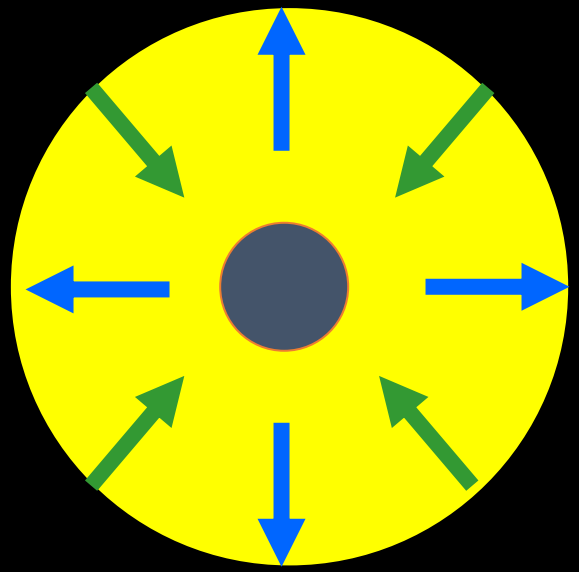
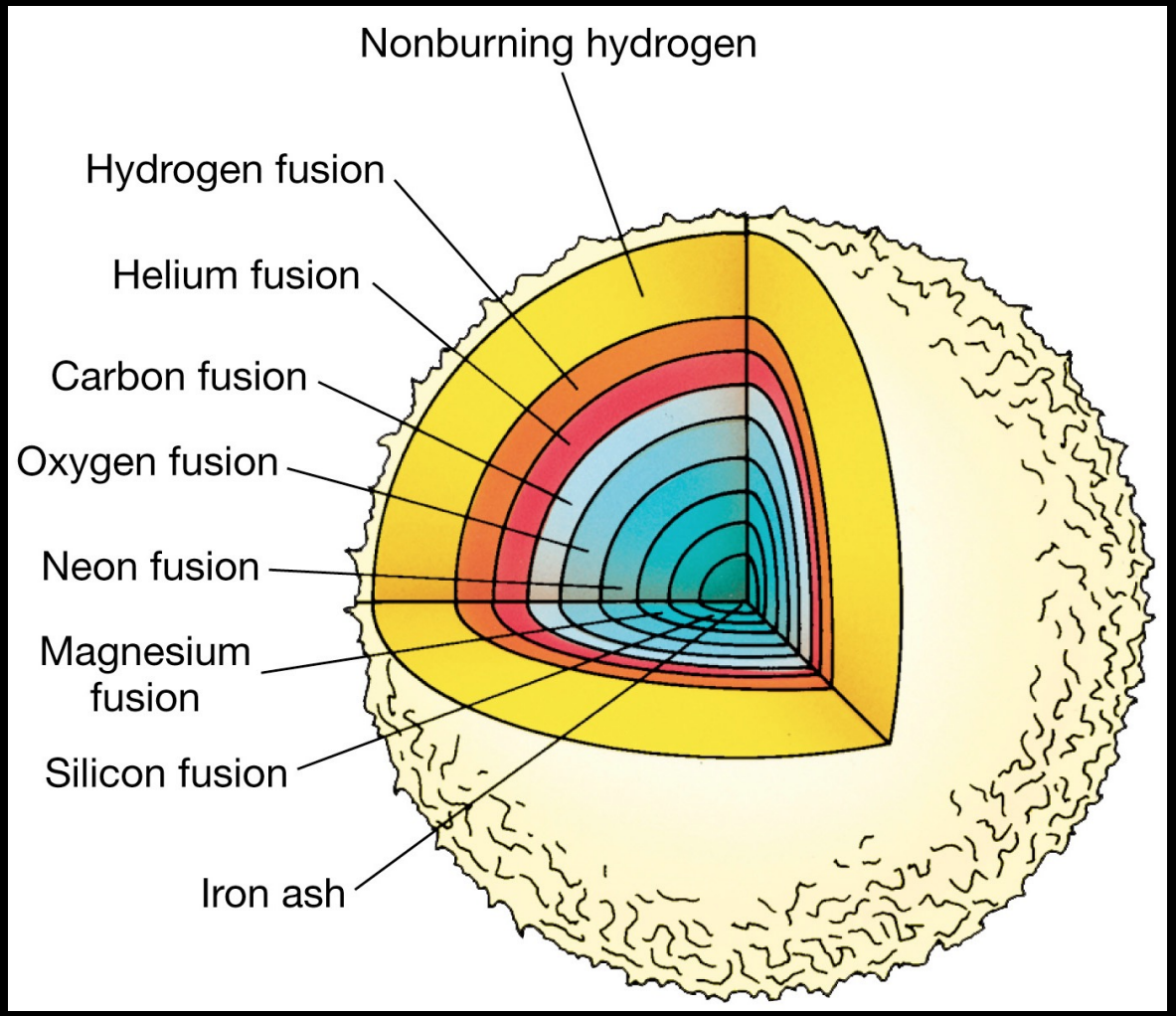
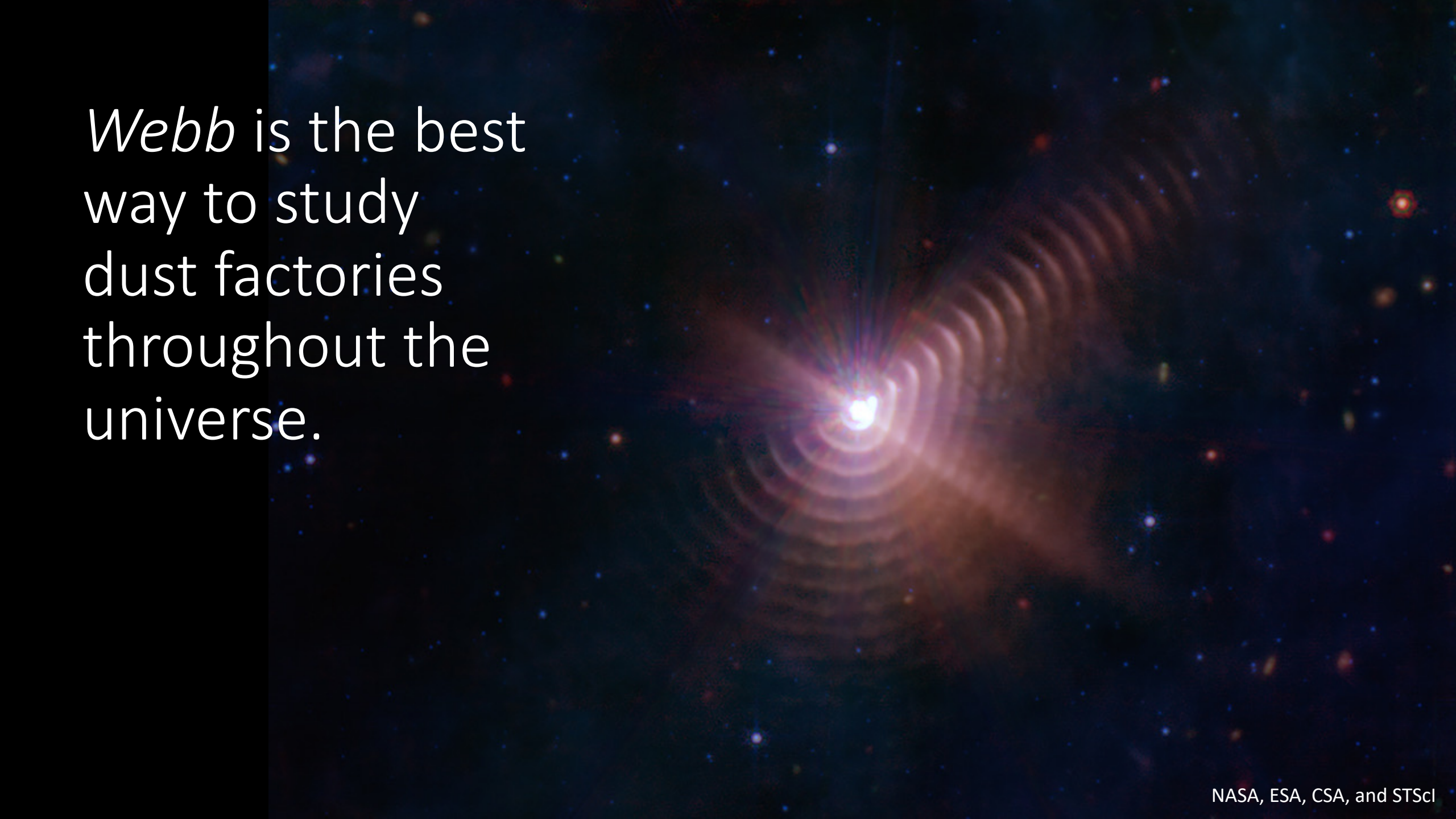




Webb is the best way to study dust factories throughout the universe.



NASA, ESA, CSA, and STScI

Dying high-mass stars supply elements (^{26}Al) that may determine the water budget of Earth-like planets.

$^{26}\mathrm{Al} \gtrapprox {}^{26}\mathrm{Al}_{\oplus}$

⇩

extra heat → dehydrates planetesimals

⇩

rocky (Earth-like) planet

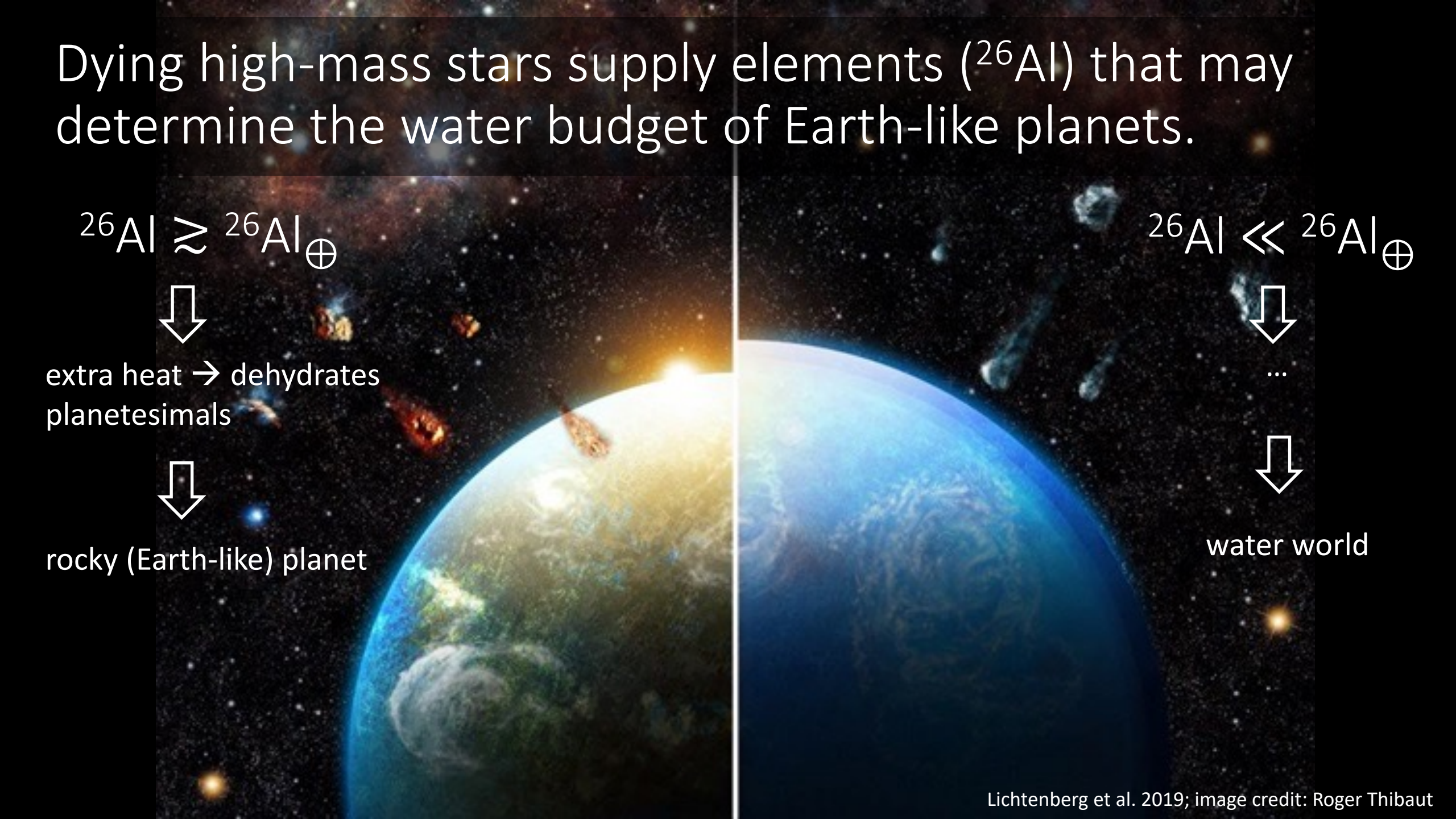
$^{26}\mathrm{Al} \ll {}^{26}\mathrm{Al}_{\oplus}$

⇩

…

⇩

water world



Lichtenberg et al. 2019; image credit: Roger Thibaut

Great! But how do you get this stuff into planets?

Low-mass stars are the most likely to host planets; high-mass stars have the strongest influence on the environment.

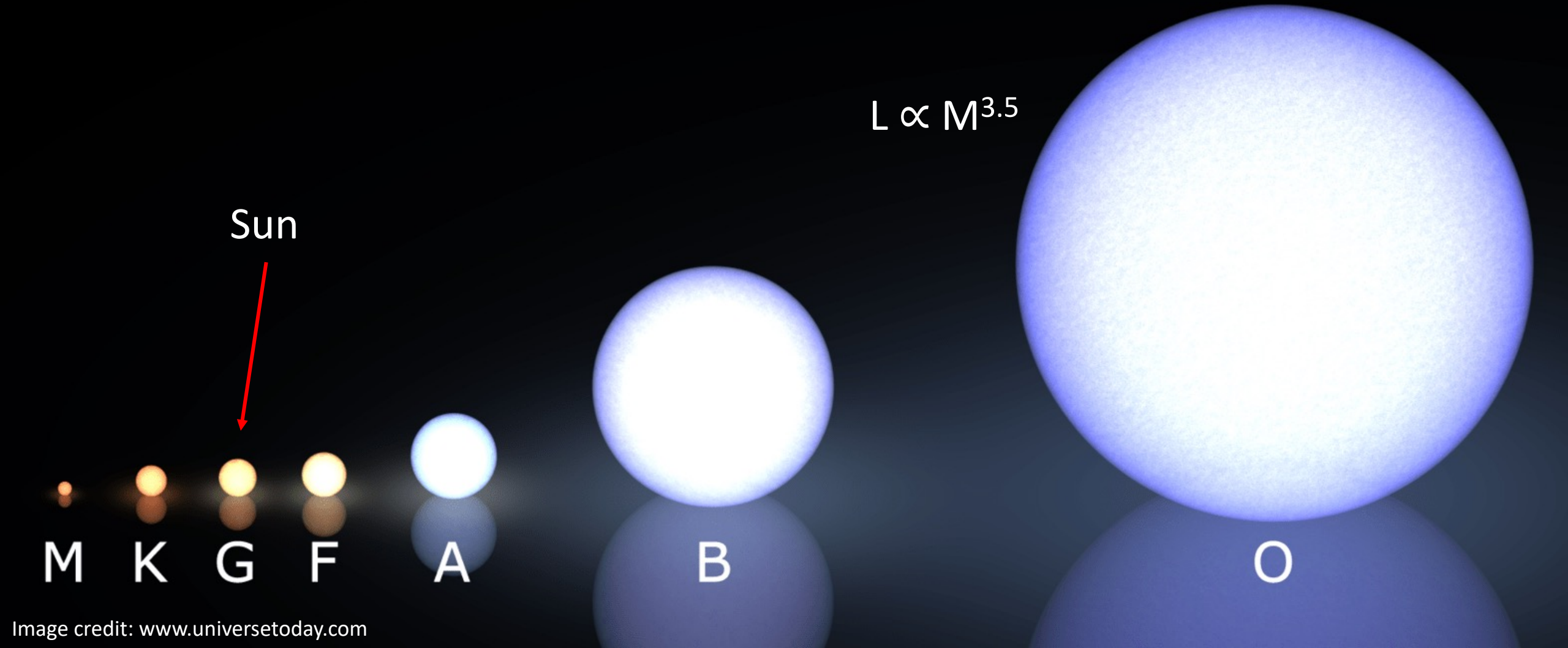
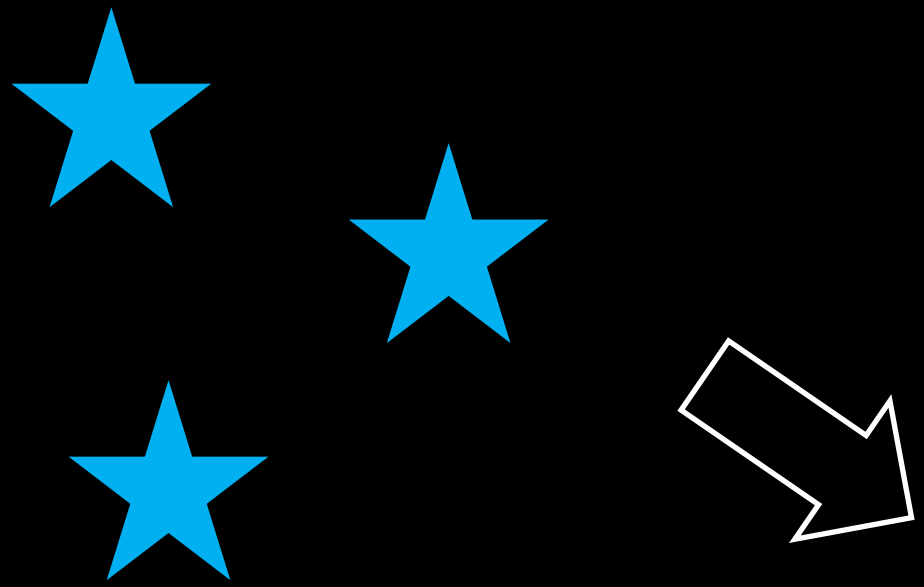
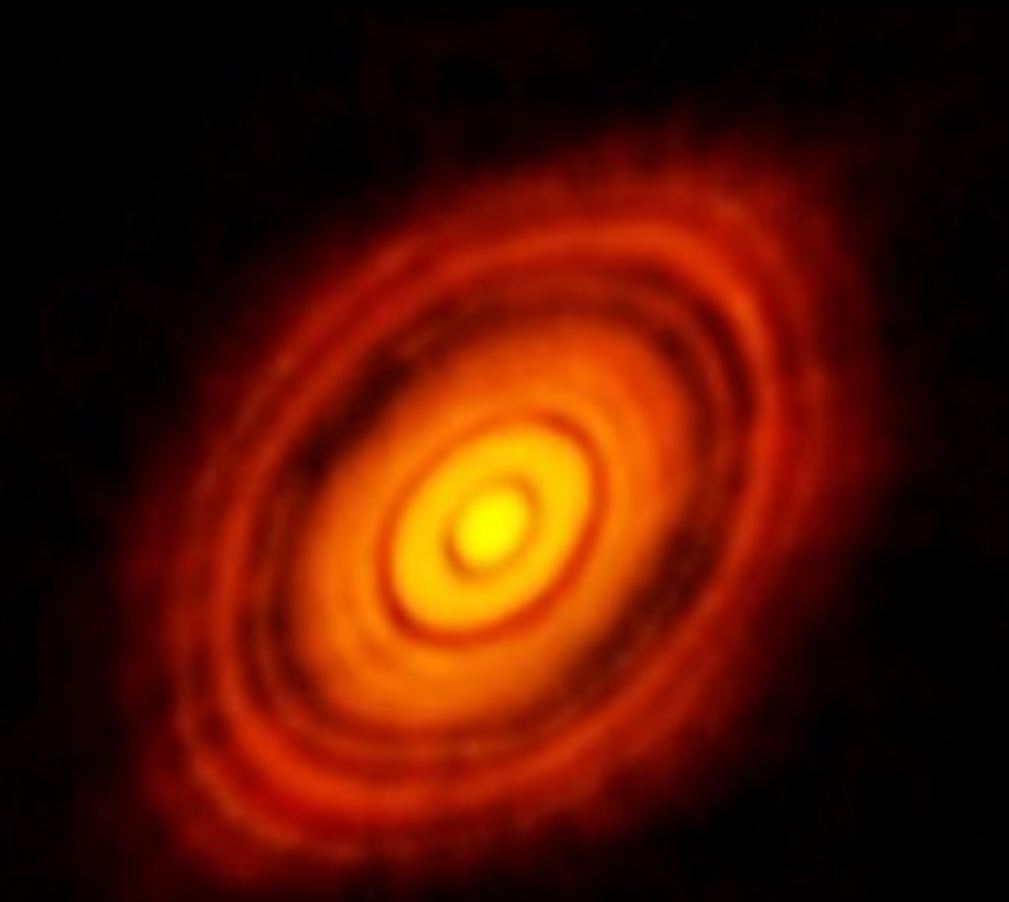


Image credit: www.universetoday.com

Neighbors in the star-forming region can reduce the time and materials to make planets.





ALMA partnership

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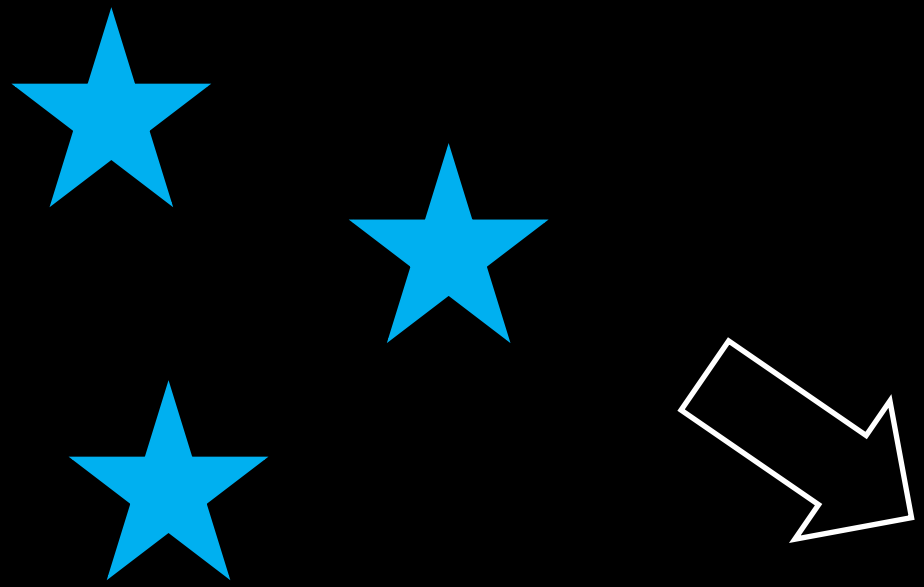
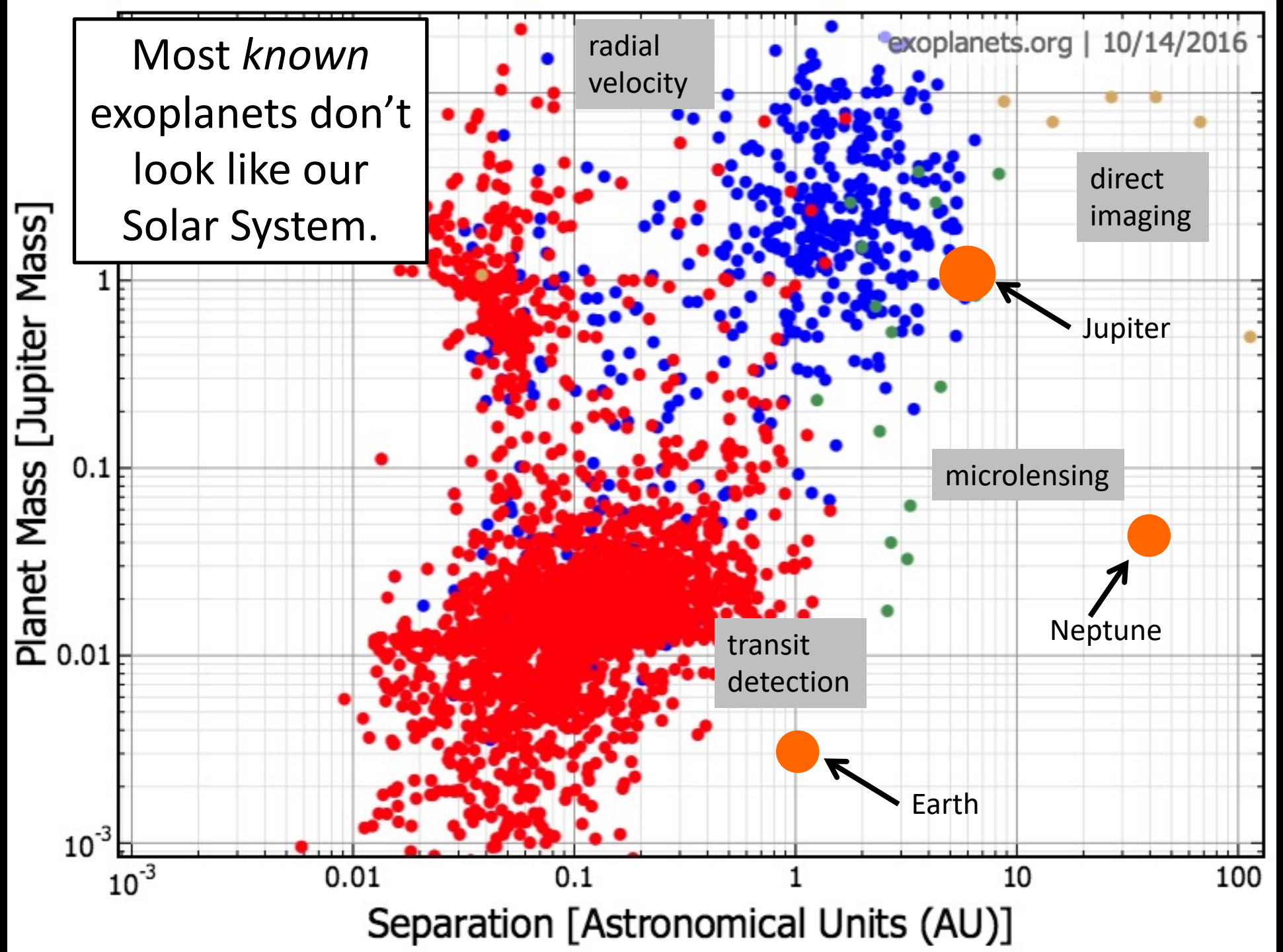
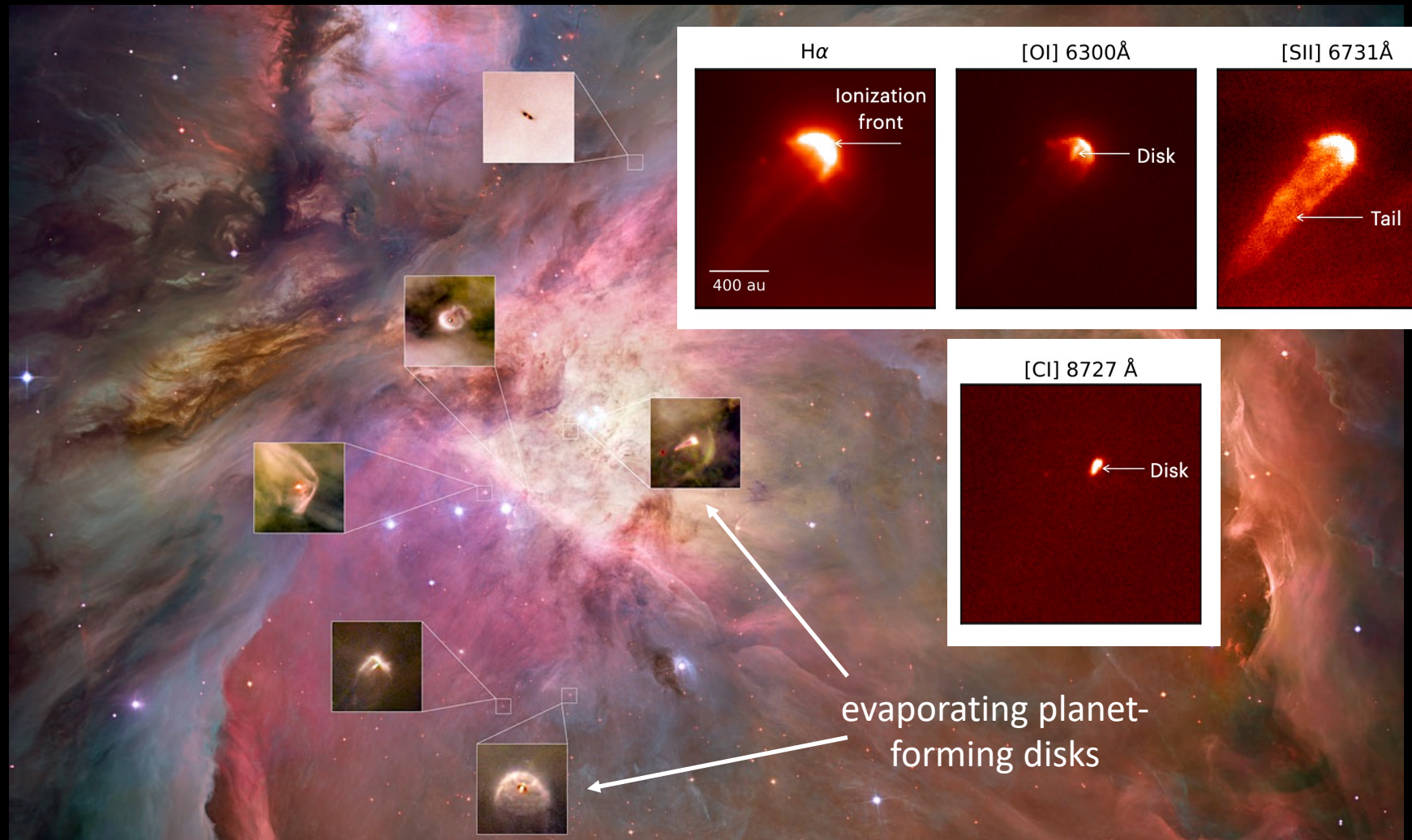



Most *known* exoplanets don't look like our Solar System.
exoplanets.org | 10/14/2016
radial velocity
direct imaging
Jupiter
microlensing
Neptune
transit detection
Earth
Planet Mass [Jupiter Mass]
Separation [Astronomical Units (AU)]
1
0.1
0.01
10^{-3}
10^{-3}
0.01
0.1
1
10
100

High-mass stars profoundly shape the birthplaces where most stars and planets form.



Aru et al. 2024a,b

evaporating planet-forming disks

NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA), the Hubble Space Telescope Orion Treasury Project Team and L. Ricci (ESO)

shielded planet-forming disk!

Seek shade and use sunscreen to reduce how quickly you evaporate (or, in Houston, melt).

Dust is great sunscreen for stars and their planet-forming disks but we *can't* see through it at visual wavelengths.

Dust is great sunscreen for stars and their planet-forming disks and we *can* see through it at infrared wavelengths.

Webb images revealed dozens of newborn stars in a pretty quiet region of a high-mass star-forming region (NGC 3324).

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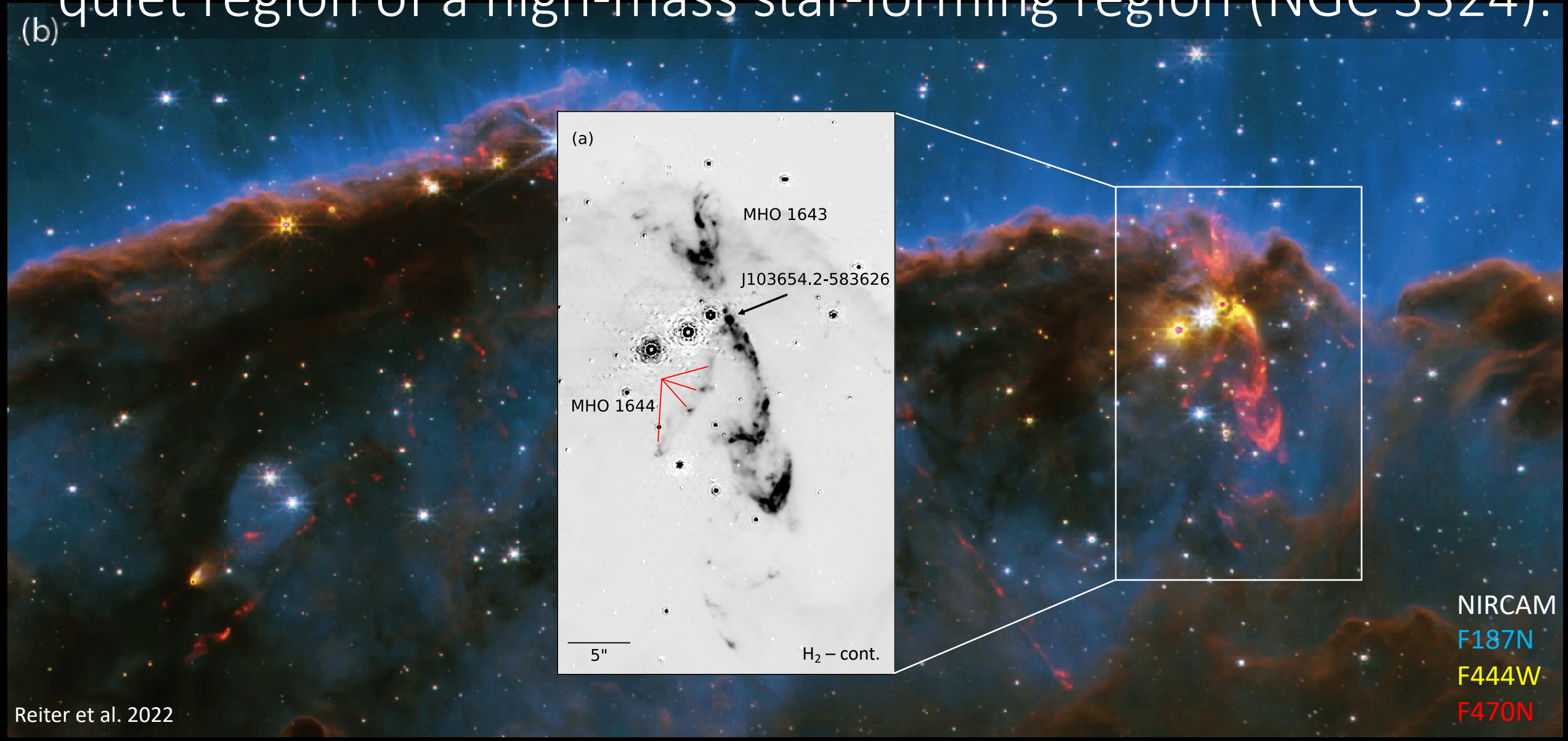
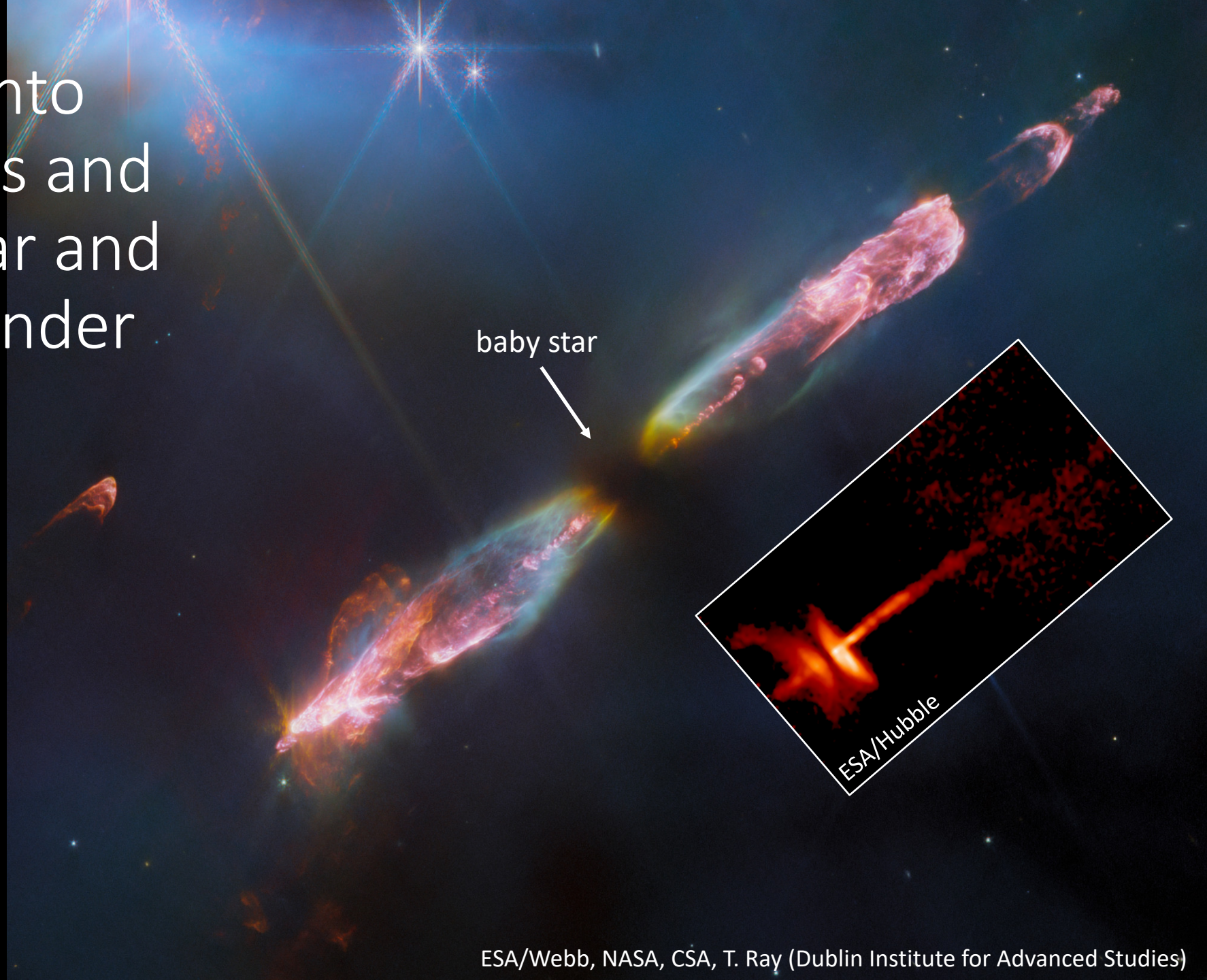


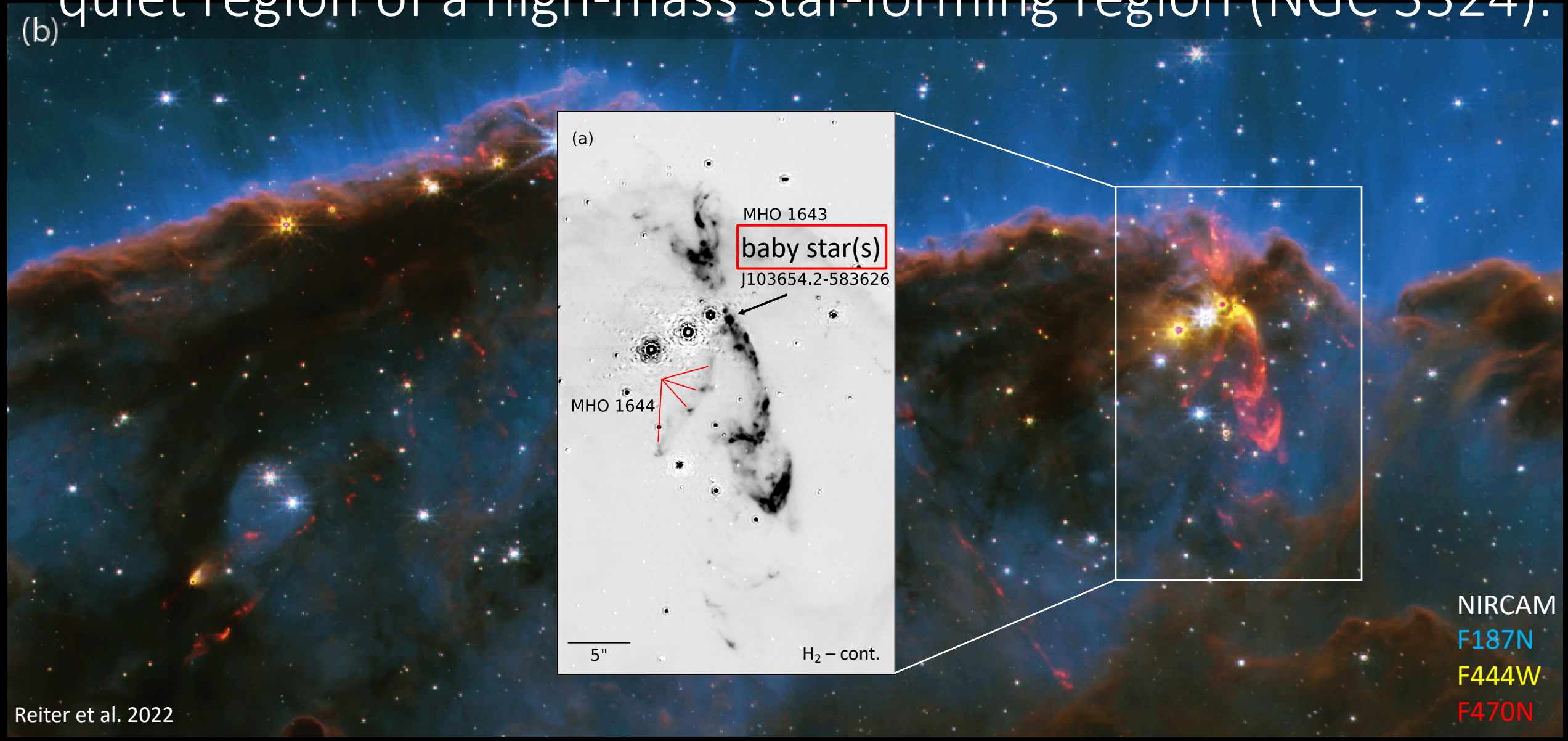
Reiter et al. 2022

Webb can peer into clouds of cold gas and dust to reveal star and planet systems under construction.



ESA/Webb, NASA, CSA, T. Ray (Dublin Institute for Advanced Studies)

Webb images revealed dozens of newborn stars in a pretty quiet region of a high-mass star-forming region (NGC 3324).



Reiter et al. 2022

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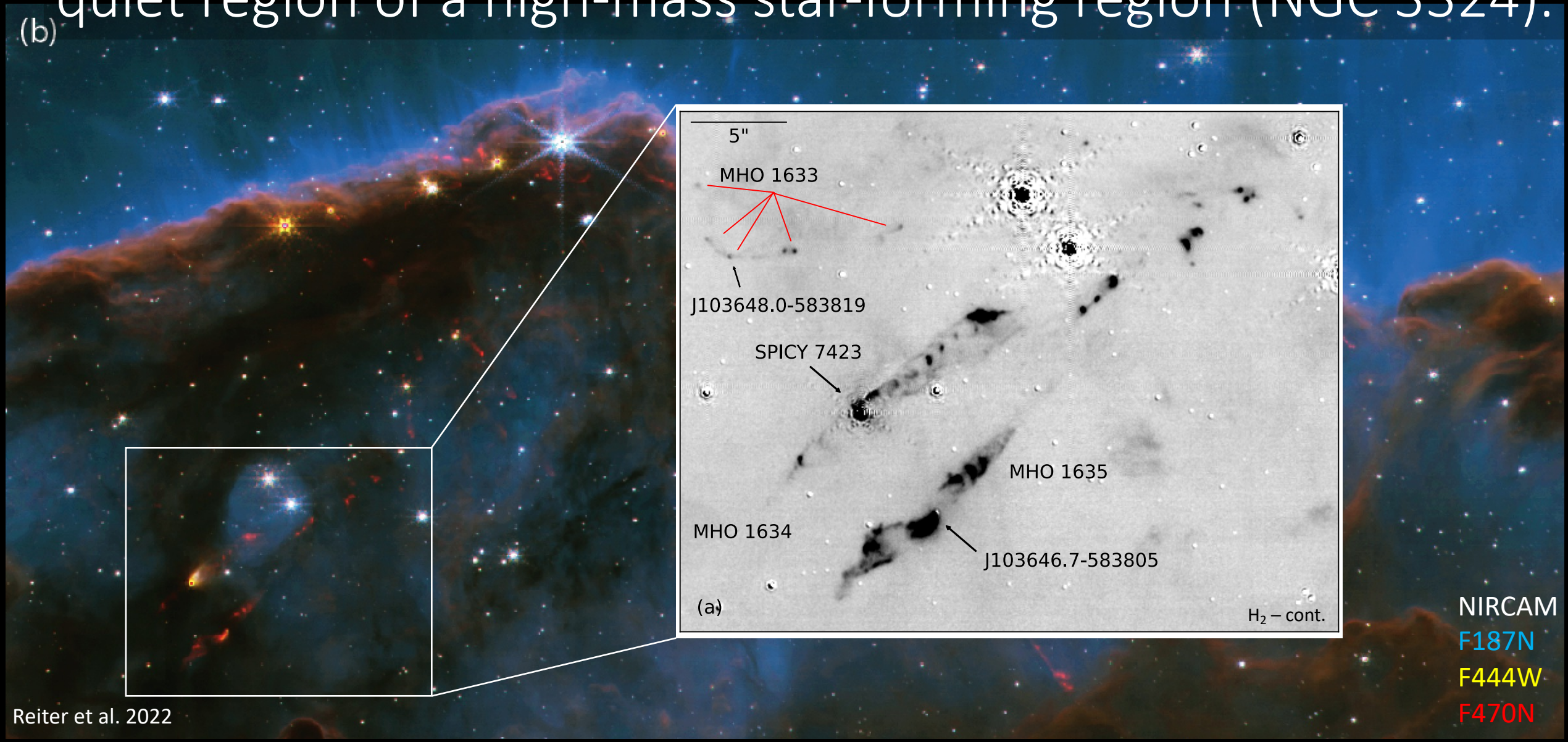

Reiter et al. 2022

Webb and *Hubble* imaged the same area ~16 years apart – this allows us to measure how things are moving.

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Taking pictures several years apart allows us to measure how fast stars, jets, and outflows are moving.

Reiter et al. 2015

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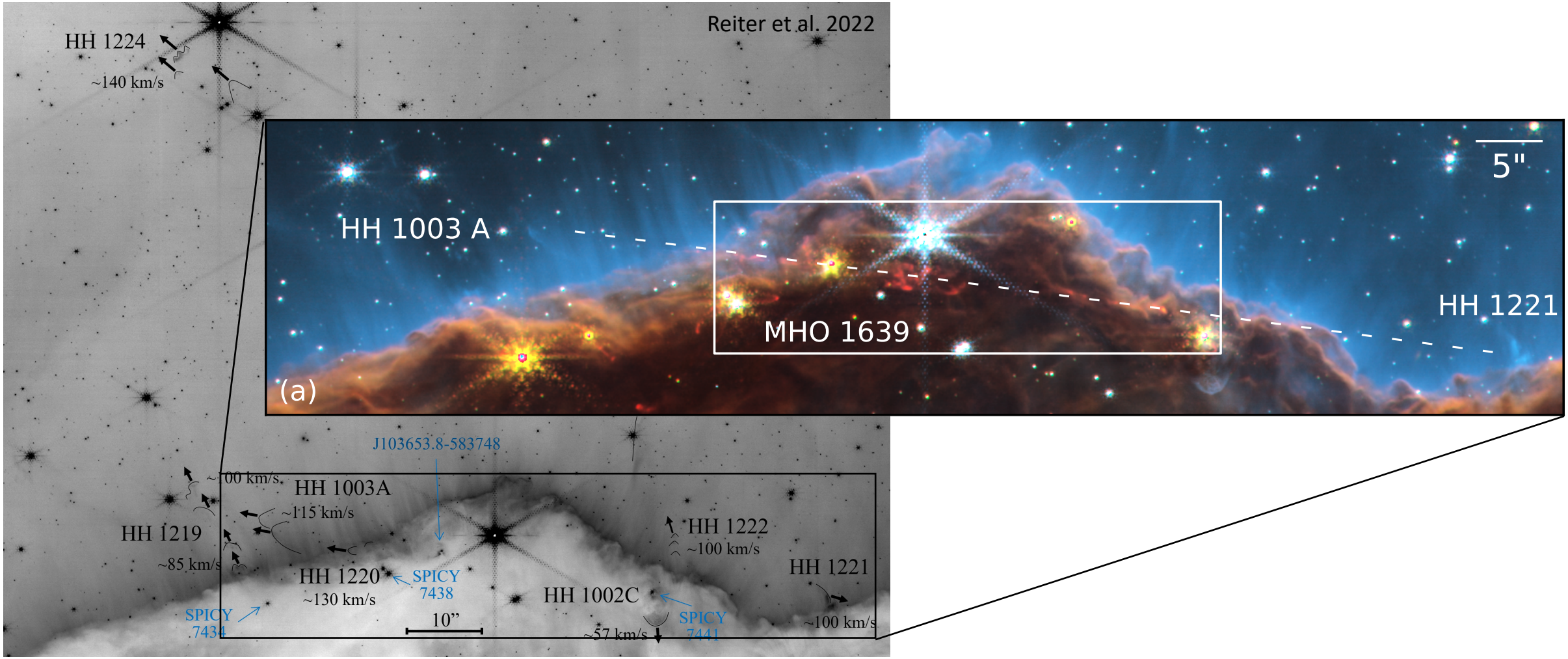
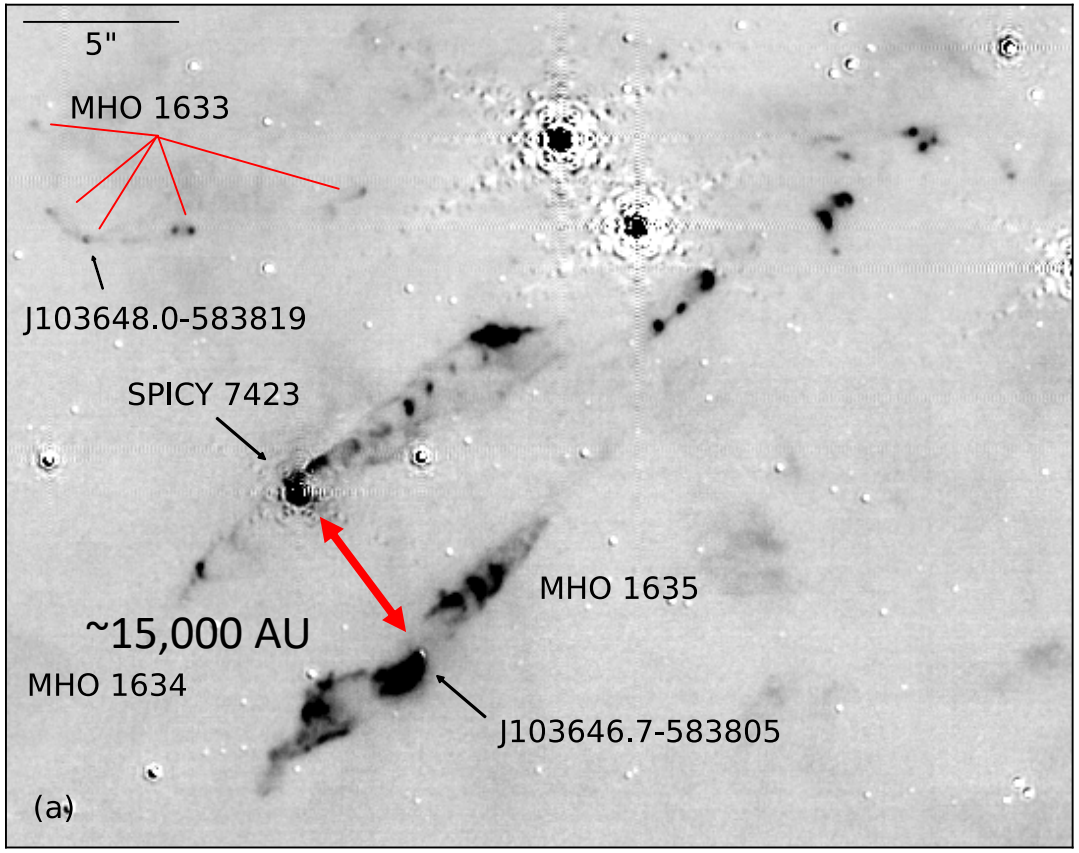
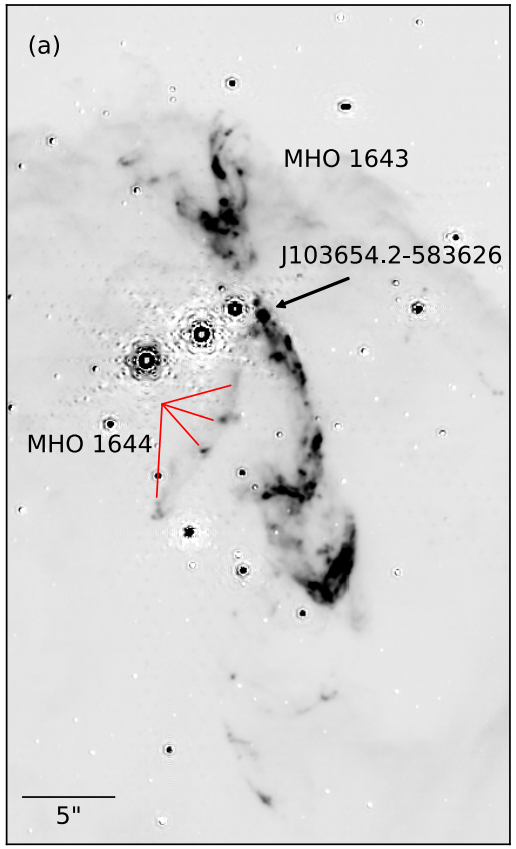


The historical record: jets and outflows reveal the growth history of stars, prevailing winds, how stars are moving, …



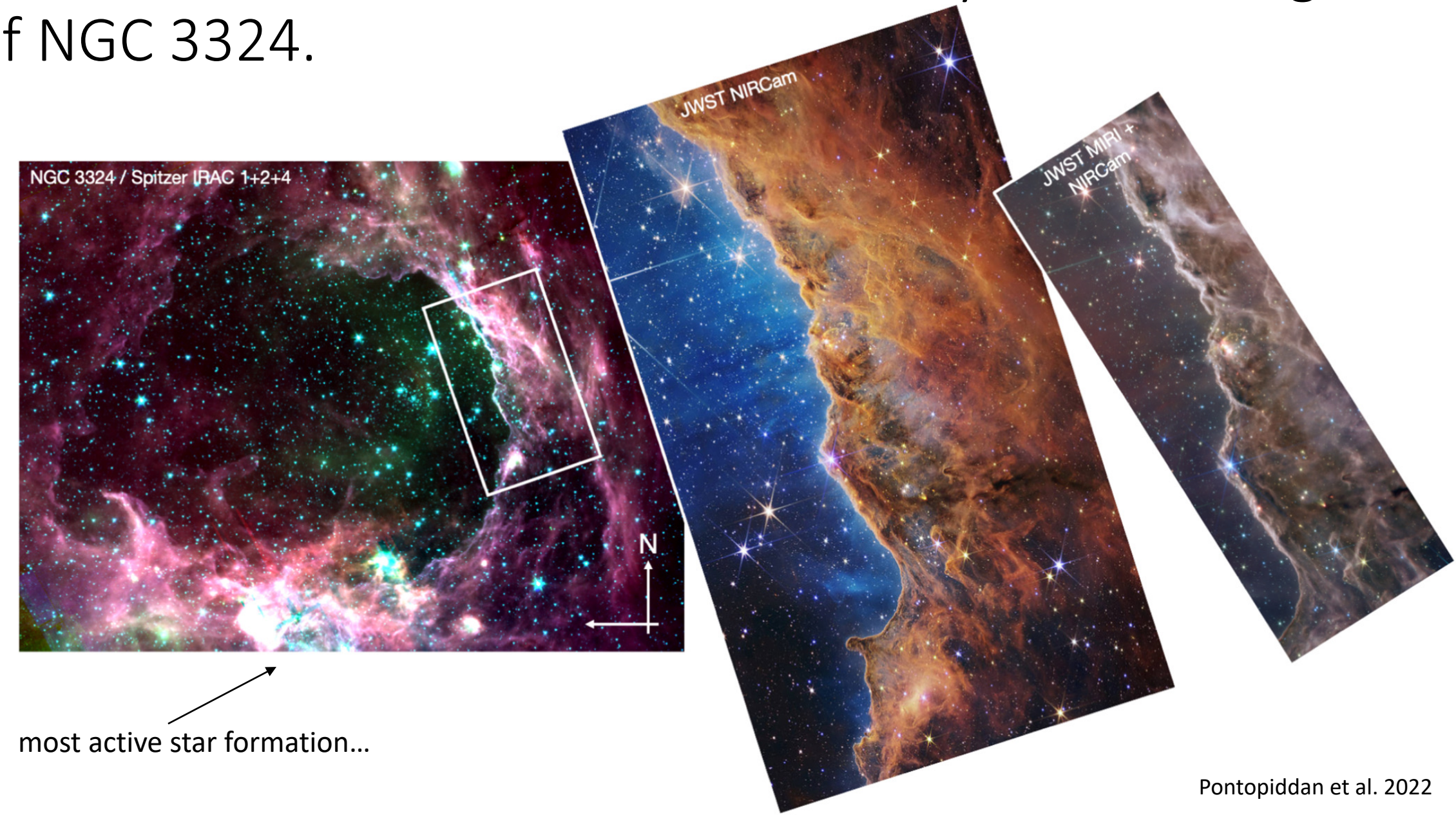
inching away from each other?



gone wandering?

(ask me again in about ~10 years)

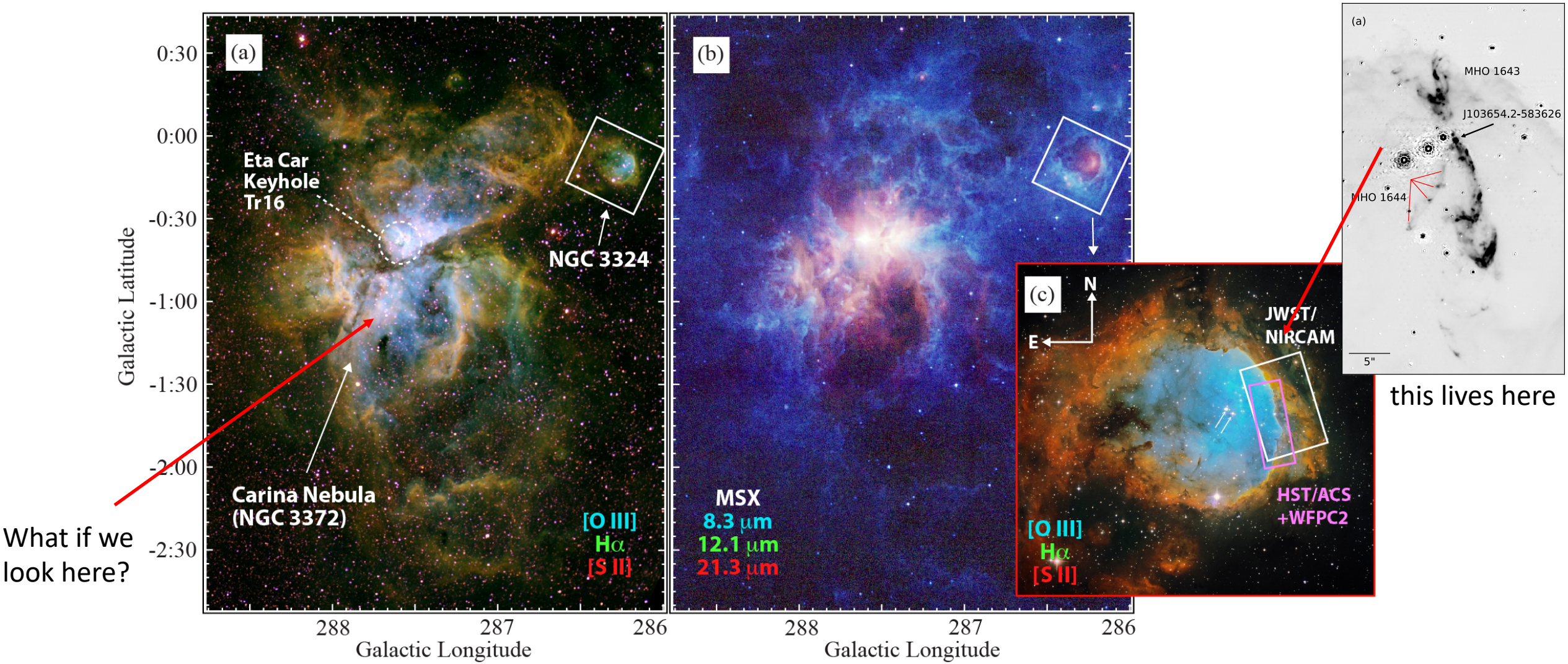
The ‘Cosmic Cliffs’ are not the most actively star-forming part of NGC 3324.



most active star formation…

Pontopiddan et al. 2022

NGC 3324 is in the constellation Carina, but is relatively isolated in the suburbs of the Carina star-forming complex.



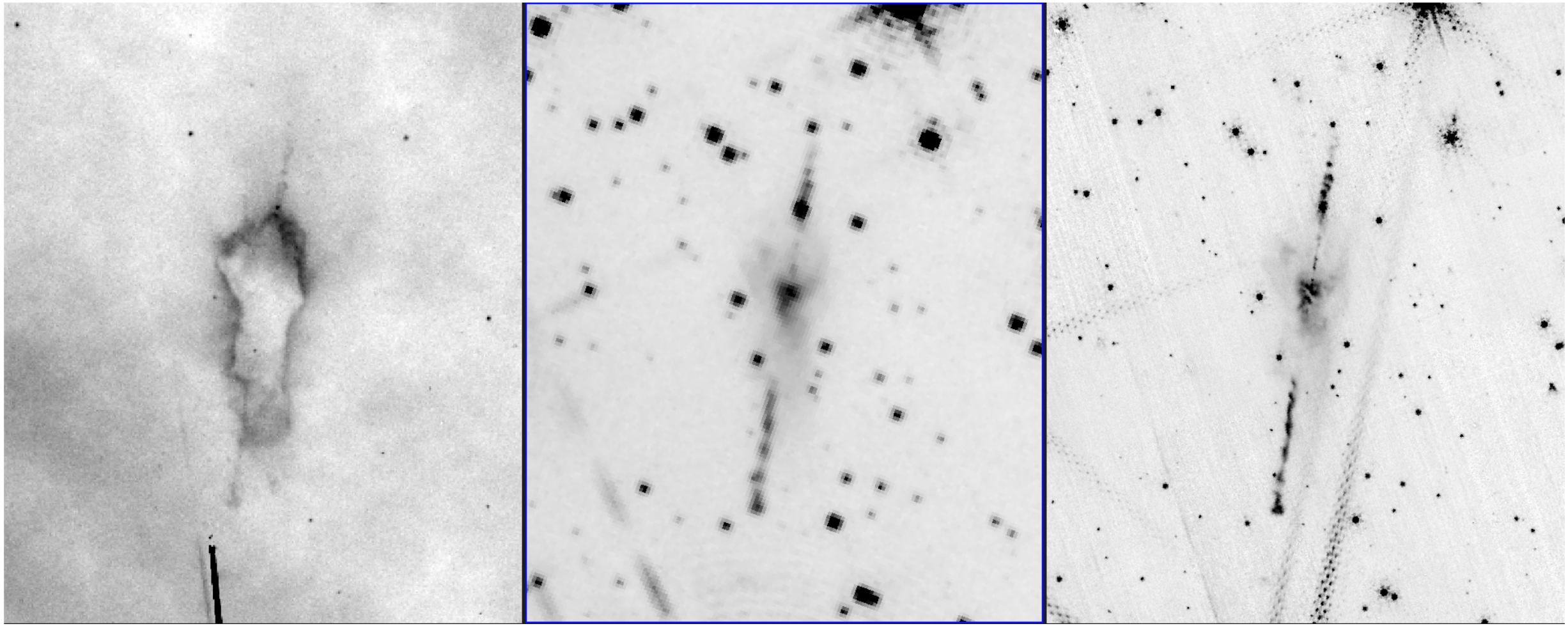
Reiter et al. 2022; adapted from Smith et al. 2000 and Smith & Brooks 2007 and Telescope Live with permission (image credit: V. Unguru / Telescope Live).

Hot off the telescope! Diving deeper than Hubble…

The original Hubble image in Hα (2006)

[Fe II] image from Hubble (2015)

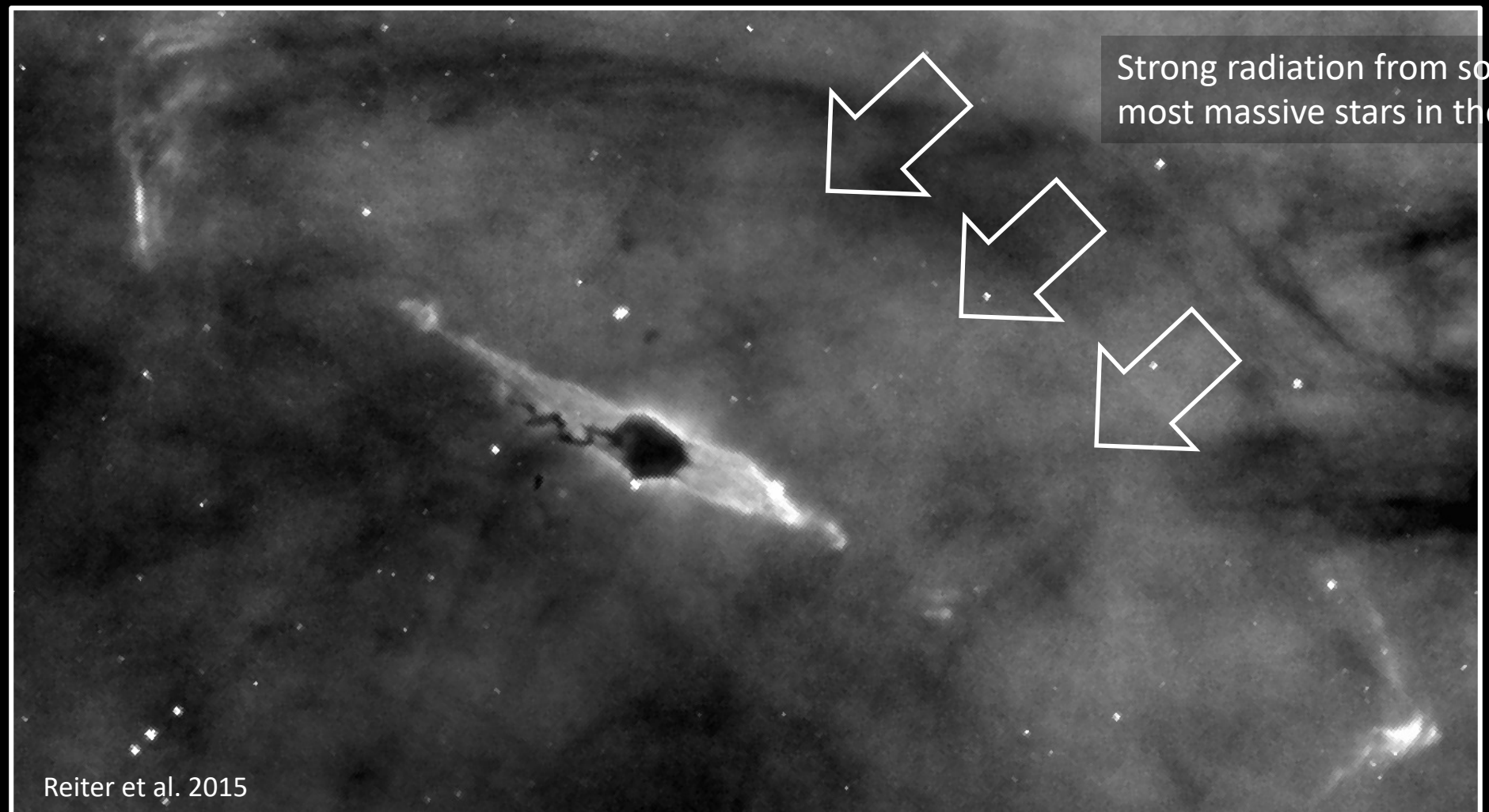
[Fe II] image from Webb (Wednesday)



This is about 5% of the data
we will get with this program.

(I guess you know what our summer plans are)

In the future: determine how these environments affect the time and materials for planet formation with *Webb*.



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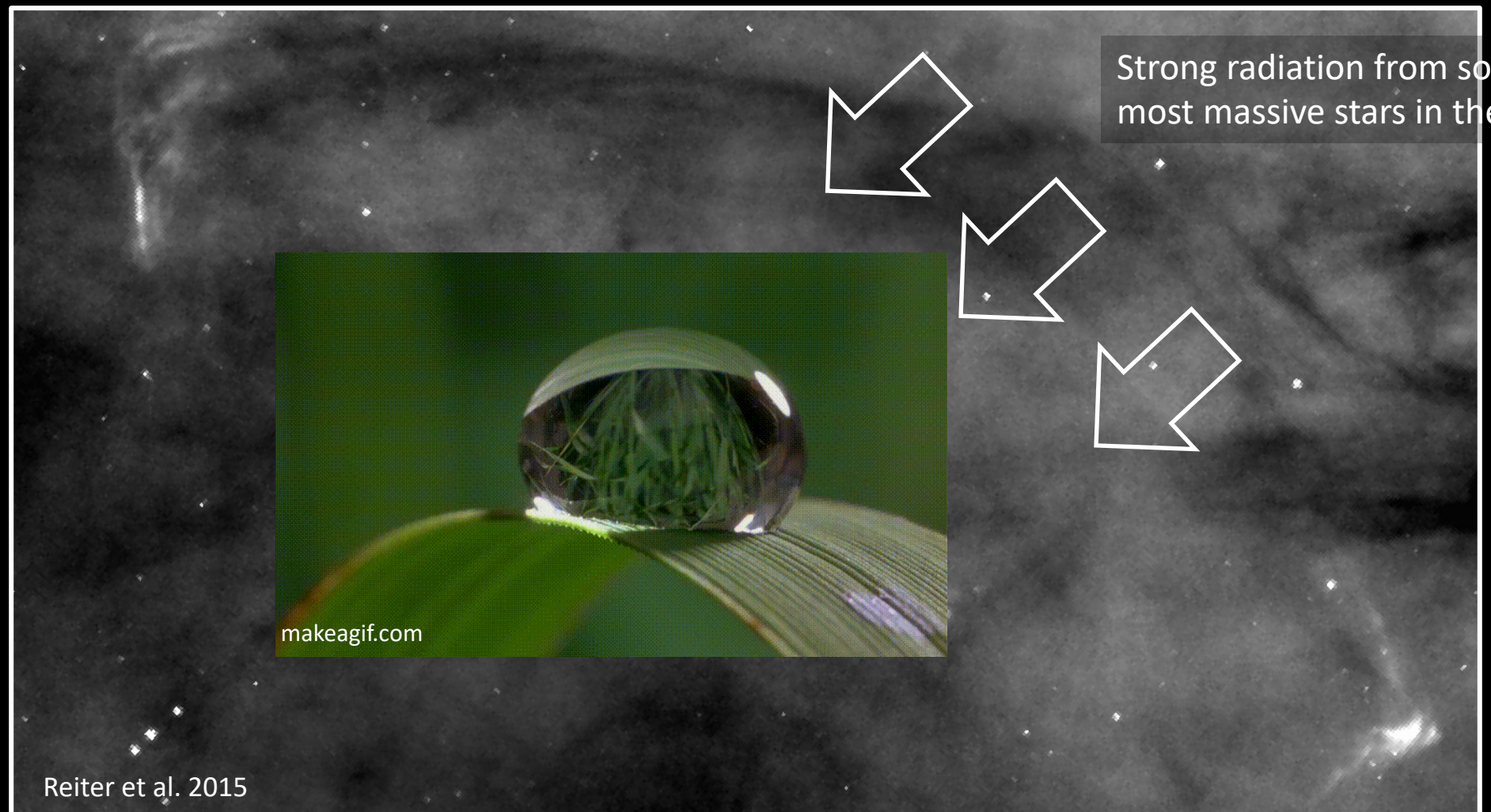
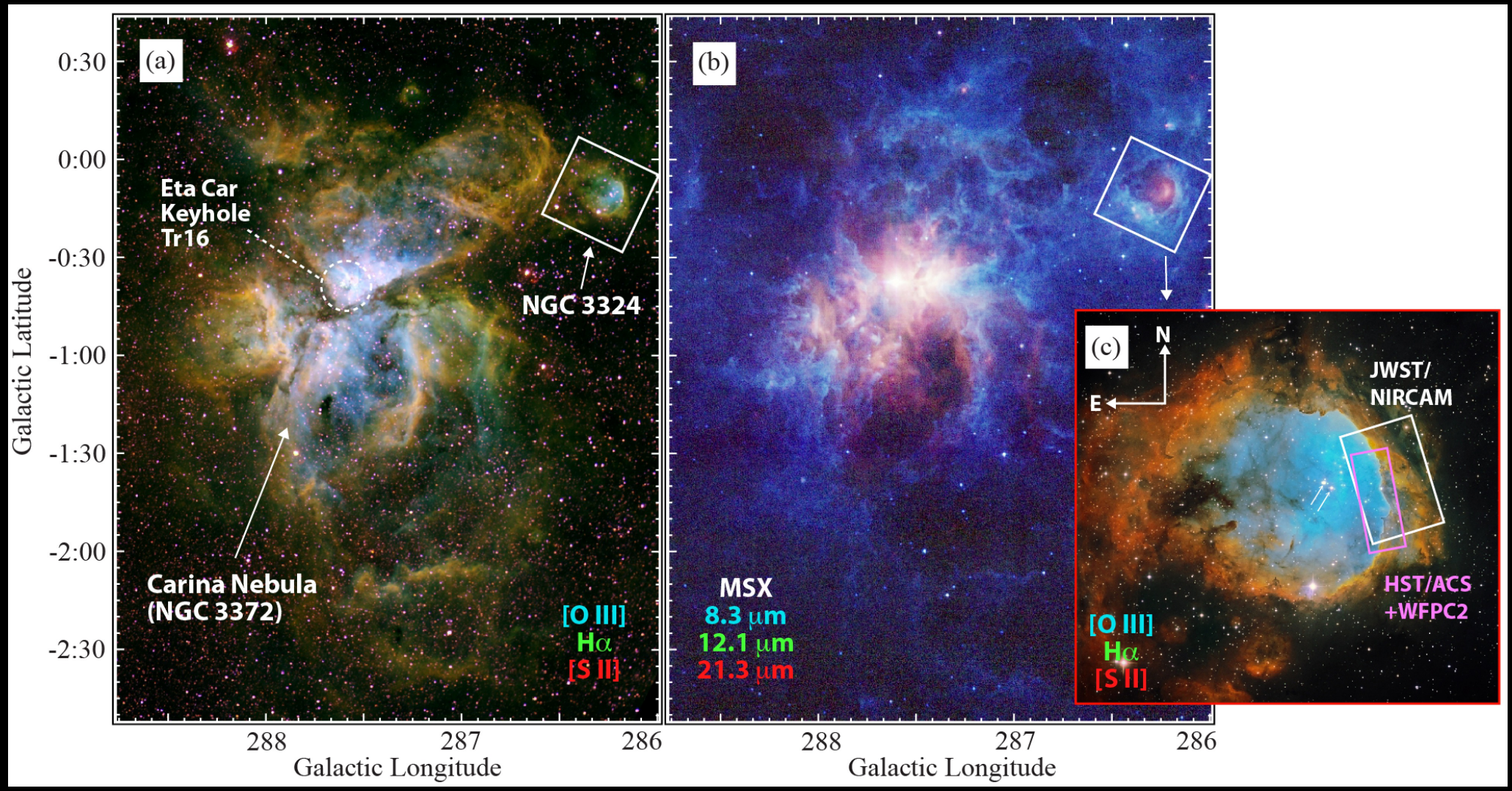


With Webb, we can finally see typical (baby) stars in their typical birthplaces to put the pieces together.



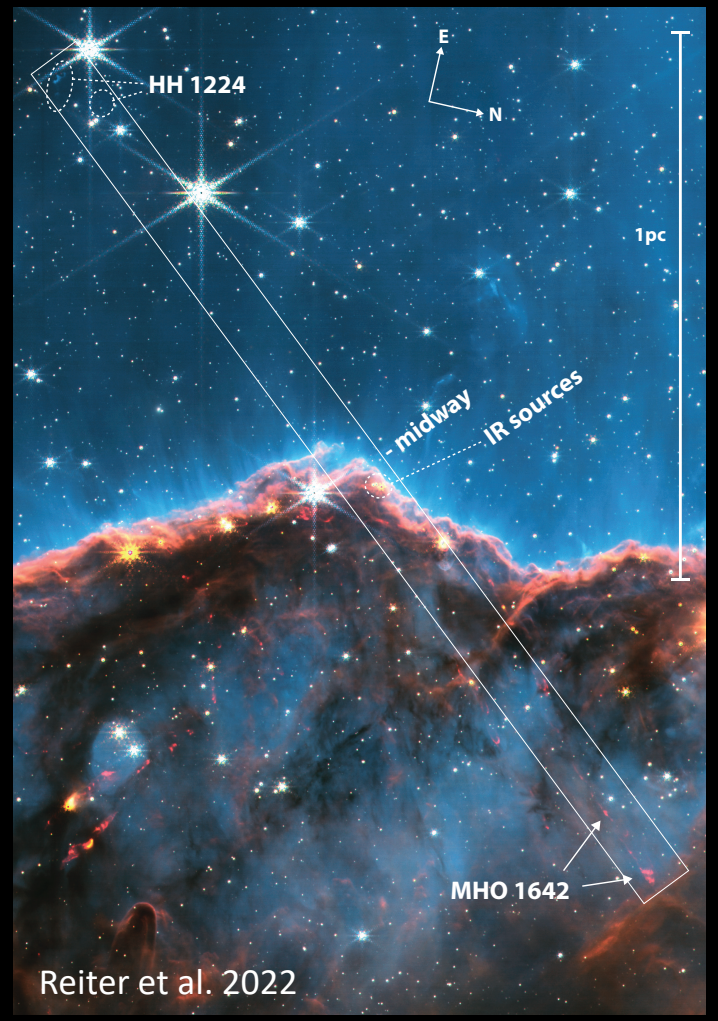
Reiter et al. 2022; adapted from Smith et al. 2000 and Smith & Brooks 2007 and Telescope Live with permission (image credit: V. Unguru / Telescope Live).

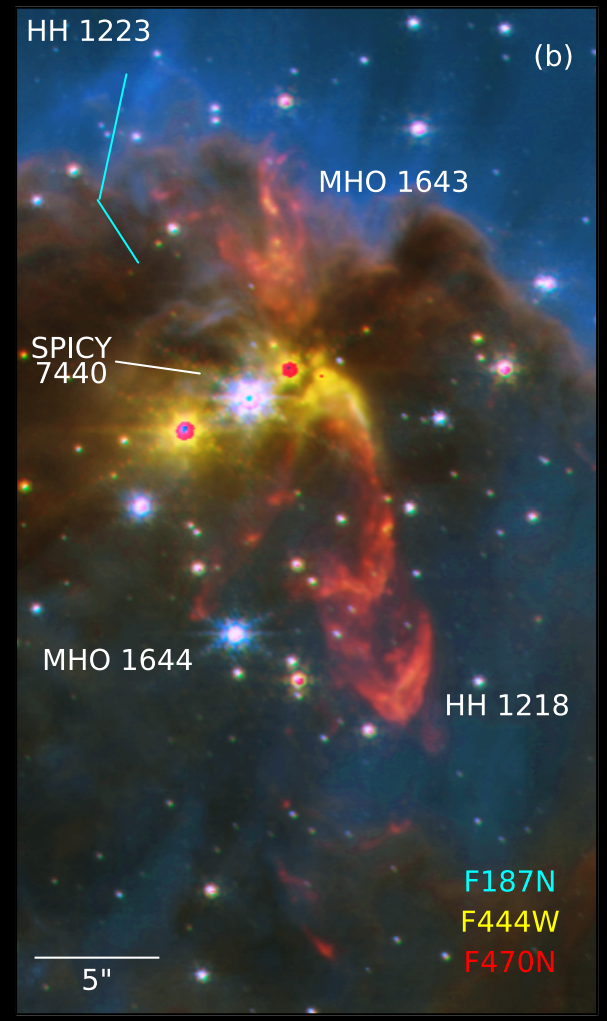
This is just the beginning for *Webb*…

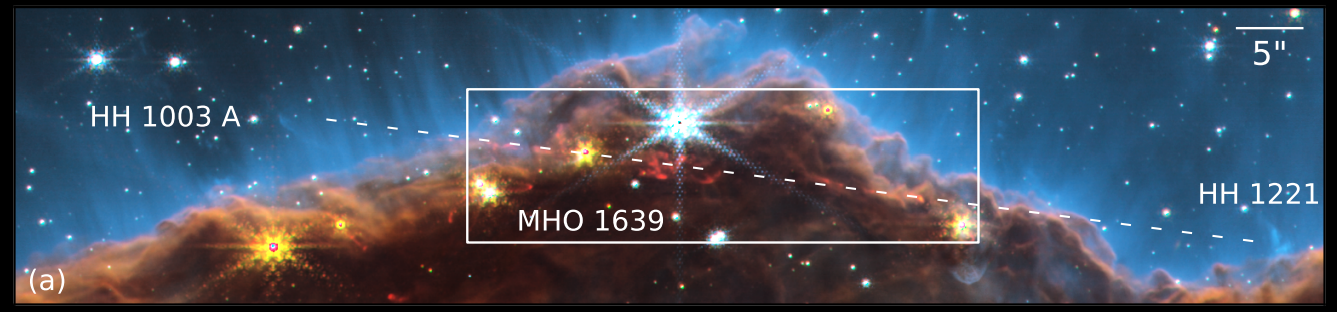
** JWST first anniversary image!

NASA, ESA, CSA, STScI, Klaus Pontoppidan (STScI)

Thanks!


HH 1224
E
N
1pc
midway
IR sources
MHO 1642
Reiter et al. 2022


HH 1223
(b)
MHO 1643
SPICY
7440
MHO 1644
HH 1218
F187N
F444W
F470N
5"


HH 1003 A
MHO 1639
HH 1221
5"
(a)