Some challenges of contemporary Astrophysics

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7th INFIERI

INtelligent signal processing for FrontIEr Research and Industry

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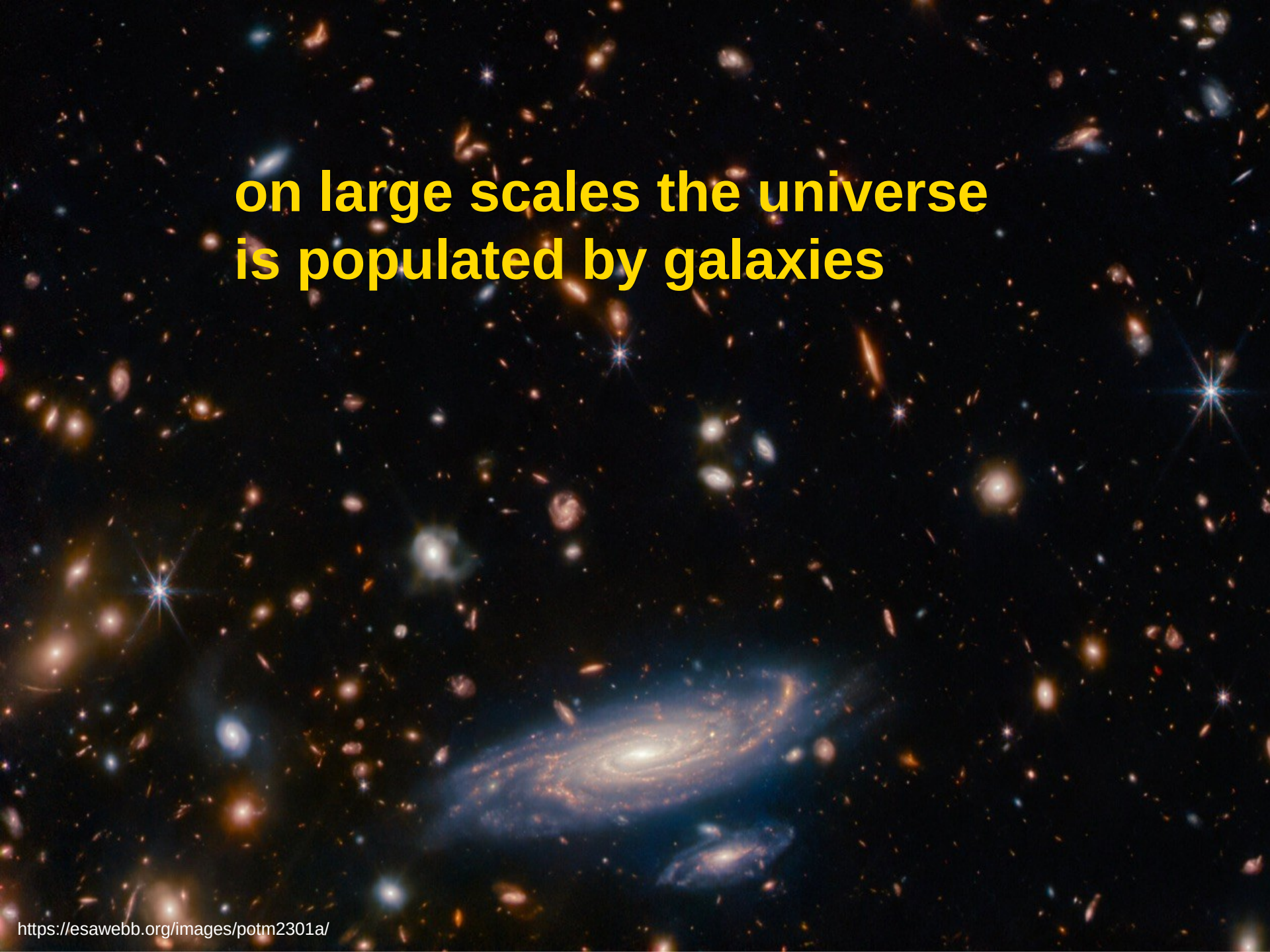
some big questions in Astronomy today
and the telescopes that will help answer them
GMT
Giant Magellan Telescope



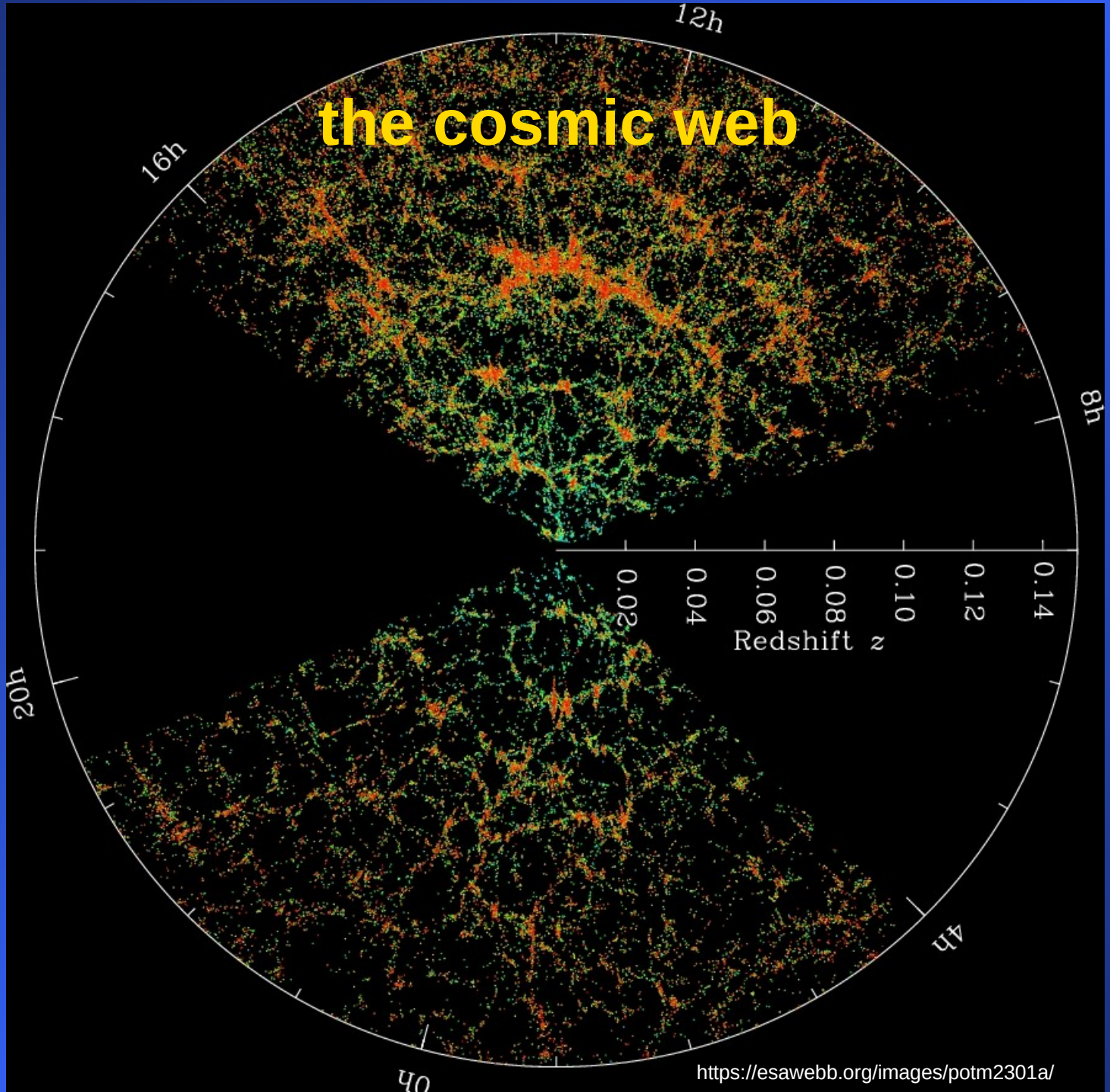
https://esawebb.org/images/potm2301a/

galaxies

- many forms
- many sizes
- many masses
- many stellar populations

- stars
- cold & hot gas
- dust
- dark matter

the cosmic web



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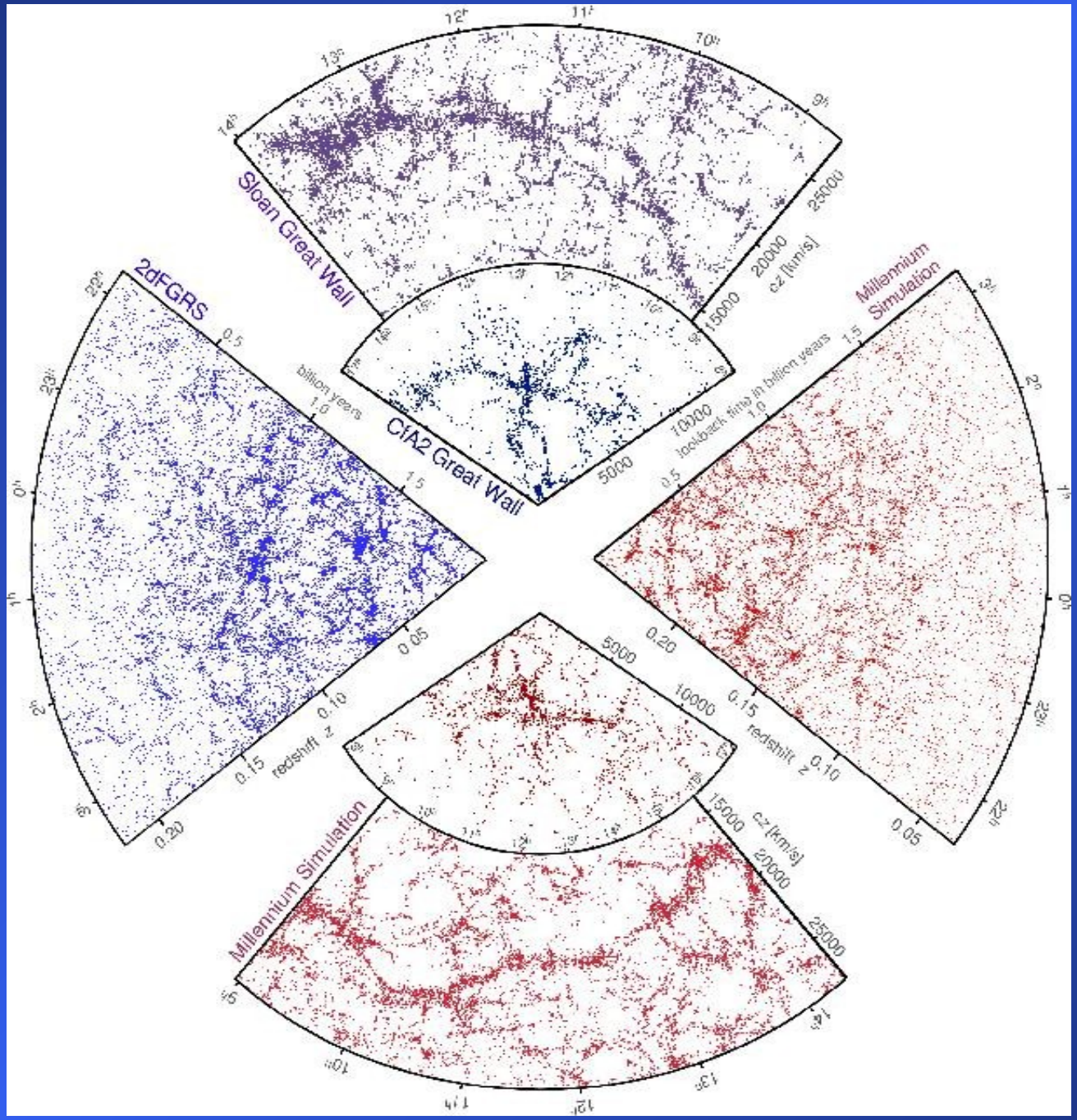
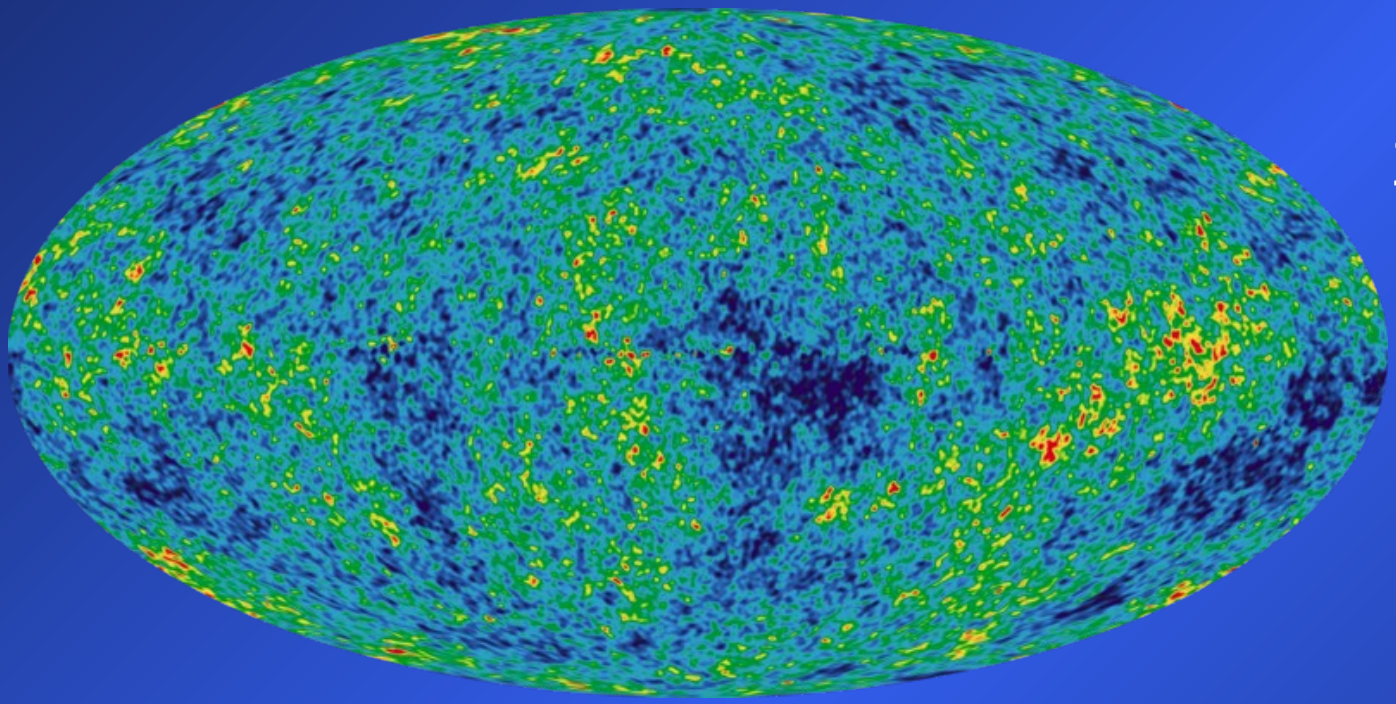
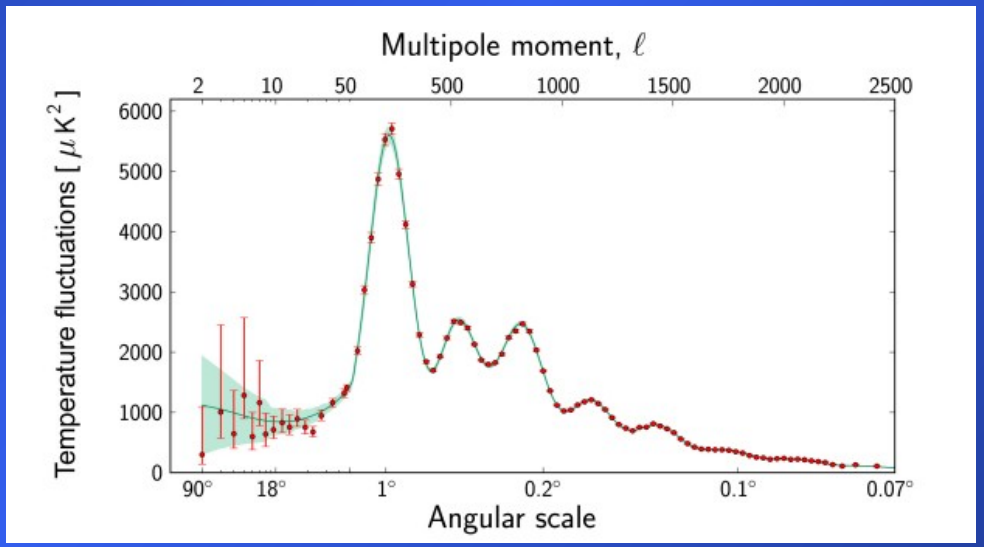

Sloan Great Wall
2dFGRS
CfA2 Great Wall
Millennium Simulation
Millennium Simulation
billion years
lookback time in billion years
redshift z
cz [km/s]

cosmic microwave background



z~1100
T~380,000 yrs

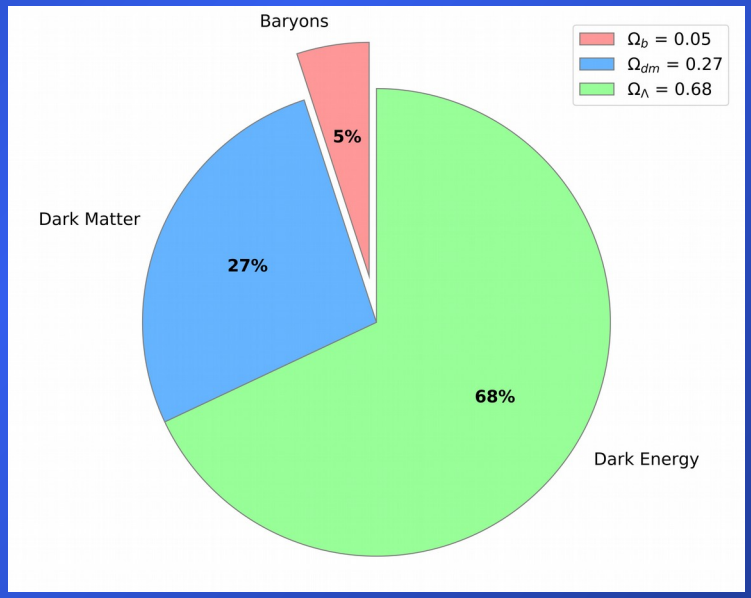
rms of fluctuations
~18 μK



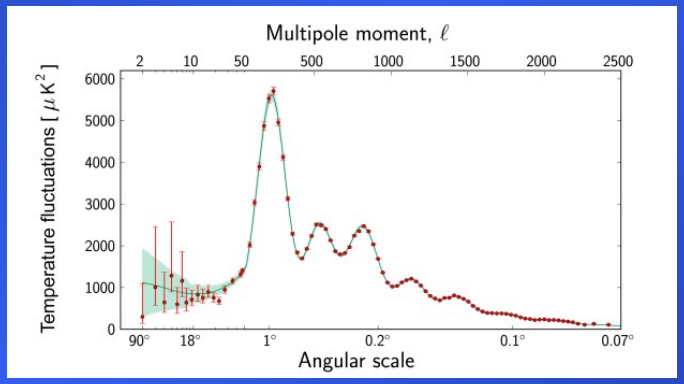
the cosmological model: ΛCDM universe

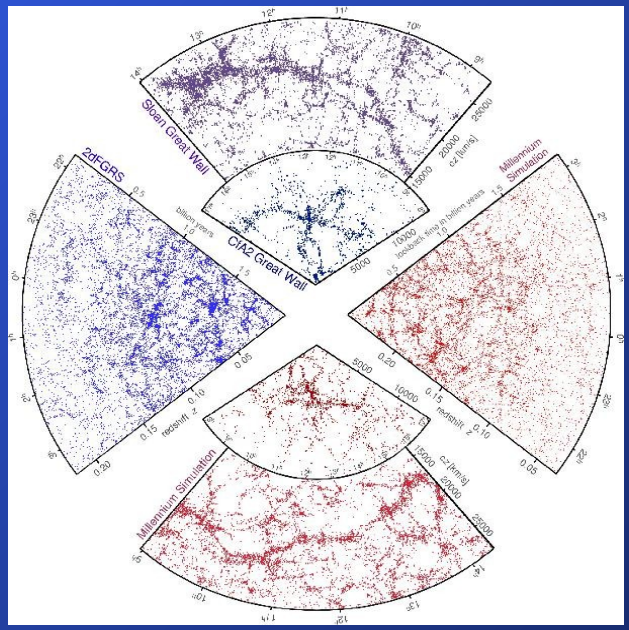
Described by Einstein's General Relativity with:

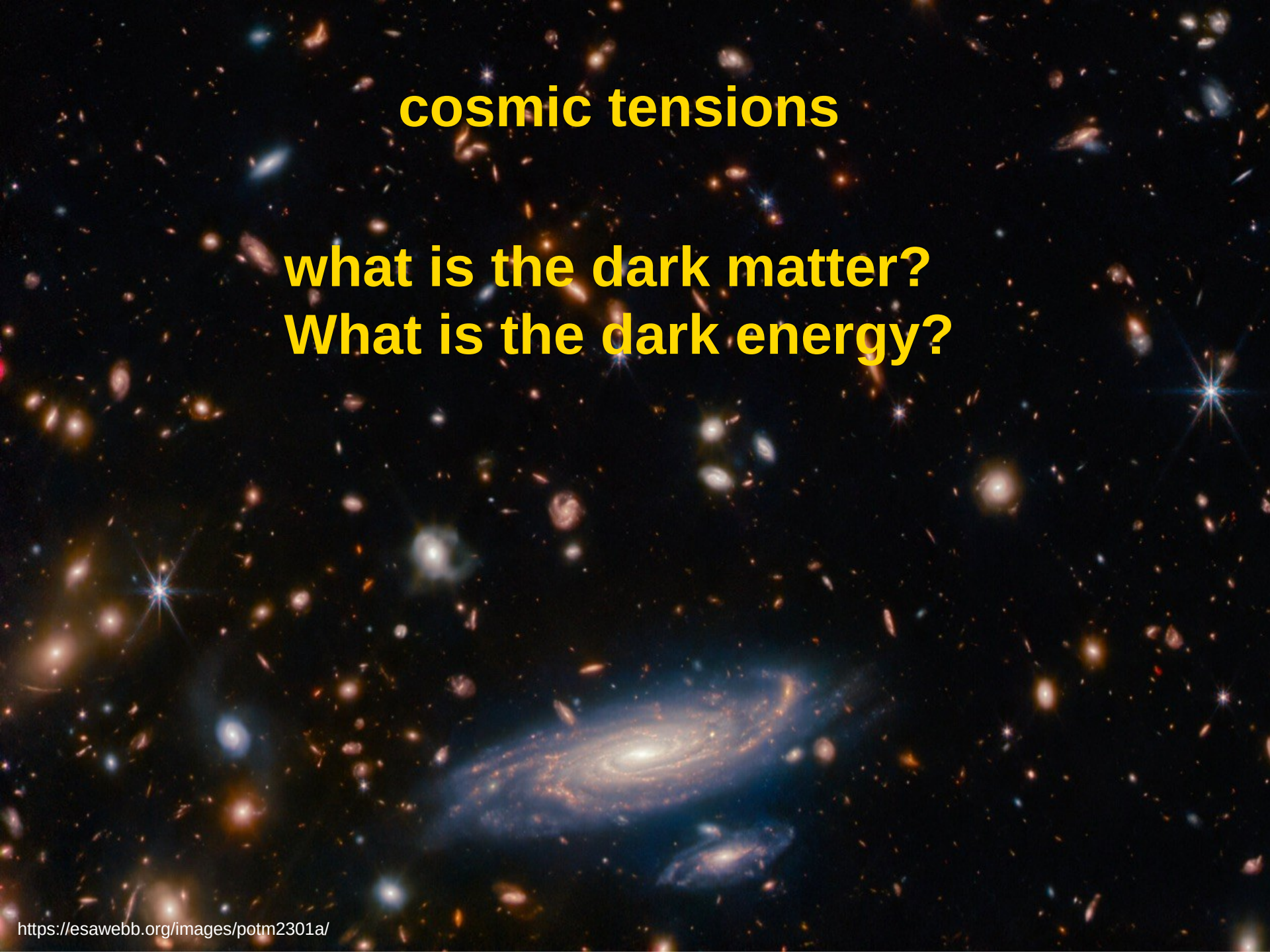
- ***zero curvature***
- **dominated by *dark energy Λ (~68%)***
- **with *cold dark matter*, *CDM* (~27%)**
- ***A bit of baryons (~5%)***
- ***+ fotons, neutrinos...***
  (% in units of the critical density)



Universe with accelerated expansion!






cosmic tensions
what is the dark matter?
What is the dark energy?
https://esawebb.org/images/potm2301a/

Dark Matter

Fritz Zwicky (1933)

Virial Theorem:

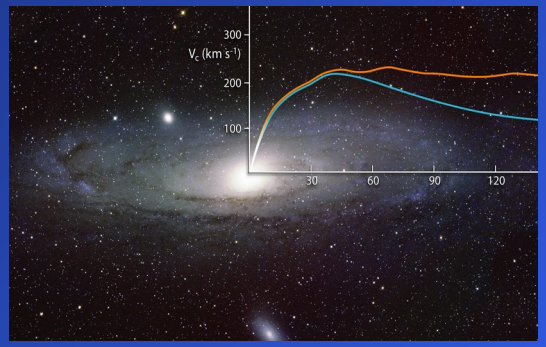
$$M \sim v^2 R / G$$

There is much more mass in galaxy clusters than we can attribute to known matter!

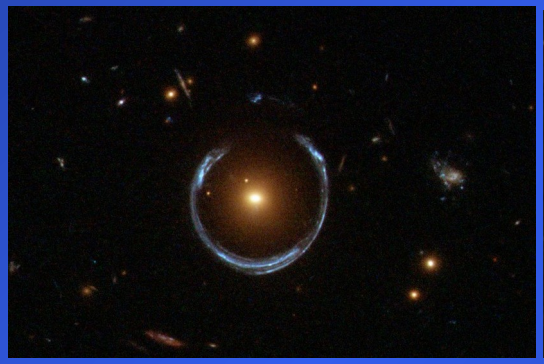
Dark Matter

Fritz Zwicky (1933)

- **rotation curves of spiral galaxies**



- **gravitational lensing**



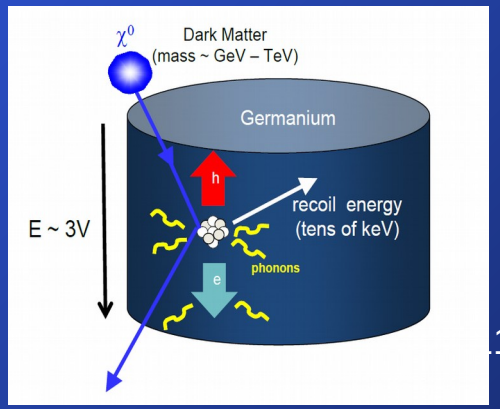
cold dark matter (CDM):

- **non relativistic**
- **interacts gravitationally**
- **does not interact with light**

Candidates

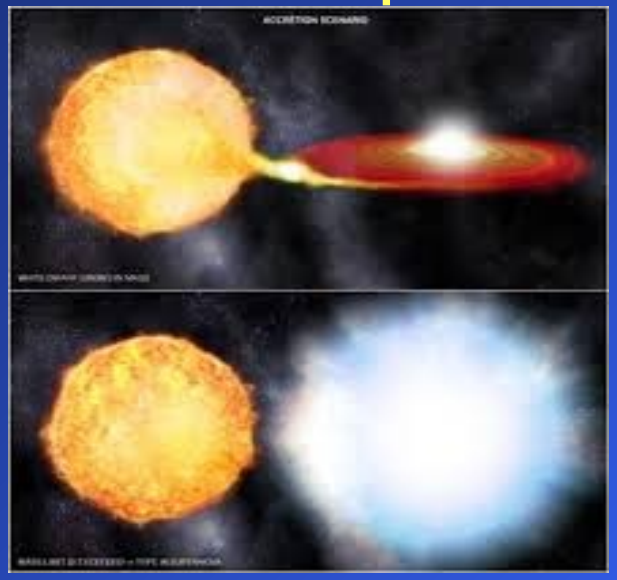
- **neutralino: m ~ 100 GeV**
- **axion: m ~ 10^{-6} eV**
- **...???**

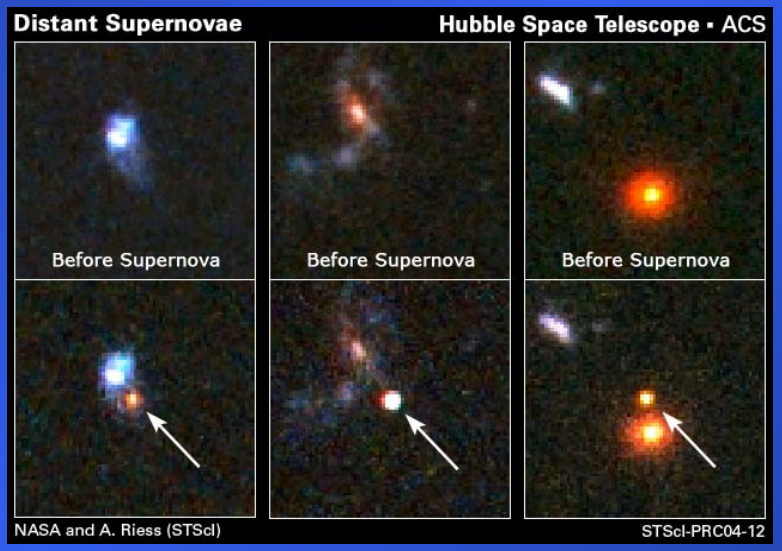
So far unsuccessful detection attempts!!



Dark Energy

Distances to Supernovae Ia





- excellent distance indicators
- luminous
- standard candles

The expansion of the universe is accelerating!

- GR: a "cosmological constant Λ" or a fluid of negative pressure(!) can produce an accelerated universe

- Weak field limit of GR:

$F = -GM/r^2 + \Lambda r/3$

anti-gravity or energy/fluid?

cosmic tensions...

- The universe is expanding faster than expected!

  CMB: H0 = 67.4 ± 0.5 km/s/Mpc (Planck 2018)

  local universe: H0 = 73.3 ± 0.9 km/s/Mpc (Murakami+ 2023 arXiv:2306.00070)

  tension > 5.7 sigmas…

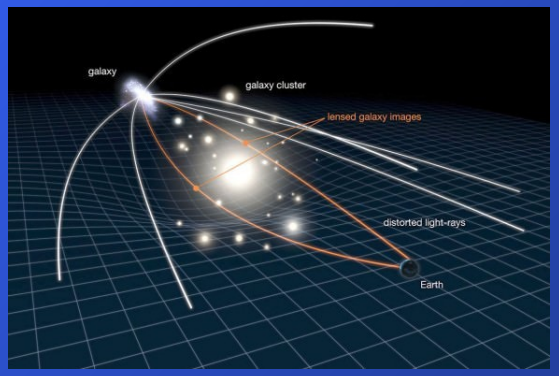
- but… Refsdal supernovae:

$$H_0 = 66.6^{+4.1}_{-3.3}\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$$

Kelly+ (2023)
arXiv:2305.06367

Refsdal SN

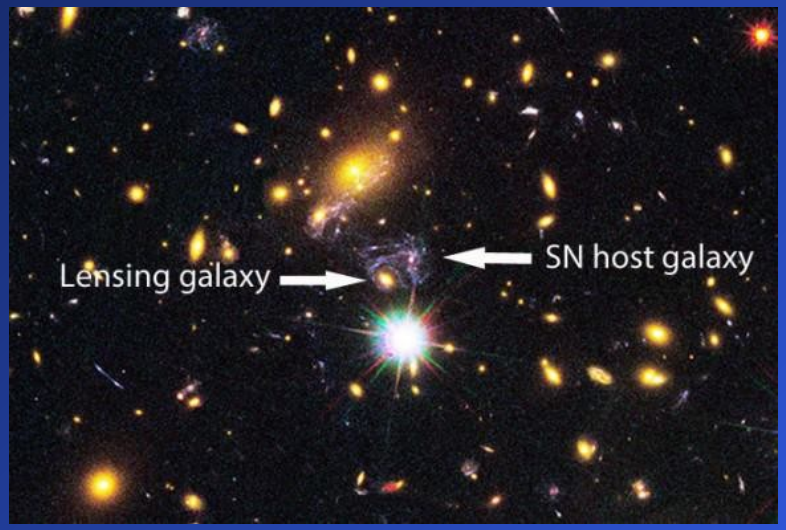
- The cluster acts as a gravitational lens



- multiple images of a background galaxy

Galaxy cluster MACS J1149.5+2223
z = 0.54

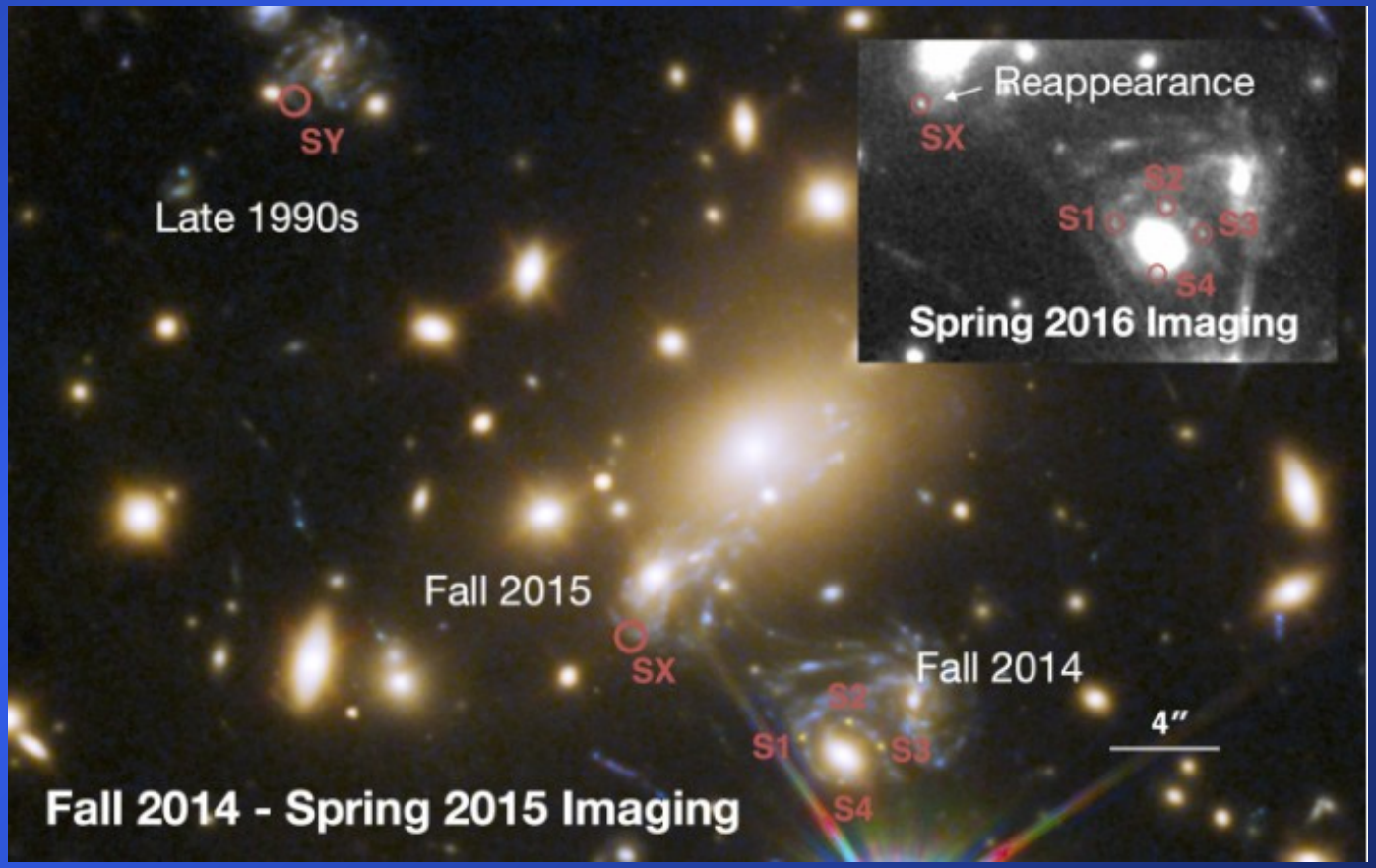
Refsdal SN



km s^{-1} Mpc^{-1}, where Mpc is the megaparsec. Using the two models most consistent with the observations, we find $H_0 = 66.6^{+4.1}_{-3.3}$ km s^{-1} Mpc^{-1}. Models that assign dark-matter halos to individual galaxies and the overall cluster best reproduce the observations.

Kelly+ (2023)

Einstein cross

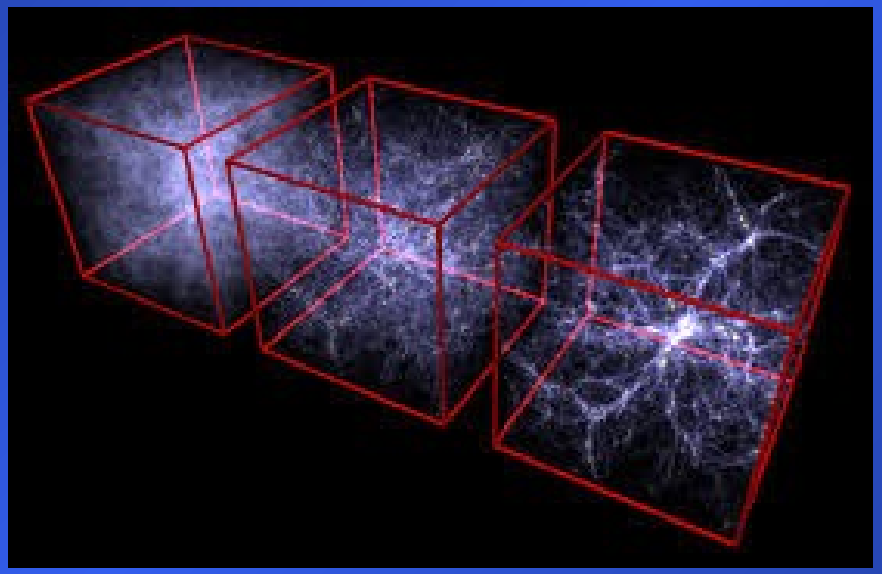


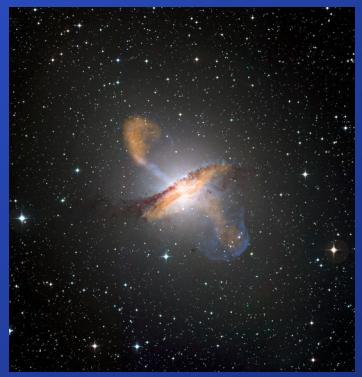
a big question: how galaxies form and evolve?

- We can observe galaxies in the past, at high redshifts
- problem: observational bias

  the dominant populations vary with the redshift and it is not clear how galaxies at different redshifts are related

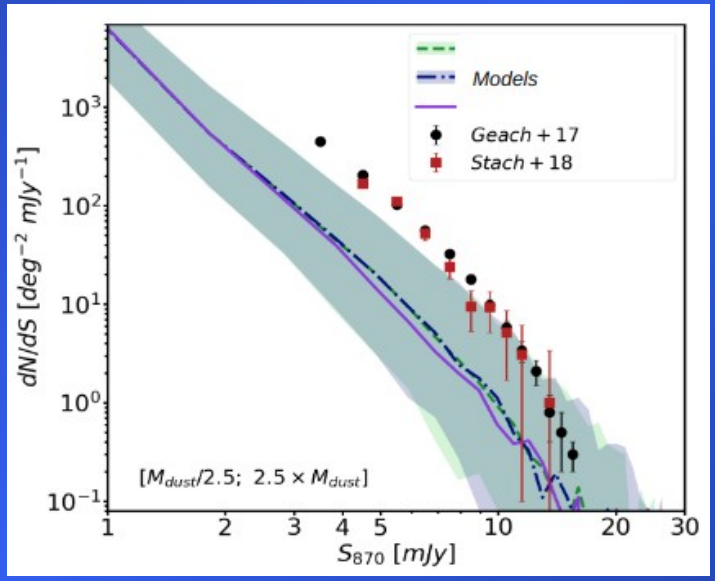
  we need models to unveil how a given population has evolved

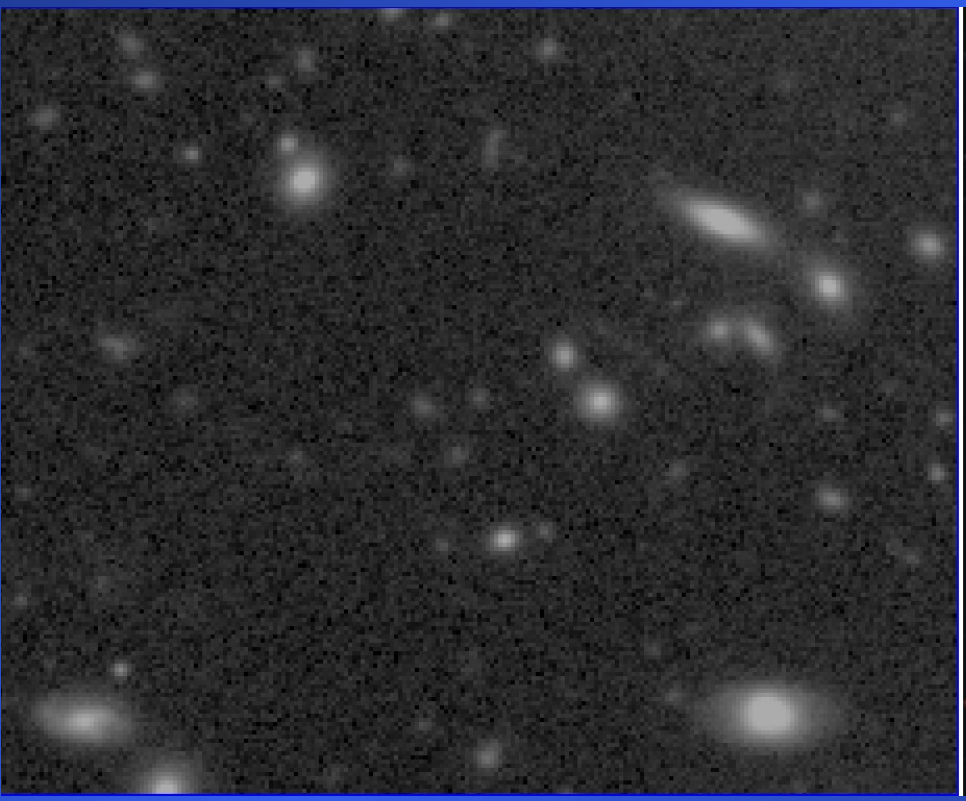




cosmic tensions

galaxies shrouded in dust





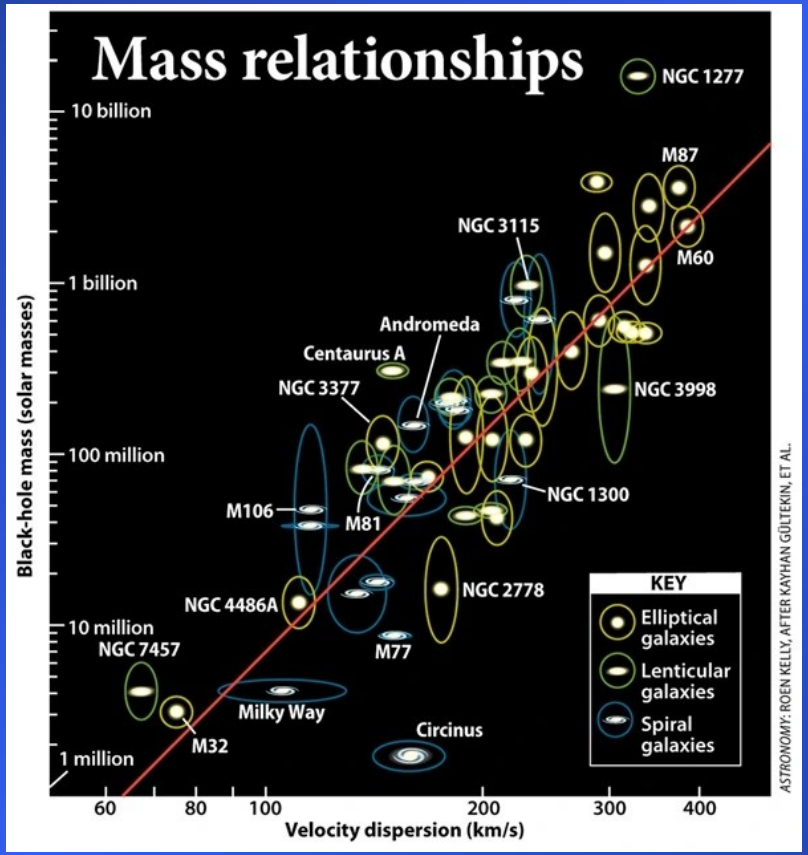
optical

medium IR

cosmic tensions

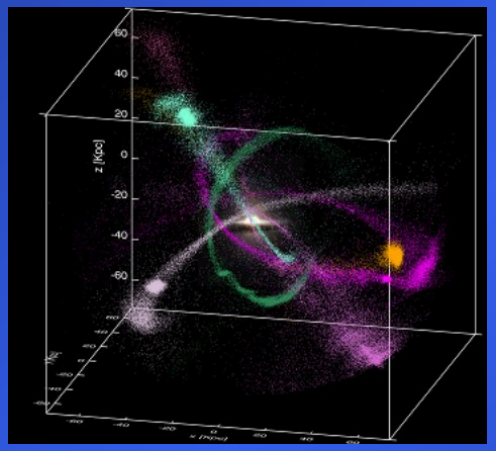
- how do supermassive black holes form and evolve?
- collapse of a star cluster? Collapse of a gas cloud?
- how do they co-evolve with galaxies?

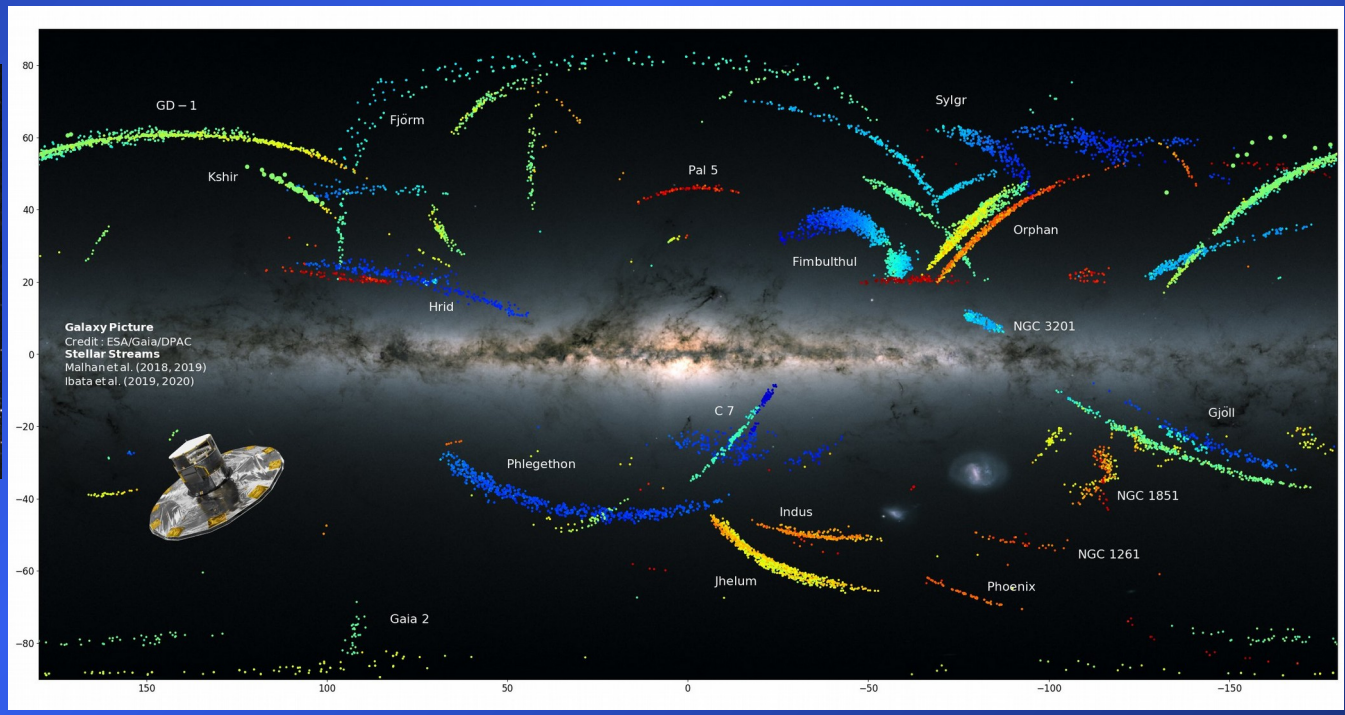
Cen A in X-rays



a big question: how did the Milk Way form? galactic archeology

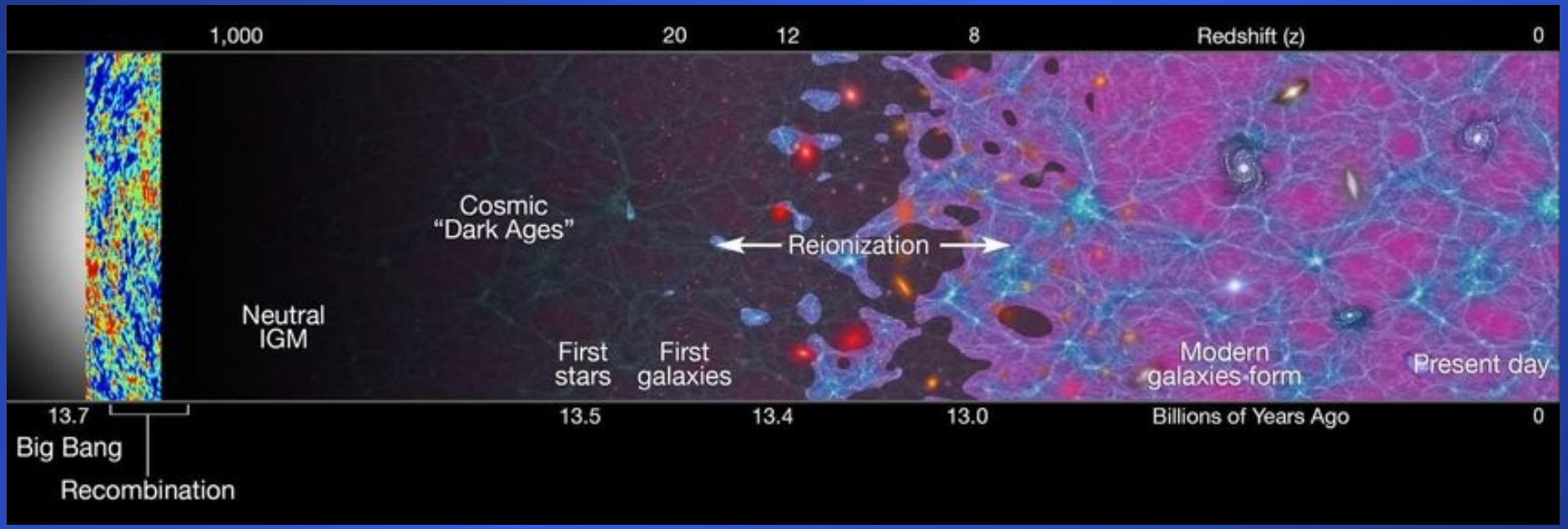
- *galaxy streams*

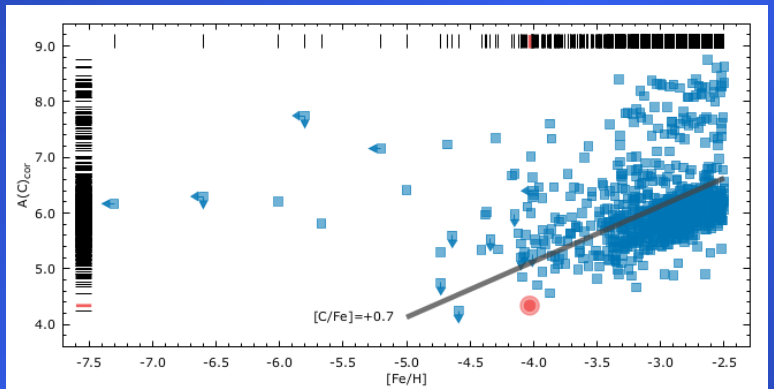




galactic archeology: how did the Milk Way form?

- *where are the first stars?*



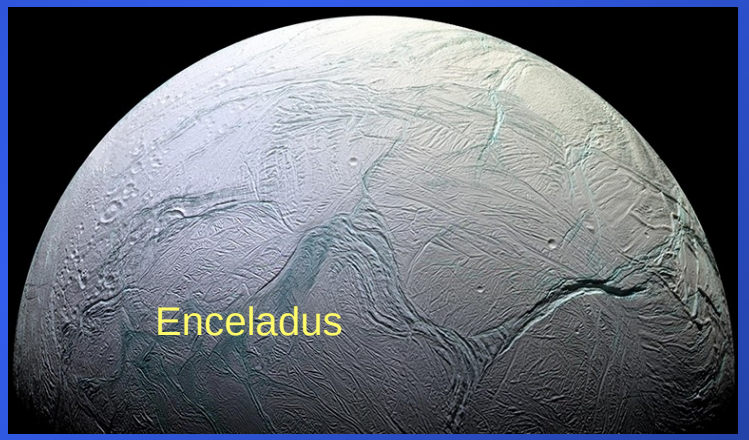


SPLUS J210428.01−004934.2: An Ultra Metal-Poor Star Identified from Narrowband Photometry*

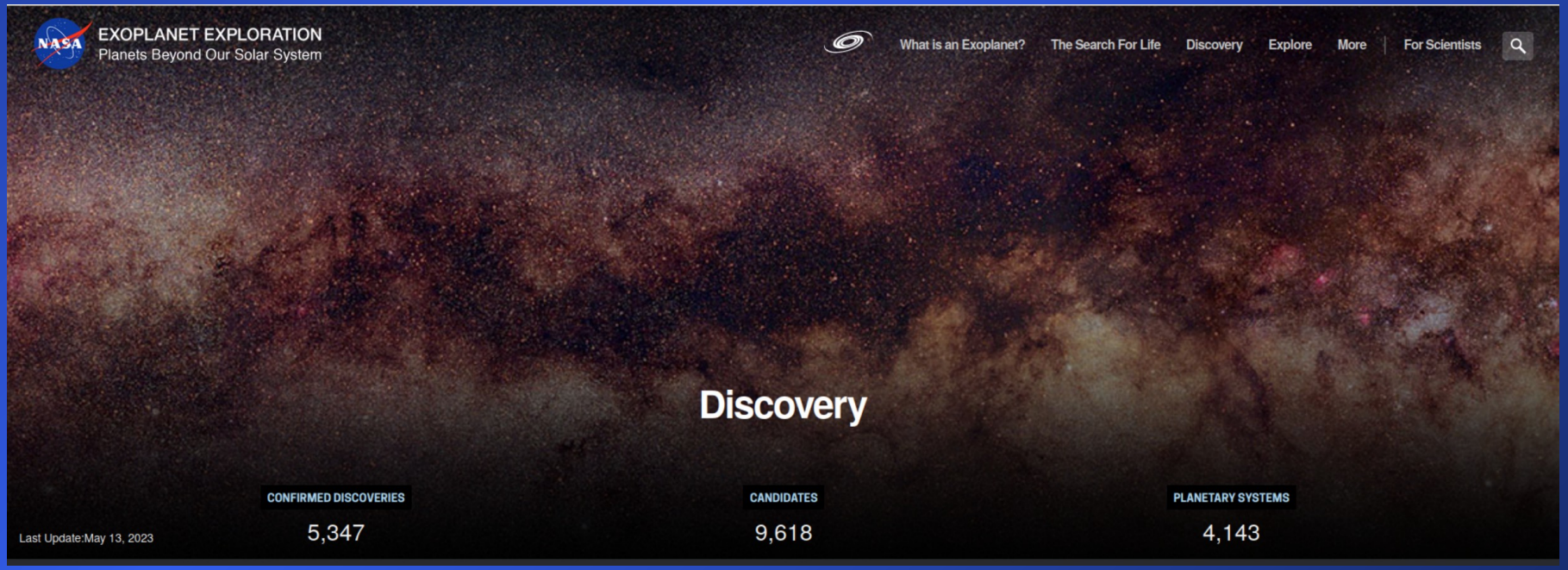
Vinicius M. Placco,[1] Ian U. Roederer,[2,3] Young Sun Lee,[4] Felipe Almeida-Fernandes,[5] Fábio R. Herpich,[5] Hélio D. Perottoni,[5] William Schoenell,[6] Tiago Ribeiro,[7] and Antonio Kanaan[8]

a very big question: is there life outside the Earth?

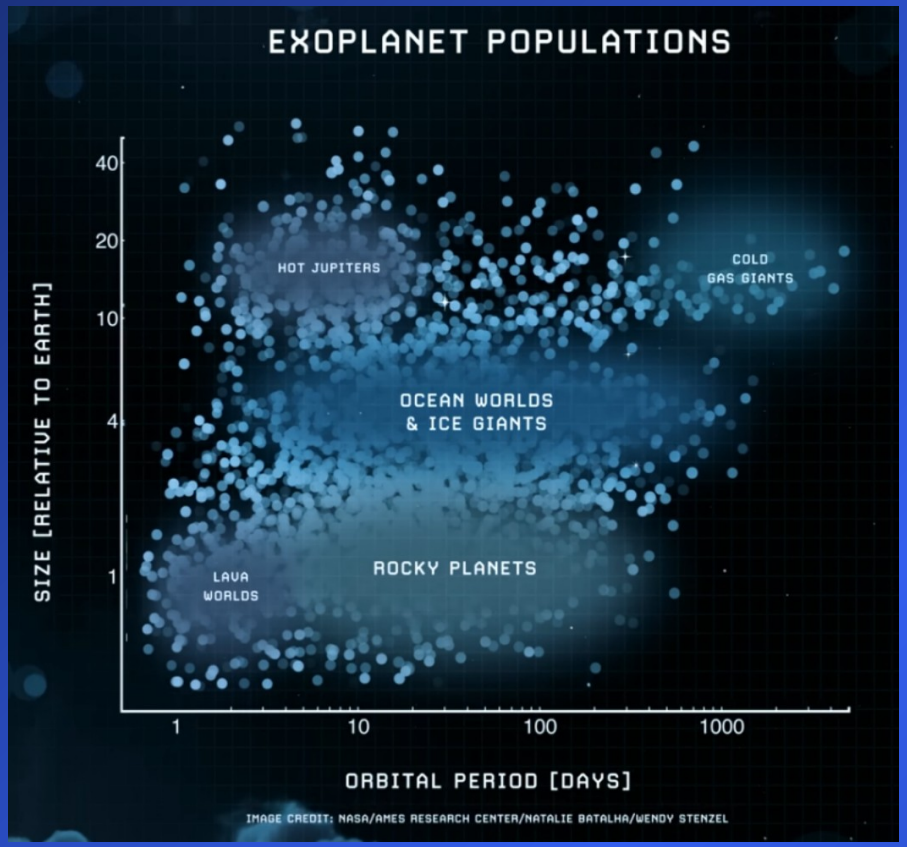
- oceans in some moons in the Solar system



- thousands of known exoplanets

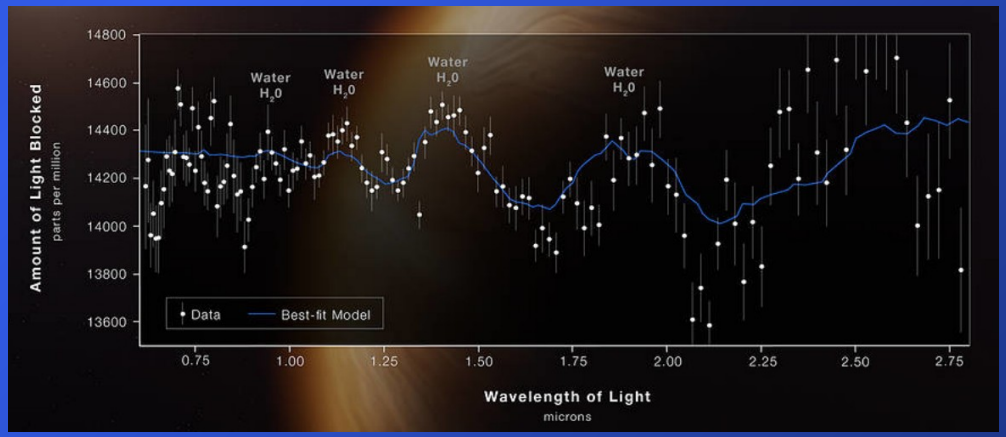


is there life outside the Earth?



James Webb

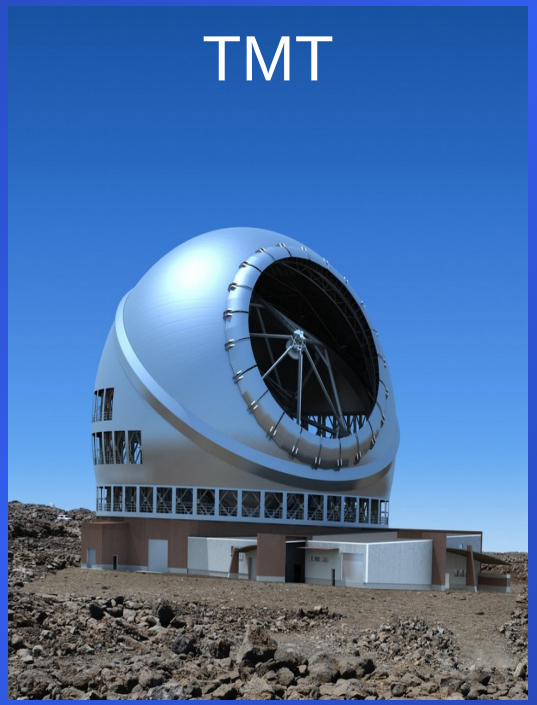
water in WASP 96b

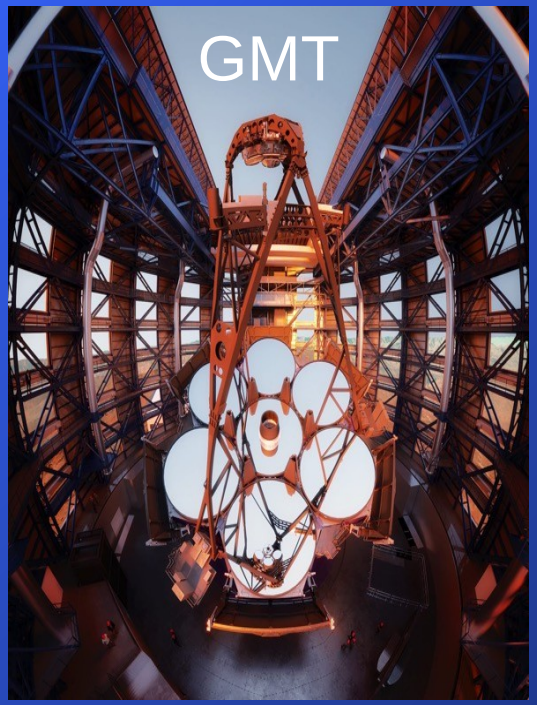


challenge: find biomarkers in the atmosphere of exoplanets

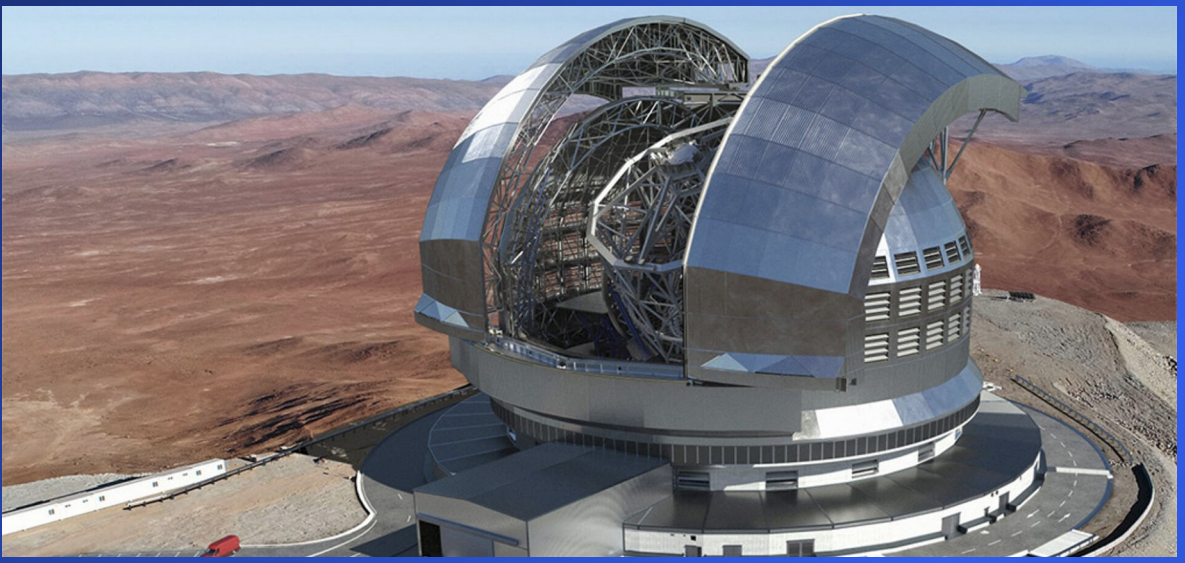
water, O2, O3, methane, complex organic molecules

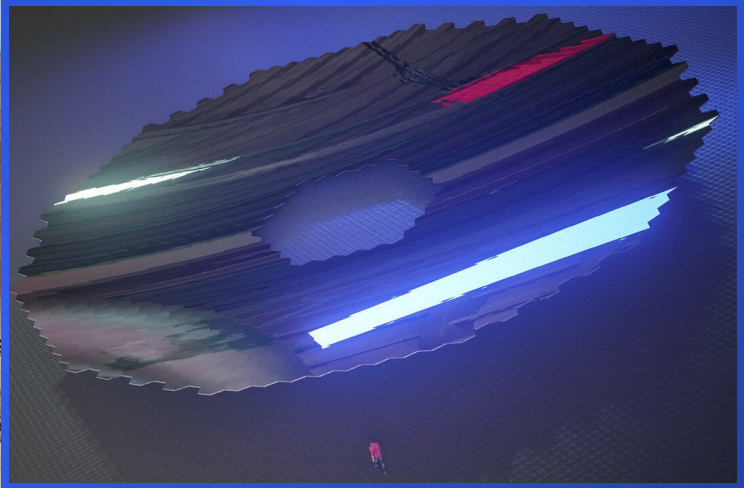
The new generation megatelescopes





E-ELT: ESO EXTREMELY LARGE TELESCOPE

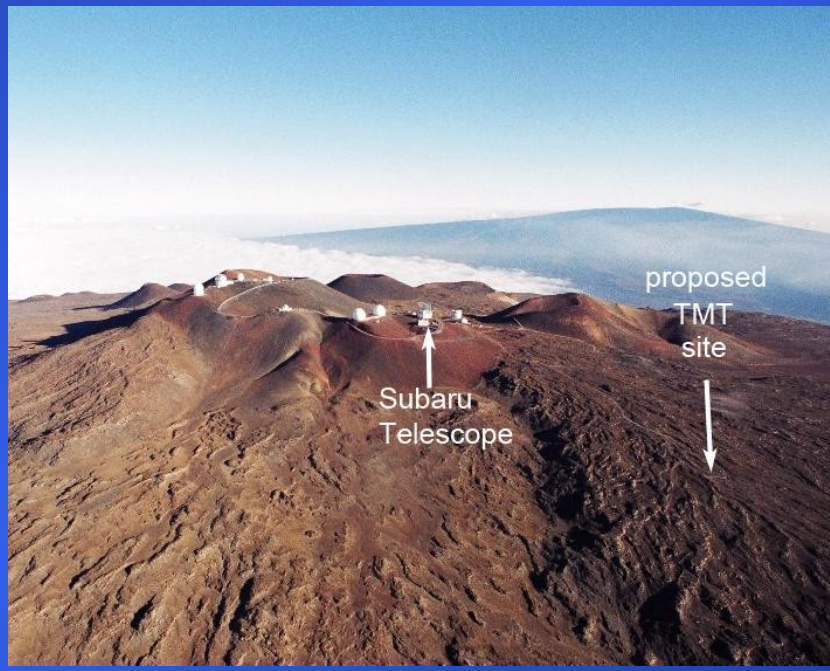


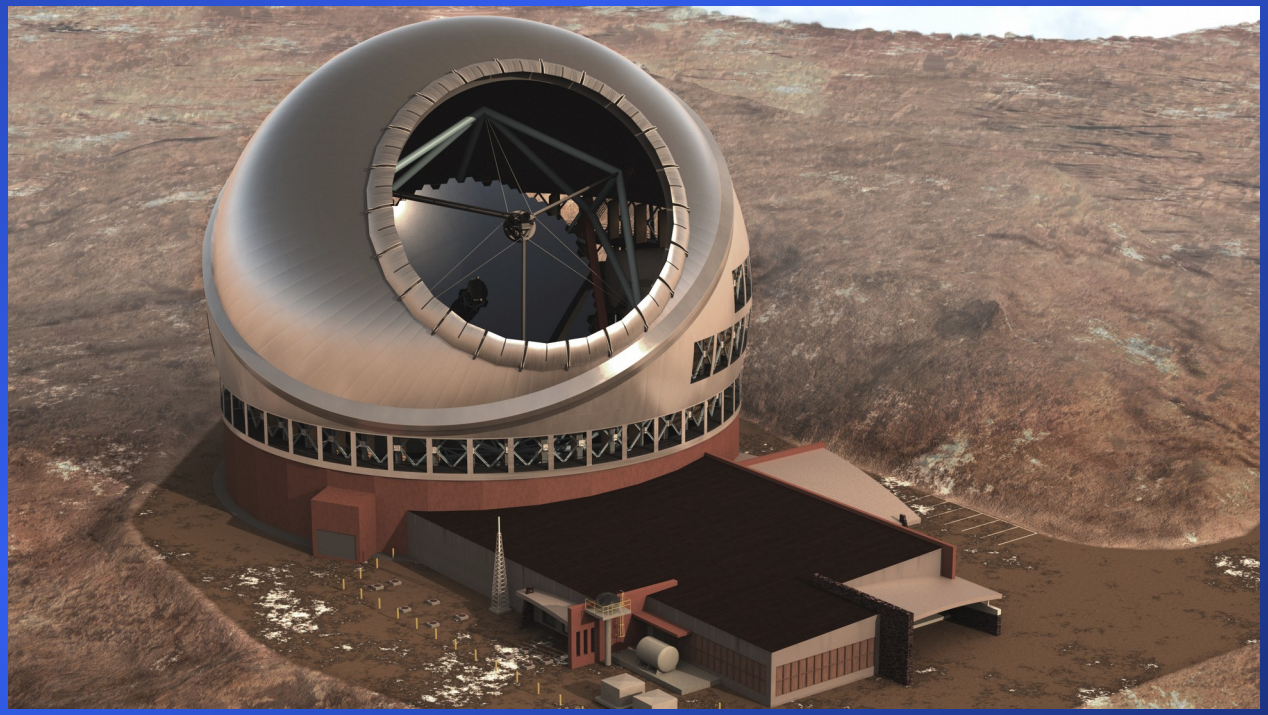


- @Cerro Amazonas (Chile)
- diameter of primary mirror: 39.3 m
- mosaic of 798 hexagonal segments of 1.4 m diameter, positioned with a precision of tens of nanometers
- FOV 10 arcmin

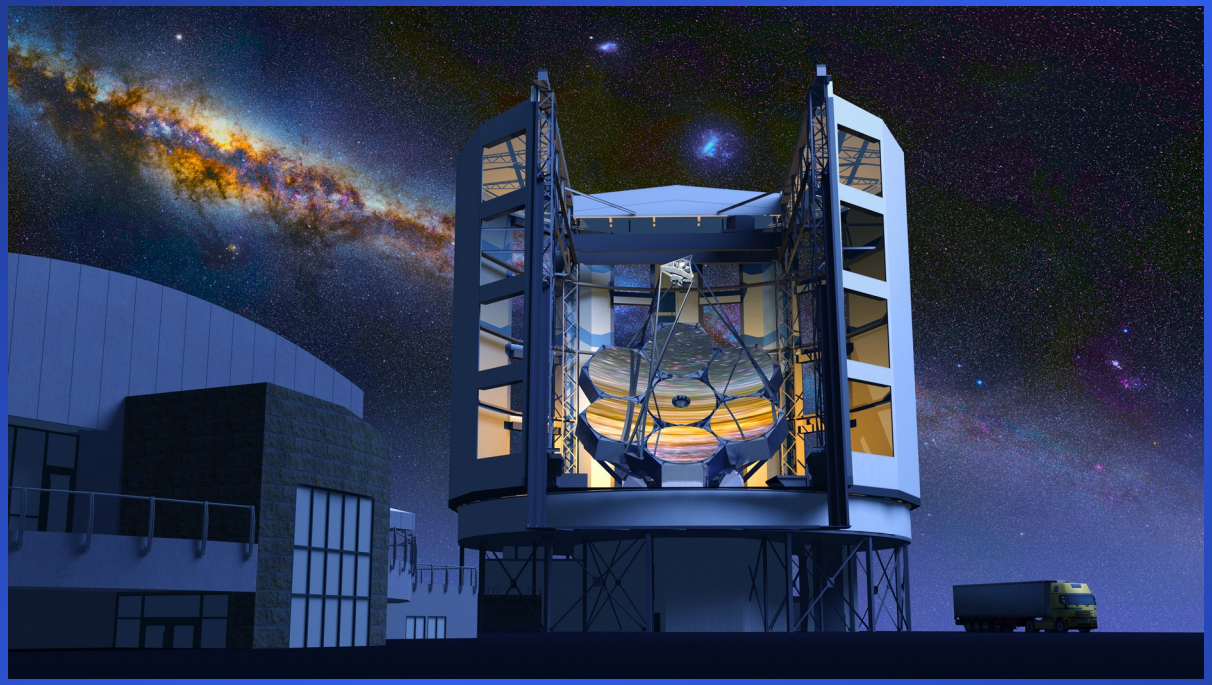
Thirty Meter Telescope

- site: Mauna Kea???
- primary mirror: 30m
  492 segments of 1.4m each
- FOV: 15 arcmin





GMT – Giant Magellan Telescope



- 7 8.4m primary mirrors, equivalent to ~24.5 m diameter
- FOV: 20 arcmin

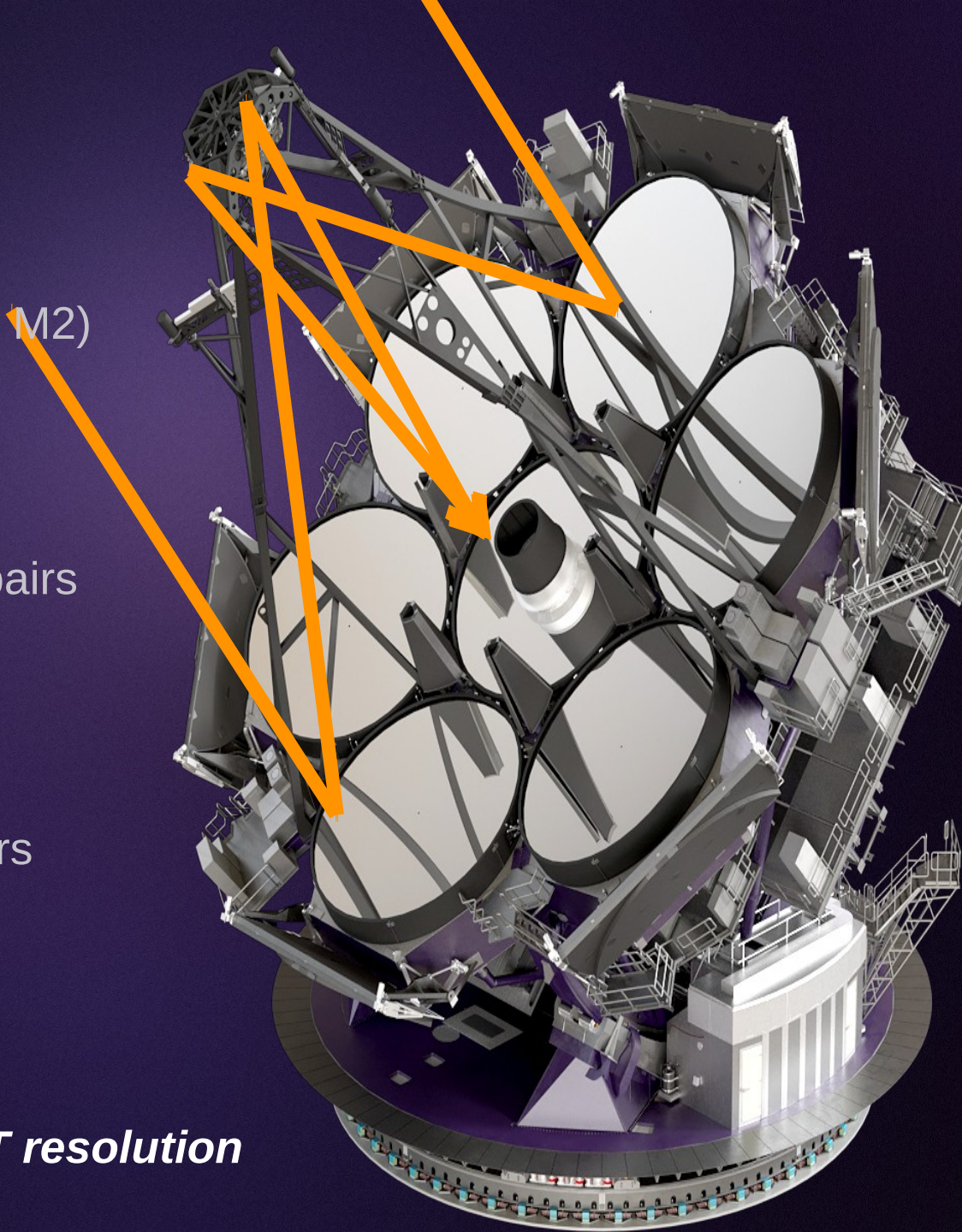
first light ~2030

FAPESP is a GMT *Founder*

13 international research institutions and universities. GMTO Corp (formed 2006)

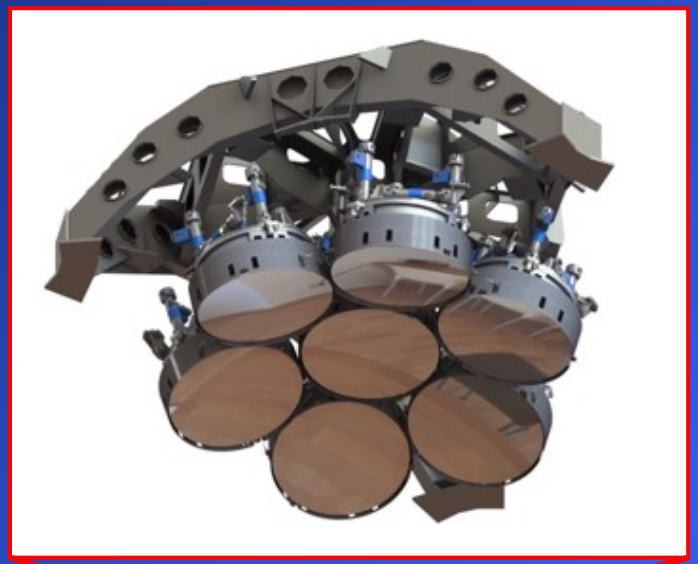
Main design features

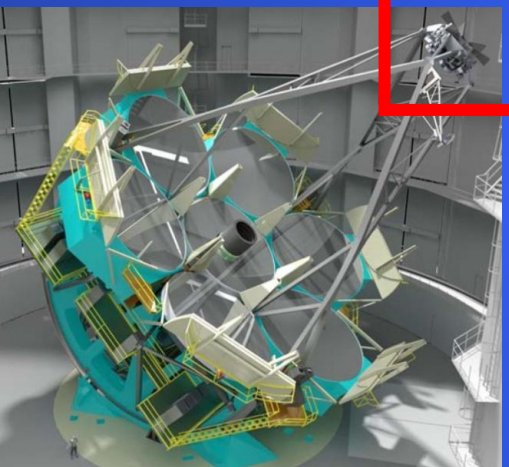
- Gregorian focus (concave M2)
- FOV: ~20 minutos
- Segmented in 1:1 mirror pairs
  - M1: 7x 8.4m segments
  - M2: 7x 1.1m segments
- Adaptive secondary mirrors



10x the area and 4x the JWST resolution

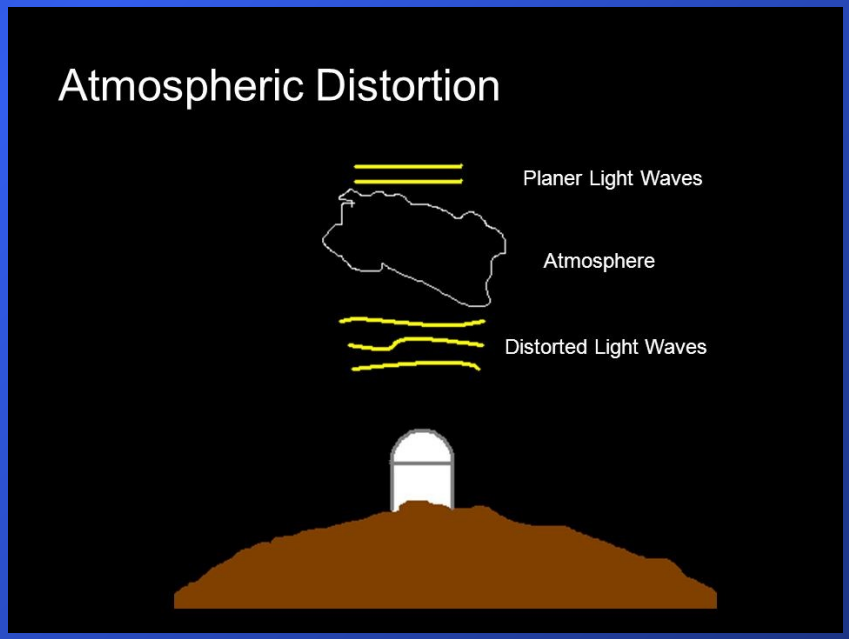
secondary mirrors
7 x 1.1m





the 7 secondary mirrors are *adaptive*

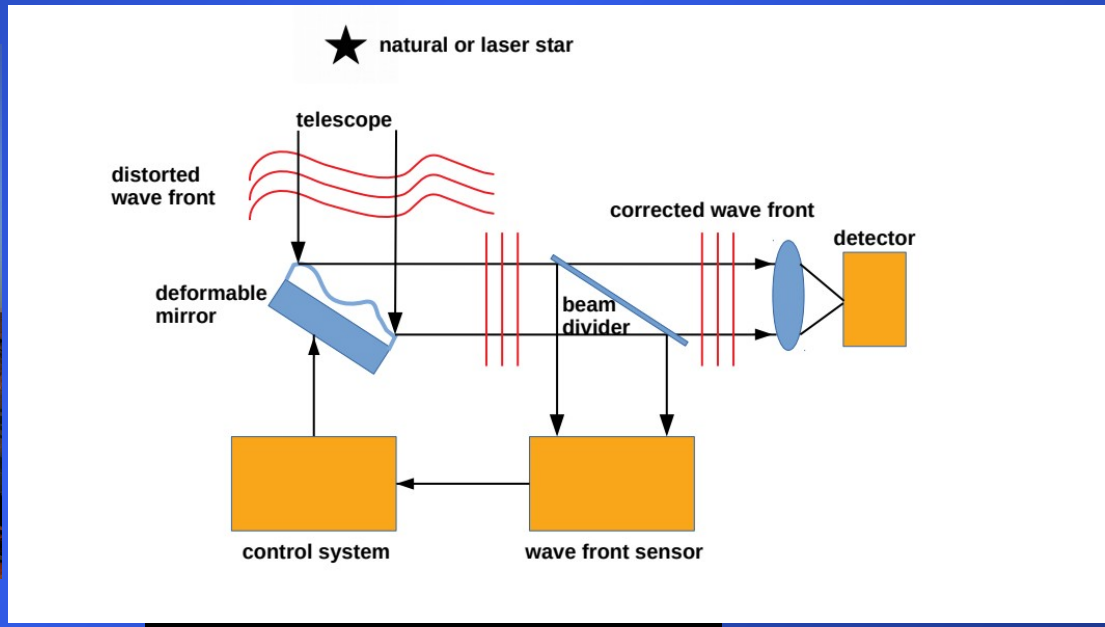
- atmospheric turbulence distorts images
- adaptive optics aim to dynamically correct them by *deforming* the mirrors

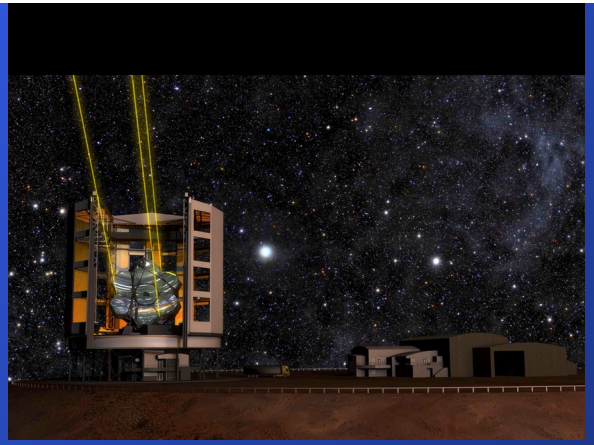


- more than 7000 independent actuators, acting at a rate more than 1000 times per second

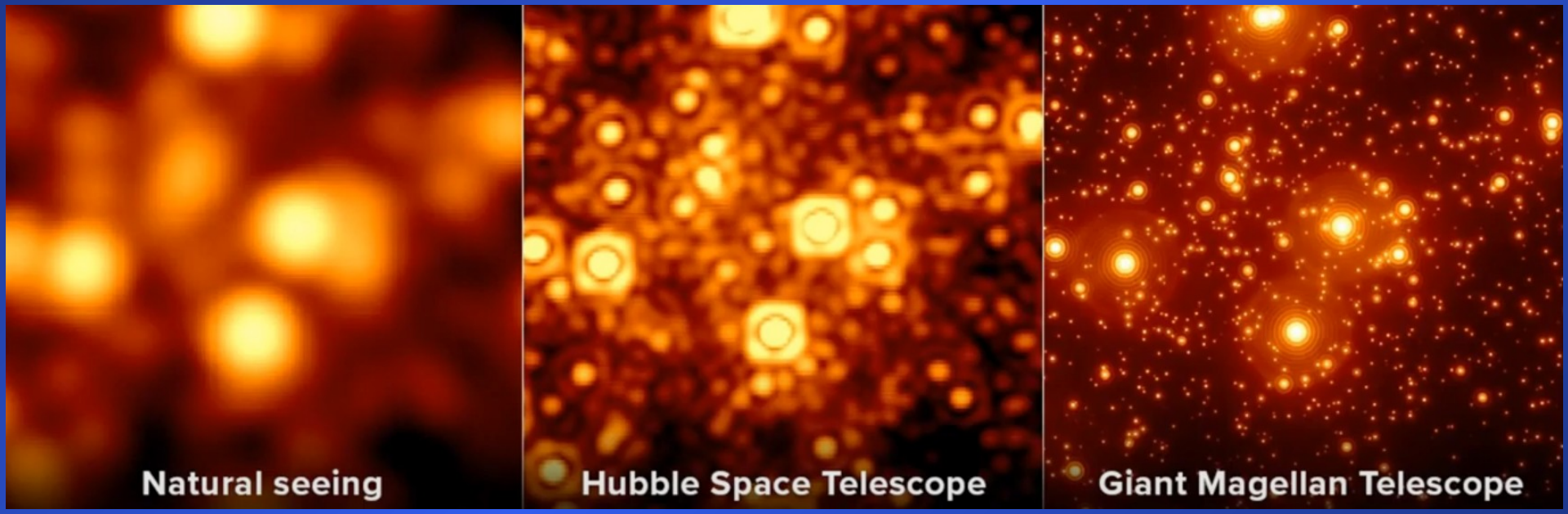
SAMplus:
upgrade of the adaptive system of SOAR telescope (4m)

Cerro Pachon





adaptive optics

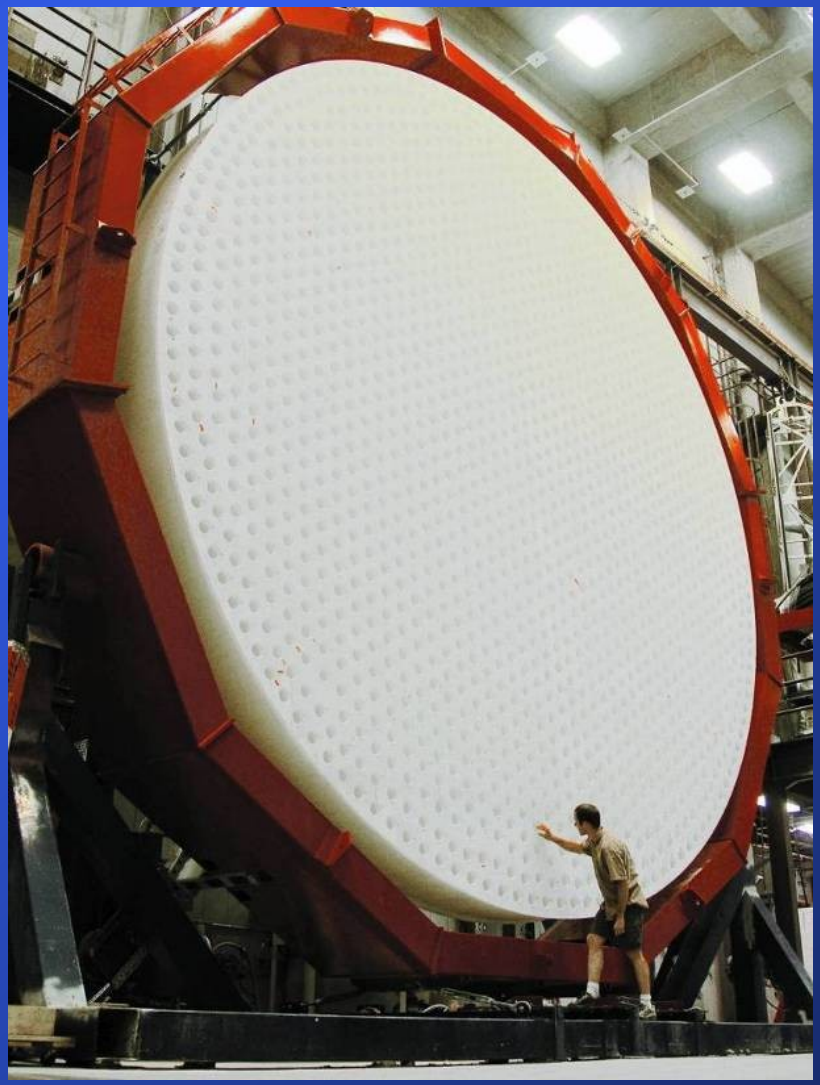


seeing: a measure of the width of point sources

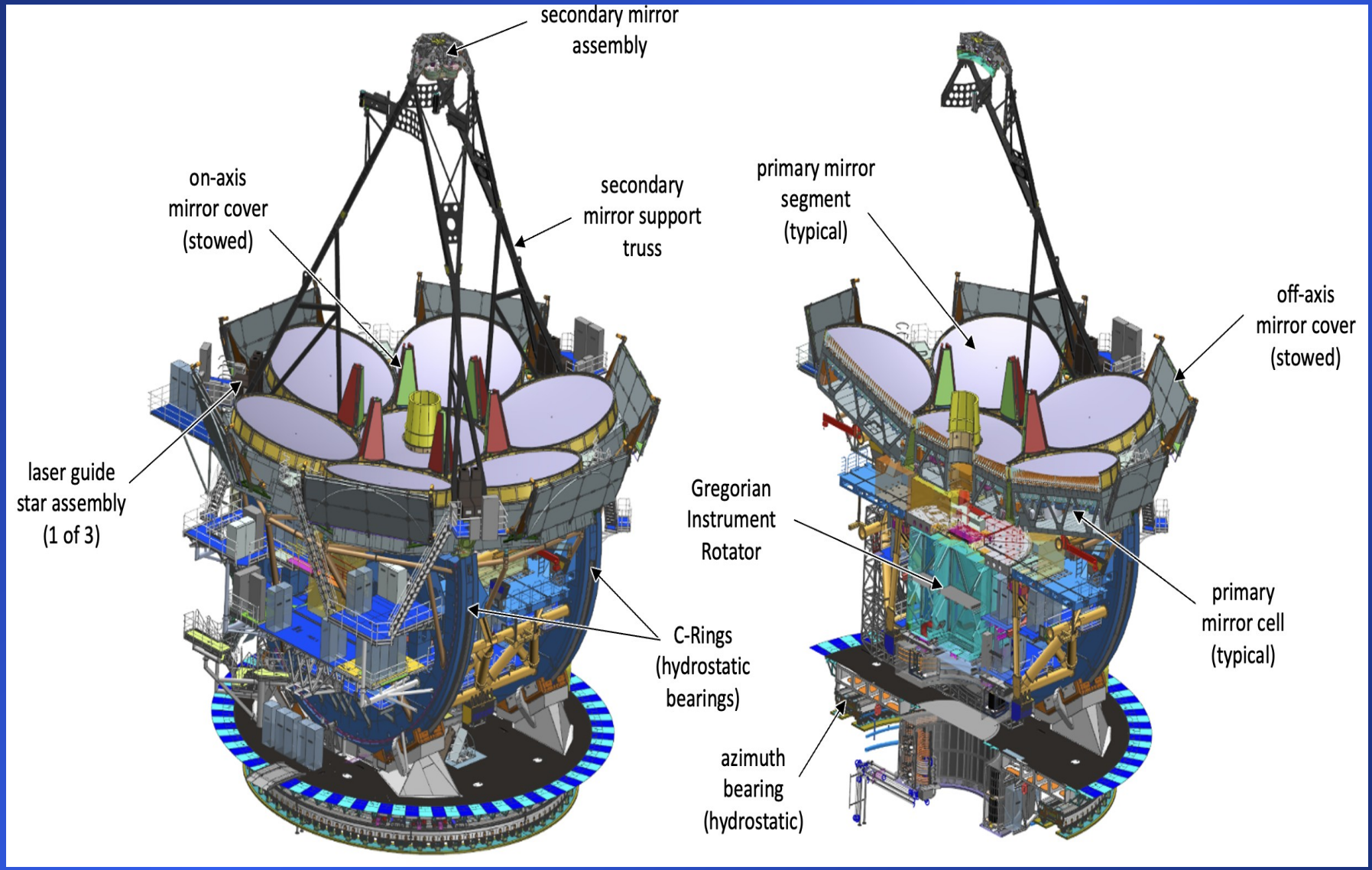
GMT: 7 primary mirrors of 8.4m

Each mirror takes ~3.5 yrs to be fabricated

2 ready, 1 in tests, 3 in processing, 2 to start



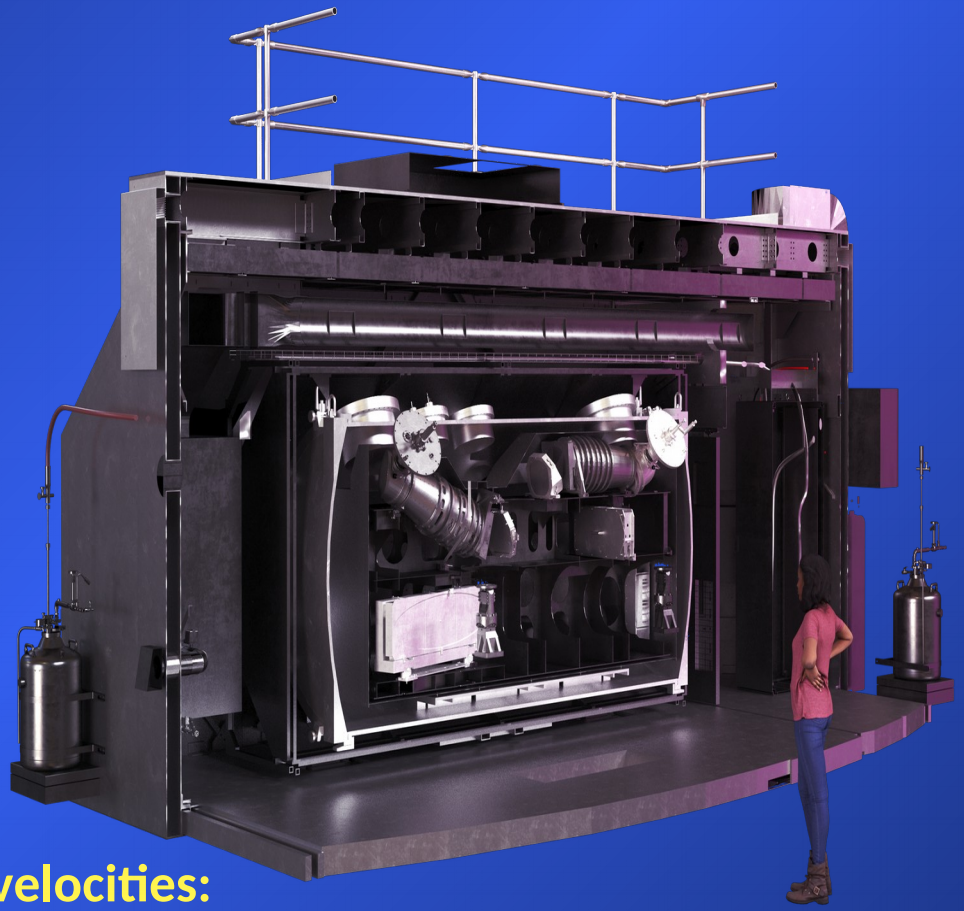
structure



notice that Chile is a very active geological region!

G-CLEF

Optical Echelle spectrograph



λ = 0.35-0.95μm blue and red arms

R = 20,000–150,000

FOV~1.5’ for 1-7 objects

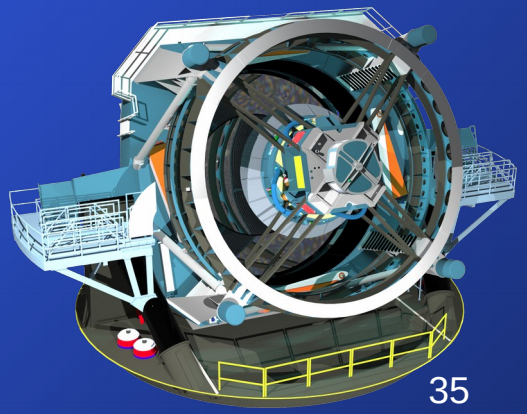
Performance in measurements of radial velocities:
< 50 cm/s per exposition

< 10 cm/s combined!

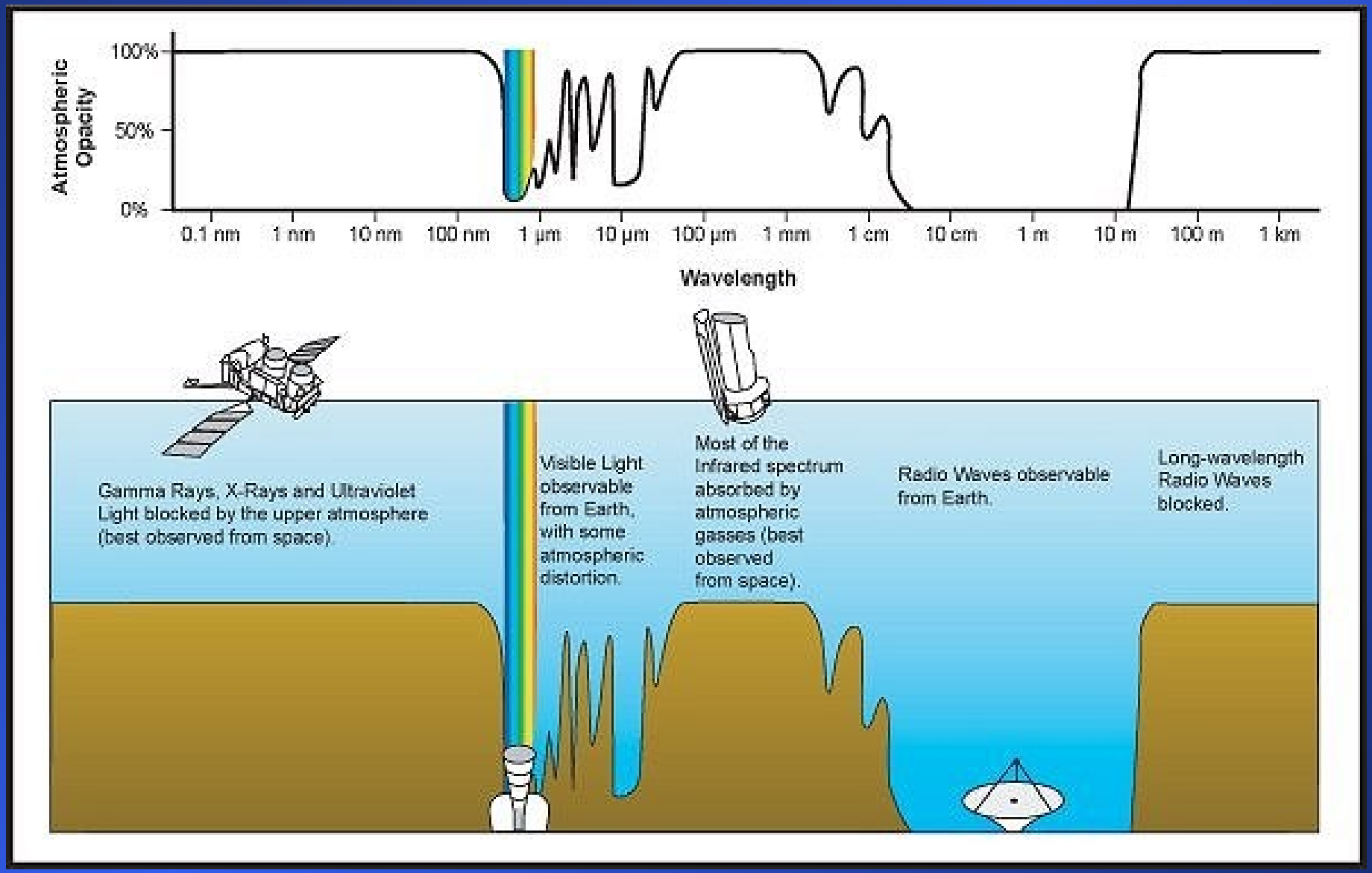
Legacy Survey of Space and Time -LSST Vera C. Rubin Observatory

- ~20 terabytes of data per night
- each area of the visible night sky will be observed every few days and will be imaged 1000 times during
- the initial 10-year survey → deep images!
- film of the night sky → the variable universe!
- ~20 terabytes of data per night → data tsunami

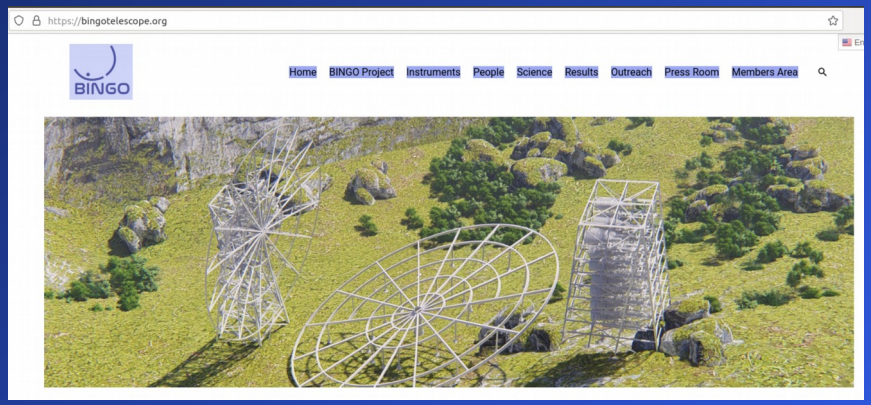
enormous opportunities for development and application of data science/AI tools



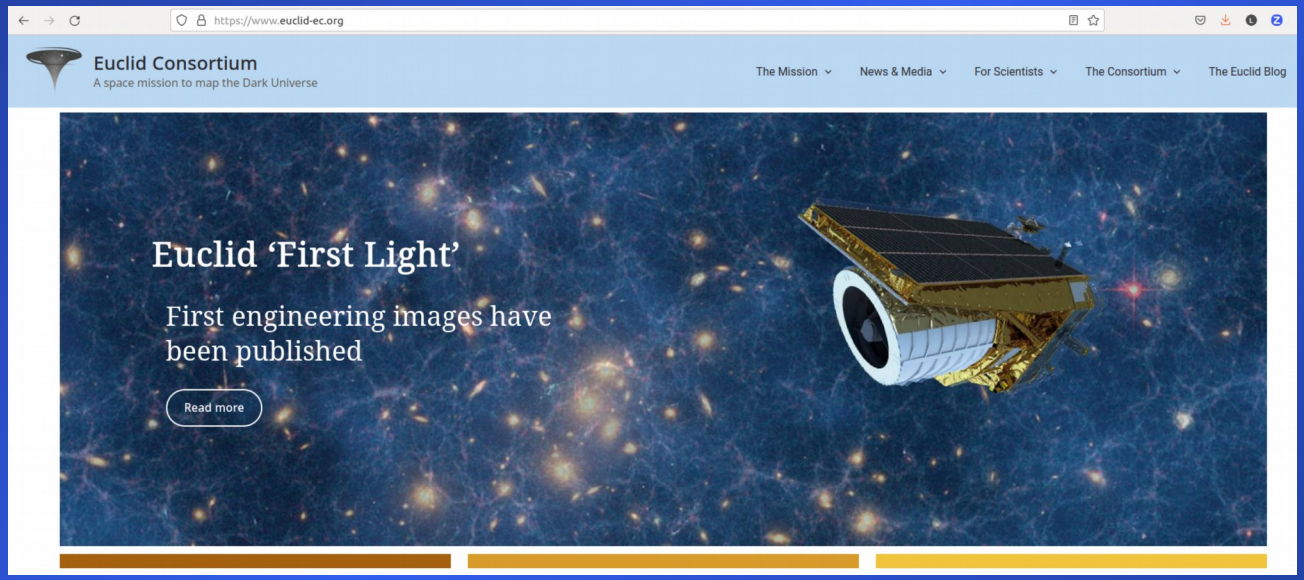
but Astronomy goes beyond optical wavelengths!



Keep alert! Talks/labs on radio astronomy & space science



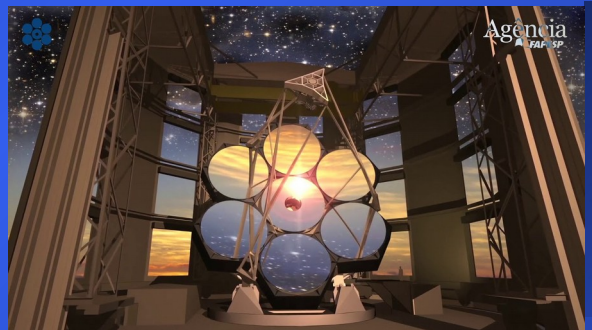
Keep alert! Talks/labs on radio astronomy & space science



eXTP enhanced X-ray Timing and Polarimetry mission
http://english.ihep.cas.cn/nw/han/y18/201807/t20180704_298169.html

summary

- Astronomy has many deep questions
- Astronomy makes use of cutting-edge technologies
- The data space of astronomical data is hudge! enormous opportunities for data science



to know more:

GMT – Giant Magellan Telescope
https://giantmagellan.org/
https://www.gmt.iag.usp.br/index.php/
https://youtu.be/l8Opckzn_aY
https://noirlab.edu/public/products/books/books002/

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