Planck JWST
Euclid ARIEL

Latest news from the Universe

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From cosmology, galaxies and black-holes to exoplanets and Solar System

Interstellar
PAHs
Fullerenes

Latest news from the Universe

(from the 3-5 last years or so)

- **Galaxies:** New light on galaxy birth and infancy (JWST), and the Milky Way (Gaia)
- **Cosmology:** Slow progress of cosmology faced with the challenges of physics
- **Black Holes:** Many more about black holes
- **Exoplanets**: Exploring their diversity and habitability (JWST, etc.)
- **Solar System:** Search for life in the Solar System outside the Earth?

- The new window of **variability, Vera Rubin Telescope**

- Other **highest-energy** achievements

NASA with ESA participation
Launch: December 25 2021
Total cost: $9,7 billion + operations
3400 papers with JWST in title!

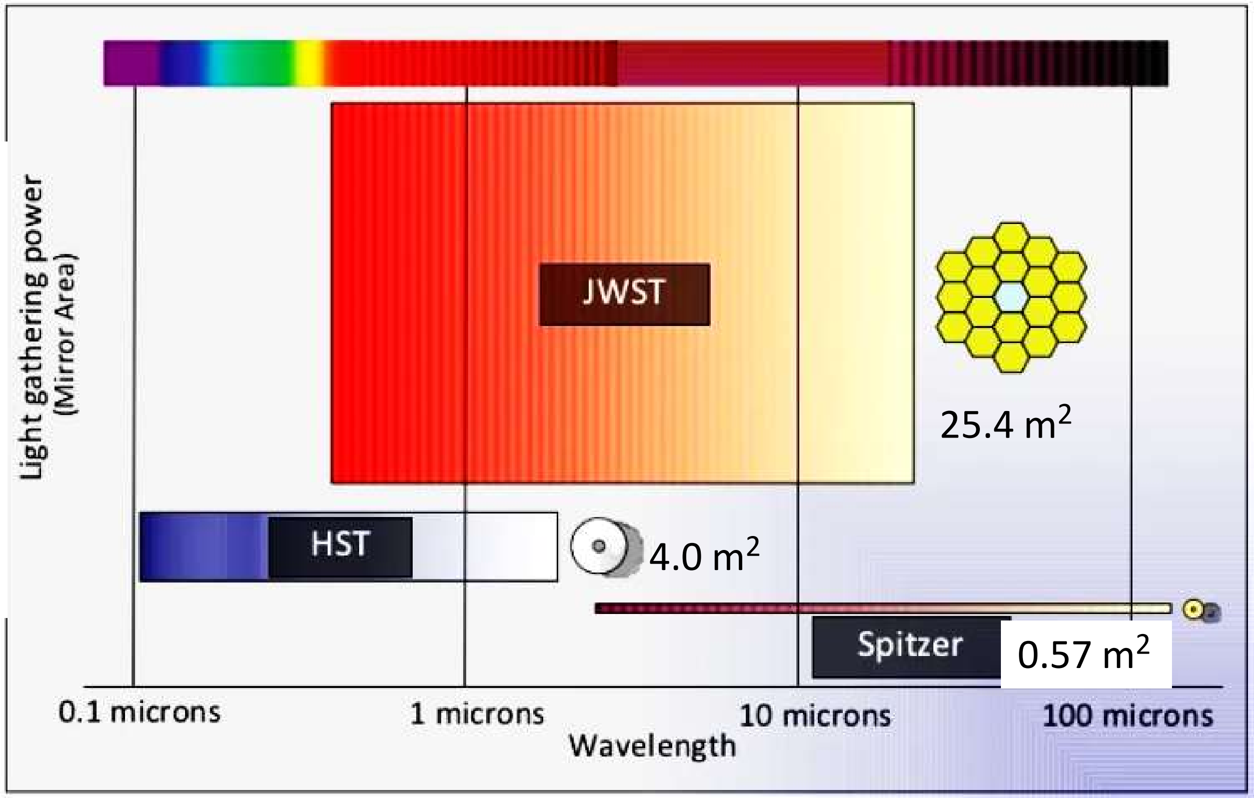
The Power of JWST

James Webb Space Telescope

Successor of Hubble Space Telescope

Surface/sensitivity 6 times larger
IR→ molecules, redshifted objects

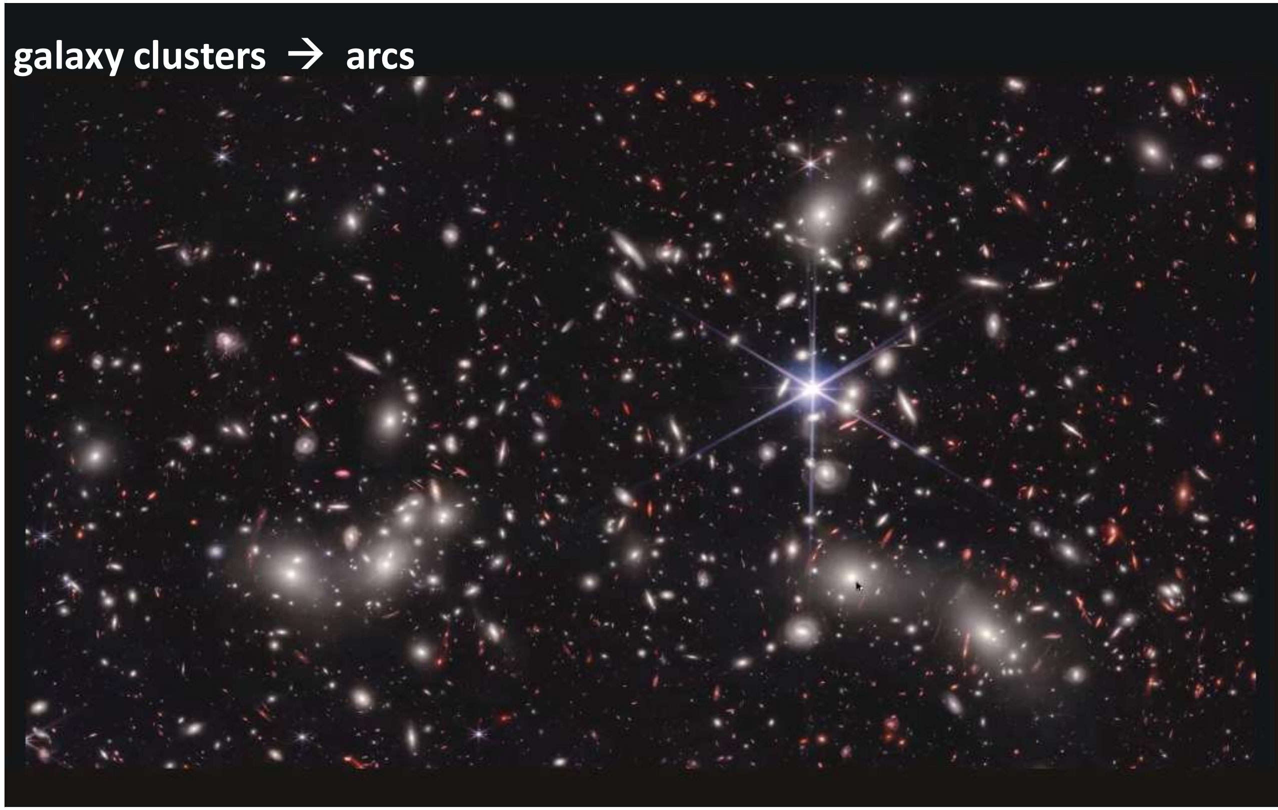
Revolution in IR astronomy
→ Exoplanets
→ (Formation of) redshifted galaxies



Credits: CBS Japan

Breathtaking JWST images from the splendid suit of JWST cameras, filters and spectrometers

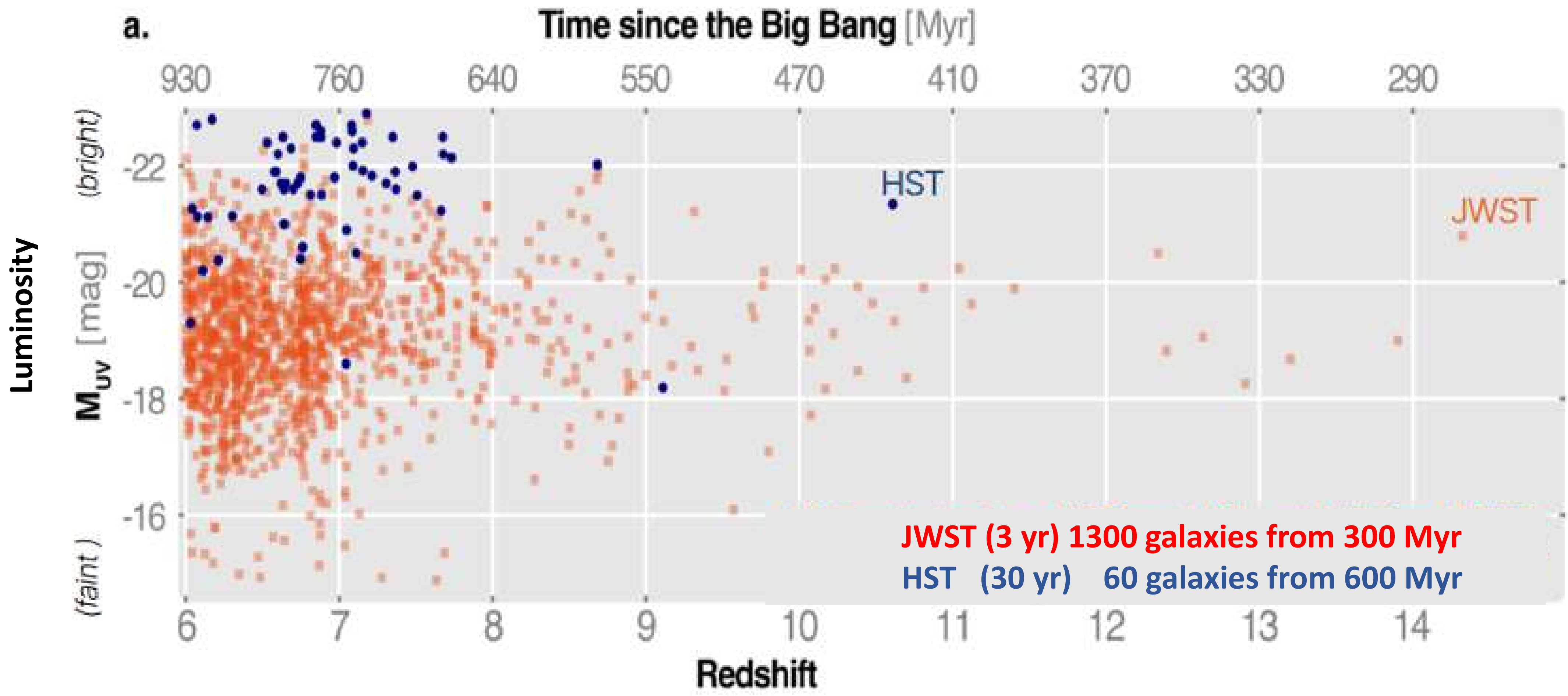
Breathtaking JWST images from the splendid suit of JWST cameras, filters and spectrometers



Adamo et al. 2024 Courtesy of Iryna Chemerynska

JWST reveals a robust population of high-redshift galaxies at z > 10

age < 500 Myr

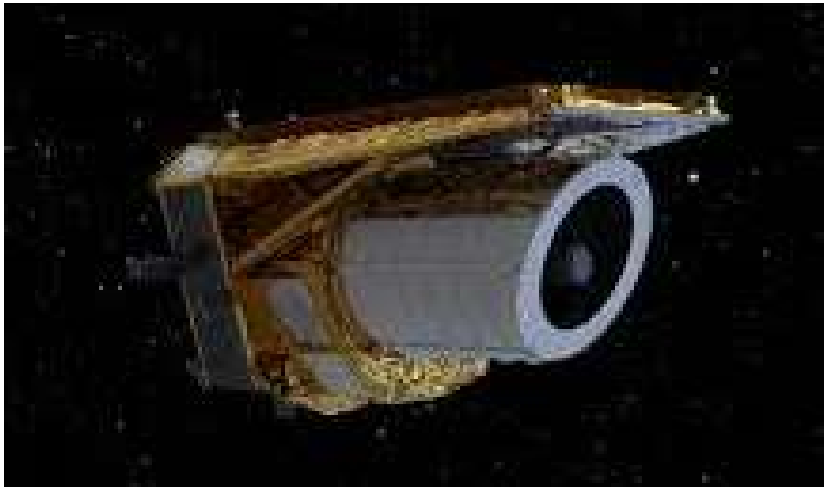


JWST surprises about young galaxies

Young (distant) galaxies in the first billion years of the Universe are much more numerous (factor up to **100**) and luminous than expected before JWST.

This might imply:

- Either flaws in the standard cosmological model?
- Or, as well, changing the very complex parameters of the models of galaxy formation?



ESA space mission
2023-2030
space image-quality
partly in near-IR
Φ = 1.20 m

Other breakthroughs in galaxy research: 1. EUCLID

- **Explores dark energy (variation in time?) and dark matter**
- **3D census of billions of galaxies in the whole sky**
- *Only promising first results up to now*

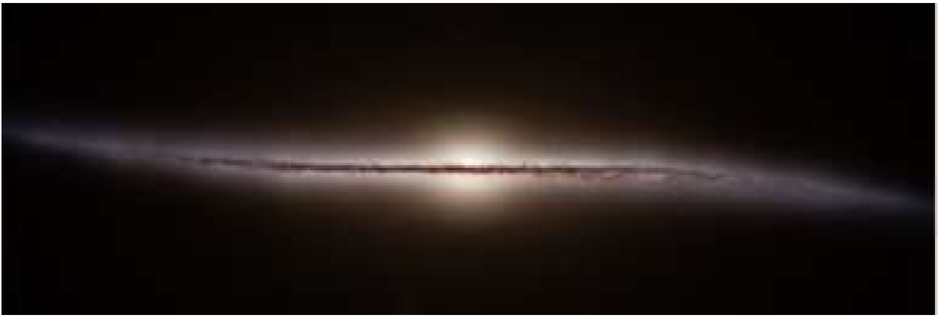
ESA, 2014-2025
Position *<~10^{-4} arc second*
Motion *<~10^{-3} "/year*
5000 papers with Gaia in title

Other breakthroughs in galaxy research: 2. Gaia

- **Two billion stars** of the Milky Way, our galaxy, etc: **distance, velocity**, luminosity, etc.

- Extraordinarily precise **3D map** (6D with velocity)
  → **structure and history** of our galaxy (successive absorption of dwarf galaxies, etc.)

Full amazing success. More data-releases are expected



JWST confirms the presence of massive black-holes in very young galaxies

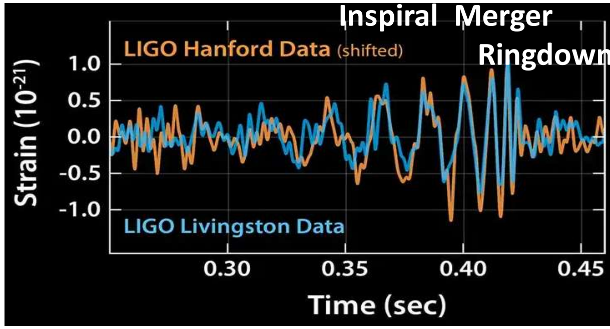
- Part of the excess energy emitted by very young JWST galaxies may come from the central Active Galactic Nucleus (**AGN,** such as quasars), rather than from stars

- JWST may have identified high-redshift objects resulting from the **collapse** of the core of young galaxies, surrounding an **intermediate-mass** black-hole (**10^4-10^5 M_{sun}**)

These might be the ''**seeds**'' at the origin of the mass of supermassive black-holes of galaxies and quasars, which have subsequently grown by accretion of interstellar gas up to **10^6-10^{10} M_{sun}**

But, such a conjecture needs to be confirmed

LIGO US (+Virgo/Italy-France & KAGRA/Japan)
Initial detections in 2015 of merging of 2 black holes ~30 M_{sun} (→2017, 2 neutron stars ~2 M_{sun})

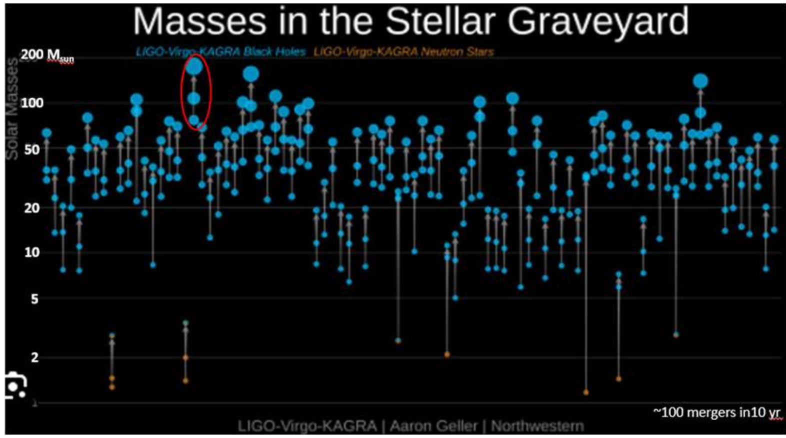


Black-Holes and gravitational waves

The detection of gravitational waves by LIGO in 2015 was one of the most amazing feats of the whole history of science (see S.Haroche) → New window for BH and GR studies.

- Now after 10 years, the **LIGO**-Virgo-KAGRA collaboration may detect one BH merging **every 3 days**

3-100 M_{sun}



→ **BH properties and physics** (consistent with General Relativity)

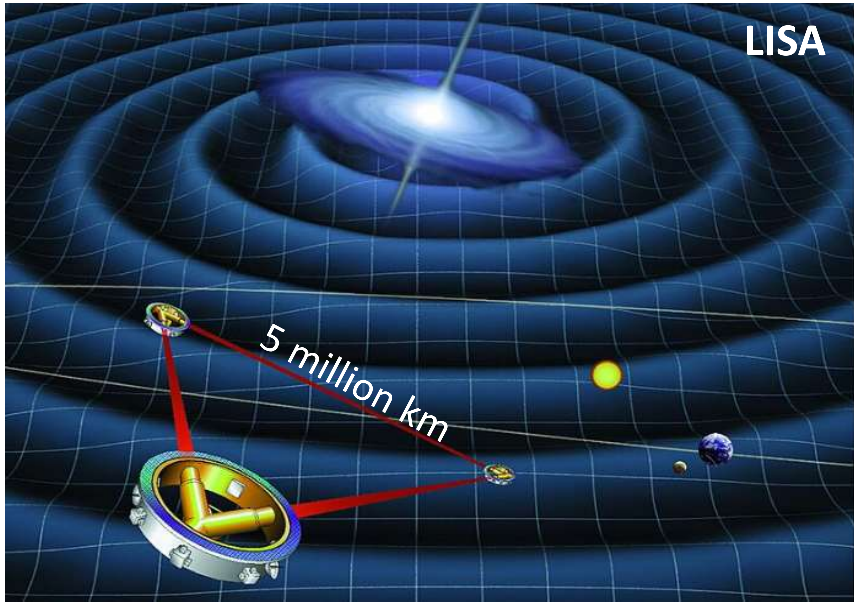
→ Aim at more **neutron star** mergings

(physics of neutron stars and nucleosynthesis)

- **IPTA** (International Pulsar Timing Array; worldwide) + **FAST** (China)
  Very-low-frequency GW-background through long **timing of ~100 pulsars**
  Close to detection?

Black-Holes and gravitational waves

2. Projects



- **Space** (ground environment is too noisy at low frequency)
  - **LISA** (decided, success of LISA-pathfinder)

    ESA ~2035: 5×10^6 km

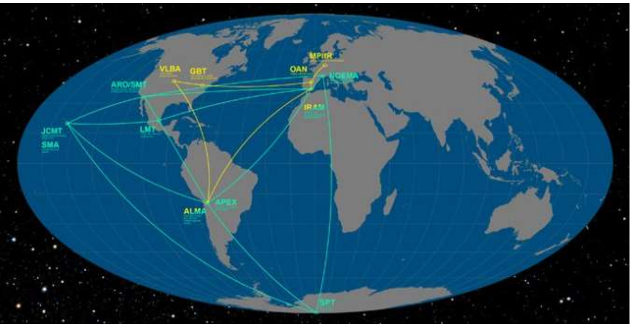
    Lower frequency than LIGO

    Massive BHs up to 10^6 M_{sun}.

    Etc.

  - **Taiji,** China: similar to LISA, 2033?

- **Ground-based** (considered)
  - Cosmic Explorer, US: 2 x 40 km, 10^5 BH mergers/yr; 10^6 neutron-star mergers/yr
  - **Einstein Telescope**, Europe, Early 1940s?: 3 x 10 km, underground, cooled mirrors

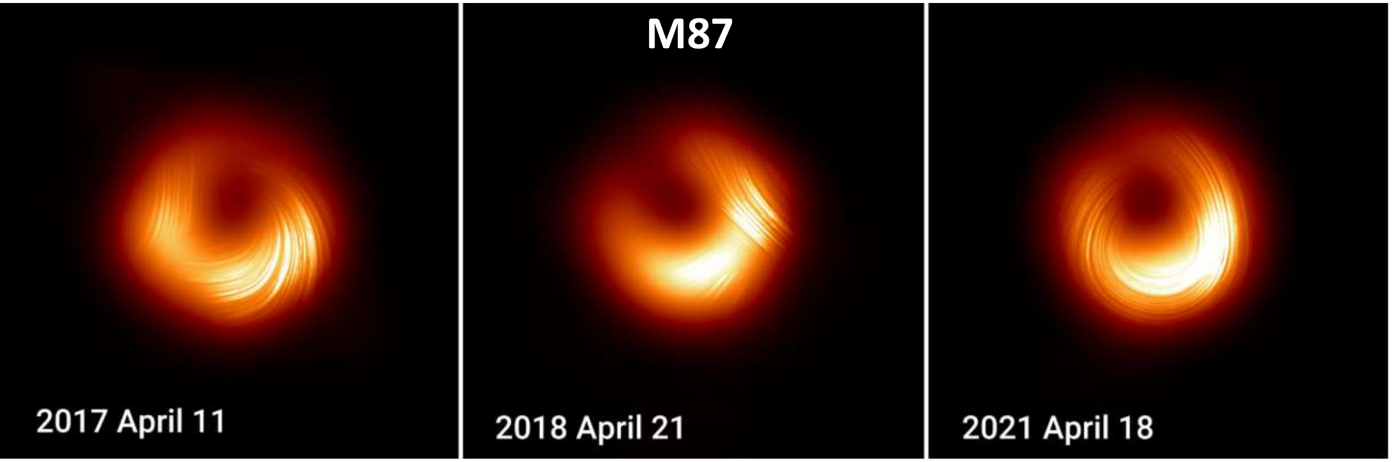


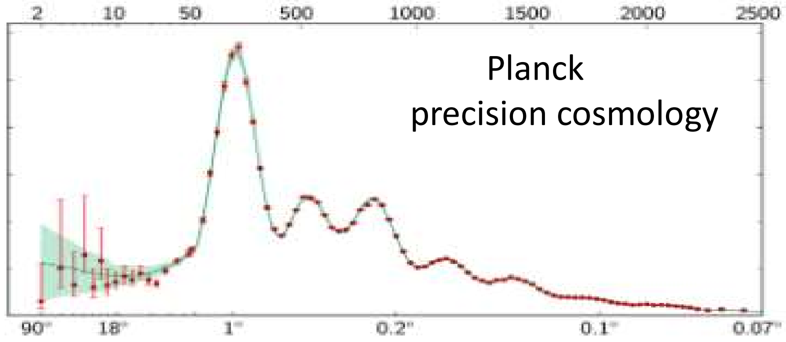
Imaging supermassive Black Holes

After the first images of the shadow of the supermassive black holes of the **elliptical galaxy M87** (2019, 4 10^9 M_{sun}) and the **Milky Way** (2022, 4.3 10^6 M_{sun}), the worldwide Event Horizon Telescope Collaboration (**EHT**) has continued deeper observations

→ Images of both sources in **polarized** 230 GHz radiation were published in 2024 and 2025.

- Both BHs **spin** at high velocity
- Information about **magnetic field** and how black holes feed and launch jets.





Latest news and question marks from cosmology

*(see **J. Doyle,** beyond standard model)*

- Standard Λ**CDM cosmological model**, mostly from cosmic microwave background, CMB (now at 2.7K); statistics of tiny sky fluctuations (Planck satellite, etc.) + supernovae, etc.

- Ordinary matter only 5% of total energy/mass

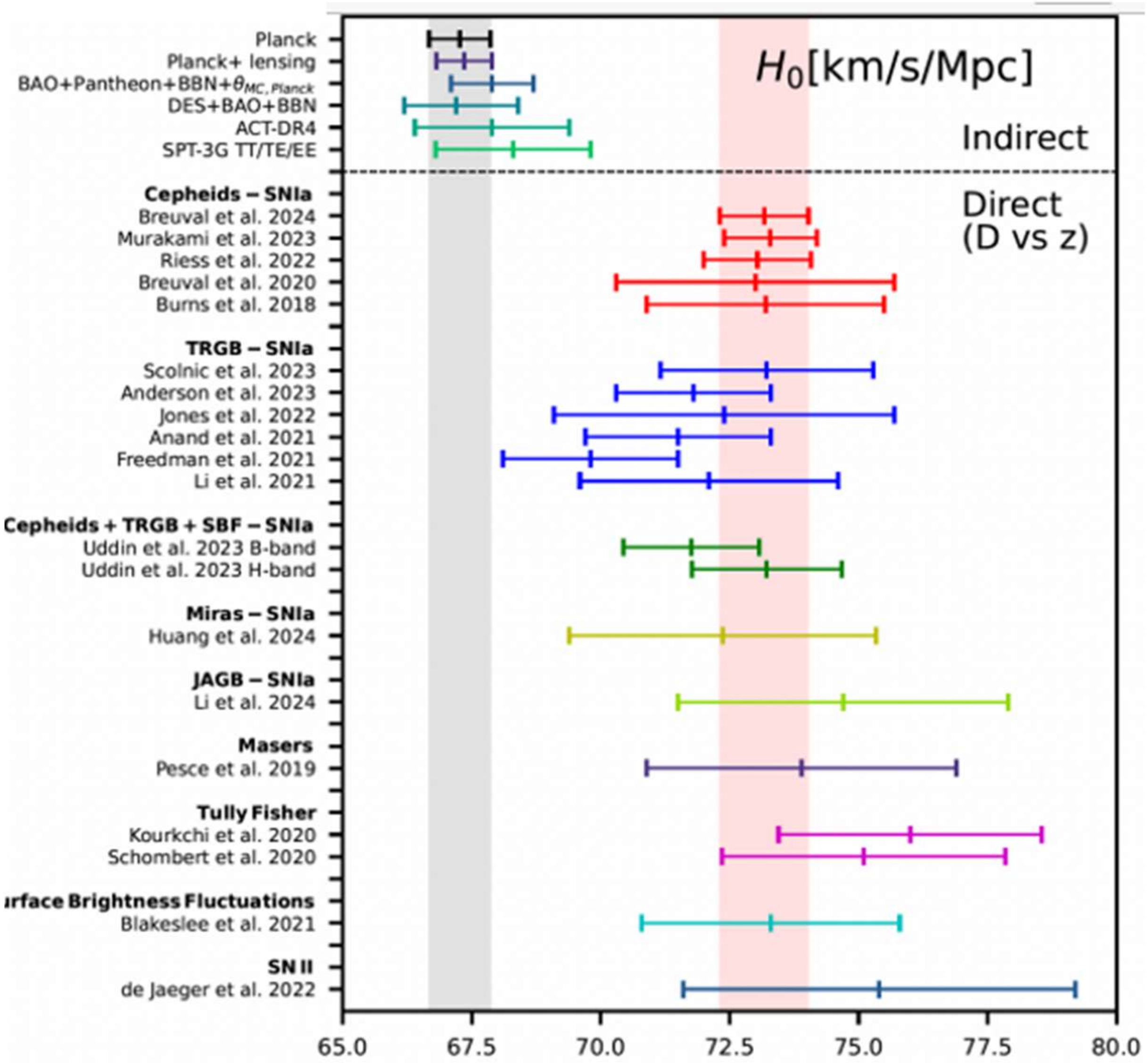
- Dark matter ~26%. No progress in the identification *(**J. Doyle**)*. Particle X (WIMPs) not seen within LHC mass-limit
→? very light axions (>~ 10^{-20} eV, BE condensates); primordial black-holes, etc.??
or modify General Relativity, but no satisfactory model

- Dark energy ~69%; hints of **time variation** of Λ by DESI collaboration
to be confirmed. Waiting for **Euclid** results.

- Rate of expansion, Hubble constant, « **H_0 tension »:**
Significant difference between **local** (supernovae-Ia candels) and **high-redshift** (CMB) determinations
Lot of speculations.

- **Inflation:** active theory; constraints from CMB (Planck + ground)
- **Matter/antimatter**

H_0 tension

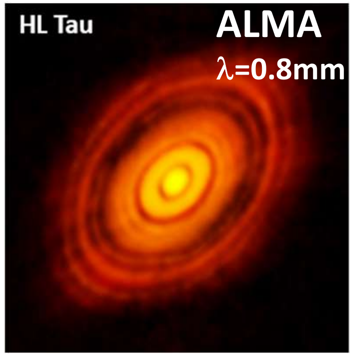


H_0[km/s/Mpc]
Indirect
Direct
(D vs z)
Planck
Planck+ lensing
BAO+Pantheon+BBN+$\theta_{MC, Planck}$
DES+BAO+BBN
ACT-DR4
SPT-3G TT/TE/EE
Cepheids – SNIa
Breuval et al. 2024
Murakami et al. 2023
Riess et al. 2022
Breuval et al. 2020
Burns et al. 2018
TRGB – SNIa
Scolnic et al. 2023
Anderson et al. 2023
Jones et al. 2022
Anand et al. 2021
Freedman et al. 2021
Li et al. 2021
Cepheids + TRGB + SBF – SNIa
Uddin et al. 2023 B-band
Uddin et al. 2023 H-band
Miras – SNIa
Huang et al. 2024
JAGB – SNIa
Li et al. 2024
Masers
Pesce et al. 2019
Tully Fisher
Kourkchi et al. 2020
Schombert et al. 2020
urface Brightness Fluctuations
Blakeslee et al. 2021
SN II
de Jaeger et al. 2022
65.0
67.5
70.0
72.5
75.0
77.5
80.0

AO2

Exoplanets

- **Planetary system formation**
- **History of exoplanet identification**
- **JWST imaging**
- **JWST spectroscopy**
- **Future projects**



+ Models

Diapositive 16

AO2 Alain Omont; 09/10/2025

Planetary system formation

- The scheme of formation of planetary and solar systems is well established

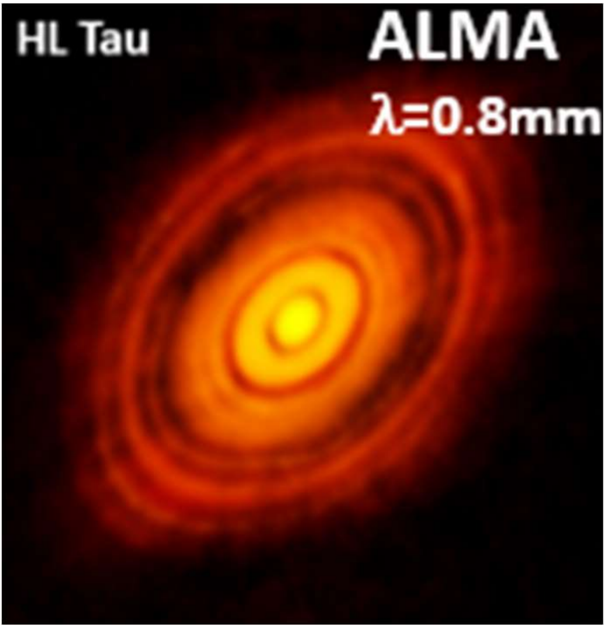
Disk around collapsing proto-stars because of conservation of angular momentum
Dust sedimentation + coagulation → planetesimals→ planets (cores) (→ jovian planets by gas accretion)

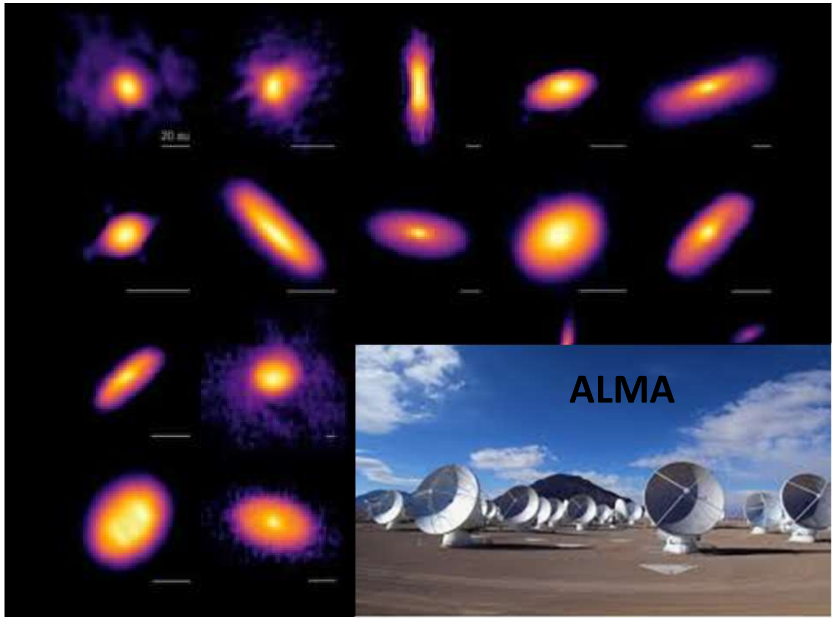
- Spectacular images

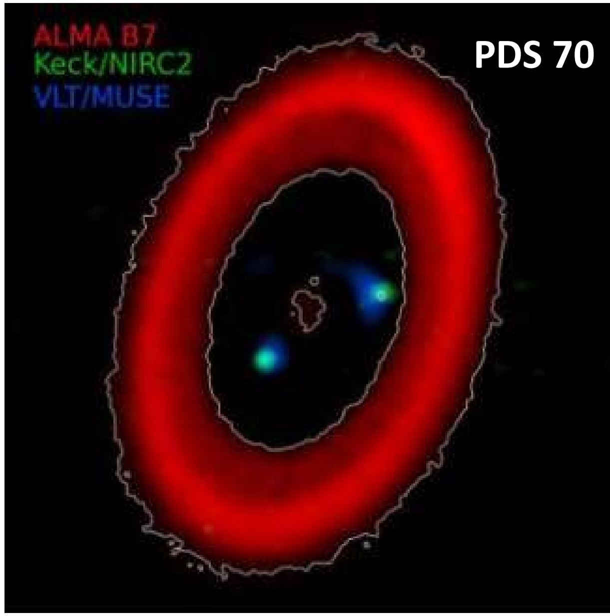
ALMA: cold dust **with rings and gaps generated by planets** in formation → JWST

- Sophiscated theoretical **modeling** (e.g. « Nice model »)

→ Massive planet formation and **migration from instabilities → diversity of systems**





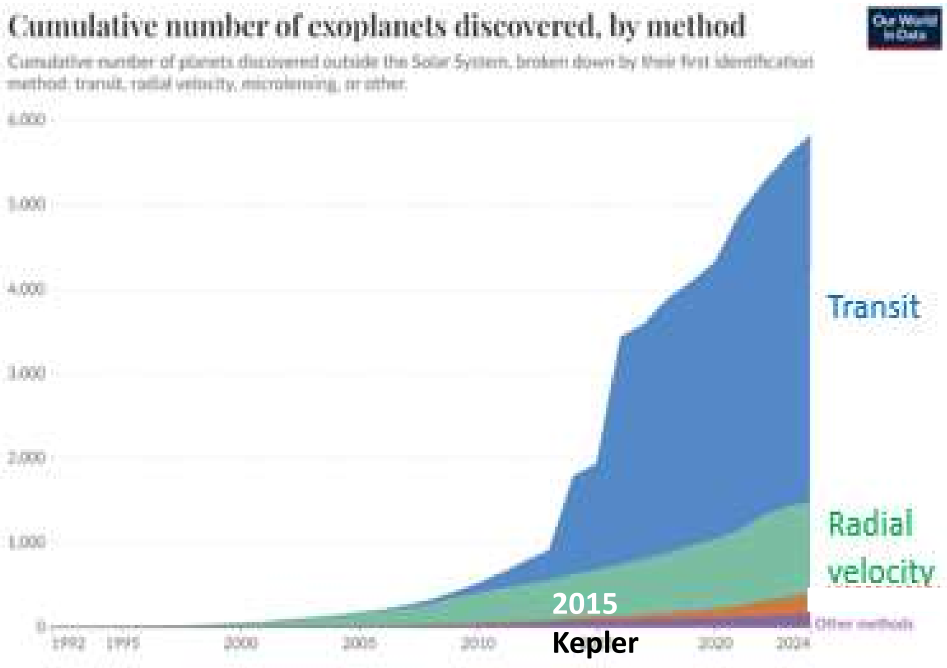


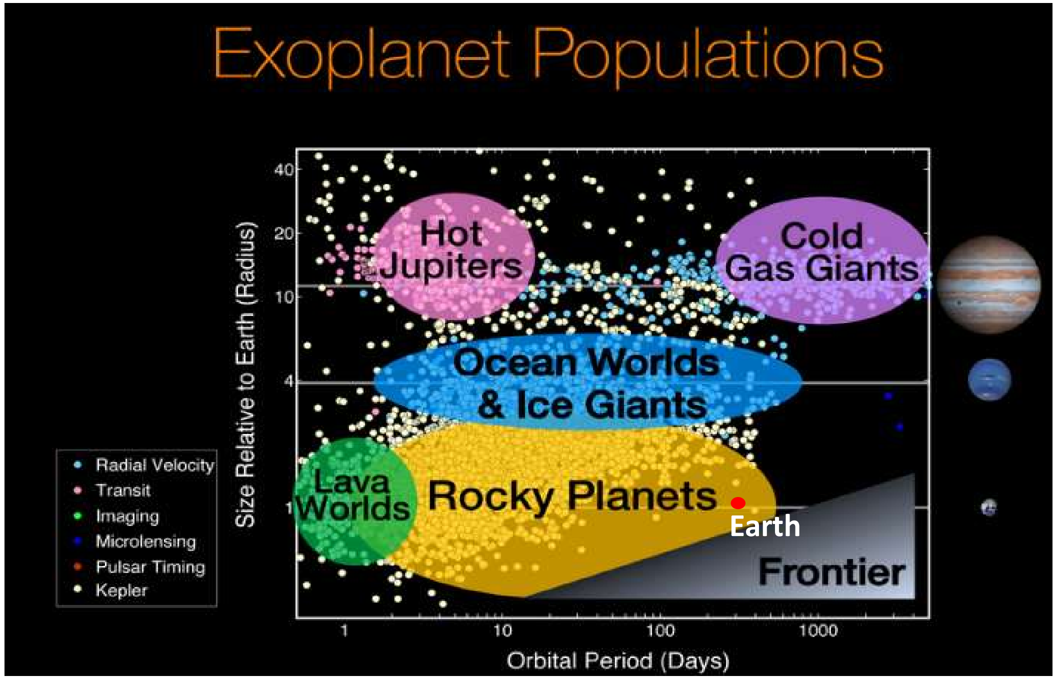
Exoplanets

- Discovery in 1995, → **6000** exoplanets (**massive,** from transits or radial velocity oscillations)
  → **The majority of stars have planets**
  → **High variety of planetary systems** (more instable than Solar System)
  → Search for ''**habitable**'' planets)

- JWST fantastic sensitivity in IR **imaging** and **transit spectroscopy** *(but be aware of Hype!)*

~1900 papers with JWST and exoplanet in the abstract





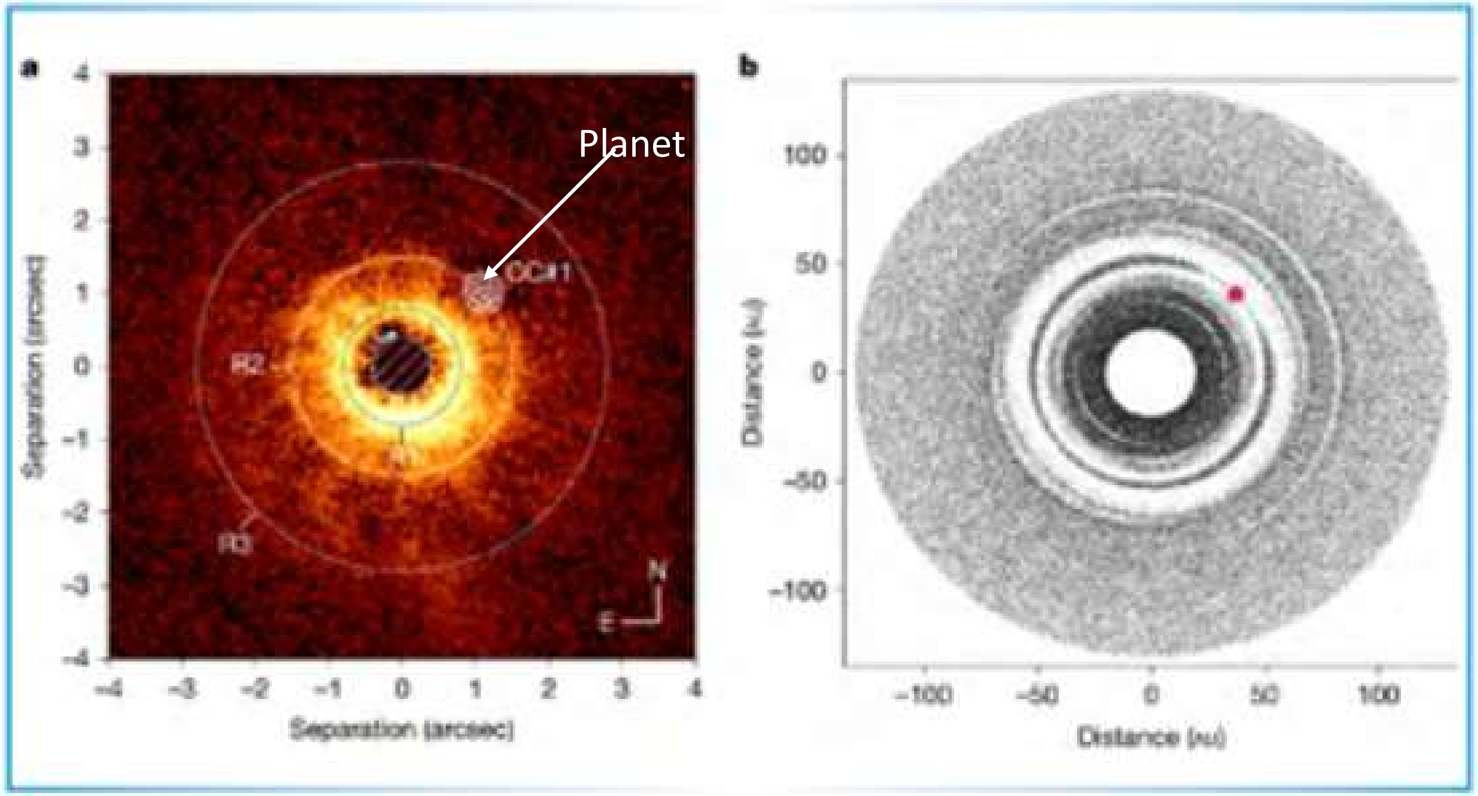
JWST exoplanets: infrared imaging

First example of an exoplanet directly detected in a mid-IR image of JWST *(Lagrange et al. Nature 2025)*

This planet (~Saturn) orbits in a dusty debris disk, where planets have formed characteristic rings and gaps.

Left. Combined coronographic **image** in mid-IR by MIRI camera of JWST and in visible by SPHERE instrument on ESO-VLT.

Right. **Simulation** of a protoplanetary disk perturbed by a planet similar to Saturn.

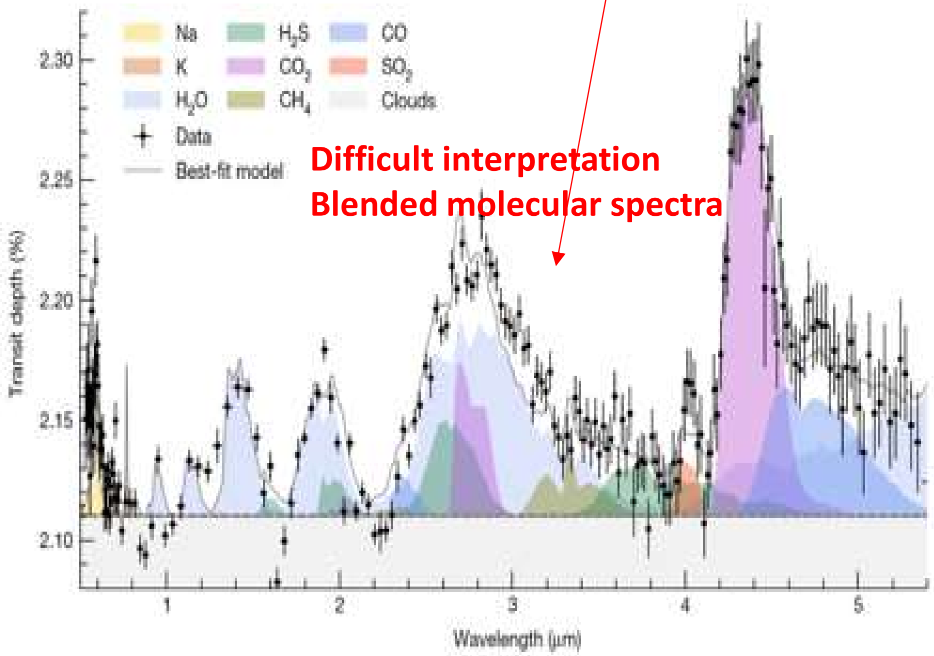


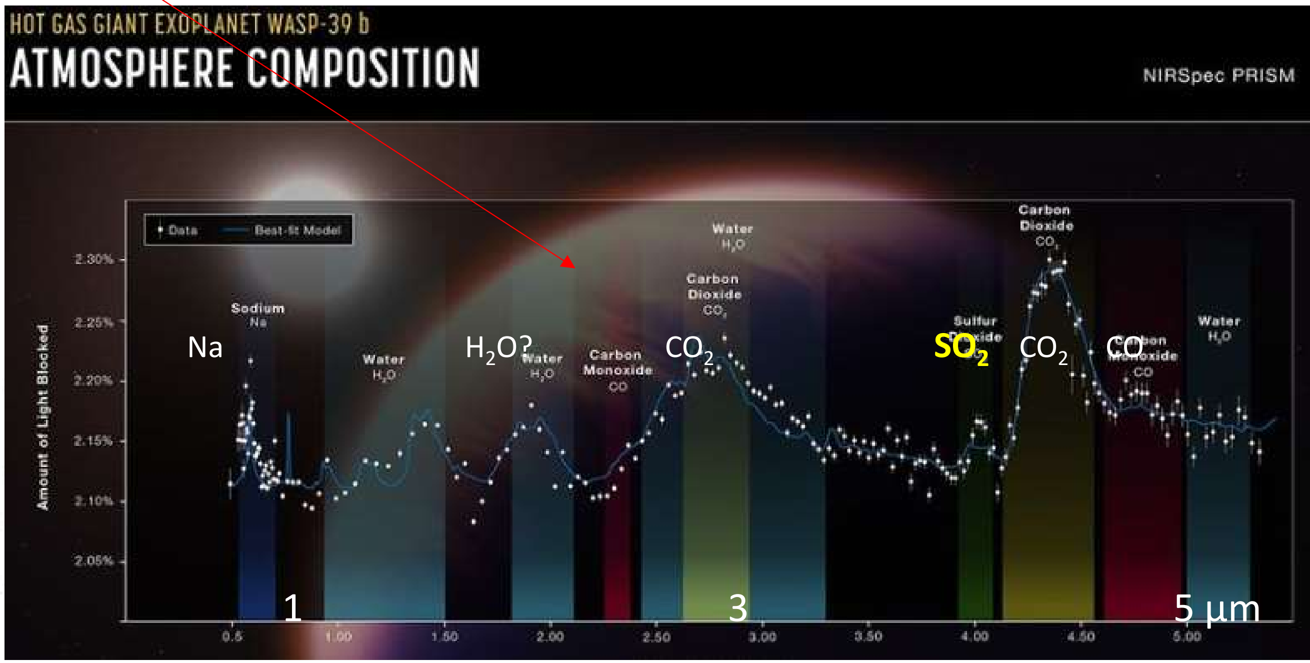
JWST exoplanets: IR spectroscopy (atmosphere transmission during transits)

IR spectroscopy of an exoplanet may be performed by 3 instruments of JWST by differential emission during **transit** (when the planet passes in front of the star) or **secondary eclipse** (when it passes behind the star), or by **transmission spectroscopy** of the atmosphere during transit.

Example of JWST transmission **spectrum** of Planet WASP-39b (mass **~Saturn**)

→ Hope to detect CO_2 with JWST in the thinner atmospheres of smaller, **rocky planets**





Exoplanets: future projects

Space

- **Gaia** will detect thousands of cold gas giant exoplanets through **astrometry** , etc.

- **Roman** (2027, NASA) 2.4m, large field of view: **100 000 transits**, 2000 **microlensing**

- **PLATO** (2026, ESA): **tens of thousands transits**; many Earth- and Super-Earth type.

- **ARIEL** (2029, ESA): ~0.9m: **Spectroscopy** of ~1000 exoplanets, mainly **hot massive**

- **HWO?** (NASA 2041??): **Flagship**, >~6m monolithic, visited by robots: biomarkers in ~25 **habitable** planets

Ground

- **ELT** (ESO, ~2030) **39m**: will **revolutionize** exoplanet studies, mainly by **direct imaging** and **spectroscopy** of habitable planets. *Web site of ELT claims that it could be the first to find extraterrestrial life!*

- **Vera Rubin** (2025, 6m): multi-repeated observations of whole sky

Solar System

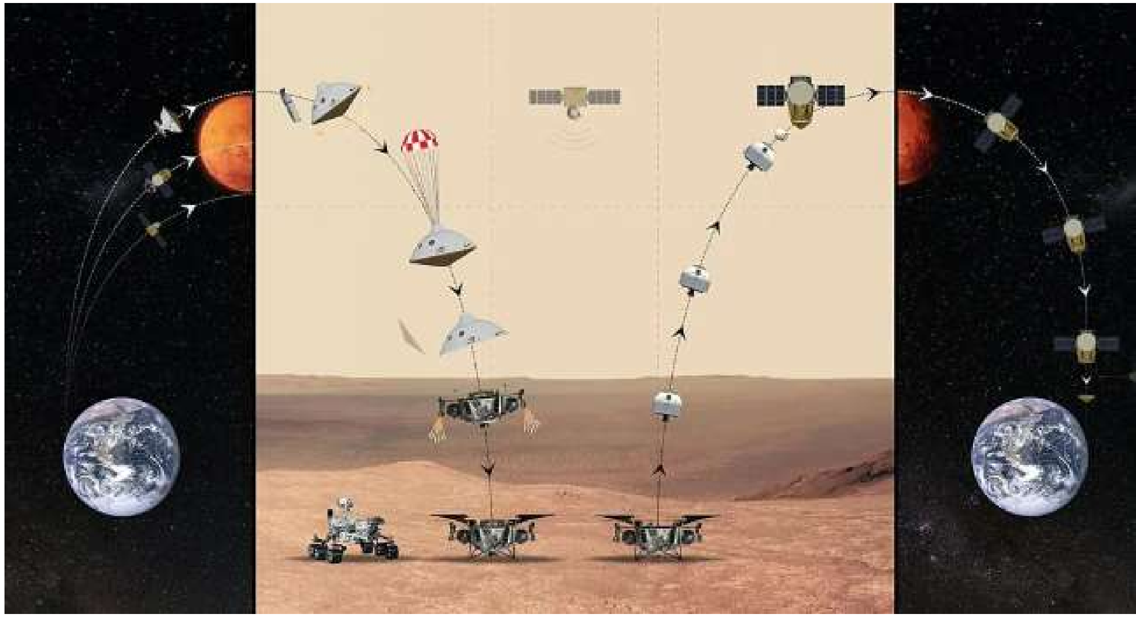
Search for traces of life outside Earth

- **Mars** sample return
- **Oceans in icy moons**
- **Asteroids** and cometary nuclei
- (Others)

Search for traces of life outside Earth

Solar System: Mars

- **Conditions similar to Earth for >10^9 yr** → possible origin of life (common or not)
- Best target for past life search → close to definitive answer
- Sill unsuccessful, but accumulation of positive signs (Perseverance rover, etc.)?
- Answer needs **sample return** and deep laboratory analyses
- Mars Sample Return (**MSR)** NASA flagship (+ESA)
- **Samples already collected** by Perseverance rover
- High cost of MSR, **cancelled** by Trump



Search for traces of life outside Earth

Solar System: underground oceans in icy moons

- Biggest moons of Jupiter and Saturn have whole-surface oceans, below ice field
- Even geysers in **Enceladus** (Saturn close moon)
- Two major missions have been **launched** and will reach Jupiter by **2030**:

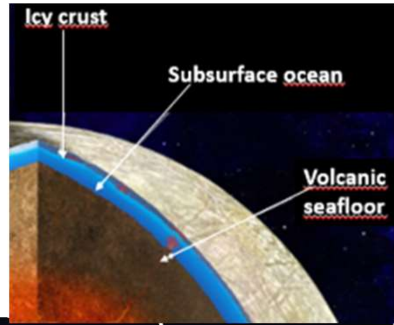
→ **Juice**: ESA, launch 2023: will orbit **Europa, Ganymede**, Callisto?
Many goals: identifying surface materials and possible communication with the oceans, etc.

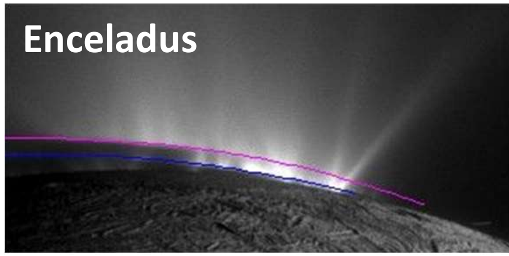
→ **Europa Clipper**: NASA, launch 2024
Will explore Europa by repeated fly-bies, its habitability and chemistry; prepare landing

or planned:

→ **Enceladus Orbilander?**: proposed NASA flagship, launch late 2030s, arr. early 2050s
Sampling water plumes and landing

→ **Dragonfly**: **Titan**, NASA, launch 2028, arr. 2034: rotorcraft, vertical takeoffs and landings
Studying prebiotic chemistry and habitability





Solar System: asteroids and cometary nuclei

- Asteroids and comets were key for providing Earth with ''**prebiotic**'' carbonaceous matter (+ perhaps H_2O)
  → importance of probing their chemical composition

- After Rosetta (ESA, 2004-2014), which detected the presence of carbonaceous macromolecules

- Major missions aimed at easier carbonaceous asteroids with **sample return**:

  Hayabusa2 /Ryugu (Japan, 2014-2020) and **OSIRIS-Rex**/Bennu (NASA, 2016-2023)
  Extreme richness of molecules, similar to meteorites. No evidence of different right- and left-handed amino acids

- **Comet sample return** mission would be needed for **testing interstellar/comet connection**, but difficult

- Identification programs of **potentially hazardous objects** (Near Earth Objects)

  DART NASA mission (2022) to test asteroid deflection

- Better knowledge of asteroid physics

- Large increased **number of asteroids** identified by Gaia and expected from Vera Rubin and Roman observatories

Solar System: others

- **Moon**: major return to the Moon has been decided by China, US, etc.

→ Permanent base? (observatory??)

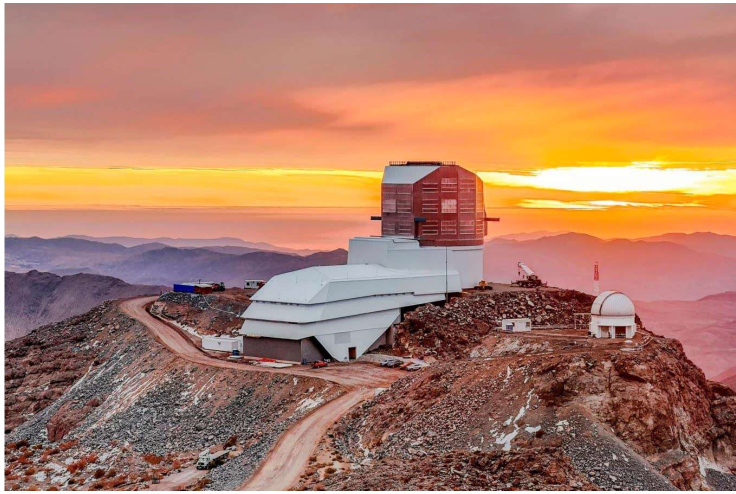
- **Uranus Orbiter and Probe?** Highest priority NASA flagship. Late 2030s? Complete study of Uranus and satellites

- **Venus:** various ESA and NASA missions

- **Mercury**: BepiColombo, ESA, launched in 2018 will start operations in 2027

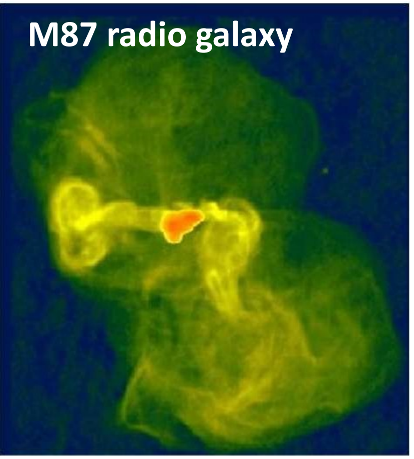
The new window of variability

Vera Rubin Observatory (/LSST), 2025 → >2035

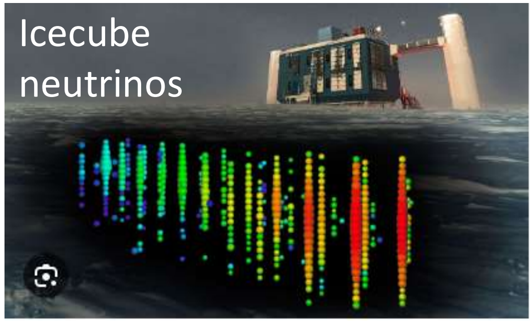


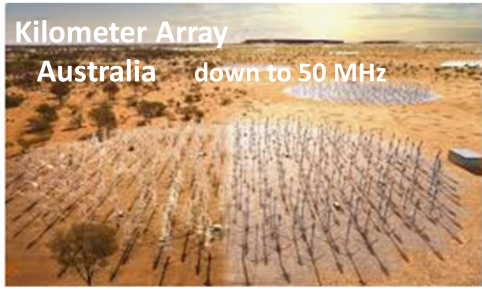
- Φ=8.4m in Chile, field of view Φ=3.5°, 3.2 gigapixel CCD camera.
- Repeated observations; **half the sky every 3 days**
- All known and unknown variable sources (10 million changes every night):
  - **10 million asteroids** (including 100 000 near-Earth objects) and small Solar System bodies (Kuiper belt)
  - **20 billion galaxies** → dark matter structures; complementary to Euclid
  - **17 billion stars** → Milky Way history complementary to Gaia
  - **Supernovae** and variable stars
  - **Optical counterparts of transient events**: BH and neutron-star mergings, fast radio bursts, stars being torn apart by black holes (tidal disruption events, TDEs), etc.

Highest energy astrophysics



- Physics of AGN, radio galaxies, QSO, blazars
- TDEs and other extragalactic X-ray transients
- Gamma-ray bursts
- Spectroscopy near compact objects
- Gravitational wave astronomy
- Neutrino astronomy
- Ultra-high energy cosmic rays and gamma-rays
- Etc





Conclusions

- Astrophysics has progressed in the last years at the same path as amazing 20th Century
- Cosmology is progressing with CMB (space → ground) but is plagued from questions of **fundamental physics**
- Astrophysics and physics share same fundamental questions. Precision quantum physics may help
- **Black-hole** studies have much progressed in various aspects → possibility to attack fundamental questions
- Complex galaxies studies are completing up to their **formation** → **SKA** will extend them even earlier → z~20?
- **Variability** is a new window
- **Exoplanet** studies impressively improve with **JWST** → comprehensive JWST studies → **ELT** will be a step further
- Life in **Solar System** outside Earth: hope answers about fundamental astrobiology questions within half a century