Reaching for the stars

New developments in ground-based astronomy

Markus Kissler-Patig

GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders

Director

Today's ground-based astronomical facilities

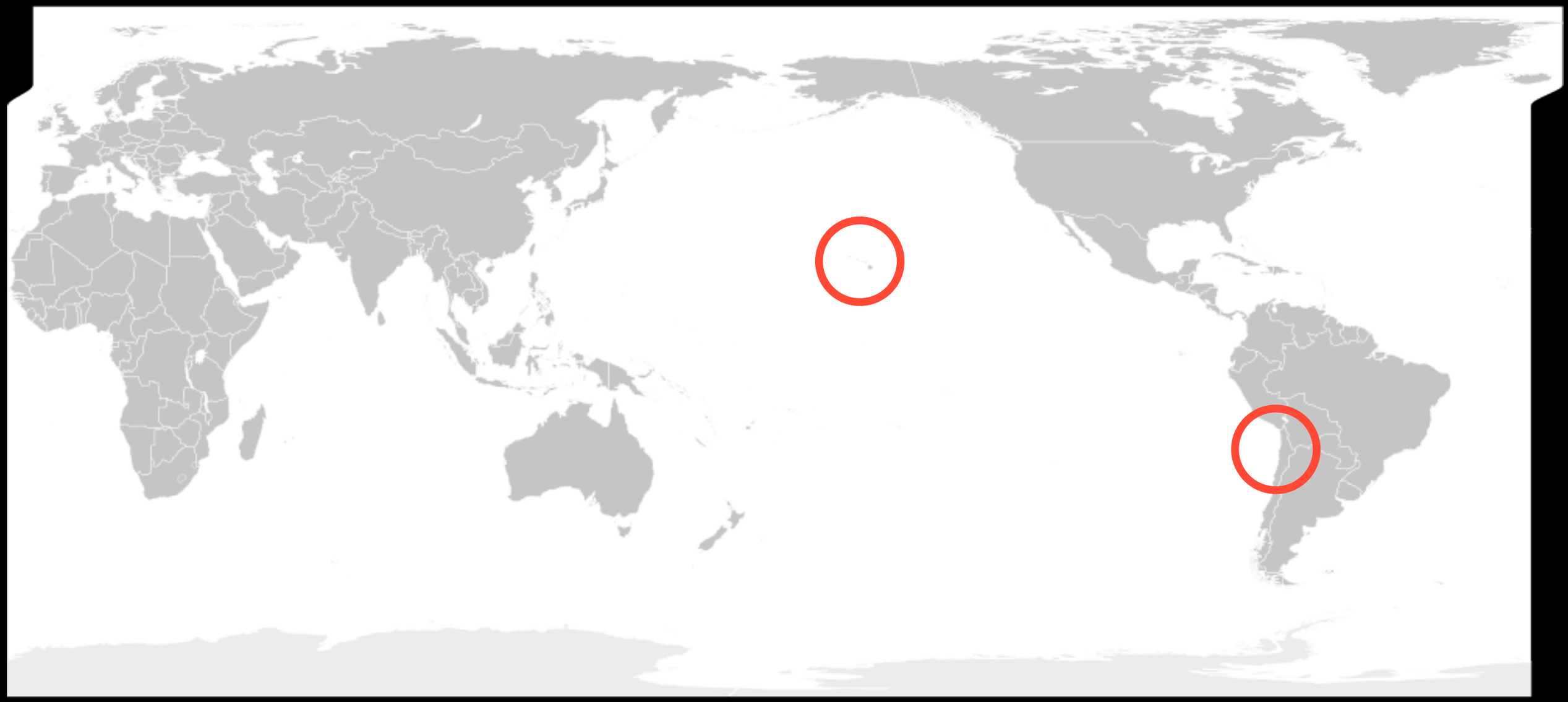
Current research in Exoplanets

Current research in Cosmology

Upcoming facilities (LSST, ELTs)

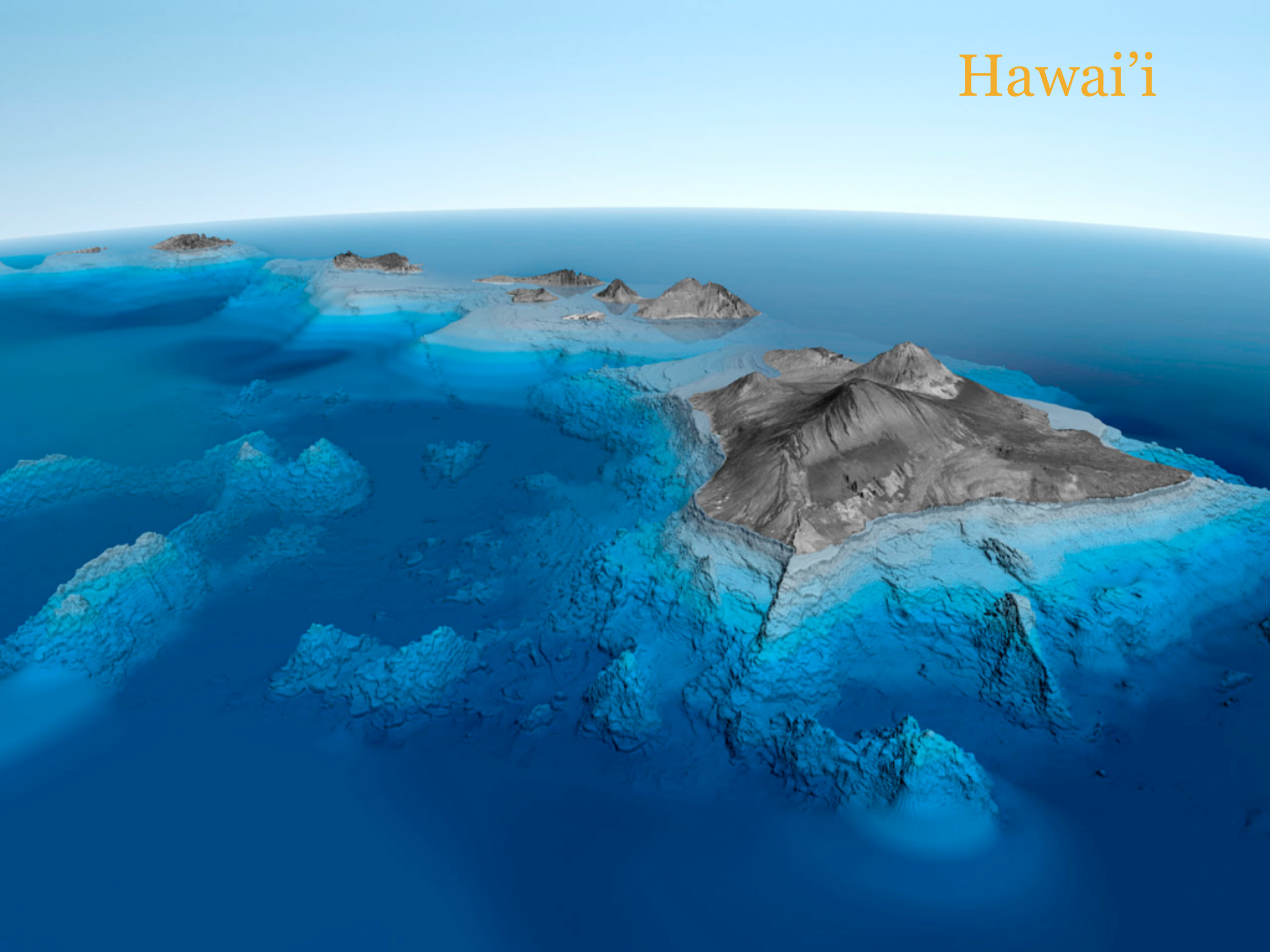
Today's ground-based astronomical facilities

The best observing sites on the planet:



Atmospheric conditions (turbulence, water vapor), accessibility, attractive to international staff, …

Hawai’i



Hilo, rainiest city in the United States


TMT
Maunakea
Keck
IRTF
Subaru
CFHT
SMA
Gemini
JCMT
UH 88’
CSO
UKIRT
VLBA

Why so many telescopes?

Astronomers exploit all the light they can get…

Covering the accessible wavelength range:

Radio: neutral gas (Hydrogen) [VLBA]

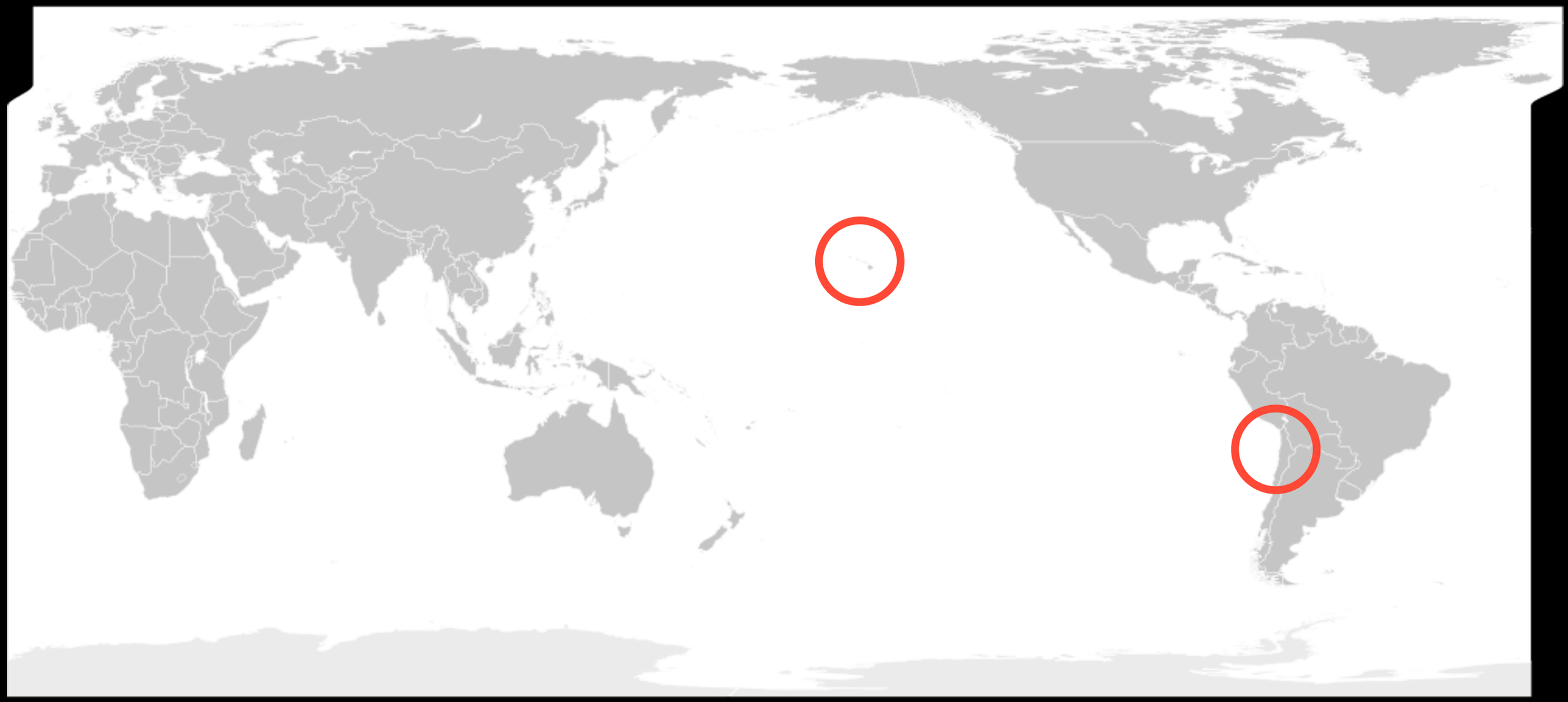
Sub-mm: cold (10-100K), molecular gas [CSO, JCMT, SMA]

Near-infrared: dust obscured light, star formation, highly redshifted objects [UKRIT, IRTF]

Optical/UV: stellar light, galaxies [Keck, Subaru, Gemini, CFHT, UH 88']

Within a wavelength range, specializing the telescopes for narrow/ wide field imaging and/or spectroscopy

The best observing sites on the planet:



Atmospheric conditions (turbulence, water vapor), accessibility, attractive to international staff, …

Chile

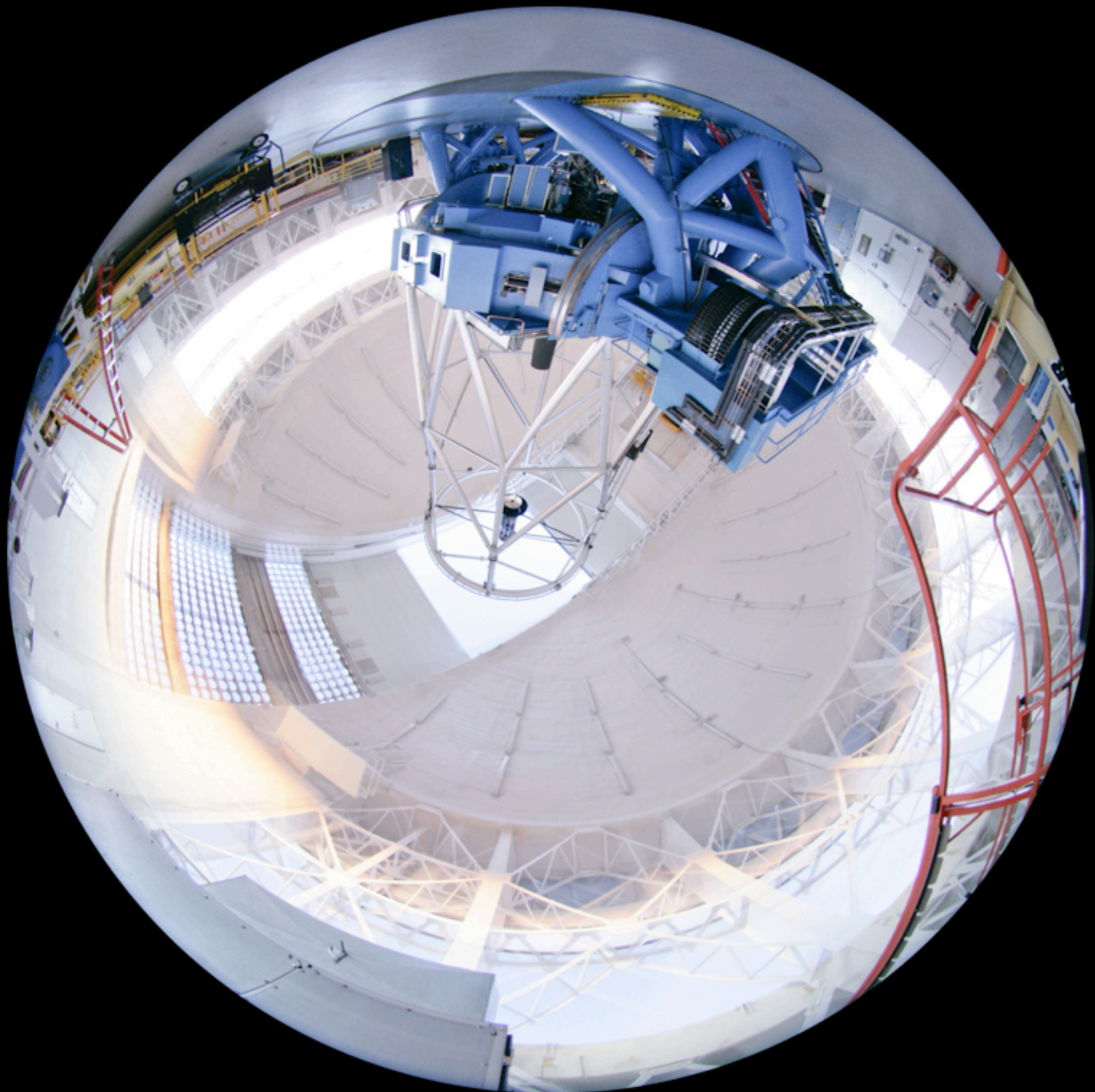
Cerro Tololo
Cerro Pachon
Las Campanas
La Silla

Cerro Paranal

Chajnantor


La Serena
Gemini South
Base Facility
50 km paved highway
Coquimbo
Puclaro Dam
& Tunnel
Vicuña
AURA
Property
(Totoral)
40 km dirt road
CTIO
Gemini
South
Telescope
SOAR
LSST

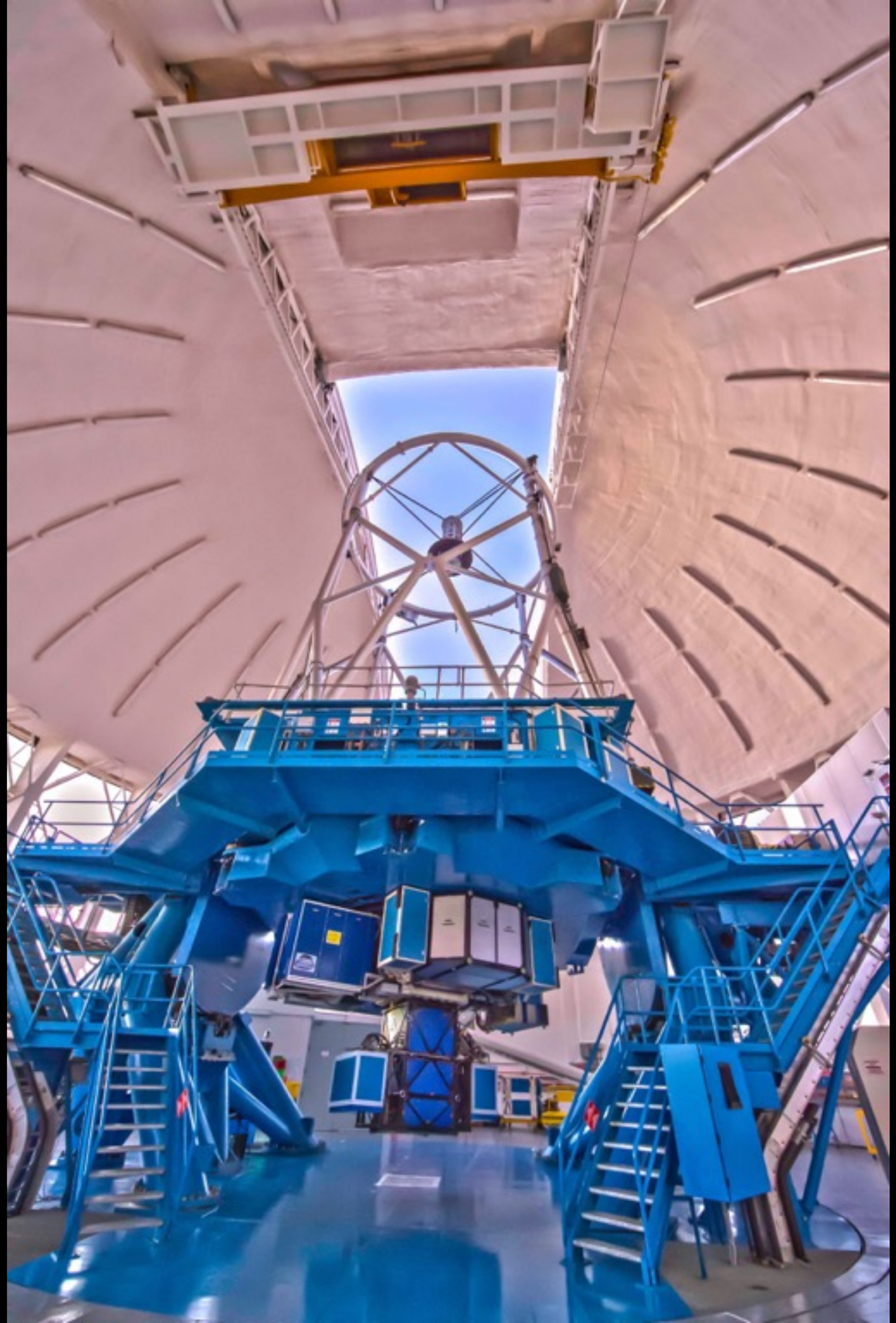
Telescopes in operations…



Telescopes basics

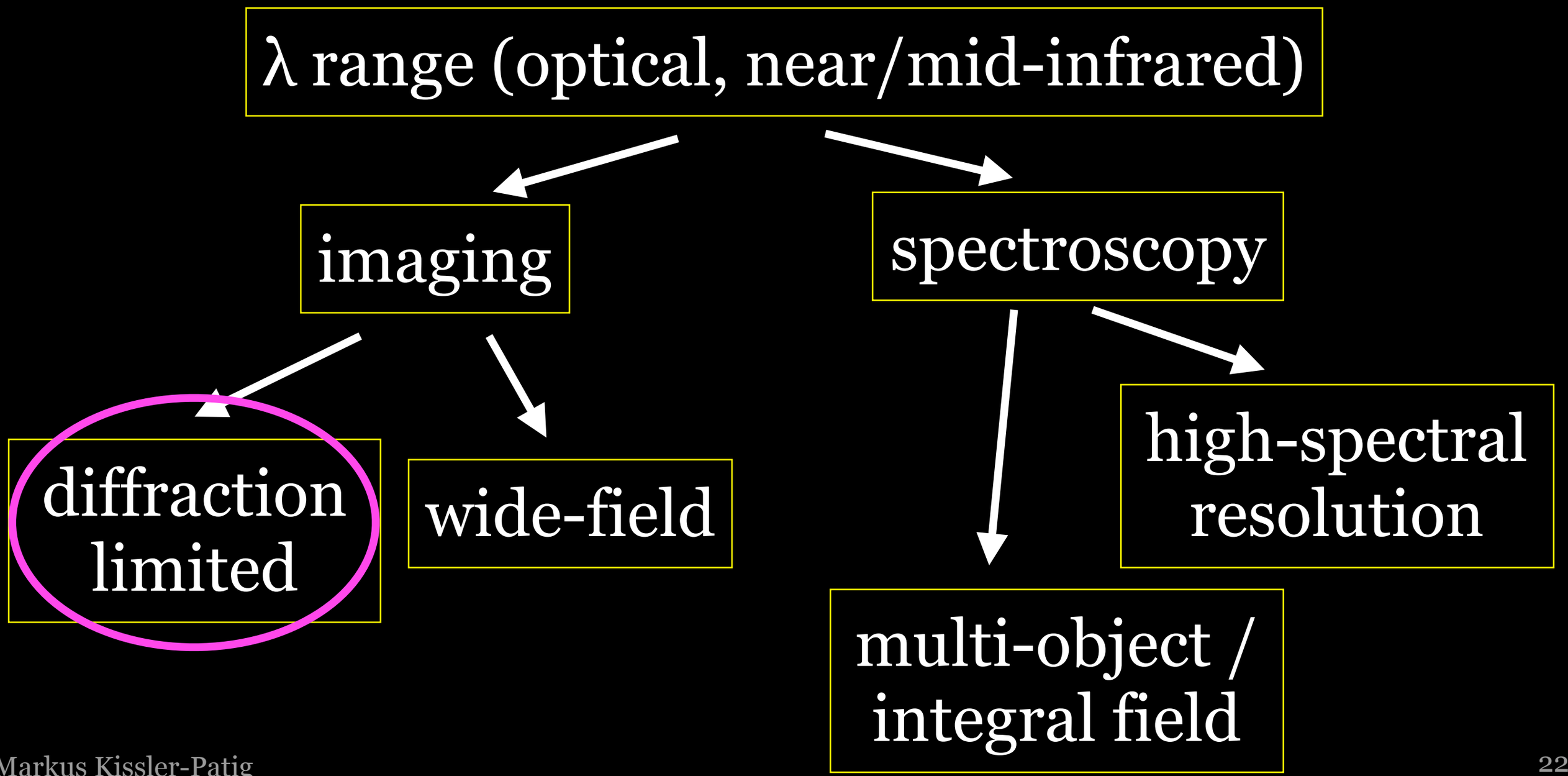
Secondary mirror
(1.0 m ∅)

Primary mirror
(8.1 m ∅)

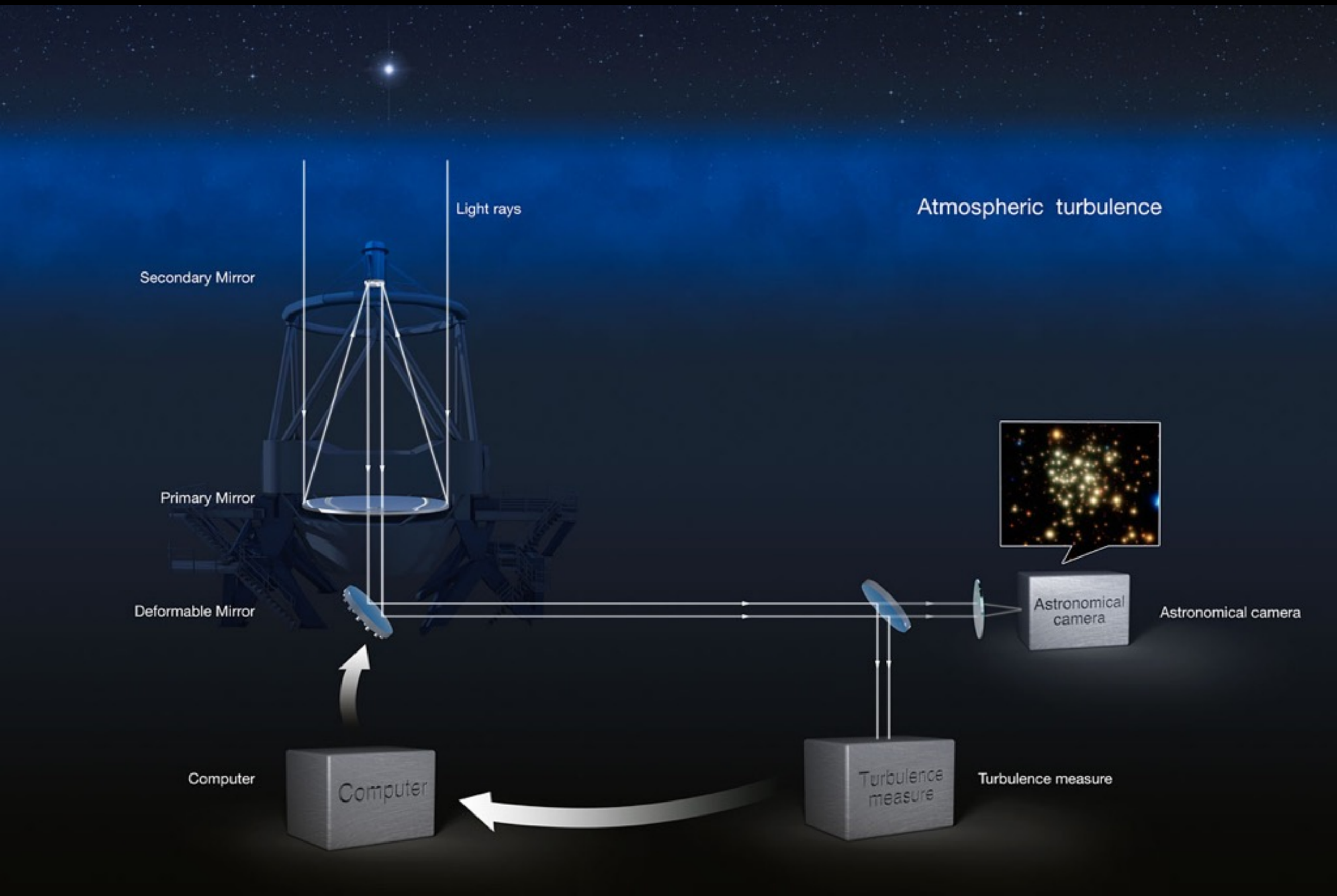


Typical 8-10m telescope cost ~$100M

Typical instruments: 3x3x3m, 5 tons, ~$20M



Lasers and adaptive optics




GEMINI
OBSERVATORY
Exploring the Universe, Sharing its Wonders

Current Research in Exoplanets

Are we alone?

A Brief history of exoplanet research

1992: First exoplanets detected around Neutron Star (still weird)

1995: First exoplanet detected around a Sun-like star
(Mayor & Queloz, Université de Genève)

2003: Exoplanet #100 detected

2005: First image (direct detection) of an exoplanet

2005: First detection of water in an exoplanet “atmosphere”

2007: First exoplanet discovered in a “habitable zone”

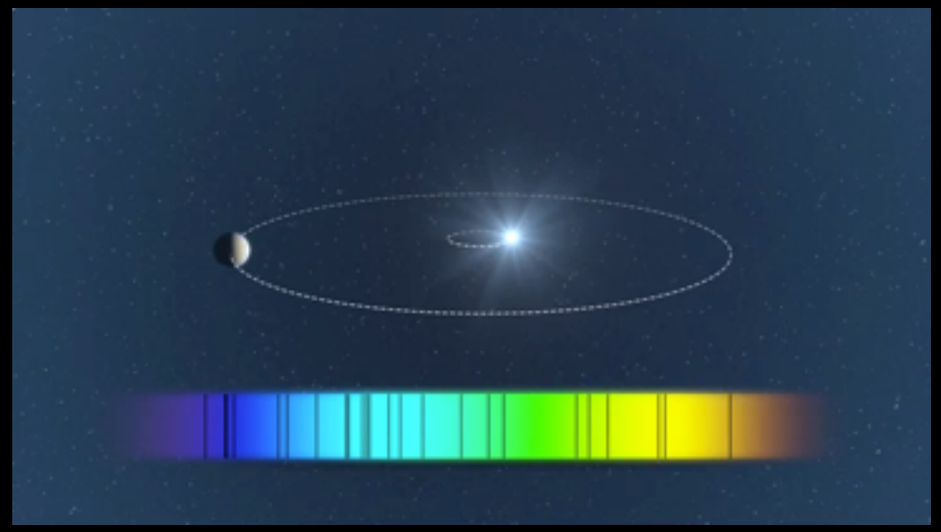
2009: First telluric exoplanet in a “habitable zone”

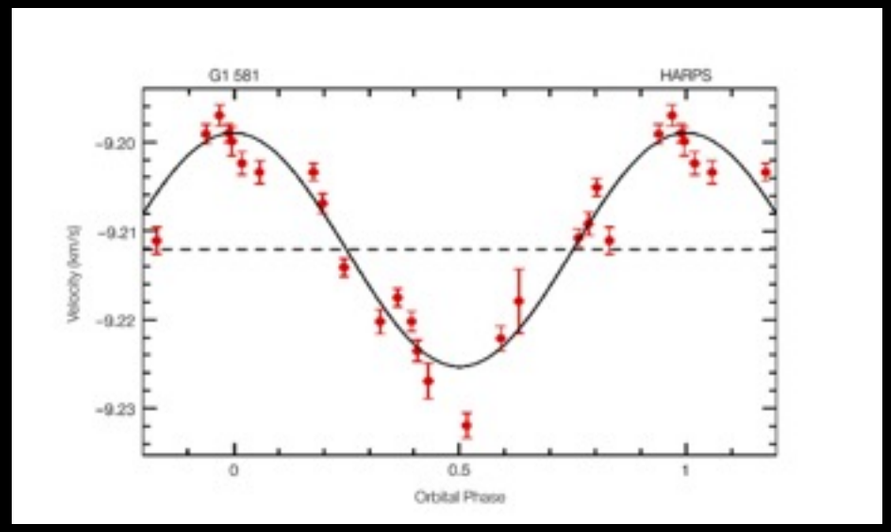
2010: Kepler releases its first few hundred planet candidates

The race for “firsts” continues - the next frontier is to go beyond detection and into characterization of exoplanets (atmospheres)

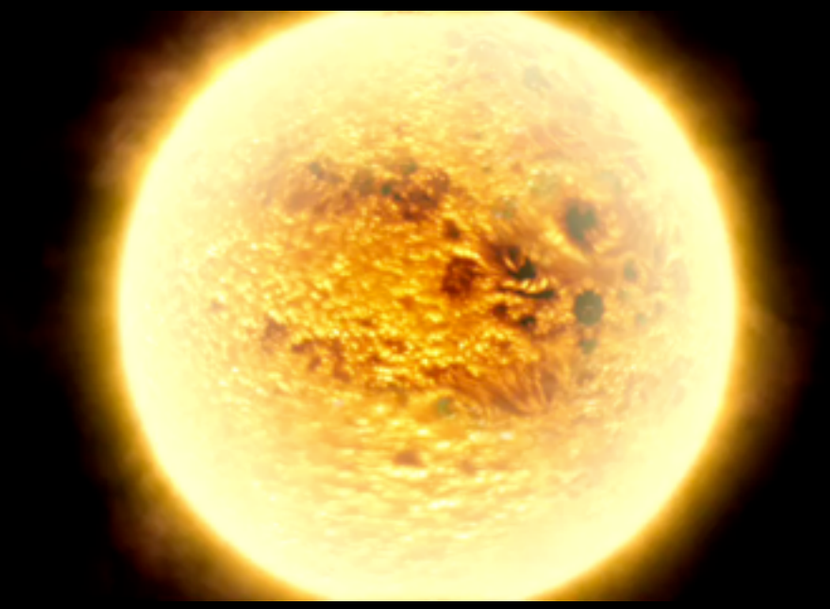
GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders

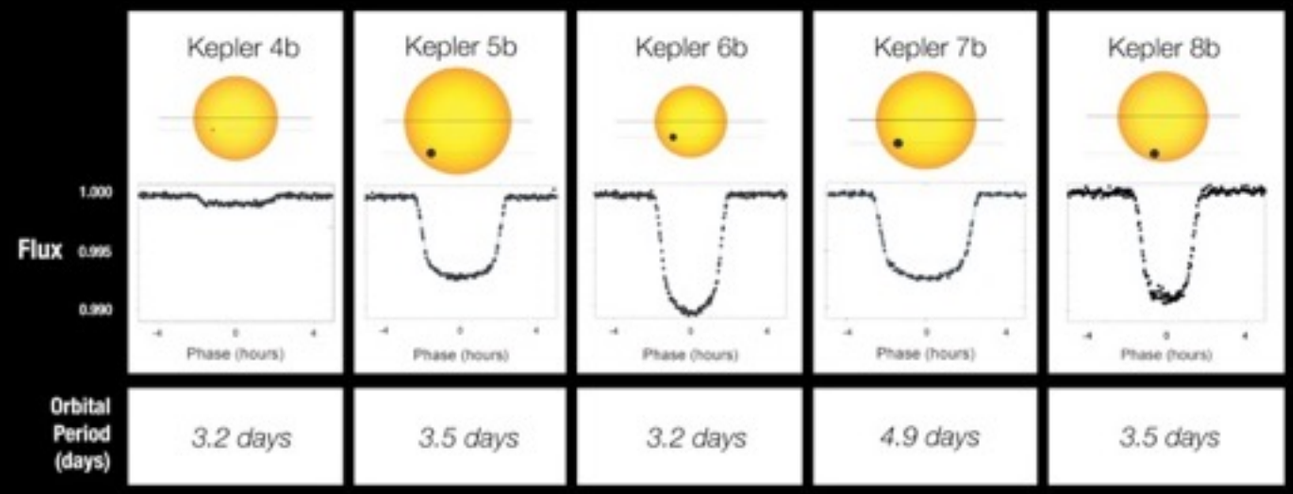
Radial Velocity



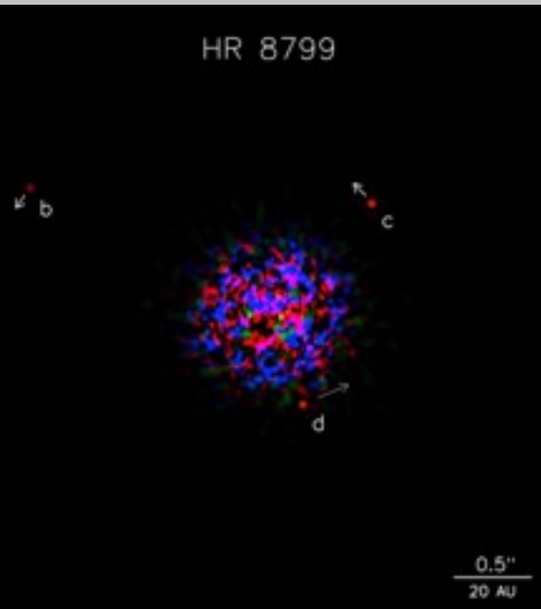


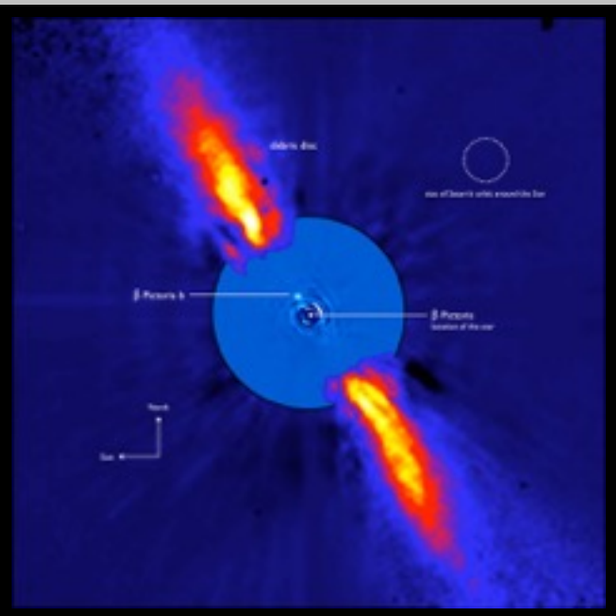
Planet Transit





Direct Imaging





Detected as of yesterday (July 1, 2015):
[www.exoplanet.eu]

Radial velocity or astrometry: 604

Transiting exoplanets: 1211

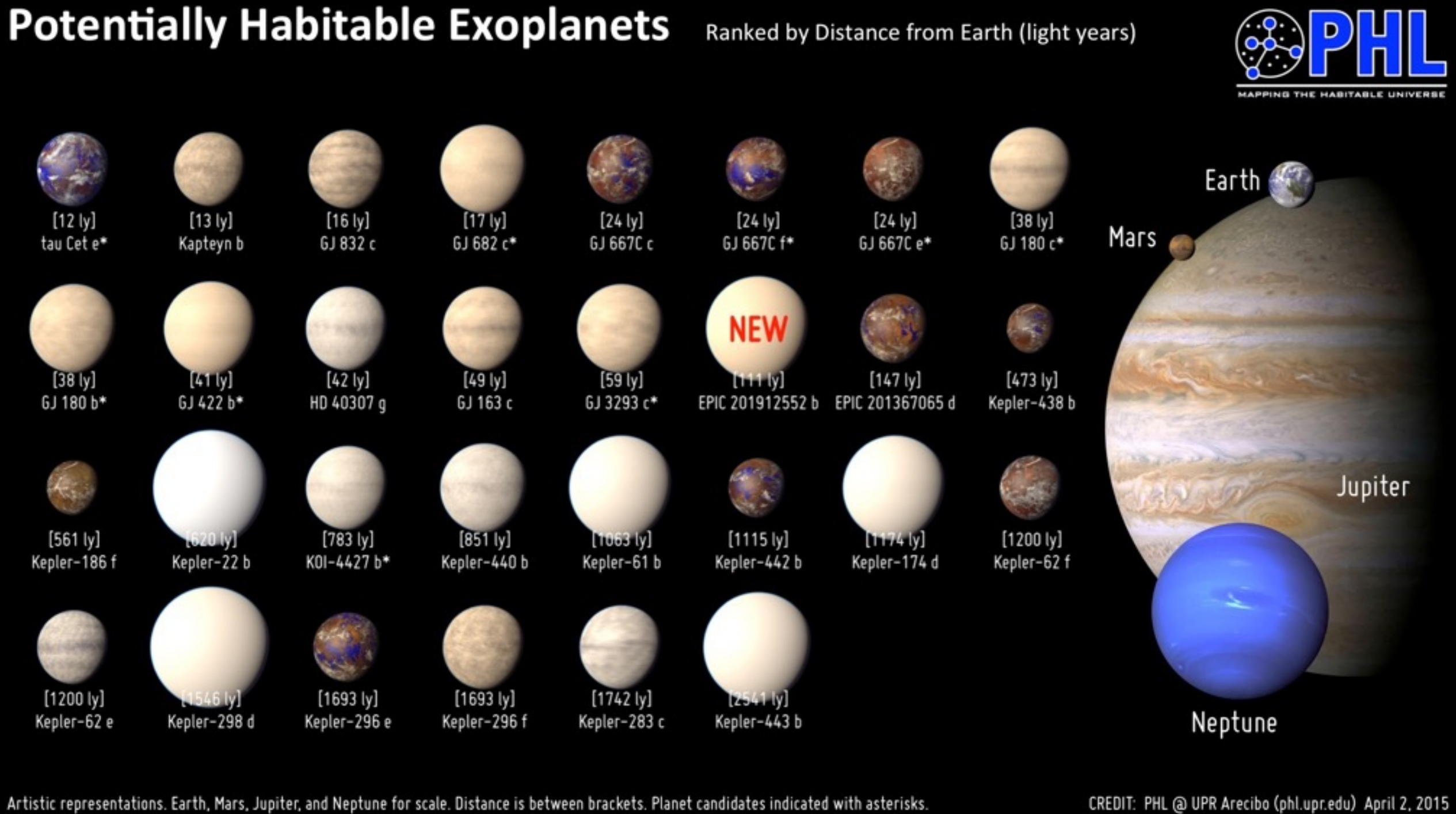
Microlensing: 35

Imaging: 59

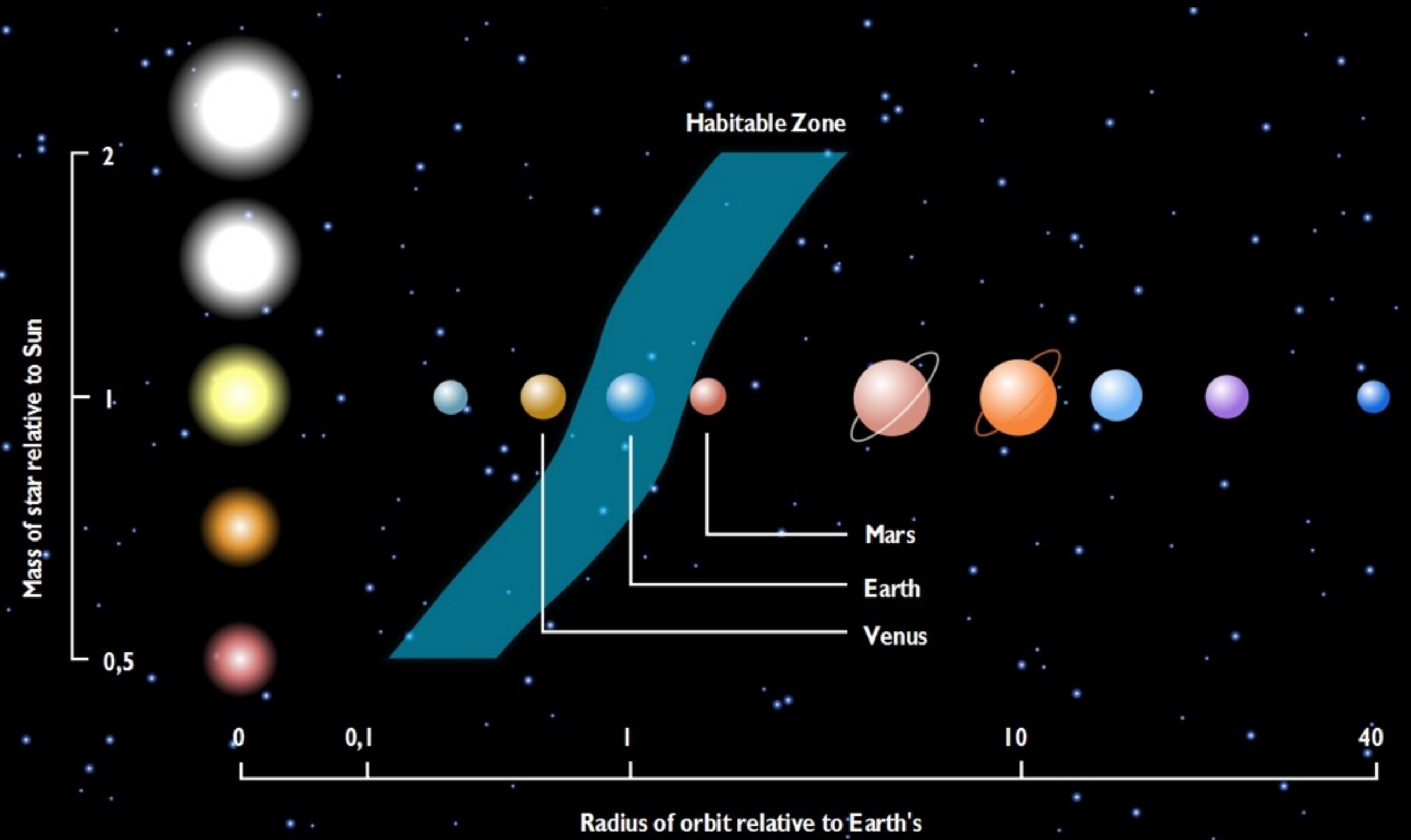
Timing: 23

Total: 1932 exoplanets in 1222 systems

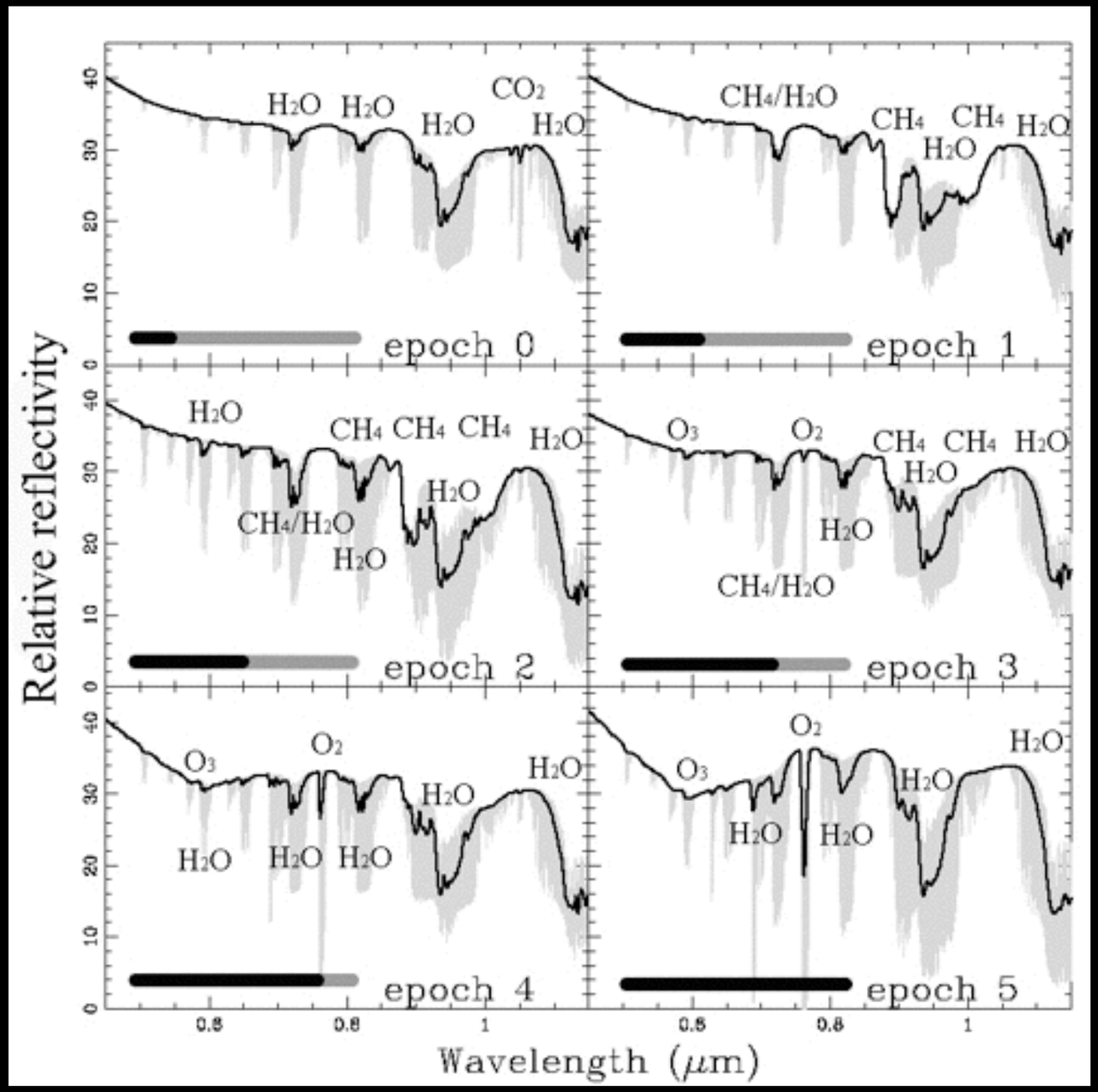
Habitable plantes as of yesterday (July 1, 2015):
[http://phl.upr.edu/projects/habitable-exoplanets-catalog/]



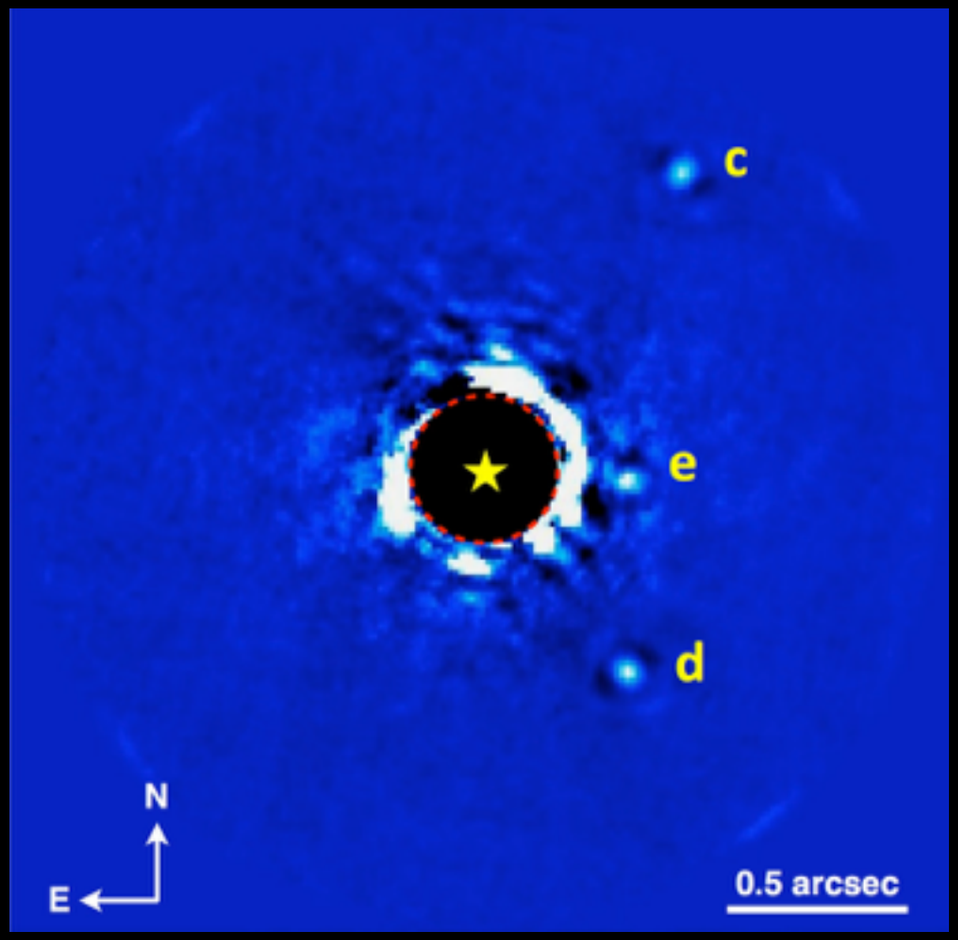
The Habitable Zone (liquid surface water):



Bio-signatures:
Life and Earth's atmosphere co-evolved



Current state-of-the-art instruments



The Gemini Planet Imager achieves contrasts of $1:10^{6-7}$ at 0.1”-0.2” (1-2 AU at 10pc distance) of the parent star

Extremely large telescopes will increase the contrast by three to four orders of magnitude

Current Research in Cosmology

[48 seconds]

Properties of the Universe

are determined by five numbers:

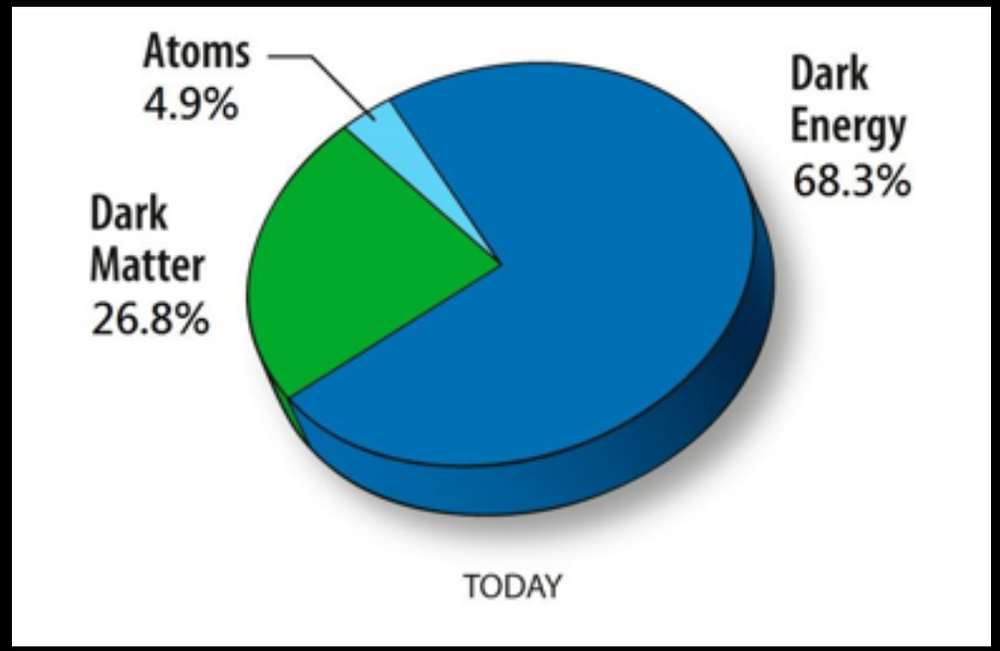
Density of matter

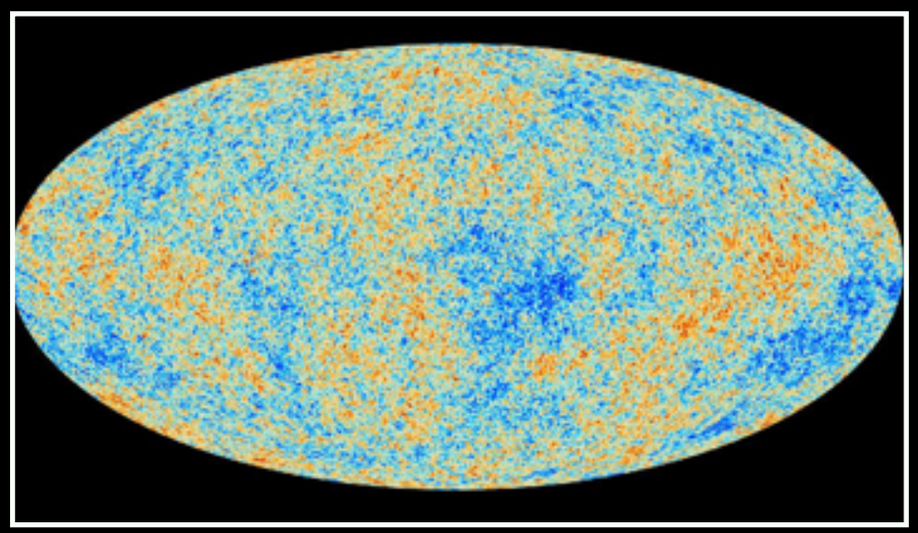
Density of atoms

Age of the Universe

Amplitude of the initial fluctuations

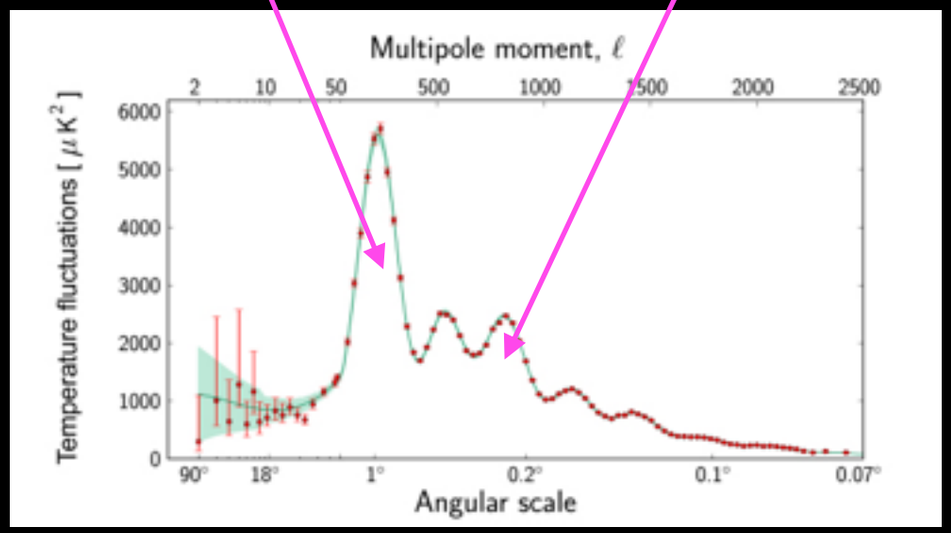
Their scale dependence



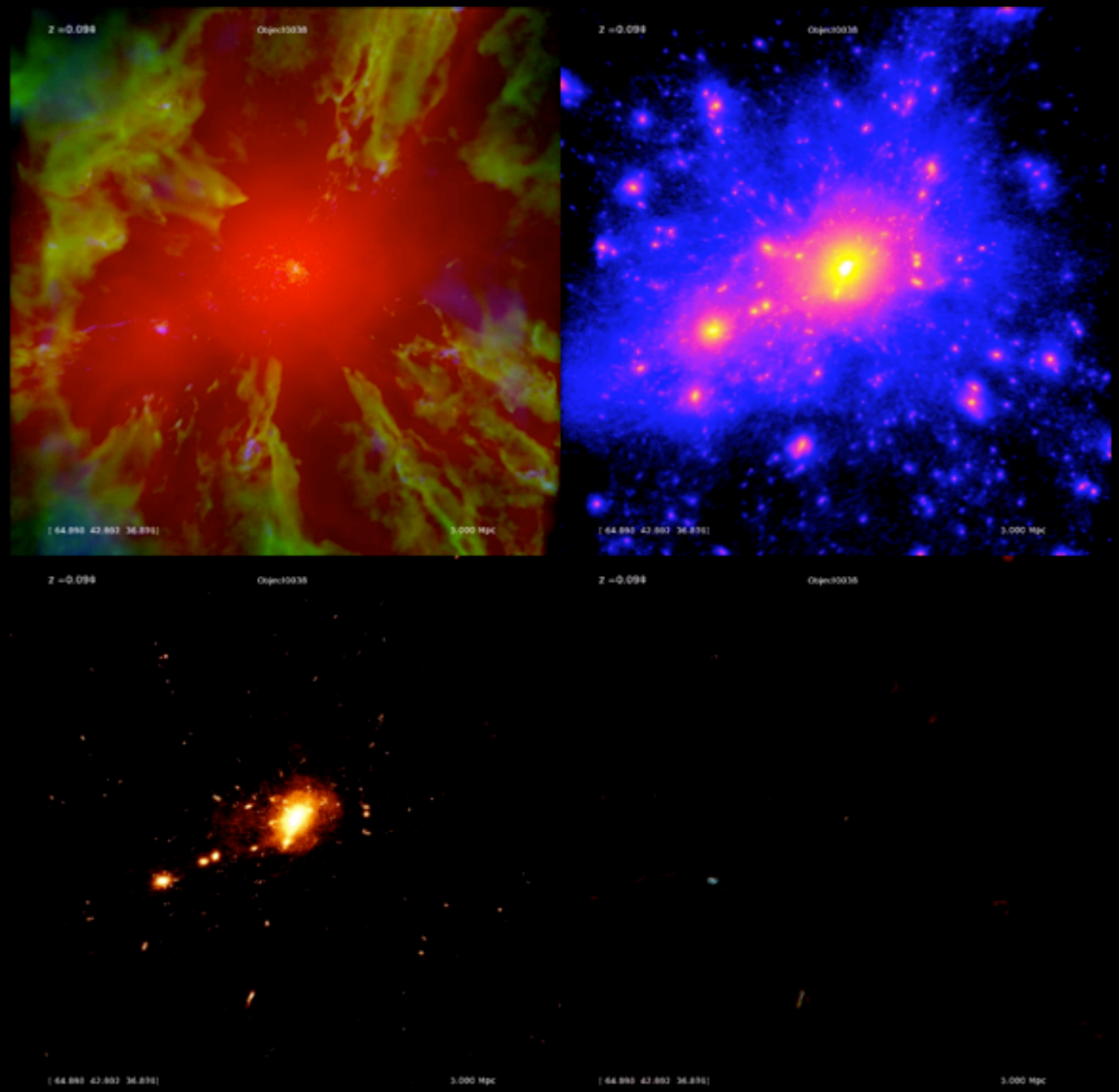


Baryonic matter density

Dark matter density



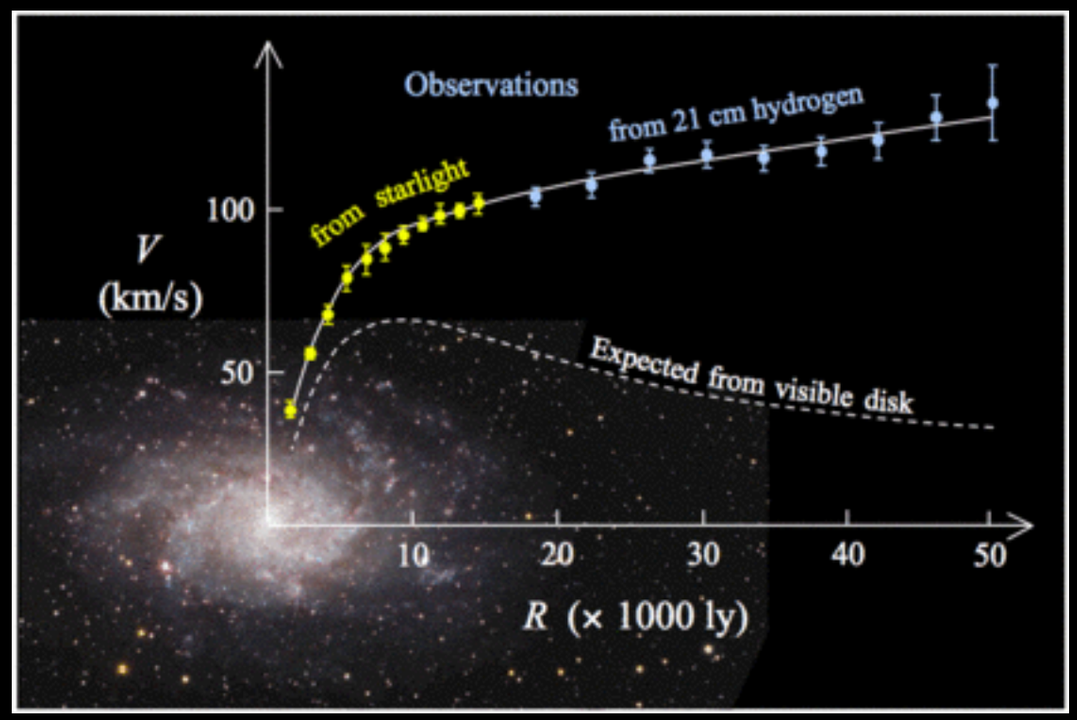
Simulations of the Universe



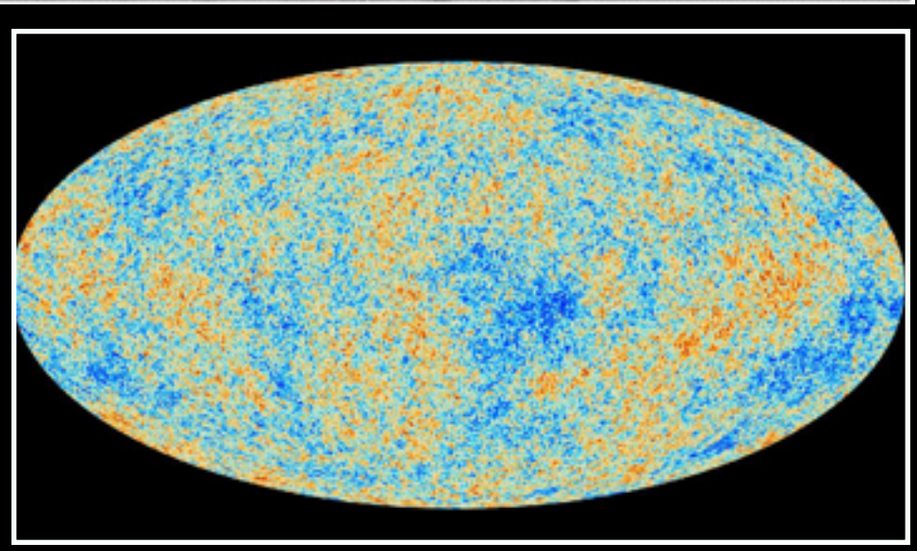
[EAGLE simulations - ICC Durham - 38 seconds]

Dark Matter

Evidence:
Velocity dispersion of galaxies in clusters
Galaxy rotation curves
Gravitational lensing
Big Bang Nucleosynthesis
Microlensing



Candidates:
Cold Dark Matter (e.g. WIMPs)
Warm Dark Matter (e.g. IMPs)
Hot Dark Matter (e.g. WILPs, Neutrinos)



Dark Energy

Evidence:

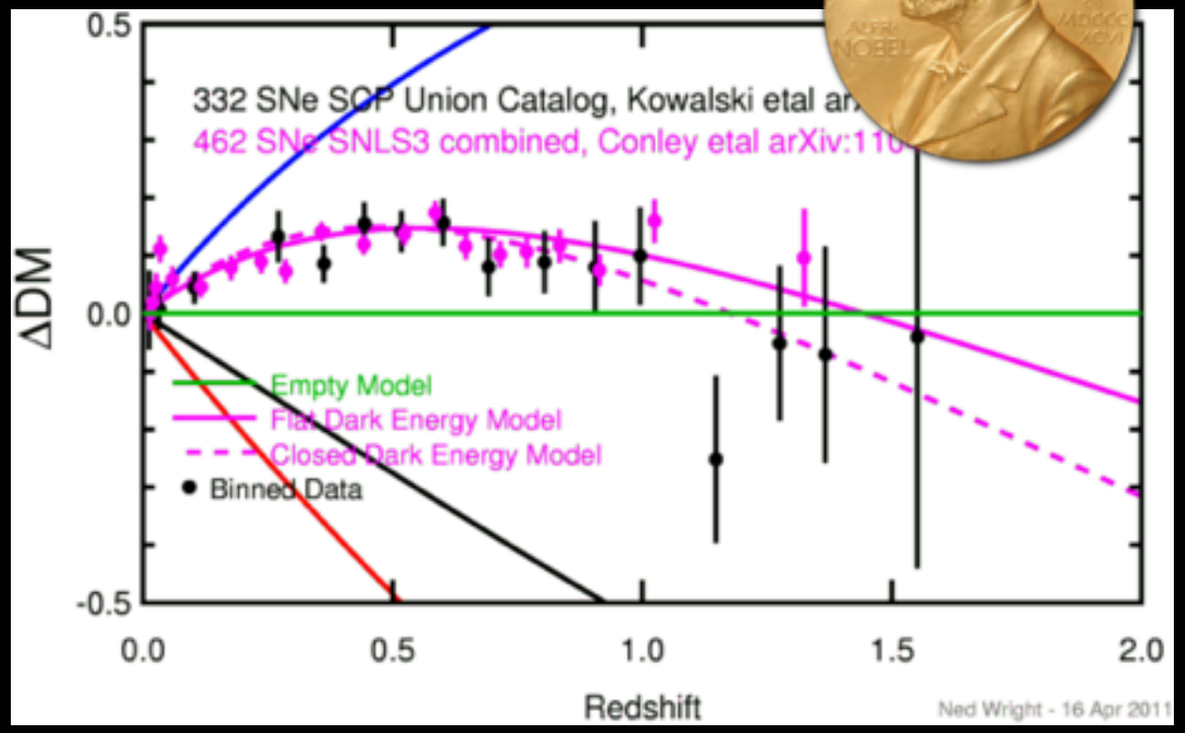
Supernovae measurement

(expansion rate)

Cosmic Microwave Background

Large Scale Structure

(flat universe)

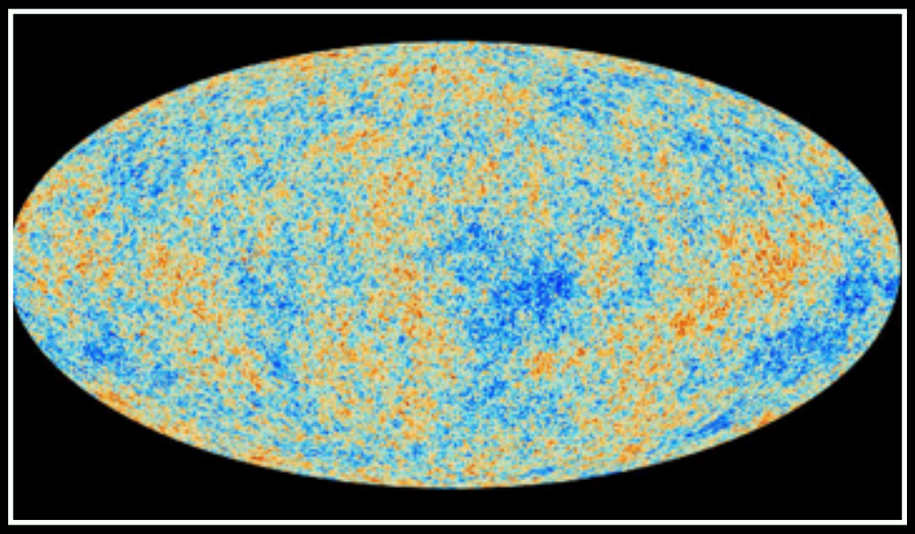


[Nobel prize in physics 2011]

Candidates:

Cosmological *constant* (vacuum energy)

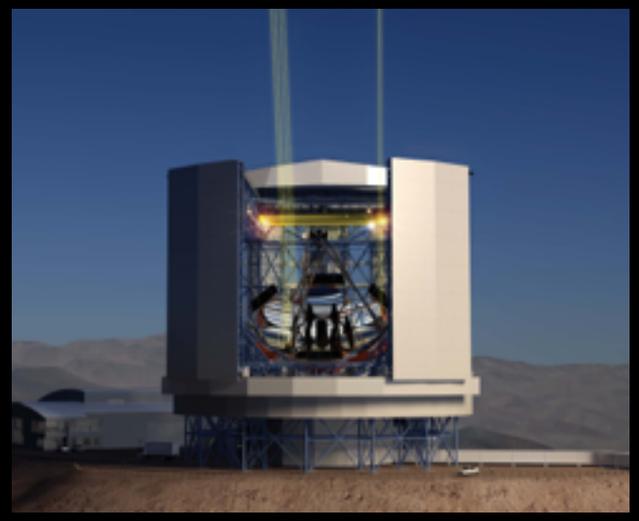
Scalar field [f(space,time)] (quintessence)



Upcoming Facilities

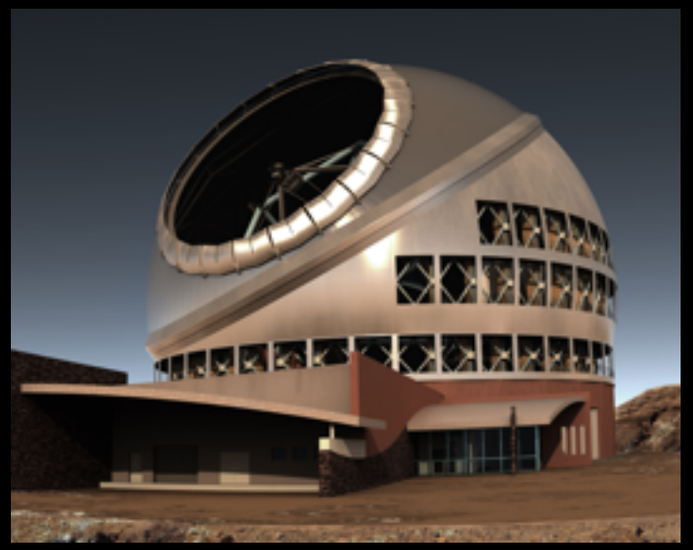
The Extremely Large Telescopes

USA, Korea, Australia, Brazil



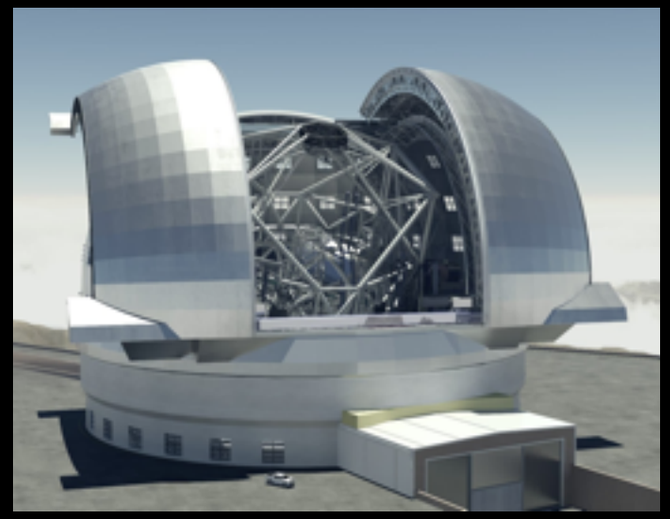
Giant Magellan Telescope
(GMT) 25m ∅, Chile

USA, Canada, China, India, Japan



Thirty Meter Telescope
(TMT) 30m ∅, Hawaii

ESO (15 member states)



European Extremely Large Telescope
(E-ELT) 40m ∅, Chile

Construction costs: $1-1.5B

All three started civil engineering work on site
First light is expected between 2022-2025

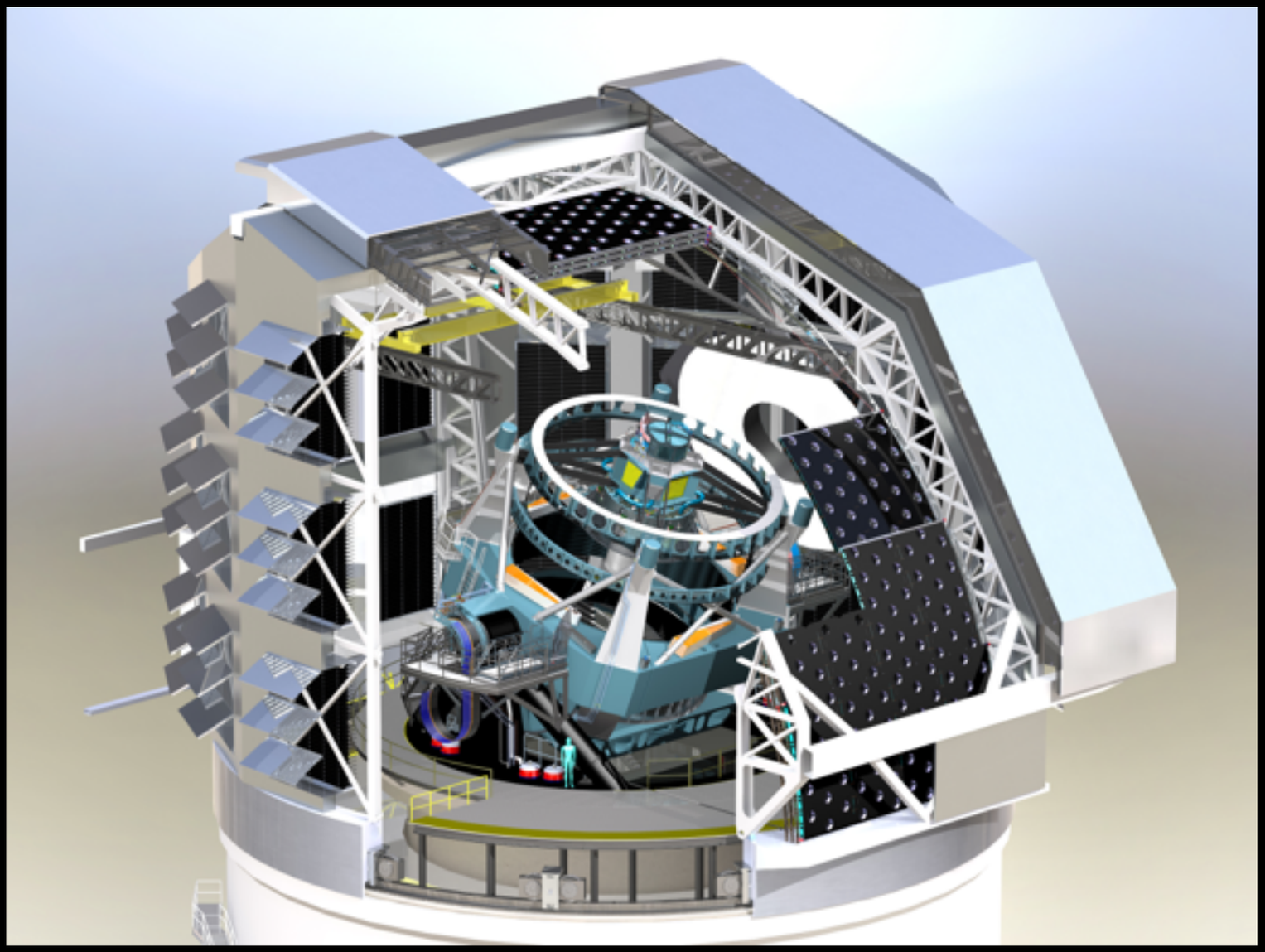
ELTs key science goals:

Characterization of Exoplanets
(detection of Earth-like planets, characterization of their atmospheres, …)

Physics of high redshift galaxies
(γ-ray bursts, supernovae, near-Earth objects, …)

Cosmology and Fundamental physics
(variations of fundamental constants, high-redshift supernovae, acceleration of the expansion of the universe, …)

The Large Synoptic Survey Telescope



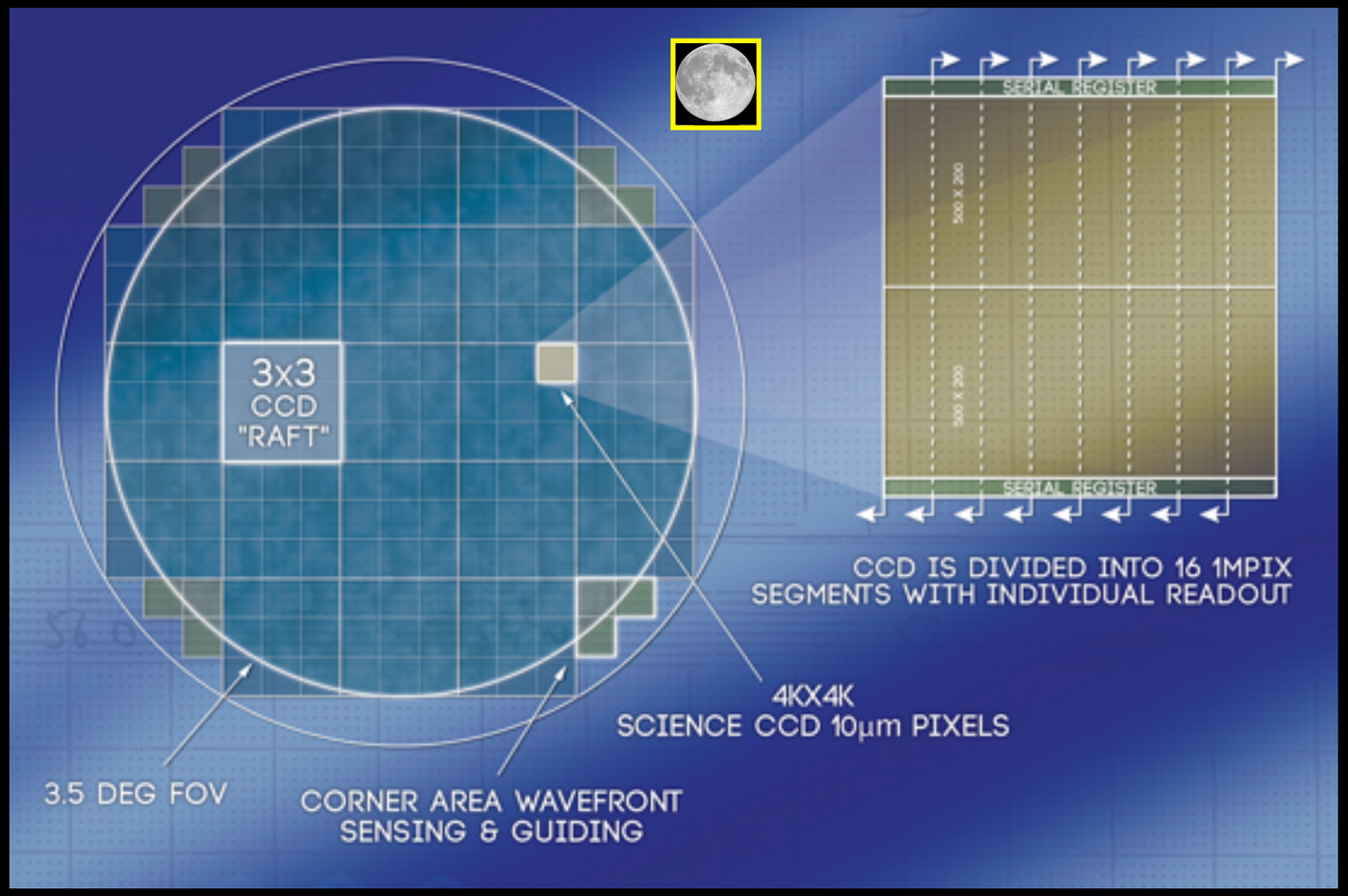
(LSST) 8m ∅

Consortium of US and international institutions

Construction costs: $400M

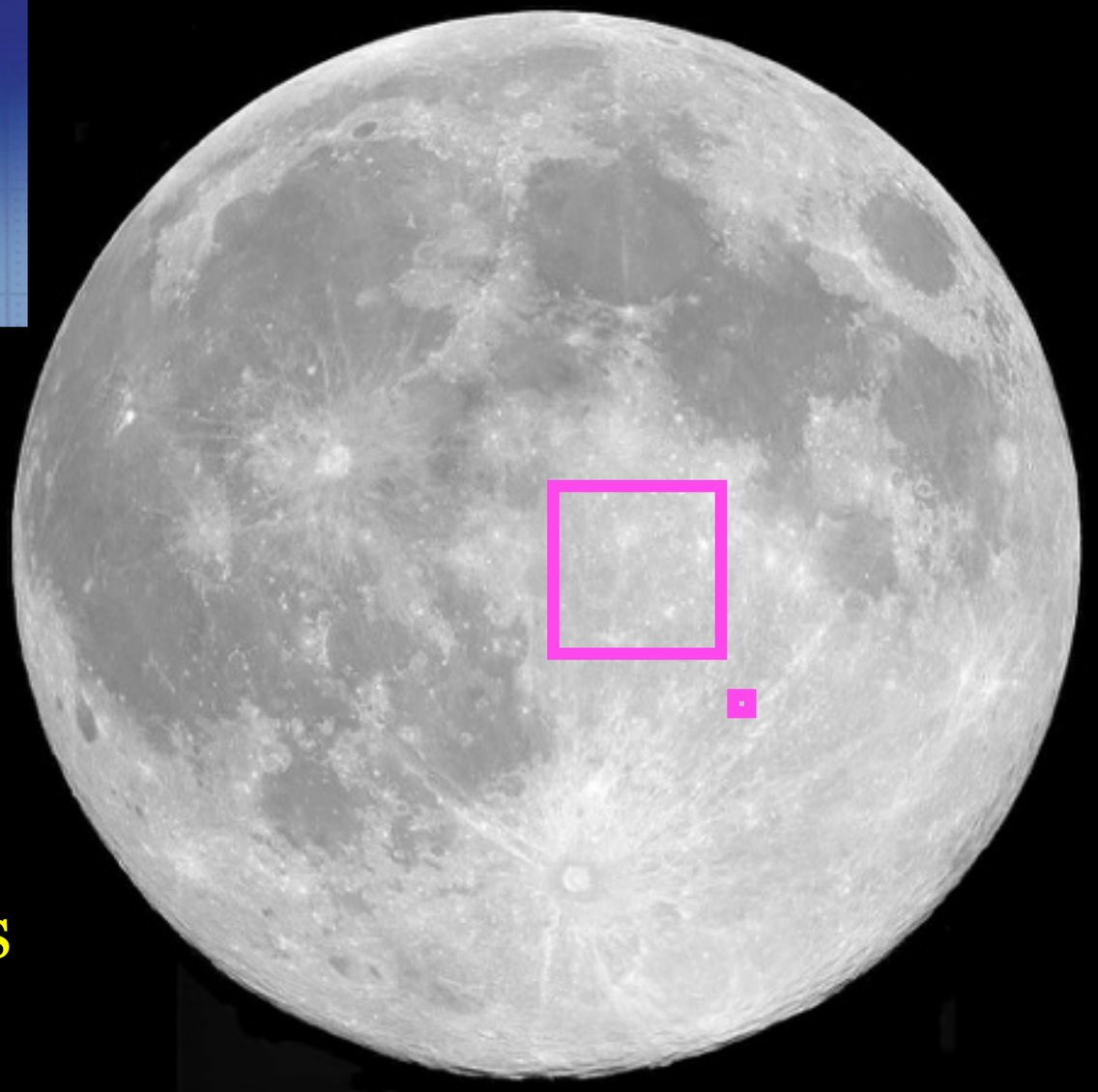
Construction has started
Site: Cerro Pachon, Chile

Start of survey ~2020
Database of 30-60 PByte



LSST field of view
3.5 deg ∅

ELT field of view
0.1 (0.001) deg ∅

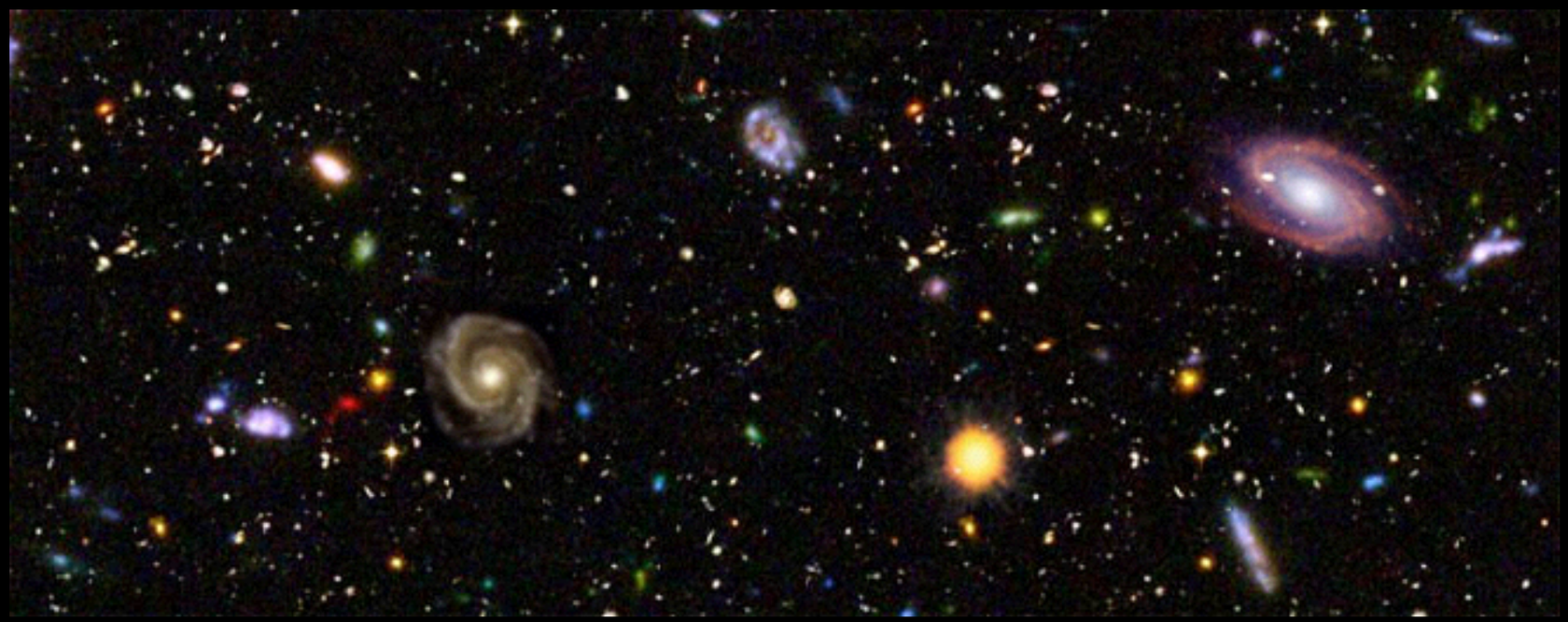


The LSST will visit each patch of the southern sky >1000 times in ten years

LSST key science goals:

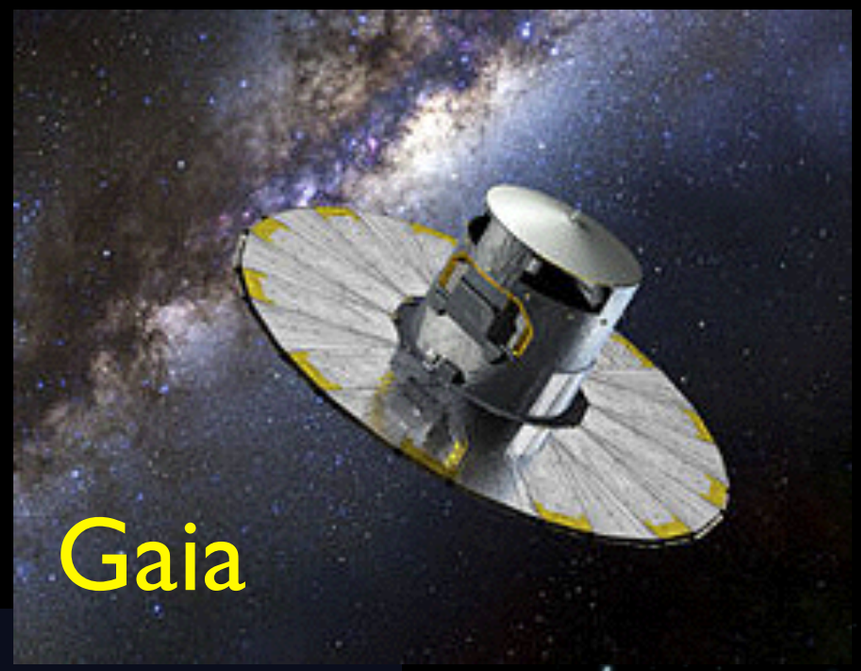
Nature of Dark Energy (and Dark Matter)
(weak lensing cosmic shear, baryonic acoustic oscillations, galaxy cluster counts, …)

Explore the Transient Universe
(γ-ray bursts, supernovae, near-Earth objects, …)

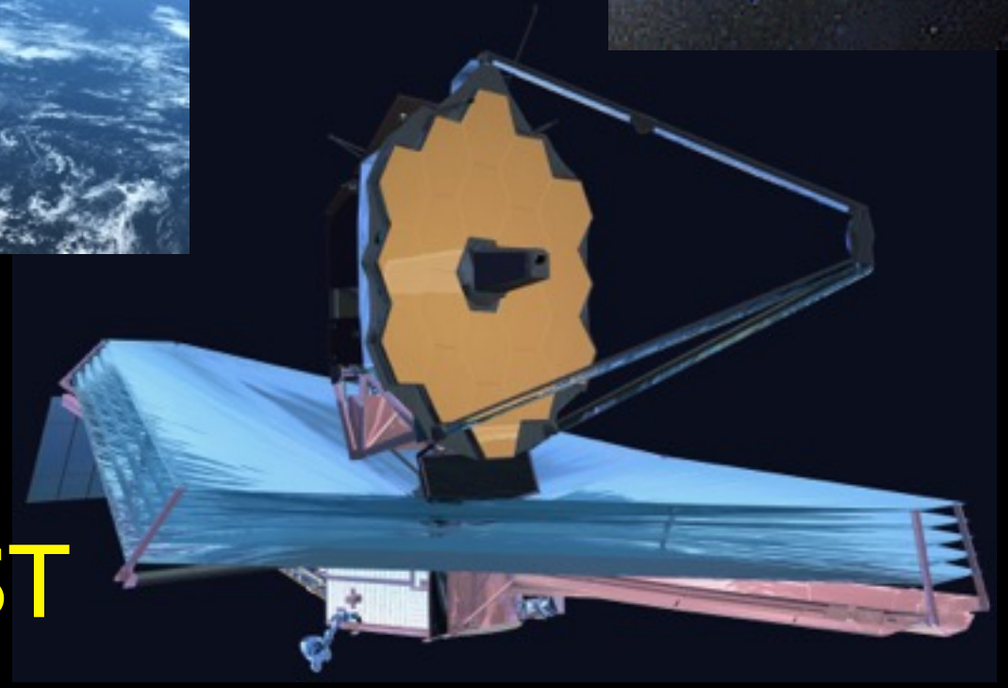


And of course, there is space-based astronomy…

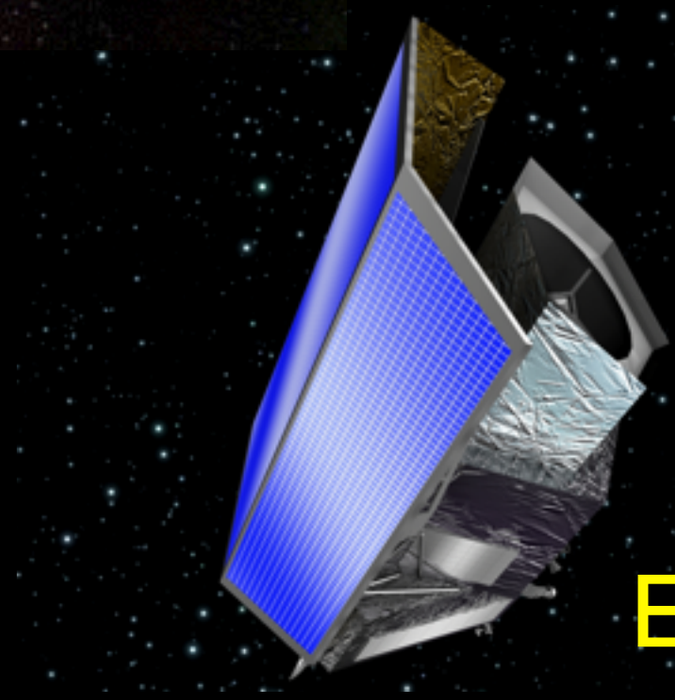
Hubble



Gaia



JWST



Euclid

… but this would be another talk

Thank you!