Announcements

- Last quiz due tonight :-)
- Review for final this Wednesday
- Final:
  December 17, 10-12 am, this room
  - ~90 – 100 questions, including some bonus questions
  - no calculator, notes, books, etc.
  - counts for 30% of final grade

Future of Astronomy

- Ground-based Astronomy:
  Extremely Large Telescopes
  Time-resolved Astronomy
- Space:
  James Webb Space Telescope – Hubble 2.0
  Mission to Pluto – early/mid 2015
  Search for Exo-planets
- Advanced LIGO: Search for gravitational waves
- Particle Astrophysics: IceCube → neutrinos

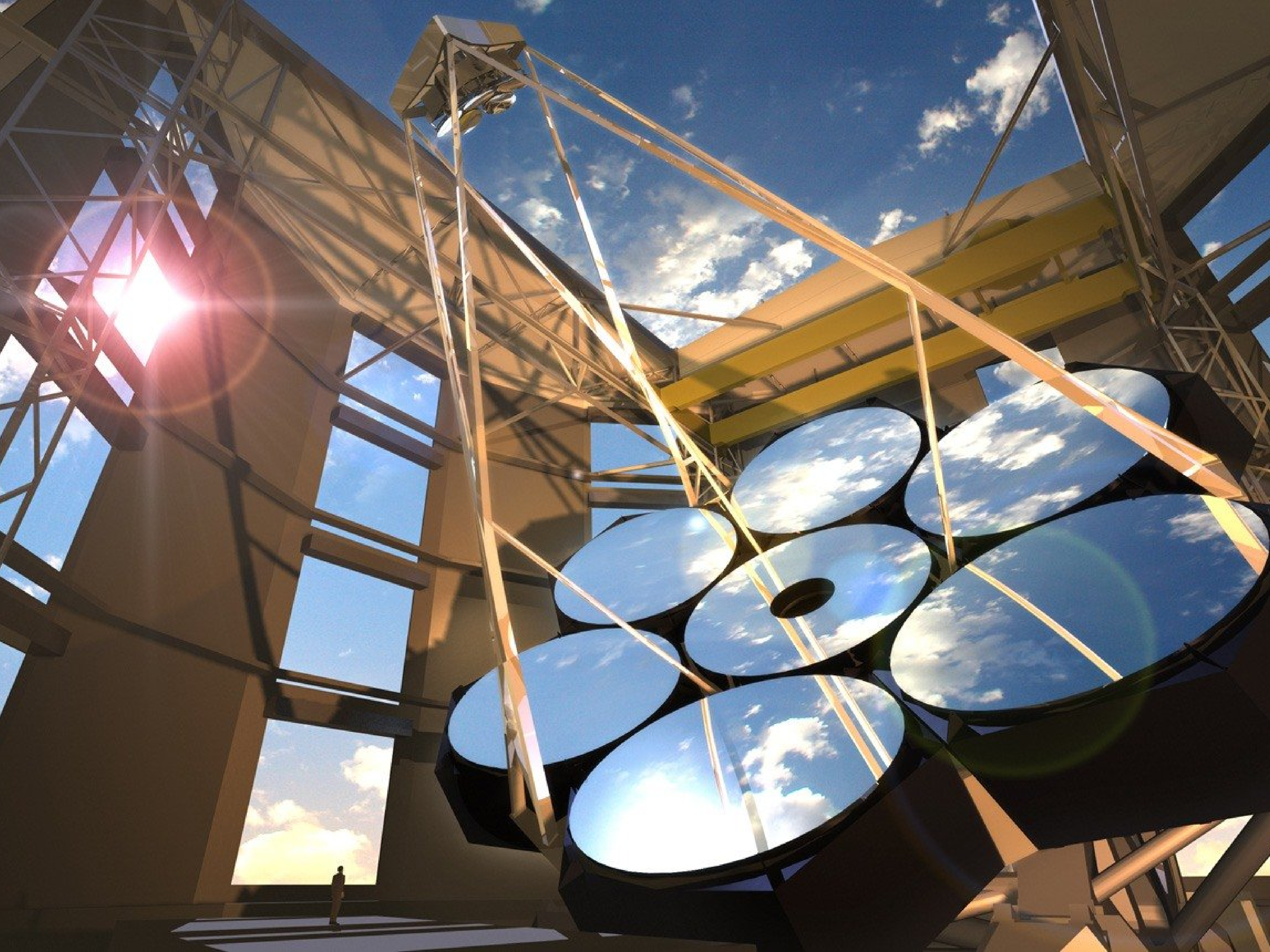
Why Extremely Large Telescopes?

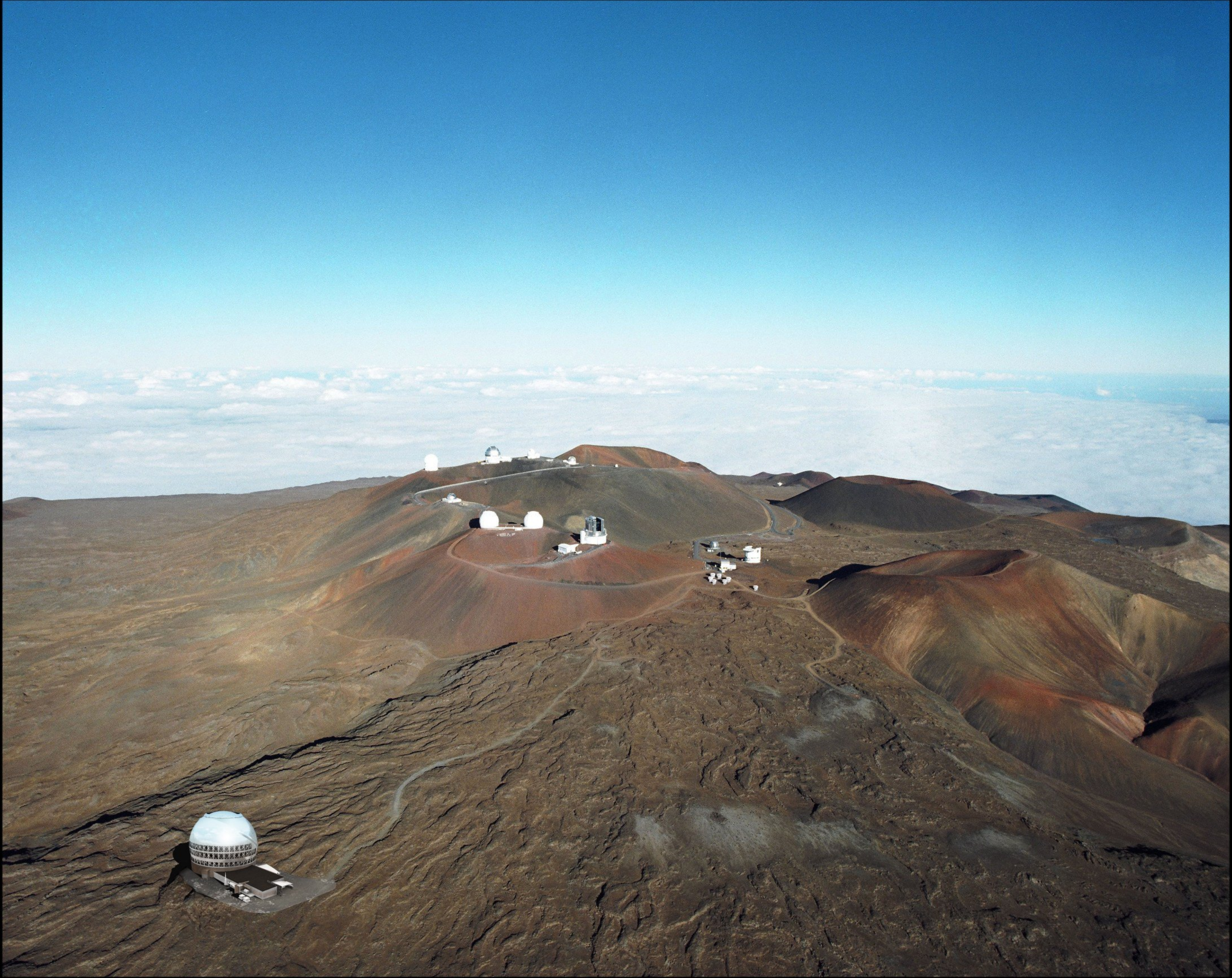
- More light gathering power
  → Study fainter objects: Galaxies at high redshift, faint stars in Galaxy and galactic neighborhood
  → Higher-resolution spectroscopy: Study bright things in more detail
- More aperture → higher spatial resolution detect/study exo-planets, planet formation, study individual stars in nearby galaxies

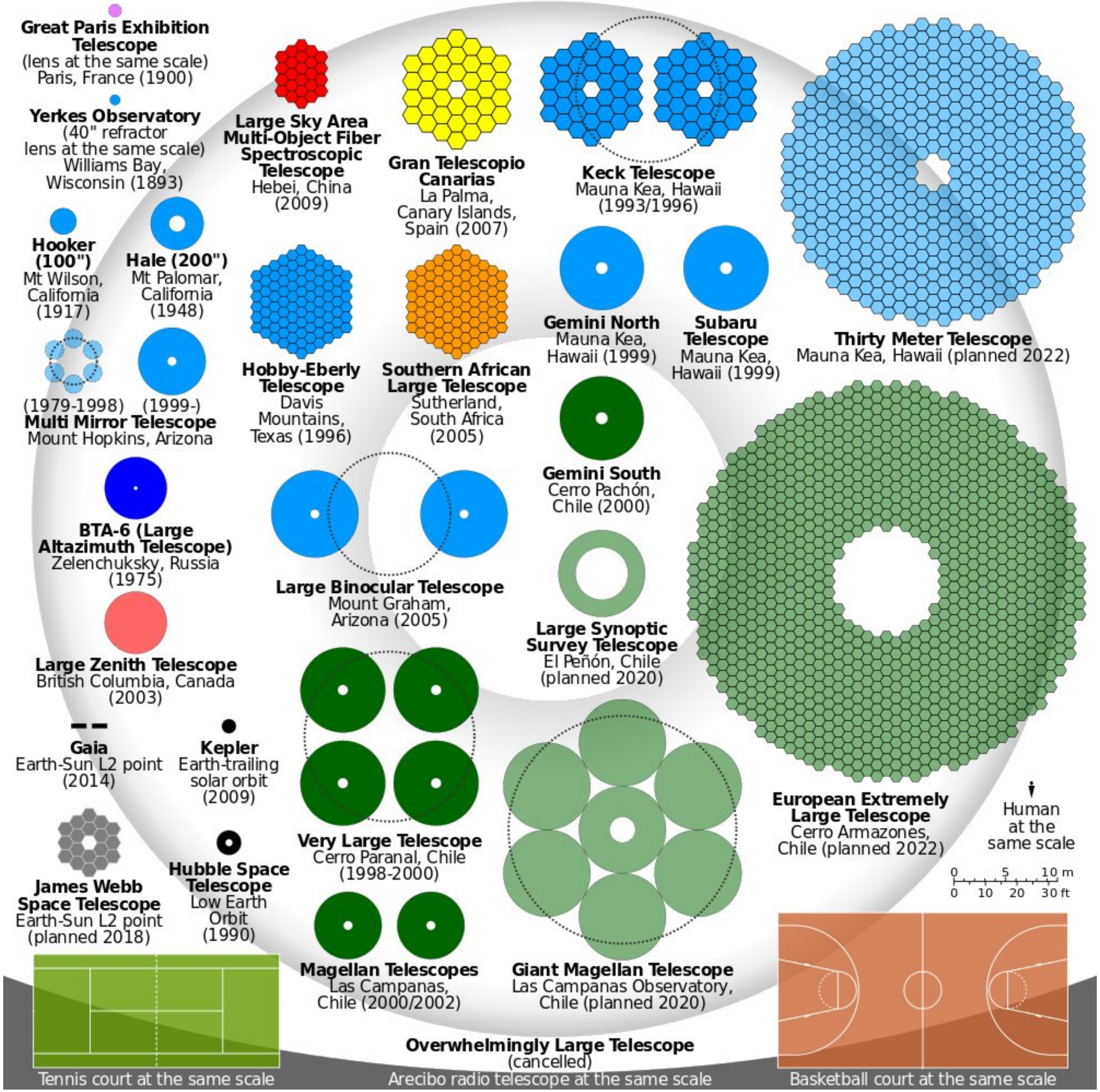
Aperture and spatial resolution

Extremely Large Telescopes

- with US involvement
  - Thirty Meter Telescope (TMT)
  - Giant Magellan Telescope
- Europe:
  European Extremely Large Telescope (E-ELT)







Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor lens at the same scale)
Williams Bay, Wisconsin (1893)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China (2009)
Gran Telescopio Canarias
La Palma, Canary Islands, Spain (2007)
Keck Telescope
Mauna Kea, Hawaii (1993/1996)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Hooker (100")
Mt Wilson, California (1917)
Hale (200")
Mt Palomar, California (1948)
(1979-1998) (1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
Hobby-Eberly Telescope
Davis Mountains, Texas (1996)
Southern African Large Telescope
Sutherland, South Africa (2005)
Gemini North
Mauna Kea, Hawaii (1999)
Subaru Telescope
Mauna Kea, Hawaii (1999)
Gemini South
Cerro Pachón, Chile (2000)
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia (1975)
Large Binocular Telescope
Mount Graham, Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
Large Zenith Telescope
British Columbia, Canada (2003)
Gaia
Earth-Sun L2 point (2014)
Kepler
Earth-trailing solar orbit (2009)
Very Large Telescope
Cerro Paranal, Chile (1998-2000)
European Extremely Large Telescope
Cerro Armazones, Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
James Webb Space Telescope
Earth-Sun L2 point (planned 2018)
Hubble Space Telescope
Low Earth Orbit (1990)
Magellan Telescopes
Las Campanas, Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory, Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

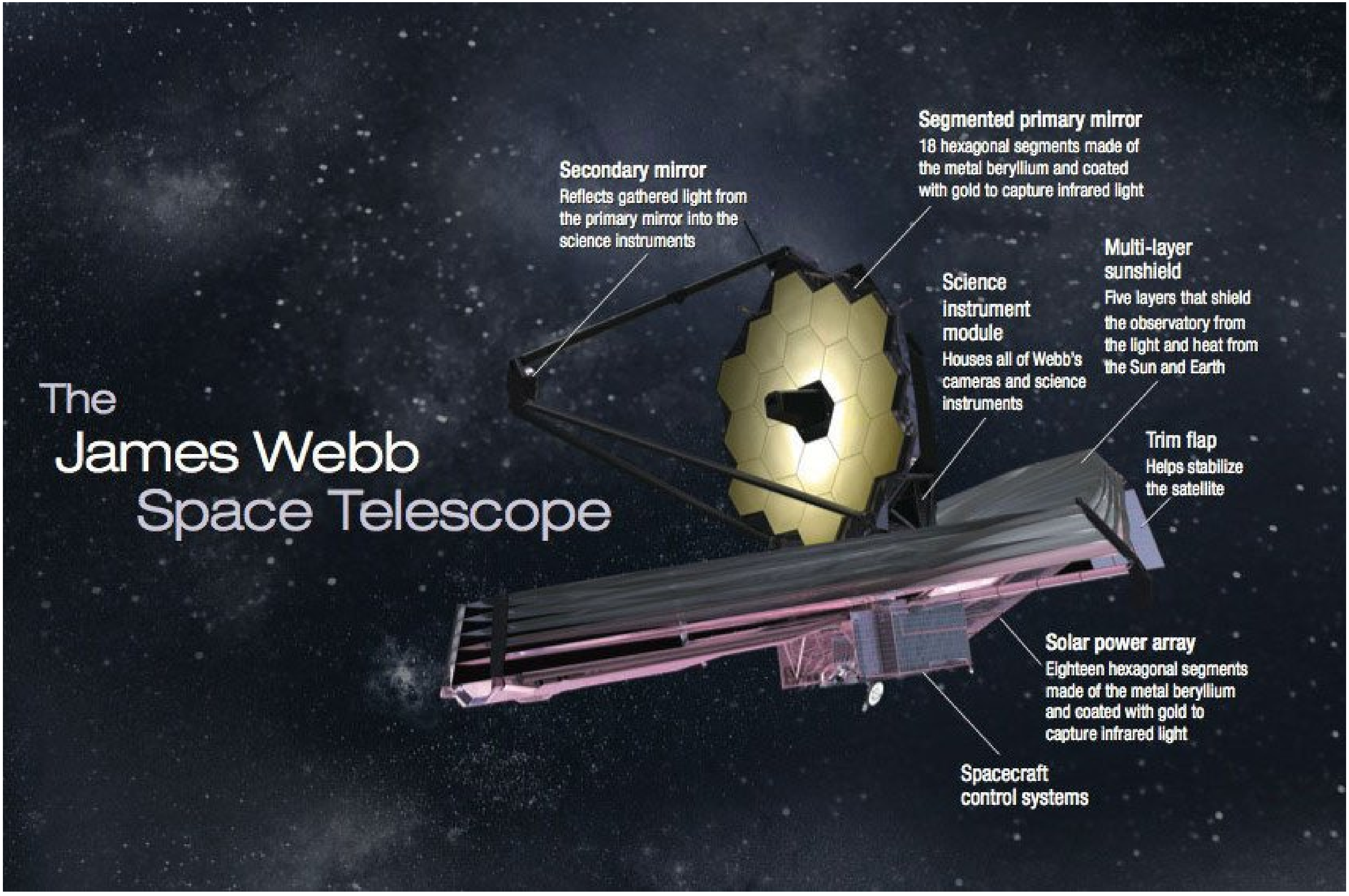
Large Synoptic Survey Telescope

- compact 8-m telescope
- Camera: 3.5 Giga Pixel, 5 filters
  field-of-view: 3 degrees (6 full moons)
- Survey the entire visible sky every three nights
- Take 2 15 second images, move on to next point on sky
- Repeat for 10 years
  → The greatest movie ever made

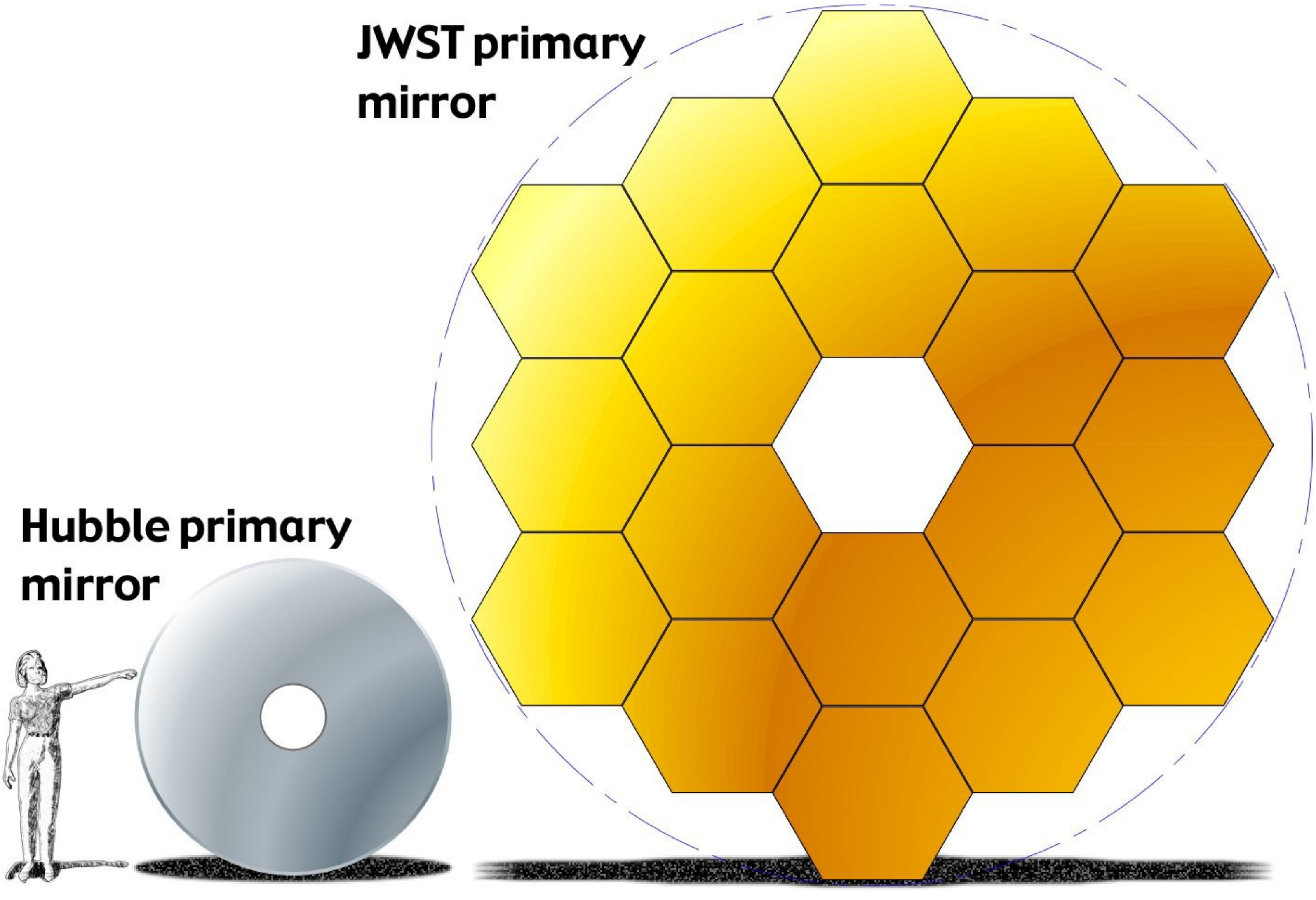
Why LSST

- Static sky reasonably well understood, time-domain still largely unexplored
  → several similar/smaller projects underway
- Search for supernova, variable stars
- Also great to find moving things: asteroids
- In the end:
  Co-add all images to get a deep view of most of the southern sky
- LSST = SDSS on steroids

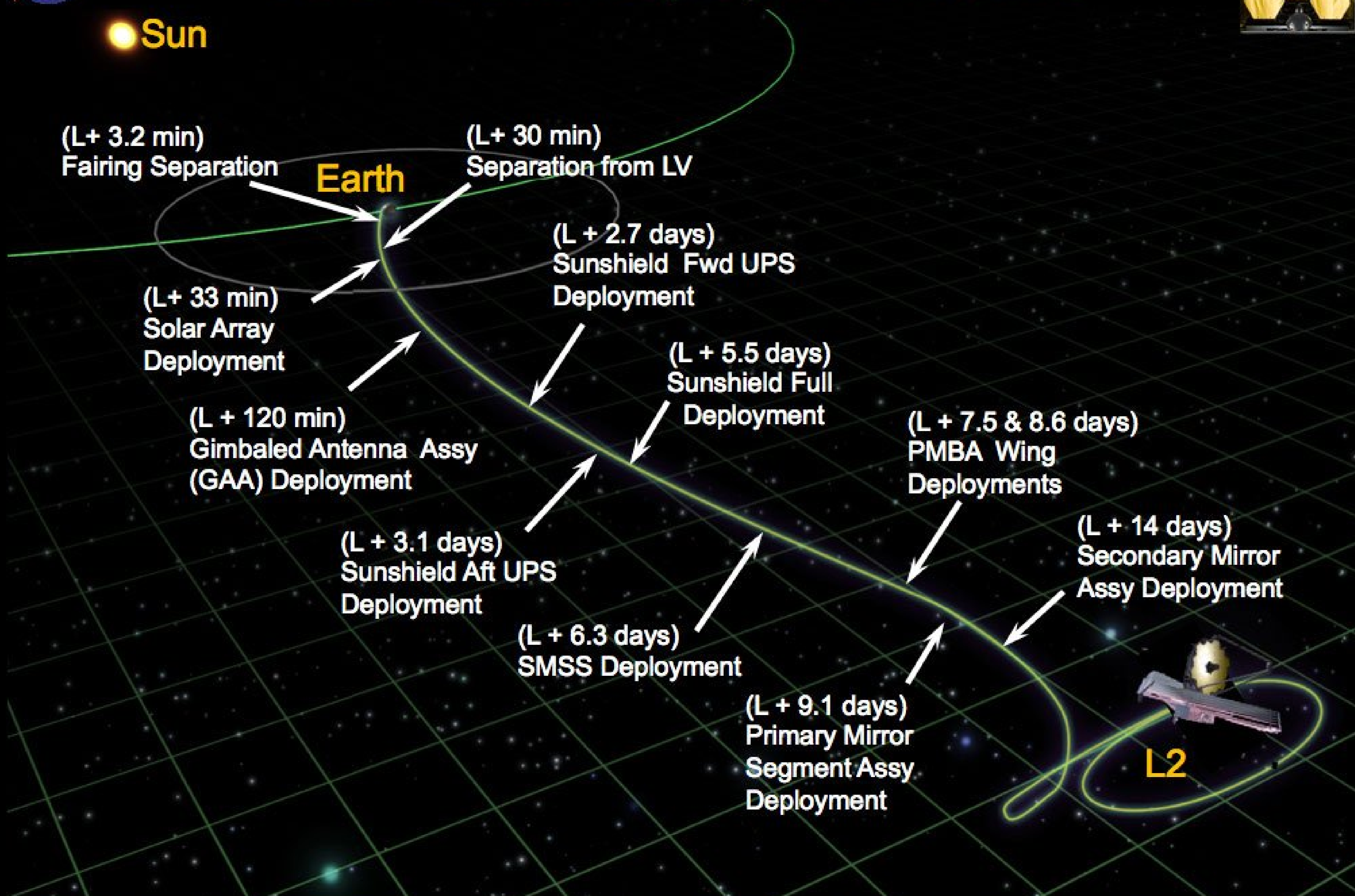
James Webb Space Telescope



James Webb Space Telescope

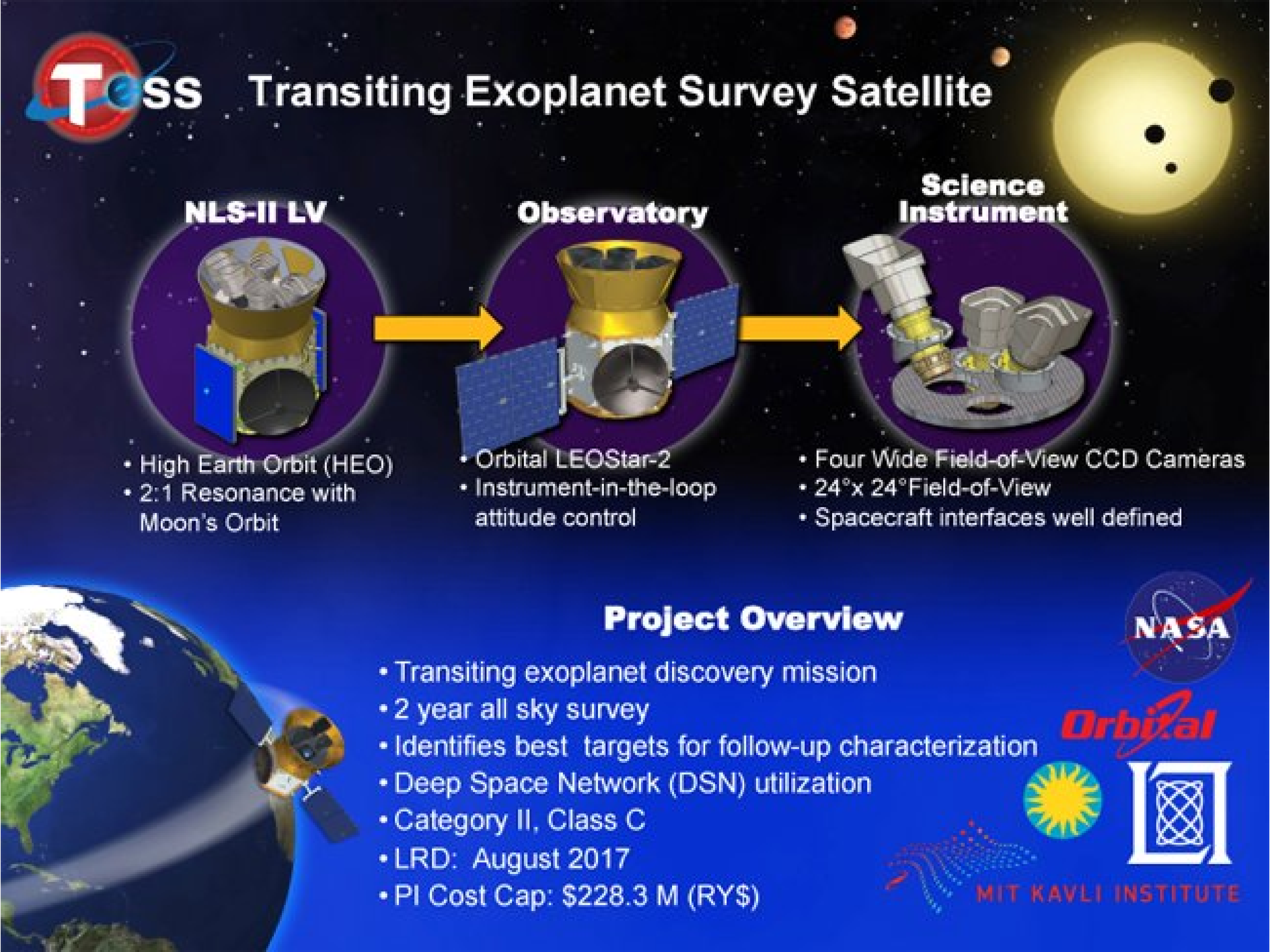


JWST Launch/Deployment Timeline



JWST unfolding

New Horizons on the way to Pluto


TESS Transiting Exoplanet Survey Satellite
NLS-II LV
Observatory
Science Instrument
• High Earth Orbit (HEO)
• 2:1 Resonance with Moon's Orbit
• Orbital LEOStar-2
• Instrument-in-the-loop attitude control
• Four Wide Field-of-View CCD Cameras
• 24°x 24°Field-of-View
• Spacecraft interfaces well defined
Project Overview
• Transiting exoplanet discovery mission
• 2 year all sky survey
• Identifies best targets for follow-up characterization
• Deep Space Network (DSN) utilization
• Category II, Class C
• LRD: August 2017
• PI Cost Cap: $228.3 M (RY$)
NASA
Orbital
MIT KAVLI INSTITUTE

Space Mission: Tess

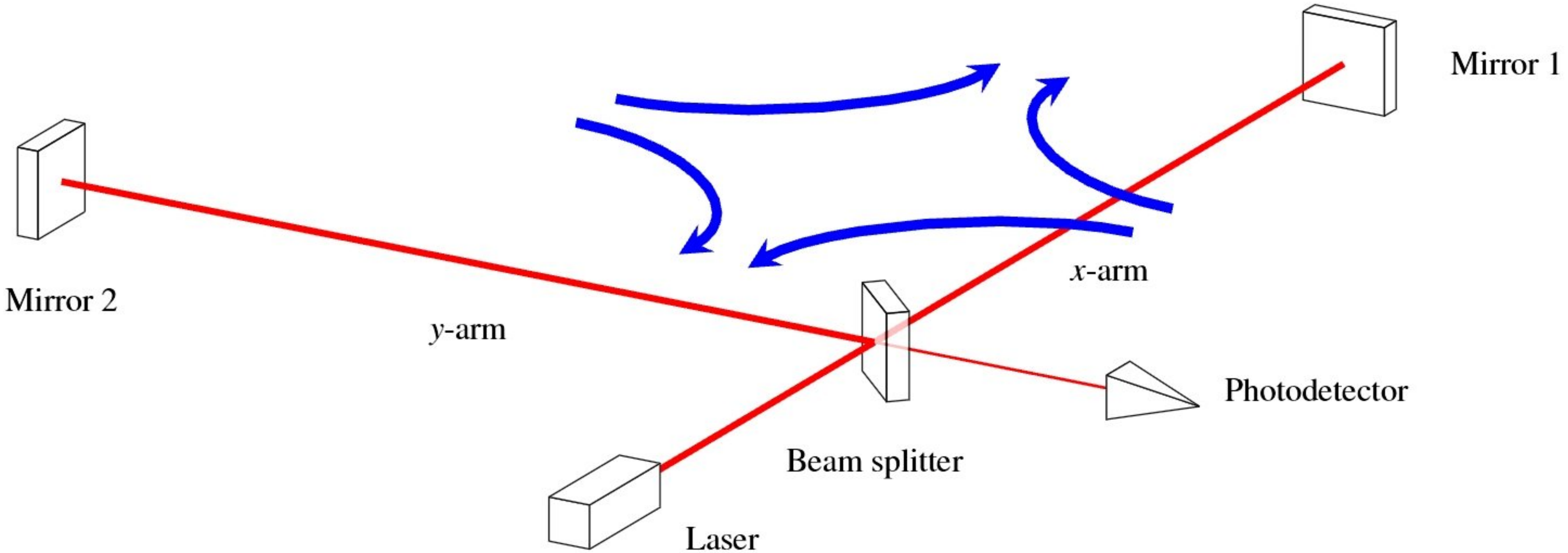
TESS will tile the sky with 26 observation sectors:

- At least 27 days staring at each 24° × 96° sector
- Brightest 100,000 stars at 1-minute cadence
- Full frame images with 30-minute cadence
- Map Northern hemisphere in first year
- Map Southern hemisphere in second year
- Sectors overlap at ecliptic poles for sensitivity to smaller and longer period planets in JWST Continuous Viewing Zone (CVZ)

Advanced LIGO

- Search for Gravitational Waves from merging compact objects (neutron stars & black holes)
- Major involvement by researchers at UWM
- currently being upgraded, operational in 2015, with sensitivity increasing until 2020
-

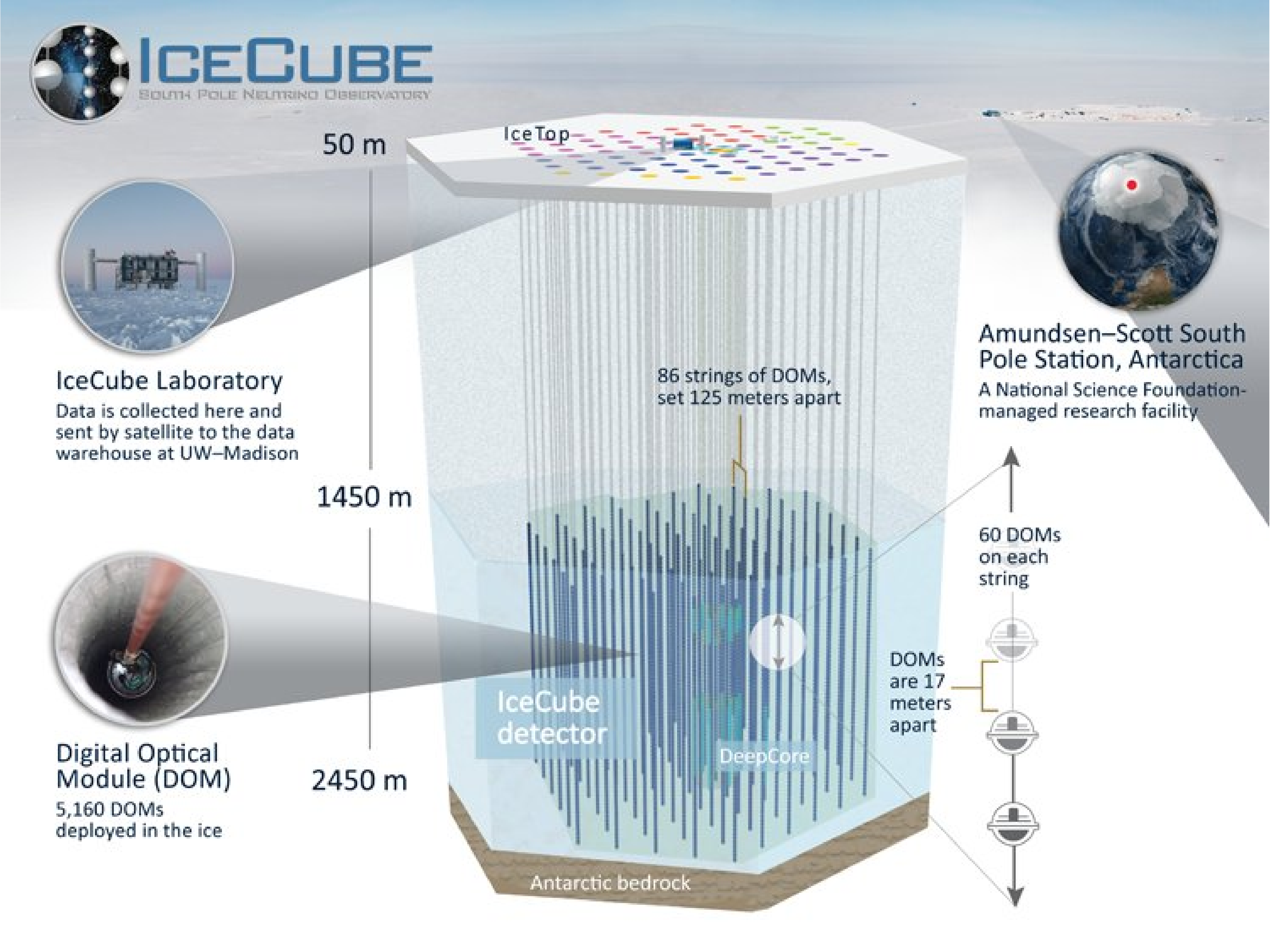
LIGO: A Michelson Interferometer at Hears



Advanced LIGO

Astro-particle Physics

- Electromagnetic radiation is not the only means of learning about the cosmos:
- Neutrinos
  → Need large Detectors → ground-based
- Elementary Particles
  Either from ground or from space
  Space: Direct detection of particles
  Ground: Indirect detection via Cherenkov radiation

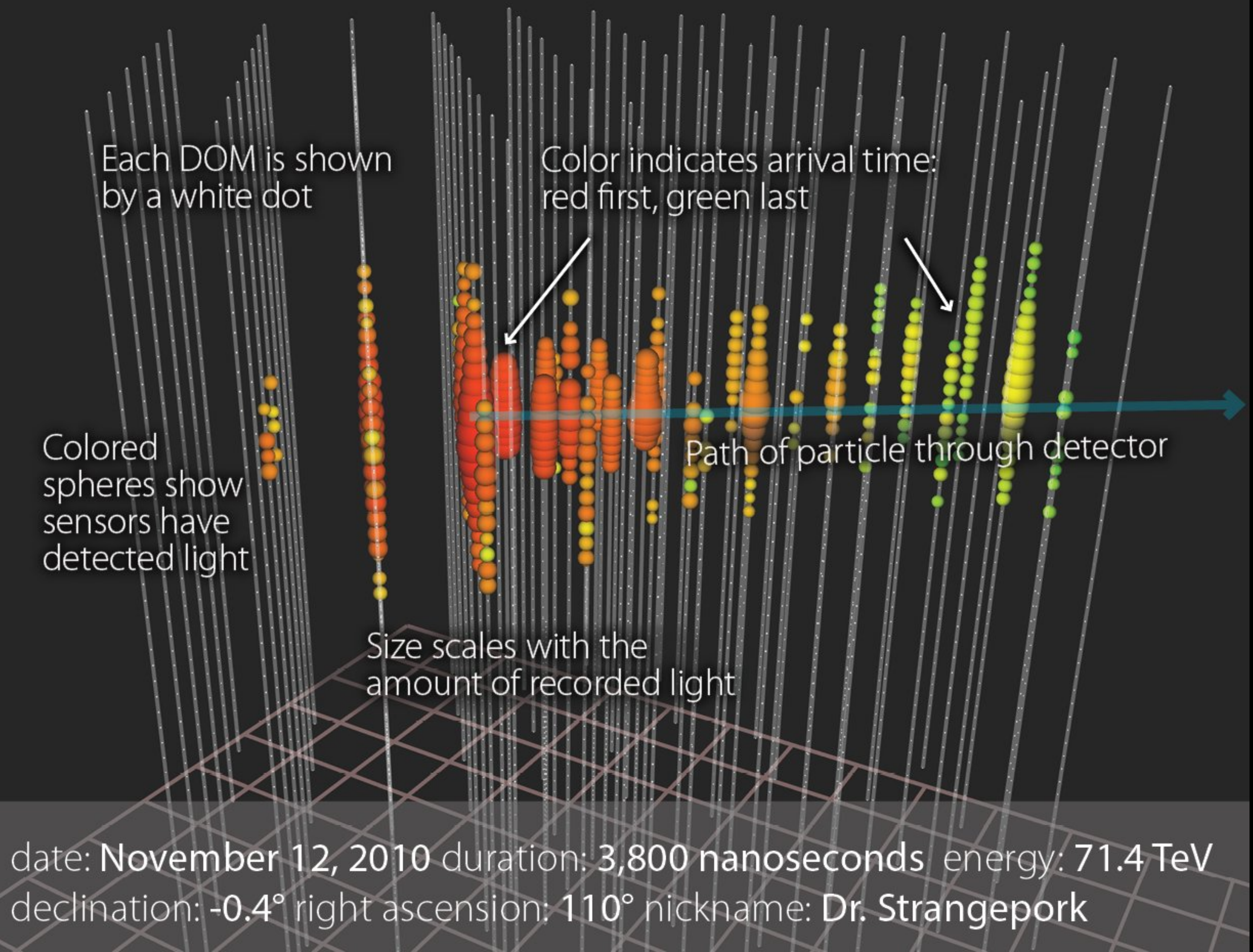

IceCube
South Pole Neutrino Observatory
IceTop
50 m
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Antarctic bedrock

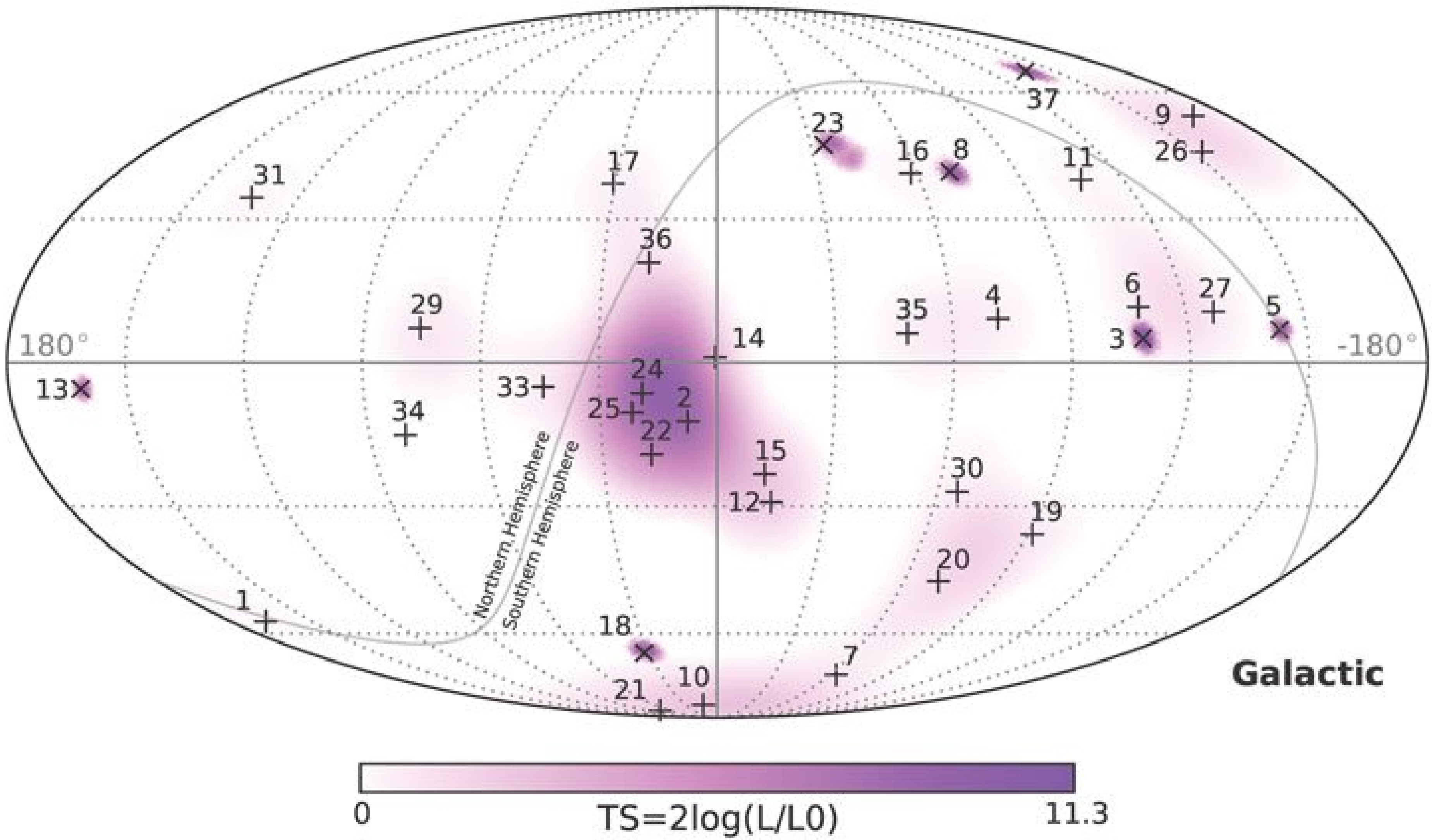
IceCube

- IceCube headquarter: UW-Madison
- Located at South Pole, using Ice as detector volume
- Search for neutrinos from Northern Hemisphere! Neutrinos hardly interact with anything, and easily penetrate earth
- Use Earth as shield from atmospheric particles (neutrinos, muons)

How does IceCube work?

When a neutrino interacts with the Antarctic ice, it creates other particles. In this event graphic, a muon was created that traveled through the detector almost at the speed of light. The pattern and the amount of light recorded by the IceCube sensors indicate the particle's direction and energy.





180°
-180°
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36
37
Northern Hemisphere
Southern Hemisphere
Galactic
0
TS=2log(L/L0)
11.3

ODI: Specs

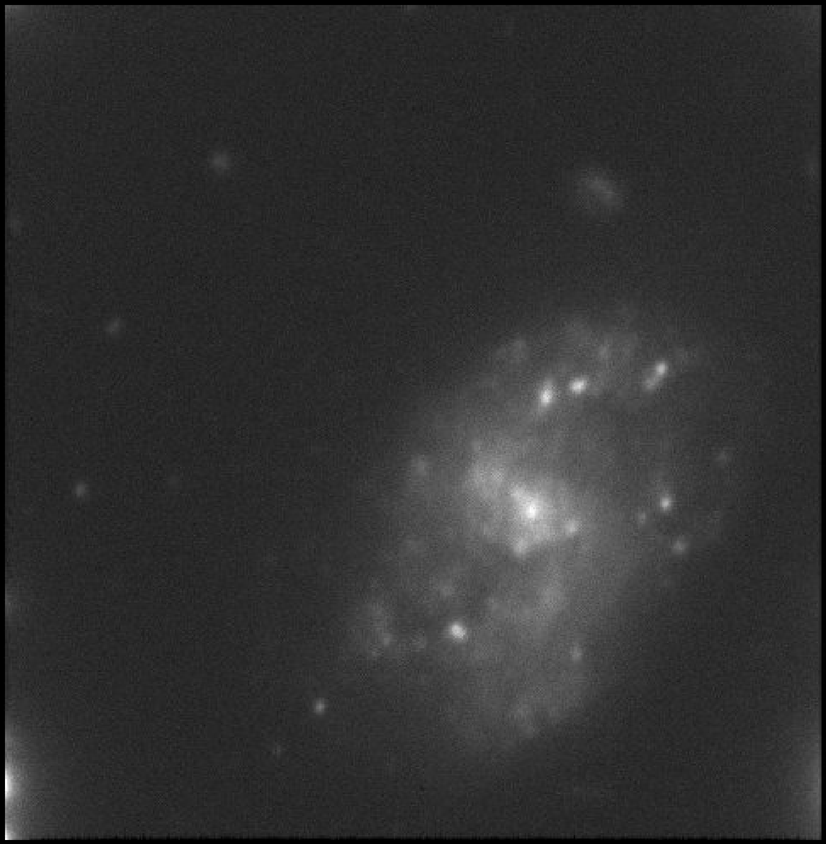
Field of view:
- ~25x25 arcmin in center
- + 4x 8x8 “guide fields”

Pixelscale: 0.11''

Readout-time: 7s

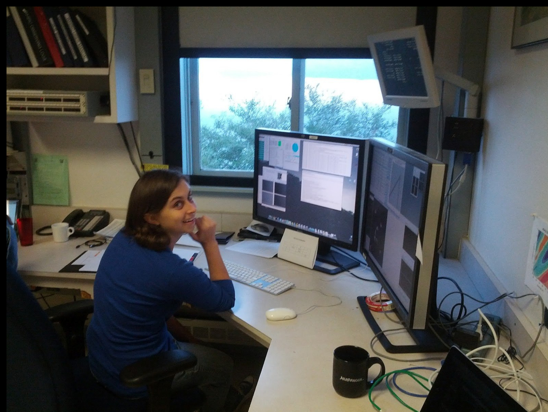
Filters: SDSS griz + SDSS u, Hα, OIII
- + all Mosaic filters on request

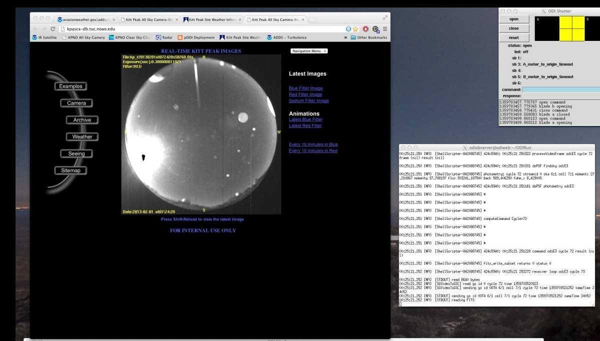
Science targets for WIYN/ODI

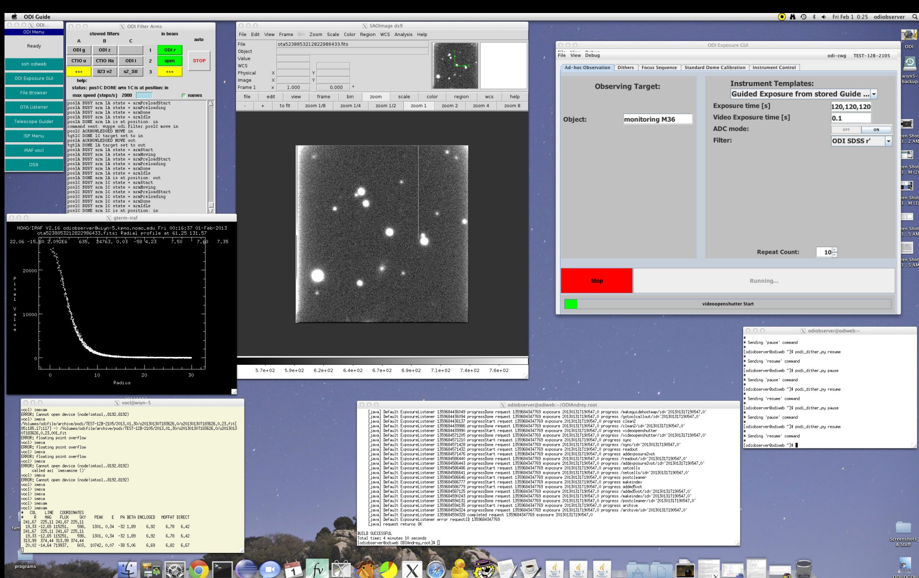


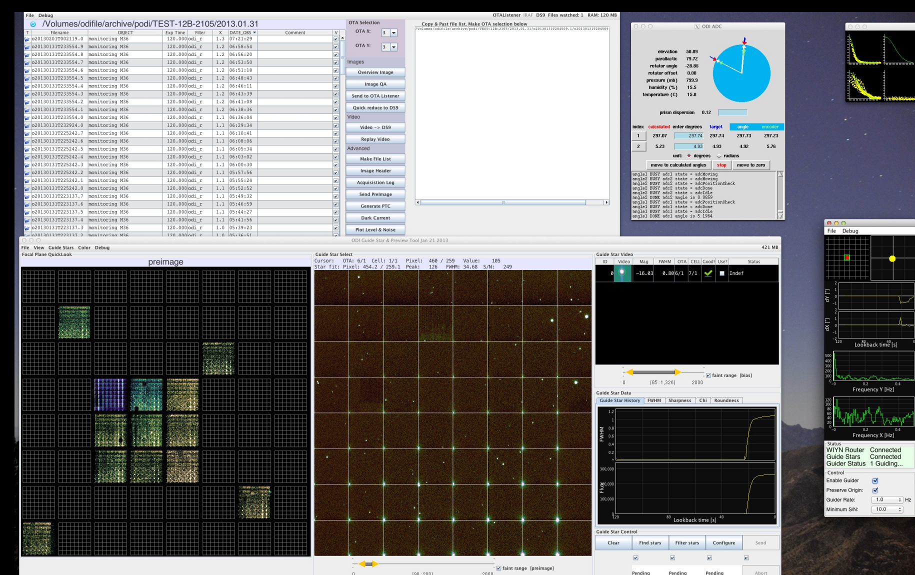
Resolved field galaxies at seeing 0.42''

User interface







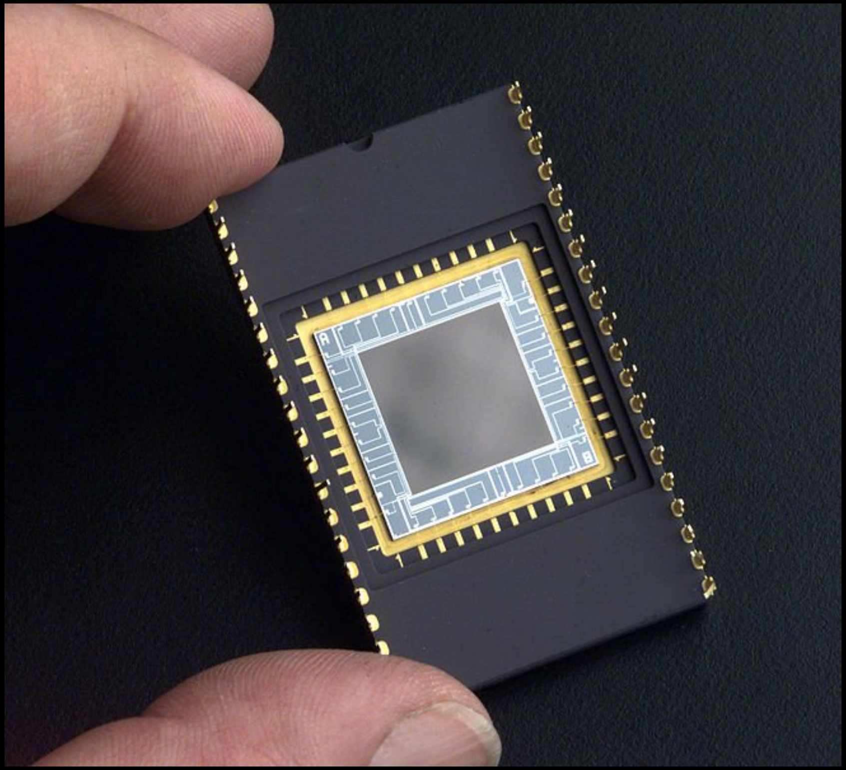


Astro imaging – then and now

1 Camera
1 CCD
1 exposure

↓

1 image
few MegaPixels



reduce and process at home

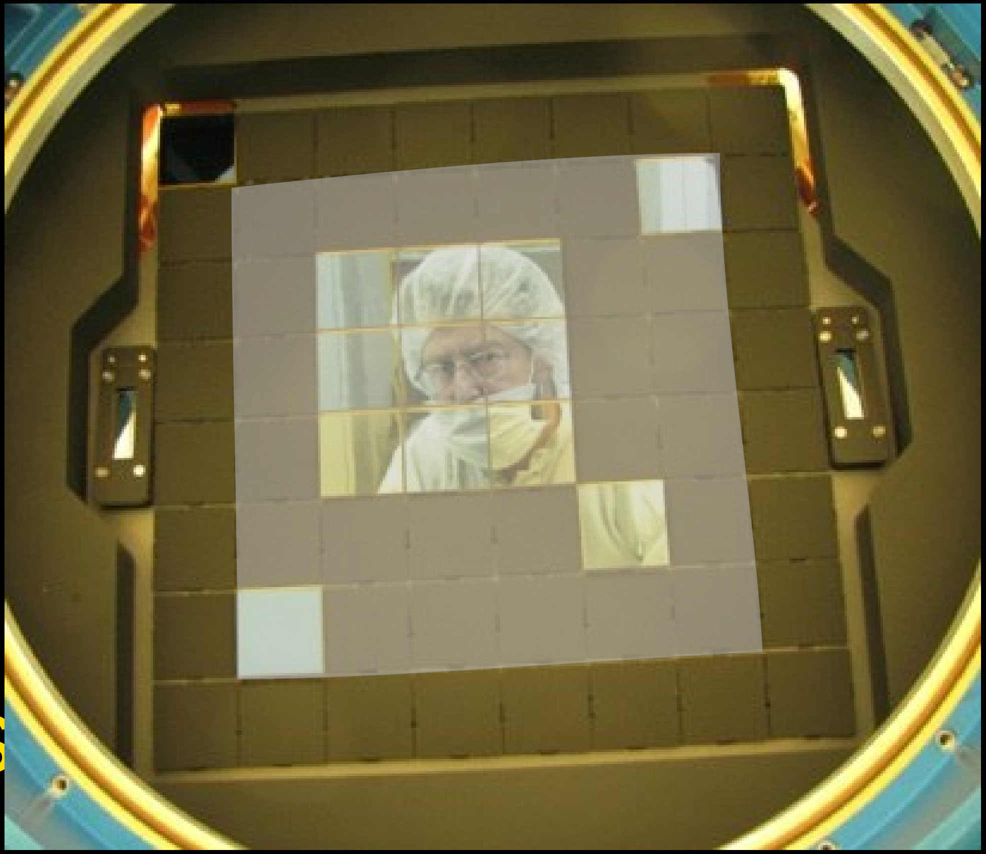
image credit: wikipedia

Astro imaging – then and now

1 Camera
13 CCD
1 exposure

↓

832 images
208 MegaPixels



Data processing no longer trivial

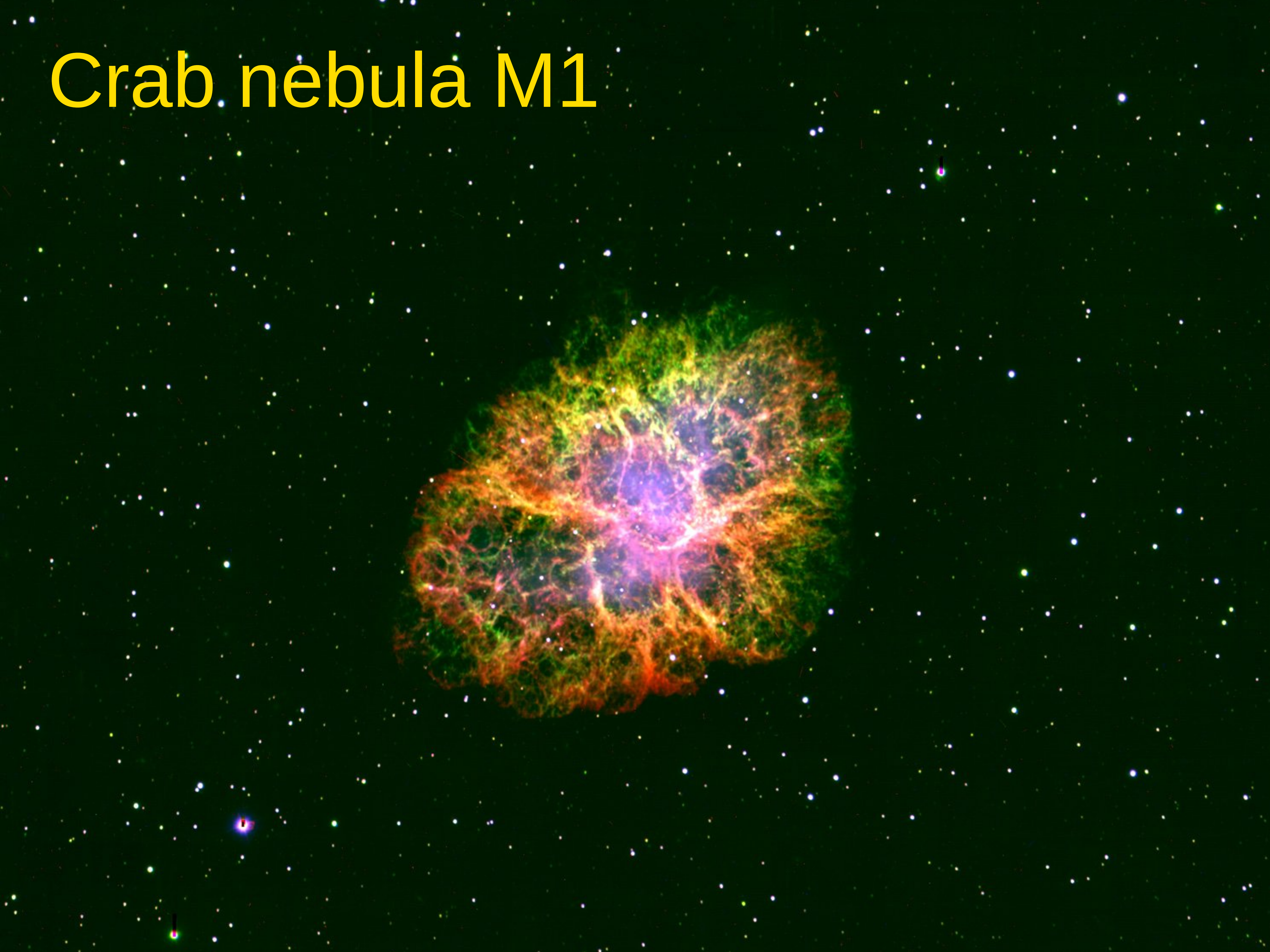
image credit: WIYN/NOAO

ODI Data challenges

- **Data complexity**
  832 images → need 832 separate calibrations
- **Data volume**
  raw data: 450 MB/exposure
  reduced data: 850 MB/exposure
  typical night: 100s of GB to TeraByte
- **Optical & instrumental challenges**
  Pupilghost, fringing, persistency, saturation

→ Need special software

Crab nebula M1

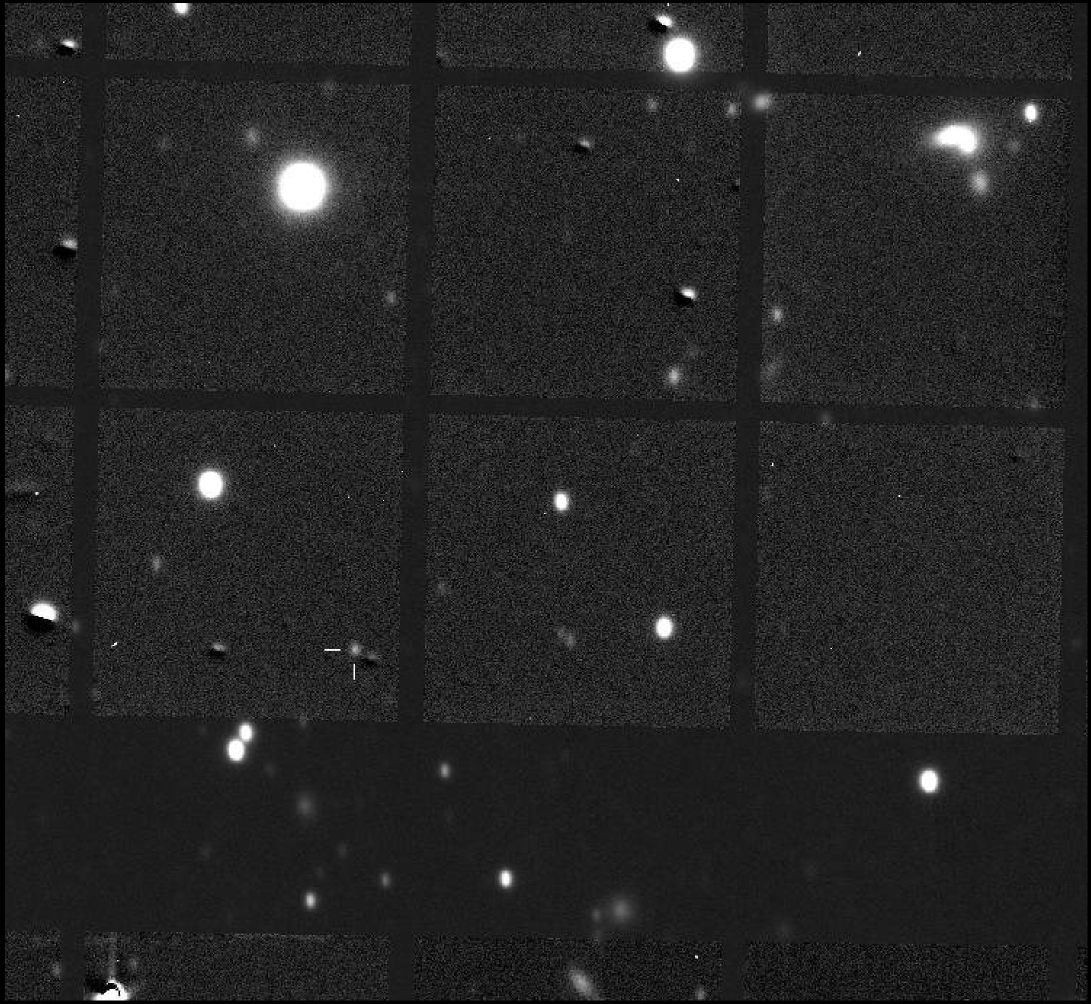


WIYN & ODI hunting for asteroids

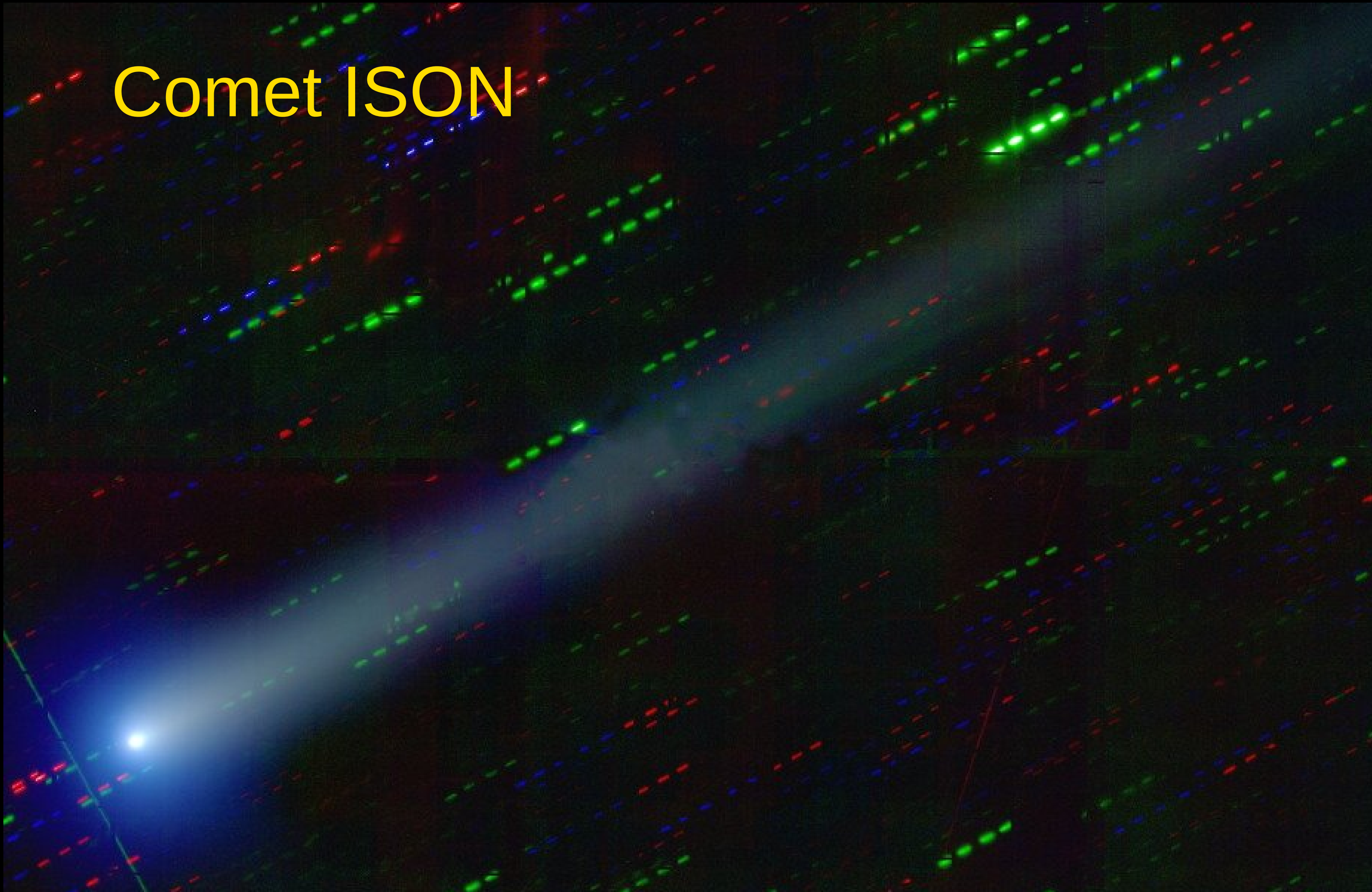
In observations of a known asteroid:

Search for new asteroids, report findings to Minor Planet Center

So far: found ~ 10 previously unknown asteroids



Comet ISON



(5g,4r,3i x 110s)

Thank you!