Astrophysics in the 2020's and the role of High Energy Astrophysics

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NASA's Goddard Space Flight Center

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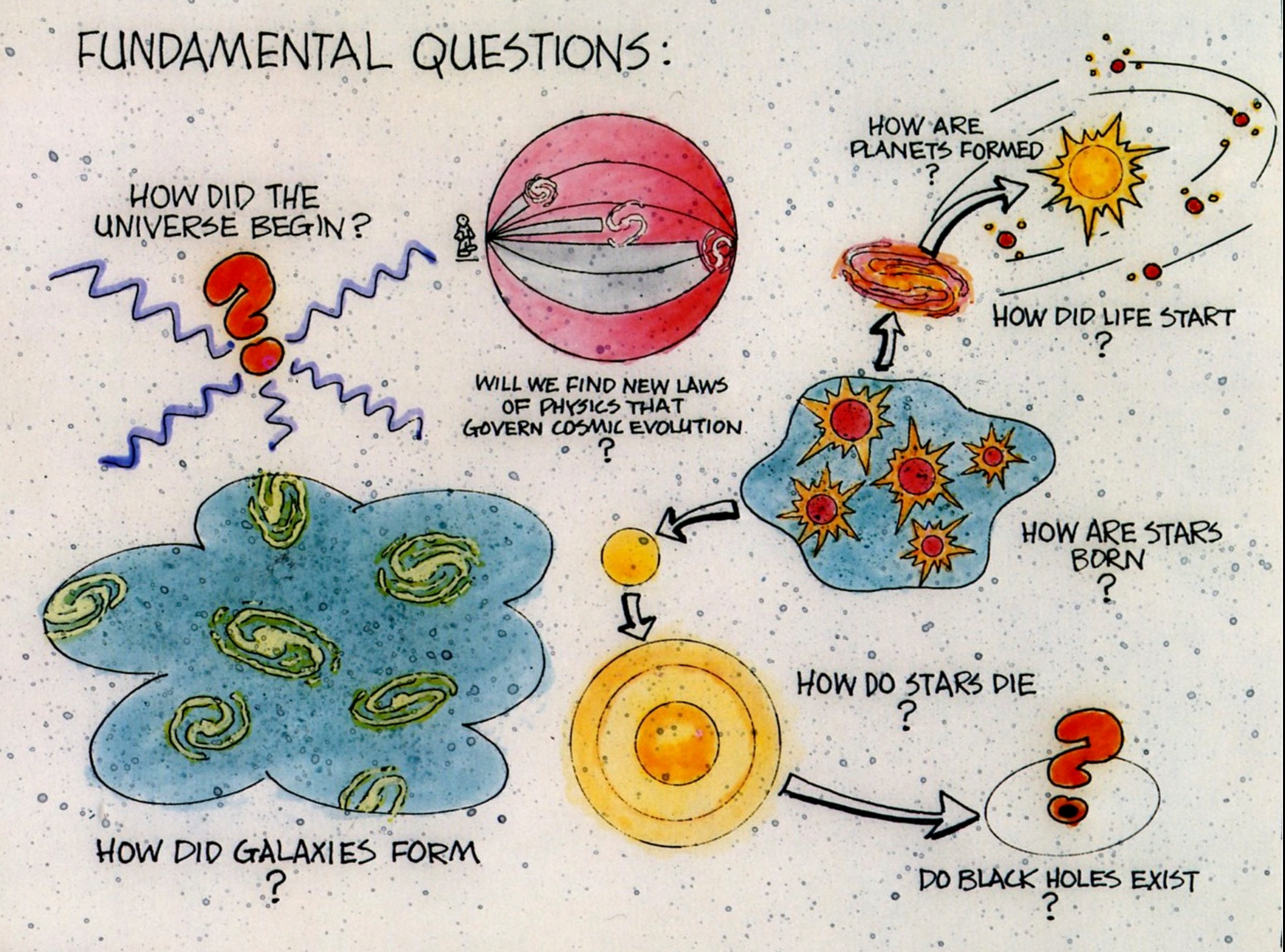
The Crystal Ball

The Crystal Ball has been waiting for your visit! Do you have a question that you have been waiting to ask? Click on the Crystal Ball and your personal fortune-teller browser window will appear and ask for your question. Follow the instructions carefully and you will soon receive the answers to all your questions.

(http://predictions.astrology.com/cb/)
but 404 - File or directory not found


FUNDAMENTAL QUESTIONS:
HOW DID THE UNIVERSE BEGIN?
WILL WE FIND NEW LAWS OF PHYSICS THAT GOVERN COSMIC EVOLUTION ?
HOW ARE PLANETS FORMED ?
HOW DID LIFE START ?
HOW ARE STARS BORN ?
HOW DID GALAXIES FORM ?
HOW DO STARS DIE ?
DO BLACK HOLES EXIST ?

"Mrs. Marsha Mullhouse, of Kenosha, Wisconsin, asks, 'Are You subject to the laws of physics, or are the laws of physics subject to You?' "

Why & How?

- Intense public curiosity
- Stunning, startling science opportunities
- Beautiful images
- Exponentially growing technical infrastructure
- ➔ a spectacular century

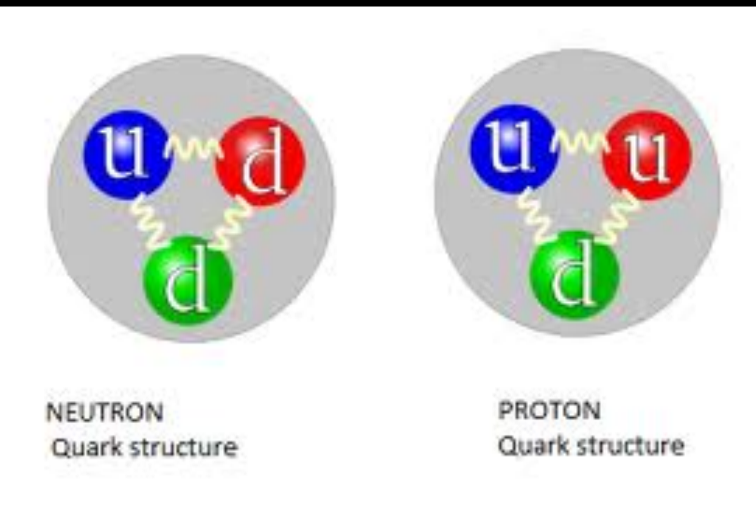
Some Questions

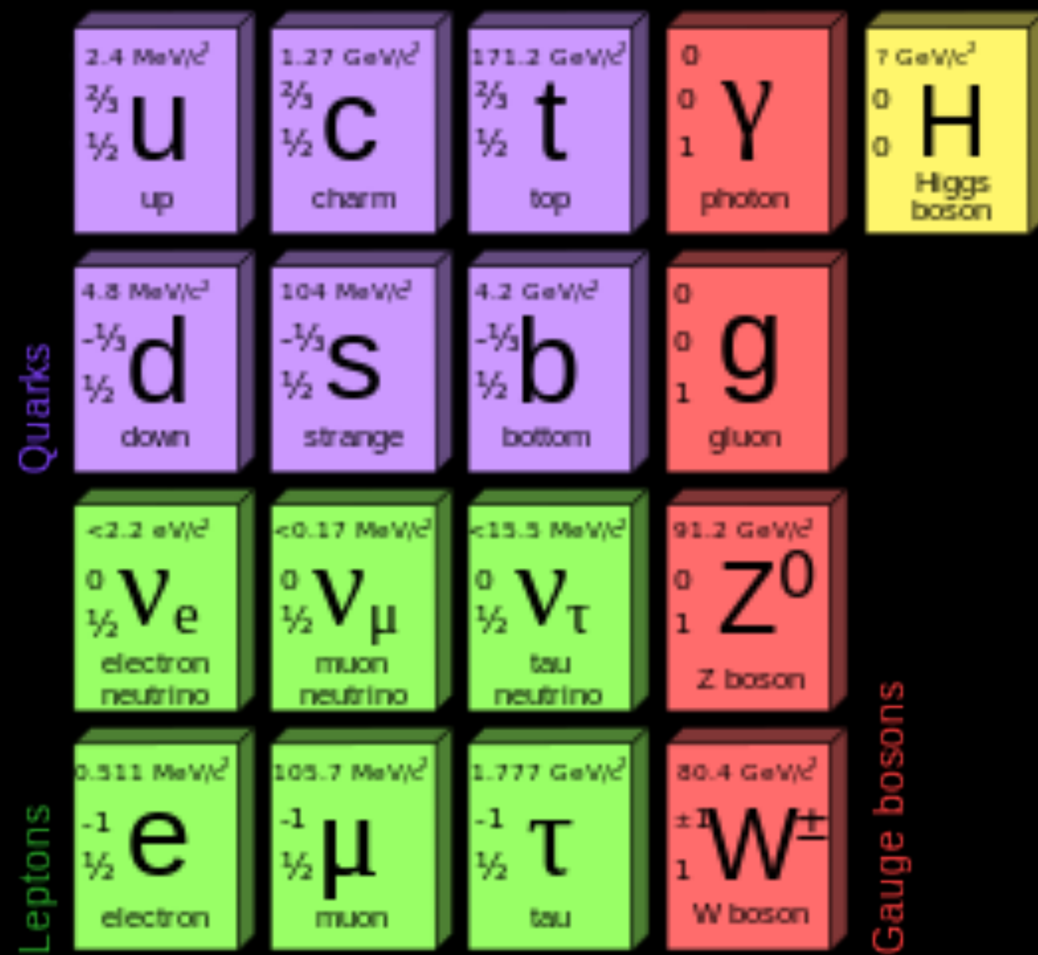
- How did we get here?: Big Bang, first stars & galaxies, galaxy evolution, star formation
- Are we alone?: planet formation, planetary system evolution, atmospheric conditions & chemistry, liquid water, signs of life
- Fundamental physics: relativity, quantum gravity, dark matter, dark energy, ...

How much would you pay for all the secrets of the Universe?

- Worldwide budget to build great space observatories: ~ 700 M$? (~$1/ person/yr for North America, Europe, & Japan)
- Cost for each: $2 - $8 B
- ➔ one every 3 – 12 years for all topics
- But HST to JWST is ~ 28 yrs

Standard Model of Particles





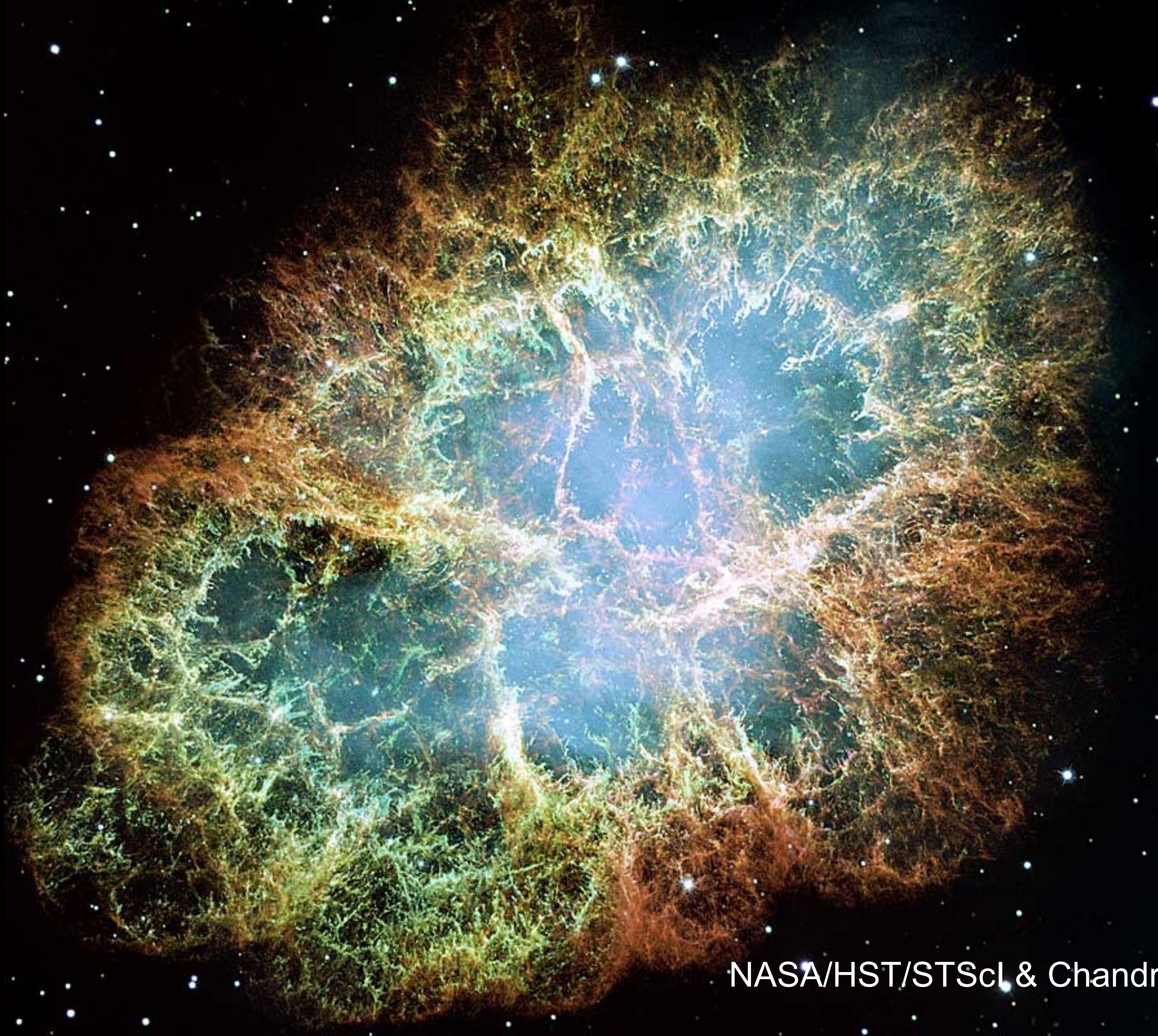
Quarks have mass, spin, charge, and “color charge”, hence “quantum chromodynamics” (QCD). But where’s my graviton, DM, & DE?

Nobel Prize, 2011 Dark Energy

MacArthur Fellow
2008 - Adam Riess

S. Perlmutter, A. Riess, B. Schmidt
Shaw Prize, Hong Kong, 2006

Hubble is 28 in April 2018! And working well!

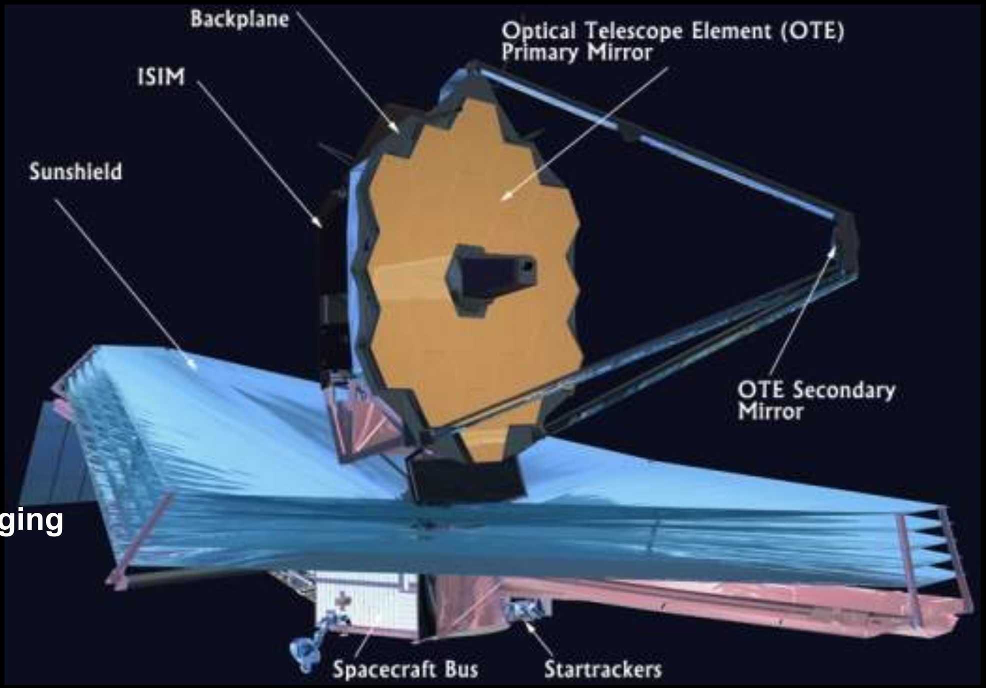


NASA/HST/STScI & Chandra teams

James Webb Space Telescope (JWST)

<u>Organization</u>

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  – Near Infrared Camera (NIRCam) – Univ. of Arizona
  – Near Infrared Spectrograph (NIRSpec) – ESA
  – Mid-Infrared Instrument (MIRI) – JPL/ESA
  – Fine Guidance Sensor (FGS) and Near IR Imaging Slitless Spectrograph (NIRISS) – CSA
- Operations: Space Telescope Science Institute

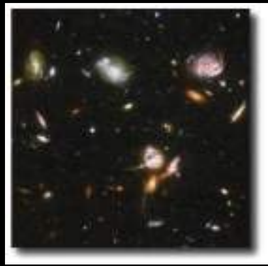


<u>Description</u>

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

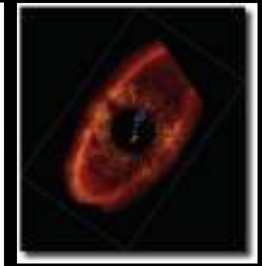
www.JWST.nasa.gov

<u>JWST Science Themes</u>


End of the dark ages: First light and reionization


The assembly of galaxies

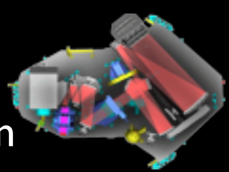
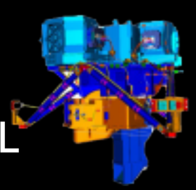

Birth of stars and proto-planetary systems


Planetary systems and the origin of life

JWST Science Requirements

- Alan Dressler HST & Beyond Report, 1996
- Volunteers + 3 competitively selected Science Working Groups
- "Design Reference Mission" voted on by SWG
- Science Requirements Document
- HQ Level 1 Requirements
- Science Assessment Team (external review)

JWST Instrumentation

Instrument	Science Requirement	Capability
NIRCam Univ. Az/LMATC 	Wide field, deep imaging ‣0.6 µm - 2.3 µm (SW) ‣2.4 µm - 5.0 µm (LW)	Two 2.2' x 2.2' SW Two 2.2' x 2.2' LW Coronagraph
NIRSpec ESA/Astrium 	Multi-object spectroscopy ‣0.6 µm - 5.0 µm	9.7 Sq arcmin Ω + IFU + slits 100 selectable targets: MSA R=100, 1000, 3000
MIRI ESA/UKATC/JPL 	Mid-infrared imaging ‣ 5 µm - 27 µm Mid-infrared spectroscopy ‣ 4.9 µm - 28.8 µm	1.9' x1.4' with coronagraph 3.7"x3.7" – 7.1"x7.7" IFU R=3000 - 2250
FGS/NIRISS CSA 	Fine Guidance Sensor 0.8 µm - 5.0 µm Near IR Imaging Slitless Spectrometer, ‣1.6 µm - 4.9 µm	Two 2.3' x 2.3' 2.2' x 2.2' R=100 with coronagraph

JWST Plans

- Guaranteed Time Observers: Google “JWST GTO observations” (about 4000 hours total, mostly in first year)
- Early Release Science program: Google “JWST ERS selection”
- General Observers to submit proposals
- About 10% of time for Director’s Discretionary
- Targets of Opportunity: 2 day turnaround
- Sensitivity: 1 nJy = mag 31.4_AB: see a bumblebee at the distance of the Moon (reflected sunlight & thermal emission); can also see Mars

JWST Early Release Science (HEA gets ~ 3 of 13)

- A JWST Study of the Starburst-AGN Connection in Merging LIRGs (PI: Lee Armus)
- Q-3D: Imaging Spectroscopy of Quasar Hosts with JWST Analyzed with a Powerful New PSF Decomposition and Spectral Analysis Package (PI: Dominika Wylezalek)
- Nuclear Dynamics of a Nearby Seyfert with NIRSpec Integral Field Spectroscopy (PI: Misty Bentz)

JWST GTO HEA observations

- IFU Spectroscopy of the Host Galaxies of Strongly Lensed Quasars, Massimo Stiavelli
- Formation Histories and Stellar Masses of Very High-z Quasars, George Rieke
- NIRSpec-IFU Observations of Two QSOs at z=6, Pierre Ferruit
- NIRSpec and MIRI spectroscopy of QSOs - part #3, Pierre Ferruit
- NIRSpec IFS of BR1202, Pierre Ferruit
- Cosmic Re-ionization, Metal Enrichment, and Host Galaxies from Quasar Spectroscopy, Chris Willott
- Exploring the End of Cosmic Reionization, Simon Lilly
- NIRSpec and MIRI IFS of SMGs & QSOs, Luis Colina Robledo
- Are There AGN Embedded in All Ultraluminous Infrared Galaxies (ULIRGs)?, George Rieke

Possible Discoveries in 2020's

- Galaxy observations match simulations??
- New population of faint high-z objects found, implications for BH formation, galaxy formation, particle physics
- Hot IGM mapped, and is not where it was supposed to be
- DM annihilation signal found in Fermi γ maps
- High z supernovae found, differ from known types
- Dark Matter in a lab – particles, axions, or nothing
- More Higgs particles found at LHC
- Supernova in Milky Way found – long overdue!
- Einstein's Λ constant fits most dark energy data, drat!
- CIB – CXB spatial correlation explained by ?

Possible Discoveries in 2020s

- BUT: Continuing tension between SN, BAO, CMB, weak lensing, clustering measurements of H_0 and Dark Energy
- FRB's localized and explained, very surprising story
- CMB B-mode polarization detected (on ground) from primordial gravitational waves, supports equipartition with other modes; demand for a space mission
- Magnetic reconnection events observed by MMS and explained by theory and simulations (magnetic lightning bolts); implications for HE astrophysics
- HE cosmic ray acceleration mechanism misunderstood, again
- Neutron star- black hole mergers observed – LIGO + Fermi + every available telescope
- Microlensing finds population of stellar mass black holes

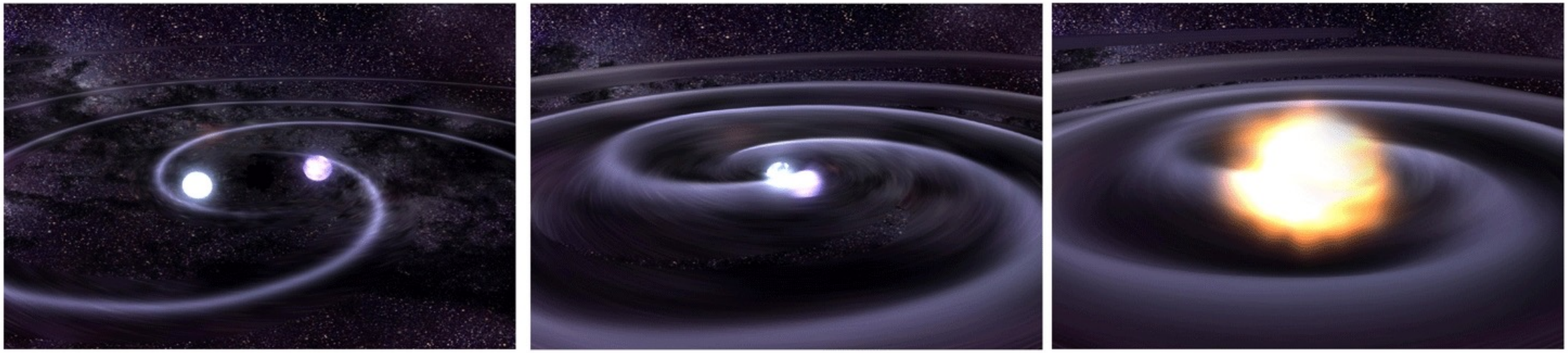
Possible Discoveries in 2020s

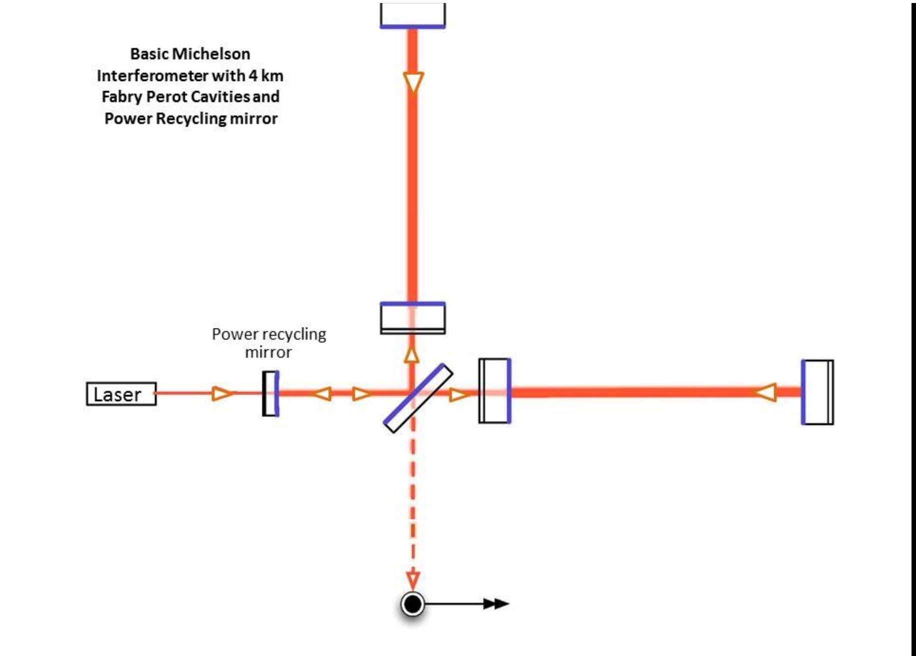
- Dip in 78 MHz redshifted 21 cm from CMB implies strange processes at high z>10, maybe dark matter cools baryons, maybe early galaxy formation, TBC
- Simulated supernova in 3D matches real one
- NANOGrav sees low frequency gravitational waves
- Event Horizon Telescope maps a black hole close up
- Einstein is still not wrong
- Theory of Everything emerges
- Black hole evaporation verified in lab model
- X-ray and radio emission from exoplanets
- X-ray and radio flares found on exoplanet host stars
- High energy neutrino sources (IceCube) identified

Possible new technologies

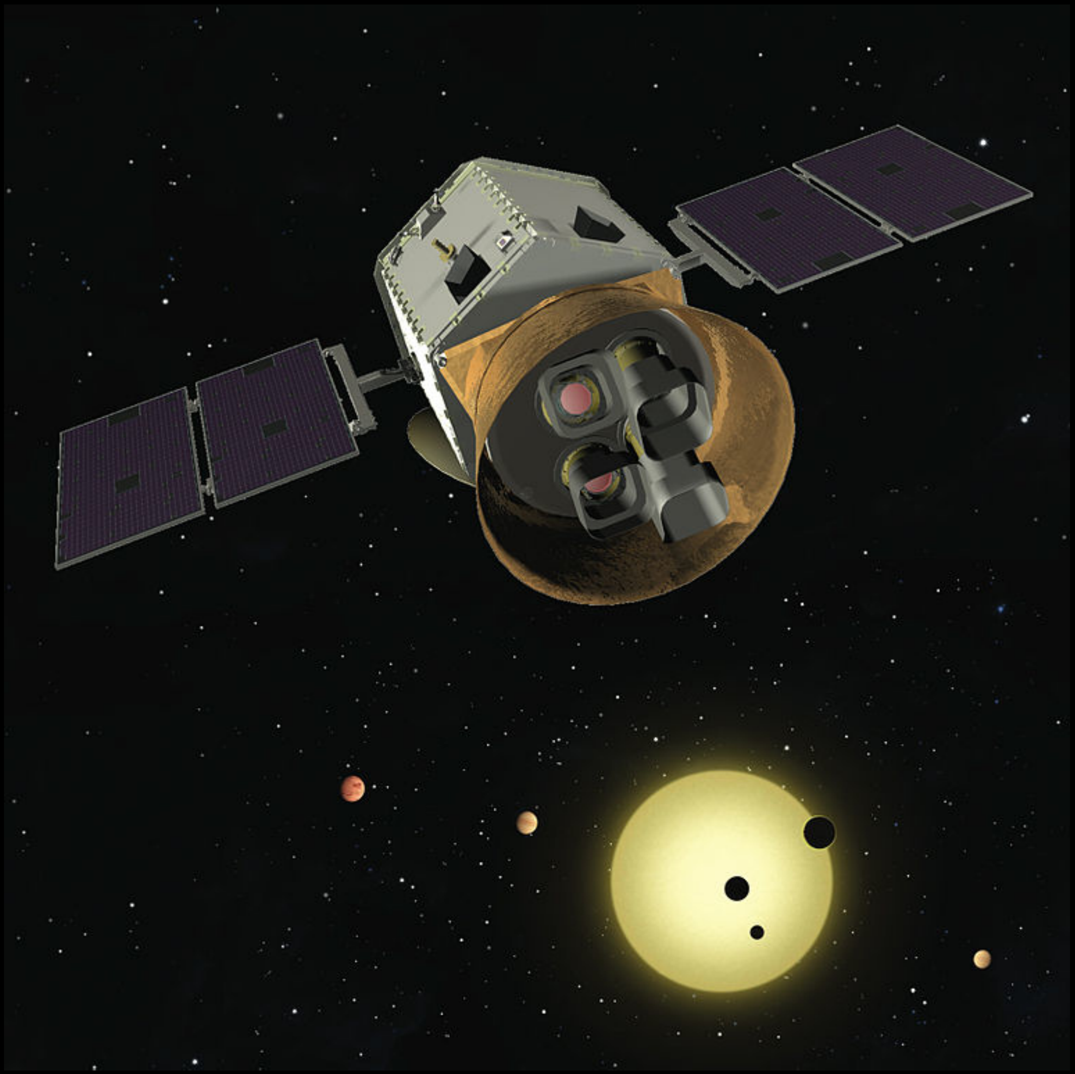
- Much better imaging/energy resolving X-ray detectors (shared technology with CMB, exoplanets, etc.)
- Super-super computers solve multiscale problems
- Much better imaging (A, $\delta\theta$) for X-rays
- Extreme formation flying (cf starshade for exoplanets, 50,000 km spacing), enables extreme angular resolution for X and γ
- X-ray interferometry, X-ray Fresnel telescopes get 1000x better resolution
- GRB monitors x4 throughout solar system get direction from timing
- Heavy lift rockets enable huge gamma ray telescopes

Advanced LIGO (Laser Interferometer Gravitational wave Observatory) – daily announcements?





Transiting Exoplanet Survey Telescope (TESS)

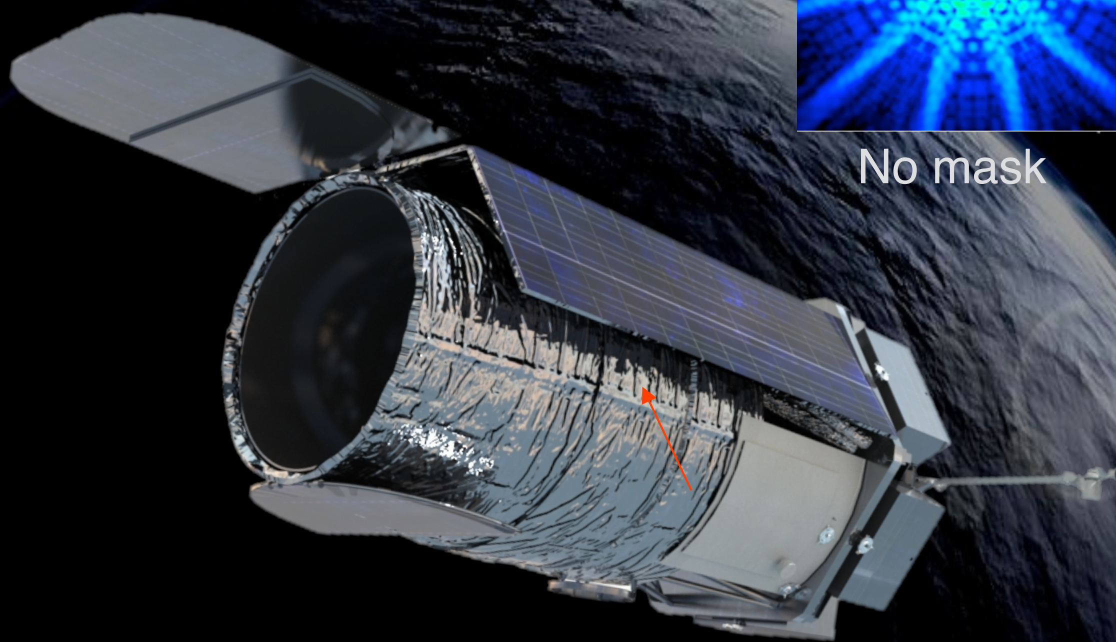


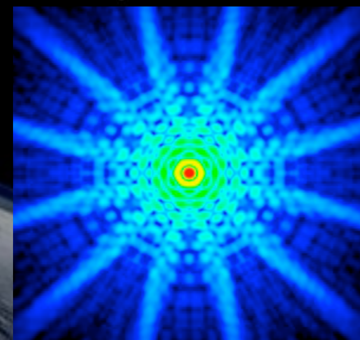
"TESS has just accelerated our chances of finding life on another planet within the next decade."

Sara Seager, a professor of planetary science and physics at MIT and TESS project member

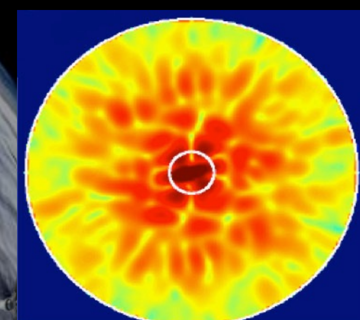
closest 1,000 M stars
and source list for JWST

WFIRST surveys NIR sky, measures Dark Energy, finds rare extreme objects, high z supernovae, examines AGN hosts with coronagraph

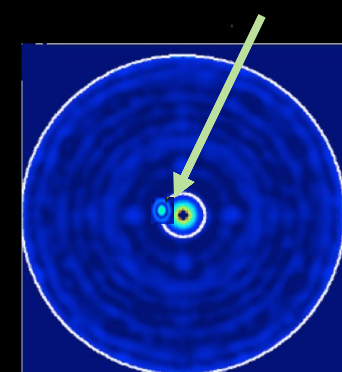




No mask



With mask

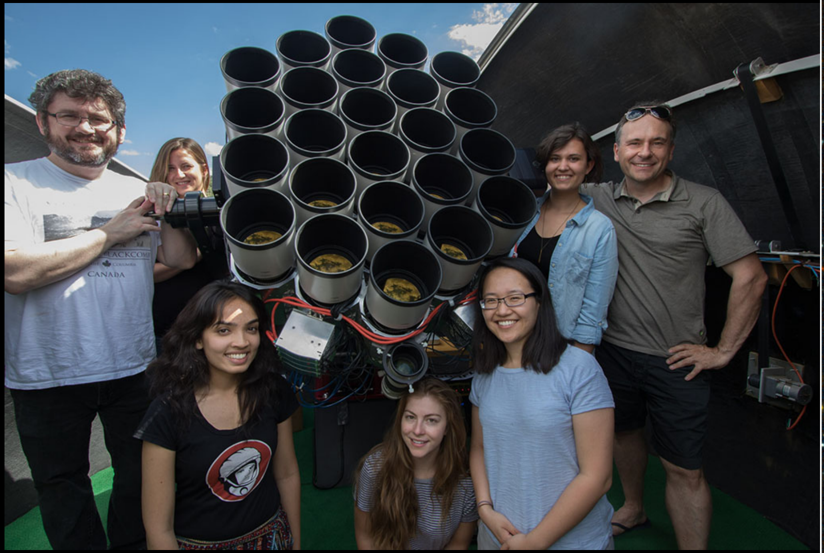


With mask and deformable mirrors

WFIRST Coronagraphy

WFIRST will achieve a **>100,000,000 contrast ratio** to enable **direct** imaging of exoplanets

Dragonfly discovers Galaxy of 99.99% Dark Matter, will find many more



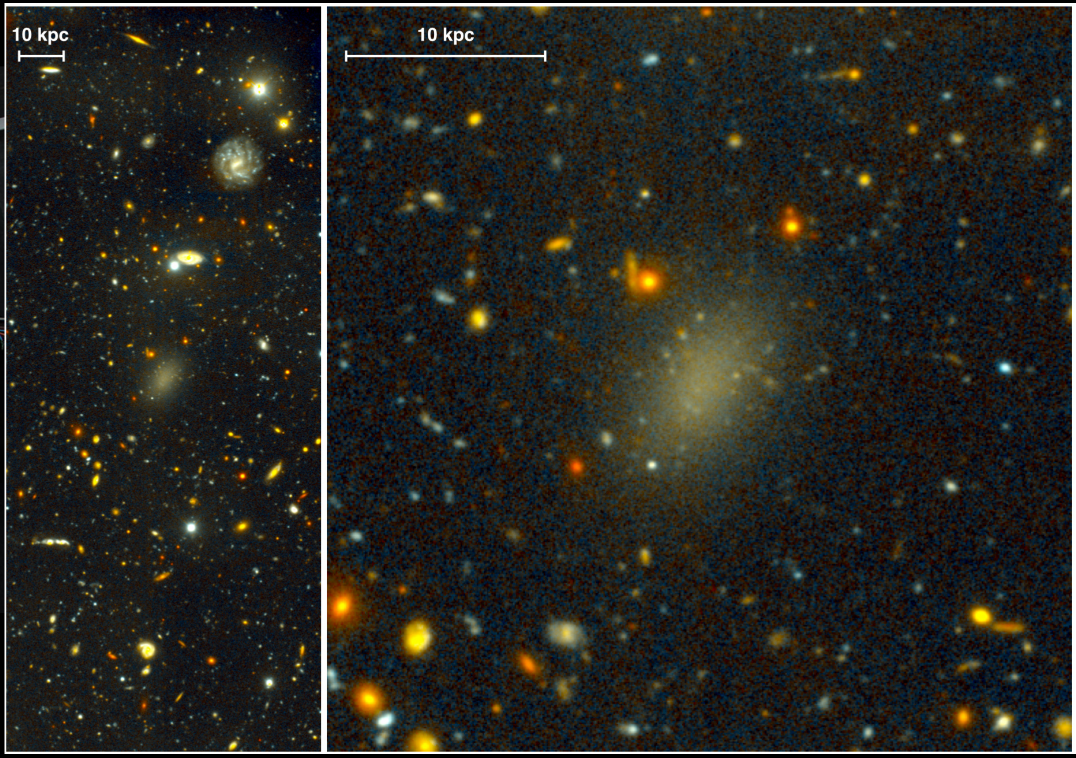
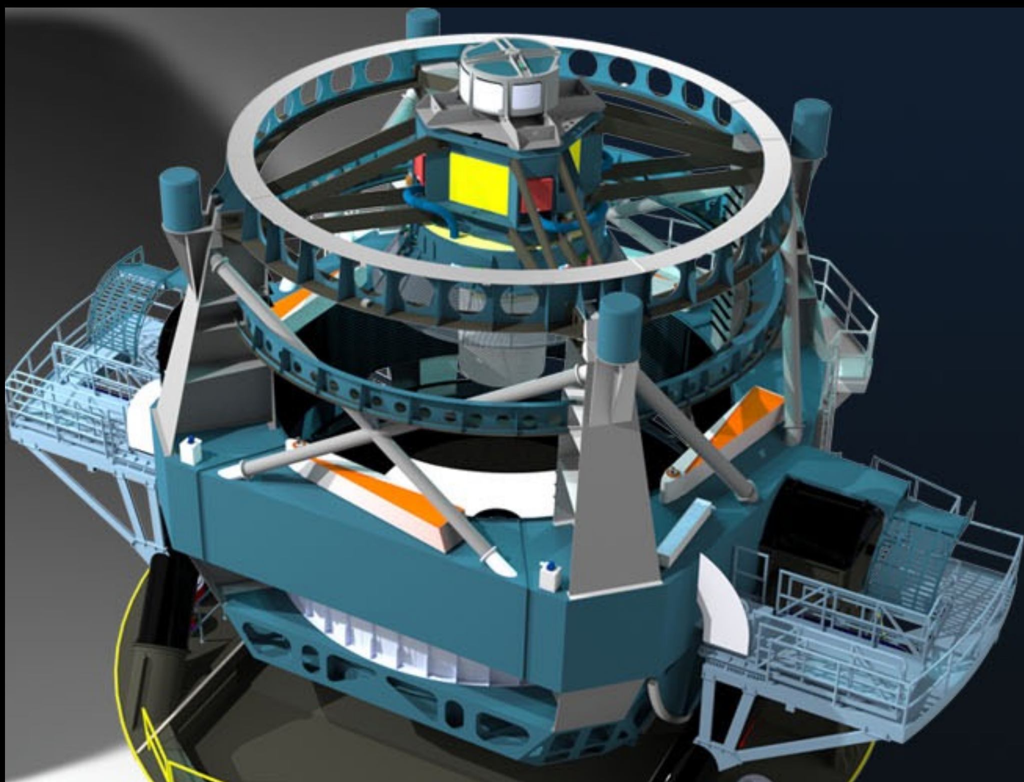


Image credit: Pieter van Dokkum, Roberto Abraham, Gemini Observatory/ AURA.

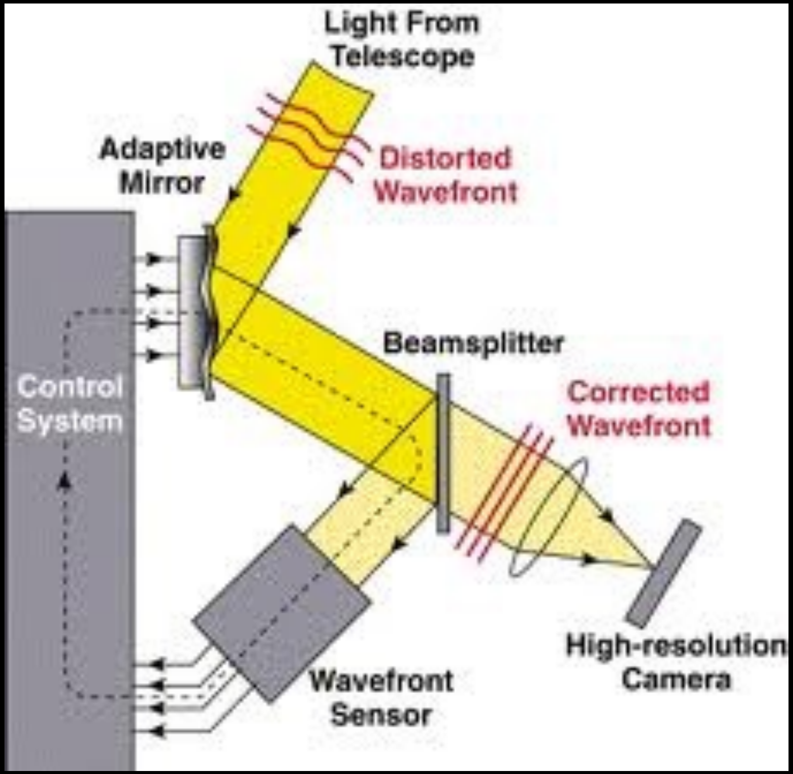
Large Synoptic Survey Telescope
LSST.org

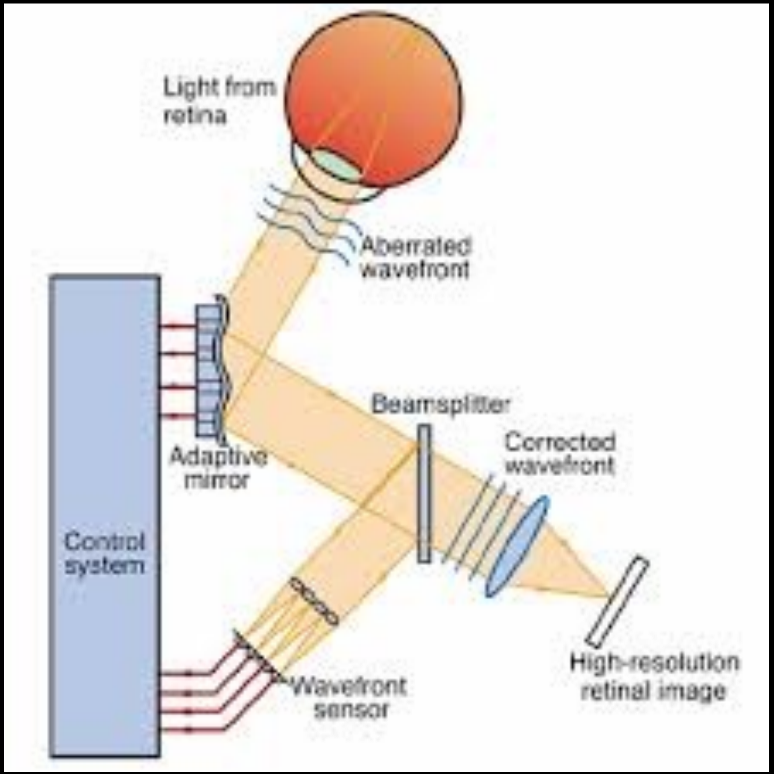


This telescope will produce the deepest, widest, image of the Universe:

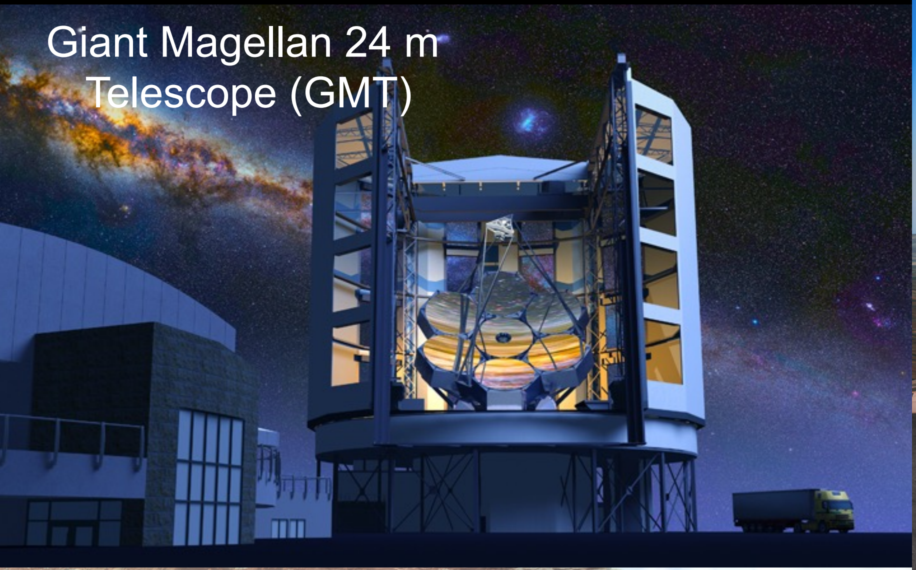
- **27-ft (8.4-m) mirror, the width of a singles tennis court**
- **3200 megapixel camera**
- **Each image the size of 40 full moons**
- **37 billion stars and galaxies**
- **10 year survey of the sky**
- **10 million alerts, 1000 pairs of exposures, 15 Terabytes of data .. every night!**

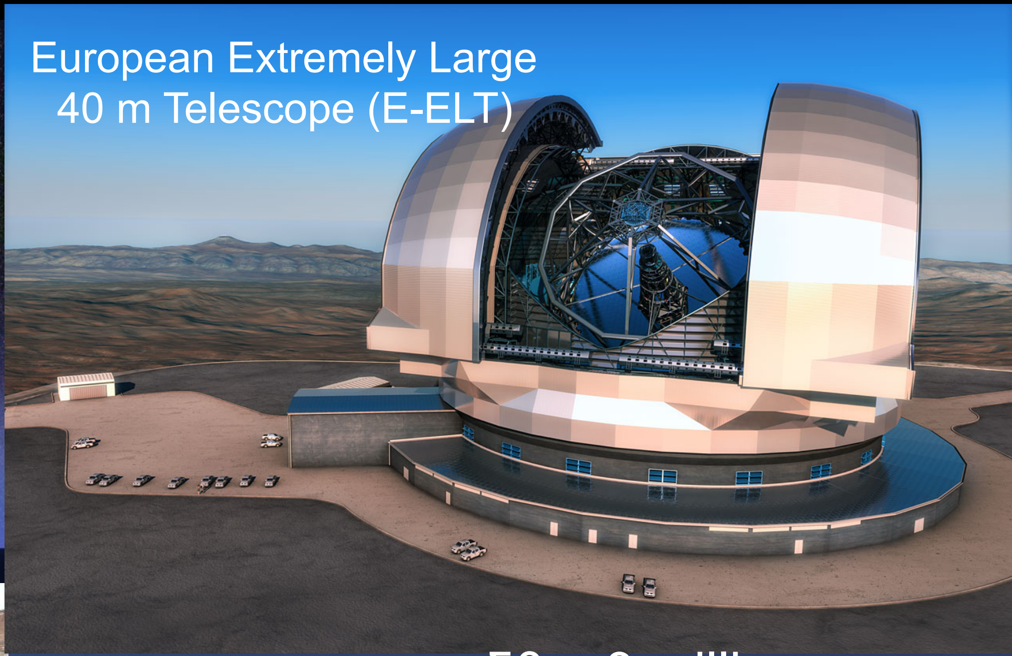
Adaptive Optics was for weapons, now astronomy & football



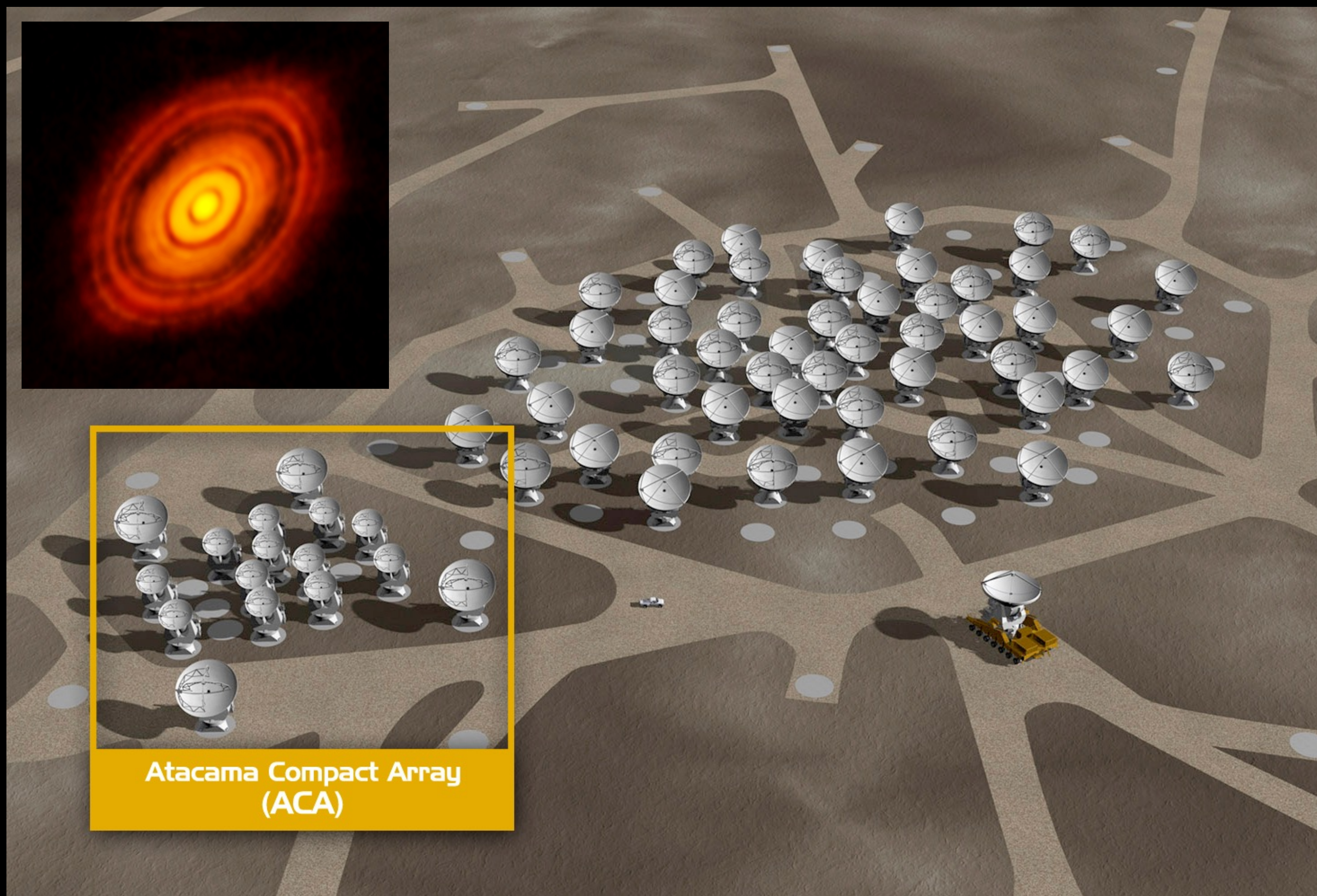


25 meters (1000 inches) and up!





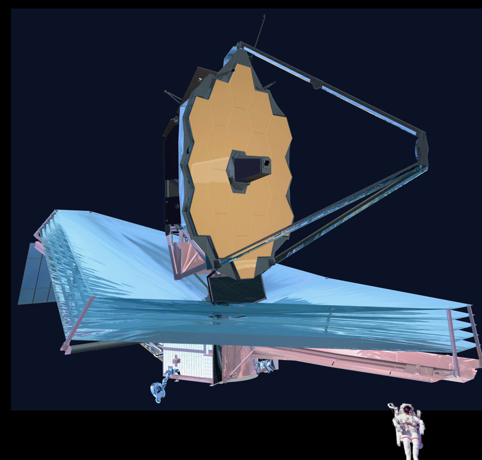
ALMA (Atacama Large Millimeter Array) sees proto-planetary disk



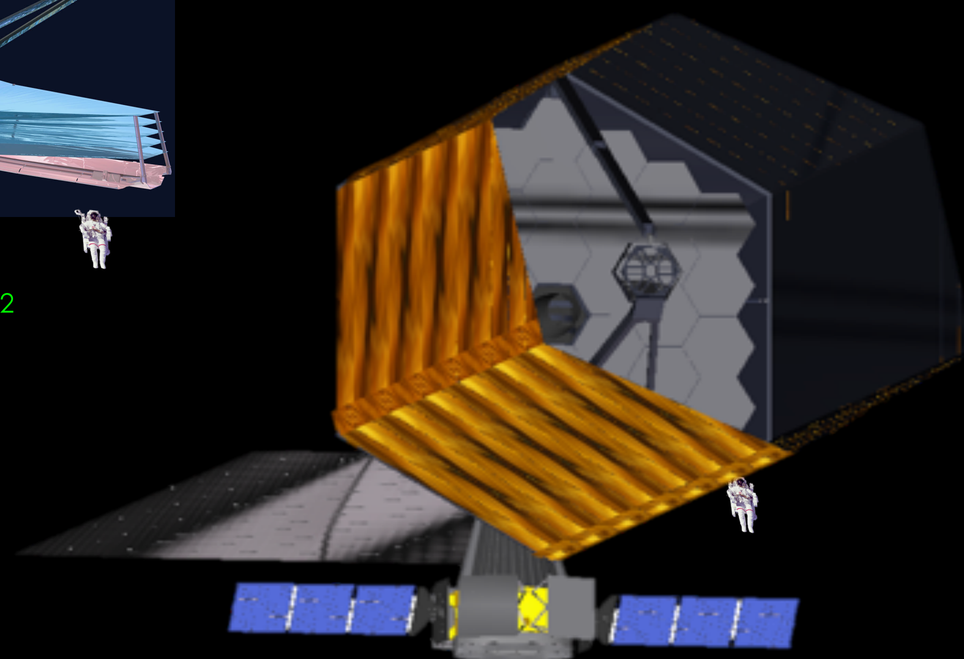
Astronomy beyond 2030

The Search for Life requires larger, lighter space telescopes

2540 kg/m^2

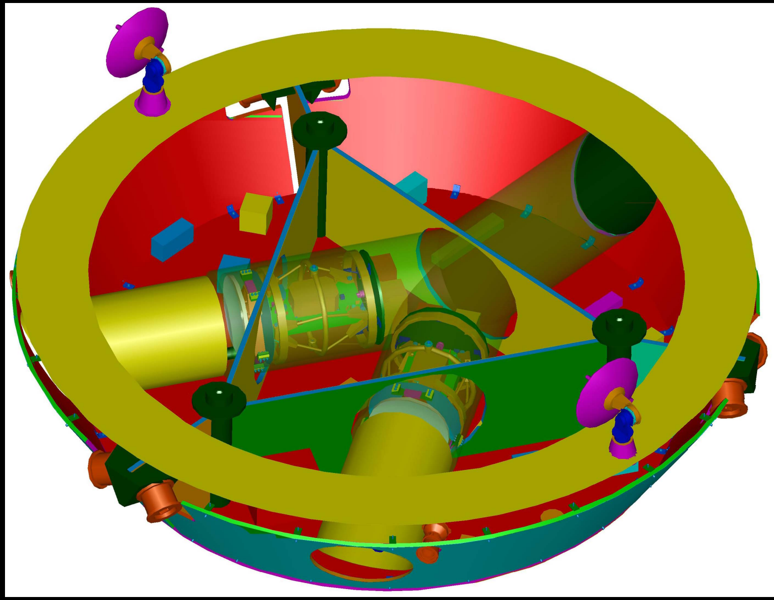


240 kg/m^2



<80 kg/m^2

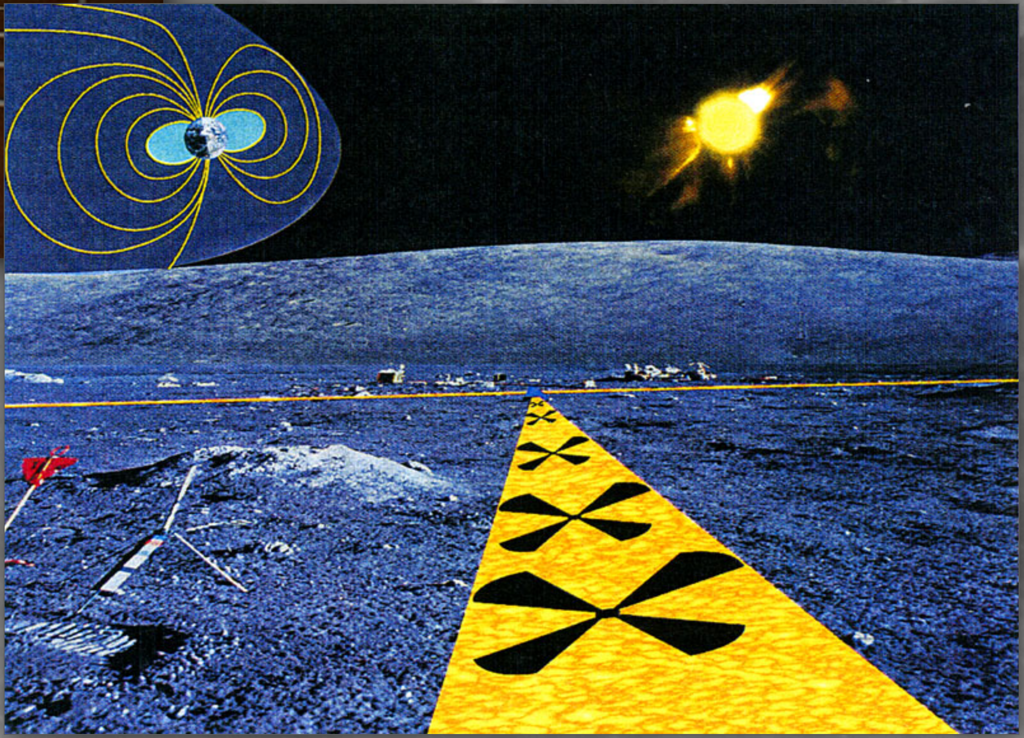
The Laser Interferometer Space Antenna (LISA)



- New branch of astronomy!
- Space-based gravitational wave detector
- 3 spacecraft in 5,000,000 km equilateral triangle
- Laser interferometer senses changes of 1/100 size of an atom

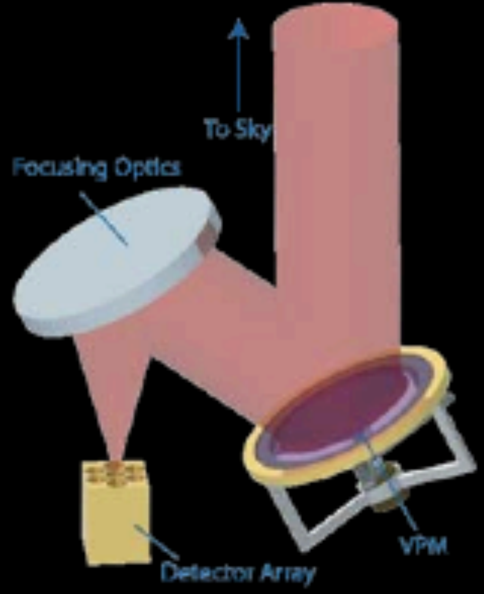
30 – 300 m Wavelength Radio Telescope on Far Side of Moon

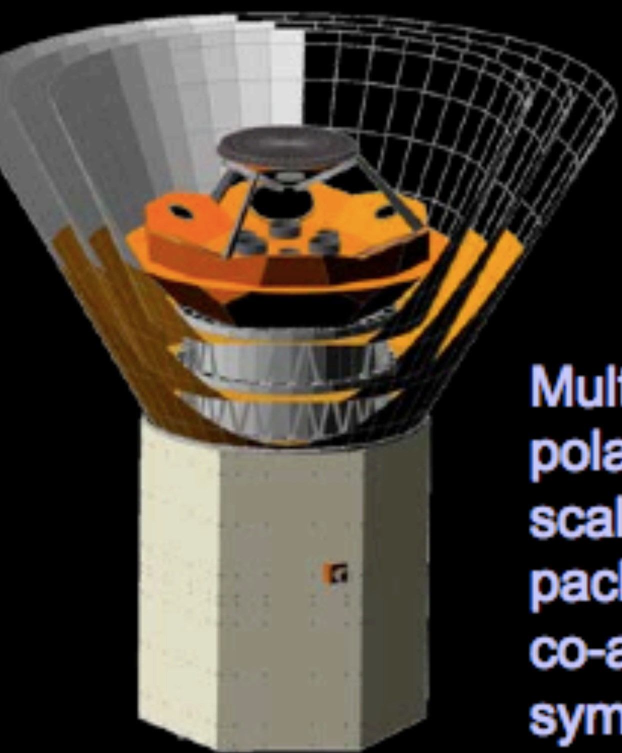
Low frequency radio observations require only lightweight dipoles

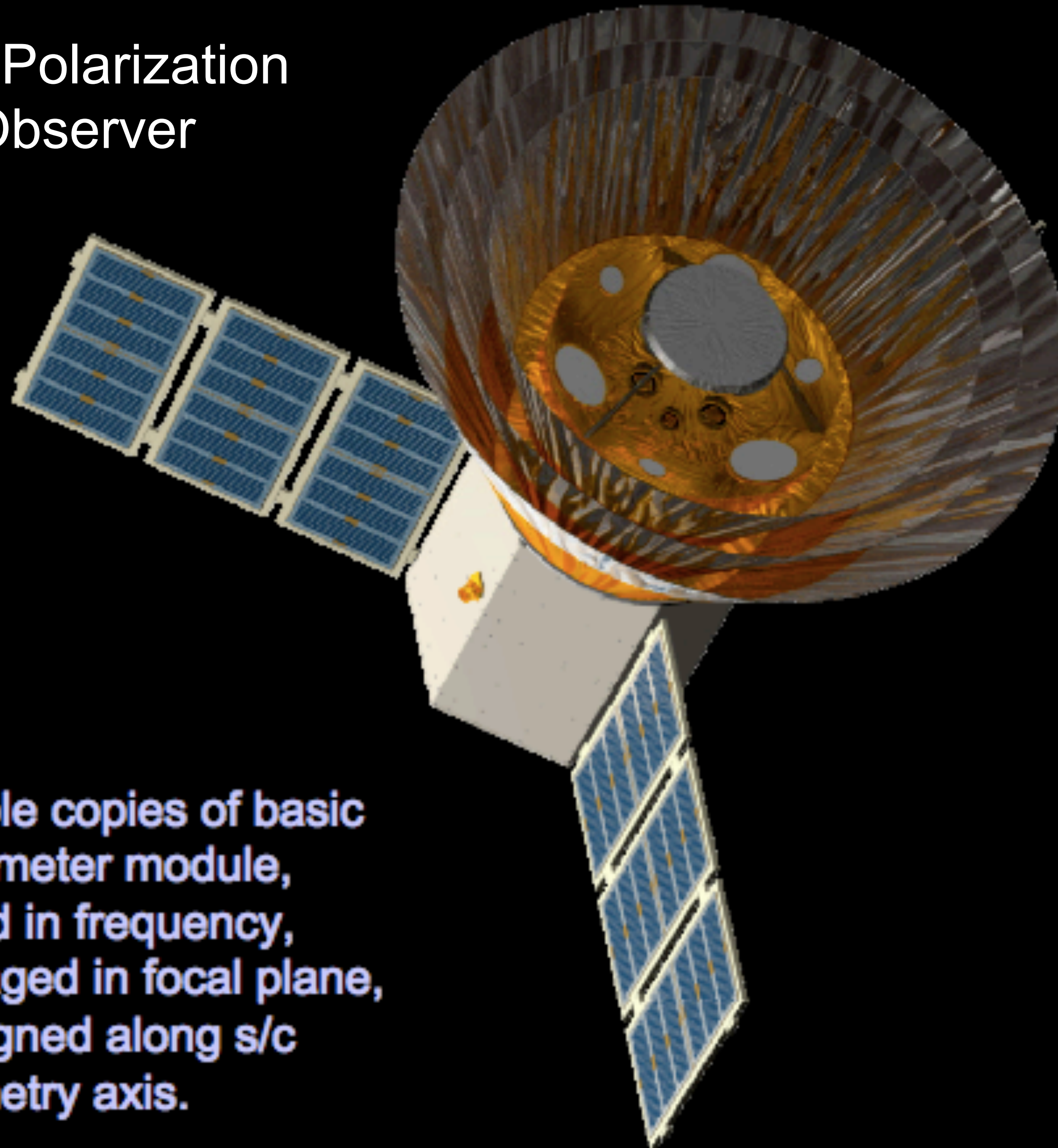


Ionosphere blocks access from Earth surface

CMB Polarization Observer

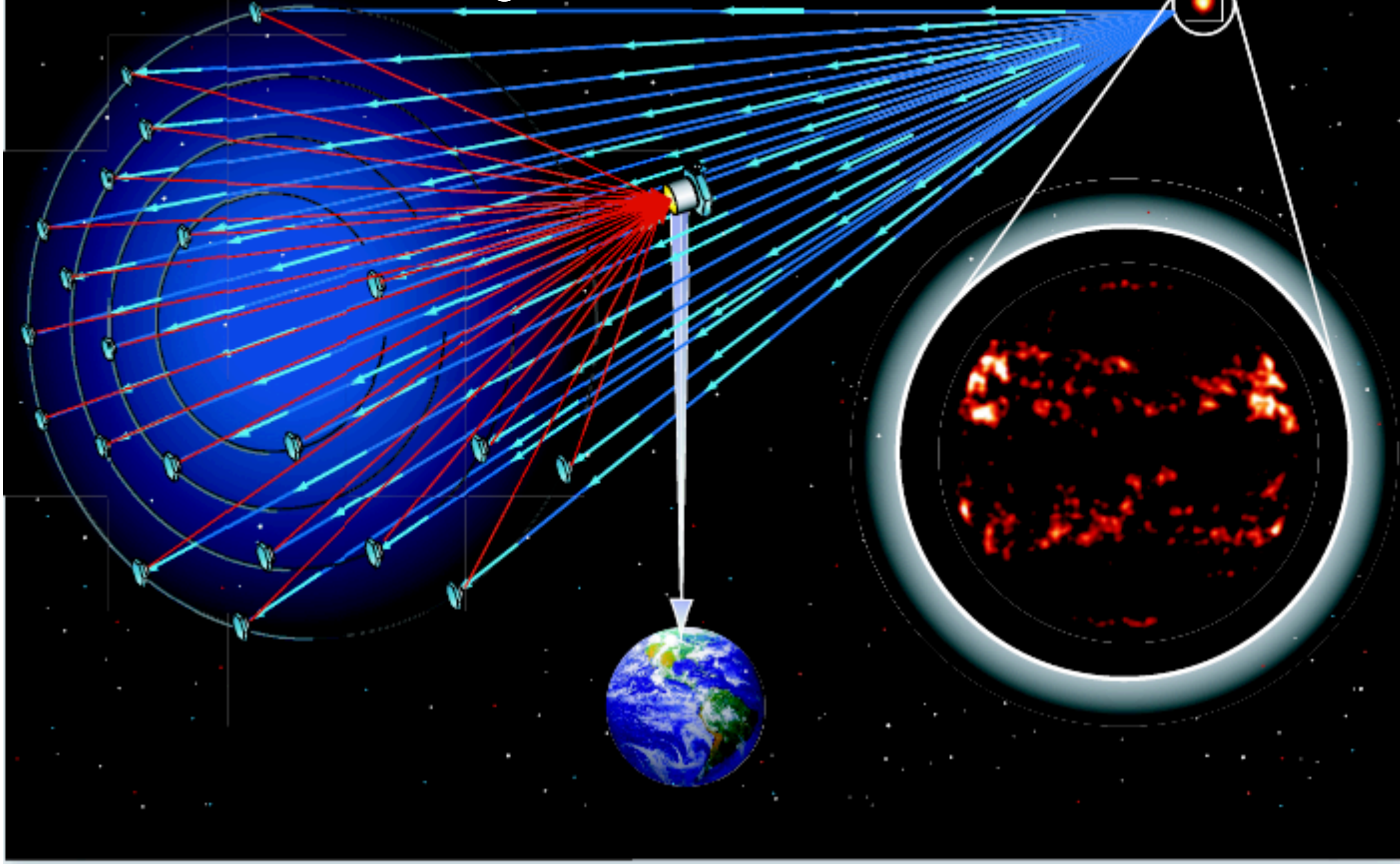






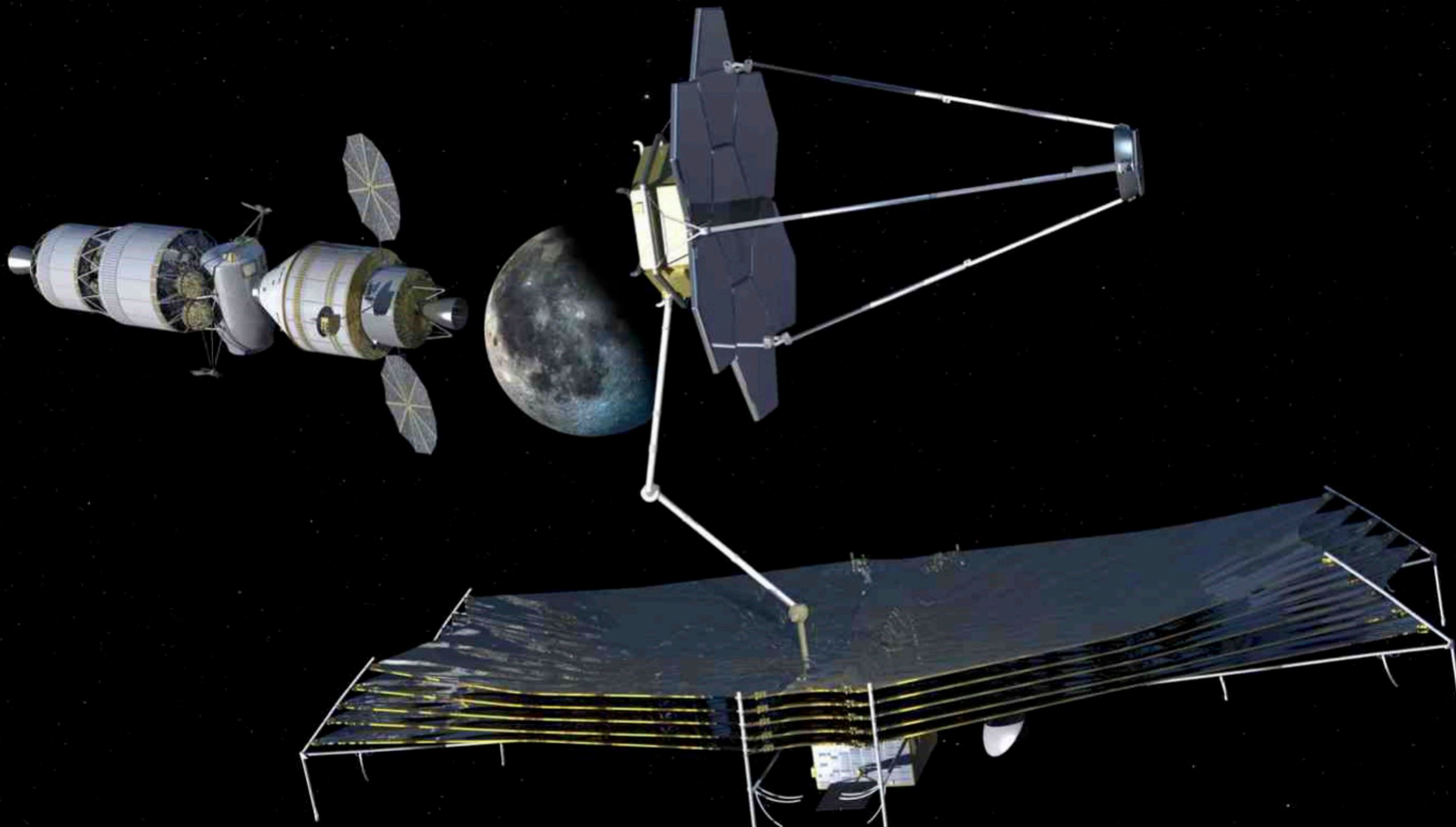
Multiple copies of basic polarimeter module, scaled in frequency, packaged in focal plane, co-aligned along s/c symmetry axis.

Stellar Imager sees Sun-like stars



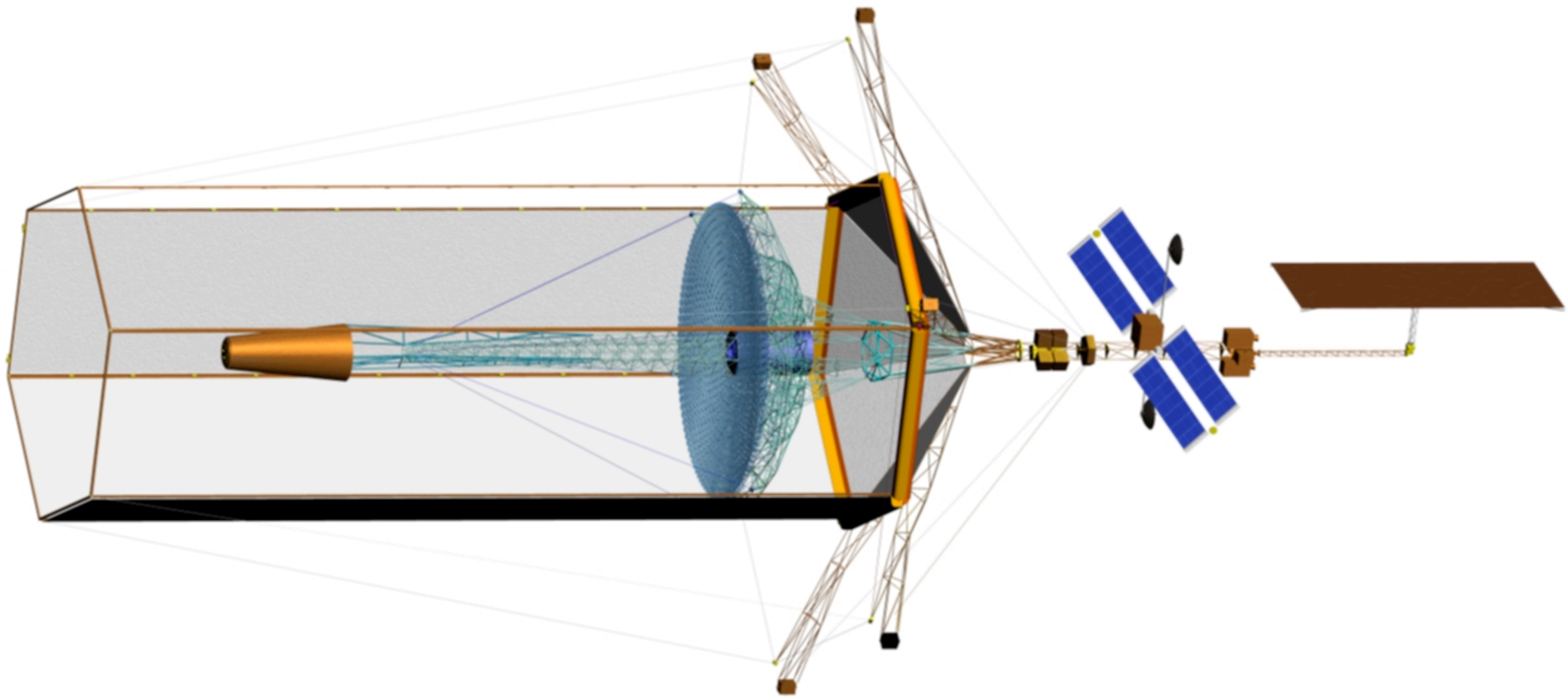
One possible architecture for the SI mission: An array of many (≥20) mirrorsats, each with a meter-class mirror, directing light to a primary hub in which the light beams are combined. A simulated observation is shown in the circle at the right. Alternative architectures utilize a smaller number of mirrorsats that are reconfigured with much greater frequency. The outer diameter of the array must be ~500 meters to enable resolution of the surface features of a typical stellar target.

Servicing at EM L2



Orion/MPCV crew exploration vehicle stack at the Earth-Moon L1 or L2 jobsite preparing for upgrade of mid-2020s observatory, which transferred from its Sun-Earth L2 observing site. Source: H. Thronson and J. Frassanito & Associates (2007)

30 m telescope ideas – Oegerle study



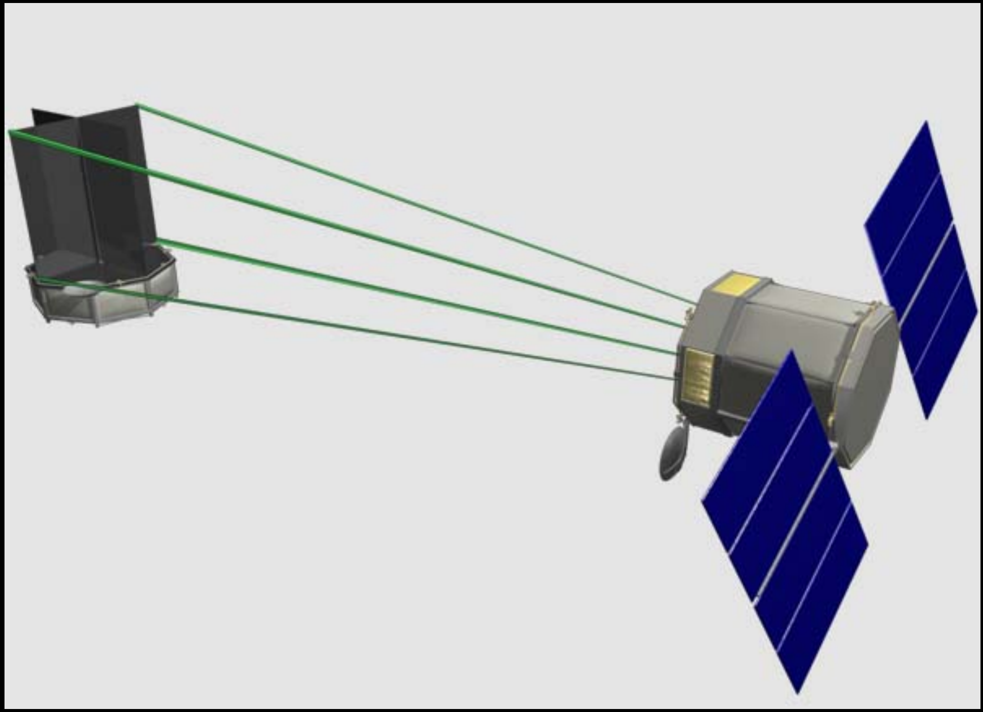
New Worlds Imager

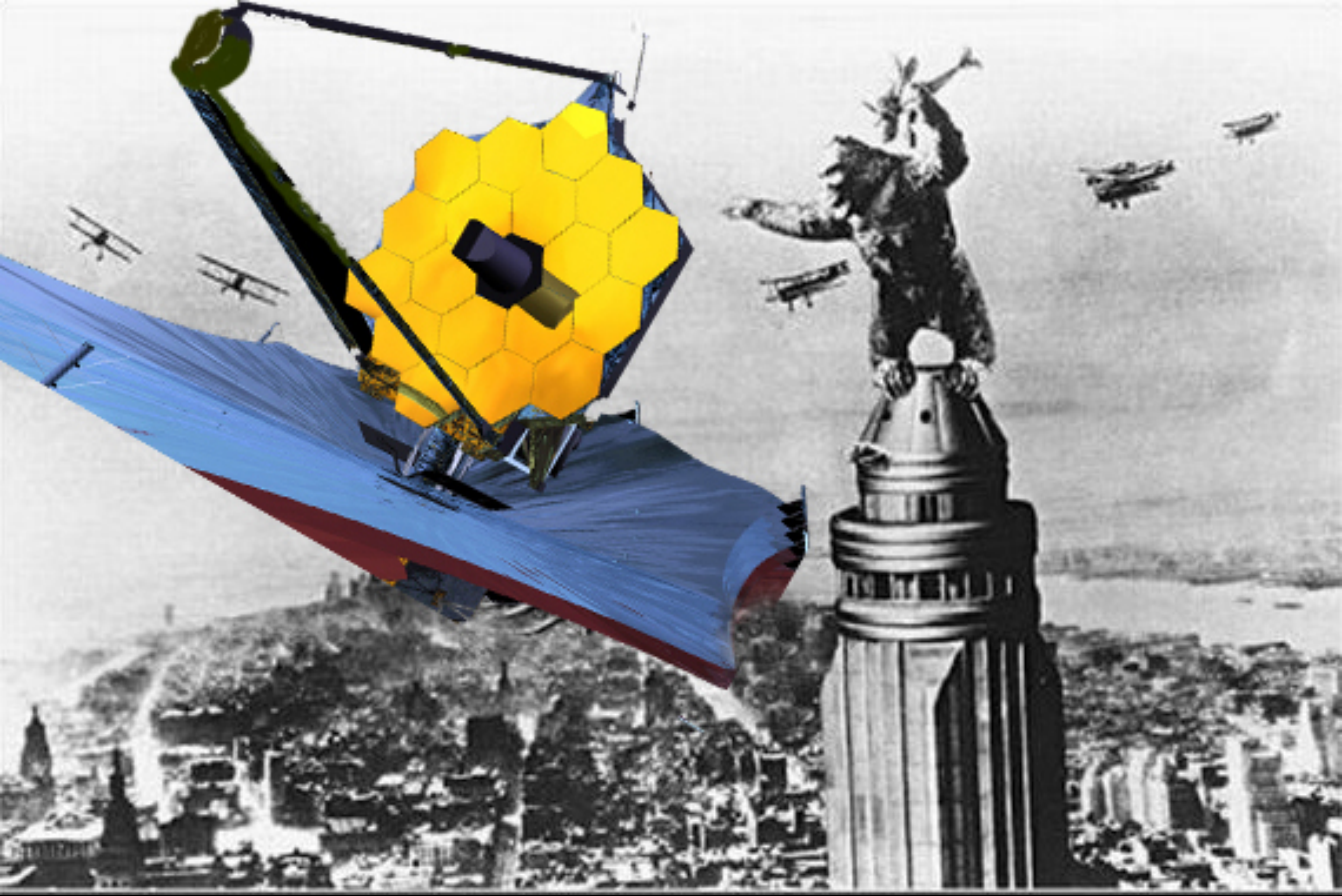
Webster Cash, University of Colorado

Formation Flying Fresnel Telescope

X-ray/Gamma-ray Imaging

- **Diffractive Fresnel optics**
- **Milli-arcsecond resolution → 1 - 100 km spacecraft separation**
- **Micro-arcsecond angular resolution → 10^4 - 10^6 km spacecraft separation**
- **x-ray/gamma-ray band (5 - 1000 keV)**
- **Formation flying of lens-craft and detector-craft**





Why astronomy doesn’t pay for everything

Can this future happen?

- Scientific questions still exciting
  - Beginnings of everything, dark matter, dark energy, and life elsewhere?
- Other people pay for growing infrastructure
  - Electronics, robotics, optics, detectors, space hardware
  - NASA < 10% of worldwide space budget
  - Astronomy < 10% of NASA budget
- YES!