The Crystal Ball: What Discoveries are in Store?

Neil Gehrels Memorial Symposium

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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
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
James Webb Space Telescope (JWST)

**Organization**
- 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

**Description**
- 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)

**JWST Science Themes**
- 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

www.JWST.nasa.gov
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
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!
24 meters (1000 inches) and up!

Giant Magellan 24 m Telescope (GMT)

European Extremely Large 39 m Telescope (E-ELT)

δθ = 3 milliarcsec

Thirty Meter Telescope (TMT)

Flattening the mountain top for E-ELT
Formation Flying Fresnel Telescope
X-ray/Gamma-ray Imaging

- Diffractive Fresnel optics
- Milli-arcsecond resolution $\rightarrow 1 - 100$ km spacecraft separation
- Micro-arcsecond angular resolution $\rightarrow 10^4 - 10^6$ km spacecraft separation
- x-ray/gamma-ray band (5 - 1000 keV)
- Formation flying of lens-craft and detector-craft
And now for something completely different*: Starshade with E-ELT, GMT, TMT
John Mather & Eliad Peretz, GSFC

- $D^4$ advantage: 1 hr with 30 m = 1 yr with 3 m
- All the instrumentation you can imagine
- Extreme AO for visible bands, 0.003” res
- High elliptical orbit to match velocity of observatory; return every 3 sidereal days
- Thrust to match acceleration of telescope
- Refueling for long life
- Can move to deep space any time
- Weekly images of planetary systems

* Monty Python, 1971
Thank you Neil!