How Lonely (or not) is the Universe?  
aka “future IROUV flagship”  
aka Habitable Worlds Observatory

Shawn Domagal-Goldman  
Program Scientist, Great Observatories Maturation Program  

Julie Crooke  
Program Executive, Great Observatories Maturation Program  

Astrophysics Division, NASA Headquarters
Sagan Exoplanet Summer Workshops

The Sagan Exoplanet Summer Workshops are held annually and provide opportunities for students, postdocs, and researchers to learn about the engineering and scientific application of exoplanet-related techniques used in NASA’s Exoplanet Exploration Program.

2023: Characterizing Exoplanet Atmospheres: The Next Twenty Years
2022: Exoplanet Science in the Gaia Era
2021: Circumstellar Disks and Young Planets
2020: Extreme Precision Radial Velocity
2019: Astrobiology for Astronomers
2018: Did I Really Just Find an Exoplanet?
2017: Microlensing in the Era of WFIRST
2016: Is There a Planet in My Data? Statistical Approaches to Finding and Characterizing Planets in Astronomical Data
2015: Exoplanetary System Demographics: Theory and Observations
2014: Imaging Planets and Disks
2013: workshop cancelled due to federal government sequestration
2012: Working with Exoplanet Light Curves
2011: Exploring Exoplanets with Microlensing
2010: Stars as Homes for Habitable Planetary Systems
2009: Exoplanetary Atmospheres
Tilt-a-Worlds: Effects of High Rates of Obliquity Change on the Habitability of Extrasolar Planets

Show affiliations

Domagal-Goldman, Shawn ; Barnes, R. ; Armstrong, J. C. ; Breiner, J. ; Meadows, V. S.

We explore the impact of obliquity variations on planetary habitability in hypothetical systems with high mutual inclination. For the hypothetical systems, we restrict our exploration to systems consisting of a solar-mass star, an Earth-mass planet at 1 AU, and 1 or 2 giant planets. We verify that these systems are stable for $10^8$ years with N-body simulations. We then calculate the obliquity variations induced by the orbital architecture on the Earth-mass planets. We find that in some cases the spin axes can rotate through 360 degrees in as little as 10,000 years (John is that right? Can you look through the systems and find the most extreme case of obliquity variation?)

Next, we run energy balance models (EBM) on the terrestrial planets to assess surface temperature and ice coverage on the planets' oceans. Finally, we explore differences in the outer edge of the habitable zone for planets with rapid obliquity variations. We run EBM simulations for a range of values for the semi-major axis, assuming that the obliquity variations of the nominal system (terrestrial planet at 1 AU) are typical for each orbital architecture. We find that planets undergoing extreme axial perturbations may be habitable at larger distances than those with static
We are here.

\[ N = R_\star \times f_p \times n_e \times f_e \times f_i \times f_c \times L \]

- **N**: The number of technologically advanced civilizations in the Milky Way galaxy
- **R_\star**: The rate of formation of stars in the galaxy
- **f_p**: The fraction of those stars with planetary systems
- **n_e**: The number of planets, per solar system, with an environment suitable for life
- **f_e**: The fraction of habitable planets on which life actually appears
- **f_i**: The fraction of life-bearing planets on which intelligent life emerges
- **f_c**: The fraction of civilizations that develop a technology that releases detectable signals of their existence into space
- **L**: The length of time such civilizations release detectable signals into space

\[ A = N_{ast} \times f_{bt} \]

- **A**: The number of technological species that have formed over the history of the observable universe
- **N_{ast}**: The number of habitable planets in a given volume of the universe
- **f_{bt}**: The likelihood of a technological species arising on one of these planets
HWO takes us here.

\[ N = R_p \times f_p \times n_e \times f_e \times f_i \times f_c \times L \]

- \( N_{ast} \) = \( A \times f_{bt} \)
  - \( A \) = Number of technological species that have formed over the history of the observable universe
  - \( N_{ast} \) = Number of habitable planets in a given volume of the universe
  - \( f_{bt} \) = Likelihood of a technological species arising on one of these planets
Simulated Spectra

Planet star flux ratio \times 10^{-10}

Wavelength [\mu m]
Earth is more than one planet

Earth’s atmospheric composition through time
Earth is more than one planet
EARTH IS MORE THAN ONE PLANET
BIOSIGNATURES NEED CONTEXT

False positive?
True biosignature?
BIOSIGNATURES DEPEND ON CONTEXT...

Modern Sun

Proxima Centauri
... AND HWO CAN OBTAIN THAT CONTEXT!
HWO will need to give us the needed context

UV instrument
100-1000 nm spectra

enabled by

stellar spectrum
(especially UV)
HWO will explore planets holistically, in the context of the other planets in their system and of their host star.
HWO will continue the chemical characterization of transiting worlds, extending the wavelength range of JWST and other facilities.
**HABITABLE ENVIRONMENTS? SOLAR SYSTEM OCEAN MOONS**

Europa in far-UV Lyman-α emission

HWO can *monitor cryovolcanic activity* from the Solar System’s ocean worlds at high resolution

Roth et al. (2014)

Input model: G. Ballester
PROBING THE PROPERTIES OF DARK MATTER WITH DWARF GALAXIES

Hubble

HWO Simulated Image
A variety of documents from internal, external, and oversight groups all point to a consistent set of problems & solutions for large/flagship projects, across sectors.
Which decadal science questions can HWO help address?

What observations do we need to answer those questions?

What capabilities will deliver those observations?

What performance can we expect?

Where do performance breakpoints exist?

What models do we need to predict performance?
What architecture trades remain?
How are those trades related/coupled to each other?
Which trades are the most important to study now?
What are the technologies associated with those trades?
What cost/schedule risks exist for those trades?
How might those risks be mitigated?
How can external partners be involved?
Community Participation

Multi-generational approach to a multi-generation mission

Training/development/mentorship programs throughout lifecycle

Diversification of the HWO community

“Badgeless” culture that places expertise over institution

Safe and just team culture

Team culture that adapts to a changing culture

Changing leadership over time

Compensation for people’s work
HWO Early Career Initiatives

START/TAG members will be allowed to include their institution/research group members in technical work related to the START

We will create an HWO mentorship program, focused on early career members from institutions not represented on the START

Creation of an HWO Early Career Community/Council for discussions within the HWO early career community, and for feedback on HWO culture from that community

We will have a workshop (date/location very TBD) to discuss plans for HWO workforce development. Will include "primers" on HWO science/technology, networking/job fair to connect early career members to HWO-relevant institutions, and presentations and discussion on ideas for a welcoming, just, safe, and inclusive culture for HWO.
How do we get involved?

What is TAG?

How big is it?

How much of it is luvoir or habex?

Is the telescope actually a real thing?

What still needs to happen to make it a real thing?

What is START?

What’s the timeline?
Questions and more information

NASA Astrophysics Statement of Principles:
go.nasa.gov/3Kwn07s

NASA GOMAP website:
go.nasa.gov/4107ZzC

julie.a.crooke@nasa.gov
shawn.goldman@nasa.gov
The Habitable Worlds Observatory: Big Picture Strategy

• **Build to schedule**: Mission Level 1 Requirement - like planetary

• **Evolve technology from what we have done before**:  
  - Build upon current NASA investments and TRL-9 technology  
  - Segmented optical telescope system from JWST  
  - Coronagraph from Roman’s coronagraphic imager program

• **Next Generation Rockets**:  
  - Larger telescope aperture sizes  
  - Leverage opportunities for mass & volume trades

• **Planned Servicing**: Robotic servicing at L2

• **Robust Margins**: Large scientific, technical, and programmatic margins

• **Mature technologies first**: Reduce risk by fully maturing the technologies prior to development phase.
DESIGN DRIVER – CONTRAST STABILITY FOR EXOEARTHS

Corresponds to wavefront stability of “10 pm per 10 minutes”

How do we enable that level of ultra-stability?

Through design

Through control

Through tolerance
ULTRA-STABILITY THROUGH DESIGN

Lightweight ULE mirror segment

Picometer-scale dynamics measured with high-speed interferometry
ULTRA-STABILITY THROUGH CONTROL

Sub-milli-Kelvin thermal control

Measurement of 5 pm resolution piezo actuator at 1 Hz

Credit: SAO / NASA GSFC

Credit: Lockheed Martin

Vibration-isolation and precision pointing system

Credit: NASA GSFC
ULTRA-STABILITY THROUGH TOLERANCE

Contrast Sensitivity to Wavefront Errors

LUVOIR-A APLC Global aberrations

LUVOIR-A APLC Segment Phasing errors

Credit: Juanola-Parramon / NASA GSFC
ULTRA-STABILITY THROUGH TOLERANCE

Post-processing Extraction of Exoplanet Image

Credit: Pogorelyuk / Princeton University
Ultra-stability through control

Dynamic Disturbances
- 6x10^{-6} Hz (48 hrs)
- 10^{-3} Hz (17 min)
- 10^{-2} Hz (100 s)
- 10^{-1} Hz (10 s)
- 1 Hz (1 s)
- 10 Hz (0.1 s)
- 100 Hz (0.01 s)
- 1000 Hz (0.001 s)

Thermal Disturbances
- Speckle Control
- Low-Order / Out-of-band WFS
- Active Thermal Control
- Segment Active Control
- Secondary Mirror Alignment Control

Passive Isolation
Active Isolation

See “Ultra-stable Telescope Research and Analysis (ULTRA) Program Phase 1 Report”, Ball Aerospace, L3/Harris, Northrop Grumman, SGT, Space Telescope Science Institute
Ultra-stability through control

Active control relaxes stability requirements and provides an easier path to verification

See “Ultra-stable Telescope Research and Analysis (ULTRA) Program Phase 1 Report”, Ball Aerospace, L3/Harris, Northrop Grumman, SGT, Space Telescope Science Institute