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California Institute of Technology
Pasadena, California

Technology Development for Exoplanet Direct Imaging Missions

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AIAA Space 2014
Session “Astronomy from Space 30 Years in the Future”

San Diego, CA
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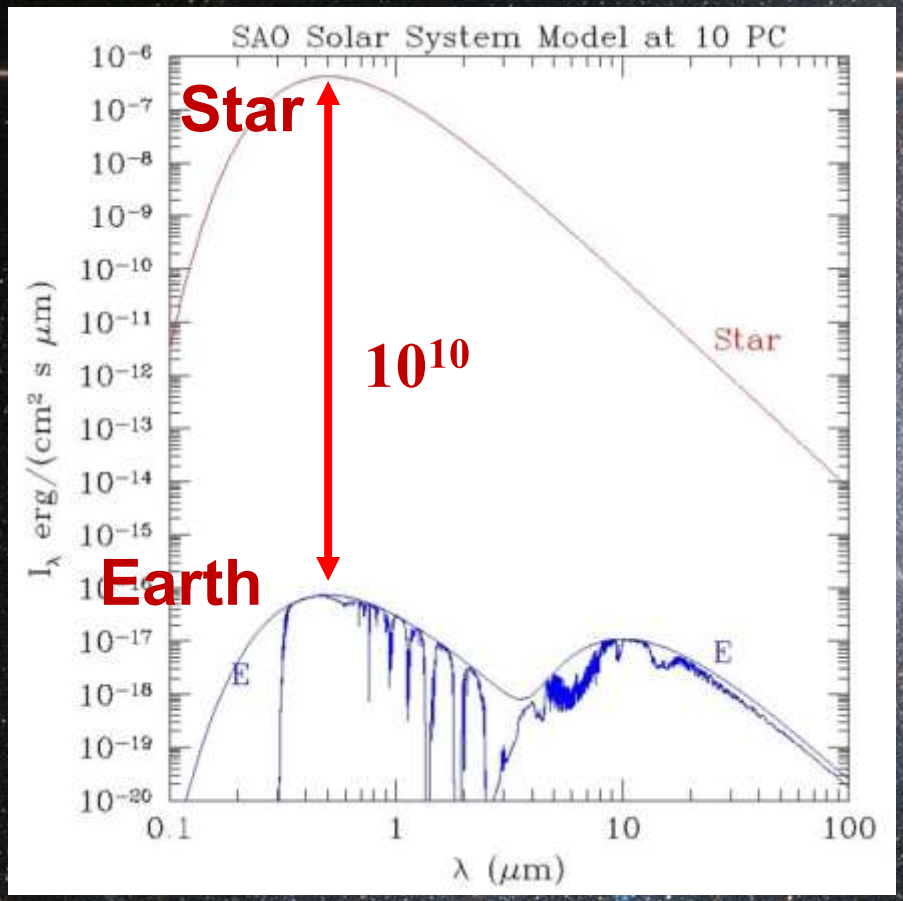
Looking Back Nearly 30 years…to 1990

Are we Alone?
The Search for Other Earths,
The Search for Life in the Universe

The Challenge



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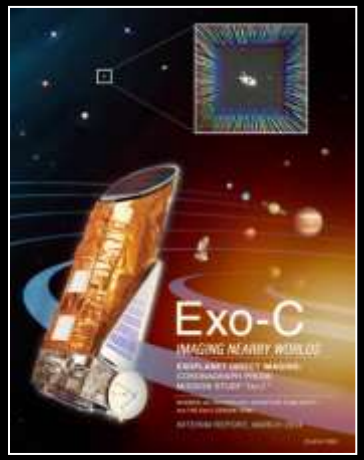
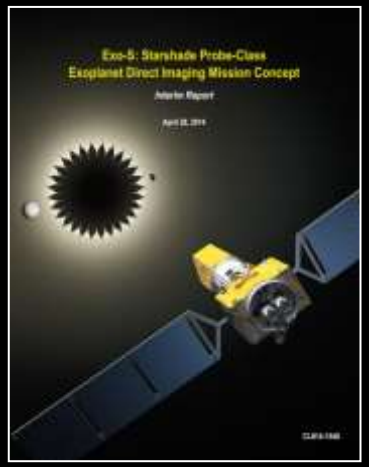
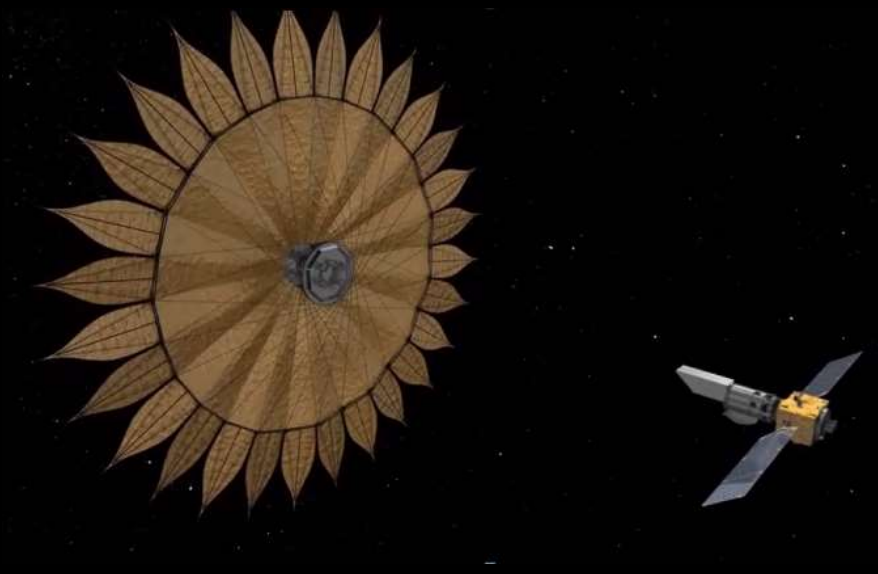
Starlight Suppression for High-Contrast Imaging

ExoPlanet Exploration Program

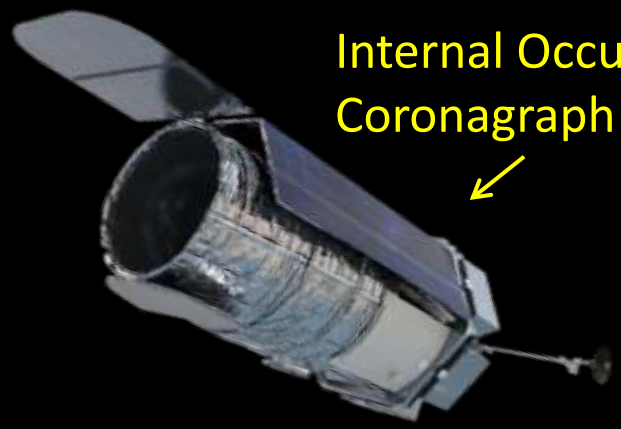




External Occulter - Starshade



Internal Occulter – Coronagraph



http://exep.jpl.nasa.gov

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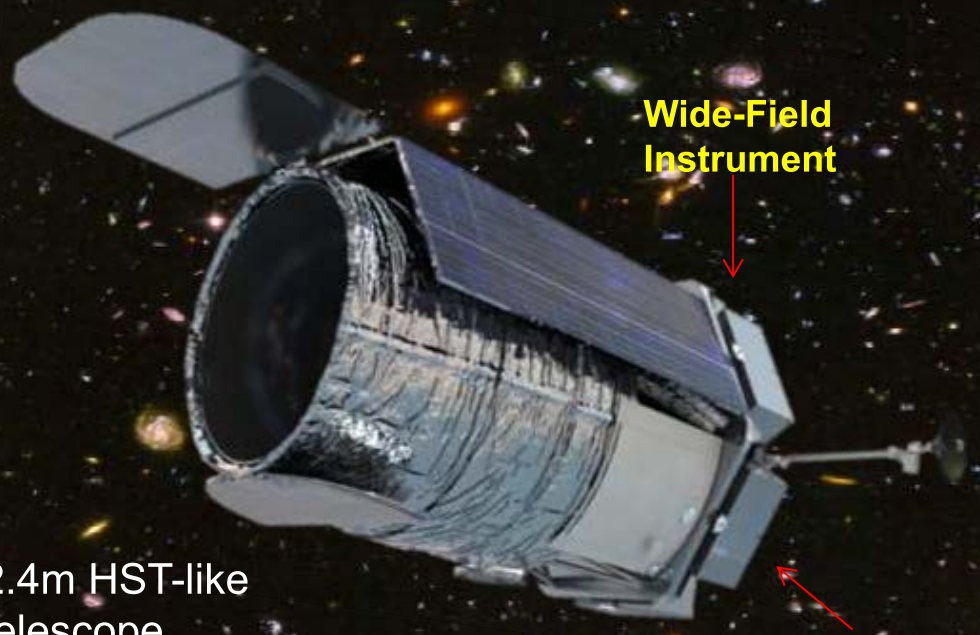
WFIRST-AFTA

Wide-Field Infrared Survey Telescope (WFIRST)
Astrophysics Focused Telescope Assets (AFTA)

ExEP
ExoPlanet Exploration Program



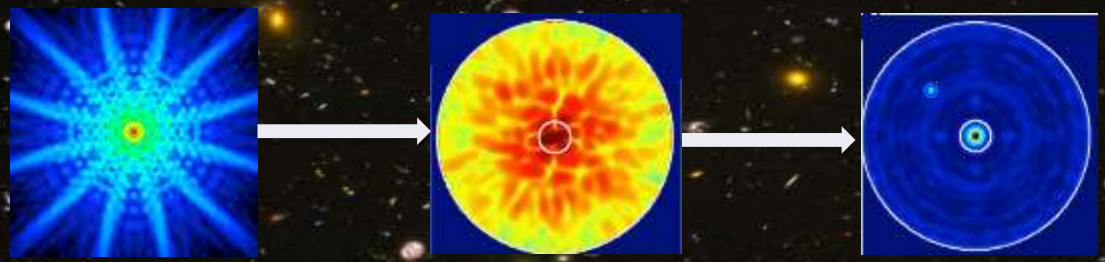
2.4m HST-like telescope

Coronagraph Instrument

- Imaging and spectra channels
- 0.4 – 1 μm bandpass
- ≤ 10^{-9} detection contrast
- 100 mas inner working angle at 0.4 μm
- R ~ 70

Coronagraph Science

- Imaging and spectroscopy of exoplanet atmospheres down to a few Earth masses
- Study populations of debris disks



AFTA's coronagraph will develop the technologies for a future exo-Earth mission

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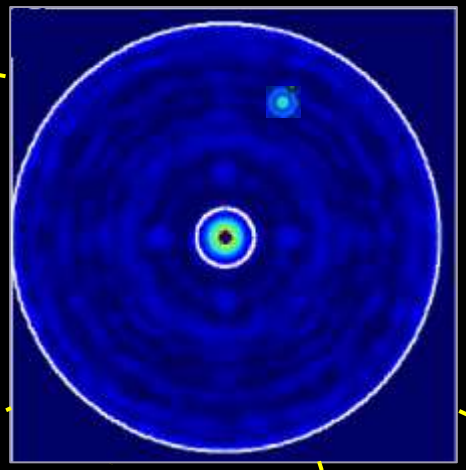
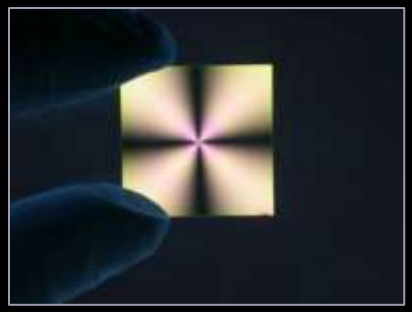
Technology Development for Coronagraphs (Internal Occulters)

ExoPlanet Exploration Program



Occulting Masks/ Apodizers

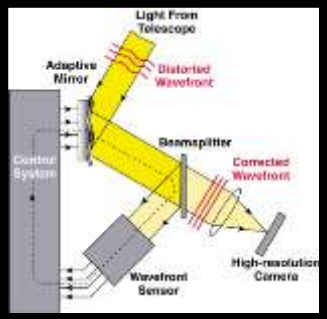


Serabyn – Vector Vortex Mask

System Demonstration

Jet Propulsion Laboratory

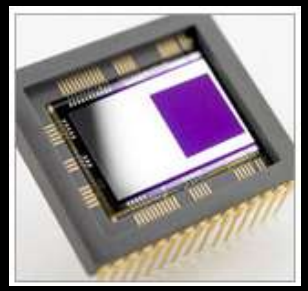
Low Order Wavefront Sensing and Control



Deformable Mirrors

Xinetics

Ultra-Low-Noise Visible Detectors



e2v Electron Multiplying CCD

Image Post Processing

Soummer et al. 2011

The External Occulter – the Starshade

The starshade could launch together with a telescope. Once in space, it would split off and move into position to block the starlight.

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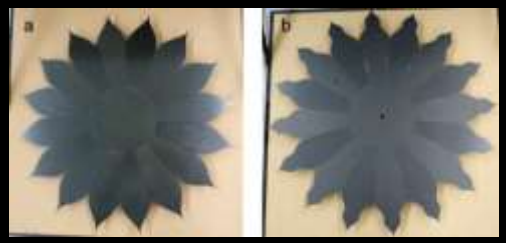
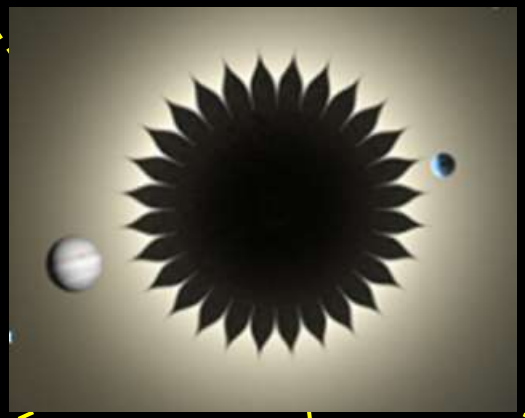
Technology Development for Starshades (External Occulters)

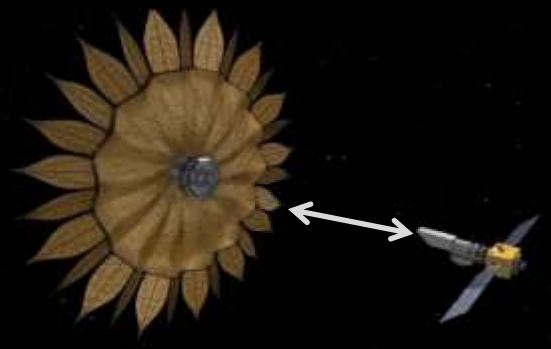
ExoPlanet Exploration Program

Control of Scattered Light





Formation Flying



Validation of Optical Models

NGAS

Starshade Deployment

NGAS, Princeton, JPL

Petal Prototype

Princeton, JPL

Deployment Testing at Northrop Grumman (Astro-Aerospace)

Demonstration of starshade development model

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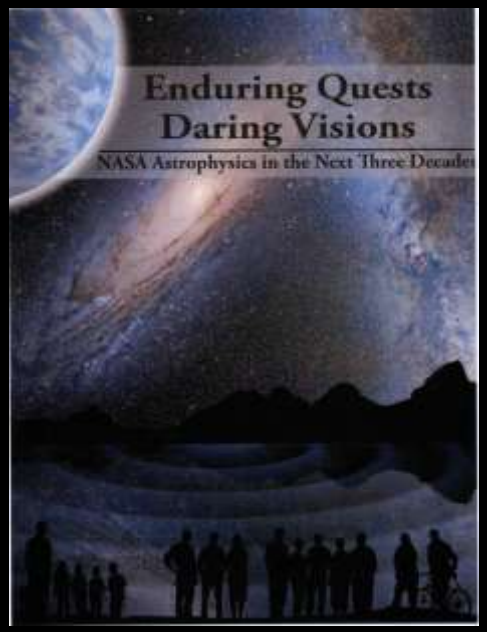
Formative Era: Large UV-Optical-IR Telescope

ExoPlanet Exploration Program



	LUVOIR Surveyor
Formation flying	
Interferometry: precision metrology	
X-ray interferometry	
High-contrast imaging techniques	
Optics deployment and assembly	
Broadband coatings	
X-ray optics	
Large-format detector arrays	
New detector capabilities	
Cryogenics	

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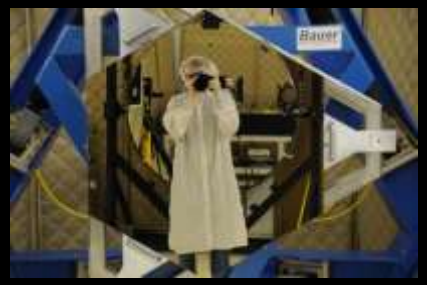
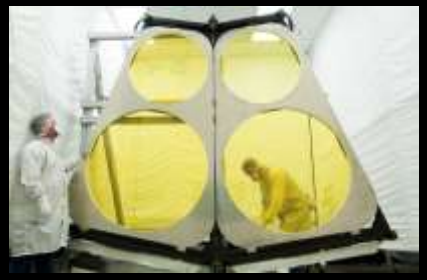
Formative Era: Large UV-Optical-IR Telescope (LUVOIR)

ExoPlanet Exploration Program

Optics Deployment and Assy

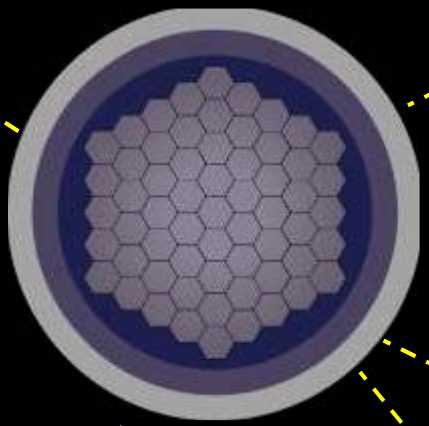


SiC Active Hybrid Mirror, Xinetics

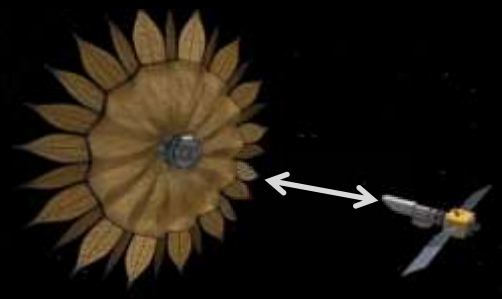


MOIRE, BATC

Lightweight ULE, ITT



Formation Flying



Broadband Mirror Coatings

Telescope Mechanical Isolation Systems

Starlight Suppression Systems

Visible Nuller, GSFC

Pupil Mapping, Univ. Arizona

Starshade
NGAS, Princeton, JPL

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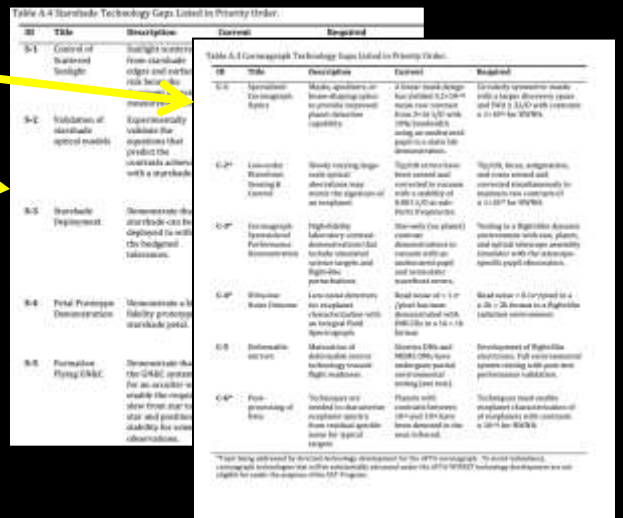
Technology Needs and Priorities

- You are invited to read more about
  - Quantified technology gaps (needs, capabilities)
  - Past and current work conducted through SAT / ROSES / TDEM

    http://exep.jpl.nasa.gov

- Next call: November 2014

Science Goal	Capability	Needed Technologies	Technology Gaps
Detection of life	Spectroscopy of light from direct exo-planet imaging	starlight suppression (internal and external occulters)	Coronagraph Technology Gap List Starshade Technology Gap List



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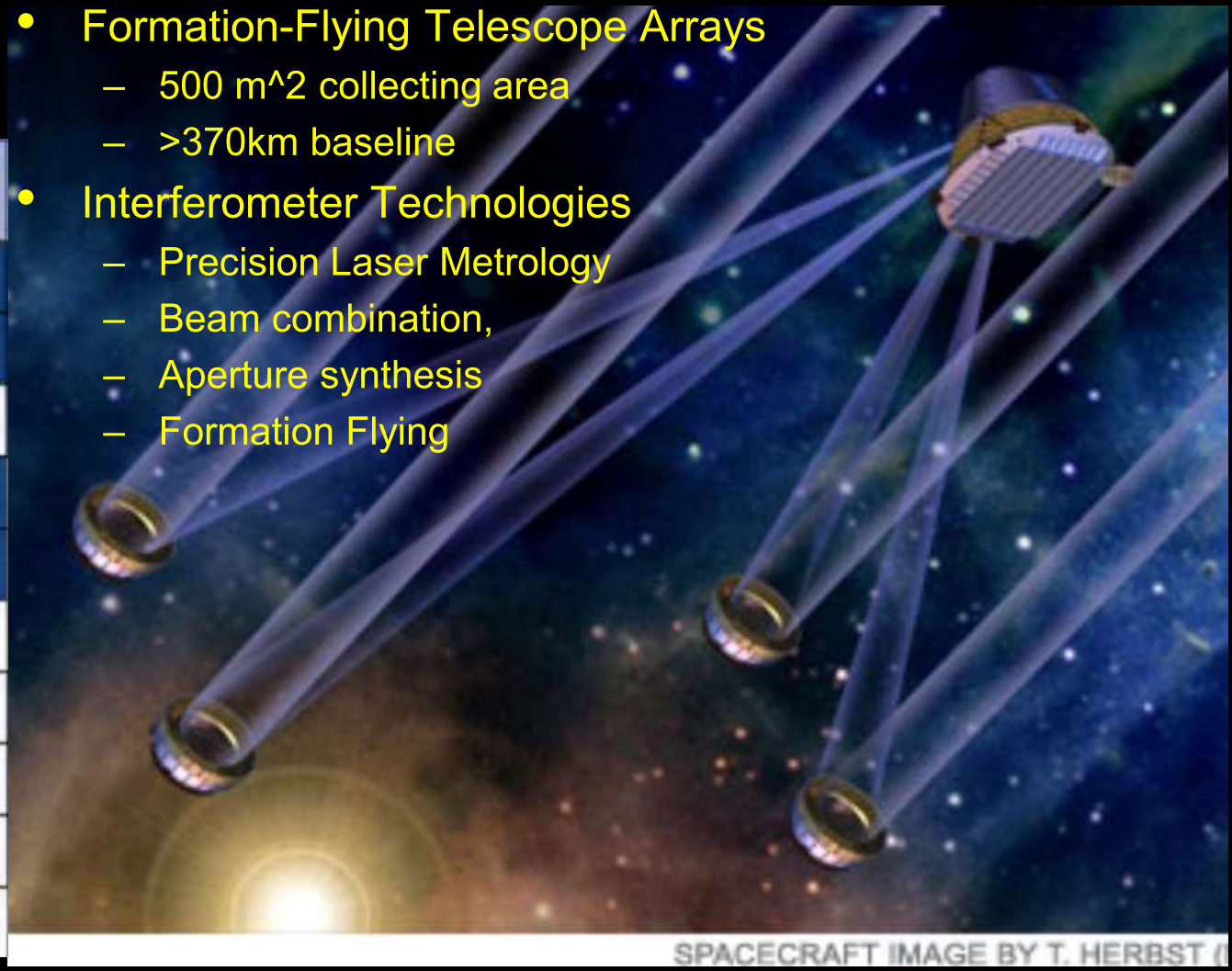
Visionary Era: Exo Earth Mapper

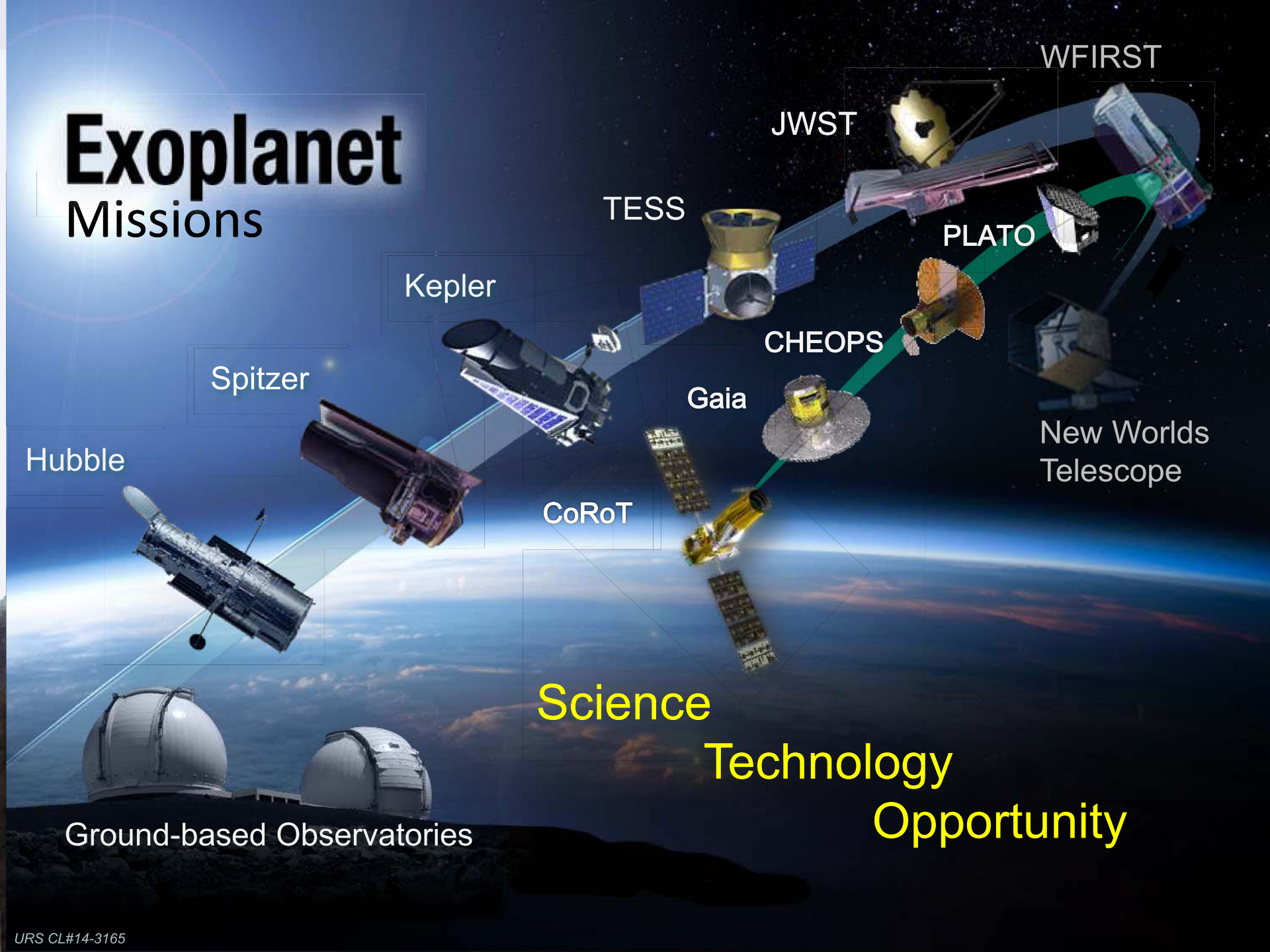
ExEP
ExoPlanet Exploration Program

Exo-Earth Mapper

	LUVOIR Surveyor	ExoEarth Mapper
Formation flying		
Interferometry: precision metrology		
X-ray interferometry		
High-contrast imaging techniques		
Optics deployment and assembly		
Broadband coatings		
X-ray optics		
Large-format detector arrays		
New detector capabilities		
Cryogenics		

- Formation-Flying Telescope Arrays
  - 500 m^2 collecting area
  - >370km baseline
- Interferometer Technologies
  - Precision Laser Metrology
  - Beam combination,
  - Aperture synthesis
  - Formation Flying





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Acknowledgements

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