EXCEDE *Technology Development and Maturation Program*

Studying the formation, evolution, and architectures of exoplanetary systems, and characterizing circumstellar environments into habitable zones.

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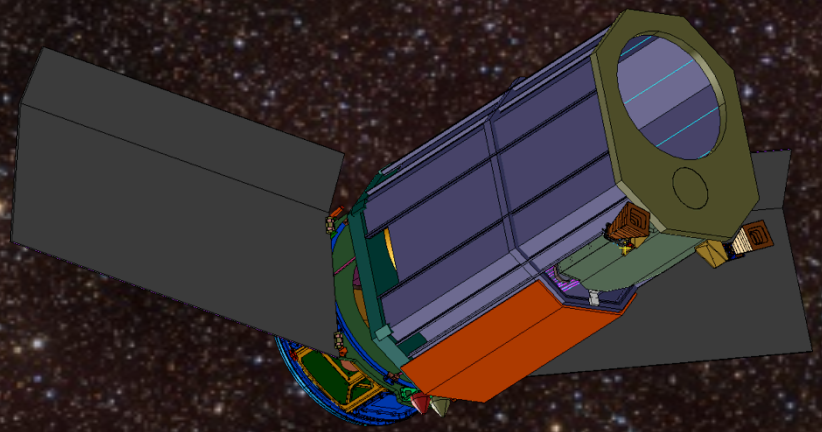


Selected by NASA's EXPLORER
Program Office as a "Category 3" Investigation
Funded for Technology Development and Maturation

KEY PARTICIPATING INSTITUTIONS

Academic
The University of Arizona
Eureka Scientific
Space Telescope Science Institute
University of California, Berkeley
Carnegie Institute of Washington
Cambridge University

NASA Centers
NASA/Ames Research Center
NASA/Goddard Space Flight Center

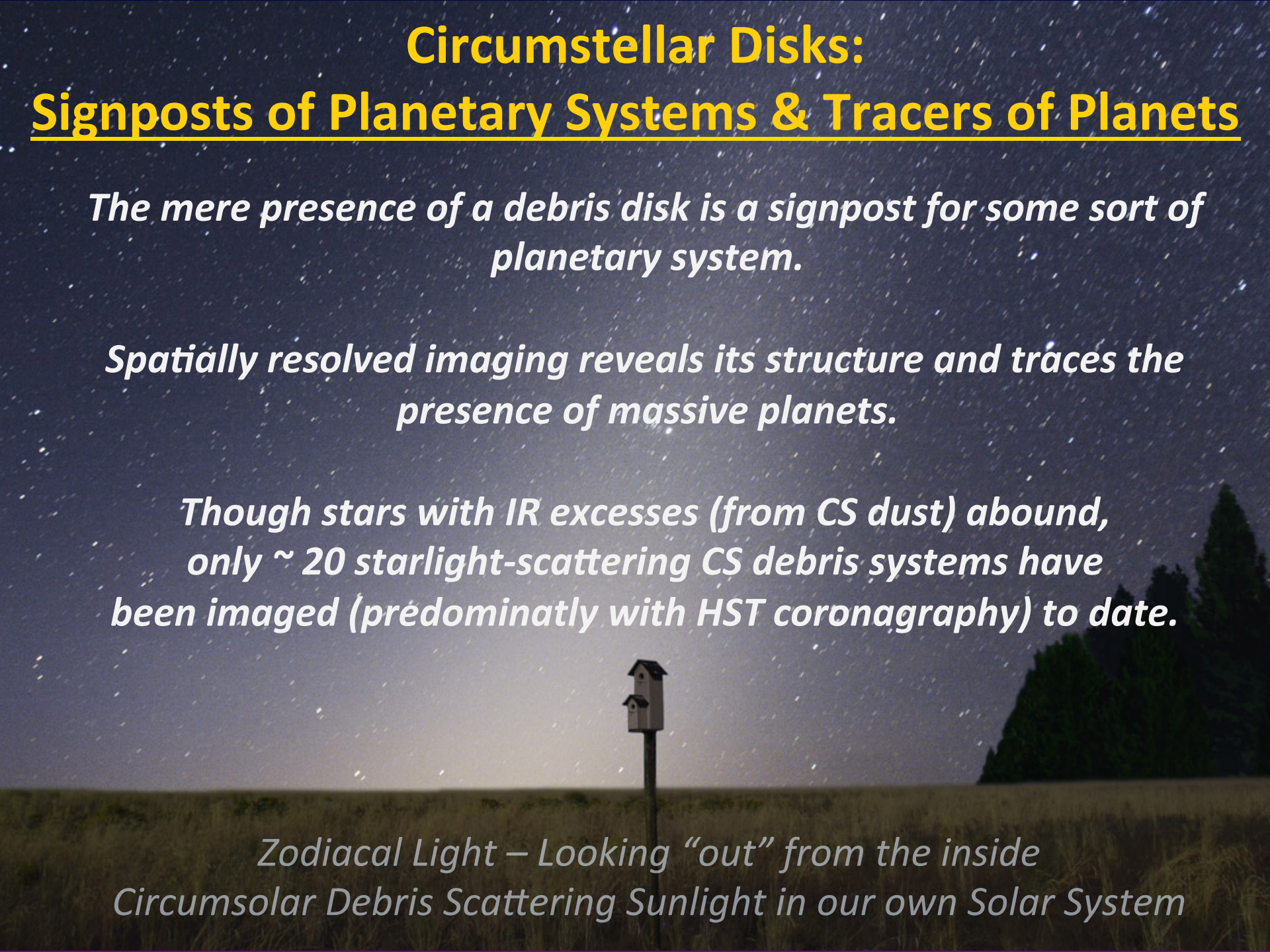
Industry
Lockheed-Martin Space Systems
ITT Corp.
Boston Micromachines Corp.
Broad Reach Engineering Co.

Circumstellar Disks:
Signposts of Planetary Systems & Tracers of Planets

The mere presence of a debris disk is a signpost for some sort of planetary system.

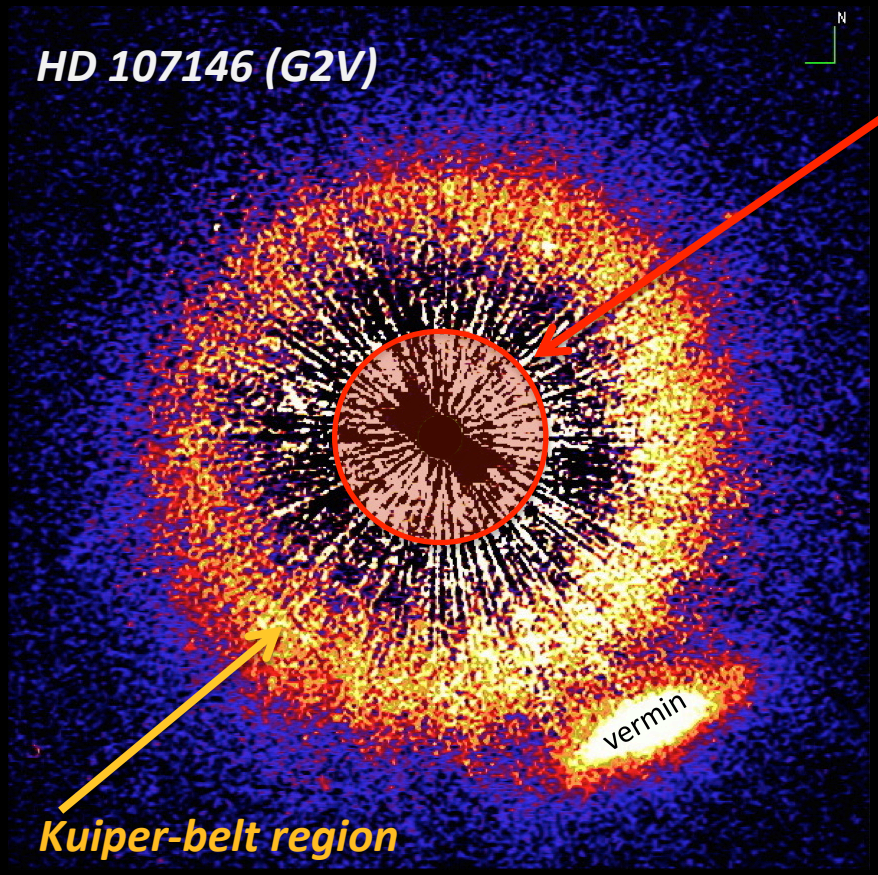
Spatially resolved imaging reveals its structure and traces the presence of massive planets.

Though stars with IR excesses (from CS dust) abound, only ~ 20 starlight-scattering CS debris systems have been imaged (predominatly with HST coronagraphy) to date.

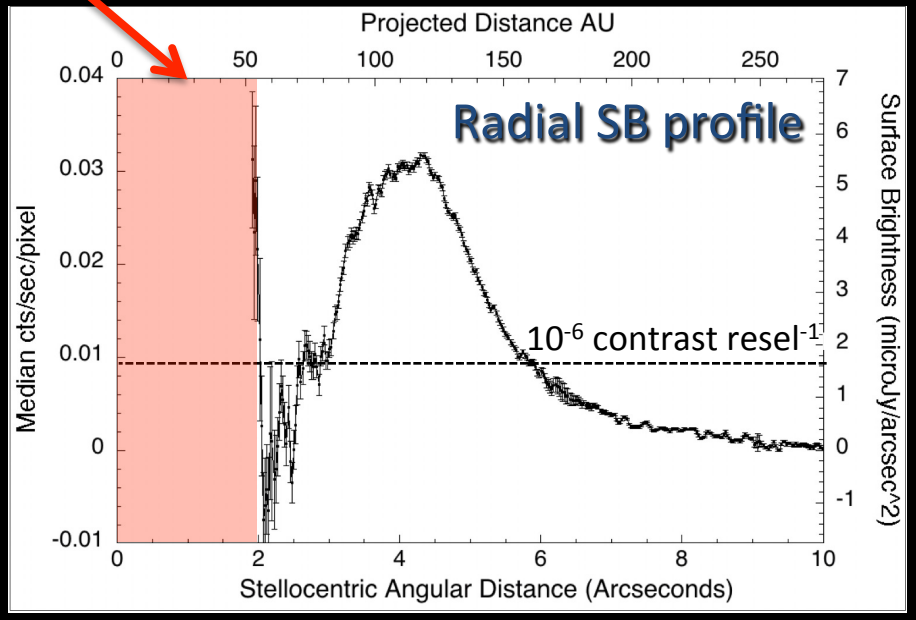


Zodiacal Light – Looking "out" from the inside
Circumsolar Debris Scattering Sunlight in our own Solar System

State-of-the-Art Space Coronagraphy Today (HST)



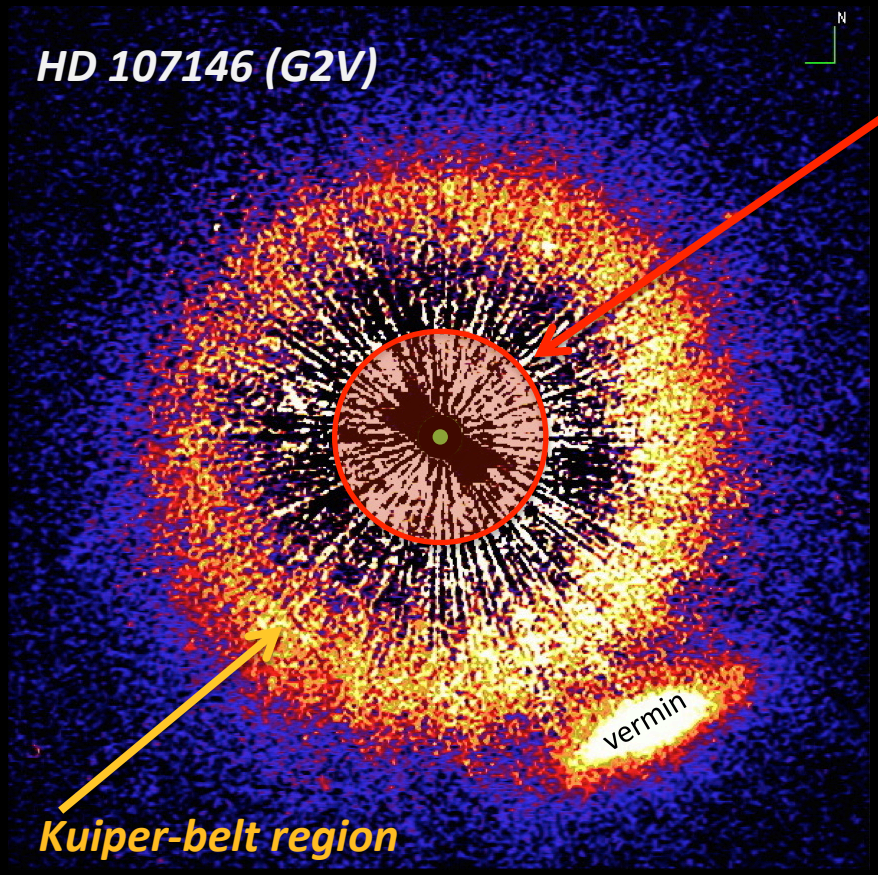
HERE (≤ 55 AU) BE DRAGONS!



Schneider et al. 2013: AAS Session 104.05

Looking "in" from the outside
Circumstellar Debris Scattering Starlight in the HD 107146 System

State-of-the-Art Space Coronagraphy Today (HST)



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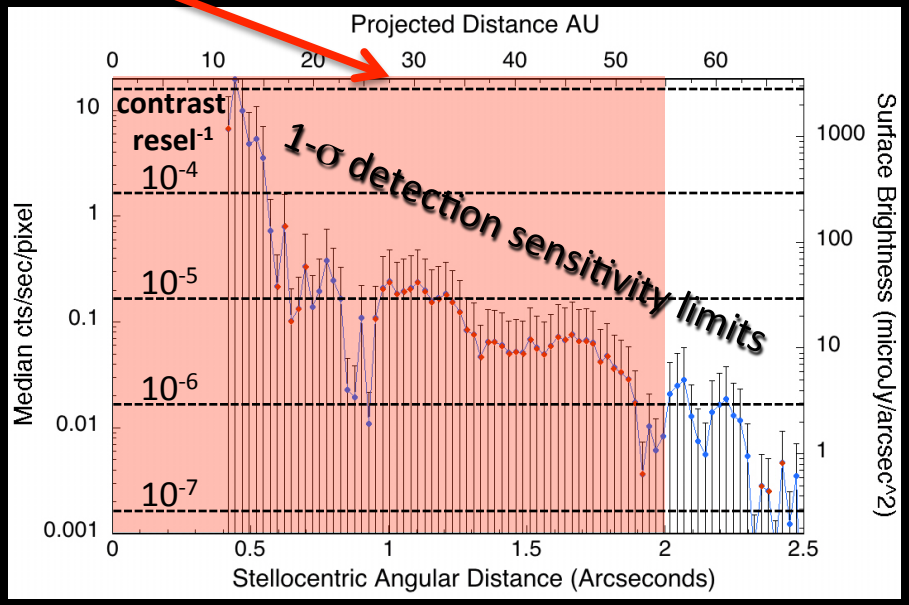
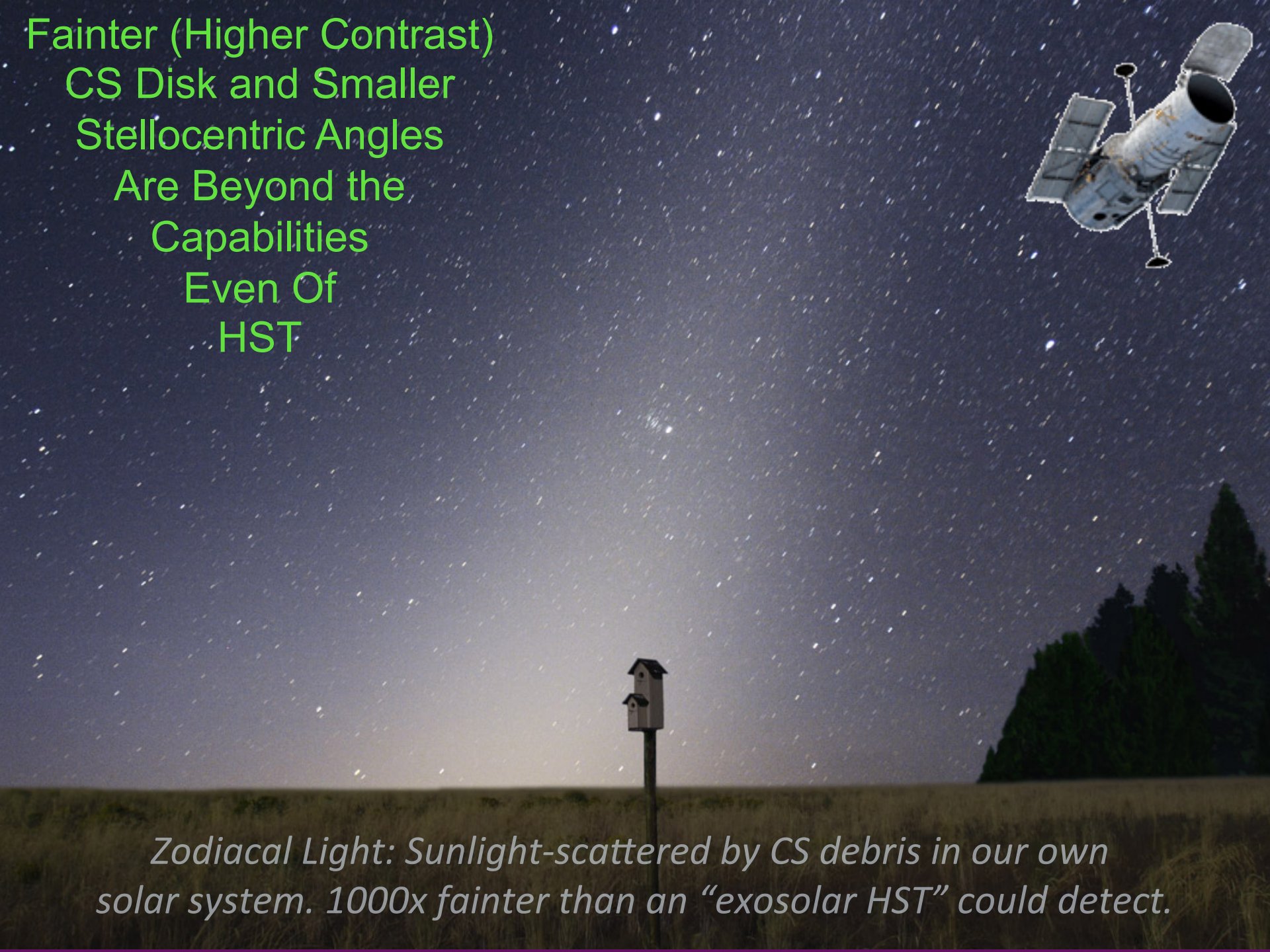


Schneider et al. 2013: AAS Session 104.05

New Capabilities are Needed to Open up the IWA/Contrast Discovery Space in Planet Forming/Hosting Regions in Circumstellar Environments

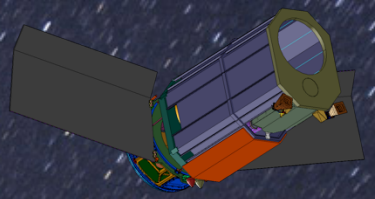
Looking "in" from the outside

Circumstellar Debris Scattering Starlight in the HD 107146 System


Fainter (Higher Contrast)
CS Disk and Smaller
Stellocentric Angles
Are Beyond the
Capabilities
Even Of
HST
Zodiacal Light: Sunlight-scattered by CS debris in our own
solar system. 1000x fainter than an "exosolar HST" could detect.

The Next Step:
One Giant Leap for
CS Disk Science…

*EXCEDE**



Good Things
Come In
Small
Packages

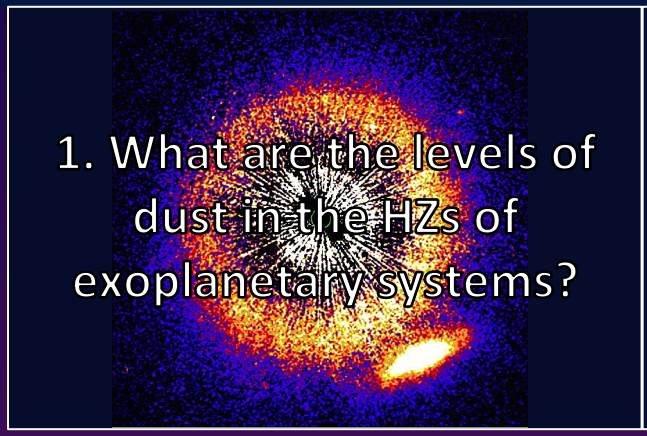
**EXoplanetary Circumstellar Environments and Disk Explorer*

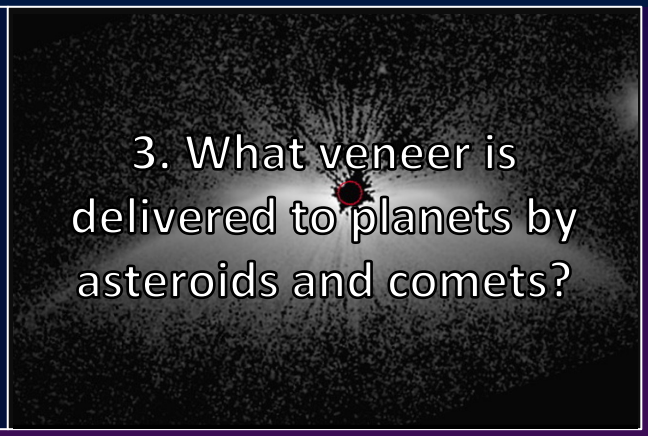
Studying the formation, evolution, and architectures of exoplanetary systems, and characterizing circumstellar environments into habitable zones.

EXCEDE SCIENCE/MISSION OBJECTIVES

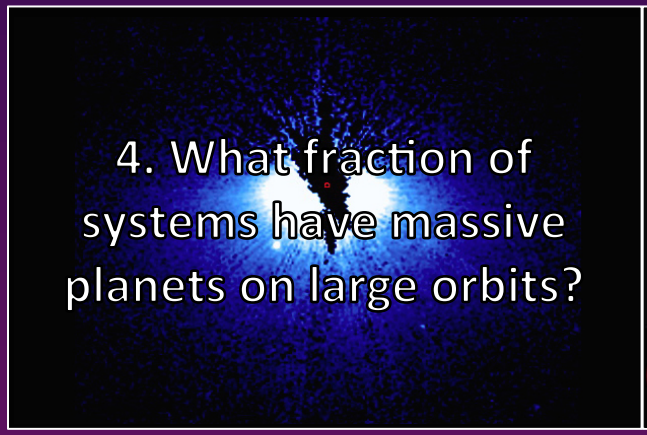
EXCEDE WILL UTILIZE OBSERVATIONS OF DUSTY CS DISKS TO:

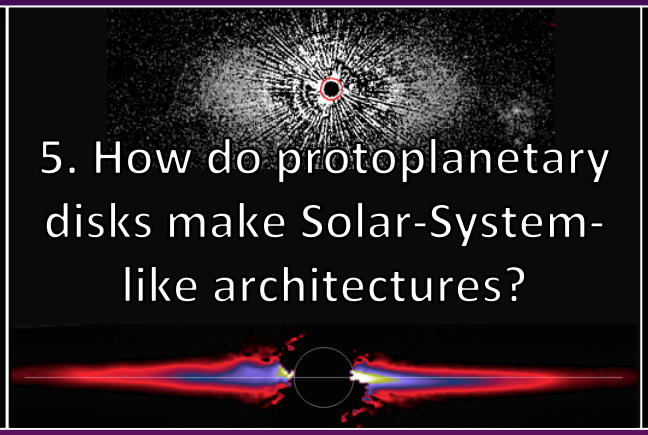
I. Characterize CS environments into HZs and determine the potential for habitable planets.





II. Understand the formation, evolution, and architecture of planetary systems.





III. Develop & demonstrate advanced coronagraphy in space for use in future major missions.

EXCEDE — EXOPLANETARY CIRCUMSTELLAR ENVIRONMENTS and DISK EXPLORER

- **Provides high spatial resolution optical imaging polarimetry of planet-forming regions in circumstellar (CS) environments.**
  Raw **Contrast resel^{-1}: $10^{-6 - -7}$ @ 1.2 – 2 λ/D, 10^{-7} @ > 2 λ/D**

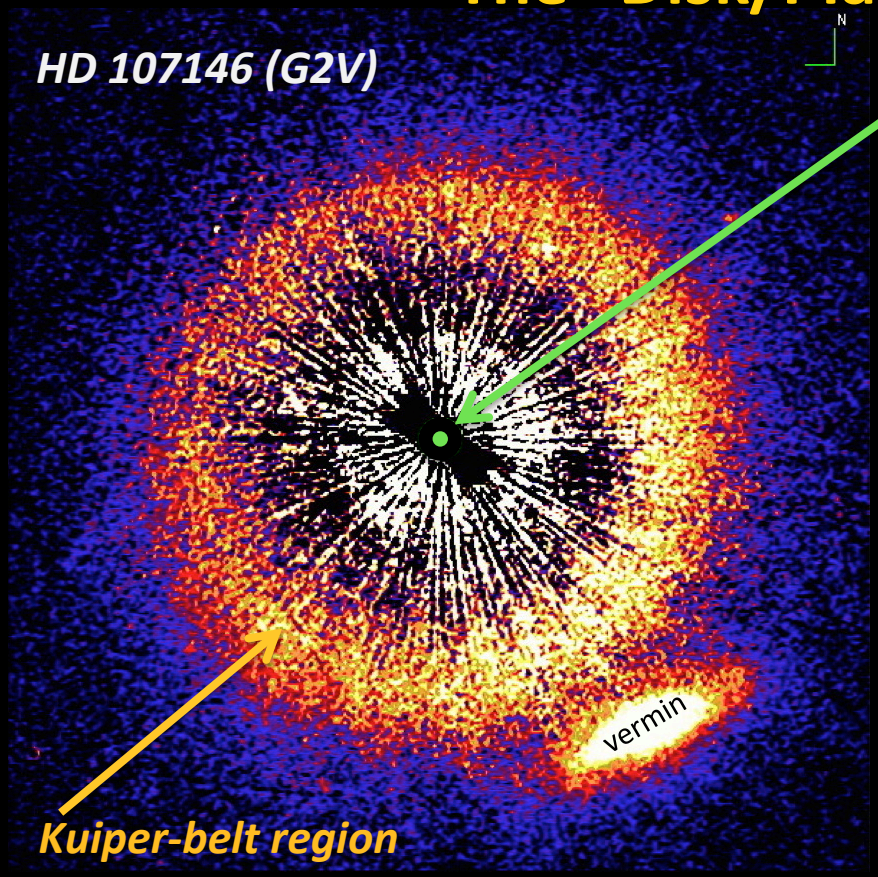
- **Characterizes CS environments into stellar habitable zones to assess the potential for planets.**
  Inner Working Angle: 0.14" @ 0.4 μm; > 90% throughput @ > 2 λ/D

- **Explores the formation, evolution, architectures and diversity of exoplanetary systems *and* reveals the presence of previously undetected planets by imaging the CS dust-scattered starlight.**
  –Diffraction-limited imaging polarimetry @ 0.4 & 0.8 μm
  –Stellocentric high-contrast FOV: 1.2 to $\geq$ 20 λ/D

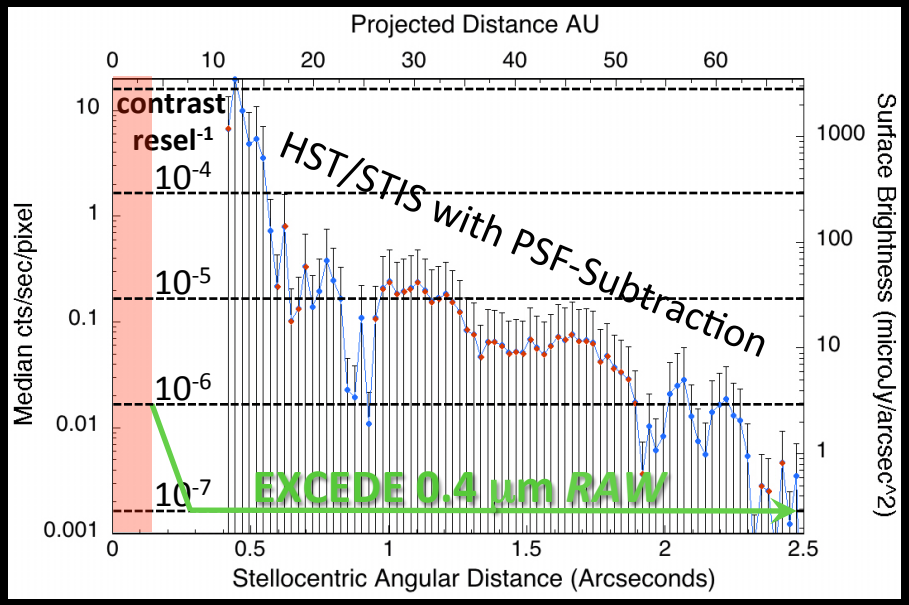
- **Develops and demonstrates advanced coronagraphy in space enabling future exoplanet imaging & characterization missions.**
  –Starlight Suppression with active WFE control using DM & LOWFS
  –High-efficiency PIAA coronagraph in broadband (20%) light

EXCEDE Stellocentric Angle/Contrast Discovery Space

The "Disk/Planet Connection"



EXCEDE 0.4μm IWA



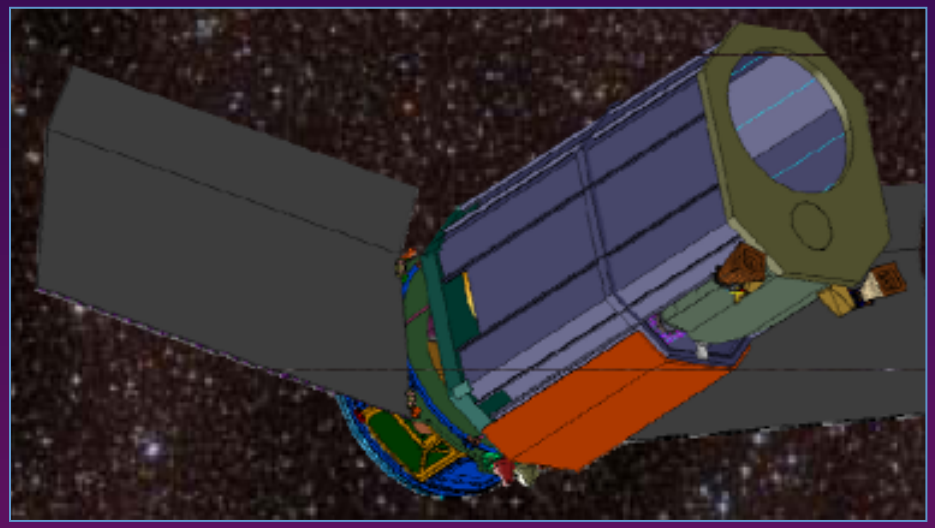
Schneider et al. 2013: AAS Session 104.05

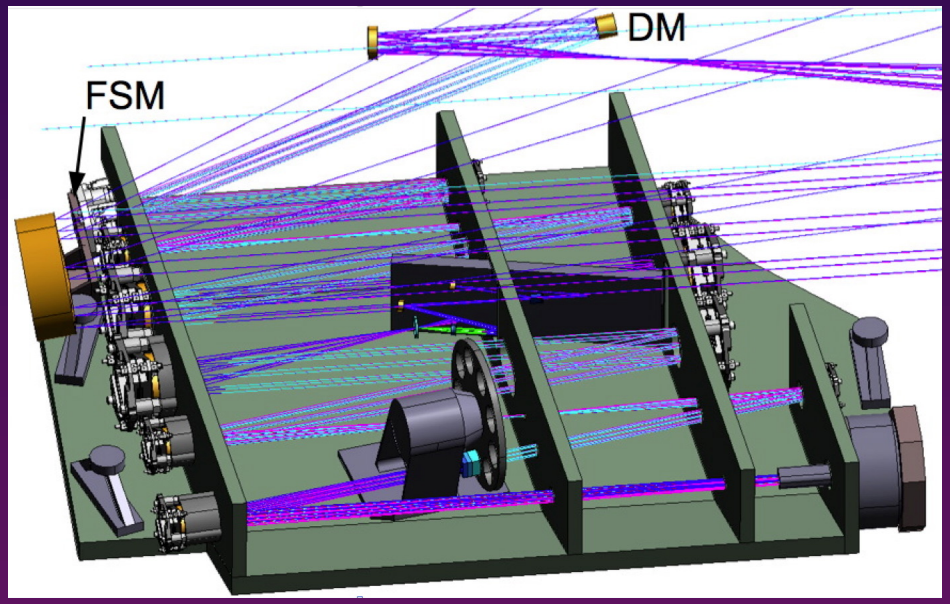
Dynamical interactions between planets and disks are predicted to play vital roles in generating the architectures of planetary systems, but the inner regions of such systems, <u>today</u>, remain obscured.

EXCEDE is Needed to Open up the IWA/Contrast Discovery Space in Planet Forming/Hosting Regions in Circumstellar Environments

FLIGHT INSTRUMENT CONCEPT

- Small (0.7 m) TMA optical telescope (fully unobscured pupil)
- Highly-efficient PIAA coronagraph
- Active/Closed-loop Wavefront-Error (WFE) Control System
- Two-Band Diffraction-Limited Imaging Polarimeter





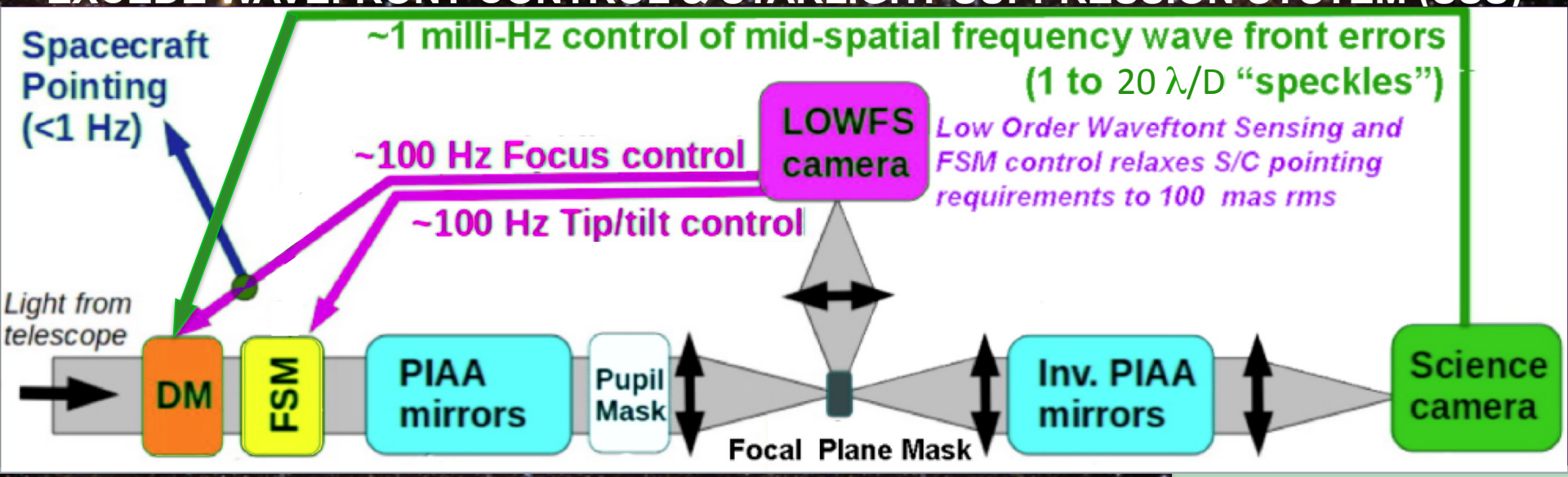
EXCEDE — EXOPLANETARY CIRCUMSTELLAR ENVIRONMENTS and DISK EXPLORER

Imaging CS dust at small IWA is a contrast problem.

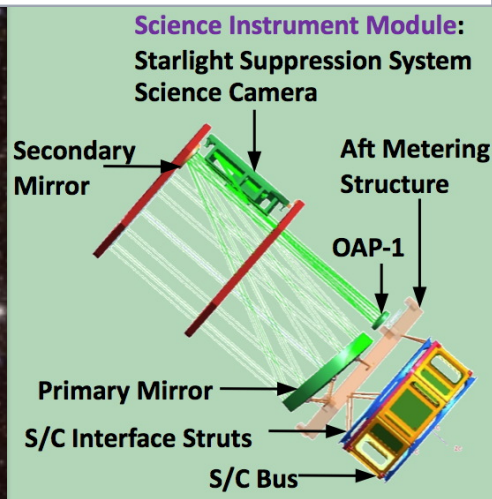
A large aperture telescope is not required.

EXCEDE Provides Integrated STARLIGHT SUPPRESSION Technologies

EXCEDE WAVEFRONT CONTROL & STARLIGHT SUPPRESSION SYSTEM (SSS)



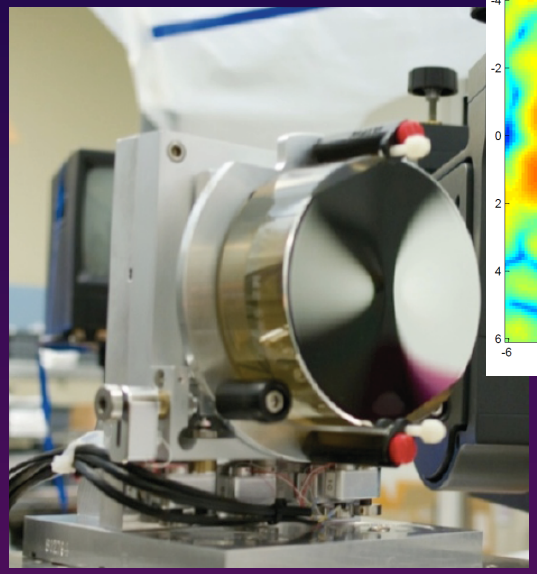
- 70 cm unobscured aperture off-axis telescope
- 2000-element Deformable Mirror for wavefront error control
- Fine Steering Mirror for high precision pointing control
- Phase Induced Amplitude Apodization (PIAA) coronagraph
- Low Order Wave Front Sensor for focus & tip/tilt control
- Camera with 2-band Nyquist-sampled imaging polarimeter

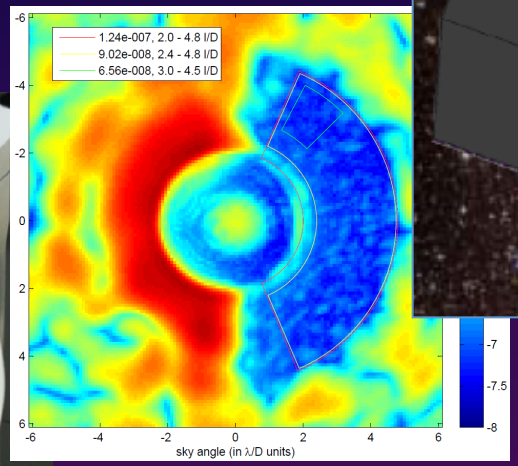


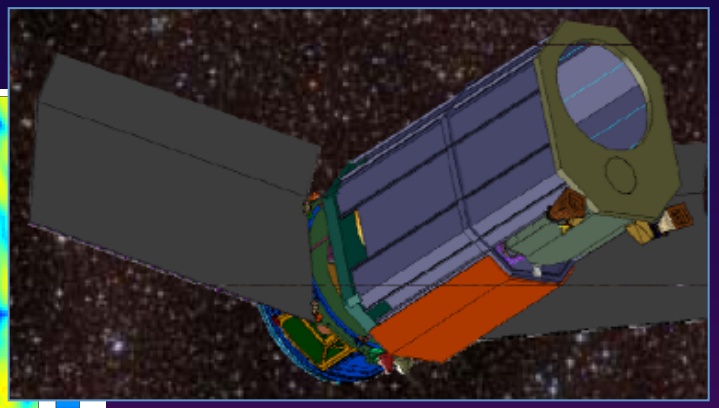
TECHNOLOGY DEVELOPMENT PROGRAM

NASA Funded EXPLORER Category III Technology Development Investigation

University of Arizona Lead Investigation
CY's 2012 - 2014







KEY PARTICIPAING INSTITUTIONS

The University of Arizona
NASA/Ames Research Center
Lockheed-Martin Corp.

Also see: Belikov et al. 2013: AAS Session 305.02

KEY PERSONNEL

Glenn Schneider (UofA) – Principal Investigator
Olivier Guyon (UofA) – Instrument Scientist; PIAA-Coronagraph
Ruslan Belikov (ARC) – Ames Coronagraph Experiment Technical Director
Rick Kendrick (LM) – Vacuum Test/Validation Project Manager
Alan Duncan (LM) – LM Technology Development co-PI

NASA EXPLORER CATAGORY III INVESTIGATION: DIRECTION & SCOPE

To further mature … elements of the EXCEDE {SSS} technologies:

- Phase Induced Amplitude Apodization Coronagraph Optics
- Deformable Mirror
- Low Order Wavefront Sensor
- Wavefront Control Algorithms
- SSSS technologies and WF control integration

EXCEDE TECHNOLOGY DEVELOPMENT FOCUS

- PIAA Performance to EXCEDE Requirements in Broadband Light
- Demonstrate functionality/operability in vacuum environment
- Performance Stability of SSS on observation timescales

TEST ELEMENT FACILITIES

- In-Air Testbed Development & Testing: ACE Lab / NASA ARC
- Vacuum-Environment Testing & Demonstration: Lockheed-Martin