WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

# CGI Detection and Characterization of Circumstellar Disks

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## The WFIRST CGI Instrument

The WFIRST Coronagraphic Instrument (CGI) will be capable of obtaining high contrasts to an inner working angle of $3\lambda/D$ for at least two 10% bandwidth visible light filters using shaped pupil coronagraph (SPC) and hybrid Lyot coronagraph (HLC) designs. The HLC will have a dark hole from $3\text{-}10\lambda/D$, while the SPC in disk detection mode will have a dark hole between $6.5\text{-}20\lambda/D$. We look at an overview of selected science cases for circumstellar disks unique to CGI.

## Detecting Exo-Zodiacal Disks with HLC

The CGI will potentially detect exo-zodiacal disks (exo-zodis) around nearby stars with the small inner working angle of the HLC. We estimate the sensitivity to exo-zodis [1 Zodi ~ 22 mag/sq"+$5\log_{10}(r_{AU})$-$2.5\log_{10}(L_*/L_\odot)$] for 47 UMa and $\tau$ Ceti. We assume the contrast performance of the HLC using results from Krist et al., (2006) [1], assuming 4mas of uncorrected jitter. We assume detector parameters provided by B. Nemati and that post-processing will decrease systematic speckle noise by a factor of 5 and that the disk emission is marginally resolved. Note for extended sources, the PSF speckle ***intensity*** (not contrast) drives sensitivity. For the latest CGI contrast performance and minimum contrast requirements, see poster **246.32**.

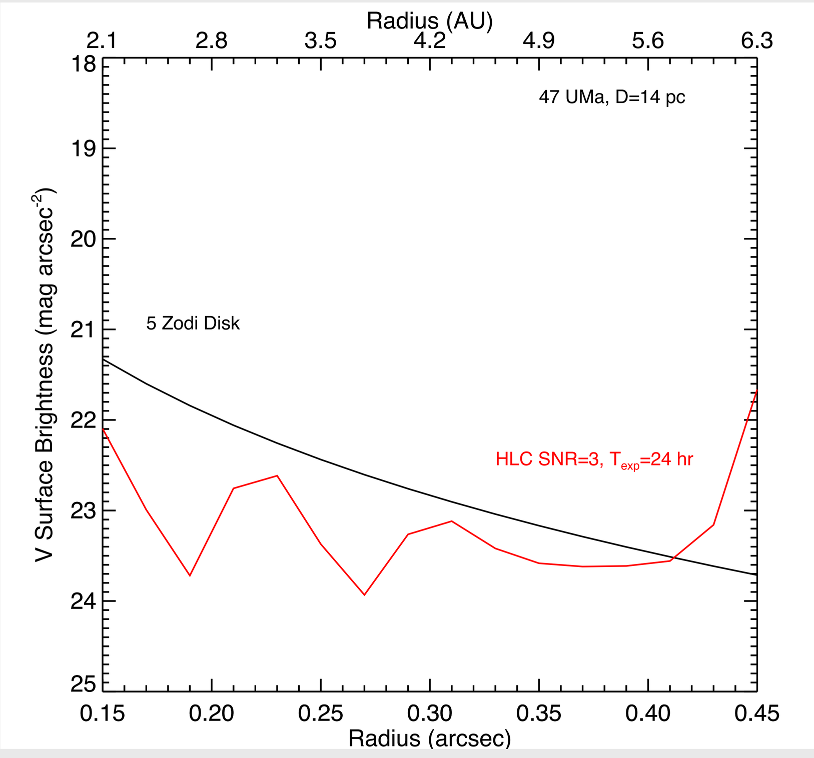
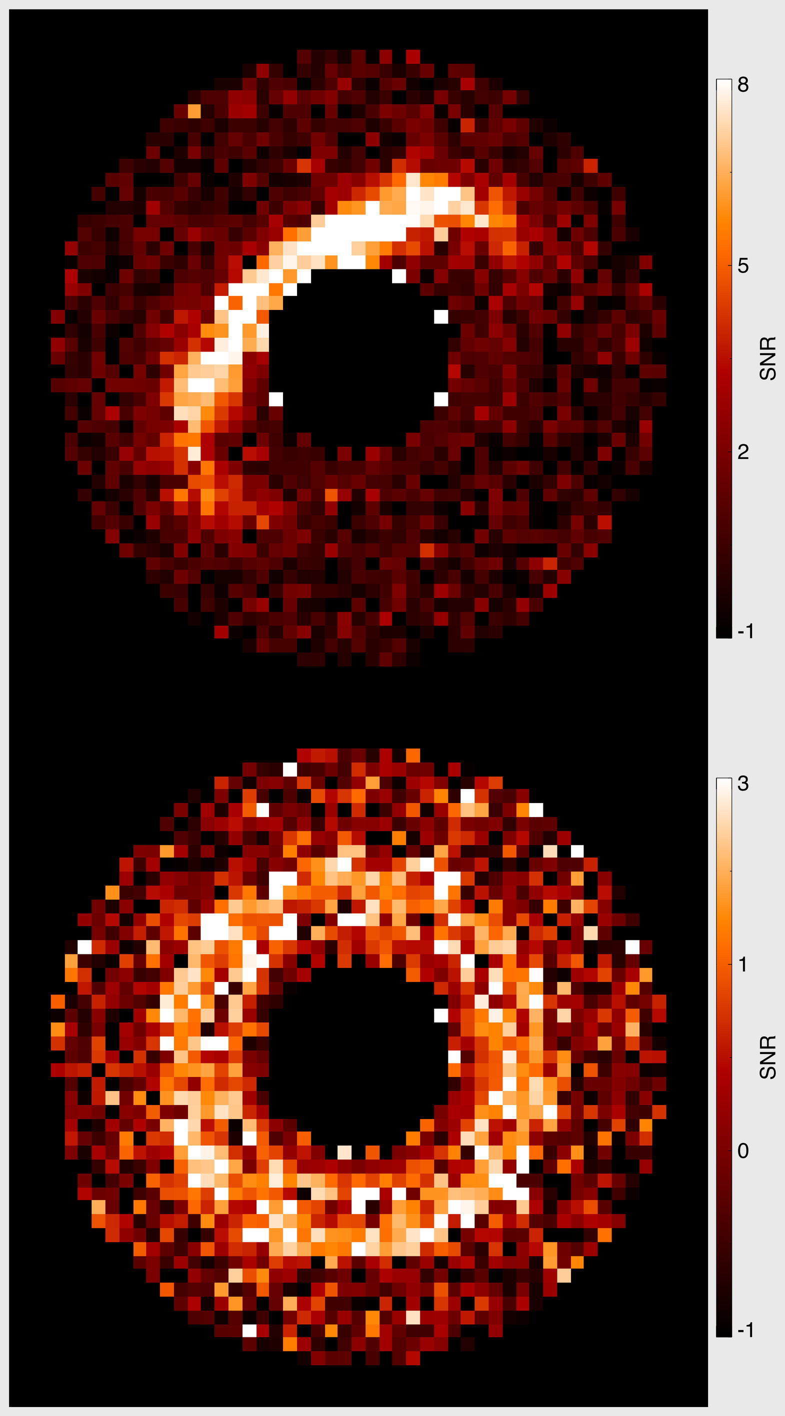



Figure 1:Limiting surface brightness of the CGI/HLC (red line), assuming a detection limit of SNR=3/resel and exposure time of 24 hours for expected performance. For comparison, we have overplotted a 1-D dust disk model (black line) with a surface brightness of 5 times the Solar System zodiacal dust cloud.

**47 UMa**
**5 Zodi Disk**
**R~4.2 AU**
**ΔR~0.8 AU**
**i=60 degrees**




**$\tau$ Ceti**
**1 Zodi Disk**
**R~0.9 AU**
**ΔR~0.5 AU**
**i=0 degrees**

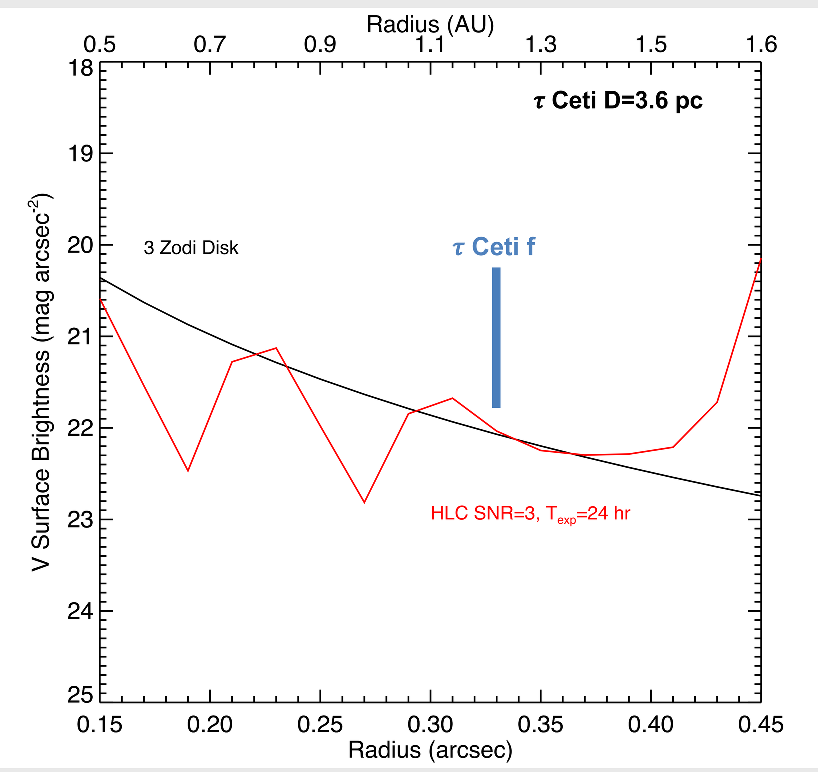



Figure 2: Same as Figure 1, but for Tau Ceti, which is much closer and was recently reported to have at least one super-Earth candidate planet within the dark hole of the HLC, tau Ceti f[2]. While the planet may be undetectable, it may sculpt any dust that may be present in the inner stellar system.

**A survey of ~20 Stars using CGI with D<14 pc can determine the median surface brightness of exo-zodi contamination for the direct imaging of Earths**

## Characterizing Bright Disks in the Visible

### Time Variable Disk Phenomena

Some protoplanetary disks have shadows which may vary on timescales of years or decades, such as TW Hya [3]. AU Mic, a debris disk, also shows radially moving dust features [4]. The physical origin of these variations is currently poorly known. Variable phenomena can be probed with a combination of data taken with existing coronagraphs and the CGI, providing time baselines of as much as 25 years. If a dark hole is not needed, the full CGI FOV can be used to observe bright disks.

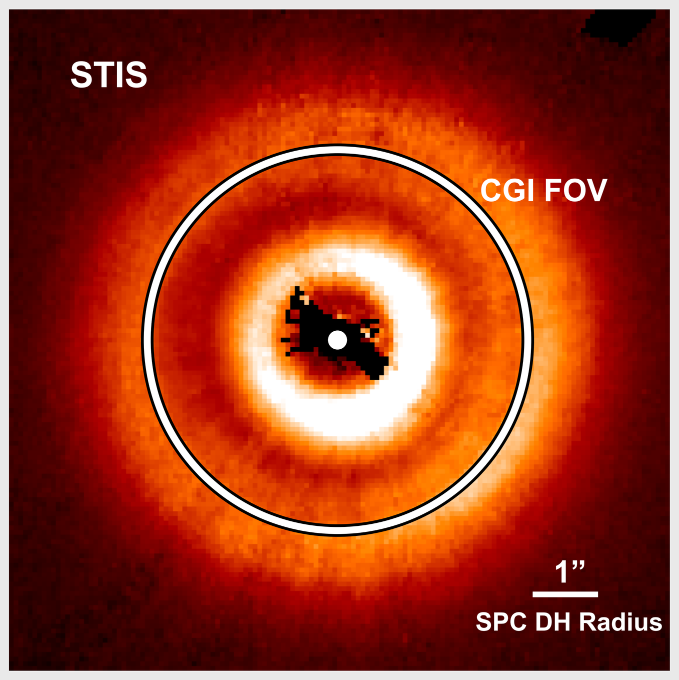



Figure 3: STIS Image of TW Hya with the full CGI Field of View (FOV). TW Hya has a brightness asymmetry due to a shadow that moves ~20 degrees/yr counterclockwise in PA. It will be visible to the CGI, which can continue to track the shadow through the mid 2020's to beter characterize.

### Disk Composition

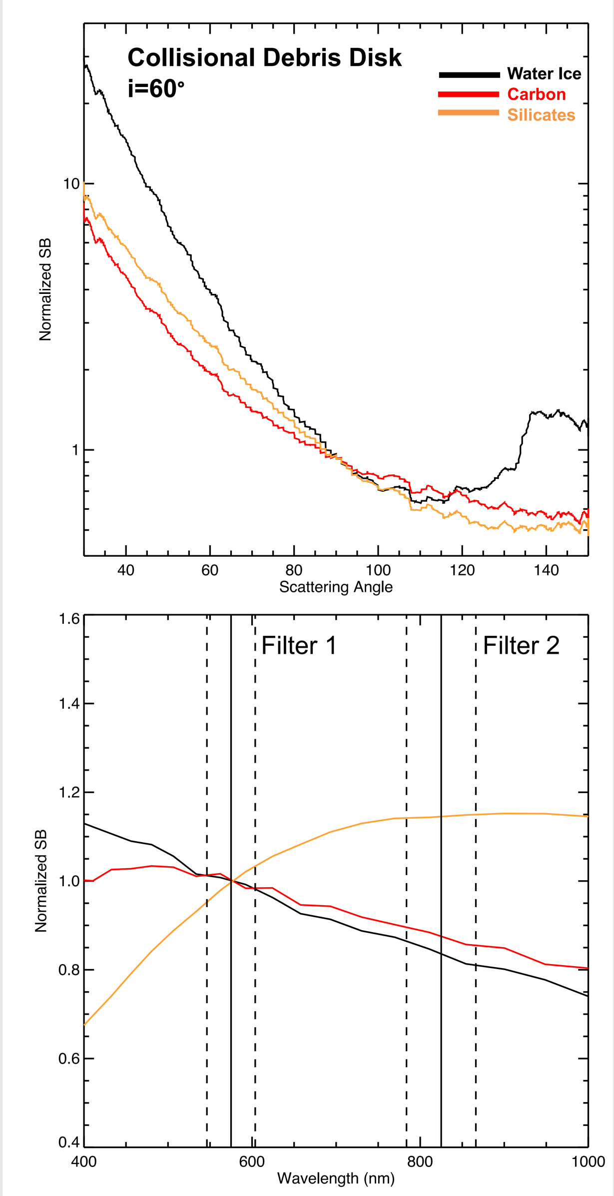



Figure 4: (Top) Empirical phase function of disks with 3 different pure dust compositions. (Bottom) The spectra of the same disks normalized to CGI Filter 1 (575 nm). CGI Filter 2 (825 nm) is also shown. Color and phase functions can be used to help constrain the composition of dust.

### Thermal to Scattered Light relations

A key unknown to direct imaging of Earths is the scattered light contamination from exo-zodis. CGI will determine how debris disks scattered light contrast relative to stellar flux varies with dust optical depth (~$L_{IR}/L_*$). CGI can probe cold dust disks around A stars ($R_{disk}$~100 AU) of varying optical depth out to ~300 pc to construct a volume limited population of characterized dust disks.

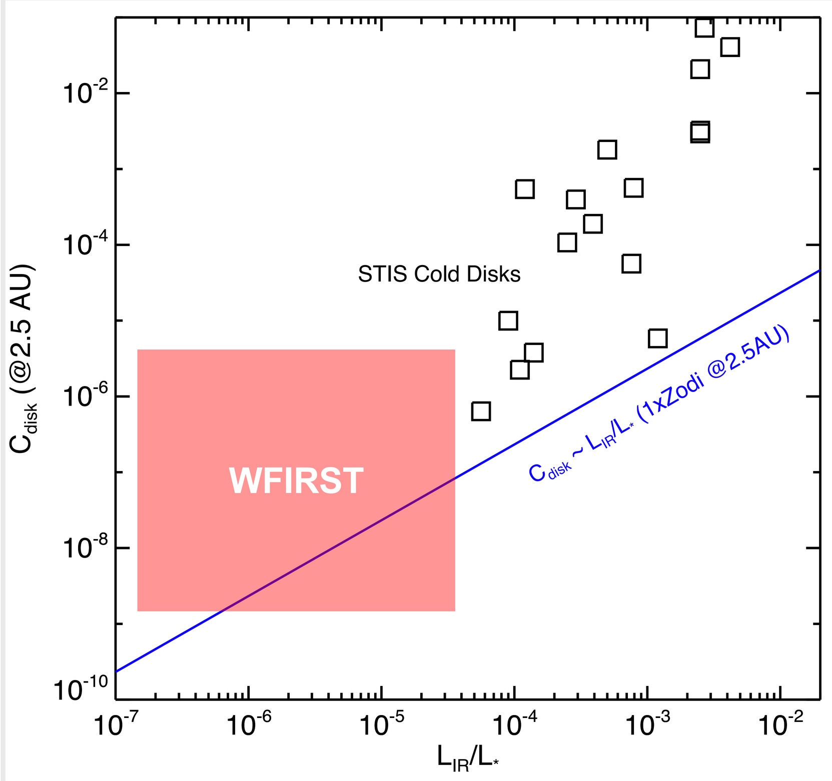



Figure 5: We take the population of HST/STIS observed debris disks and scale their disk surface brightness/pixel relative to the peak stellar flux to 2.5 AU as a function of $L_{IR}/L_*$ to determine if cold dust from debris disks is similar to Zodiacal dust assumed for exo-zodis. In general, cold dust is brighter, and the CGI will help to determine what scattered light relations hold for low optical depth disks, which will start to be dominated by transport dynamics such as Poynting-Robertson drag. The box labeled WFIRST shows the rough parameter space that the HLC and SPC will be sensitive to for stars from 2.5-17 pc.

## Indirectly Detecting Planets

CGI's spatial resolution in Filter 1 is ~60 mas, implying that it can detect gaps in circumstellar disks with W=0.6 AU(d/10pc).

### Planets in Exo-Zodi Disks

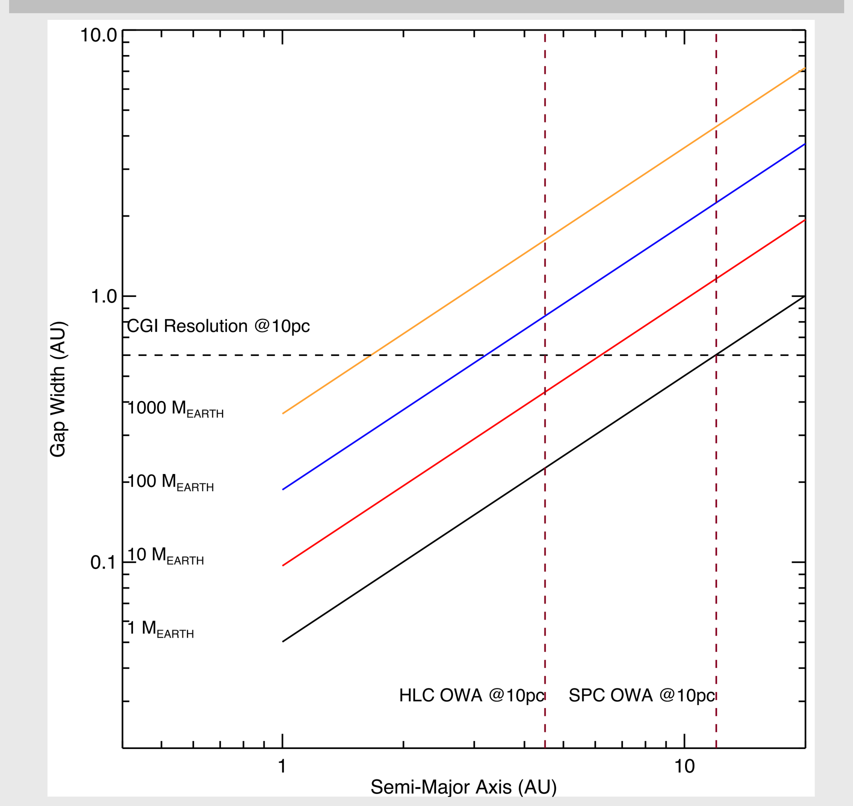



Figure 6: We use the Wisdom (1980)[5] resonance overlap criterion to estimate gap widths in debris disks caused by different planets at 10 pc. The HLC and SPC masks will observe disk gaps from Super-Earths and Jupiters at <12 AU.

### Planets in Protoplanetary Disks

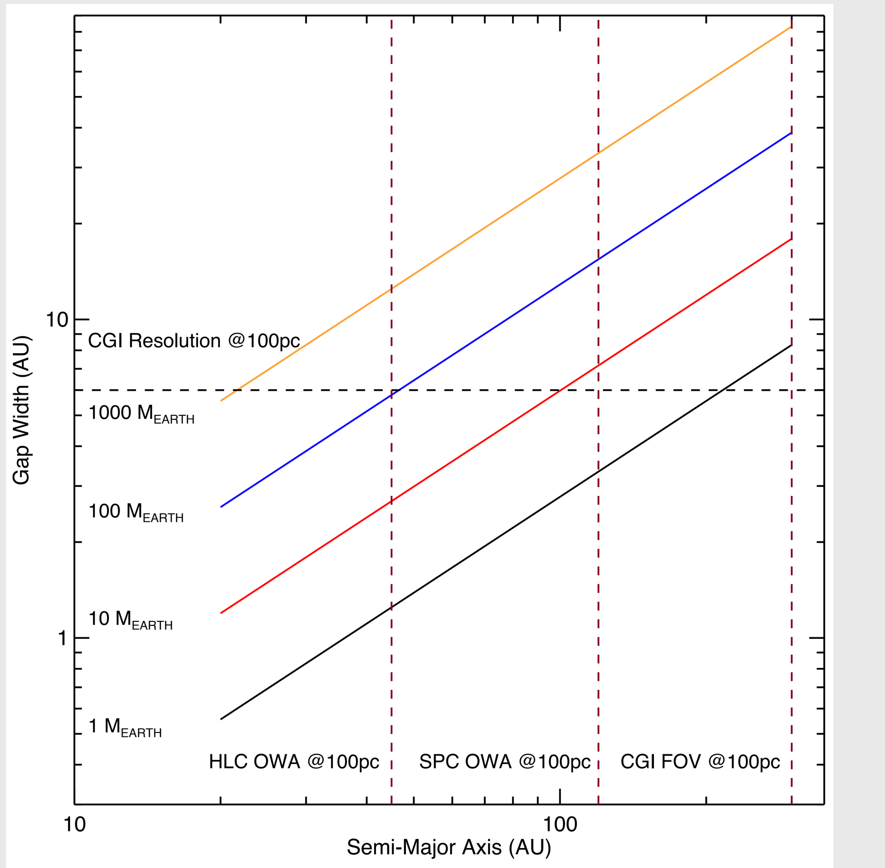



Figure 7: We estimate the width of gaps caused by various planet masses protoplanetary disks by assuming width of ~$2R_{Hill}$[6]. The HLC and SPC masks will observe disk gaps from proto-Jupiters and Saturns at >15 AU, while for bright disks gaps from less massive planets can be observed in the outer parts of disks.

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**REFERENCES**
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[4] Boccaletti, A. et al., 2015, *Nature*, 526, 230
[5] Wisdom, J. 1980, *AJ*, 85, 1122
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