SAG 23: THE IMPACT OF EXO-ZODIACAL DUST ON EXOPLANET DIRECT IMAGING SURVEYS

John Debes, on behalf of SAG 23

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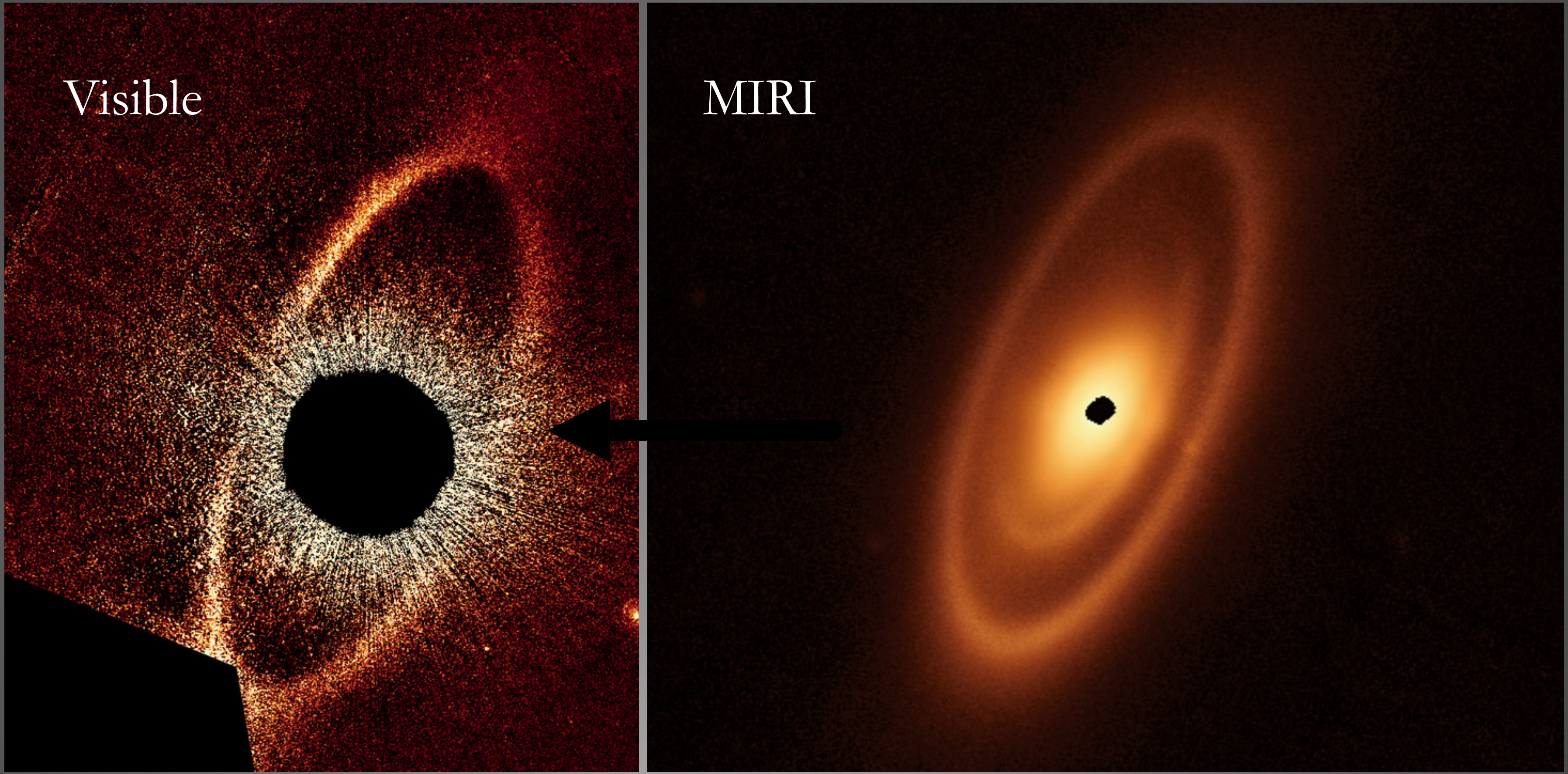
ARE WE READY FOR HWO?

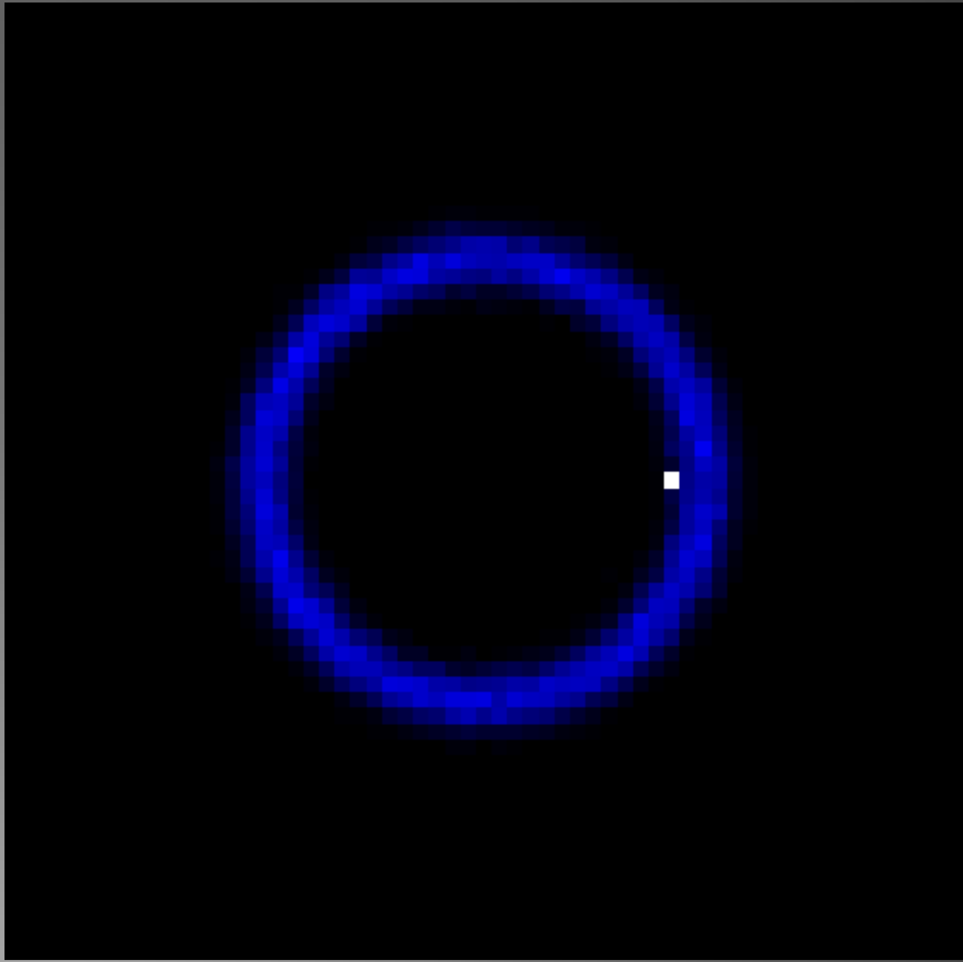


Credits: P. Kalas, A. Gaspar, STScI, NASA

V=5 star

3×10^{-9} Companion at 2.5 AU

5 Zodi disk at 3 AU



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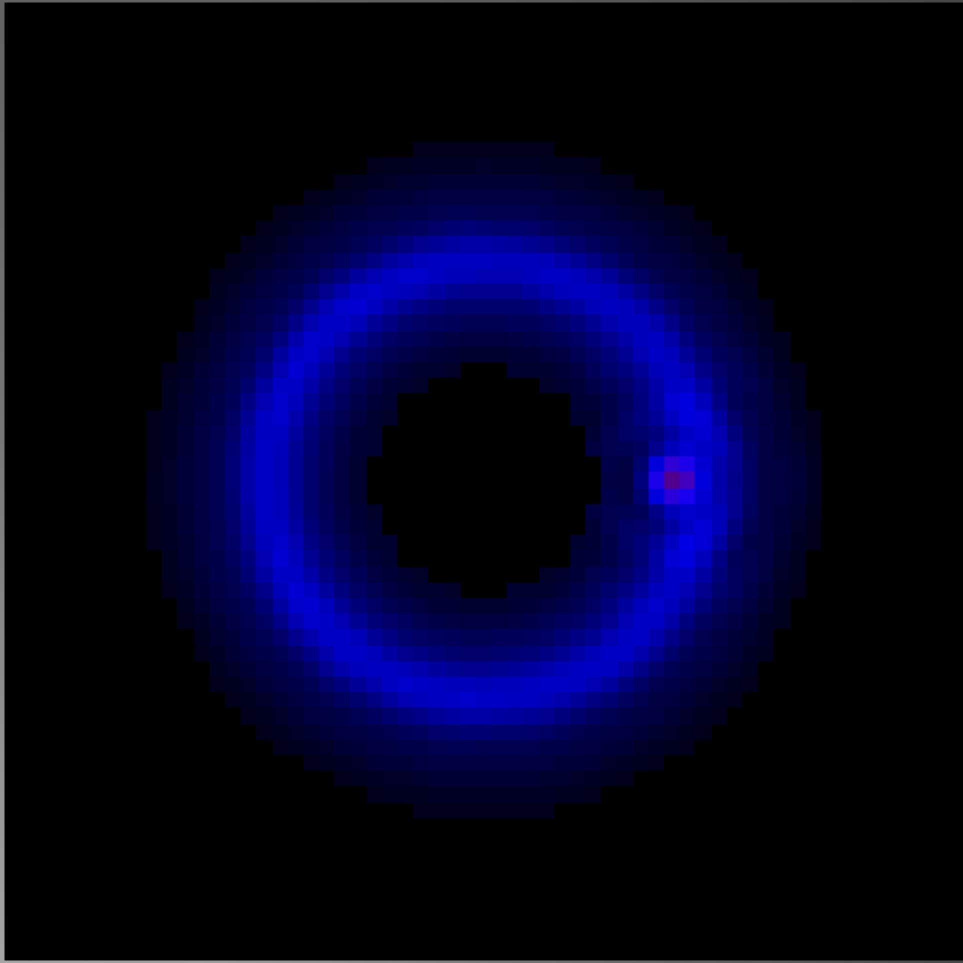
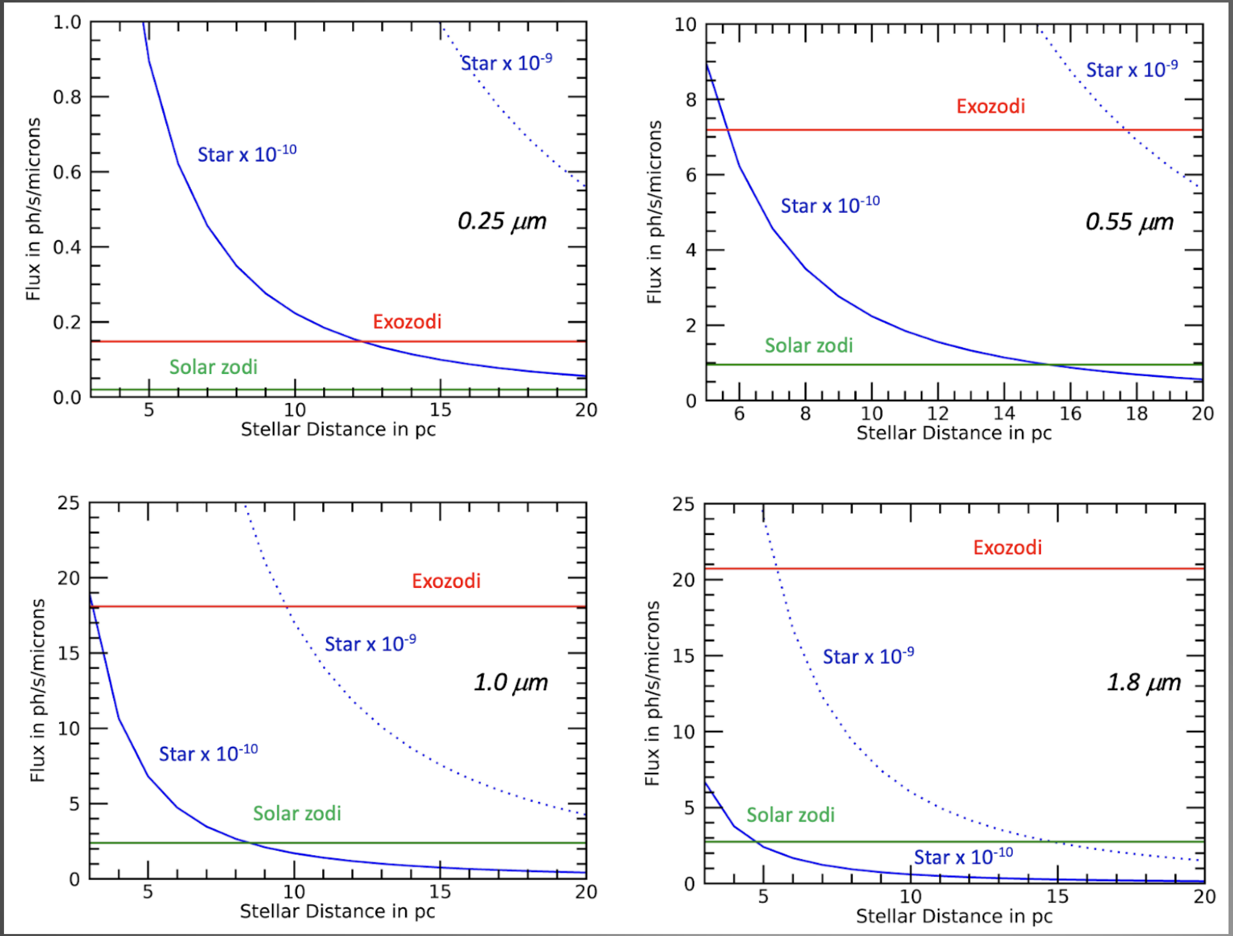




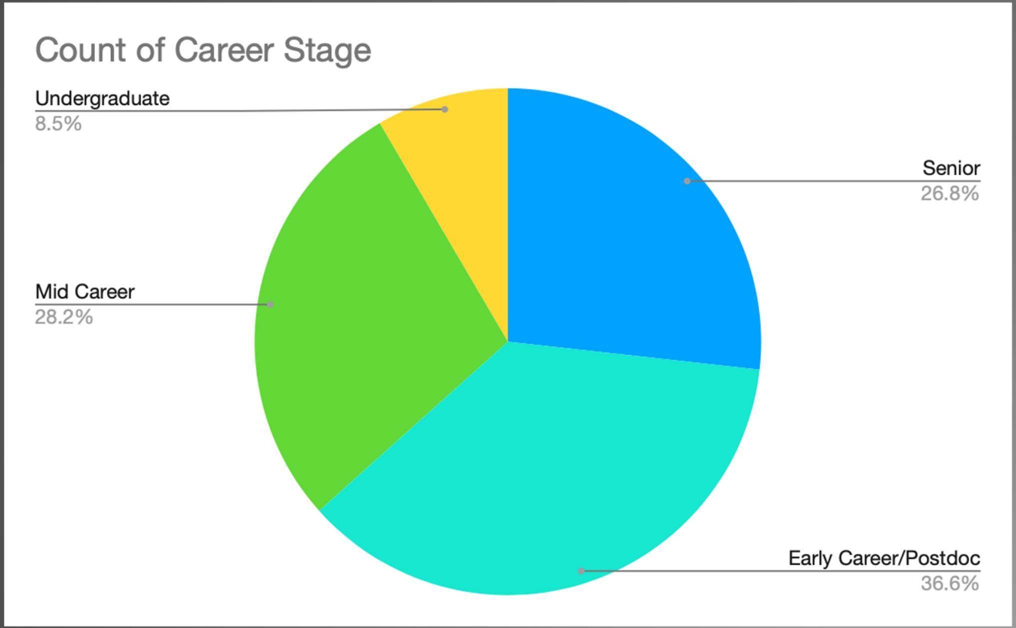
- Median HOSTS exozodis dominate the background for exoplanet searches.
- Upper limits are~50, meaning things could be 20x worse
- Incomplete coverage of HWO targets
- Uncertainty in IR to scattered light conversions
- Unknown “typical” structure

Mennesson et al., (2023, in prep.)

SAG23 WORKSHOP: SEPTEMBER 15 @STSCI

- Hybrid 1-Day Meeting after the "First Year of Science with JWST" conference
- Status updates from all subject areas
- Half the scheduled time left for discussion
- 19 in-person registrants, 50 remote participants
- Remote attendance fluctuated between 30-40 attendees

DEMOGRAPHICS OF REGISTERED PARTICIPANTS

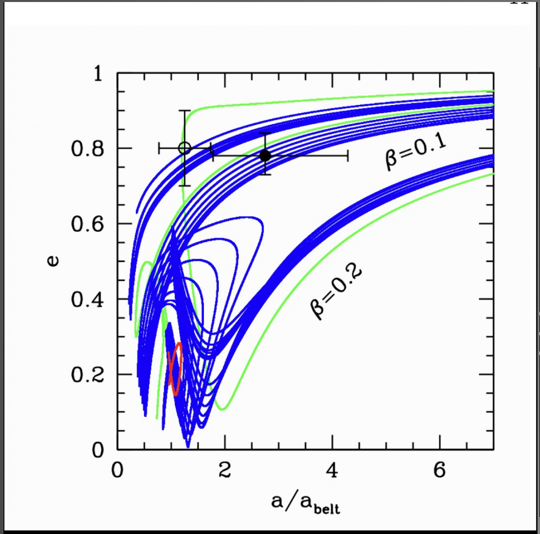


- Did not actively collect gender or racial demographic information
- Rough binary gender breakdown: ~28% female presenting attendees

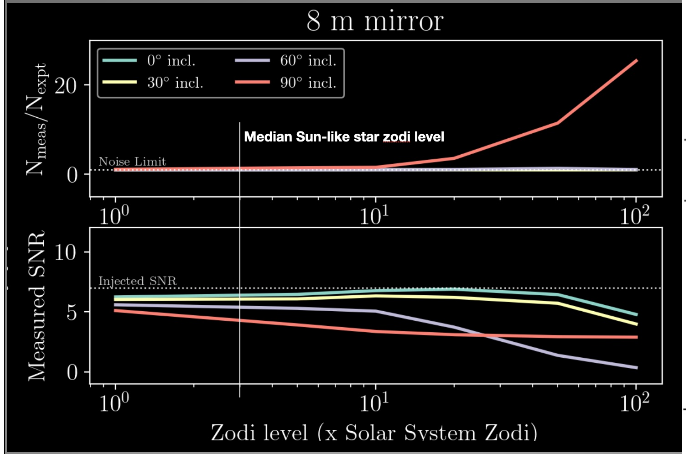
Brad Hansen (UCLA)
Irregular satellites around giant planets as the origin of narrow debris disks

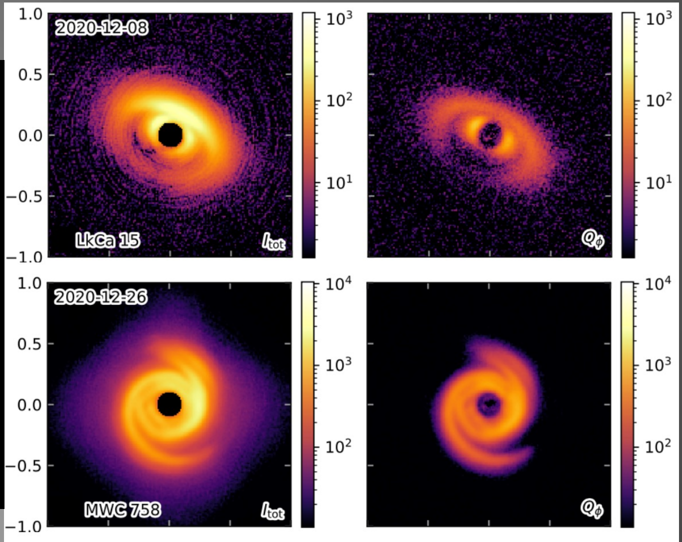
Miles Currie (U of W.)
Mitigating Worst-Case Exozodi Dust Structure in High Contrast Images of Exo-Earths

Bin Ren (OCA)
High Contrast Imaging Disk Recovery with Data Imputation



Hansen & Hayakawa (2023) arXiv:2308.07994

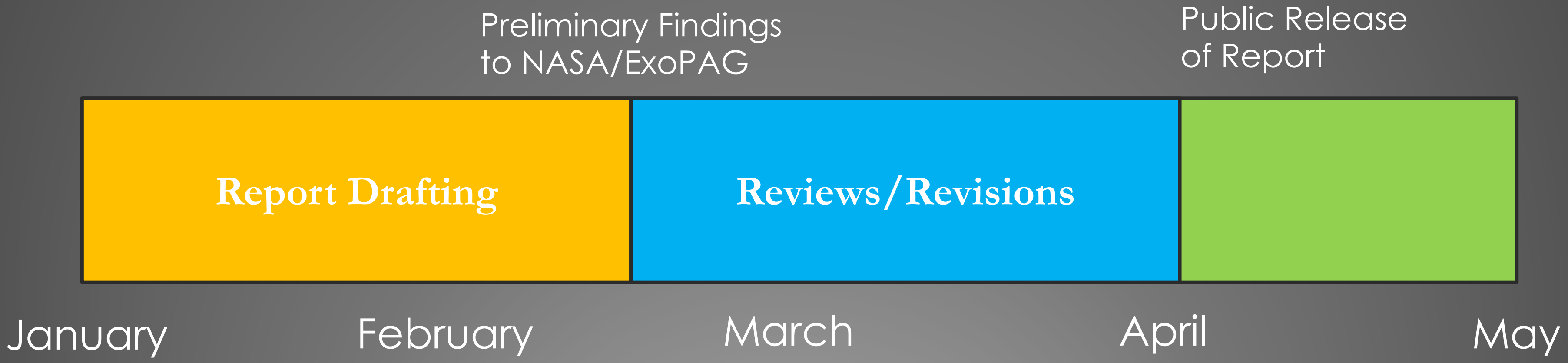




NEW FINDINGS DISCUSSED IN THE WORKSHOP

- While the median exozodi value is better constrained, it is still the dominant noise source for exoplanet direct imaging—the details will matter for final yields and mission planning
- Hot dust systems could complicate or thwart direct imaging of earths and it is not well studied enough to retire the risk
- Identifying the origin of exozodi dust could constrain dust properties and exozodi structure, lowering the risk exo-Earth imaging
- Synergy with Solar System studies of our own Zodi will enhance predictions about dust around other stars—investing in this could be strategic for HWO
- Roman CGI and IR interferometry play a key role in better constraining not just a median zodi level, but also the luminosity function of zodi dust in thermal IR and scattered light

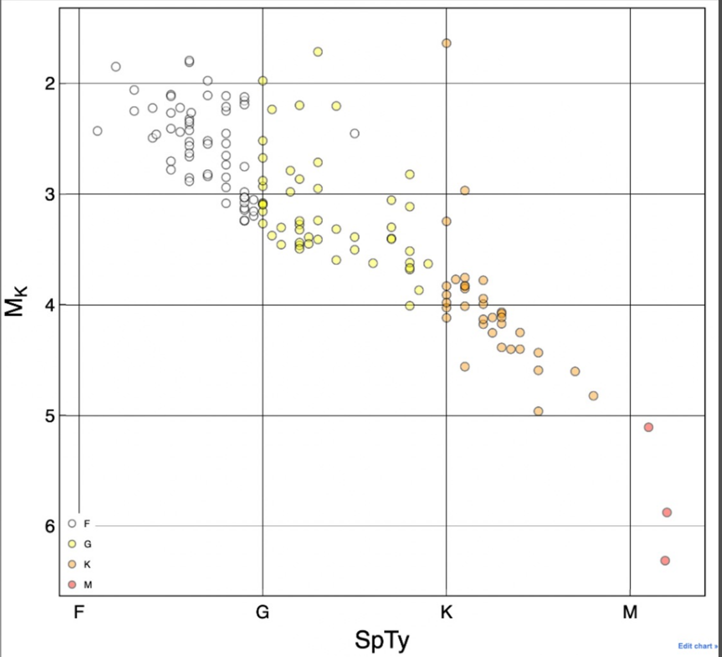
DRAFT TIMELINE FOR SAG23 WRAP-UP:



A CATALOG OF DUSTY SYSTEMS AROUND NEARBY STARS

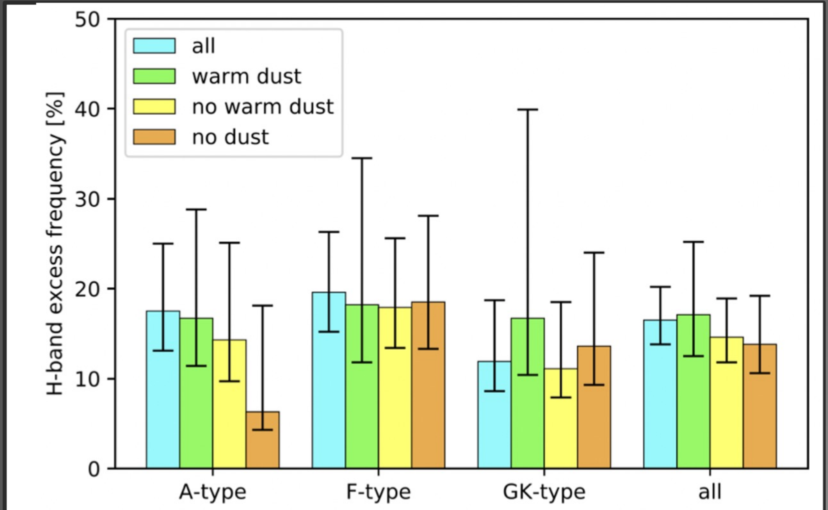
- **>85 IR/disk papers ingested into Starchive database for SAG 23**
- Mid-IR Interferometry for HWO stars:
  - **Keck Nuller: 17/164** - 1 excess (Mennesson et al. 2014)
  - **LBTI: 21/164** - 4 excesses (Ertel et al. 2020)
- Near-IR interferometry
  - **VLTI: 34/164** - 5 excesses (Ertel et al 2014)
  - **CHARA: 16/164** - 1 excess (Absil et al. 2013; Nunez et al. 2017)

Key Result: More interferometry needed to assess zodi levels! **<50% of HWO targets have been surveyed**

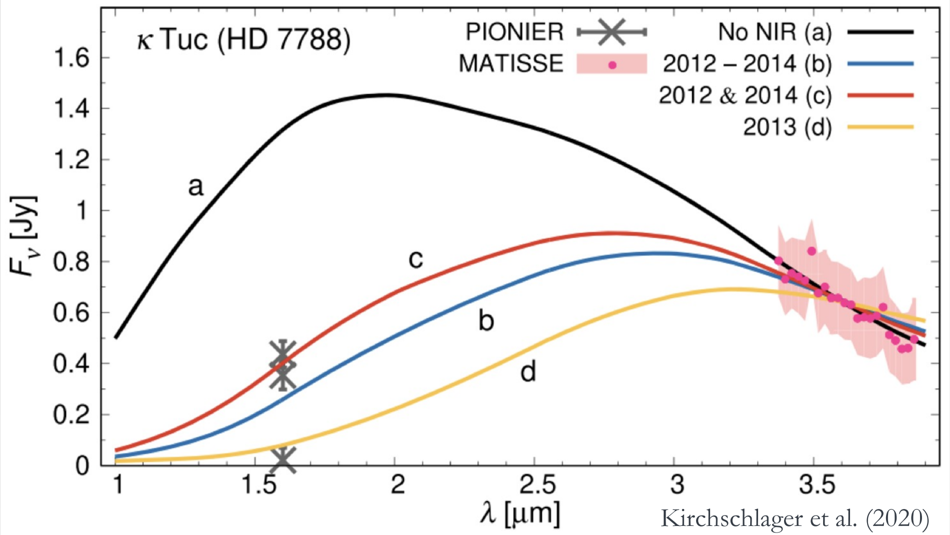


Starchive HR diagram of HWO sample

HOT DUST REVIEW



Absil et al. (2021)



Kirchschlager et al. (2020)

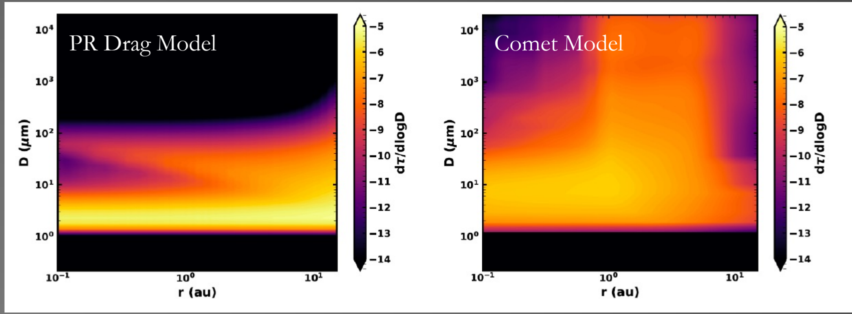
Hot dust is detected around ~20% of MS stars, repeatedly confirmed, it is real

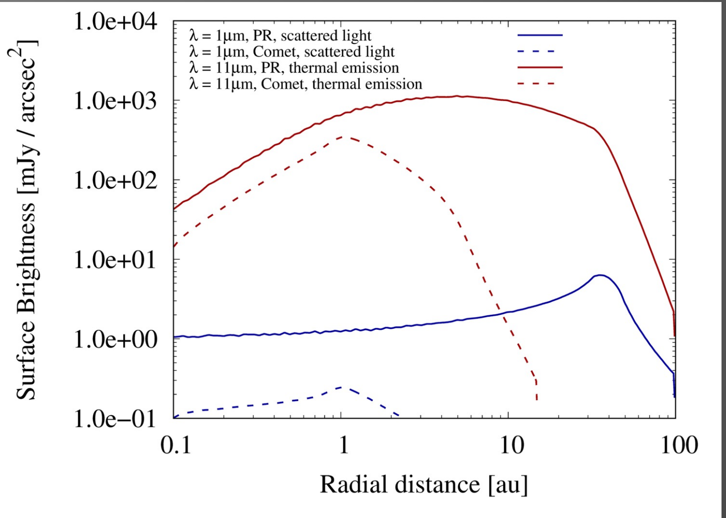
So far no good understanding of its origin, formation, properties

Plausibly a significant risk to exo-Earth imaging from supply scenarios & coronagraph leakage

THEORY OF EXOZODI SOURCES AND DUST EVOLUTION

- What is our current understanding of exozodi sources and how does that feed into questions about exozodi?
- Theoretical insights into key questions:
  - What is the size and spatial distribution of dust in exozodi?
  - What is the dominant exozodi delivery mechanism?
  - How do exozodi pinpoint planets?
  - How do exozodi affect a planet’s physical properties and habitability?
  - How do dust size and composition affect exozodi observable properties?
  - How common are different exozodi levels?
  - What information is needed to predict exozodi levels in a system?
  - What is the connection between hot and warm exozodi?



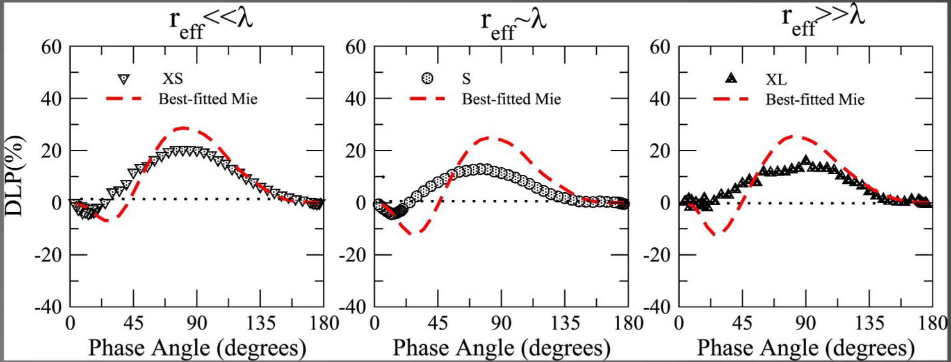


UPDATE AND PRIORITIZATION OF EXEP GAPS RELEVANT TO EXOZODIS

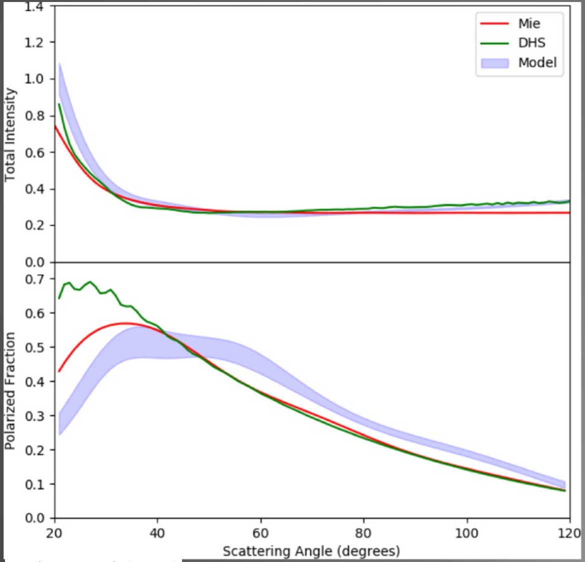
- Which gap list topics are **impacted** by **exozodi**?
- Currently listed:
  - *SCI-03:* Spectral signature retrieval
  - *SCI-11:* Understanding the abundance and distribution of exozodiacal dust
    - Didn't mention **hot dust constraints** for **individual stars** as a capability needed
    - **Direct measurement** of exozodi in **visible wavelength** should be *higher priority* than statistical knowledge of exozodi levels (capability today to be moved down)
- What **other** gap list topics could be **impacted**?
  - *SCI-07:* stellar variability can be **linked** to exozodi levels
  - *SCI-10:* include **exozodi information** in **catalog** of prior knowledge of **host stars**
- What else needs to be included?
  - The NOTT instrument on the gap list
  - MID IR emission from stars is not well characterized and should be prioritized

PAN-CHROMATIC RADIATIVE TRANSFER OF EXOZODIS

- Development/exploring realistic dust grain models as Mie theory not efficient to reproduce observables.
- Laboratory measurements of cometary dust and more collaboration with observers.



Muñoz et al. (2021b) polarization curves for a set of different narrow grain size distributions compared to Mie models. Mie models fail to reproduce the peak and negative polarization branch



Arriaga et al (2020)

Mie and DHS models cannot reproduce all debris disk observables simultaneously

- Multi-wavelength, SPF and polarimetric observations to better inform the scattering properties of disks.
- Better data management of optical constants used in grain modelling

PRIORITIZATION OF PRECURSOR THEORETICAL STUDIES OF DEBRIS DISKS/EXOZODIS FOR FUTURE DIRECT IMAGING MISSIONS

Key questions that need to be addressed to make the most out of current/future observatories

Prioritized list of topics:

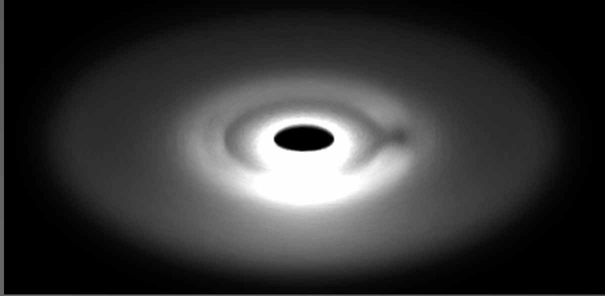
1) Predict the location and amount of dust contained in an exozodi.
2) Infer underlying planets from dynamical structures in exozodiacal dust.
3) Characterize the effect of exozodiacal dust on the habitability of exoplanets.
4) Predict exozodiacal dust characteristics and properties.
5) Make testable predictions on the link -- or lack thereof -- between warm and hot exozodis.

Report: why these objectives are important and the precursor theoretical studies we recommended to achieve these objectives.

PRECURSOR OBSERVATIONAL STUDIES OF DEBRIS DISKS/EXOZODIS FOR FUTURE DIRECT IMAGING MISSIONS

- Exozodi dominate noise budget; asymmetric disks masquerading as planetary point source signals remains an unquantified risk.
- Critical need to quantify surface brightness function of exozodi in scattered light, and the prevalence of asymmetric disks. **Roman CGI/Picture-C missions**
- Critical need to quantify surface brightness function of exozodi in thermally emitted light, and the prevalence of asymmetric disks
- Possible options:
    - VLTI/NOTT nulling instrument,
    - VLTI/MATISSE spectro-interferometer
    - Upgraded L'/N band for LBTI; extending HOSTS survey

CONCLUSIONS



- Much progress has been made on the study of dust interior to 5 AU around nearby stars, but significant uncertainties remain that are critical to direct imaging surveys
- The window is rapidly closing to retire some of these risks before architectures are solidified
- The SAG 23 report will help to prioritize efforts surrounding exozodis at a critical time