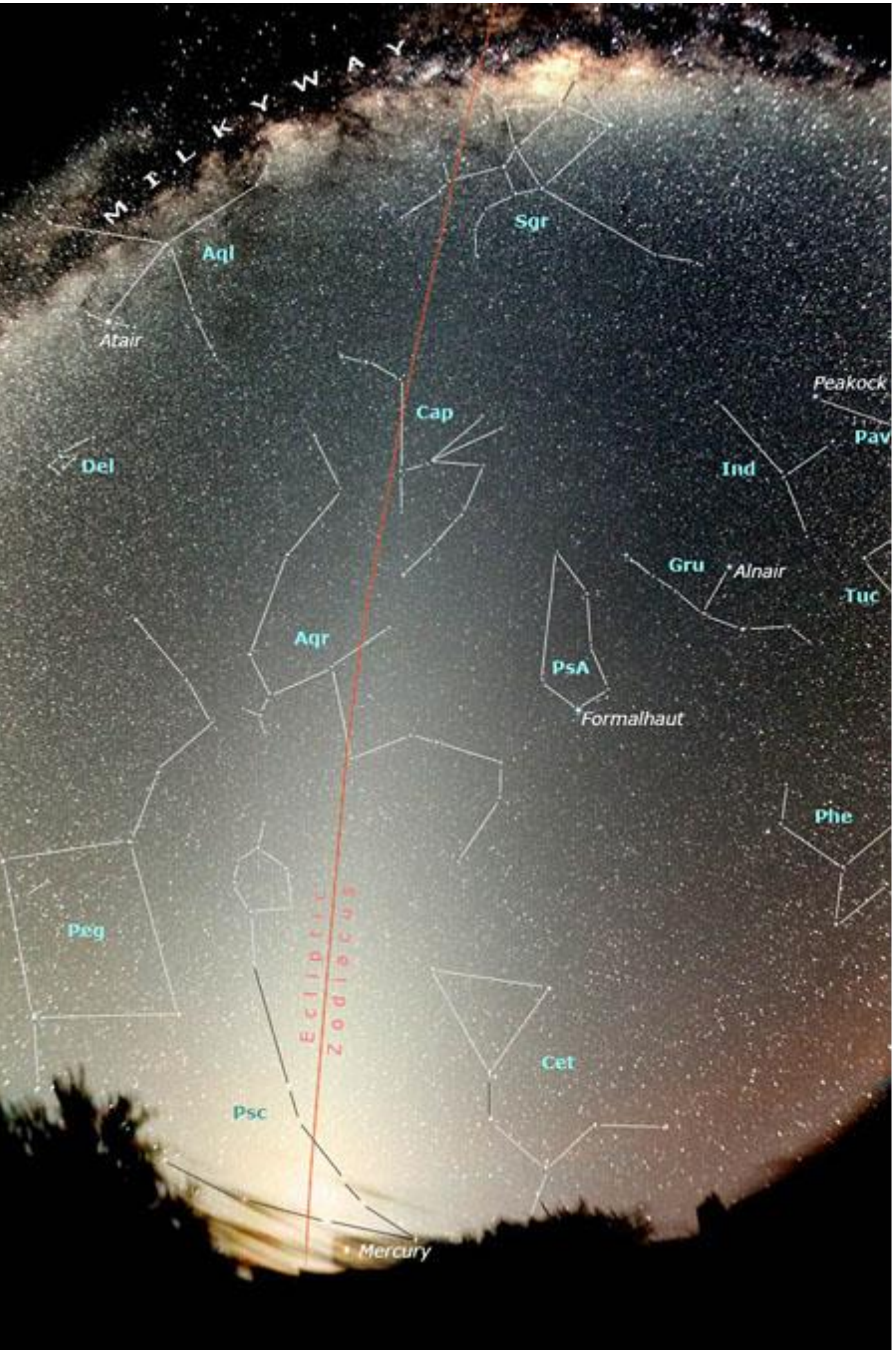
LBTI Update: Reconnaissance of Warm Dust and Giant Planets

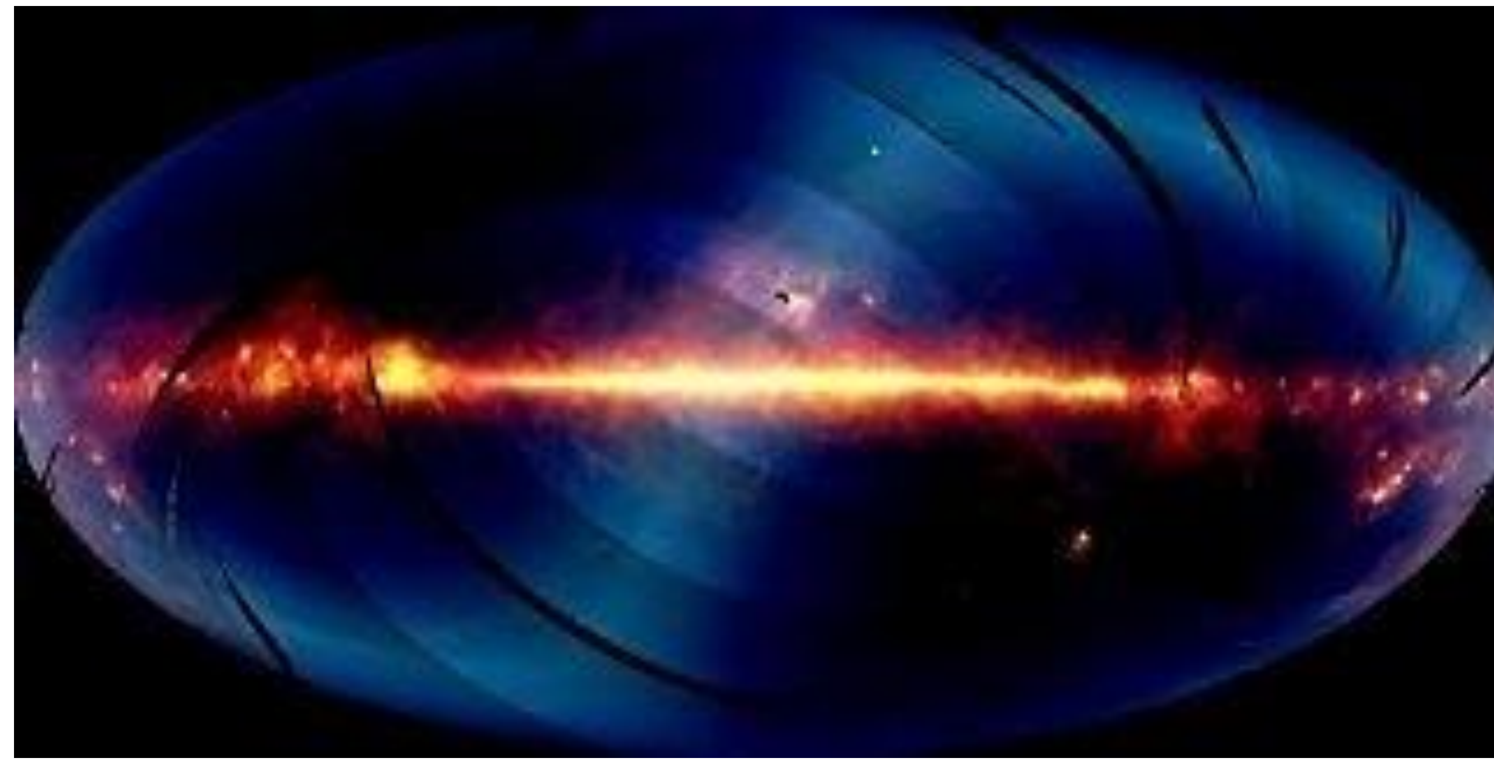
Phil Hinz
University of Arizona
for the LBTI Instrument and Science Teams

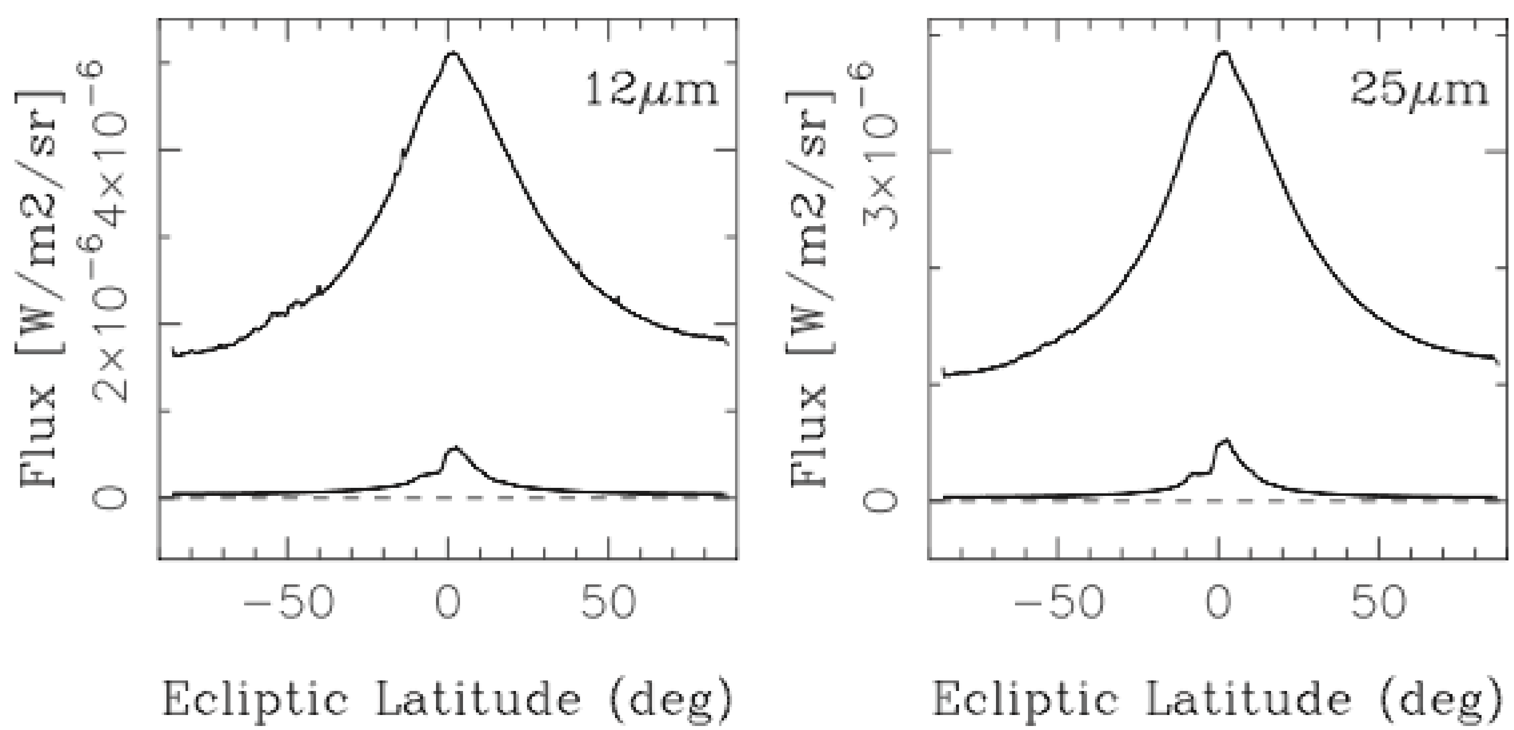
With specific contributions from

Denis Defrere, Andy Skemer, Alycia Weinberger, and Bertrand Mennesson

Zodiacal Dust







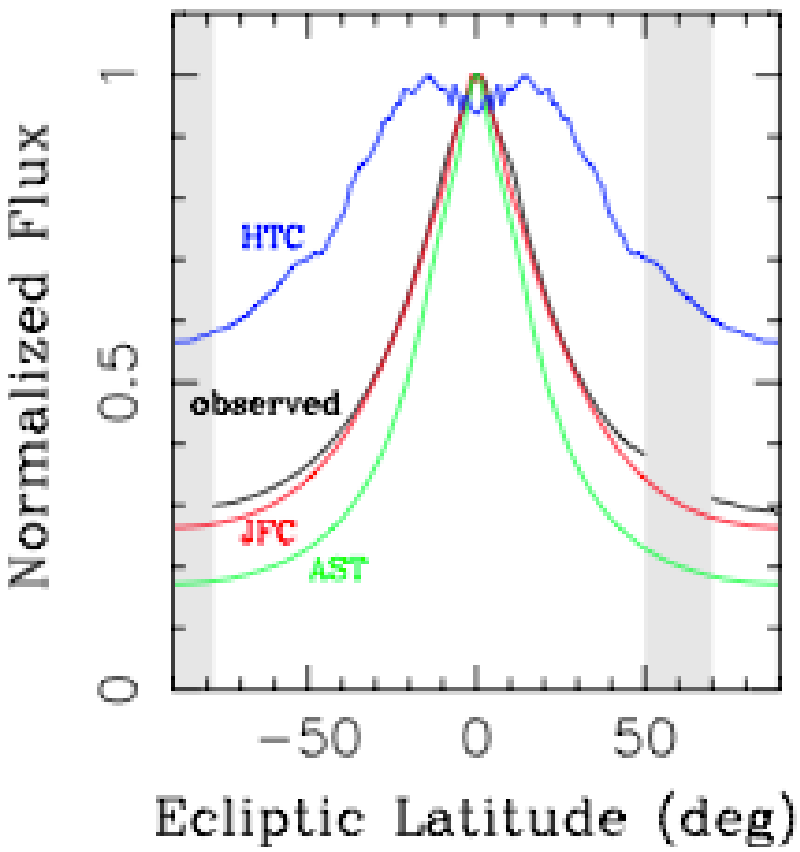
- Scattered light in ecliptic plane
- Infrared emission first seen by IRAS.

from Nesvorney et al. 2010

Origin of Zodiacal Dust

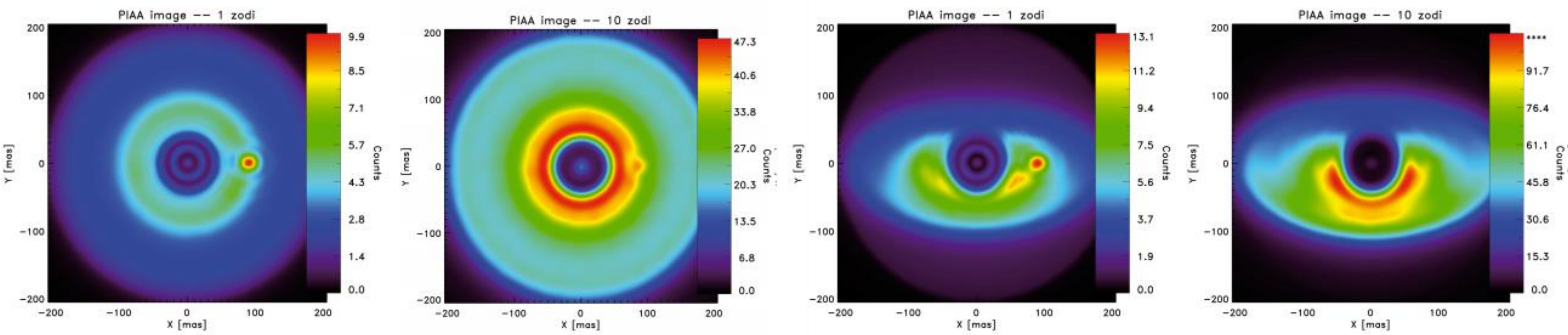
- Asteroid belt thought to provide much of the dust seen at Earth (Dermott et al. 2002).

- Recent Dynamical models (cf. Nesvorney et al. 2010) suggest Jupiter-family comets provide the majority of the dust for the zodiacal cloud.



from Nesvorney et al. 2010

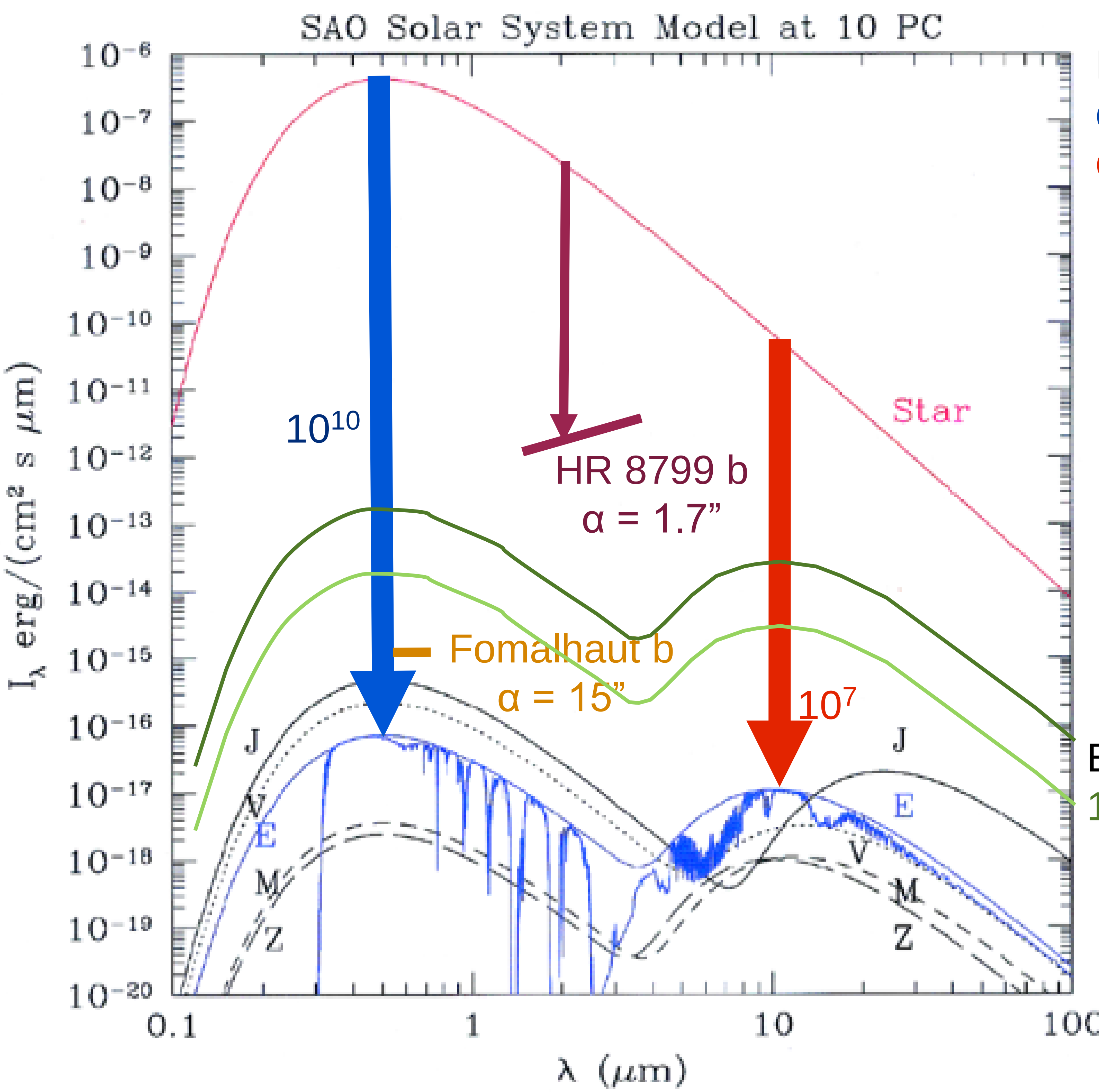
The problem with exozodiacal dust



from Defrere et al. 2012

- Flux is problematic for any imaging mission.
- Clumpiness (resonances) complicates the detection.

The Contrast Problem



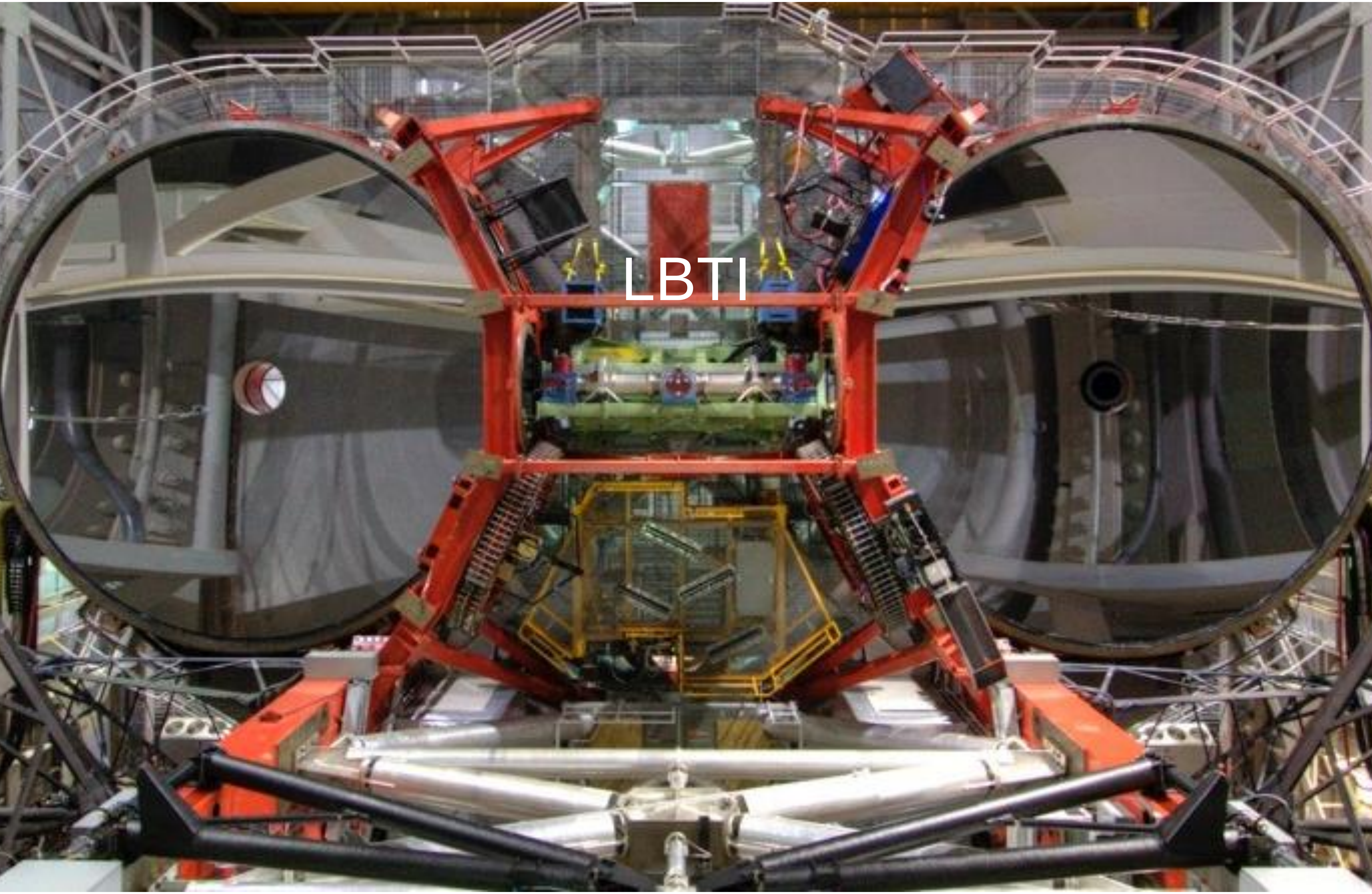
Planet Finding missions aim to:
detect Earths 10^{-10} fainter in visible.
detect Earth 10^{-7} in the IR.

Current state of the art:
Fomalhaut b: 10^{-9}, but 150x separation.
HR 8799b: 10^{-4} but 17x separation.

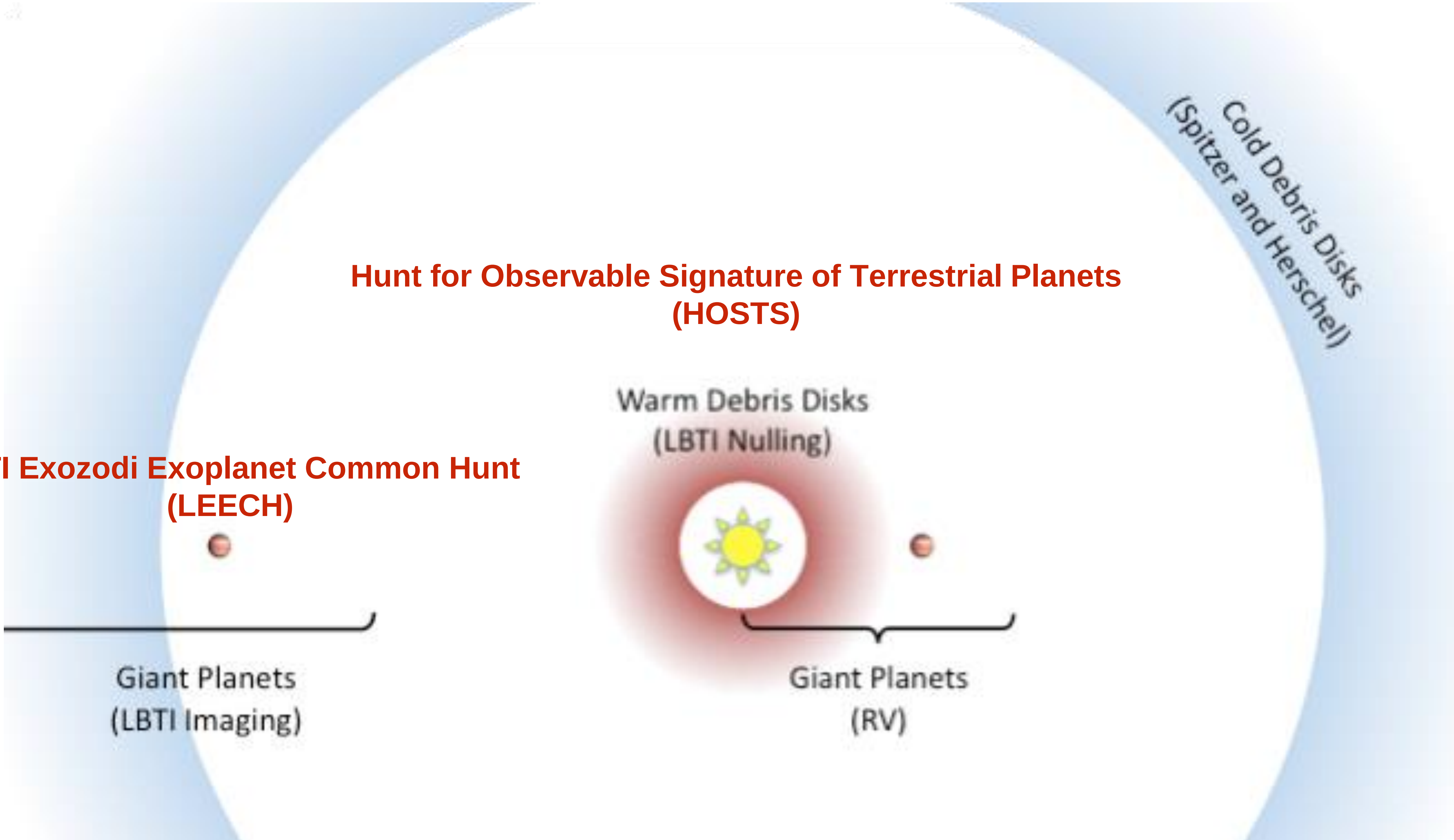
Our own Zodiacal dust:
5x 10^{-5} at 10 μm =1 zody.

Exozodiacal dust becomes a problem:
10 zody or above.

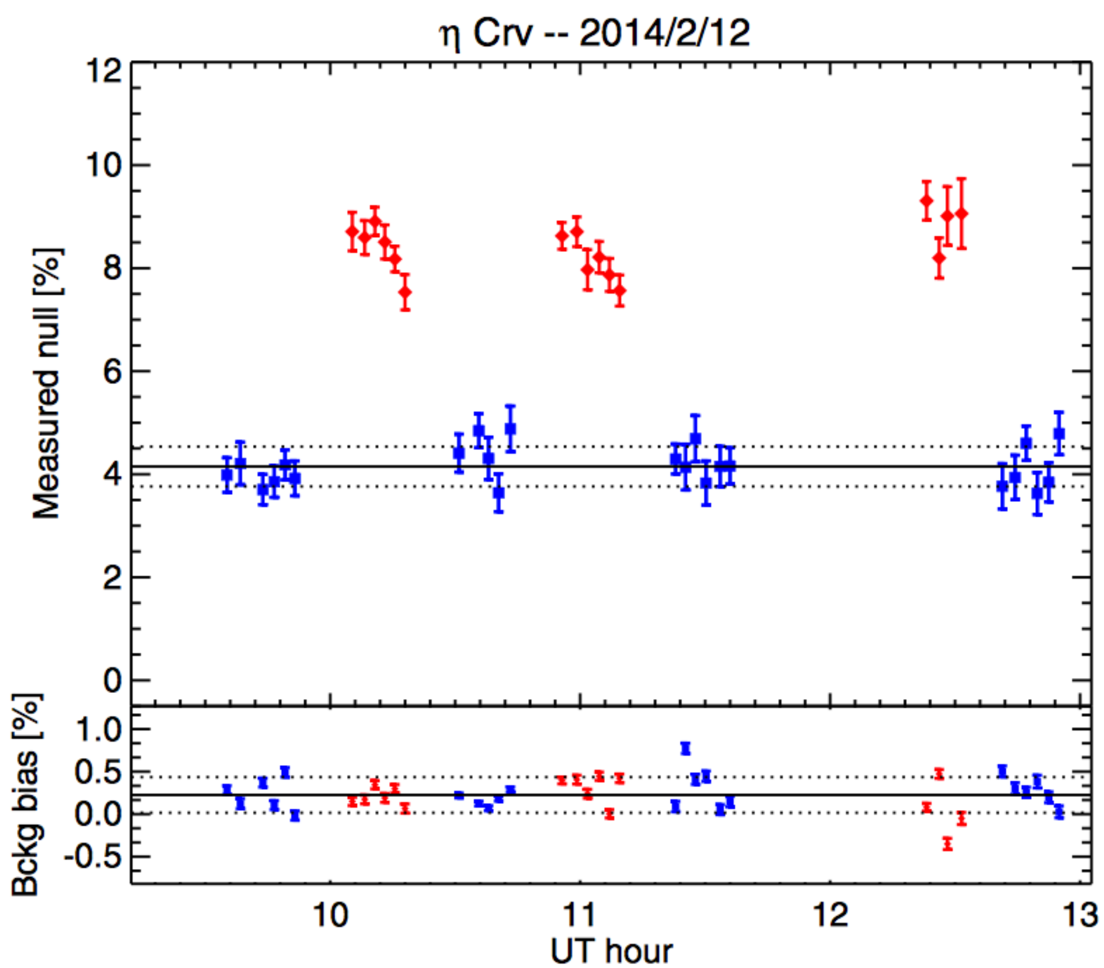
LBTI can show us what exists (planets or dust disks) at faint levels around nearby stars.


LBTI

LBTI Reconnaissance

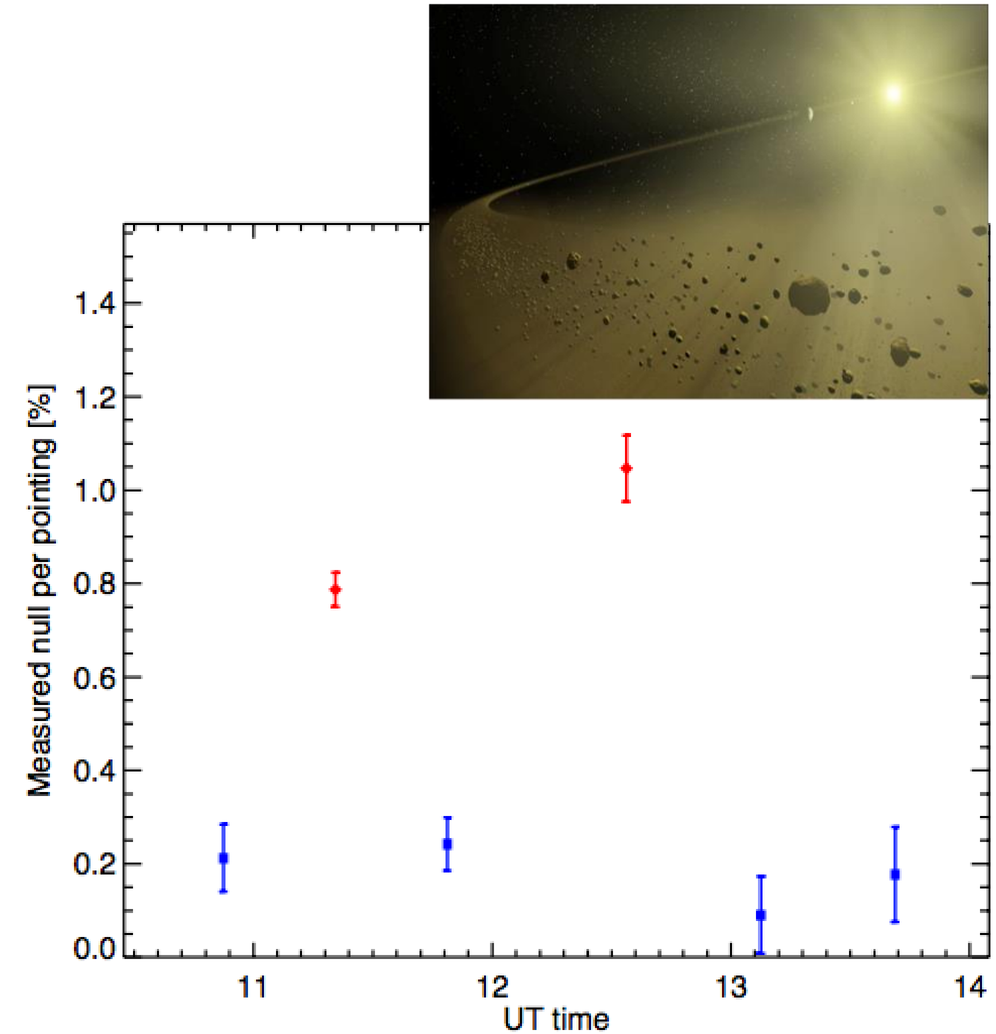


LBTI's first disk detections



Commissioning tests on the star eta Crv detected a bright disk (Defrere et al. 2015).

Modeling indicates dust is at < 1 AU.

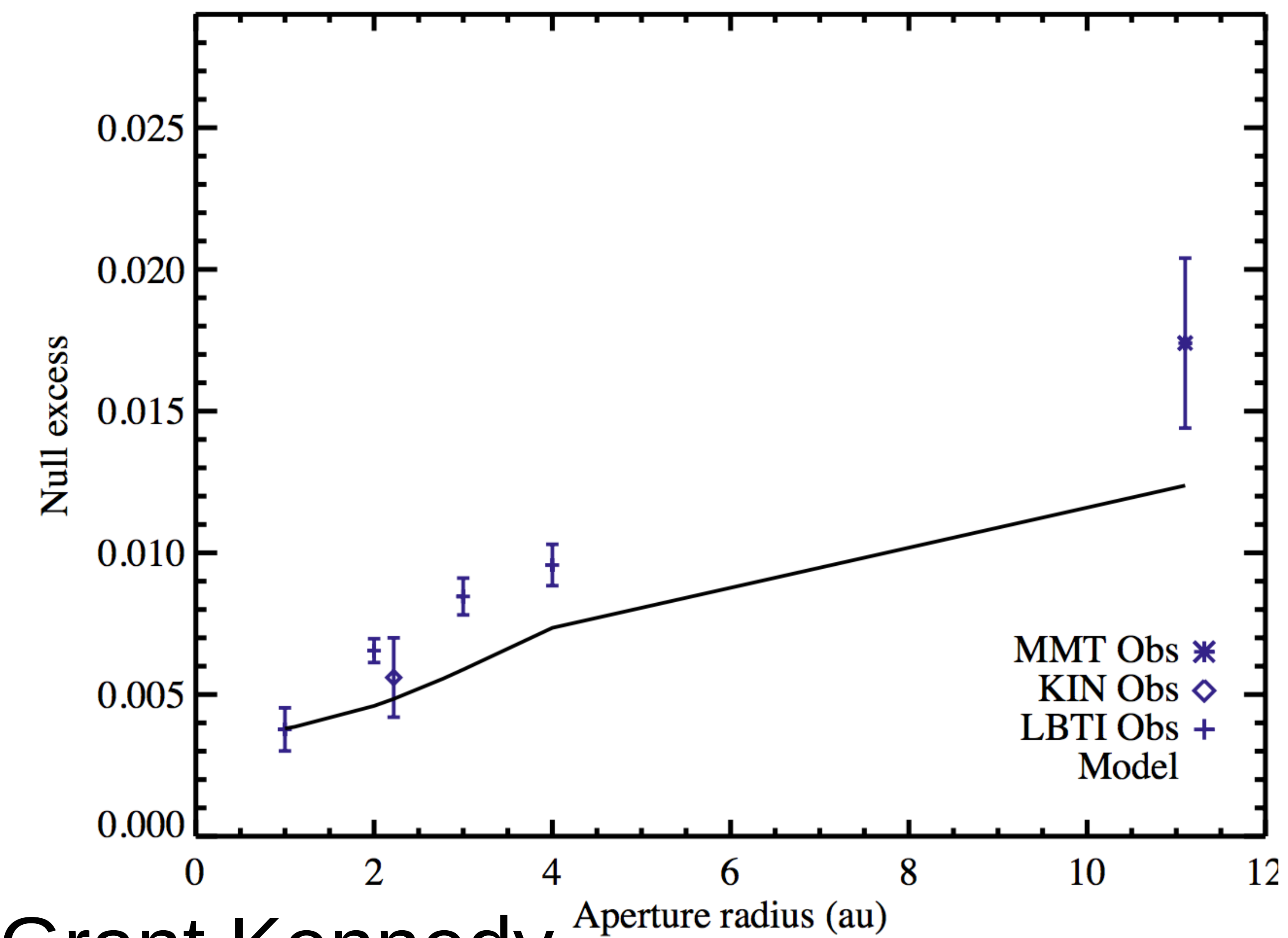


Commissioning tests on the star β Leo detected a disk at the level of 6000±500 ppm.

This corresponds to a disk that is **90 ± 8 zodi.**

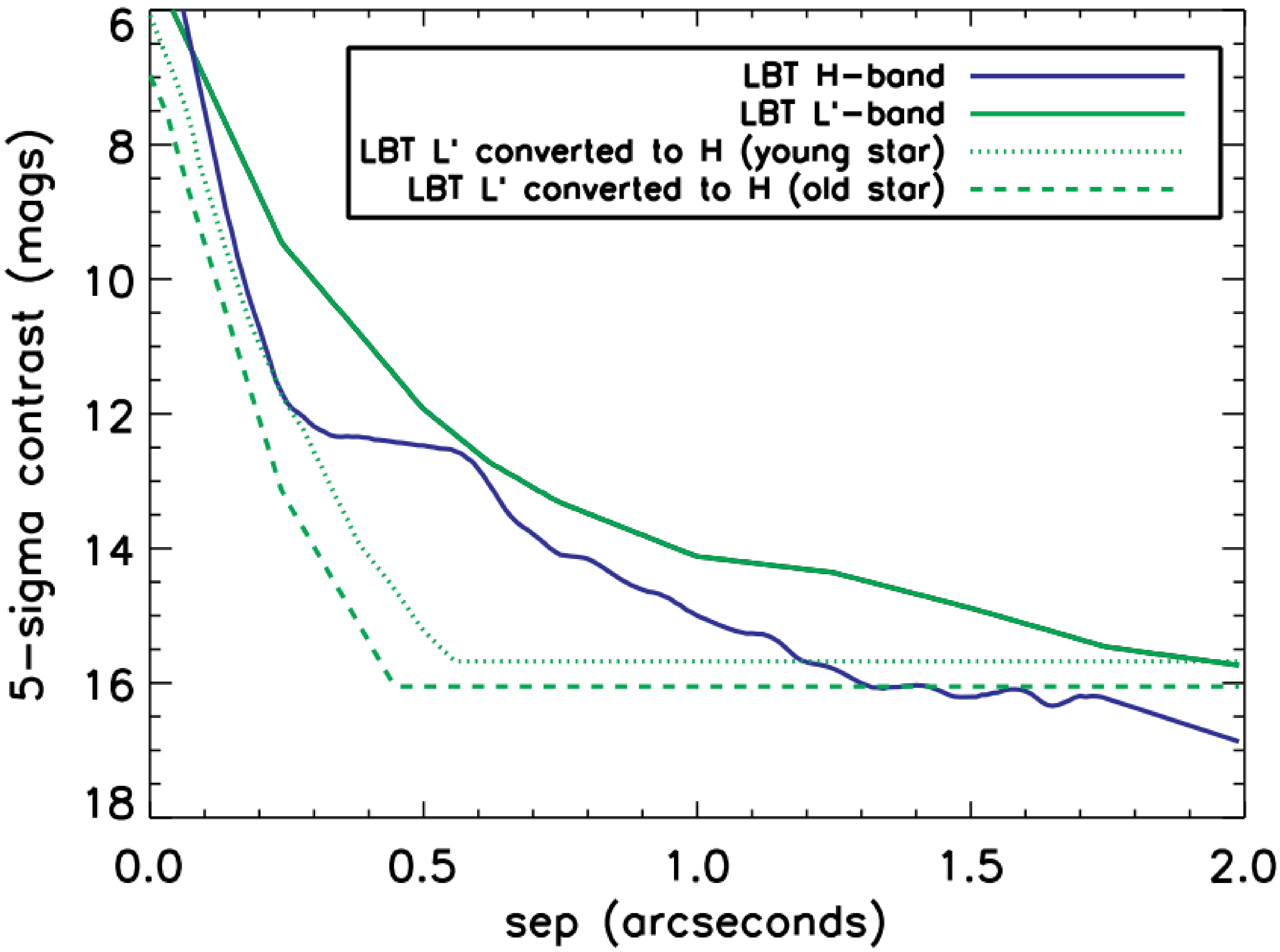
Cold Disk vs. Warm Disk

- Cold Disk resolved by Herschel.
- P-R drag from this reservoir appears to be consistent with the warm emission



Model from Grant Kennedy

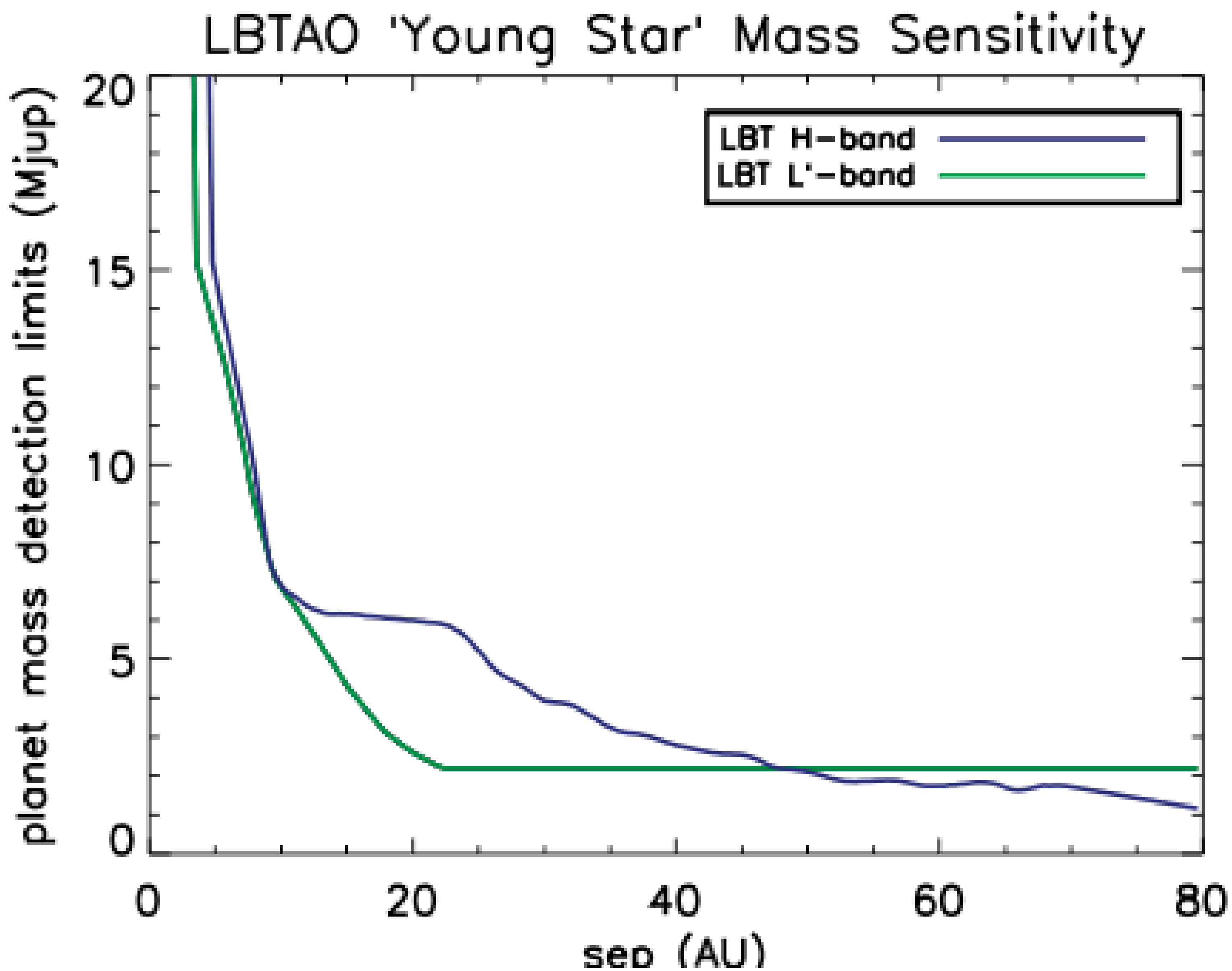
LEECH Sensitivity



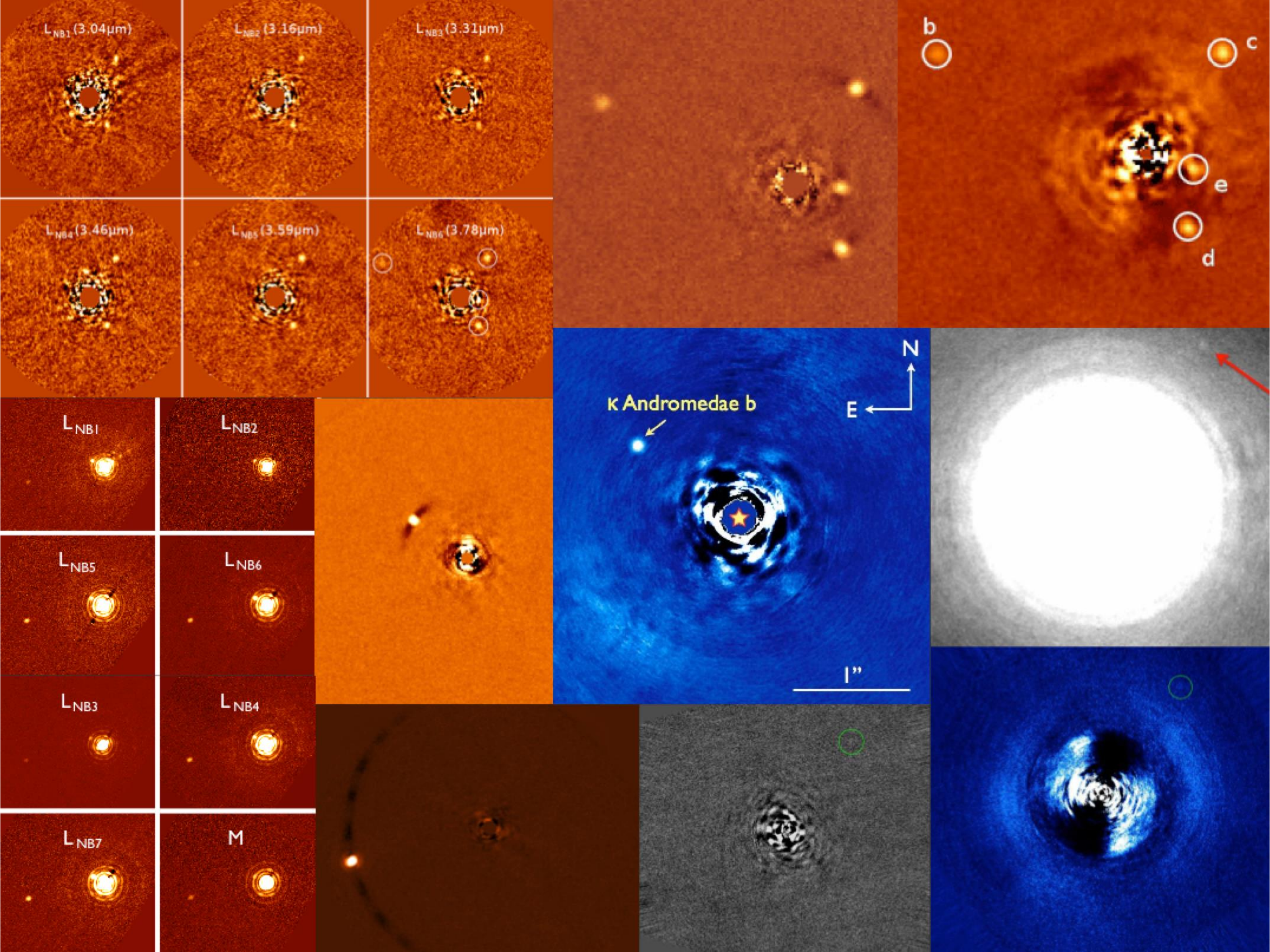
THE UNIVERSITY OF ARIZONA®

JPL

Sensitivity for beta Leo



Skemer et al. 2014



LNB1 (3.04μm)
LNB2 (3.16μm)
LNB3 (3.31μm)
LNB4 (3.46μm)
LNB5 (3.59μm)
LNB6 (3.78μm)
b
c
e
d
LNB1
LNB2
LNB5
LNB6
LNB3
LNB4
LNB7
M
κ Andromedae b
N
E
1”

HOSTS Survey Plans

- Carry out HOSTS survey in FY16-17. We expect to be able to observe 32 stars during this time.
- Improve performance to Requirements level (150 ppm= 6 zodies) during 9 month Science Verification Phase (SVP).
- Additional ~15-20 stars could be observed in FY18, funding permitting.

HOSTS Objectives

Satisfy:

1. Observe ACTUAL stars that would be good targets for a future direct imaging mission#
2. Observe a SAMPLE of stars that enable sensible extrapolations to those stars that cannot be observed

For simplicity, hereafter referred to as TPF without prejudice as to the precise architecture of such a mission, but with knowledge that currently a large aperture visual wavelength telescope with internal or external coronagraph looks most likely.

Note: Not every star can be observed by LBTI to the same depth

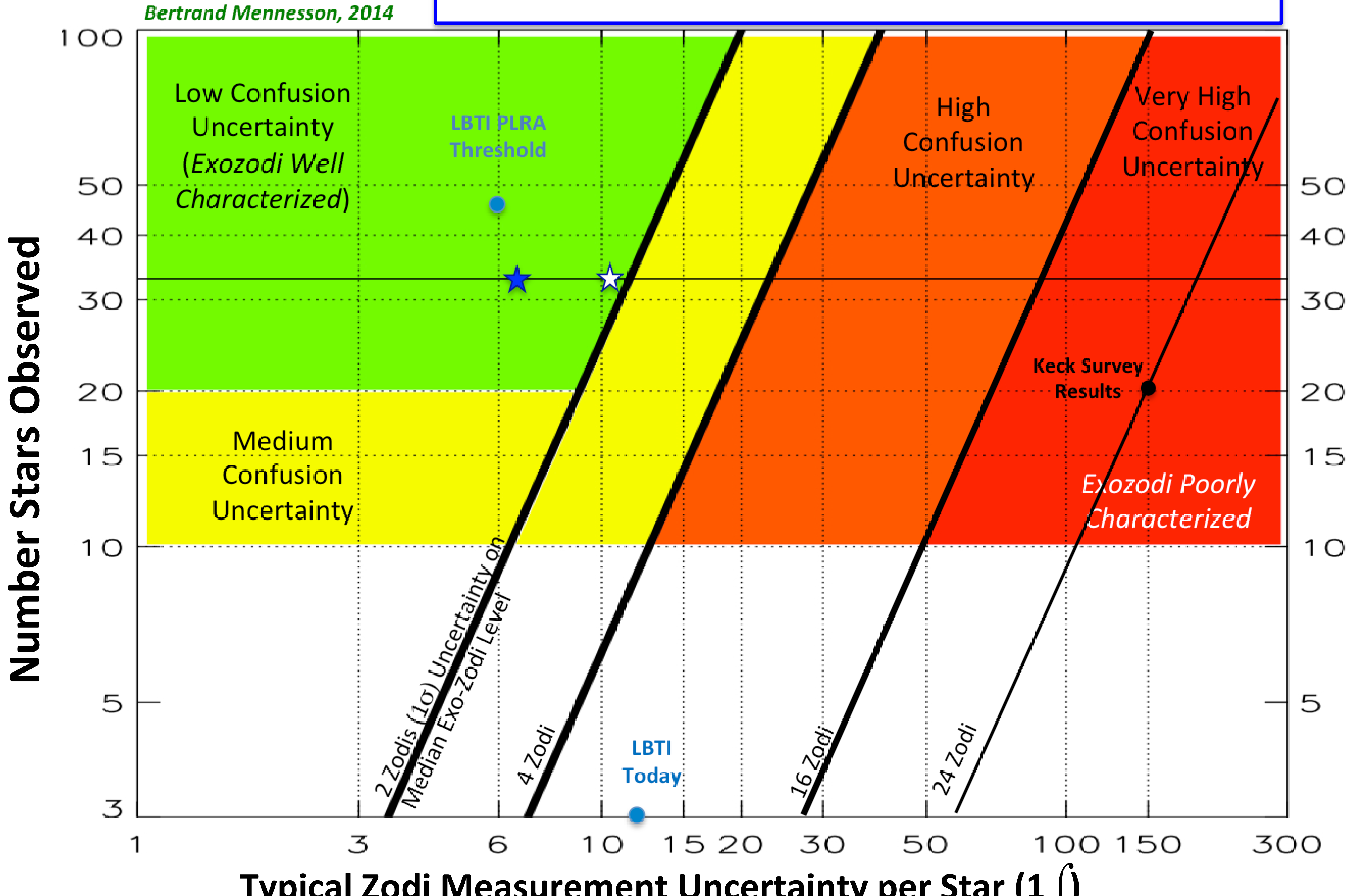
LBTI Requirements to Inform Design of Future Missions

- **How to derive the uncertainty of the median exo-zodi level for given target list and LBTI null measurement accuracy:**
  - Compute null uncertainty per star given current performance
    - incorporates null floor term as would be measured on infinitely bright star and stellar flux dependent null error term
  - Compute corresponding zodi level uncertainty per star
  - Rank targets in order of increasing zodi level uncertainty, i.e from “best” to “worse”
  - Compute resulting uncertainty on the median zodi level, as a function of the number of “best” targets observed

LBTI Requirements to Inform Design of Future Missions

- *Uses star dependent Null Uncertainty, including:*
  - *Null Floor = 350 ppm (irreducible, 400 ppm for 7 Jy star)*
  - *Photometric Null error*
- *Uses best 32 Stars from the HOSTS target list*
  - *Mean uncertainty is 10.3 zodi*

Bertrand Mennesson, 2014



Uncertainties on the Median Exozodi Level

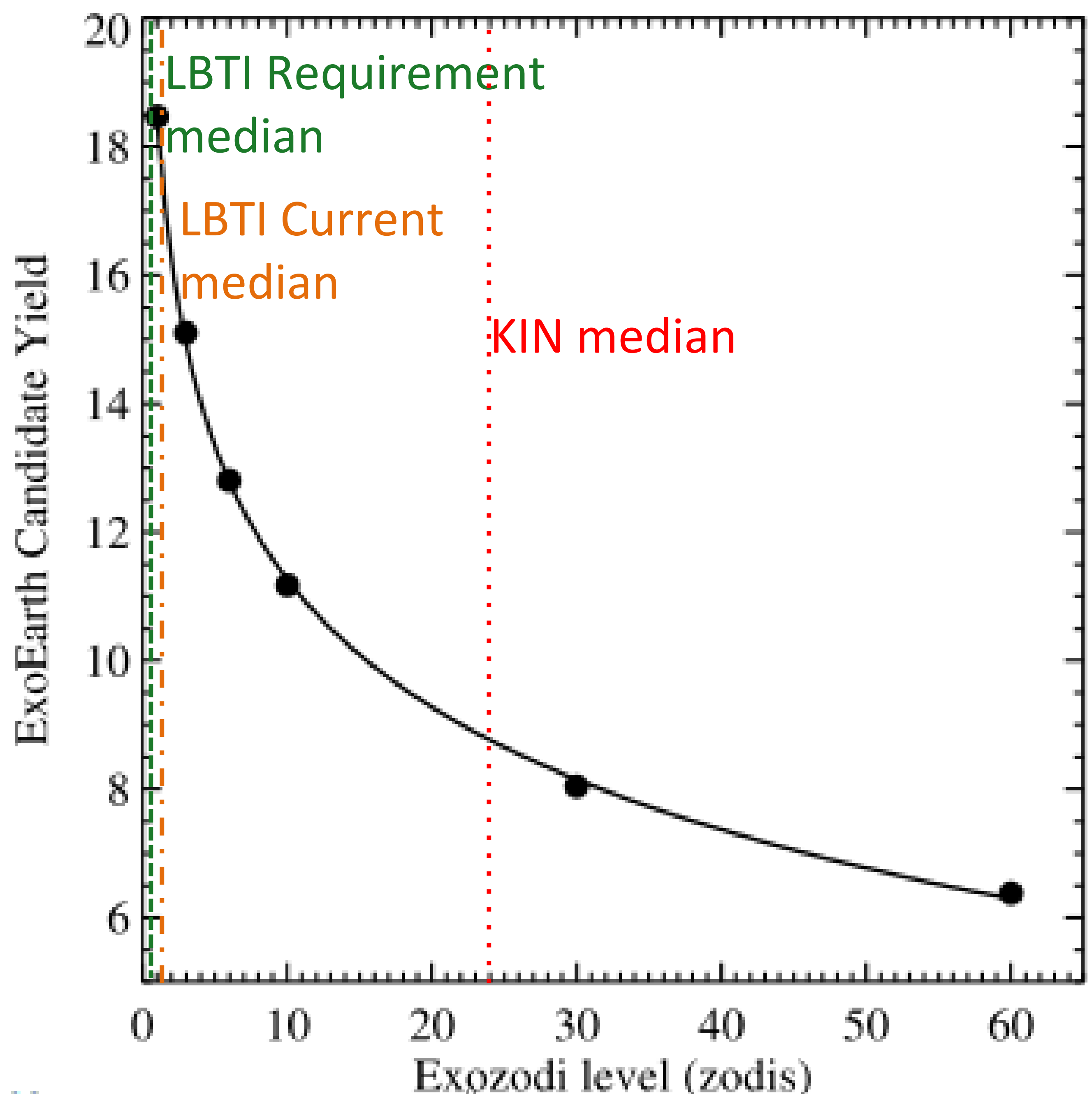
- Individual Stars Exozodi measurement uncertainties are different: $(\sigma_z^i)_{\{1<= i <=N\}}$
- Resulting measurement uncertainty on the median exozodi level *of the N-sample* is: $\sigma_{median} \approx [\Sigma_i 1/(\sigma_z^i)^2]^{-1/2}$
- The typical uncertainty per star (yielding the same median error) is $N^{1/2} . \sigma_{median}$
- N=32 “best accuracy” targets case is indicated by blue star
- This uncertainty on the sample median is 0 for a perfect instrument
- Final uncertainty on the median of the *parent (infinite) population* must also include finite sampling uncertainty:
  - $\sigma_{median} = [\Sigma_i 1/(\sigma_z^i)^2 + K/N]^{-1/2}$, where K value depends on the exozodi LF and can not be predicted a priori
  - E.g., measuring a single star with an accuracy better than 2 zodis is not sufficient !
  - White star shows final uncertainty for a uniform exozodi distribution btw 0 and 20 zodis and is still below 2 zodis when observing the best accuracy 32 stars.

HOSTS Objectives

Understand the level of exozodi around nearby stars because it is a potential noise source for direct imaging / spectroscopy of planets

How many planets can a telescope find?

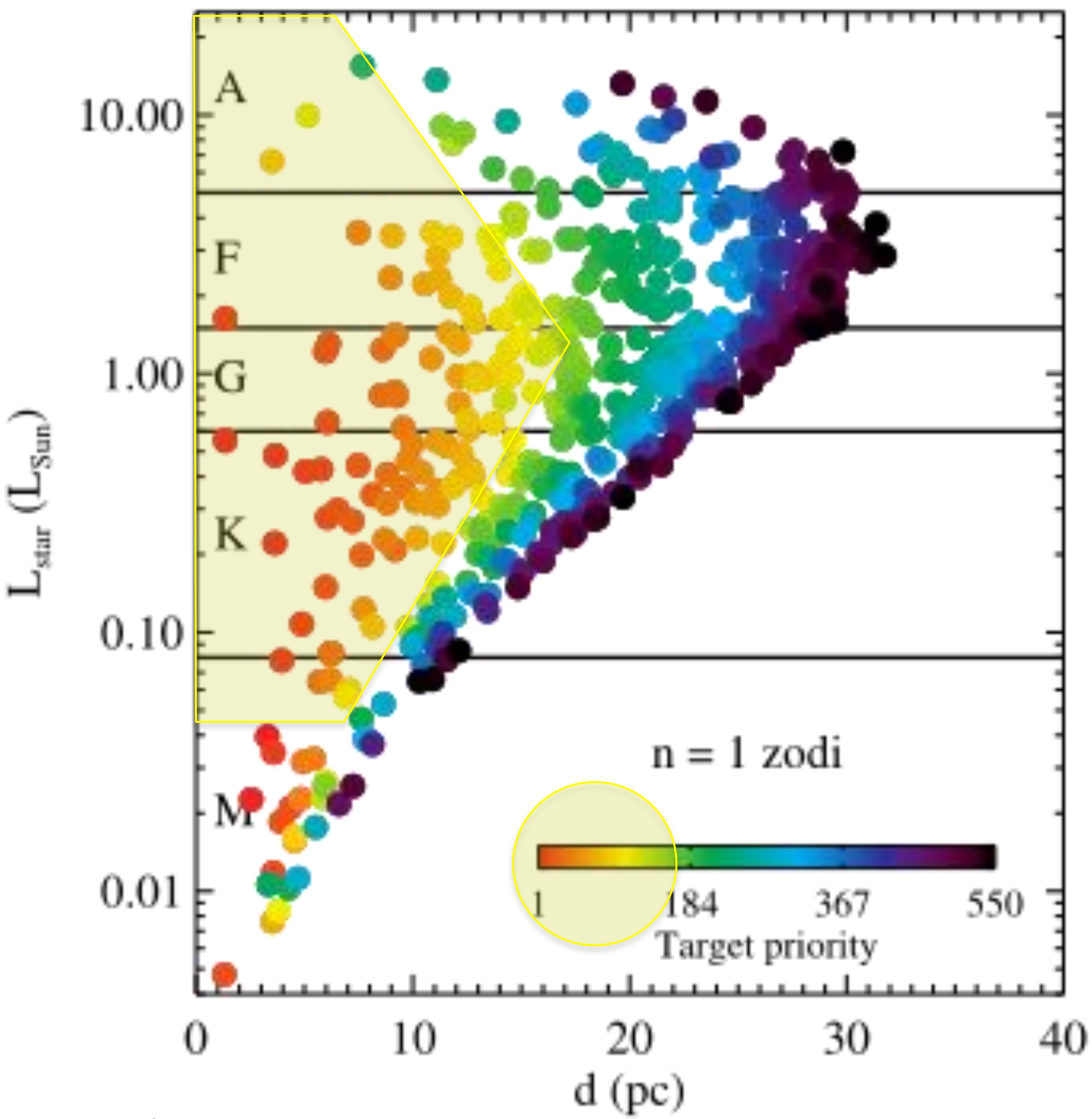
Stark et al. 2014 “Altruistic Yield Optimization” for their baseline 8 m telescope and IWA= 2 λ /D



THE UNIVERSITY OF ARIZONA®

Choices Driven by Mission Considerations

Sweet spot for TPF is F-G-K stars, but A stars are included



Stark et al. 2014 "Altruistic Yield Optimization" for their baseline 8 m telescope and IWA=2⌊/D

THE UNIVERSITY OF ARIZONA®

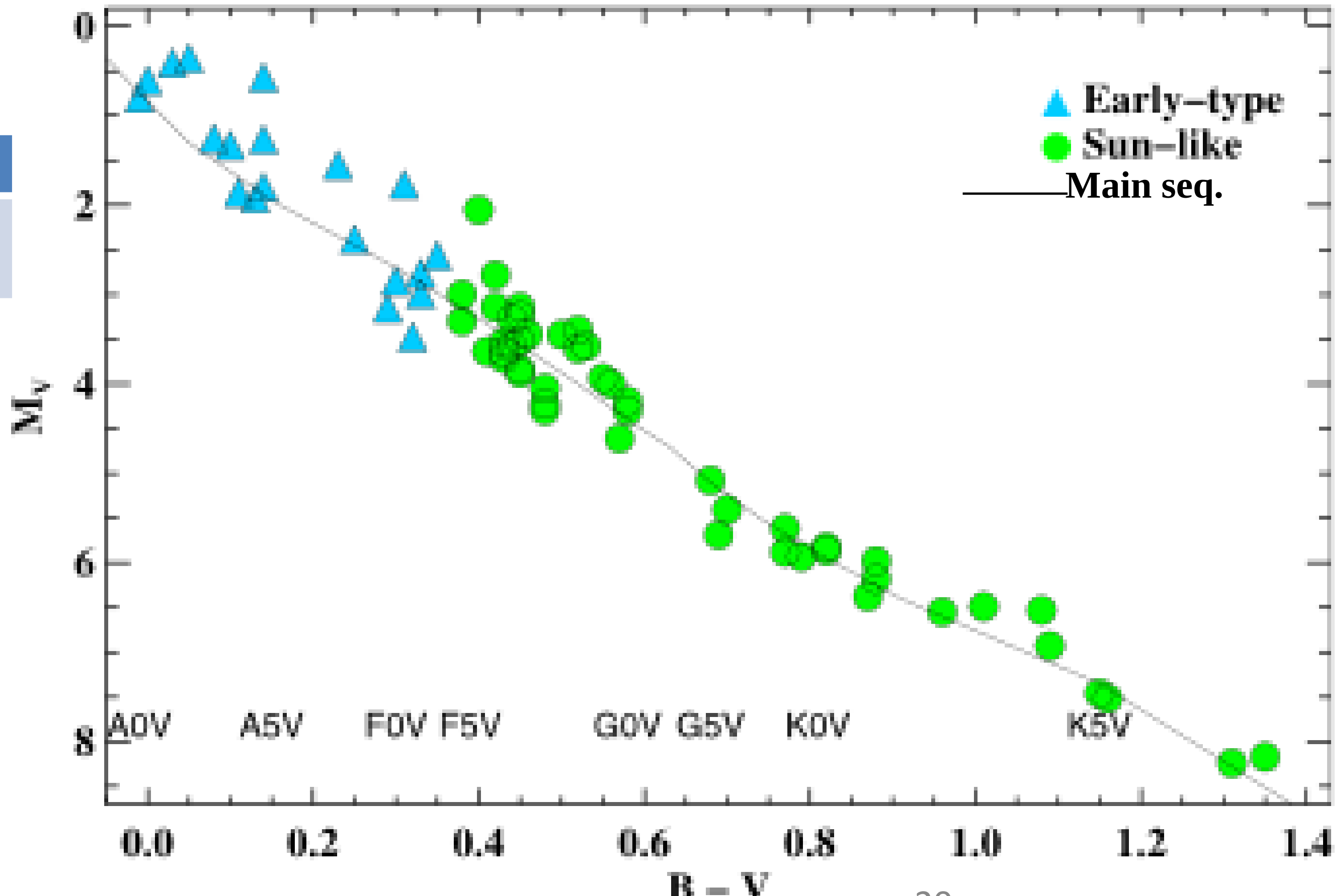
‹#›

JPL

Overview of 68 Star Target List

1. **Sun-like Sample**
   F5 – K7 type (analogous to Kepler targets) – 48 stars
2. **Early-type Sample**
   A0 – F4 type (Bright nearby stars) – 20 stars

	A type	F type	G type	K type	Total
Number	*13*	*32*	*8*	*15*	*68*



Targets lists published in Weinberger et al. 2015, ApJS, 216:24

Our 68 Best LBTI targets are likely TPF targets

51 are on a sample TPF list

	HD	Name	Sp Type	DIST
✹	216956	Fomalhaut	A4V	7.7
	102647	Altair	A7V	11.0
✹	187642	bet Leo	A3Va	5.1
✹	97603	del Leo	A4V	17.9
	203280	Alderamin	A7IV	15.0
	48737	ksi Gem	F5IV	18.0
✹	38678	zet Lep	A2IV-V(n	21.6
	81937	h UMa	F0IV	23.8
✹	40136	eta Lep	F2V	14.9
	38393	gam Lep	F6V	8.9
✹	10700	tau Cet	G8.5V	3.7
	102870	bet Vir	F9V	10.9
	105452	alf Crv	F1V	14.9
	142860	gam Ser	F6IV	11.3
✹	128167	sig Boo	F2V	15.8
	197692	psi Cap	F5V	14.7
✹	109085	eta Crv	F2V	18.3
	164259	zet Ser	F2IV	23.6
	17206	tau01 Eri	F75	14.2
	16895	13 Per	F7V	11.1
	23754	tau06 Eri	F5IV-V	17.6
	222368	iot Psc	F7V	13.7
	9826	ups And	F9V	13.5
	173667	110 Her	F6V	19.2
	215648	ksi Peg A	F7V	16.3
	126660	tet Boo	F7V	14.5
	89449	40 Leo	F6IV	21.4
✹	22484	LHS 1569	F8V	14.0
	19373	iot Per	F9.5V	10.5
✹	90839	36 Uma	F8V	12.8
	142373	LHS 3127	F8Ve	15.9
	34411	lam Aur	G1.5IV-V	12.6
	141004	lam Ser	G0IV-V	12.1
	693	6 Cet	F8V	18.7

Example List Here:

- TPF list is for a 4m telescope, 2 ⎣ /D IWA, 2 yr total integration time (Stark et al. 2014)
- This list is ranked by LBTI sensitivity (34 targets shown, 2 observed already).
- Actual targets will be chosen by science and technical prioritization plus weather plus scheduling

✹ Cold IR Excess

Additional Science Goals

Likely to require more than a 32 star sample to satisfy

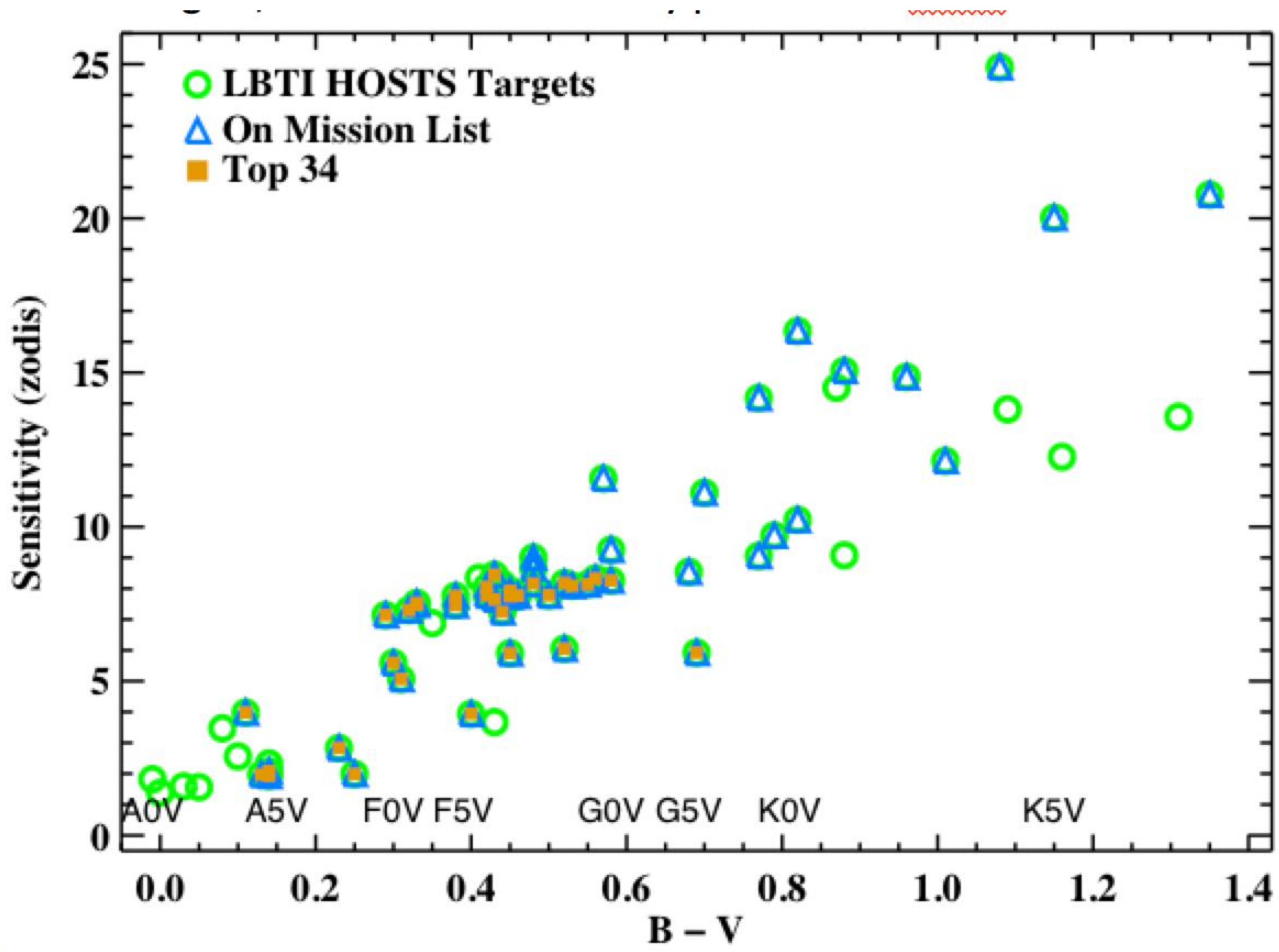
1. Do all mass/luminosity stars have the same exozodi brightness distribution?

   → Observe stars of a range of spectral types
2. How correlated is the level of cold dust with exozodi level? (KIN showed a correlation, but not its distribution)
3. What is hot excess observed by near-IR interferometers?
4. How does dust luminosity change with age? (our target list is not designed for this)

If median exozodi level is high, we should consider an extended program to observe more actual TPF targets

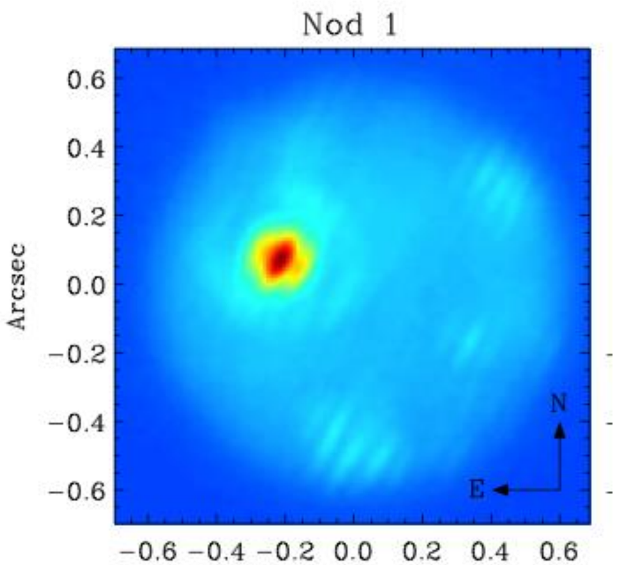
LBTI Target Sensitivity

We can observe a subsample of 32 targets, all of which are good TPF targets, and achieve sensitivity per star < 9 zodis.



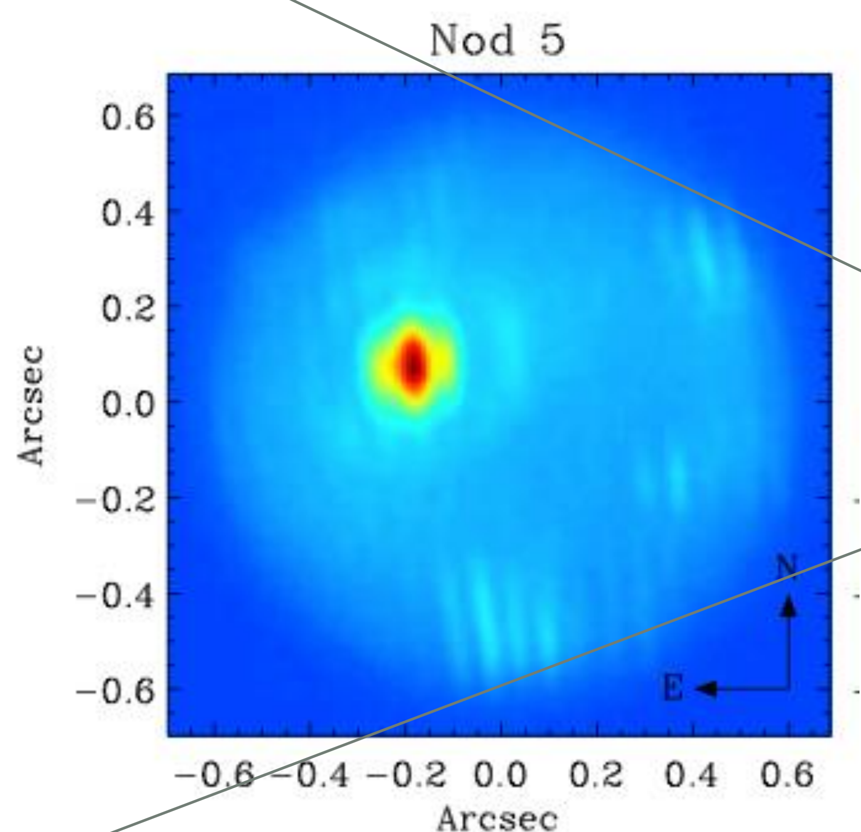
PLRA (ring) Zodi Model with F_{dust}/F_{*} scaled realistically

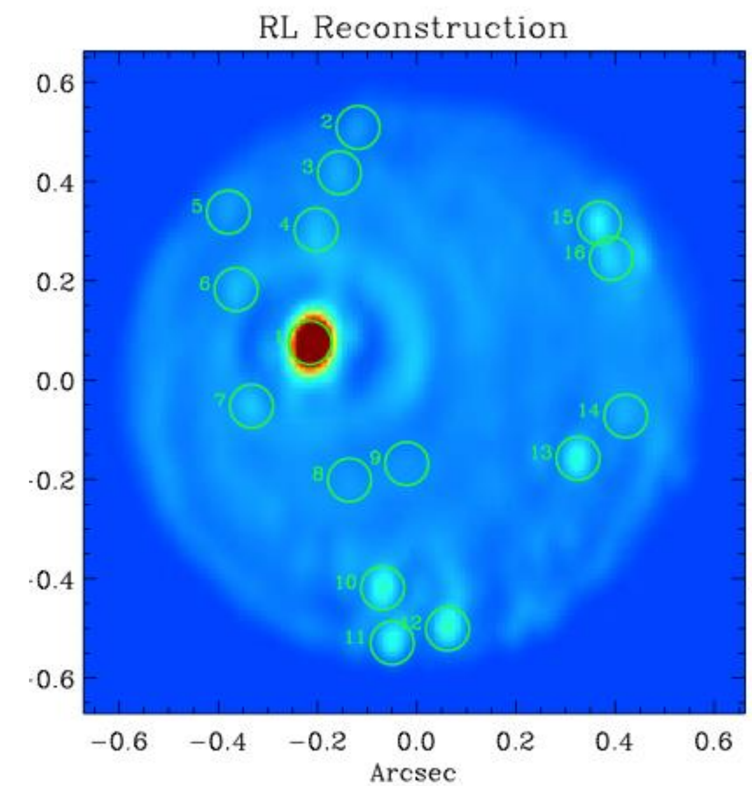
Other LBTI Capabilities: Imaging at 23 m resolution

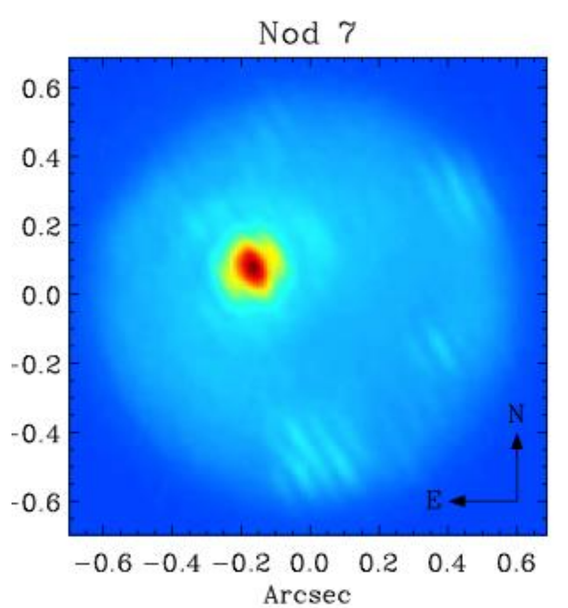


Jupiter’s moon Io, at 4.7 μm wavelength

14 volcanoes resolved





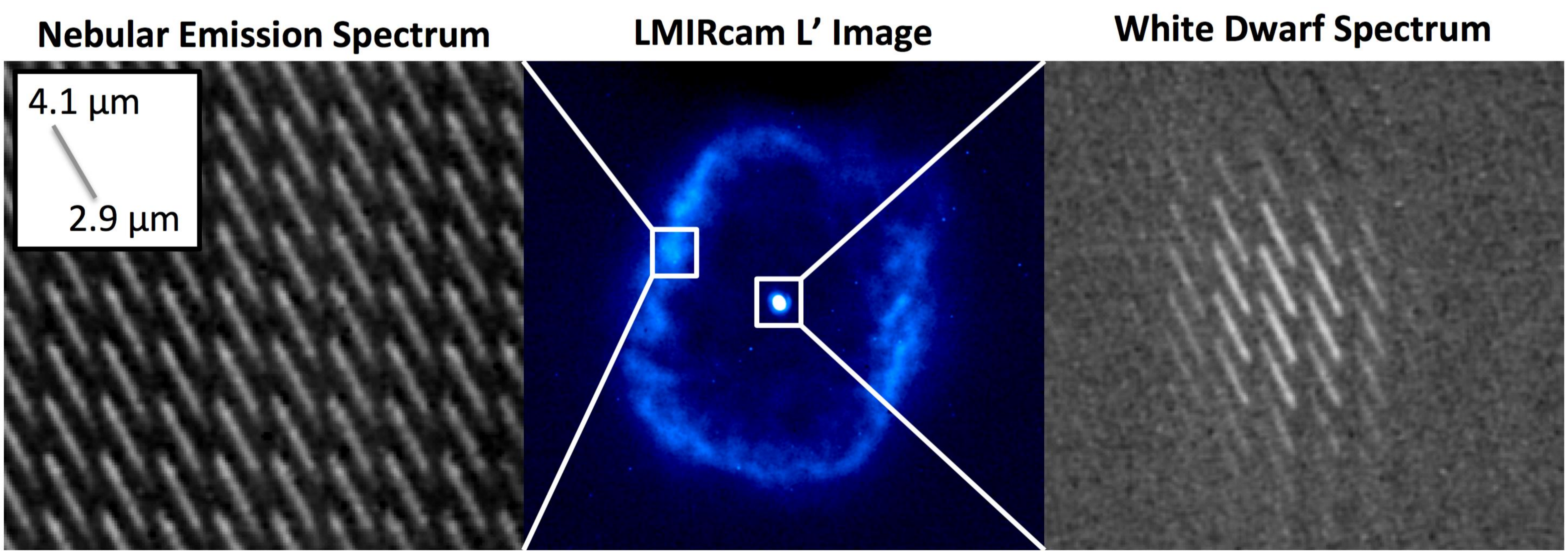


43 mas resolution on a complex structure

Conrad et al. 2015

Other LBTI Capabilities 2: An IFU for exoplanets at 3-4 µm

- First tests of system carried out on June 1-3.
  - spaxels are 25 mas.
  - FOV is 1.3" (to be upgraded to 2.6")



Summary

- The LBTI HOSTS survey for dust is beginning this fall.
  - Typical sensitivity is 11 zodies in the habitable zone.

- LBTI is observing nearby stars for giant planets with the LEECH Survey.
  - Typical sensitivity is 1-5 MJ at 5-20 AU.

- Results from these surveys will provide helpful context and input for future exo-Earth imaging missions.

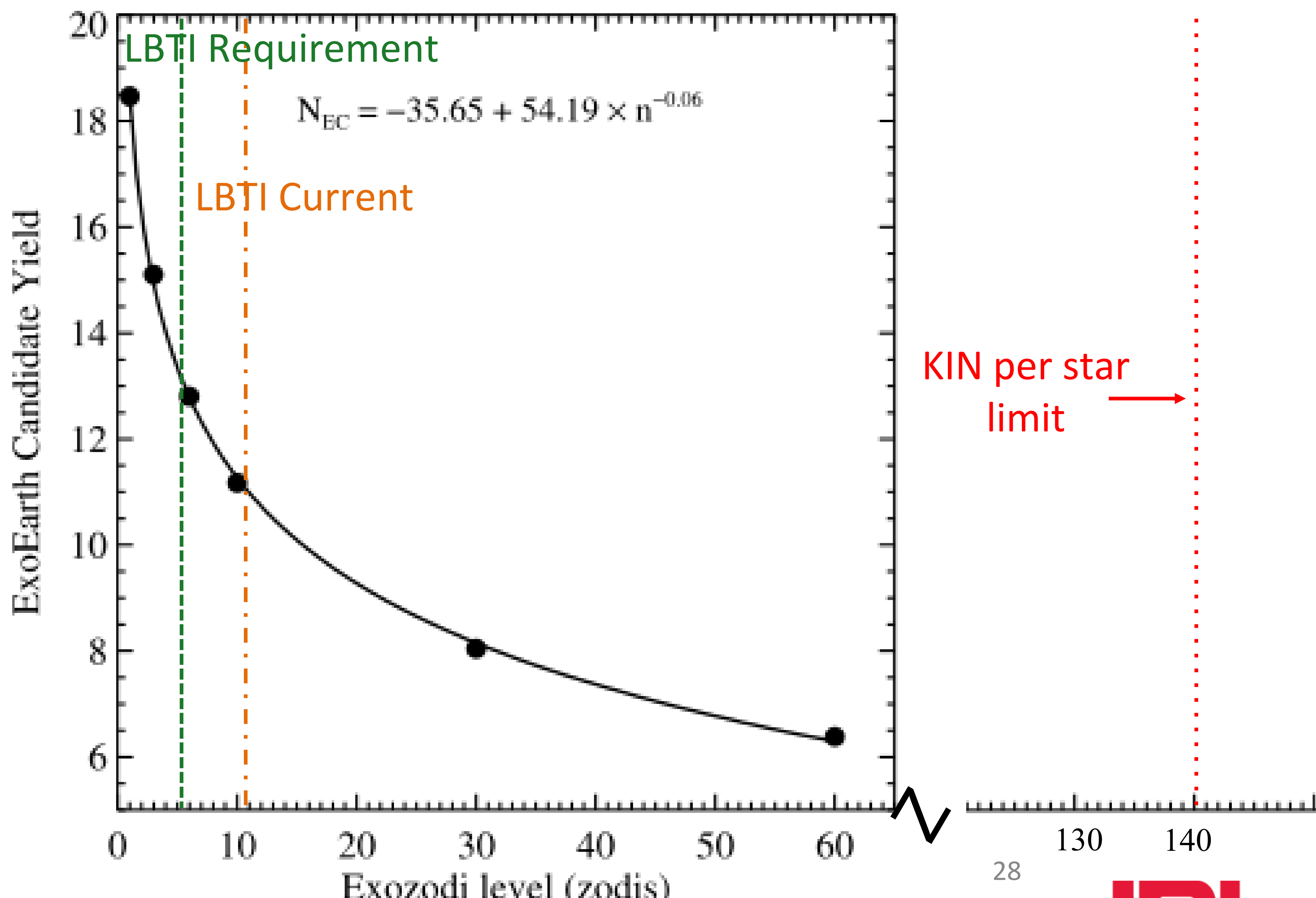
Backup Slides

HOSTS Objectives

Understand the level of exozodi around nearby stars because it is a potential noise source for direct imaging / spectroscopy of planets

How many planets can a telescope find?

Stark et al. 2014 "Altruistic Yield Optimization" for their baseline 8 m telescope and IWA= 2⎣/D

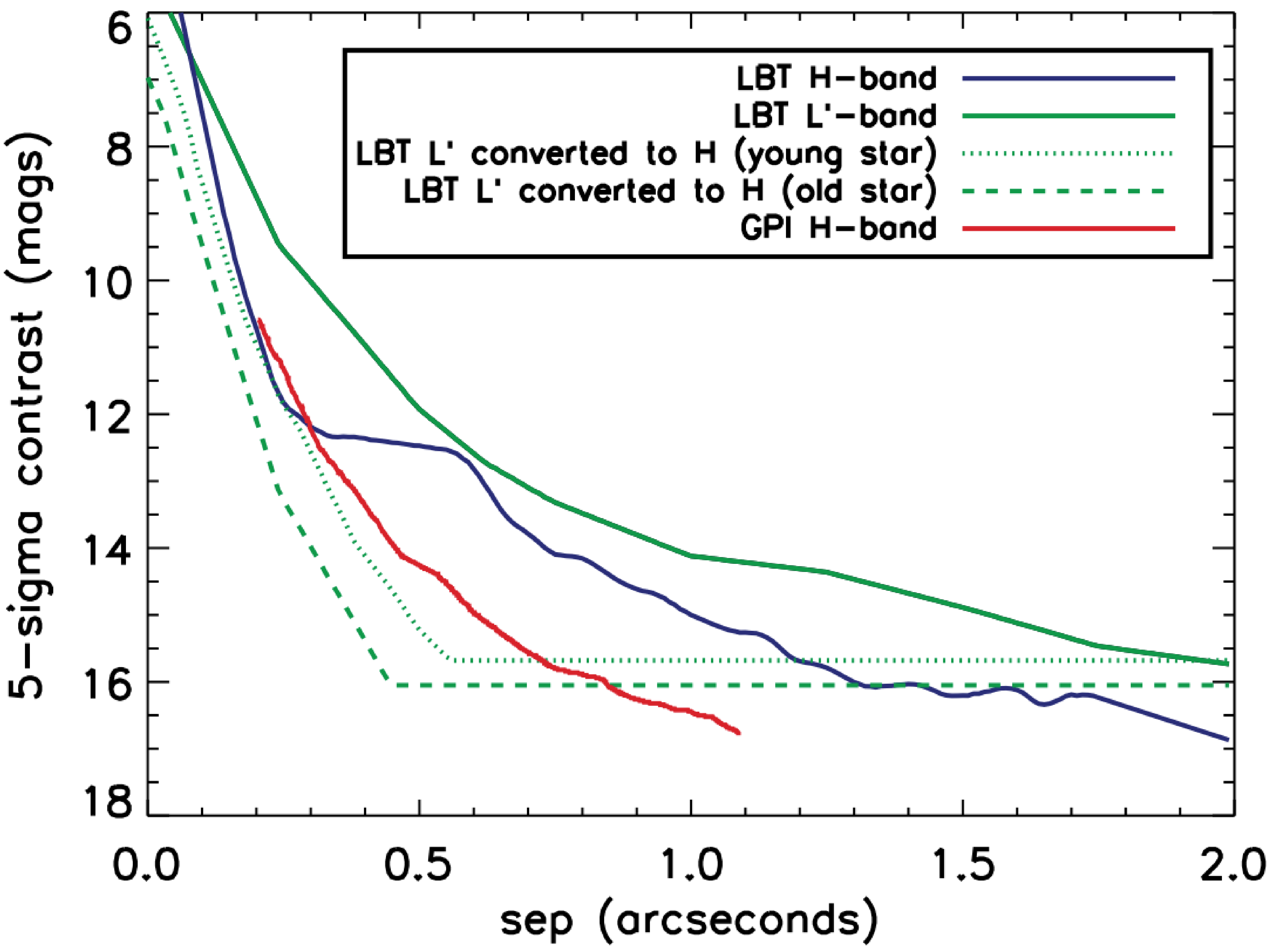


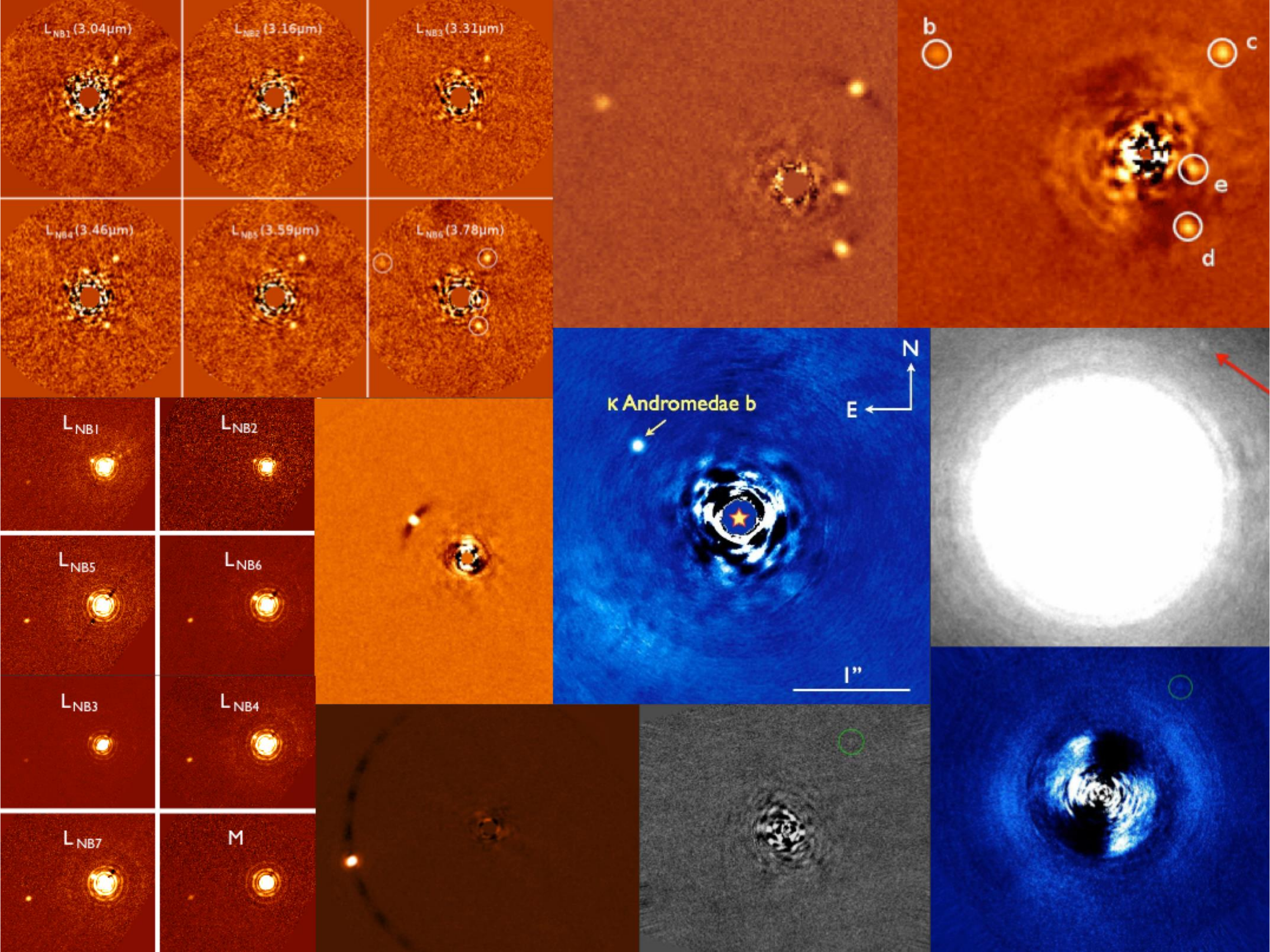
Binary and Multiple System Exclusion

Applies to all categories of targets

- Separation 0.1″– 1.5″ contaminates null and/or can interfere with AO lock
  - These are <50 AU separations
- <100 AU separations deplete circumstellar disks faster and more completely (e.g. Andrews & Williams 2005, Bouwman et al. 2006)

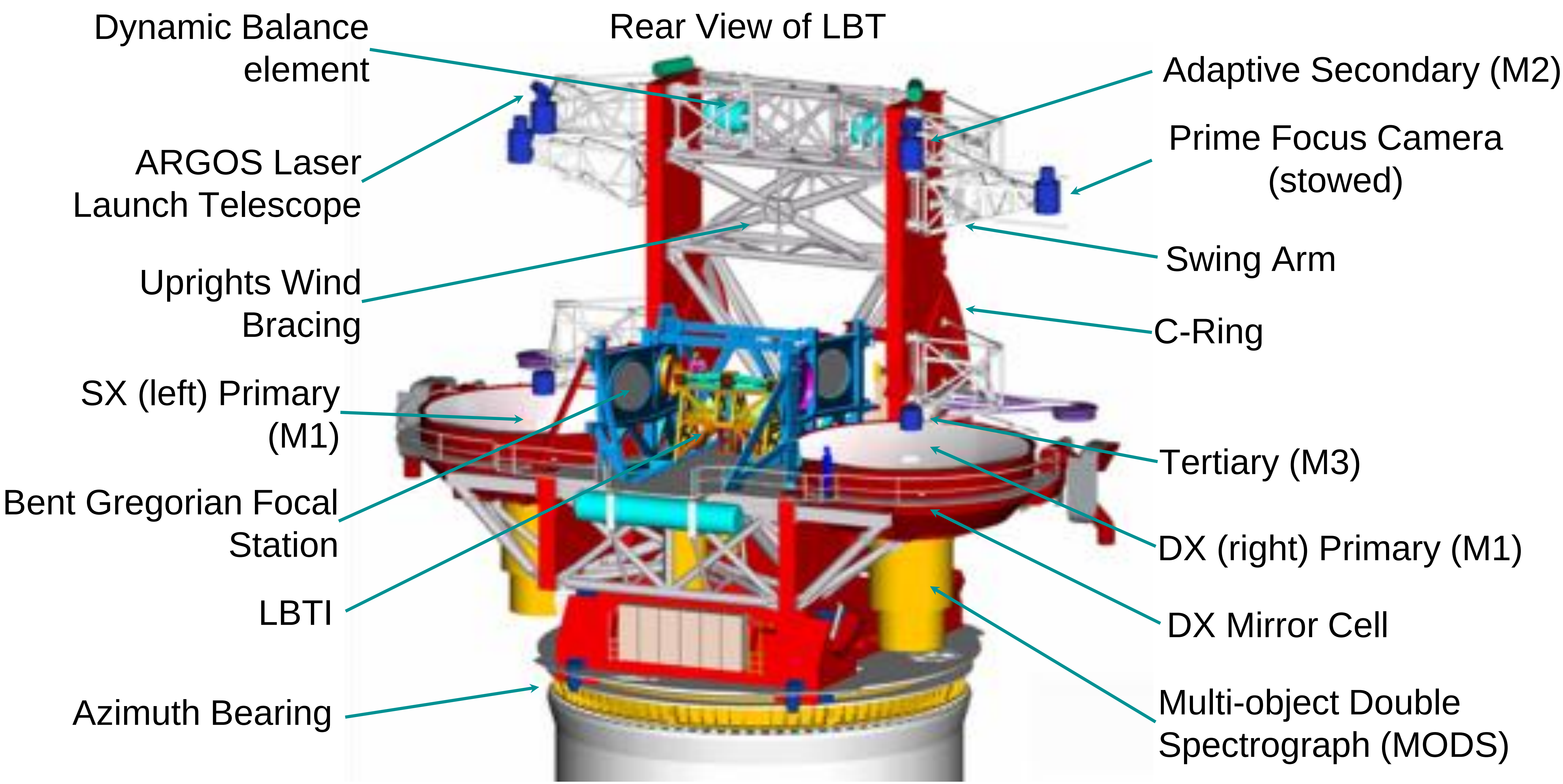
LEECH Sensitivity





LNB1 (3.04μm)
LNB2 (3.16μm)
LNB3 (3.31μm)
LNB4 (3.46μm)
LNB5 (3.59μm)
LNB6 (3.78μm)
b
c
e
d
LNB1
LNB2
LNB5
LNB6
LNB3
LNB4
LNB7
M
κ Andromedae b
N
E
1”

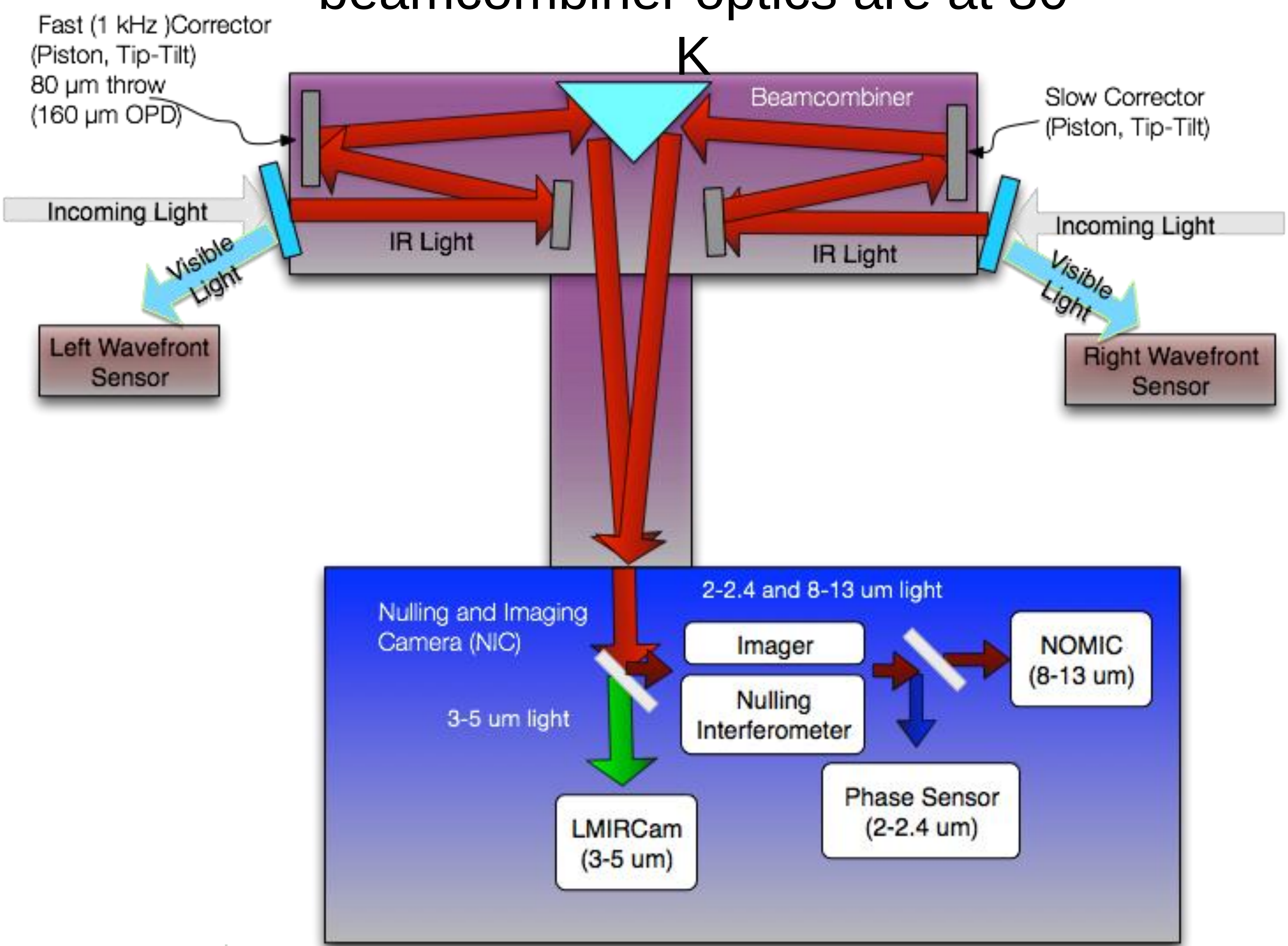
A quick tour of the LBT



All telescope optics outfitted with seismic accelerometer to completely define their motion in all 6-DOF at 1 kHz.

LBTI Layout

beamcombiner optics are at 80 K

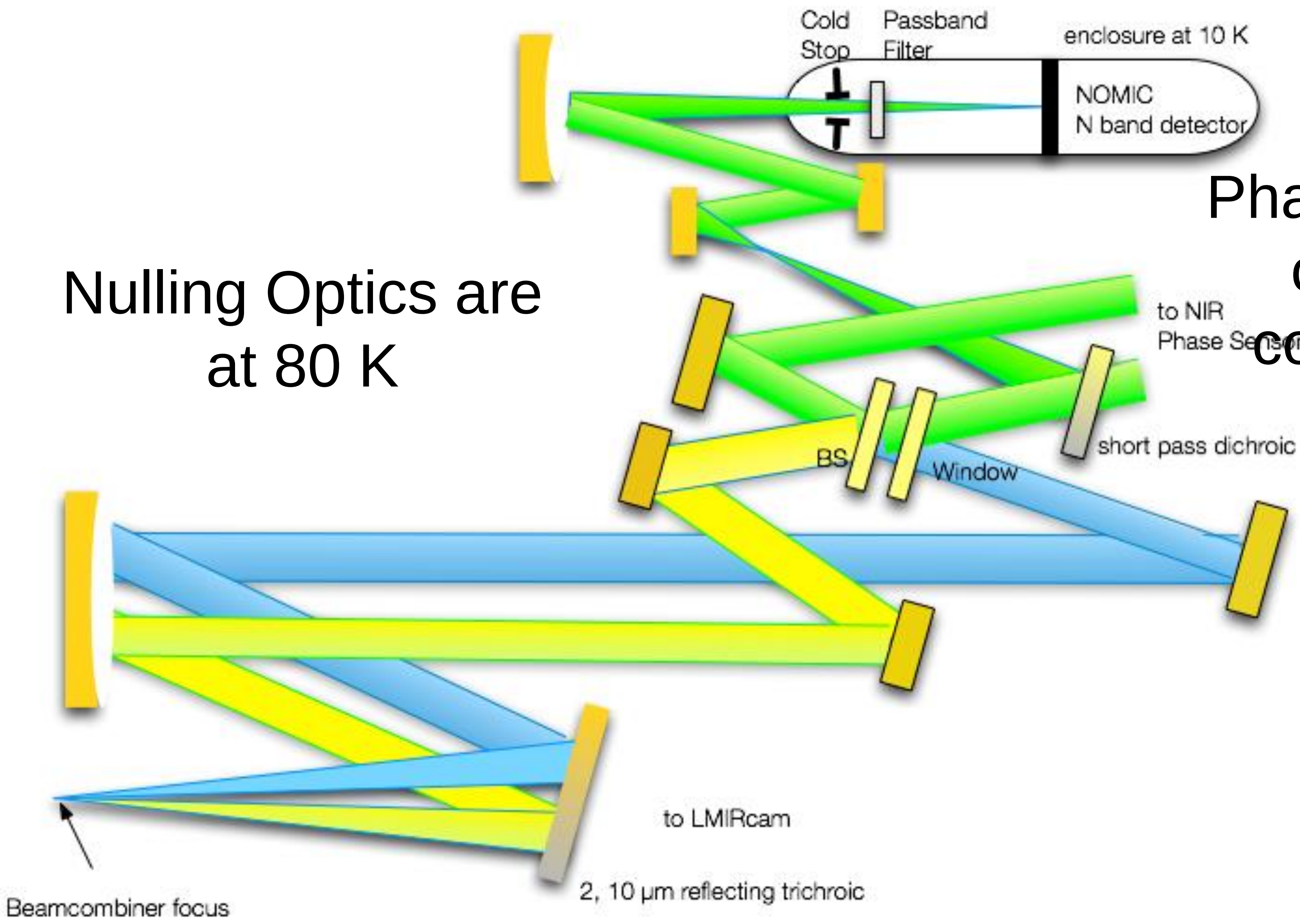


THE UNIVERSITY OF ARIZONA®

Nulling Optical Path

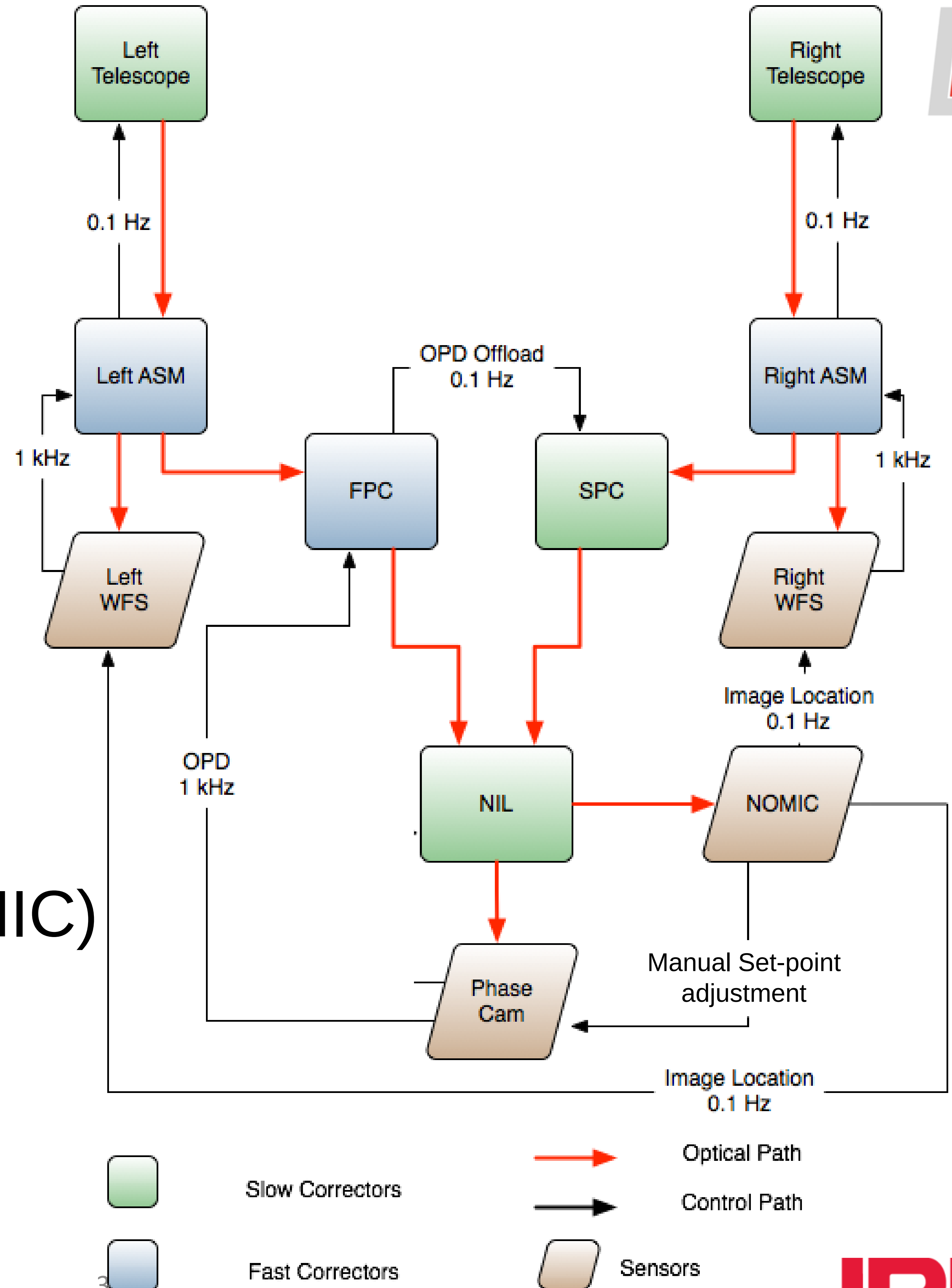
Nulling Optics are at 80 K

Phase sensing is completely common path



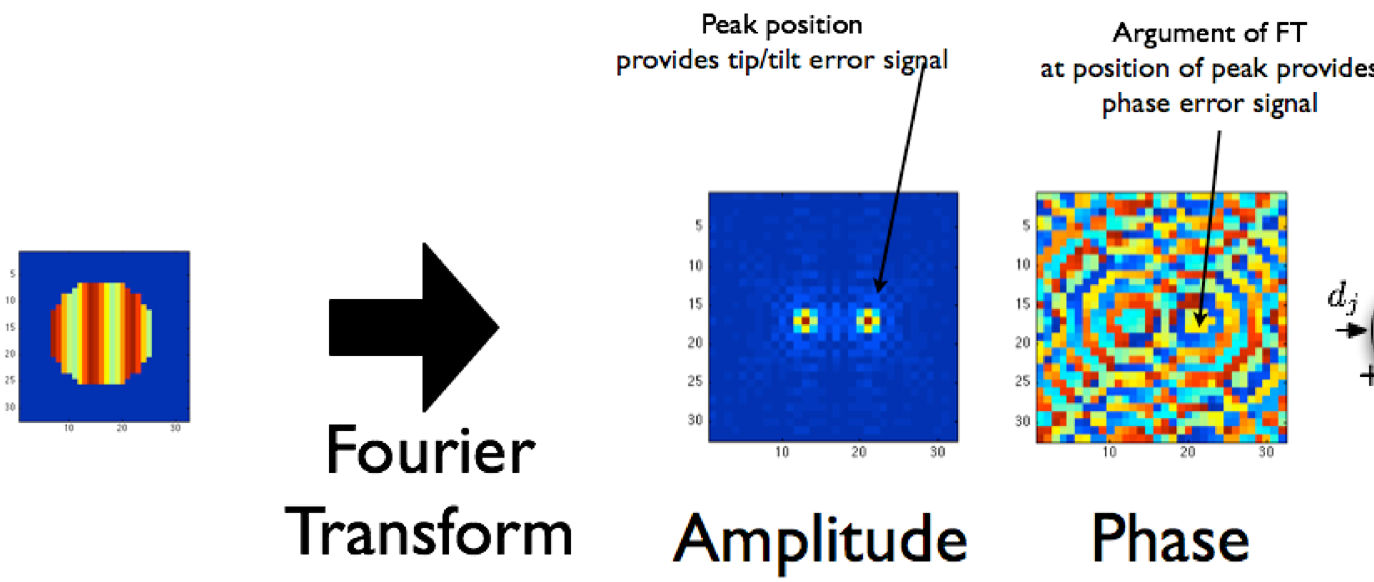
Control System

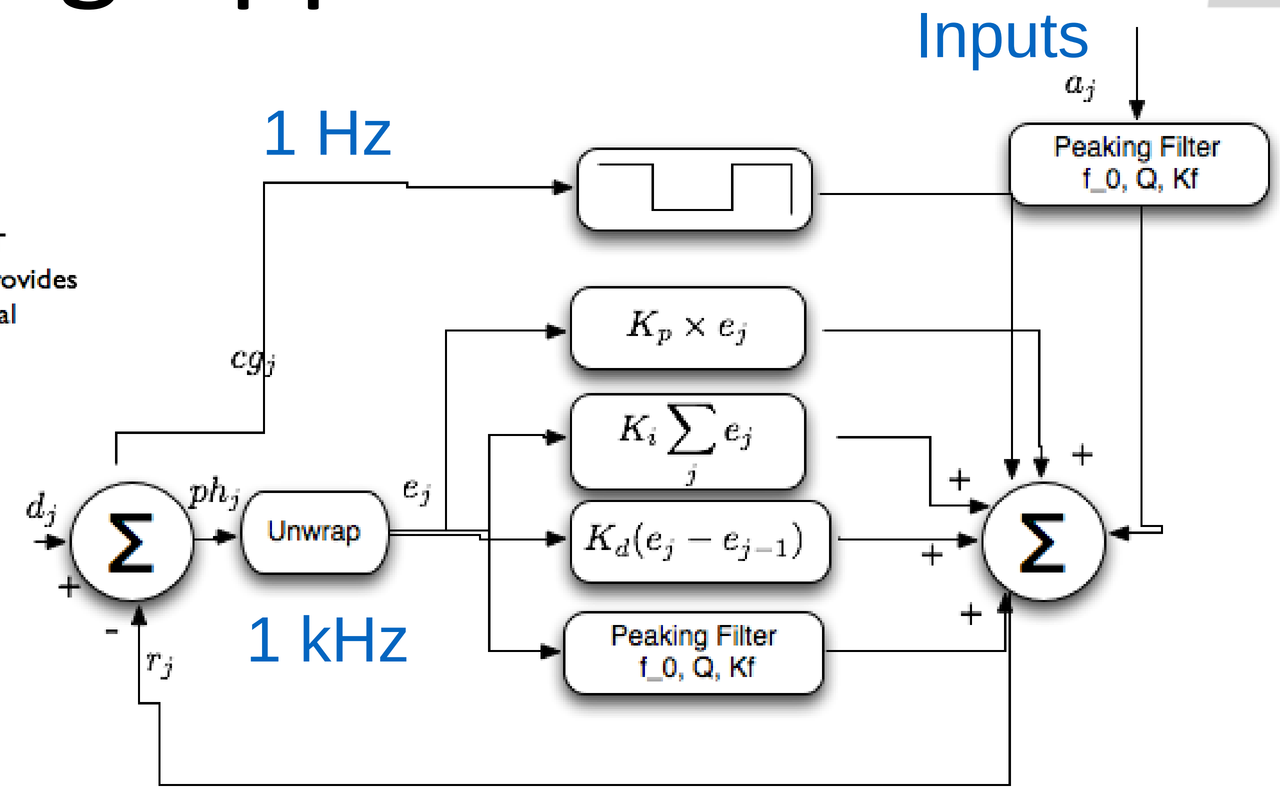
- Three Main Loops:
  - Left AO system
  - Right AO system
  - Phasing System
- All coordinated by the science camera (NOMIC)



THE UNIVERSITY OF ARIZONA®

Phase Sensing Approach



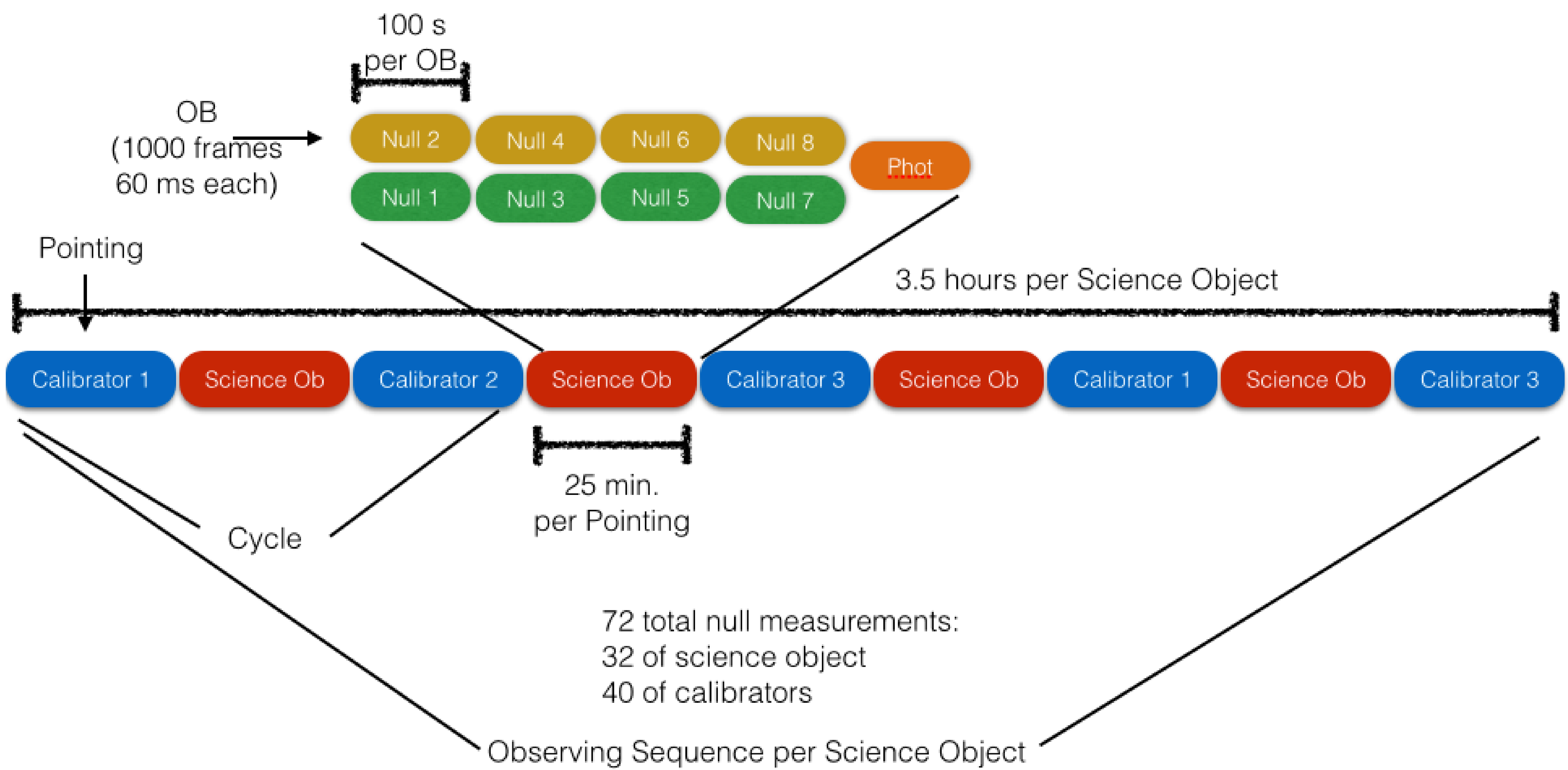


- Pupil image is formed at 2.2 µm wavelength.
  - Wedge in the beamsplitter creates a tilt at K band for overlapped 11 µm images.
  - Argument from Fourier Transform gives phase error signal at 1 kHz.
  - Group delay is encoded in the visibility of the fringes across the pupil.

- PID and discrete vibration filtering used for closed loop control.
  - Feed-forward from accelerometers gives error signal at 1 kHz.

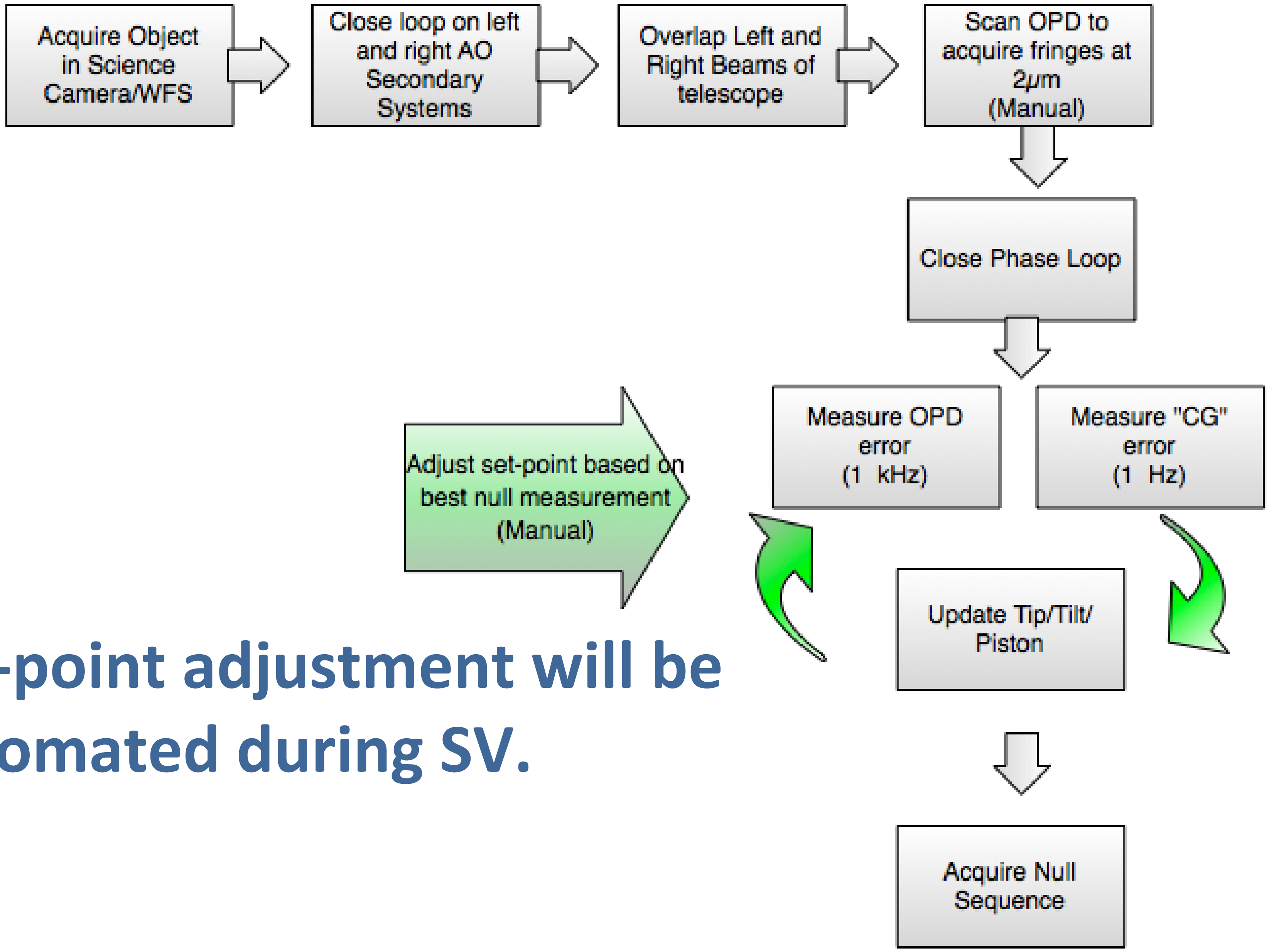
Overall Observing Sequence

- The HOSTS observing sequence for each science object is set up as follows:



Acquisition Process (Once per pointing)

- Each pointing requires:
  - Object acquisition
  - AO setup
  - Fringe acquisition
  - Phase Sensor setup
  - Null acquisition



Set-point adjustment will be automated during SV.

Offset Process (Once per nod)

- Each offset requires:
  - Telescope offset command
  - AO pause and resume
  - Manual phase loop closing.

Phase loop automated pause and resume will be implemented during SV.