LBTI Status

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June 12, 2016

Outline:

- Need for LBTI and the HOSTS program
- HOSTS Status
- Instrument Update
- Observational Results

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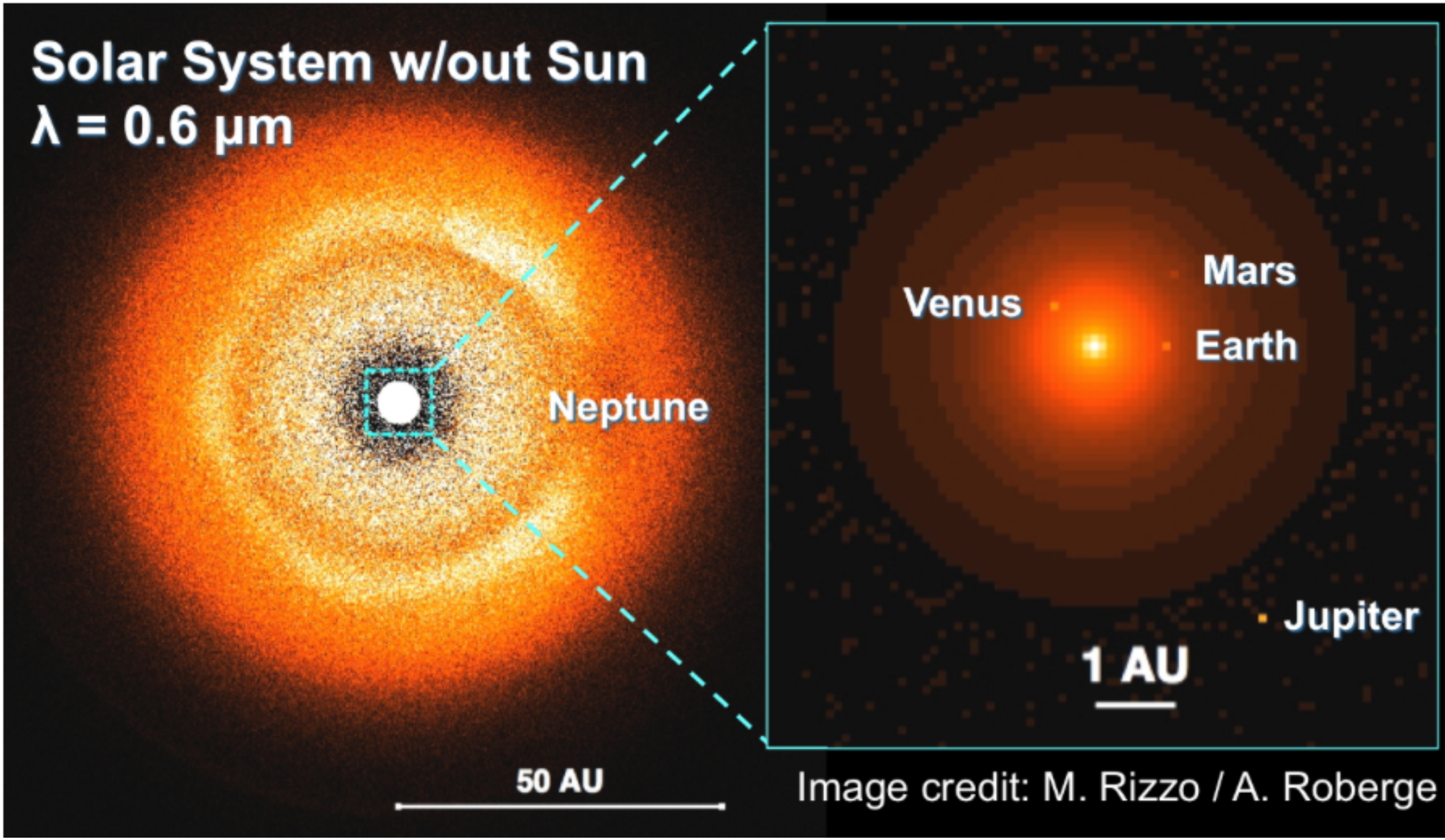
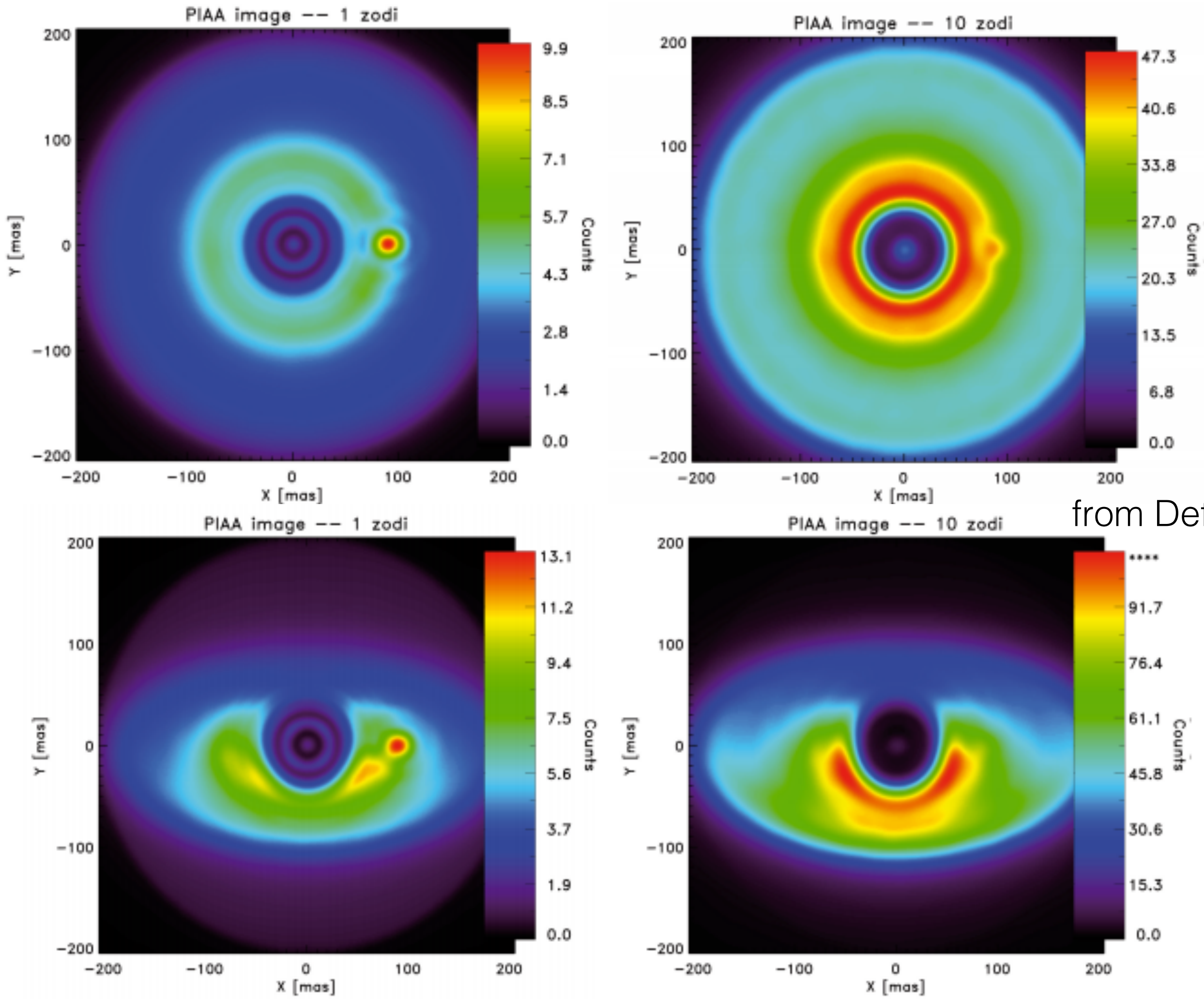
Zodiacal Dust in the Solar System



The problem with exozodiacal dust

(i=0)
face-on disk

(i=60)
typical disk

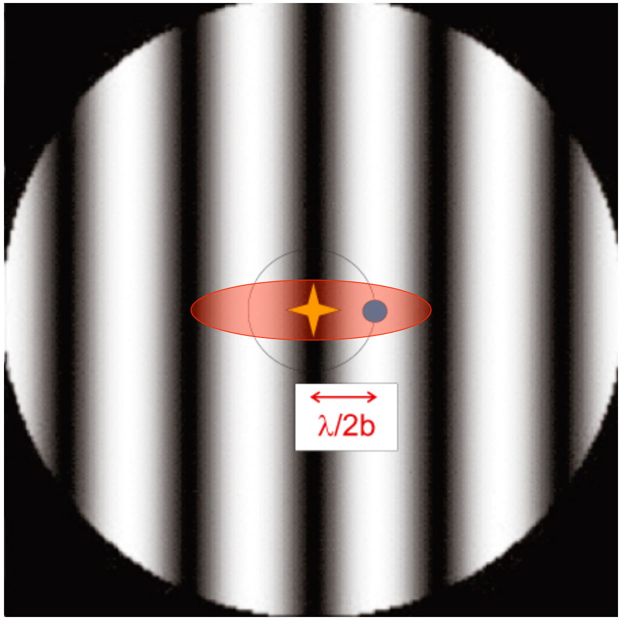


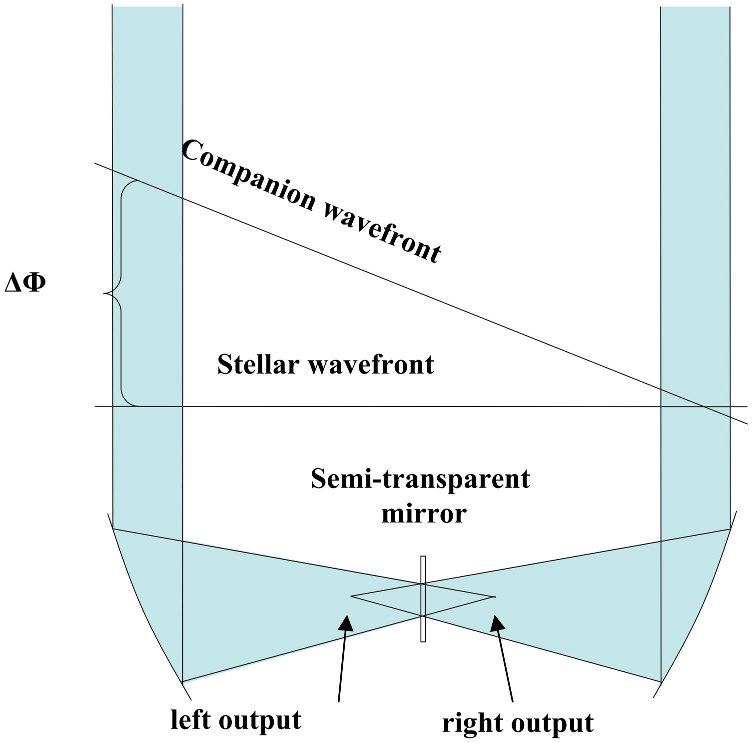
from Defrere et al. 2012

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

How nulling interferometry works

- First proposed by Bracewell (1978) to directly detect "non-Solar" planets;
- Subtracts starlight by destructive interference;





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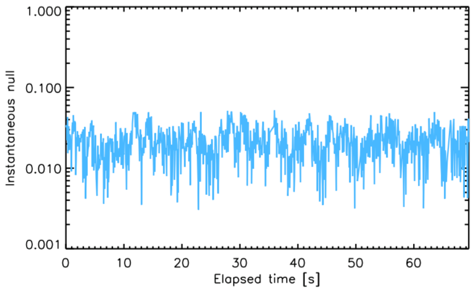
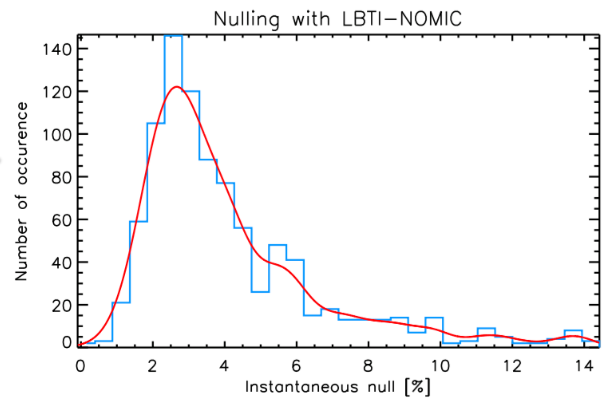
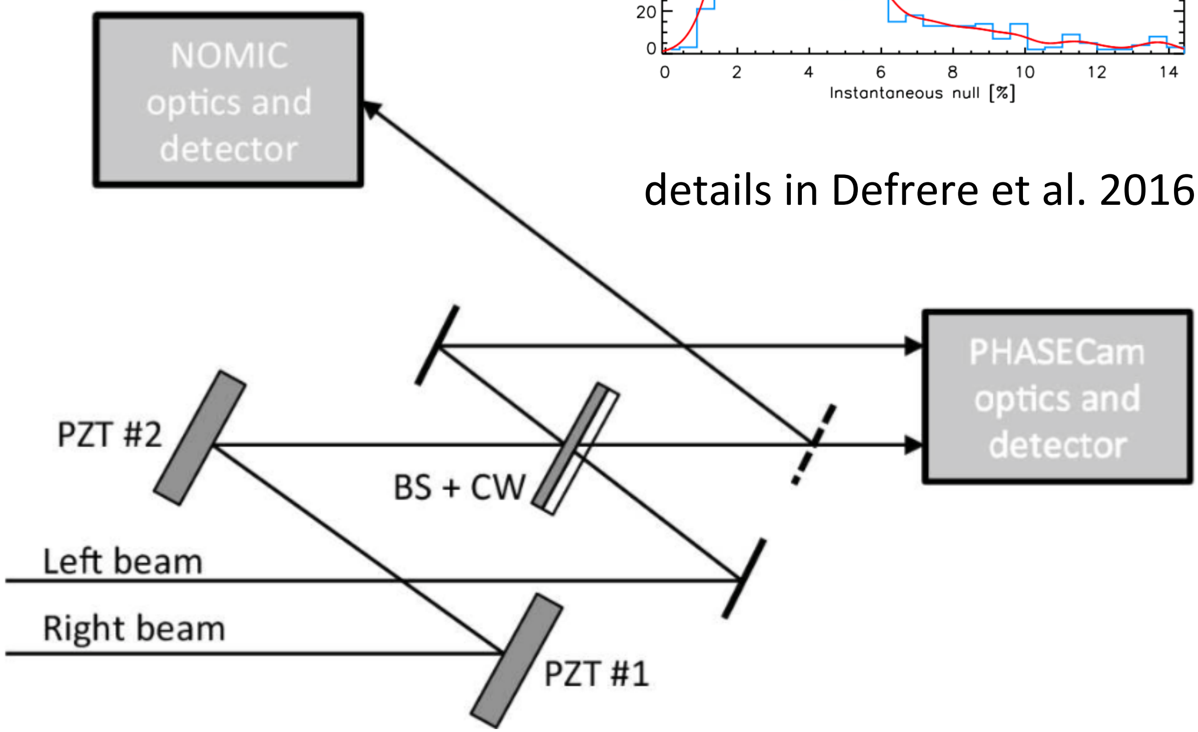
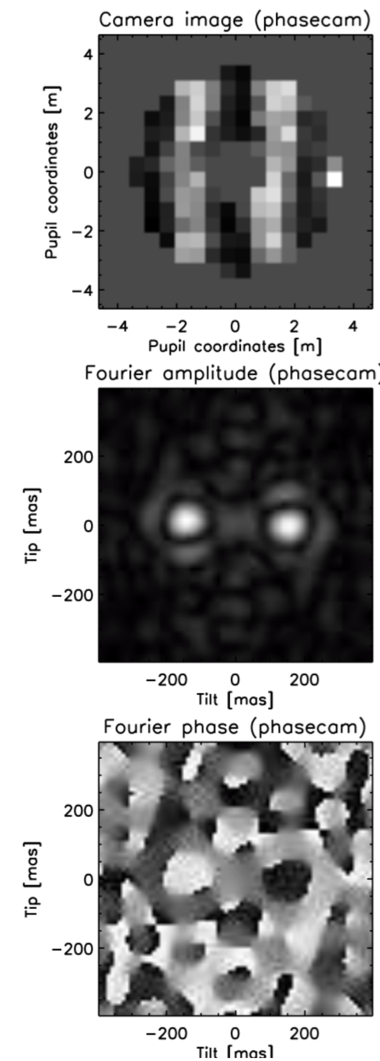
Nulling Implementation

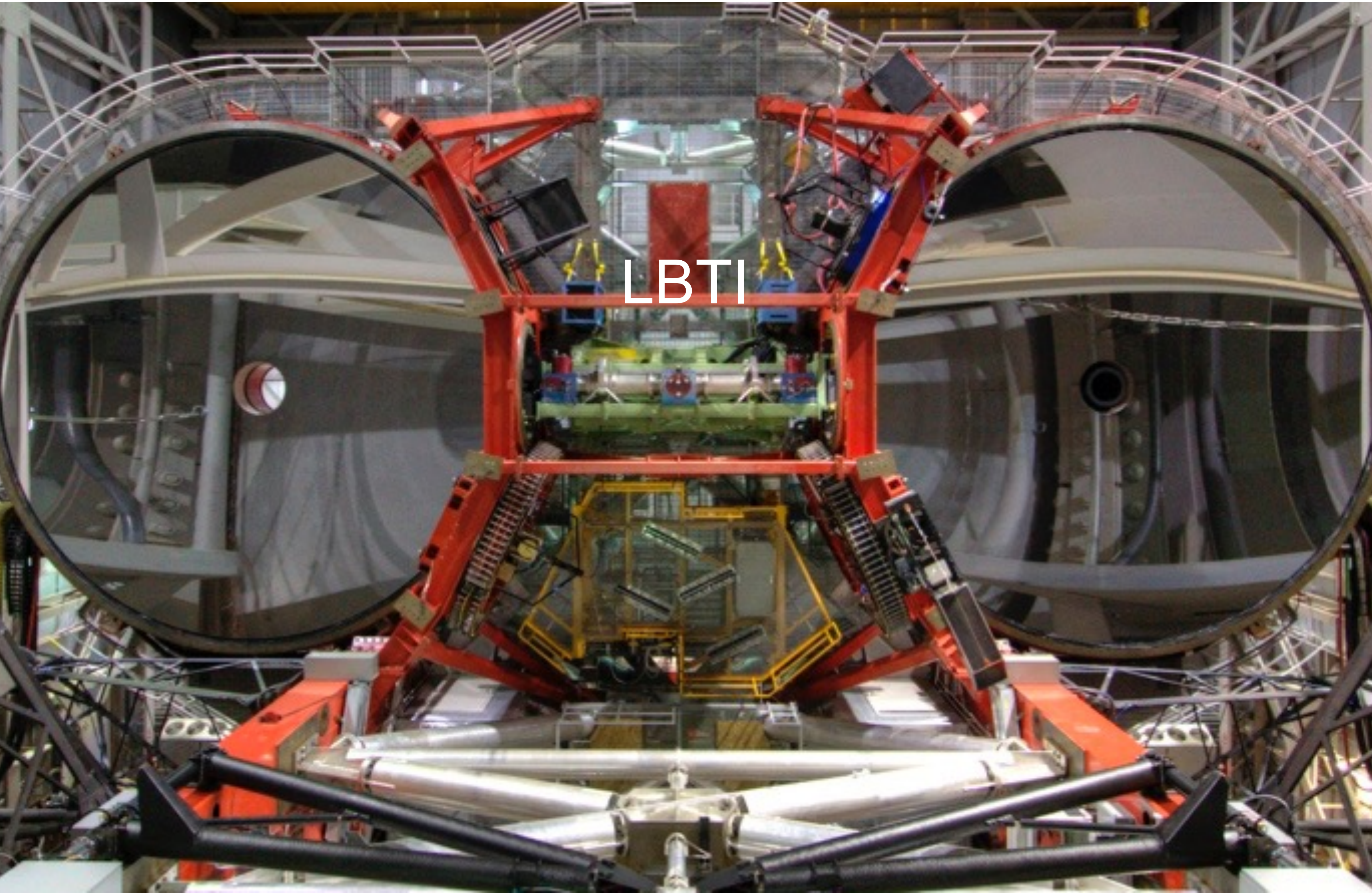




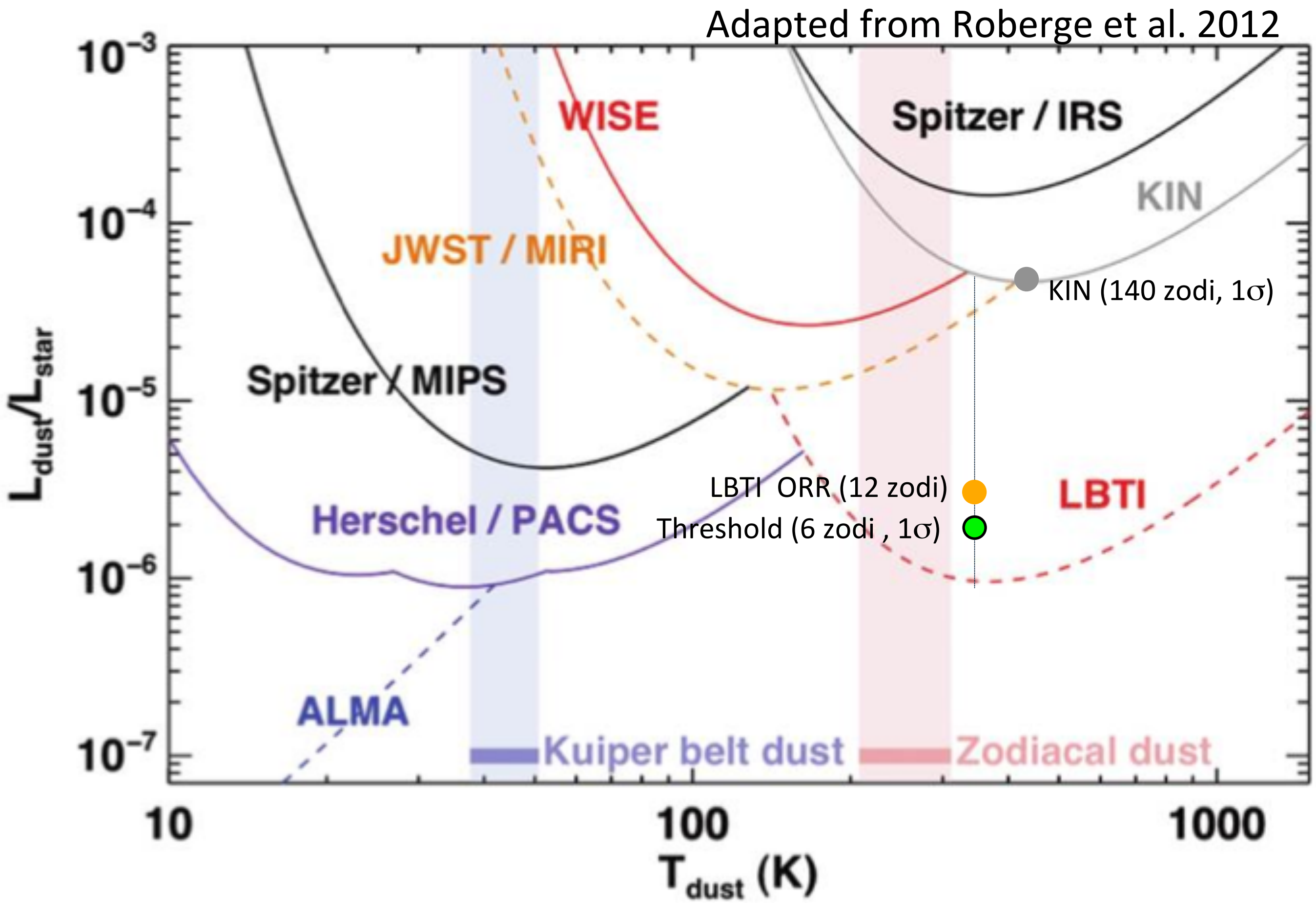
details in Defrere et al. 2016






LBTI

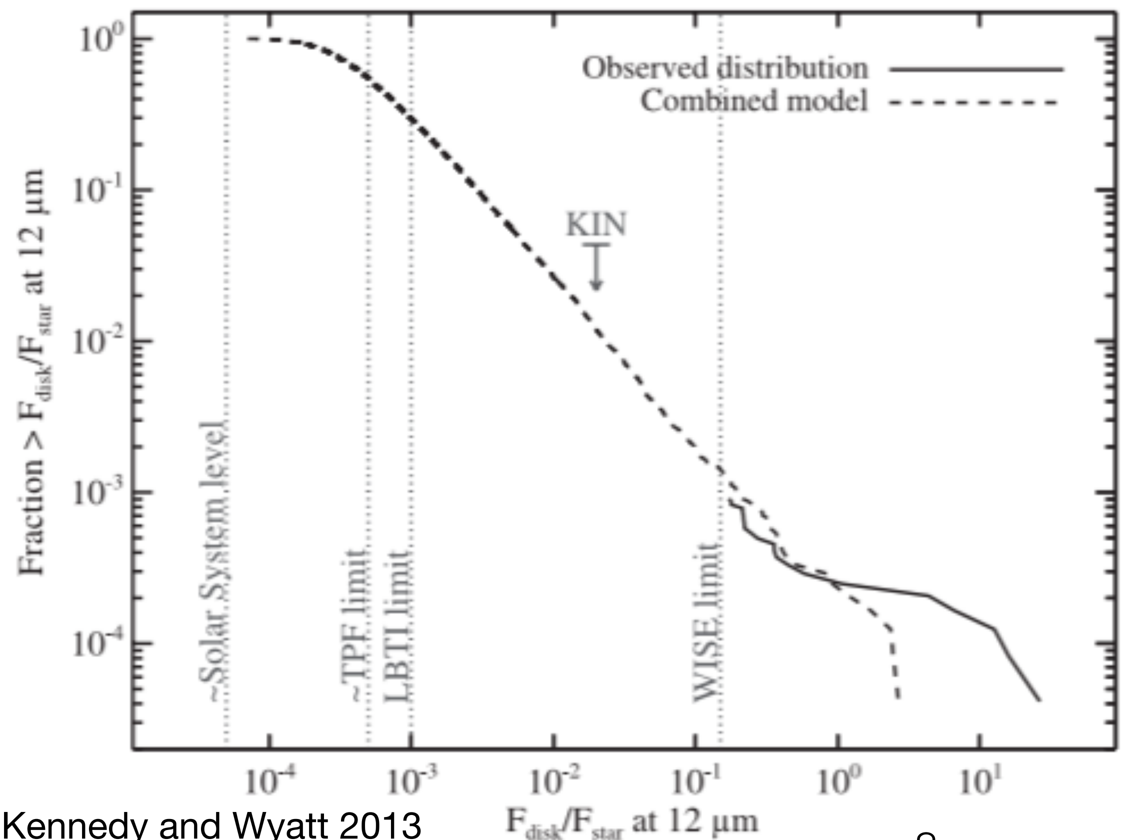
LBTI is uniquely sensitive for measuring warm dust



- Performance is currently 10-12X improved over KIN.
- Nulling Self-Calibration provides much of this improvement.

The Hunt for Observable Signatures of Terrestial planetary Systems (HOSTS)

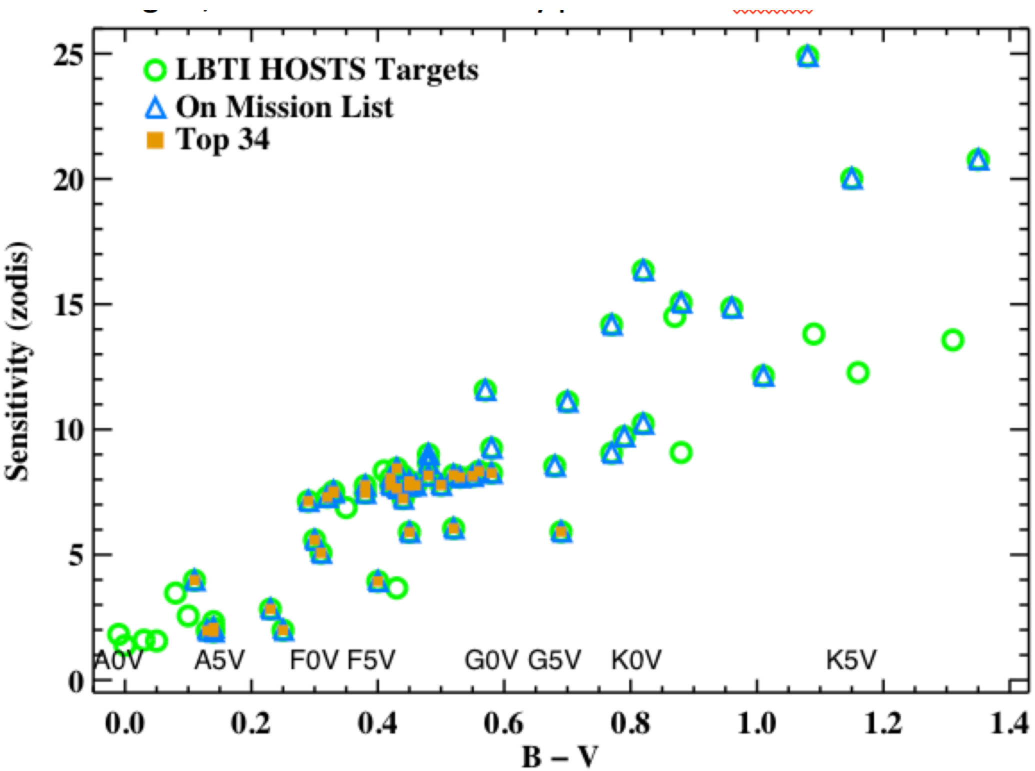
- Survey of ~50 nearby stars defined by LBTI's science team:
  1. What is the exozodi luminosity function for nearby stars?
  2. Does the level of cold/hot dust correlate with exozodi level?
  3. How does the exozodi level vary with stellar type?



Kennedy and Wyatt 2013

HOSTS Objectives

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

	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

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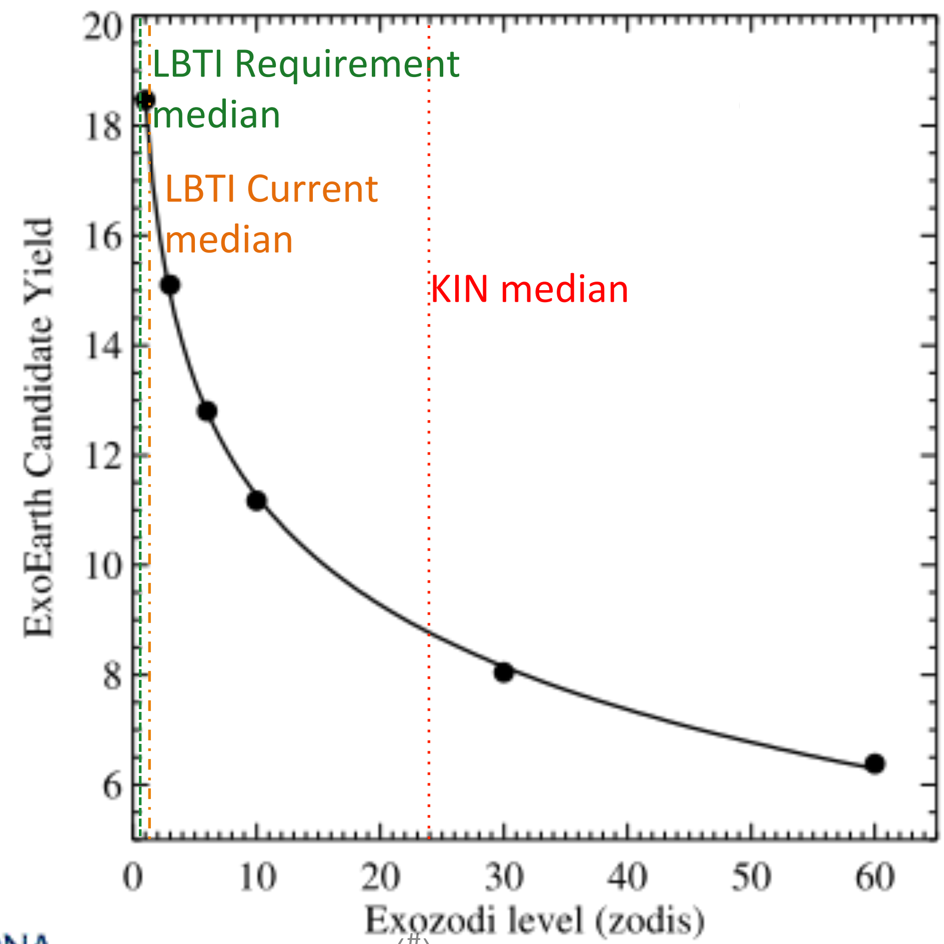
HOSTS Objectives

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



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HOSTS Status

HOSTS Context

- Proposed as a 52 night survey executed from FY14-17
  - Assumed efficiency of 3 stars per night - 35% of nights usable.
  - Challenging requirement: 6 zodi sensitivity
- Telescope, weather, and instrument performance have affected availability.
  - Adaptive Secondaries (AdSec's) have failure modes with long downtime. These are being mitigated.
  - Instrument improvement efforts are difficult to balance with survey reliability.
  - Productive nights can vary when 35% of the time is usable.

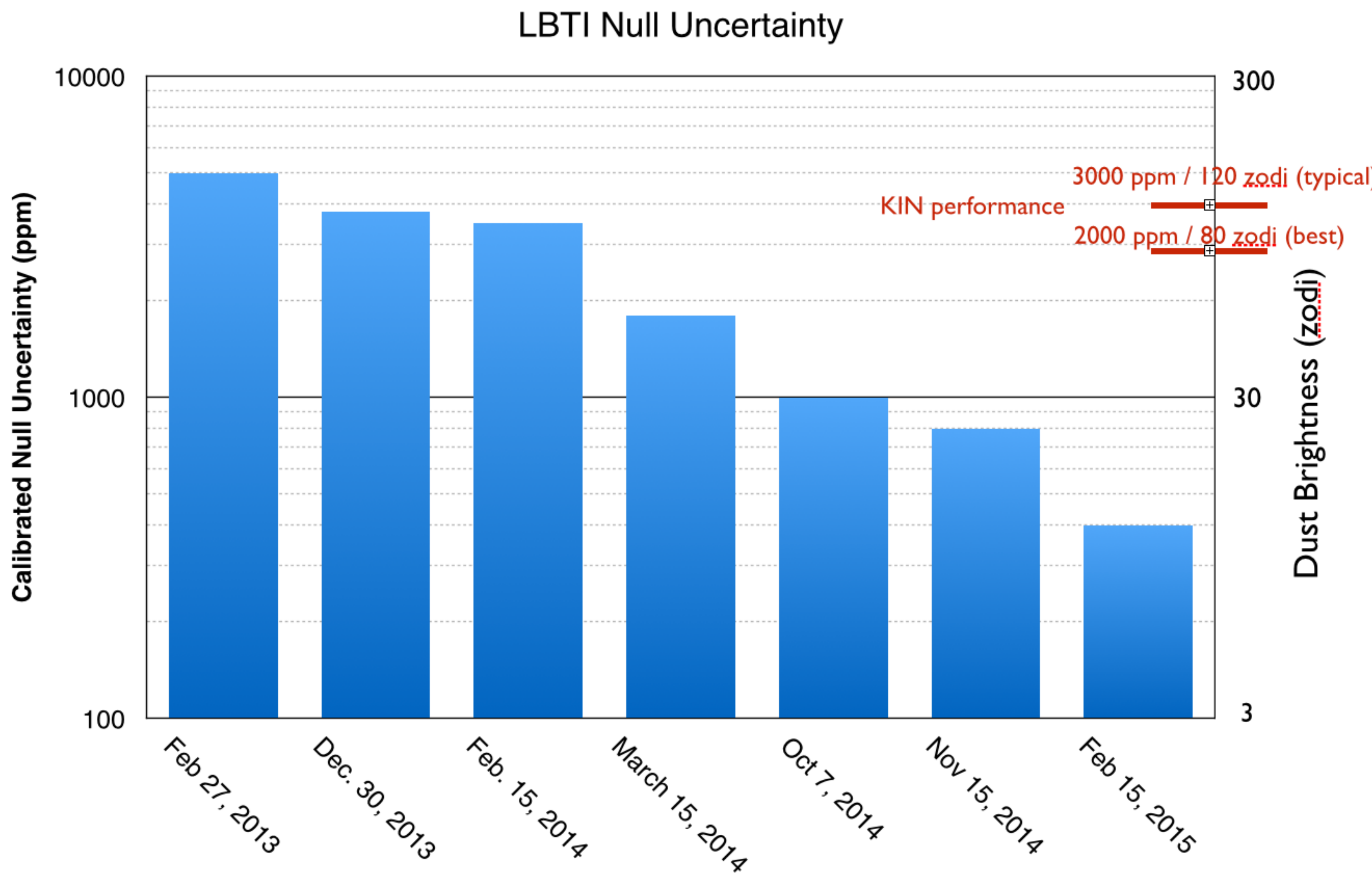
HOSTS History

- FY14 - Initial Performance Assessment (4 nights).
  - Adaptive Secondaries issues limited fall 2013 availability.
  - Phase Control Loop initially implemented.
  - dust around eta Crv characterized (Defrere et al. 2015)
- FY15 - Performance Improvement (16 nights).
  - Improved null uncertainty to 500 ppm (15 zodis on a solar type star).
  - Observed 5 additional stars to varying levels of sensitivity.
- FY16 - Program Refinement (11 nights).
  - Schedule compressed by AdSec failure in fall 2016.
  - Poor weather and instrument reliability limited progress.
  - Detection of a ~35 zodi disk around Vega.

Improving Progress on HOSTS

- Instrument reliability is being assessed.
  - Critical spares identified and replacement procedures refined.
  - Early Instrument Checkout is being formalized.
- A queue-based observing approach has been developed for 2016B and onward.
  - low PWV and good seeing nights will be used for HOSTS.
- Telescope/AO reliability is being improved.
  - Improved preventive maintenance of Adaptive Secondaries.
  - Margin in proposed schedule to allow for future down time.

Instrument Update



Nulling Uncertainty has been **reduced by 10X** in FY2015.

Accelerometer Feed-Forward (OVMS)

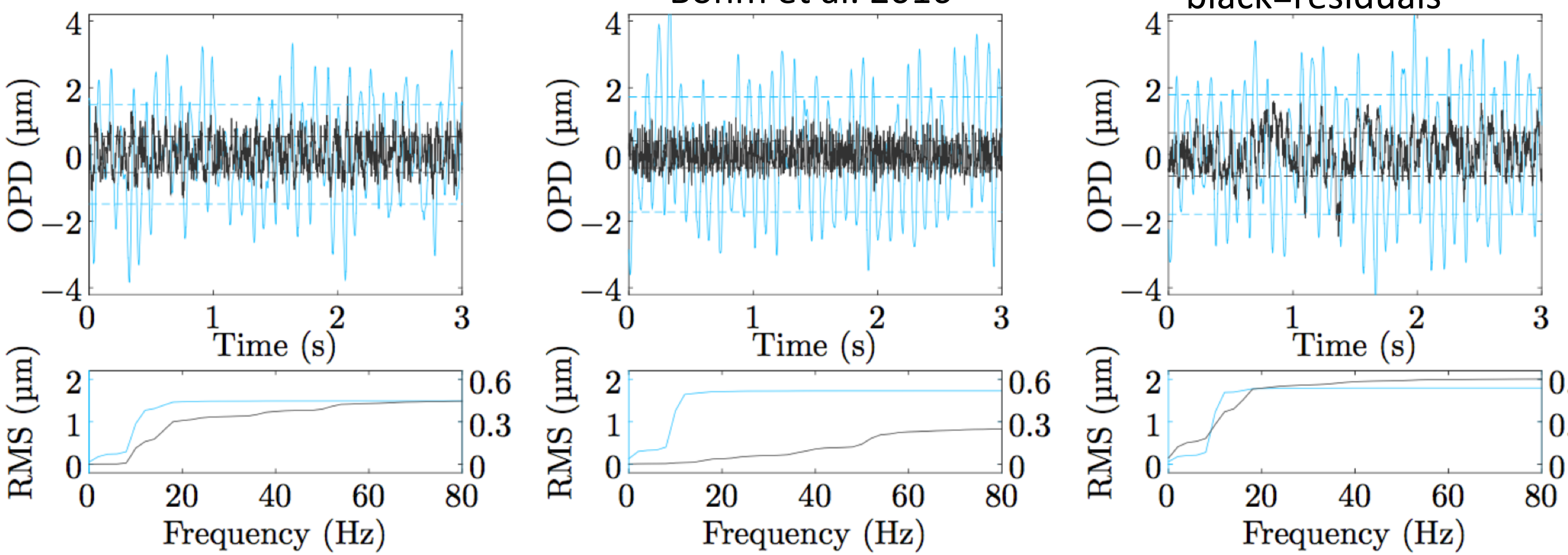
- A complete path length feed-forward system was implemented in summer/fall 2015 by Jorg-Uwe Pott and Michael Bohm (MPIA).
  - System is called OPD and Vibration Monitoring System (OVMS)
- Tested in Feb-March 2016.
  - Very good correlation with NIR Phasecam data.
  - Reduced phase residuals by 25% (560 nm -> 410 nm RMS) when used in conjunction with phase sensing.
  - Mainly eliminates an 11 Hz vibration in structure.
- Used routinely starting in March 2016.

OVMS Results

- Residuals are reduced to 410 nm RMS from 560 nm RMS in March testing.

Bohm et al. 2016

blue=modeled variations.
black=residuals



(a) OVMS$^+$ OFF, $K_i = 300$ (b) OVMS$^+$ ON, $K_i = 300$ (c) OVMS$^+$ ON, $K_i = 30$

Water Vapor Feed-Forward

- Installation of a dual wavelength filter, and realignment of the NIR phase sensor was carried out in summer 2015.
- Software changes to calculate phase at both 1.65 and 2.2 μm completed in fall 2015.
- On-sky testing carried out in Feb. 2016.
  - Off-line analysis allowed us to determine the correct algorithm and predict null values taken at the time.
- On-sky feed-forward needs to be verified.

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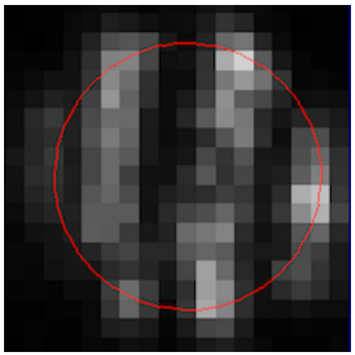
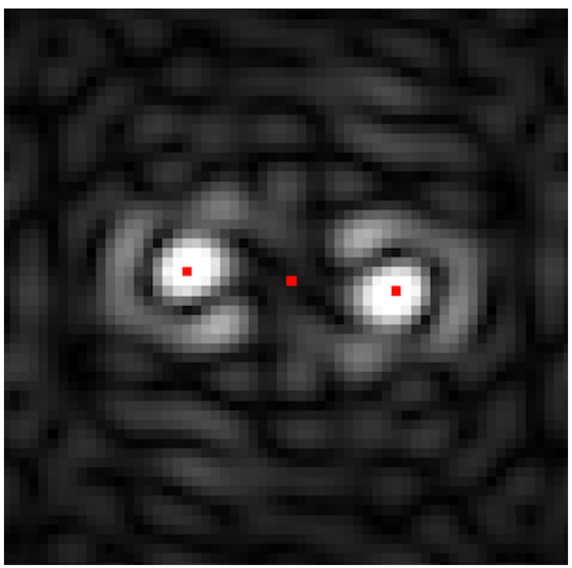
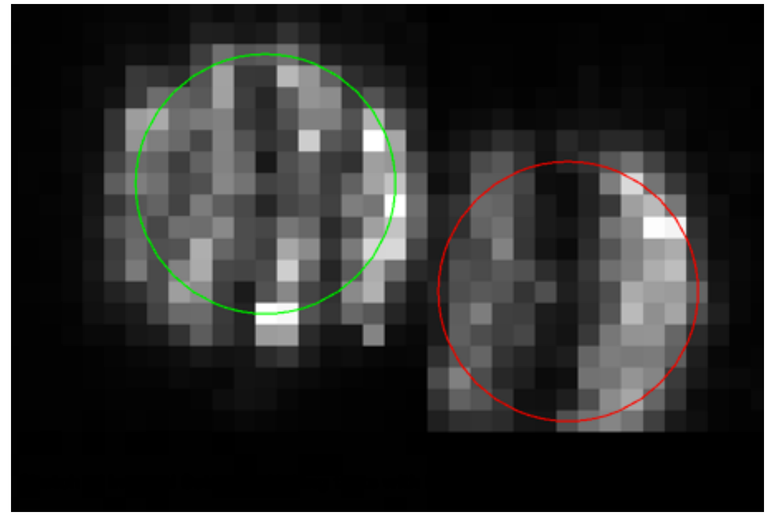
Improved Phasecam Measurements

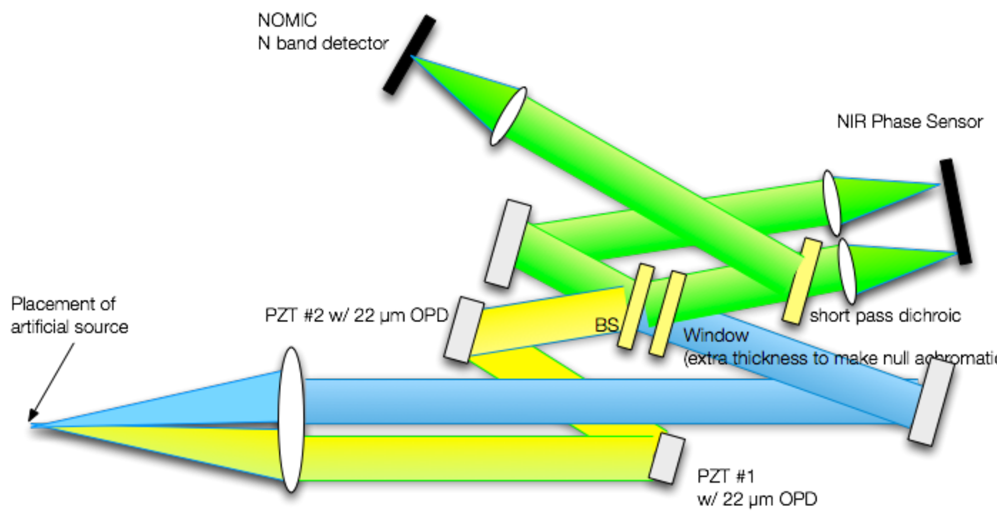
K band measurement.
Only uses one output.





H band measurement K band measurement





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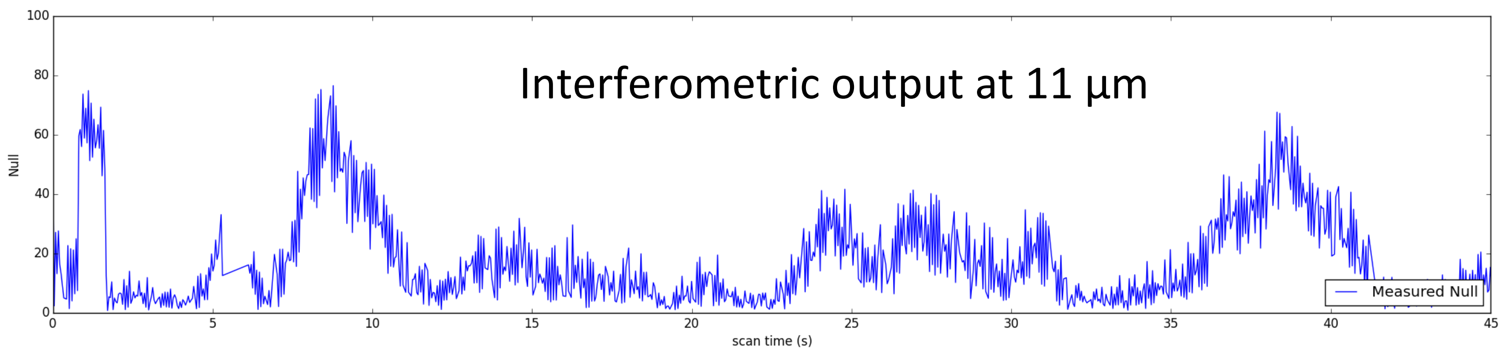
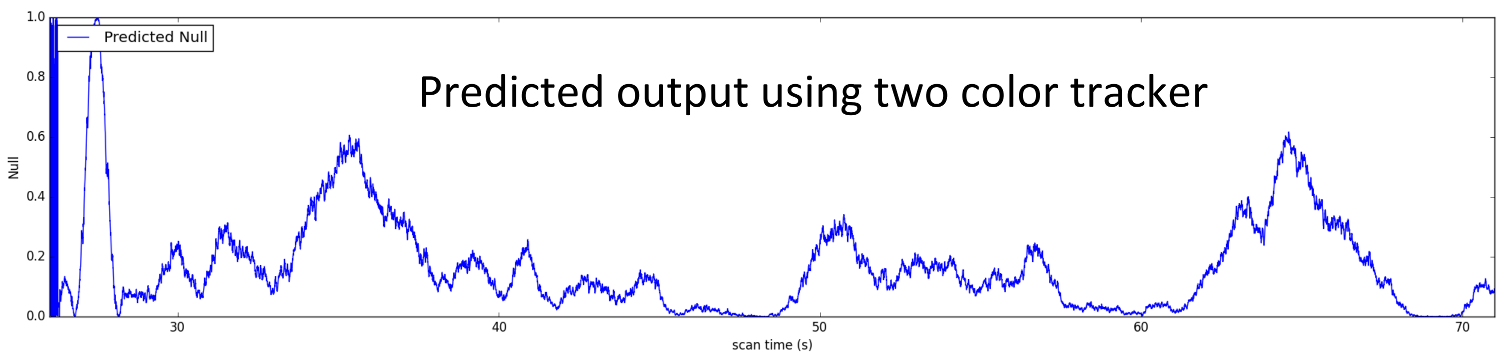
PWV Results

- Basic Approach:
  - Use (phase_H - Phase_K) to predict phase variation due to water vapor.
  - Adjust K band tracking set point to minimize variations at 11. μm.
- Feb. data can be predicted using revised algorithm.

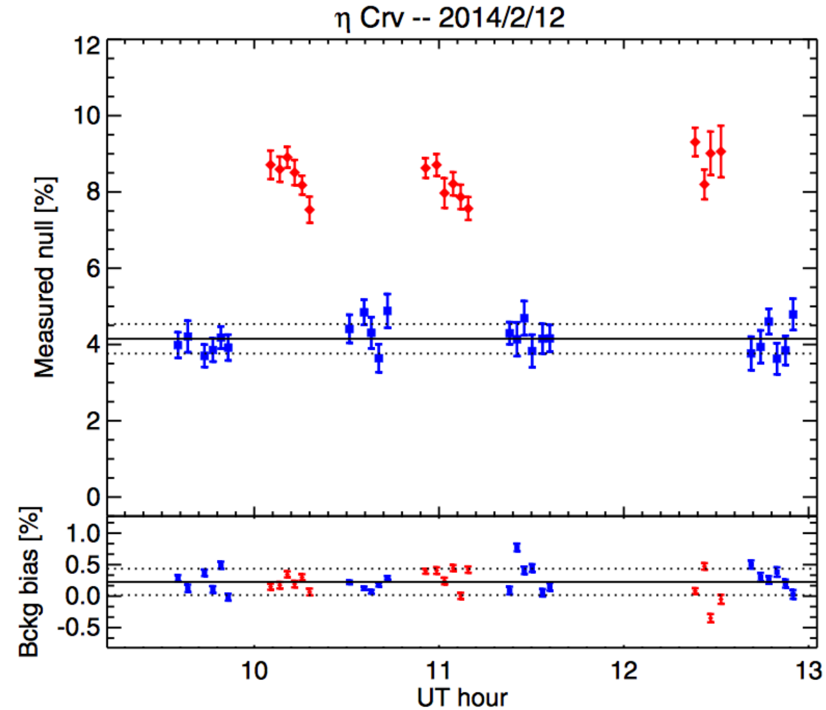


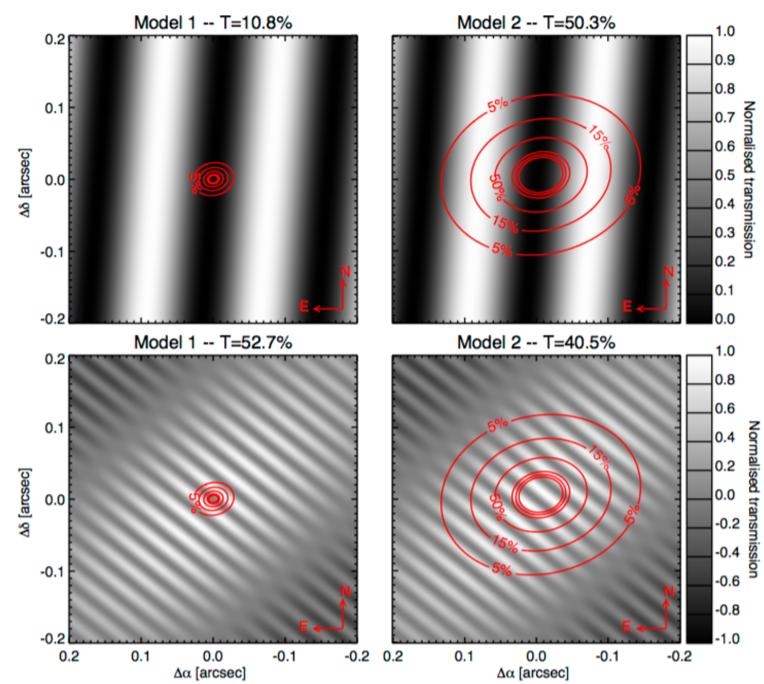


Observational Results to Date

LBTI nulling first light

- Commissioning tests on the star eta Crv detected a bright disk (Defrere et al. 2015).
- Modeling indicates dust is at < 1 AU (Kennedy et al. 2015).
- Data are consistent with a ~1200 zodi surface density in the habitable zone (although the model actually predicts most of the dust is inside of the HZ).





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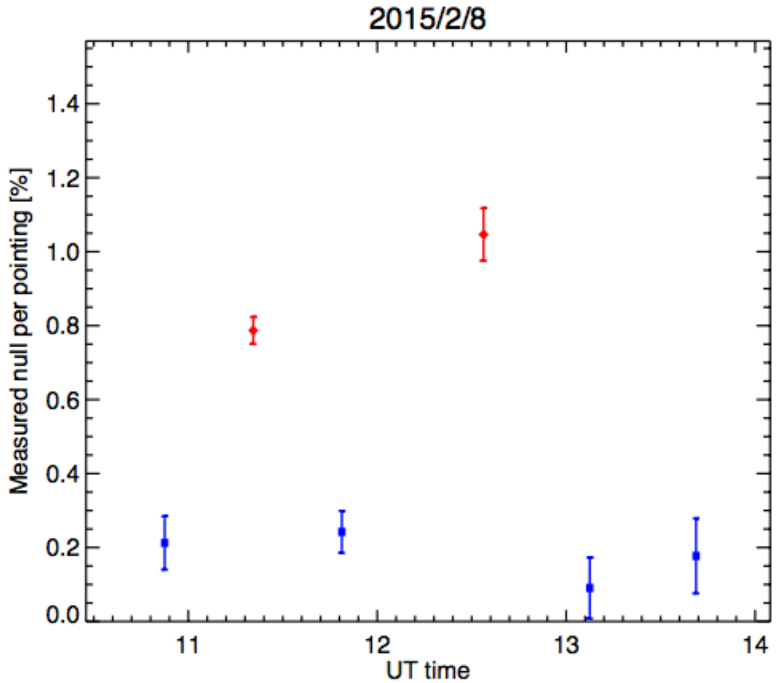
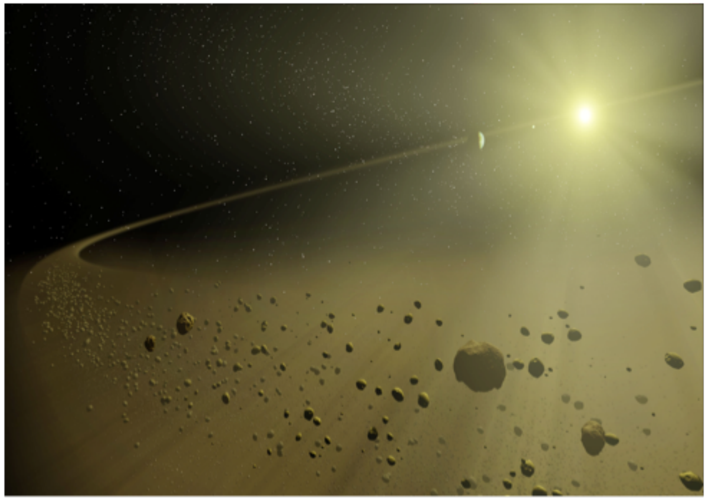
beta Leo





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 known from Herschel to be at R=40 AU.

11 μm emission detected by LBTI is likely at ~4 AU.

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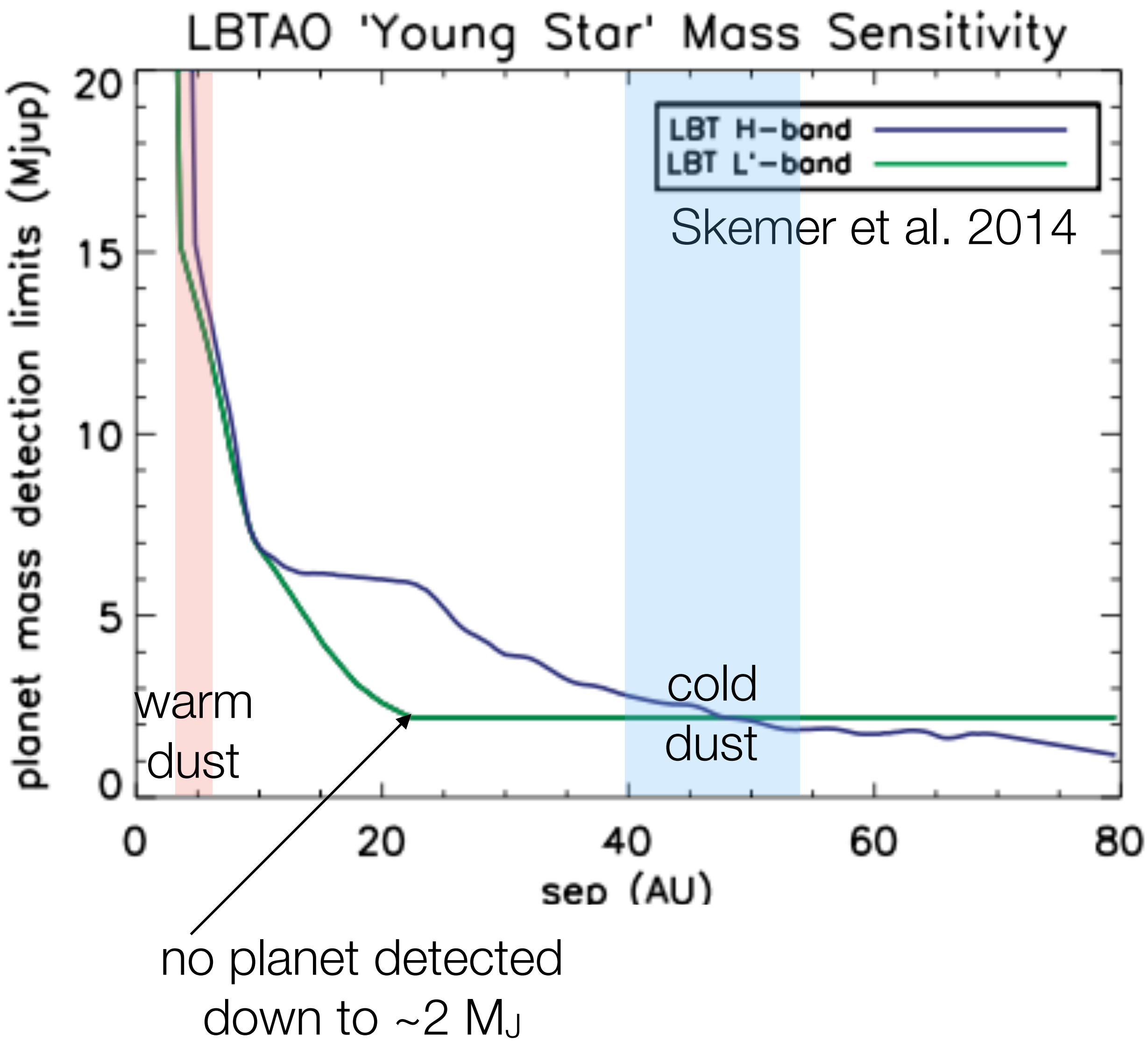
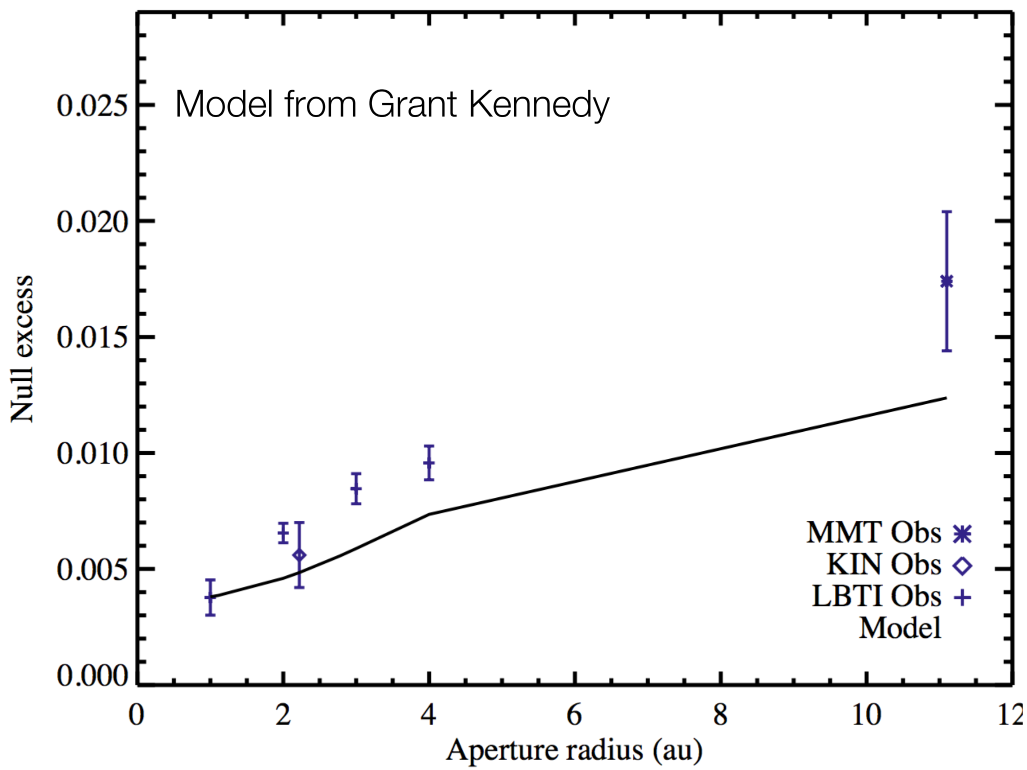
Limits to planets around beta Leo



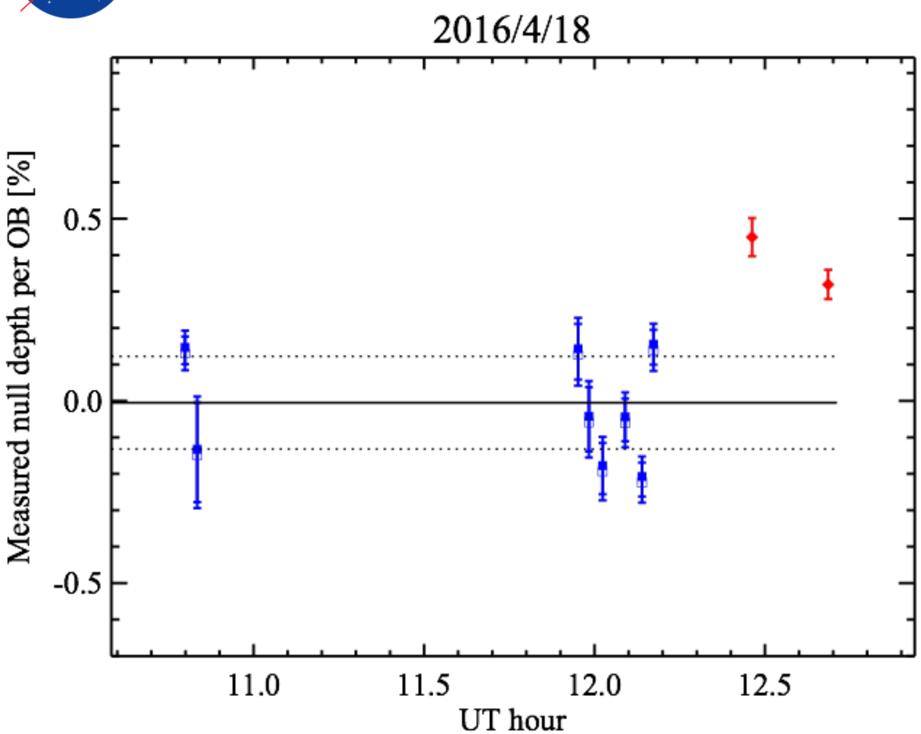
The beta Leo planetary system

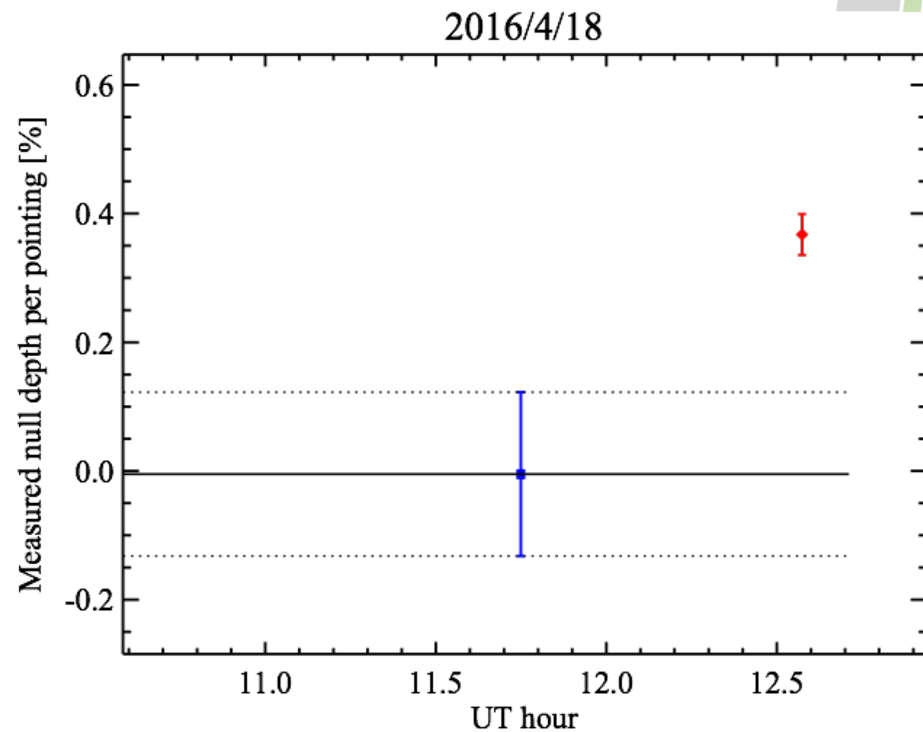
- Warm dust can be predicted from a colder parent body belt using analytic models (Wyatt et al. 2005, Kennedy and Piette 2015)
- P-R drag from this reservoir appears to be consistent with the warm emission



Combined, the data are all consistent with a single parent body belt at 40 AU, creating **both** the warm and cold dust, and **no giant planets** capable of clearing out the intervening material.

Vega Observations



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Number of bootstrap        : 200
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Excess = 3500 +/- 1300 ppm

Consistent with lower SNR detection in 2014 data

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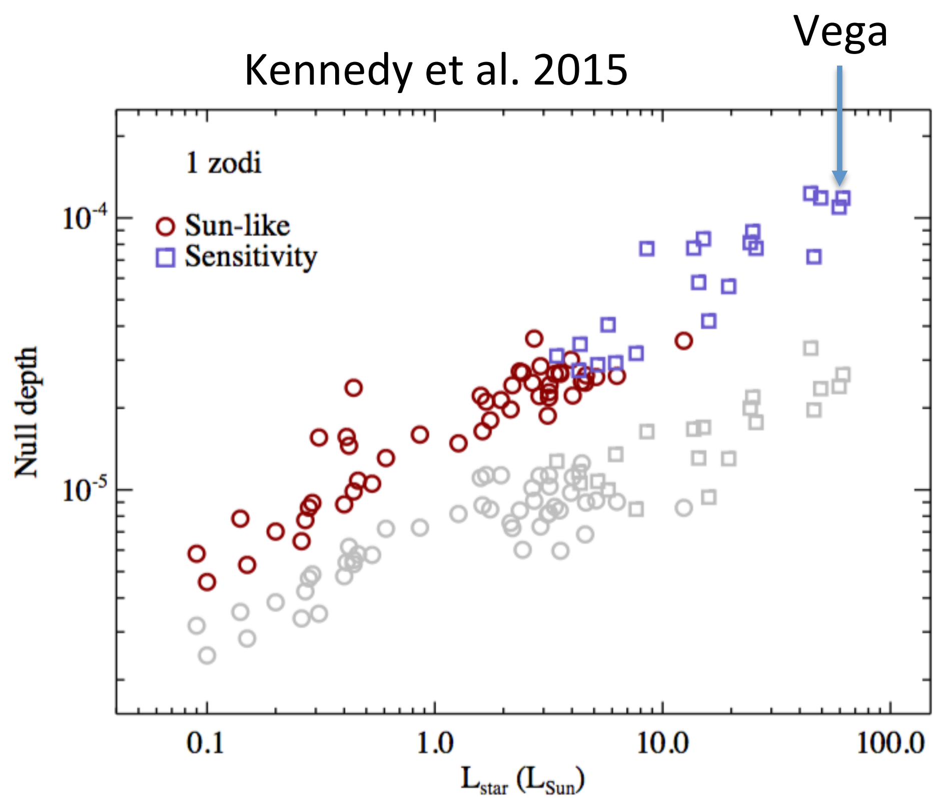
Scientific Interpretation

- Disks are more readily detectable around early type stars (Kennedy and LBTI team. 2015).
- A detection of 3500+/-1300 ppm excess around Vega is equivalent to a ~35+/-13 zodi disk around the star.
  - If confirmed, this is the faintest warm disk ever detected.



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HOSTS Proposed Forward Plan

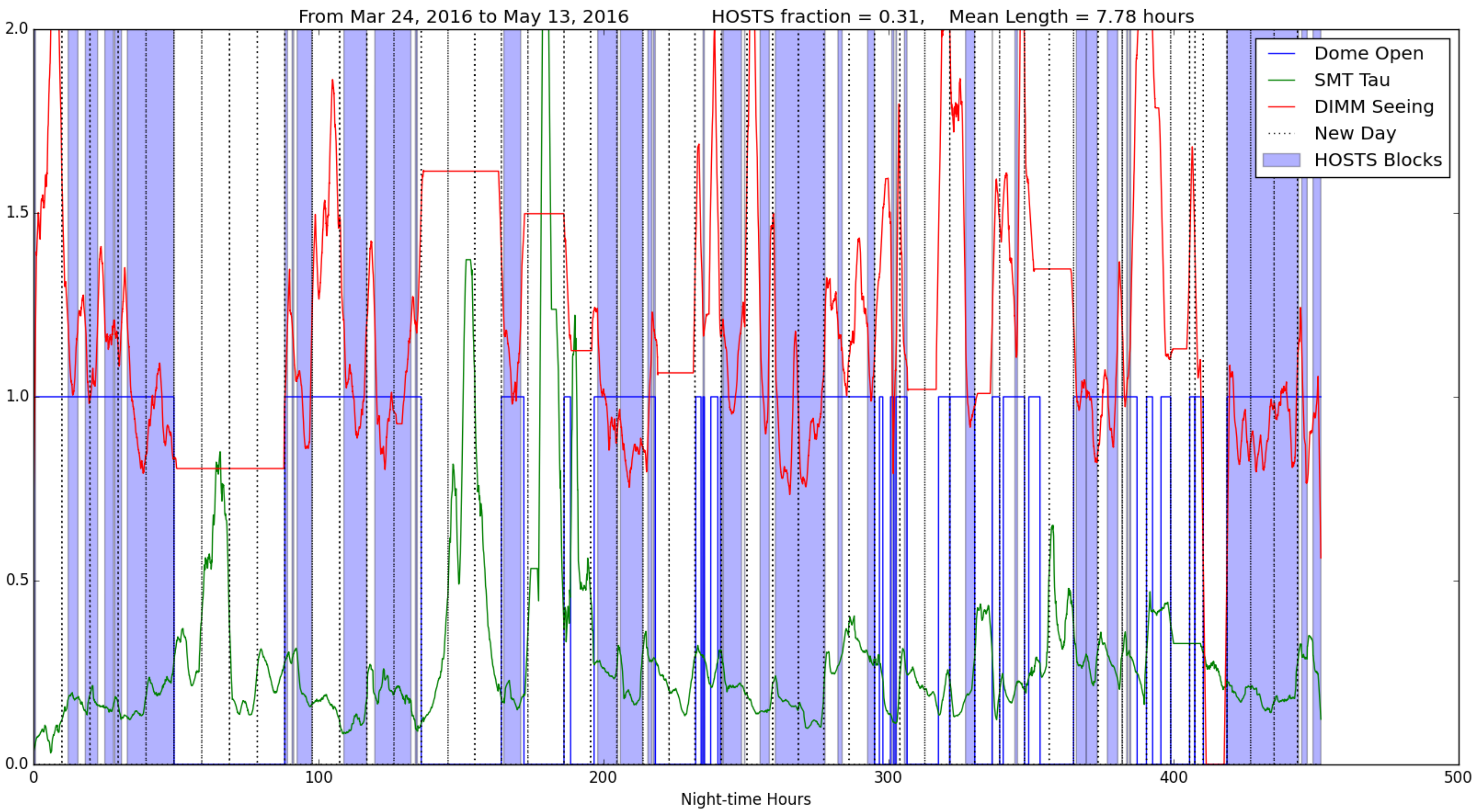
- Plan addresses the minimum number of star (32) with margin (15 stars).
- Requires 20 additional nights (40 total), or equivalently, an additional year of LBTI observations (FY18).
- Queued observation analysis predicts we will be able to observe for eight nights per year, yielding 24 stars per year.
  - 48 stars achievable with plan.
  - Provides margin for any unplanned downtime.

Summary

- HOSTS observations are in progress. Slower than planned progress can be mitigated by:
  - Implementing telescope and instrument reliability improvements.
  - Implementing a Queue-based observing strategy.
- The HOSTS survey can provide unique constraints on exozodiacal dust with continued observations.

Supplementary Slides

Weather Analysis



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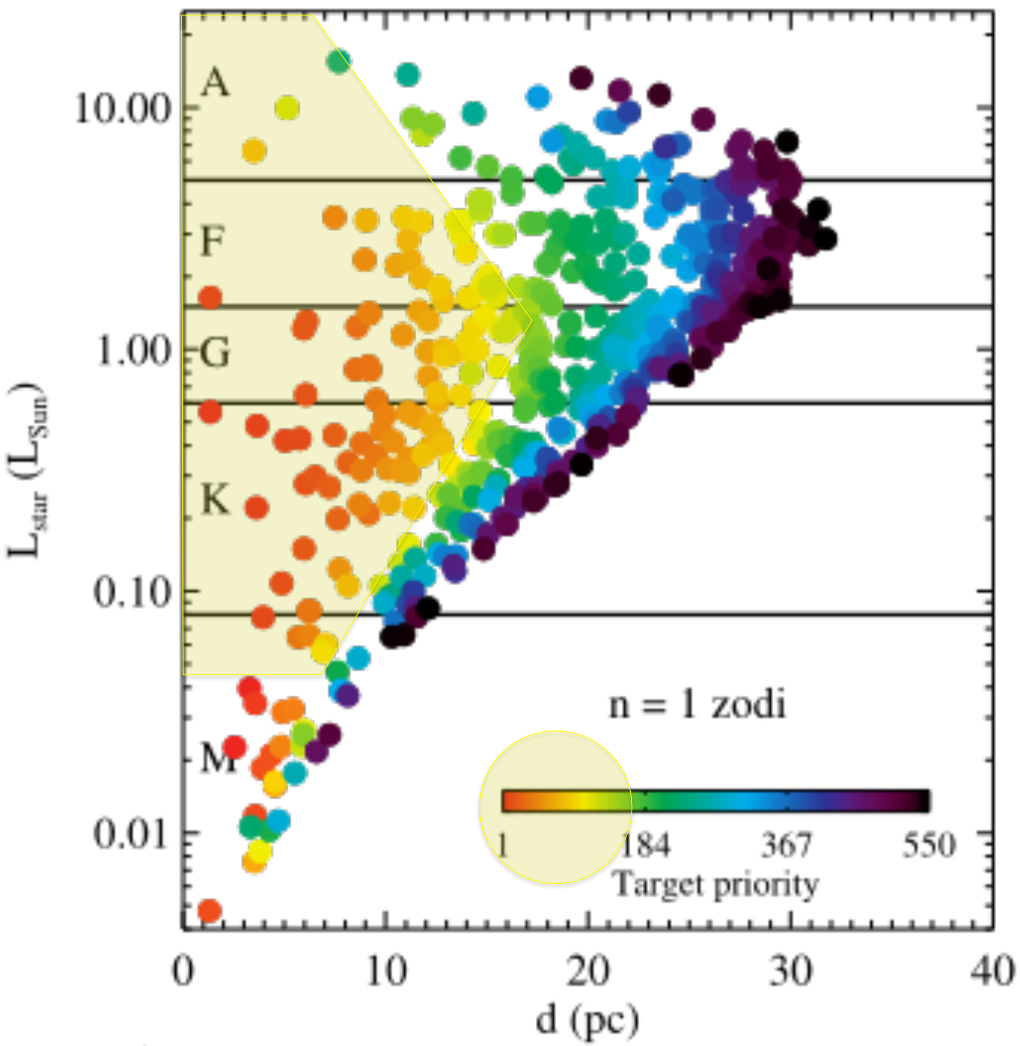
Choices Driven by Mission Considerations

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



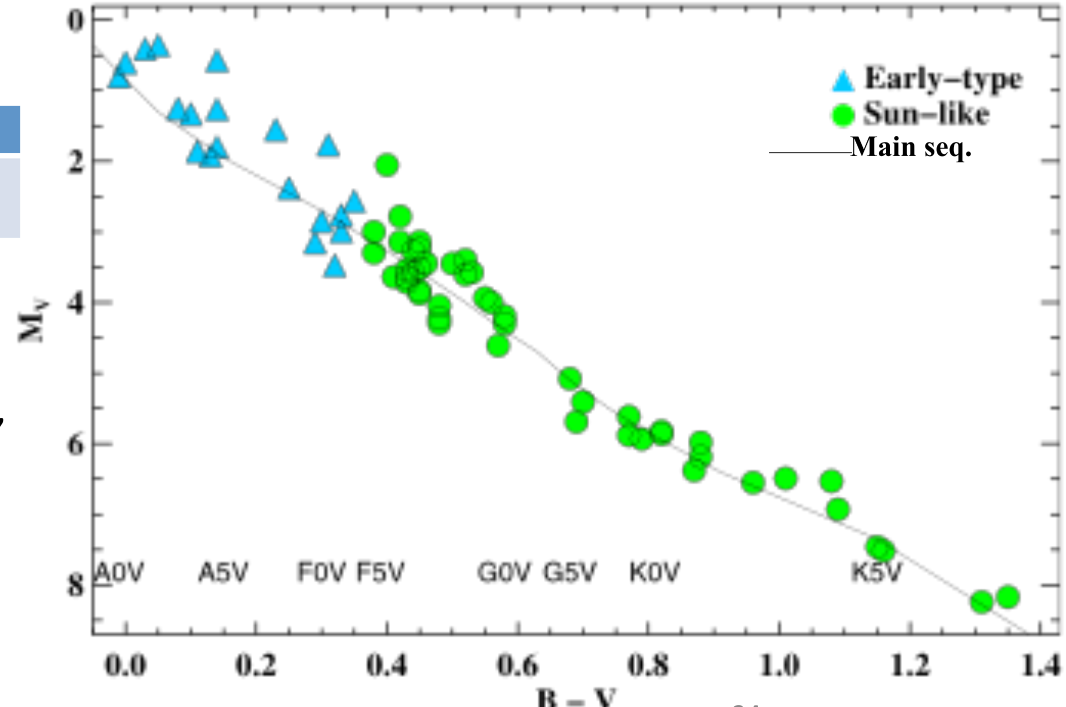
Stark et al. 2014
"Altruistic Yield Optimization"
for their baseline 8 m
telescope and IWA=2 λ/D

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

✹ Cold IR Excess

Example List Here:

- TPF list is for a 4m telescope, 2 λ/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

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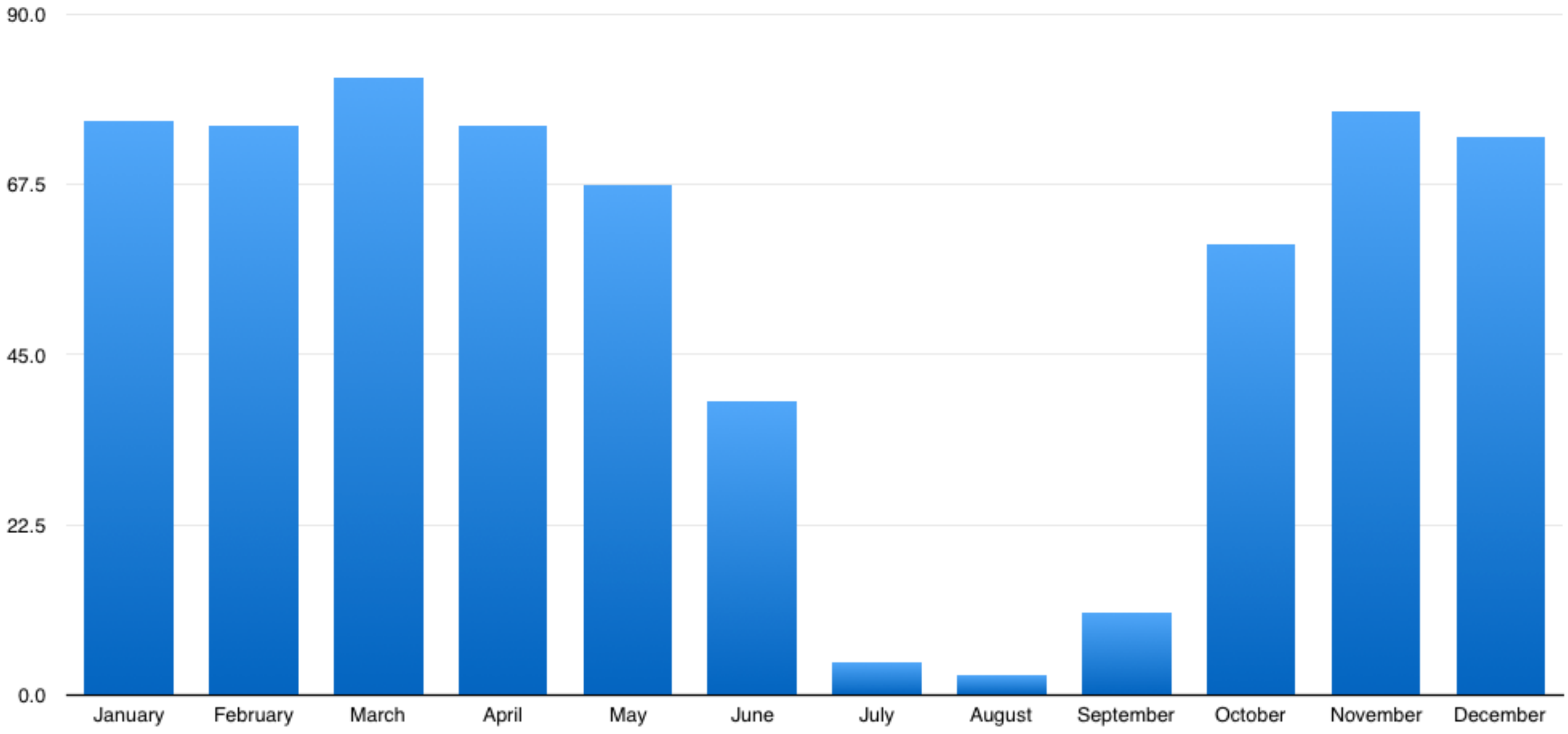
PWV < 6 mm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67.5
45.0
22.5
0.0
January
February
March
April
May
June
July
August
September
October
November
December