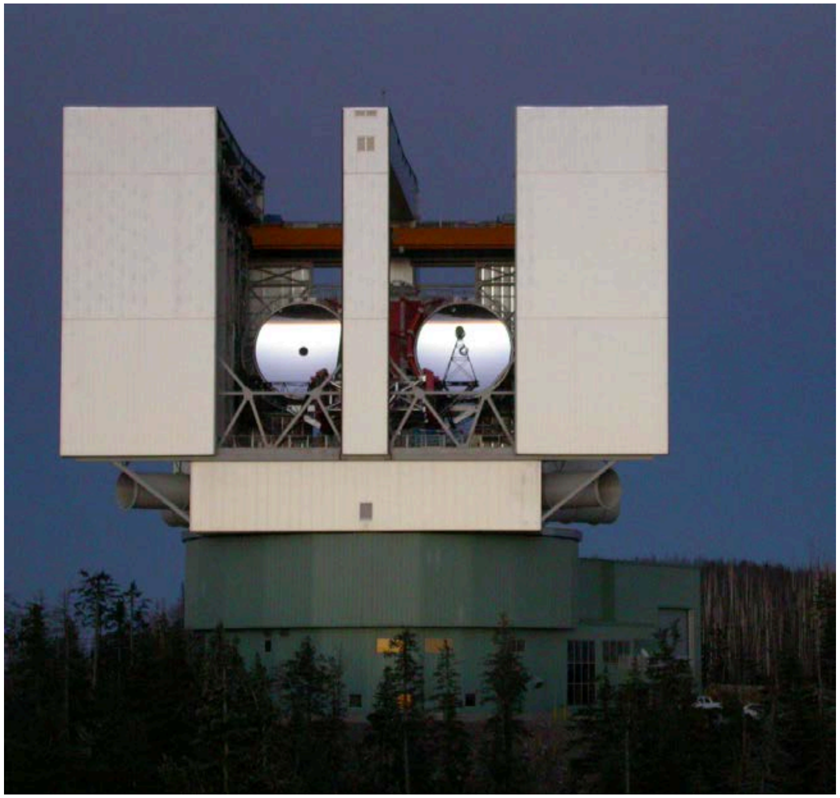
Large Binocular Telescope Interferometer Update



Rafael Millan-Gabet
Caltech / NExScI

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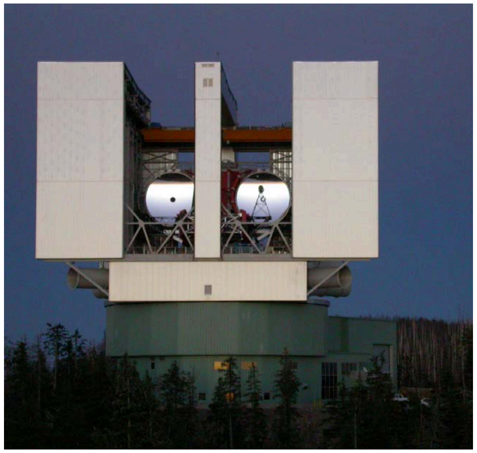
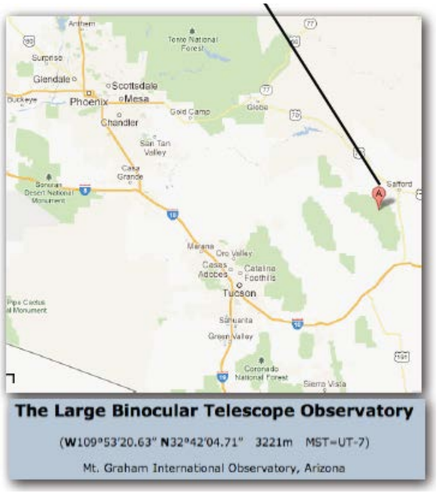
LBTO & LBTI



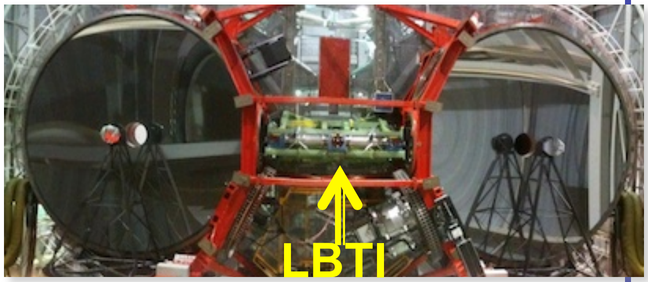
- **LBTO (Mt Graham, AZ)**

  - First light: 2005, 2008
  - Partners: UA, Italy, Germany, Research Corporation, Ohio State U.
  - Observatory operated by UA.
  - Instruments for Vis-IR imaging, photometry & spectroscopy.
  - AO on each telescope (deformable secs, piramid wavefront sensor).



- **LBTI:**

  - UA instrument, funded by NASA. PI: Phil Hinz.
  - Installed Sep 2010. First fringes Oct 2010.
  - NASA science drivers: sensitive exozodi survey, exoplanet imaging.



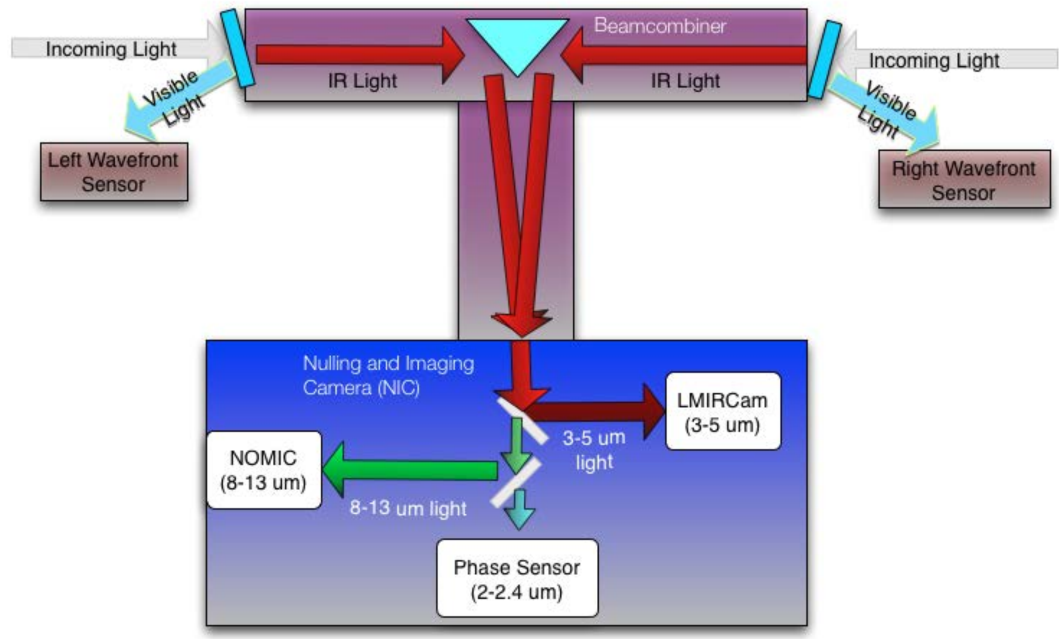
Instrument Overview

- **Sensitivity:**
  - 2 x D = 8.4m telescopes on a single mount.
  - Simple optical path and cooled optics combiner.

- **Resolution:**
  - 22.7 m max. baseline.

  (14.4 m center-to-center)

- **High contrast:**
  - AO delivers e.g. Strehl >95% at 3.8um.



- **Science cameras:**
  - NOMIC: 8-14 um
  - LMIRCAM: 2.9-5.1 um (NSF funded)
  - Imaging, spectroscopic, interferometric modes.

Science Goals

- **HOSTS** (P.I. P. Hinz, UA): NASA exozodi survey using the MIR nulling mode. 50 nights/50 stars. Competitively selected science team members.

- **LEECH** (P.I. A. Skemer, UA). Exoplanet imaging. 50 possible nights in parallel w. HOSTS. Additional 70 nights from other LBT partners.

- Many other astrophysics themes in a variety of modes.






Nulling Requirements

Inform the design of a future space mission to directly image and characterize exo-Earths, by providing measurements of the exo-zodi brightness around the target stars or representative stars. Exo-zodi levels x10-20 higher than that in our Solar system are considered prohibitive for such a mission

➔ Goal: 3-6 zodi sensitivity (1σ); this implies (for a G5V star at 10pc):

Photometric sensitivity:

150-300 μJy per observing sequence (1σ, 10mins).

Null calibration:

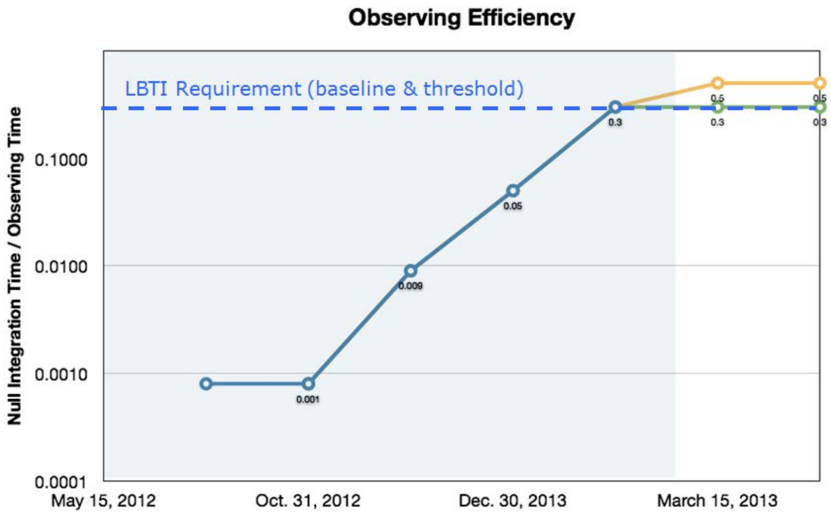
0.75-1.5x10^{-4} in a 3hr observation (1σ, 3 visits, including calibrators)

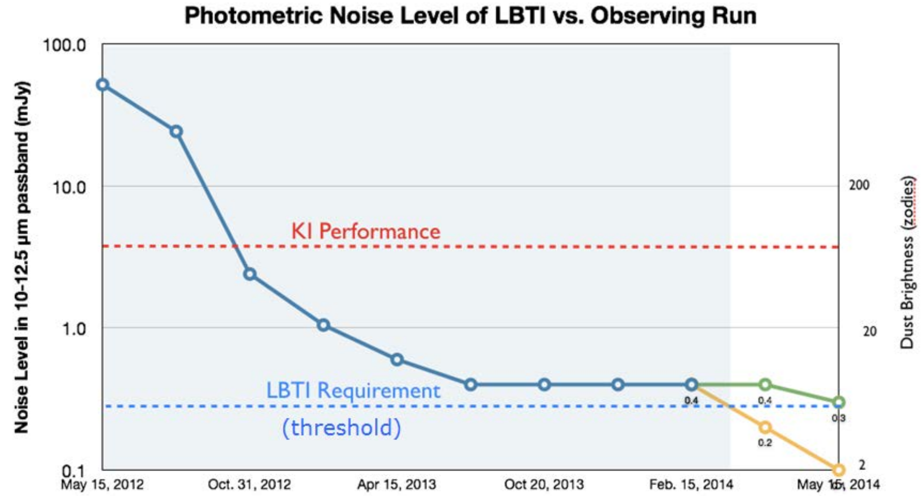
This is x20-40 better than KIN.

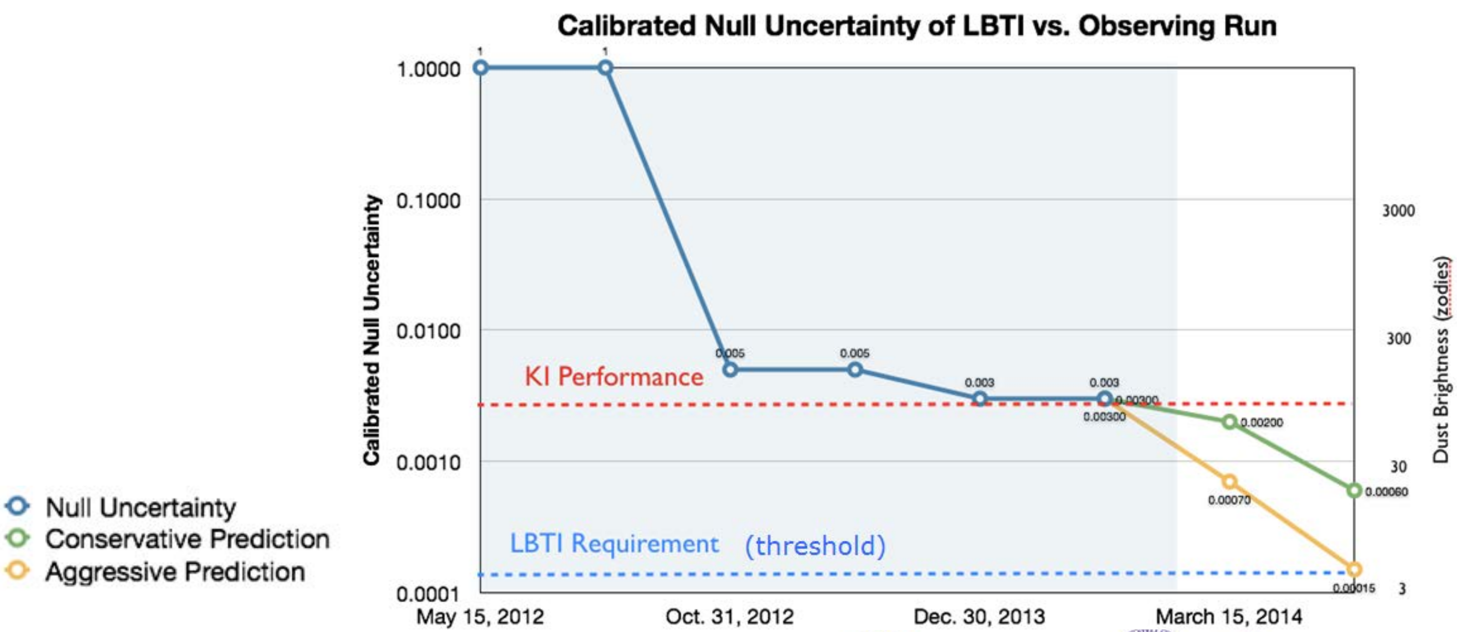
Nulling Instrument Status

- ✓ Under commissioning.
- ✓ First nulls: Sep 2012.
- ✓ Spring & Fall 2013 issues with adaptive secondaries. Now resolved.
- ✓ First stabilized nulls: Dec 2013.
- ✓ Now a completely integrated system, producing science quality nulling sequences, down to 1 Jy stars.
- ✓ Demonstrated efficiency goal of 30 mins per observing sequence (allows 3-4 science targets per night, 3 visits each, including cals).

- Facing issues with phase control:
  - Control algorithm needs improvement (metric, phasing approach, controller …)
  - Telescope vibration, appears to originate in AO sec support arm (0.5-0.7 μm amplitude each telescope, at 11, 13 Hz)
- NOMIC read noise ~x5 higher than spec (we are read noise limited because we need short integration times 10-30msec to freeze seeing and use "Null Self-Calibration" technique - Mennesson et al.).
- Need more investigation of the optimum observing sequence to minimize background estimation biases.

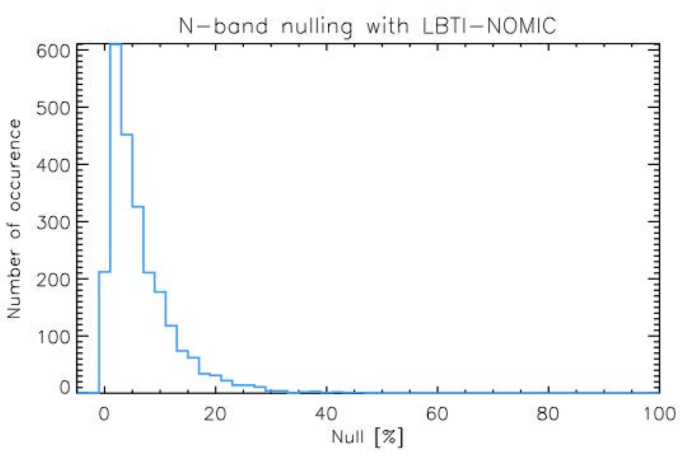

Observing Efficiency
LBTI Requirement (baseline & threshold)
Null Integration Time / Observing Time
0.1000
0.0100
0.0010
0.0001
May 15, 2012
Oct. 31, 2012
Dec. 30, 2013
March 15, 2013

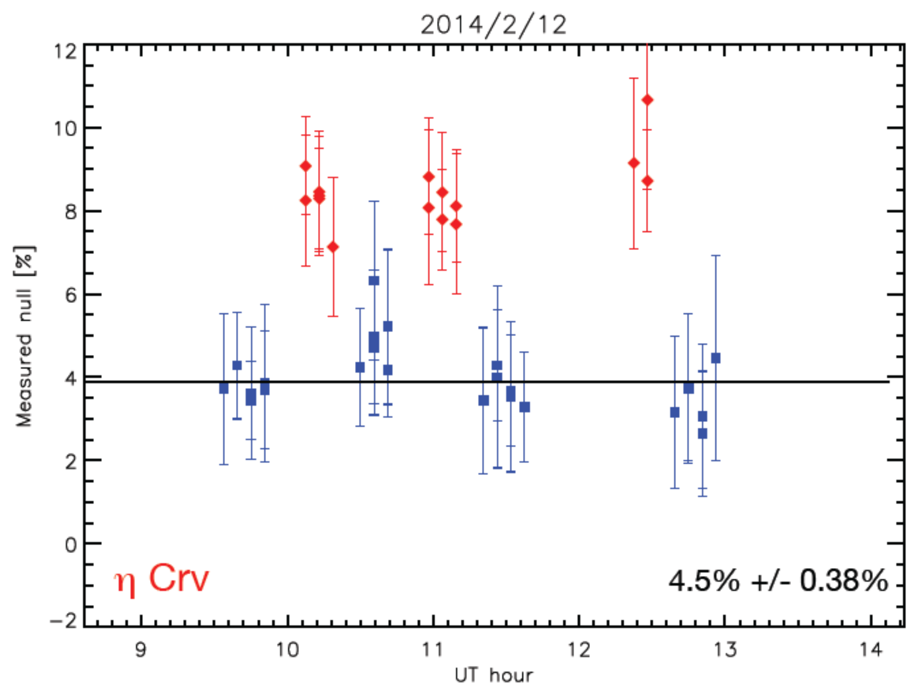

Photometric Noise Level of LBTI vs. Observing Run
Noise Level in 10-12.5 μm passband (mJy)
100.0
10.0
1.0
0.1
KI Performance
LBTI Requirement
(threshold)
Dust Brightness (zodies)
200
20
2
May 15, 2012
Oct. 31, 2012
Apr 15, 2013
Oct 20, 2013
Feb. 15, 2014
May 15, 2014


Calibrated Null Uncertainty of LBTI vs. Observing Run
Calibrated Null Uncertainty
1.0000
0.1000
0.0100
0.0010
0.0001
KI Performance
LBTI Requirement
(threshold)
Dust Brightness (zodies)
3000
300
30
3
May 15, 2012
Oct. 31, 2012
Dec. 30, 2013
March 15, 2014
Null Uncertainty
Conservative Prediction
Aggressive Prediction

Preliminary Science

- β Leo (A3V,7Jy): no or marginal detection at 0.15-0.3% level.
- H Crv (F2V,2Jy): solid detection.
- β UMa (A1IV,7Jy): marginal detection.
- HD69830 (G8V,1Jy): marginal data.
- Vega (A0V,28Jy): good data, just acquired.





Plans

- One more observing run in 2014A (May, 3 nights for nulling).
- Team is formulating a detailed plan for mitigating vibration and for getting to the required performance (with help from UA/JPL Tiger Team), between now and xxx?
- Summer Monsoon shutdown.
- Resume commissioning runs in Fall 2014.
- Operational Readiness Review.
- HOSTS survey until end of FY17 (nominally).

backup

Expected Performance

	LMIRcam	NOMIC	Phasecam
Wavelength Coverage (µm)	2.9-5.1(1.5-5.1 capable)	8-14 (8-25 capable)	2-2.4
Throughput	>30%	>20%	>10%
Pixel Size	0.011"	0.018"	0.1"
FOV	20"	12"	10"
minimum Strehl	88% (3.8 µm)	98% (11 µm)	-
Spectral Resolution	350	100	40
5 sigma detection, 1 hour	19.0 (7 µJy) @ L'	13.3 (200 µJy) @ N	
Spatial Resolution	40 mas @ L'	100 mas @ N'	

3? M_J planet at 1 Gyr

0.4 AU at 10 pc

0.8? zodi debris disk

1 AU at 10 pc

Expected calibration:

3 – 6 zodis (1σ)

Nulling Requirements

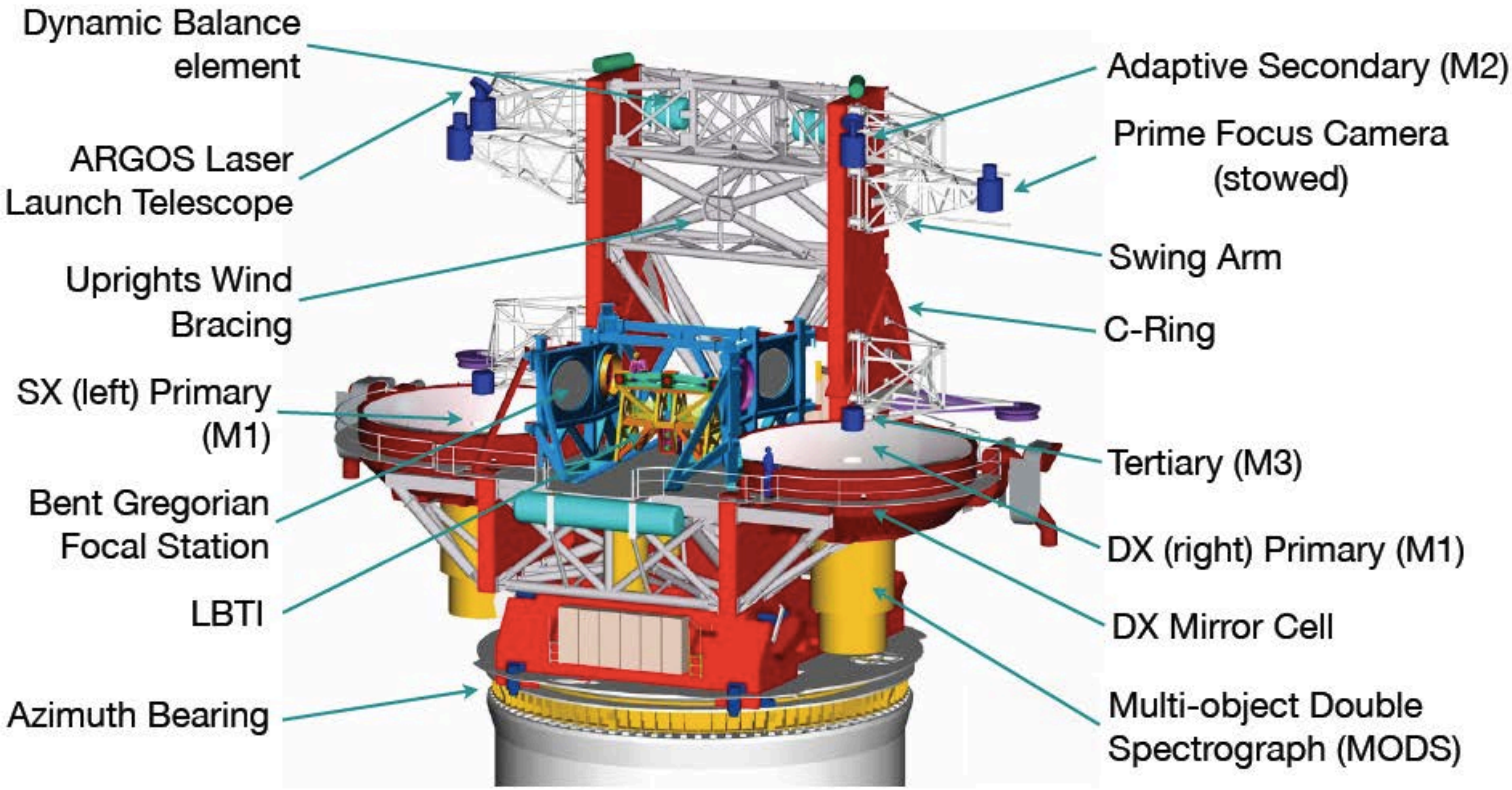
Required Performance

Photometric Sensitivity

- A solar level zodiacal dust disk around a G5 star at 10 pc results in a flux of 42 μJy in the nulled focal plane.
- The PLRA requires a 1-sigma limit of 150-300 μJy for a 10 min. integration.
  - This is a 1-sigma detection level of 3-6 zodies.

Calibrated Null Stability

- A G5 star at 10 pc has an 11 μm flux of 1.2 Jy.
  - The flux of a solar level zodiacal dust disk is 5x10^-5 of its star.
  - Approximately 1/2 of the flux is transmitted to the final focal plane.
- The PLRA requires a calibrated uncertainty in the nulled star of 0.75-1.5x10^-4 for a 3 hour integration time.
  - This is a 1-sigma detection limit of 3-6 zodies.

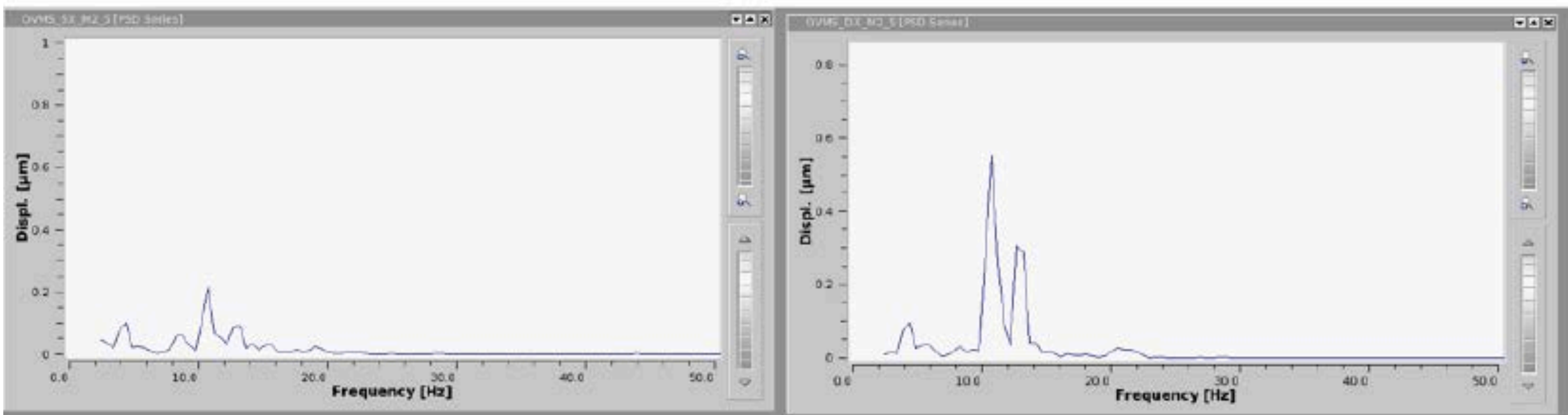


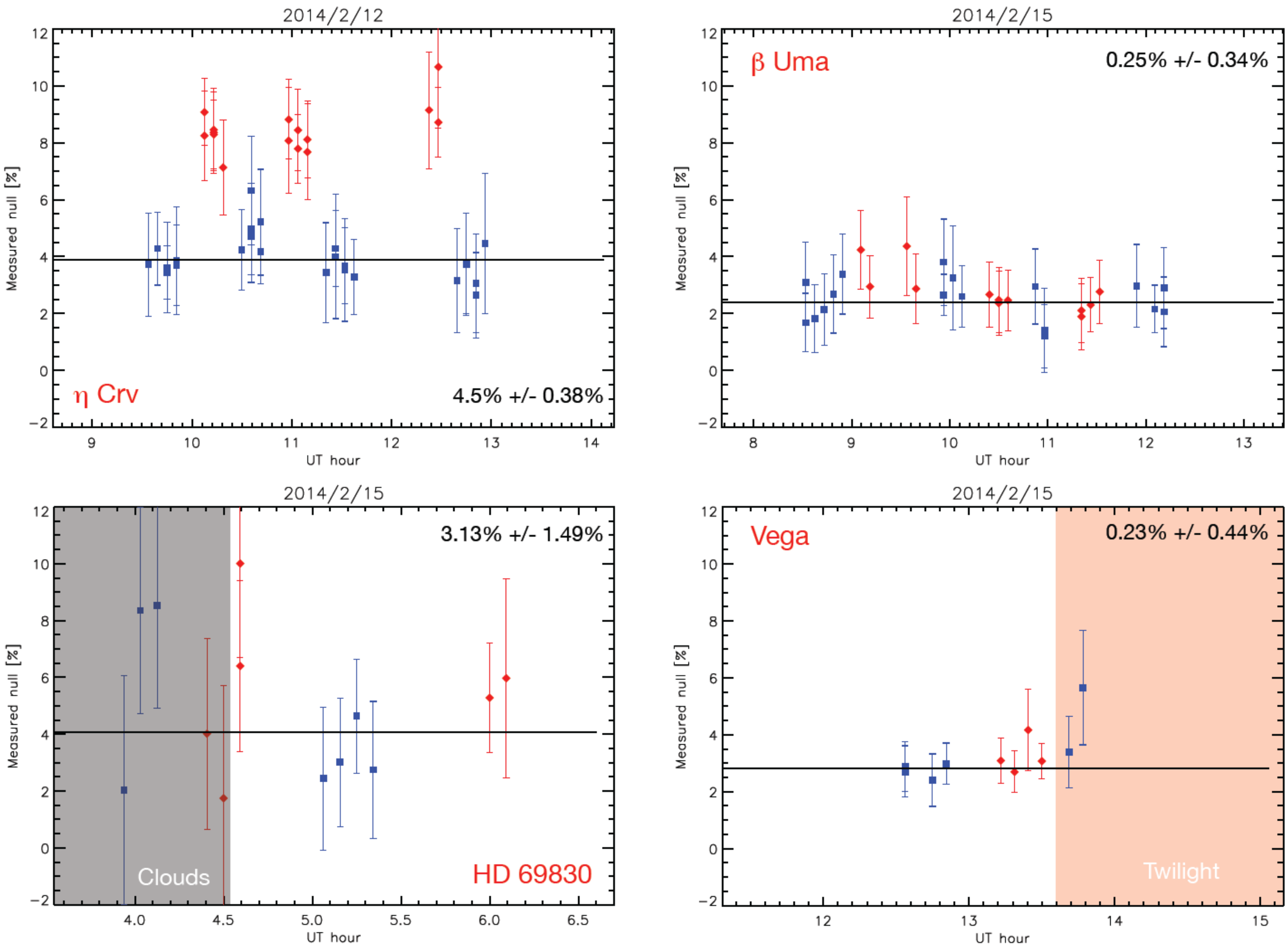
Rear View of LBT

- Phase measurements show variations with a strong component at 11-12 Hz.

- Accelerometers on the M2 swing arms show two peaks: 11 and 13 Hz.

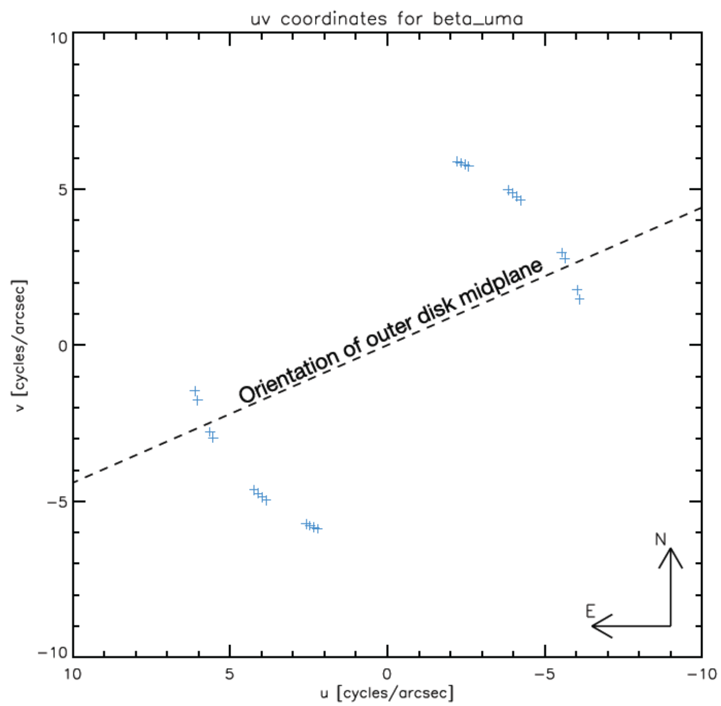
  - Typical on-sky amplitude is 0.5-0.7 um for each arm.

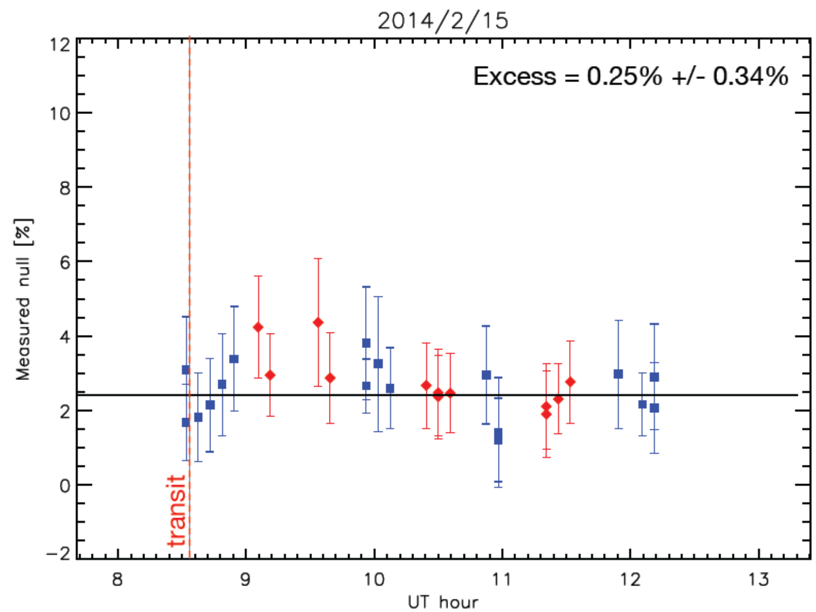



2014/2/12
η Crv
4.5% +/- 0.38%
Measured null [%]
UT hour
2014/2/15
β Uma
0.25% +/- 0.34%
Measured null [%]
UT hour
2014/2/15
3.13% +/- 1.49%
Clouds
HD 69830
Measured null [%]
UT hour
2014/2/15
Vega
0.23% +/- 0.44%
Twilight
Measured null [%]
UT hour

Results: β Uma

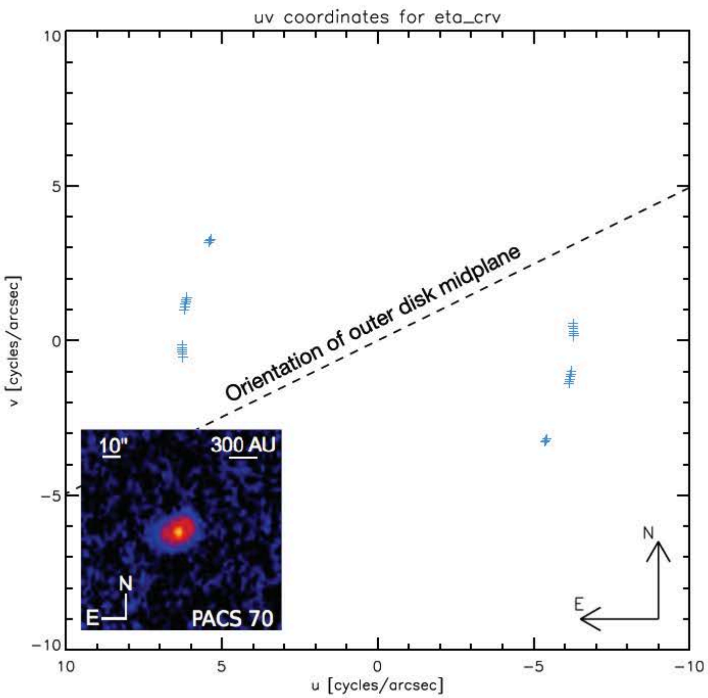
- Outer disk ~edge-on (i = 46.8°, Booth et al. 2013)
- PA = 113.8° (Booth et al. 2013)
- KIN excess: 0.64%
- Poor setpoint adjustment => good candidate for VSC technique

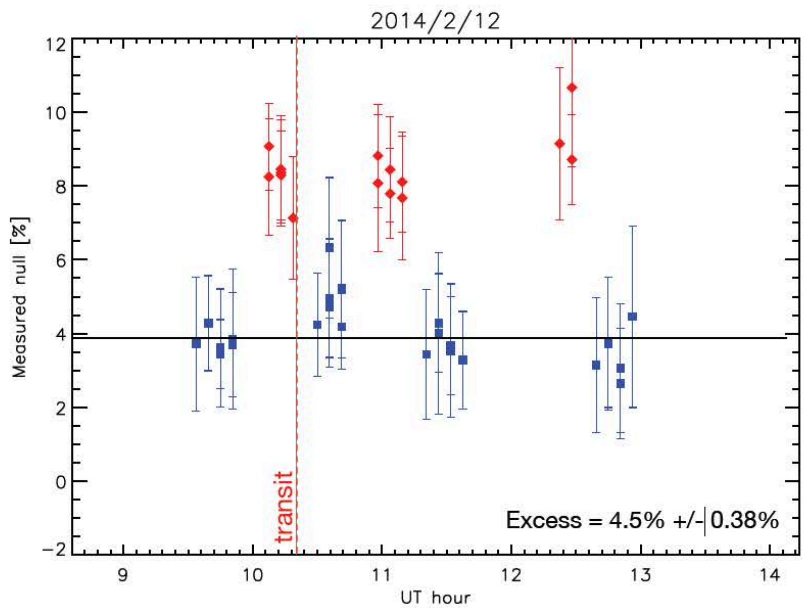




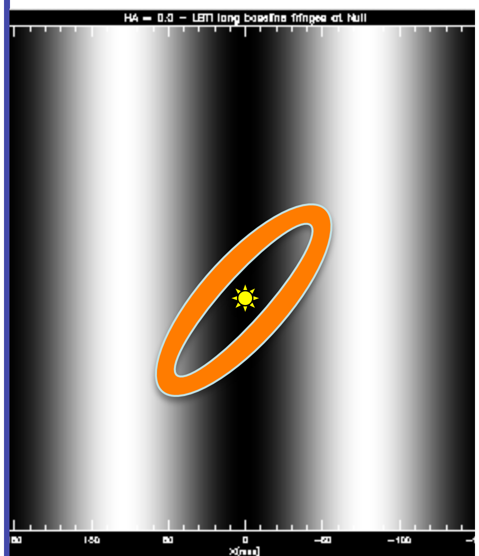
Results: η Crv

- Outer disk ~edge-on (i = 46.8°, Duchene et al. 2014)
- PA = 116.3° (Duchene et al. 2014)
- Excess: 17% (IRS), 4% (KIN)





Some Basics



- **Compared to hotter stars (early-type), for cooler stars (late-type) the N-band dust emission arises closer to the star, where is it partially nulled, and therefore leads to a smaller signal.**
- **Thus, at a given distance, exozodi around a hotter (early-type) star is easier to detect.**
- **To achieve greater sensitivity for a given spectral type, the star must be closer to us.**
- **Eventually you run out of FGK stars close enough to resolve the dust, then if you really want those spectral types, you accept a penalty in exozodi sensitivity.**

Target Selection Criteria

- **Suitability for exo-Earth imaging:**
  - **Trade off between:**
    - **HZ location α Lstar**
    - **Flux ratio Fearth/Fstar α 1/Lstar**
  - **Assume an internal coronograph in the visible. (similar conclusions for an IR interferometer).**

➔ Best targets are nearby Solar type stars (FGK dwarfs).

- **Instrument constraints:**
  - **Fstar > 1Jy (to be photometrically sensitive to 3-6 zodi).**
  - **Declination (observability).**
  - **Exclude binaries for which the companion can confuse AO or contaminate the null; or with separation <100AU (not favorable for planet formation).**

Results

List of 72 stars in Science Team collaborative Google spreadsheet

- **Spectral type F: 25 stars**
- **Spectral type G: 13 stars**
- **Spectral type K: 20 stars**

- **Plus 14 bright A stars for best LBTI sensitivity even under mediocre seeing conditions.**

Note: all the LBTI targets are also in ExoCat, except 2 (HD37507, HD108767; have not yet looked into why these are not in ExoCat).

Results

If σ_{leak} = 0.75e-4 (Baseline):

Number of stars for which we reach 3 zodi equivalent noise = 57

(48 FGK)

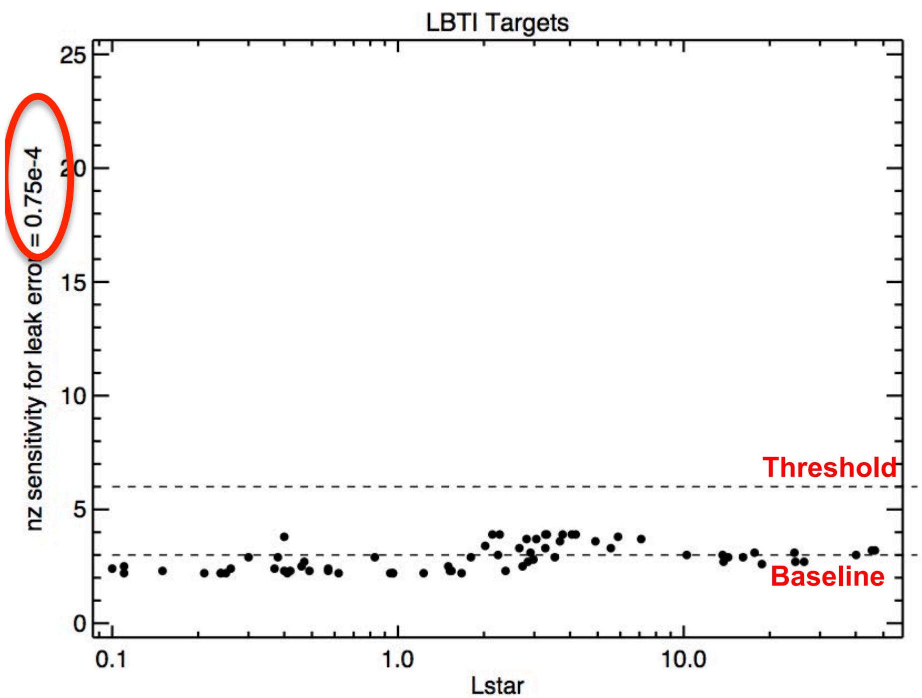
If σ_{leak} = 1.5e-4 (Threshold):

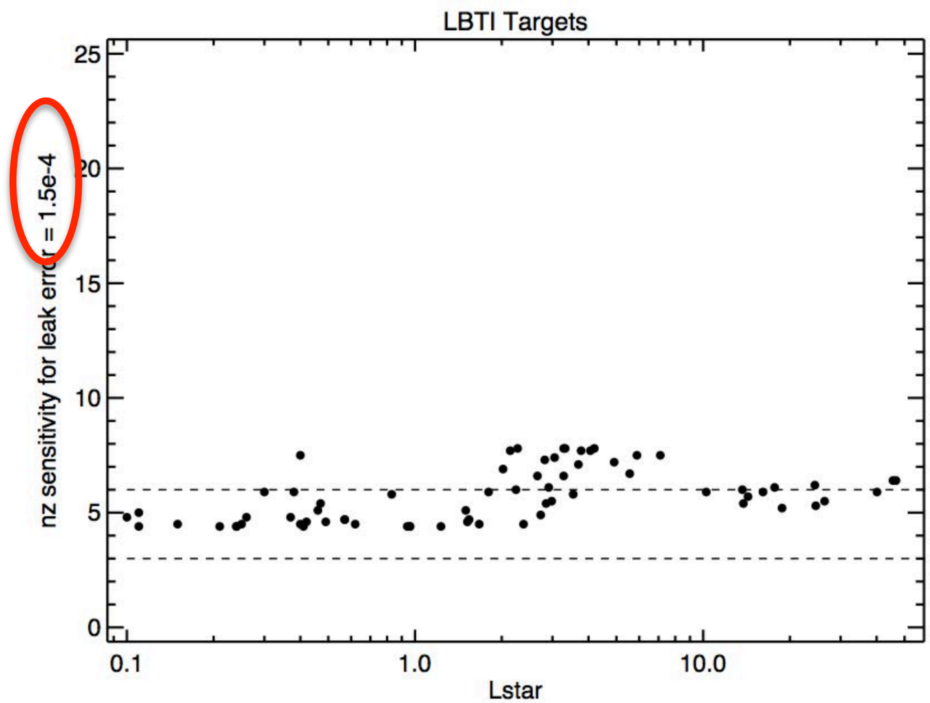
Number of stars for which we reach 6 zodi equivalent noise = 53

(38 FGK)

➔ The target list satisfies the PLRA requirements.

Note: assumed 0.5 zodi "tolerance" on the requirements.


LBTI Targets
nz sensitivity for leak error = 0.75e-4
Threshold
Baseline
Lstar
0.1
1.0
10.0
0
5
10
15
20
25


LBTI Targets
nz sensitivity for leak error = 1.5e-4
Lstar
0.1
1.0
10.0
0
5
10
15
20
25

Additional Considerations on Targets and Models

- The Science Team may favor a somewhat different sub-sample from the list, in order to e.g.:
  - Have a sample with more Solar-type stars, even at the expense of somewhat degraded sensitivity ➔ enhanced statistics for Solar-type stars and ability to predict exozodi levels for un-observed exo-Earth mission targets.
  - Include younger (early-type) stars ➔ inform models of how dust production declines with age; needed in order to know how to extrapolate to un-observed stars.
  - Include stars known to have cold dust (Spitzer, Herschel) ➔ connect the evolution of cold/warm dust; also provides detailed measurements of dust distribution which will enhance our ability to model exozodi.

- In the final analysis, the Science Team may choose to interpret the LBTI measurements considering a variety of plausible models and may adopt a different zodi definition, in order to most robustly inform the design of an exo-Earth imaging mission.