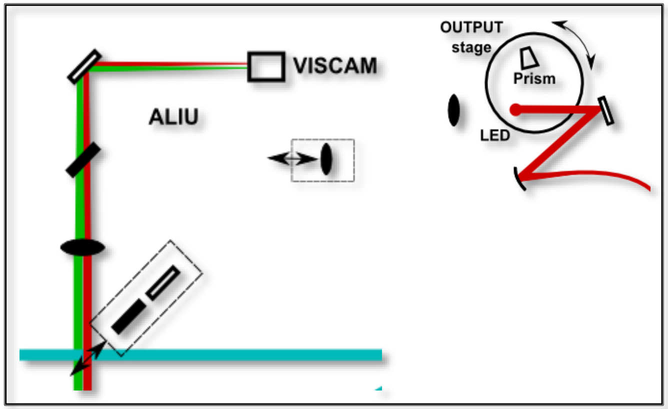
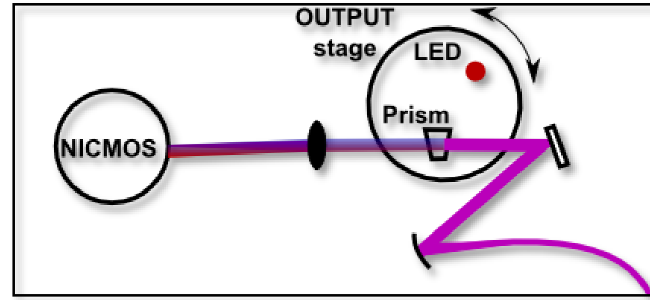
First Science with JouFLU

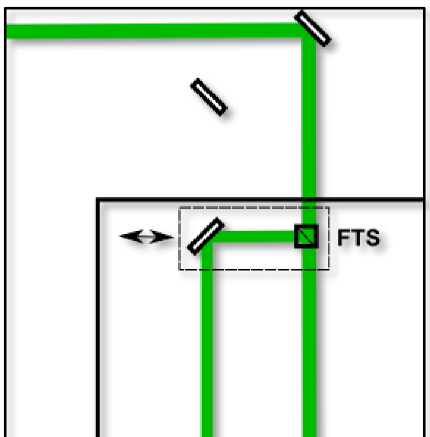
and some instrument updates

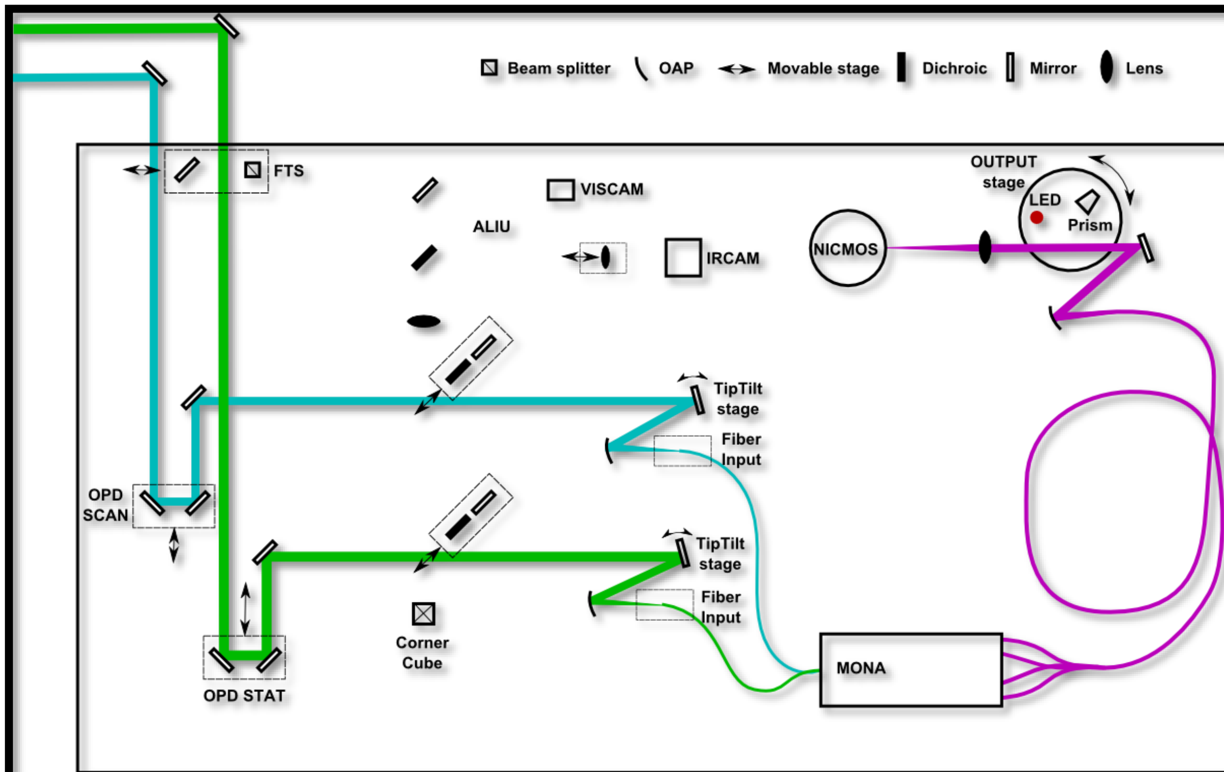
Nicholas J Scott

March 2015





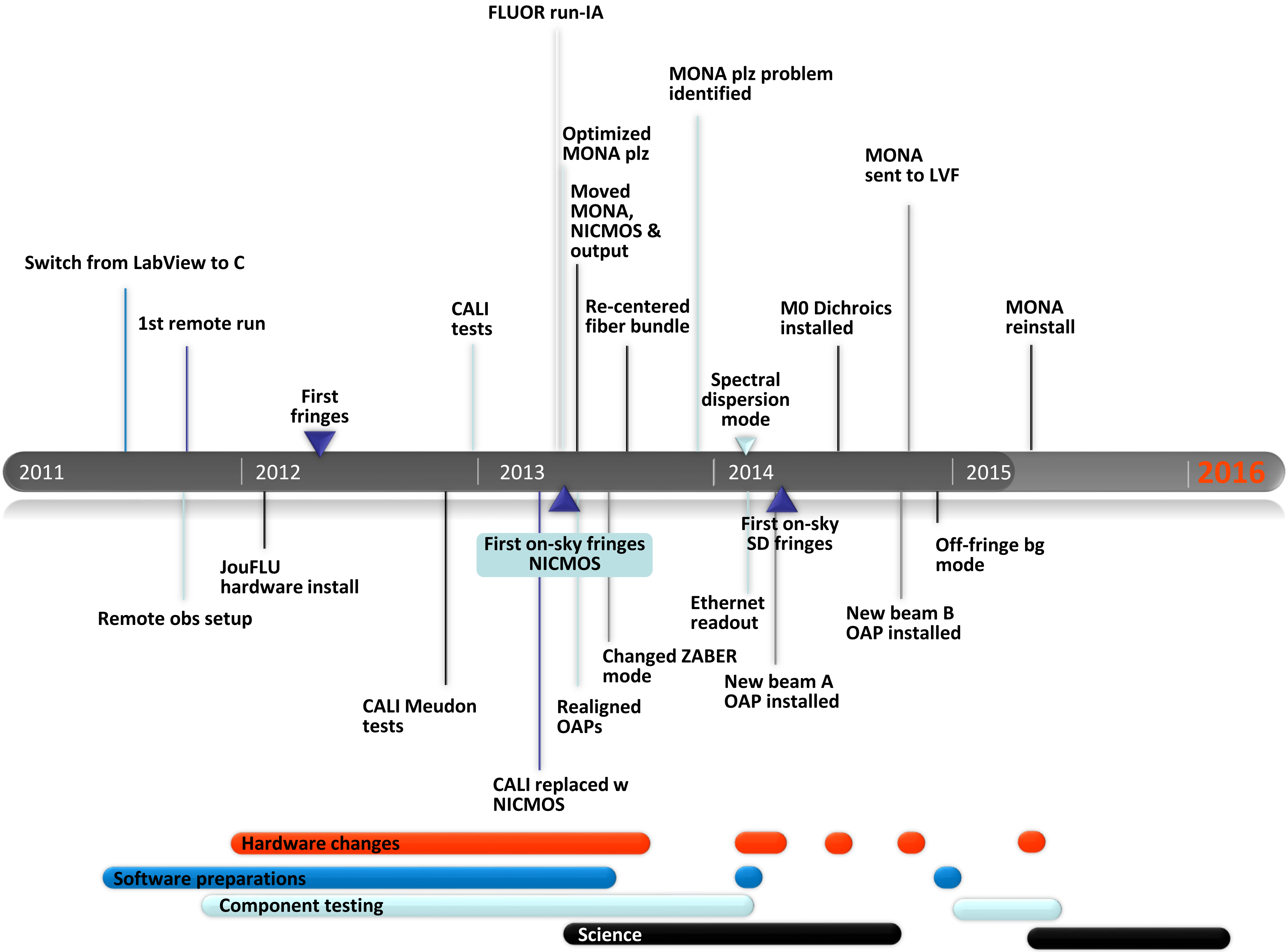




Georgia State University · NSF · NOAO · l'Observatoire de Paris · LESIA · The University of Michigan · NExScI NASA Exoplanet Science Institute · SUSI · Observatoire de la Côte d'Azur · Max-Planck-Institut für Radioastronomie

JouFLU

- Software integrated with CHARA environment
- Remote operations
- Pupil imaging
- Upgraded fiber injection
- Improved alignment procedure
- Spectral dispersion mode
- Fourier Transform Spectrograph mode
- New Data Reduction Software


FLUOR run-IA
MONA plz problem identified
Optimized MONA plz
MONA sent to LVF
Moved MONA, NICMOS & output
Switch from LabView to C
1st remote run
CALI tests
Re-centered fiber bundle
M0 Dichroics installed
MONA reinstall
First fringes
Spectral dispersion mode
2011
2012
2013
2014
2015
2016
First on-sky SD fringes
First on-sky fringes NICMOS
Off-fringe bg mode
JouFLU hardware install
Remote obs setup
Ethernet readout
New beam B OAP installed
Changed ZABER mode
New beam A OAP installed
CALI Meudon tests
Realigned OAPs
CALI replaced w NICMOS
Hardware changes
Software preparations
Component testing
Science

Current status report

Science data taken 2013-2014

New **data reduction pipeline** coming soon (Paul's talk)

- Initial science data reduced
- Convertor available for old data

User manual and alignment procedures being documented

Spectrally dispersed data taken

Input OAPs replaced

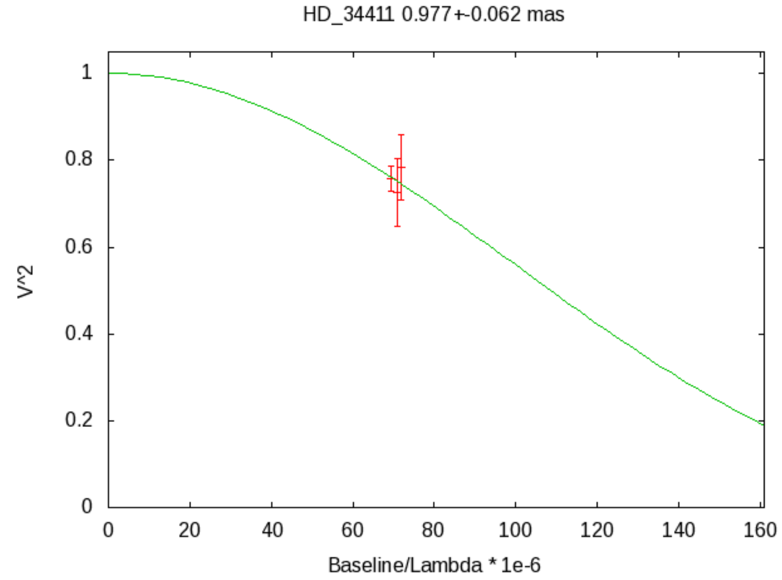
Polarization issues investigated

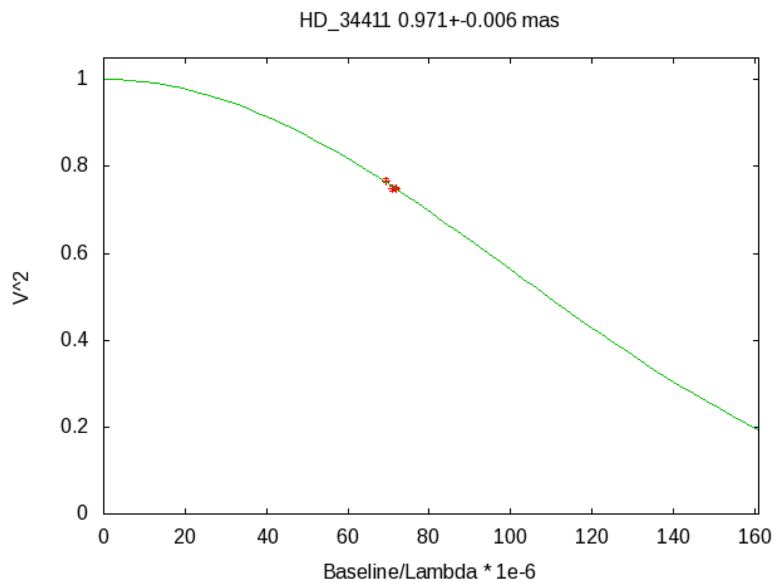
MONA sent to LVF for correction

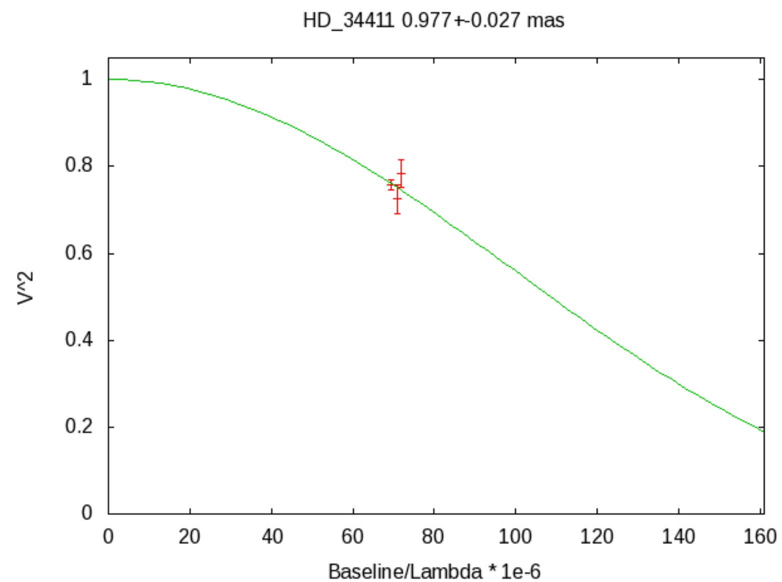
Comparison to known diameter

Tabby 0.981 0.015

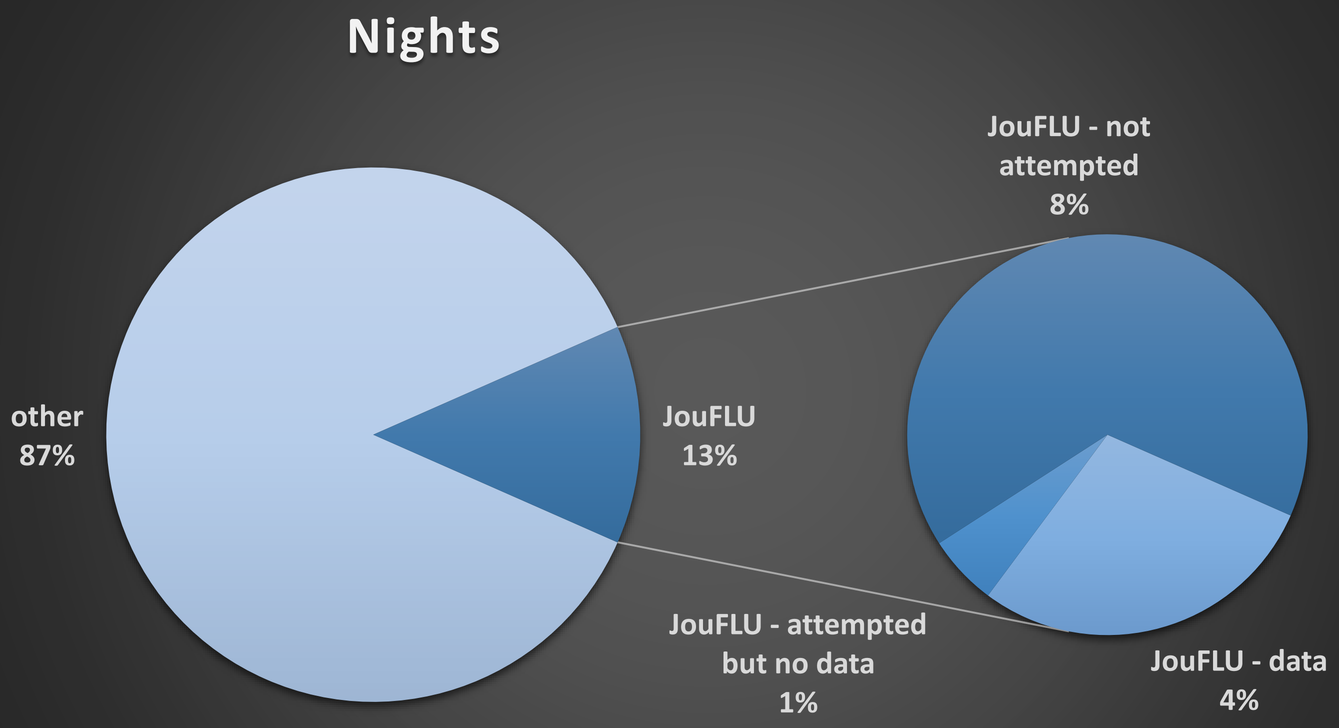
- Included in DRS development tests



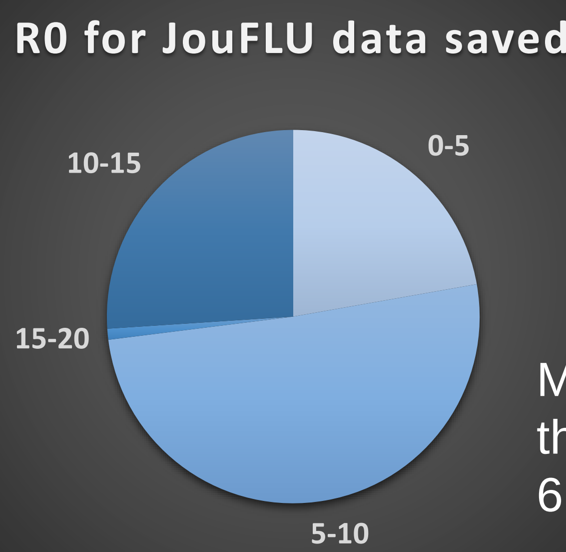




Log stats



- 265 nights in 2014, 35 JouFLU
- Data collected on 13 nights
  - Poor MONA performance forced some programs to switch to CLASSIC
- Clouds reported on 2 nights



Most of this from 6 nights

Number of brackets (1o2o3o1)

0.5 per hour

4-5 per night

In May K=4.4 was giving strong fringes!

Previous JouFLU K limit

4.86 HD 27789

5.17 FU Ori

Most recent K limit

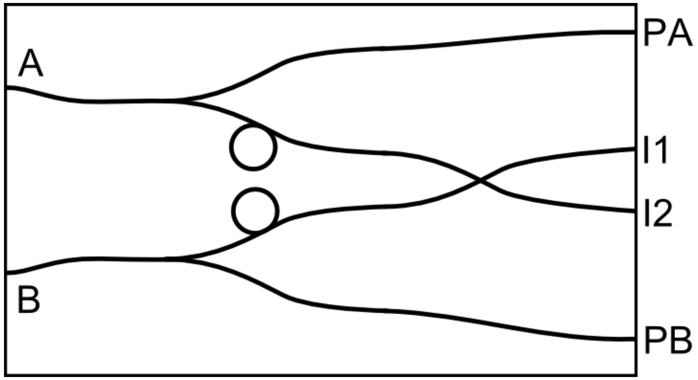
3.55 HD 213930

3.96 HD 14055

K limit after MONA repair

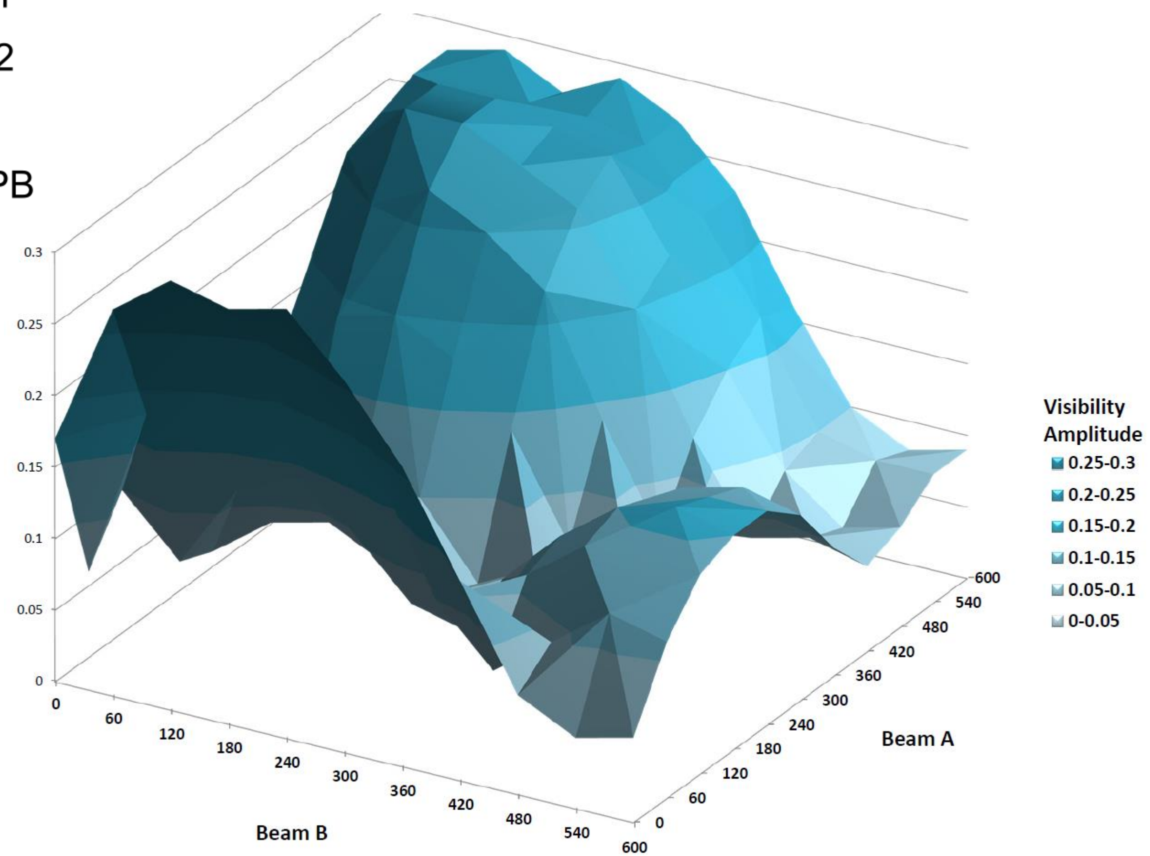
?

Polarization



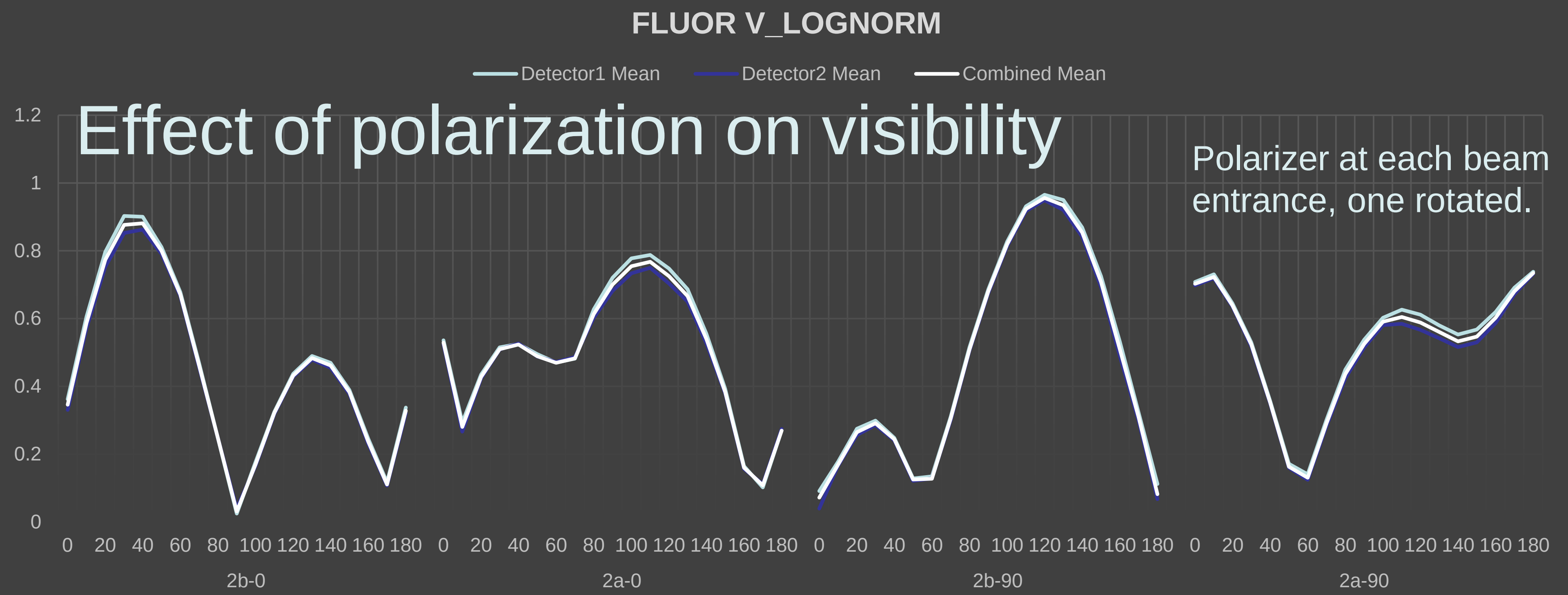
MONA

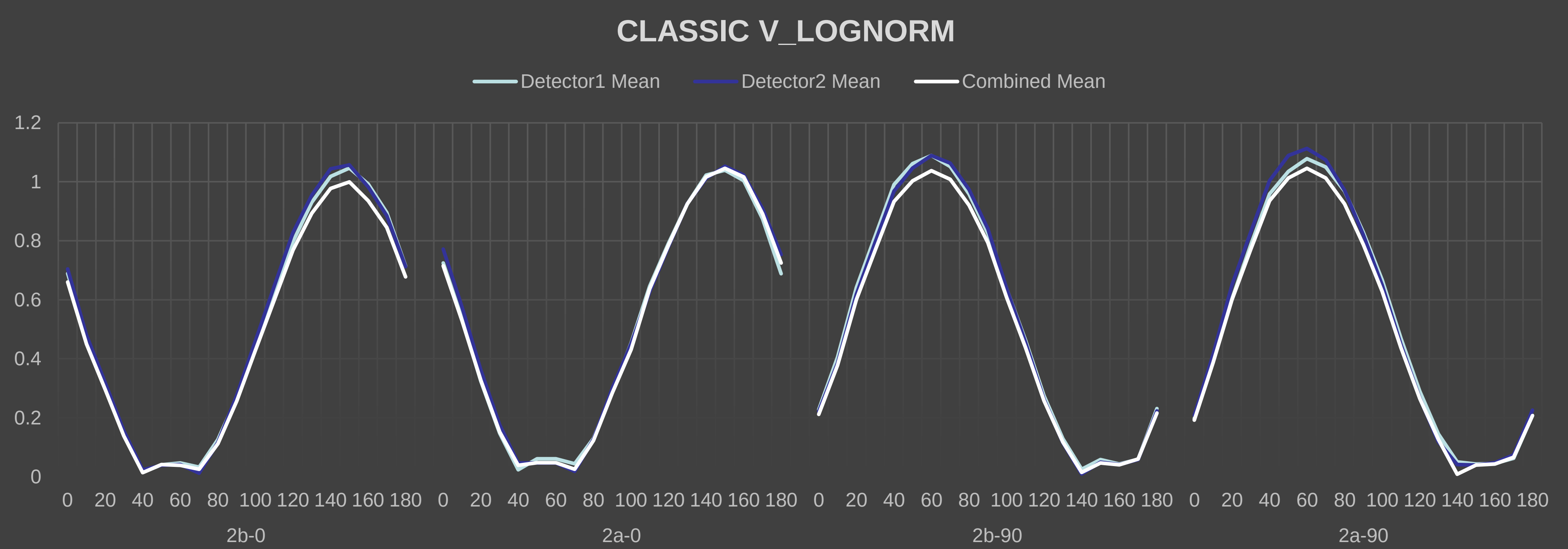
Why can we only get a maximum V of ≈0.3?



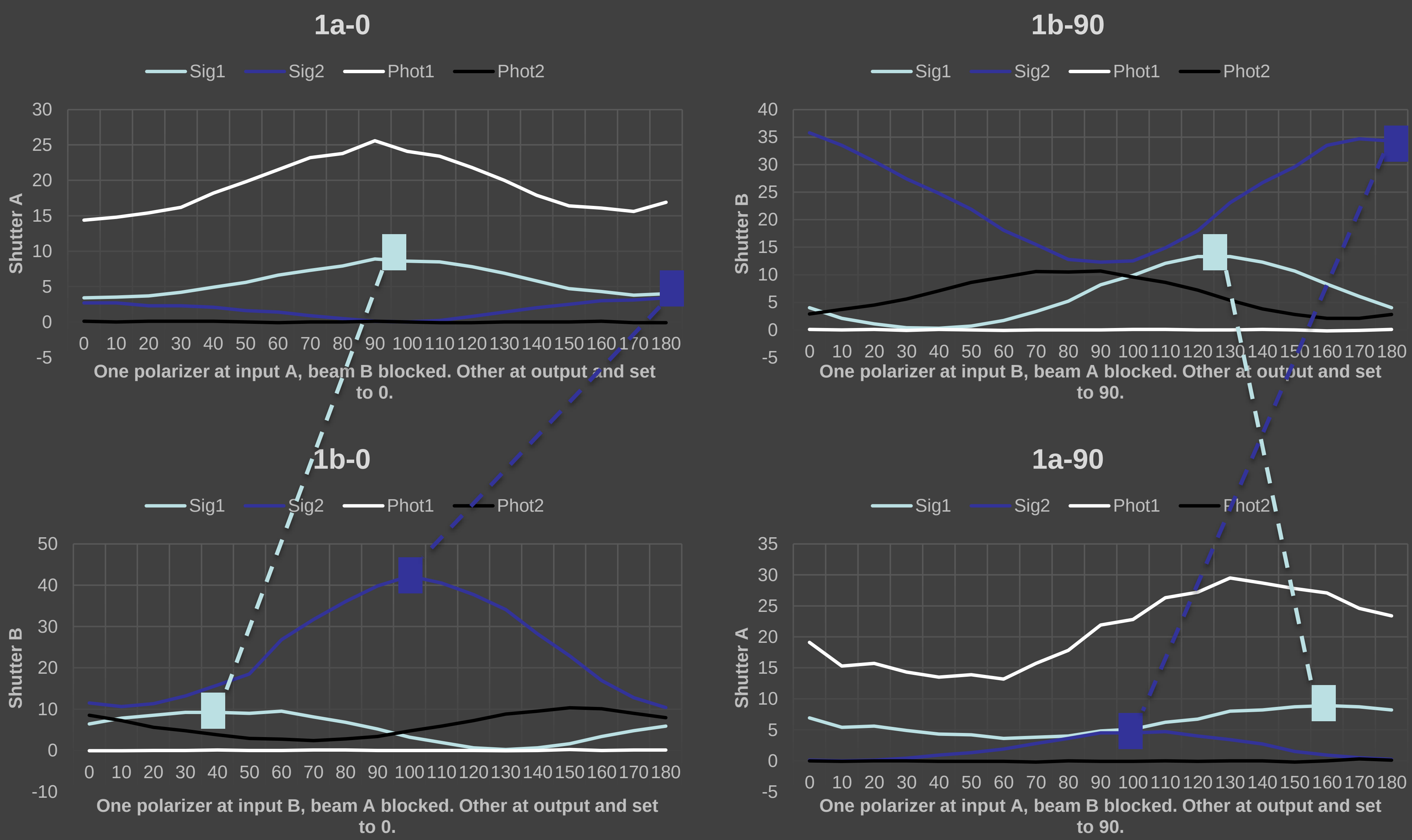
Effect of polarization on visibility

Polarizer at each beam entrance, one rotated.

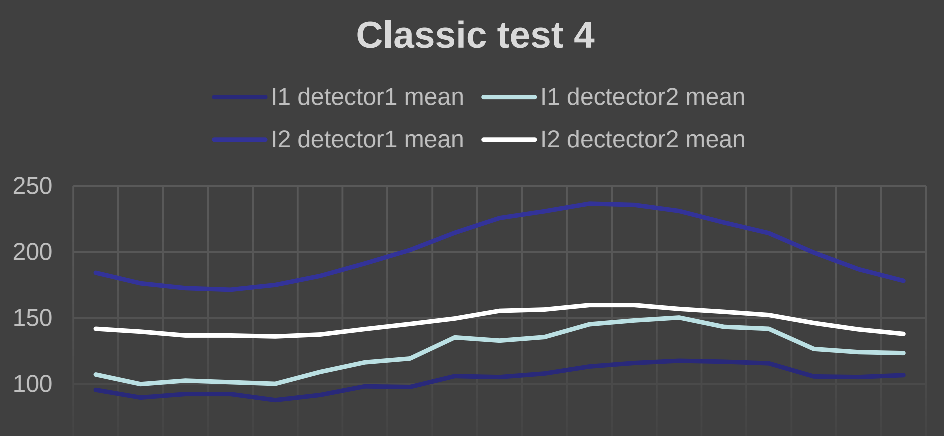




Differential polarization rotation



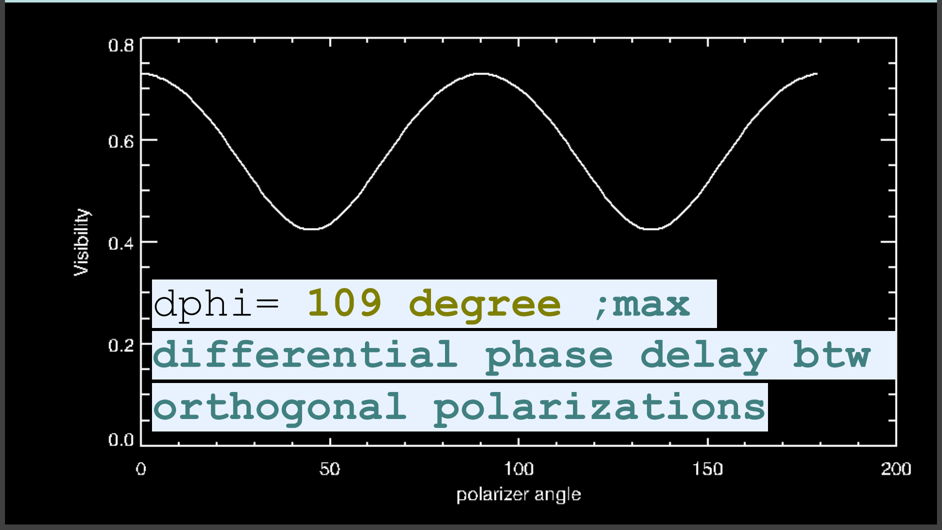
Differential polarization delay

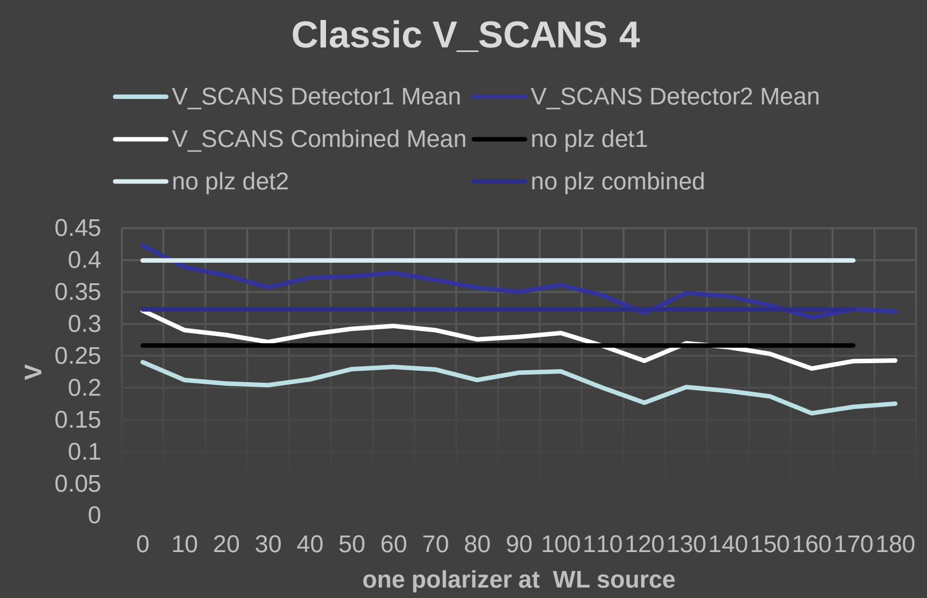


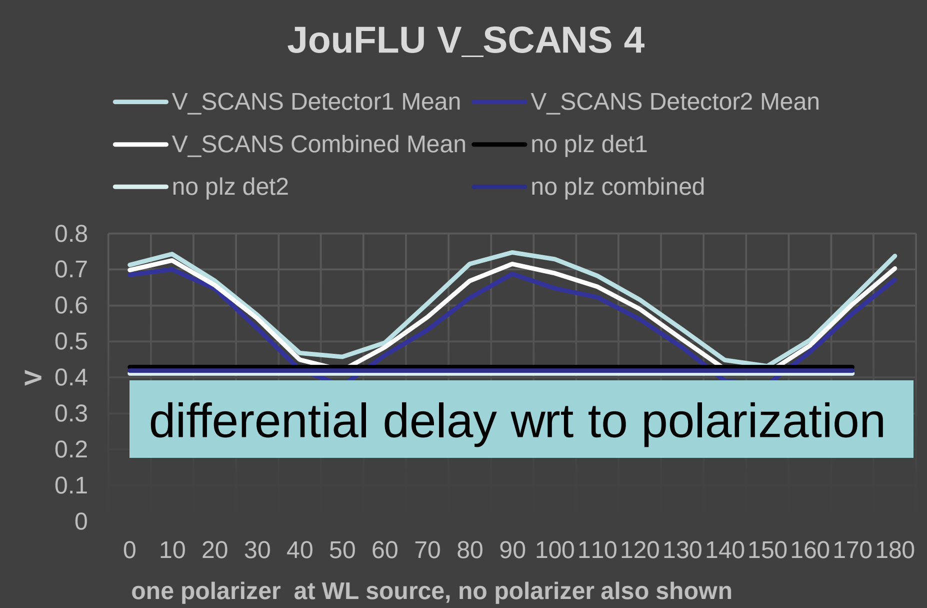
Max V ~ 0.73

- bandwidth smearing / dispersion
- beam intensity imbalance
- fringe sampling & finite integration effects

AND differential polarization rotation.



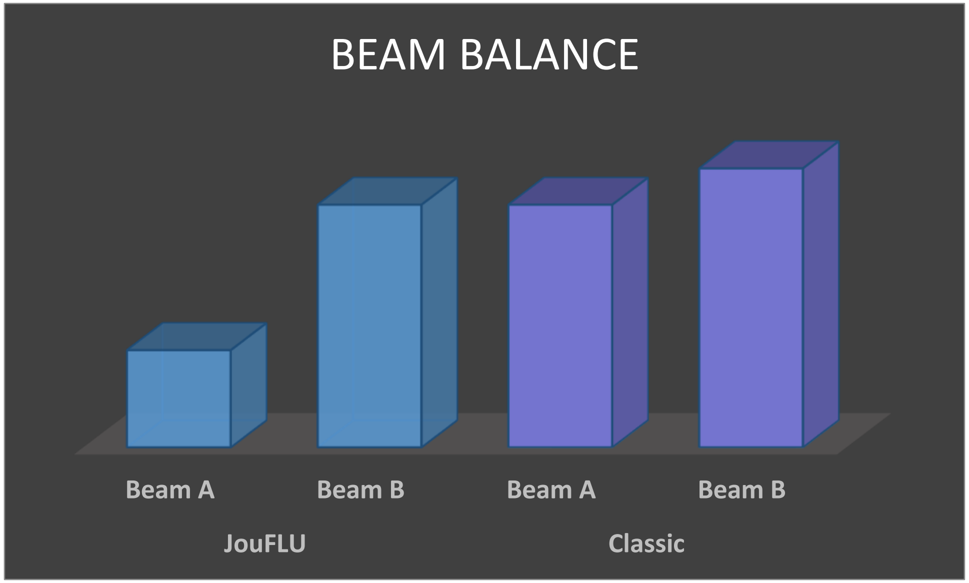




Beam (Im)Balance

Factor of 2-3 between FLUOR beams

- Only 15% difference between CLASSIC beams
- Reduces maximum visibility
- Corrected in DRS
- Replaced OAPs

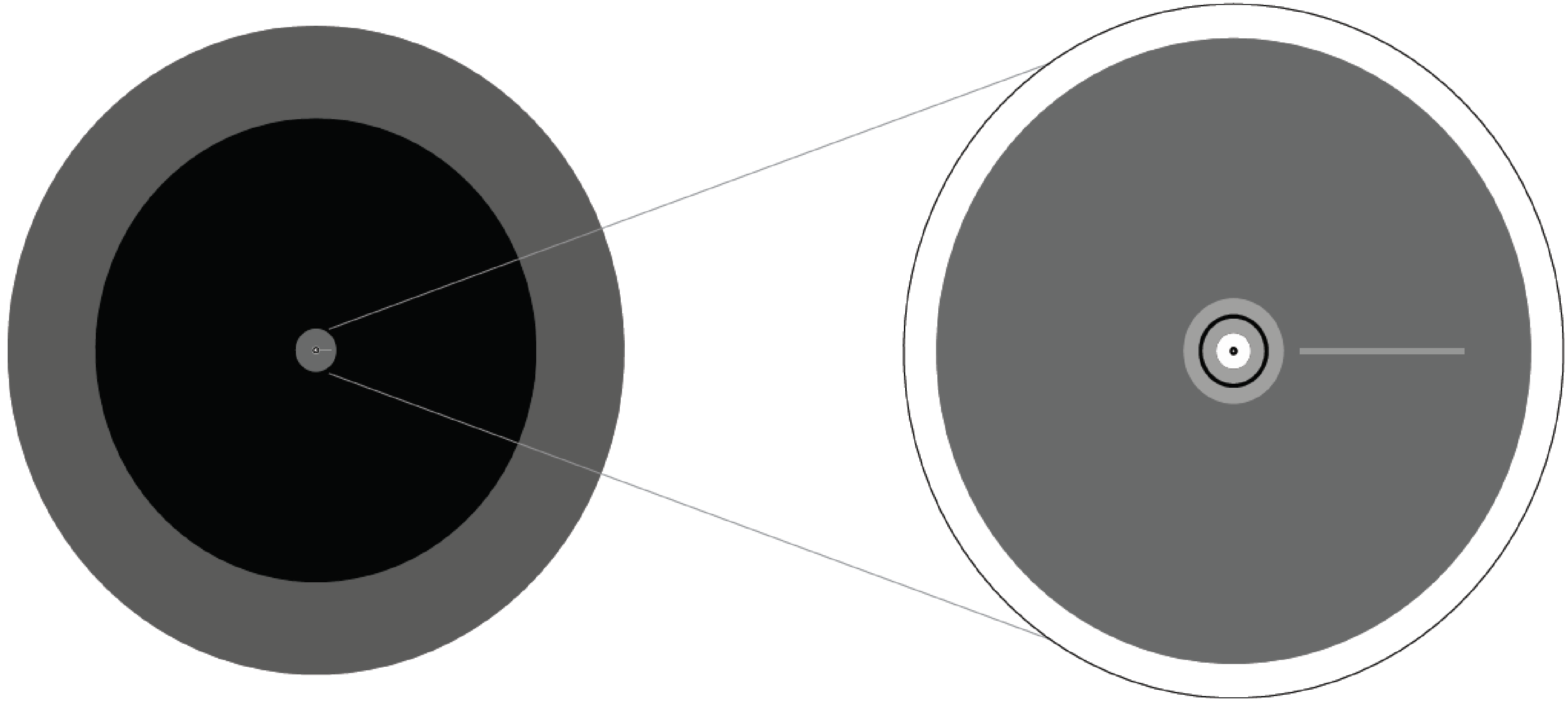


Unable to test until MONA re-install

MONA sent to LVF

Return by end of April

- Polarization controllers
  - Lithium/Niobate plates
- Tested X-coupler
- VINCI combiner to arrive soon
- other combiner back-ups (GRAVITY/IONIC)
- New MONA (jouMONA?)



Conventional detection level
Spitzer, Herschel

>100AU cold debris disk (<100K)
10AU giant planet
<10AU exozodiacal dust disk (100-1400K)

Interferometric field-of-view (at 10pc)

<10AU exozodiacal dust disk (100-1400K)
2-7AU habitable zone (line)
1AU earth-like planet with gap
0.5-1.5AU warm dust disk (500K)
0.1-0.5AU hot dust disk (>1000K)
A0 star

Dusty Puzzle

Debris disks left over from planet formation, little known about the inner dust component

NIR interferometric results → large populations of hot small grains close in to nearby MS stars

- Sub-micron grains should be short lived in this region

Trapped or replenished by catastrophes – different timescale for each mechanism

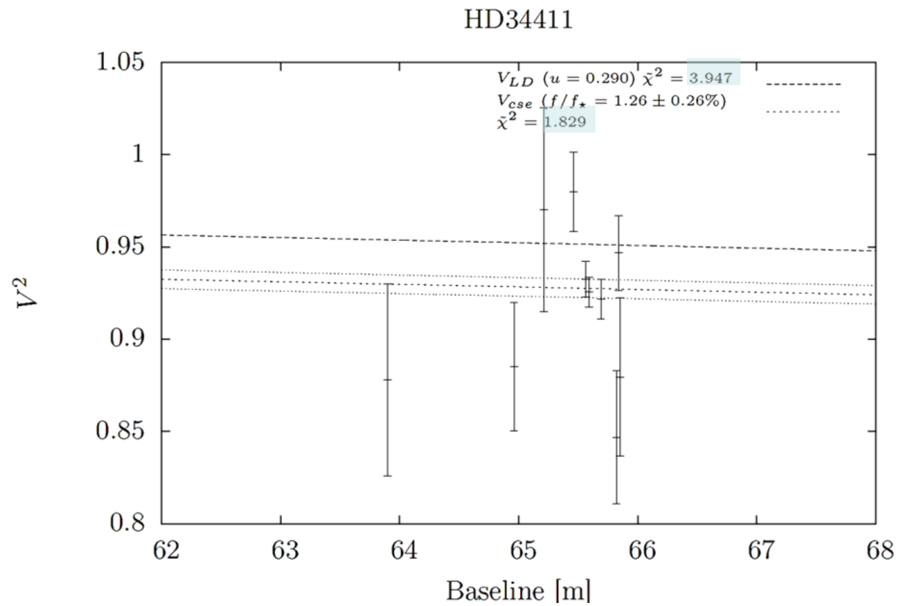
Highly variable on short time-scales due to short orbital period

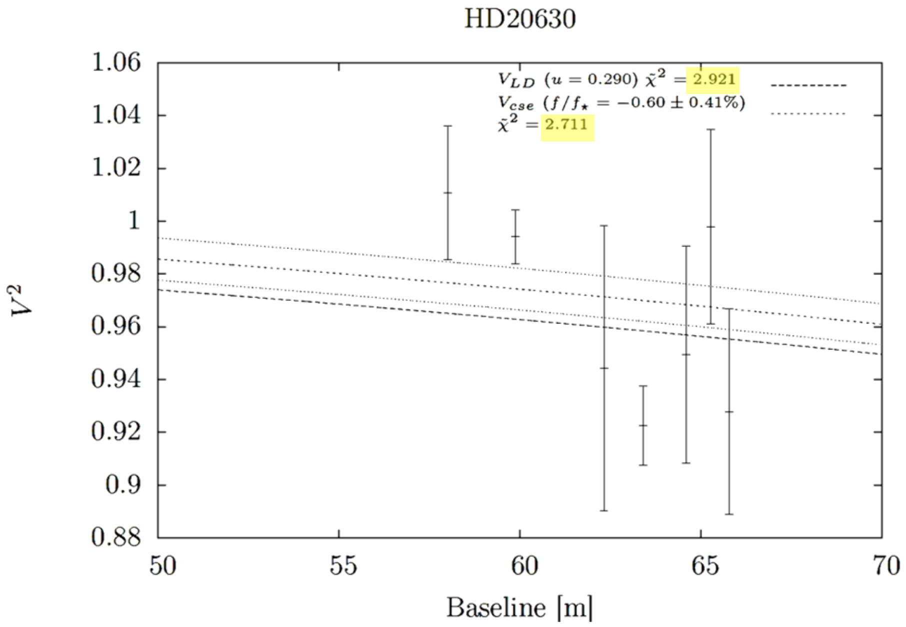
- Meng et al. (2014) reports quasi-periodic (P≈70 days) disk flux modulation
- Giant impact resulted in a thick cloud of silicate spherules that were then ground into dust 'panel' by collisions
- Mass loss rate ≈ 180 km diameter asteroid every < 10 yrs,
  5-7 dex > Hale-Bopp or Halley
- Not uncommon,
  4 other similar systems

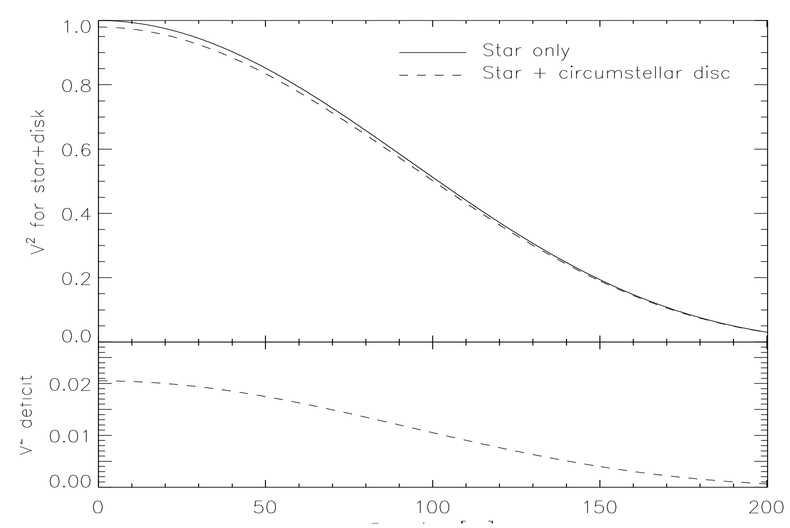
New data

More work on needed on DRS

- Improve errors / calibration



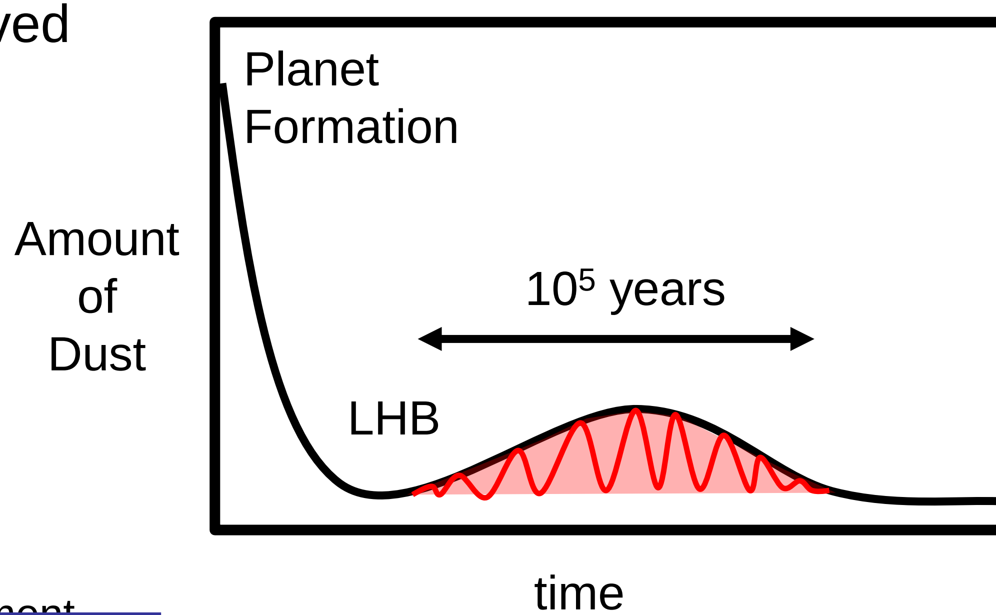




Evolution / dynamics

Dust production mechanism poorly understood

- Close-in dust extremely short lived
  - ≈ few yrs
  - ≈ 10^{-8} $M_{\oplus}$/yr to replenish (10 Hale-Bopps per day)
- Destruction factors:
  - Sublimation
  - Radiation Pressure
  - Poynting-Robertson (P-R) drag
- Models:
  - ~~Steady state/continuous replenishment~~
  - Steady state/trapped nano-grains
  - Catastrophes – LHB, large asteroid collisions, massive comet infall and outgassing – <u>each has different time scales</u>



Programs

Near Infrared Exozodi Survey First statistics on 42 nearby stars observed with FLUOR

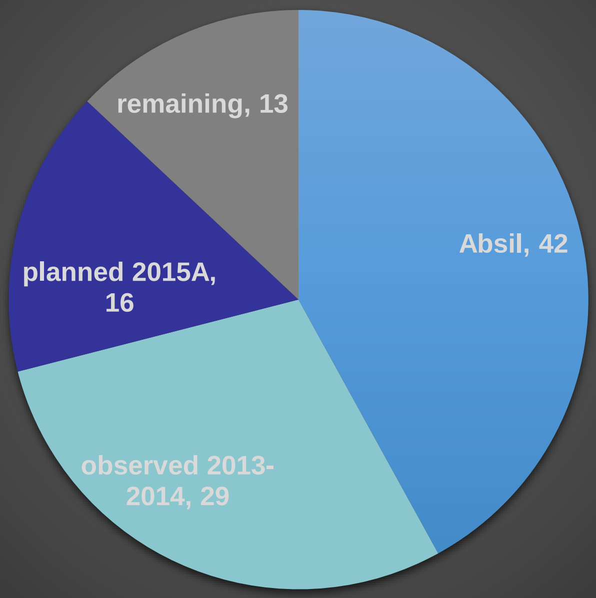
Near Infrared Exozodi Survey Extension 3 year program observing ≈100 MS A-K stars. Hot dust expected in 25-30% of systems. Goal is 1% excess detection at 5σ to $m_K < 5$. Determine grain properties, disk morphology, correlations between stellar properties

Near Infrared Exozodi Variability Study Revisit 12 of the bright A-K stars from the complete survey list with previously detected excesses

IRTF/SpeX Spectrophotometric Survey Provide confirmation of dust from NIR excesses, obtain spectra, and develop survey campaign

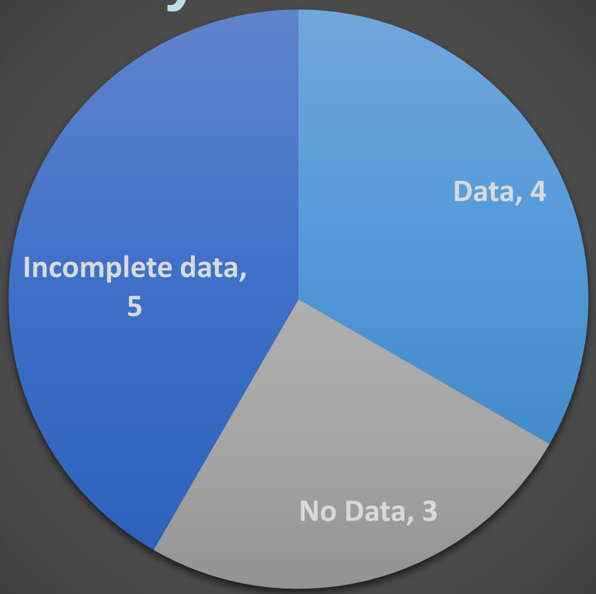
Progress of Surveys

Total exozodi survey



Evolution study

12 of the Absil Targets revisited



A successful 2015 program will complete the evolution survey

IRTF

Follow-up to survey

Photosphere-subtracted SED slope

Confirm and cross-correlate with Interferometric data

Add constraints to dust disk models

temperature, size of the dust grains, age estimate, composition, mass, albedo

Look for spectroscopic debris disk markers

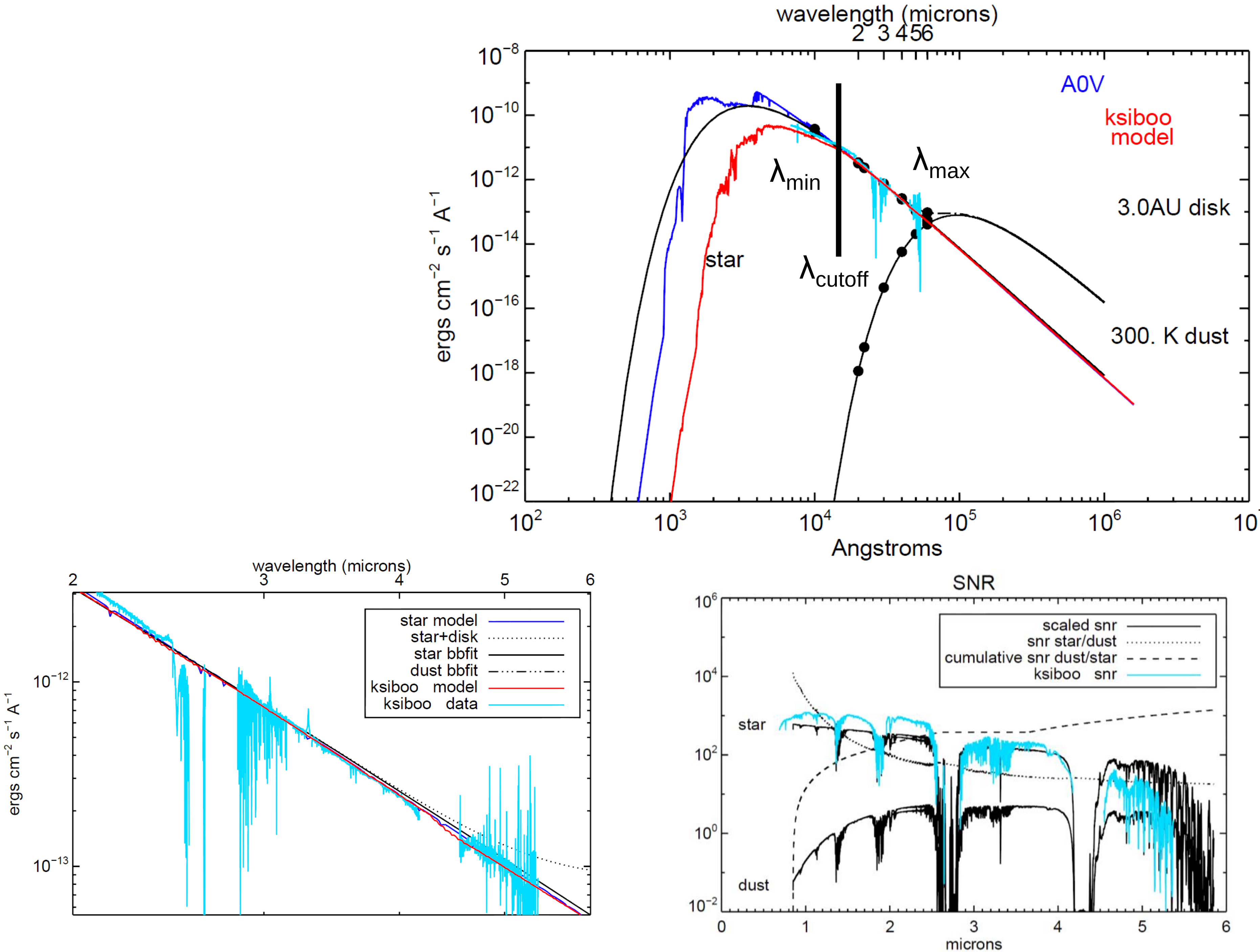
- Pilot study – 3 partial night runs complete
- Targets overlap with evolution study
  - 3 o / 0.5 c (LXD only)
  - 1 o / 3 c
  - 2 o / 3 c

Technique

- Record spectra using the newly upgraded SpeX at IRTF from **0.68- 5.3 μm**
- Known **excess stars + control stars**, matched by spectral type
- Use the short wavelength spectrum **λ_{min} to λ_{cutoff} to fit** a stellar model (Kurucz, Nextgen, or MARCS)
- Re-bin the observed spectra S_{obs} then use its measurement uncertainty n(λ) and the model to compute a mean offset significance from λ_{min} to λ_{cutoff}
- Use the derived best fit photospheric model to compete a similar mean offset between λ_{cutoff} to λ_{max}

Challenges

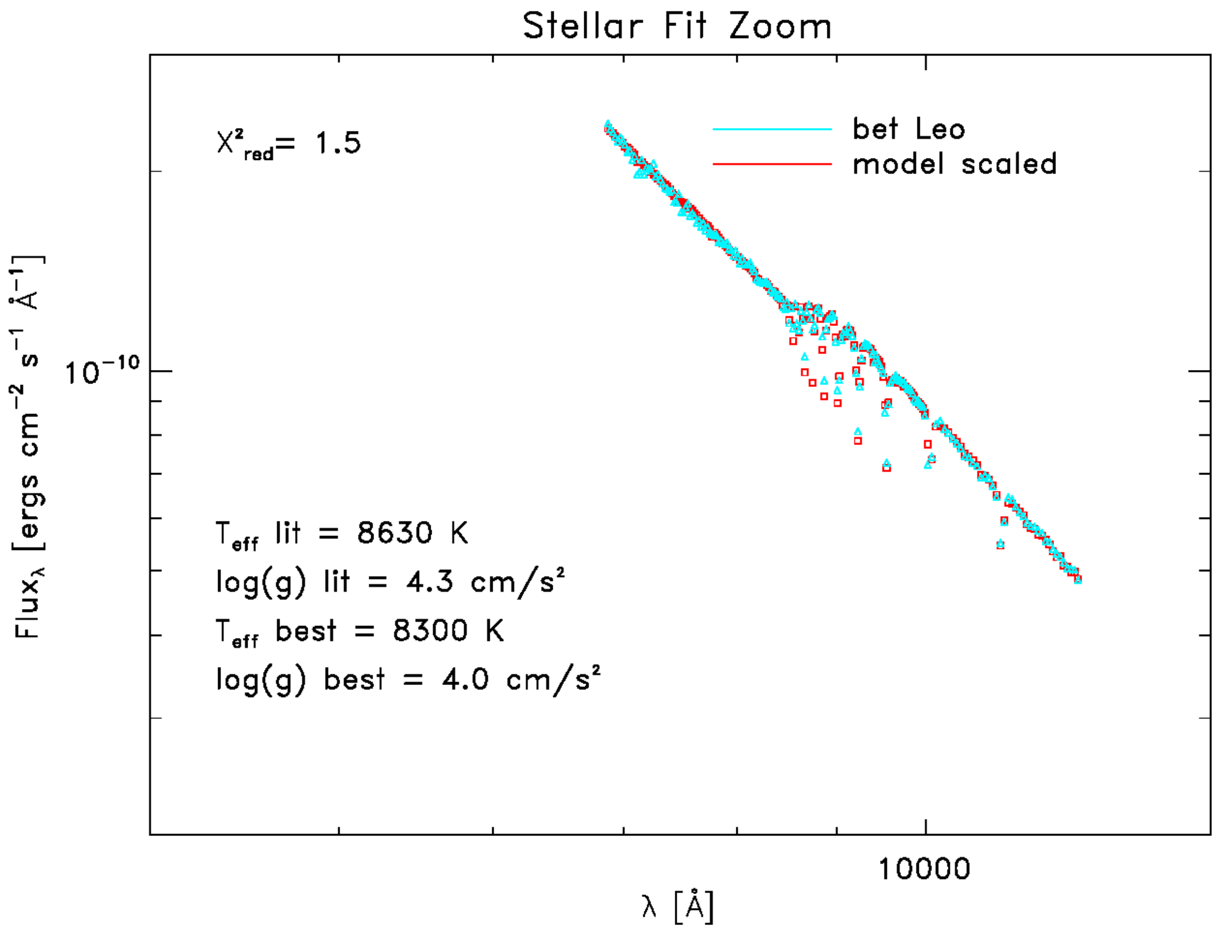
- Data is combined from SXD & LXD modes
  - Scaling properly and fit can be difficult
- λ_{cutoff}; scaling factors:SXD, LXD, photosphere, slope; stellar model (T_{eff} and log g), and binning parameter space



wavelength (microns)
2 3 456
A0V
ksiboo
model
λmin
λmax
3.0AU disk
star
λcutoff
300. K dust
ergs cm⁻² s⁻¹ A⁻¹
Angstroms
wavelength (microns)
star model
star+disk
star bbfit
dust bbfit
ksiboo model
ksiboo data
ergs cm⁻² s⁻¹ A⁻¹
SNR
scaled snr
snr star/dust
cumulative snr dust/star
ksiboo snr
star
dust
microns

Example of photosphere fit

$T_{\mathrm{eff}} = [7500, 8750]\ K$
$\log g = [2.0, 5.0]\ \mathrm{cm}/s^2$
$\lambda_{\mathrm{cutoff}} = 1.2\ \mu\mathrm{m}$

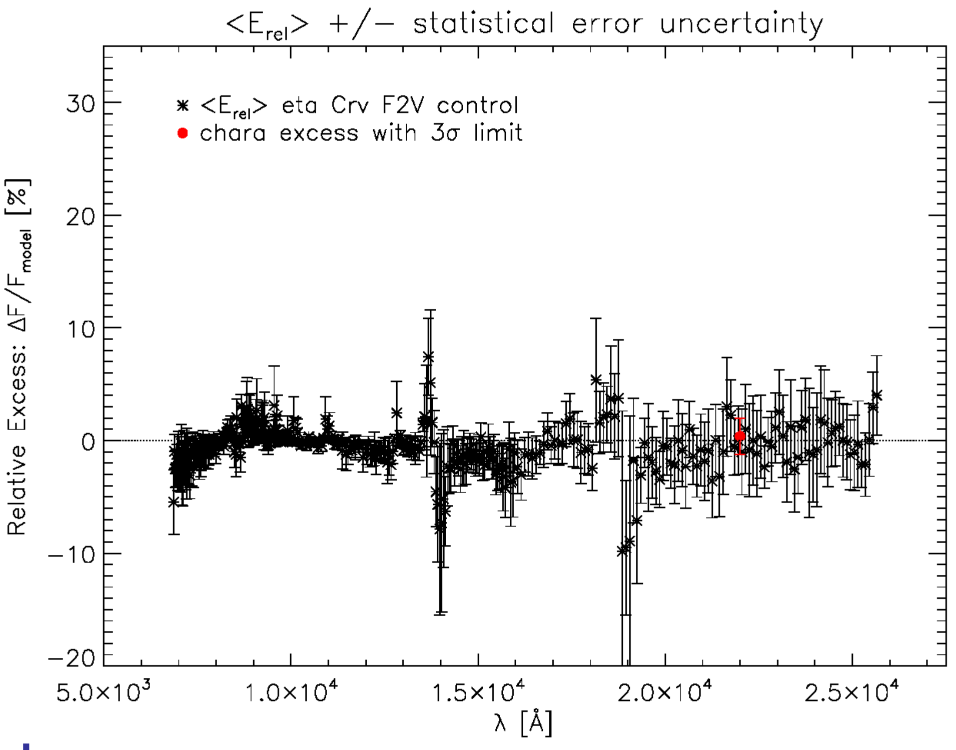


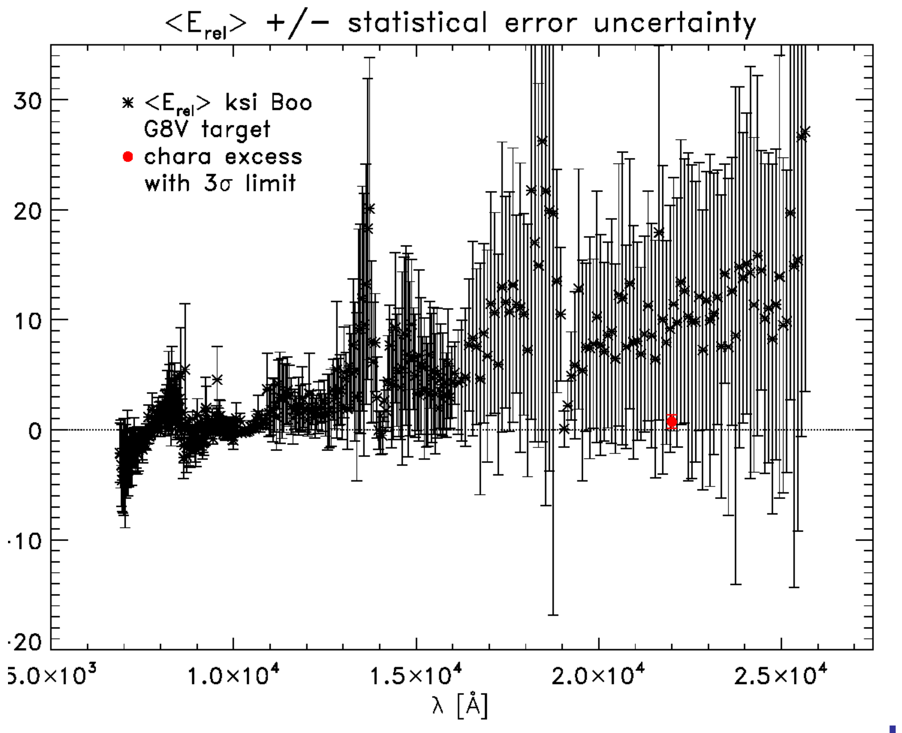
6 to 20 spectra (0.68-2.56 μm) for each object and reduce individually
Bin spectra at wavelengths of kurucz models

Interpolate models at 50 K and 0.1 cm/s^2

Control star

Excess star





How to explain huge excesses compared to CHARA results?

- Slit size SpeX: 0.3x15''
- CHARA FOV = 0.8''

Outlook

- Currently trying to access systematics
- Extending analysis further out to 5.3 μm for objects known to have outer disk reservoir (eta Lep, bet Leo, eta Crv)
- Analyze standard stars (part of control group)
- Modeling dust spectra
  - Change models since $R_{\mathrm{kurucz}} < R_{\mathrm{irtf\,data}}$?

Overall Goals

Identify exozodiacal disk hosts

Constrain disk size, luminosity

Correlate with host star properties

Search for variability

Monitor most active disks

Identify variability timescales

Determine dust production mechanism

Model disk / dust – size, shape / grain size, temperature, composition

Correlate with planet host properties

Improve system formation models

Steer planet detection surveys, reduce false positives

Future plans for JouFLU

- Finish surveys
- Complete data analysis

- CHARA AO
  - Improved fiber coupling
  - Greatly increased observing efficiency
  - Slightly fainter magnitude limit
  - More targets

- Replace MONA
- Polarization control
- More spectral dispersion mode observations
- FTS
- Integration with CHAMP
- Further camera and software improvements

AO will allow JouFLU to be limited by the instrument rather than the seeing

References

- Absil et al. Circumstellar material in the Vega inner system revealed by CHARA/FLUOR. AAP, 452:237244, (2006)
- Absil, O. et al. A near-infrared interferometric survey of debris-disc stars. III. First statistics based on 42 stars observed with CHARA/FLUOR, A&A, 555, A104 (2013)
- Akeson et al. Dust in the inner regions of debris disks around A stars. The Astrophysical Journal, Volume 691, Issue 2, pp. 1896-1908 (2009)
- Beichman et al. New Debris Disks around Nearby Main-Sequence Stars: Impact on the Direct Detection of Planets. The Astrophysical Journal, Volume 652, Issue 2, pp. 1674-1693 (2006)
- Cassan et al. One or more bound planets per Milky Way star from microlensing observations. Nature, Volume 481, Issue 7380, pp. 167-169 (2012)
- Coudé du Foresto, et al. FLUOR infrared beam combiner at the CHARA array. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, volume 4838 SPIE conference, pages 280-285, February 2003.
- Di Folco et al. A near-infrared interferometric survey of debris disk stars. I. Probing the hot dust content around ? Eridani and t Ceti with CHARA/FLUOR Astronomy and Astrophysics, Volume 475, Issue 1, November III 2007, pp.243-250 (2007)
- Gomes et al. Origin of the cataclysmic Late Heavy Bombardment period of the terrestrial planets Nature, Volume 435, Issue 7041, pp. 466-469 (2005)
- Hanot et al. Improving Interferometric Null Depth Measurements using Statistical Distributions: Theory and First Results with the Palomar Fiber Nuller The Astrophysical Journal, Volume 729, Issue 2,110 (2011)
- Holland et al. Submillimetre images of dusty debris around nearby stars Nature, Volume 392, Issue 6678, pp. 788-791 (1998)
- Kalas et al. Optical Images of an Exosolar Planet 25 Light-Years from Earth Science, Volume 322, Issue 5906, pp. 1345- (2008)
- Kuchner, Marc J.; Holman, Matthew J. The Geometry of Resonant Signatures in Debris Disks with Planets The Astrophysical Journal, Volume 588, Issue 2, pp. 1110-1120 (2003)
- Lawler et al. Explorations Beyond the Snow Line: Spitzer/IRS Spectra of Debris Disks Around Solar-type Stars. The Astrophysical Journal, Volume 705, Issue 1, pp. 89-111 (2009)
- Lebreton, J. et al. An interferometric study of the Fomalhaut inner debris disk. III. Detailed models of the exozodiacal disk and its origin, A&A, 555, A146 (2013)
- Meng et al. Large impacts around a solar-analog star in the era of terrestrial planet formation.Science, Vol 345, Issue 6200, pp. 1032-1035 (2014)
- Nesvorný et al. Cometary Origin of the Zodiacal Cloud and Carbonaceous Micrometeorites. Implications for Hot Debris Disks The Astrophysical Journal, Volume 713, Issue 2, pp. 816-836 (2010)
- Exoplanets by Sara Seager. University of Arizona Press, 2011. ISBN: 978-0-8165-2945-2
- Su, K. Y. L. et al. Asteroid Belts in Debris Disk Twins: Vega and Fomalhaut, ApJ, 763, 118 (2013)
- Tsiganis et al. Origin of the orbital architecture of the giant planets of the Solar System Nature, Volume 435, Issue 7041, pp. 459-461 (2005)
- Wilner et al. Structure in the Dusty Debris around Vega The Astrophysical Journal, Volume 569, Issue 2, pp. L115-L119 (2002)
- Wyatt, Mark C. Evolutions of Debris Disks Annual Review of Astronomy & Astrophysics, vol. 46, Issue 1, pp.339-383 (2008)
- Wyatt, Mark C. Transience of hot Dust Around Sun-like Stars The Astrophysical Journal, Volume 658, pp. 569-583 (2007)