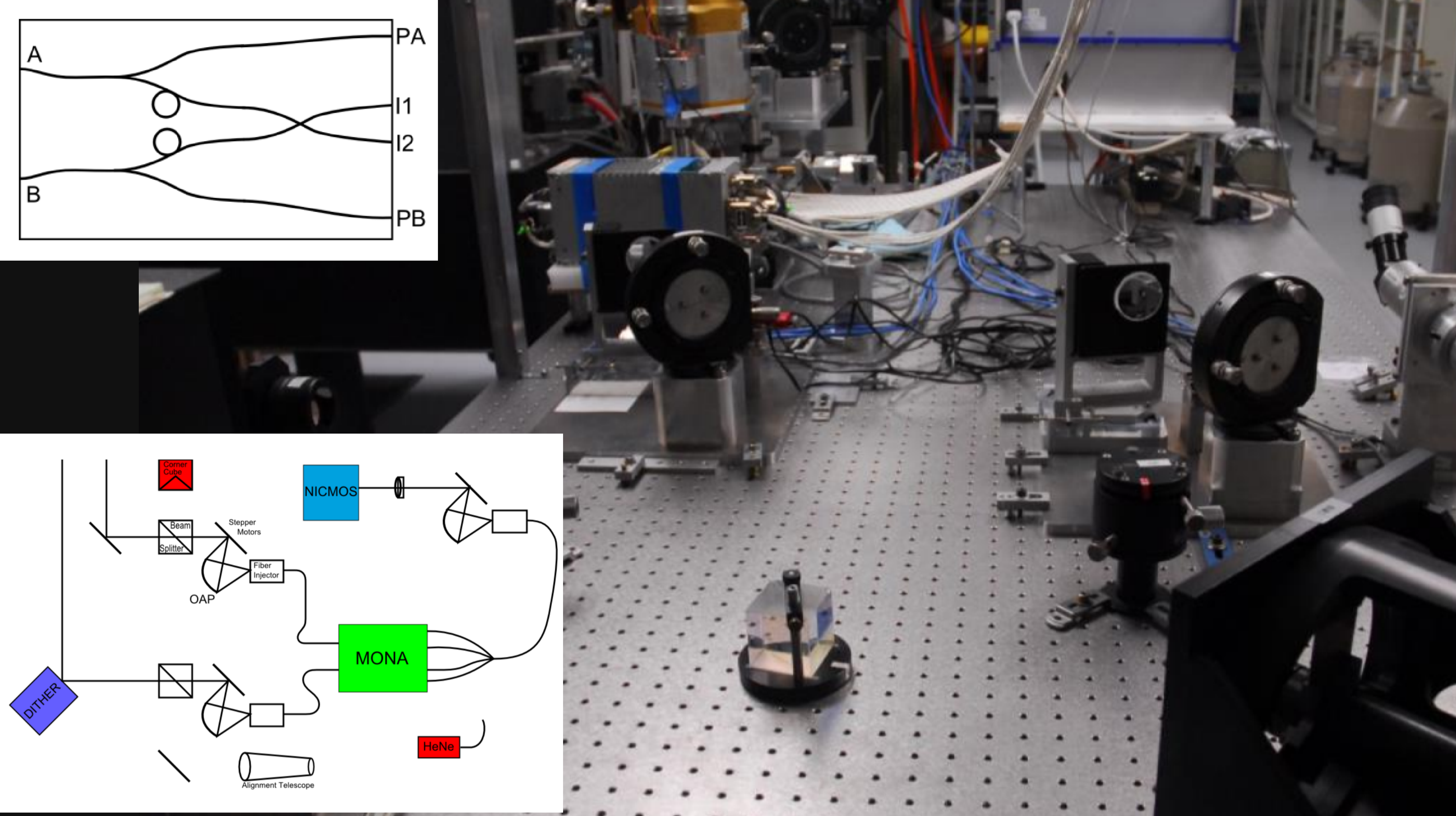
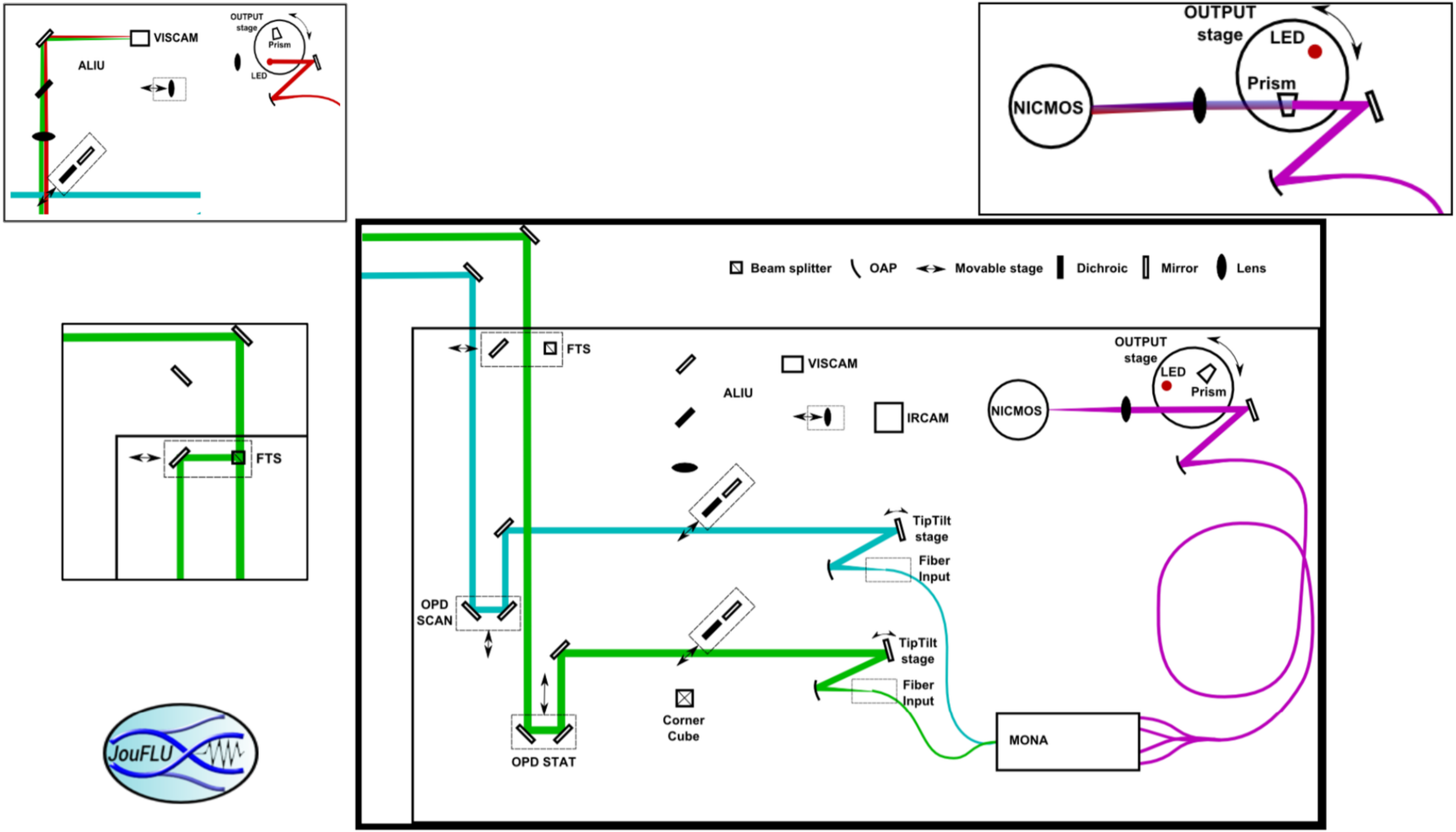
The future of FLUOR

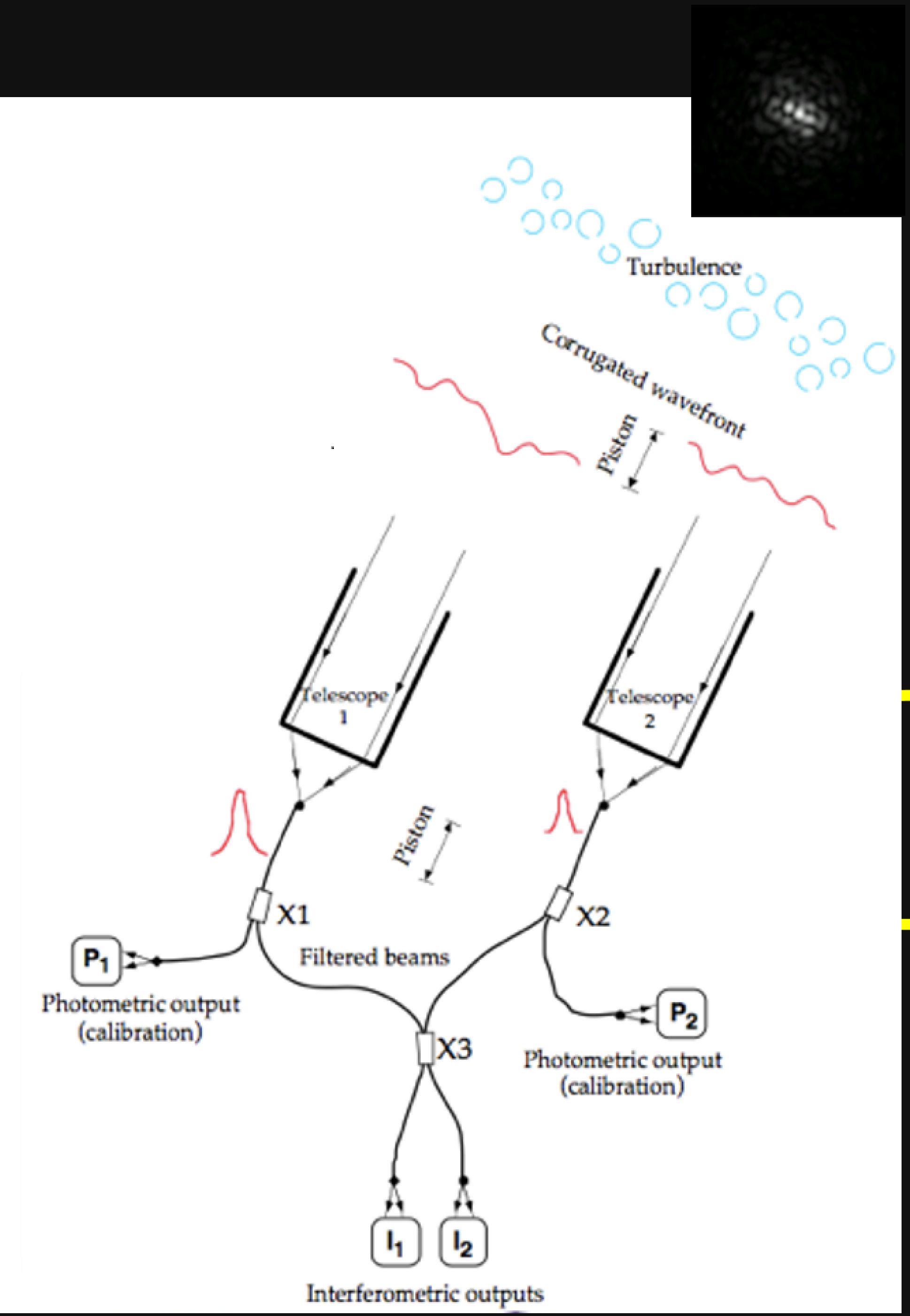
nic scott

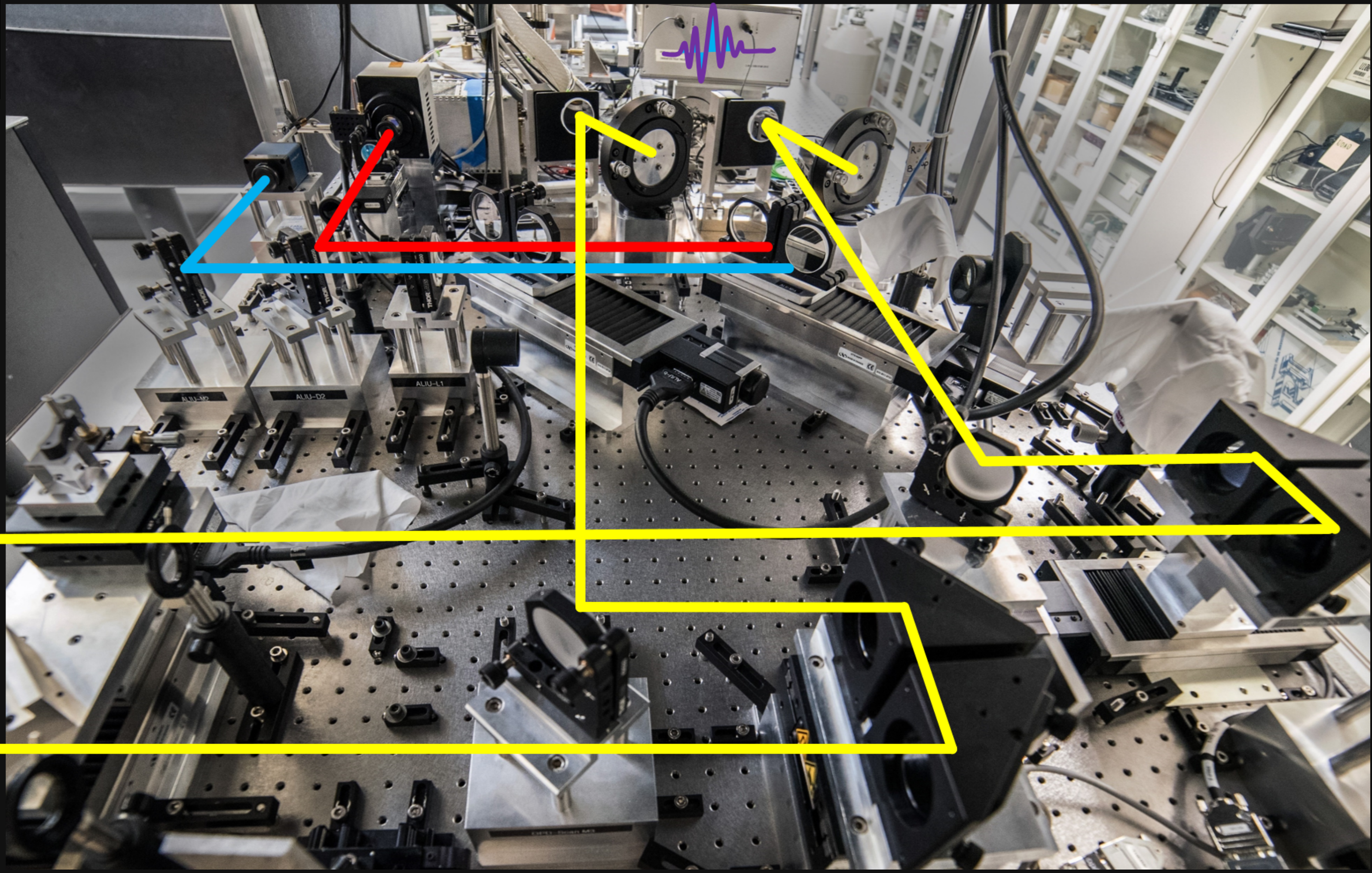
NASA ARC

FLUOR to JouFLU


A
B
PA
I1
I2
PB
Corner Cube
NICMOS
Beam Splitter
Stepper Motors
Fiber Injector
OAP
MONA
DITHER
HeNe
Alignment Telescope


VISCAM
OUTPUT
stage
Prism
ALIU
LED
OUTPUT
stage
LED
Prism
NICMOS
Beam splitter
OAP
Movable stage
Dichroic
Mirror
Lens
FTS
FTS
VISCAM
ALIU
IRCAM
OUTPUT
stage
LED
Prism
NICMOS
TipTilt
stage
Fiber
Input
OPD
SCAN
TipTilt
stage
Fiber
Input
Corner
Cube
OPD STAT
MONA
JouFLU


Turbulence
Corrugated wavefront
Piston
Telescope 1
Telescope 2
Piston
X1
X2
Filtered beams
P1
Photometric output (calibration)
X3
P2
Photometric output (calibration)
I1
I2
Interferometric outputs

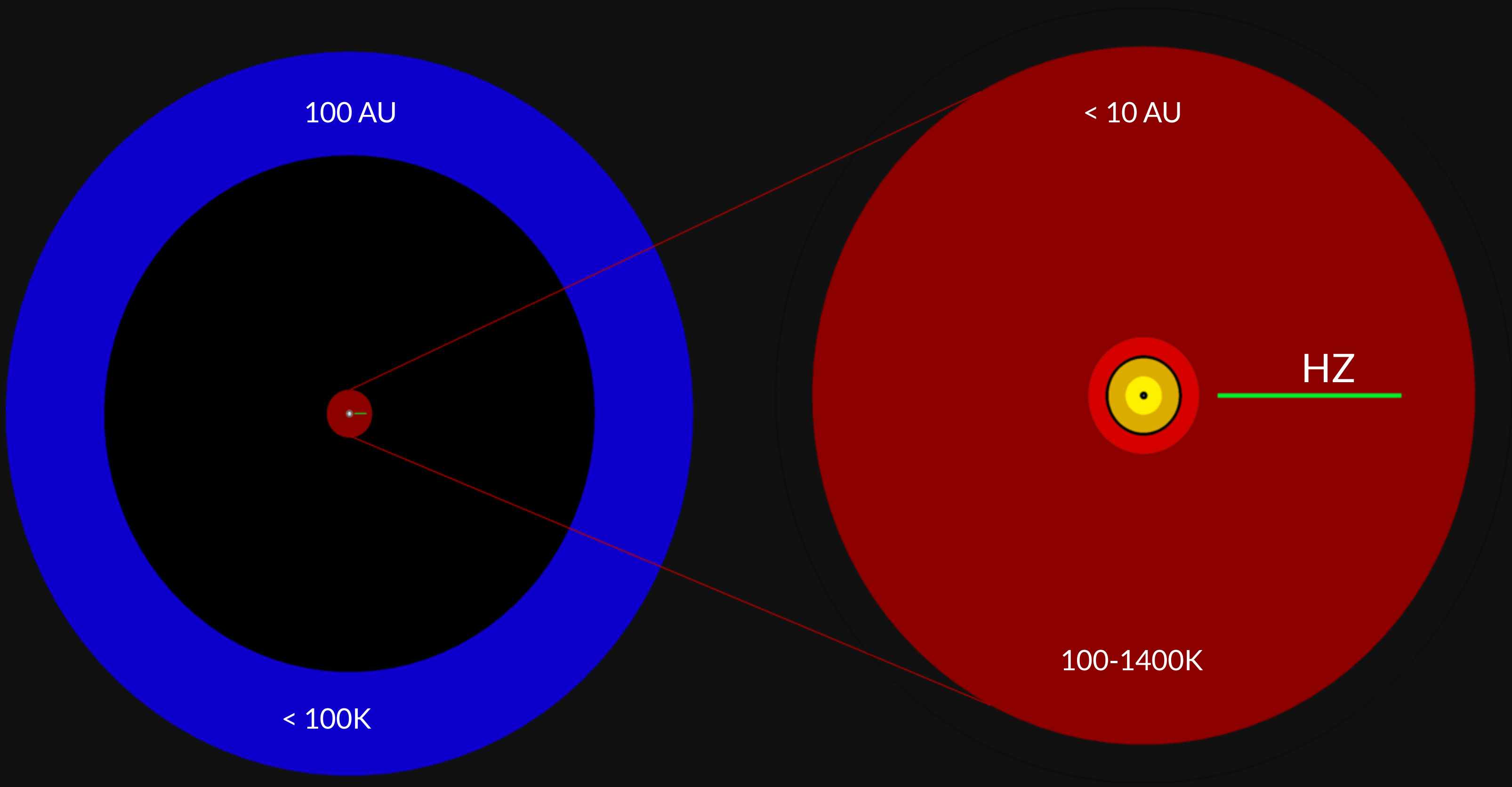


- **Stellar astrophysics** Angular diameters (Perrin et al. 2004), Teff (Perrin et al. 1998), limb darkening (Aufdenberg et al. 2008), hydrodynamical modeling (Chiavassa et al. 2010)
- **Rapid rotators** (Aufdenberg et al. 2006) rotation geometry, gravity darkening (Aufdenberg et al. 2007)
- **Asteroseismology** (Kervella et al. 2008; Mazumdar et al. 2009; Bruntt et al. 2010) P-mode oscillations
- **Circumstellar environment** extended envelopes (Mérand et al. 2007)
- **Binaries** Masses, orbital parallax, tidal effects, mass transfer, low mass or faint companions (Aufdenberg et al. 2009)
- **Be stars** (Touhami et al. 2007)
- **Debris disks and exozodiacal dust** (Absil et al. 2006, di Folco et al. 2007)
- **Young star circumstellar environments** (Akeson et al. 2005)
- **Cepheid variables** P-L calibration (Kervella et al. 2004a) and Baade-Wesselink distance measures (Kervella et al. 1999), diameters and distance (Kervella et al. 2001) and pulsation modes (Gallenne et al. 2012)
- **Mira variables** pulsation properties (Mennesson et al. 2002)
- **High precision measurement of extended sources** (di Folco et al. 2007)
- **High dynamic range sources** (Absil et al. 2008a; Berger et al. 2008) Contrast ratios of 5-15 magnitudes.

Science Case: Exozodis

Exozodiacal Disks

- Not to be confused with debris disks
- Require interferometry to detect
- High levels (100-1000 zodi) even in >100 Myr systems
- Confound the detection of exoEarths
- Probe the structure of inner system



1 AU	terrestrial planet with gap	
0.5 – 1.5 AU	warm dust disk	500K
0.1 – 0.5 AU	hot dust disk	> 1000K
Center	A0 star @ 10 pc.	

Our disk is the most luminous object in SS after the Sun.

Zodi levels of dust affect Earth detection

Earth would be a clump in the zodi at visible and IR [1]

10-20 zodi would compromise exoEarth detection
[2,3] Interferometric, astrometric, direct, photometric, ...

exoEarth detection becomes challenging if exozodi level is ~20 zodis and clumpy [4]

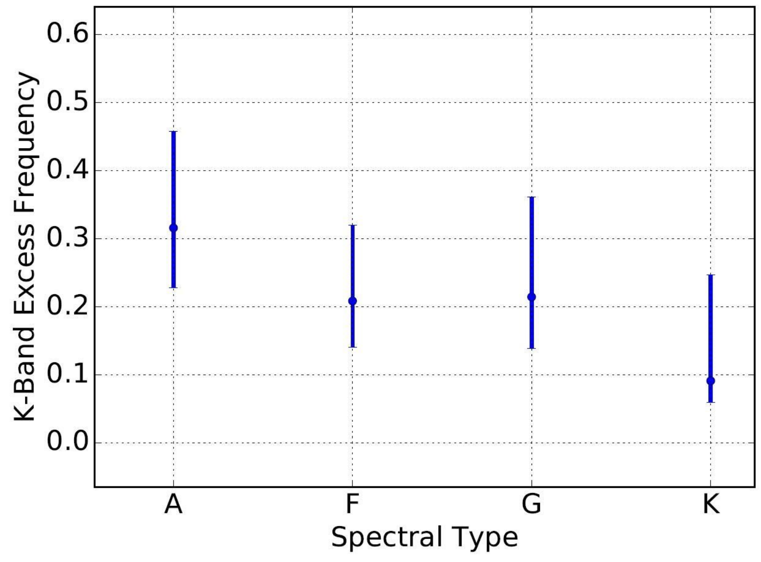
exoEarth detection is divided by factor of 2 for exozodi level increase of 10 [5]

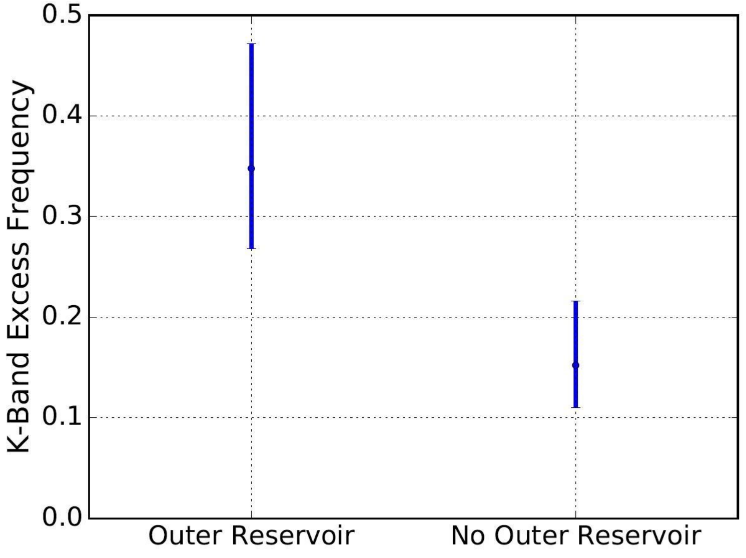
$\geq$10% of Gyr old MS stars may have enough exozodi dust to complicate exoEarth imaging [6]

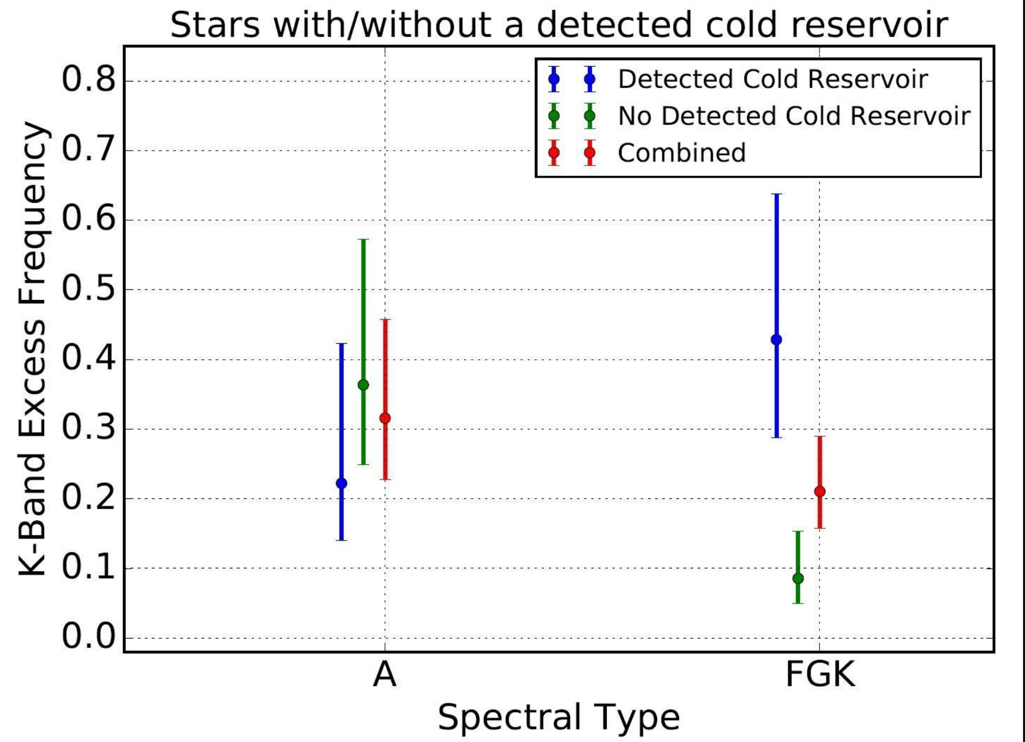
Resonant structures could indicate planets indirectly [7]

Correlation with spectral type or outer reservoir?

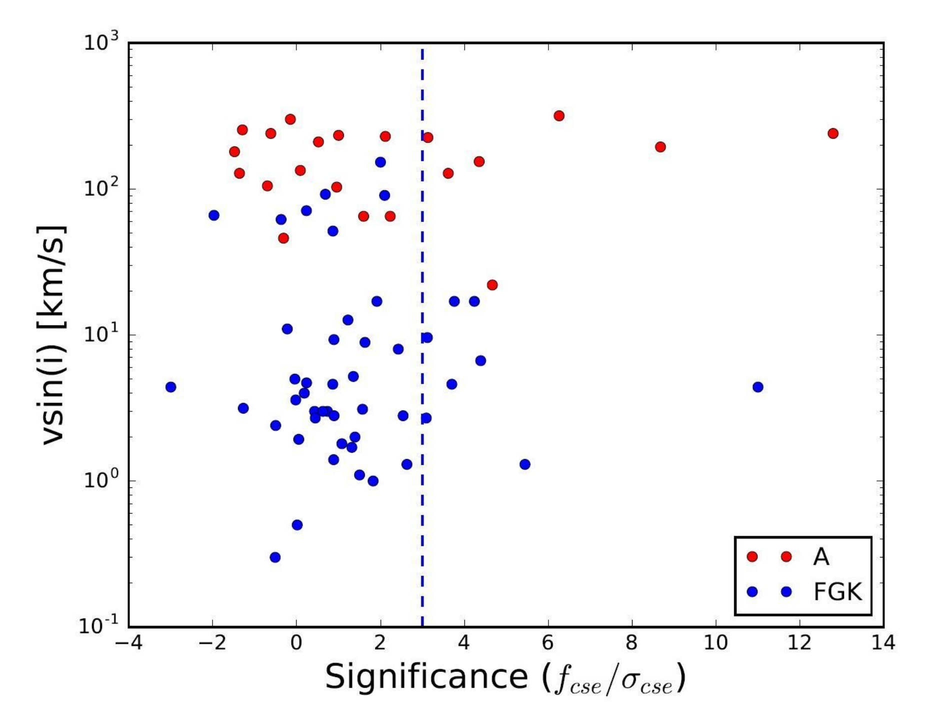
Nuñez et al. 2017







	A	F	G-K	Total
Outer res	2/9	4/9	2/5	8/23
No outer res	4/11	1/15	2/20	7/46
Total	6/20	5/24	4/25	15/69

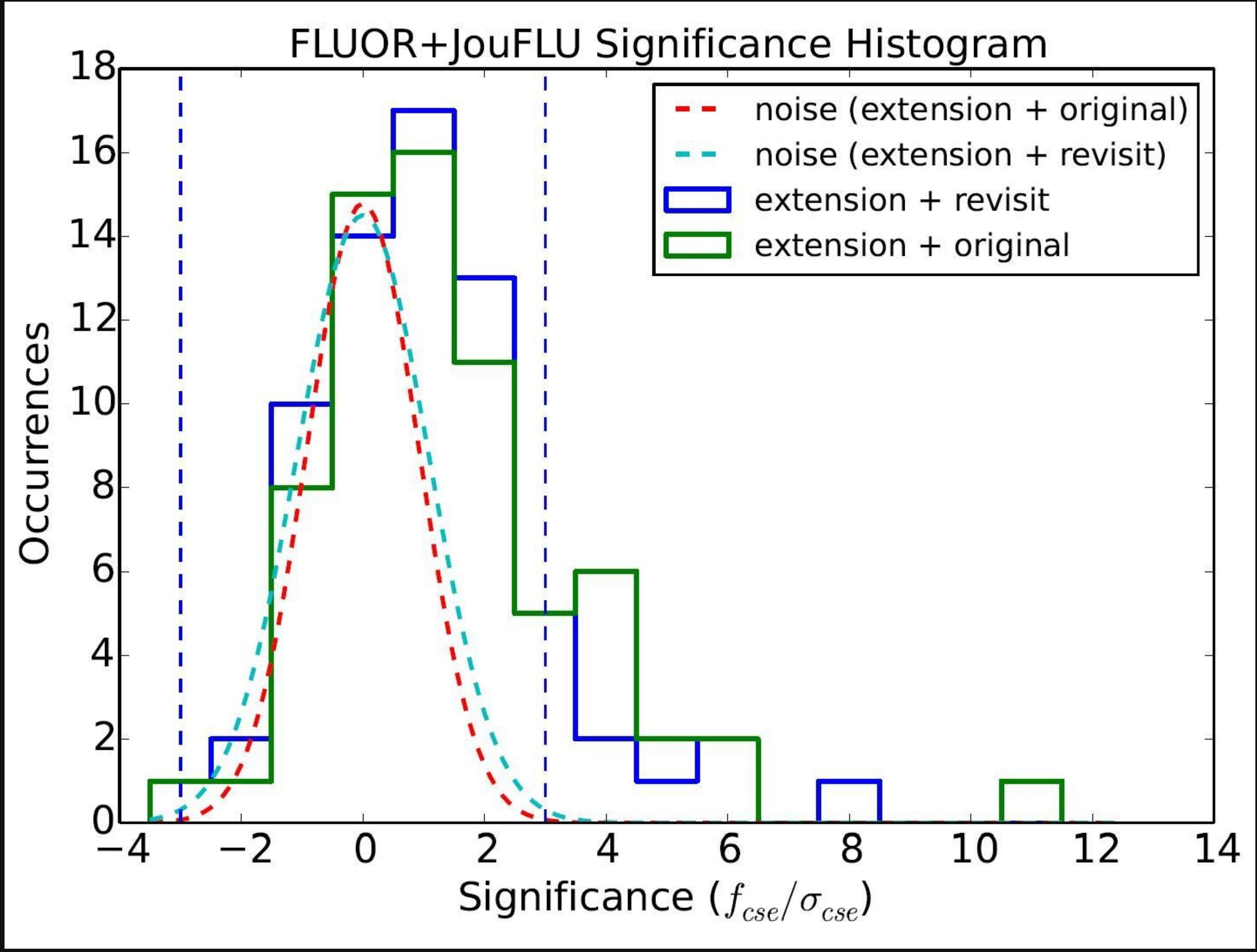


← tentative correlation with stellar rotation supports the magnetic trapping model but not conclusive.

Nuñez et al. 2017

6/33 new circumstellar excesses at $\geq$1% level

- 2 of these detections can be attributed to uniform CSE
- 4 are known or suspected binaries.



The difference of between the instrumental noise and the JouFLU significance distribution yields an estimate of 9 undetected excesses.

NIR

- Interferometric detections found ~20% systems have exozodis [15]
- Collisional cascade (Kupier belt-like) is insufficient to produce the dust [12]

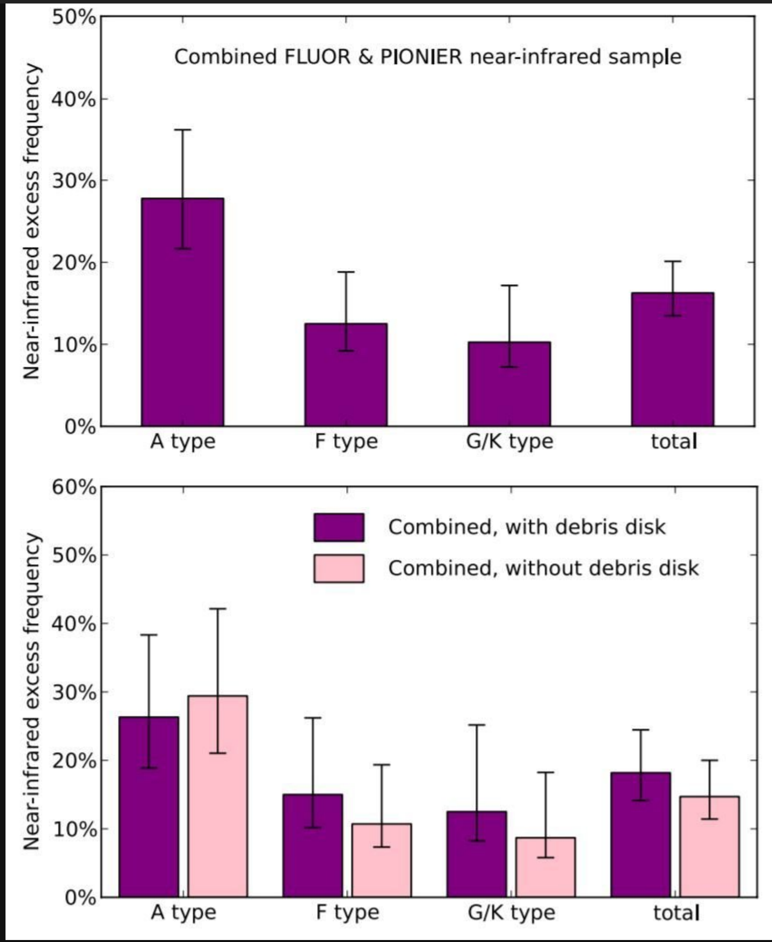
Ertel et al 2014 merged FLUOR+PIONIER samples (n~125) reaching 0.25% precision

VLTI - PIONIER

- Rate decreases across spectral type
  - Matches cold disk trend. Common origin?
- No correlation b/t hot dust and cold dust.*
  - Different origin for hot and cold discs?
- Slight increase in exozodi detection with stellar age
  - Stochastic rather than steady-state process [46,33,34,35]?
- No correlation b/t exoplanets and exozodi.

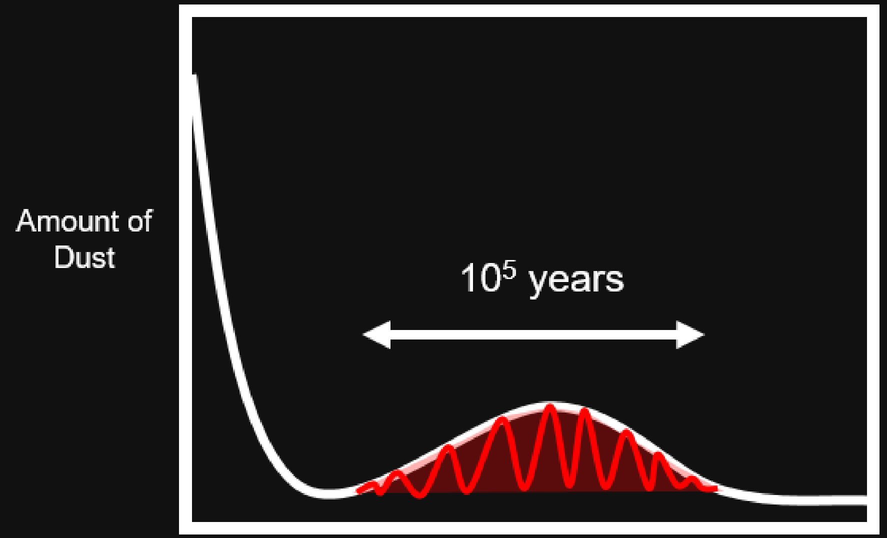
HD 7788 shows variability

- excess disappeared for a year



Near Infrared Exozodi Variability Study

Dust production mechanism poorly understood



Close-in dust extremely short lived

- ≈ few yrs [42]
- ≈ 10^{-9} $M_{\oplus}$/yr to replenish
  - (10 Hale-Bopps per day) [23]
- Keplerian time scale ~weeks/months

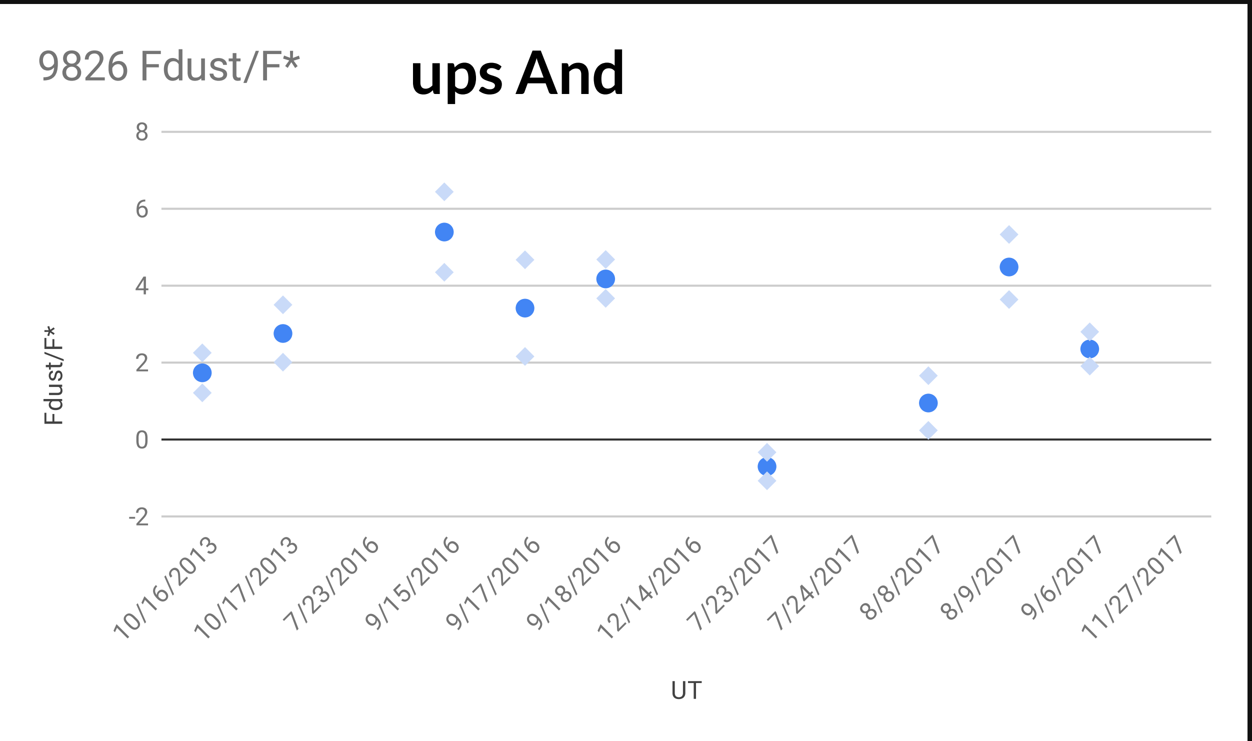
Destruction factors:

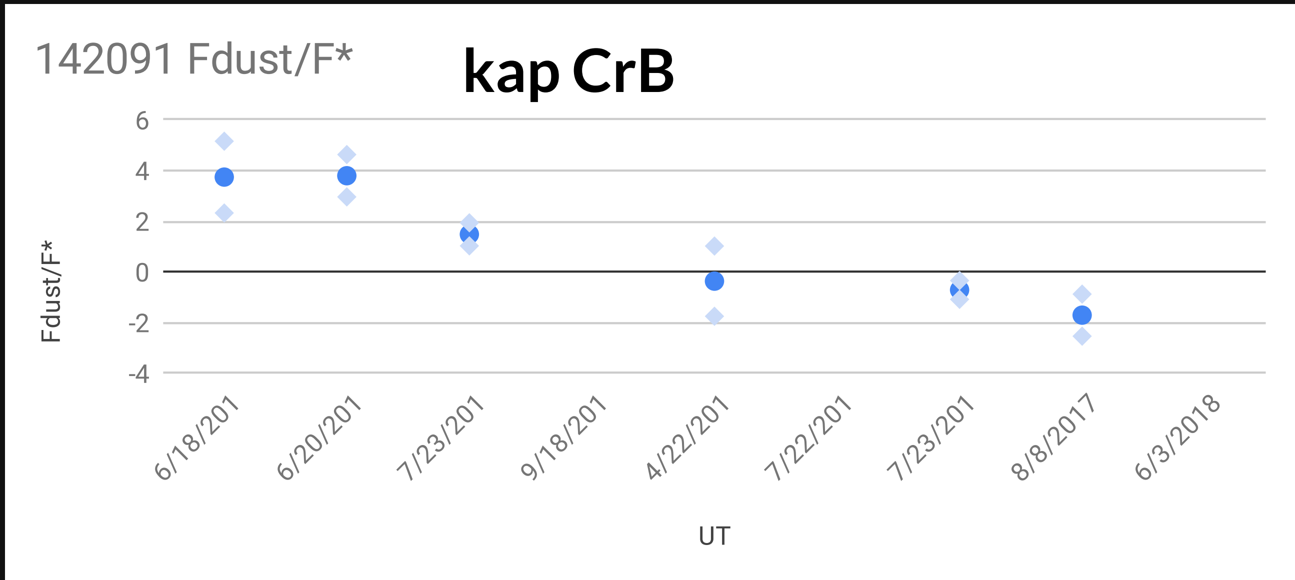
- Sublimation
- Radiation Pressure
- Poynting-Robertson (P-R) drag

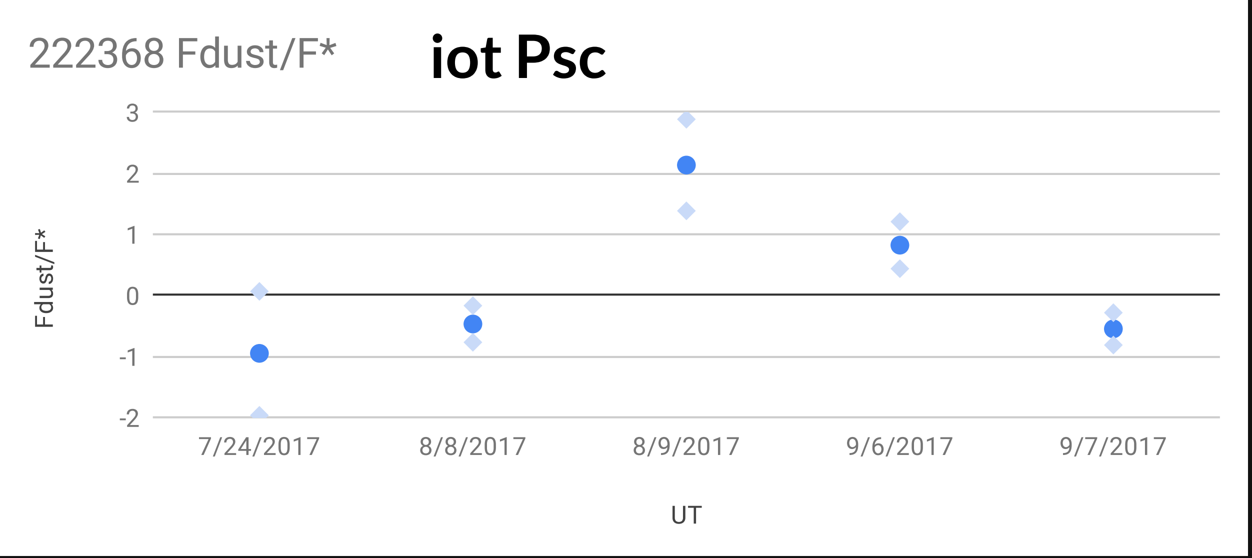
Models:

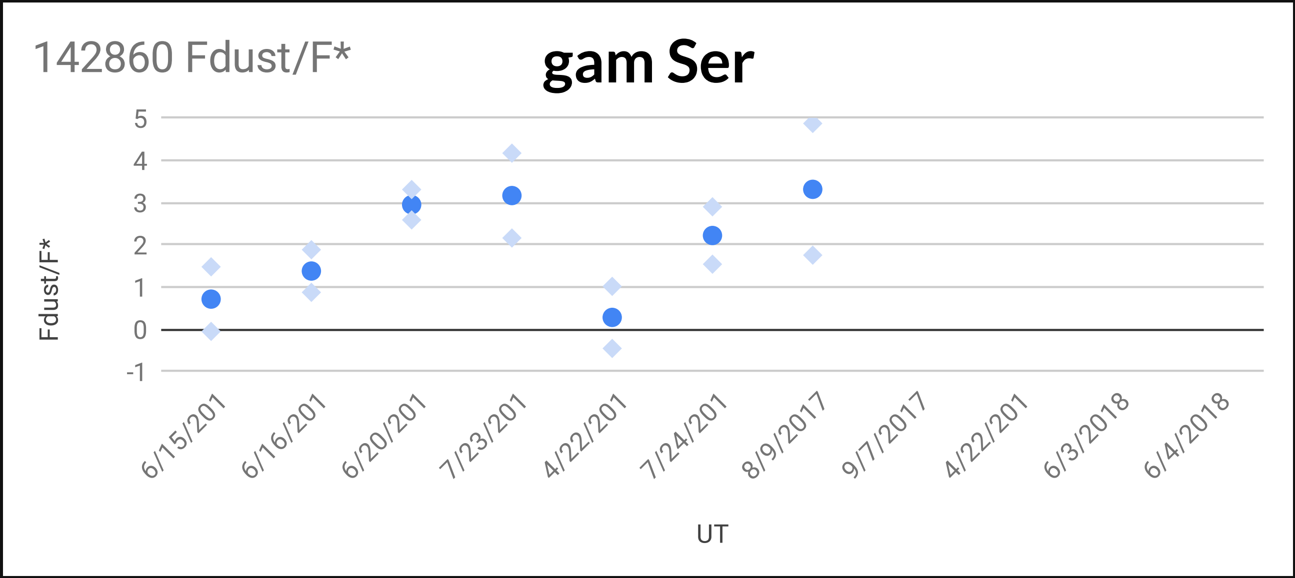
- Steady state/continuous replenishment
- Steady state/trapped nano-grains
- LHB & outgassing

exozodi monitoring (link)









New Exozodi Monitoring targets

HD 98058

- Φ Leo spectra shows signs of exocomet infall and evaporation [45]

HD 210418

- A-type with 1.7 ± 0.5% excess from 2013

HD 222368

- F-type with 1.3 ± 0.3% excess from 2013

Tet Boo

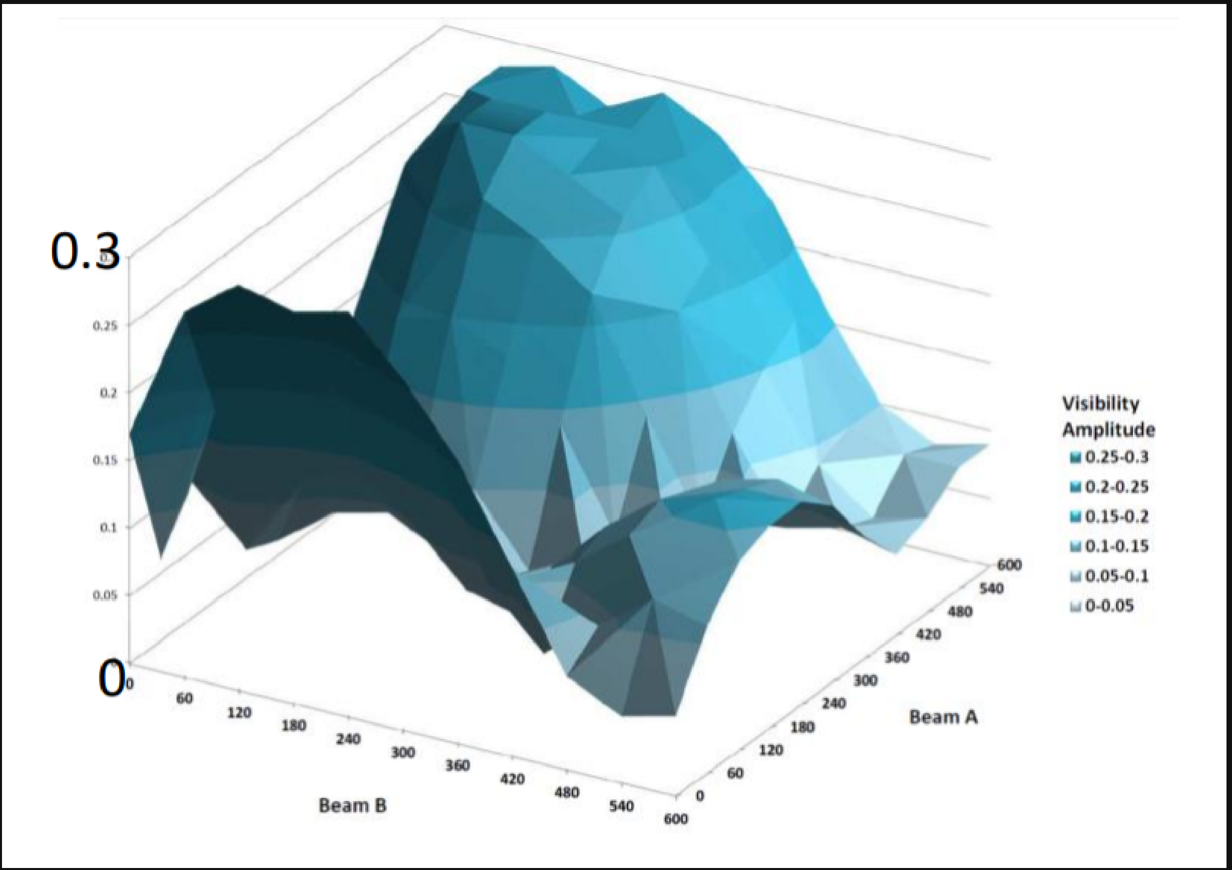
- Solar type star with no previously known dust excess
- Significant excess at 10 micron with the LBTI nuller.
- Potentially huge implications on our understanding of exozodi level upper limits, and dust generation mechanisms around such stars.

From LBTI		
tau ceti	10700	exoplanet host
13 Uma	78154	LBTI excess
kap01 ceti	20630	exoplanet host
1 Ori	30652	
tau Boo	120136	

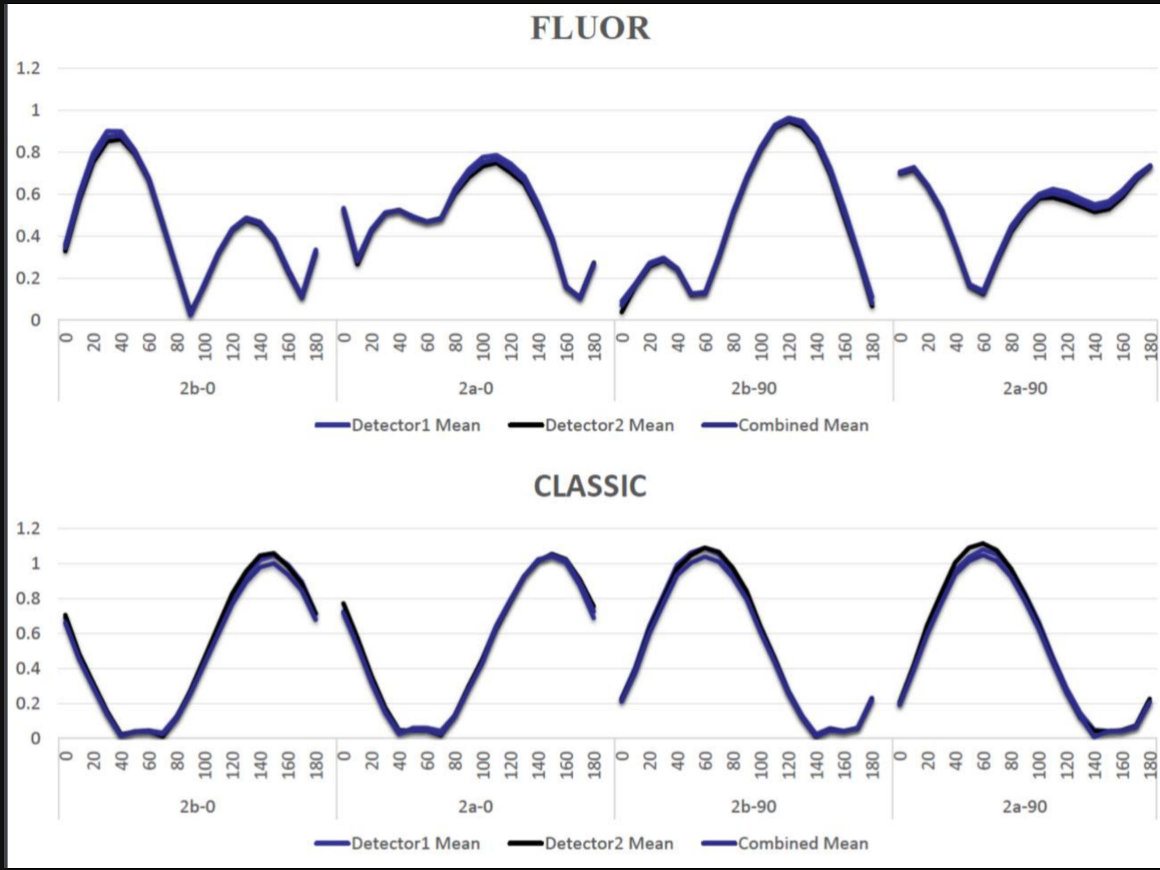
The Problem

Signs of problems

differential polarization rotation



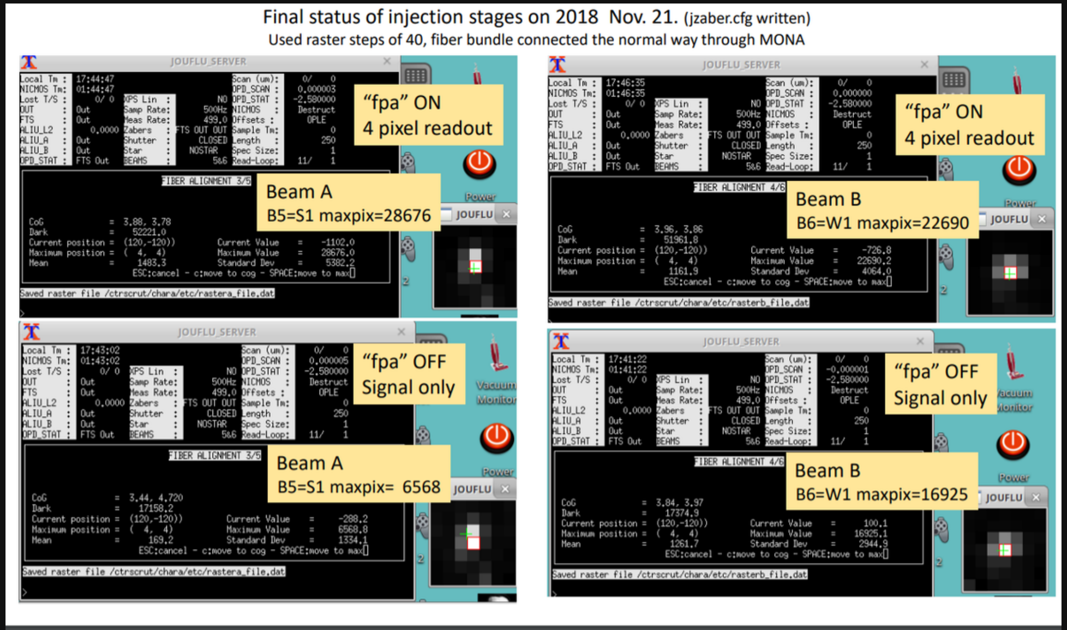
differential polarization phase delay

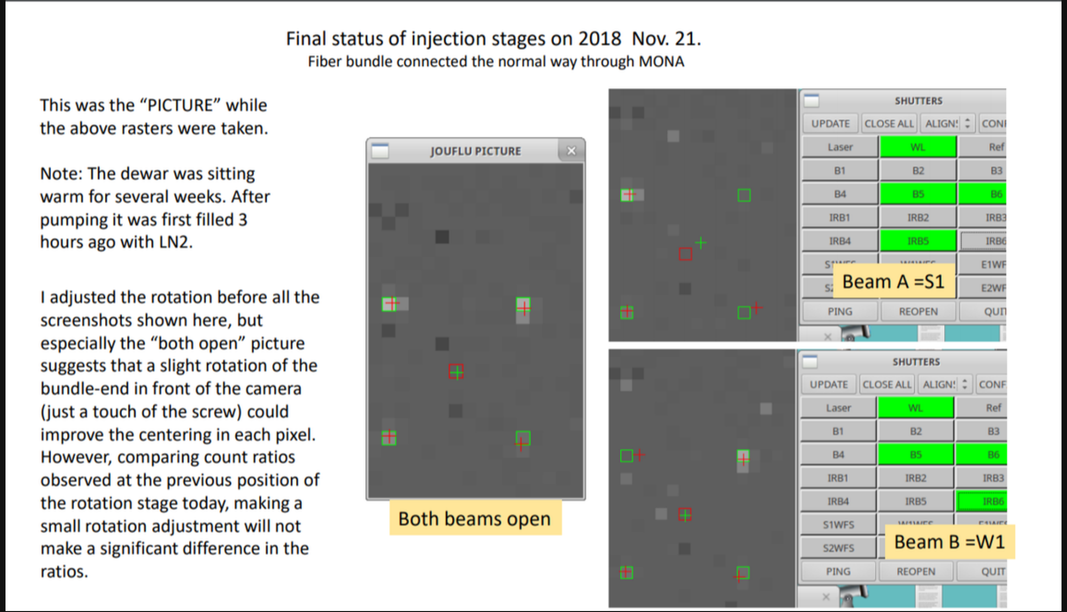


Added Lithium Niobate plates to correct polarization, but decreases throughput.

Limiting Kmag ~4.5-5.2 from 2015-2016 is now ~3

MONA analysis (link)





1. Connect Beam 5 fiber to input A and Beam 6 fiber to input B. (default arrangement)
2. Close the beam 6 shutter and measure the four outputs.
3. Open the beam 6 shutter, close the beam 5 shutter, and measure the four outputs.
4. Open both shutters and measure the four outputs.
5. Move the beam 5 fiber to input B, move the beam 6 fiber to input A, and repeat all 3 measurements.
6. Swap beam 5 and beam 6 on the beam sampler and repeat the complete set of 6 measurments.

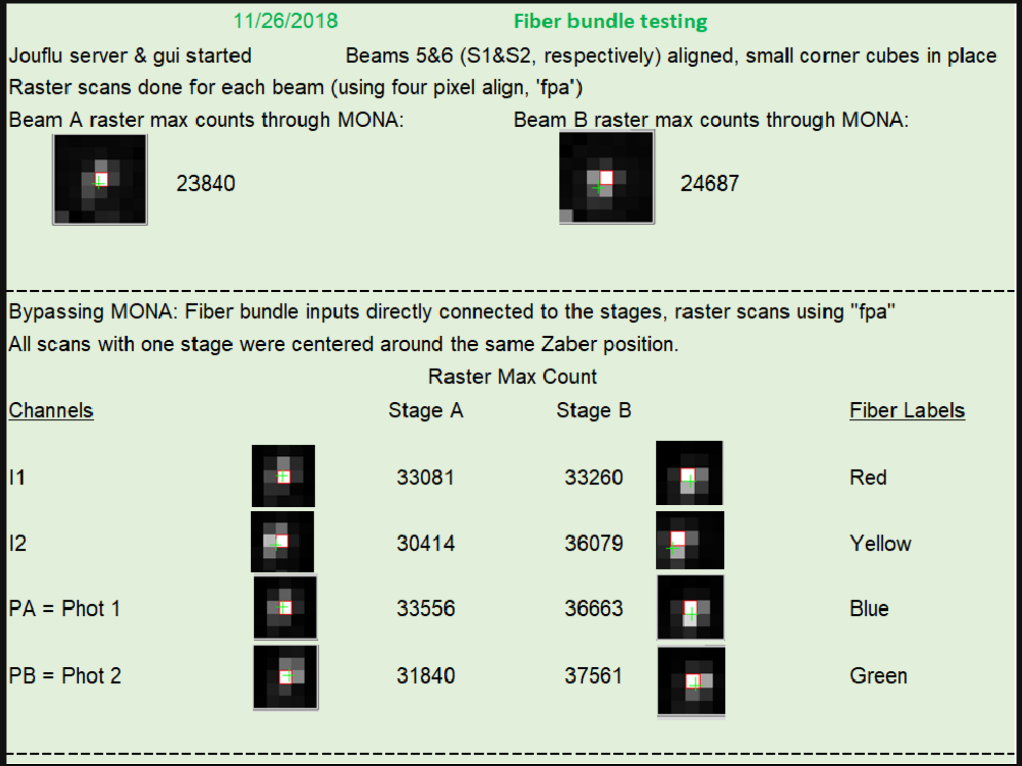
TR. 98

determined beam ratio and coupling efficiency for each input

- no sig difference in coupling efficiency of the two stages.
- no sig difference in light in beam 5 and beam 6
- Most significant difference:
  - input A 80% to photometric output
  - input B 13% to the photometric output

I2 interferometric channel does not see anything from beam A. Could be a broken fiber in MONA?

- Each branch of the fiber bundle transmits basically the same (max counts well w/i +/- 8%)
  - Bundle still seems fine
- Confirms that the two stages have essentially the same efficiency.
- MONA seems to be the problematic part.



11/26/2018 Fiber bundle testing

Jouflu server & gui started Beams 5&6 (S1&S2, respectively) aligned, small corner cubes in place

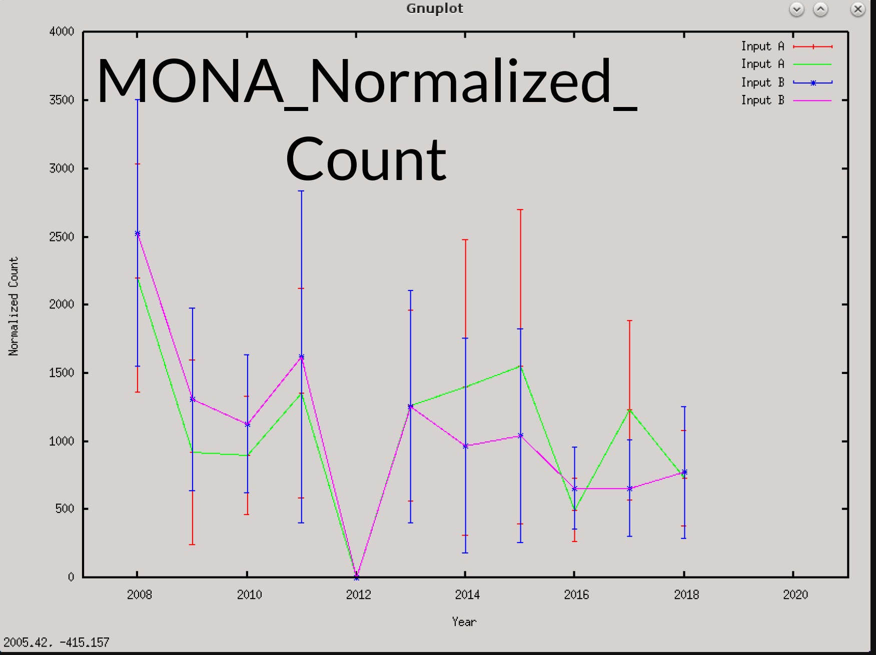
Raster scans done for each beam (using four pixel align, 'fpa')

Beam A raster max counts through MONA:	Beam B raster max counts through MONA:
23840	24687

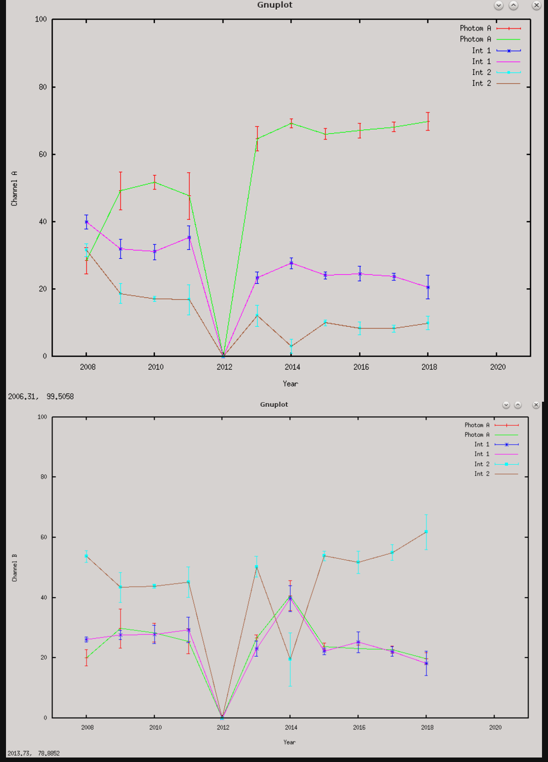
Bypassing MONA: Fiber bundle inputs directly connected to the stages, raster scans using "fpa"

All scans with one stage were centered around the same Zaber position.

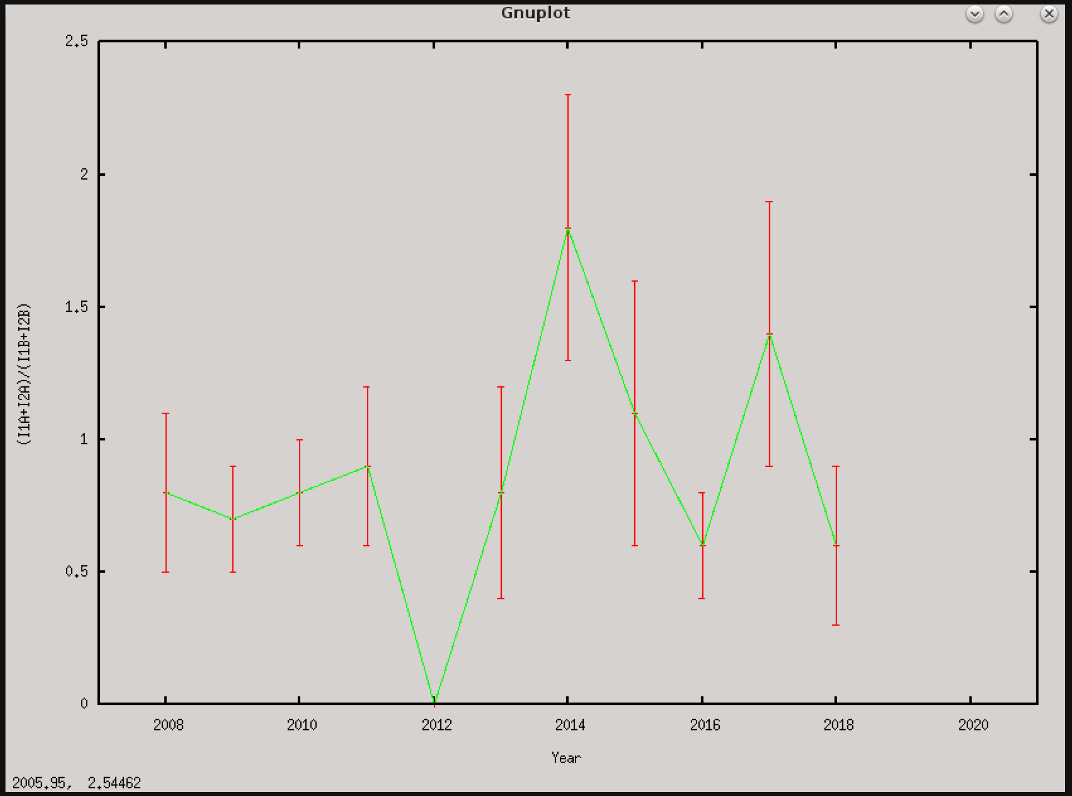
	Raster Max Count		
Channels	Stage A	Stage B	Fiber Labels
I1	33081	33260	Red
I2	30414	36079	Yellow
PA = Phot 1	33556	36663	Blue
PB = Phot 2	31840	37561	Green



This shows the total amount of light getting through normalize for Kmag, ie Count / $10^{(mag/-2.5)}$. Decline in 2016 after we put the polarization corrector plates in.

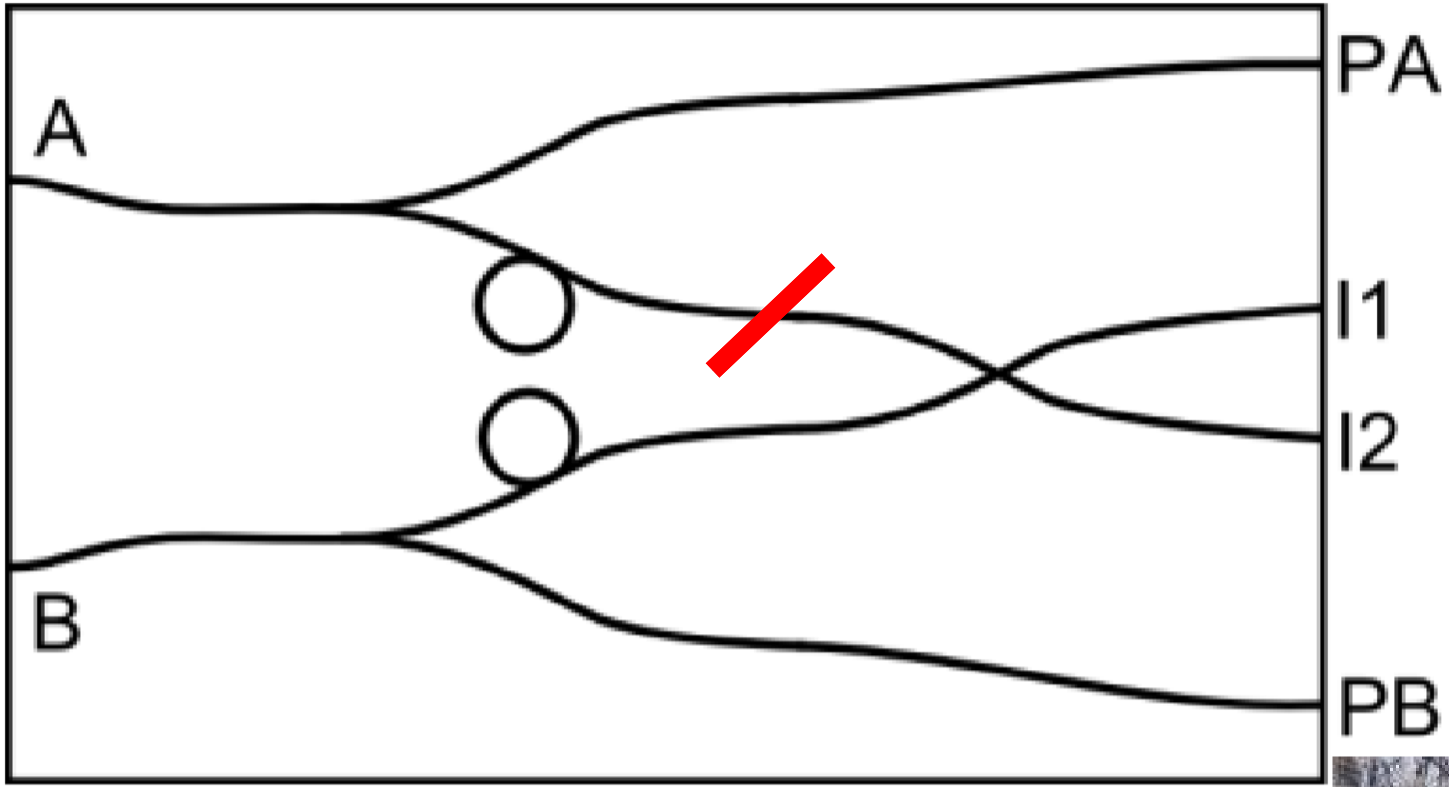


Percentage of light from input A(top) and B(bottom) reaching it's photometric output and the two inteferometeric outputs. There is a clear change after the unit was sent back to France. It seems much more light is going to the photometric channel and much less to the interferometric outputs.



The ratio of light reaching the interferometric output from input A and Input B.

"The conclusion we seem to converge upon is that the problem is in the MONA box. Not enough light coming from Input A to the inteferometric channels."

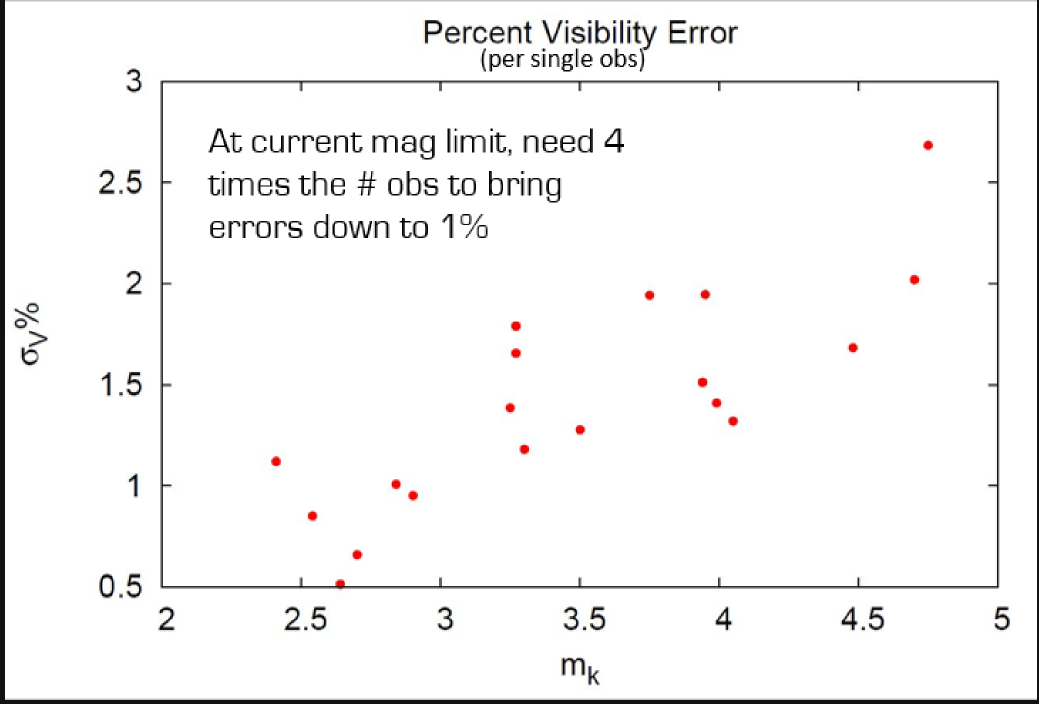

A
B
PA
I1
I2
PB


MONA
IOTA TO JOUFLU
1991 - 2018

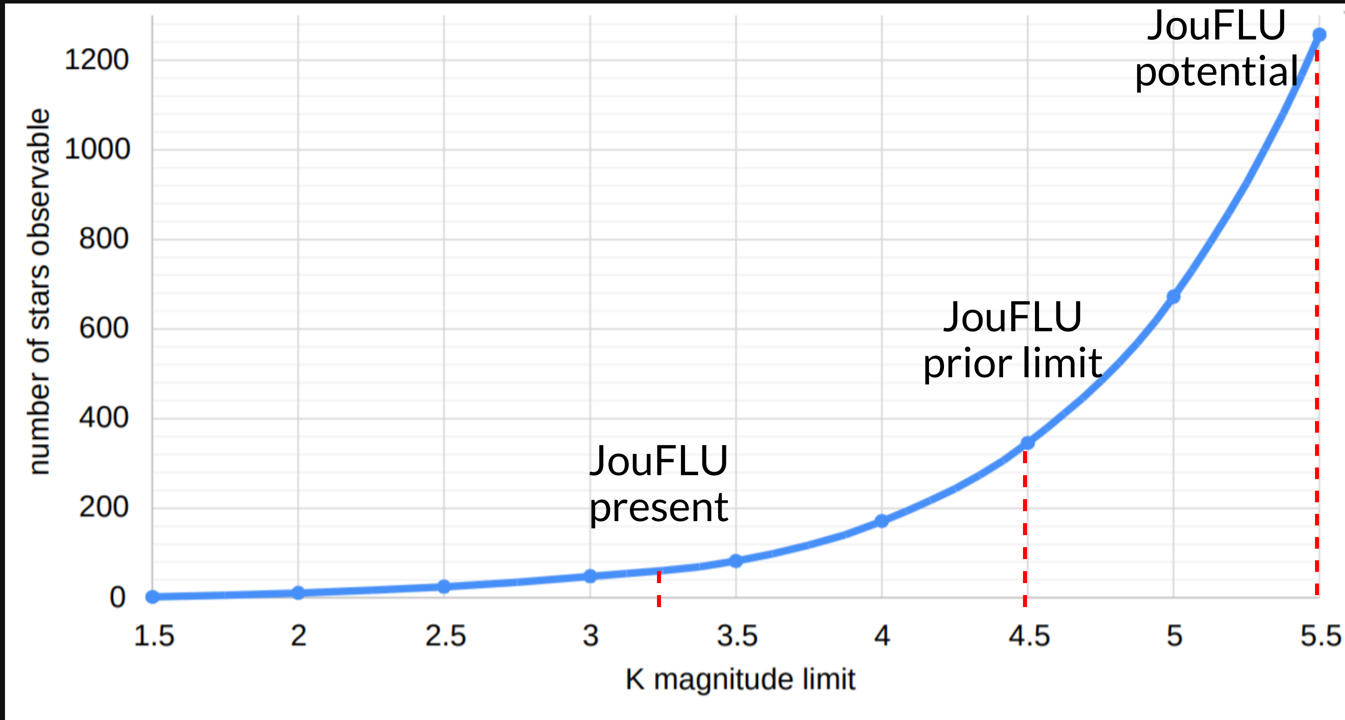
Possible Solutions

JouFLU upgrade paths

- Replace MONA
  - IO (GRAVITY/GLINT)
  - Increase spectral dispersion
- Replace NICMOS
  - Selex SAPHIRA? PICNIC?
- Add Fringe-tracker
  - Make a nuller



Getting to 5th mag could more than double the number of targets observable



CHARA AO is now coming online
$\rightarrow$ greatly improved obs efficiency

Goal is 1% excess detection at 5σ to mK < 5.

combiner requirements (link)

transmission	<0.01	db/m
bandpass	2 - 2.3	μm
NA/lambda_c	0.089	μm

20-30% to photom, 70-80% to Interferometric. I1 & I2 balanced

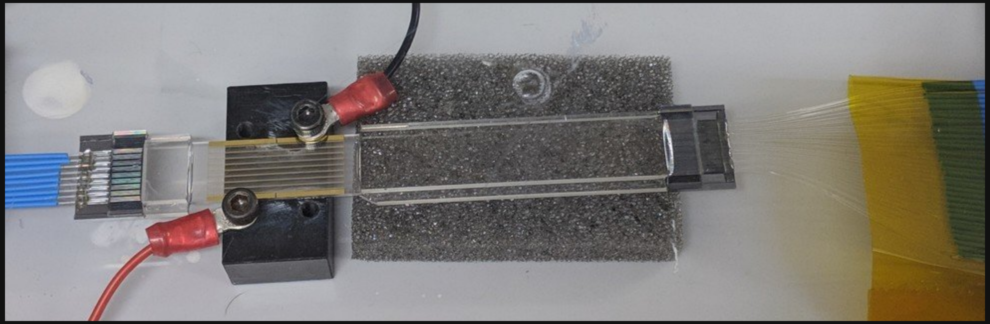
NA	0.17 ± 0.01
cutoff	< 1.95 μm
bandpass	2.0 - 2.4 μm

budget estimate (link)

- ZBLAN IO chip
  - losses ~0.4 db/cm
  - get H band IO chip as "bonus"
- v-groove and coupling optics (Ozoptics)
- input and output mounts
- option: 4 beam H+K simultaneous

Saphira Selex detector

- will enable drastically better spectrally dispersed results
- +350k



Takeaway

- Explore the apparent variability of known exozodis
  - long-term monitoring
  - clues to source and formation of the dust
- Expand strong exozodi sample
  - leveraging LBTI and prior surveys
  - from ~100 $\rightarrow$ ~1000 objects
- Use spectral dispersion to resolve the thermal/scattered dilemma
- Risk mitigation for coronagraphy/starshade missions
- Target selection and characterization for mid/large missions (TESS, LUVOIR, HabEx, etc)
  - exozodis likely to be dominant noise source
- Precision diameters and fundamental astrophysics

ExEP Science Overview (link)

Science gaps on Exoplanet program office list

- Science gap Number 4
  - Planetary System Architecture
- Science gap Number 6
  - Yield estimation for exoplanet direct imaging missions
- Science gap number 7
  - Improve target lists and compilations of stellar parameters for exoplanet missions in operation or under study
- Science gap number 10
  - Precursor surveys of direct image targets
- Science gap Number 11
  - Understanding the abundance and distribution of exozodiacal dust

NN-Explore/NASA
ExoZodiacal
Monitoring
Observatory

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