Hi-5
High-contrast Interferometry up to 5 microns

High-contrast interferometry: science cases and measurement approach

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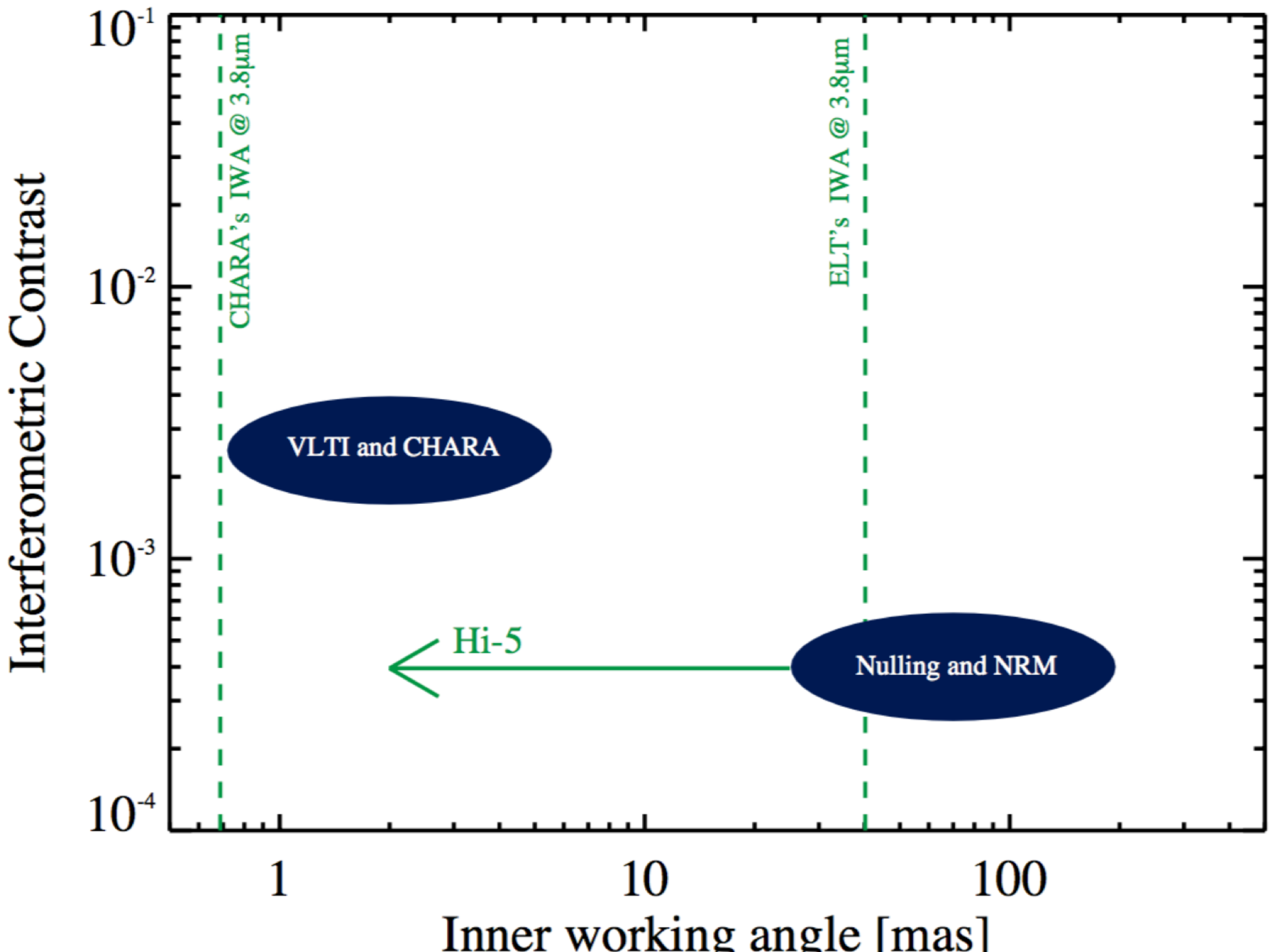
Absil, O., Berger, J.-P., Boulet, T., Danchi, W. C., Ertel, S., Gallenne, A., Hénault, F., Hinz, P., Huby, E., Ireland, M., Kraus, S., Labadie, L., Le Bouquin, J.-B., Martin, G., Matter, A., Mérand, A., Mennesson, B., Minardi, S., Monnier, J., Norris, B., Orban De Xivry, G., Pedretti, E., Pott, J.-U., Reggiani, M., Serabyn, E., Surdej, J., Tristram, K. R. W., & Woillez

Status of high-contrast interferometry



History of high-contrast stellar Interferometry

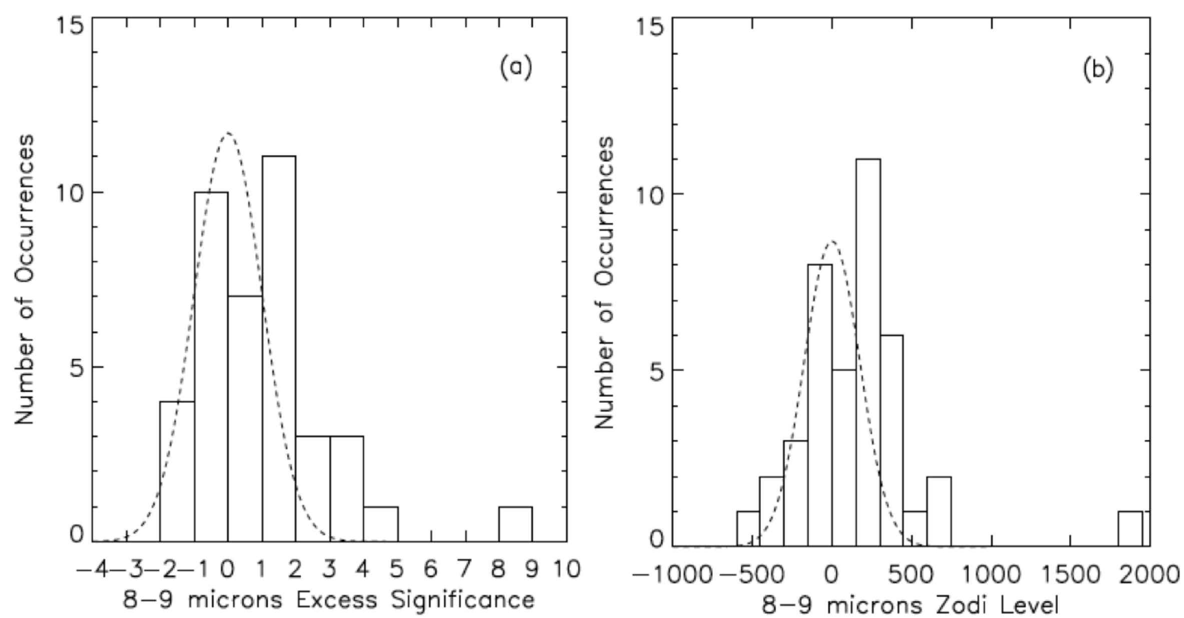
- Four nulling experiments
  - ✓ Keck Interferometer Nuller (KIN)
  - ✓ Palomar Fiber Nuller (PFN)
  - ✓ Large Binocular Telescope Interferometer (LBTI)
  - ✓ DRAGONFLY/GLINT
- Two high-precision V^2 instruments
  - ✓ CHARA/FLUOR (& VLTI/GRAVITY & VLTI/VINCI)
  - ✓ VLTI/PIONIER (& IOTA/IONIC)
- Several closure-phase instruments
  - ✓ CHARA/MIRC
  - ✓ VLTI/PIONIER
  - ✓ Aperture masking experiments

Nulling at Keck (KIN: 2008-2011)

- N-band nulling with **~0.2% null accuracy (= dynamic range)**
  Mostly limited by background residuals

- Survey of exozodiacal disks
  5/47 stars have mid-IR excess ~1%

Mennesson et al. 2014

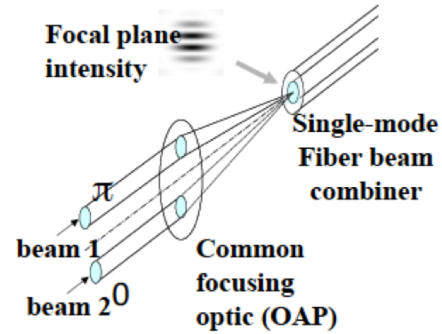


Nulling at Palomar (PFN: 2008-2014)

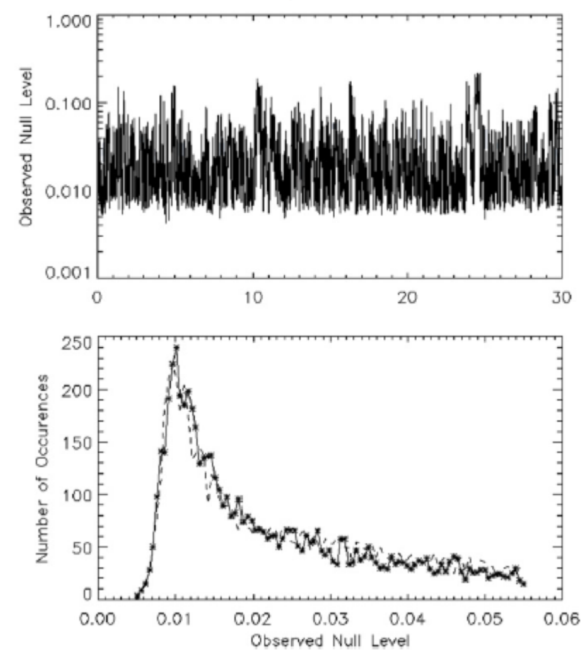
- Two sub-pupils on Hale 200-inch telescope
  - In-fiber beam combination (nulling)
  - K-band instrument

- Development of a statistical “null self calibration” technique (NSC)
  - Model the null fluctuations
  - Final **accuracy ~0.01%** after processing

- Used to constrain circumstellar emission around various targets



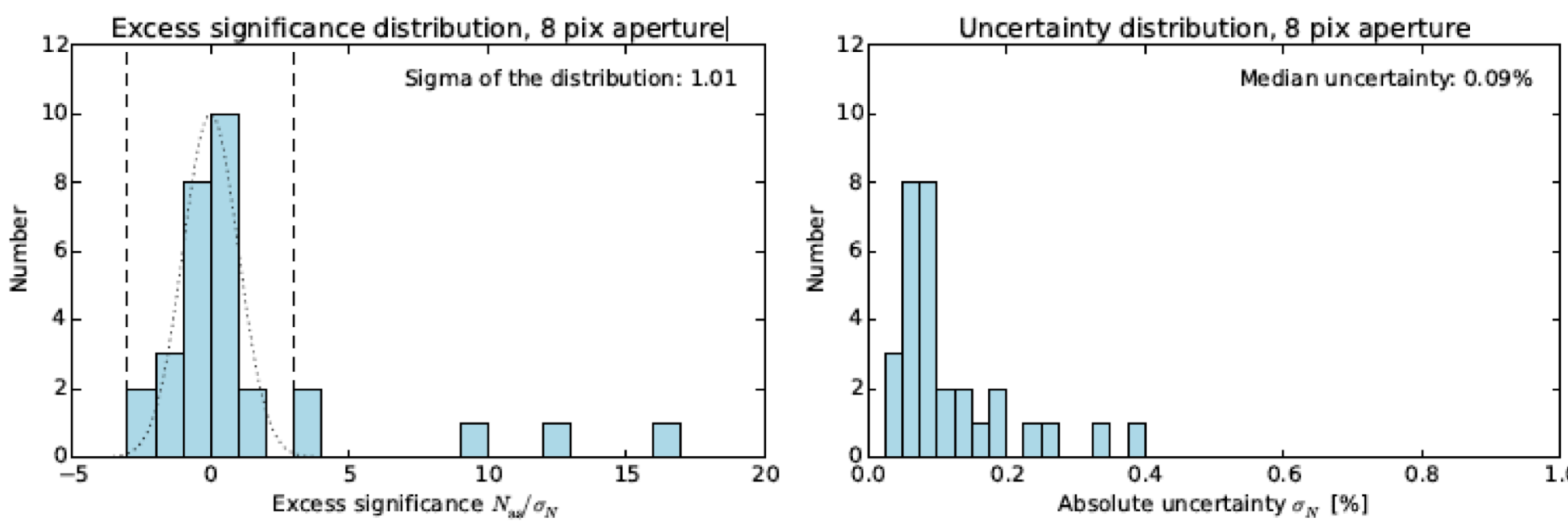
Hanot et al. 2011, Mennesson et al. 2011



Nulling at the LBTI (2013-…)

- N-band nulling interferometer
  - Takes advantage of statistical NSC data reduction
  - Current null accuracy **~0.04 – 0.2%**
  - Limited by background residuals

- On-going survey of exozodiacal disks (Ertel et al., submitted)



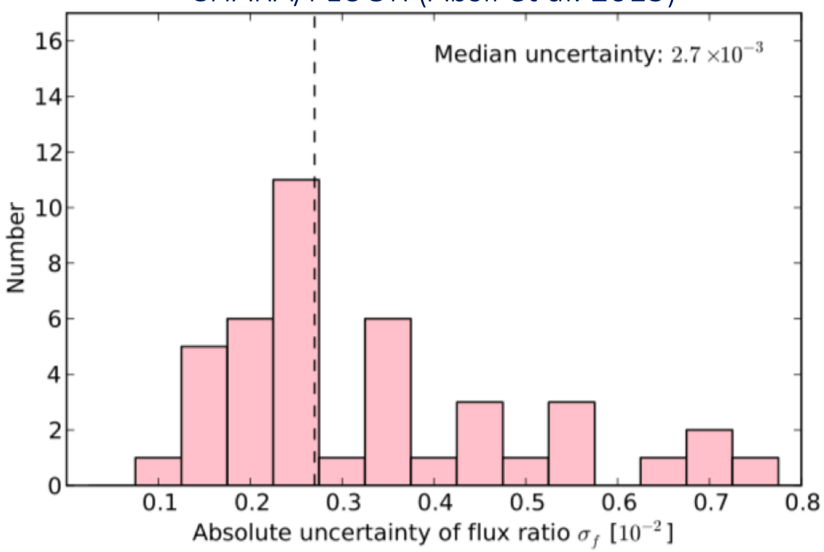
Ertel et al., submitted

High-precision squared visibilities

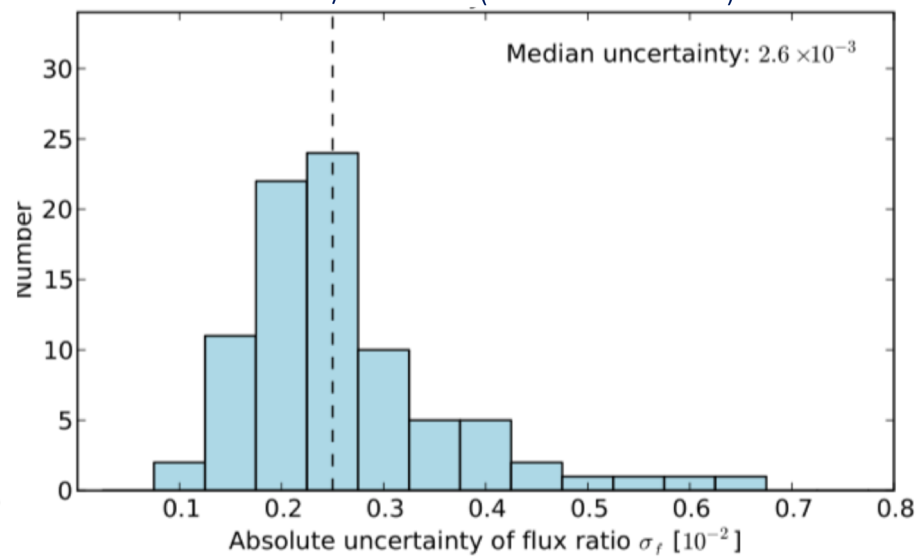
- FLUOR, VINCI, PIONIER, GRAVITY
  - Fibered /integrated optics beam combiners
  - Working at H/K bands
  - **~0.3% median dynamic range** (individual V2 accuracy in the 0.5%- 1% range)

- Used to search for faint circumstellar emission
  - Exozodiacal disk surveys
  - Envelopes around Cepheids

CHARA/FLUOR (Absil et al. 2013)



VLTI/PIONIER (Ertel et al. 2014)

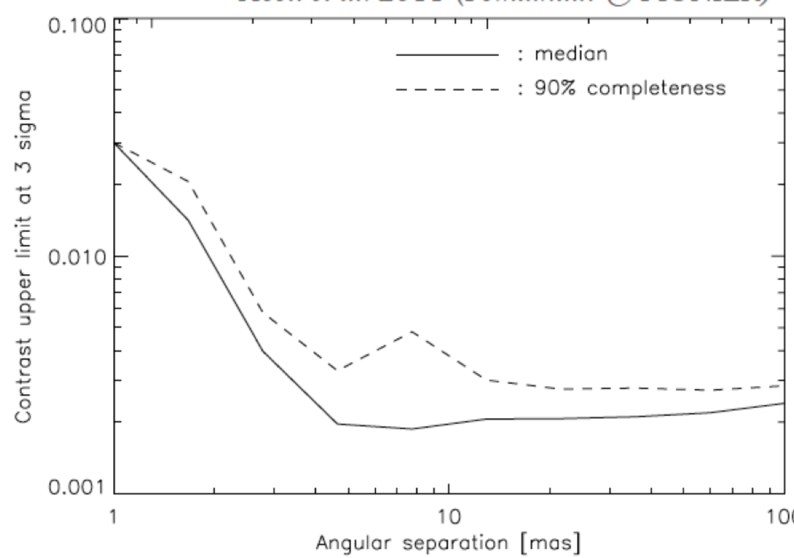


High-precision closure phases

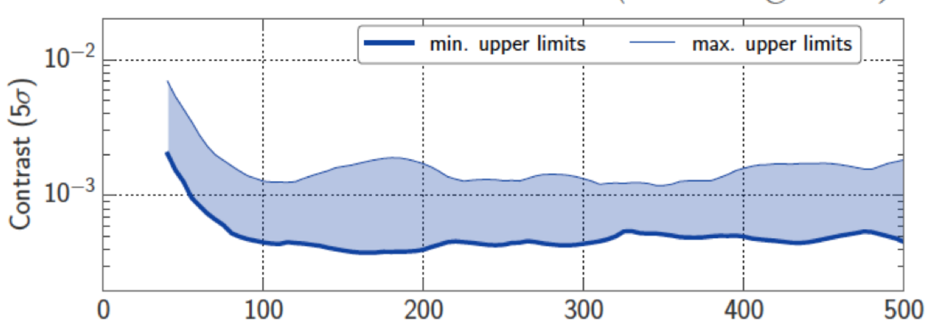
- MIRC, PIONIER
  - Typical accuracy of 1 deg on individual data points
  - Dynamic range down to **~0.1%** when accumulating data

- Aperture masking
  - Many CP measured at once
  - Typical dynamic range of **0.05% - 0.1%**

Absil et al. 2011 (Fomalhaut @ PIONIER)



Gauchet et al. 2016 (Fomalhaut @ NACO)



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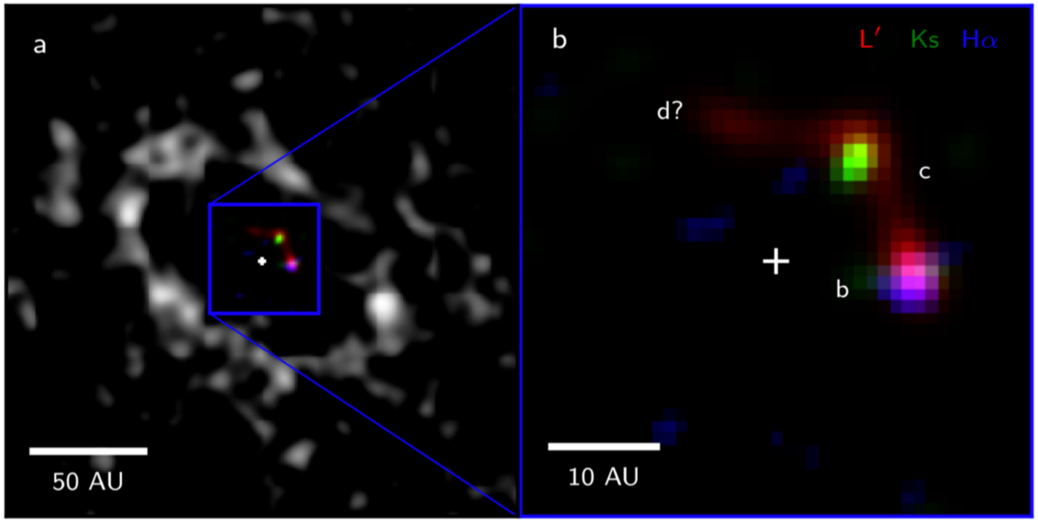


Sallum et al. 2015

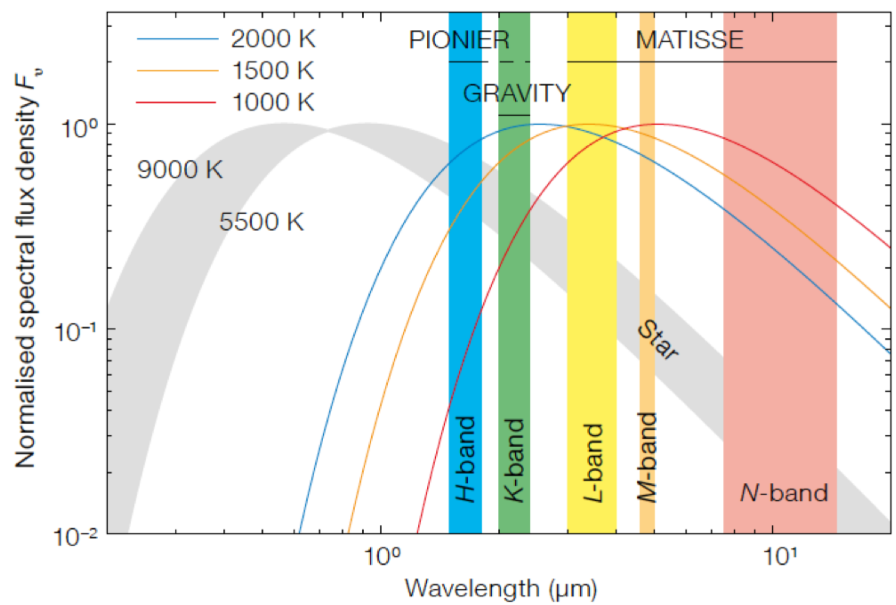
The near-IR/mid-IR gap

- Dynamic range of a few 10^{-4} now at H/K and N bands

- Thermal near-infrared **(3- 5 µm) not addressed**
  - Onset of thermal emission
  - Sweet spot for imaging young planetary systems
  - Many molecular species
  - Less thermal background wrt KIN and LBTI

—> potential for higher accuracy

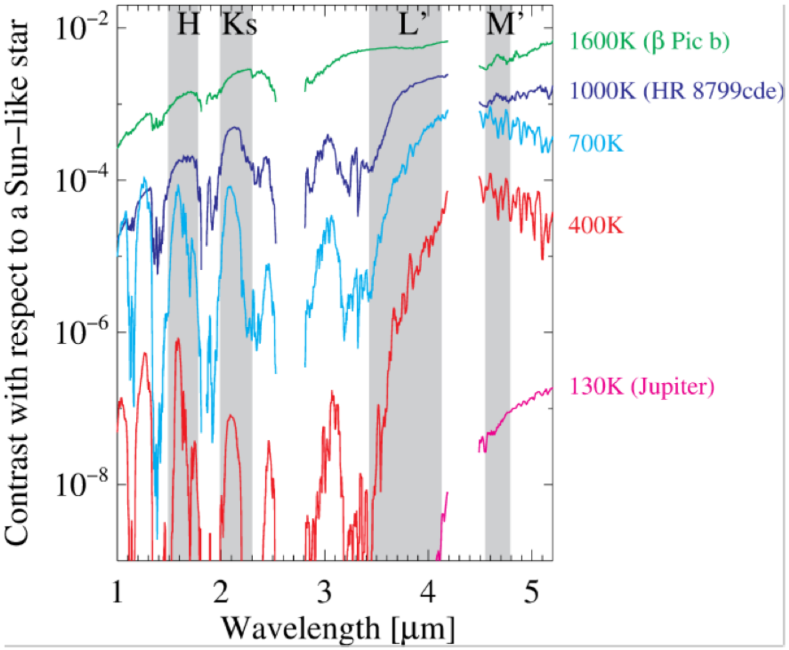
Ertel et al. 2015



Science case 1: exoplanets

- L-band = sweet spot for direct exoplanet imaging
  - Favorable star/planet contrast
  - Access to planet radius and temperature
  - Molecular bands / nonequilibrium chemistry

- 10 mag contrast enough for dedicated (sub)AU-scale survey in moving groups



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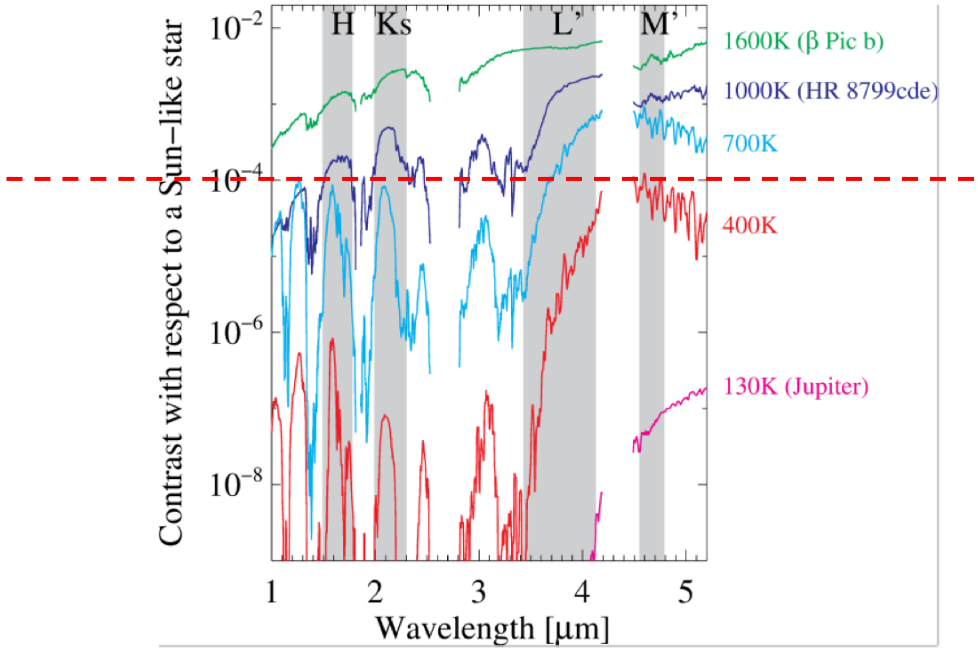

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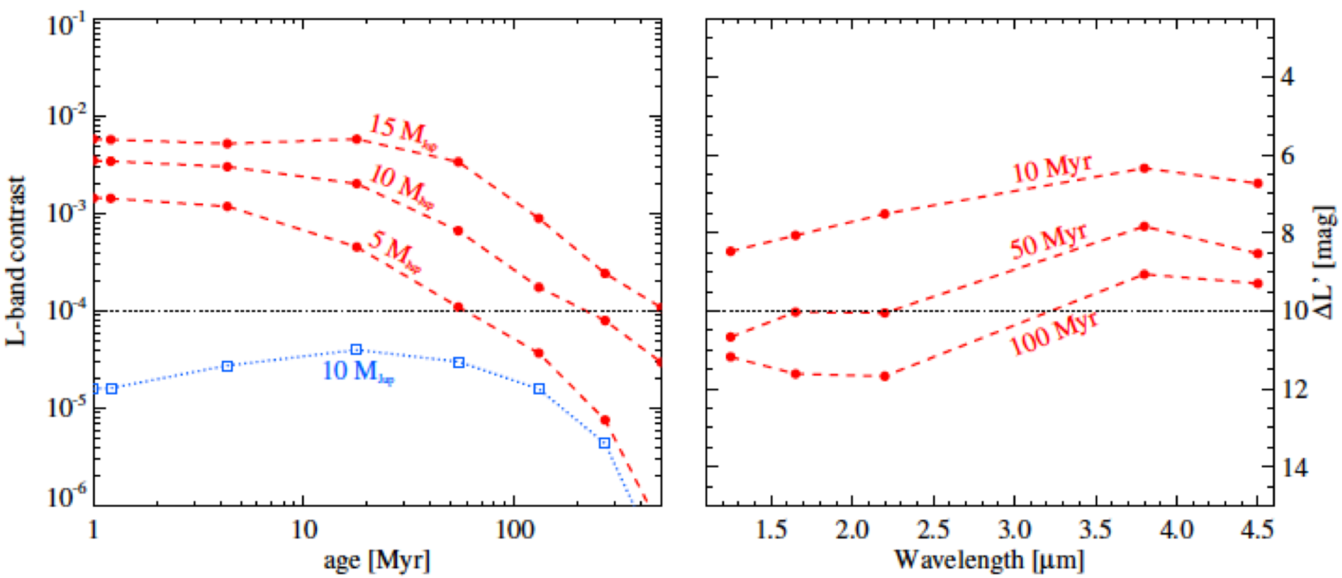

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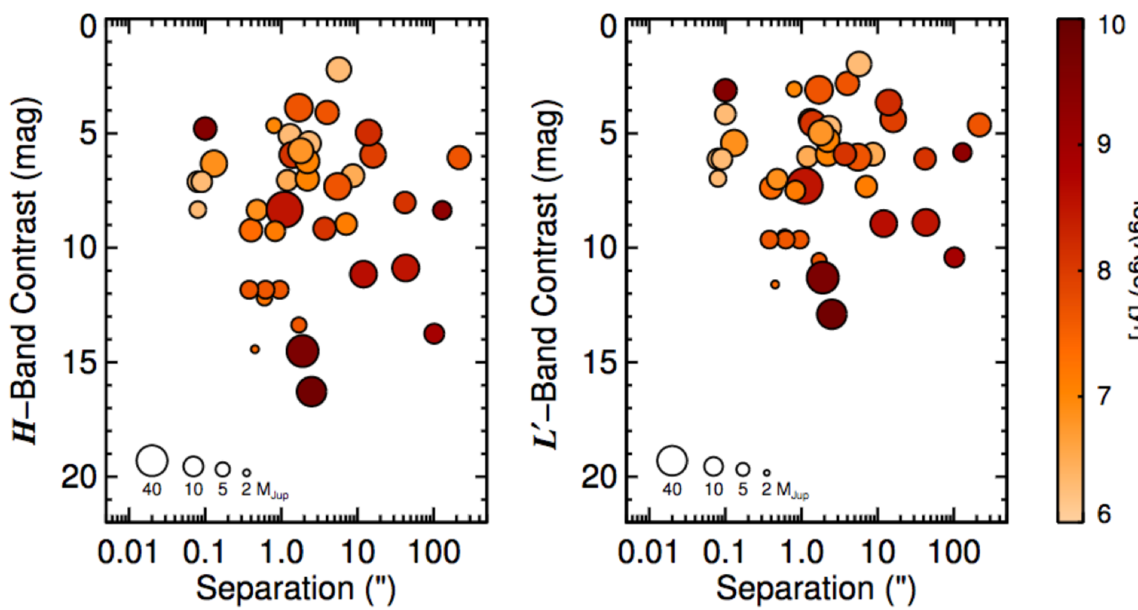
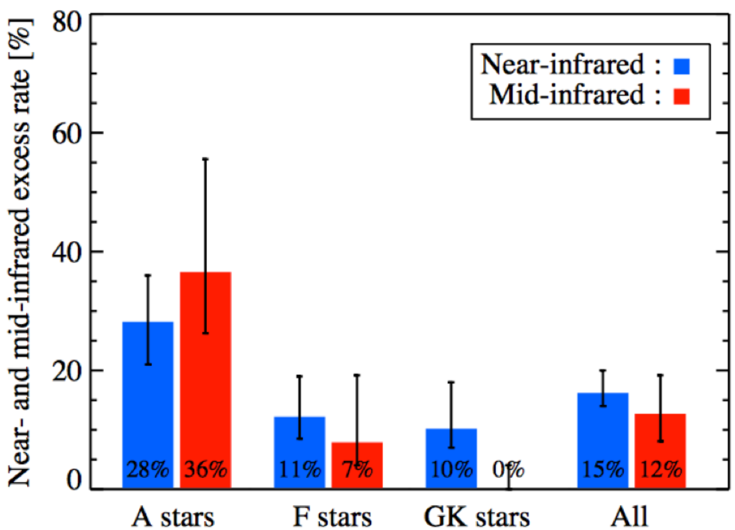


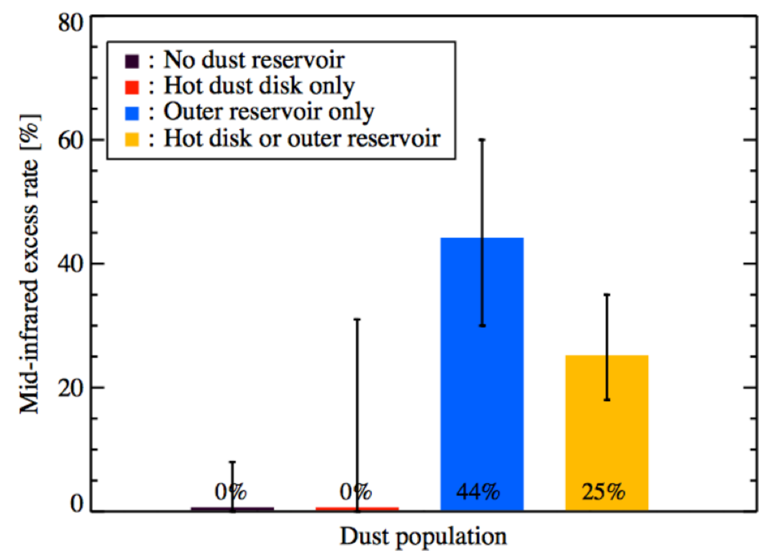
Bowler 2018

Science case 2: faint circumstellar disks

- Exozodiacal disks
  - Thermal near-IR = missing link in current exozodiacal disk models (interactions between hot dust and asteroid belts)
  - Measuring the faint end of the exozodi luminosity function (complementary with LBTI in northern hemisphere)

- Other circumstellar disks
  - Cepheids, AGBs, etc





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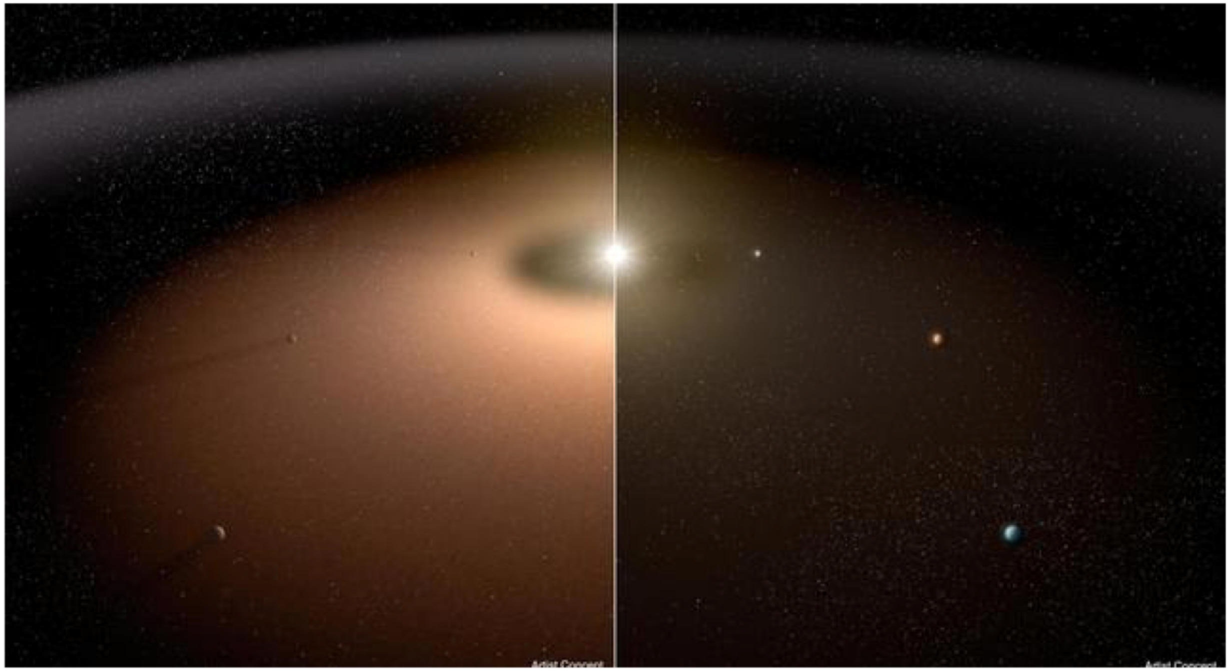
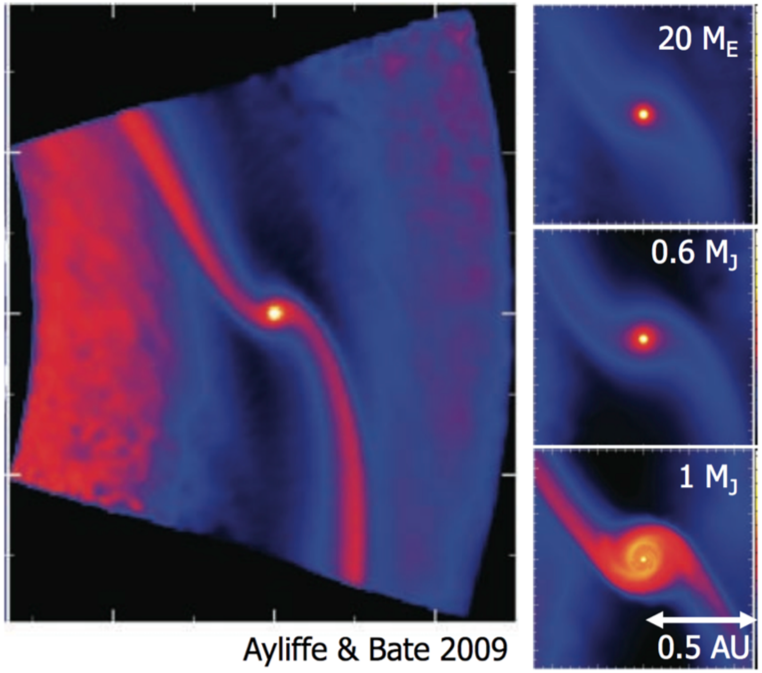
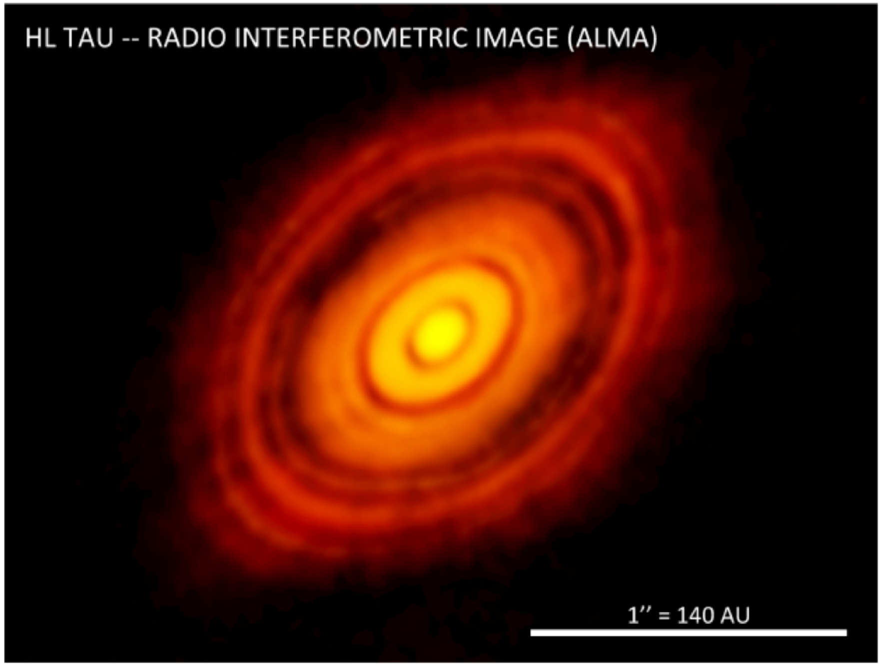


Science case 3: planet formation

- Imaging young stars in nearby star forming regions
  - Search for young, forming planets (e.g., explore the cavities of transitions disks)
  - Need good imaging capabilities in addition to high contrast
  - Prepare for PFI science



Ayliffe & Bate 2009



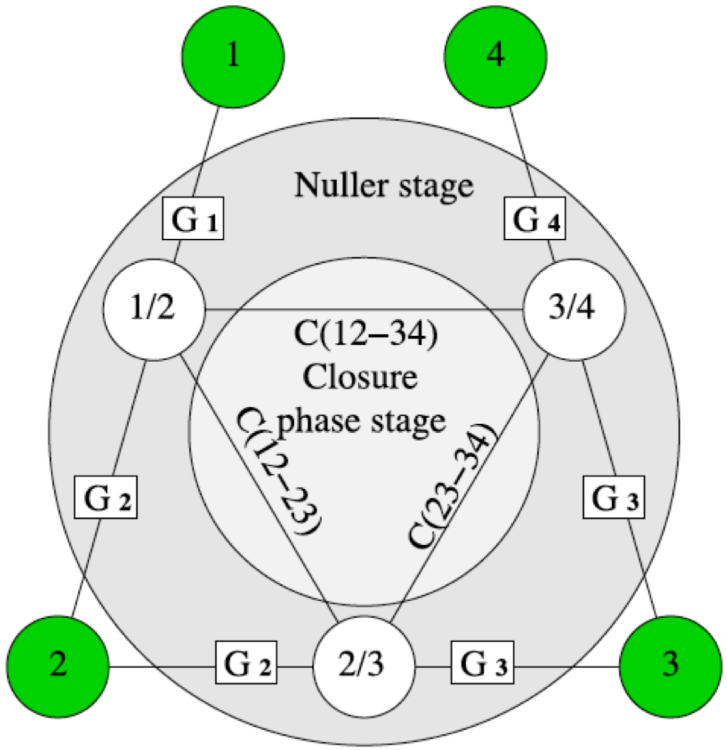
Instrument concept

- L- and M-band beam combiner
  - At least four beams
  - Single-mode fibers and/or integrated optics

- A few possible architectures
  - PIONIER-like 4T-ABCD combiner
  - Multi-telescope nulling interferometer
  - Combination of nulling + close phases
  - Kernel nulling

- Spectroscopic capabilities

Lacour et al. 2014



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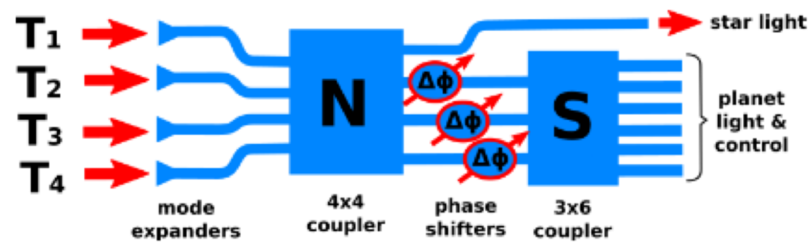
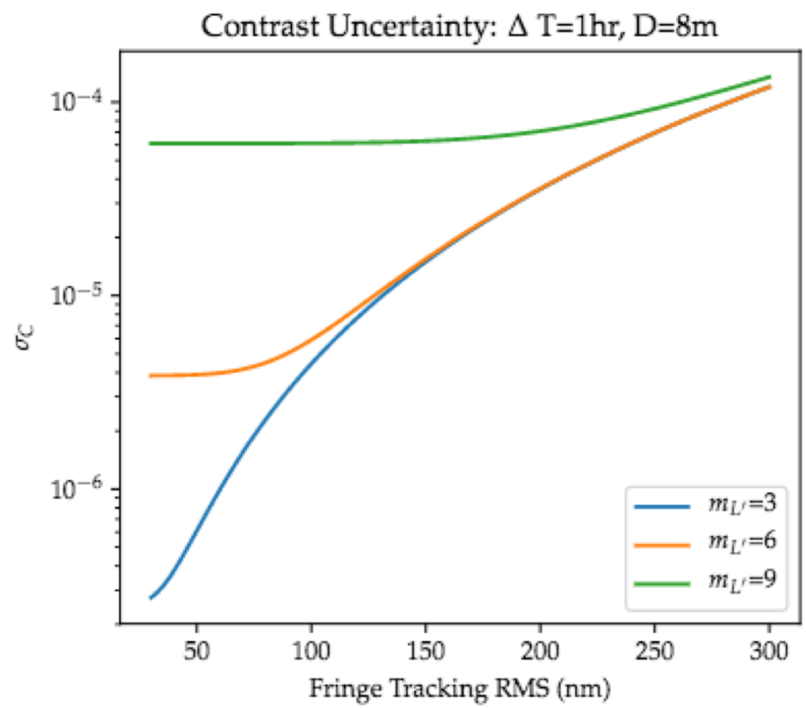
Martinache and Ireland 2018





The Hi-5 study context

- OPTICON funding for 2-yr study
- Refine the science cases
- Identify and understand contrast limitations at L band (background, polarization, …)
- Test & compare available technologies
  - Lithium niobate vs chalcogenide beam combiners
  - In-lab study of intensity balance, chromaticity, polarization, etc
- Explore impact of data processing
  - Statistical NSC method has potential to significantly relax constraints on beam combination & fringe tracking
  - Develop framework for multi-telescope NSC method + lab tests

Hi-5 kickoff meeting

- Hi-5 kickoff meeting held in Liège in October 2017;
- Meeting website with presentations: http://www.biosignatures.ulg.ac.be/hi-5/index.html

A couple of pictures taken during the meeting. Left, the team in the beautiful "Horloge" room of our downtown campus. From left to right around the table, J. Surdej, T. Boulet, M. Ireland, G. Martin, S. Minardi, J.-P. Berger, B. Norris, P. Bendjoya, A. Matter, E. Serabyn , W.C. Danchi, O. Absil, A. Gallene, and K. Tristram. Right, picture taken in front of the building on the second day. From left to right, E. Pedretti, A. Mérand, J.-P. Berger, G. Martin, S. Minardi, E. Huby, O. Absil, M. Ireland, T. Boulet, E. Serabyn, D. Defrère, W.C. Danchi, B. Norris, F. Henault, K. Tristram, L. Labadie, A. Gallenne, G. Orban, M. Reggiani, J.-U. Pott, and S. Kraus.

The Hi-5 study objectives

- Identify implementation pathway

- Deliverable: report including performance analysis and implementation plan

- Timeline:
    - Study phase: 2018-2019
    - Final report: early 2020

- Contributions welcome! (ddefrere@uliege.be)