High Contrast Observations with Slicer Based Integral Field Spectrographs for direct exoplanet detections

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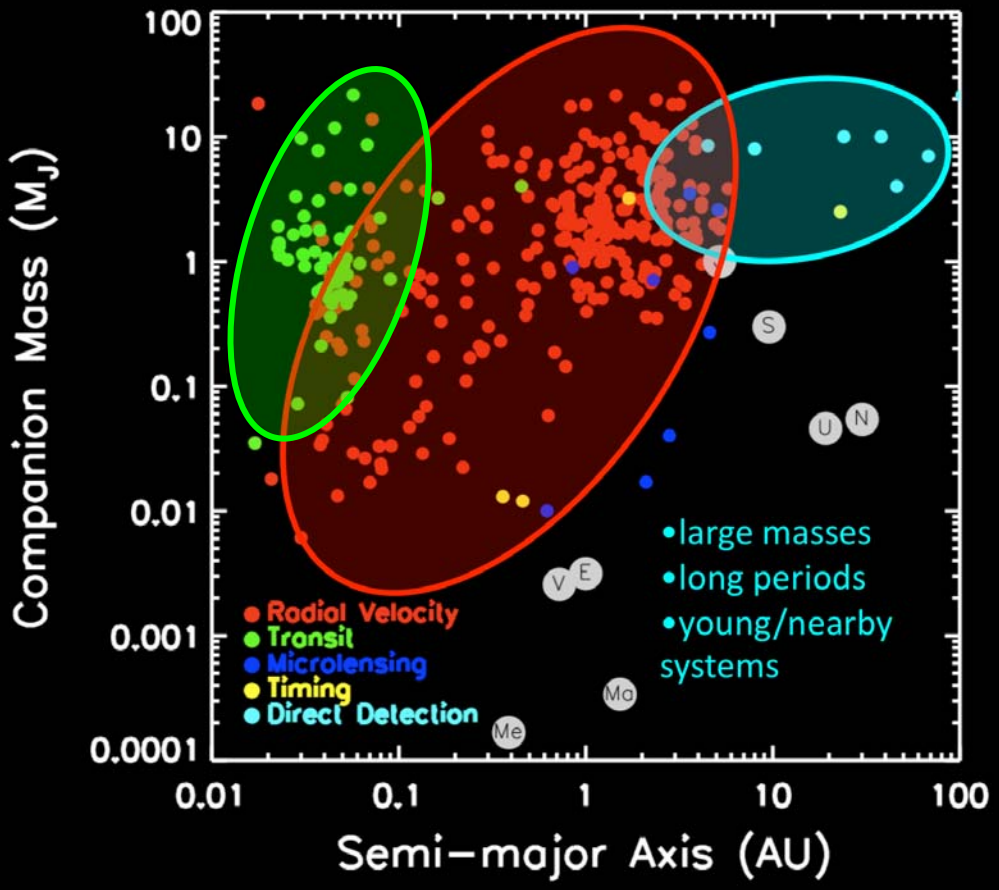
Graeme Salter, Niranjan Thatte, Fraser Clarke

Direct Detection - the way to go!

Radial Velocity & Transit methods are biased towards giant planets at small separations

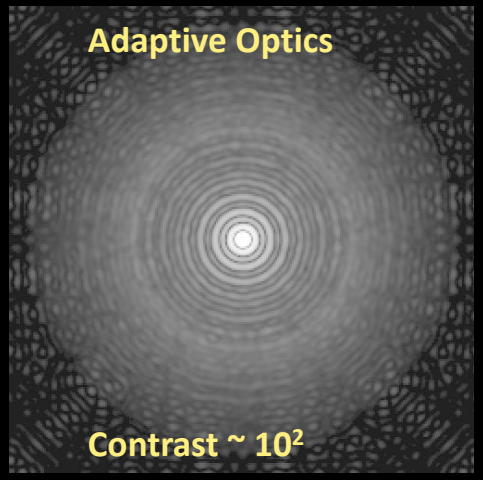


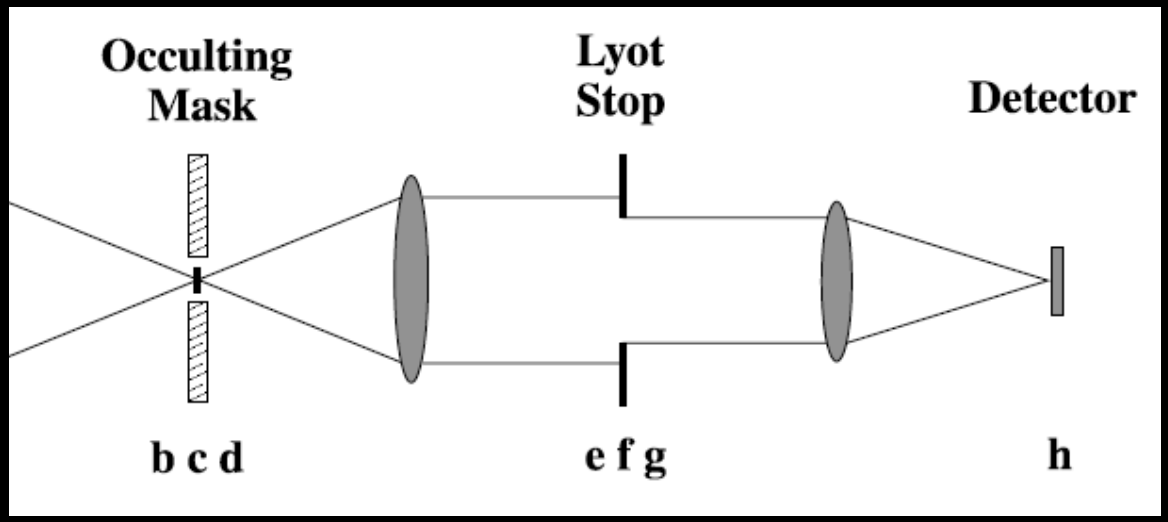
- Large separations (3-40AU) are crucial to understand formation mechanisms of planetary systems
- Indirect methods are not efficient at large separations:
  - Radial velocity signal very small
  - Transits too rare and inefficient
  - Astrometry very slow
  - Microlensing very rare

- Direct detection allows planet characterisation
- Direct detection of faint planets is challenging
  - For young giant planets if contrast is ~10^6-10^7
  - For rocky planets in the habitable zone and old giant planets if contrast is ~10^9!

High Contrast Imaging

- Highest contrast observations require multiple stages
  - Atmospheric turbulence (“fast speckles”)
    - » Adaptive Optics
  - Diffraction pattern
    - » Coronagraph/Apodiser
  - Quasi-static instrumental aberrations (or “Super-speckles”)
    - » Differential methods
- Best in NIR due to AO correction





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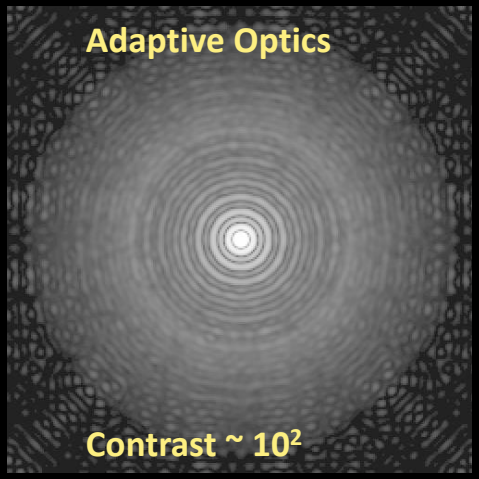

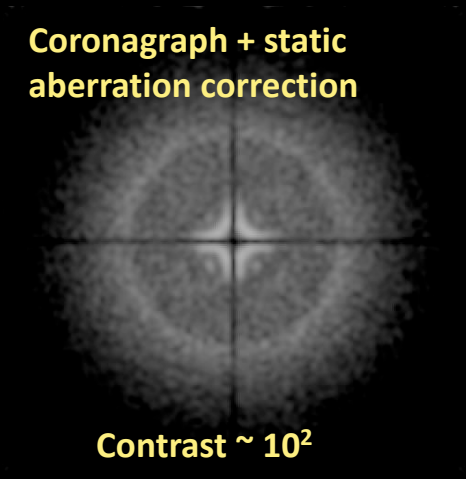

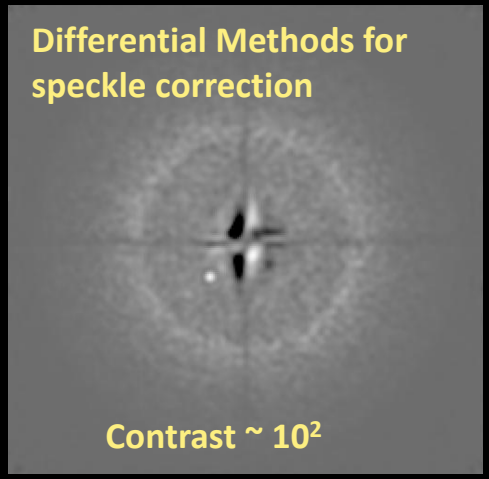

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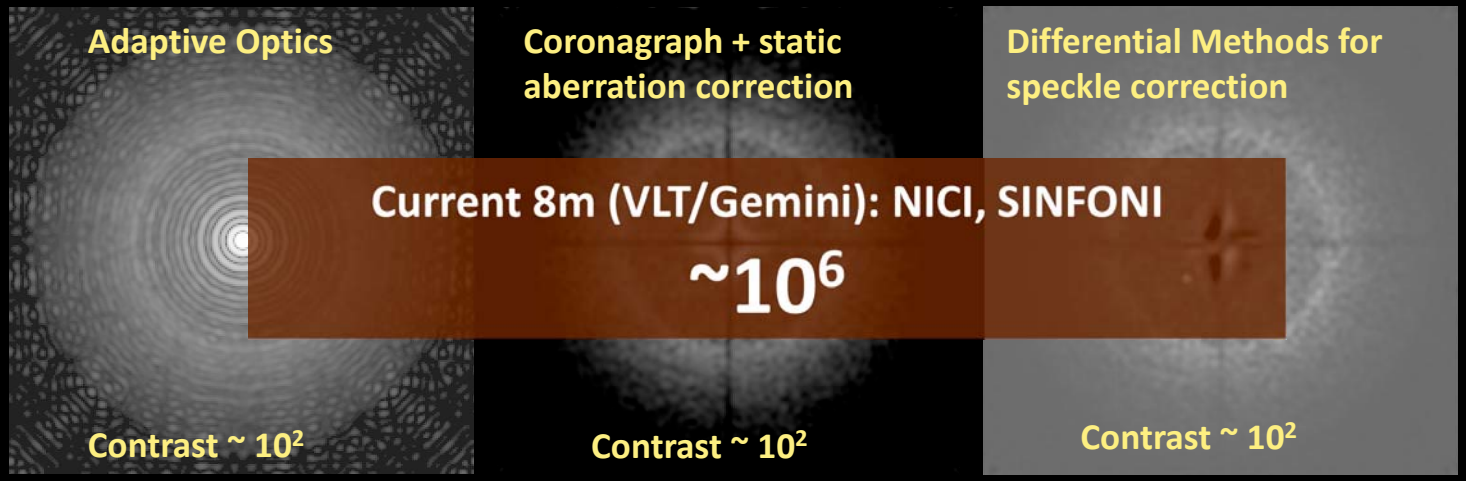

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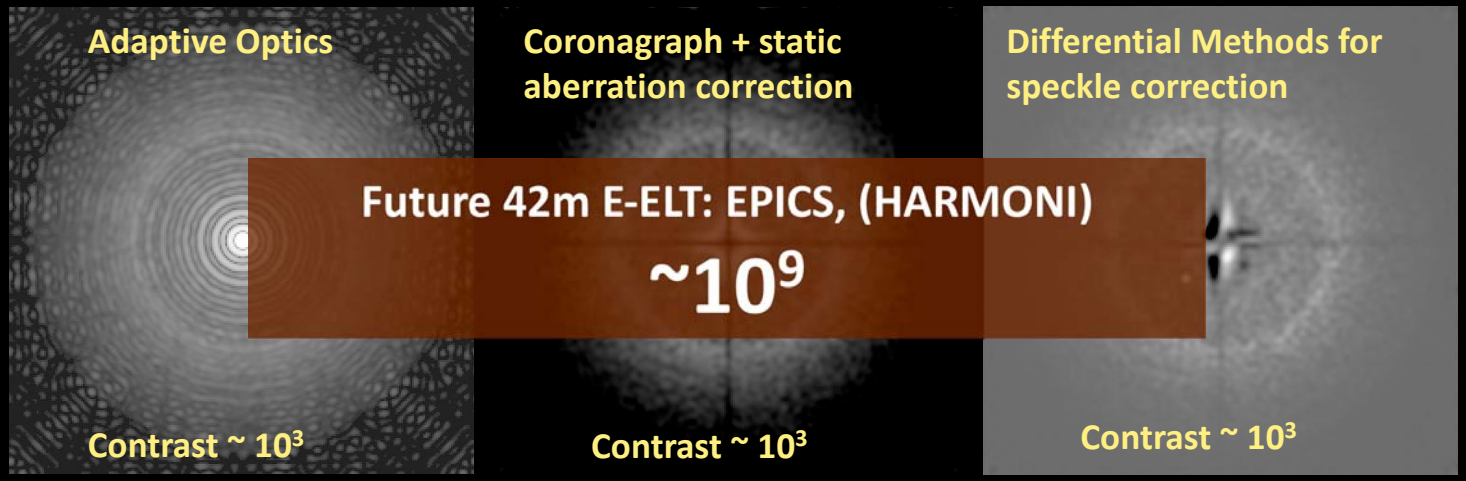
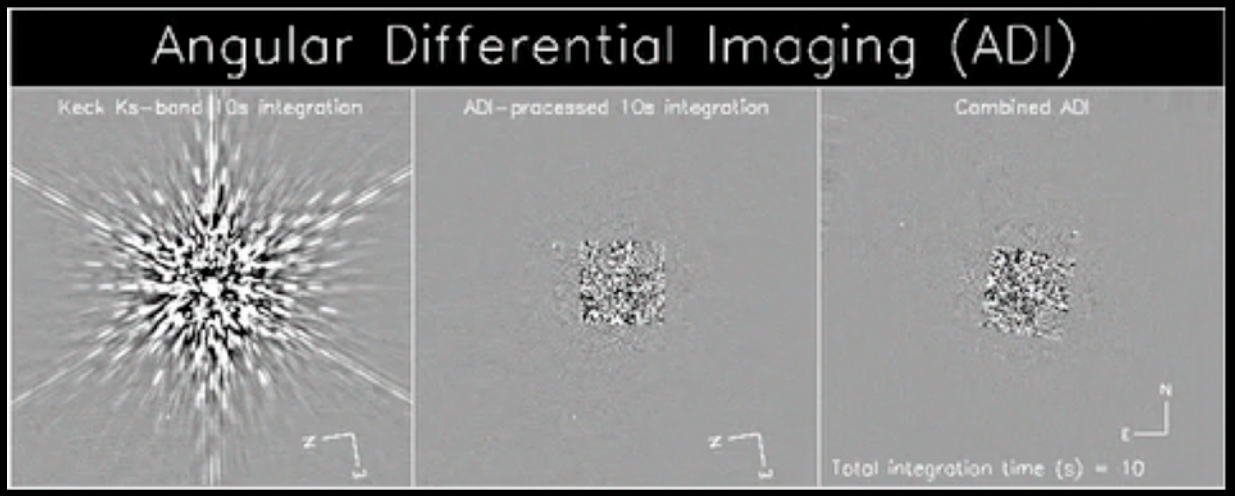


Differential Imaging

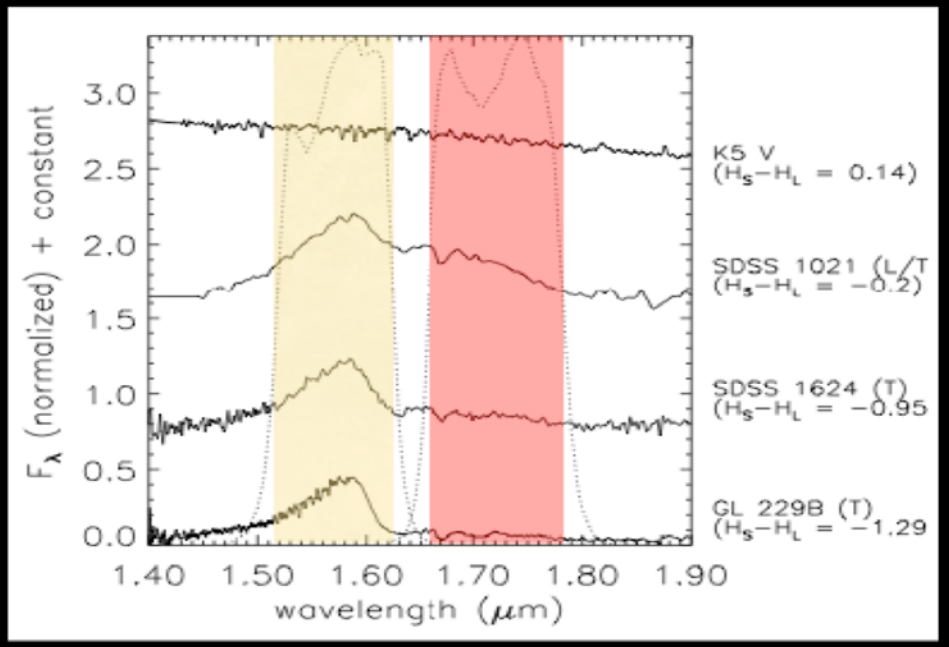
Angular Differential Imaging

- Uses rotation of the sky to distinguish planets from super-speckles
- Super-speckles are quasi-static wrt instrument optics
- Planets are fixed on sky
- Fast (atmospheric) speckles are smeared out over “long” exposures



Spectral Differential Imaging

- around the 1.6μm methane absorption feature



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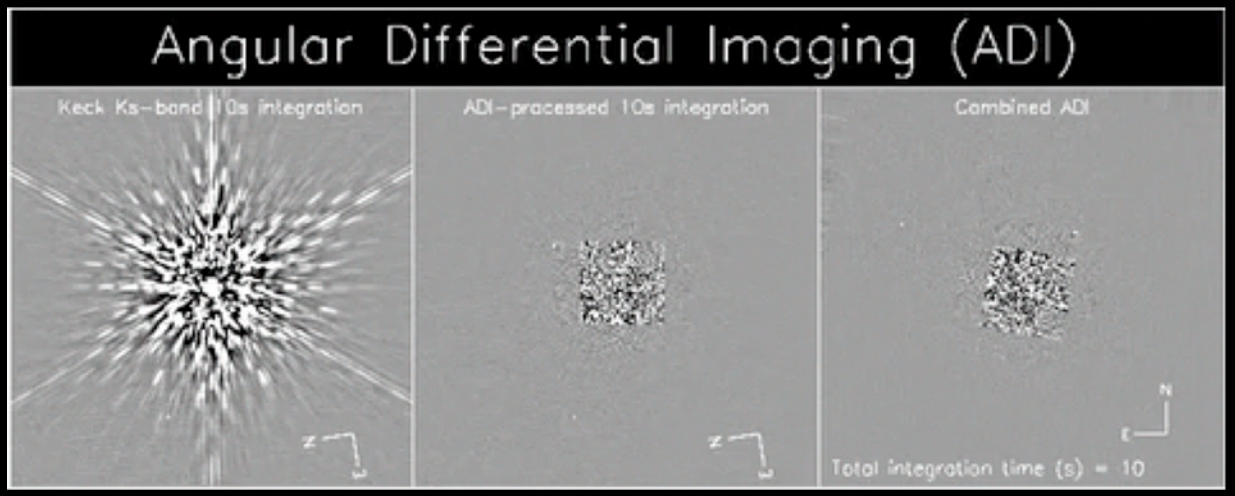

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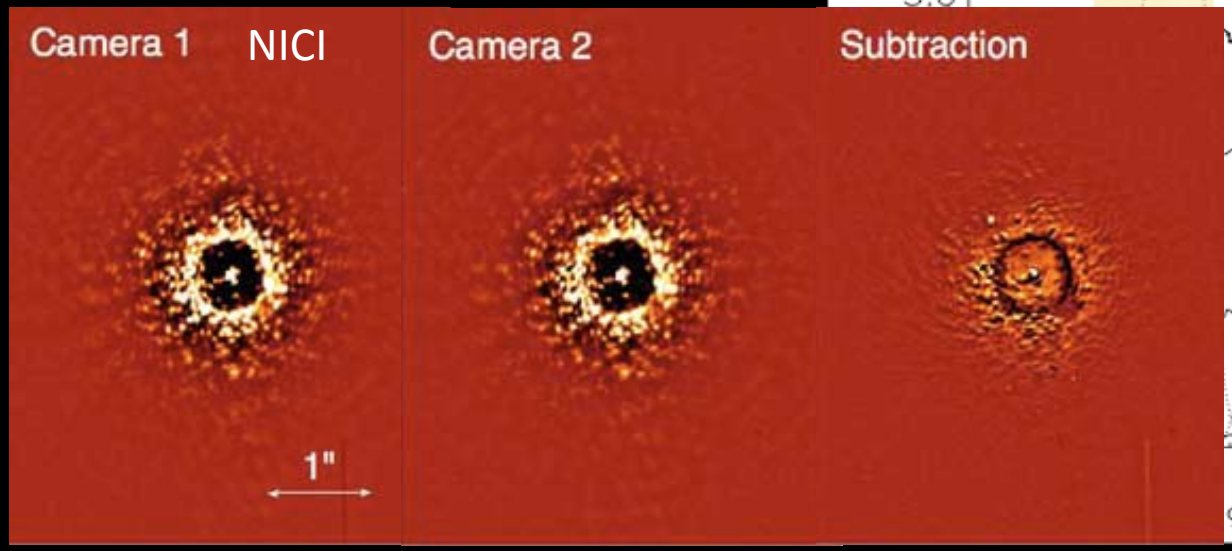
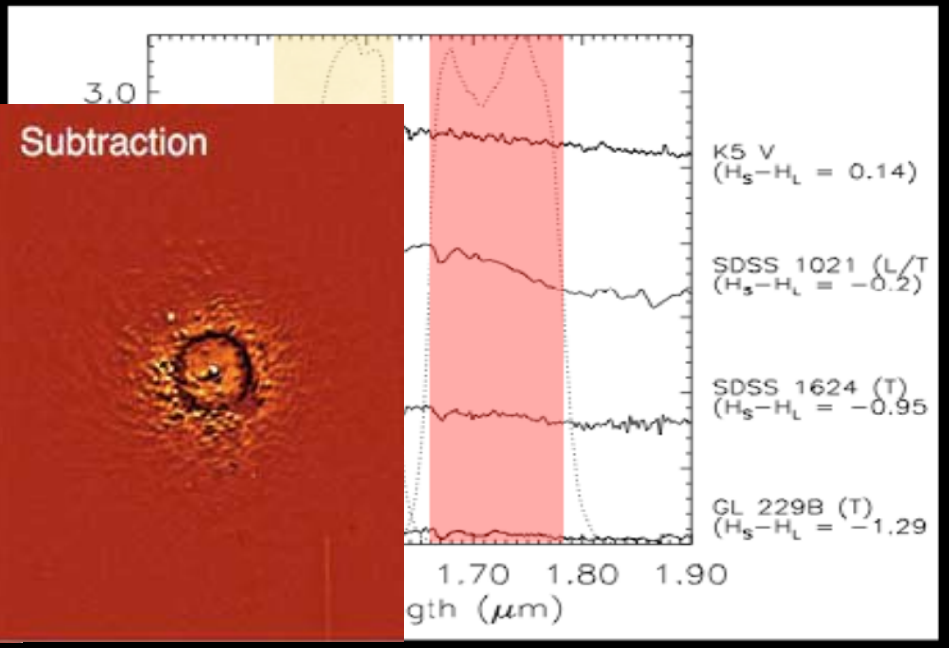
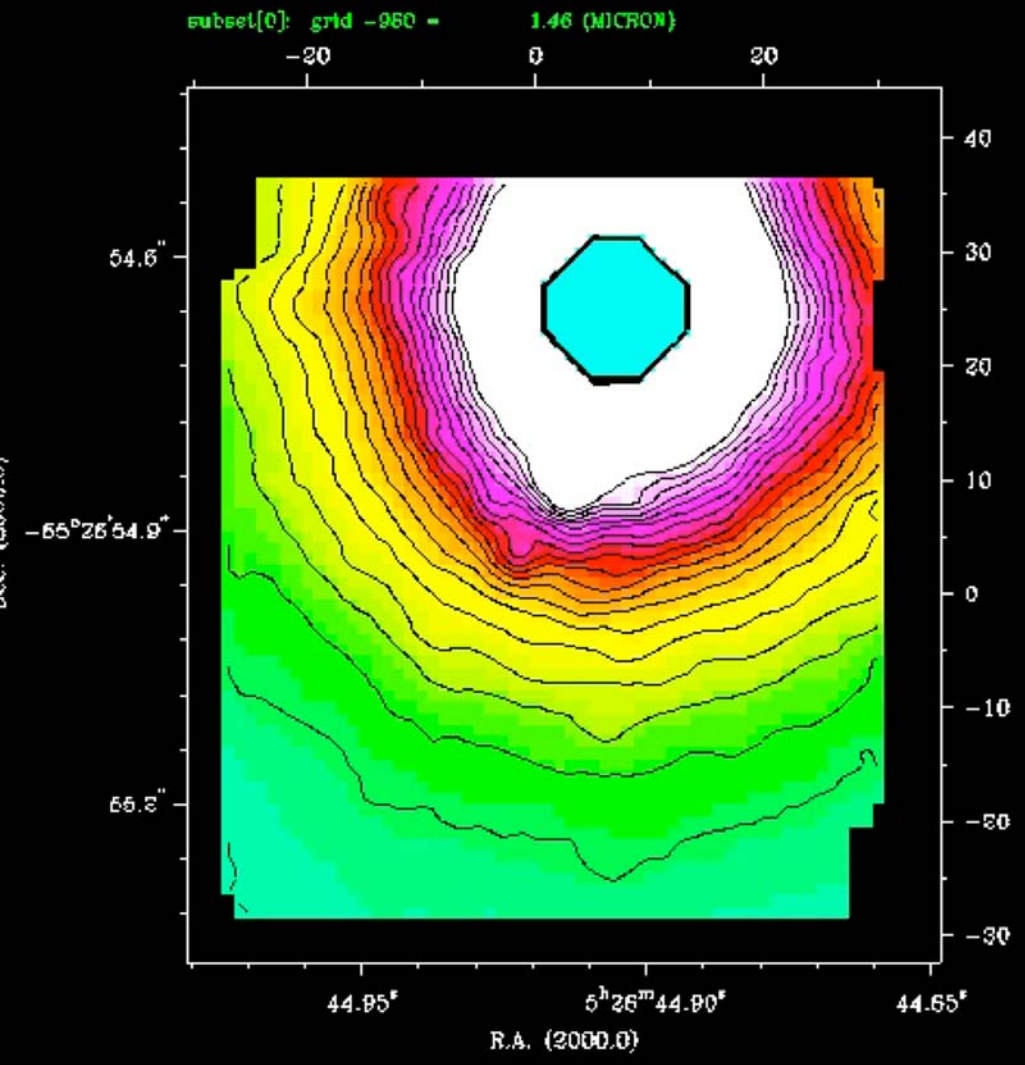


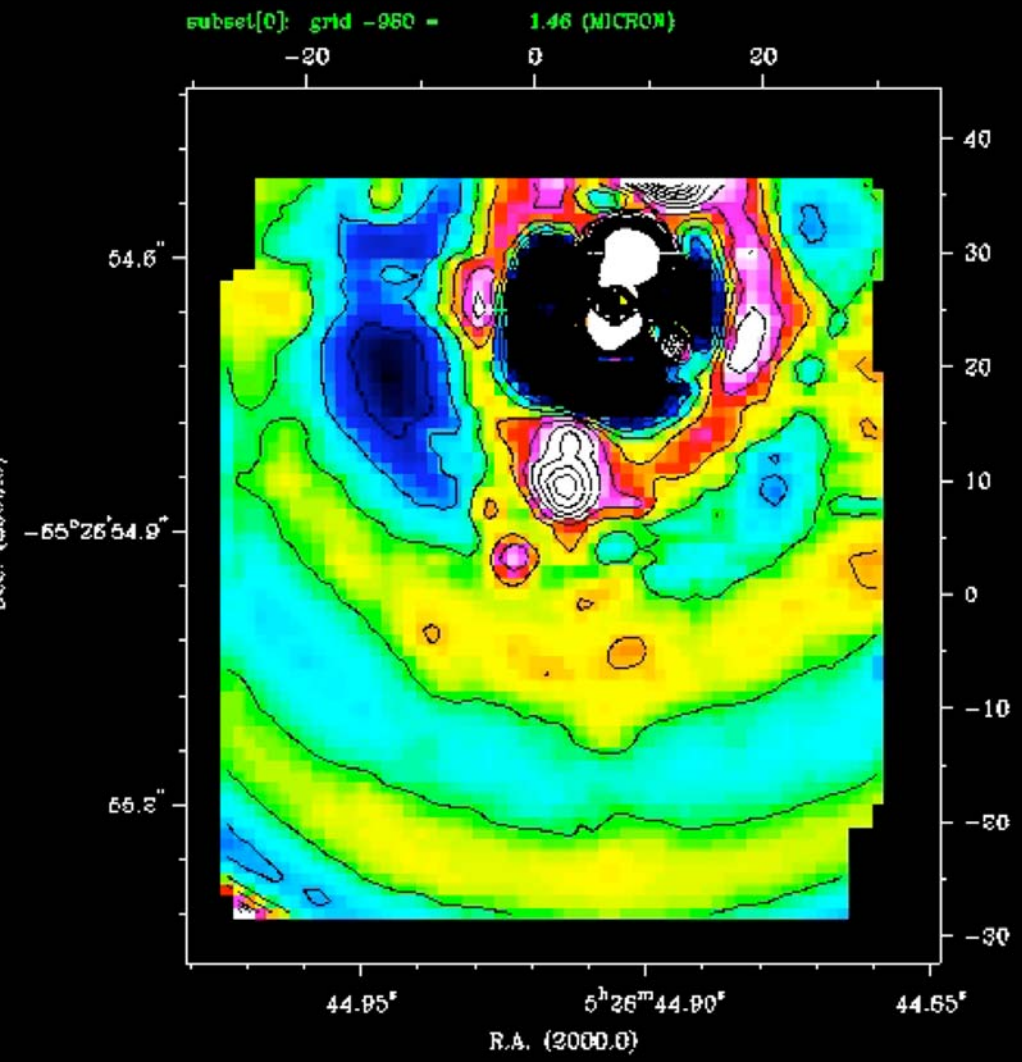


Spectral Deconvolution



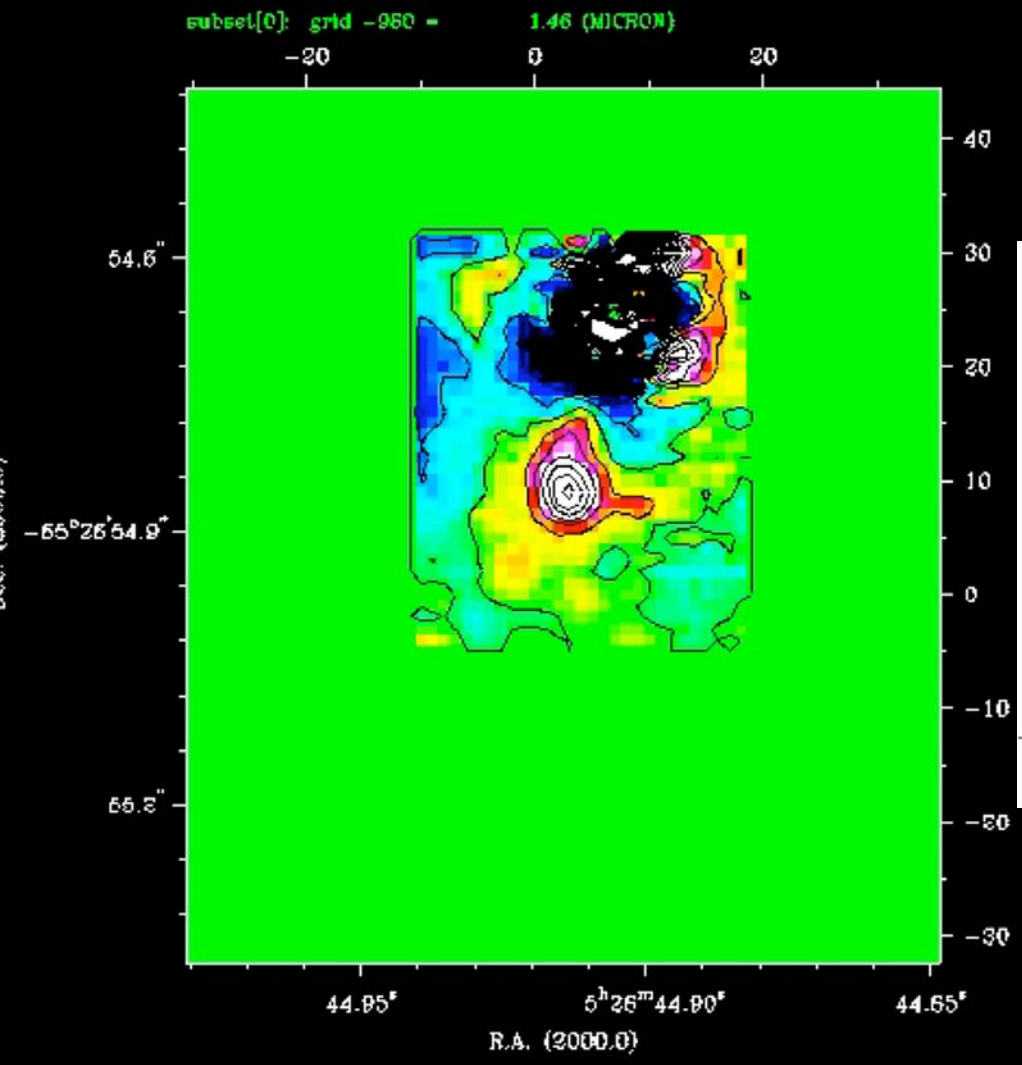
- Raw data cube
  - Diffraction & speckle pattern scales as function of wave-length
  - Pattern moves out from star with increasing wave-length
  - Exoplanet position is fixed
  - Hence distinguish speckles from exoplanets/companions (Sparks & Ford 2002)
- AB Doradus C
  - SINFONI/VLT
  - 25mas, H+K band
  - 20 min on-source
  - 3 AU separation
  - 15pc distance

Spectral Deconvolution

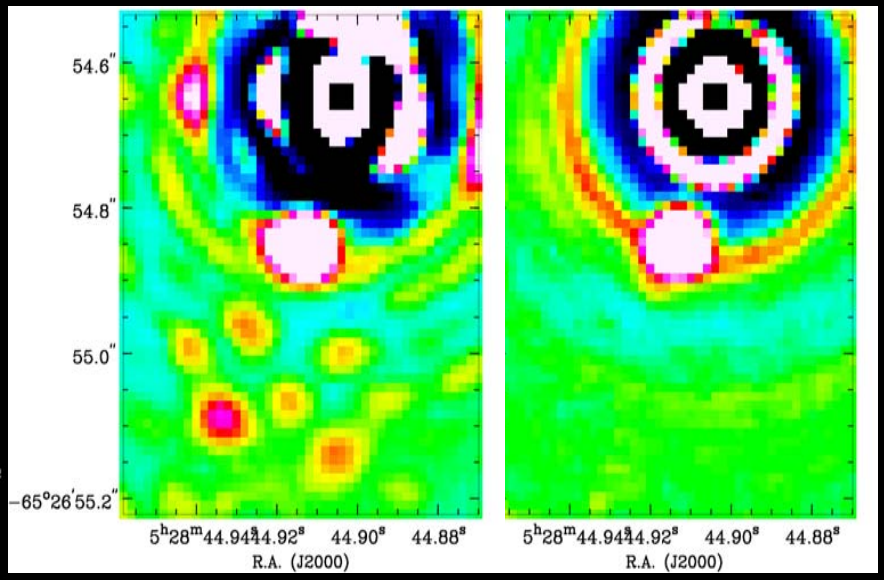


- Highlighting Speckles
  - Radial profile fitted & removed (azimuthally symmetric component).
  - Super-speckles move in RA & Dec as a function of wavelength
  - Wide wavelength range is advantageous to distinguish speckles and exoplanets

Spectral Deconvolution

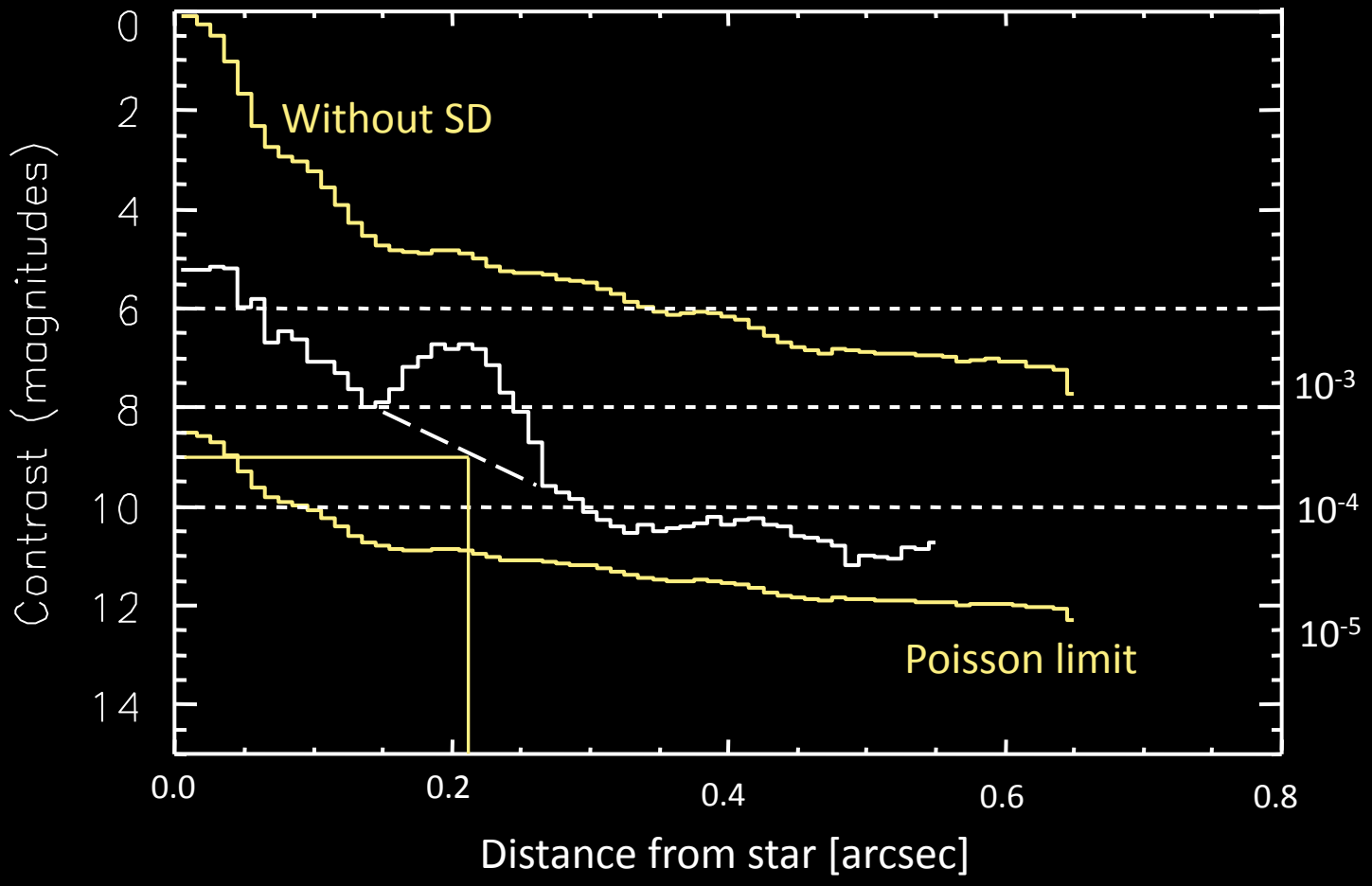


- Cleaned data cube
  - Full spectral deconvolution applied



- Single wavelength channels
  - Radial profile removed
  - Full SD applied

Spectral Deconvolution - Contrast



Thatte, Abuter, Tecza et al 2007, MNRAS, 378, 1229

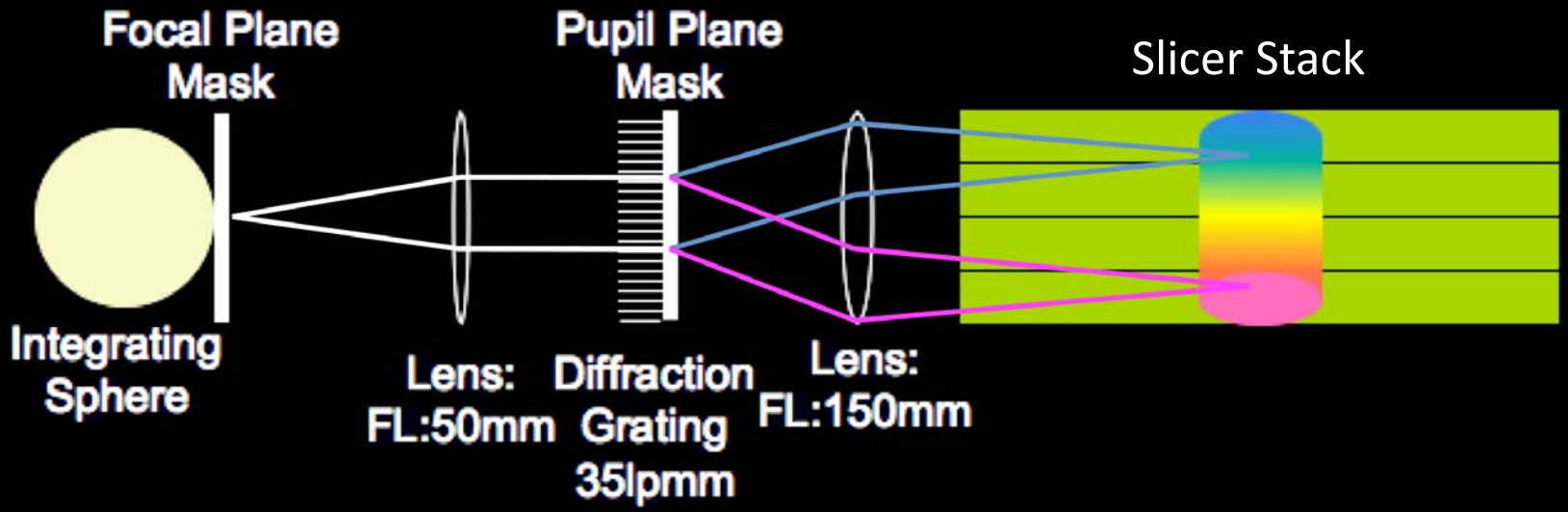
Spectral Deconvolution – Advantages

- Distinguish between exoplanets and speckles without prior assumption on exoplanet spectrum
- Detect and characterise exoplanets at the same time
- Planet finding instruments at 8m and future extremely large telescope have integral field spectrographs as major science instrument
  - GPI @ Gemini (PI Bruce Macintosh)
  - SPHERE @ VLT (PI Jean-Luc Beuzit)
  - EPICS @ E-ELT (PI M. Kasper, ESO)
  - HARMONI @ E-ELT (PI Thatte, IS Tecza, SE Clarke, Oxford)
    - Talk by Fraser Clarke, Thursday
- 2 main Integral Field Unit technologies
  - Slicer (SINFONI, NIFS)
    - Wide wavelength range
    - Efficient use of detector pixels
  - Lenslet based (GPI & SPHERE)
    - Many but short spectra

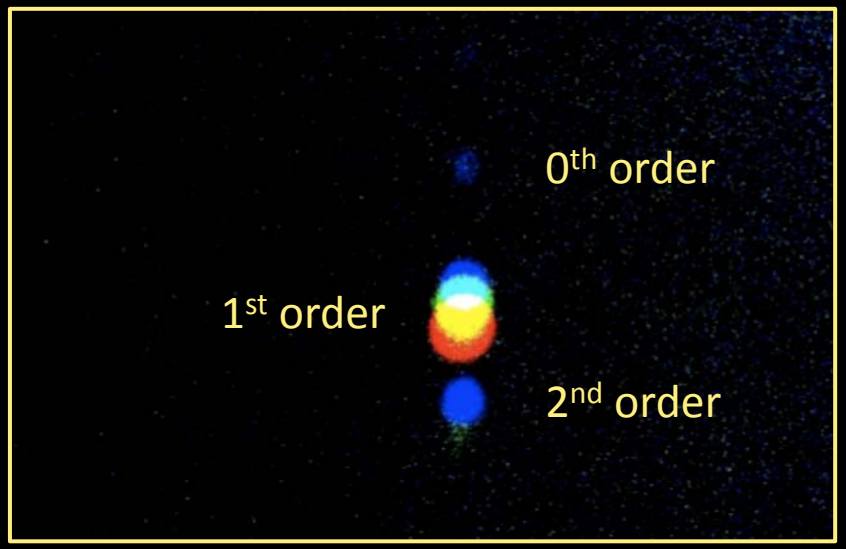
EPICS Phase A Study

- To be able to select best IFS concept the EPICS consortium investigated lenslet based (Padova) and slicer based (Oxford) integral field spectgrographs:
  - Simulations
    - Carry out detailed simulations of a slicer based IFS to determine how the speckle pattern is modified by adding NCP-WFE to the pupil plane
    - Develop and test improved SD algorithms
  - Experiment
    - Build a test bed to look in to the effect of the errors not addresses by the simulations
    - Non-pupil plane errors, scattered light, diffraction and manufacturing errors
    - Use SWIFT spare optics to build test bed slicer IFS with new, diffraction limited pre-optics

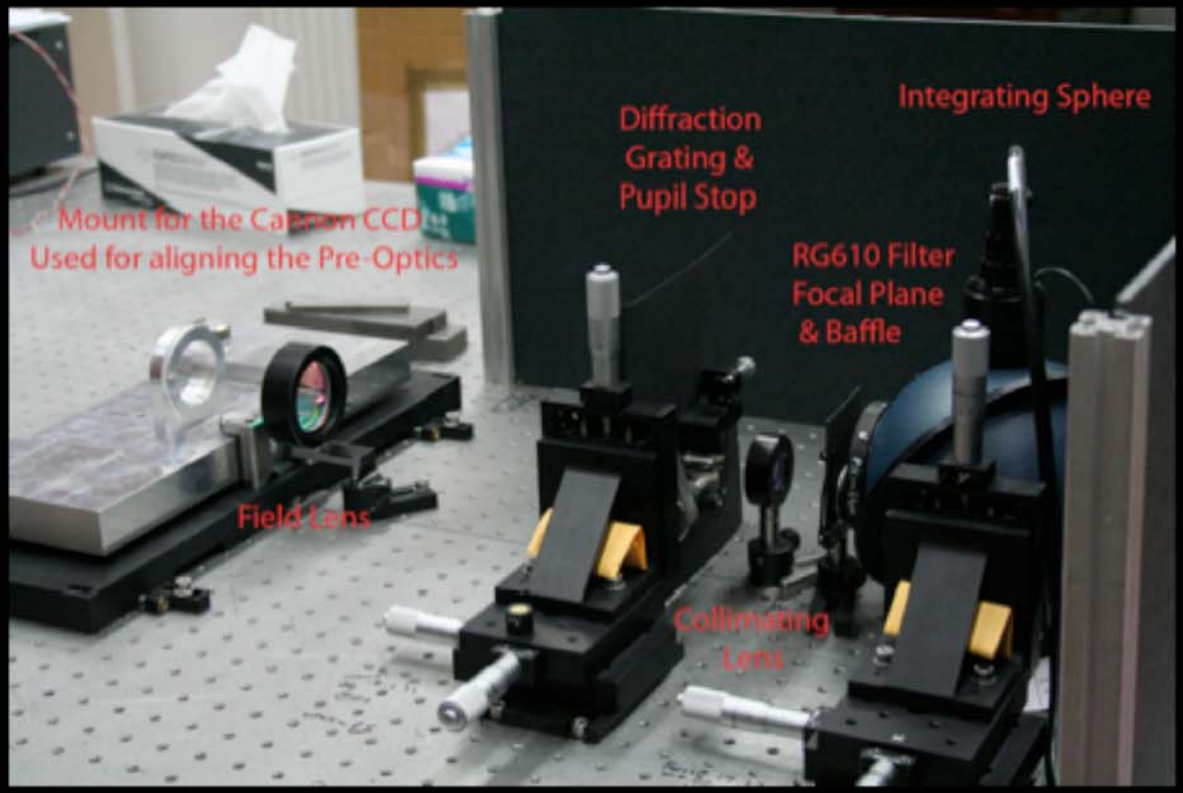
Test bed – Speckle Generation



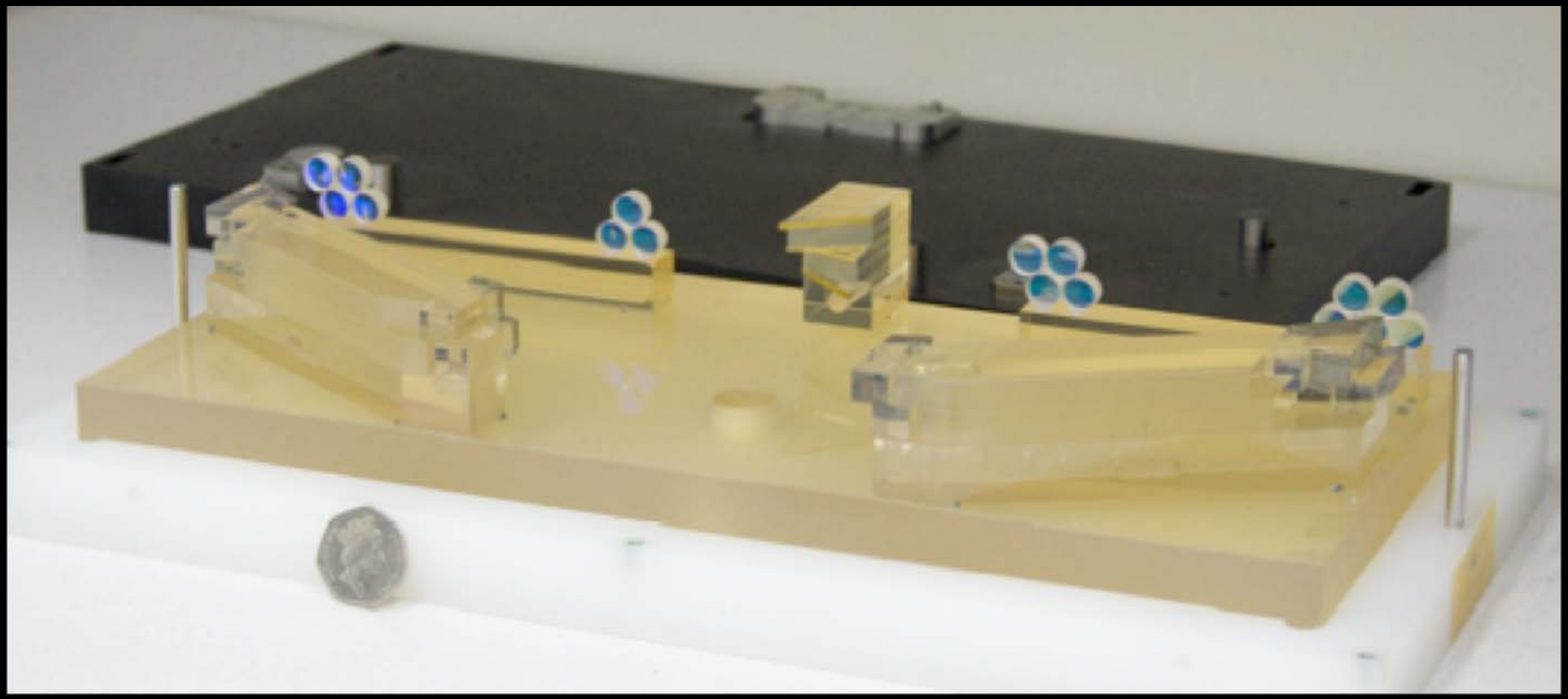
Test image with SLR



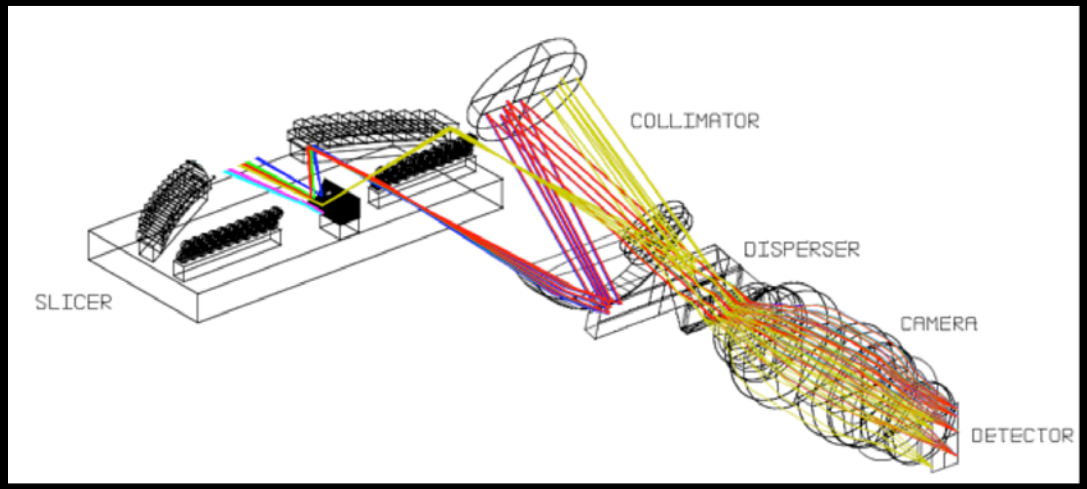
Test bed – Pre-optics

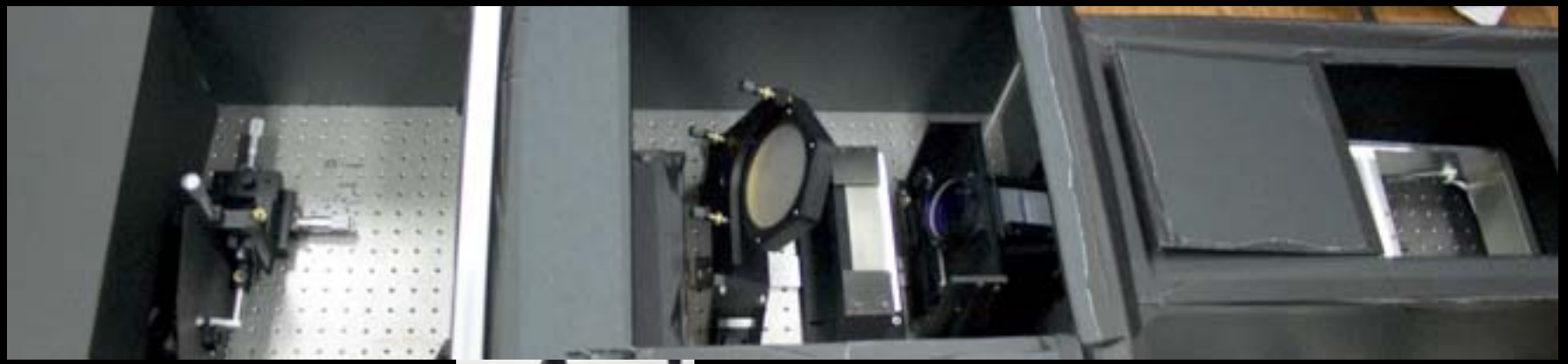


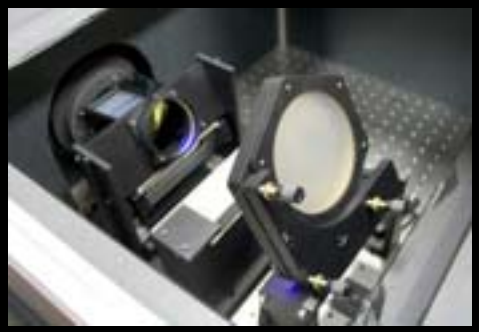
Test bed – Slicer

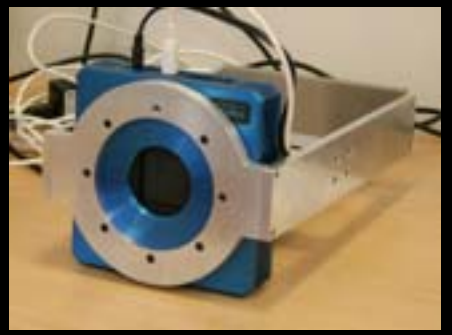


Test bed – Spectrograph

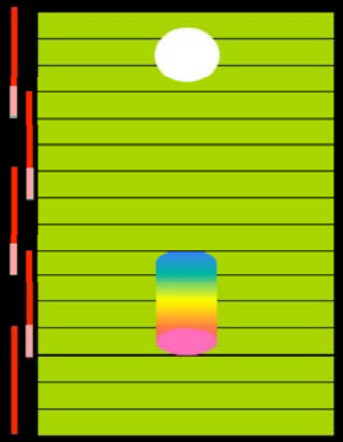


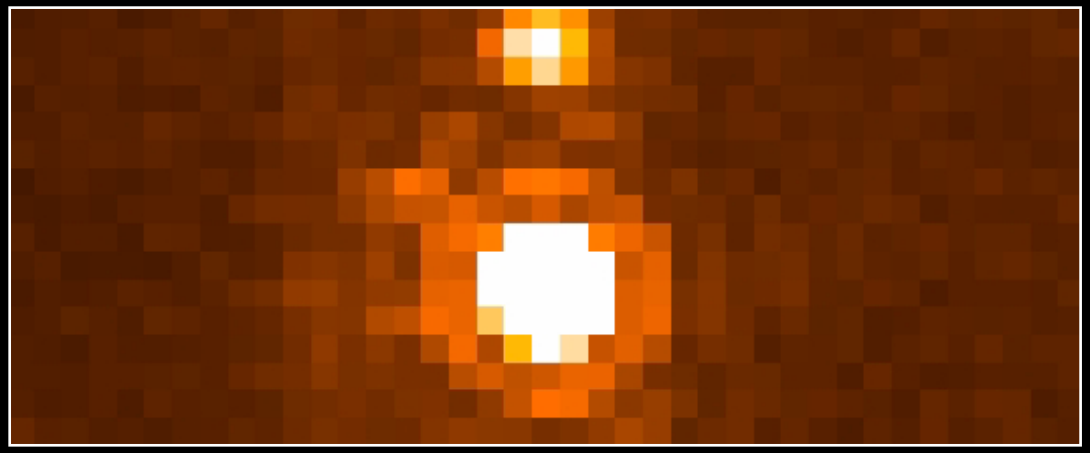


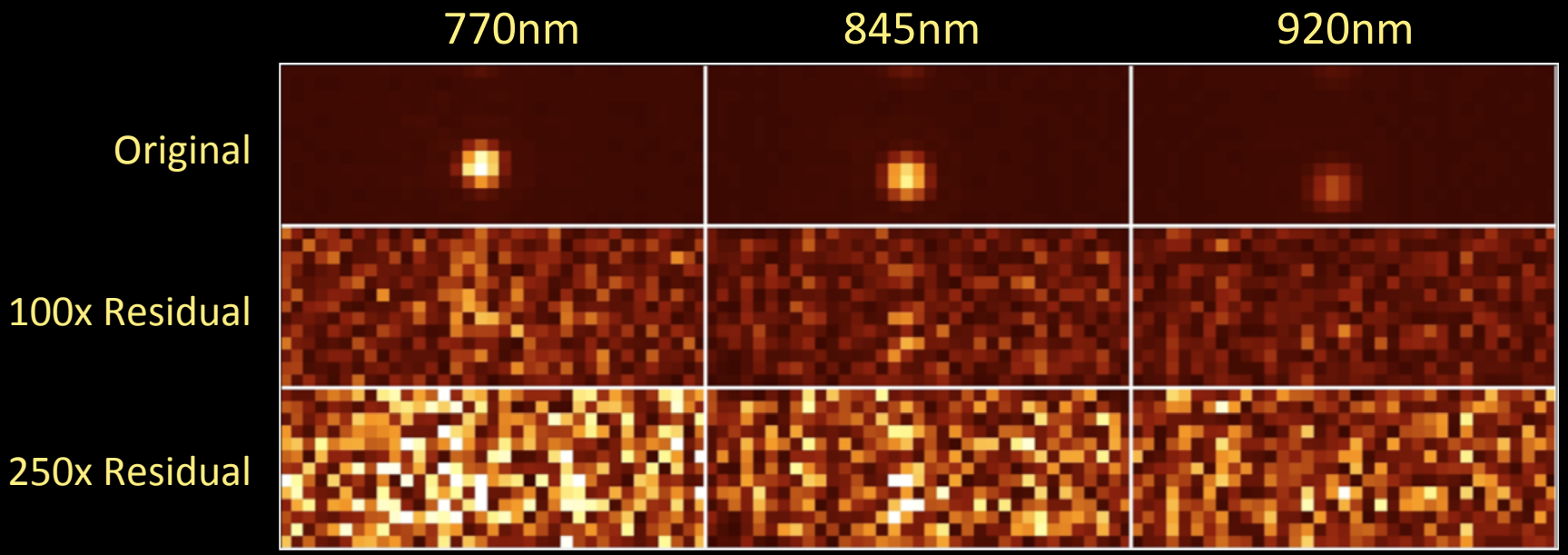




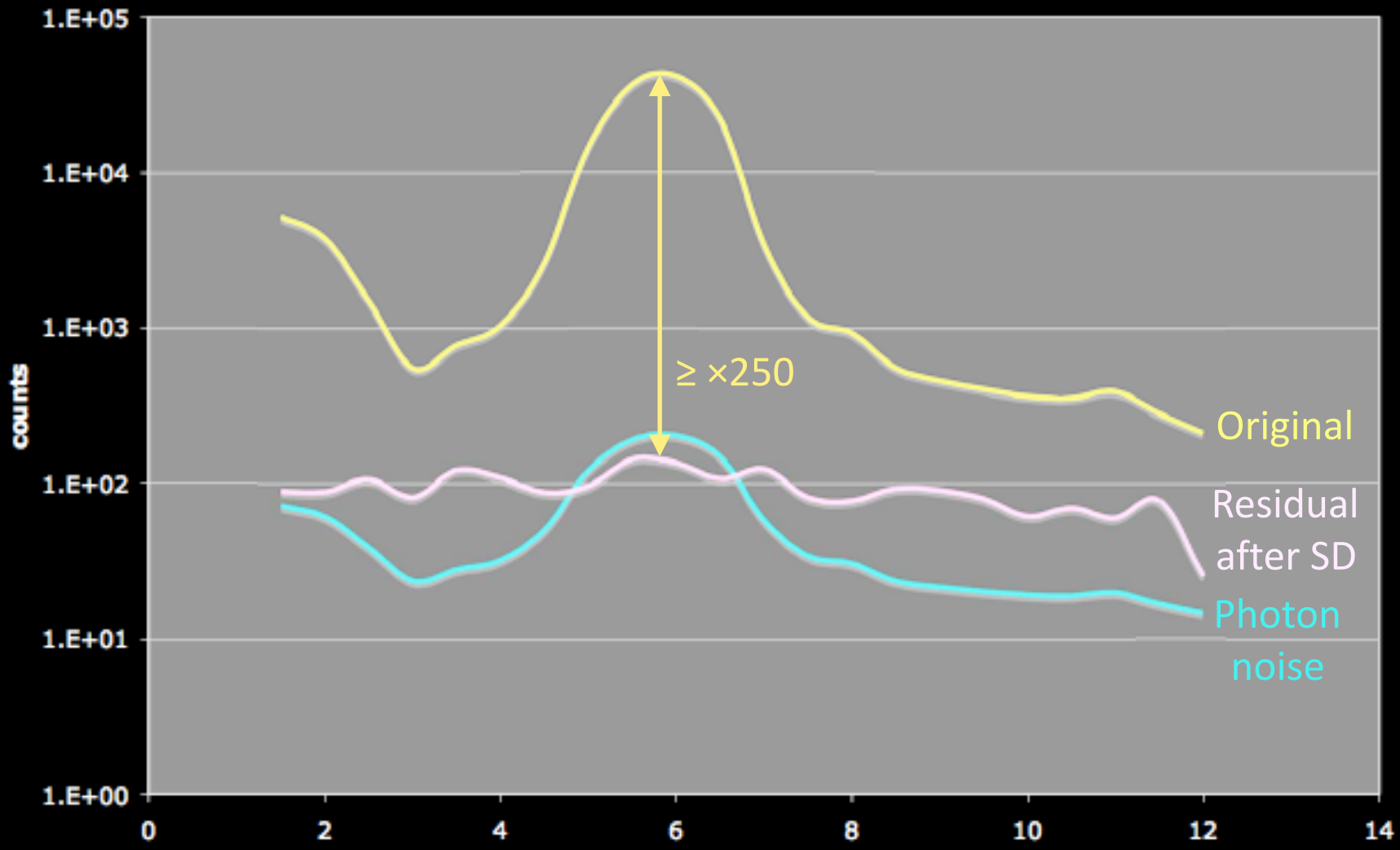
Test bed – Data & Results







Test bed – Rejection Factor



Conclusions

- Spectral deconvolution is powerful differential technique for high-contrast spectroscopy
  - Distinguish between exoplanets and speckles without prior assumption on exoplanet spectrum
  - Detect and characterise exoplanets at the same time
- Test bed
  - Achievable contrasts ≈250 are currently limited by the amount of light getting through the system
  - Modify the light source
  - So far, no significant limit in achievable contrast due to the use of a slicer is seen.
- Simulation
  - Only slices likely to be affected by secondary speckle noise are those containing the primary star, which can be suppressed by occulting disk