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Spectro-astrometry with the E-ELT
versus Differential Interferometry with the VLTI

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The position of the photocenter of a compact source can be measured with an accuracy much better than the telescope or interferometer diffraction limit. Spectro-astrometry (also called "color differential astrometry" or "differential interferometry" for interferometers) measures the variation of the source photocenter with λ:

$$\vec{\varepsilon}(\lambda) = \frac{\int \vec{r}\, o(\vec{r},\lambda)\, d\vec{r}}{\int o(\vec{r},\lambda)\, d\vec{r}}$$

The spectrum $s(\lambda) = \int o(\vec{r},\lambda)\, d\vec{r}$ is the zero-order moment of the brightness distribution $o(\vec{r},\lambda)$ and $\vec{\varepsilon}(\lambda)s(\lambda)$ yields its first-order moments. In interferometry, the photocenter displacement is directly deduced from the fringes phases. This technique provided many examples of the rich spatio-spectral information that can be extracted from the photocenter alone. The simplest application is when the source is dominated by a binary structure with components that cannot be separated from spectroscopy or interferometry alone. Then the spectrum contains the sum of the individual spectra, while the first order moment is proportional to their difference. The combination of the two measures yields the individual spectra and the angular separation. Measuring $\vec{\varepsilon}(\lambda)$ through a spectral line decisively constrains the kinematics of the source, as it has been illustrated in the study of circumstellar material.

The very preliminary analysis presented here shows that the application of this technique to some of the E-ELT spectrograph has a large scientific potential. We have considered both the « fundamental » noises, which show the potential to measure extremely small displacement, and tested calibration methods that take into account the limitations introduced by the instrumental (mainly the detector) instability.

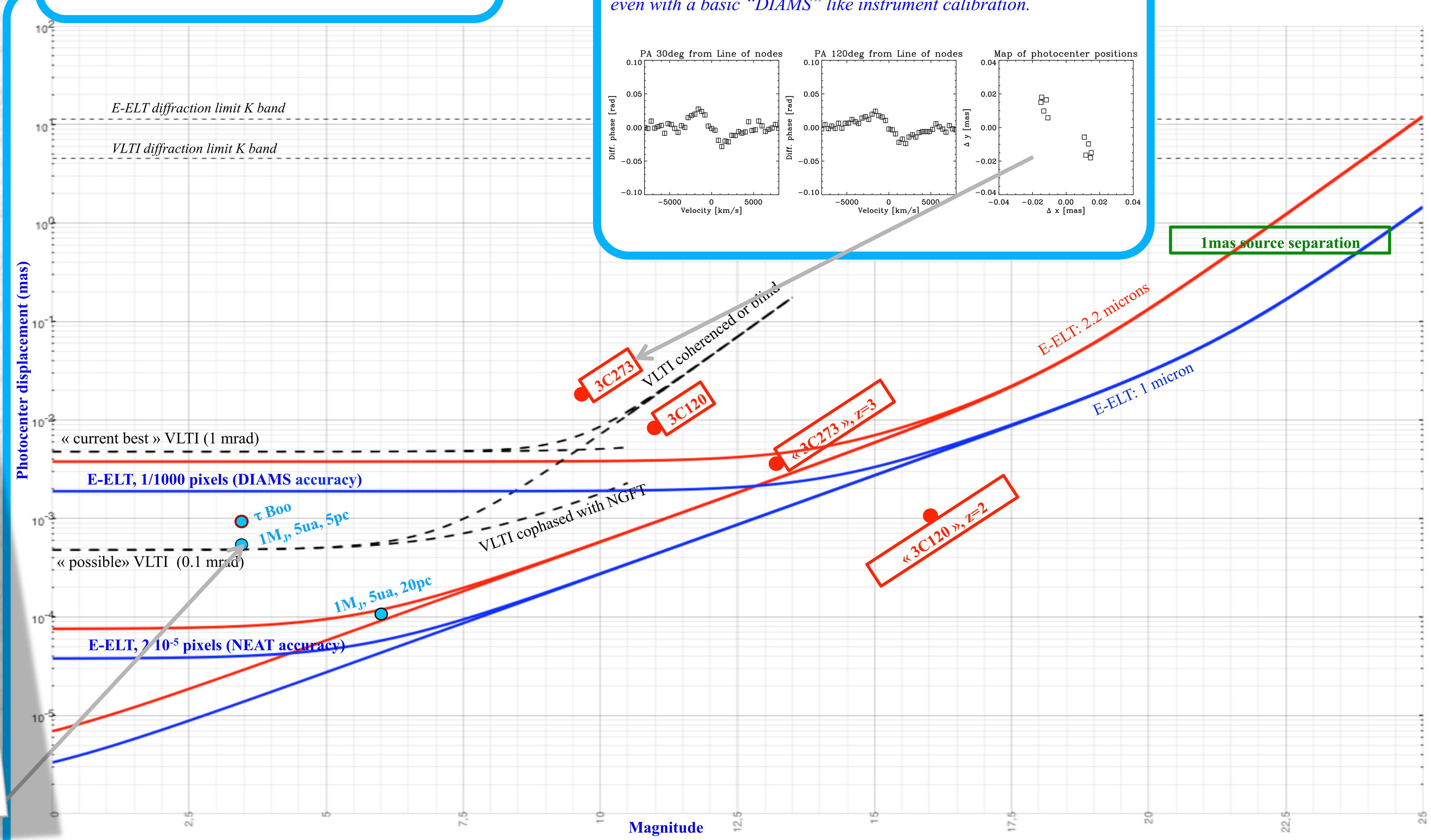
The specific need of spectro astrometry is that the telescope Airy disk is sampled at Shannon frequency. It seems often easy to add some modules with such an additional magnification in the two concepts proposed for multi-objects spectrographs.

Our provisional conclusion is that the possibility to have a spectro-astrometric mode in some E-ELT spectrographs is worth some additional investigation.

Spectro-astrometry of Quasars BLR

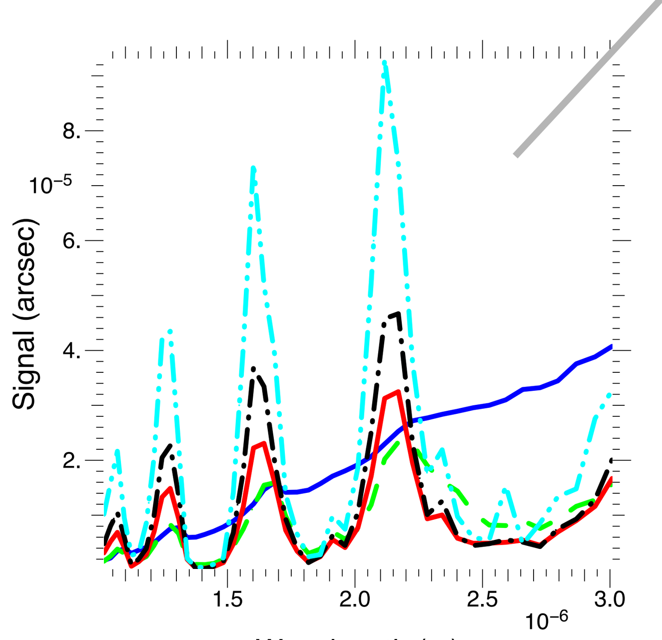
Expected photocenter variation through the Pa_α emission line of the quasar 3C273, assuming that the BLR is dominated by a flat keplerian disk. Spectro-astrometry with the E-ELT would allow caracterizing the central SMBH in a very large sample of quasars, even with a basic "DIAMS" like instrument calibration.

Spectro-astrometry potential



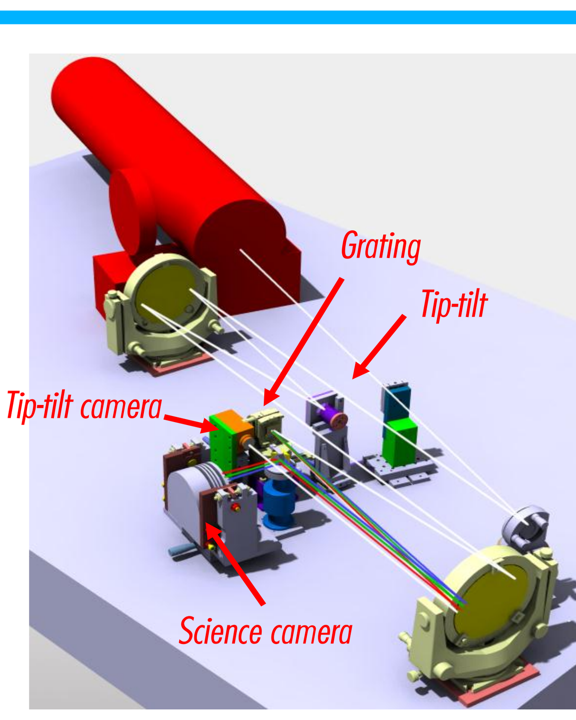
Expected photocenter accuracy as a function of magnitude, per spectral channel with a resolution 5000. The analysis considered the source photon noise, the thermal background noise and the detector noise. It also included an hypothesis on the quality of the instrumental calibration based on the two test benches described below. We assumed a global Strehl ratio of 0.3. The other experimental parameters are copied from our VLTI experiment (AMBER) and might be pessimistic for a single aperture instrument. The "current" VLTI values indicated in the figure have been actually achieved. The plot shows that spectro-astrometry with the E-ELT can achieve indeed very high angular resolution measurements: it will have a higher resolution than the VLTI, for the photocenter displacement, without the severe magnitude limitation resulting from the need to cophase or coherence an interferometer.

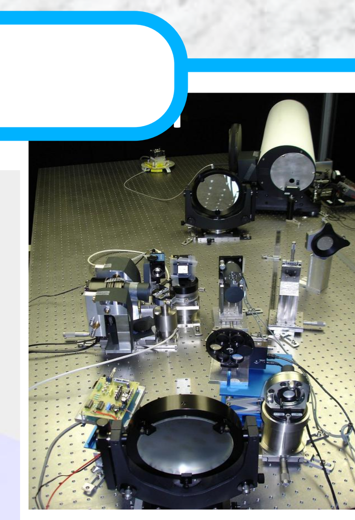
Spectro-astrometry of extrasolar planets



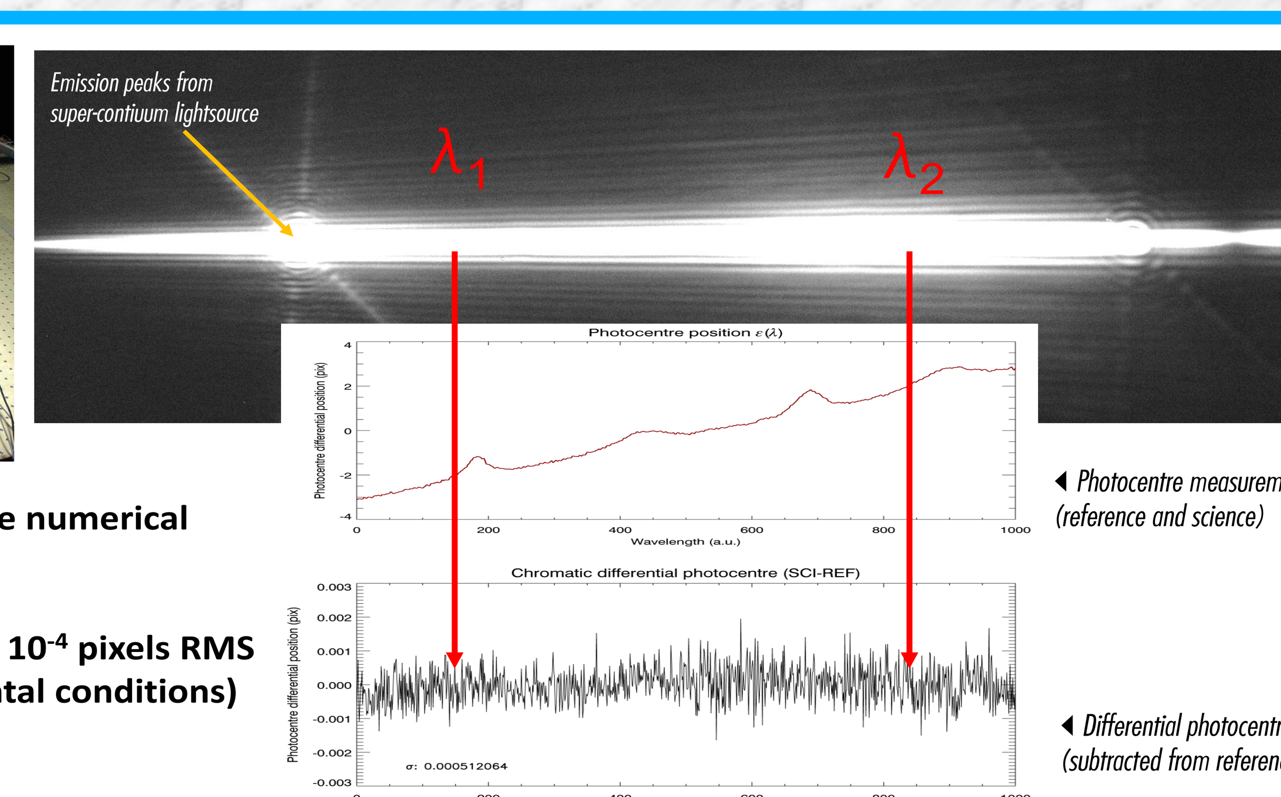
Photocenter displacement expected from a Jupiter mass planet orbiting at various distances of a star at 10 pc (from 0.05 au – solid-blue- to 1 au –dash-dot-dot-cyan-). Achieving an instrumental calibration down to the NEAT study performance would allow measuring high resolution spectra of a large variety of Jupiters.

"DIAMS" testbed



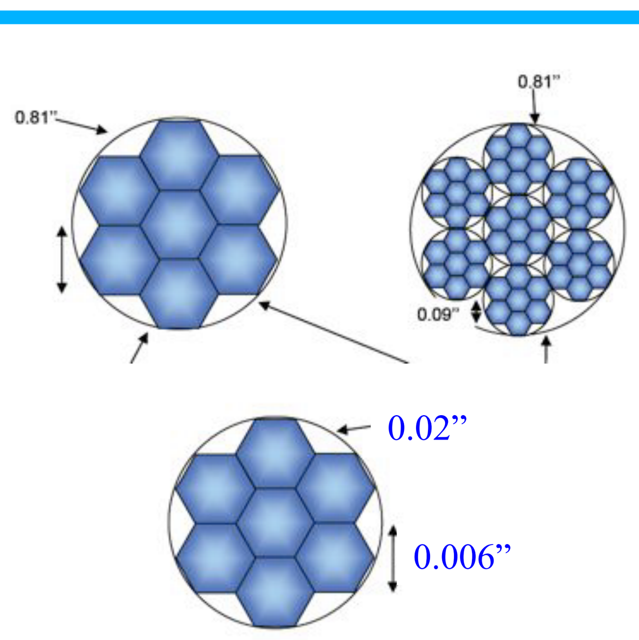


- Goal: validate the numerical model of CDA.
- Current status: 5 10^{-4} pixels RMS (ideal experimental conditions)



We have developped a laboratory test (DIAMS) to test the accuracy of the differential photocenter position when it is not possible to introduce any additional calibration system (The study was made for spectro-astrometry (or color differential astrometry) with the SPICA space telescope. It shows that it is enough to maintain the global photocenter of the spectrum on the same pixels, with the tip-tilt corrector, to obtain an accuracy on the spectral variation of the photocenter of 0.5 10^{-3} pixels. (Abe et al., SPIE 8442)

Implementation requirements

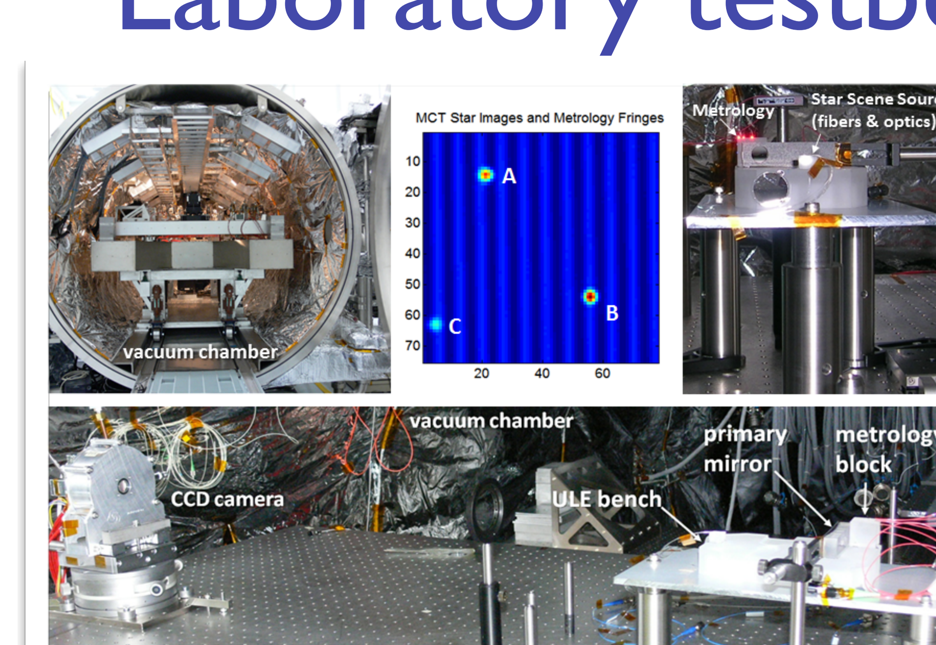


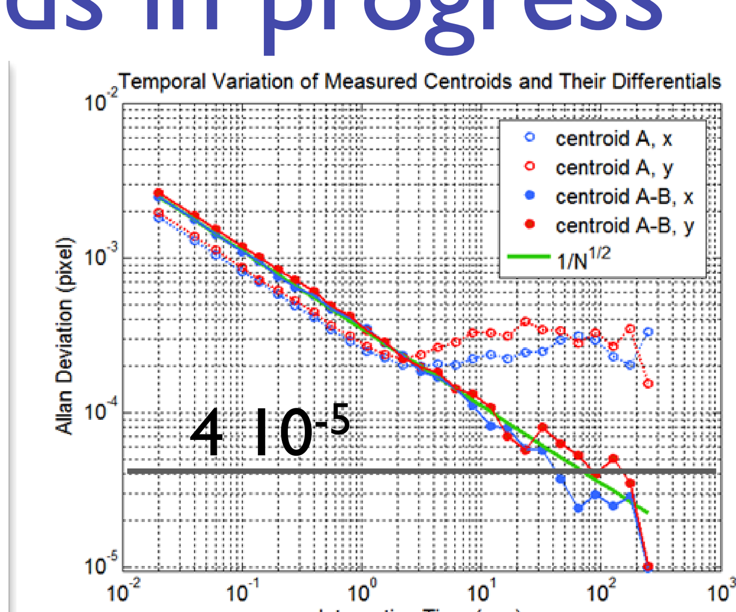
The sufficient condition for optimal spectro-astrometry is that the Airy size λ/D is sampled at Shannon. A multi-object spectrograph could have a set of "fiber launchers" fulfilling this condition. The subsequent spectrograph would be unchanged. Some of the fibers could be used to inject a calibration interferogram.

"NEAT" testbed

In the context of the space astrometry proposal NEAT, a method merging the signal and a reference interferogram is developed. The current achievement is 4 10^{-5} pixels accuracy on the difference of position between two quite far away parts of the detector. Further progress is expected, but this accuracy would already allow spectro-astrometry with the ELT to study a fair sample of Jupiter mass extrasolar planets, at virtually any distance from the central source. Under certain conditions, the method developed for NEAT could be simplified and applied to spectro-astrometry. (figure is courtesy of F. Malbet, from the NEAT study)

Laboratory testbeds in progress





JPL testbed
Nemati et al. (2011, SPIE 8151, E28)
Nemati et al. (2012, SPIE 8442, in press)