The ASTRA-extension of the Keck Interferometer

What Dual-field interferometry will do for You!

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The Keck Interferometer

The Keck Interferometer (KI) combines the two 10m Keck telescopes with a baseline separation of 85m, and is one of the two large aperture optical long baseline interferometric (OLBI) facilities in the world. The KI is funded by the National Aeronautics and Space Administration (NASA). The 10m telescope diameters provide a unique sensitivity advantage and has lead to several 'first OLBI' science such as visibility measurements of an AGN[1]. The visibility (V^2) and Nuller modes, are in operation and offered to the Keck community. Now a new major development effort is underway to broaden the astrophysical applications of this unique instrument.

The ASTRA upgrade concept

ASTRA stands for the ASTrometric and phase-Referenced Astronomy upgrade of the KI project. ASTRA has been funded by the NSF-Major Research Instrumentation program and will be implemented in three steps over the next 3 years. Besides the NSF engagement a number of science institutes contributes to the ASTRA collaboration to advance and profit from large-aperture OLBI.

Both of the primary measurables of a two-element interferometer, the *visibility* of a star and the *angular distance* between two stars, suffer from the phase distortions produced by turbulence in the earth's atmosphere.

As indicated in the figure below ASTRA will overcome the current sensitivity limits of the KI by *continuously correcting for those phase distortions*. A bright star is monitored by a fringe tracker similar to natural guide star adaptive optics. Then *a fainter, second star in the same isoplanatic patch of the atmosphere* (~1' diam. at 2µm) *can be observed while integrating beyond the atmospheric coherence time limits*. Further, if *the difference Δ in optical path* between the occurrence of both fringe packets is precisely monitored, it *can be transformed into the angular distance between both stars*[2]. A second laser guide star is currently being implemented on the Keck I telescope which will enable LGS-AO corrections on both telescopes, leading to further sensitivity improvements for the Keck Interferometer.

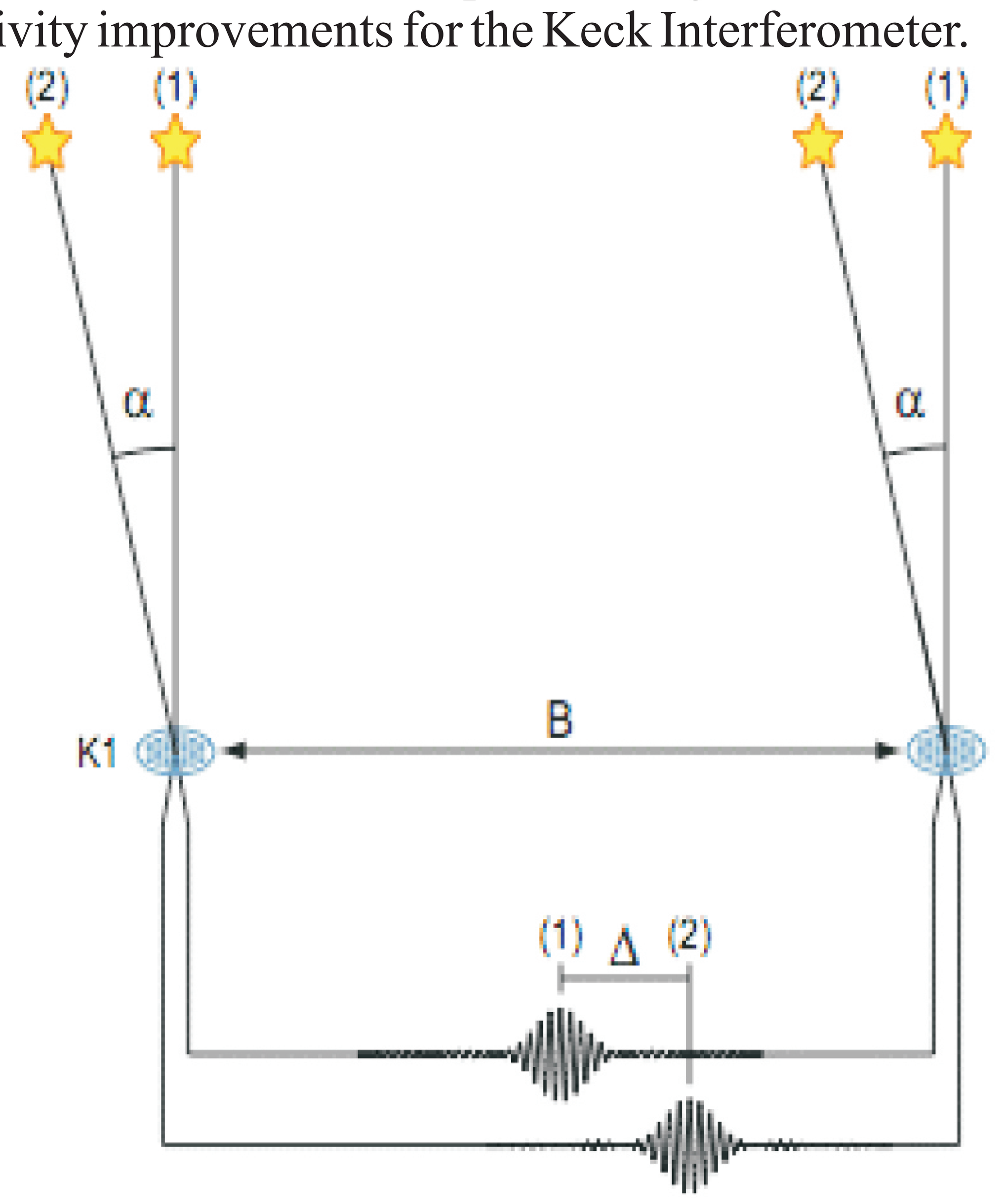

Fig.1: (1): Existing V^2-mode single-field KI-OLBI, the fringe contrast scales with the source extension after equalizing the optical path
(2): ASTRA extensions: The atmosphere can be stabilized by fringe tracking on the on-axis star, enabling Phase-Referenced visibility measurements of fainter stars; in the Astrometric Mode the difference in fringe location Δ relates to the angle between both stars at up to 30 µas precision.

1. Self-referenced spectroscopy

In the first phase of ASTRA, two fringe detecting cameras will be utilized. The instantaneous fringe detection on the first fringe camera will be used to stabilize the atmosphere and enable longer integration times on the same target with the second camera. By doing so, fringes can be dispersed to a spectral resolution of a few thousand $\lambda/\Delta\lambda$ at 2 µm. This is sufficient to e.g. *distinguish emission lines like Brγ, CO, and H_2O and locate them around young stellar objects and their disks* (Fig.2).

Eventually the brightest AGNs and their host galaxies will be observable, revealing *unique spatial information about the compactness of nuclear emission line regions and infalling gas* (Fig.3).

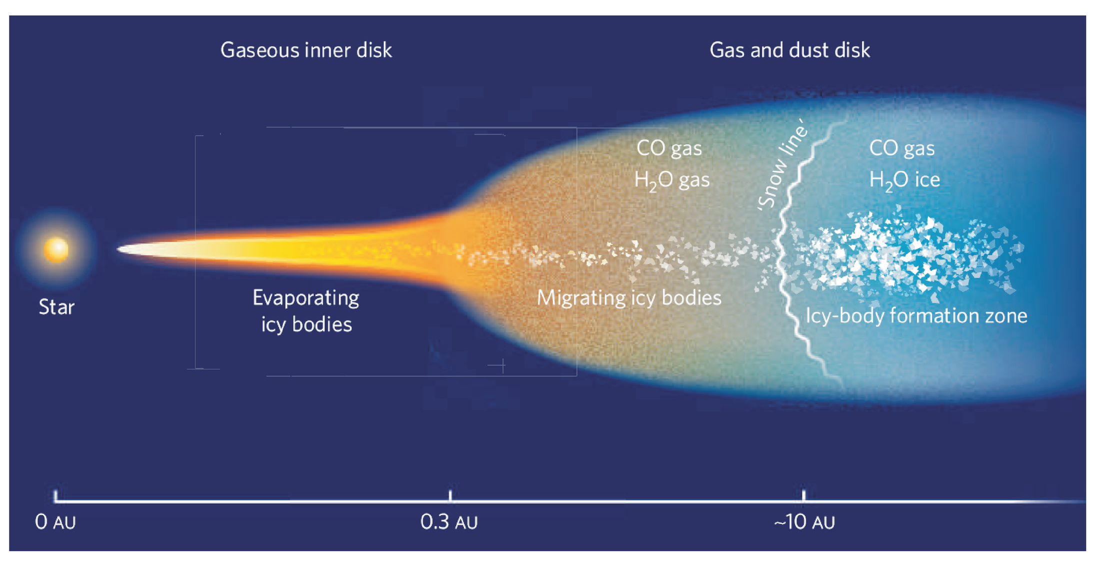

Fig.2: Current informative disc model of a YSO[3] showing the different zones (not to scale). Since 1AU equals ~15mas in the nearest starforming regions, only infrared OLBI can spatially resolve emission lines originating in stellar winds or discs, and determine outflow properties depending on the actual line-of-sight in planet-forming systems. Eisner et al. have found imprints of water in the inner disc around MWC 480, using the KI in dispersed V^2-mode[8].

2. Dual-field visibilities

The primary goal of this second step is to improve the current limiting magnitude of the V^2-measurements, K~10.3, by using a guide star slightly brighter than this limit to provide the phase reference *for K<15 science objects*. To do so a so-called star separator picks up both stars in the image plane, separates them, and sends them along different internal delay lines.

After achievement a number of targets can be investigated at the 5mas NIR resolution of the KI which are currently too faint to be observed with an interferometer.

The science will range *from spectroscopic observations over resolving the binary population in distant star forming regions to overcoming the source confusion in the Galactic center (GC) and investigating dim quasars* at significant redshifts up to $z \sim 1$.

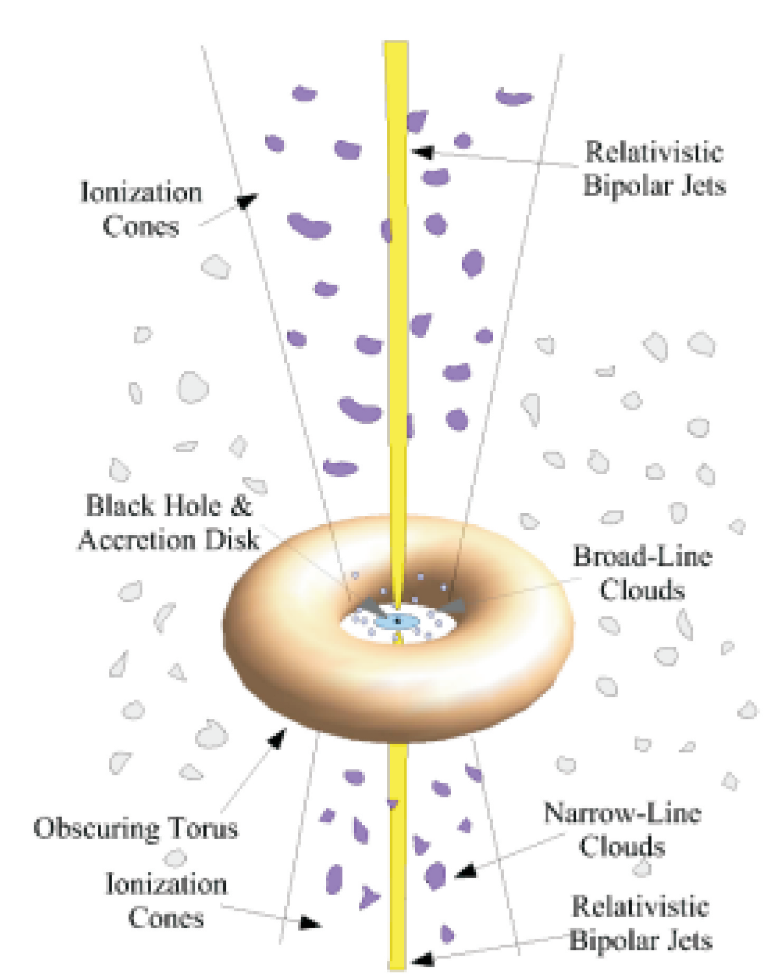

Fig.3: Sketch of the central few hundred parsecs of an AGN following the unified torus model. While NIR continuum OLBI can probe geometry and structure of the torus, the emission line regions and infalling gas feeding the central engine can be probed with spectrally dispersed fringe measurements.

Star formation at the GC turns out to be a special case due to the enormous tidal forces exerted by the massive central black hole[4]. The actual fraction of binary systems and their putative disruption at a close black hole encounter might play a key role in understanding the phenomenon of hypervelocity stars in the galaxy[5].

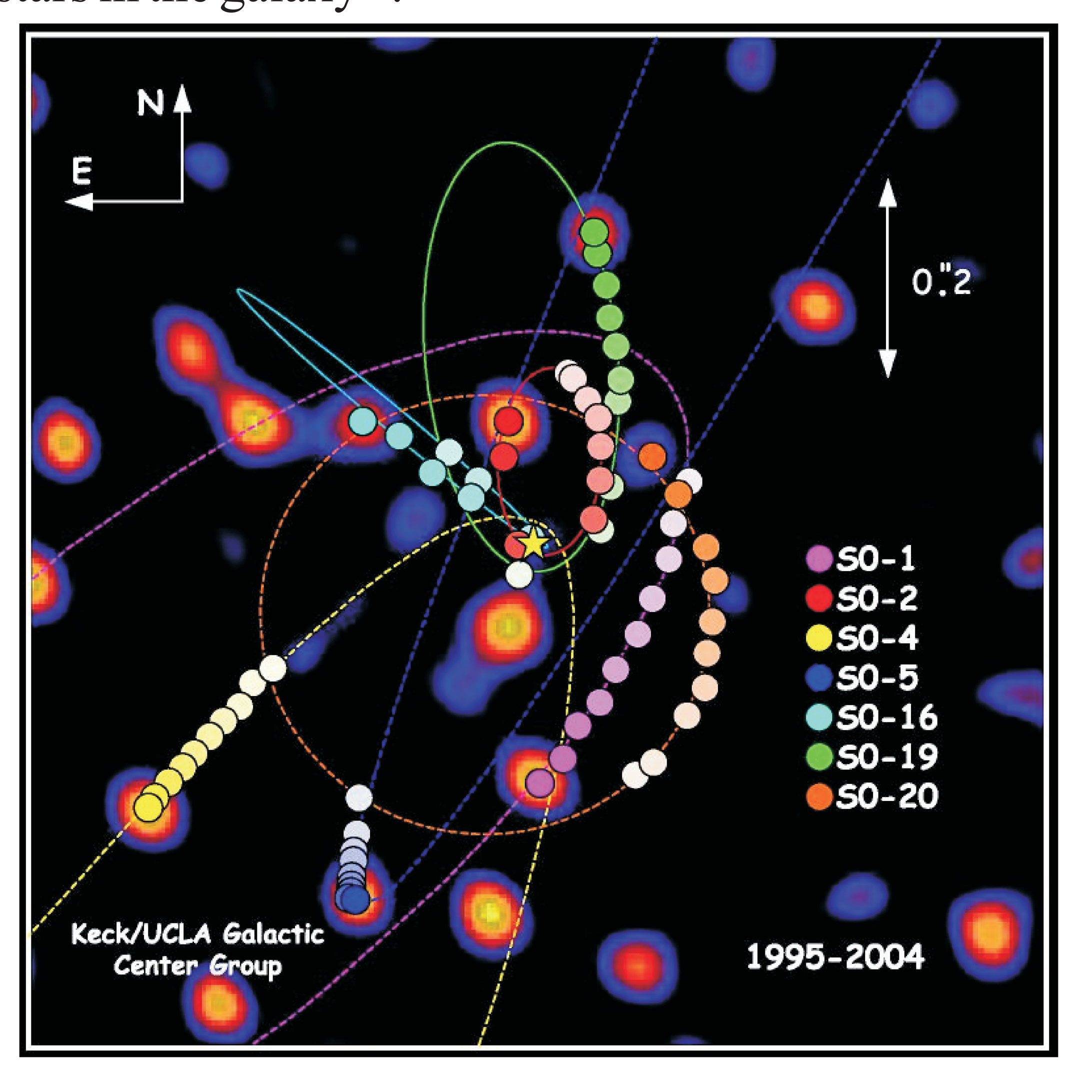

Fig.4: Stellar orbits around the massive black hole of the Galactic center based on single telescope astrometry. ASTRA will help improving this astrometry by reducing the source confusion and eventually being able to track stars at higher velocities closer to the black hole[6,7].

3. µas Astrometry

The stellar orbits of the stars closest to the Galactic center of gravity have been shown to be the most stringent proof of the existence of a massive black hole and have been used to derive precise GC distance estimates (Fig.4). An accuracy improvement on the obtained numbers require the KI angular resolution to deal with the source confusion at the extremly dense central stellar cluster. Astrometric KI observations, based on a new precise internal laser metrology, will help to *improve the astrometry relative to the bright super giant IRS 7*.

Another key science case of the astrometry mode of the KI-ASTRA upgrade is the astrometric monitoring of stars known to host exo-planets as estimated from radial velocity measurements. The proper motion of those star on the plane of the sky gives the second dimension needed to *precisely estimate the planetary masses* in those systems without orbit inclination ambiguities. The mass is a primary ingredient to actual models of planet formation.

Summary

The recently funded ASTRA upgrade of the Keck Interferometer will enable unprecedented contributions to several fields of astrophysical research ranging from planet formation to the unique properties of the central parsec of the Milky Way to extragalactic active nuclei. The realization will incorporate challenging technical applications of OLBI extending the limits of ground-based astronomy.

References

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