New results from the Keck interferometer
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Recent observations of several AGN demonstrate extended capabilities

"Physics of galactic nuclei"

Scientific workshop at Ringberg Castle

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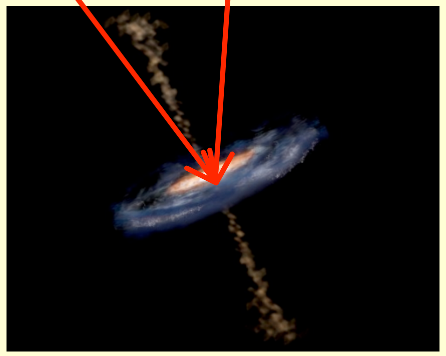
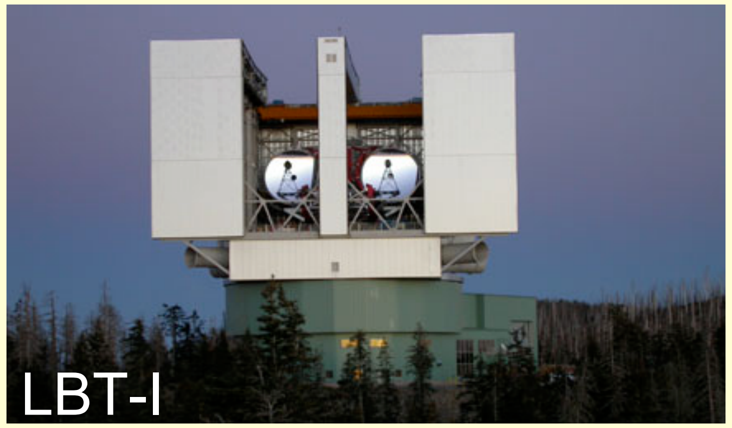
Outline of this presentation

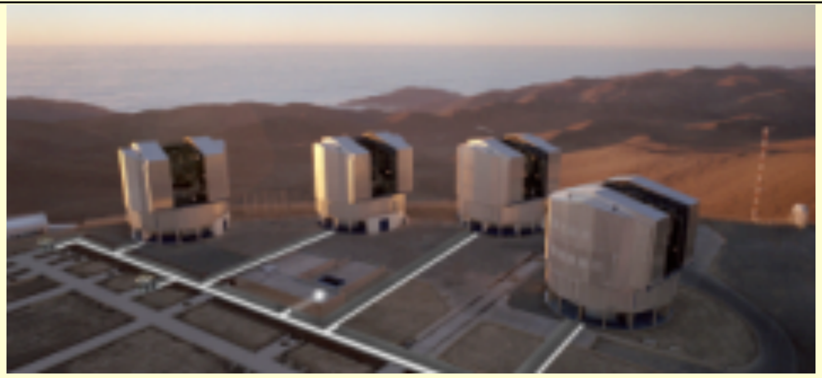
- *Starter*: Why is currently the Keck interferometer the best IF-tool to study AGN at 2μ?
- *Salad*: What do you measure with one baseline? (follow-up on Torun07…)
- *Entree*: Resolve the K-band emission from the nearest AGN: from tori to jets
- *Dessert*: The newest observations from May'09: AGN from *z=0.003 -> 0.16*
- *Coffee*: LBT-I: the new tool for high resolution AGN observations

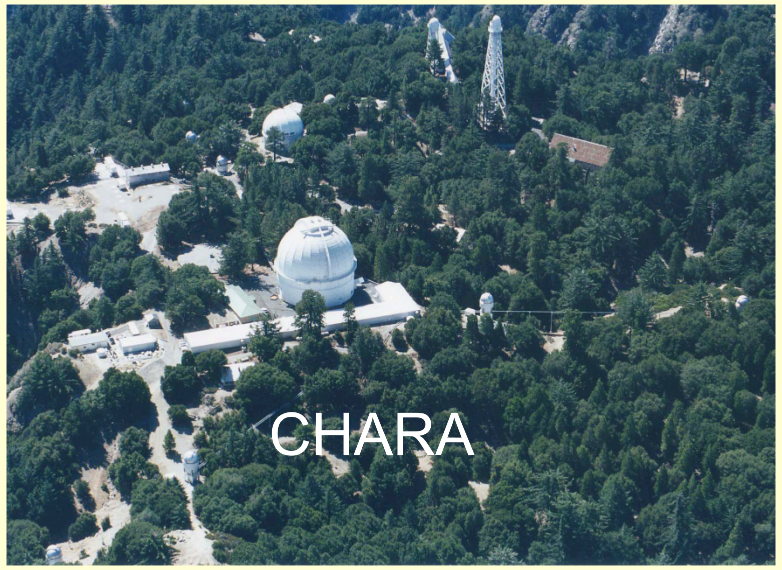




Why optical IF with Large Apertures?

– Small apertures (e.g. VLTI-AT, ISI & CHARA on Mount Wilson) have technological advantages





- Same angular resolution, smaller phase-variance, no AO-requirement, less vibrations -> easier, but …
- Same atmospheric coherence time -> less sensitive!
- Limited to nearby and very bright stars
- IR-sources are thermal sources -> smaller = fainter

- Keck-Interferometer
  (access: UC/Caltech/NASA/NOAO)

- The numbers:
  - H/K ~ 10mag (100 / 70 mJy) @ 3% precision in K
  - R~30: quasi continuum
  - 85 m baseline -> λ / B = 5 mas resolution
  - PA = 38 degr East of North
  - Latitude: 20 degr North

- This is 3 mag (15x) deeper than current VLTI-UT in a comparable mode
- K~10 mag allows for exciting new science cases, new to NIR-interferometry, including the observations of several AGN.

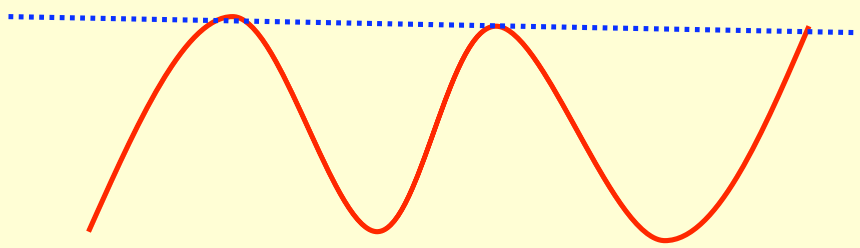
Recent improvements to enable the AGN-grade K-band performance

- AO wavefront sensor & controller upgrade increases sensitivity (+1.5mag) and Strehl (+10%)
  → NIR-bright AGN are often dusty, and faint in the visible
- Replacement of opto-mechanical elements
  → higher throughput
- Shifting the default angle-tracking from *J* to *H*
  - better Strehl in the lab
  - slower atmosphere
  - now sensitive down to *H* ~ 10.5 mag
  - slower detector rates for good weather (seeing better than 0.6”-0.8”)
- Current performance K ≥ 10mag (70 mJy) @ 3% precision in K
  → ~10 AGN are observable

One baselines measures a few spatial properties, such as:

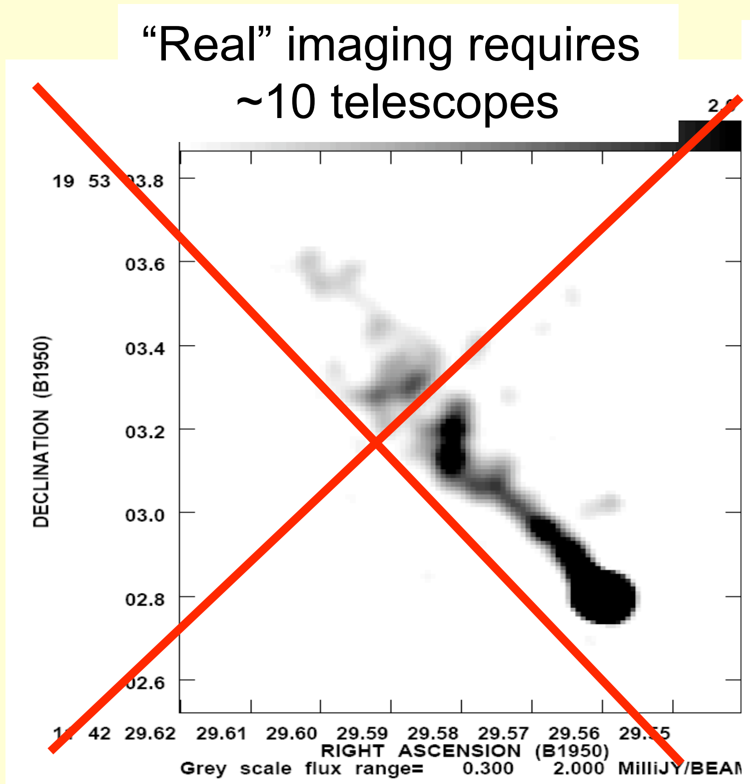
- Binary properties (separation, brightness ratio, PA)
- 1-component models: diameter or disks, Gaussians, etc.
- 2-component models: pointsource + disk, disk plus jet, several point sources etc
- flux contribution from the compact source

Example: extended, but no binary



Rule of thumb for few baseline IF:
Do NOT ask too many questions at the same time!

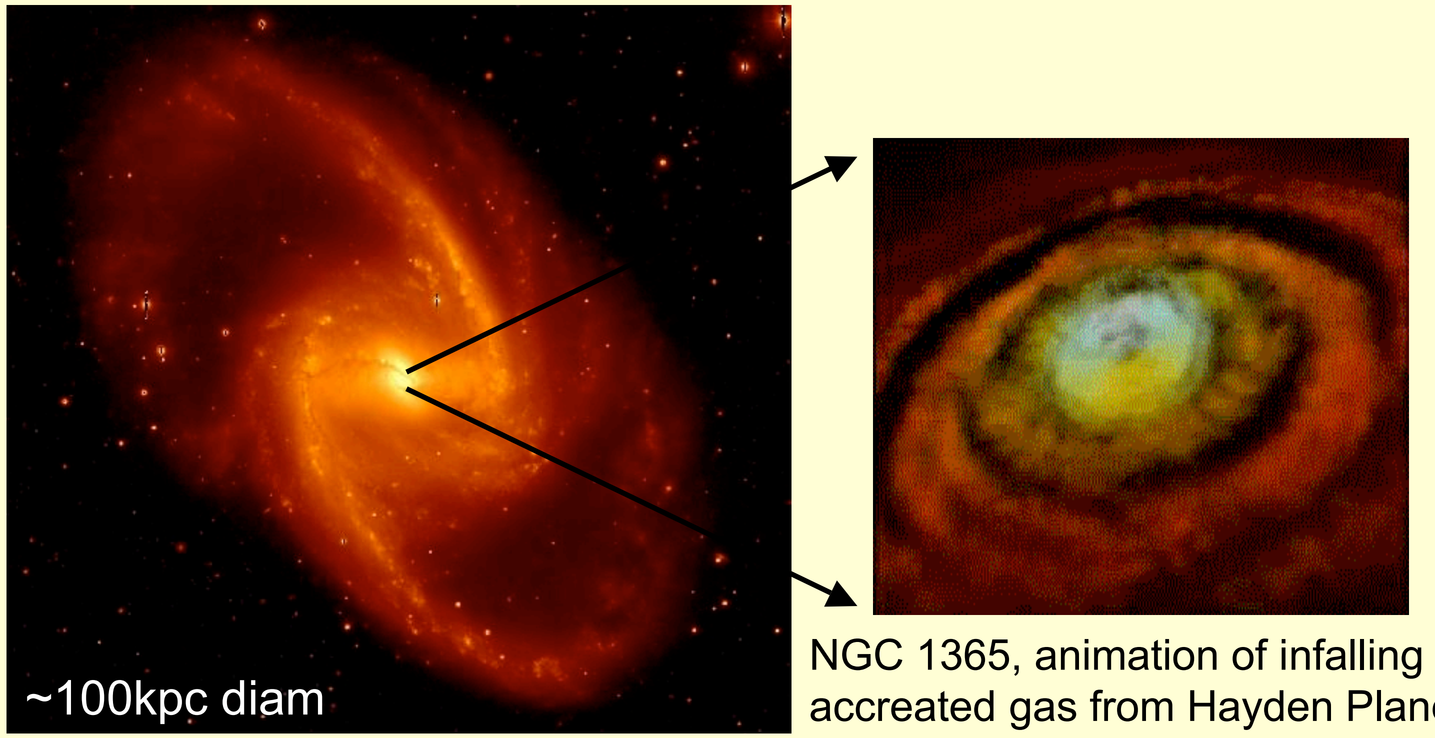
- One baseline IF can estimate order of magnitude size constraints, in particular for given models
- The compact contribution can be distinguished against circumnuclear emission
- Spectro-interferometry can compare line emission / absorption regions agains the surrounding continuum
- The situation is similar to high resolution spectroscopy:
  complementary data taken at different wavelengths and resolutions typically GREATLY improve the ways to interpret the data



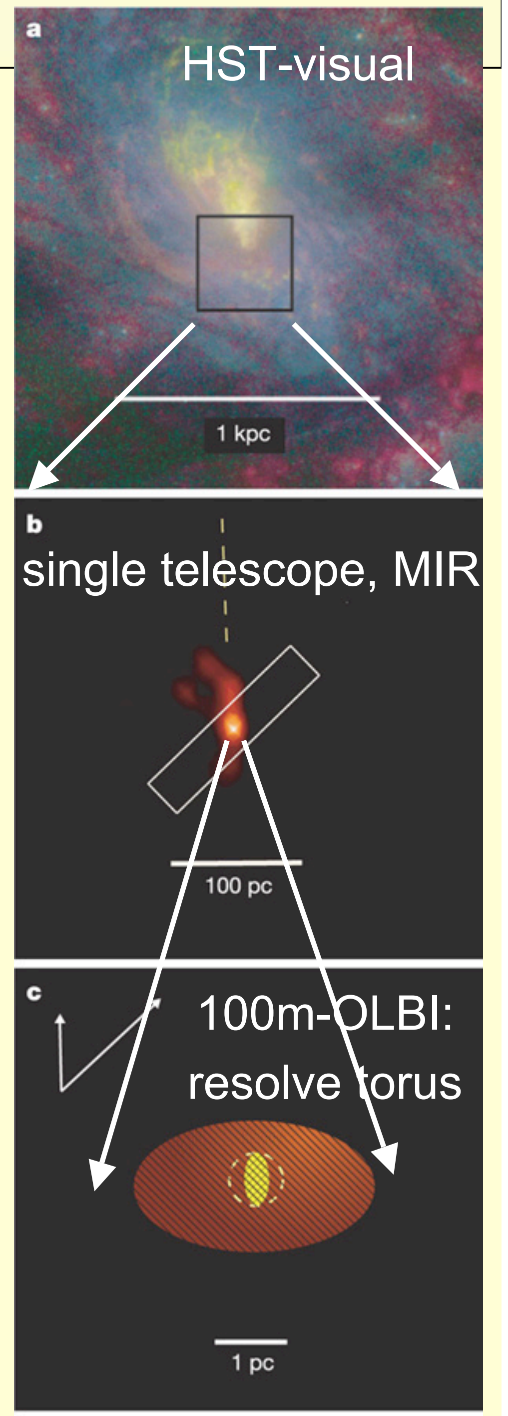
Radio-Jet with VLBI: Baum+97

Why interferometric AGN measurements with KI?

- IR-interferometry delivers crucial spatial constraints on the unification models of the AGN
- 10μ-IF (VLTI-MIDI) probes a few 100K dust. This matter is found much closer to the AGN than expected from smooth toroidal geom. and opt. thick distributions: strong support for clumpy tori
- 2μ IF will investigate where and how the dust and jets form



NGC 1365, animation of infalling / accreated gas from Hayden Planetar.



NGC 1068, first MIR fringes, from W. Jaffe et al. '04

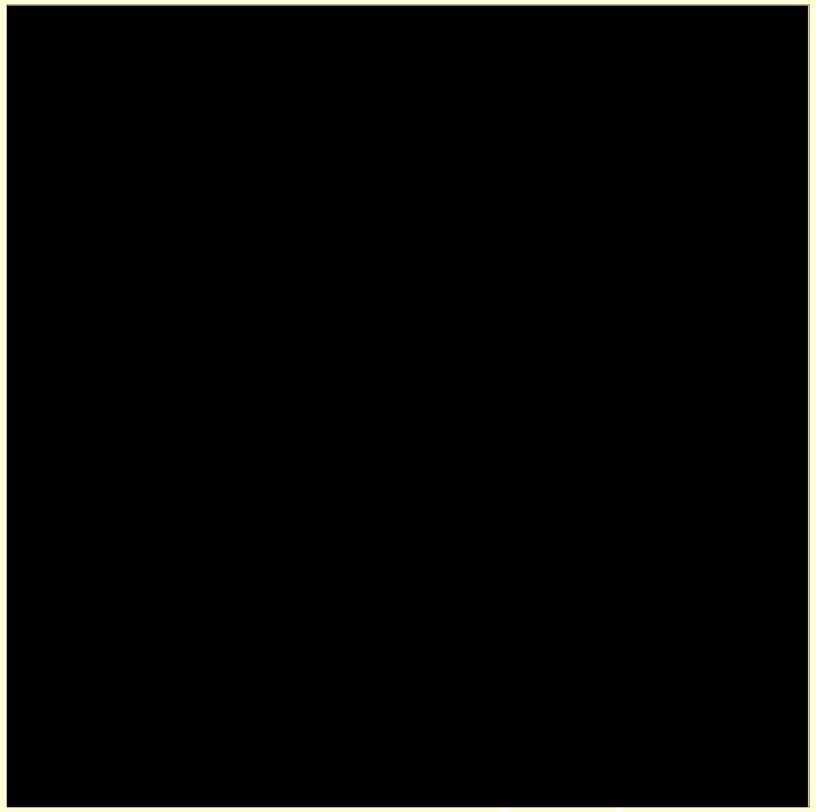
Why interferometric AGN measurements with KI?

– IR-interferometry adds data to understand the *existence* and *nature* of the torus

– Spatial and spectral properties in dusty tori are very different from smooth dust distribution

– Nenkova+08: “[…] a fundamental difference from smooth density distributions is that in a clumpy medium, a large range of dust temperatures coexist at the *same* distance from the radiation central source”

– Torus details decide on the attentuated AGN radiation field seen outside of the nuclues



Elitzur et al. 07, Nenkova et al. 08

We started an AGN survey with the Keck Interferometer (KI) to get a better picture of the K-band AGN emission

- KIAWE: ***K***eck ***I***nterferometer ***A***GN ***W***ide-band ***E***mission (KIAWE) Collaborators: M. Elitzur, M. Malkan, R. Schodel, J.Woillez

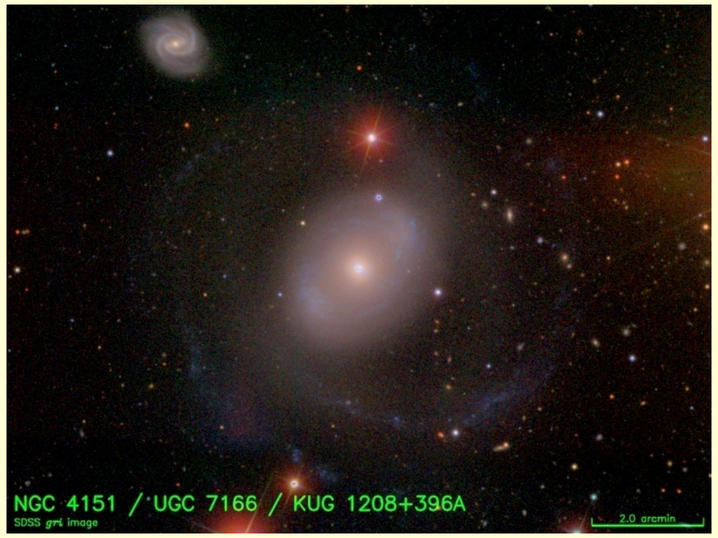
- Main goals:
  - resolve the emission region
  - Get first order size estimates
  - Relate the findings to the amount of activity ($R \sim L^{0.5}$), and source variability
  - Connect to the 10μ VLTI-MIDI results (talks of Meisenheimer, Burtscher, Tristram)

- 4 targets observed with M_{abs}= -18..-27mag

Kiawe *Tree, Wailea, Maui, Hawaii*

NGC 4151 - facts

- Dist.:13.6Mpc (1mas = 65 mpc):
  NGC 4151 hosts the closest and apparently brightest Seyfert 1 nucleus; M_{abs} = -18.7
- First AGN ever observed with long baseline optical interferometry (Swain et al. 2003, Keck-I) -> very compact (≤ 100 mpc)
- Early observations succeed once, and marginally resolved the source: to be confirmed



IF-questions

- Is the K-band emission really inner, hot dust from the torus, or rather an extended Broad-Line region (expected from NIR reverb. mapping)?
- Is it smaller than torus models suggest?
- Do we see any sign of variability correlated with the strong total flux variation?

NGC 4151 - IF-questions

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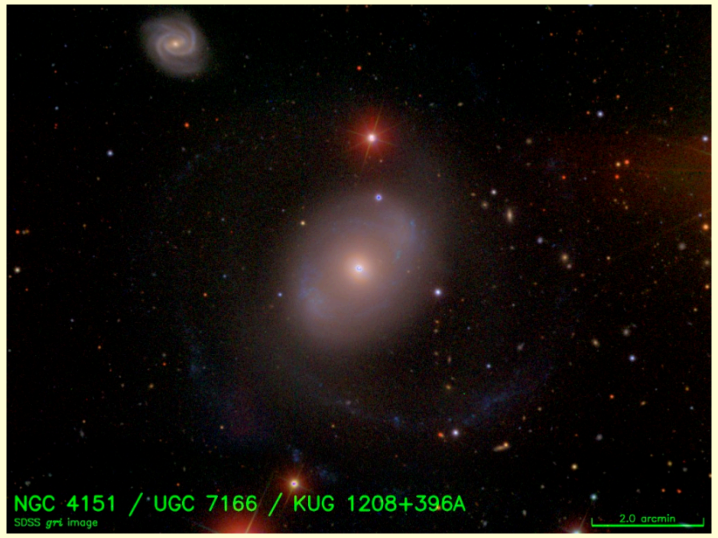
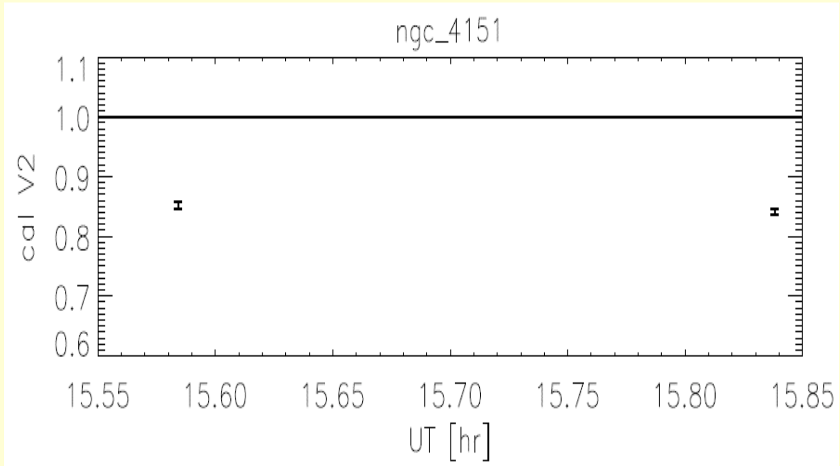


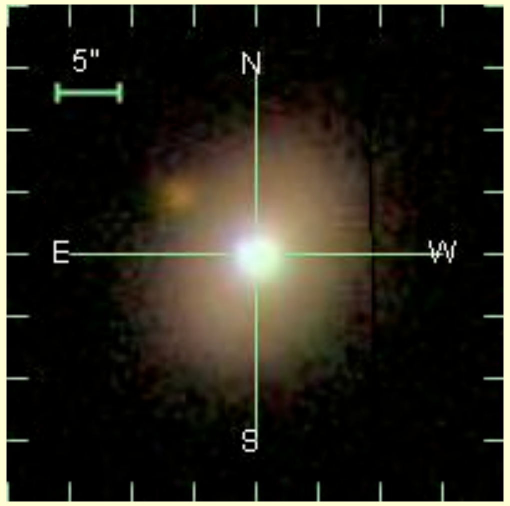
New results:

- Swain et al.03-results were eventually confirmed at high precision, under regular observing conditions
- NGC 4151 is definitely resolved, but dominated by the compact source (~90% of the flux from r<50mpc) -> BLR?
- Variability monitoring appears possible: ΔKmag(May03.. Dec08)=1..1.5 mag, but we do not measure any change in visibility → only the compact source varies, the extended flux is probably overresolved (→ MIDI (10µ) finding)



Mrk 1239 – facts

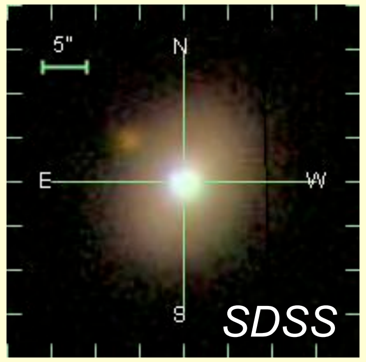
- Dist: 80Mpc (1 mas = 380 mpc); M_{abs} = -20.3
- Narrow-line Seyfert 1 (NLS1) galaxy
- Near-infrared emission shows a very hot dust near its sublimation temperature (*T ~ 1200K), very likely* located both in the upper layers of the torus (Rodriguez-Ardilar et al. 2006)



SDSS image

IF- questions

- Similar extension to NGC 4151, including the $L^{0.5}$-scaling?
- 2d-extension?



Mrk 1239 – IF-questions

- Similar extension to NGC 4151, including the $L^{0.5}$-scaling?
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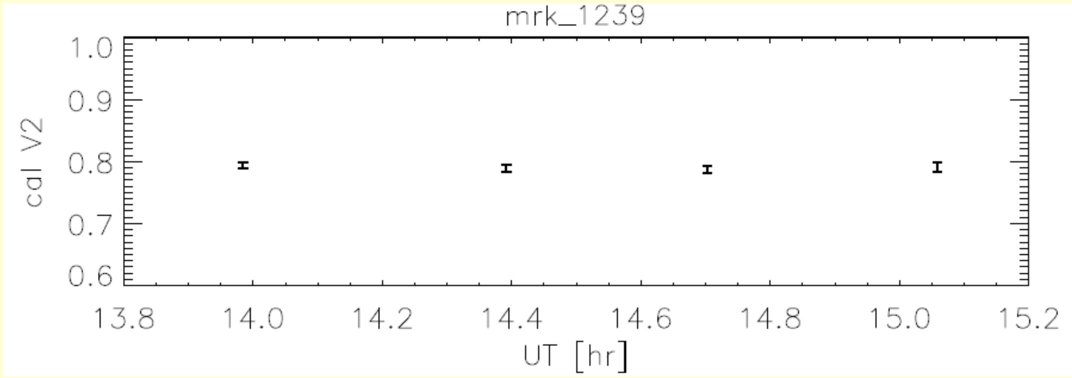
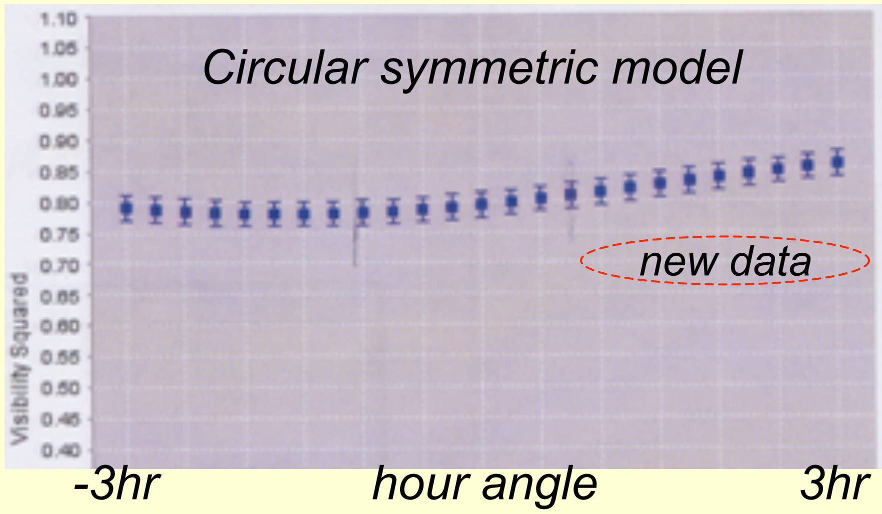
First results:

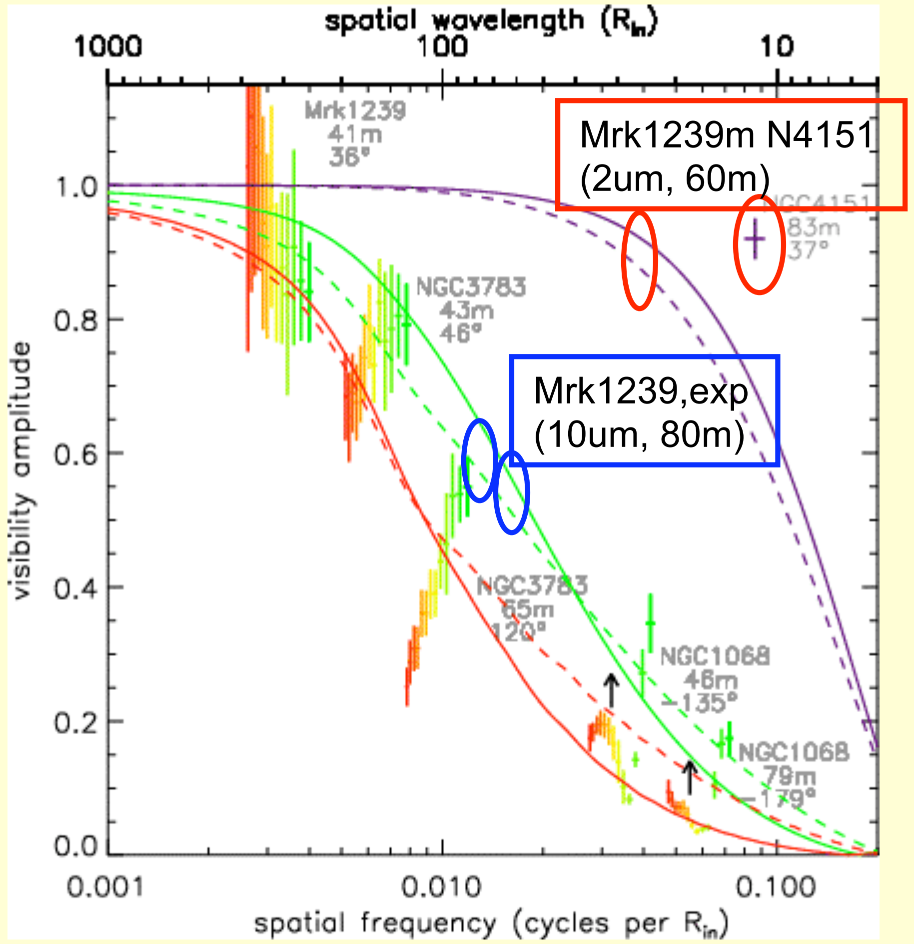
- Luminosity-normalized size is significantly larger than N4151
- uv-coverage and precision are sufficient to check for spatial asymmetry
- We probably see the dust inclination





Results:

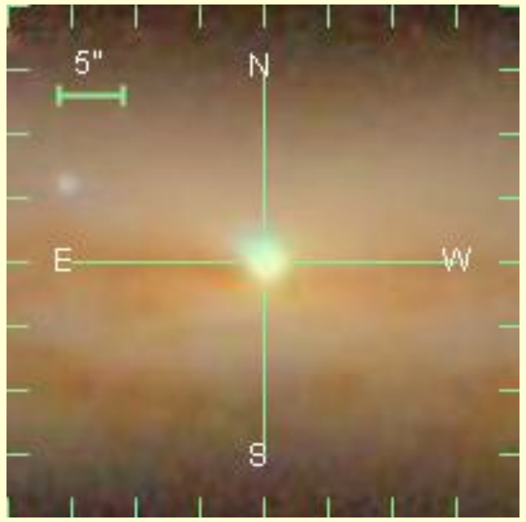
- Both sources were resolved, and do not coincide according to the $R \sim L^{0.5}$ law, although the spectral appearances (Sy type) are similar
- NGC4151 appears to be too small: significant contribution from the accretion disk: red AGN? How similar are the innermost regions of Seyferts?
- High angular resolution is needed for reliable NIR nuclear variability studies (reverberation measurements)
- More AGN data required …



'Unified dust model' [Kishimoto'09] does not work right away.

NGC 5506 – facts

- 26 Mpc(125mpc=1mas), M_{abs} = -18
- NLSy1 instead of Type2? Nagar et al. 2001 detect OI & FeII lines of the BLR
- Large nuclear obscuration (A_V > 5)
- Brightest known NLSy1



SDSS image

IF-questions

- Similar compactness as other NLSy1 (Mrk 1239)?
- Will the extended dust emission (high obscuration) still dominate at 2µ?

First results

- no fringes, appears to be overresolved (too large due to the obscuring dust), but the observing conditions were poor also

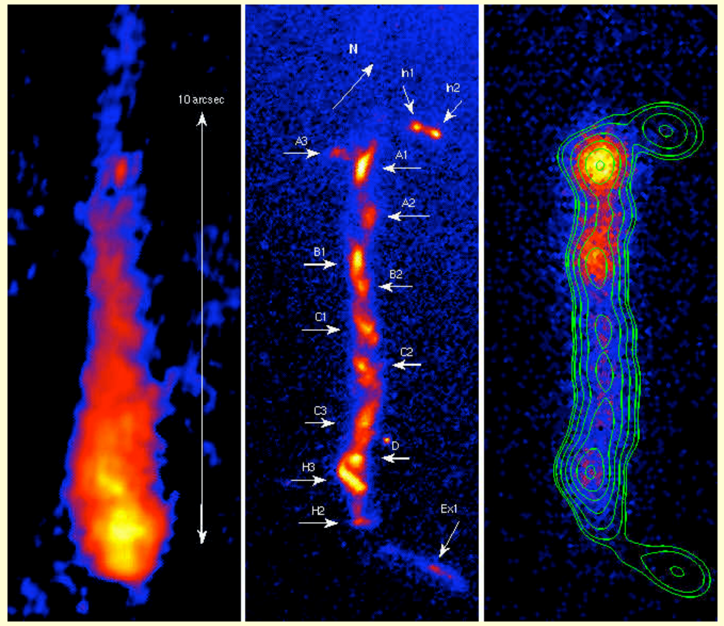
3C 273 – facts

- Located at a distance of 650Mpc (1mas = 3.1 pc
- First quasar to be discovered (Schmidt 1963).
- One-sided powerful jet (radio to γ-rays)
- M_{abs} = -27mag: the quasar dominates the galaxy

Location of the Nucleus (KI-target)

IF-questions:

- Do we resolve the emission?
- Can we observe the jet nozzle in NIR?



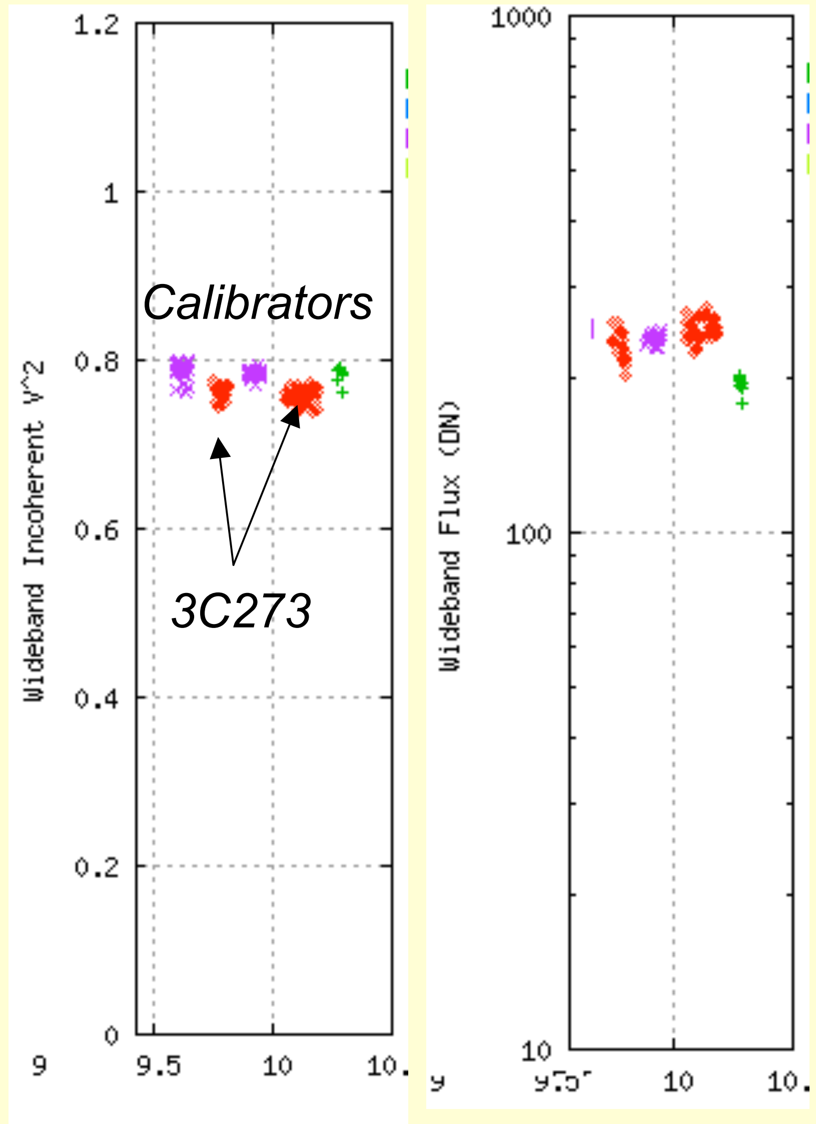
Radio / Visible / X-ray (jet-only: Marshall et al. 2001)

3C 273 – IF-questions:

- Do we resolve the emission?
- Can we observe the jet nozzle in NIR?

Results of the recent observation (May09)

- Clear fringe detection, but not yet properly calibrated ☺
- 2µ emission appears to be slightly, but significantly resolved
- Jet contribution of a few percent

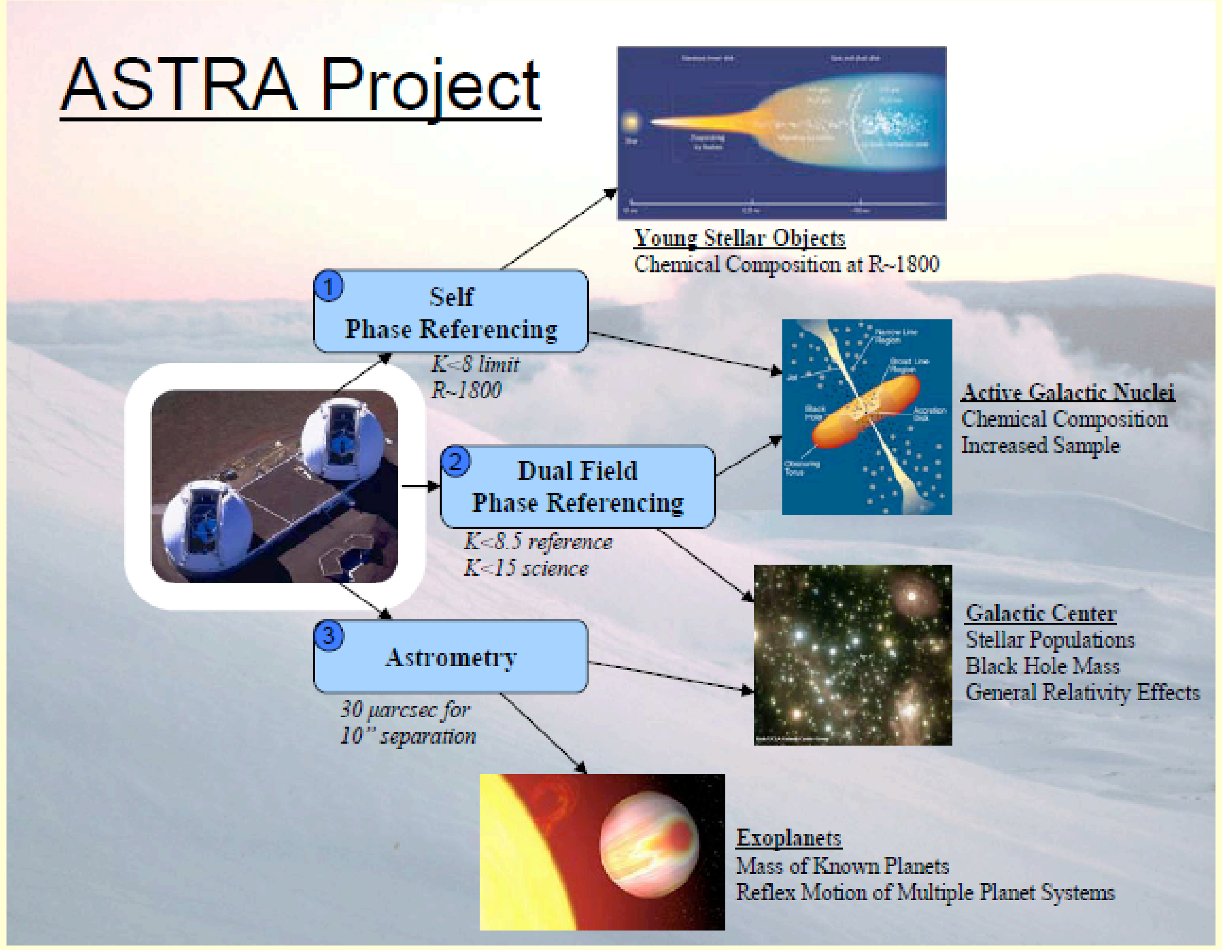


Uncalibrated visibility / Total Flux

AGN KI-measurements – first conclusions, and new questions

- Tristram et al. 09 (10µ VLTI/MIDI AGN survey): *Individual sources look more different than a simple unified scheme would predict.* > same at 2µ
- Are there too many parameters to easily unify the NIR/MIR emission?
- 2um is crucial to go closer to the central source and probe the contributions of a 'red' the accretion disk, of an extended, optically thick BLR, or of a jet
- Is the K-band emission dominated from the hot dust / torus emission?
- KI works reliable down to K~10.5, with respective angle tracking down to H~10.5
  → KIAWE is work in progress, stay tuned

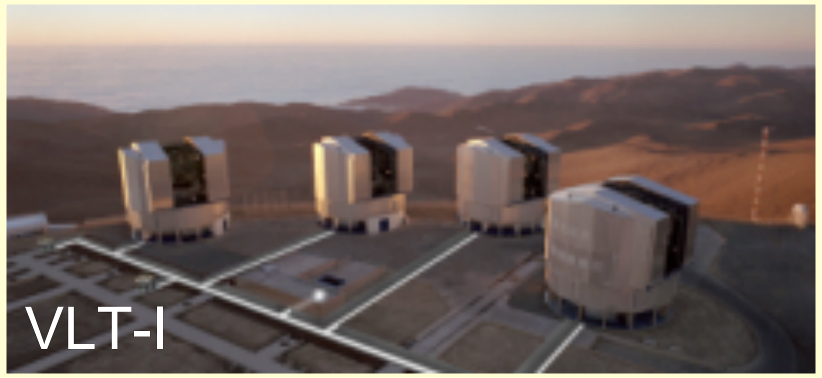
Outlook: the future of the KI



Three ASTRA phases:

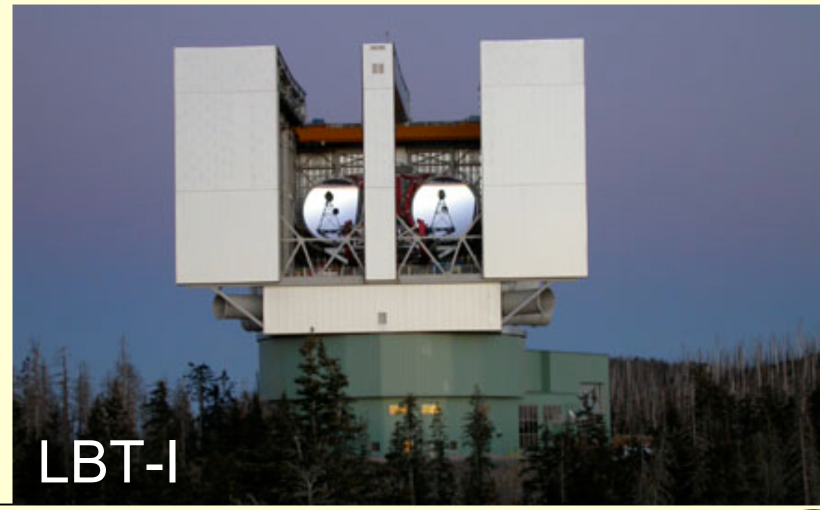
- Self-phase referencing: R~1800: in place
- Dual-field phase-referencing increase sensitivity by 5mag if an IF guide star is available: end of ’09
- Interferometric narrow-angle astrometry: differential astrometry at 30uas level, first test in 2010?

NSF-funded KI sensitivity upgrade, development is based at WMKO
Team:
P. Wizinowich (PrincipalInvestigatel), J. Woillez (SystemArchitect), J.-U. Pott (InstrumentScientist), J. Eisner (ProjectScientist),
Eng: K. Tsubota, E. Wetherell, M. Hrynevych, M. Colavita, R. Akeson, R. Millan-Gabet et al
Sci: A. Ghez, L. Hillenbrand, J. Graham, E. Quataert et al.

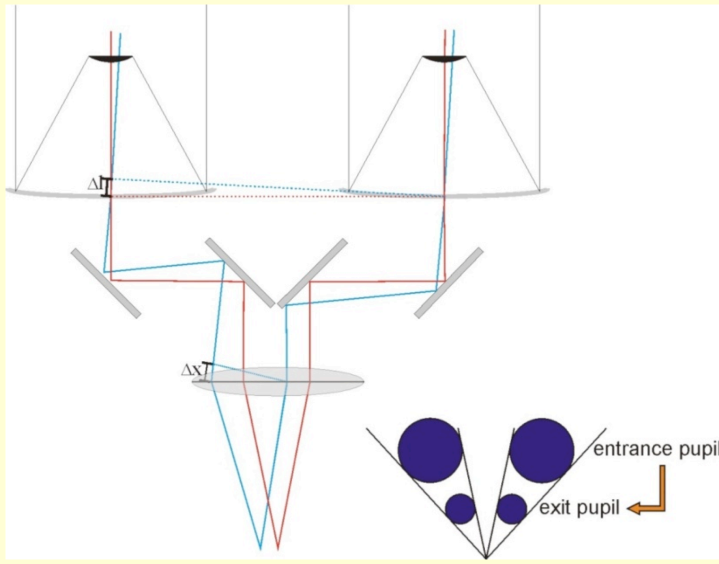


The new toy for high resolution at high sensitivity, suitable for AGN research:

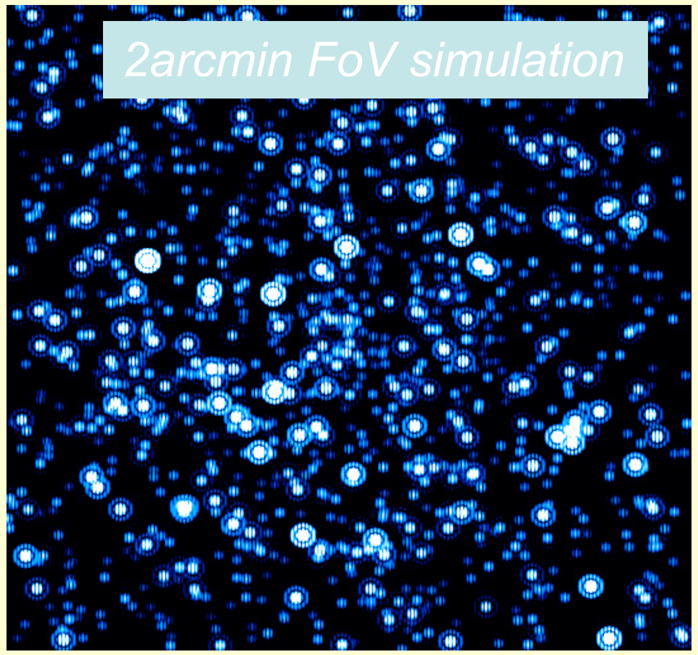
- Linc-Nirvana, the 2µ-Fizeau interferometer of the LBT

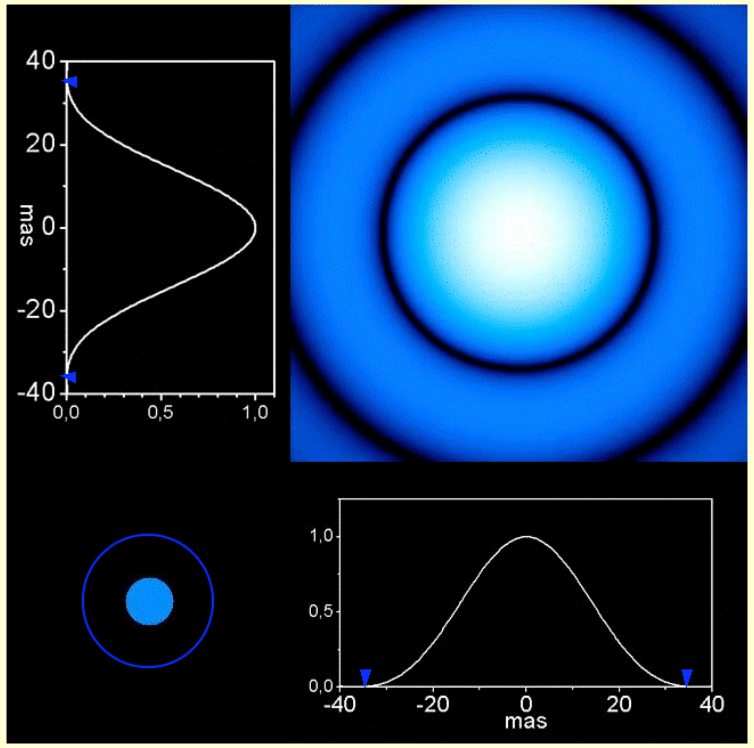


LBT-I: Homothetic imaging:



- Large collecting area → sensitivity
- Large field of view
  (→ Michelson stellar interferometer:
  50mas field of view)
- High angular resolution (~ 9 mas @
  J-band)





Courtesy of T. Bertram (Linc-Nirvana)

Danke
for your attention!