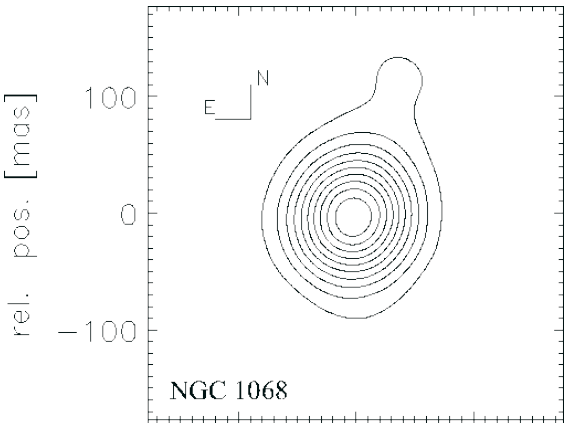
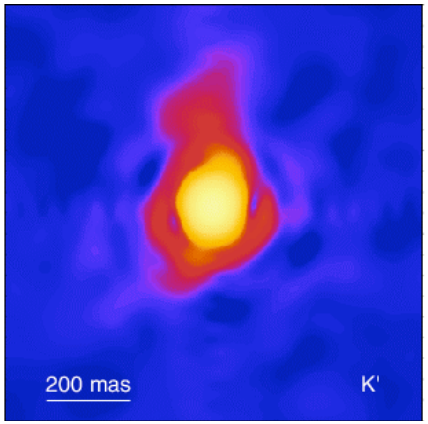
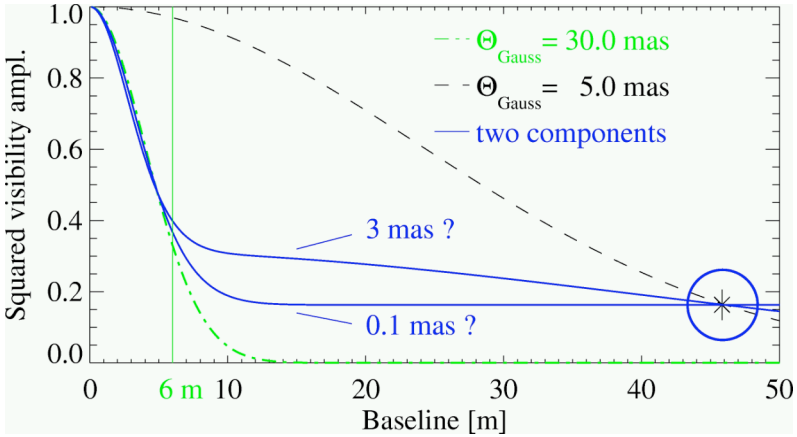
# Near-infrared interferometry of NGC 1068



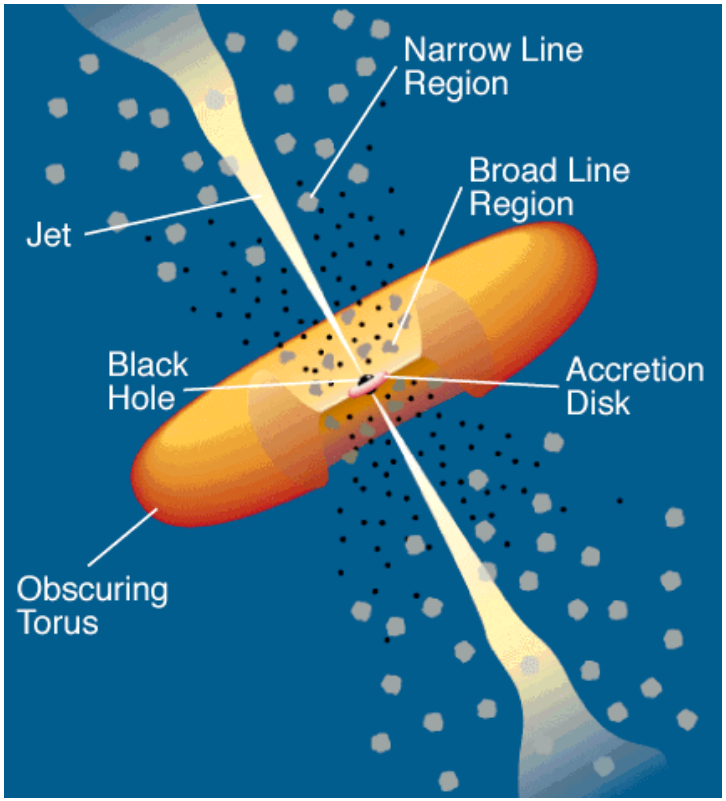




Markus Wittkowski (ESO)

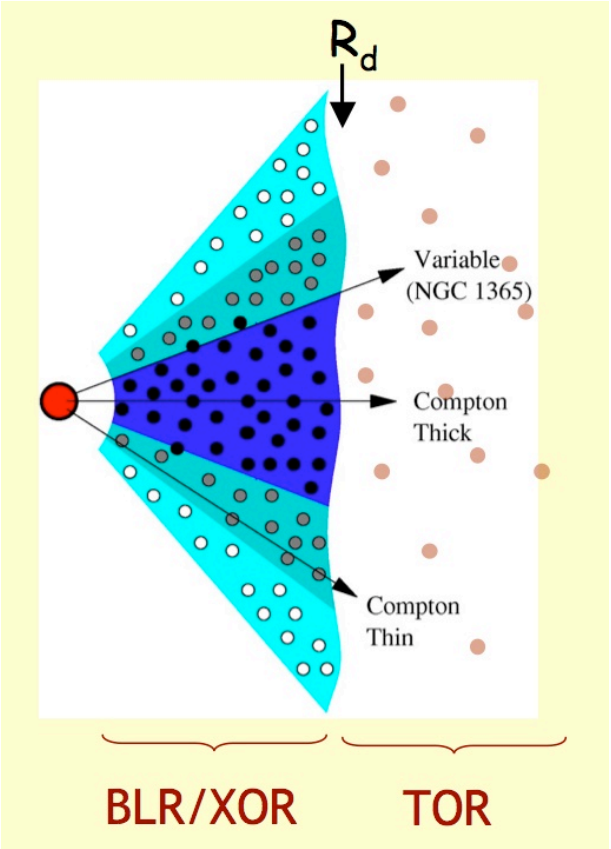
Based on work (1998-2004) with R. Arsenault, Y. Balega, T. Beckert, W. J. Duschl, K.-H. Hofmann, P. Kervella, A. B. Men`shchikov, F. Paresce, D. Schertl, G. Weigelt

# The immediate environment of the AGN




Uddy & Padovani

Standard unification scheme of AGN




Elitzur 2007

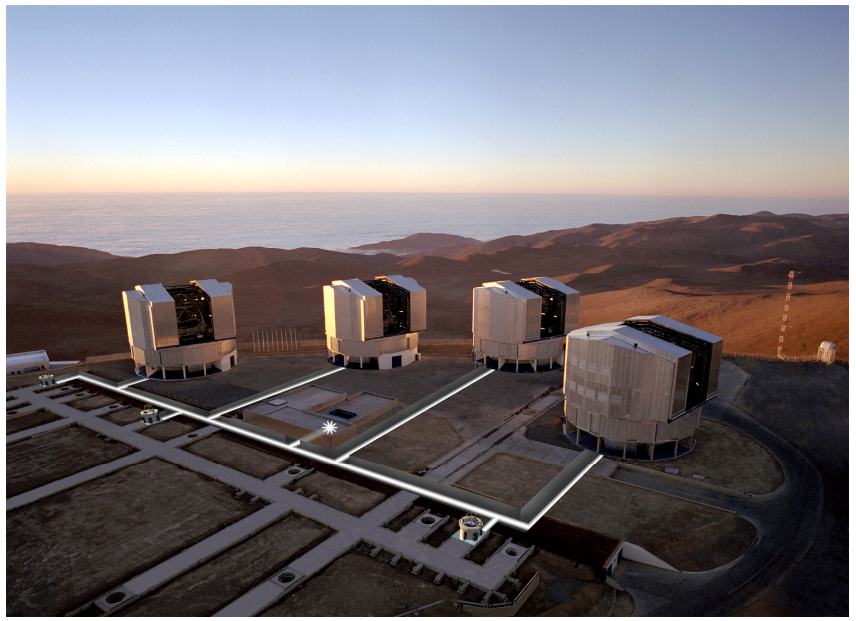
Clumpy structure in BLR and Torus

# AGN: Scientific results based on optical interferometers

- Swain et al. 2003, ApJ, 596, L163, Keck/near-IR,
  "Interferometer Observations of Subparsec-Scale Infrared Emission in the Nucleus of NGC 4151"
- Wittkowski et al. 2004, A&A, 418, L39, VLTI-VINCI/near-IR,
  "VLTI/VINCI observations of the nucleus of NGC 1068 using the adaptive optics system MACAO"
- Jaffe et al. 2004, Nature, 429, 47, VLTI-MIDI/mid-IR,
  "The central dusty torus in the active nucleus of NGC 1068"
- Poncelet et al. 2006, A&A, 450, 482, VLTI-MIDI/mid-IR,
  "A new analysis of the nucleus of NGC 1068 with MIDI observations"
- Meisenheimer et al. 2007, A&A, 471, 452, VLTI-MIDI/mid-IR,
  "Resolving the innermost parsec of Centaurus A at mid-infrared wavelengths"
- Tristram et al. 2007, A&A, 474, 837 VLTI-MIDI/mid-IR
  "Resolving the complex structure of the dust torus in the active nucleus of the Circinus galaxy"

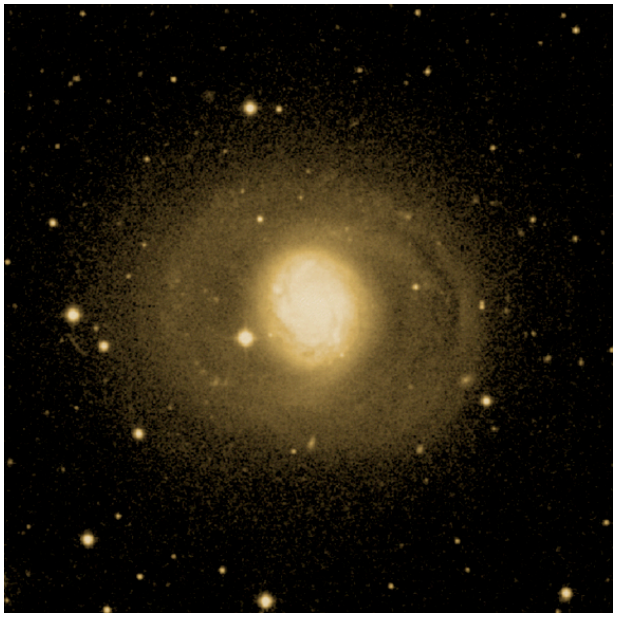
# The ESO VLT Interferometer

- Four fixed 8-m Unit Telescopes (UTs). Max. Baseline 130m.
- Four 1.8-m Auxiliary Telescopes (ATs), relocateable on 30 different stations. Baselines 8 – 200m.
- Near-infrared (J, H, K) closure-phase instrument AMBER. Spectral resolutions 35, 1500, 10000. Currently offered limiting magnitude K=7.
- Mid-infrared 8-13 μm 2-beam instrument MIDI. Spectral resolutions 30, 230. Currently offered limiting magnitude N=4 (1 Jy).
- Fringe tracker (FINITO).
- Dual feed phase referencing (PRIMA).
- Second generation instruments.

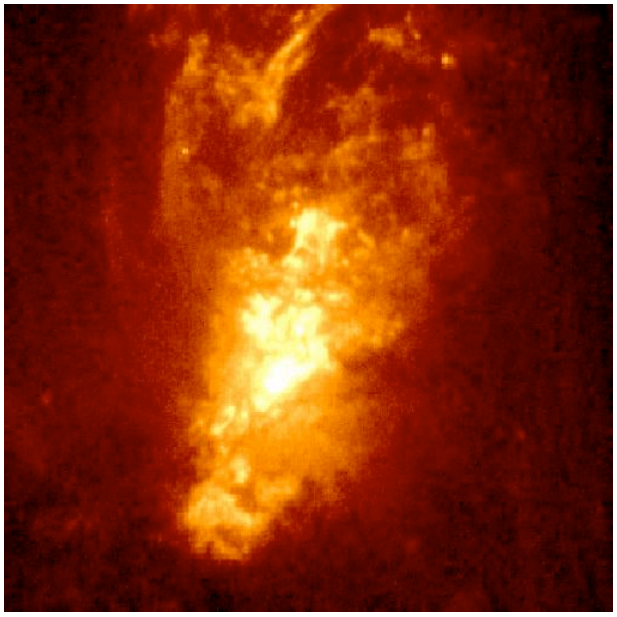


AT1 and AT2 with Open Domes

# The Seyfert galaxy NGC 1068

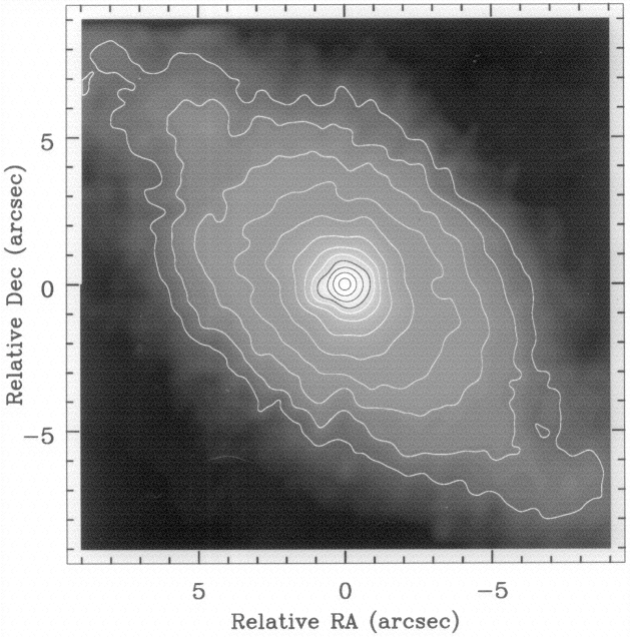


Optical DSS image
12x12 arcmin



Optical [OIII] HST image 1994
~7x7 arcsec

N

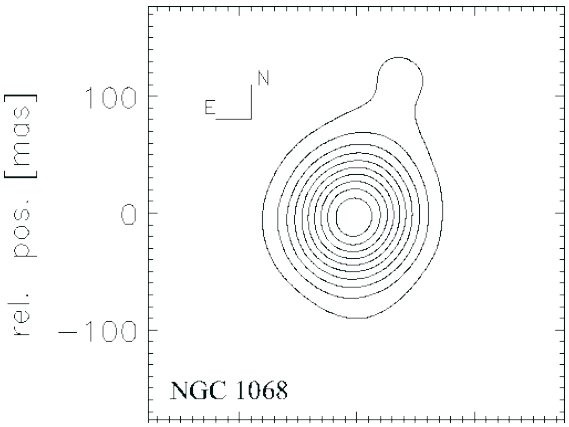



K-band speckle image
Thatte et al. 1997
9x9 arcsec

“94% of the K-band light in the central 1" originates from a <=30 mas diameter source whose position we determine to coincide within +/-0."15 with the apex of the cone structure seen in the optical narrow emission lines…”

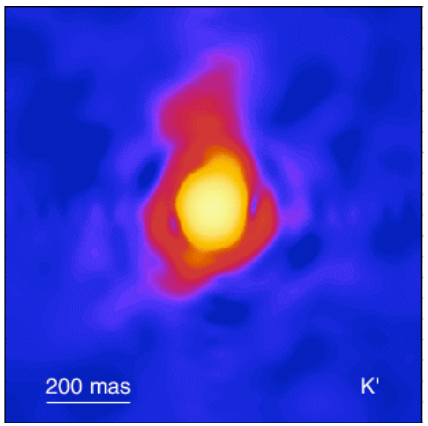
# Near-infrared K-band interferometry

6m SAO



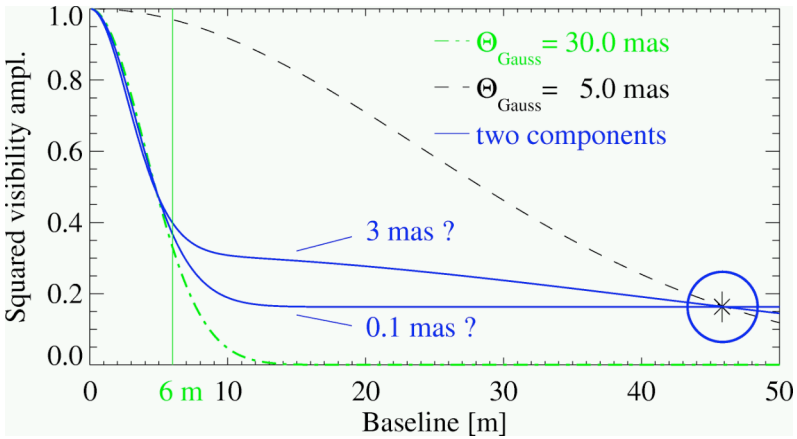

Wittkowski et al.1998

6m SAO




Weigelt, Wittkowski et al. 2004

46m VLTI




Wittkowski et al.2004

K-band core resolved with FWHM 30 mas ~ 2pc.

Nuclear torus and/or scattering halo.

18x39 mas ~ 1.3x2.8 pc, PA -16 deg.
Northern extension 400 mas~ 30 pc.

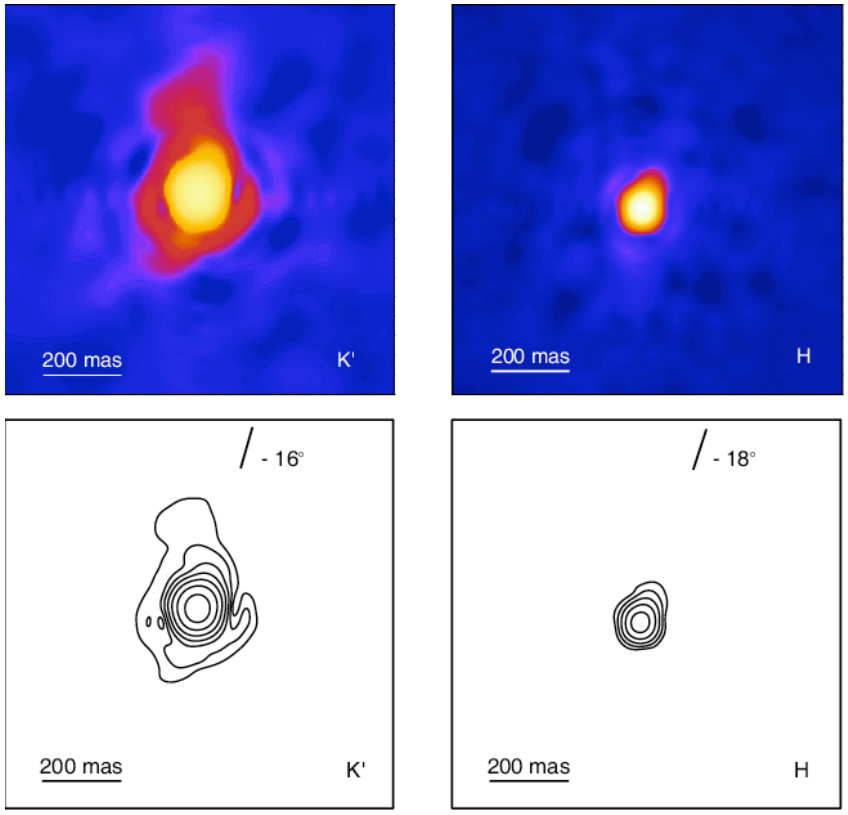
Compact core: innermost region of parsec-scale dusty torus or thermal and scattered emission from the western wall of the conical cavity.

Scattered light from the cone (wall).

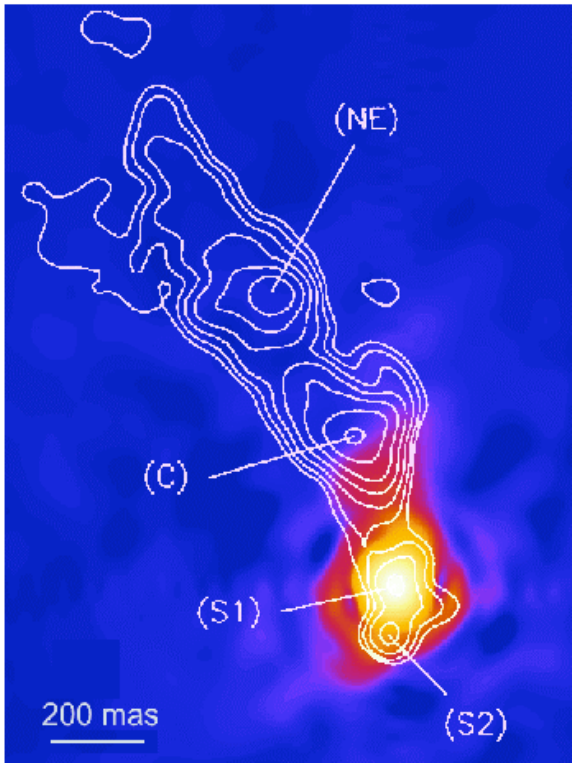
A considerable part of the flux originates from scales <5 mas or < 0.4 pc.

Substructrue of the nuclear torus or central accretion flow viewed through only moderate extinction.

# *K* and *H* speckle interferometry (Weigelt et al. 2004)




K' and H band images reconstructed by bispectrum speckle interferometry.
K-band: 18x39 mas ~ 1.3x2.8 pc, PA -16deg.
H-band: 18x45 mas ~ PA -18 deg.




K' band image and overlay of the MERLIN 5 GHz contour map (Gallimore et al. 1996).

# Dust sublimation radius

- The dust sublimation radius for NGC 1068 is estimated to $r_{sub}$ ~ 0.5-1 pc.
  Similar to the size of the compact speckle comp. (3x1.5 pc)
  Seems to be larger than the VLTI component (< 0.4 pc)

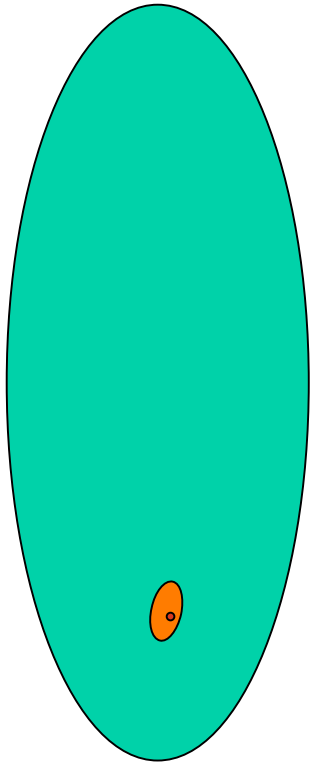
- BLR is dust-bound (Netzer & Laor 1993). NIR reverberation measurements indicate radii that are just outside the edge of the BLR and systematically smaller by a factor of 3 than predicted dust sublimation radii (Suganuma et al. 2006;Kishimoto et al. 2007).
  VLTI component (<0.4 pc) could be consistent with the NIR reverberation radius.

# Summary of observational results in the K band

Component 1 (speckle): 500 mas x 200 mas, PA 0 deg, 40 pc x 20 pc

Component 2 (speckle): 20 mas x 40 mas, PA -18 deg, 1.5 pc x 3.0 pc

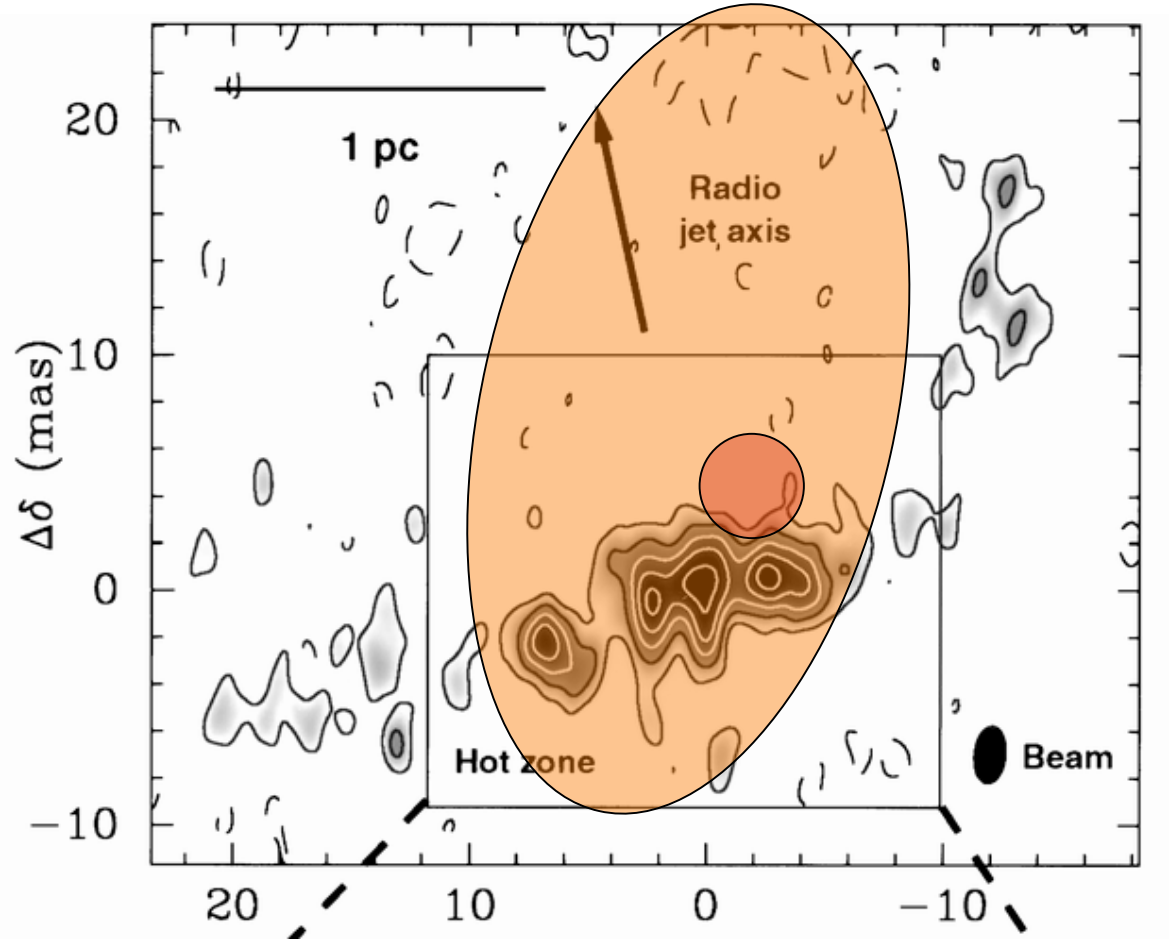
Component 3 (VLTI) : <~5 mas, PA unknown, <~ 0.4 pc,
relative astrometry unknown.



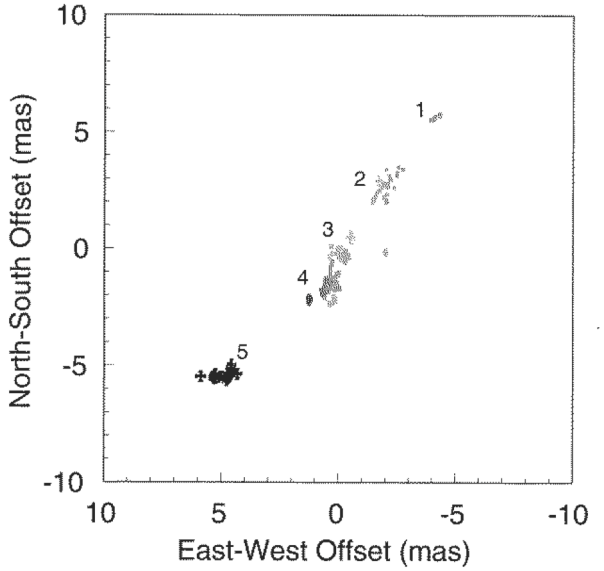
Fluxes:
Comp. 2: K-band: 350 +- 90 mJy
H-band: 70 +- 20 mJy

Comp 3 : K-band: > 50 mJy

# Comparison to the radio torus




Radio continuum map (VLBA), Gallimore et al. 1997




Water maser, Greenhill et al. 1996

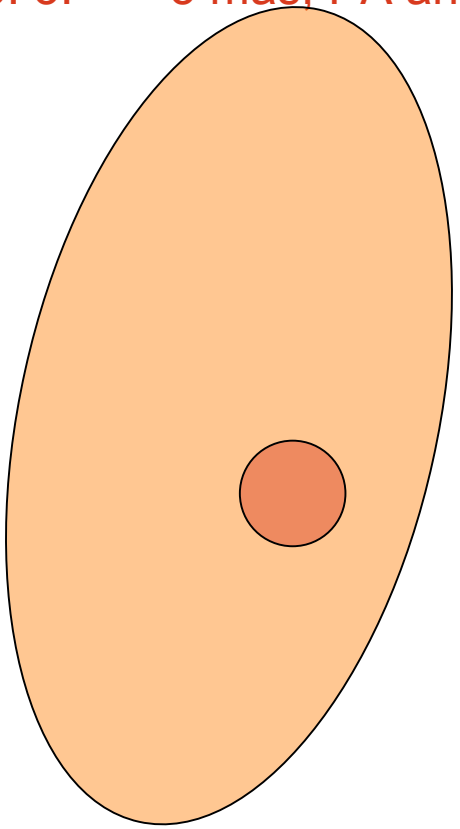
# Comparison to mid-infrared interferometry (MIDI)

NIR (Speckle +VLTI):

Comp. 1  500 x 200 mas, PA 0 deg

Comp. 2:  40 x  20  mas, PA -18 deg

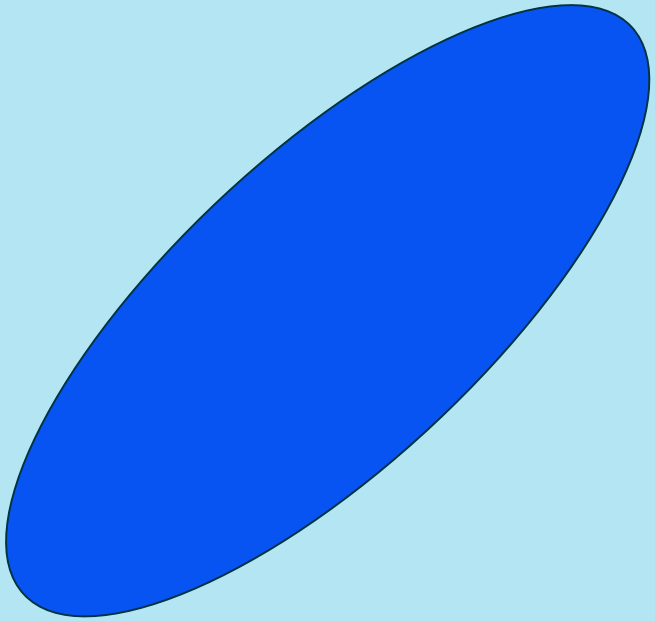
Comp. 3:  <~5 mas, PA and pos. unknown



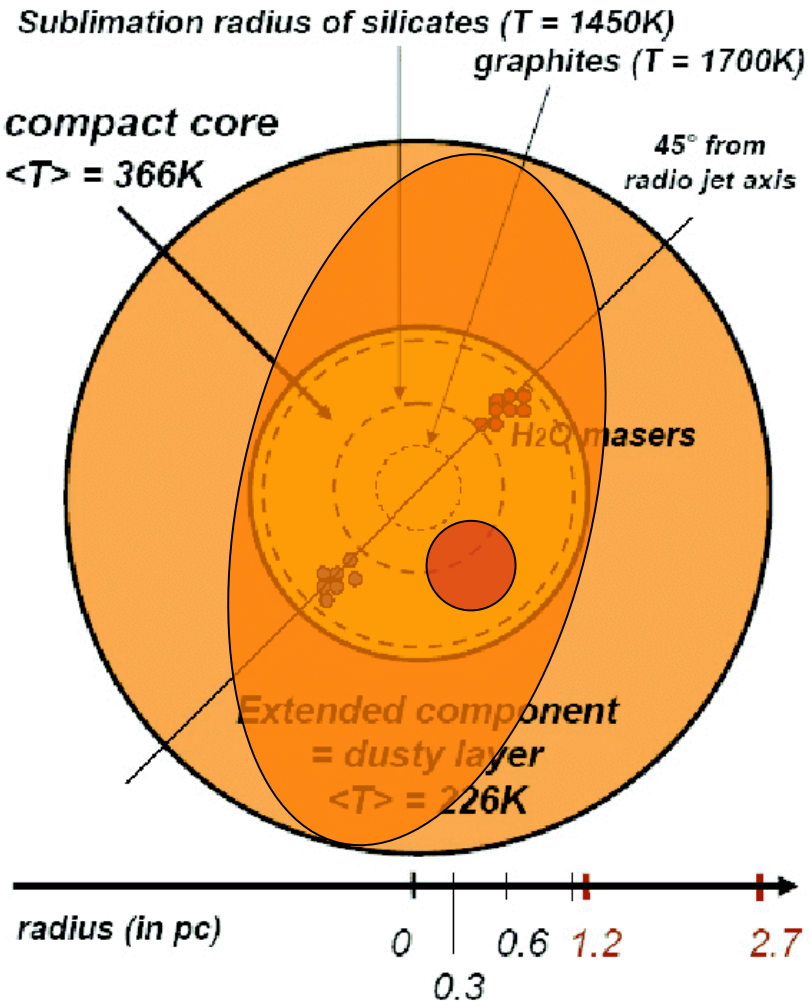
Mid-Infrared (MIDI), Jaffe et al. 2007:

Comp. A: 80x80 mas (?), PA 0, cooler

Comp. B: 40x15 mas,  PA -45, T>~600K



# Comparison to MIDI results (II)

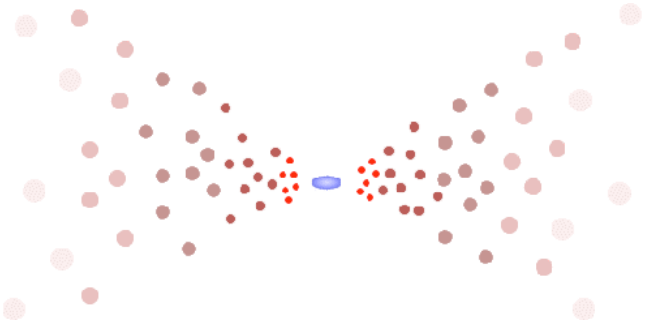


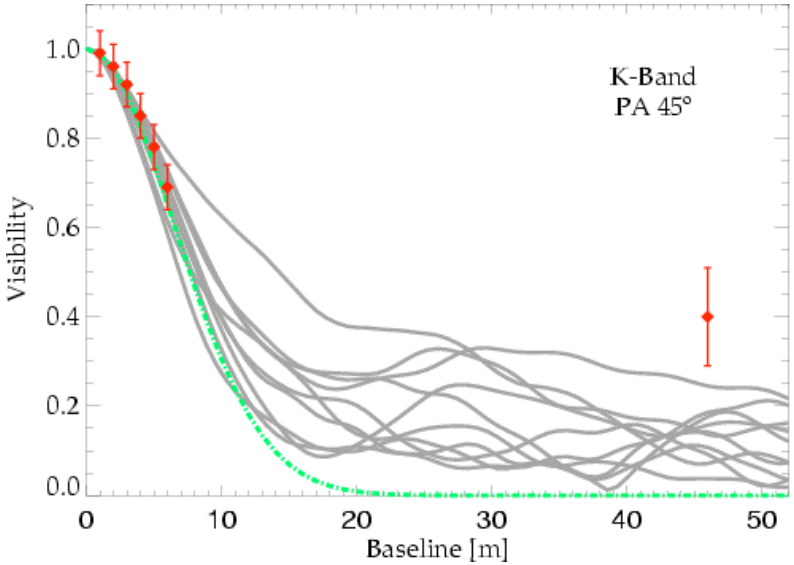

Poncelet et al. 2006:
Two concentric spherical components.

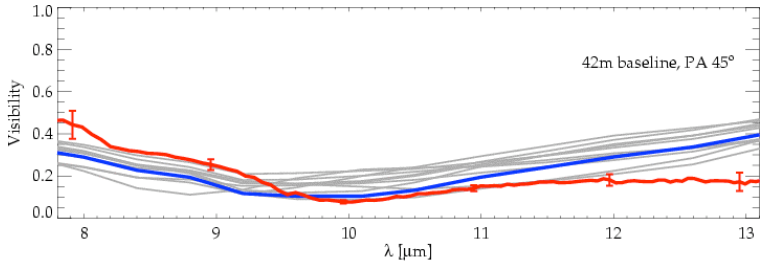
Inner compact component:
Radius ~ 17 mas, T ~ 361 K

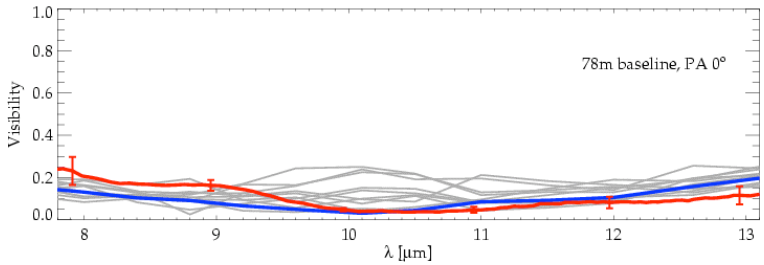
Outer layer:
Radius ~41 mas, T~ 226 K

# Clumpy AGN tori compared to NGC 1068 Hoenig et al. 2006





# Summary

- NIR speckle imaging together with one VLTI/VINCI interferometric measurements can be modeled with three components,

  ~ 40 x 20 pc at PA 0 deg / ~3 x 1.5 pc at PA -18 deg / < 0.4 pc
- Dust sublimation radius of the order of 1 pc. NIR reverberation radius systematically smaller. Origin of these three NIR components not yet clear. May include thermal emission from the inner part of the torus or substructure (clumps), scattered light from similar scales, scattered light from the western wall of the conus.
- NIR ~3 x 1.5 pc structure is remarkably similar in size to the modeling of the mid-infrared MIDI data.