Observations of Dusty Molecular Tori

Klaus Meisenheimer

Max-Planck-Institut für Astronomie

Physics of Galactic Nuclei

Ringberg Castle – June 16, 2009

Observations of Dusty Molecular Tori

Overview:

1. Dusty molecular tori – what do we expect ?
2. Dusty molecular tori – what can be observed ?
3. Observations of dusty tory: status quo
4. Torus research with interferometers: the challenges ahead

Physics of Galactic Nuclei

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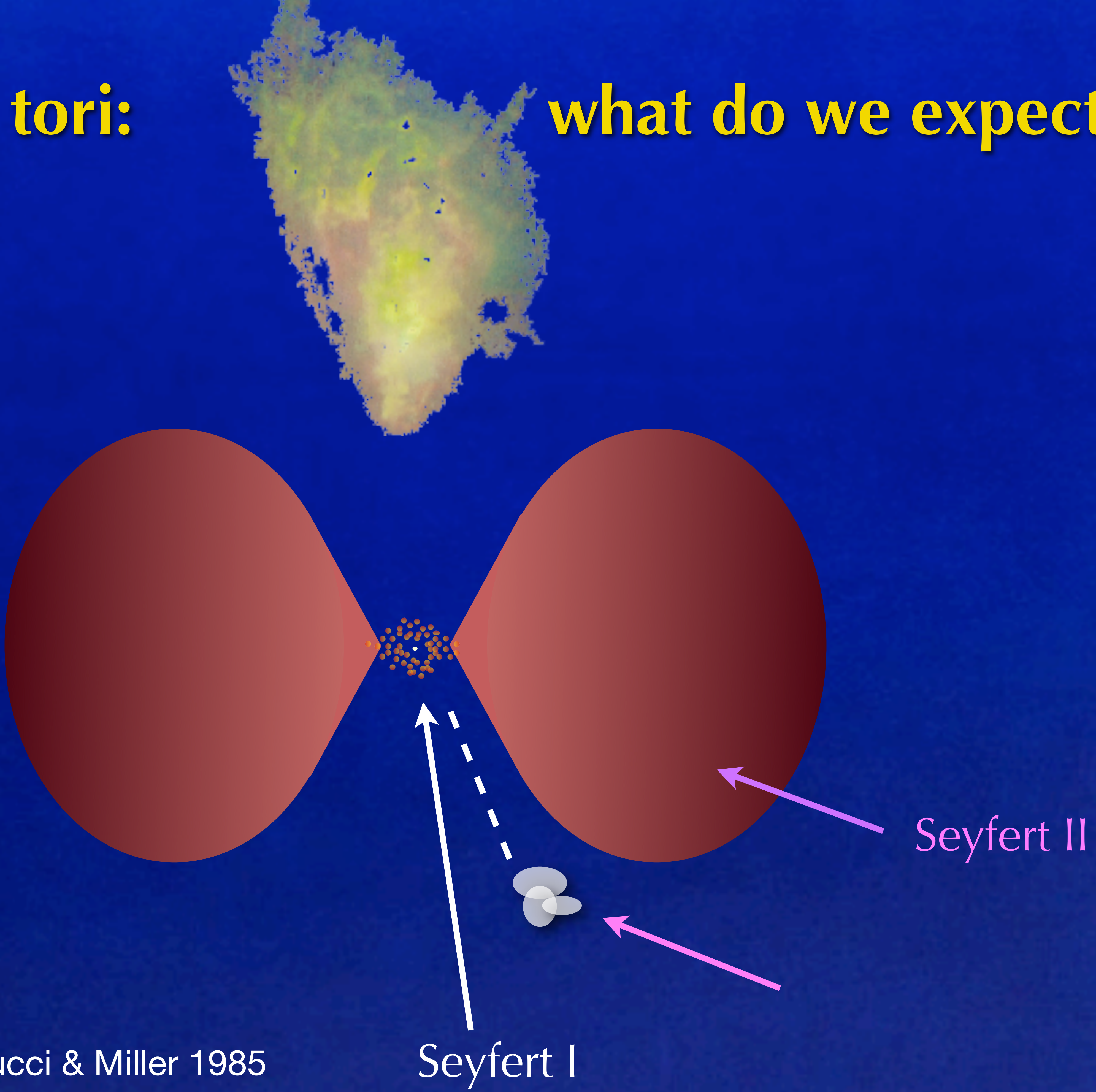
1. Dusty tori: what do we expect?



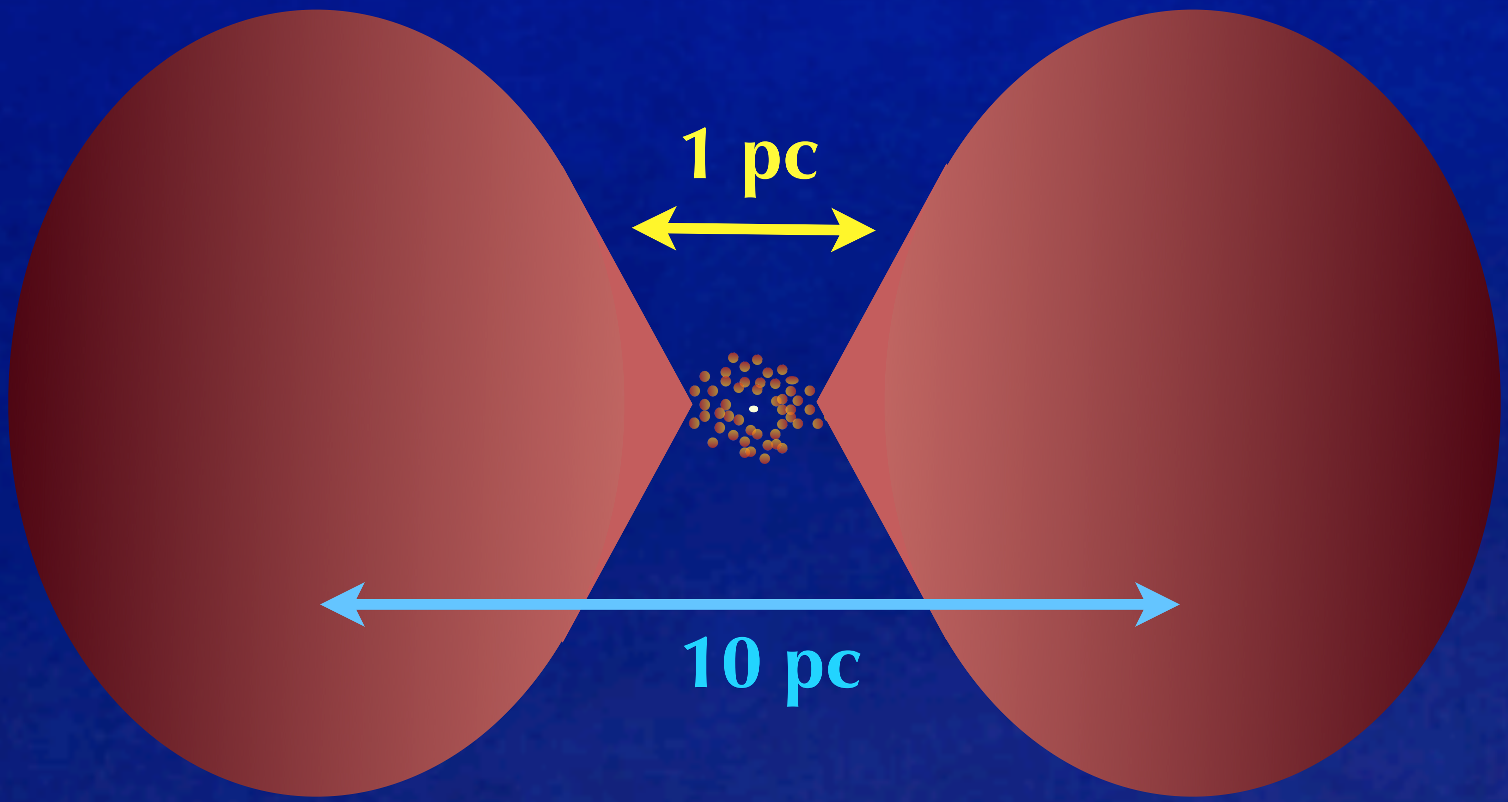
proposed by Antonucci & Miller 1985

1. Dusty tori: what do we expect?

Emission processes:

- Molecular lines
- Maser emission (e.g. H_20)
- Dust emission: 1200 … 200 K

Size:

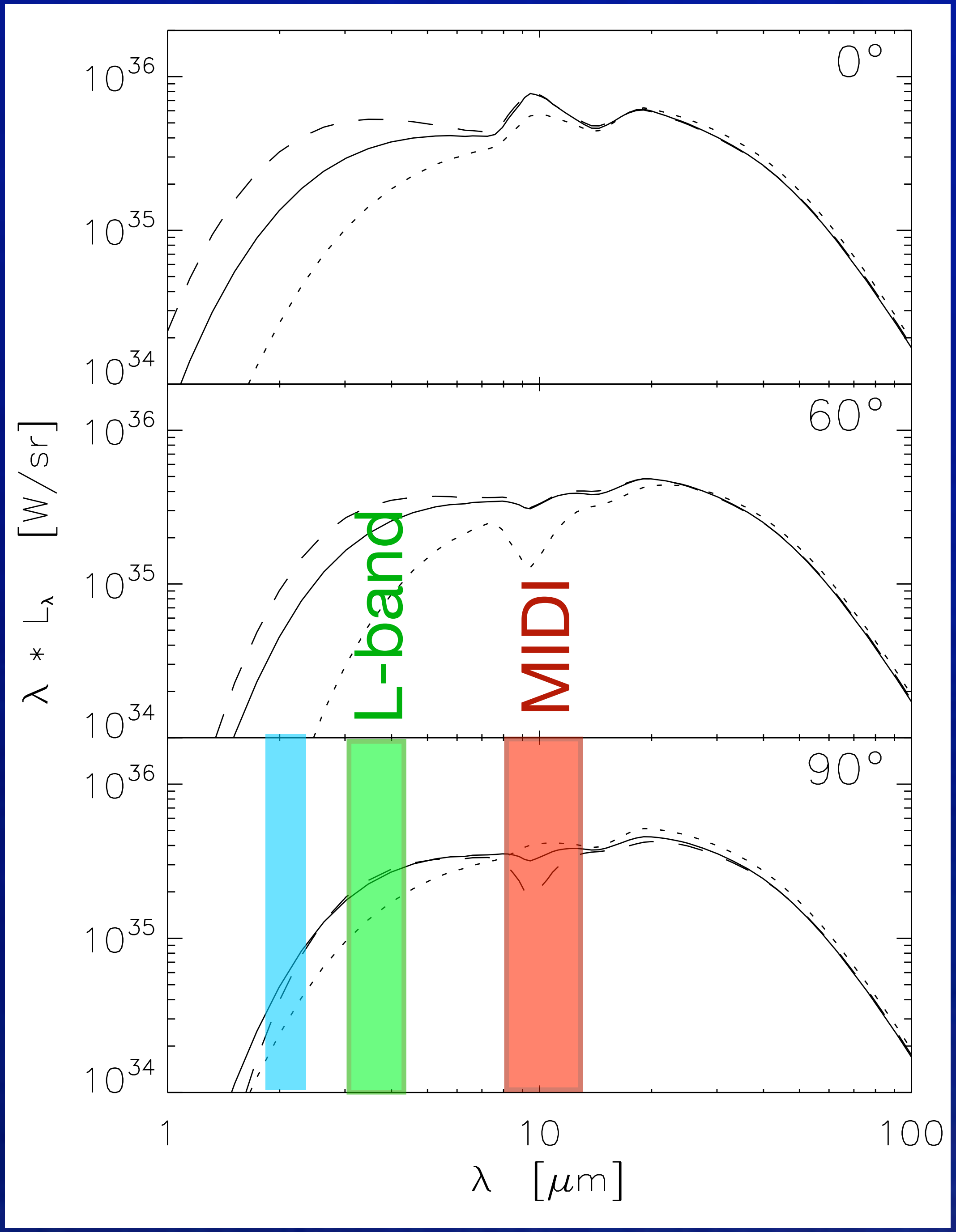


2. Dusty tori: what observations are possible?

- mm observations of molecules — needs high density tracers + < 1” resolution → **ALMA**
- radio VLBI observations of masers — e.g. H_2O masers, ~1mas resolution ✔
- observing the dust emission ...

Dusty tori: what observations are possible?

Torus spectra (RT models)



Marc Schartmann et al. 2008

- dust emission:
  1. gobal SEDs (resolution > 1″, i.e. > 100 pc)
  2. high resolution SEDs (0.1″)
  3. resolving the dust emission by interferometry

1 pc = 14 mas @ NGC 1068

D_tel	λ	FWHM
8 m	2.1 μm	60 mas
8 m	3.5 μm	100 mas
8 m	10 μm	250 mas
100 m	10 μm	20 mas
VLTI	10 μm	10 mas

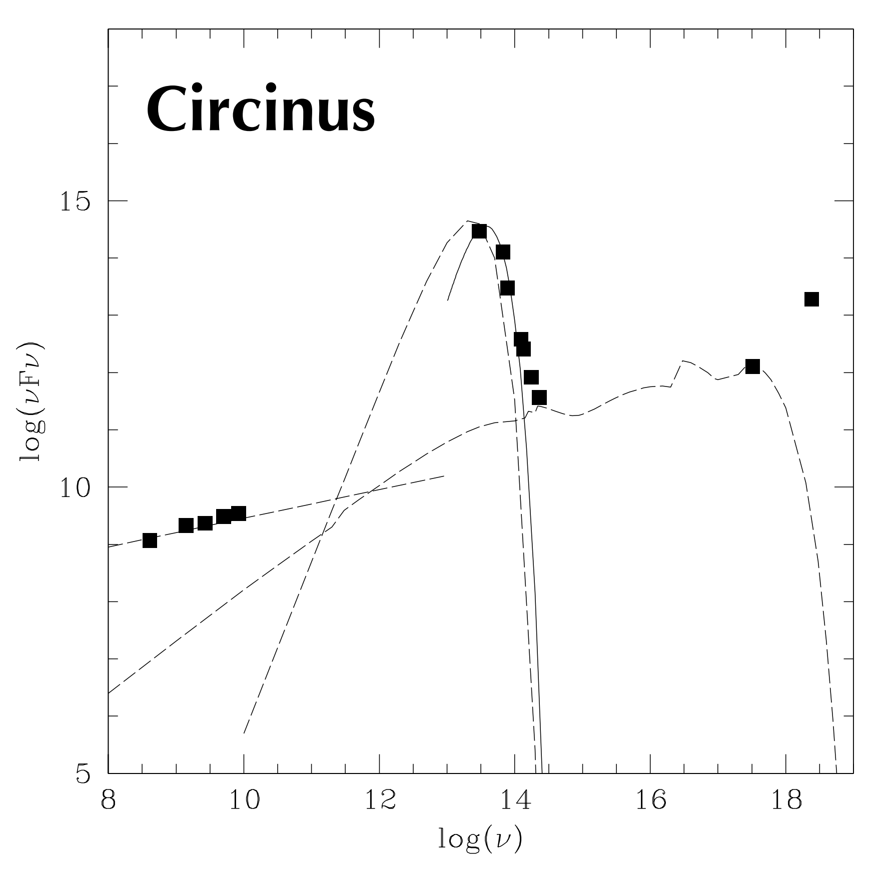
3. Observations of dusty molecular tori
status quo

3.1 Observations of the SED

Global SED (> 1"):

many AGN observed with Spitzer

➥ **Christian Leipski on Friday**



Prieto et al. 2004

High-resolution SED (~0.1"):

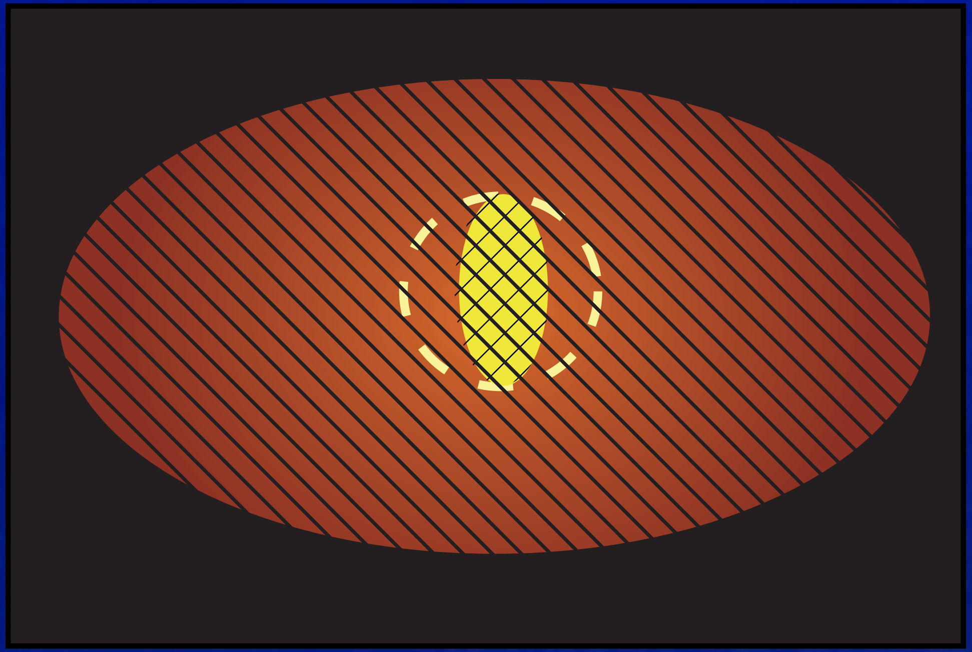
e.g. NACO, VISIR @ VLT, Keck, GEMINI ...

➥ **Talks by Sebastian Hönig, Christina Almeida, Almudena Prieto this afternoon**

3. Observations of dusty molecular tori
status quo

3.2 Resolving the dust distribution by interferometry

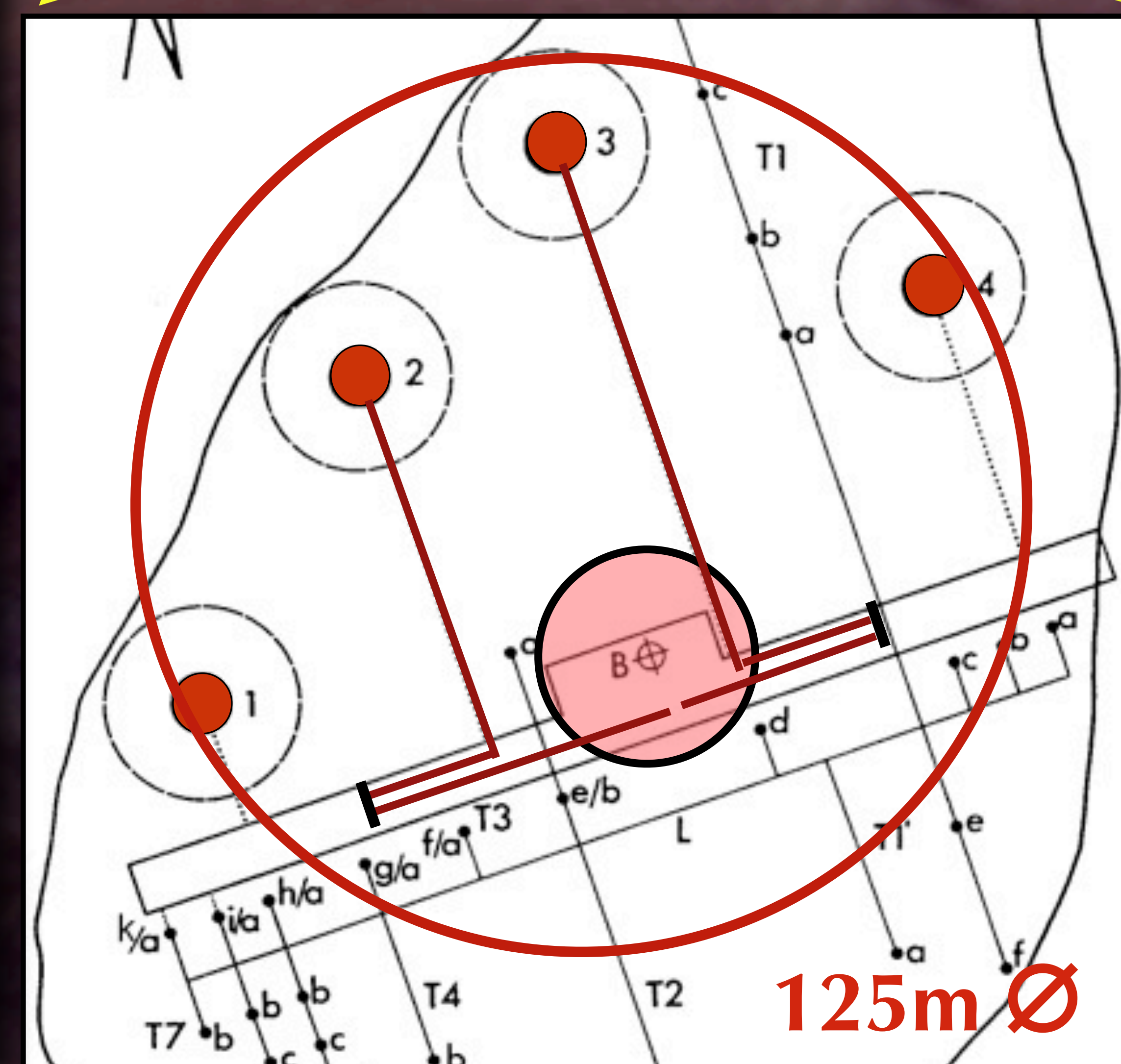
First result: NGC 1068



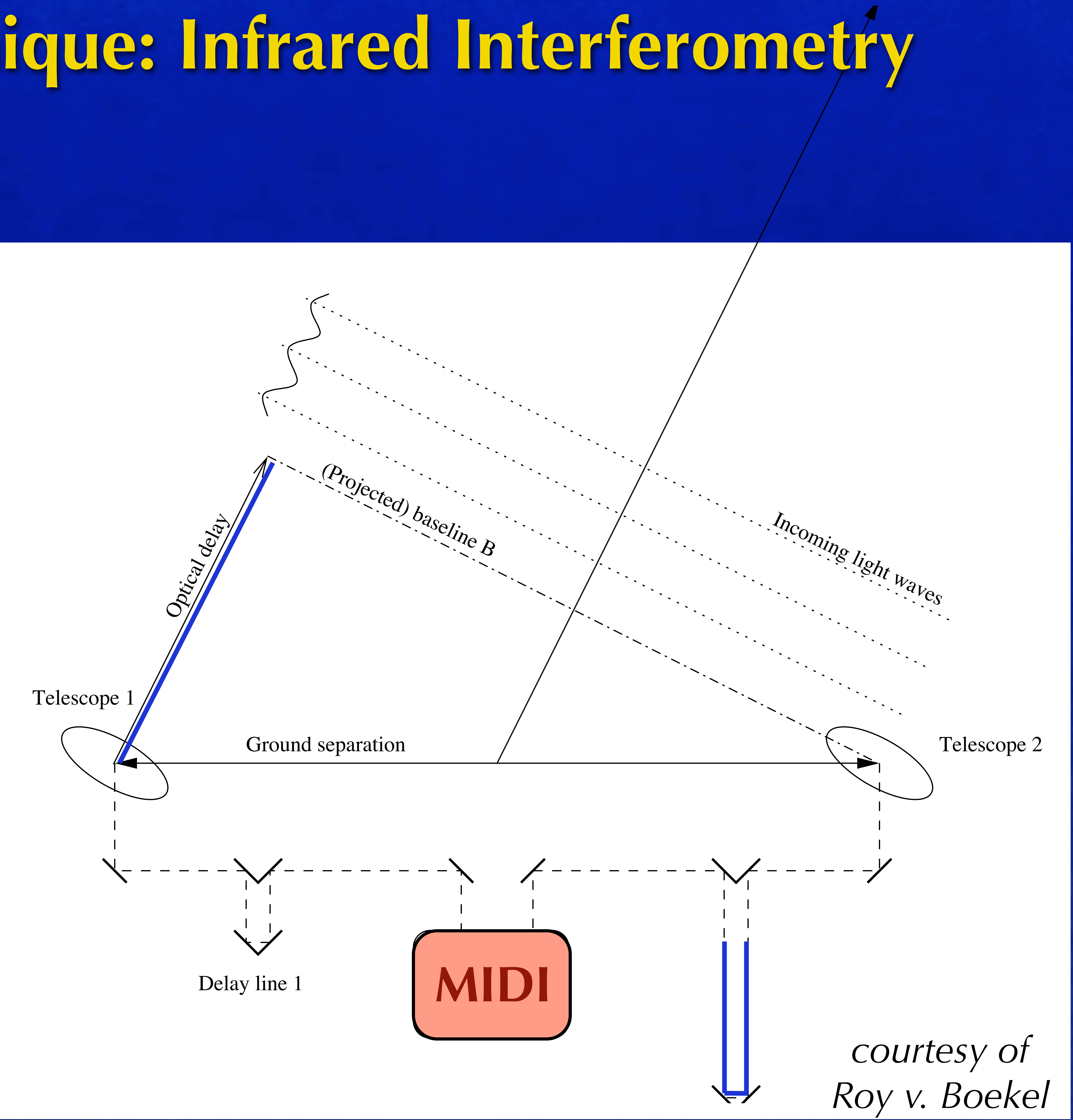
Jaffe et al. 2004

Very Large Telescope Interferometer
VLTI

MIDI – MID-infrared Interferometer



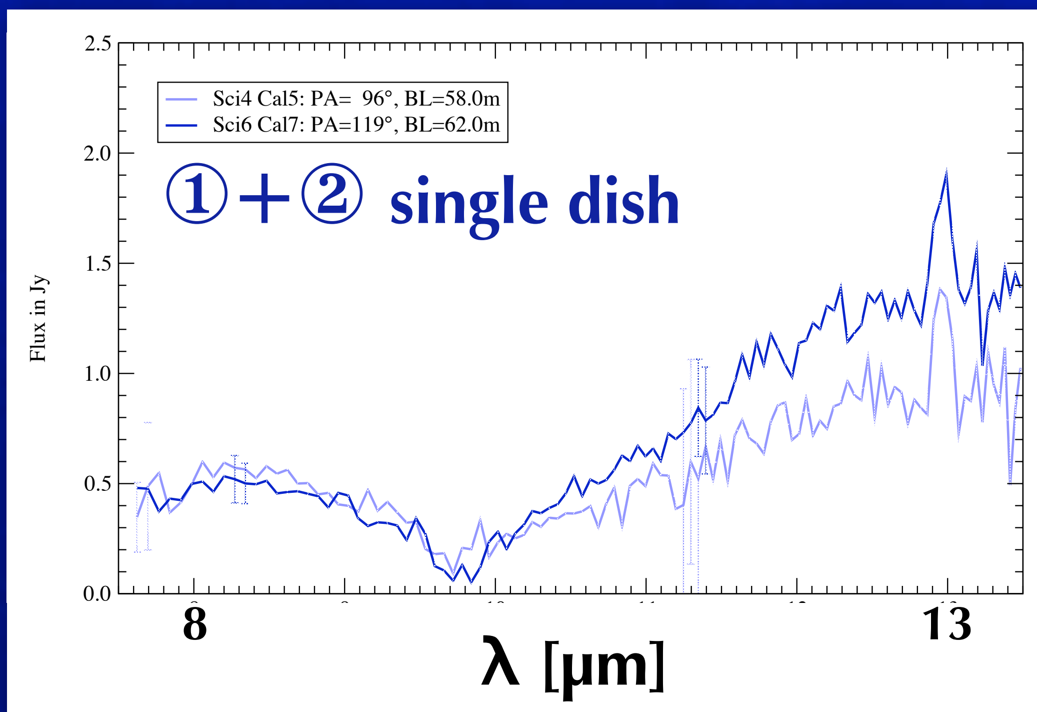
The technique: Infrared Interferometry

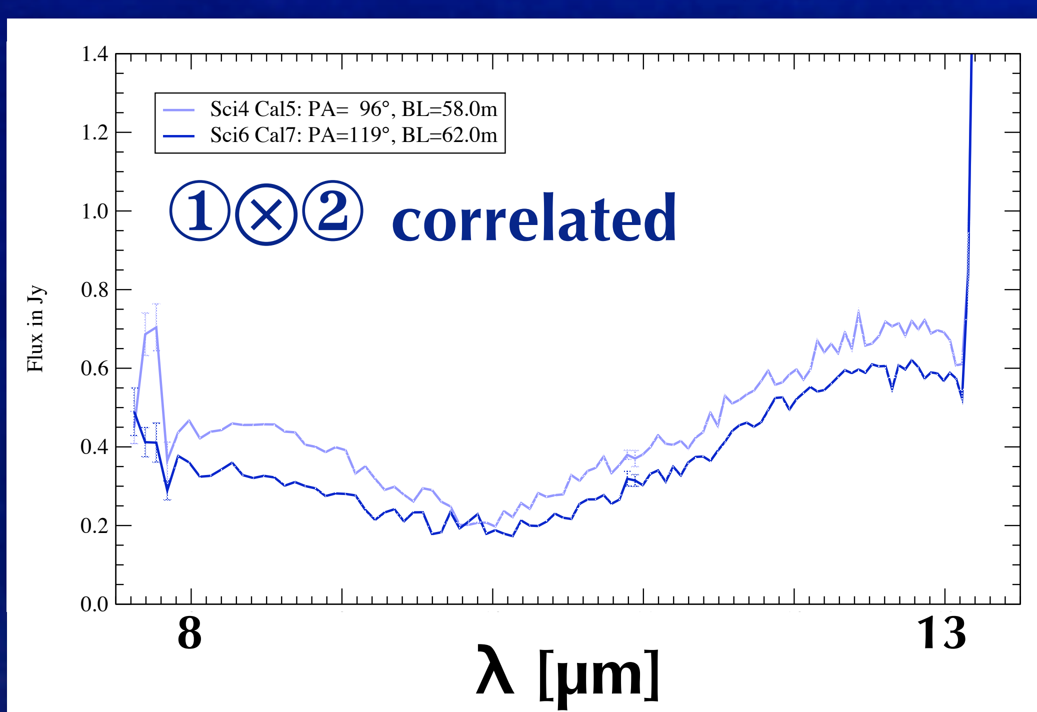


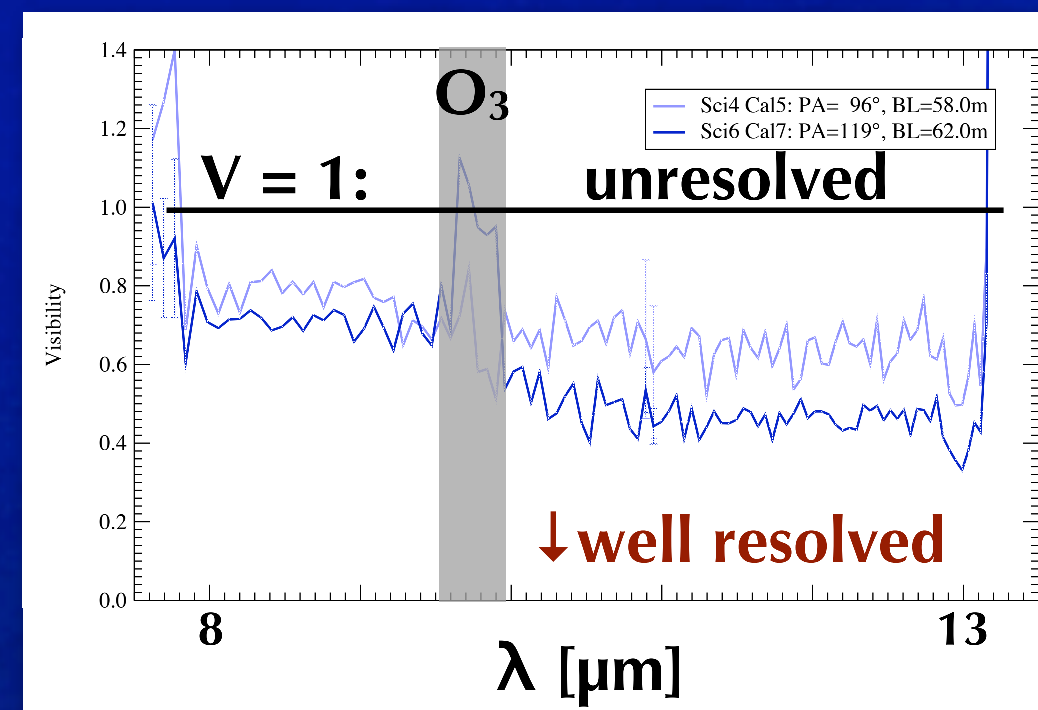
courtesy of Roy v. Boekel

The MID-infrared Interferometer MIDI

Output from the instrument







3. Observations of dusty molecular tori

status quo

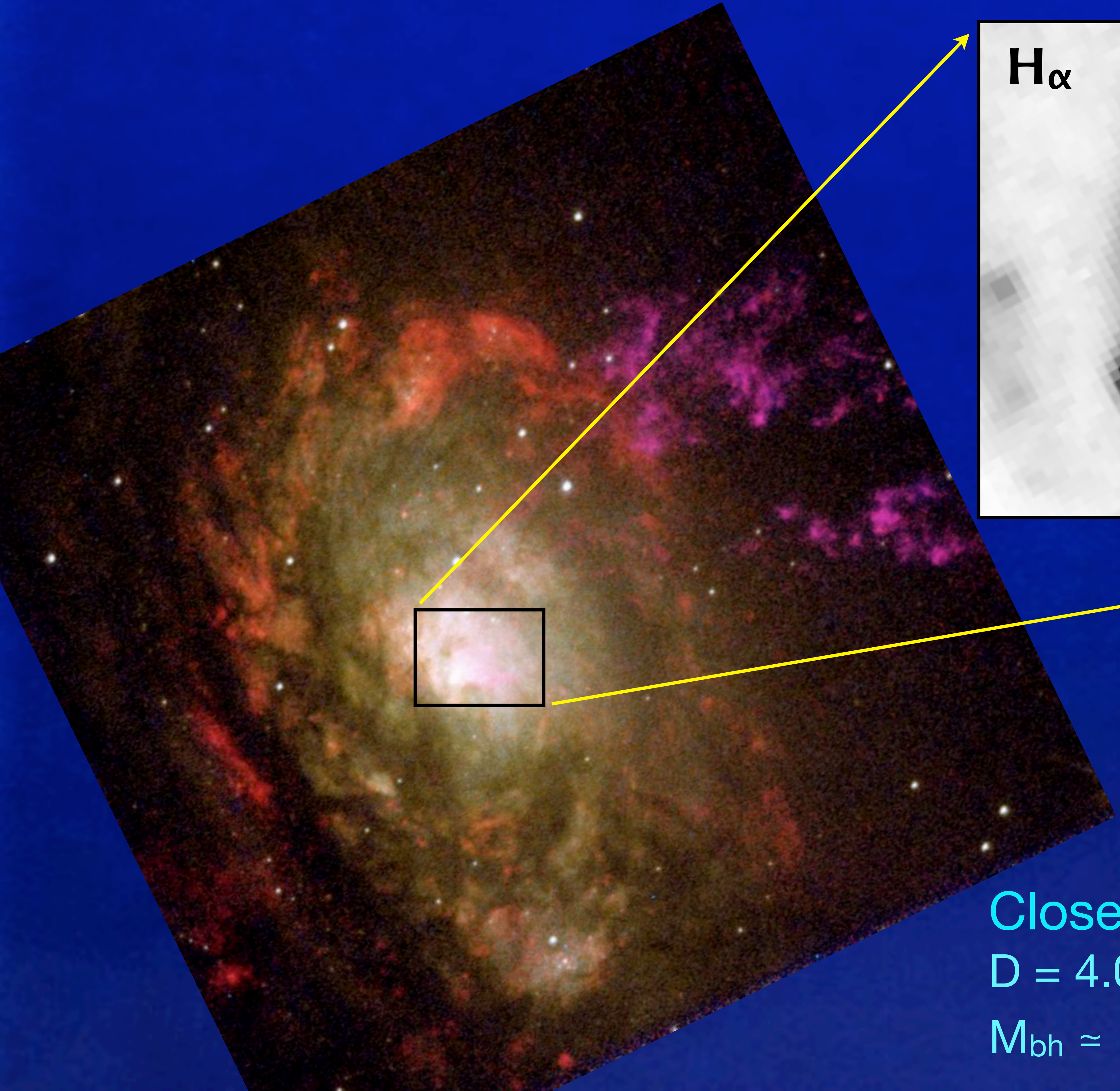
3.2 Resolving the dust distribution by interferometry

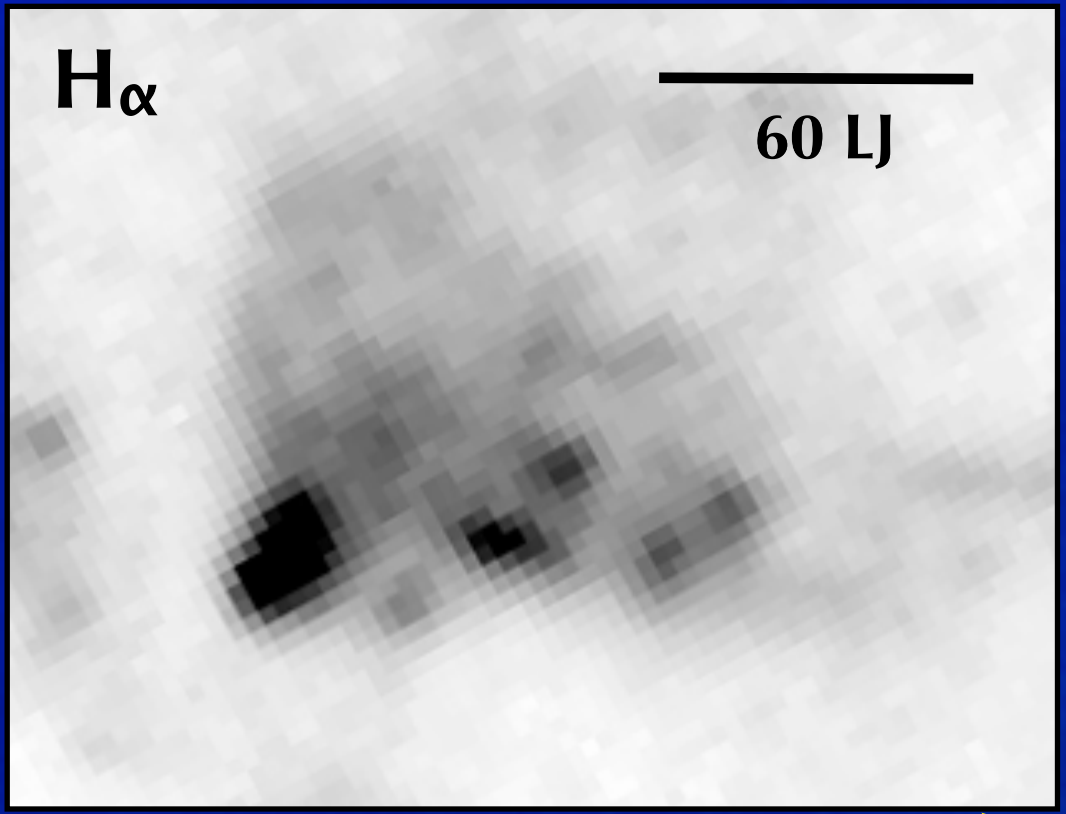
3.2.1 Dust torus in the Circinus galaxy

3.2.2 Dust torus in NGC 1068

3.2.3 The odd source: Centaurus A

Dust torus in the Circinus galaxy



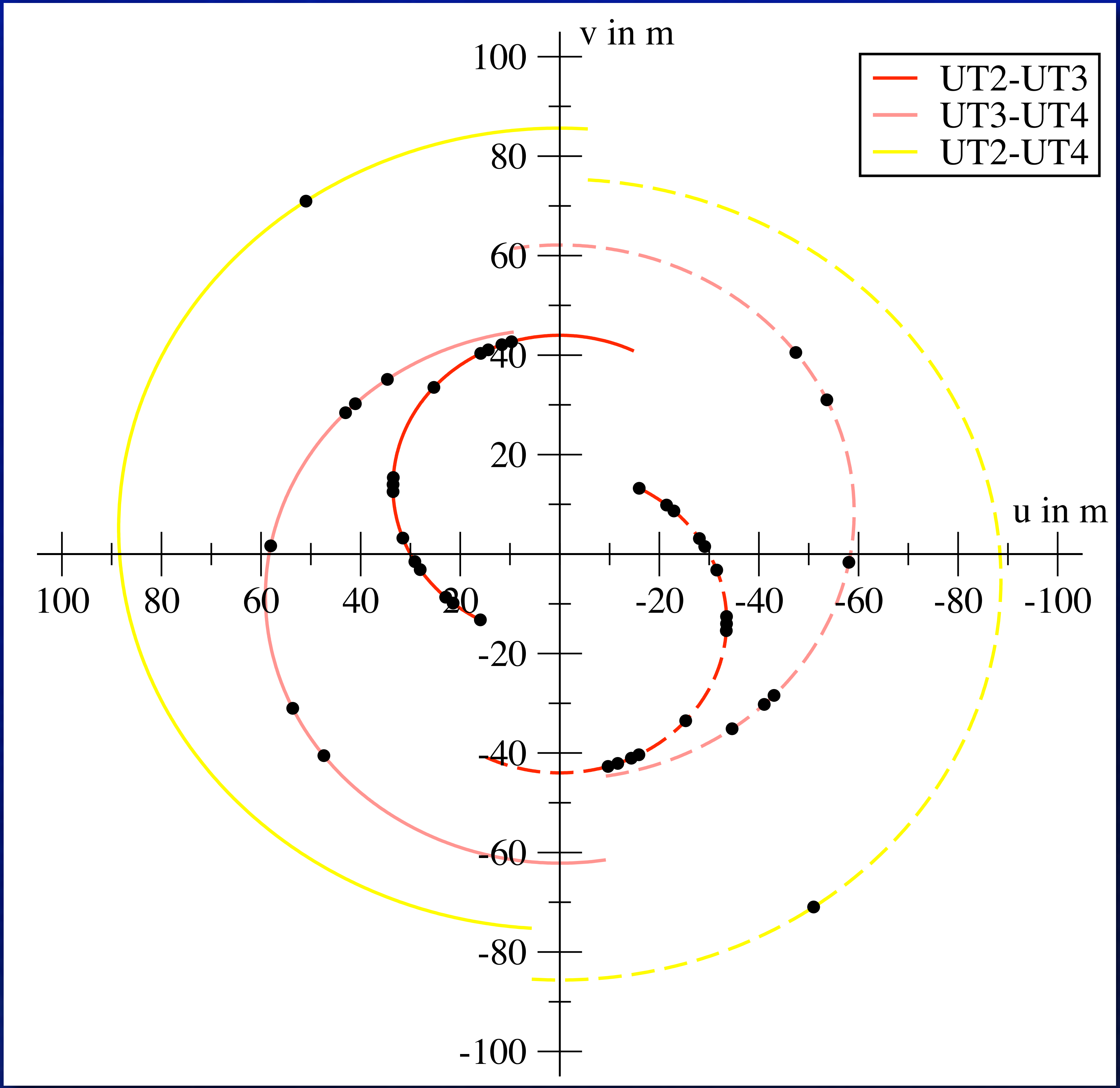


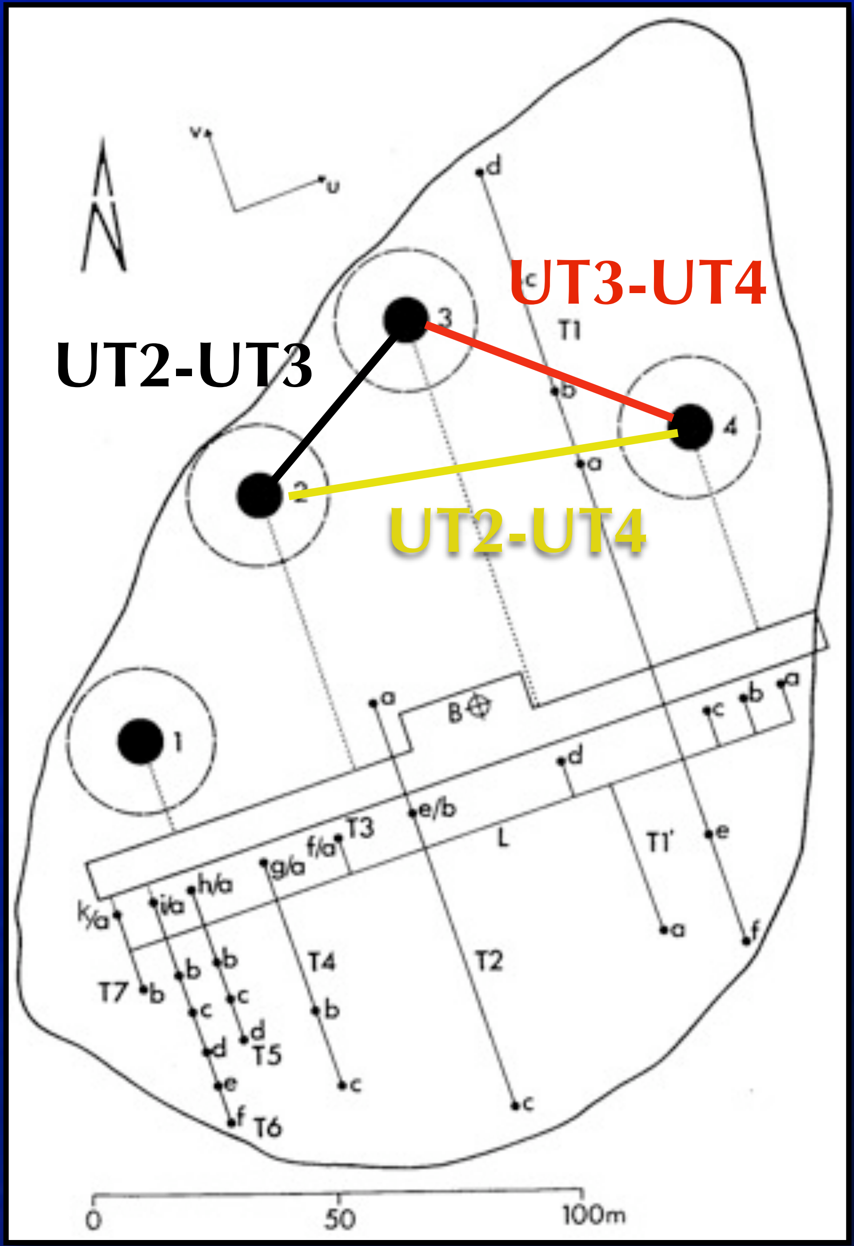
Closest Seyfert 2 galaxy

D = 4.0 Mpc → 1 pc = 50 mas

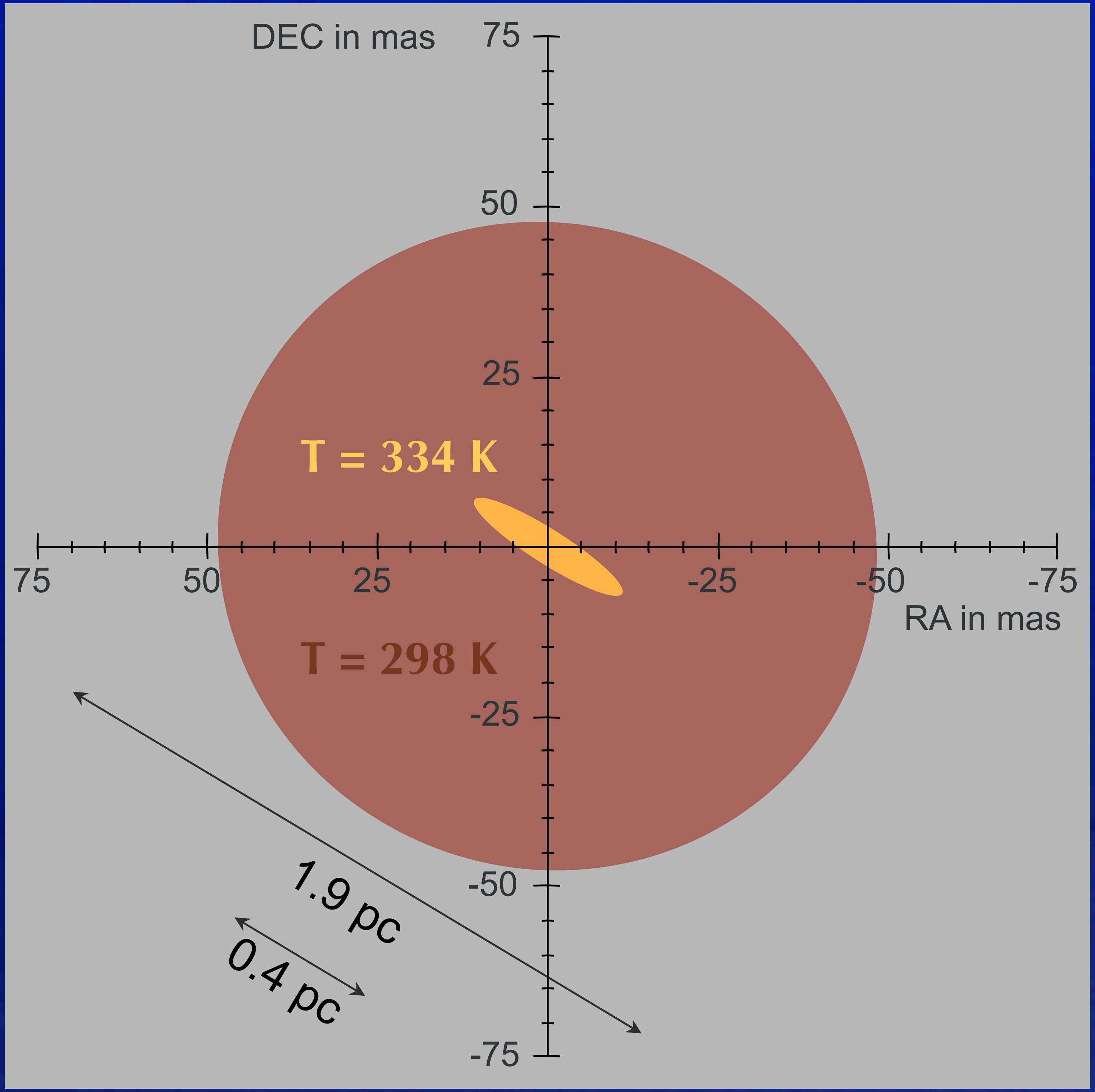
$M_{bh} \simeq 10^6 M_{sun}$

Dust torus in the Circinus galaxy



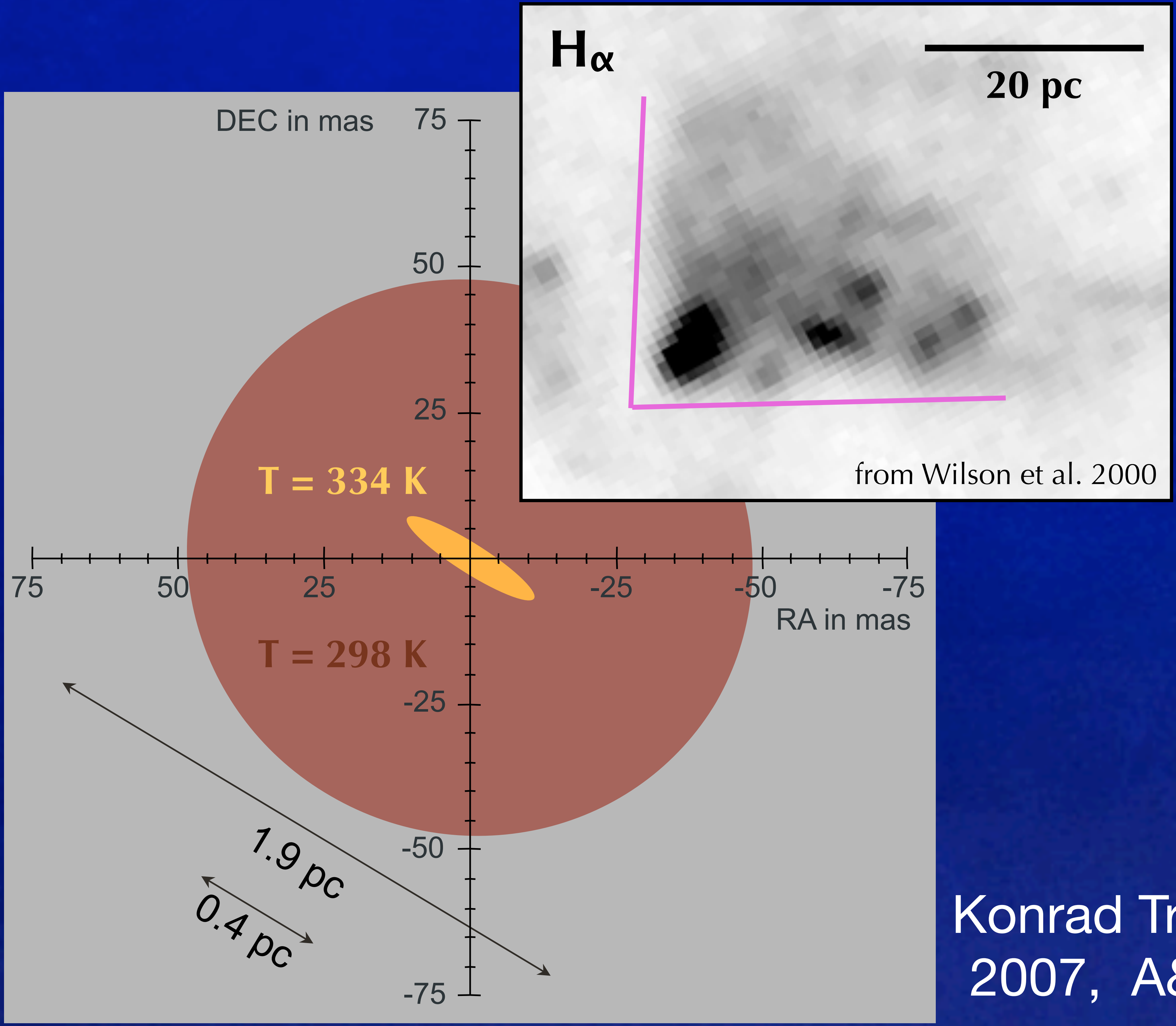


Dust torus in the Circinus galaxy



Konrad Tristram et al.
2007, A&A 474, 837

Dust torus in the Circinus galaxy



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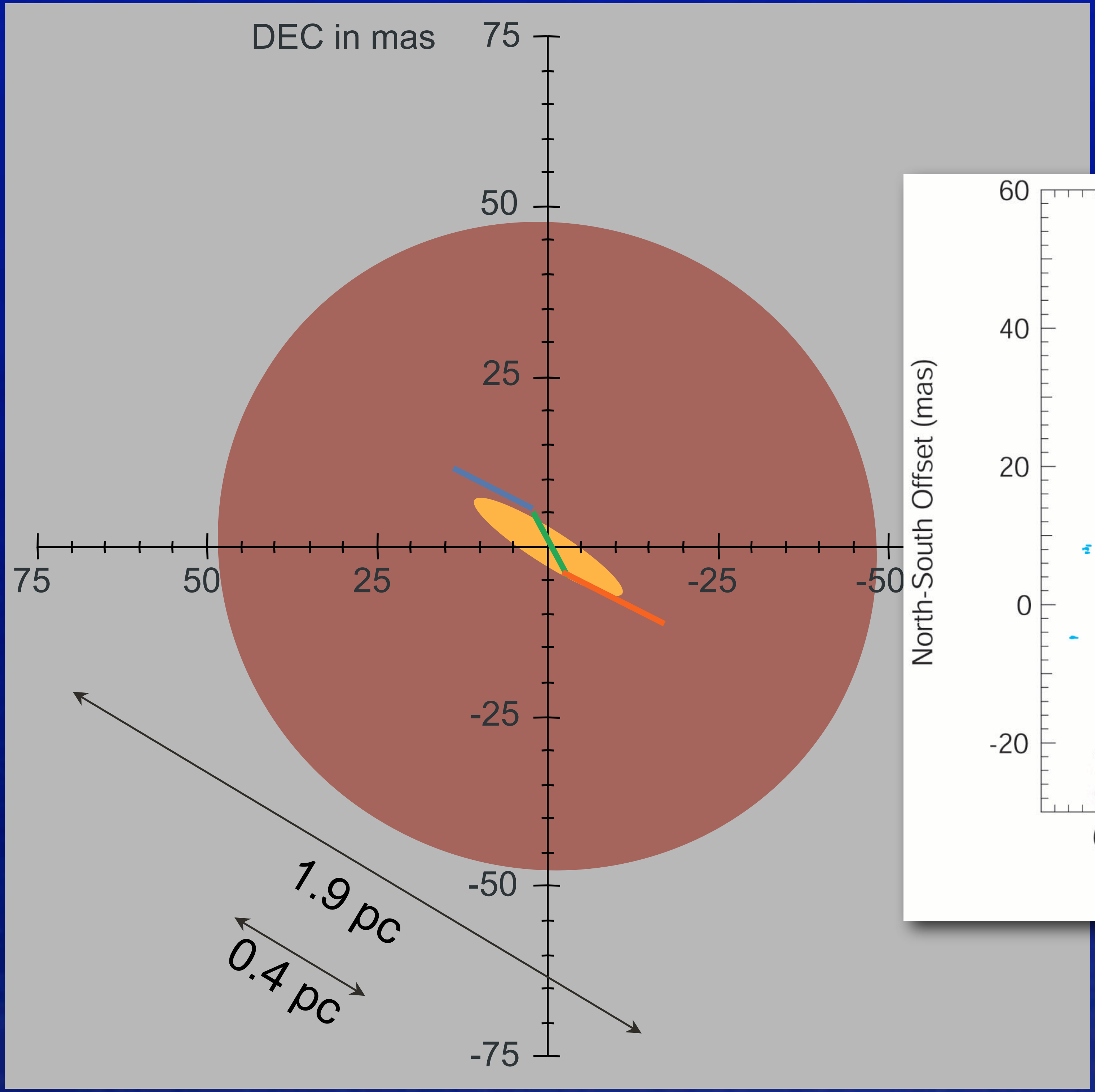
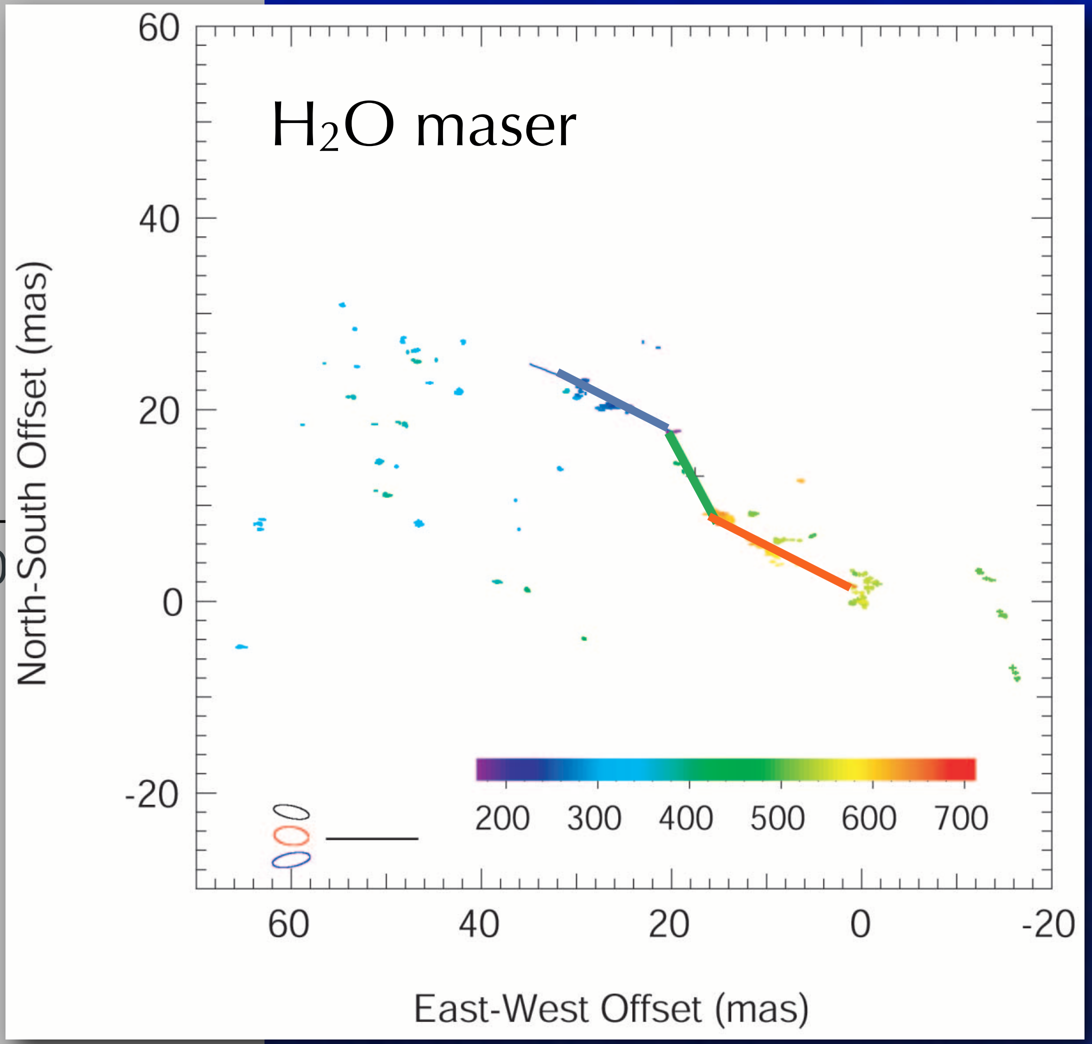
Dust torus in the Circinus galaxy



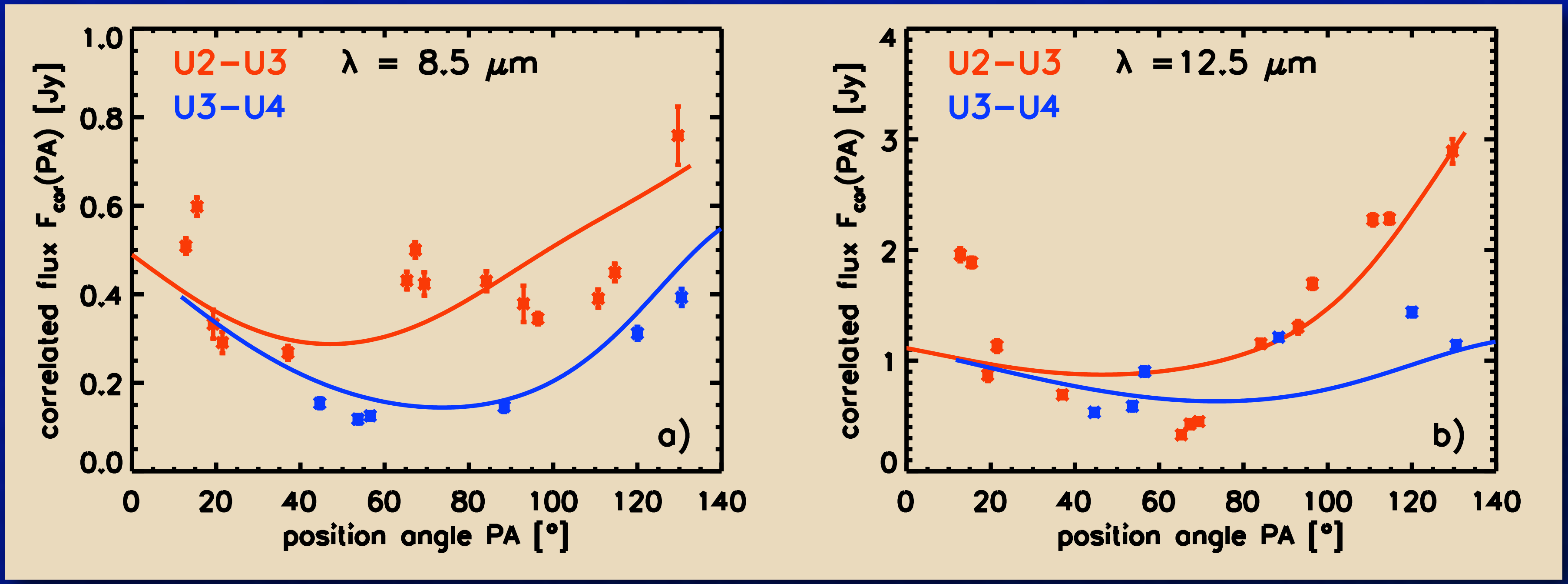


Greenhill et al. 2003

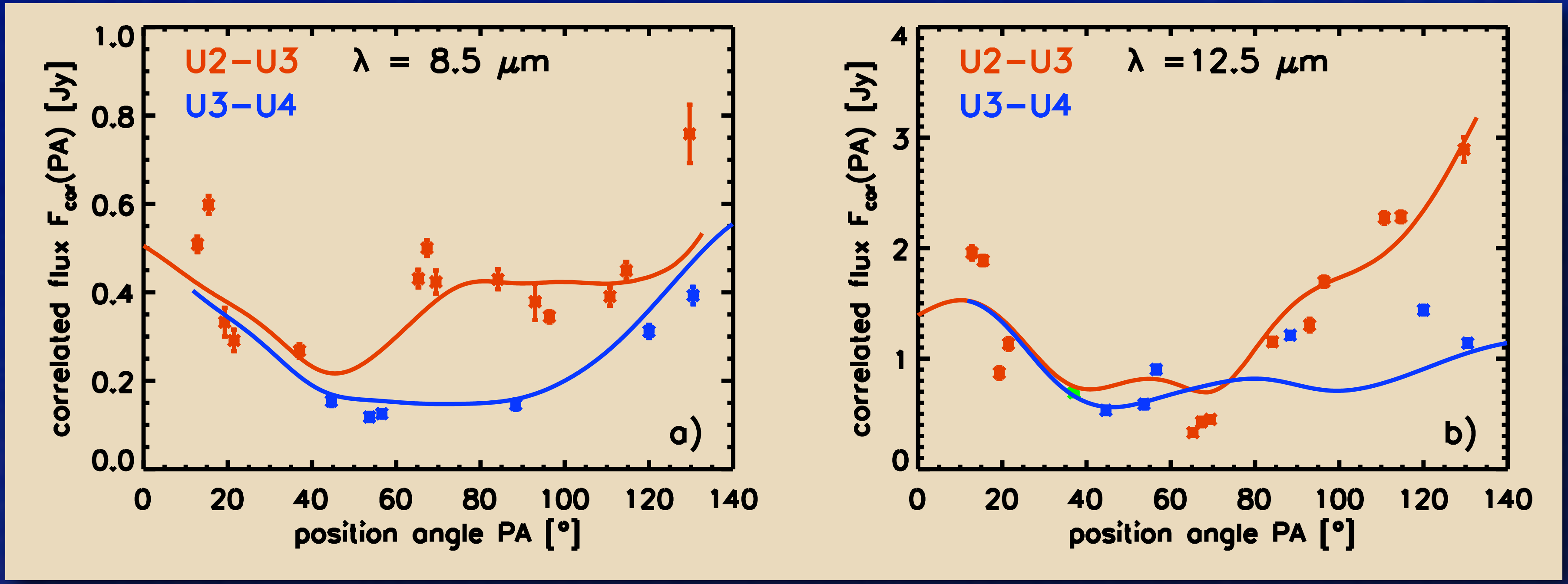
Dust torus in the Circinus galaxy

BUT ...

the smooth model is a rather poor fit to the visibilities:

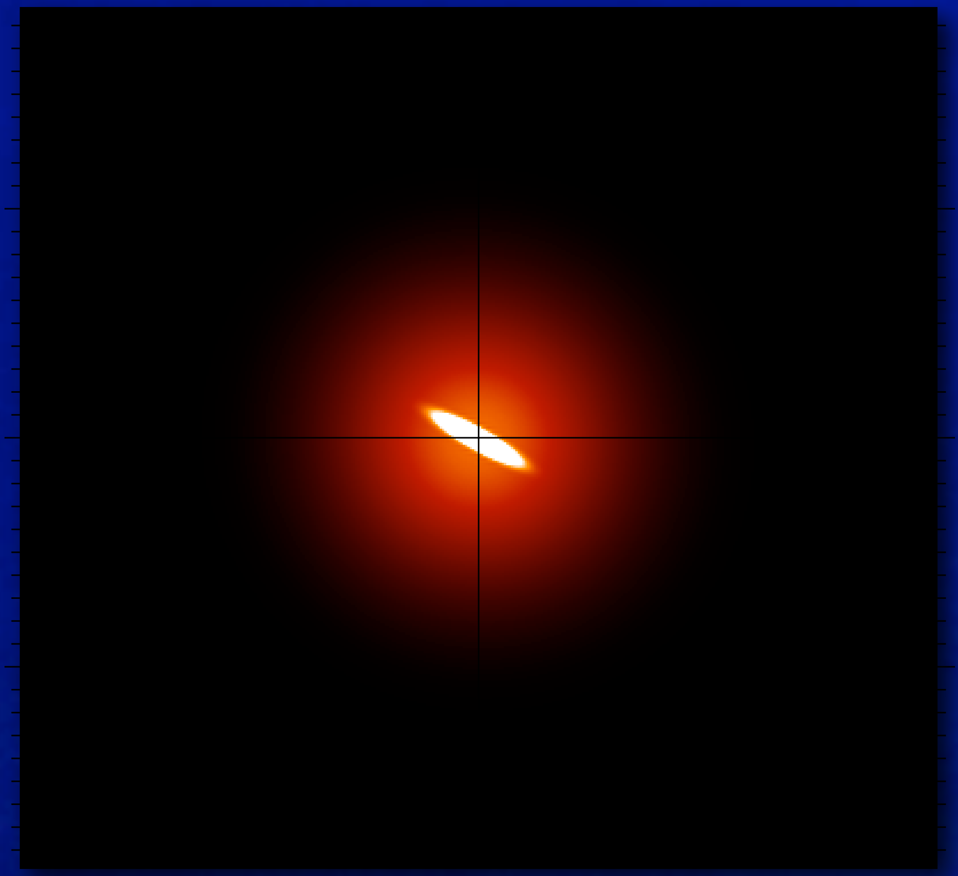


modify model by irregular screen:

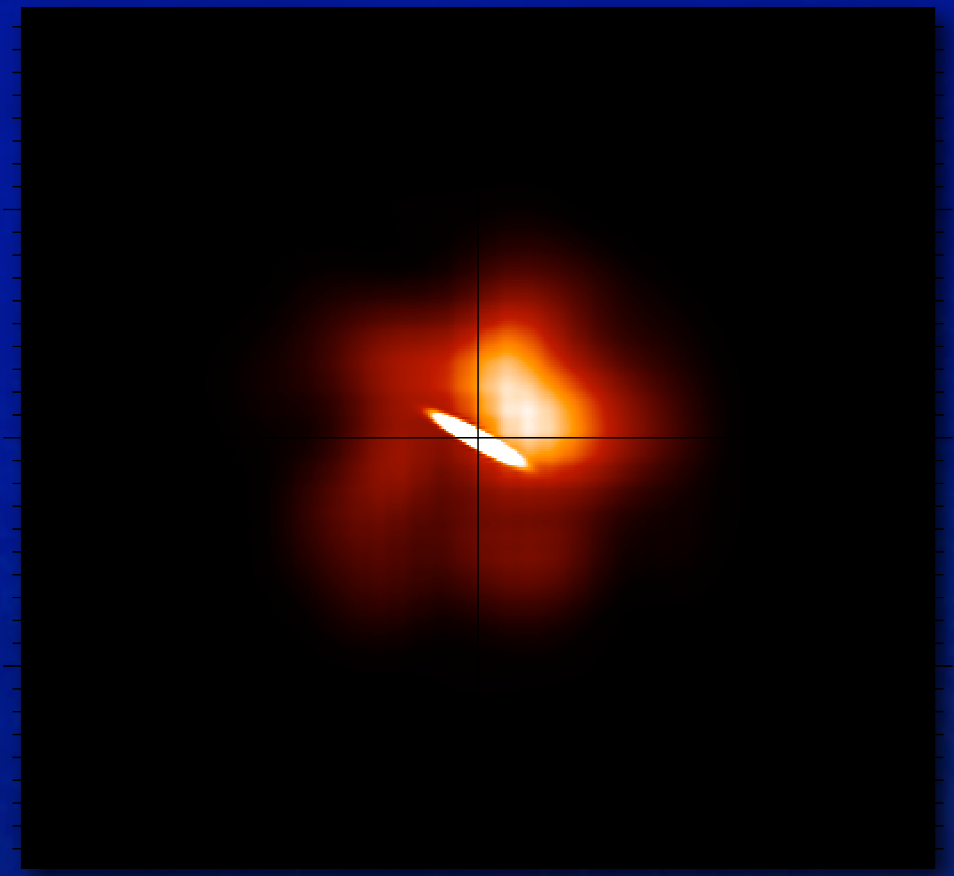


Dust torus in the Circinus galaxy

Images: smooth model

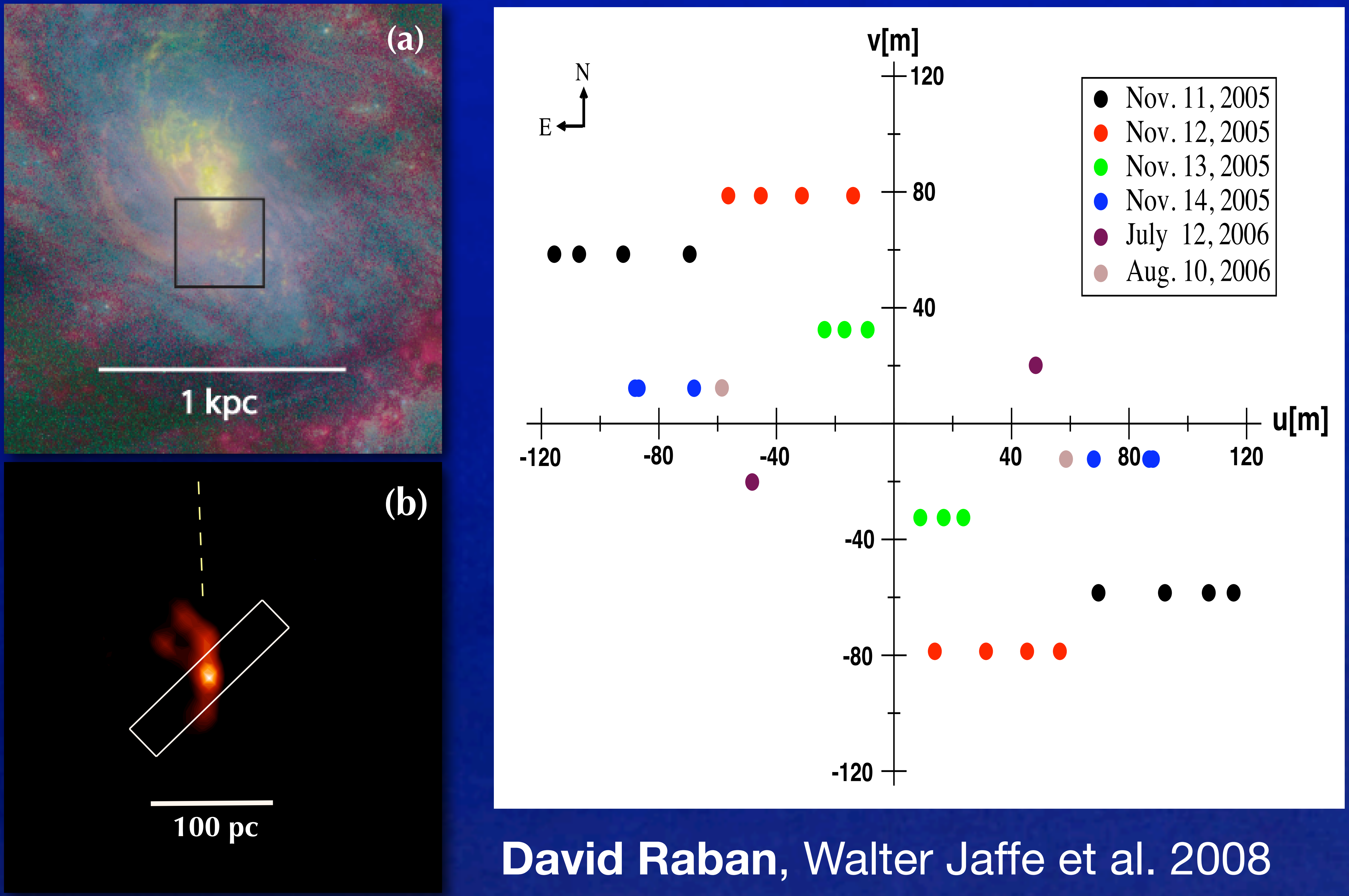


irregular/clumpy model



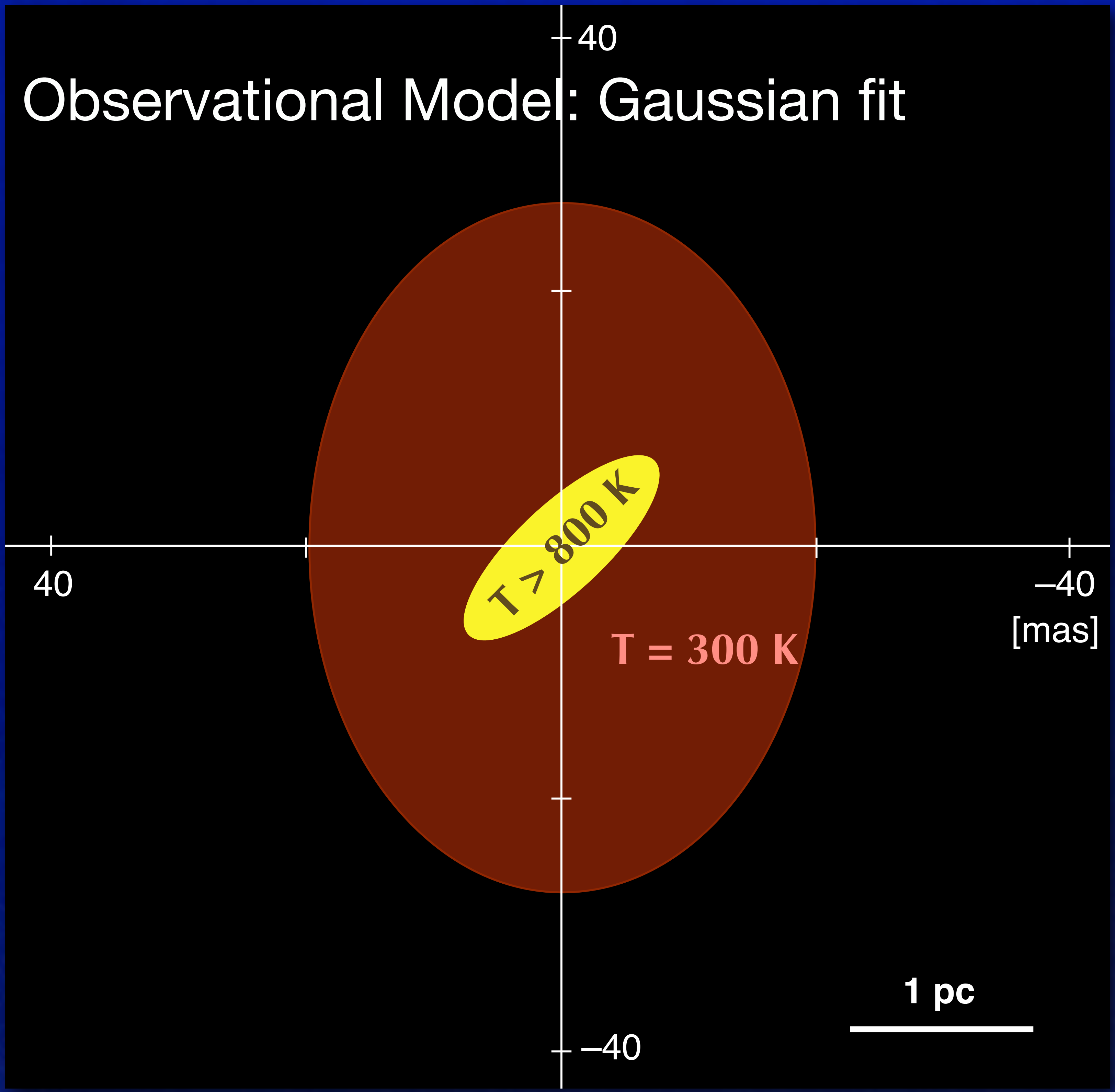
➥ talk by Konrad Tristram

Dust torus in NGC 1068



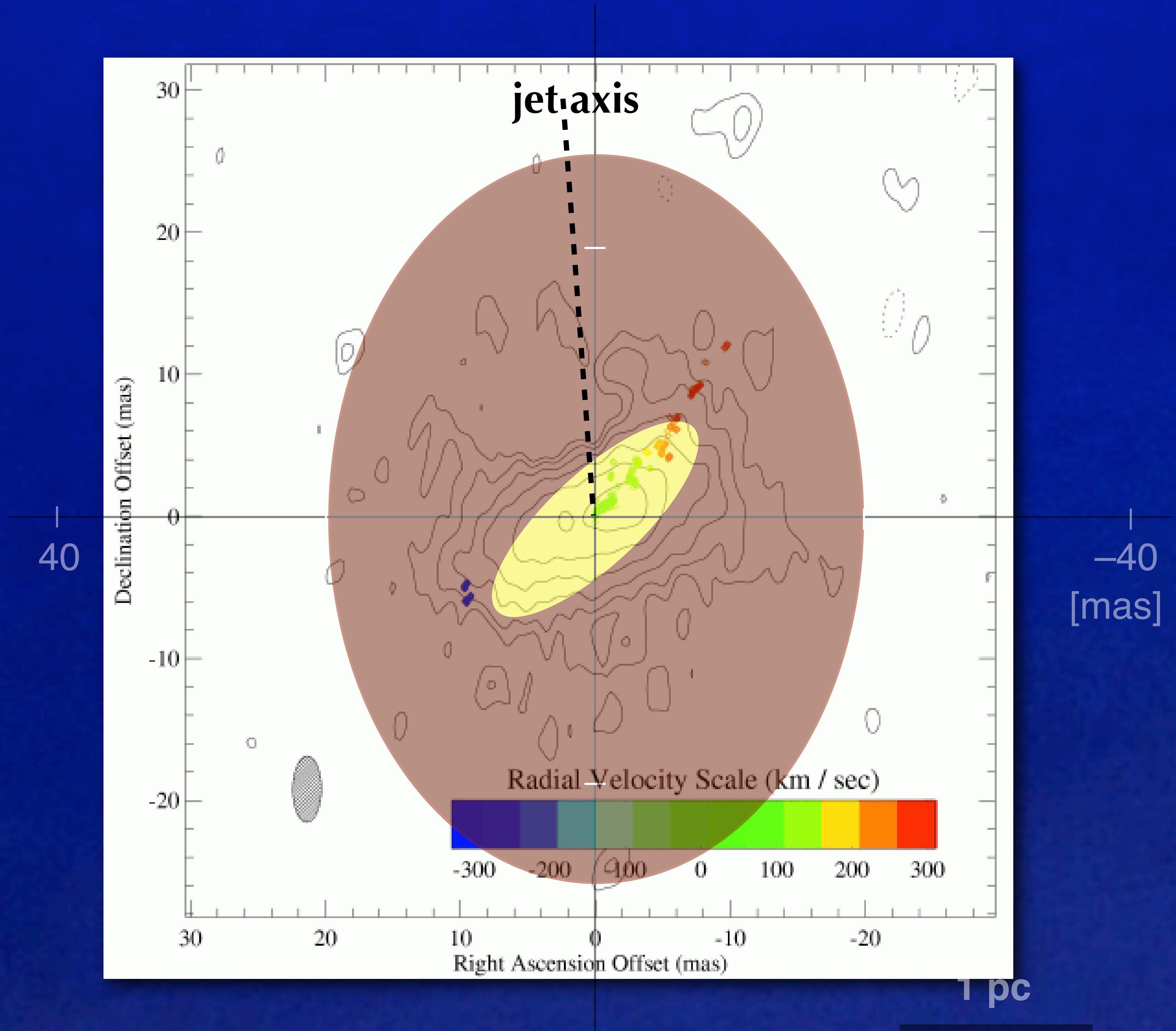
David Raban, Walter Jaffe et al. 2008

Dust torus in NGC 1068



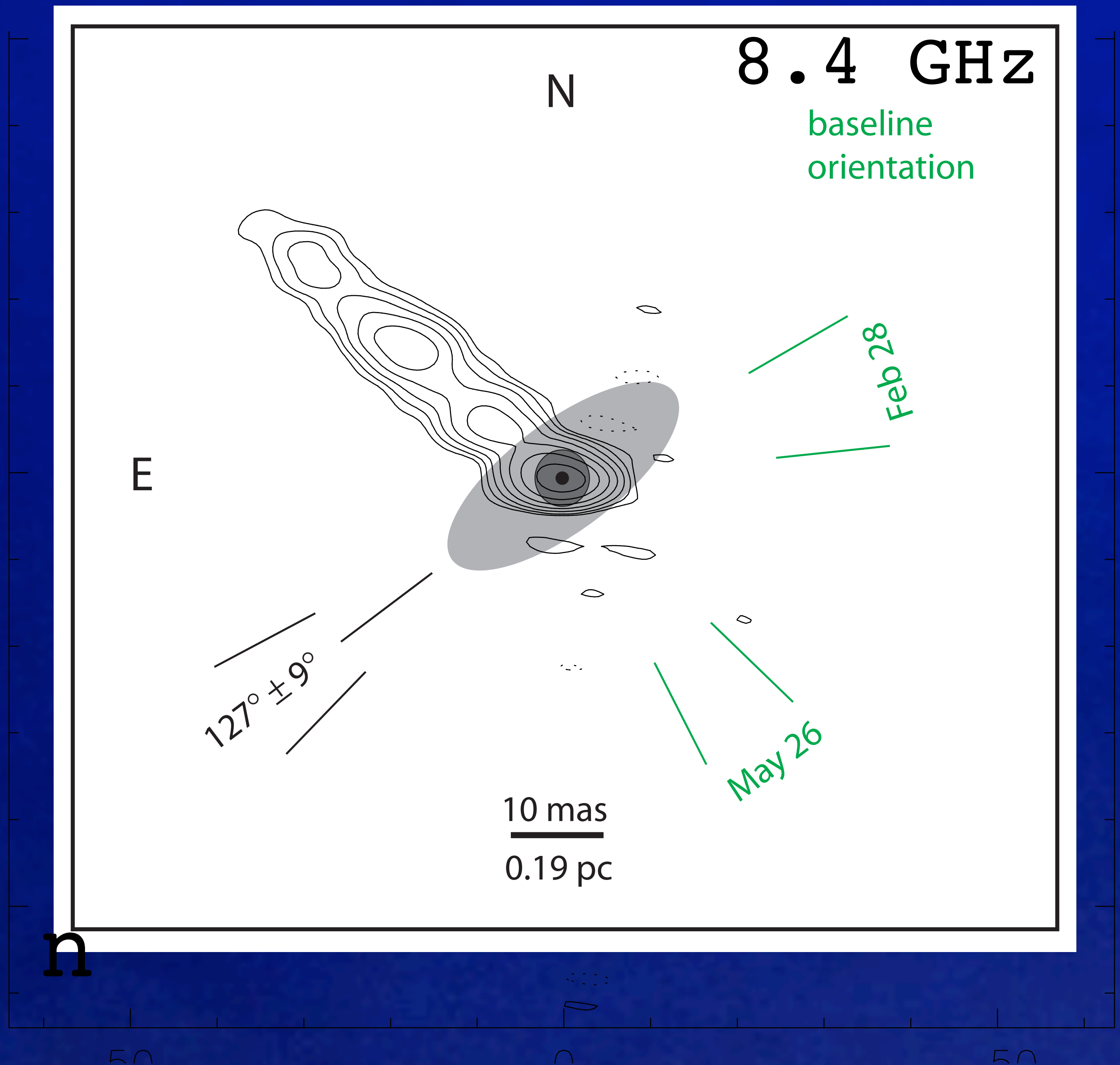
Dust torus in NGC 1068

Comparison with radio continuum and water masers



MIDI - VLTI observations of Centaurus A

Basic result:



1. Unresolved **core:**
   ~60% of 8...13 µm flux
2. **Dust disk:** d ≃ 0.6 pc,
   b:a = 1:3 (i = 66° ?),
   T = 240 K,
   $L_{10\mu} = 0.05\ L_{10\mu}$ (Circinus)

➥ talk by Leonard Burtscher

Outlook: Next steps with MIDI & AMBER

But a lot more can be done !

Name	α(J2000)	δ(J2000)	Type	z	Dist [Mpc]	Δ(1pc) [mas]	S_N(core) [mJy]	beam	Imme
NGC 1068	02 40 40.7	-00 00 48	S2	0.00379	17.4	11.9	3400	$0''.2$	torus,
✔ NGC 1365	03 33 36.4	-36 08 25	S1.8	0.00546	25.2	8.2	610	$0''.5$	torus,
? IRS 0518-25	05 21 01.7	-25 22 14	S2	0.0425	196.4	1.0	550	$0''.5$	size ?
MCG-5-23-16	09 47 40.2	-30 56 54	S2	0.00827	38.1	5.4	650	$0''.5$	size, o
Mrk 1239	09 52 19.1	-01 36 43	S1	0.0199	91.9	2.2	640	$0''.5$	size ?
NGC 3256	10 27 51.8	-43 54 09	HII	0.00913	42.1	4.9	550	$0''.5$	size ?
NGC 3281	10 31 52.1	-34 51 13	S2	0.01067	49.2	4.2	620	$0''.5$	size ?
✔ NGC 3783	11 39 01.8	-37 44 19	S1	0.00973	44.9	4.6	590	$0''.5$	size ?
NGC 5128	13 25 27.6	-43 01 09	RG	0.00182	8.4	24.6	1220	$0''.5$	size, o
✔ IC 4329A	13 49 19.3	-30 18 34	S1	0.01605	74.0	2.8	350-500	$0''.5$	detect
Mrk 463	13 56 02.9	+18 22 19	S1	0.0504	232.3	0.9	340	$0''.5$	detect
Circinus	14 13 09.3	-65 20 21	S?	0.00145	6.6	31.3	9700	$0''.5$	size, t
? NGC 5506	14 13 15.0	-03 12 27	S2	0.00618	28.5	7.2	910	$0''.5$	size, o
✔ NGC 7469	23 03 15.6	+08 52 26	S1	0.01631	75.2	2.7	410	$0''.5$	detect
NGC 7582	23 18 23.5	-42 22 14	S2	0.00539	24.8	8.3	320	$0''.5$	detect
3C 273	12 29 06.7	+02 03 08	RQ	0.1583	731.0	0.3	350var	$0''.5$	detect
NGC 253 core	00 47 33.1	-25 17 17	LE	0.00080	3.6	57.3	380-1160	$0''.5$	detect

Observations of Dusty Molecular Tori

Summary of *status quo*:

1. MIDI @ VLTI allow us to study the dust distribution in Seyfert galaxies with 15 mas (~ 1pc) resolution.
2. We see fine structure (dusty disks, clumpiness) !
3. Large differences from source to source
4. Centaurus A: feeble disk which hardly obscures
5. Interpretation of the MIDI observations needs models!

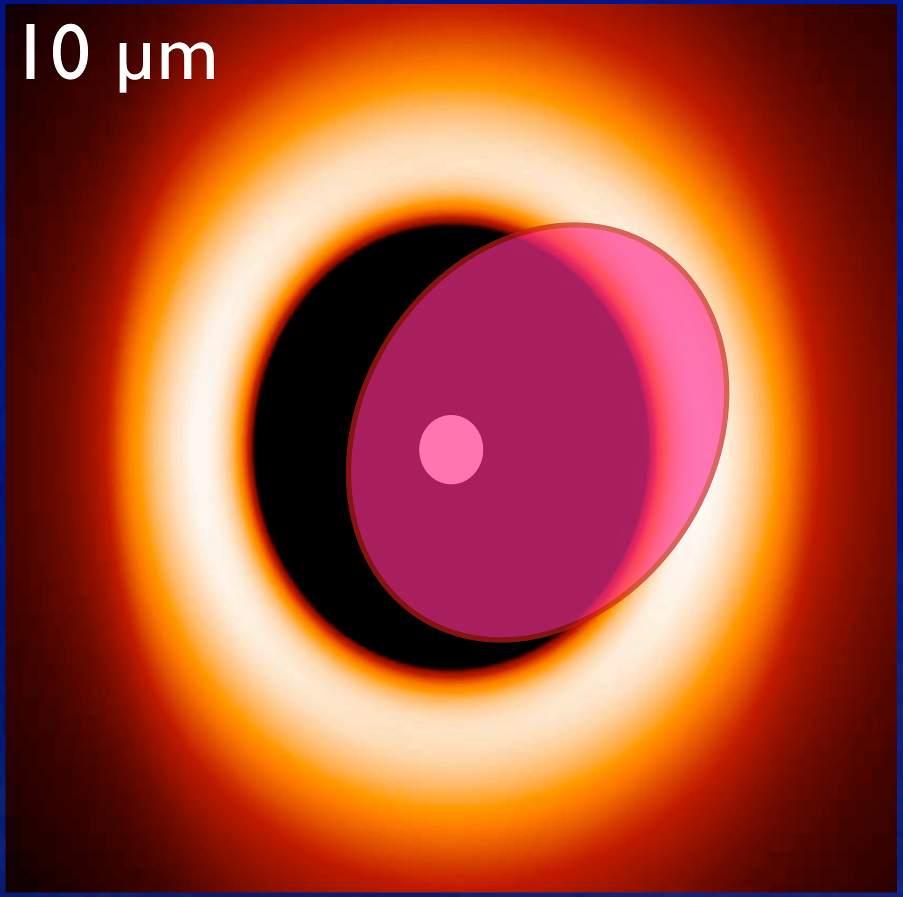
Torus research with interferometers: the challenges ahead

1. Verify the unified scheme: Seyfert 1 = Seyfert 2

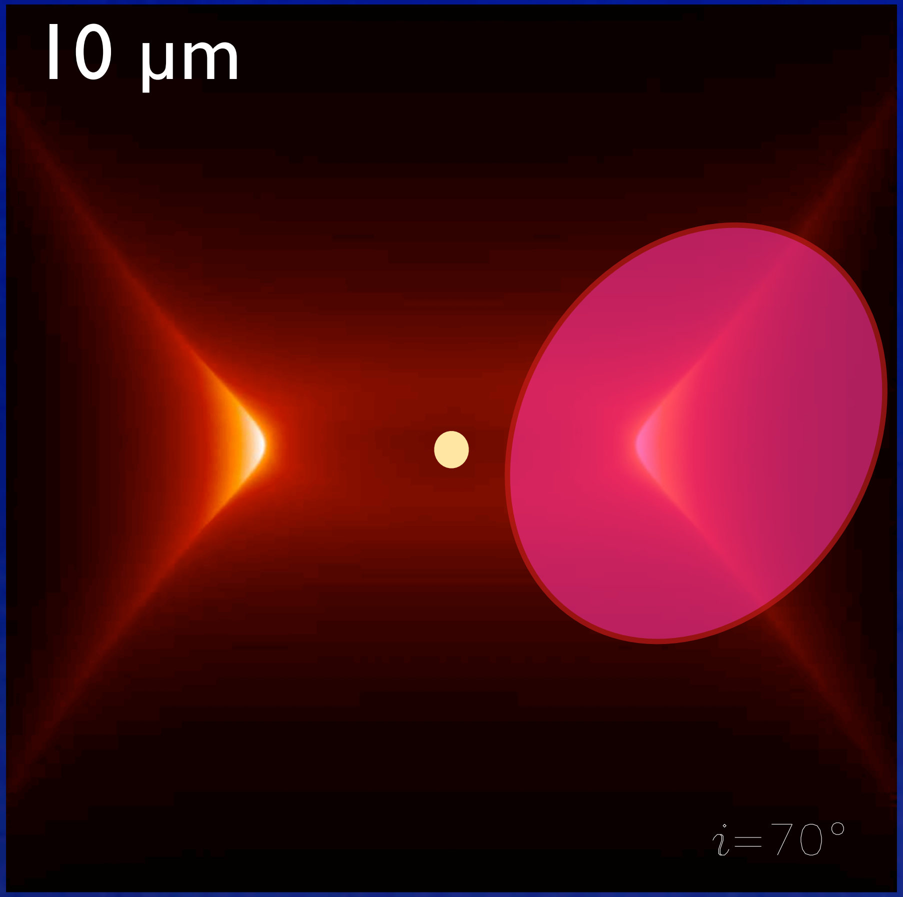
Seyfert 1 NGC 4151 has been resolved with MIDI.

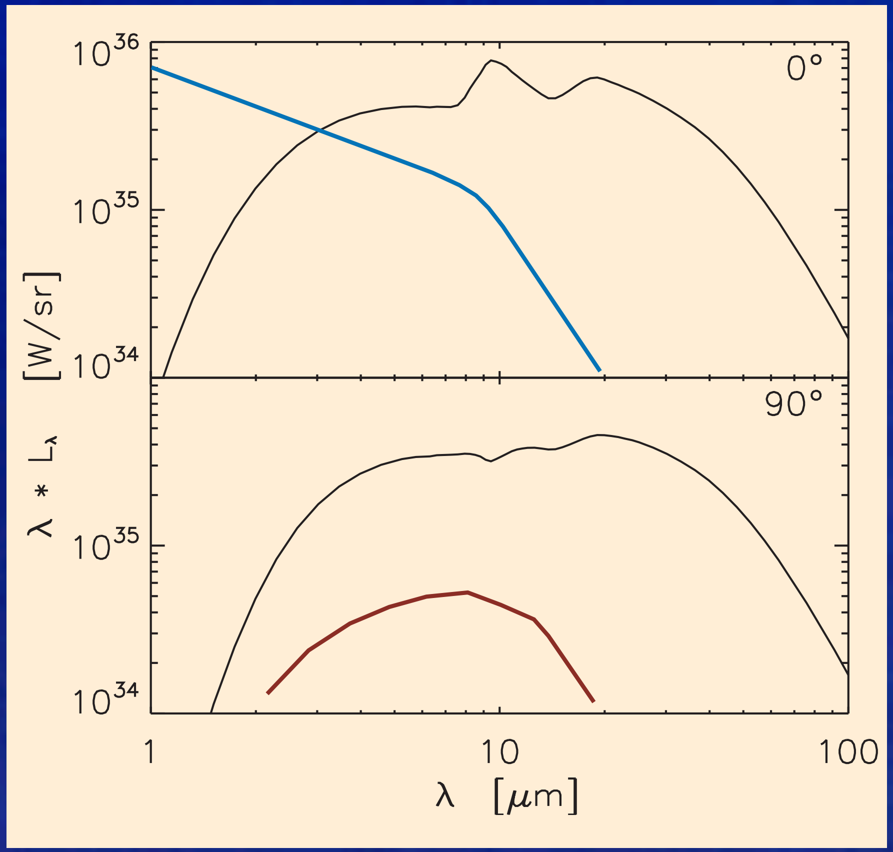
➥ talk by Leonard Burtscher

Seyfert 1



Seyfert 2





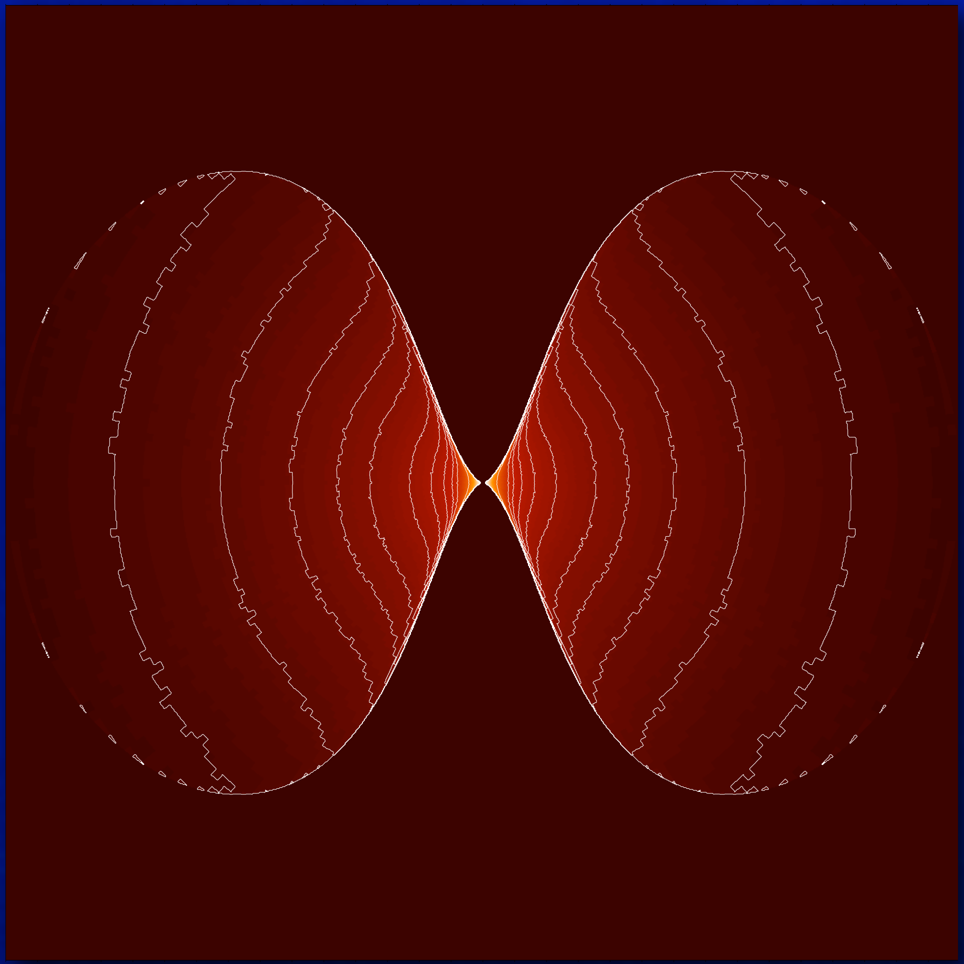
Torus research with interferometers: the challenges ahead

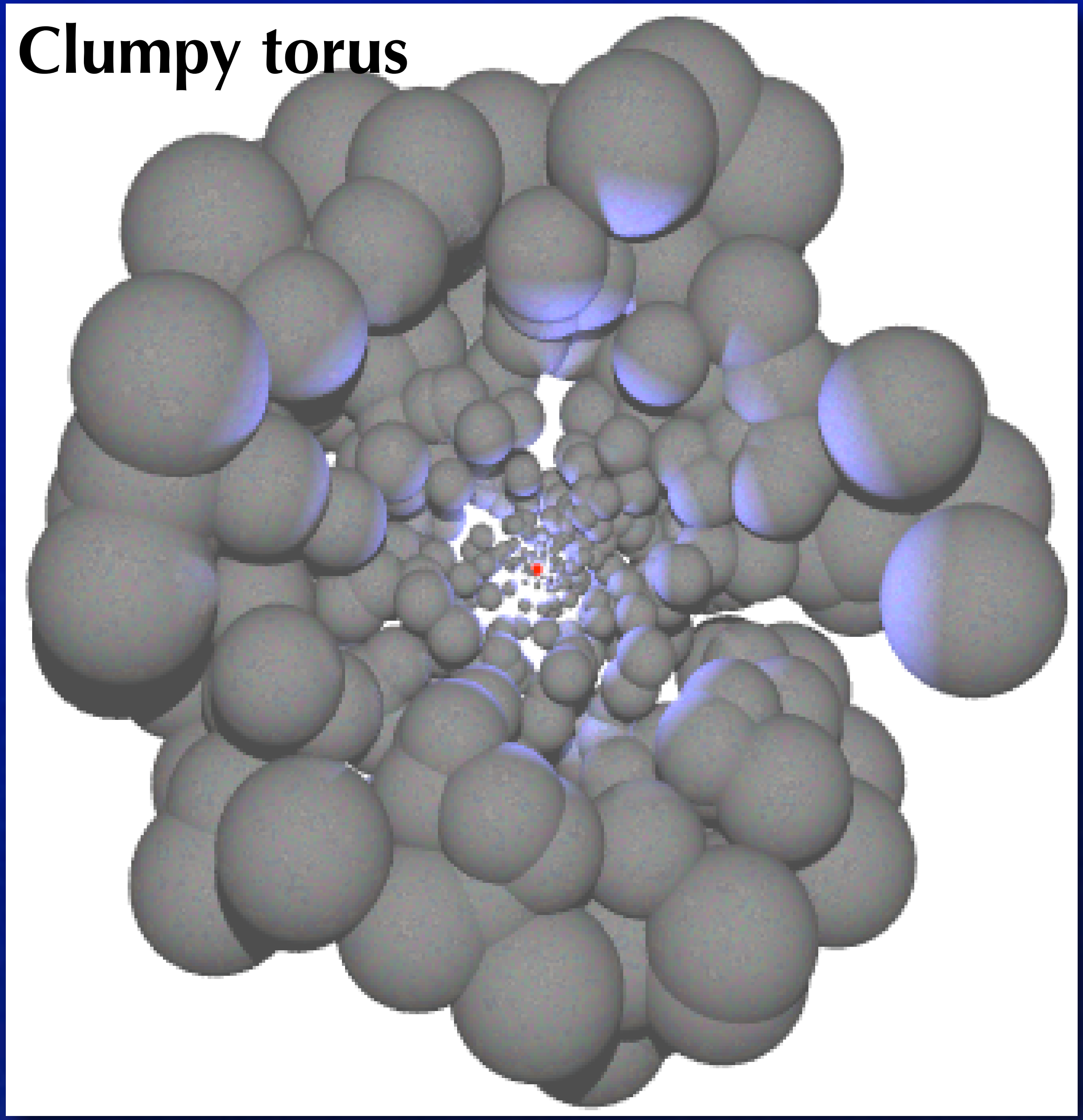
1. Verify the unified scheme: Seyfert 1 = Seyfert 2

2. Dissecting the "dust torus"

Dissecting the dust torus

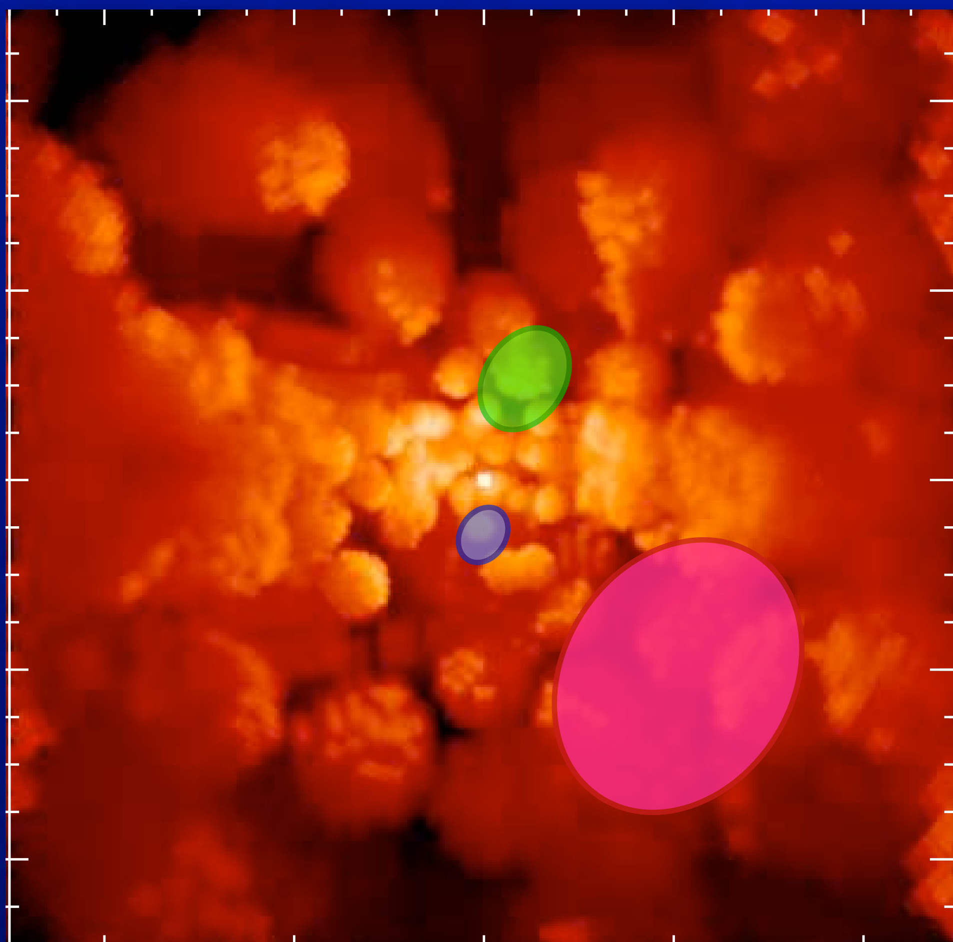
Continuous dust torus

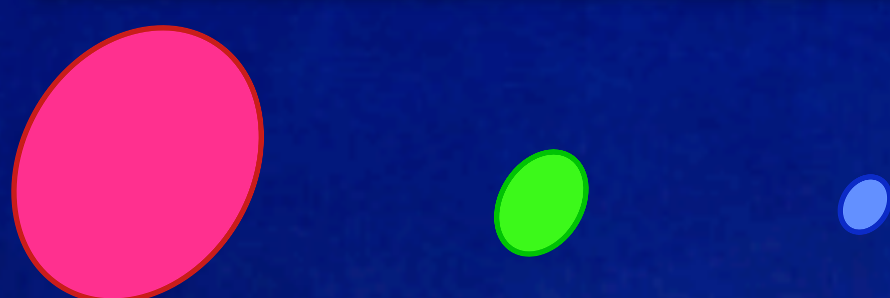




Dissecting the dust torus

Clumpy dust torus





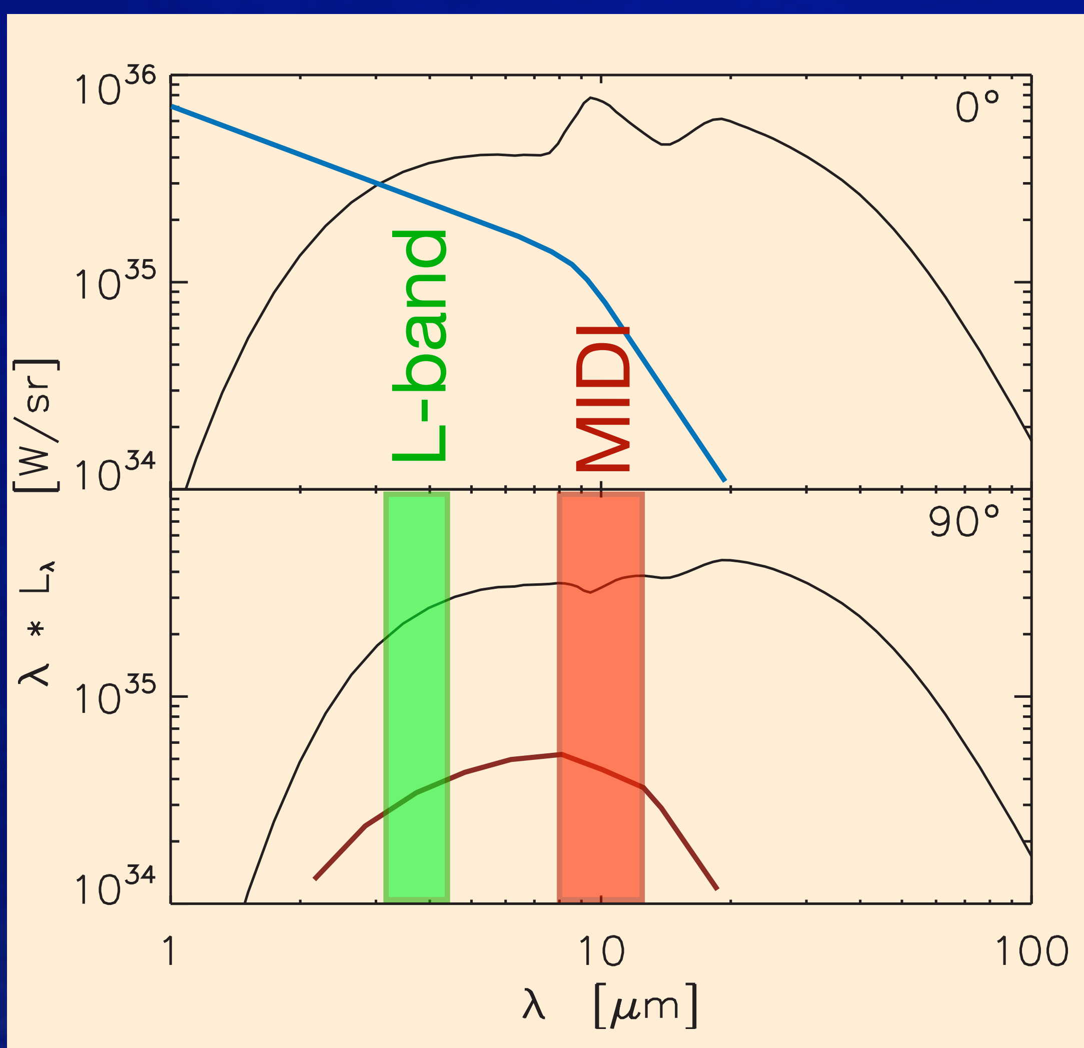
λ = 10 µm   3.6 µm   2 µm

Imaging is needed !

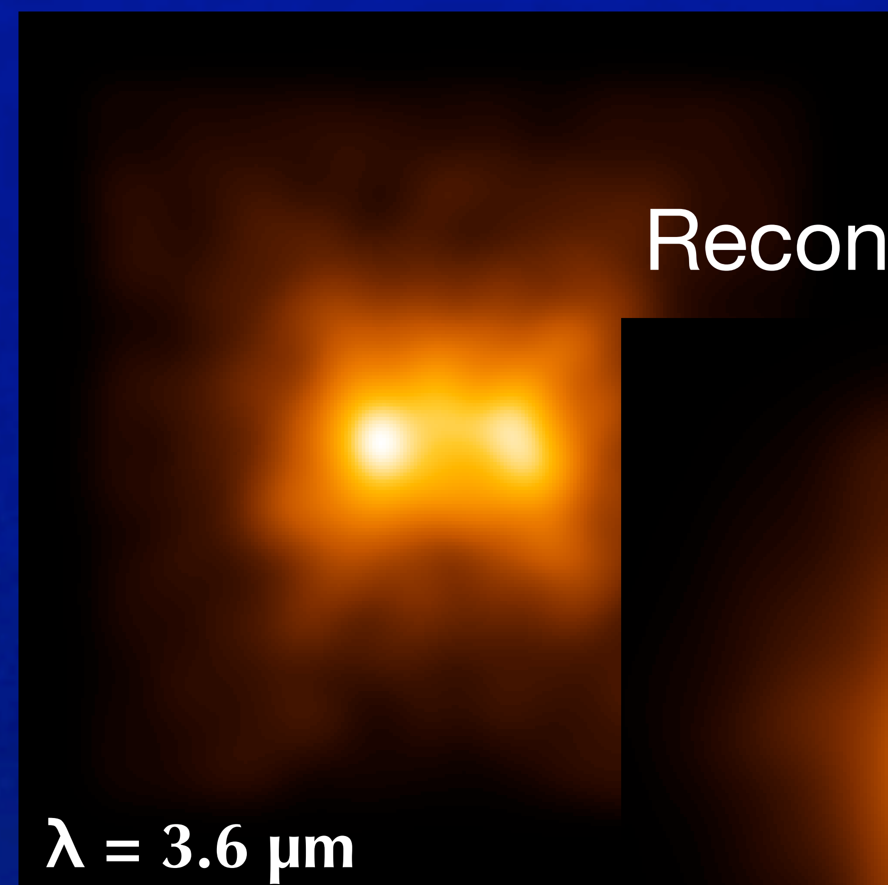
2nd generation instruments at the VLTI

2nd generation instruments at the VLTI

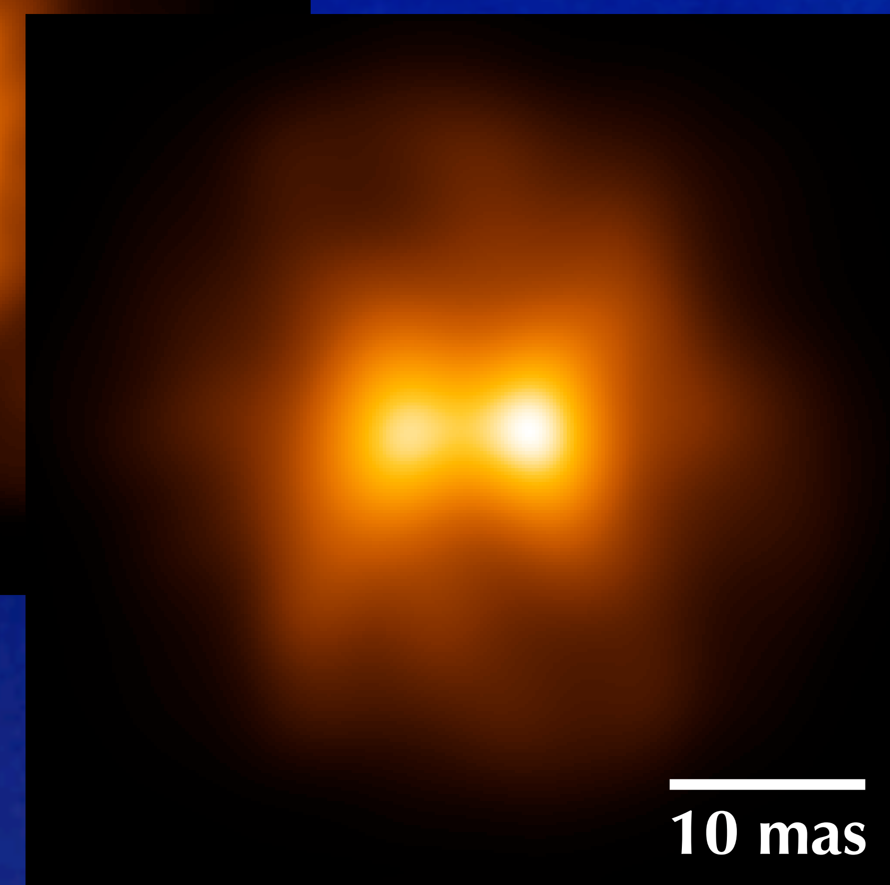
MATISSE will allow imaging (4 UT) at 10 μm (as MIDI)and in L-band (3.6 μm)



Input image:



Reconstructed image:



from K.-H.Hofmann, MPIfR

AGN research with interferometers: the challenges ahead

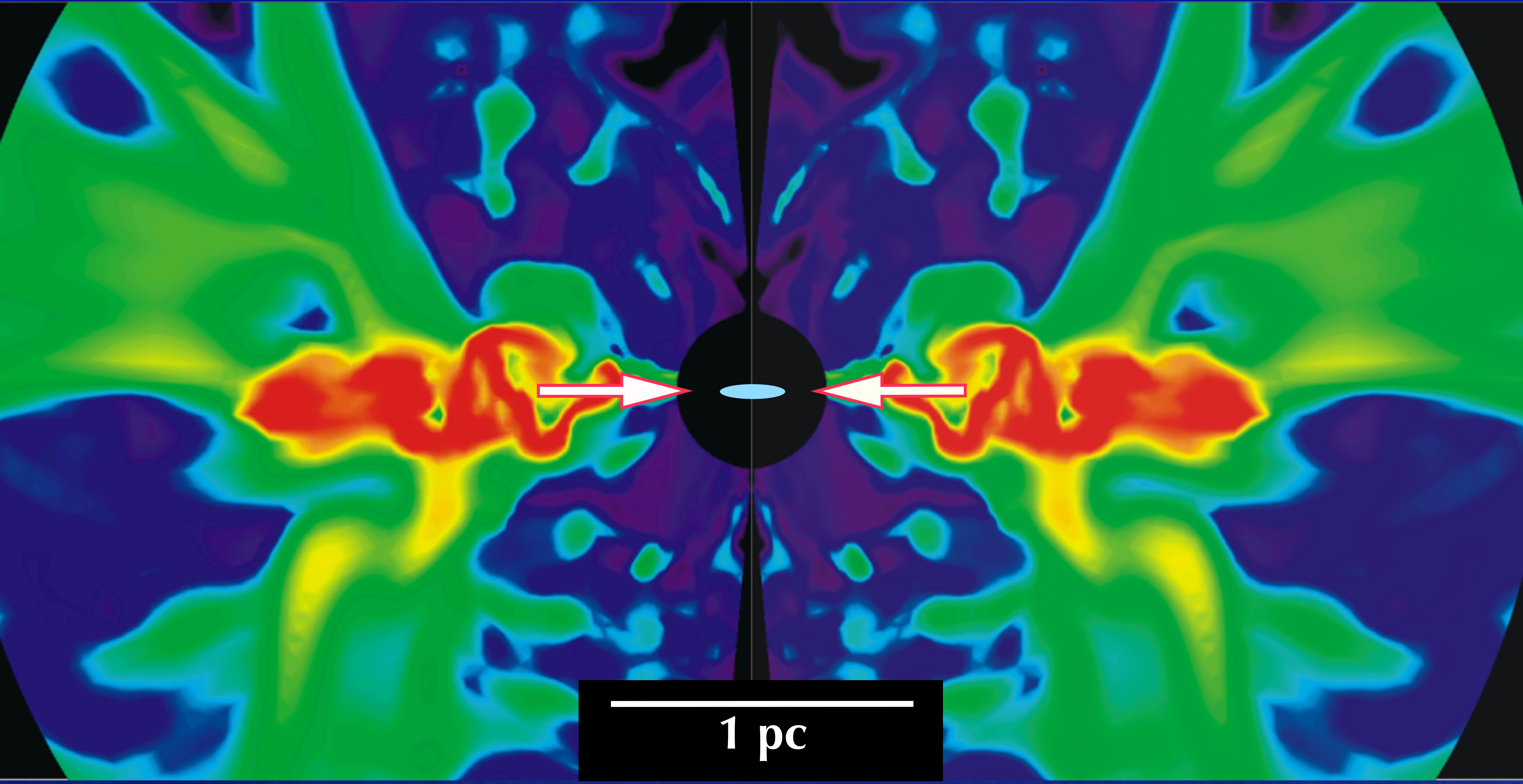
1. Verify the unified scheme: Seyfert 1 = Seyfert 2
2. Dissecting the “dust torus”
3. The fueling problem

Fueling the AGN – the role of the torus

Hydrodynamical Torus Model
(Marc Schartmann 2007)

needs ~1 mas resolution

AMBER+PRIMA ?   GRAVITY ?



Observations of Dusty Molecular Tori

Summary: the challenges ahead

1. Verify the unified scheme: Seyfert 1 = Seyfert 2.
→ needs larger samples of (more distant) galaxies.

2. Investigate the internal structure of the tori:
inclined dusty disks, clumps, filaments, ... ?

3. Understand the role of the dusty molecular tori
in fueling the accretion disk.