# High-Resolution studies of AGN tori

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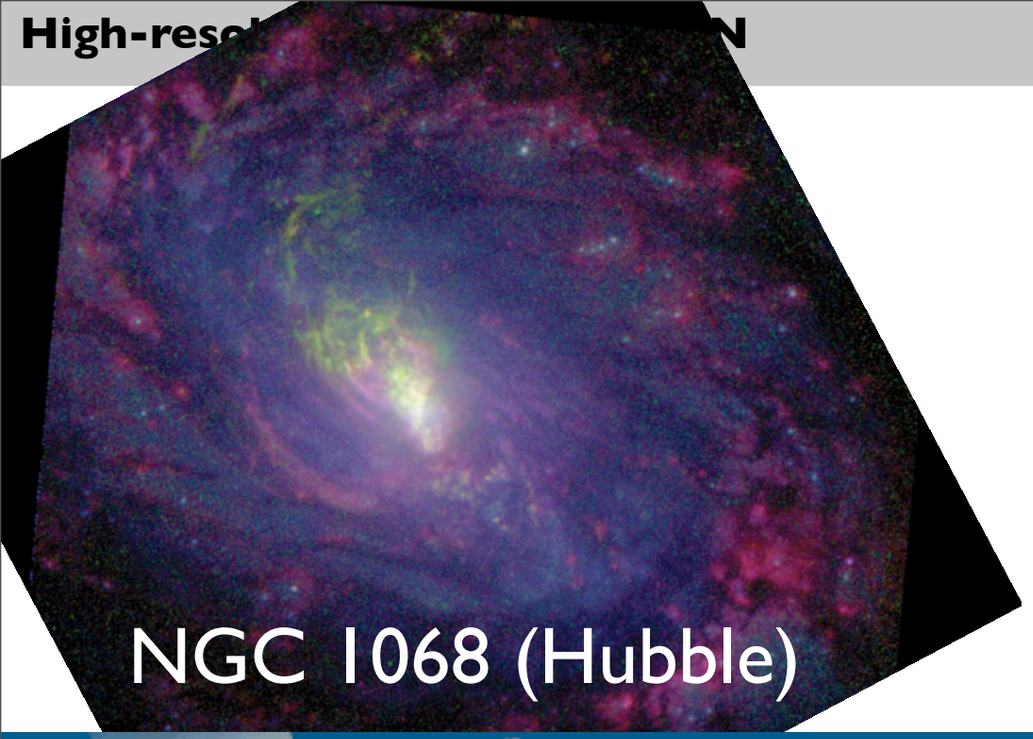
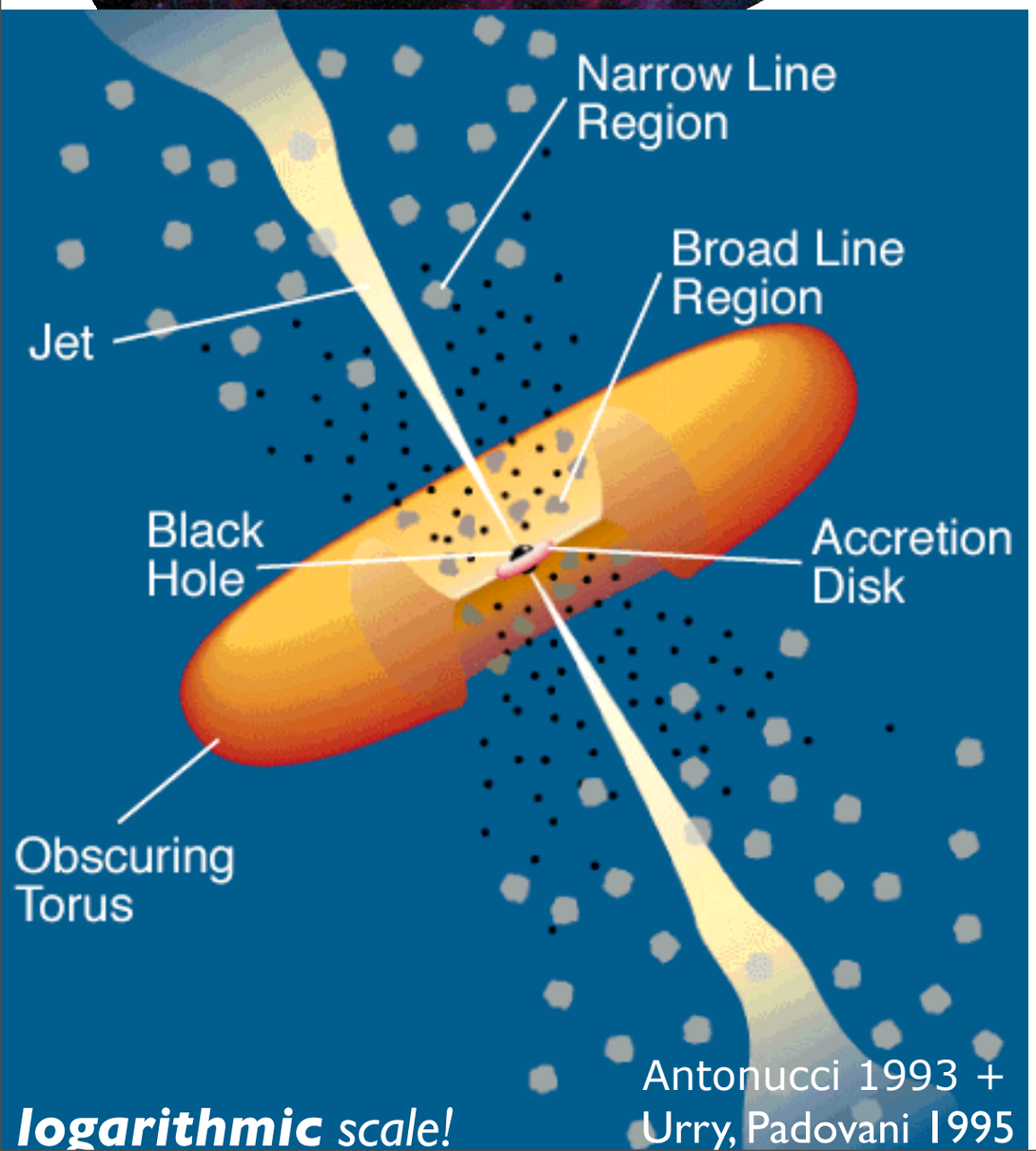
# Outline

1. Active Galactic Nuclei (AGN)
2. Interferometry / MIDI / VLTI
3. Observations / Results
4. Modelling
5. Conclusions / Outlook / My project

# Active Galactic Nuclei


NGC 1068 (Hubble)

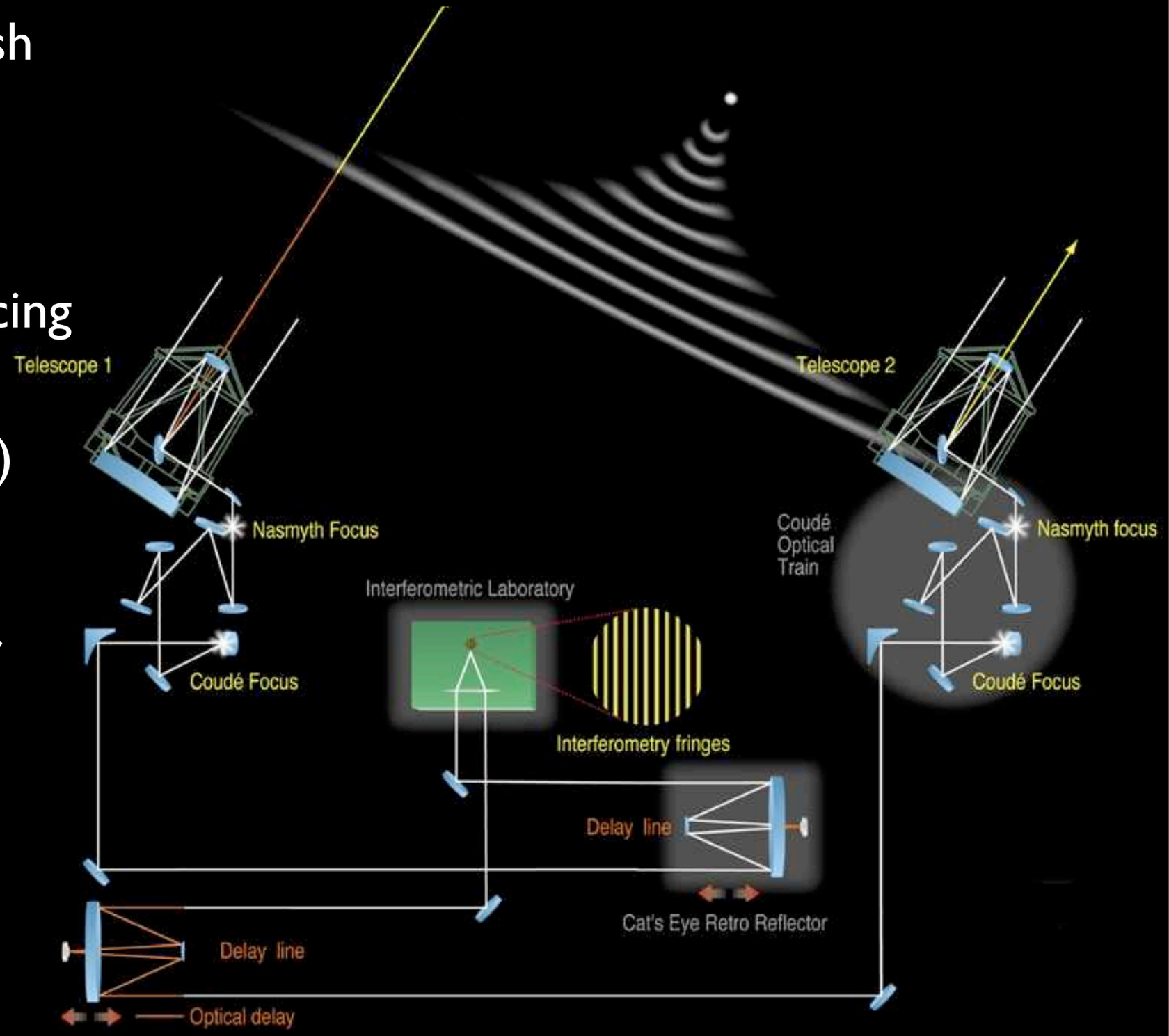


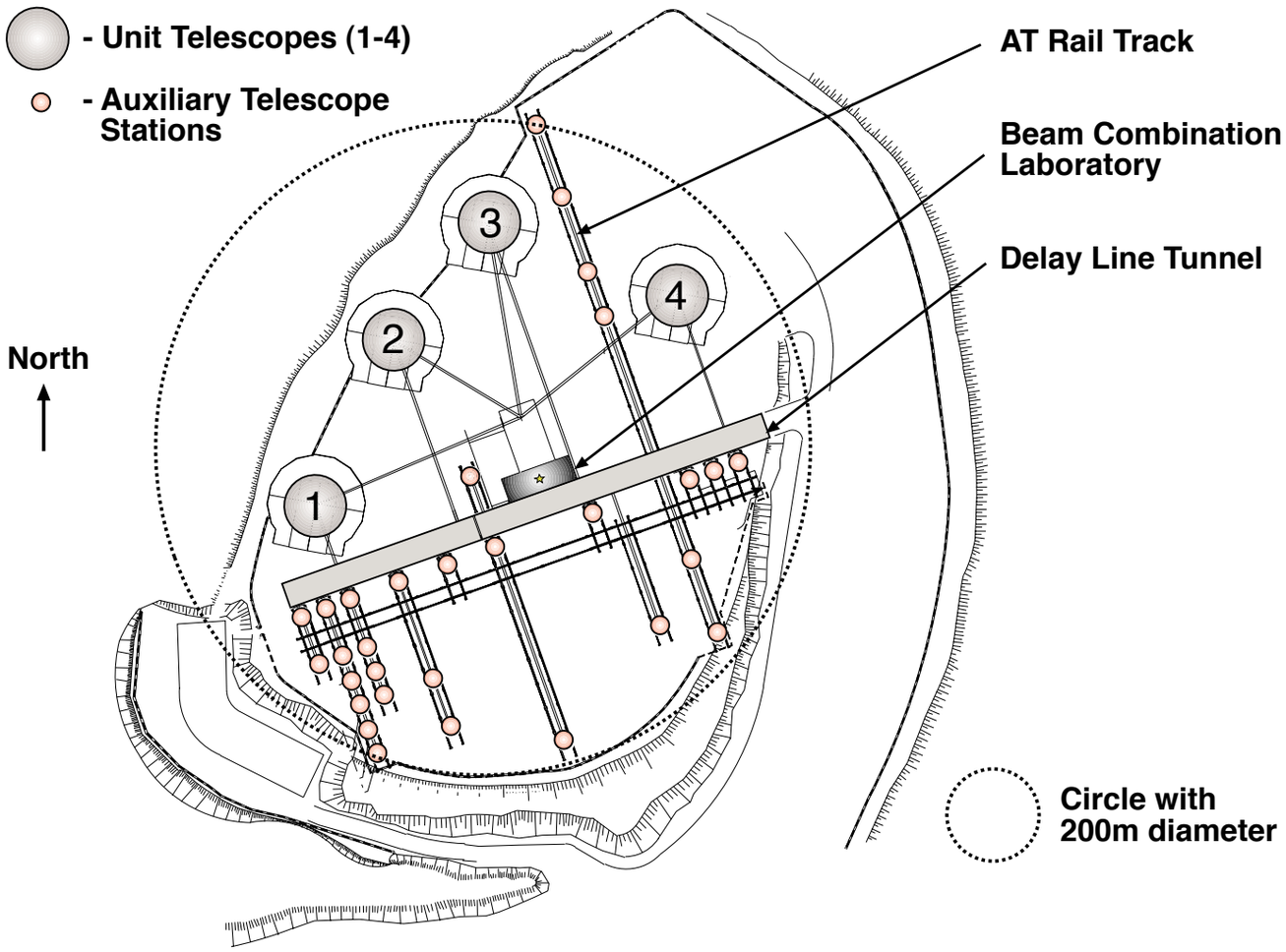

| component | physical size | angular size in NGC 1068 (14 MPc) |
|---|---|---|
| Central SMBH | $10^{-5}$ pc * $M_{BH}/10^8$ $M_{Sun}$ | |
| Accretion disk | ~ $10^{-3}$ pc | |
| Broad Line Region | ~ 0.01 pc | 0.15 mas |
| Torus | ~ 2x3 pc | 40 mas |
| Narrow Line Region | ~ 300 pc | |
| The starburst | ~ 1 kpc | |

Closest Sy 2 galaxy: Circinus (4 MPc, 1 pc ~ 50 mas)

# Interferometry

- Resolution of a single dish telescope $\theta_{min} \sim \lambda/D$
  (8m @ 10μ: 300 mas)
- Interferometry: D ~ spacing between telescopes!
  (130m @ 10μ: ~ 15 mas)
- I(u,v) = T(u,v) * O(u,v)
  Intensity = **F.T.**(Transfer function) * **F.T.**(image)
  → Know your interferometer (the transfer function)!






# VLTI / MIDI

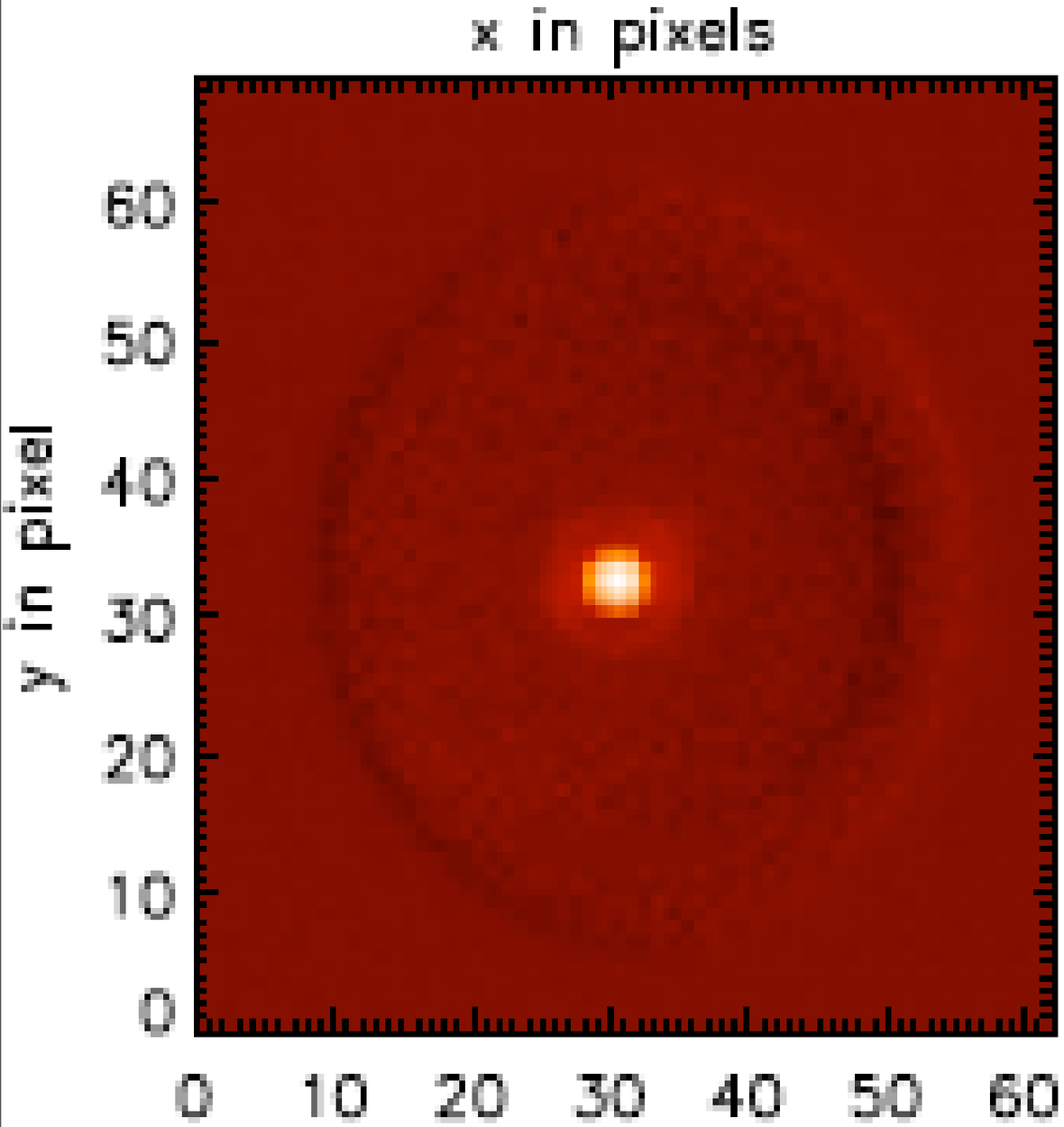
- Min. 46 m (U2-U3), Max. 130m (U1-U4)

- MIDI: The **M**id **I**nfrare**D** **I**nterferometric Instrument
  - N band (8-13 μ), R = 30, 230, max. angular resolution ~ 15 mas
  - Two beams (UTs/ATs)

# Observations

## Observational strategy / data reduction

**Tristram 2007**



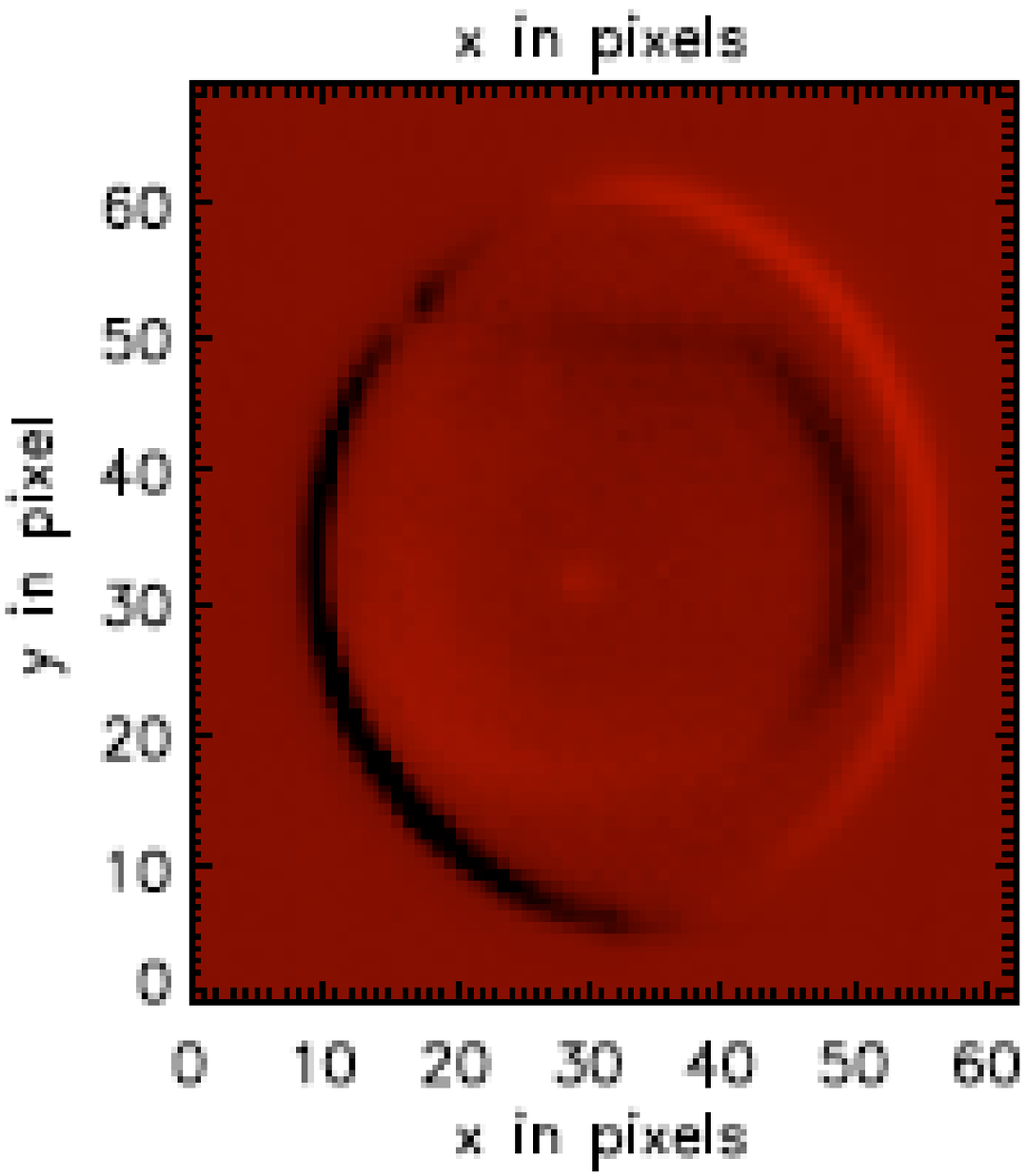

**final acquisition image of calibrator**

- Large background (sky / mirrors) ➔ ‘chopping‘
- Short atmospheric coherence time (~ ms) ➔ take many short frames
- Data reduction using MIA +EWS IDL scripts

# Observations

## Observational strategy / data reduction

**Tristram 2007**

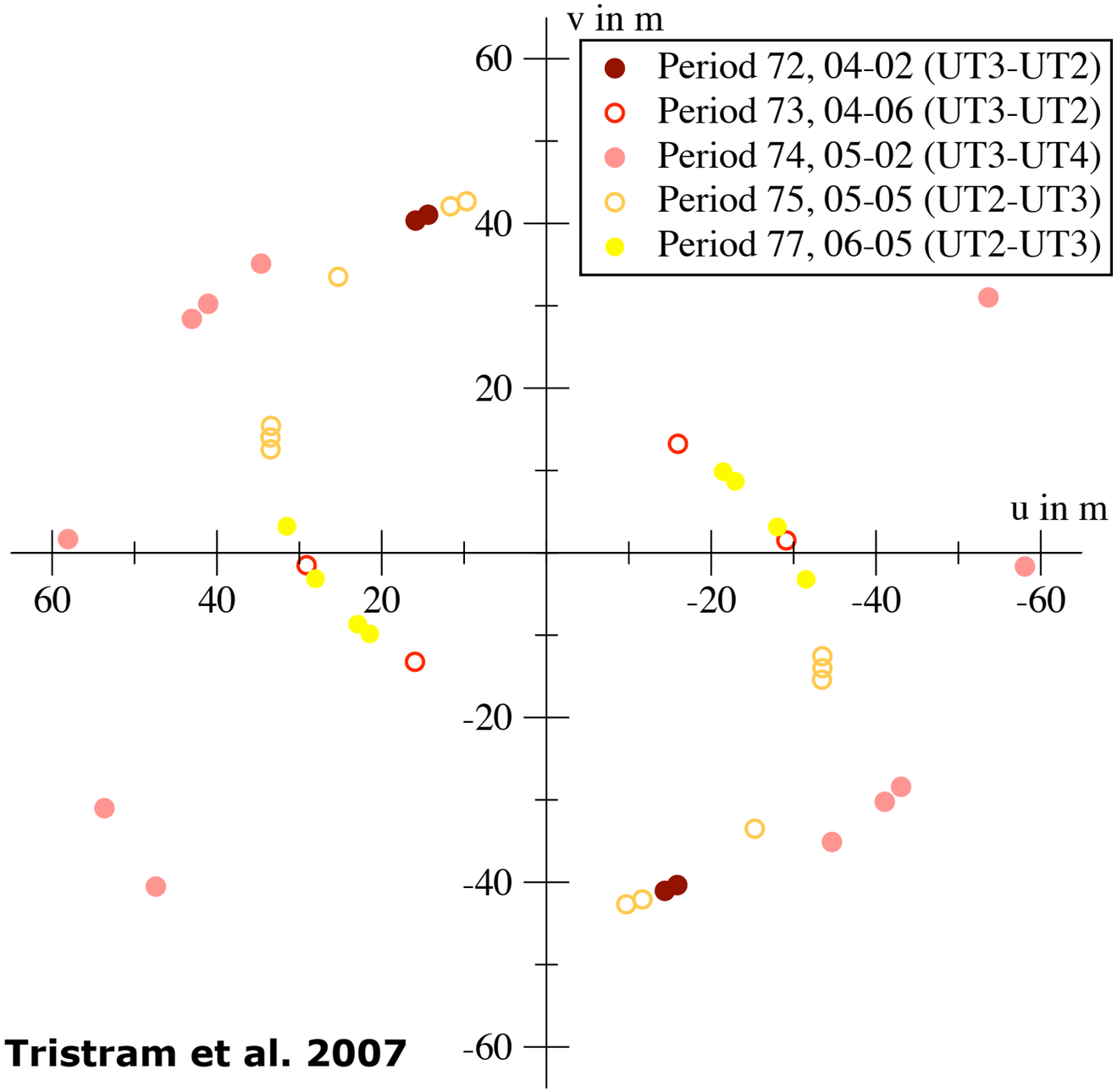



**final acquisition image of Mrk 1239**

- Large background (sky / mirrors) ➔ ‘chopping‘
- Short atmospheric coherence time (~ ms) ➔ take many short frames
- Data reduction using MIA +EWS IDL scripts

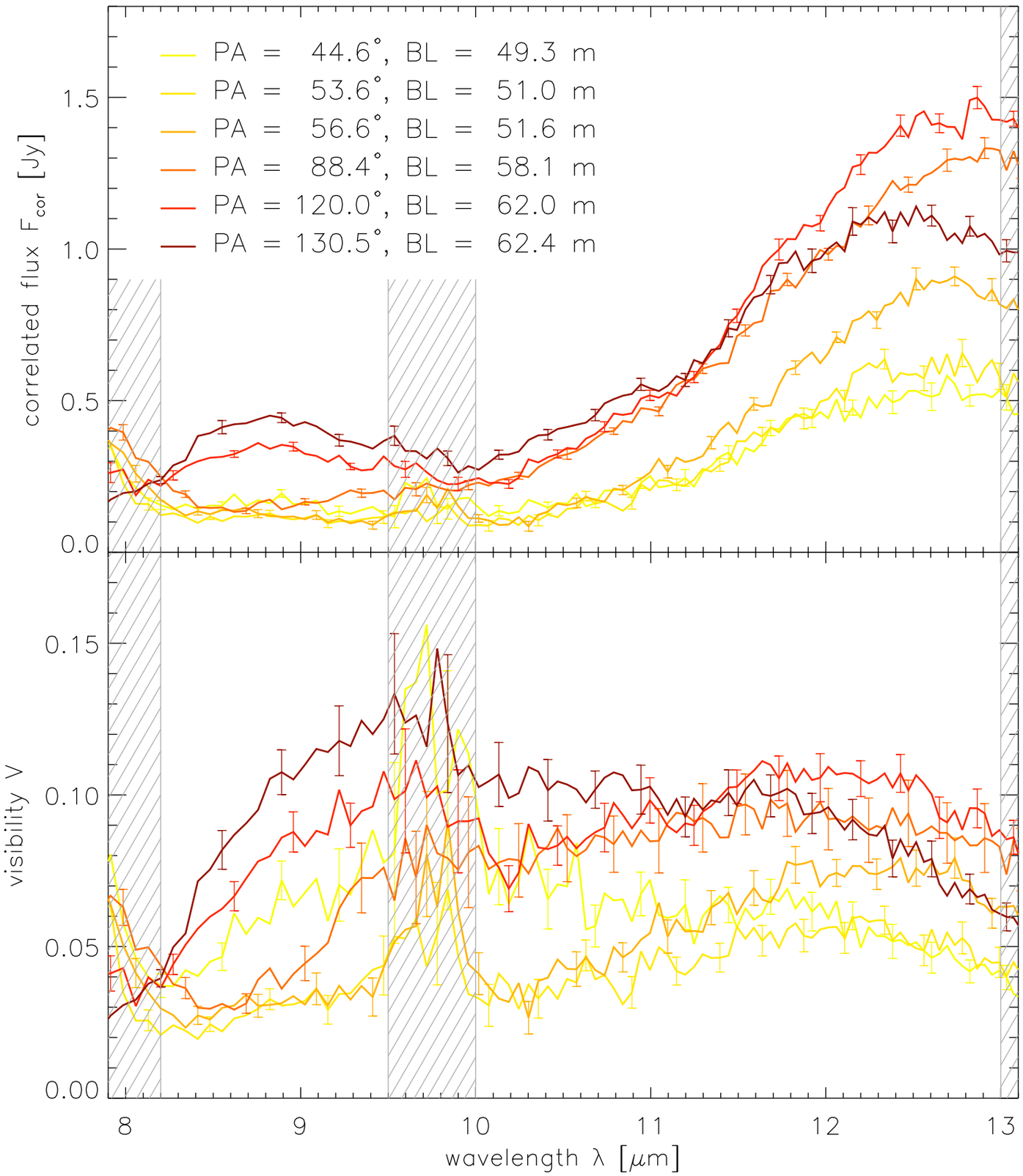
# Circinus

# u-v plot




**Tristram et al. 2007**

- 21 'uv points' obtained during 2002-2006
- various baselines and position angles




Tristram et al. 2007

## Circinus

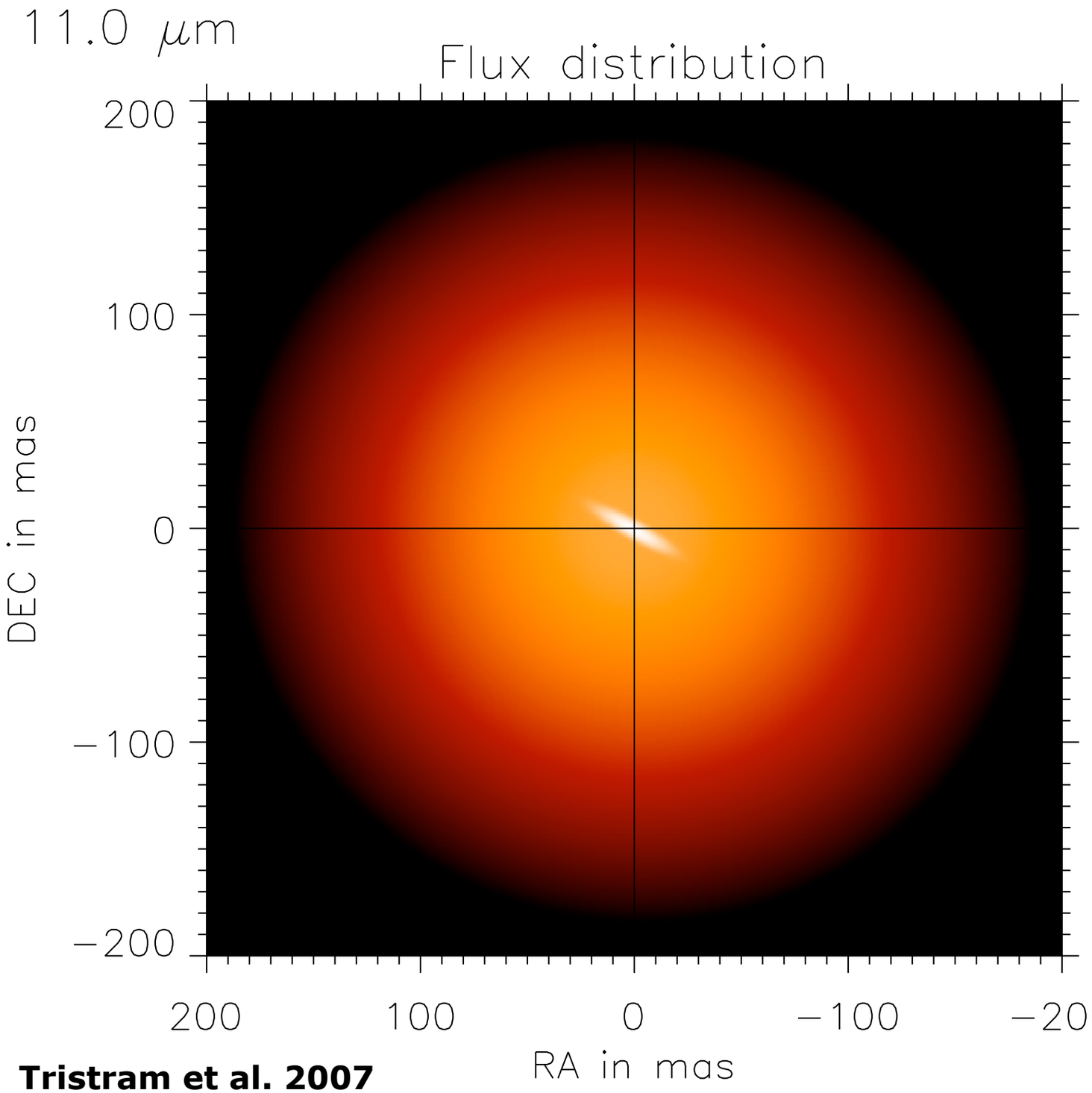
# (Correlated) Spectrum

- **Visibility**
  $V = (I_{max}-I_{min})/(I_{max}+I_{min})$
- Visibility: needs good photometry!
- If not available, use Correlated Flux instead

## Circinus

# Observational Model: Gaussian Fit

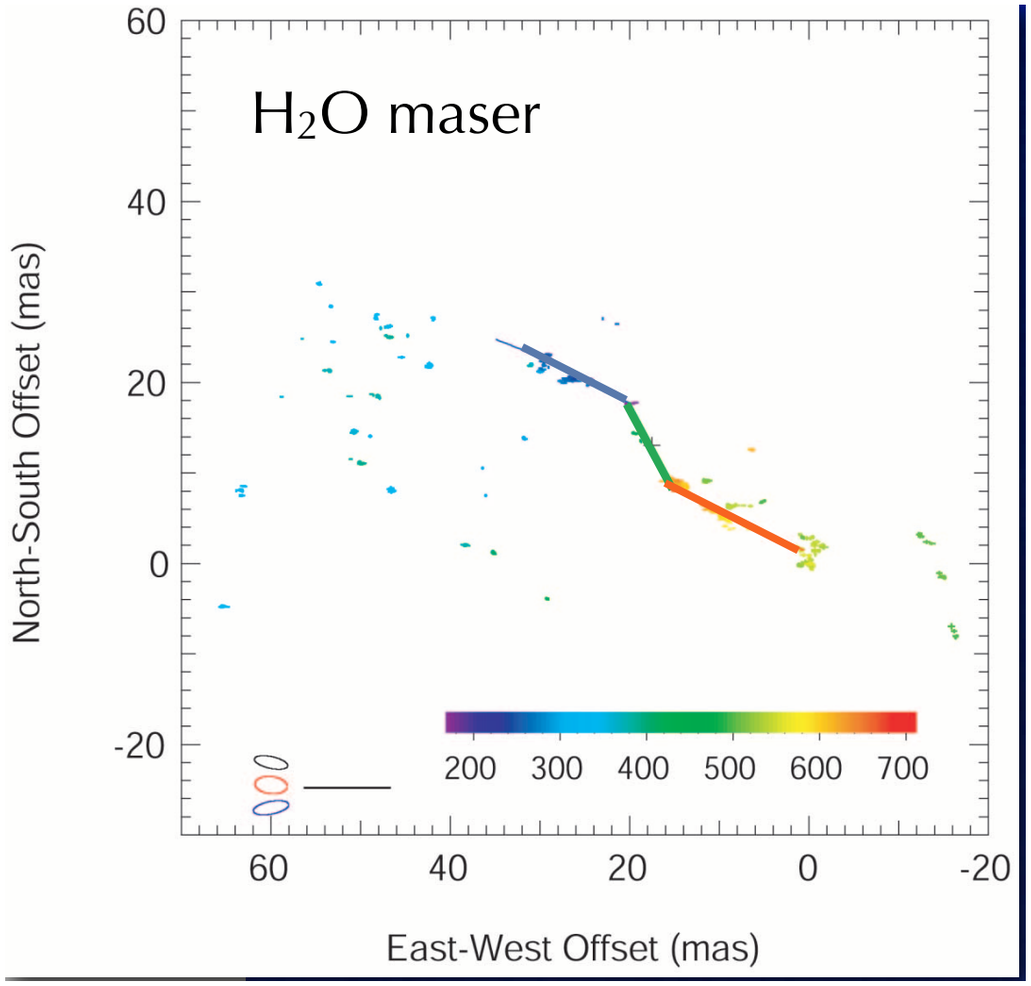
| Parameter | Gaussian Fit |
|---|---|
| *FWHM* $\Delta_1$ | 21.1 mas (0.4 pc) |
| axis ratio $r_1$ | 0.21 |
| *optical depth* $\tau_1$ | 1.18 |
| temp. $T_1$ [K] | 333.7 |
| flux norm. $f_1$ | 1.00 |
| *FWHM* $\Delta_2$ | 96.7 mas (1.9 pc) |
| *axis ratio* $r_2$ | 0.97 |
| *optical depth* $\tau_2$ | 2.22 |
| *temp.* $T_2$ *[K]* | 298.4 |
| *flux norm.* $f_2$ | 0.20 |
| *angle* $\varphi$ *[°]* | 60.9 |
| $\chi^2$ / $N_{free}$ | 36.86 |




**Tristram et al. 2007**

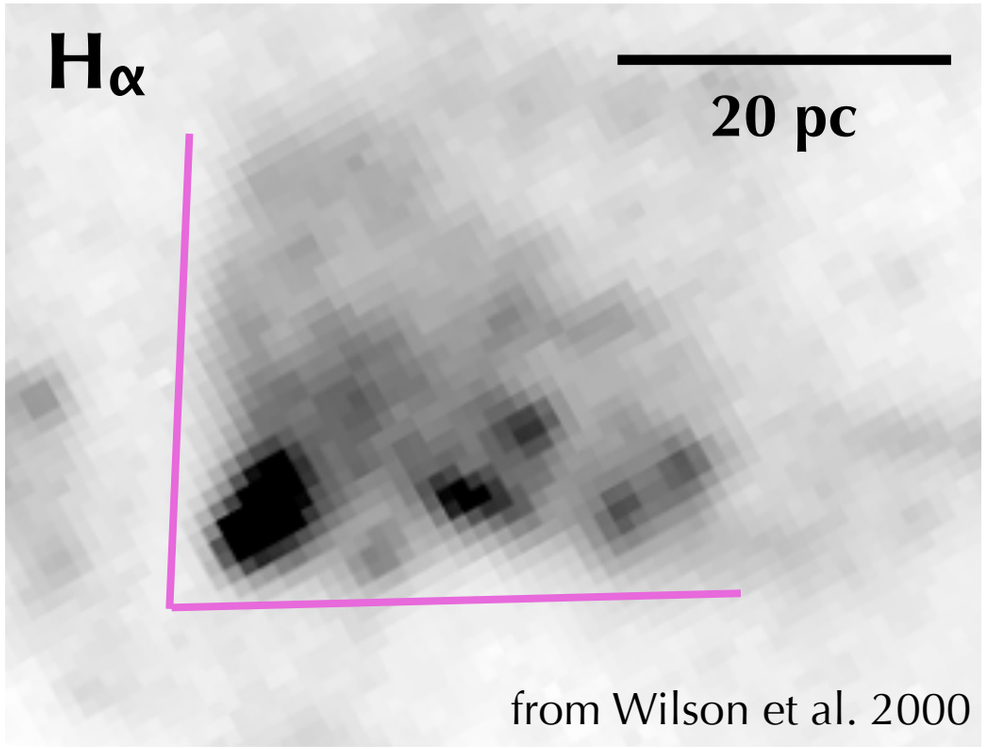
## Circinus

# Multi-wavelength data



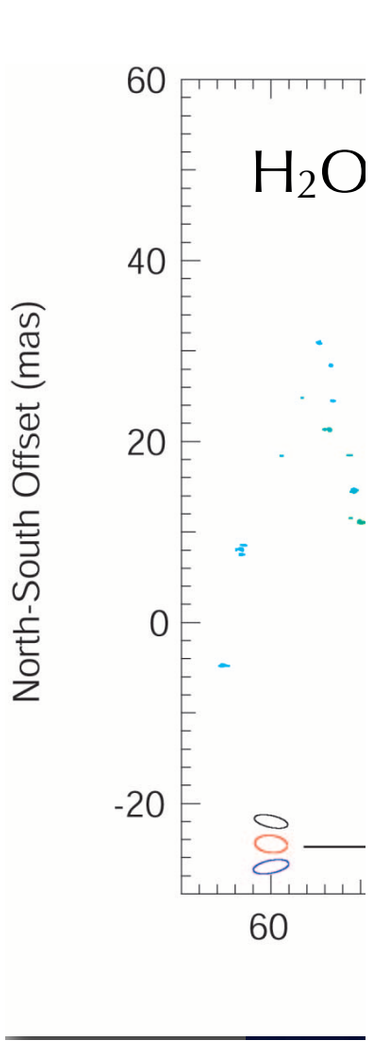

**Greenhill et al. 2003**

## ionisation cone

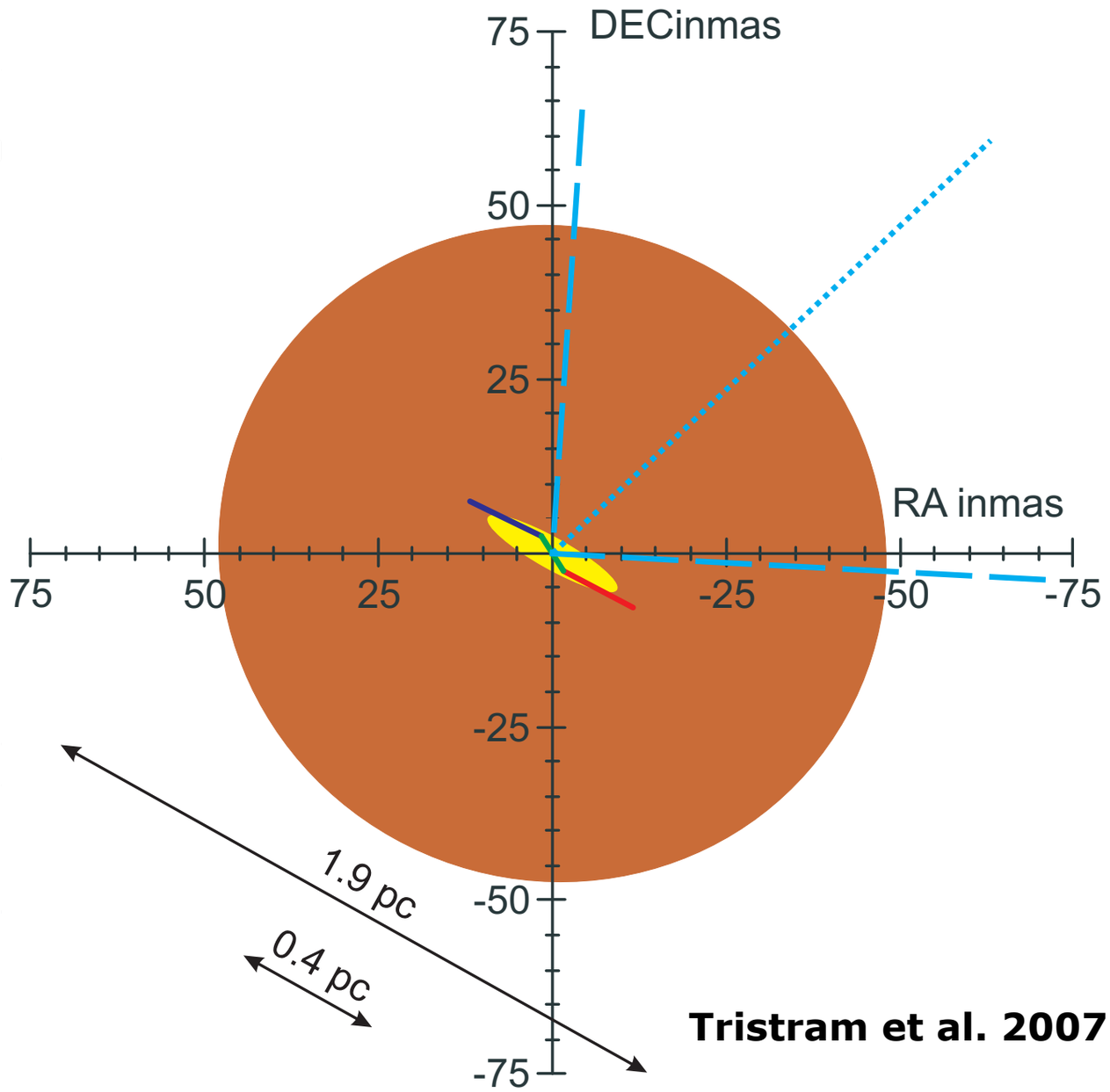


## Circinus

# Multi-wavelength data

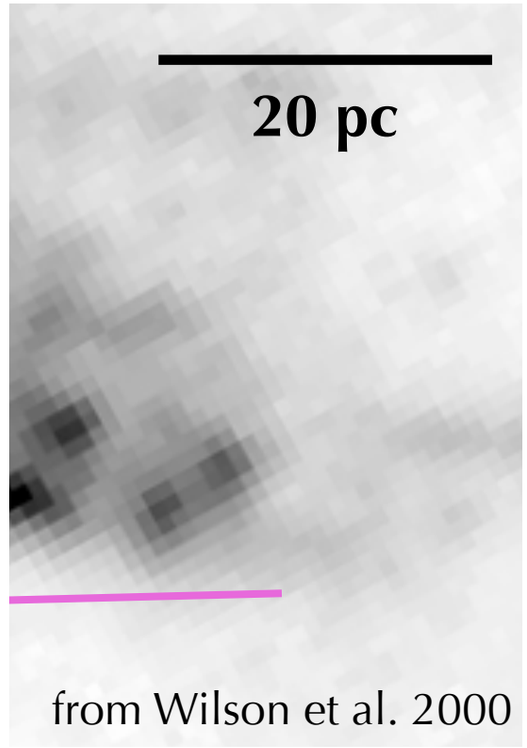



**Greenhill et al.**




**Tristram et al. 2007**

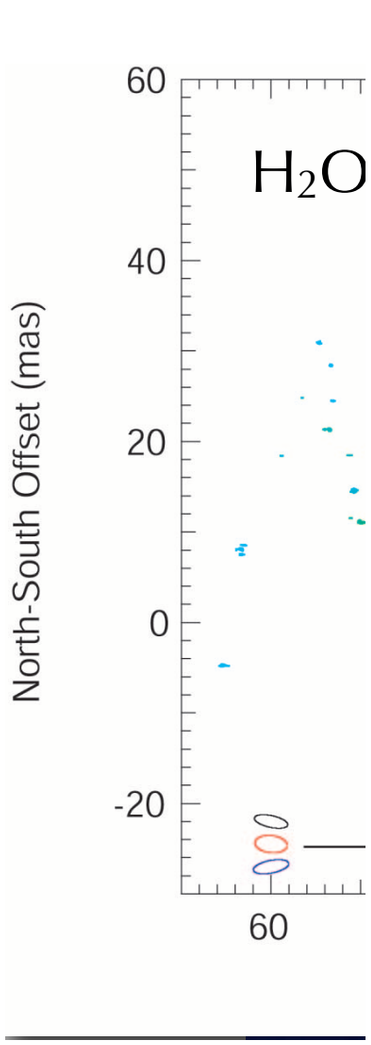
**ion cone**



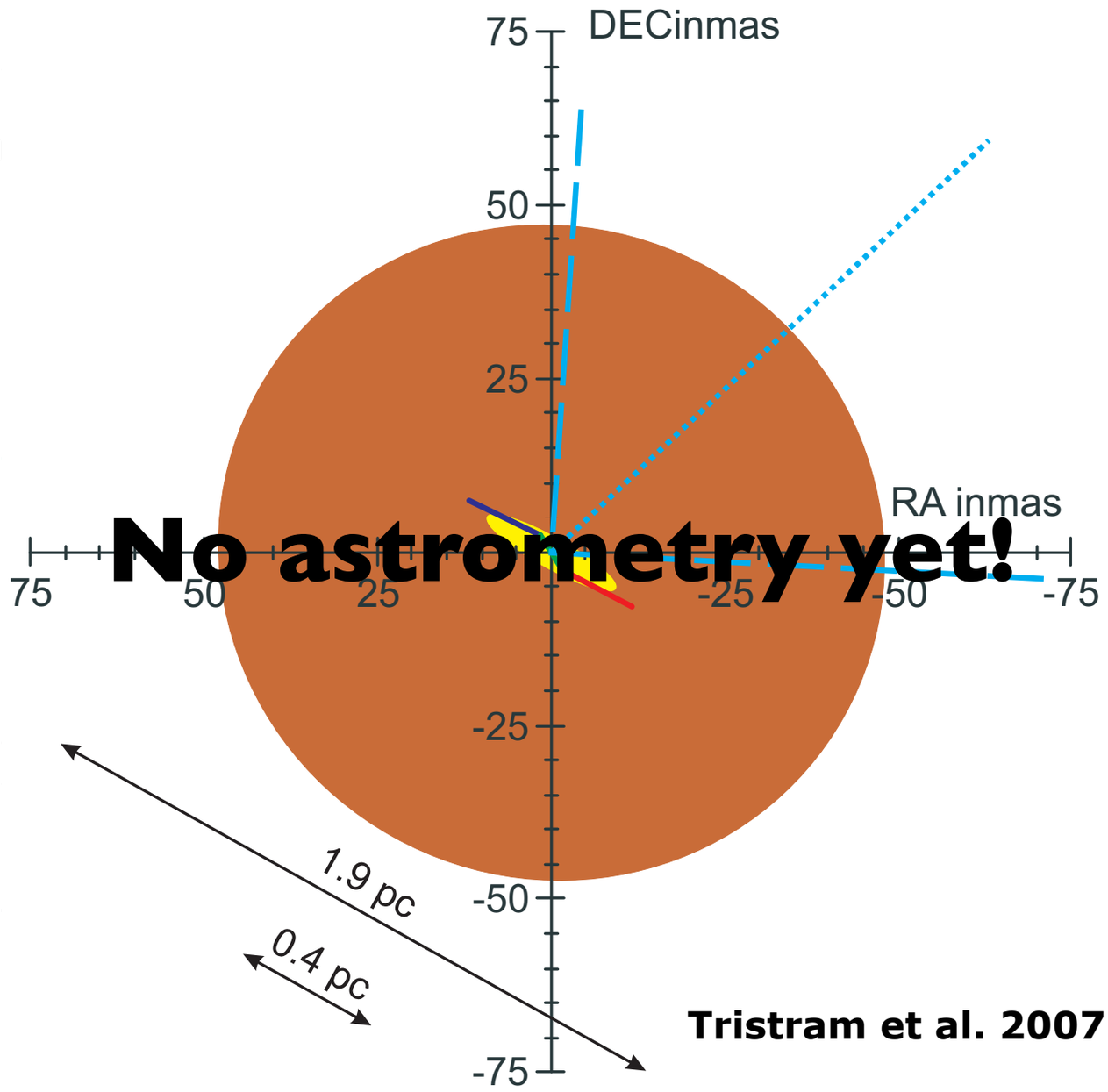

from Wilson et al. 2000

## Circinus

# Multi-wavelength data



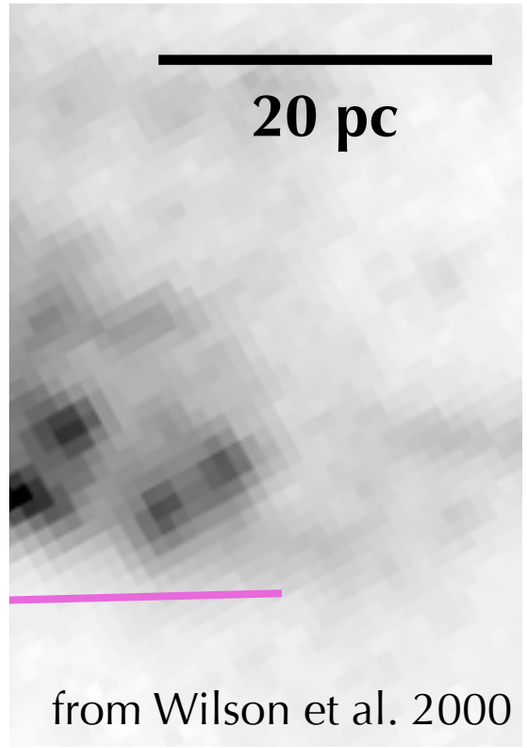

**Greenhill et al.**




**No astrometry yet!**

**Tristram et al. 2007**

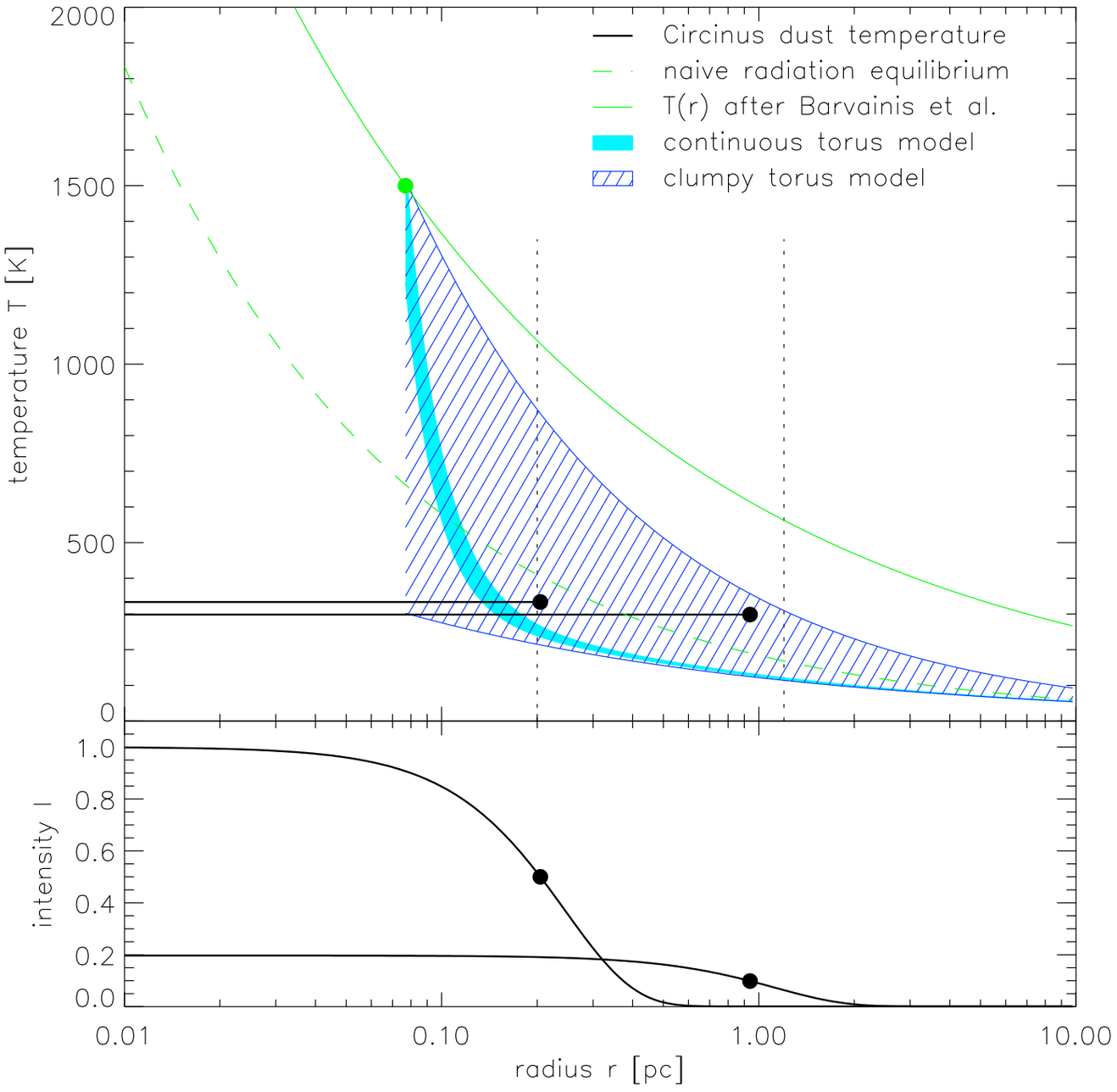
**ion cone**




from Wilson et al. 2000

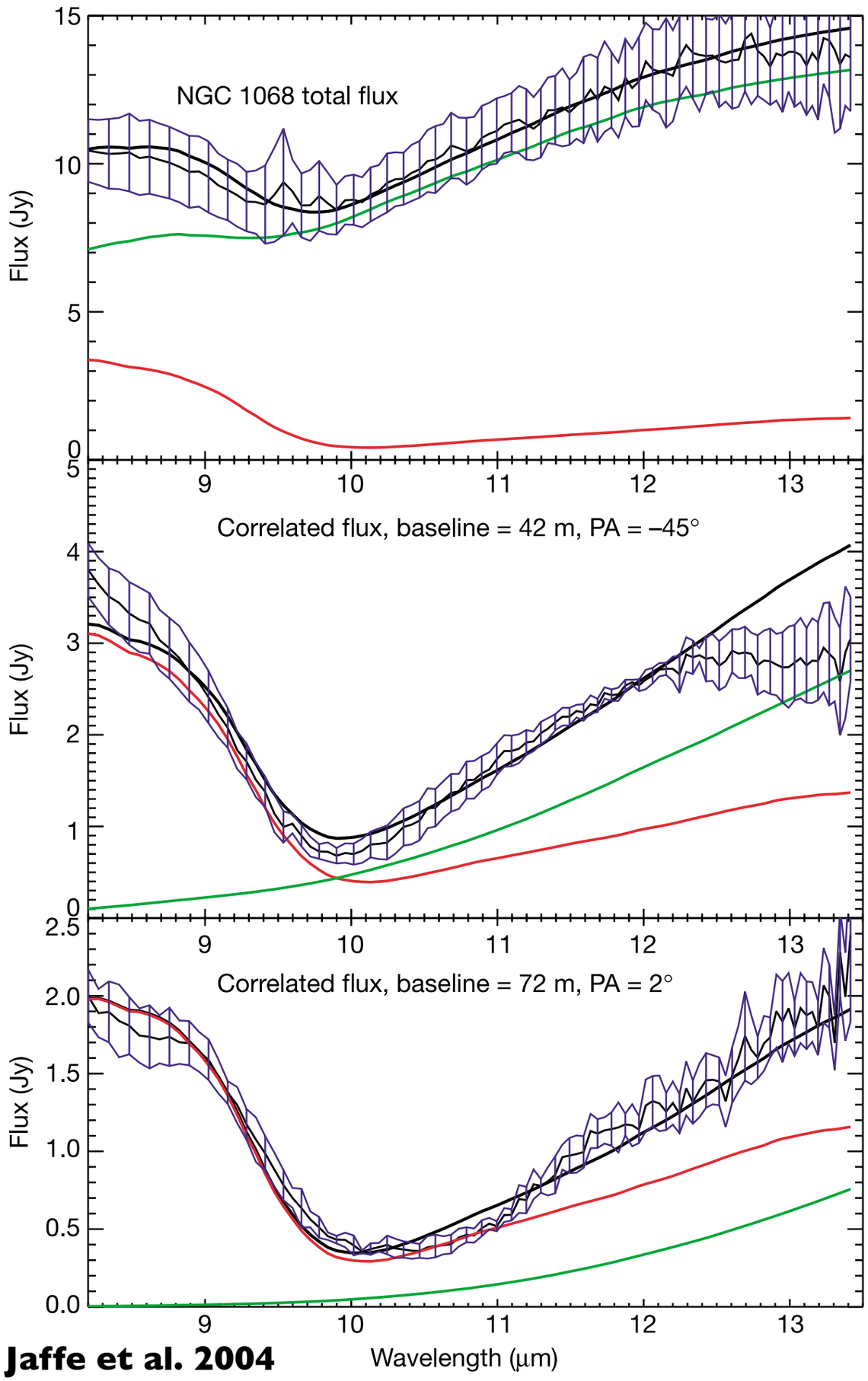
## Circinus

# Dust temperature




**Tristram et al. 2007**

- The temperature (T)-radius profile does not fit to continuous torus models: observed T too high
- Clumpiness provides direct lines of sight also for large radii, increasing T




**Jaffe et al. 2004**

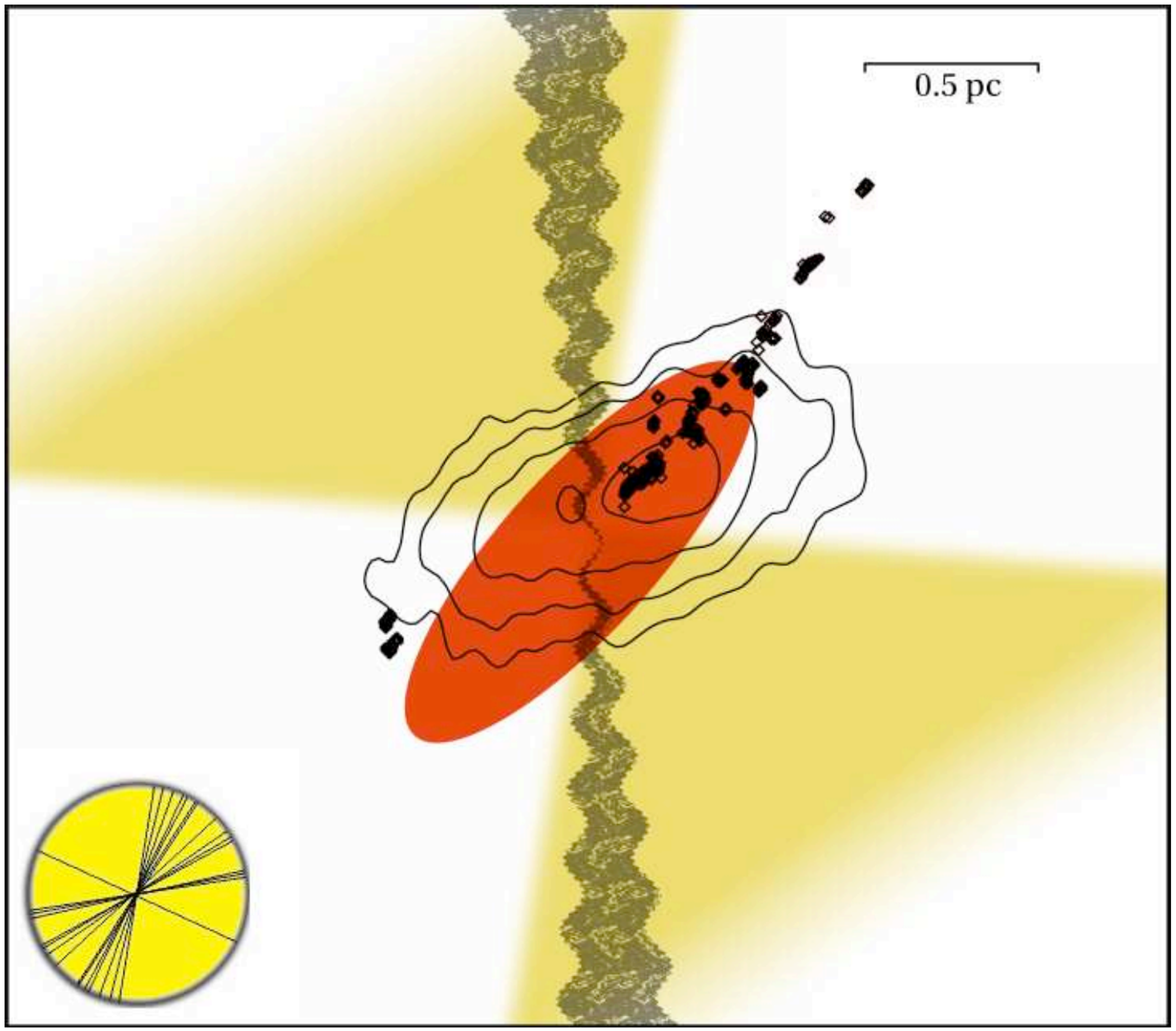
# NGC 1068

# Results

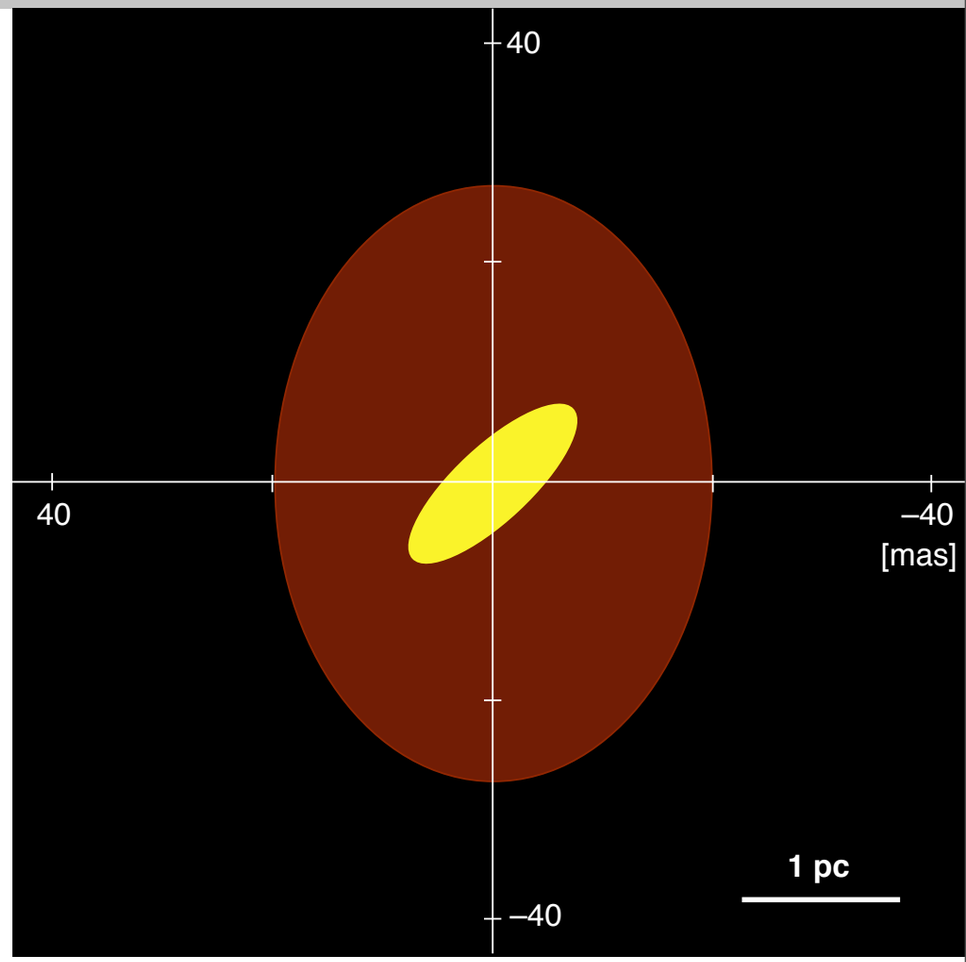
- Best studied (16 baselines) AGN
- prototype, near (14.4 MPc) Sy II

## NGC 1068

# Interpretation

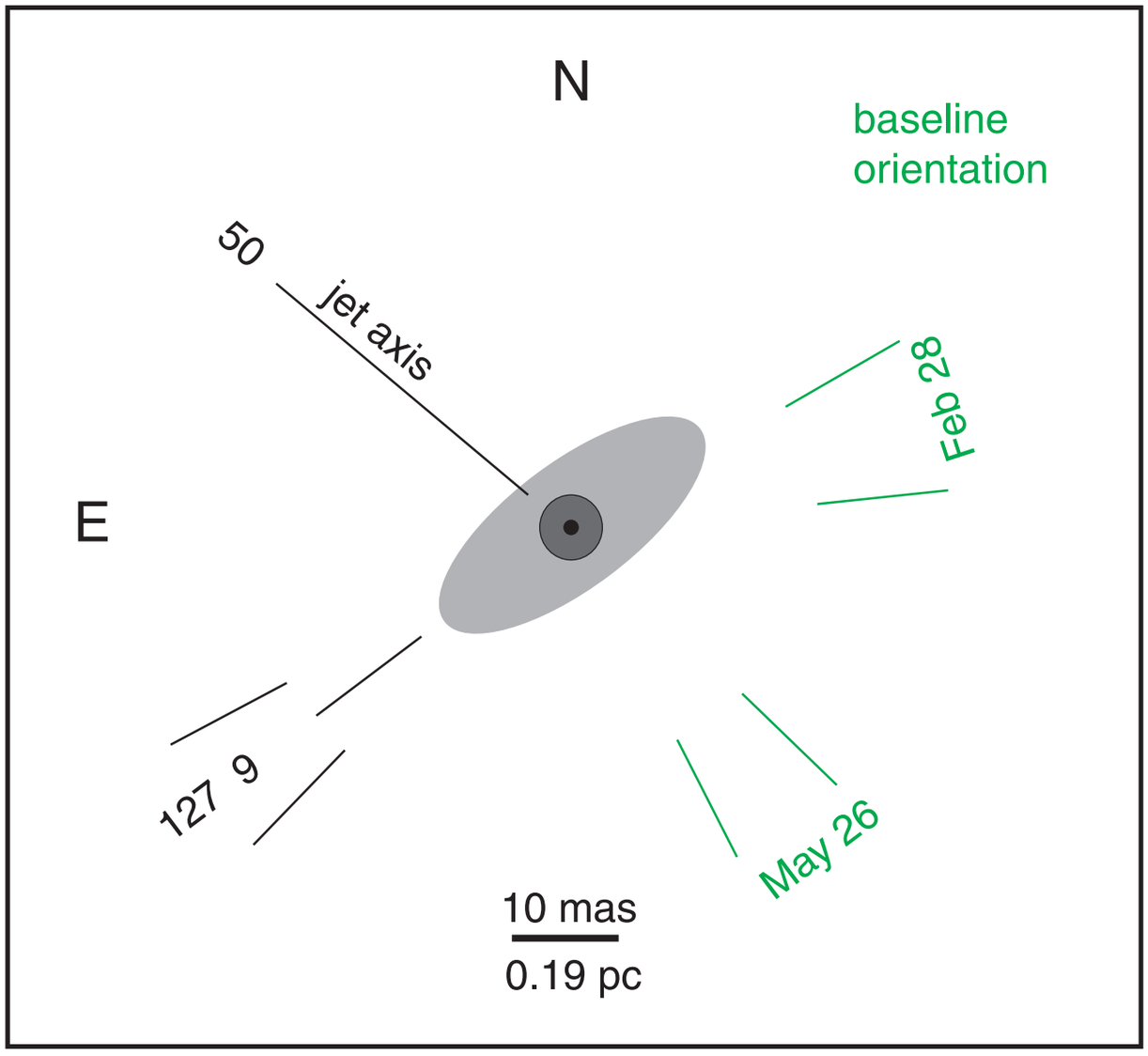



**Raban et al. 2007 (in preparation)**




- Again: disk aligns well with MASERs from the center and with the ionisation cone, but not with other (more inner) radio parts!
  → misaligned accretion?

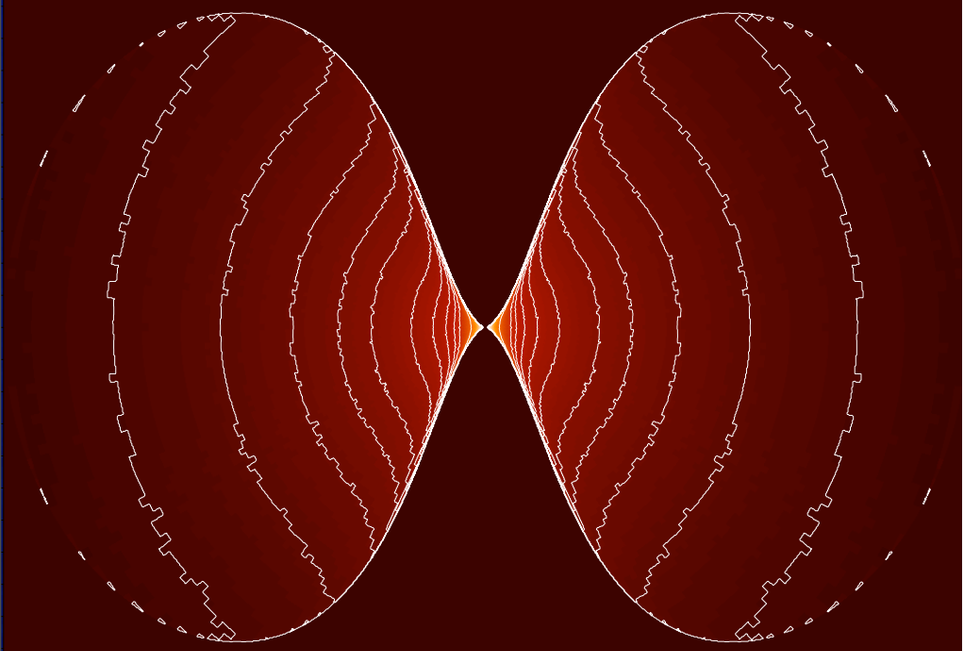
# Centaurus A



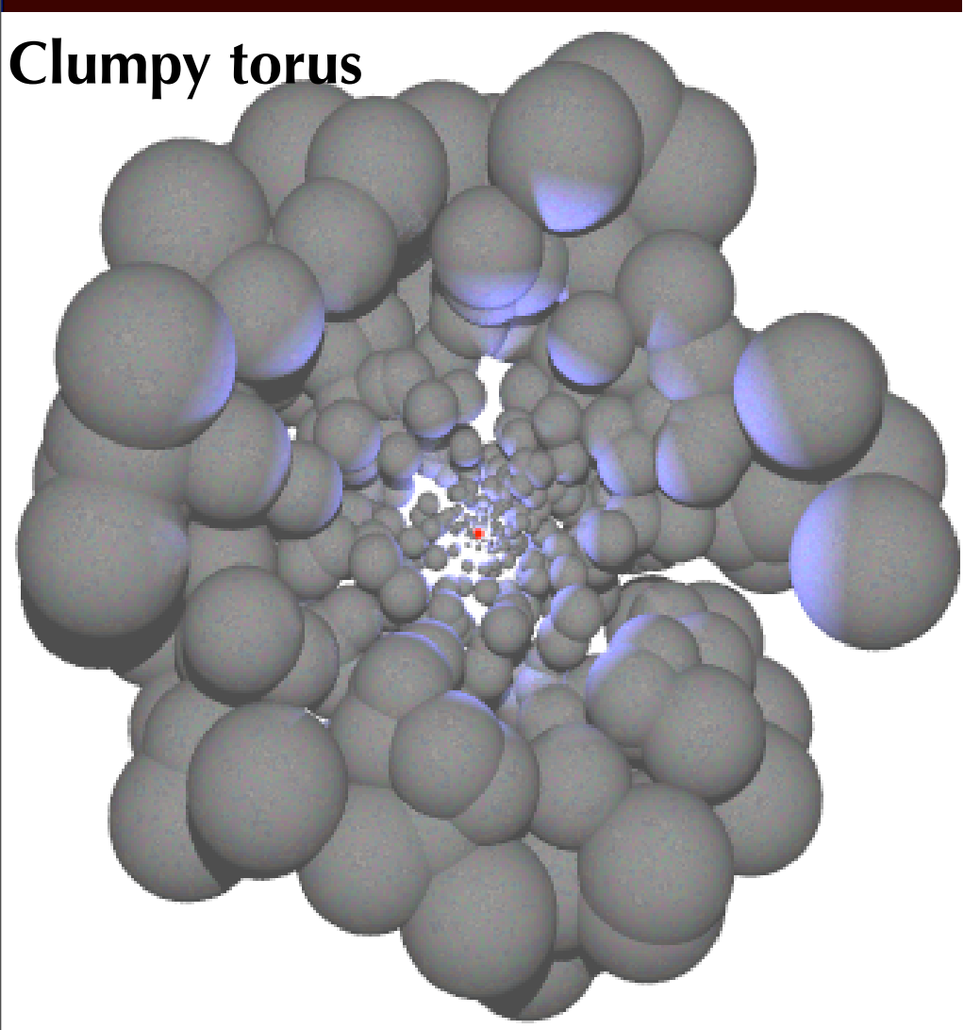

**Meisenheimer et al. 2007**

- Nearest (D = 3.8 MPc) merger and radio galaxy, $M_{BH} = 7 * 10^7 M_{sun}$
- **In MIR**
  - Dust disk (d = 0.6 pc, T = 240 K)
  - Non-resolvable point-source (~ 70% of IR flux), most likely base of the radio jet, i.e. Synchrotron source

Continuous dust torus



Clumpy torus

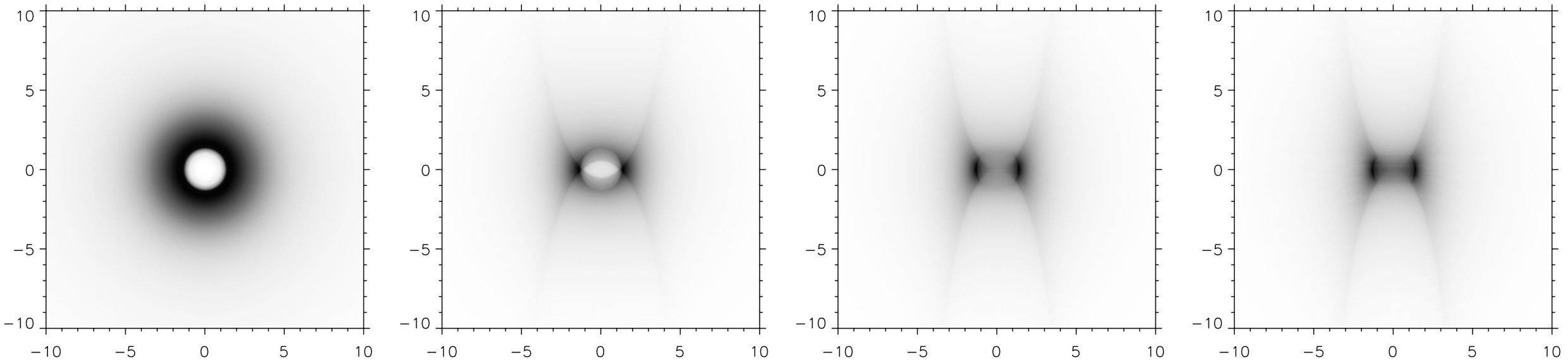


# Modelling

- **continuous**: easiest, but Silicate feature too strong in emission
- **clumpy**: explains most observations already very good (needs more observations to constrain model!)
- **hydrodynamic**: physical model, needs lots of CPU time

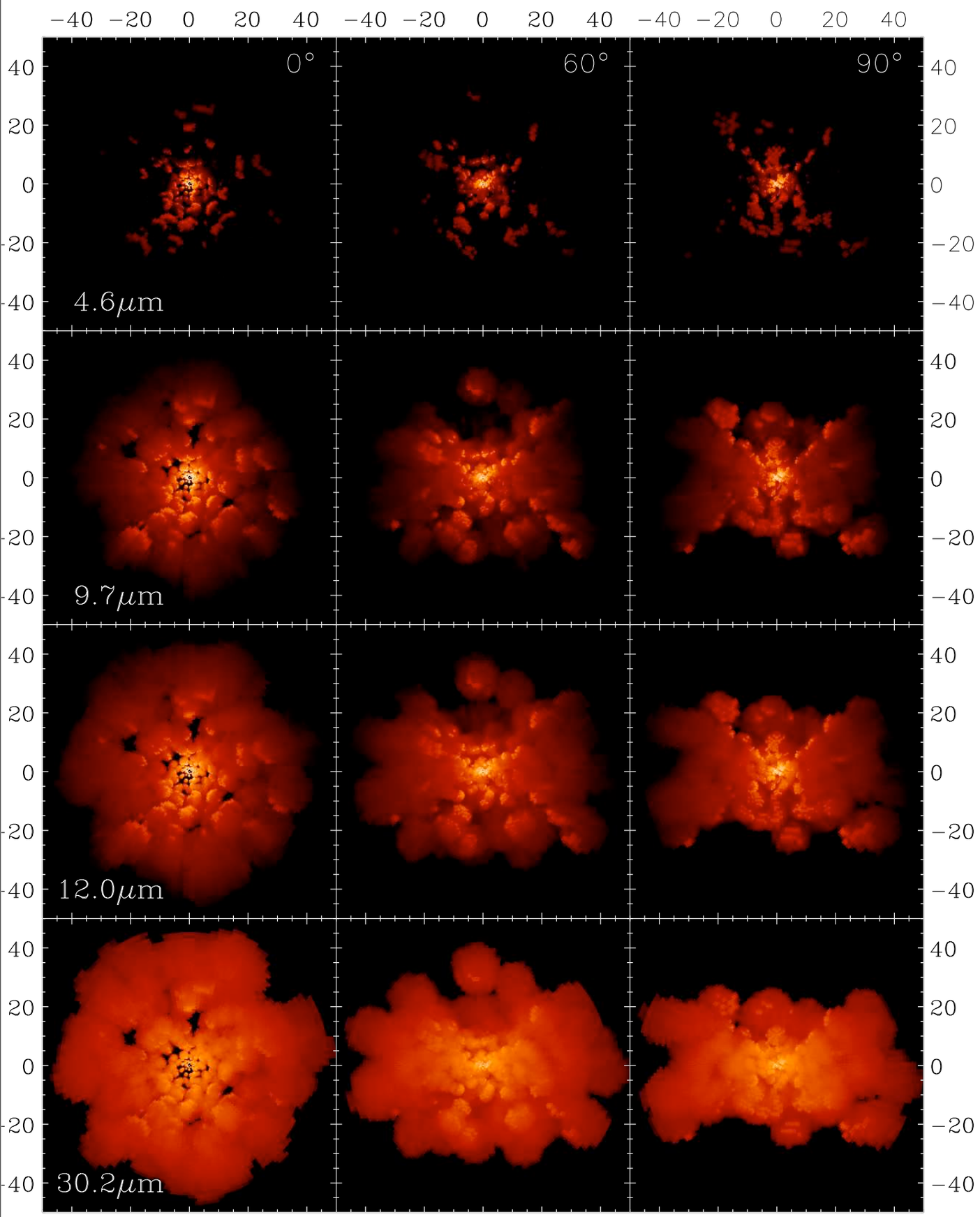
# Continuous Model

**Schartmann et al. 2005**




0° 30° 60° 90°

viewing angle




## Clumpy Model

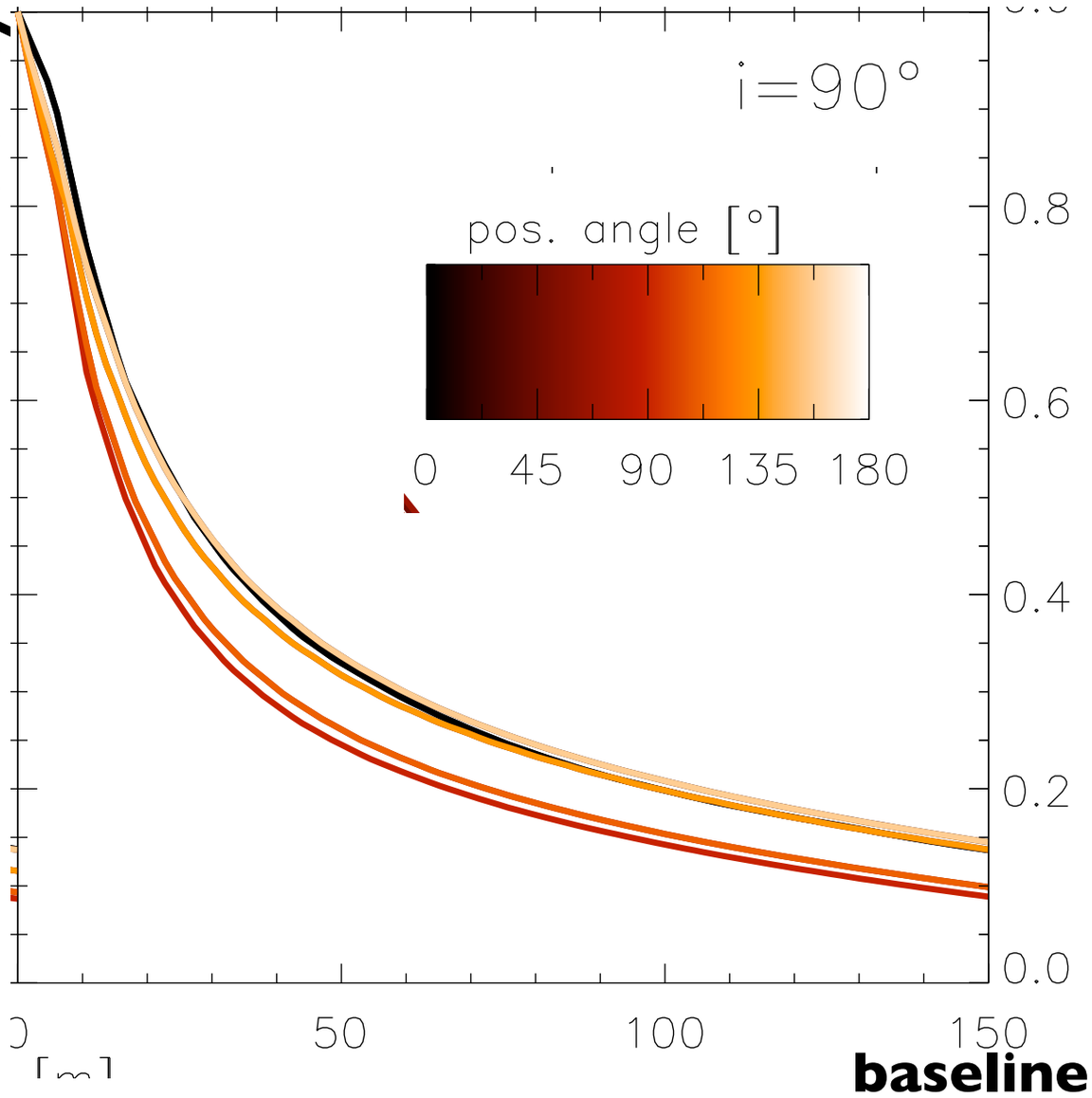
# Wavelength and inclination angle studies

**Schartmann et al. 2007 (submitted)**

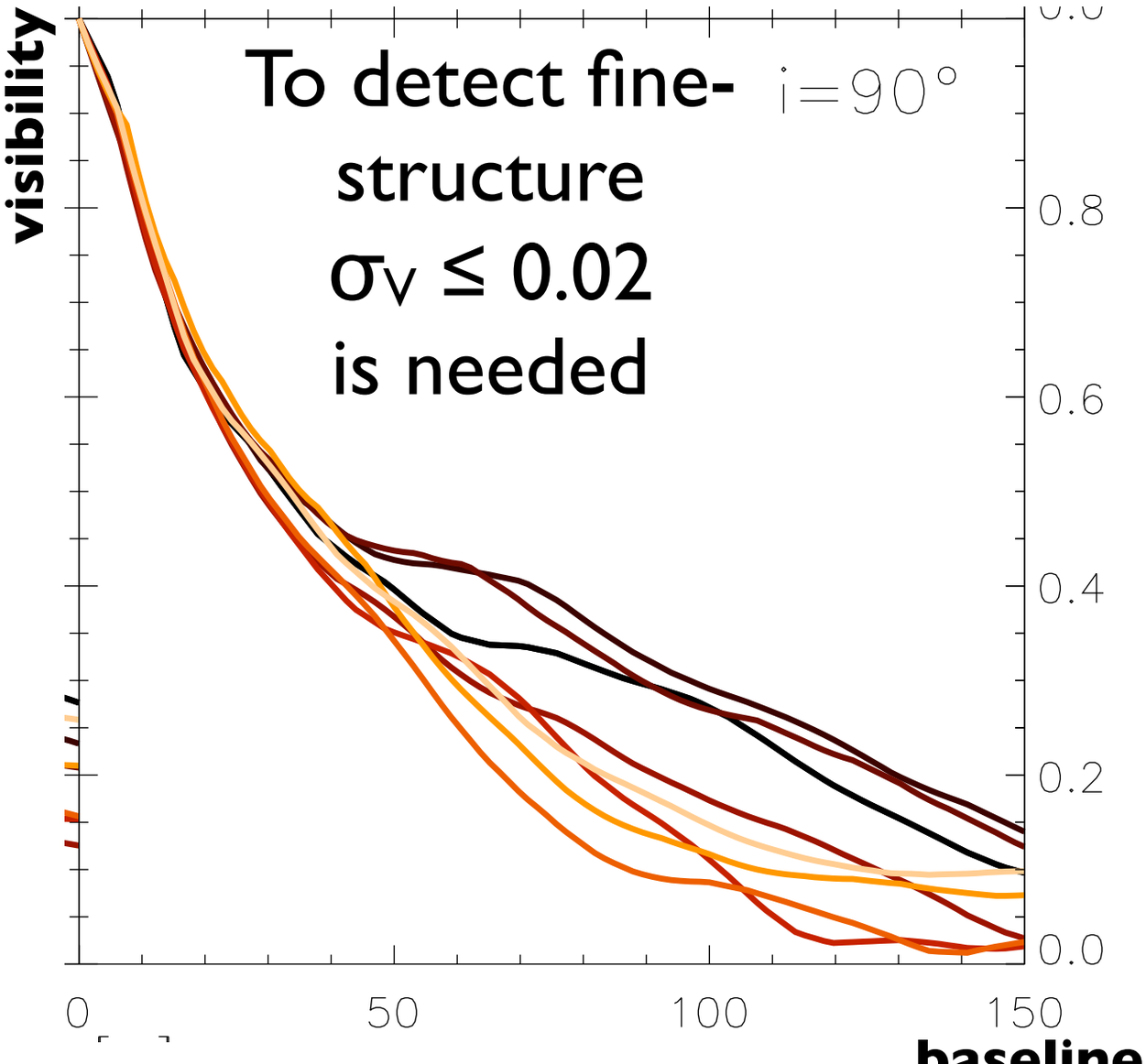
## Clumpy Model

# Clumpiness

Schartmann et al. 2007 (submitted)




**not clumpy**




**clumpy**

# Conclusions so far

- Seyfert II galaxies contain dust tori with diameters 2 ... 10 pc
- MIDI observations fit to the multiwavelength picture (maser disk, ionisation cone, radio jet) – except for NGC 1068!
- Need more data to constrain models!

# Outlook

- **This run** (5 days ago) Observed galaxies further away: no fringes on NGC 7469 (Sy 1) and IRAS 0518-25 (Sy 2), but good and interesting results on NGC 1365 (Sy 1.8)
- Try nearest Sy 1, NGC 4151 ($\delta = +40°$)
- Future: MATISSE: 10 μ (N band, like MIDI) and L band (3.6 μ), ~ 3 times better resolution, better temperature measurement, higher sensitiviy

MATISSE

# My Ph.D. project

- **Do all AGN contain a dusty torus?**
  (Are there ‘true‘ Seyfert 2 galaxies?
  → Resolve Seyfert 1 cores!)
- **What is the dust structure?**
  (clumpy...)
- How does the **fuelling mechanism** work and what role does the torus play?

**Contact: Leonard Burtscher, burtscher@mpia.de**