Dissecting the center of Centaurus A and NGC 4151

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Image credit: Marc Schartmann
MIDI AGN programme

MIDI is the MID-infrared Interferometric Instrument (VLTI)

- **Detailed studies**
  - NGC 1068 (Sy 2), Raban et al. 2009
  - Circinus (Sy 2), Tristram et al. 2008
  - Cen A (Radio Gal.), Meisenheimer et al. 2007

- **Snapshot survey** of 7 other, weaker galaxies, Tristram et al. 2009

- **Results**: torus exists, very different [temperature, chemical comp., orientation] in the three well-studied galaxies
High-resolution studies of AGNs

Centaurus A

Credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)
High-resolution studies of AGNs

- **Centaurus A**
  - closest major merger / radio galaxy / AGN at ~3.8 Mpc (54 mas / pc)
  - dust lane from interaction with other gal 500 Myrs ago
  - possible source of UHE cosmic rays
  - warped molecular gas disk 110 pc x 280 pc / P.A. = 140° at the center

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(u,v) coverage with MIDI

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NGC5128
High-resolution studies of AGNs

- closest major merger / radio galaxy / AGN at ~3.8 Mpc (54 mas / pc)
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High-resolution studies of AGNs

CenA – UT1–UT4

BL=128.80m, PA=40.5
BL=129.22, PA=42.65
BL=113.86, PA=79.35
BL=113.10m, PA=79.95

130 m, 40°
113 m, 80°
High-resolution studies of AGNs

CenA – UT1–UT4

jet axis
51°

major axis of the dust disk
148.5°

130 m, 40°

113 m, 80°

wavelength $\lambda$ [\(\mu\m\)]
Centaurus A

- only weakly emitting dust disk ($L_{dust} \sim 0.1 L_{dust}$, Circinus), no optically thick torus
- disk $\perp$ VLBI jet axis
- disk size: $\sim 0.6$ pc $\times$ 0.2 pc ($68^\circ$ inclined thin disk?)
- point source flux ratio $\sim 50\%$ (synchrotron core)
High-resolution studies of AGNs

Centaurus A
Connection to larger scales?

Neumayer et al. 2007

jet axis
51°

major axis of the dust disk
148.5°

10.8 mas
0.2 pc

~ 145°
High-resolution studies of AGNs

NGC 4151

- Brightest (N ~ 1 Jy) and nearest (D ~ 14 Mpc) Sy galaxy
- Difficult to observe (mag. limit for VLTI, very northern DEC)
- Successfully observed in April 2008 with fringes on two different baselines (60m, 90m, at similar P.A.s)

*gri* image – Hogg, Blanton and SDSS
High-resolution studies of AGNs

NGC 4151

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- Difficult to observe (mag. limit for VLTI, very northern DEC)
- Successfully observed in April 2008 with fringes on two different baselines (60m, 90m, at similar P.A.s)
Dust (color) temperature $\sim 300$ K, i.e. similar to other AGNs observed with MIDI.
High-resolution studies of AGNs

Type 2 galaxies: NGC 1068, Circinus, ...

Radiative transfer models of dusty tori

Type 1 galaxies: now for the first time torus in **NGC 4151** resolved

Schartmann et al., 2008
NGC 4151 – correlated flux

- UT2-UT4 (~90m)
- UT3-UT4 (~60m)
NGC 4151 – correlated flux

- Mid-IR Emission has been resolved.
- Possible weak silicate emission feature (non-standard-ISM dust?)

• UT2-UT4 (~90m)
• UT3-UT4 (~60m)
Two component model: blackbody (25 mas, ~300 K) + point source (<15% of total flux)

FWHM size (25 mas, i.e. 1.7 pc) is comparable to the sizes of tori in type 2 galaxies (NGC 1068)
High-resolution studies of AGNs

**NGC 4151 – Size of the Mid-IR emitter**

- **Two component model:** blackbody (25 mas, ~300 K) + point source (<15% of total flux)
- **FWHM size:** (25 mas, i.e. 1.7 pc) is comparable to the sizes of tori in type 2 galaxies (NGC 1068)

12 µm: (31 ± 7) mas

Point source: 0.26 Jy
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10.5 µm:
- (23^{+6}_{-4}) mas
High-resolution studies of AGNs

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12 µm: $(31 \pm 7)$ mas
point source: 0.26 Jy

10.5 µm: $(23^{+6}_{-4})$ mas

9 µm: $(25^{+5}_{-5})$ mas
point source: 0.13 Jy

12 µm:
(31 ± 7) mas
point source:
0.26 Jy
High-resolution studies of AGNs

- K band interferometry from Keck: majority of K band emission comes from $r < 0.05$ pc (Swain et al. 2003)

- Lag time between K and V band flares: $r_{\text{reverberation}} \sim 0.04$ pc $\sim r_{\text{sublimation}}$ (Minezaki et al. 2004)

- Radio observations: H I absorption seen against background by Mundell et al. 2003

Compared to...

Mundell et al. 2003
NGC 4151 – Open questions

• **Silicate emission** feature? Spitzer data inconclusive... (Buchanan et al. 2006)

• Warm vs. hot dust: We see ~ 300 K warm dust – **where is the hot dust** that should be seen face on in a type 1 (1.5) Seyfert?

• **Cool point source** spectrum (0.13 Jy @ 9 µm, 0.26 Jy @ 12 µm). This is not what one would expect to see from the hot unresolved dust...
Summary

• To test the unified model we observe the dusty torus of nearby Active Galactic Nuclei with mid-infrared interferometry

• Detailed observations of the nearest radio galaxy Centaurus A have revealed a thin disk \( \perp \) VLBI jet axis

• For the first time, a torus is now resolved in a "type 1" (unobscured) galaxy, NGC 4151

• Outlook: Studies of more AGNs will allow us to get statistical information, further modelling (hydro + rad. transfer) will give more physical insight