The molecular torus around NGC 1052
(and other AGN)

Violette Impellizzeri (NRAO)

Alan Roy (MPIfR), Christian Henkel (MPIfR), and John McKean (ASTRON)
The torus

$N_H \ 10^{22} \text{ cm}^{-2} ; \text{OH opacities} \ll 1$

$N_H \ 10^{24} \text{ cm}^{-2} ; \text{OH opacities} > 1$

Molecular abundances in tori: $N(\text{OH})/N(\text{HI}) \leq 10^{-3}$

(Krolik & Lepp 1989)

Dusty AGN torus is molecular gas rich
OH surveys

- Expect to observe molecular absorption against the compact, flat spectrum radio cores of NLRs.
- Not only confirm the existence of a torus, but also derive valuable physical and kinematical information.

**OH surveys at 1.6 GHz**
- Schmelz et al. 1986,
- Staveley-Smith et al. 1992,
- Baan et al. 1992
- ... (sensitivities of few percent)

**CO, HCN and HNC searches**
- Drinkwater et al. 1997

Observed ~ 300 galaxies
Low detection rates
(absorption towards two Seyferts maser emission in five).

*Surprisingly few detections!*

OH abundance lower than predicted? No torus?
No CO absorption in Cygnus A

- Of all AGN, Cygnus A is expected to have a molecular torus
- NLRG
- Large X-ray absorbing column \((10^{23.5} \text{ cm}^{-2})\)

Search for CO (1-0) absorption yielded non detection!

Search for OH (1.6 GHz) non detection

\(\text{H}_2\text{CO} \quad \text{non detection}\)

HI detected (Coway & Blanco 1995)
Radiative excitation I

① Gas in a hot (5000 - 10000 K) mainly atomic phase.

② Radiative excitation of CO, OH and NH3 due to the central radio source causes the non detection of molecular absorption (Maloney, Begelman & Rees 1994).
Radiative excitation effects

Maloney, Begelman, & Rees (1994) postulate that lack of CO absorption is due to radiative excitation by non-thermal radio source: High $T_{ex}$ depletes lower rotational levels, decreasing optical depth

Is OH, too, radiatively excited?

For torus located 10 pc from AGN:

- opacity in 1.6 GHz transition suppressed by factor $10^3$
- opacity in 6 GHz transition suppressed by factor $10^2$
- opacity in 13.4 GHz transition will increase slightly by factor 2.

Black (1998)

Thus, absorption will strongly depend on transition one chooses to observe.

Have we been looking at the right transitions?
A new survey for OH

Search for highly excited rotational states of OH at 6.035 GHz & 6.031 GHz, 4.750 GHz and 13.4 GHz.

The sample:
- 31 Seyfert 2 galaxies
- High X-ray absorbing columns (> $10^{22}$ cm$^{-2}$)
- Continuum flux density at 6 GHz > 50 mJy
- HPBL

Effelsberg observations:
- 3-10 hours per source at 4.7 GHz and 6 GHz, PSW
- Velocity coverage 2000 km/s (4 km/s per channel)
- Sensitivity 3.5 mJy (5 $\sigma$) = line opacity of 0.002 to 0.07
Effelsberg spectra (4.7 GHz)

Sample of 20 objects.

no detections down to 3 mJy/channel.

(channel width 1.2 km s$^{-1}$).
Effelsberg spectra (6 GHz)
Best targets due to high X-ray columns and high background continuum at 6.0 GHz.
Effelsberg spectra (6 GHz)

Too strong continuum - Large standing wave ripple!
5 new detections - detection rate 18 %
Effelsberg spectra (6 GHz)

Let's look at NGC 3079 & NGC 5793.
Galaxy NGC 3079
G. Cecil (University of North Carolina)

- Width $\sim 800$ km s$^{-1}$
- Line opacity $\tau \sim 0.055$
- 4.7 GHz non-detection
- 1.6 GHz abs (Baan et al. 1995)
  $T_{\text{ex}} = 30$ K

$N_{\text{OH}} = 1.5 \times 10^{18}$ cm$^{-2}$

from X-rays: $N_{\text{H}} = 1.0 \times 10^{25}$ cm$^{-2}$

---

NGC 5793

- Width $\sim$ up to 1000 km s$^{-1}$
- Line opacity $\tau \sim 0.036$
- 4.7 GHz non-detection
- 1.6 GHz abs (Hagiwara et al. 2000)
  $T_{\text{ex}} = 67$ K

$N_{\text{OH}} = 2.2 \times 10^{17}$ cm$^{-2}$
VLBI observations

VLBA observations carried out with interferometric observations to detect OH at 13.4 GHz towards the core of NGC 1052 and Cynus A.

\[ \alpha \propto \frac{\lambda}{D} \Rightarrow 0.9 \text{ mas beam} \]

Observing time:

NGC 1052 – 7 hours
Cygnus A – 8 hours

Bandwidth 16 MHz (256 channels) per IF.

Velocity coverage ~ 560 km/s.
**NGC 1052**

- Nearby radio galaxy classified as LINER ($z=0.0049$)
- Hosts well-defined double-sided radio jet w/ P.A. $65^0$
- Jet extends up to kpc scale, angle of jet axis is $> 76^0$. 
NGC 1052

- Nearby radio galaxy classified as LINER (z=0.0049)
- Hosts well-defined double-sided radio jet w/ P.A. 65°
- Jet extends up to kpc scale, angle of jet axis is > 76°.
- Multi-frequency VLBI observations have revealed the presence of a dense circumnuclear structure.
NGC 1052

- Nearby radio galaxy classified as LINER ($z=0.0049$)
- Hosts well-defined double-sided radio jet w/ P.A. 65°
- Jet extends up to kpc scale.
- Multi-frequency VLBI observations have revealed the presence of a dense circumnuclear structure.

Vermeulen et al. 2003
NGC 1052

- Nearby radio galaxy classified as LINER ($z=0.0049$).
- Hosts well-defined double-sided radio jet w/ P.A. 65°.
- Jet extends up to kpc scale, angle of jet axis is > 76°.
- Multi-frequency VLBI observations have revealed the presence of a dense circumnuclear structure.
- Plasma condensation covers 0.1 pc and 0.7 pc of approaching and receding jet (Kameno et al. 2001).
- X-ray column is $10^{22} - 10^{23}$ cm$^{-2}$ (e.g. Kadler et al. 2004).
- H$_2$O megamasers found towards the centre redshifted by 50-350 km/s wrt systemic (e.g. Braatz et al. 2003).
NGC 1052

- H$_2$O detected where free-free opacity large.

Other lines have been detected:
- HI, OH, HCO$^+$, HCN and CO…

Sawada-Satoh et al. 2008
NGC 1052

Vermeulen et al. 2003

Sawada-Satoh et al. 2008

H$_2$O detected where free-free opacity large.

Other lines have been detected: HI, OH, HCO, HCN and CO.

Sawada-Satoh et al. 2008
NGC 1052 – VLBA 13.4 GHz

Broad Width:
FWHM ≈ 200 km/s

Optical depth (counter jet)

\( \tau_{\text{OH}} \approx 0.264 \)

Obscuration in the inner jet region (< 0.3 pc), coincident with free-free absorption.
NGC 1052 – VLBA 13.4 GHz

Broad Width: FWHM ≈ 200 km/s

Optical depth (counter jet) τ_{OH} ≈ 0.264

Obscuration in the inner jet region (< 0.3 pc), coincident with free-free absorption.
NGC 1052 – VLBA 13.4 GHz

Broad Width: FWHM ≈ 200 km/s

Optical depth (counter jet) \( \tau_{\text{OH}} \approx 0.264 \)

Obscuration in the inner jet region (< 0.3 pc), coincident with free-free absorption.
NGC 1052 – where is absorption located?

Optical depth map
NGC 1052 – where is absorption located?

Optical depth map
Fitting into the picture

Sawada-Satoh et al. 2008
Fitting into the picture

Sawada-Satoh et al. 2008
Cygnus A

Continuum peak flux
453 mJy per beam

Optical depth (core)
$\tau_{\text{OH}} \approx 0.12$

Absorbing gas is diffuse around the inner jets.

Profile strongest over the entire continuum.
Cygnus A

Continuum peak flux
453 mJy per beam

Optical depth (core)
\( \tau_{\text{OH}} \approx 0.12 \)

Absorbing gas is diffuse around the inner jets.

Profile strongest over the entire continuum.
Conclusions from VLBA observations

- 13.4 GHz OH was detected for the first time in the core of an AGN (NGC 1052 and Cygnus A).

  Evidence for molecular gas in the region we would expect to see a torus.

- In Cygnus A, if real the detection is consistent with radiative excitation models proposed for this source.

- In NGC 1052, redshifted OH gas cloud detected toward the counterjet

  Part of rotating torus/infalling material?

- Detection consistent with previous H$_2$O observations.
New surveys for OH

- Future surveys for the molecular component of AGN should include the 13.441 GHz and 13.434 GHz lines of OH.

- We plan to observe the whole sample with the GBT and the newly upgraded EVLA.
Conclusions from OH survey

- A survey for 6.0 GHz and 4.7 GHz with Effelsberg found highly excited, broad absorption lines in 5 out of 28 sources, i.e. 18%.
- Selection criteria improved detection rate c.f. other OH surveys (< 7%).
- Line widths are 100s-1000 km/s (close to nuclear region?).
- No new detections at 6.0 GHz were made where there was no previous OH absorption/emission at 1.6 GHz.
- Still some sources with high column density didn’t show absorption.

Results do not support radiative excitation models alone to explain the lack of detections.

But still the non detections must be explained !!
Conclusions from OH survey

- Bimodal distribution of absorptions $\rightarrow$ very compact clouds?
- Broad lines in infall/outflow? Not a simple rotating torus?
- X-ray absorber may be non-molecular in most galaxies??