A Plasma Obscuring Torus and H2O Maser Emission in NGC 1052

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NGC 1052 ....

- A nearby GPS source
  - $z=0.0049$; Knapp+ 1978
- A double-sided jet structure
- Proper motion of the jet
  - $v/c = \beta = 0.64$; Kellermann+ 1998, Vermeulen+ 2003
- $V_{\text{sys}} = 1490$ km/s
  - based on HI observation; de Vaucouleurs+ 1991
- H$_2$O megamaser emission
  - A broad velocity width (1500-1900 km/s)
  - Variable

NGC 1052....

- Highly rising spectra in the center
- Fit the continuum spectra to free-free absorption (FFA) model
  - A pc-scale dense plasma torus; Kameno+ 2001
- Absorption lines
  - HI; van Gorkom+ 1986
  - OH; Omar+ 2002
  - HCO+, HCN, CO; Liszt & Lucas 2004

Kameno et al. (2001)
Origin of H2O Maser ~hypothesis 1~

**Case 1: Claussen et al. (1998)**

- A velocity range of 1585-1685 km/s
  - Not same as the whole velocity width
- Distributed along the western receding jet
- Velocity gradient along the jet axis
  \( \sim 100 \text{ km s}^{-1} \text{ mas}^{-1} \)
- Excited by jet
Case 2: Kameno et al. (2005)

- Central condensation of the plasma where the H2O masers are distributed
- Circumnuclear torus model to explain the time variability
  - Jet components run behind the torus

Important to confirm the positional relation between the H2O maser and the torus
Observations & Data Reductions

- Multifrequency simultaneous VLBA at 15, 22, 43 GHz.
- Four 8 MHz IF channels with 256 spectral channels for each IF.
- At 22GHz, two IF channels for continuum emission, other two IF channels for the H2O maser emission.
- Channel maps of H2O maser emission made every 6.74 km/s.

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Beam size (mas²)</th>
<th>Rms level (mJy/beam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1.3 x 0.5</td>
<td>0.24</td>
</tr>
<tr>
<td>22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.9 x 0.3</td>
<td>1.07</td>
</tr>
<tr>
<td>22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.9 x 0.3</td>
<td>5.66</td>
</tr>
<tr>
<td>43</td>
<td>0.4 x 0.2</td>
<td>1.45</td>
</tr>
</tbody>
</table>

(a): Continuum map.
(b): Channel map of H2O maser.
Results ~ Continuum jet knots ~
• The double-sided jet structure, which consists of several knots.
• Most parts of the jet structure have optically thin spectra at 15-43 GHz.
• A steeply rising spectrum at the inner edge.

\[
\alpha^{22}_{15} = 3.2 \pm 0.1 \\
\alpha^{43}_{22} = 3.1 \pm 0.1
\]

Exceed the limit of SSA
Results ~ FFA Opacity Distribution ~

\[ S_\nu \propto \nu^\alpha \exp (-\tau_0 \nu^{-2.1}) \]

- Fit the continuum spectra to the FFA model
- High opacity in the inner edge (~1000)
- FFA plasma covers ~1mas (0.1pc)
  - A dense plasma torus
Results ~ H2O Maser (1) ~

• A velocity range 1550-1850 km/s
  – Same as the whole velocity width
  – Note that Claussen et al. (1998) detected at velocity range of 1585-1685 km/s

• Two clusters
  – Distributed along the jet direction
  – The eastern cluster:
    • the first detection
    • within the approaching jet knot B
  – The western cluster:
    • within the receding jet knot C3
  – Positional coincidence to the FFA plasma
Results  ~ H2O Maser (2) ~

• The redshifted masers seen closer to the center.

• Velocity gradient
  – The eastern cluster: seem to include several substructures in velocity
  – The western cluster: a clear trend 250 km s$^{-1}$ mas$^{-1}$
  – The western cluster is similar to the masers Claussen et al. (1998) detected
    • Detected within the receding jet
    • Velocity gradient of $\sim$ 100 km s$^{-1}$ mas$^{-1}$
Discussions ~ Orientation of the Jet Axis ~

- The brightness temperature ratio between the approaching and receding jets is a function of the viewing angle of the jet axis and the true jet speed.
- Assuming that knots A and C1 forms a symmetric pair of jets on either side
  - $\theta = 79-80$ degree at 15 GHz, $\theta = 76-90$ degree at 22 GHz
  - Considered to be nearly parallel to the sky plane

$$R = \frac{S_A \cdot \phi_{maj}^{C1} \cdot \phi_{min}^{C1}}{S_{C1} \cdot \phi_{maj}^{A} \cdot \phi_{min}^{A}} = \left( \frac{1 + \beta \cos \theta}{1 - \beta \cos \theta} \right)^{3-\alpha}$$
Discussions

To account for these observed characters:

- FFA plasma spanning $\sim 1$ pc
- Redshifted velocity of the H2O maser with respect to the $V_{\text{sys}}$
- H2O masers that appear to be projected against knots B and C3
- A Velocity gradient of H2O maser along the jet axis
- More dominant FFA opacity and H2O maser emission
Discussions ~ interpretation of maser ~

Scenario 1: A circumnuclear torus model

- Consists of several layers
  - FFA plasma layer on the inner surface
  - The X-ray dissociation region (XDR) next to the plasma layer
  - Excited H2O molecules in the XDR amplify the continuum emission from the jet knots in the background. => H2O maser
- Acceleration of the infalling gas toward the center
  - The redshifted H2O maser
Discussions ~ interpretation of maser ~

Scenario 2: The jet excitation model

- Excitation of H2O masers by the outflowing jet
- An advantage in explaining the velocity gradient along the jet axis
- Easy to explain the western maser cluster
  - All redshifted
  - Appear projected against the receding jet
- Do not explain why the masers of the eastern cluster also redshifted
  - If the exact Vsys is not 1490 km/s but around 1700 km/s, it would be OK.
Conclusions

- Multifrequency observation toward the center of NGC 1052 at 15, 22, 43 GHz with the VLBA.
- The angles of the jet axis to the line of sight is > 76 deg, nearly parallel to the sky plane.
- Steeply rising spectra spanned in the inner 0.2 pc around the nucleus, which imply FFA by plasma in the torus.
- The H2O maser clusters are projected against the inner knots of both the approaching and receding jets, where the FFA opacity is large.
- The more redshifted masers lie closer to the center
- Positional coincidence between the H2O masers and a plasma torus => H2O maser could arise from the torus.