Class I Methanol Maser Emission in NGC 4945



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Tiege McCarthy
PhD Candidate
Supervisor: Simon Ellingsen

NGC 4945

- Nearby (3.7 ± 0.3 Mpc)
- Southern declination (-49°)
- Barred Spiral
- Seyfert 2 Nucleus
- Classified as Starburst & AGN
- Systemic velocity of 561 km s^{-1} (Barycentric)



NGC 4945

- The AGN is one of the strongest hard x-ray sources observed from Earth

- The AGN is heavily obscured by dust

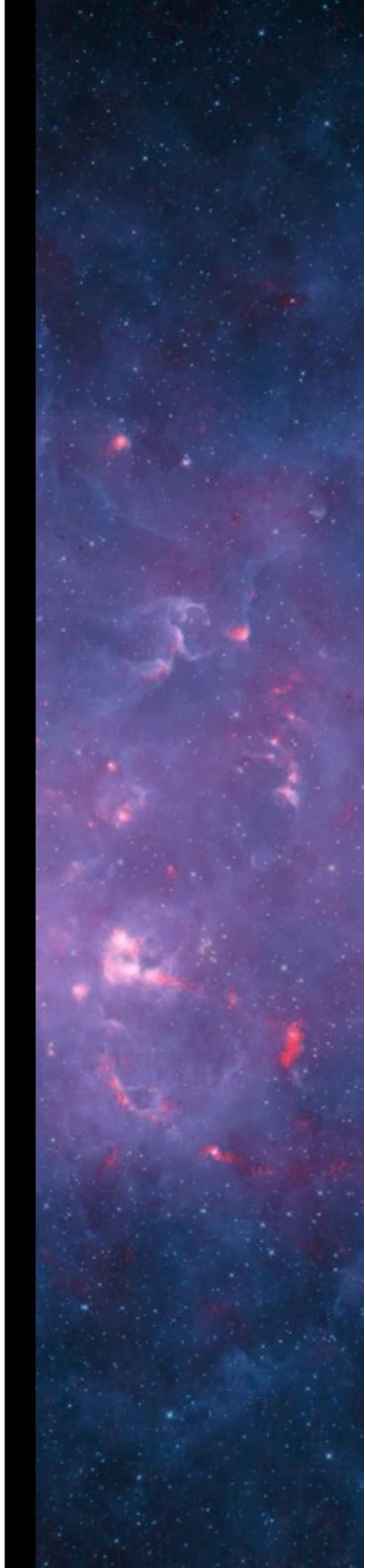
  → Starburst process is responsible for majority of energy exciting photoionized gas (Marconi et al. 2000, Bendo et al. 2016, etc.)

- Star formation rate is approximately a factor of three higher than for the Milky Way

  → NGC4945 SFR: $4.35 \pm 0.25\ M_{sol}\ yr^{-1}$ (Bendo et al. 2016)

  → Milky Way SFR: $1.65 \pm 0.19\ M_{sol}\ yr^{-1}$ (Licquia & Newman 2015)

- 400 pc long elliptical rotating molecular cloud complex



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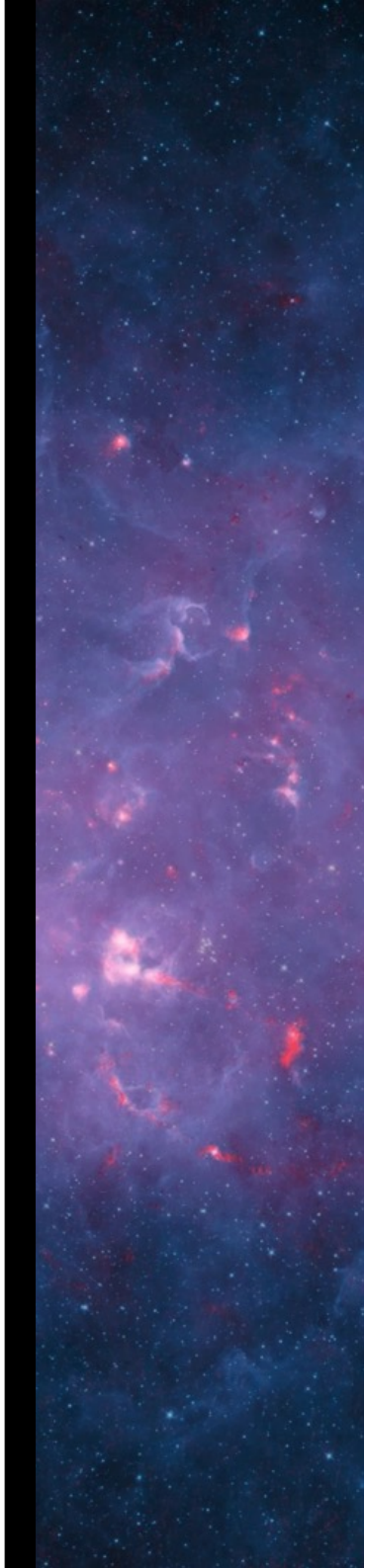
Extragalactic Class I Masers

- 36.2-GHz is most commonly observed in extragalactic sources (NGC 4945 makes four confirmed detections)
- Pumping mechanism (for extragalactic sources) not well understood
- Extragalactic class I methanol masers do not appear to be simply large-scale emission from Galactic-style maser regions
- Expected association with molecular infall within host galaxies (Ellingsen et al. 2014)



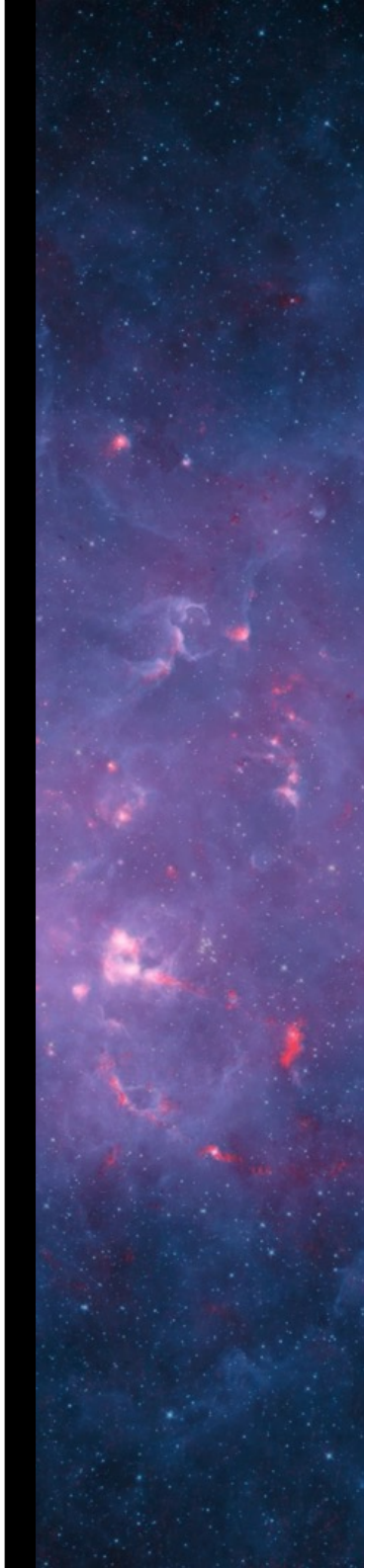
Observations

Australia Telescope Compact Array (ATCA)

- 25th and 26th of August 2015
  - → EW352 array
  - → baselines: 31 – 352 metres
  - → beam size: 26.2 × 3.9 arcsec (poor hour-angle coverage)
  - → Spectral resolution of 0.259 km s^{-1}

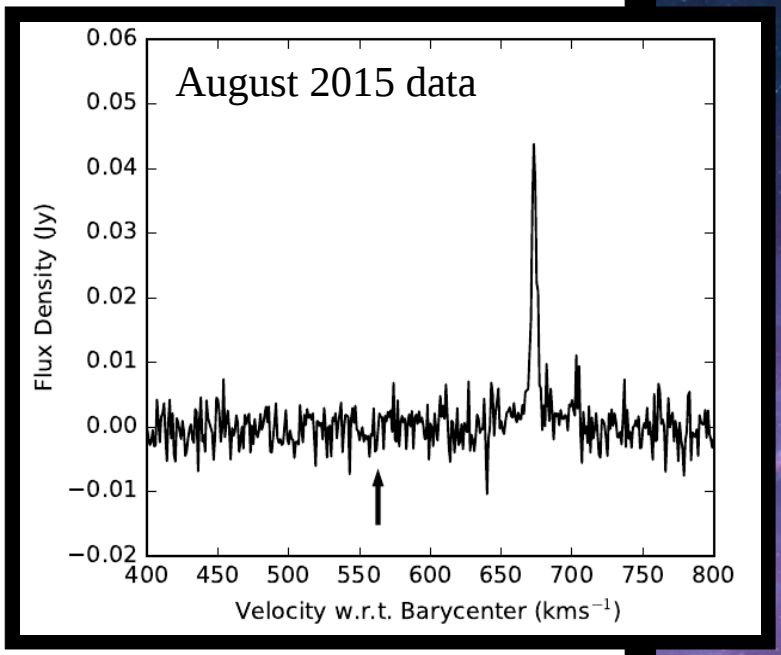
  Limited hour-angle coverage + East-West array (EW352) prevents accurate determination of position

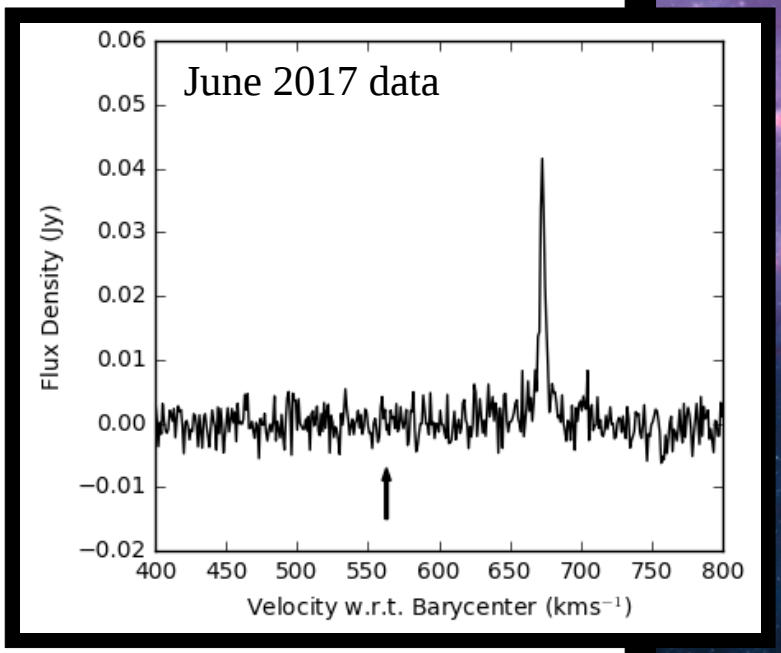
- 30th June and 2 July 2017
  - → H168 array
  - → baselines: 61 – 192 metres
  - → beam size: 5.2 × 4.5 arcsec
  - → Spectral resolution of 0.259 km s^{-1}



Class I Maser Emission

- Narrow emission detected red-shifted from systemic velocity
  - → S_{peak} = 43.8 mJy
  - → V_{peak} = 674 km s^{-1}
- Total velocity range of 50 km s^{-1}
  - → 660 – 710 km s^{-1}
- Integrated flux-density of 256 mJy km s^{-1}
- Isotropic luminosity of 4.44×10^7 Jy km s^{-1} kpc^2
  - → 10^5 brighter than galactic equivalent





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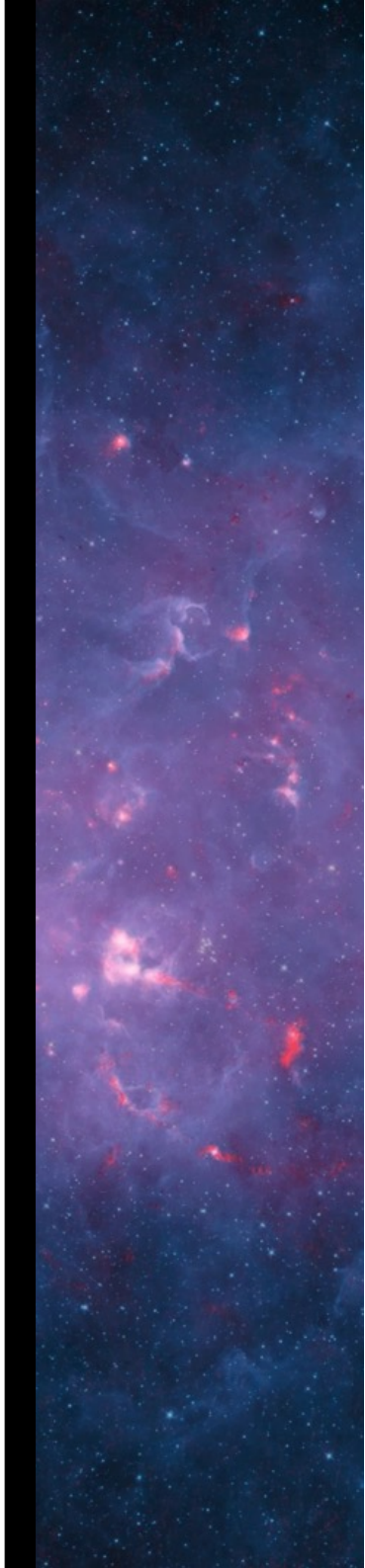
Is it a maser?

- Narrow linewidth (~10 km s^{-1})
- Second weaker component red shifted by ~30 km s^{-1}
  → Same narrow linewidth
- Compact emission
- No association with previous observations of thermal emission
- Within a factor of two of the luminosity of the NGC 253 maser emission

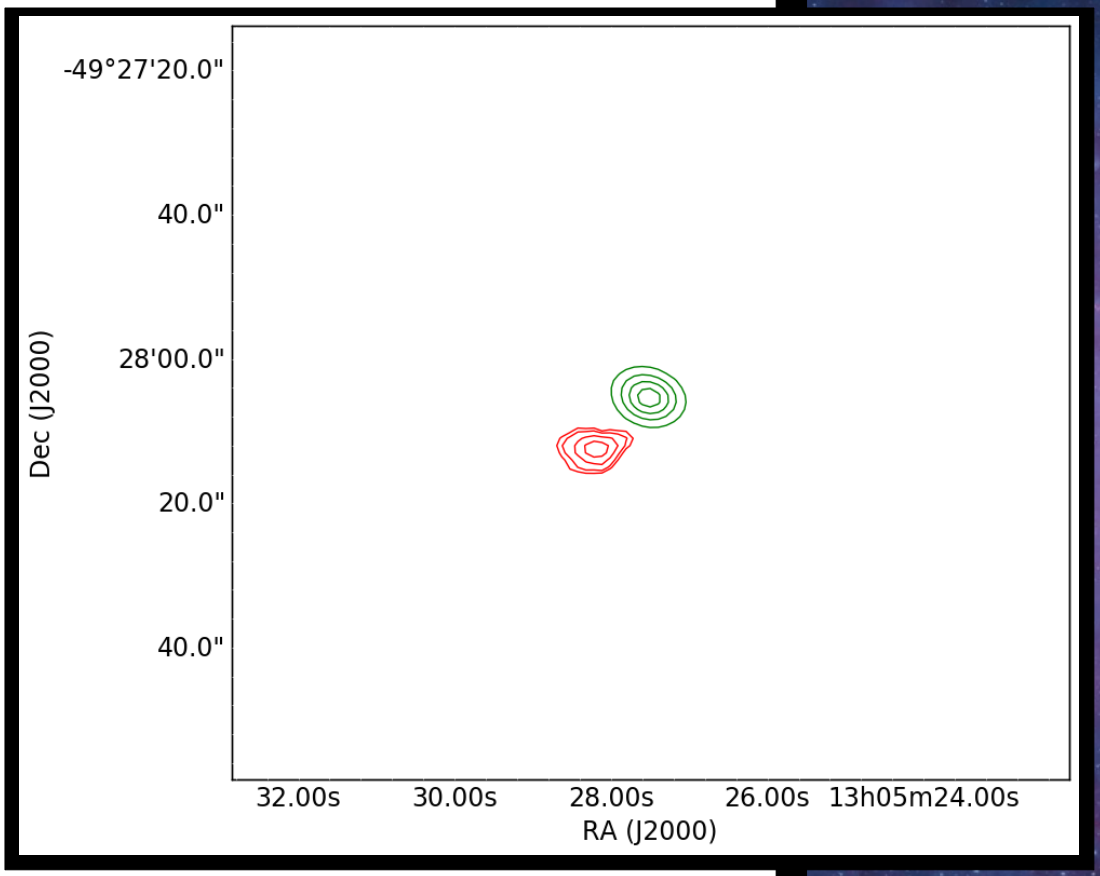


Imaging Maser Emission

Can determine positions to better than 0.4 arcsecs

- Maser emission:
  - → RA: 13:05:28.093
  - → Dec: -49: 28: 12.306
- Continuum emission:
  - → RA: 13:05:27.467
  - → Dec: -49: 28:04.797
- Masers offset by approximately 10 arcsec

June 2017 data



7mm Continuum Emission

36-GHz Methanol Emission

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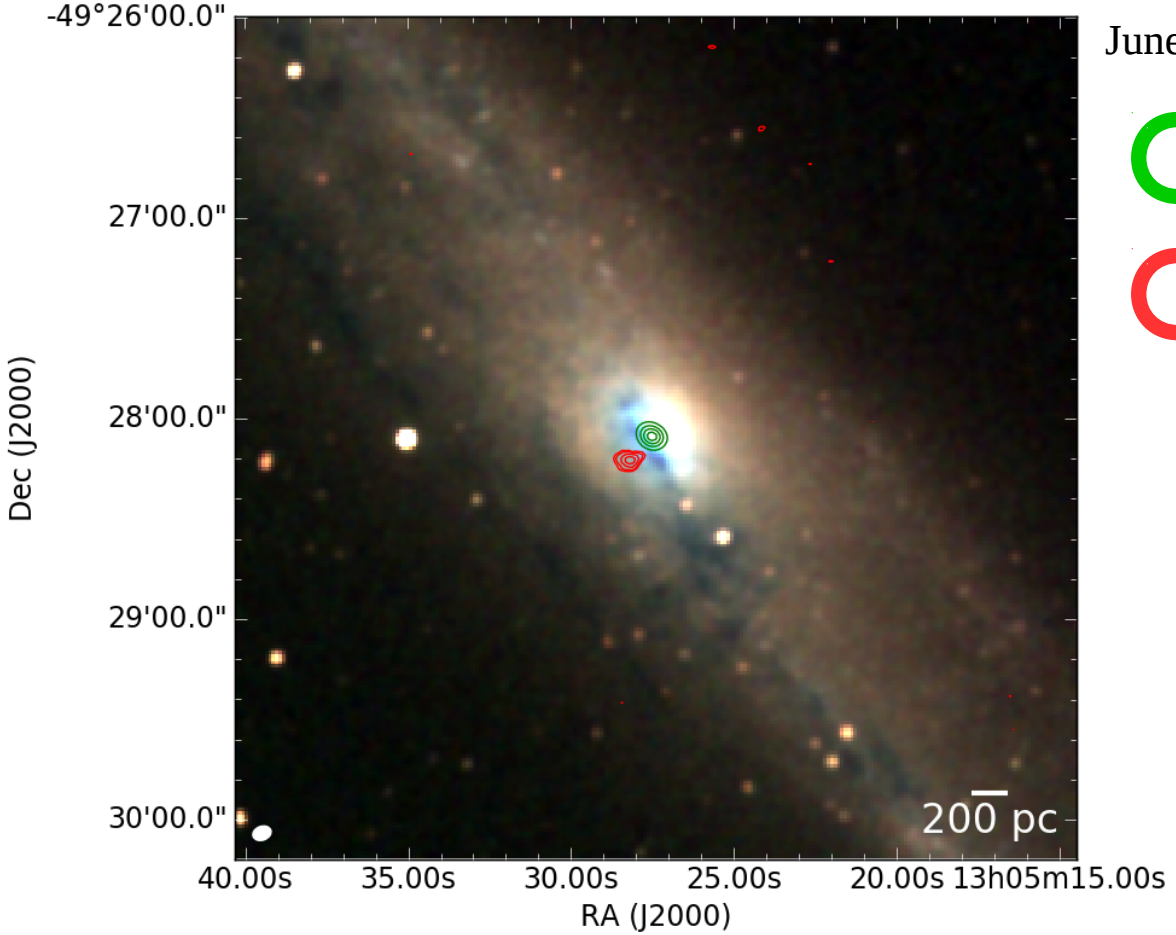
The maser environment



June 2017 data

7mm Continuum Emission

36-GHz Methanol Emission

- Methanol emission offset SE from nucleus by 174±14 pc (at assumed distance of 3.7±0.3 Mpc)
- Similar linear offset as seen in other examples of extragalactic class I masers (e.g. Ellingsen et al. 2014)

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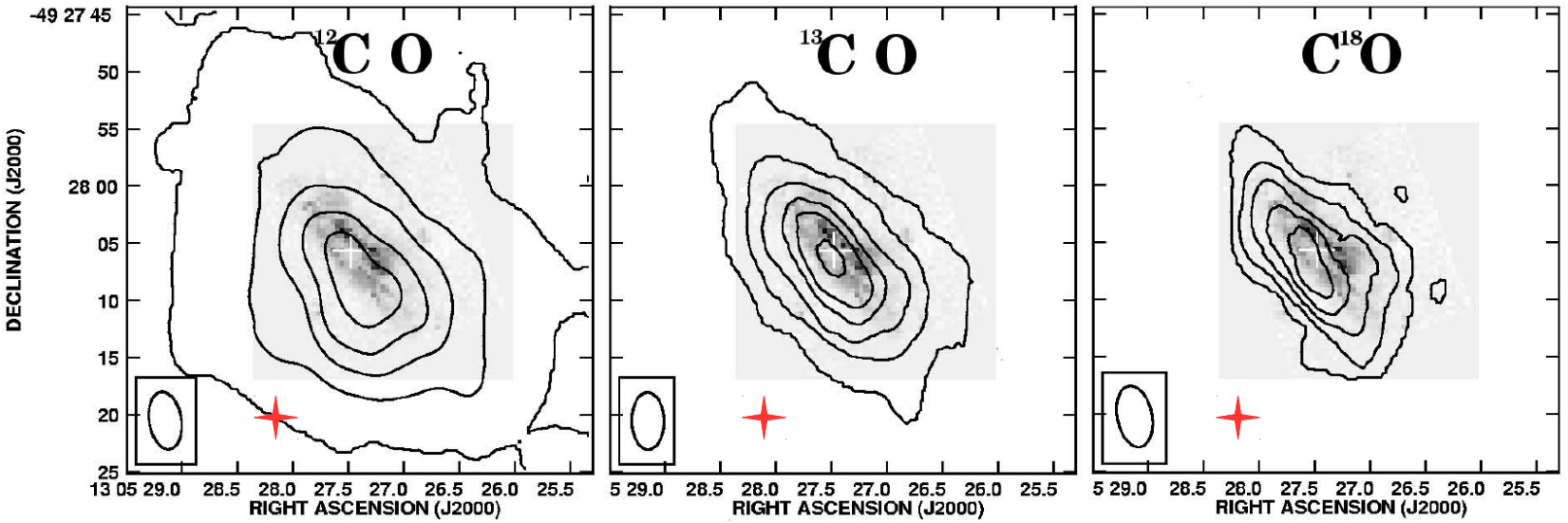
The maser environment

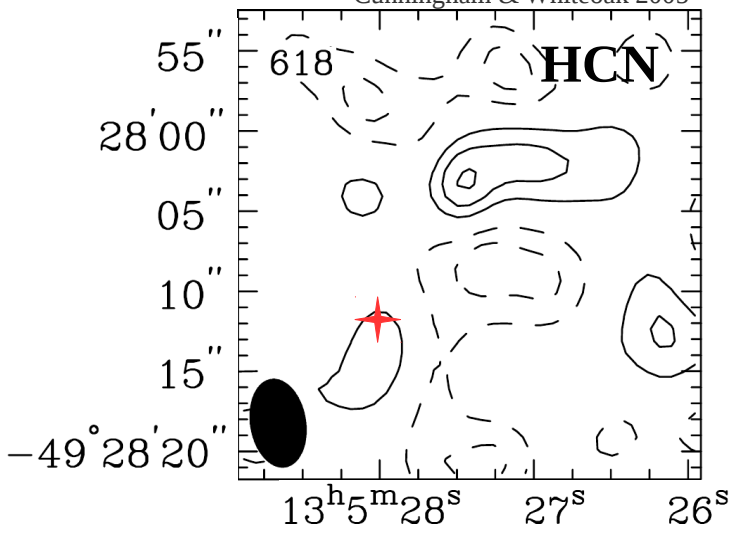
Figure originally presented by Chou et al. (2007)

Methanol maser location



- Located at the outer edge of the CO and HCN circumnuclear molecular clouds (Cunningham & Whiteoak 2005,Chou et al. 2007)
  - → No significant enhancement in the gas tracers at the location of the methanol maser

Cunningham & Whiteoak 2005



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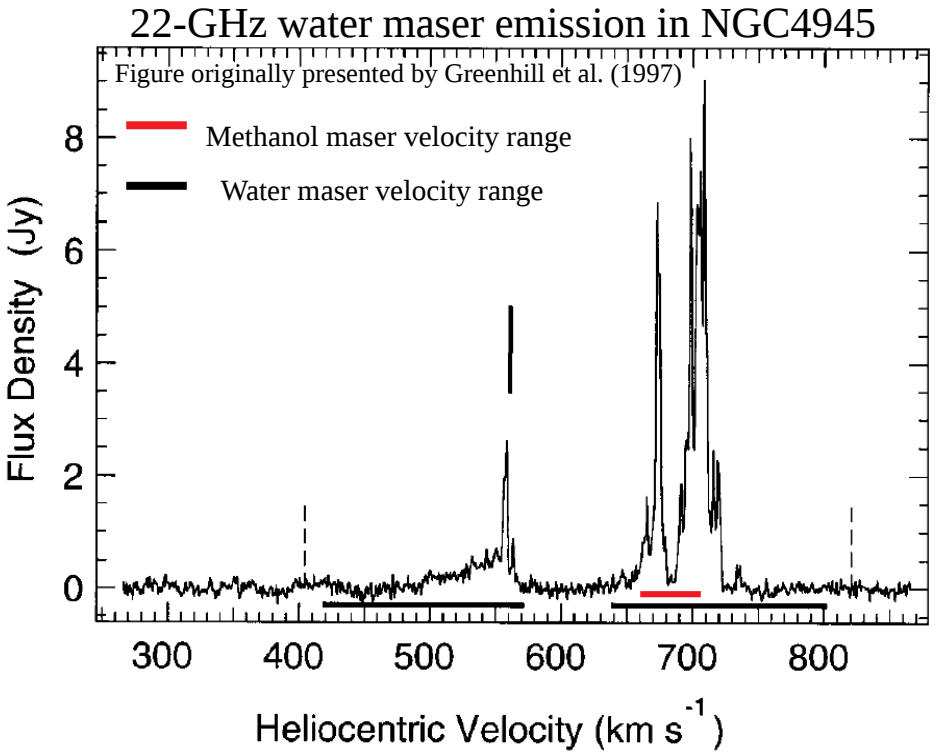
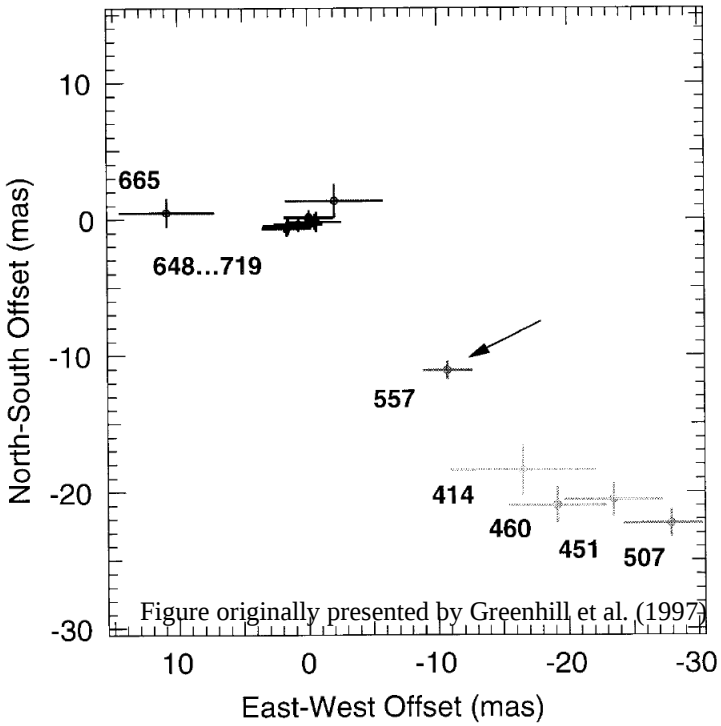
The maser environment





- Not aligned with location of known H_2O megamasers (reported by Greenhill et al. 1997, Hagiwara et al. 2016 etc.)
  → <1 pc from nucleus

- Velocity of red-shifted water masers overlaps with methanol velocity range

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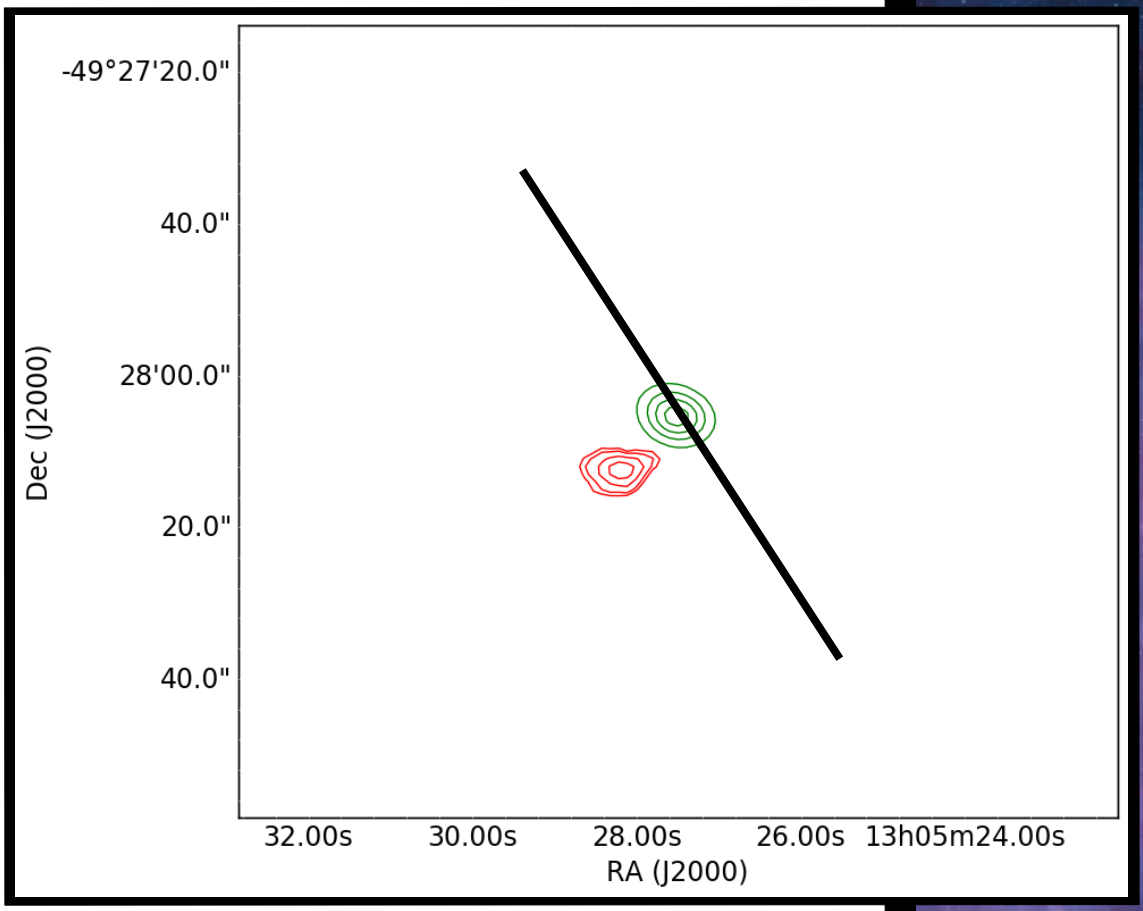
Bar association?

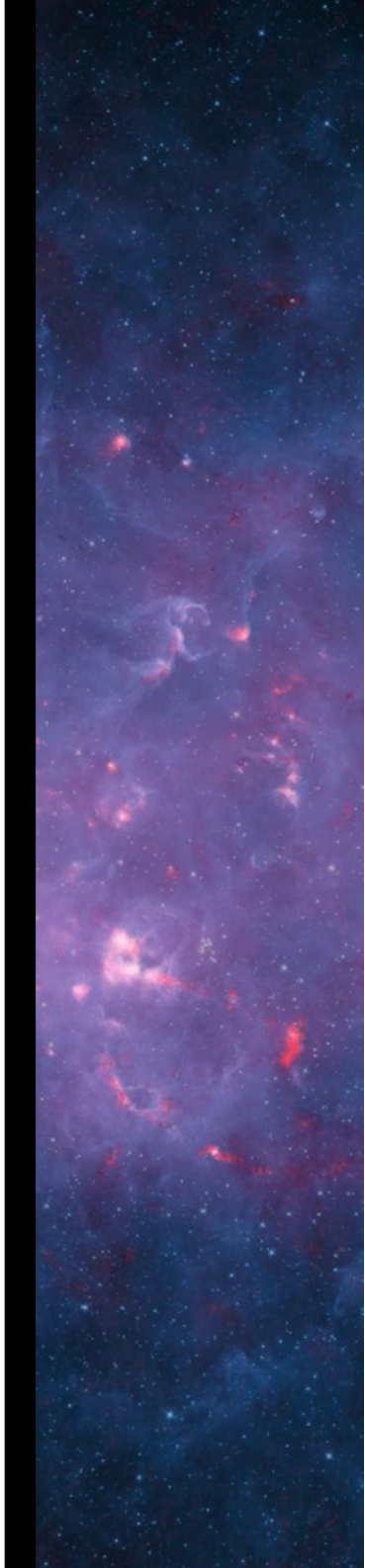
June 2017 data



- NGC 253 (and potentially NGC 1068) show association with galactic bar
- Bar in NGC 4945 is not well studied
- Bar PA of 33° (Chou et al. 2007)
- Does not appear to be any co-location between maser emission and bar position

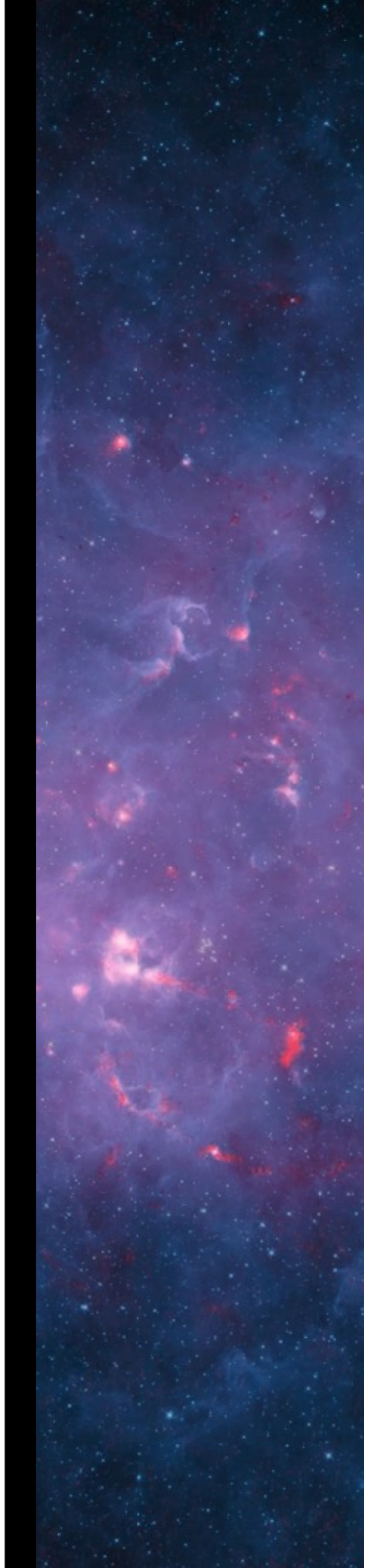
Molecular inflow?

- Monje et al. 2014 report the **possibility** of molecular inflow from observations of hydrogen fluoride (HF) absorption towards NGC 4945
- Velocity range of 560 – 720 km s^{-1}
- Upper limit of ~200 pc on radius of molecular inflow
- Maximum inflow velocity of 152 km s^{-1}
- Maser emission from NGC 4945 satisfies both of these conditions!
- Fits hypothesis presented by Ellingsen et al. (2014, 2017)



Unanswered questions?

- How are these extragalactic masers pumped? What environments allow for these masers to develop?
- Why do we only see one region of maser emission in NGC 4945?
  → Understanding optimal environment helps answer this
- Why do we not see extragalactic 44.1-GHz masers as readily as 36.2-GHz?



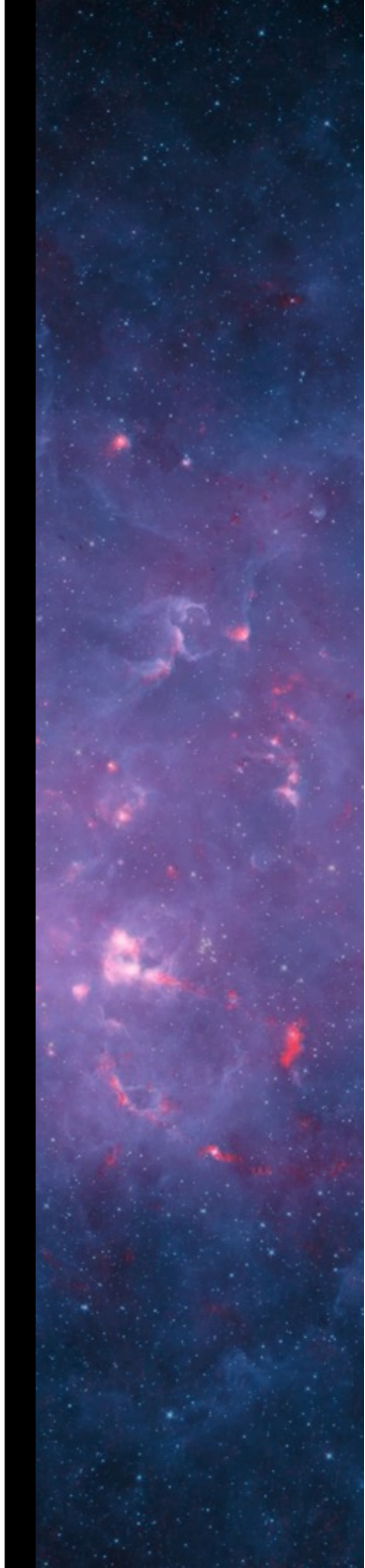
Future searches

What can adding NGC 4945 to the growing sample tell us?

- Search towards sources with reported molecular inflows
- Three out of four host galaxies contain bars

Unlike NGC 253, the dynamics and molecular gas composition of NGC4945 has not been significantly studied

→ Further investigation of this will allow us to determine why NGC4945 is host to an extragalactic methanol maser!



Conclusions

- We detect extragalactic class I maser emission towards NGC 4945
- Emission has been observed across multiple epochs
- Maser region does not appear to be associated with galactic bar in NGC 4945
- Masing region may be associated with a possible molecular inflow
- Further observations and study of NGC 4945 is required in order to understand the nature of the maser environment

