The Maser-Starburst connection in NGC253

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Collaborators

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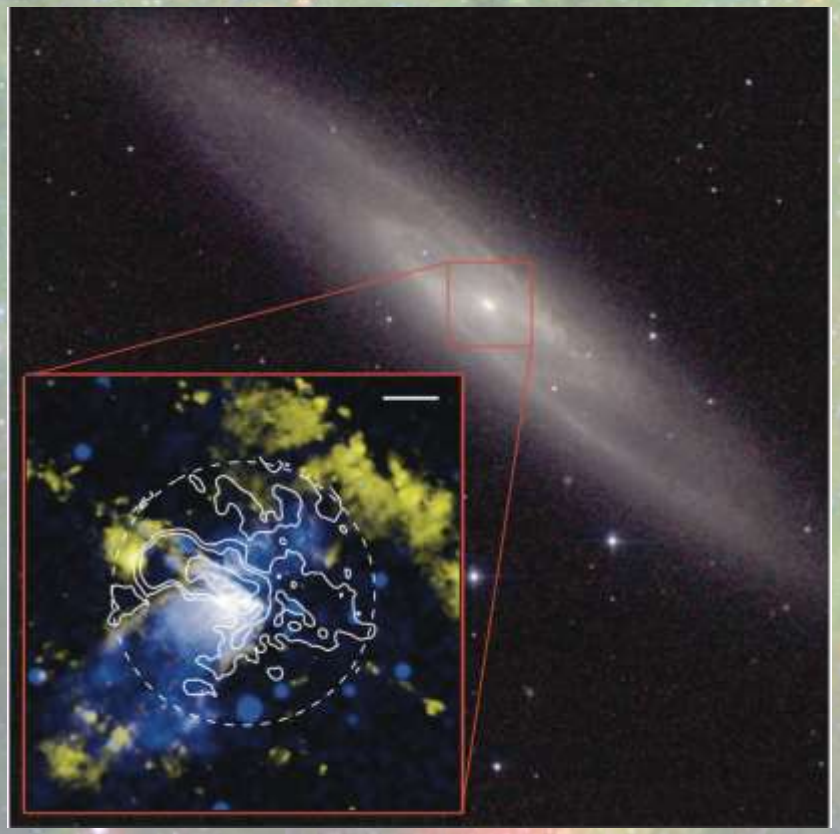
NGC253

NGC253 is the closest starburst galaxy (distance 3.4 Mpc), the largest galaxy in the Sculptor group.

It is a barred spiral galaxy at an inclination of around 76° .

Nuclear starburst with outflow perpendicular to the disk but no detected AGN/nuclear emission.



2MASS JHK composite image of NGC253 with soft x-ray (blue) and Hα (yellow), CO (white contours) (Bolatto et al. 2013)

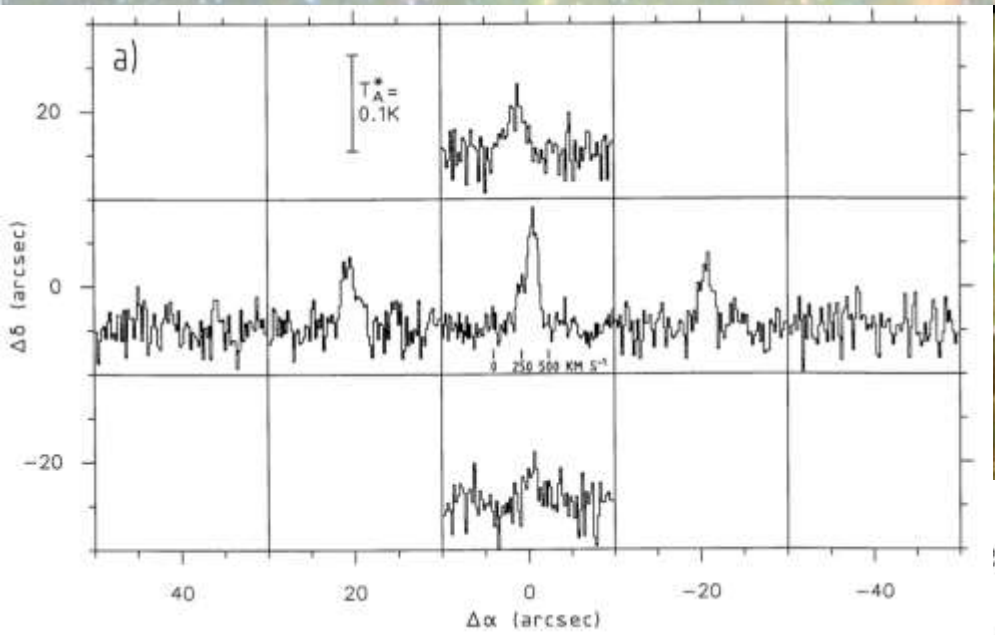
A long time ago in a galaxy not so far, far away....

1987

Trump was on the cover of Newsweek "A *Billion Dollar Empire* and an Ego to match"

and Henkel et al. made the first detection *of methanol in* an extragalactic source, *observing the* 96 GHz methanol series *towards NGC* 253 with the IRAM 30m









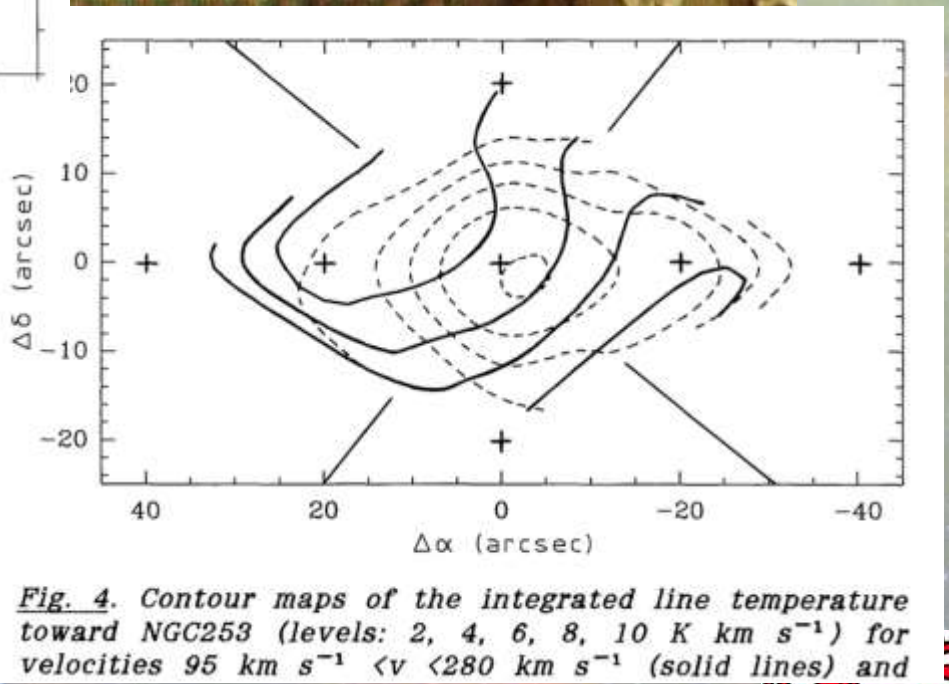


Fig. 4. Contour maps of the integrated line temperature toward NGC253 (levels: 2, 4, 6, 8, 10 K km s^{-1}) for velocities 95 km s^{-1} <v <280 km s^{-1} (solid lines) and

Henkel et al. 1987, *A&A* **188**, L1

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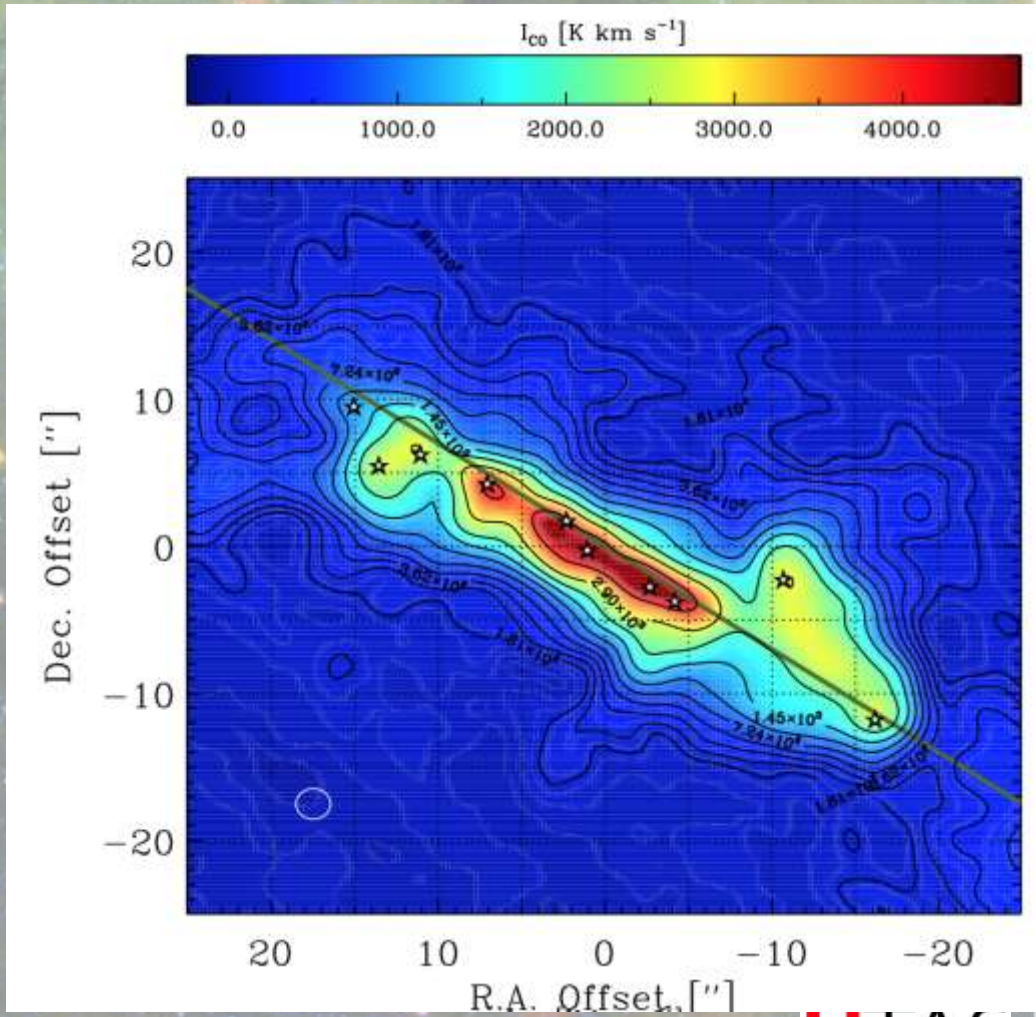
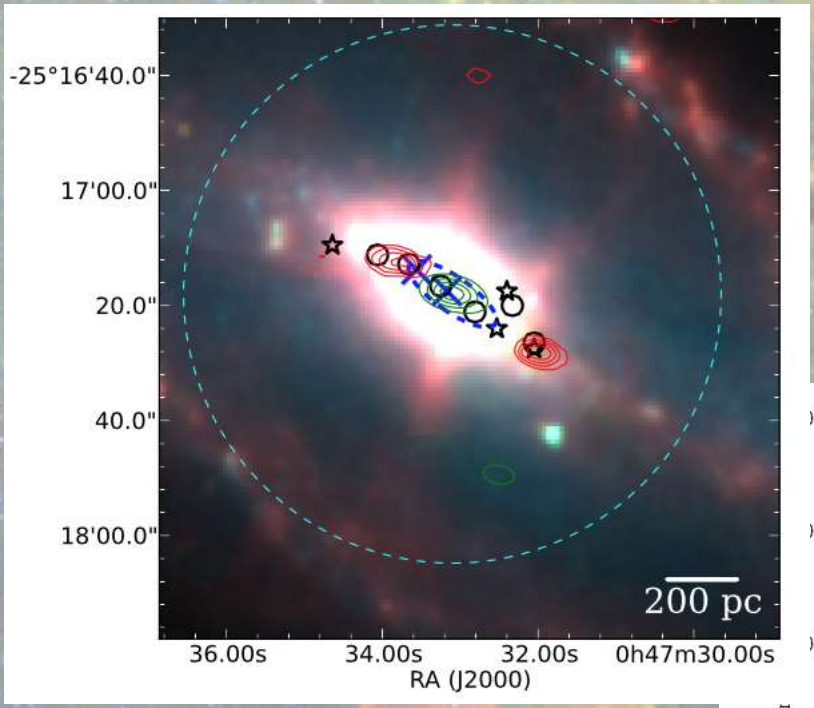
NGC253 diffuse molecular gas

CO (1-0) as observed by ALMA at ~2 arcsecond resolution (Leroy et al. 2015). The stars represent the location of 10 molecular cores seen in dense gas.





Ellingsen et al. (2017b) (arXiv:1708.02602), highest resolution ~ 1”

Ellingsen et al. (2014), discovery paper, angular resolution ~ 5”.
Weak, diffuse masers or a mix of thermal and maser emission?

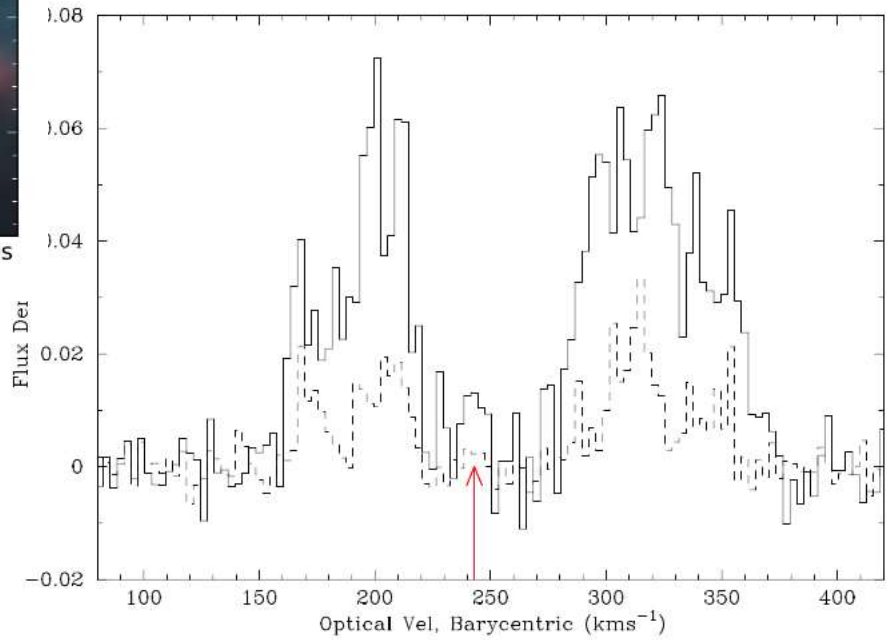
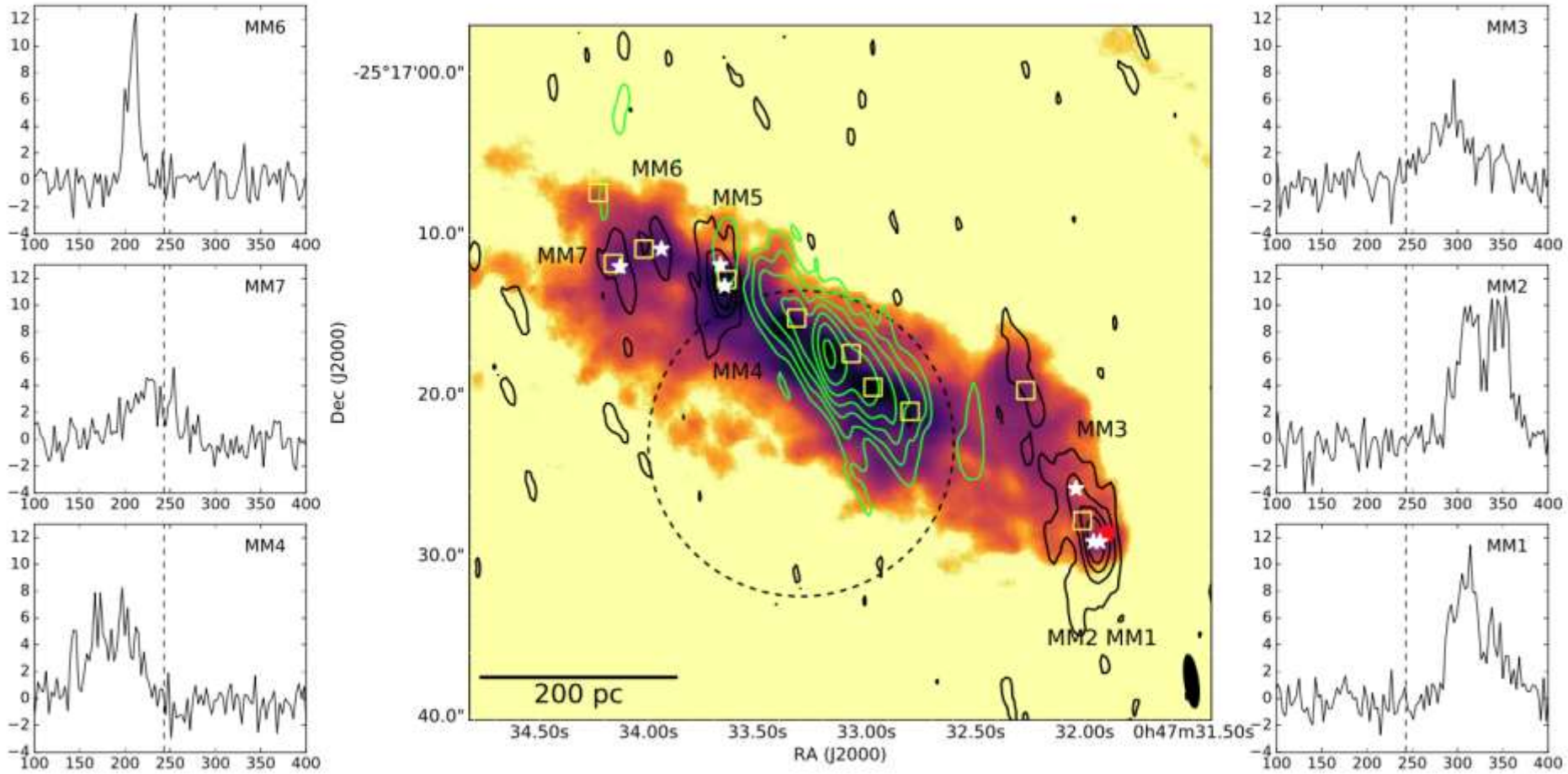
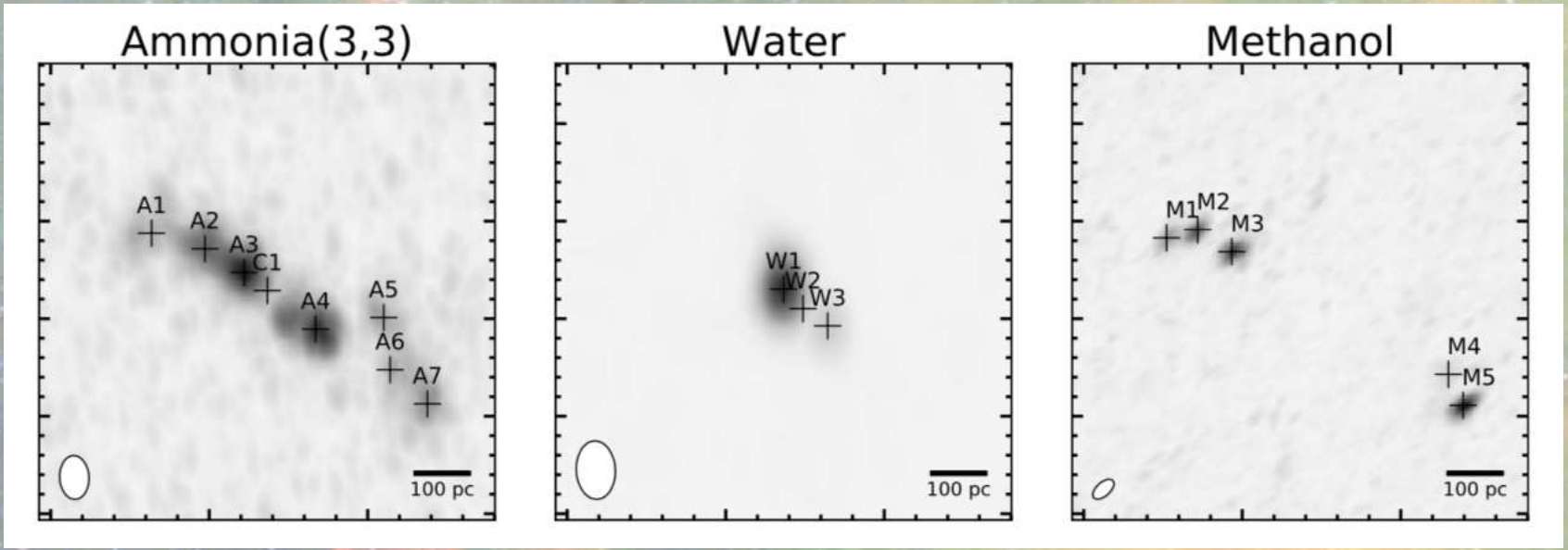


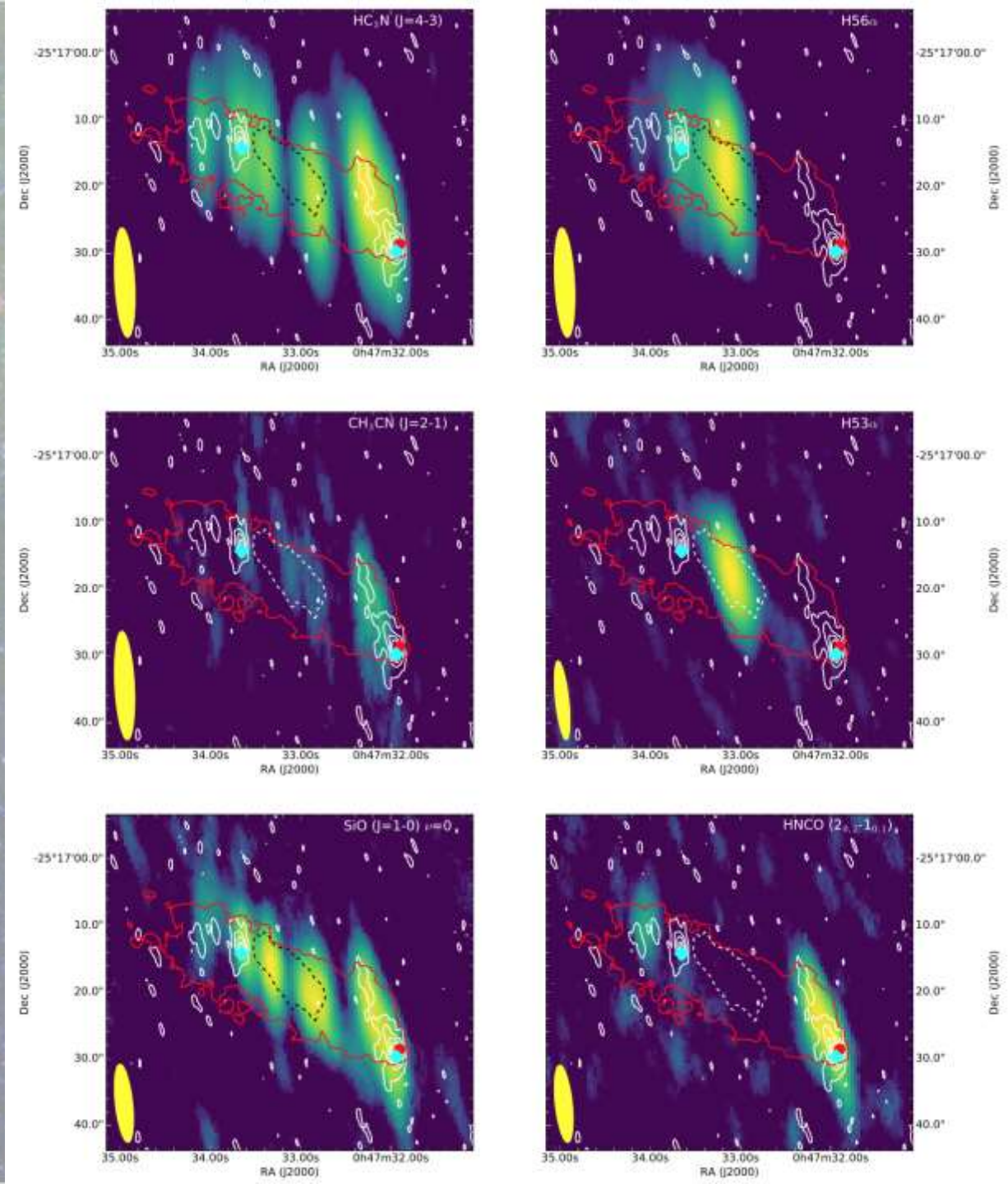
Figure 1. The integrated 36.2-GHz methanol emission from NGC 253 from the ATCA EW367 array observations (solid line) and 1.5A array observations (dashed line). The red arrow marks the systemic velocity of the Galaxy (243 ± 2) km s^{-1}



ATCA observations of the 36.2 GHz methanol masers made combining data from H168, EW367 and 1.5A arrays (Ellingsen et al. (2017b)



- Gorski et al. (2017) used the the JVLA to image a range of molecular lines in the frequency range 21-37 GHz.
- Focus of the observations was the NH_3 inversion transitions, water masers and 36.2 GHz class I methanol masers.
- Independent confirmation of the detection of 36.2 GHz methanol masers by the JVLA.



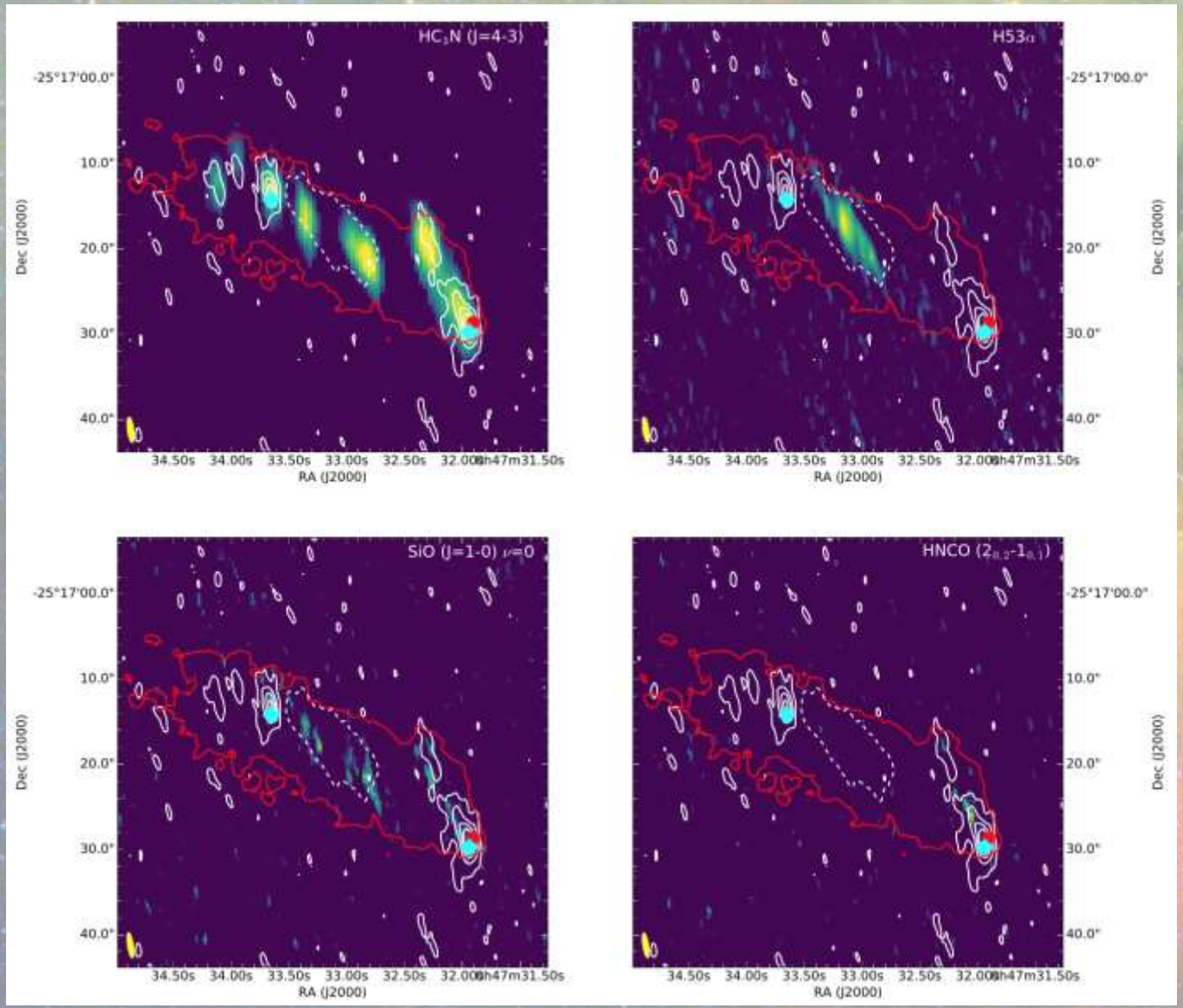
EW367 observations with 16x3 arcsec resolution

With CABB, at higher frequencies you get lots of extra spectral lines for free.

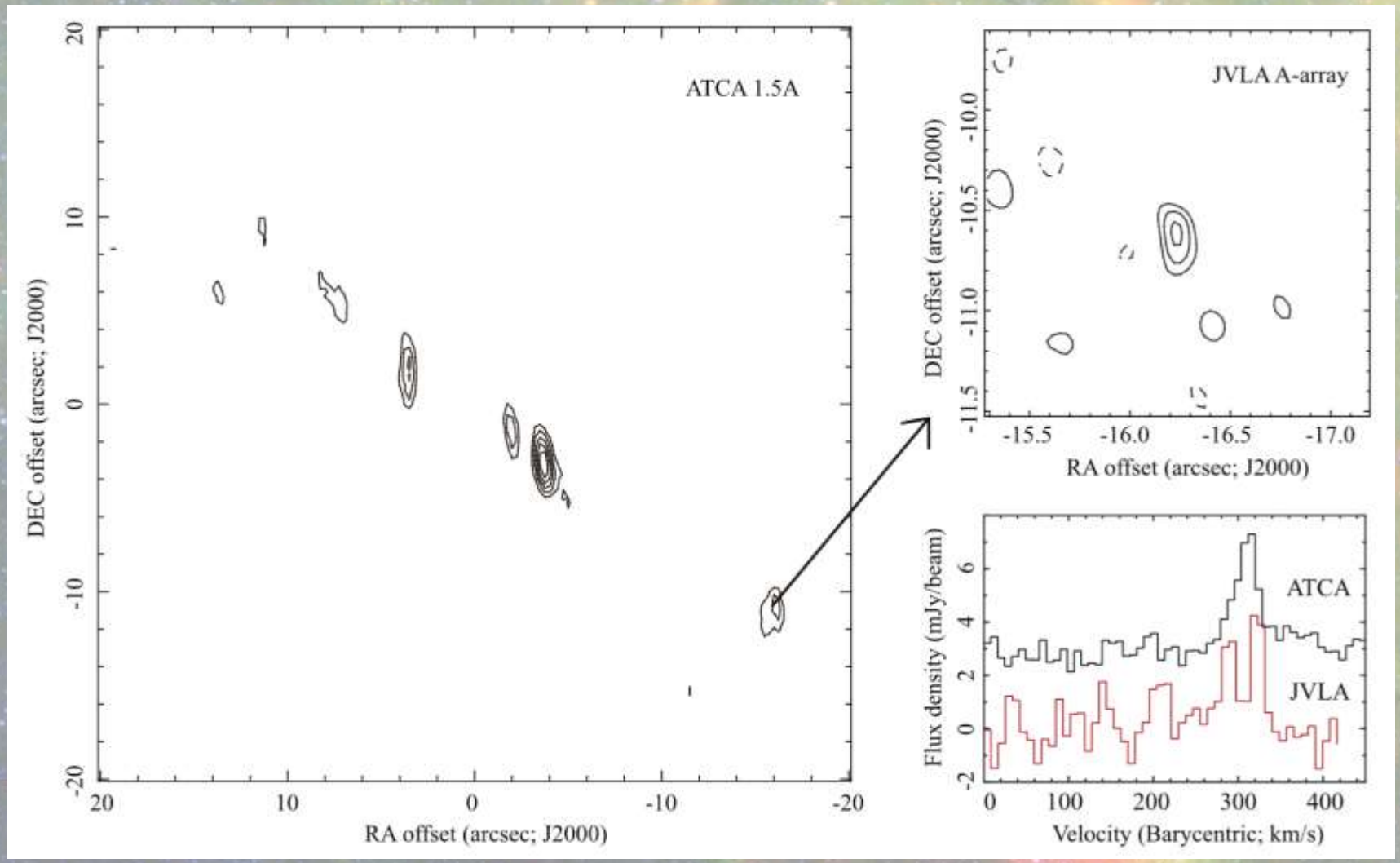
HC_3N and CH_3CN – hot molecular cores.

H56α, H53α recombination lines – star formation.

SiO and HNCO - shocks



At 3”x1” resolution most of the thermal transitions are nearly entirely resolved out. The exception is the HC_3N, which has very similar distribution to the 36.2 GHz methanol.

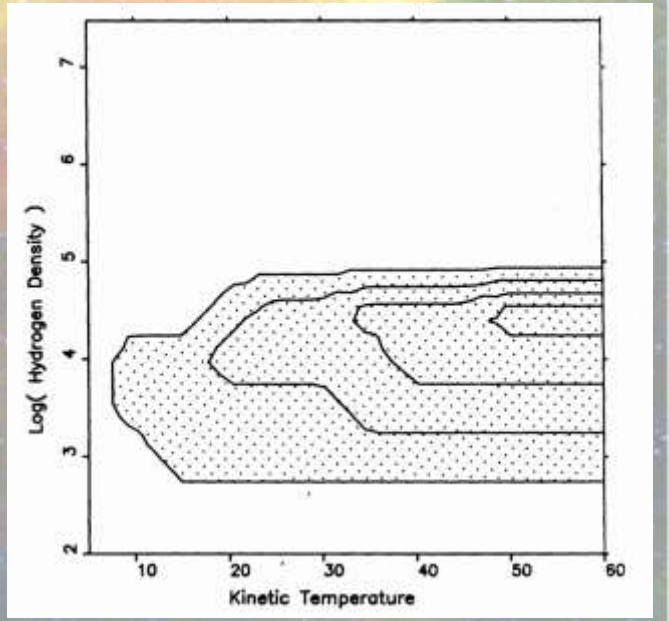


The HC_3N (J=4-3) component towards the strongest methanol maser is detected at 0.1” resolution:

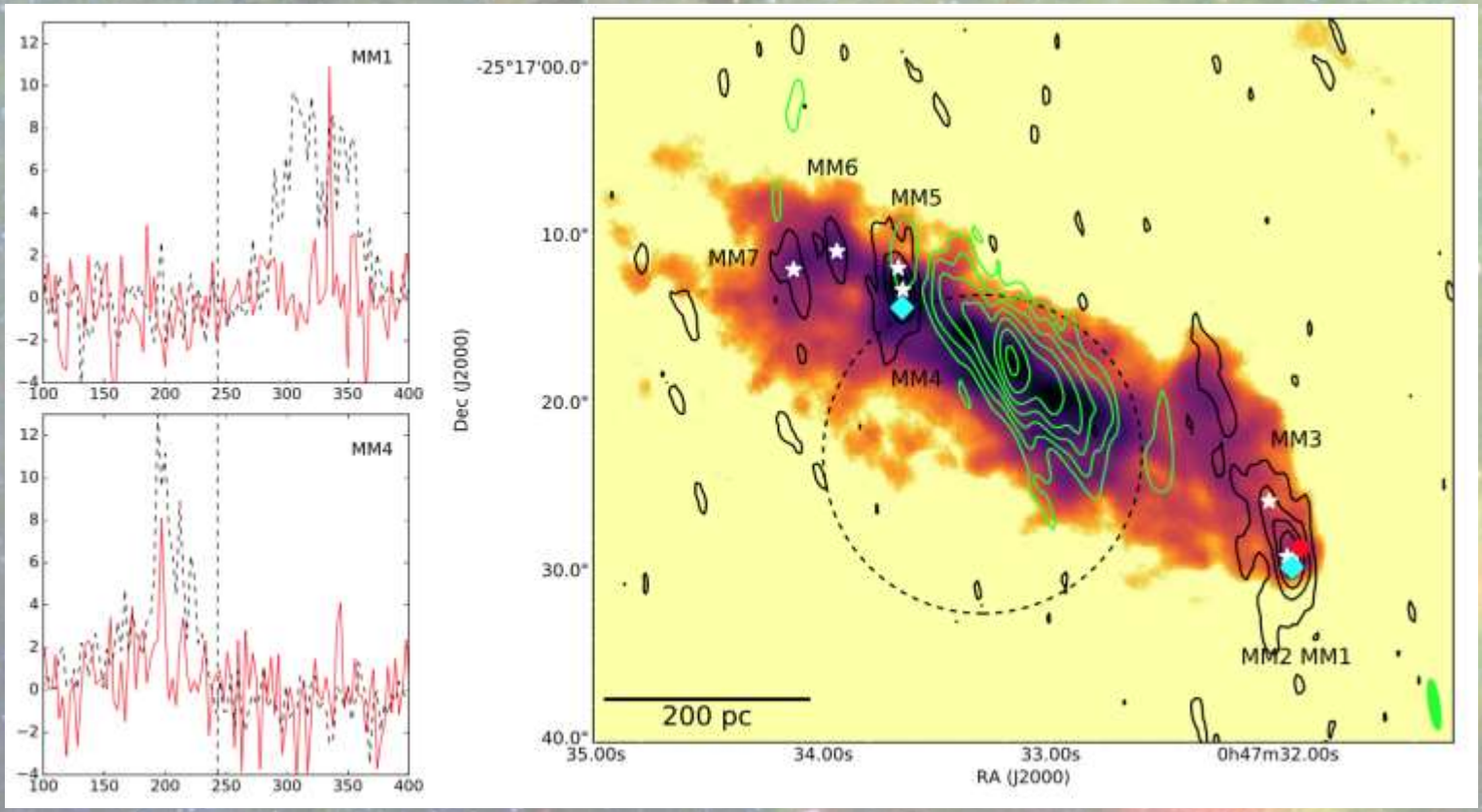
First detection of an extragalactic HC_3N maser! (Ellingsen et al. 2017a)

Cyanoacetlyne (HC_3N) masers

- HC_3N was studied quite intensively in the 1970s and early 1980s.
- Sgr B2 is the proto-typical Galactic source and shows anomalously strong J=1-0 emission.
- High resolution observations by Cunningham et al. 1999 proved that the J=1-0 in Sgr B2 is a maser – the only known HC_3N maser, until now.
- LVG modeling by Brown & Cragg (1985) found the J=1-0, 1-2, 2-3 and 3-4 transitions inverted over an increasingly narrower range of densities and temperatures.



Going for a three-peat.



First detection of an extragalactic 44.1 GHz methanol maser (cyan diamonds) (red spectrum), with the 36.2 GHz emission from the same location (black-dashed).

Class I methanol – What does it trace?

- The eastern and western 36 GHz methanol masers are close to supershells identified from CO and dense gas tracers.
- Gorski et al. (2017) "The broad spectral profile could be constructed from many masers from protostellar outflows or supernovae remnants."…. Perhaps, but:
  - Protostellar outflows = Star formation: 44 GHz transition usually stronger than 36 GHz. Where are the water masers?
  - There are lots of supernovae in NGC253, but they are closer to the nucleus.
- What can we deduce from the other molecular lines?

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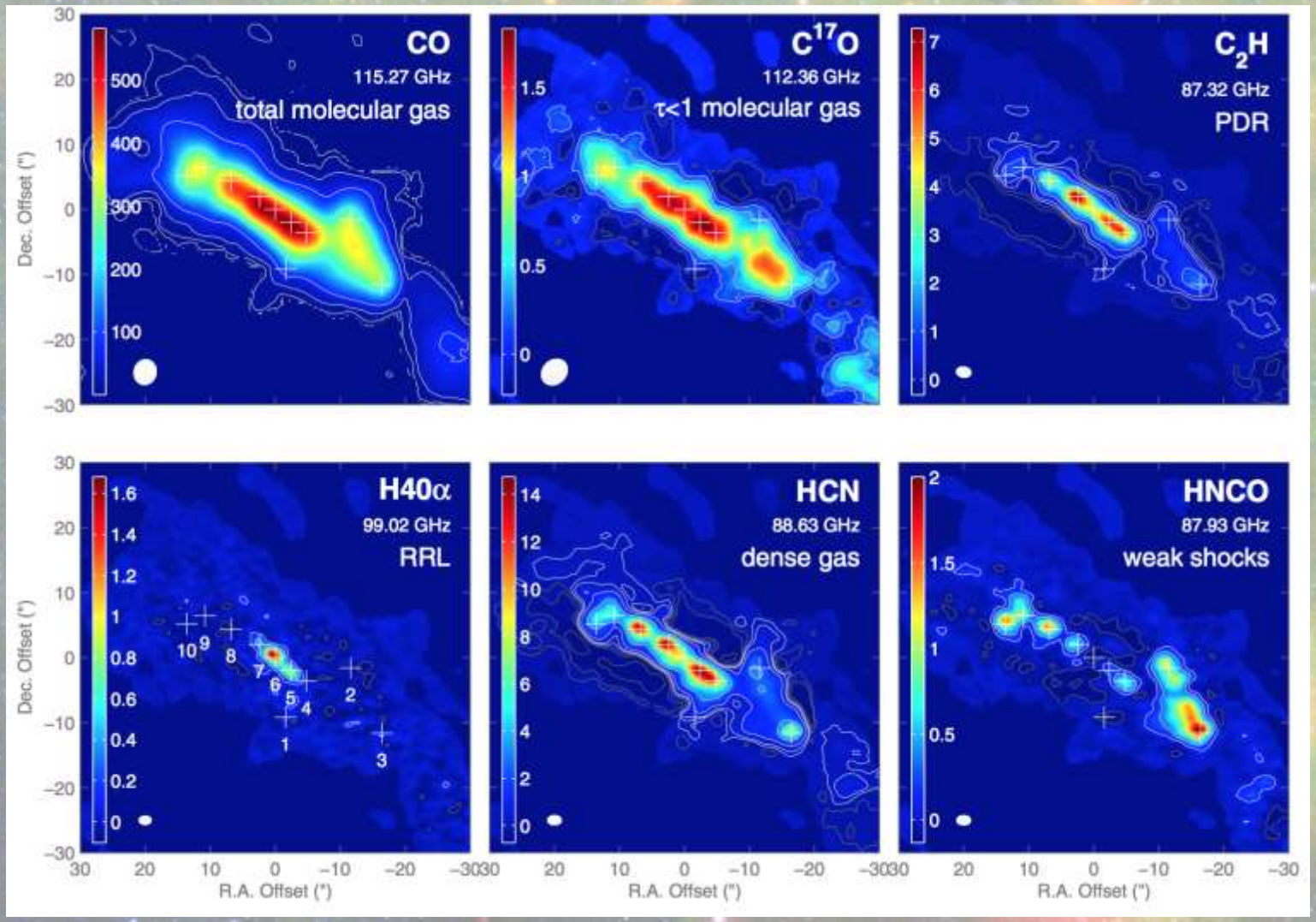
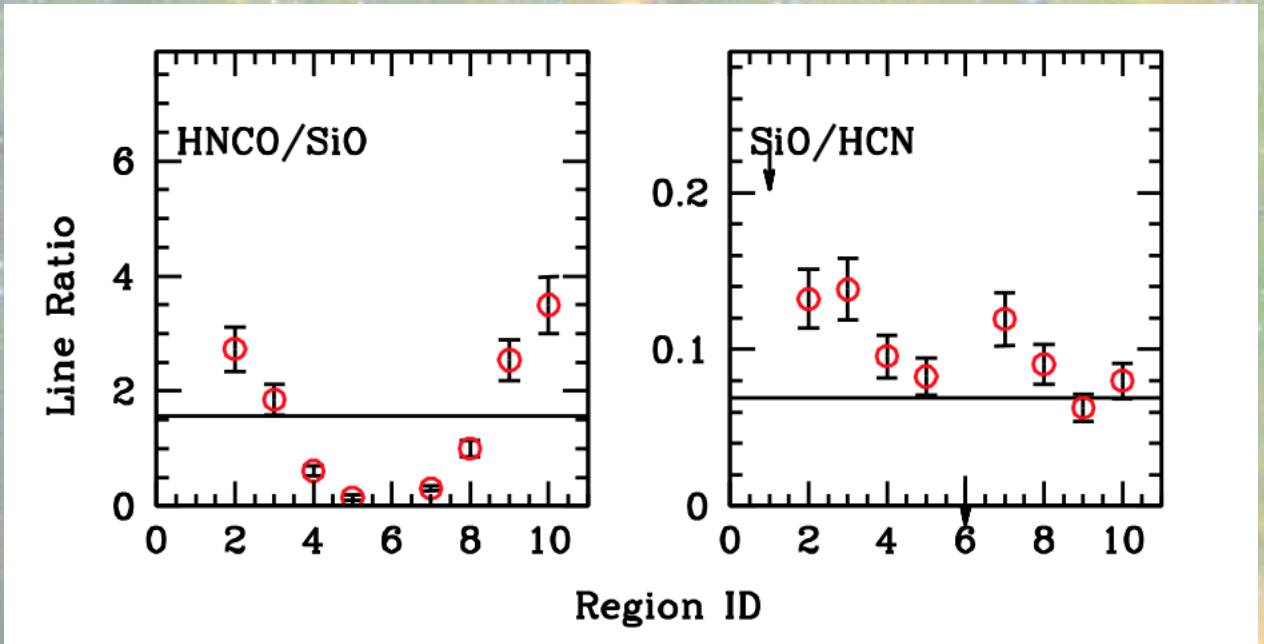


ALMA 2”x1” resolution images by Meier et al. (2015)



SiO: sputtered from silicate dust grains in shocks. Present throughout the nuclear region.

HNCO: from sublimation of ice-mantles from dust grains heated through shocks. Relatively stronger compared to SiO in the outer nuclear region. Why?

Photodissociation of HNCO in the inner nuclear region.

Large-scale, low-velocity shocks

- The central molecular zone in NGC253 is often compared to the inner 100pc or so of the Milky Way.
- Yusef-Zadeh et al. (2013) and McEwen et al. (2016) have detected widespread 36.2 and 44.1 GHz methanol masers from this region.
- The 44.1 GHz methanol masers are generally significantly weaker than the 36.2 and this has also been observed in a few class I methanol maser sources associated with SNR-molecular cloud interactions (McEwen et al. 2014).
- Galactic bars bring molecular gas inwards – so the interface between the CMZ and the bar is a region of extensive, low-energy shocks due to cloud-cloud collisions.

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Conclusions/Future work

- Class I methanol and HC_3N masers give us a new tool for studying starburst systems.
- How common are they?
- How do they relate to the structure/physical processes at work in the host galaxy?
- Will they be detectable in more distant galaxies?
- What fraction of the observed methanol and HC_3N emission is masing, what is thermal?
- Are there other HC_3N transitions which are masers?

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Recent Observations

Transition	Detection?	Comment
HC_3N (1-0) 9.1 GHz	Yes	Looks purely thermal
HC_3N (2-1) 18.2 GHz	Yes	Looks purely thermal
HC_3N (5-4) 45.5 GHz	Yes	Needs investigation
CH_3OH (9_{-1}-8_{-2}E) 9.9 GHz	No, < ~5 mJy in 6 km/s	
CH_3OH (J_2 - J_1E) J=2,3,4,5 25 GHz	No < ~10 mJy in 3 km/s	
CH_3OH (5_1-6_0A^+) 6.7 GHz	No < ~10 mJy in 1 km/s	
CH_3OH (1_0-0_0A^+, E) 48.3 GHz	No < ~15 mJy in 6 km/s	
SiO (*v*=0 ; J=1-0)	Yes	Ellingsen et al. 2017b
SiO (*v*=1,2,3 ; J=1-0)	No < ~5 mJy in 3 km/s	Ellingsen et al. 2017b
CS (1-0)	Yes	Purely thermal

ATCA Director's time observations following up the HC_3N in June and July.

NGC253 dense molecular gas

HCN (1-0) as observed by ALMA at ~2 arcsecond resolution (Leroy et al. 2015). The line is the angle of the bar.

