Methanol Masers in the Andromeda Galaxy



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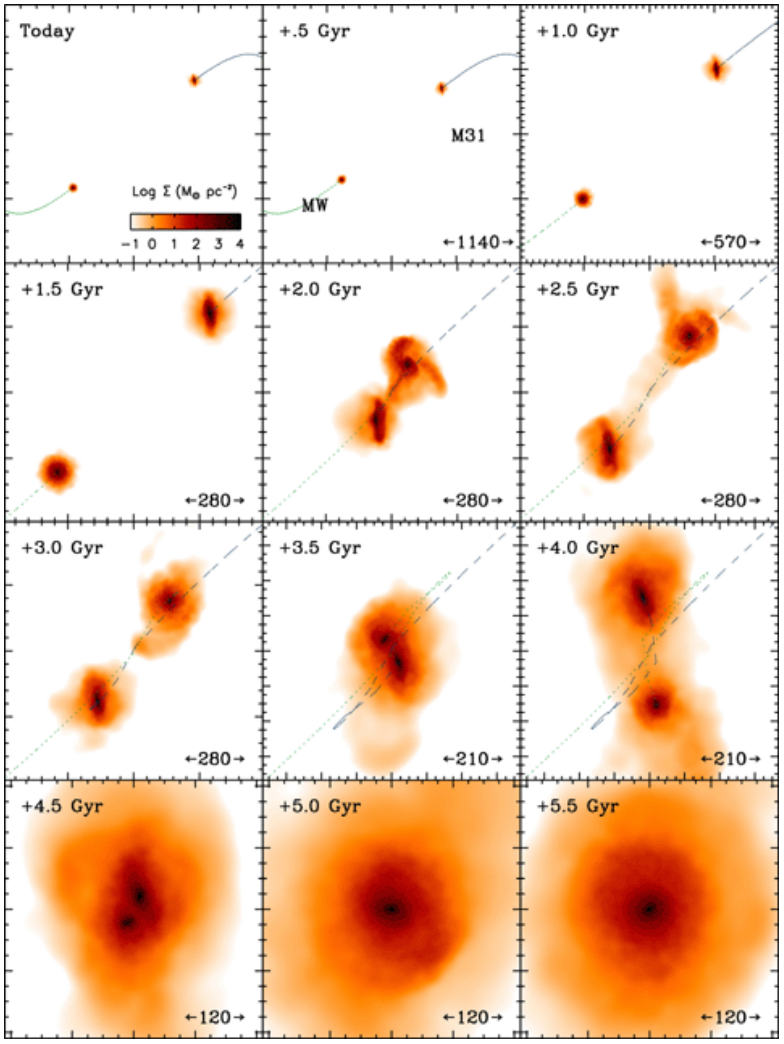
Motivation

Aim:

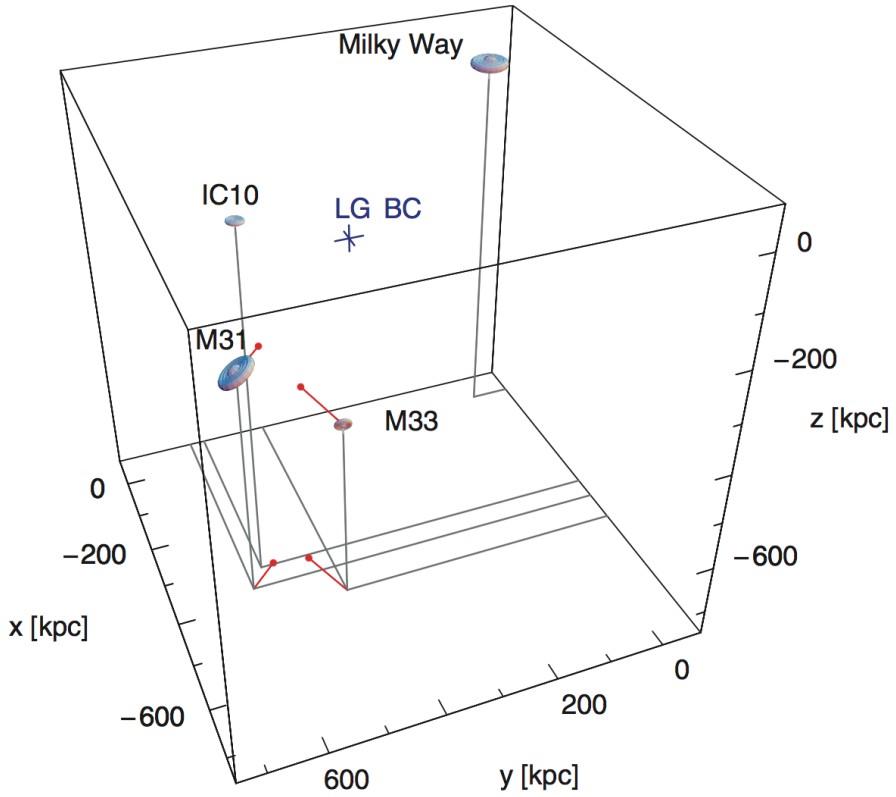
To find the proper motion of M31

- Dynamical history and evolution of the Local Group
- Depends strongly on the velocity of M31
  - Only have radial velocities, need 3D
  - Statistical approaches have large uncertainties



Cox & Loeb 2008

M33 & IC10



Brunthaler, Reid, Falcke, Henkel & Menten 2007

H_2O masers successfully observed in M33 and IC10, giving proper motions (Brunthaler et al. 2005, 2007)

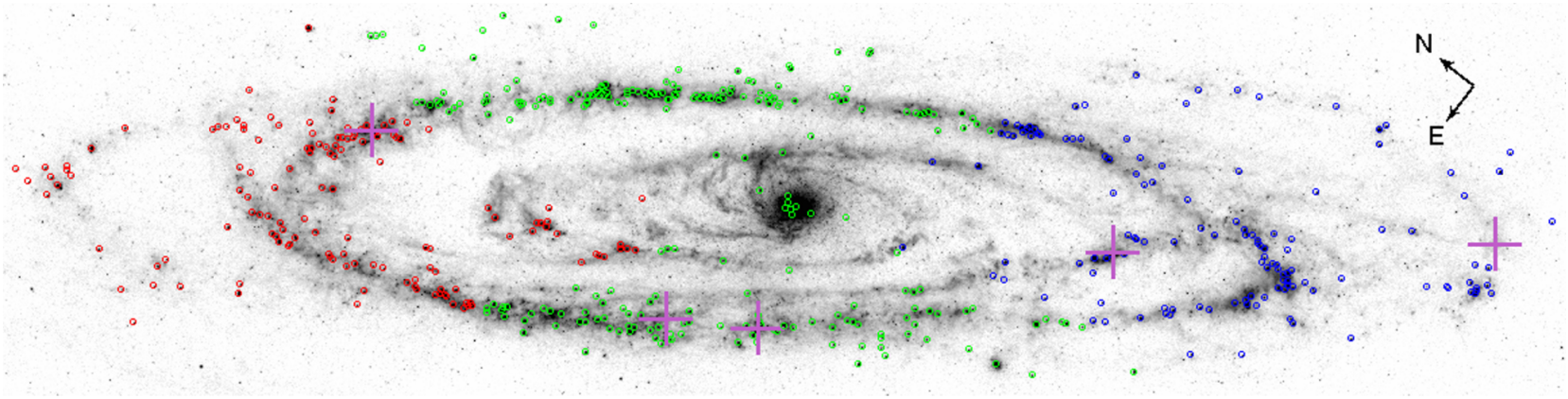
Two groups of masers in M33 allowed for comparing their proper motion to the expected from the rotation curve, giving a 'rotational parallax'.

M31: radial component only

Method

- Find suitable masers that are VLBI bright!
  - Continuum sources are often more extended
  - In M31, no good continuum sources despite searches (Brunthaler/Sjouwerman et al.), including M31* and a few XRBs
- Requirement
  - Estimates of transverse motion 50-200 km/s
  - Proper motion of 15-50 μas/yr

Darling et al. 2016



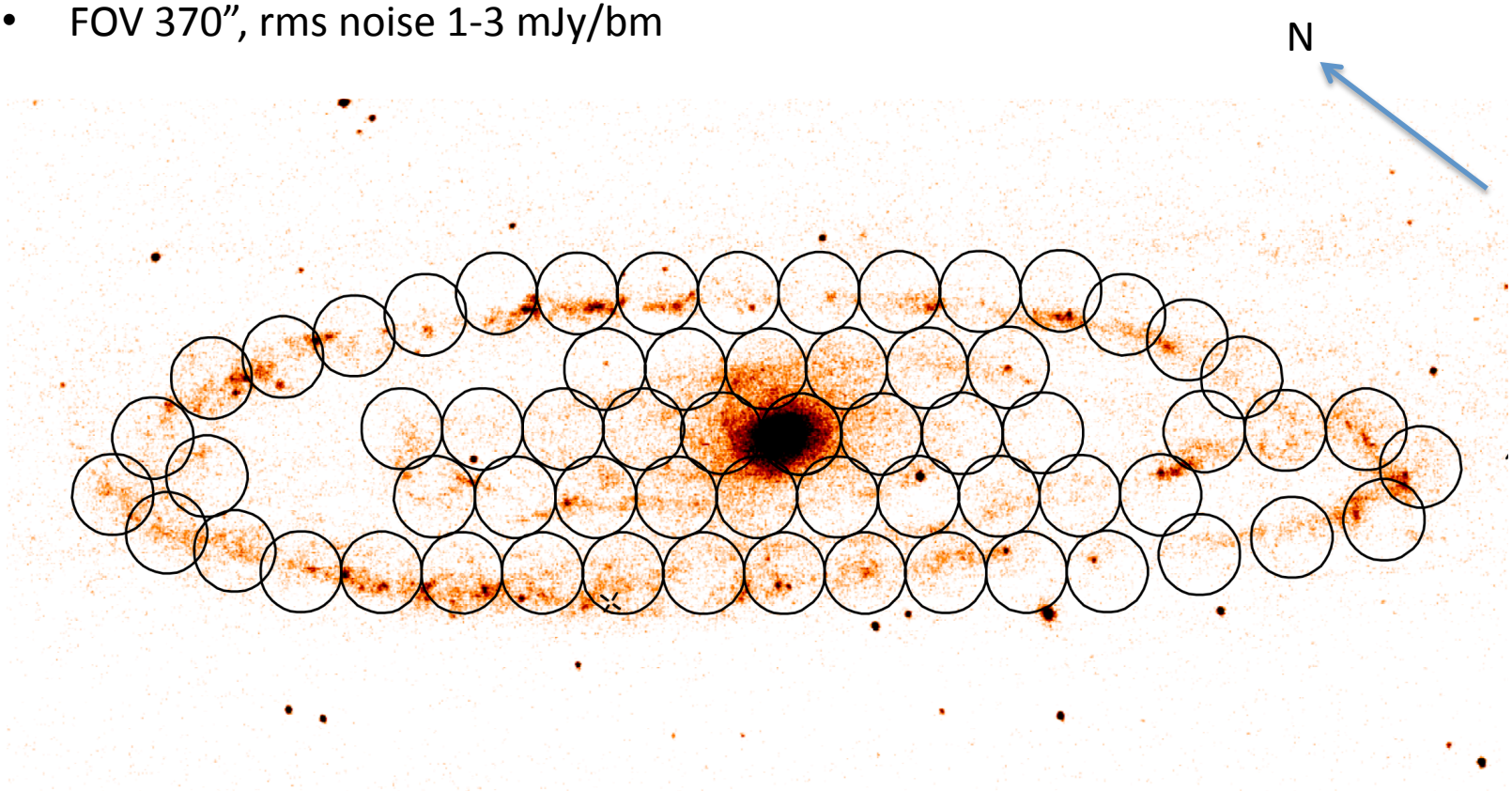
- Targeted searches at 22 GHz challenging
  - FOV is small, M31 large (see, e.g., Brunthaler 2006; Darling et al. 2016)

- 1.6 GHz OH
  - larger FOV but worse resolution => much too long time baseline
  - Also, no OH masers…

- Methanol at 6.7/12.2 GHz
  - Decently behaved atmosphere, decent calibrators
  - M31 has sufficient metallicity

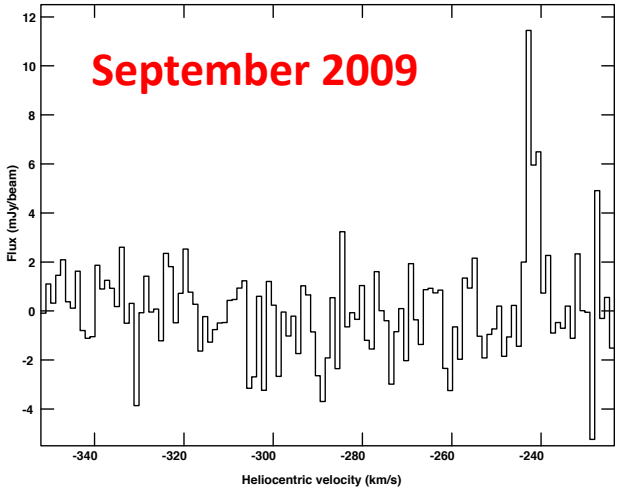
Methanol at 6.7 GHz

- With new 6 GHz receivers at the VLA in 2009, we began a blind survey
- Searching for Class II 6.7 GHz methanol masers
- FOV 370”, rms noise 1-3 mJy/bm

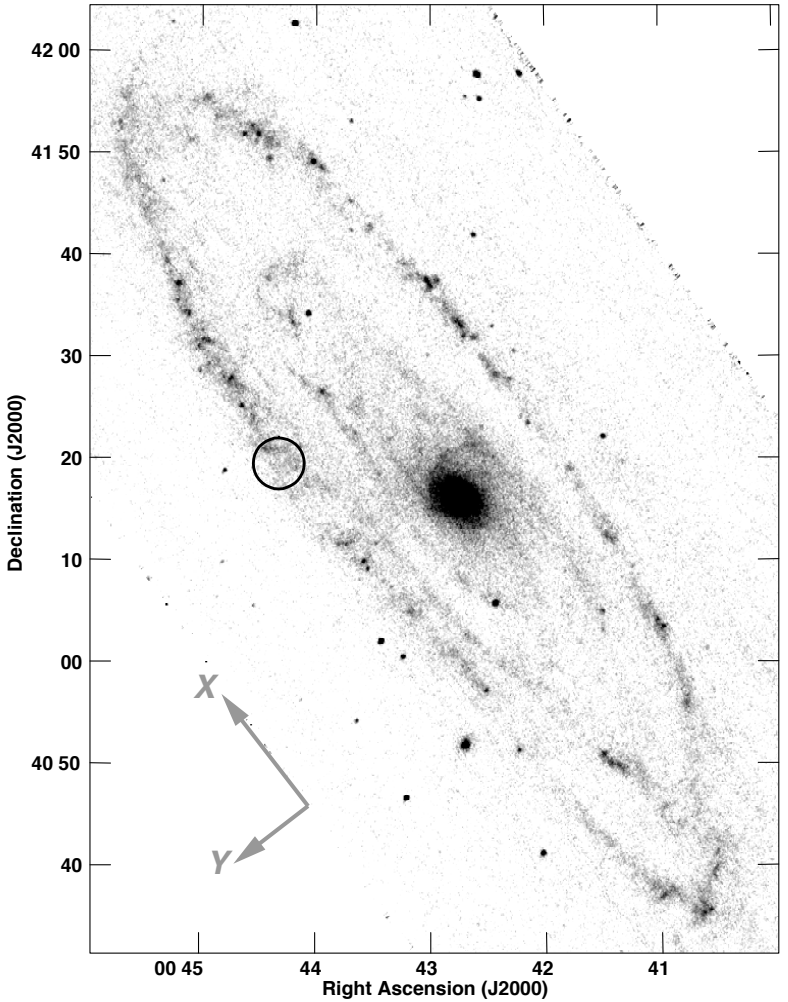


Initial results

- Several weak tentative masers detected, so far most in the mid-galaxy in terms of velocity

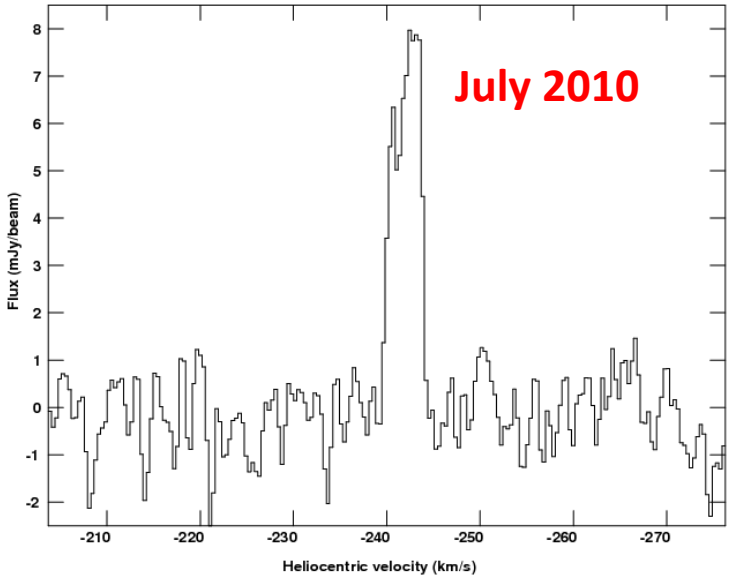


Follow up observations using WIDAR of one of the tentative detections confirmed the feature.



VLA maser detection

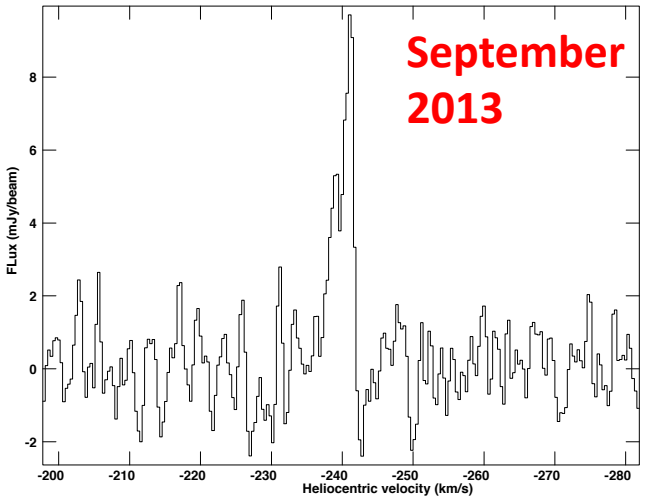
- Width about 5 km/s, peak about 8 mJy/ beam.
- High-end tail of the 6.7 GHz methanol maser distribution in the Milky Way
  - W3(OH) 3700 Jy => M31 maser at same distance 1300 Jy
- No associated 22 GHz water maser
- Not close (<50pc) of a star forming region, H-alpha emission line region or a compact HII region.

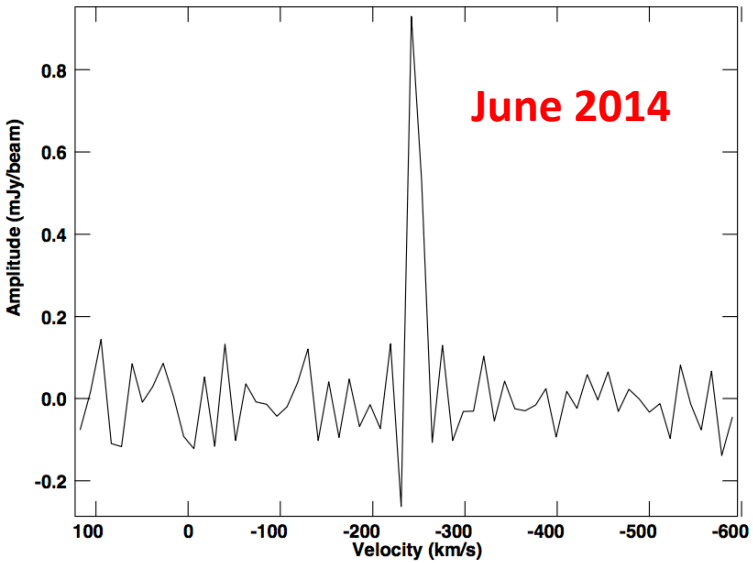


Sjouwerman et al. 2010

A good (sufficiently bright) VLBI target?

- Marginal, but we attempted to detect it
- Global VLBI including VLBA, EVN, and phased VLA
  - 4x6 hrs
- RFI along with some other issues affected sensitivity to levels of 2-4σ detection
- No significant detection yet
  - Maser position within field uncertain
  - Maser was still active and detected on VLA baselines during the observations





Results from the VLBI observations

- Maser seen with the VLA-only data
  - Possible it got weaker since original detection
- Likely resolved on VLBI baselines, but unresolved VLA
  - 0.004-1.3 pc size at a distance of 780 kpc
  - $\gtrsim$ W3(OH) distribution
- Not directly associated with star formation activity
  - Interstellar cloud?
  - Spectral features indicated in VLA spectra may suggest several spatial features

Summary & continuing work

- If sufficiently compact, methanol masers could be an alternative to 22 GHz water masers for astrometry
  - 6 GHz easier to observe, but masers still very weak

- M31 masers still elusive in terms of VLBI observations and proper motion studies!

- Complete VLA mapping to see if any other, brighter masers exist
  - Luminosity function (tail) of methanol masers
  - Low star formation rate in M31

- Complete VLBI mapping of full field of view
  - Challenging achieving a sufficient SNR on global baselines