VLBI observations of OH megamaser galaxies (A research plan introduction)

Zhongzu Wu(GZU) & Yongjun Chen (SHAO)

Collaborated with xingwu zheng(NJU), Zhiqiang Shen(SHAO), Dongrong Jiang(SHAO) , Zhang Bo, etc.

Contents

- Introduction about OH megamsers
- The radio continuum emission in OHMs
- The OH megamasers with VLBI observations in the literature
- our observations with EVN+MERLIN and VLBA

What are OH Megamasers

- Luminous 18 cm masers produced in major galaxy mergers
- Associated with starburst nuclei in merging galaxies ([U]LIRGs)
- LOH = 10^6-10^9 “typical” OH masers
- Main lines at 1665 & 1667 MHz

Satellite lines at 1612 & 1720 MHz.

- Extremely rare: ~100 known

A SEARCH FOR OH MEGAMASERS AT $z > 0.1$. III. THE COMPLETE SURVEY

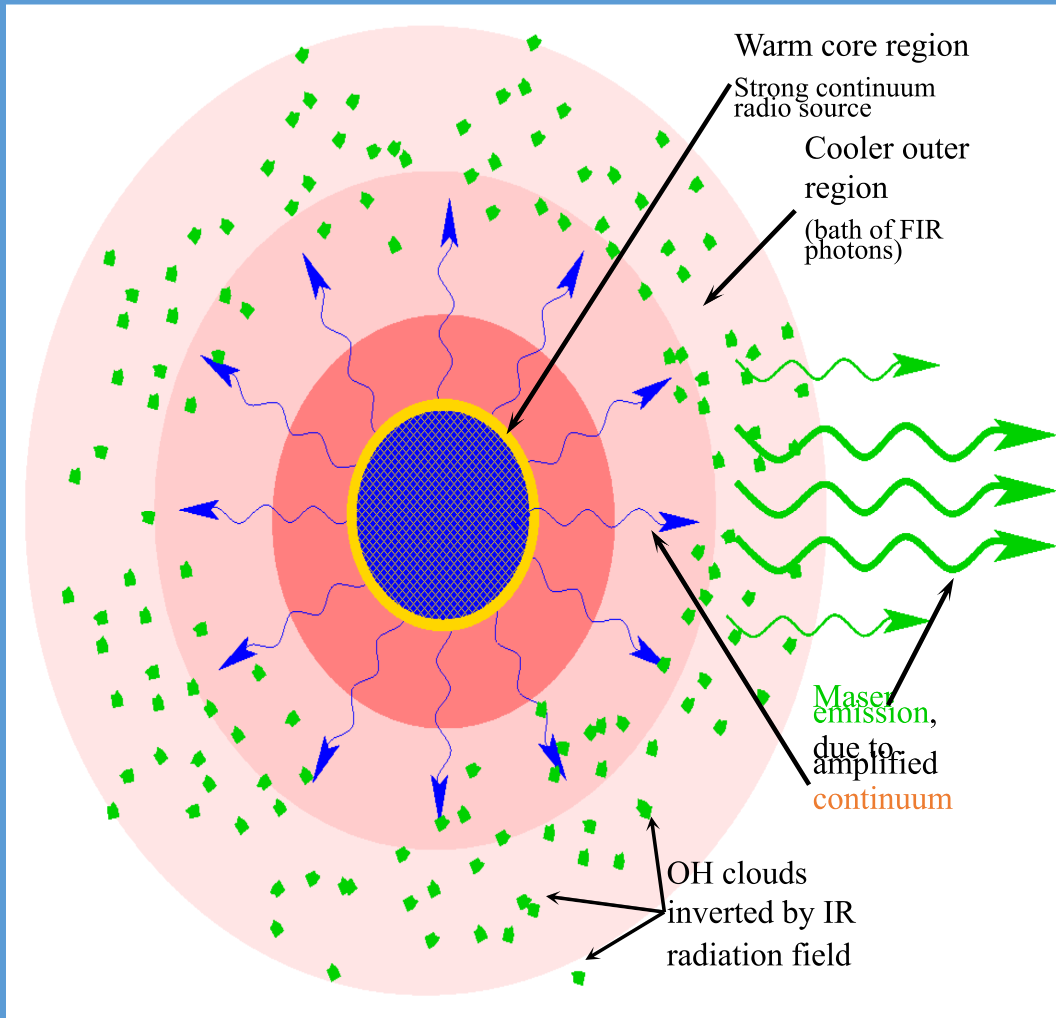
JEREMY DARLING AND RICCARDO GIOVANELLI

FAST and OH megamaser(Li et al. 2016)

FAST will be a powerful instrument for molecular spectroscopy. Targeted galaxy surveys are expected to increase the sample of currently known extragalactic OH mega-masers by a factor of 10 with a total of about 1000 detections out to z=2 (Zhang, Li & Wang 2012). The sky density of OH mega-masers could provide constraints on the galaxy merger rates in the most active epochs of cosmic star formation.

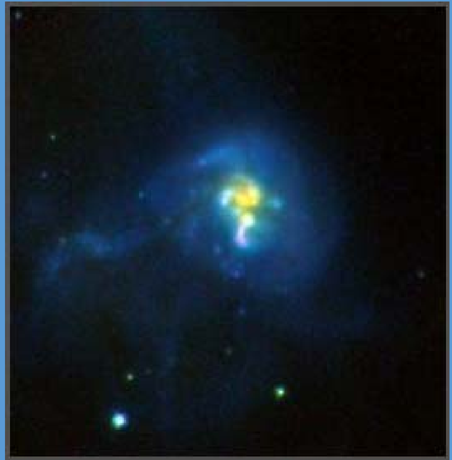
Standard Model

- By early 1990s, consensus on basic OH megamaser model (originally outlined by Baan (1985))
  - Diffuse screen of unsaturated low-gain masers
  - Weak amplification of diffuse nuclear continuum synchrotron
  - Masers pumped radiatively by FIR radiation field (35, 53 µm?)
  - Disk or torus geometry, leading to observed OHM fraction
  - Large masing volume (>100pc across, typically)
  - Main line ratio (1667/1665) determined by opacity
  - Covering factors less than unity
- Model became fairly well developed (e.g. Henkel & Wilson 1990), and detailed (e.g. Randell et al., 1995)



The host galaxies of OHMs((U)LIRG's - (Ultra) Luminous IR Galaxies)

- First detected in IRAS all-sky survey (infrared – 12 to 100 microns)
- Galaxies that emit most of their light in IR → $L_{IR} > 10^{12} L_{sun}$
  ($10^{11} L_{sun}$ for LIRGS)
- Few in local universe; most beyond z > 1
- Most luminous are undergoing mergers
- IR light is likely a combination of dust reprocessed AGN emission and starbursts (Gas streams converge from different directions causing shocks which compress material and trigger star formation)
- Some AGN may manifest as ULIRGs during different stages of evolution.



Color composite image of ultra-luminous infrared galaxy IRAS 19297-0406 made by the Hubble Space Telescope

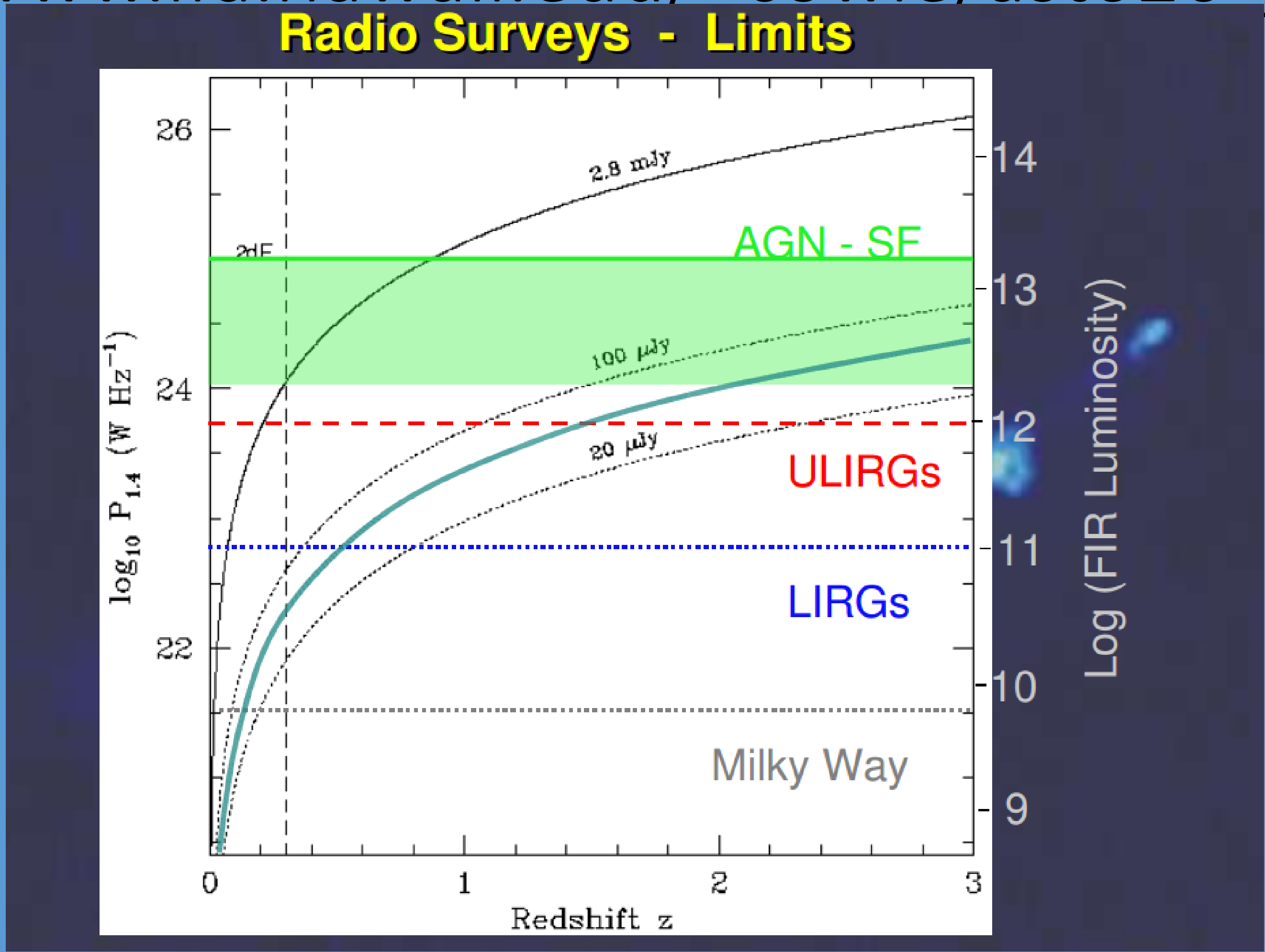
- Ultraluminous IR Galaxies and OHMs:
  - Merger events “caught in the act”, but very heavily obscured
  - VLBI of OH megamasers and continuum offers the sharpest view of activity within ULIRGs.
  - OH megamasers (1.66 GHz) can be used to trace the galaxy merger rate out to z~1.8 (Briggs, 1998)

The radio continuum in OH megamasers galaxies([U]LIRGs) (Kandalyan 2005Ap.....48...99K)

- Many radio sources in OH megamaser galaxies exhibit relatively flat(>-0.5)
- high brightness temperatures ($T_b \geq 10^4$ K).
- line and radio continuum fluxes are not correlated
- predominantly nonthermal and associated either with an active nucleus or with compact star formation

flat radio spectra and high brightness temperatures imply the existence of an active galactic nucleus, although some megamasers may be associated with compact star formation

This figure is from http://www.ifa.hawaii.edu/~cowie/ast626_dir/



The high senitivitivity VLBI

- High Sensitivity Array(HSA) (VLBA+Arecibo+GBT+VLA)
- EVN+FAST FAST at L-band will improve the EVN sensitivity by about a factor of four (better than the HSA with Arecibo, GBT, phased VLA (Very Large Array), Effelsberg and VLBA (Very Long Baseline Array)) (LI Di 2016RaSc...51.1060L)
- EVN+ FAST+QTT+TM65+KM120m?+XA120m?
- SKA

The sensitivity of continuum observation can be improved by increaing the Datarate, while the spectral line observation needs large collecting area

$$NOISE\ [\mathrm{Jy/beam}] = \frac{1}{\eta}\ SEFD^{*}\ [\mathrm{Jy}]\ /\ (DATARATE/2\ [\mathrm{bit/s}]\ T_{\mathrm{obs}}\ [\mathrm{s}])^{1/2},$$

$$SEFD^{*} = \frac{1}{\sqrt{\sum_{i,j=1}^{n;i<j} \frac{1}{SEFD_i \times SEFD_j}}}$$

datarate [Mbit/s] = bandwidth/polarization [MHz] * Npol * Nbit (1 or 2 bit sampling) * 2.

The OH megamasers with VLBI observations in the literature

Investigation of the obscuring circumnuclear torus in the active galaxy Mrk231

Hans-Rainer Klöckner*†, Willem A. Baan† & Michael A. Garrett‡

* *Kapteyn Institute, PO Box 800, 9700 AV Groningen, The Netherlands*
† *ASTRON, Westerbork Observatory,* ‡ *JIVE, Joint Institute for VLBI in Europe, PO Box 2, 7990 AA Dwingeloo, The Netherlands*

The OHM-maser emission shows the characteristics of a rotating, dusty, molecular torus (or thick disk) located between 30 and 100 pc from the central engine. confirming the main tenets of unification models

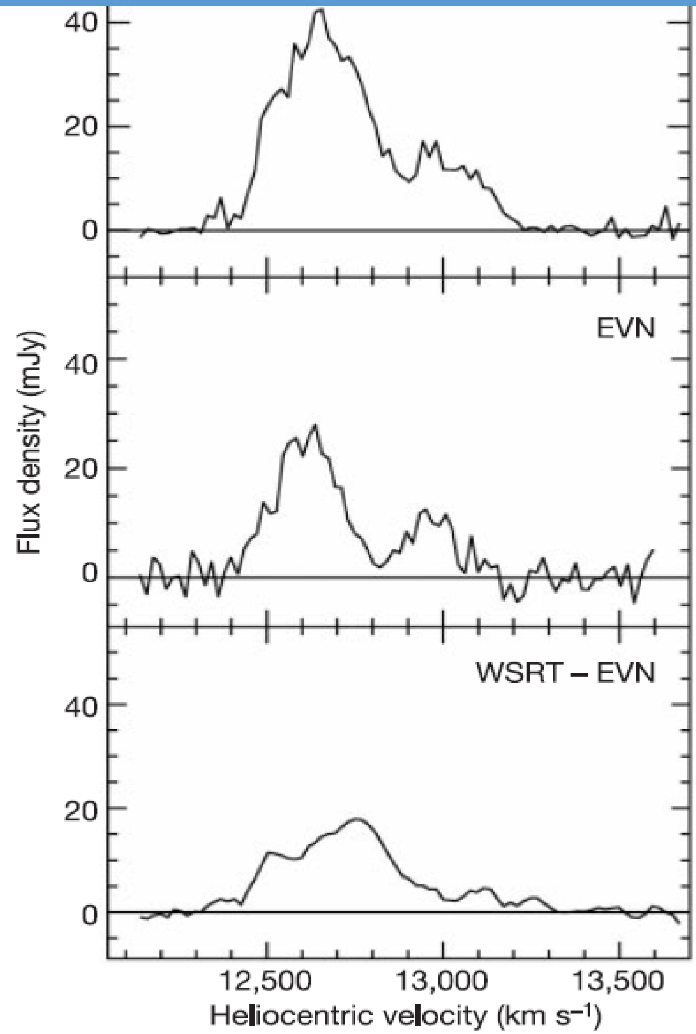
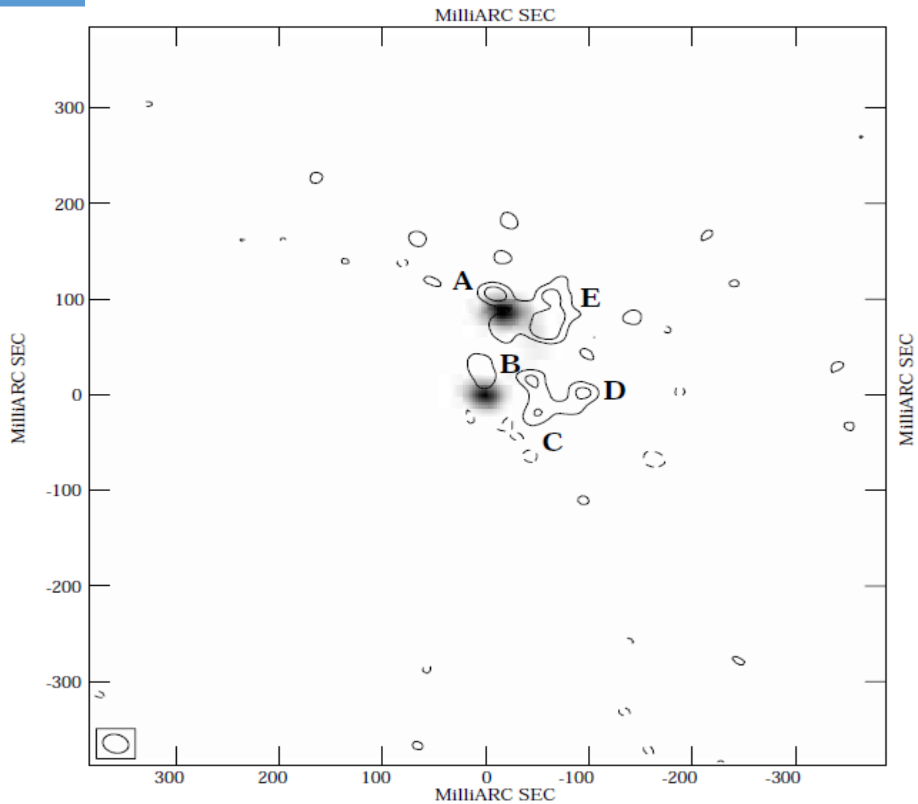


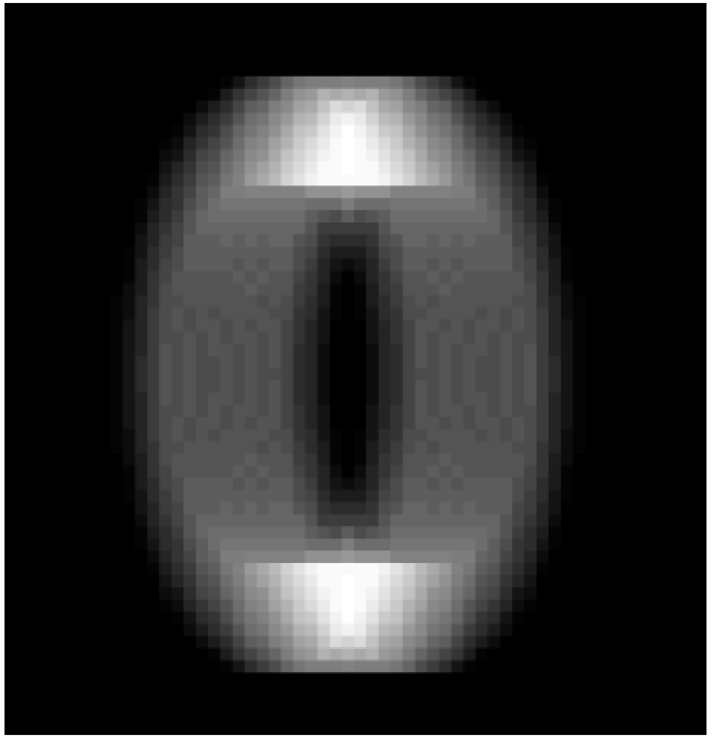
Figure 2 Hydroxyl emission spectra of Mrk231 traced at different scale sizes. Top panel, the WSRT spectrum taken at 14-arcsec resolution; middle panel, the spectrum for the EVN observations at 39-mas resolution; bottom panel, the difference spectrum of both observations. The emission line features show both OH main lines at 1,667 and

EVN and MERLIN observations of III Zw 35

A starburst continuum and an OH maser ring

Y. M. Pihlström[1], J. E. Conway[1], R. S. Booth[1], P. J. Diamond[2], and A. G. Polatidis[1]



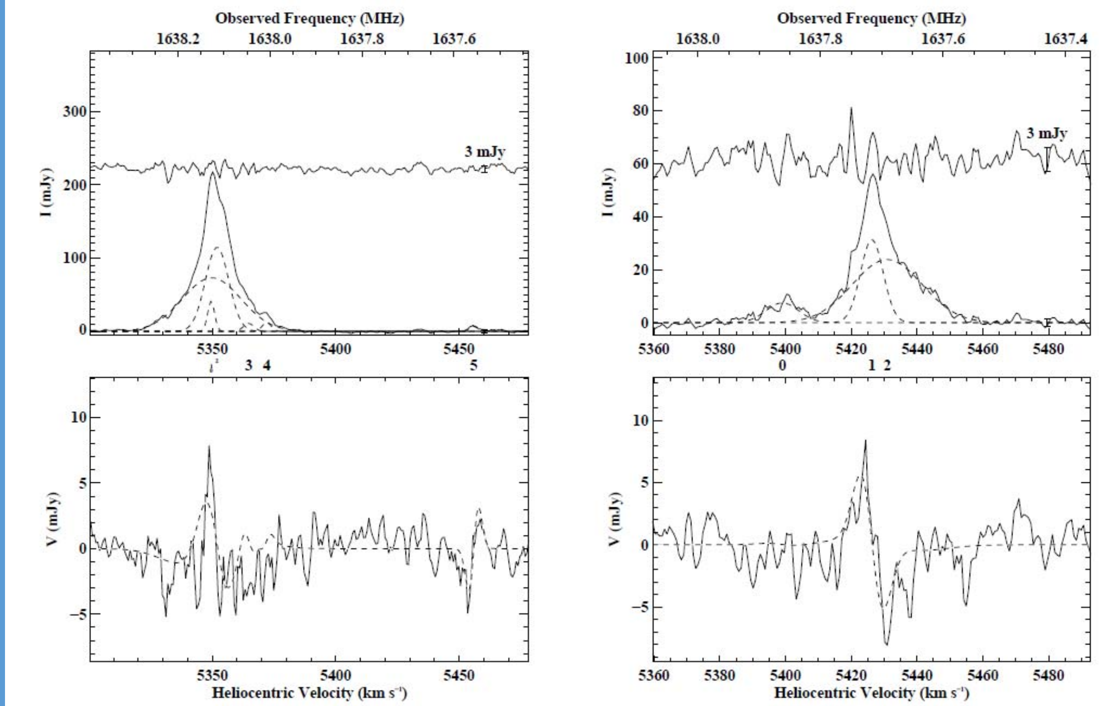


Parsec-scale magnetic fields in Arp 220

James McBride[1⋆], Timothy Robishaw[2], Carl Heiles[1], Geoffrey C. Bower[3], and Anuj P. Sarma[4]

The first very-long-baseline interferometry (VLBI) detections of Zeeman splitting in another galaxy.

This result demonstrate the potential for using high-sensitivity VLBI to study magnetic fields on small spatial scales in extragalactic systems.



(a) Stokes I and V for the OH maser spot at W1 ($15^h34^m57^s.225$, $+23°30'11.562''$).

(b) Stokes I and V for the OH maser spot at E1.1 ($15^h34^m57^s.295$, $+23°30'11.235''$).

The numbers of other OHMs with VLBI observations in the literature are limited

- Arp 220 （IC 4553） Lonsdale et al , ApJL, 493, L13, 1998
- IRAS 17208-0014 Momjian et al， ApJ, 2006， 653, 1172
- Mrk 273 Yates et al, MNRAS, 2000， 317, 28
- IRAS 12032+1707 Pihlstrom et al, ApJ,,2005， 618, 705
- IRAS 14070+0525 Pihlstrom et al, ApJ, 2005， 618, 705
- Arp 299(Mrk 171) Polatidis et al. 2001,IAU Symp. 205.p1

Our achieved observations

- EVN+MERLIN EW019 Jb2 Wb1 Ef Mc −− On85 T6 Ur Tr −− Sv Zc Bd Hh −− −− −−−− MER EVN 30.41 2.53 Eu 152 1130(01/06)−2230(01/06) +e−MERLIN (11 hours observations of IRAS 10173+0828)

- VLBA A sample of 6 OHMs approved for VLBA observations. 2 of them have been observed for 16 hours on March 2017.

The radio properties of IRAS 10173+0828

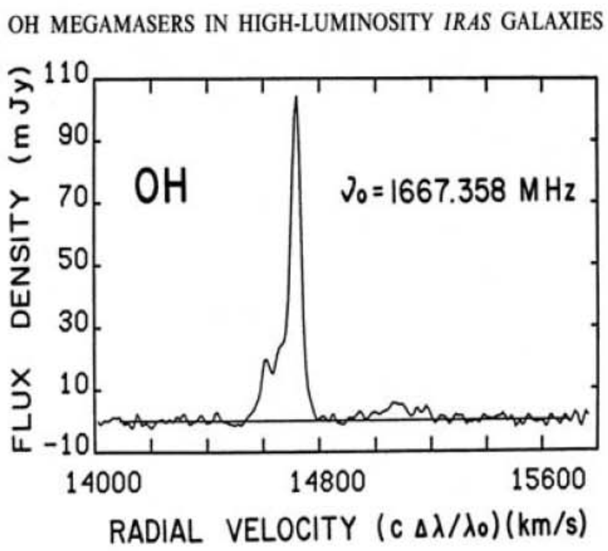


Figure 1: The single dish OH spectrum from Mirabel & Sanders (1987) observed by the Arecibo telescope in 1986

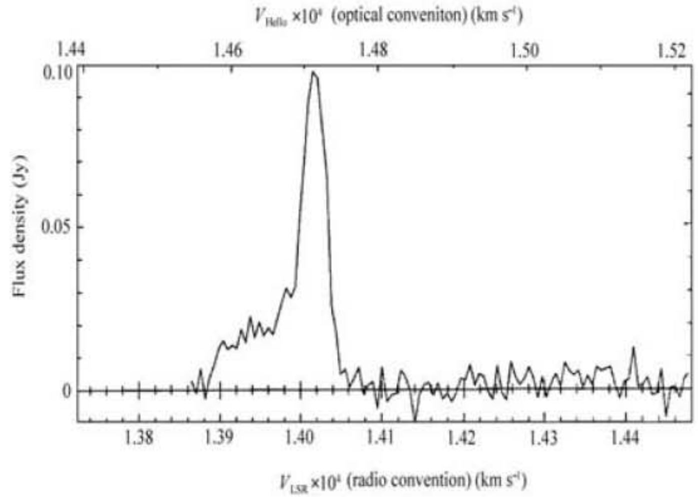


Figure 2: The spectrum of OH megamaser from Yu (2005) observed by Merlin array in 2002

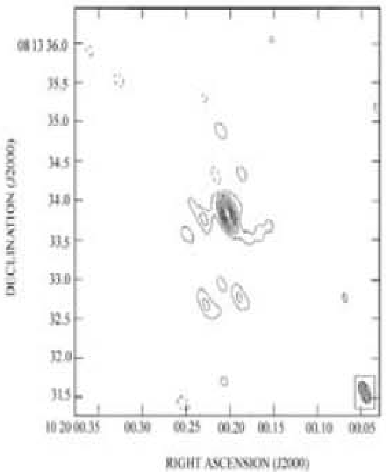


Figure 3: Contour map of OH megamaser galaxy toward 1RAS 10173+0828 from Yu (2005) observed by Merlin array in 2002

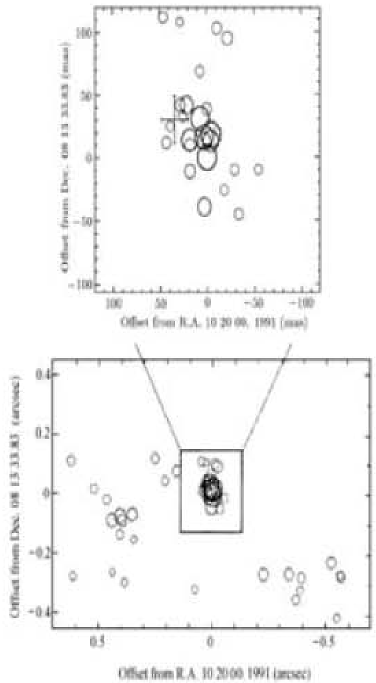
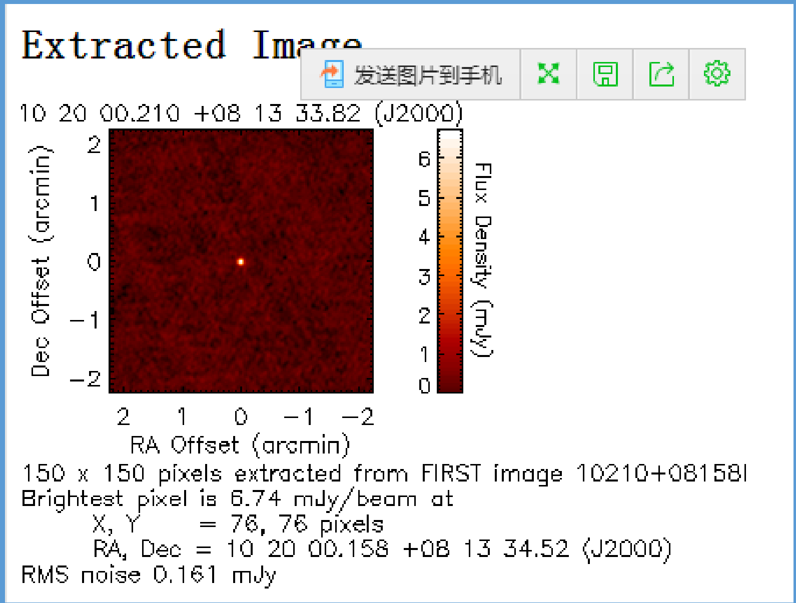


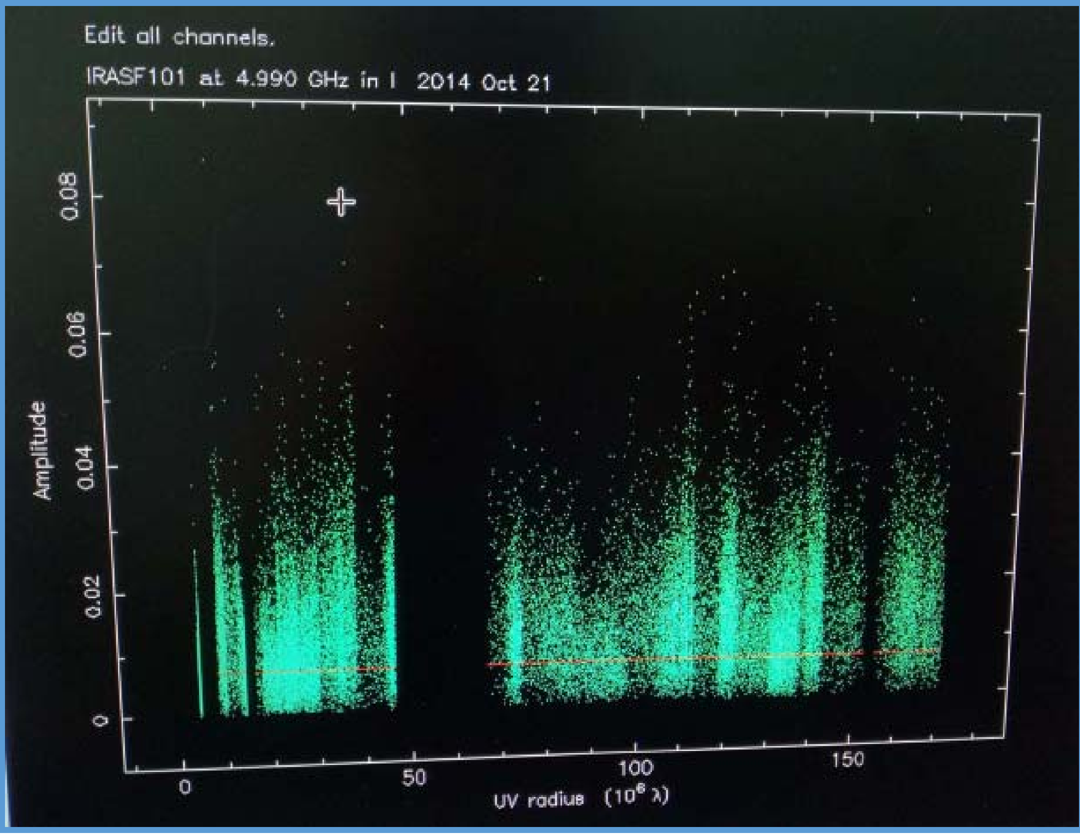
Figure 4: The OH megamaser spots toward 1RAS 10173+0828 from Yu (2005) observed by Merlin array in 2002

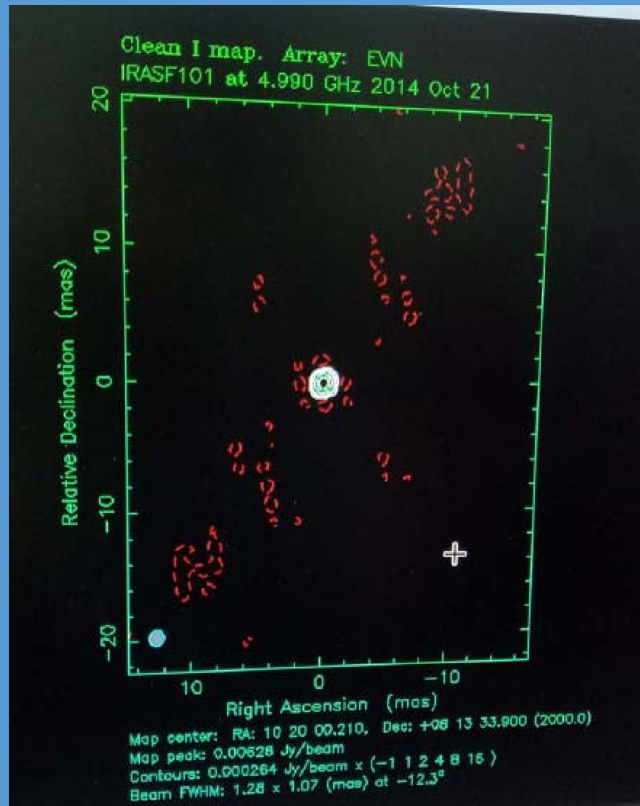
The radio continuum from archive data



The VLA FIRST image of this source with continuum peak emission is around 6.74 mJy

The EVN image of IRAS 10173+0828 from pipelined archive data   The data shows peak flux less than 6 mJy, needs high sensitivity VLBI observations





Results from Merlin observation(yu et al. 2005)

- the OH megamaser spots are almost distributed on a line. Moreover, the three lines run in different di-rections, indicated that all the OH megamasers in the spots of three clumps are distributed on an edge-on warped circumnuclear torus.
- The position of peak flux contours of the OH megamaser

is consistent with that of the continuum in IRAS 10173+0828.

Our EVN+MERLIN observations of this source

- Mapping all of the OH megamaser emission in this source: locate both the compact and diffuse OH emission, velocity of edge-on disk/torus structure, origin and mechanism of OH megamaser emission
- Determining the structure of the continuum emission and its connection with the OH megamaser emission: the EVN and

Merlin observation will enable us map any jet-like over a wide range of angular resolution, as well as locate this emission with respect to the masers

The aim of our VLBA project of OHMs observations

Investigation of Nuclear Power Sources and OHM Structure Evolution in (U)LIRGs

Abstract:

OHMs represent a subsample of (U)LIRGs, which will evolve as galaxies merging proceeds. An OH flux-limited sample of 6 OHMs (>~35 mJy), which may roughly characterize the various phases of OHMs evolution, and has never been observed with VLBI before, are chosen to be observed with VLBA at 18 cm OH line and continuum. The observation will be taken to obtain high-resolution spatial and velocity OHM structure and radio continuum structure for each of the source. The compactness of radio continuum and OHM structure, their relative locations to each other may help to understand the nature of the nuclear power sources (AGNs and/or starbursts), pumping mechanism of the population inversion, and to roughly determine the phase of OHM evolution due to galaxy merging. The OHM velocity gradient, if present, may be used to enhance our understanding of the kinematics on parsec scales in their nuclear regions, especially for IRAS 02524+2046 and IRAS 12112+0305 with multiple OH velocity components. The proposed observation will almost double the amount of OHMs with VLBI measurements, and help to better understand the galaxy merging process and hence the cosmological evolution of galaxies and large scale.

The sample with OH line emission > than 35 mJy and no VLBI observations approved for VLBA observations

Source	Z	Freq (MHz)	F (OH)	F (L)	α	Type
1	2	3	4	5	6	7
01298-0744	0.136	1467.55	118.3	4.8	-0.28	ULIRG
02524+2046*	0.181	1411.38	39.8	2.9		
10173+0828	0.049	1589.38	105.0	8.4	-0.38	LIRG
12112+0305	0.073	1553.50	45.0	20.1	-0.48	ULIRG
15107+0724	0.013	1646.01	35.0	51.0	-0.35	LIRG
20550+1656	0.036	1609.31	40.0	36.3	-0.69	LIRG

Furture plan

1 Try using the observation we have achieved to got good results

hope to got at least 6 OHMs with VLBI observations results

2 For weak and interesting OHMs trying to firstly apply VLA, GBT or MERLIN observations.

3 Find suitable candidates for furture high sensitivity VLBI observations, eg EVN+FAST