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Multi-Wavelength Studies on H_2O Maser Host Galaxies

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Abstract. H_2O maser emissions have been found in external galaxies for more than 30 years. Main sciences associated with extragalactic H_2O masers can be summarized roughly into three parts: maser emission itself, AGN sciences and cosmology exploration. Our work in this field focusses on two projects: X-ray data analysis of individual maser source using X-ray penetrability to explore maser host obscured AGN; multi-wavelength statistical properties of the whole published H_2O maser sample. Here their nuclear radio properties were investigated in detail, based on their 6-cm and 20-cm radio observation data. Comparing the radio properties between maser-detected sources and non-detected sources at similar distance scale, we find that: (1) maser host galaxies tend to have higher nuclear radio luminosity; (2) the spectral index of both samples is comparable (∼0.6), within the error ranges. In addition, for AGN-maser sources, the isotropic maser luminosity tends to increase with rising radio luminosity. Thus we propose the nuclear radio luminosity as one good indicator for searching AGN-masers in the future.

Key words. Maser—multi-wavelength—statistics—AGN.

1. Introduction

Extragalactic H_2O masers have been detected and studied for more than 30 years from the first detection towards M 33 (Churchwell *et al.* 1977, $\lambda = 1.3$ cm). So far, there are 85 published maser sources at distances larger than those of the Magellanic clouds, out of $\sim$ 3000 source targets (e.g., Zhang *et al.* 2006; Braatz & Gugliucci 2008; Greenhill *et al.* 2008; Darling *et al.* 2008). Among the 85 published H_2O maser sources, there are 66 AGN masers (63 'megamasers' with isotropic luminosities $L_{H_2O} > 10\,L_\odot$ and 3 'kilomasers' with $L_{H_2O} < 10\,L_\odot$). Ten kilomasers are related to star formation regions and another nine kilomasers are still awaiting interferometric observations to investigate their nature. Among AGN maser sources, a large portion (∼40%) has been identified as disk maser candidates (e.g., Zhang *et al.* 2010). Their maser spots are located within the central few pc, forming parts of a molecular accretion disk around the nuclear engine. In addition to 'systemic' features, 'high velocity' components are also found, representing the approaching and receding edges of the disks, which are viewed approximately edge-on.

Main sciences associated with extragalactic H_2O masers may include three subjects:

- maser emission itself, which needs much modeling work to probe maser's formation and excitation etc.;
- *AGN sciences*: Analysis of nuclear X-ray emission can probe the circumnuclear environment of maser host obscured AGN; high resolution VLBI mapping of disk maser can help us reveal structure of maser accretion disk and weight of the mass of central supermassive black hole;
- *Cosmology exploration*: Combining VLBI mapping of disk masers and monitoring systemic maser spots, the angular diameter distance of maser host galaxy can be estimated accurately.

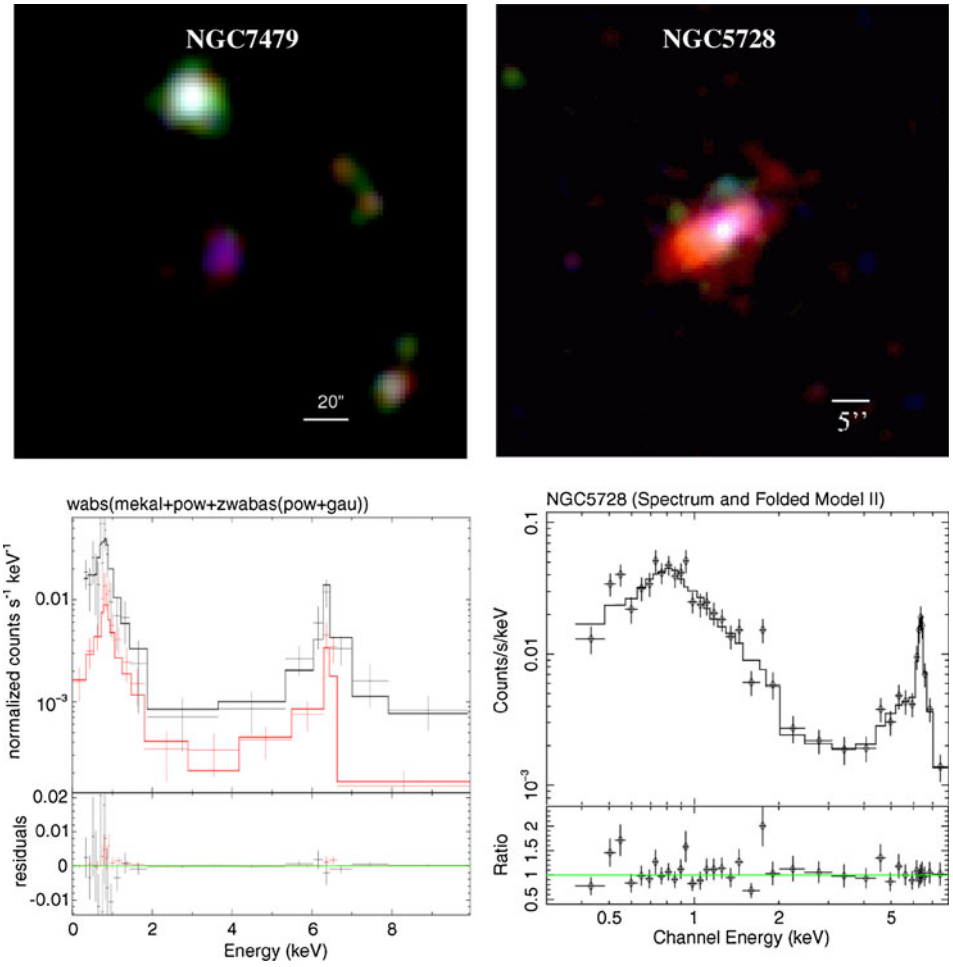

Figure 1. Adaptively smoothed three-color image in 0.3–8.0 keV and spectra with fitting model of NGC 7479 (XMM-Newton observation, left panels, Wang *et al*. 2010) and NGC 5728 (Chandra, right panels, Zhang *et al*. 2006).

It provides a perspective to improve the accuracy of the Hubble constant H_0 and to constrain the equation of state for the elusive dark energy. This has become currently the main stream of extragalactic H_2O maser researches. A large project, Megamaser Cosmology Project (MCP), has been performed for a key goal of accurate H_0 (within 3% rms, e.g., Braatz *et al.* 2010, or https://safe.nrao.edu/wiki/bin/view/Main/MegamaserCosmologyProject).

Here we introduce our work in this field briefly: (1) X-ray data analysis of individual maser host AGN; (2) statistical studies on the entire maser sample. Our main goal is to focus on investigating possible intrinsic properties of this special kind of AGN and galaxy, and probe possible indicators of H_2O megamaser emission to guide future megamaser searches. Radio properties of the entire maser sample is investigated and presented here.

2. X-ray properties

Chandra and XMM-Newton data were analyzed for maser sources. Our analysis show that maser sources always present evidence of obscured AGN. The soft excess and the strong iron emission lines are commonly presented in their X-ray spectrum. Modeling their X-ray spectra shows that high absorbing column density is prevalent in megamaser host AGN (see details in Guo *et al.* 2009). Figure 1 shows the X-ray morphology and spectra with fitting models for several examples.

3. Statistical properties

As mentioned above, the detection rate of extragalactic H_2O is low (<10%). As a special sample, maser sources may hint at some intrinsic properties. For current

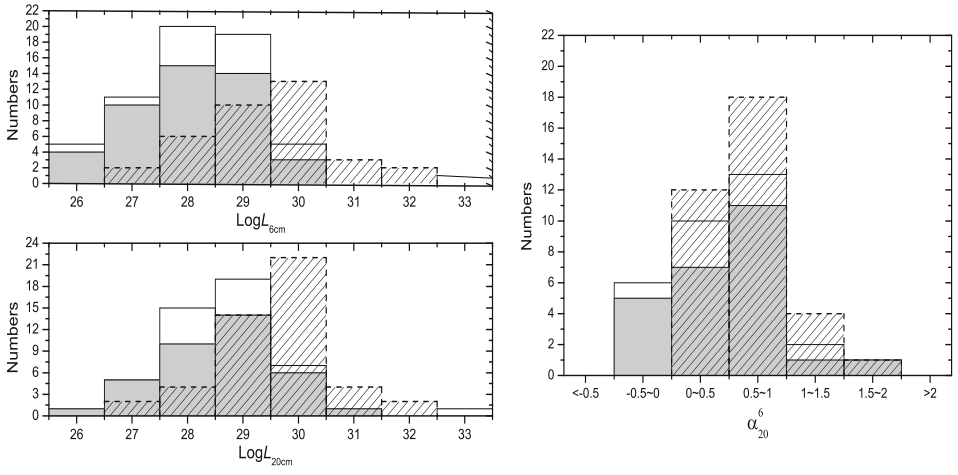

Figure 2. For the sample of nearby Seyfert galaxies without detected maser emission and its subsample of Seyfert 2s (shaded regions): Left: the distributions of 6-cm (log $L_{6\,\mathrm{cm}}$, upper panel) and 20-cm luminosities (log $L_{20\,\mathrm{cm}}$, lower panel); Right: the distributions of the spectral index between 6 and 20 cm. For comparison, the distributions of Seyfert 2s with maser detections are also presented (dashed lines, filled with diagonal lines).

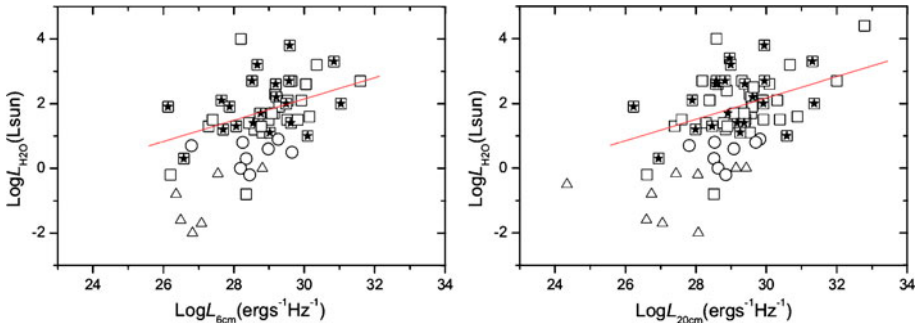

Figure 3. H_2O maser luminosities against the nuclear radio luminosity of maser host galaxies at 6 cm (left panel) and 20 cm (right panel). Squares, triangles and circles represent AGN-masers, SF-masers and masers of unknown type, respectively. Pentacles inside squares indicate disk-maser candidates.

big maser sample, we can investigate the multi-wavelength properties of maser host AGN and galaxies. A comparison between sources with and without maser detection may help us to find some indicators of megamaser emission.

Here we compile radio measurements for the entire sample of H_2O maser host galaxies to investigate their radio properties and probe possible correlations between H_2O megamasers and the nuclear radio emission. AGNs are considered to be the ultimate energy source of H_2O megamasers. On the one hand, the radio continuum luminosity has been established as a useful isotropic luminosity indicator of AGN power (e.g., Diamond-Stanic *et al.* 2009). On the other hand, H_2O line emission may be produced by amplification of the nuclear radio emission, which can provide 'seed' photons for masers located on the front side of the nucleus or an associated nuclear jet (Braatz *et al.* 1997). So we may expect some kind of correlation between maser power and the nuclear radio luminosity (Zhang *et al.* 2011).

Our results show that: (1) H_2O maser sources tend to be more luminous than non-masers (left panels in Fig. 2); (2) no significant difference can be found for the spectral index between them. The mean value of the index is 0.63 ± 0.06 for our H_2O maser sample and 0.52 ± 0.09 for the comparison sample (right panel in Fig. 2); (3) for the subsample of AGN-masers, H_2O maser isotropic luminosity tends to correlate with the nuclear radio power of the host galaxy (Fig. 3). The nuclear radio luminosity provides a clear signature for the presence of AGN-masers, possibly providing suitable constraints for future H_2O megamaser surveys.

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