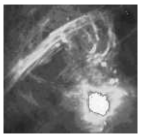
GCNEWS



The Newsletter of Galactic Center Research

Vol.8 **August 1998**

email: gcnews@mpifr-bonn.mpg.de **http://www.mpifr-bonn.mpg.de/gcnews/**

GCNEWS INVITED ARTICLE - REPRINT

(Yusef-Zadeh, F. 1998, GCNEWS, Vol. 8, p. 3-5)

On the Nature of OH (1720 MHz) Masers in the Galactic Center

Farhad Yusef-Zadeh (Department of Physics and Astronomy, Northwestern University)

Introduction

The association of 1720 MHz OH masers with supernova remnants, a possibility which was ignored for more than 25 years (e.g. Goss and Robinson 1968), was recently brought to the spotlight by a high-resolution study of the supernova remnant W28 (Frail, Goss & Slysh 1994). These maser clumps – sometimes called supernova masers – are observed along the interface of the supernova remnant and an adjacent molecular cloud (the extreme evolutionary endpoints of the stars and gas), leading these authors to support the idea that the collision is the pumping source of the masers as had been suggested by Elitzur (1976) more than 20 years ago. The OH 1720 MHz masers are uncommon and appear to be different from those OH emission features seen along the spiral arms and are in stark contrast to OH 1665 and 1667 MHz maser spots generally observed toward star-forming regions and in circumstellar envelopes of evolved stars. Theoretical studies of the pumping of the OH maser lines (e.g. Elitzur 1976; Pavlakis & Kylafis 1996; Lockett, Gauthier and Elitzur 1998) suggest that 1665 and 1667 MHz masers are pumped by far-infrared radiation and are therefore associated with HII regions and evolved stars. The OH (1720 MHz) maser is collisionally pumped in molecular gas at temperatures and densities between 15-200 K and $(10^4 - 10^6)$ cm$(^{-3})$, respectively. Thus in the absence of the 1665/7 MHz transitions, the OH (1720 MHz) line presumably traces cooling, shocked gas.

The discovery paper by Frail et al. (1994) motivated us to search for these masers at the site of the thermal/nonthermal interaction in the complex region of the Galactic Center region where a number of nonthermal features are believed to be interacting with thermal gas (Yusef-Zadeh, Uchida and Roberts 1995). Figure 1 shows a segment of the SNR G359.1-0.5 where an OH (1720 MHz) maser is detected at the location where the Snake crosses the supernova shell. The detection of these masers in the Galactic Center region has already provided a wealth of information and has a potential to be a powerful probe of the interstellar medium of this region because of the extensive reservoir of dense molecular material observed throughout this region. Here, highlights of what we have learned from observations of OH (1720 MHz) masers in this region are briefly described.

A Probe of the Magnetic Pressure

Surveys of the GC region, even at the very moderate resolution of a few arcminutes, take a lot of time: comparatively small telescopes are used for months or even years of routine observations. The resulting data are, however, the base on which our understanding of the behaviour of the $\sim 3 \cdot 10^7 M_\odot$ of material in the CMZ (central molecular zone) and, if we take the extragalactic analogy seriously, the gas in an increasing number of galactic bulges, is relying.

Since the main constituent of molecular clouds, H_2, lacks a permanent dipole moment, molecular gas that is not hot enough to excite vibrational (infrared) H_2 transitions — only very exceptional clouds manage this — has to be detected in 'tracer molecules'. The most abundant of those, and thus the workhorse of molecular spectroscopists, is the main isotope of carbon monoxide, ^{12}CO, with a relative abundance to H_2 of $\sim 10^{-4}$. Most maps of molecular gas distributions in the Milky Way and, even more pronounced, in external galaxies, are taken in the rotational $J = 1 \rightarrow 0$ transition of this molecule at 115GHz (2.6mm). CO also has the advantage of being easily excited even at low gas densities of only $\sim 10^2$cm^{-3}. Thus, it traces almost all molecular gas.

Why isn't it, then, sufficient to survey the CMZ — and external galaxies — once in ^{12}CO and be done with it? Inspection of the images obtained by surveys in a number of molecules and transitions readily provides the answer: The gas distribution looks very different, depending on what species and what excitation state is used. ^{12}CO $1 \rightarrow 0$ maps (see Bitran et al. and Jackson et al. 1996 for recent examples) tell us the morphology of molecular gas of all kinds — and little else. It is striking how little contrast is seen in ^{12}CO: These images let the observer question the concept of distinct molecular clouds in the GC. And this is, indeed, an important insight: ^{12}CO picks up (among other things) a diffuse 'intercloud medium', that, in the GC, is molecular rather than atomic. To get to the physical meat of the matter, the density and temperature distribution of the gas, multilevel studies, isotope studies and surveys in rarer, weaker molecular species are required. Since a field of at the very least $5^\circ \times 2^\circ$ has to be covered, this makes for fairly tedious work, and it sometimes seems that more data have been accumulated for the nuclear regions of some external galaxies than for our GC. Direct measurements of the magnetic field is quite difficult in the Galactic Center region due to the broad linewidths of molecular clouds and a large number of unrelated velocity features along the line of sight. Because, the OH (1720 MHz) maser line traces molecular gas densities on the order of 10^4 to 10^6 cm^{-3} which are similar to typical molecular densities of molecular clouds in the Galactic Center region, their high surface brightness over a narrow linewidth have made their identification simple and Zeeman splitting are measured with a high S/N ratio. The magnetic field measurements of Sgr A East with B$\approx$ 2-5 mG with a S/N of 10–30 are roughly an order of magnitude greater than sources outside the Galactic Center. Because of the relatively large Zeeman shift in the line profiles, Elitzur (1998) has recently argued that these masers show a direct evidence of maser saturation. We also note extended maser emission clearly associated with the remnants such as G359.1-0.5 (Yusef-Zadeh, Uchida and Roberts 1995). Future study of the extended masing structure should be useful in learning the structure of the magnetic field behind the shock front.

A Probe of the C-type Shock

The intense UV radiation field exciting the high density, intrinsically large linewidths of H_2 in a photodissociation region have made the detection of shocked molecular gas in the Galactic Center region quite difficult. Shocks driven into the molecular gas clouds by the ram pressure of SNRs or winds are considered to be important in two prominent molecular features in the Galactic Center: the circumnuclear disk (CND) and the Sgr A East molecular cloud.

Detection of OH (1720 MHz) masers at the boundary of Sgr A East and the CND (Yusef-Zadeh et al. 1996) was used to argue that these masers are indicators of C-type shocks (Wardle, Yusef-Zadeh and Geballe 1998). The magnetic pressure behind the shock front was equated to the pressure of preshock gas, thus constraining the shock speed to 25–30 km/s. The X-ray pressure observed within the interior of the Sgr A East shell and the detection of molecular H_2 emission at the boundary of Sgr A East are all consistent with the C-type shock hypothesis. Another independent study of the OH (1720 MHz) masers by Lockett, Gauthier and Elitzur (1998) conclude that the presence of such masers is a powerful indicator of C-type shocks.

A Probe of Low and High Energy Processes

Although shock chemistry predicts that OH is not abundant in the postshock gas as it is rapidly converted to water within the shock front, Wardle et al. (1998) argue that the weak X-ray flux from the interior of the SNR is responsible for dissociation of H_2O to OH molecule. This situation is unlike the environment of compact HII regions where OH masers are produced from water by the photodissociating flux of UV from the star. The dissociating flux is largely absorbed and reradiated in the FIR by grains, to pump the 1665/7 MHz transitions which cannot be the case for the unaccompanied 1720 MHz masers associated with SNR-molecular cloud interactions. The presence of OH (1720 MHz) masers near SNRs suggests a strong coupling between the low and high-energy activities co-existing with each other.

A Probe of the Scattering Medium

The OH (1720 MHz) masers associated with Sgr A East and the CND appear to broadened by the scattering medium toward the Galactic Center. Anisotropic scattering has been observed toward Sgr A* and a number of OH/IR stars in the Galactic Center region. What is potentially interesting about the scattered size and shape of OH (1720 MHz) masers is the small angular separation of maser spots from each other from which the scattering properties on small angular scales can be studied. The correlation of the position angles of scatter-broadened maser spots are used to measure the length scale of the magnetic fluctuations in the turbulent medium of the Galactic Center. Recent study by Yusef-Zadeh et al. (1998) estimates the size of this fluctuation to be of the order of 0.1-0.2 pc.

A Probe of the Gas Dynamics

The maser sources generally arise at the edge of supernova shells where the acceleration is tangential to the line of sight and the condition for velocity coherence is achieved by having a small velocity gradient along the line of sight. Most sources with OH (1720 MHz) masers outside the Galactic Center show small velocity dispersion along the rim of the supernova shells. This implies that the radial velocity of the masers is close to the systemic velocity of the molecular cloud. However, the masers associated with the shell of Sgr A East show a large velocity dispersion across the shell. This large velocity difference is considered to be to due to a strong shear that Sgr A East is experiencing near the deep gravitational potential of the Galactic Center. In this scenario, Yusef-Zadeh et al. (1998) argue that the Sgr A East molecular cloud has to be located within 5 pc behind the Galactic Center if tidal shear is responsible for the observed velocity difference across the shell of the SNR.

References

Elitzur, M. 1976, ApJ, 203, 124
Elitzur, M. 1998, ApJ, in press.
Frail, D.A., Diamond, P.J., Cordes, J.M. and van Langevelde, H.J. 1994, ApJ, 427, L43
Frail, D.A., Goss, M.W. and Slysh, V.I. 1994, ApJ, 424, L111
Goss, W.M. and Robinson, B.J. 1968, ApJ, 2, 81
Lockett, P., Gauthier, E. and Elitzur, M. 1998, ApJ, submitted
Pavlakis, K.G. and Kylafis, N.D. 1996, ApJ, 467, 300
Wardle, M., Yusef-Zadeh, F., & Geballe 1998, ApJ, submitted
Yusef-Zadeh, F., Uchida, K.I., & Roberts, D.A. 1995, Science 270, 1801.
Yusef-Zadeh, F., Roberts, D.A., Goss, W.M., Frail, D. & Green, A. 1996, ApJ 466, L25.
Yusef-Zadeh, F., Roberts, D.A., Goss, W.M., Frail, D. & Green, A. 1998, ApJ submitted.
Yusef-Zadeh, F. & Morris, M. 1987, ApJ, 320, 545.

Figures:

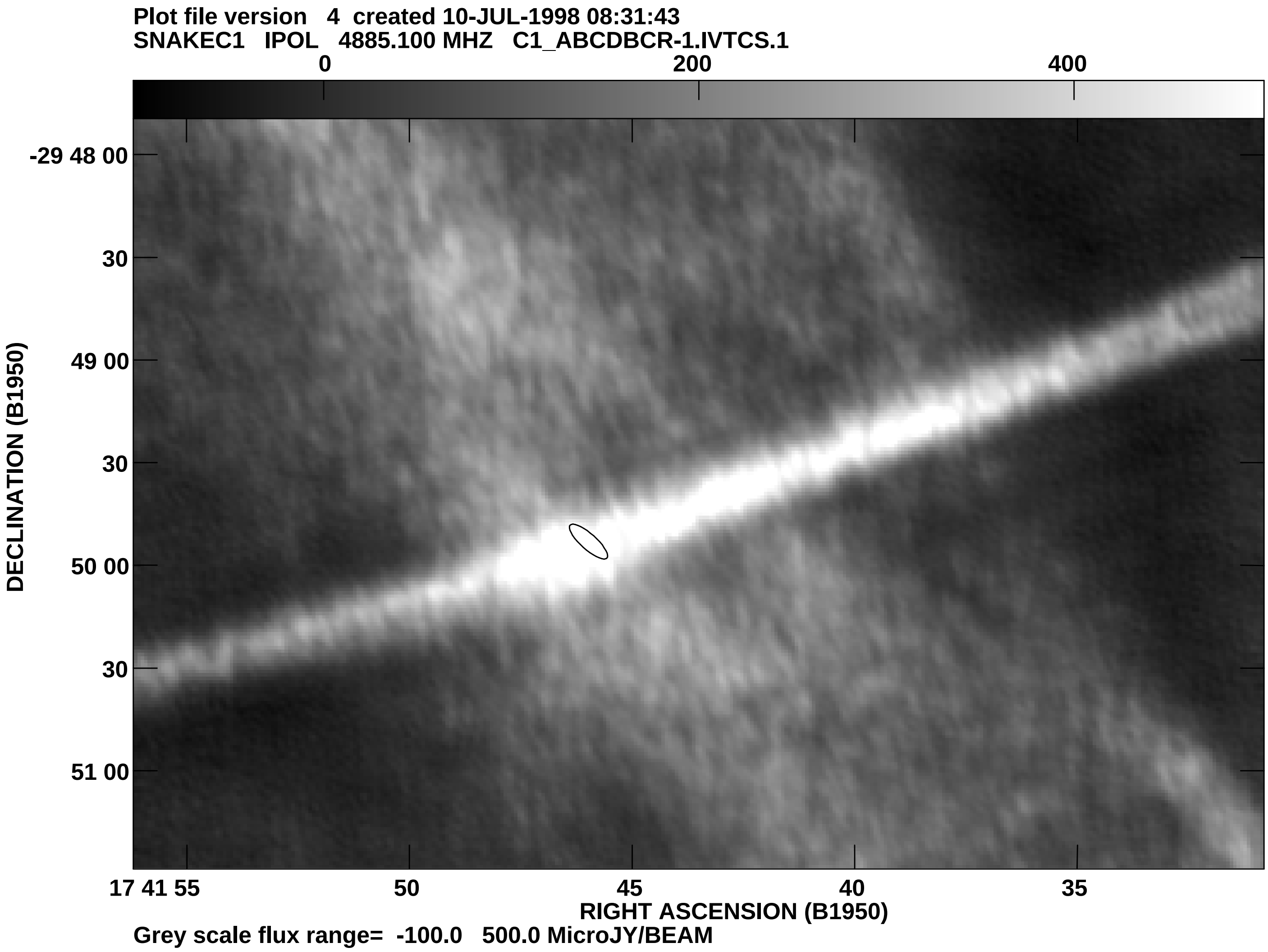


Figure 1: A greyscale continuum image of a small segment of G359.1-0.5 at λ6cm with a resolution of $5'' \times 3''$. The filamentary Snake appears to cross the remnant. The position of the OH (1720 MHz) maser is drawn as a contour with a size 20 times bigger than the actual value (Yusef-Zadeh, Uchida and Roberts 1995, see article page 4). The position angle of the maser represents the direction of the anisotropy of the scatter broadened maser source.

GCNEWS is brought to you by

Angela Cotera	Heino Falcke
Steward Observatory Rm. 274	Max-Planck-Institut für Radioastronomie
University of Arizona	Auf den Hügel 69
Tucson, AZ 85721	D-53121 Bonn, Germany
(cotera@as.arizona.edu)	(hfalcke@mpifr-bonn.mpg.de)
+1 (602) 315-1899	+49 (228) 525-217

GCNEWS appears quarterly. The electronic version is free of charge, for hard copies a fee for postage and copying may be required. We are grateful to the Max-Planck-Institut für Radioastronomie in Bonn for providing us with Internet access. The Newsletter is made possible in part by the DFG under grant Fa 358/1-2.