# OH (1720 MHz) Masers: Signposts of SNR/Molecular Cloud Interactions

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# The Discovery of OH (1720 MHz) SNR Masers

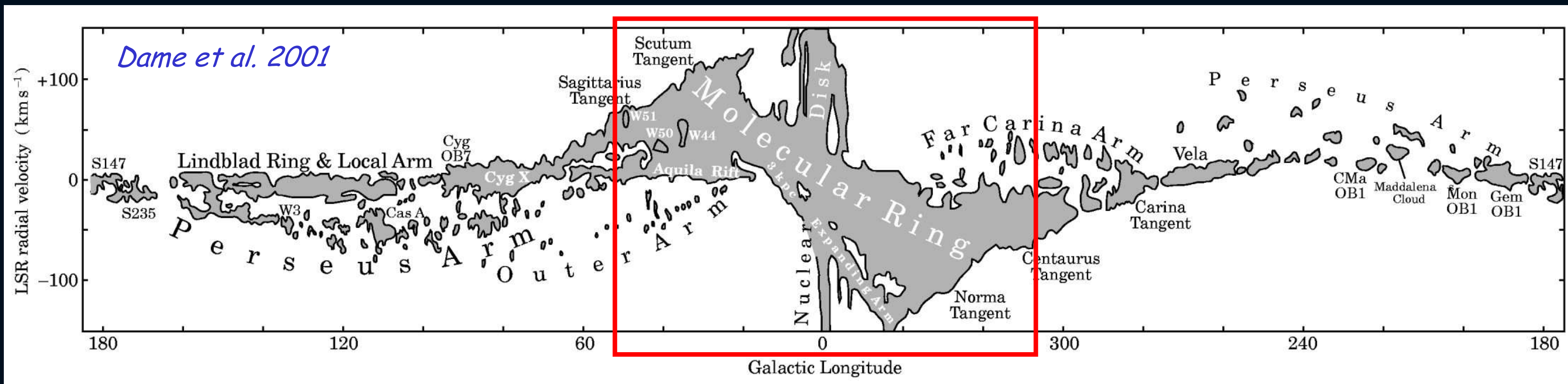
## A Brief History:

- (1968) Goss & Robinson observe "anomolous" OH (1720 MHz) emission toward SNRs W28, W44, & GC

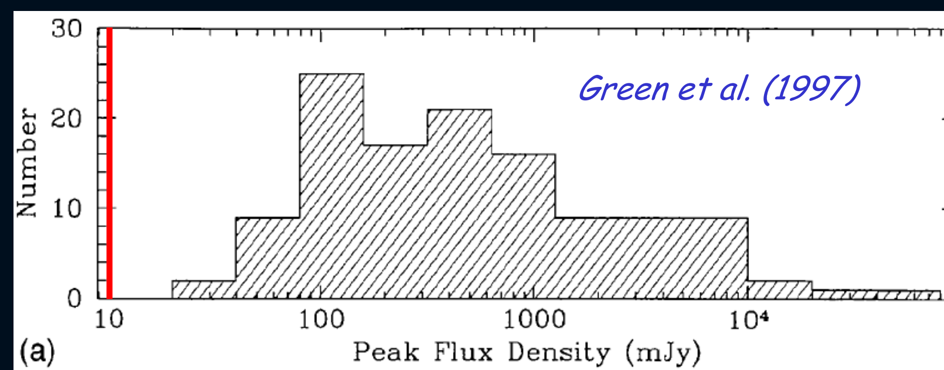
- (1993) Frail, Goss & Slysh identify with maser emission

- (1996, 1997) SNR surveys by Frail et al.; Green et al.; Yusef-Zadeh et al. (1996, 1999); Koralesky et al. (1998)

# The Discovery of OH (1720 MHz) SNR Masers



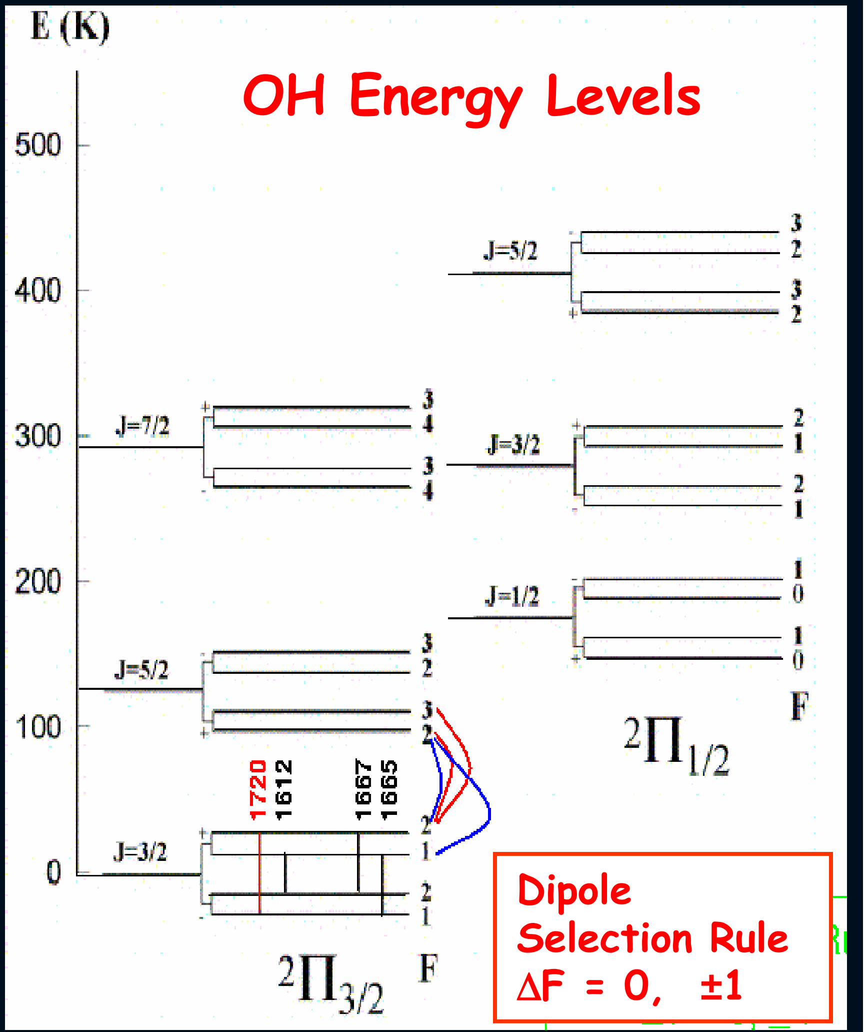

- OH (1720 MHz) masers are found toward 10% of Galactic SNRs (~20) [and one in the LMC, *Brogan et al 2003*]
- All but one SNR OH maser is inside the Molecular Ring
- They are rather weak, < few 10s of Jy
- Has a lower flux density cutoff - at least for compact emission (e.g. methanol class II)
- No accompanying mainline OH or $H_2O$ masers



# Properties of SNR OH (1720 MHz) Masers

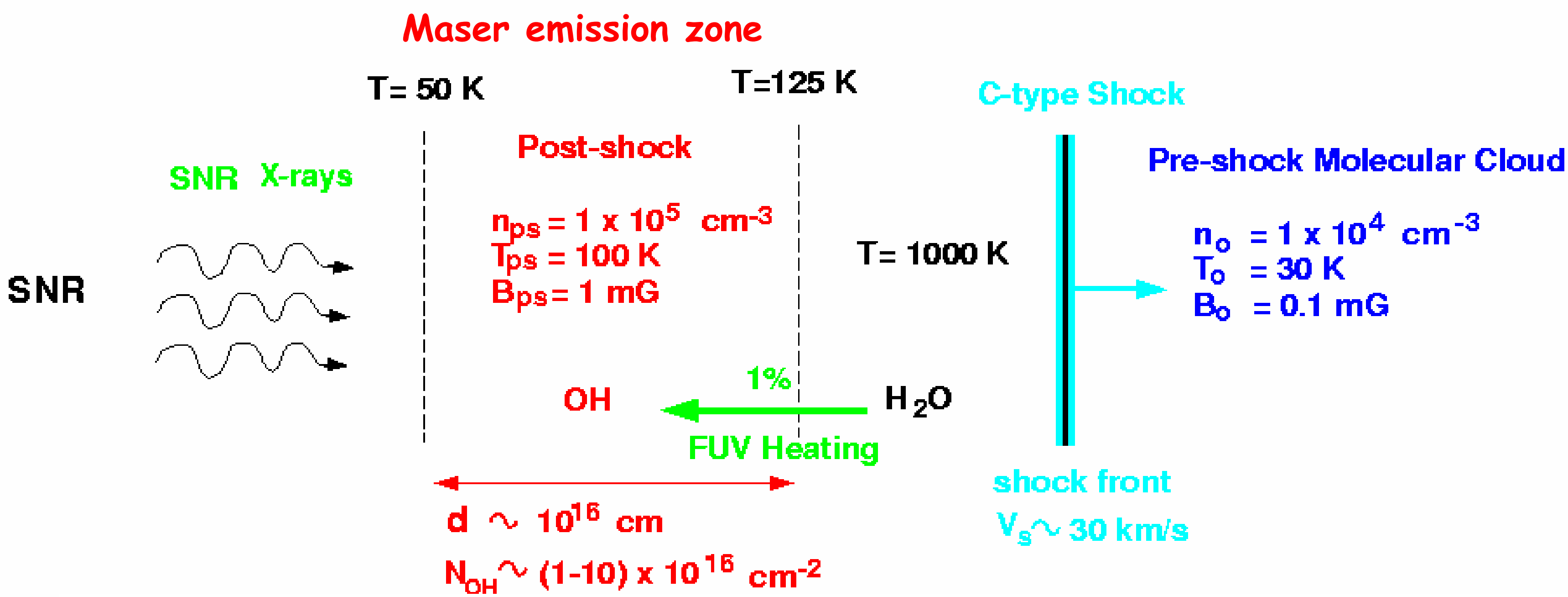
- Collisional pump requires strict range of physical conditions (*Wardle 1999; Lockett et al. 1999*):
  - Temperature 50 to 125 K
  - Density $10^4$ to $10^5$ $cm^{-3}$
- These conditions are easily met when a C-type SNR shock hits a molecular cloud
  - X-rays from SNR help dissociate $H_2O$
- Only shocks (more or less) transverse to our line of site give enough velocity coherence
- Can get magnetic field strength from the Zeeman effect (Z=0.65 Hz/μG)

  ⇨ Provides only means of directly observing strength of B-field in SNRs (but only if we can figure out the proper conversion)




These masers probe SNR/ molecular cloud interactions

# Simplified Model of SNR/Molecular Cloud Interaction




*Based on Wardle (1999) and Lockett et al. (1999) models*

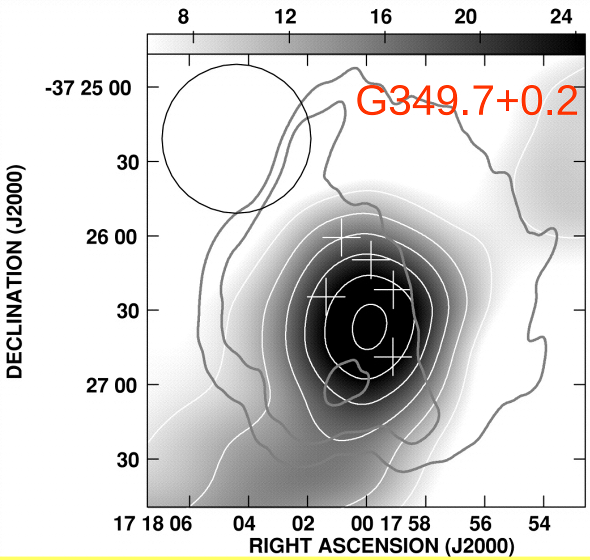
**A few notes about directions and angles**

- The shock compression suggests that the B-field should be in the plane of the shock – only this component is amplified
- Linear P.A.$_{maser}$ can be || or ⊥ to the magnetic field
- Linear P.A.$_{synch}$ is ⊥ to the magnetic field

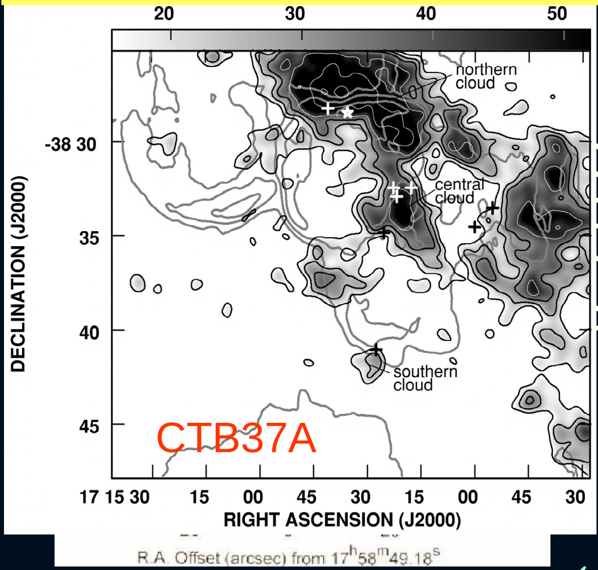
# SNR (1720 MHz ) Properties (< 2002)

- Simple Zeeman patterns with $B_\theta$ = 0.2 – 5 mG and weak (~ 10%) linear polarization
- Magnetic pressure ≈ ram pressure
- B-field <u>appears</u> to be stronger with higher resolution
- Except GC, scatter broadening not important and they are not significantly variable
- Significant internal Faraday depolarization unlikely because Faraday length > gain length
- Show excellent correlation with density/shock tracing molecular gas
- Follow-up revealed shocked molecular gas in previously unknown cases

*Claussen et al. (1997, 1999, 2002); Koralesky et al. (1998); Frail & Mitchell (1998); Yusef-Zadeh et al. (1999); Brogan et al. (2000)*



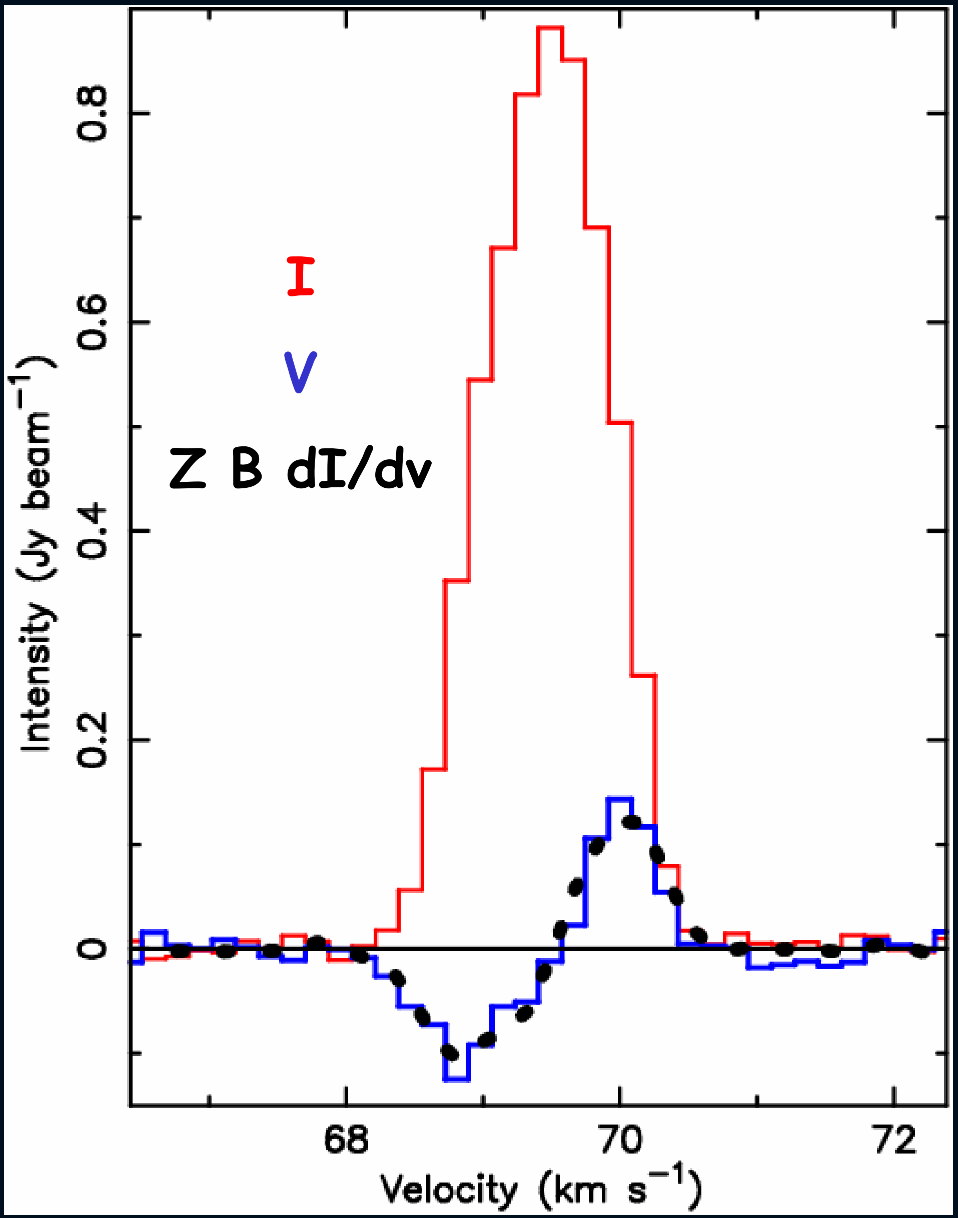

**Greyscale: CO (1-0) emission**
*Reynoso & Mangum (2000)*



# Open Questions

- What are the detailed properties of the polarization and can we distinguish between theoretical models?
- How is the maser flux distributed on small size scales and what are the brightness temperatures?
- Does the B-field really increase with higher resolution ⇨ which might be indicative of more tangled B-fields on larger size scales?
- Are these masers saturated?

# Zeeman Effect in SNR OH Masers




SNR OH (1720) maser line splitting is not fully resolved so that:

V ~ c Z B dI/2dν

But for these masers the line splitting/line width ~ 0.1

i.e. NOT splitting << line width

⇨ this case has not been studied in detail, limiting analysis may not apply

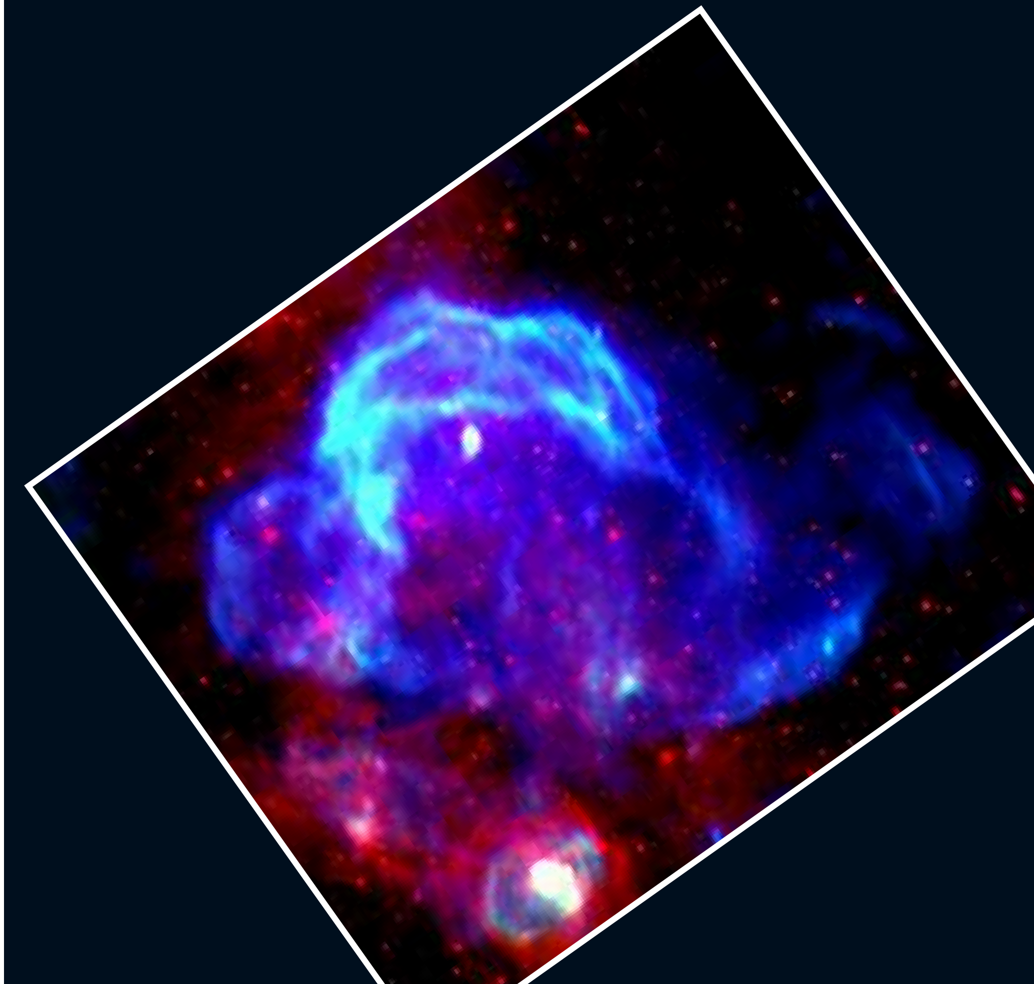
Could be different than thermal case where c=cosθ

(*Elitzur 1998; Watson & Wyld 2001*)

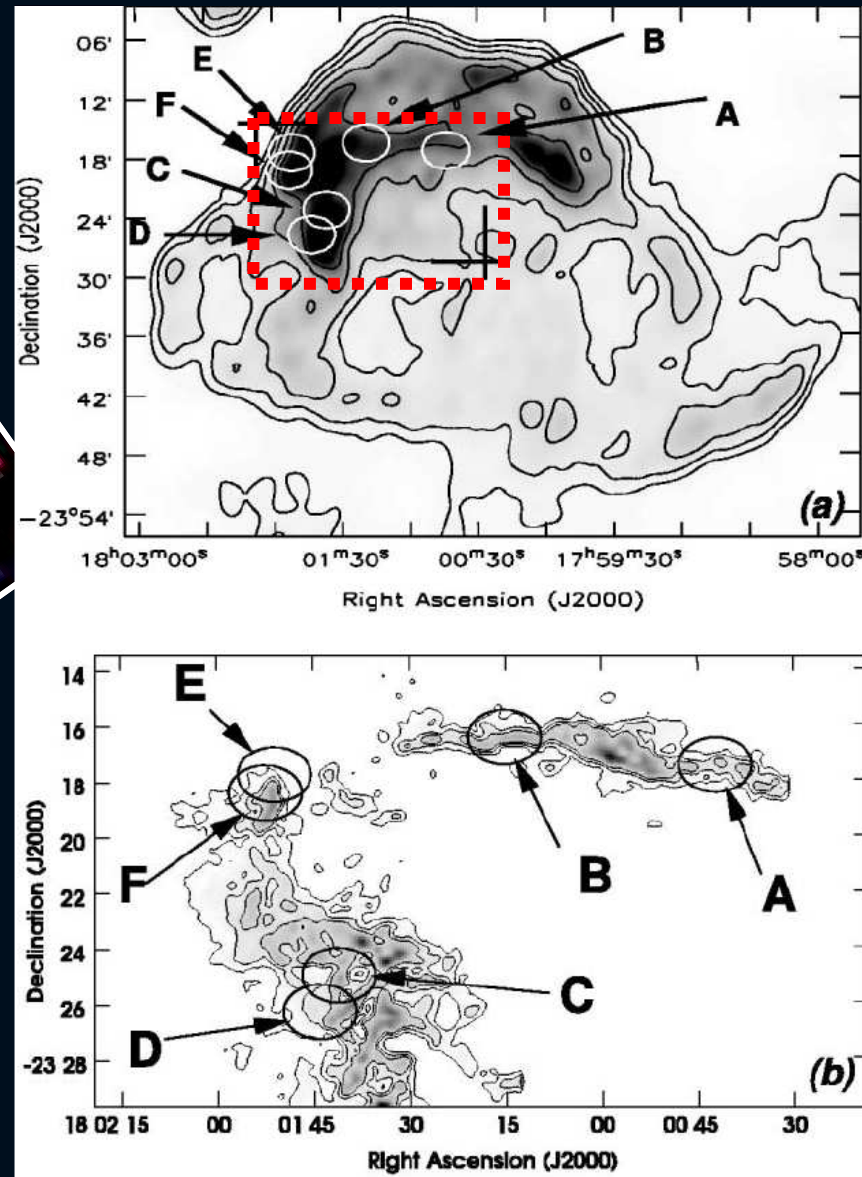
The keys to understanding the B/maser relationship:

- linear polarization
- high enough S/N to measure line splitting between R-L directly

# OH (1720 MHz) Masers in W28



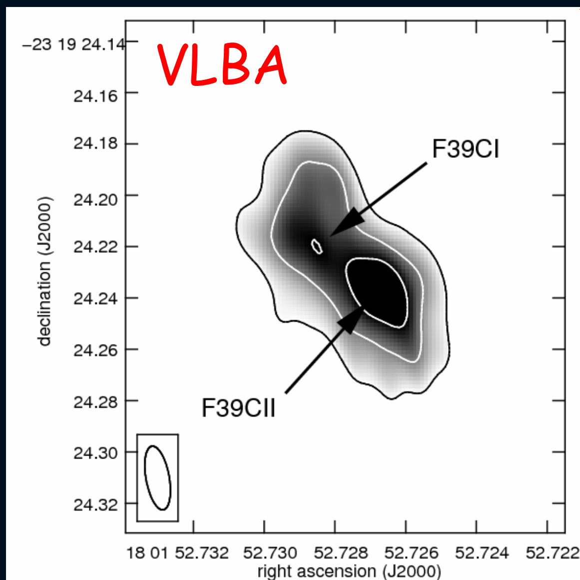
Red = MSX 8 $\mu$m
Green = SGPS+VLA 20cm
Blue = VLA 90cm

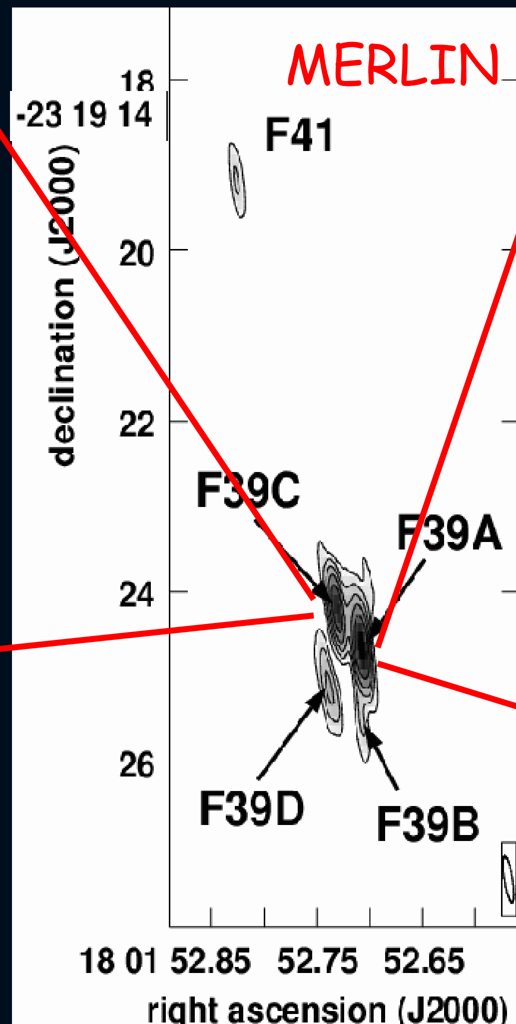


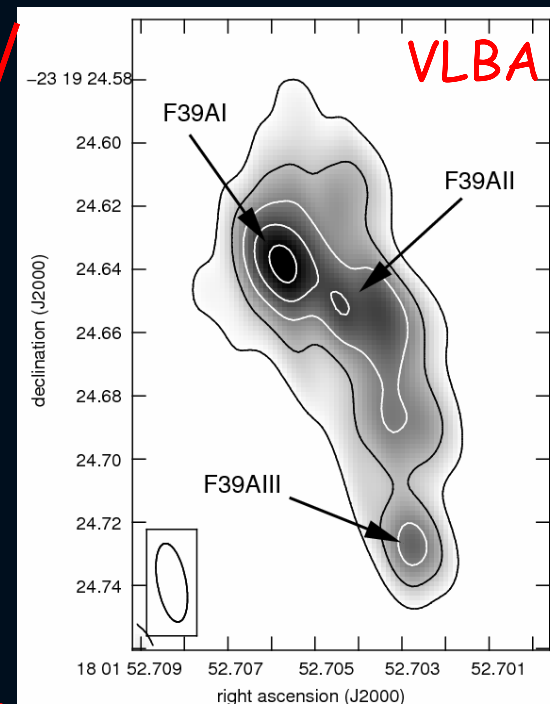

*Brogan et al. (2005)*

*Hoffman et al. (2005a)*

# Morphology of W28 Masers




At D~2.5 kpc

50 mas = 2 x $10^{15}$ cm (125 AU)

Merlin $V_{lsr}$ range = 1.4 km/s

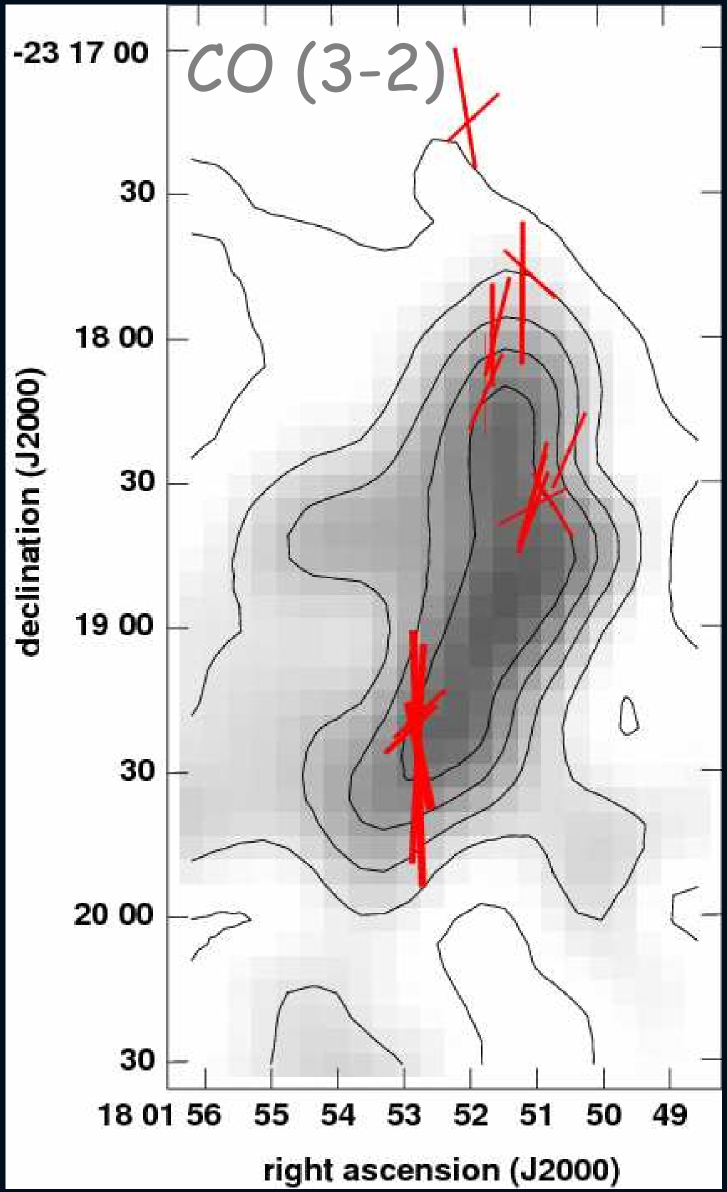
VLBA $V_{lsr}$ range = 0.1 km/s

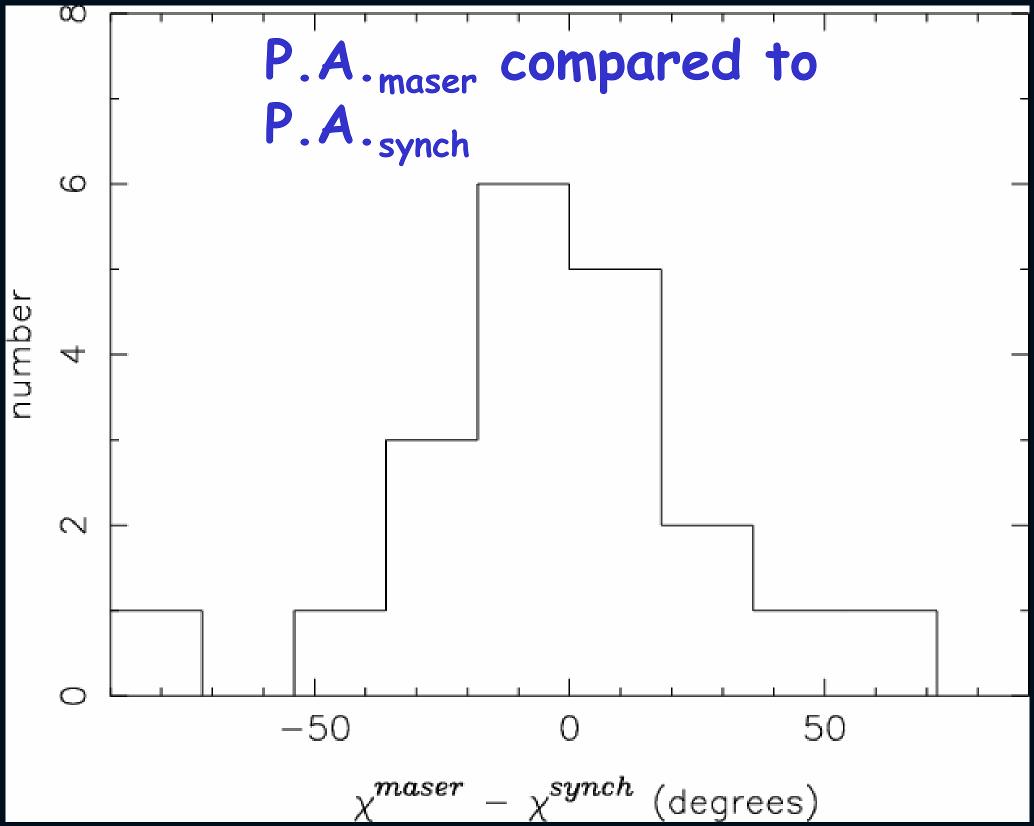
~50% of VLA flux recovered by MERLIN data

~70-85% of MERLIN flux recovered by VLBA data

*Hoffman et al. (2005a)*

# W28 Linear Polarization



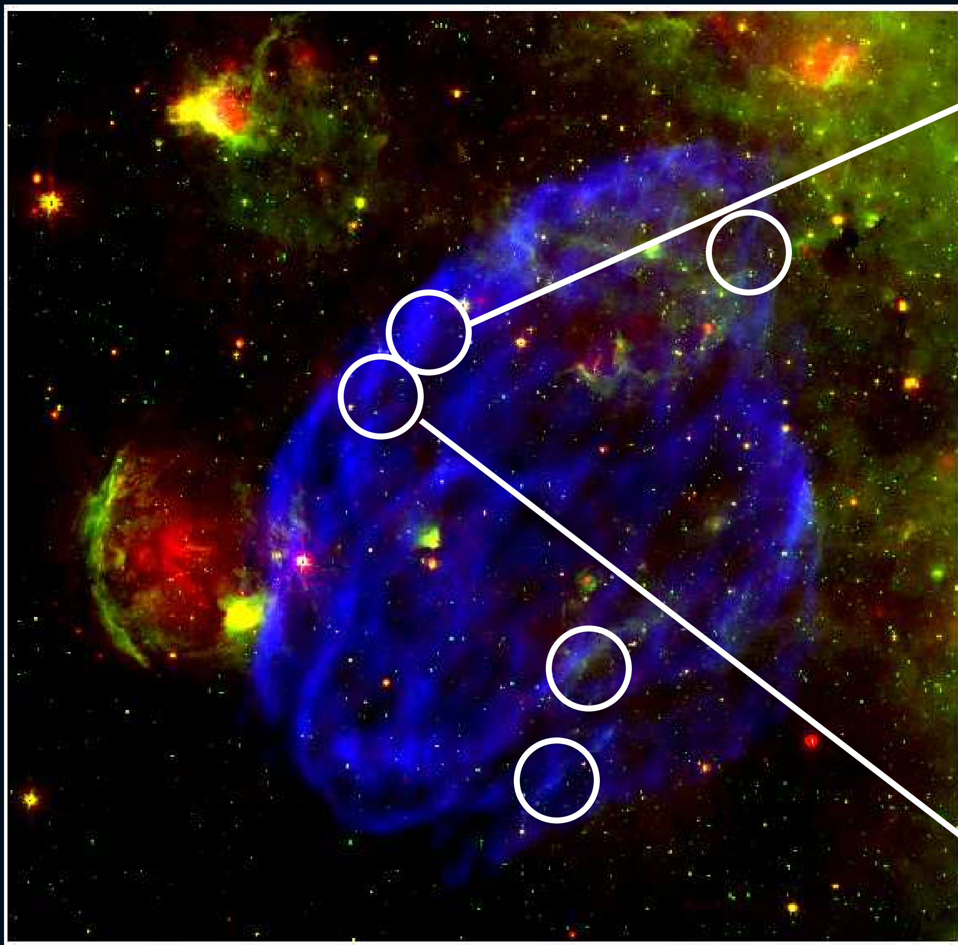



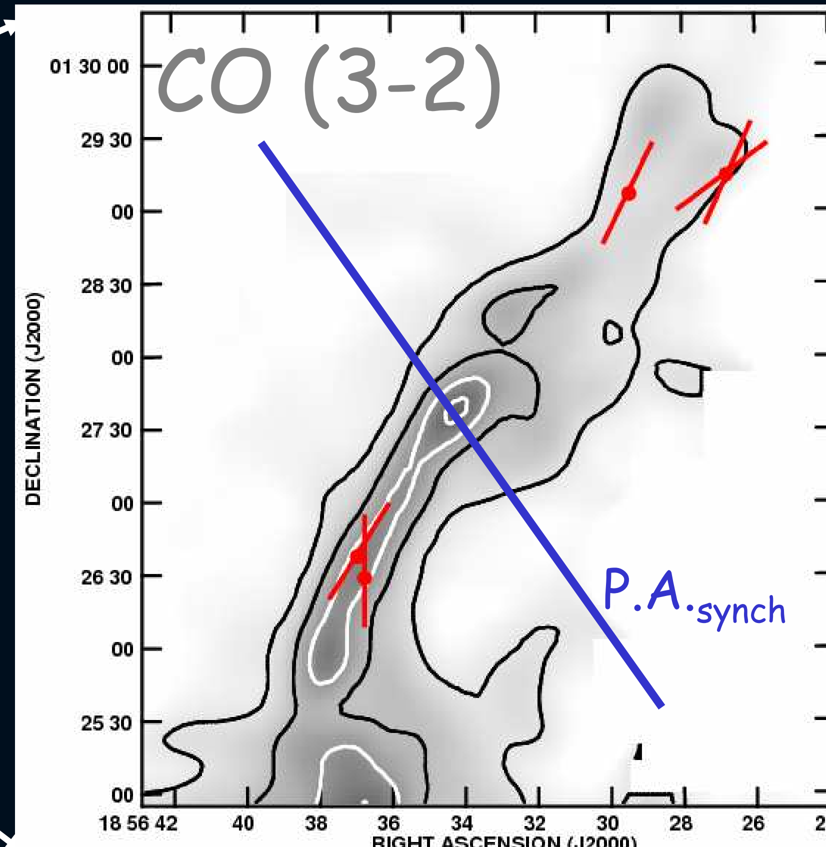

P.I. = 2% - 20%

$P.A._{maser}$ Vectors rotated by $90^{o}$

*Frail & Mitchell (1998); Hoffman et al. (2005a)*

# OH (1720 MHz) Masers in W44






Red = MIPSGAL 24 μm
Green = GLIMPSE 8 μm
Blue = VLA 90cm

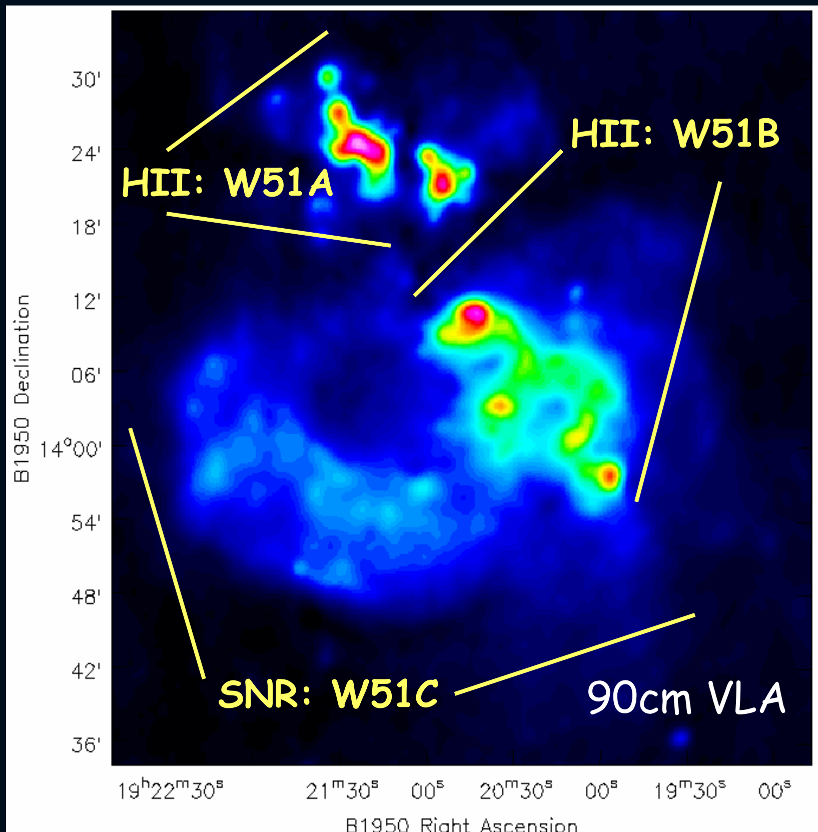
P.I. = 7% - 14%

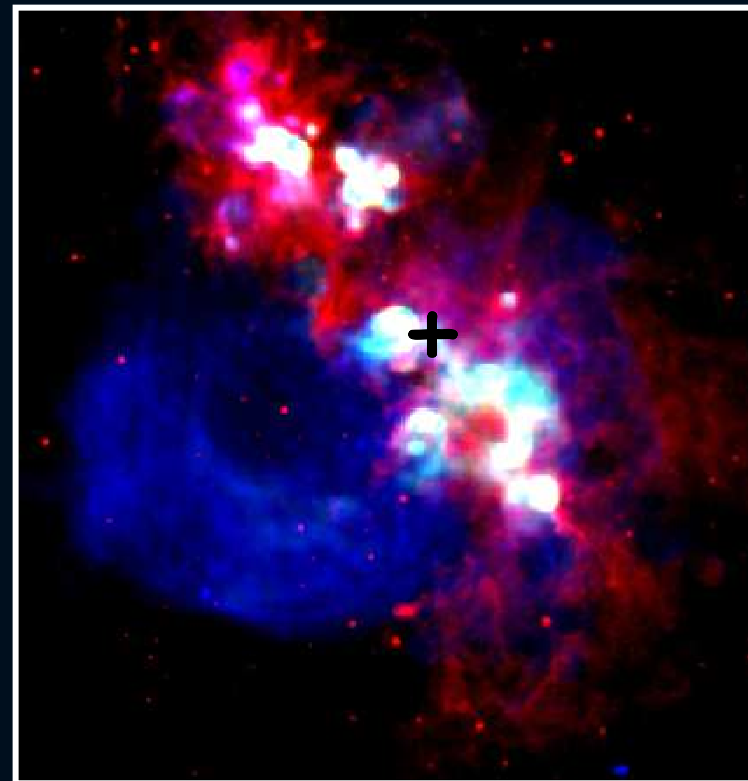
$P.A._{maser}$ vectors NOT rotated by 90°

*Castelletti et al. (2007)*

*Hoffman et al. (2005b)*

# OH (1720 MHz) Masers in W51B



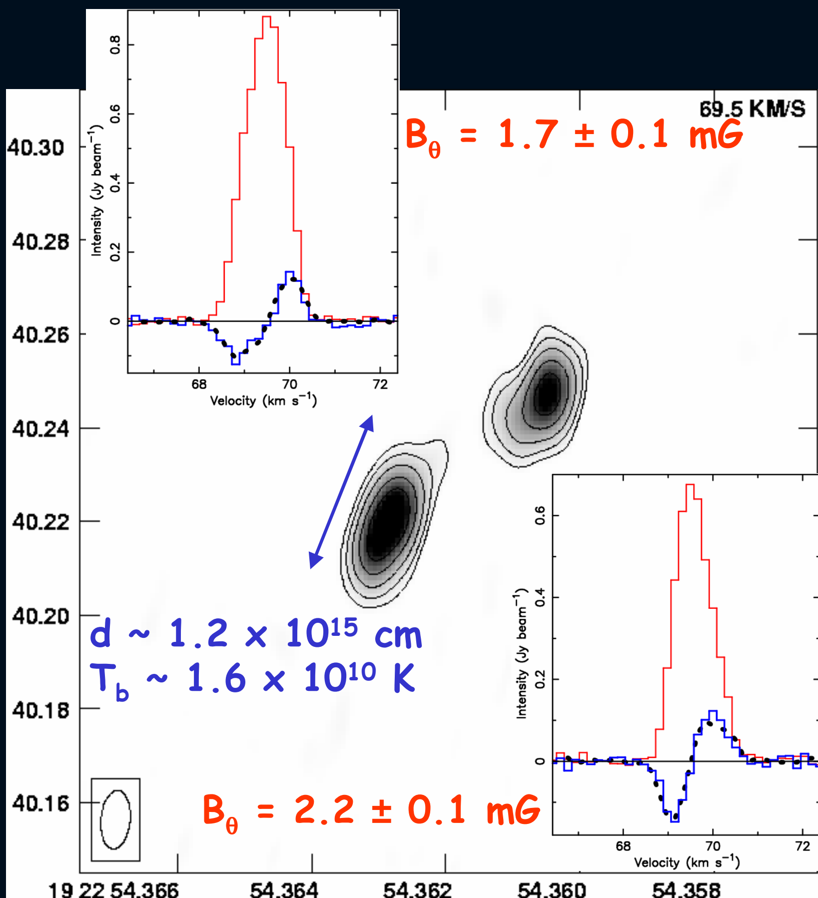
Red = MSX 8 μm
Green = VLA 20cm
Blue = VLA 90cm

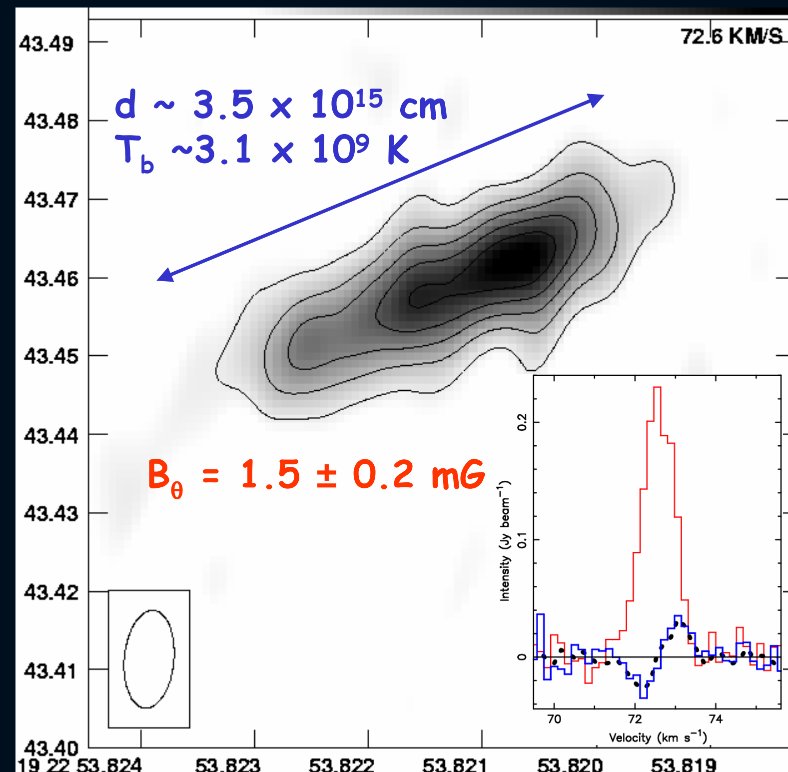
- One of most luminous SFRs in Galaxy
- Located at the tangent point of Sagittarius Arm ⇨ lots of material piled up along the line of sight; very complex kinematics

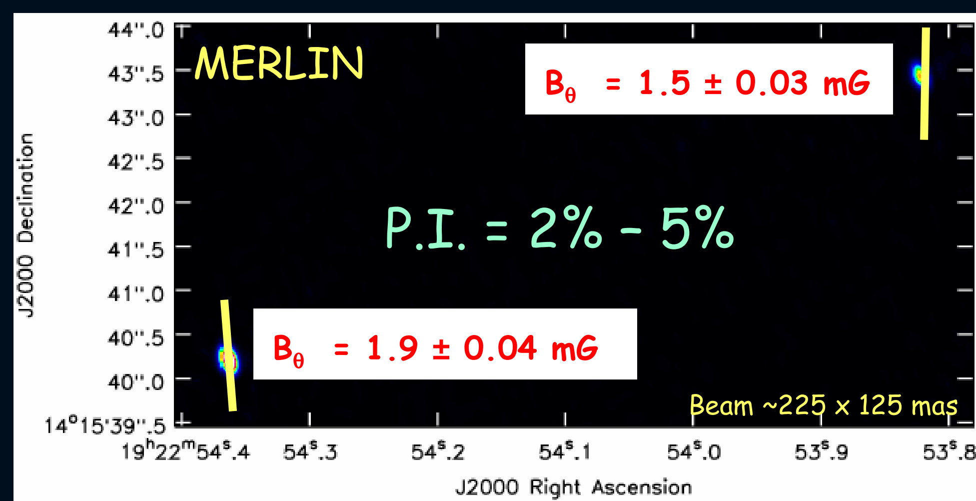
*Brogan et al. (in prep.)*

# MERLIN & VLBA Toward W51C Maser

- VLBA Resolution 12.5 x 6.3 mas
- At MERLIN and VLBA scales, both regions are missing about half of the VLA flux density

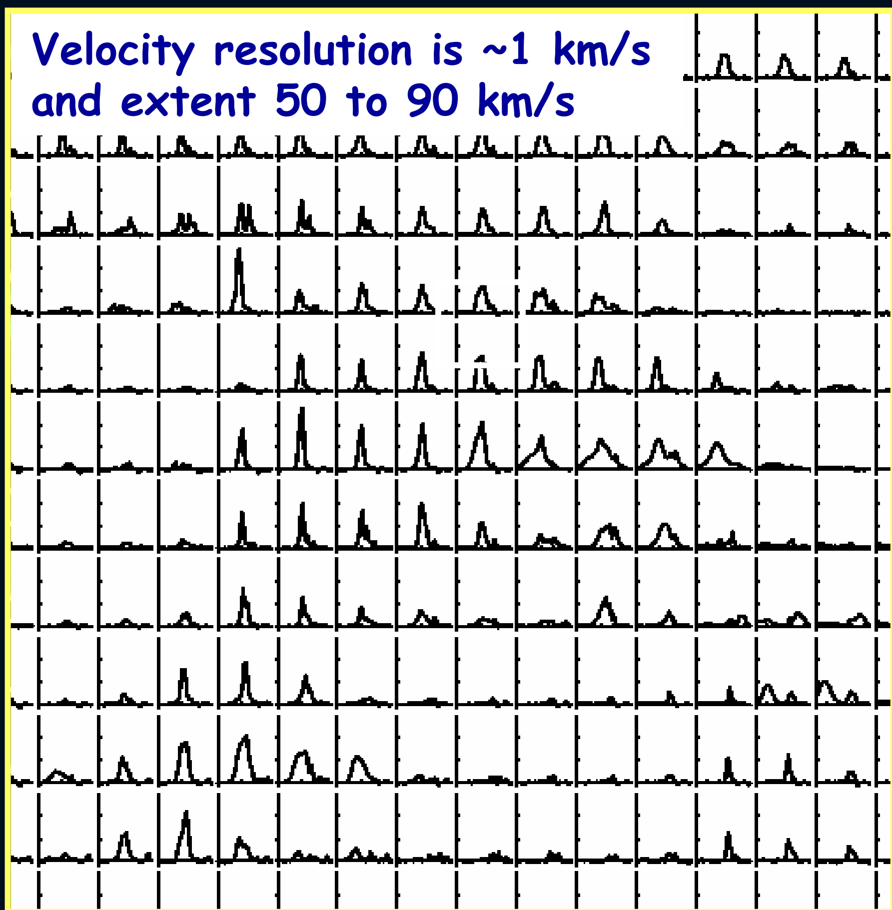


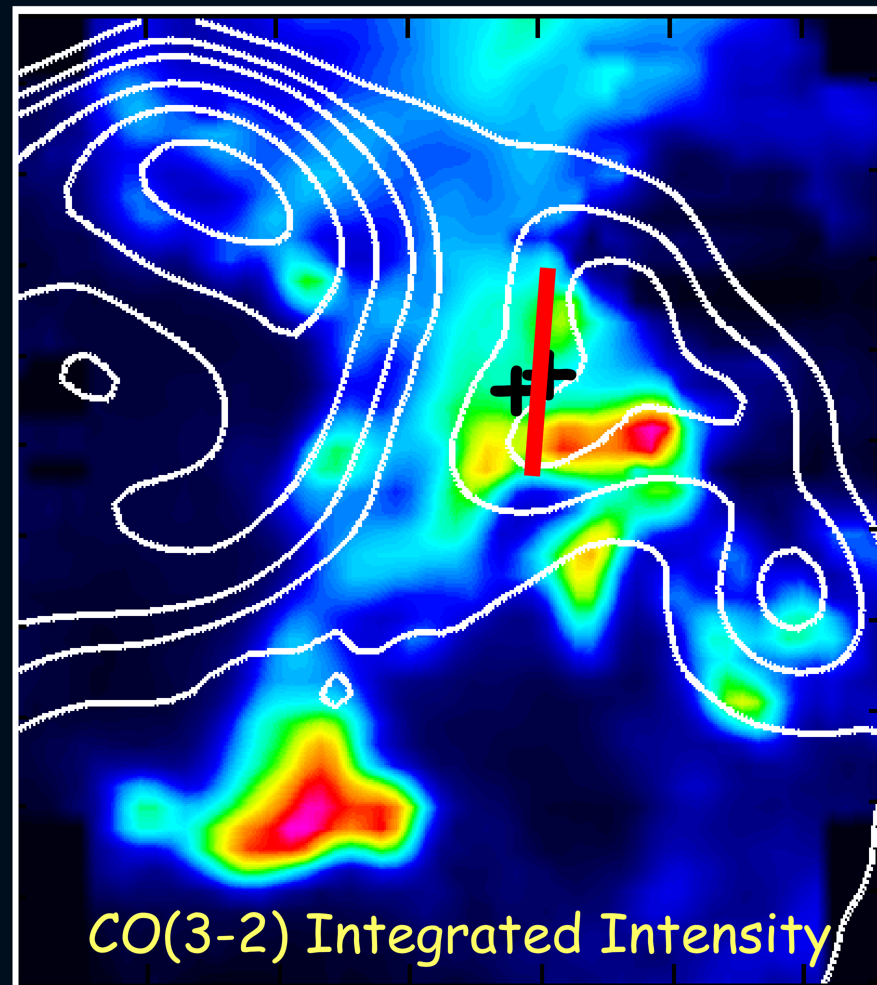




*Brogan (2003); Brogan et al., in prep.*

# Spitzer mid-IR and JCMT Observations



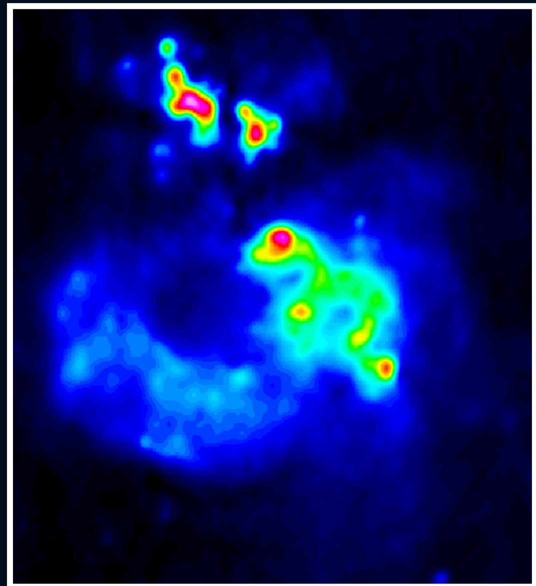

Red = GLIMPSE 8 μm
Green = GLIMPSE 4.5 μm
Blue = GLIMPSE 3 μm



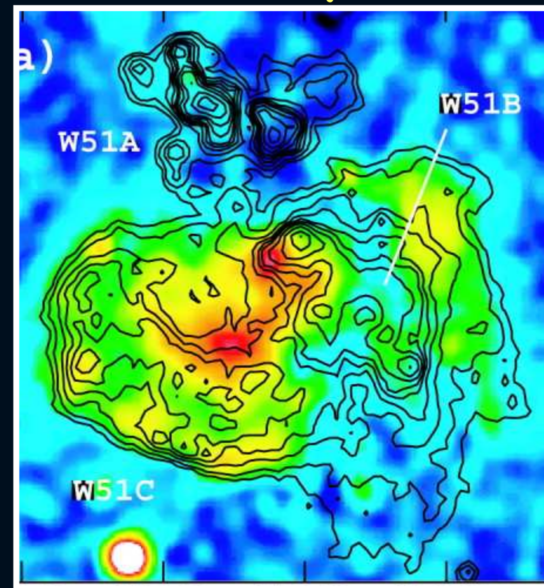

White contours show 90cm VLA

Like W44, P.A. is || to shock front

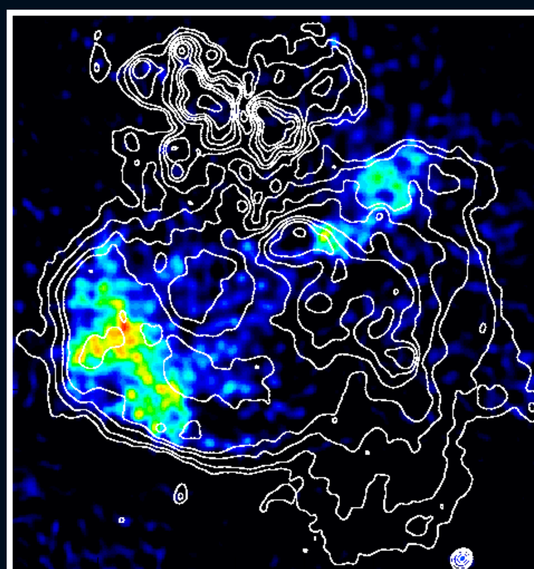
# W51 in Radio and X-rays



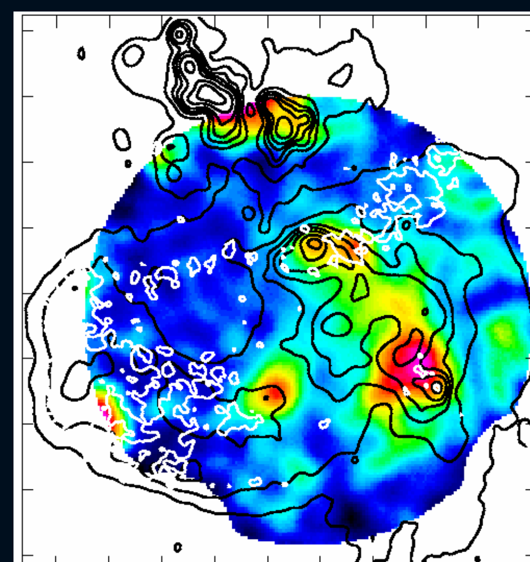
330 MHz VLA




ROSAT Soft X-rays
*Koo et al. (2002)*



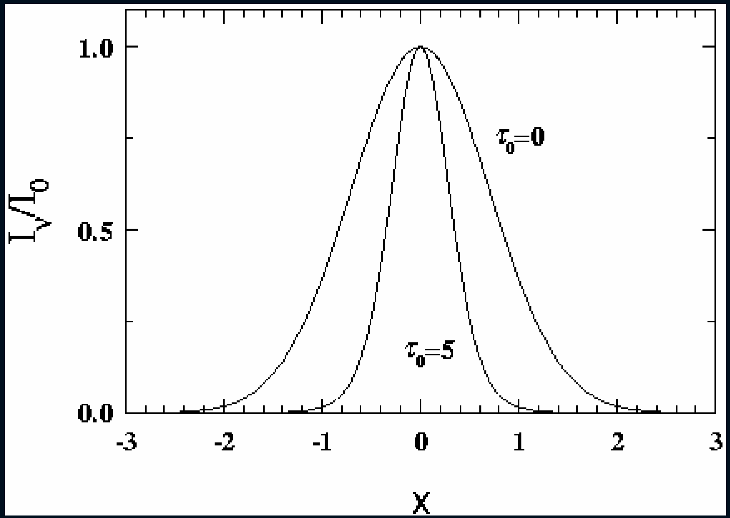
74 MHz VLA



ASCA Hard X-rays
*Koo et al. (2002)*

⇨ Previously undiscovered SNR in front of W51C responsible for masers

# Are OH (1720 MHz) SNR Masers Saturated?




Saturated

Stokes $I=I_{th}$ ⇨ $\Delta v$ = Doppler width

Stokes $V_{th}= b\, dI_{th}/dv$

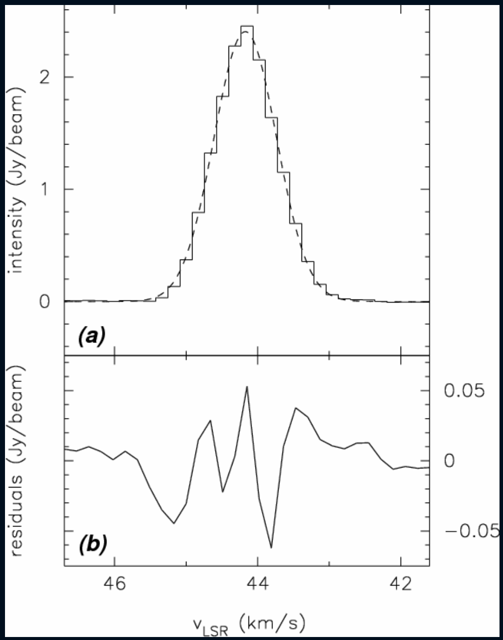
Unsaturated

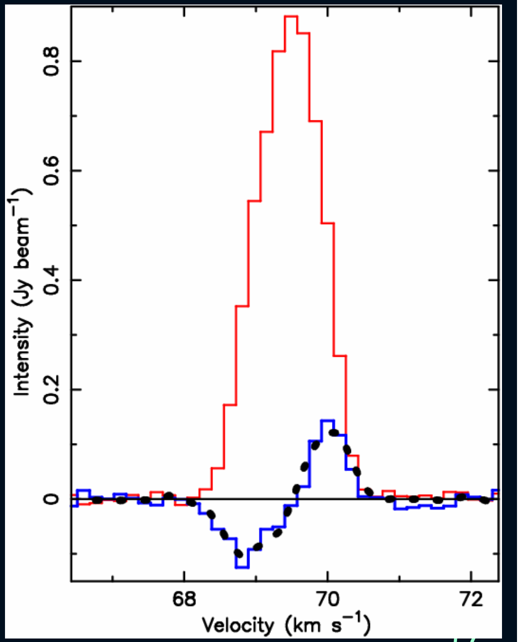
Stokes $I=I_{th}e^{\tau(v)}$ ⇨ $\Delta v$ << Doppler width

Stokes $V= V_{th}e^{\tau(v)} = (b\, dI_{th}/dv)\, e^{\tau(v)}$

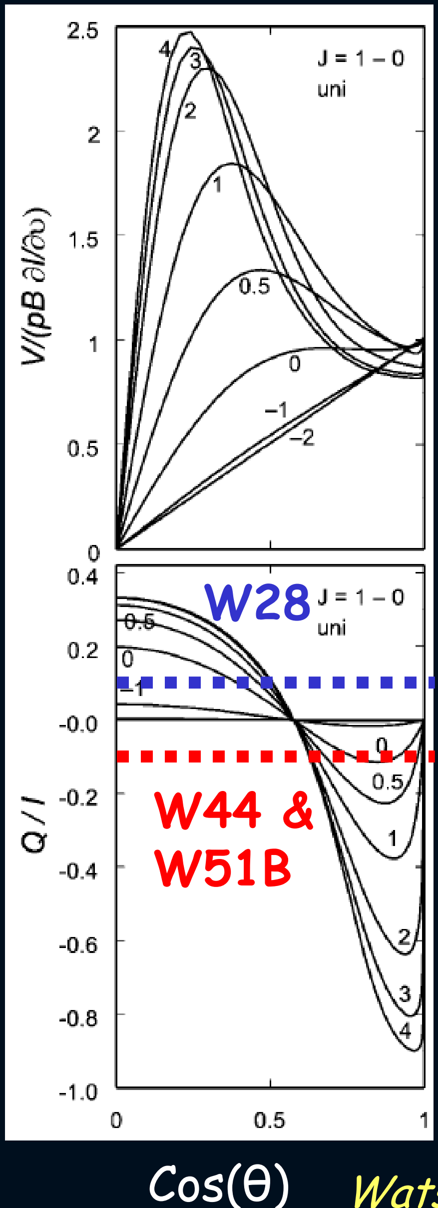
Most likely somewhat saturated

- Goodness of fit
- High Brightness temperatures
- Non-variability



# An Uncomfortable Coincidence?




$q = 1 - 2/(3\sin^2\theta)$

GKK for completely saturated case

For all SNR OH (1720 Mz) masers to date, $q$ = 2 – 20% implying θ ~ 60 degrees for ALL 3 sources

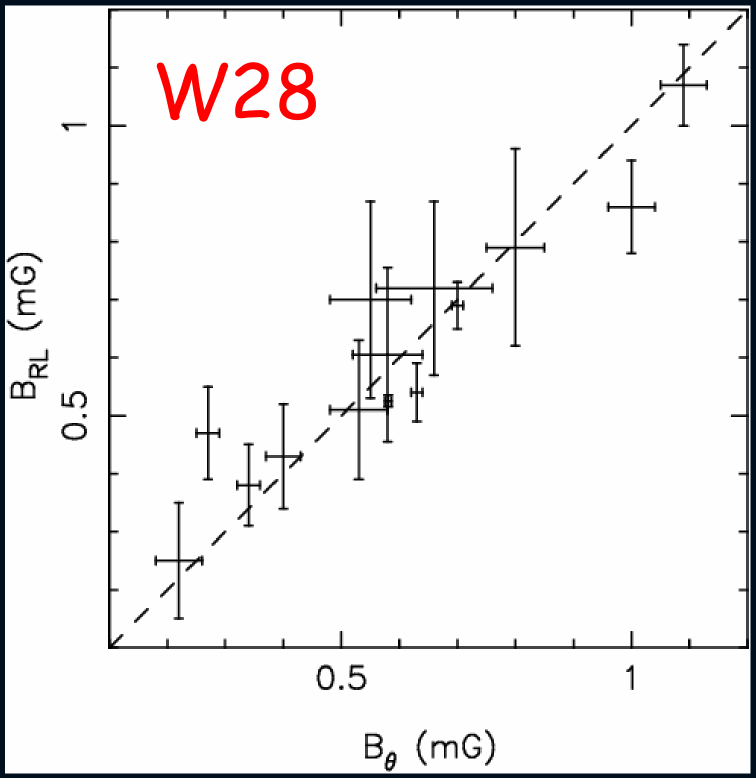
However, $P.A._{maser}$ ⊥ or || to field breaks degeneracy

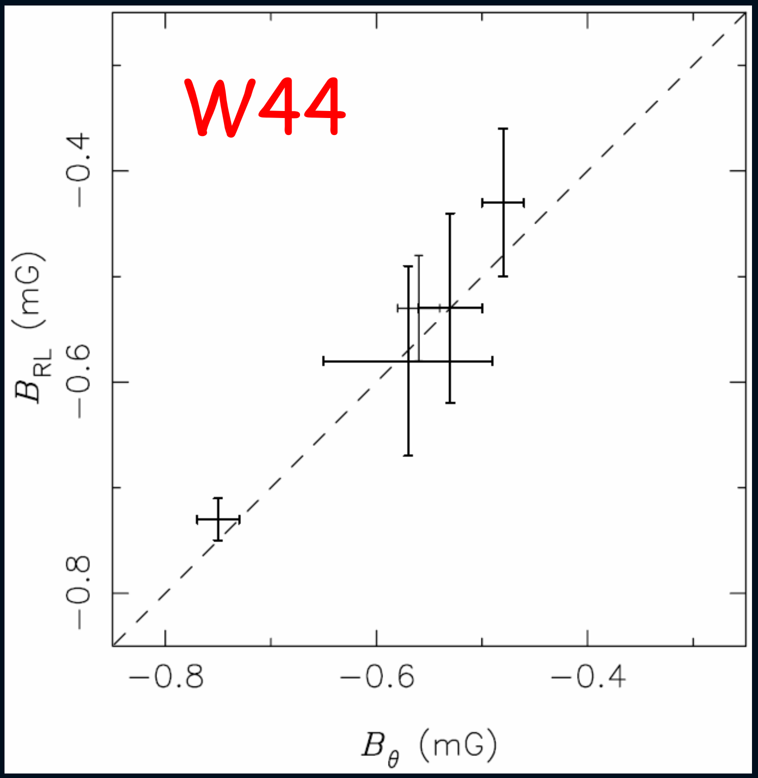
Q positive for ⊥ case and 10% ⇨ 60°

Q negative for || case and 10% ⇨ 40°

*Watson & Wylde (2001) and not inconsistent with Elitzur (1996, 1998)*

# An Interesting Correlation…




$$B_{RL} = (\nu_{RCP} - \nu_{LCP})/Z$$

$$B_\theta = V/(c\ Z\ dI/2d\nu)$$

# Conclusions

- What are the detailed properties of the polarization and can we distinguish between theoretical models?
  - Not quite there yet but it is encouraging
- How is the maser flux distributed on small size scales and what are the brightness temperatures?
  - Core-Halo structure with about ½ of flux missing at MERLIN/VLBA scales (see J. Hewitt talk)
  - Tb ~ $10^{9-10}$ K
- Does the B-field really increase with higher resolution ⇨ which might be indicative of more tangled B-fields on larger size scales?
  - No, this is purely a spatial/spectral blending issue, but maybe it does indicate something interesting about turbulence
- Are these masers saturated?
  - Yes, at least moderately so