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Magnetic fields of AGB and post-AGB stars

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Magnetic Fields during the birth and death of stars

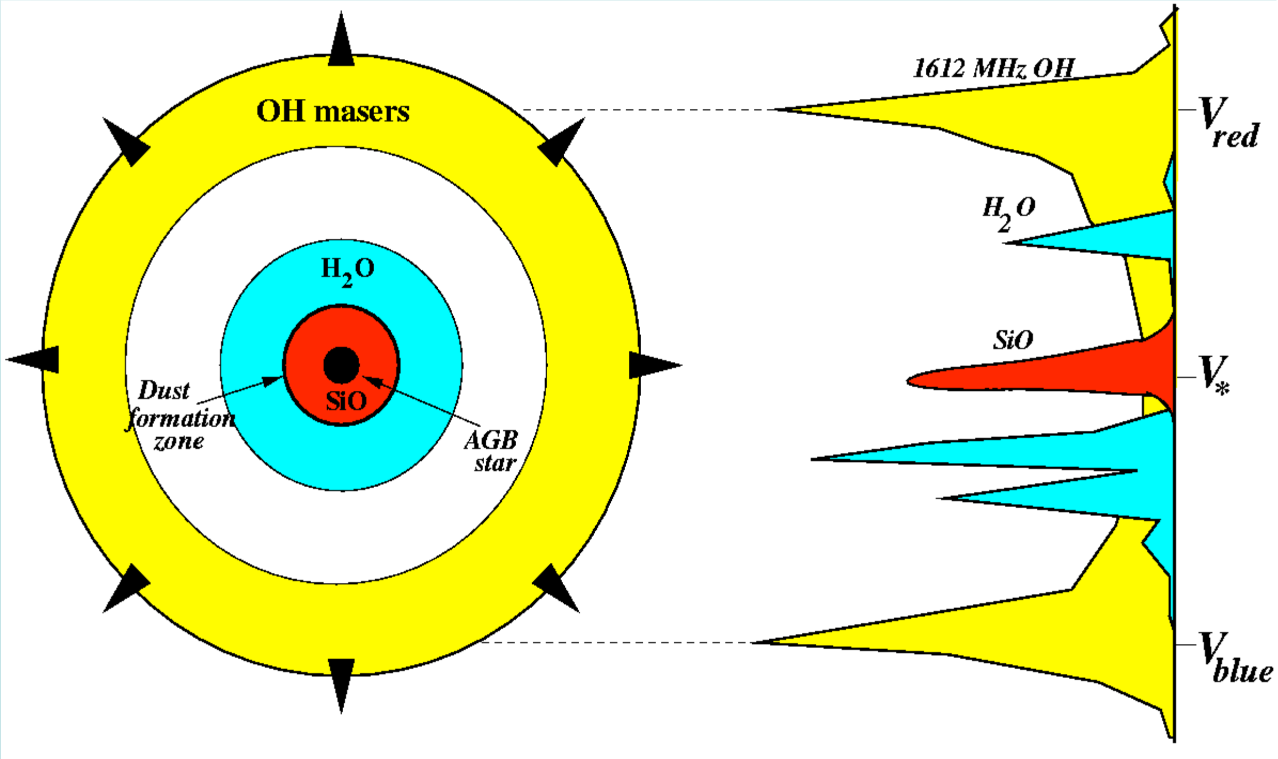
Deutsche Forschungsgemeinschaft DFG

Outline

- Magnetic fields in (post-)AGB envelopes
  - SiO, H_2O and OH maser polarization observations
  - Comparison of energy densities
- Implications and questions
  - Mass-loss - Magnetic field relation?
  - Origin of the measured fields
  - Further field tracers
    - dust & line polarization with ALMA
    - (polarized) radiative transfer (ARTIST)
- Summary
  - role for (new) interferometry instruments

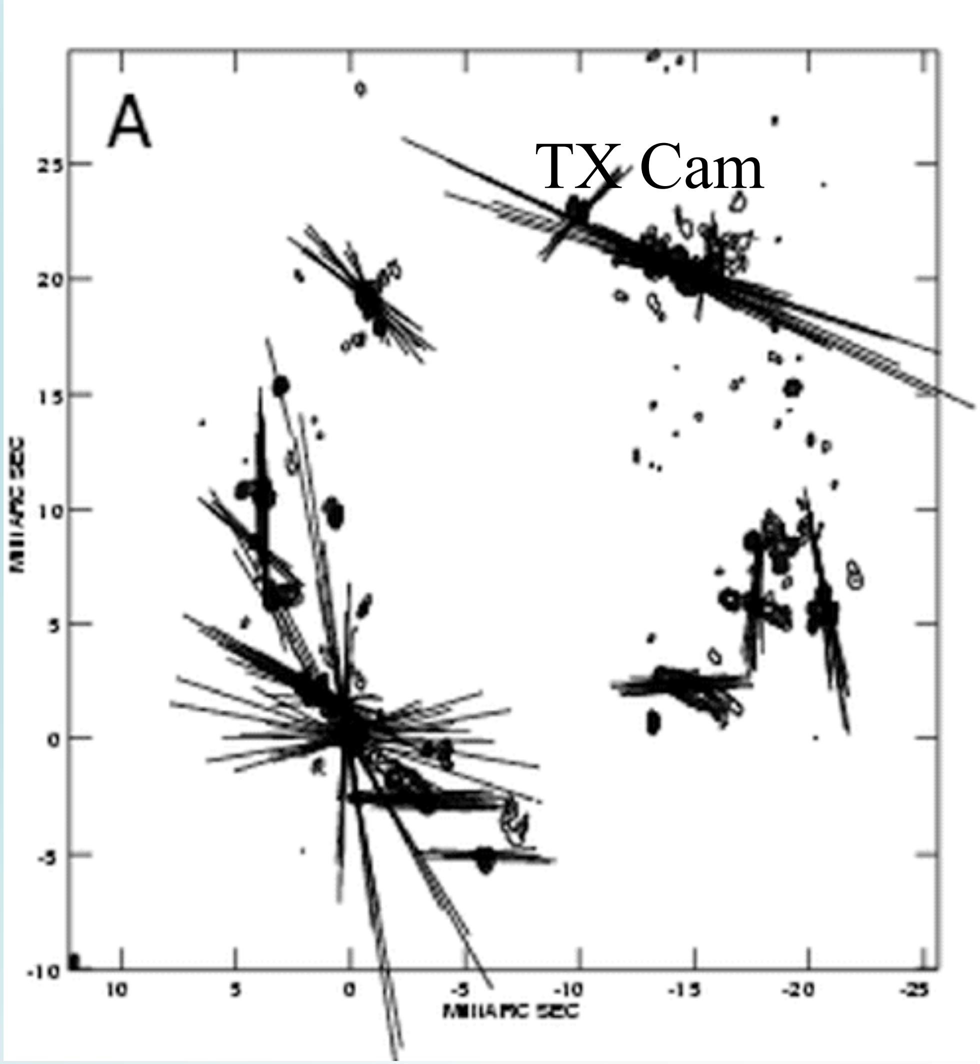
Circumstellar Masers

- “Onion model”
  - –Dust at few AU
  - –Molecules until dissociation by UV
- Excitation varies
  - –SiO at few AU
  - –H_2O up to few 100 AU
  - –OH at 500 – 10.000 AU
- As V_{exp} increases
  - –from tangential to radial amplification



CSE Fields: SiO Masers

- SiO Masers:
  - Highly ordered Magnetic Fields
  - Field Strengths (Zeeman):
    - Supergiants: up to 100 G
    - Miras: up to several 10s G
      - Average 3.5 G, single dish, lower limit due to blending (Herpin et al. 2006, A&A 450 667)
  - *But*: non-Zeeman interpretation:
    - Fields factor 1000 less (Nedoluha & Watson 1990, ApJ 361 L53)

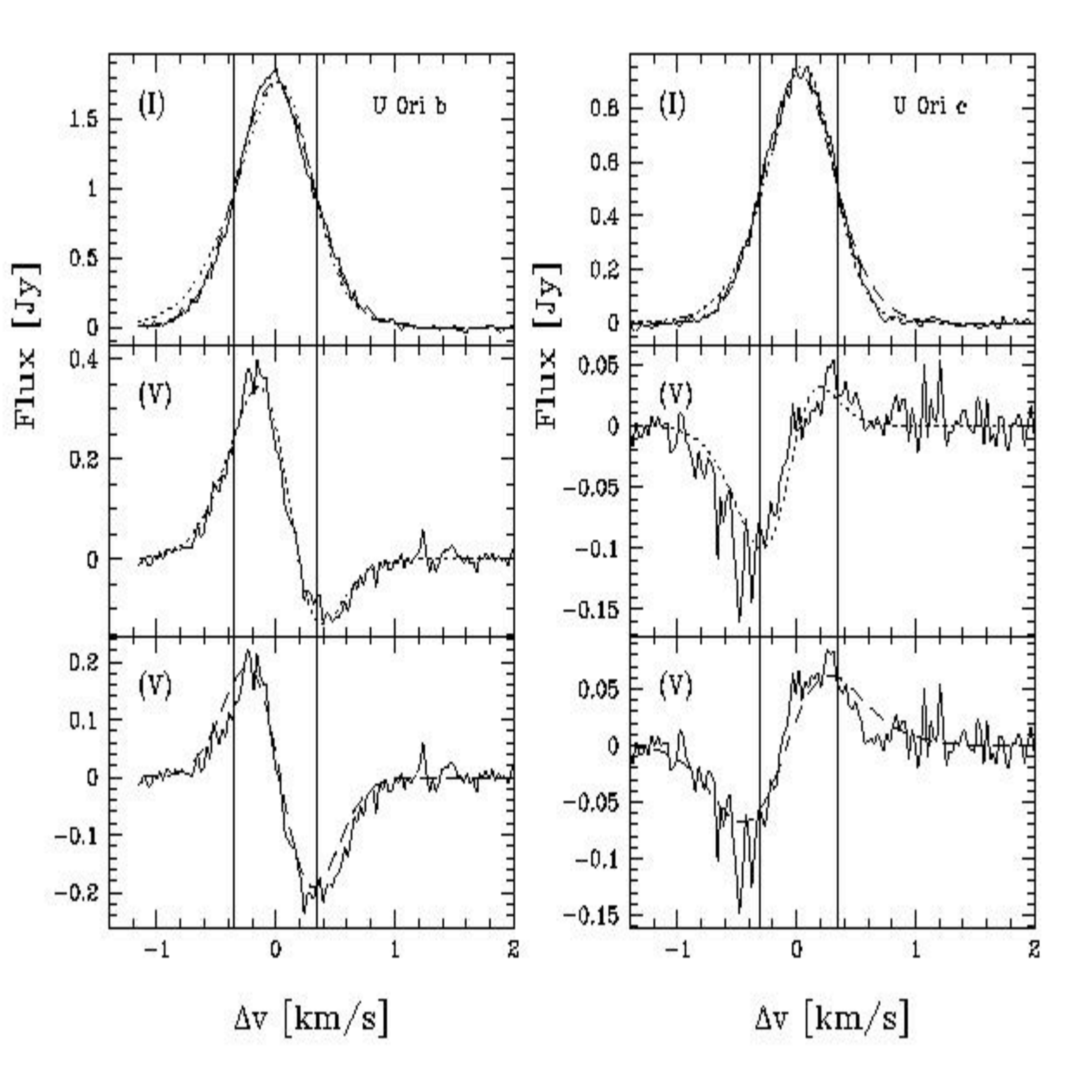


Kemball and Diamond, 1997, ApJ 481 L111

Kemball et al. 2009, arXiv/0904.262

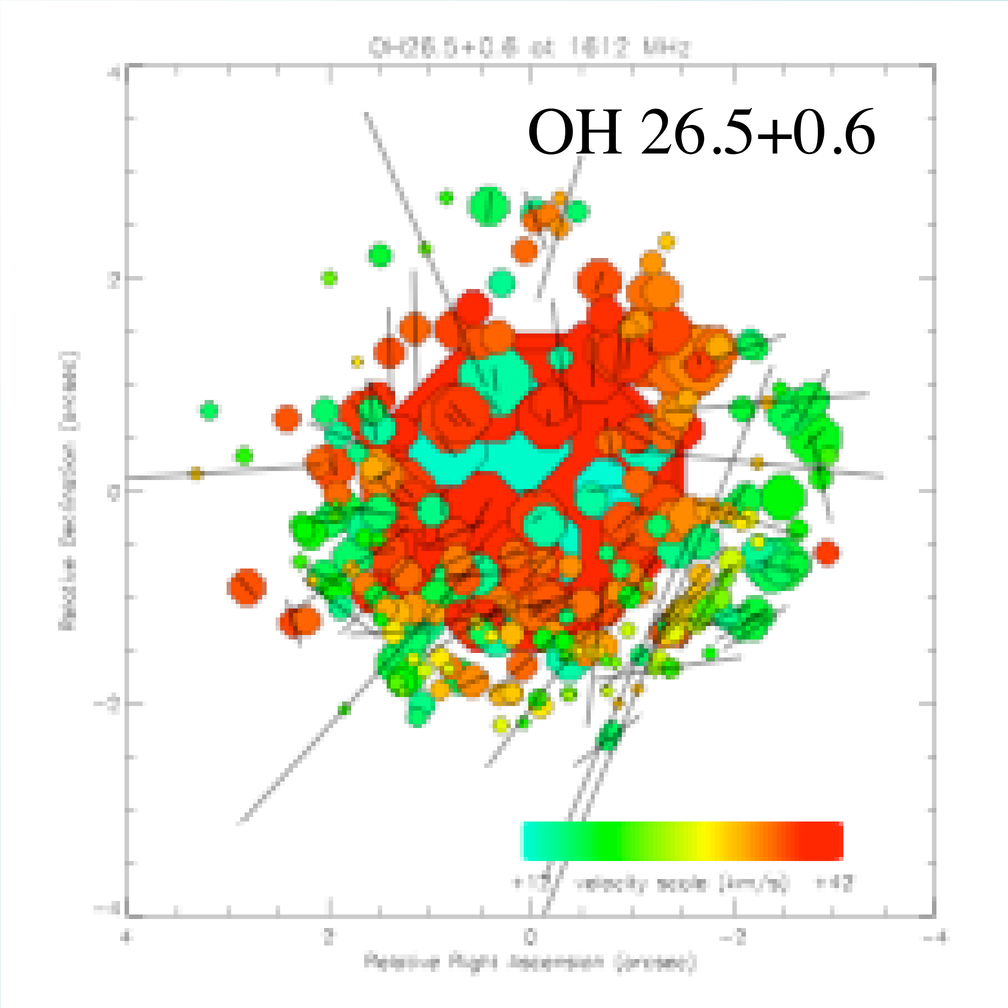
CSE fields: H_2O masers

- H_2O masers:
  - Field strengths (Zeeman, non-LTE):
    - 0.1-2 Gauss
  - No linear polarization
  - Indications for large scale structure
    - VX Sgr
  - Supports SiO Zeeman interpretation



(Vlemmings et al. 2001, 2002, 2005)

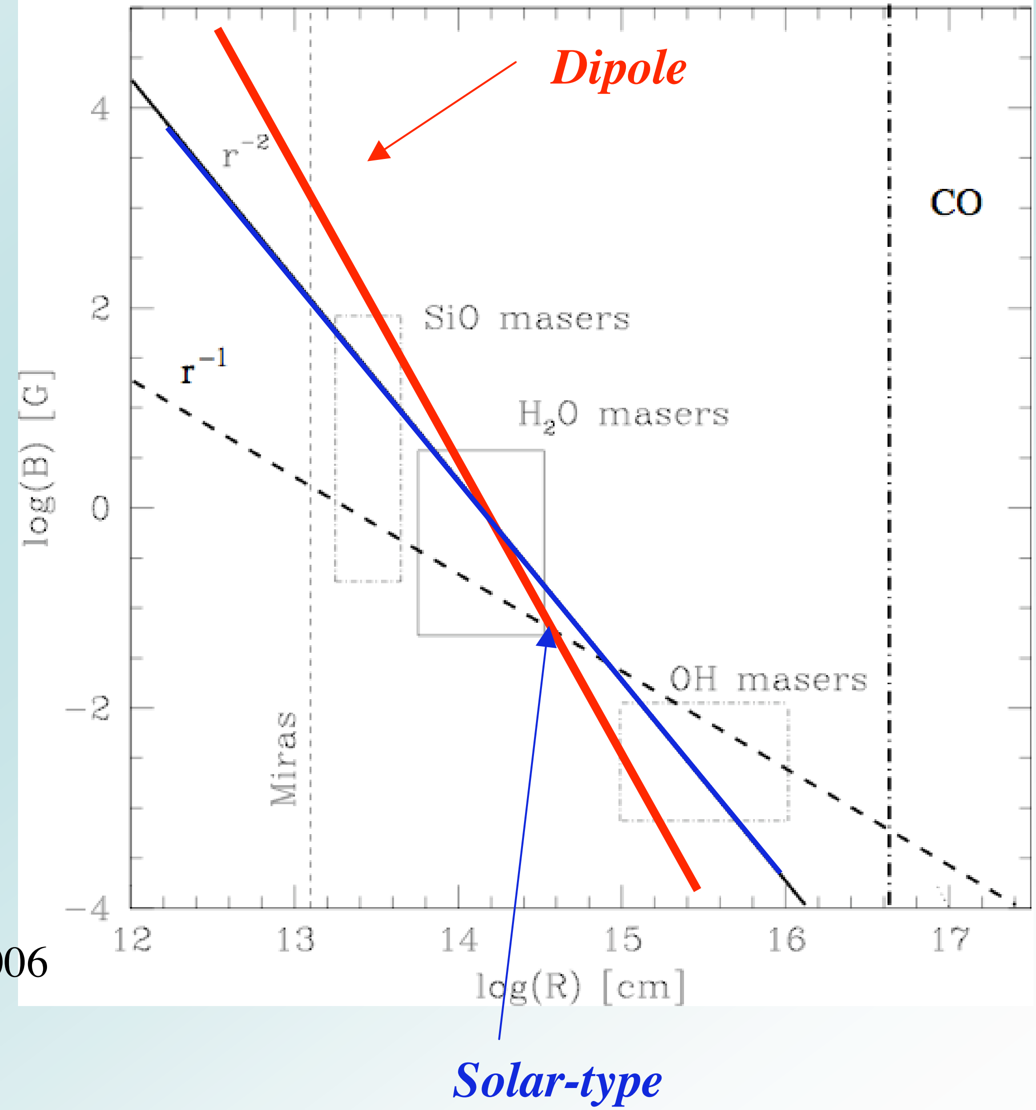
CSE fields: OH Masers



- OH Masers:
  - Indication of alignment with CSE structure
  - Supergiants and Miras $\Rightarrow$ few mG fields
  - Extrapolation to the star uncertain
- Polarimetric map of 1612 and 1665 MHz OH masers shows clear alignment with the CSE
  (Etoka & Diamond, EVN symposium)
  - 2-4 mG field strength

Evolved star CSE Magnetic Fields

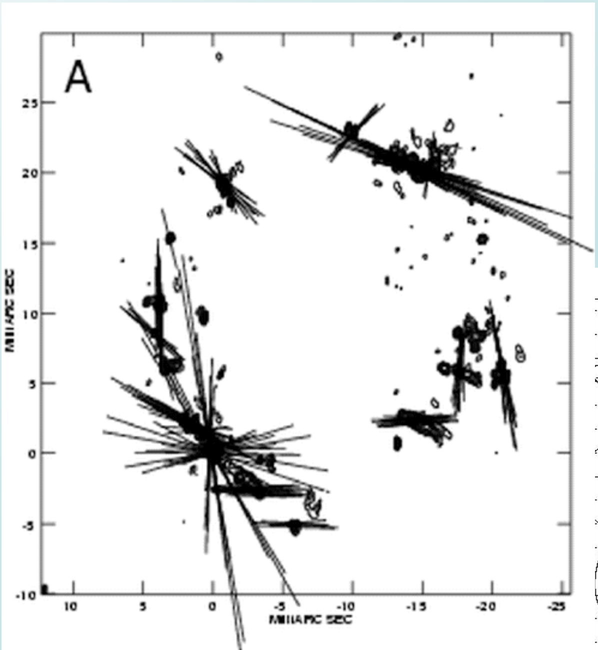
- SiO at ~2 stellar radii
  - B~3.5 G
    - up to tens of Gauss
  - Radial magnetic field
- H2O at ~50-500 AU
  - B~0.1-2 G
  - Supergiant VX Sgr shows dipole field
- OH at ~250-10.000 AU
  - B~1-10 mG
  - Alignment with circumstellar envelope



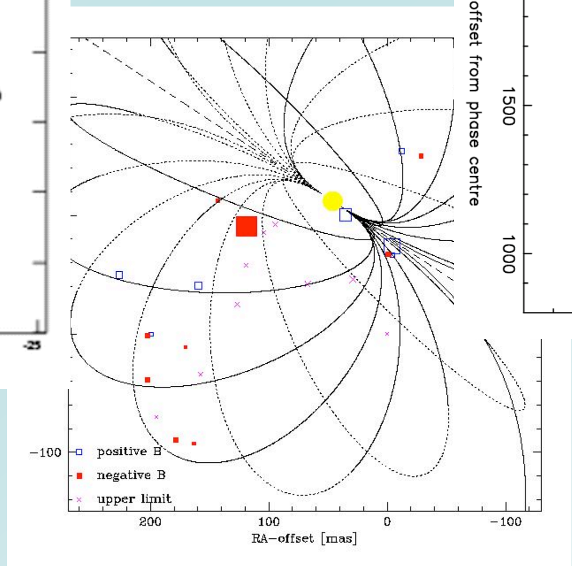
Kemball et al. 1997, 2009; Herpin et al. 2006
Vlemmings et al. 2002, 2005
Etoka et al. 2004, Reid et al. 1976

Large vs. Small scale fields

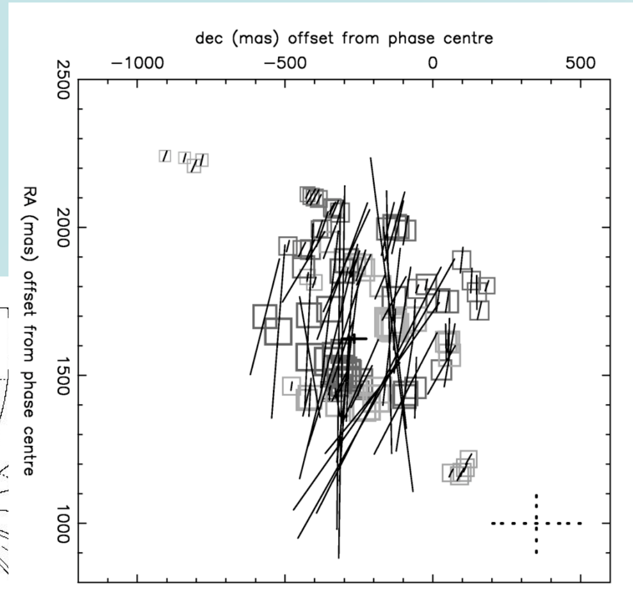
- Are we measuring isolated pockets of compressed field lines, or a large scale field?
  - polarization structure consistent through the CSE, but sample is still small.

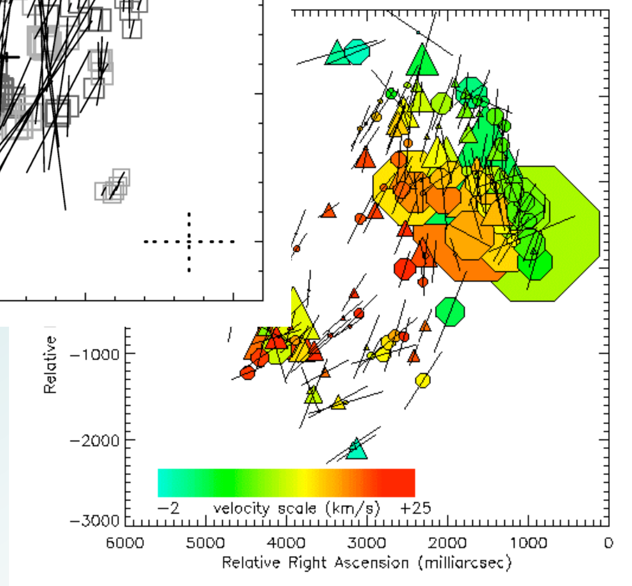


SiO



H_2O





OH

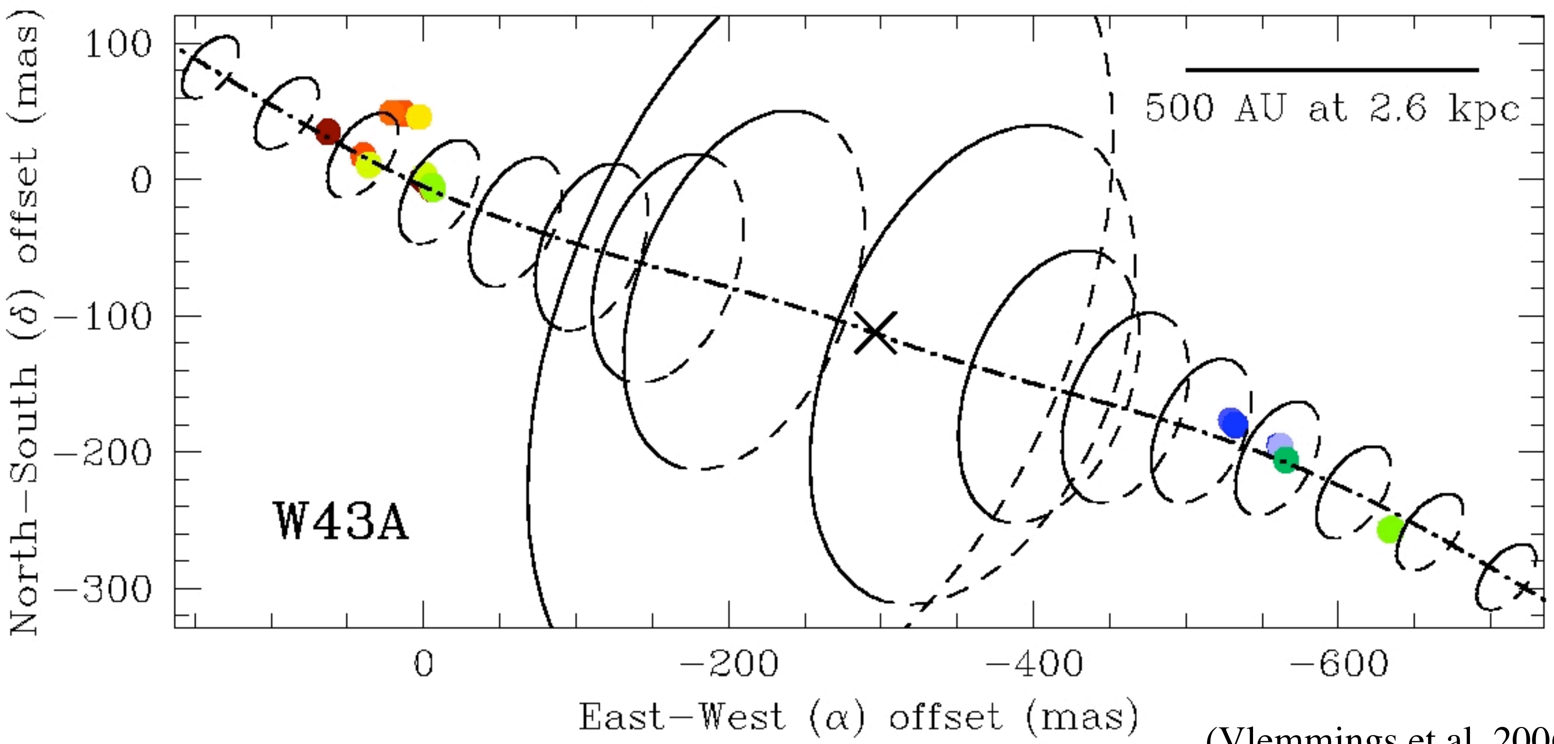
Pressures throughout the CSE

Maser	V_{exp} [km/s]	B [G]	n [cm^{-3}]	T [K]	$B^2/8\pi$ [dyne/cm²]	nkT [dyne/cm²]	ρV^2_{exp} [dyne/cm²]
OH	~10	~0.003	~10^6	~300	$10^{-6.4}$	$10^{-7.4}$	**$10^{-5.9}$**
H_2O	~8	~0.3	~10^8	~500	**$10^{-2.4}$**	$10^{-5.2}$	$10^{-4.1}$
SiO	~5	~3.5	~10^{10}	~1300	**$10^{+0.1}$**	$10^{-2.7}$	$10^{-2.5}$
photo-sphere	~15	?	~10^{14}	~2500	?	$10^{+1.5}$	$10^{+2.4}$

from Reid 2007

Beyond the AGB-phase: W43A

- Toroidal, collimating magnetic field: Bφ = 200 mG
- Enhanced in the H_2O masers
  - Around the jet B = 100 μG from OH masers (see Talk by Amiri)
  - GBT confirmed strength and reversal.
  - Extrapolated (Bφ ∝ r-1) indicates a surface magnetic field of B~2 G.



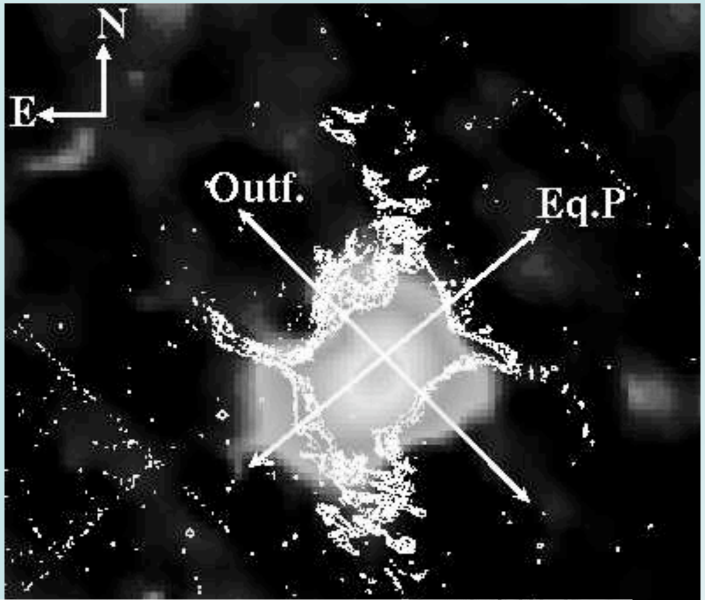
(Vlemmings et al. 2006, Nature 440, 58)

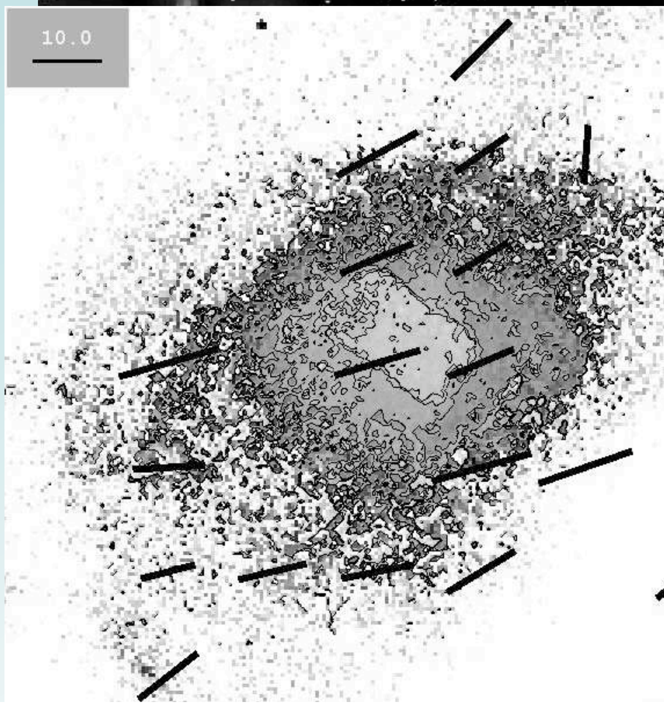
PNe Dust Polarization

- Submm dust polarization observations of PNe support magnetic shaping
  - asymmetric dust grain distribution aligned with magnetic field
  - primarily toroidal magnetic fields
  - At distances of several 10^{16} cm typical field strengths ~1 mG
    - Timescale for dust alignment $t \propto B^{-2}$, for 1 mG fields is ~10^6 yr
    - However, nebula timescale is ~10^4 yr
      - Alignment occurs closer to the star and is maintained in the outflow

⇒ magnetic shaping of the outflow

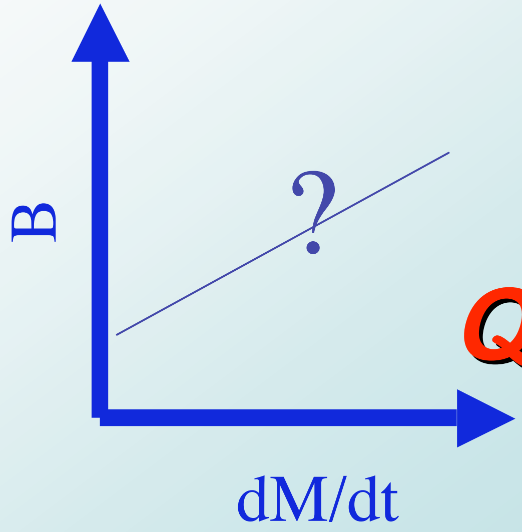
NGC 6537





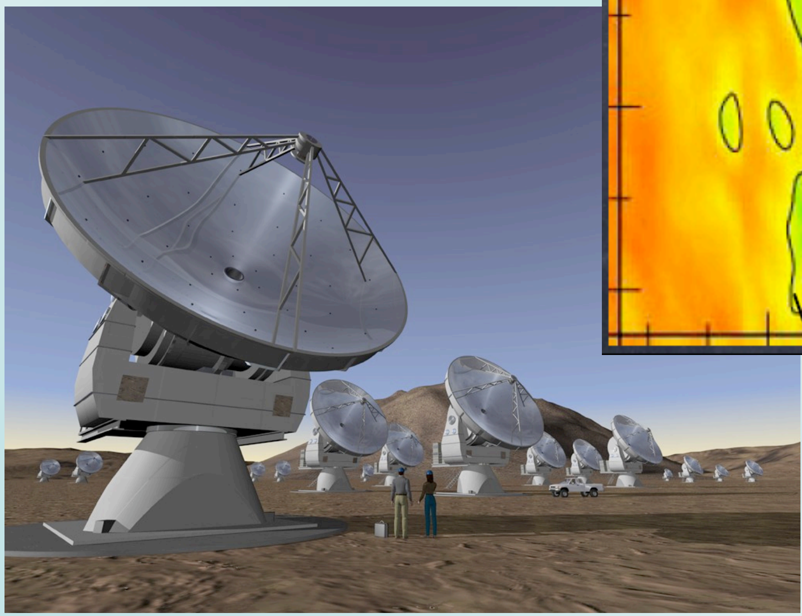
850 µm SCUBA polarization

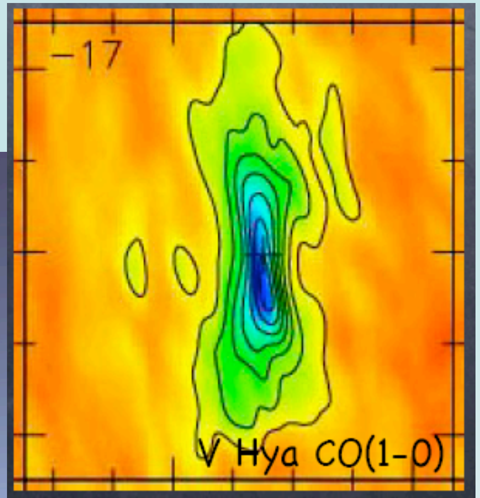
(Sabin et al. 2007, Greaves 2002)

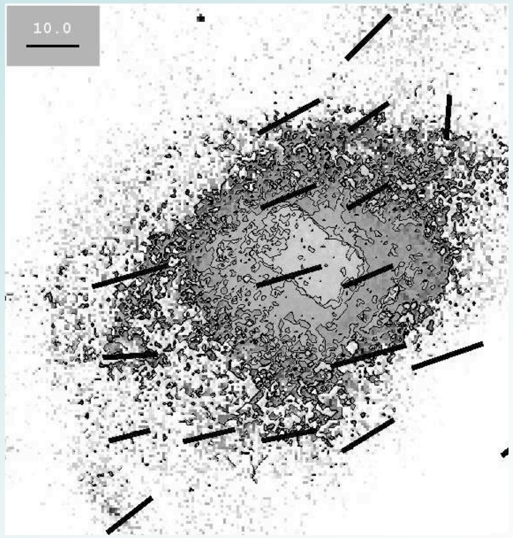


Effect on mass-loss?

Questions needing answers





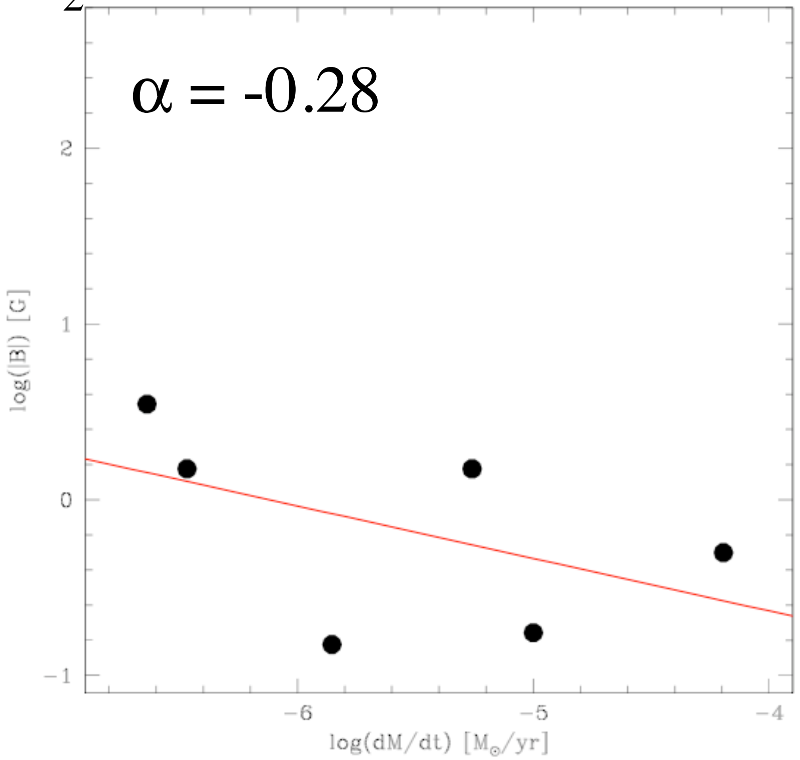


Mass-loss vs. Magnetic Field

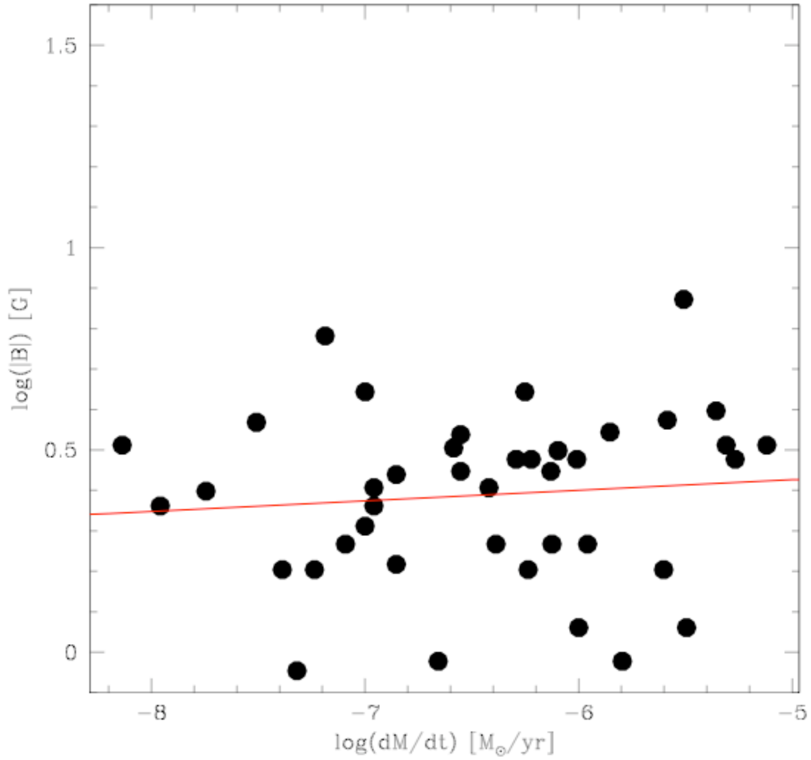
- Does magnetic pressure contribute to AGB mass-loss
  - recent 3D radiation pressure models not sufficient (e.g. Woitke 2006)
  - Alternatives e.g. different grain composition (talks Höfner/Ramstedt)
- Measuring direct relation difficult due to different maser distances and unknown CSE ⇒ star extrapolation
  - current observations indicate changing slope from $B \propto R^{-1.2}$ (close to star) to $B \propto R^{-(2\text{-}3)}$ (after few AU)
  - not unreasonable considering predictions

Mass-loss vs. Magnetic field (II)

H_2O masers



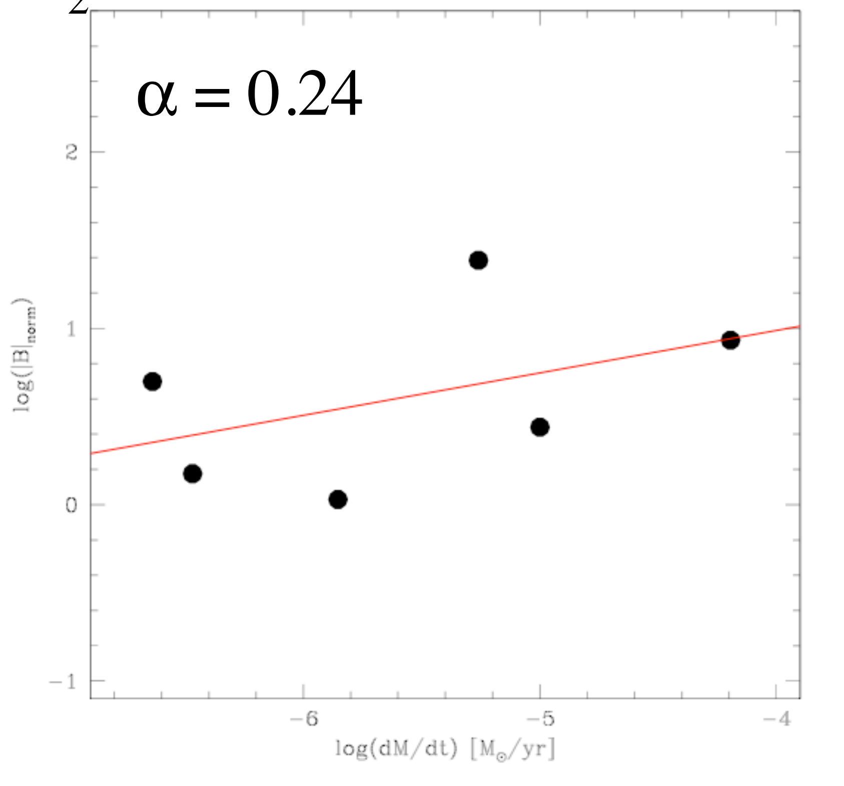
SiO masers



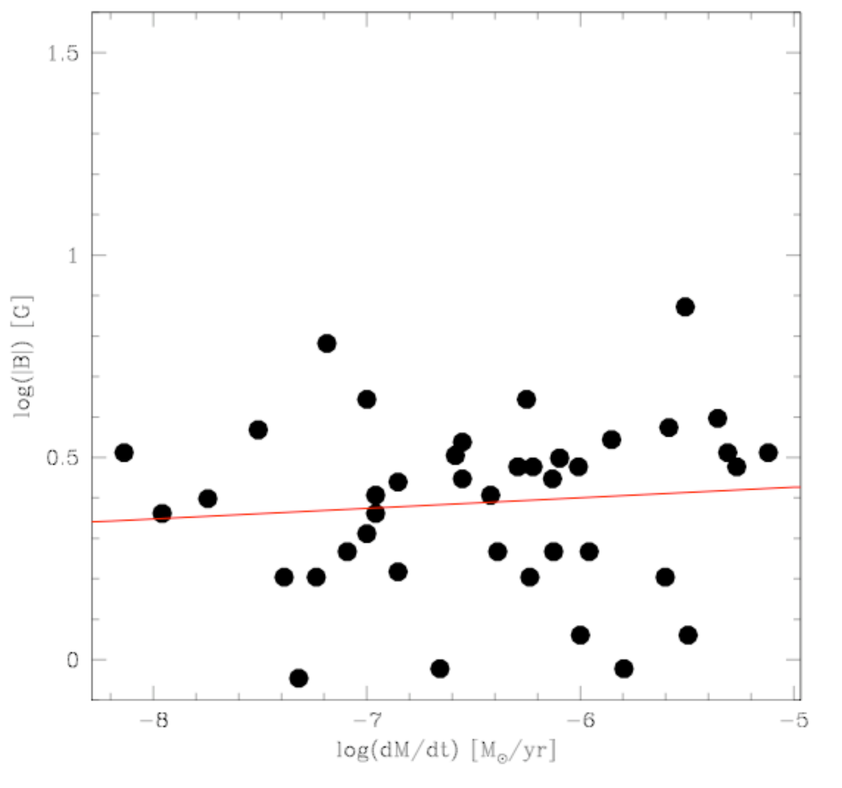
- Hypothesis:
  - $(dM/dt) \propto B_0^{\beta}$; $B(H_2O) \propto R(H_2O)^{-x}$
  - H_2O masers (unknown radius): $R(H_2O) \propto (dM/dt)^{0.52}$ (Cooke & Elitzur 1985)
    - $\Rightarrow B_{H2O} \propto B_0 (dM/dt)^{-0.52x} \Rightarrow B_{H2O} \propto (dM/dt)^{-0.52x+1/\beta}$
    - $\alpha=-0.28=-0.52x+1/\beta \Rightarrow \beta=1/(0.52x-0.28)$ **$\Rightarrow \beta \sim 1\text{-}4$**

Mass-loss vs. Magnetic field (II)

H$_2$O masers

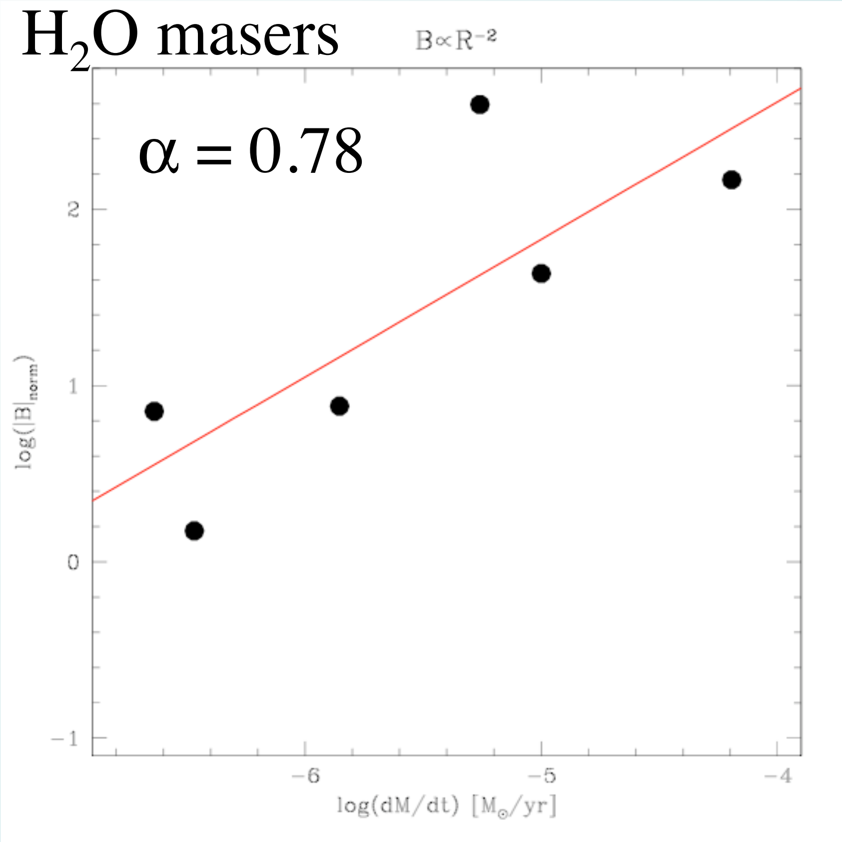


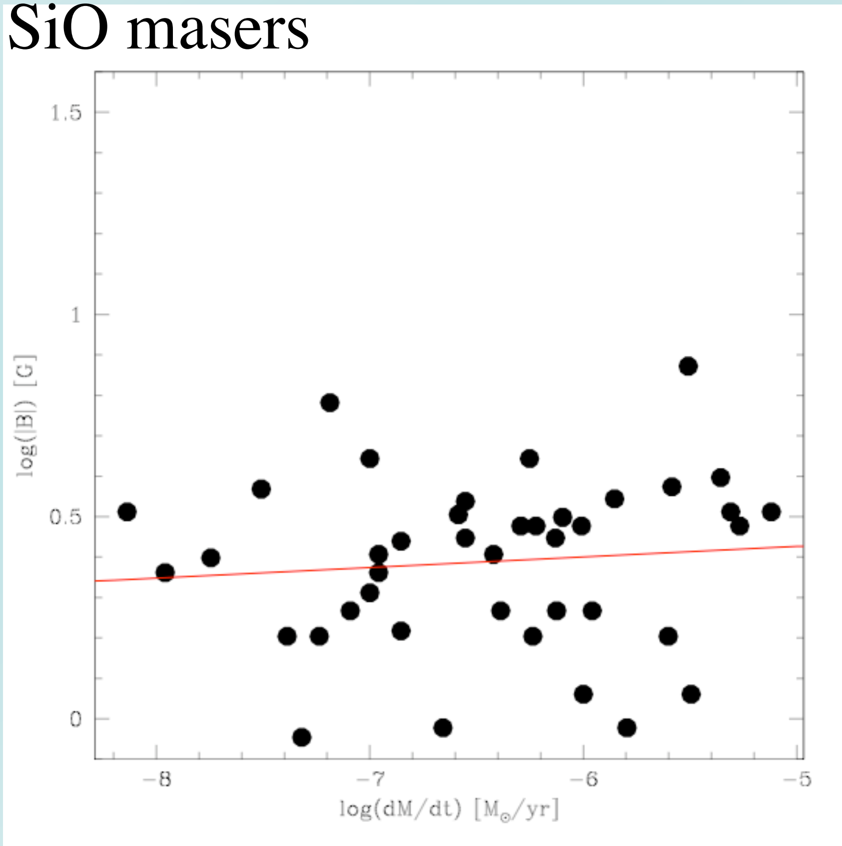
SiO masers



- Hypothesis:
  - $(dM/dt) \propto B_0^{\beta}$; $B(H_2O) \propto R(H_2O)^{-x}$
  - H_2O masers at known radius!!:
    - Taking $B \propto R^{-1}$
    - $\alpha = 1/\beta = 0.24 \Rightarrow$ **$\beta \sim 4$**

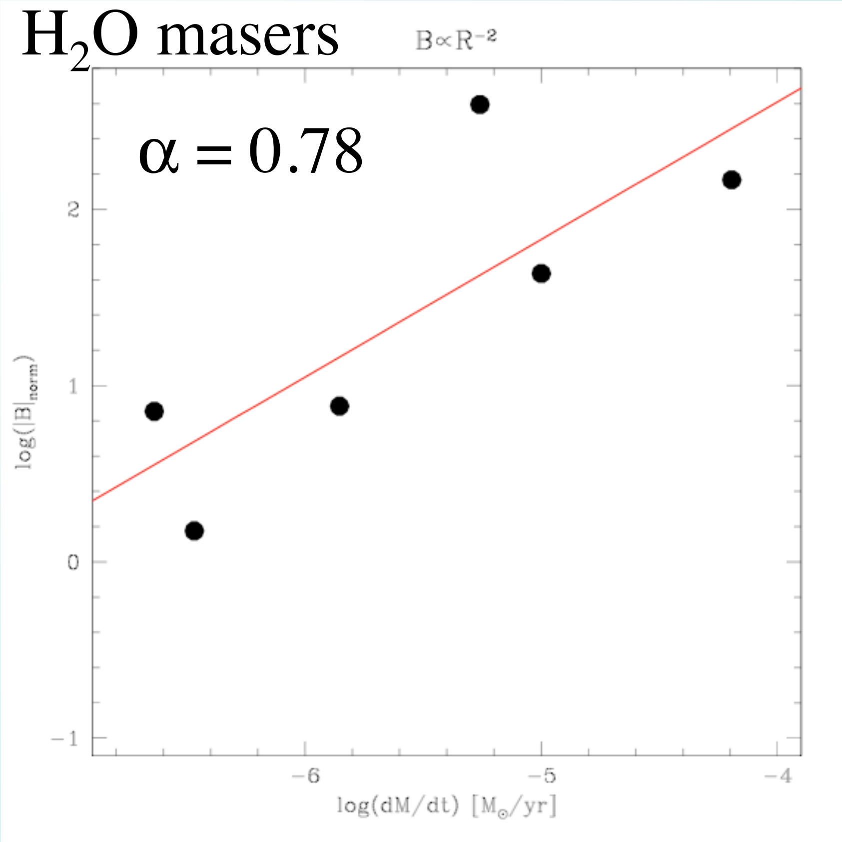
Mass-loss vs. Magnetic field (II)

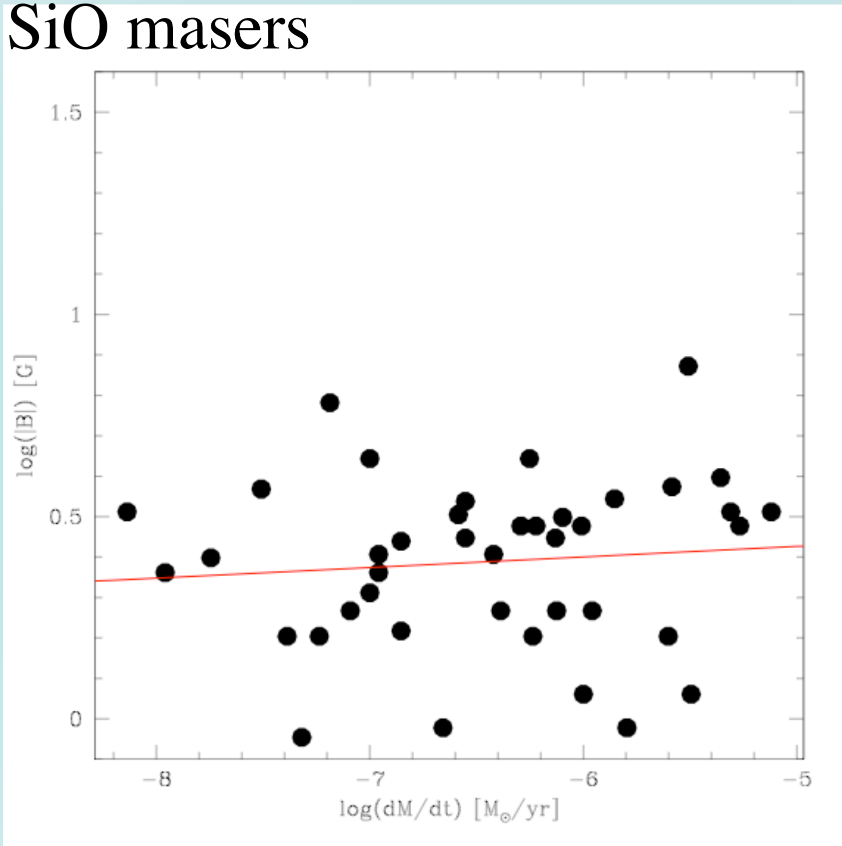




- Hypothesis:
  - $(dM/dt) \propto B_0^{\beta}$; $B(H_2O) \propto R(H_2O)^{-x}$
  - H_2O masers at known radius!!:
    - Taking $B \propto R^{-2}$
    - $\alpha = 1/\beta = 0.78 \Rightarrow \beta \sim 1.3$

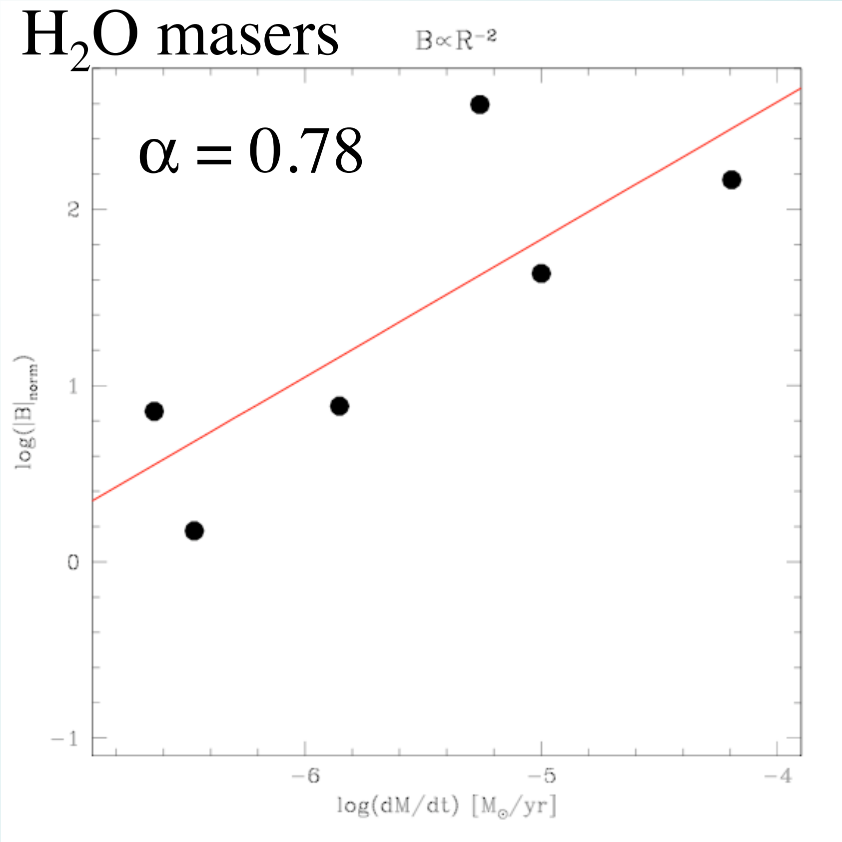
Mass-loss vs. Magnetic field (II)

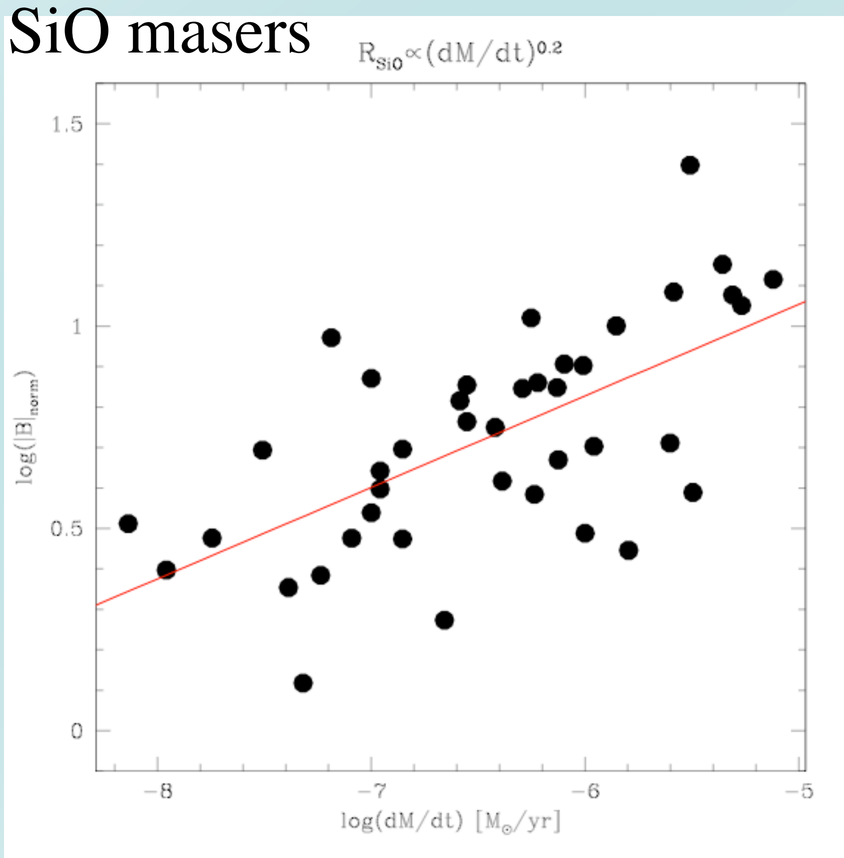




- Hypothesis:
  - (dM/dt) ∝ B_0^{β}; B(SiO) ∝R(SiO)$^{-x}$
  - SiO masers at unknown radius!!
    - No relation known between dM/dt and SiO maser radius
    - Observations cannot determine mass-loss vs. B relation

Mass-loss vs. Magnetic field (II)





- Hypothesis:
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Origin of the Magnetic Field

- Observations only show local magnetic fields ?
  - *Unable to explain large scale structure in SiO, H_2O, OH maser observations and dust alignment (but what about AGB X-rays ?)*
- Internal dynamo between stellar envelope and fast rotating core ?
  - *Extra source of rotation needed to counteract energy loss due to field drag*
- Interaction with circumstellar disk ?
  - *But what is the origin of the disk ?*
- Spin-up due to binary or heavy planet ?
  - *Possible source of the W43A jet precession though large sample of magnetic stars show no indication of companion (yet)*
- ***Look for sources of collimation/magnetic fields and the effect of fields close to the star***
  - ALMA/SMA will image dust continuum and polarization as well as other high density tracers
  - Infrared/mm interferometers studies (many examples during this meeting)

ALMA Dust/Line polarization

- Polarization will be a by-product of most ALMA observations
- Potentially detect polarization of circumstellar dust and polarization of lines emission such as CO, CN, HCN and SiO.
- Adaptable Radiative Transfer Innovations for Submm Telescopes (ARTIST)
  - Joergensen, Vlemmings (Bonn), Girart (Barcelona), Hogerheijde (Leiden)
  - 3D (polarization) radiative transfer
  - main driver star-formation, adaptable to evolved stars
  - Need: model library or direct input from e.g. MHD simulations

ARTIST

Summary / Questions

- Dynamically important large scale magnetic fields occur in the envelopes of evolved stars
    - SiO, H_2O and OH maser observations consistent with solar-type or dipole magnetic field
- The observations of W43A are the first ever direct measurements of an astrophysical magnetically collimated jet
- The strong magnetic fields could be the missing component needed to explain AGB mass-loss
    - Alfvén waves can help drive mass-loss
- *Questions:*
    - How widespread are AGB magnetic fields ?
    - What is the origin of the magnetic field ?
        - Single star dynamo, binary, heavy planet, disk interaction
    - Are magnetically collimated jets common features of the proto-planetary water fountain sources ?
        - Are they the explanation for asymmetric (bi-polar) PNe ?

Summary / Questions

Next generation of interferometers!!

- ***Polarization observations of a large sample of AGB stars and PNe***
    - Look for correlations with stellar parameters (mass-loss etc.)
    - SKA at 22 GHz will be able to map B-fields
    - ALMA will do high-frequency lines and dust
- ***eMERLIN observations of stellar photosphere***
    - High resolution can further reveal asymmetries in nearby stars
    - Will accurately tie maser observations to star to study outflow dynamics
        - maser distances needed for B-field vs. Distance relation
- ***Look for sources of collimation / magnetic fields***
    - ALMA will image dust continuum and polarization as well as other high density tracers
    - VLTI will reveal disks and other asymmetries