Magnetic Fields Around Evolved Stars

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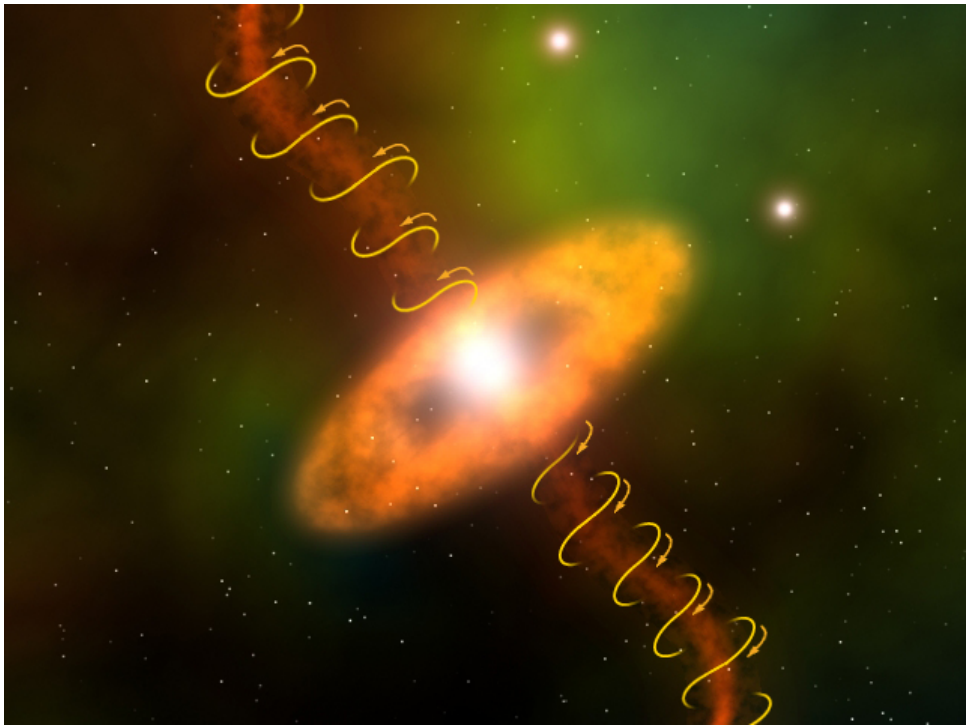

(Artistic impression of W43A; credit: NRAO/AUI/NSF)

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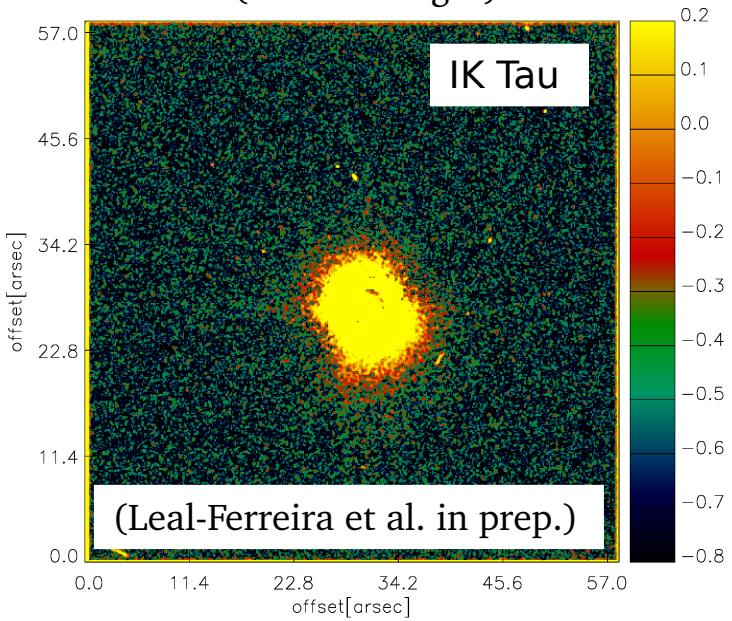
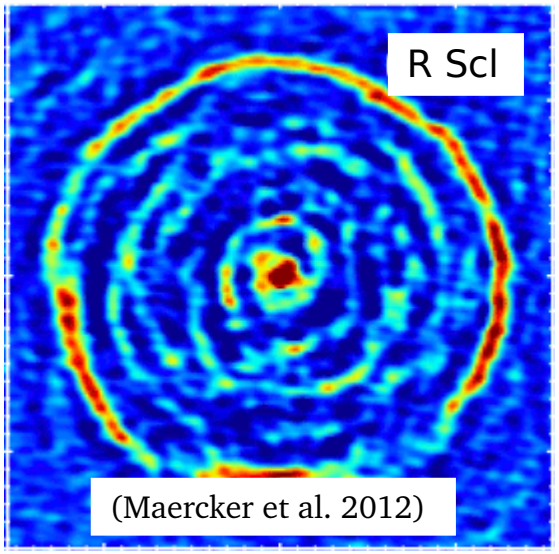
DAAD

Introduction

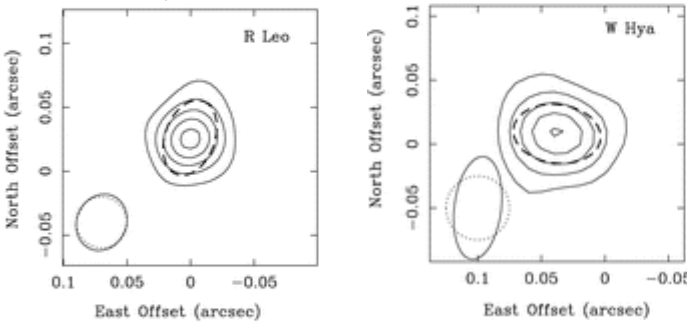
R Filter (Polarized light)



Radio; 345 GHz CO J=3-2



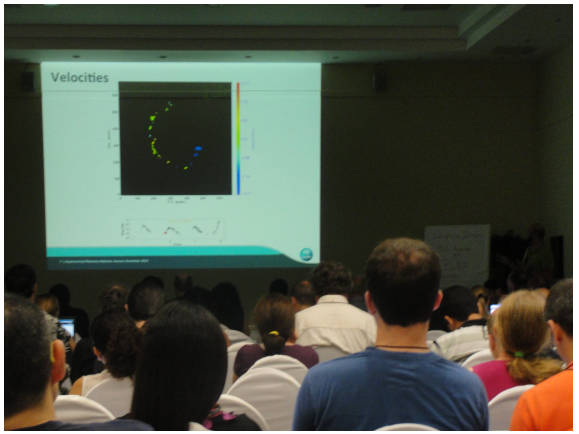
Radio; 43 GHz continuum



(Reid & Menten 2007)

Talk from Claudia Paladini

Talk from Ioannis Gonidakis



Talk from Foteini “Claire” Lykou

Introduction

- SHAPING MECHANISMS:
  - MAGNETIC FIELDS
  - BINARITY OF THE CENTRAL STAR
  - JETS AND ACCRETION DISKS
  - CENTRAL WAISTS/TORII/DISKS
  - WHAT ELSE? ⇨ . Interaction with ISM
    . Interacting winds
    . Fast AGB envelope rotation

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  - WHAT ELSE?

Highly discussed during APN IV!

(http://www.iac.es/proyecto/apn4/pages/conference-photo.php)

Football:
Binaries x Single Stars

(credit: Christophe Morissete)

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Football:
Binaries x Single Stars

(credit: Christophe Morissete)

Closing speech:
"We need to find those binaries!!"

(Noam Soker)

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How significant is each mechanism?

Introduction

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"We need to find those magnetic fields!!"

MHD simulations support that the fields can play a significant role on the shaping process!
(e.g. García-Segura et al. 1999, 2005; García-Díaz et al. 2008; Dennis et al. 2009; Pascoli & Lahoche 2010)

Introduction

Magnetic Fields are indeed being detected
around AGB & post-AGB stars!

. Wolak et al. 2012
. Vlemmings et al. 2012
. Pérez-Sánchez et al. 2011
. Amiri et al. 2011
...

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Polarization detection in
75% of 117 sources (AGBs and
post-AGBs)

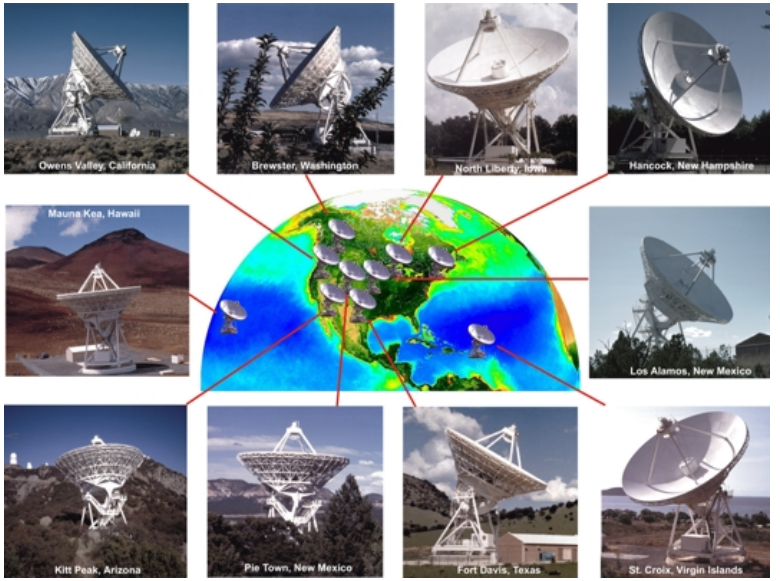
But we still need to measure the properties of the fields.
And at different distances to the (central) star.

Observations

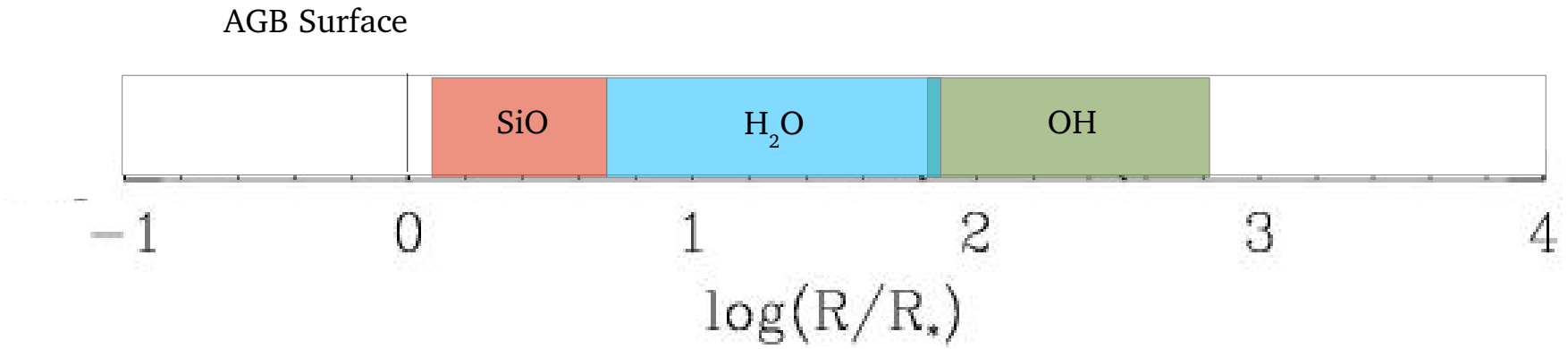
. Five evolved stars:
OH231.8 (pPN),
IK Tau, IRC60370, AP Lyn (Miras),
RT Vir (semi-regular variable)

. VLBA, in Feb/Mar 2009

. H_2O masers at 22.235 GHz:
Rotational transition $6_{1,6} - 5_{2,3}$

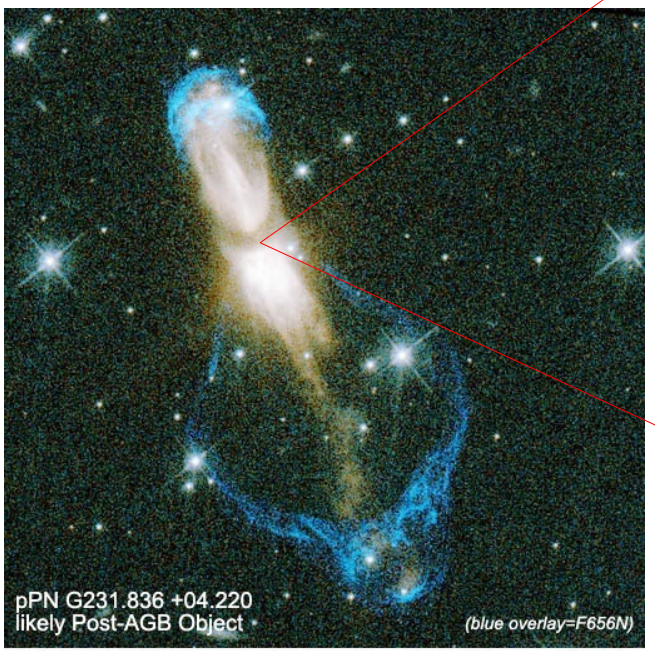


(Credit: NRAO/AUI/NSF)

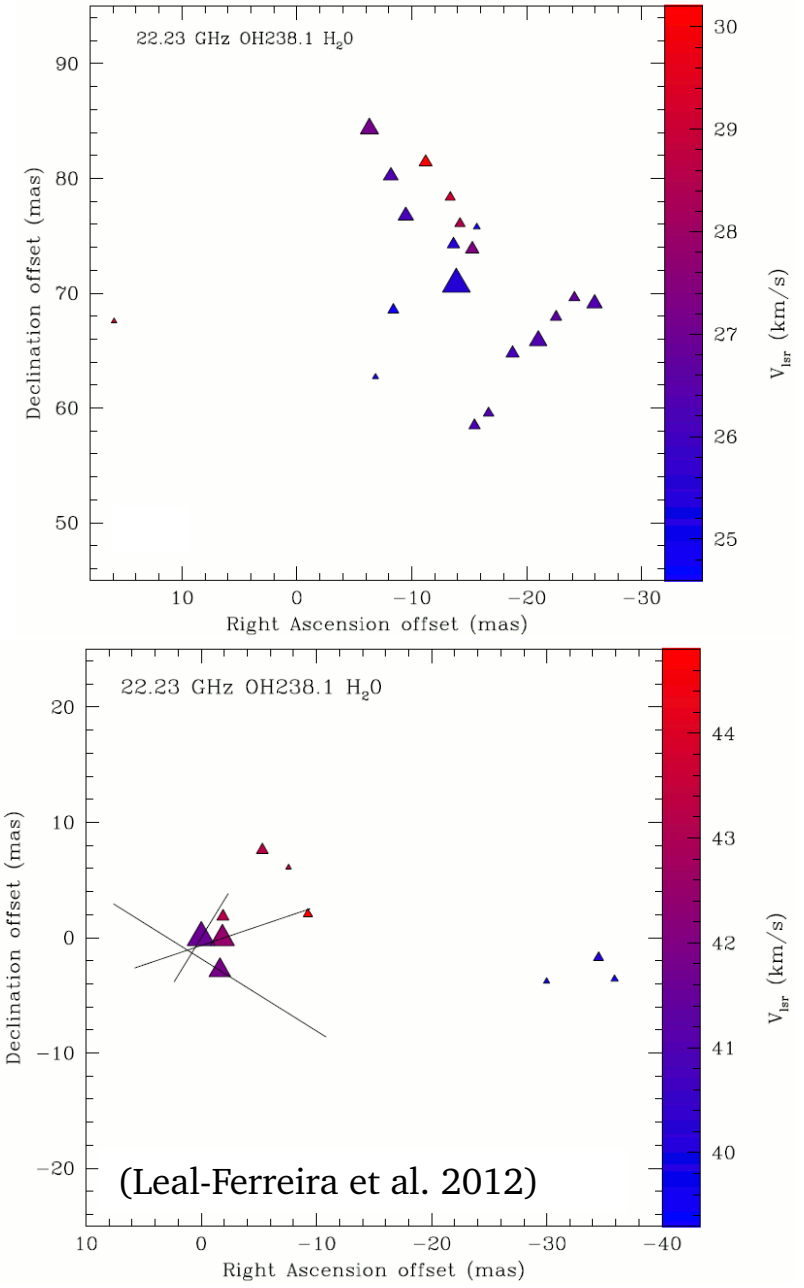


Results: OH231.8

. Detection of 30 maser features (~40 AU from the stellar pair)
. Detection of linear polarization in 3 features



IRAS 07399-1435 [OH231.8+04.2, Rotten Egg, GLMP191] (4/2008)
07 42 16.83 -14 42 52.1 (2000), FOV=64.0", R:G:B = F814W:comb:F555W
WFPC2/WF3, credit PI:BUJARRABAL GO8326 NASA/ESA/STScI, Hubble Archives



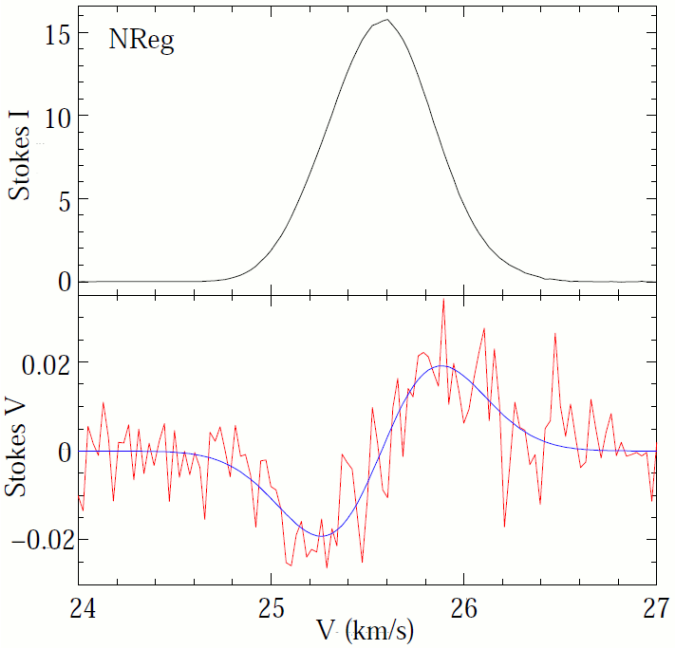
Results: OH231.8

. Detection of 30 maser features
. Detection of linear polarization in 3 features
. Detection of circular polarization in 2 features.

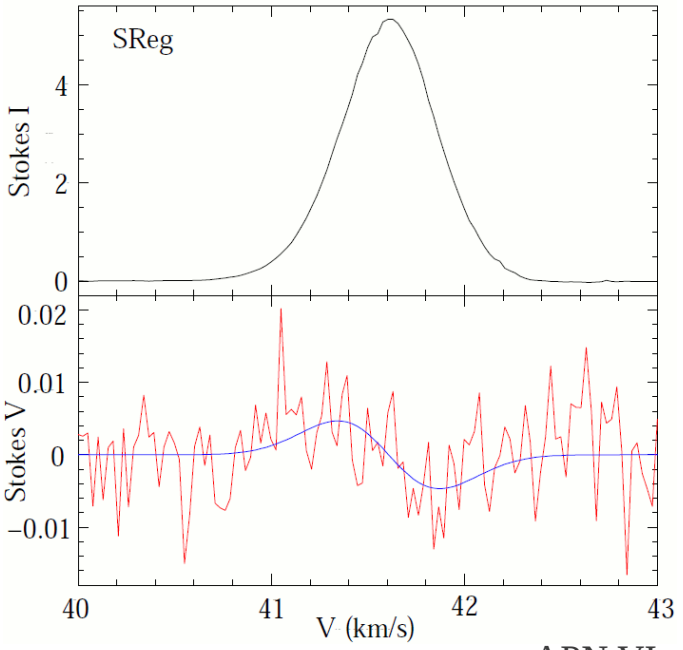
→ $B_{||}$ (NReg): 73 ± 11 mG

→ $B_{||}$ (SReg): -47 ± 34 mG

. Adopting $B \propto r^{-1}$ (toroidal field): $B_{star} = \sim 2.5$ G



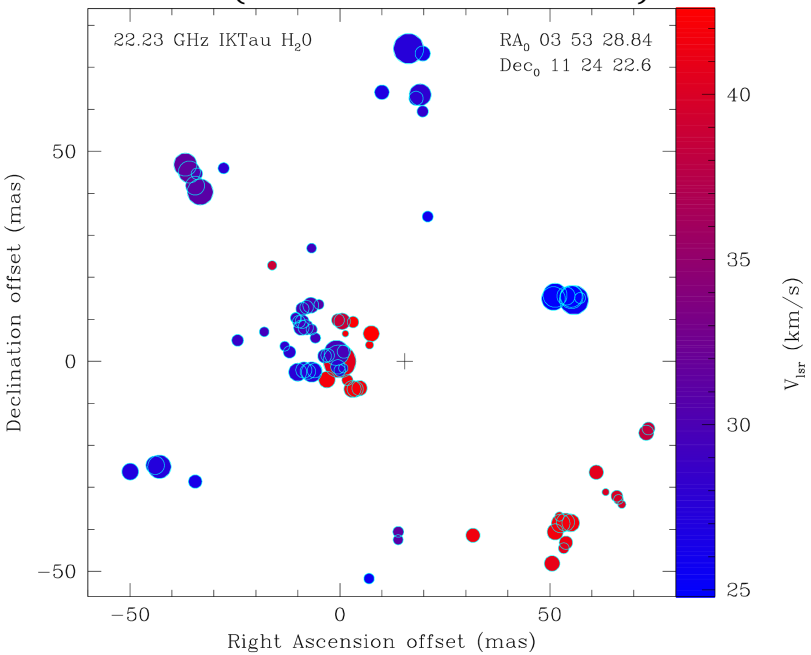
(Leal-Ferreira et al. 2012)



Results: IK Tau

. Detection of 85 maser features
(~10 AU to ~30 AU from the central star)

(Leal-Ferreira et al. 2013)



Results: IK Tau

(Leal-Ferreira et al. 2013)

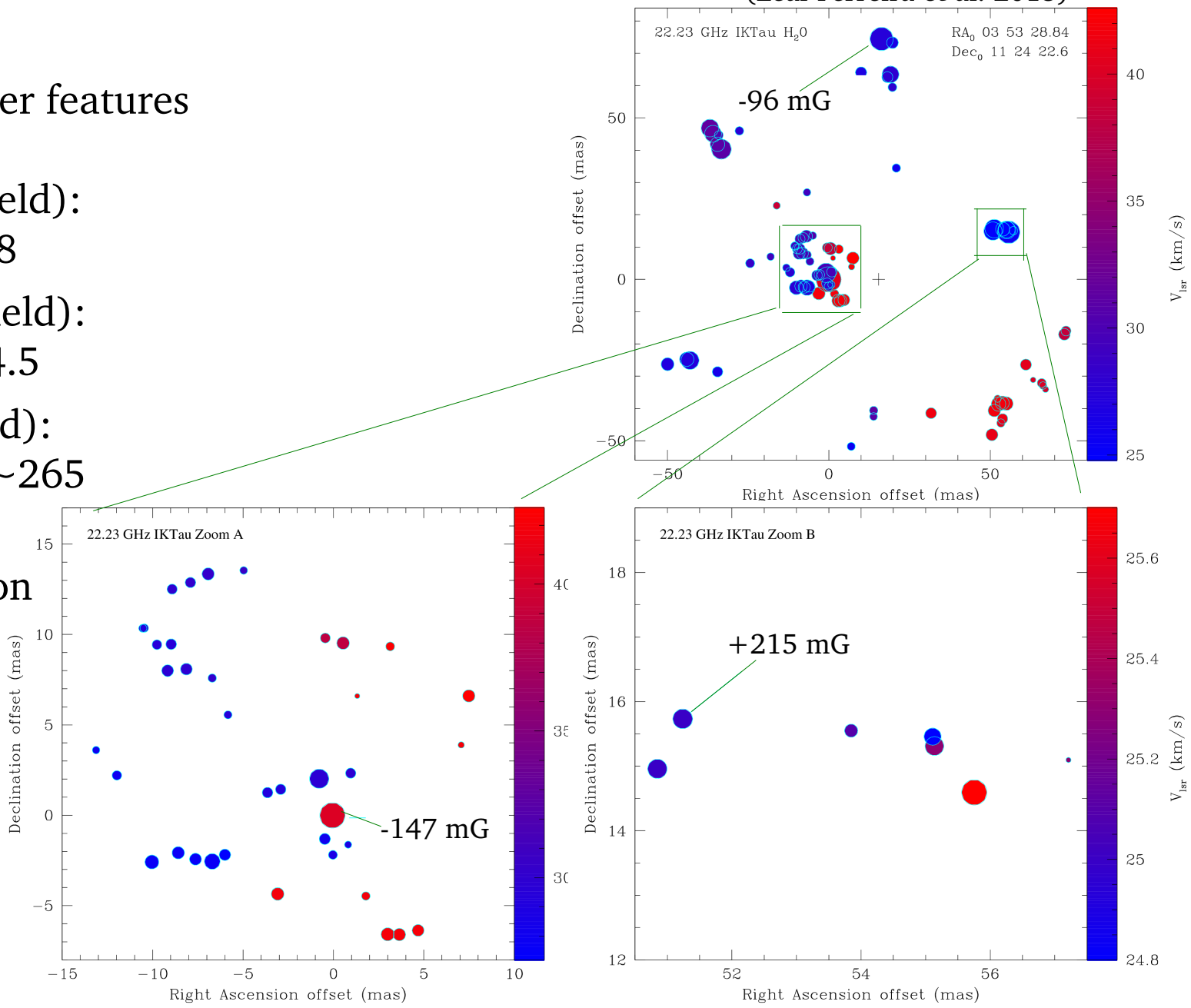
. Detection of 85 maser features

. If B ∝ r^{-1} (toroidal field):
→ 0.7 < B_{star}[G] < 3.8

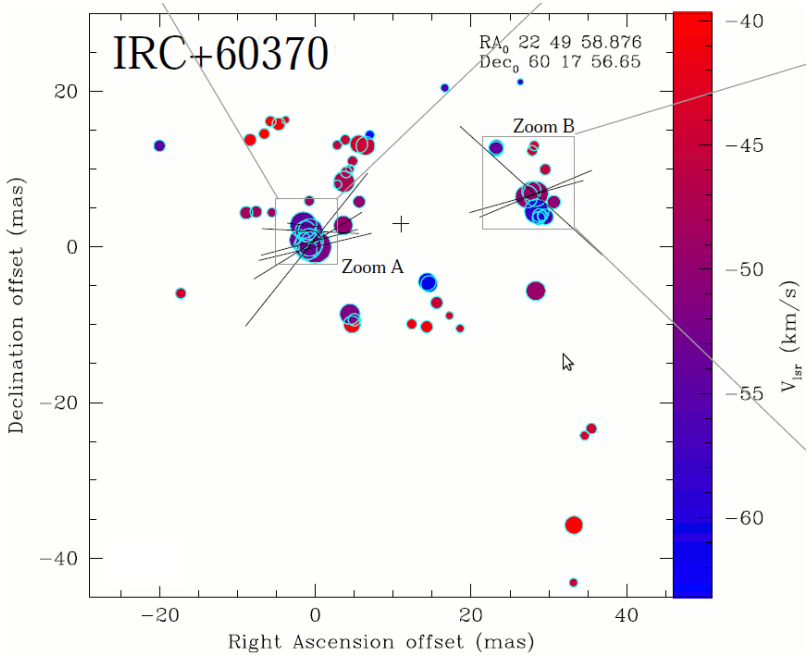
. If B ∝ r^{-2} (poloidal field):
→ 6.6 < B_{star}[G] < 54.5

. If B ∝ r^{-3} (dipole field):
→ 33.8 < B_{star}[G] < ~265

. No linear polarization detection



Results: RT Vir, IRC 60370, AP Lyn



IRC 60370

→ 62 maser features (~5.5 AU to ~55 AU)

→ Circular polarization on 5 features

→ $47 < |B_{||}$ (IRC 60370)$|$ [mG] < 331

→ If $B \propto r^{-1}$: $0.25 < B_{star}$ [G] < 22

→ Linear polarization on 9 features

(Leal-Ferreira et al. 2013)

RT Vir:

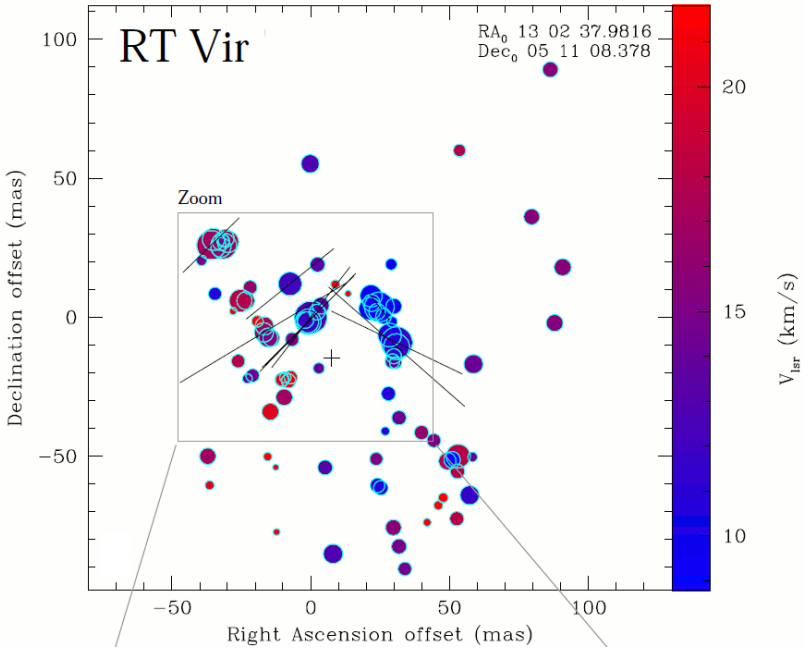
→ 91 maser features (~2.5 AU to ~20 AU)

→ Circular polarization on 2 (+1) features

→ $143 < |B_{||}$ (RT Vir)$|$ [mG] < 188

→ If $B \propto r^{-1}$: $0.3 < B_{star}$ [G] < 2.9

→ Linear polarization on 9 features

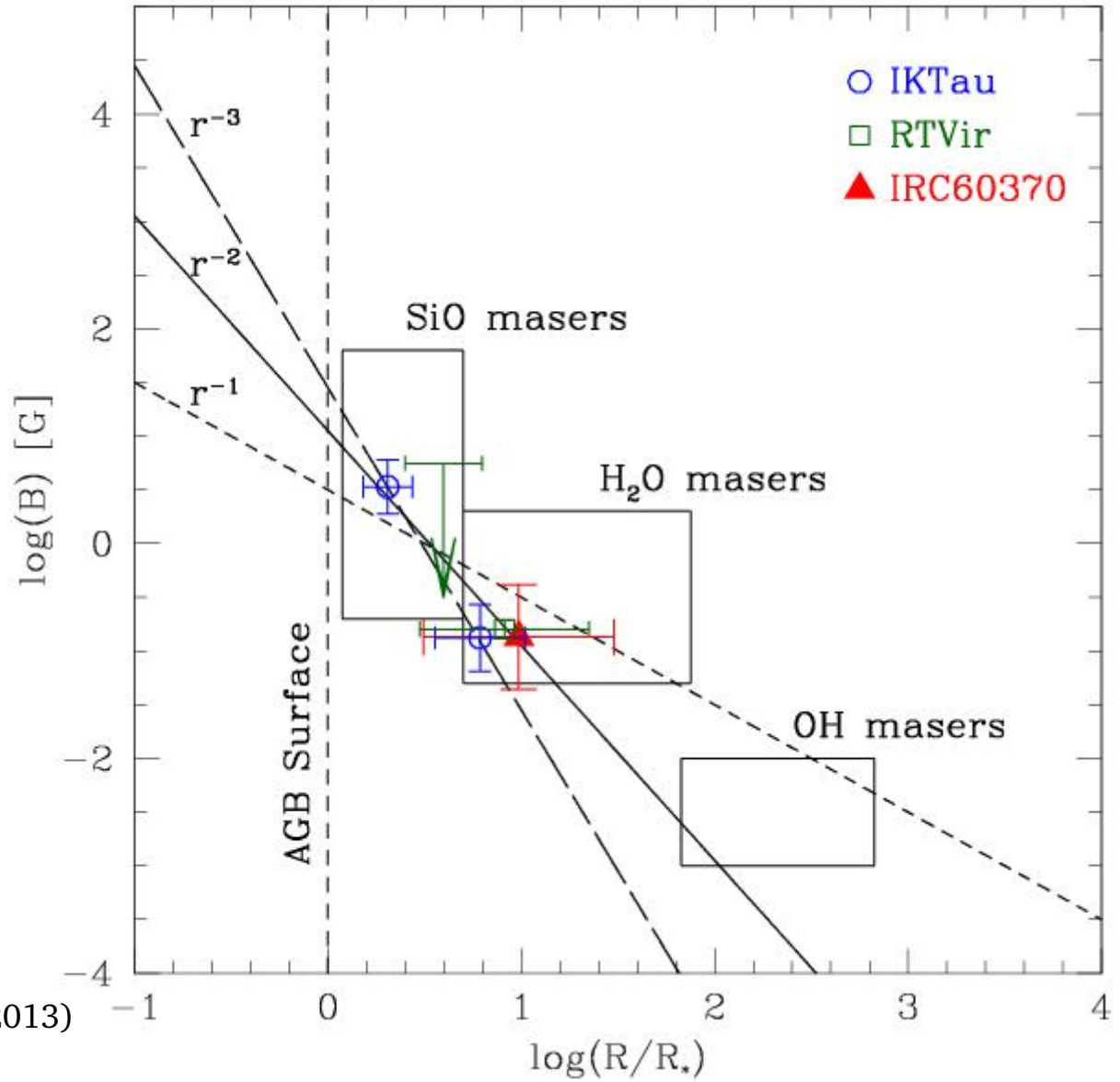


AP Lyn: No maser detection

Discussion

. The magnetic field dependence is yet not determined

→ For IKTau, a B ∝ r^{-2} or r^{-3} behavior looks more likely.



(Leal-Ferreira et al. 2013)

Discussion

. The observed magnetic field energy is similar or dominates the kinematic and thermal energy

→ $nkT\ (H_2O)\ [dyne/cm^2] \sim 10^{-5.2}$

→ $\rho\ V^2_{exp}\ (H_2O)\ [dyne/cm^2] \sim 10^{-4.1}$

→ $10^{-4.1} < B^2/8\pi\ (H_2O)\ [dyne/cm^2] < 10^{-2.4}$

The magnetic fields should not be ignored as one of the important mechanisms in shaping PNe!

Summary

. More details in **Leal-Ferreira et al. 2012 (A&A, 540, 42)** and **Leal-Ferreira et al. 2013 (A&A, 554, 134)**

. Magnetic Field measurements on all 4 sources where water masers were detected

. The Rotten Egg Nebula: the first evolved star, known to be a binary, in which the presence of the magnetic field is confirmed throughout the circumstellar envelope

. Field strength between ~50 mG and ~330 mG in the water maser region

. Further observations are needed to better investigate the field morphology

. Magnetic Energy higher than thermal and kinematic energy in the H_2O maser region

The magnetic fields should not be ignored as one of the important mechanisms in shaping PNe!