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Winds and Circumstellar Morphology of Binary AGB stars with ALMA

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N.L.J. Cox, E. Lagadec, M.L. Leal-Ferreira, C. Paladini,
A. Perez-Sanchez, S. Sacuto

M. Brunner, T. Danilovich, L. Doan, M. Saberi

Image credit: Julian Pittard

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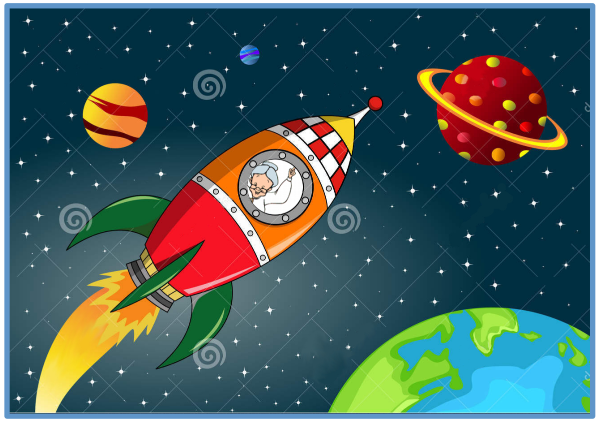
Topics to be covered:

- Some words about single-dish observations of circumstellar CO gas and interpretation
- Models of wind shaping
- ALMA project description
- Observational results and interpretation
- Lessons learnt

- Beyond…



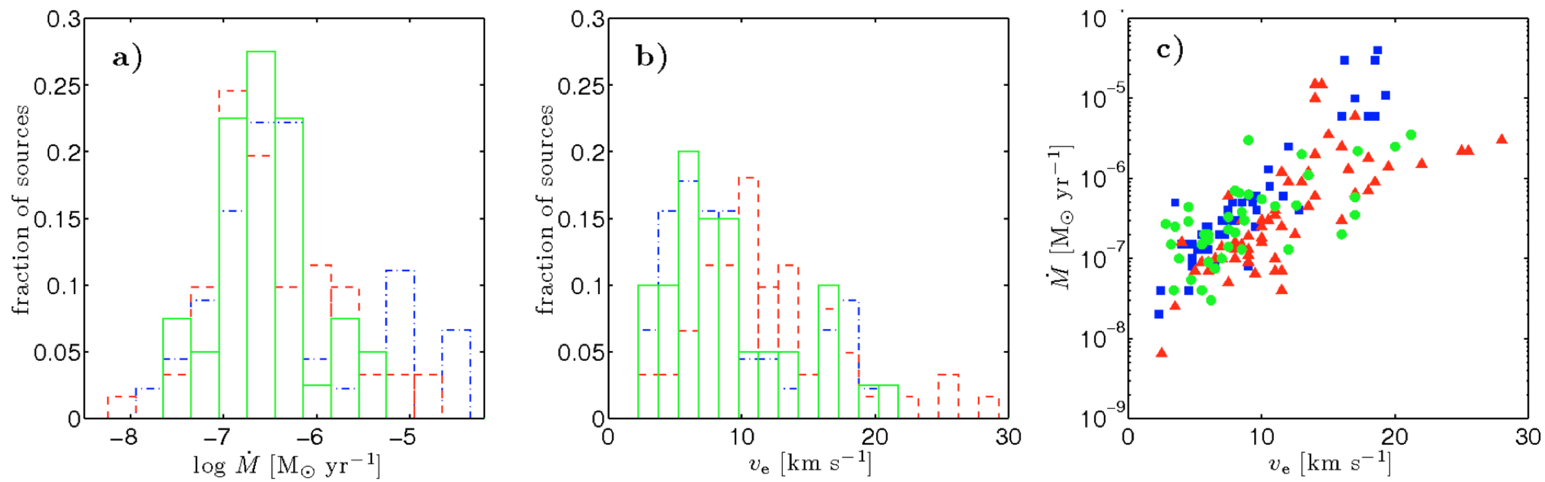


Fig. 6. a) Mass-loss-rate distributions for S-type stars (solid, green line; 40 stars), M-type stars (dashed-dotted, blue line), and carbon AGB stars (dashed, red line) samples. **b)** Gas expansion velocity distributions derived from fitting the CO line widths for the S-type (solid, green line), M-type (dotted, blue line) and carbon AGB star (dashed, red line) samples. **c)** Mass-loss rates plotted against the gas expansion velocities for S-type stars (green dots), M-type stars (blue squares), and carbon AGB stars (red triangles) samples.

Schöier & Olofsson 2001
Gonzalez-Delgado et al. 2003
Ramstedt et al. 2009

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Spherically symmetric CSEs, one star, lower rotational transitions, single-dish

- CO emission is the main tracer of the circumstellar gas density and temperature
- Used as mass-loss rate estimator (over time)
- The extent of the emission is limited by excitation and the physical extent which is photodissociation limited
- CO(3-2) emission from 500-1000 AU
- Photodissociation radius ranges from 1500-30000 AU

Colour scheme:

(red)	a lot
(green)	a little less
(blue)	even lesser

Sensitivity to change:

Parameter	10^{-5} $M_\odot$ yr^{-1} 1-0 2-1 3-2 4-3	10^{-6} $M_\odot$ yr^{-1} 1-0 2-1 3-2 4-3	10^{-7} $M_\odot$ yr^{-1} 1-0 2-1 3-2 4-3
dM/dt	optically thick	optically thin	optically thin
L	collisionally excited	collitionally excited	radiatively excited
r_p	optically thick	optically thinner	optically thin

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Colour scheme:

Colour	
(red)	a lot
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(blue)	even lesser

Sensitivity to change:

Parameter	High dM/dt 10^{-5} $M_{\odot}$ yr^{-1}	Intermed. dM/dt 10^{-6} $M_{\odot}$ yr^{-1}	Low dM/dt 10^{-7} $M_{\odot}$ yr^{-1}
dM/dt	optically thick	optically thin	optically thin
L	collisionally excited	collisionally excited	radiatively excited
r_p	optically thick	optically thinner	optically thin

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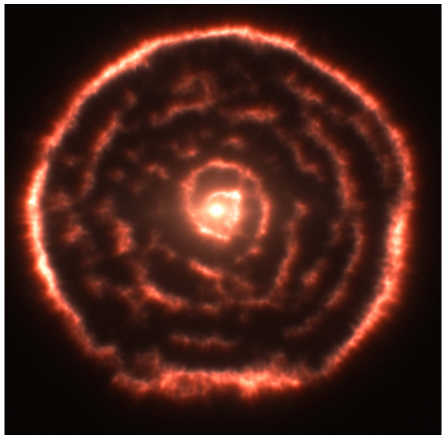
Interferometric observations of binary stars

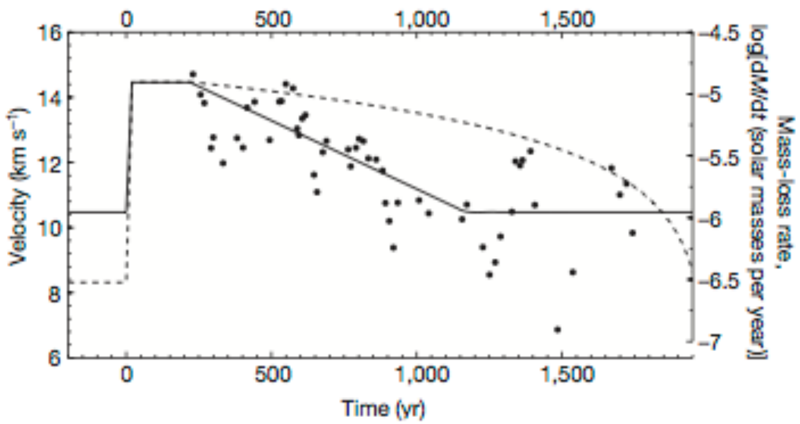
Increasing the complexity:

- ➢A companion will shape the envelope
- ➢A companion will affect emission and extent (and chemistry)
- ➢3D radiative transfer modelling will be necessary

- Show detail we have not seen before
- Shaping can enforce structures

Maercker et al. 2012





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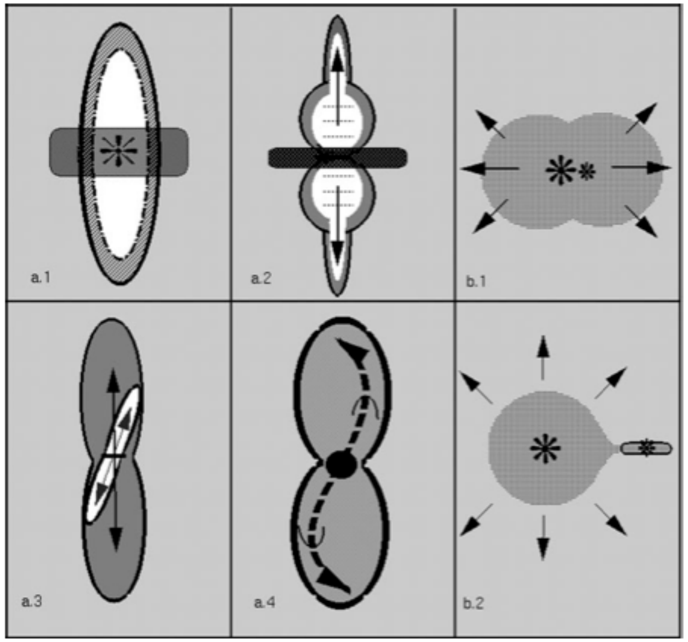
Models of wind shaping (low mass)

1. RLOF models
2. GISW models
3. MHD models
4. Colliding winds models
5. …

Can be coupled to radiative transfer model or radiative transfer can be performed on pre-defined structures and compared.



Balick & Frank 2002, ref. therein

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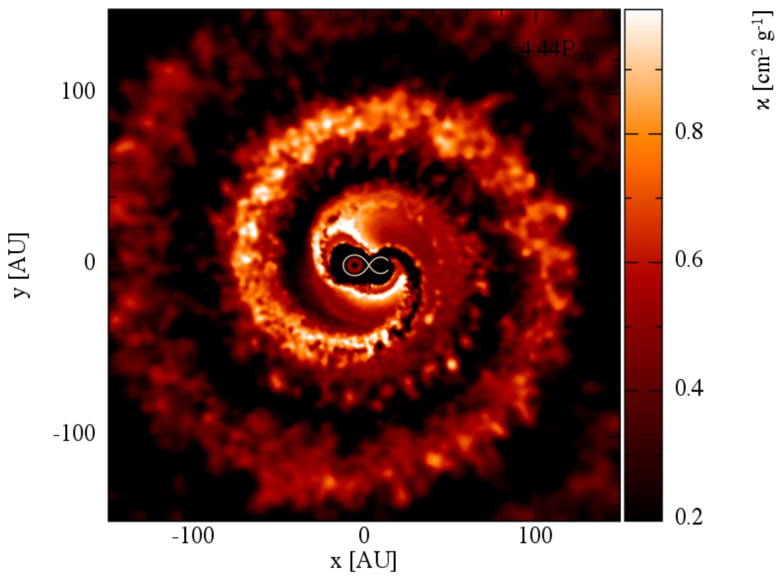
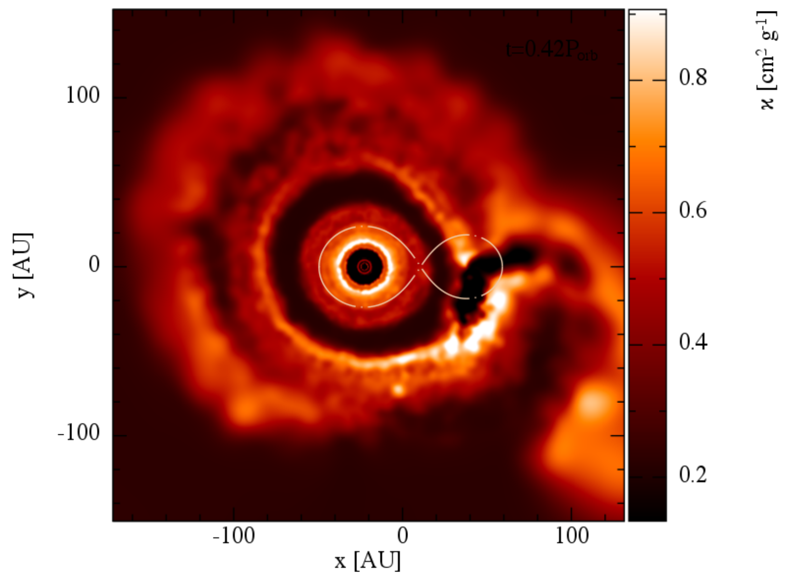
Models of binary interaction



15 AU separation



60 AU separation

Mohamed & Podsiadlowski 2007, 2012

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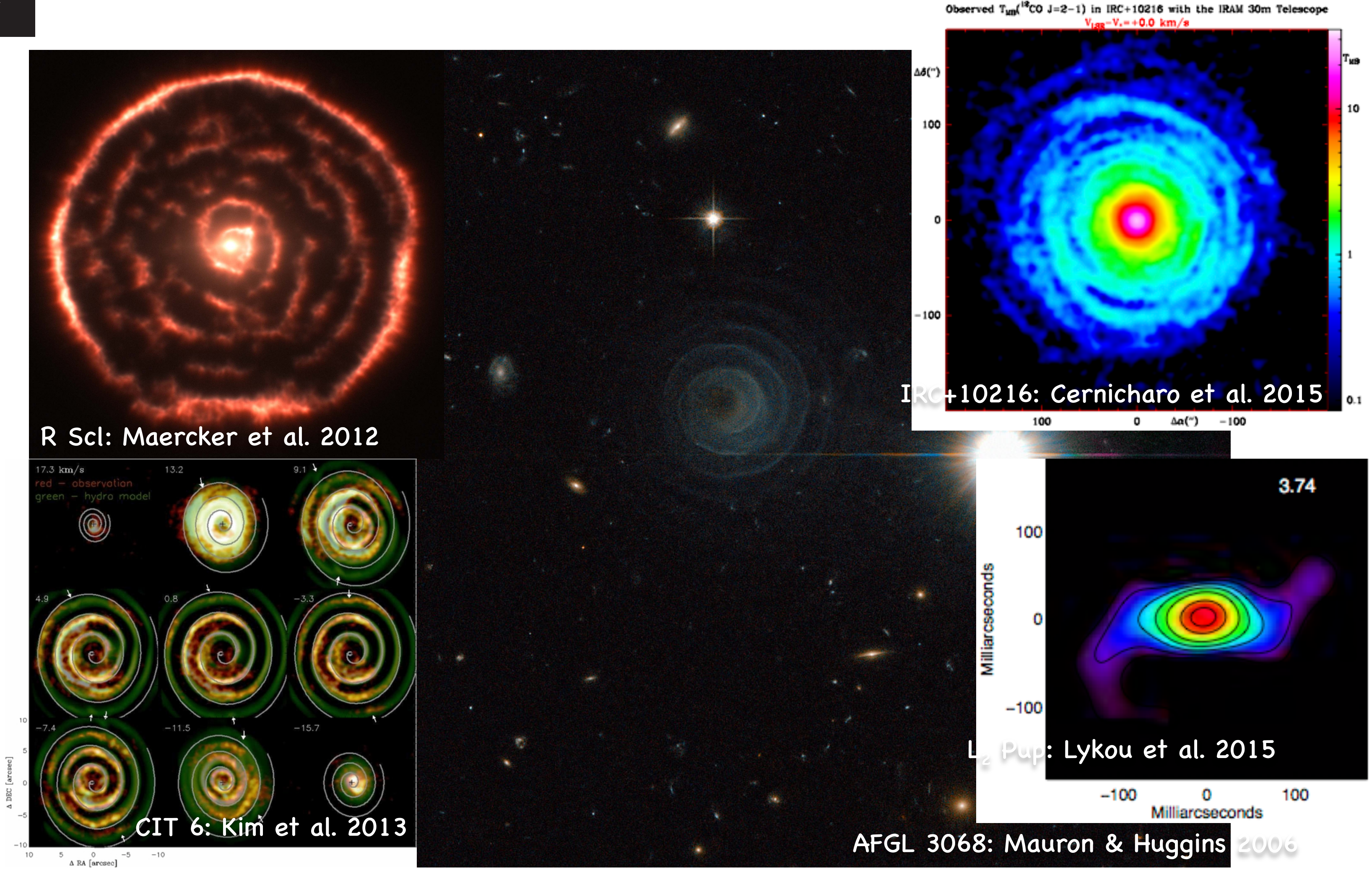
Observations of circumstellar effects of binarity



R Scl: Maercker et al. 2012

IRC+10216: Cernicharo et al. 2015

CIT 6: Kim et al. 2013

L_2 Pup: Lykou et al. 2015

AFGL 3068: Mauron & Huggins 2006

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Binary ALMA AGB sources:

R Aqr, a=55 mas=12 AU@218 pc
o Cet, a=0.47″=43 AU@92 pc
W Aql, a=0.47″=160 AU@340 pc
π^1 Gru, a=2.7″=440 AU@163 pc

Observations:
^{12}CO(3-2), ^{13}CO(3-2) mosaics @ 0.5″
CS, SiS, H^{13}CN, ^{29}SiO, and more…
≈30 antennas 12m, ACA & TP

See Magdalena Brunner's poster No. 3!!

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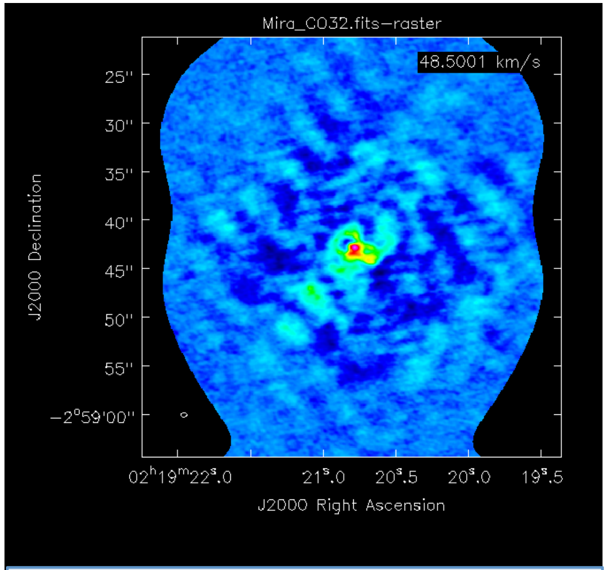
Goals:

- Dependence on separation
- Dependence on wind velocity
- Templates for binarity

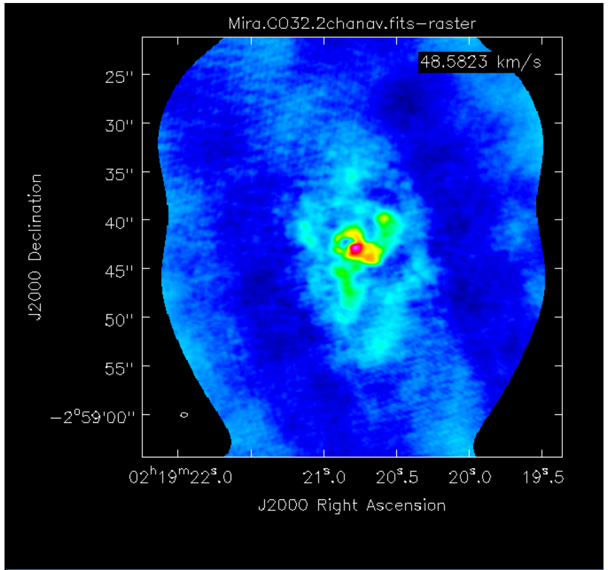
- Mass-loss-rate modulations
- Accretion efficiency

- Resolved carbon isotopic ratios

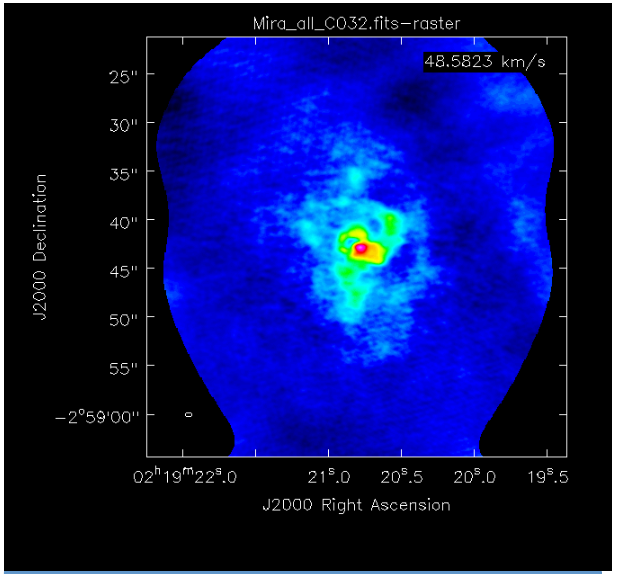
Mira - a brief note on image fidelity



12m array



12m array+ACA



12m array+ACA+APEX map

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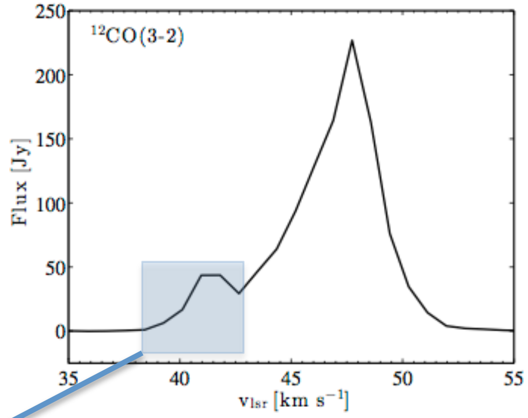
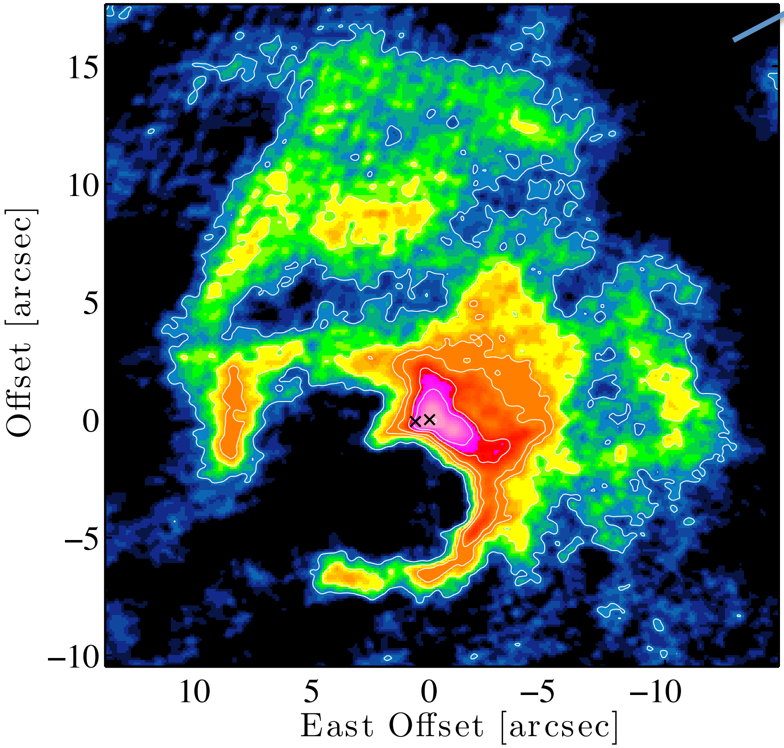
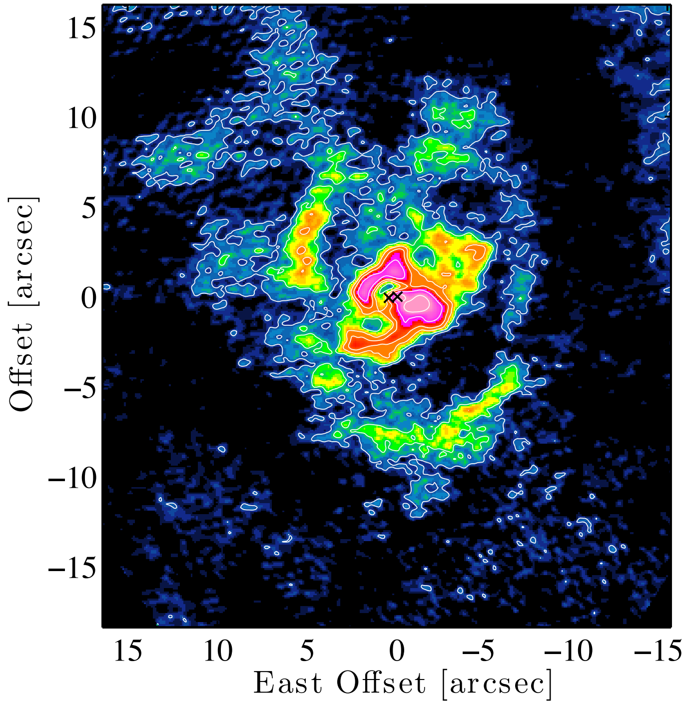
Mira







Ramstedt et al. 2014

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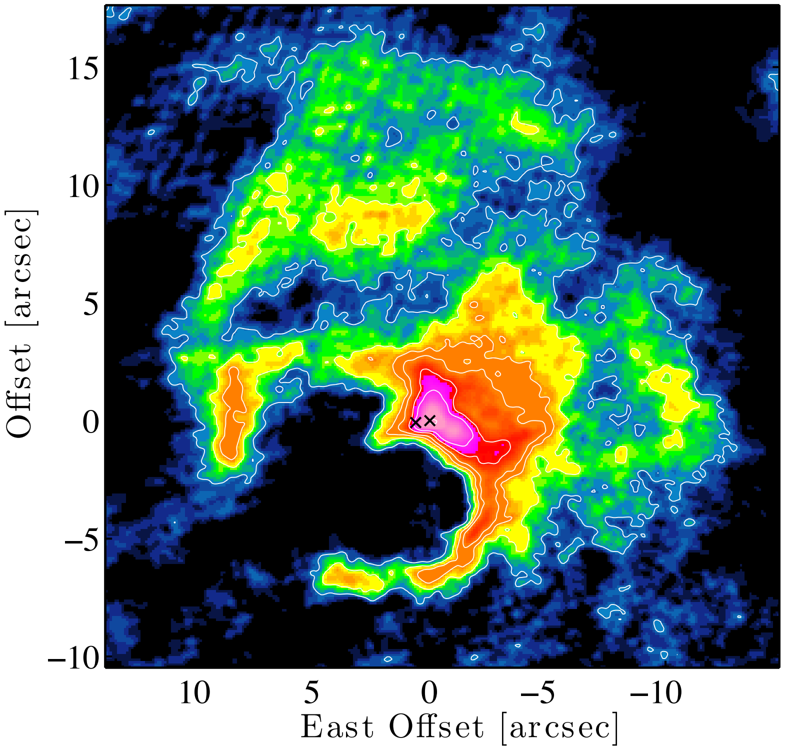
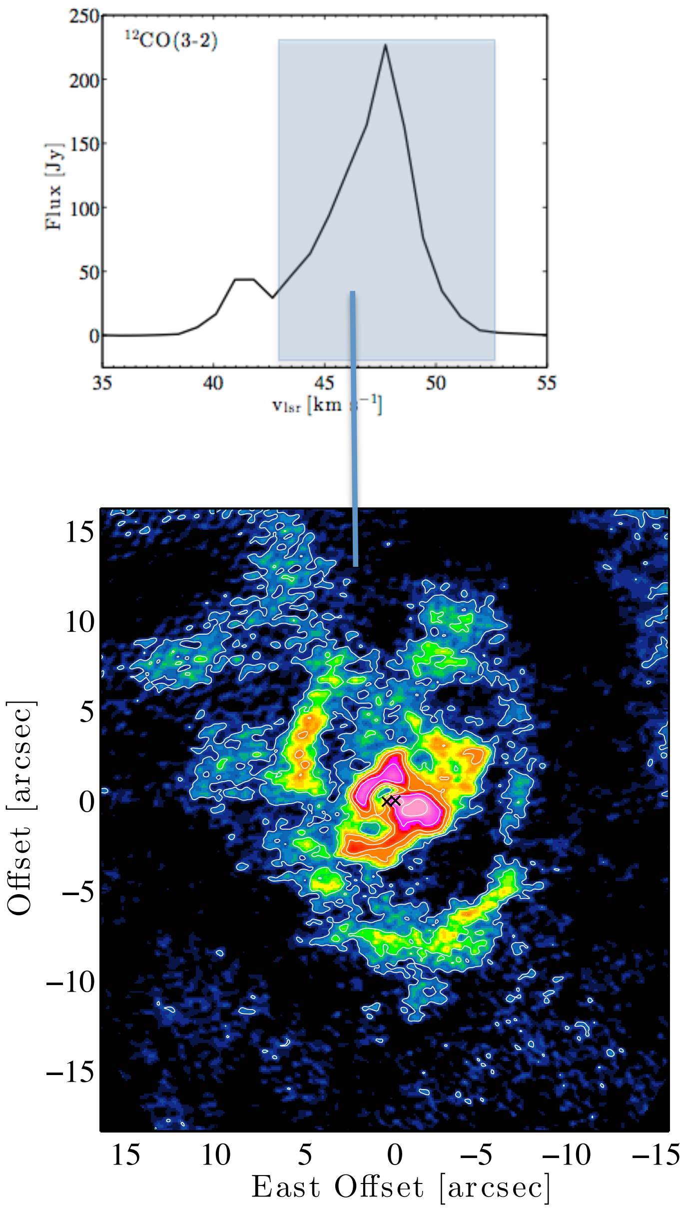
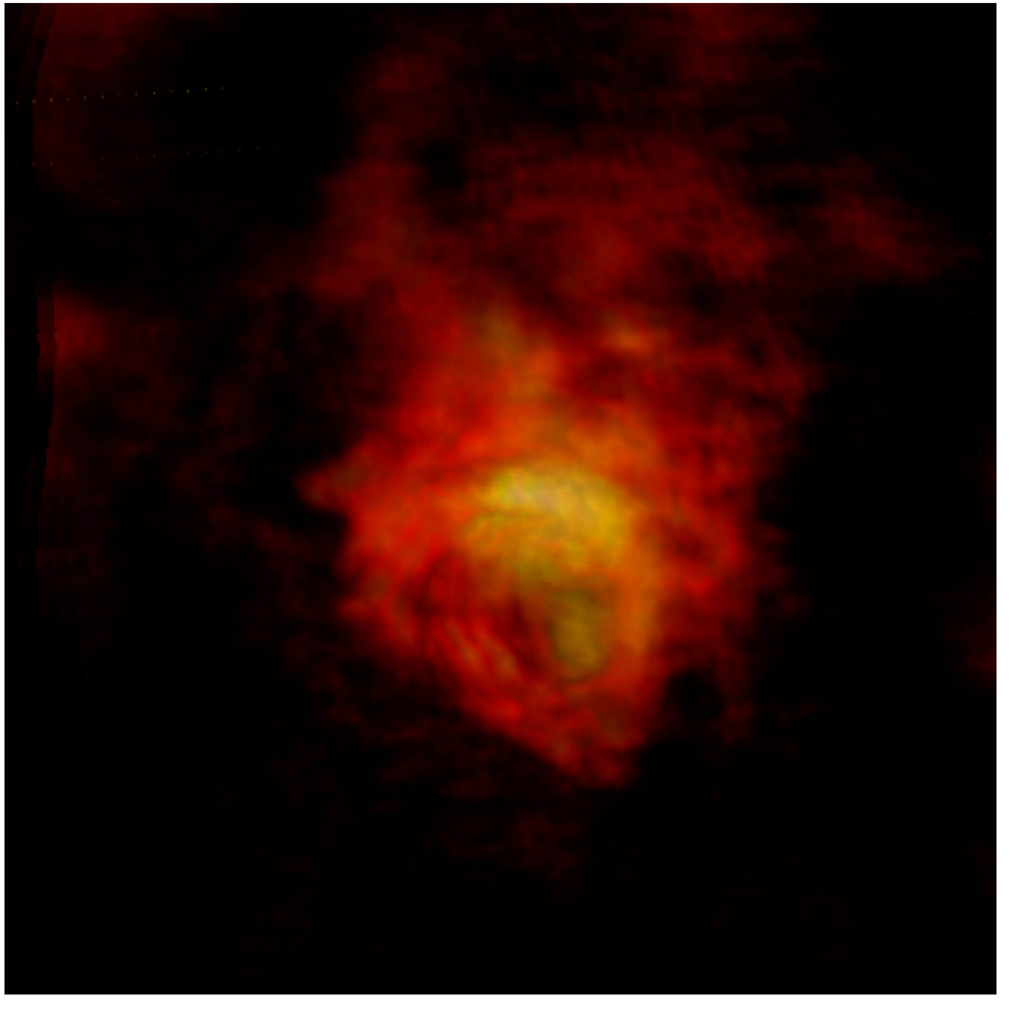
Mira





Ramstedt et al. 2014

Mira



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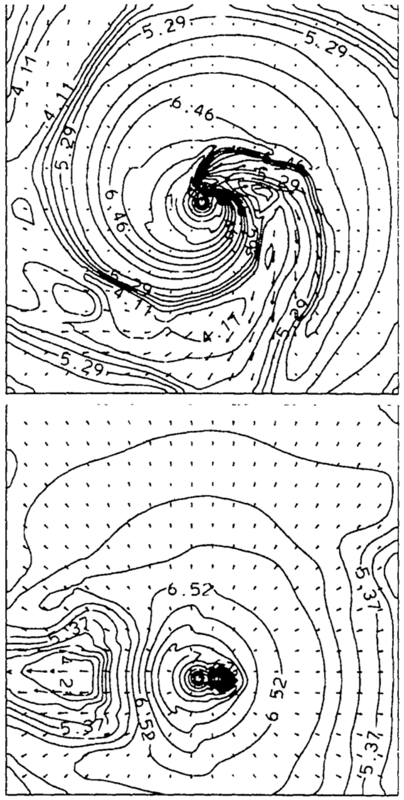
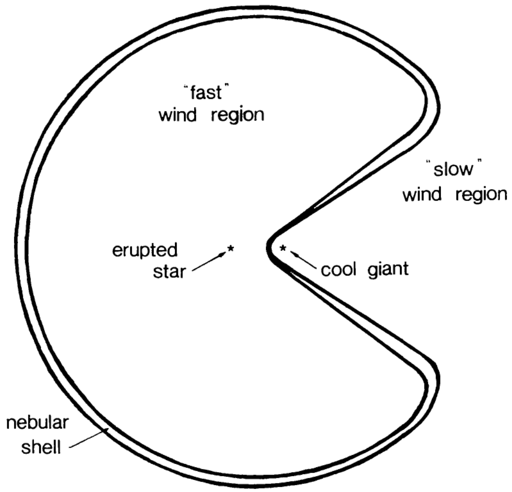
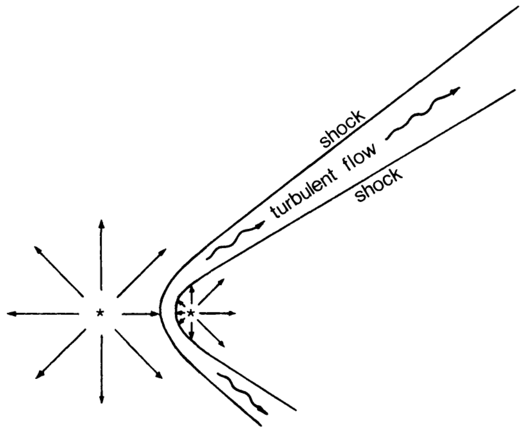
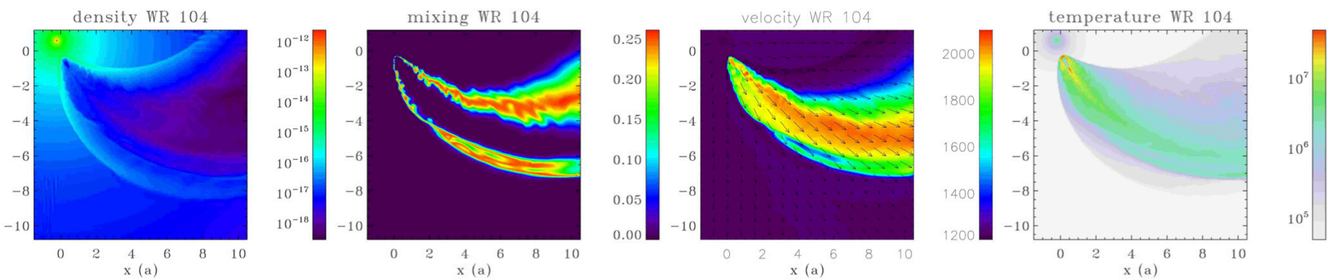
Mira - Colliding winds



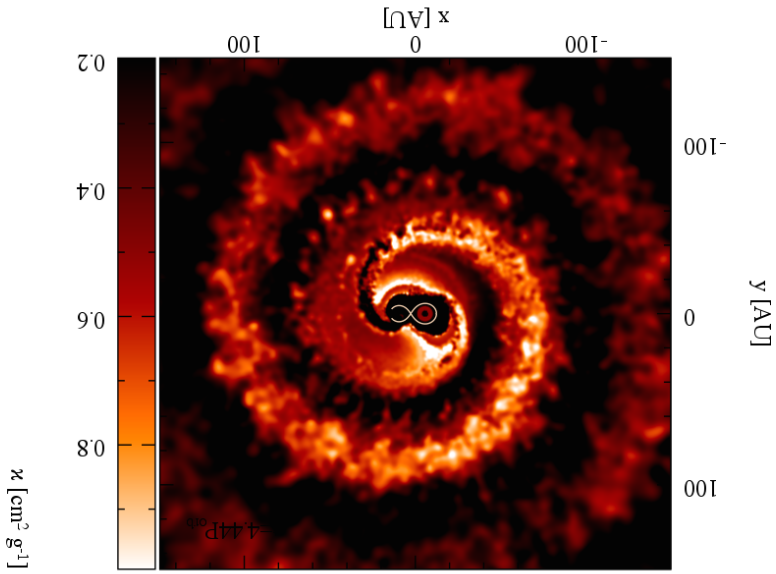




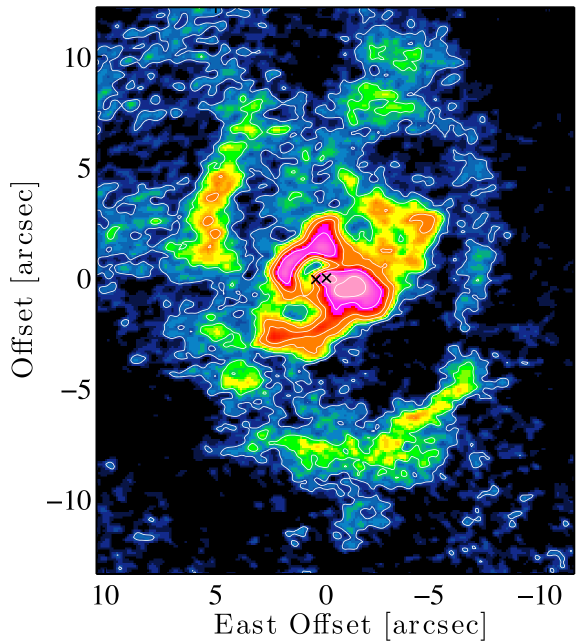


Girard & Willson 1987; Walder & Folini 2000; Lamberts et al. 2012

Mira



x [AU]
100
0
-100
y [AU]
0.2
0.4
0.6
0.8
κ [cm² g⁻¹]



10
5
0
−5
−10
Offset [arcsec]
East Offset [arcsec]

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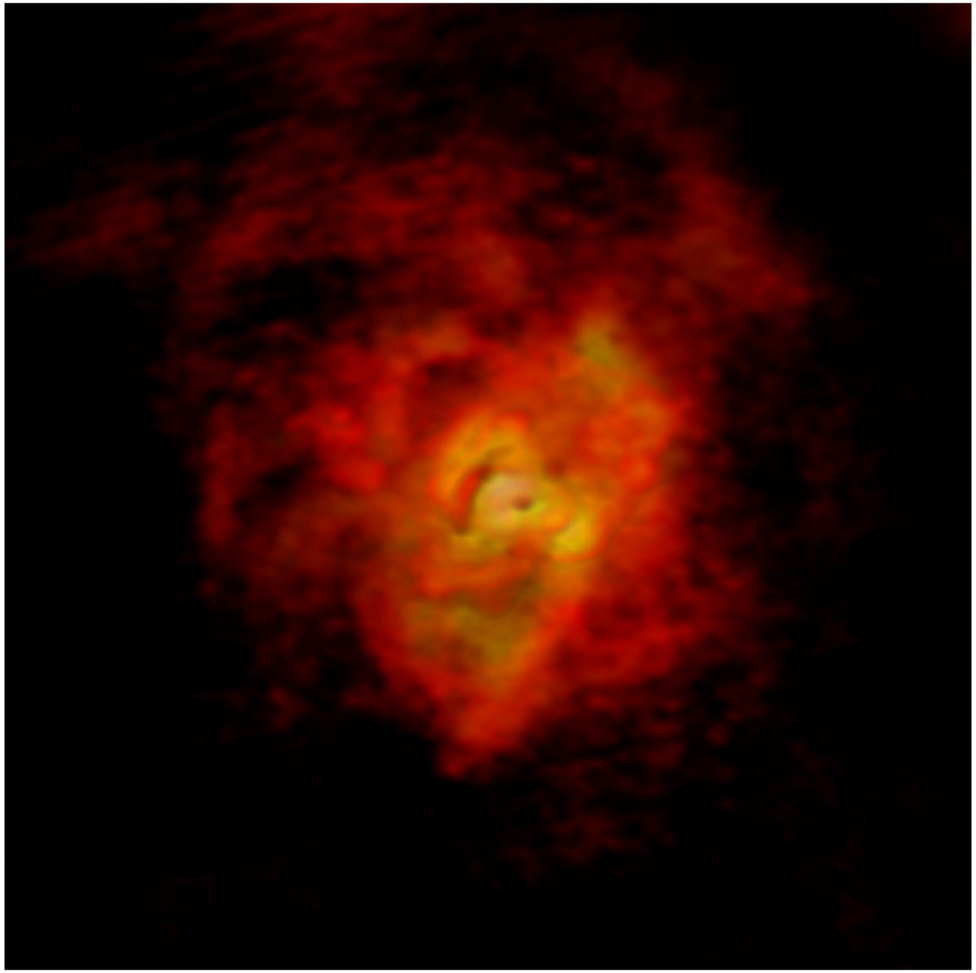
Mira



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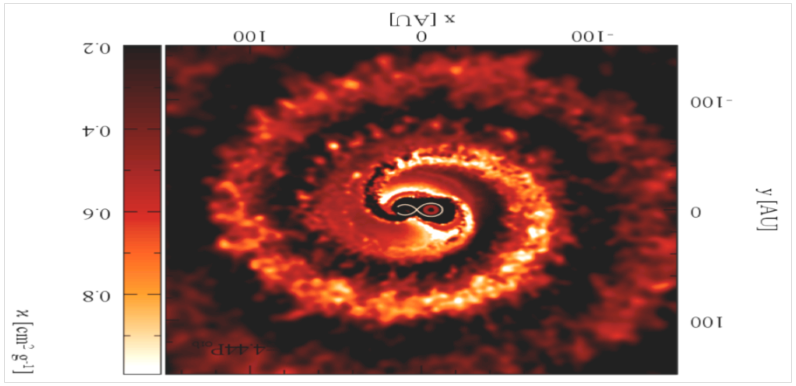
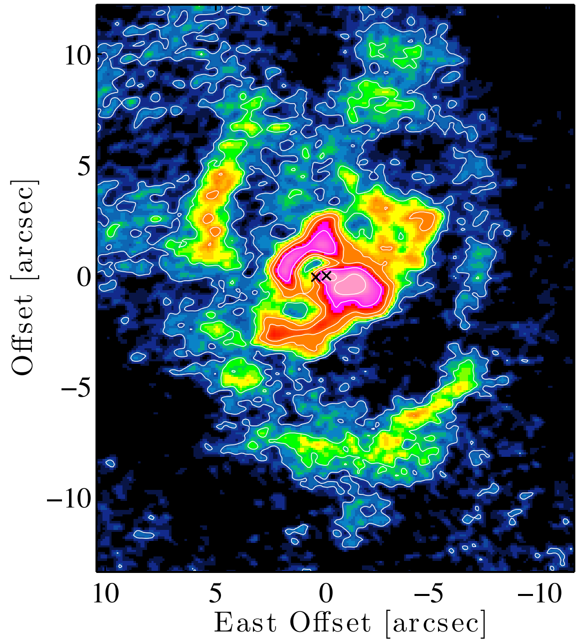
Mira





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Mira - The Explanation

The companion plows a spiral-shaped tunnel when moving through the AGB CSE and seen edge-on this tunnel will look like a hole

We see this structure somewhat inclined compared to edge-on, and at the companion the tunnel is puffed up due to the wind of B

The material is more concentrated toward the orbital plane (wind-RLOF) confirmed by that different sections of the spiral arms appear in different velocity channels

The puffed-up tunnel appears at blue-shifted velocities since the material is flowing along the tunnel walls toward us (and B is moving away)

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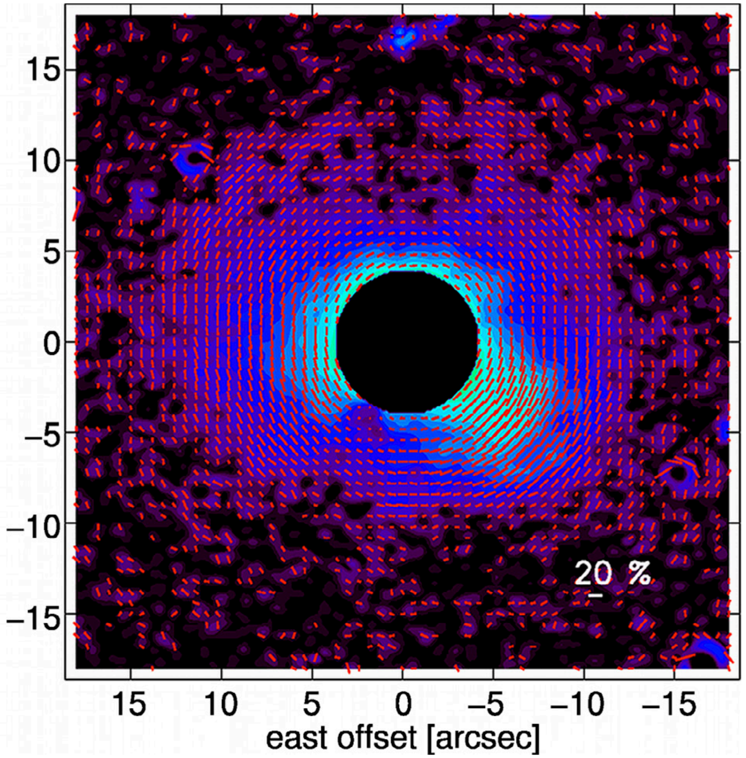
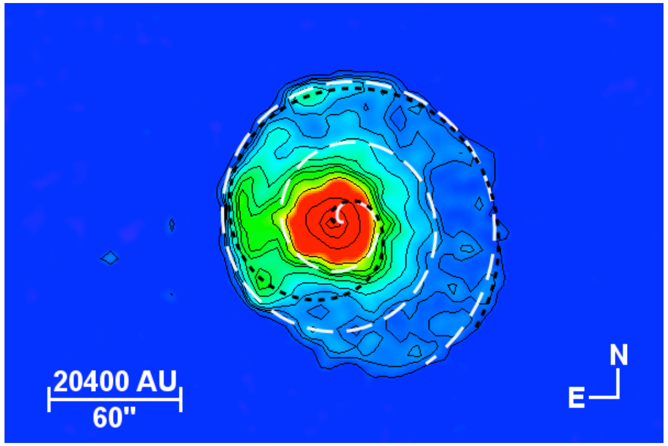
W Aql



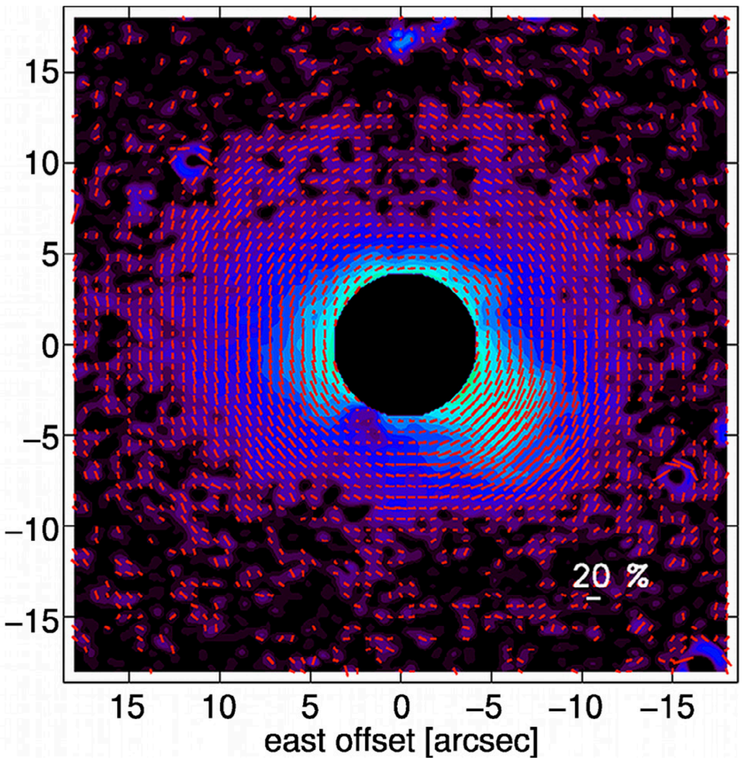
Ramstedt et al. 2011

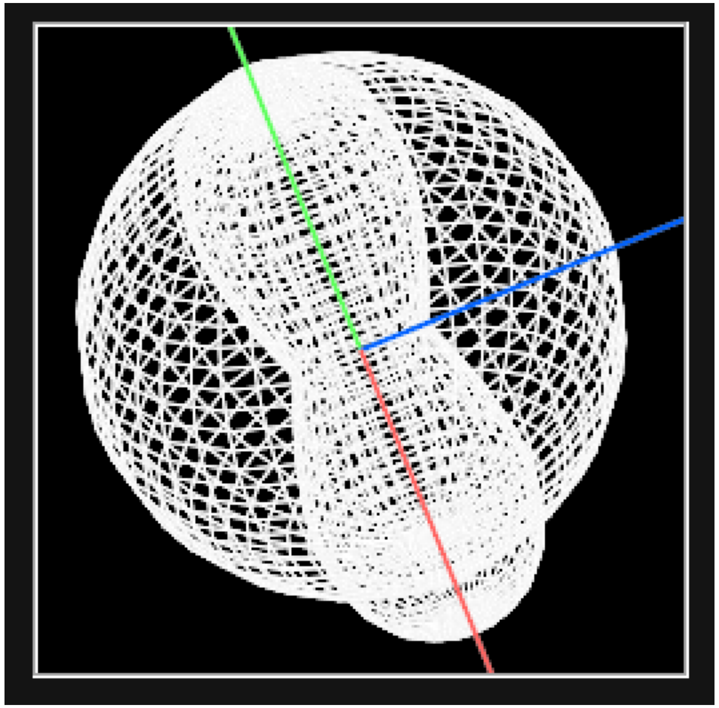
0.46" separation binary (200-400 pc)
W Aql A: S-type AGB star
W Aql B: F8-G0 main sequence
(Danilovich et al. 2015)

Herschel PACS: (Mayer et al. 2013)



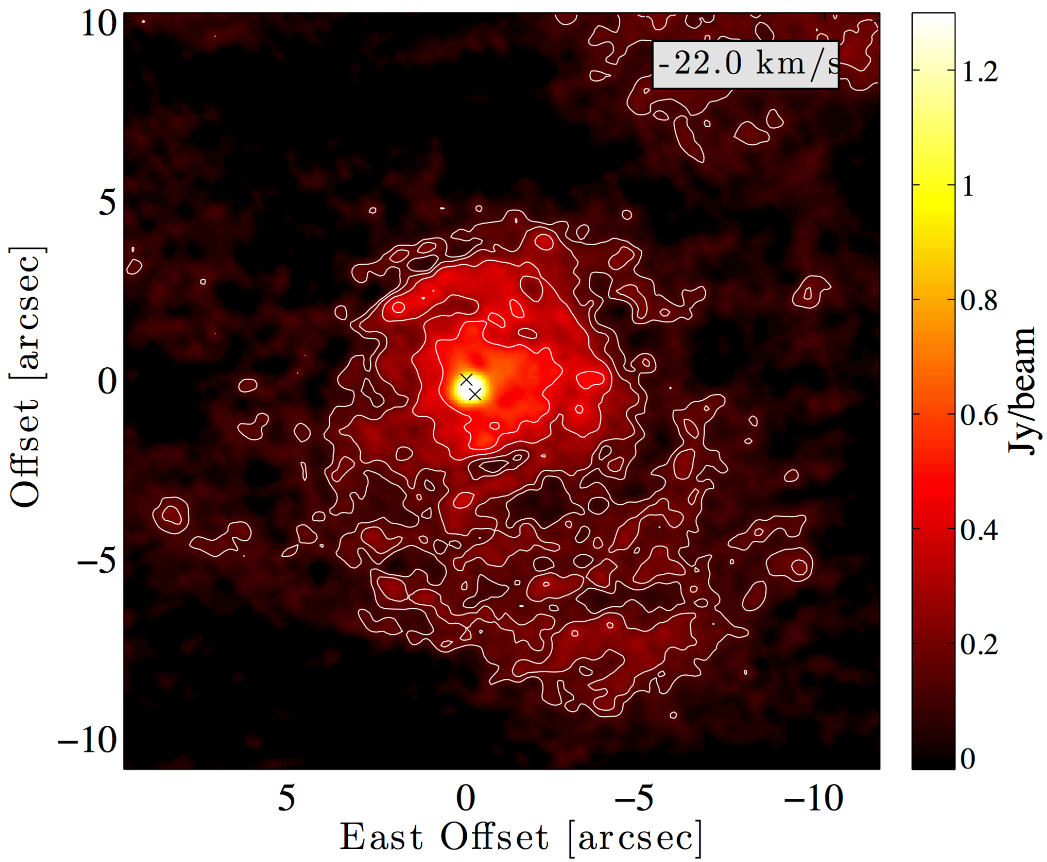
W Aql



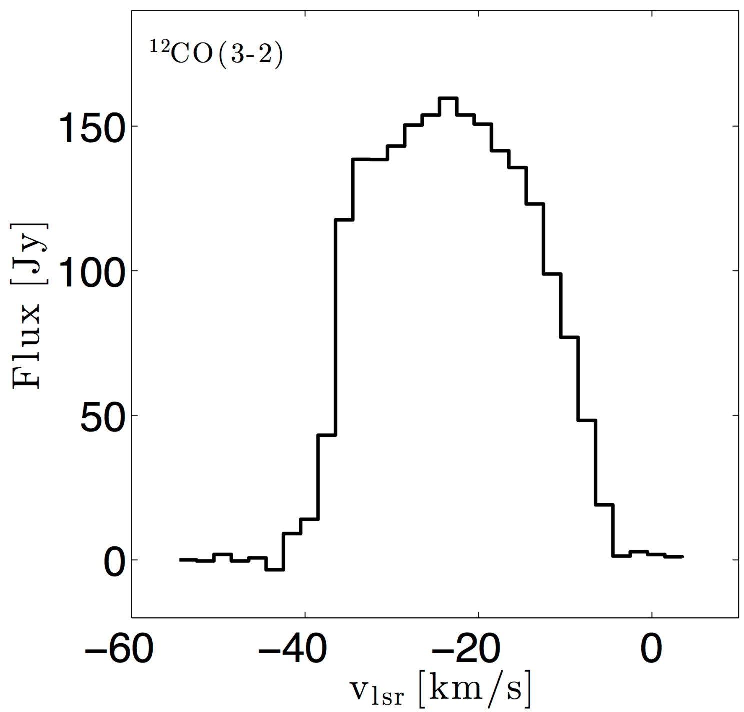


Ramstedt et al. 2011

W Aql



-22.0 km/s
10
5
0
-5
-10
Offset [arcsec]
East Offset [arcsec]
1.2
1
0.8
0.6
0.4
0.2
0
Jy/beam



^{12}CO(3-2)
150
100
50
0
-60
-40
-20
0
Flux [Jy]
v_{lsr} [km/s]

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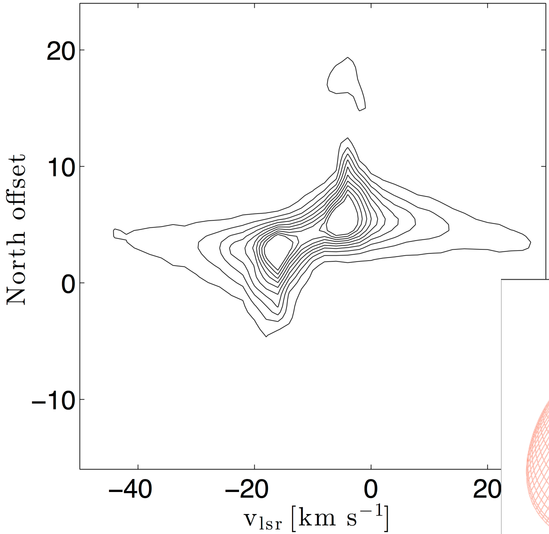
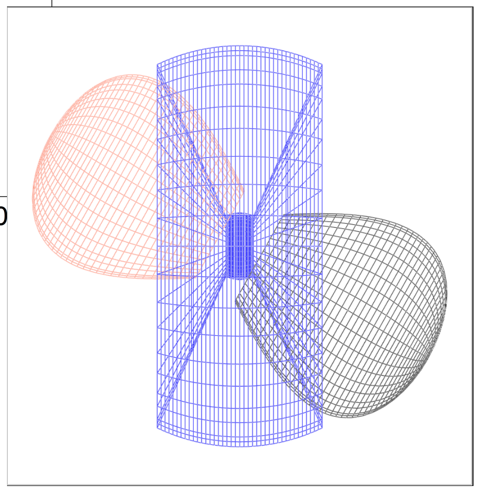
W Aql - Conclusions

- R Scl-like (vertically extended) spiral present across almost all channels
- Expected from the relatively high expansion velocity (17 km/s) where the material is not confined to the Roche-lobe
- The asymmetry can be explained if the orbit is eccentric

π^1 Gru? & R Aqr?

See Lam Doan's poster No. 21!!





Some observations, but data yet to be released

Credit: Adam Block/Mount Lemmon SkyCenter/University of Arizona

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Lessons learnt

- Reality is always more complicated
- Combination of models

- Extended emission needed
- Velocity information is necessary

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Beyond…

Goals:

- Dependence on separation ✔
- Dependence on wind velocity ✔
- Templates for binarity ✔

Larger sample?

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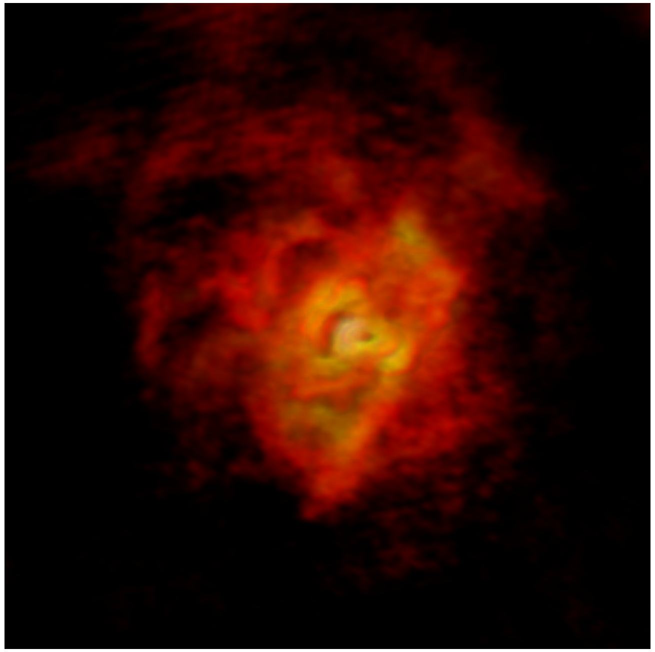
Thank you for your attention!
Questions?



3D PV diagrams were created using FRELLED developed by Rhys Taylor (www.rhysy.net/frelled)