

LARGE-SCALE ASYMMETRIES IN THE WINDS OF (BINARY) AGB STARS

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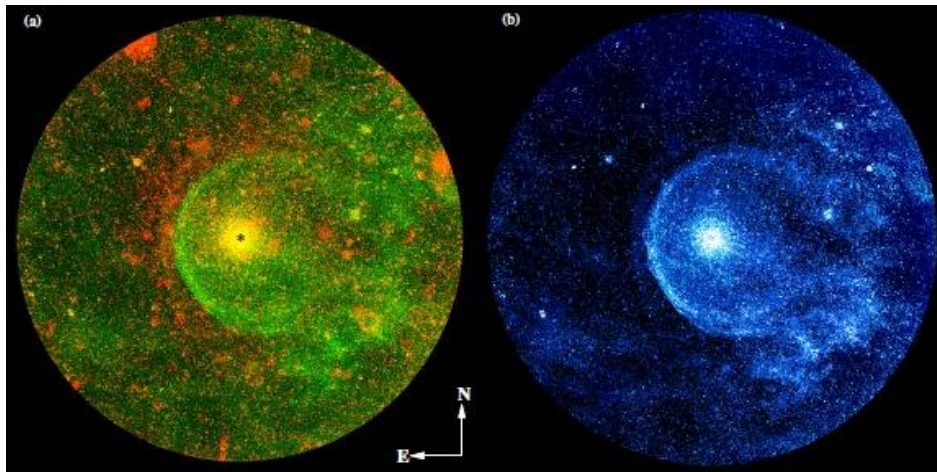
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AGB wind – ISM interaction

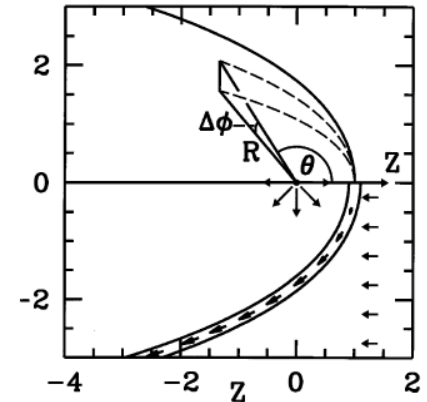
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- IRC+10 216 (CW Leonis)
 - ▣ GALEX (FUV & NUV)
 - ▣ Parabolic wind shape
 - ▣ Fast moving star ($v^* > 50$ km/s)



- AGB: $v^* > 30$ km/s
- Shock interface where ram pressure of wind and ISM are balanced
- Apex of bow shock in direction of space motion at standoff-distance

$$R_0 = \sqrt{\frac{\dot{m}_w V_w}{4\pi\rho_a V_*^2}}$$

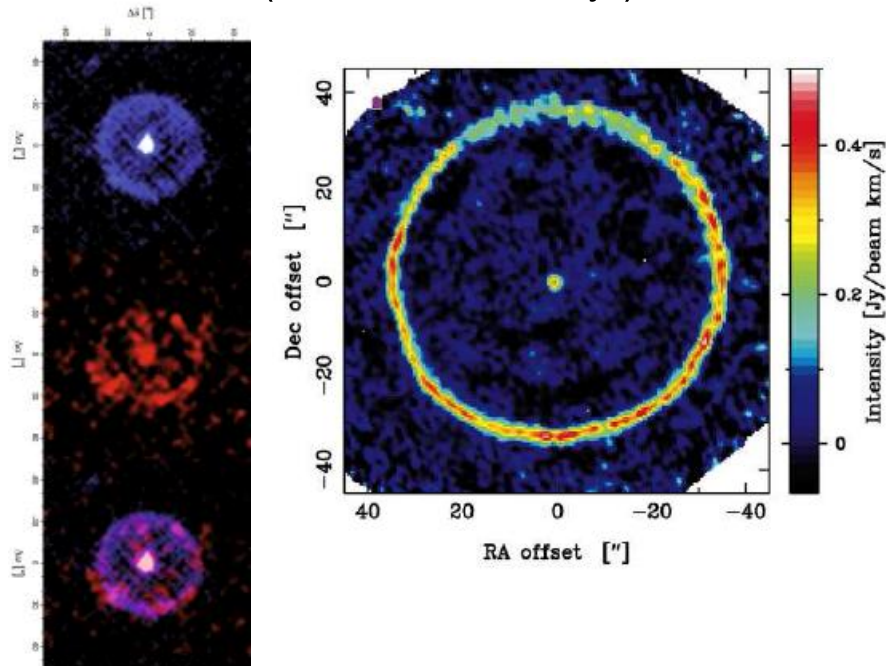


- Observations mainly in far-IR + in rare cases UV

AGB wind – AGB wind interaction

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- TT Cygni
 - ▣ CO & far-IR
 - ▣ Clumpy, thin shell (width of 2.5")
 - ▣ Dynamical age of 6800 yr (shell width: 500 yr)

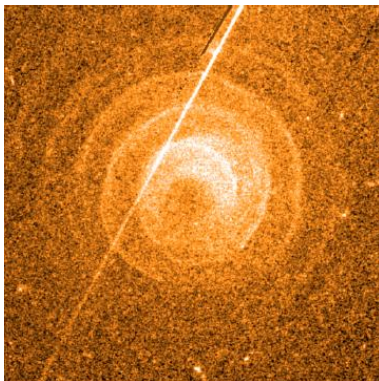


- Young fast wind sweeps up old slow wind, shock front at interface
- Occurs in late stages on AGB, young fast wind during (short) TP, old slow wind is regular AGB outflow
- All detached shell objects are carbon stars
- Shells traced as gas (CO) and/or dust (far-IR; optical as scattered light)

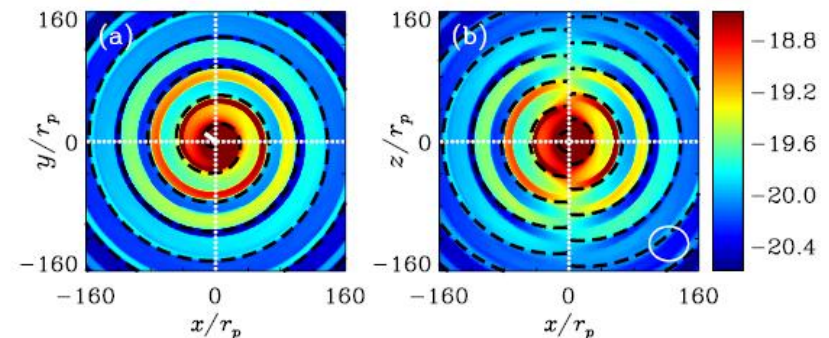
AGB wind – companion interaction

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- AFGL 3068 (LL Pegasi)
 - HST scattered light
 - 5 windings with 25" diameter
 - Spiral spacing $\rho = P_{\text{orb}} \cdot v_w$
 - Proposed companion separated by 120 AU
 - Confirmed later with $a=109$ AU



- **Wide binary systems** ($a > 5$ AU)
- CoM motion of primary + mass transfer on companion
- Supersonic orbital motion leads to accretion wake
- Spiral shock frozen in stellar wind over several thousand AU
- Appearance changes to broken concentric shells (edge-on)



Herschel's contribution

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- Herschel
 - ▣ Herschel/PACS imaging at 70 μm and 160 μm [cold dust]
 - ▣ Pixel size: 1" (70 μm) and 2" (160 μm) (oversampled)

- Mass loss of Evolved StarS GTKP (MESS)
 - ▣ 78 objects: mainly AGB stars + few SNRs, RSGs
 - ▣ 60% show extended envelopes

 - ▣ 70% of extended envelopes are asymmetric (5 \rightarrow 33)
 - ▣ 30% of extended envelopes are „rings“ (10 \rightarrow 13)

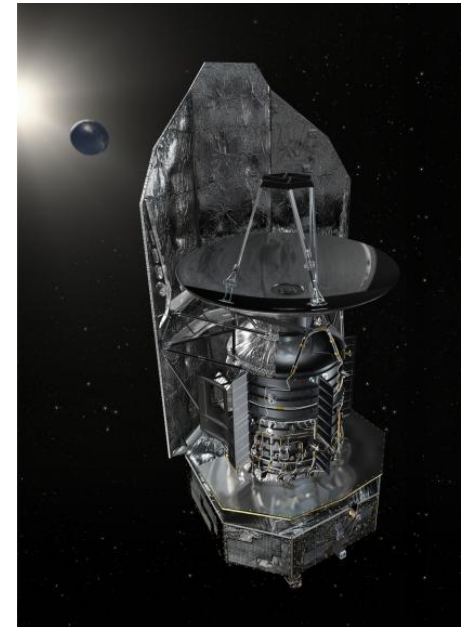
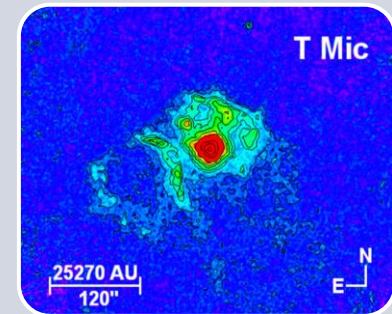
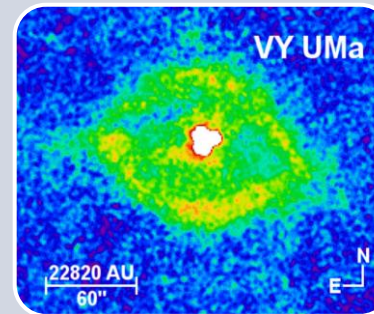
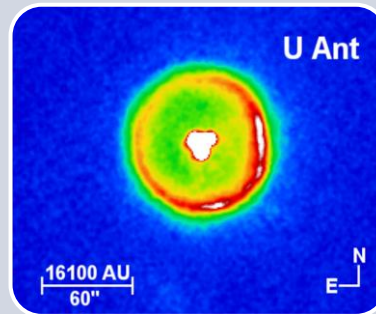
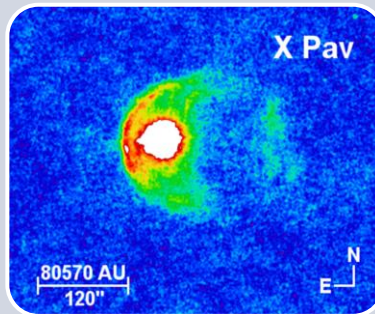


Image (ESA): Herschel

Known binaries in the MESS sample

6

18 of 78 objects are physically related binary systems (10 with extended envelope)



Bow shock
(Wind-ISM
interaction)

o Cet
θ Aps
EP Aqr
W Aql
R Scl

[5/24]

Ring (Wind-wind
interaction)

R Scl

[1/13]

Eye (unknown)

VY UMa
U Cam

[2/7]

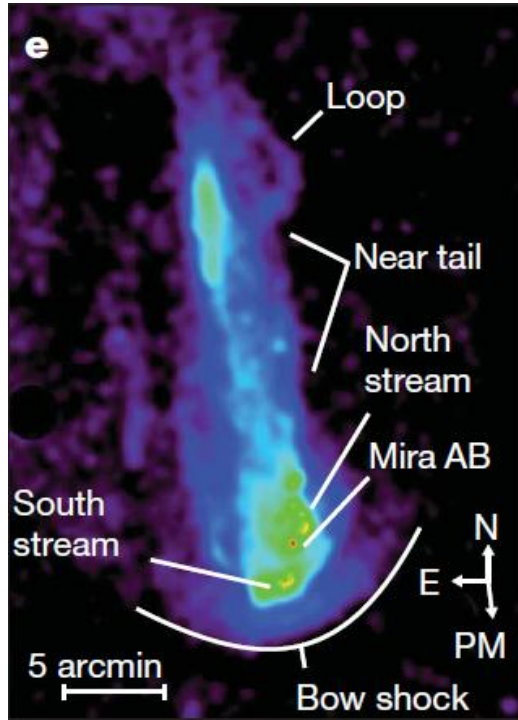
Irregular (binary
interaction?)

o Cet
π¹ Gru
o¹ Ori
R Aqr

[4/7]

o Ceti (Mira)

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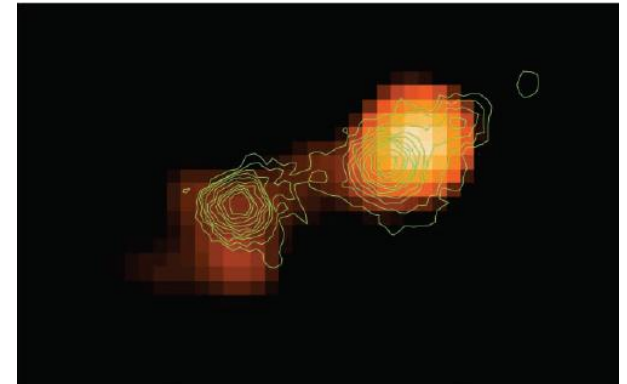
Galaxy FUV

□ FUV

- Very high space velocity (105 km/s) forms bow shock + tail structure (4 pc)
- Collisional excitation of H_2 by hot e^-
- Knotty streams north & south (bipolar outflow)

□ X-ray

- WD companion at 55 AU
- Unknown orbit (>800 yr)

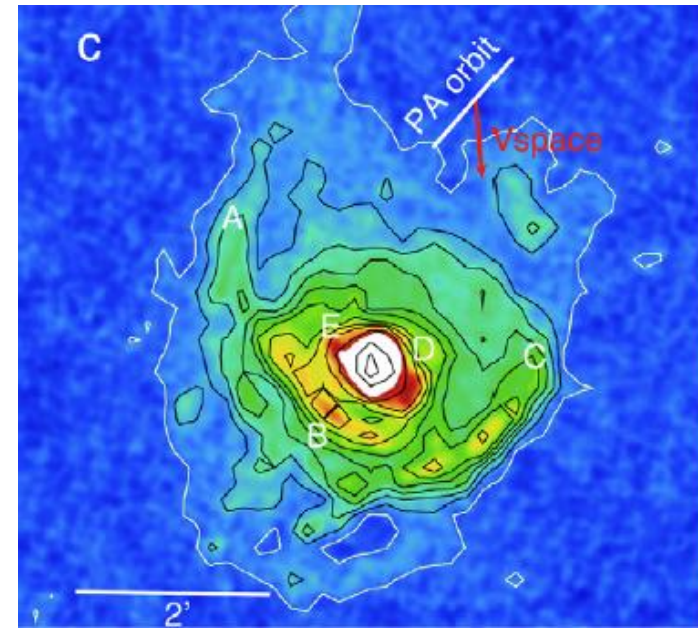
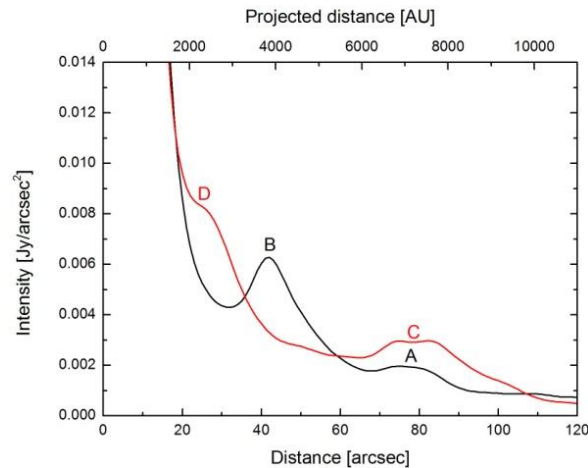
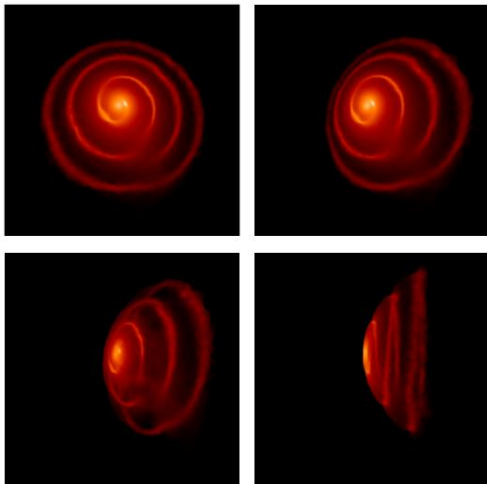


Chandra

Mira in far-IR

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- No bow shock but squeezed astrosphere
- 4 broken arcs reflecting interaction of wind with companion
 - ▣ SPH simulations with Mira config. show spiral pattern inside bow shock

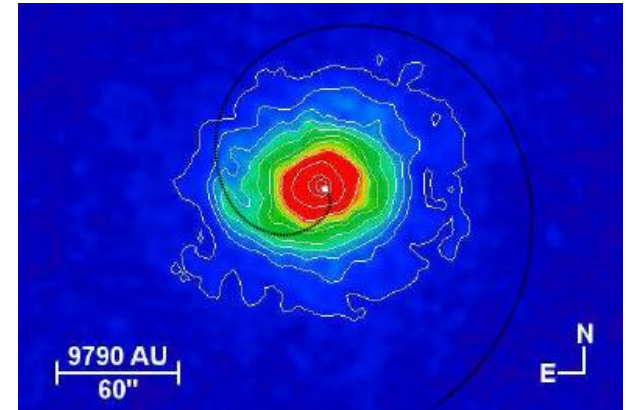


Herschel /PACS 70 μ m

π^1 Gruis

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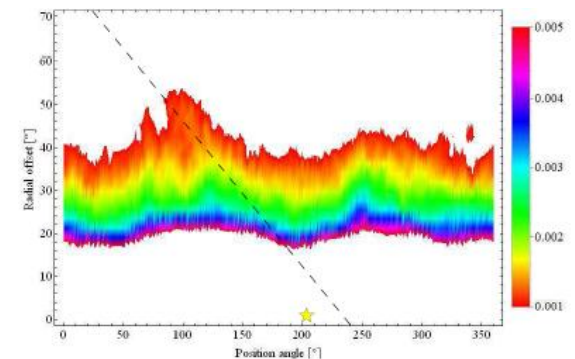
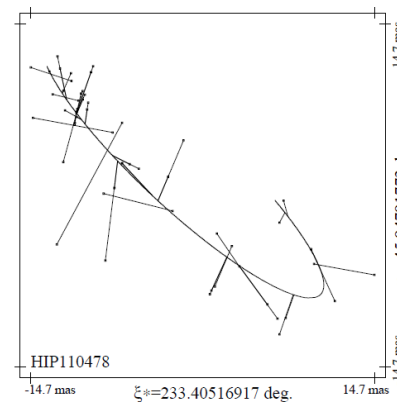
- Very evolved AGB star
 - Known G0V comp.
 - $a = 2.8''$ (450 AU; projected), $P > 6200$ yr
 - Putative 2nd comp. ($\Delta\mu$ and Hipparcos IAD)
 - $4 < a$ (AU) < 30 , $P \approx 10$ yr



- Elliptical CSE

- Arc east of star

- Spiral? 2 possibilities
 - Close comp.: $\rho \approx 0.2''$ ❌
 - G0V comp.: $\rho \approx 117''$

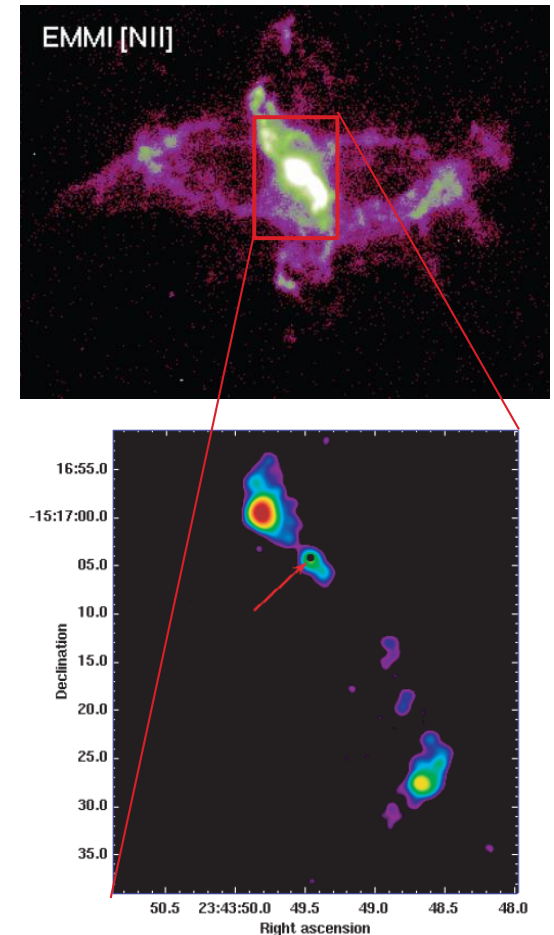


- 2nd condition: start of spiral
- Perfectly fitting spiral: $P_{\text{orb}} = 9000$ yr ($d = 650$ AU; $i = 46^\circ$) or 5 km/s higher v_w

R Aquarii

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- Symbiotic system
 - $d = 12 \text{ AU}$
 - $P_{\text{orb}} = 43.6 \text{ yrs}$
- Optical: surrounded by nebula
 - Ring: radius 9000 AU, tilted by 72°
 - Associated to nova outburst 660 yrs ago, Korean history books: 1074 A.D.
- X-ray: 2 jets north-east & south-west
 - PA: 46° & 211°
 - curved trajectory at large scales ($\approx 5500 \text{ AU}$)

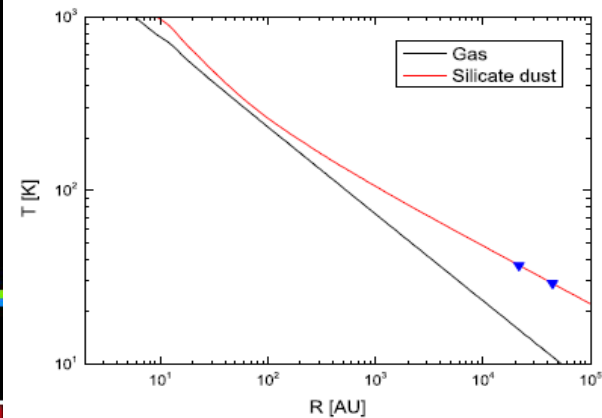
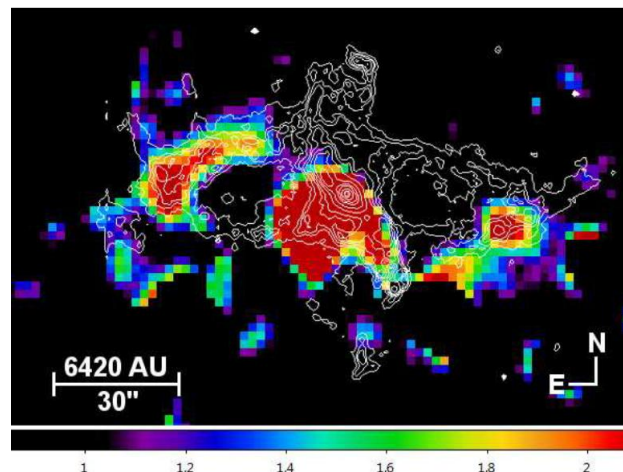
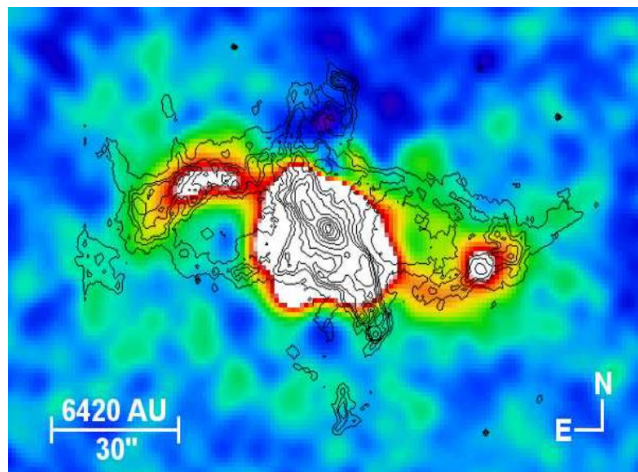


R Aqr in far-IR

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- Counterpart of optical ring
 - ▣ Fits well parts of ring
 - ▣ But: temperature map reveals gradient so structure not circular?

- Temperature gradient
 - ▣ Combined MARCS+wind model
 - ▣ Constant for distances >500 AU
 - ▣ De-projection of arms shows inclination of 77° (close to $i=72^\circ$ of orbital plane)



Mayer et al. (2013), Nowotny et al. (2013), Aringer et al. (2009)

Conclusions & Outlook

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- many stellar AGB winds are asymmetric (on large scales)
- Presence of companion alters wind morphology
 - ▣ Indications for interaction: spiral/arc and bipolar outflow
 - ▣ Multiple morphologies possible
 - ▣ „Ring“ morphology lacks binaries (only 1/13):
companion destroys spherical symmetry of wind bubble?
 - ▣ Only 3 of 10 objects show no binary interaction signs
- ALMA observations will reveal close environments of \omicron Cet, W Aql, π^1 Gru & R Aqr (PI: S. Ramstedt)

Binaries with ext. CSE :

- ▣ \omicron Cet
- ▣ θ Aps
- ▣ EP Aqr
- ▣ R Scl
- ▣ W Aql
- ▣ ~~VY UMa~~
- ▣ ~~U Cam~~
- ▣ π^1 Gru
- ▣ ~~σ^1 Ori~~
- ▣ R Aqr