MESS - Mass loss of Evolved StarS
An overview

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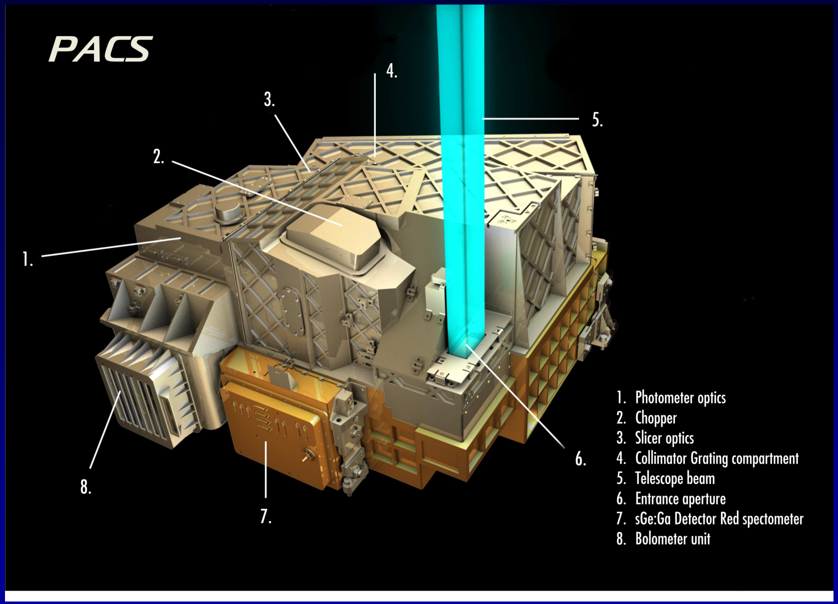
on behalf of the MESS consortium
www.univie.ac.at/space/MESS (consortium website)

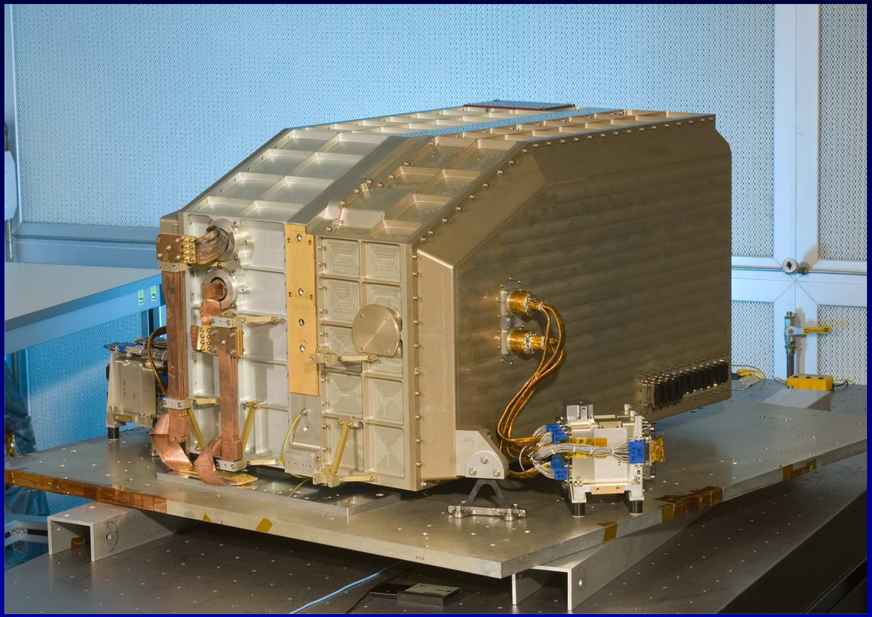
Herschel - Planck launch 14 May 2009

3.3m effective diameter

3 year of Routine Phase starting Dec. 2009

Herschel instruments

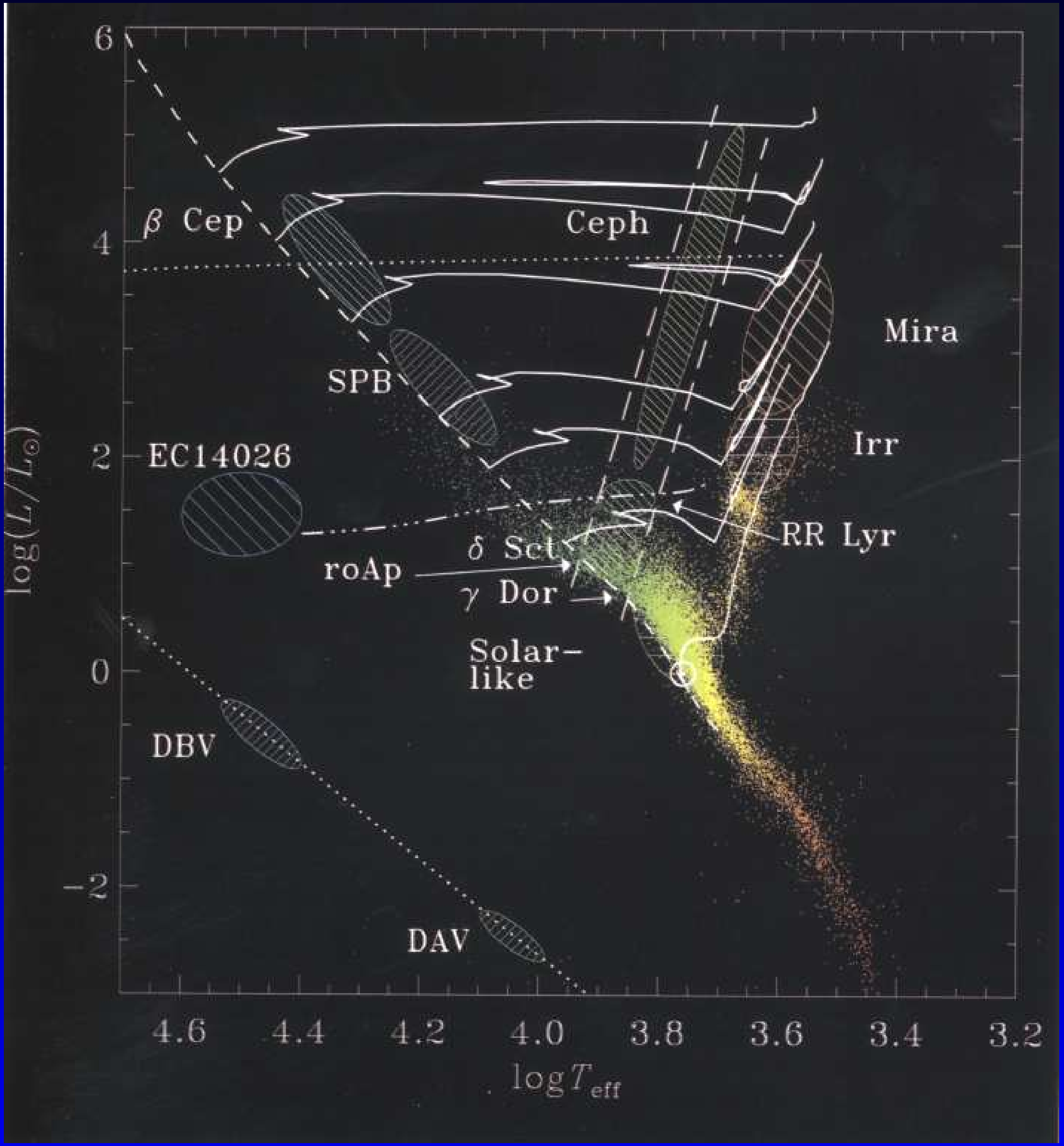




PACS - SPIRE - HIFI

FWHM:
5.6, 6.8, 11.4″ (PACS) 18.1, 25.2, 36.6″ (SPIRE)

Evolved stars



Evolved stars GT Key Programs

MESS (Mass loss of Evolved StarS) - PACS + SPIRE
(PI: Martin Groenewegen
PACS Co-PI:Christoffel Waelkens,KUL,IMEC,CSL)

PACS (50-200 μm) SPIRE (200-650 μm)

both have bolometer arrays (FOV of a few arcmin)

both have a spectrometer (R= 1000-2000)

HIFISTARS - HIFI (PI: Valentin Bujarrabal)

Other smaller programs in OT1, GT2,
OT2 (June 9 - Sep 15)

MESS

This GT KP aims at studying the circumstellar matter in evolved objects

- AGB, Post-AGB, PNe, RSG, WR, LBV, SN
  - Photometric mapping of nearby objects
  - Spectroscopy of nearby objects
  - SPIRE and PACS
- Mass-loss dominates the evolution
  How? How much? Time evolution? Spherical?
  Production of dust
- $\dot{M}(Z)$
  AGB vs. SN gas & dust return at high-z

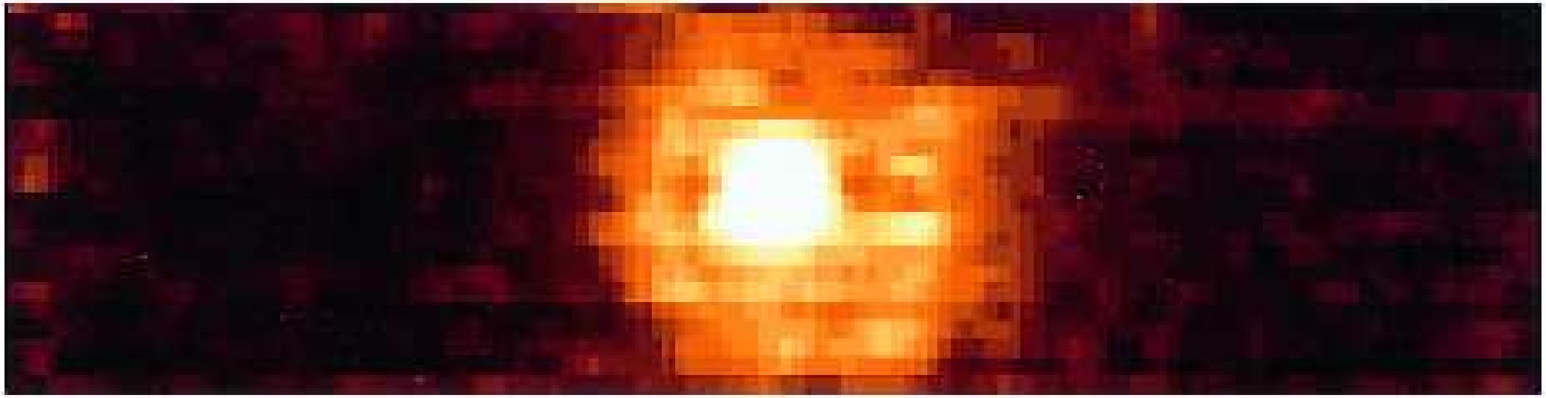


Fig. 1. 90 μm image of Y CVn taken with PHT-C100 array detector and C90 filter displayed in linear brightness scale.

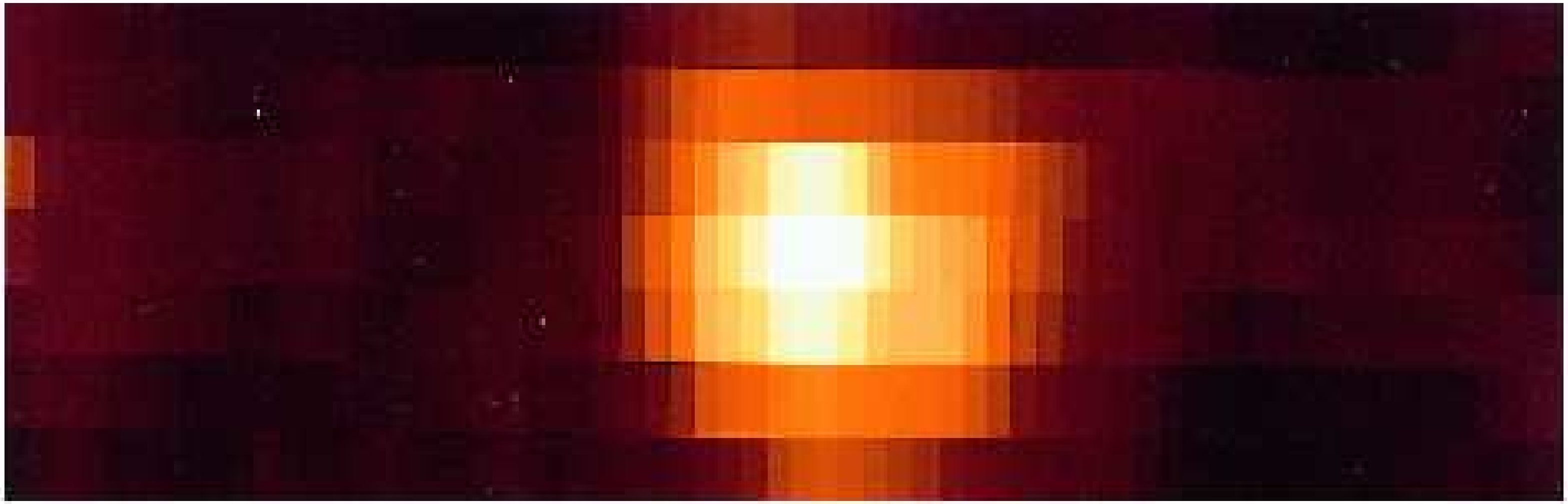
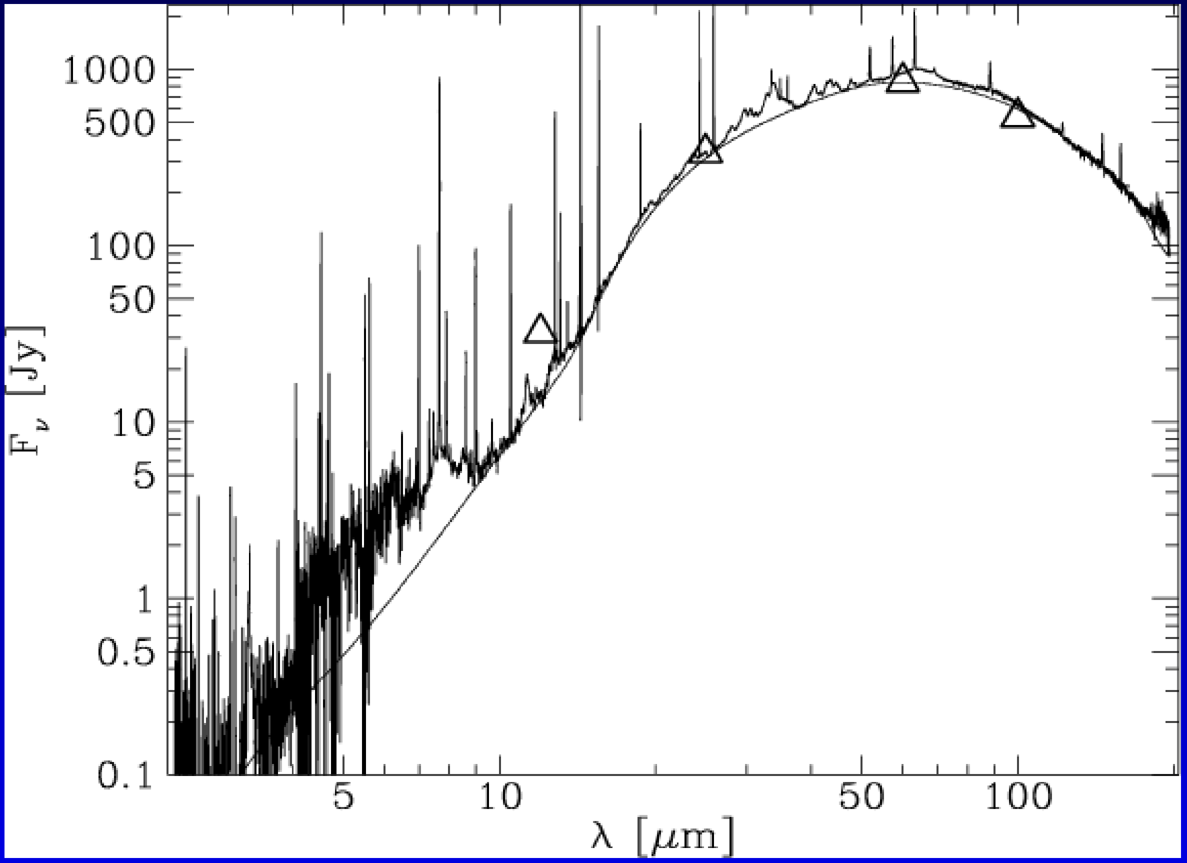


Fig. 2. 160 μm image of Y CVn taken with PHT-C200 array detector and C160 filter displayed in linear brightness scale.

Y CVn
Izumiura et al. (1996), $8' \times 35'$ ISOPHOT map

Spectroscopy of nearby objects

Goal: Study of
dust properties, molecular lines, emission lines



NGC 6302; Molster et al., SWS + LWS spectrum

Dust and Ices

mineral	chemical formula	'60+' band positions [μm]
fosterite	Mg_2SiO_4	69–70
fayalite	Fe_2SiO_4	93–94, 110
diopside	$CaMgSi_2O_6$	65-66
calcite	$CaCO_3$	92
dolomite	$CaMg(CO_3)_2$	62
water ice	H_2O	62
methanol ice	α-CH_3OH	68, 88.5
dry ice	CO_2	85
PAHs "flopping modes"		(far-IR)

Partners involved

Partner	"origin"	hours	special interest
Belgium	PACS GT	145	KUL (AGB, post-AGB, PN, WR, LBV)
			ROB (AGB, PN)
			ULB (binary AGB)
			IAGL (WR, LBV)
Vienna	PACS GT	47	AGB
Heidelberg	PACS GT	10	SN remnants
SAG 6	SPIRE GT	80	SN, AGB, post-AGB, PN
HSC	HSC	26	special type of post-AGB
MS	MS	5	Molecules in specific stars
		—-	
		313	

Implementation (Photo)

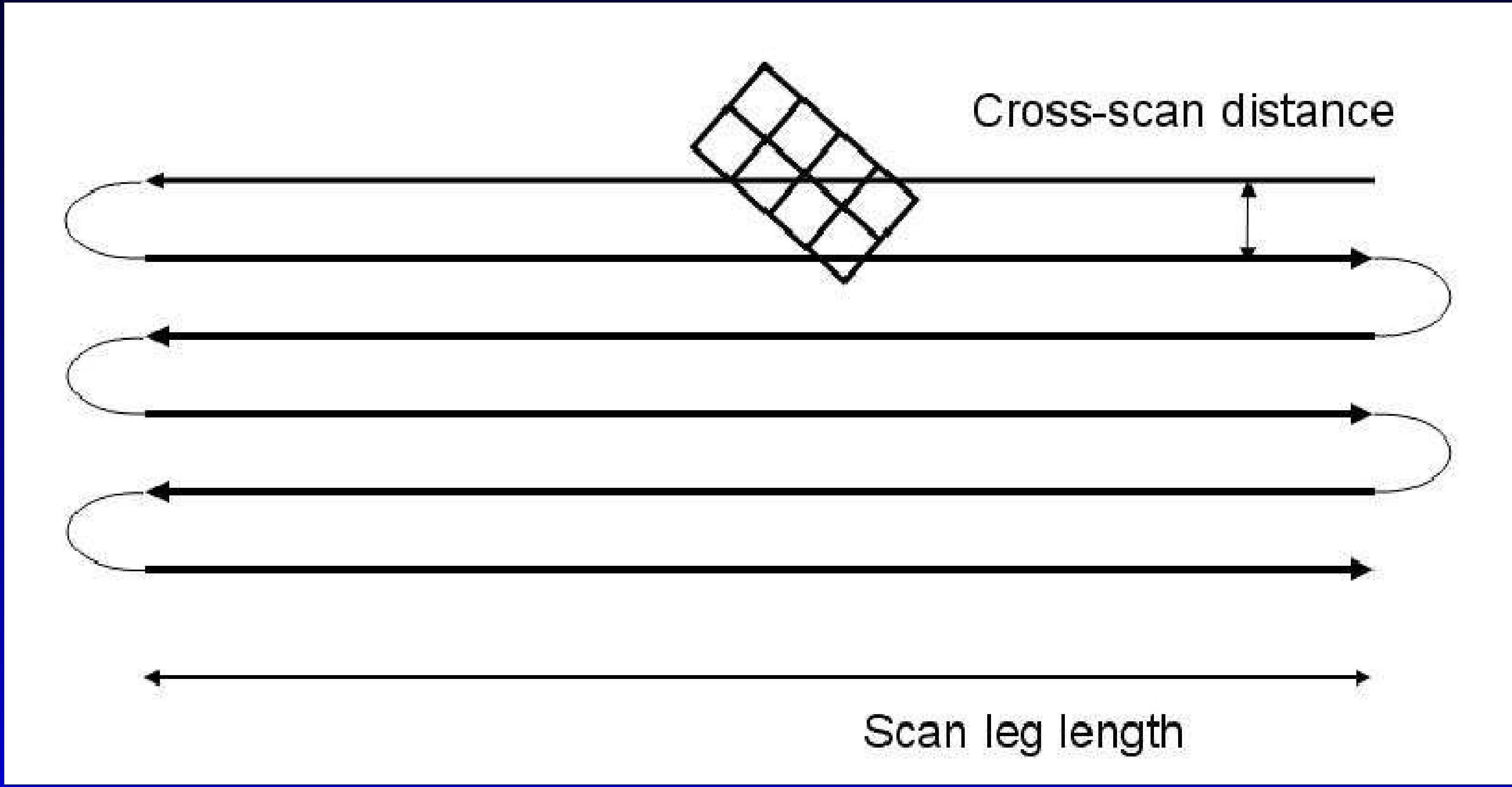
PACS:
"Scan Maps" at 70 + 160 μm

78 AGB/RSG, 16 post-AGB/PN, 8 WR/LBV, 5 SN

SPIRE:
"Large maps" at 250, 350, 500 μm

26 AGB/RSG, 8 post-AGB/PN, 5 SN

Mapping strategy



PACS: concatenate scan and cross-scan;
for SPIRE this is done in a single AOR.

Implementation (Spectro)

PACS:
Concatenation of two AORs to cover entire 60-210 μm region

27 AGB/RSG, 26 post-AGB/PN, 2 WR/LBV, 4 SN

SPIRE:
Complete FTS scan in a single AOR

9 AGB/RSG, 10 post-AGB/PN, 2 WR/LBV, 5 SN

Results

8 papers in the A&A Volume 518 Special Issue

+ 1 Nature paper

+ Overview paper
(Groenewegen et al. 2011, A&A 526, A162)

+ several in preparation

NOT:

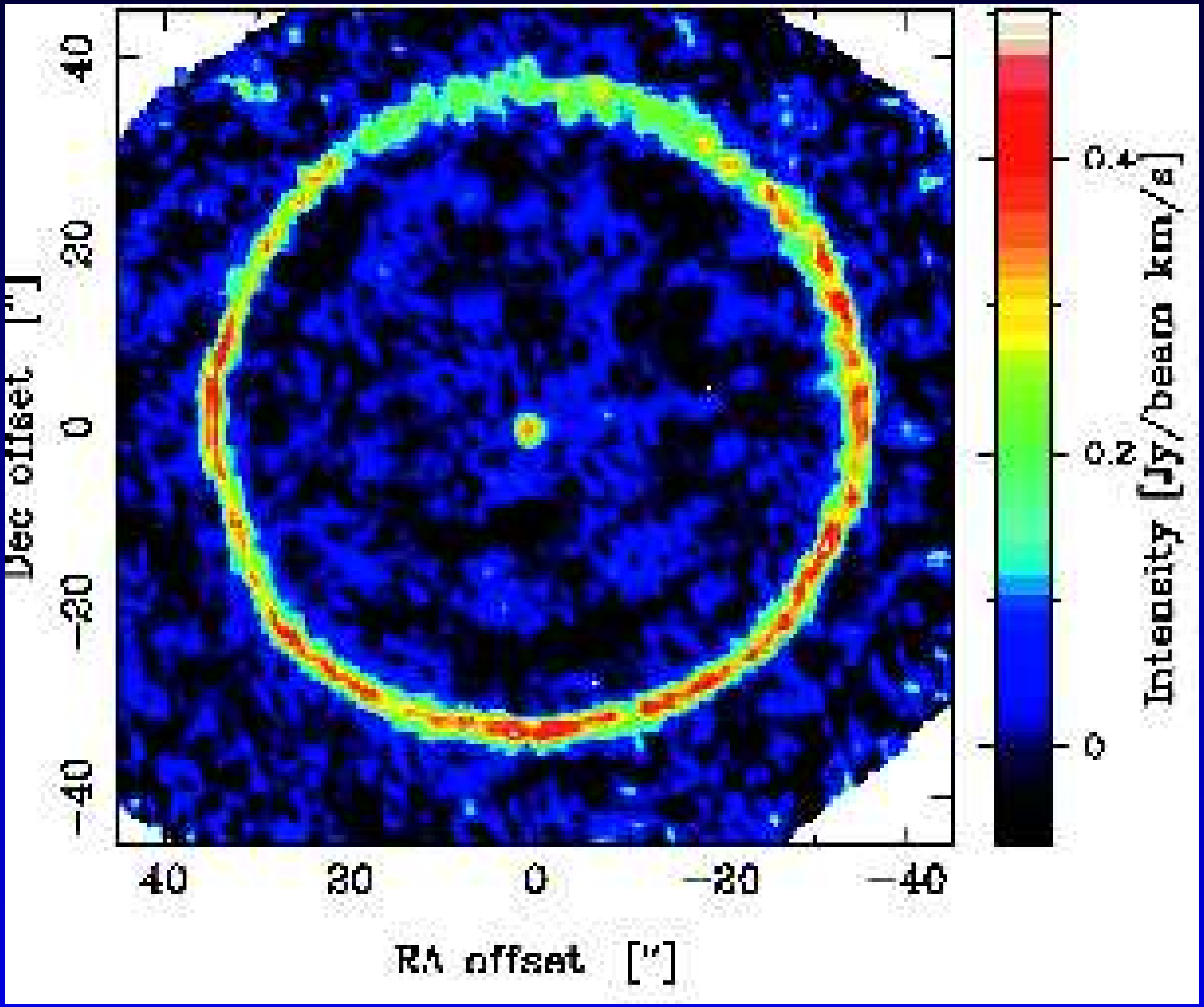
-SNe
-Massive stars
-PNe

In more detail:

-AGB imaging and modelling

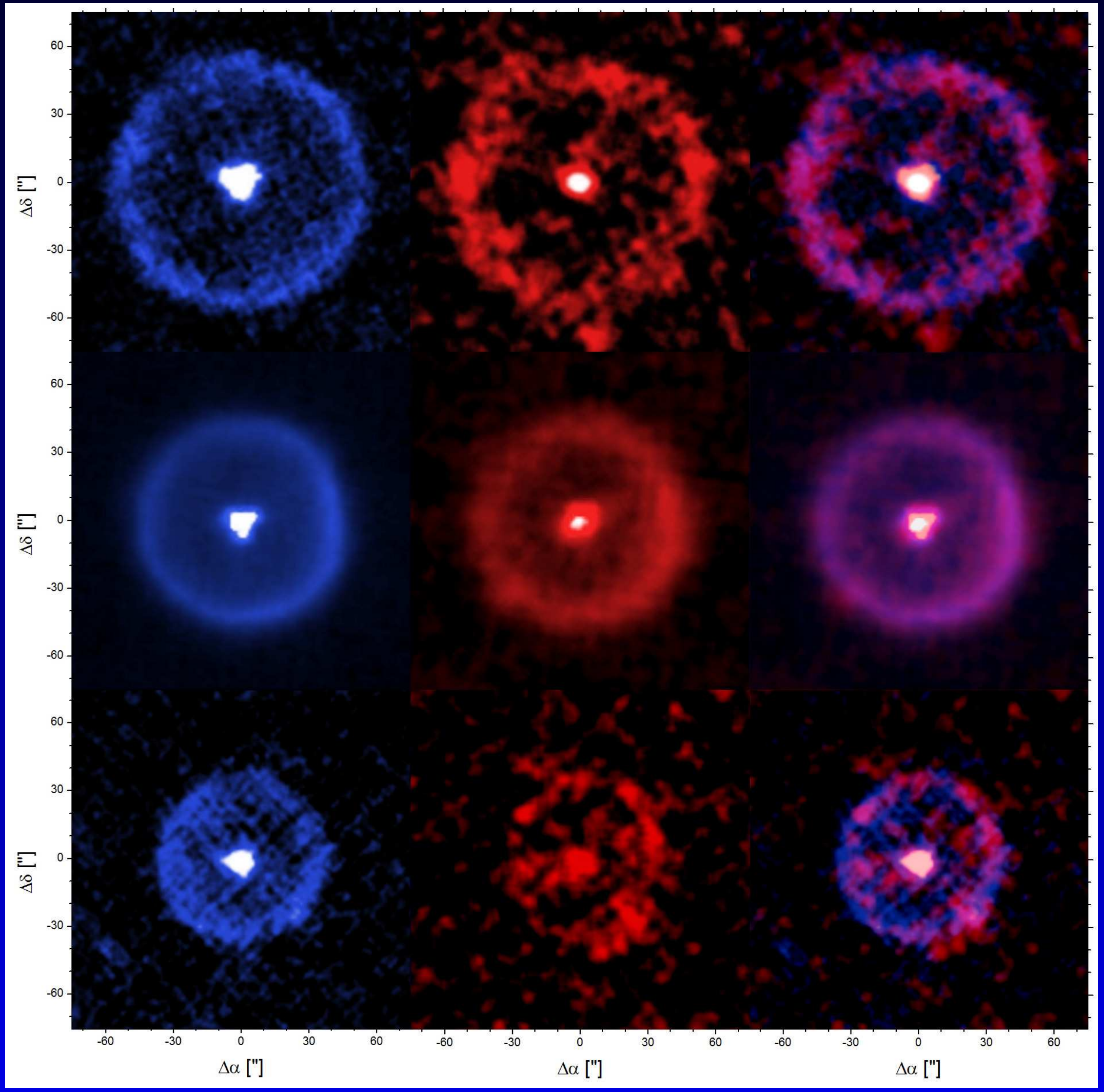
-AGB spectroscopy

Detached shells



TT Cyg; Olofsson et al. (2000). PdB CO (1-0)

Detached shells

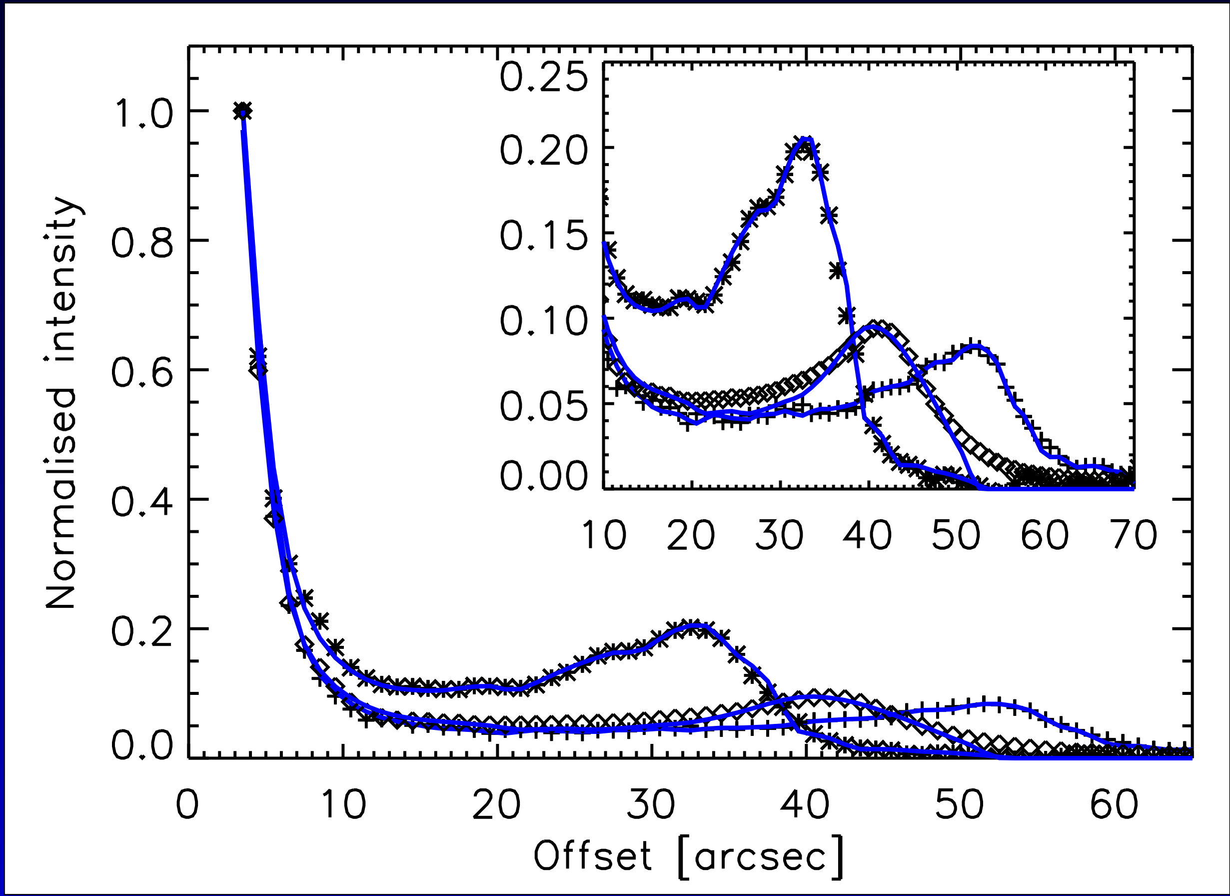


Kerschbaum et al. (2010)

PACS:
blue / red / combined

AQ And,
U Ant,
TT Cyg

Detached shells

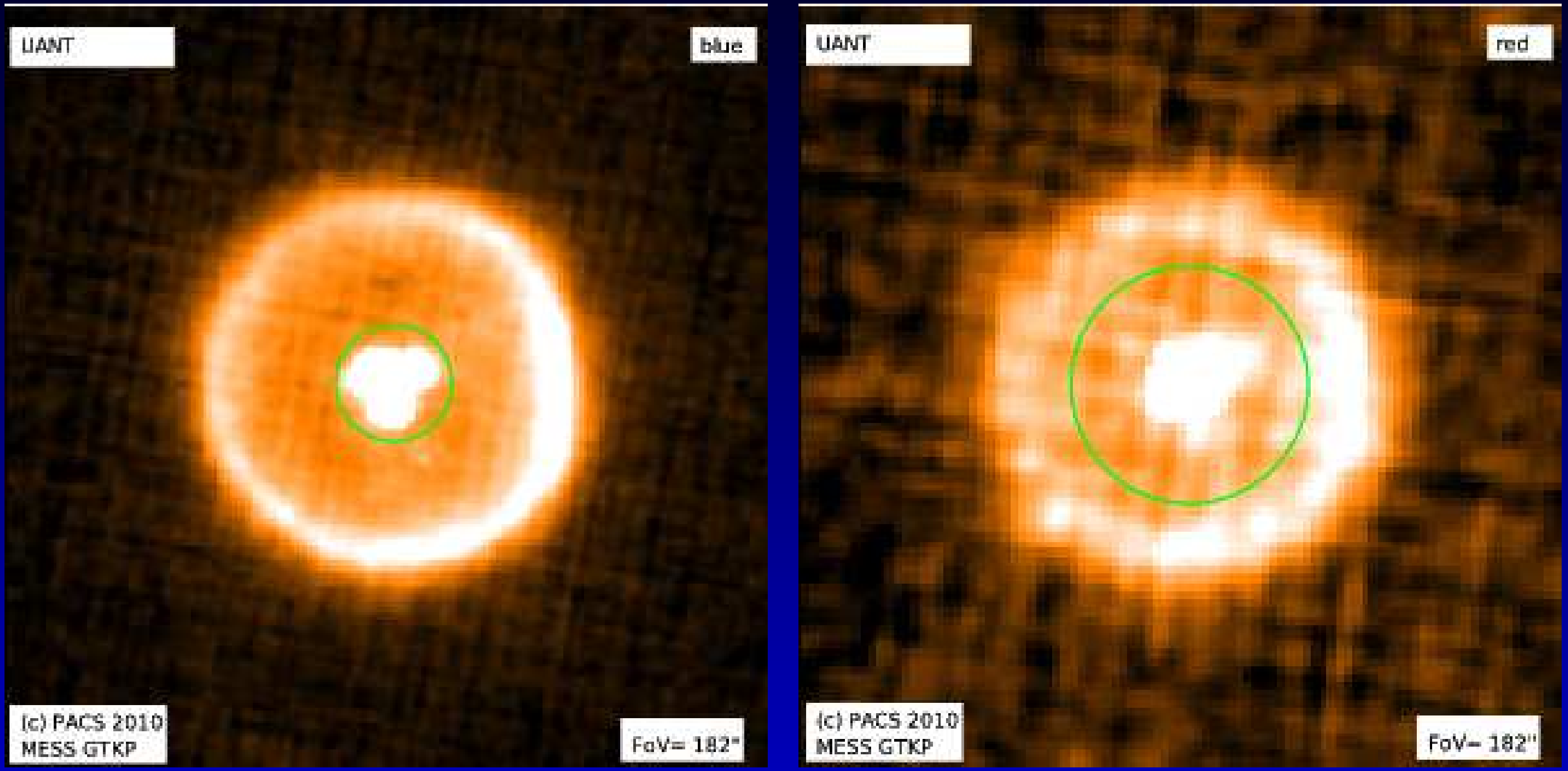


AQ And=+
U Ant=◇
TT Cyg=×

DUSTY multiple-shells $T_{\rm dust}$ = 25-50 K

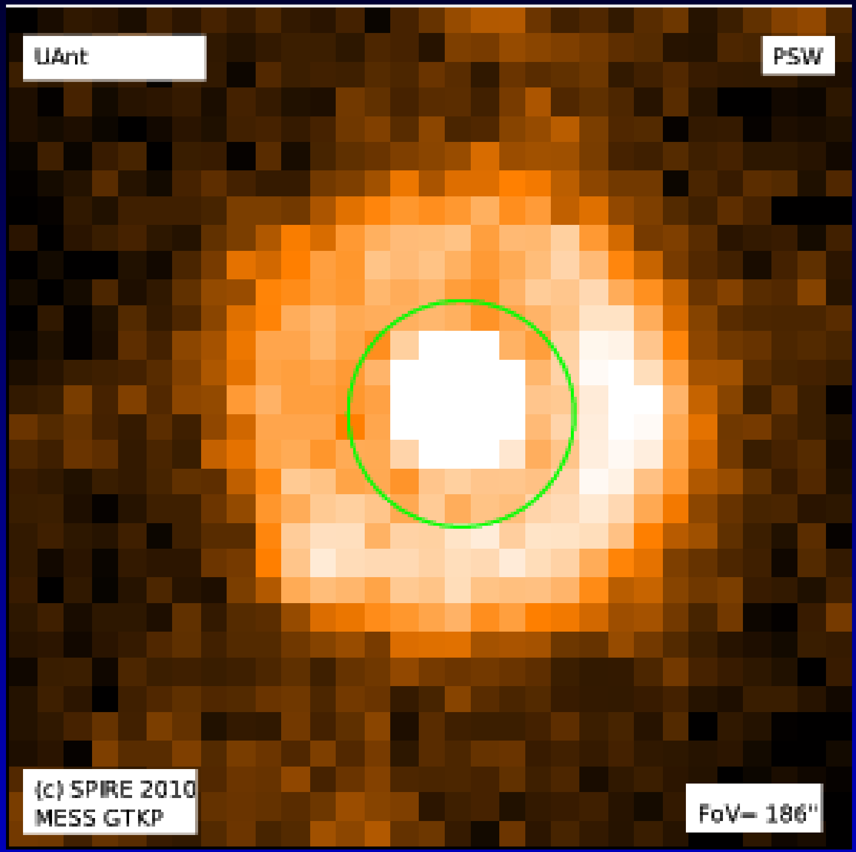
Kerschbaum et al. (2010, A&A Special Issue)

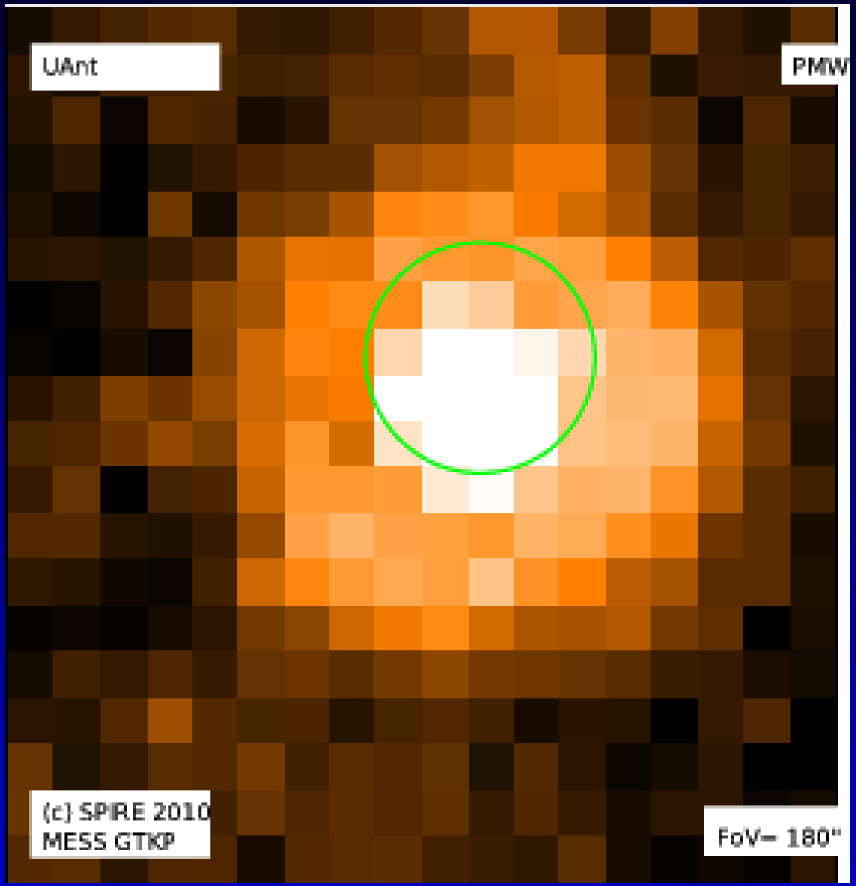
Spatial Resolution



U Ant PACS blue and red

U Ant



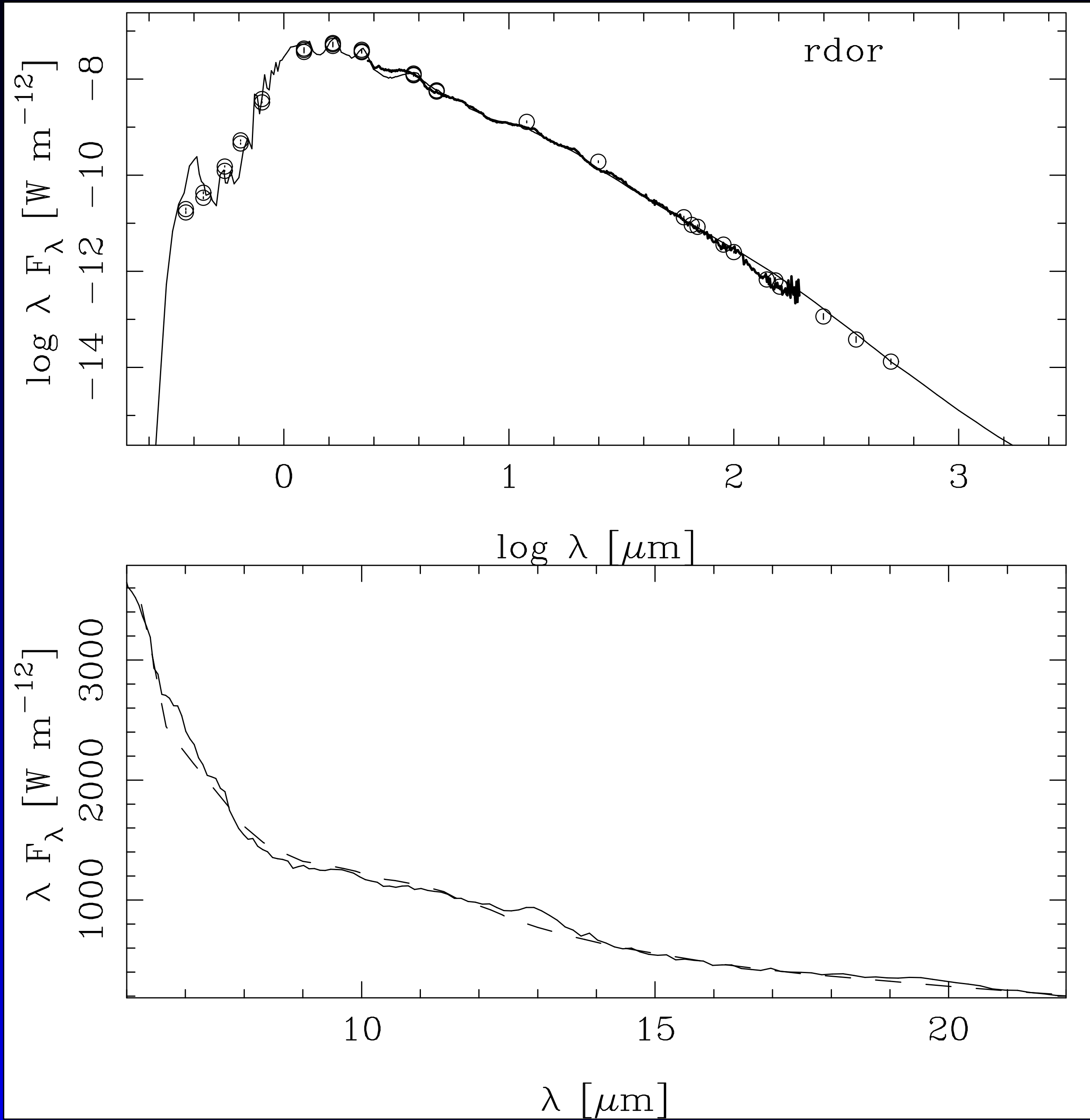


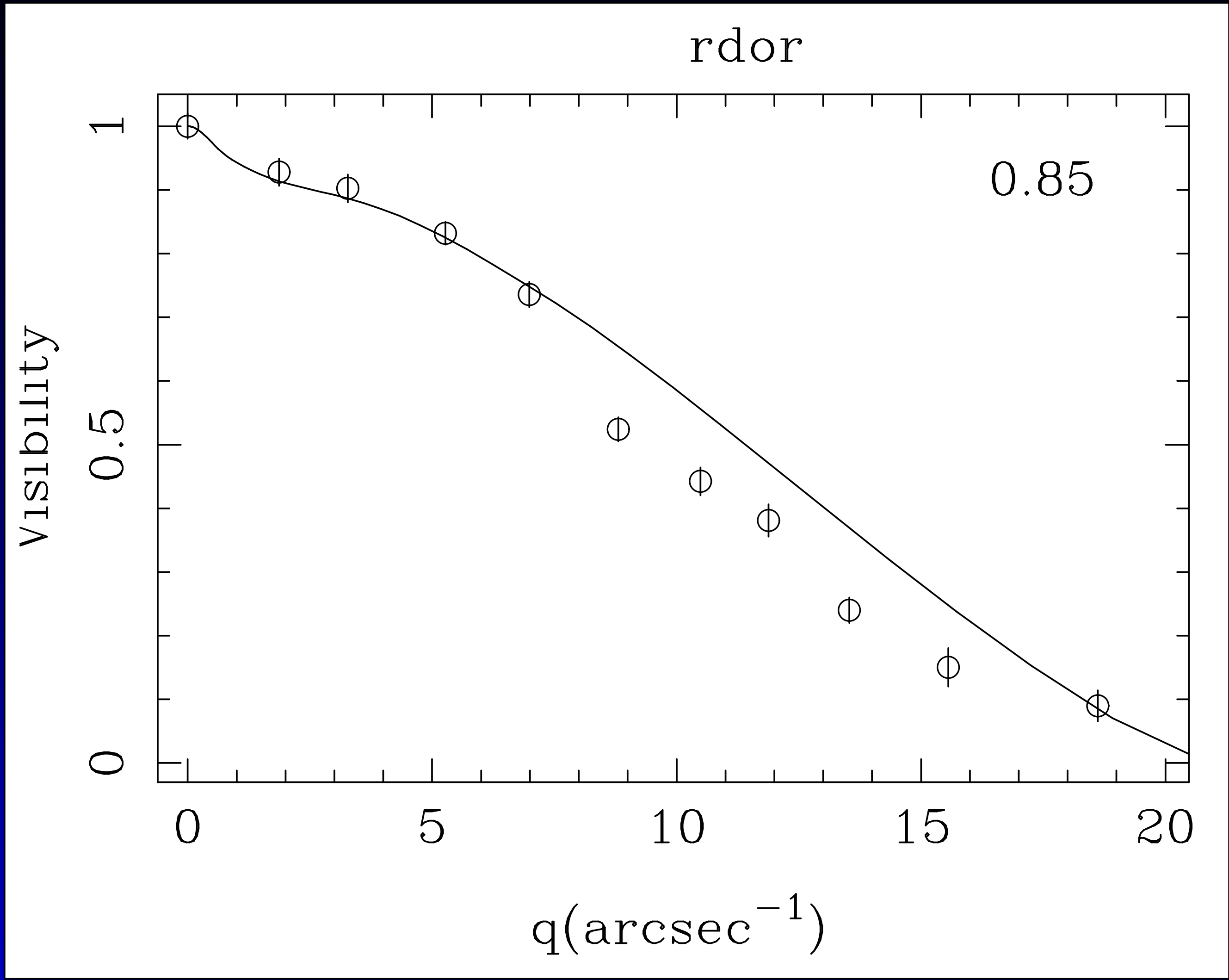
SPIRE PSW and PMW

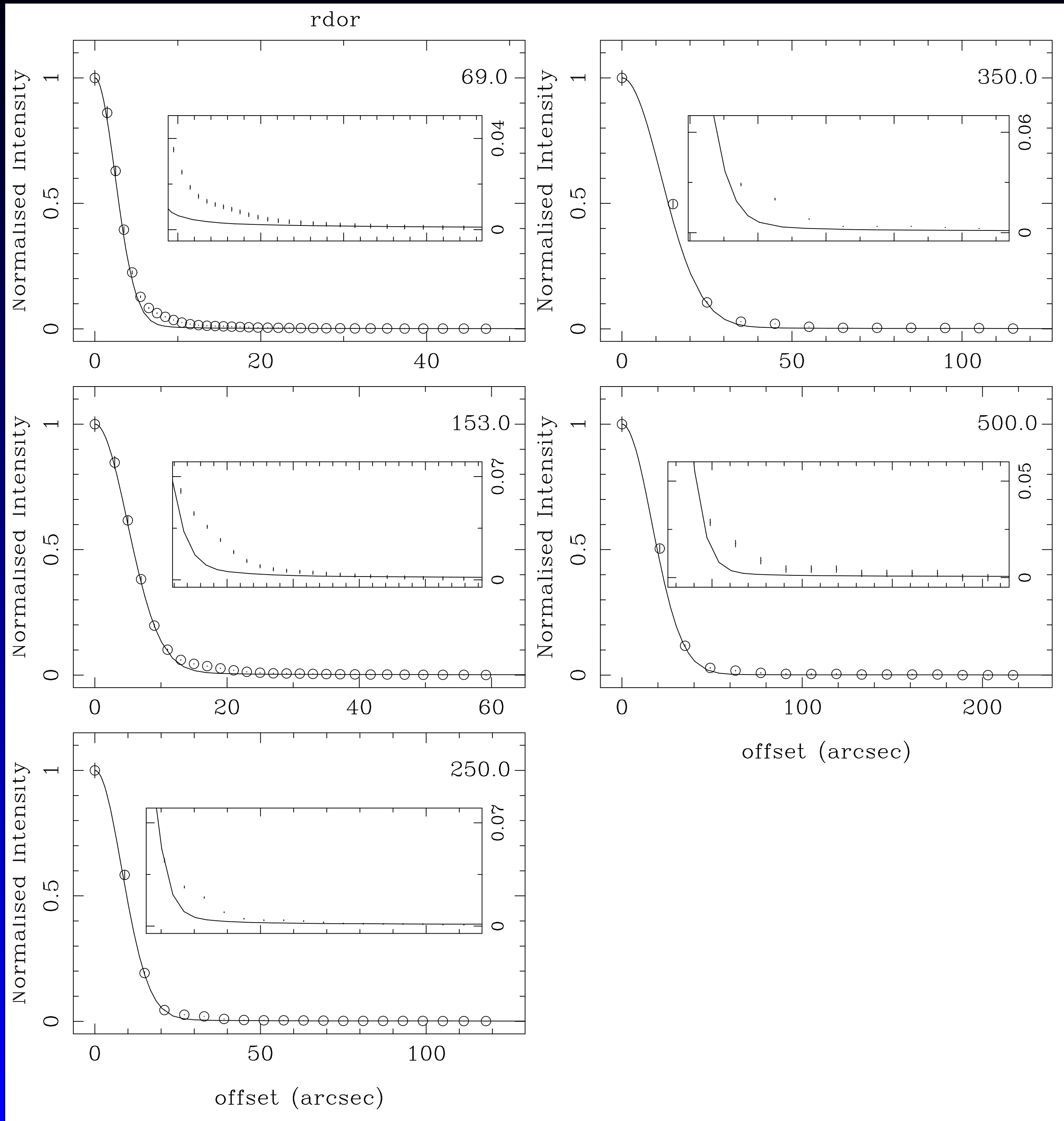
MoD - More of DUSTY

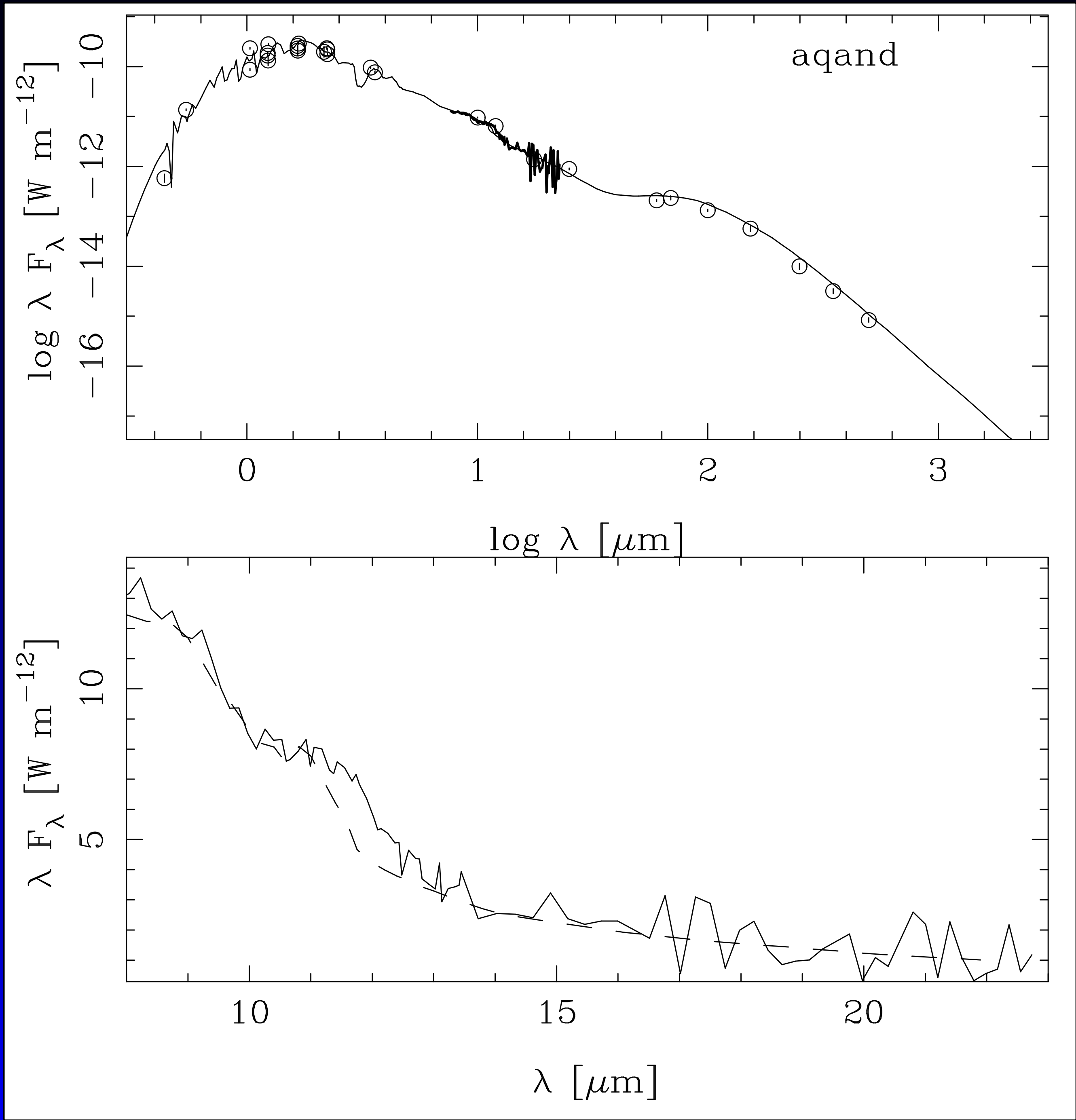
- Improved DUSTY
  (discontinuous density distribution)
- embedded DUSTY code into a minimisation routine
- Can fit photometry, spectra, intensity distributions and visibility data

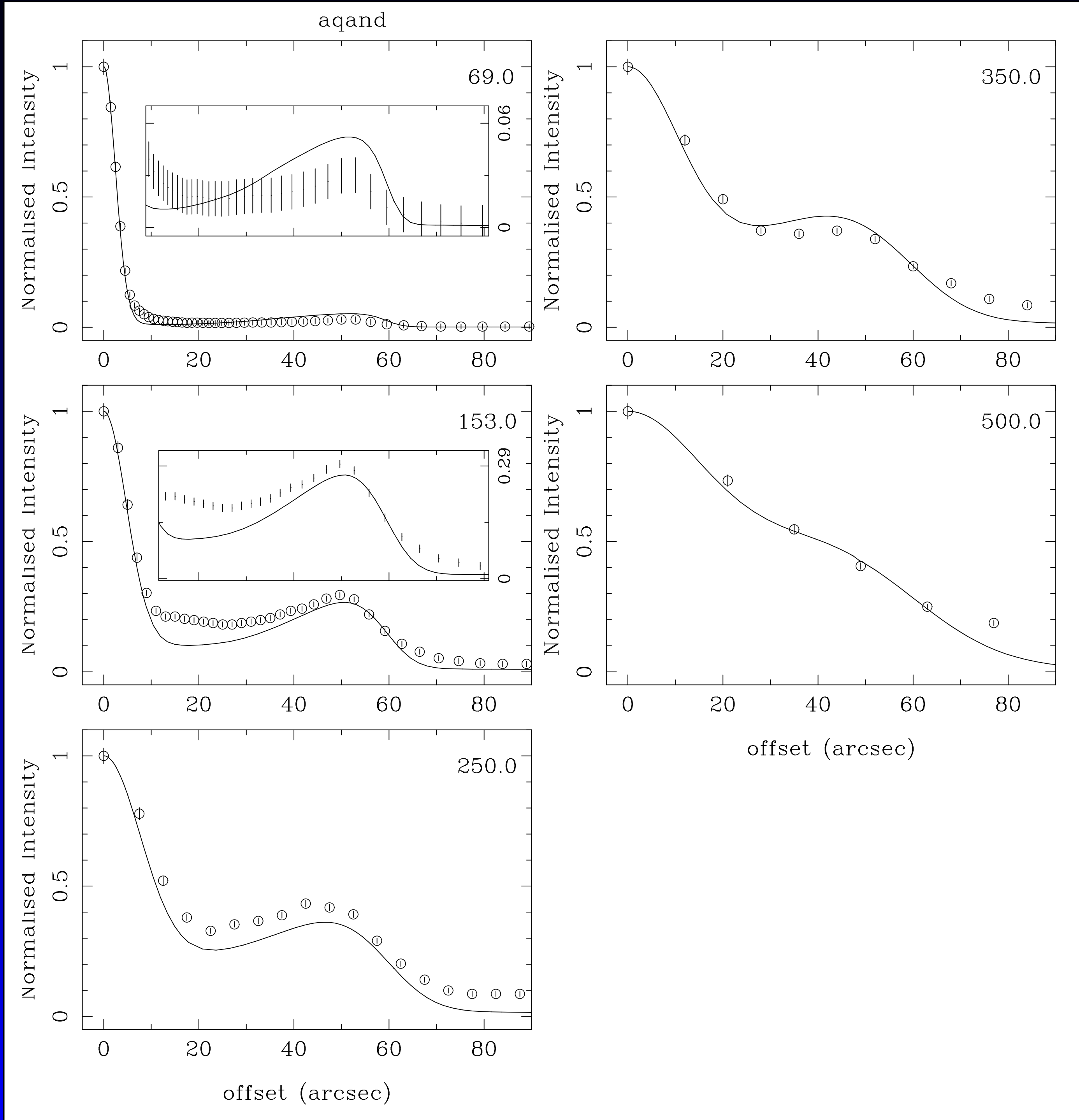
- R Dor: 4 parameters
  L, $\tau_{\rm V}$, $T_{\rm inner}$, $p_{\rm o}$
- AQ And: 7 parameters
  L, $\tau_{\rm V}$, $R_{\rm in,shell}$, $\Delta R_{\rm shell}$, $p_{\rm o}$, $p_{\rm shell}$, 'density jump'

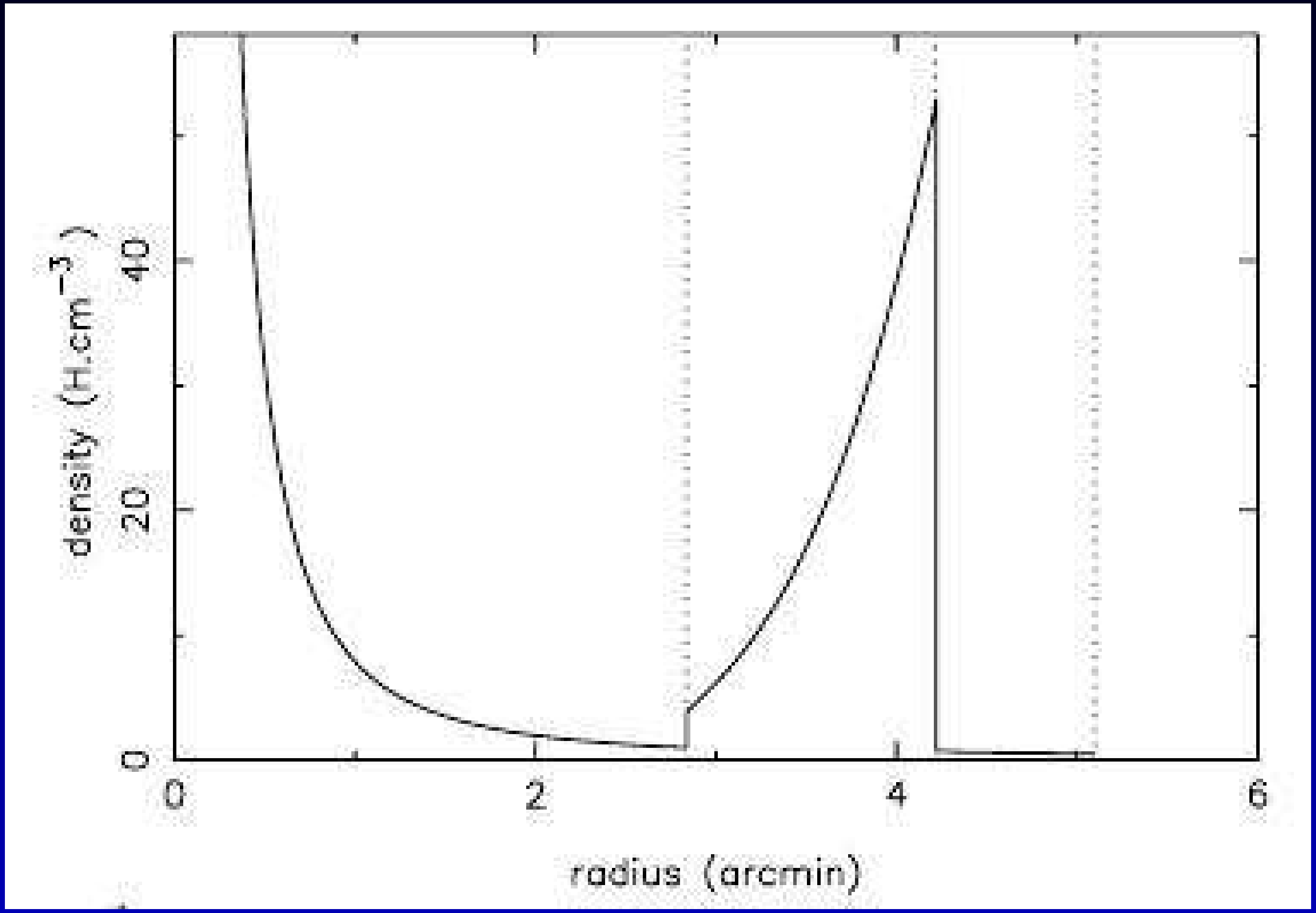

rdor
log λ F_λ [W m^−12]
−8
−10
−12
−14
0
1
2
3
log λ [μm]
λ F_λ [W m^−12]
1000
2000
3000
10
15
20
λ [μm]


rdor
0.85
Visibility
1
0.5
0
0
5
10
15
20
q(arcsec^{-1})


rdor
69.0
350.0
153.0
500.0
250.0
Normalised Intensity
offset (arcsec)
0
0.5
1
0.04
0.06
0.07
0.05
20
40
60
50
100
200

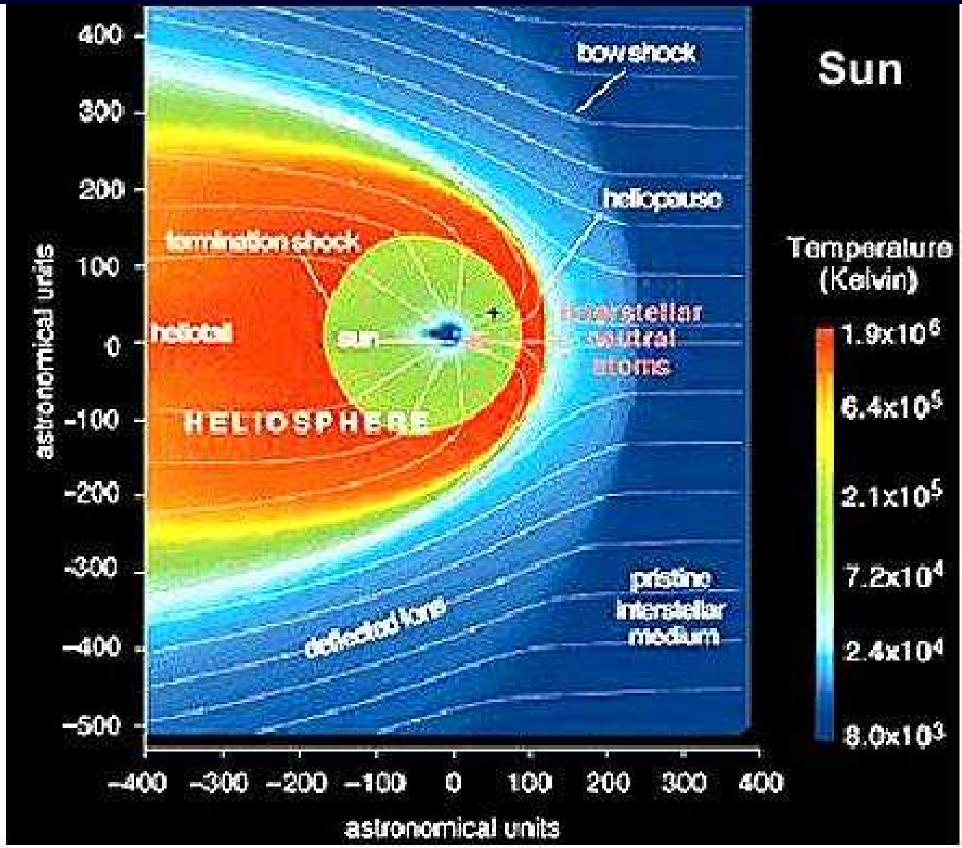

aqand
log λ F$_\lambda$ [W m^{-12}]
−10
−12
−14
−16
0
1
2
3
log λ [μm]
λ F$_\lambda$ [W m^{-12}]
10
5
10
15
20
λ [μm]

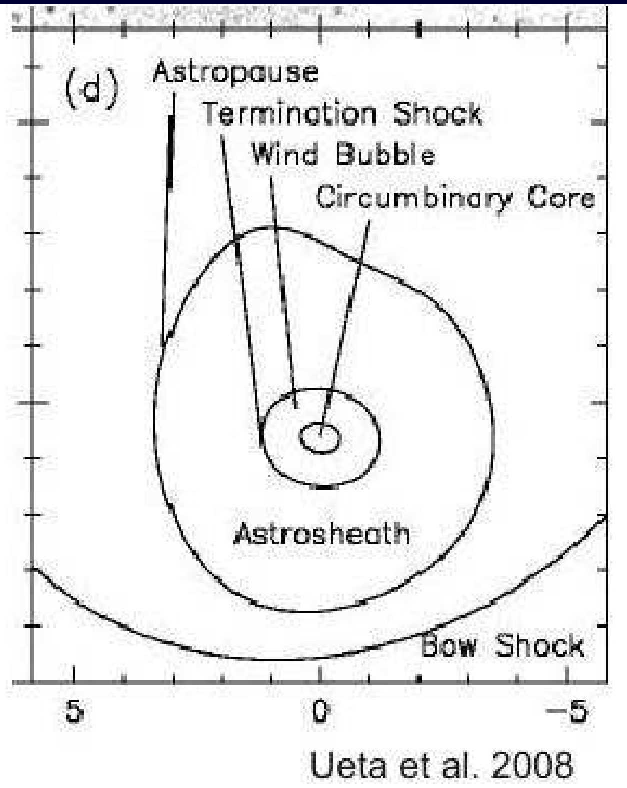

aqand
69.0
350.0
153.0
500.0
250.0
Normalised Intensity
offset (arcsec)
0.06
0.29



Libert et al. 2007, Y CVn, $p_{\rm shell}$= +6

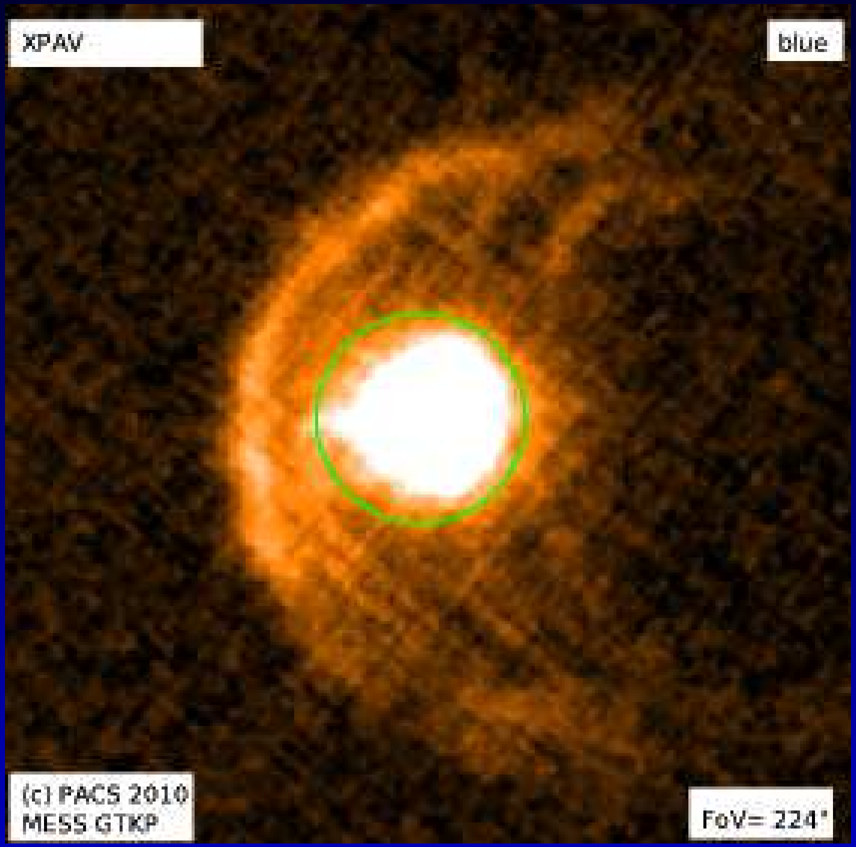
Interaction ISM

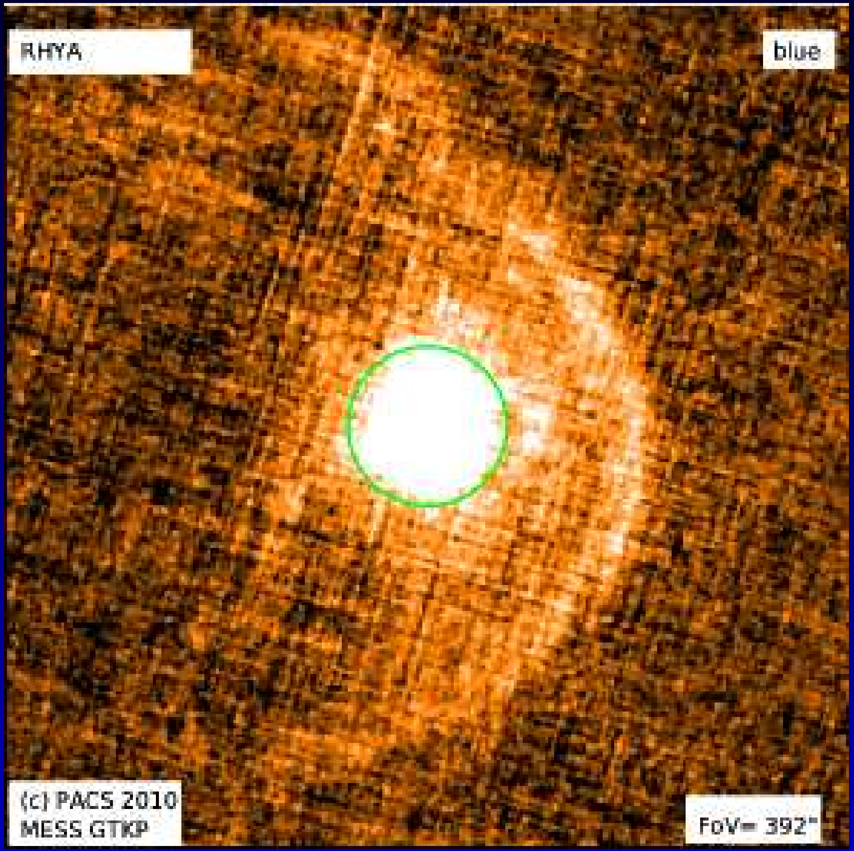




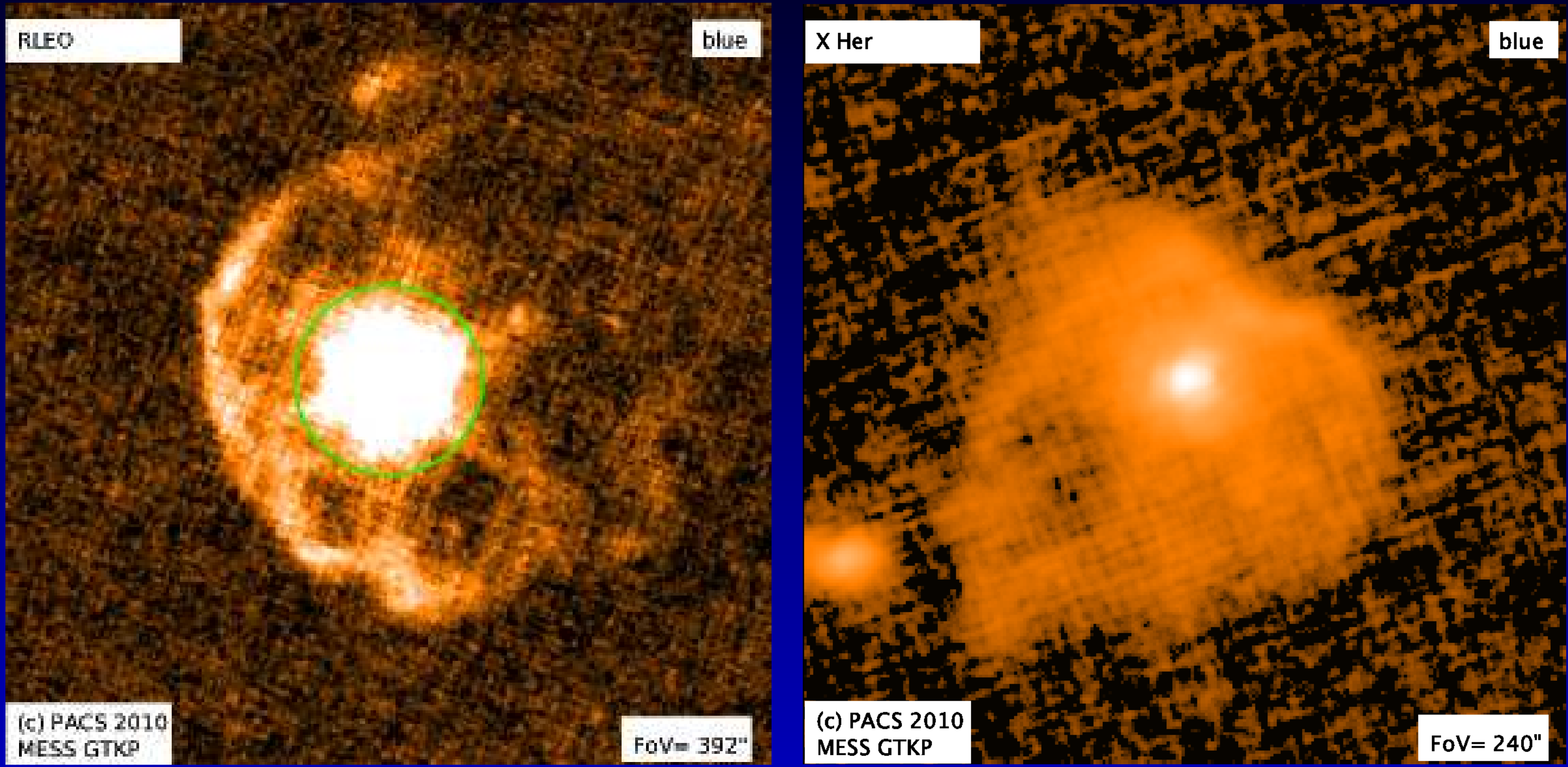
bow shock: where $V_{\rm ISM}$ goes from super- to subsonic
astropause: where $P_{\rm ISM} = P_{\rm CSE}$
termination shock: where $V_{\rm CSE}$ goes from super- to subsonic

The Zoo

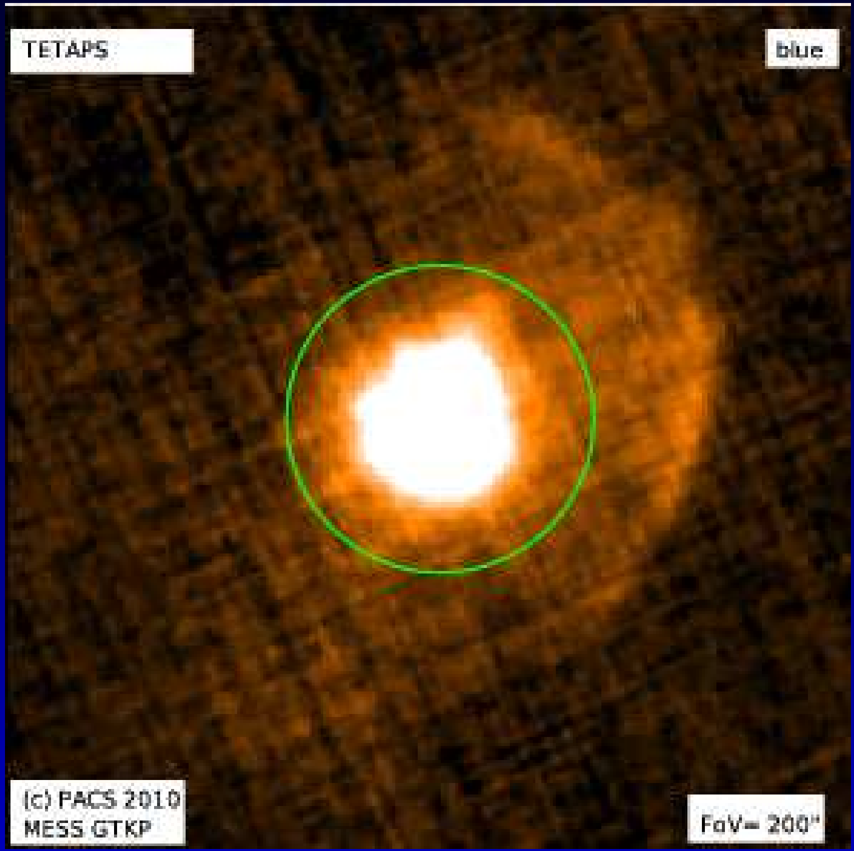


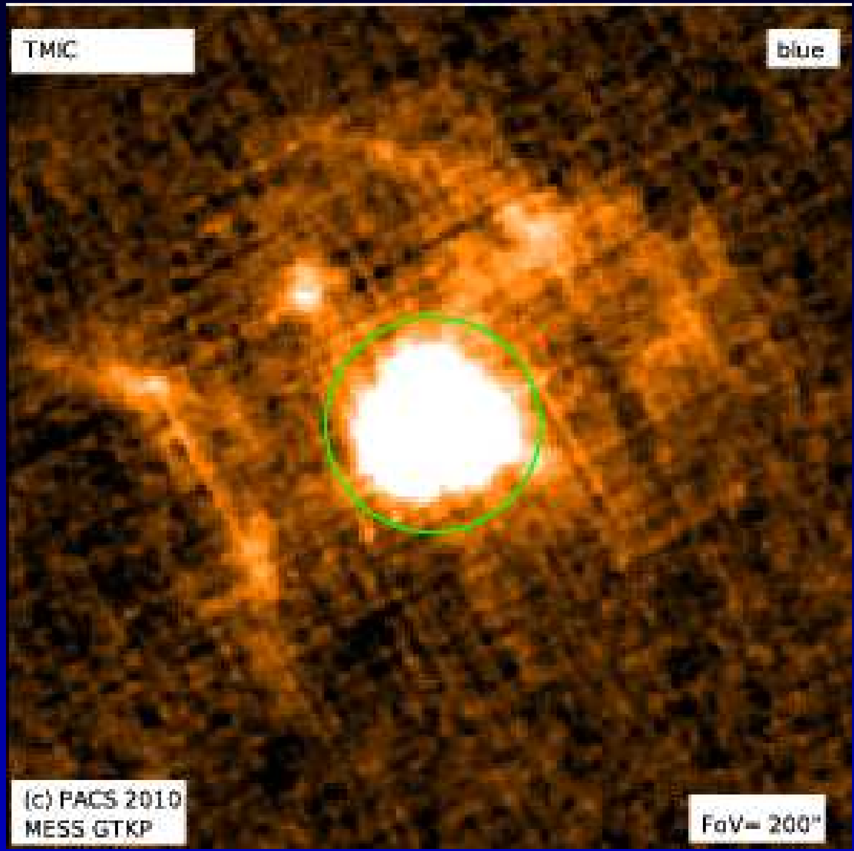


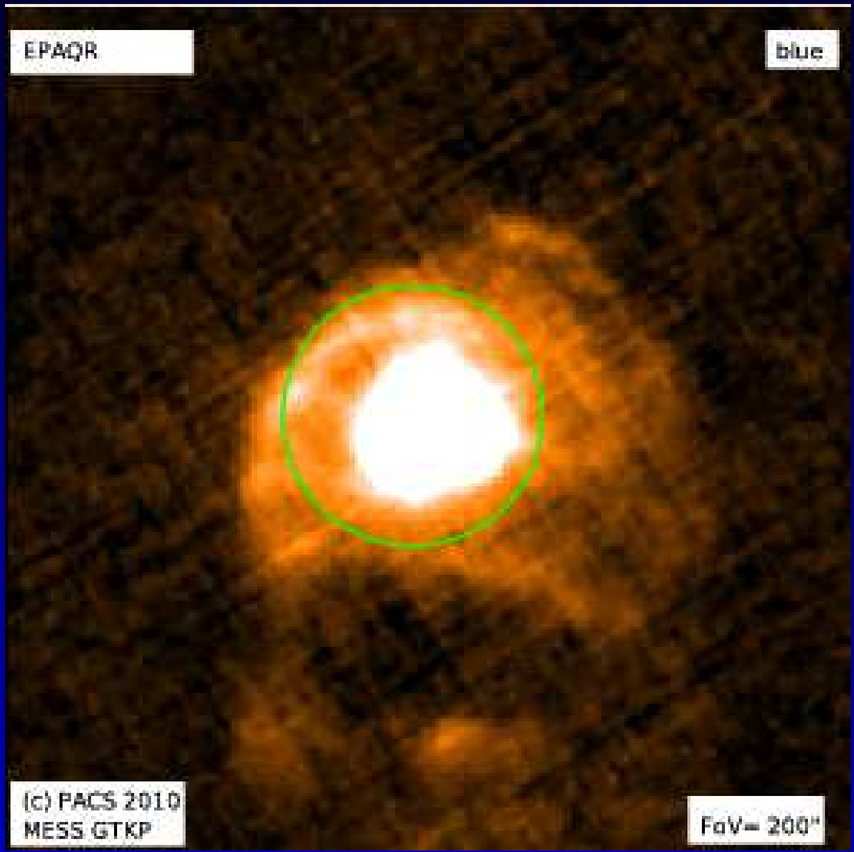
Cox et al. (in prep).

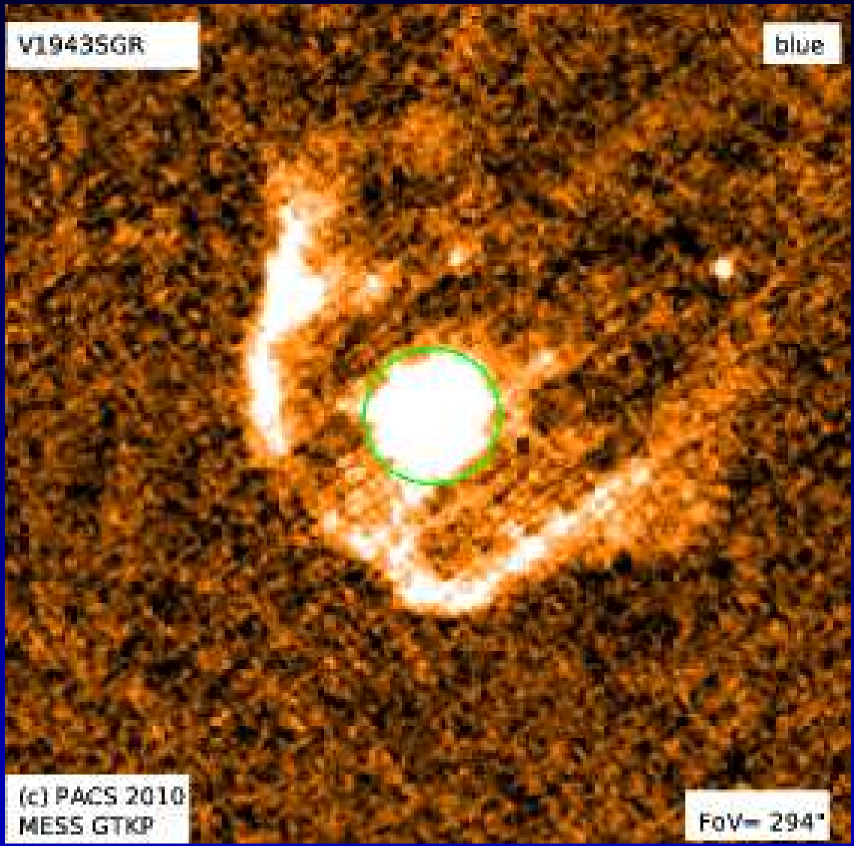


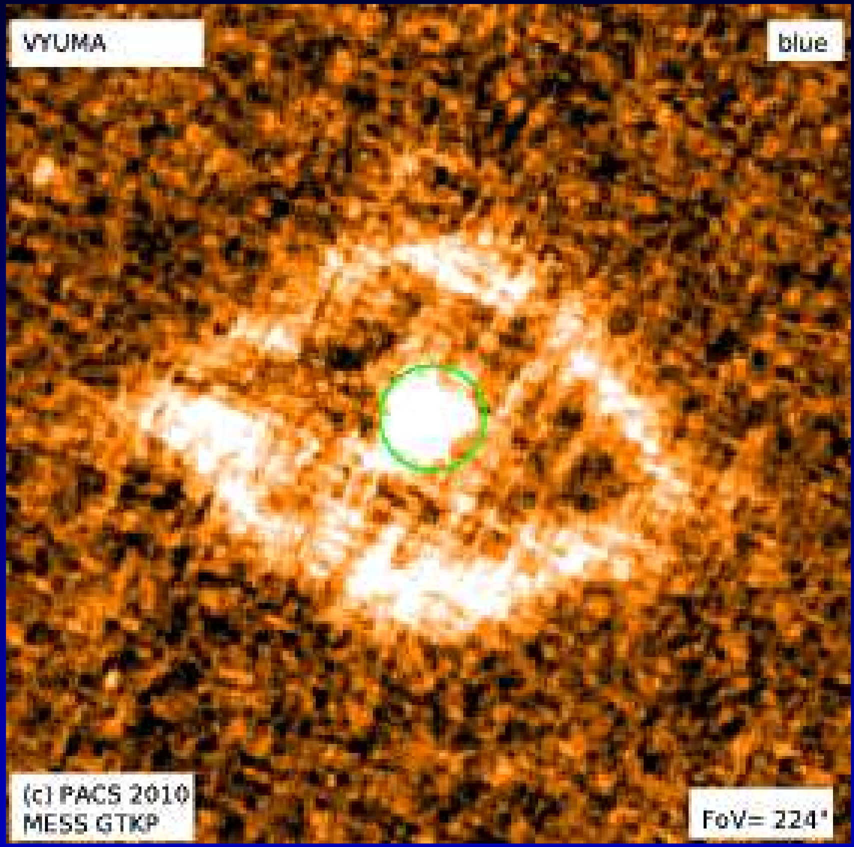
X Her & TX Psc (Jorissen et al. submitted)

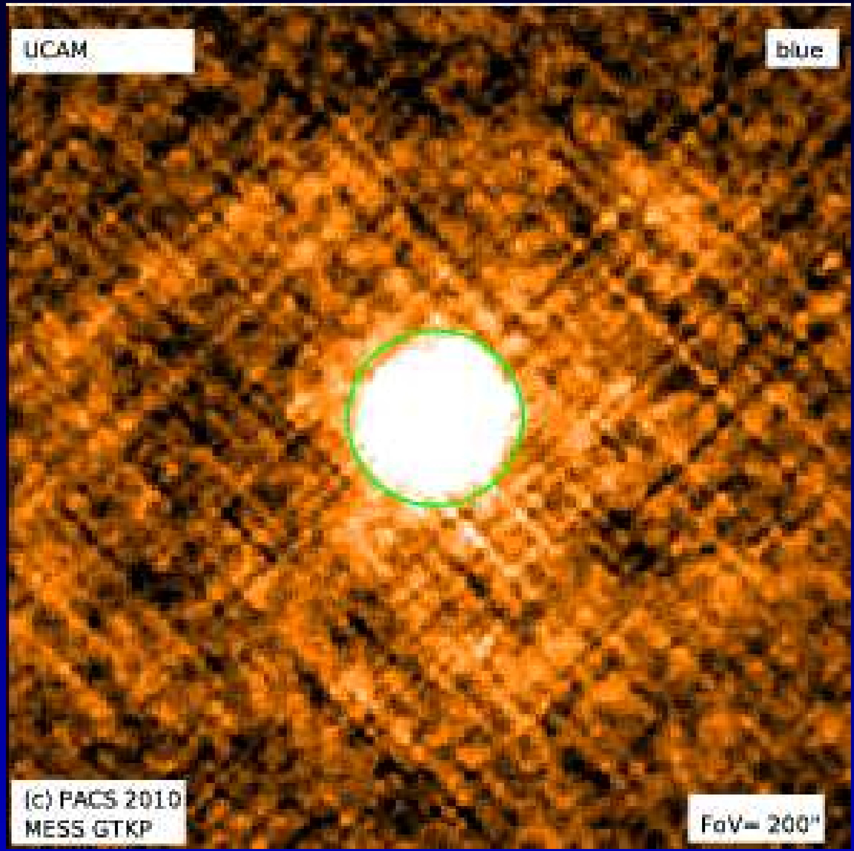

TETAPS
blue
(c) PACS 2010
MESS GTKP
FoV= 200"


TMIC
blue
(c) PACS 2010
MESS GTKP
FoV= 200"

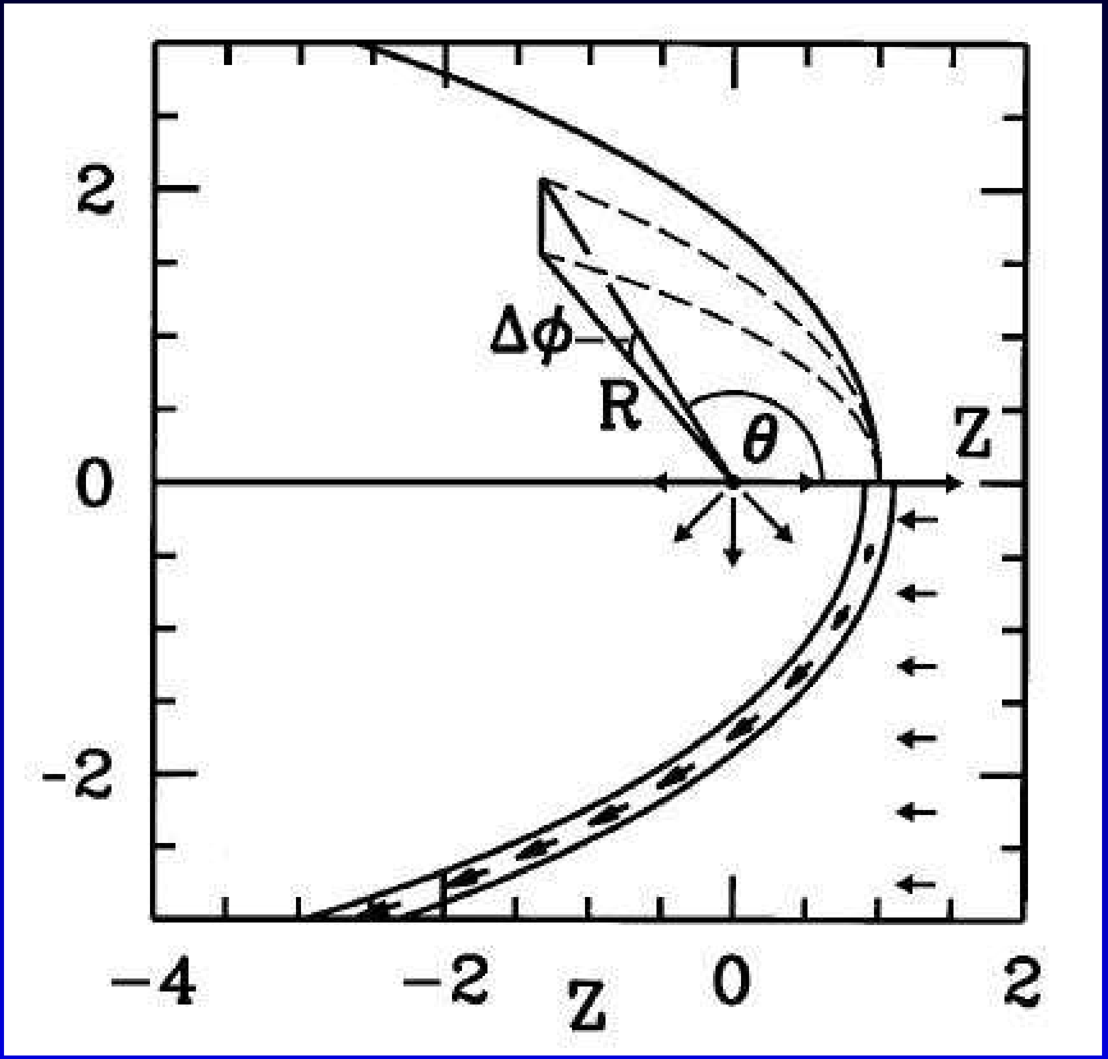

EPAQR
blue
(c) PACS 2010
MESS GTKP
FoV= 200"


V1943SGR
blue
(c) PACS 2010
MESS GTKP
FoV= 294"


VYUMA
blue
(c) PACS 2010
MESS GTKP
FoV= 224"


UCAM
blue
(c) PACS 2010
MESS GTKP
FoV= 200"

Wilkin model



Thin-shell shock model (Wilkin 1996)

Wilkin model

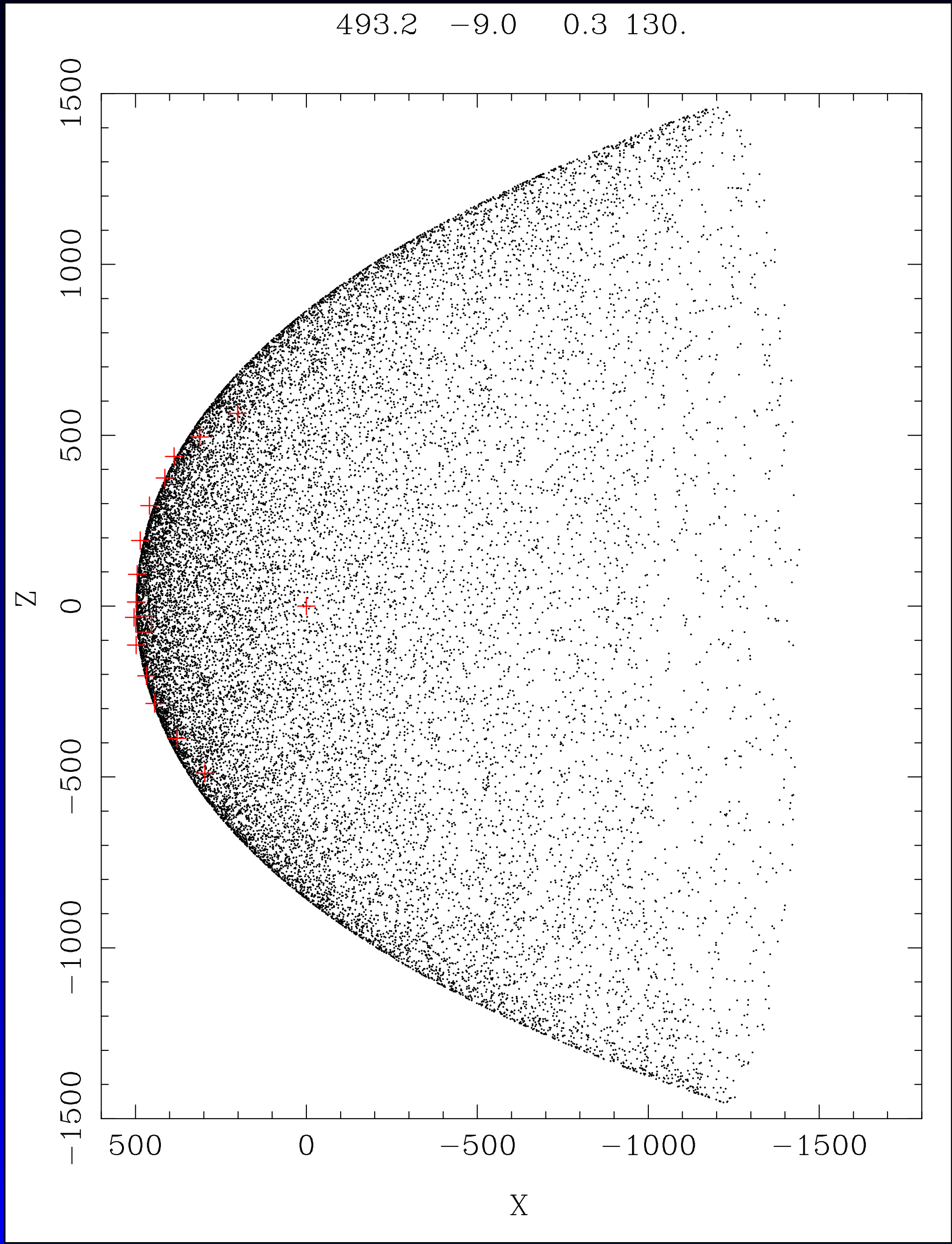
$$R(\theta) = R_0 \sqrt{3 \cdot (1 - \theta / \tan(\theta))} / \sin(\theta)$$

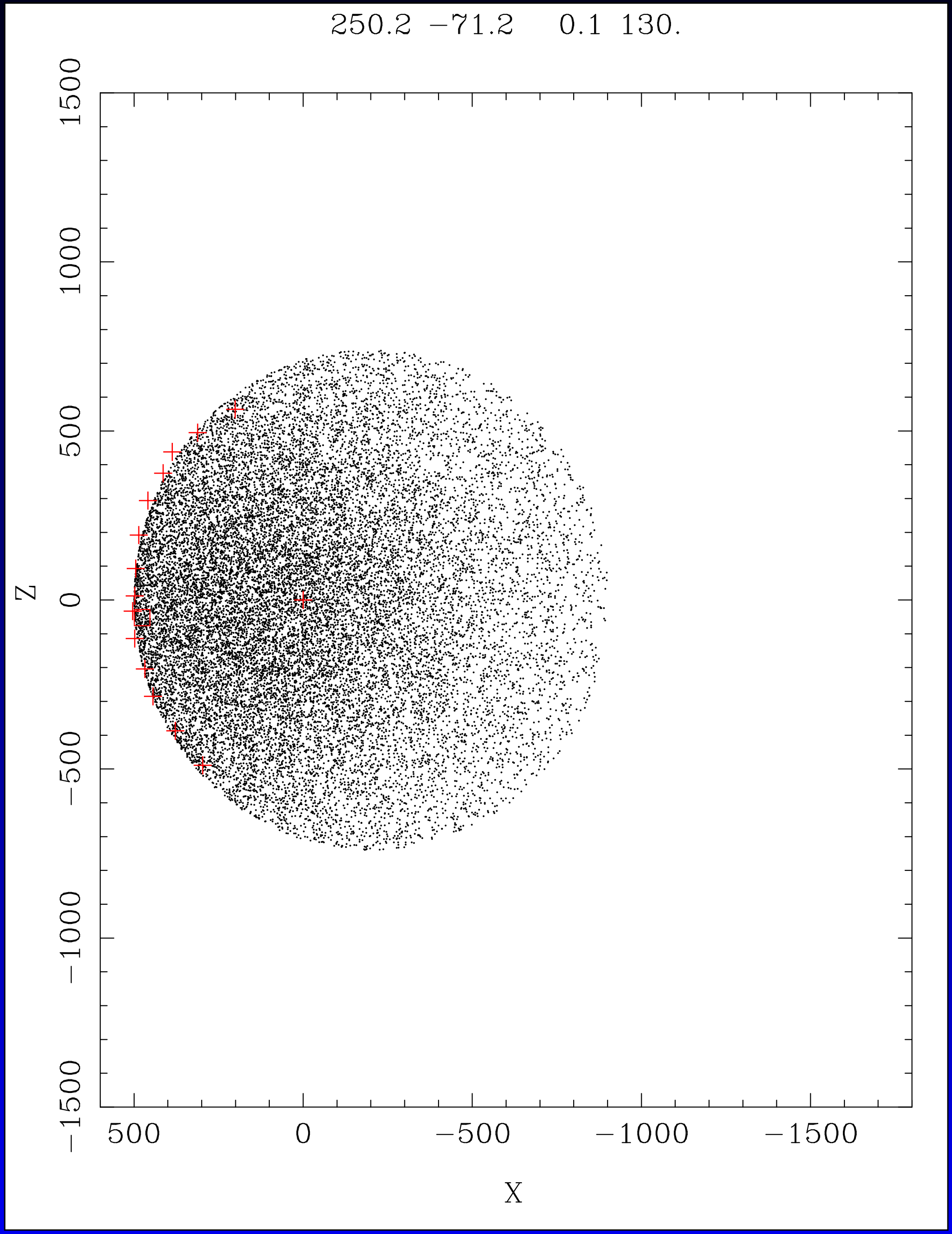
standoff distance:

$$R_0 = \sqrt{(\dot{M}\, V_{\mathrm{exp}})/(4\pi\, \rho_0\, V_{\mathrm{w}}^2)}$$

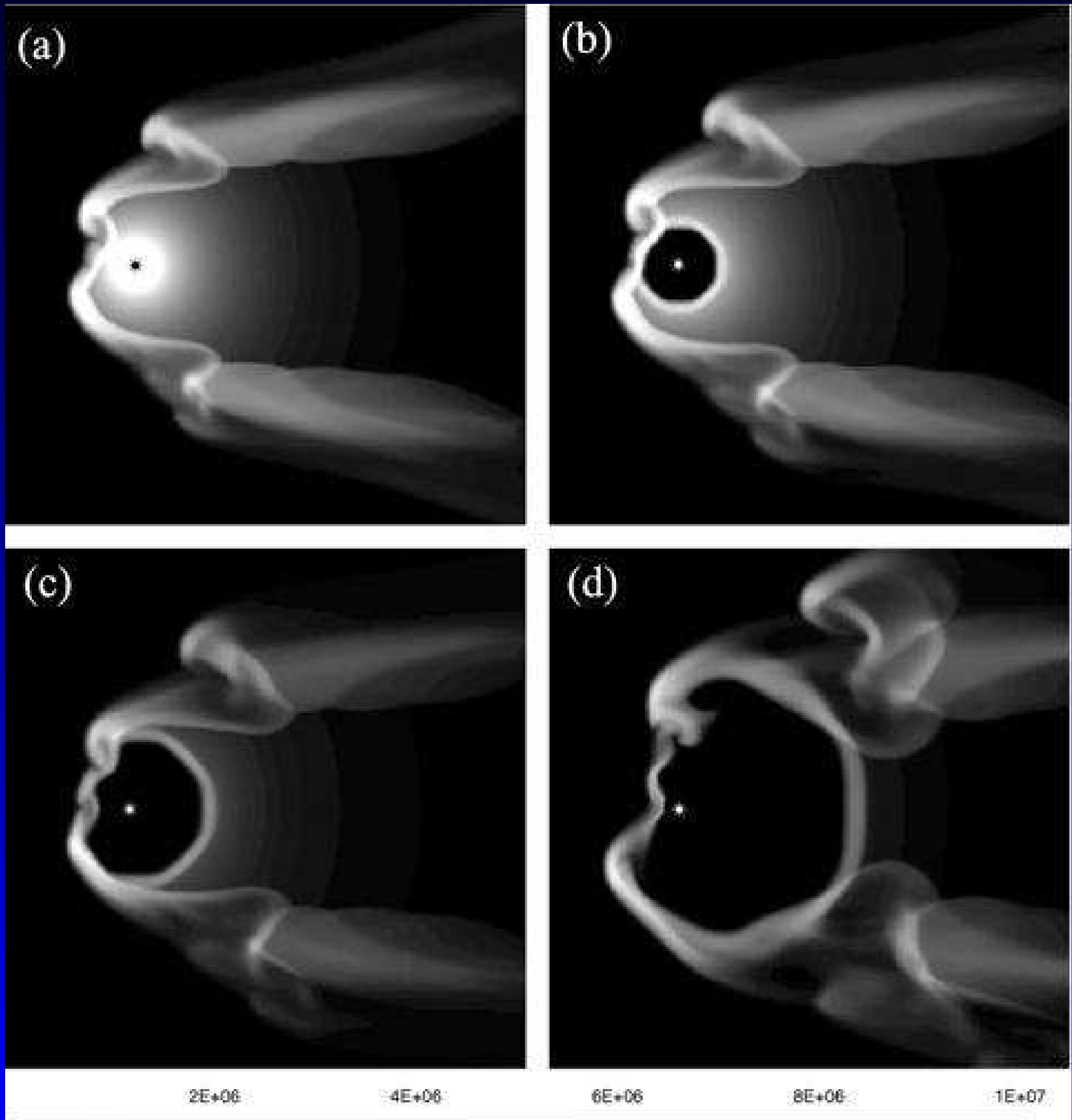
3D Wilkinoid

- Monte Carlo simulation
- Fit the outline to an observed profile
- Predict velocities


493.2 −9.0 0.3 130.
Z
X
1500
1000
500
0
−500
−1000
−1500
500
0
−500
−1000
−1500

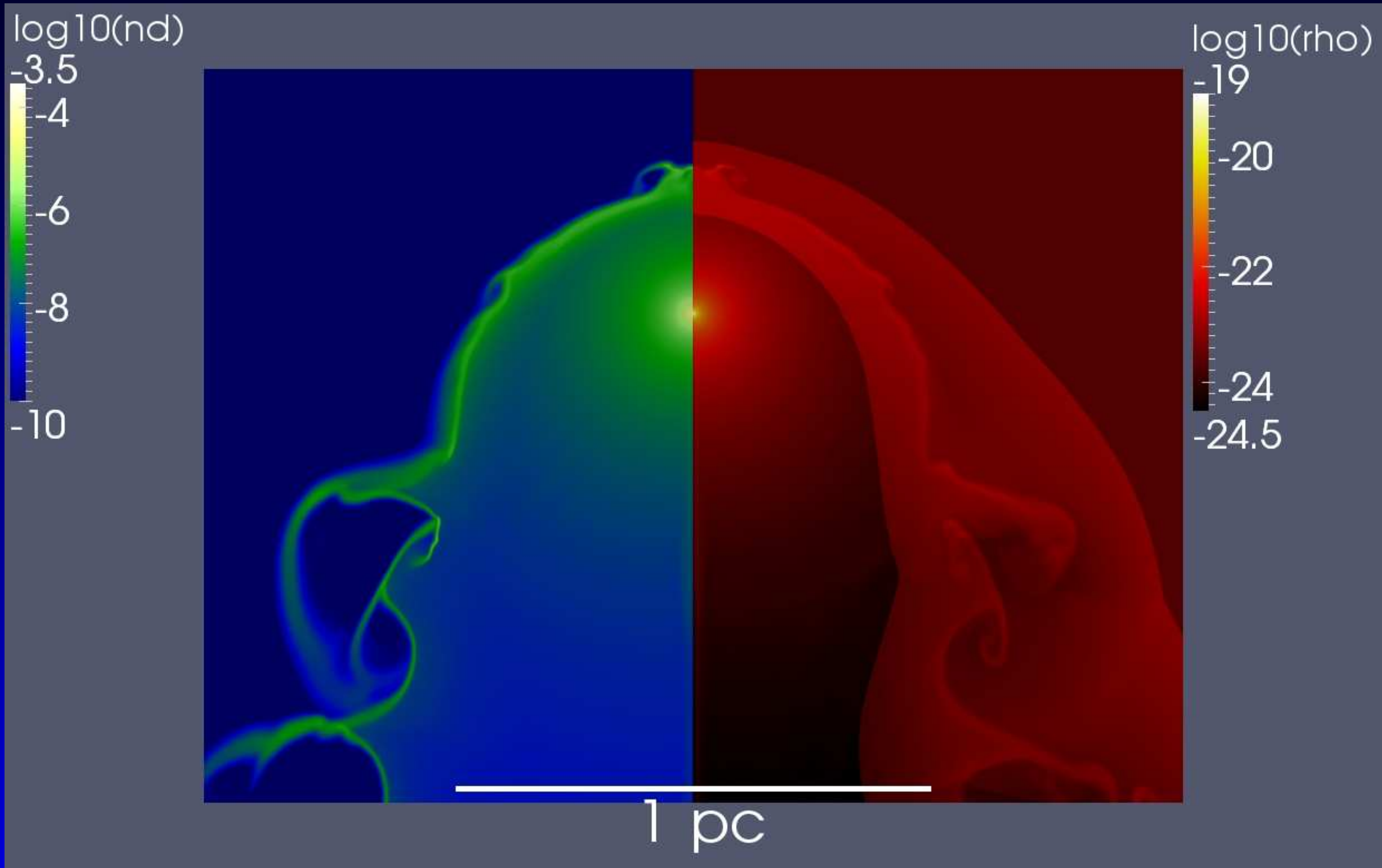

250.2 −71.2 0.1 130.
Z
X
1500
1000
500
0
−500
−1000
−1500
500
0
−500
−1000
−1500

Hydro Models



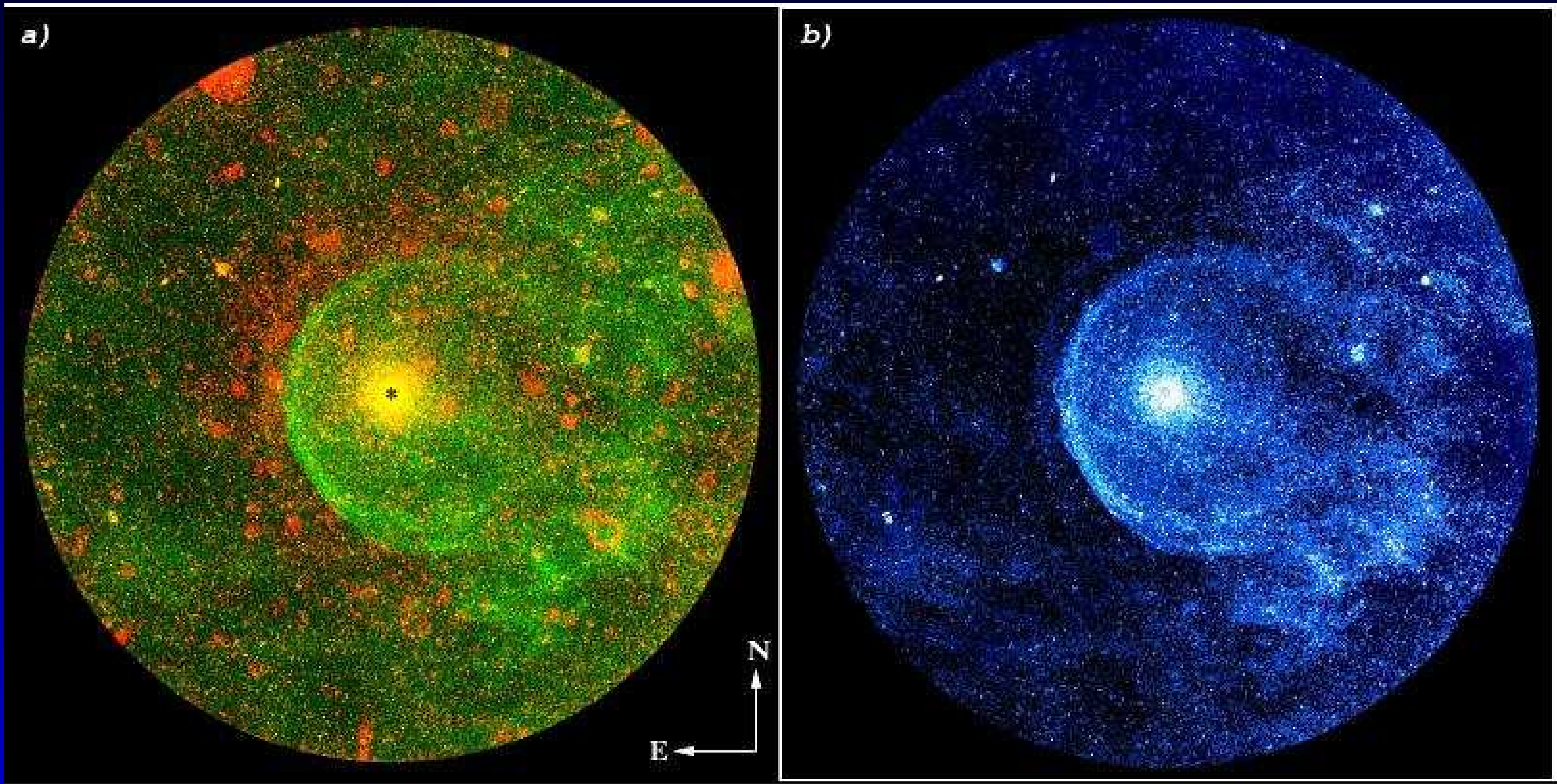
Wareing et al. (2007)

Models



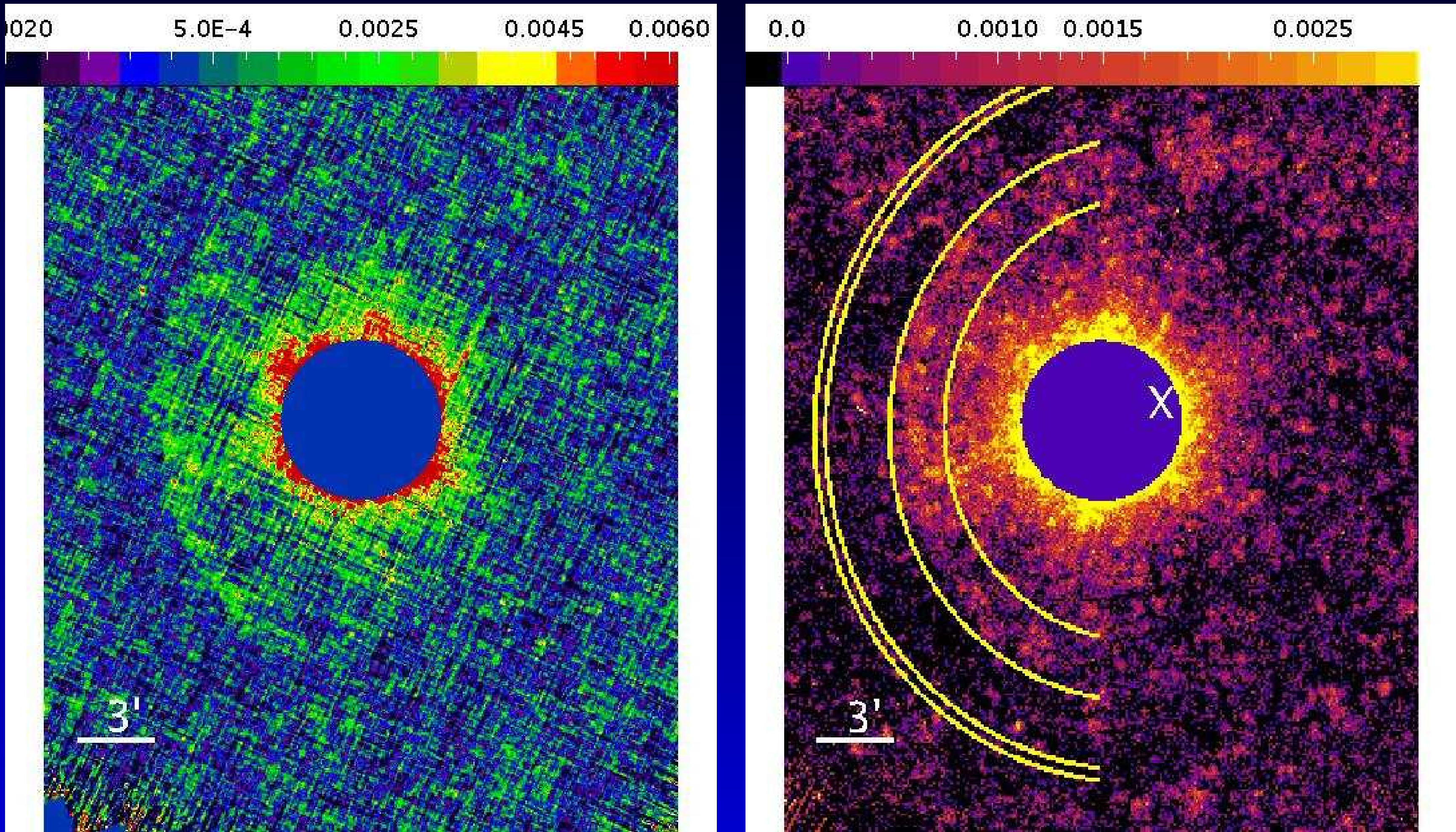
van Arle et al. (2011)

CW Leo - bowshock



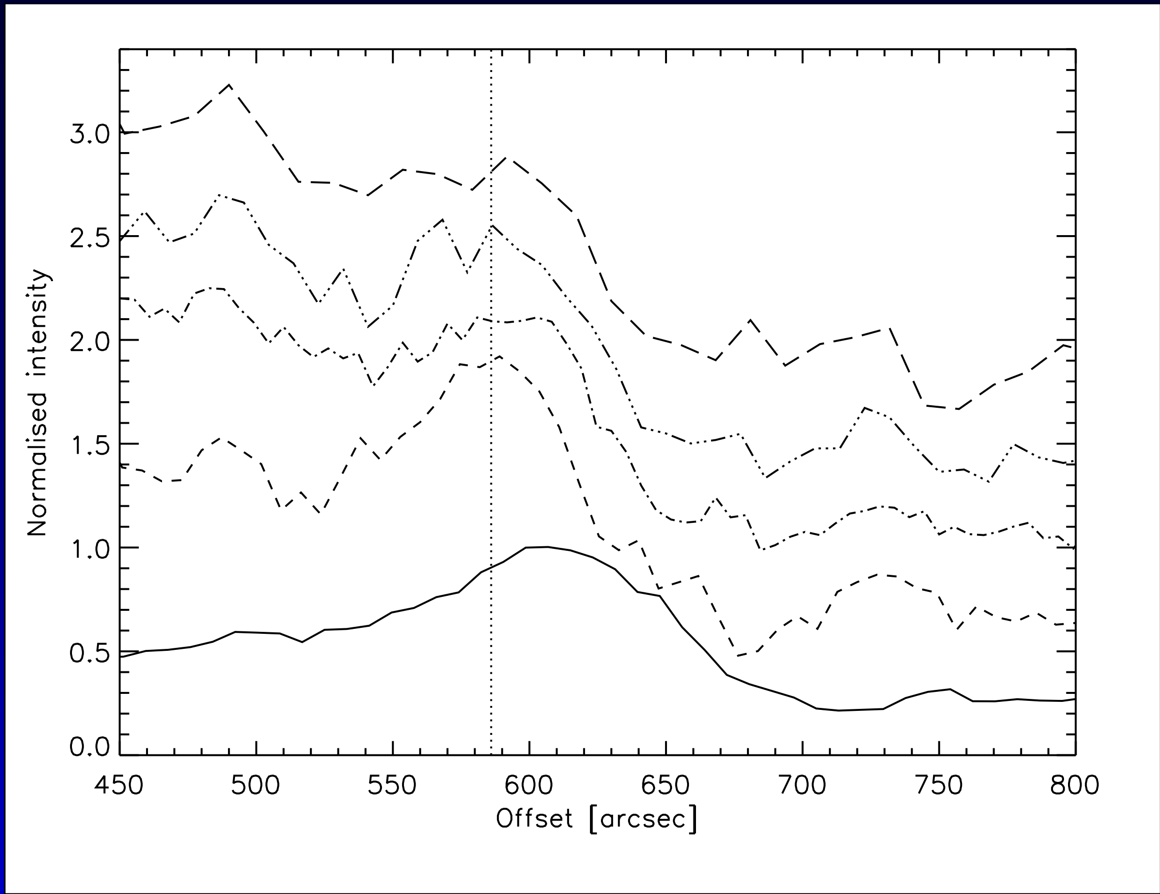
GALEX NUV/FUV composite (left), FUV (right).
Sahai & Chronopoulos (2010)

CW Leo - bowshock



PACS 160 and SPIRE 250 micron
$23' \times 27'$ (Ladjal et al. 2010)

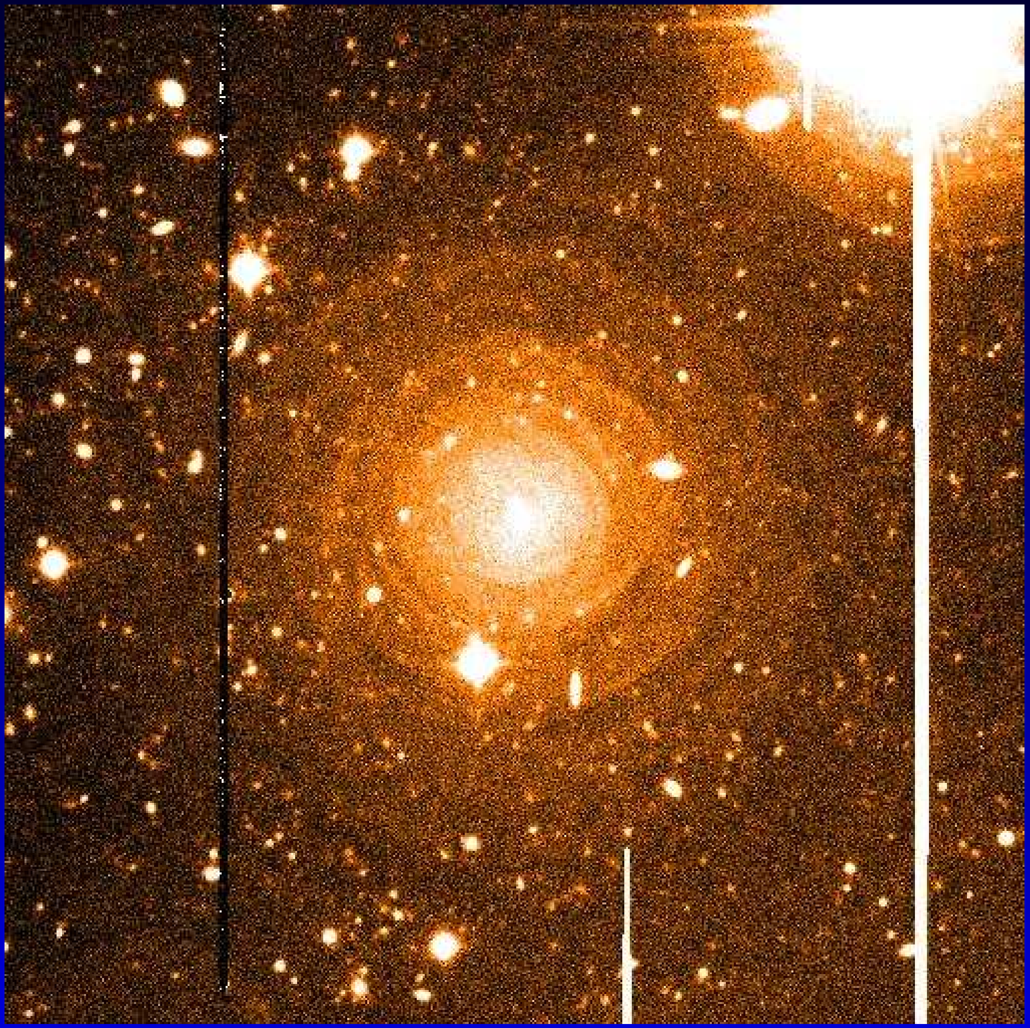
CW Leo - bowshock



Intensity profiles FUV, 160, 250,350,550 micron

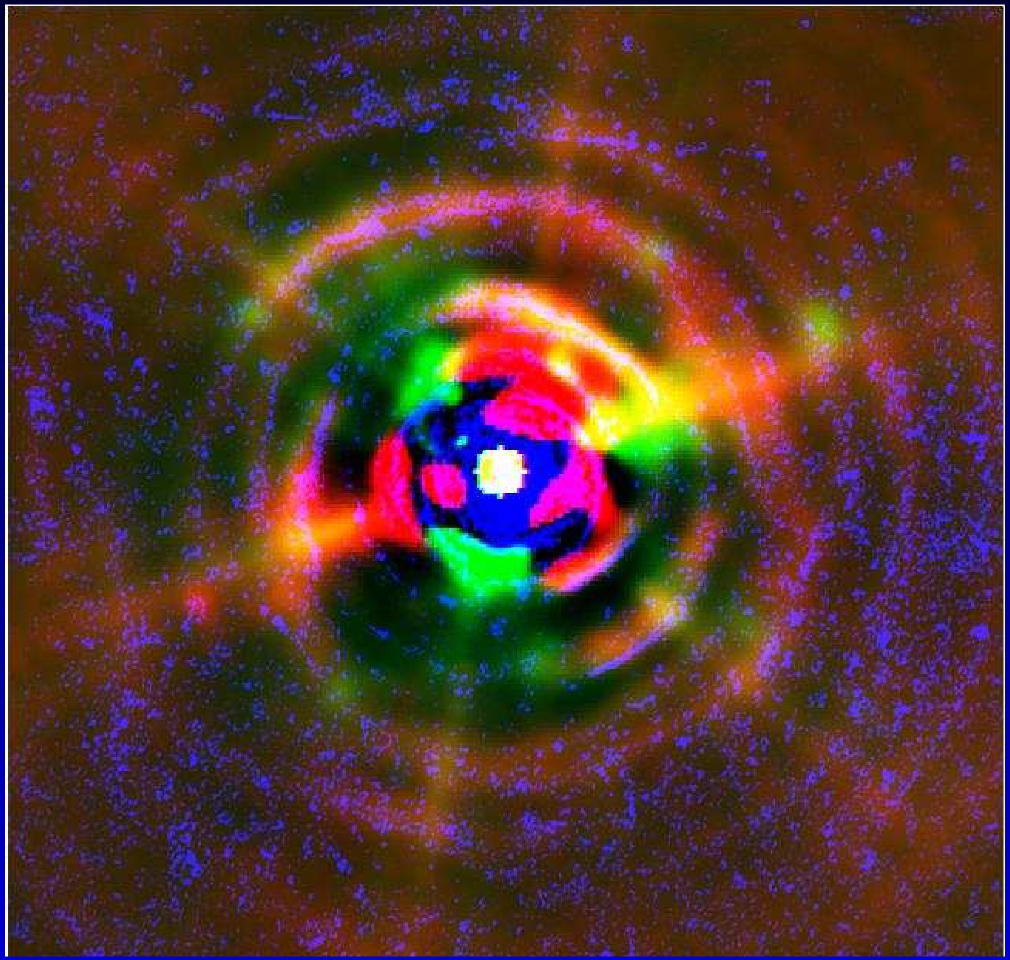
T_{dust} = 25 K $\quad$ $V_{\star\mathrm{relativeISM}} = 107/\sqrt{n_{\mathrm{ISM}}}$ km s^{-1}

CW Leo - inner part



(Mauron & Huggins 1999) V-band, FoV= 223 x 223″

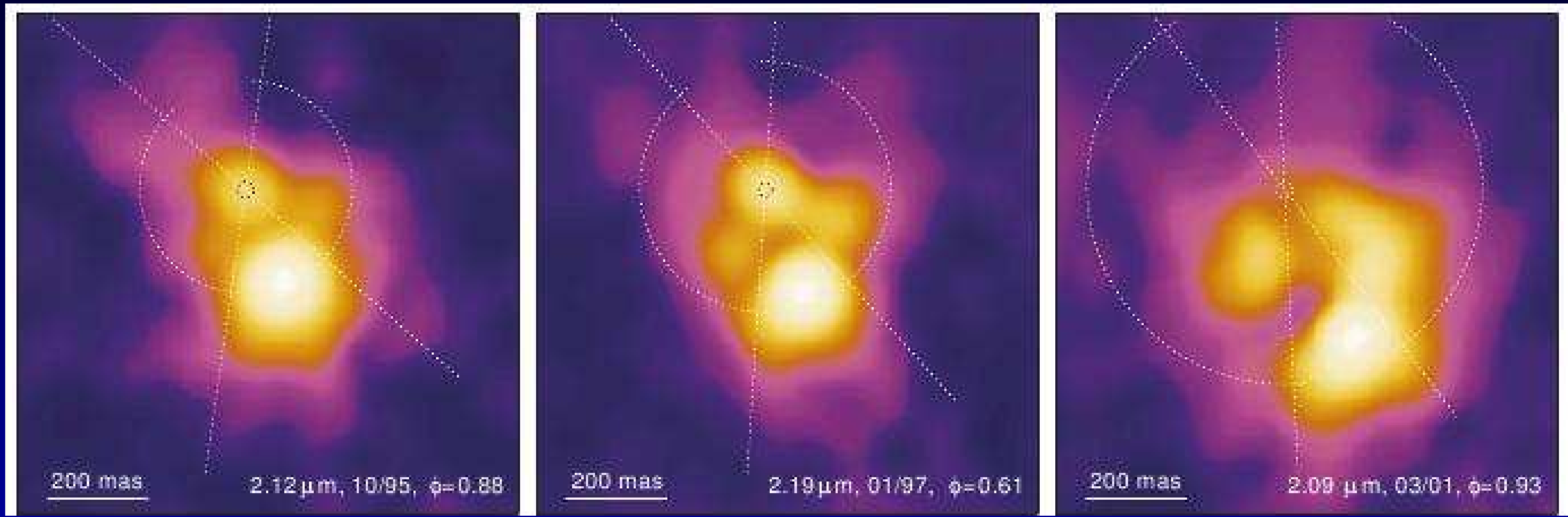
CW Leo - inner part



Combined image of the PACS 70 μm (green), PACS 100 μm (red) and V-band (blue).
FoV= 204 x 204$''$

Decin et al. (in prep.)
non-isotropic mass-loss events and clumpy dust formation

CW Leo - inner part

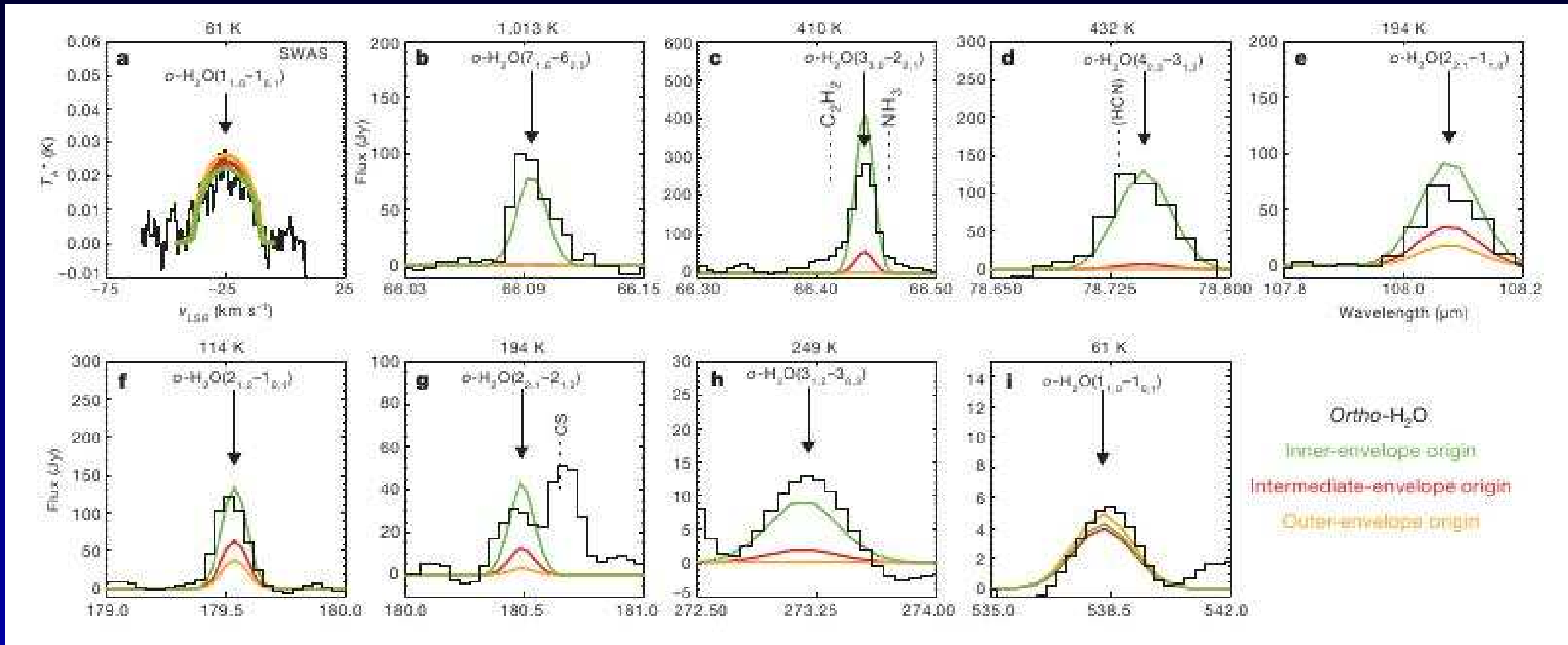


(Menshchikov et al. 2002) K-band speckle
FoV= 1 x 1$''$

CW Leo - Water

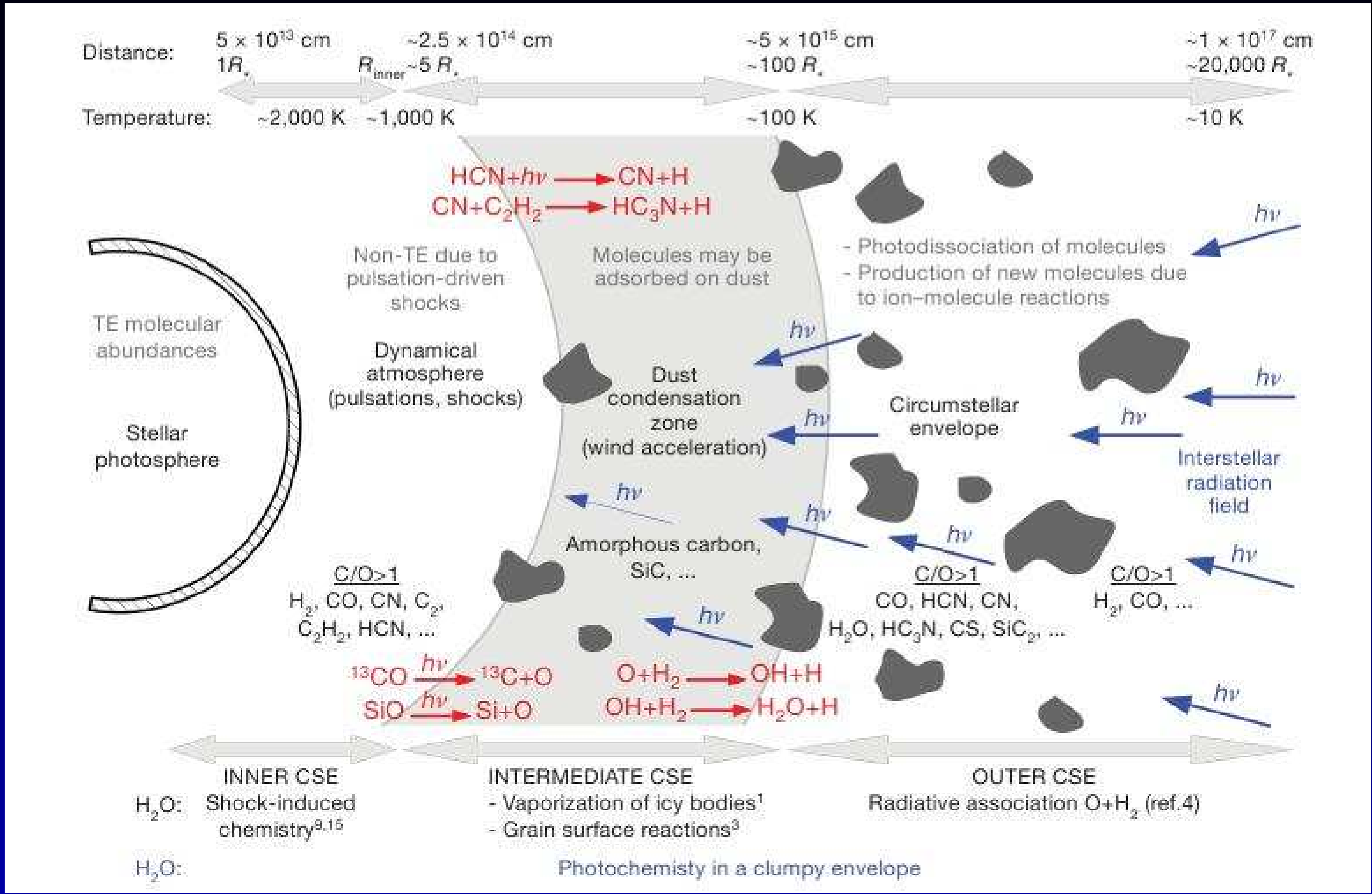
Decin et al. 2010, Nature 467, 64

CW Leo - Water



1 line with SWAS

Melnick et al. 2001, Nature 412, 160
"Discovery of water vapour around IRC +10216 as evidence for comets orbiting another star"



39 ortho-H_2O and 22 para-H_2O with T_{ex} up to 1000 K

"A plausible explanation for the warm water appears to be the penetration of ultraviolet photons deep into a clumpy circumstellar envelope. This mechanism also triggers the formation of other molecules, such as ammonia, whose observed abundances are much higher than hitherto predicted"

MESS - Spectroscopy

- CW Leo

-Water
(Decin et al. 2010, Nature, as shown earlier)

-HCl lines from J=1-0 up to J=7-6 have been detected.
(Cernicharo et al. 2010, A&A Special Issue)

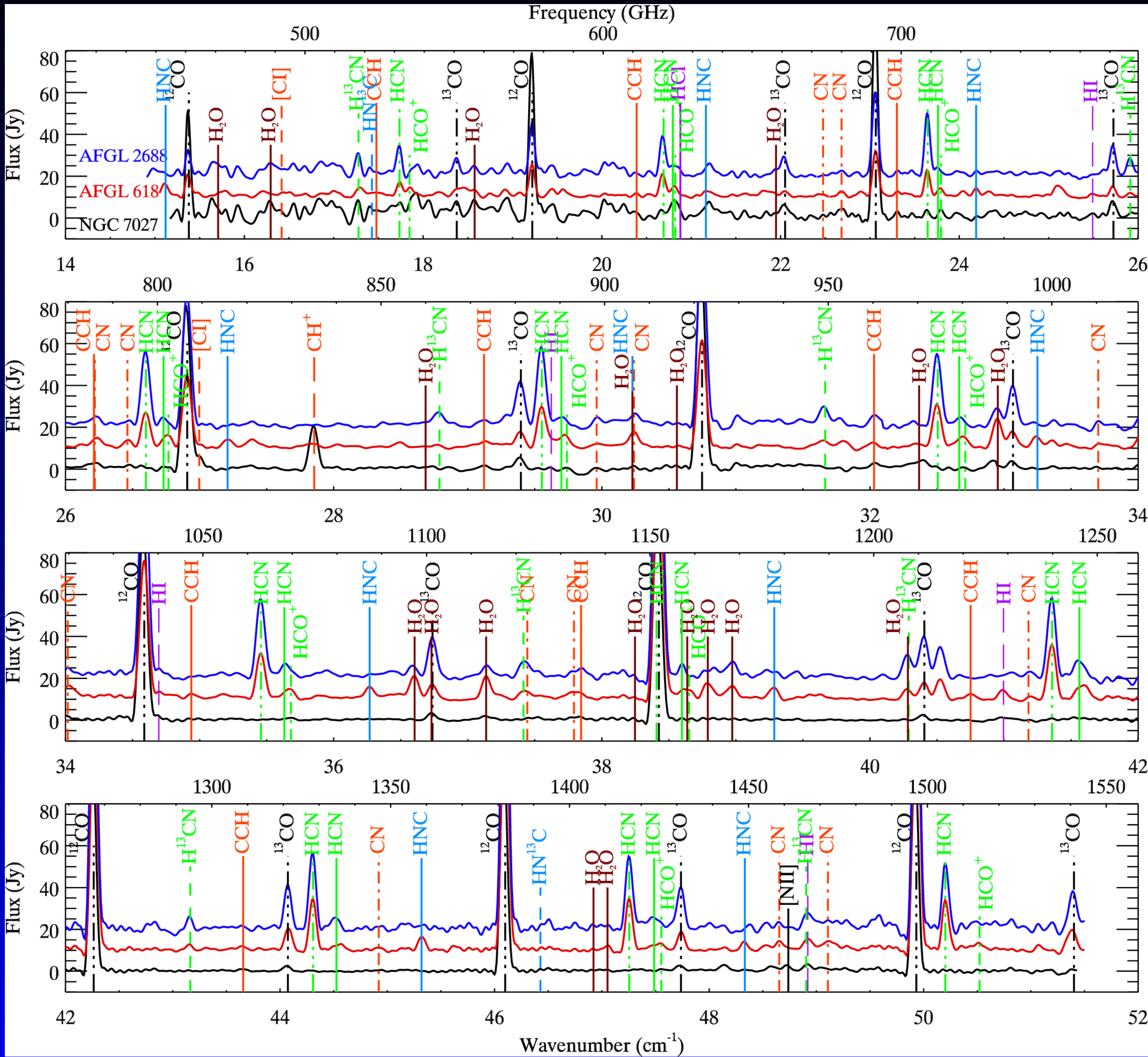
-Tens of lines from SiS and SiO, including lines from the v=1 vibrational level.
Both species trace the dust formation zone.
(Decin et al. 2010, A&A Special Issue)

MESS - Spectroscopy

- AFGL 2688, AFGL 618 and NGC 7027
Wesson et al. 2010, A&A special issue

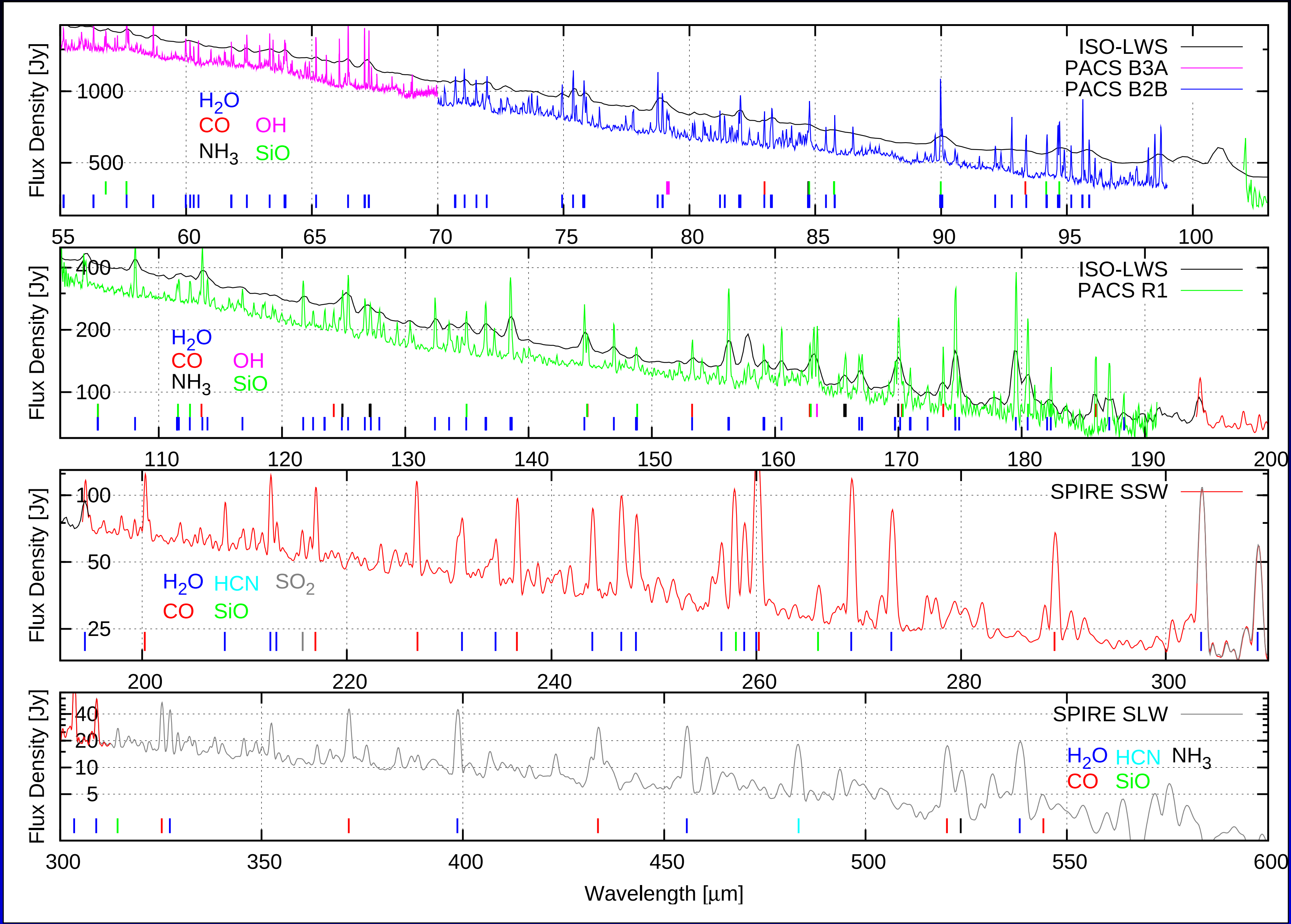
- VY CMa
Royer et al. 2010, A&A special issue

More sophisticated modelling is ongoing by Matsauura, Yates



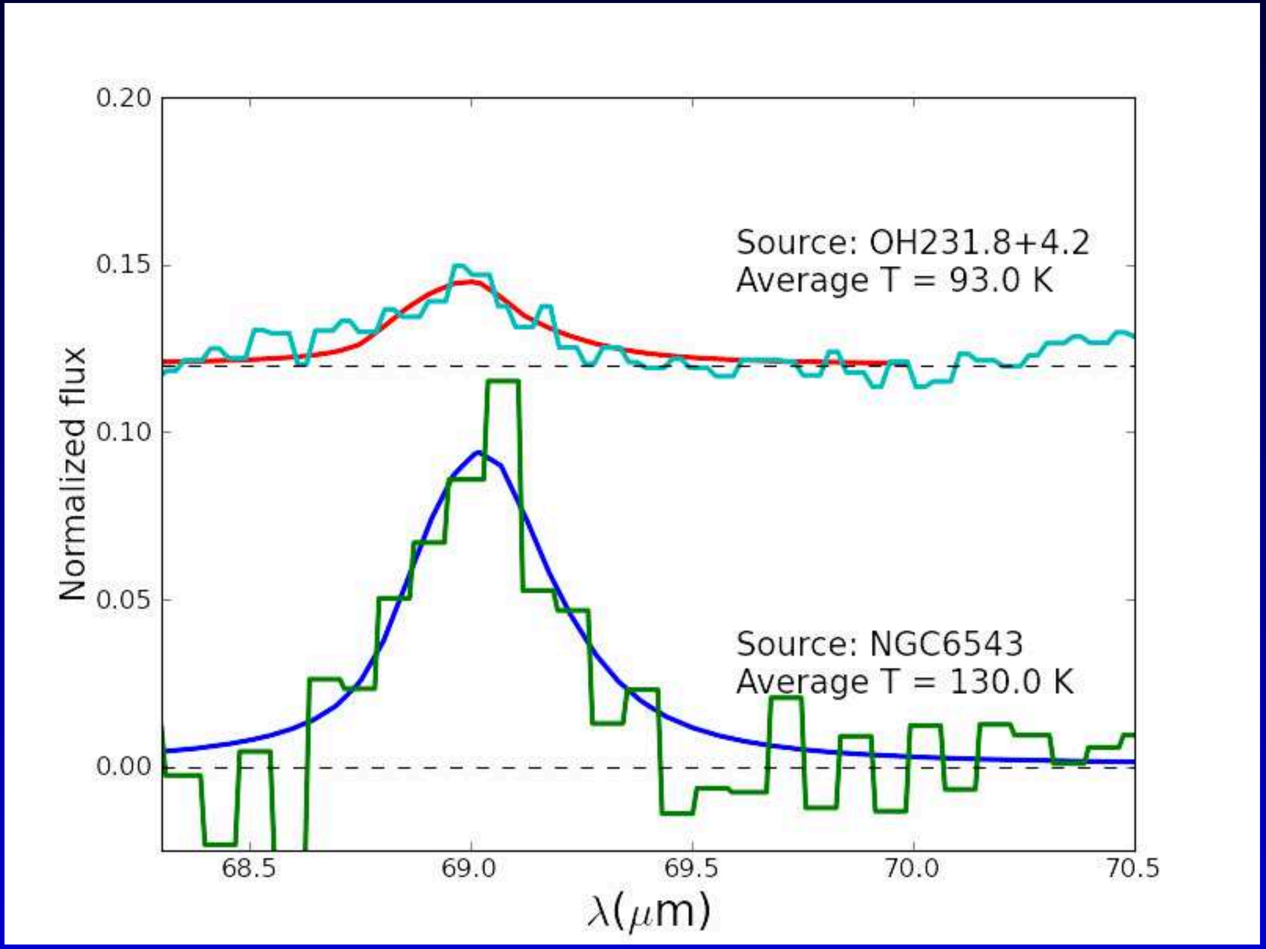
Wesson et al. (2010).

Continuum-subtracted SPIRE FTS spectra of NGC 7027 (black), AFGL 618 (red) and AFGL 2688 (blue)



VY CMa, Royer et al. (2010)

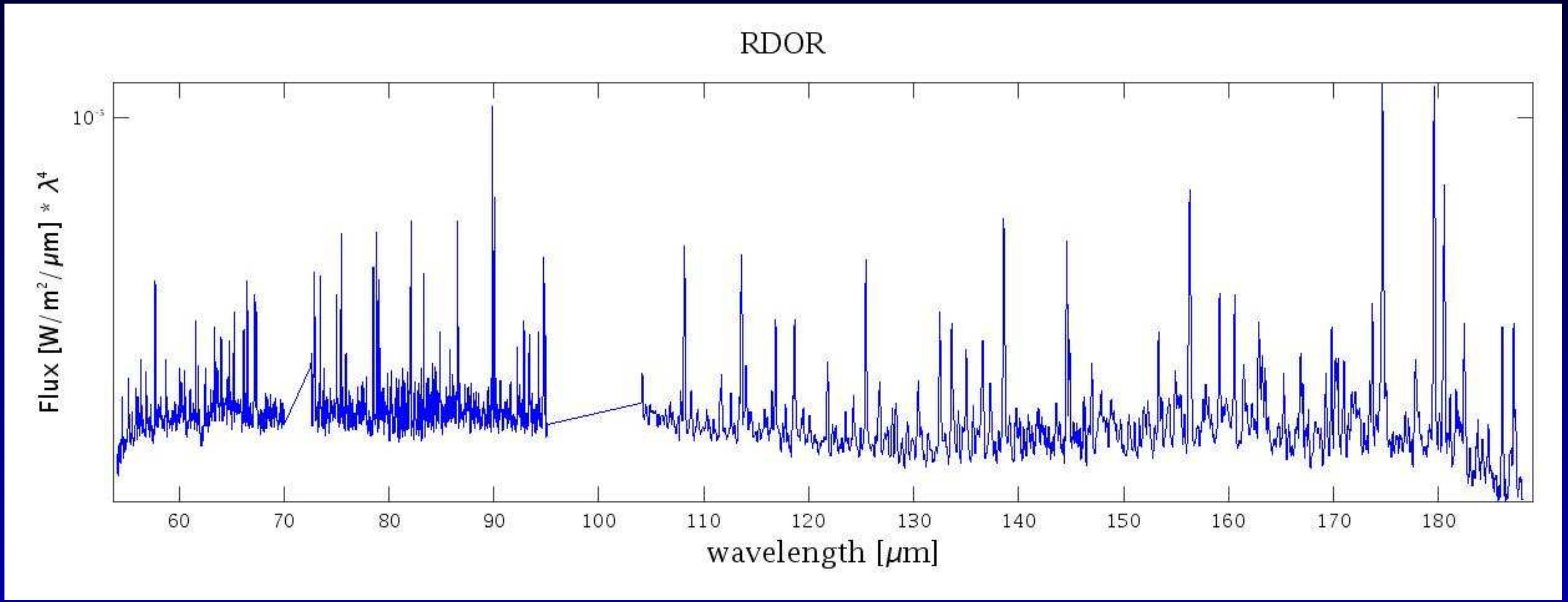
Dust spectroscopy



de Vries et al. (2011)

Fosterite at 69μm

Dust spectroscopy



R Dor, full PACS spectrum

Where's the dust ??

Conclusions

- Detected ”old” dust mass loss in AGB stars !
- Interaction with the ISM is common
- Line spectroscopy very succesfull
- Issues
  - Dust spectroscopy
    Improved data reduction; RSRF;
    removal of molecular lines
- Up to the modellers ....
  - Dust + molecules RT modelling ...!!
  - Hydrodynamical simulations ...!!

This MESS is produced by

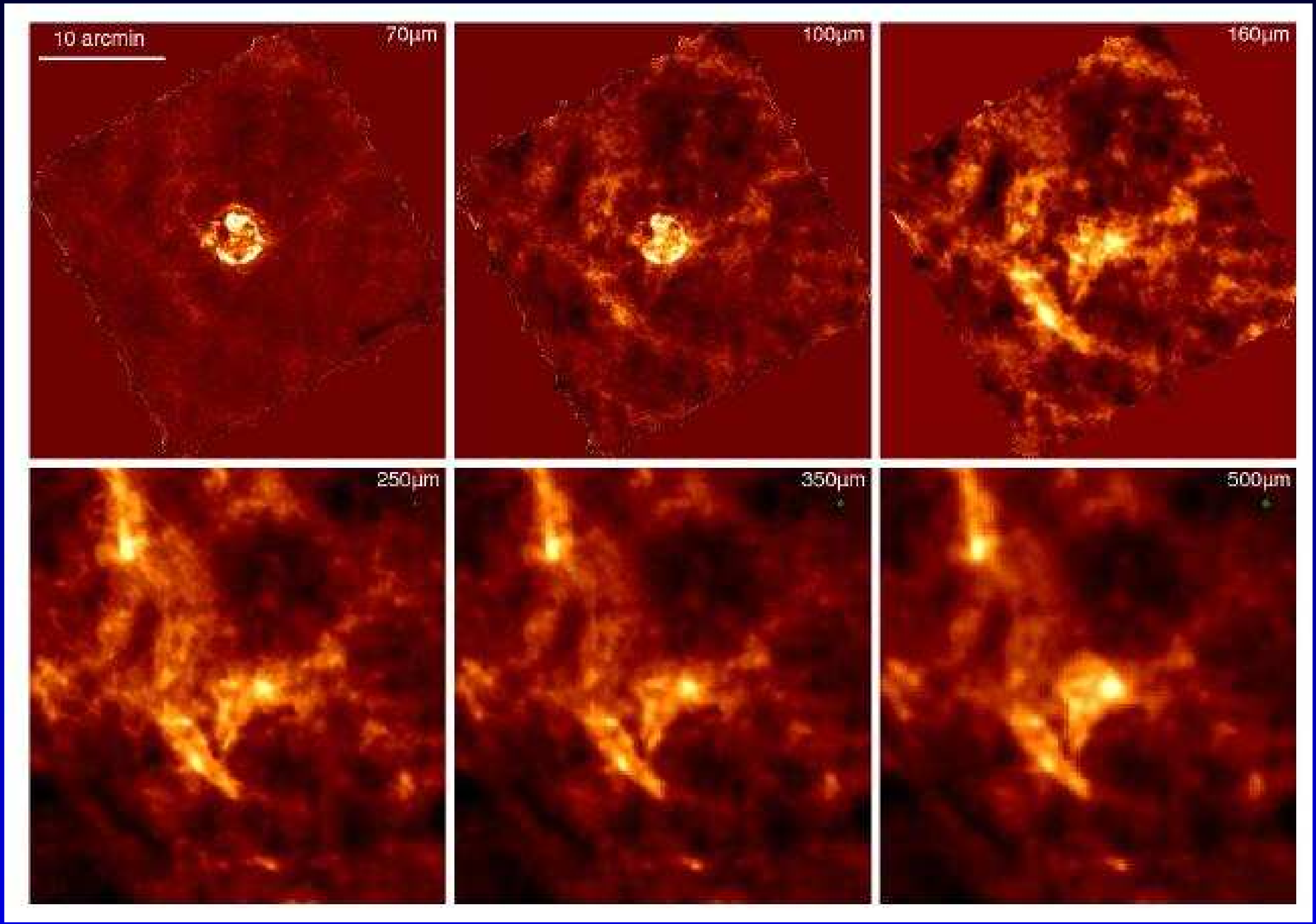
A. Baier, M. Barlow, B. Baumann, J. Blommaert, J. Bouwman, P. Cernicharo, M. Cohen, L. Decin, L. Dunne, K. Exter, P. Garcia-Lario, H. Gomez, M.A.T. Groenewegen, P. Hargrave, Th. Henning, D. Hutsemékers, R. Ivison, A. Jorissen, F. Kerschbaum, O. Krause, D. Ladjal, T. Lim, M. Mecina, W. Novotny-Schipper, G. Olofsson, R. Ottensamer, E. Polehampton, Th. Posch, G. Rauw, P. Royer, B. Sibthorpe, B. Swinyard, T. Ueta, C. Vamvatira-Nakou, B. Vandenbussche, G. Van de Steene, S. van Eck, P. van Hoof, H. Van Winckel, E. Verdugo, H. Walker, C. Waelkens, R. Wesson

FWF-projects: P18939-N16 & I163, P21988
FWO
STFC
ASAP-CO-016/03
PRODEX C90371

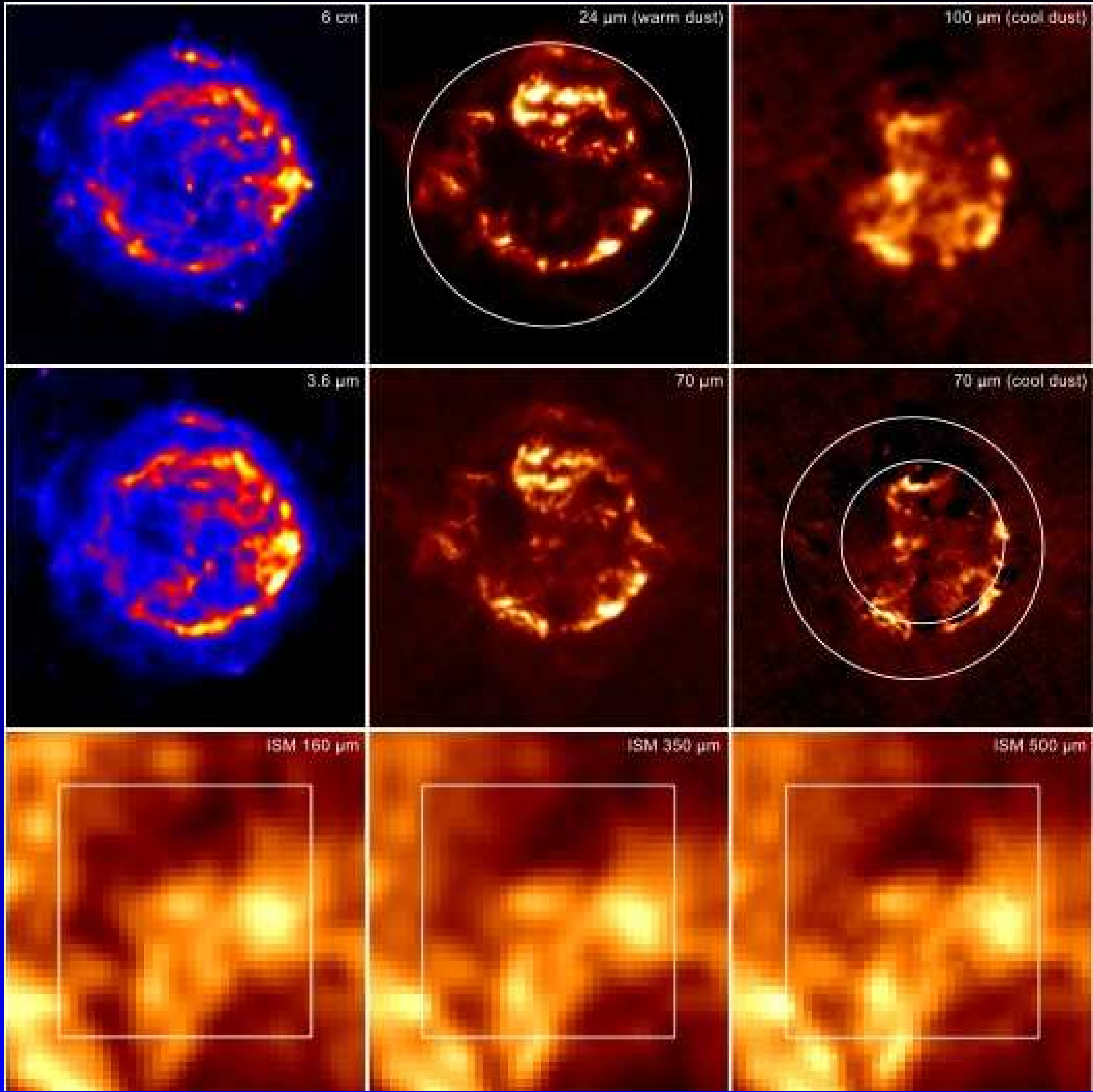
THE END

(play movie!)

SN remnant: Cas A



Barlow et al. (2010)   (Tycho, Kepler, Crab, SN 1181)


6 cm
24 µm (warm dust)
100 µm (cool dust)
3.6 µm
70 µm
70 µm (cool dust)
ISM 160 µm
ISM 350 µm
ISM 500 µm

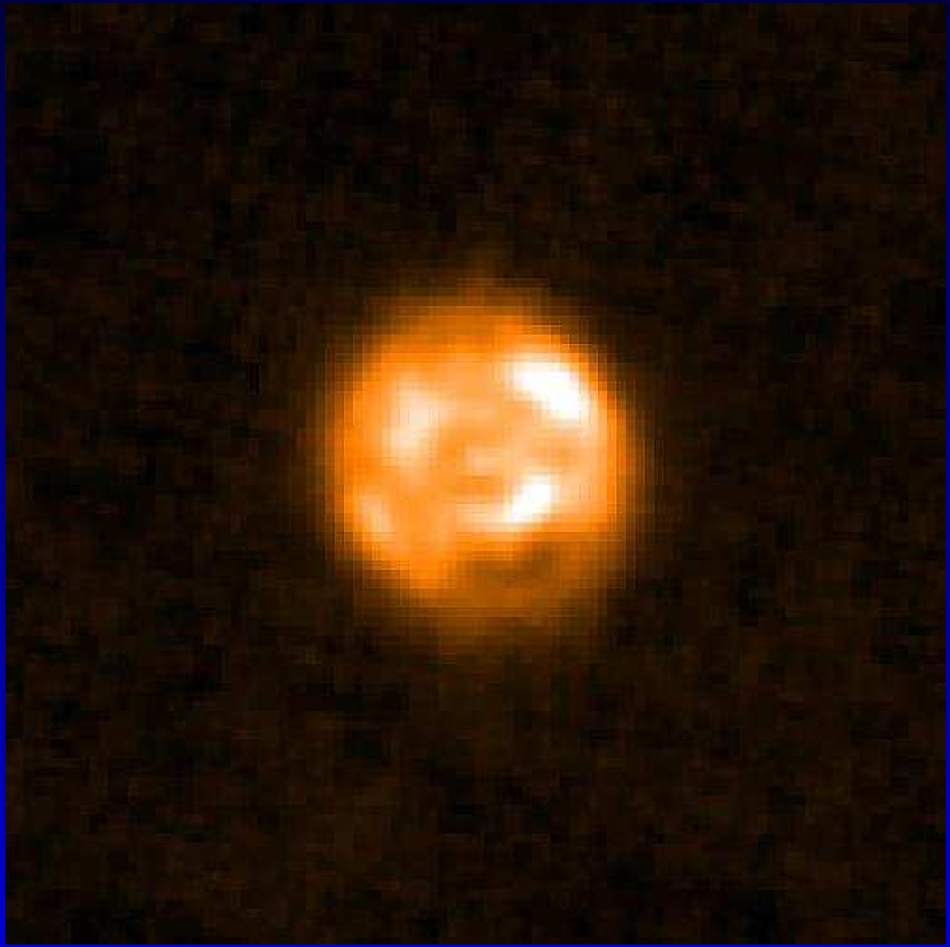
SN remnant: Cas A

- non-thermal component: based on 6-cm VLA and 3.6-μm IRAC image
- warm dust component: based on scaled 24-μm MIPS image
- cold interstellar component: iterative procedure
- line contributions: archival LWS spectrum

"We confirm ..... a cool dust component, emitting at 70-160 um, that is located interior to the reverse shock region, with an estimated mass of 0.075 $M_\odot$"

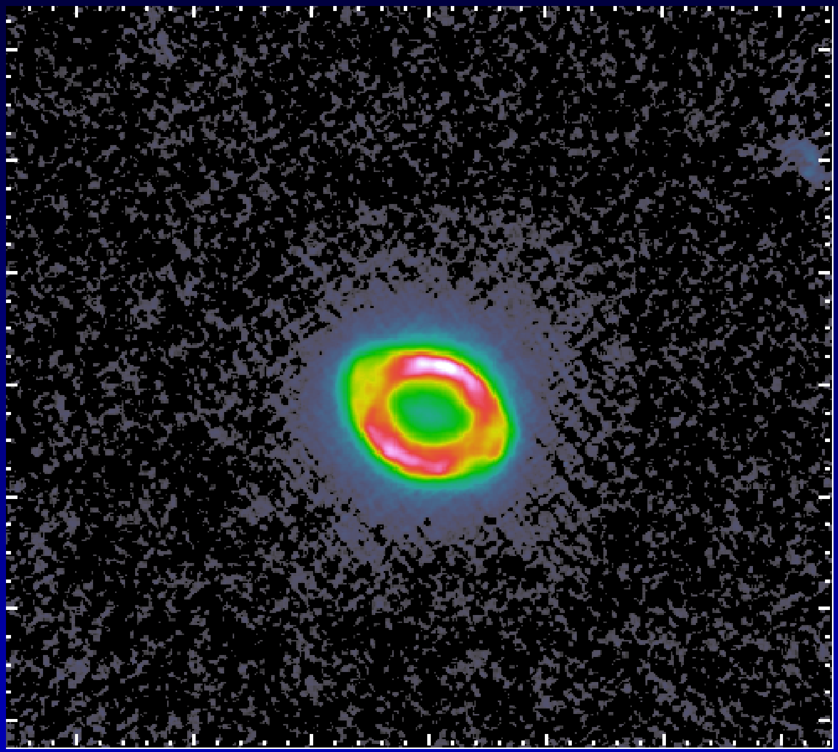
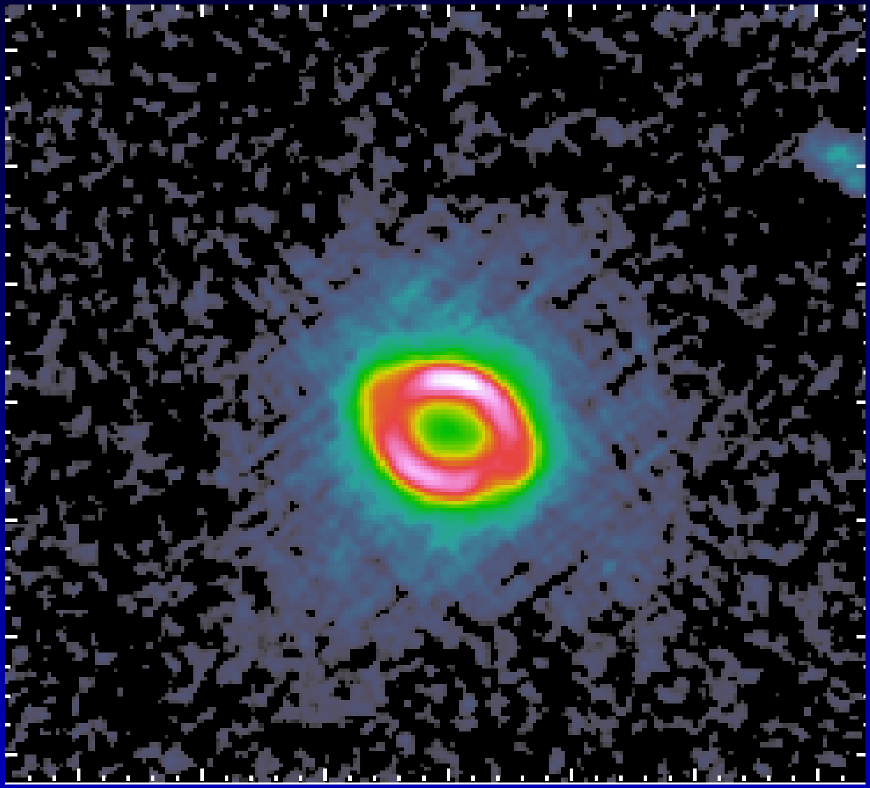
"The present observations provide no direct evidence for the presence of significant quantities of cold dust. The cause of the 850-μm excess in the SCUBA map of the northern part of the remnant is therefore unresolved. "

Massive stars



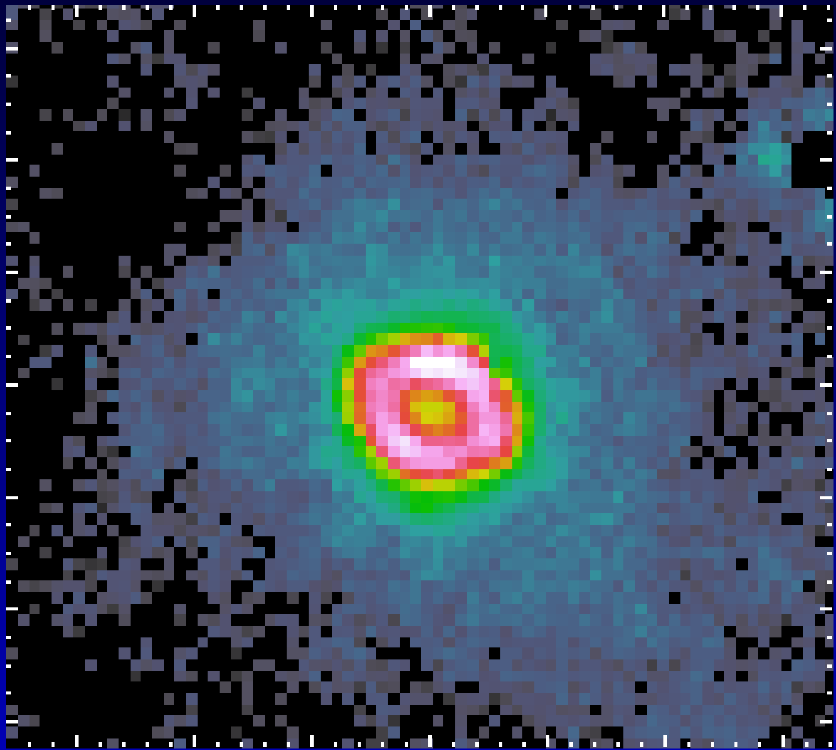
Vamvatira-Nakou et al. (in prep.) Hen 3-519

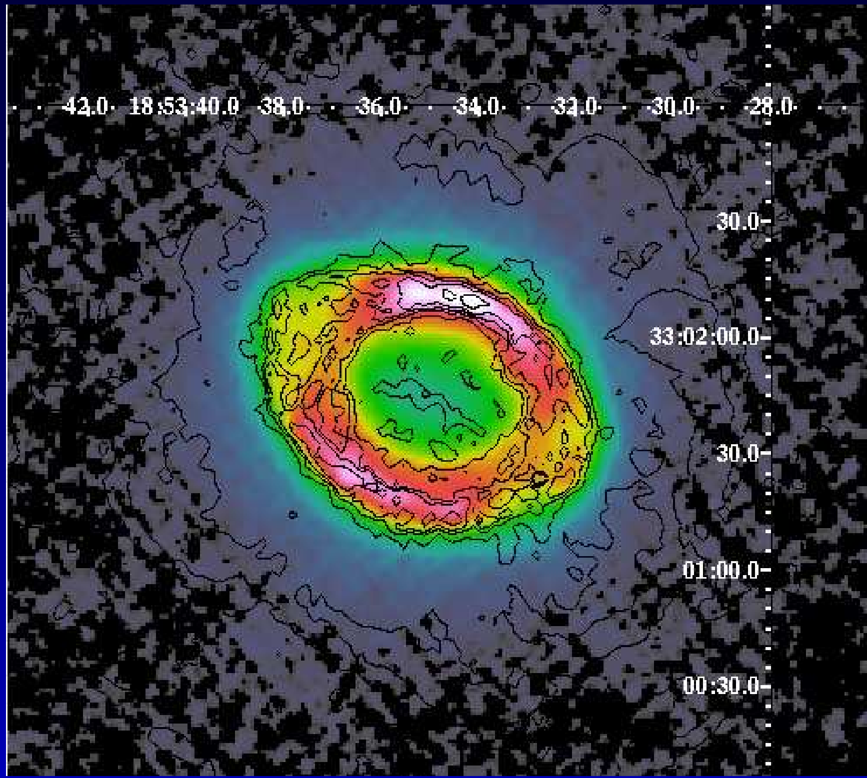
NGC 6720

van Hoof et al. (2010)
PACS 60 and 160 micron

NGC 6720





van Hoof et al. (2010)
SPIRE 250, and PACS 70 micron with H_2 contours
⇒ H_2 formation on dust grains, in high density knots.