The Herschel MESS program on evolved stars

MESS - Mass loss of Evolved Stars

Martin Groenewegen
marting@oma.be

on behalf of the MESS consortium

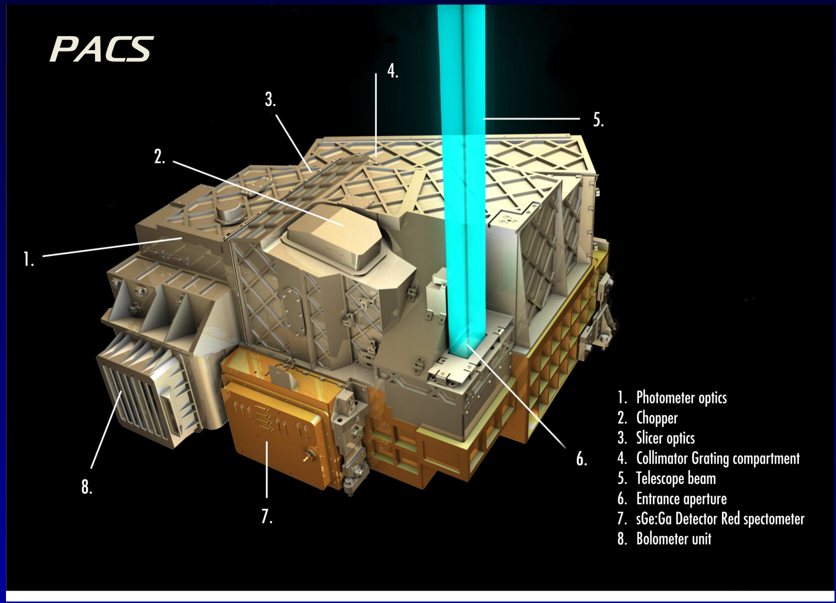
www.univie.ac.at/space/MESS (consortium website)

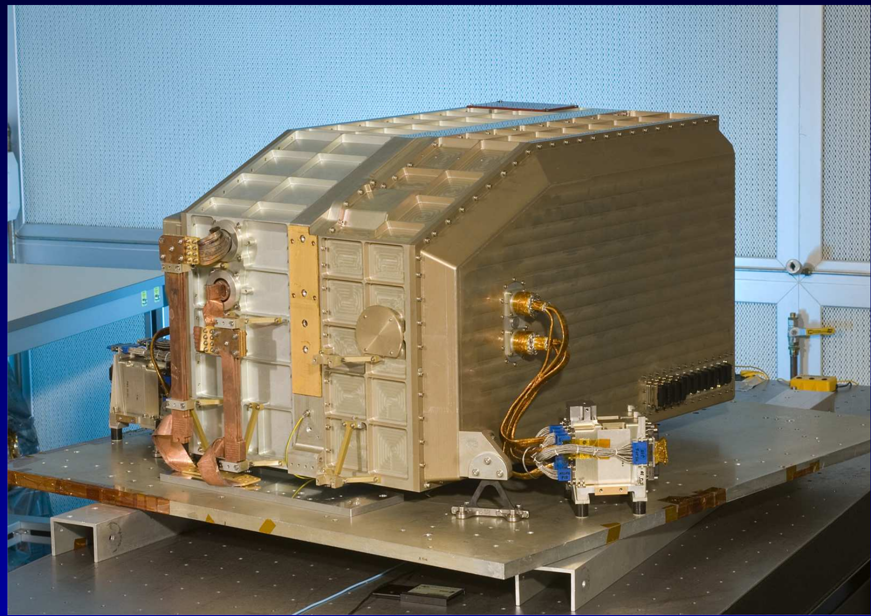
Herschel - Planck launch 14 May 2009

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 GT Key Programs

MESS (Mass loss of Evolved StarS) - PACS + SPIRE
(PI: Martin Groenewegen)
310h: Belgium, SPIRE SAG-6, Vienna, Heidelberg,
HSC, MS

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)
talks on Thursday

Other smaller programs in OT1, GT1, 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

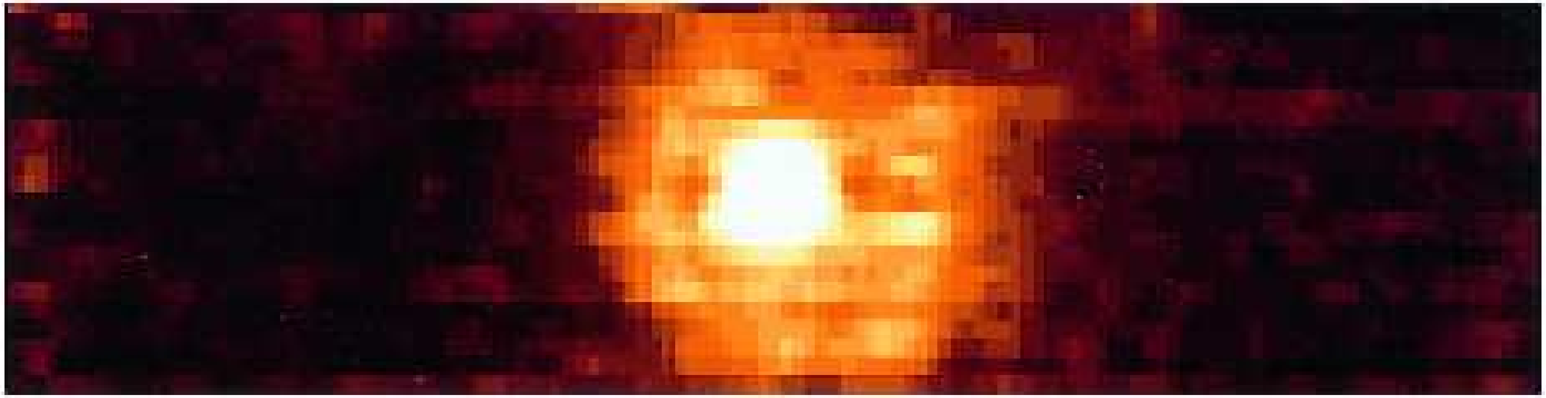


Fig. 1. 90 μm image of Y CVn taken with PHT-C100 array detector and C90 filter displayed in linear brightness scale.

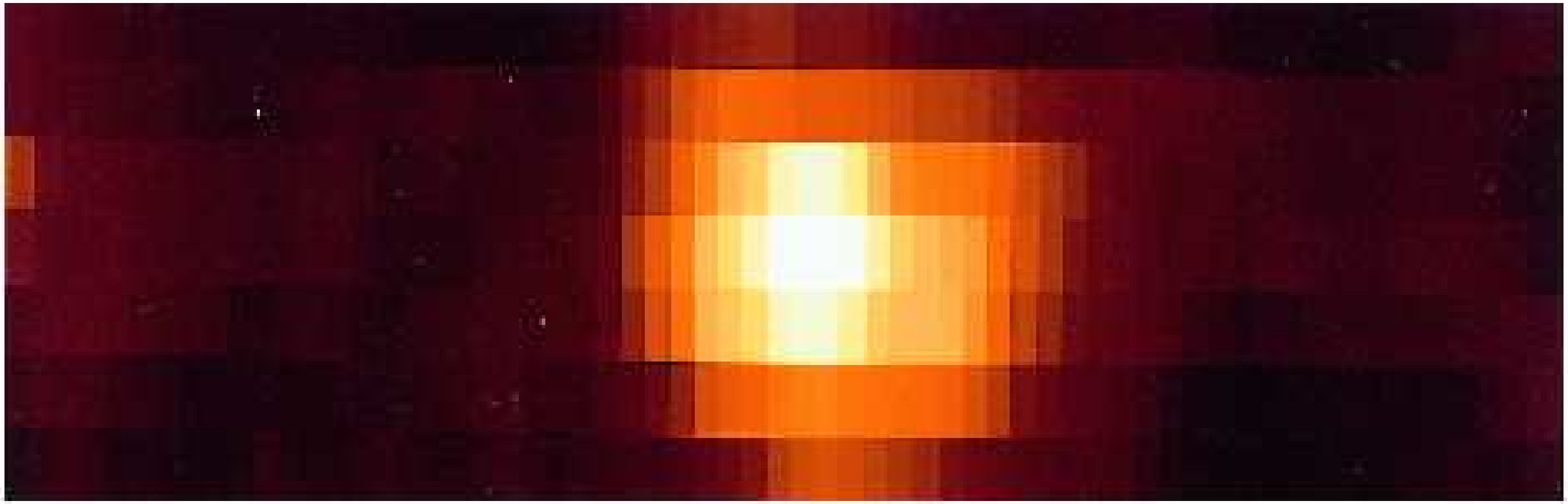


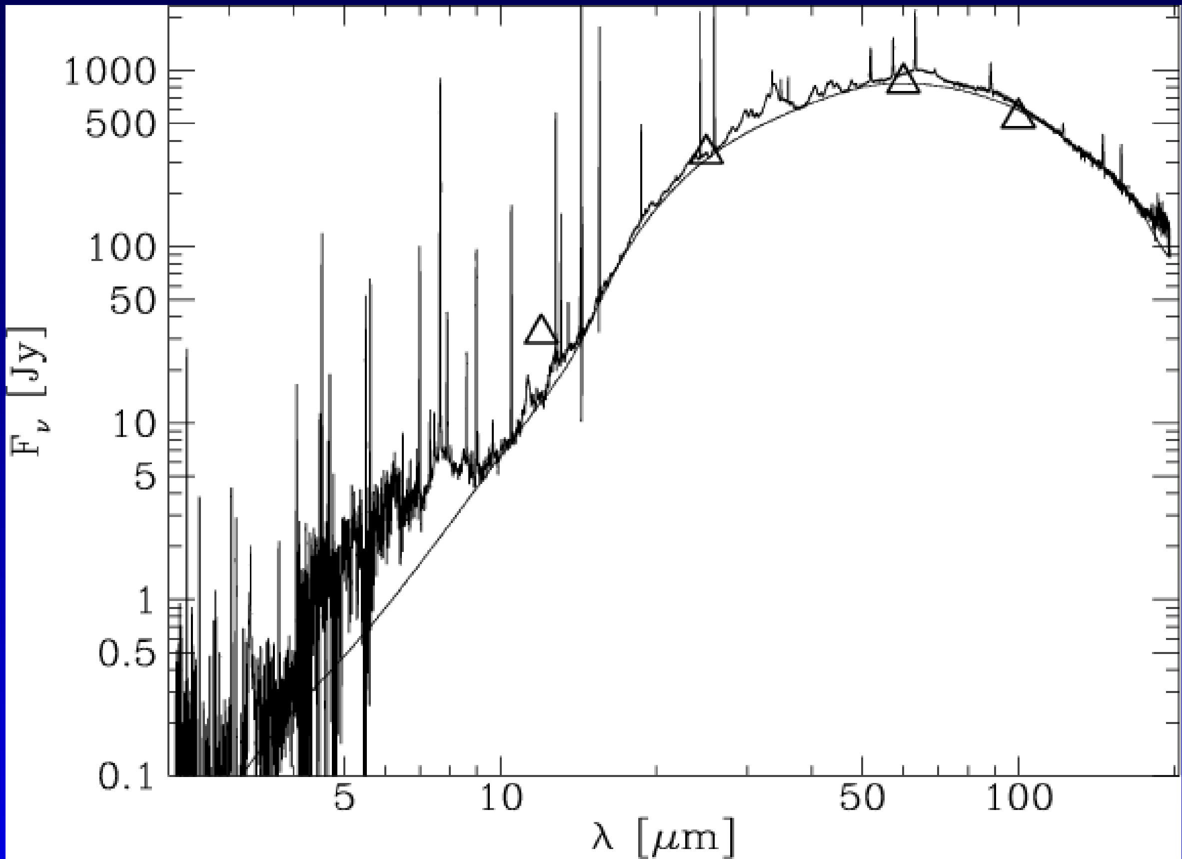
Fig. 2. 160 μm image of Y CVn taken with PHT-C200 array detector and C160 filter displayed in linear brightness scale.

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)

Implementation (Photo)

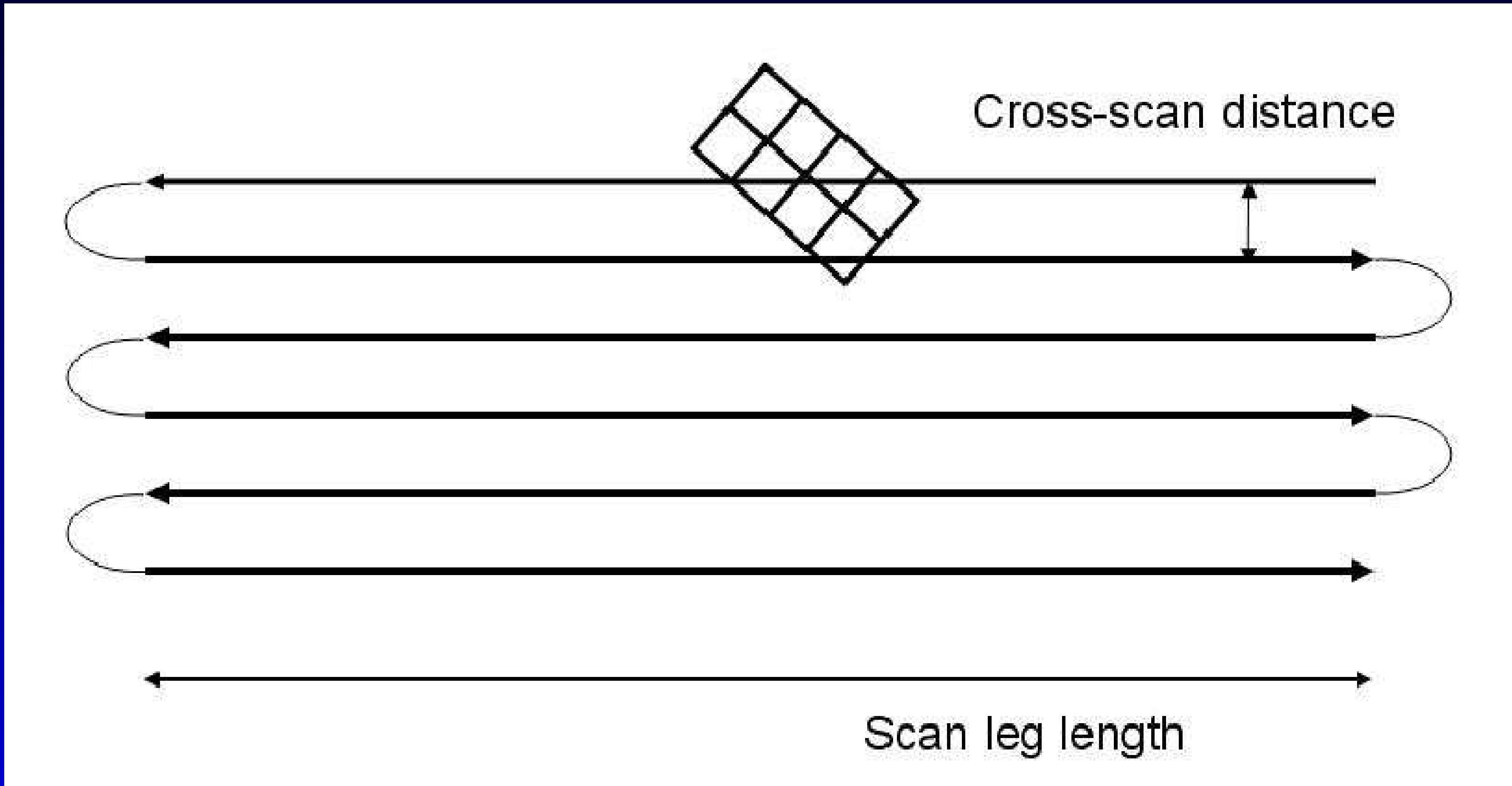
PACS:
"Scan Maps" at 70 + 160 μm

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 so far

8 papers in the A&A Volume 518 Special Issue

+ 1 Nature paper

+ Overview paper

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

+ papers on TX Psc and X Her, and Mira
talk by Alain tomorrow

+ several in preparation

Results so far

NOT DISCUSS:

-SNe (Barlow et al. 2010)

-PNe (van Hoof et al. 2010)

-Massive stars

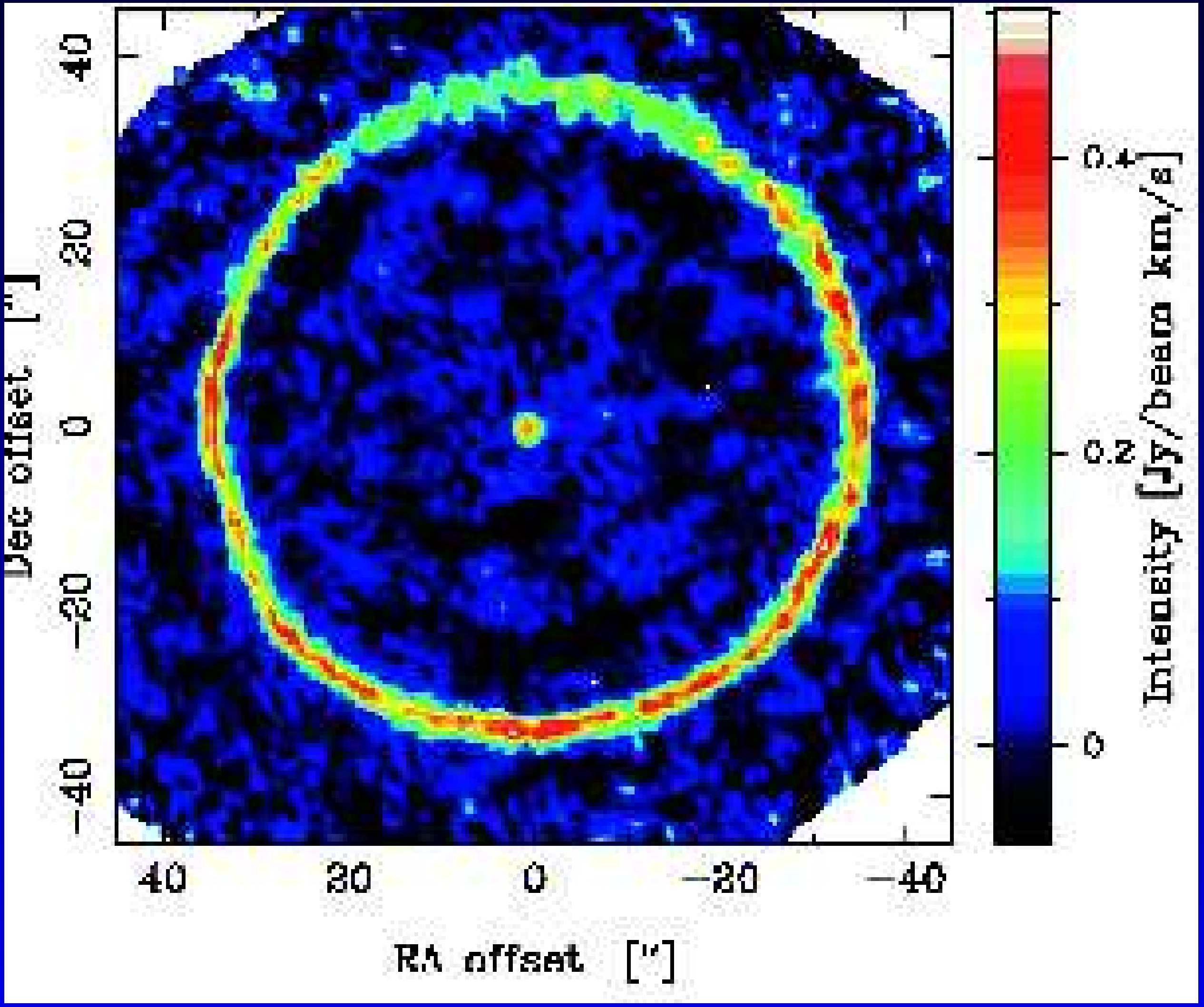
-AGB Dust
talk by Joris on wednesday

In more detail:

-AGB imaging and modelling
talk by Alain
posters by Mayer (P10), and Mecina (P6)

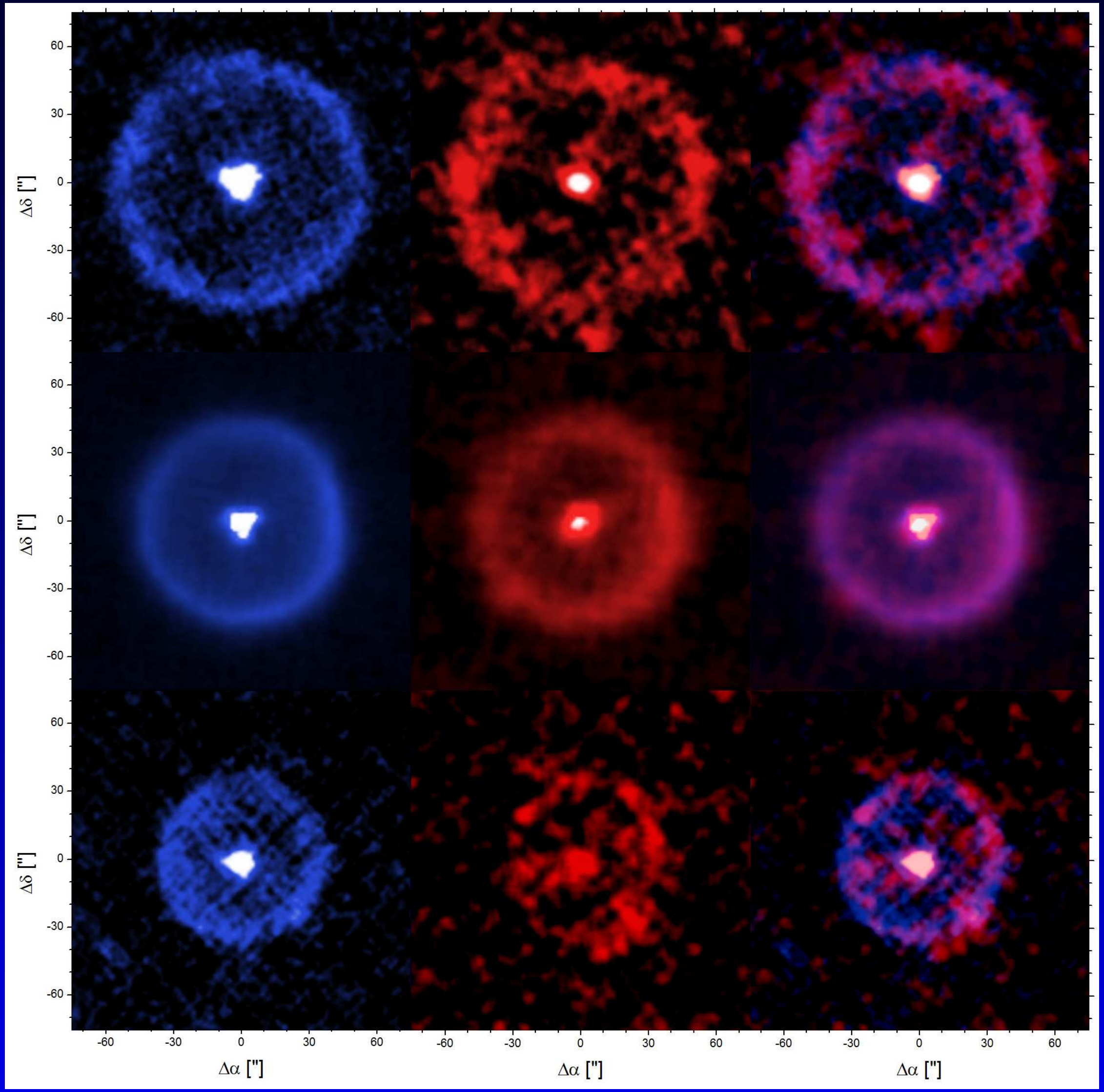
-AGB molecular spectroscopy

Detached shells



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

Detached shells

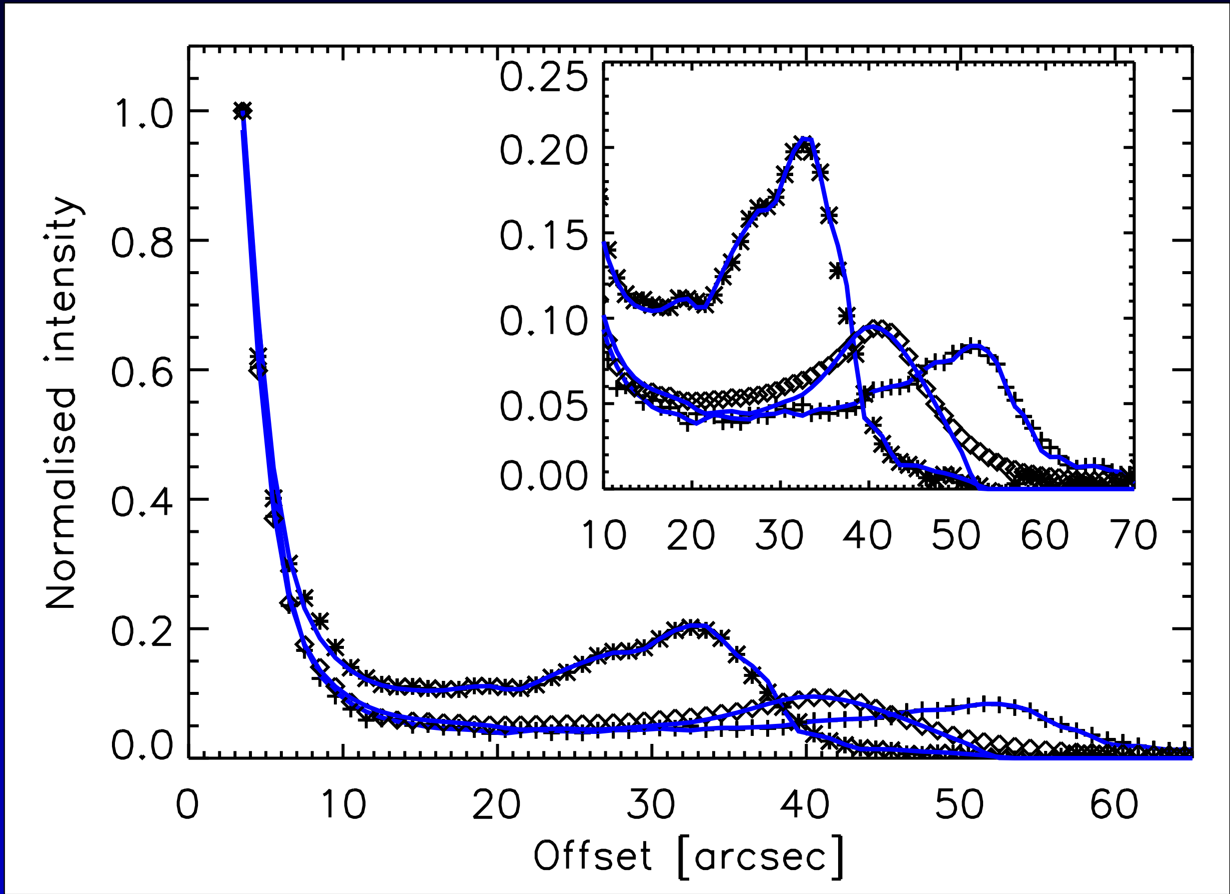


Kerschbaum et al. (2010)

PACS:
blue / red / combined

AQ And,
U Ant,
TT Cyg

Detached shells

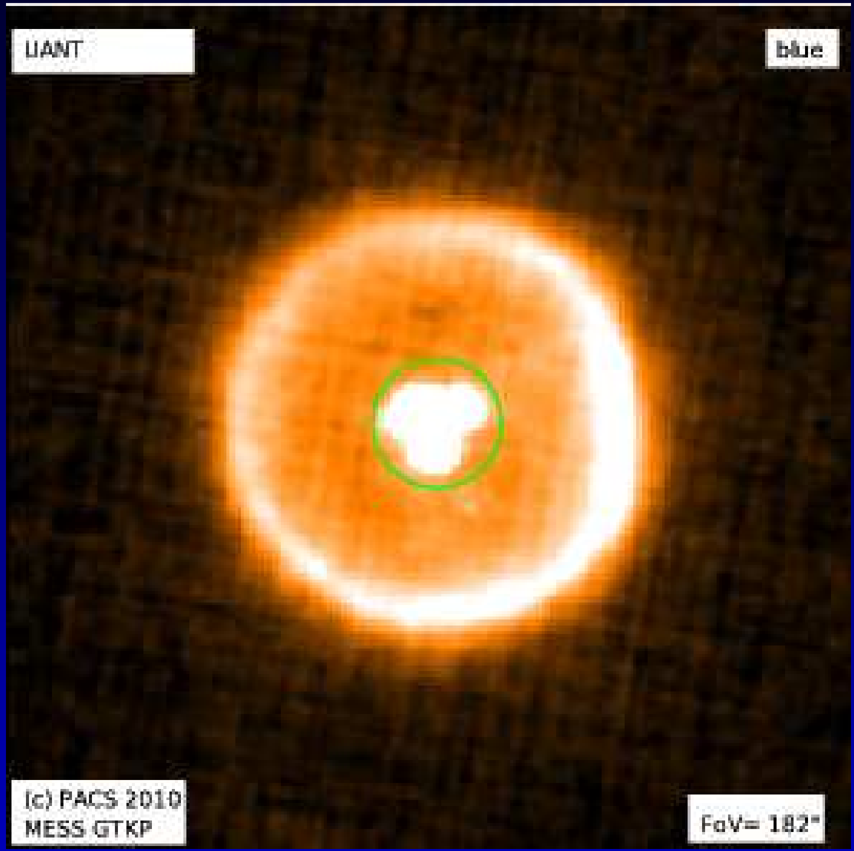


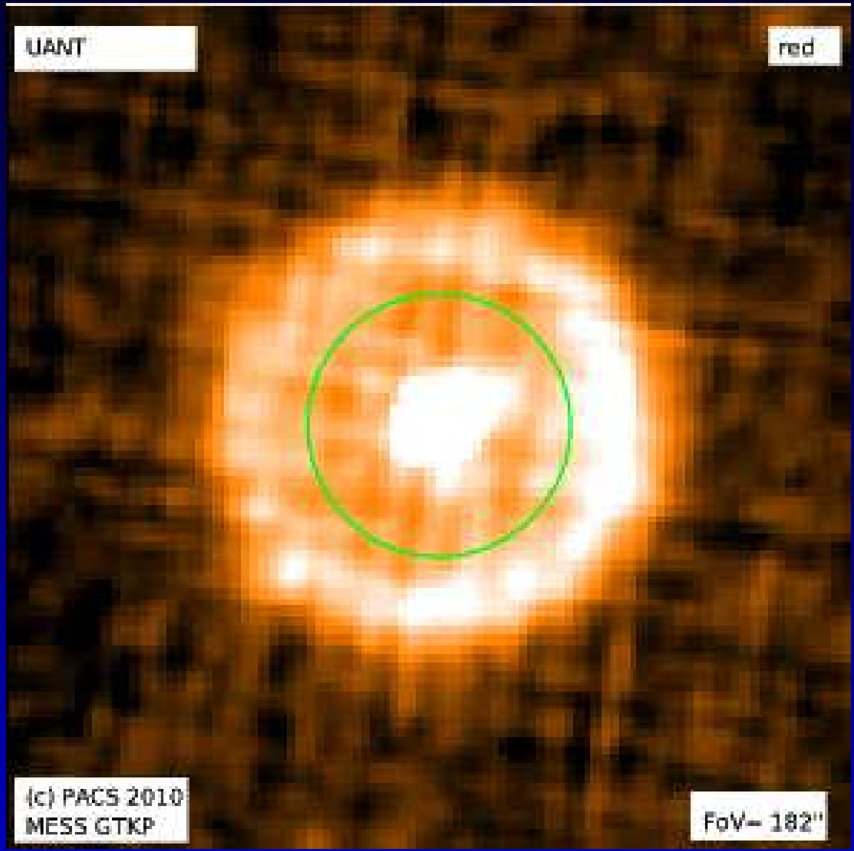
AQ And=$+$
U Ant=$\diamond$
TT Cyg=$\times$

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

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

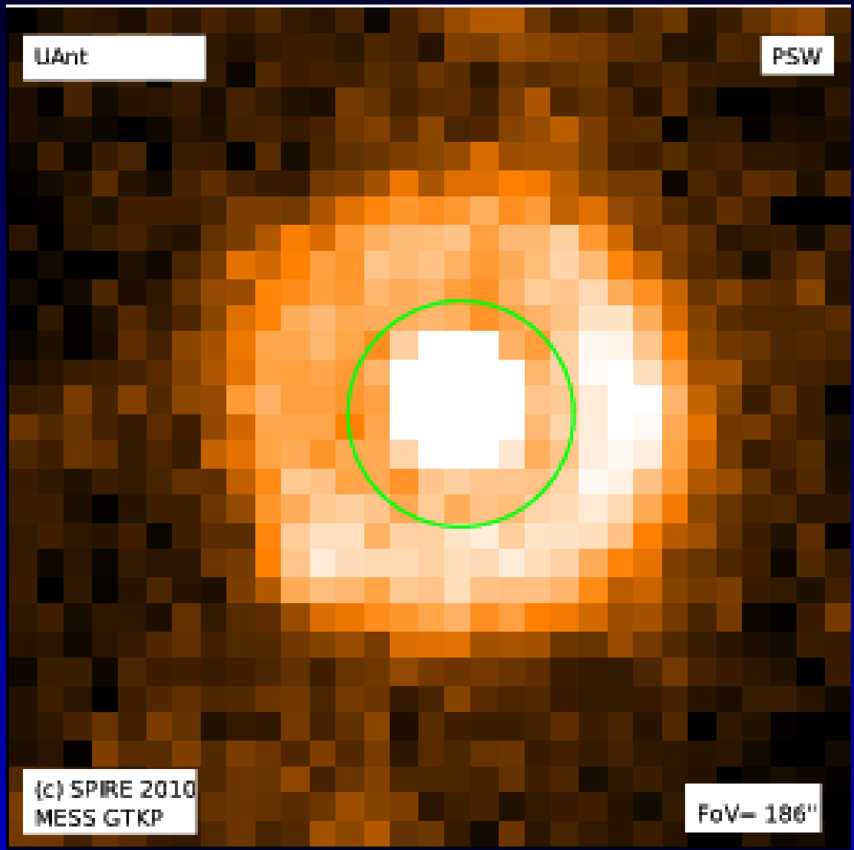
Spatial Resolution

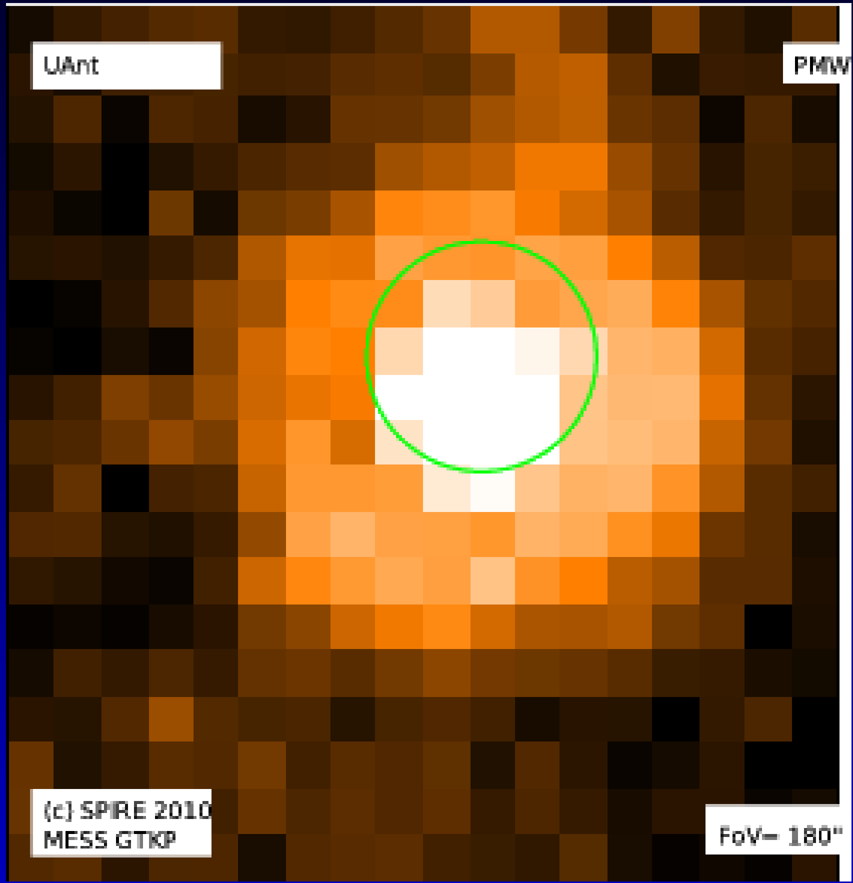




U Ant PACS blue and red

U Ant



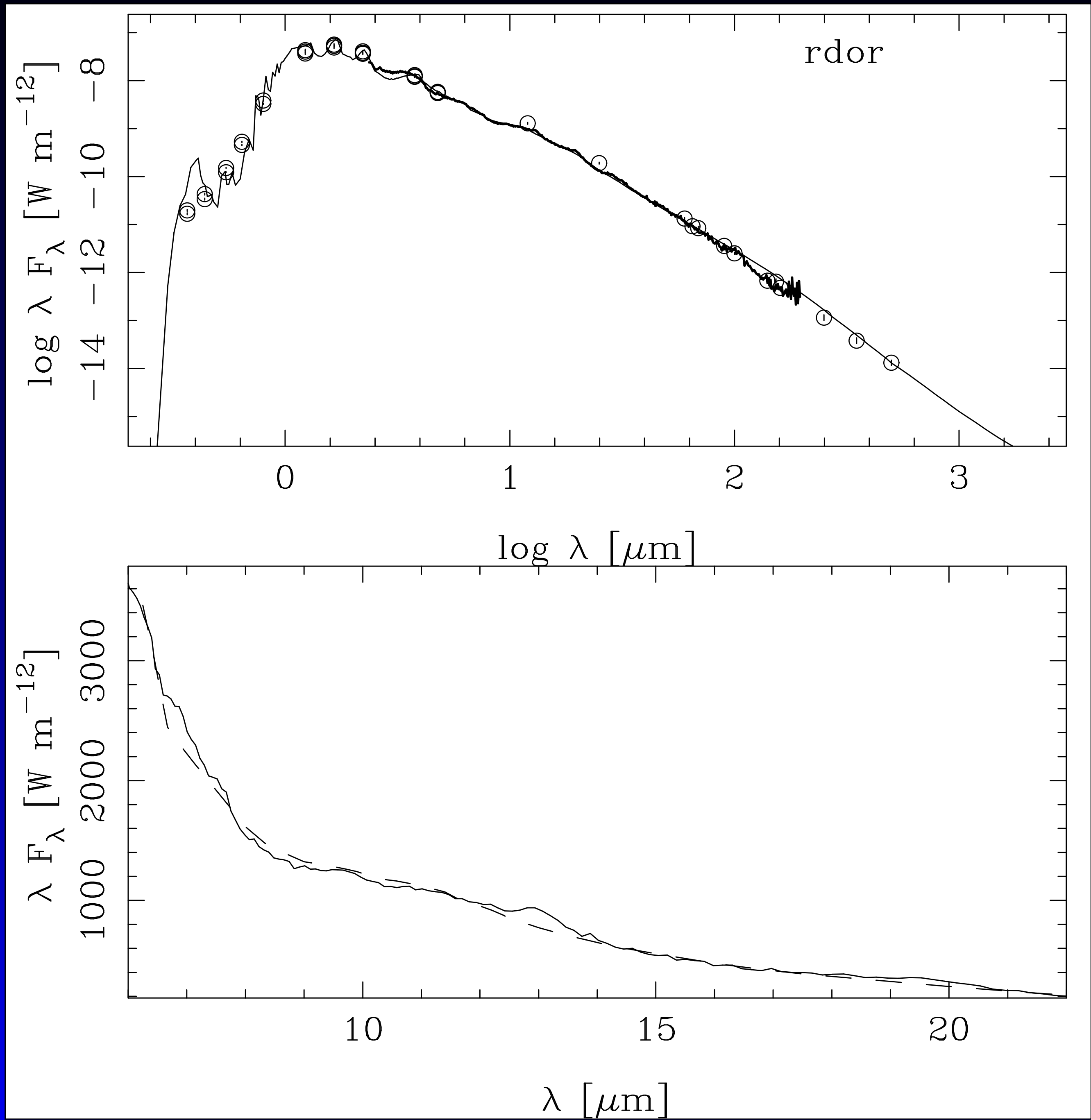


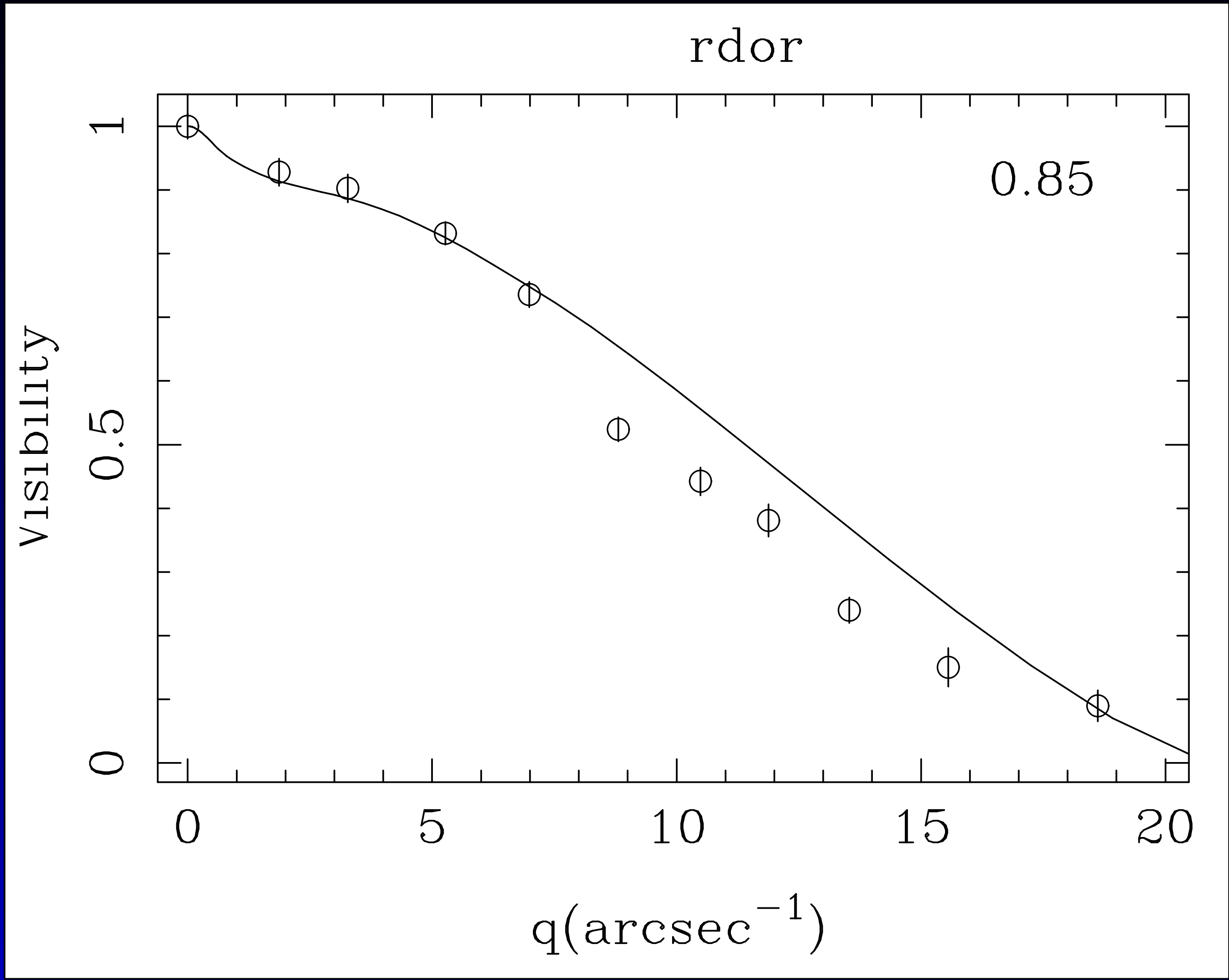
SPIRE PSW and PMW

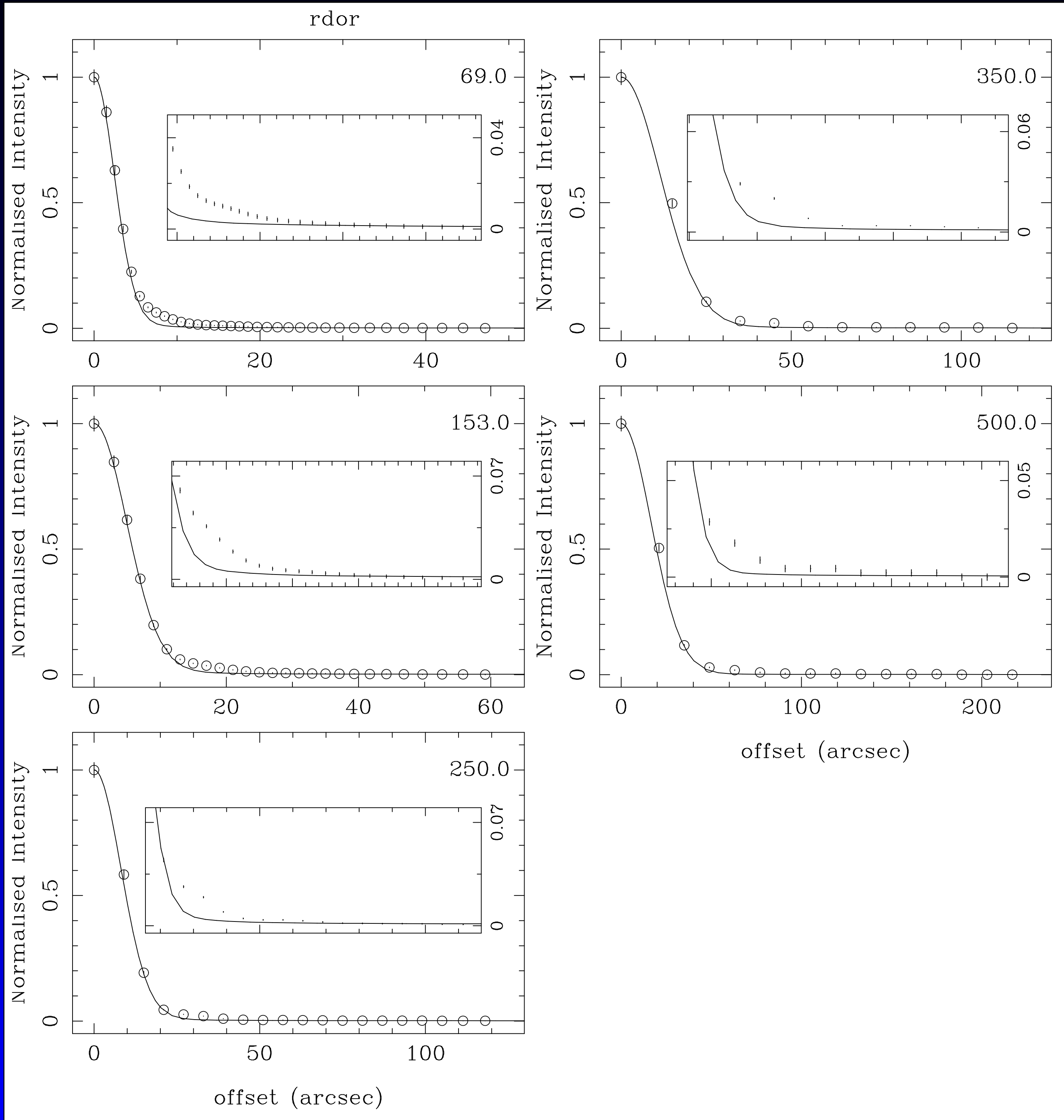
MoD - More of DUSTY

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

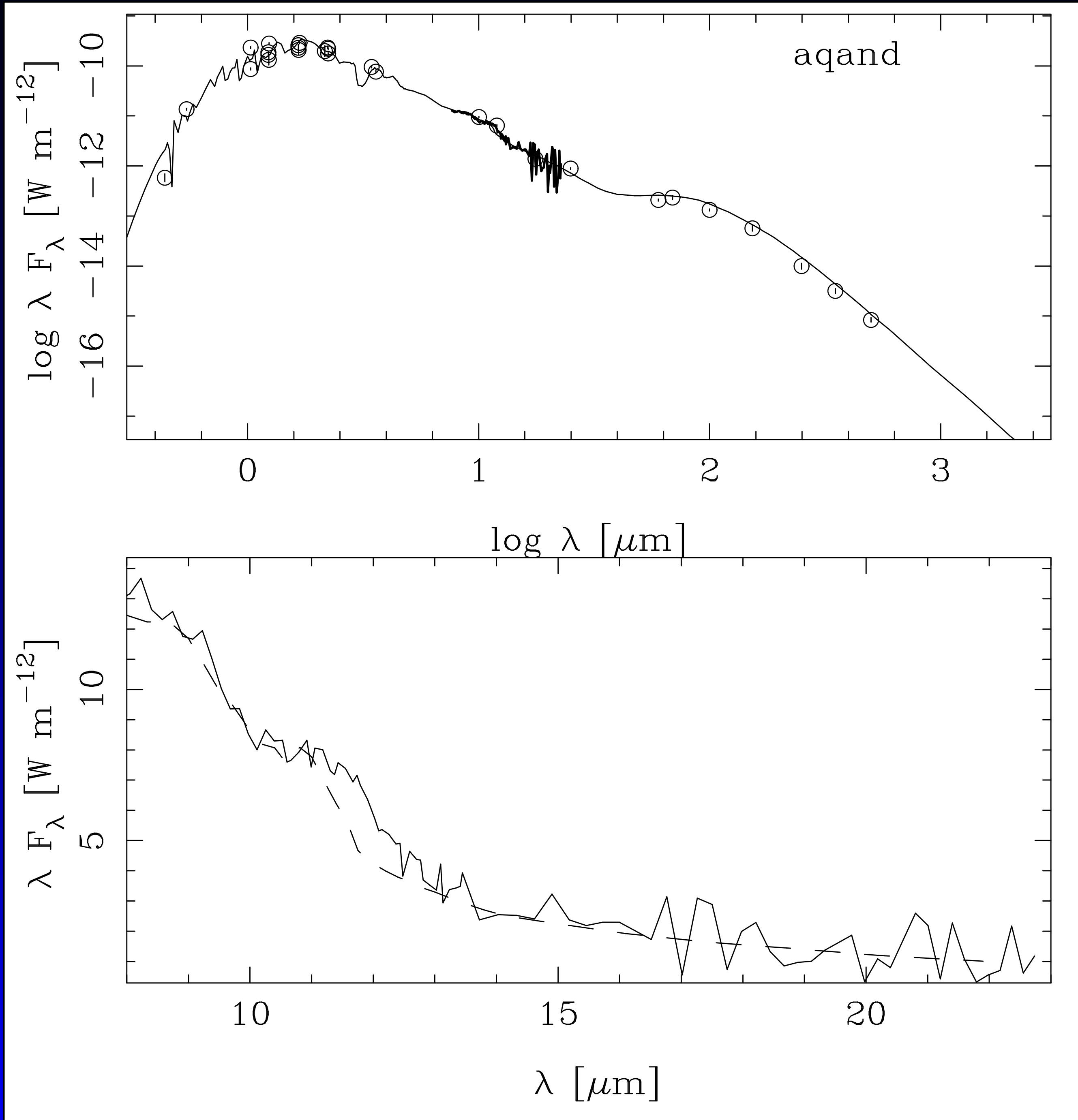
- R Dor: 4 parameters
  L, $\tau_{\rm V}$, $T_{\rm inner}$, $p_{\rm o}$
- AQ And: 7 parameters
  L, $\tau_{\rm V}$, $R_{\rm in,shell}$, $\Delta R_{\rm shell}$, $p_{\rm o}$, $p_{\rm shell}$, 'density jump'

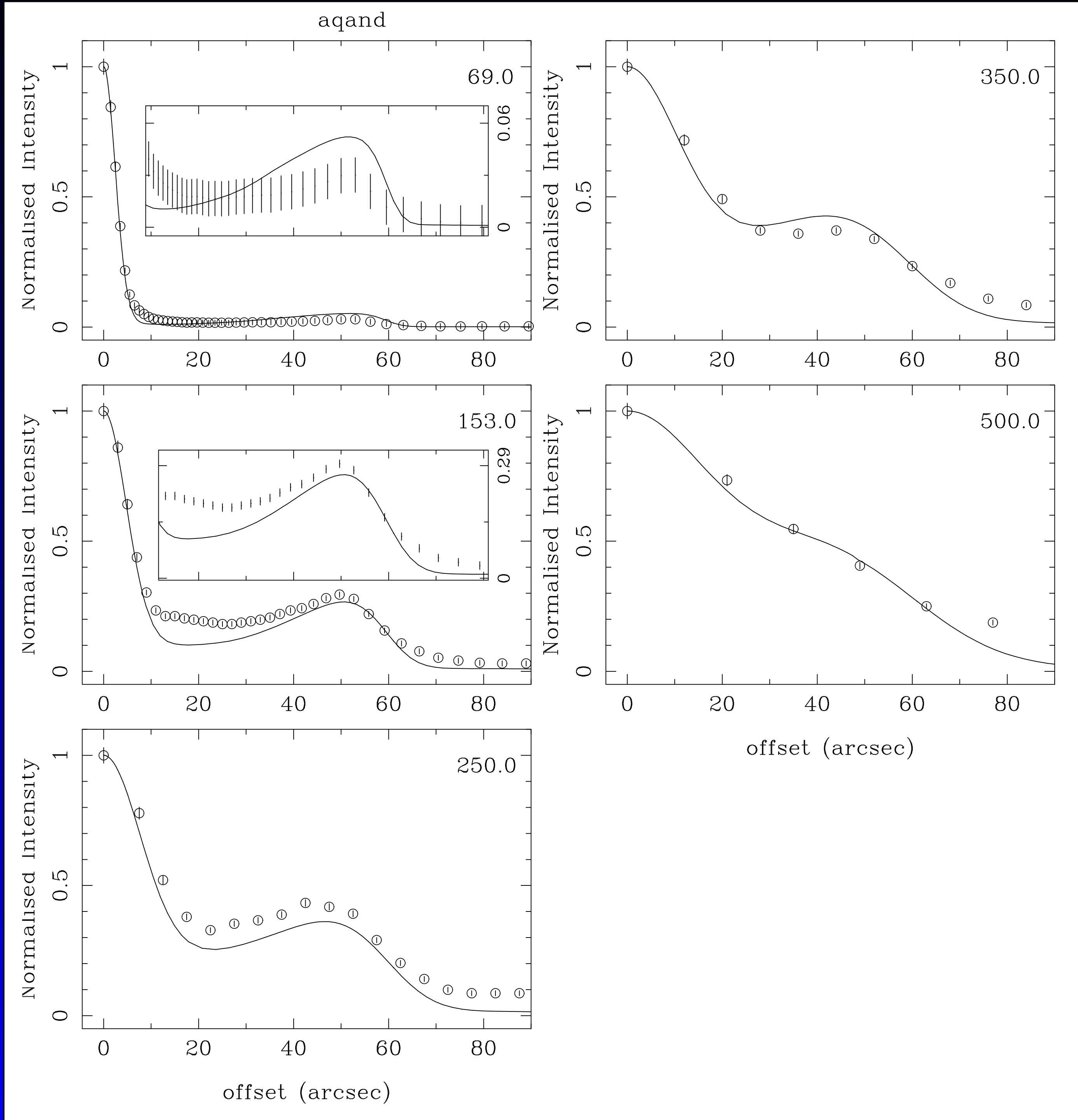

rdor
log λ F_λ [W m^-12]
−14
−12
−10
−8
0
1
2
3
log λ [μm]
λ F_λ [W m^-12]
1000
2000
3000
10
15
20
λ [μm]

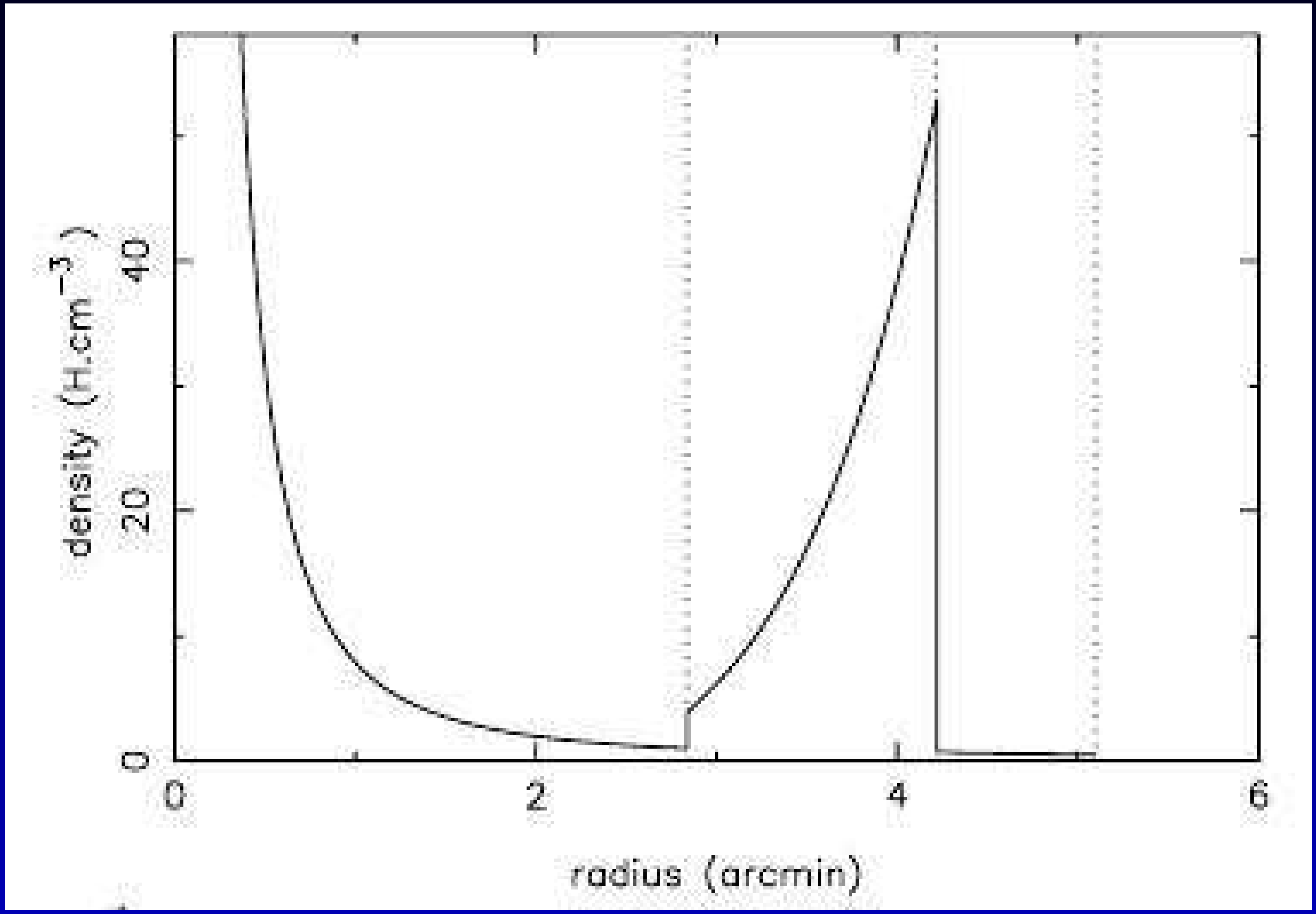

rdor
0.85
Visibility
0
0.5
1
0
5
10
15
20
q(arcsec^{-1})



rdor
69.0
350.0
153.0
500.0
250.0
Normalised Intensity
offset (arcsec)

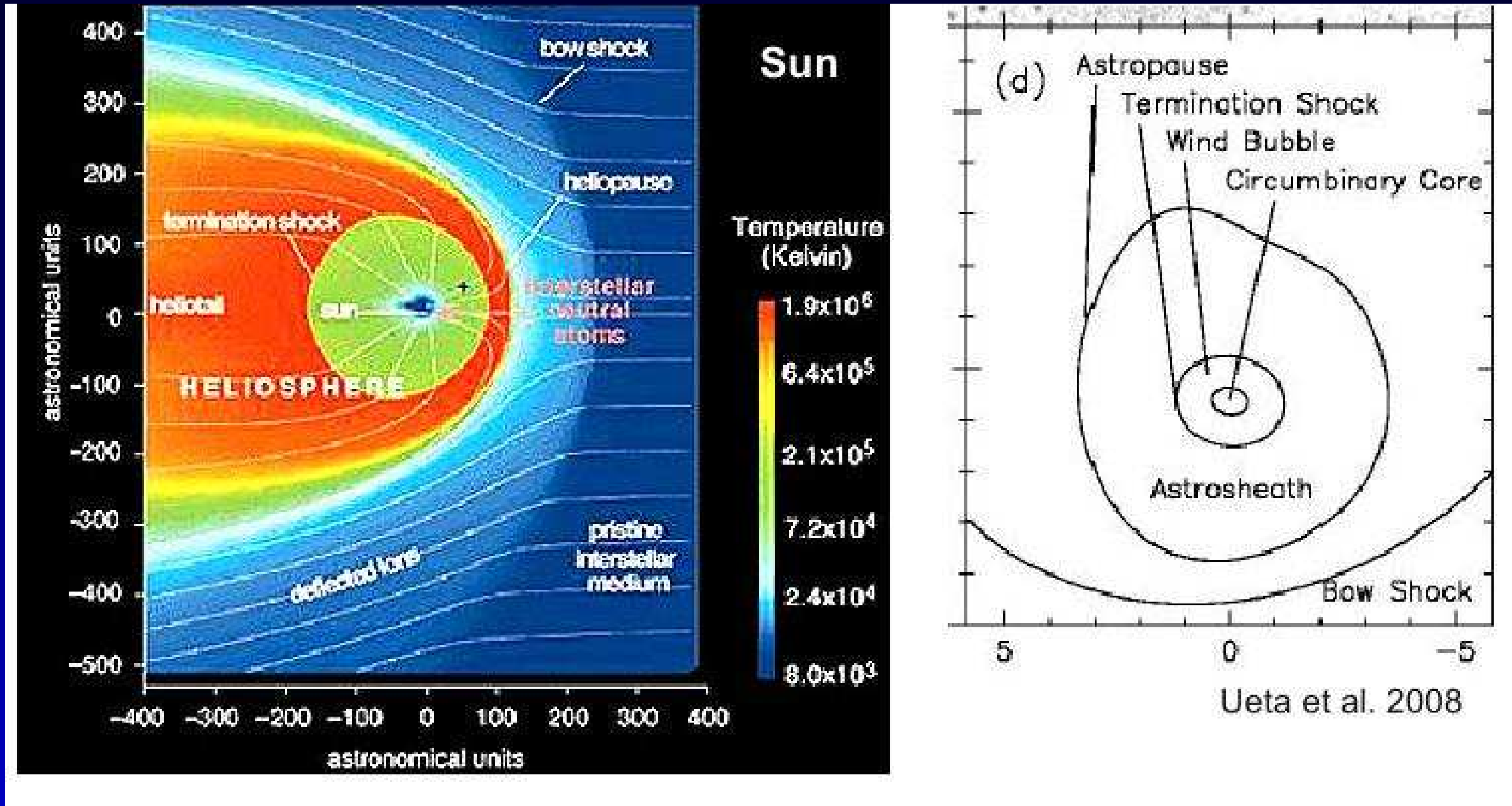

aqand
log λ F_λ [W m^-12]
-10
-12
-14
-16
0
1
2
3
log λ [μm]
λ F_λ [W m^-12]
10
5
10
15
20
λ [μm]


aqand
69.0
350.0
153.0
500.0
250.0
Normalised Intensity
offset (arcsec)
0
0.5
1
0
20
40
60
80
0.06
0.29



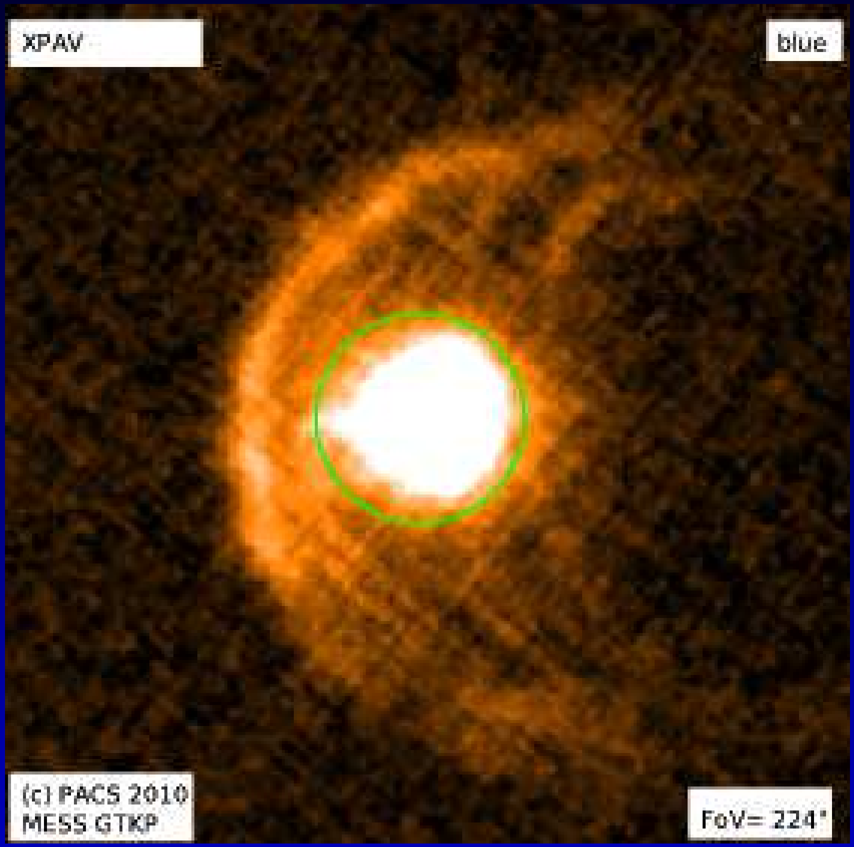
Libert et al. 2007, Y CVn, $p_{\rm shell}$= +6

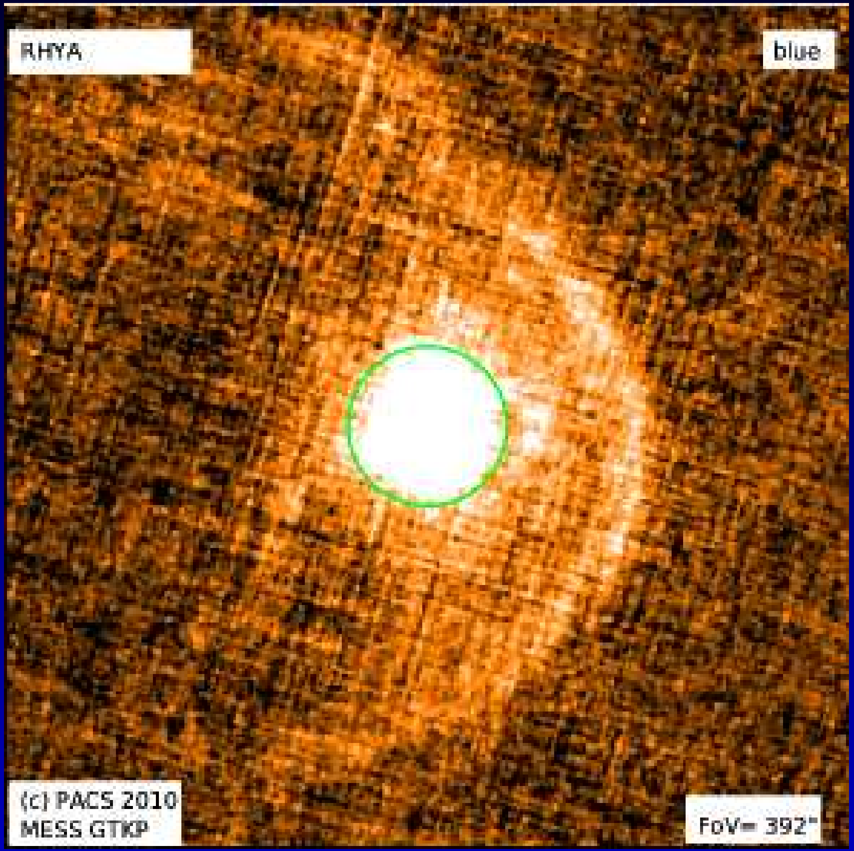
Interaction ISM



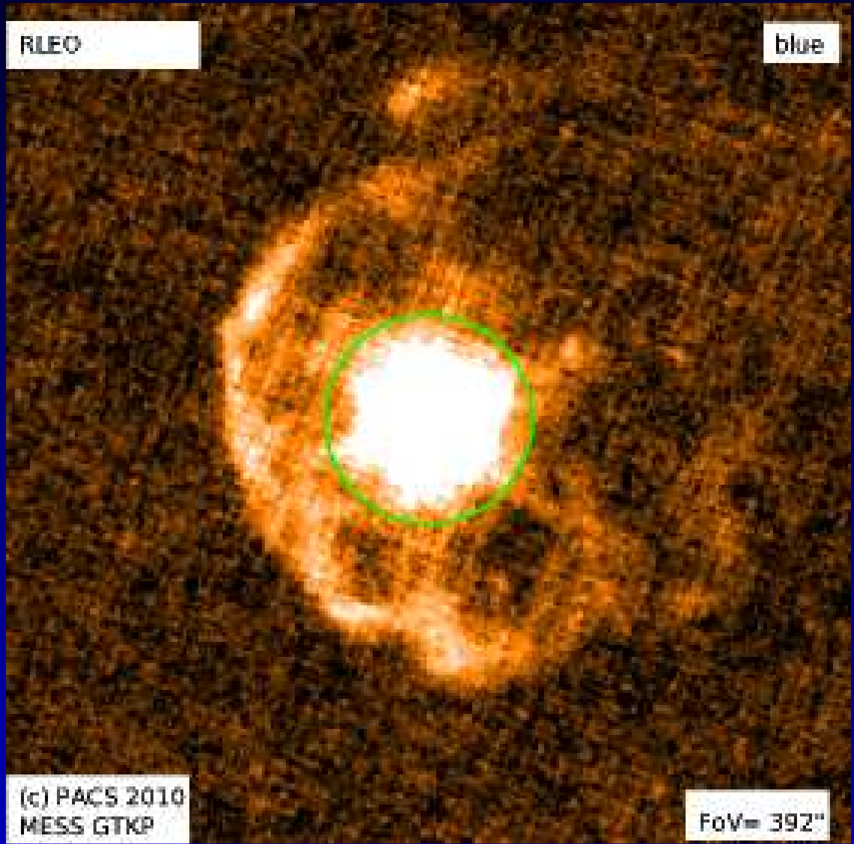
bow shock: where $V_{\rm ISM}$ goes from super- to subsonic
astropause: where $P_{\rm ISM} = P_{\rm CSE}$
termination shock: where $V_{\rm CSE}$ goes from super- to subsonic

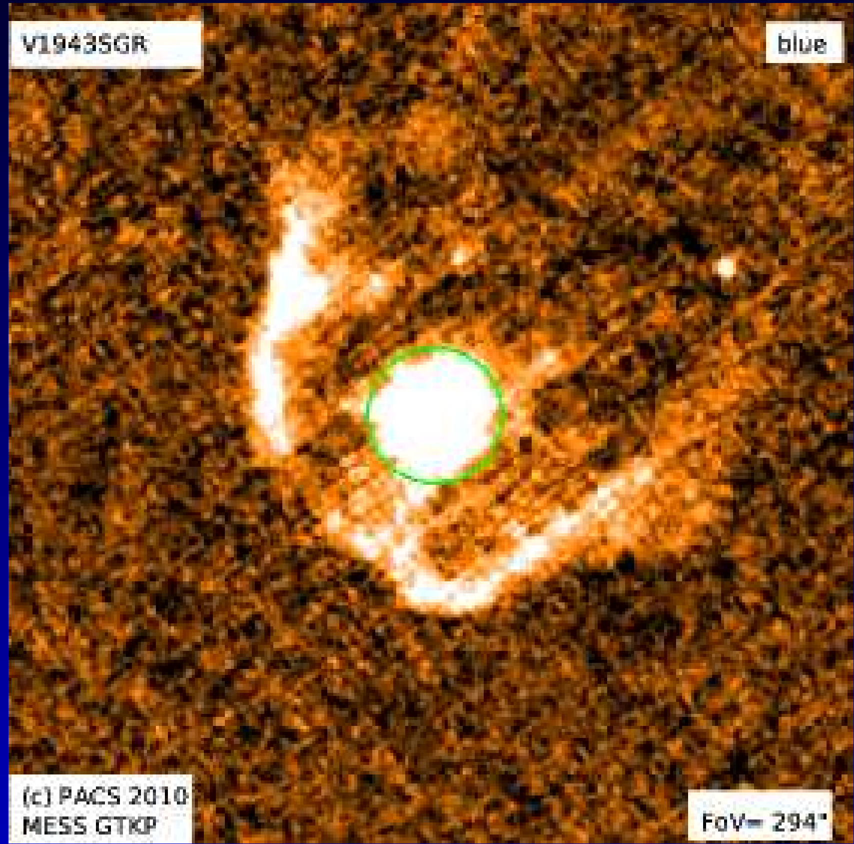
The Zoo

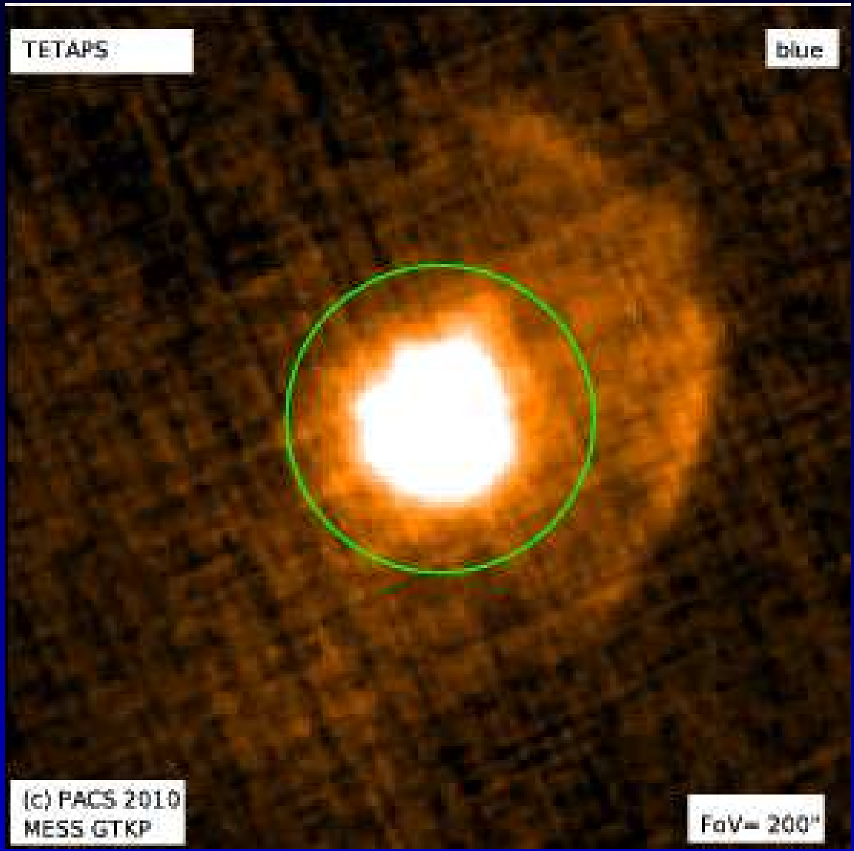


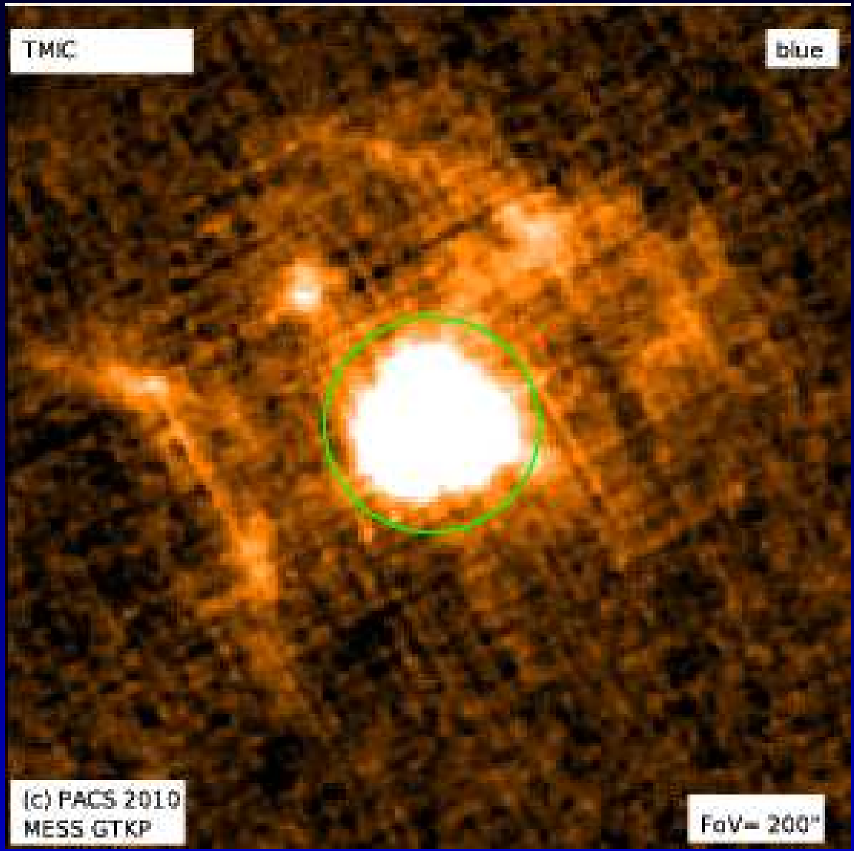


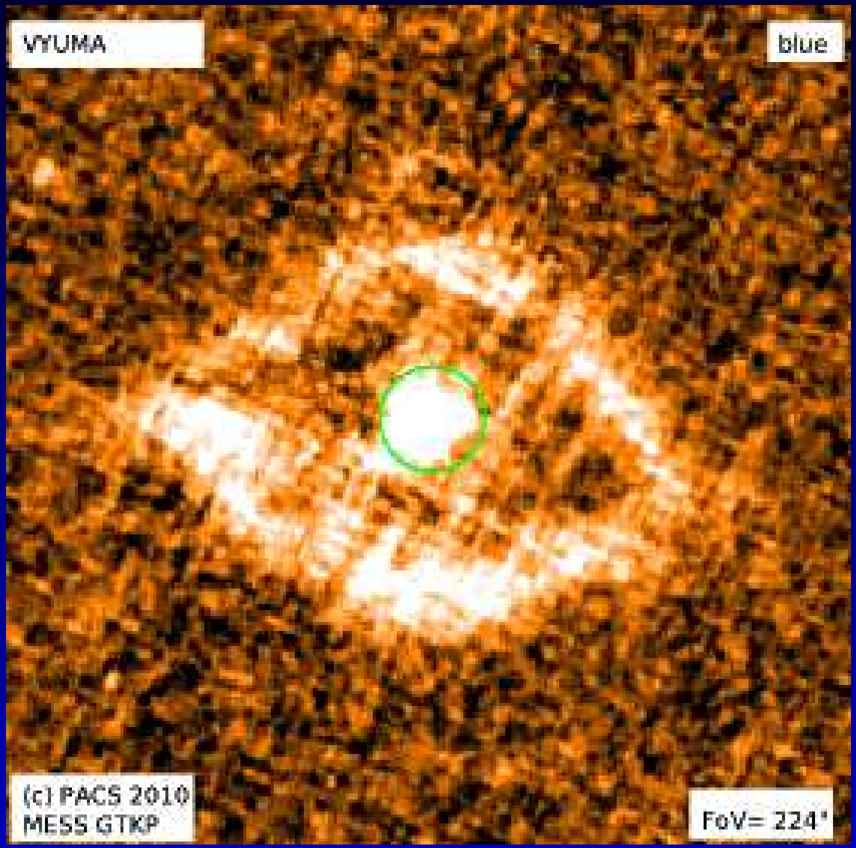
Cox et al. (in prep). Alain's talk

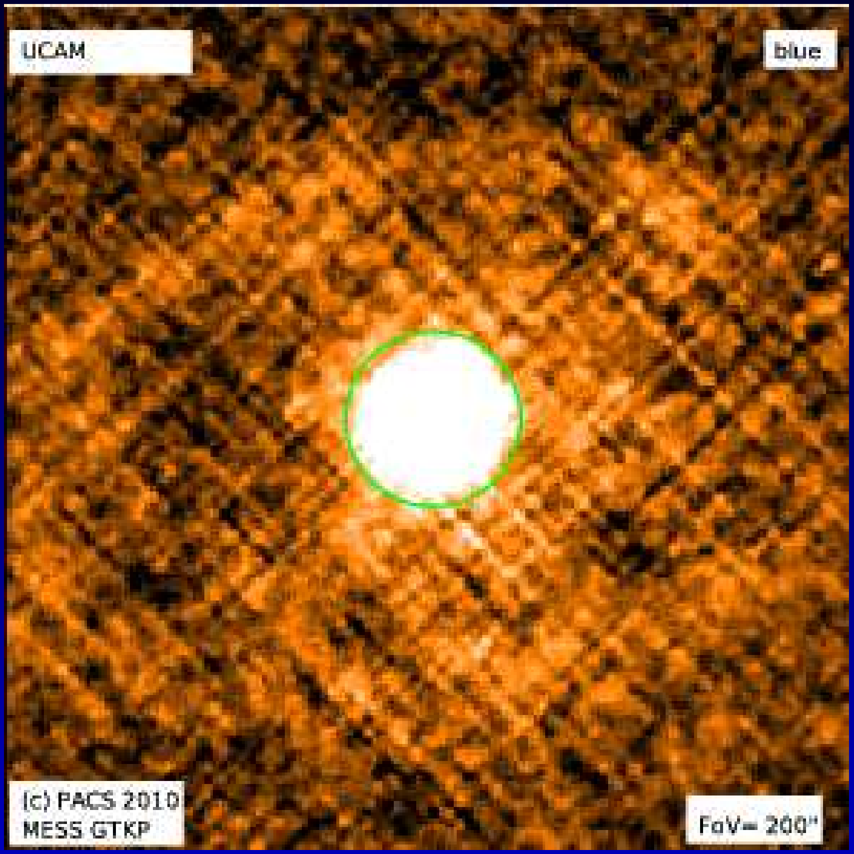

RLEO
blue
(c) PACS 2010
MESS GTKP
FoV= 392"


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

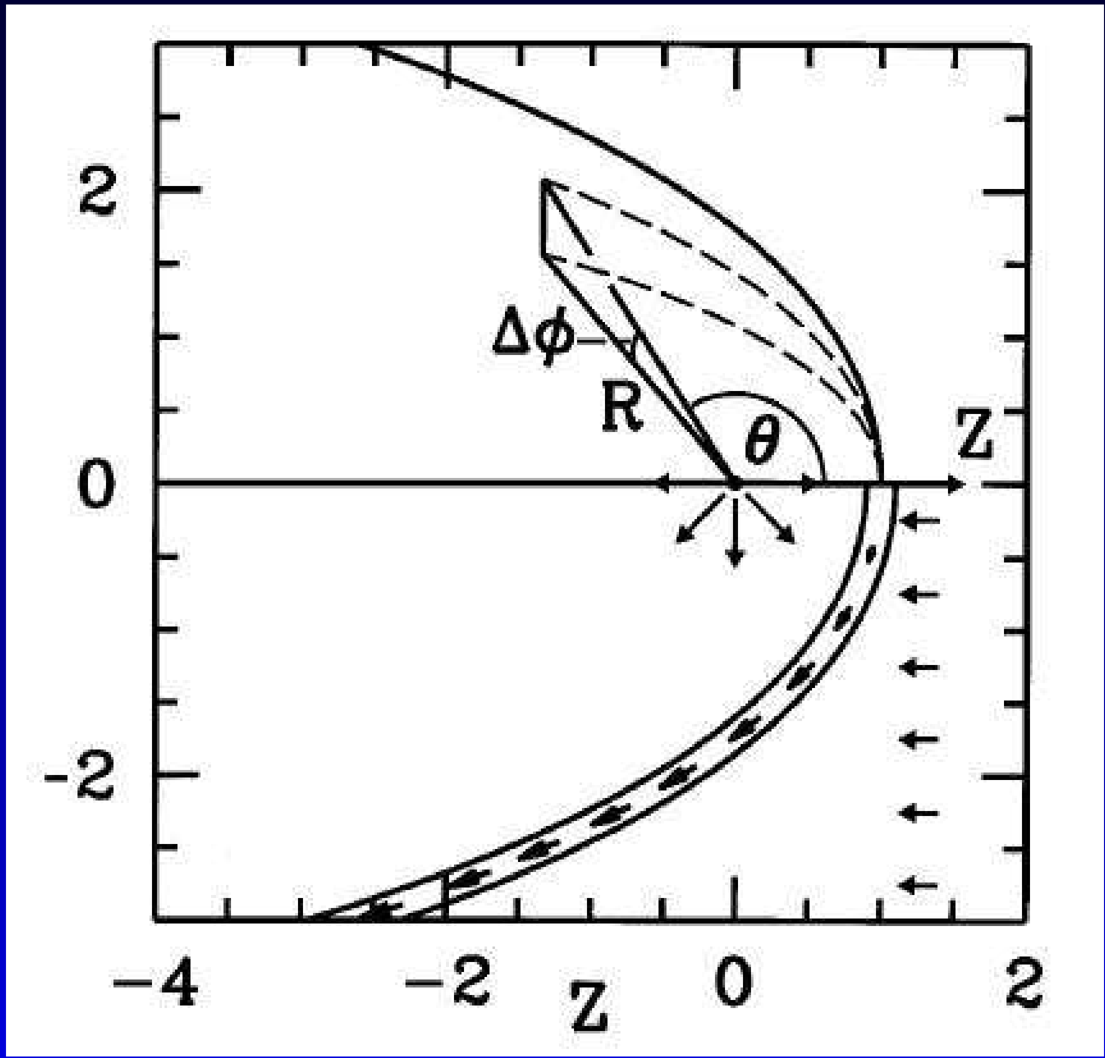

TETAPS
blue
(c) PACS 2010
MESS GTKP
FoV= 200"


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


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)

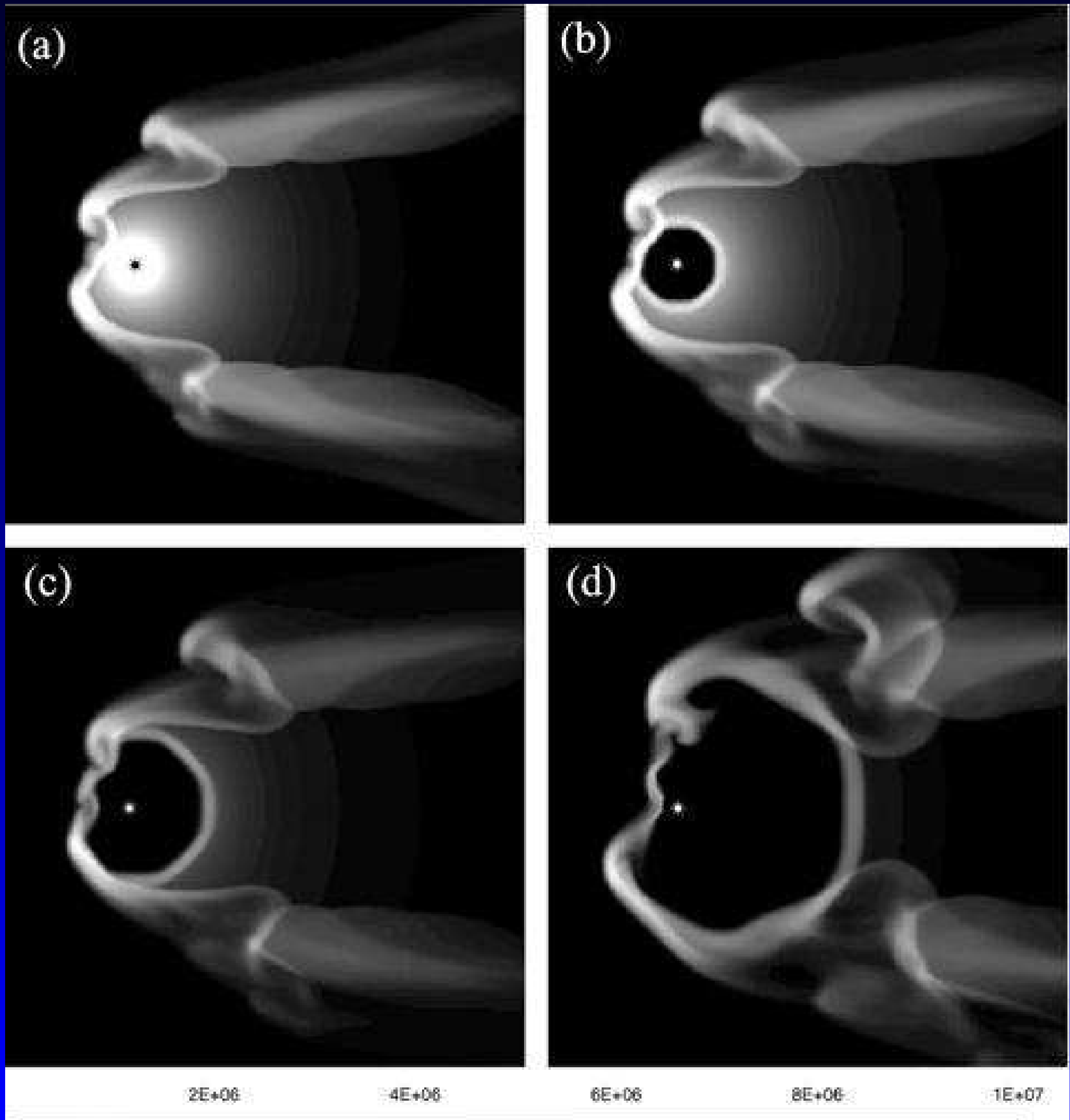
Wilkin model

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

standoff distance:

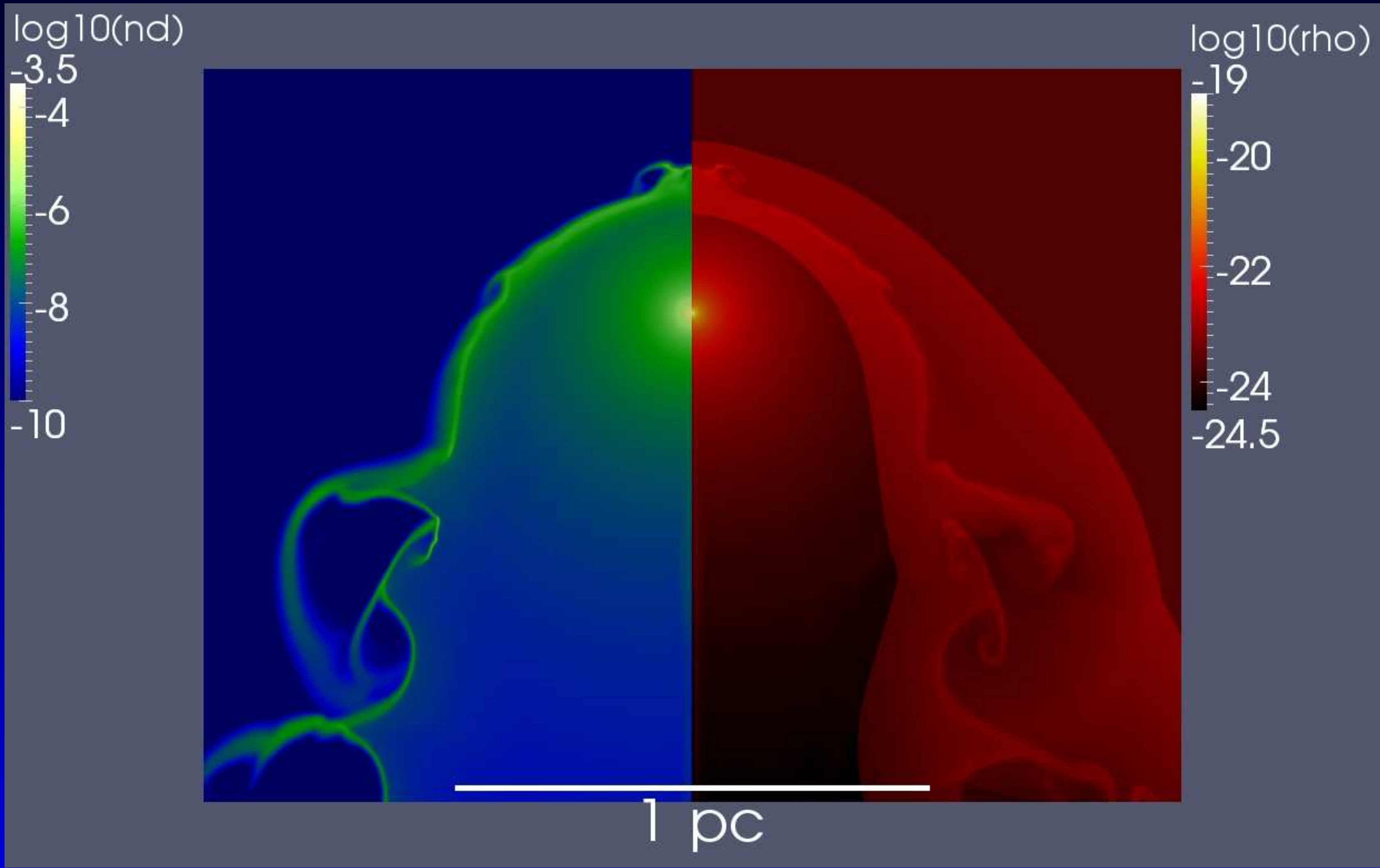
$$R_0 = \sqrt{(\dot{M}\, V_{\rm exp}) / (4\pi\, \rho_0\, V_{\rm w}^2)}$$

Hydro Models



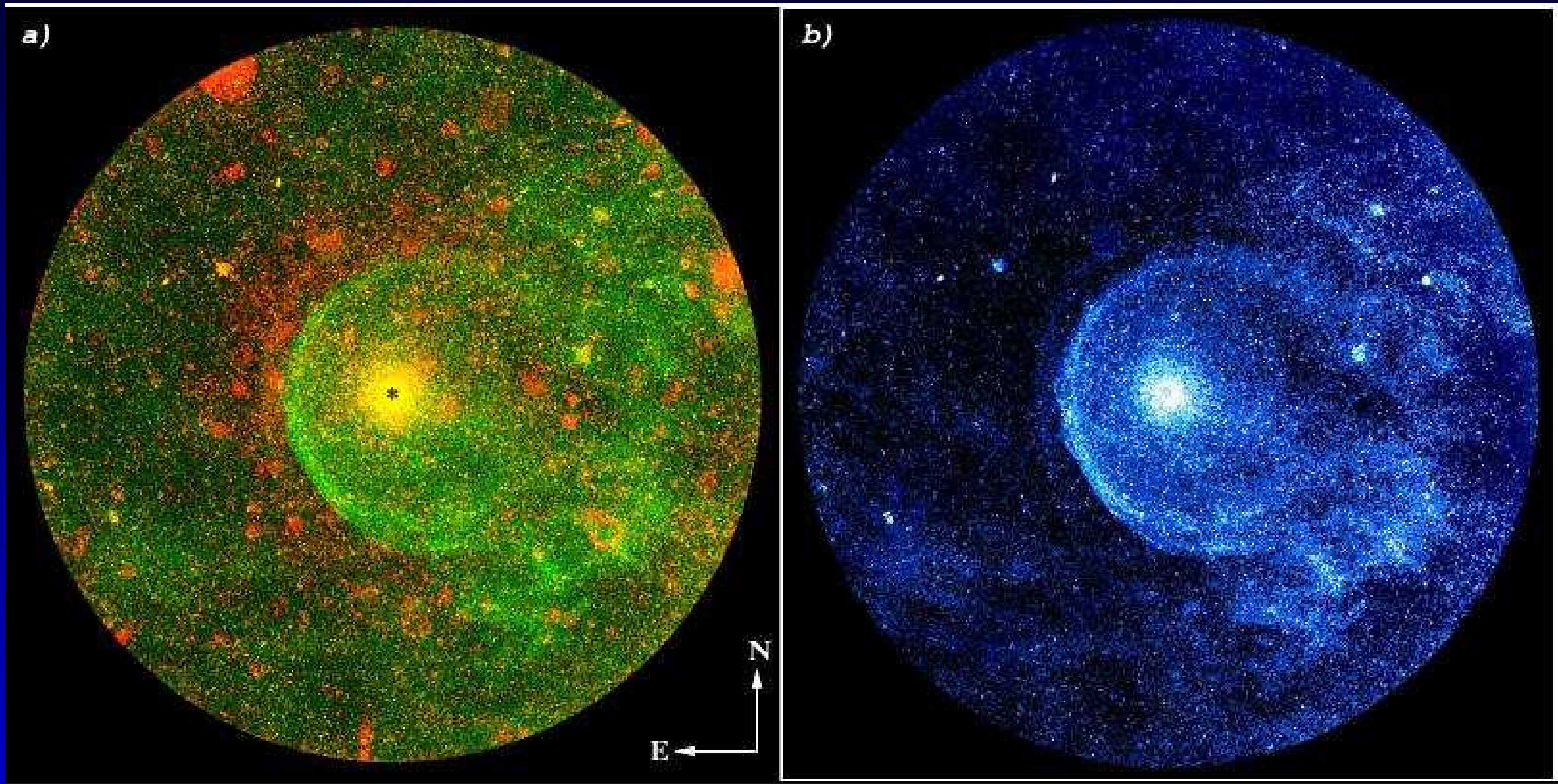
Wareing et al. (2007)

Models



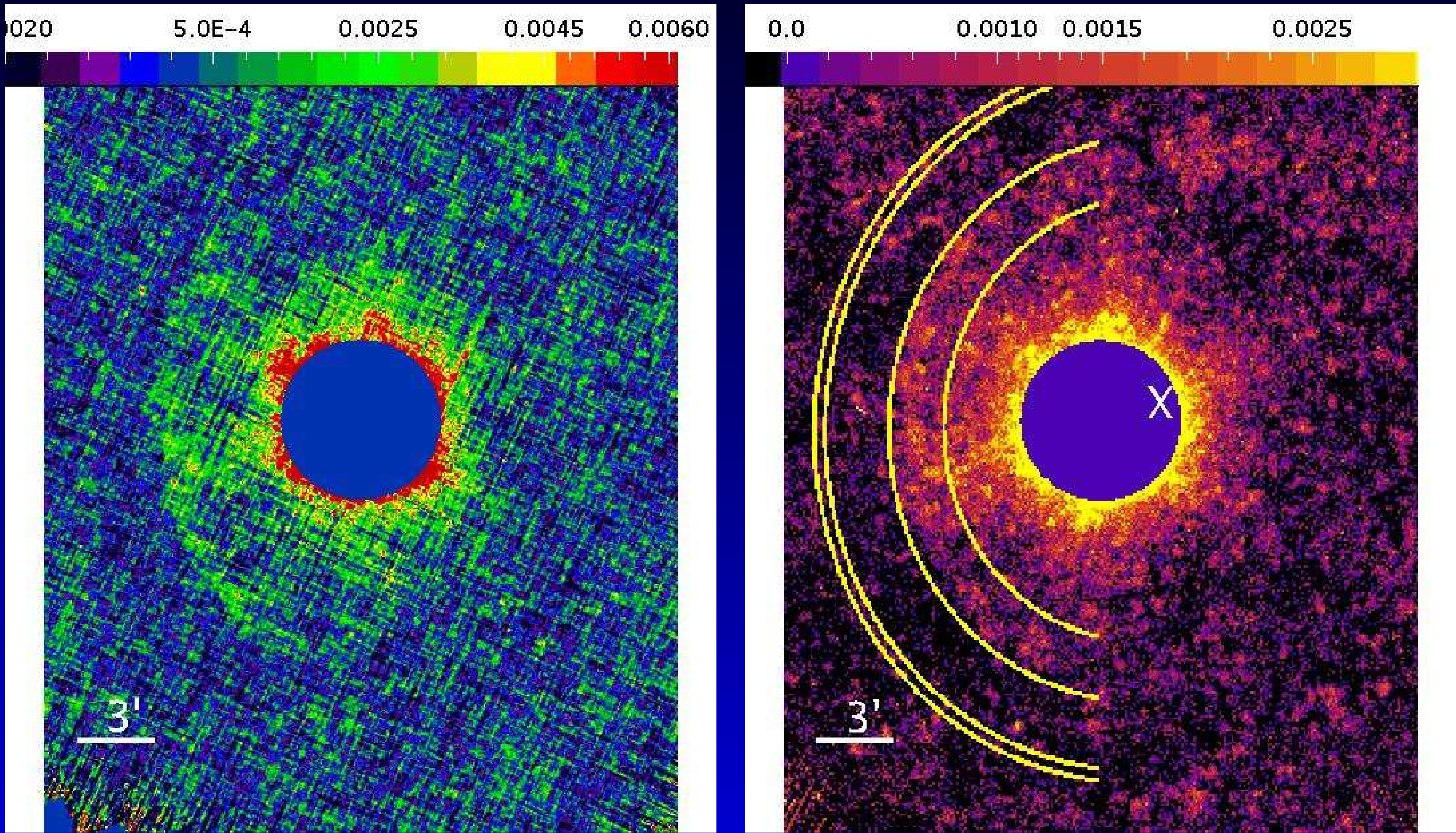
van Arle et al. (2011)

CW Leo - bowshock



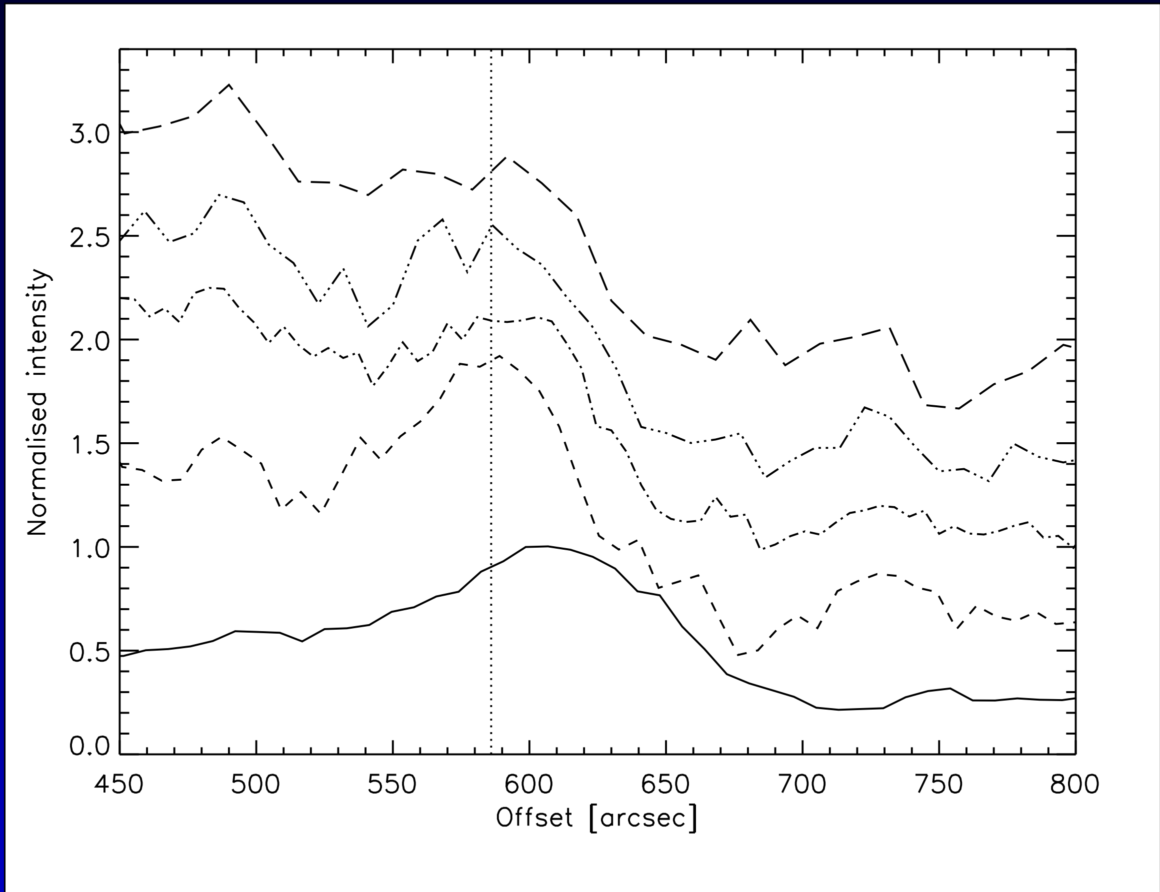
GALEX NUV/FUV composite (left), FUV (right).
Sahai & Chronopoulos (2010)

CW Leo - bowshock



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

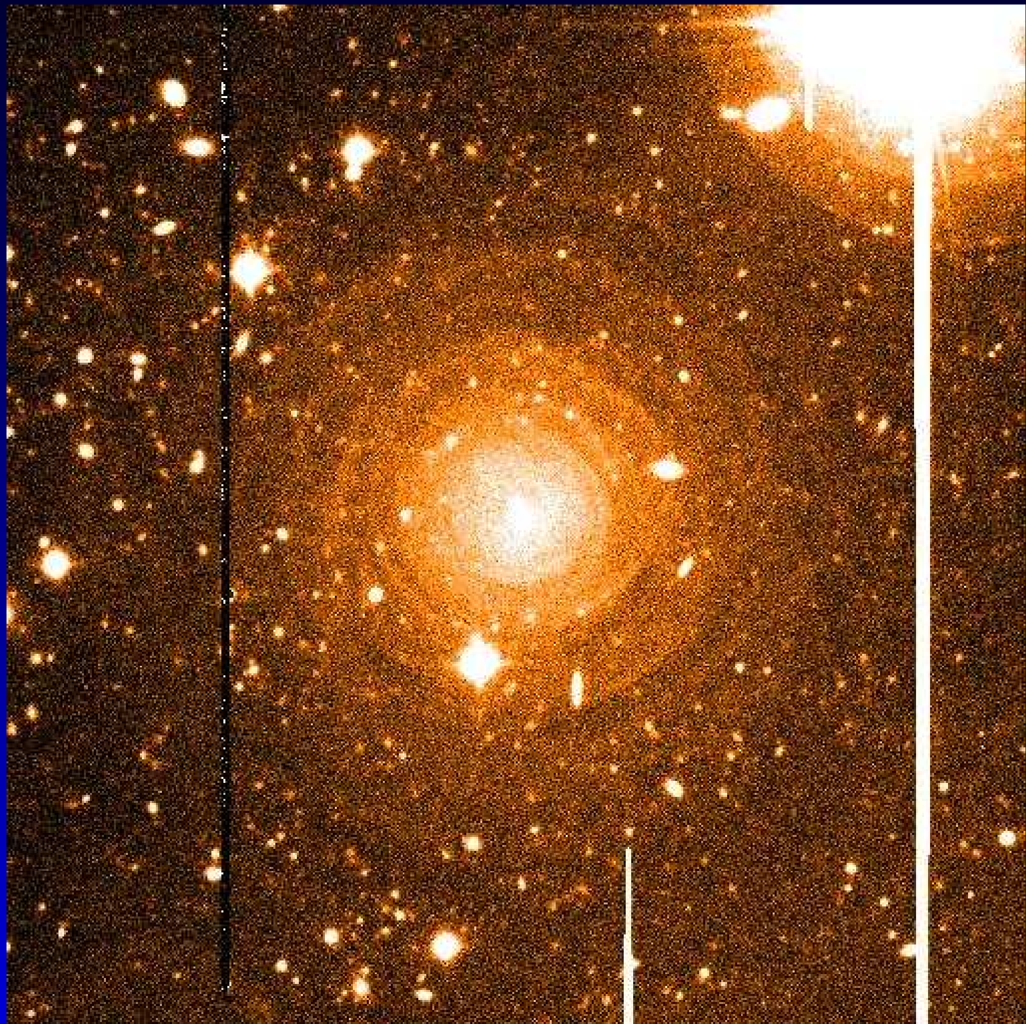
CW Leo - bowshock



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

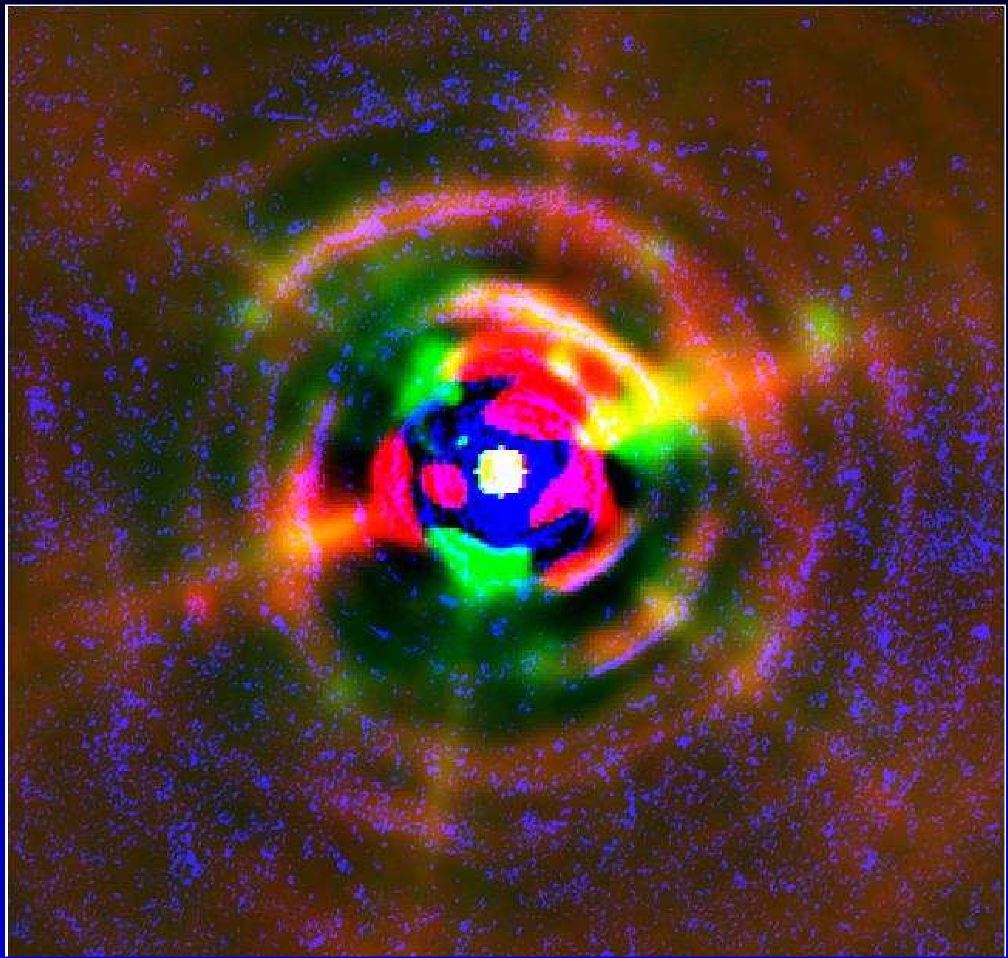
$T_{\text{dust}} = 25$ K $\qquad V_{\star\text{relativeISM}} = 107/\sqrt{n_{\text{ISM}}}$ km s^{-1}

CW Leo - inner part



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

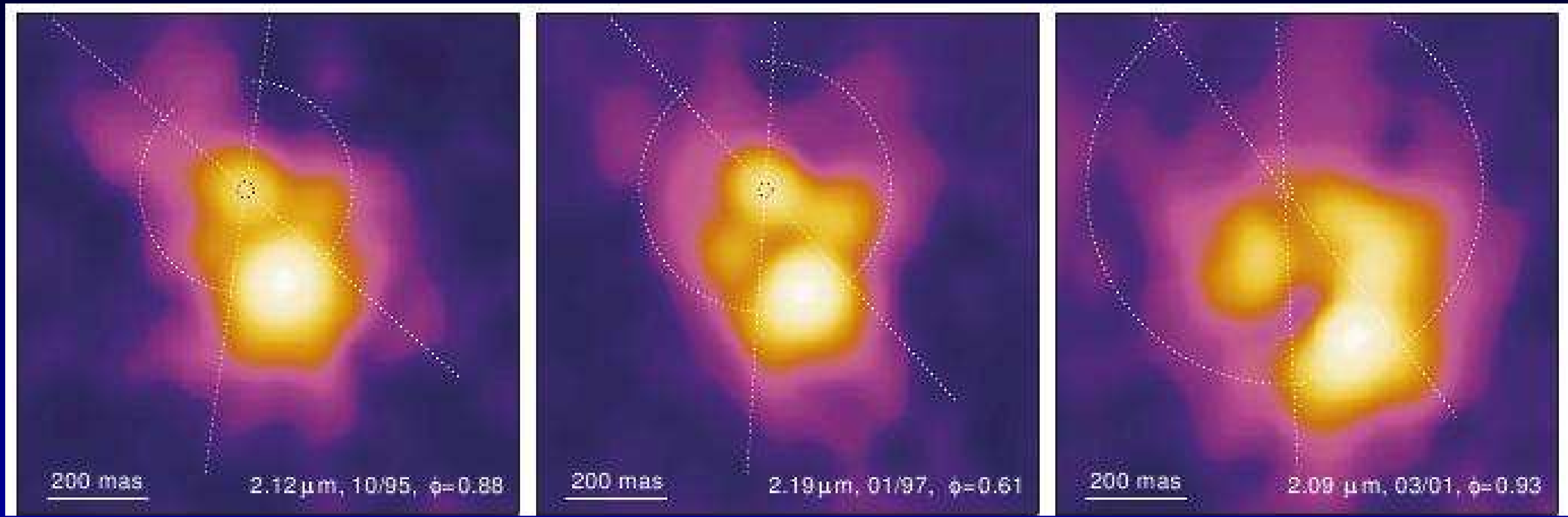
CW Leo - inner part



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

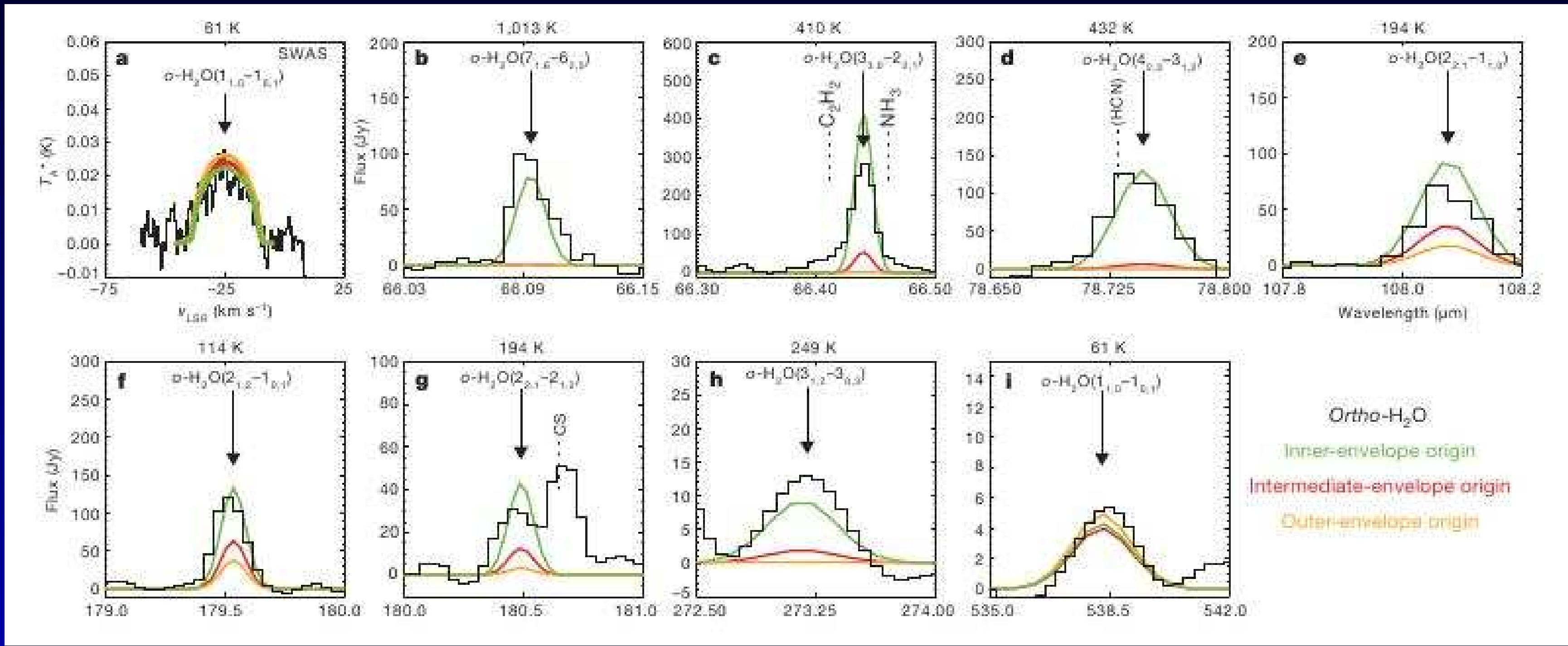


(Menshchikov et al. 2002) K-band speckle
FoV= 1 x 1$''$

CW Leo - Water

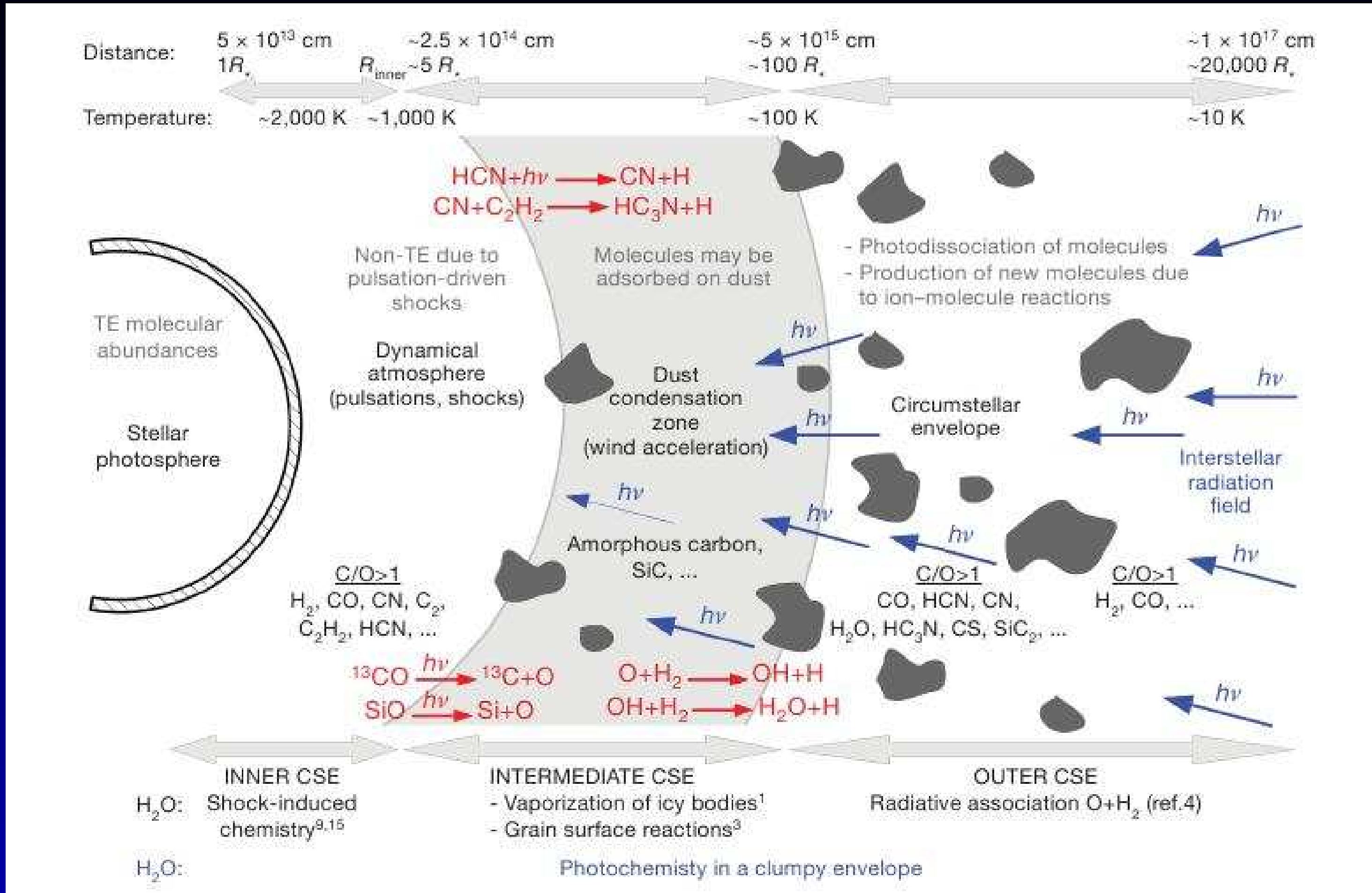
Decin et al. 2010, Nature 467, 64
First *Nature* paper based on Herschel data

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 $T_{\rm ex}$ 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)

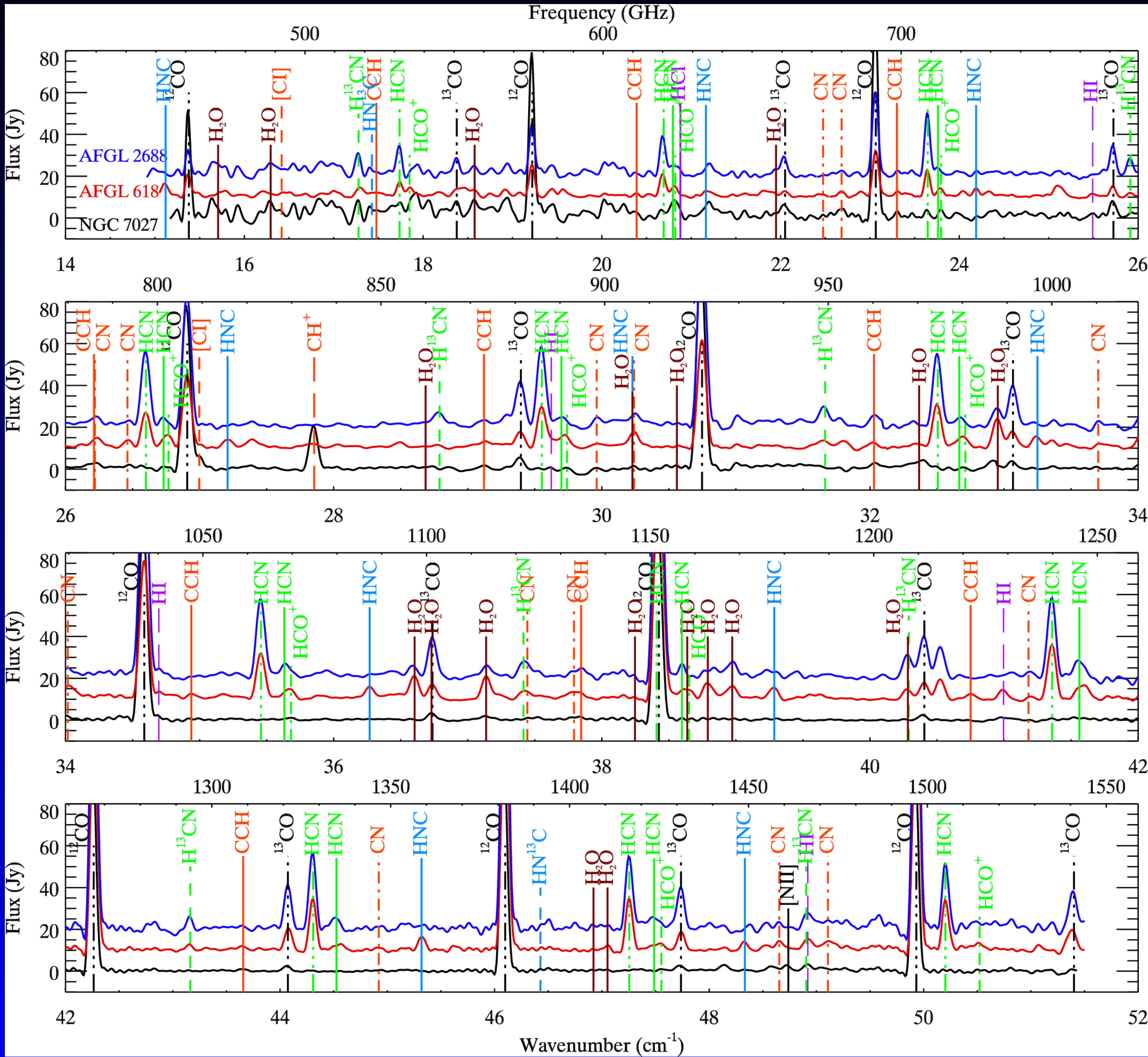
-Tens of lines from SiS and SiO, including lines from the v=1 vibrational level.
Both species trace the dust formation zone.
(Decin et al. 2010, A&A Special Issue)

MESS - Spectroscopy

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

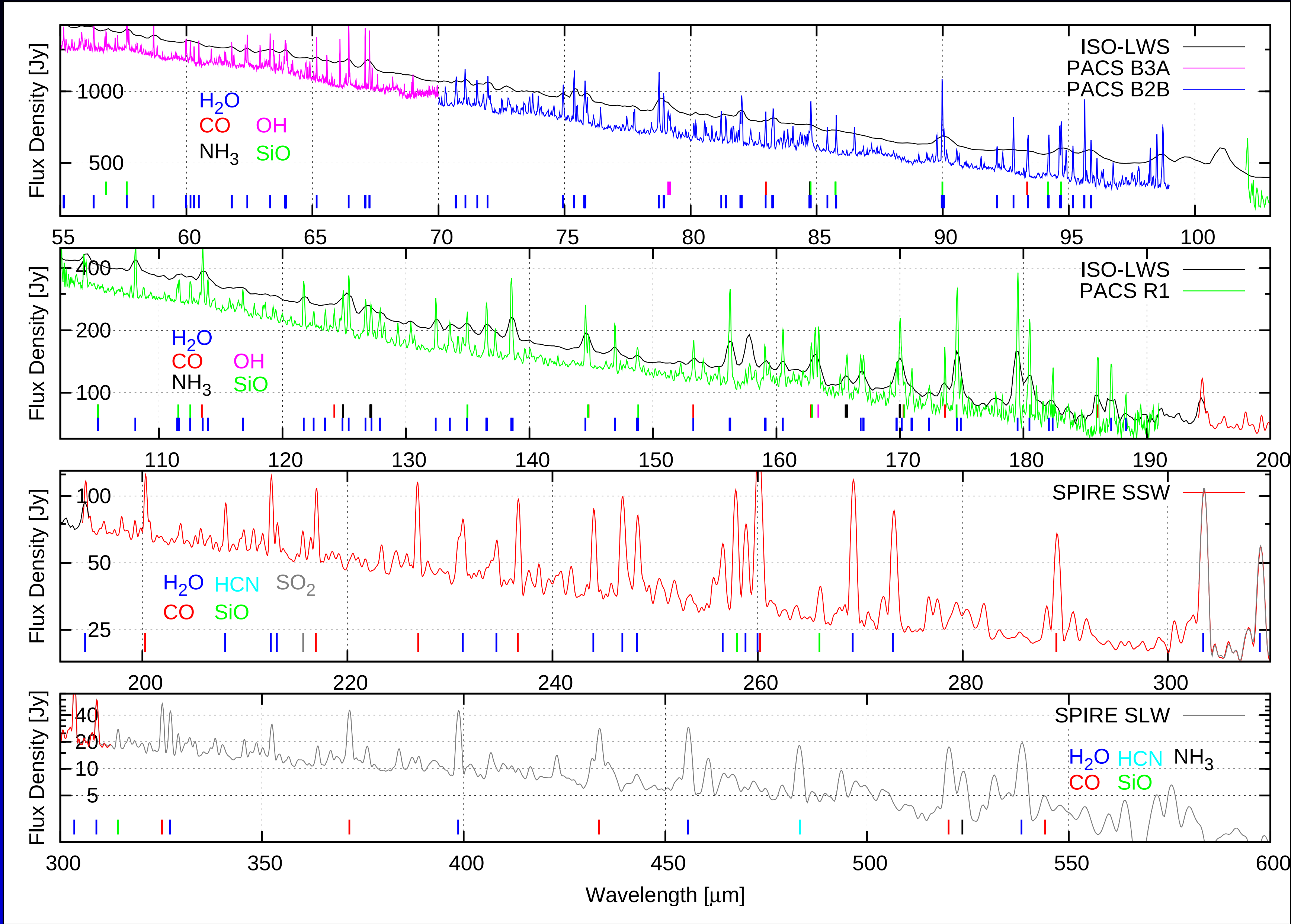
- VY CMa
Royer et al. 2010, A&A special issue

More sophisticated modelling is ongoing by Matsuura, 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)

Conclusions

- Detected ”old” dust mass loss in AGB stars !
- Interaction with the ISM is common
- Line spectroscopy very succesfull
- 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