A possible solution to the problem of mass-loss in M-type AGB stars

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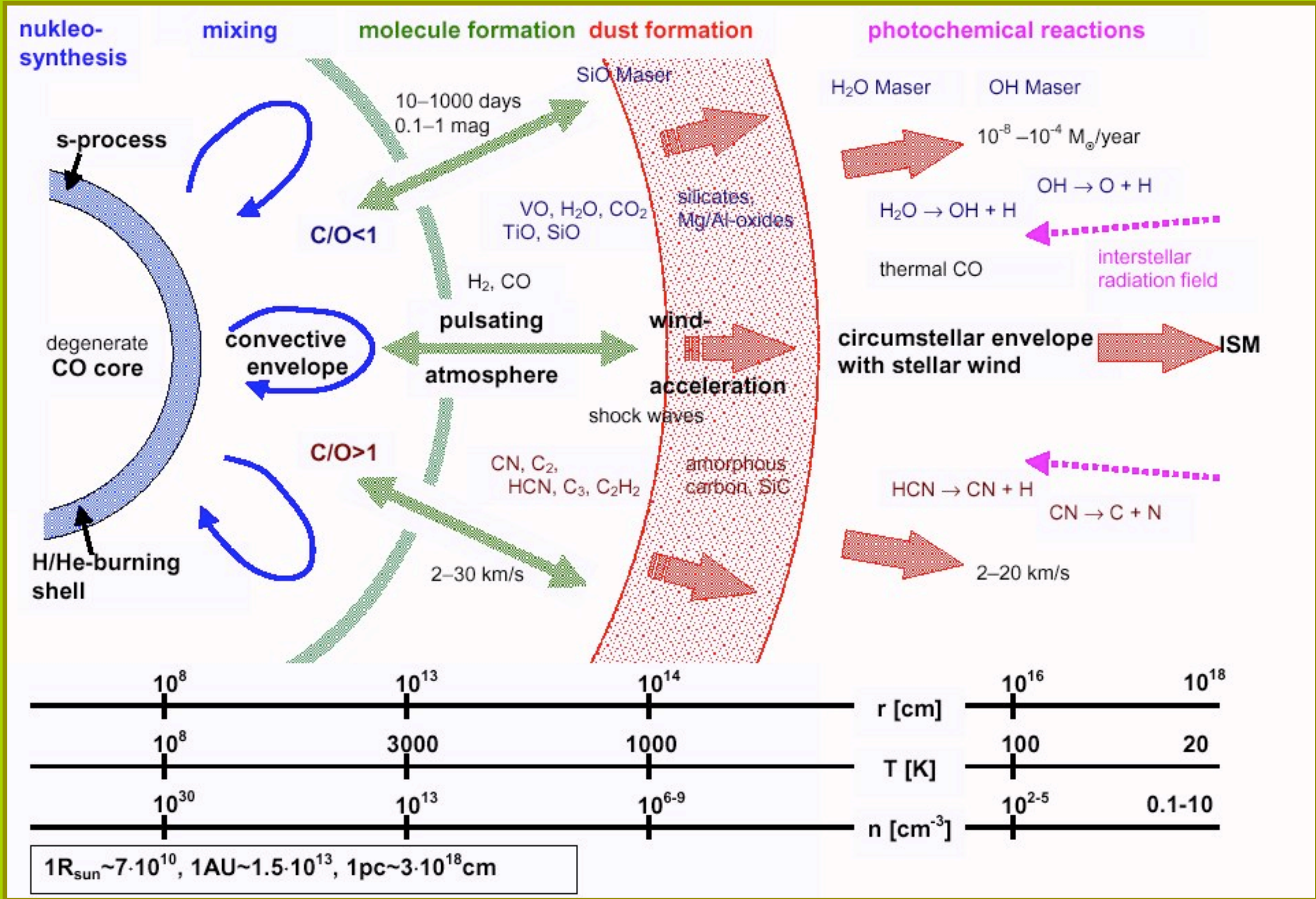
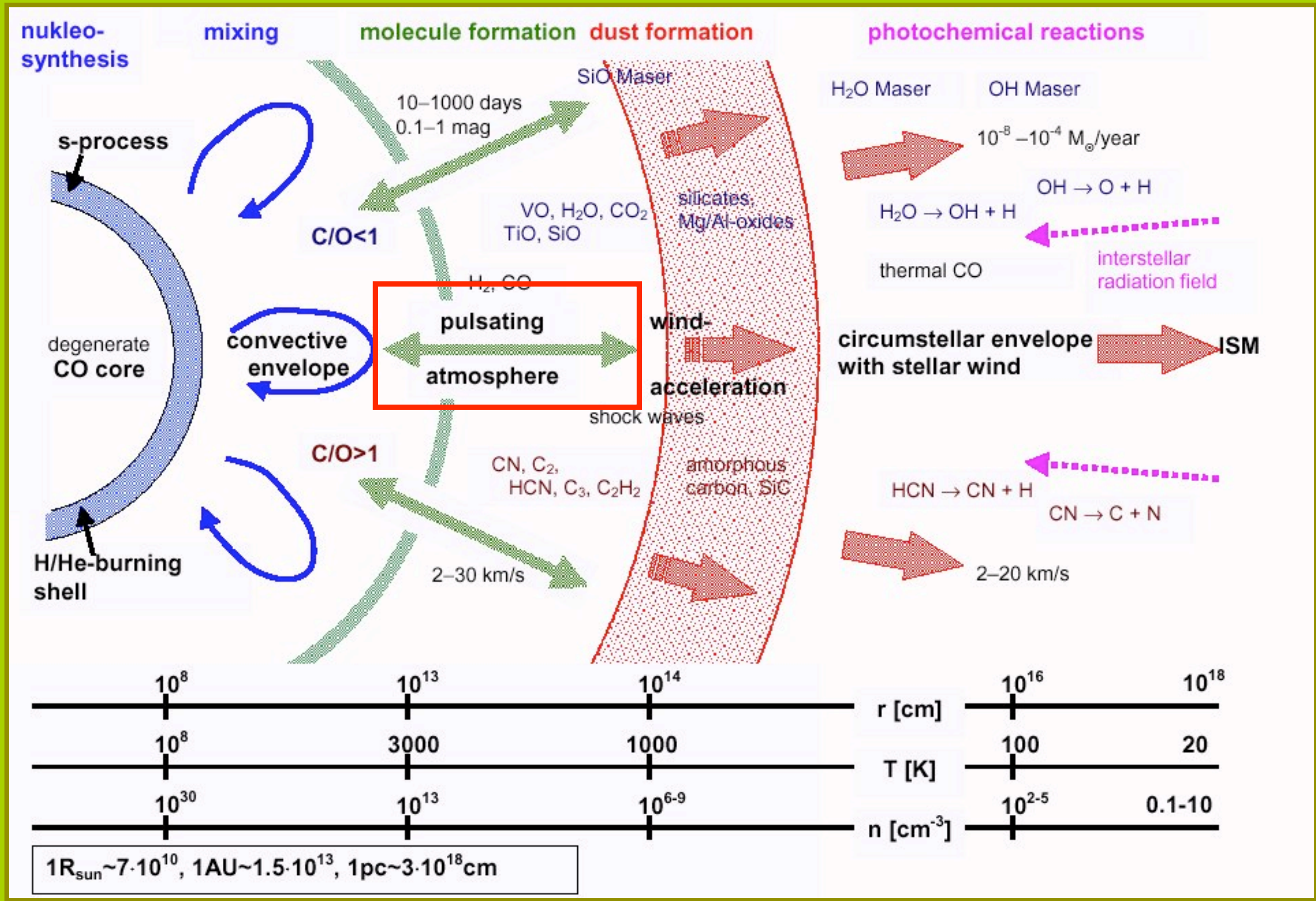
Outline

- Background
- ’The problem’ and possible solutions
- VLTI/MIDI observations
- So far…
- Left to do…



Credit: J. Hron, Inst. for Astronomy, Univ. of Vienna

The Origin and Fate of the Sun



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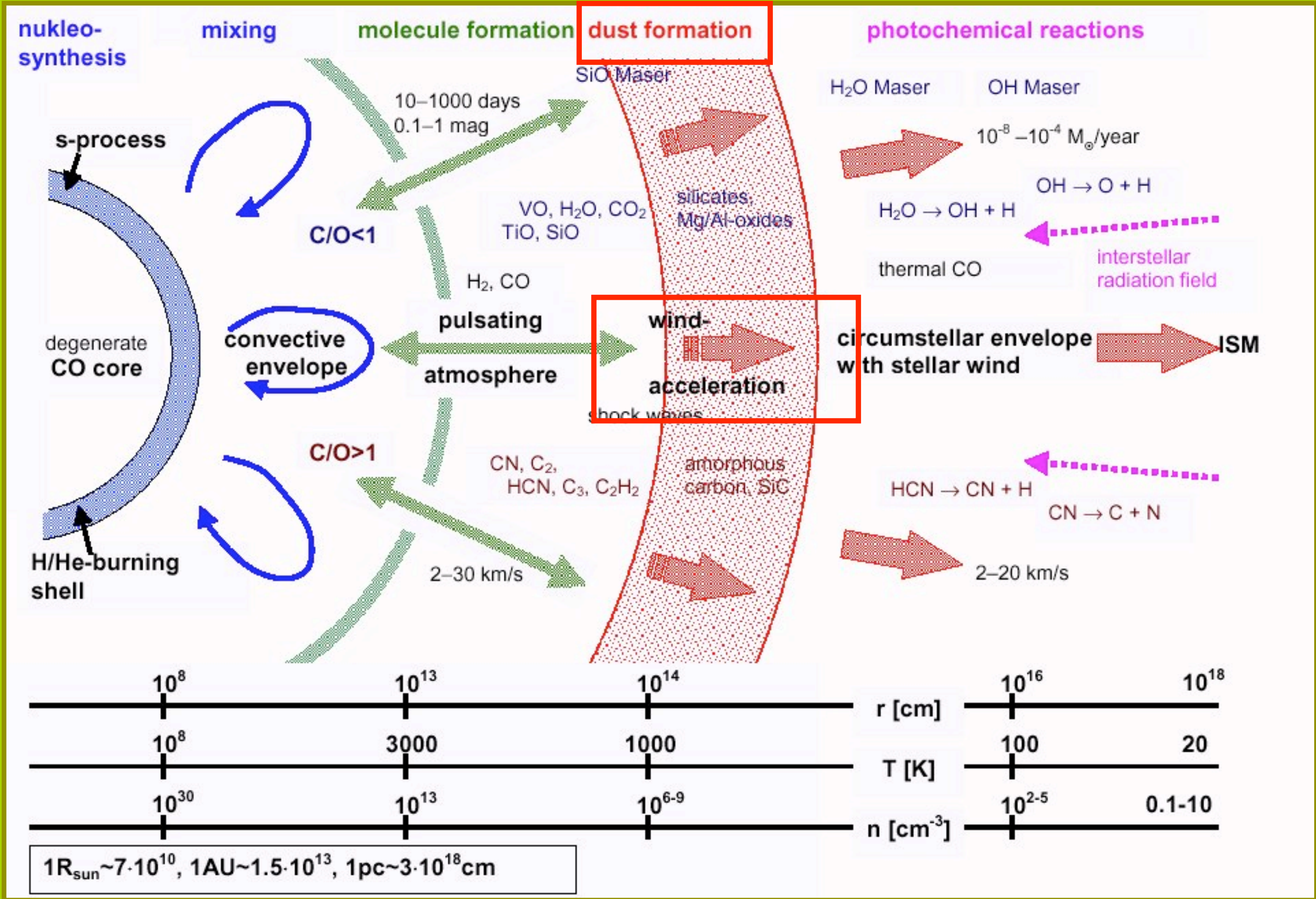
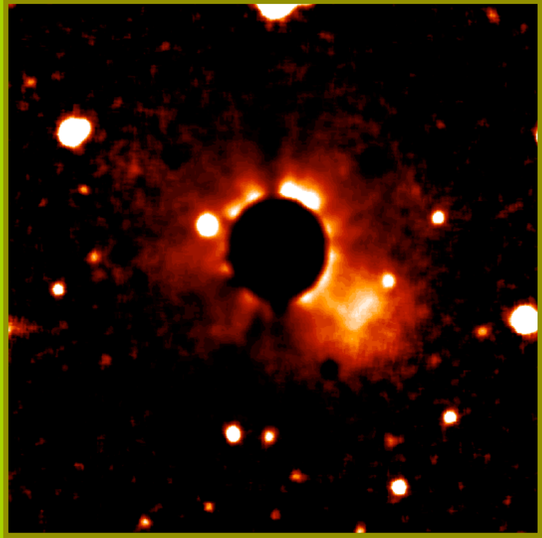


Credit: J. Hron, Inst. for Astronomy, Univ. of Vienna

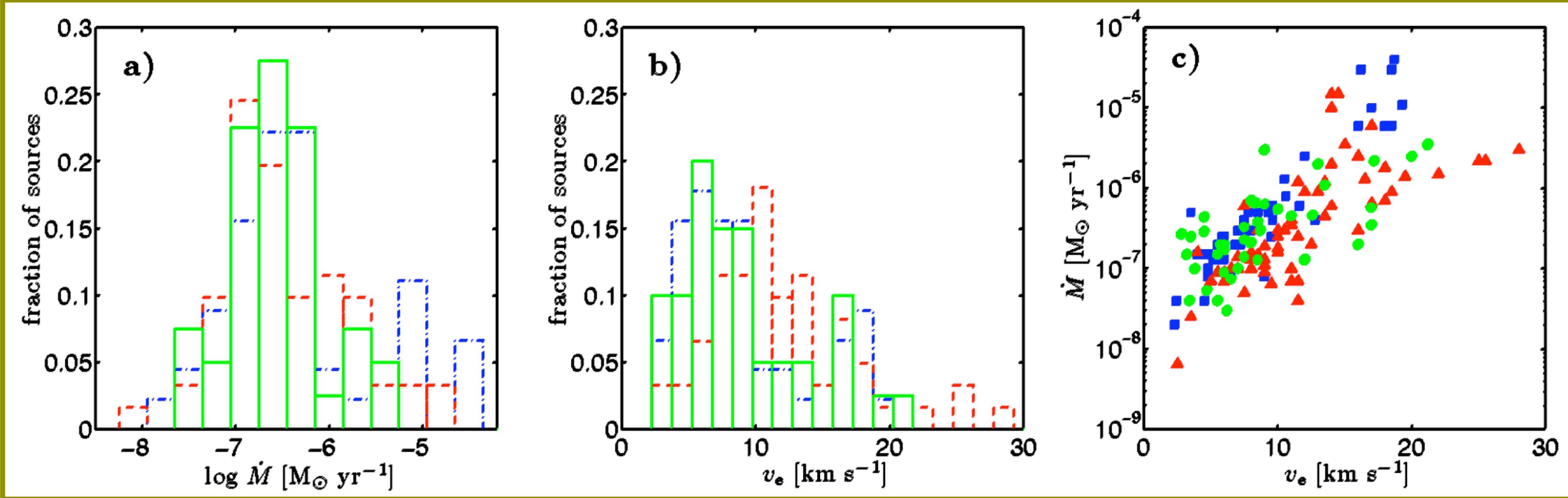
HST image of M-type star Mira
Credit: M. Karovska and NASA



NOT image of S-type star W Aql
Credit: Ramstedt et al. 2010, in prep.

VLT image of carbon star IRC+10216
Credit: Leao et al. 2006

M-type	S-type	C-type
C/O<1	C/O~1	C/O>1
silicate dust	??? dust	carbon dust



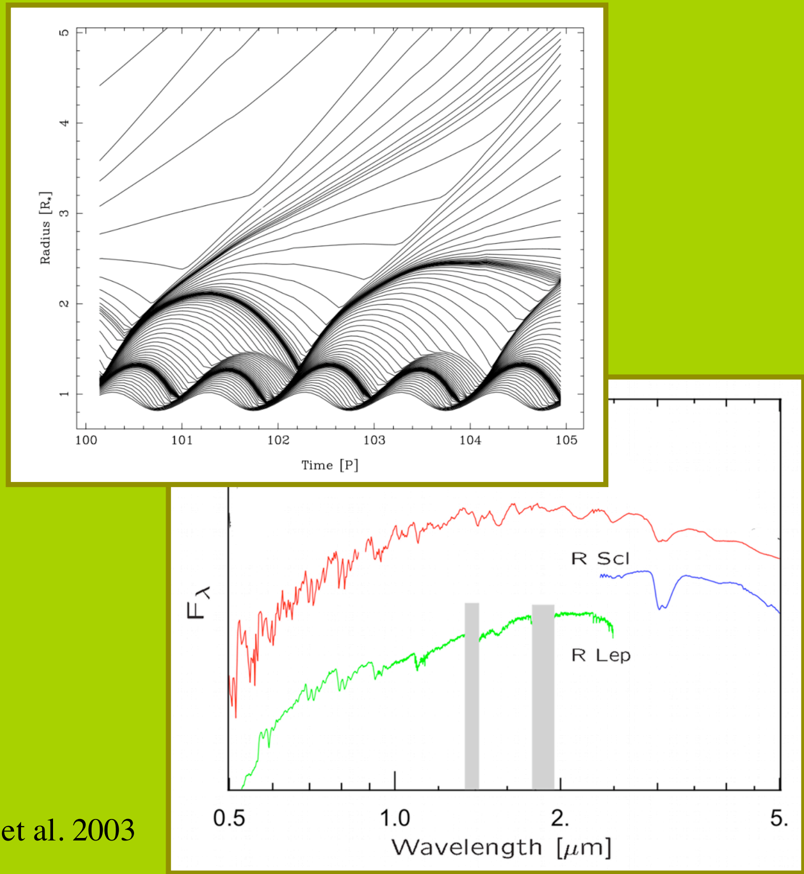
From Ramstedt et al. 2009

S-type in green, M-type in blue, and C-type in red

a) Mass-loss rate distribution
b) Expansion velocity distribution
c) Mass-loss rate vs. expansion velocity

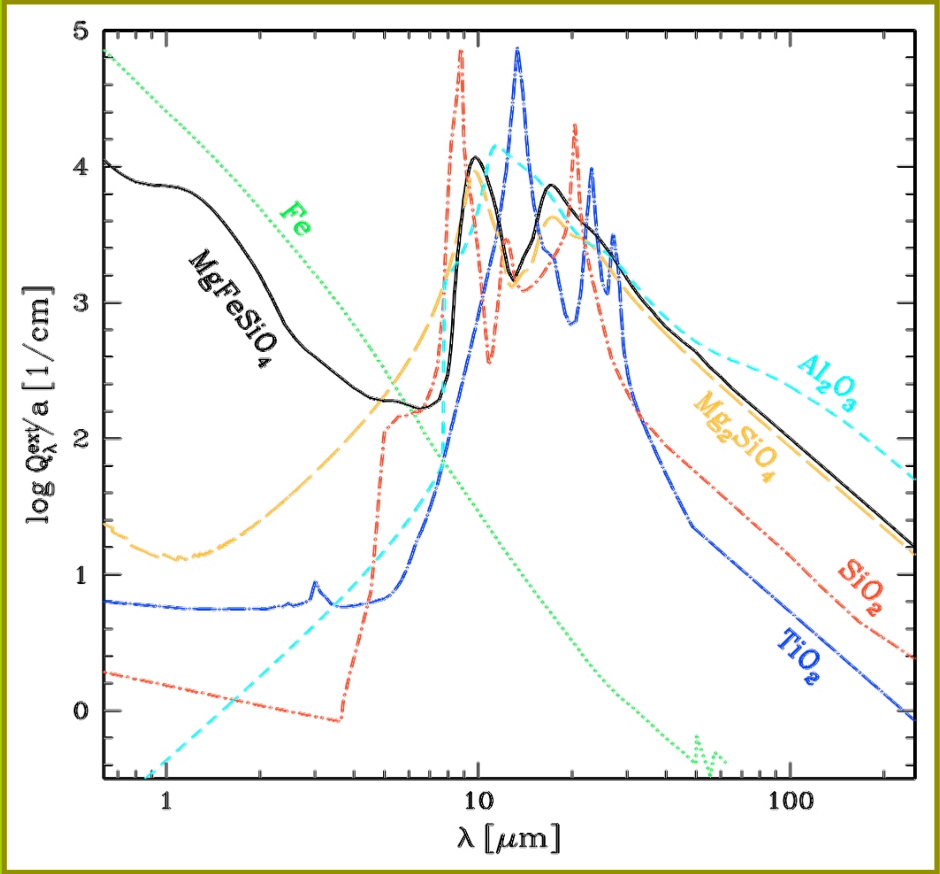
Dynamical models

- Attempts to model mass loss
- Complexity increased
- Very successful for carbon stars



From Höfner et al. 2003

Freq. dep. rad. transf. => No mass loss



From Woitke 2006

Freq. dep. rad. transf. => No mass loss

solid material	$\frac{\rho_{dust}}{\rho_{gas}}$ $[10^{-3}]$	$r = 1.5\,R_\star$	$r = 2\,R_\star$	$r = 5\,R_\star$
TiO_2	0.0061	1030 K	750 K	380 K
		0.00004	0.00004	0.00005
Al_2O_3	0.11	1090 K	810 K	420 K
		0.0013	0.0014	0.0015
SiO_2	1.6	1000 K	740 K	380 K
		0.032	0.034	0.036
Mg_2SiO_4	1.9	1150 K	850 K	430 K
		0.022	0.024	0.025
$MgFeSiO_4$	4.0	1930 K⋆	1710 K⋆	**1170 K**
		1.3	1.4	**1.4**
$MgSiO_3$	2.3	1010 K	740 K	380 K
		0.025	0.027	0.029
$Mg_{0.5}Fe_{0.5}SiO_3$	3.0	1880 K⋆	1580 K⋆	690 K
		0.21	0.21	0.18
Fe	1.3	1980 K⋆	1770 K⋆	**1280 K**
		0.85	0.89	**0.88**
am. carbon	3.0	1870 K⋆	**1640 K**	**1130 K**
(C/O = 1.5)		20	**21**	**21**

From Woitke 2006

Possible solutions:

- Magnetic fields, Alfvén waves

  Vidotto et al. 2006, 2009, Vlemmings et al. 2005, 2006, tomorrow

- Grain composition and/or shape

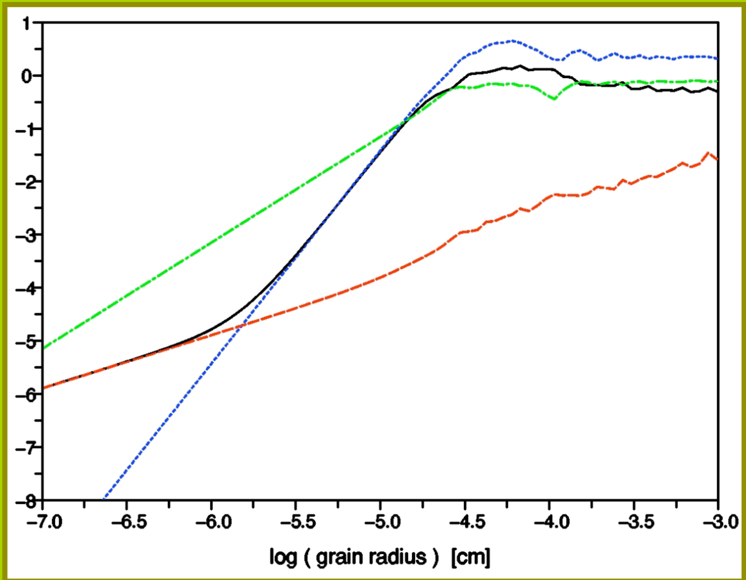
  Höfner & Andersen 2006, Fogel & Leung 1998

- Grain size

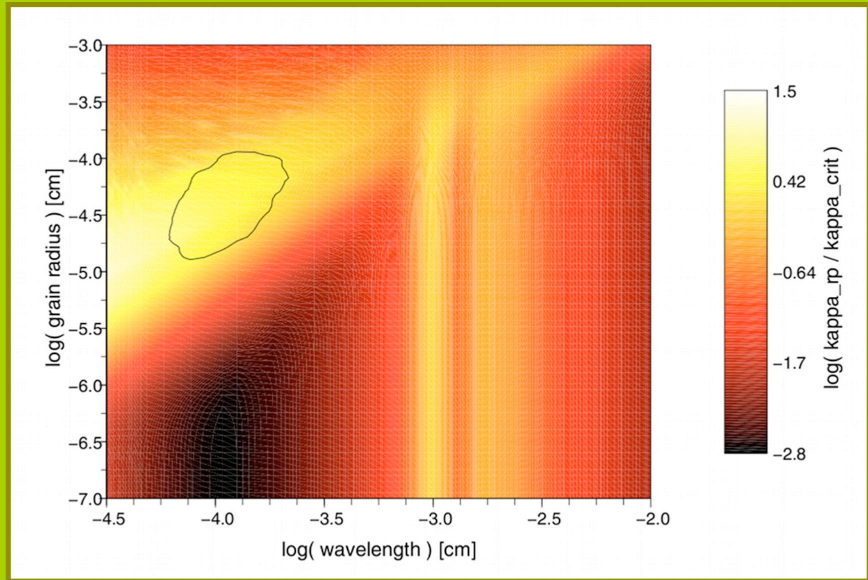
  Höfner 2008

In a wind driven by radiation pressure on dust grains: mass loss ∝ wind acceleration ∝ rad. press. eff. Q_{rp}

$$Q_{rp} = Q_{abs} + (1 - g(\theta))Q_{sca}$$

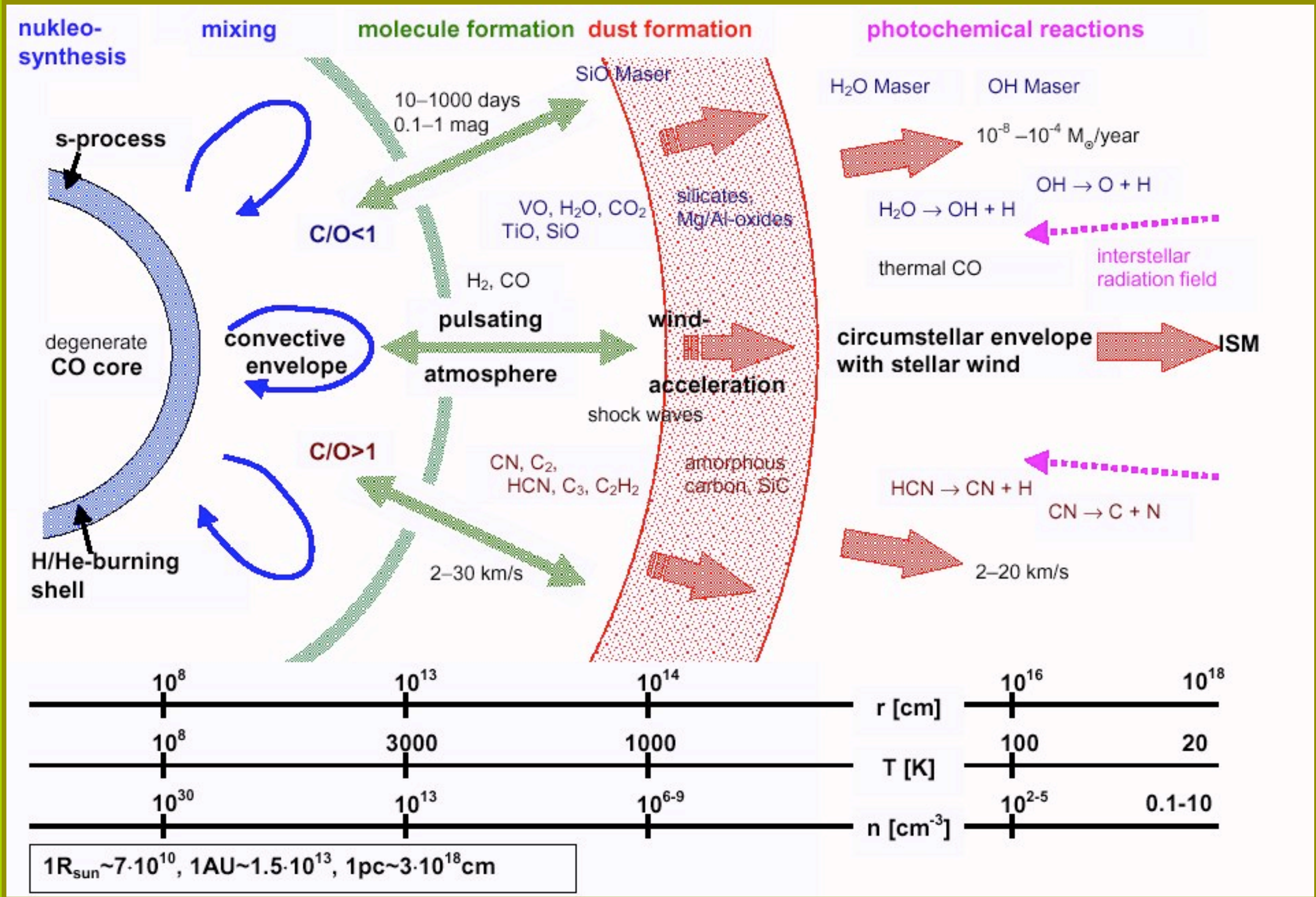


From Höfner 2009



From Höfner 2008

The Origin and Fate of the Sun



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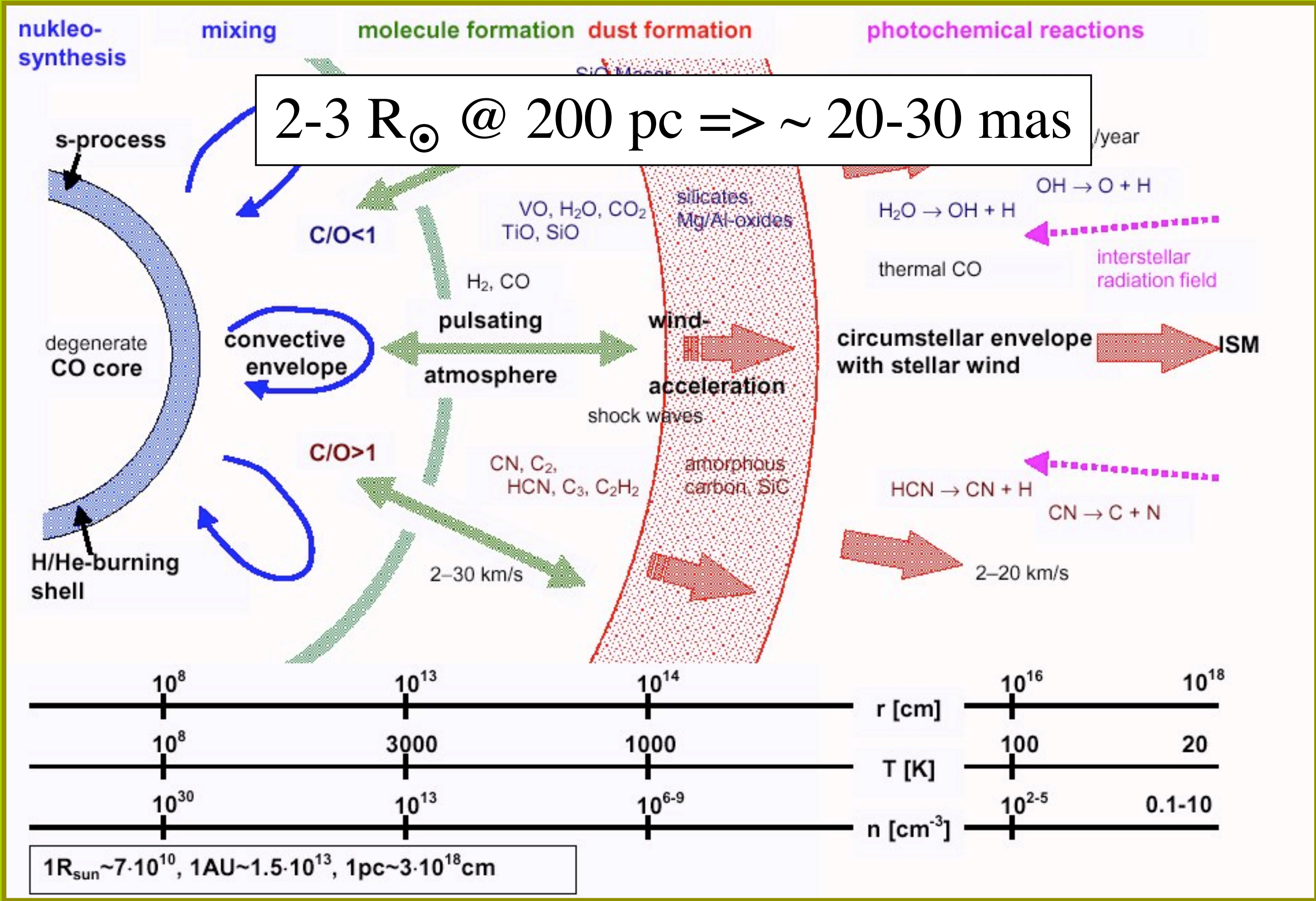

2-3 $R_\odot$ @ 200 pc => ~ 20-30 mas

Credit: J. Hron, Inst. for Astronomy, Univ. of Vienna

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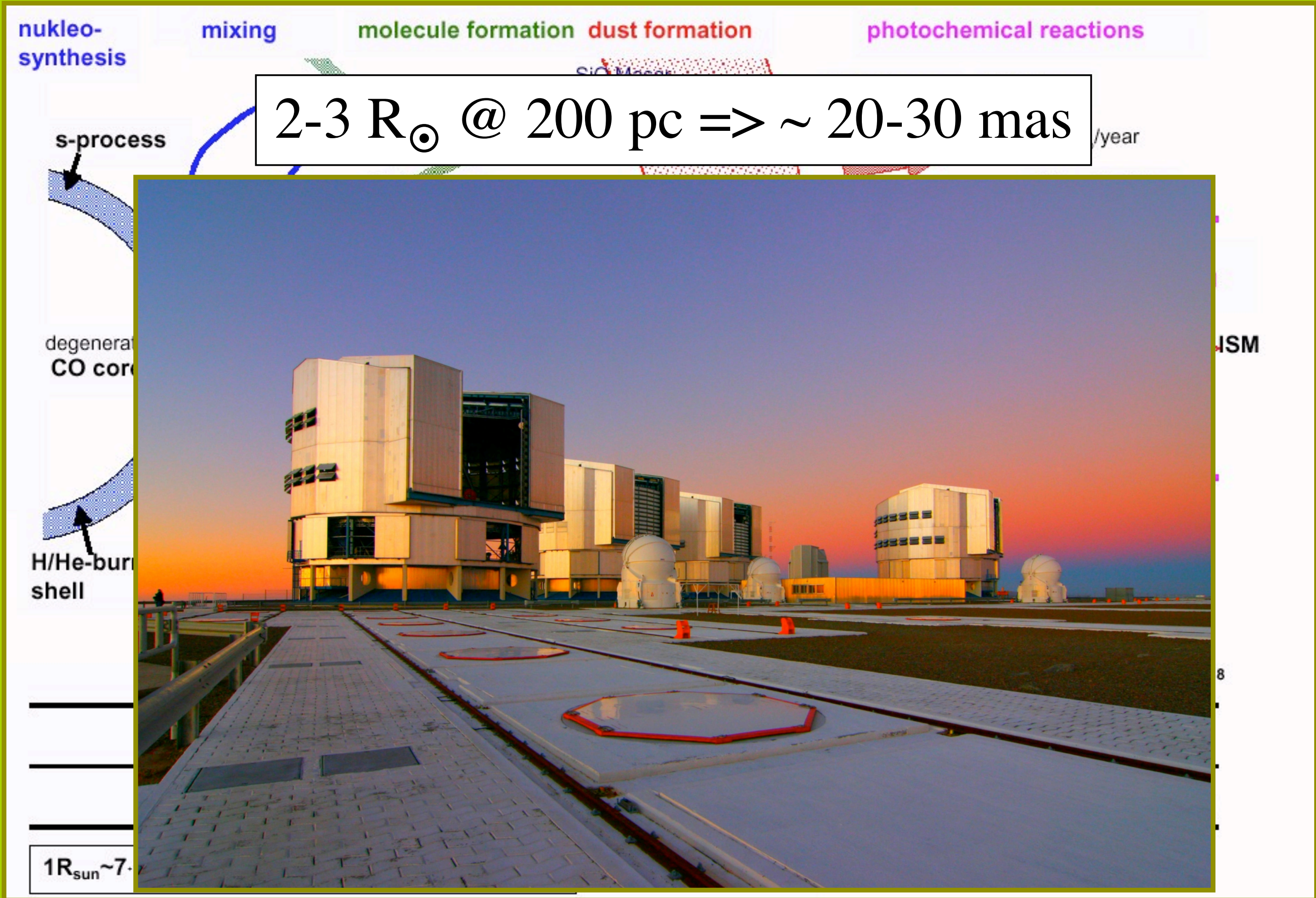

$2\text{-}3\ R_{\odot}$ @ 200 pc => ~ 20-30 mas

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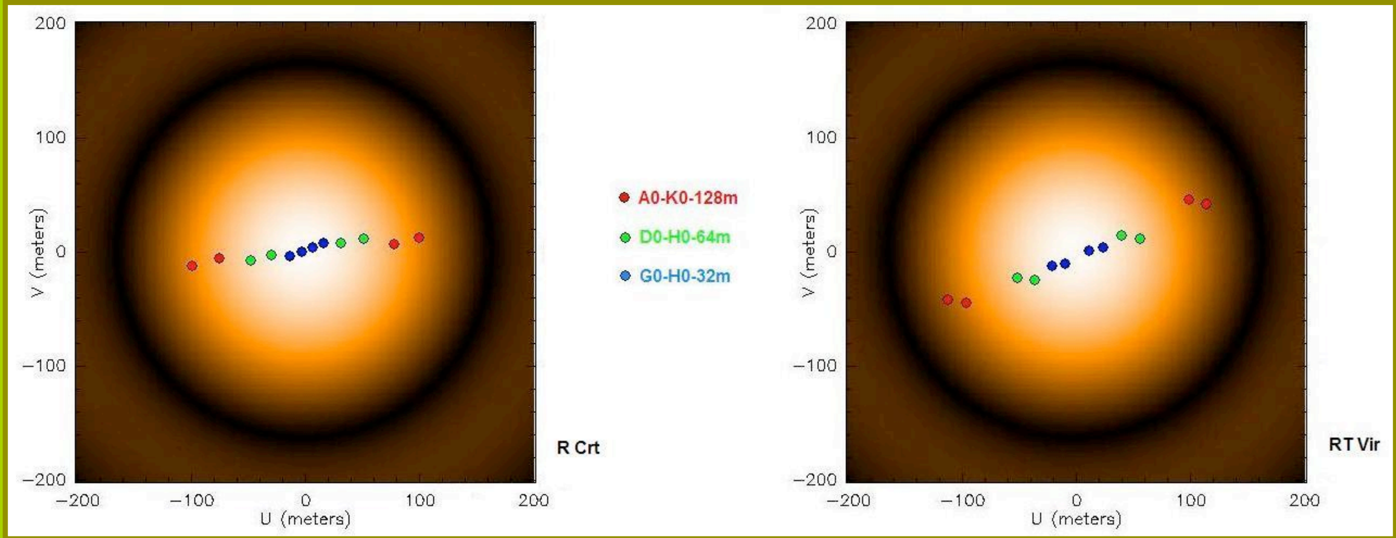
VLTI/MIDI observations

- Two low-mass-loss-rate M-type AGB stars, RT Vir & R Crt
- MIDI, 8-13 μm, R = 230
- 4 baselines, 2 ATs, 1 baseline position angle (RT Vir)



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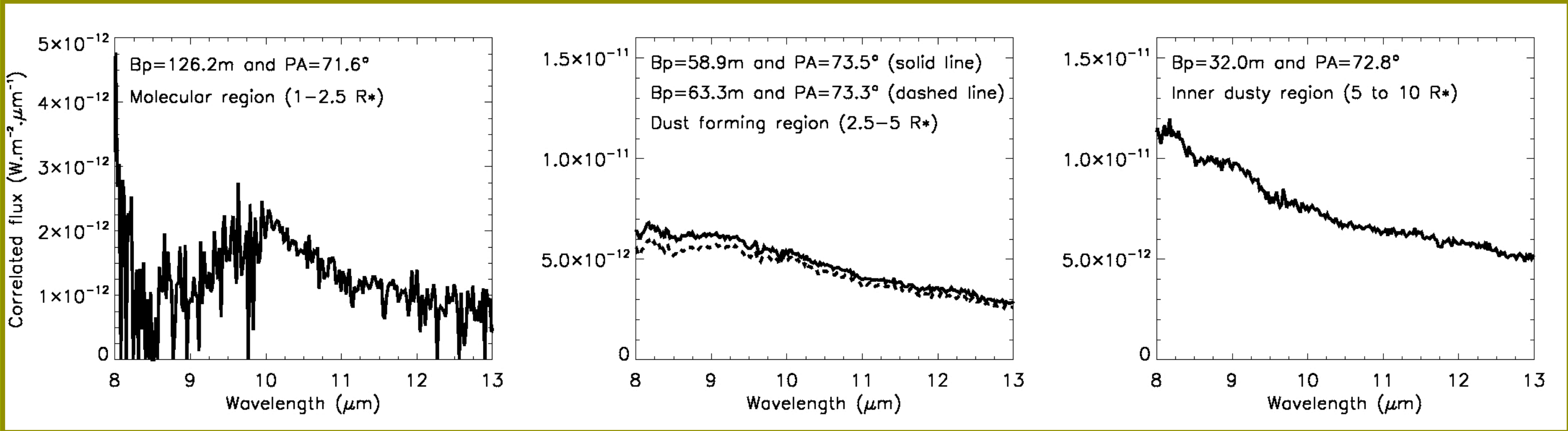
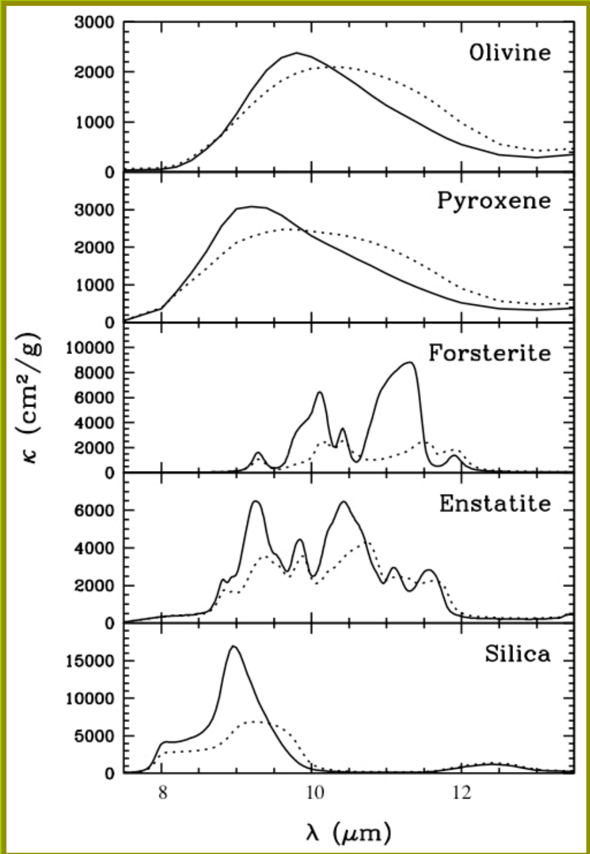
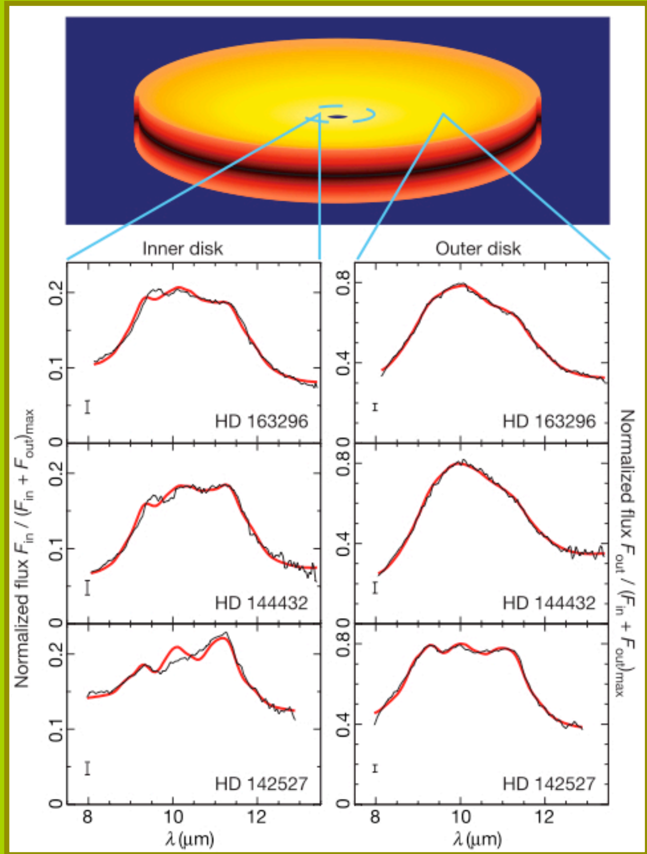
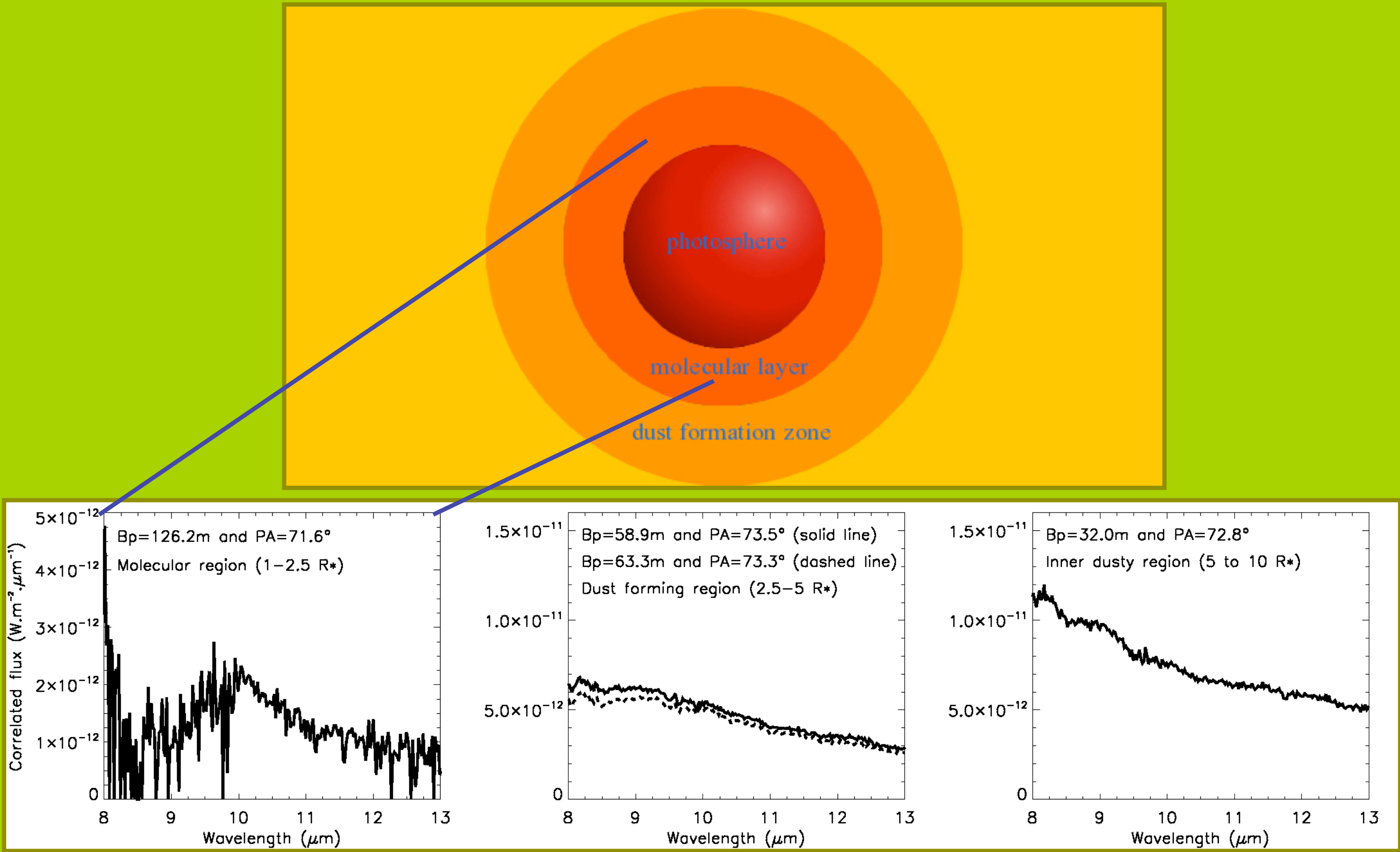


Silicate feature

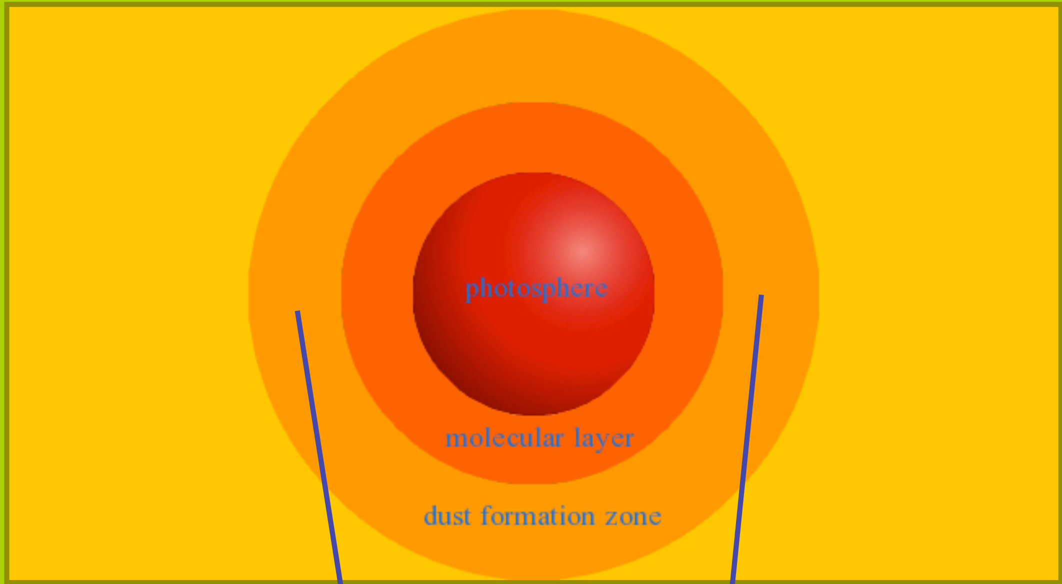




van Boekel et al. 2004



photosphere
molecular layer
dust formation zone
Bp=126.2m and PA=71.6°
Molecular region (1–2.5 R*)
Correlated flux (W.m⁻².µm⁻¹)
Wavelength (µm)
Bp=58.9m and PA=73.5° (solid line)
Bp=63.3m and PA=73.3° (dashed line)
Dust forming region (2.5–5 R*)
Wavelength (µm)
Bp=32.0m and PA=72.8°
Inner dusty region (5 to 10 R*)
Wavelength (µm)



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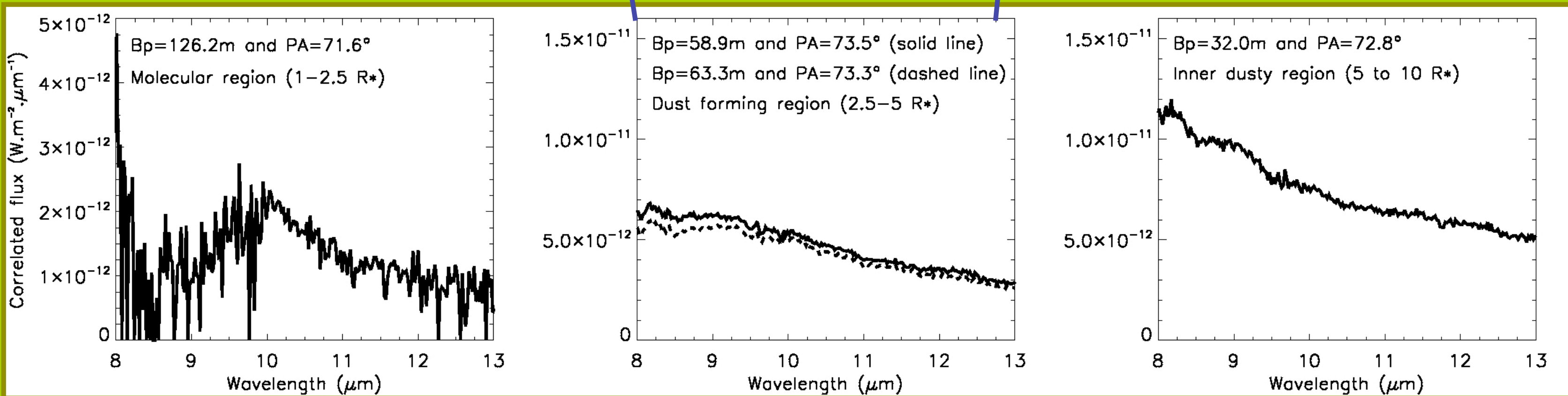

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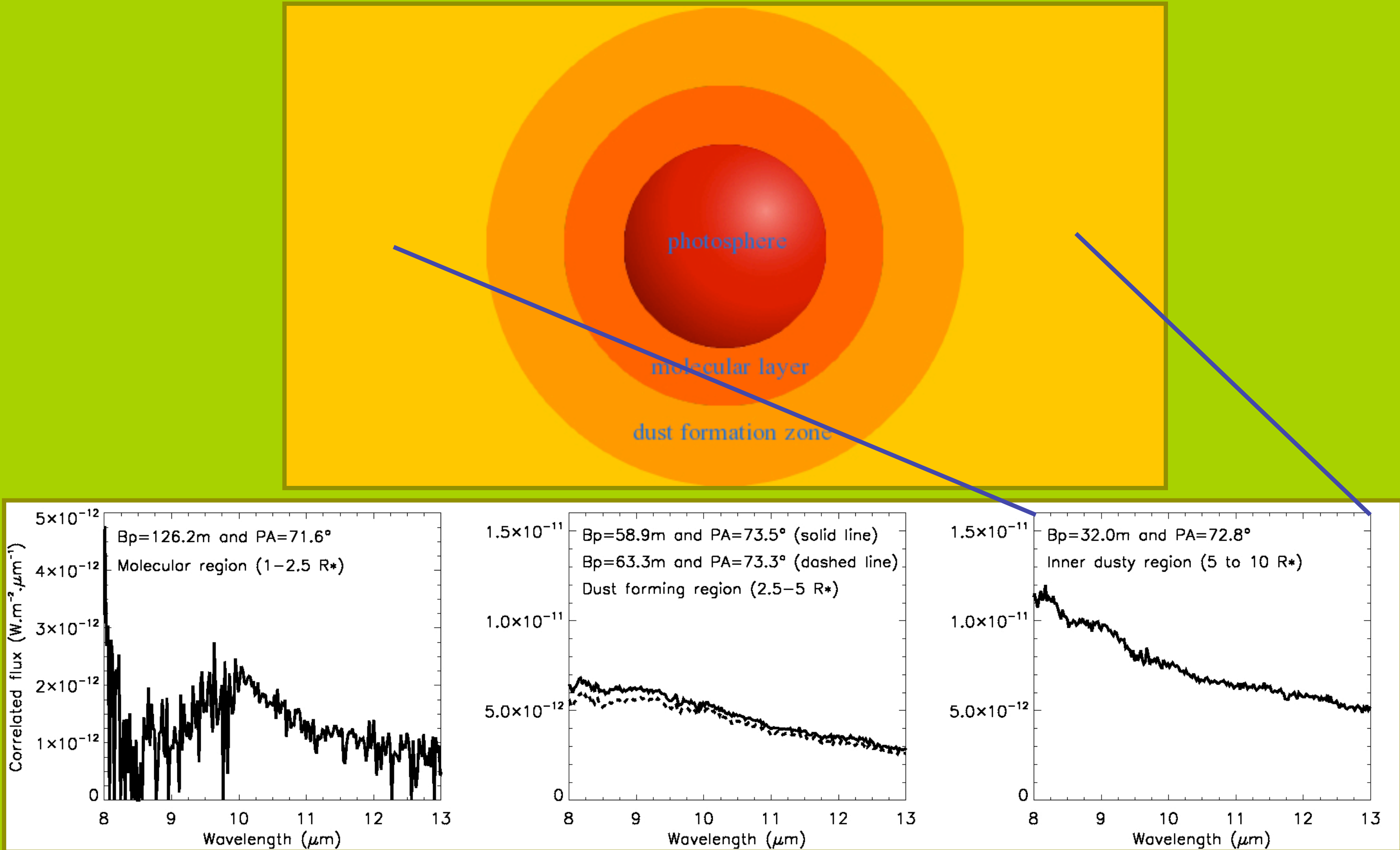
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Steps

- Find a stellar spectrum
  ISO-SWS, 2-5 μm, + stellar parameters
  => best-fit MARCS model

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- Find a stellar spectrum
  ISO-SWS, 2-5 μm, + stellar parameters
  => best-fit MARCS model
- Add a molecular layer*
  130m baseline MIDI/VLTI
  => best-fit model

***Ohnaka 2004**

Steps

continuum

- Find a stellar spectrum
  ISO-SWS, 2-5 µm, + stellar parameters
  => best-fit MARCS model
- Add a molecular layer*
  130m baseline MIDI/VLTI
  => best-fit model
- Constrain the dust parameters
  60m baseline MIDI/VLTI
  => dust radiative transfer

***Ohnaka 2004**

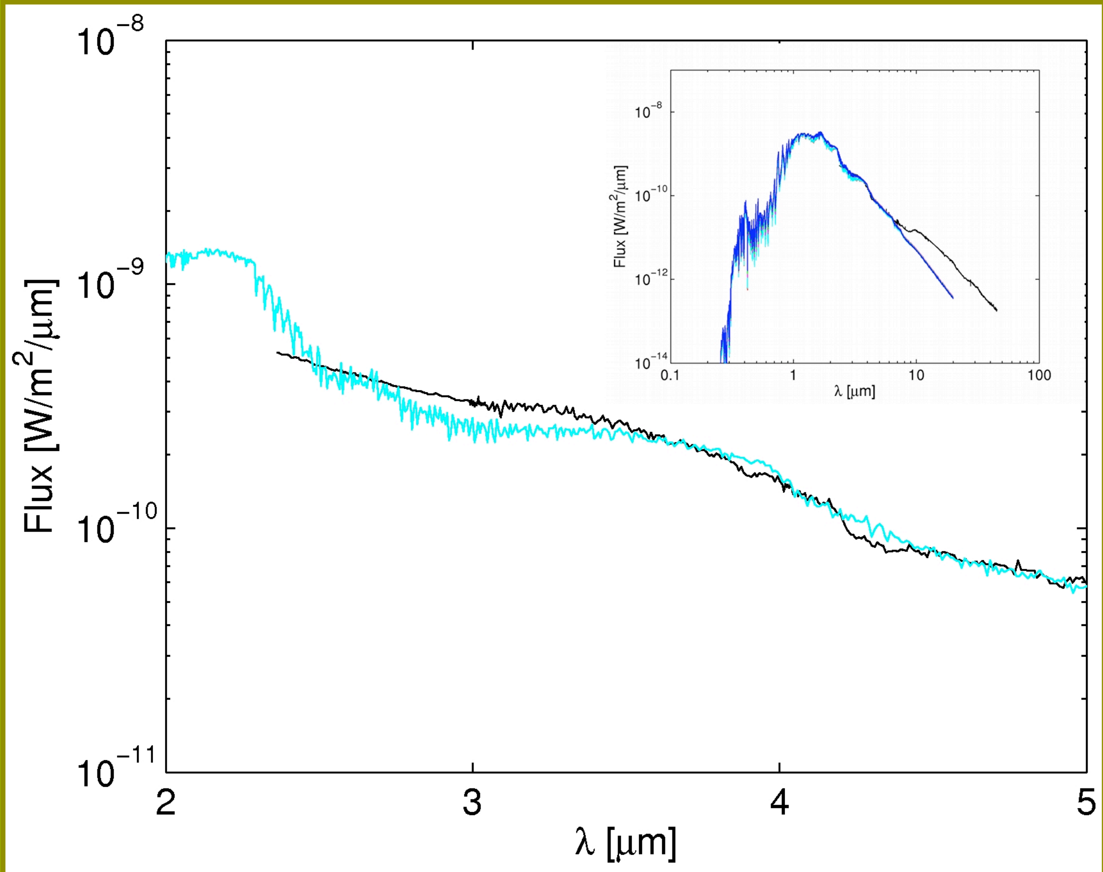
Steps

- Find a stellar spectrum
  ISO-SWS, 2-5 μm, + stellar parameters
  => best-fit MARCS model
- Add a molecular layer*
  130m baseline MIDI/VLTI
  => best-fit model
- Constrain the dust parameters
  60m baseline MIDI/VLTI
  => dust radiative transfer
- Compare with dynamical model

continuum

***Ohnaka 2004**

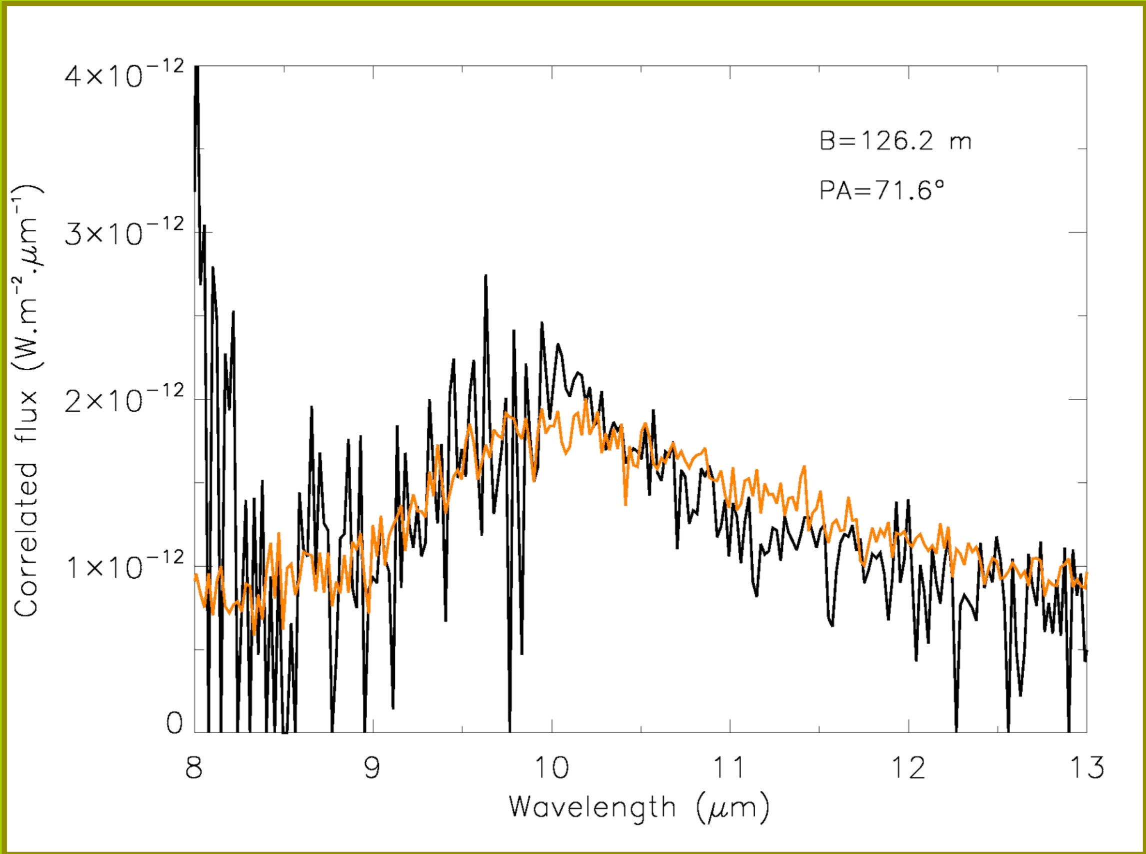
Results so far…



Best-fit MARCS

T_{eff} = 2900 K
M = 1 $M_\odot$
V_t = 2 km/s
[Fe/H] = 0.0
[α/H]=0.0

Results so far…



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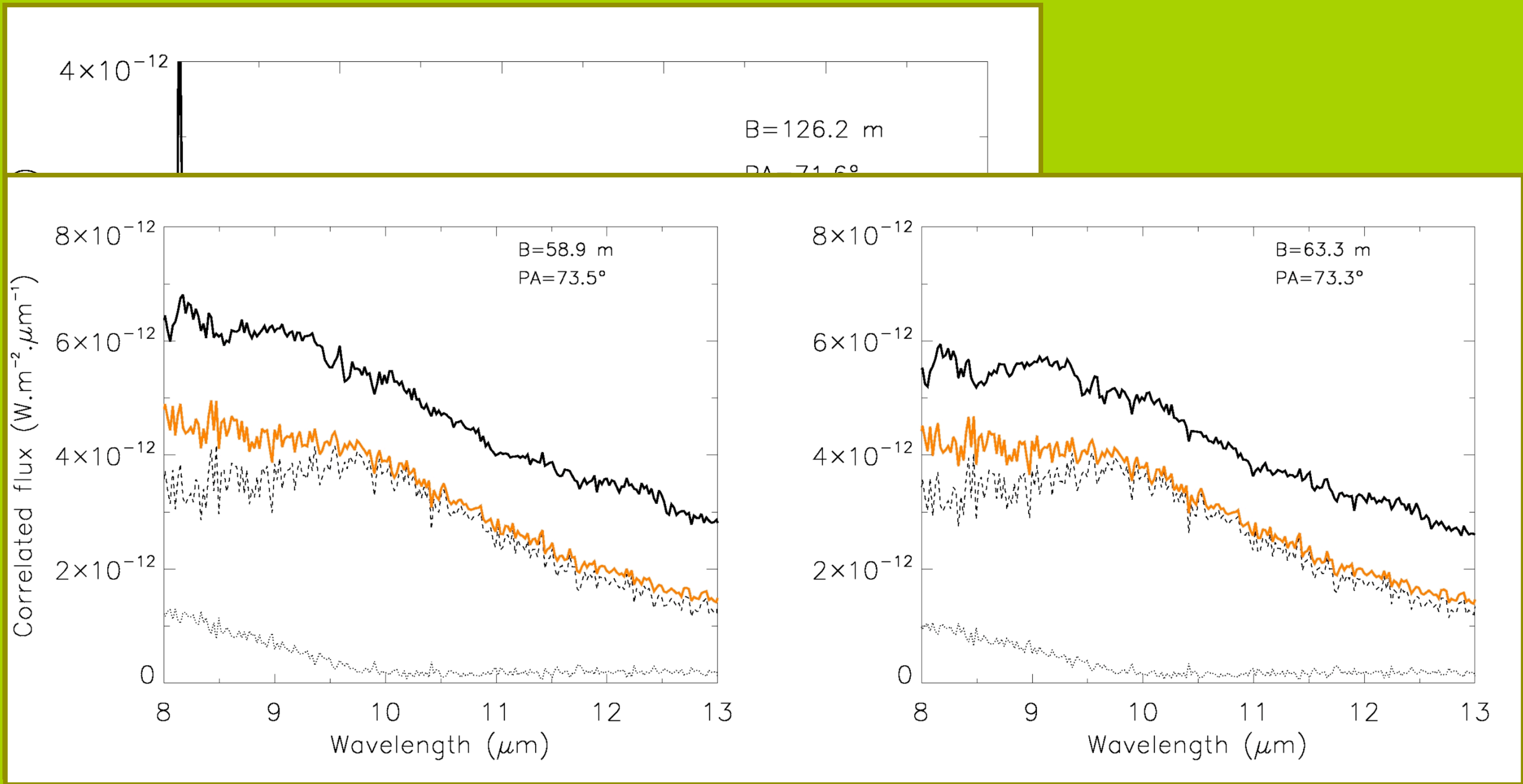

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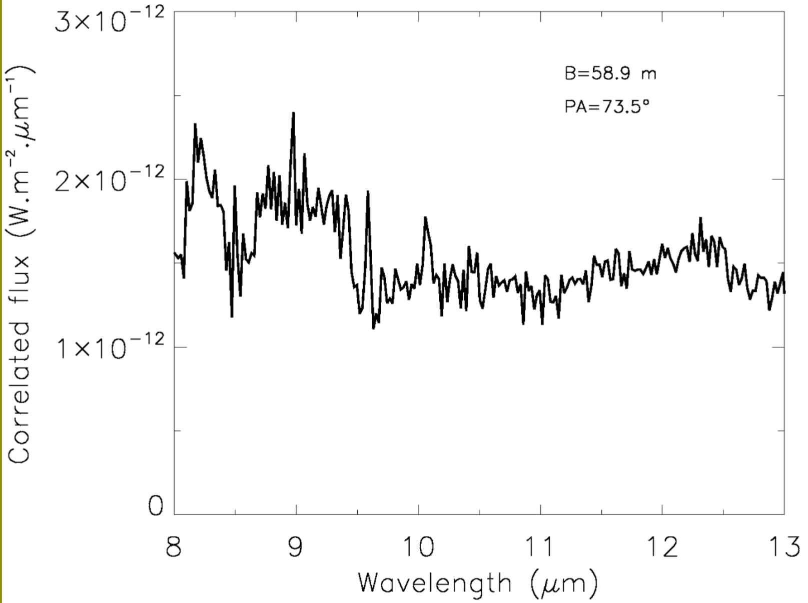
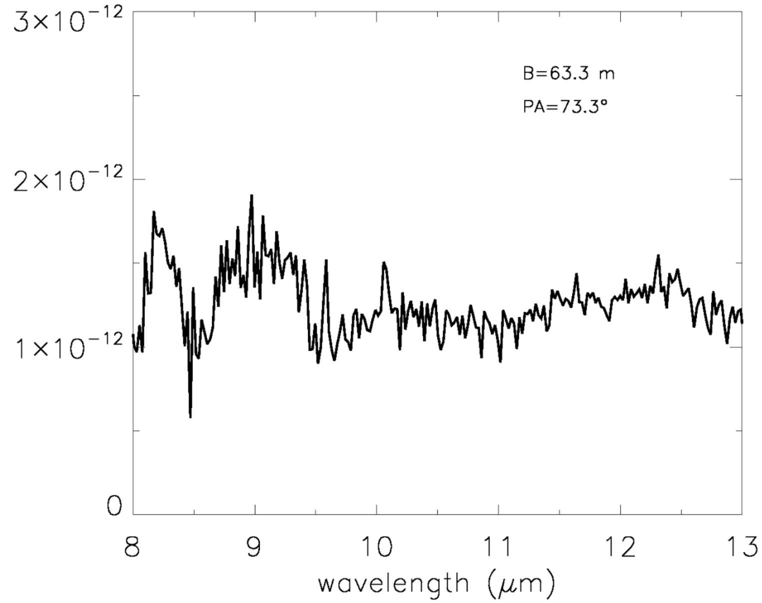
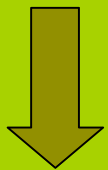




Concluding remarks

- Finished first two steps
- Modelling to constrain dust parameters remains



- Non-trivial (degeneracy), but optimistic to be able to evaluate the large-grain scenario
- Only two sources…

Thank you!