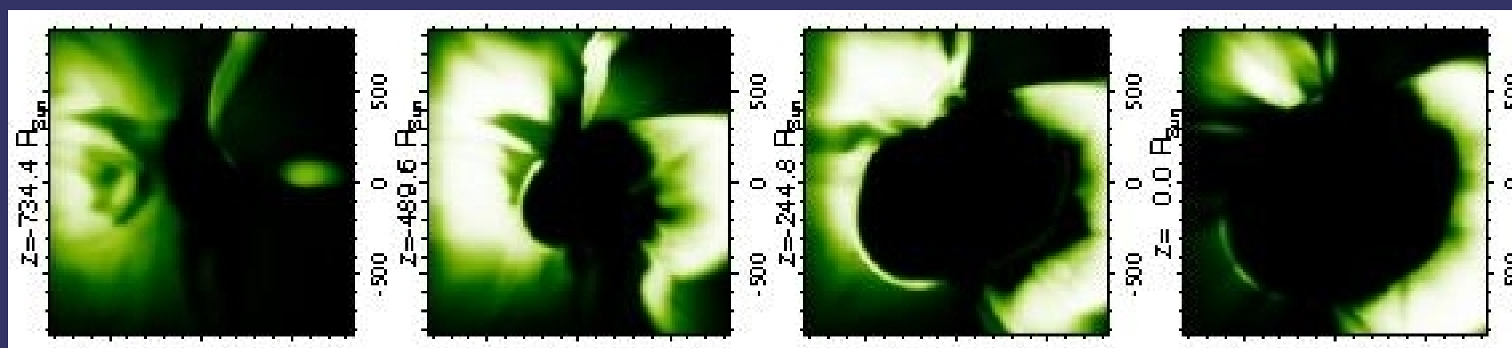
Mass Loss: The Role of Grains

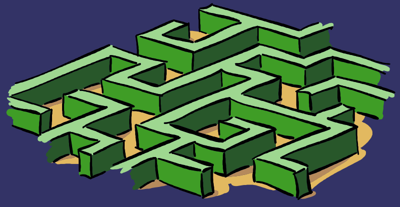


Susanne Höfner
Dept. of Astronomy & Space Physics, Uppsala

Invited talk presented at JD 11, XXVIth IAU GA, Prague, 2006

The facts ...

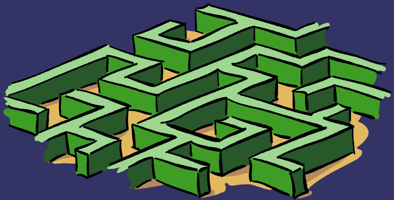
- AGB stars lose copious amounts of matter
- Winds are slow, dense, cool
- Pulsation plays a crucial role
- Molecules and dust are important



Most common scenario

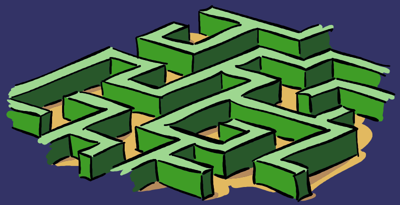
- Force:
  radiation pressure (dust)
- Conditions:
  set by shocks (pulsation)
  - levitation
  - temporal variations

“pulsation-enhanced dust-driven wind”



Crucial ingredients

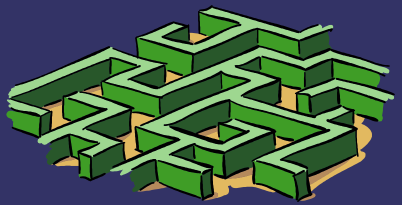
- Radiation field:
  complex (molecules, dust), variable
- Gas dynamics:
  convection/pulsation (boundary conditions) $\rightarrow$ shock waves
- Dust formation:
  chemistry
  non-equilibrium processes



Dust formation: non-equilibrium

- Temperature acts as a threshold
- Density of gas determines the efficiency
- Dynamics sets the timescales ....

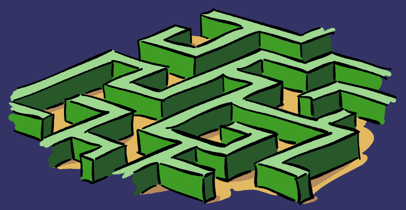
    shock waves: restrict time available,
    but also help through increasing density



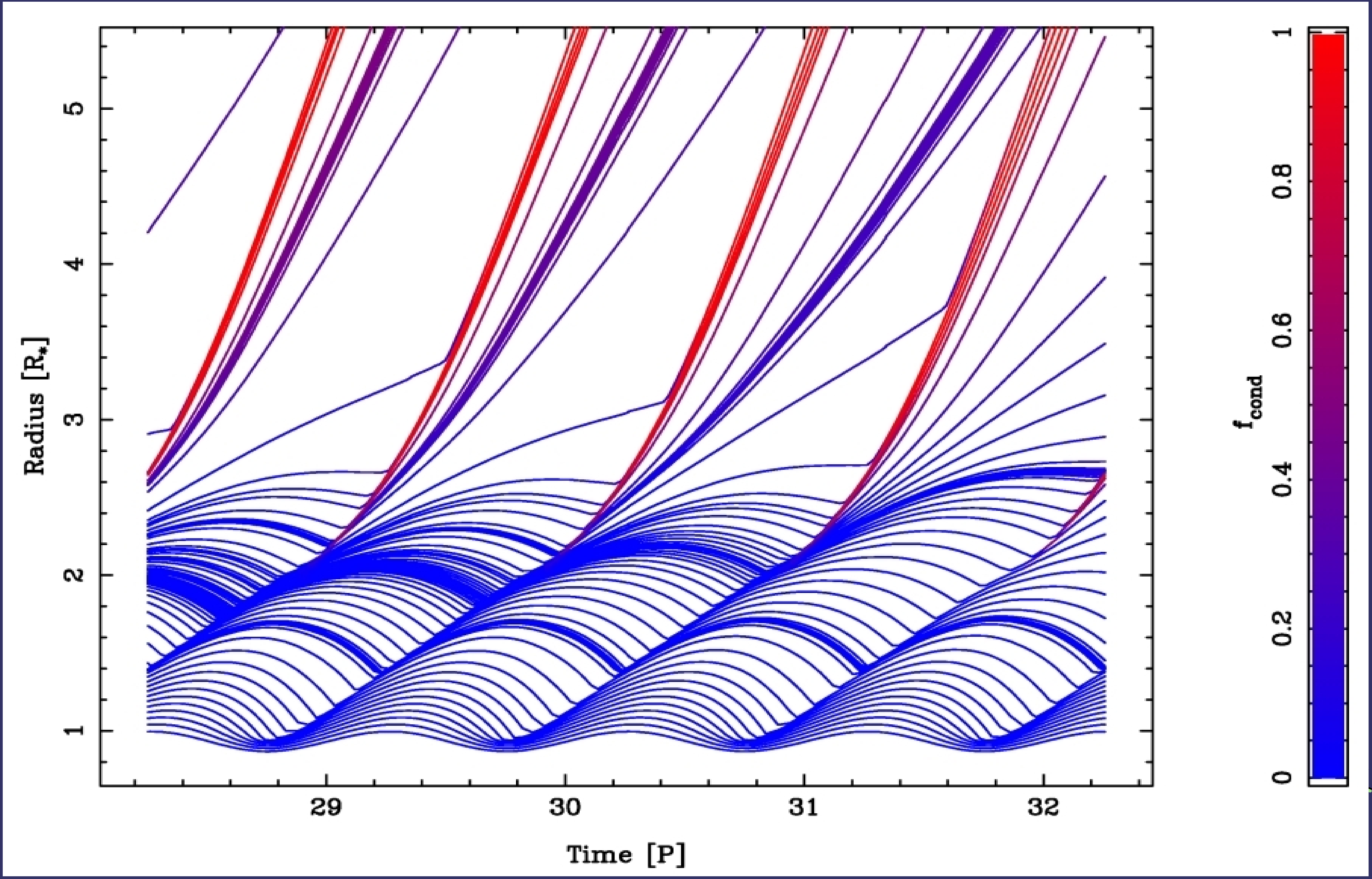
Dust formation: non-equilibrium

- Temperature: ~ 1000 K → 2-3 R_*
- Density of gas: typically 10^{-14} g/cm^3
- Simple kinetic estimate for growth time ~ 10^7 seconds

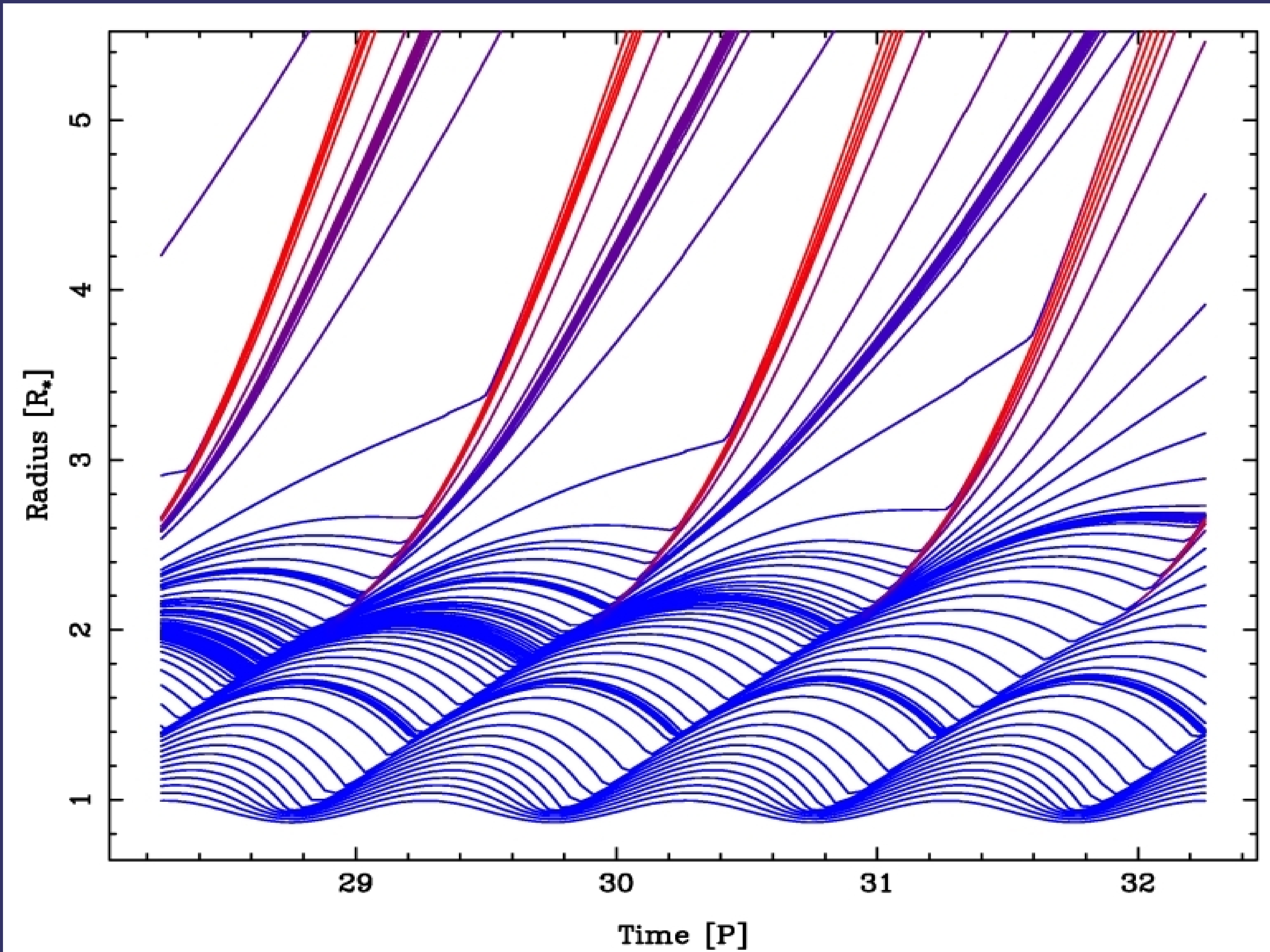
→ the grain growth time is comparable to the pulsation period



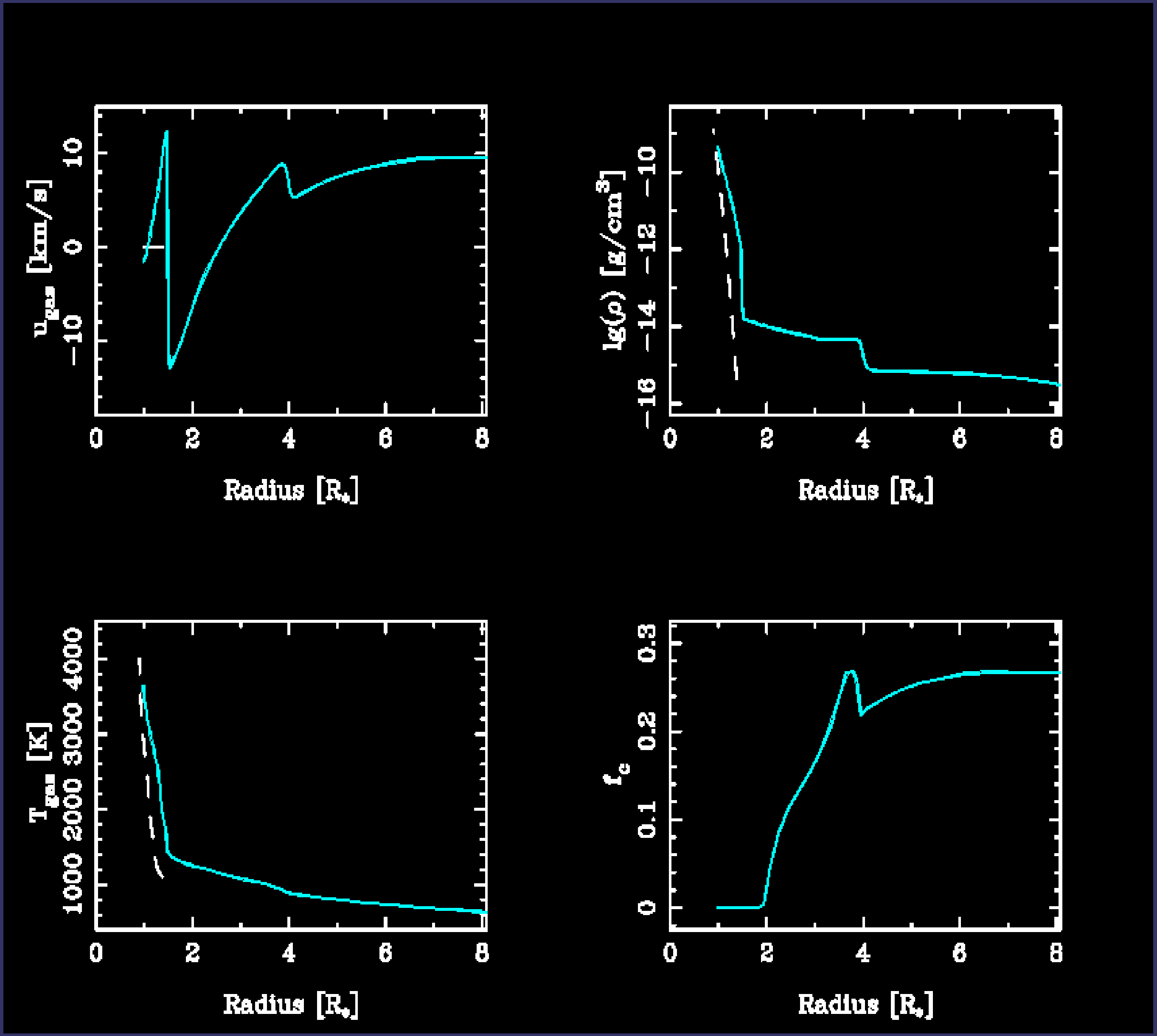
Dust formation: non-equilibrium



Dust formation: non-equilibrium



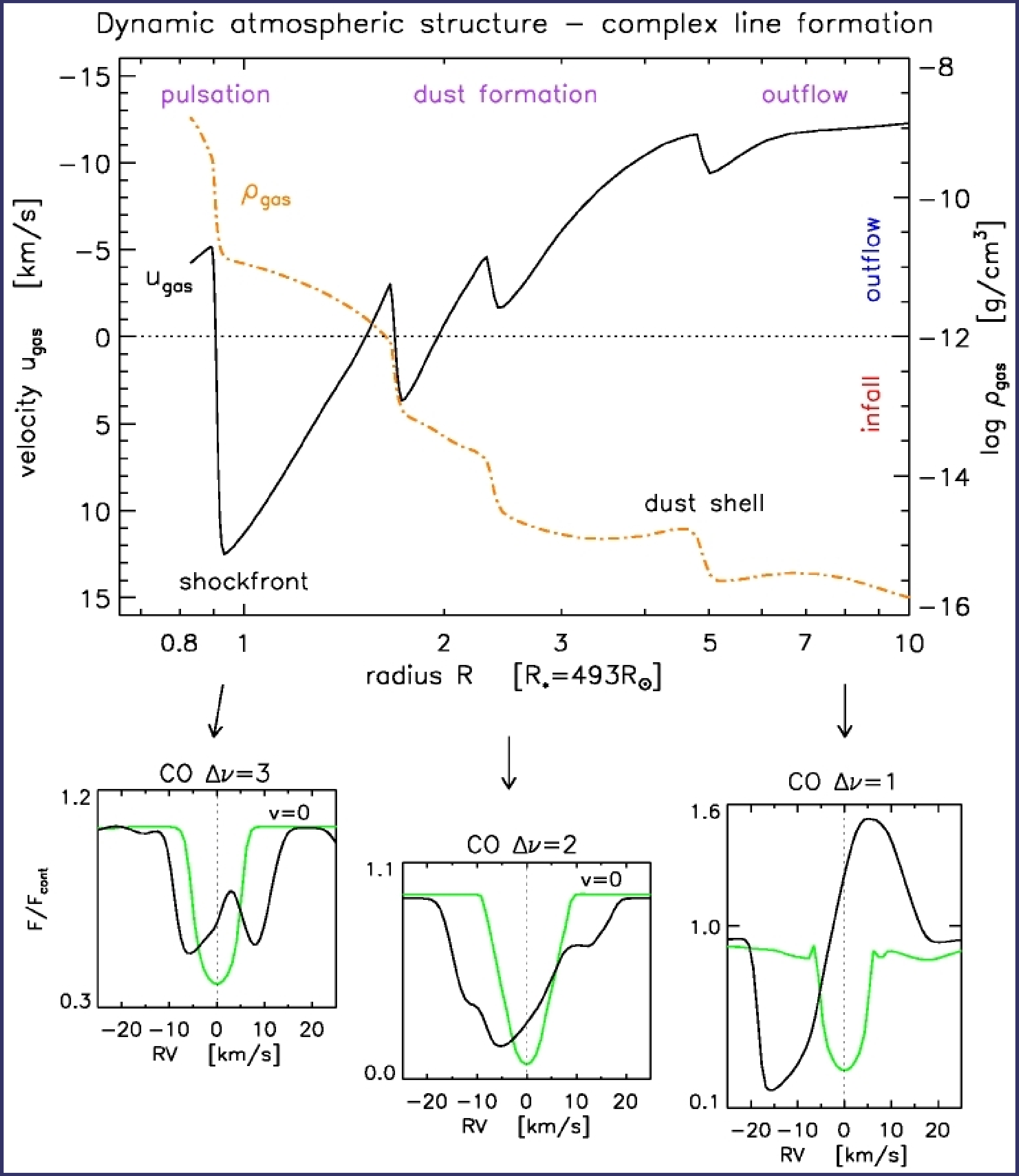
Dust-driven wind models



dust-driven winds of C stars with frequency-dep. radiative transfer

Höfner et al. 2003 (A&A 399, 589)

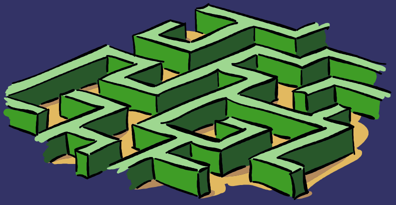
Dust-driven wind models



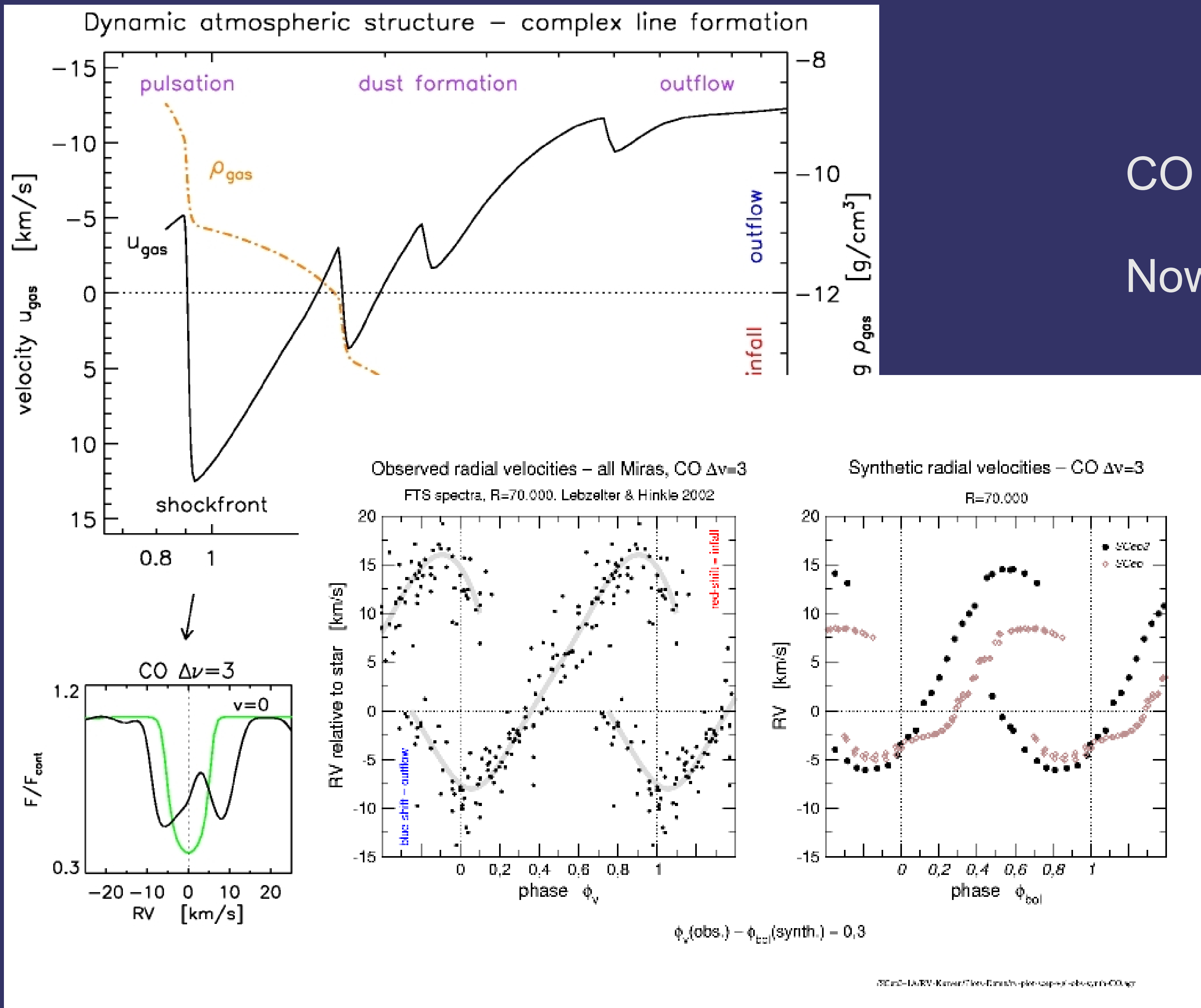
CO line profiles

Nowotny et al. 2005

(A&A 437, 273;
A&A 437, 285)



Dust-driven wind models



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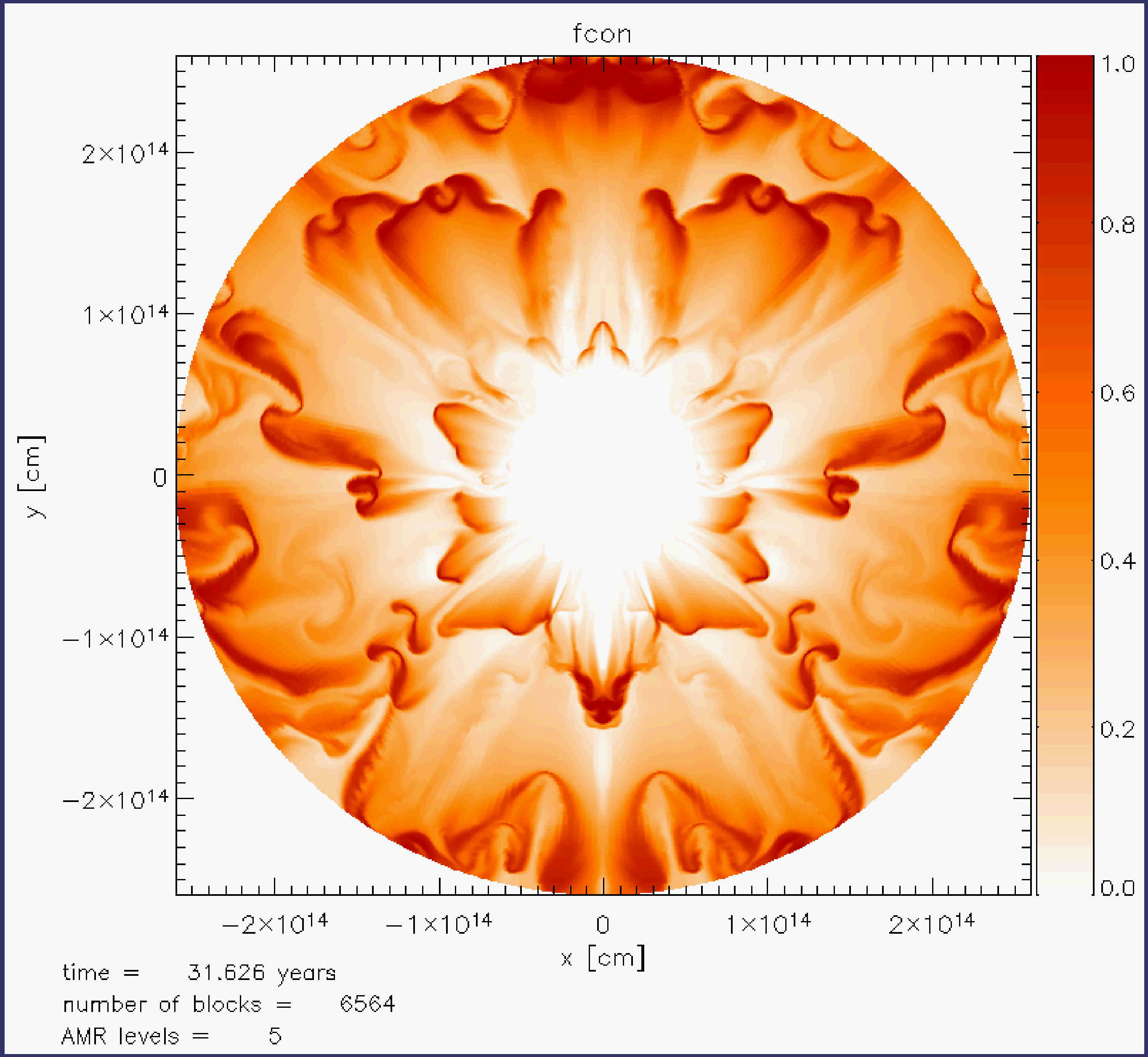
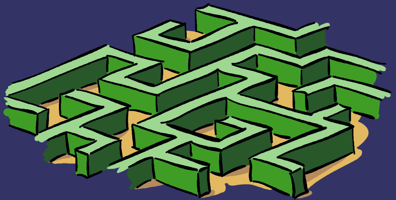


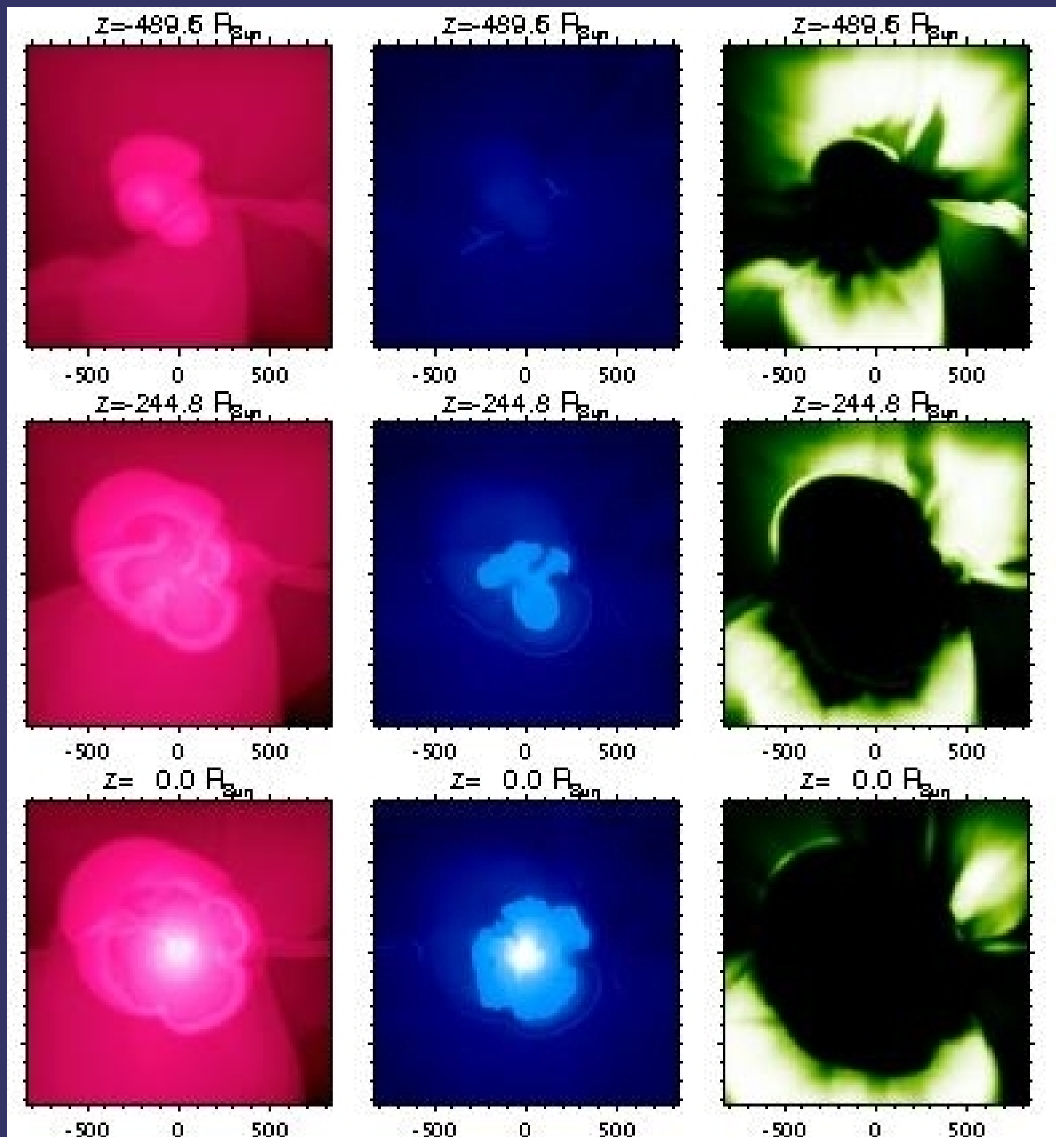
2D models:
structure formation
dust-driven winds

Woitke & Niccolini
2005
(A&A 433,1101)

Woitke 2006
(A&A 452, 537)



Dust-driven wind models



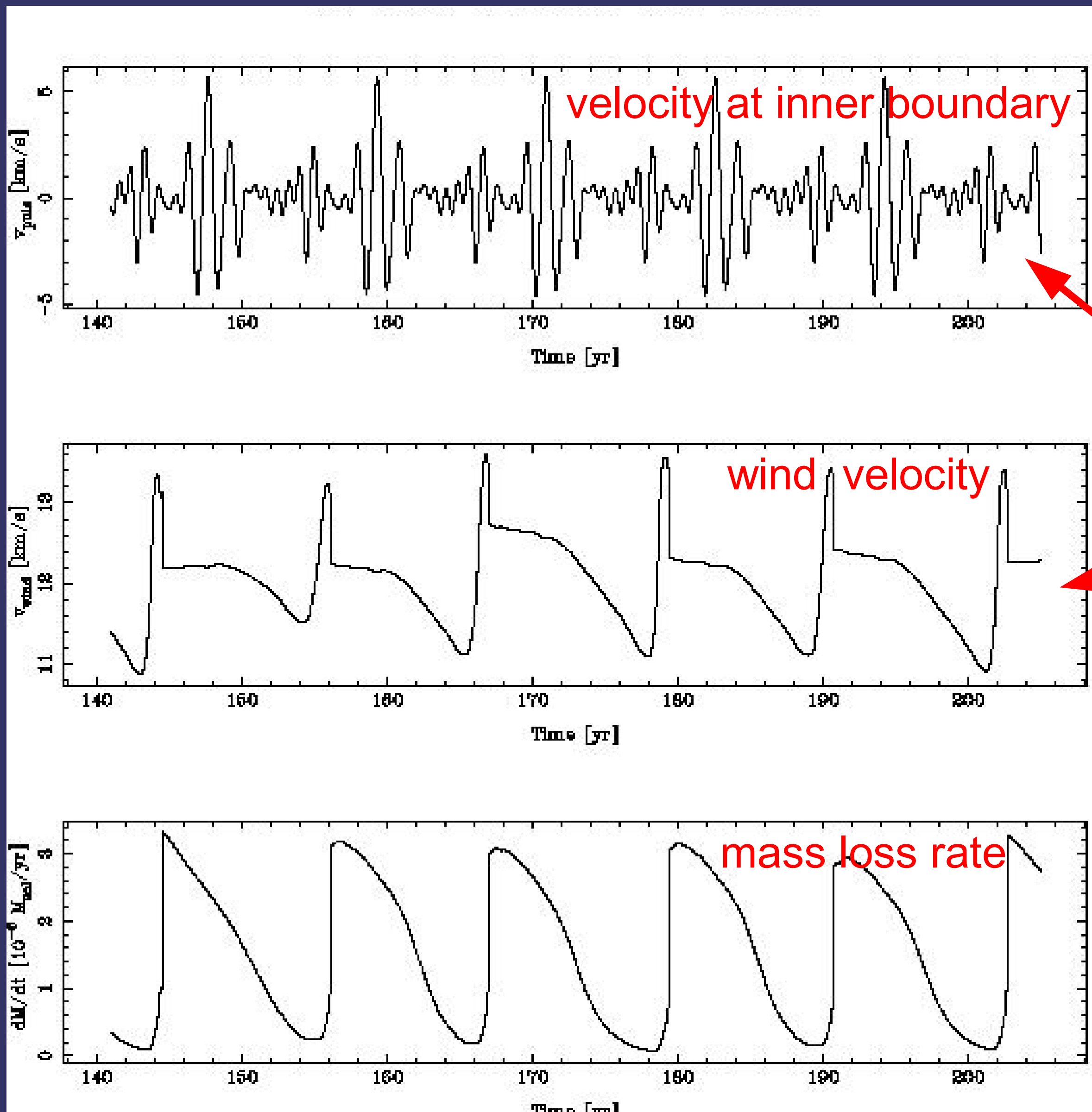
density temperature dust

3D star-in-a-box:
convection
dust formation

tomography of
star & envelope

Freytag & Höfner
(in preparation)

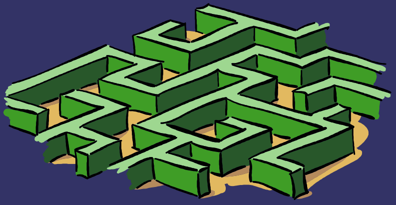
Dust-driven wind models



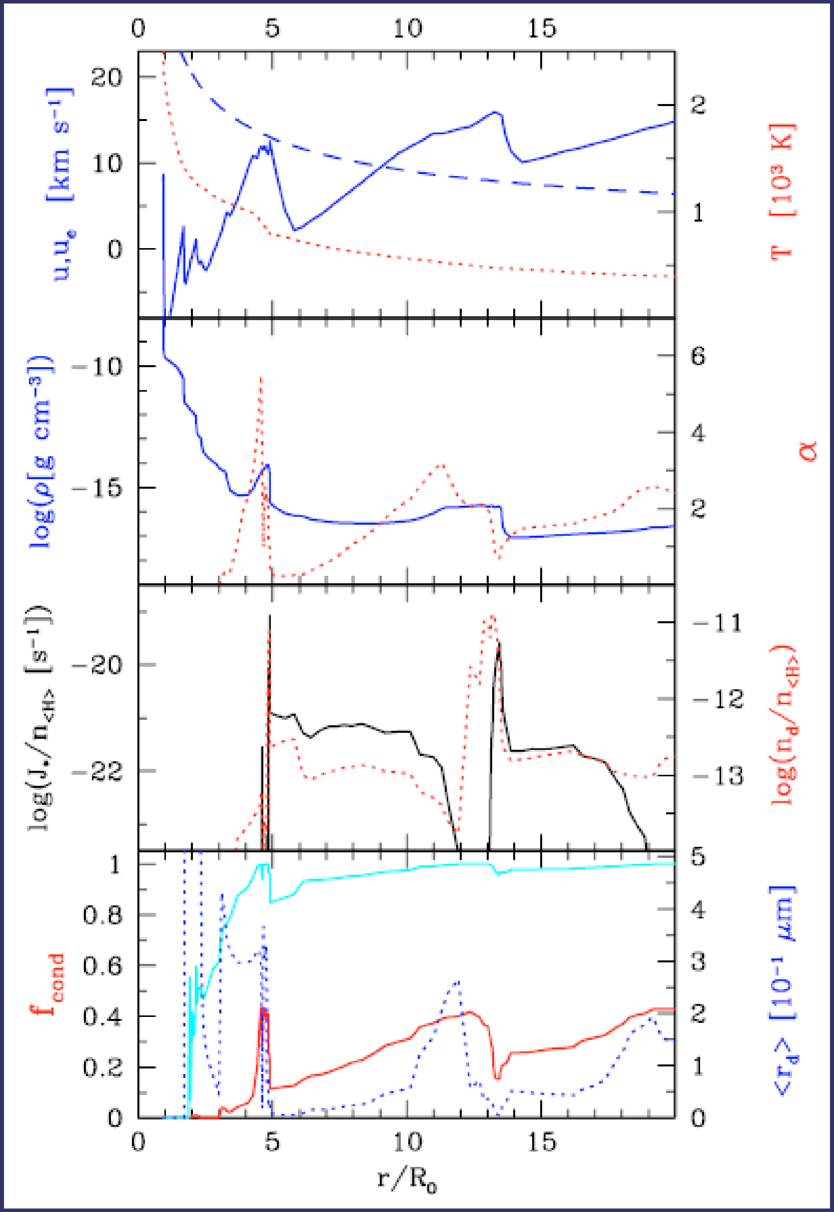
3D star-in-a-box:
convection
dust formation

boundary condition
for 1D wind

Freytag & Höfner
(in preparation)

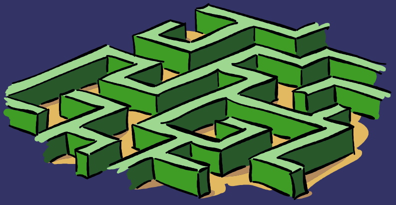


Dust-driven wind models

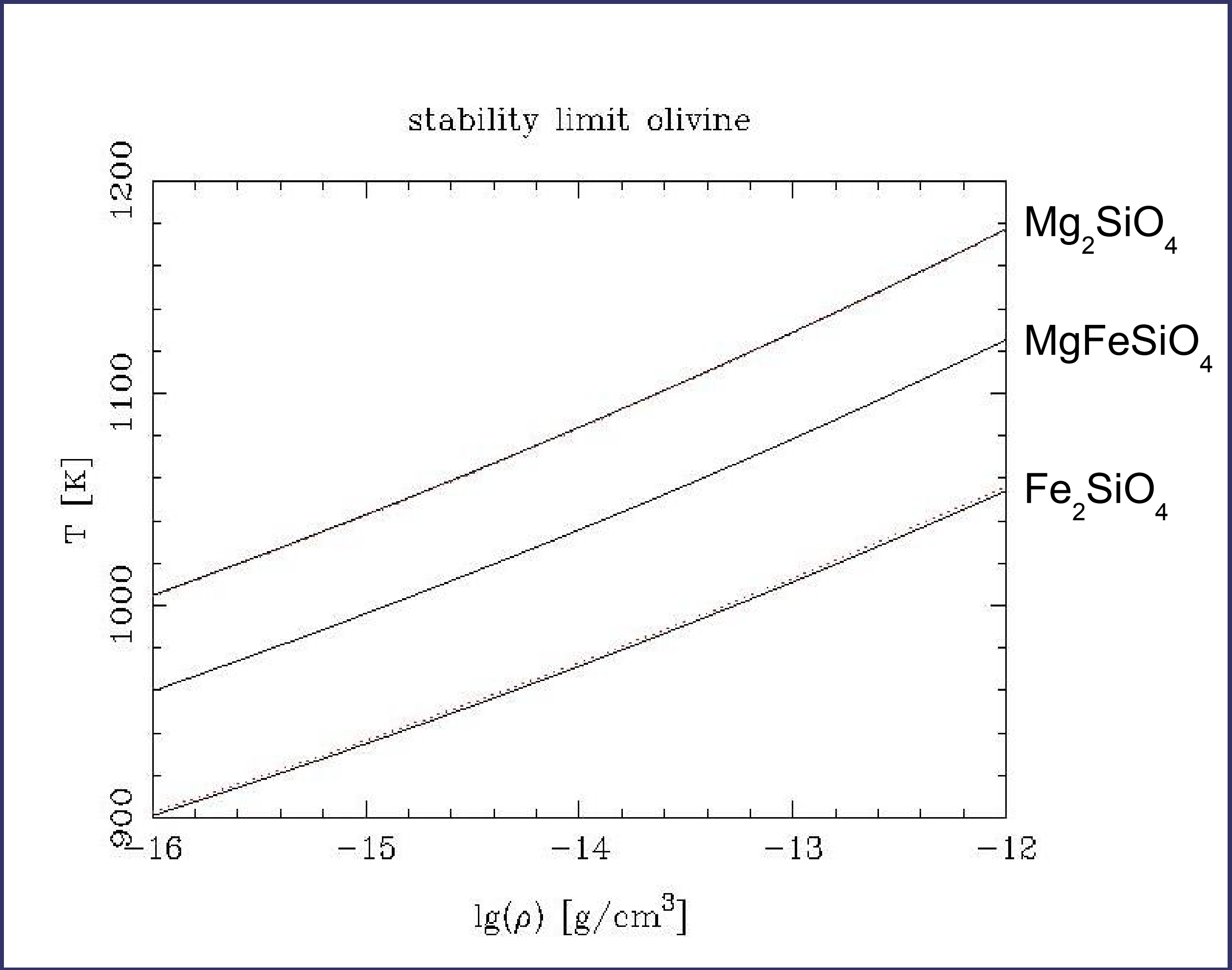


dust-driven winds
of M stars with
>>> grey <<<
radiative transfer

Jeong et al. 2003
(A&A 407, 191)

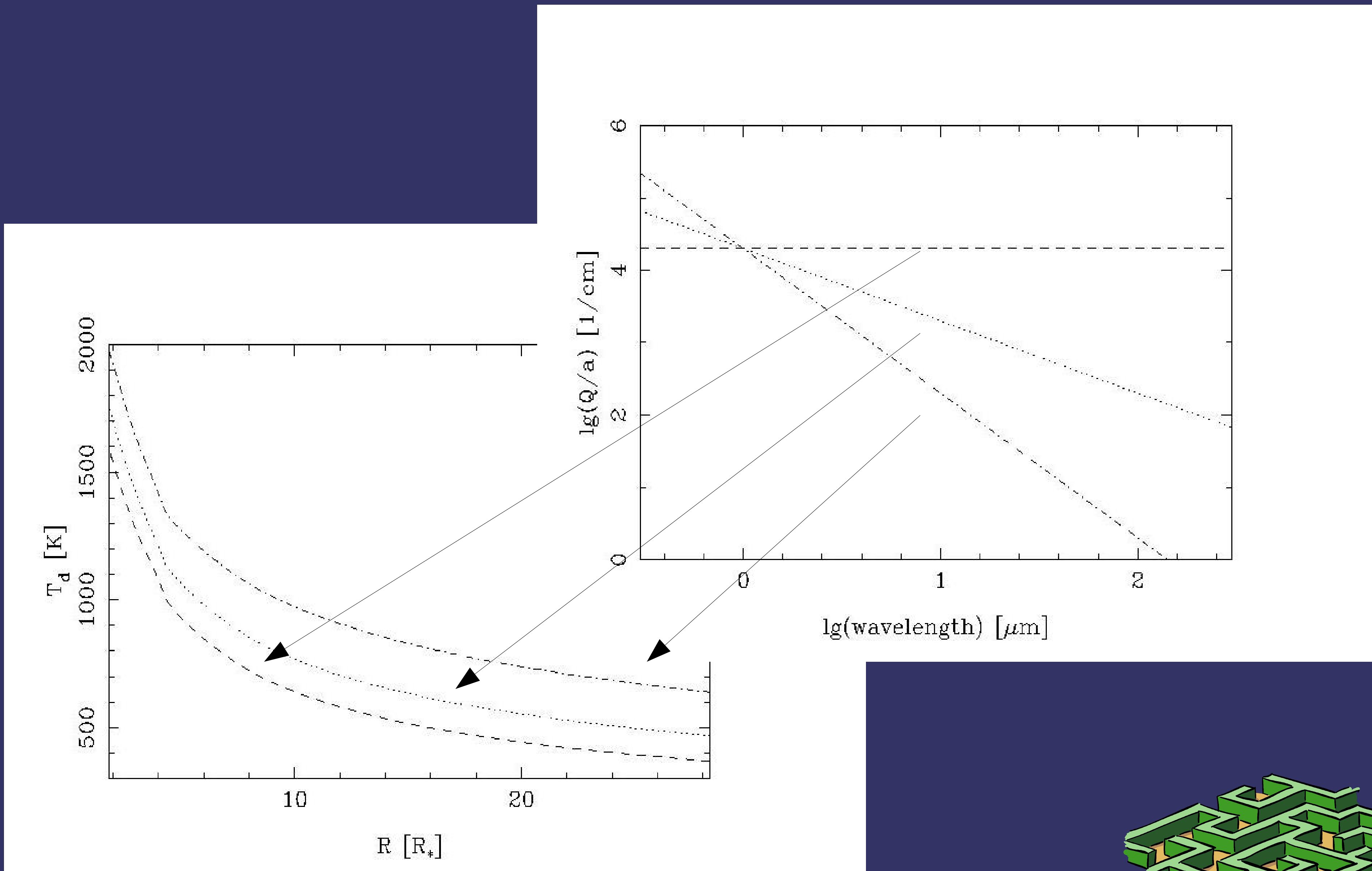


Dust formation: C/O < 1



stability limit
for olivine

Grain temperature and opacity



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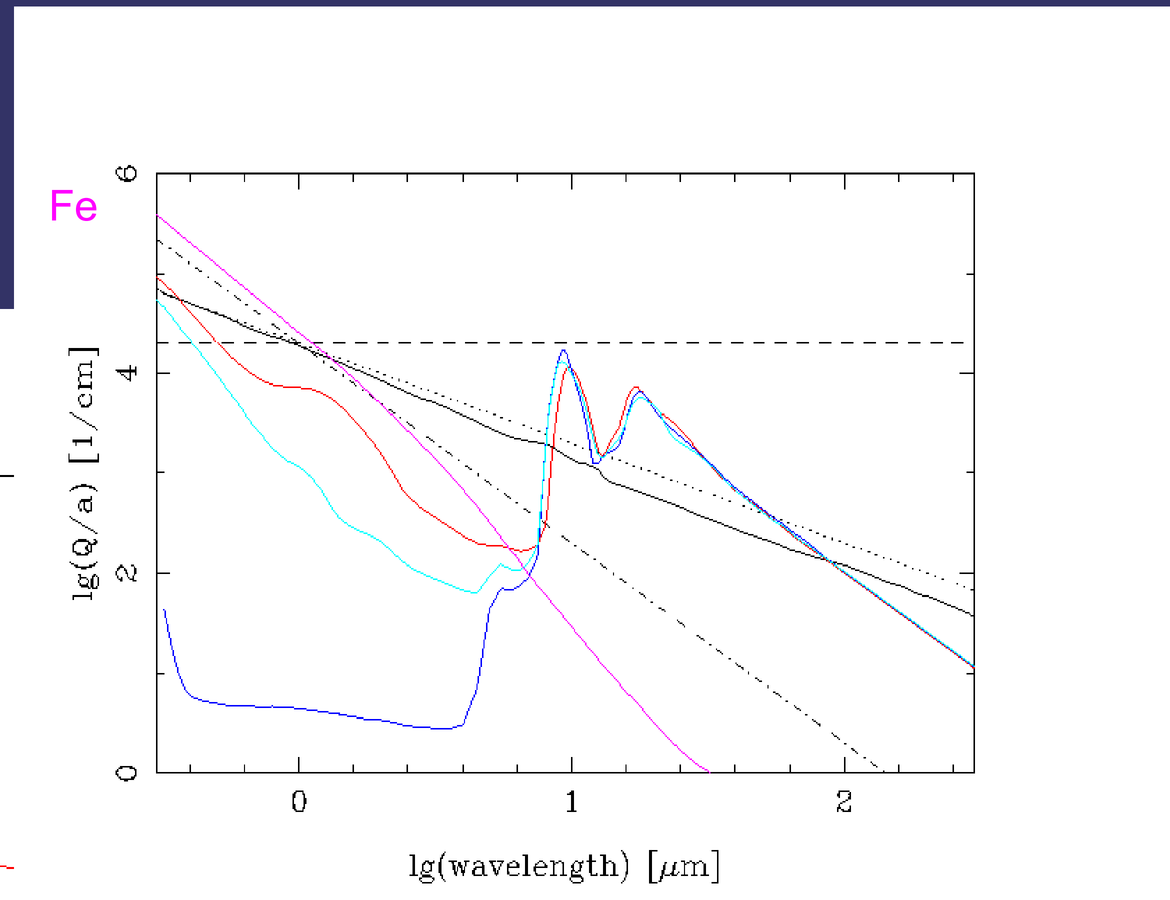
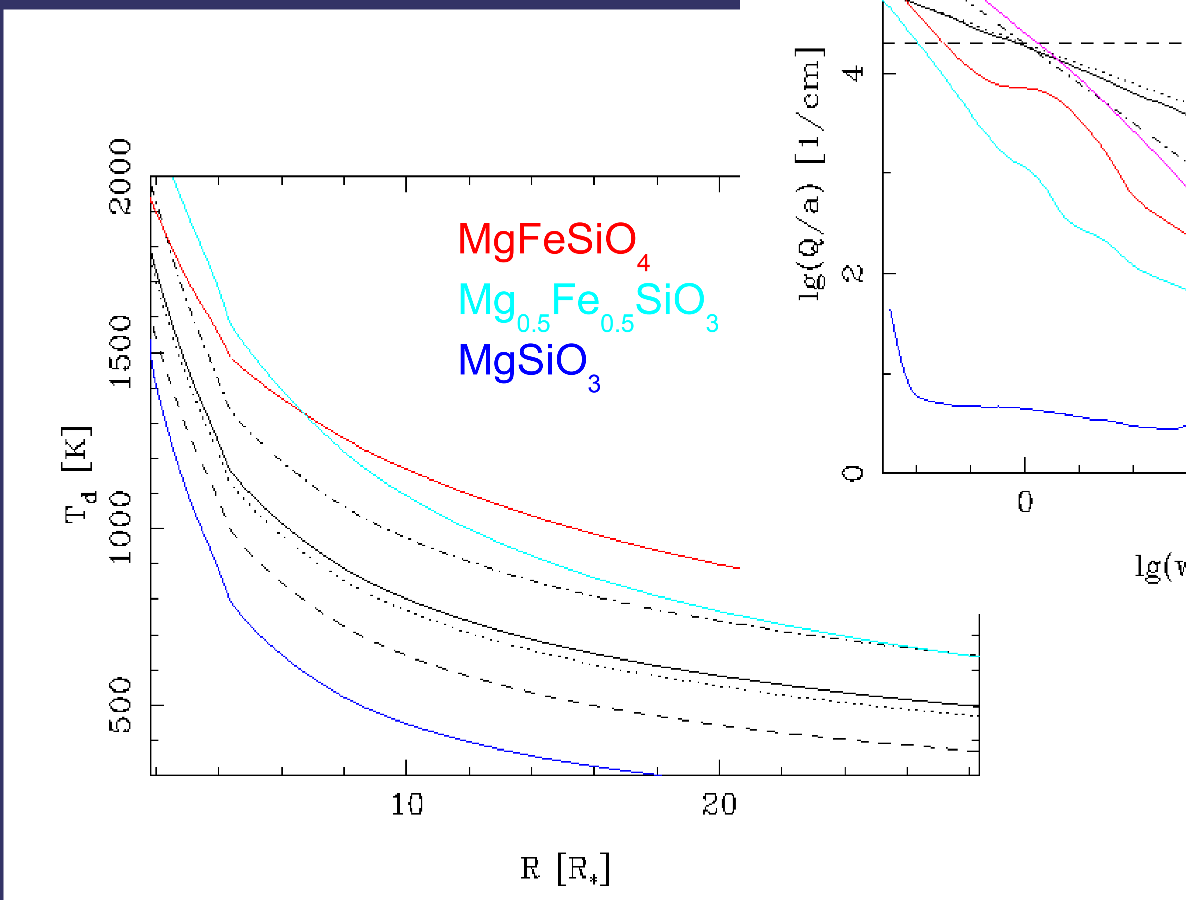




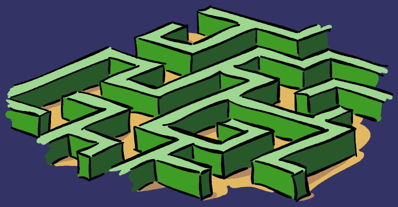
Dust formation: C/O < 1

grey models: (Jeong et al. 2003)

- dust-driven wind scenario seems to work
- chemical details ?

frequency-dept. models: (2006: Woitke; Höfner)

- grain temperature forces low Fe content in silicates
- low opacity at wavelengths around flux maximum – driving mechanism ?



Most common scenario

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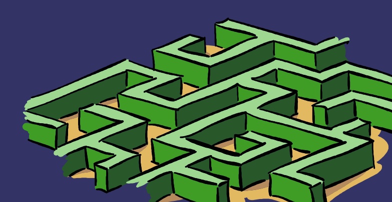
"pulsation-enhanced dust-driven wind"



Most common scenario

- Force:
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C/O>1
!!!

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*"pulsation-enhanced
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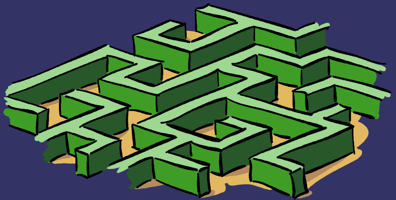

Most common scenario

- Force: C/O<1
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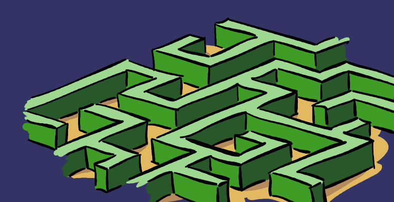
“pulsation-enhanced dust-driven wind” ???



Most common scenario

Houston, we have a problem ....

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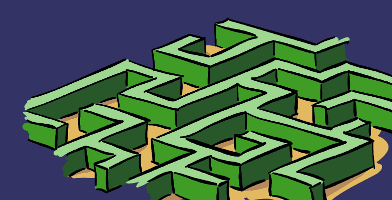
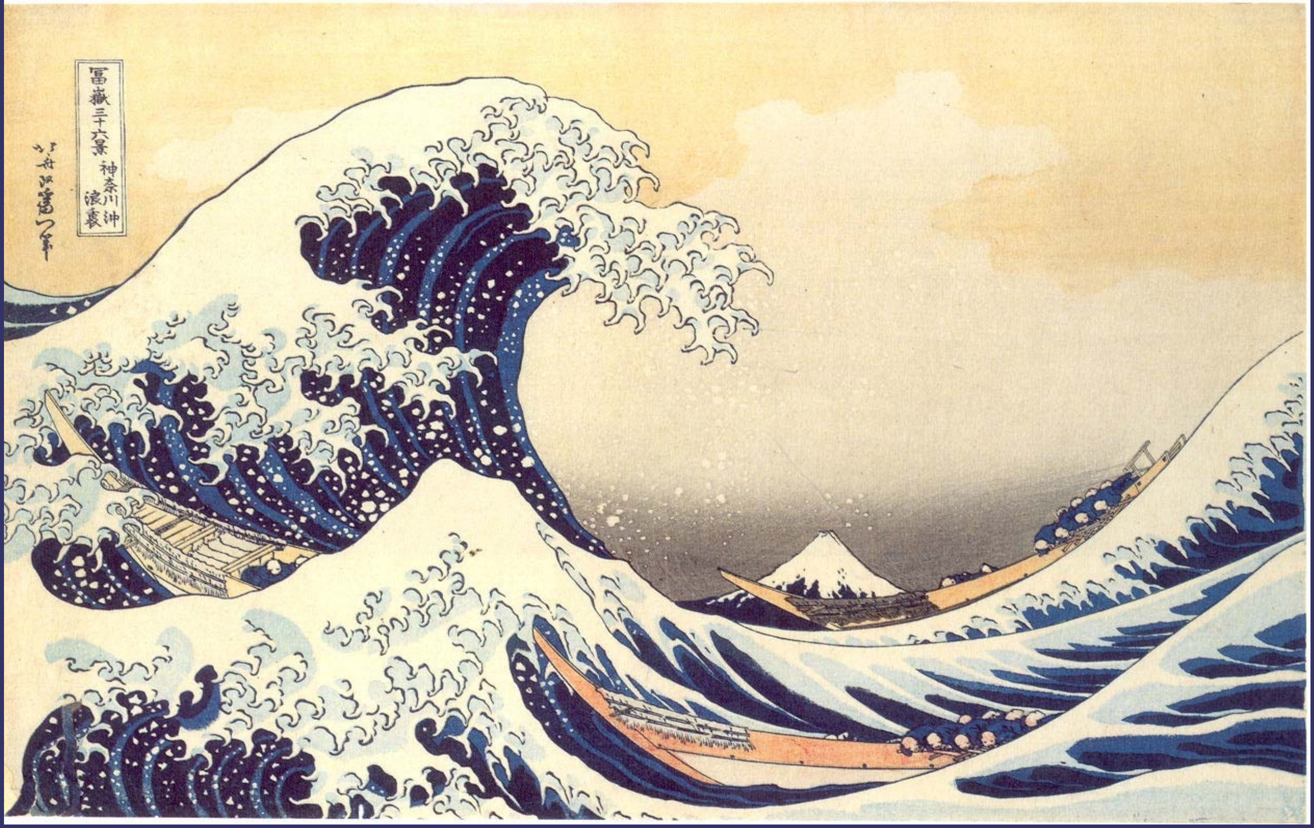


Alternative scenarios ?

- Can shock waves alone do the trick ?



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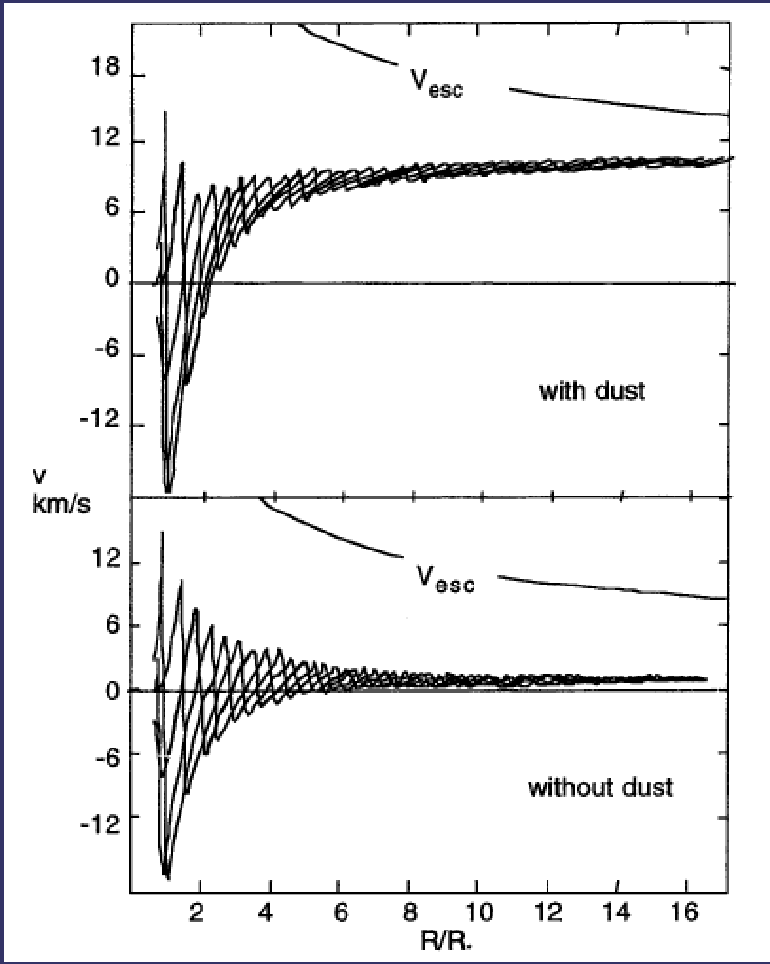
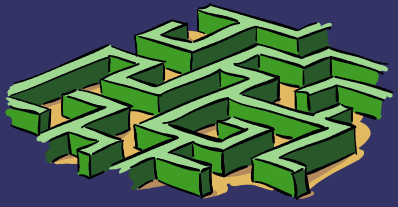


wind models
of M stars with
>>> non-LTE <<<
cooling in shocks

Willson 2000
(ARA&A 38, 573)

models by
G.Bowen



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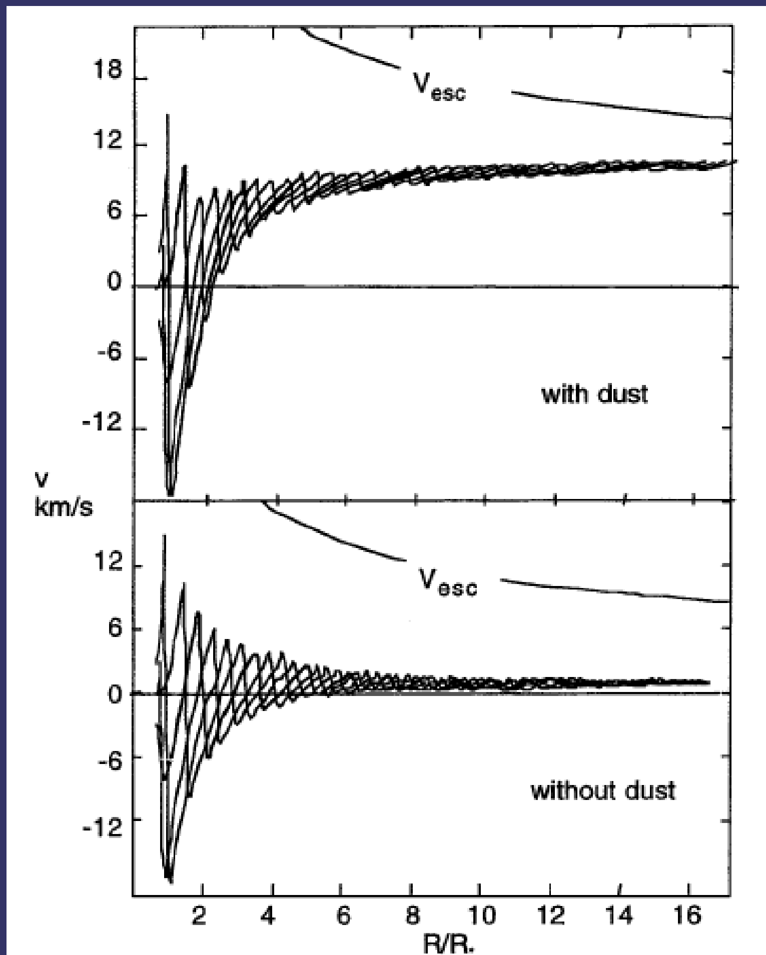

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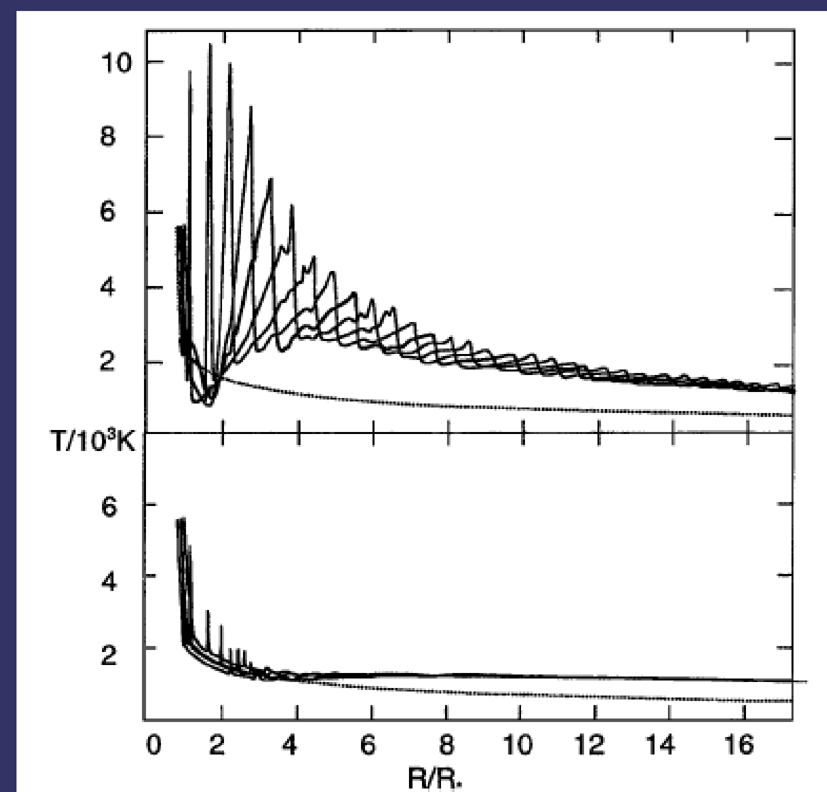

Alternative scenarios ?

- Can shock waves alone do the trick ?
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- Pressure-driven winds:
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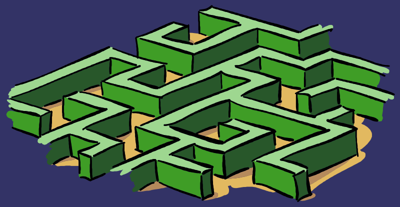
... direct comparison with observations currently not possible ...



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The jury is still out ...

Mass loss: the role of grains ...

C/O > 1:

- pulsation-enhanced dust-driven winds work nicely
- good agreement of detailed models with observations

C/O < 1:

- detailed models indicate serious prob-lems with dust-driven wind scenario
- back to the drawing board ???