Headwind: Modeling Mass Loss Against All Odds

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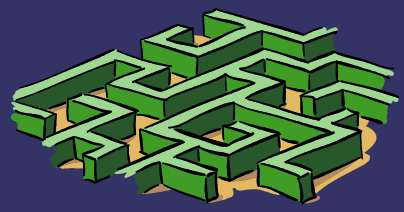
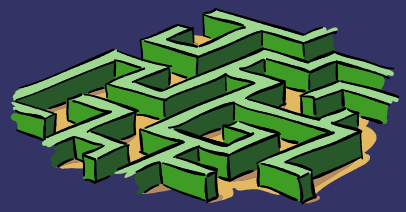


Invited talk at *Why Galaxies Care About AGB Stars*, Vienna, 2006

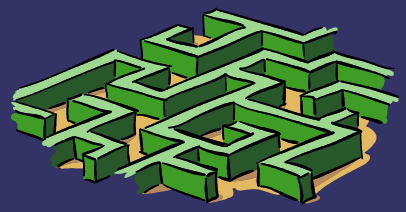
The facts ... we think ...

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



The nagging question:

After about 20 years of modeling,
WHY
don't we have a decent, usable description
of mass loss on the AGB
?



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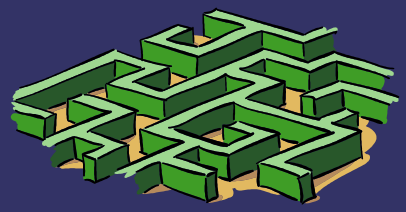
The simple answer: it's complicated!



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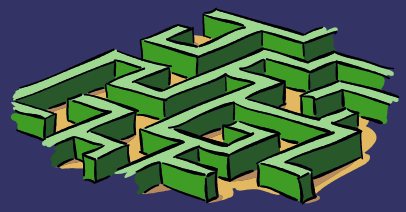
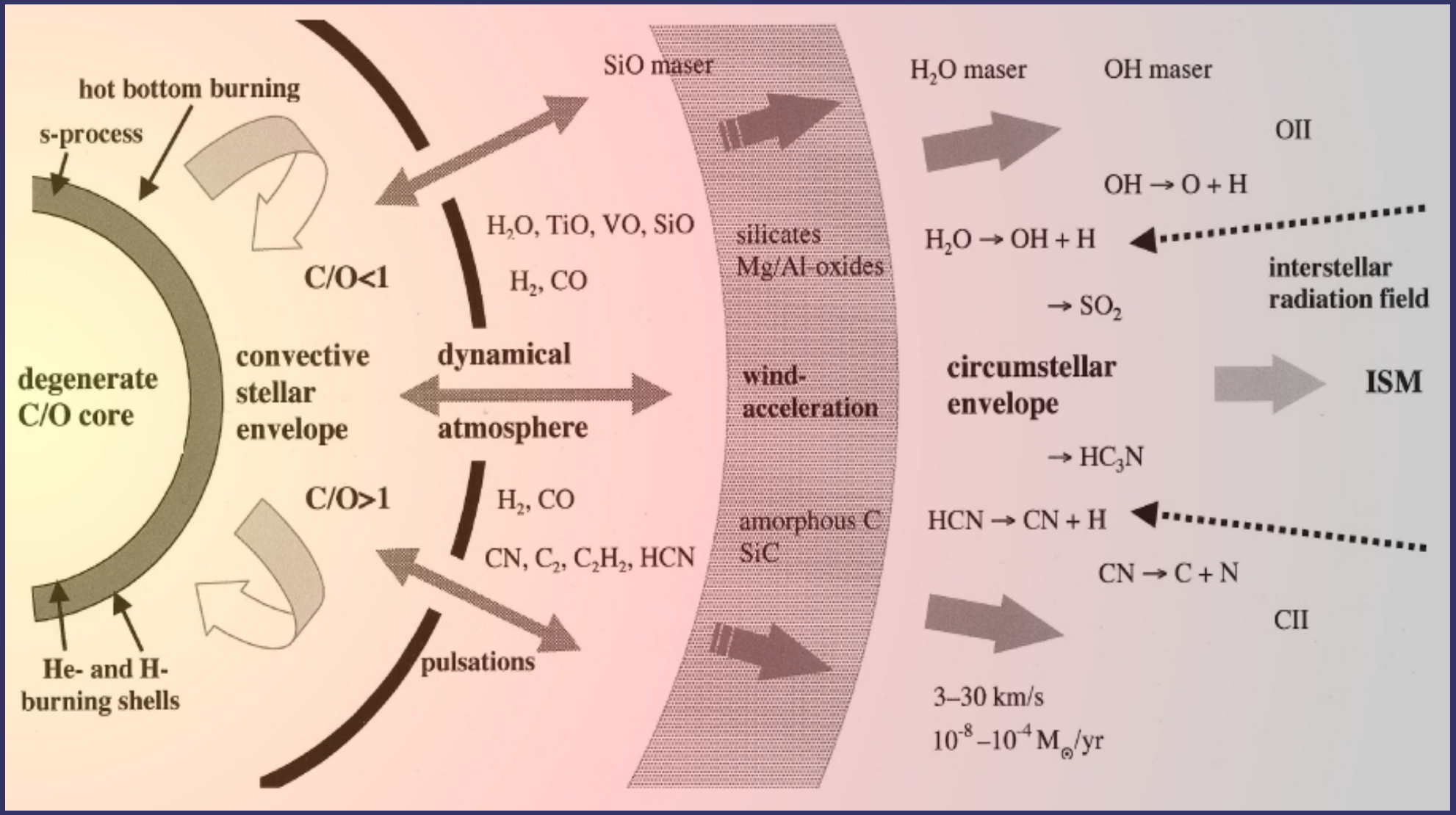
The complicated answer ...

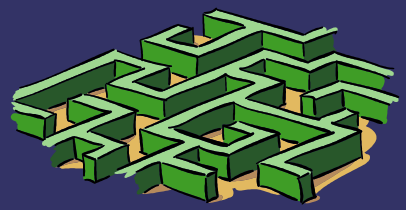




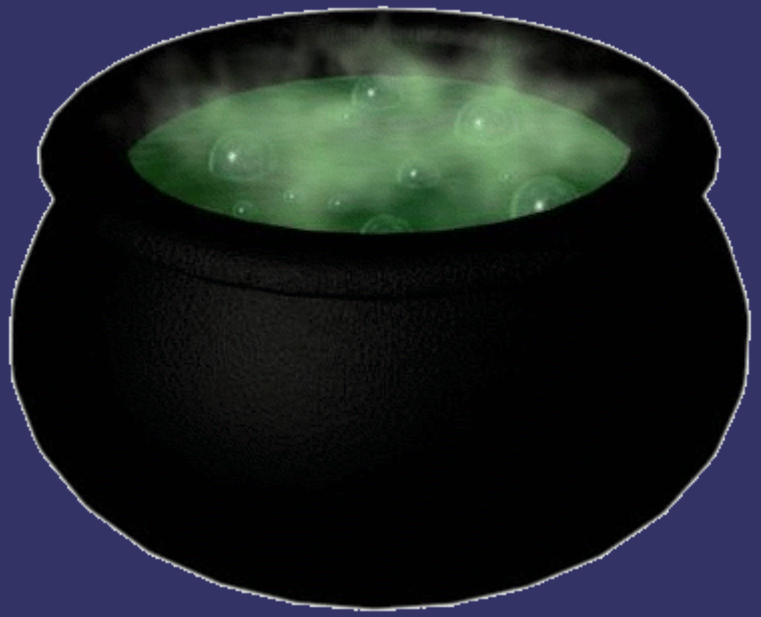
(adapted from Habing & Olofsson 2004)

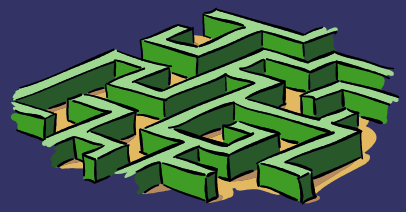
What to expect from this talk:

- Part one:
  Basics – setting the scene
- Part two:
  Models – milestones & recent examples
- Part three:
  Conclusions & getting on with life



Stellar winds in a nut shell





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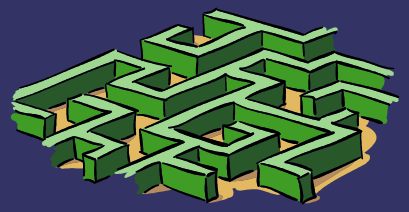
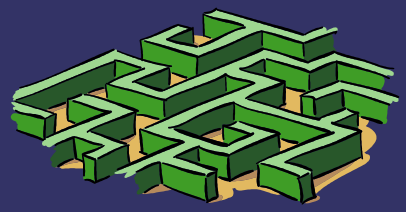


Stellar winds in a nut shell

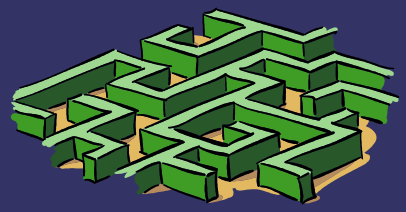
Force

Conditions



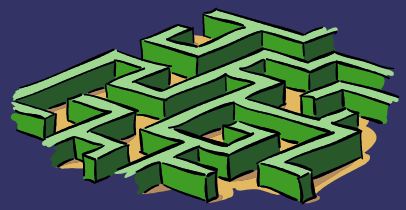
Most common scenario

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



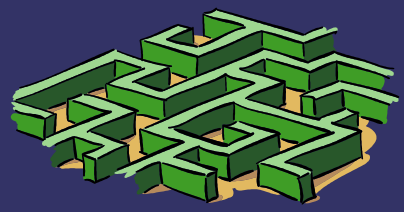
Crucial ingredients

- 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



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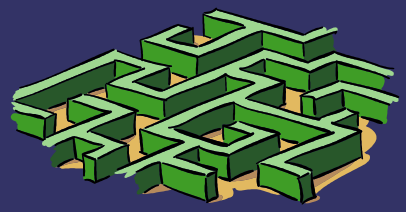
... in other words:
incomplete condensation, dust/gas ratio is NOT a simple function of abundances

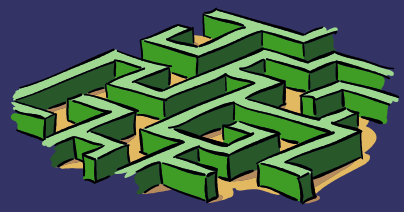
(thanks to Peter Wood for asking ...)



Dust formation: non-equilibrium

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

$\rightarrow$ the grain growth time is comparable to the pulsation period



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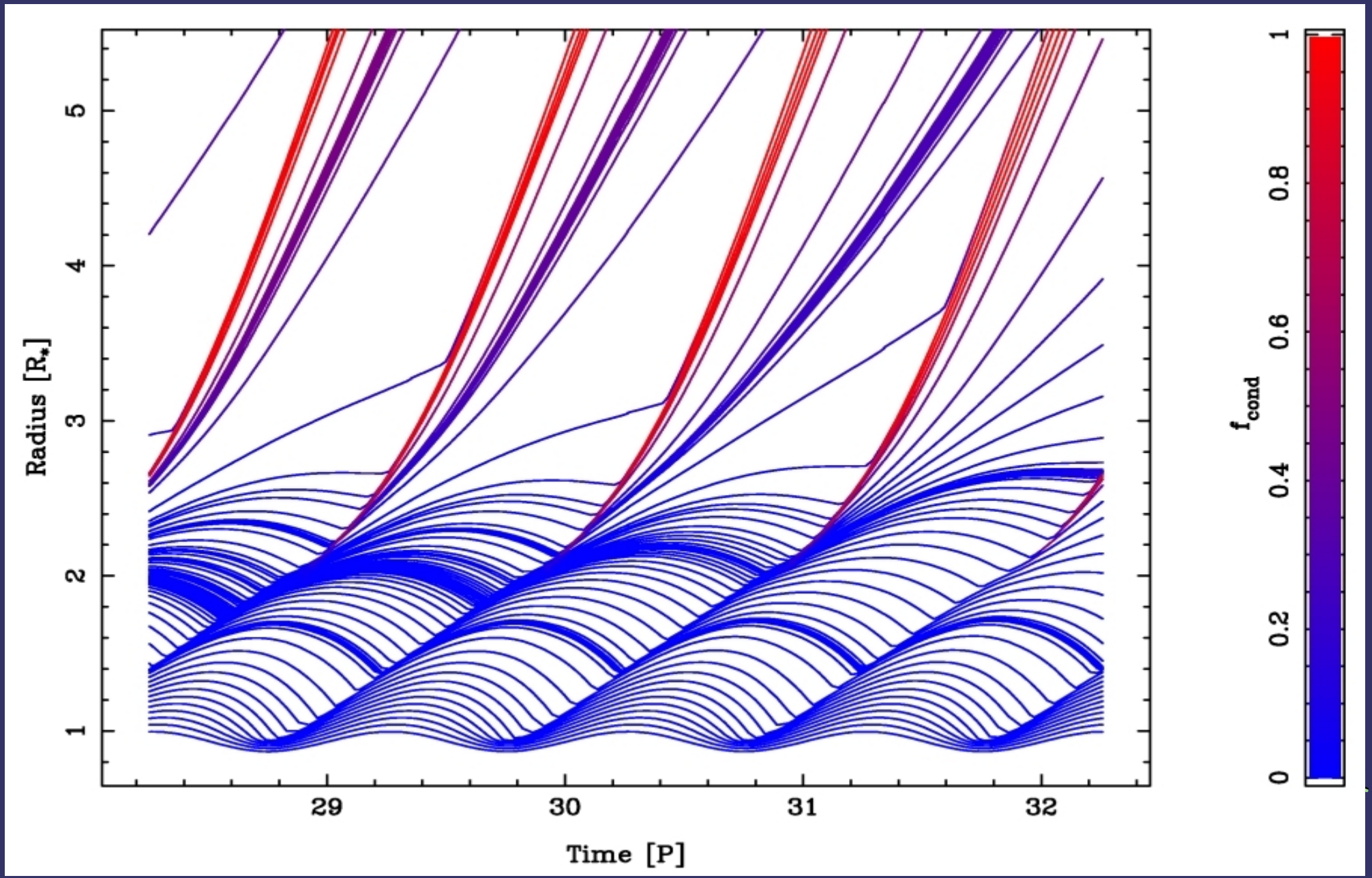

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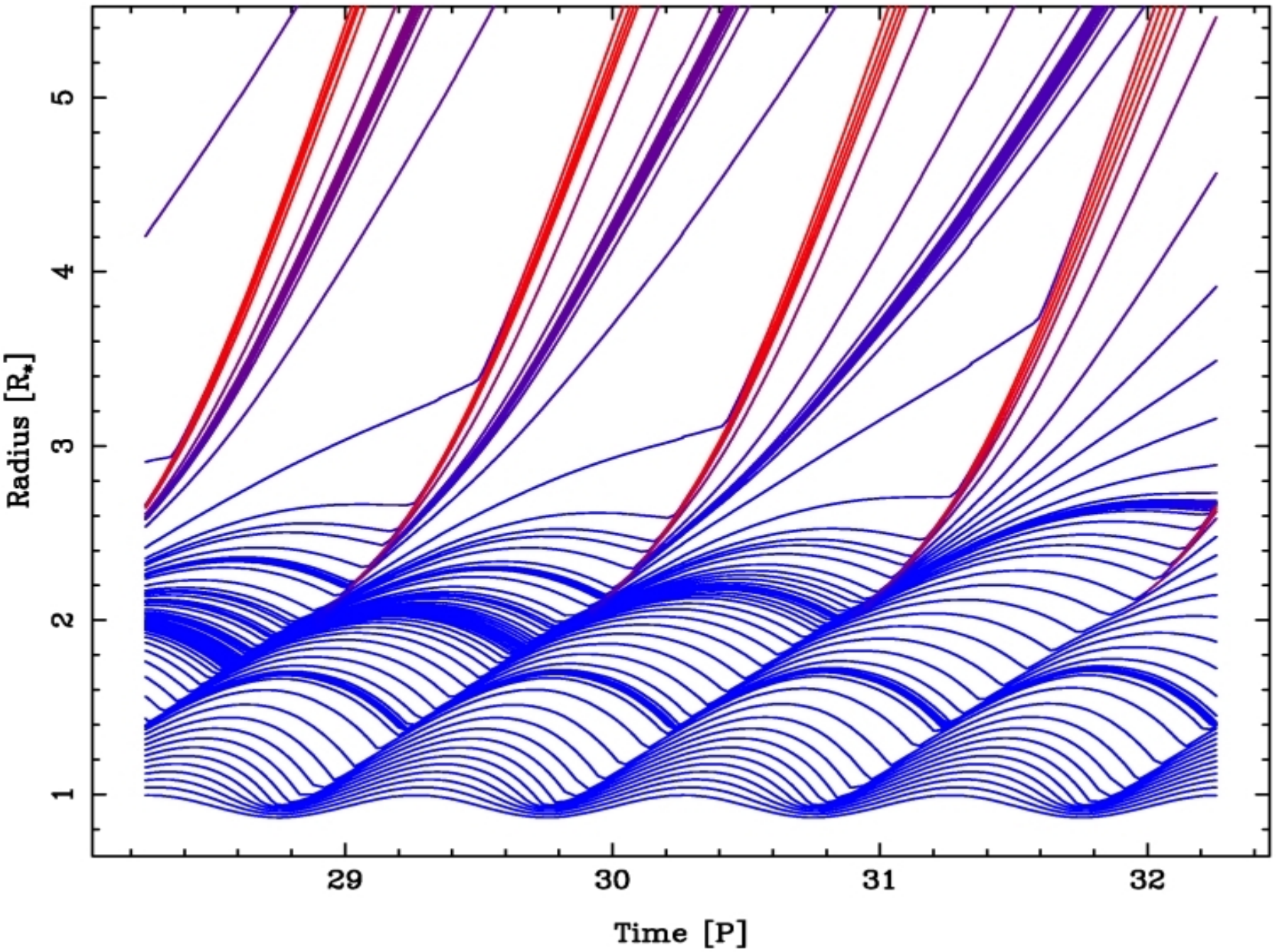
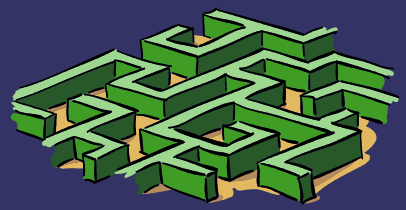


Alternative scenarios ?

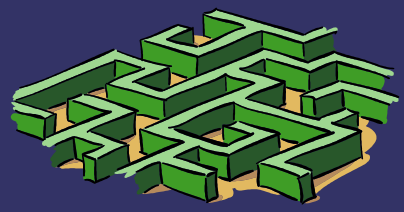
- Can shock waves alone do the trick ?



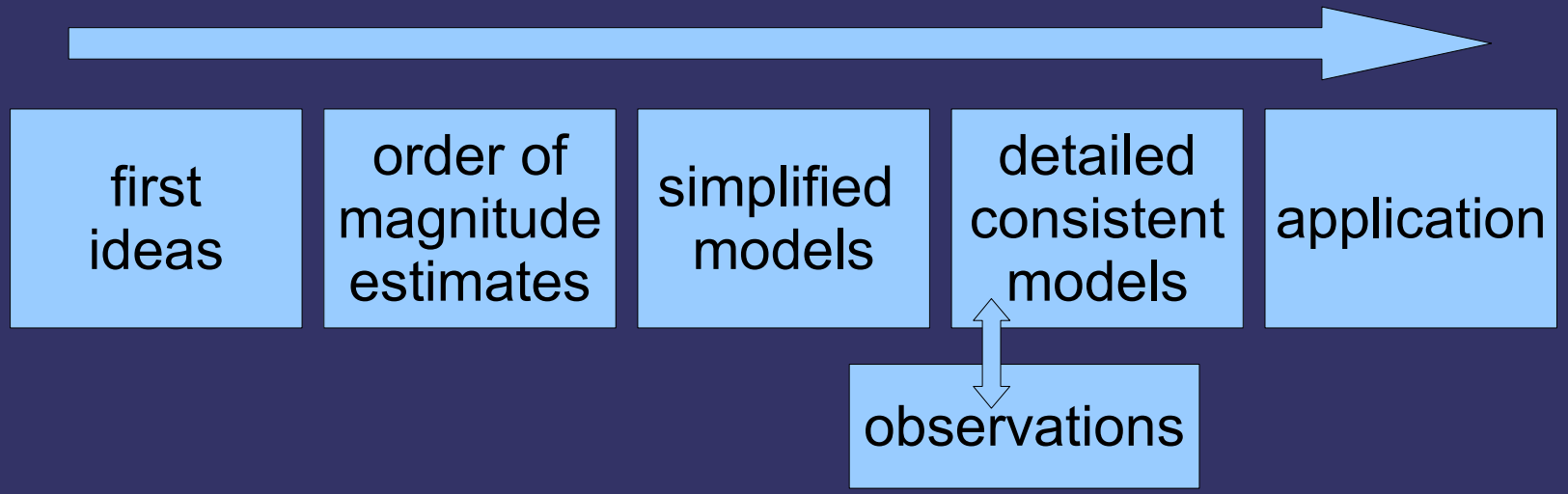
Alternative scenarios ?

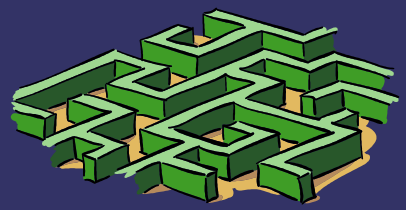
- Can shock waves alone do the trick ?
- Cooling in shocks ? ... an issue ?
- Pressure-driven winds:
  'calorisphere', dust as a by-product ?

... no observational evidence ...



Development of wind models





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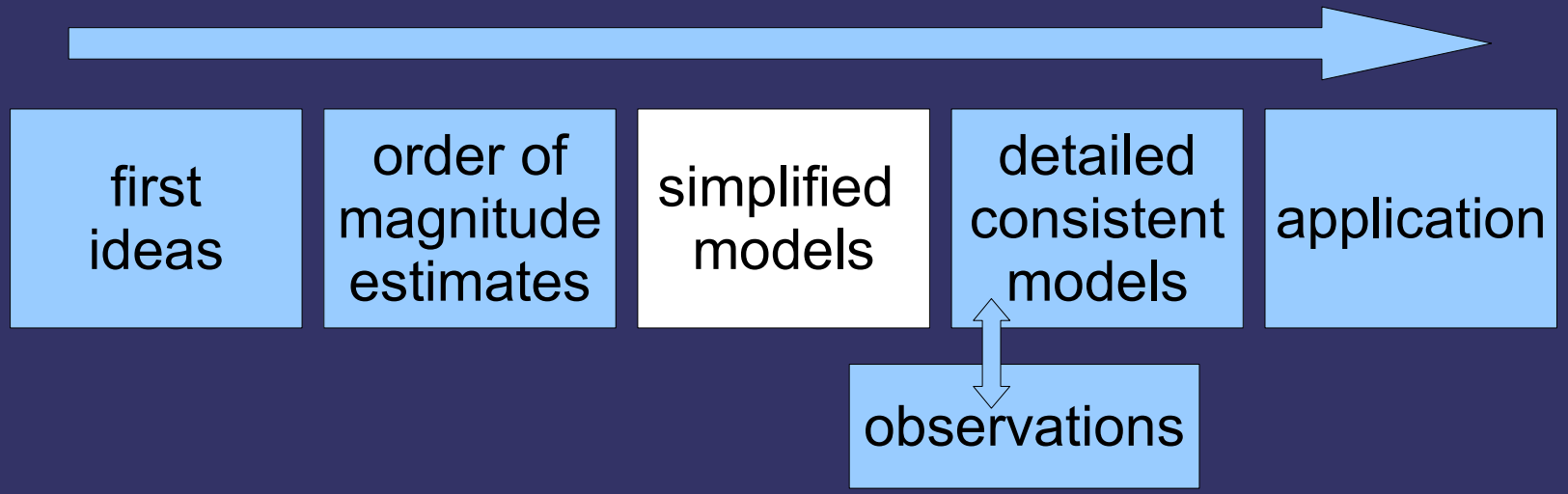
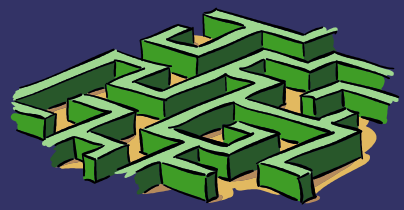


basic mechanisms:
pulsation, shocks,
radiation pressure

Wood 1979
Bowen 1988



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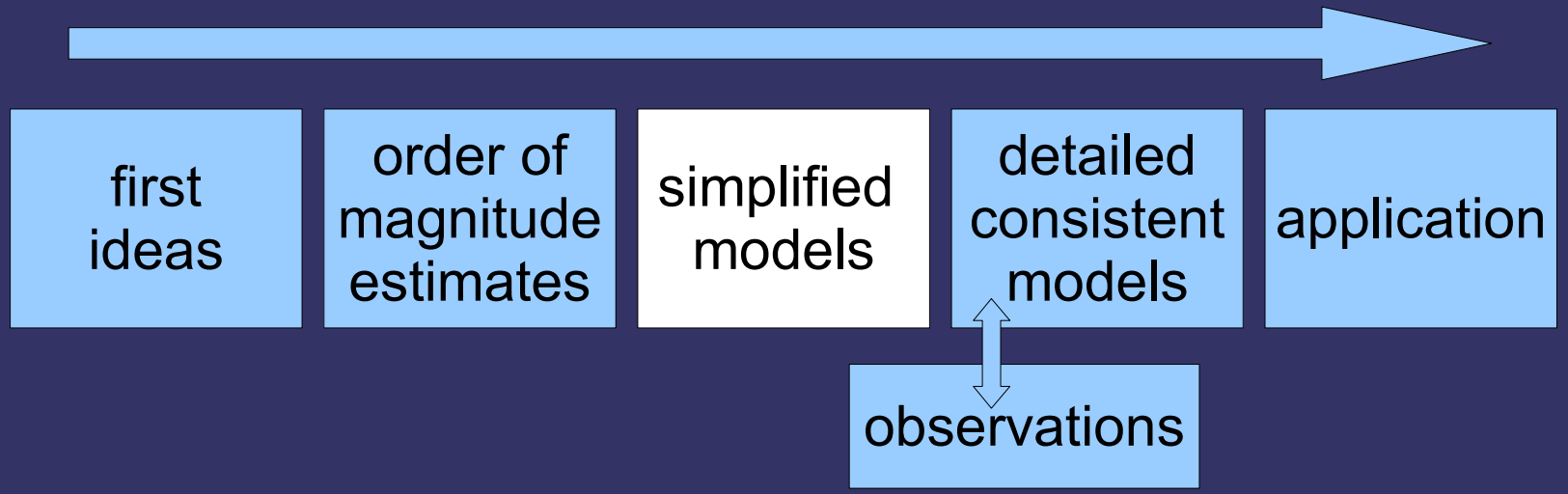
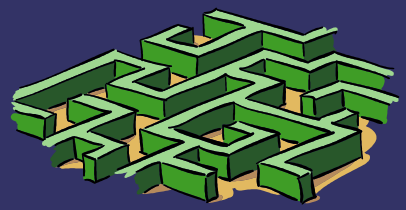


dust formation:
C-stars

Fleischer et al. 1992
Höfner & Dorfi 1997
Winters et al. 2000



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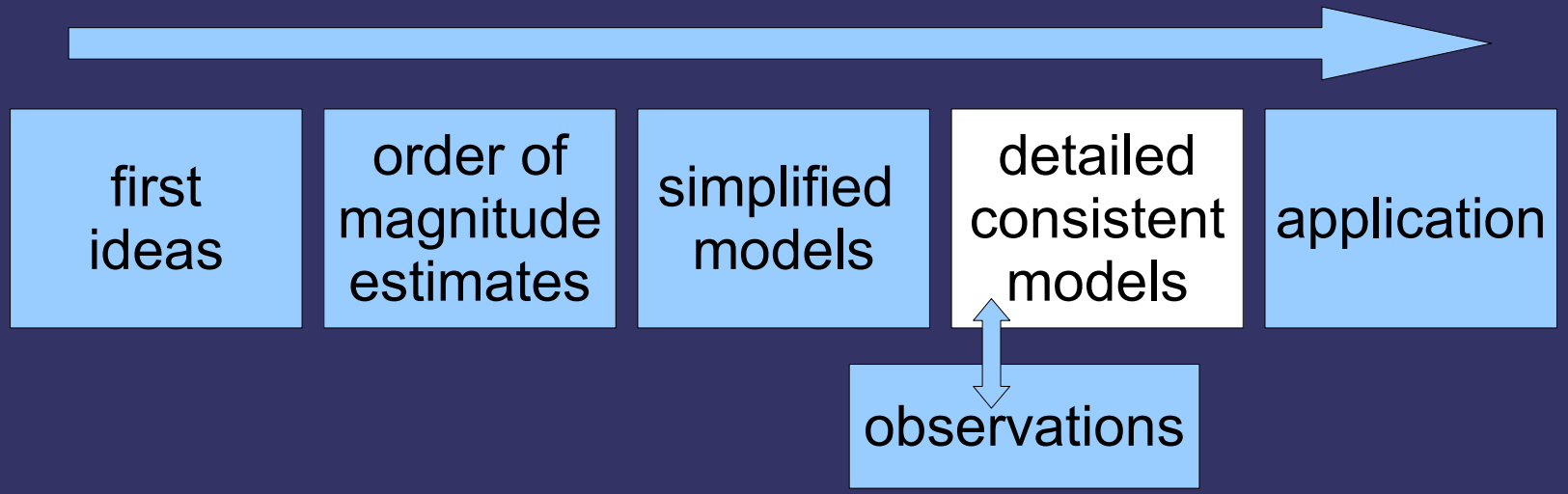
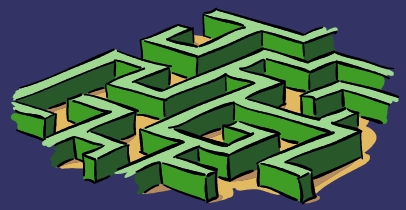


dyn. atmospheres:
pulsation, shocks,
NO WIND

Bessell et al. 1996
Scholz & Wood
Tej et al. 2003



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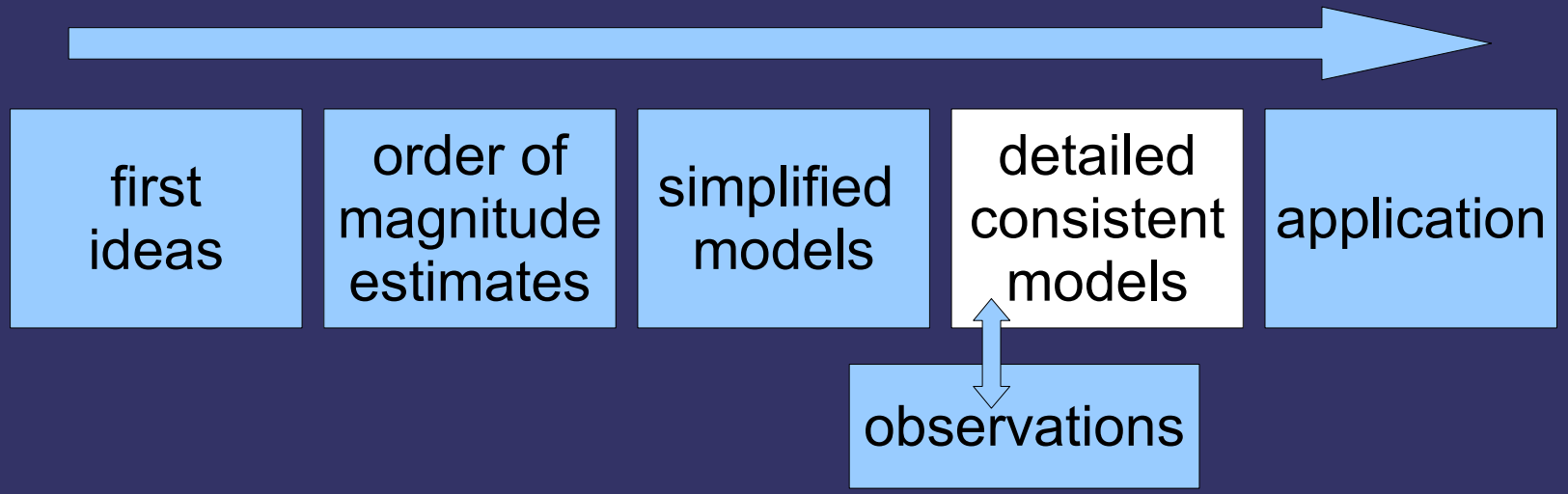
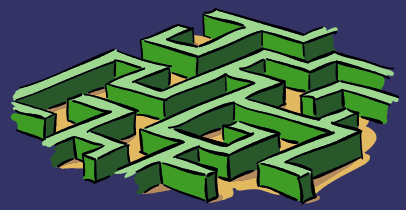


C star winds:
shocks, dust,
frequ.-dep. RT

Höfner et al. 2003,
Nowotny et al. 2005



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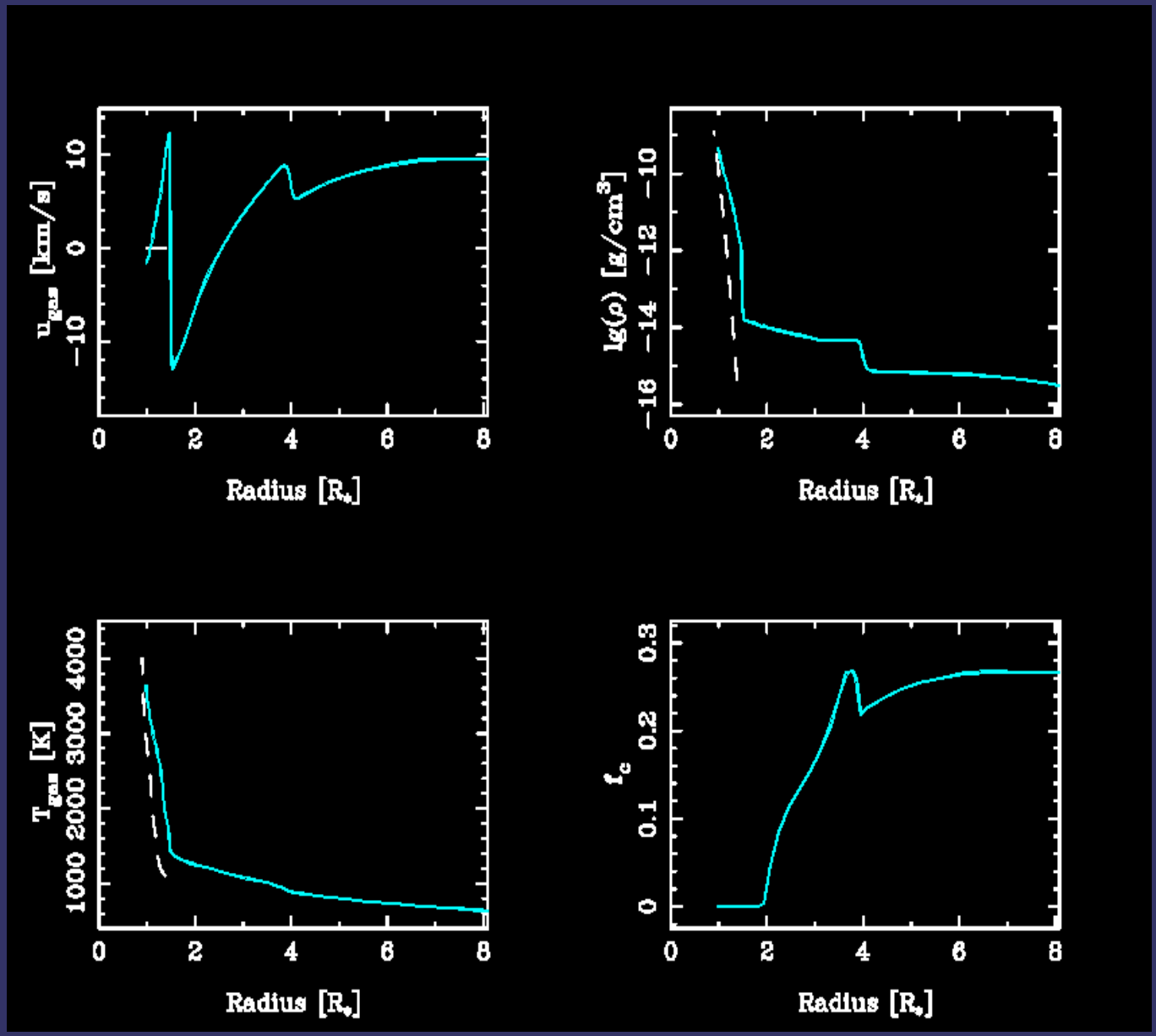
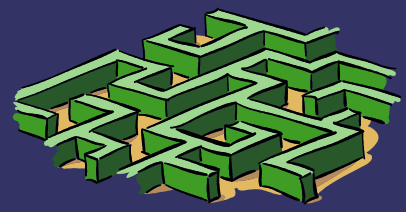


detailed models: dust-driven winds of C stars with frequency-dependent radiative transfer

Höfner et al. 2003 (A&A 399, 589)



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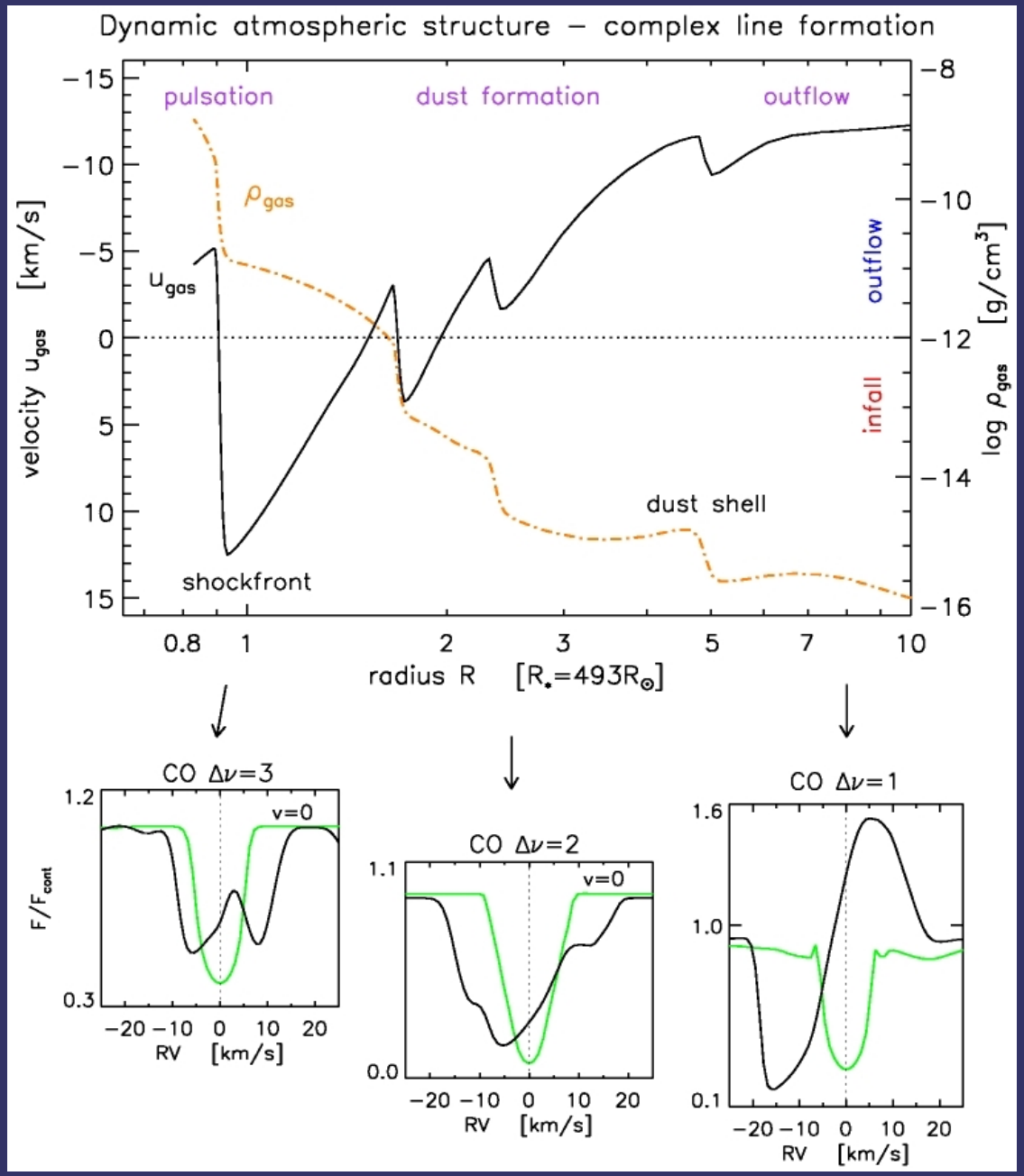
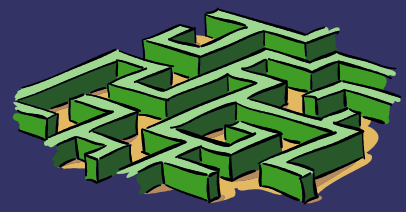


detailed models:
line profiles

Nowotny et al. 2005
(A&A 437, 273;
A&A 437, 285)



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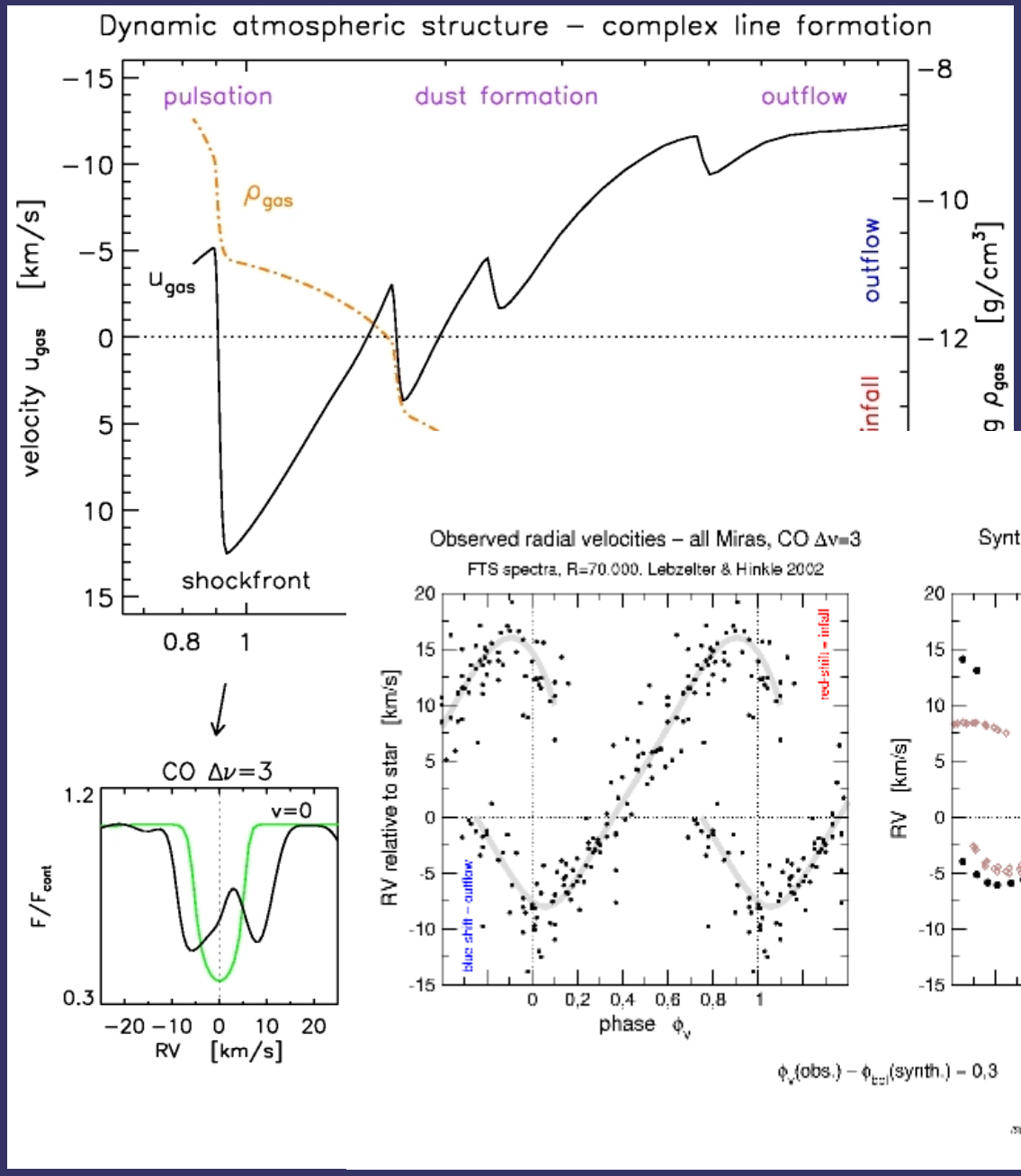

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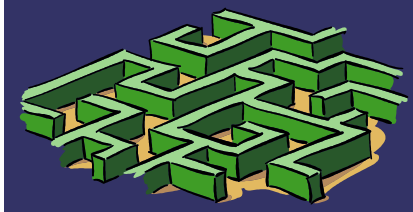

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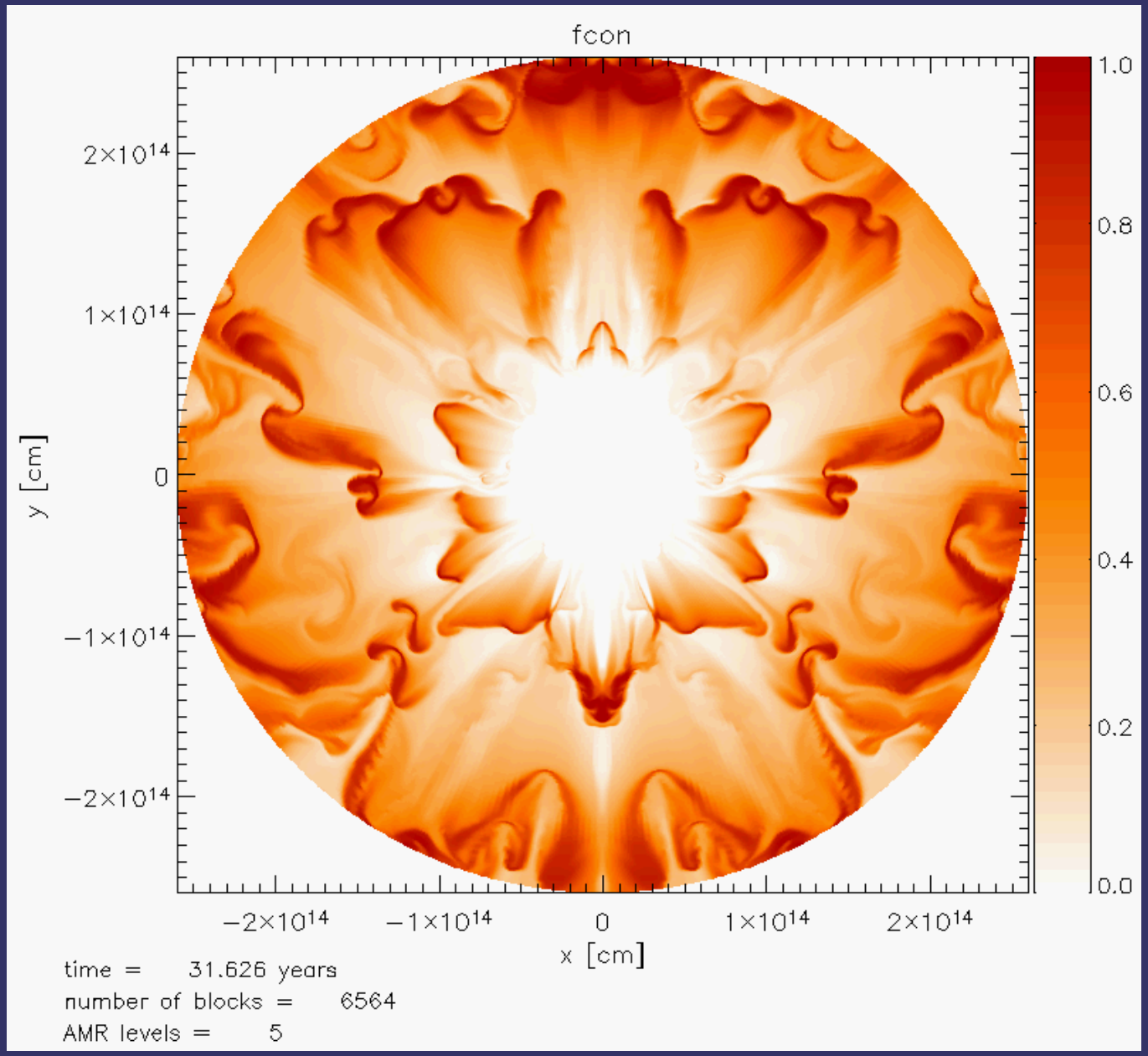
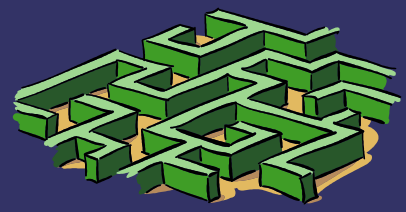


2D models:
structure formation
dust-driven winds

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

Woitke 2006
(A&A 452, 537)



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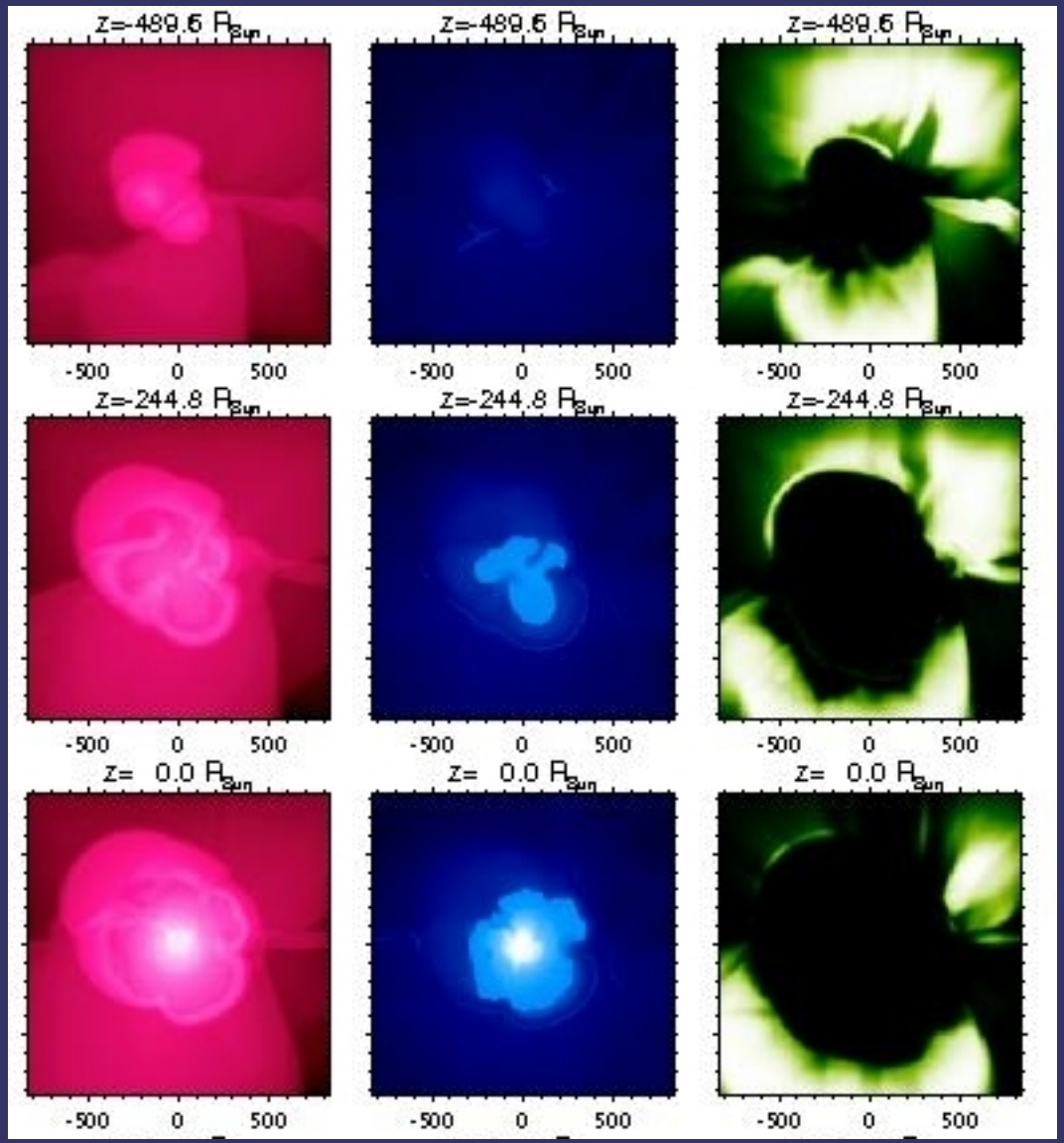
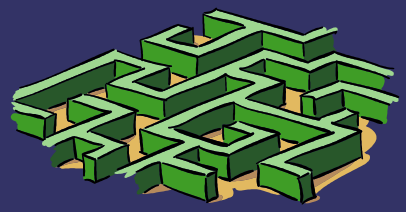


density temperature dust

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

tomography of
star & envelope

Freytag & Höfner
(in preparation)



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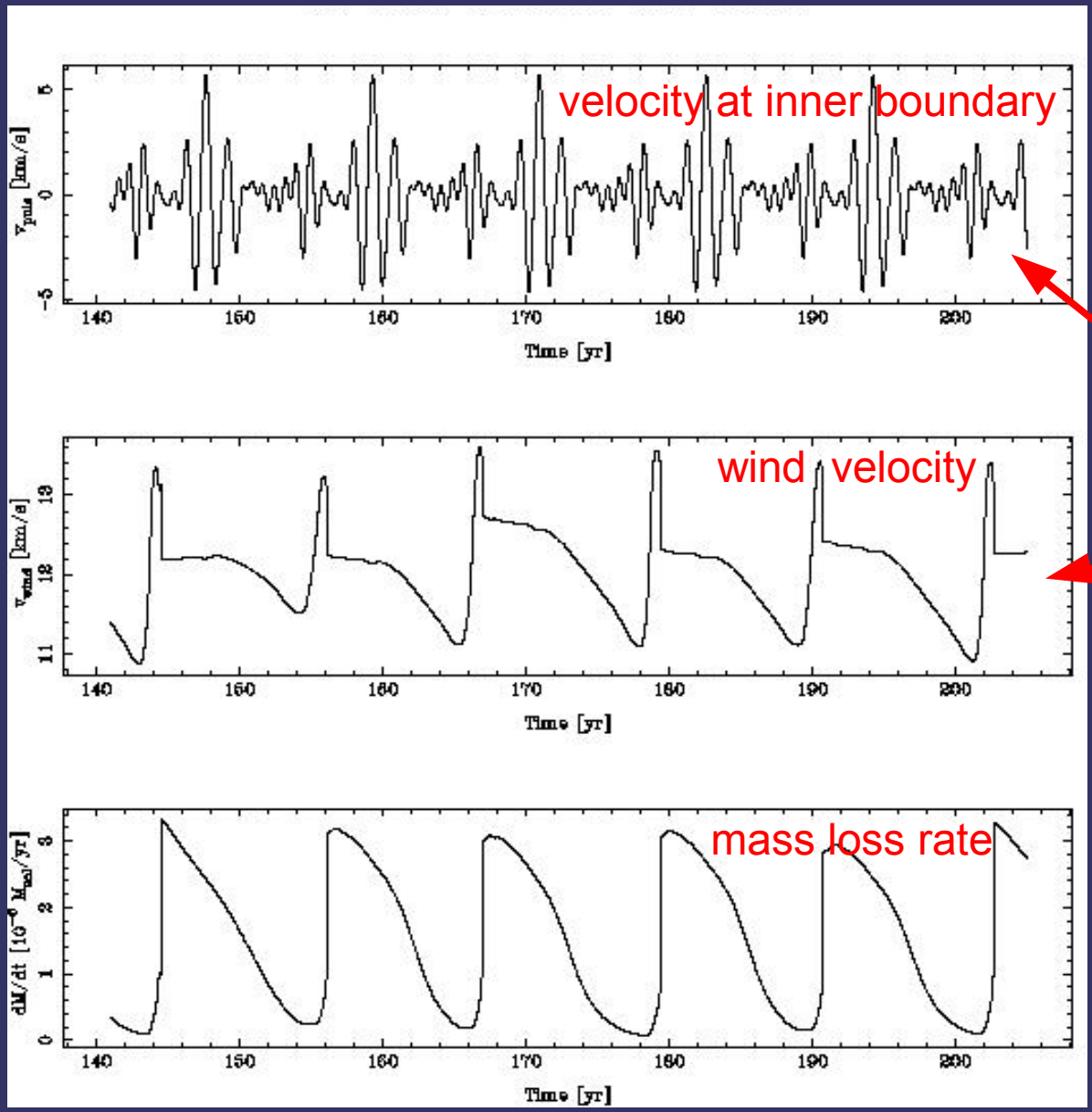

3D star-in-a-box:
convection
dust formation

boundary condition
for 1D wind

Freytag & Höfner
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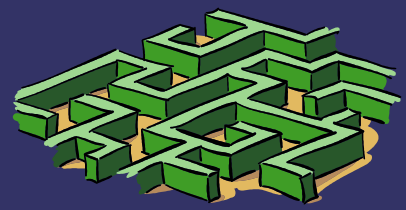

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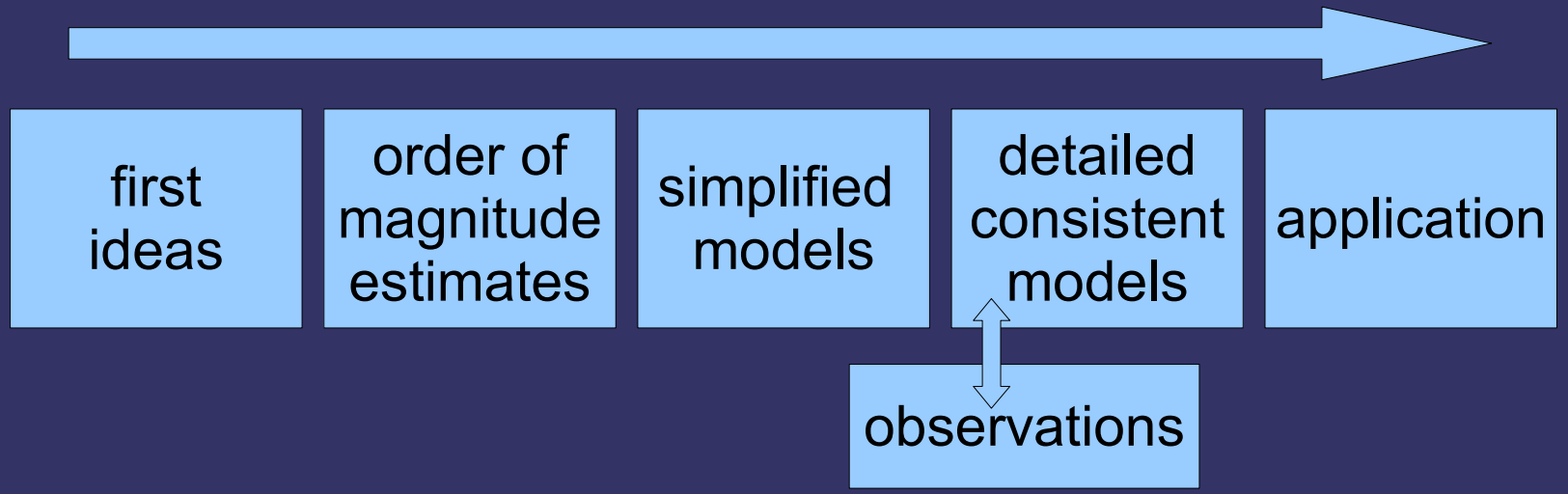
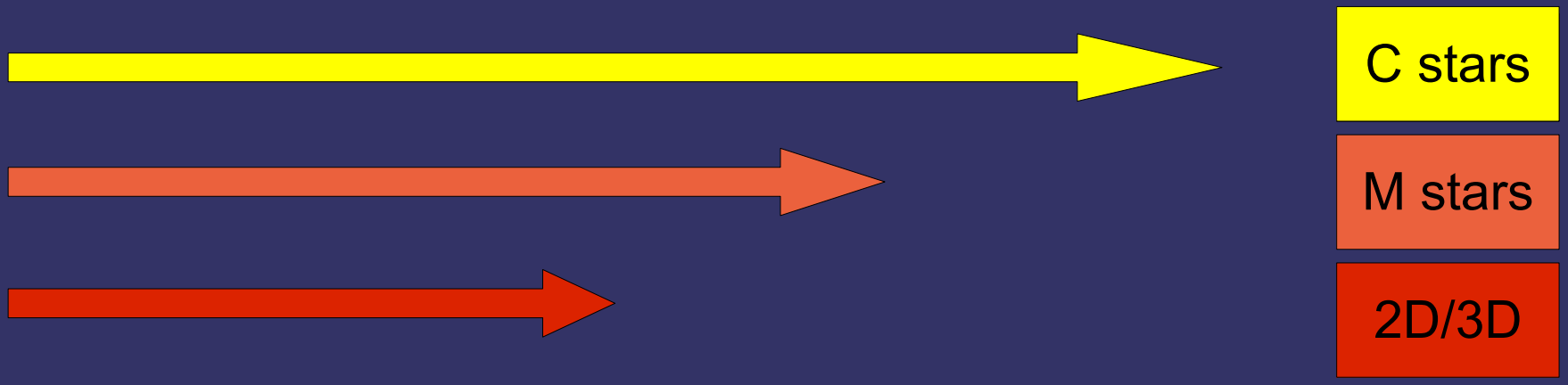
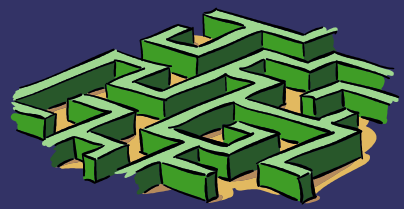
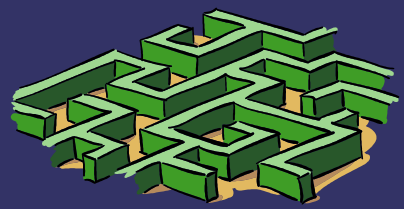




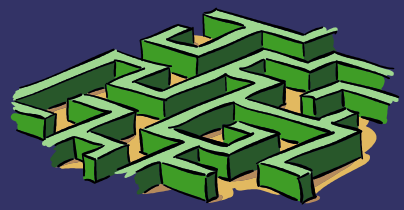


Target audience ?



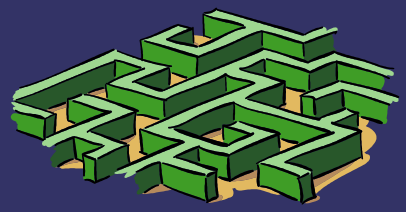
Target audience ?

actual audience
(estimated)



What can observers do?

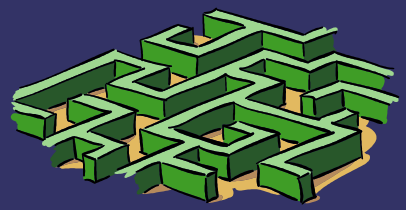
- Pinning down conditions in atmosphere and wind formation zone
  - $\rightarrow$ mass loss mechanism
  - $\rightarrow$ input for models
- Giving constraints for checking models
  - spectra, visibilities
  - velocities



Key word: high resolution

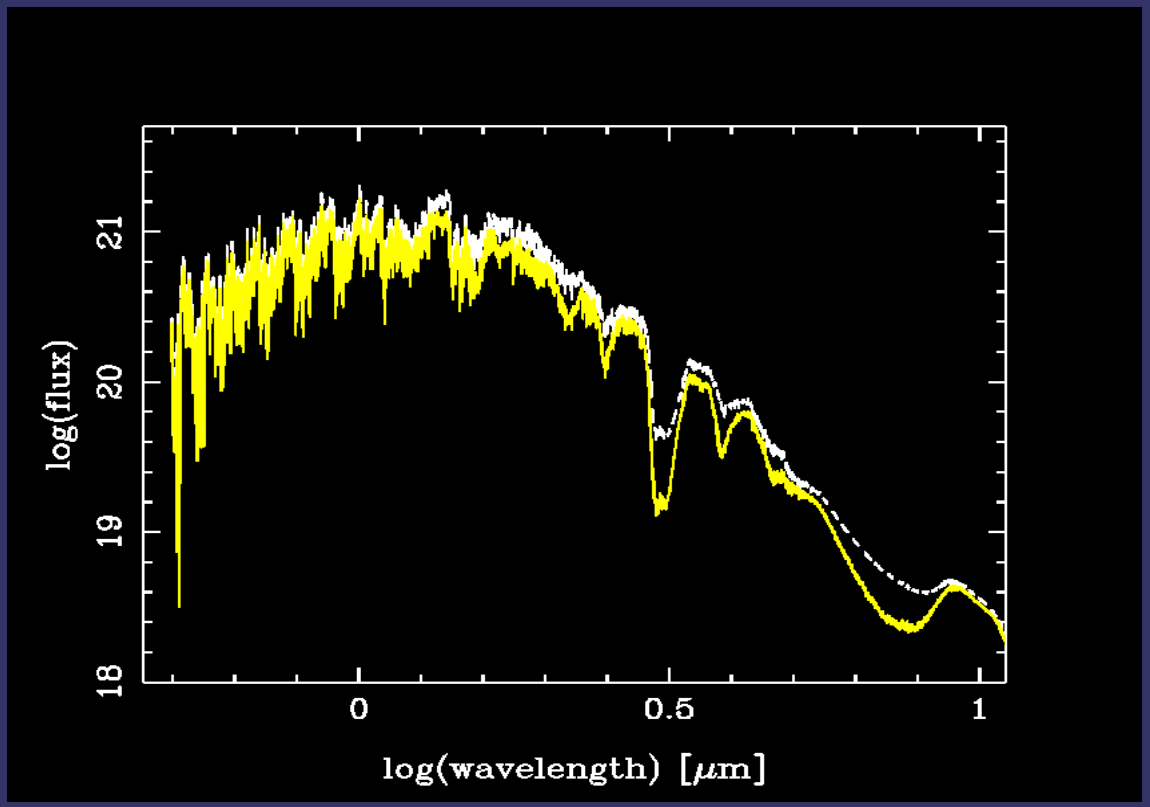
- Spatial structures:
  radial gradients, non-spherical effects

- Spectroscopy:
  - direct access to dynamics
  - separating processes / layers



Key word: variability

Whatever your favorite technique, instrument, object, ...



TIME SERIES!