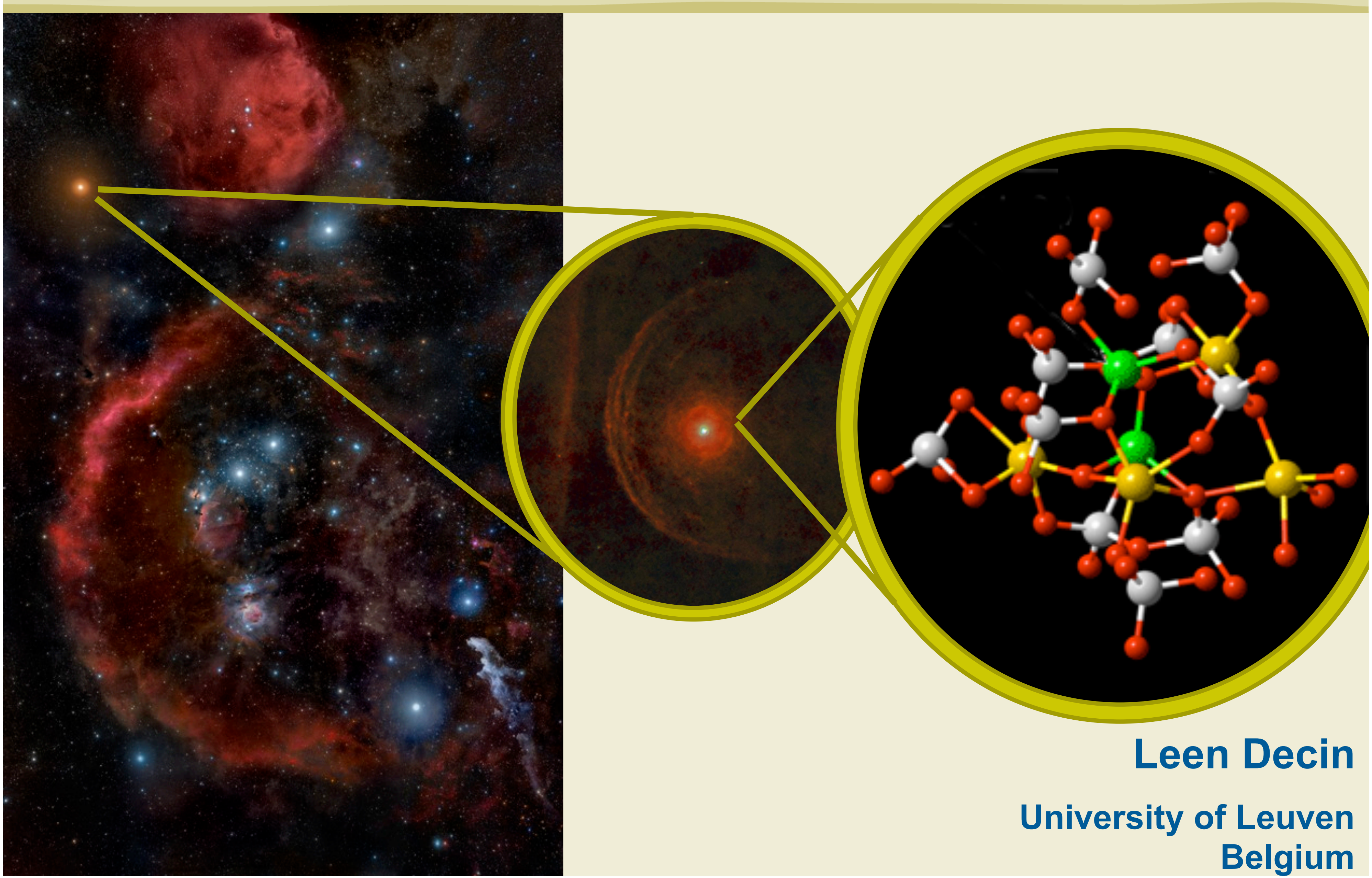
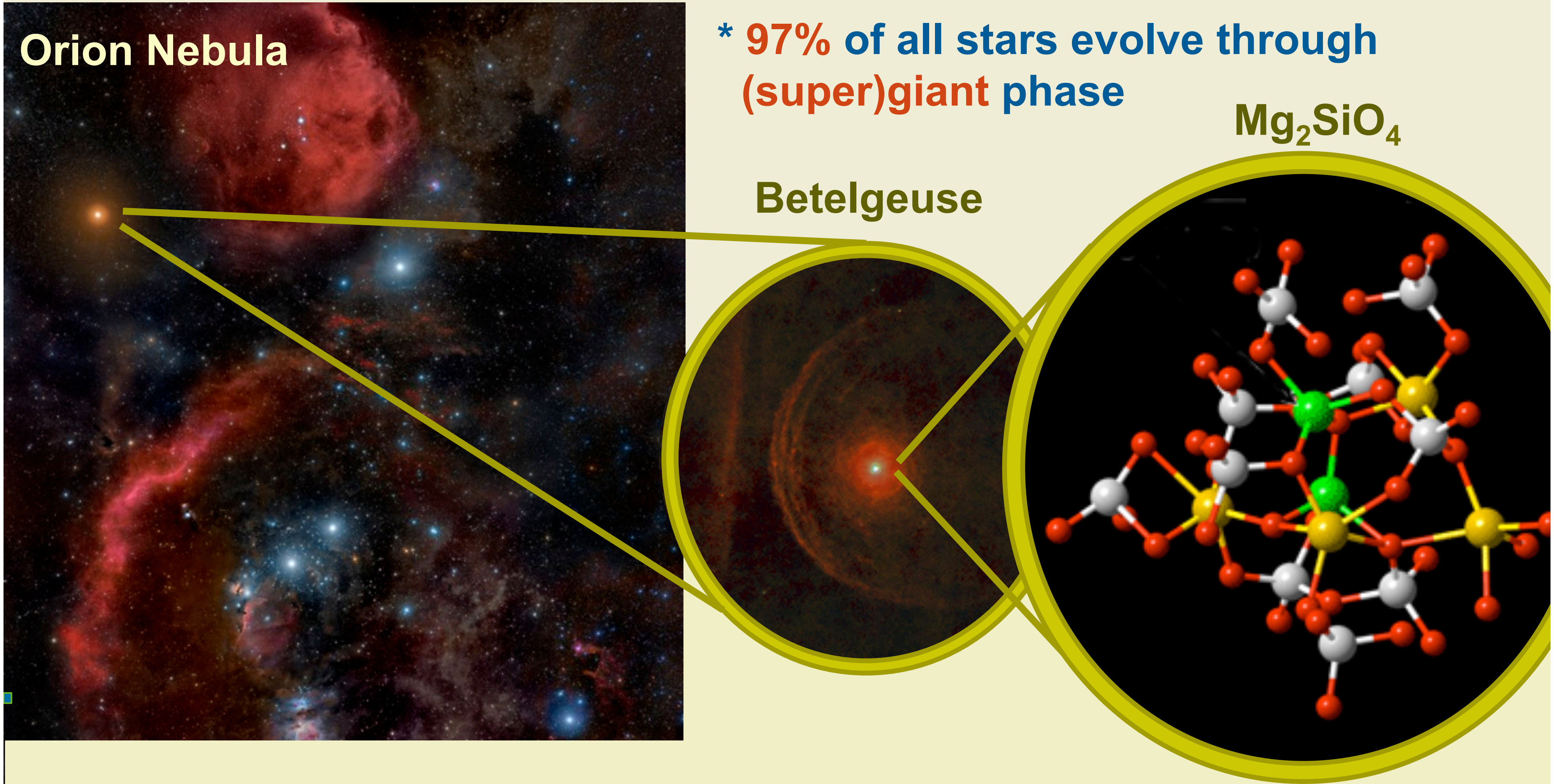
Chemical enrichment of the Interstellar Medium through the Mass Loss of Evolved Stars



Leen Decin

University of Leuven
Belgium

1. Introduction



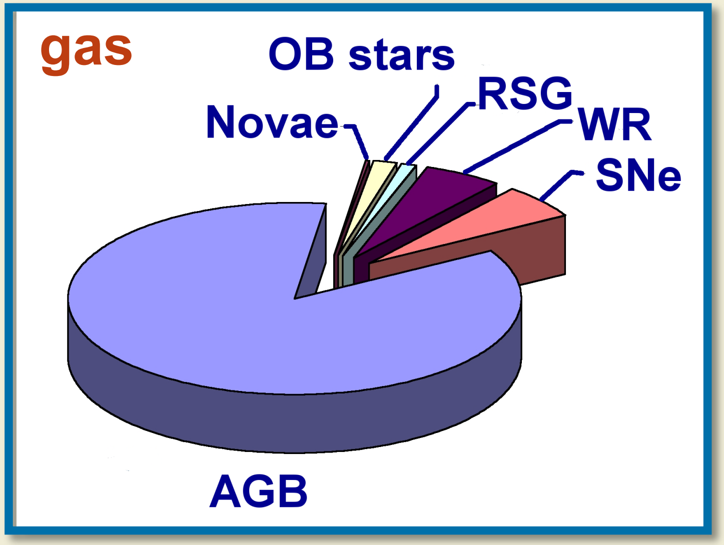
* 97% of all stars evolve through (super)giant phase

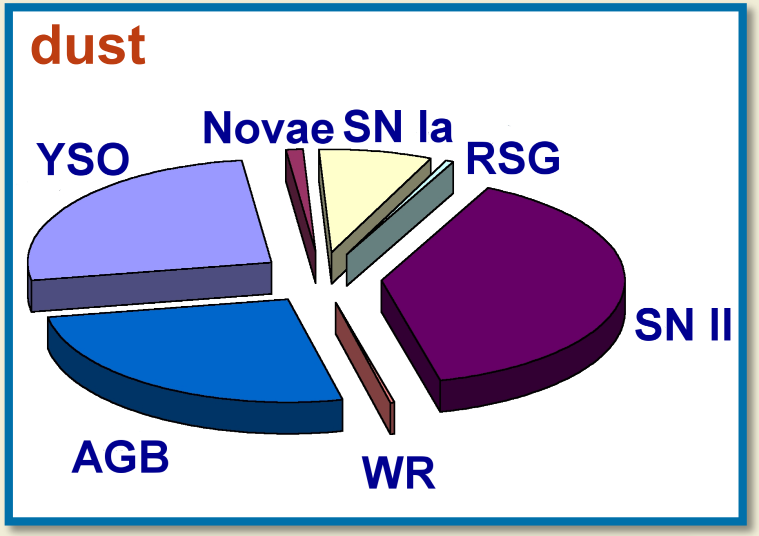
* old giant stars: lose mass via stellar wind

* wind: molecules (>70) + dust (>15)
→ unique chemical laboratories

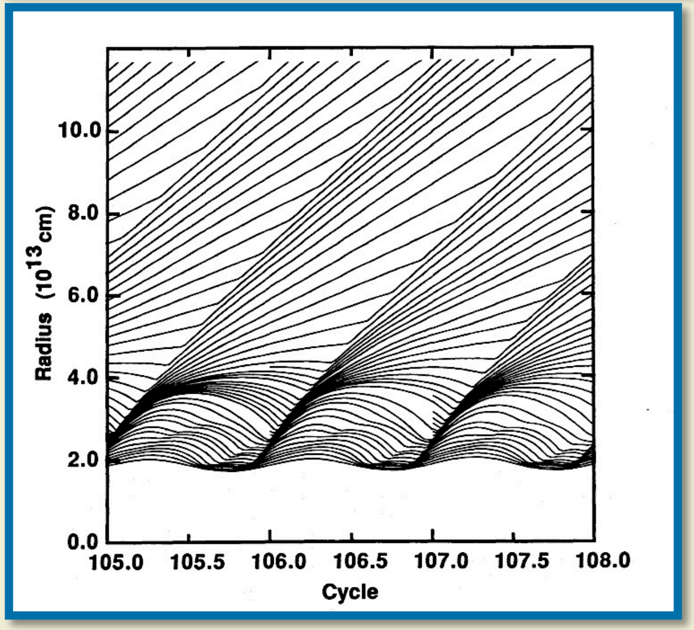
2. Importance (super)giant stars

✓most important sources for enrichment ISM



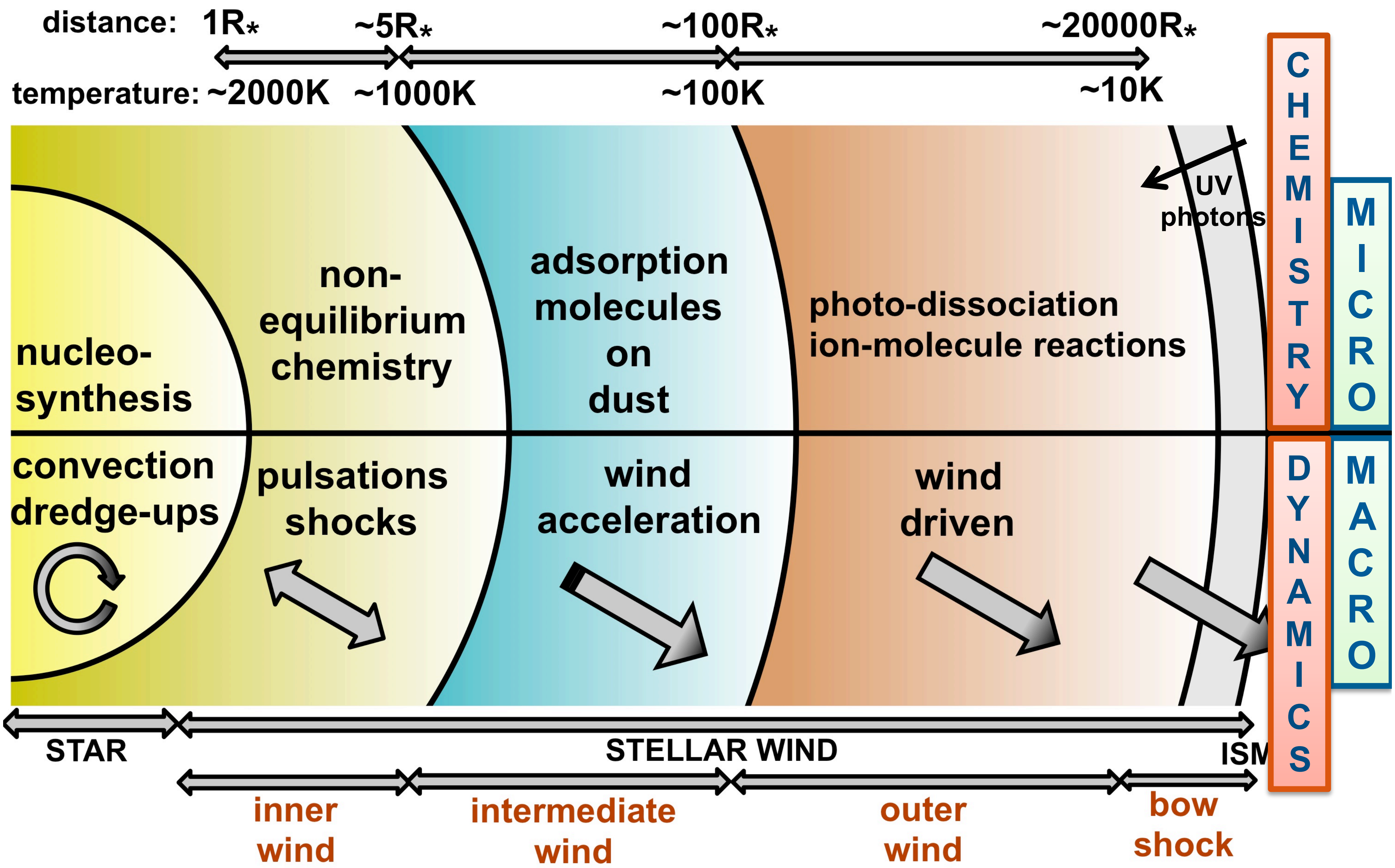


✓dynamically quite `simple'
molecules + dust

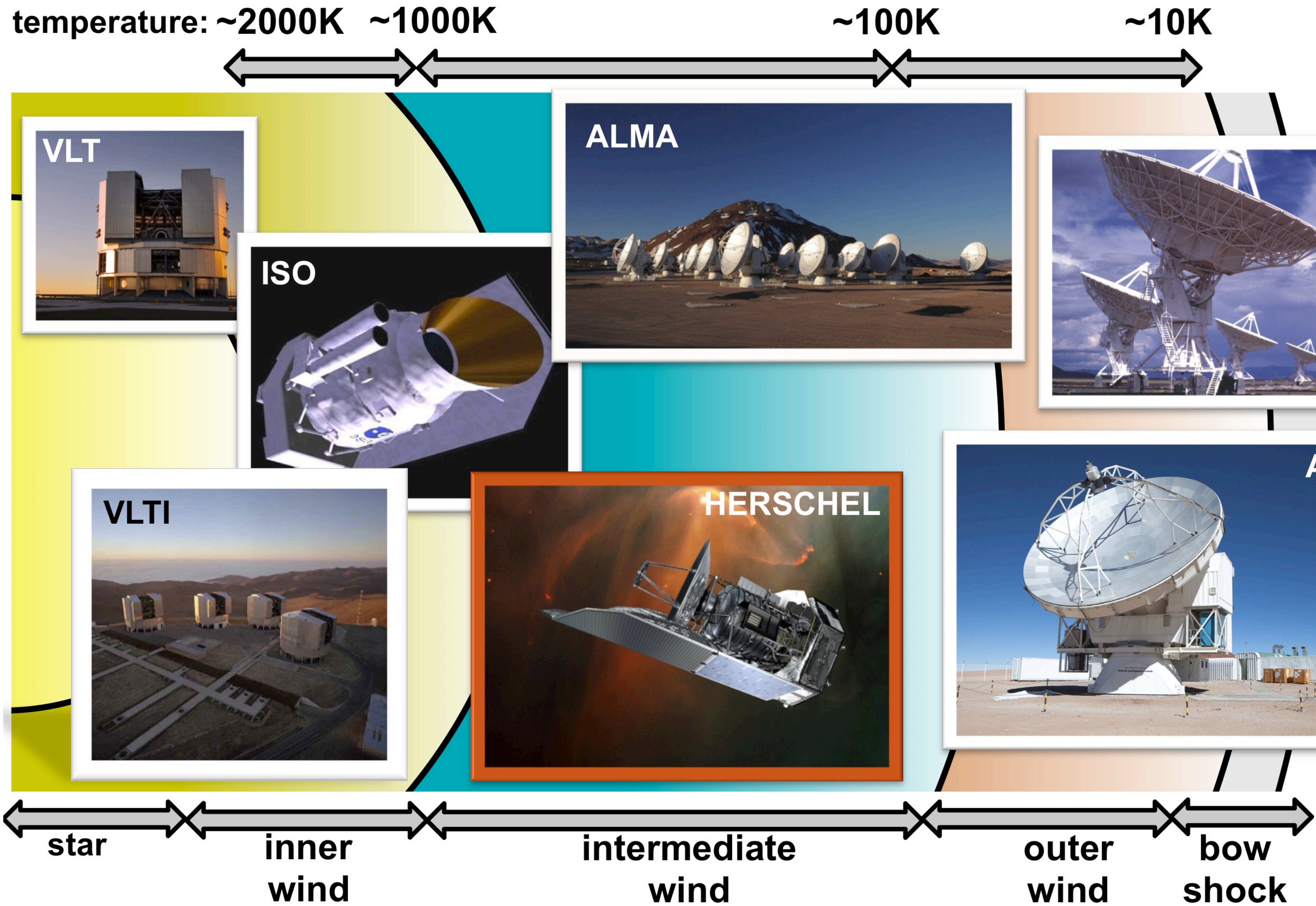


astrochemistry in giant winds → more complex systems

3. Stellar wind: from micro-scale chemistry to macro-scale dynamics



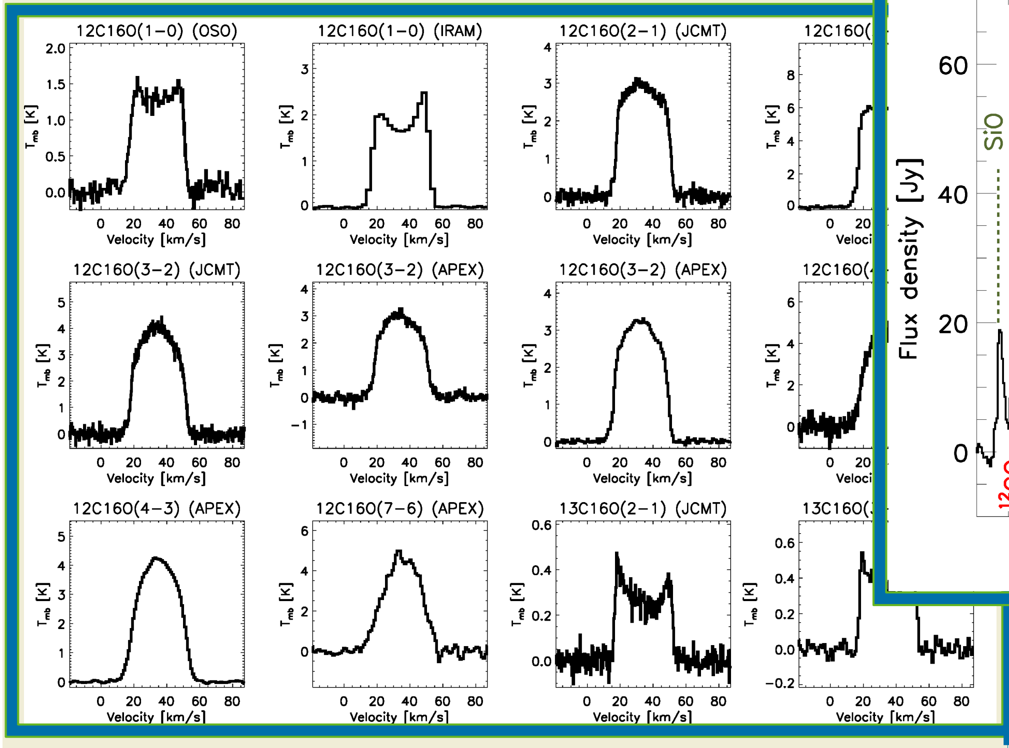
4. Role of Herschel: historical move from 1 to ~50 targets

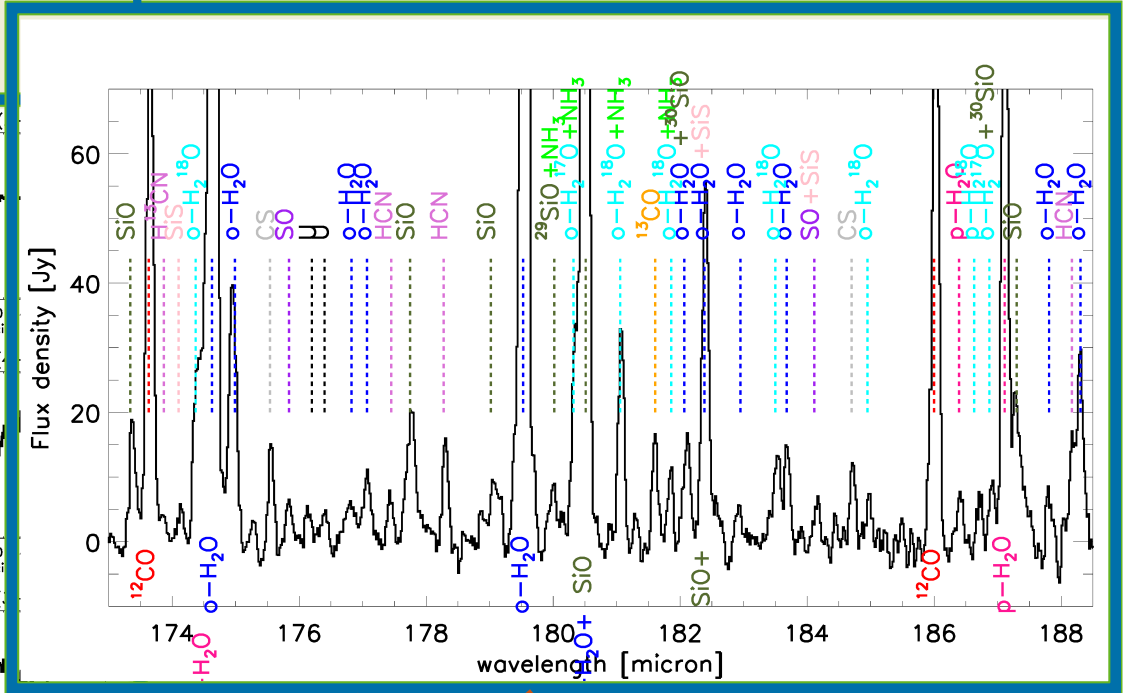


4. Role of Herschel

→ 12 molecular line transitions: ~40hr

→ 930 molecular line transitions: 2hr





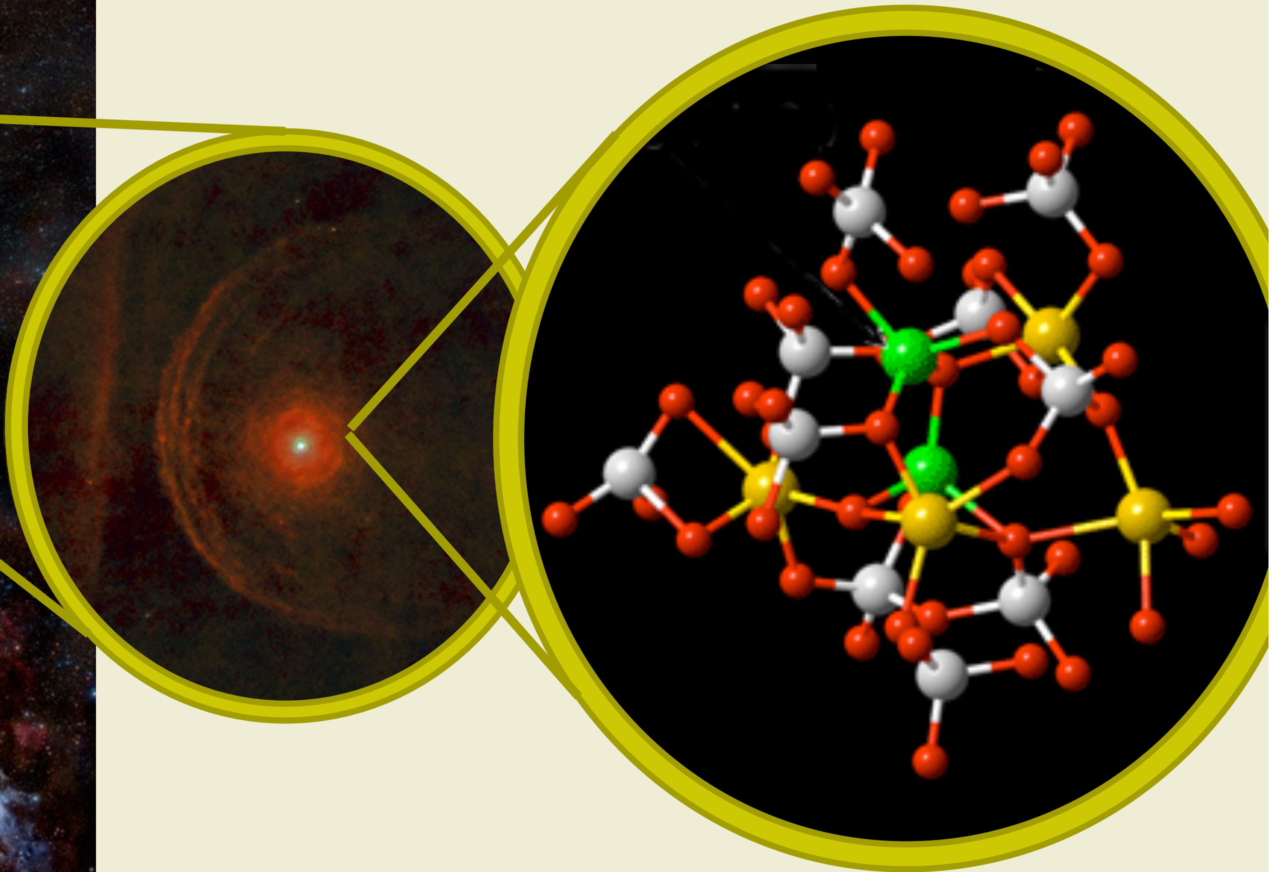
Decin et al. 2010

Royer,Decin et al. 2010

>50 targets

4. Role of Herschel

✓CO, H_2O, HCN, SiO, OH, SiS, C_2H, …
✓Mg_2SiO_4, …



4. Role of Herschel: H_2O

✓CO, H_2O, HCN, SiO, OH, SiS, C_2H, …
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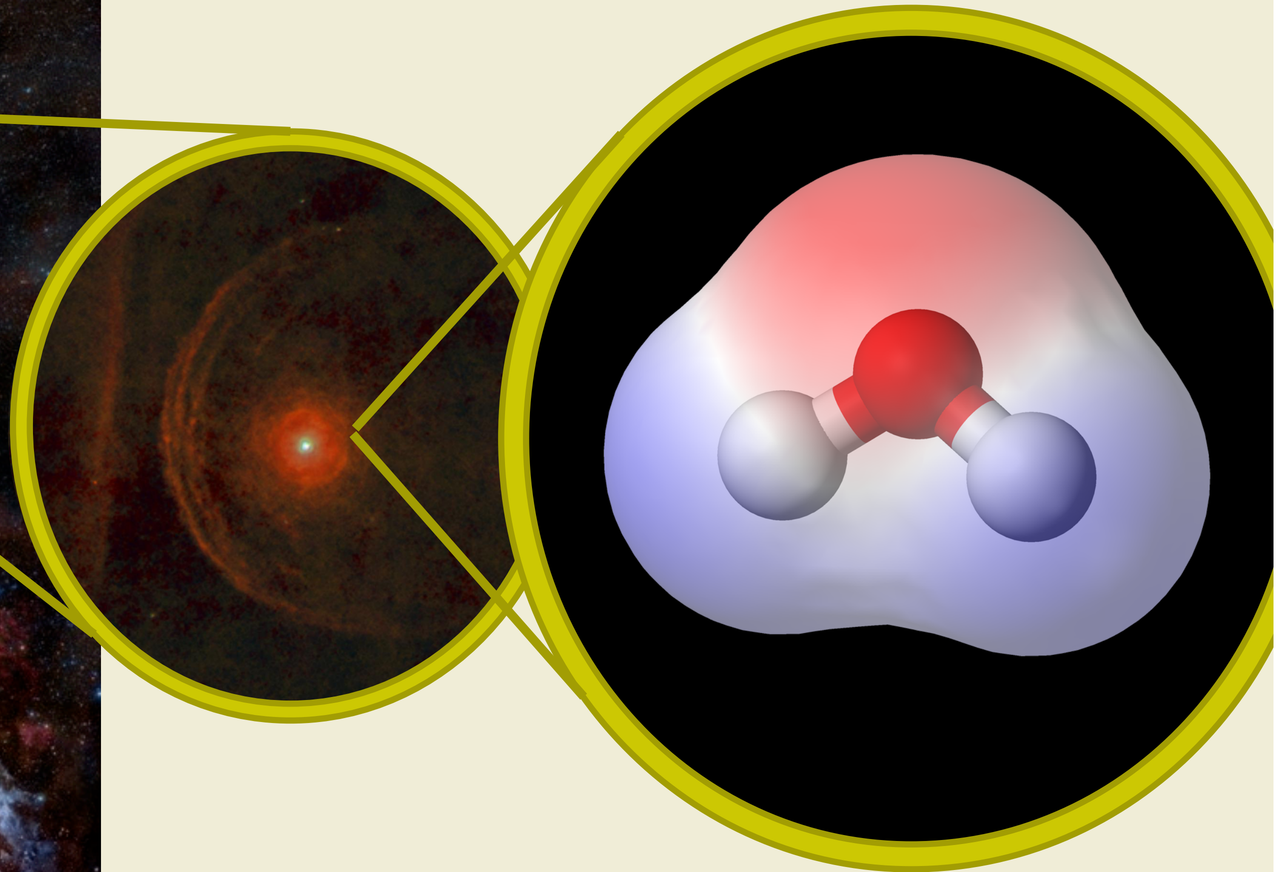


tracer of *all* chemical processes in wind

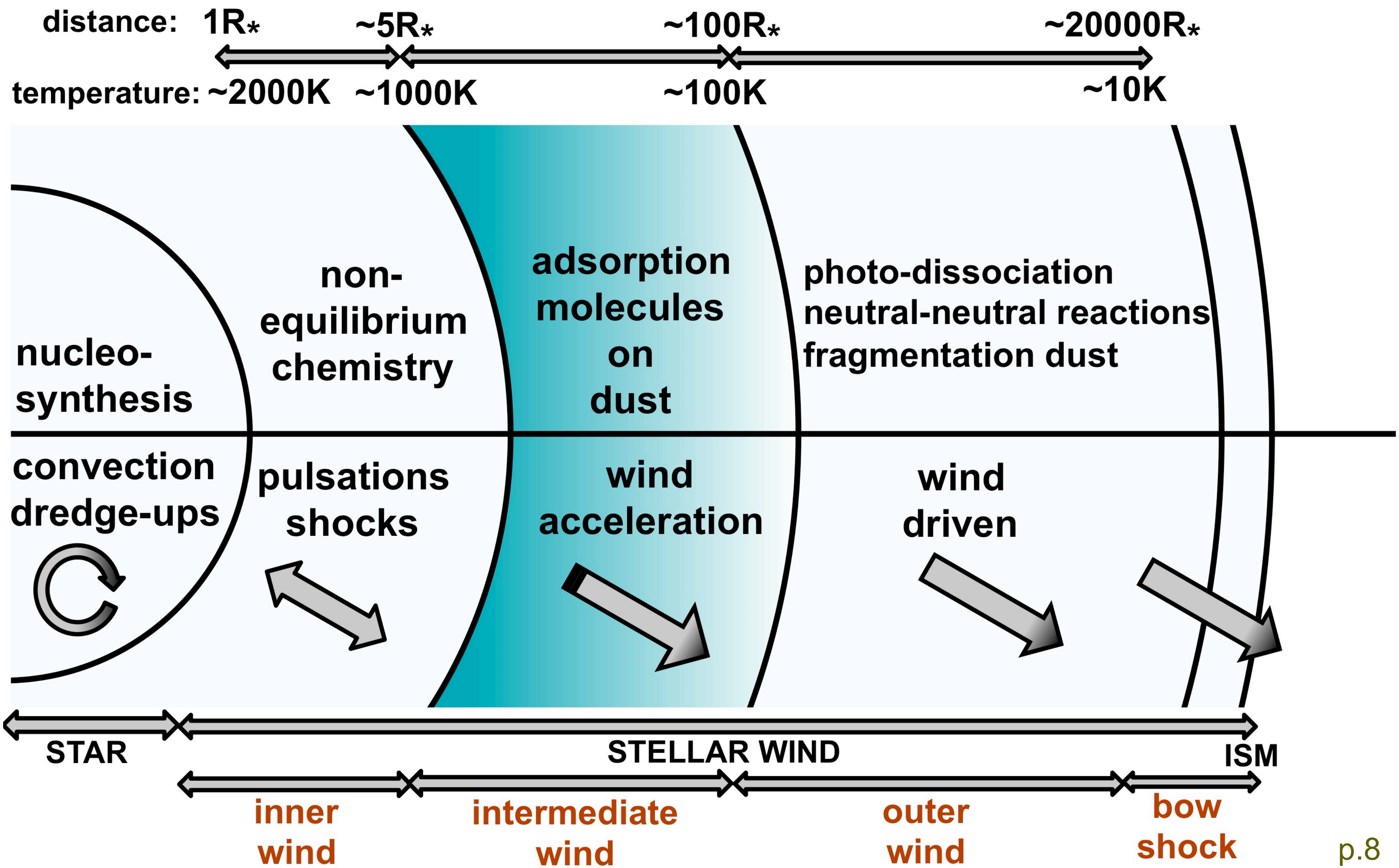
4. Role of Herschel: H_2O

H_2O in oxygen-rich winds (C/O<1)

H_2O in carbon-rich winds (C/O>1)

5. H_2O in oxygen-rich winds

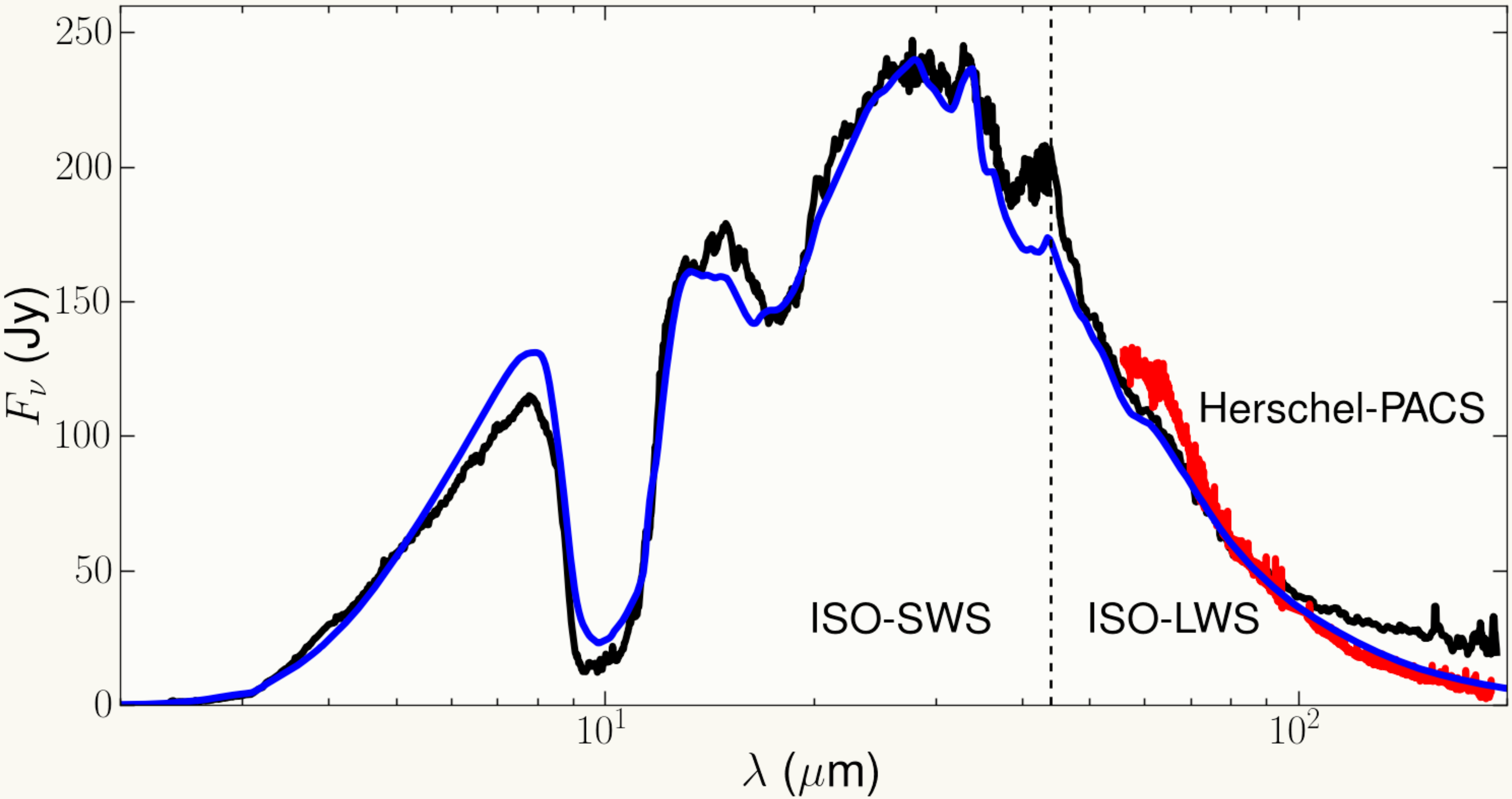
→ Gas-dust interaction



5. H_2O in oxygen-rich winds

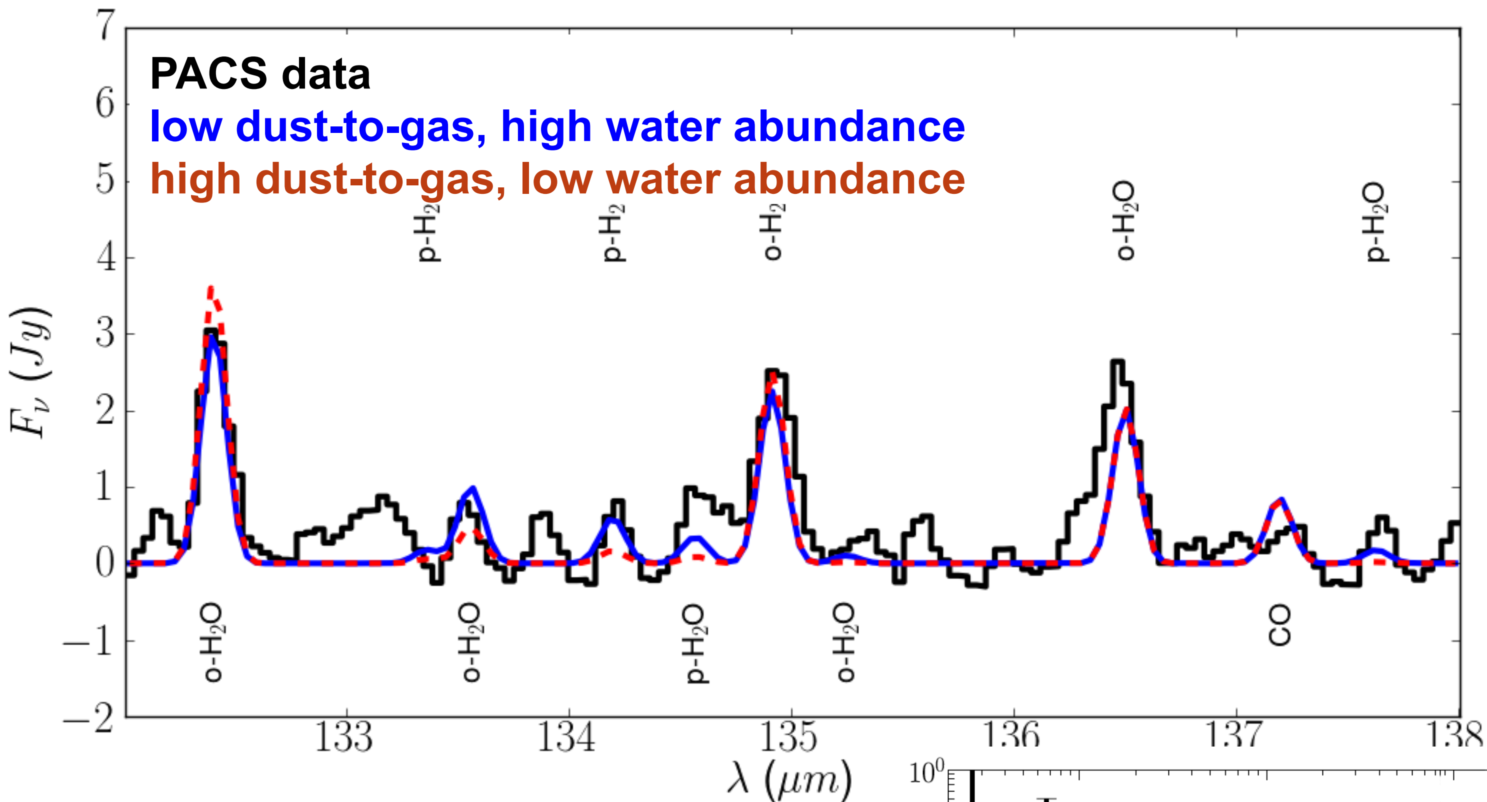
Example 1

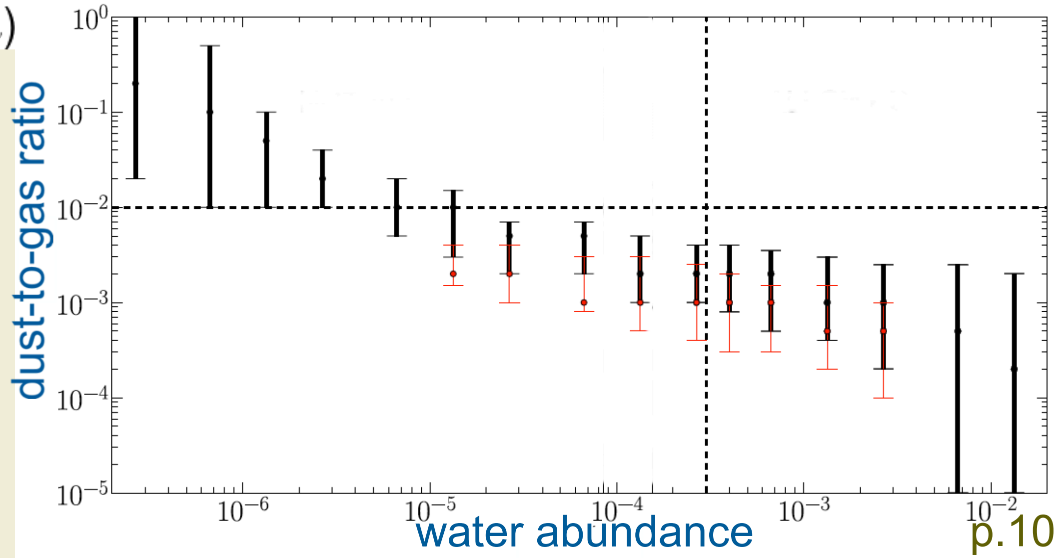
high mass-loss rate: OH/IR 127.8+0.0



Lombaert et al. 2013

5. H_2O in oxygen-rich winds





Lombaert et al. 2013

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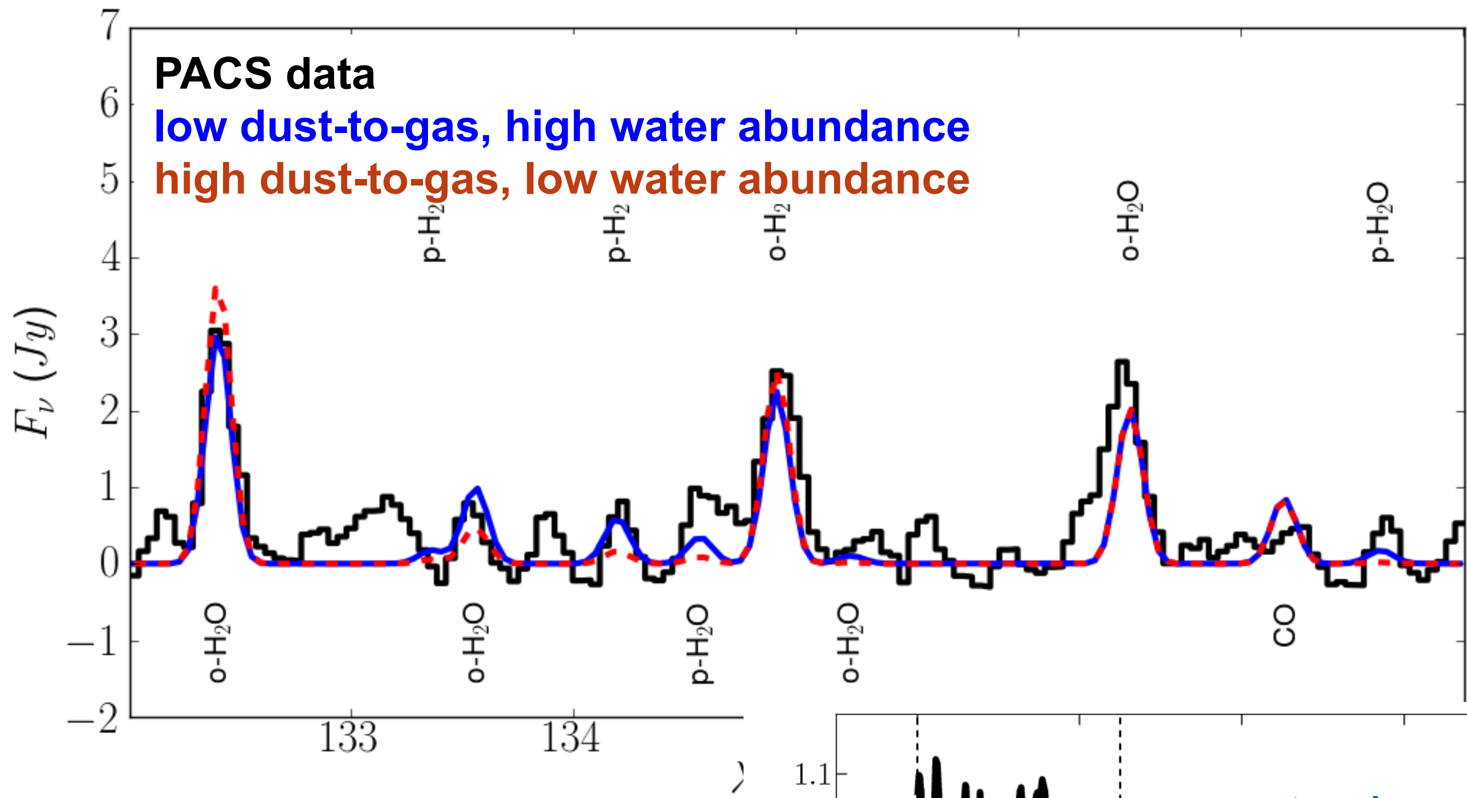
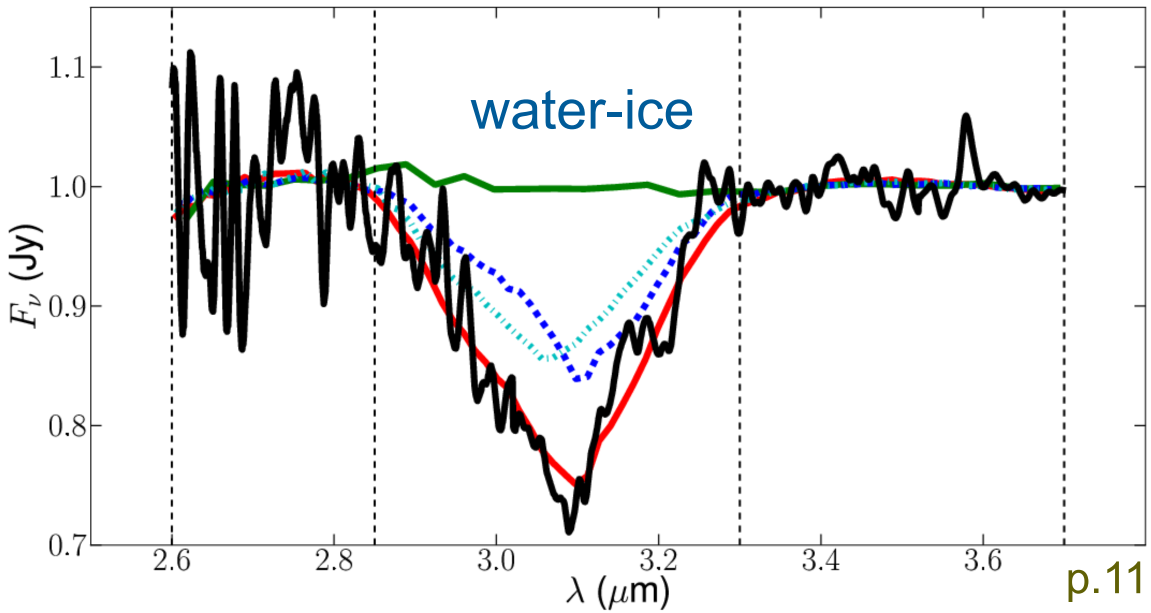
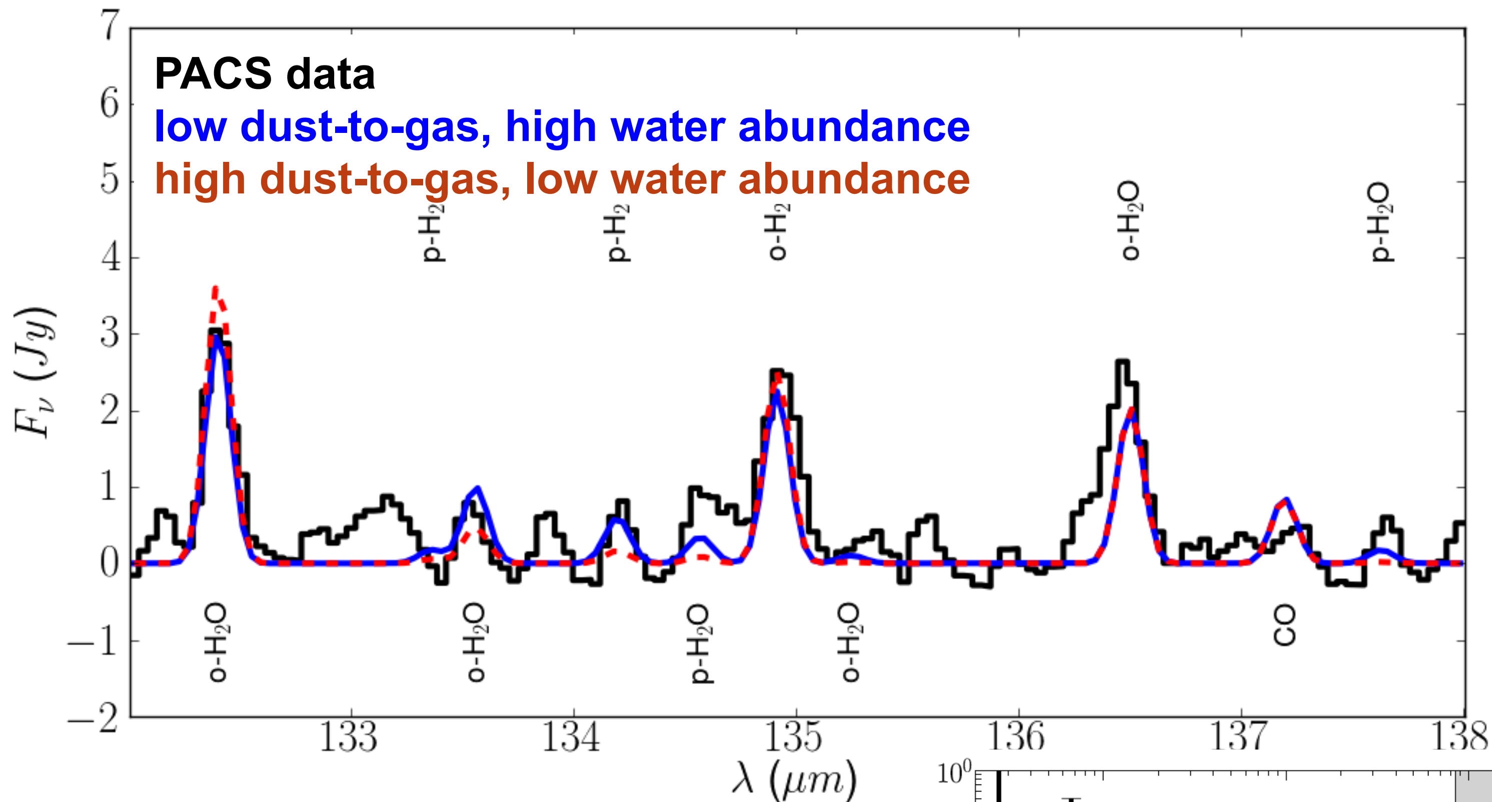




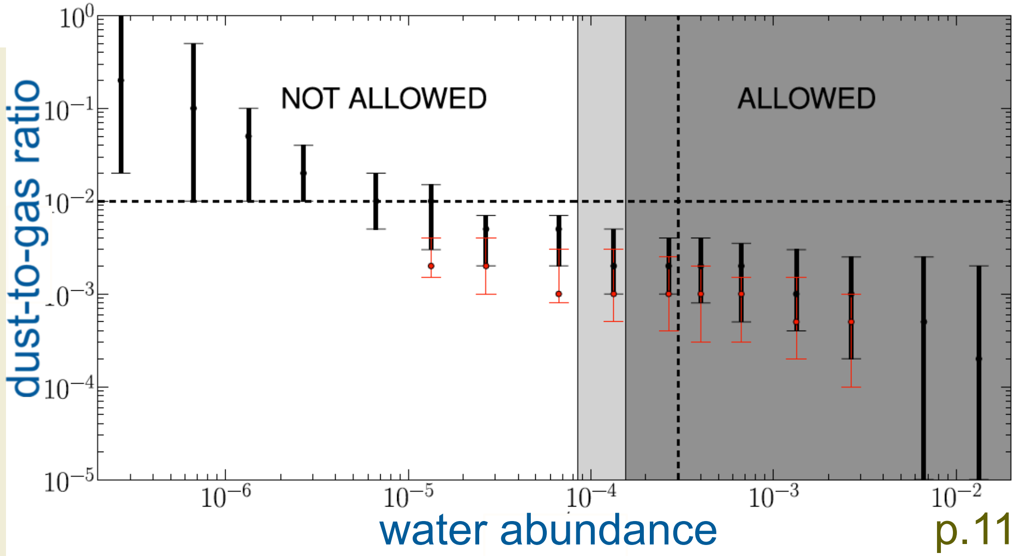
n(H_2O-ice) → n^{min}(H_2O-gas)

Lombaert et al. 2013

5. H_2O in oxygen-rich winds



$n(H_2O\text{-ice}) \rightarrow n^{min}(H_2O\text{-gas})$



Lombaert et al. 2013

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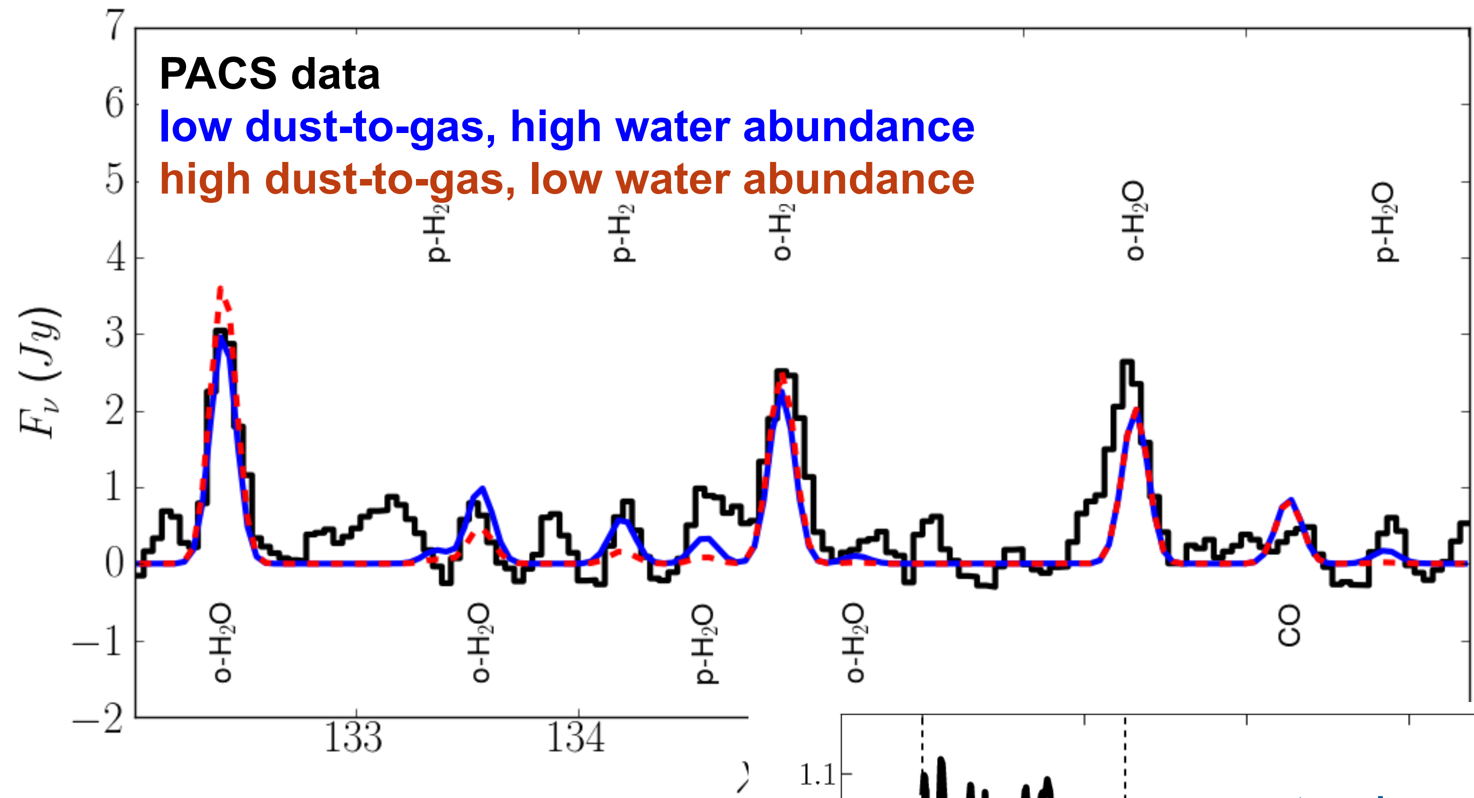
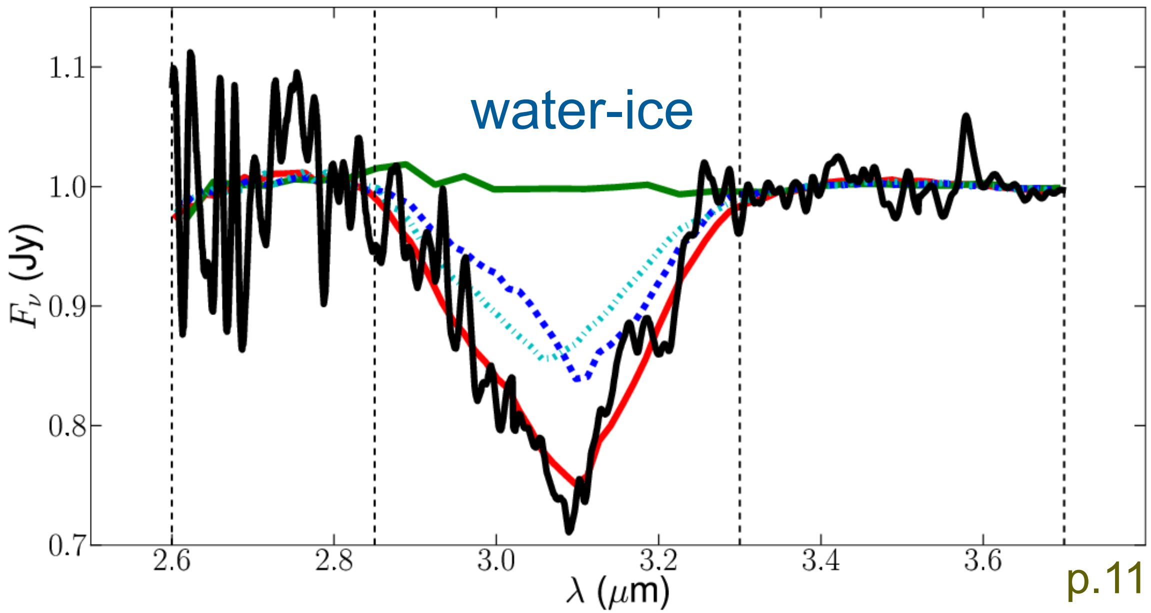




n(H_2O-ice) → n^{min}(H_2O-gas)

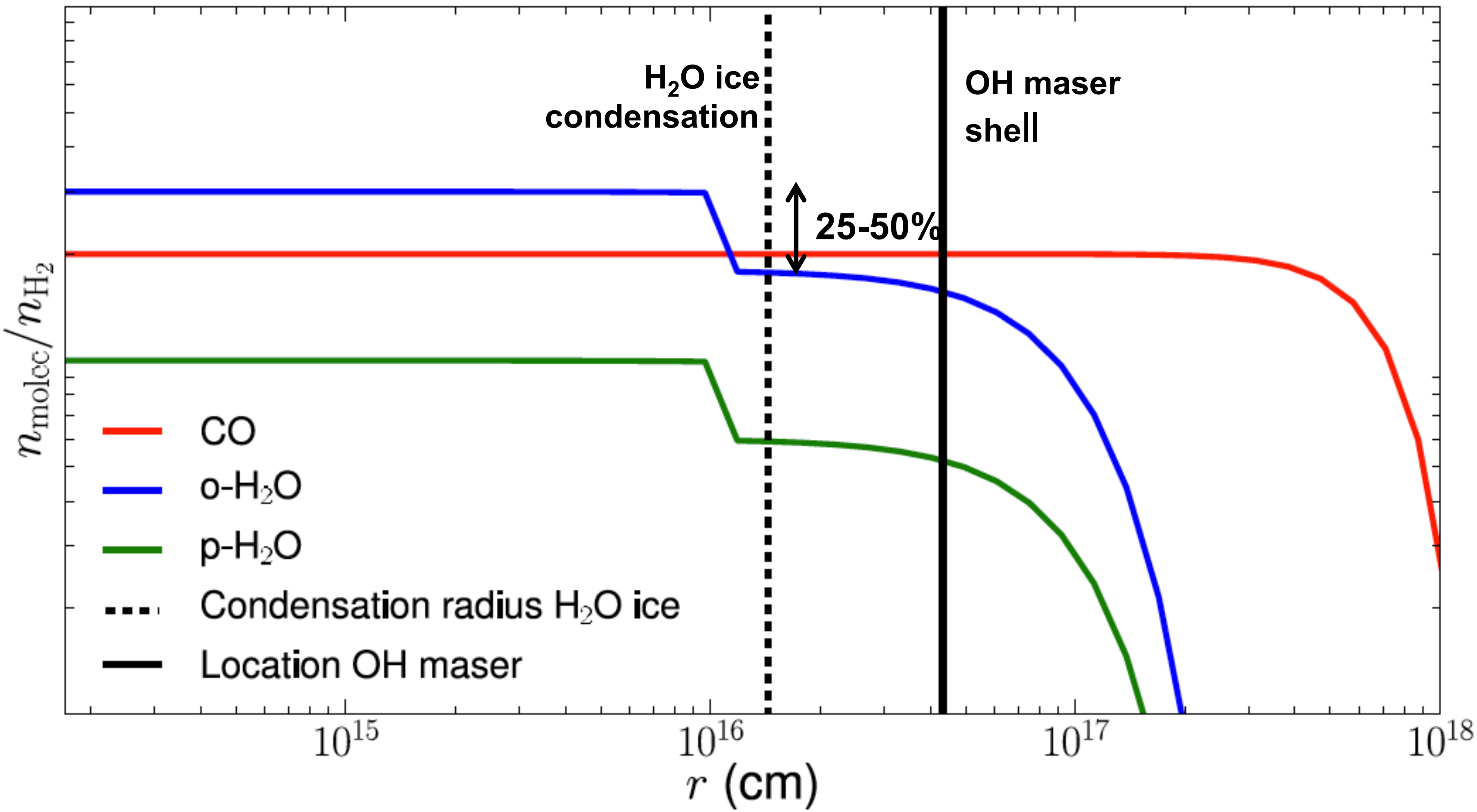
efficiency ice formation?

Lombaert et al. 2013

5. H_2O in oxygen-rich winds

efficiency ice formation? → from OH maser

$H_2O \rightarrow OH+H$



→ **impact on temperature structure (see talk Maercker)**

5. H_2O in oxygen-rich winds

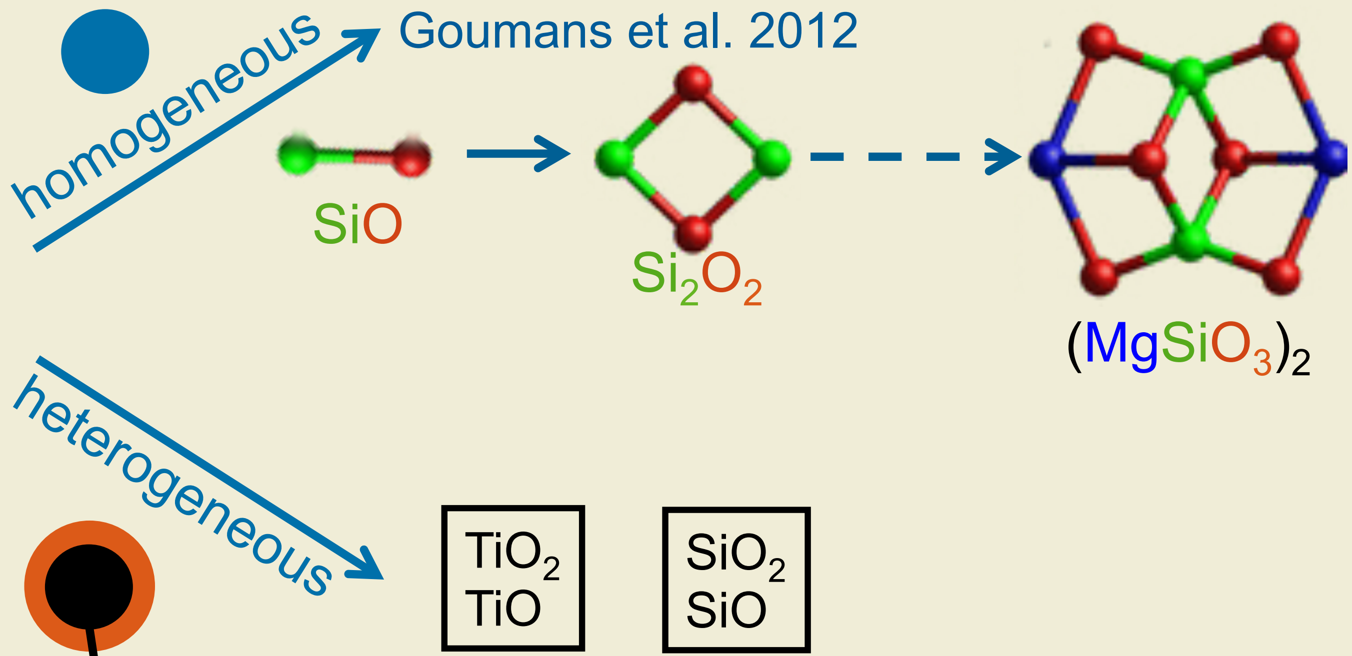
Example 2

atoms ⟹ molecules ⟹ clusters ⟹ dust grains

? nucleation (molecules → clusters)

? condensation (clusters → dust grains)

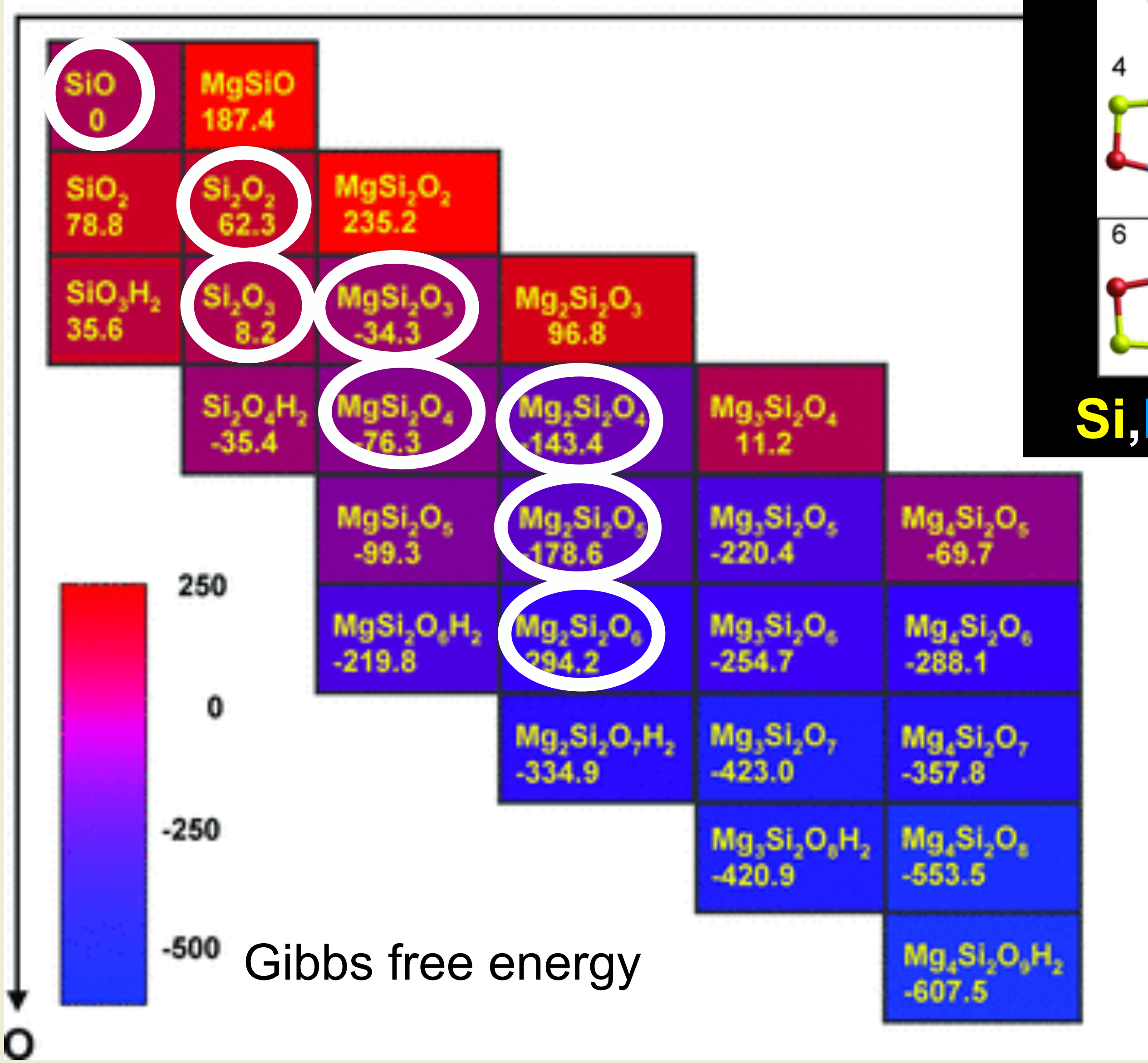
O-rich giants
silicates: $MgSiO_3$, Mg_2SiO_4
alumina: Al_2O_3
silica: SiO_2

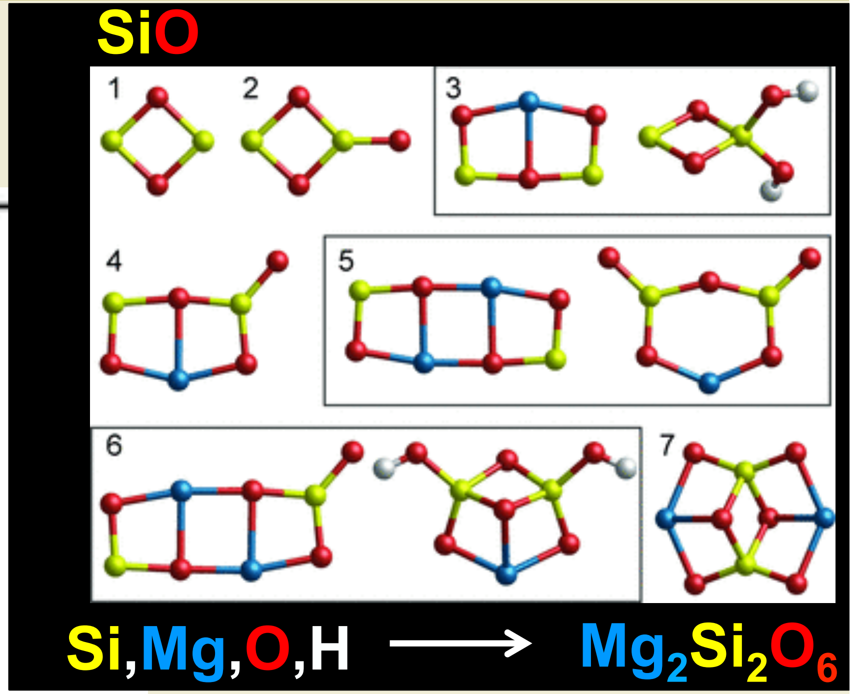


high abundance
high bond energy

5. H_2O in oxygen-rich winds

Goumans et al. 2012





enstatite dimer $Mg_2Si_2O_6$

↓

crucial role of H_2O

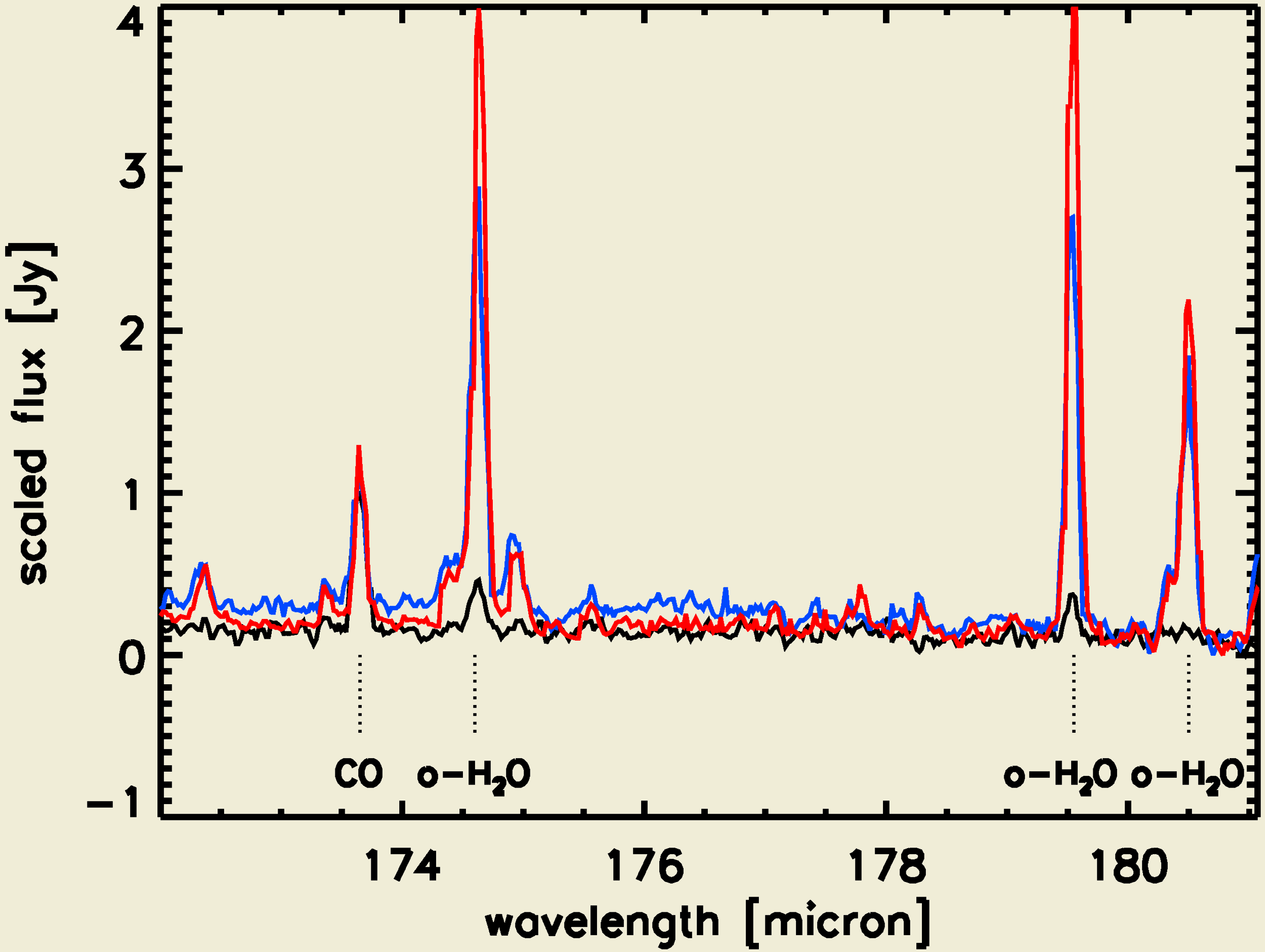
5. H_2O in oxygen-rich winds

Betelgeuse: Mdot ~ $2x10^{-6}$ Msun/yr

NML Cyg: Mdot ~ $1x10^{-4}$ Msun/yr

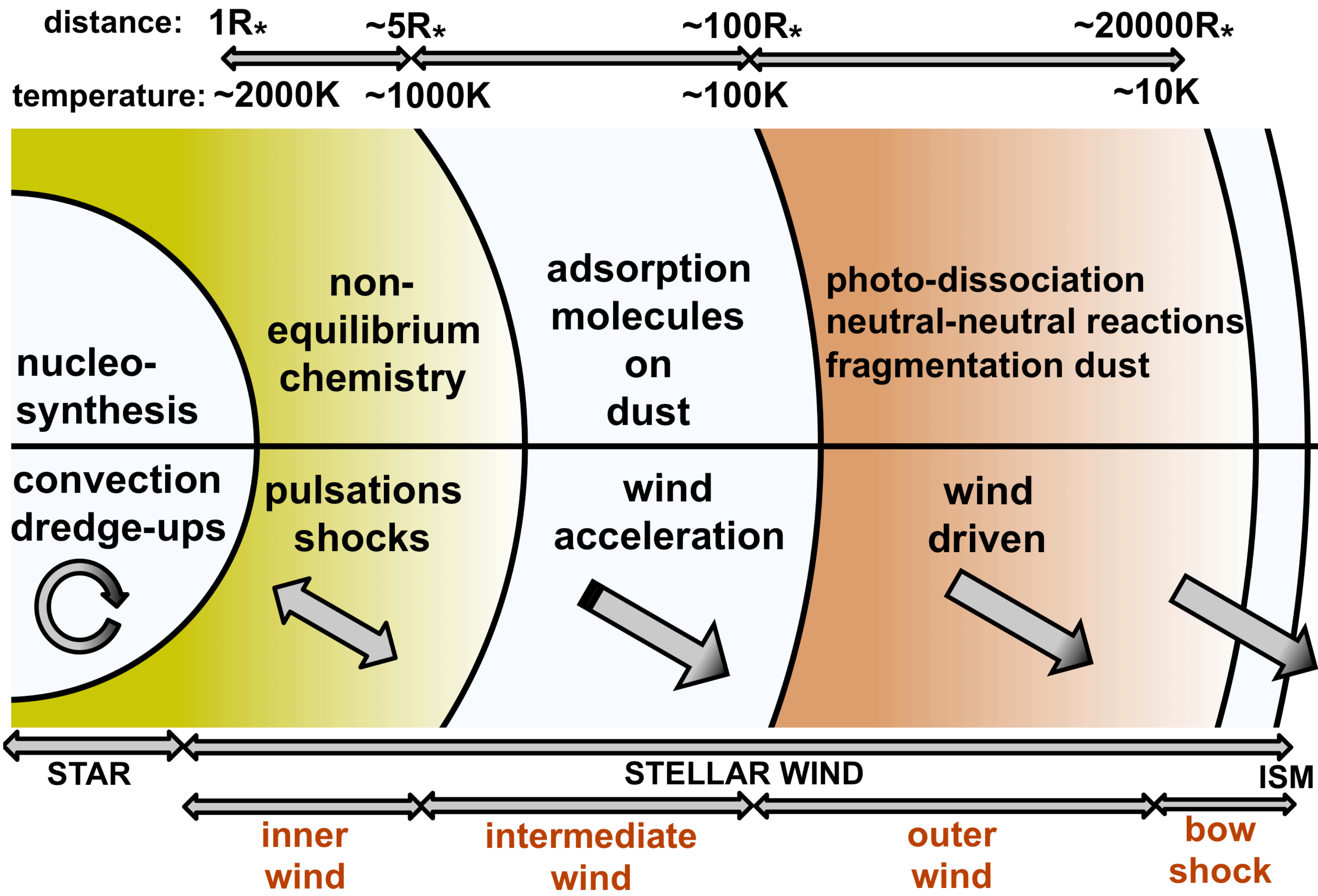
VY CMa: Mdot ~ $3x10^{-4}$ Msun/yr

Role of H_2O



6. H_2O in carbon-rich winds

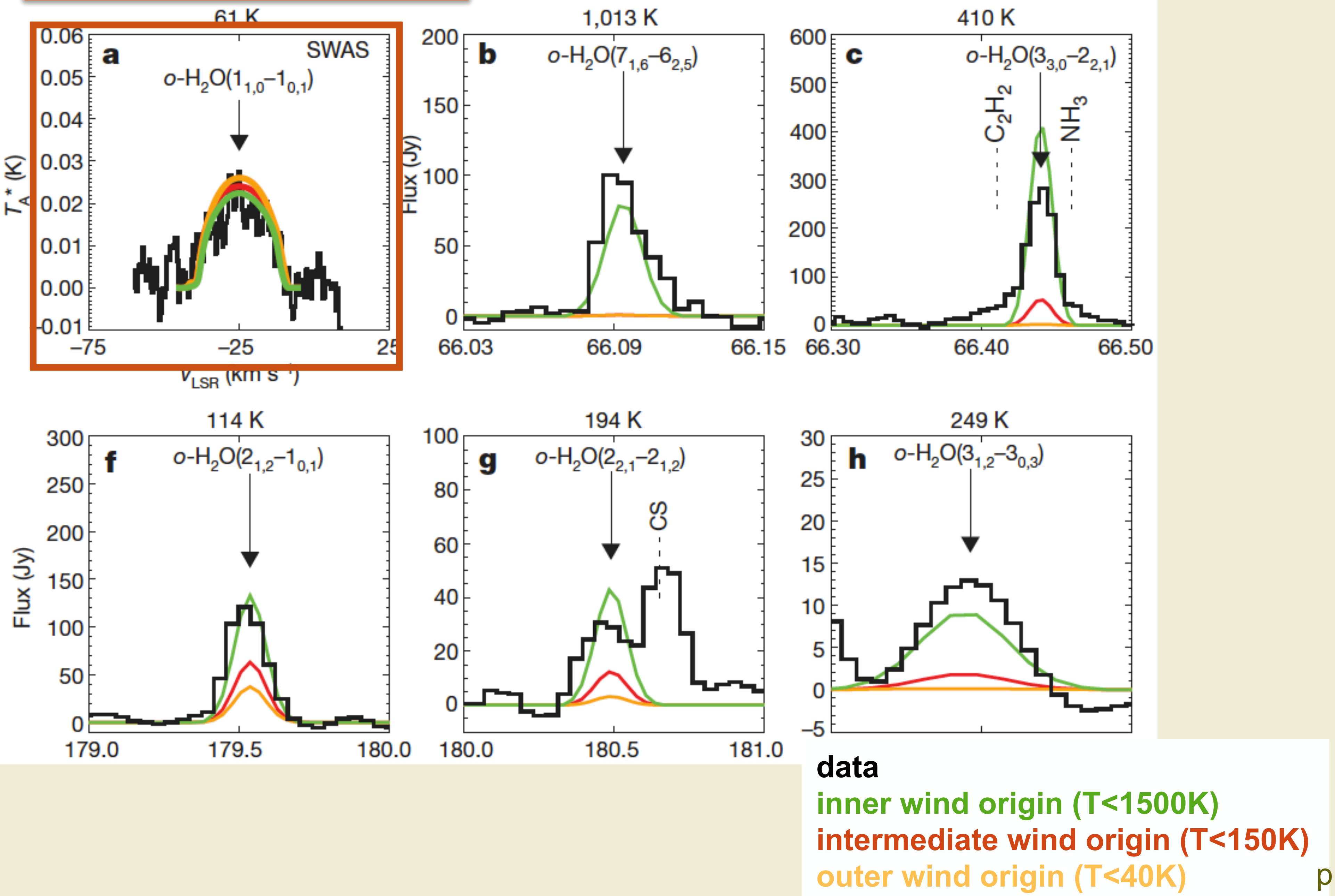
→ Formation of warm H_2O-vapour in the sooty outflow of giant stars



6. H_2O in carbon-rich winds

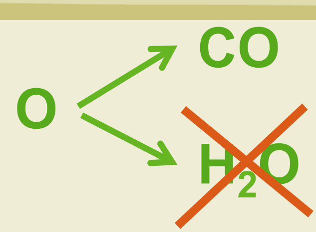
Melnick et al. 2001, Nature

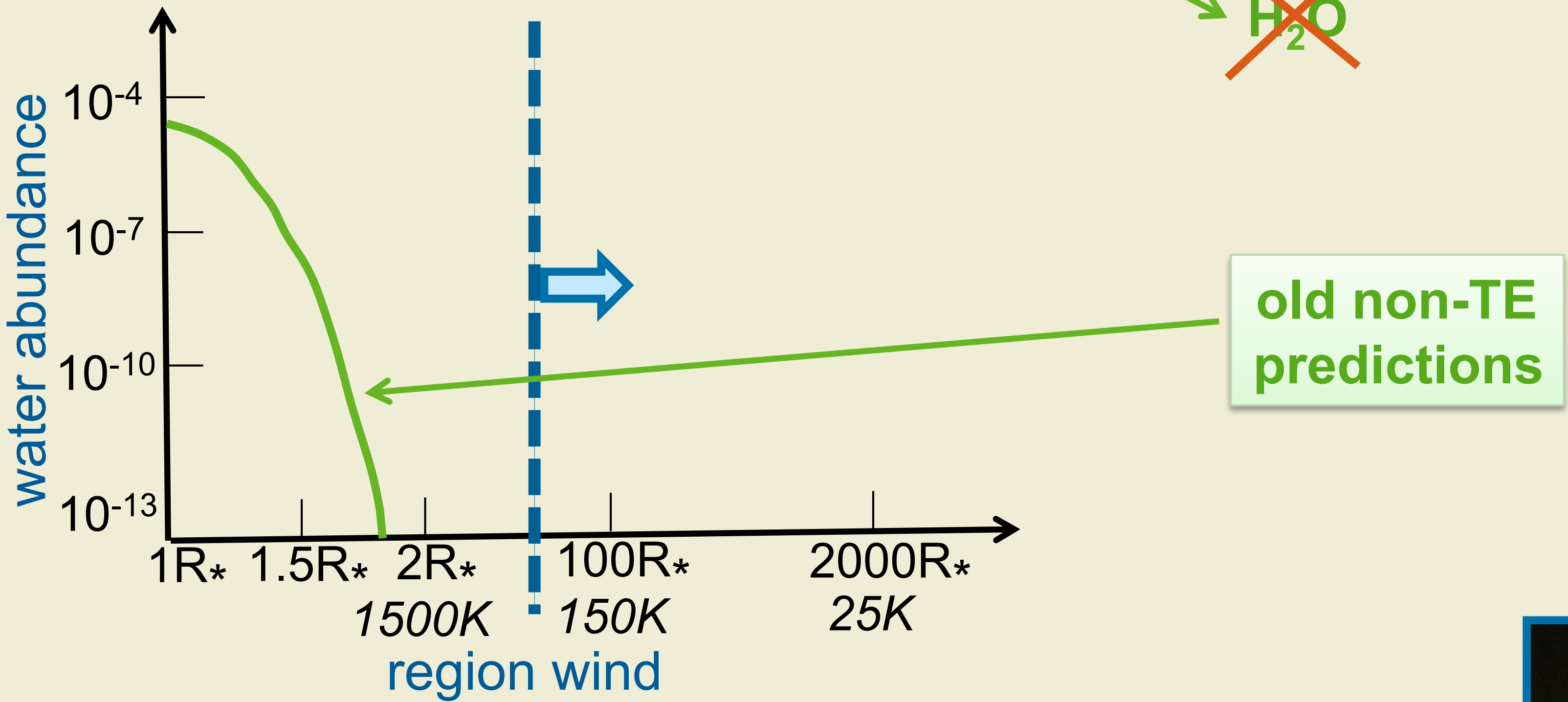
Decin et al. 2010, Nature; Neufeld et al. 2011



6. H_2O in carbon-rich winds: Origin?

→ solving chemical network: no water





Before Herschel: origin (cool) water vapour

(1) ***R>15 R*:*** sublimation of icy bodies (Melnick et al. 2001)

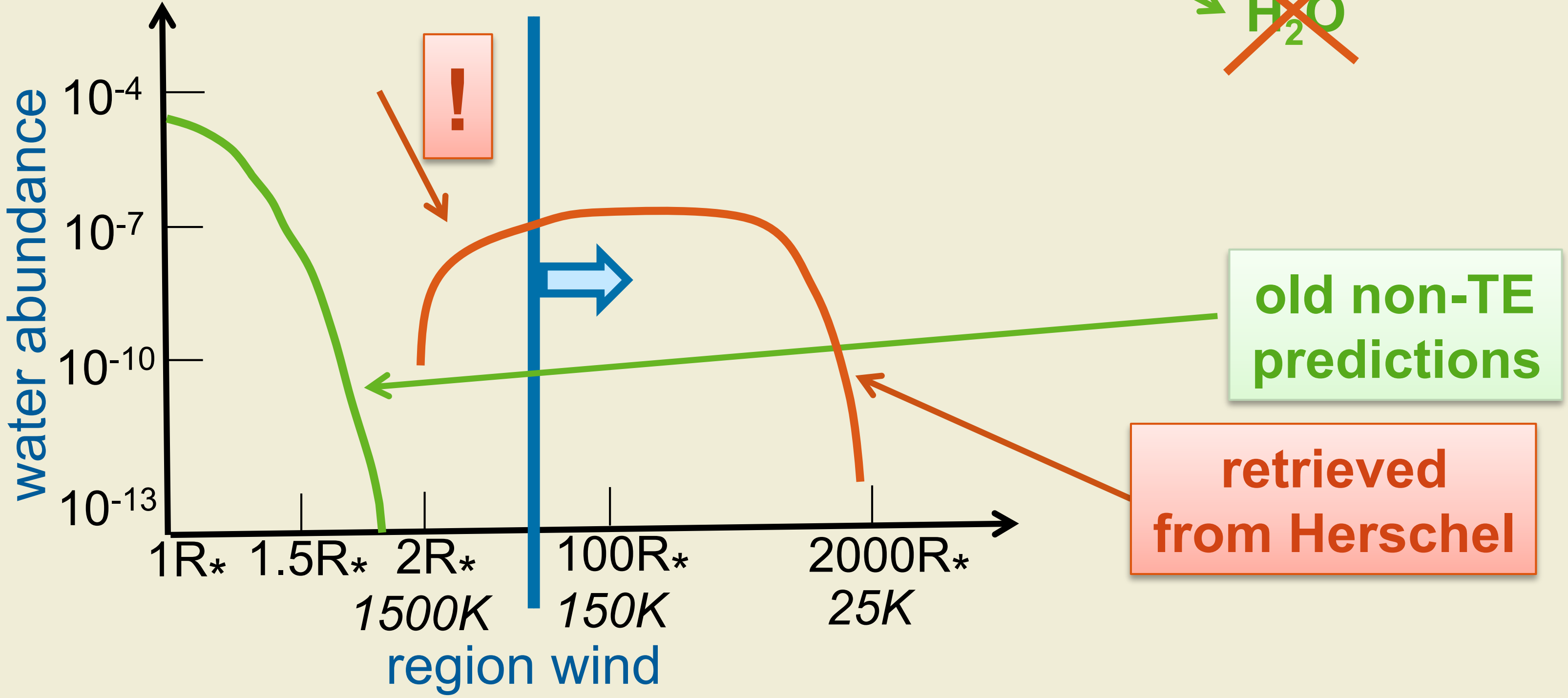
(2) ***R>15 R*:*** grain surface reactions (Fischer-Tropsch catalysis, Willacy 2004)

(3) ***R>150 R*:*** radiative association $O+H_2$ (Agúndez et al. 2006)

6. H_2O in carbon-rich winds: Origin?

→ solving chemical network: no water

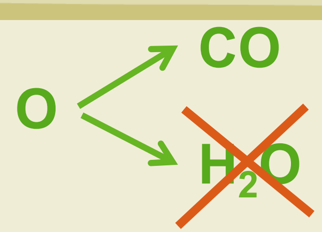
O → CO
O → ~~H_2O~~

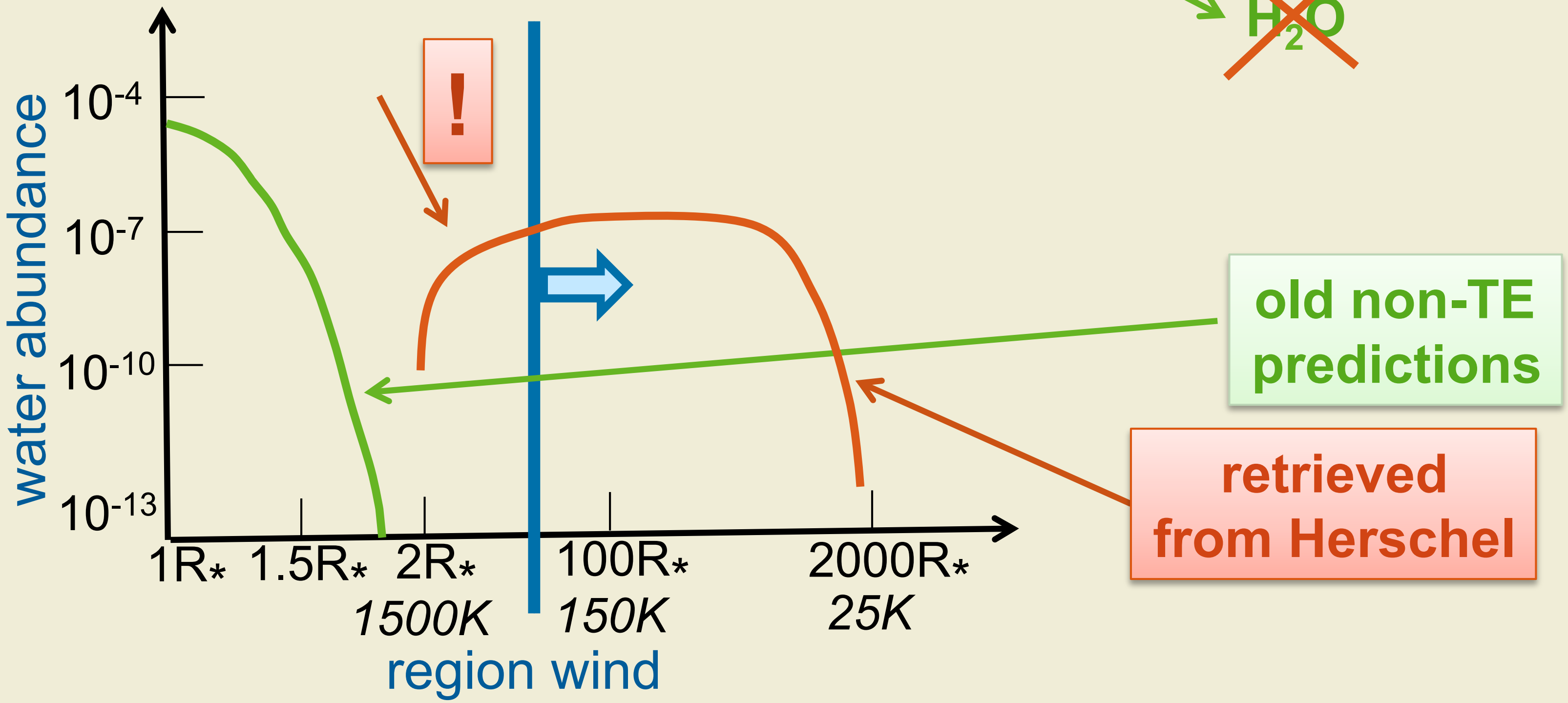


After Herschel: origin *warm* water vapour

6. H_2O in carbon-rich winds: Origin?

→ solving chemical network: no water





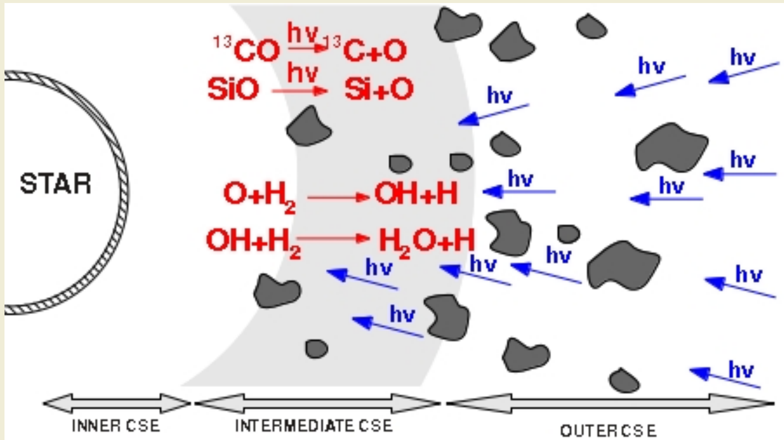
After Herschel: origin *warm* water vapour

(1) penetration of UV photons in clumpy wind

→*photo-dissociation* of CO, SiO: free O

→*reaction with H_2*: creation OH and H_2O

(Decin et al. 2010, Agúndez et al. 2010)



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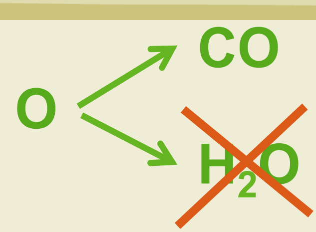

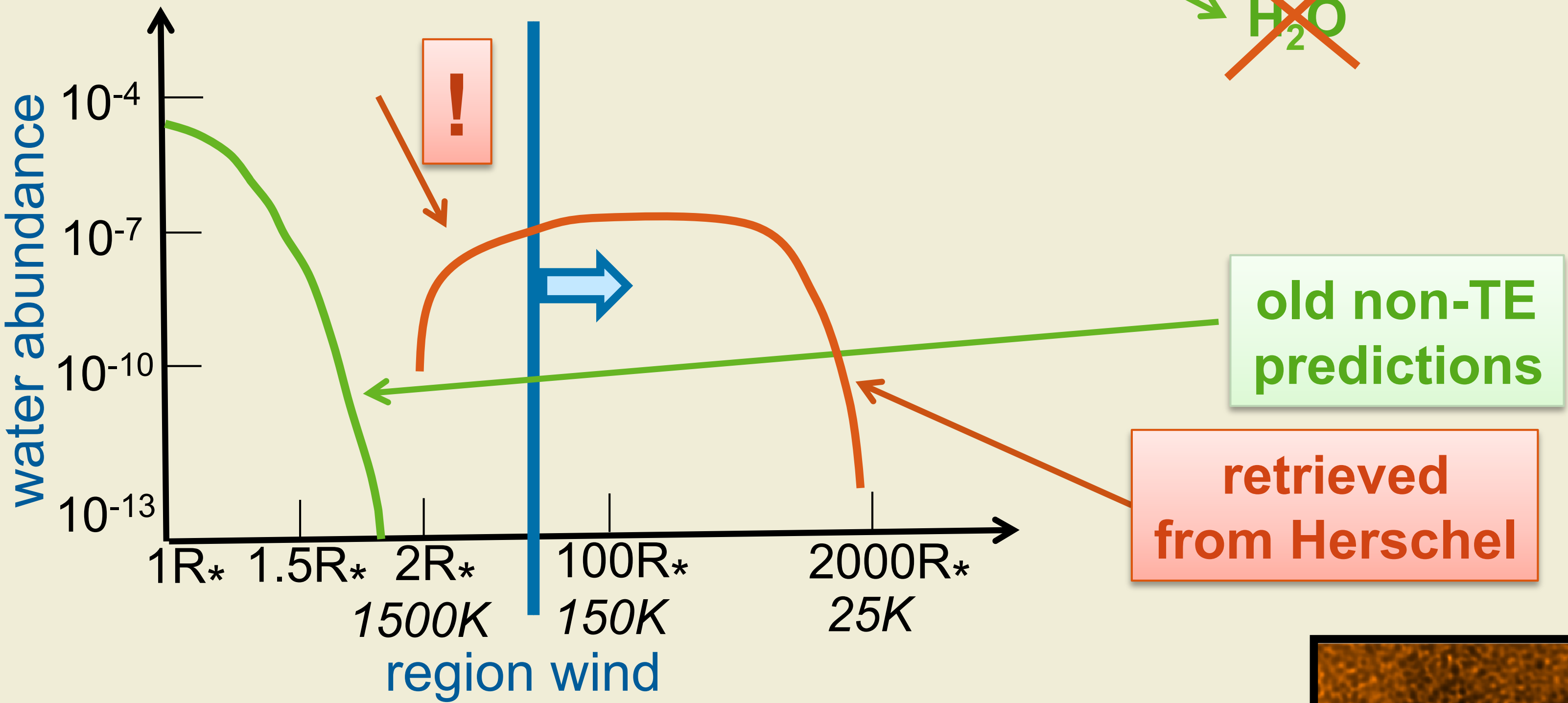

<u>After Herschel: origin *warm* water vapour</u>

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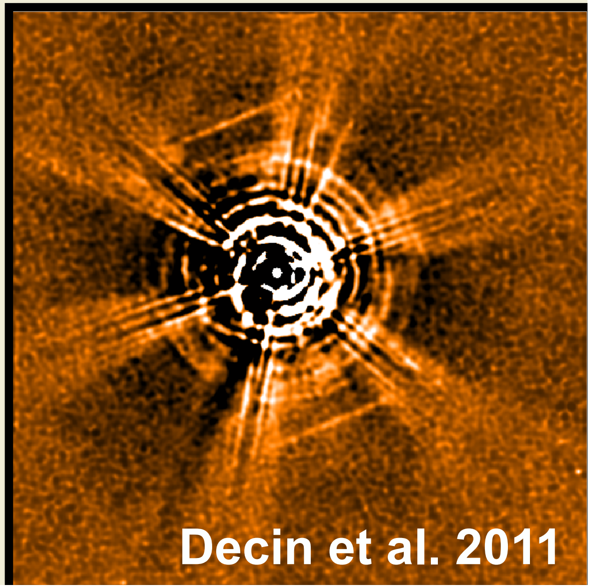

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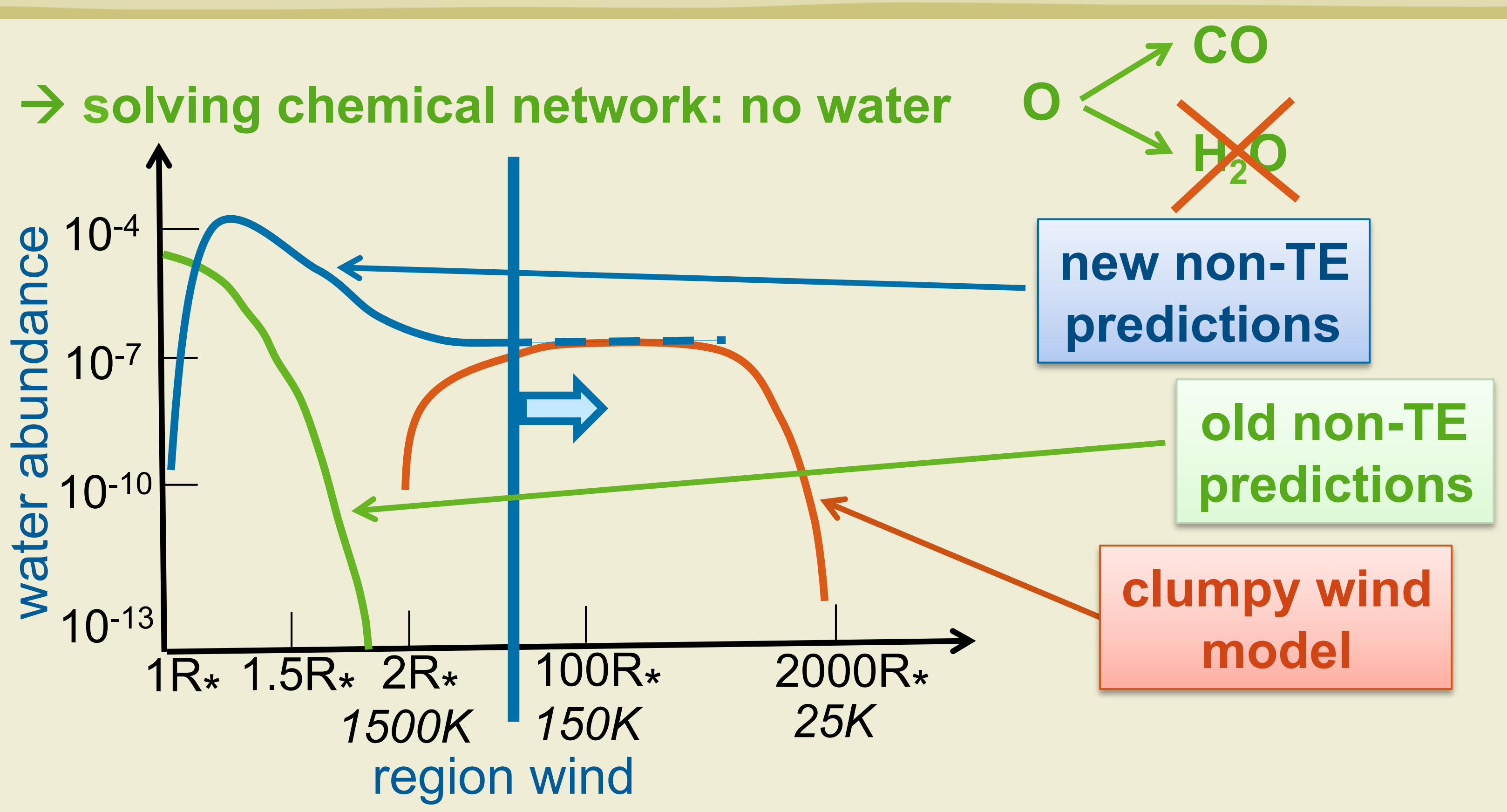


After Herschel: origin *warm* water vapour

(1) penetration of UV photons in clumpy wind

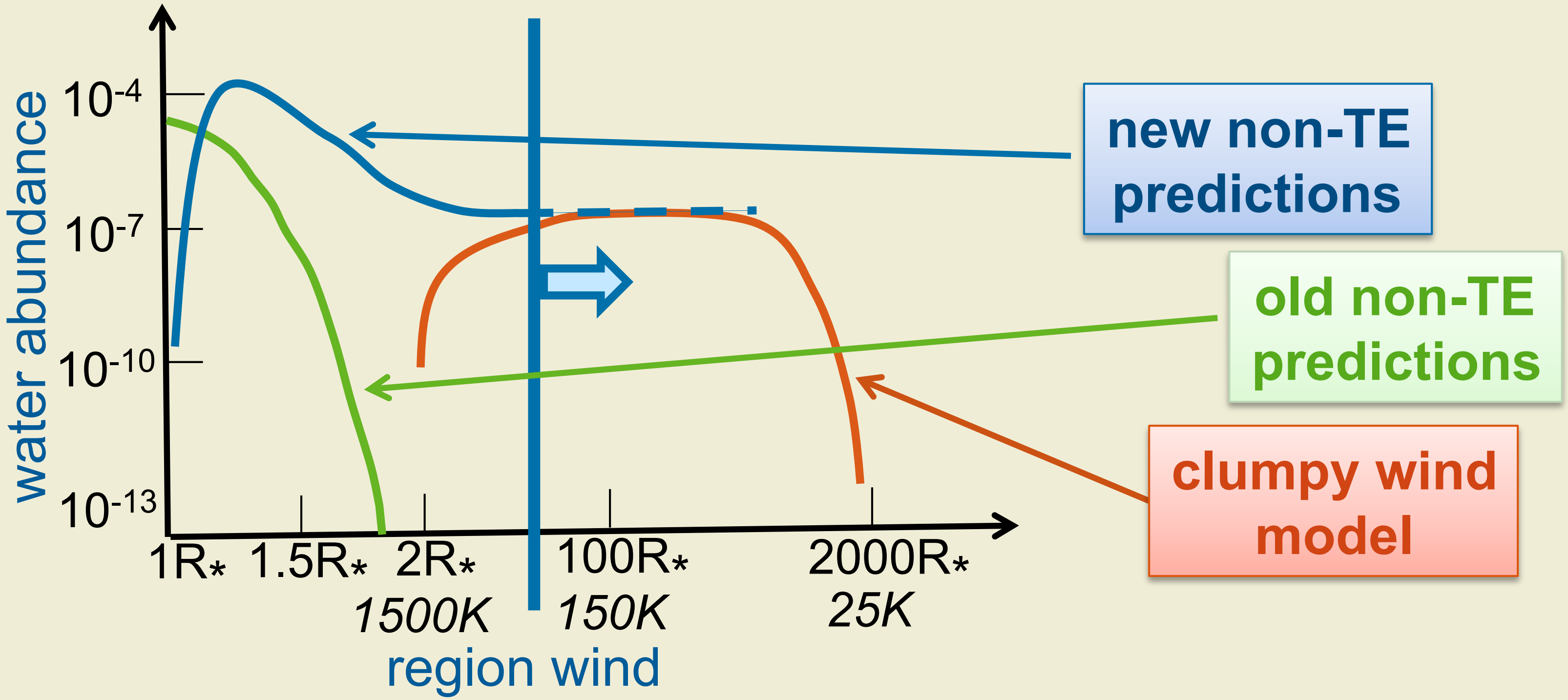
(2) shock-induced non-equilibrium chemistry

→ adapt Si + OH → SiO + H

(Cherchneff 2011, 2012)

HOW TO DISTINGUISH?

6. H_2O in carbon-rich winds: Origin?



After Herschel: origin *warm* water vapour

- ✓**ALMA**
- ✓**isotopic ratios**
- ✓**sample analysis**

HOW TO DISTINGUISH?

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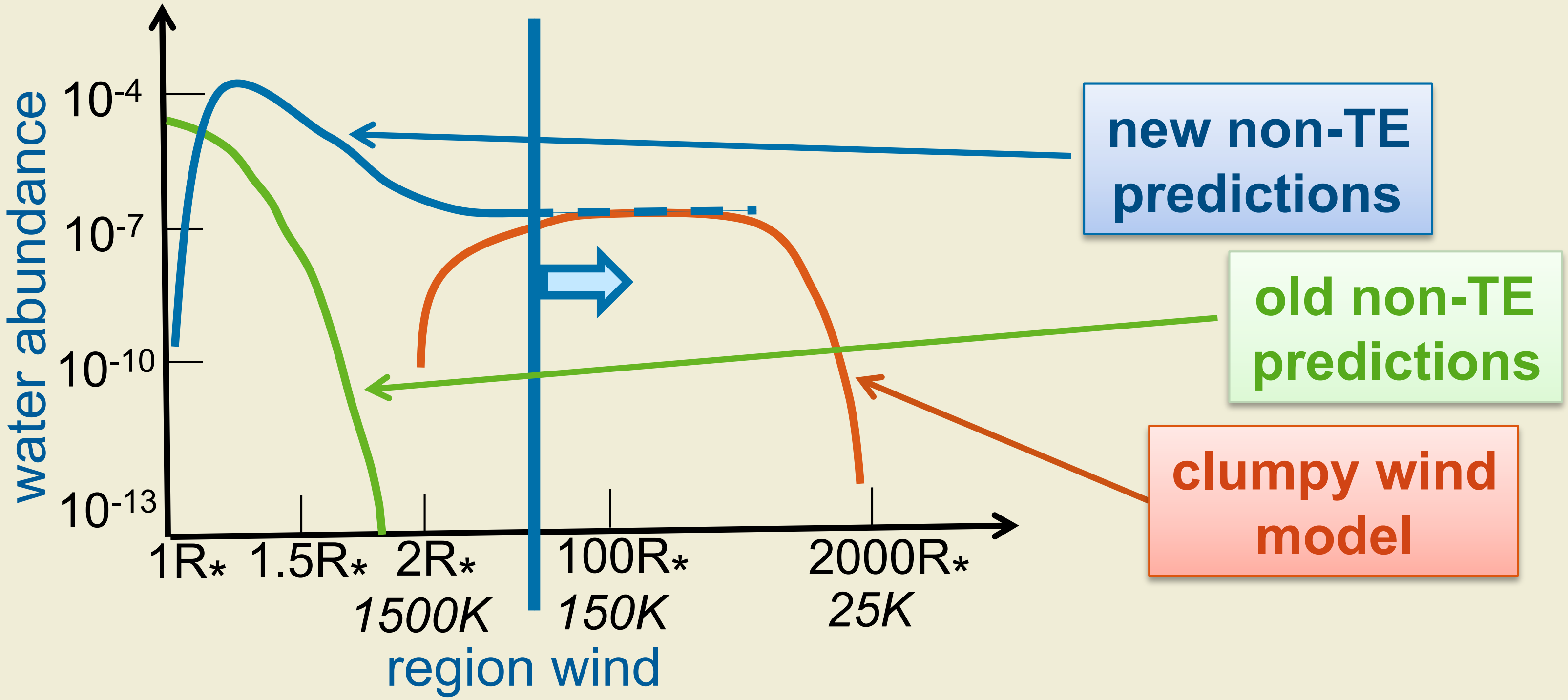


After Herschel: origin *warm* water vapour

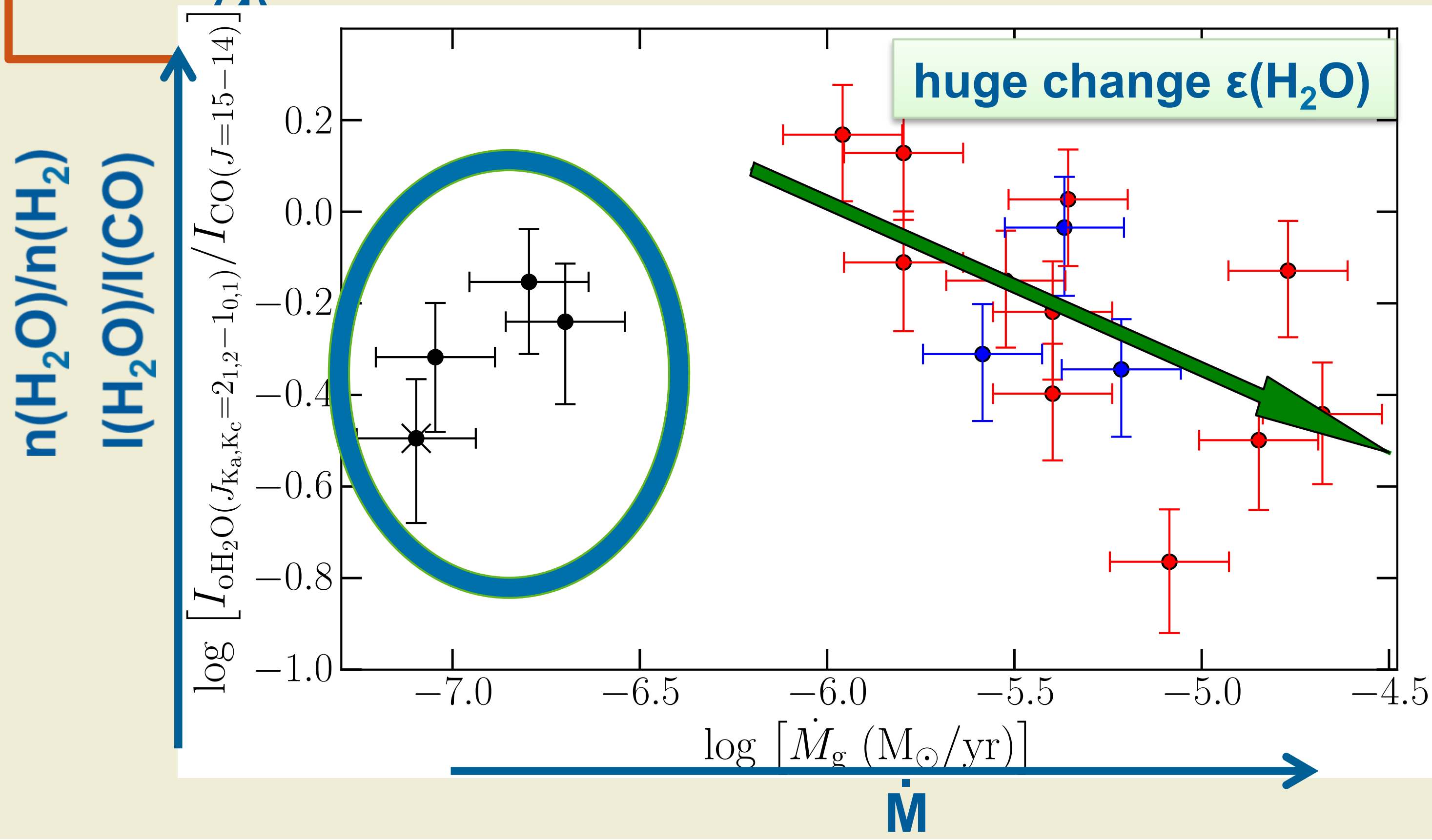
- ✓**ALMA**
- ✓**isotopic ratios**
- ✓**sample analysis**

HOW TO DISTINGUISH?

6. H_2O in carbon-rich winds: sample analysis (Lombaert et al. 2013)

Method: * observe **18** carbon stars with PACS (MESS GTKP + OT2)
* different **mass-loss rate, variability type, expansion velocity**, …
* select 7 unblended **H_2O** lines and 6 **CO** lines

Result: (1) H_2O (up to E_{up} = 200K) detected in ***all*** carbon stars
(2) H_2O (E_{up} > 200K) detected for all ***low mass-loss rate*** stars
(3) opposite trend H_2O strength with mass-loss rate, except SRb



high Ṁ, high P,
high shock velocity

Miras
SRa
SRb

low Ṁ,
low (multiple) P,
low shock velocity

6. H_2O in carbon-rich winds: sample analysis (Lombaert et al. 2013)

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(3) opposite trend H_2O strength with mass-loss rate, except SRb
→ change H_2O abundance with 3 orders of magnitude
(4) increase H_2O abundance ($r<50R_*$) – outside acceleration zone from line excitation analysis

6. H_2O in carbon-rich winds: sample analysis (Lombaert et al. 2013)

Model 1:
UV photons penetrate in clumpy wind

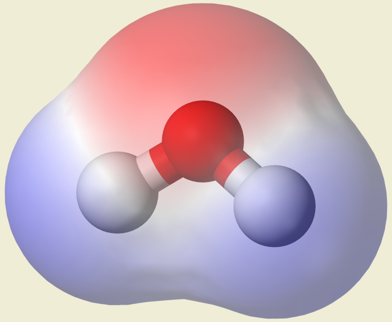
Model 2:
shock-induced non-equilibrium chemistry

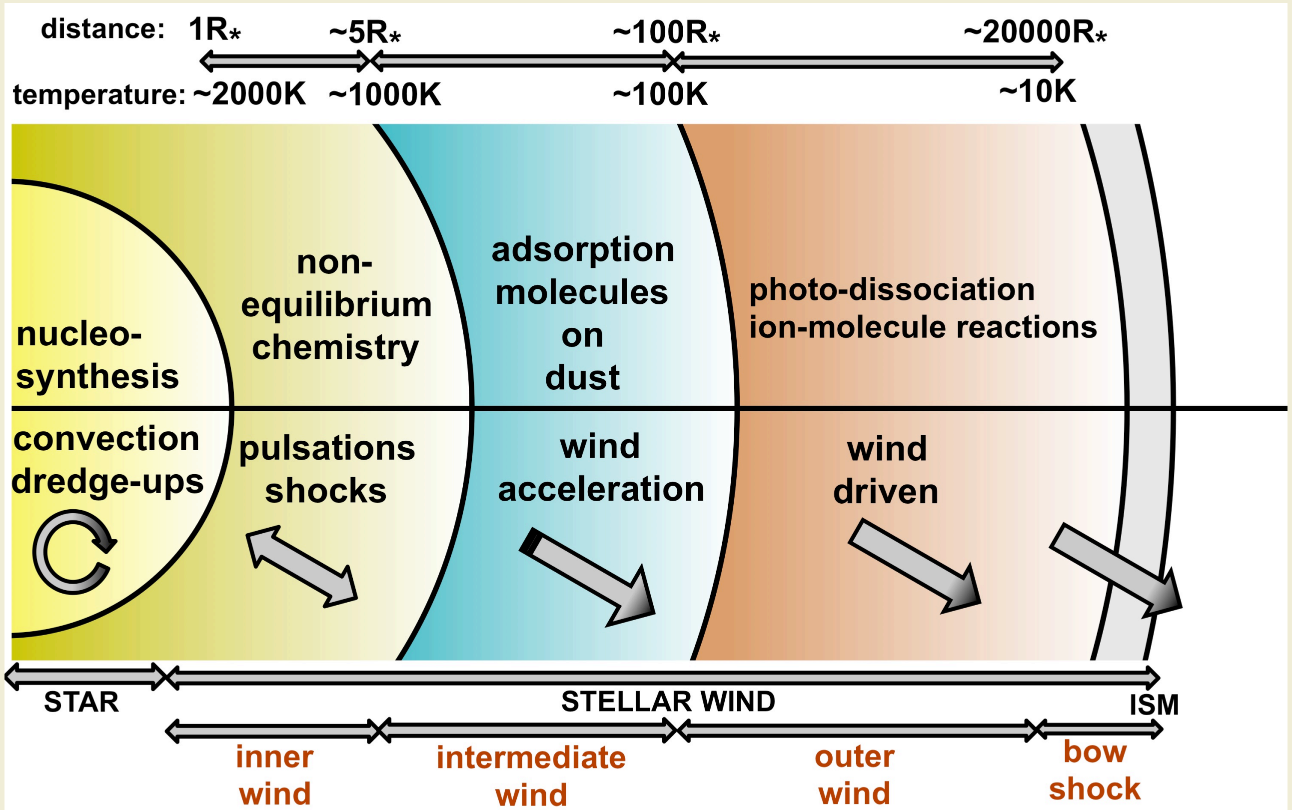
4 constraints:

Model 1	Constraint	Model 2
☑	in *all* carbon stars	☑
☑	$\varepsilon(H_2O)$↓ when $\dot{M}$↑	☑
☒	except SRb	☒ ☒ no models difficult to predict
☑	$\varepsilon(H_2O)$↑ up to ~50 R_* outside acceleration region	☒ ☒ + Fischer-Tropsch catalysis on grains

+ isotopic constraint on selective photo-dissociation (Neufeld et al. 2012)

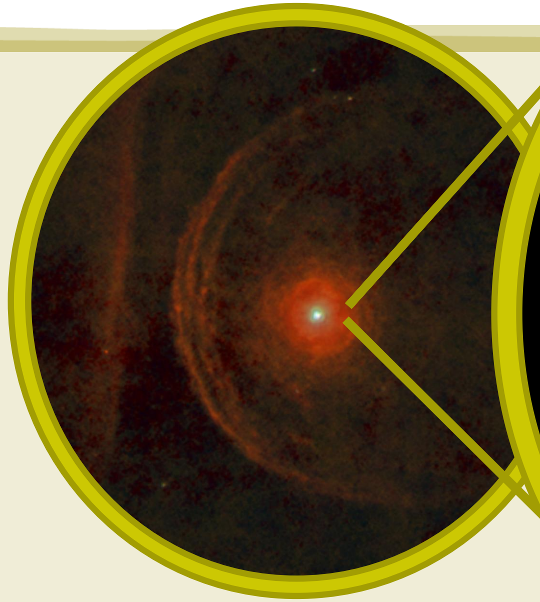
7. Conclusion

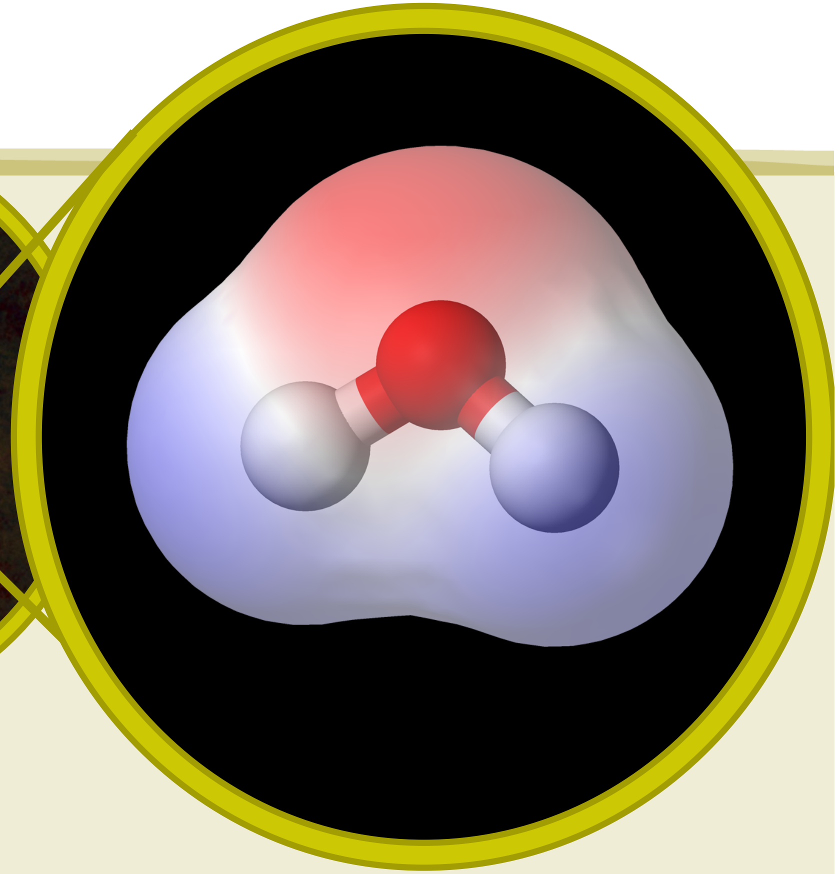




7. Conclusion

- **P1-76:** 'HCN emission around IRC+10216: the HIFI view', De Beck et al
- **P1-77:** 'When twins are not identical: a HIFI scan of IRAS 15194-5115, the stellar twin of IRC+10216', De Beck et al.
- **P1-106:** 'First results from the Molecular Line Survey with HSO/HIFI of the Rotten Egg Nebula', Sanchez-Contreras et al.
- **P2-35:** 'Study of th 69 micron band of crystalline olivine around evolved stars', Blommaert et al.
- **P2-36:** 'The Herschel View of Yellow Hypergiants as post-red Super-giants in a pre-luminous blue variable phase', Cox et al.
- **P2-38:** 'Revealing Astrospheres Around Young and Old Stars in the Far Infared', Cox et al.
- **P2-41:** 'The case of the Exploding Star V838 Mon Observed with Herschel', Exter et al.
- **P2-43:** 'An independent Distance Estimate to CW Leonis', Groenewegen et al.
- **P2-48:** 'Superwinds from extreme OH/IR stars', Justtanont et al.
- **P2-50:** 'Herschel probes The Mass Loss Evolution During the AGB Phase', Kerschbaum et al.
- **P2-53:** 'The Herschel Planetary Nebulae Survey HerPlaNS', Ladjal et al.
- **P2-57:** 'SPIRE and PACS observations of the red supergiant VY CMa', Matsuura
- **P2-76:** 'Observations of the circumstellar ammonia lines in carbon-rich AGB stars by Herschel Space Observatory', Schmidt et al.
- **P2-81:** 'Time Variability of Thermal Molecular Emission in IRC+10216', Teyssier





Thank you