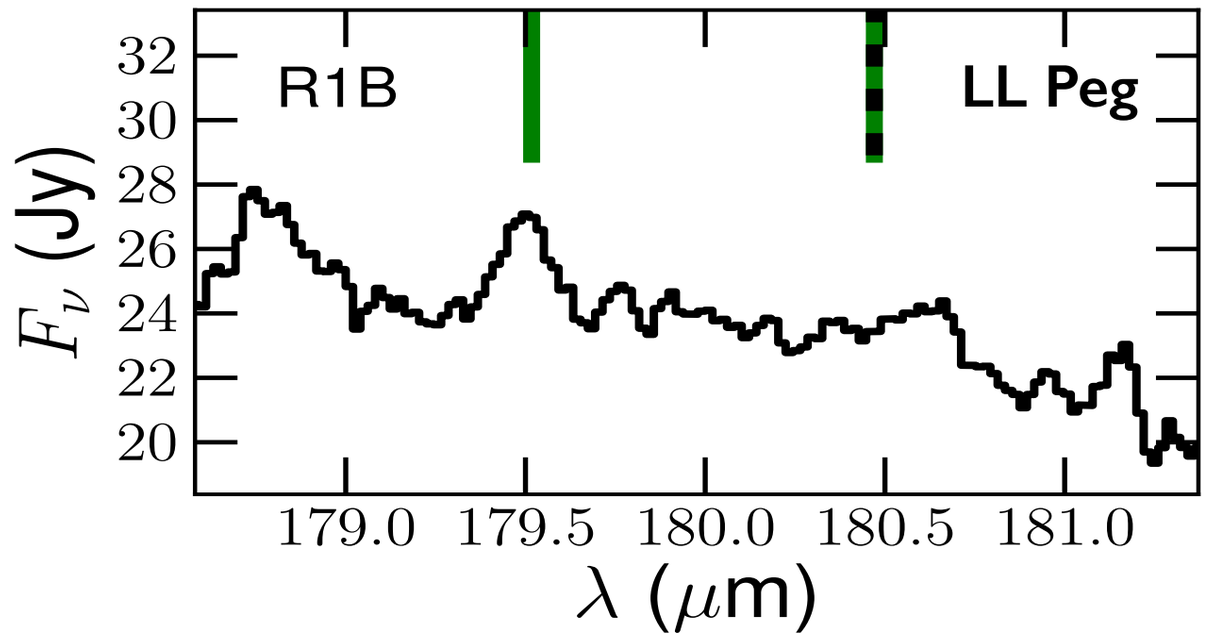
HERSCHEL OBSERVATIONS OF WATER IN WINDS OF CARBON-RICH EVOLVED STARS



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B. VANDENBUSSCHE
C.WAELKENS

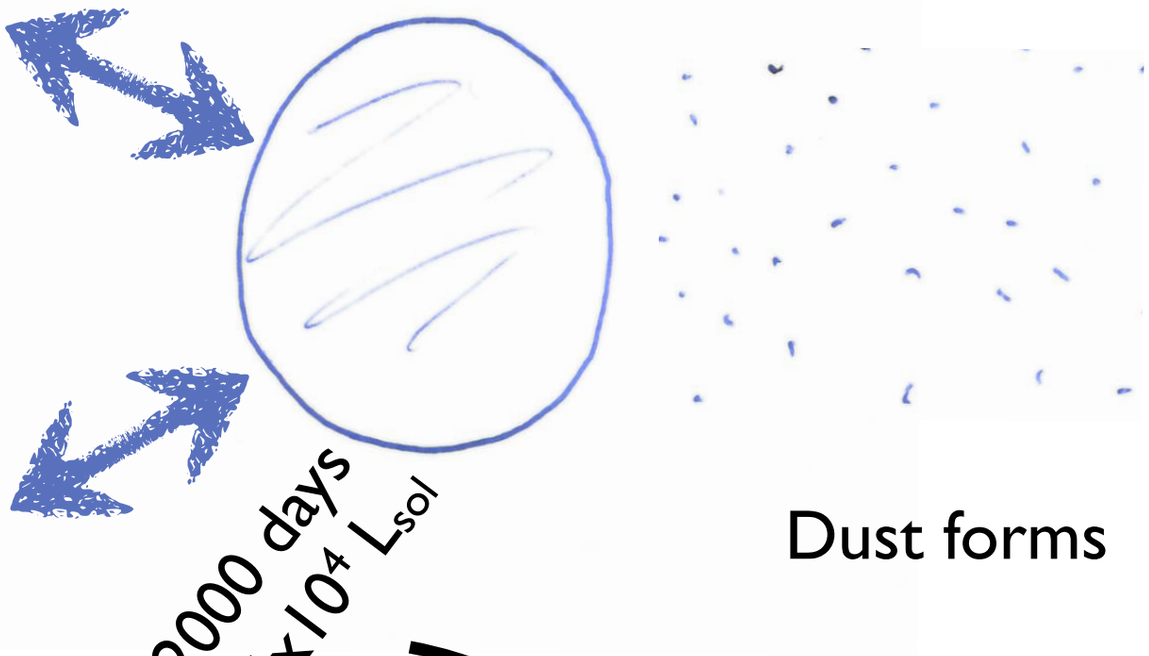
A&A 588, A124 (2016)

Water in the Universe: from clouds to oceans - Noordwijk - Apr 2016

LOW-TO-INTERMEDIATE STARS: ASYMPTOTIC GIANT BRANCH

YOU ARE HERE

MS mass ≲ 8 M_{sol}

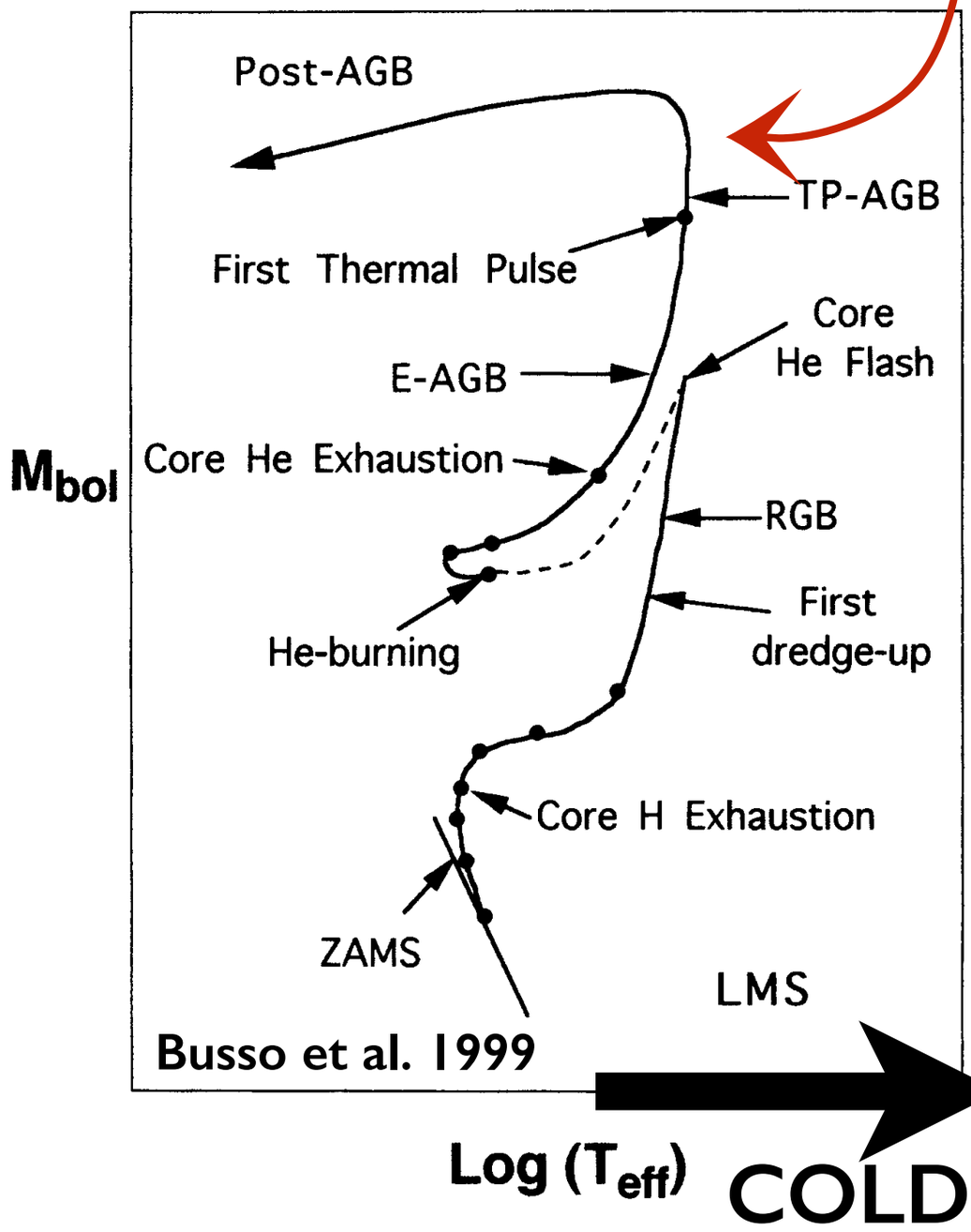


P up to 2000 days
$L_\star$ up to ~$5x10^4$ L_{sol}

Dust forms

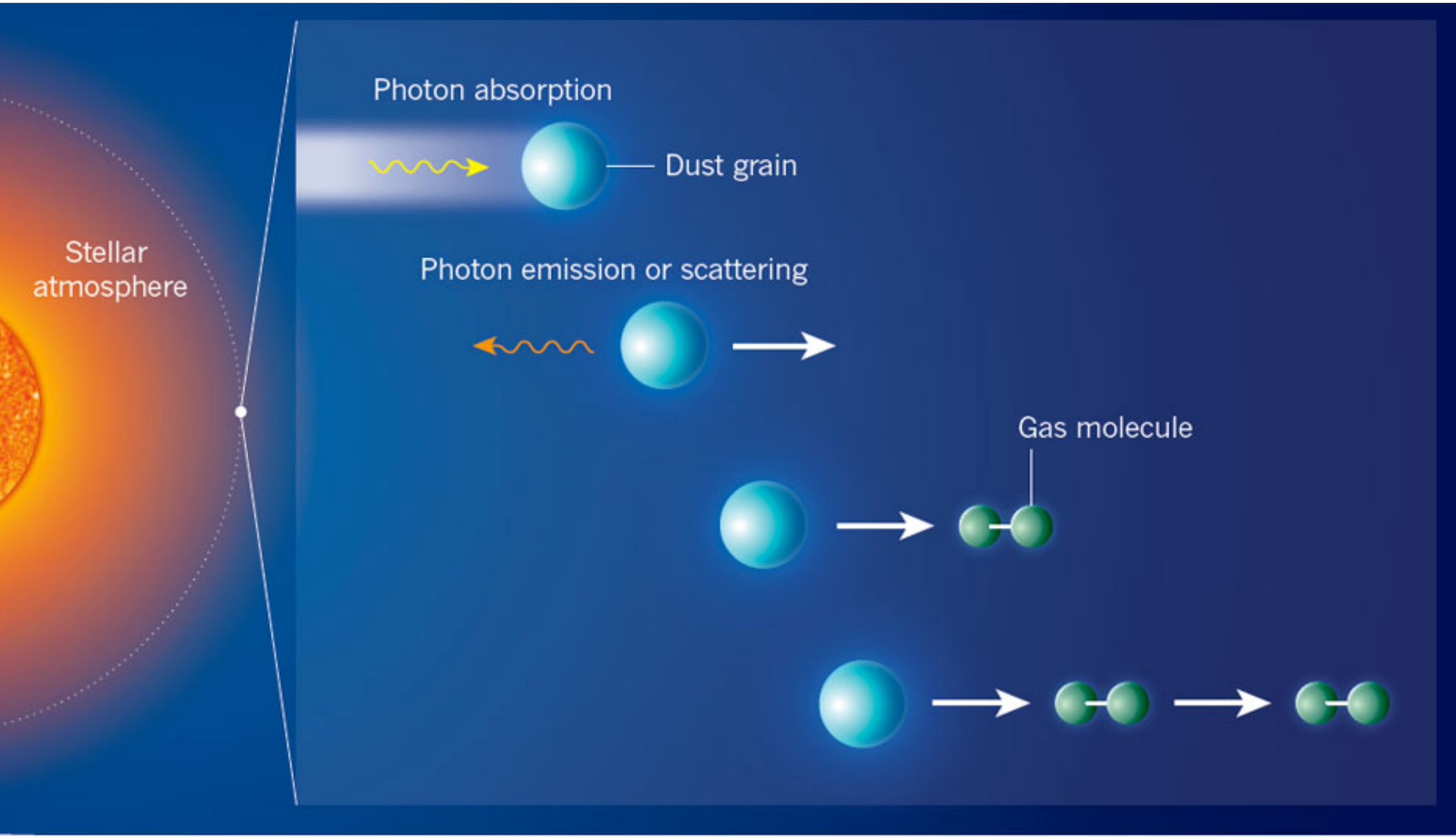
Different pulsation types:
Mira > Semi-regular a (SRa) > SRb

Evolution on the AGB



FORMATION OF STELLAR WIND: MASS LOSS

Höfner 2012



STRUCTURE OF THE STELLAR WIND

$1\ R_\star \approx 3 \times 10^{13}$ cm ≈ 2 AU

1 $R_\star$ — 10 $R_\star$ — 100 $R_\star$ — 1000 $R_\star$

AGB

Inner Wind

- ✓ Dust seed formation
- ✓ Wind acceleration
- ✓ Stellar pulsation
- ✓ Shocks

Intermediate Wind

- ✓ Continued dust growth
- ✓ Wind reaches terminal velocity
- ✓ Grain-surface reactions

Outer Wind

IS UV

- ✓ Chemical fractionation
- ✓ UV photodissociation
- ✓ Ion-molecule reactions

HERSCHEL CO AND H_2O EMISSION

(LINE FORMATION REGION)

1 $R_\star \approx 3 \times 10^{13}$ cm ≈ 2 AU

1 $R_\star$ 10 $R_\star$ 100 $R_\star$ 1000 $R_\star$

Inner Wind

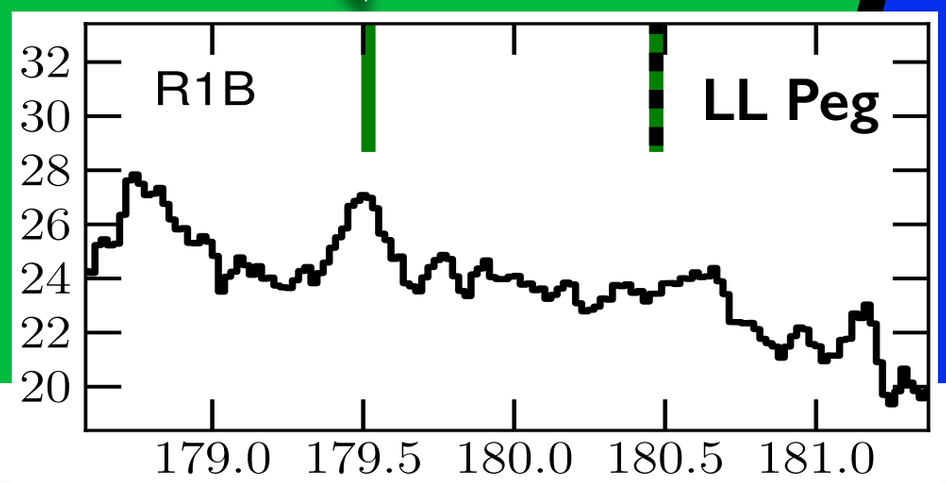
AGB

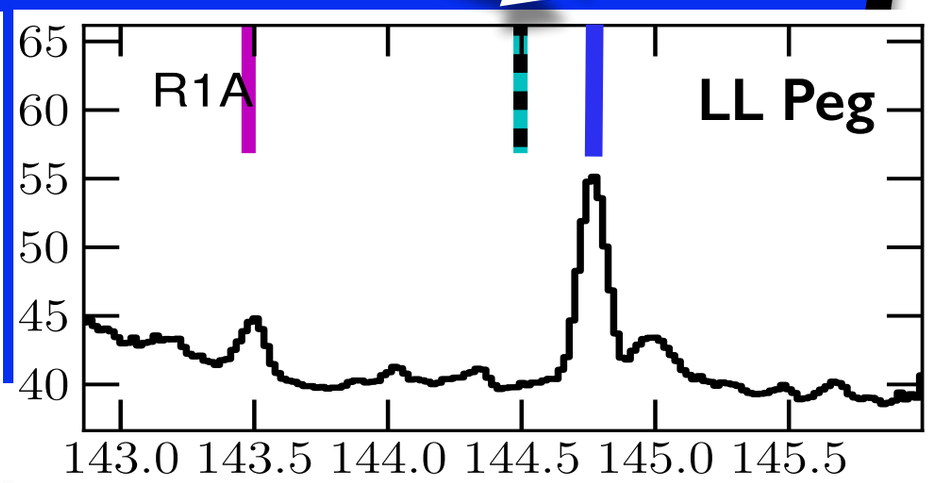
Intermediate Wind

H_2O + CO

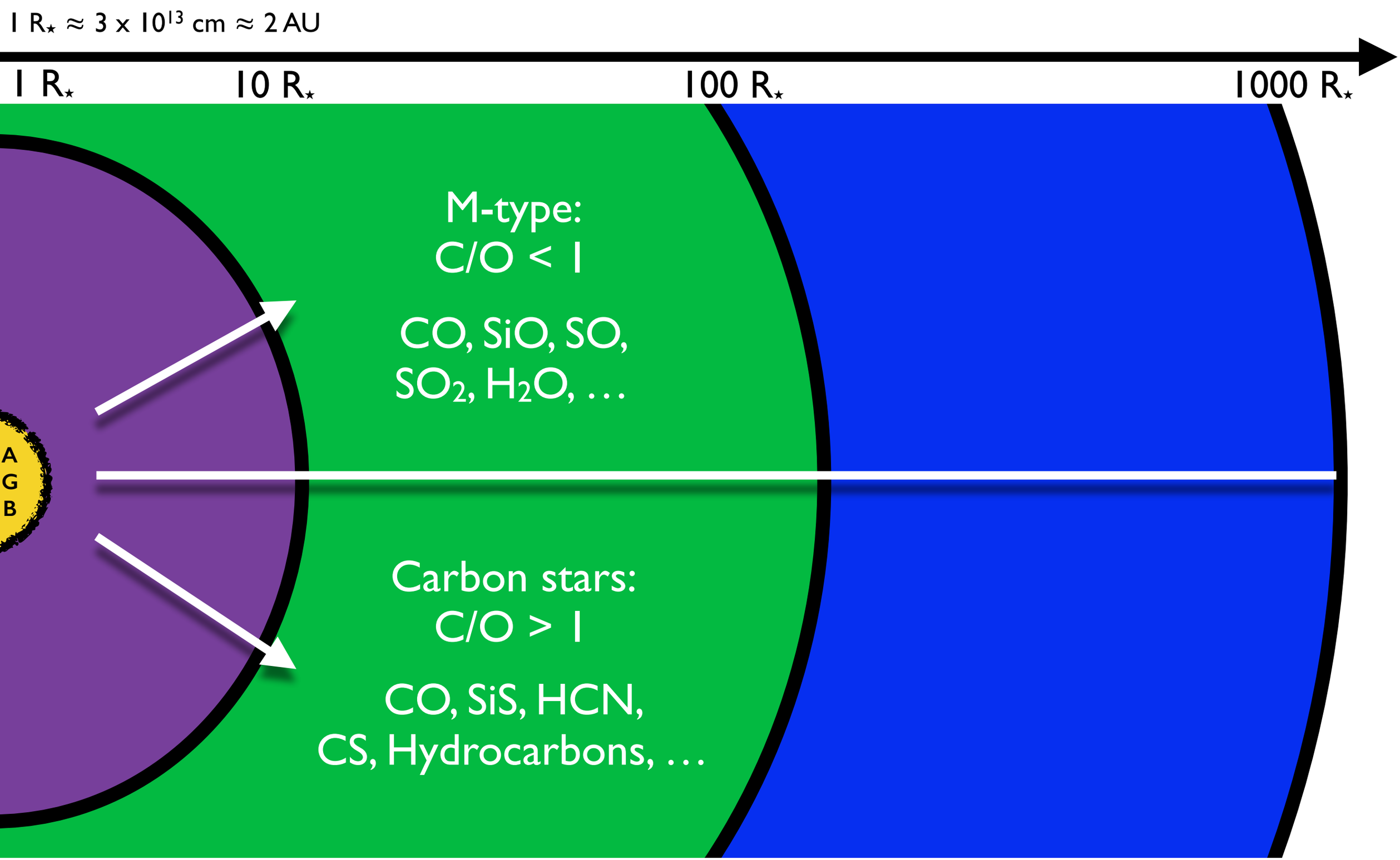
Outer Wind

CO



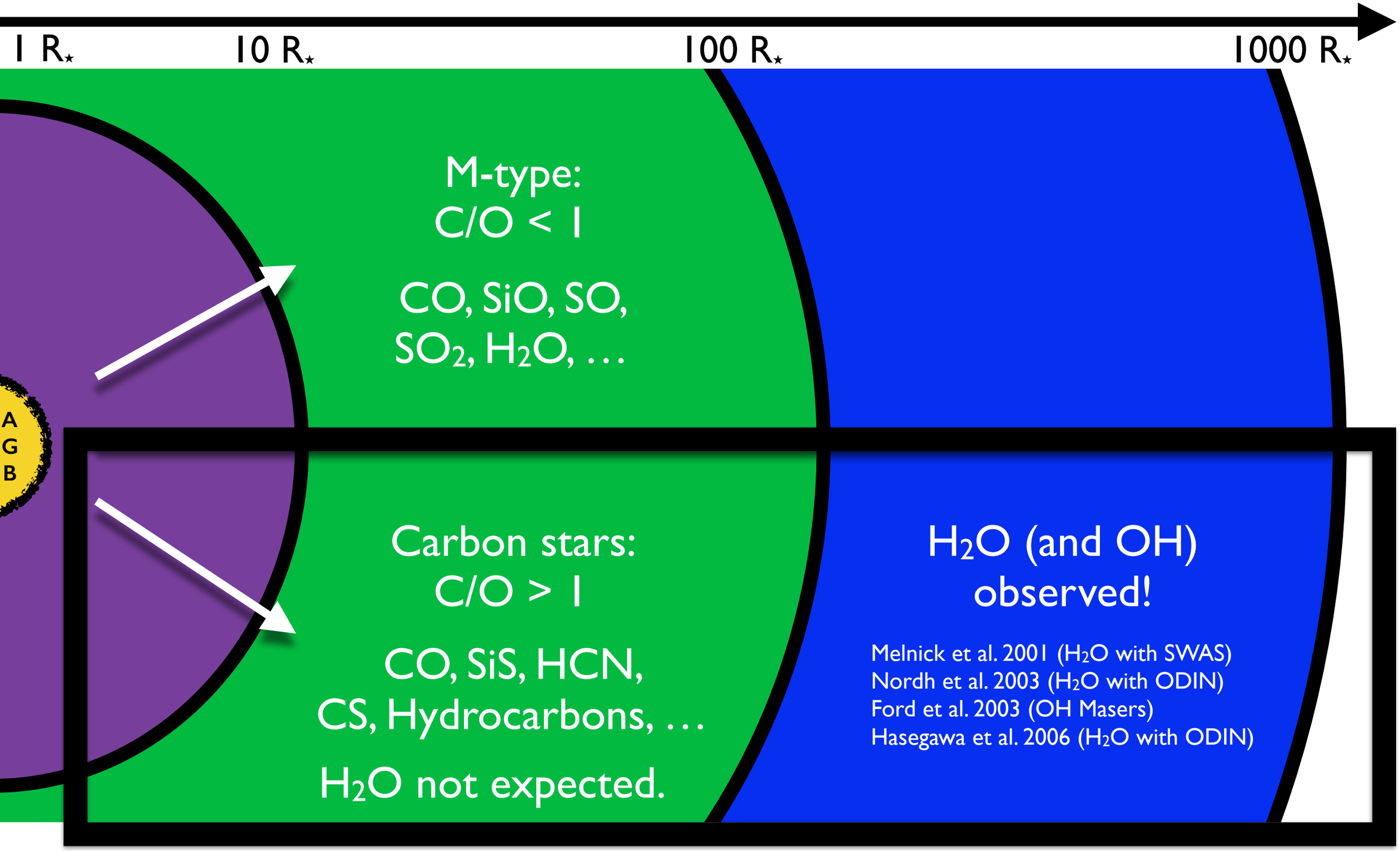


TWO CHEMICAL TYPES



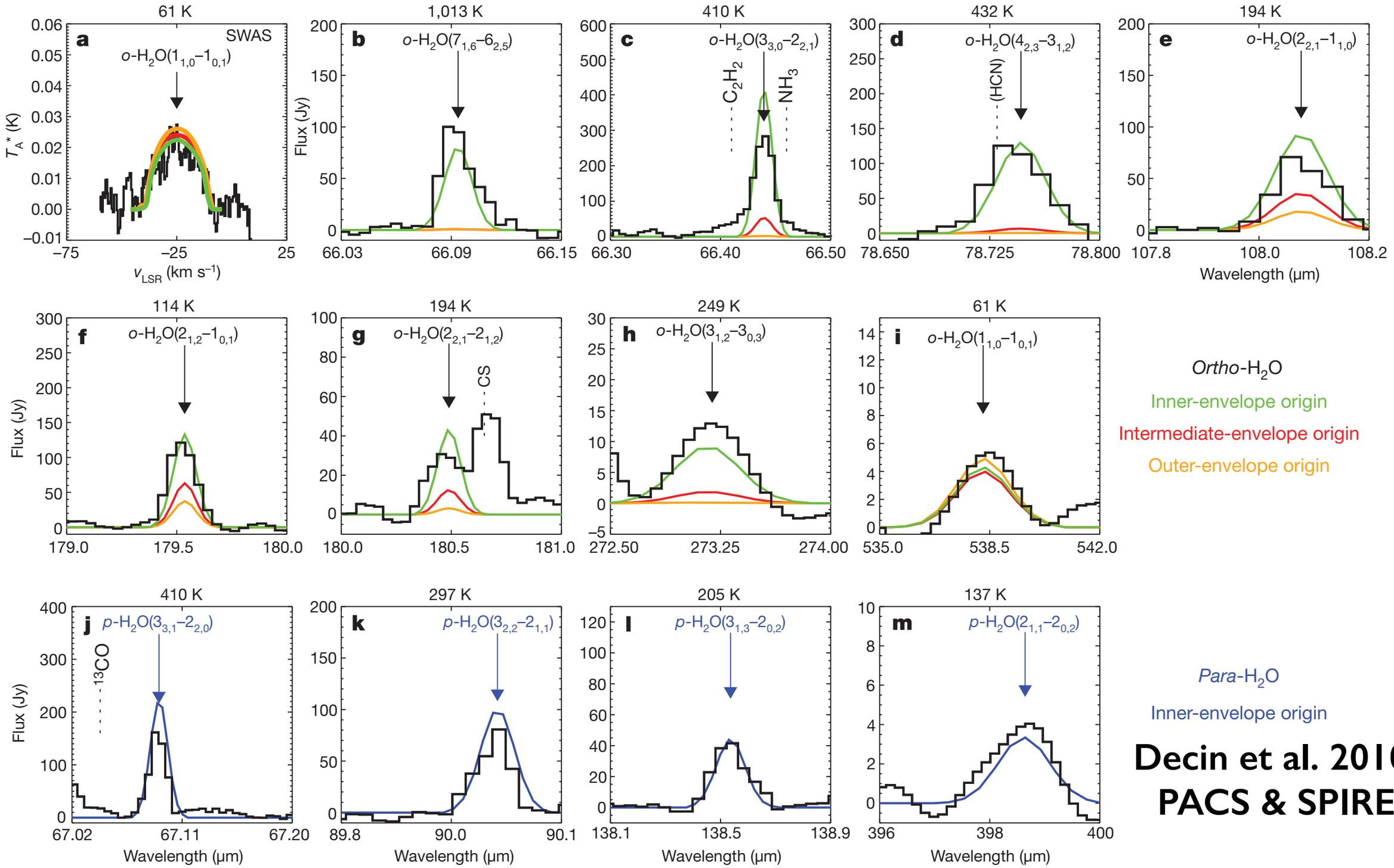
CARBON STARS SPECIFICALLY

$1\ R_\star \approx 3 \times 10^{13}$ cm ≈ 2 AU



HERSCHEL: H_2O IN INNER WIND OF CW LEO

CHALLENGE FOR ALL PROPOSED FORMATION MECHANISMS



Decin et al. 2010: PACS & SPIRE

H_2O IN MANY CARBON STARS!

Followed by lots of HIFI H_2O detections:

1. CW Leo (Neufeld et al. 2010a)
2. V Cyg (Neufeld et al. 2010b)
3. Widespread occurrence of H_2O in 8 carbon stars (Neufeld et al. 2011)
4. H_2O isotopologues in CW Leo (Neufeld et al. 2013)

DEEP-ENVELOPE PENETRATION OF INTERSTELLAR UV

(MECHANISM I)

$1\ R_\star \approx 3 \times 10^{13}$ cm ≈ 2 AU

$1\ R_\star$ $10\ R_\star$ $100\ R_\star$ $1000\ R_\star$

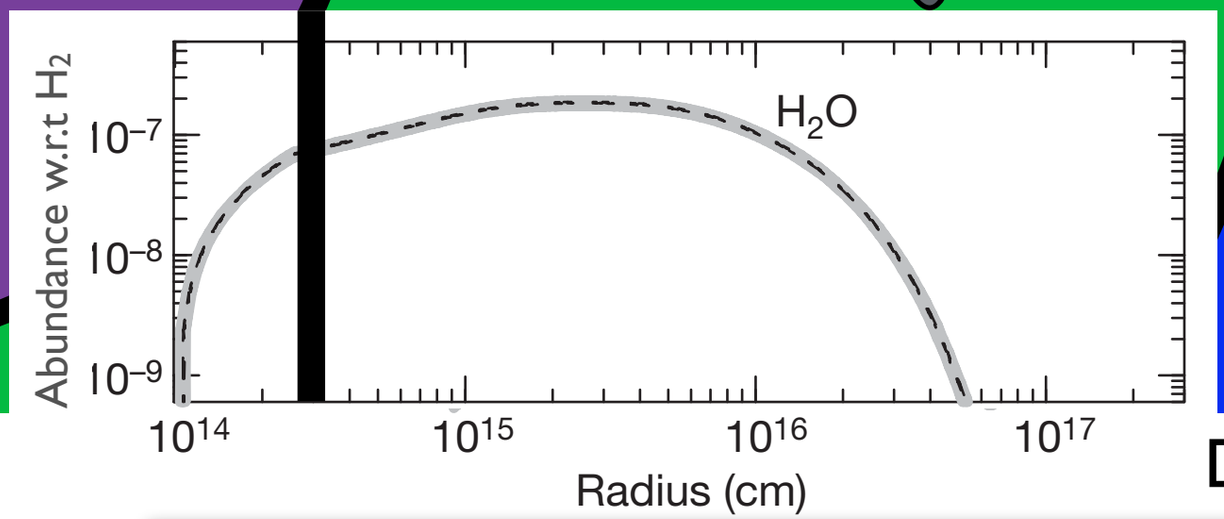
IS UV

Inner Wind

Intermediate Wind

Outer Wind

AGB



Decin et al. 2010, Agùndez et al. 2010

SHOCK-INDUCED NON-EQUILIBRIUM CHEMISTRY

(MECHANISM II)

$1\ R_\star \approx 3 \times 10^{13}$ cm ≈ 2 AU

$1\ R_\star$ $10\ R_\star$ $100\ R_\star$ $1000\ R_\star$

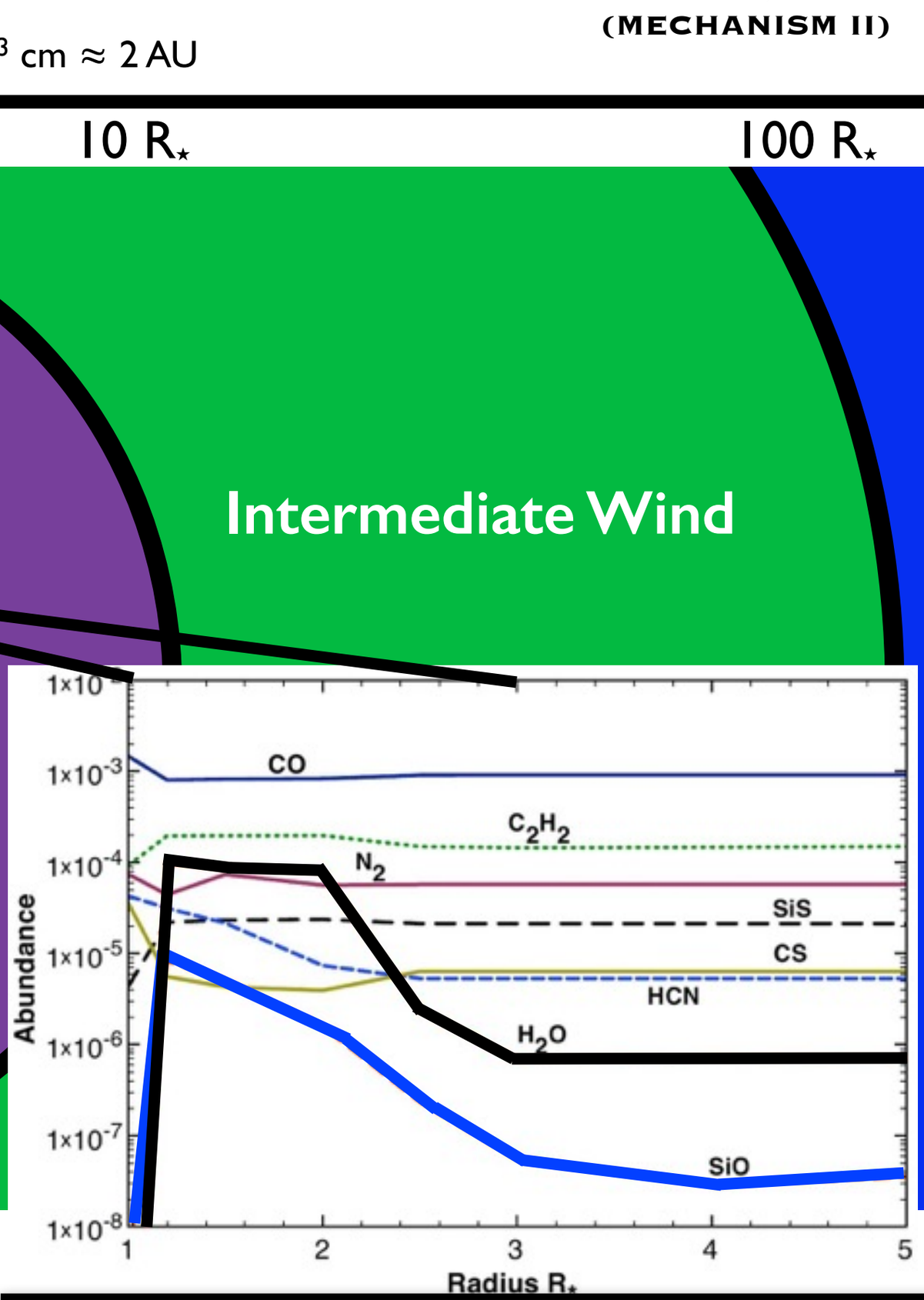
Inner Wind

AGB

Intermediate Wind

IS UV

Outer Wind



Cherchneff 2011

CHOOSE NOW!

Camp Interstellar UV:

According to:

Decin et al. 2010

Agùndez et al. 2010

Camp Shocks:

According to:

Cherchneff 2011

(Neufeld et al. 2013)

HERSCHEL OBSERVATIONS

GTKP: MESS P.I.: M. Groenewegen	OT2: P.I.: L. Decin
Spectral scans	Line scans focused on H_2O
4 Miras	7 Miras + LL Peg
2 SRa variables	1 SRa variable (?)
0 SRb variables	4 SRb variables

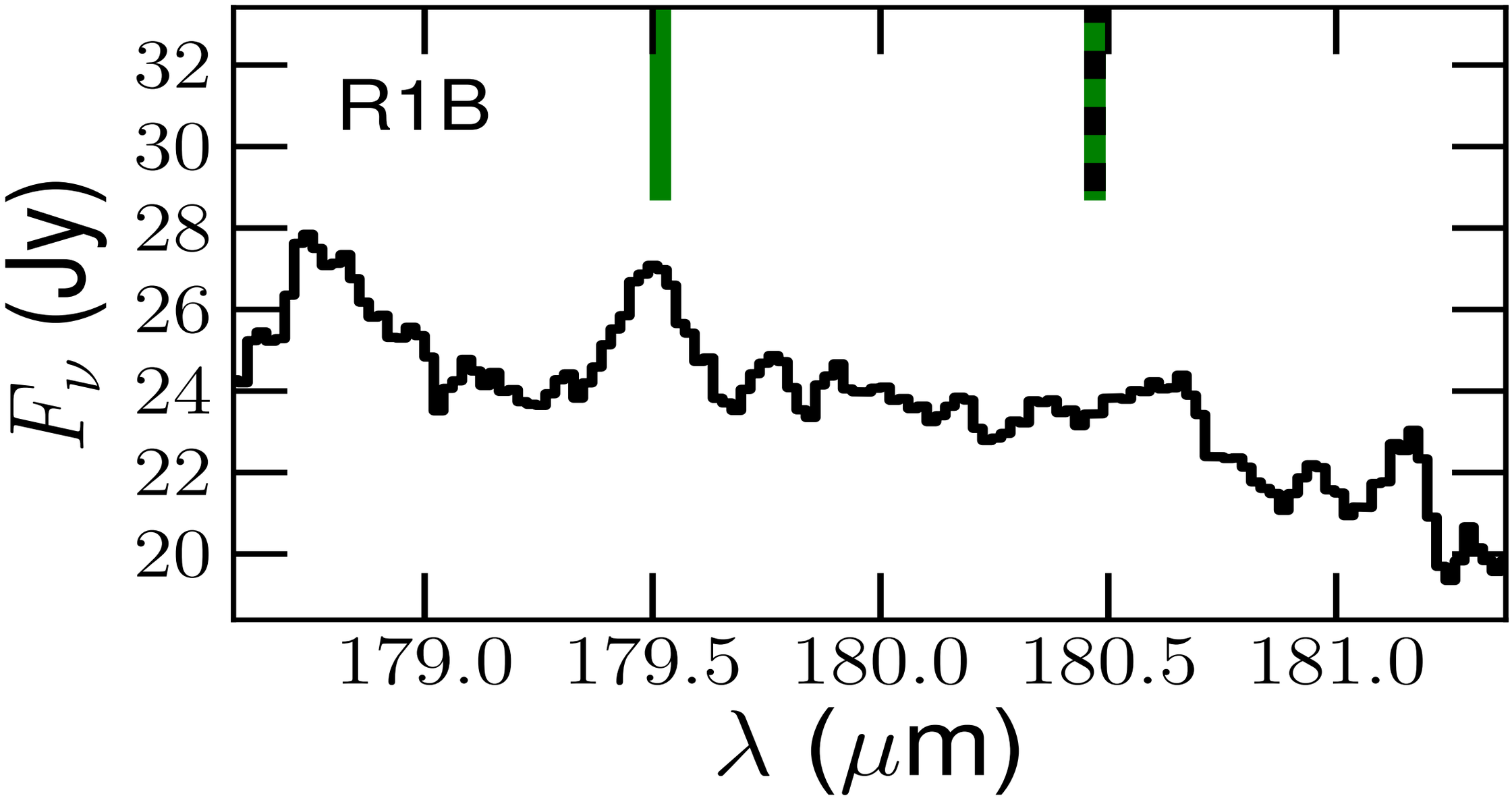
Total: 18 sources

Approach:

1. Trend analysis of distance-independent observed line-strength ratios
2. Theoretical model grid for qualitative comparison

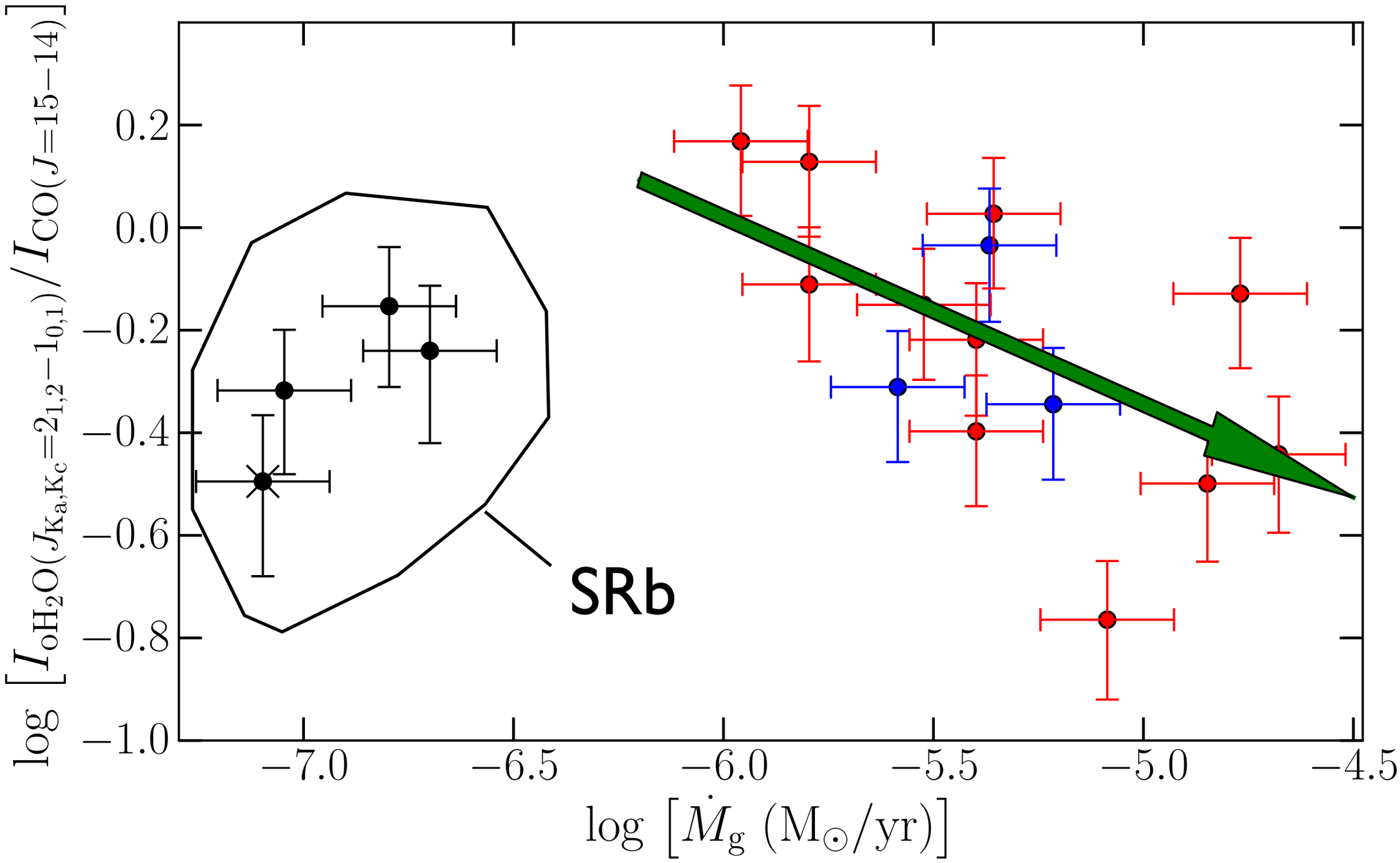
AFGL 3068 AKA LL PEG

FROM ENIGMA TO JUST ANOTHER CARBON STAR... AS FAR AS H_2O IS CONCERNED



H_2O DEPENDENCE ON MASS LOSS

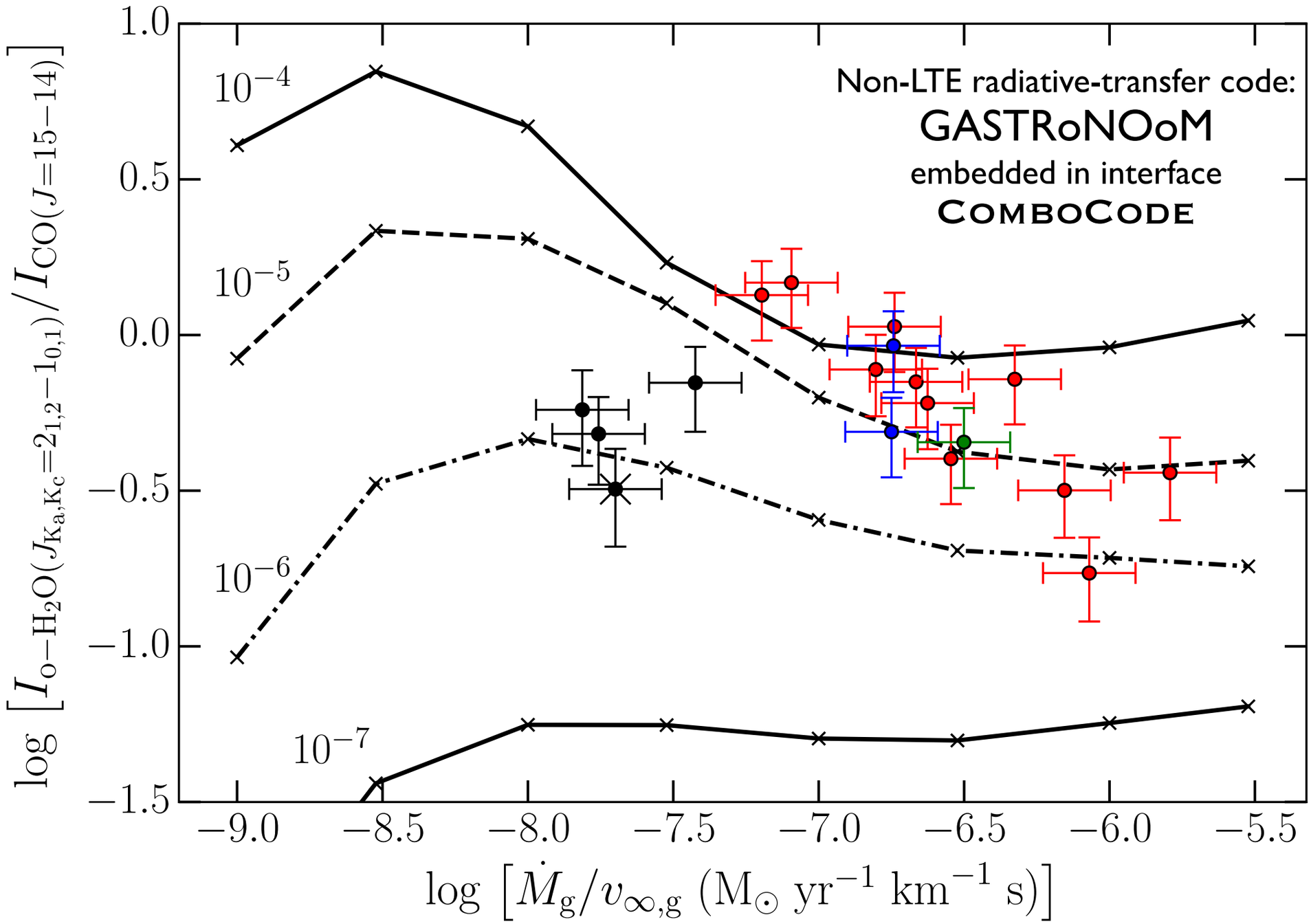
Assumption: H_2O abundance ~ I_{H2O} / I_{CO} ~ (I_{H2O} / I_{H2}) x (I_{H2} / I_{CO}) if $\dot{M}$ ~ I_{CO}



COMPARISON WITH RADIATIVE-TRANSFER MODELS

IN NON-LTE!

Account for effects of dust (radiative pumping), velocity & temperature profile, …



H_2O IN CARBON STARS: CONSTRAINTS

CONCLUDING...

		Shocks	Interstellar UV
1.	H_2O is present in the inner and intermediate wind Confirmed for full sample of 18 carbon stars	✔	✔
2.	H_2O abundances ~ 10^{-6} - 10^{-4} Depending on wind density	(✔)	✗
3.	Formation mechanism less efficient with increasing wind density	(✔)	✔
4.	Correlation breaks down for SRb stars: dependence on pulsation type?	(✔)	✗

IMPLICATIONS AND PROSPECTS

CONCLUDING...

1. Expand parameter space for chemical models

Can we reach higher abundances?

2. H_2O important coolant, when abundant

Energy balance in carbon-rich AGB winds?

Self-consistent H_2O cooling currently does not work!

3. Resolve clumpy winds with ALMA

We need constraints for the interstellar UV mechanism.

4. In-depth RT modeling of individual sources

What about 1D versus 3D?

THANK YOU!