Photodissociation in dying stars

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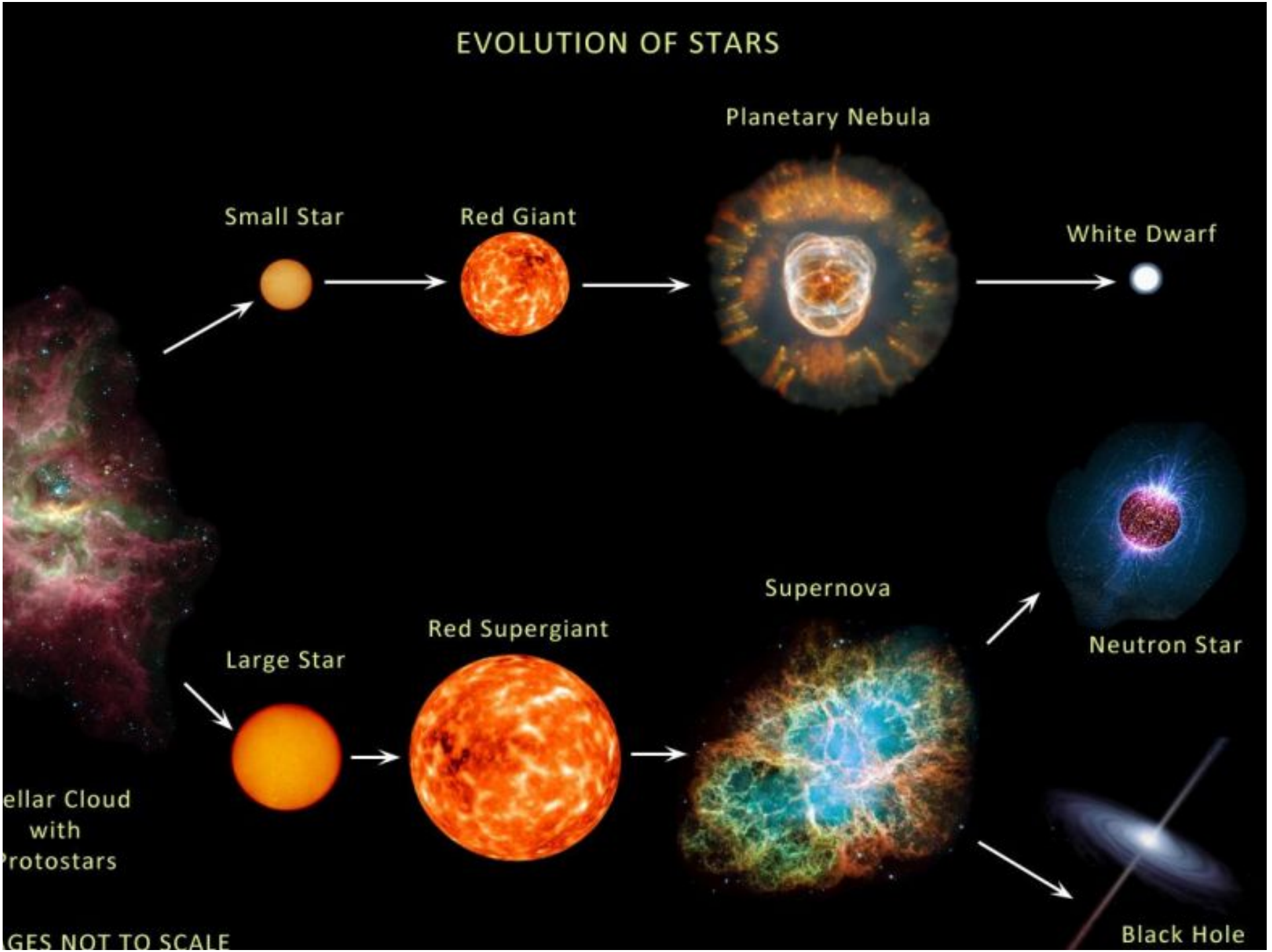
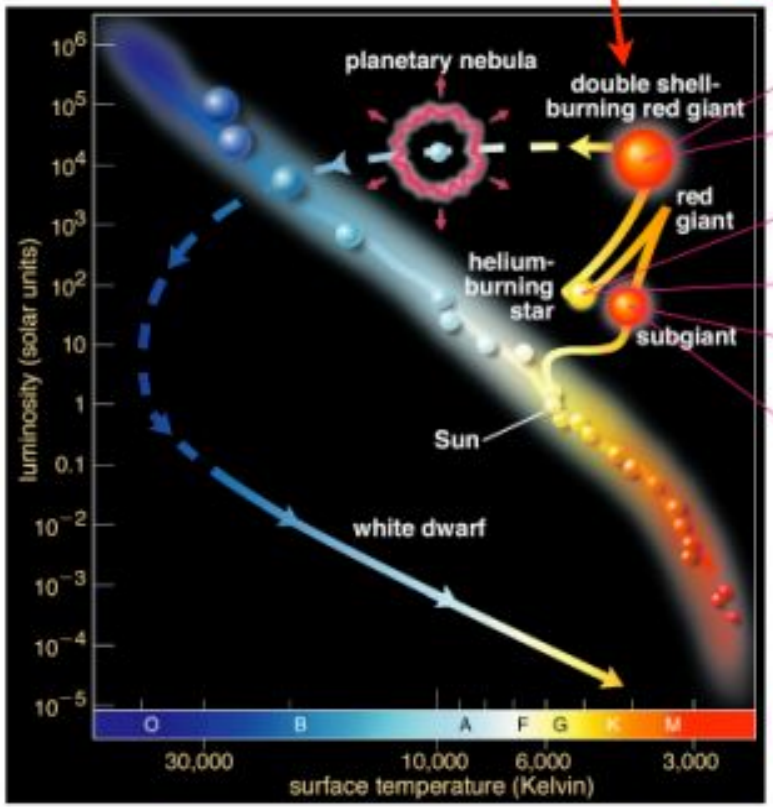
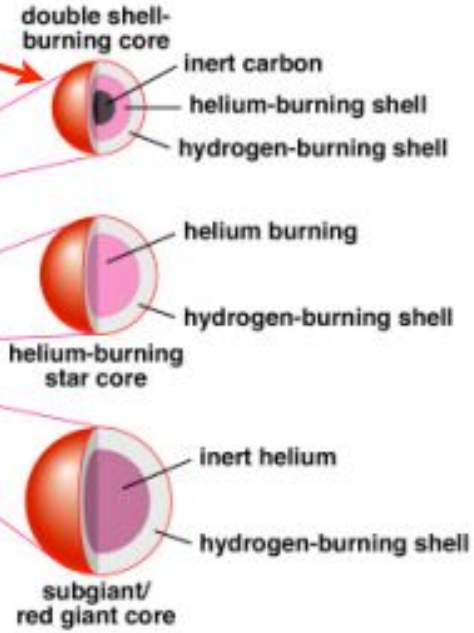

EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
Supernova
Red Supergiant
Large Star
Neutron Star
ellar Cloud
with
rotostars
Black Hole
GES NOT TO SCALE

An AGB star

Asymptotic Giant Branch: the final evolutionary stage of stars in the range $0.8 < M < 8\ M_{\odot}$



Hertzsprung–Russell diagram



Only ≈1% of the red giants are AGB stars

The Sun will eventually become an O-rich AGB star!

Circumstellar molecules in AGB-CSEs

Table 1: Molecules detected in AGB CSEs

2-atoms:	AlCl	CP	NaCl	SiN
	AlF	CS	OH	SiO
	C_2	FH	PN	SiS
	CO	KCl	SiC	SO
	CN			
3-atoms:	AlNC	HCN	KCN	SiC_2
	C_3	HCP	MgCN	SiCN
	C_2H	H_2O	MgNC	SiNC
	C_2S	H_2S	NaCN	SO_2
	CO_2	HNC		
4-atoms:	ℓ-C_3H	C_3S	H_2CO	PH_3?
	C_3N	C_2H_2	H_2CS	SiC_3
	C_3O	HC_2N	NH_3	
5-atoms:	C_5	c-C_3H_2	HC_3N	HNC_3
	C_4H	CH_2CN	HC_2NC	SiH_4
	C_4Si	CH_4	H_2C_3	
6-atoms:	C_5H	C_2H_4	HC_4N	H_2C_4
	C_5N	CH_3CN		
≥7-atoms:	C_6H	CH_2CHCN	HC_5N	HC_9N
	C_7H	CH_3CCH	HC_7N	H_2C_6
	C_8H			
Ions:	C_4H^-	C_6H^-	C_8H^-	
	CN^-	C_3N^-	C_5N^-	HCO^+

> 75 molecular species detected in CSEs around AGB stars

A large fraction is unique to the circumstellar medium

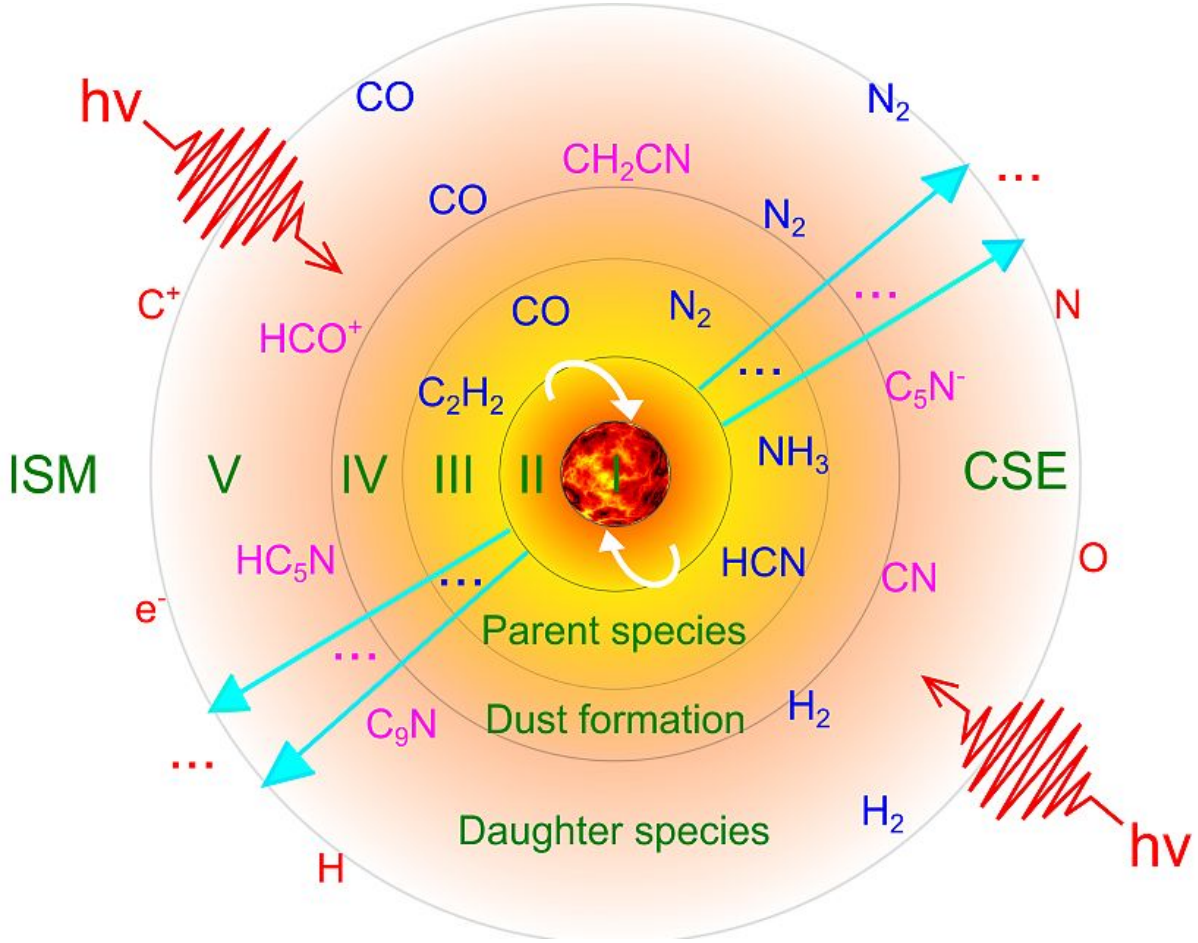
≈50% have been detected in <u>only</u> IRC+10216

Some new species were first detected in +10216,

FeCN, CN^-, ...

C-rich AGB star
(C/O > 1)

A model of an AGB star (Li et al. 2014)

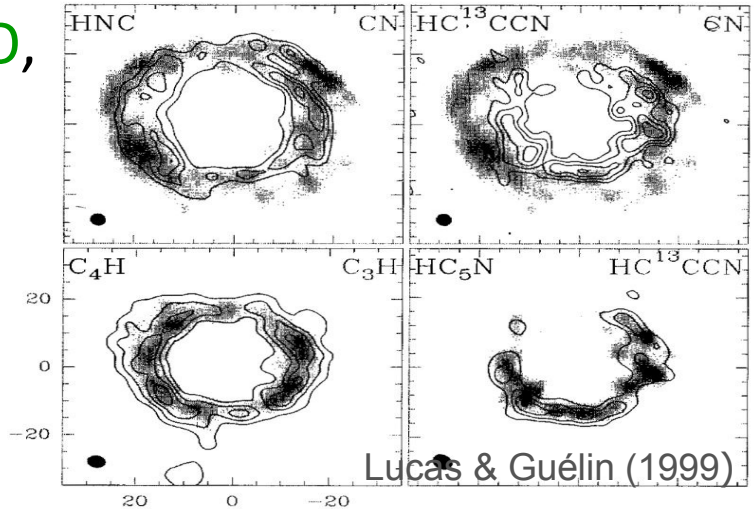


Outer CSE, photodissociation process drives the chemistry

N_2 and CO: high abundances, significantly shielded from photodissociation

IRC+10216 (CW Leo) -- Molecule factory!

- Nearest C-rich AGB star (~150 pc), with high mass-loss rate
- The brightest object in the sky at mid-infrared wavelengths outside the solar system
- "Molecule factory": > 80 species observed in its envelope, e.g., CO, C_3N^-, C_5N^- NaCN etc. This is ~ 50% over the totally known species (~ 160). Even H_2O, was detected
- Among these, more than 30 are N-bearing species, **Nitrogen Chemistry is a "hot" topic!**
- Ongoing discoveries driven by sensitive telescopes (ALMA, PdBI, ...)

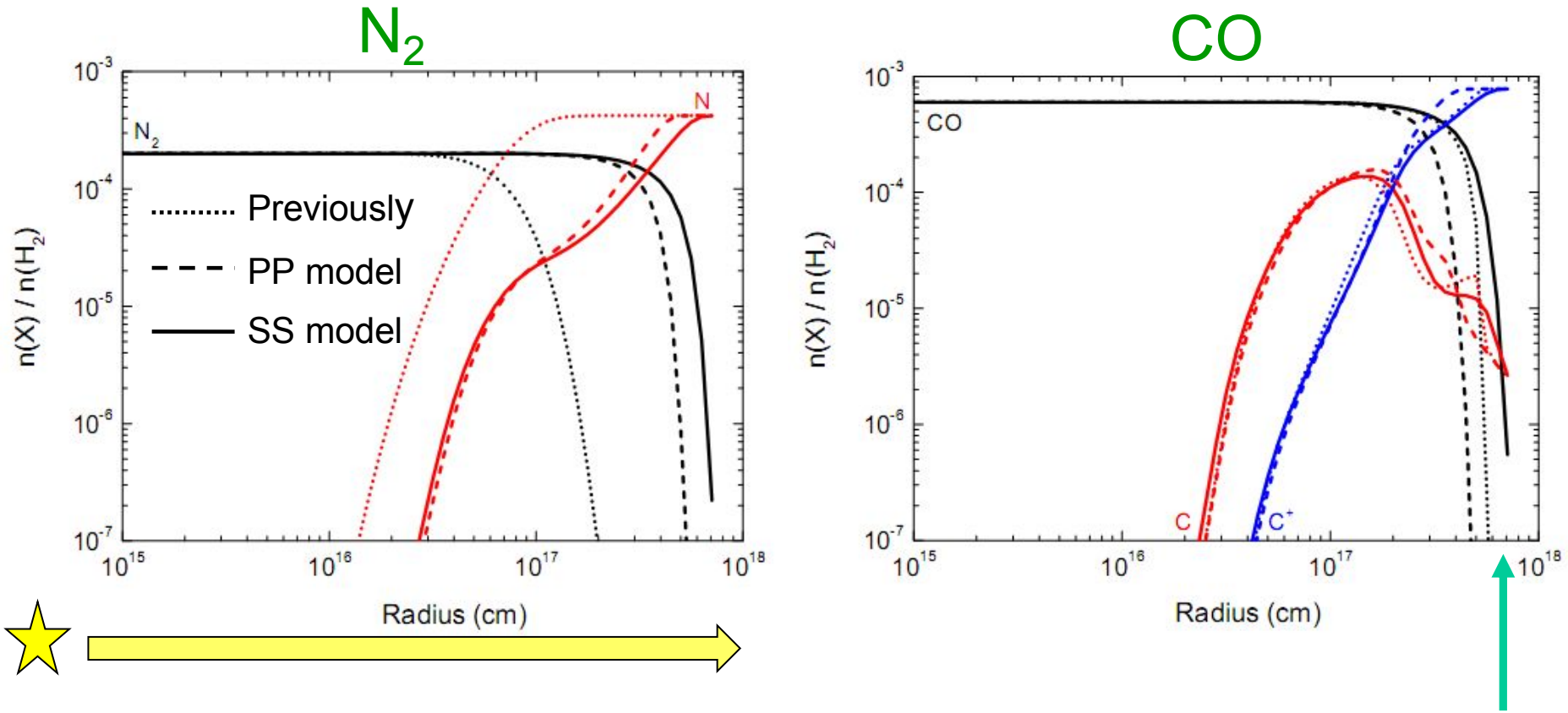


It has a complex structure!

Improvements in our model (Li et al., 2014, 2015)

Rate12 (McElroy et al. 2013)	vs	Our model
2.0×10^{-10} s^{-1} (van Dishoeck, 1988), 2.0×10^{-10} s^{-1} (van Dishoeck, 1988).	1. Photodissociation rate a. CO b. N_2	2.6×10^{-10} s^{-1} (Visser et al., 2009), 1.7×10^{-10} s^{-1} (Li et al., 2013).
Dust + Self-shielding (Morris & Jura (1983), did not consider H_2 shielding.	2. Shielding functions a. CO	Dust + Self-shielding + H_2 Full shielding! (Visser et al., 2009)
Excluded.	b. N_2	Dust + Self-shielding + H_2 Full shielding (Li et al., 2013)
"Single-band" approximation	3. Method for Implementing of shielding functions.	We employed a new method, much more accurate!

The abundance distributions of N_2 and CO



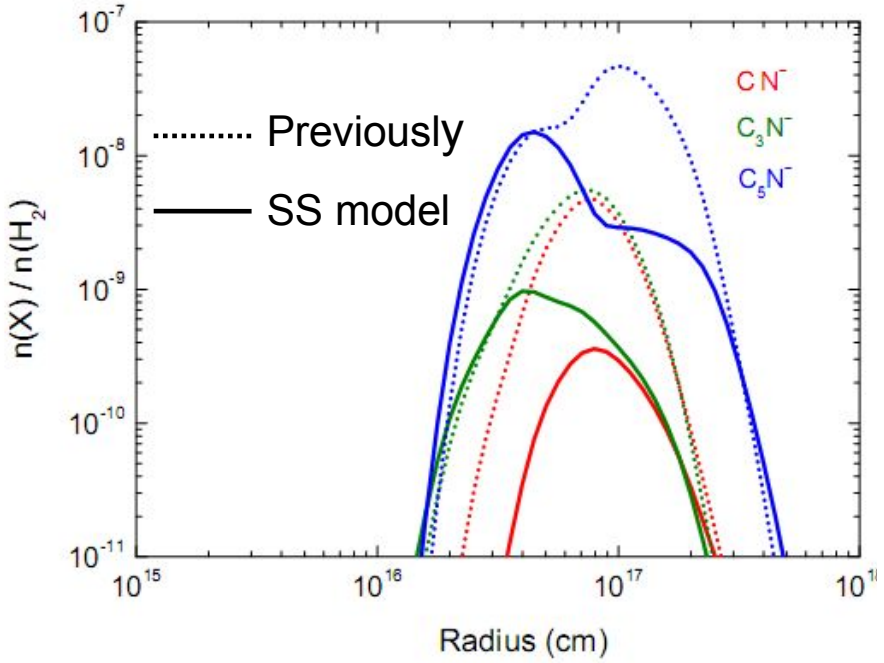
Observations: weak CO emission detected up to R=300”!

spherically- symmetric (SS) vs. plane-parallel (PP) model

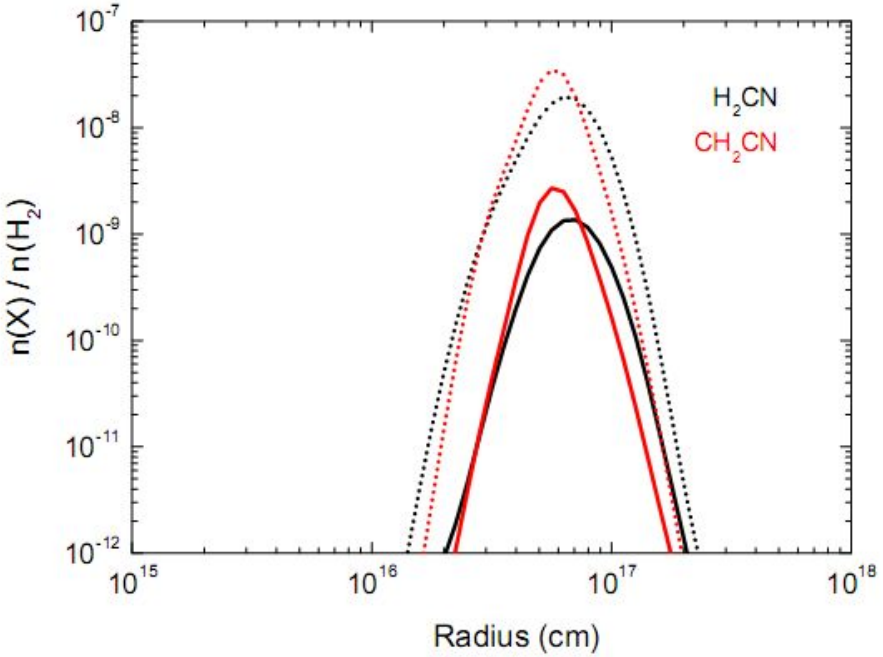
SS model, considering photons from all directions

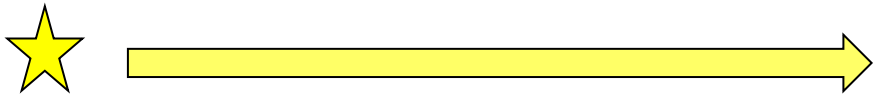
Other N-bearing species

C_nN^-



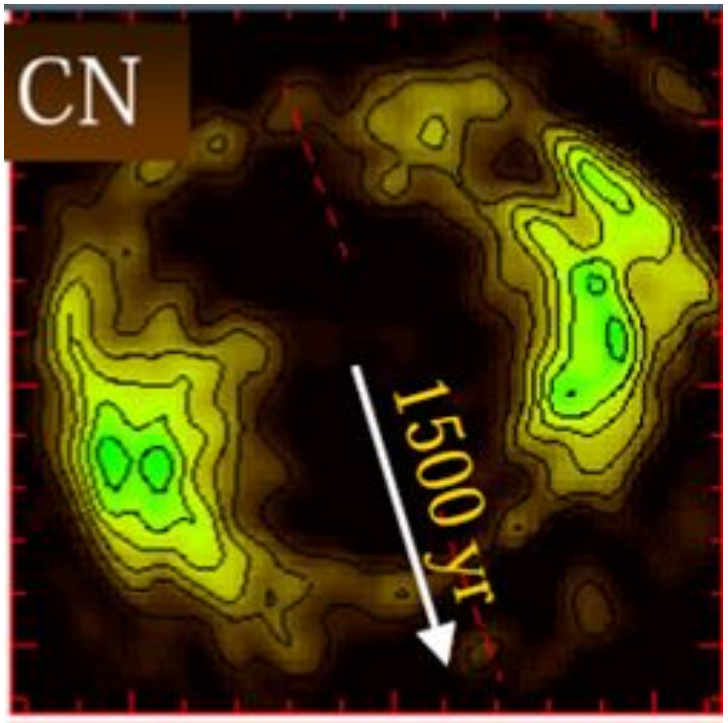
H_2CN & CH_2CN





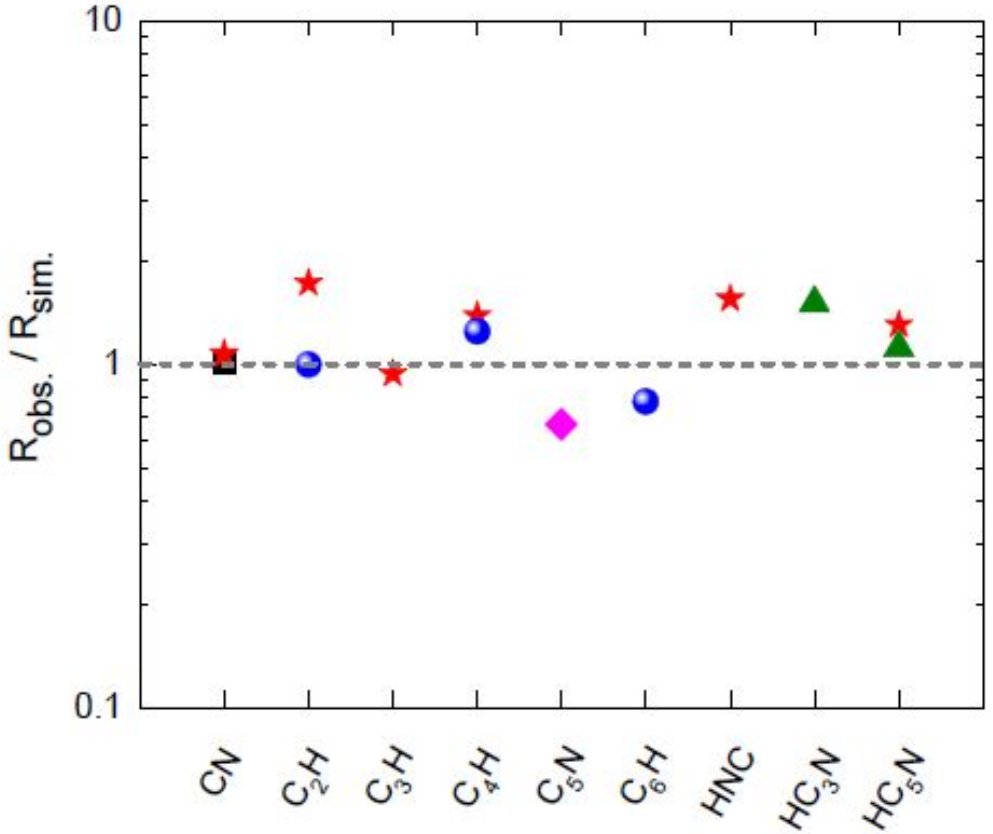
Major effects: (1) radii of peak abundances (2) total column densities

Radius of peak abundances



IRAM Plateau de Bure interferometer

(Lucas and Guélin, 1993)

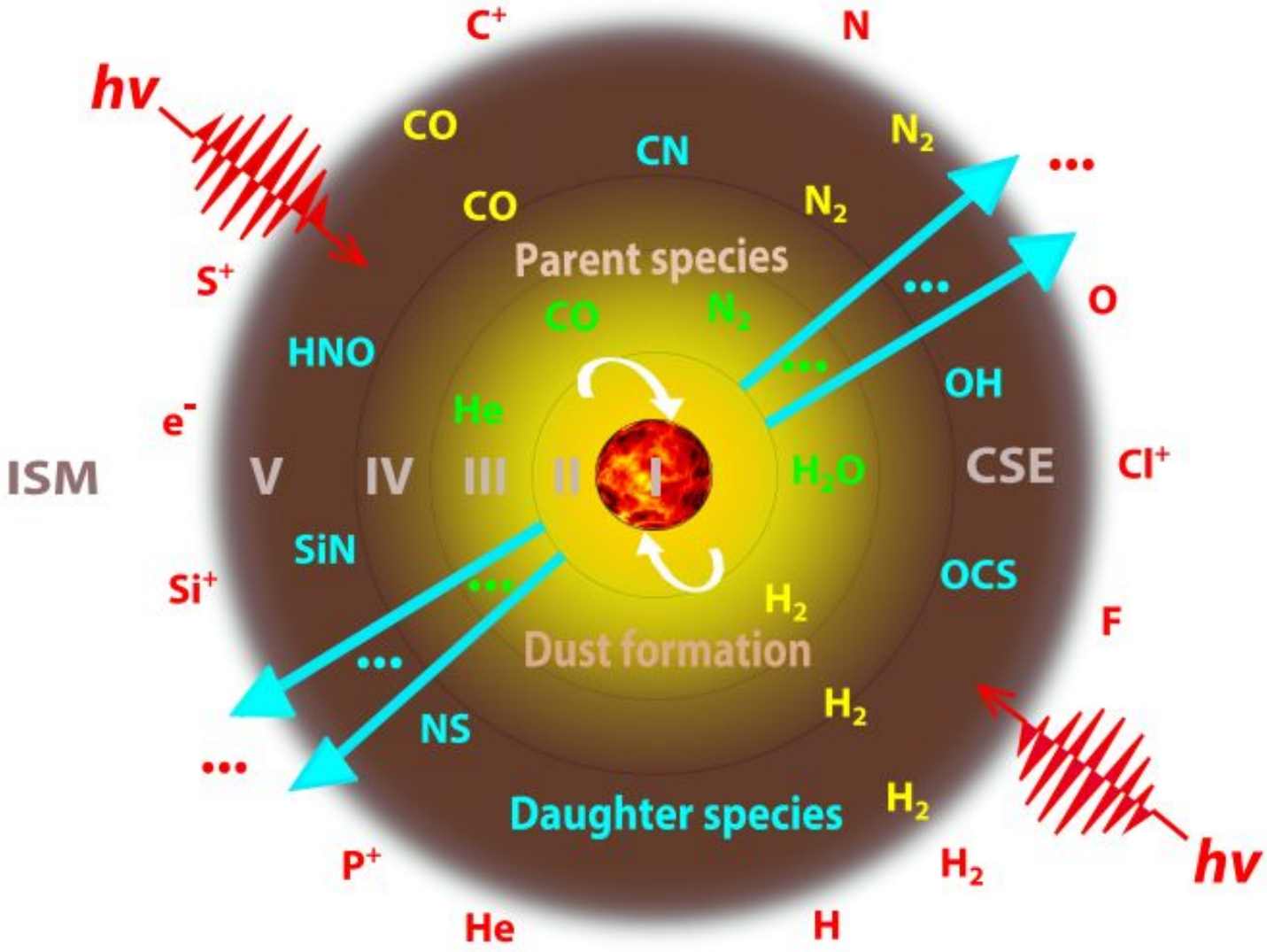


Observations vs. Simulations: differences are within a factor of two

ALMA, PdBI ... may verify other new predictions (> 46 species)

O-rich AGB star
(C/O < 1)

A model of an O-rich AGB star: IK Tau (Li et al. 2015)

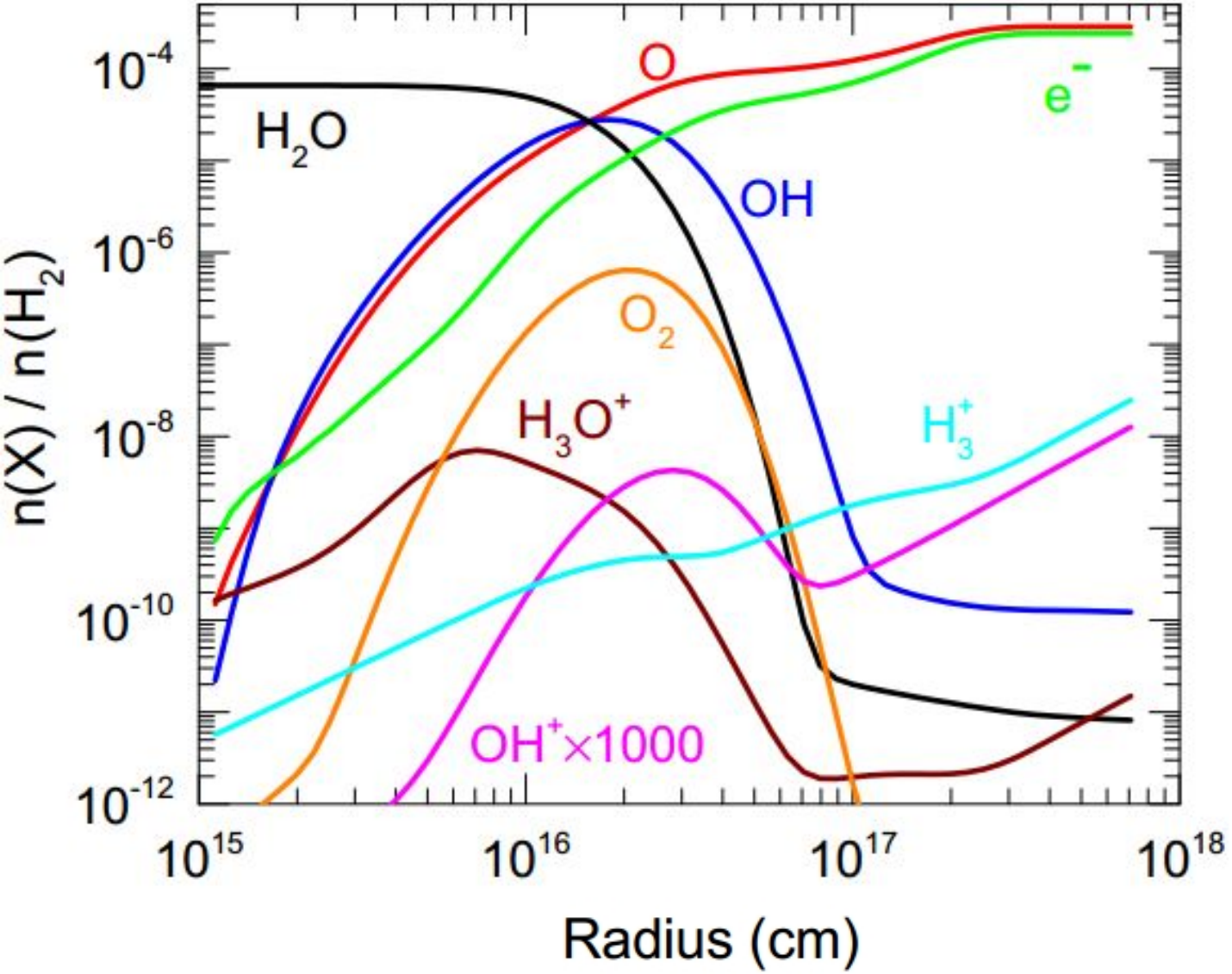


Results

We studied all C-, N-, O-, **Si-, S-, P-, Cl-, and F-** bearing species

We found 36 high-abundant species which are possible to be detected in the near future

Results (one example)



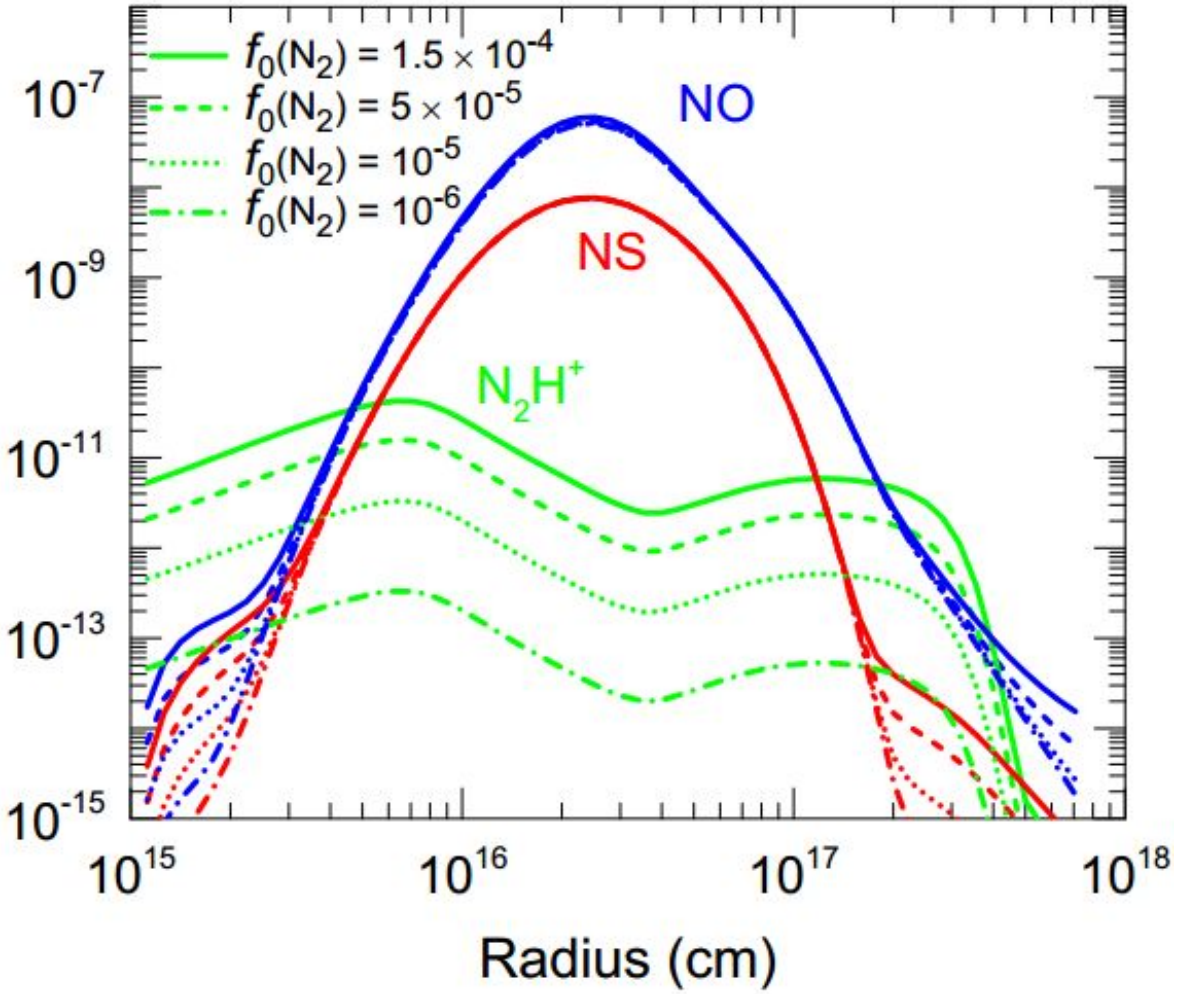
Future

Something interesting to do:

Seek observational evidences for our new discoveries!

Our hope is ALMA!

Observe N_2H^+ (daughter) to infer N_2 (parent) abundance



$$N_2 + H_3^+ \Rightarrow N_2H^+ + H$$

Conclusions

- Photodissociation of N_2 is fully understood, accurate rate and shielding functions are avaliable (Li et al. 2013)
- Large effect on $N_2 \rightarrow N$ transition radius and nitrogen chemistry.
- Newly studied: AGB chemistry (both C- and O- rich) (Li et al. 2014, 2015)
- Found observable sensitivities of chemical products to parent species, e.g.,N_2H^+
- N_2 and CO shielding functions are available at http://home.strw.leidenuniv.nl/~ewine/photo/

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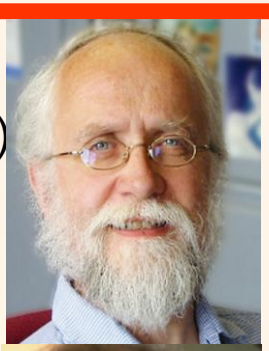

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Thanks for your attention!