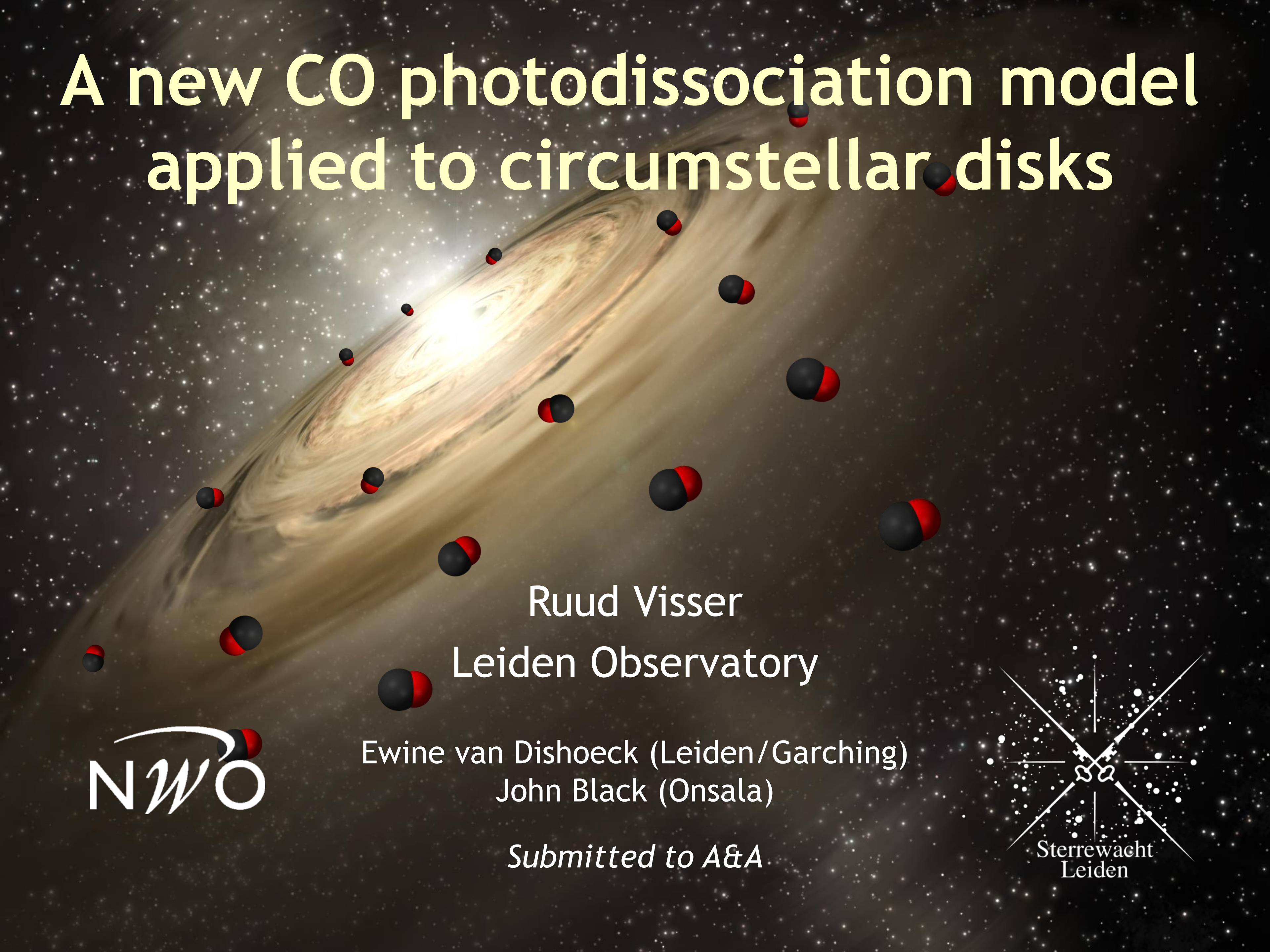


A new CO photodissociation model applied to circumstellar disks

Ruud Visser

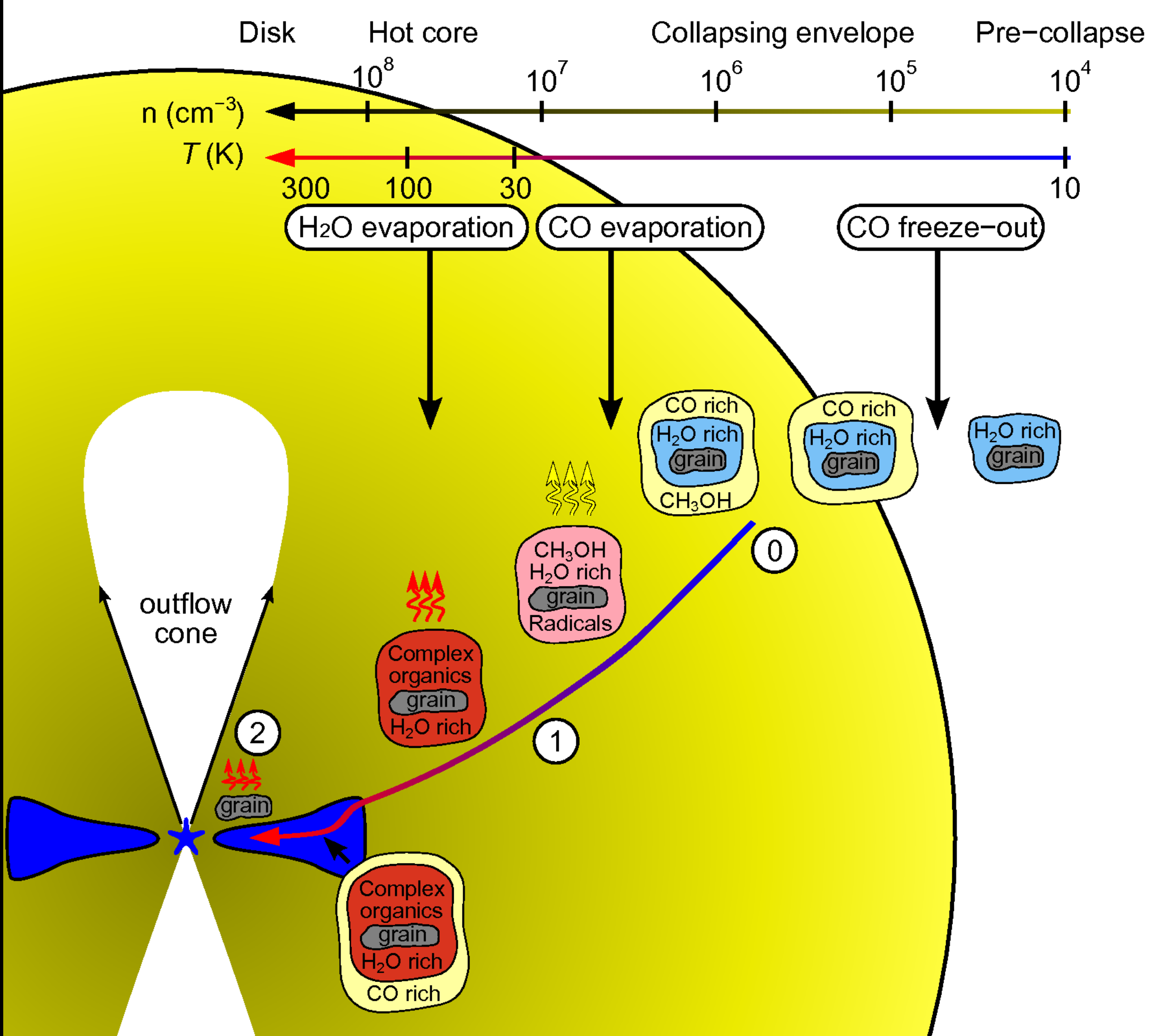
Leiden Observatory

Ewine van Dishoeck (Leiden/Garching)
John Black (Onsala)

Submitted to A&A

Low-mass star formation

Evolution of gas and dust



Oxygen isotopes in meteorites

- Stability at low temperature:

$$Si^{18}O_4 > Si^{17}O_4 > Si^{16}O_4$$

- Isotope enhancement (typically a few %):

$$\varepsilon({}^{y}O) = \frac{([{}^{y}O]/[{}^{16}O])_{silicate}}{([{}^{y}O]/[{}^{16}O])_{elemental}} \qquad (y=17 \text{ or } 18)$$

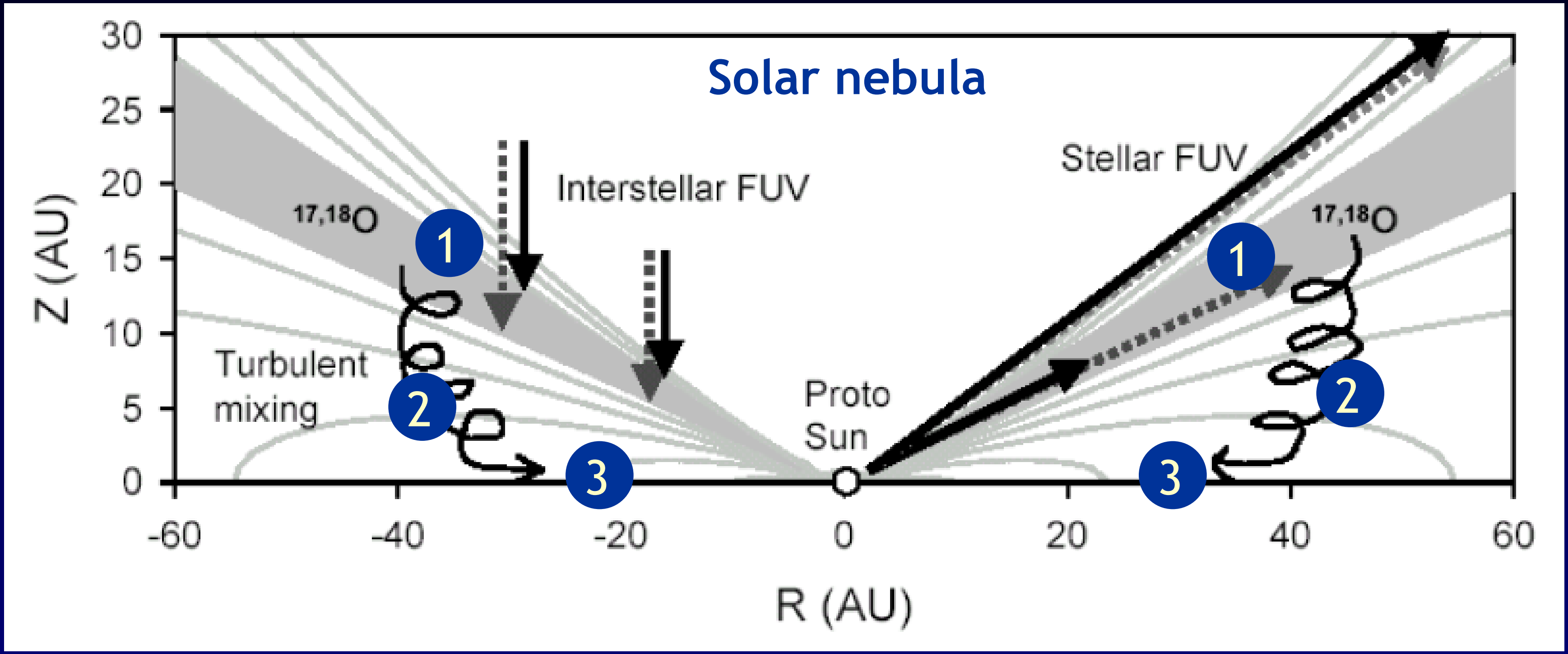
- Expected in meteorites (Matsuhisa et al. 1978):

$$\varepsilon({}^{17}O) = (0.52 \pm 0.01)\ \varepsilon({}^{18}O)$$

- Measured (Clayton et al. 1973):

$$\varepsilon({}^{17}O) = (1.0 \pm 0.1)\ \varepsilon({}^{18}O)$$

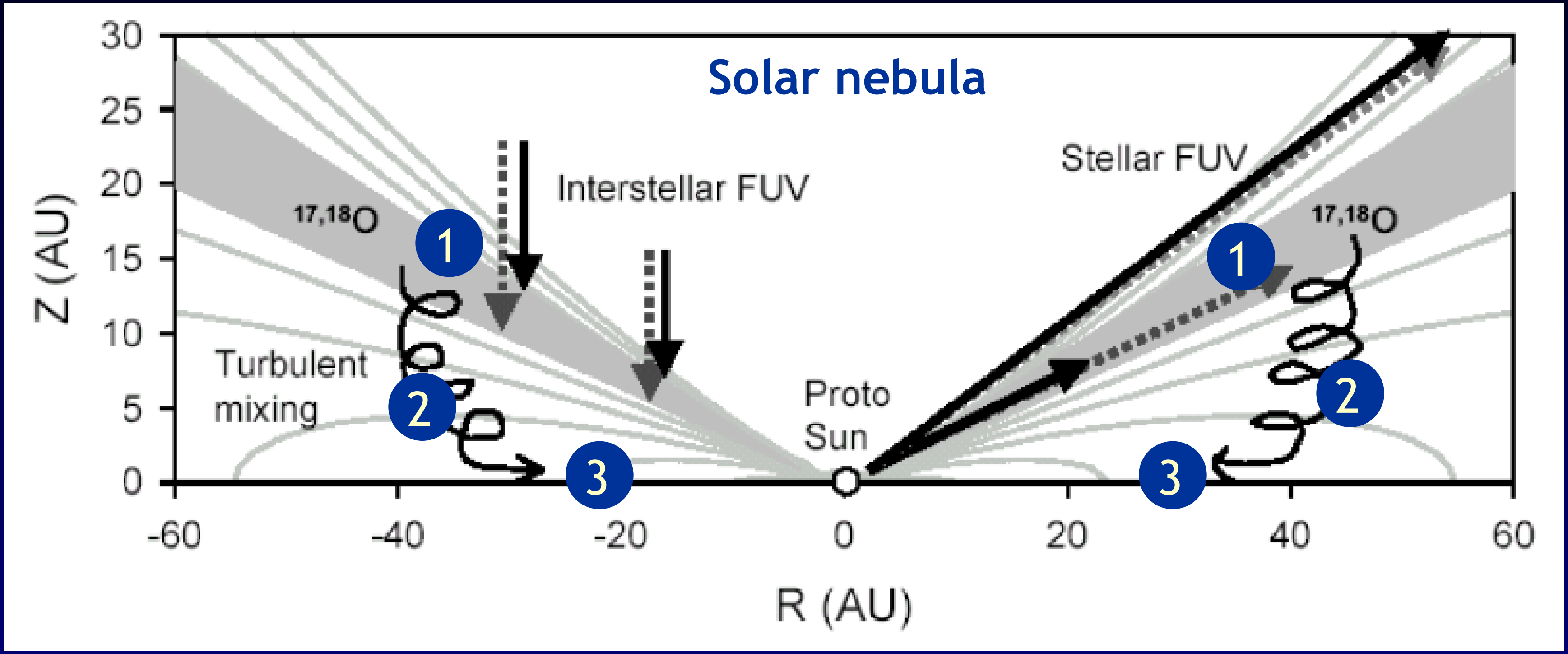
Origin of the isotope anomaly?



1. $C^{17}O$, $C^{18}O$ dissociate faster than $C^{16}O$
2. Enhanced ^{17}O, ^{18}O transported down from surface
3. Enhanced ^{17}O, ^{18}O incorporated into meteoroids

Lyons & Young (2005)

Origin of the isotope anomaly?



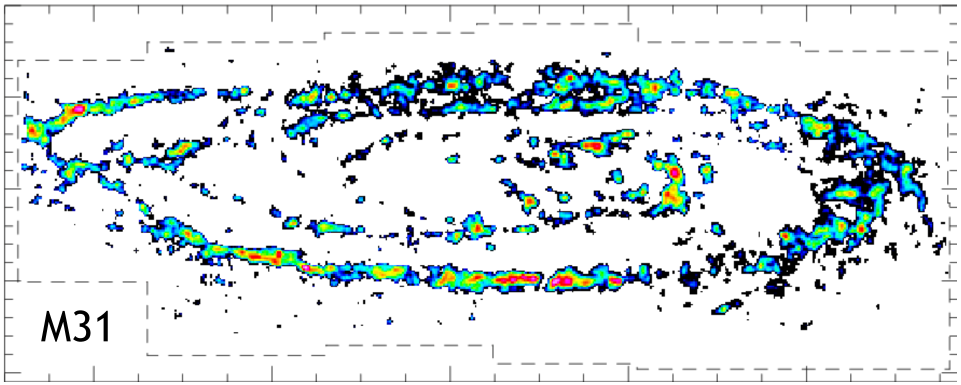
Untested assumption:

C^{17}O dissociates at same rate as C^{18}O

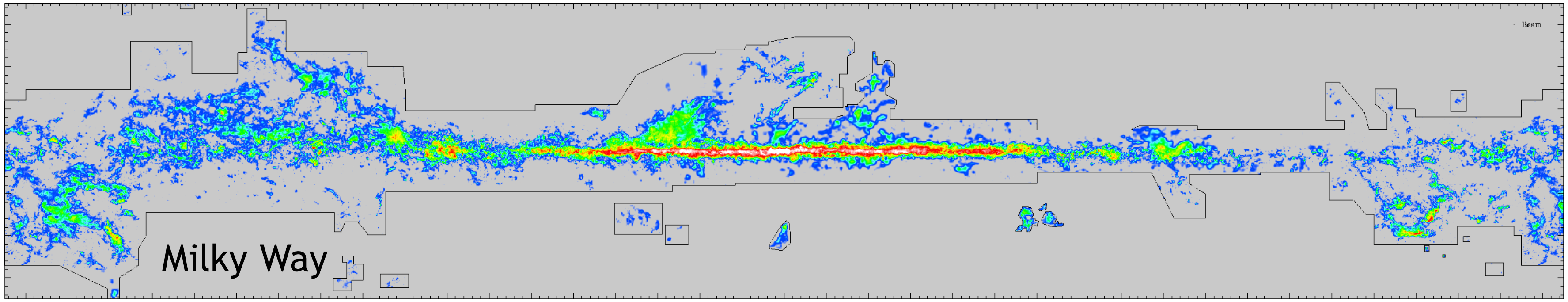
Lyons & Young (2005)

Carbon monoxide

- Main reservoir of gas-phase carbon
- Chemically stable
- Used as gas tracer
- Precursor to more complex molecules

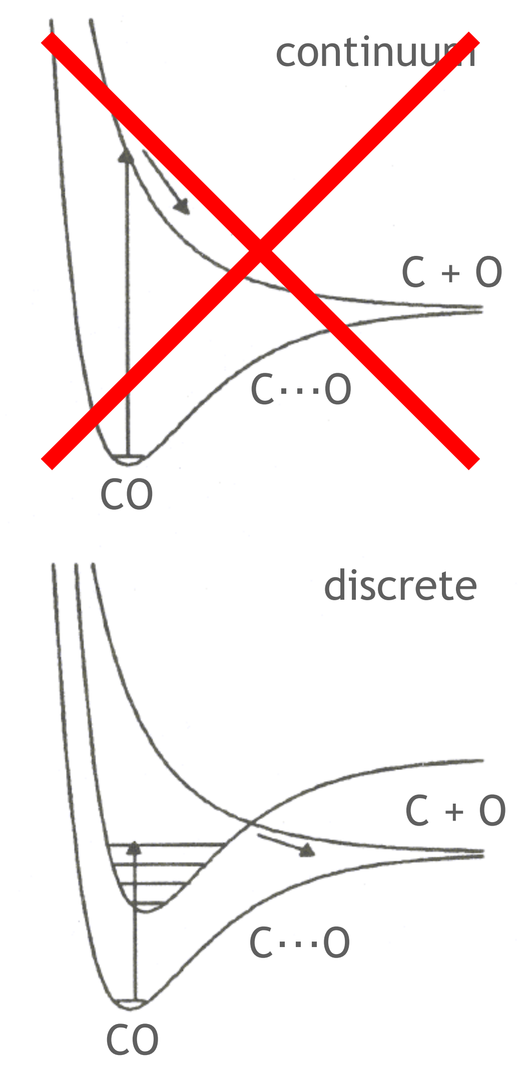


Nieten et al. (2006), Dame et al. (2001)

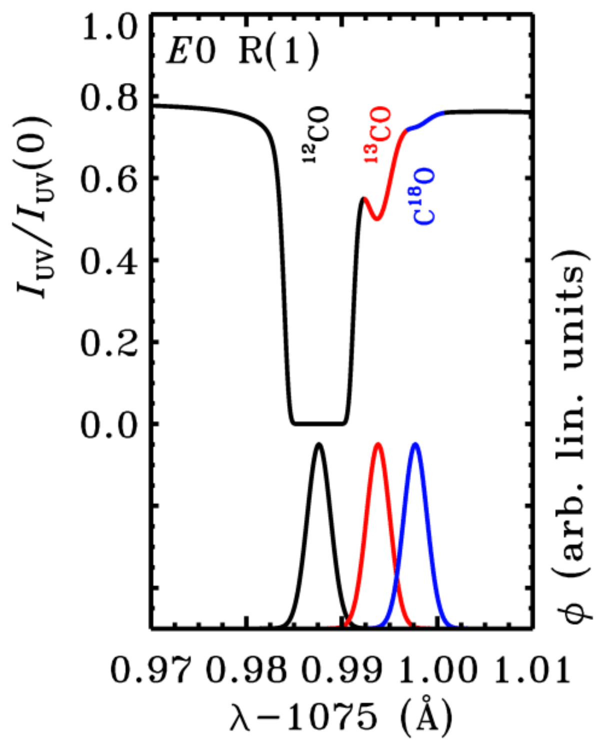


Isotopologues	$C^{16}O$	$C^{17}O$	$C^{18}O$	$^{13}C^{16}O$	$^{13}C^{17}O$	$^{13}C^{18}O$
Relative abundances	1	5.0(-4)	1.8(-3)	1.4(-2)	7.2(-6)	2.6(-5)

CO photodissociation



- $911.75 < \lambda < 1117.80$ Å ($13.6 > h\nu > 11.09$ eV)
- Discrete transitions only
- Subject to self-shielding



Self-shielding:

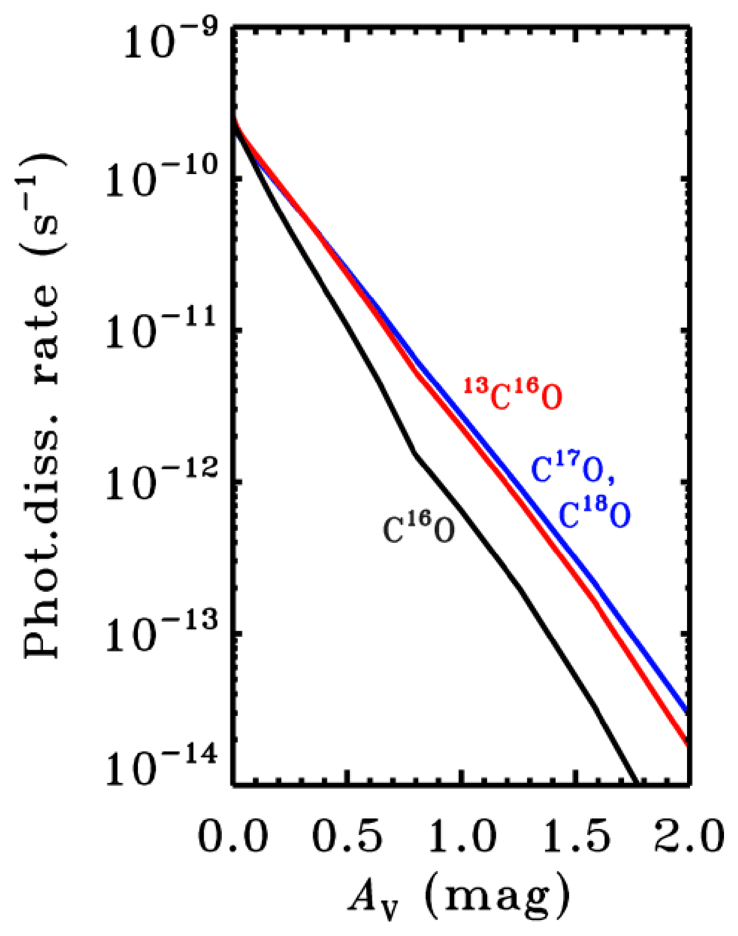
- ^{12}CO full
- ^{13}CO, C^{18}O partial
- C^{17}O, ^{13}C^{17}O, ^{13}C^{18}O not

Phot.diss. rate:

- ^{12}CO low
- ^{13}CO, C^{17}O, C^{18}O medium
- ^{13}C^{17}O, ^{13}C^{18}O high

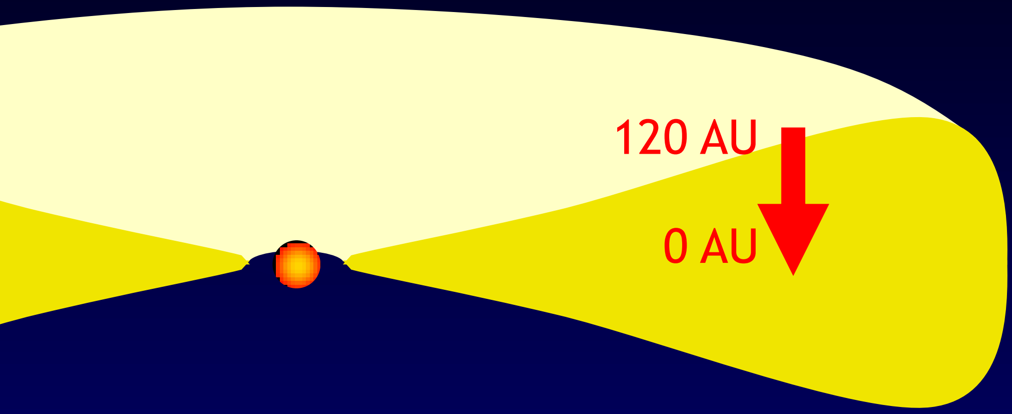
UV photodissociation model

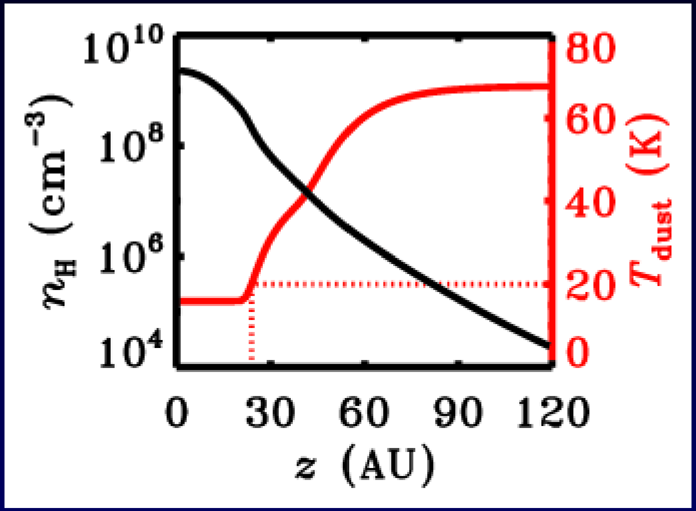
- Same method as van Dishoeck & Black (1988)
- 37 electronic transitions, 5000 individual lines
  - wavelength, oscillator strength, Einstein A from lab data
- Include H/H_2 lines and dust shielding
- Synthesize absorption spectrum for each isotopologue
- Integrate over UV radiation field (Draine, blackbody, …) to get photodissociation rate



Unshielded ISM rate: 2.6×10^{-10} s^{-1}
(30% higher than previous models)

Circumstellar disk model (1)

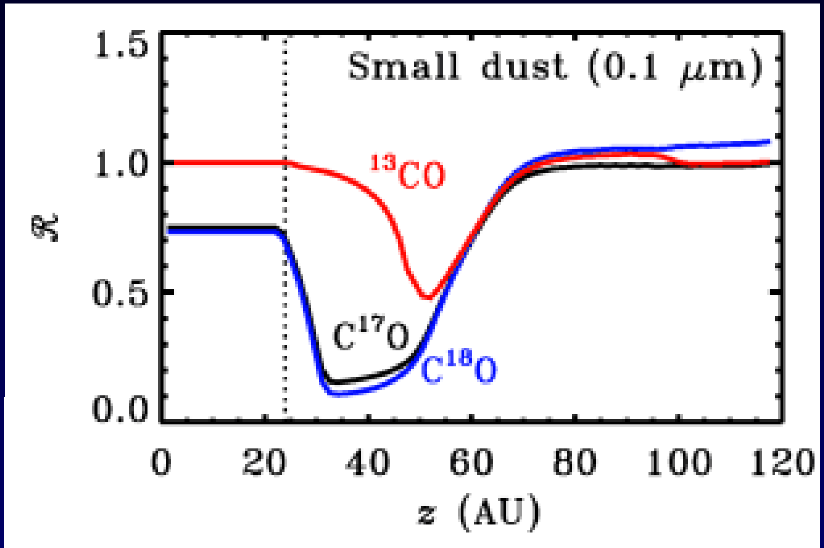




- Vertical cut at r = 105 AU
- CO freezes out below z = 24 AU (T_{dust} = 20 K)
- Normalized column density ratio:

$$R_i(z) = \frac{N_z({}^{x}\mathrm{C}{}^{y}\mathrm{O})}{N_z(\mathrm{C}{}^{16}\mathrm{O})}\,\frac{[{}^{12}\mathrm{C}]}{[{}^{x}\mathrm{C}]}\,\frac{[{}^{16}\mathrm{O}]}{[{}^{y}\mathrm{O}]}$$

Circumstellar disk model (2)



- ^{13}CO, C^{17}O, C^{18}O, ^{13}C^{17}O, ^{13}C^{18}O all reduced w.r.t. C^{16}O
- Low-T chemistry replenishes some ^{13}C^{16}O
- ^{17}O and ^{18}O are equally fractionated [$\varepsilon(^{18}O) = \varepsilon(^{17}O)$]

Conclusions

- New CO photodissociation rate 30% higher than in previous models
- C^{17}O dissociates at same rate as C^{18}O
  - Confirms Lyons & Young hypothesis for ^{17}O/^{18}O ratio in meteorites
- Isotope ratios in disks can vary by a factor of 10 from elemental ratios