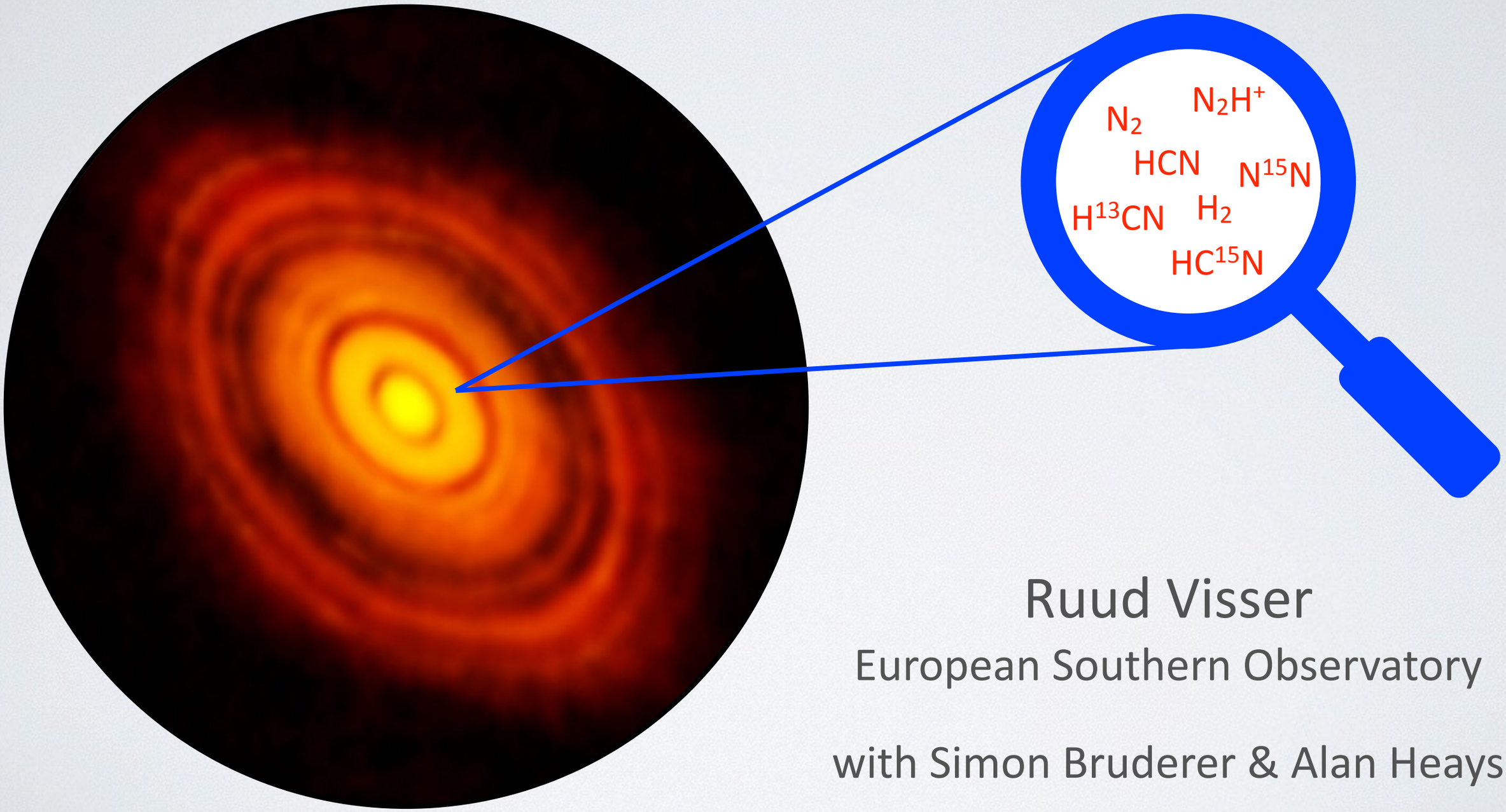
Isotopic Fractionation of Nitrogen in Protoplanetary Disks



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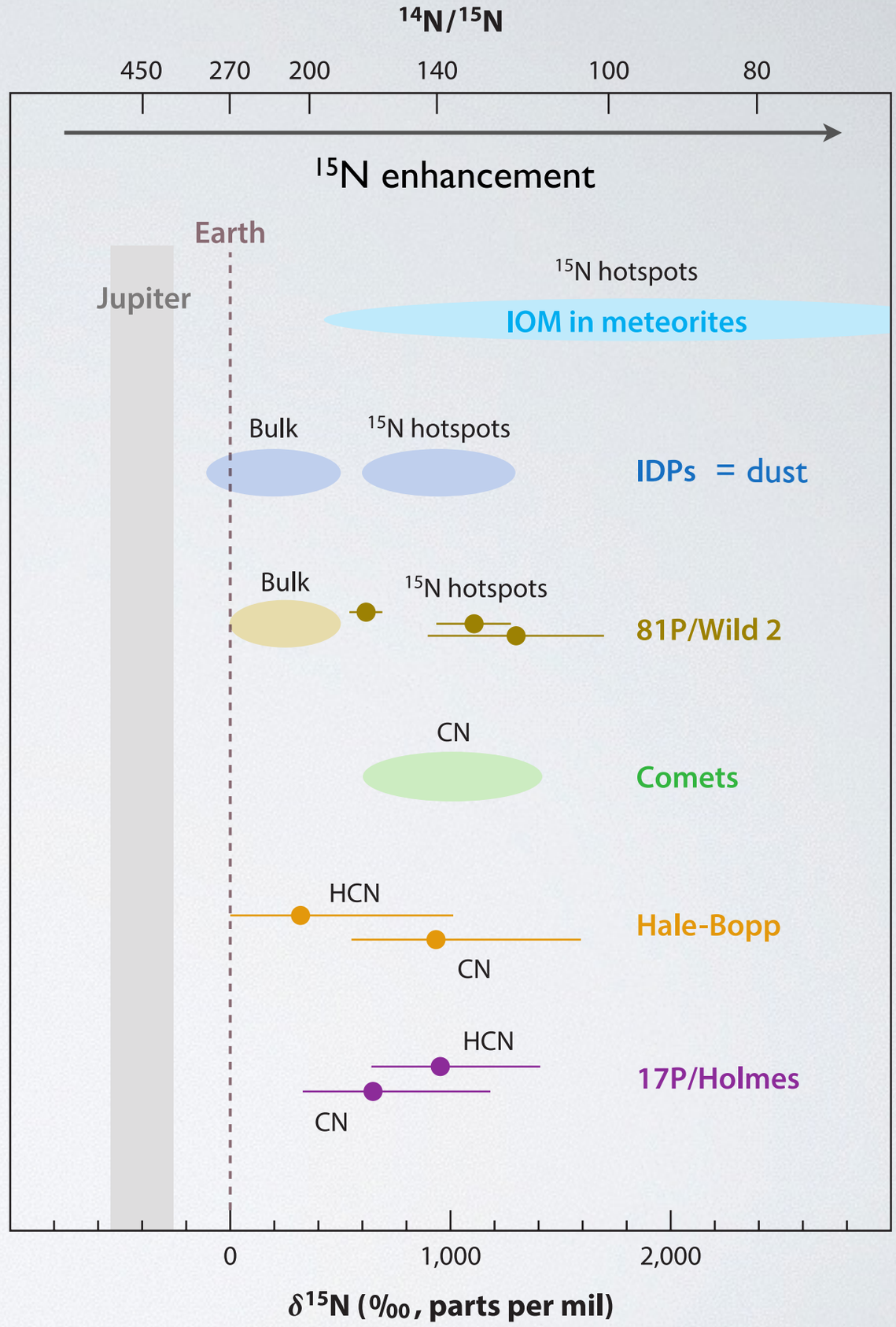
European Southern Observatory

with Simon Bruderer & Alan Heays

February 4, 2015

NITROGEN FRACTIONATION

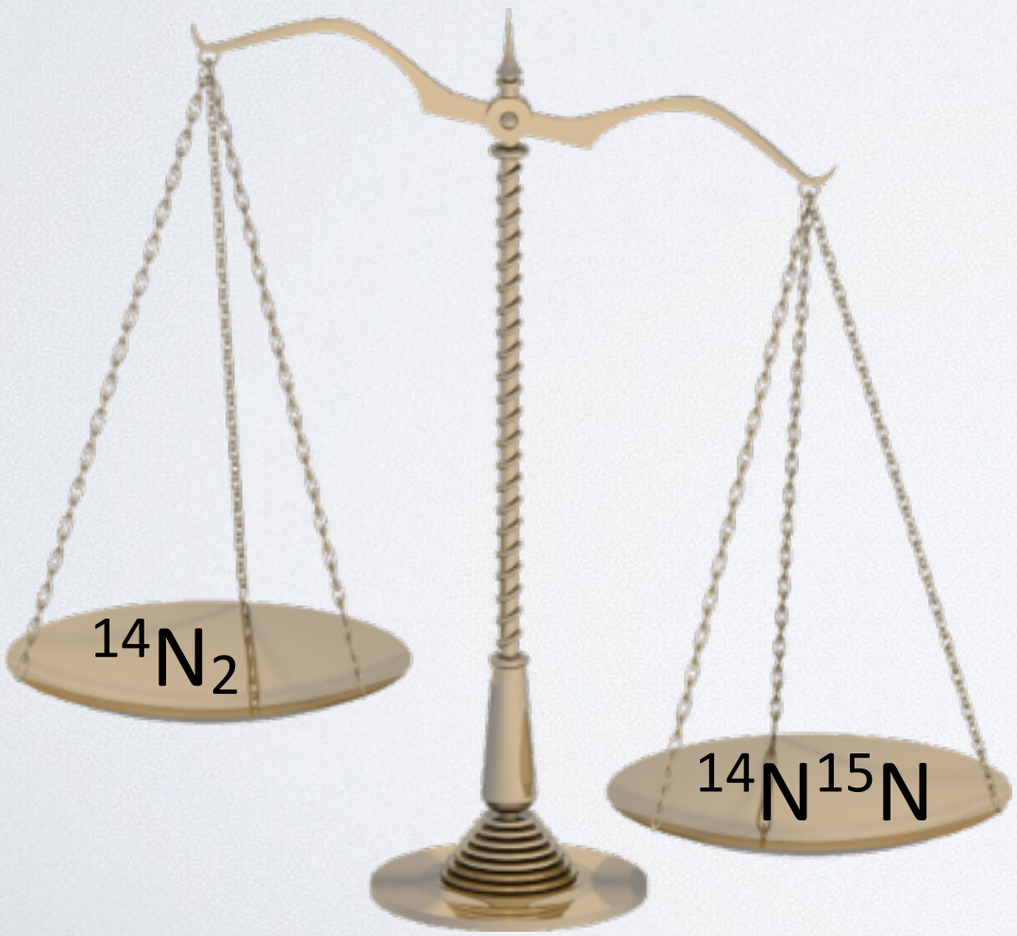
- $^{14}N/^{15}N \approx 450$ in local ISM
- Ratio is reduced in much of the solar system (measured in CN and HCN)
- What is the origin of the ^{15}N enhancement?

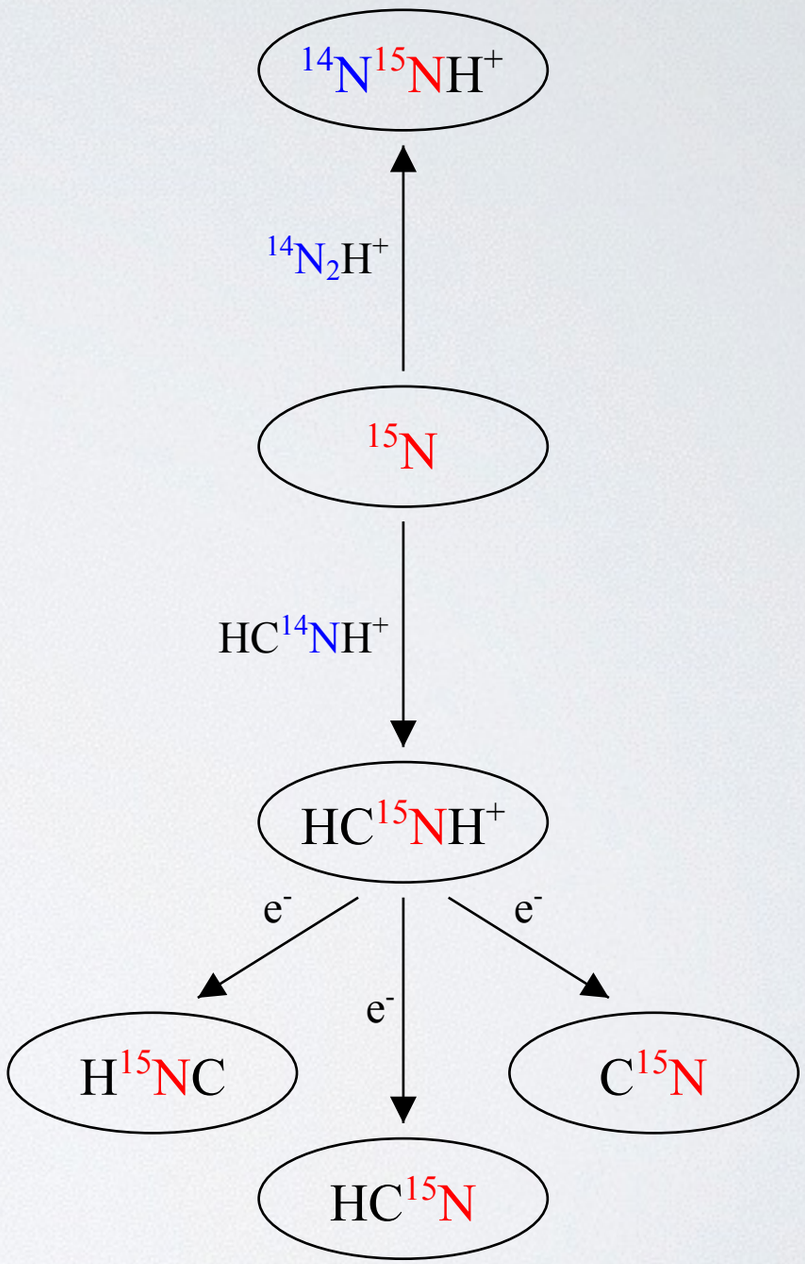


Bockelée-Morvan (2010), Mumma & Charnley (2011)

LOW-*T* ISOTOPE EXCHANGE

- Zero-point vibrational energy depends on molecular mass
- At $T \lesssim 20$ K, abundance of ^{15}NX enhanced relative to ^{14}NX





Terzieva & Herbst (2000), Wirström et al. (2012)

LOW-*T* ISOTOPE EXCHANGE

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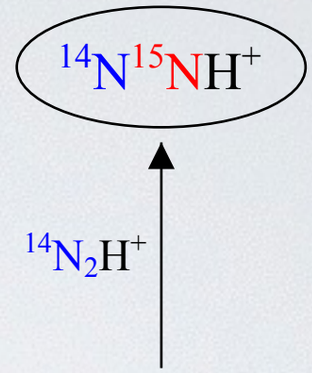
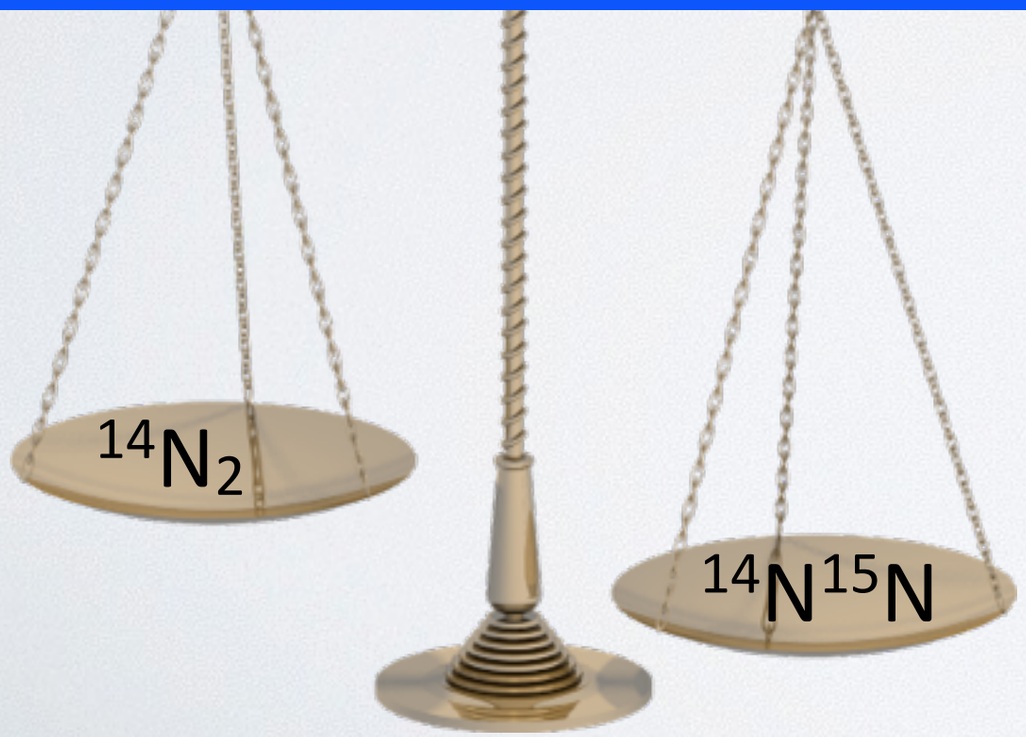
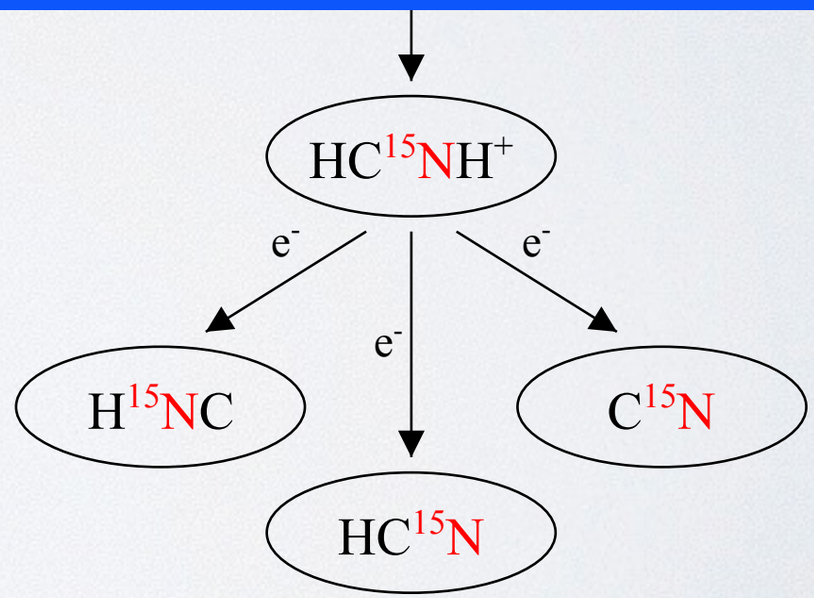


Is this enough to explain fractionation in the solar system?

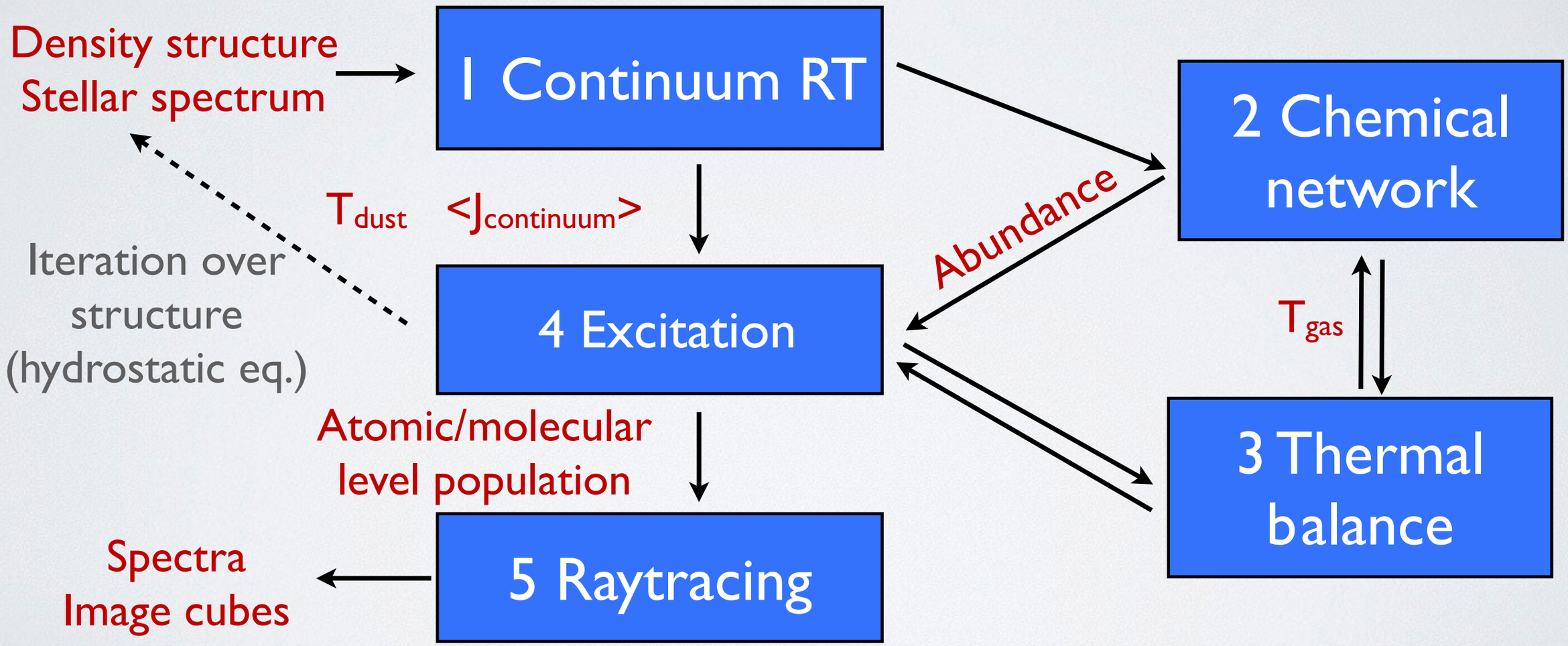




Terzieva & Herbst (2000), Wirström et al. (2012)

CIRCUMSTELLAR DISK MODEL

Dust And LInes: DALI
(Bruderer et al. 2009–2013, details & tests in 2012, 2013)



HCN / $HC^{15}N$

- $M_\star$ = 2.6 $M_\odot$, $M_{\rm disk}$ = 10^{-4} $M_\odot$
- Age = 10^6 yr
- $L_\star$ = 1.2 $L_\odot$, $L_{\rm UV}$ = 0.018 $L_\odot$

A figure with unpublished results
has been removed before posting on the web.

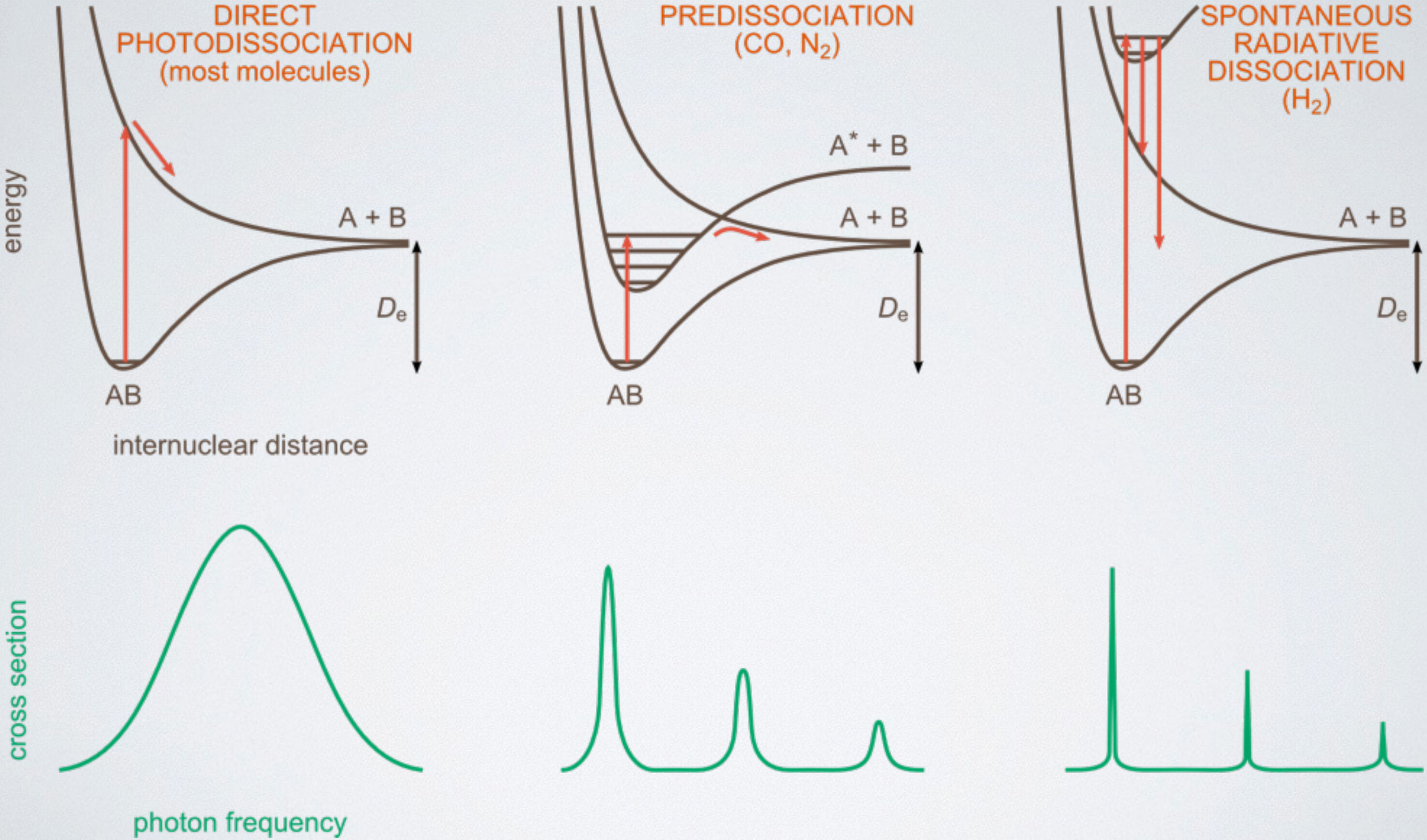
Contact rvisser@eso.org for details.

- Grain populations:
  - 99% small (0.005–1 μm)
  - 1% large (1–1000 μm)

Enhancement too small and too far out

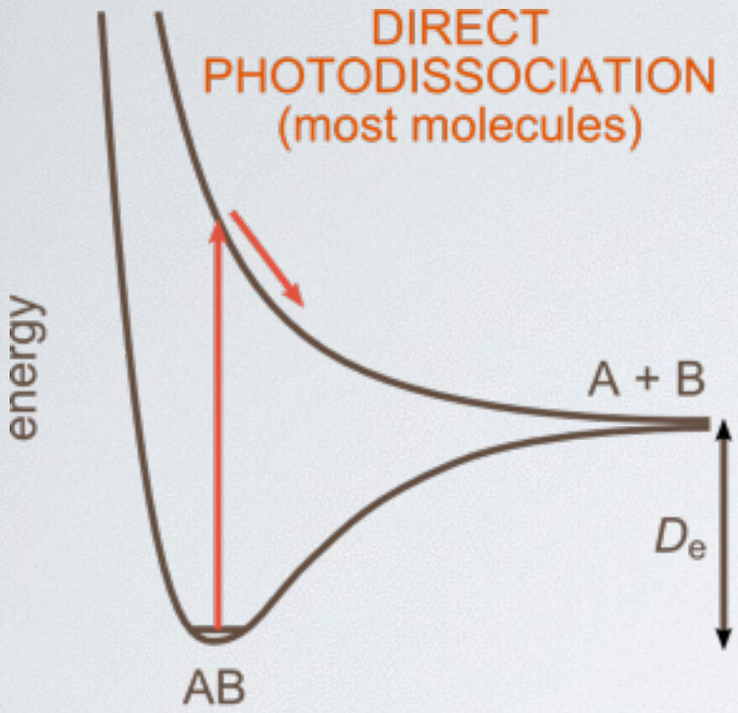
Visser et al. (in prep.)

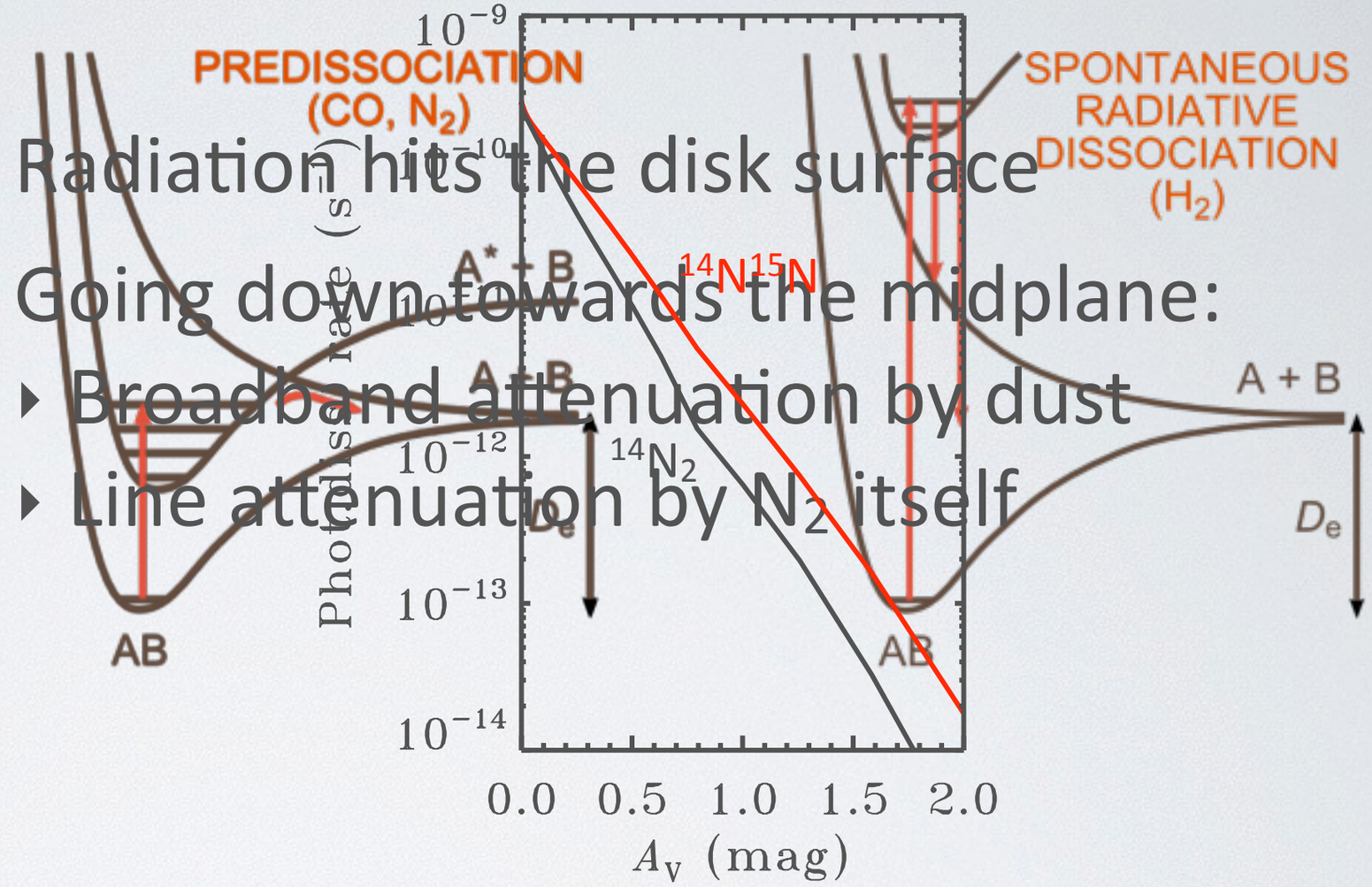
PHOTODISSOCIATION PROCESSES



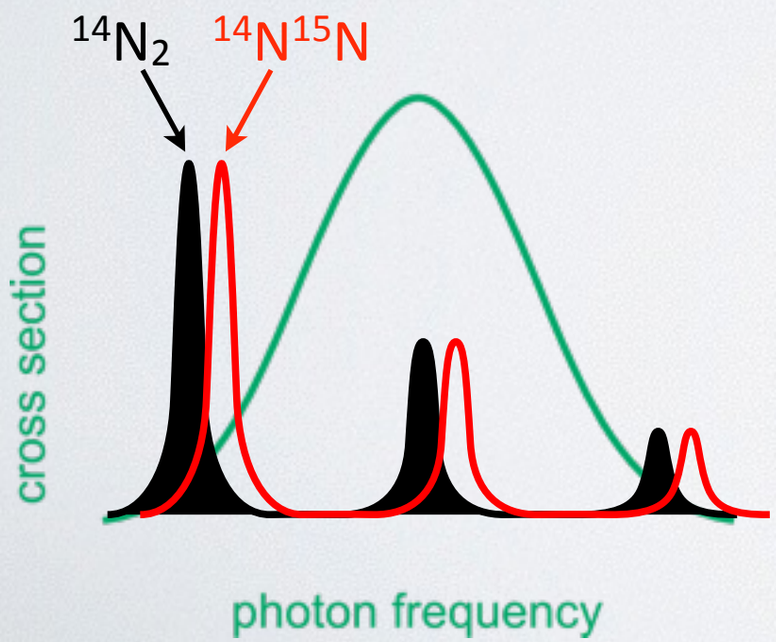
van Dishoeck (1988), van Dishoeck & Visser (2015)

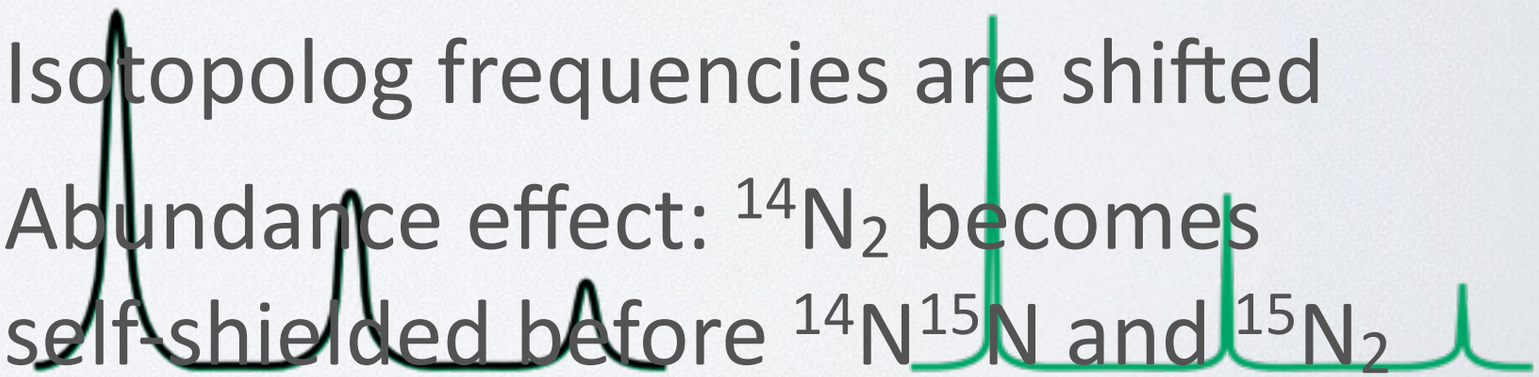
PHOTODISSOCIATION PROCESSES





- Radiation hits the disk surface
- Going down towards the midplane:
  - Broadband attenuation by dust
  - Line attenuation by N_2 itself





- Isotopolog frequencies are shifted
- Abundance effect: $^{14}N_2$ becomes self-shielded before $^{14}N^{15}N$ and $^{15}N_2$

van Dishoeck (1988), van Dishoeck & Visser (2015)

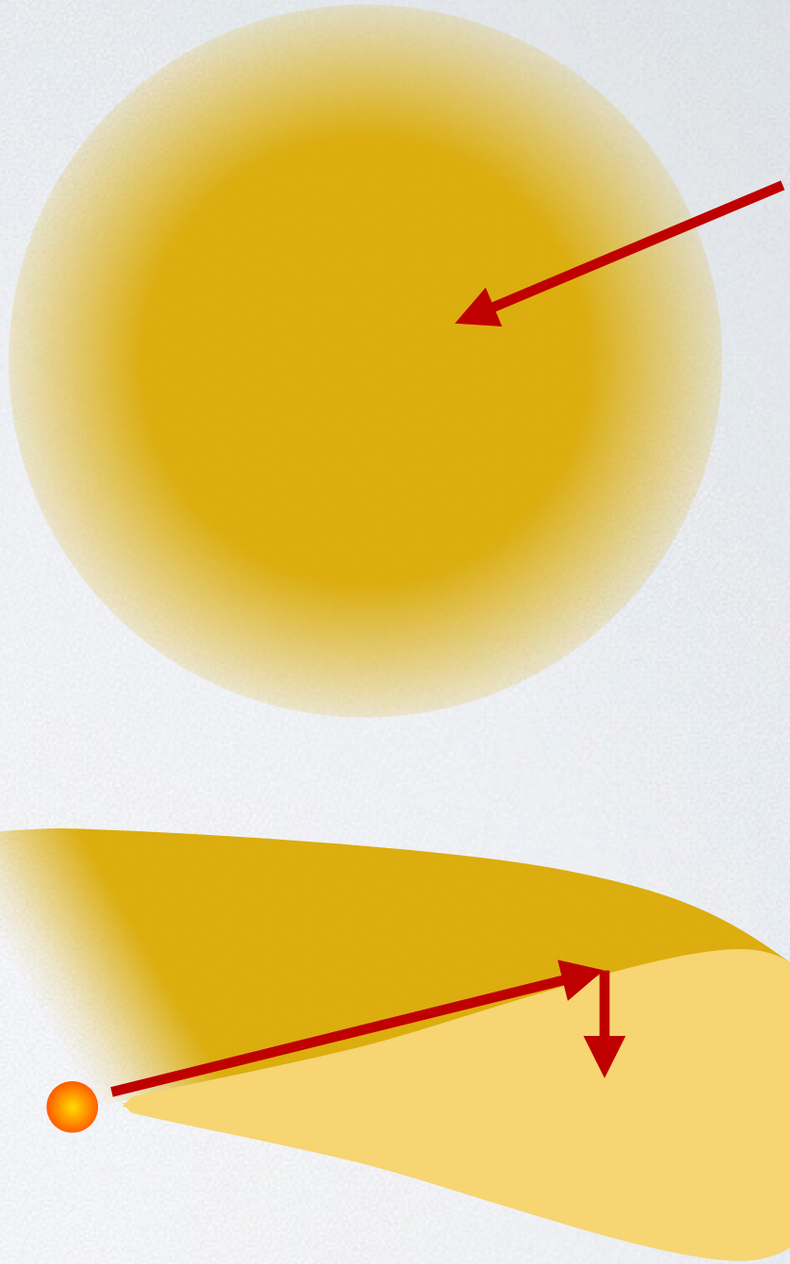
Self-shielding in models

- Synthetic UV absorption spectra based on lab data
- Include H and H_2
- Use shielding functions:

$$k_{pd} = k_0 \, \Theta \, \exp(-\gamma A_V)$$

Θ depends on $N(N_2)$, $N(H)$, $N(H_2)$, T, …

- Trivial in 1D geometry, much harder in 2D



Li et al. (2013), Heays et al. (2014), Miotello et al. (2014), Visser et al. (in prep.)

$HCN / HC^{15}N$

Without self-shielding

With self-shielding

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have been removed before posting on the web.

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Stronger enhancement, still too far out

Visser et al. (in prep.)

GRAIN GROWTH

With self-shielding, 1% large grains

With self-shielding, 99% large grains

Two figures with unpublished results
have been removed before posting on the web.

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Even stronger enhancement, well into planet/comet-forming zone

Visser et al. (in prep.)

CONCLUSIONS

- $^{14}N/^{15}N$ is reduced in much of the solar system (measured in CN and HCN)
- N_2 is prone to isotope-selective self-shielding
- Produces factor 10–100 enhancement in $HC^{15}N/HCN$ in disk models
- Beware: work in progress

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