ISOTOPIC FRACTIONATION OF NITROGEN IN PROTOPLANETARY DISKS

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NITROGEN FRACTIONATION

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

Bockelée-Morvan (2010), Mumma & Charnley (2011)
LOW-$T$ ISOTOPE EXCHANGE

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

Terzieva & Herbst (2000), Wirström et al. (2012)
LOW-$T$ ISOTOPE EXCHANGE

- Zero-point vibrational energy depends on molecular mass
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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
HCN / HC$^{15}$N

- $M_\star = 2.6 \, M_\odot, \, M_{\text{disk}} = 10^{-4} \, M_\odot$
- Age = $10^6$ yr
- $L_\star = 1.2 \, L_\odot, \, L_{\text{UV}} = 0.018 \, L_\odot$
- Grain populations:
  - 99% small (0.005–1 μm)
  - 1% large (1–1000 μm)

Enhancement too small and too far out

A figure with unpublished results has been removed before posting on the web.

Contact rvisser@eso.org for details.
PHOTODISSOCIATION PROCESSES

DIRECT PHOTODISSOCIATION (most molecules)

PREDISSOCIATION (CO, N₂)

SPONTANEOUS RADIATIVE DISSOCIATION (H₂)

PHOTODISSOCIATION PROCESSES

• Radiation hits the disk surface
• Going down towards the midplane:
  ‣ Broadband attenuation by dust
  ‣ Line attenuation by N\textsubscript{2} itself
• Isotopolog frequencies are shifted
• Abundance effect: \textsuperscript{14}N\textsubscript{2} becomes self-shielded before \textsuperscript{14}N\textsubscript{15}N and \textsuperscript{15}N\textsubscript{2}

SELF-SHIELDING IN MODELS

- Synthetic UV absorption spectra based on lab data
- Include H and H₂
- Use shielding functions:
  \[ k_{pd} = k_0 \Theta \exp(-\gamma A_v) \]
  \( \Theta \) depends on \( N(N_2), N(H), N(H_2), T, \ldots \)
- 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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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

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

Visser et al. (in prep.)
CONCLUSIONS

• $^{14}\text{N}/^{15}\text{N}$ is reduced in much of the solar system (measured in CN and HCN)

• $\text{N}_2$ is prone to isotope-selective self-shielding

• Produces factor 10–100 enhancement in $\text{HC}^{15}\text{N}/\text{HCN}$ in disk models

• Beware: work in progress

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