15N Fractionation in Infrared Dark Cloud Cores

Shaoshan (Sandy) Zeng, Izaskun Jiménez-Serra, Giuliana Cosentino, Serena Viti, Ashley Barnes, Jonathan Henshaw, Paola Caselli, Francesco Fontani, Piere Hily-Blant


NITROGEN FRACTIONATION IN SPACE
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Nitrogen fractionation

Interstellar ratios spread in a wide range!

Origin of N-fractionation is poorly constrained!

The $^{14}\text{N}/^{15}\text{N}$ isotopic ratio has been measured across different astronomical environments:

- **Small Solar System bodies** e.g. comets, meteorites, interplanetary dust particles (IDPs)  

- **Protoplanetary disks and Planets**  

- **Low-mass prestellar/starless cores and protostars**  
  *(Lis et al. 2010; Bizzocchi et al. 2013; Hily-Blant et al. 2013, Wampfler et al. 2014)*

- **High-mass regions with relatively active star-forming activities**  
  *(Adande & Ziurys 2012, Fontani et al. 2015, Colzi et al. 2017)*
Nitrogen fractionation

The Birthplace of our Solar System?

Most likely a **high-mass star cluster** containing at least 1000 stars with a few massive stars.

(Adams+2010; Dukes & Krumholz 2012; Pfalzner+2013)

Nitrogen chemistry depends on the temperature and density of the primordial gas in the parental cloud

(Roueff et al. 2015)

IRDCs cores show $T_{\text{kin}}$ 5-10 K + Densities ~ a factor of 10 higher than low-mass regions

Establish how N-fractionation is transferred from the pristine conditions to the subsequent stages of planetary system formation

Dependence of N-fractionation on $T_{\text{kin}}$ and density
IRDCs: general properties

Infrared Dark Clouds (IRDCs)

- Observed against the bright diffuse emission at mid-IR wavelength
- Cores = coldest and densest region within Giant Molecular Clouds
- Physical conditions resembling the early stages of the Solar System formation
  - \( T_{\text{kin}} = 15 - 20 \, \text{K} \) (Pillai et al. 2006)
  - \( n_H \approx 10^5 \, \text{cm}^{-3} \) (Bulter & Tan 2012)
  - \( H_2 \) column densities > \( 10^{22} \, \text{cm}^{-2} \) (Av~100 mag) (Kainulainen & Tan 2013)

IRDCs
- Size \( \sim \) few pc
- Mass \( \sim \) few 1000\( M_\odot \)

IRDC compact cores
- Size \( \sim \) 0.5 pc
- Mass \( \sim \) 100 \( M_\odot \)

- Active/Star-forming (masers/mid-IR/UC HIIIs)
- Intermediate
- Quiescent/Starless

(Chambers et al. 2009, Rathborne et al. 2010)
IRDCs: our sample

- Selected from the IRDCs sample studied by Rathborne et al. 2006

- 10 of these clouds (studied in Butler & Tan 2012) are selected with different morphologies and with different levels of star-formation activity based on the detection of 24µm and 8µm sources

- 4 IRDCs are targeted in this study:

<table>
<thead>
<tr>
<th>IRDCs</th>
<th>l [°]</th>
<th>b [°]</th>
<th>$V_{LSR}$ [kms$^{-1}$]</th>
<th>$\Sigma$ [gcm$^{-2}$]</th>
<th>M [M$_{\odot}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(G028.37+00.07)</td>
<td>28.373</td>
<td>0.076</td>
<td>78.6</td>
<td>0.520</td>
<td>45000</td>
</tr>
<tr>
<td>F(G034.43+00.24)</td>
<td>34.437</td>
<td>0.245</td>
<td>57.1</td>
<td>0.370</td>
<td>4460</td>
</tr>
<tr>
<td>G(G034.77-00.55)</td>
<td>34.771</td>
<td>-0.557</td>
<td>43.5</td>
<td>0.347</td>
<td>2010</td>
</tr>
<tr>
<td>H(G035.39-00.33)</td>
<td>35.395</td>
<td>-0.336</td>
<td>44.7</td>
<td>0.416</td>
<td>13340</td>
</tr>
</tbody>
</table>
Observation & Analysis

- GILDAS-CLASS software package
- Assuming LTE conditions and optically thin emission, $T_{\text{ex}} = 15K$
- Adopting Galactic gradient of $^{12}\text{C}/^{13}\text{C}$ ratio infer from $\text{CN}$ (Milam et al. 2005)

$^{12}\text{C}/^{13}\text{C}$ ratio calculated for each targeted IRDC regarding their galactocentric distance:

<table>
<thead>
<tr>
<th>IRDCs</th>
<th>$R_{gc}$ [kpc]</th>
<th>$^{12}\text{C}/^{13}\text{C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(G028.37+00.07)</td>
<td>4.65</td>
<td>40.2</td>
</tr>
<tr>
<td>F(G034.43+00.24)</td>
<td>5.74</td>
<td>46.8</td>
</tr>
<tr>
<td>G(G034.77-00.55)</td>
<td>6.24</td>
<td>49.8</td>
</tr>
<tr>
<td>H(G035.39-00.33)</td>
<td>6.27</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Examples of molecular spectra (Zeng et al. 2017)
No correlation between HCN and HNC isotopologues and level of star formation in IRDCs cores

(Zeng et al. 2017)
No correlation between HCN and HNC isotopologues and level of star formation in IRDCs cores

(Zeng et al. 2017)
Comparison: literature studies

**Comparison:**

<table>
<thead>
<tr>
<th></th>
<th>Literature studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCN</td>
<td>~70 -- ≥763</td>
</tr>
<tr>
<td>HNC</td>
<td>~161 -- ~541</td>
</tr>
</tbody>
</table>

**Propose idea:**
Density of the parental molecular gas may be the governing parameter of nitrogen fractionation in IRDCs.

Terrestrial Atmosphere (TA) = 272 (*Junk & Svec 1958*)
Proto-solar Nebula (PSN) = 440 (*Marty et al. 2011*)

**Properties of Cloud G itself**
- Least massive
- Lowest gas density
- Most diffuse
- No trace of star-formation activity

Cloud G shows relatively low $^{14}\text{N}/^{15}\text{N}$ ratio (70 – 293) compared to other IRDCs.

(Zeng et al. 2017)
Comparison: chemical model

Model predictions: *(Roueff et al. 2015)*
- $T = 10$ K
- $n_H = 2 \times 10^5$ cm$^{-3}$
- Significant $^{13}$C depletion at evolution time $\sim 1$M yrs

- Up to a factor of 2 difference depends on the molecule
- We are using $^{12}$C/$^{13}$C ratio inferred from CN to derive $^{14}$N/$^{15}$N in HCN and HNC isotopologues
- Affect our derived $^{14}$N/$^{15}$N?
- Misleading conclusion on nitrogen fractionation in IRDCs?
### Comparison: chemical model

- **Direct measurement on HCN and its $^{15}$N isotopologue**

<table>
<thead>
<tr>
<th>Core</th>
<th>$\frac{HCN}{HC^{15}N}$</th>
<th>$\frac{H^{13}CN}{HC^{15}N}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>43±9</td>
<td>70±28</td>
</tr>
<tr>
<td>G3</td>
<td>$\geq 67±3$</td>
<td>$\geq 181±54$</td>
</tr>
<tr>
<td>H2</td>
<td>$\geq 282±5$</td>
<td>$\geq 366±132$</td>
</tr>
<tr>
<td>H3</td>
<td>263±49</td>
<td>458±98</td>
</tr>
<tr>
<td>H4</td>
<td>121±24</td>
<td>142±34</td>
</tr>
<tr>
<td>H5</td>
<td>259±57</td>
<td>395±97</td>
</tr>
</tbody>
</table>

- **Model predictions:** *(Roueff et al. 2015)*
  - $T = 10$ K
  - $n_H = 2 \times 10^5$ cm$^{-3}$
  - Significant $^{13}$C depletion at evolution time $\sim 1$M yrs

- **Our Case for IRDCs:**
  - $T = 15 – 20$ K *(Pillai+2006)*
  - $n_H \approx 10^5$ cm$^{-3}$ *(Bulter & Tan 2012)*
  - Time-scale for IRDC cores $\approx 10^5$ yrs *(Kong et al. 2017)*

- **Results:** $^{14}$N/$^{15}$N ratios are either **consistent**, or **lower than** those measured from the $^{13}$C isotopologues

- **i) Time-scales (age) of IRDCs cores**

- **ii) Kinetic temperature of the gas within IRDCs**
Perspective

Measuring the nitrogen fractionation as a function of Galactocentric distance using Planck Galactic cold clumps (PGCCs)

- Single-dish observations with IRAM 30m telescope
- Sample of dense PGCCs distributed across the Galactic disk (Zahorecz et al. 2016)
- Tracers: N$_2$H$^+$, CN, and HNC and their $^{15}$N isotopologues

1. To estimate the $^{14}$N/$^{15}$N ratio and its gradient in the Galaxy using different N-bearing species

2. Provide an insight into the chemical fractionation of Nitrile- (CN) and Hydride-(NH) bearing molecules