^{15}N Fractionation in Infrared Dark Cloud Cores

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Zeng et al. 2017 A&A 603, A22 arXiv:1705.04082

NITROGEN FRACTIONATION IN SPACE
Niels Bohr Institute and Centre for Star and Planet Formation at University of Copenhagen
2017 November 8-9

Nitrogen fractionation

Interstellar ratios spread in a wide range !

Origin of N-fractionation is poorly constrained !

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

- **Small Solar System bodies** e.g. comets, meteorites, interplanetary dust particles (IDPs)
  (*Bockelée-Morvan et al. 2008, Manfroid et al. 2009, Floss et al. 2006, Alexander et al. 2007*)

- **Protoplanetary disks and Planets**
  (*Junk & Svec 1958, Hoffman et al. 1979, Fouchet et al. 2004, Wong et al. 2013, Guzmán et al. 2017*)

- **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)

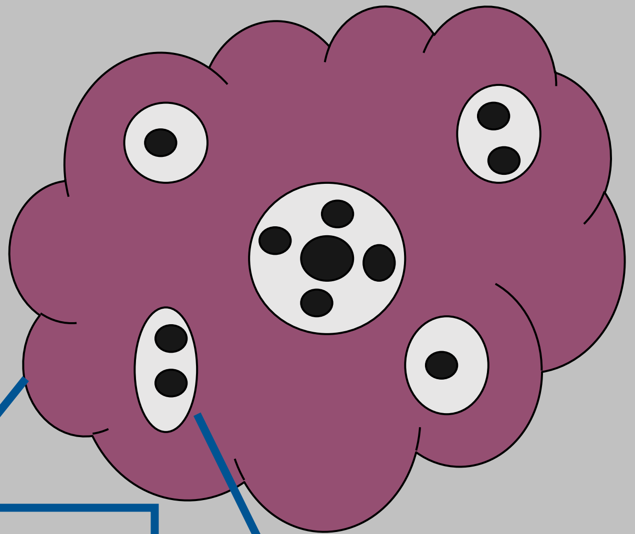
Establish how N-fractionation is transferred from the pristine conditions to the subsequent stages of planetary system formation

Nitrogen chemistry depends on the temperature and density of the primordial gas in the parental cloud
(Roueff et al. 2015)

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

Dependence of N-fractionation on T_{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_{kin} = 15 – 20 K** *(Pillai et al. 2006)*
- **$n_H \approx 10^5$ cm^{-3}** *(Bulter & Tan 2012)*
- **H_2 column densities > 10^{22} cm^{-2}** (Av~100 mag) *(Kainulainen & Tan 2013)*

IRDCs

- Size ~ few pc
- Mass ~ few 1000$M_\odot$

IRDC compact cores

- Size ~ 0.5 pc
- Mass ~ 100 $M_\odot$

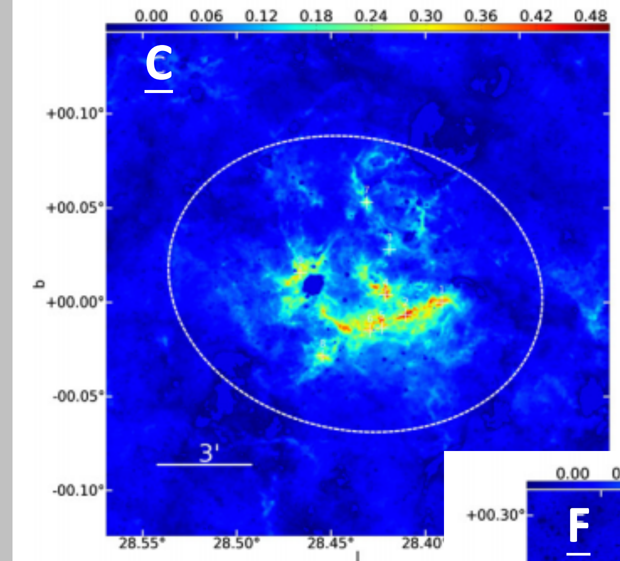
- Active/Star-forming (masers/mid-IR/UC HIIs)
- Intermediate
- Quiescent/Starless

(Chambers et al. 2009, Rathborne et al. 2010)

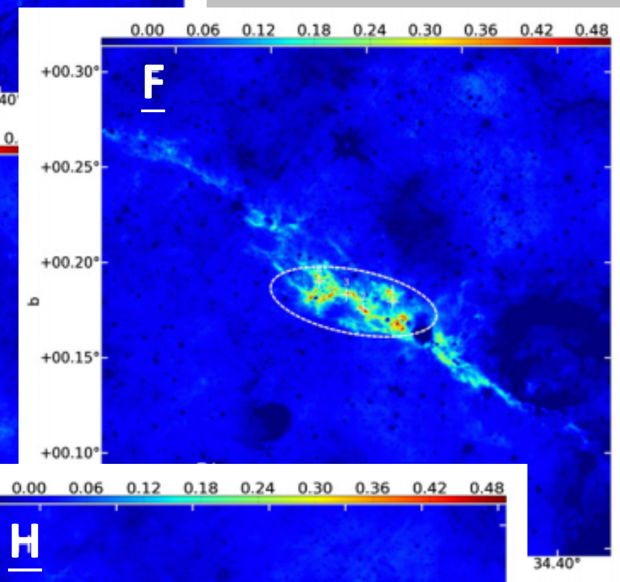
IRDCs: our sample

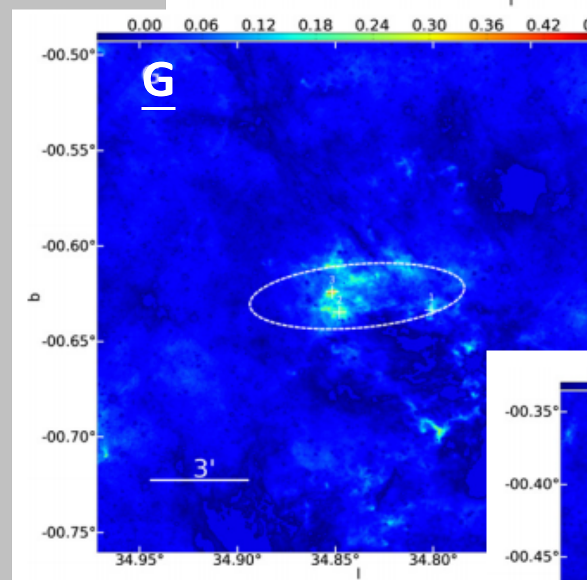
- Selected from the IRDCs sample studied by *Rathborne et al. 2006*
- 10 of these clouds (studied in Bulter & Tan 2012) are selected with different morphologies and with different levels of star-formation activity based on the detection of 24µm and 8µm sources
- 4 IRDCs are targeted in this study:

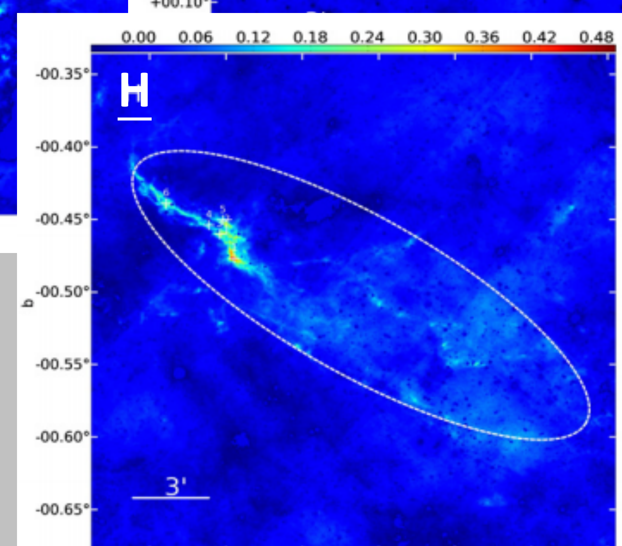
IRDCs	l [°]	b [°]	V_{LSR} [kms^{-2}]	Σ(sat) [gcm^{-2}]	M [$M_\odot$]
C(G028.37+00.07)	28.373	0.076	78.6	0.520	45000
F(G034.43+00.24)	34.437	0.245	57.1	0.370	4460
G(G034.77-00.55)	34.771	-0.557	43.5	0.347	2010
H(G035.39-00.33)	35.395	-0.336	44.7	0.416	13340



Mass surface density maps of targeted clouds and cores (Butler & Tan, 2012)







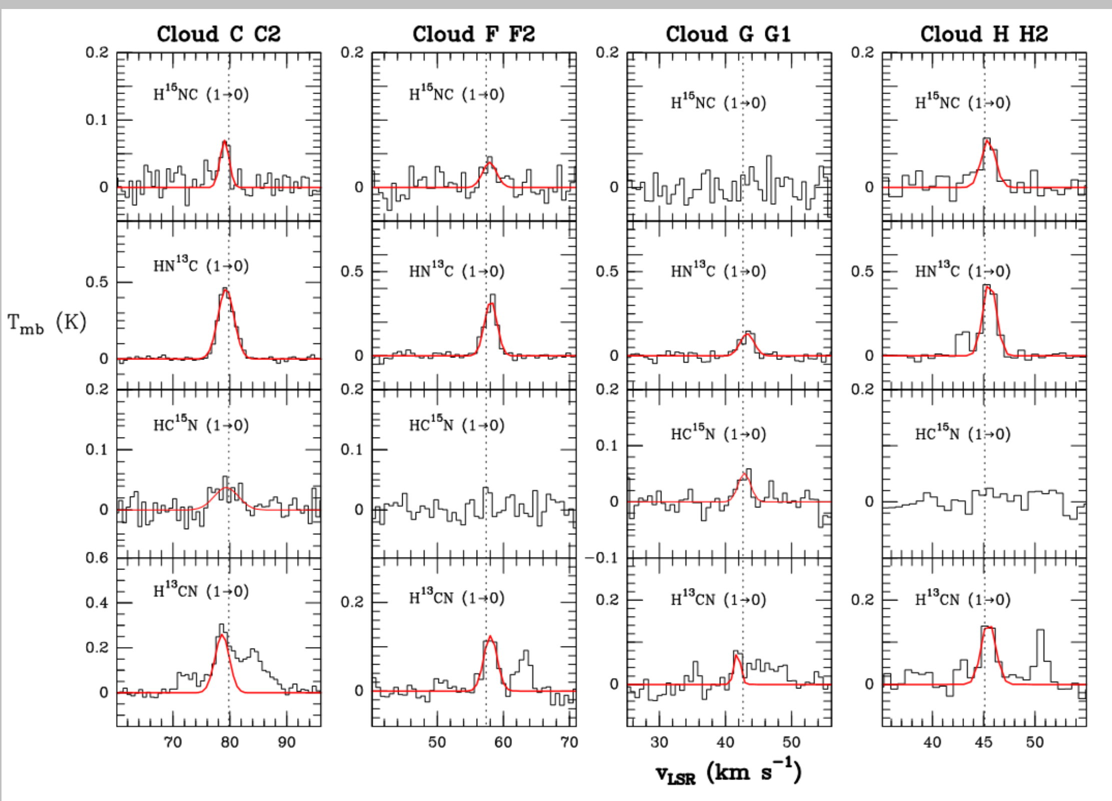
IRAM-30m telescope

Observation & Analysis

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

$HCN \rightarrow H^{13}CN$, $HC^{15}N$

$HNC \rightarrow HN^{13}C$, $H^{15}NC$

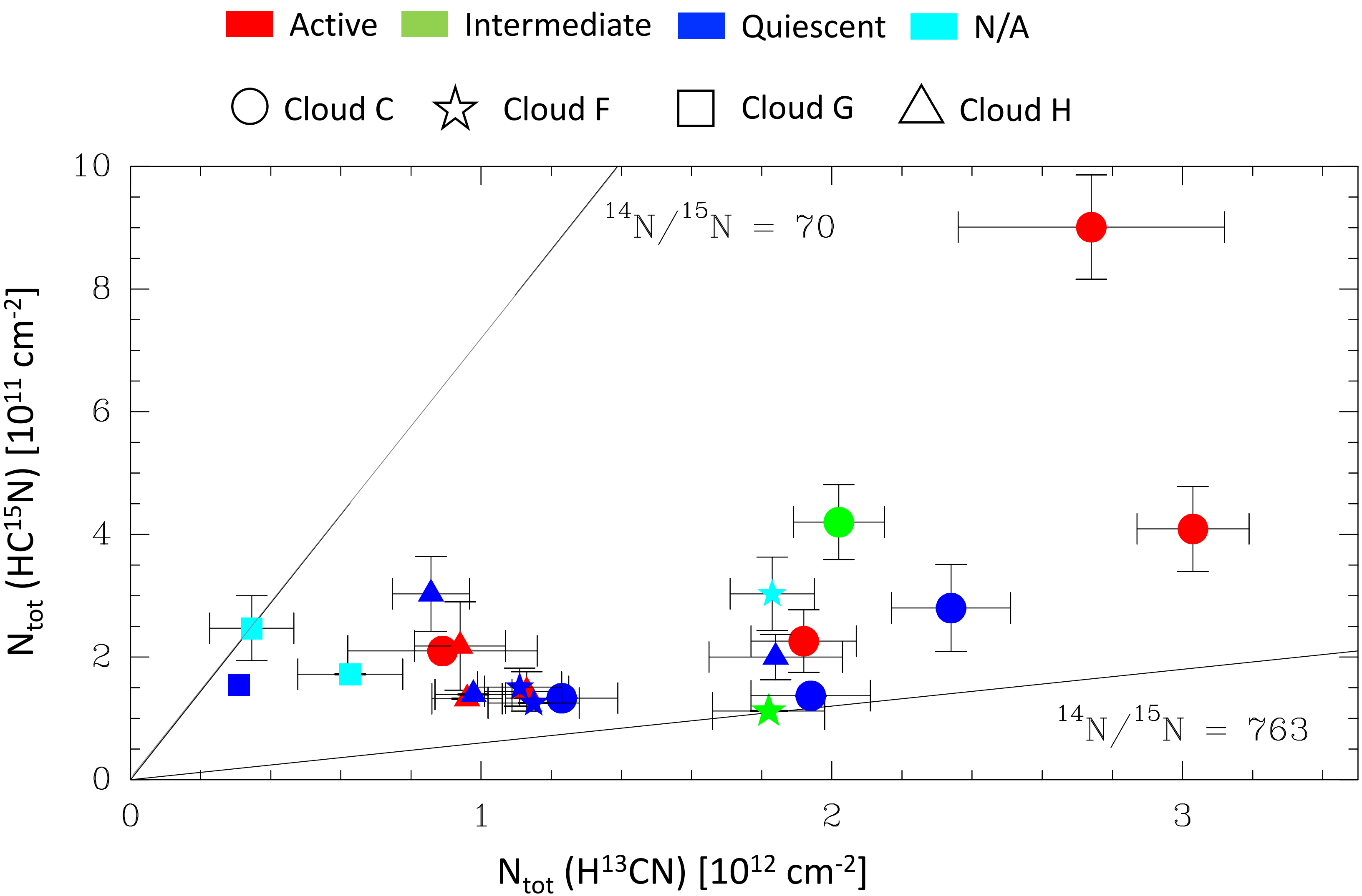


$^{12}C/^{13}C$ ratio calculated for each targeted IRDC regarding their galactocentric distance:

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

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*)

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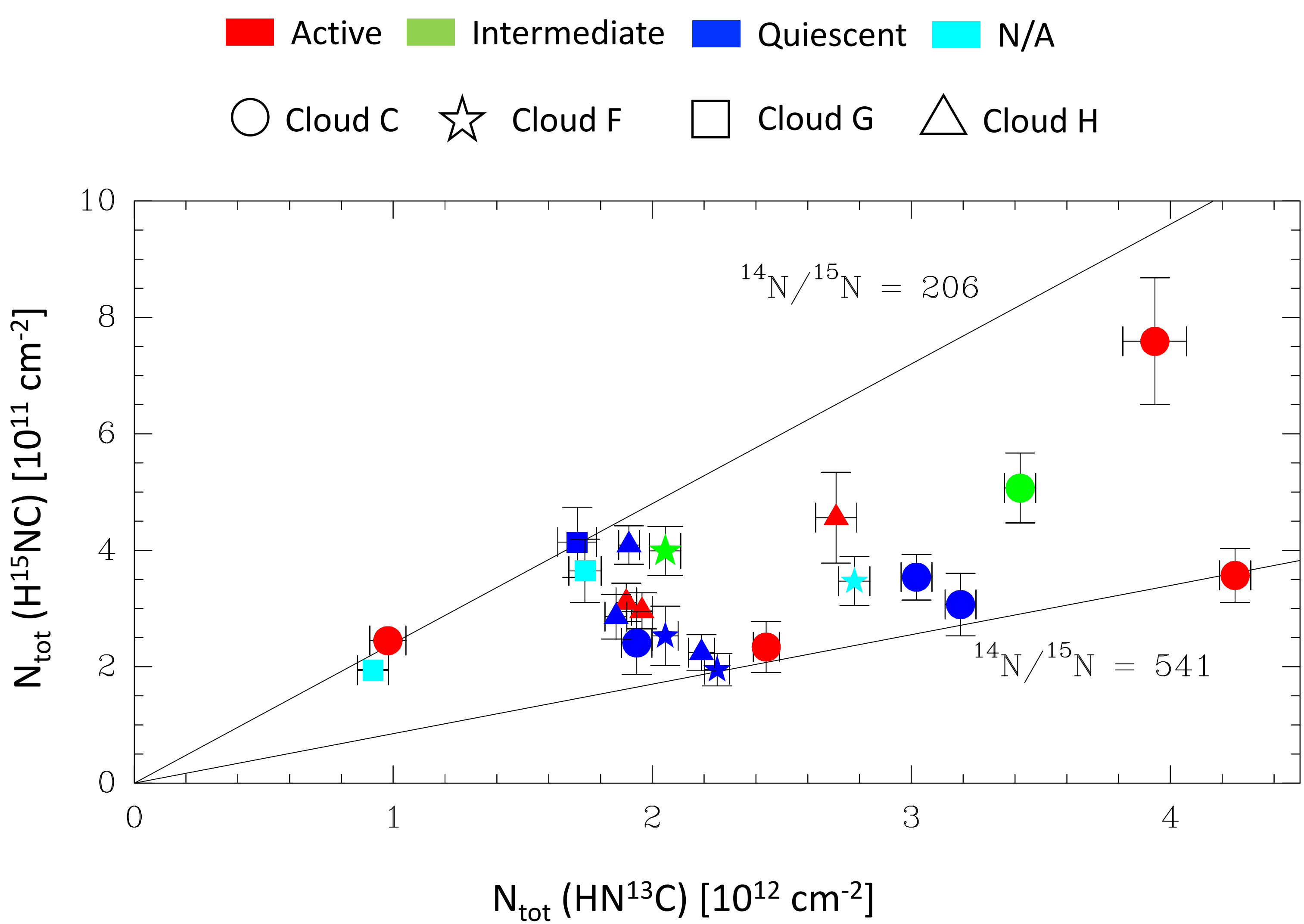


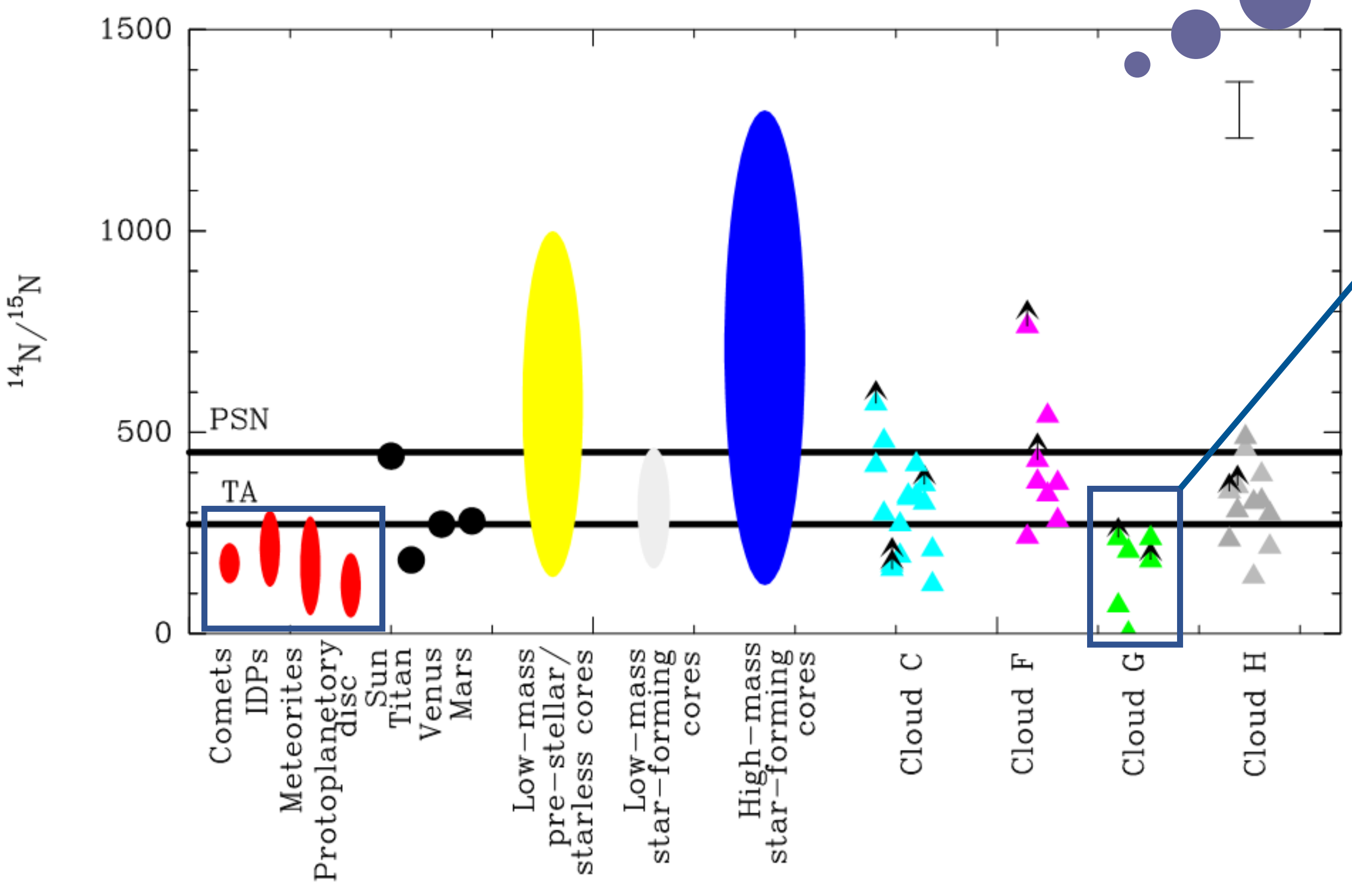
(*Zeng et al. 2017*)

Comparison: literature studies

HCN: ~70 -- ≥763
HNC: ~161 -- ~ 541

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

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



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

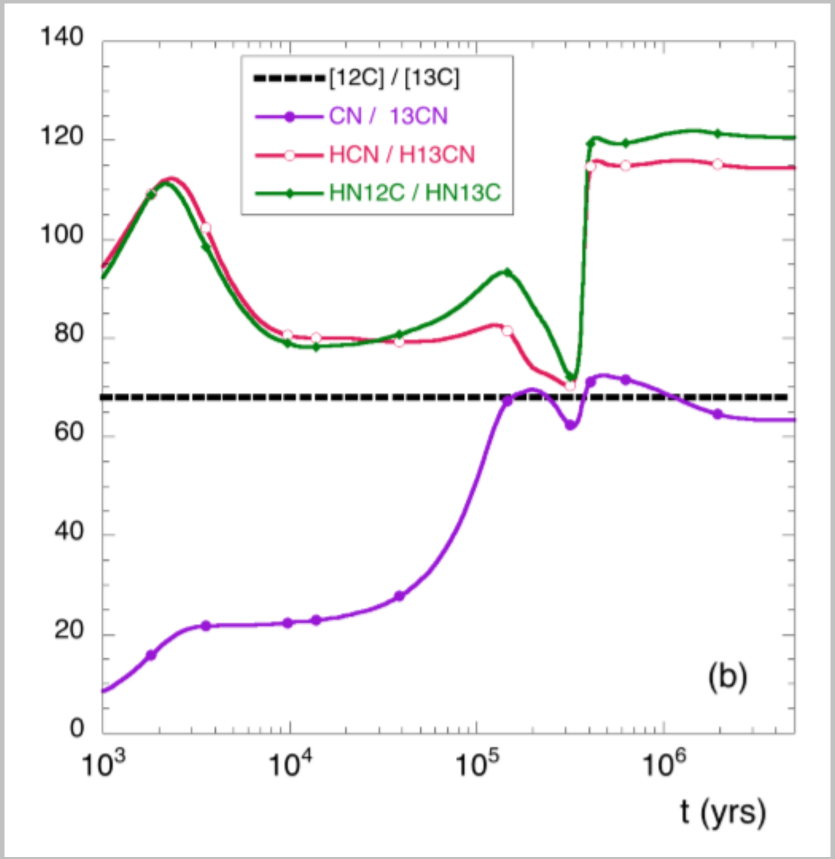
Properties of Cloud G itself
- Least massive
- **Lowest gas density**
- Most diffuse
- No trace of star-formation activity

(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 ~ 1M 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

	$^{14}N/^{15}N$	
Core	$\frac{HCN}{HC^{15}N}$	$\frac{H^{13}CN}{HC^{15}N}$
G1	43±9	70±28
G3	≥67±3	≥181±54
H2	≥282±5	≥366±132
H3	263±49	458±98
H4	121±24	142±34
H5	259±57	395±97

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

Model predictions: *(Roueff et al. 2015)*

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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 ≈10^5 yrs *(Kong et al. 2017)*

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_2H^+, 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