The elusive origin of nitrogen in the Solar System

Pierre Hily-Blant

V. Magalhaes, J. Kastner, A. Faure, T. Forveille

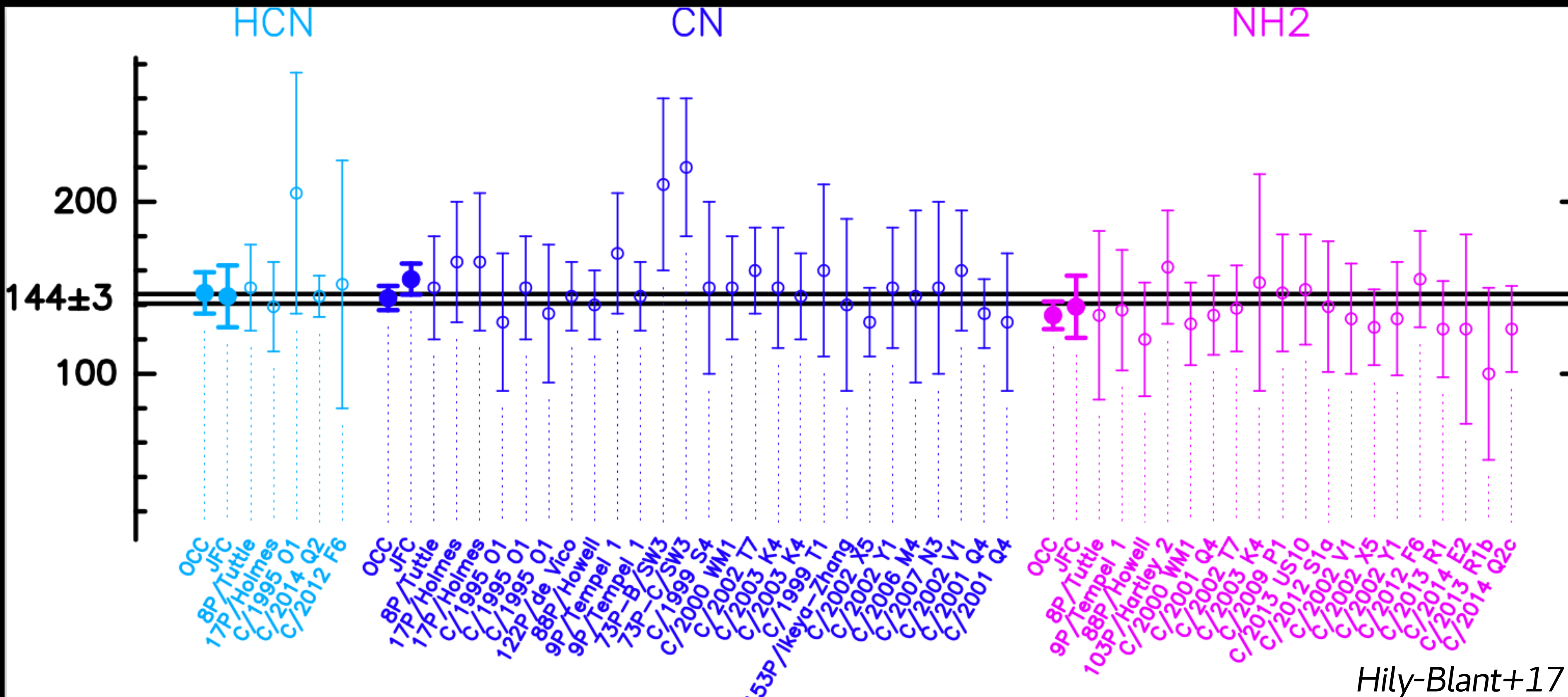
G. Pineau des Forêts, D. Flower, C. Rist

UNIVERSITÉ Grenoble Alpes

IPAG Institut de Planétologie et d'Astrophysique de Grenoble

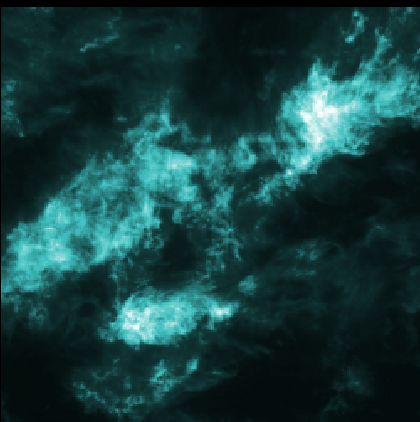
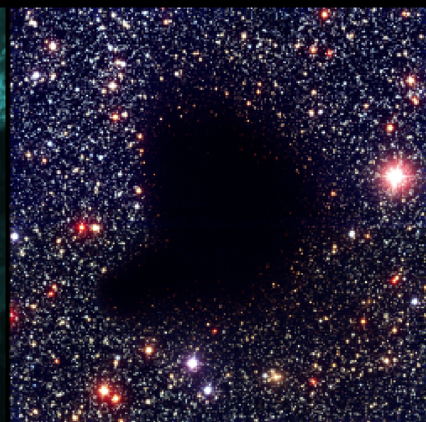
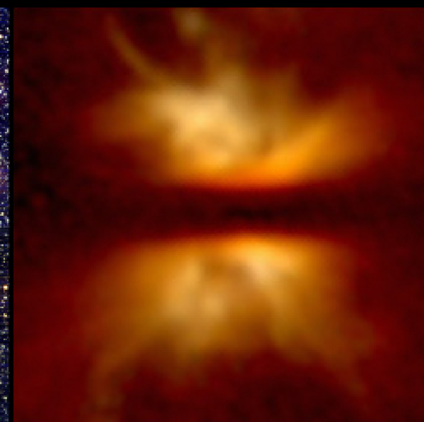
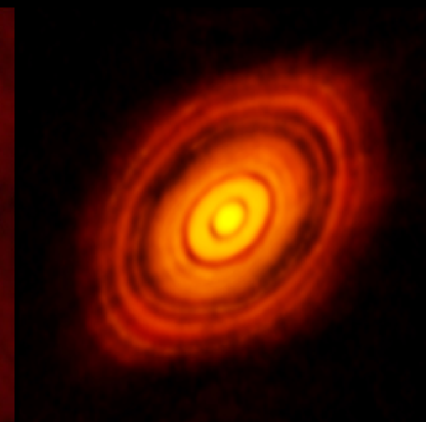
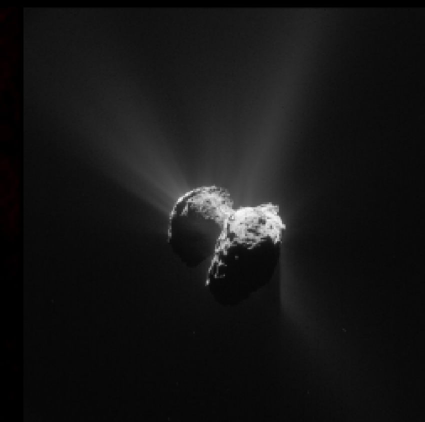
institut universitaire de France

The conendrum



- $^{14}N/^{15}N$ ratio in comets: 145 (Bockelée-Morvan+15, Hily-Blant+17)
- Elemental ratio in the protosolar nebula (PSN): 441 (Marty+11)
- Comets as a tracer of a fractionated reservoir of nitrogen in the PSN

Questions

- Formation of the solar system and of planetary systems in the galaxy
  - Origin of organic matter in primitive cosmomaterials
  - Nature of planetary atmospheres (primary vs secondary) ?
- When, where, and how, isotopic reservoirs form, from clouds to comets ?
  - Interstellar heritage ?
  - How can we learn on the protosolar nebula from protoplanetary disks ?

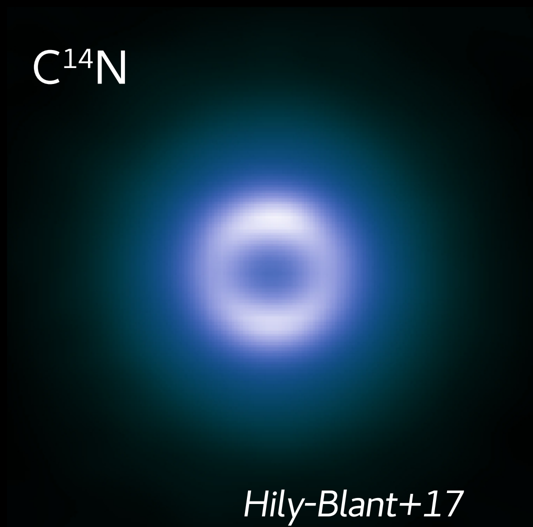
Key questions and aims

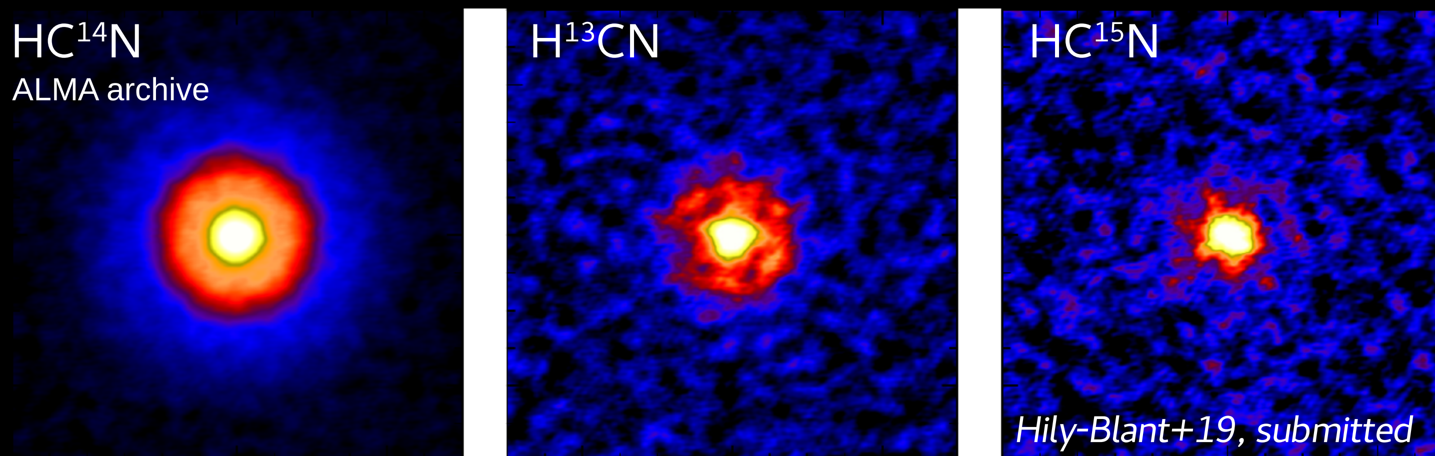
- Origin of the ^{15}N-rich reservoir seen in comets?
  - Inherited from interstellar cloud ? Created *in situ* during the formation ? Result of processes in the comets *a posteriori* ?
  - What are the fractionation processes ?

- How to follow isotopic reservoirs from clouds to meteorites?
  - Measure isotopic ratios in several species (CN, HCN, NH_3, N_2H^+, etc)
  - Towards dense clouds, protostars, protoplanetary disks
  - Precise ratios with calibration-limited accuracy (~10%)

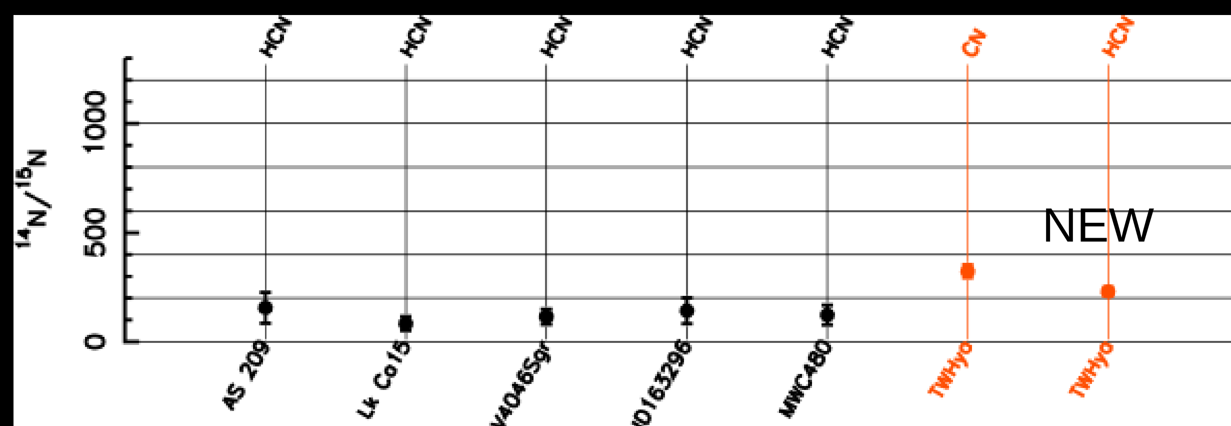
- What is the elemental $^{14}N/^{15}N$ ratio in the local ISM?
  - PSN: formed 4.6 Gyr ago, perhaps at a different location in the galaxy
  - Nucleosynthesis: evolution of the $^{14}N/^{15}N$ elemental ratio
  - Needed to compare the protosolar nebula with present-day analogs

Protoplanetary disks (1)



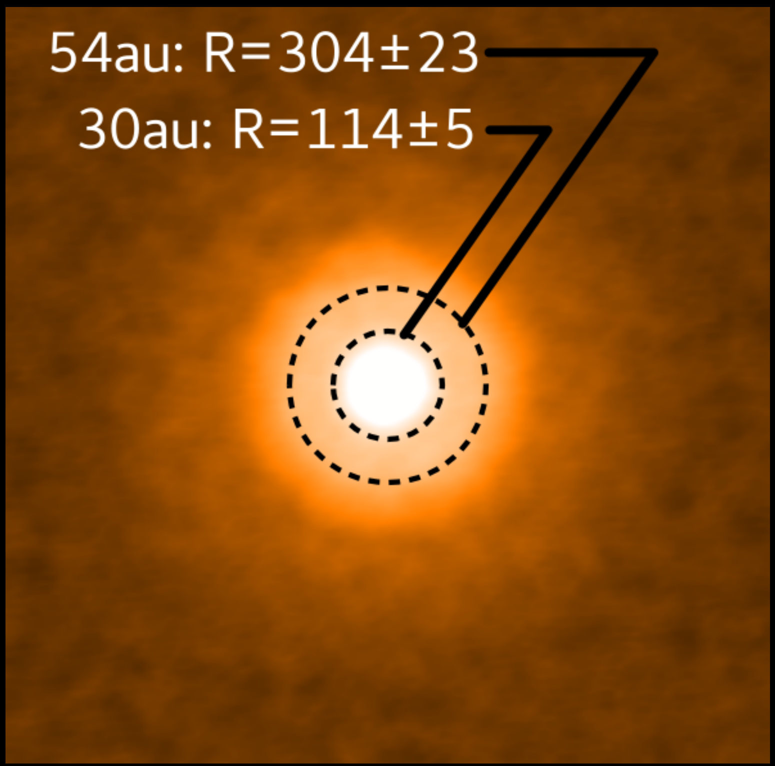


- Indirect measurements
  - HCN: <ratio> = 111±20 (Gúzman+17, Hily-Blant+17)
- Direct measurements
  - CN: 323±30 (Hily-Blant+17), HCN: 230±20 (Hily-Blant+19)



^{15}N-rich reservoir present during comet formation

Protoplanetary disks (2)

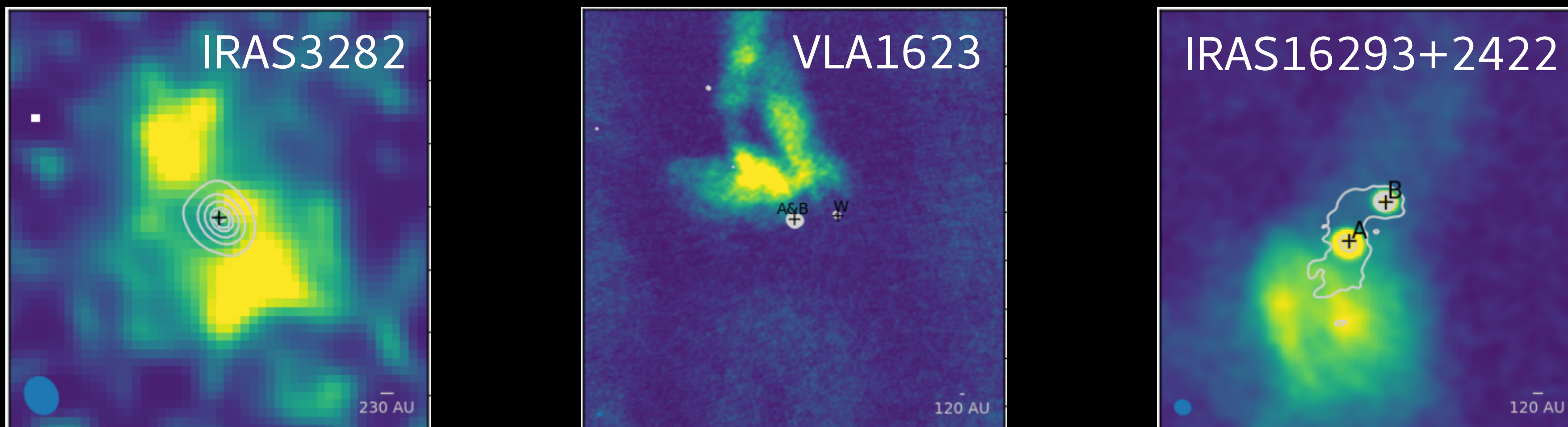


	$HCN/HC^{15}N$	$HCN/H^{13}CN$	$H^{13}CN/HC^{15}N$
Average	230±20	86±4	2.6±0.2
0.5 ± 0.1″	114±5	84±5	1.36±0.14
0.7 ± 0.1″	200±20	78±5	2.55±0.14
0.9 ± 0.1″	304±23	82±4	3.7±0.2

- Radial dependence of $HCN/HC^{15}N$ ratio
- R=114±5 in the comet formation region
- R increases to 304±23 at 60 au
- Selective photodissociation (Heays+14, Visser+18) but <u>values disagree</u>
- $HCN/H^{13}CN$ > $^{12}C/^{13}C$=70; contrary to models

Radial increase of $HCN/HC^{15}N$
Selective photodissociation of N_2: favoured process

Low-mass protostars: role of ices



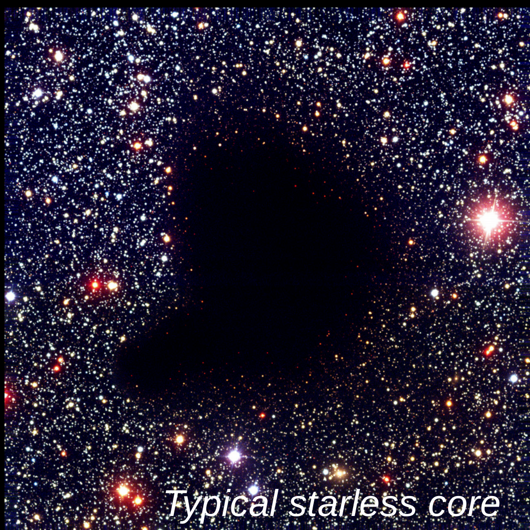
Magalhaes, in prep

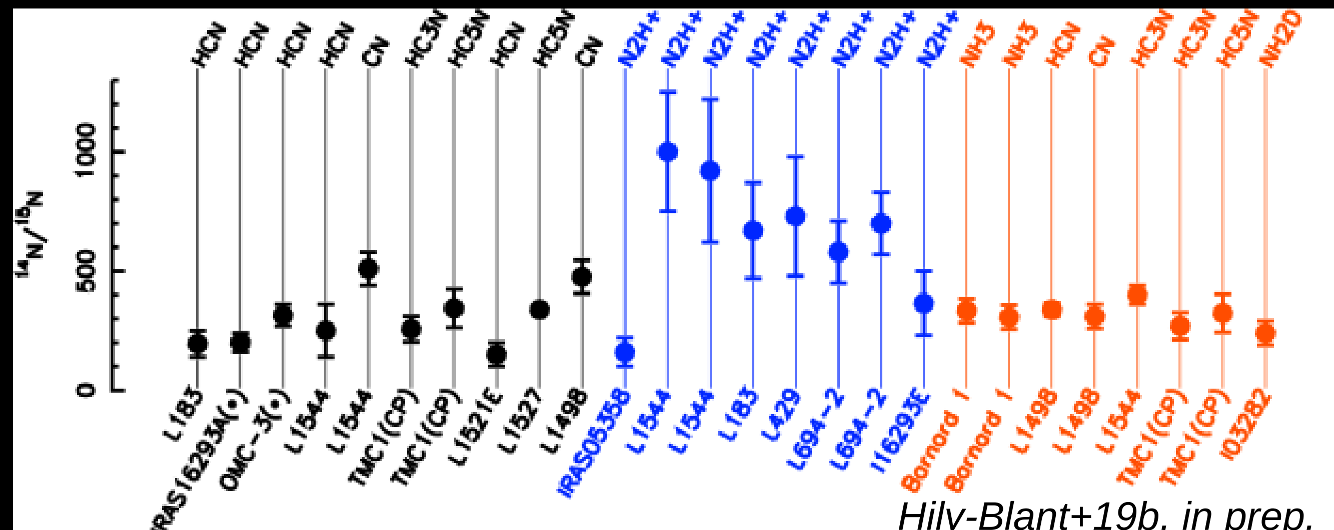
- Indirect measurement in HCN
  - 160 — 460 ± 10% in the cold envelope (Wampfler+14)

- Direct measurements: $NH_2D/^{15}NH_2D$ with ALMA/NOEMA+IRAM30m
  - Prelim. result: $^{14}N/^{15}N$ in sublimation region > 2 x envelope (Magalhaes in *prep*)

Preliminary result: fractionation in ices ?
^{15}N-poor reservoir in the sublimation zone

Dense starless cores

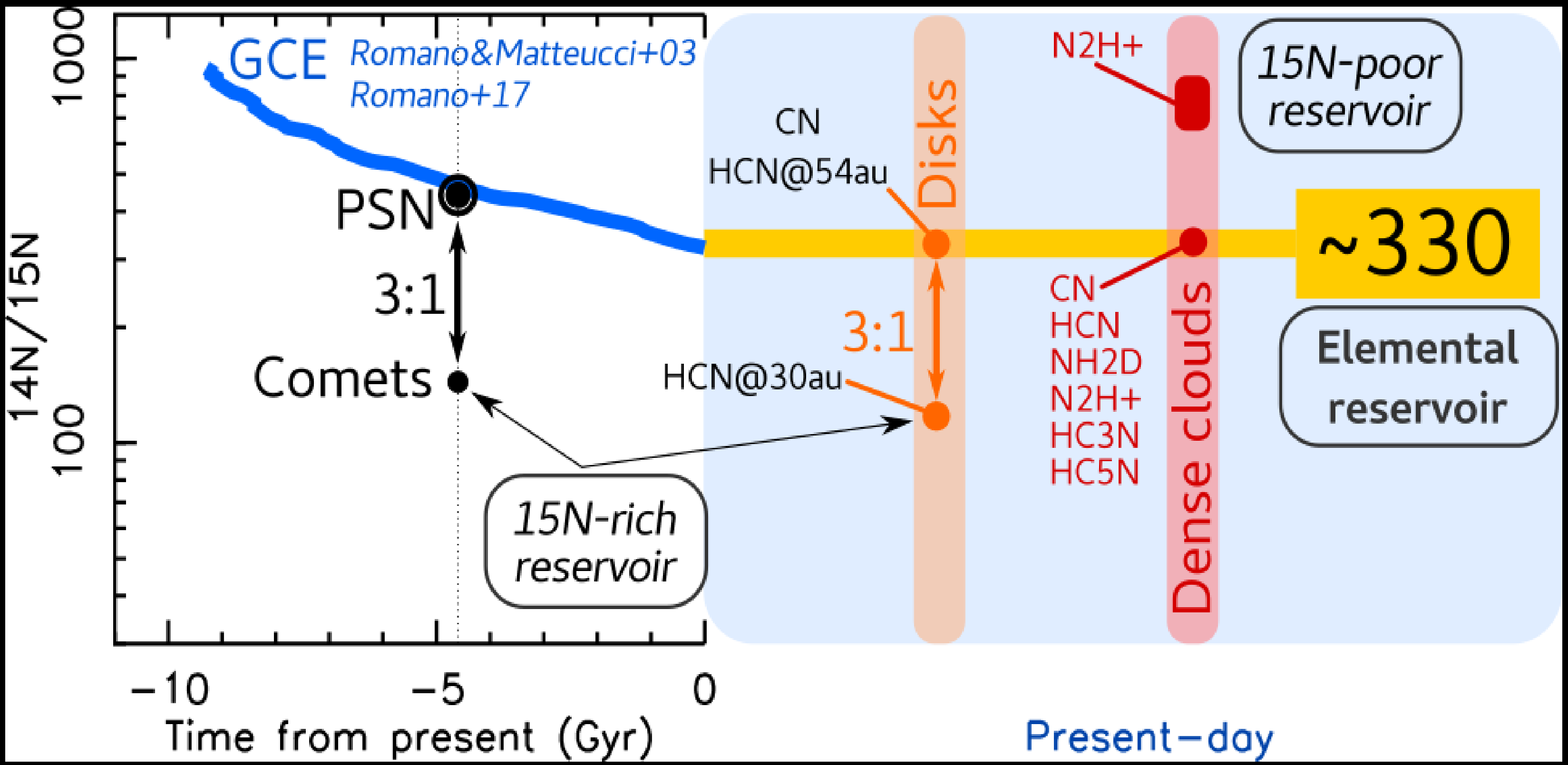




- Usual method: double isotopic ratios ($HCN/H^{13}CN$ x $H^{13}CN/HC^{15}N$)
  - Not precise; large scatter (Hily-Blant et al 2013, and many others!)
- Direct measurements
  - HCN: radiative transfer with hyperfine overlap (Magalhaes+18)
  - N_2H^+: average ratio = <u>770±140</u>; $^{14}N/^{15}N$ average (w/o N_2H^+)= <u>323±10</u>
  - Differential accretion rates in collapsing clouds could lead to fractionation (HB+19b)

Multiple reservoirs in dense cores

The present-day $^{14}N/^{15}N$ ratio



- Diffuse measurements
  - HCN = 276±34 (Lucas&Liszt 98); 304±37 after correction from selective photodissociation
  - CN: large (self-inconsistent) scatter, 234 — 452, <ratio>=274±20 (Ritchey+15)
- Galactic gradient: 290±40 (Milam+05)

Present-day elemental ratio: 330±30 (Hily-Blant+17, +19)

Conclusions

- The elemental $^{14}N/^{15}N$ ratio: 330±30 from direct measurements in the dense ISM; diffuse ISM ~ smaller
- A ^{15}N-rich reservoir is present in PSN analogs at the time of comet formation, with the same characteristic 3:1 ratio wrt elemental
- Selective photodissociation may be the main fractionation process at the origin of the ^{15}N-rich reservoir in comets
- A ^{15}N-poor reservoir, traced by N_2H^+, is present in prestellar cores
- ^{14}N-^{15}N exchange processes in ices may be efficient during the prestellar and/or sublimation phase

Perspectives

- Observations
  - More direct measurements in disks (CN, HCN, other)
  - More direct measurements in low-mass protostars and starless cores
- Experiments
  - ^{14}N-^{15}N exchange in ices
- Modeling
  - Interstellar clouds: elucidate the N_2H^+ problem
  - Disks: reconcile selective photodissocation predictions with observations
- Connection with GCE models
  - Precise and accurate value for the local ISM
  - Sun migration: independent constraints (e.g. from isotopic ratios)
  - Galactic gradient (e.g. high-mass protostars, Colzi et al)

Thank you for your attention