Enhanced nitrogen fractionation at core scales:

The high-mass star-forming region IRAS 05358+3543

Congresso Nazionale di Astrochimica e Astrobiologia (proto-) planetaria

Laura Colzi

21st October 2019

F. Fontani, P. Caselli, V. M. Rivilla, S. Leurini, L. Bizzocchi, L. Testi, M. Beltrán, Á. Sánchez-Monge, C. Ceccarelli, P. Hily-Blant, G. Quaia

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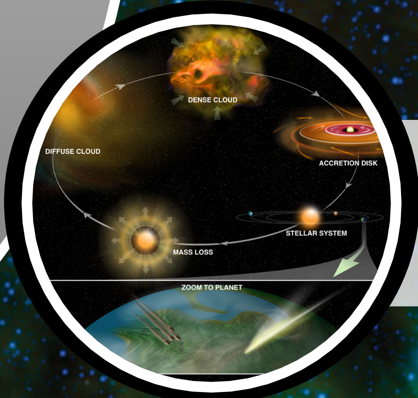
INAF - Arcetri

Outline of the talk

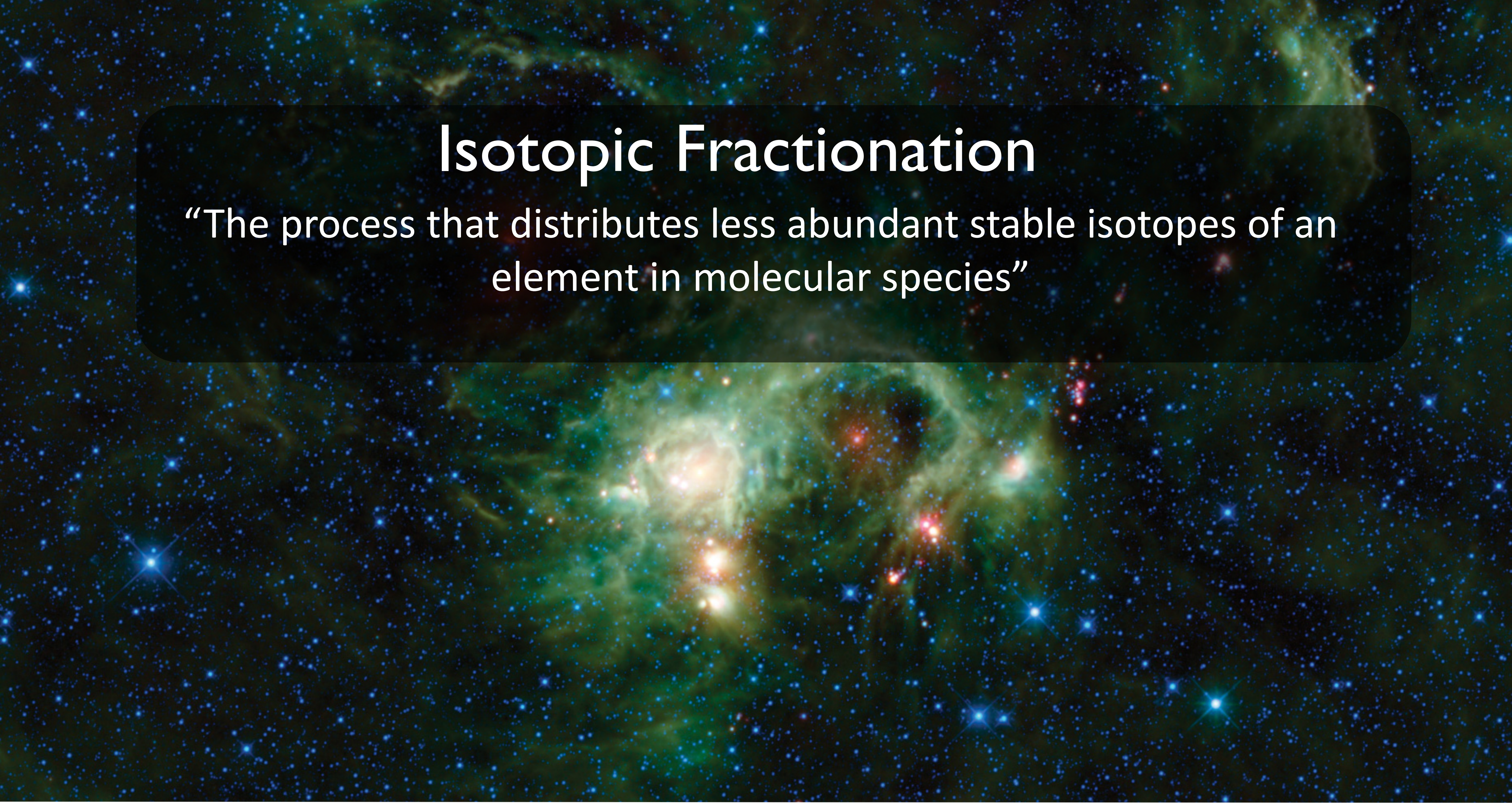


N-fractionation in the ISM → MOTIVATION

A large sample of sources:

The Galactocentric trend and its relation with GCE models

N-fractionation at high-angular resolution:
the first interferometric observations of the ^{15}N-isotopologues of N_2H^+



Isotopic Fractionation

“The process that distributes less abundant stable isotopes of an element in molecular species”

Image credit: Wide-field Infrared Survey Explorer (WISE 2011-2014)

Isotopic Fractionation

"The process that distributes less abundant stable isotopes of an element in molecular species"

N-Fractionation

"The process that distributes less abundant stable isotope of nitrogen in molecular species"

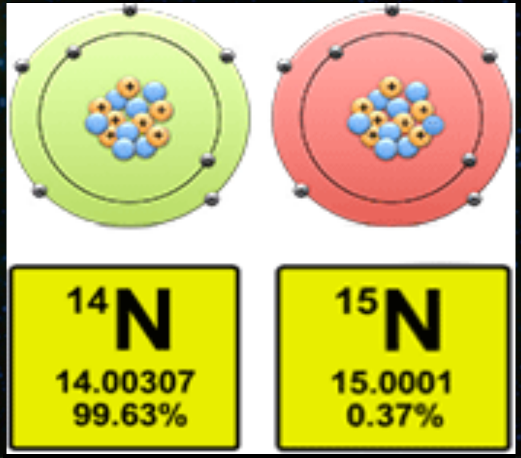
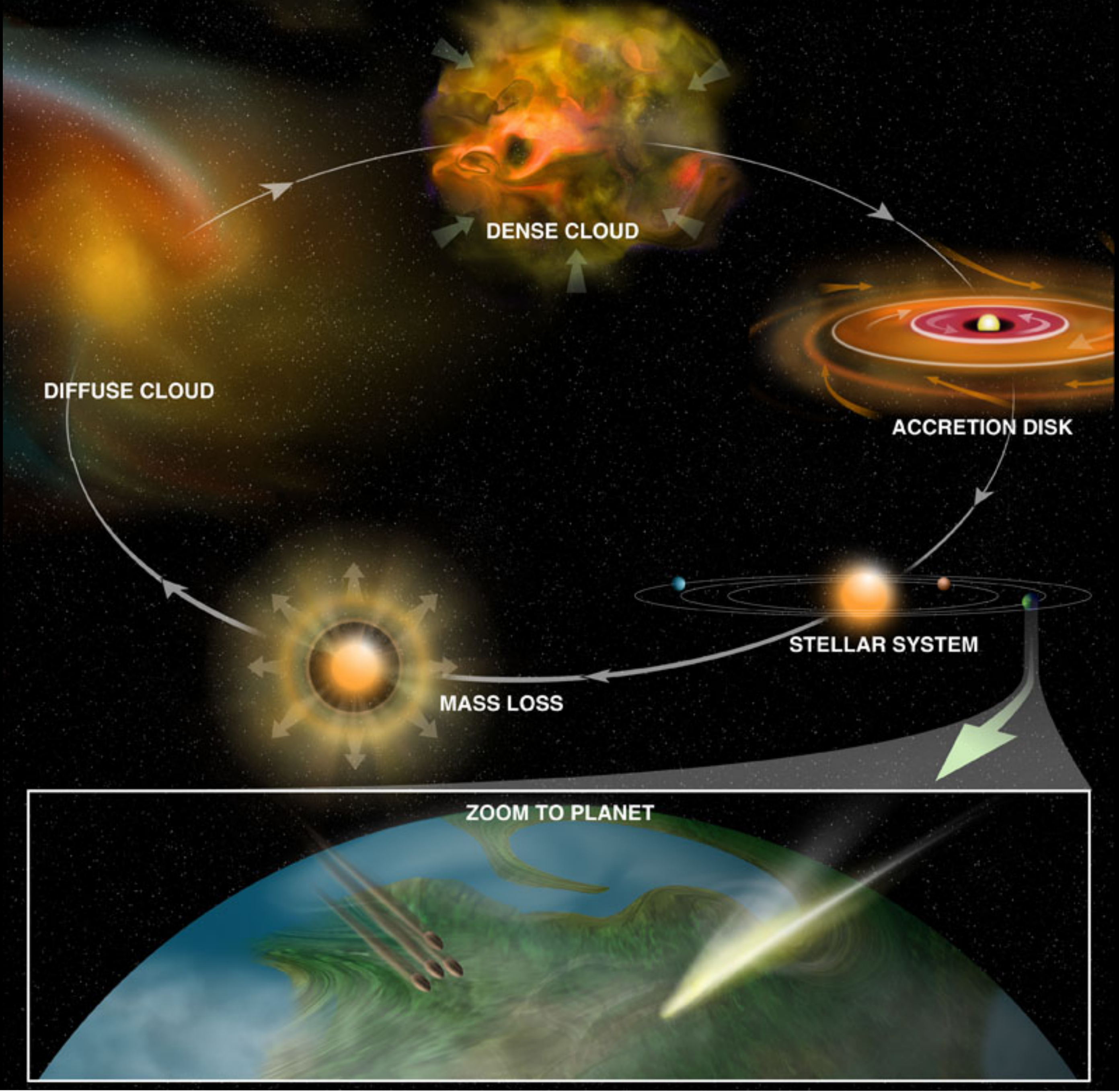


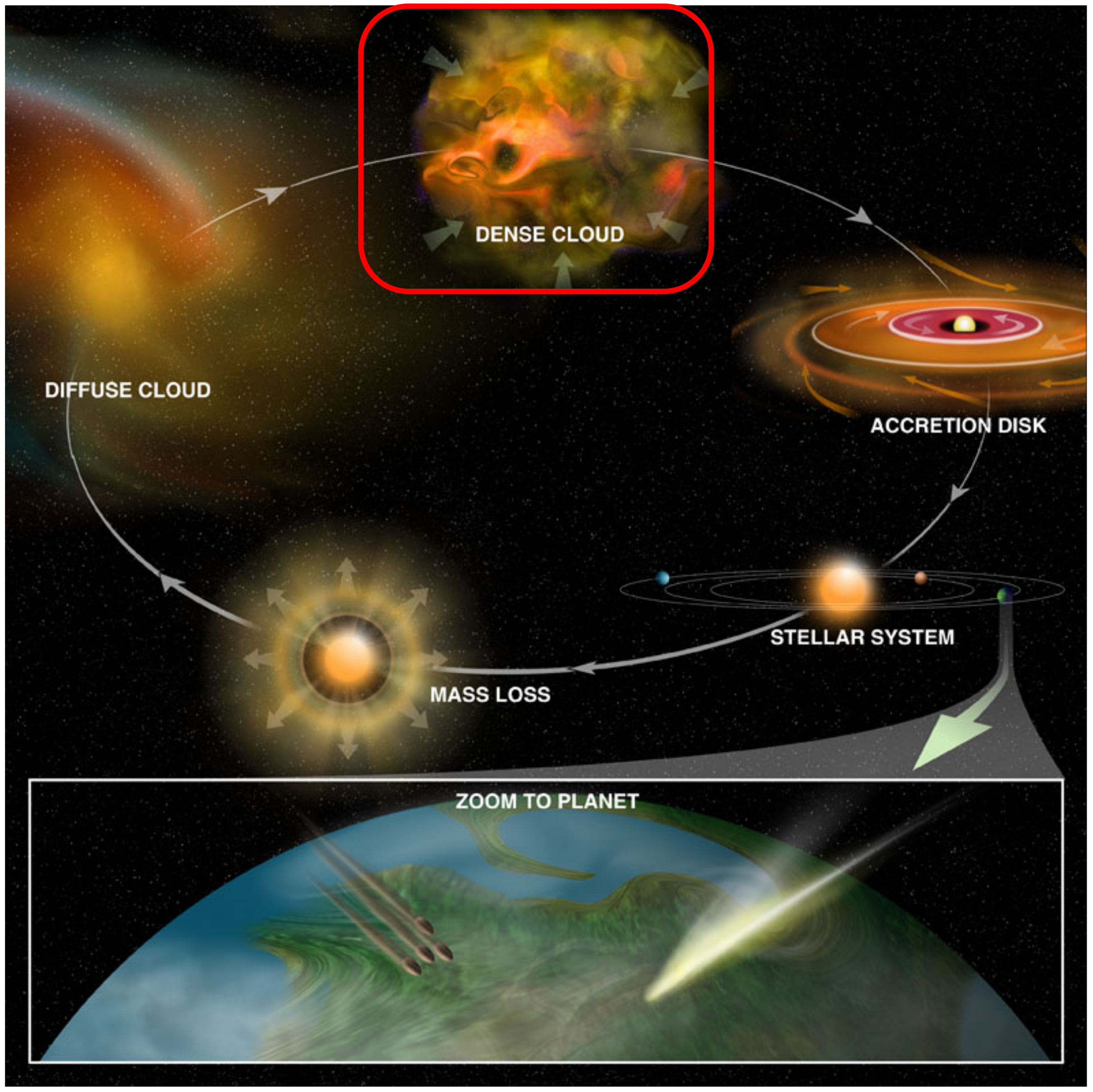
Image credit: Wide-field Infrared Survey Explorer (WISE 2011-2014)

N-fractionation Introduction



What are $^{14}N/^{15}N$ ratios measured in different phases of star formation, until now?

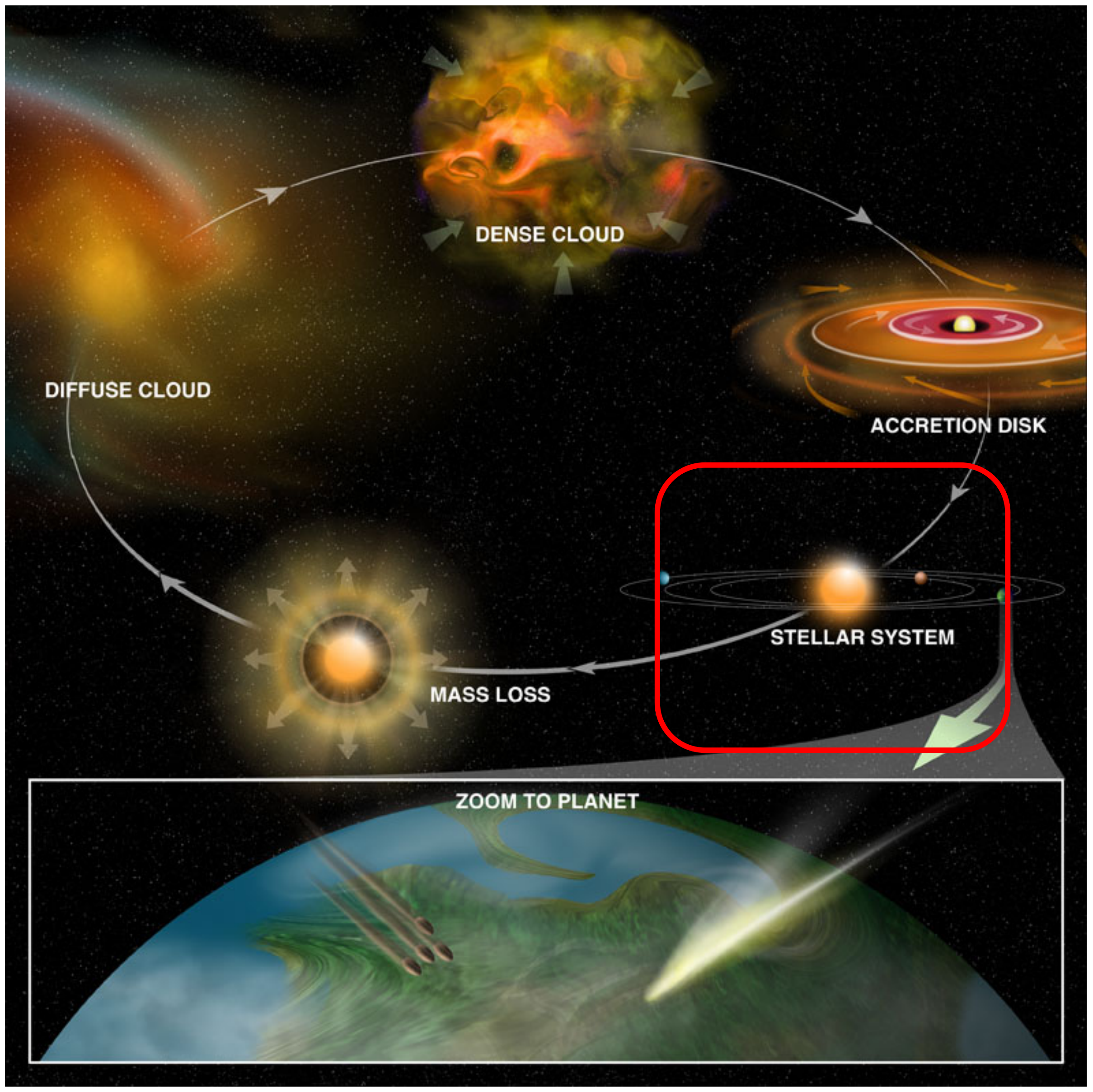
Image credit: Bill Saxton, NRAO/AUI/NSF



STARLESS CORE

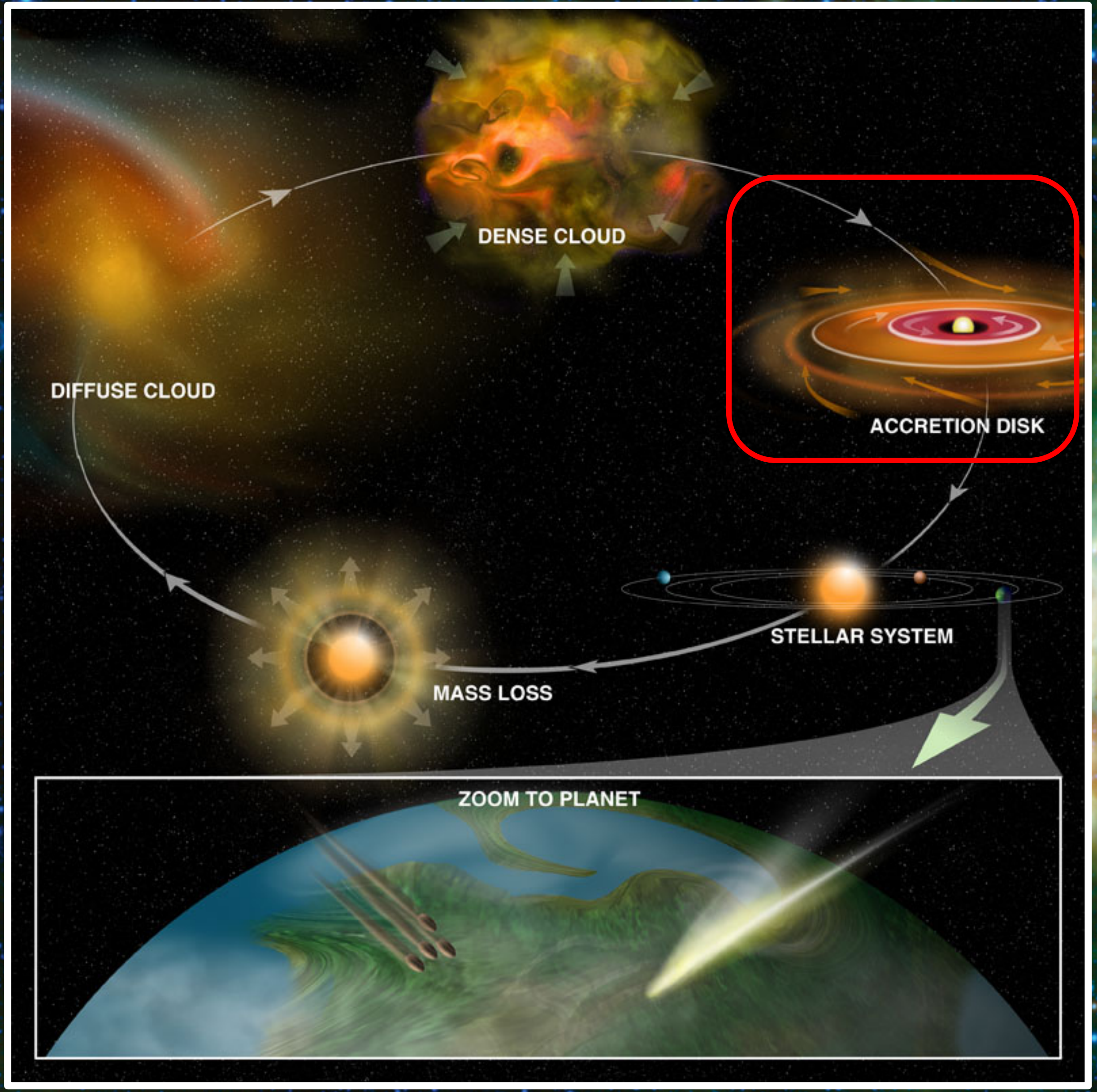
PRE/PROTOSTELLAR OBJECTS

$^{14}N/^{15}N$	molecule	Reference
330±150	N_2H^+	Daniel et al. (2016)
350 – 850	NH_3	Gerin et al. (2009)
334±50	NH_3	Lis et al. (2010)
270±20	CN, HCN, HNC, HC_3N and N_2H^+	Kahane et al. (2018)
140-360	HCN and HNC	Hily-Blant et al. (2013a)
160-290	HCN and HNC	Wamplfler et al. (2014)
1000±200	N_2H^+	Bizzocchi et al. (2013)
630-770	N_2H^+	Redaelli et al. (2018)



PRISTINE SOLAR SYSTEM MATERIAL

$^{14}N/^{15}N$		Reference
139±26	HCN comet 17P/Holmes	Bockelée-Morvan et al. (2008)
148±6	CN 18 comets	Manfroid et al. (2009)
from 44 up to 264	carbonaceous chondrite Isheyevo hotspost	van Kooten et al. (2017)



PROTOPLANETARY DISCS

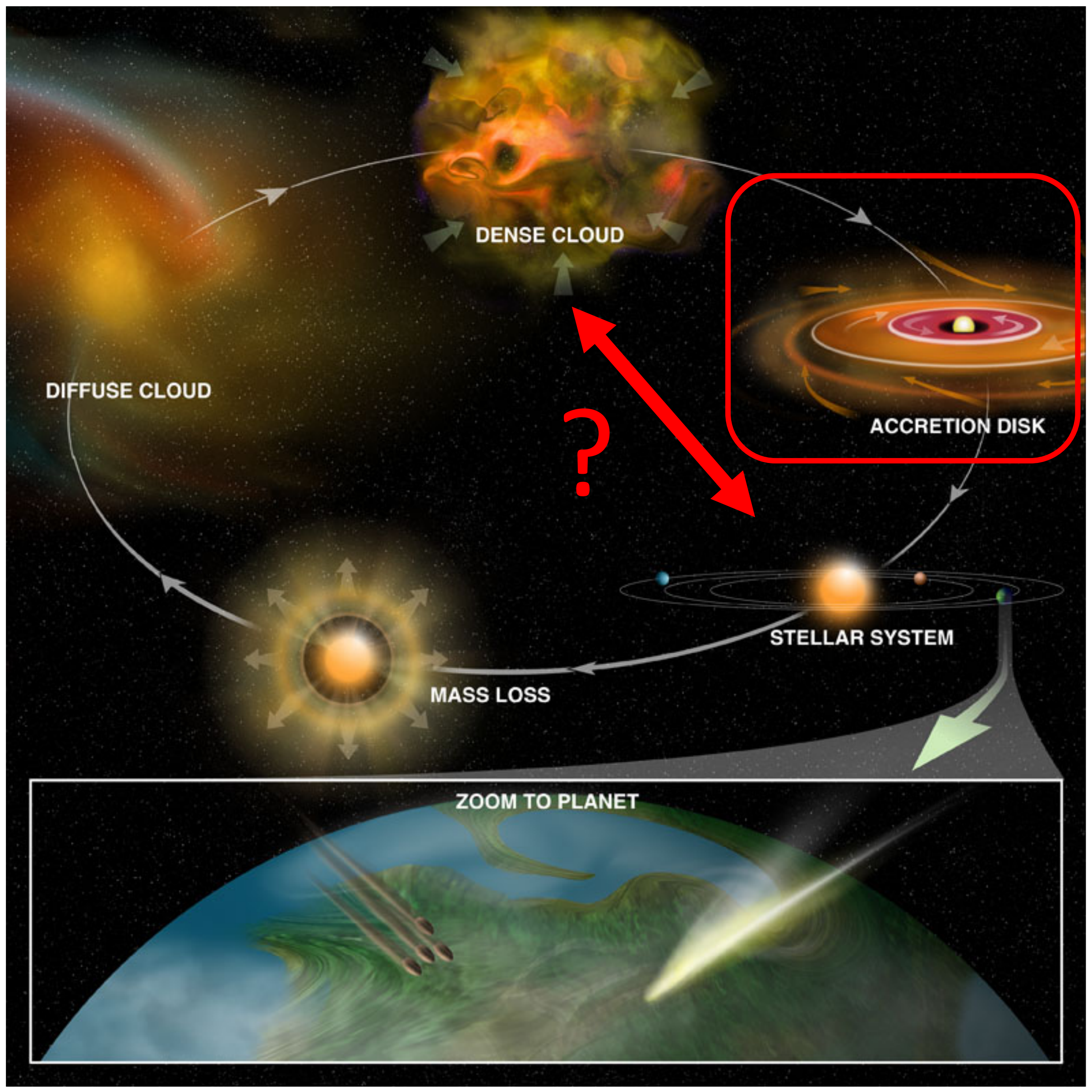
Guzmán et al. (2017), from HCN

✓ AS 209: **156±71**;
✓ LkCa 15: **83±32**;
✓ V4046 Sgr: **115±35**;
✓ MWC 480: **123±45**;
✓ HD 163296: **142±59**.

Average value: **111±19**.

Hily-Blant et al. (2017), from CN

✓ TW Hya: **323±30**



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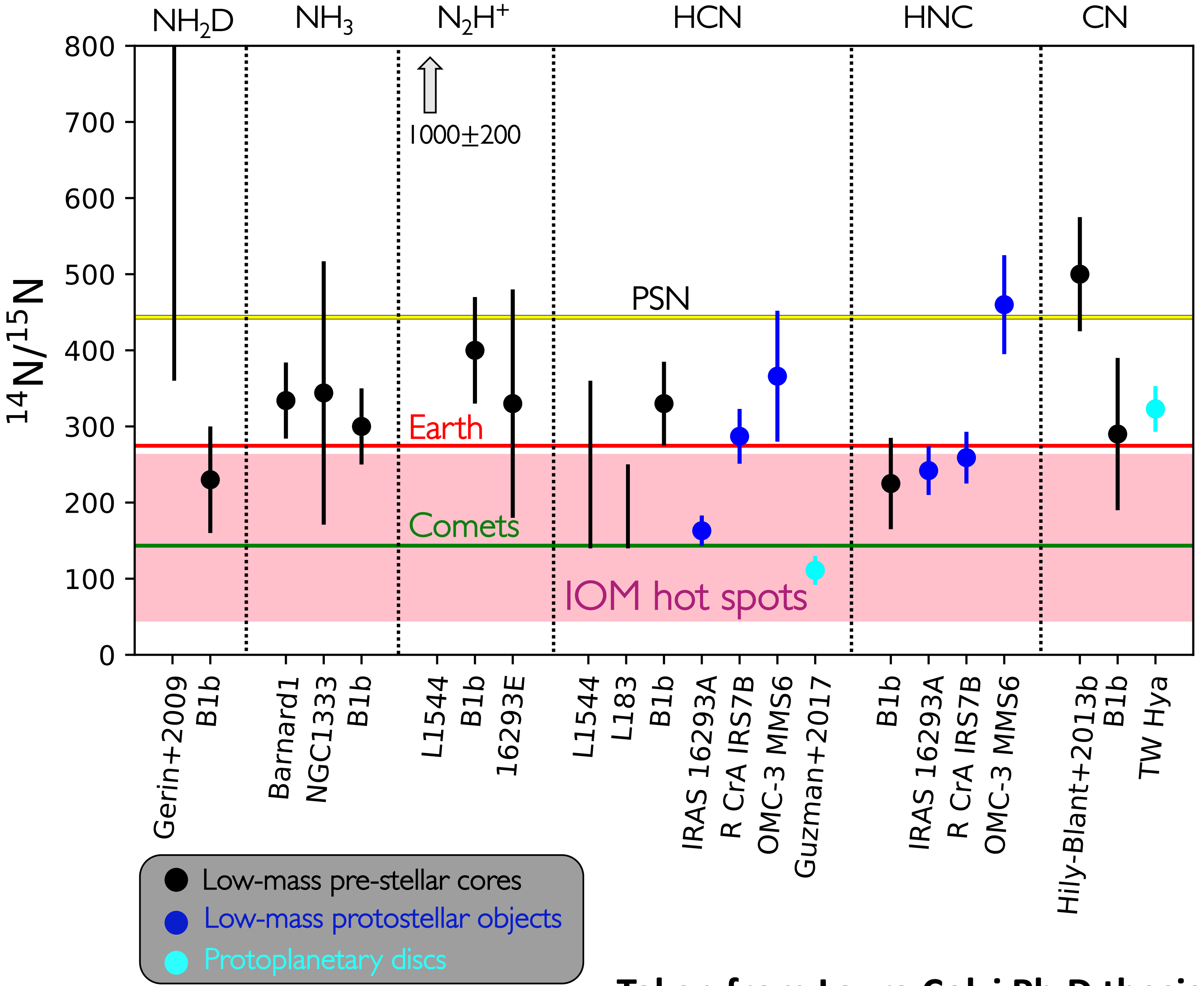
ARE PROTOPLANETARY DISKS THE MISSING LINK?...



Taken from Laura Colzi Ph.D thesis

PSN VALUE 441

TA VALUE 270

- → **Interstellar $^{14}N/^{15}N$ ratios spread in a wide range**
- → **Origin of N-fractionation is poorly constrained**

High-mass star-forming regions

(Adande & Ziurys 2012, Fontani et al., 2015, Zeng et al., 2017, Colzi et al., 2018a, 2018b)

...likely the environment in which the Sun was born

(e.g. Adams10)

<u>Supernovae explosions</u> are required to explain hints found in meteorites

^{26}Mg is found in meteorites → dauther species of ^{26}Al (with a half life of 0.72 Myr)

Only a time <1 Myr could have elapsed between the production of ^{26}Al and his incorporation into the early Solar system material

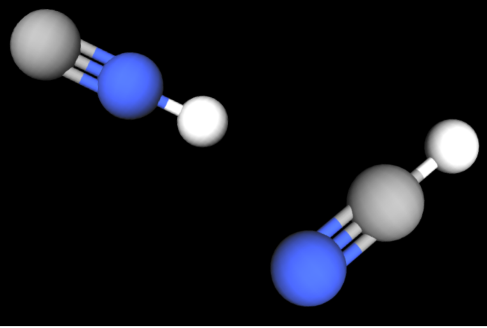
IRAM 30m telescope (Sierra Nevada, Spain)

Credit: Laura Colzi (21/05/2019)

87 High-mass star-forming regions:

27 (Fontani et al. 2011, 2015) + 60 (Mininni et al. in prep.)

- MEASURE **N-FRACTIONATION** IN NITRILE BEARING SPECIES **HNC** AND **HCN**;
- **COMPARE** WITH VALUES IN **PRISTINE SOLAR SYSTEM MATERIALS;**
- SEARCH A **GALACTOCENTRIC TREND** → **D_{GC} from 2 kpc up to 12 kpc**



Related papers: Colzi, L. et al. (2018 a,b)

- **HN^{13}C(1-0) at 87.1 GHz;**
- **H^{15}NC(1-0) at 88.9 GHz;**
- **H^{13}CN(1-0) at 86.3 GHz;**
- **HC^{15}N(1-0) at 86.1 GHz.**

MADCUBA (Martín et al. 2019)

→ Local Thermodynamic Equilibrium (LTE) fit of the spectra;

→ T_{ex} from CH_3CN(5-4) (LTE)

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DETECTIONS

$HN^{13}C$ → 78

$H^{13}CN$ → 78

$H^{15}NC$ → 65

$HC^{15}N$ → 69

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OPTICALLY THIN!!

- **$HN^{13}C$(1-0)** at 87.1 GHz;
- $H^{15}NC$(1-0) at 88.9 GHz;
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DETECTIONS

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$$N(HNC)=N(HN^{13}C)\,\frac{^{12}C}{^{13}C}$$

$$N(HCN)=N(H^{13}CN)\,\boxed{\frac{^{12}C}{^{13}C}}$$

Milam et al. (2005)

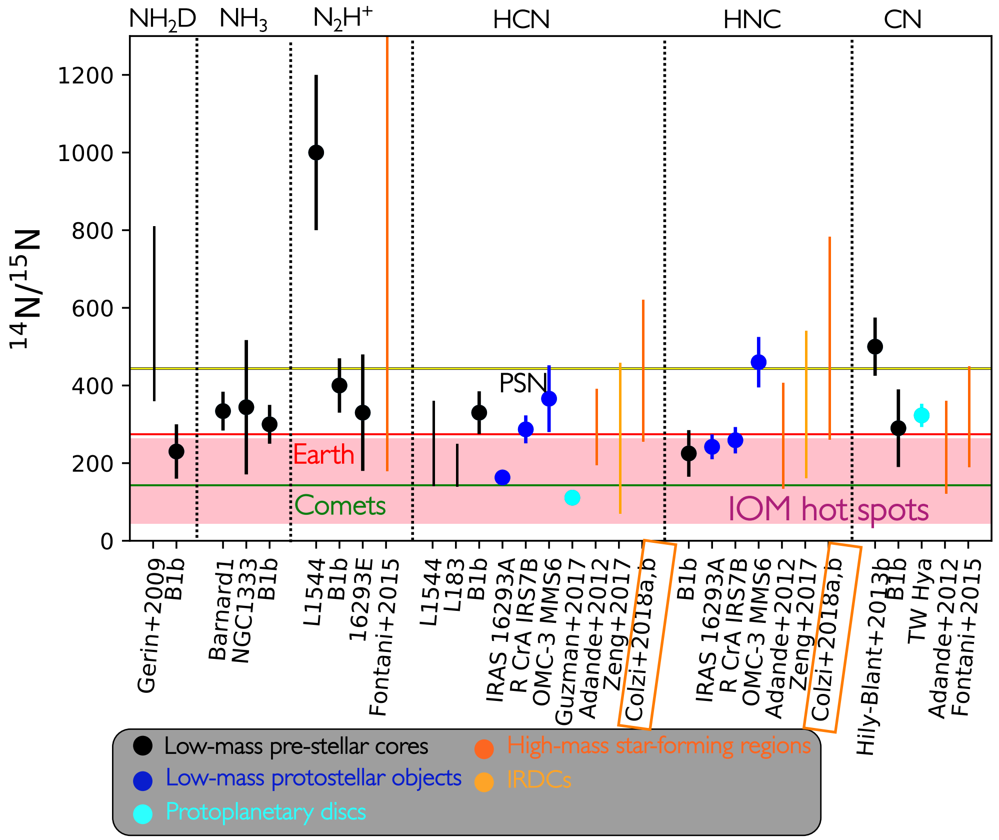
$$^{12}C/^{13}C = (6.01 \pm 1.19)\ Dgc(kpc) + (12.28 \pm 9.33)$$

Related papers: Colzi, L. et al. (2018 a,b)

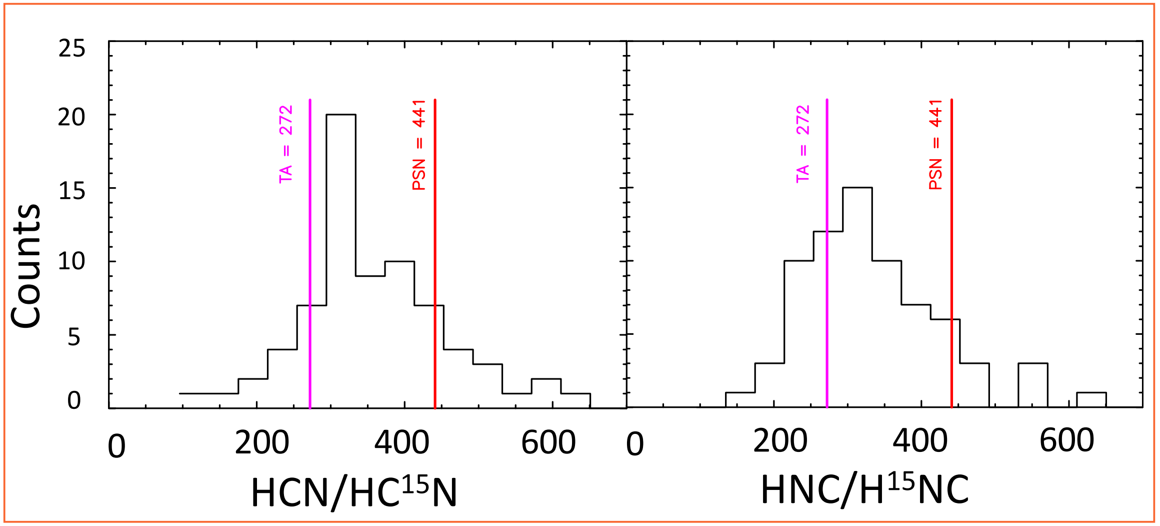
Distribution of $^{14}N/^{15}N$ ratios

In the merged total sample of 87 sources:

- $^{14}N/^{15}N$: 185-780 for HNC, 115-1305 for HCN;
- Distribution of $^{14}N/^{15}N$ peak in the bin 310-350.



Colzi+2018a,b



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$^{14}N/^{15}N$ as good indicator of nucleosynthesis

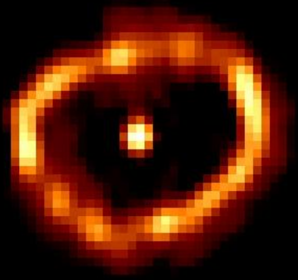
^{14}N: primary product

- Primary production from fast-rotating low-metallicity massive stars
- Primary production in the base of the convective envelope of AGB (intermediate-mass)
- Secondary production through CN cycles in MS stars and in the H-burning shells of red giants

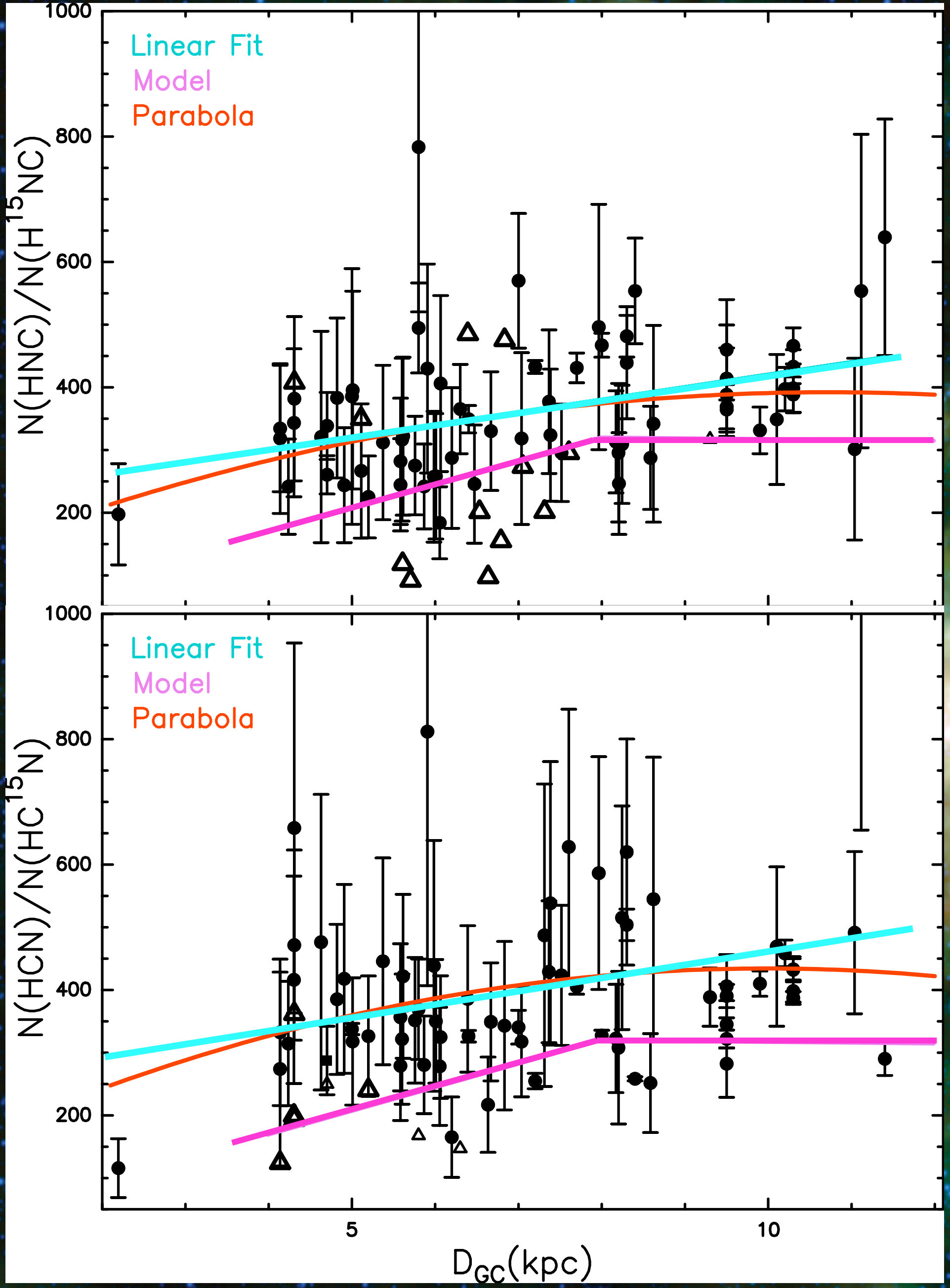
^{15}N: secondary product

- Secondary production from hot CNO cycle that occurs in **novae outbursts**

Nova Cygni 1992



What is the Galactocentric trend?



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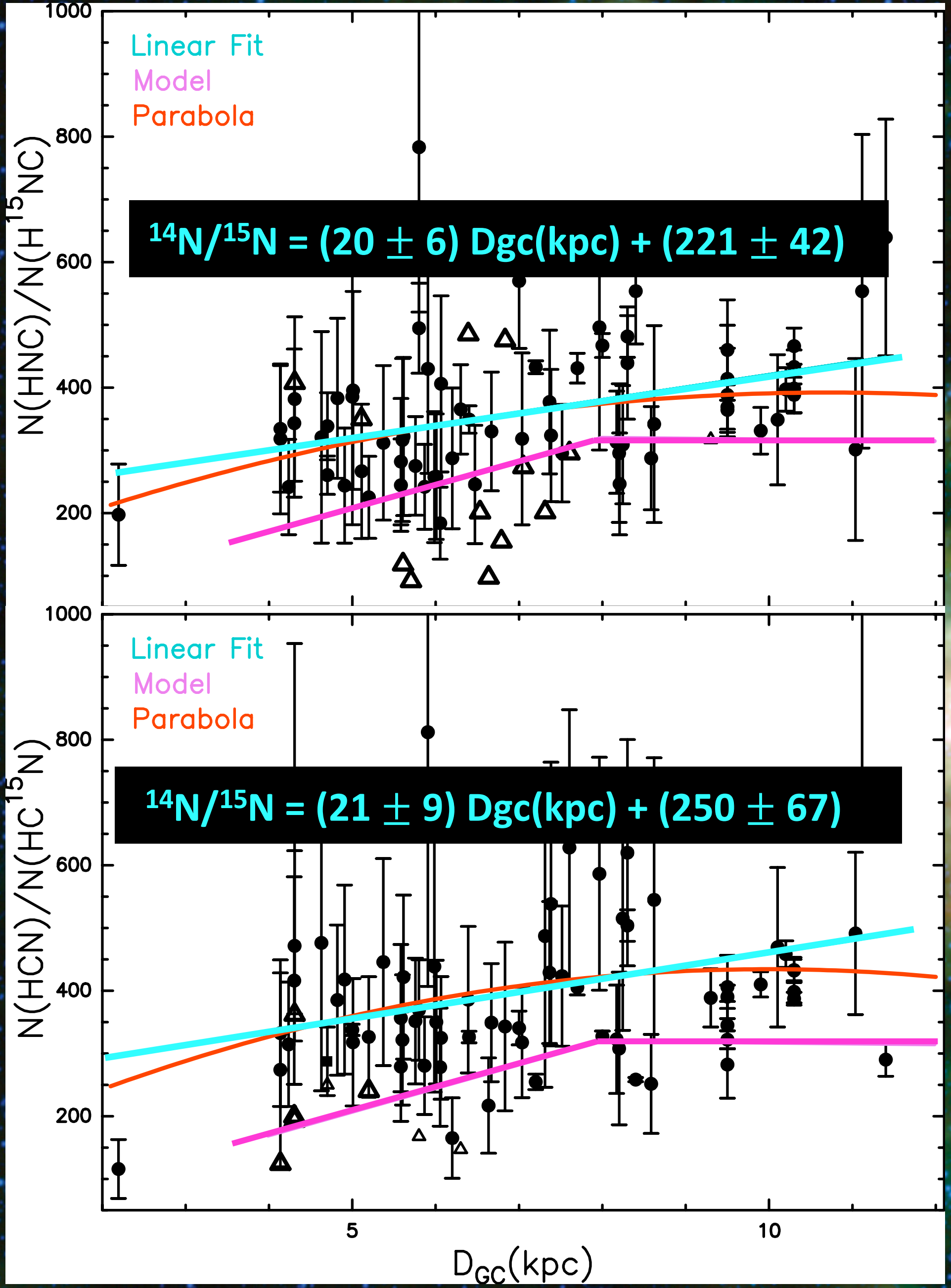
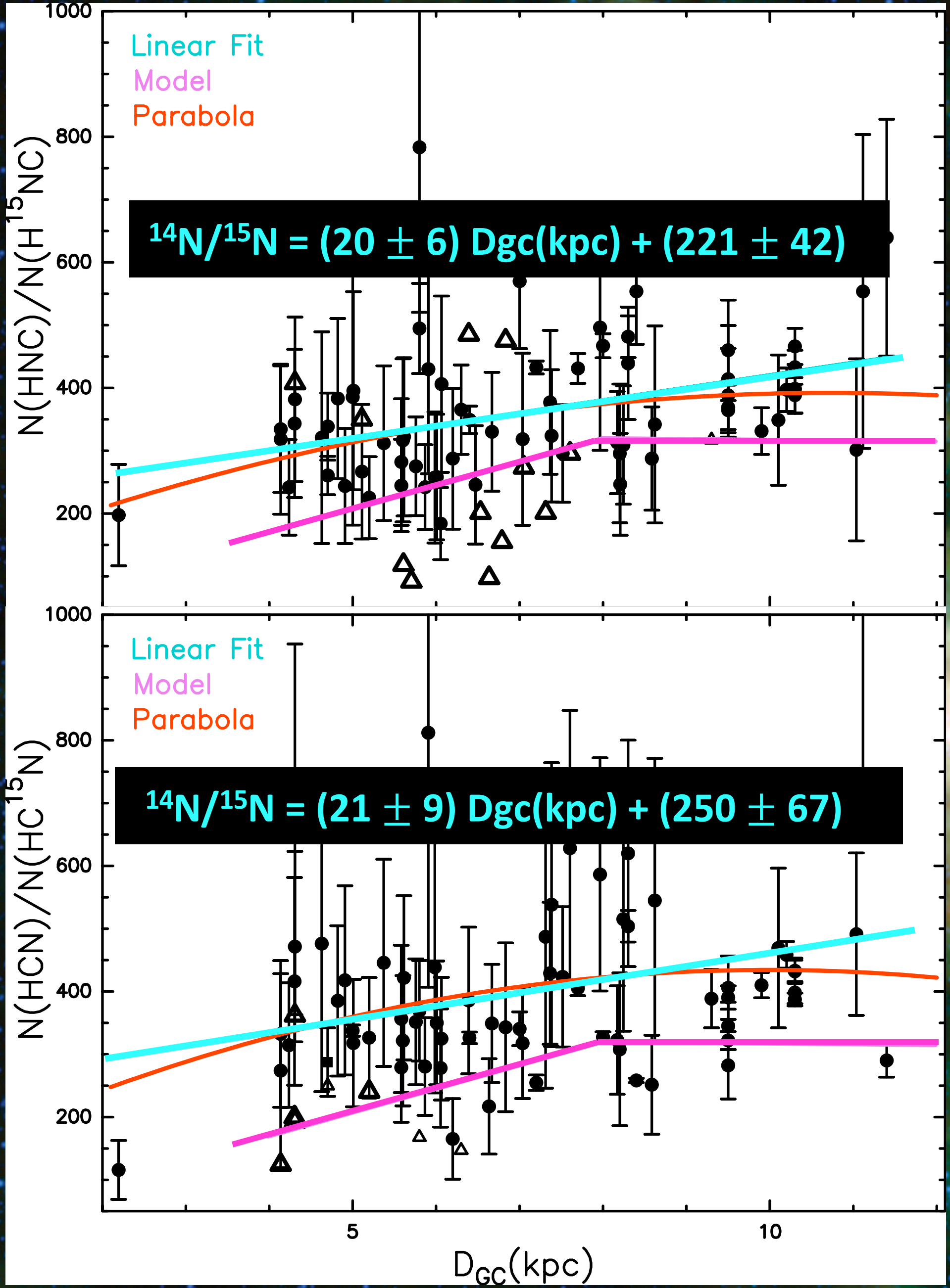


^{14}N/^{15}N = (20 ± 6) Dgc(kpc) + (221 ± 42)

^{14}N/^{15}N = (21 ± 9) Dgc(kpc) + (250 ± 67)

NEW LOCAL ISM VALUE
(8.4 kpc)
HNC: 370±50
HCN: 380±50

Related papers: Colzi, L. et al. (2018 a,b)



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Galactic chemical evolution (GCE, Romano et al., 2017) model predicts:

→ linear trend up to 8 kpc: introduction of NOVAE OUTBURST

→ flattening trend above 8-10 kpc: caused by assumed stellar yields

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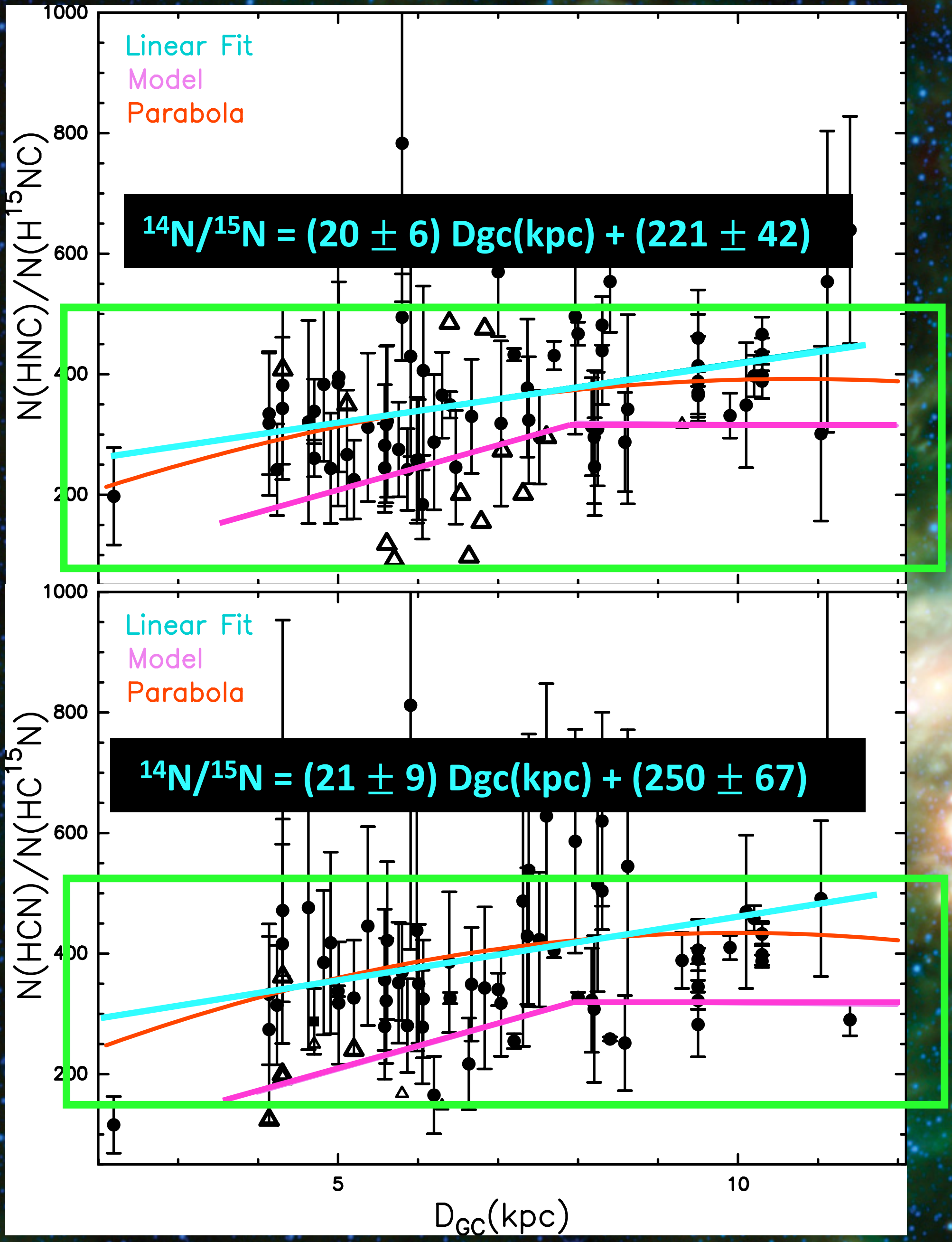

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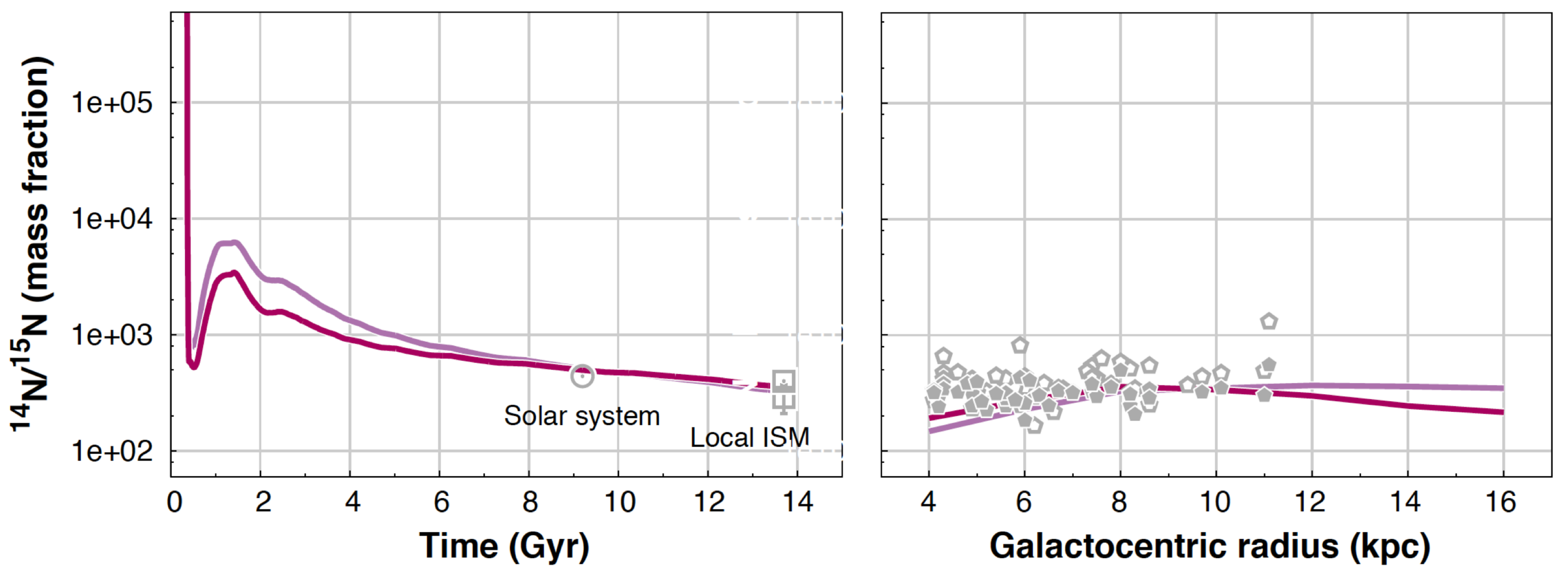
Romano et al. (2019) updated the stellar yields for massive stars taking into account different intial rotational velocities (Limongi and Chieffi 2018)



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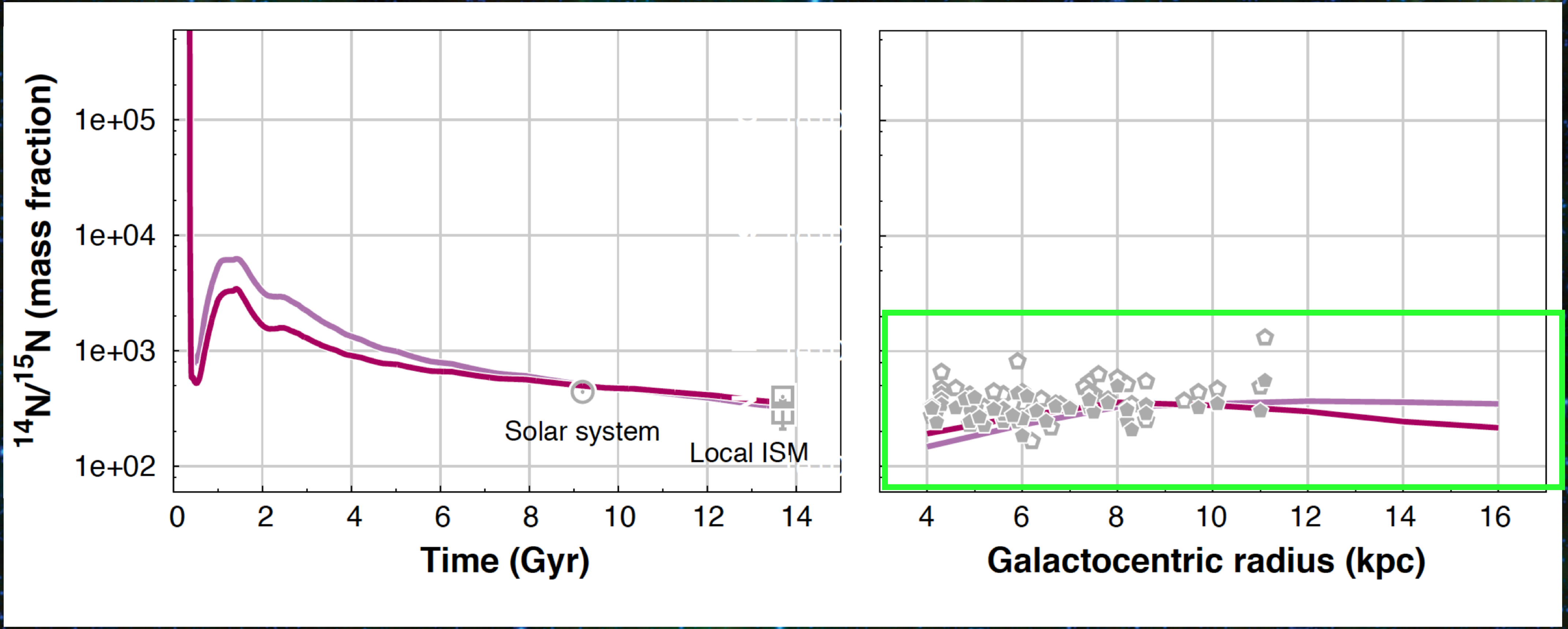


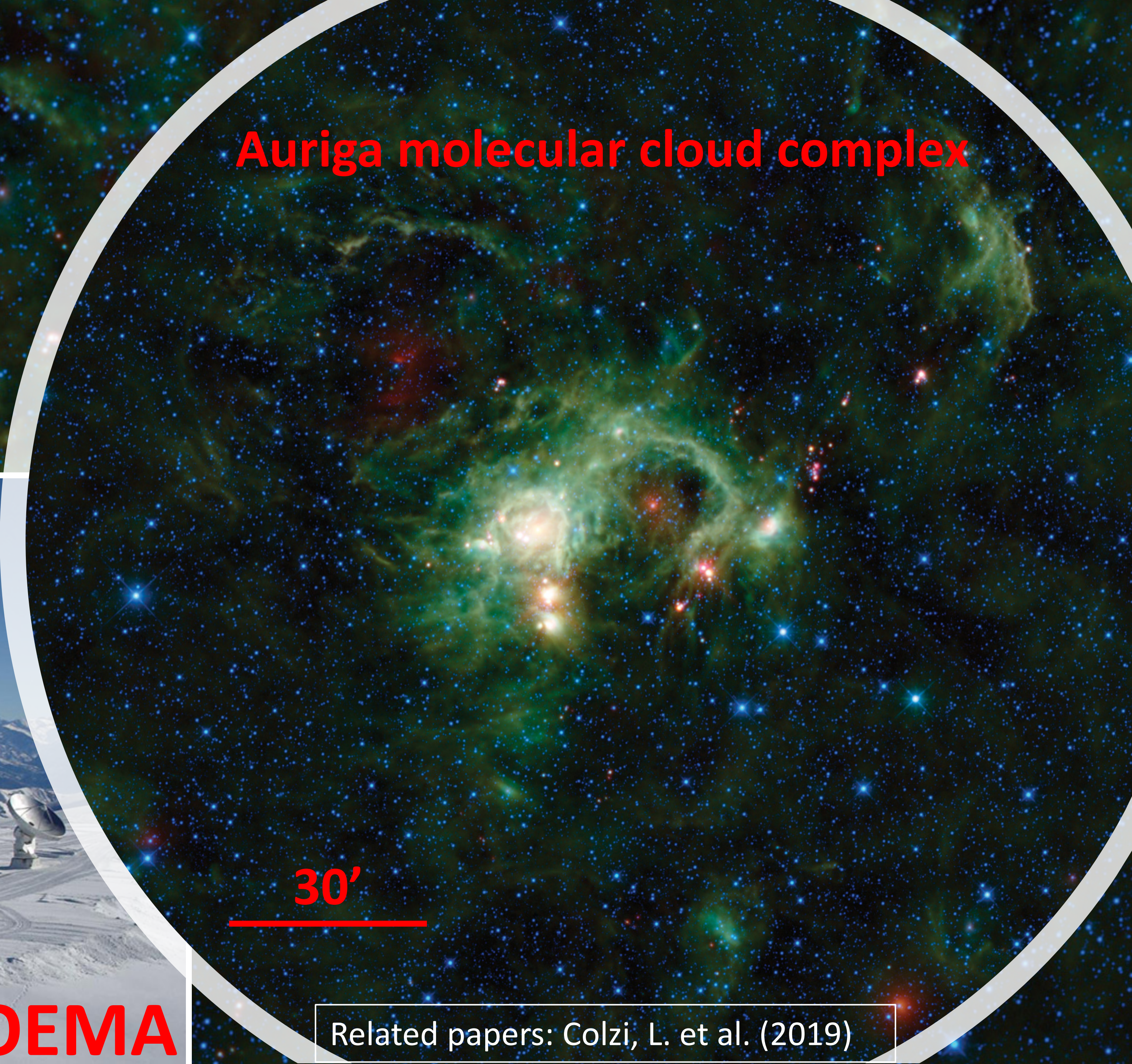
NOW THE GCE MODEL EXACTLY REPRODUCE THE TREND WE FOUND

IRAS 05358+3543

Distance 1.8 kpc

Image resolution ~3’’ –> ~0.03 pc
CORE SIZE

IRAM NOEMA



Auriga molecular cloud complex

Related papers: Colzi, L. et al. (2019)

IRAS 05358+3543

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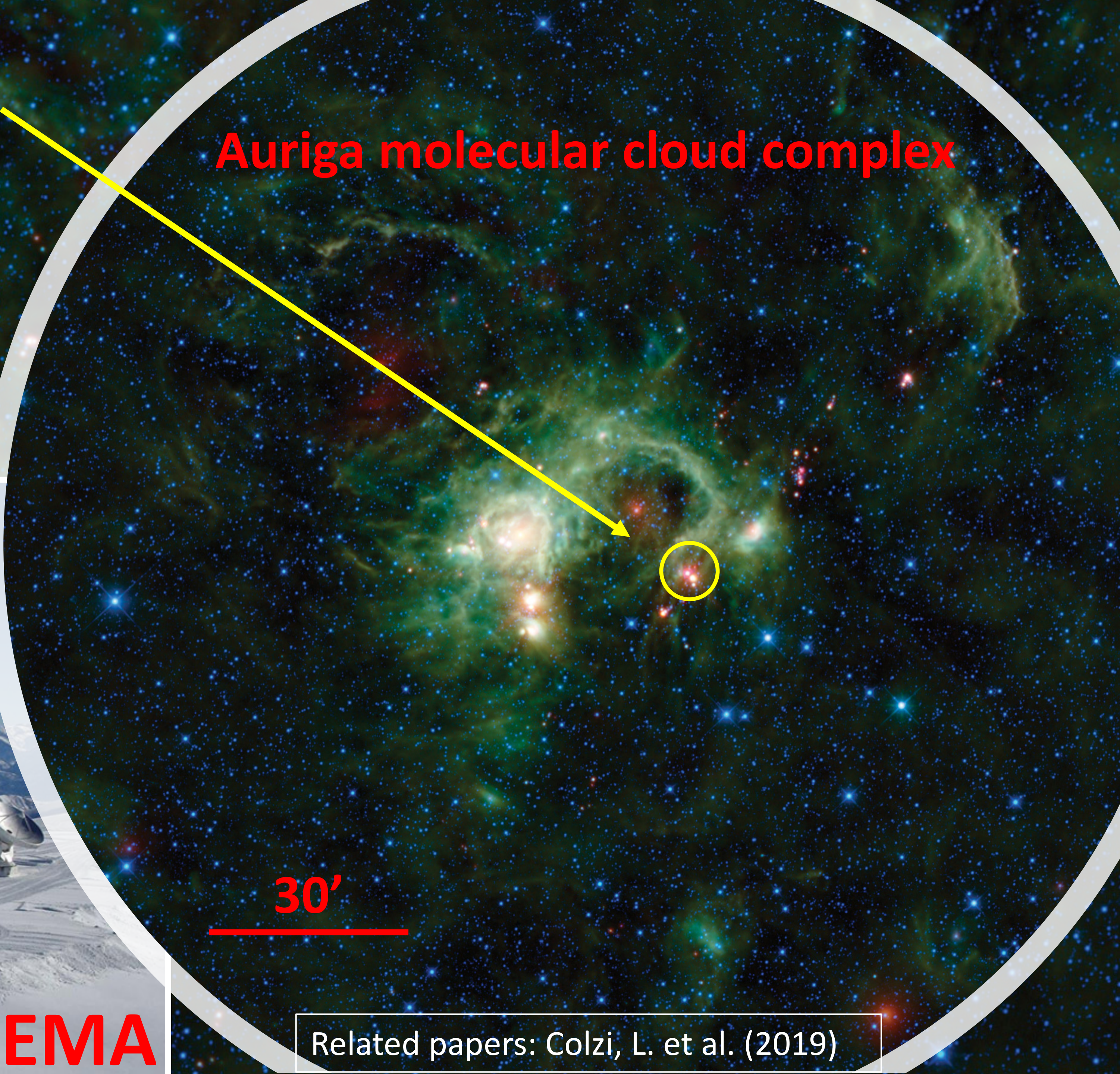

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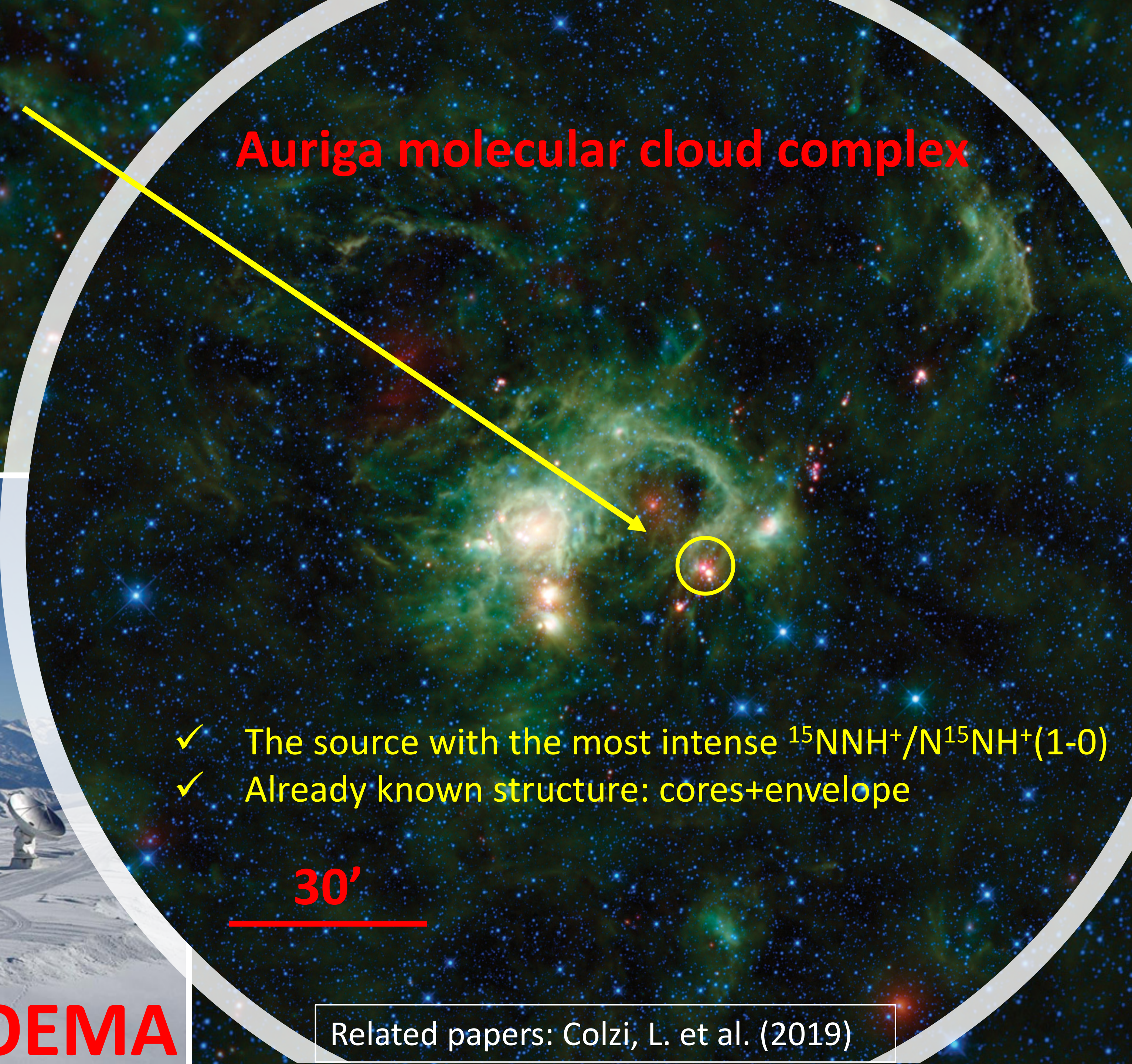
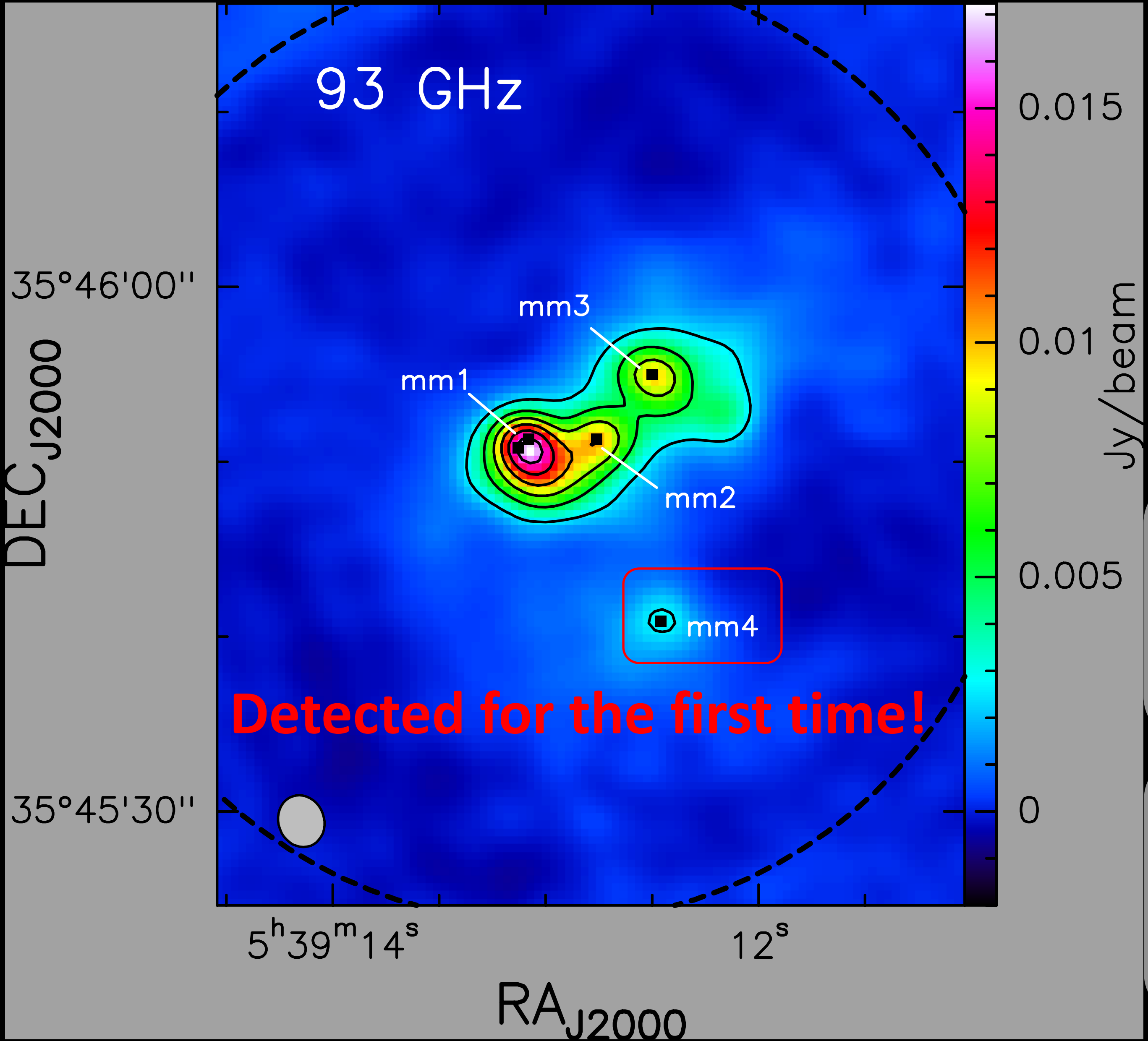


- ✓ The source with the most intense $^{15}NNH^+/N^{15}NH^+(1-0)$
- ✓ Already known structure: cores+envelope


IRAM NOEMA

Related papers: Colzi, L. et al. (2019)

The 3 mm continuum



Detected for the first time!

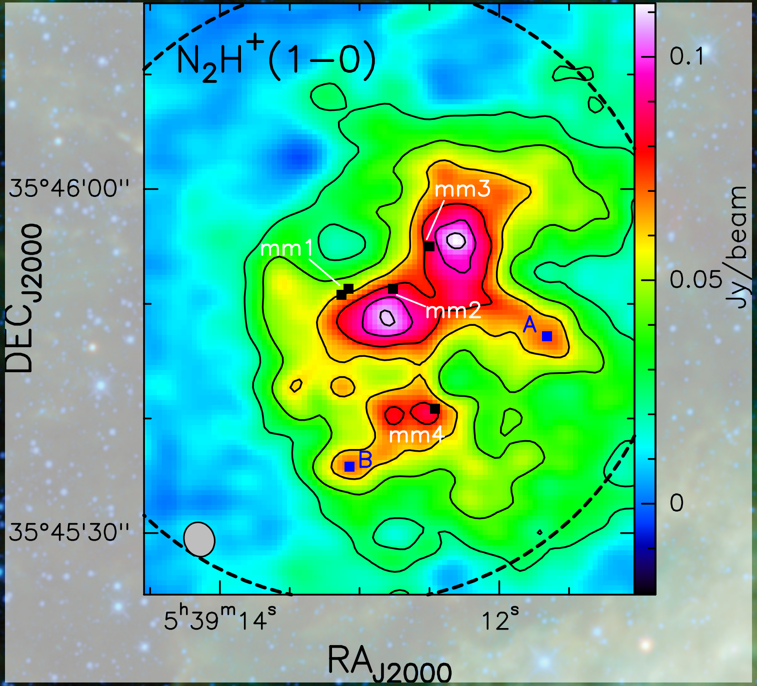
mm1 → High-mass protostellar object
Central star: B1 ZAMS
$L \sim 10^{3.72}\,L_\odot$
$M \sim 13\,M_\odot$

mm3 → High-mass starless core
NO compact line detection, T_{dust}<20 K

(Beuther+2002, 2007, Leurini+2007)

Related papers: Colzi, L. et al. (2019)

$N_2H^+(1\text{-}0)$
$^{15}NNH^+(1\text{-}0)$
$N^{15}NH^+(1\text{-}0)$

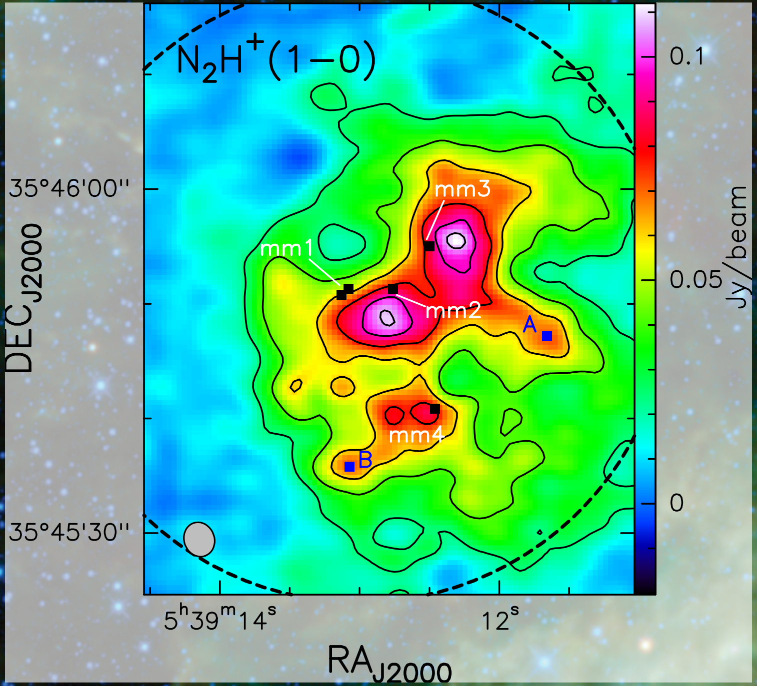


N_2H^+ (1-0) (NOEMA + 30m merged)

- THE EMISSION ARISES FROM <u>3 CORES</u>

Related papers: Colzi, L. et al. (2019)

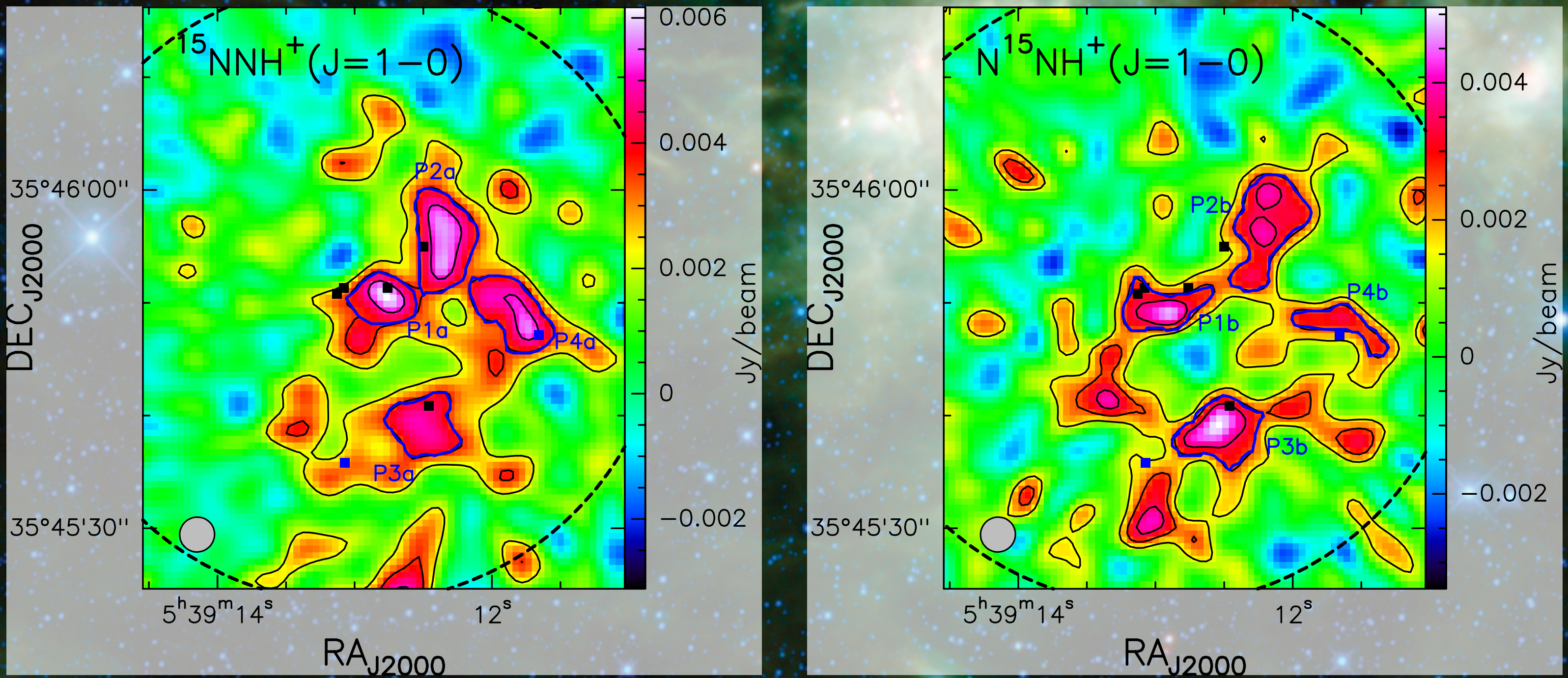
N_2H^+(1-0)
$^{15}NNH^+$(1-0)
$N^{15}NH^+$(1-0)



N_2H^+ (1-0) (NOEMA + 30m merged)

- THE EMISSION ARISES FROM <u>3 CORES</u>

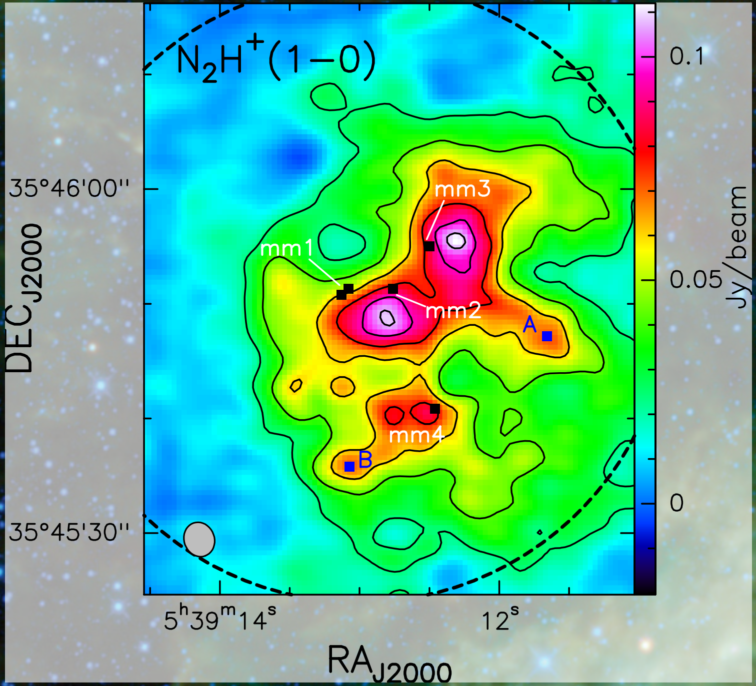
$^{15}NNH^+$ and $N^{15}NH^+$(1-0) (NOEMA + 30m merged)



- <u>COMPACT EMISSION</u> WITH RESPECT TO N_2H^+
- <u>DIFFERENT EMISSION</u> OF THE TWO ISOTOPOLOGUES

Related papers: Colzi, L. et al. (2019)

N_2H^+(1-0)
$^{15}NNH^+$(1-0)
$N^{15}NH^+$(1-0)

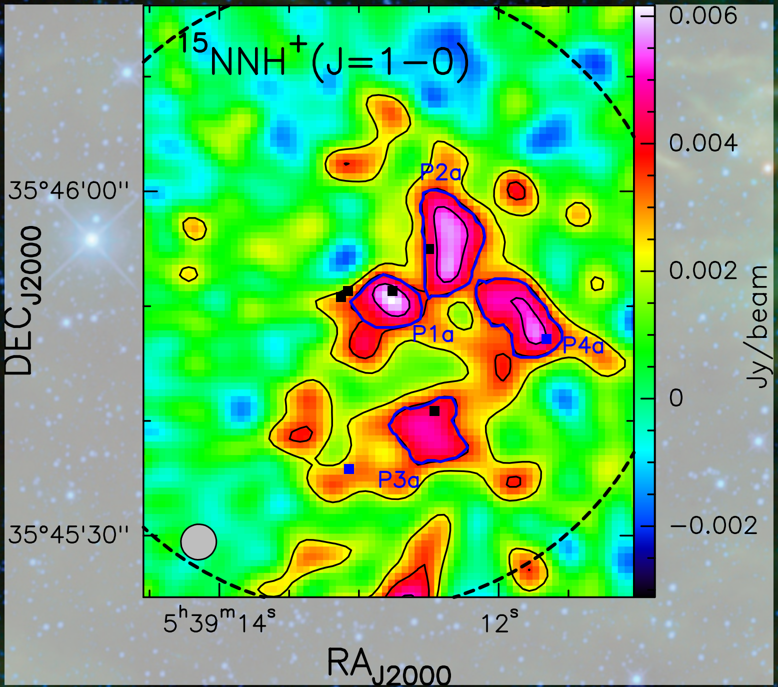


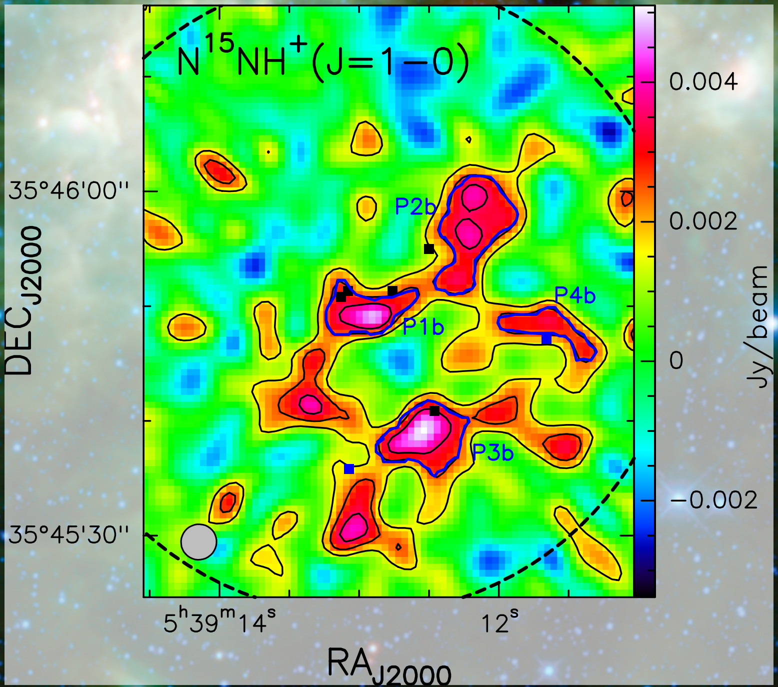
N_2H^+ (1-0) (NOEMA + 30m merged)

- THE EMISSION ARISES FROM 3 CORES

Geometrical center displaced of ~2-3"
with respect to the continuum sources

$^{15}NNH^+$ and $N^{15}NH^+$(1-0) (NOEMA + 30m merged)

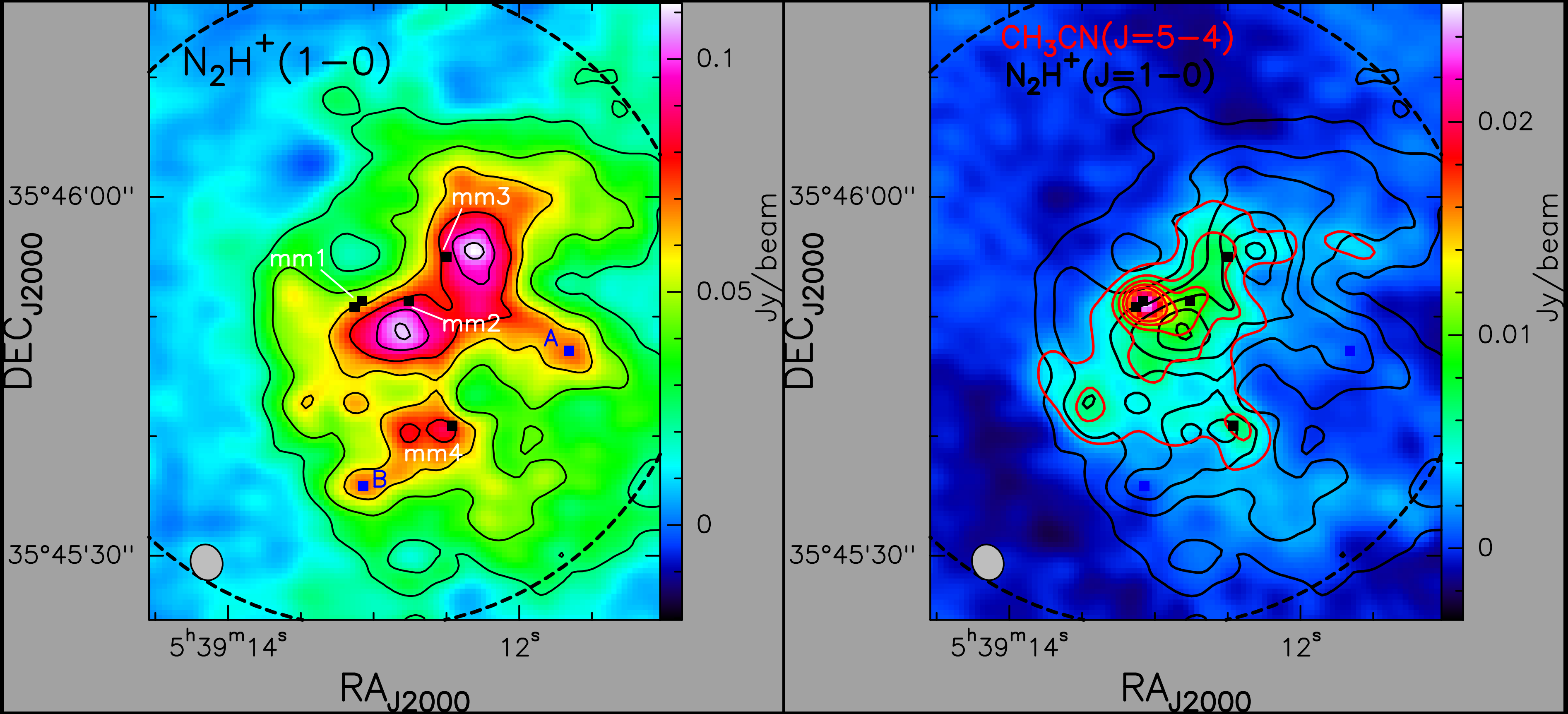




- COMPACT EMISSION WITH RESPECT TO N_2H^+
- DIFFERENT EMISSION OF THE TWO ISOTOPOLOGUES

Related papers: Colzi, L. et al. (2019)

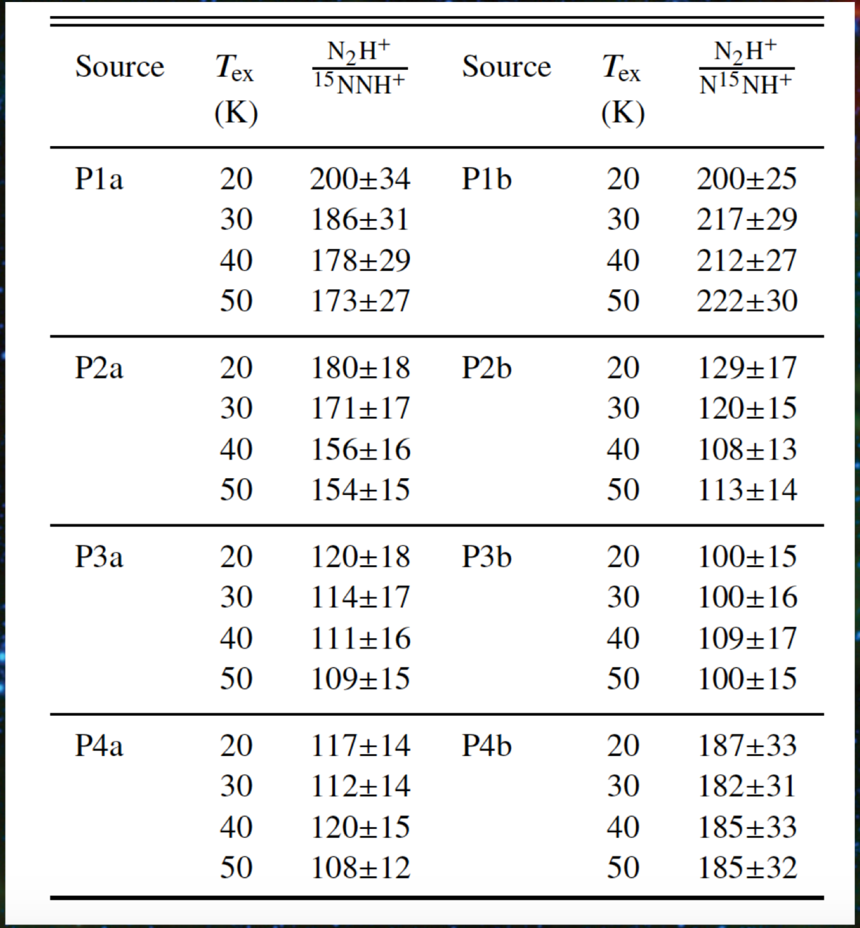
WHY THE DISPLACEMENT?



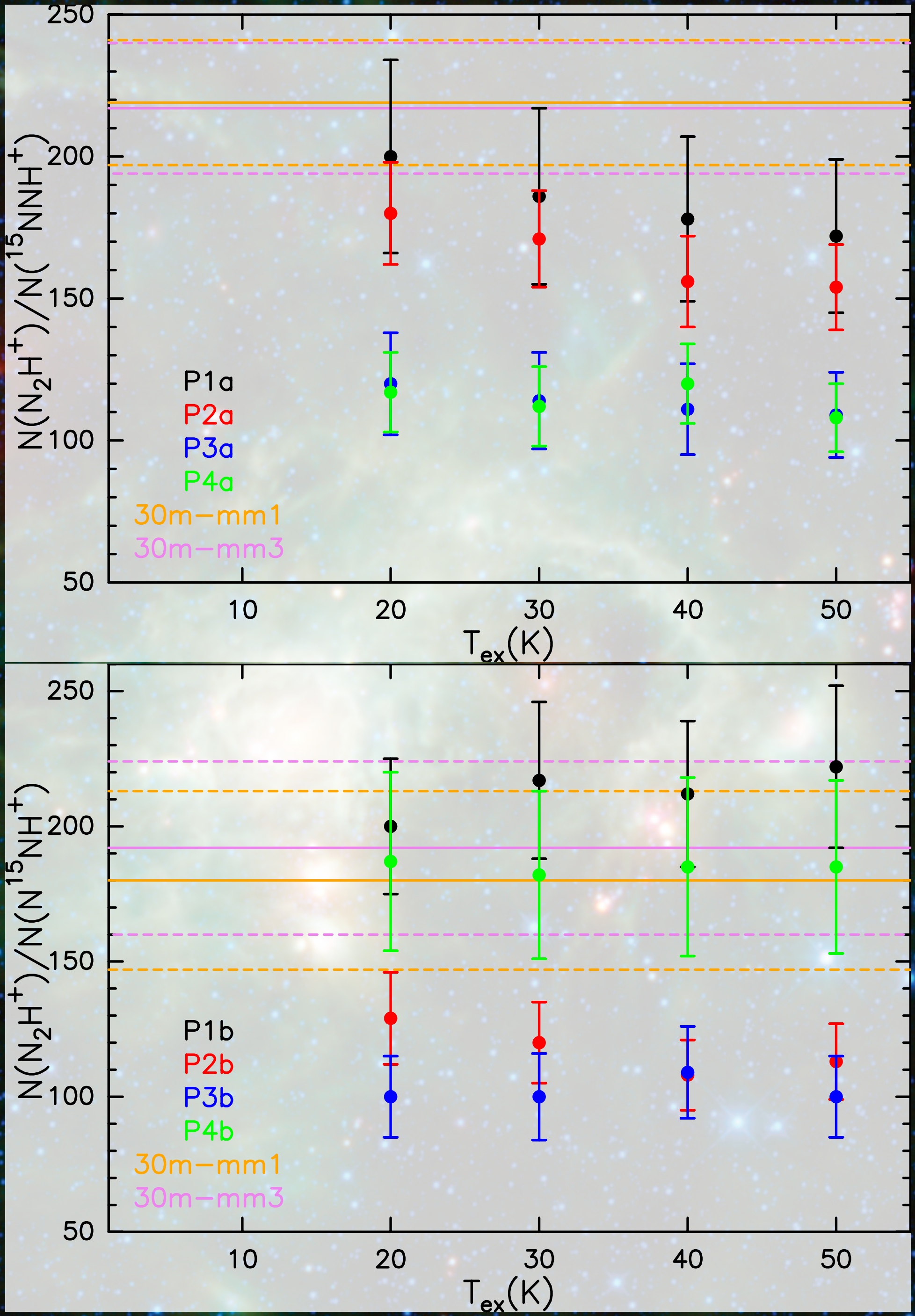
- **N_2H^+ is probably destroyed by CO, once it desorbs from ice mantles (e.g. Busquet+2011);**
- **mm1 and mm3: the heating of the protostar may have caused the desorption of CO;**
- **mm4: chemically less evolved and starless.**

Related papers: Colzi, L. et al. (2019)

$^{14}N/^{15}N$ RATIOS



Source	T_{ex} (K)	$\frac{N_2H^+}{^{15}NNH^+}$	Source	T_{ex} (K)	$\frac{N_2H^+}{N^{15}NH^+}$
P1a	20	200±34	P1b	20	200±25
	30	186±31		30	217±29
	40	178±29		40	212±27
	50	173±27		50	222±30
P2a	20	180±18	P2b	20	129±17
	30	171±17		30	120±15
	40	156±16		40	108±13
	50	154±15		50	113±14
P3a	20	120±18	P3b	20	100±15
	30	114±17		30	100±16
	40	111±16		40	109±17
	50	109±15		50	100±15
P4a	20	117±14	P4b	20	187±33
	30	112±14		30	182±31
	40	120±15		40	185±33
	50	108±12		50	185±32

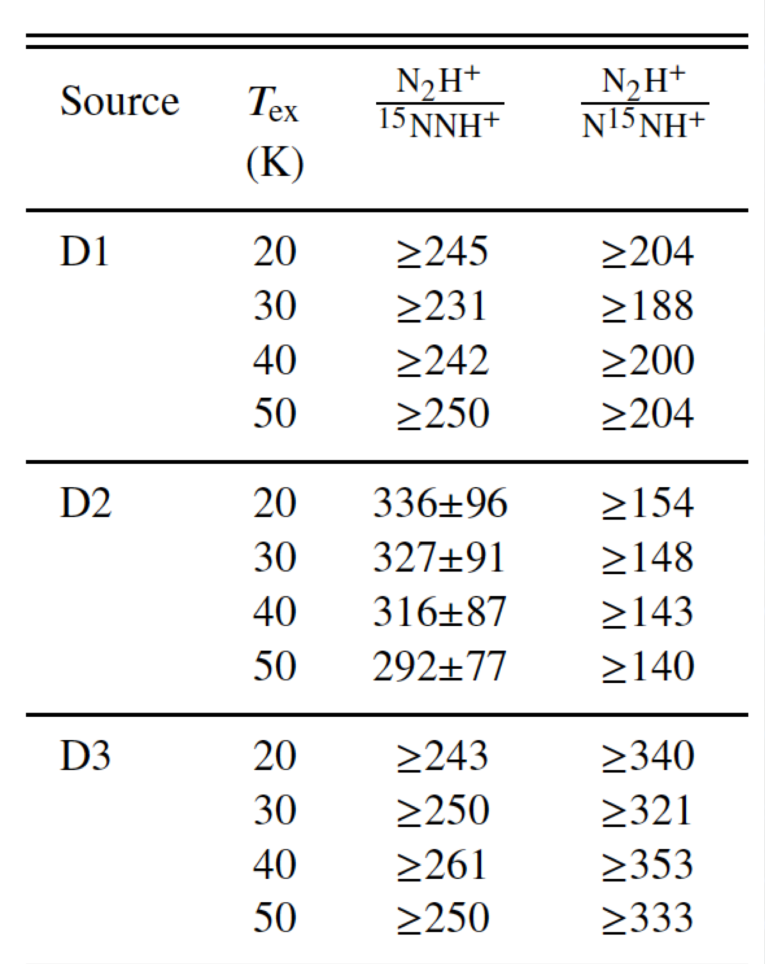


Towards mm3 and mm4 there is a clear evidence of ^{15}N-enrichment at core scales with respect to the region previously resolved with the IRAM 30m (Fontani+2015)

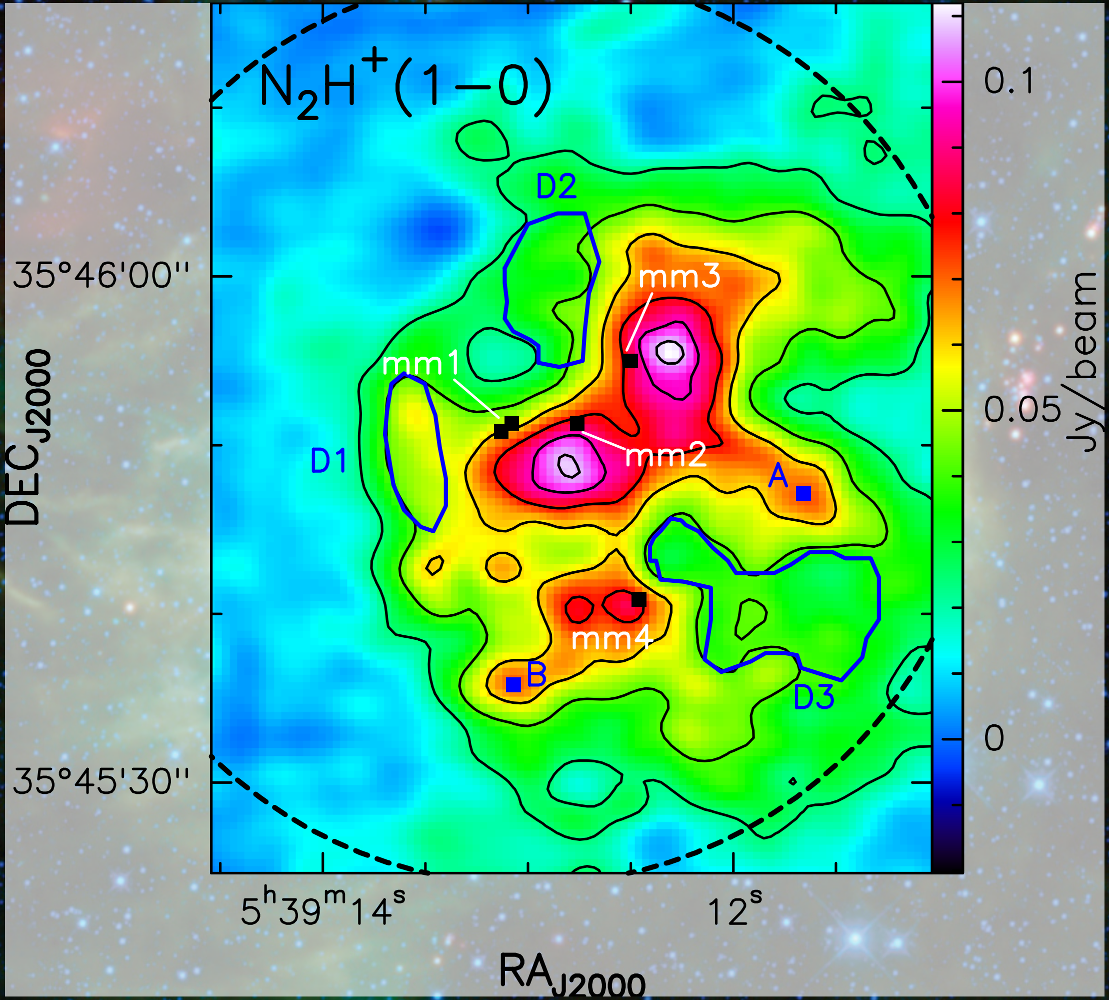
Towards A differences between $^{15}NNH^+$ and $N^{15}NH^+$
→ to be investigated!
(see e.g., Roueff et al. 2015, Wirström & Charnley 2018)

Related papers: Colzi, L. et al. (2019)

AND THE DIFFUSE REGIONS?



Source	T_{ex} (K)	$\frac{N_2H^+}{^{15}NNH^+}$	$\frac{N_2H^+}{N^{15}NH^+}$
D1	20	≥245	≥204
	30	≥231	≥188
	40	≥242	≥200
	50	≥250	≥204
D2	20	336±96	≥154
	30	327±91	≥148
	40	316±87	≥143
	50	292±77	≥140
D3	20	≥243	≥340
	30	≥250	≥321
	40	≥261	≥353
	50	≥250	≥333



Towards the N_2H^+ diffuse emission regions we have found $^{14}N/^{15}N$ >200.

Another evidence of ^{15}N-enhancement towards the cores (0.03 pc)

Related papers: Colzi, L. et al. (2019)

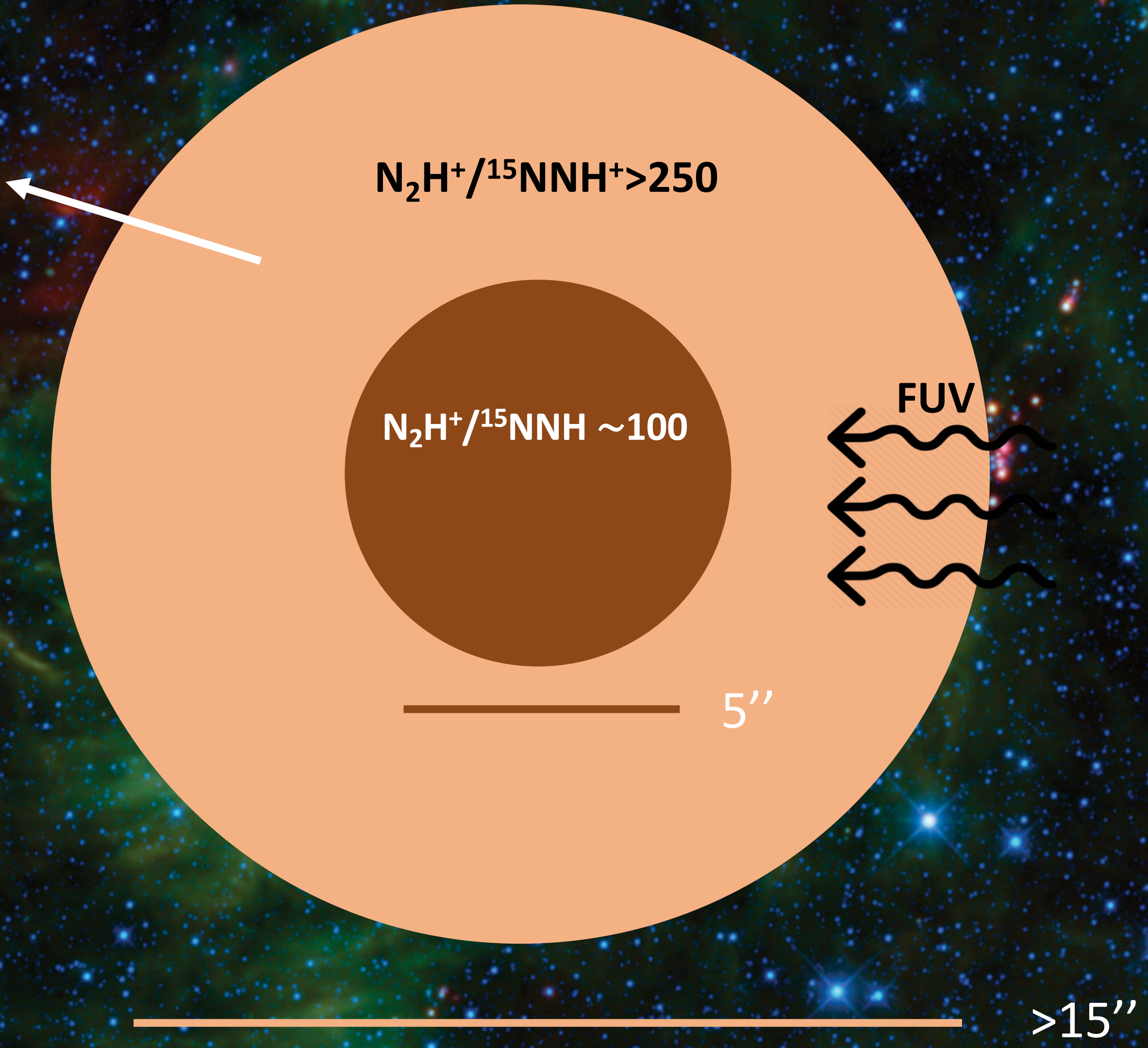
Furuya & Aikawa (2018)

ENVELOPE

- Isotope selective photodissociation of N_2
  (Heays et al. 2014)
- ^{15}N locked on grains

$^{14}N/^{15}N$ ↓

$^{14}N^{14}N/^{14}N^{15}N$ ↑



Furuya & Aikawa (2018)

ENVELOPE

- Isotope selective photodissociation of N_2 (Heays et al. 2014)
- ^{15}N locked on grains

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CORE

- **Photodissociation inefficient**

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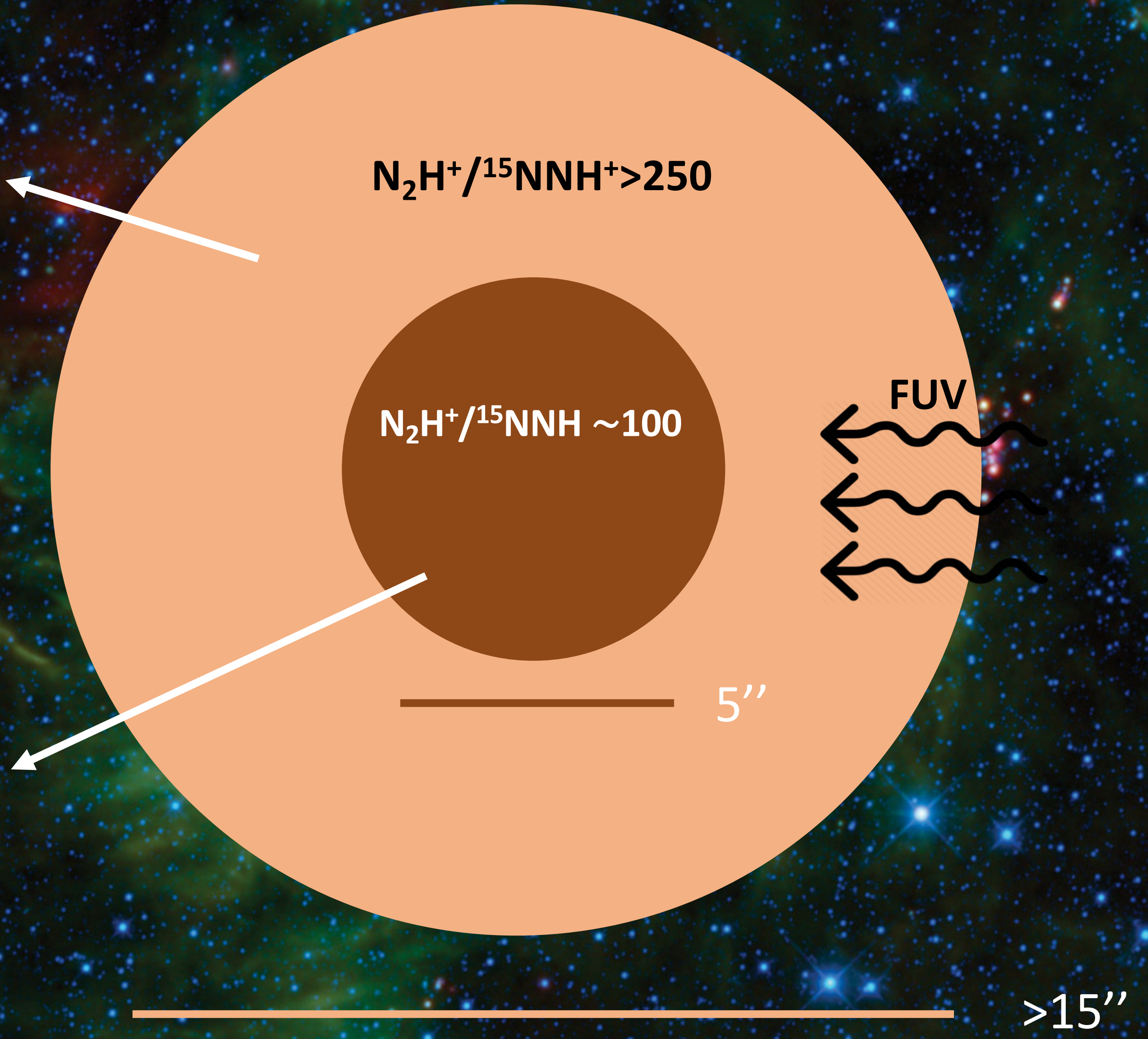

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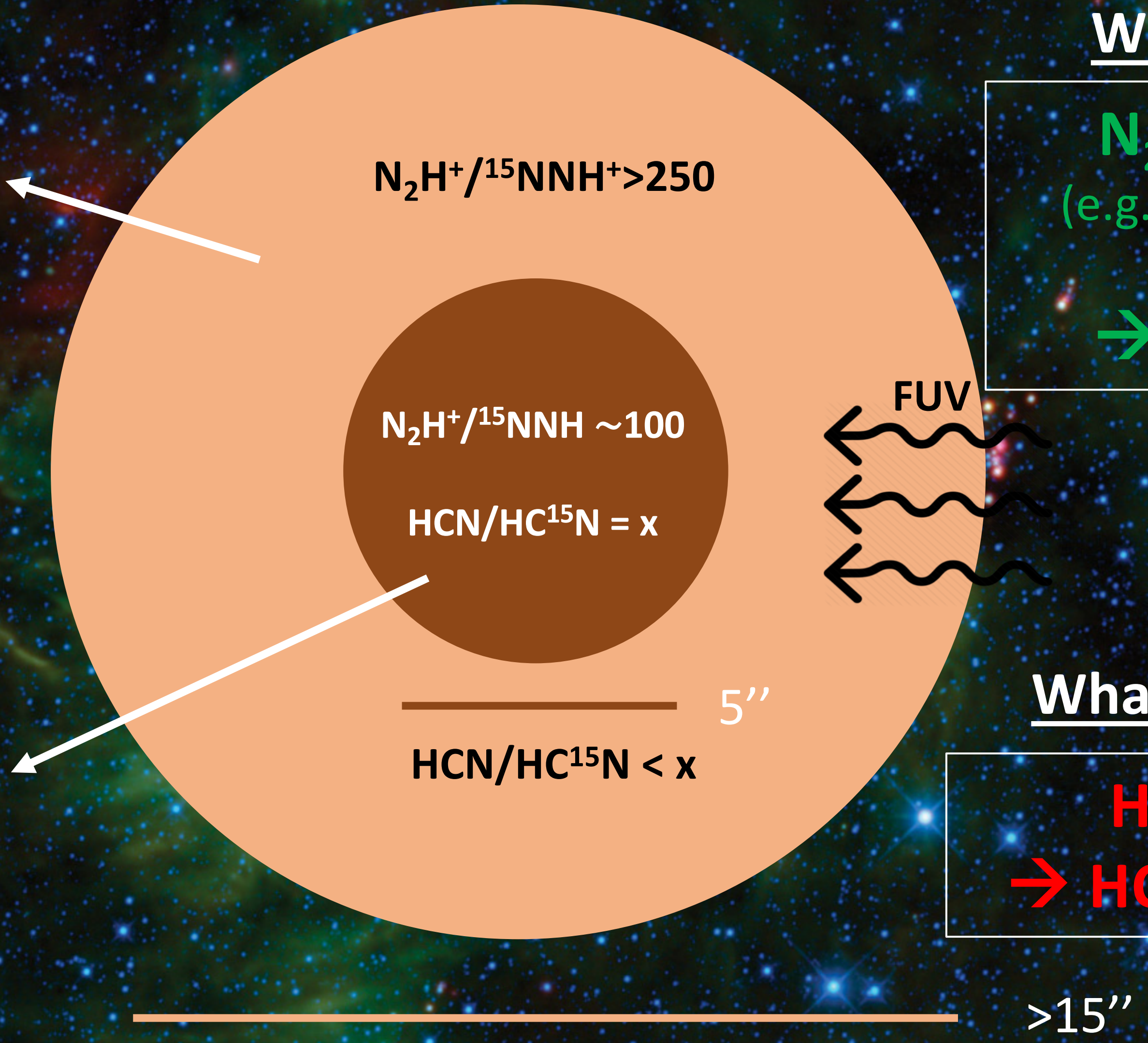


Regarding the envelope…

What we know:

N_2H^+ follows N_2

(e.g. Herbst & Klemperer 1973)

→ $N_2H^+/^{15}NNH^+$ ↑

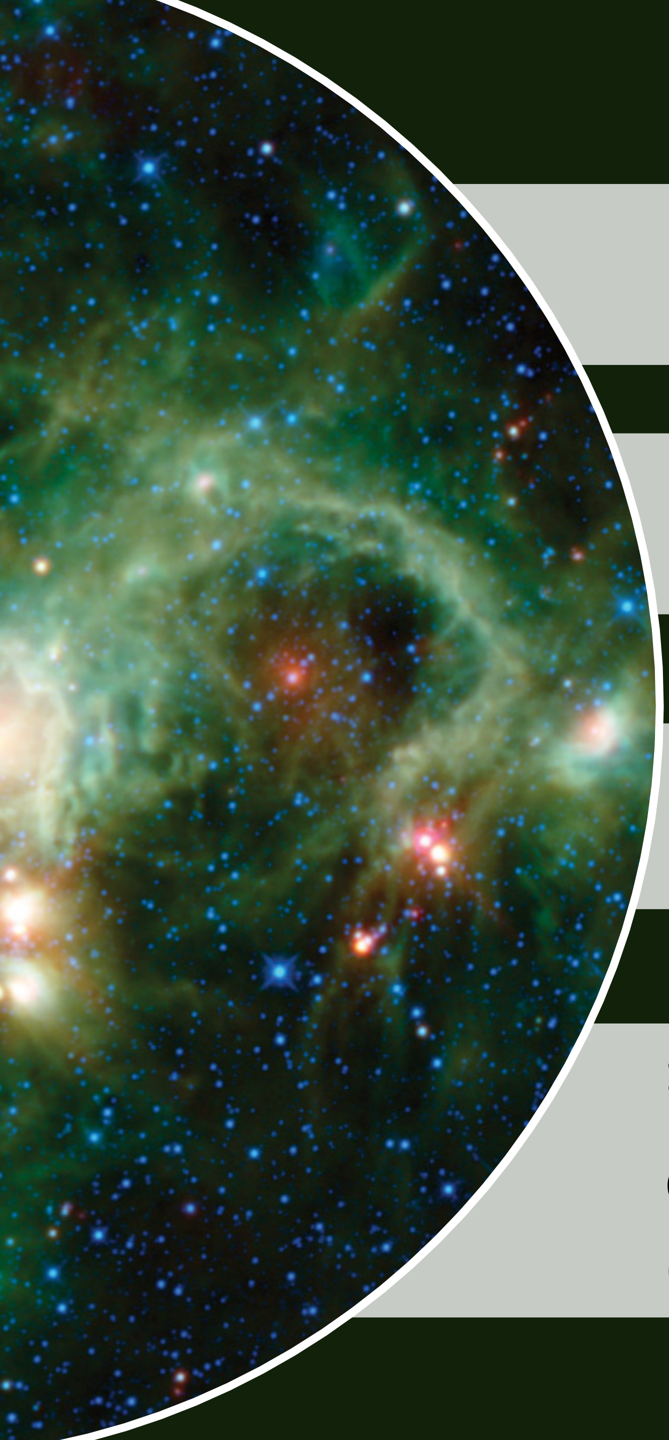
What we want to test:

HCN follows N

→ $HCN/HC^{15}N$ should ↓

NEW NOEMA + IRAM 30m OBSERVATIONS –> STAY TUNED!!

Conclusions



New LOCAL $^{14}N/^{15}N$ ISM VALUE 375±60 → closer to PSN value

Galactic chemical evolution model reproduces Galactocentric trends and absolute values

First evidence of enhanced N-fractionation in N_2H^+ towards a massive star-forming region

$^{14}N/^{15}N$ ratios towards the more diffuse regions of the cluster (>200) higher than those derived in the cores (100-200)

Enhanced nitrogen fractionation at core scales:

The high-mass star-forming region IRAS 05358+3543

Congresso Nazionale di Astrochimica e Astrobiologia (proto-) planetaria

Laura Colzi

21st October 2019

F. Fontani, P. Caselli, V. M. Rivilla, S. Leurini, L. Bizzocchi, L. Testi, M. Beltrán, Á. Sánchez-Monge, C. Ceccarelli, P. Hily-Blant, G. Quaia

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