Onsala Proposal

Law 0108.F-9316

Unmasking the Nitrogen fractionation across galactic environment

Semester: may2021 **Science Cat.: ISM and star formation**

Abstract

The nitrogen (14N/15N) abundance ratios provide strong constraints on the current paradigm of galaxy chemical evolution models, which themselves give valuable information on both astrophysical and astrochemical properties of old and young Solar System and the conditions led to the development of life on Earth. In many nitrogen fractionation studies involving single transition, the abundance ratio is reliable provided that the corresponding excitation conditions are the same among the isotopologues, which may not be always valid. Here we propose using APEX multiple receivers to observe multiple transitions of HCN, HNC and its 15N isotopologue (include also the 13C isotopologue) from J=2-1 to J=4-3 toward 2 selected massive clumps from the ALMAGAL survey. This will allow us to probe and study the excitation conditions among isotopologues of the two clumps with population diagram analyses and proper chemical modelling. The proposed observation also provides an independent additional measurement on the nitrogen fraction of the targets.

Applicants

Name	Affiliation	Email	Country		Potential observer
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Is this a long term proposal: No

Overall scheduling requirements

Both sources are above 45 deg in July only within the APEX Swedish time period

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA180 (159-211 GHz)	1h (1h)	170.9	1-2 mm		
B	APEX	SEPIA180 (159-211 GHz)	4h (4h)	175.9	1-2 mm		
C	APEX	nFLASH230 (200-270 GHz)	1h (1h)	257.0	1-2 mm		
D	APEX	nFLASH230 (200-270 GHz)	1h (1h)	266.5	1-2 mm		
E	APEX	SEPIA345 (277-371 GHz)	3h (3h)	355.8	0.5-1 mm		
F	APEX	SEPIA345 (277-371 GHz)	5h (5h)	362.0	0.5-1 mm		

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
ALMAGAL107853	16:12:09.91	-51:28:37.3	J2000	-91.8	506	A B C D E F	Include overhead
ALMAGAL865468	17:05:11.16	-41:29:05.7	J2000	-32.4	506	A B C D E F	Include overhead

1 Scientific background

The uniqueness of the Solar System architecture and the conditions that led to the development of life on Earth are still unclear today. These topics are investigated by studying the astrophysical and astrochemical properties of old and young exoplanetary systems and the conditions that led to their formation. The definition of the Galactic Habitable Zone (see review by Gonzalez 2011) is linked to the chemical evolution of the Galaxy via global chemical evolution models. Chemical evolution models predict that different stellar populations contribute to the enrichment of the interstellar medium in different isotopes. The present-day measurements of the galactic distribution of the isotopic abundances of the most abundant element (such as C, N and O) is one of the best tools we have to test the chemical evolution models of the Galaxy (see, e.g. Romano et al. 2017, 2019). In particular, the abundance ratio of the ^{15}N to ^{14}N is an essential test for the models, as the ISM enrichment of ^{15}N is driven by AGB stars, massive stars and novae (see below), hence the measurement of the ^{14}N/^{15}N ratio allows to calibrate the Galactic Chemical Evolution (GCE) models. Today's understanding of the isotope abundance ratios in representative objects of the early Solar System (e.g. meteorites, comets, solar wind, etc.) will potentially provide important hints on the chemical evolution of the ^{14}N/^{15}N ratios during the Sun formation. Figure 1 (panel A) summarises the current understanding from these early Solar System objects. In summary, a large scatter in ^{14}N/^{15}N values is detected among different regions with respect to the proto-Solar nebula value, which could not be explained by current chemical models (Wirstrom et al. 2012, Roueff, E., et al. 2015). Models ranging from the GCE to selective photo-dissociation have been proposed to explain the large scatter (e.g. Heays et al. 2014,Romano et al. 2017, Furuya & Aikawa 2018, Romano et al. 2019, Lee et al. 2021).

An important parameter to study the nitrogen fractionation is the column density measurements of the ^{14}N- and ^{15}N-bearing species, respectively. To measure reliable ^{14}N/^{15}N abundance ratio for a specific transition, it requires all the isotopologues are correspond to the same excitation temperature (e.g. Kahane et al. 2018). In single transition studies (e.g. Only using a single transition of HCN and HNC and their corresponding ^{15}N isotopologues), the abundance ratios are reliable provided that both ^{14}N- and ^{15}N-bearing species are correspond to the same excitation temperature (Kahane et al. 2018). In general, a reasonable specific temperature ranges is defined to infer the lower and upper limit of the column densities or inferred from other molecule species (e.g. NH_3,CH_3CN) (e.g. Zeng et al. 2017, Colzi et al. 2018, Kahane et al. 2018, Fontani et al. 2021). However, it is unclear if such an assumption is always valid. Hence, it is also crucial to cross-check the excitation conditions for the isotopologue lines using multiple transitions and perform proper population diagram analyses and proper modelling (e.g. Wampfler et al. 2014, Rolffs et al. 2011, Kahane et al. 2018). **Therefore, we propose to observe multi-transitions HCN and HNC lines with their corresponding ^{15}N and ^{13}C isotopologues toward two representative ALMAGAL clumps. The goal of the proposed observation will (i) study the excitation conditions of the two sources by population diagram analyses and chemical modeling and (ii) also to measure the nitrogen fractionation in these two massive clumps via HCN/HC^{15}N or HNC/H^{15}NC, and via double isotope method with ^{13}C isotopologues.**

2 Target and data justification

ALMAGAL (program ID: 2019.1.00195.L) surveys about $\geq$ 1000 Hi-GAL identified high mass clumps ($> 500 M_\odot$) across the Galaxy over a range of distances (mostly D_{GC}/kpc $\leq$ 7.5 kpc) and sampled across a wide galactic longitude and galactic environments. Thus, the survey provides a prime database to initiate the proposed observation to compare the excitation conditions toward well-defined regions. The two selected ALMAGAL sources (ALMA ID:801753 and 865468, Figure 2) are also included as part of a larger sample proposed to systematically study the nitrogen fractionation across different galactic environments with ALMA (separate proposal). The two selected ALMGAL clumps are among with strong DCN(3-2) peak intensity to assure good enough detection toward the main interest ^{14}N- and ^{15}N-bearing isotopologue lines. Previous studies (e.g. Hatchell et al. 1998, Wampfler et al. 2014, Rolffs et al. 2011) support the feasibility of multi-transition HCN and HNC line analyses. In particularly, Rolffs et al. (2011) studied multiple transitions of HCN and HNC with APEX in a sample of hot molecular cores from J=3-2 up to J=8-7 transitions, and showed good detection toward massive hot molecular cores environments with relative similar peak intensity from J=3-2 to J=4-3, and have relatively good detection for J=8-7. Thus, we plan to observe the same species as also proposed for ALMA observations and with transitions J=2-1 to J=4-3 (see Table 1).

3 Technical justification

We propose APEX observations toward 2 ALMAGAL sources in position switching ON/OFF mode with SEPIA 180, nFLASH230, and SEPIA 345 receivers to observe HCN and HCN (include their ^{13}C and ^{15}N isotopologues) (see Table 1 & 2). Both sources are above 45 deg in early to mid July 2021 (see Figure 3), within the scheduled APEX Swedish time [1]. To estimate the APEX time required per source, we start from the DCN(3-2) intensity toward each source. Based on Hatchell et al. (1998) study over a sample of hot molecular cores, the peak intensity ratio between DCN(3-2) and HC15N(3-2) is 1:1.2. Based on the other observational studies that cover a similar set of lines, we assure the detection of other isotopologues lines as they have higher or comparable intensity with HC^{15}N(3-2) (e.g. Daniel et al. 2013, Wamplfer et al. 2014, Rolffs et al. 2011). We perform the time estimate based on the lowest angular resolution toward SEPIA 180 (36.5″), we compute a beam dilution factor of 0.02. With DCN(3-2) peak intensity of about 4.6 K will led to intensity of 100 mK to the weakest line. A sensitivity of 20 mK, will assure 5 SNR for all lines. Hence, for SEPIA 180 at PWV 2.0, 1.9 hrs and 0.5 hrs are required for tuning frequency 175.9 GHz and 170.9 GHz respectively per source, meaning that 4.8 hrs required for 2 sources. For nFLASH 230 at PWV2.0, 1.17 hrs will be required to achieve the desired sensitivity for both tuning frequency, requiring a total of 2.4 hours for 2 sources. Finally for SEPIA 345, we take a slightly higher sensitivity of 25 mK, which still have about 4SNR for all lines. At PWV 1.0, 1.53 hrs and 2.56 hrs are respectively required for tuning frequency 355.8 and 362.0 respectively per source, meaning that total 8.2 hours for 2 sources. Therefore, a total observing time of 12.3 hours is required, and with 10% overhead and switching between receivers, leading to a total of 17 hours observing time.

References

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[1]http://www.apex-telescope.org/ns/science-schedule-2021/

	^{14}N-isotopologue	^{15}N-isotopologue	^{13}C-isotopologue
J=2-1	HCN(177.261∼GHz)	HC^{15}N(172.108 GHz)	H^{13}CN(172.678 GHz)
	HNC(181.325 GHz)	H^{15}NC(177.729 GHz)	HN^{13}C(174.179 GHz)
J=3-2	HCN(265.886 GHz)	HC^{15}N(258.156 GHz)	H^{13}CN(259.011 GHz)
	HNC(271.981 GHz)	H^{15}NC(266.587 GHz)	HN^{13}C(261.263 GHz)
J=4-3	HCN(354.505 GHz)	HC^{15}N(344.200 GHz)	H^{13}CN(345.340 GHz)
	HNC(362.630 GHz)	H^{15}NC(355.440 GHz)	HN^{13}C(348.340 GHz)

Table 1: Summary of the target lines to be observed for this proposal.

Receivers	Tuning frequency (GHz)/SB	Freq$_{LO}$(GHz)	Signal Band freq. range (GHz)	Image Band freq. range (GHz)
SEPIA 180	170.9 (LSB)	176.9	168.9-172.9	180.9-184.9
	175.9 (LSB)	181.9	173.9-177.9	185.9-189.9
nFLASH 230	257.0 (USB)	251.0	255.2-263.1	238.9-246.8
	266.5 (USB)	260.5	264.7-272.6	248.4-256.3
SEPIA 345	355.8 (USB)	349.8	354.0-361.9	337.7-345.6
	362.0 (USB)	356.0	360.2-368.1	343.9-351.8

Table 2: Summary of the required receivers, frequency set up.

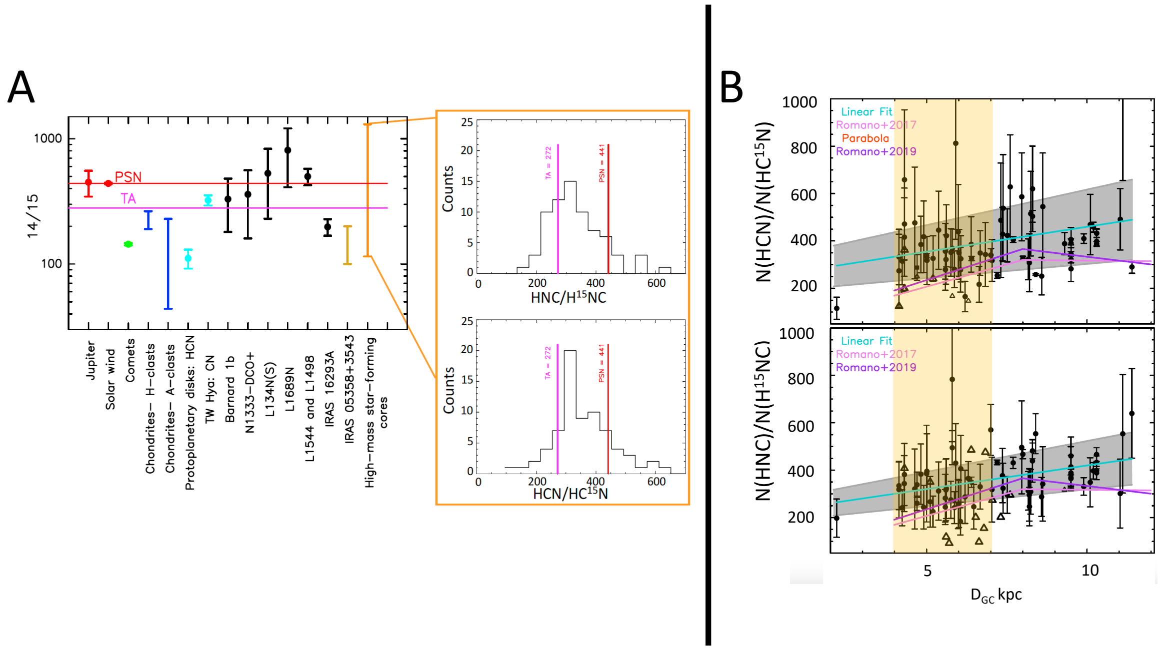

Figure 1: Summary of our current understanding toward nitrogen fractionation. A: ^{14}N/^{15}N ratio measured in different Solar system objects and different stages of the star-formation process. The inset shows the histogram distribution of ^{14}N/^{15}N measured from HNC (upper) and HCN (lower) by Colzi et al. (2018) in a sample of massive dense clumps. B: ^{14}N/^{15}N ratio for HCN (upper) and HNC (lower) as a function of Galactocentric distances of the high mass star-forming regions in Colzi et al. (2018). Black data points represent the observed ^{14}N/^{15}N ratio. The span of greyed regions designates the range of uncertainties. The solid cyan line is the linear regression fit computed for the two data sets, and the solid pink and purple lines are the model predictions from Romano et al. (2017) and Romano et al. (2019), respectively.

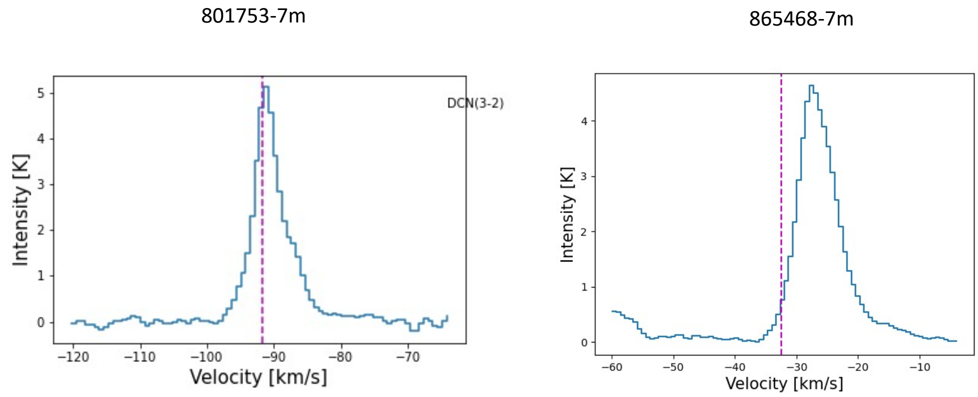

Figure 2: DCN(3-2) spectrum over an aperture of 5” of the two selected ALMAGAL sources.

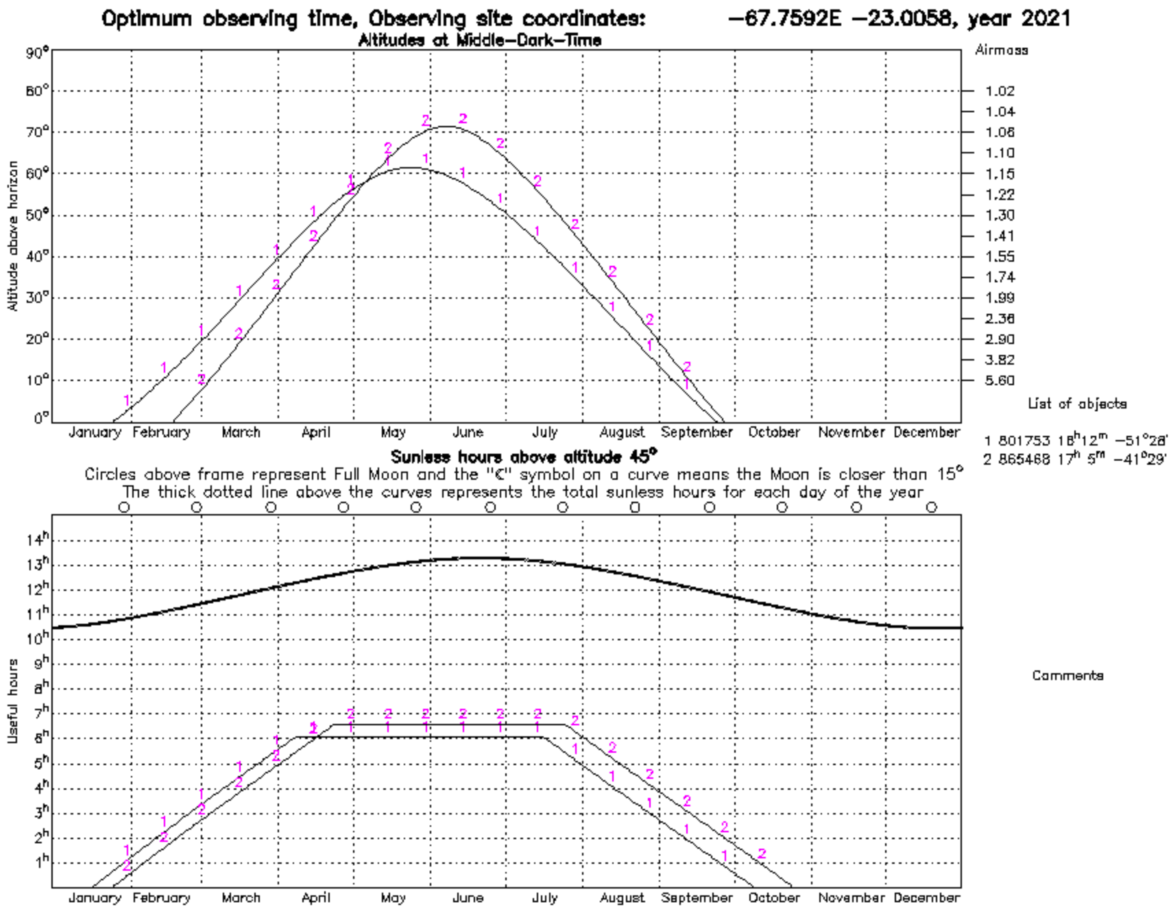

Figure 3: Observability and source elevation at APEX site. Both sources are above 45deg from Early to Mid July.

Students involved

Student	Level	Applicant	Supervisor	Applicant	Expected completion date	Data required
Mr. Chi Yan Law	Doctor	Yes	Prof Jonathan Tan	Yes	2023/12	Yes

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: No

No additional remarks

Observing run info :