Onsala Proposal

Cosentino **0108.F-9307**

The Currents of Space: Infrared Dark Cloud Formation From Shock Compression (resubmission of accepted project 0107.F-9316)

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

Abstract

Observations with the ISO, MSX and Spitzer telescopes have revealed that the dense ISM in the Galaxy contains filamentary structures called Infrared Dark Clouds (IRDCs), believed to be the birthplaces of massive stars and star clusters. Current theories suggested that dynamical processes such as molecular cloud collisions, converging atomic flows, feedback-driven shell compression, global hierarchical collapse can efficiently ignite star formation within IRDCs by shocks that lead to the compression and gravitational instability of gas. It is thus essential to investigate the kinematic structure and excitation condition of the shocked gas in IRDCs to constrain the different formation scenarios. Hence, we propose to use APEX to map the CO(6-5) transition toward a sample of 10 IRDCs, well studied by our group. With the new data, we will investigate the morphology, kinematics and excitation of the shocked gas and will compare them with predictions from different IRDCs formation models, to investigate the shock history of the clouds.

Applicants

Name	Affiliation	Email	Country		Potential observer
Dr. Giuliana Cosentino	Chalmers University of Technology (Space, Earth and Environment)	giuliana.cosentino@chalmers.se	Sweden	Pi	Yes
Prof Jonathan Tan	Chalmers	jonathan.tan@chalmers.se	Sweden		
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Izaskun Jimenez-Serra	Centro de Astrobiologia (CSIC/INTA))	ijimenez@cab.inta-csic.es	Spain		
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Dr Francesco Fontani	INAF-Arcetri	francesco.fontani@inaf.it	Italy		

Applicants are continued on the last page

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		Remarks	Country is Sweden

Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA660 (581-727 GHz)	22h (22h)	691	< 0.5mm	15-24	tuning frequency in LSB, observations in position switching and dual polarisation mode. no scheduling constrains for the proposed observations.

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
CloudG	18:56:45.00	+01:23:02.8	J2000	42.0	126	A	
CloudI	19:04:08.50	+05:09:16.7	J2000	41.6	84	A	
CloudD1	18:44:27.70	-03:57:51.6	J2000	87.0	36	A	
CloudH1	18:57:07.20	+02:11:22.4	J2000	45.0	108	A	
CloudB	18:25:55.30	-12:04:32.9	J2000	26.2	108	A	
CloudJ	19:29:18.00	+17:56:35.8	J2000	22.0	60	A	
CloudH2	18:57:09.50	+02:08:26.4	J2000	45.0	108	A	
CloudC1	18:42:51.70	-04:01:54.6	J2000	79.0	126	A	
CloudF1	18:53:19.40	+01:28:18.0	J2000	58.5	96	A	
CloudE	18:43:07.80	-03:44:36.2	J2000	79.5	84	A	
CloudD3	18:44:16.20	-04:00:17.3	J2000	87.0	72	A	
CloudD2	18:44:17.70	-03:58:32.2	J2000	87.0	72	A	
CloudC2	18:42:48.90	-04:04:09.7	J2000	79.0	72	A	
CloudA	18:26:19.40	-12:41:27.2	J2000	65.8	72	A	
CloudF2	18:53:18.40	+01:26:18.3	J2000	58.5	96	A	

Scientific Rationale

Introduction. Infrared Dark Clouds (IRDCs) are cold (T$\leq$25 K)[1,2], dense (n(H_2)$\geq 10^3$ cm^{-3}) and massive ($> 1000\ M_\odot$)[3] molecular structures known to host the initial conditions of massive star and stellar cluster formation. Theoretical models and simulations have suggested that star formation can be efficiently ignited within IRDCs as a consequence of dynamical processes that lead to the compression and gravitational instability of gas. Among current theories, IRDCs have been proposed to form as the shock-compressed layer in the collision between pre-existing Giant Molecular Clouds (GMCs)[4,5] with the collision being a consequence of GMCs natural orbital motion in the shearing Galactic disk. Other models also involve formation from compressing collisions, but driven by momentum from stellar feedback[6]. Both mechanisms imply the presence of compressing shocks at different spatial scales that leave different imprints on the kinematics and excitation conditions of the molecular gas in and around IRDCs. Hence, **we propose to investigate the excitation properties of the molecular gas toward a sample of 10 IRDCs, with the aim to investigate the shock interactions that may have led to the source formation.**

Previous Studies. Our group has been extensively studying the 10 IRDCs (A-J) of [8,9] with the aim to investigate the dynamic, kinematic and chemical properties of the 10 sources. The ten sources have been selected for showing high contrast against the mid-IR galactic background, for being relatively massive (M$>$ 500 $M_\odot$) and for being located relatively nearby (d$\leq$6 kpc) [8,9]. In addition, the ten clouds show relatively low levels of star formation activity. For all these reasons the ten clouds are representative of typical massive star forming regions. By using both IRAM30m (Henshaw et al. in prep; [10]) and archival data, we have performed a detailed study of the gas kinematics [11] in and around the cloud, as probed by low-J CO transitions and isotopes. In addition, we have reported dedicated studies of the CO depletion factor [12], deuteration fraction [13] and gas excitation [10] toward cloud H and F. Investigation of SiO shock tracer emission have been carried out by [14,15] toward the 10 sources. In order to test the shock compression from which the IRDCs may have originated, *our studies on the cloud kinematics and dynamics need to be coupled with a comprehensive study of the gas excitation conditions.* With this aim, we have preliminary performed single point observations of the CO(6-5) transition toward the IRDC G, known to be shock compressed by the nearby SNR W44 [17].

Objectives. We propose to use the SEPIA660 receiver of APEX to map the CO(6-5) rotational transitions toward the 10 cloud sample. Mid and high-J CO transitions are excellent tools to probe the excitation conditions of the shock processed gas in molecular clouds [18]. The large scale shock interactions associated with cloud-cloud collisions or driven by stellar feedback can efficiently excite these transitions which are important radiative coolants [18]. Furthermore, turbulent motions within the gas can also significantly enhance their emission, as opposite to other shock tracers that require much higher shock velocities. We will use the data from this proposal to investigate the morphology and kinematics of the high-excitation gas in relation to that of the ambient gas, probed by CO(1-0) and CO(2-1) transition lines (Henshaw et al. in prep.). Hence, we will use Large Velocity Gradients models to reproduce the integrated flux of the several CO transitions and will infer the physical conditions of the gas, i.e., average H_2 number density n(H_2), CO column density N(CO), optical depths τ, and excitation temperature T_{ex}. Hence, we will compare integrated intensity maps and kinematics of the multiple CO transitions with those predicted by cloud-cloud collision simulations ([4]; Figure 1). In addition, we will look for correspondences between the morphology of the CO(6-5) and SiO(2-1), already studied in [14,15,16] (Figure 2). Using these results, we will look for signatures of enhanced gas excitation toward the identified ambient gas velocity components with the aim to reveal signatures of the gas compression processes that may have formed the IRDCs. We will be able to correlate excitation properties with other cloud properties, such as column density probability distribution functions (N-PDFs) measured from the extinction maps [19], to see if higher excitation conditions are associated with more efficient production of dense gas.

Facilities Requested

We request to use the APEX 12m antenna to map the CO J=6-5 rotational transition toward a well-known sample of 10 IRDCs. With its receiver SEPIA660, APEX is a unique facility to fulfil our scientific goal, since it allows to efficiently observe high frequency transitions. The relatively small beam aperture ($\sim 10''$) of APEX at the proposed frequency will ensure us a detailed analysis of the shocked gas morphology.

Observing Requirements

We propose to use $\sim$22 hours of the APEX 12m telescope observing time to perform a high-sensitivity OTF map of the CO(6-5) transition, toward a sample of 10 IRDCs. Observations will be performed in position switching mode with field of view listed in Table 1 and shown in Figure 2. The receiver SEPIA660 will be used with tuning frequency at 691 GHz in Lower Side Band (LSB) and observations will be performed in dual polarization mode. In order to be consistent with previous single pointing observations obtained with APEX toward cloud G, we request velocity resolution of 0.2 km s^{-1}, enough to resolve line profiles as narrow as few km s^{-1}, typical of low velocity compressing shocks and a sensitivity if 0.5 K. With these observing requirements and assuming PWV$\sim$0.5 mm and elevation$\sim$45°, the estimated requested time is 22 hours to observe the full sample. We note that, in order to maintain the instrument stability throughout the region to be mapped, the largest possible map to perform is $150'' \times 180''$. Since clouds C, D, F and H cover larger areas, we will perform more that one map toward these clouds. We note that this proposal is a re-submission of the project 0107.F-9316. The project 0107.F-9316 was accepted in the last APEX cycle but observations may not be carried on due to the increasing restrictions related to the COVID-19 pandemic. We are thus re-submitting the proposal and will withdraw it in case of completed observations.

Observing Plan

The proposed observing run will be performed in service mode and does not require any unusual action. As it is the custom for mm observations, we request pointing to be performed every 2 hours and focus every 4 hour. Frequency of focus may be increased close to the sunset and sunrise.

References

[1] Pillai et al. 2007, 2007, A&A, 467, 207 • [2] Ragan et al. 2011, ApJ, 736, 163 • [3] Rathborne et al. 2006, ApJ, 641, 389 • [4] Wu et al. 2017a, ApJ, 841, 88 • [5] Wu et al. 2017b, 835, 137 • [6] Inutsuka et al. 2015, A&A, 580, A49 • [7] Vázquez-Semadeni et al. 2019, MNRAS, 490, 3061 • [8] Butler & Tan 2009, ApJ, 696, 484 • [9] Butler & Tan 2012, ApJ, 754, 5 • [10] Jiménez-Serra et al. 2014, MNRAS, 439, 2 • [11] Hernandez et al. 2015, ApJ, 809, 2 • [12] Hernandez et al. 2011, ApJ, 738, 1 • [13] Barnes et al. 2016, MNRAS, 458, 1990 • [14] Cosentino et al. 2018, MNRAS, 474, 3760 • [15] Cosentino et al. 2020, MNRAS, 499, 1666• [16] Jimenez-Serra et al. 2010, MNRAS, 406, 187 • [17] Cosentino et al. 2019, ApJL, 881, L42 • [18] Pon et al. 2016, A&A, 587, A96 • [19] Kainulainen & Tan 2013, A&A, 549, A53 •

Figures

ID	MAP_RA (hh:mm:ss)	MAP_DEC (dd:mm:ss)	V_{LSR} (km s^{-1})	Map ($'' \times ''$)	Time (hr)	OFF_RA (hh:mm:ss)	OFF_DEC (dd:mm:ss)
CloudA	18:26:19.4	-12:41:27.2	65.8	150×100	1.2	18:26:33.7	-12:34:36.3
CloudB	18:25:55.3	-12:04:32.9	26.2	150×150	1.8	18:25:34.3	-12:04:02.2
CloudC1	18:42:51.7	-04:01:54.6	79.0	150×180	2.1	18:42:27.6	-04:01:56.2
CloudC2	18:42:48.9	-04:04:09.7	79.0	150×100	1.2	18:42:27.6	-04:01:56.2
CloudD1	18:44:27.7	-03:57:51.6	87.0	80×80	0.6	18:43:48.7	-03:53:51.4
CloudD2	18:44:17.7	-03:58:32.2	87.0	120×100	1.2	18:43:48.7	-03:53:51.4
CloudD3	18:44:16.2	-04:00:17.3	87.0	120×120	1.2	18:43:48.7	-03:53:51.4
CloudE	18:43:07.8	-03:44:36.2	79.5	130×130	1.4	18:42:44.0	-03:45:04.3
CloudF1	18:53:19.4	+01:28:18.0	58.5	120×150	1.6	18:53:04.7	+01:27:22.1
CloudF2	18:53:18.4	+01:26:18.3	58.5	120×150	1.6	18:53:04.7	+01:27:22.1
CloudG	18:56:45.0	+01:23:02.8	42.0	150×180	2.1	18:56:29.0	+01:21:05.0
CloudH1	18:57:07.2	+02:11:22.4	45.0	120×180	1.8	18:57:28.0	+02:10:30.0
CloudH2	18:57:09.5	+02:08:26.4	45.0	120×180	1.8	18:57:28.0	+02:10:30.0
CloudI	19:04:08.5	+05:09:16.7	41.0	130×130	1.4	19:04:28.2	+05:08:25.0
CloudJ	19:29:18.0	+17:54:59.5	22.0	100×120	1.0	19:28:55.7	+17:56:30.0

Table 1: ID, central map coordinates, central velocity, map size, requested observing timea dn coordinates of the reference position for the proposed target.

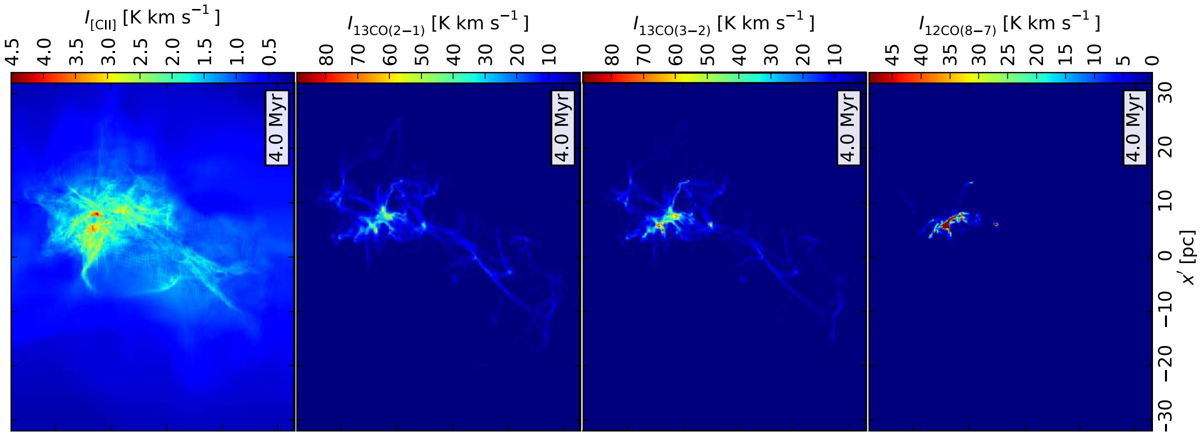

Figure 1: Integrated intensity maps of multiple atomic and molecular species predicted by the cloud-cloud collision simulation reported in [4]. The models have been obtained assuming uniform magnetic field of 10 μG strength and θ=60° orientation. The relative velocities between the two clouds is 10 km s^{-1}.

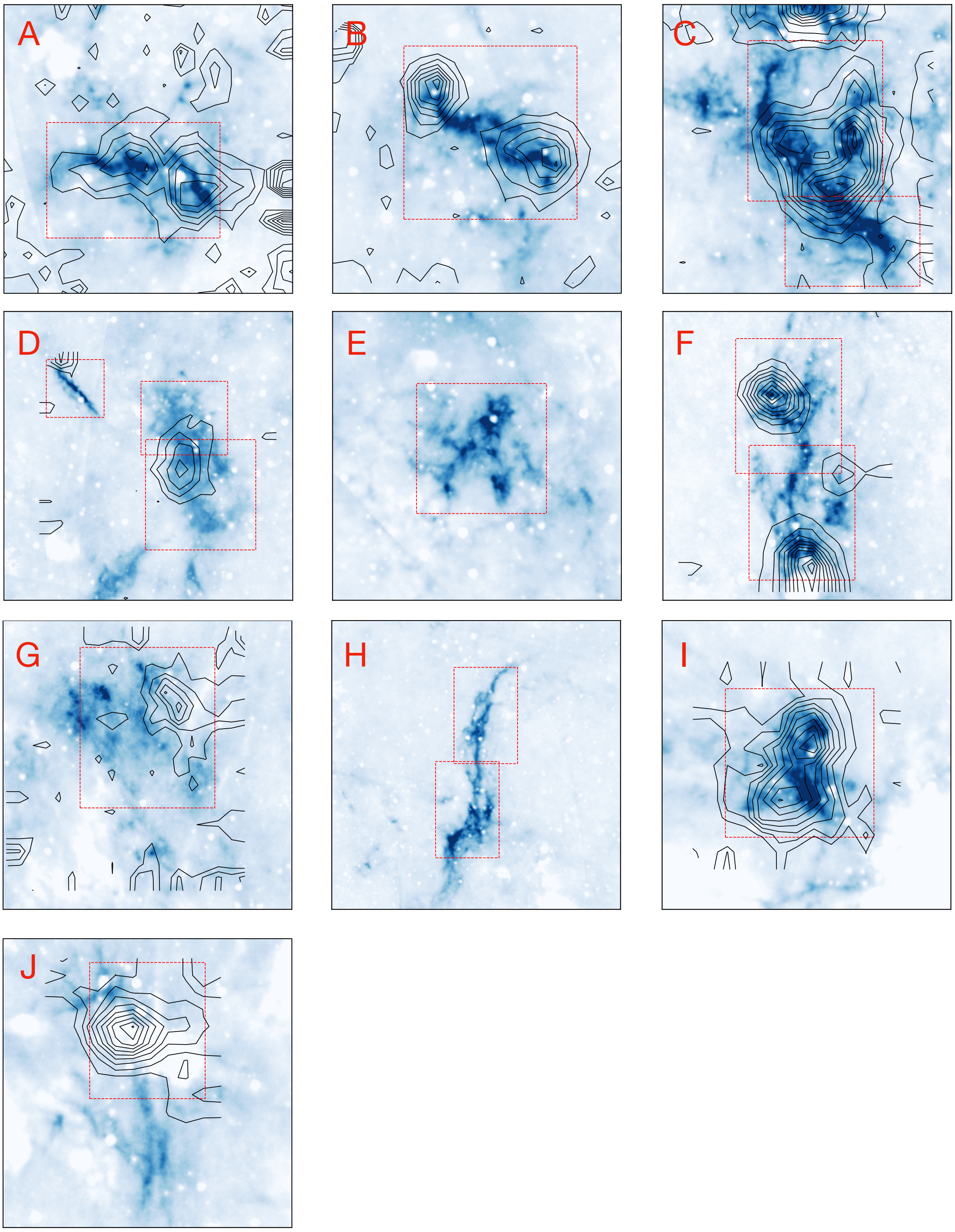

Figure 2: Mass surface density maps (blue scale) of the 9 IRDCs A, B, C, D, E, F, G, I and J obtained by [19], with superimposed the SiO(2-1) integrated intensity maps presented in [14,15]. Toward cloud E, no significant SiO emission has been detected. Toward cloud H, the SiO(2-1) emission is not shown but it has been reported by [16] and will be part of the proposed study. Black crosses mark the massive cores within the clouds. Red dashed rectangles indicates the regions to be mapped in this proposals.

Students involved

Student	Level	Applicant	Supervisor	Applicant	Expected completion date	Data required
Mr. Chi Yan Law	Doctor	Yes	Prof Jonathan Tan	Yes	2023/12	No
Chia-Jung Hsu	Doctor	Yes	Prof Jonathan Tan	Yes	2022/12	No

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

In 2019, our group has been granted 36 minutes of APEX observing time, through the ESO queue. The project aimed to perform single pointing observations of the CO(6-5) transition toward 6 different positions across the shock. The data have been collected and a paper is in preparation.

Furthermore, this project is a resubmission of the accepted proposal 0107.F-9316.
Since it is unsure whether the project will be observed we are now resubmitting and we will withdraw the proposal if the observations will be carried on.

Additional remarks

ESO=<gcosentino>

Observing run info :

Run: A backup strategy: In case of poor weather conditions we will reduce the number of targets, giving priority to those clouds that have been studied in more details.

Applicants

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