The L1157-B1 protostellar shock: Si fractionation & chemistry

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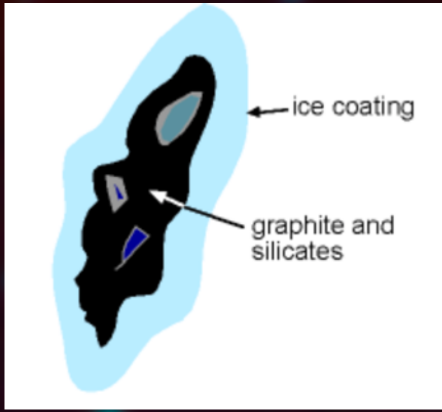
+ CHEM: N. Balucani (Universita di Perugia), V. Barone (SNS, Pisa)

Si-bearing molecules



Si in solid phase
core (and mantle) of dust grains

Si in gas-phase
SiO, SiS, SiC … in evolved C-rich (O-rich) stars (e.g. IRC +10216)
SiO/SiS ~ 1

SiO —> selective tracer of shocks & outflows from YSO
its abundance is enhanced by grain sputtering/shattering in shocks

SiS —> reported only in Orion, related to shocks as SiO
SiO/SiS ~ 13-25 (Tercero et al. 2011), 40-80 (Ziurys 1989, 1991)
formed on grains or in gas-phase ??

Si isotopic ratios

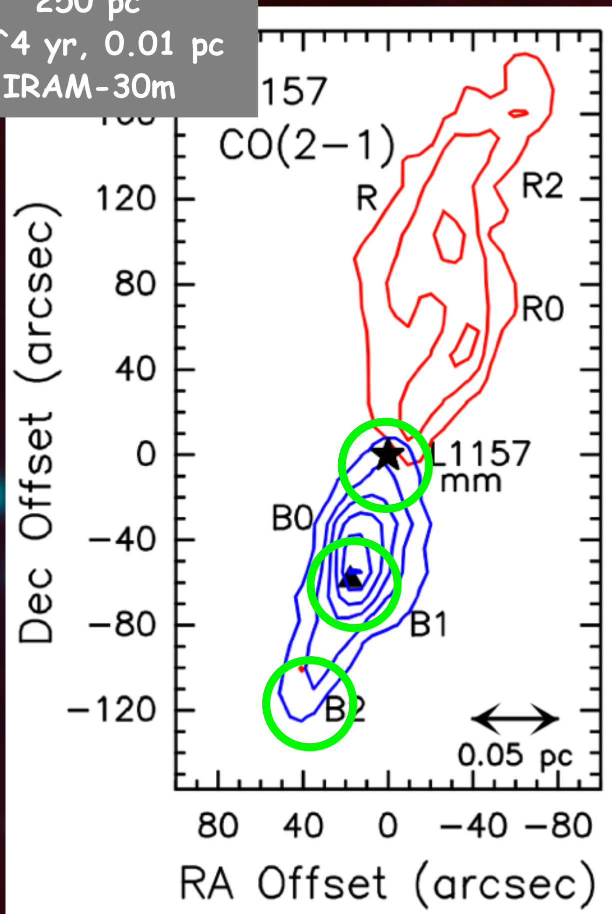
Isotope	Galactic center	4 kpc molecular ring	Local ISM[b]	Solar System[c]	Carbon stars[d]	Nuclei of galaxies
($^{12}C/^{13}C$)	~ 20	53 ± 4[b]	77 ± 7[b]	89	> 30	~ 40[h]
($^{14}N/^{15}N$)	> 600	375 ± 38[b]	450 ± 22[b]	270	> 515	...
($^{16}O/^{18}O$)	250	327 ± 32[b]	560 ± 25[b]	490	320 to 1260 > 2700	~ 200[i]
($^{18}O/^{17}O$)	3.2 ± 0.2[e]	3.2 ± 0.2[e]	3.2 ± 0.2[e]	5.5	0.6 to 0.9 < 1	8[i]
($^{32}S/^{34}S$)	~ 22[f]	~ 22[f]	~ 22[f]	22	...	...
($^{29}Si/^{30}Si$)	1.5[g]	1.5[g]	1.5[g]	1.5	...	...
($^{28}Si/^{29}Si$)			**26+-10**	**19.7**		

ORION
Pentzias+ 1981
Tercero+ 2011

SOLAR
Anders & Grevesse 1989

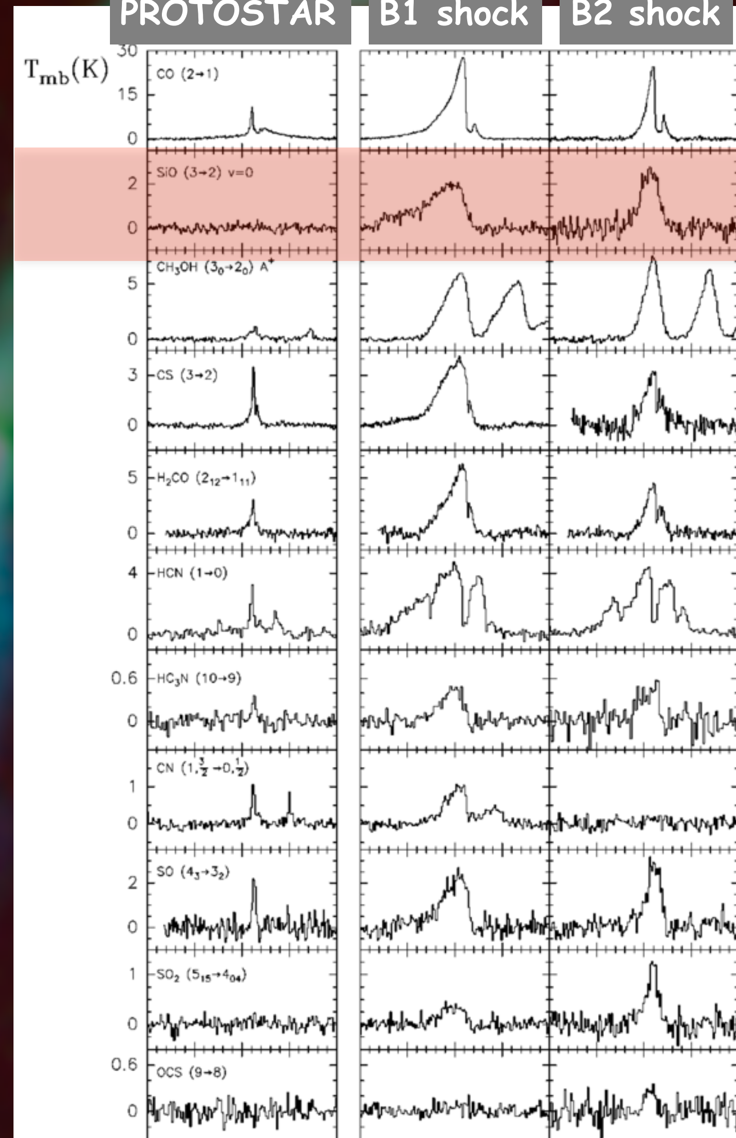
The chemical rich L1157 outflow

L1157 outflow
250 pc
10^4 yr, 0.01 pc
IRAM-30m



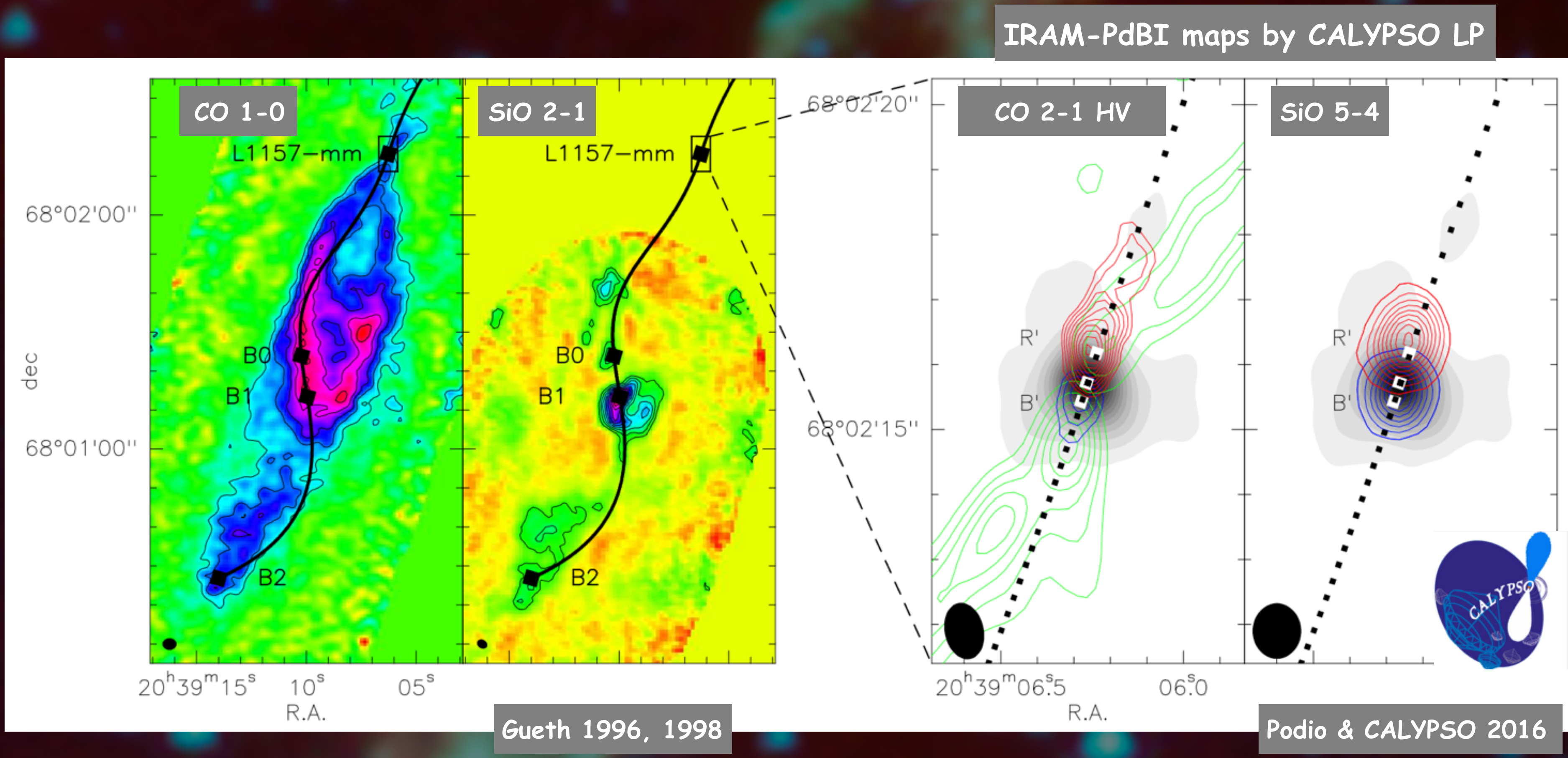
Bachiller et al. 2001

PROTOSTAR B1 shock B2 shock



Bachiller & Perez-Gutierrez 1997

SiO in L1157-B1



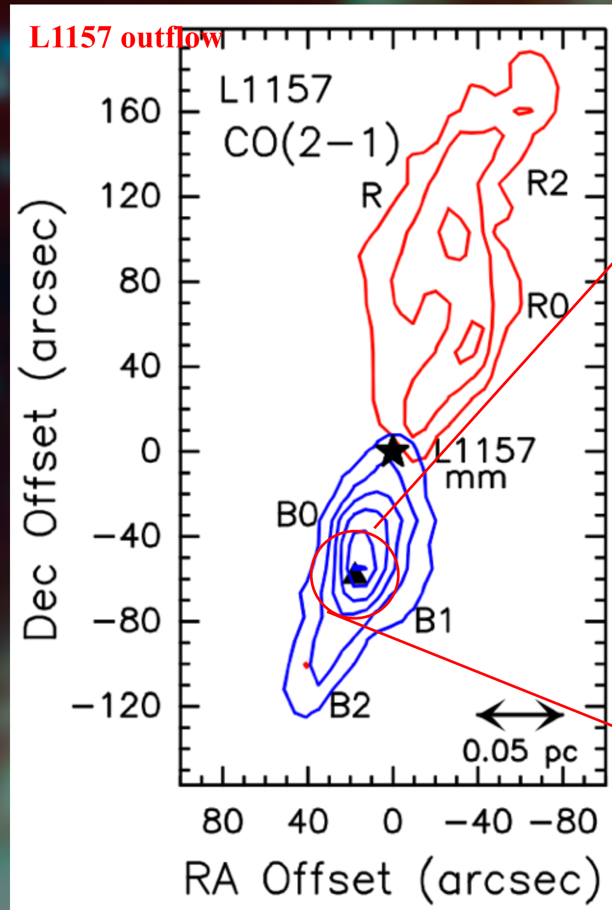
ASAI: an unbiased spectral survey of L1157-B1

A census of molecular species down to a sensitivity of ~1 mk / km/s at 3mm

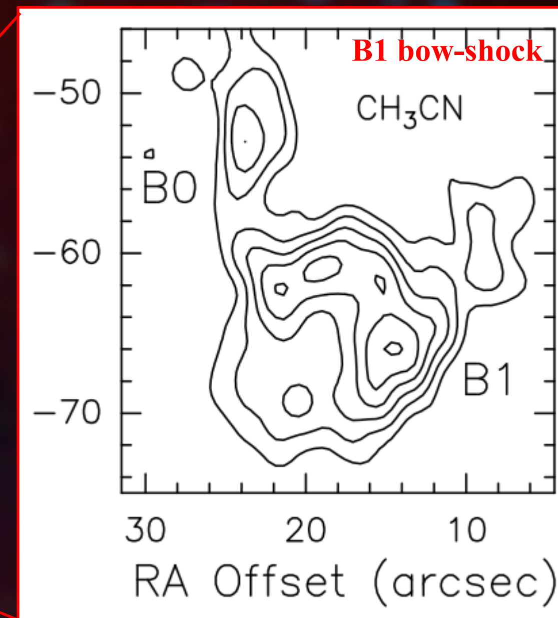
ASAI
IRAM-30m Large Program
PI: B. Lefloch, R. Bachiller

IRAM-30m
3 mm (80–116 GHz)
2 mm (128–173 GHz)
1.3 mm (200–320 GHz)
0.8 mm (328–350 GHz)
HPBW ~ 7” - 33”

Herschel/HIFI
Band 1 (488-628 GHz)
HPBW ~ 39”



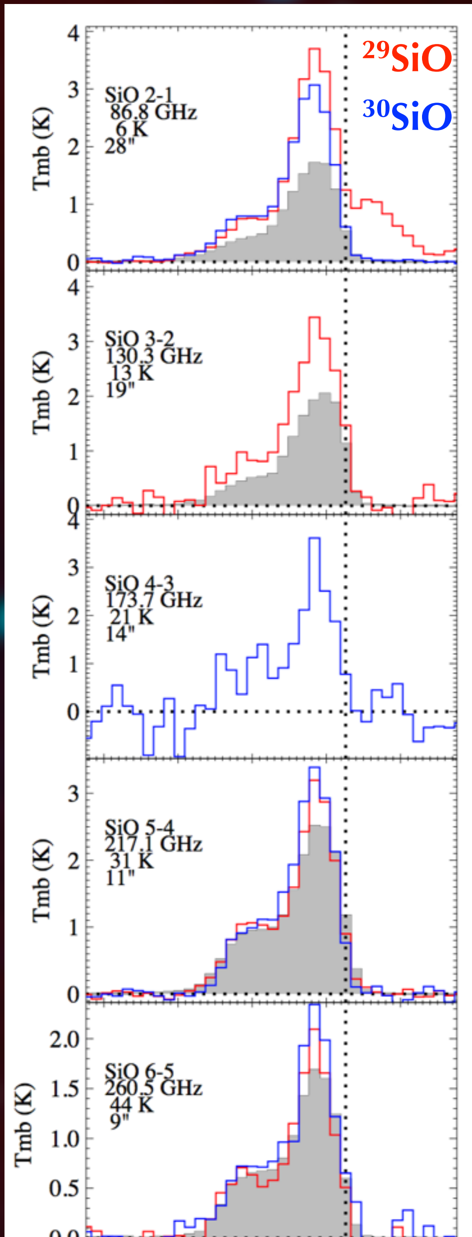
Bachiller+ 2001



Codella+ 2009

http://www.oan.es/asai/

SiO in L1157-B1: isotopic ratios



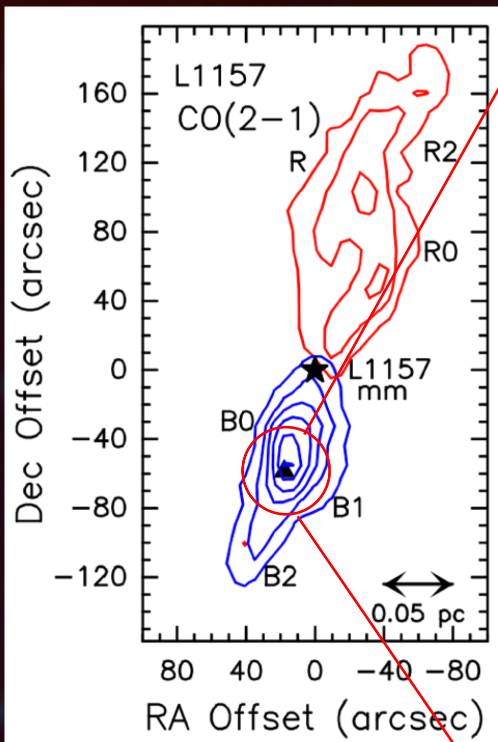
SOLAR (Anders & Grevesse 1989)

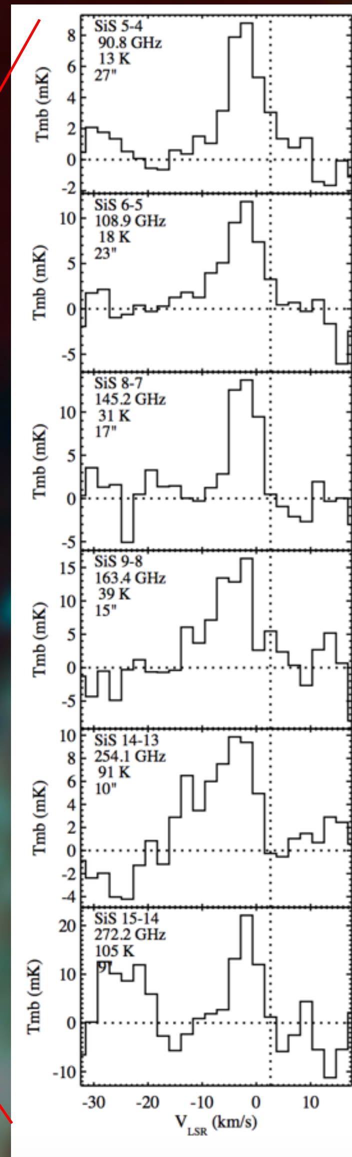
^{28}Si/^{29}Si = 19.7 ^{29}Si/^{30}Si = 1.5

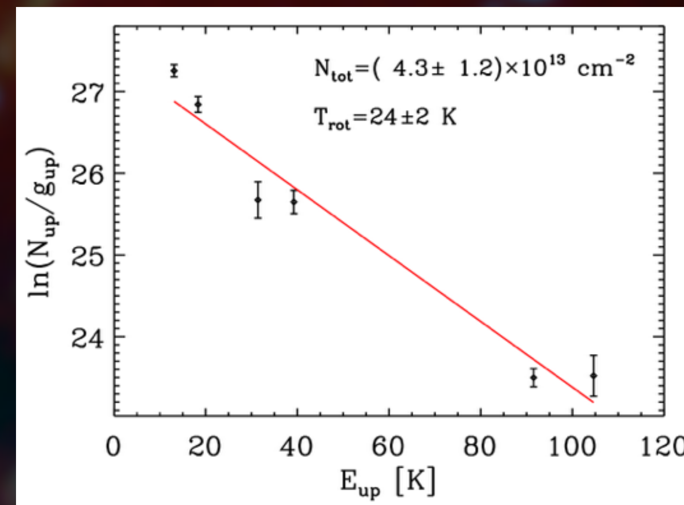
L1157-B1

^{28}Si/^{29}Si = 19.95 ^{29}Si/^{30}Si = 1.47

SiS in L1157-B1: the first detection in a protostellar shock



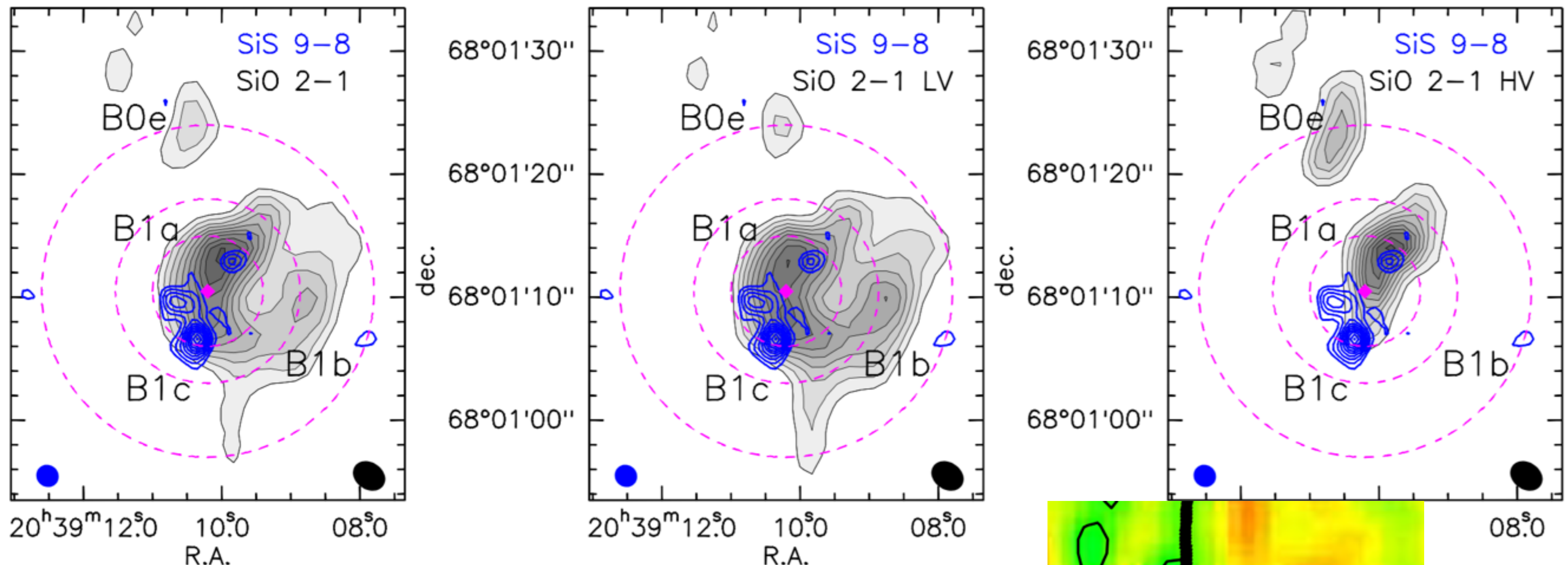




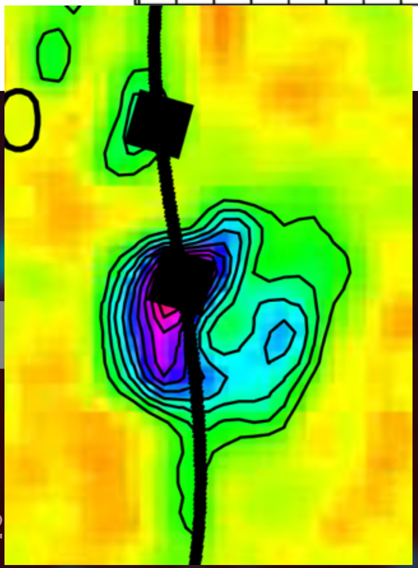
T = 25- 70 K in the cavity
Lefloch et al. 2012
Gomez-Ruiz 2015
Podio et al. 2014

SiS & SiO in L1157-B1: chemical segregation

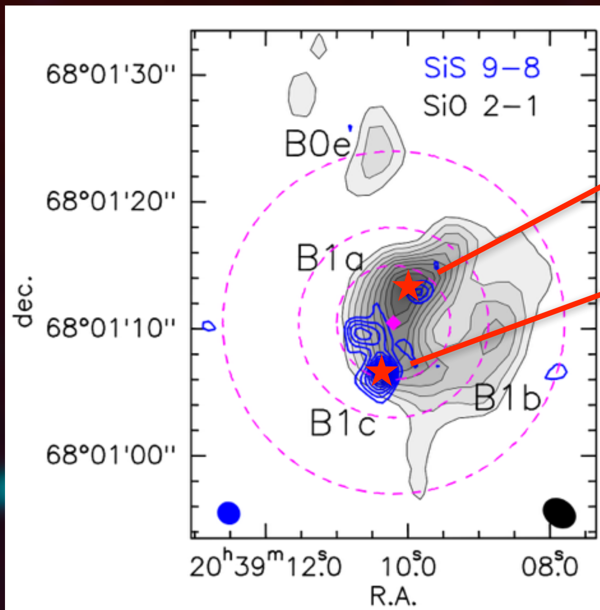
ASAI follow-up: PdBI maps of SiS

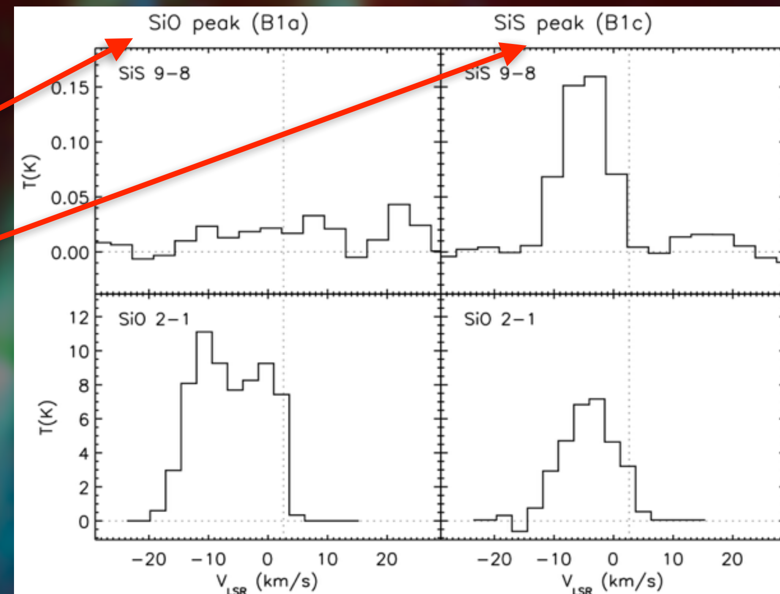


SiO 2-1 + model precessing jet



SiO / SiS abundance ratio in L1157-B1



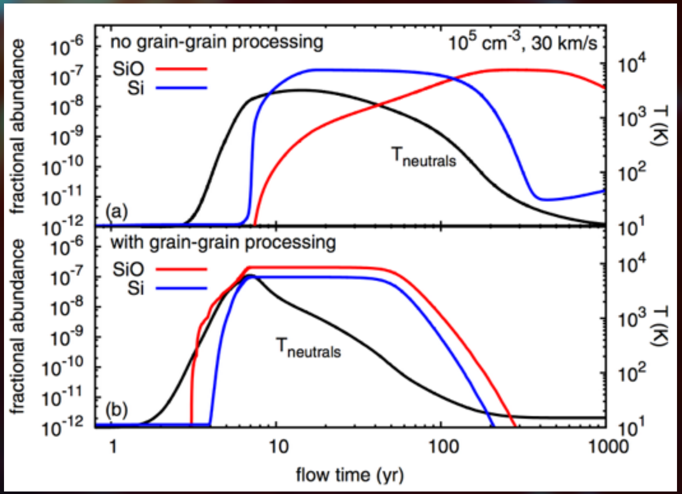


Shock spot	ΔV (kms)	N_{SiS} (10^{13} cm^{-2})	N_{SiO} (10^{14} cm^{-2})	X_{SiS} (10^{-8})	X_{SiO} (10^{-6})	SiS/SiO
B1a	[−17,+8]	0.5	9.3	0.6	1.0	0.006
B1c	[−17,+8]	1.8	4.4	2.0	0.5	0.04

SiO & SiS chemistry: gas-phase vs grain chemistry

<u>STEP 1: SiO & Si released from grains</u>
due to gas-grain and grain-grain processing (sputtering & shattering)

Guillet et al. 2011



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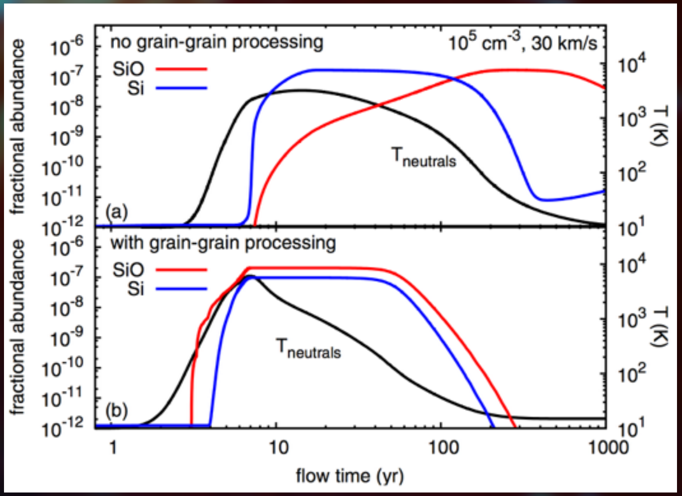

Guillet et al. 2011

<u>STEP 2: gas-phase chemistry</u>
producing Si-bearing molecules

SiO & SiS chemistry: gas-phase vs grain chemistry

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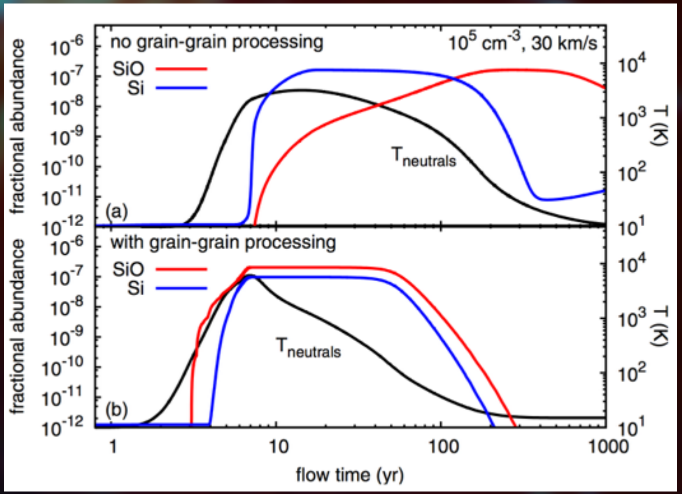


<u>STEP 2: gas-phase chemistry</u>
producing Si-bearing molecules

Si + O/O2 —> SiO
SiH + O/O2 —> SiO + H/OH

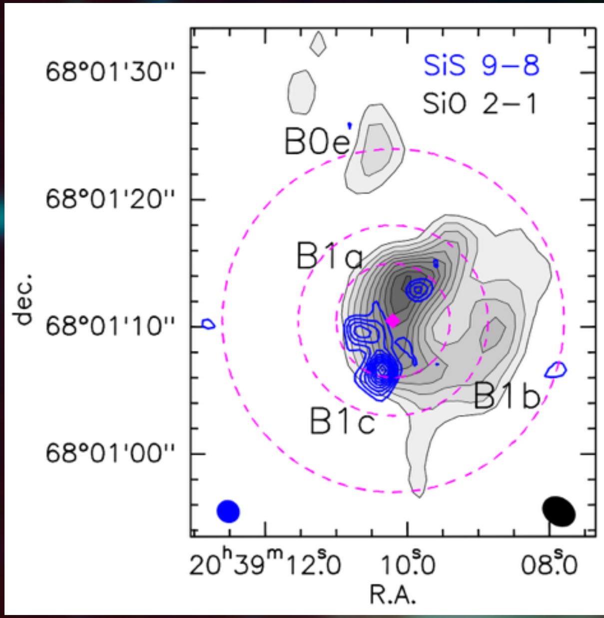
Si + S/S2 —> SiS
SiH + S/S2 —> SiS + H/OH

SiS gas-phase routes
by our chemist expert: Nadia Balucani

Previous modelling suggested that SiS formed on grains (Tercero+ 2011)
based on UMIST-KIDA —> only reactions producing SiS involve SiS+

SiO & SiS chemistry: gas-phase vs grain chemistry

SiO probes direct release from grains (+ gas-phase)
SiS probes (only) **gas-phase chemistry**



Why the observed SiO / SiS gradient across L1157-B1

OPTION 1:
more Si (wrt SiO) released in the B1c shock ?

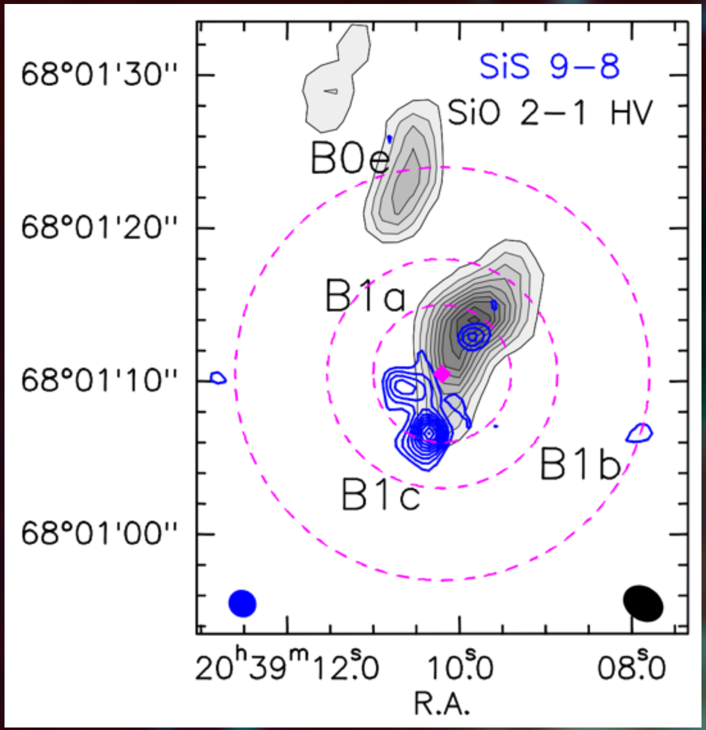
OPTION 2:
in B1c shock-generated CRs destroys SiO, releasing atomic Si, which then reacts with O/O2 or S/S2

Padovani et al. 2015

OPTION 3:
B1c = O-poor, S-rich region ?

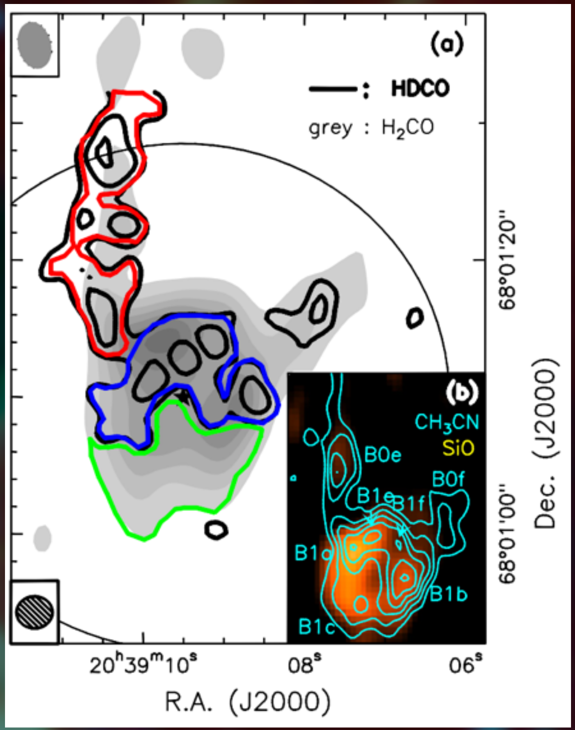
gas-phase vs grain chemistry

SiO vs SiS



SiO —> direct release from grains
SiS —> gas-phase chemistry

HDCO vs H2CO

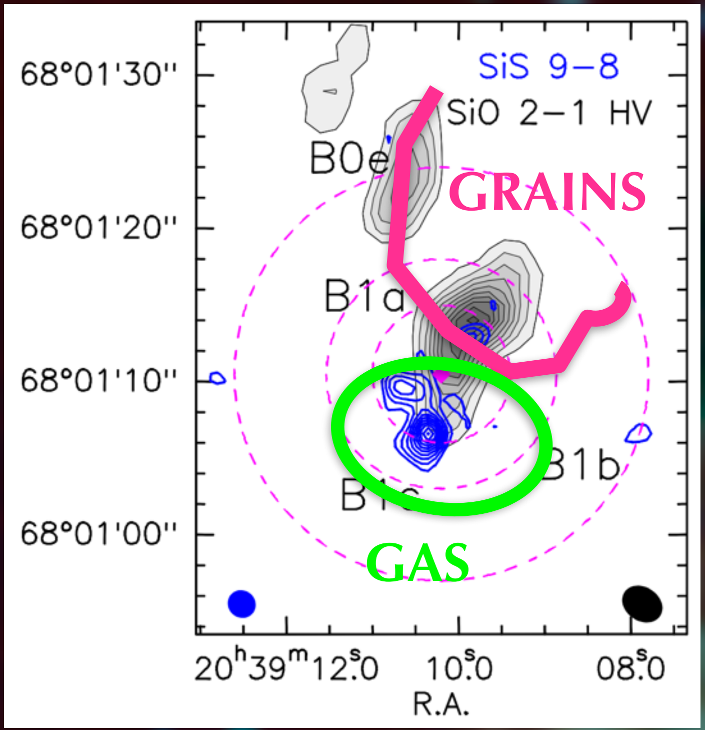


HDCO —>freshly sputtered from ices
H2CO —> grain + gas-phase

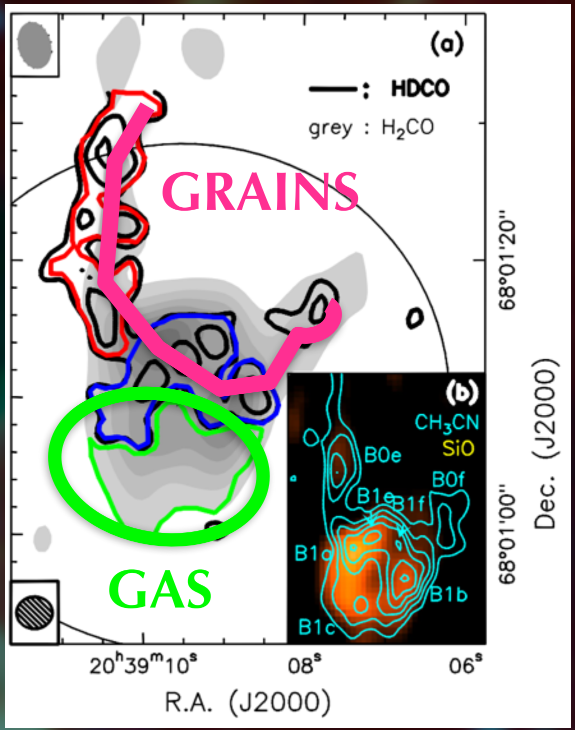
Fontani et al. 2014

gas-phase vs grain chemistry

SiO vs SiS



HDCO vs H2CO



SiO —> direct release from grains
SiS —> gas-phase chemistry

HDCO —>freshly sputtered from ices
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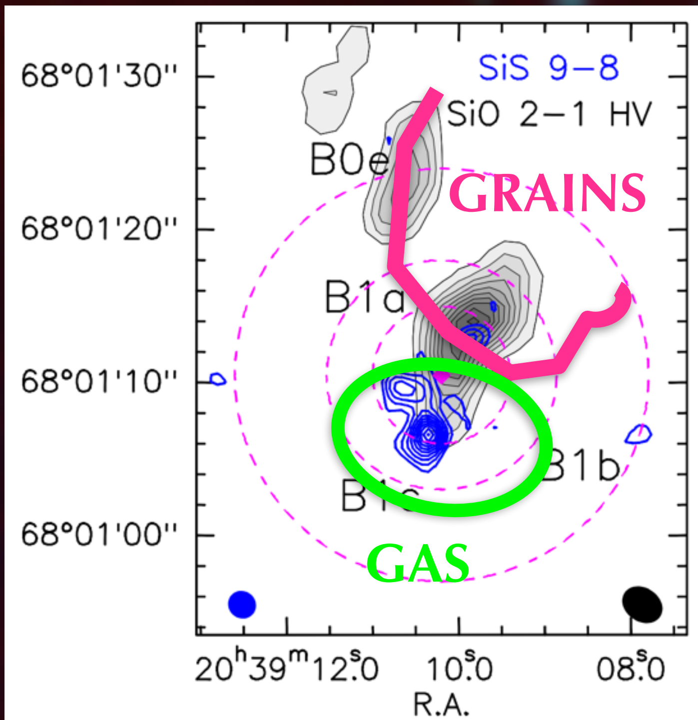
Fontani et al. 2014

gas-phase vs grain chemistry: origin of COMs ?

SiO vs SiS



SiO —> direct release from grains
SiS —> gas-phase chemistry

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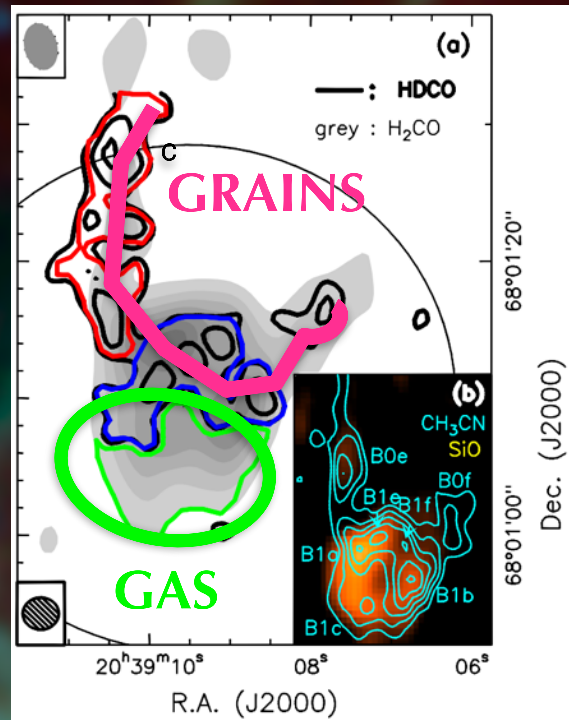
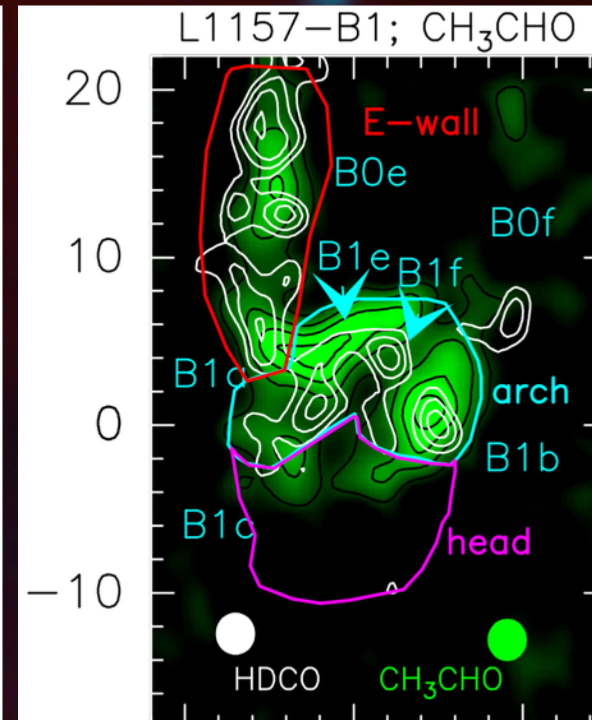


HDCO —>freshly sputtered from ices
H2CO —> grain + gas-phase

CH3CHO vs HDCO



CH3CHO
—> sputtered from ices ?

Fontani et al. 2014

Codella et al. 2016

gas-phase vs grain chemistry: the chemical origin of COMs

IRAM-NOEMA Large Program
SOLIS (Seeds Of Life in Space)
COMS in Sun precursors

PI: Ceccarelli - Caselli

Conclusions

We perfomed a survey of Si-bearing molecules in the protostellar shock L1157-B1

SiO isotopic ratios ($^{28}Si/^{29}Si$, $^{29}Si/^{30}Si$) consistent with Solar values

SiO released from grains due to sputtering/shattering in the shock
SiS produced in gas-phase after Si release (directly from grains or SiO dissociation)

deuteration & Si-chemistry can help us to "localize" regions where grain or gas-phase chemistry dominates —> origin of COMs ?