CARMA Observations of L1157: Chemical Complexity in the Shocked Outflow

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ISMS

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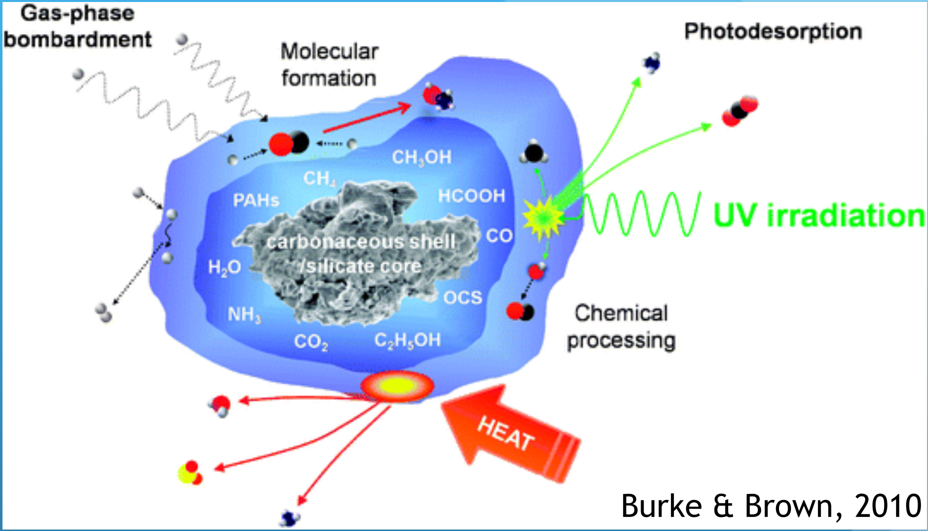
Shock Chemistry

- Shocks are ubiquitous throughout the ISM
- Theoretical work predicts many complex molecules form more efficiently in ice on dust (Garrod & Herbst, 2006)

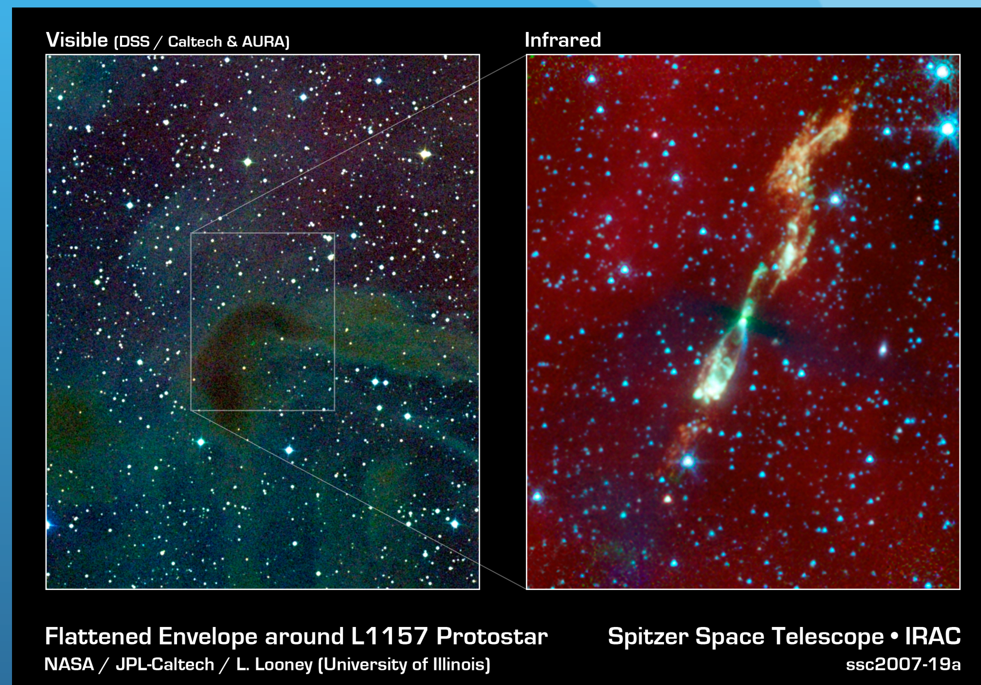


Burke & Brown, 2010

- C-Shocks can liberate species from grain without destroying them, allowing for gas-phase probes of condensed-phase chemistry (Requena-Torres et al. 2006)
- Transient phenomena such as shocks may be necessary to explain enhances abundances of complex species compared to theoretical predictions

L1157

- Class 0 protostar with prototypical "chemically -active" outflow
- Bow shocks cause non-thermal desorption of mantles (Fontani et al. 2014)
- L1157-B1 & B2: recent shock events
  - B1: warmer and younger shock
    T_{kin}~ 80-100 K, t_{shock} ~ 2000 yr
  - B2: cooler and older shocker
    T_{kin}~ 20-60 K, t_{shock} ~ 4000 yr



(Gueth, Guilloteau & Bachiller 1996; Tafalla & Bachiller 1995; Lefloch et al. 2012)

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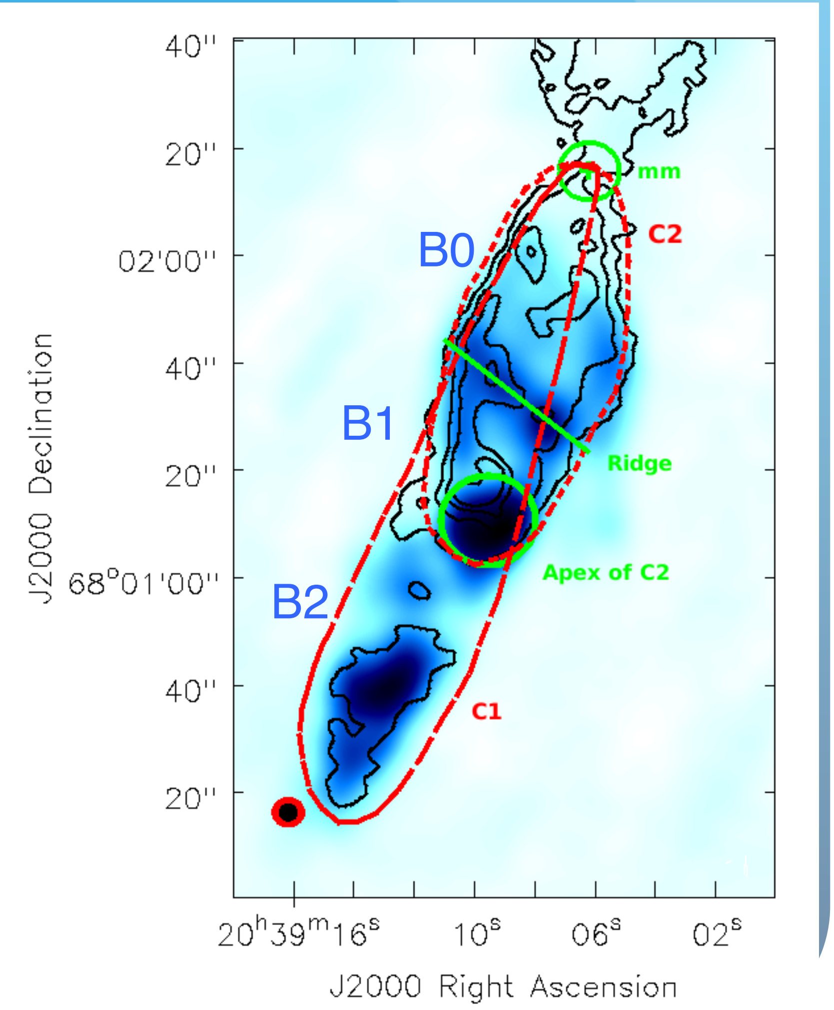
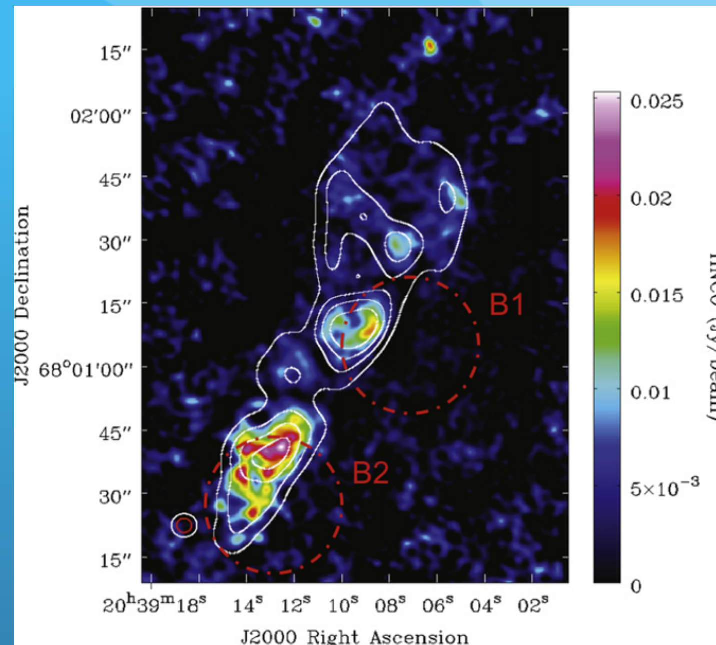


Observations

- Supplementary CARMA data toward L1157B from search for NH2OH from McGuire et al. 2015
- Observations of CH_3OH, HCN, HCO^+, & HNCO emission toward (also partially CH_3CN)



McGuire et al. 2015

Targeted CARMA Transitions

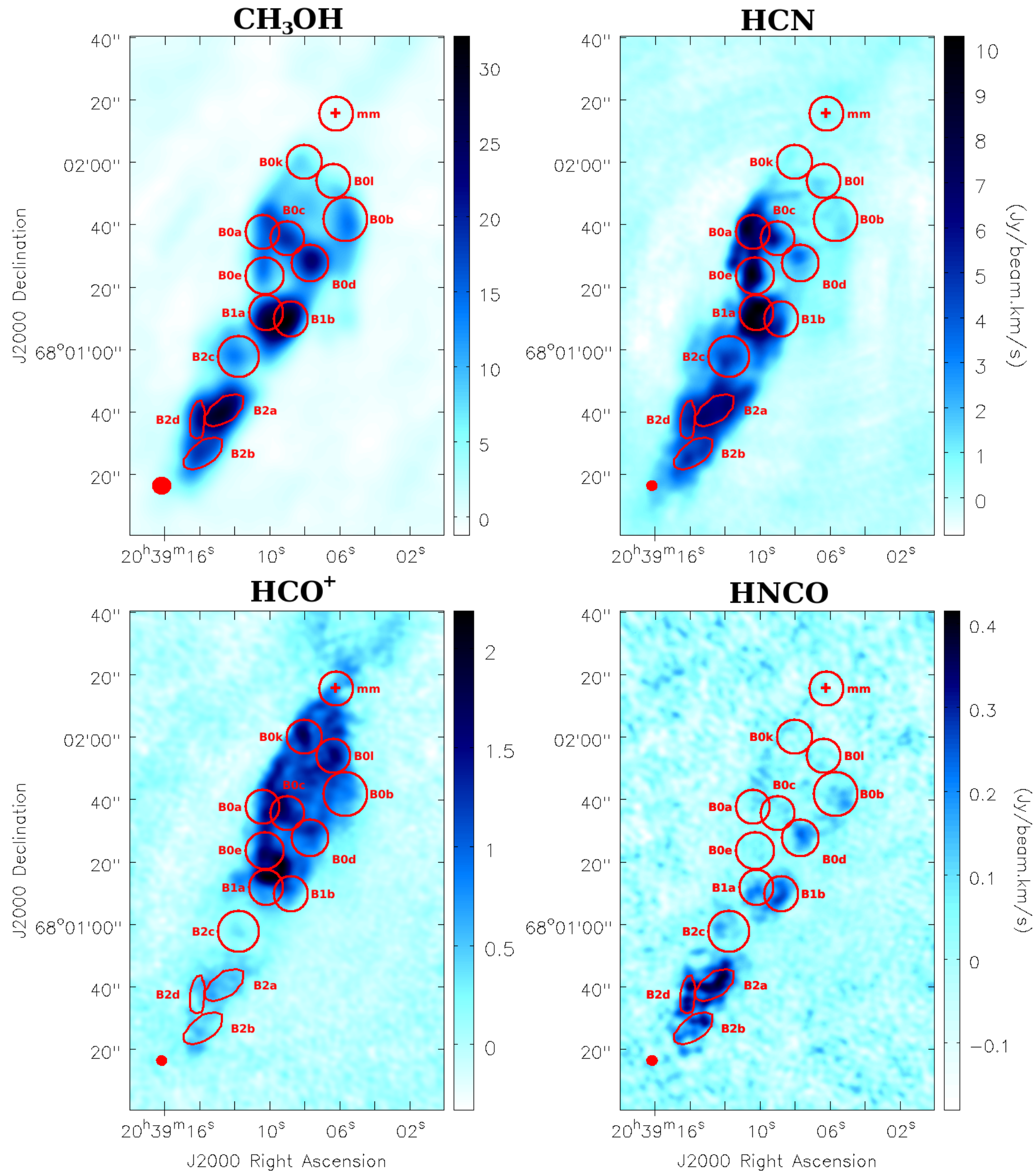
Molecule	Transition	ν (GHz)	E_u (K)	Beam (arcsec^2)	RMS (σ) (mJy beam^{-1})
CH_3OH (methanol)	$2_{-1,2} - 1_{-1,1}$	96.73936(5)	12.9	6.″03 × 5.″53	8.5
	$2_{0,2} - 1_{0,1}$ ++	96.74138(5)	6.9		
	$2_{0,2} - 1_{0,1}$	96.74455(5)	20.1		
	$2_{1,1} - 1_{1,0}$	96.75551(5)	28.0		
HCN (hydrogen cyanide)	$J = 1-0, F = 1-1$	88.63042(2)	4.25	3.″45 × 3.″27	4.8
	$J = 1-0, F = 2-1$	88.63185(3)	4.25		
	$J = 1-0, F = 0-1$	88.63394(3)	4.25		
HCO^+ (formylium)	$J = 1-0$	89.18853(4)	4.28	3.″39 × 3.″23	5.1
HNCO (isocyanic acid)	$J = 4_{0,4} - 3_{0,3}$	87.92524(8)	10.6	3.″50 × 3.″28	7.0

- Nearly 90 hr in C, D, & E configurations
- Spectral resolution: 243 kHz (~0.7 km s-1)

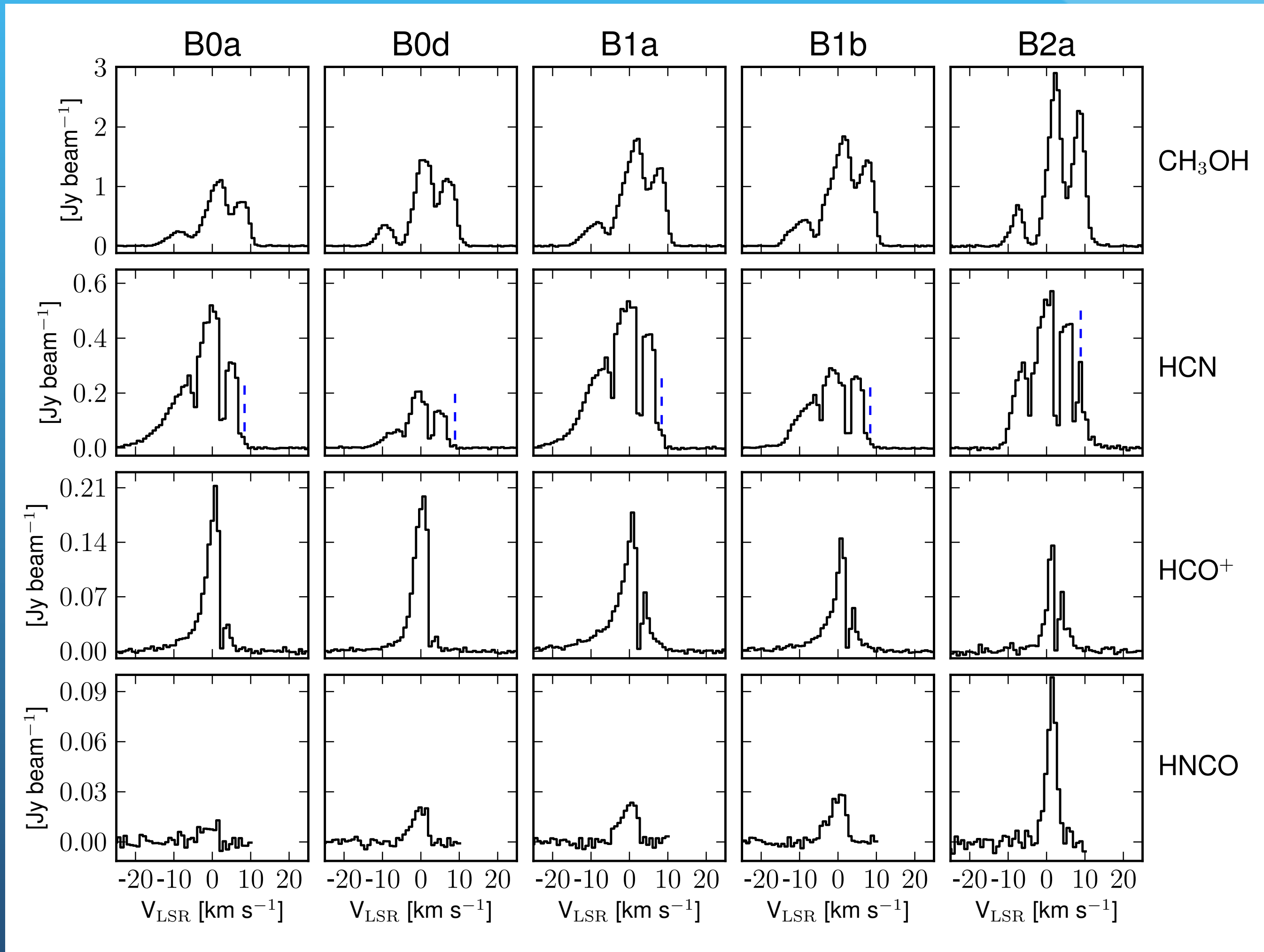
Transitions and parameters accessible at www.splatalogue.net (Remijan et al. 2007)

Maps

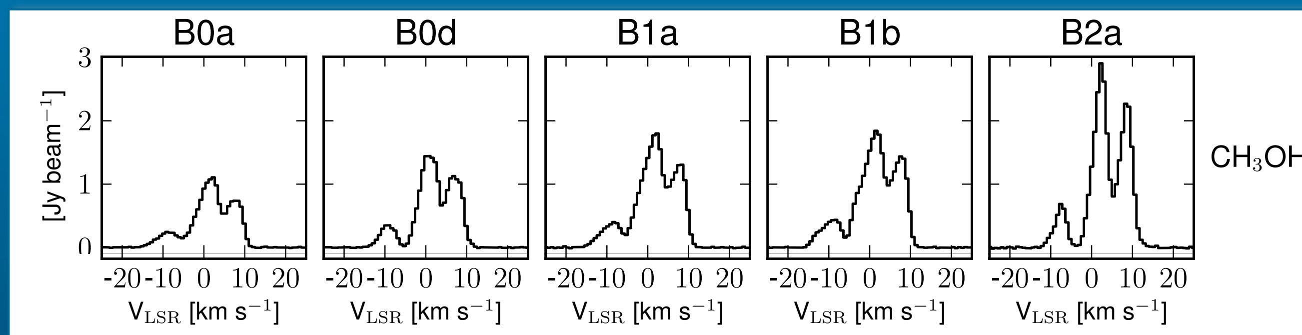
- E/W Chemical Differentiation
- First maps of HNCO for this source
- Enhancement of HNCO in B2

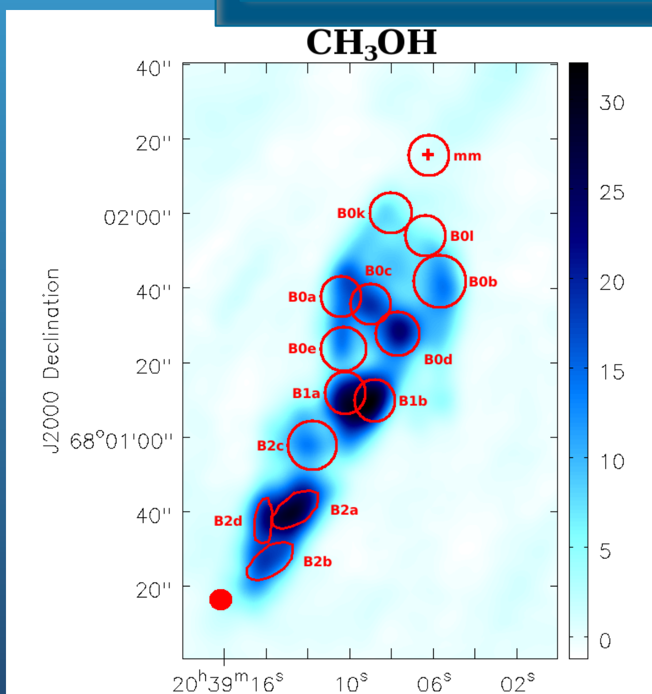


Spectra



Spectra – CH_3OH





Relatively consistent enhancement toward shocks

Primarily produced by grain liberation

Can compare shock enhancements of other species relative to CH_3OH

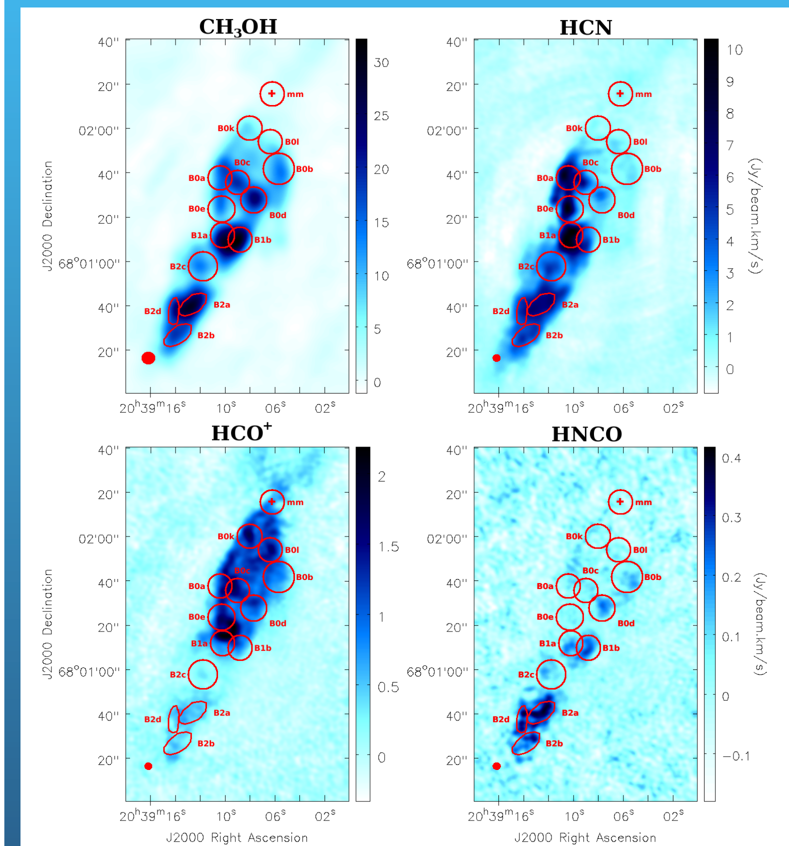
RADEX

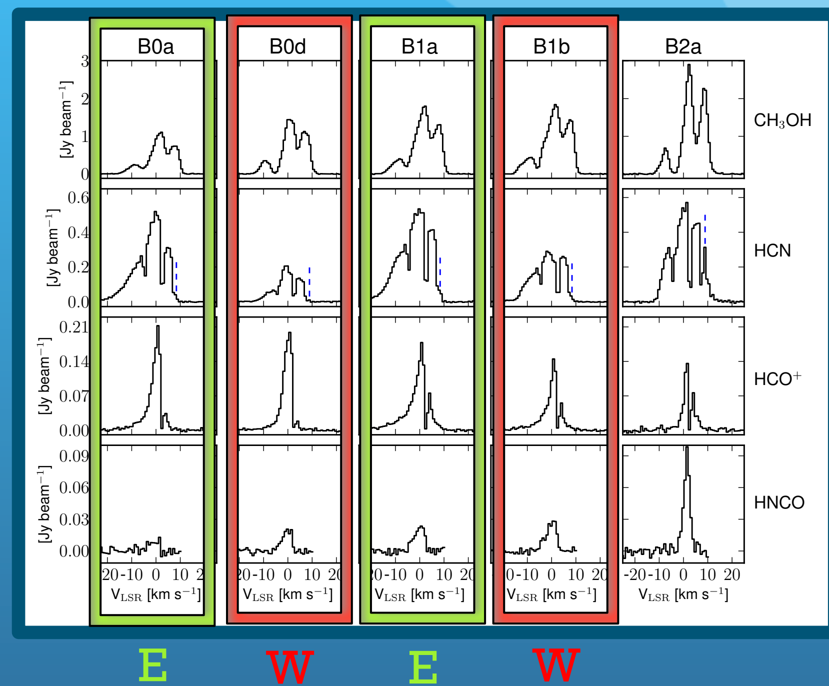
Molecular Abundances and Enhancements

	CH_3OH		HCN			HNCO		
	N	$\frac{N}{N_{H_2}}$	N	$\frac{N}{N_{CH_3OH}}$	$\frac{N}{N_{H_2}}$	N	$\frac{N}{N_{CH_3OH}}$	$\frac{N}{N_{H_2}}$
	$(10^{15}\ cm^{-2})$	(10^{-6})	$(10^{13}\ cm^{-2})$	(10^{-2})	(10^{-8})	$(10^{13}\ cm^{-2})$	(10^{-2})	(10^{-8})
B0d	1.5	1.5	2.6	1.7	2.6	2.5	1.6	2.5
B1a	1.9	1.9	10.	5.3	10.	3.2	1.7	3.2
B1b	2.1	2.1	5.3	2.5	5.3	3.8	1.8	3.8
B2a	2.7	2.7	9.9	3.7	9.9	8.0	3.0	8.0
B2b	1.6	1.6	6.6	4.2	6.6	5.5	3.5	5.5
B2d	2.1	2.0	8.0	3.9	7.9	7.5	3.6	7.5

- Derived column densities & abundances for CH_3OH, HCN, HNCO using non-LTE radiative transfer code, RADEX (Van der Tak et al. 2007)
  - Used physical constraints from CSO observation of CH_3OH in McGuire et al. 2015
- Compared enhancement relative to CH_3OH and H_2
- HCN, strong enhancement in East C2 and B2b
- HNCO displays strongest enhancements in galaxy in B2

E/W Differentiation in C2

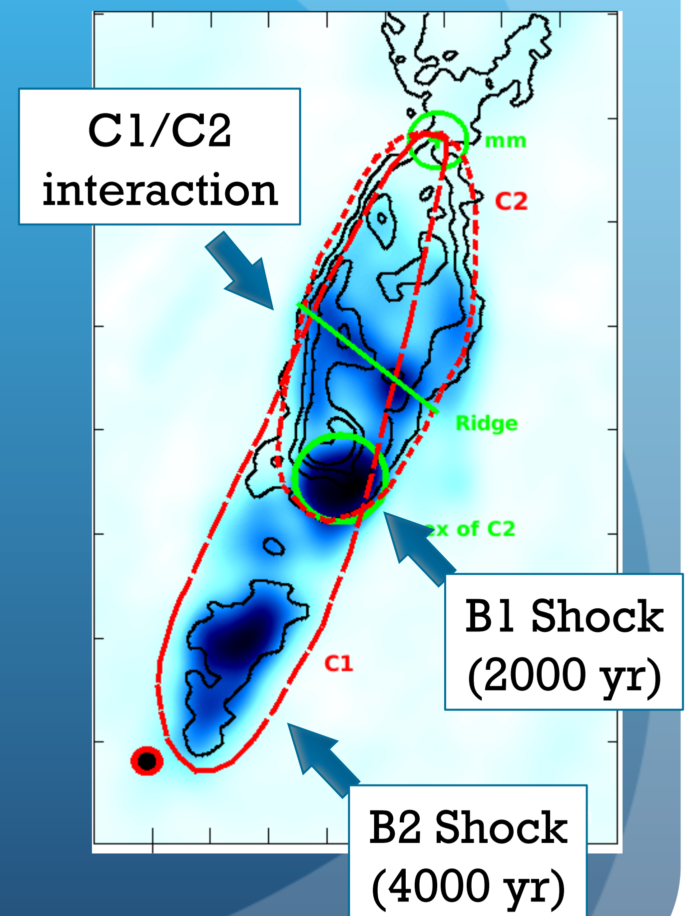




- Previously reported in literature with for most species (Benedettini et al. 2007)
- W wall = liberation of grain species
- E wall = Destruction of complex species, Core sputtering (SiO)

E/W Differentiation in C2

- Proposed scenario for C2:
  - Western wall is shocking cold, pristine material
    - CH_3OH, HNCO liberated off grains
  - Eastern wall is interacting with pre-shocked material within C1
    - HCN, HCO^+ produced from destruction of complex species in gas-phase
    - SiO enhanced as bare grains shocked



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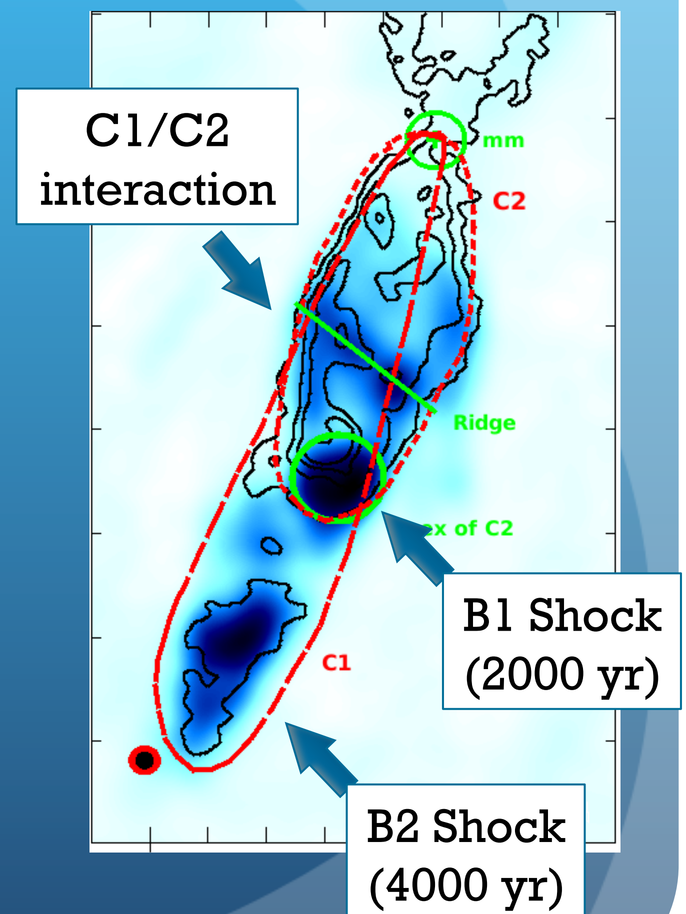
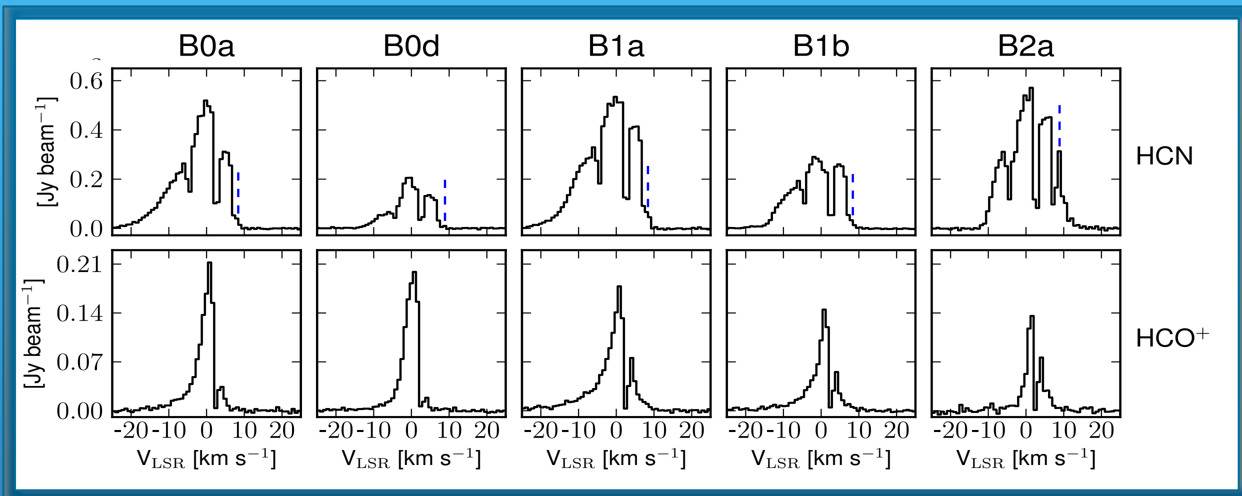
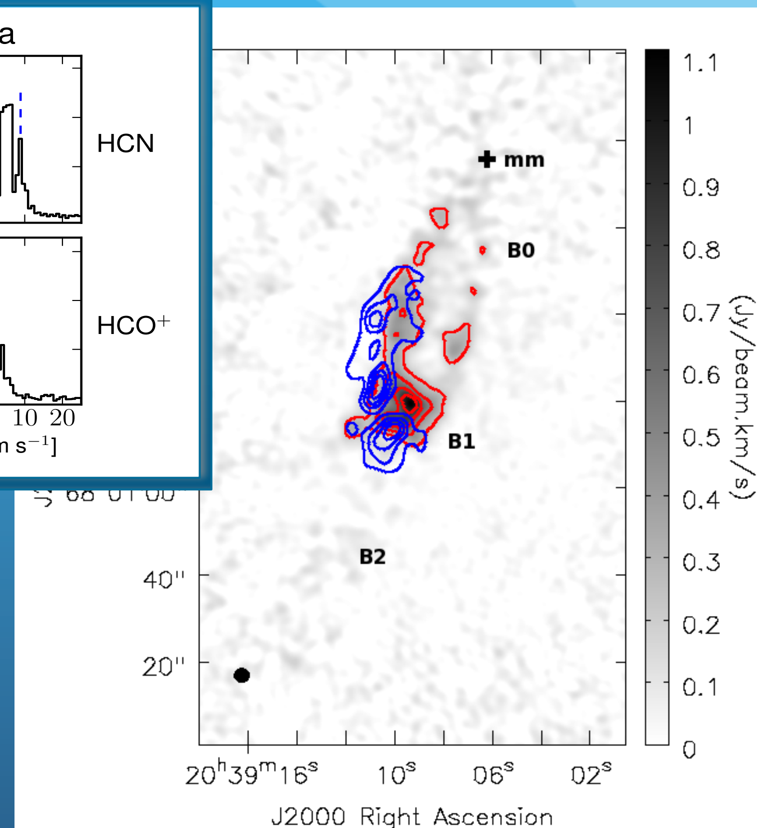


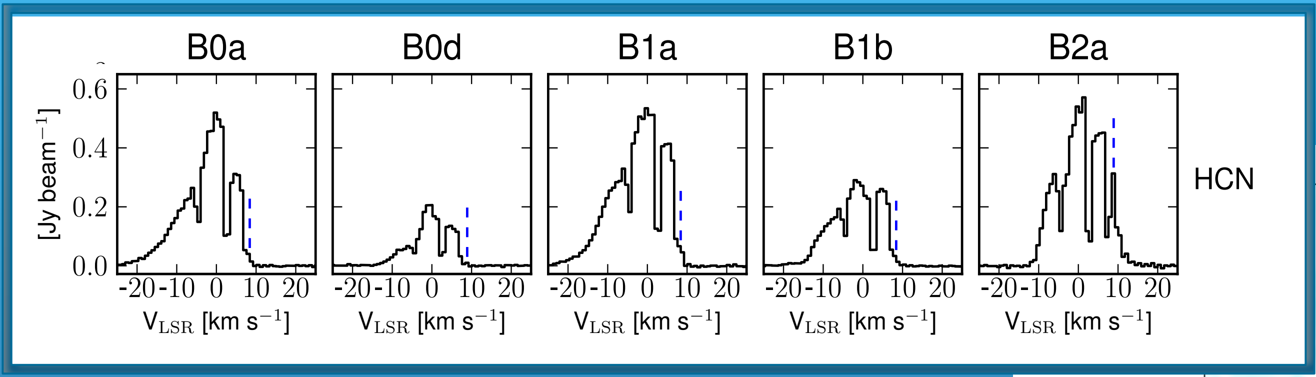
Spectra – Wing Components



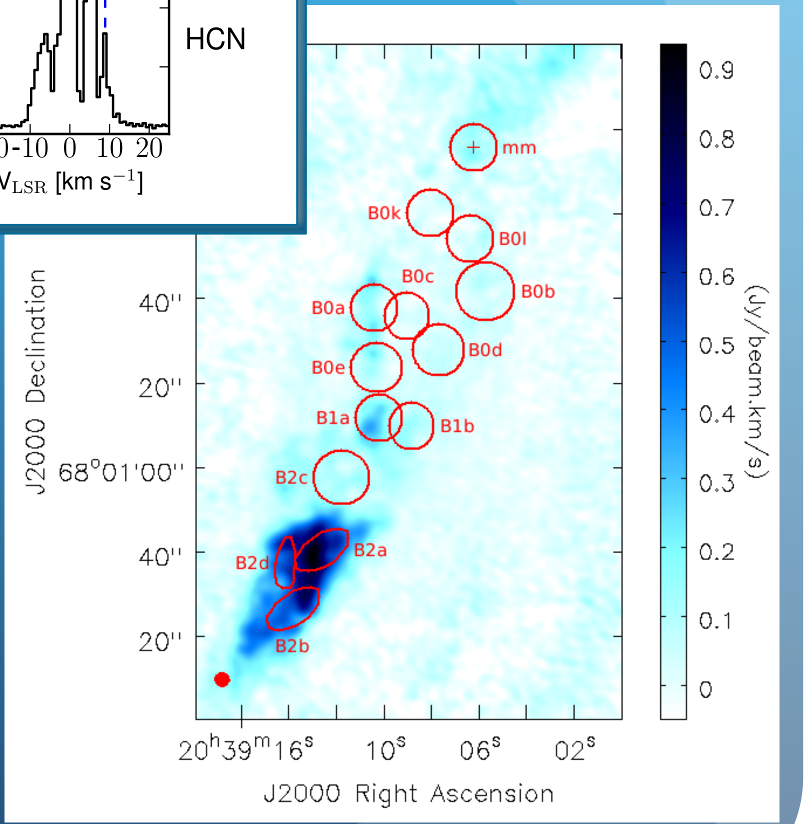


- -15 -> -4 km s^{-1} wings of HCN, HCO^+ exclusively on East C2
  - Also, ~4 km s^{-1} wing seen for CH_3OH, HNCO on West C2
- Supports E/W differentation scenario
- Pre-shocked material -> Less drag on shock

HCN 4th Feature



- 4th feature seen in HCN spectra
- Possibilities:
  - Velocity shifted component?
    - Hyperfine line ratios
  - Different species?
    - None as strong as HCN (1-0)
  - Self-absorption?
    - Significant underestimation of shock enhancements



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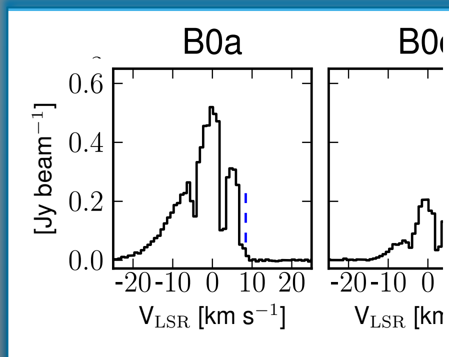
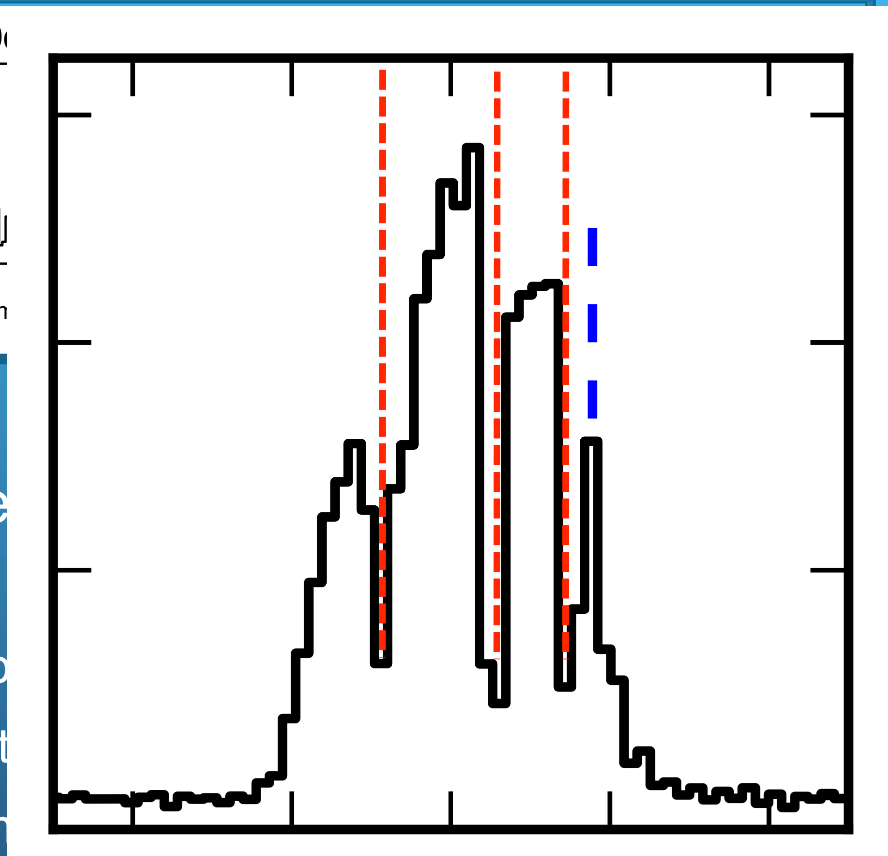
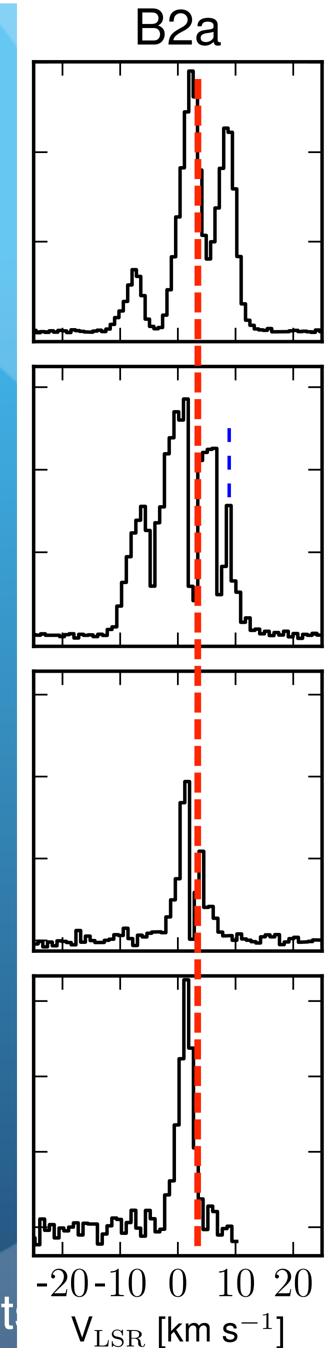


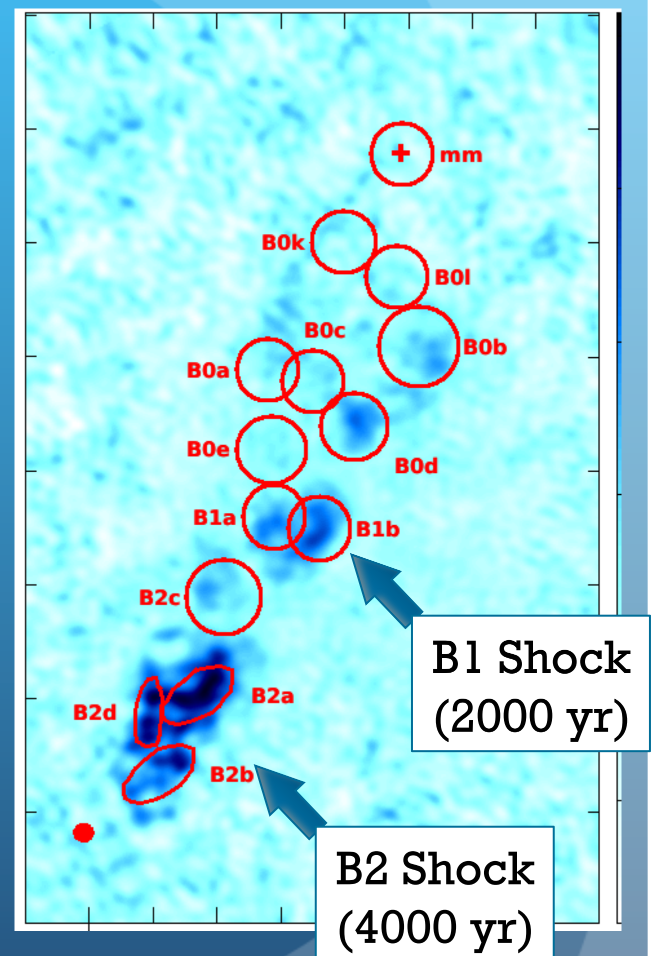




- 4th feature
- Possibilitie
  - Velocity
    - Hyp
  - Different
    - Non
  - Self-absorption?
    - Significant underestimation of shock enhancements

B2 Enhancement

- Enhancements observed for HCN, CH_3OH, and HNCO toward B2
  - Largest HNCO enhancement in galaxy
    (Rodríguez-Fernández et al. 2010; Mendoza et al. 2014)
- B2 = older, potential chemical clock?
  - post-shock, gas-phase reactions may become significant
  - Additional chemistry from enhancement of O_2 from ice (Bergin et al. 1998; Gusdorf et al. 2008)
- HNCO, proposed dominant pathways:
  a) initial grain erosion, then
  b) gas phase rx CN + O_2 ➔ OCN
  then OCN + H ➔ HNCO (Rodríguez-Fernández et al. 2010)



Conclusions

- Report high-resolution CARMA maps of CH_3OH, HCN, HCO^+, HNCO toward L1157
- CH_3OH abundance consistent across regions, produced by liberation off of grains due to shocks
- HCN/HCO^+ & CH_3OH/HNCO velocity profiles indicative of originating from the same physical regions
- E/W differentiation in C2 perhaps because difference in shock-chemistry when the impacted medium is pristine or previously-shocked, shown by molecular enhancement & velocity profiles

Thanks

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