# Observational Evidence for Turbulence Dissipating in Giant Molecular Clouds

**A. Pon** (University of Western Ontario), D. Johnstone (NRC-Herzberg; University of Victoria), M. J. Kaufman (San Jose State University; NASA Ames), P. Caselli (MPE), F. Fontani (INAF), M. J. Butler (MPIA), I. Jiménez-Serra (UCL), A. Palau (IRyA-UNAM), R. Plume (University of Calgary), J. C. Tan (University of Florida)

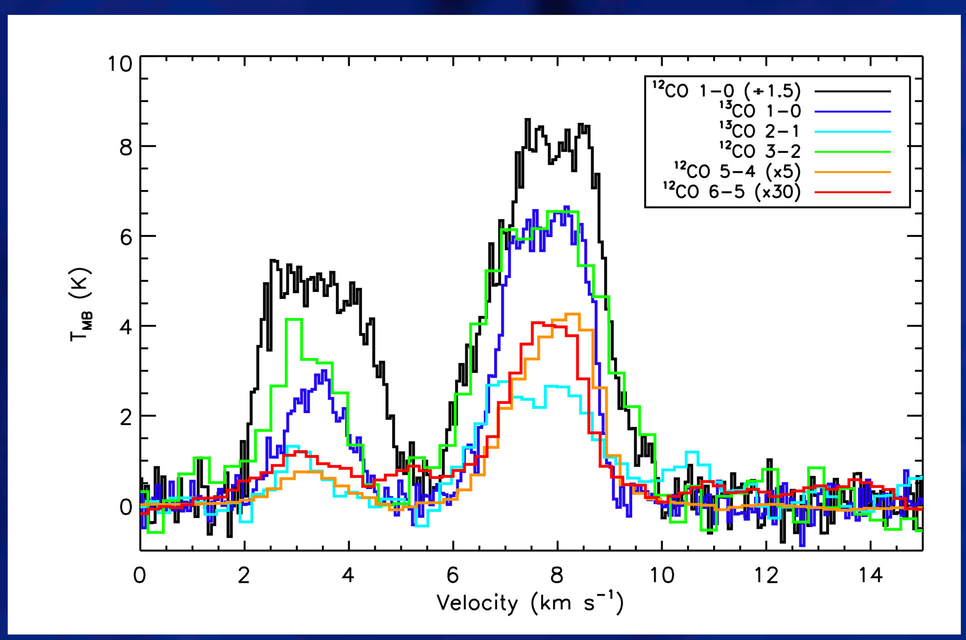



**Figure 1 (above)**: Spectra of various CO lines observed towards B1-E5. The (5-4) and (6-5) spectra are scaled up by factors of 5 and 30 respectively. Note the two different velocity components detected.

## Low Mass: Perseus B1-E5

Herschel was used to observe the CO (6-5) and (5-4) transitions towards the Perseus B1-E5 starless clump (Figure 1). These observations were combined with archival measurements to form a spectral line energy diagram (SLED). Photodissociation region (PDR) models fit to this SLED were able to reproduce the lines up to and including the (5-4) line, but all such models fitting the low J CO lines underpredict the (6-5) intensity (Figure 2). Such excess mid-J CO emission indicates the presence of a hot gas component. **The emission is consistent with turbulence decaying via low velocity shocks in 1/3 of the crossing time and filling 0.15% of the volume of the clump.** See Pon et al. (2014) for further details and Larson et al. (2015) for additional observations in Taurus.

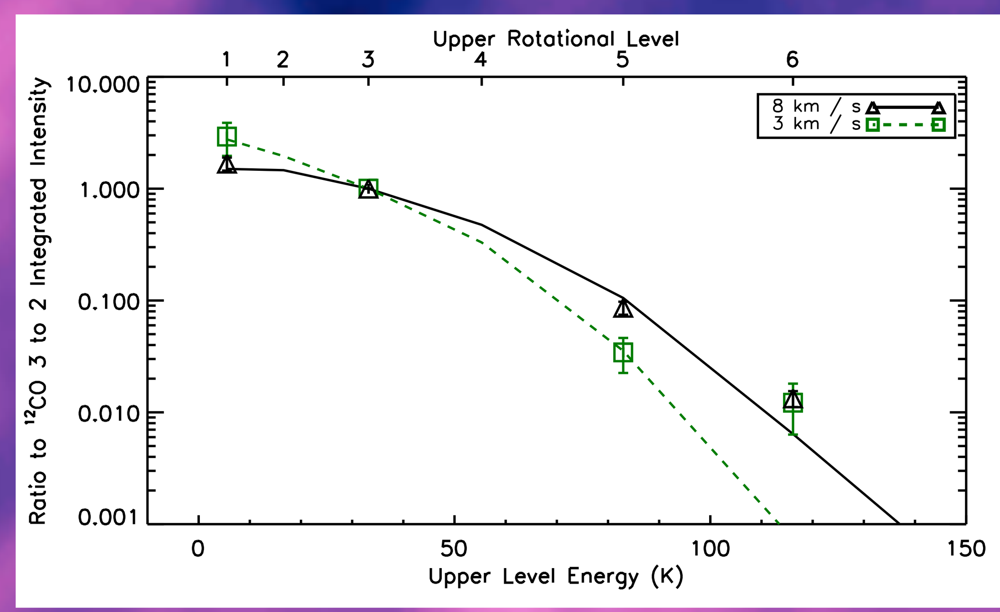
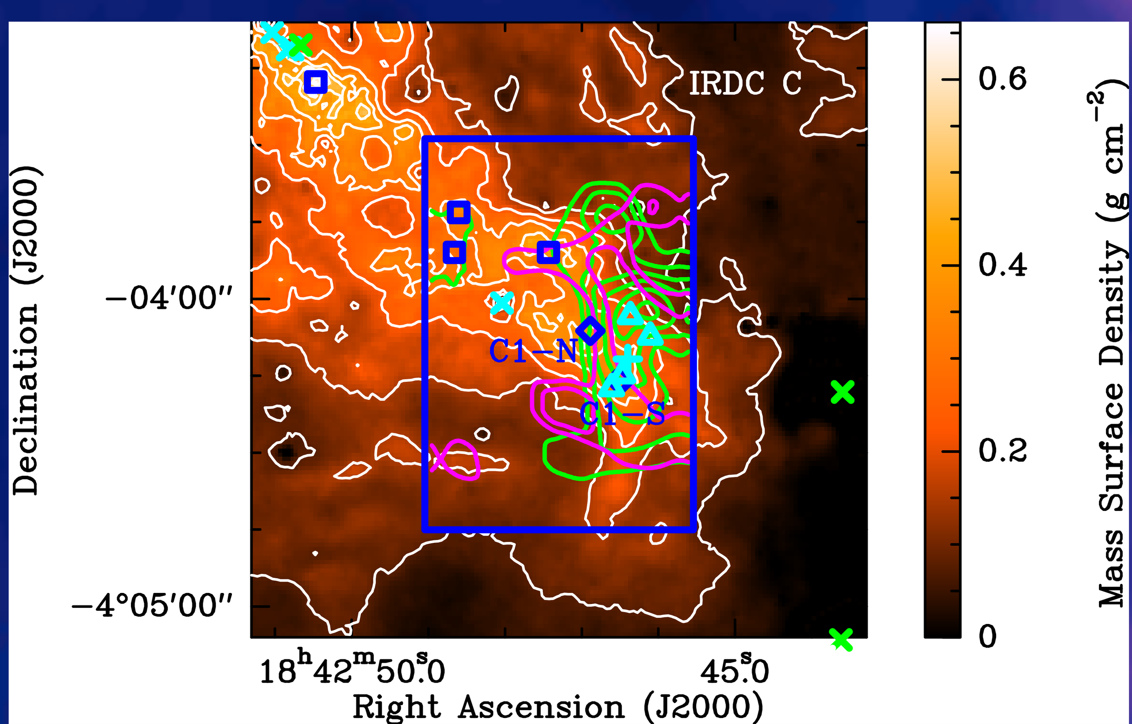
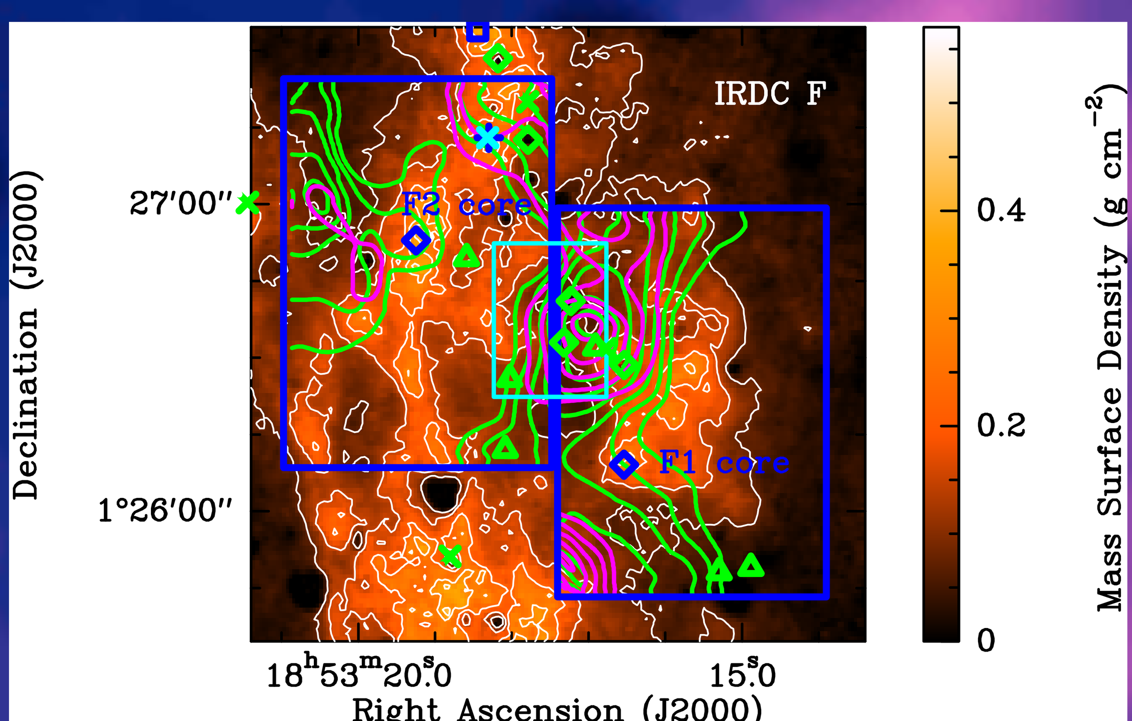
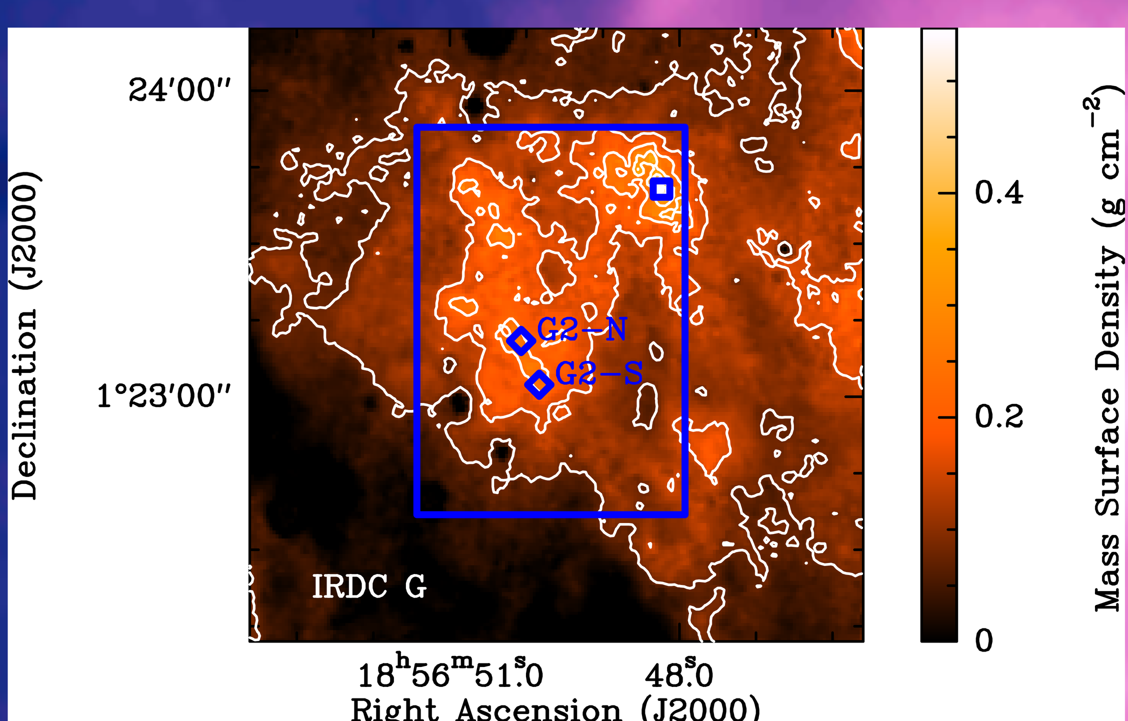



**Figure 2 (above)**: The points show the observed integrated intensity ratios with respect to the (3-2) line. The lines are the best fitting Kosma-τ PDR models. The colours are for the two different velocity components. Note how there is excess emission in the (6-5) line, consistent with shock heating.



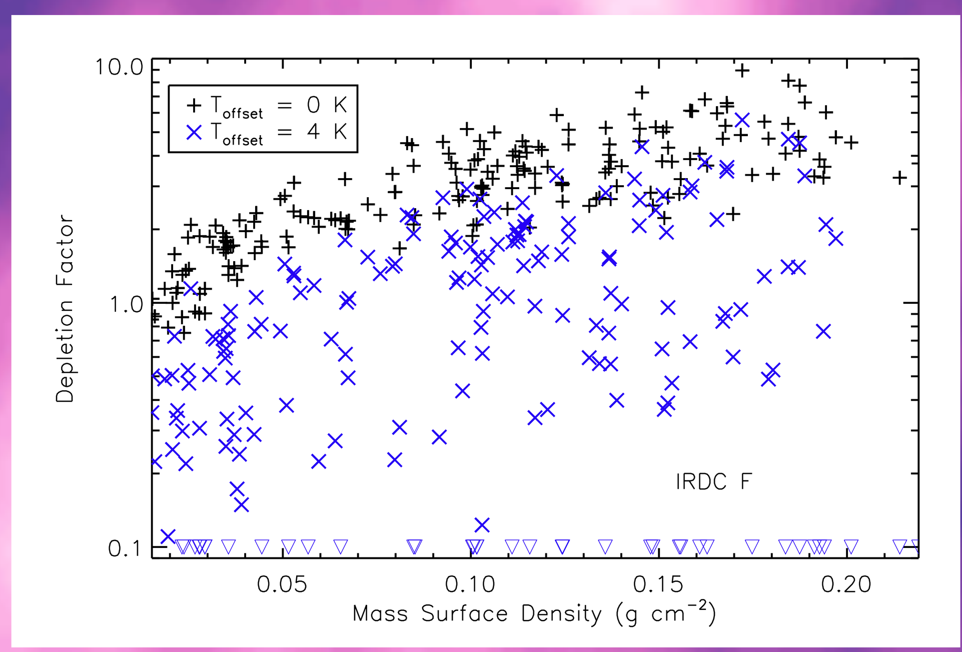



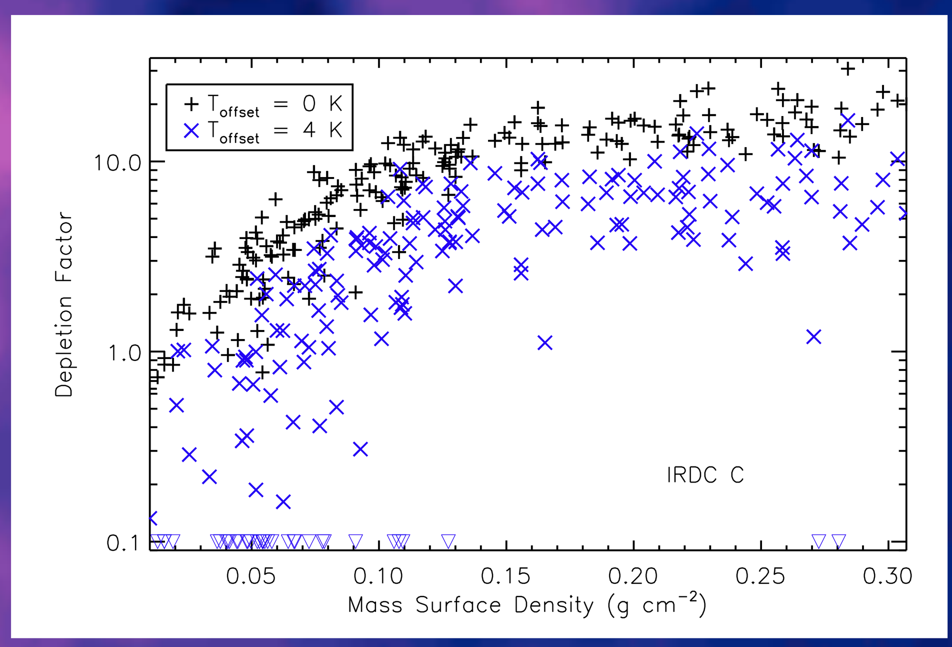




**Figures 3-5**: CO (8-7) and (9-8) integrated intensities are shown as the green and fuchsia contours. The colour scale is the mass surface density. Dark blue symbols show cores, while the other coloured symbols show embedded protostellar sources. The large blue rectangles are the areas observed with Herschel.

## High Mass: IRDCs C, F and G

IRDCs C, F, and G were observed in the CO (8-7), (9-8), and (10-9) lines with Herschel (Figure 3; Pon et al. 2015) and in the $^{12}$CO, $^{13}$CO, and $C^{18}O$ (3-2) lines with the James Clerk Maxwell Telescope (JCMT; Pon et al. 2016a). The mid-J CO emission (CO 8-7 and 9-8) was only detected in a subset of the pointings, with the emission often associated with embedded protostellar objects. **PDR fits to the SLEDs show that there is excess (8-7) and (9-8) emission (the 10-9 line was not detected) requiring a secondary hot gas component**. Much of this hot gas component is likely due to feedback from protostellar sources, but some of the hot gas could be due to turbulence decaying in low velocity shocks. The emission is consistent with turbulence decaying in 3 times the turbulent crossing time. Where detected, this mid-J CO emission requires hot gas to fill 0.3% of the volume of the line of sight. The multiple non-detections are likely due to the turbulence dissipating at lower densities (~$10^4$ $cm^{-3}$) than initially predicted for these IRDCs ($10^5$ $cm^{-3}$ ; Pon et al. 2016b).




## CO Depletion

CO excitation temperatures were estimated from both $^{12}$CO (3-2) observations and from multiple $^{13}$CO and $C^{18}O$ lines, revealing that the $^{13}$CO excitation temperature can be up to 4 K lower than for $^{12}$CO (Pon et al. 2016a). **IRDC F shows CO depletion up to a factor of 5 to 9 and IRDC C has CO frozen out up to a factor of 16 to 31**, with the uncertainty primarily due to possible excitation temperature differences between $^{12}$CO and $^{13}$CO.

**Figures 6-7 (above)**: CO depletion factors across IRDCs C and F. The black crosses show the depletion factor assuming no temperature offset between the $^{12}$CO and $^{13}$CO excitation temperatures while the blue X's are for a 4 K offset.

## References

Larson, R. et al. 2015, ApJ, 806, 70
Pon, A. et al. 2014, MNRAS, 445, 1508
Pon, A. et al. 2015, A&A, 577, A75
Pon, A. et al. 2016a, A&A, 587, A96
Pon, A. et al. 2016b, ApJ, in press

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