

Intermittency and dissipative structures of ISM turbulence

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- What is intermittency?
- Compared statistical & structural properties of extrema of line Centroid Velocity Increments (CVI) in two different environments
- Why dissipative structures?

“Star formation, Then and Now”, Santa Barbara, 13-17 August 2007
What is the link with star formation?

Taurus-Auriga clouds: cold dust emission Hily-Blant 2004
Intermittency in incompressible and mildly compressible turbulence

[1] non-Gaussian statistics of velocity derivative signals more pronounced at small scale

[2] anomalous scaling of $p^{th}$ order structures functions $\zeta_p \neq p/3$ She & Levêque 1994

[3] existence of coherent structures of intense vorticity, shear, rate of strain, ...


Large scale environments: 30-parsec scale

**Polaris flare**: 27 pc × 27 pc field
100 (red), 60 (green) and 12 µm (blue) reprocessed IRAS maps Miville-Deschênes & Lagache 2005

**Taurus-Auriga clouds**: cold dust emission and $B_\perp$ Heiles 2000

**30 pc-scale**:

same virial mass, $M_V \sim 4 \times 10^4 \, M_\odot$

- Polaris: $M_{\text{gas}}/M_V \sim 0.16$
- Taurus: $M_{\text{gas}}/M_V \sim 1$
Compared properties of the two parsec-scale fields

Taurus (left) – Polaris (right)

**Parsec-scale:**
- turbulent
  - \( M \sim 5 \) in Polaris,
  - \( M \sim 2 \) in Taurus
- translucent
  - \( A_v \sim 0.8 \) to 1 mag in both fields
- Polaris: trans-Alfvénic turbulence
dense core environment
- Taurus: cloud edge, no dense core
The tool: statistics of increments of line centroid velocities

IRAM-30m,
8000 spectra (now 35000, resol 11"")
Fully sampled, resolution 20"

\[ \delta v_l = (v_1 - v_2) \]

Line centroid velocity:
\[ C(r) = \int T(r, v_x) v_x dv_x / \int T(r, v_x) dv_x \]
Miesch & Scalo 1999, Pety & Falgarone 2003, Brunt et al. 2003, ...
Extrema of line centroid increments trace extrema of
\[ (\langle \omega_y \rangle^2 + \langle \omega_z \rangle^2)^{1/2} \]
Lis et al. 1996
PDFs of Centroid Velocity Increments with variable lags

Polaris

Taurus

\[ P(\delta C_t) \]

\[ \sigma(\delta C_t) = 0.1 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.15 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.04 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.07 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.21 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.34 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.09 \text{ km/s} \]

\[ \sigma(\delta C_t) = 0.15 \text{ km/s} \]
Spatial distribution of largest CVIs

Polaris

- Elongated structures of thickness $\leq 0.03$ pc
- Taurus: parallel to $B_\perp$
- Polaris: rms orientation of $30^\circ$
- CVI$_{max}$ in Polaris $\sim 3$ CVI$_{max}$ in Taurus
Self-similarity of PDFs of CVIs

Polaris large scale (5 pc)
KOSMA data, resolution 120", Bensch et al. 2001
From 7 mpc to 3 pc
Scaling of CV $p^{th}$-order structure functions with $p$

Extended Self-Similarity exponents Benzi et al. 1993

**HD scaling:** She & Lévêque 1994, $\theta = 1/3$, $D = 1$, $\beta = 2/3$

**MHD scaling:** Boldyrev et al. 2002, $\theta = 1/3$, $D = 2$, $\beta = 1/3
Space-velocity slices: observations and MHD simulations

$\delta(\text{R.A.}) = -500''$

$1^{2}\text{CO}(1-0)$ l-v slices

in Polaris Flare, across a large-CVI structure

SuperAlfvénic MHD turbulence and radiative transfer

(Padoan & Juvela, private communication)
CVIs extrema as tracers of “intermittency”

Same statistical and structural properties as intermittency of velocity field in incompressible or mildly compressible turbulence, magnetized or not:
• non-Gaussian wings of PDFs increase at small lags [1]
• anomalous scaling of CV structure functions [2]
• thin (0.02 pc) elongated structures of CVIs extrema, coherent over > 1 pc [3]
• CVIs extrema trace intense velocity shears (PdBI data: velocity shear $\sim 200 \text{ km s}^{-1} \text{ pc}^{-1}$ over 7 mpc) [1]
not associated with density/column density peaks
• most turbulent field at large scale (Polaris) is most intermittent at small scale [4]
CVIs extrema as tracers of local enhanced dissipation: CO emission

Optically thin $^{12}$CO(1-0) emission: $[^{12}\text{CO}]/[^{13}\text{CO}] > 35$

**LVG analysis and translucent constraint:**
dense and cold solutions ruled out: $n_{\text{H}_2} < 10^3 \text{ cm}^{-3}$, $T_k > 25$K
CVIs extrema as tracers of local enhanced dissipation: \( \text{HCO}^+ (1-0) \)

Observed \( \text{HCO}^+ \) abundances are more than one order of magnitude above predictions of steady-state chemical models: non-equilibrium chemistry

Falgarone, Pineau des Forêts, Hily-Blant & Schilke 2006
Relaxation tracks versus observed $\text{HCO}^+$ abundances

Cooling tracks for same initial density and two different UV shieldings, $A_v = 0.5$ and 1 mag. Observations meet models in the range $T = 100–200$ K, $n = 200–10^3$ cm$^{-3}$
Conclusions and Open Questions

In translucent molecular gas:
- intermittency of velocity field similar to that of incompressible/mildly compressible turbulence
- intermittency more pronounced in most turbulent field at large scale
- observed intermittent structures: thickness: $\leq 0.02$ pc, down to 7mpc, coherent over $\sim 3$pc or more
- signposts of turbulence dissipation (thermal, chemical, radiative)

Open questions:
- nature of these structures, unlikely to be shocks
- role of magnetic fields
- actual smallest scale (ALMA) and radiative cooling rate
- observable helicity?