Snakes in the (Galactic) Plane: Direct Imaging of Interstellar Turbulence

Bryan Gaensler — Sydney Institute for Astronomy

with M. Haverkorn, B. Burkhart, R. Ekers, K. Newton-McGee, N. McClure-Griffiths, A. Lazarian, N. Gheissari, E. Petroff, T. Robishaw, J. Dickey & A. Green

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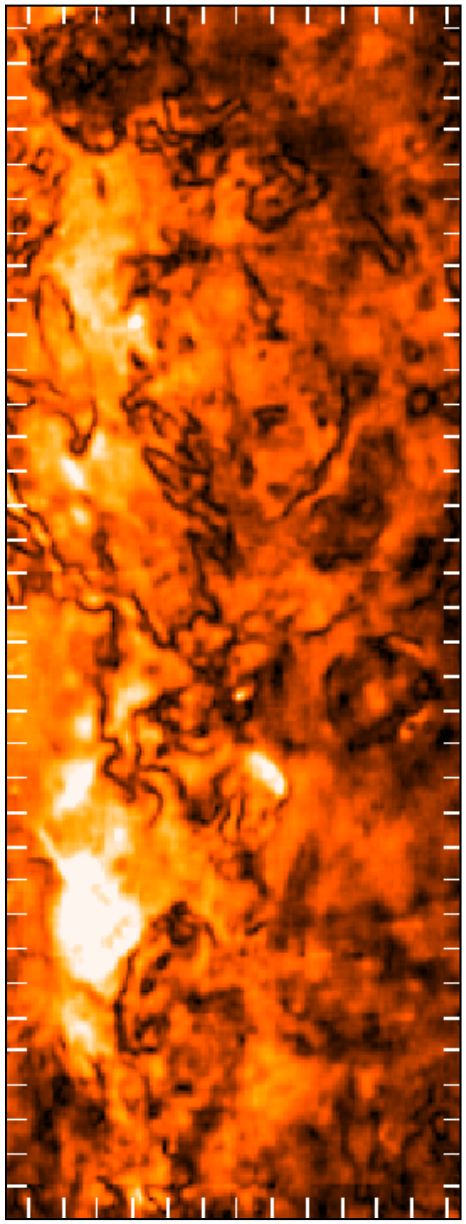
THE UNIVERSITY OF SYDNEY

Polarisation Canals

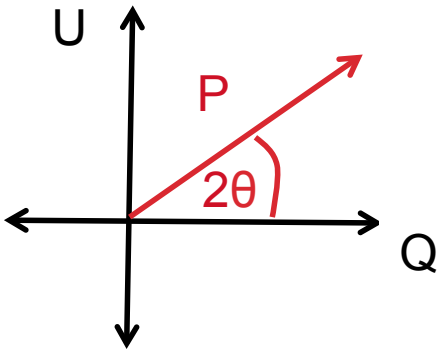
- Channels of reduced radio polarisation
  (e.g., Uyanıker et al. 1998; Haverkorn et al. 2000; Gaensler et al. 2001; Reich et al. 2004)
  - seen w. both interferometer & single dish
  - one beam wide
  - not related to structure in total intensity
  - 90° change in pol angle across canal
- Possible explanations:
  - Beam depolarisation due to RM gradients (Haverkorn & Heitsch 2004)
  - Contours of depth depolarisation (Shukurov & Berkhuijsen 2003)
  - Discontinuities in angle due to shocks (Fletcher & Shukurov 2006)

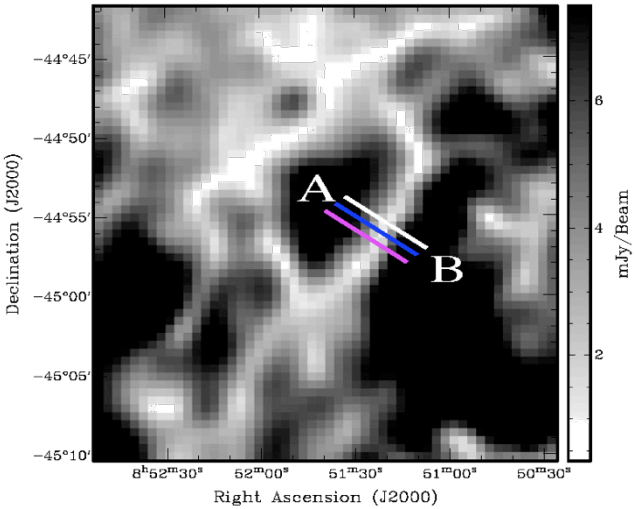


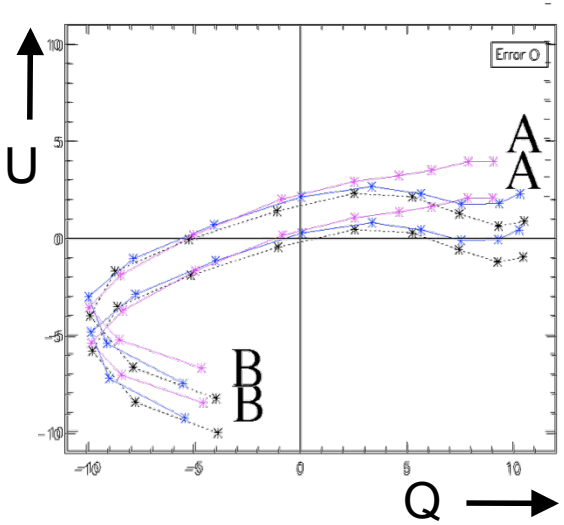
Reich et al. (2004)

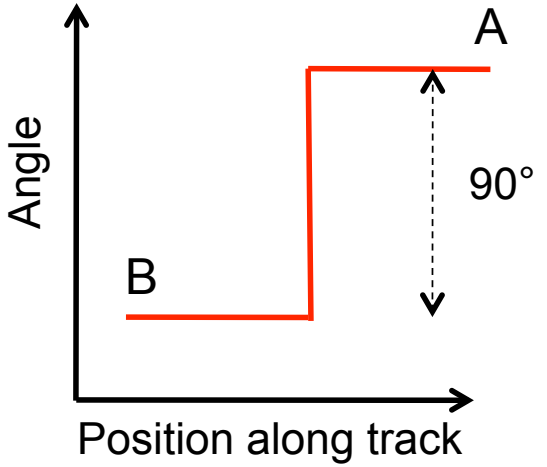
Canals in the (Q,U) Plane

- A trajectory in the (*Q*,*U*) plane must pass through (0,0) at a canal
- $2\theta = \tan^{-1}(U/Q)$ will usually change by 180° at this point

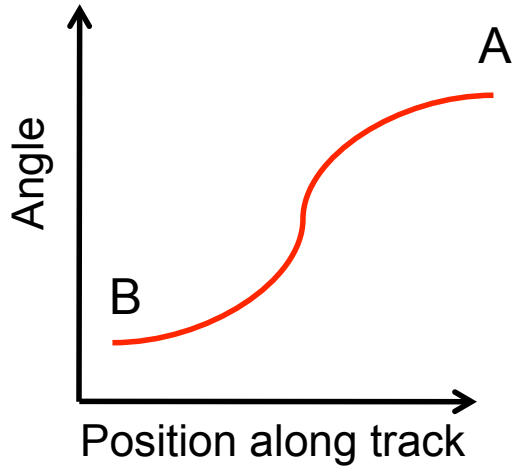








- What if tracks shift?
  Not a canal, but potentially physically identical to a canal
- Subset of a wider population
- Defining intrinsic properties?

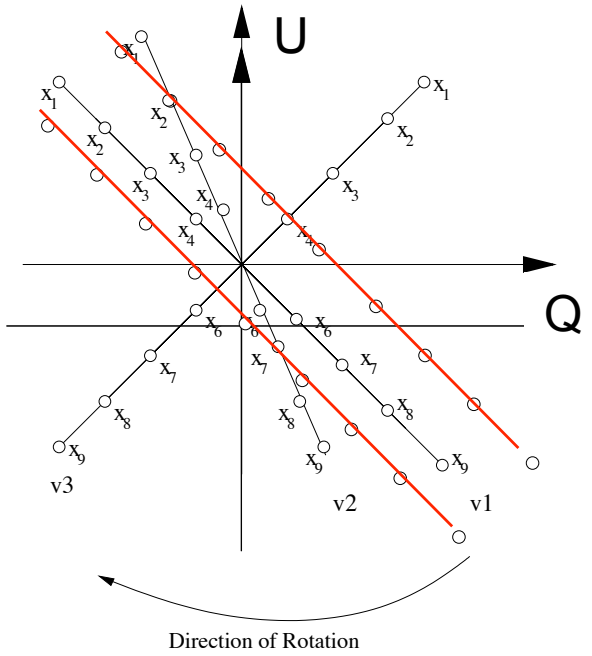


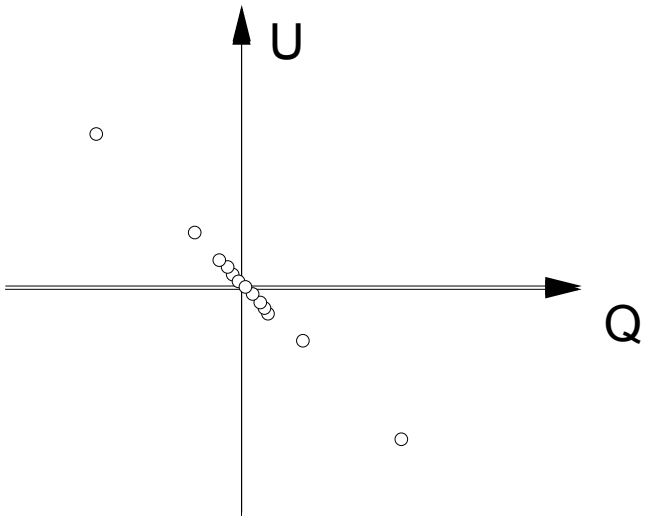
Newton-McGee (2009)

Invariance

- Rotational invariance
  - Faraday rotation
  - change of coordinate system
- Translational invariance
  - foreground/background screen
  - missing short spacings
- So what are the defining intrinsic properties of a canal?
- Spacing of points along the track
  - “high velocity”: potential canal
  - “low velocity”: can never be canal

→ under rotational/translational invariance, canals are contours of *high gradient* in the Stokes vector





Newton-McGee et al. (2008)

Gradient of (Q,U)

$$\vec{P} = (Q,\ U) \qquad \frac{\partial \vec{P}}{\partial x} = \left(\frac{\partial Q}{dx},\ \frac{\partial U}{dx}\right),\ \frac{\partial \vec{P}}{\partial y} = \left(\frac{\partial Q}{dy},\ \frac{\partial U}{dy}\right)$$

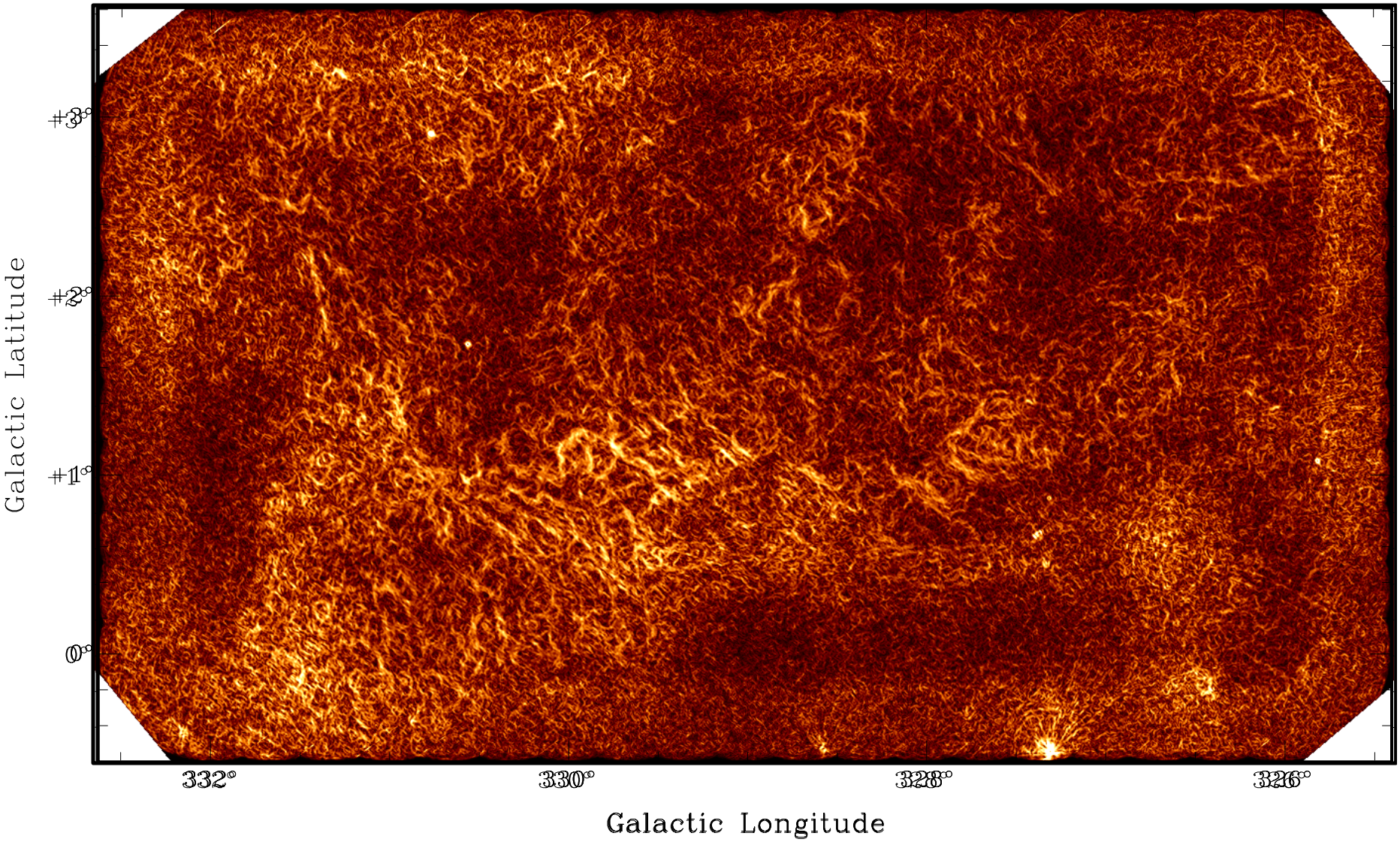
$$\nabla \vec{P} = \frac{\partial \vec{P}}{\partial x}\hat{e}_1 + \frac{\partial \vec{P}}{\partial y}\hat{e}_2 = \left(\frac{\partial Q}{dx},\ \frac{\partial U}{dx}\right)\hat{e}_1 + \left(\frac{\partial Q}{dy},\ \frac{\partial U}{dy}\right)\hat{e}_2$$

$$\left|\nabla \vec{P}\right| = \sqrt{\left(\frac{\partial Q}{\partial x}\right)^2 + \left(\frac{\partial U}{\partial x}\right)^2 + \left(\frac{\partial Q}{\partial y}\right)^2 + \left(\frac{\partial U}{\partial y}\right)^2}$$

$$\arg(\nabla \vec{P}) = \tan^{-1}\left[\operatorname{sgn}\left(\frac{\partial Q}{\partial x}\frac{\partial Q}{\partial y} + \frac{\partial U}{\partial x}\frac{\partial U}{\partial y}\right)\frac{\sqrt{\left(\frac{\partial Q}{\partial y}\right)^2 + \left(\frac{\partial U}{\partial y}\right)^2}}{\sqrt{\left(\frac{\partial Q}{\partial x}\right)^2 + \left(\frac{\partial U}{\partial x}\right)^2}}\right]$$

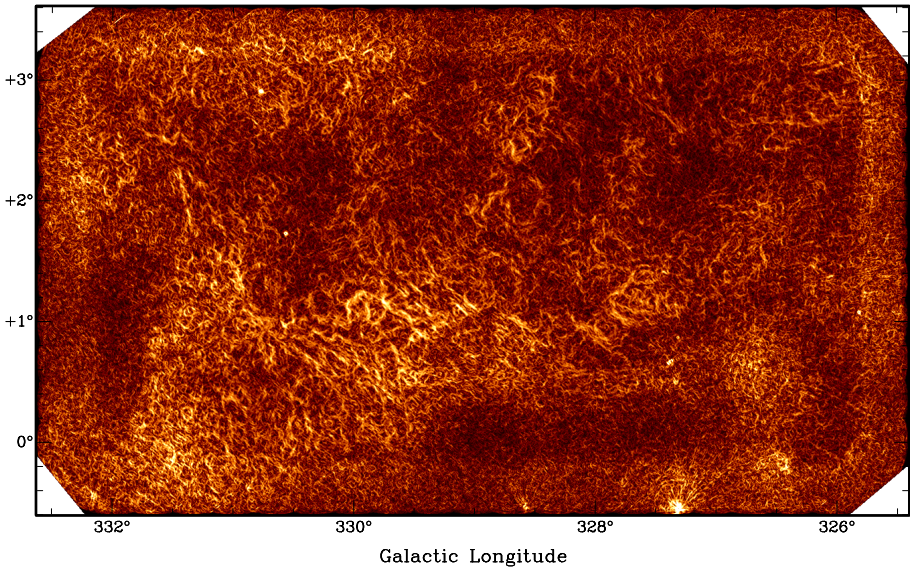
The Polarisation Gradient

Linear Polarisation Gradients in the Southern Galactic Plane (Gaensler et al. 2001, 2011)

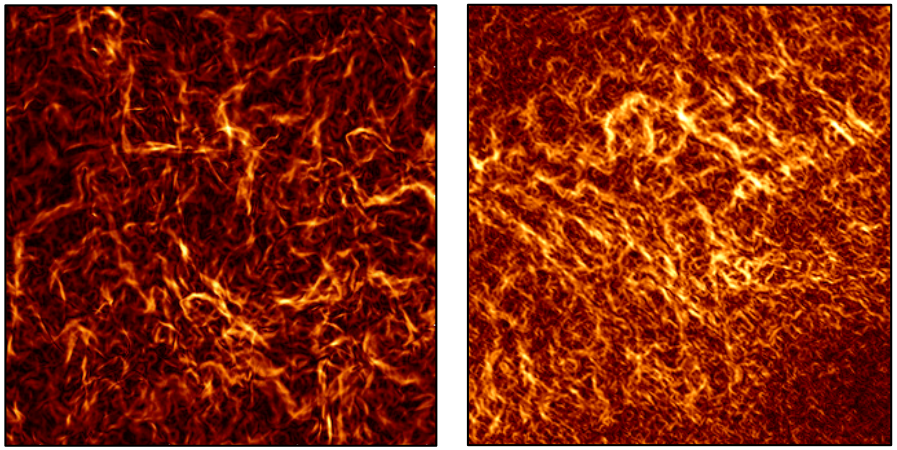


Snakes in the Plane

- $|\nabla \boldsymbol{P}|$: locations of high gradient (i.e. rapid changes in Q or U with position)
  - superset of potential canals
  - tangled filaments (no “patches” seen)
- No frequency dependence: not a “contour”
  → physical structures in interstellar gas
- Not intrinsic to emitting region, no association with structures or gradients in Stokes I, H I, or Hα
  → gradients are due to Faraday rotation
  → *canals are cusps/jumps in foreground electron density or magnetic field*
- Similar structures seen in simulations (produced by shocks, vortices, shear)
  - *characteristic feature of magnetised turbulence*

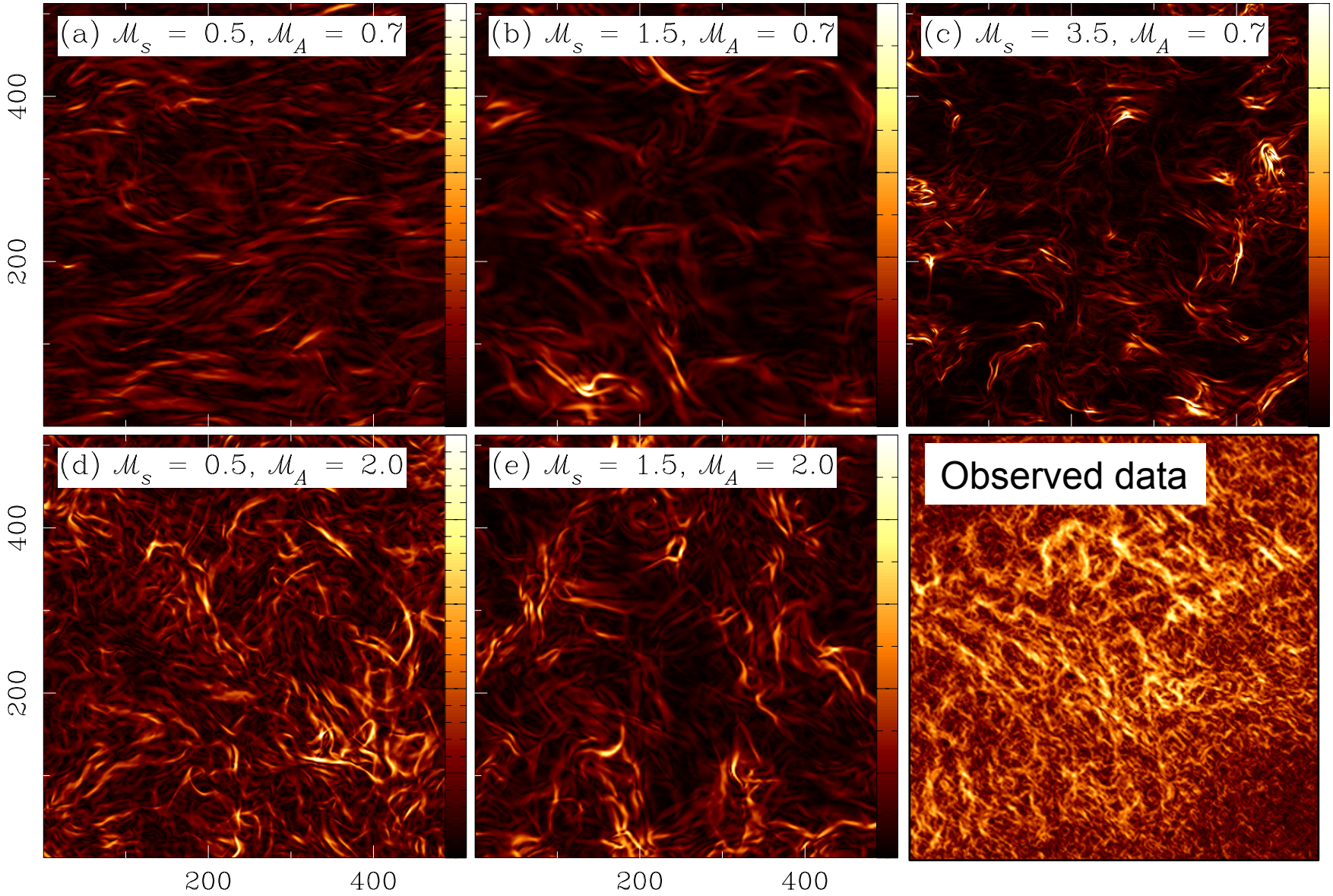


Gaensler et al. (2001, 2011)



$|\nabla \boldsymbol{P}|$ for MHD simulations and observations
(Haverkorn & Heitsch 2004; Gaensler et al. 2011)

Visualising Turbulence



Gaensler et al. (2011)

Conclusions, M#$%@!

- Galaxy is suffused with $\nabla \boldsymbol{P}$ filaments
  - loci of sharp edges in foreground n_e or B
  - stochastic network of turbulence & shocks
  - sonic Mach number $M_s \sim 0.5 - 2$
- Work in progress:
  - calculation of $\nabla \boldsymbol{P}$ for other fields & frequencies
  - quantitative diagnostics of M_s, M_A, Re, etc (moments, genus, probability distrib function; Burkhart et al. 2012)
- Gradient of polarisation can:
  - reveal invariant features in radio polarisation
  - directly visualise interstellar turbulence
  - give quantitative info on turbulent parameters

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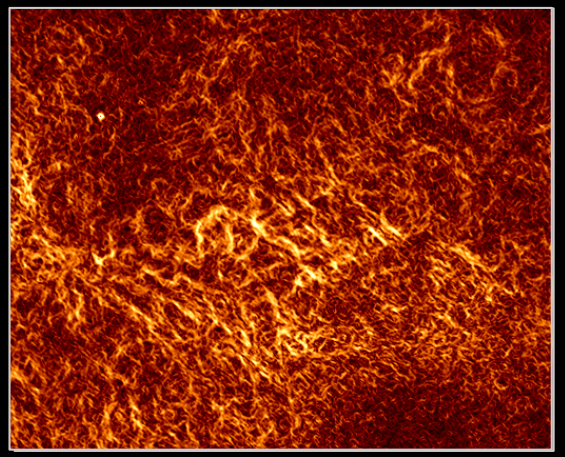
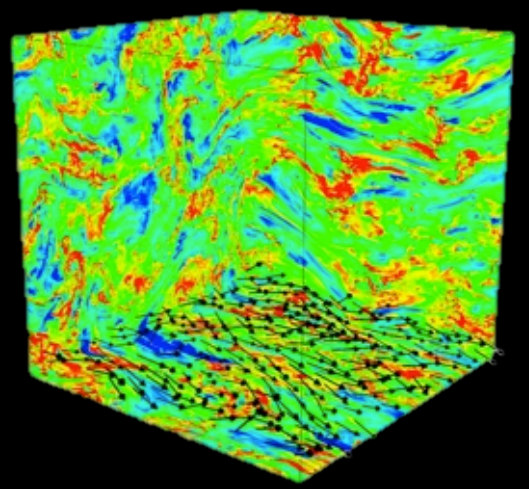


Gaensler et al. (2011)



Lemaster & Stone (2009)