VELOCITY GRADIENTS OF INTERMEDIATE DENSITY AMMONIA GAS IN THE TAURUS MOLECULAR CLOUD

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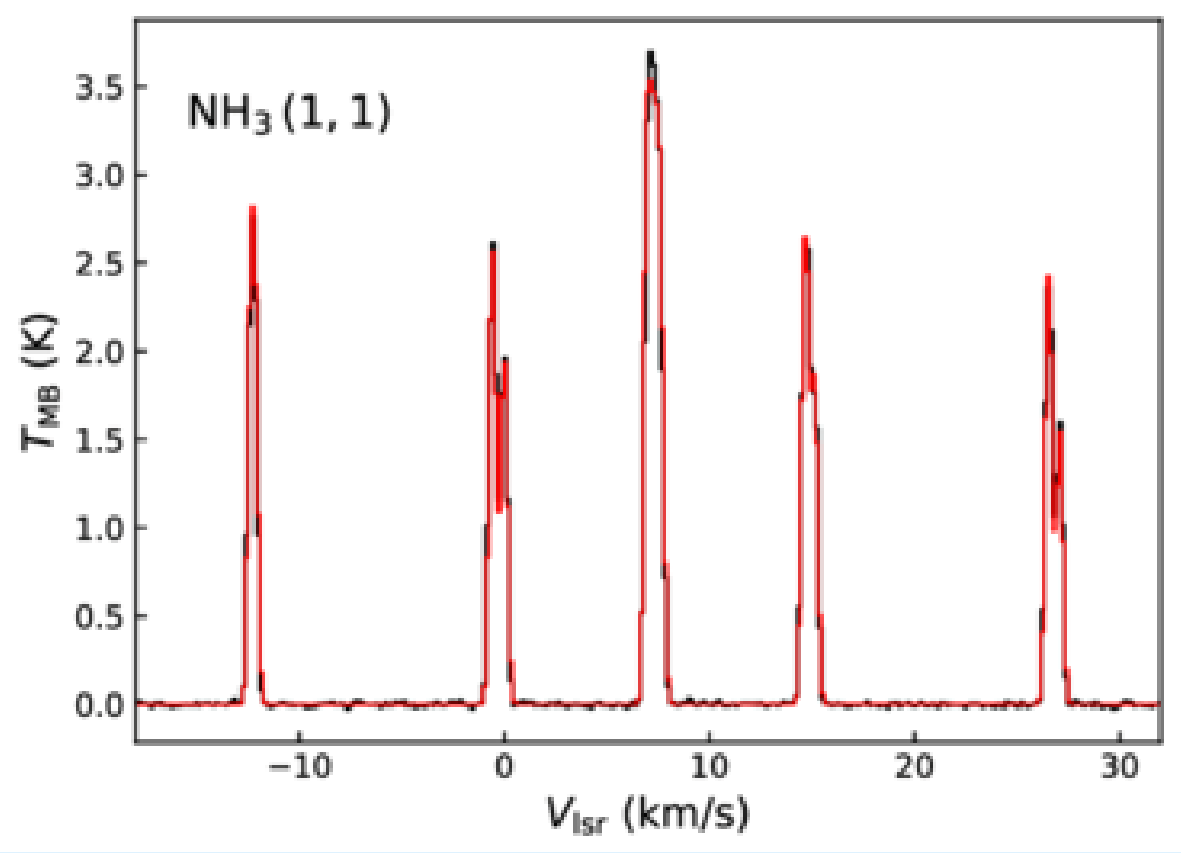
The Taurus Molecular Cloud

- Nearby star-forming region
  - 140 pc
  - Quiescent laboratory for astrochemistry and star formation
- GAS Team mapped Taurus at the (1, 1) and (2, 2) inversion transitions of ammonia (NH_3)
  - 23.69 GHz & 23.72 GHz (Kukolich, 1967)
  - Spatial resolution: 33”
  - Spectral resolution: 0.08 km/s → 0.02 km/s

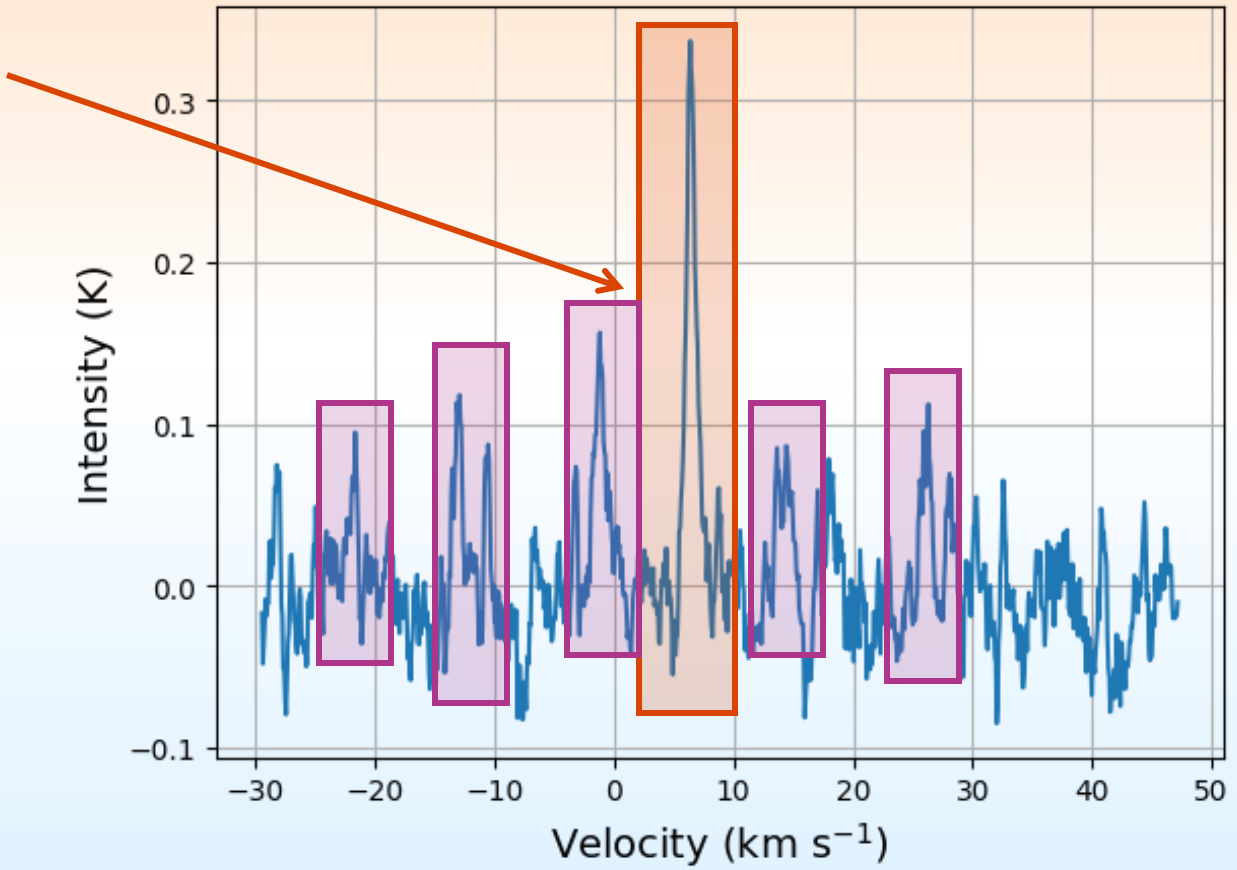
Ammonia Inversion Transitions

- Nitrogen atom tunnels through classically forbidden plane of hydrogen atoms
    - Energy of transition dependent on rotational state of ammonia
- Contain 18 and 24 hyperfine transitions clumped into 5 and 7 groups respectively



The Problem

- Main central peak is clearly identifiable
- What are the remaining peaks?
  - Hyperfine transitions
    - Frequency spacing known
  - Other velocity components
  - Noise
- How do we conduct kinematics analysis?

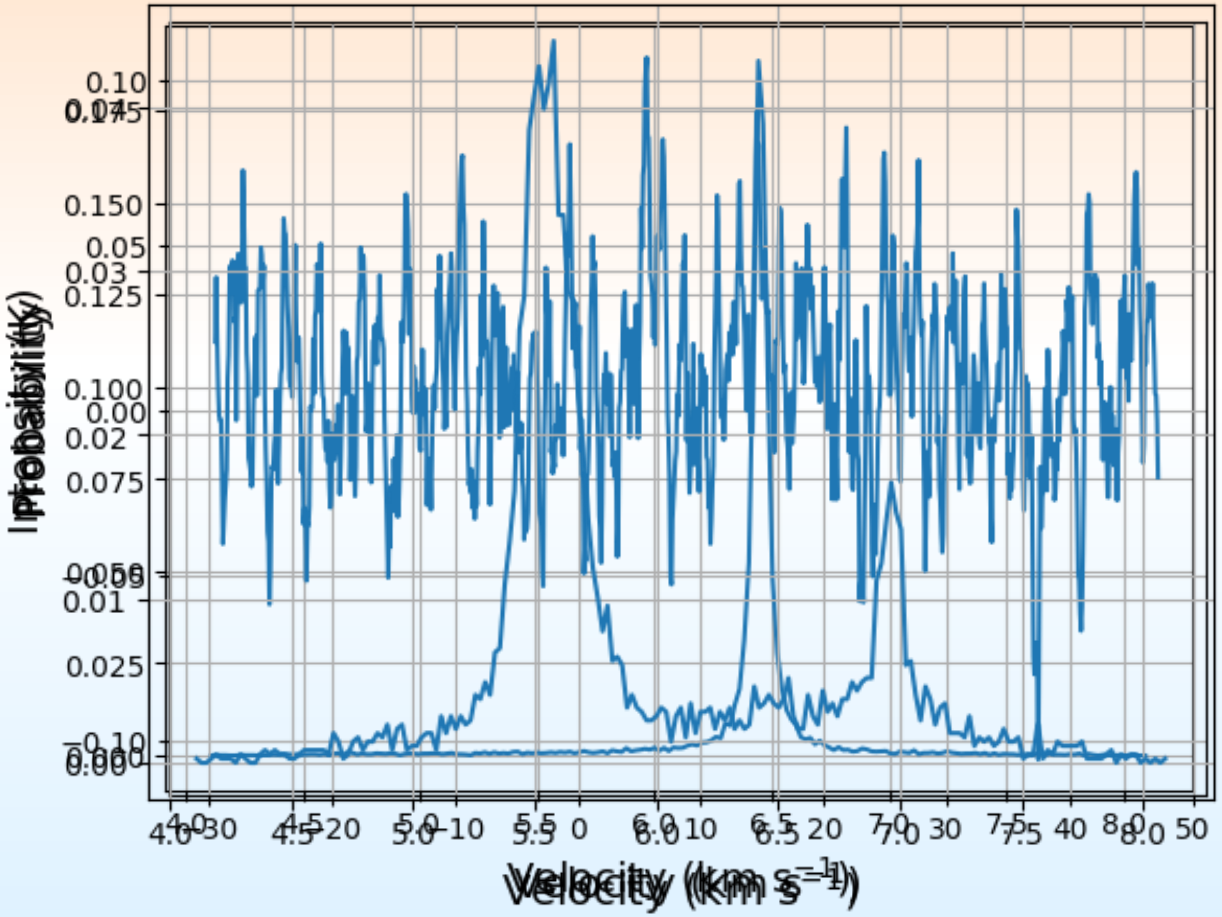


The Solution: Bayesian Analysis

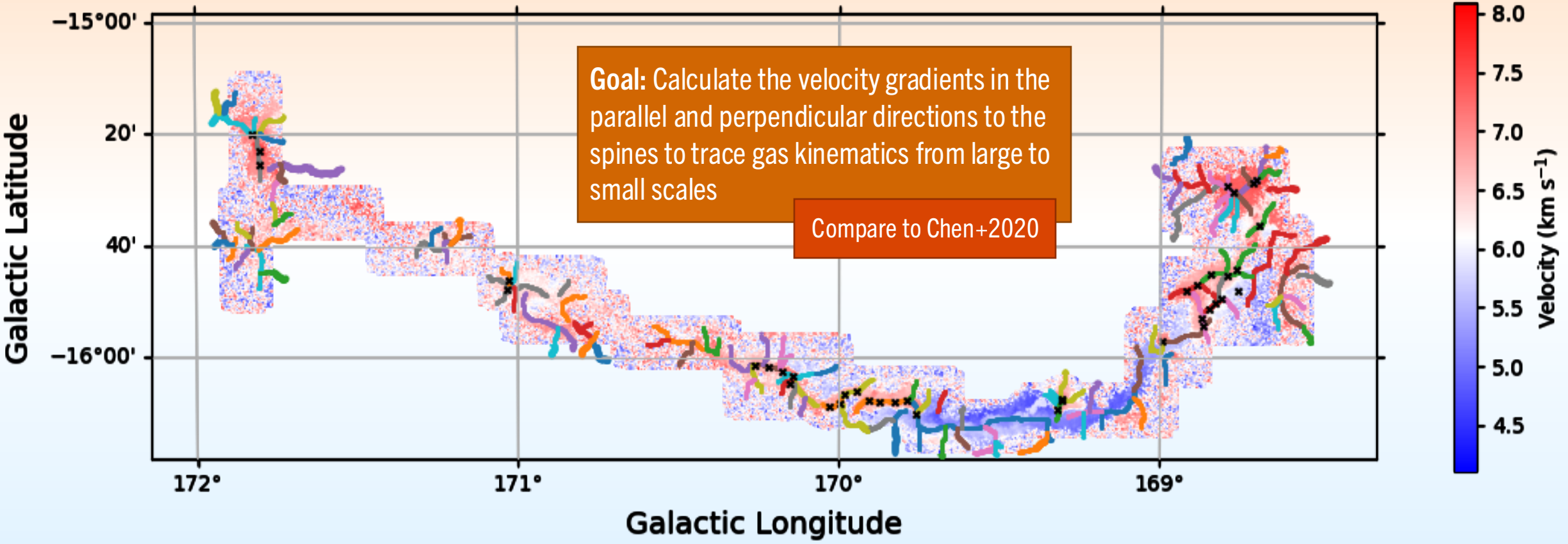
- Use Ammonia (1,1) and (2,2) inversion spectra as prior

$$\underbrace{\mathrm{P}(\theta|D)}_{\text{Posterior}} = \underbrace{P(\theta)}_{\text{Prior}} \times \frac{P(D|\theta)}{P(D)}$$

- Forms posterior distributions for velocity, excitation temperature, column density, dispersion, etc.



Maximum Likelihood Velocity



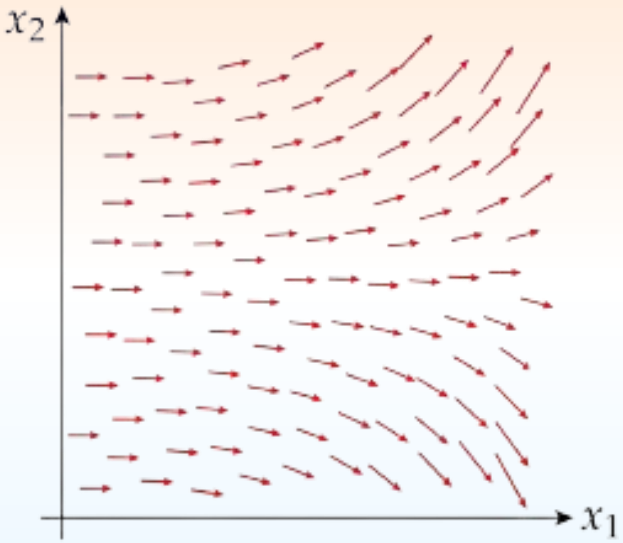
Goal: Calculate the velocity gradients in the parallel and perpendicular directions to the spines to trace gas kinematics from large to small scales

Compare to Chen+2020

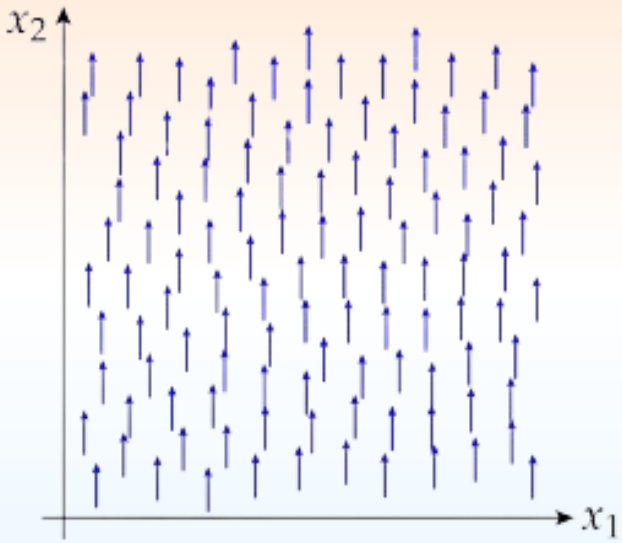
Herschel Gould Belt Survey (Ladjelate+20)

Differential Geometry

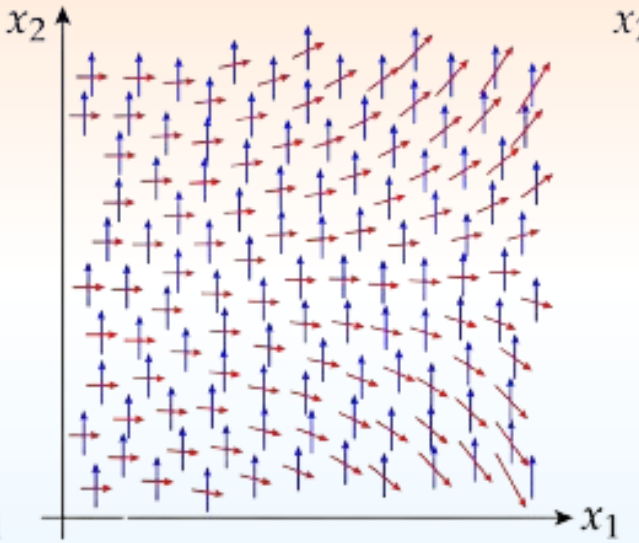
Crane 2021

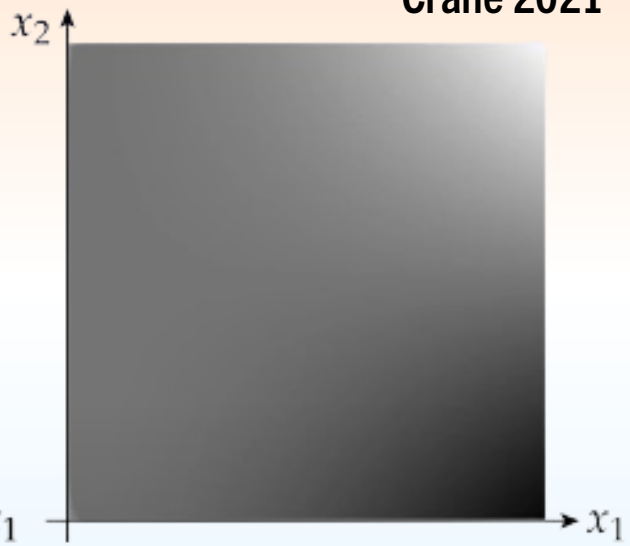


Differential 1-Form



Vector Field





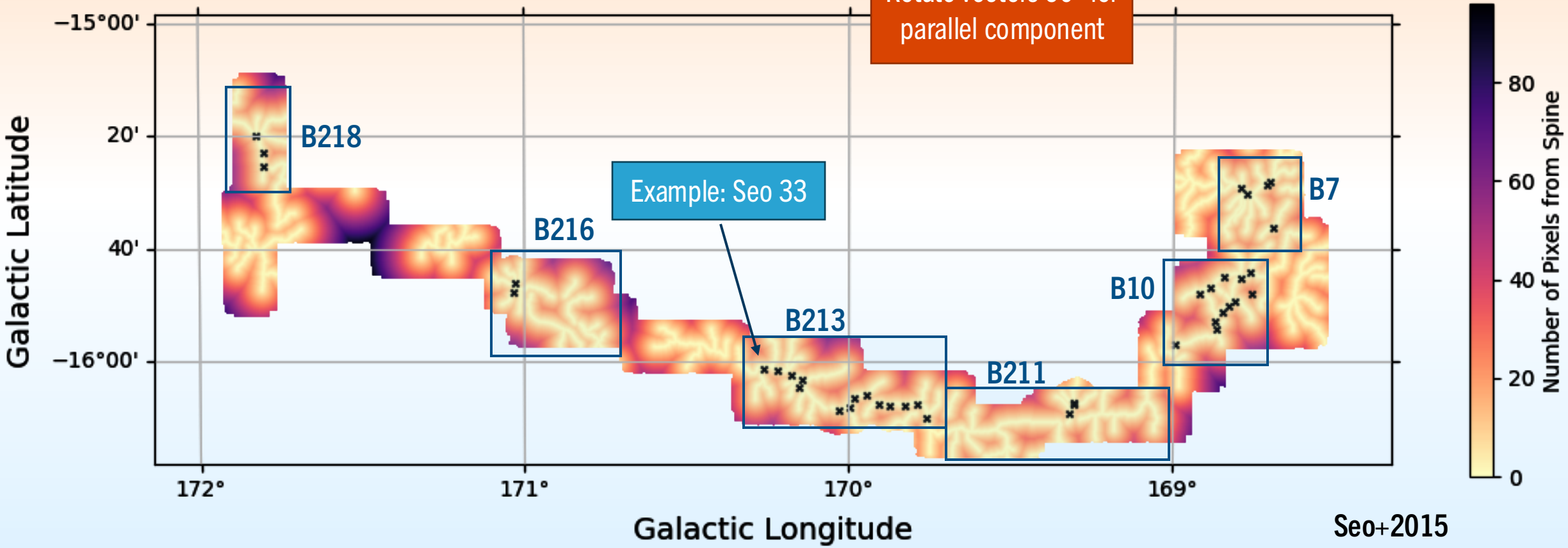
Use the differential 1-form to measure the vector field

Tells how to measure

Differential Geometry

The gradient of the distance transform acts as the differential 1-form for perpendicular component

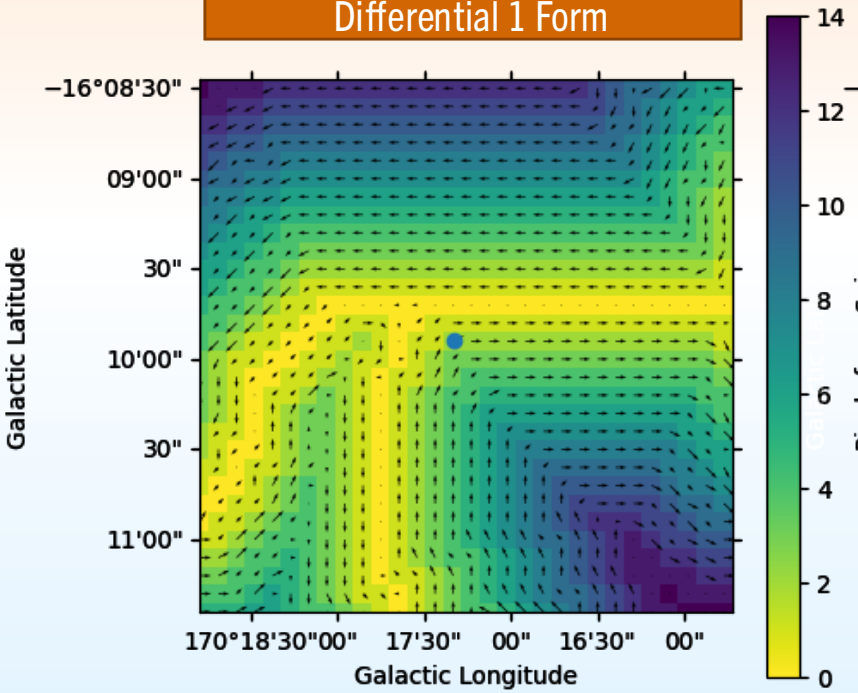
Rotate vectors 90° for parallel component



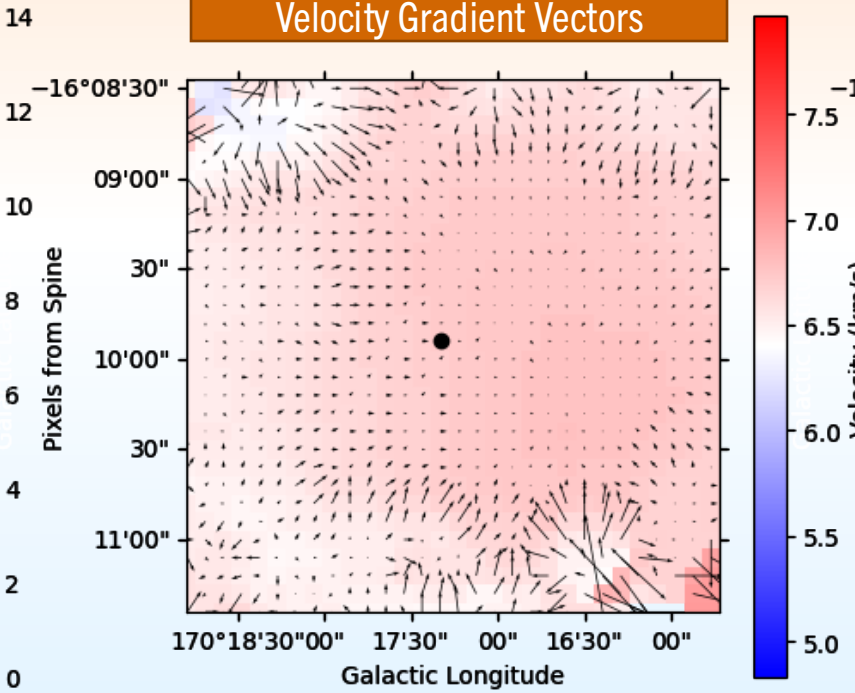
Seo+2015

Gradients in Subregions

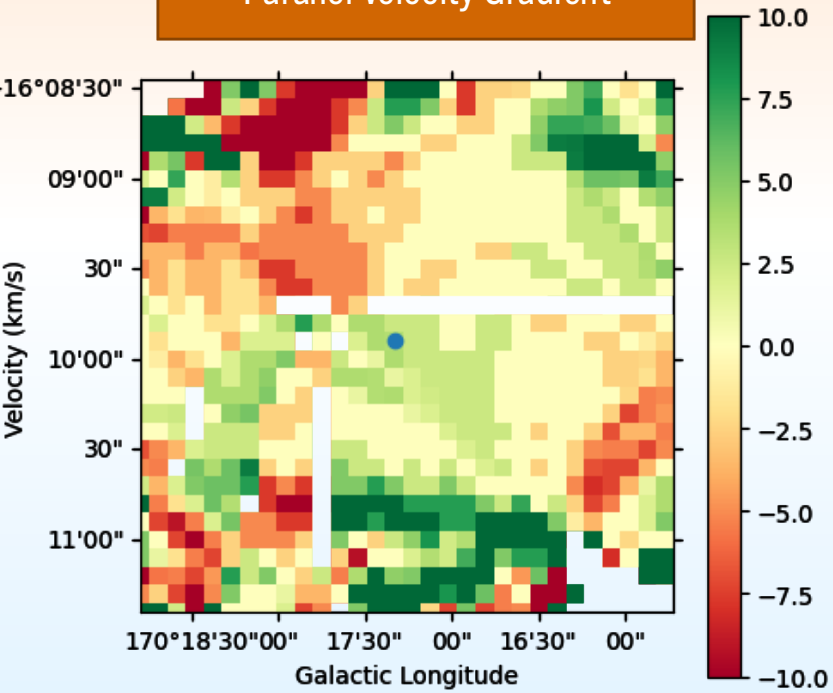
Distance Transform with Parallel Differential 1 Form



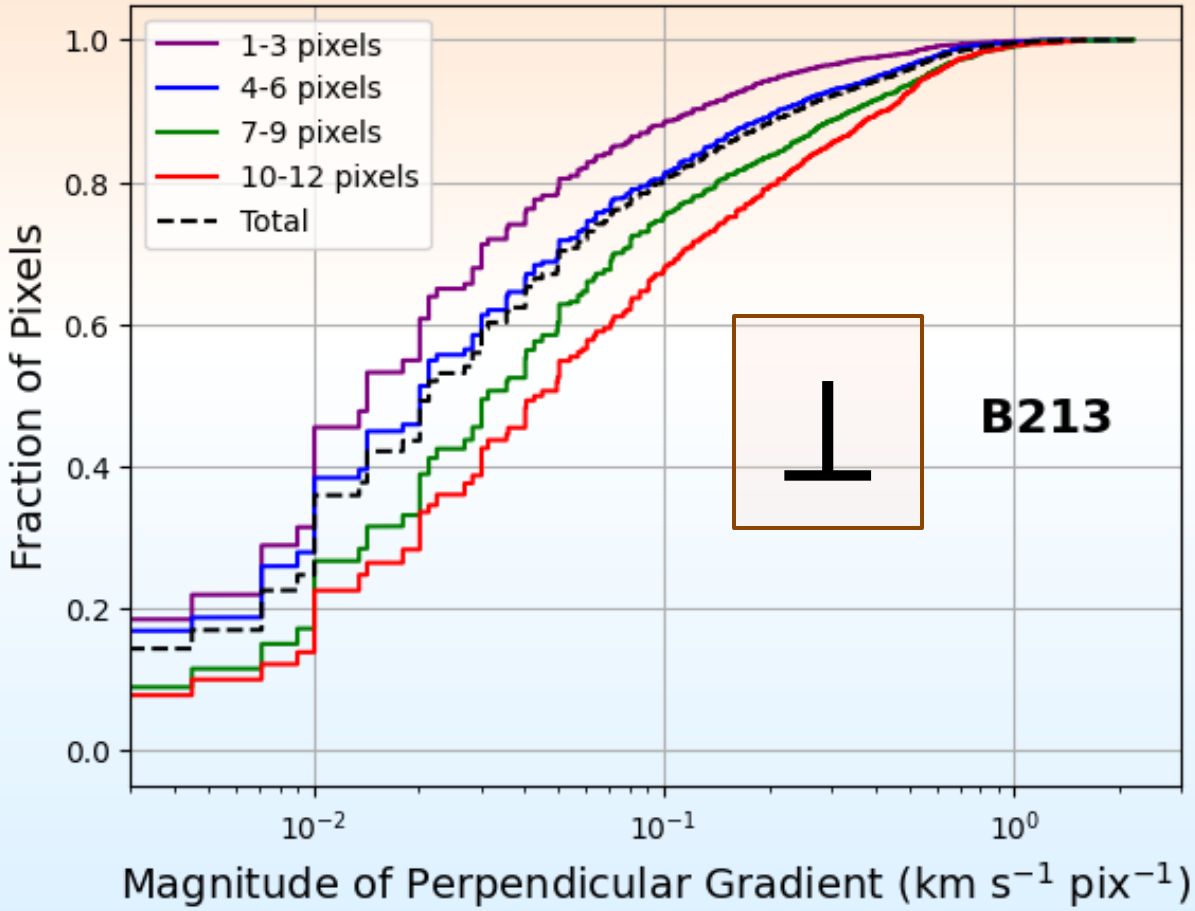
Maximum Likelihood Velocity with Velocity Gradient Vectors

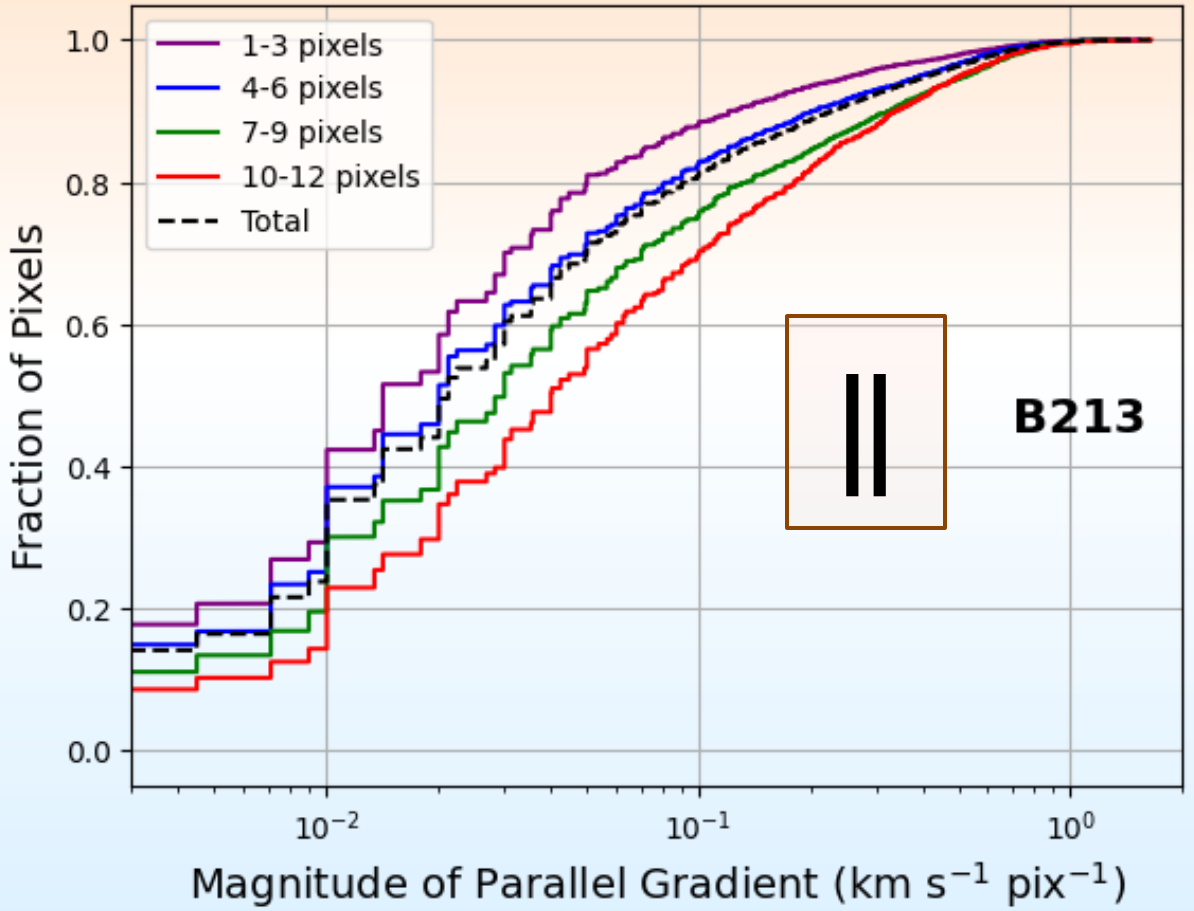


Parallel Velocity Gradient



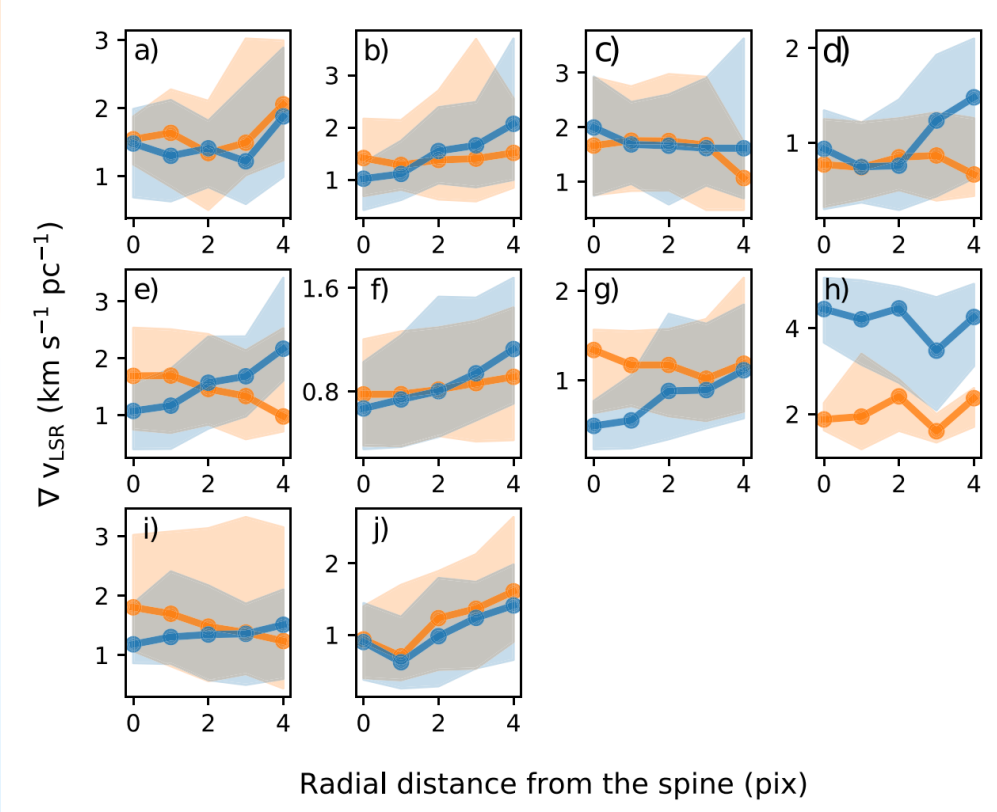
Gradient as a Function of Distance





Comparing to Literature

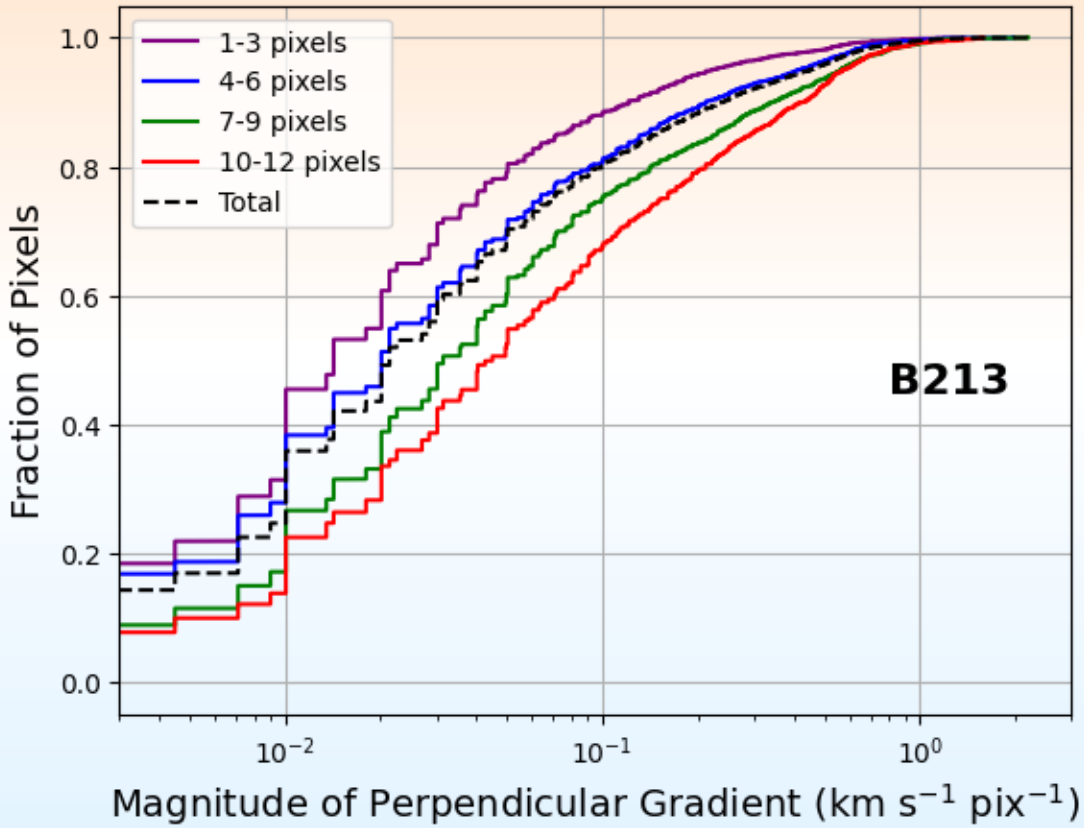
- Perseus is at a distance twice as far as Taurus
  - Same beam size
  - Blurs out some features
- Dust filaments trace both high density and diffuse environments
  - Ammonia traces intermediate and high-density gas
    - Dust is sensitive to wider range of densities and structures
  - Using Bayesian statistics, now able to probe more diffuse ammonia gas
  - Next: Classify dust spines into core containing and feeder spines



Velocity gradients for Perseus molecular cloud (Chen+20)

Conclusions

- Ammonia inversion transitions used to map intermediate and high-density gas in Taurus
  - Complex hyperfine spectral structure and velocity structure of cloud encourage use of Bayesian analysis
- Use differential geometry to measure gradients of gas in parallel and perpendicular directions to spines
  - Velocity gradients larger further from spines in both directions
- Next: Use simple vector models to replicate results



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