# Billowing Hydrogen

## Simulating Turbulence in HII Regions

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# Outline

# HII Regions



Image of an HII region, the Trifid Nebula.
Nebula image: M20 — Trifid Nebula HII Region in Sagittarius 6° from Kaus Borealis (top of the teapot) taken by R Jay GaBany

▶ What is an HII Region?

▶ Physical Traits

  ▶ Powered by hot stars
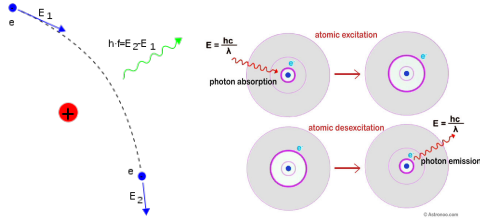
  ▶ Can range from AU to parsecs

  ▶ A type of nebulae

Image 1: Process in which the free-free continuum is created.
Image 2: Process in which radio recombination lines are created.
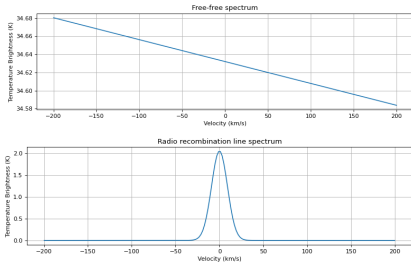Free-free emission: https://en.wikipedia.org/wiki/Bremsstrahlung#/media/File:Bremsstrahlung.svg

Radio recombination lines: https://astronoo.com/images/lumiere/absorption-et-emission.jpg

- ▶ A way we observe HII regions
- ▶ Why use radio?
- ▶ Free-free continuum
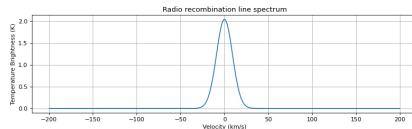- ▶ Radio recombination lines (RRLs)

Spectra of free-free emission and a radio recombination line with respect to doppler shift velocity.

- ▶ A way we observe HII regions
- ▶ Why use radio?
- ▶ Free-free continuum
- ▶ Radio recombination lines (RRLs)

# Radio Imaging

- Multiple frequencies
- Doppler shift
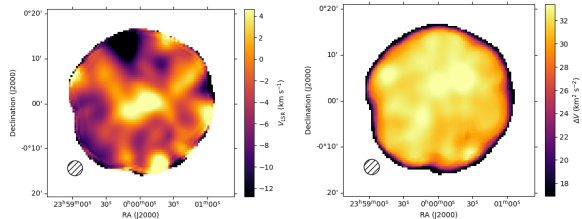- Velocity compared to Local Standard of Rest (VLSR)
- Velocity line width



Radio recombination line to discuss how velocity is mapped.

# Radio Imaging

- ▶ Multiple frequencies
- ▶ Doppler shift
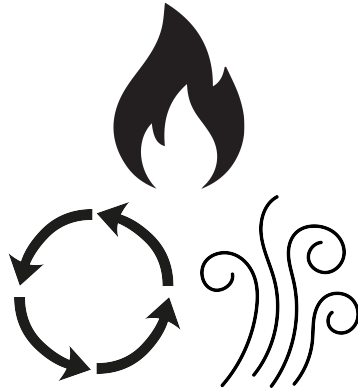- ▶ Velocity compared to Local Standard of Rest (VLSR)
- ▶ Velocity line width



First and second moment maps of an HII region.

- Thermal motion
- Bulk motion
  - Outflow
  - Expansion
  - Rotation
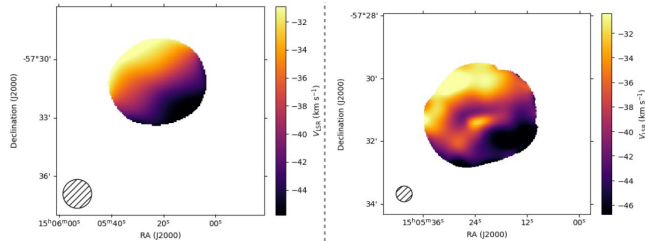- Turbulence

Fire: https://www.vecteezy.com/png/19787026-fire-icon-on-transparent-background
Cycle: https://www.vecteezy.com/png/18723264-roundabout-directional-arrow-sign-on-transparent-background

Wind: https://www.vecteezy.com/png/22183351-hand-drawn-doodle-vaporize-icon

## Motivations

▶ Previous work had shown what looked like rotation

▶ Later observations show a more complex story

▶ Can turbulence explain this behavior?



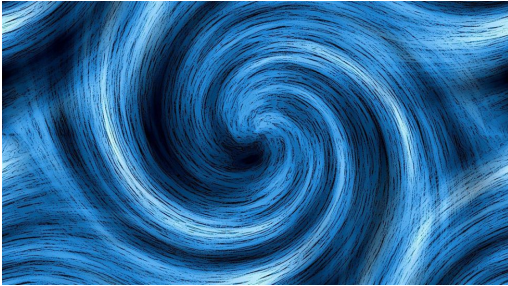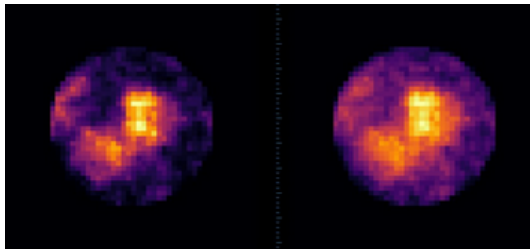Showing the how the same object can act differently based on the beam width.

Image attribution: https://www.advancedsciencenews.com/wp-content/uploads/2023/07/swirl-g52ac5d4ac_1280.jpg

▶ Hard to model

▶ Not well understood

▶ But can be predicted to a degree!

► Why not use existing software?
  ► Similar programs don't use RRLs
  ► Unique problem of density squared



Comparing optically thin tracers, one of density (right) and one of density squared (left).
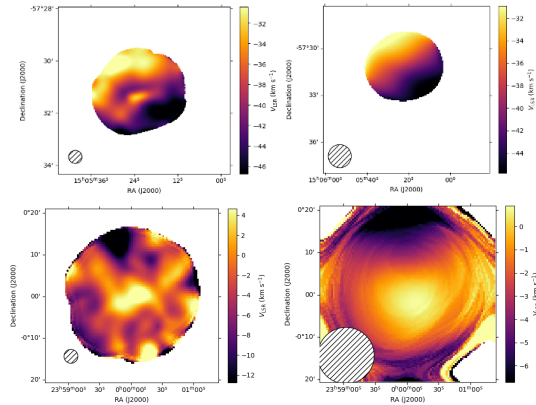
# Project Goals

- ▶ Simulate turbulence in HII regions
- ▶ Test different turbulence parameters
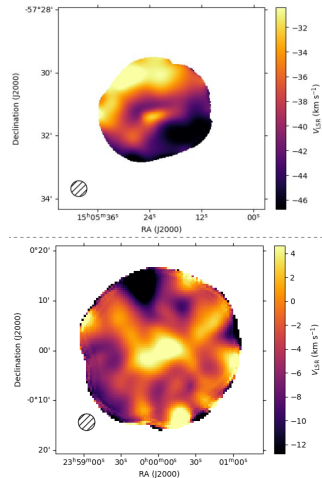- ▶ Compare to reality

# Results



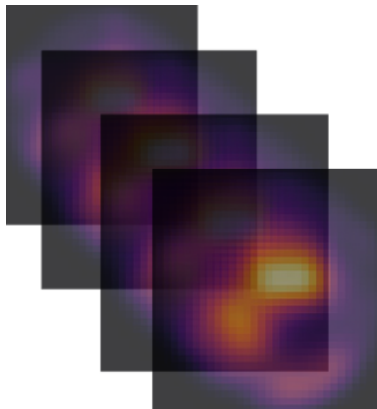Comparing the effects of a higher resolution on the first moment map.

- ▶ Similarity to reality
  - ▶ Turbulence looking like angular momentum
  - ▶ Similar velocity scales

- ▶ Comparing with more radio data
- ▶ Refining simulation
- ▶ Testing under various conditions

# Conclusion

▶ New data has discrepencies with rotation model

▶ Could turbulence explain HII region behavior?

▶ Tested with simulation

▶ Turbulence is a potential cause for what we see
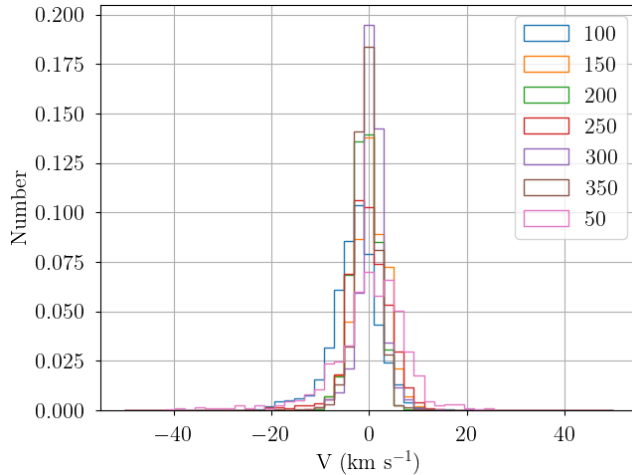
# Thank you!
# Any questions?

## Pipeline

- ▶ Generate and truncate turbustat data
  - ▶ Creates cubes to represent density and velocity in 3d space
- ▶ Calculate emission measure for each physical "voxel" of HII region
- ▶ Calculate RRL strength for each pixel
  - ▶ Gaussian treating velocity cube as line centers
  - ▶ Add free-free emission afterwards

# Resolution Dependance



Demonstrating that the resolution dependance is negligible past 300 pixels.