Visualizing Numerical Simulations of Magnetized Stellar Winds and the Synthesis of Observational Diagnostics

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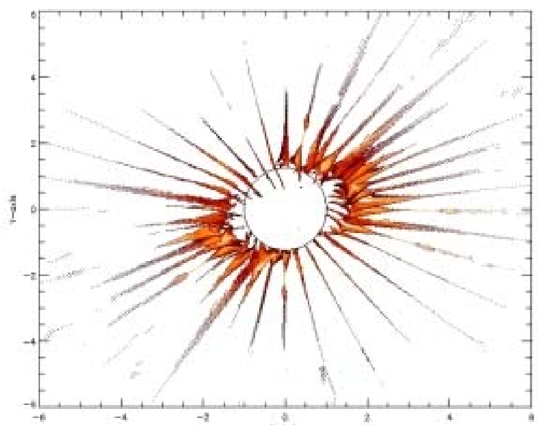
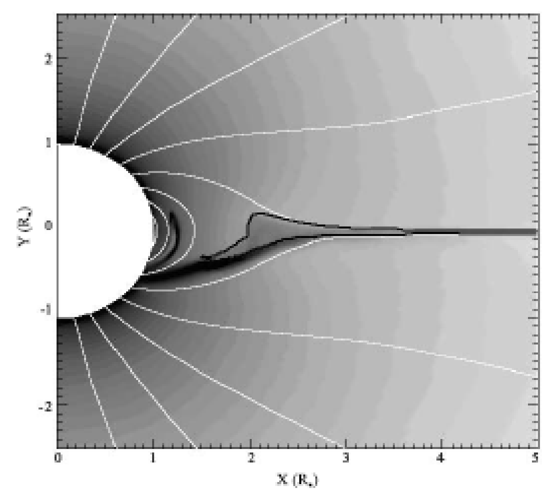


We are working with a group doing numerical simulations of magnetized stellar winds, led by Stan Owocki and Asif ud-Doula here at the University of Delaware.

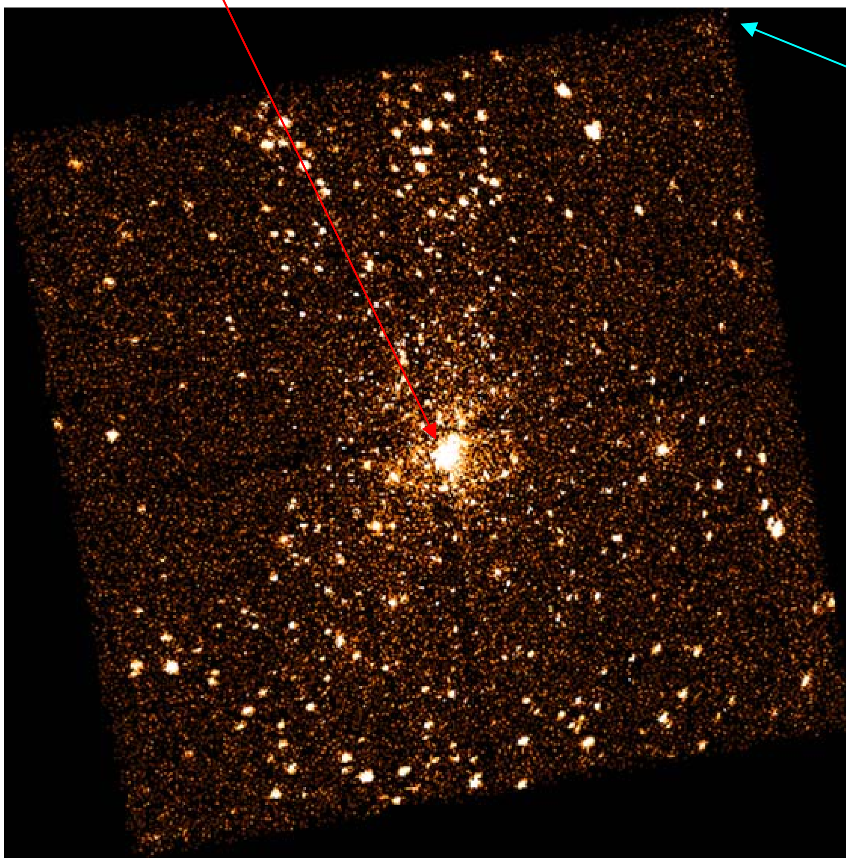
Basic scientific question: how do the combined effects of a large scale **magnetic field** and rapid **stellar rotation** influence the dynamics of the stellar winds of young, hot, magnetized stars. Can such a *Magnetically Channeled Wind Shock* (MCWS) model explain:

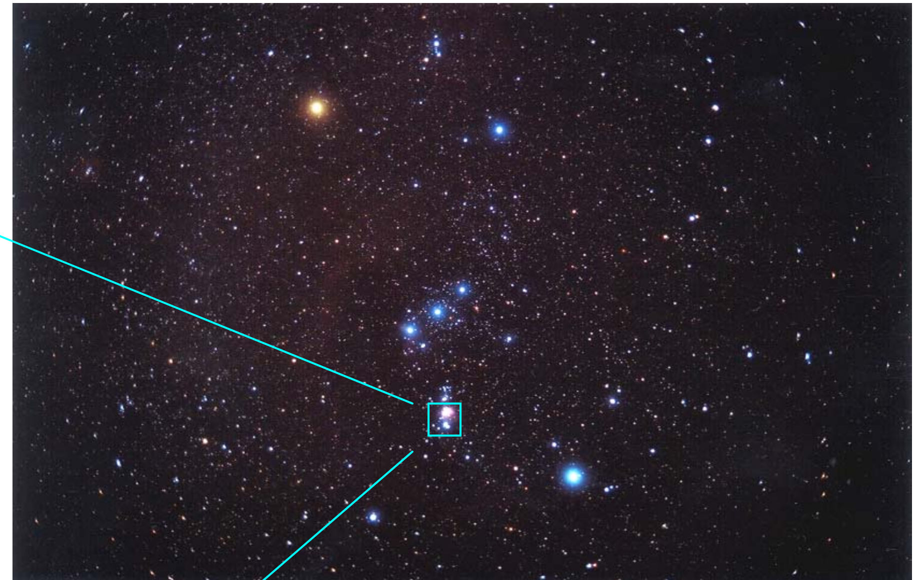
- The strong and hard (i.e. high energy) x-ray emission seen from this class of stars?
- Strong x-ray flaring seen in some of these stars?
- The rotational modulation of x-rays and optical light?
- The signatures of infalling material seen in H-alpha (optical) spectra?



About ten years ago, it was proposed that this MCWS model can apply to the star that illuminates the Orion nebula *theta1 Ori C*.

theta1 Ori C is very bright in this x-ray telescope image

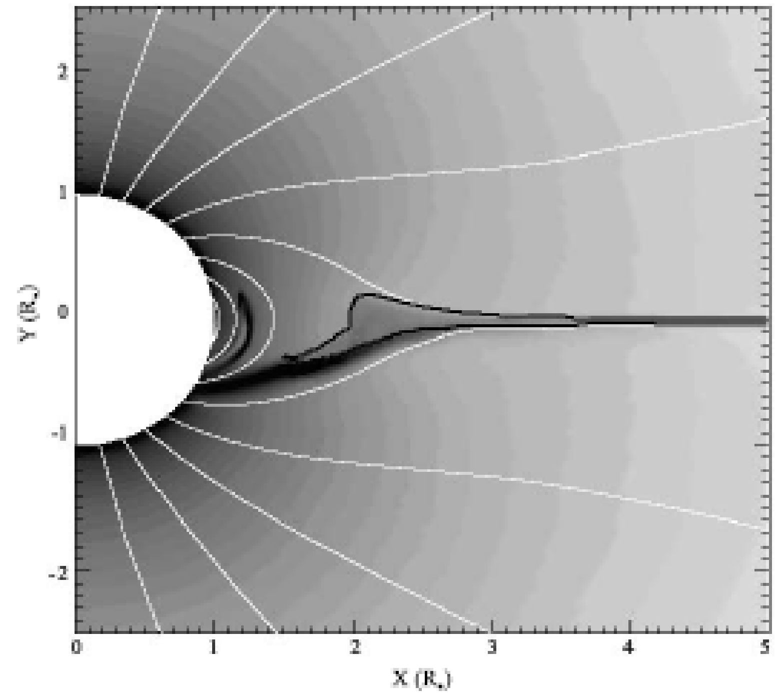




Asif ud-Doula and Stan Owocki here at U. Delaware (Bartol) do numerical simulations of the MCWS model, in which the magnetic field structure and the stellar wind flow is solved time-dependently and self-consistently.

These simulations produce time-dependent physical parameter values (density, temperature, magnetic field, velocity) on a three-dimensional spatial grid.

We want to
(a) visualize the simulations;
(b) characterize the overall properties (e.g. monitor rate of material falling back onto the star);
(c) synthesize observables for comparison with data.



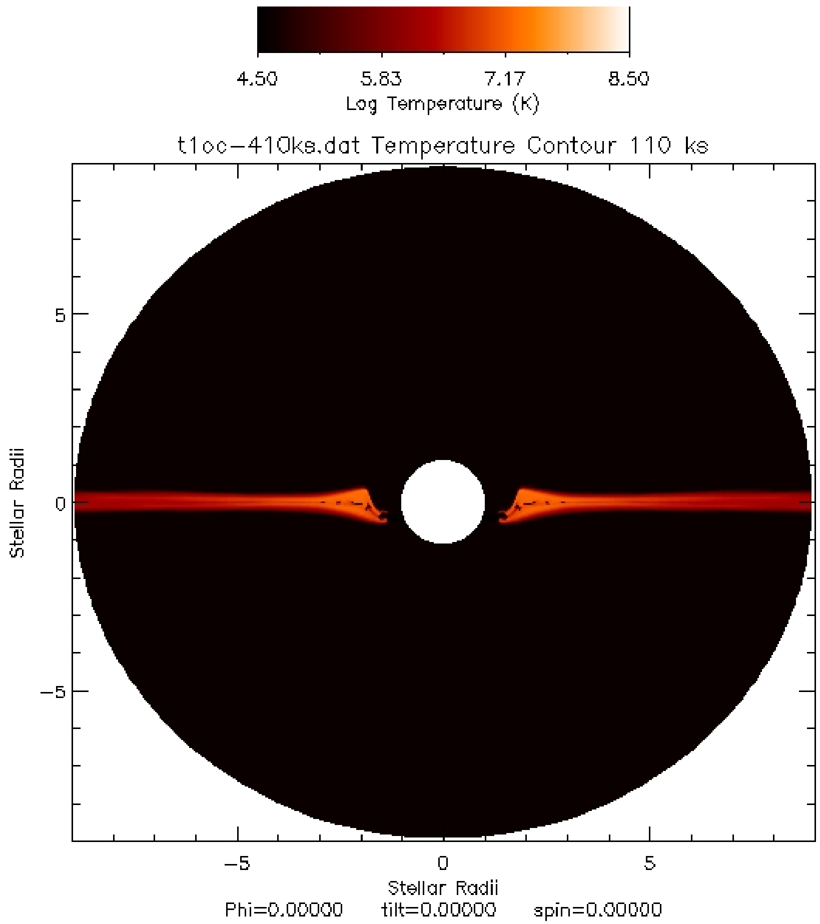
A snapshot of the density (grayscale) and magnetic field lines (white lines) from Asif's simulations.

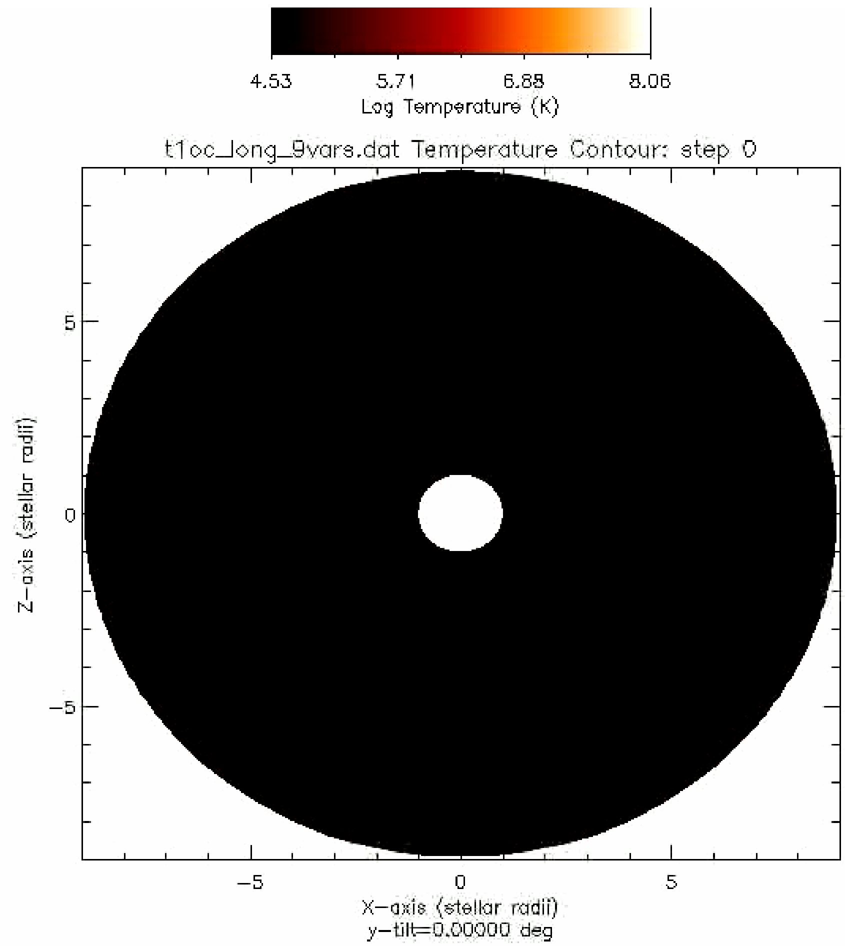
Steve is a dual computer science - astronomy major

His goal is to produce a well tested and documented code with an intuitive GUI – a package that other members of the group, and future students, can use, even after Steve graduates.

Steve working in the astronomy lab this past summer.

Visualizations



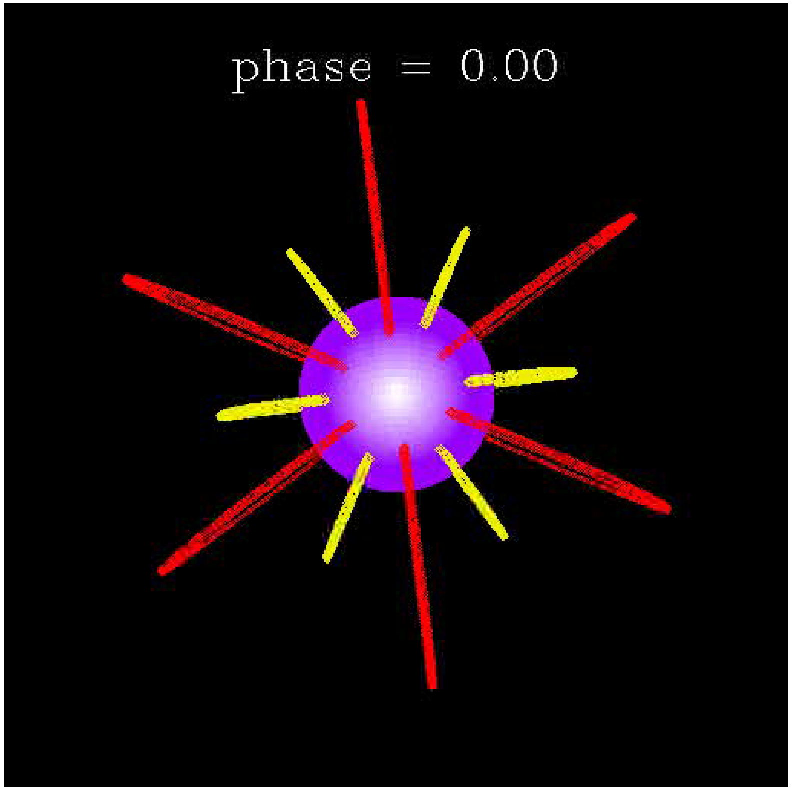


link to movie

Here's a **snapshot** (on the **left**) showing high-temperature material in the magnetic equator. The **movie** this snapshot was taken from is on the **right**.

Because the magnetic field is tilted with respect to the rotation axis, as the star rotates, we get different views of its magnetosphere.

Visualization of rotating magnetic field geometry.



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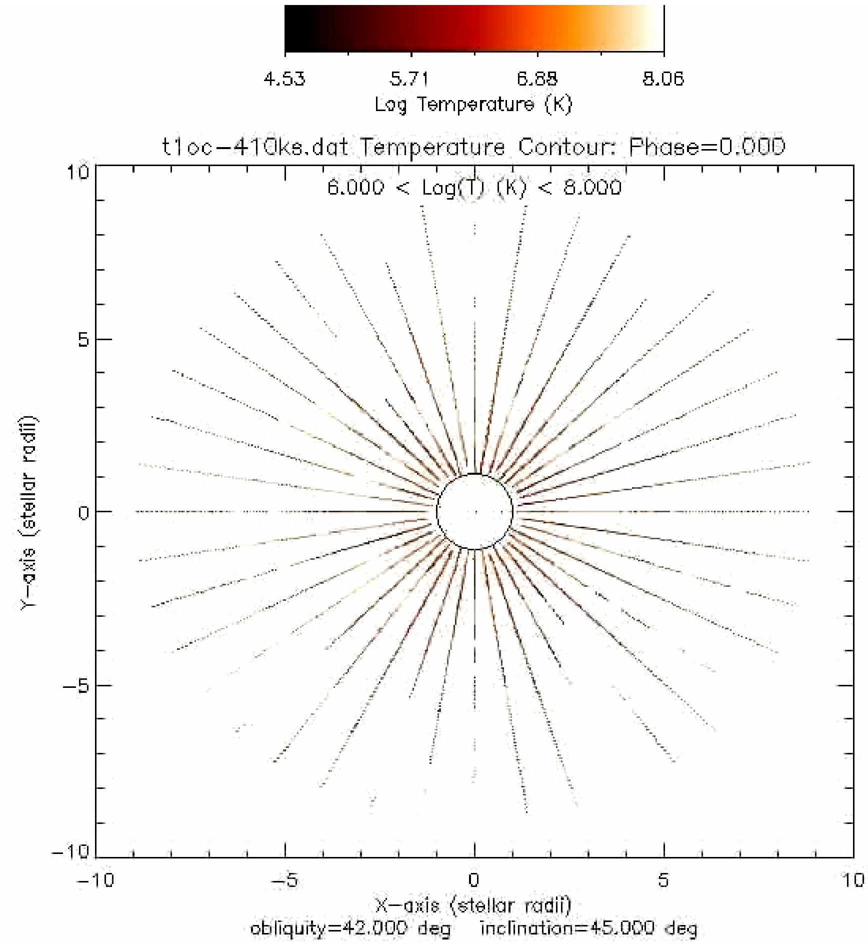
One of our simulations, emphasizing the computational grid, also rotating.



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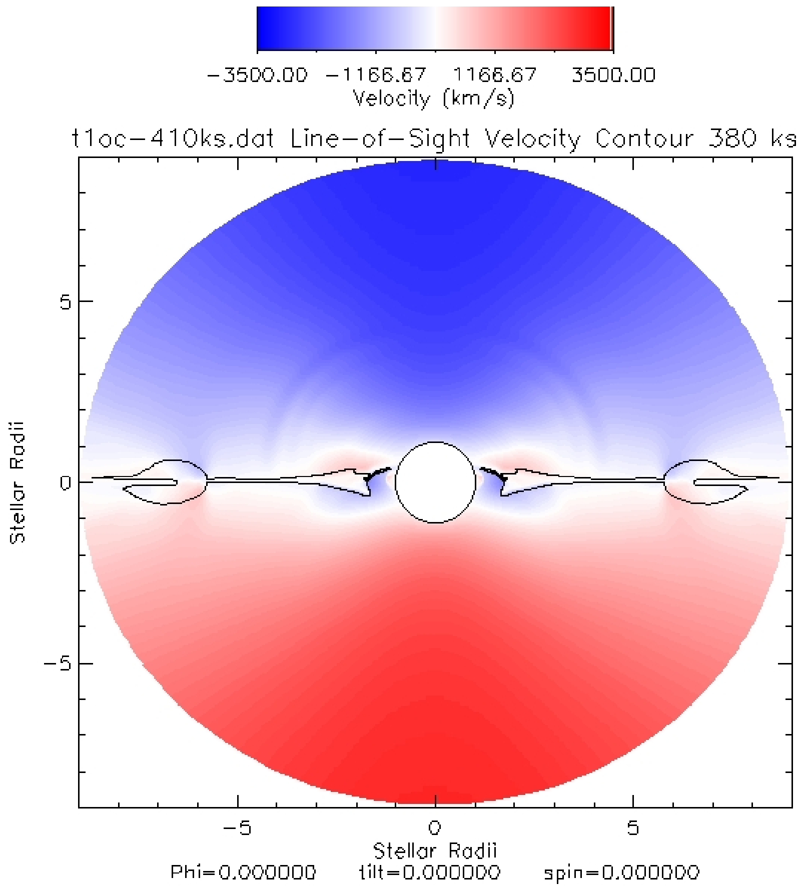
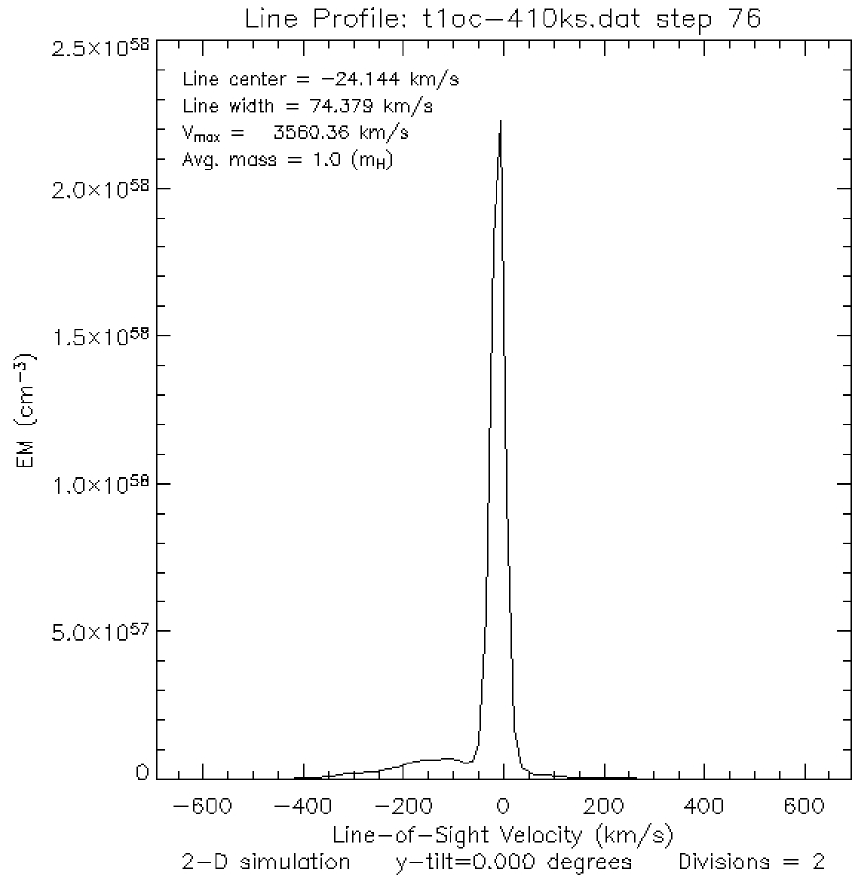
Taking the Simulations Further

- While the original 2D simulations are useful, we need specific diagnostics that ultimately can be compared with data
  - Line profiles
  - Light curves
  - Rotation phase dependent information
- How do I accomplish this?
  - Take existing data (density, velocity vectors) and calculate synthesized diagnostics (emission measure, line-of-sight velocity) - include effects like occultation of emitting material by the star, and spectral line broadening
  - Create quasi-3D models from 2D slices
  - Rotate these models according to the star's rotation to model phase-dependence - i.e. the user can control the viewing angle for synthesized observables.

Line-of-sight Velocity



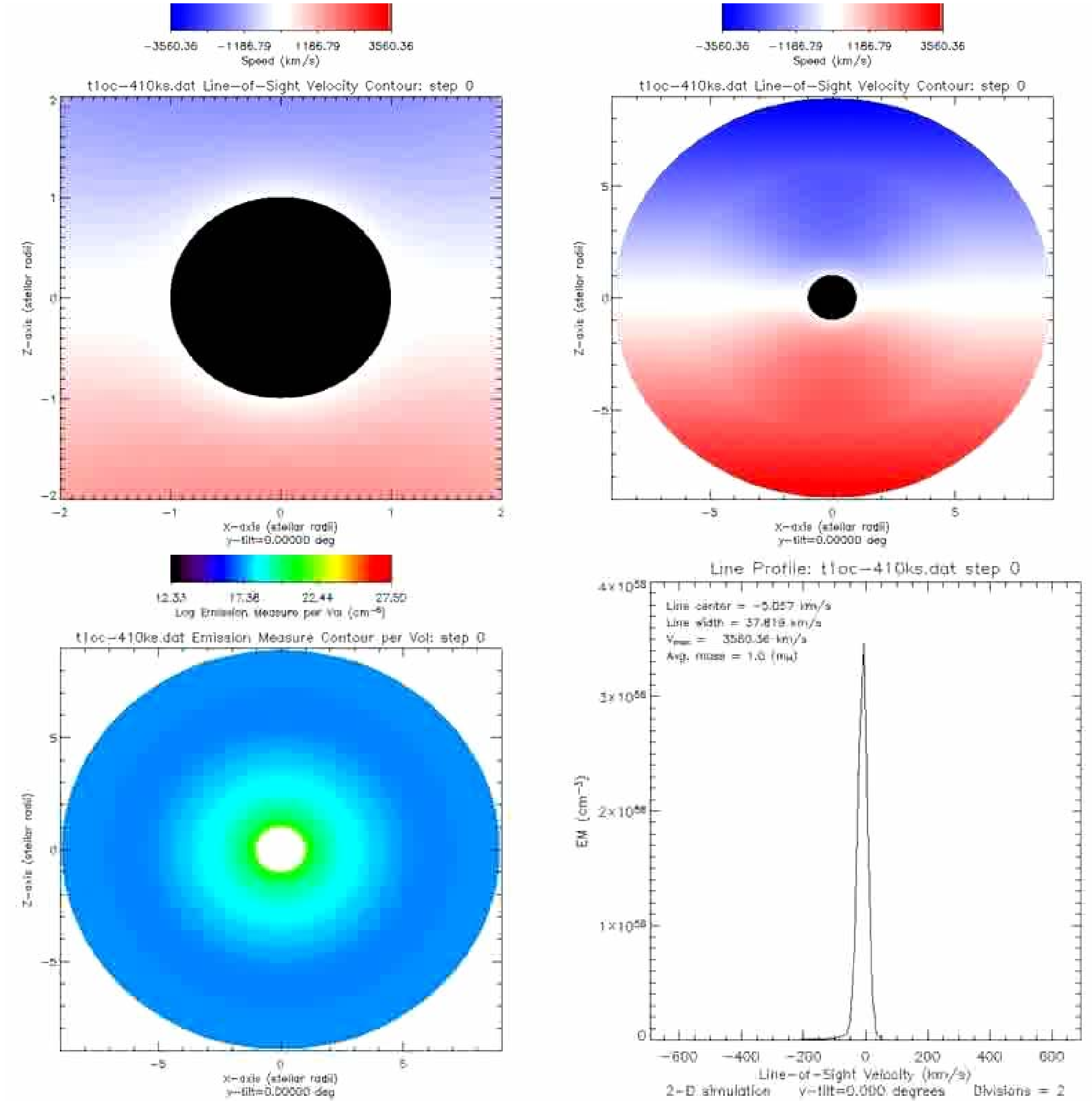
Contour plot (line-of-sight velocities for an observer at the *top* of the frame)



Spectral line profile

At each point on the grid, the material has a different *Doppler shift*, which then affects the overall spectral line profile

Line-of-sight Velocity Movie



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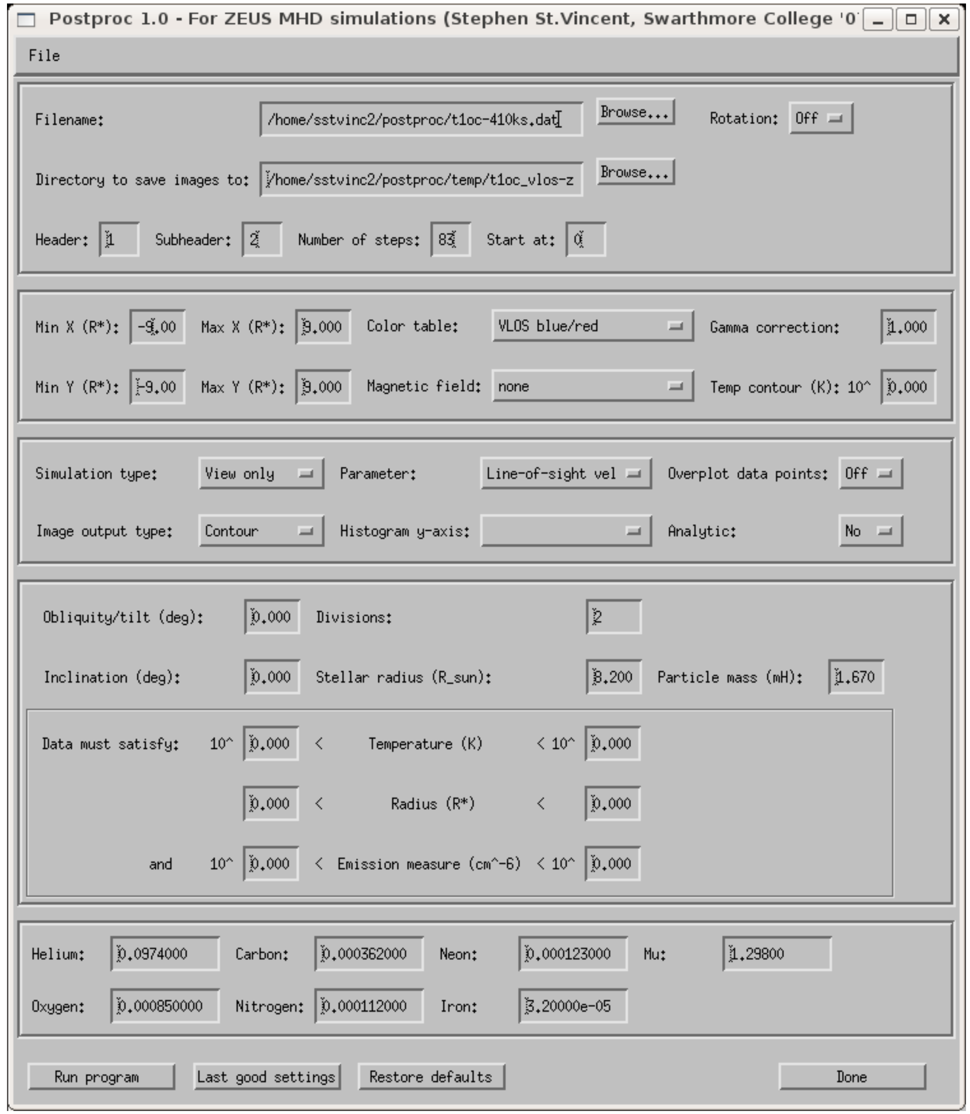
The Graphical User Interface (GUI)

- Entering all parameters at command line is painful
- GUI can save/restore settings to avoid frequent re-entering of parameters
- Also checks validity of parameters ($min_x < max_x$, etc)
- Hopefully, someone else can run the code with relative ease using the GUI



Website as a Paradigm for Research Organization

- For the past two years, I've maintained a personal research website to organize my thoughts, ideas, results, and future plans.
    - http://www.sccs.swarthmore.edu/users/07/sstvinc2/research
- Can easily refer to work I've previously done (like a lab notebook)
- Prof. Cohen can check my progress; so can off-site collaborators
- I can access my notes from anywhere
- Handy for showing results quickly

Application Documentation

- Future usability is a major concern – someone besides myself needs to be able to run my code
- Three major steps to achieving this:
    - Well-commented, modular code
    - GUI
    - Documentation: http://astro.swarthmore.edu/~sstvinc2/manual.pdf
- Documentation acts as a user's manual for my program
- Also includes any important equations and concepts that went into calculations or overall design

Conclusions

- Undergraduates - especially with programming experience and a C.S. background - can make useful contributions to large-scale scientific computing projects
- Organization and usability are key if a students' scientific productivity is to be more than transient
- Connecting numerical simulations to observations/experiment provides an opportunity for students to learn about several aspects of scientific research
- The MCWS model looks very promising for explaining the observed properties of magnetized hot stars
- Steve will be presenting his research results at the American Astronomical Society meeting in Seattle in January