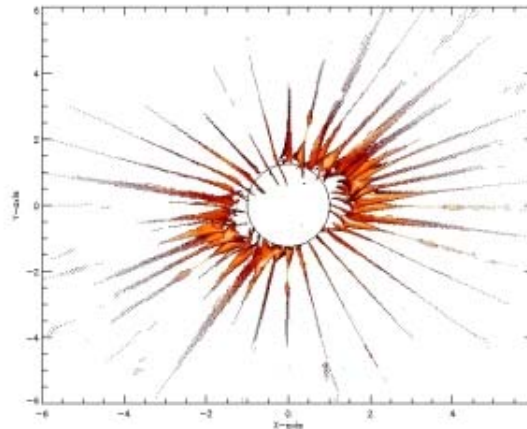


Visualizing Numerical Simulations of Magnetized Stellar Winds and the Synthesis of Observational Diagnostics

Stephen St.Vincent (Swarthmore, class of 2007)

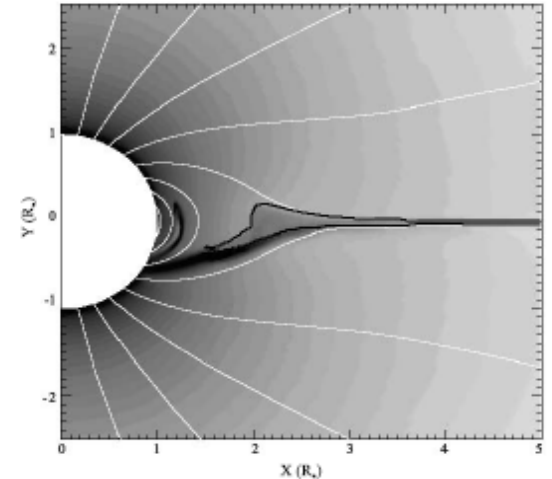
Advisor: Prof. David Cohen



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.

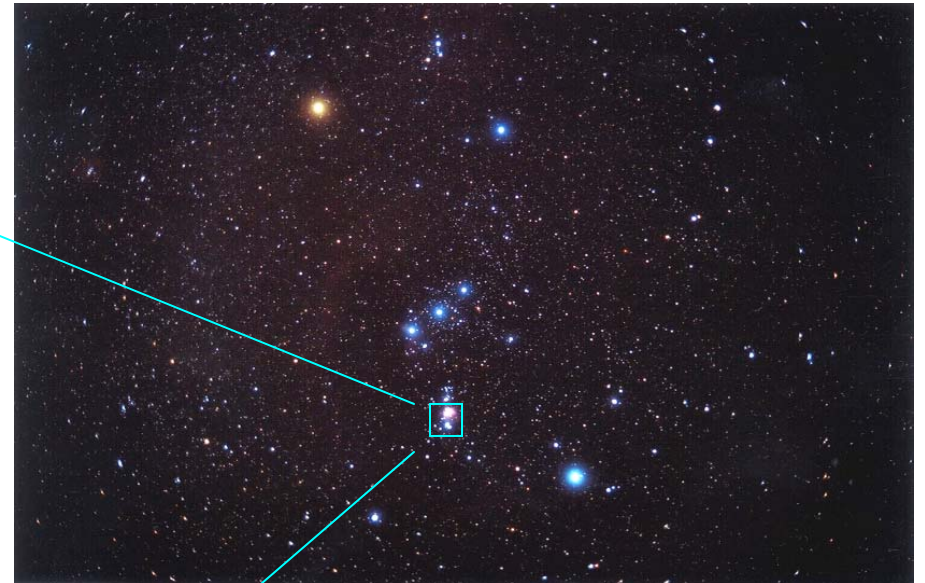
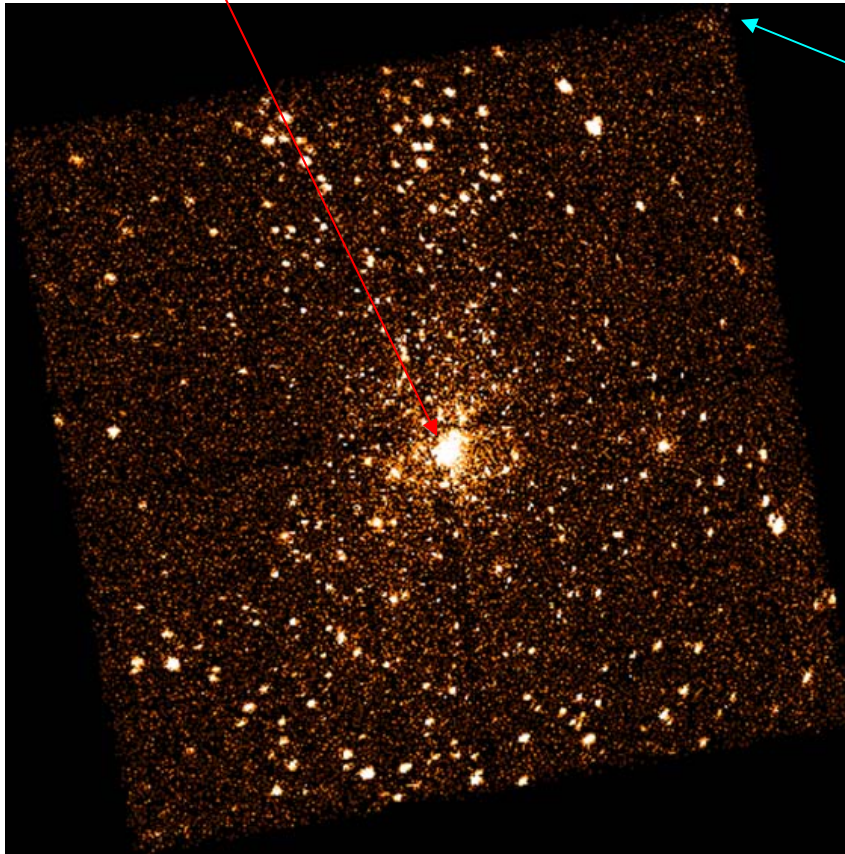
Basic scientific question: how do the combined effects of a large scale **magnetic field** and rapid **stellar rotation** influence the dynamics of the stellar winds of young, hot, magnetized stars. Can such a *Magnetically Channeled Wind Shock* (MCWS) model explain:

- 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

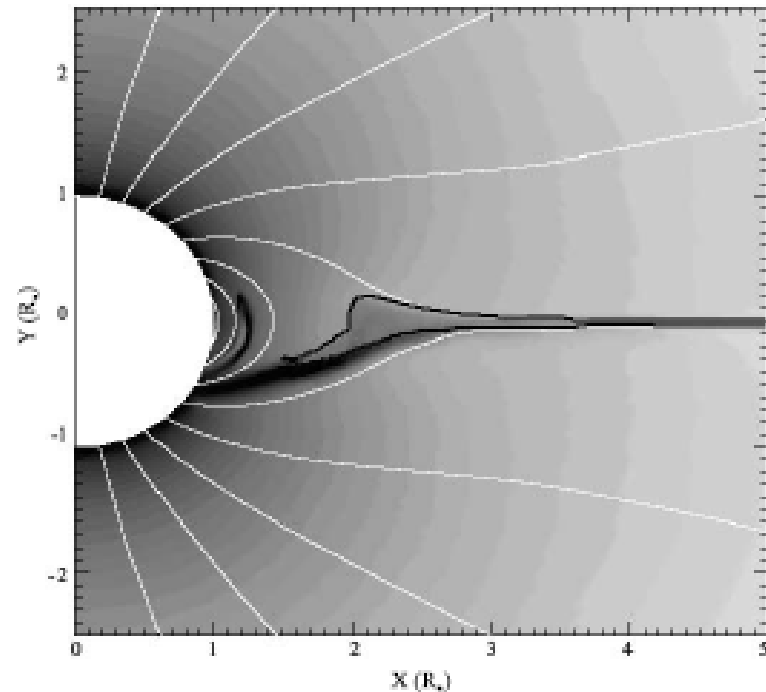


Asif ud-Doula and Stan Owocki here at U. Delaware (Bartol) do numerical simulations of the MCWS model, in which the magnetic field structure and the stellar wind flow is solved time-dependently and self-consistently.

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.

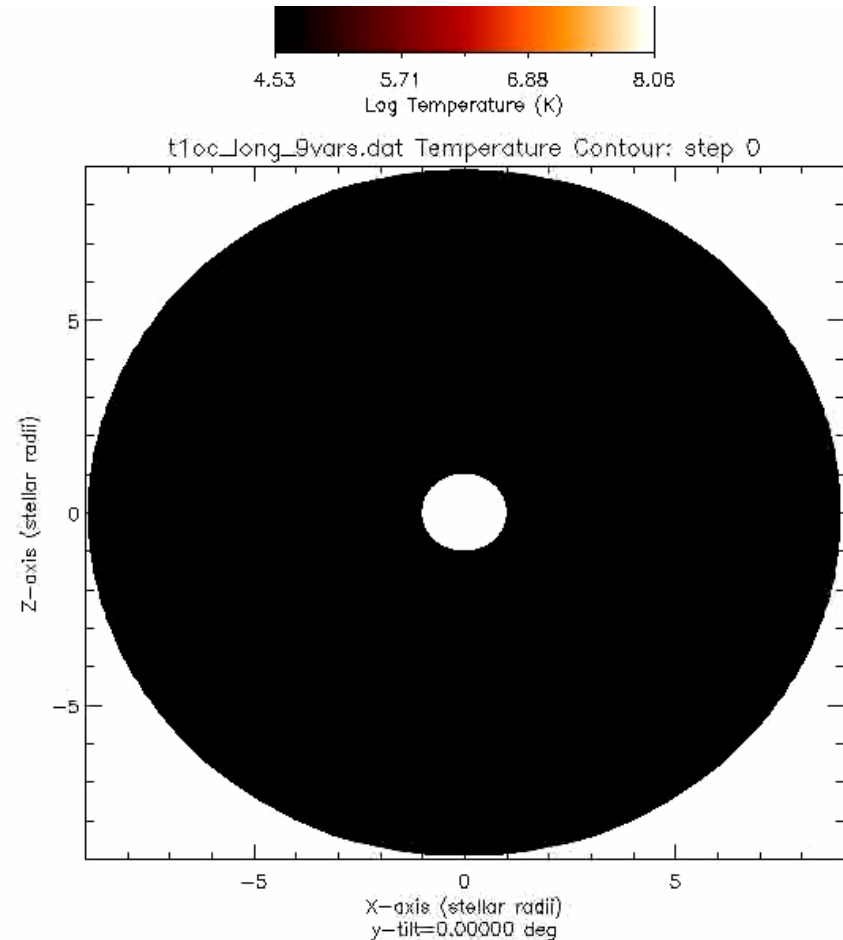
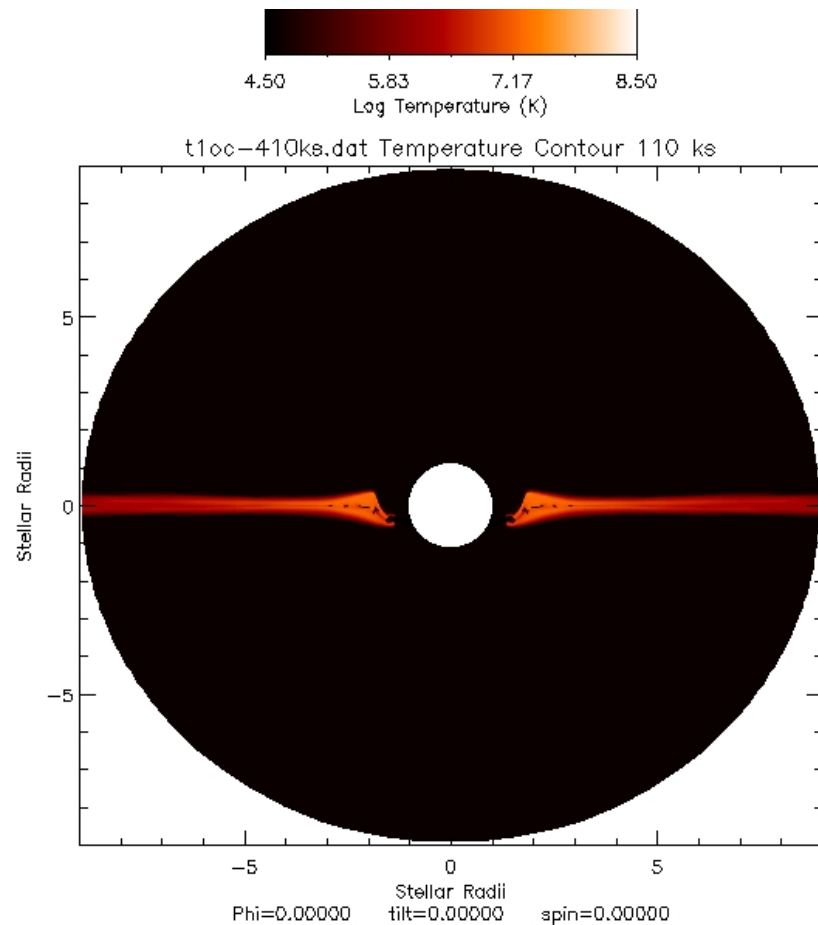
Steve is a dual computer science - astronomy major

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

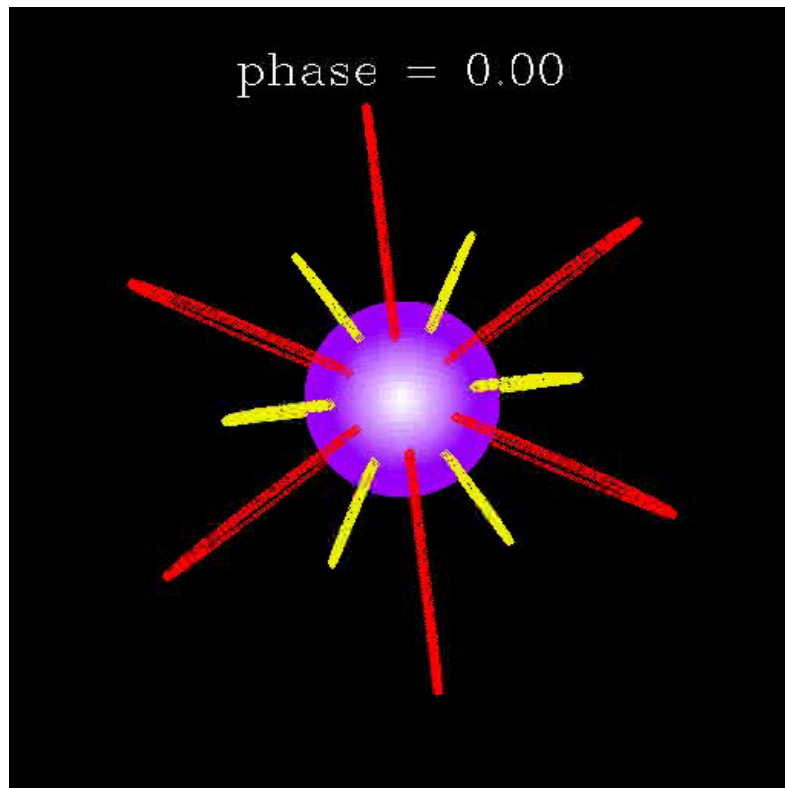


[link to movie](#)

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**.

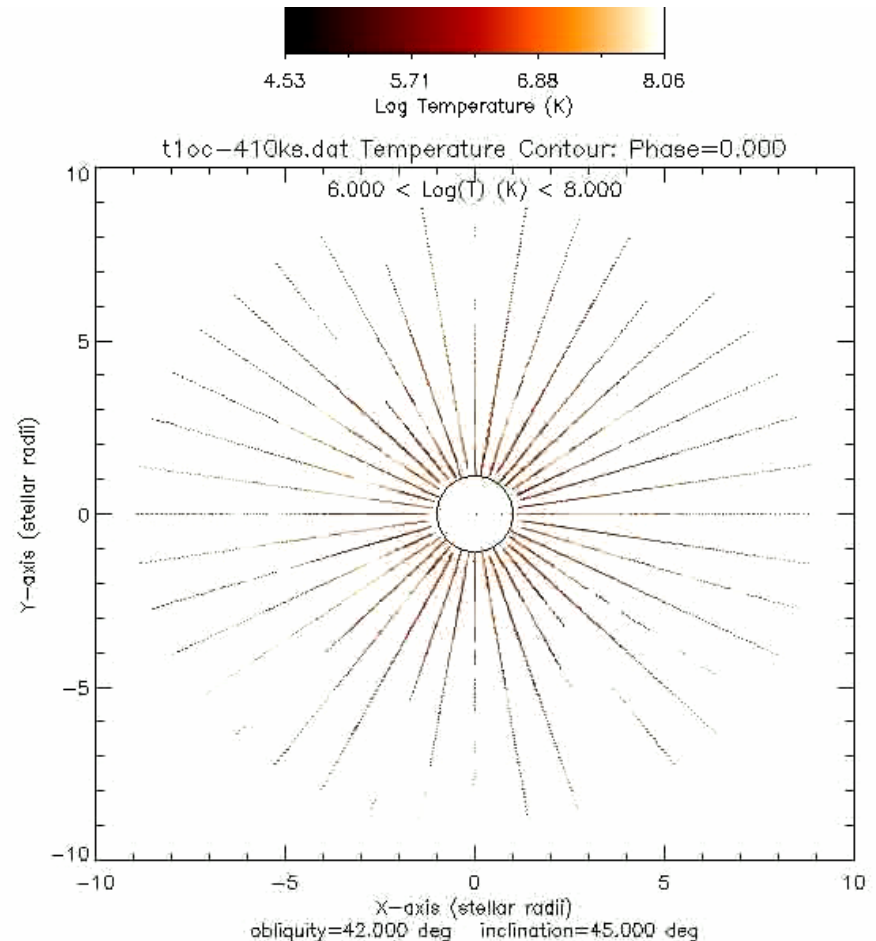
Because the magnetic field is tilted with respect to the rotation axis, as the star rotates, we get different views of its magnetosphere.

Visualization of rotating magnetic field geometry.



[*link to movie*](#)

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

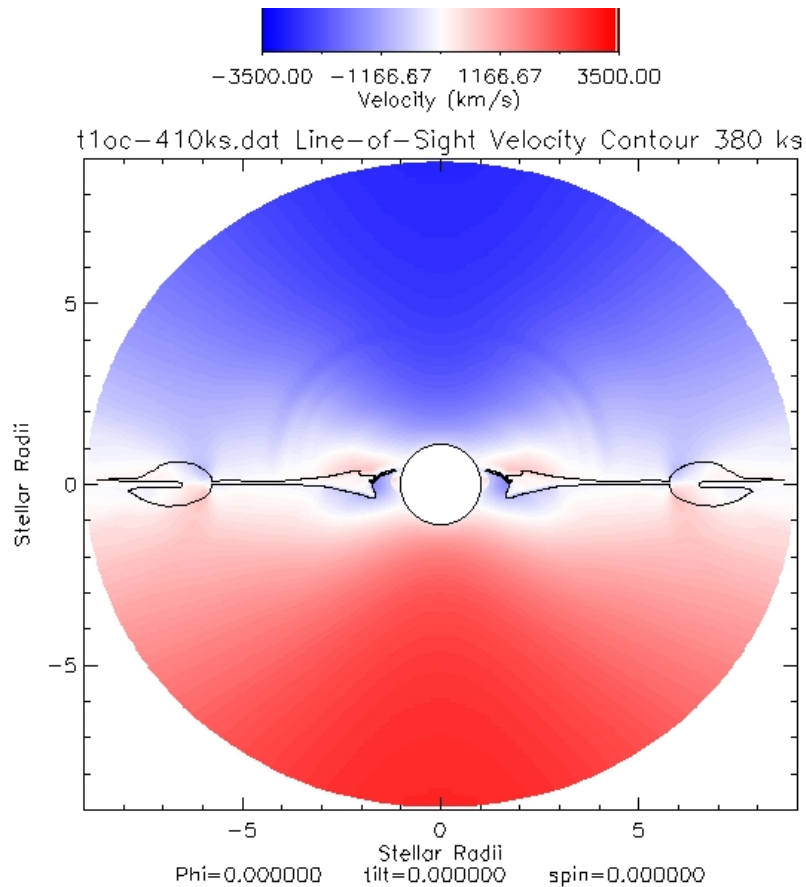


[*link to movie*](#)

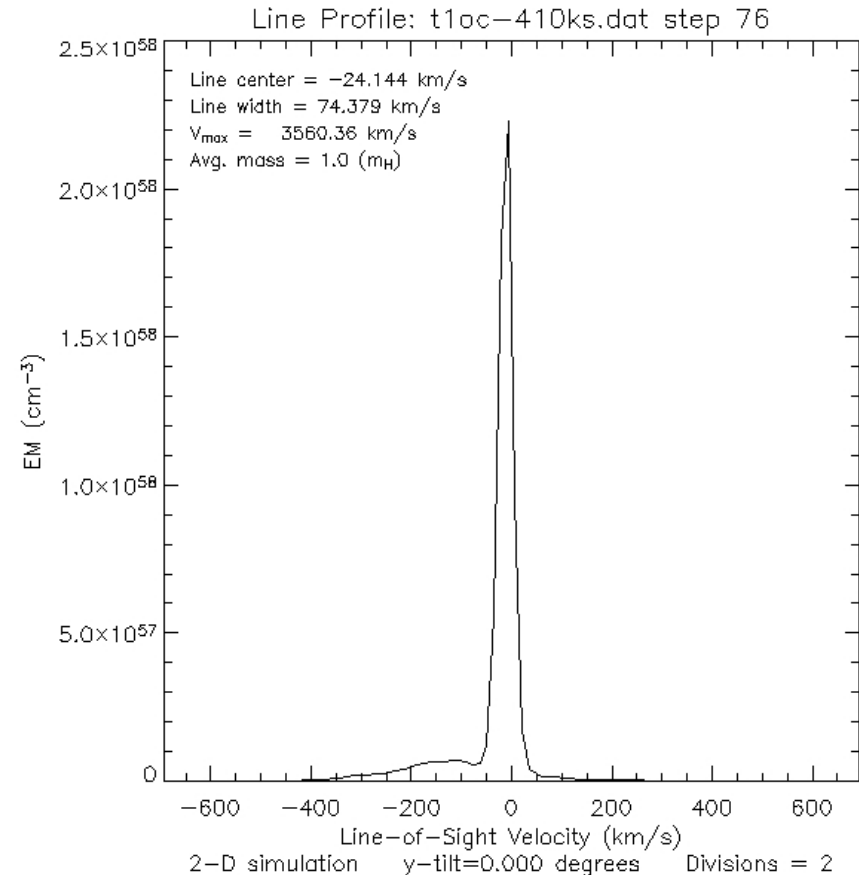
Taking the Simulations Further

- 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



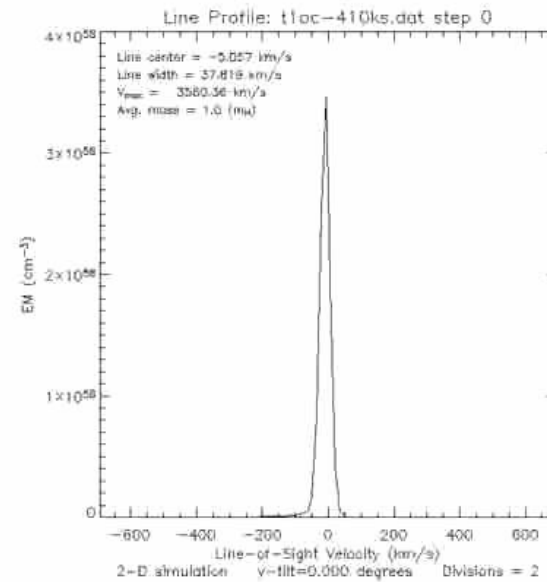
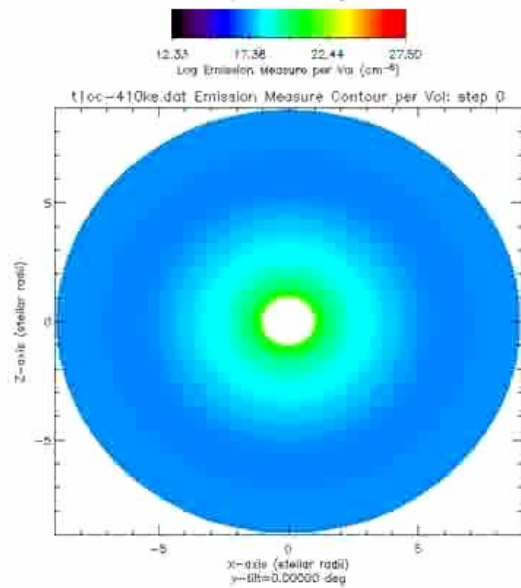
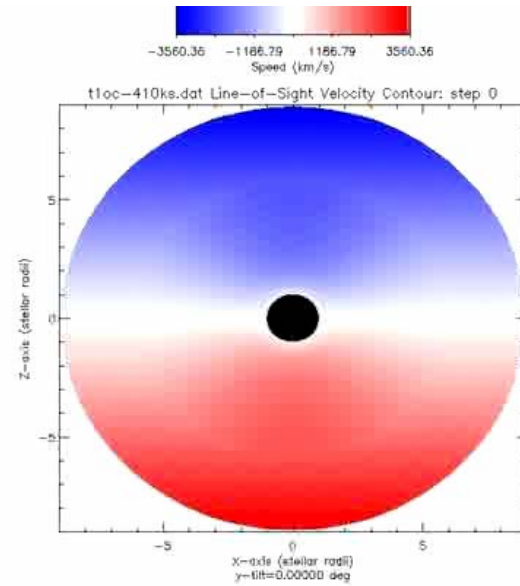
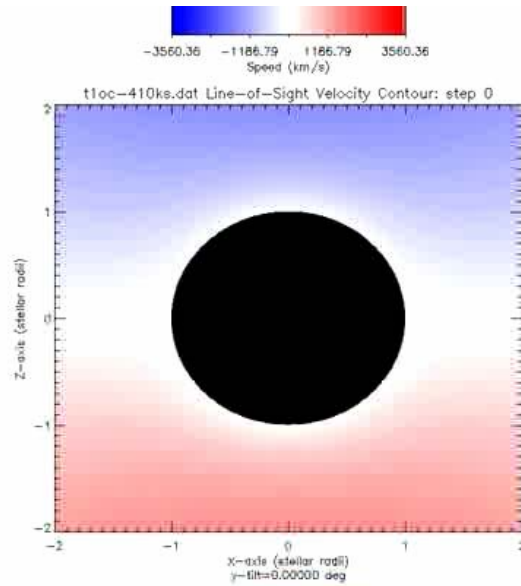
Contour plot (line-of-sight velocities for an observer at the top of the frame)



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



[link to movie](#)

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

The screenshot shows the 'Postproc 1.0 - For ZEUS MHD simulations' window. The interface is organized into several sections:

- File:** Includes fields for 'Filename:' (set to /home/sstvinc2/postproc/tloc-410ks.dat), 'Directory to save images to:' (set to /home/sstvinc2/postproc/temp/tloc_vlos-z), 'Header:' (1), 'Subheader:' (2), 'Number of steps:' (83), and 'Start at:' (0). There are 'Browse...' buttons for the filename and directory fields, and a 'Rotation:' dropdown set to 'Off'.
- Axis and Color Settings:** Includes 'Min X (R*):' (-9.00), 'Max X (R*):' (9.00), 'Color table:' (VLOS blue/red), 'Gamma correction:' (1.000), 'Min Y (R*):' (-9.00), 'Max Y (R*):' (9.00), 'Magnetic field:' (none), and 'Temp contour (K):' (10^0.000).
- Simulation and Output:** Includes 'Simulation type:' (View only), 'Parameter:' (Line-of-sight vel), 'Overplot data points:' (Off), 'Image output type:' (Contour), 'Histogram y-axis:' (empty), and 'Analytic:' (No).
- Geometry and Physical Parameters:** Includes 'Obliquity/tilt (deg):' (0.000), 'Divisions:' (2), 'Inclination (deg):' (0.000), 'Stellar radius (R_sun):' (8.200), and 'Particle mass (mH):' (1.670).
- Data Constraints:** A section titled 'Data must satisfy:' with four constraints:
 - $10^0 0.000 < \text{Temperature (K)} < 10^0 0.000$
 - $0.000 < \text{Radius (R}^*) < 0.000$
 - and $10^0 0.000 < \text{Emission measure (cm}^{-6}) < 10^0 0.000$
- Chemical Composition:** Includes fields for 'Helium:' (0.0974000), 'Carbon:' (0.000362000), 'Neon:' (0.000123000), 'Mu:' (1.29800), 'Oxygen:' (0.000850000), 'Nitrogen:' (0.000112000), and 'Iron:' (3.20000e-05).
- Buttons:** 'Run program', 'Last good settings', 'Restore defaults', and 'Done'.

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/sstvnc2/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