Multidimensional Diffusive Shock Acceleration in Winds from Massive Stars

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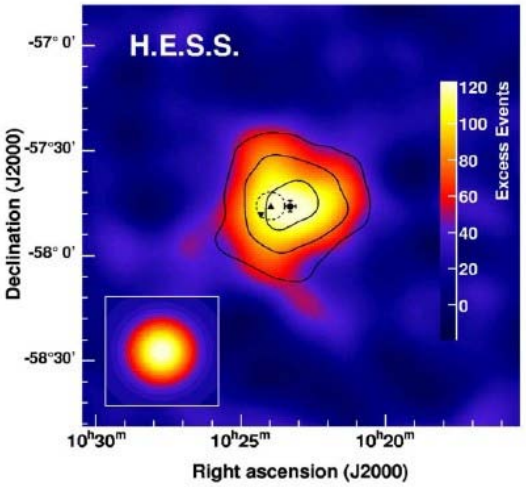
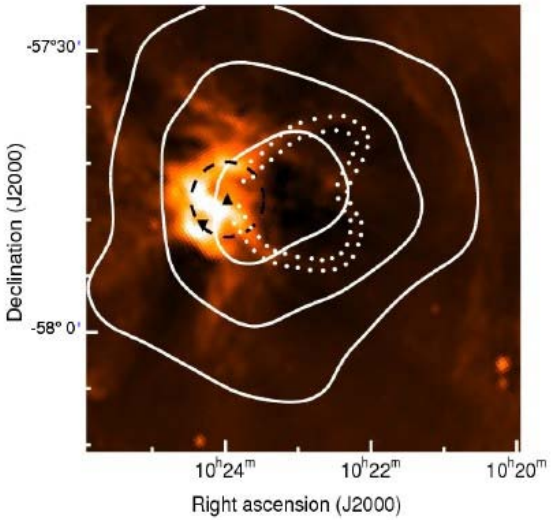
Outline

- Background
- Numerical Method
- Simulation Setup
- Results
- Summary

Background

- Non-thermal Emitting WR and O-Stars
  - Radio: About a quarter of all WR and O-stars
  - X-ray: Thought to be a few from WR Stars
  - TeV Gamma-Ray: Seen in some young star clusters and single WR Stars

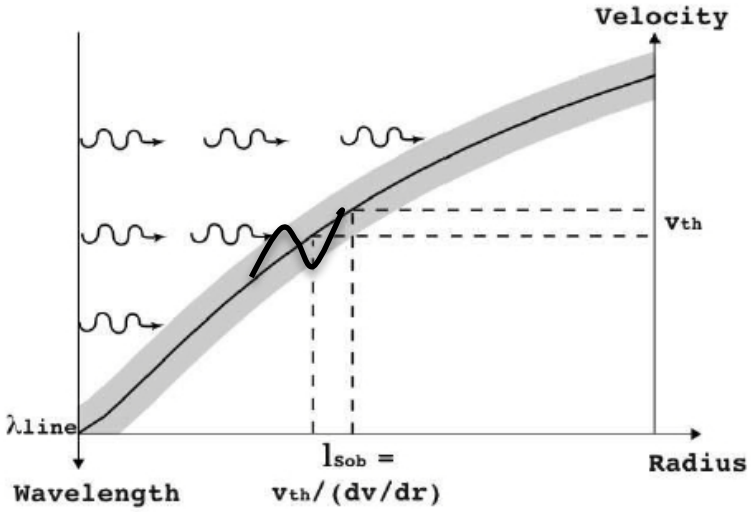


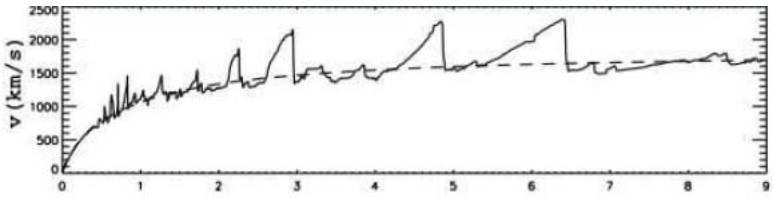


Credit: HESS page on Westerlund 2

Model

- Diffusive Shock Acceleration:
  - Internal Wind Shocks
    - Shocks caused by Line Driving Instability
  - Colliding Wind Binary
- Current Status
  - Dougherty & Williams (2000): Non-thermal Radio emitting WR Stars are most likely Binaries with Colliding Winds
  - Van Loo (2005, 2006): 1-D Hydro Simulations of O-stars indicate that non-thermal emitting O-stars are also Binaries with Colliding Winds





Credit: Owocki AIPC 1175 (2009) 173

Open Questions

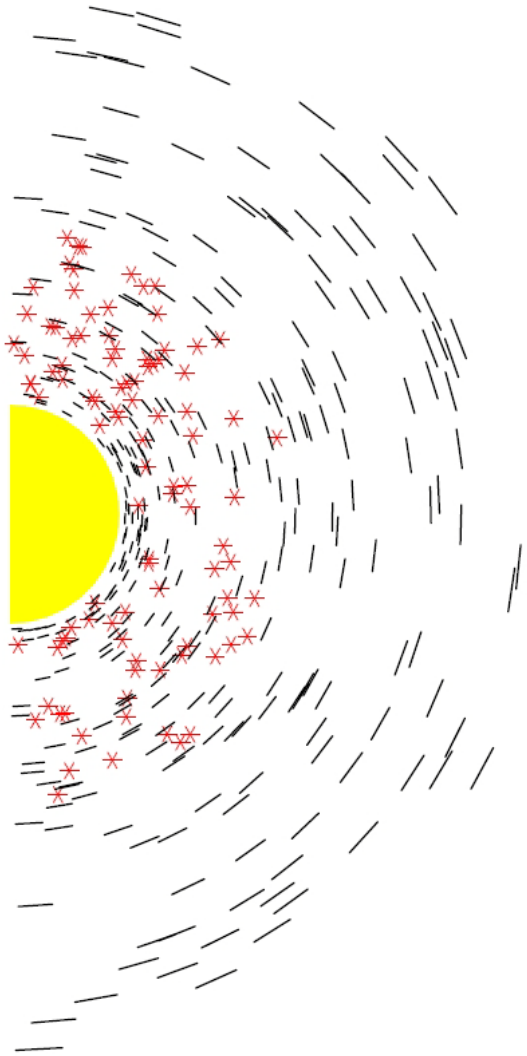
- Is cosmic ray (CR) acceleration efficient enough to significantly modify the shocks?
- Is electron reacceleration important in the internal shock scenario?
- What role do multidimensional effects play in this problem?

Numerical Method

- AstroBEAR (Astronomical Boundary Embedded Adaptive Refinement) MHD Code (Cunningham et al. 2009)
- Coarse-Grained Momentum finite Volume (Jones & Kang 2005)
  - Method reduces number of momentum zones by an order of magnitude
  - Assumes CR spectrum can be represented with a powerlaw
- Crank-Nicolson Scheme with a tridiagonal solver for Diffusion

Simulation Setup

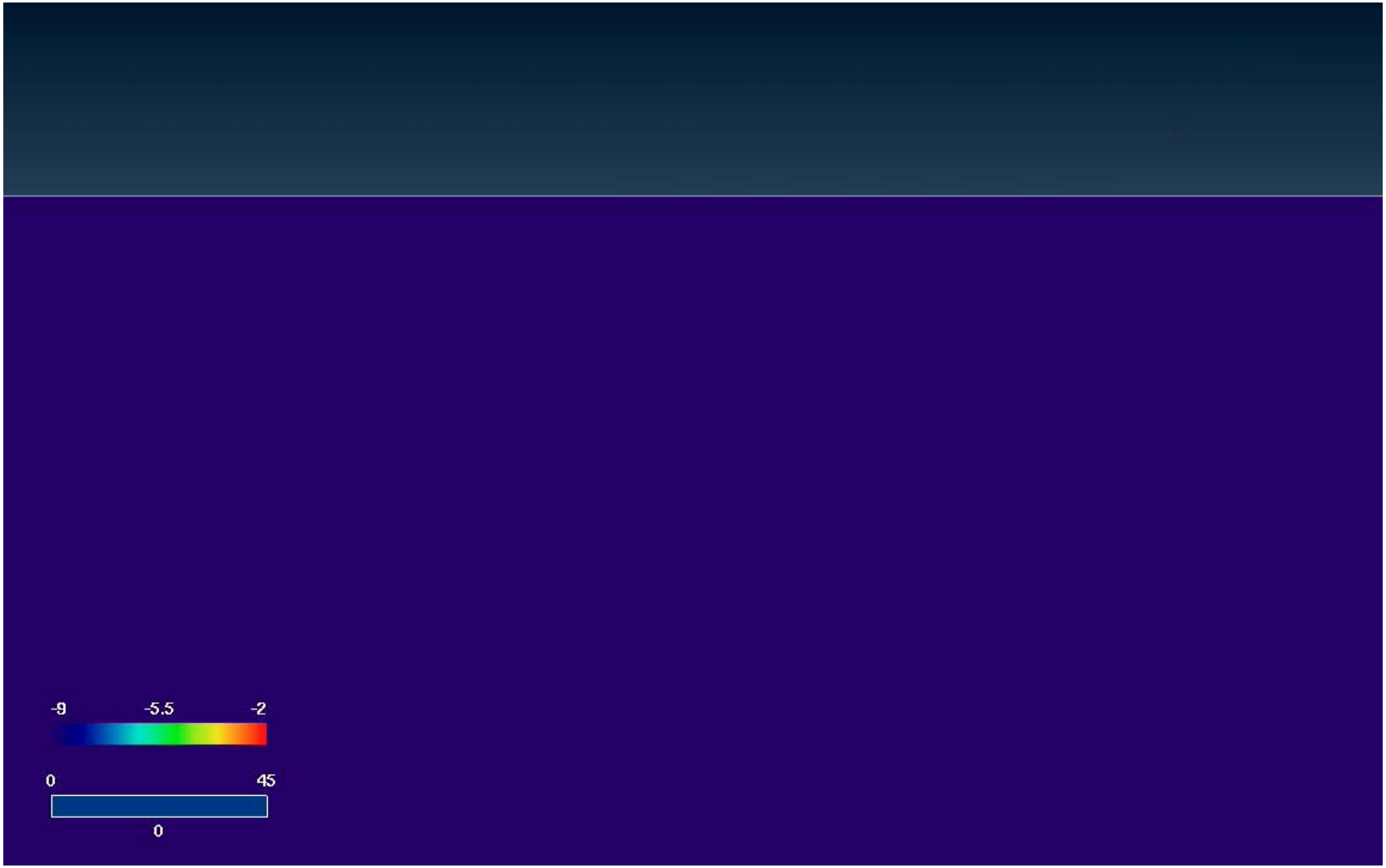
- 2.5-D Cylindrical
- Effective Resolution: 6144 x 3072 x 14 momentum bins
- Isotropic Bohm-like Diffusion
- O-type Star: 22 M_{sun}
- V_w: 2000 km/sec
- Mdot: 10^{-6} M_{sun}/yr
- Stellar Radius: 8.5 R_{sun}
- Inner Radius: 50 R_{star}
- dx: 0.3 R_{star}
- Field Geometry
  - Radial Field~ $1/R^2$
  - Azimuthal Field~ 1/R
  - Field Strength at Star: 10 G
- Frame dt: 4.7 hrs
- Final Frame: 9 days



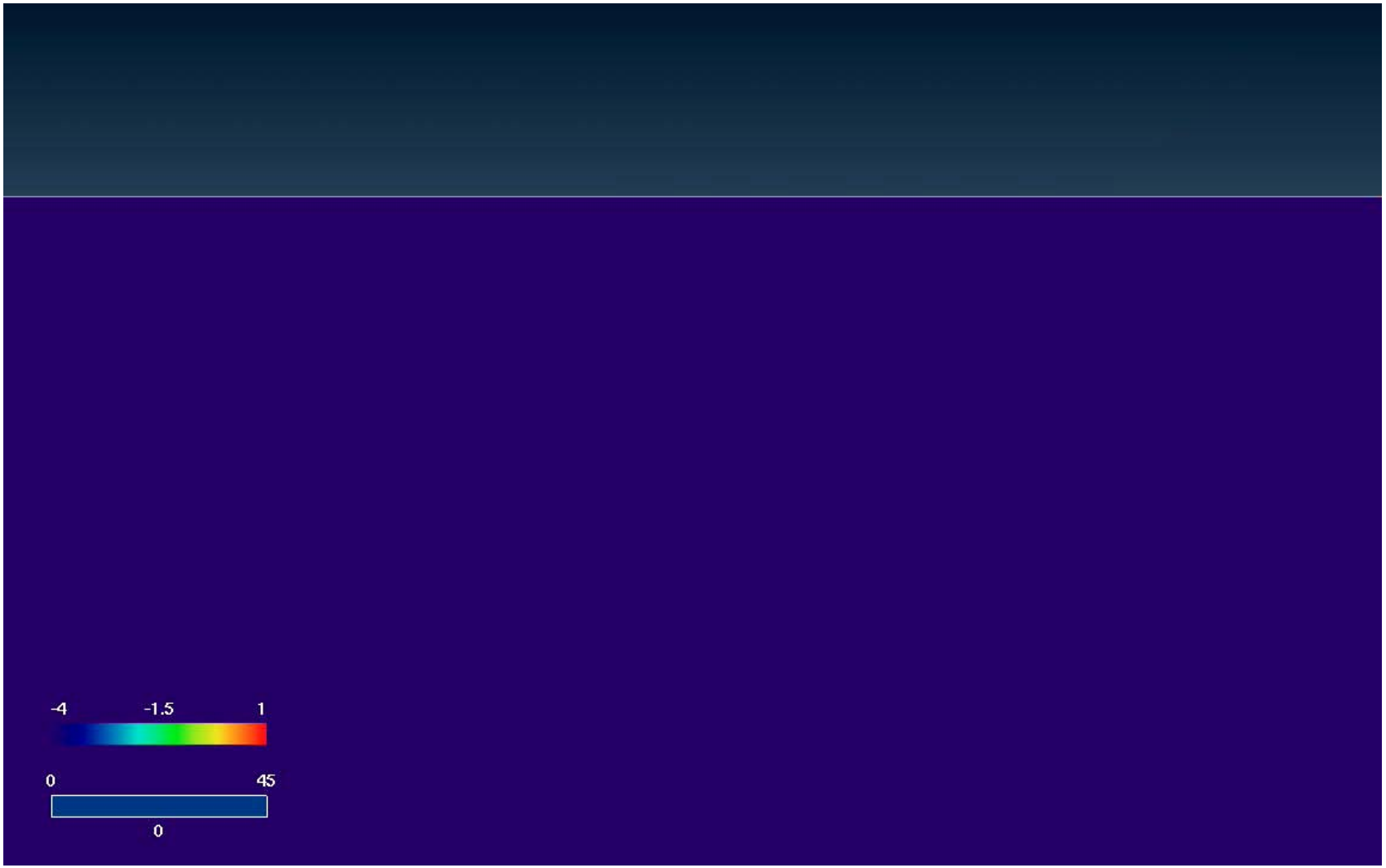
Credit: Hamann, et al. AIPC 1175 (2009) 136

Log of Number Density

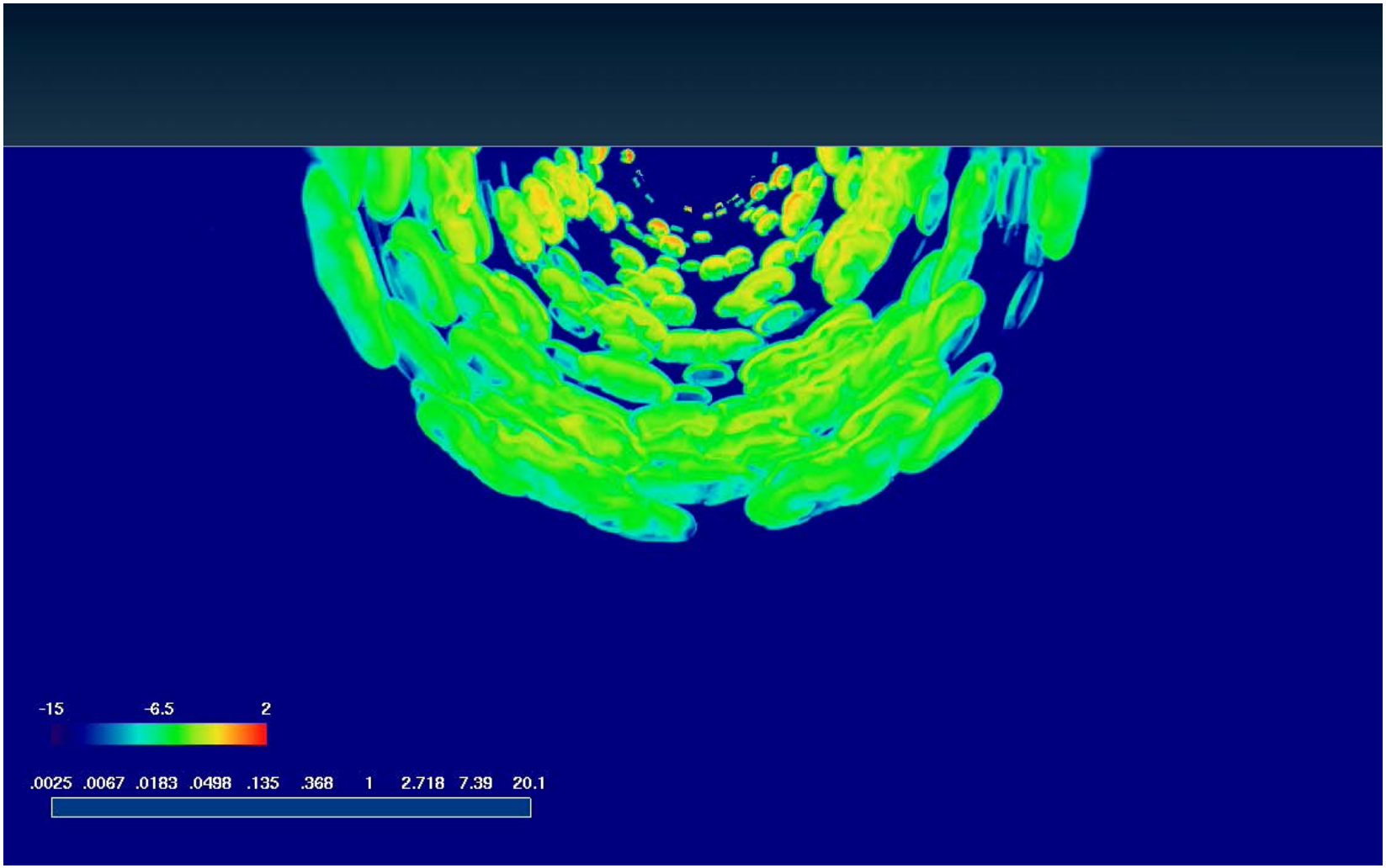
Log of Cosmic Ray Pressure



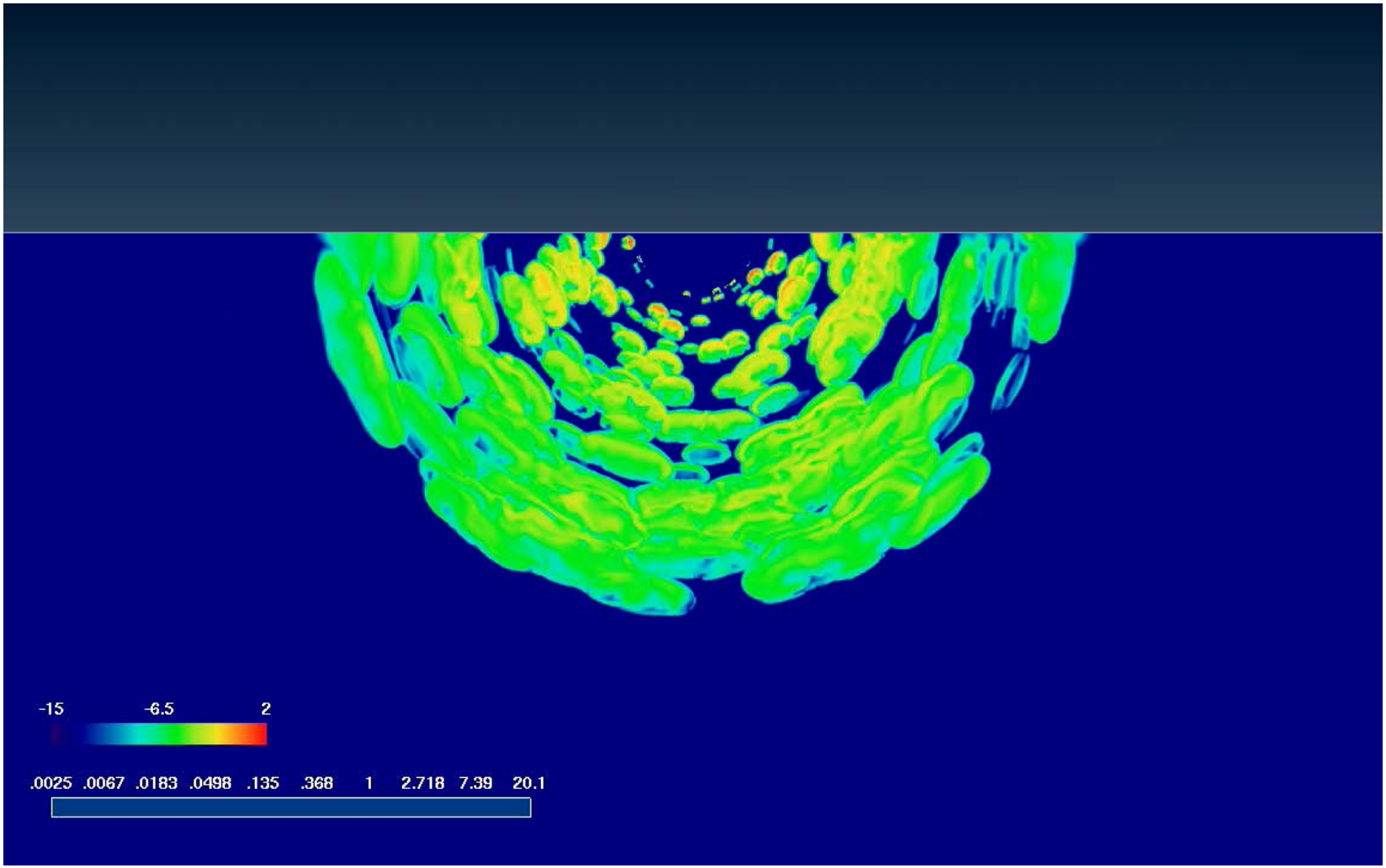
Log of the Ratio of P_c/P_g



Cosmic Ray Protons



Cosmic Ray Electrons



Summary and Future Work

- Currently running and analyzing single O-star wind with internal shocks
  - CR pressure appears to be not important in the inner wind
  - Protons can be accelerated to at least tens of GeV
  - Electrons can be accelerated to at least a GeV
- Future Work
  - Implement CR solver into WOMBAT
  - Single Wind Runs
    - Synthetic Observations of Synchrotron, Bremsstrahlung, Inverse Compton and Neutral Pion Decays
    - Detailed analysis of CR interactions
  - Colliding Wind Binaries

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Crank-Nicolson Scheme

- Uses a CN Scheme with a tridiagonal solver to solve the Diffusion Equation
- Adaptive Subcylcing
  - Minimum amount of subcycling based on size of grid patch relative to the diffusion length for that momentum
- Internal Boundary Conditions
  - Floating linear interpolation for internal boundaries