Particle acceleration in colliding winds of massive binaries

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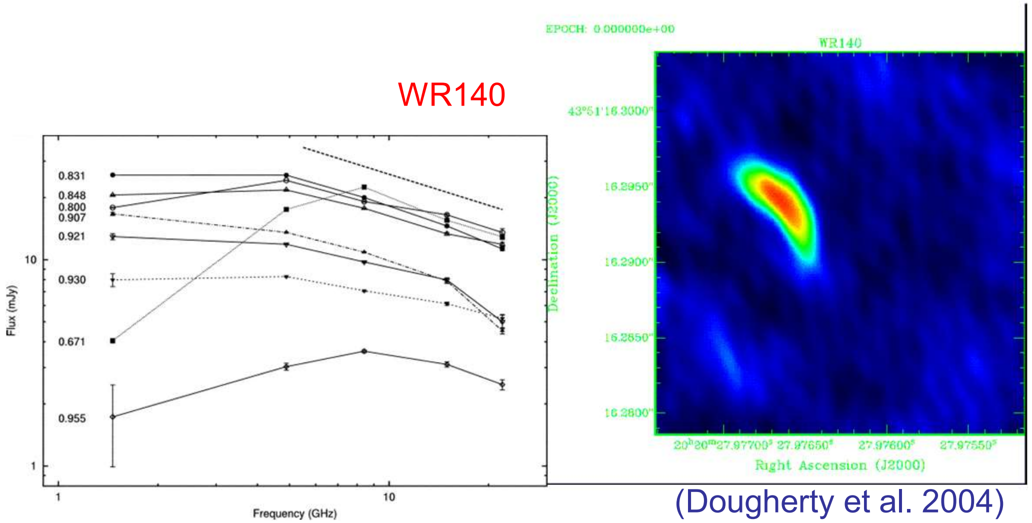
- Massive stars formed with large binarity fraction (> 50%), with close orbits

Motivation

- large **mass loss** rates: **dM/dt ~ 10^{-7} - 10^{-4} $M_\odot$/yr**
- **supersonic winds**: **u_∞ ~ 700 – 5000 km s^{-1}**
- **large binary fraction**
- **Synchrotron emission commonly observed:**
- **HE electrons + strong B-fields**



(Dougherty et al. 2004)

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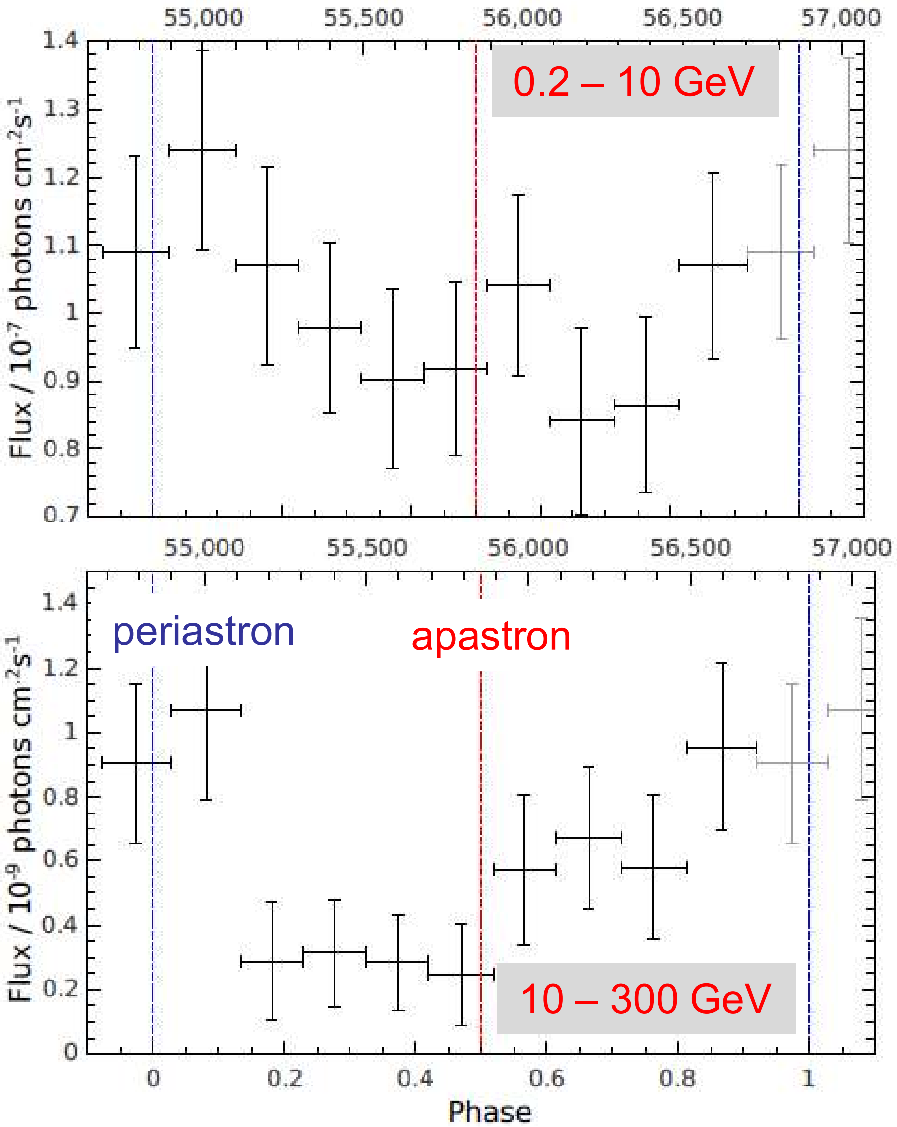
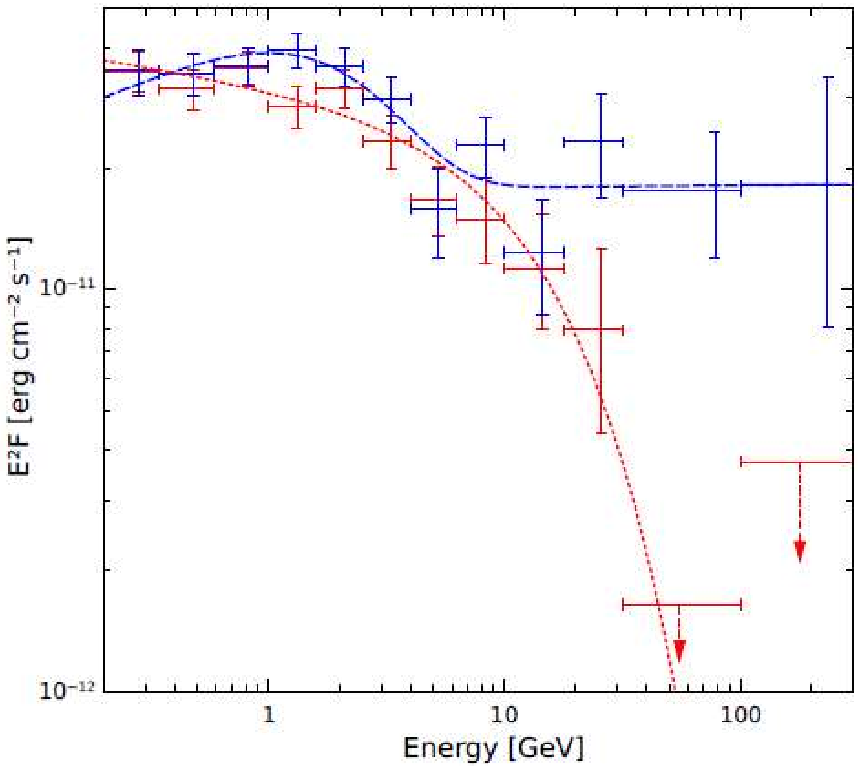
“High” Energy photons from CWBs



FERMI observations of eta Car

(Reitberger et al. 2015)

$$N(E)dE = CE^{-\sigma}dE \qquad \sigma \sim 1.3 - 2.3$$



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Motivation

- Synchrotron radio emission indicates the presence of **relativistic particles & magnetic fields**!
- High energy gamma-rays indicate presence of **relativistic particles**
- non-linear dynamics makes analytical models for synthetic emissions too complicated,
- Numerical simulations are needed to fully describe the physics of wind-wind collision region.

Modelling

“Dream World”

- Self-consistent dynamics of shocks (cooling, instabilities, etc.)
- Self-consistent evolution of B-fields (MHD)
- Consistently obtain particle distributions from acceleration processes
- First High-Resolution numerical simulations of MHD CWBs (Falceta-Gonçalves et al. 2012, 2015)
- First Self-Consistent particle trajectory integration (Kowal & Falceta-Gonçalves 2021)

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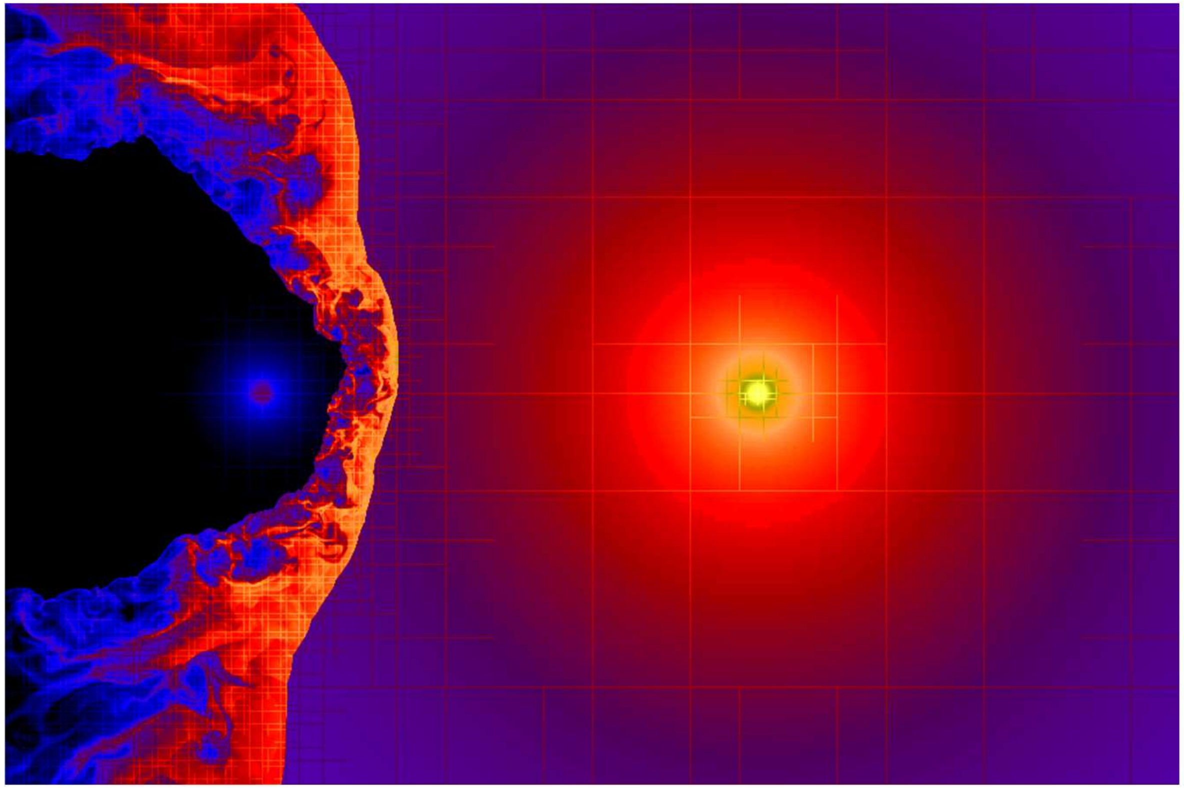
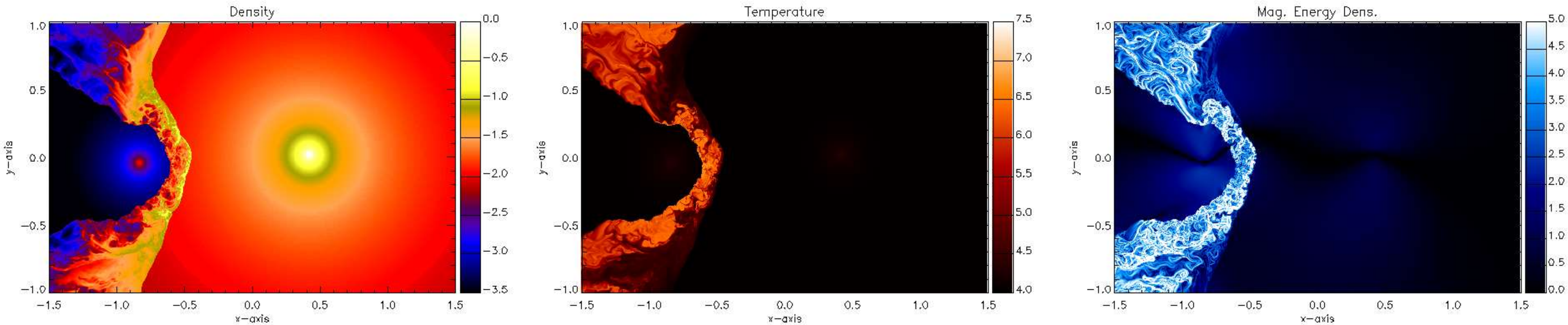


$$\frac{m_1}{m_2} = 5 \quad \frac{\rho_1}{\rho_2} = 200 \quad \frac{u_1}{u_2} = 0.2$$

$$e = 0.9$$

AMUN CODE

- MHD
- AMR, 7 levels of refinement, max res 2048^3
- Godunov scheme, with RK4 time integration method, MP-interpolation technique, and HLLD Rieman Solver.



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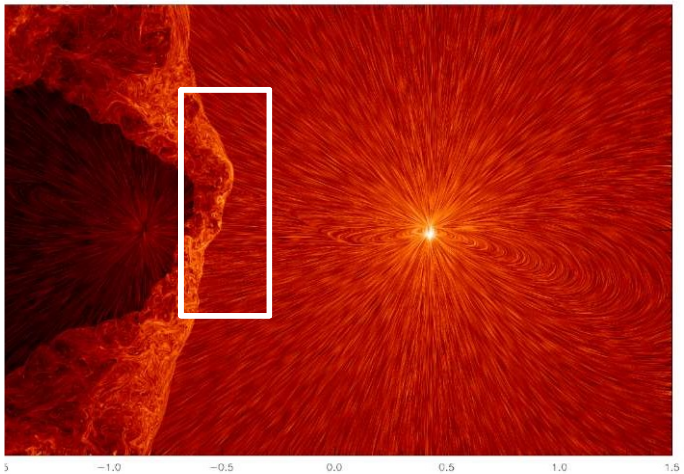
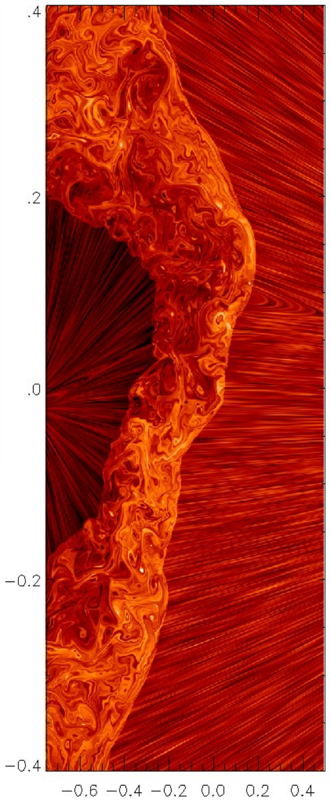
Modelling





- Magnetic field geometry much complex within shocks

Amplification of B depends on:

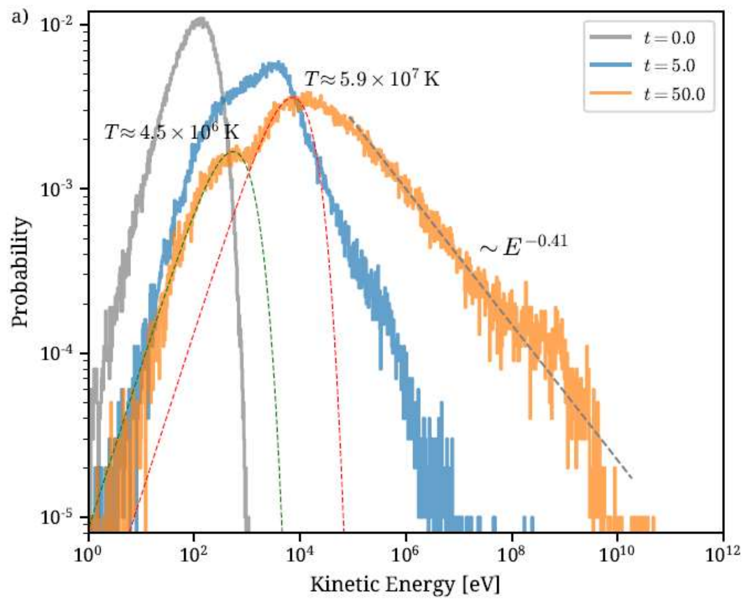
- stellar B (intensity basically)
- distance between stars
- mass loss rate (determine turbulent diffusion and cooling regime)

Particle Acceleration

- 100 000 particles are injected with thermal distribution of randomly oriented momenta
- Trajectories are integrated following dynamical evolution:

$$\frac{d}{dt}(\gamma \mathbf{v}) = \frac{q}{m}(\mathbf{E} + \mathbf{v} \times \mathbf{B}), \quad \frac{d\mathbf{x}}{dt} = \mathbf{v},$$

- 8^{th} order Dormand-Prince Method with adaptive time-step



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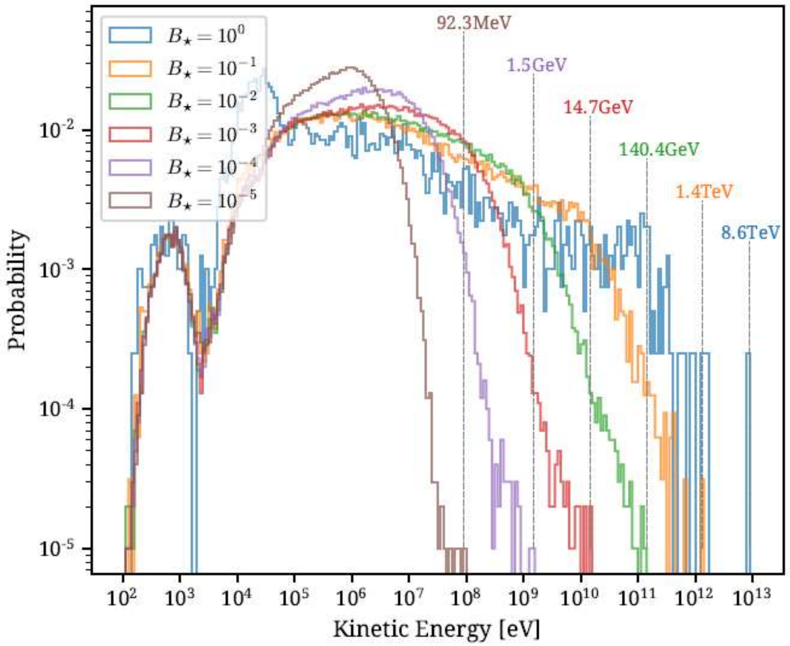
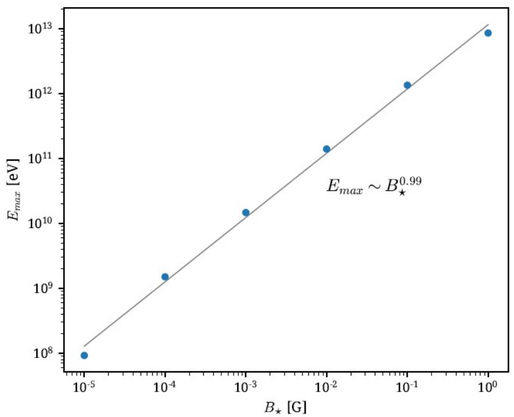
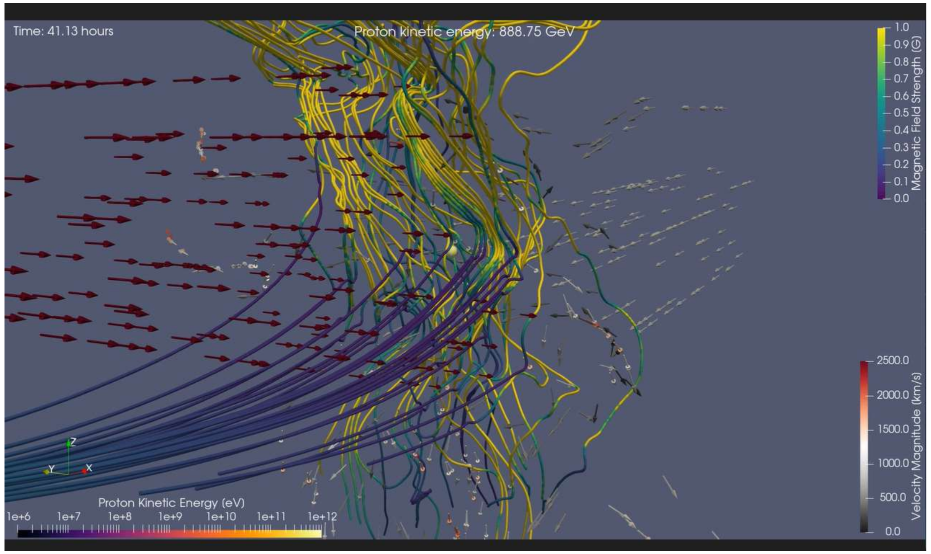
Particle Acceleration





- Non-thermal distribution depend on stellar B;
- Max energies grow linearly to stellar B



Conclusions

- MHD simulations show that equipartition assumptions are far from reality
- Turbulence in the shock region is important for shock structure & particle acceleration (mostly DSA mechanism)
- CWBs are shown to be source candidates for Galactic VHE particles (future targets for CTA observations in star forming regions)