CONSTRUCTING MODELS FOR SUPERNOVA REMNANT EVOLUTION USING NUMERICAL SIMULATIONS

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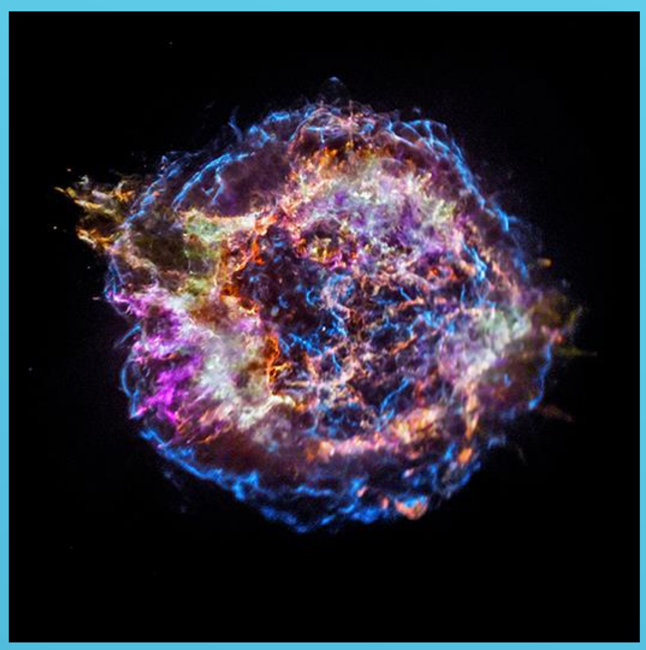
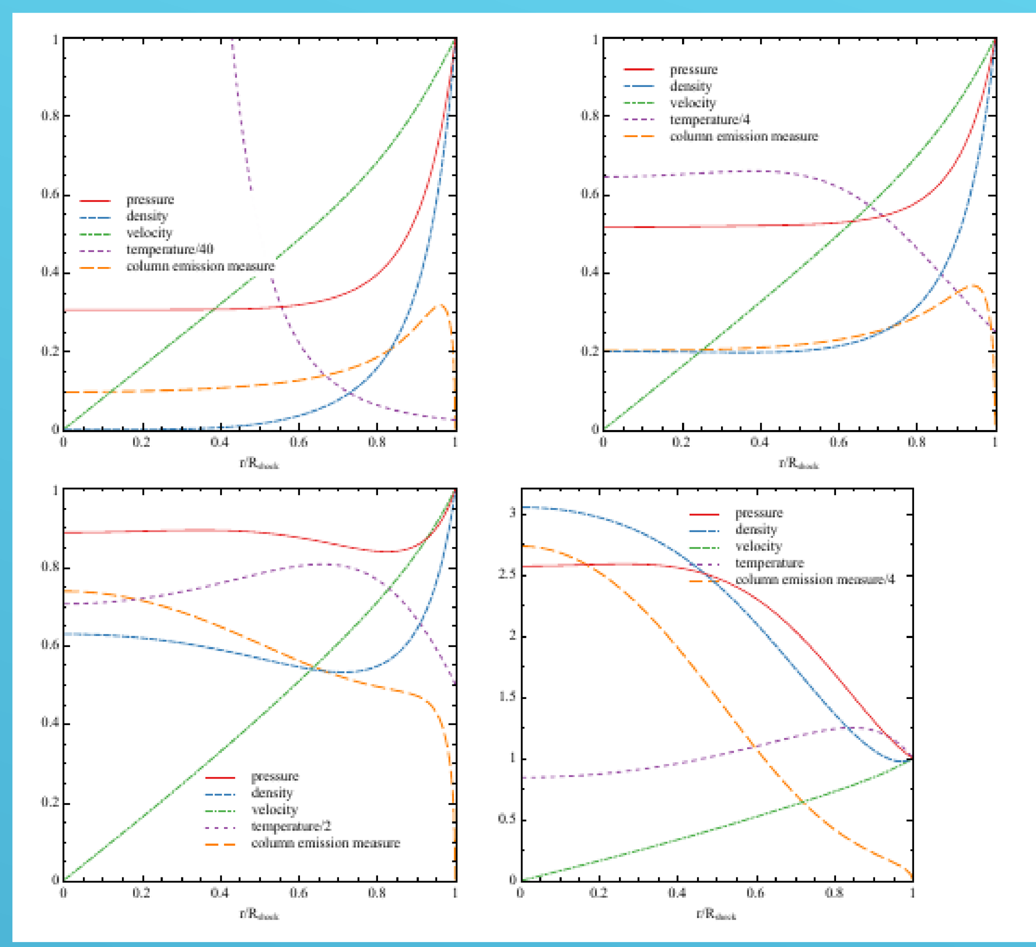


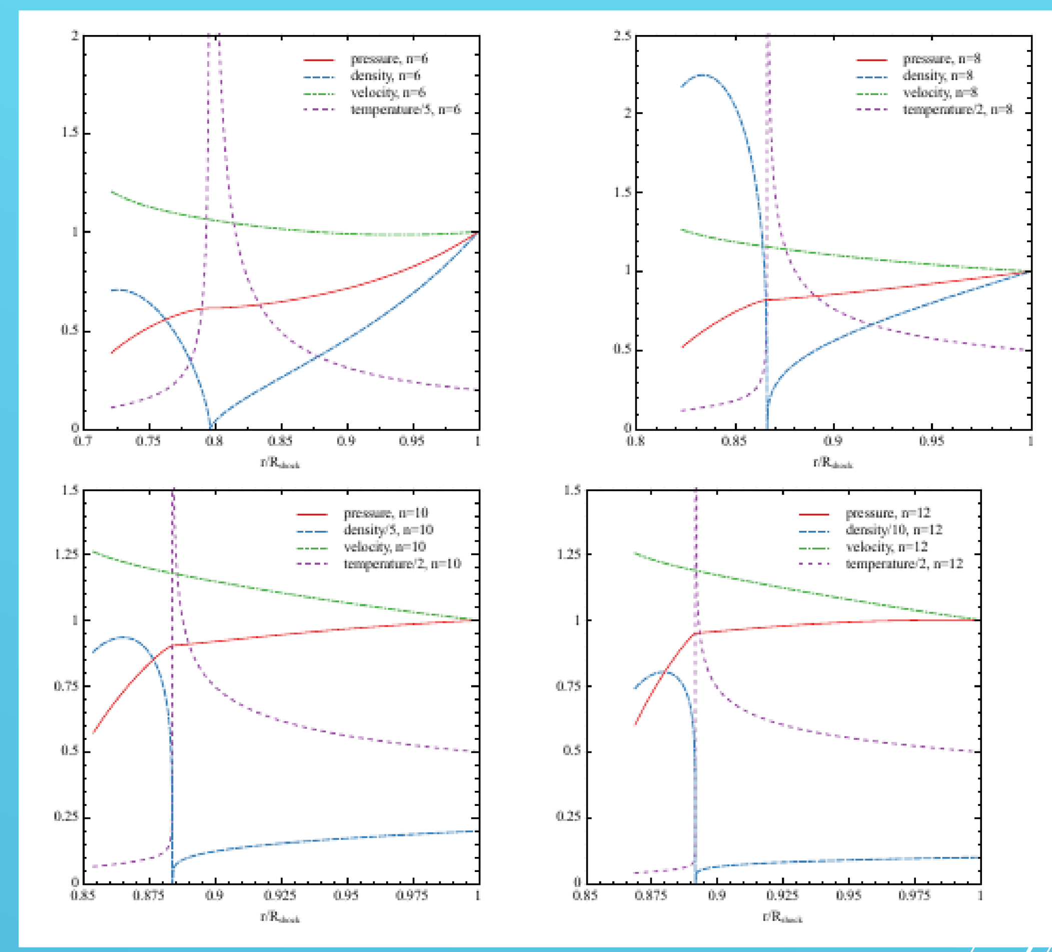
Cas A, Dec. 2017 image from NASA/CXC image gallery

SUMMARY

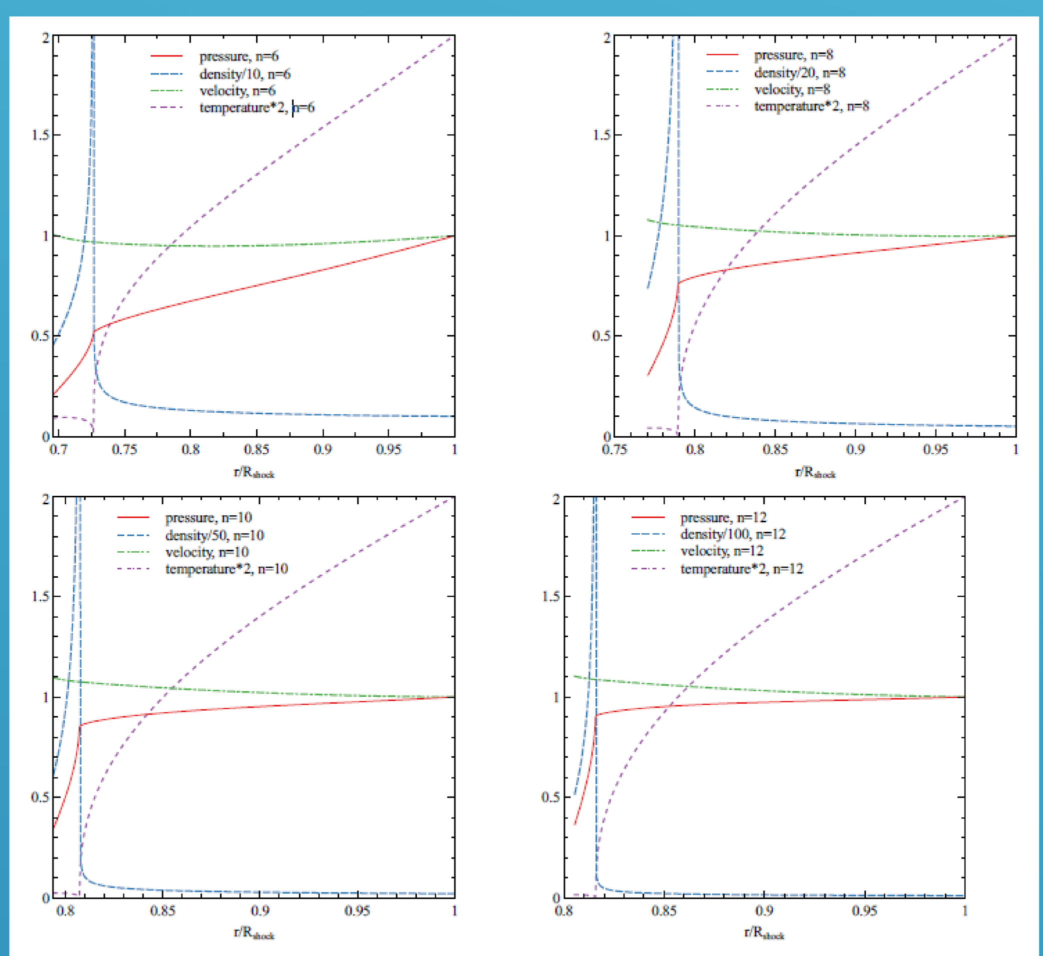
The evolution of supernova remnants is followed using numerical simulations, with the public PLUTO code (Mignone et al 2012). The full evolution from days after explosion to late in the adiabatic phase is calculated. For these calculations we consider spherically symmetric evolution and "power-law plus core" ejecta. Before the reverse shock encounters the core, the evolution agrees with the Chevalier self-similar results. For the late evolution the existence of finite ejecta mass causes significant differences from the standard Sedov solution. Analytic fits for a number of quantities of interest, including shock radii and emission measures, are derived.



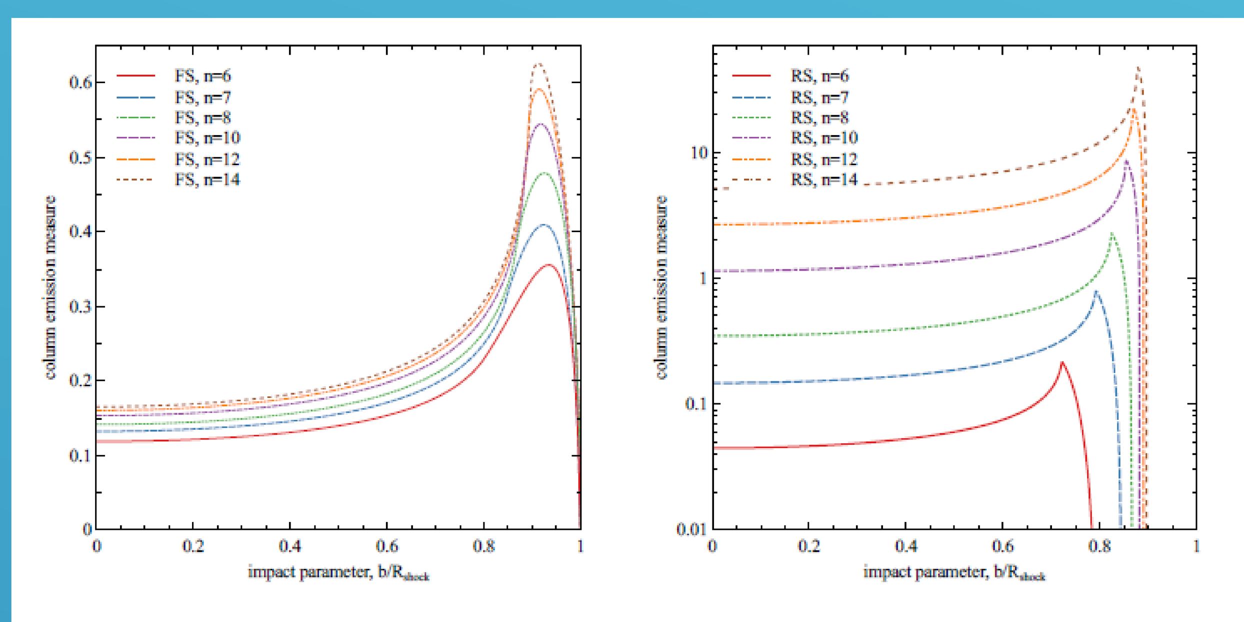
The interior structure of the WL91 self-similar solutions for C/Tau=0 (top left), 1 (top right), 2 (bottom left) and 4 (bottom right). The pressure, density, velocity and temperature are plotted vs. radius and are scaled to their values at the forward shock (FS). Further scaling factors are applied to temperature, as noted in the figure legend. The dimensionless column emission measure (long dash line) is plotted vs. impact parameter.



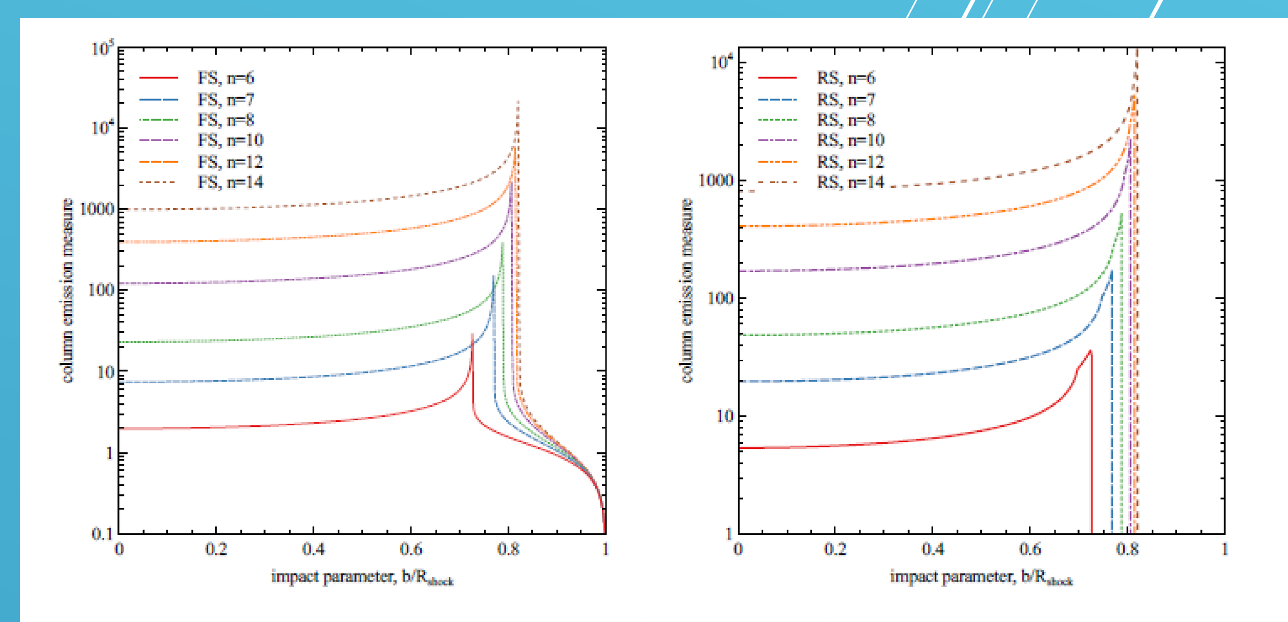
The interior structure of the Chevalier-Parker self-similar solutions for s=0 and n= 6 (top left), 8 (top right), 10 (bottom left), 12 (bottom right). The values are scaled to the post-forward-shock (FS) values of pressure, density and temperature and the FS velocity. Further scaling factors are applied to density and temperature, as noted in the figure legend. The reverse shock (RS) is the point at smallest radius, and the contact discontinuity is where the density goes to zero.



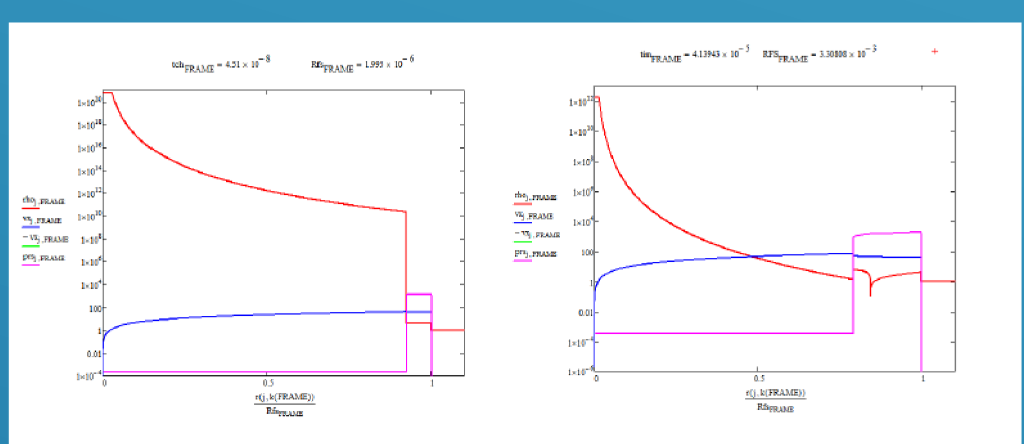
The interior structure of the Chevalier-Parker self-similar solutions for s=2 and n= 6 (top left), 8 (top right), 10 (bottom left), 12 (bottom right). The values are scaled to the post-forward-shock values of pressure, density and temperature and the FS velocity. Further scaling factors are applied to density and temperature, as noted in the figure legend. The RS is the point at smallest radius, and the contact discontinuity is where the density goes to infinity.



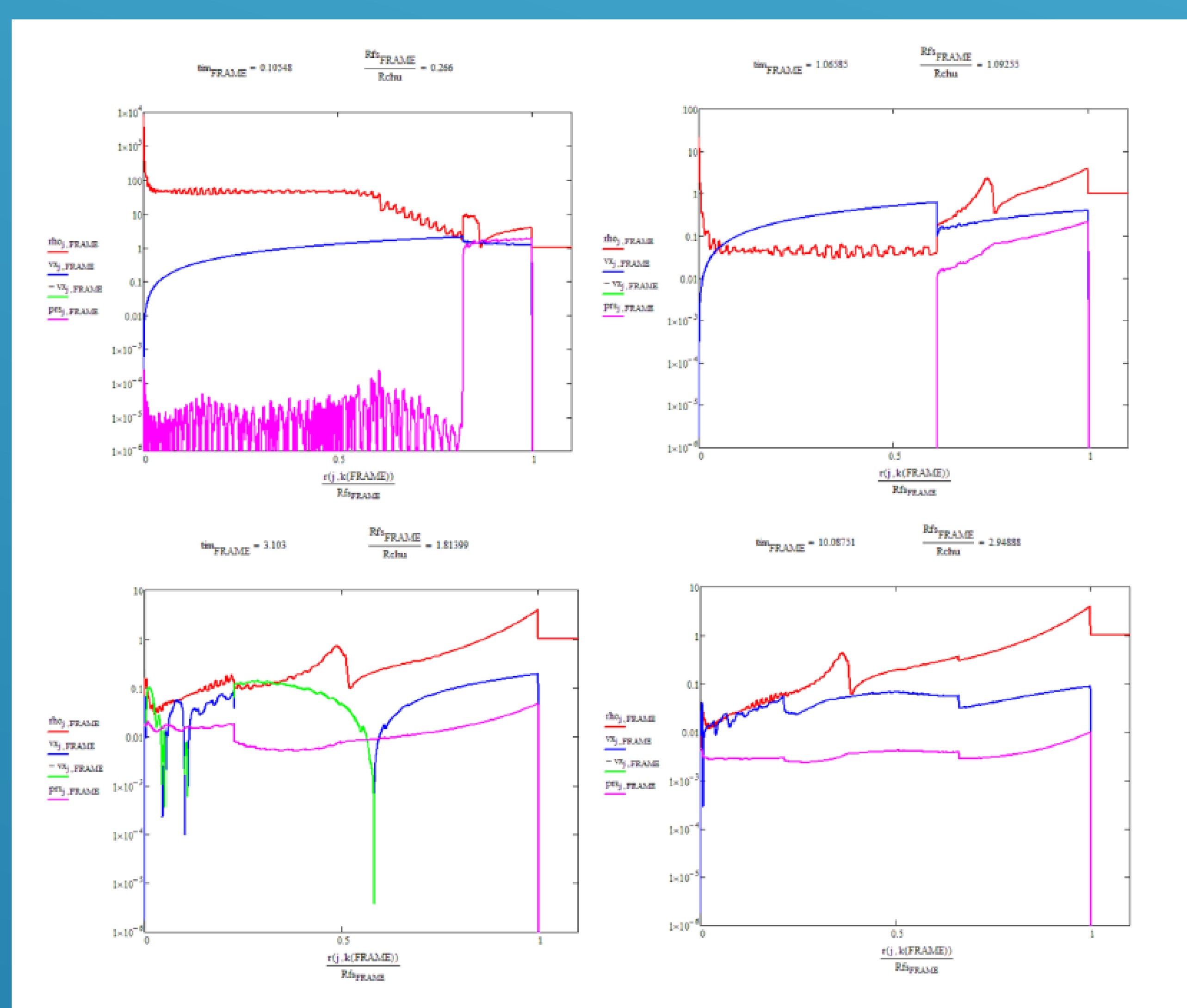
The dimensionless column emission measures vs. impact parameter b for the Chevalier-Parker self-similar solutions for s=0 and n= 6, 7, 8, 10, 12 and 14. The left panel is for material heated by the FS, plotted with linear scale. The right panel is for material heated by the RS, plotted with log scale.



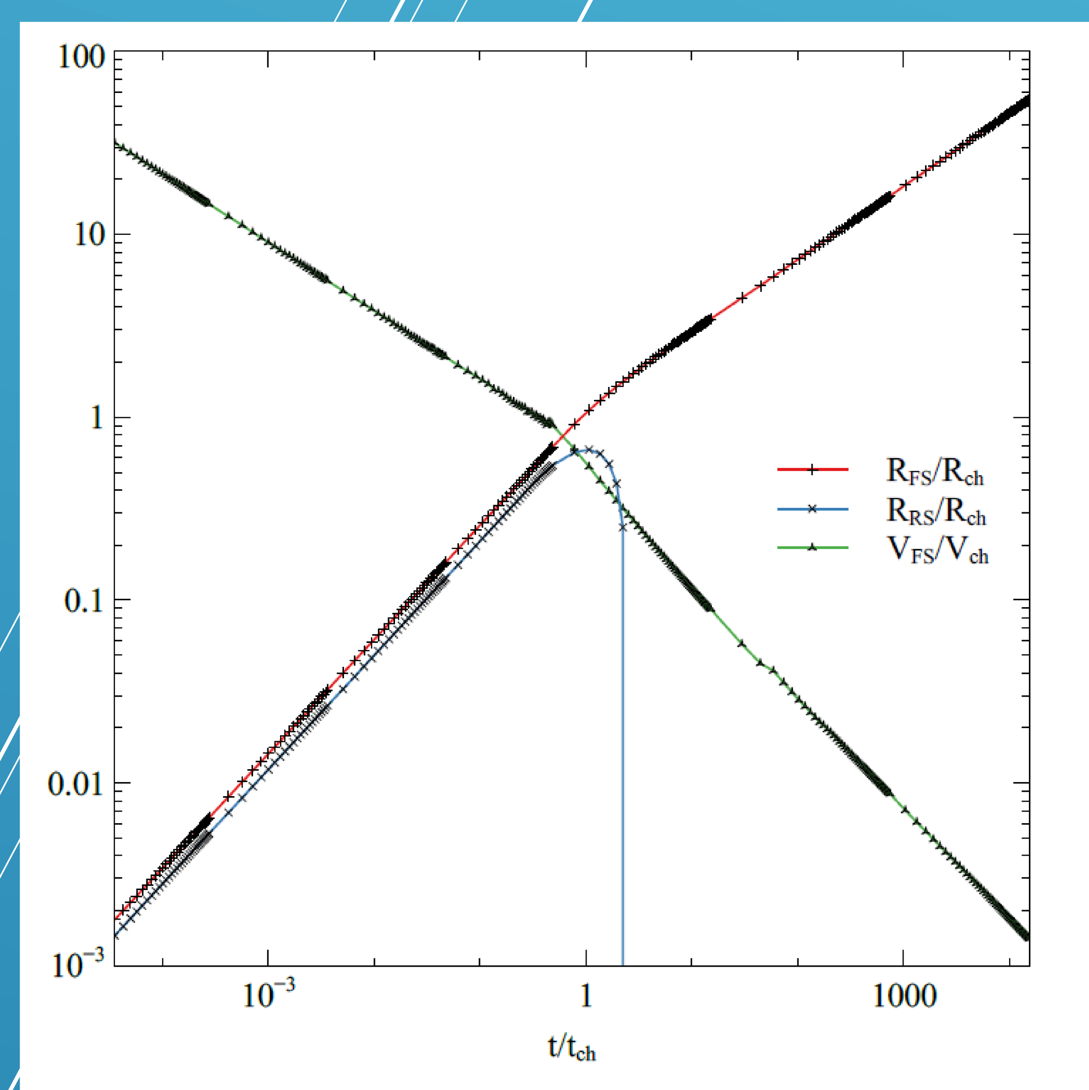
The dimensionless column emission measures vs. impact parameter b for the Chevalier-Parker self-similar solutions for s=2 and n= 6, 7, 8, 10, 12 and 14. The left panel is for material heated by the FS and the right panel is for material heated by the RS.



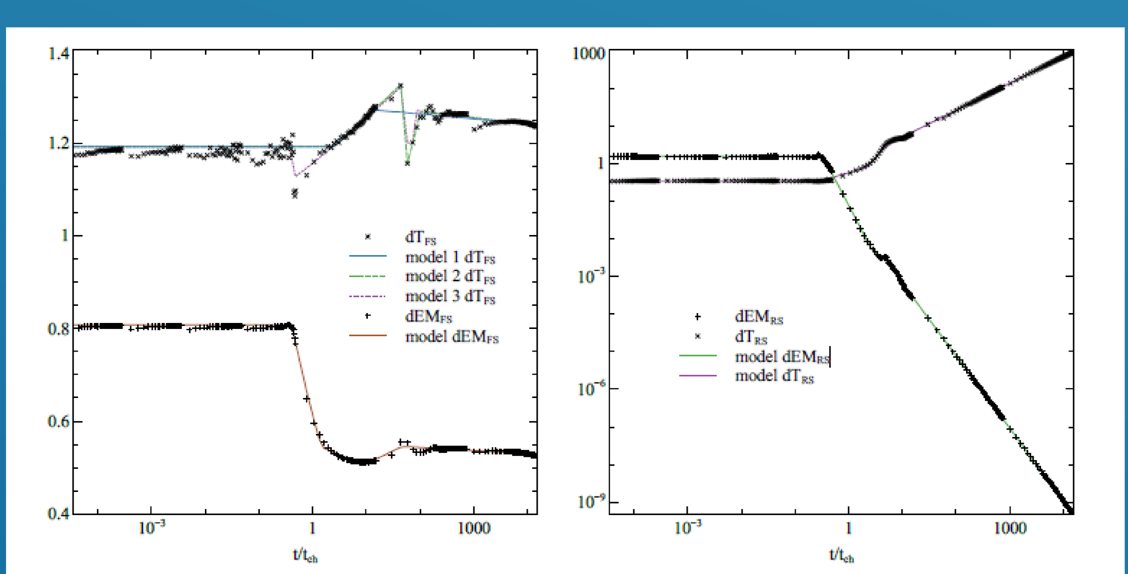
PLUTO hydrodynamic simulation of an SNR with s=0, n=7: Left panel: case 1 initial conditions of unshocked ejecta with shocked ISM. Right panel: case 2 initial conditions using the CP self-similar solution with shocked ejecta and shocked ISM. Density, velocity, pressure, time and FS radius R_{FS} are in characteristic units, the x-axis is in units of $r=R_{FS}$.



Snapshots of the interior structure for s=0, n=8 from hydrodynamic simulations at 4 characteristic times: t/t_{ch} = 0.1 (top left), t/t_{ch} =1 (top right), t/t_{ch} =3 (bottom left) and t/t_{ch} =10 (bottom right). The time t/tch and the FS radius in units of characteristic radius (R_{FS}/R_{ch}) are given at the top of each panel. The density (rho/rho_{ch}), velocity (vx = v/v_{ch}) and pressure (prs = p/p_{ch}) are scaled to their characteristic values, and are plotted vs. radius in units of the FS radius ($r=R_{FS}$). Negative (inward) gas velocities are plotted in green.

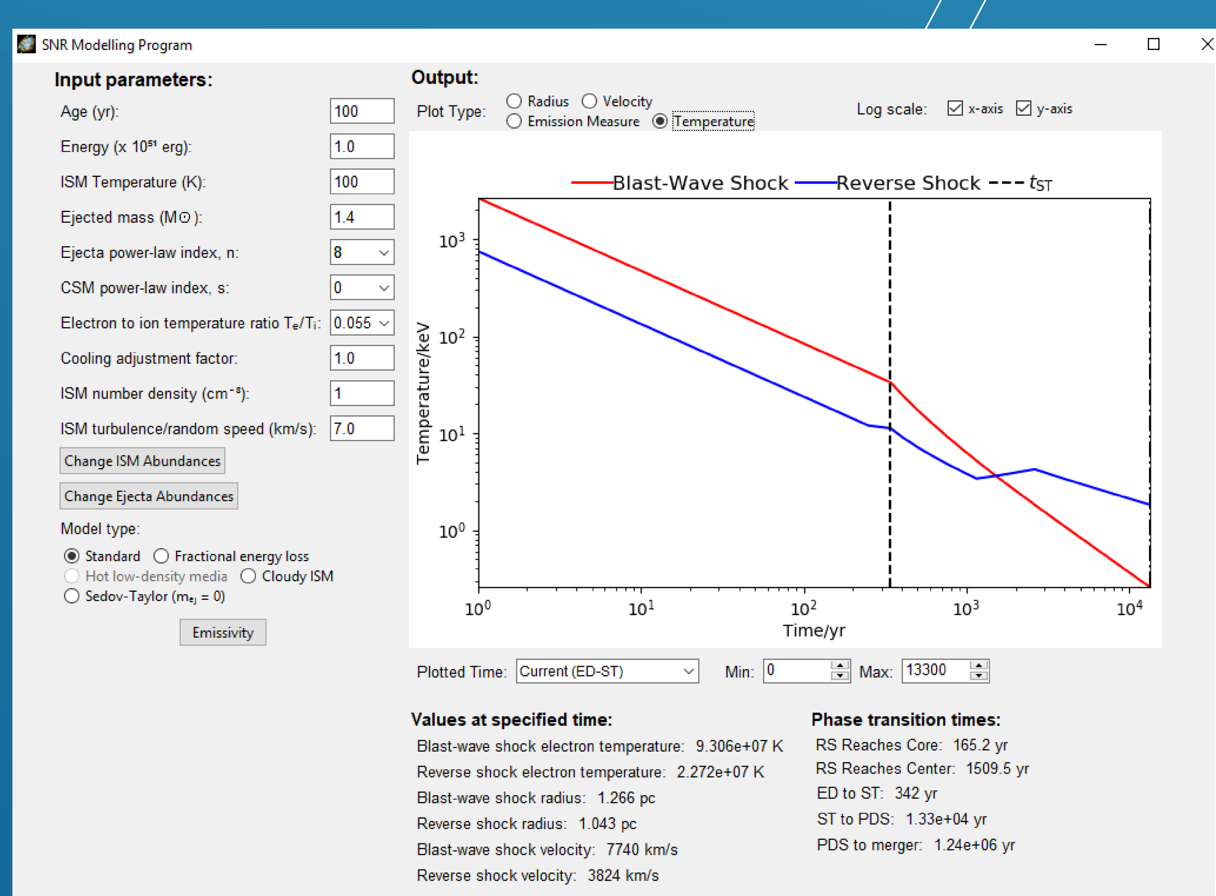


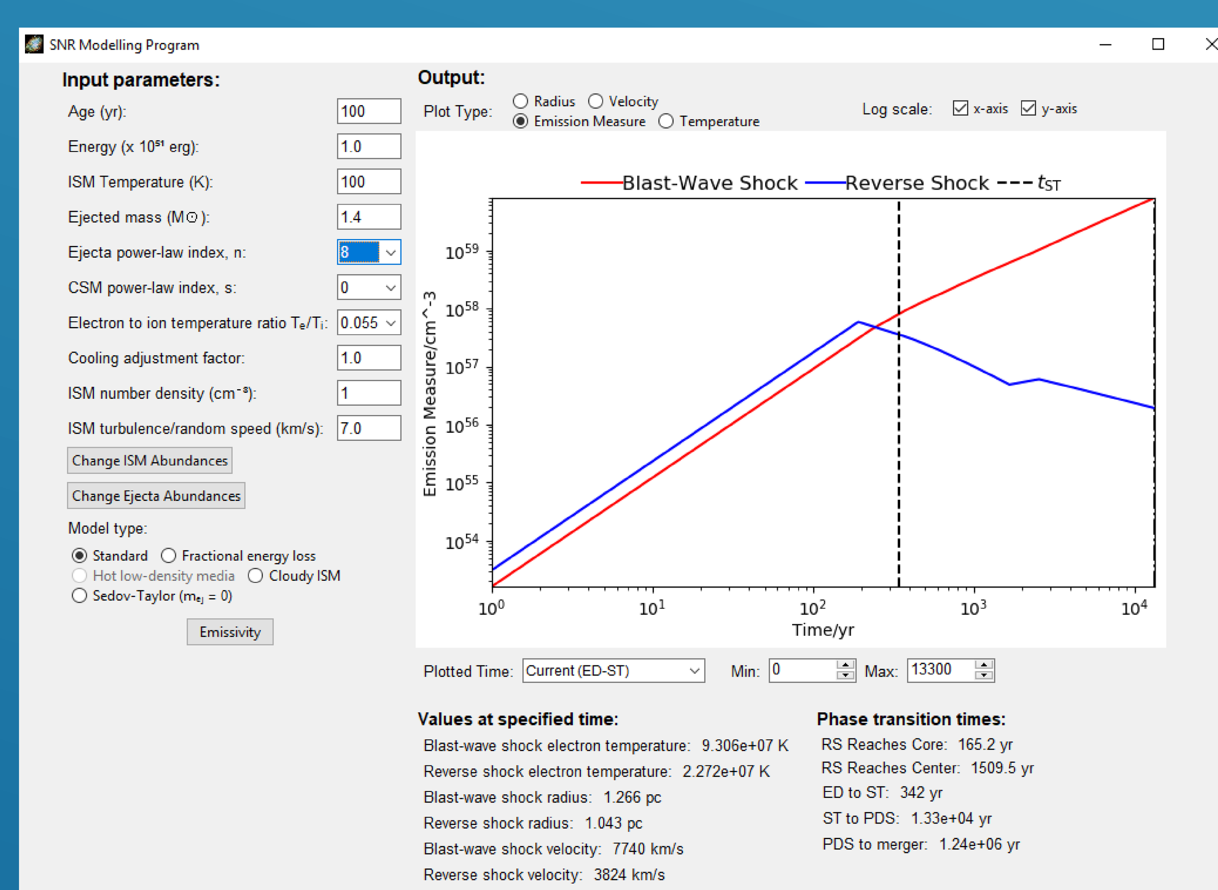
FS radius R_{FS} and velocity V_{FS}, and RS radius R_{RS} extracted from the hydrodynamic simulations for s=0, n=8. Quantities are plotted as in units of characteristic radius or velocity as a function of characteristic time, t/t_{ch}.



Extracted quantities from the hydrodynamic simulations for s=0, n=8 as a function of characteristic time, t/tch. Left: dimensionless temperature dT_{FS} and dimensionless emission measure dEM_{FS} of FS-shocked gas. Right: dimensionless temperature dT_{RS} and dimensionless emission measure dEM_{RS} of RS-shocked gas. The functions fit to dT_{FS}, dEM_{FS}, dT_{RS} and dEM_{RS} vs. t/t_{ch} are shown by the lines labelled model.

The Python code SNR modelling software, SNRPy, was presented by Leahy & Williams 2017. This calculated positions of FS and RS vs. time for several values of s and n from the TM99 solutions, and for some other models. SNRPy has been updated to include the new high resolution CP and WL91 solutions. It now provides FS and RS radii, emission measures, interior structure and surface brightness profiles for all values of s=0 and s=2 for all n from 6 to 14. It also provides plots of EM and EM-weighted T for both shocked ISM and shocked ejecta as functions of time. The new SNRPy is available from quarknova.ca and from GitHub (denisleahy/SNRmodels).





Temperature (left) and Emission Measure (right) in physical units as a function of time as calculated by the new software SNRPy. The case shown has s=0, n=8 and other parameters as shown in the screenshot.