Modeling Shock Emission in the Cygnus Loop Including Dust Destruction

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Abstract

Supernova remnant shocks play a central role in the dust budget of the interstellar medium, being the main destroyers of dust grains. Models for grain destruction find that fast shocks, v_s > 100 km/s, will destroy grains via sputtering and vaporization by grain-grain collisions. However, many aspects of these models have been difficult to test observationally.
Here we present new HST COS observations of shocks in the "Witch's Broom" region on the west side of the Cygnus Loop SNR. These shocks all have speeds that have been determined by proper motions. We model the shock emission including the dust destruction and the ionization of the gas liberated from grains.

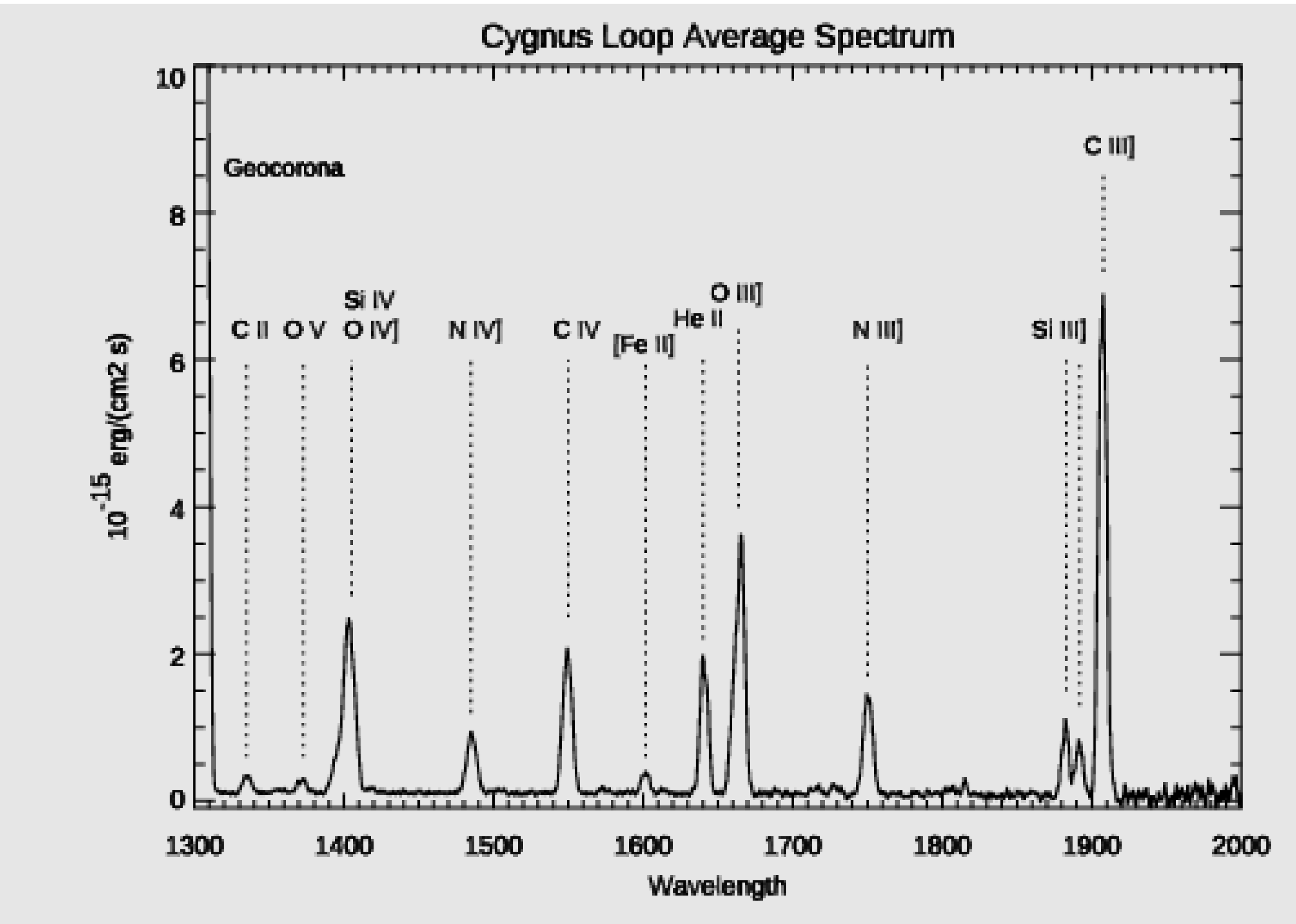

Figure 2 – Average spectrum derived from new HST COS observations in the positions shown by black numbers in Fig. 3. Lines are identified that correspond to a wide range of ionization stages including C II, C III and C IV; O III, O IV and O V; Si III and Si IV. A goal of this work is determine if these emission lines provide evidence of the contribution of atoms sputtered off grains in the shock.

Goals

- Evaluate the amount of dust destruction occurring in these Cygnus Loop shocks
- Examine the effects of dust destruction on shock emission, especially from atoms sputtered off grains
- Assess effects of grain destruction model parameters on predicted emission

Modeling

We calculate the destruction and processing of dust in the shock, building on the codes of Jones et al. (1994, 1996) and Slavin et al. (2015) and shock code of Raymond (1979). Two types of grain are followed, carbonaceous and silicates. Grains are assumed to be tightly coupled to the gas via the magnetic field and are collected into logarithmically spaced size bins ranging from 0.005 – 0.25 μm.
The grain processes included are:

- thermo-kinetic sputtering (i.e. including the skewed Maxwellian seen by grains with significant speed relative to the gas)
- shattering caused by grain-grain collisions – only redistributes the grain mass from larger mass bins to smaller ones
- vaporization – catastrophic destruction via grain-grain collisions

Sputtered mass from the grains is incorporated into the gas phase with the assumption that it's singly ionized initially.

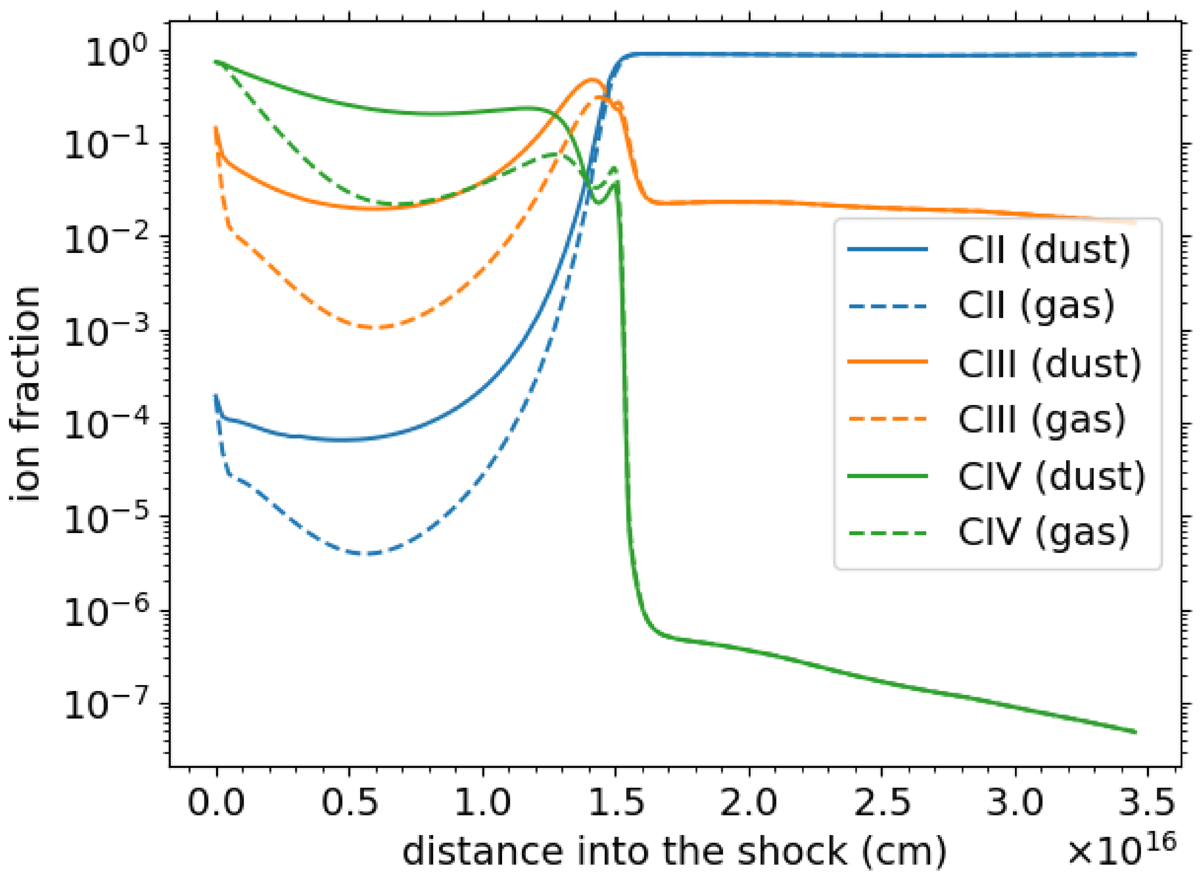

Figure 5 – Ion fractions from sputtered grains and from gas vs. distance into the shock for C. The dust has higher ion fractions because new mass is continually added with low ionization level as dust is sputtered. The gas (not originally in the dust phase) gets ionized up beyond CIV in the hot post-shock gas before recombining in the cooling zone.

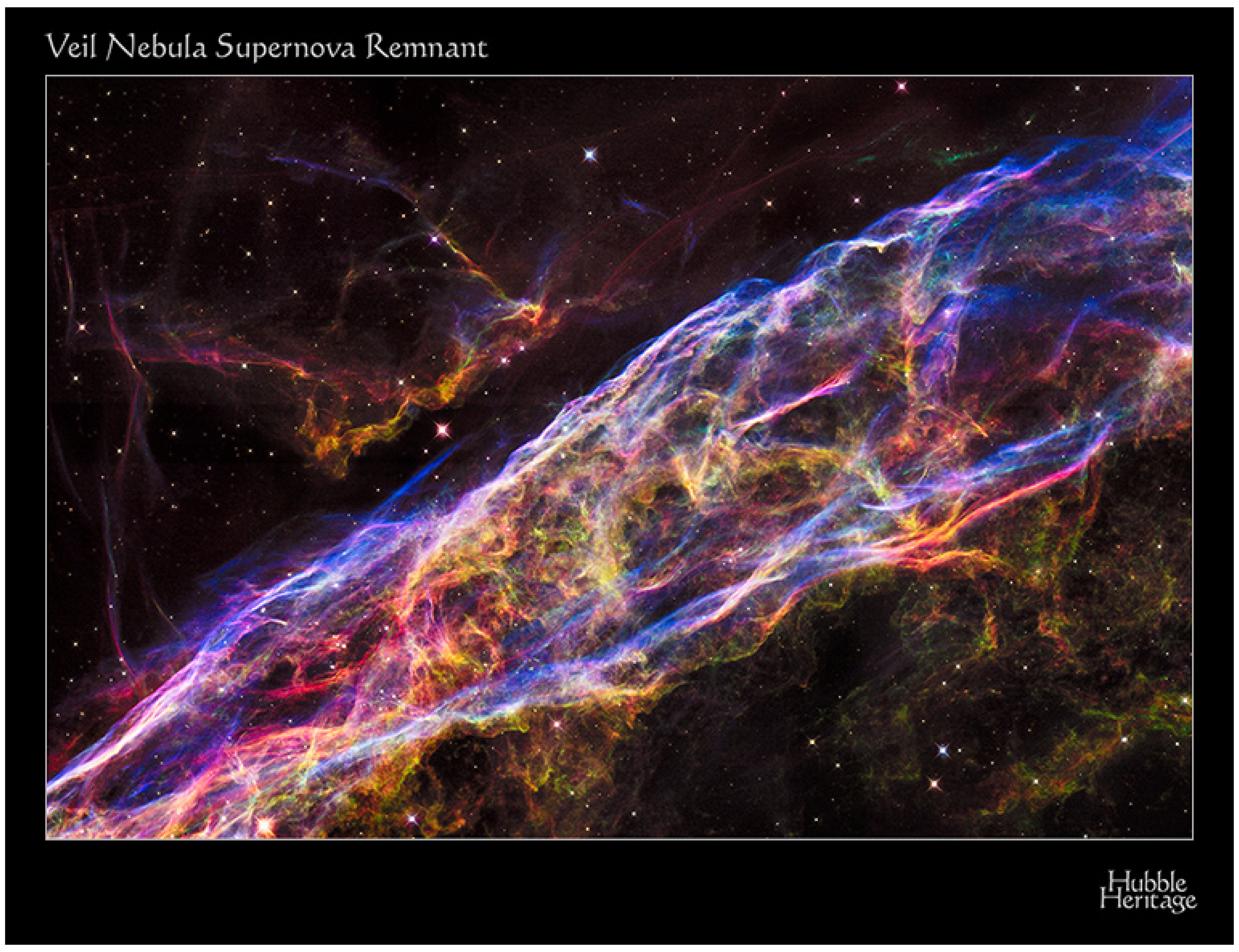

Figure 1 – Hubble Heritage mosaic of the "Witch's Broom" region in the western Cygnus Loop. The colors correspond to [O III] (blue), Hα (red), and [S II] (green). North is toward the lower left. The image is 7' across.

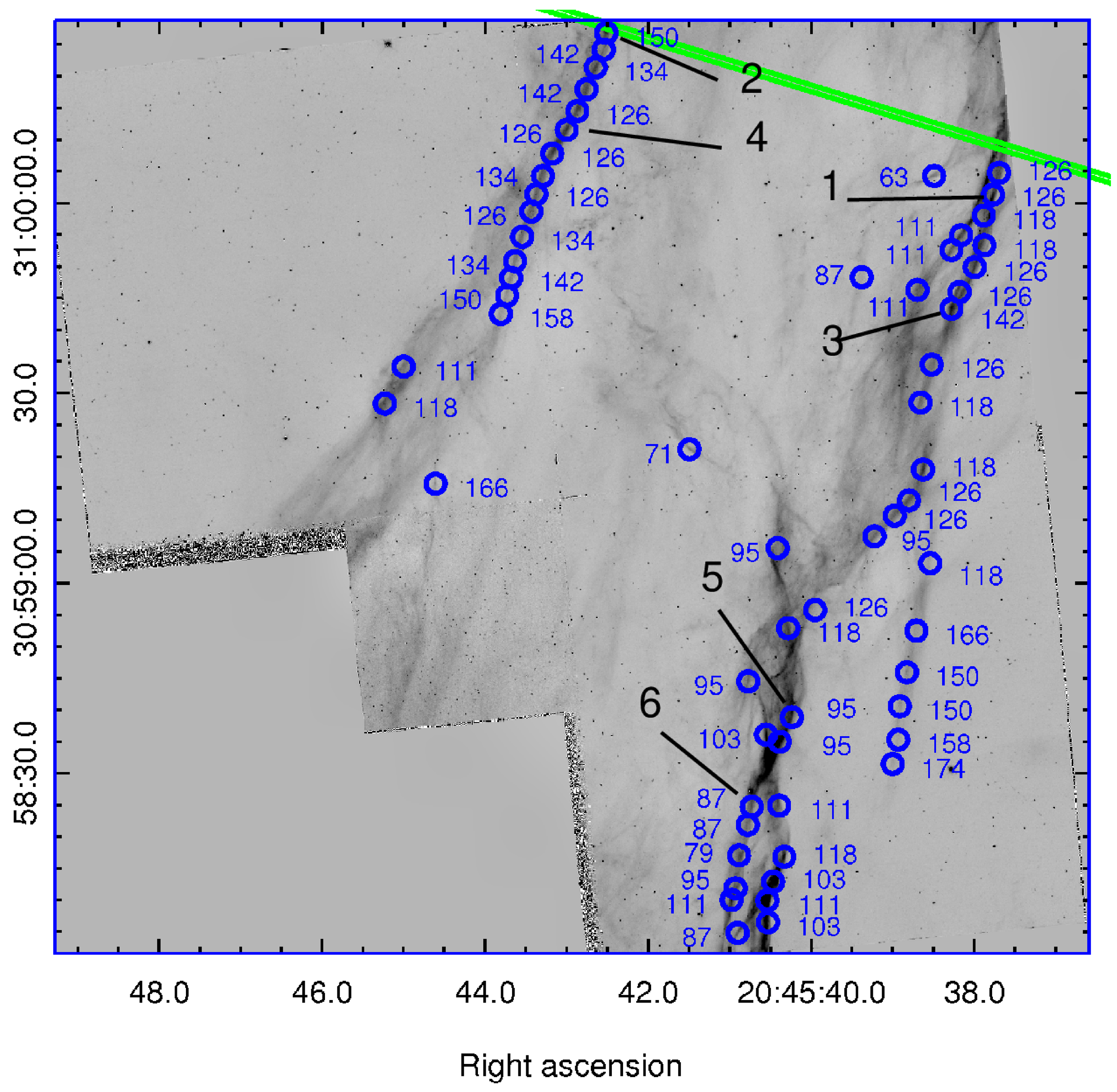

Figure 3 – Region of the Cygnus Loop in the west, part of the "Witch's Broom" region (note; rotation relative to the image above). The blue points indicate locations where the shock speed has been determined from HST proper motions. The derived speed is shown for a distance of 735 pc (Fesen et al. 2018). The green bar indicates the position of the longslit spectrum obtained by Raymond et al. (2020). The locations indicated by black numbers are where the new HST COS observations were taken.

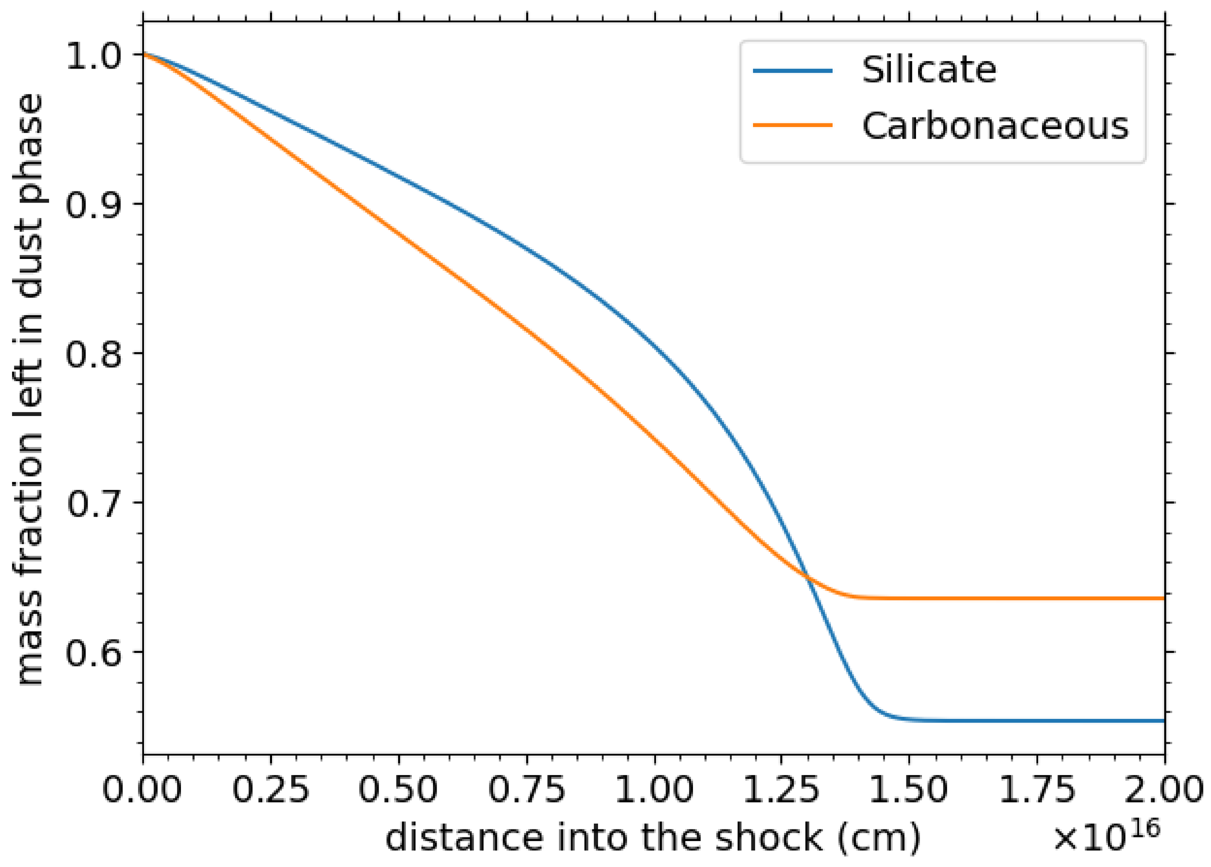

Figure 4 – Evolution in the shock of the fraction of original dust mass remaining in the dust phase. This is for a 150 km/s shock. Grains are primarily thermally sputtered in the hot gas just behind the shock front, but in the cooling zone the extra compression leads to betatron acceleration and inertial sputtering dominates

Summary

- Shocks in the western Cygnus Loop have speeds that are well constrained by their proper motions
- New HST COS data of the shocks show a wide variety of ionization stages, which may indicate that sputtered atoms in the shock are contributing to the emission
- Our models for these shocks indicate that there should be substantial grain destruction in the shock, ~37% of C and ~45% Si grain mass
- With our assumptions for the pre-shock abundances, this leads to ~10% - 80% of the emission coming from gas that had been locked up in grains in the pre-shock medium

These results are preliminary! Stay tuned...

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