Radiative Reverse Shock Laser Experiments

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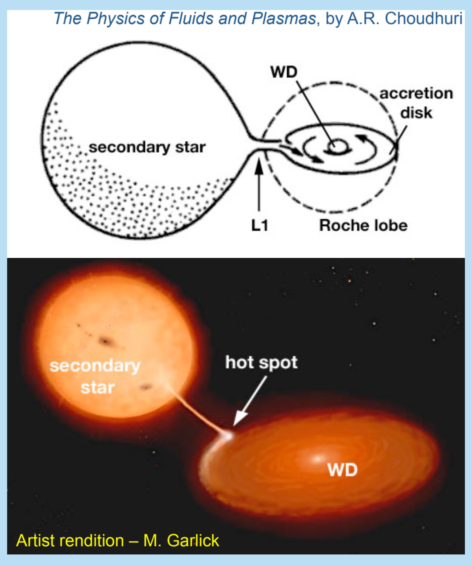
Background on Cataclysmic Variables

Cataclysmic Variables (CVs) are binary systems comprised of a white dwarf (WD) and a companion low mass main-sequence star. The nature of CVs depends primarily on the gas flow from the cool secondary star to the white dwarf.



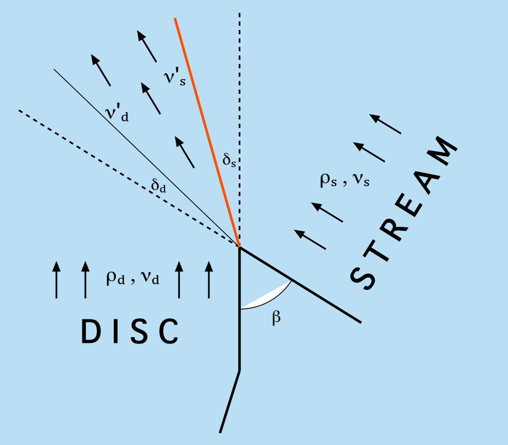
With enough material over-flow from the secondary star, an accretion disk forms:

- Roche lobe overflow through L1
- Coherent supersonic stream connecting WD and secondary star
- 'Hot spot' formed at collision of stream and disk

'Hot spot' or bright spot, evidenced in spectral data, is a strongly radiating reverse shock that occurs at the obliquely colliding flow of the stream to the disk. (see diagram in next section)

The shocked stream radiates as much or more energy at optical wavelengths as the WD, secondary, and disk combined.

Optical Depth vs. Mass Flow and Structure



Adapted from Rozyczka & Schwarzenberg-Czerny (1987)

'Hot spot' dynamics involve two shocks established in the vicinity of the collision,

$\rho_d > \rho_s$

$\rho_s / \rho_d \sim 10^{-2}$

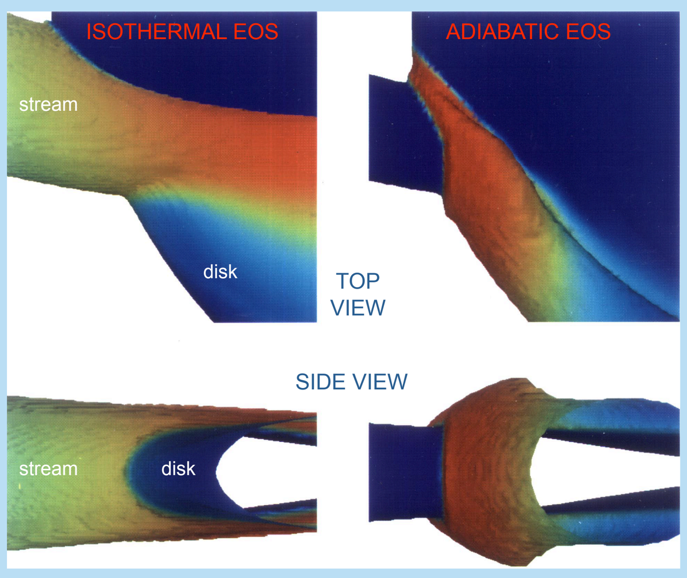
$M_s >> 1$

with the reverse shock in the stream being a strong shock

Optical depth, τ, of shocked regions can be linked to the mass accretion rate, M [M_{sun} yr^{-1}] (stream material from the secondary star) such that:

- τ α M
- Low accretion rate systems ➔ optically thin to intermediate
- High accretion rate systems ➔ optically thick

Simulations using different EOS's to distinguish these systems, show very different structure in the hot spot region



Armitage & Livio (1997)

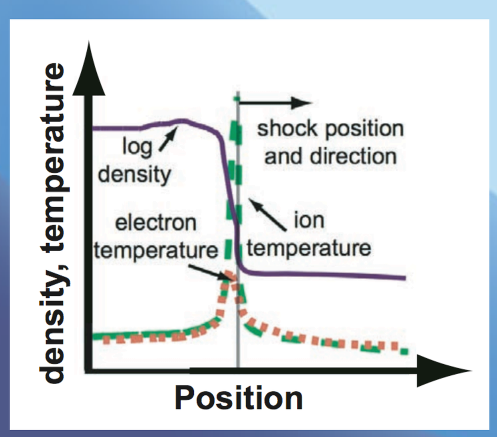
Isothermal EOS (optically thin)
- stream flows over disc
- region downstream of collision possesses significant inward velocity

Adiabatic EOS (optically thick)
- hot bulge extending along rim of the disc
- some overflowing but not coherent stream
- even in the absence of radiative cooling, the temperature declines rapidly downstream of impact

Reverse Shocks in the Radiative Regime, $R_{rad} \sim 1$

Radiative energy flux Material energy flux

downstream $\sigma T^4 \gtrsim \rho_o u_s^3/2$ upstream



$$R_{rad} = \frac{radiative flux}{material flux}$$

$$\frac{radiative flux}{material flux} \sim \frac{\sigma T^4}{\rho_o u_s^3} \propto \frac{u_s^5}{\rho_o}$$

where $T \propto u_s^2$

u_s is the upstream flow velocity into shock

Abstract

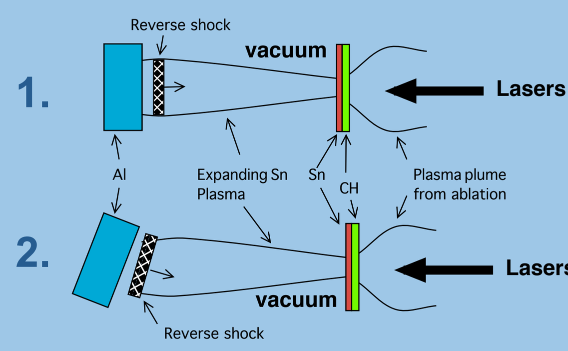
In many Cataclysmic Binary systems, mass onto an accretion disk produces a 'hot spot' where the infalling supersonic flow obliquely strikes the rotating accretion disk. This collision region has many ambiguities as a radiation hydrodynamic system, but shock development in the infalling flow can be modeled. Depending upon conditions, it has been argued (Armitage & Livio, ApJ 493, 898) that the shocked region may be optically thin, thick, or intermediate, which has the potential to significantly alter the hot spot's structure and emissions.

We report the first experimental attempt to produce colliding flows that create a radiative reverse shock at the Omega-60 laser facility. Obtaining a radiative reverse shock in the laboratory requires producing a sufficiently fast flow (> 100 km/s) within a material whose opacity is large enough to produce energetically significant emission from experimentally achievable layers. We will discuss the experimental design, the available data, and our astrophysical context. Insight to further iterations of the experiment will also be presented.

Proof-of-Principle Experiment

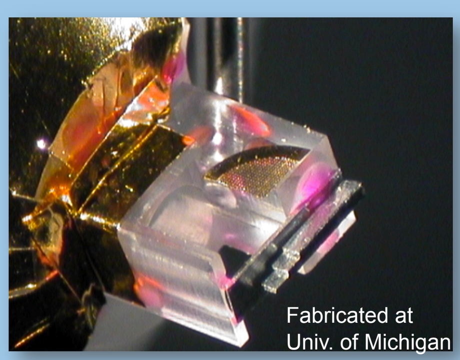
Long-term Experimental Question: In colliding winds where a less dense stream impacts a denser stream, how do the morphology and light curves vary as the optical depth of the shocked layer changes from thin to thick?

Primary Experimental Goal: After a plasma stream impacts a wall, how does the reverse radiative shock morphology appear and what does its spectrum look like?



Designed experiments

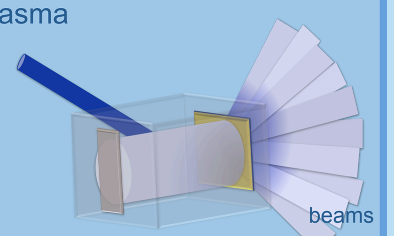
Built target



acrylic structure with 2 mm diameter cylinder milled out and attached foils

Designed target

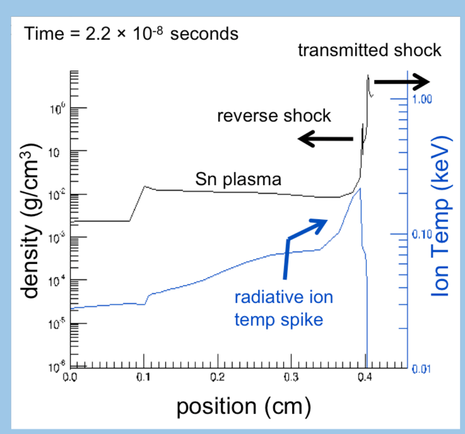
Laser beams ionize then drive motion of the plasma foils forward. Flow will decompress and accelerate through the experimental cylinder.



Eventually plasma reaches the dense end wall of Al and a reverse shock will develop in the flow while a forward shock will be driven into the end wall.

1-D (HYADES) and 2-D (CRASH) Simulations

HYADES Lagrangian radiation hydrodynamics code



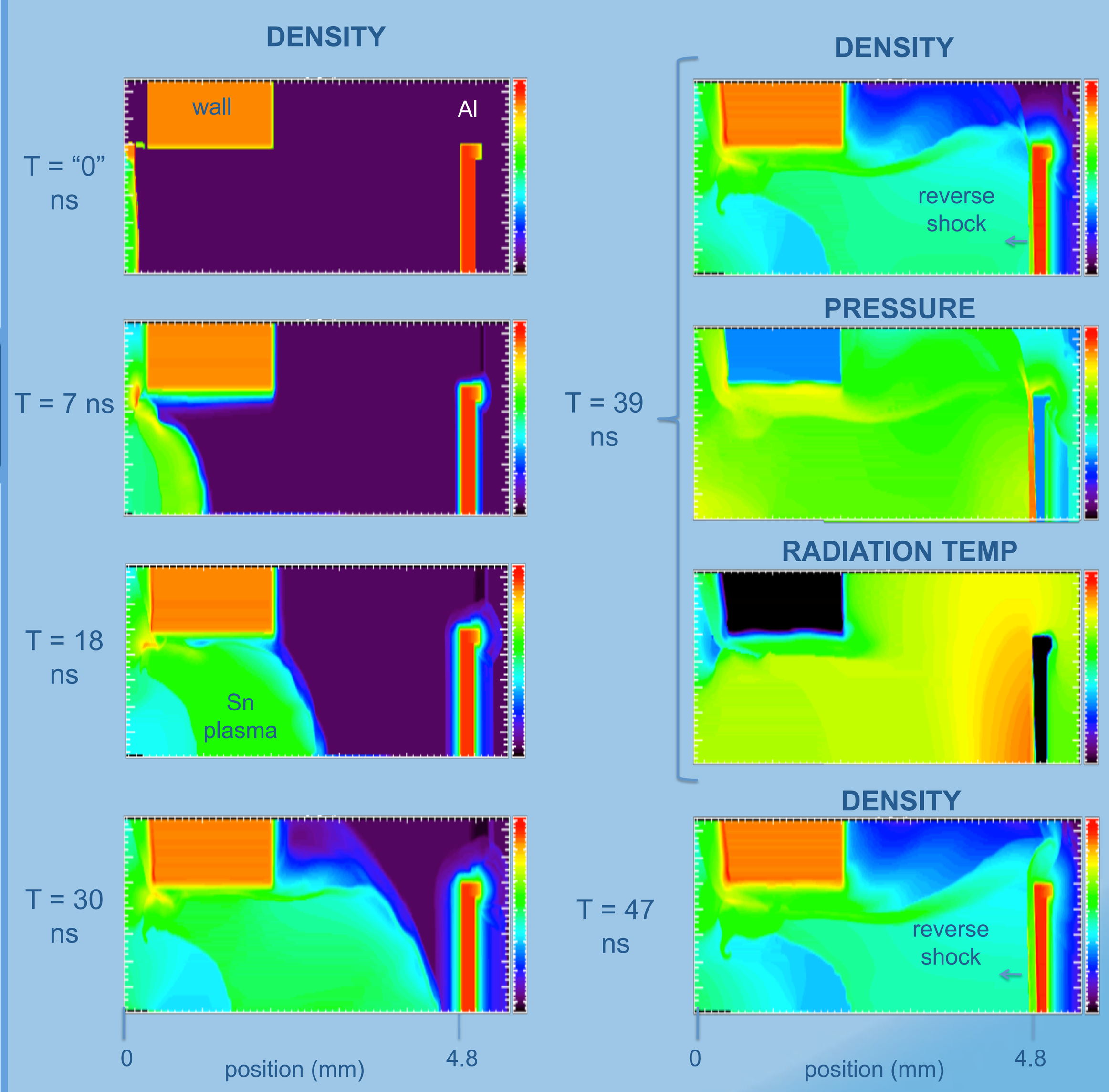
Both 1D and 2D simulations show evidence of radiative reverse shock formation.

We can use both codes to scope experimental parameters for carrying out shots:

e.g. 1D – materials
2D – plasma flow expansion

Note: magnitudes of parameters differ between 1D and 2D.
e.g. timing of stream wall impact

CRASH code with H2D laser input for initiation



Experimental Progression

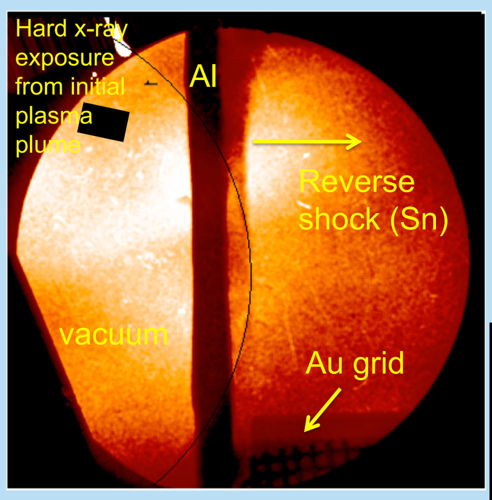
August 2010 – half day campaign on OMEGA-60

Normal incidence flows with Al wall.

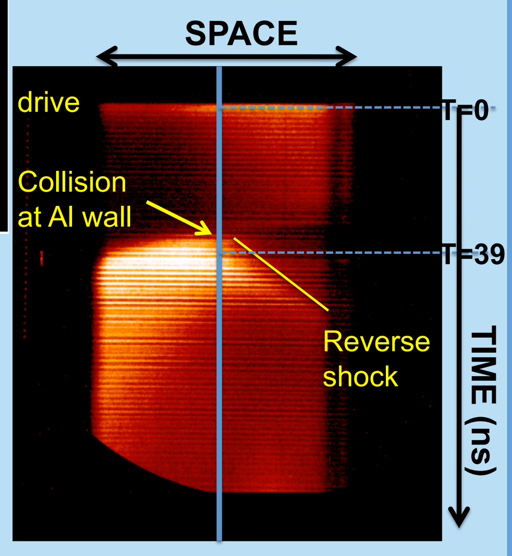
Multiple target designs

Primary diagnostics

- X-ray radiography – imaging experimental target at set time can give estimates of mass density, shock position, and morphology
- DANTE – x-ray spectrometer consisting of a filtered array of absolutely characterized x-ray diodes (XRDs). These are positioned to view the spectral soft x-ray emission from the formed reverse shock.
- SOP – optical pyrometer used to detect the thermal emission from the target and allow for time-streaked temperature measurements.



Radiograph at T = 39 ns



SOP data over 100 ns sweep

Dante didn't appear to be sensitive enough to low energy.

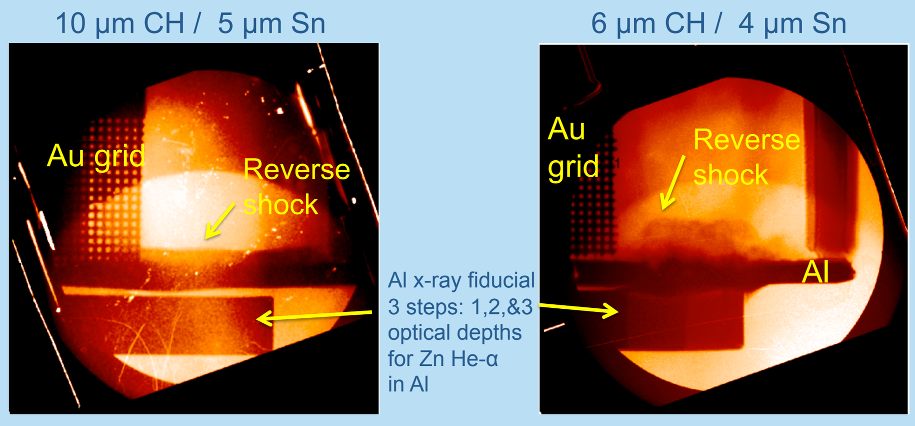
June 2011 – full day campaign on OMEGA-60

Normal incidence flows with Al wall.

Multiple target drive foils

Primary diagnostics

- X-ray radiography
- SOP
- µDMX – TIM specific x-ray spectrometer with lower channel capabilities.



At 32 ns after drive At 31 ns after drive

➔ µDMX received great data from reverse shock emission. Ongoing analysis by B. Loupias (CEA).

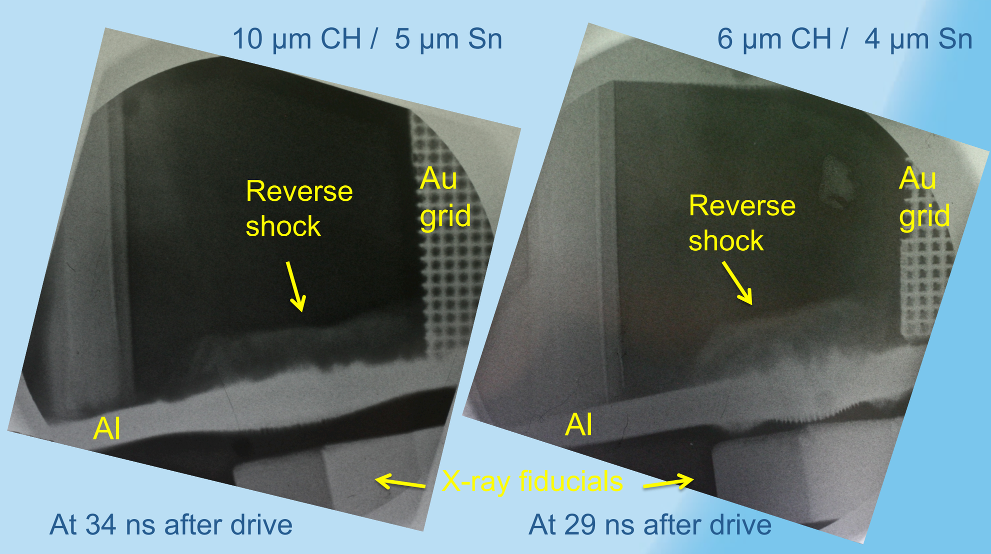
Sept 8, 2011 – half day campaign on OMEGA-60

Oblique incidence flows with Al wall.

Target shielding tests

Primary diagnostics

- X-ray radiography



At 34 ns after drive At 29 ns after drive

NOTE: images are photographs of developed film on light table.

Conclusions / Future Directions

Evidence of shock is in both x-ray radiography and SOP, and newest set experiments appears to have solved shielding issues in drive plume emission

In order to better represent the CV system, we hope to also achieve radiative reverse shocks in the laboratory under conditions of :

- obliquely colliding plasma stream with another denser stream - foam?
- changing materials for different optical depths

Acknowledgements

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