Shock Waves in Interstellar Space

Prof. Wayne G. Roberge
A Passion for Physics
Sept. 27, 2007
Outline

• Examples
• Properties in Common
• The Speed of Information
• Speed of Sound
• Shock Waves in Space
F/A 18 in Transonic Flight

Prandtl-Glauert Condensation (makes shock visible)
F 14 in Transonic Flight
Rifle Bullet in Air

cone-shaped shock

spherical shock
Supersonic Object in Air

object

“bow shock”
Battleship Firing Big Guns

shock front
Bursting Balloon

shock front
Nuclear Explosion

shock front
Moving Shock Front
What Causes Shock Waves?

In every example there is:

- a supersonic disturbance (jet, explosion...)
- in a compressible fluid (air, water).
Shock Wave in Traffic

\[ \text{undisturbed fluid} \quad \text{shock front} \quad \text{disturbance} \]

- Initially: uniform speed \( v \) and separation, \( L \).
- Next: driver on right touches brakes.
- Next: a traffic pileup ("shock") ensues.

\[ \text{WHY?} \]
Speed of Information

- Left driver sees light reacts.
- News travels left with speed \( c \) relative to traffic.

\[
c = \frac{L}{\Delta t}
\]

\( \Delta t \approx \text{human reaction time} \)
Signal Velocity Rel. to Ground

\[ u = v - c \]

- Shock (pileup) if \( u > 0 \) or \( v > c \).
- Now put in some numbers!

\[ V = 70 \text{ mph} = 100 \text{ ft/s} \]
\[ L = (N+1)h \]
\[ h = 13 \text{ ft (one car length)} \]
\[ \Delta t = 1.5 \text{ s}^* \]

**HOW MANY CAR LENGTHS (=N)?**

*Marc Green, ”How Long Does it Take to Stop?”, Transportation Human Factors, vol. 2, p. 195.*
A: Undisturbed (=cold) gas.
B: Deceleration in ~ few collisions (thin!).
C: Ordered motion $\rightarrow$ disordered (hot!).
Earth’s Bow Shock

solar wind
Aurora Borealis

11 May 1999
14:01:09 UT
Protostars Have Jets!

Jets from Young Stars • HH1/HH2
PRC95-24c • ST ScI OPO • June 6, 1995 • J. Hester (AZ State U.), NASA
HH47: 3 trillion Mile Jet
A Theoretical Model

Diagram of HH 30 Circumstellar Disk & Jet

- Accretion Disk
- Proto-Star
- Jet
HH30: Disk Detected!
Summary

• Shock waves = hydrodynamical surprises.
• Caused by supersonic disturbances.
• Found almost everywhere in space.
• Light up and heat cold interstellar gas.
• Allow us to see, study star-forming material.