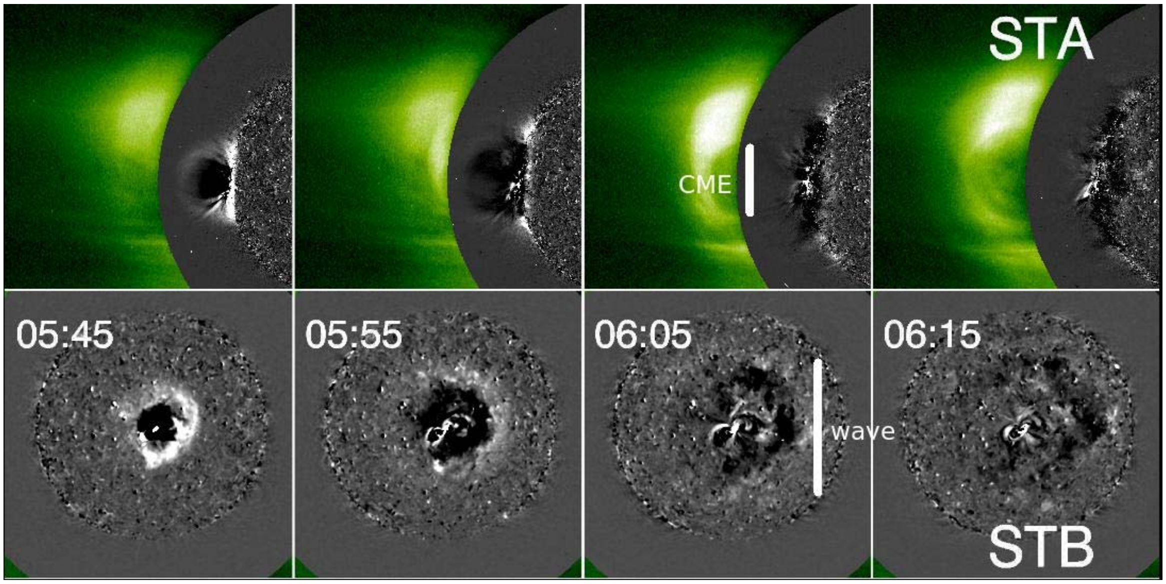


A solar tsunami that occurred in February 13, 2009 has recently been identified in the data from NASA's STEREO satellites. It was spotted rushing across the Sun's surface. The blast hurled a billion-ton CME into space and sent a tsunami racing along the sun's surface. STEREO recorded the wave from two positions separated by 90 degrees, giving researchers a spectacular view of the event. Satellite A (STA) provided a side-view of the explosion, called a Coronal Mass Ejection (CME), while Satellite B (STB) viewed the explosion from directly above. The technical name is "fast-mode magnetohydrodynamic wave" – or "MHD wave" for short. The one STEREO saw raced outward at 560,000 mph (250 km/s) packing as much energy as 2,400 megatons of TNT.

**Problem 1** - In the lower strip of images, the sun's disk is defined by the mottled circular area, which has a physical radius of 696,000 kilometers. Use a millimeter ruler to determine the scale of these images in kilometers/mm.

**Problem 2** - The white circular ring defines the outer edge of the expanding MHD wave. How many kilometers did the ring expand between 05:45 and 06:15? ( Note '05:45' means 5:45 o'clock Universal Time).

**Problem 3** - From your answers to Problem 1 and 2, what was the approximate speed of this MHD wave in kilometers/sec?

**Problem 4** - Kinetic Energy is defined by the equation K.E. = $1/2\ m\ V^2$ where m is the mass of the object in kilograms, and V is its speed in meters/sec. Suppose the mass of the CME was about 1 million metric tons, use your answer to Problem 3 to calculate the K.E., which will be in units of Joules.

**Problem 5** - If 1 kiloton of TNT has the explosive energy of $4.1 \times 10^{12}$ Joules, how many megatons of TNT does the kinetic energy of the tsunami represent?

**Problem 1** - In the lower strip of images, the sun's disk is defined by the mottled circular area, which has a physical radius of 696,000 kilometers. Use a millimeter ruler to determine the scale of these images in kilometers/mm.

Answer: The diameter is 31 millimeters ,which corresponds to 2 x 696,000 km or 1,392,000 km. The scale is then 1,392,000 km/31mm = 45,000 km/mm.

**Problem 2** - The white circular ring defines the outer edge of the expanding MHD wave. How many kilometers did the ring expand between 05:45 and 06:15? ( Note '05:45' means 5:45 o'clock Universal Time).

Answer: From the scale of 45,000 km/mm, the difference in the ring radii is 12mm - 5 mm = 7mm which corresponds to 7 mm x (45,000 km/1 mm) = 315,000 kilometers. Students answers may vary depending on where they defined the outer edge of the ring.

**Problem 3** - From your answers to Problem 1 and 2, what was the approximate speed of this MHD wave in kilometers/sec?

Answer: The time difference is 06:15 - 05:45 = 30 minutes. The speed was about 315,000 km / 30 minutes = 11,000 kilometers/minute, which is 11,000 km/minute x (1 minute/60 seconds) = 180 kilometers/sec.

**Problem 4** - Kinetic Energy is defined by the equation K.E. = 1/2 m $V^2$ where m is the mass of the object in kilograms, and V is its speed in meters/sec. Suppose the mass of the CME was about 1 million metric tons, use your answer to Problem 3 to calculate the K.E., which will be in units of Joules.

Answer: The mass of the CME was 1 billion metric tons. There are 1,000 kilograms in 1 metric ton, so the mass was 1.0 x $10^{12}$ kilograms. The speed is 180 km/sec which is 180,000 meters/sec. The kinetic energy is then about 0.5 x 1.0 x $10^{12}$ x $(180,000)^2$ = **1.6 x $10^{22}$ Joules.**

**Problem 5** - If 1 kiloton of TNT has the explosive energy of 4.1 x $10^{12}$ Joules, how many megatons of TNT does the kinetic energy of the tsunami represent?

Amswer: 1.6 x $10^{22}$ Joules x (1 kiloton TNT/4.1 x $10^{12}$ Joules) = 3.9 x $10^9$ kilotons TNT. Since 1 megaton = 1,000 kilotons, we have an explosive yield of **3,900,000 megatons TNT**. (Note; this answer differs from the STEREO estimate because the speed is approximate, and does not include the curvature of the sun).

**Teacher Note:** Additional information, and movies of the event, can be found at the STEREO website: **http://stereo.gsfc.nasa.gov/news/SolarTsunami.shtml.** Also published in the Astrophysical Journal Letters (*ApJ* **700** L182-L186)