Observations of Low-Frequency Radio Bursts with the STEREO Spacecraft

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STEREO Spacecraft

- Solar TERrestrial RELations Observatory
- Launched October 26, 2006
- Two identical satellites
  - STEREO A ("Ahead")
  - STEREO B ("Behind")
  - STEREO/WAVES instrument: low frequency (0.1 to 16 MHz) radio observations

![Locations on January 1, 2010](chart.png)
Calculating Source Location from Signal Delay

If a signal delay has been measured, the possible locations (on the sky) of the source can be calculated.

\[ l(t) = c \tau \]

- \( l(t) \): Distance between spacecraft at time \( t \)
- \( c \): Speed of light
- \( \tau \): Light-travel time between spacecraft
- \( \Delta t \): Signal delay (arrival time at B relative to A)

Potential locations (on the sky) of the source
Outline

- Delays in the arrival of signals for specific sources
- Processing STEREO/WAVES data
- Examples of observed events
  - Solar radio bursts
  - Jovian radio bursts
  - Null for GRB
- Future work
Low-Frequency Radio Sources

- **Known sources**
  - Earth (natural and human-made)
  - Sun
  - Jupiter (per se and with Io)
  - Saturn

- **Potential sources**
  - Sagittarius A*
  - Gamma-Ray Bursts
Delays in Signals from Extra-Solar ("Far-Field") Sources

Vastness of Interstellar Space

STEREO A

STEREO B
Delays in Signals from Extra-Solar ("Far-Field") Sources

Vastness of Interstellar Space

STEREO A

STEREO B

$\Delta t$

$\tau$

$c$

$c$
Delays in Signals from Solar System Sources
Delays in Signals from Solar System Sources
Signal Delays for STEREO Spacecraft

Comparison of Signal Delays

Signal Delay [min]

Time Since January 1, 2007 [d]

-15
-10
-5
0
5
10
15

2007
2008
2009

Jupiter
Sun
Earth
Sag A*
Delays in Signals from the Jupiter-Io System

- Radiation from the Jupiter-Io system is beamed.
- Two separate factors contribute to delay in arrival of a burst.
  - Distances of spacecraft from Jupiter
  - Angular separation of spacecraft in Io’s orbital plane

Gurnett and Goertz, 1981
Delays in Signals from the Jupiter-Io System

Orbital period: 1.77 d

- Factors affecting arrival of signals at STEREO spacecraft
  - Distances of spacecraft from Jupiter
  - Angular separation of spacecraft in Io’s orbital plane
Signal Delays for STEREO Spacecraft

Comparison of Signal Delays

- **Jupiter-Io**
- **Jupiter**

Time Since January 1, 2007 [d]

Signal Delay [min]
STEREO/WAVES (SWAVES)

Instrument

- **Antennas**
  - Number: 3
  - Description: orthogonal 6-meter monopoles

- **Number of receivers**: 2

- **Frequency range**: 0.1 - 16 MHz

- **Frequency channels**
  - Number: 319
  - Channel spacing: linear (50 kHz)

- **Duration of sweep**: 38.8 s
Processing STEREO/WAVES Data

1. Read in the measurements: auto-correlation of signal from each receiver of each spacecraft.
   - Function of time and frequency
   - Arbitrary units proportional to power
2. Convert all measurement values to a logarithmic scale.
3. Histogram the measurement values from each frequency channel.
4. Remove frequency channel’s whose histograms are not Gaussian.
5. Calculate the mean and standard deviation of the remaining frequency channels.
6. Convert the data to significance: for each datum, subtract the mean and divide by the standard deviation.
Solar Burst (Type III)
Solar Burst (Type III)

- Characteristic shape of burst
- Delay consistent with STEREO A being closer to the Sun than STEREO B
- Noisy frequency channels removed

Individual frequency sweeps

Significant Measurement Values — AUTO1

Frequency [MHz]

Time [min] after 12:54 UTC on 05/19/2007
Solar Burst (Type III)
Jupiter-Io Burst (Type A or C)
Jupiter-Io Burst (Type A or C)

Separate arcs

Characteristic shape: arcs swept back at high frequency

Delay consistent with signals from the Jupiter-Io system
Jupiter-Io Burst (Type A or C)
Jupiter-Io Burst (Type D)
Jupiter-Io Burst (Type D)

Characteristic shape of burst

Significant Measurement Values — AUTO1

- 4.0 to 8.0
- 8.0 to 12.0
- 12.0 to 16.0
- 16.0 to 20.0
- 20.0 to 24.0
- 24.0 to 28.0
- 28.0 to 32.0
- 32.0 to 36.0
- 36.0 to 40.0
- 40.0 <

Time [min] After 08:55 UTC on 10/02/2008
Gamma-Ray Burst (Null Result)
Conclusions

- **Summary of progress**
  - Development of code for calculating signal delays
  - Identification of Solar and Jovian radio bursts
  - Null result for detection of extra-solar bursts (i.e., from Sag A* and GRB’s)

- **Current lines of investigation**
  - Statistical analysis to search for frequent but weak events (e.g., from Sag A*)
  - Rigorous measurements of signal delays (versus just consistency checks)
  - Automatic identification of events