

Improved Test of General Relativity with Radio Doppler Data from the Cassini Spacecraft

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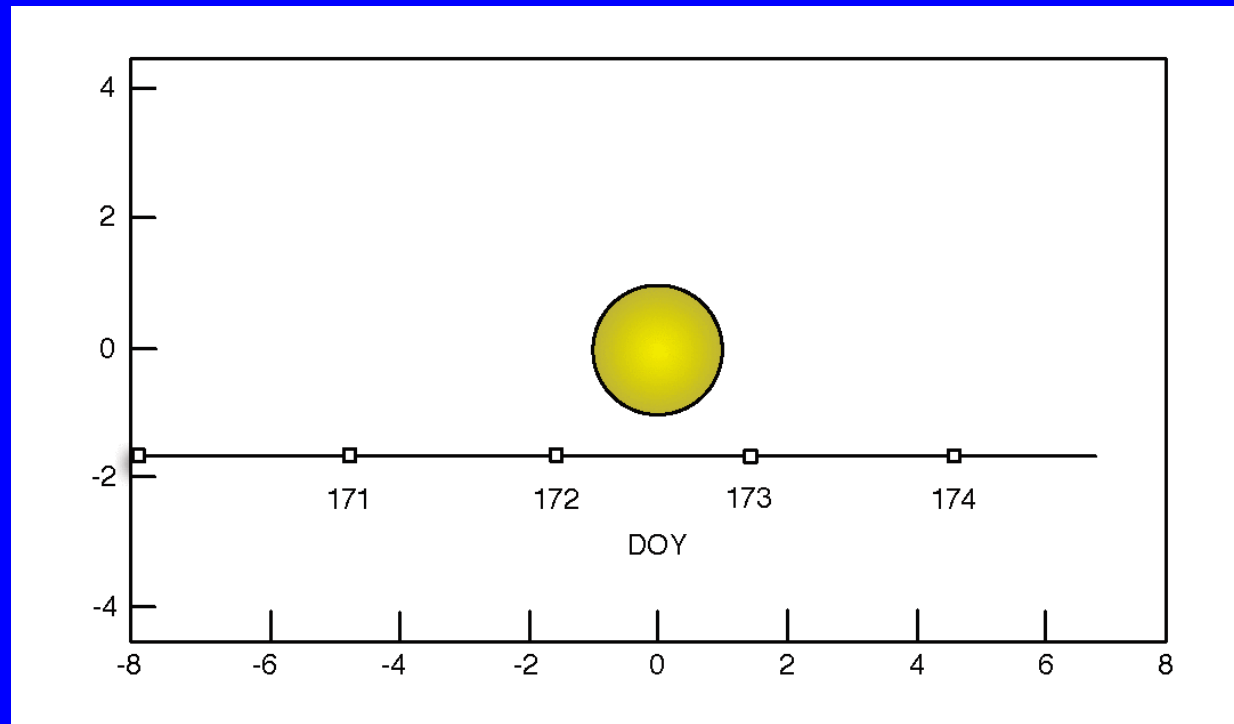
Talk Outline

- Propagation effects:
 - Solar corona plasma
 - Troposphere
- Results from closed loop data.
- Open issues

Cassini Relativity Tests

- The spacecraft Cassini, currently orbiting Saturn, is equipped with a multi-frequency radio link dedicated to Radio Science Doppler experiments.
- Two solar conjunctions in 2002 and 2003 were originally planned for Relativity tests. However, after the success of the SCE1, SCE2 was canceled by the Cassini Project due to technical problems with the reaction wheels.

2002 Solar Conjunction



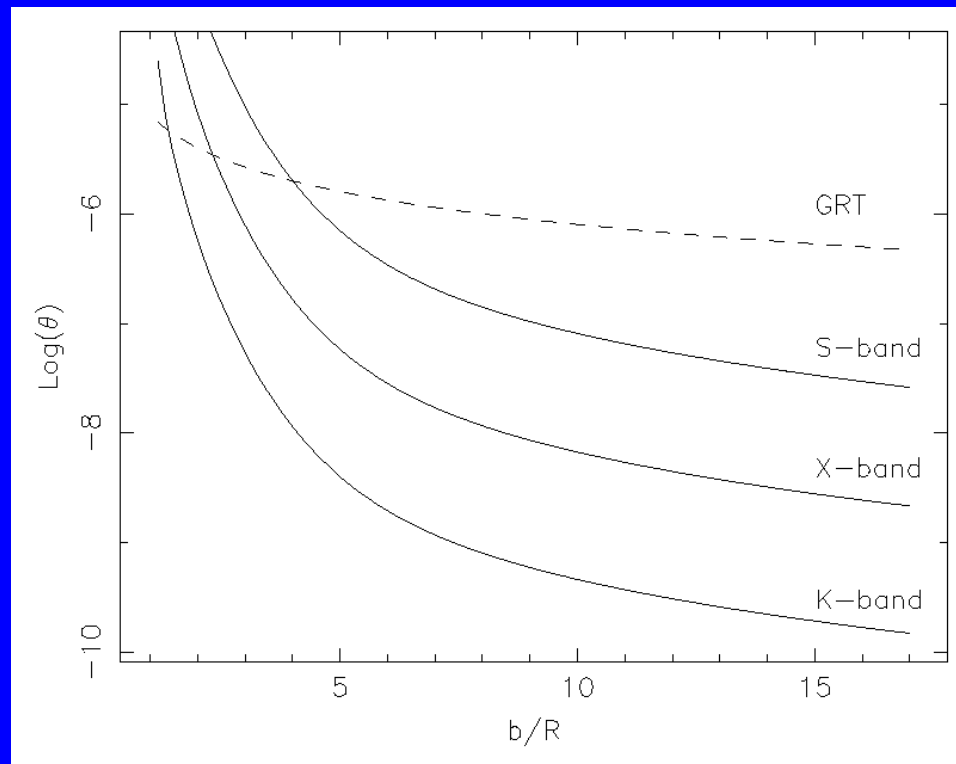
Plasma effect

The plasma in the solar corona produces a deflection and consequently a Doppler effect.

Compared to the relativistic effect, the plasma contribution:

1. is dispersive,
2. has opposite sign,
3. has different dependence on the impact parameter.

Deflection angle vs. impact parameter



Plasma calibration

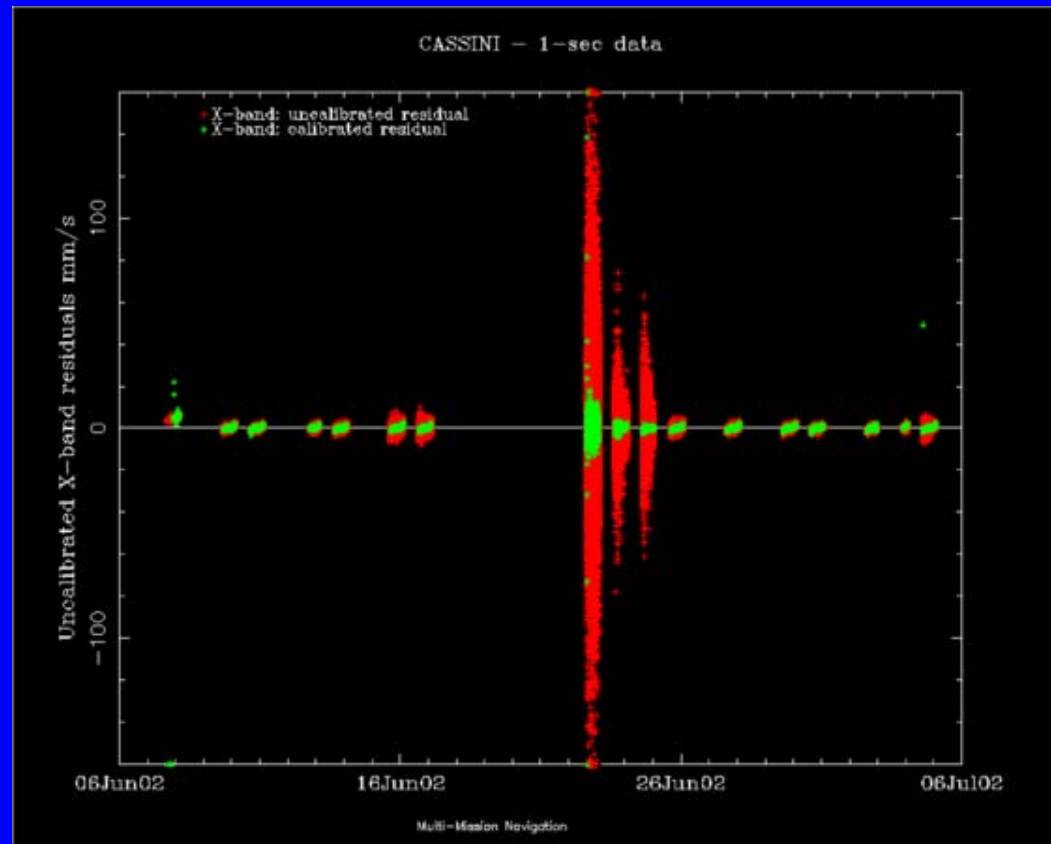
- The actual plasma noise is highly variable over all time scales, due to solar activity, solar flares in particular, coronal holes, solar rotation, etc.
- Thanks to the frequency dependence, the Doppler due to the solar plasma can be eliminated using multi-frequency radio links.
- The plasma can be almost completely eliminated with 3 distinct links.
- With only two links, a partial cancelation is still possible (Bertotti & Giampieri, 1997).
- Higher order effects (due to magnetic refraction index, differential paths, diffraction, etc) remains, but not important for $b > 4R_{\odot}$.

Cassini coherent Doppler links

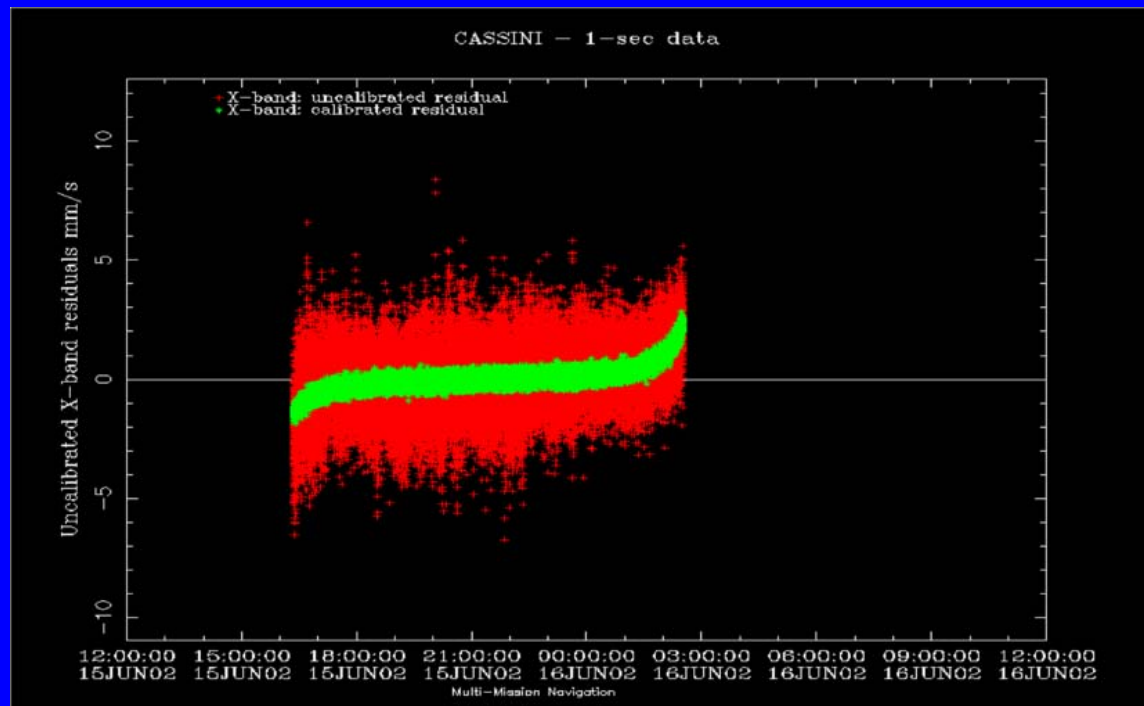
- Open loop data from JPL's Radio Science System can fully exploit the three links (X-band = 8 GHz, K_a -band = 32 GHz):
 1. X-band up, X-band down.
 2. K_a -band up, K_a -band down.
 3. X-band up, K_a -band down.

Note: link 2 is only available one third of the time, since only DSS25 has K_a -band transmission capability.
- Closed loop data from JPL's Navigation System only works in a two-link mode:
 1. X-band up, X-band down.
 2. K_a -band up, K_a -band down.

Calibrated X/X Residual during Solar Conjunction



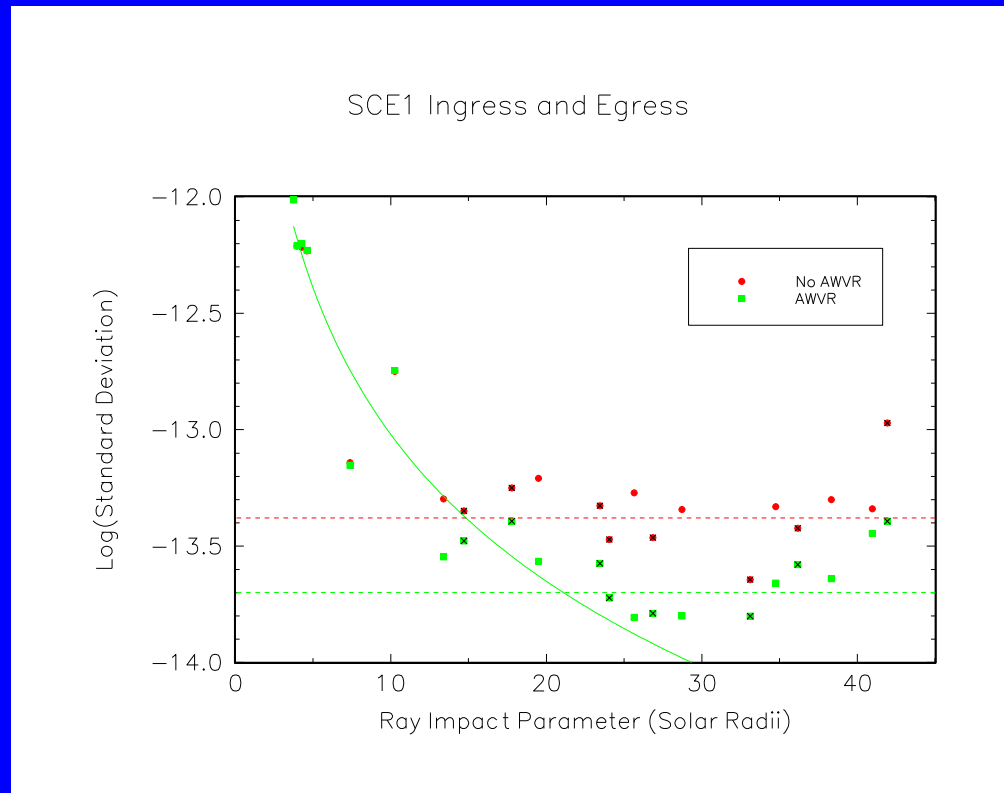
Example of Calibrated X/X Residuals



Doppler Calibration for Troposphere

- Apply JPL/ODP Doppler calibrations for both wet and dry troposphere.
- Read files containing Radio Science processed zenith path delays from two Goldstone water vapor radiometers at 30 s sample interval.
- Interpolate for Doppler data times and calculate uplink plus downlink Doppler corrections for wet component.
- Remove the long-term trend from the wet corrections and apply the resulting random residuals to the Doppler data.

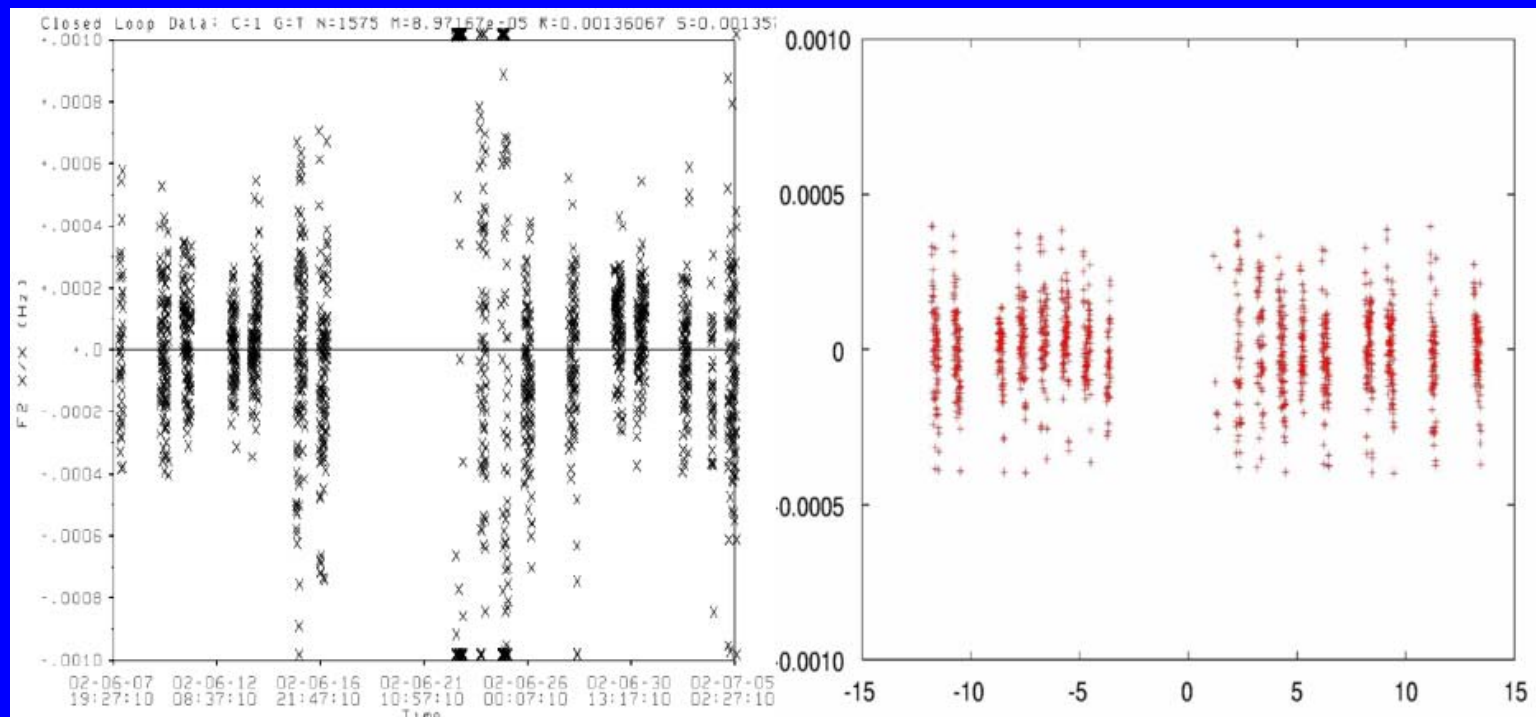
Effect of Tropospheric calibration



Post-calibration residuals

Closed Loop Data

Open Loop Data

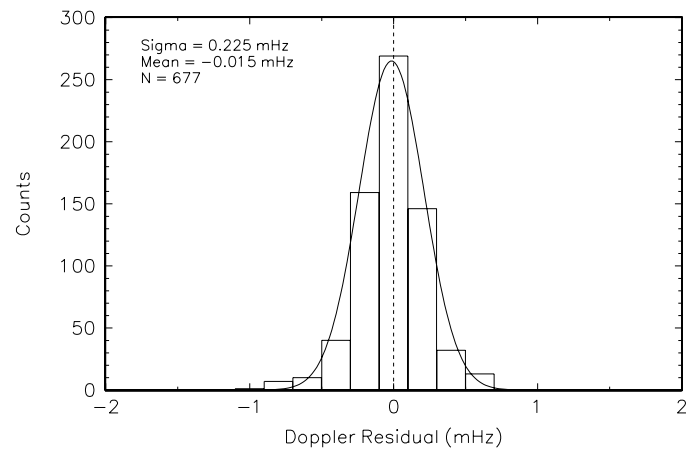


Results

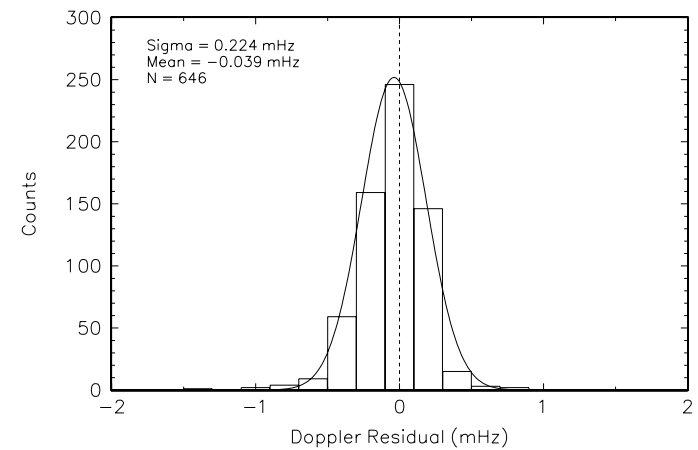
| | Closed loop NAV | Open loop RS |
|--------------------|--|--------------------------------|
| Data in the Fit | 1575 pts 17 passes | 1094 pts 18 passes |
| Calibration method | 2-link | 3-link |
| Media Calibration | Advanced media cals for wet troposphere | same |
| $\gamma - 1$ | $(6.0 \pm 4.9) \times 10^{-5}$ | $(2.1 \pm 2.3) \times 10^{-5}$ |

Evidence of systematic effects

Pre Conjunction Histogram



Post Conjunction Histogram



Correlation with non-grav forces

