rss_ringoccs: An Open-Source Analysis Package for Cassini RSS Ring Occultation Observations

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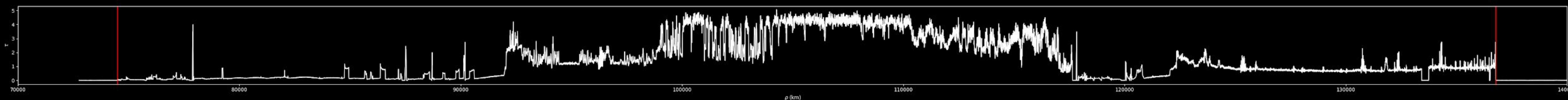
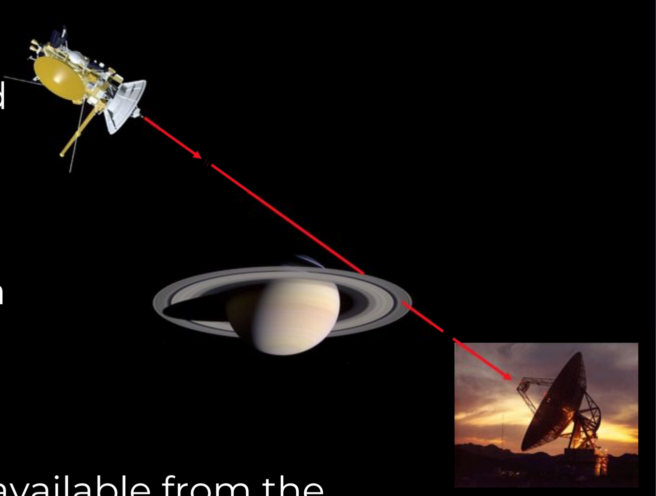
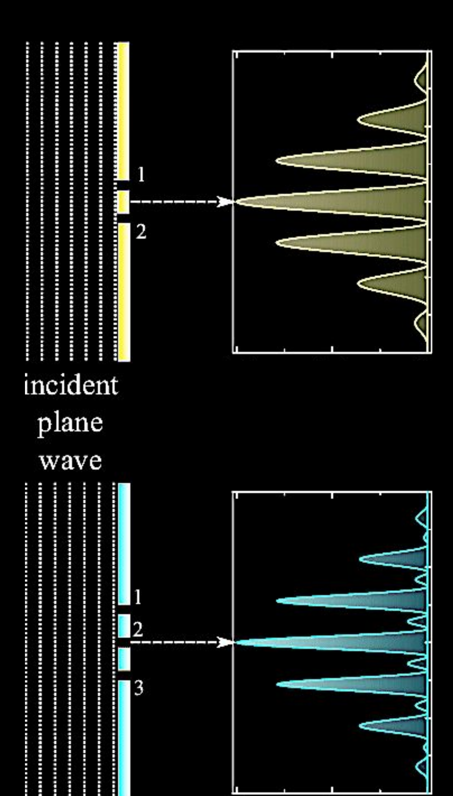


Motivation

- Over the course of the Cassini mission, the Radio Science Subsystems (RSS) team planned, observed, and recorded dozens of ring occultations at three wavelengths (0.9, 3.6, 13 cm, or Ka-, X-, and S-band, respectively).
- High-resolution raw radio science data from these observations are available from NASA's Planetary Data System (PDS) but are diffraction-limited.
- Diffraction-corrected ring profiles are available from the PDS at 1- and 10-km resolution for selected ring occultations.
- Our goal is to enable scientists to produce their own diffraction-corrected profiles at any desired resolution, using well-documented open-source code.



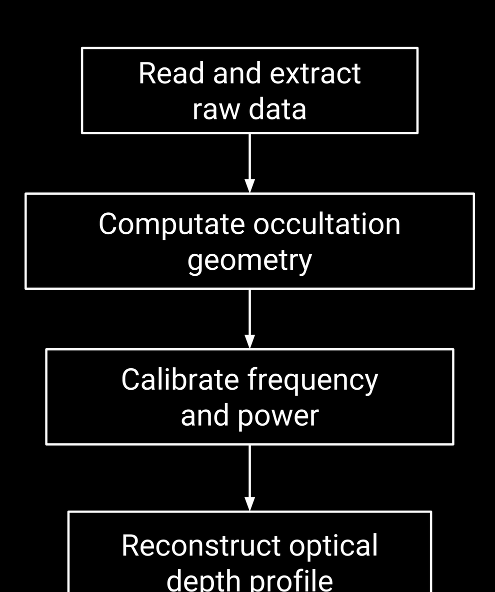
The Problem



- The radio signal received on Earth is diffracted by Saturn's rings.
  - This is similar to diffraction in a double slit experiment.
  - The goal is to determine the ring profile that produces the observed diffraction pattern.
  - This is possible because we observe both intensity and phase.
- Retrieving the diffraction-corrected ring profile is challenging because:
  - Diffraction theory has many subtleties.
  - Phase estimation requires sophisticated signal processing.
  - Signal-to-noise sets limits on the reconstructed resolution.
  - Saturn's ring structure is complex.
  - Each occultation is unique.

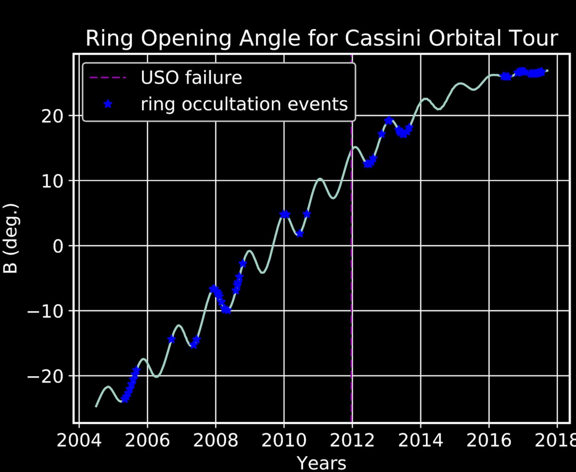
Features of rss_ringoccs

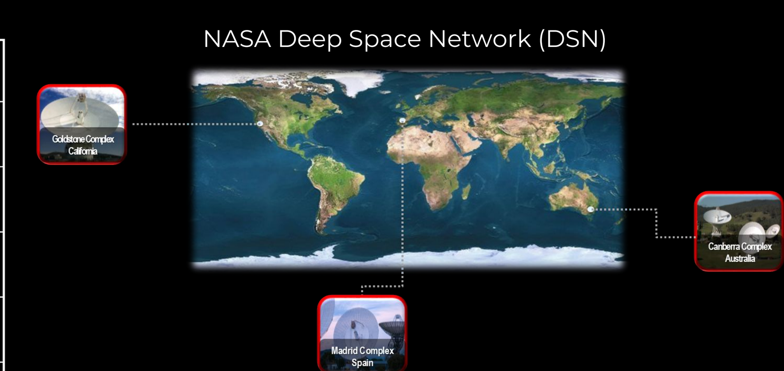
- Unix-based open-source Python 3 code available on GitHub
- Extensively documented
- Based on published algorithms
- Straightforward processing pipeline
- Simple user interface
- Output data files are in the same format as those on the PDS
- Saves input to re-run later, allowing a push-button process on subsequent runs
- Solid platform for users to develop and test their own algorithms

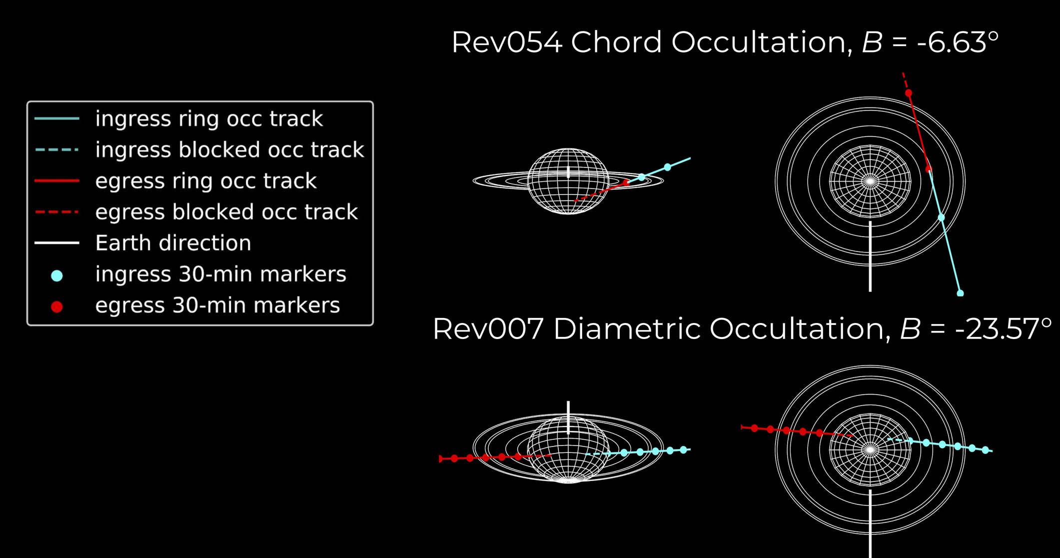


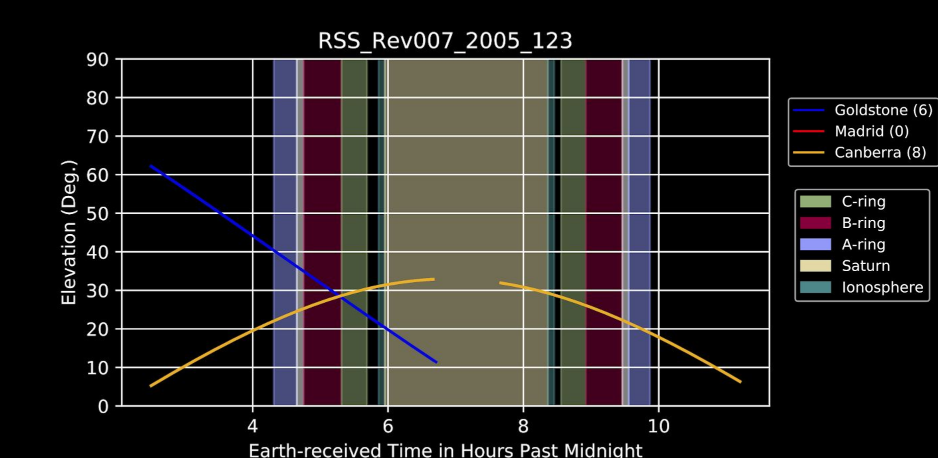
Processing Steps

1. **Choose a data file based on:**
   - Ring opening angle (*B*)
   - Elevation angle
   - Ring radius (*ρ*) range
   - Wavelength
   - Earth station antenna size
2. **Read and extract raw data from data file**
3. **Calculate geometry using NAIF SPICE Toolkit**

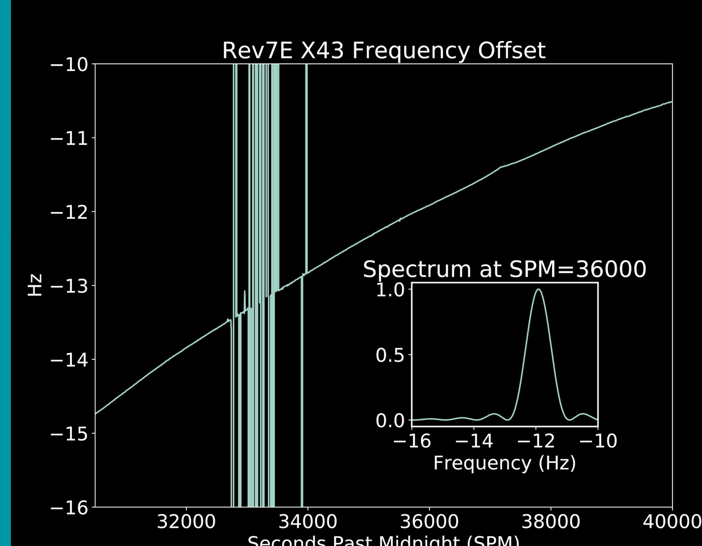




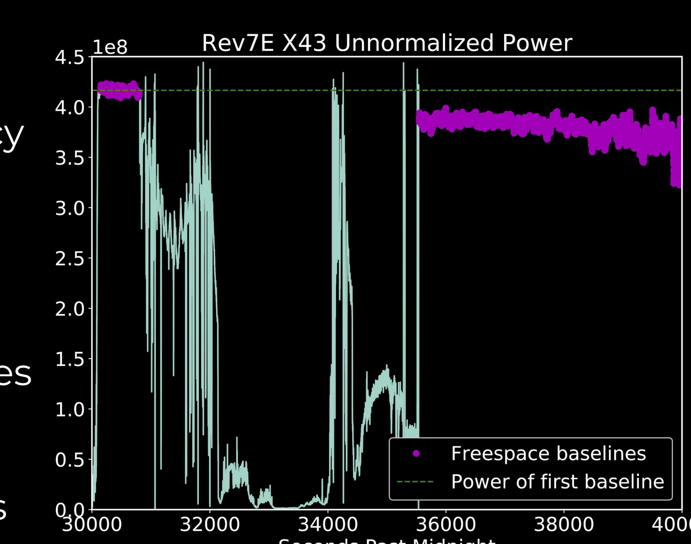




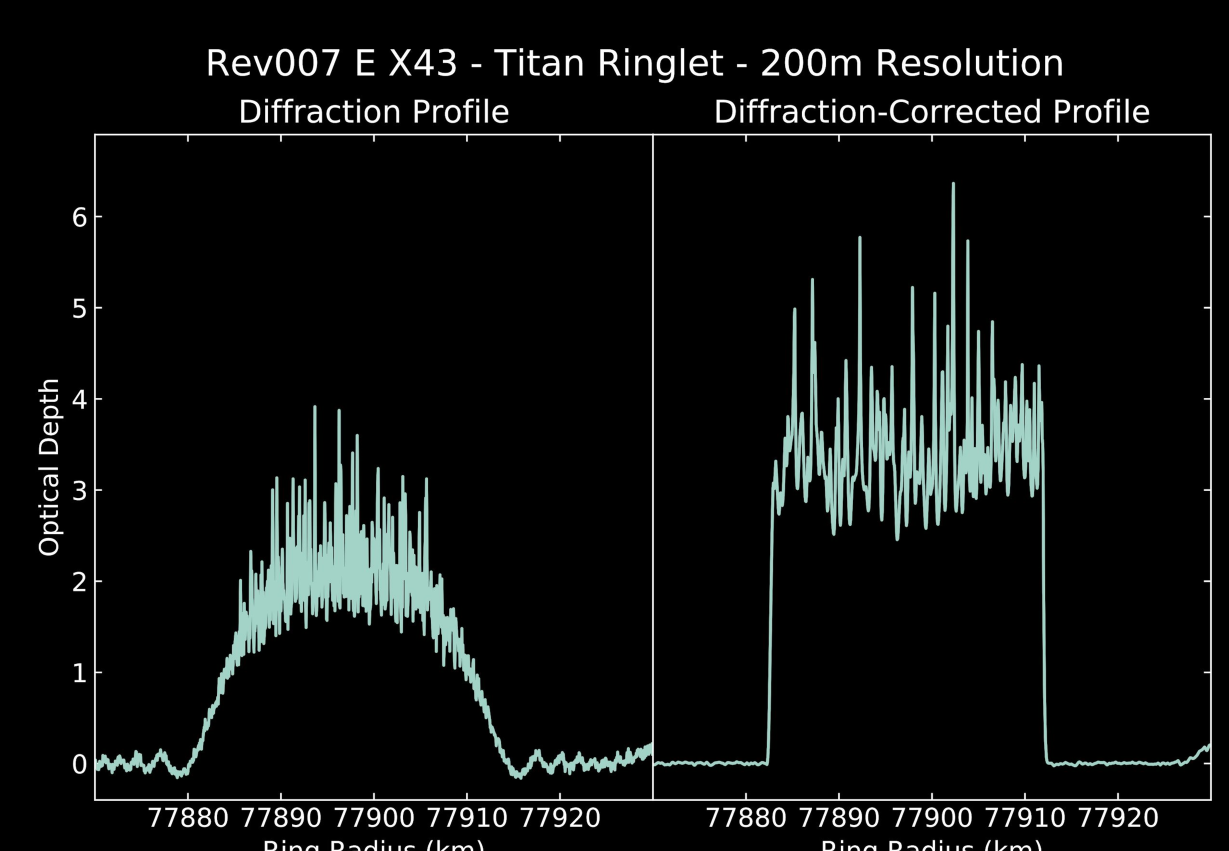
4. **Calibrate frequency and power using steps outlined in *Cassini Radio Science User's Guide***



- Frequency calibration (left)
  - Measure difference between received and expected frequency
  - Correct for frequency drift by fitting the observed curve
  - Sample spectrum (inset)
- Power normalization (right)
  - Observed free-space power varies during the occultation
  - We correct for this using a least-squares fit to these regions



5. **Reconstruct optical depth using algorithm from Marouf et al., 1986**

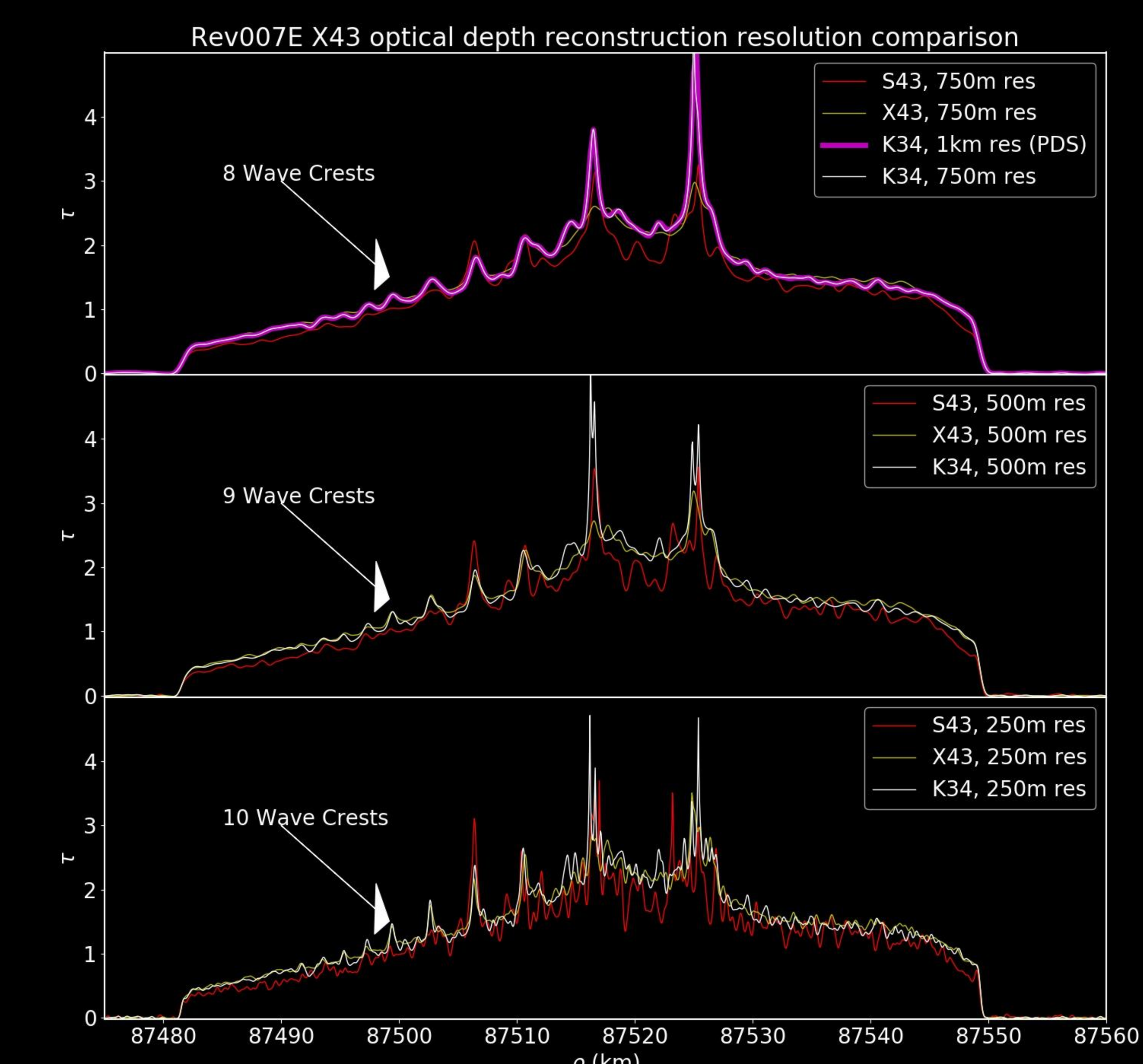


The sharp-edged Titan ringlet is an excellent test of diffraction correction.

- Observed diffraction pattern (left):
  - Resembles single-slit diffraction
  - Fringes appear outside ringlet
  - Ring edges are gradual and unresolved
- Diffraction-corrected profile (right):
  - Accurately retrieves sharp edges of the ringlet at 200m resolution
  - Diffraction fringes are gone
  - Internal structure is noise-limited

The Maxwell Ringlet

- Diffraction-corrected profiles at all 3 radio wavelengths
  - Resolutions of 750m, 500m, and 250m at S-, X-, and Ka-band
  - Similar structure seen at all three wavelengths
- As resolution is increased:
  - More detailed internal structure is revealed
  - Wave crests are sharper and well-defined
  - Reliability of the profile becomes limited by signal-to-noise
- Our results closely match those on the PDS



Summary

- rss_ringoccs results match PDS to high accuracy
- Users can produce their own diffraction-corrected profiles at any desired resolution, limited only by signal-to-noise
- A complete end-to-end run takes less than five minutes for Rev007 X-band egress at 750m resolution
- Extensive documentation includes sample runs
- The entire open-source Python package is available on GitHub

Acknowledgements & References

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