Jet Propulsion Laboratory
California Institute of Technology

Rosetta Shadow Navigation Analysis Tools

Aka My Internship at JPL

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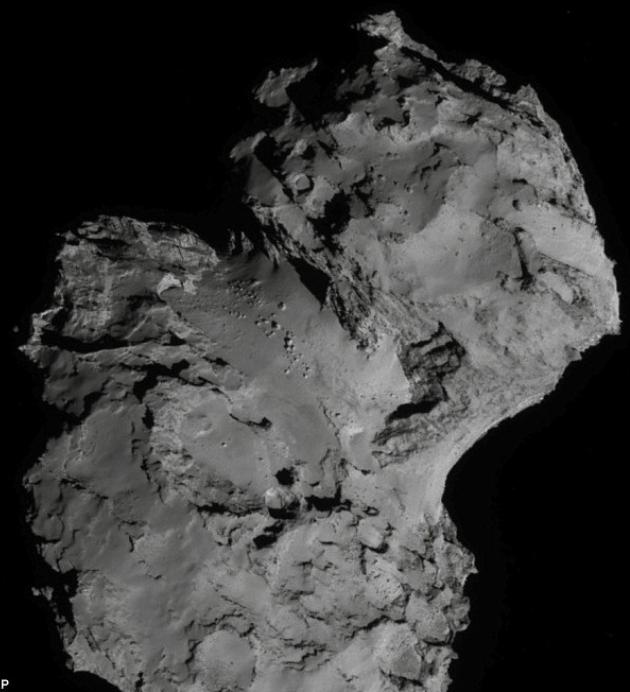
Friday, September 23, 2016



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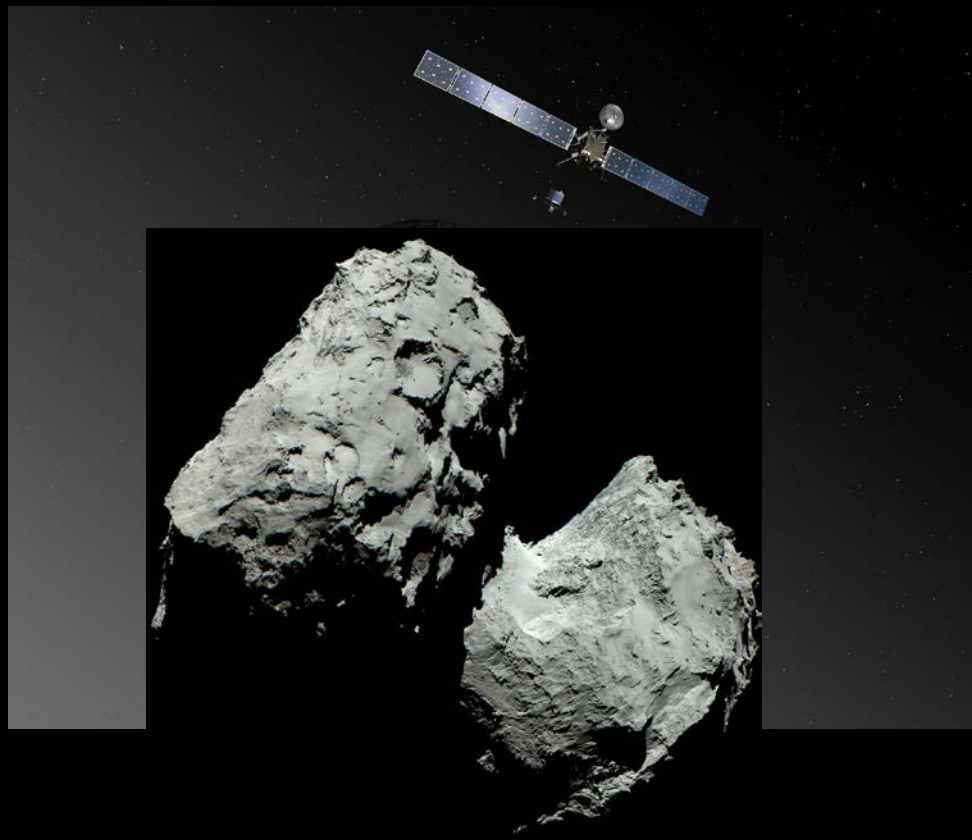
Rosetta Mission Overview

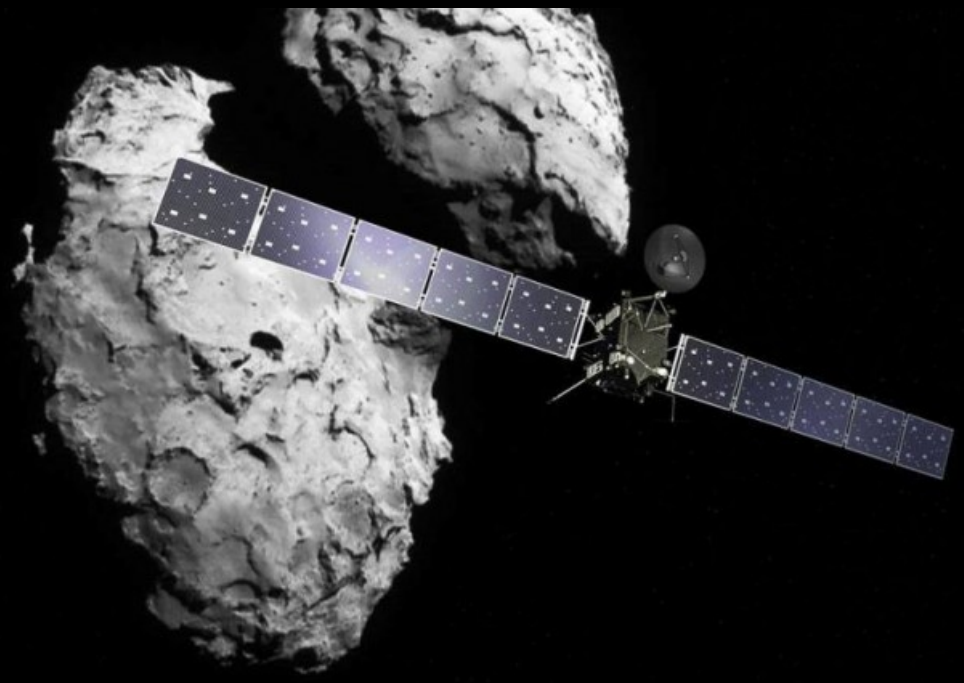
- Rosetta orbiter, Philae lander
- Operated by European Space Agency
- Launched March 2004
- Arrived at Comet 67P/ Churyumov-Gerasimenko May 2014
- Philae hopped around the surface in November 2014
  - Entered into hibernation a few days after landing
- Plan: Land Rosetta on Sept 30th, 2016



*http://www.esa.int/Our_Activities/Space_Science/Rosetta

JPL Shadow Navigation

- JPL produces independent orbit determination (OD) solutions
  - eg. Optical navigation landmarks, dynamical modeling, estimation procedures
- Compare with ESA
- Weekly telecoms and solution exchanges
  - Began in Aug 2016



Analysis Tools Overview

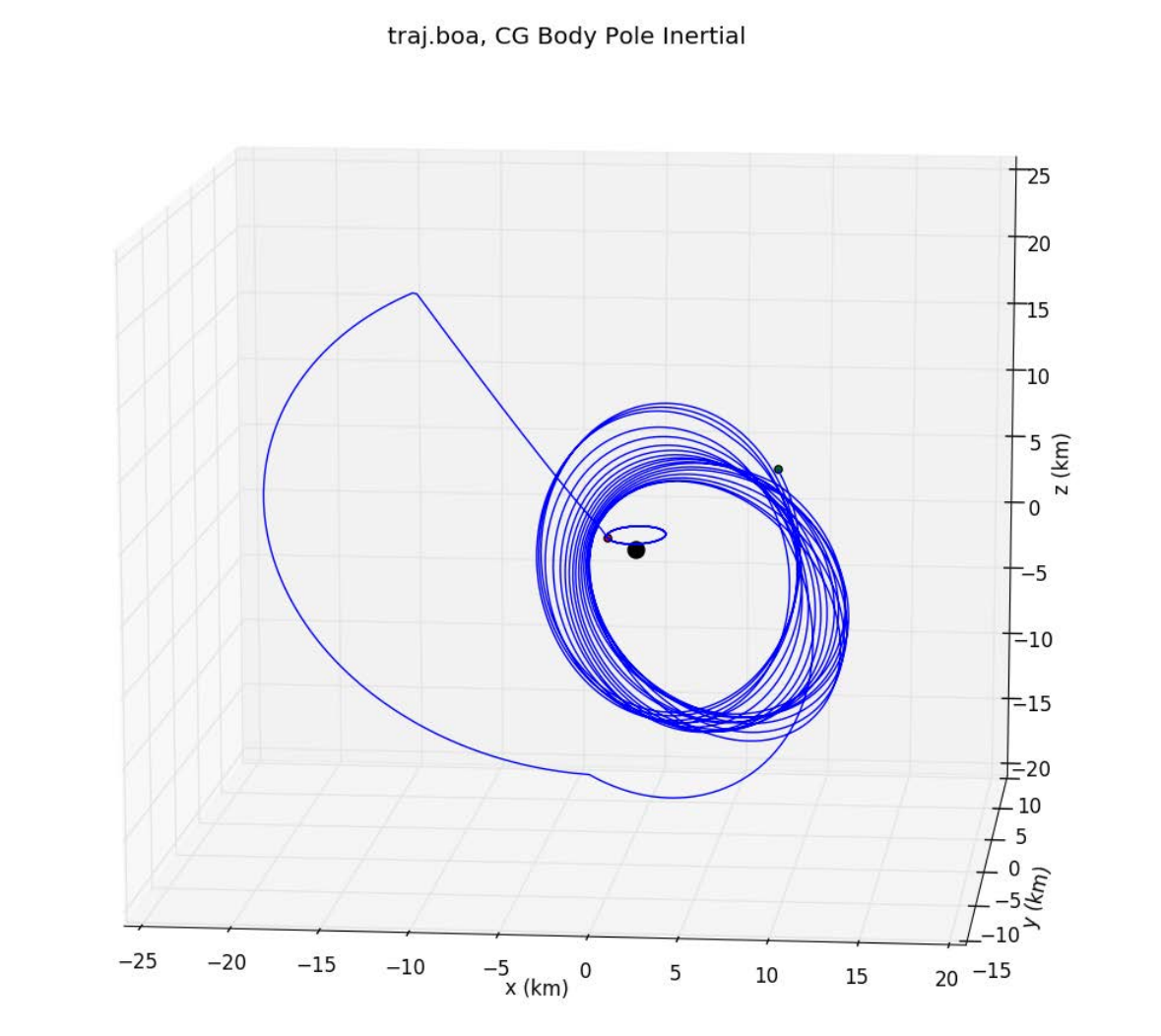
- Trajectory Analysis
- Gravity Sensitivities
- Filter Analysis
- Comparing Solutions
- OD Variations
- Lessons Learned

Trajectory Plots

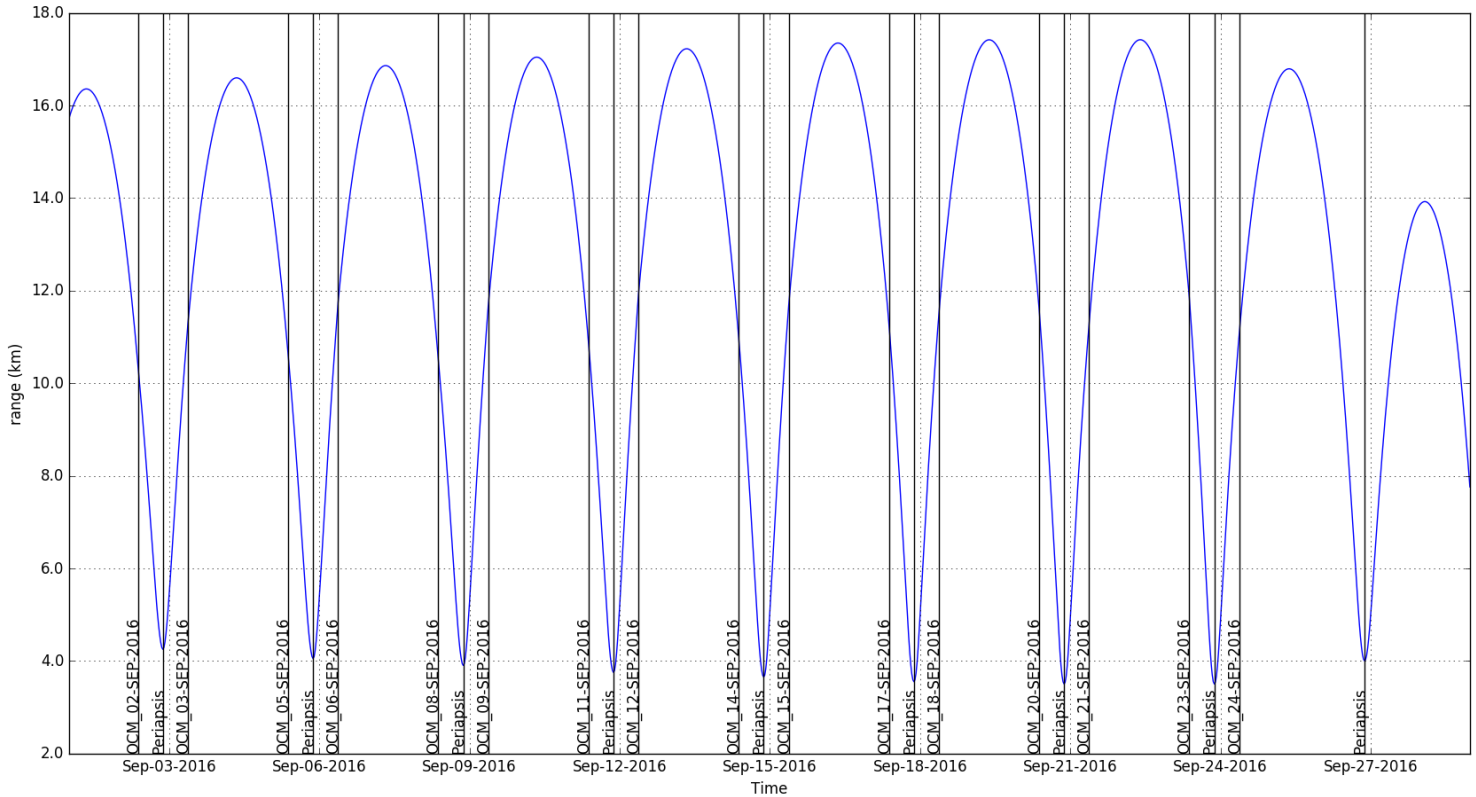
What's actually happening?

Aug 01 – Oct 02

CG Body Pole Inertial Frame

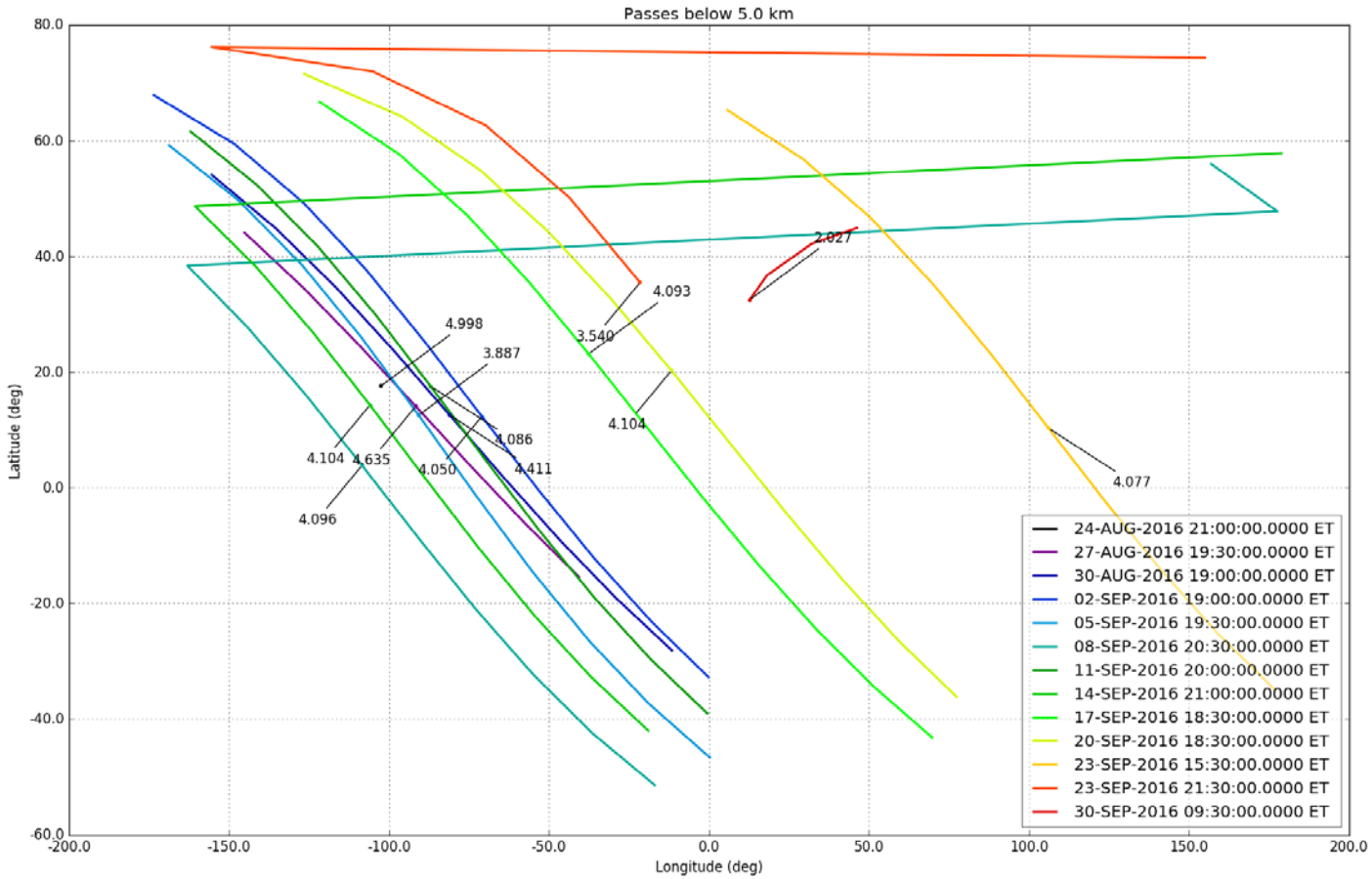


Trajectory Range Plots



Latitude/Longitude Ground Tracks

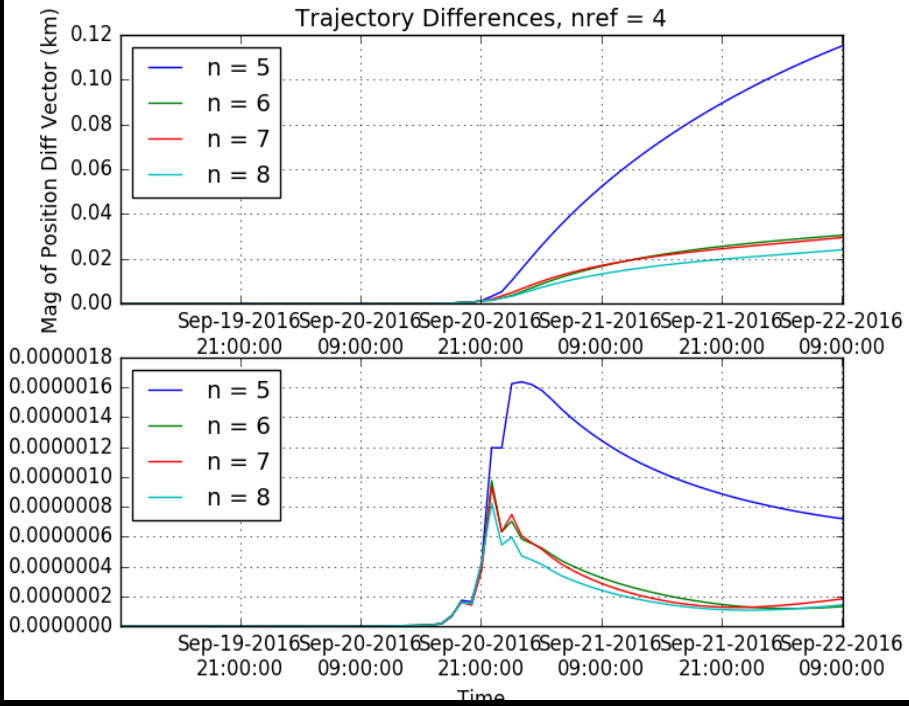
Ground tracks below 5 km, and minimum range

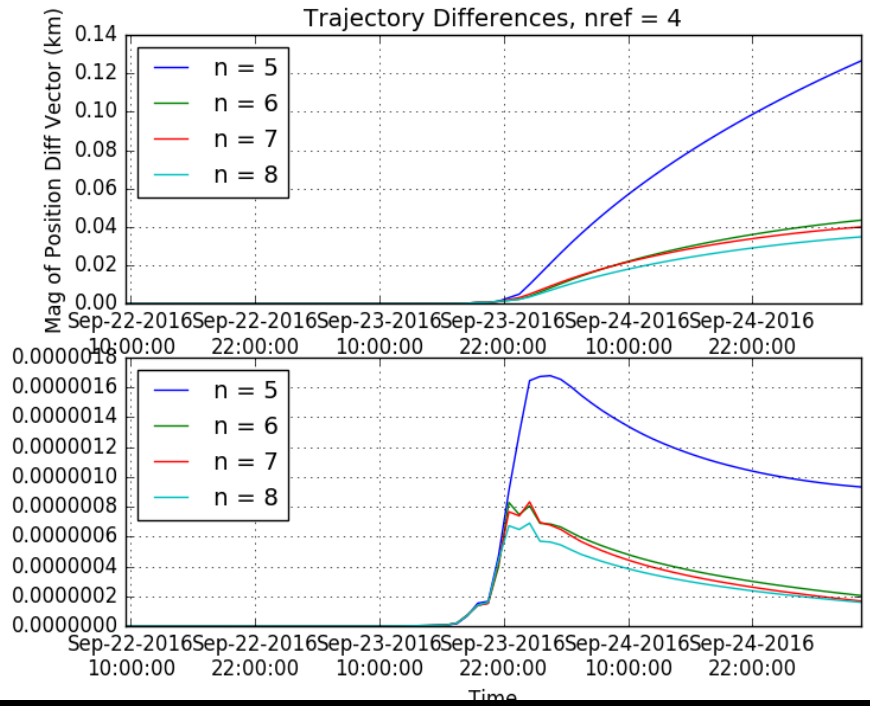


Gravity Sensitivity: Integration

Trajectory propagation with different spherical harmonic degrees

- Extracted initial state from longterm reference trajectory
- Integrated from apopasis to apoapsis with increasing degrees of spherical harmonics
  - Compared to lower degree trajectory





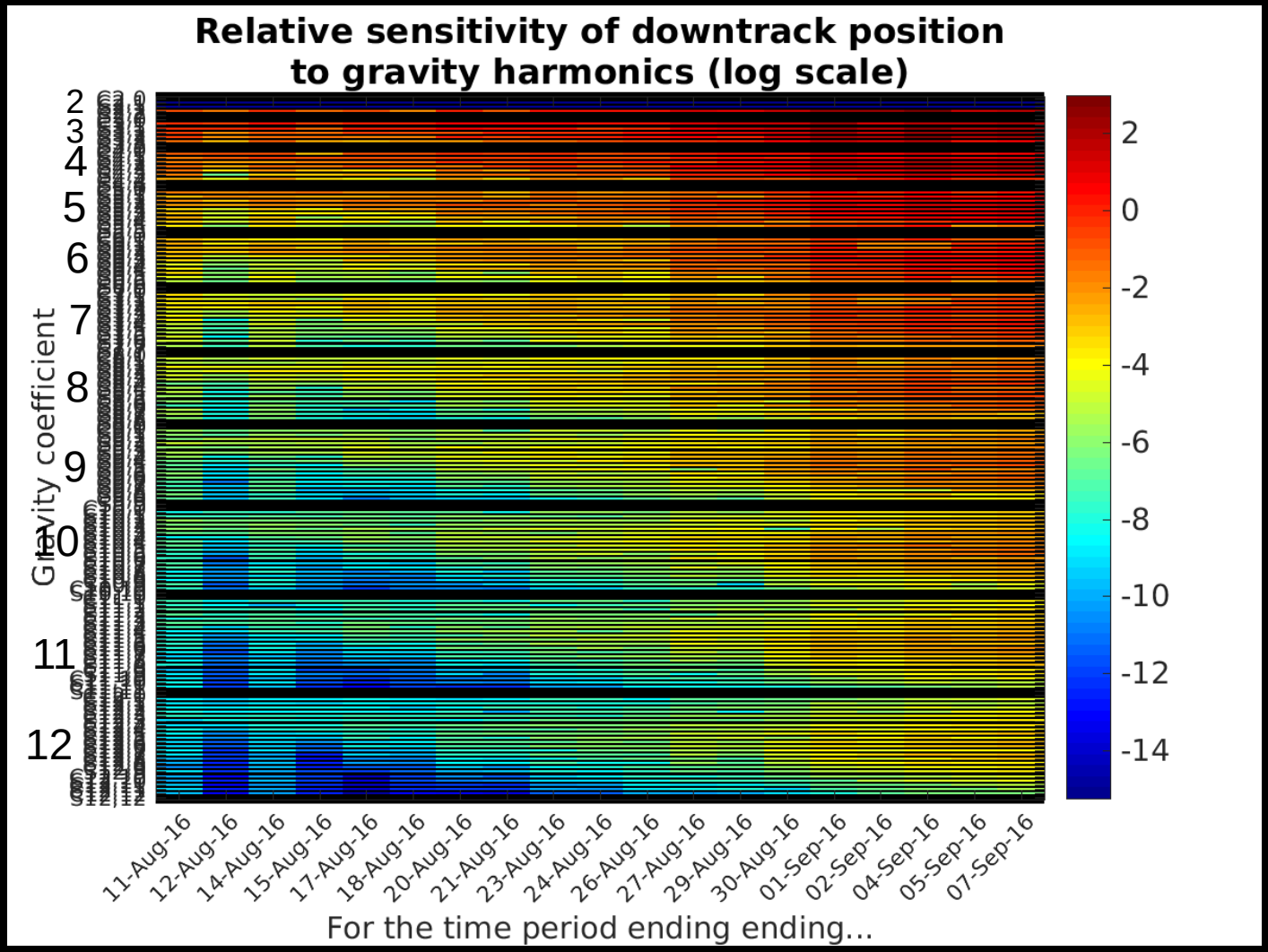
Gravity Sensitivity: State Transition Matrix

Analyzing the STM

- Tool adapted from DAWN
- Initial state from a reference trajectory
  - Propagated for 8 days
- Record state transition matrix of the position with respect to the gravity parameters
  - At end of propagation
- Move initial state +1.5 days
- Repeat
- -> How the harmonics of the gravity field affect the state over 8 days

Gravity Sensitivity: STM

Downtrack position sensitivity

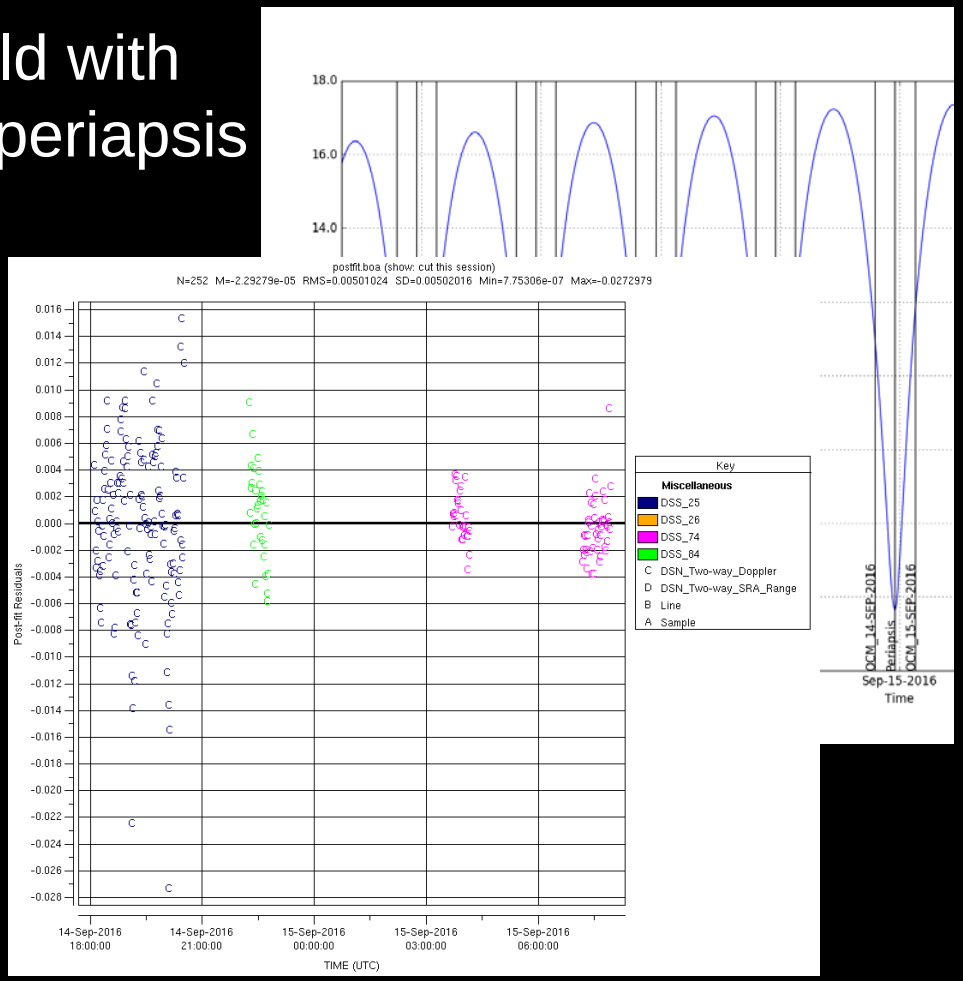


Case:
0803-0823_das

Gravity Estimation with Periapsis Data

Estimation

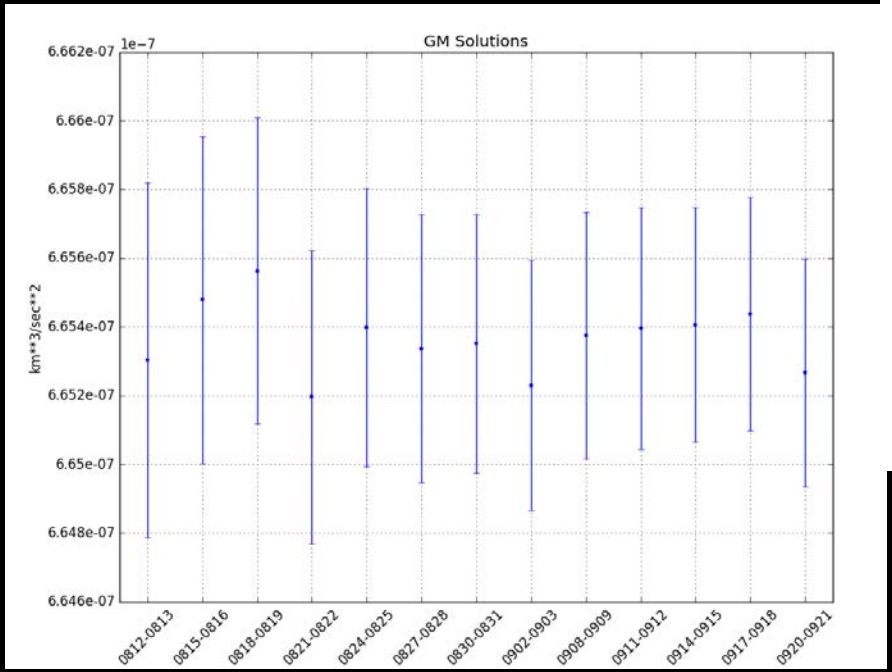
- Estimated the gravity field with "clean" arcs around the periapsis
- Take gravity solution from one arc and use it as a priori for next arc
- 0812-0813 – 0920-0921
  - 14 periapsis passes



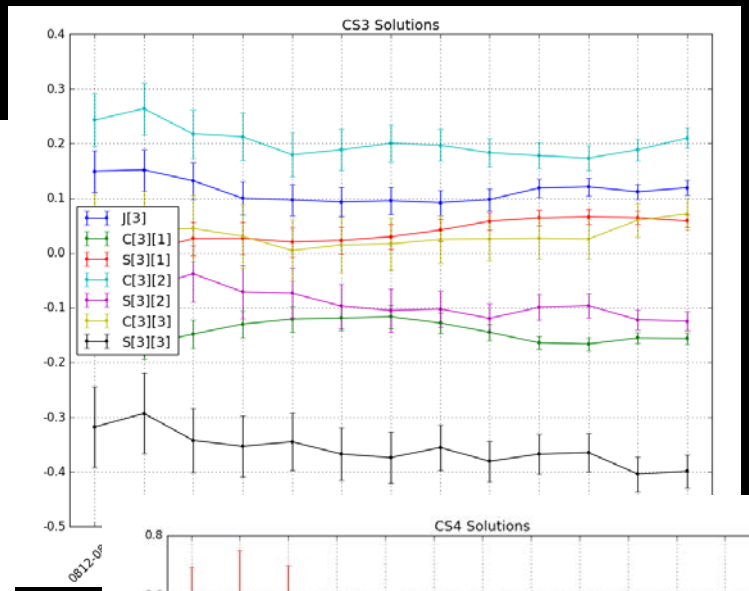
Gravity Estimation with Periapsis Data

Evolution of Coefficients

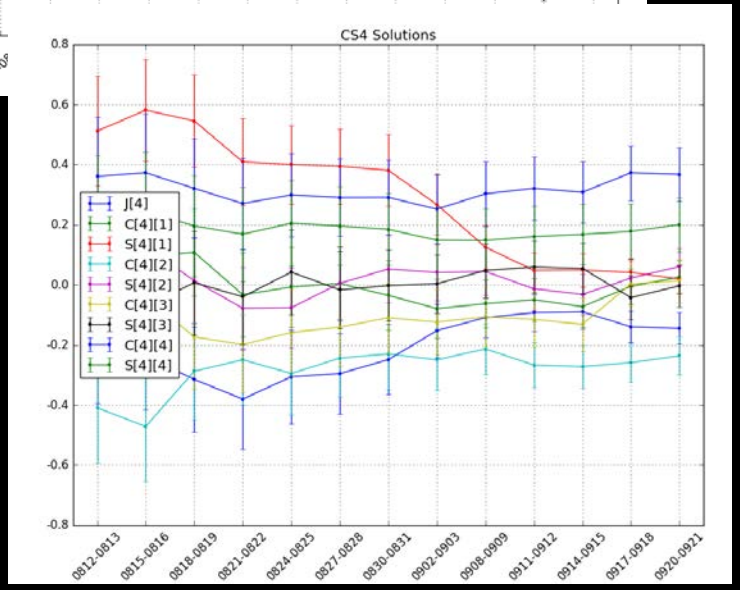
GM Evolution



CS n=3



CS n=4

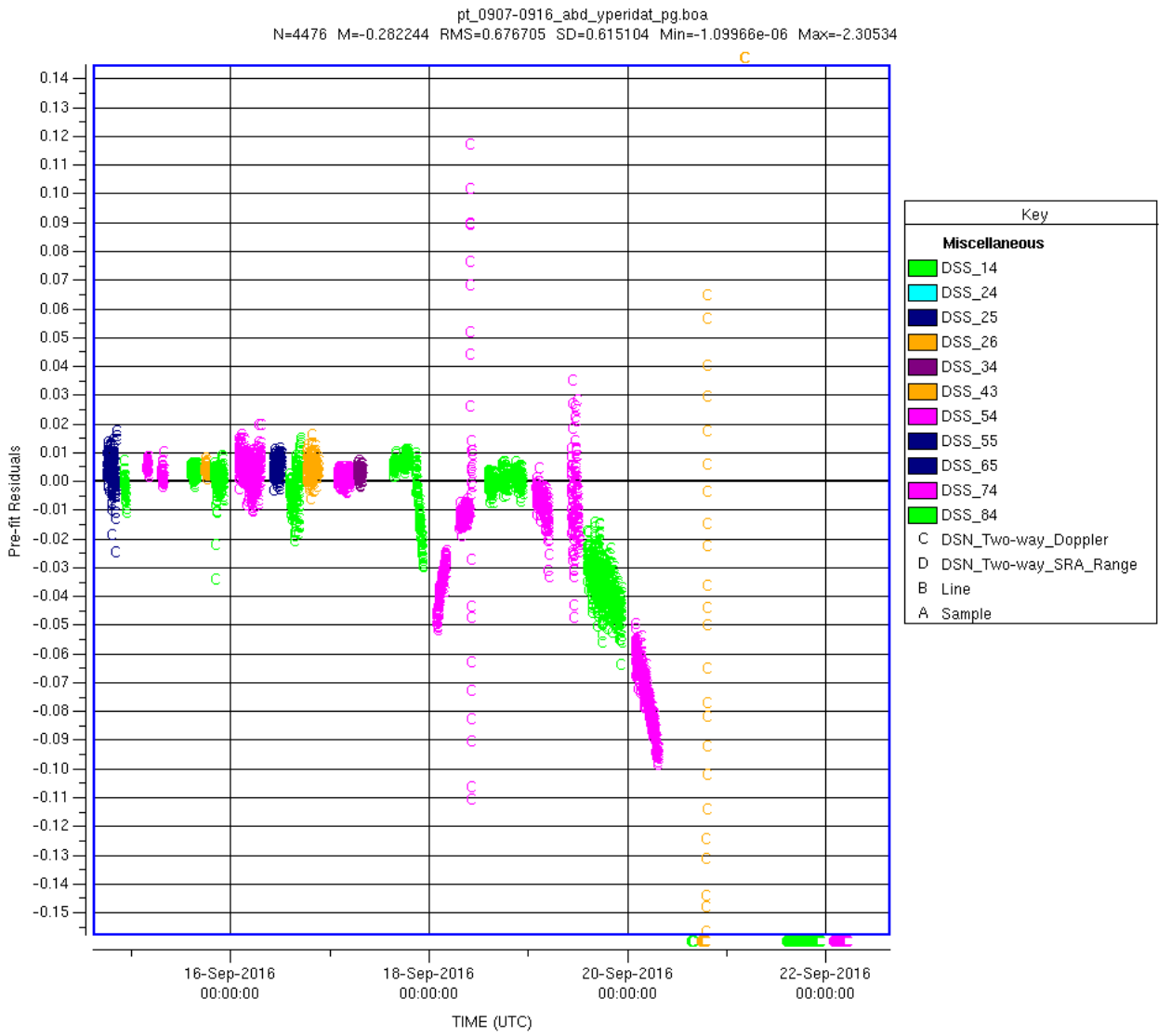


Gravity Estimation with Periapsis Data

Performance

- Reconstruction: 0907-0916 data arc
- Pass thru until 0922
  (periapsis at 0921)
- Curvature around apoapsis

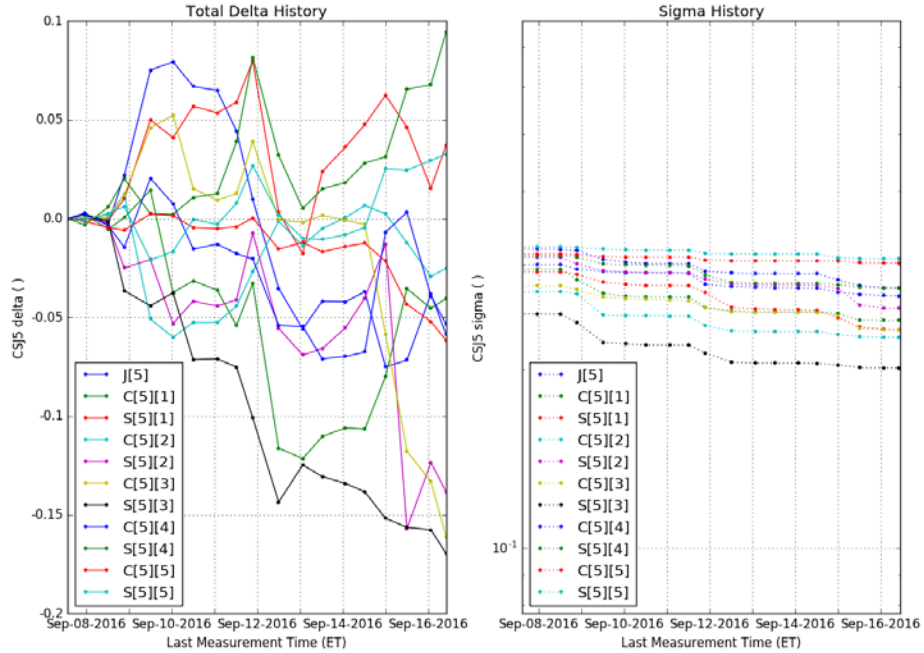
0907-0916_abd_yperidat_pg



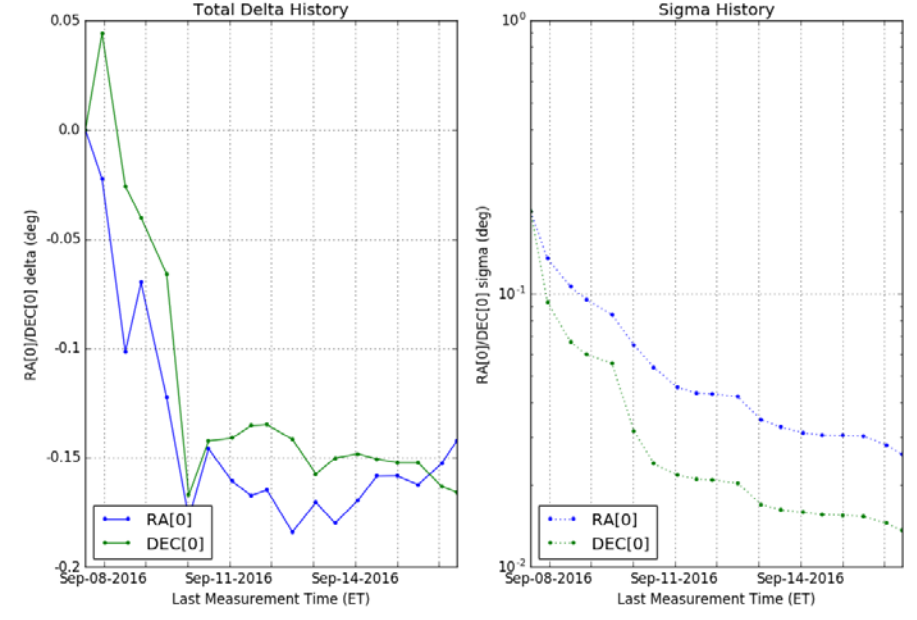
Filter Analysis: Parameter Filter Mapping

- Created a ‘FullSol’ filter mapping
  - Tracked non-state parameters as measurements were added
- Plot from command line

Gravity 5th degree and order



RA and DEC of the pole

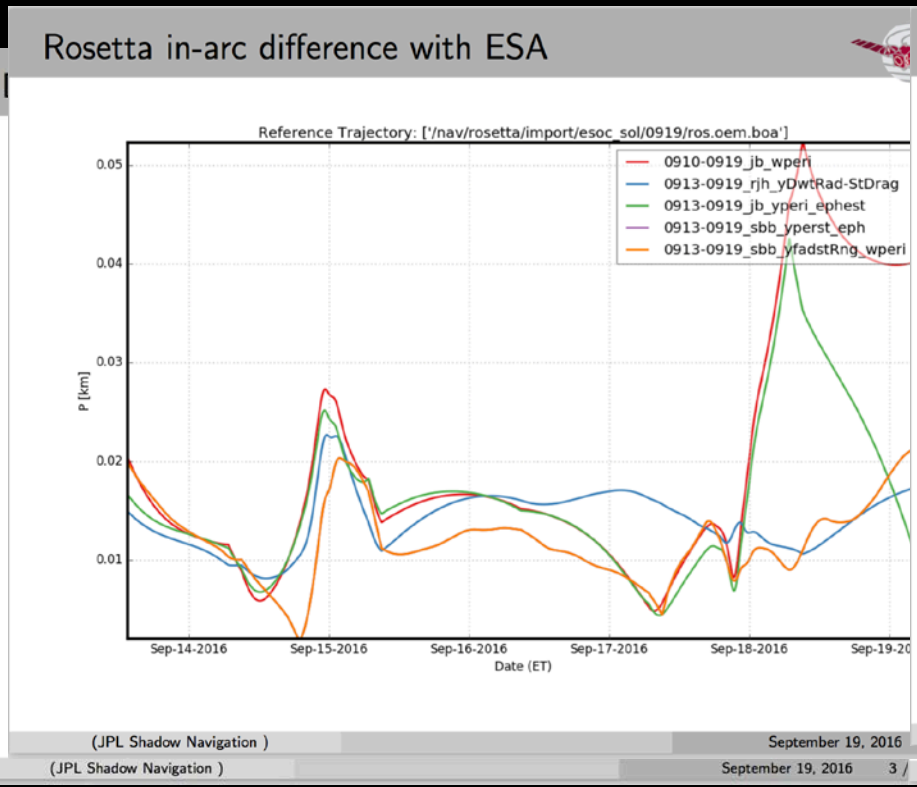


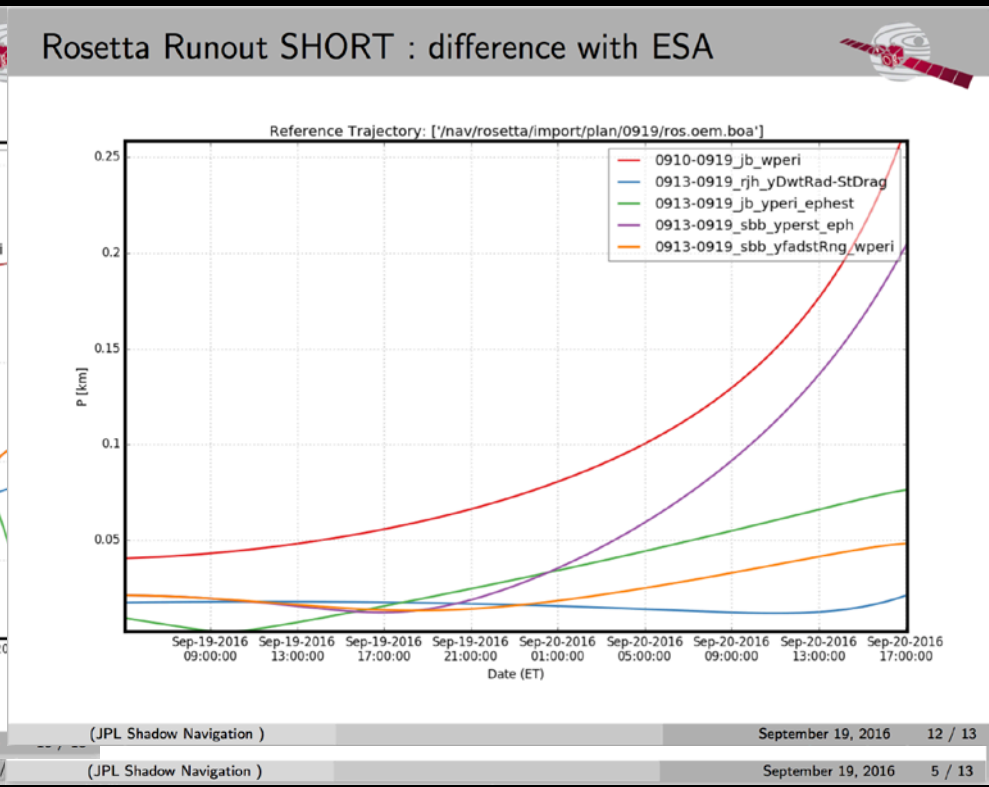
0907-0916_abd_kss2

Comparing Solutions

MSTAR Reports

- Team produced many different cases
  - Filter setups, data arcs, estimation parameters
- Created MSTAR template to internally compare solutions

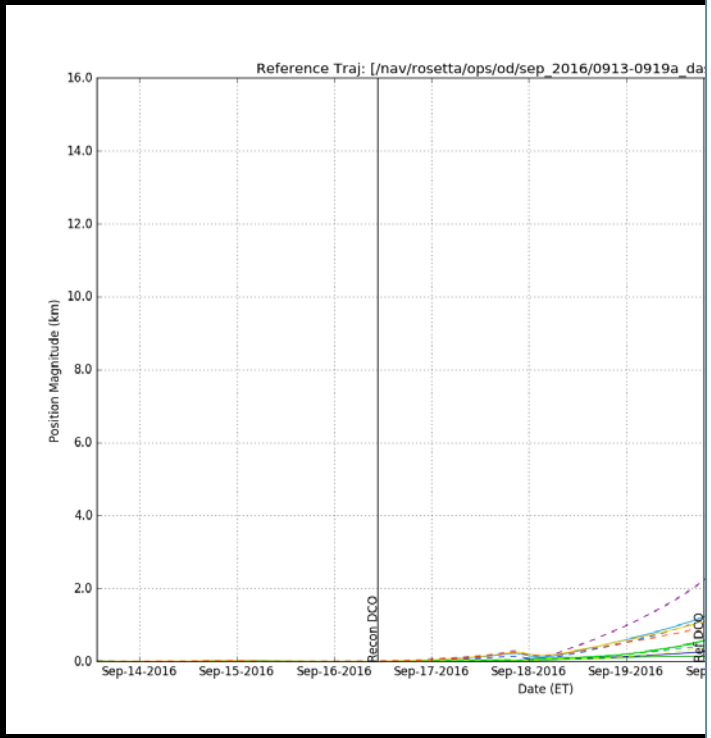


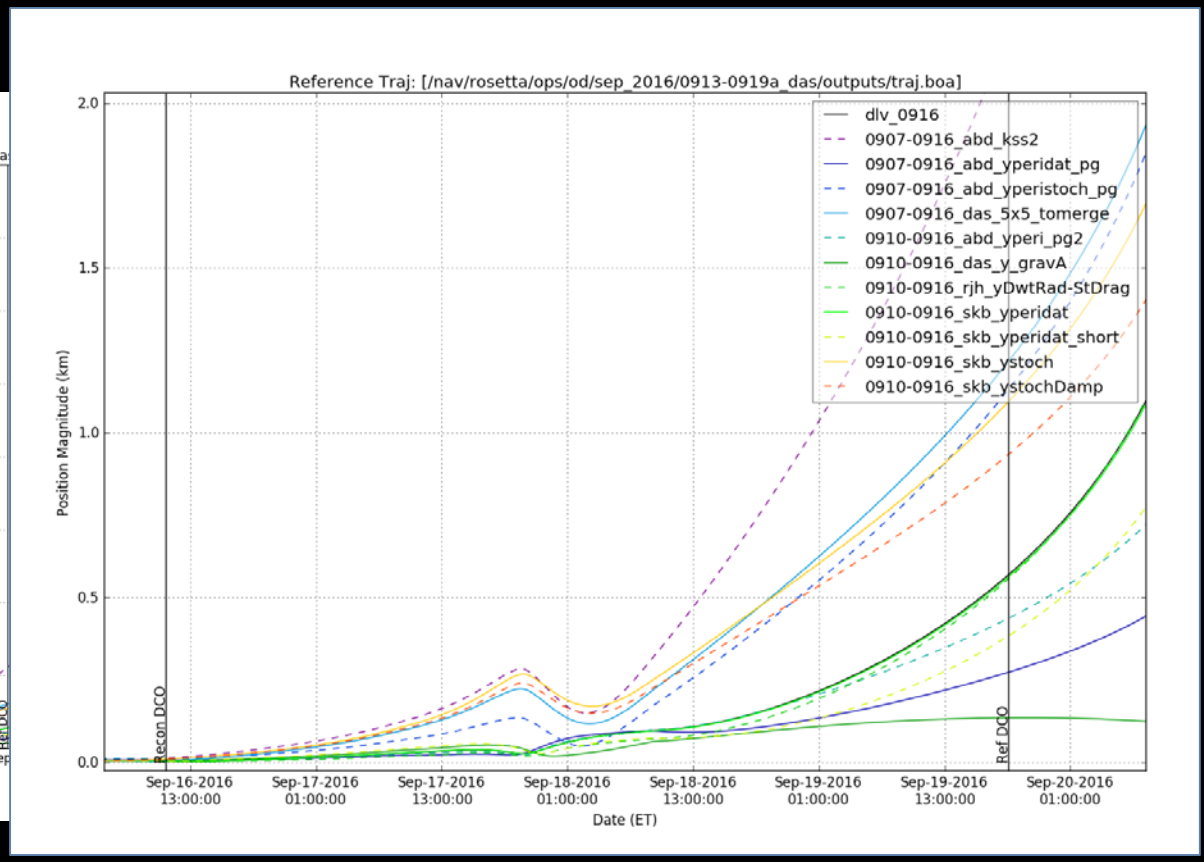


Comparing Solutions

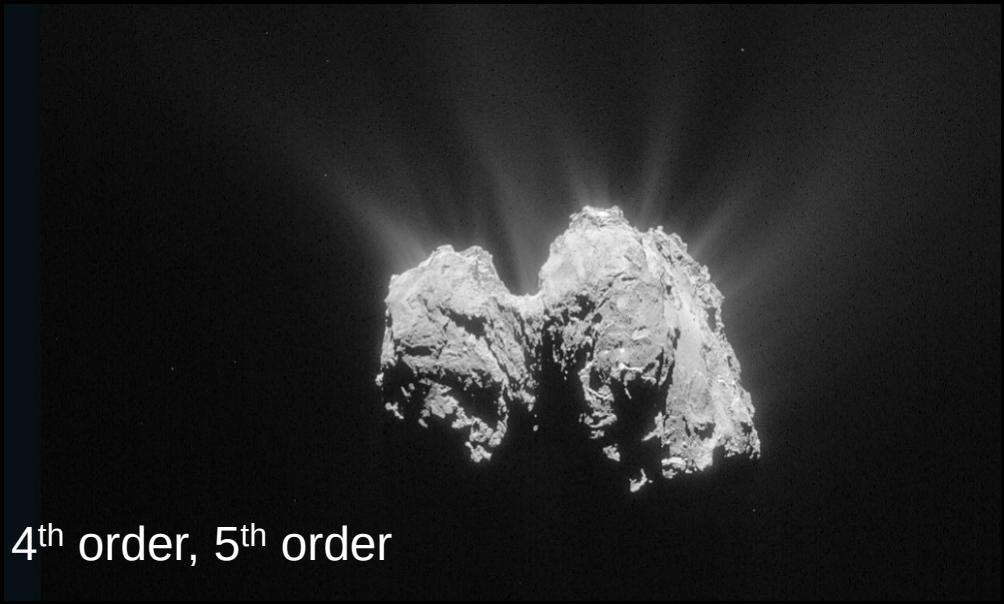
Interactive Trajectory Runout Plot

- The trajectory comparison plots proved the most useful
- Created an interactive version
- 0916 Reconstruction:





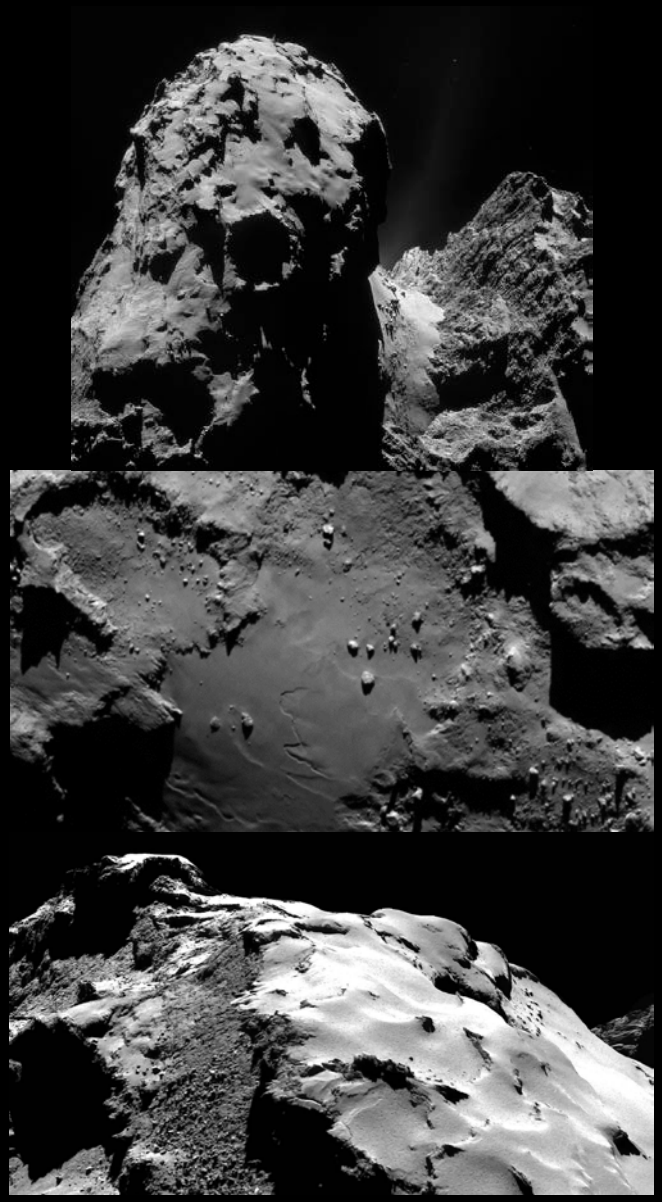
OD Variations



- Drag
  - CD model, Rosina data
- Gravity
  - Estimating vs not estimating, 4th order, 5th order
- CG ephemeris estimating
- Long vs short arcs
  - 2-3 orbits okay, but 4 orbits was trouble as we reduced altitude
- Periapsis passes
  - Always proved troublesome (gravity?, drag?, aliens?)
- Stochastic Accelerations
  - Soak up gravity and drag mismodeling
- Estimating pole drift

Lessons Learned

- Simulations behave much better.
- Working with real data
- Operations on a real mission
- Modeling a real system is tough
  - Using the estimation to extract information
  - Many more parameters to estimate and model
- Developing tools
  - Figure out what Rosetta was doing
  - Comparing experiments



Thank you!

Shyam Bhaskaran, Steve Broschart

JPL Nav team

All of NASA JPL

Questions?

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Backup Slides

https://www.youtube.com/watch?v=pC6lBFeDsGo

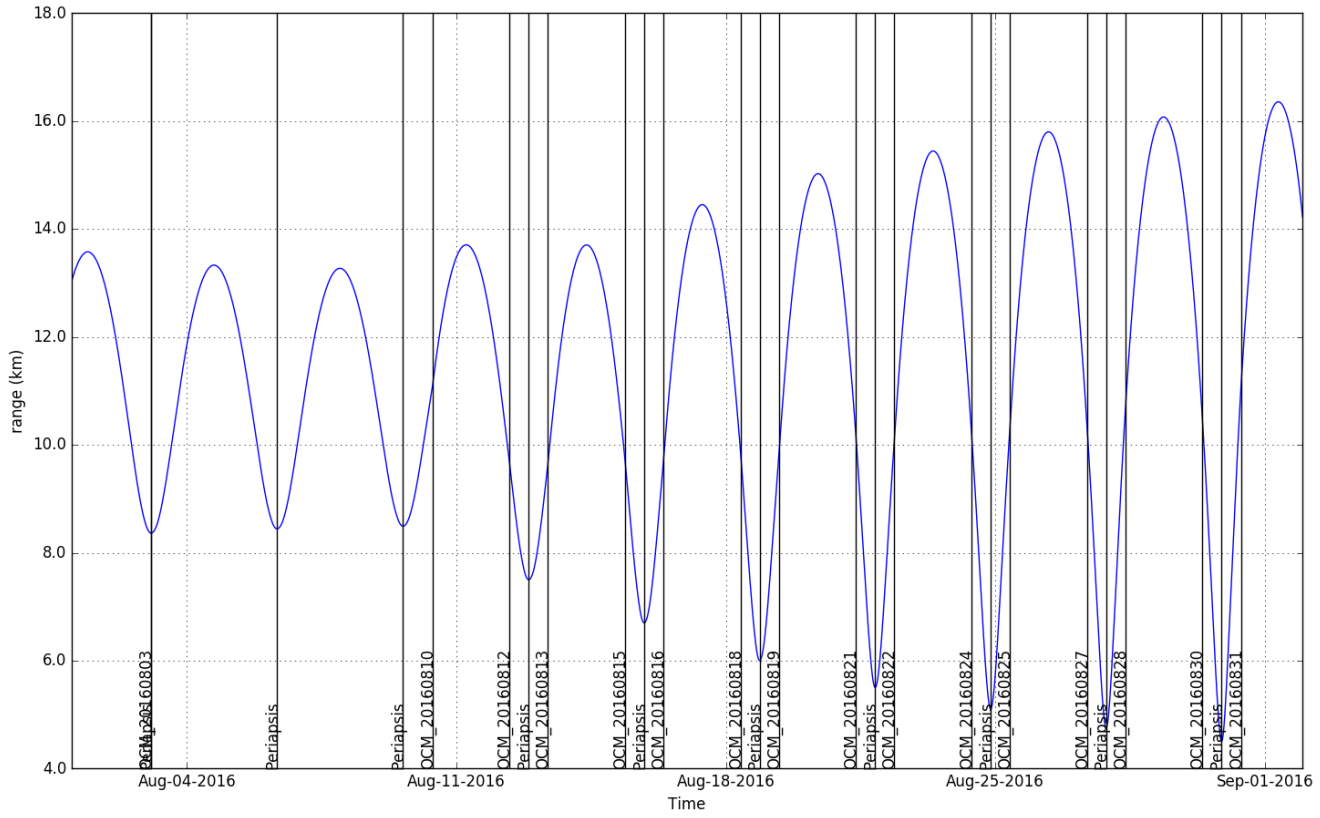
https://www.youtube.com/watch?v=tD4c8evE4YA

Trajectory Analysis

- What’s actually happening?
- 3D trajectory plot
- Range plots with events
- Lat/Long ground track plots

Trajectory Analysis, cont

- Trajectory range plots



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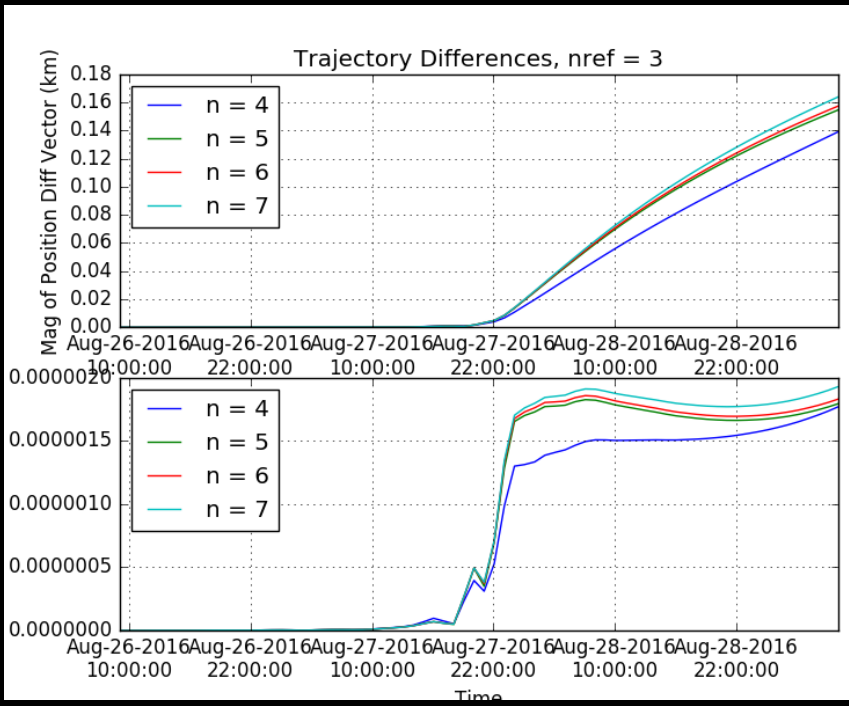
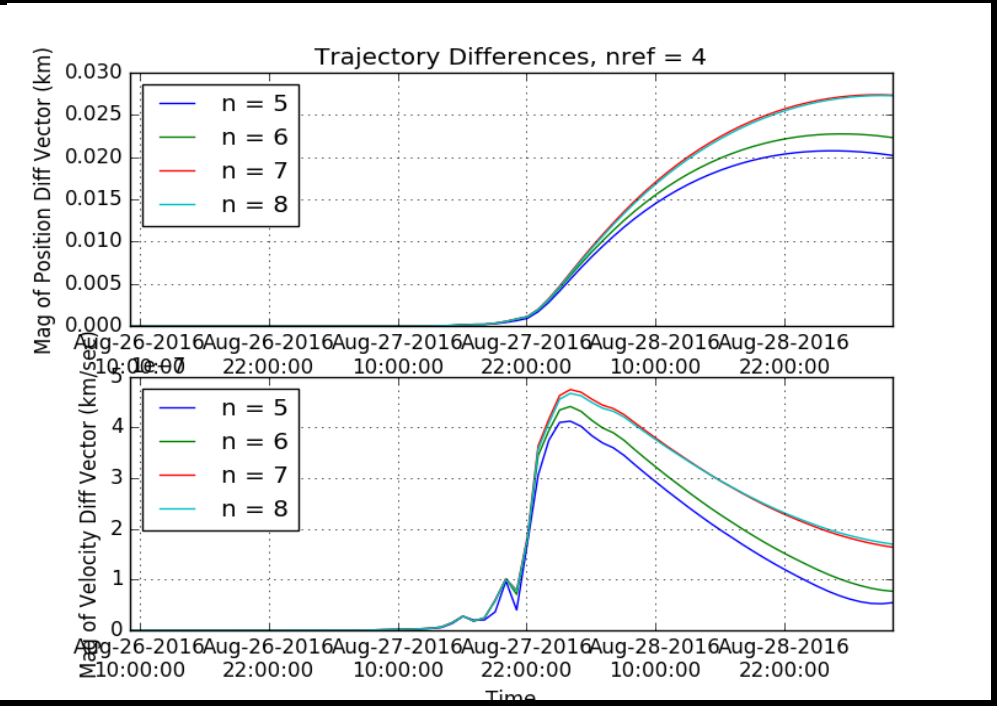


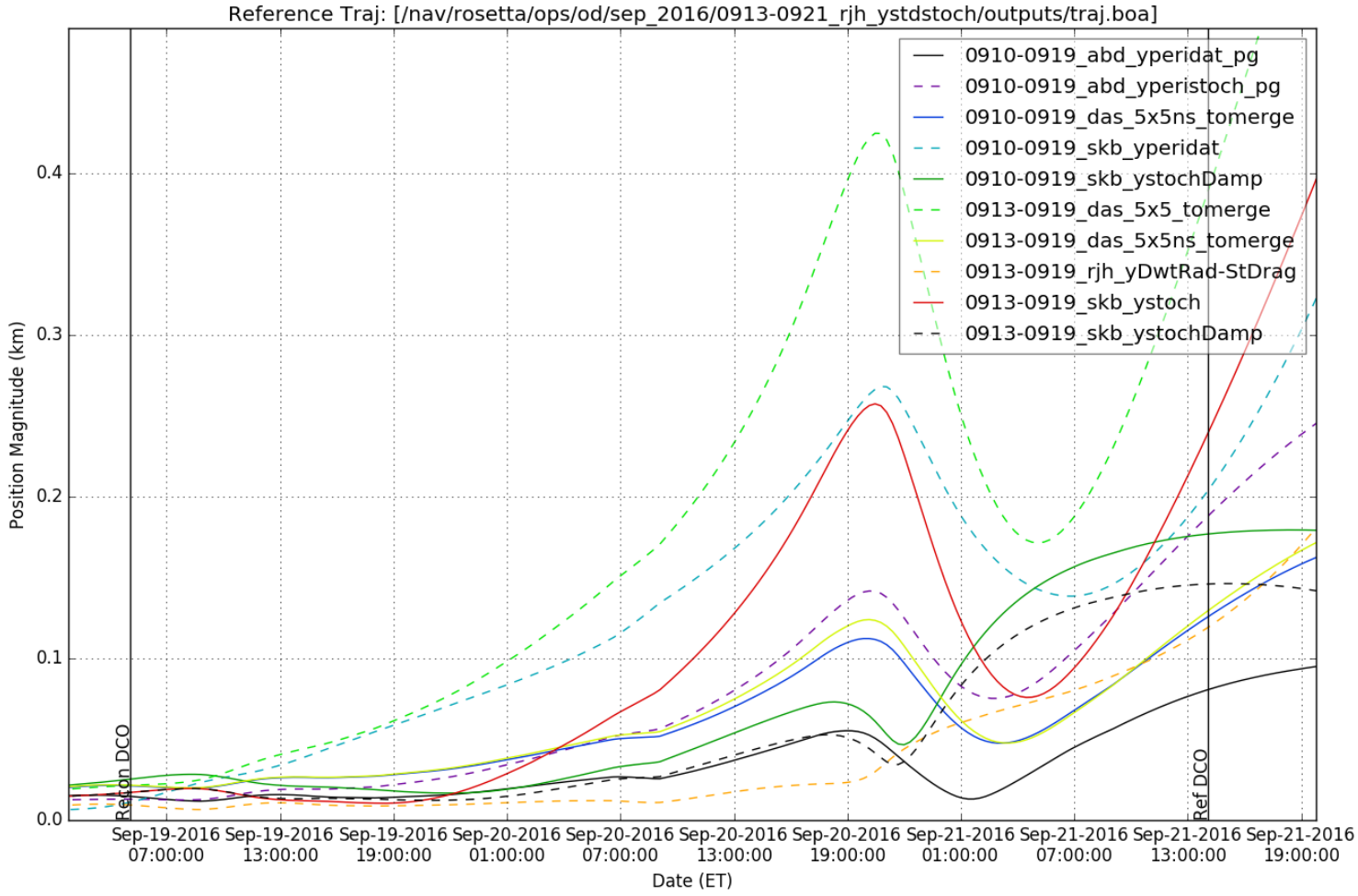


Gravity Sensitivities

- Integration with different degrees of acceleration
  - Using spherical harmonics – what degree are we sensitive to? As we get lower?
- Gravity sensitivity with DAWN tools
  - Extracting the STM after 1 week
  - Plotting for different degrees
- Estimating gravity with just periapsis data
  - Feeding in coeff and uncertainty into next periapsis passage
  - Between OCMs (plot), ”clean” data arc
  - Plot of residual data (not much data)
  - Performance, pass throughs.

Comparing Solutions

Interactive Trajectory Runout Plot : 0919 recon



Comparing Solutions

- Lots of different solutions for different data arcs and set ups
- MSTAR reports
  - Examples: events in tracking data, comparing parameters, pulling in esoc values, runout images short, long etc
- Runout plot, interactive