MAVEN Navigation During the First Mars Year of the Science Mission

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Presentation Purpose

Review MAVEN Navigation operations over the past Mars year.

- MAVEN mission
- Navigation requirements
- Navigation operations
- Atmosphere behavior
- Navigation accuracies

MAVEN Mission

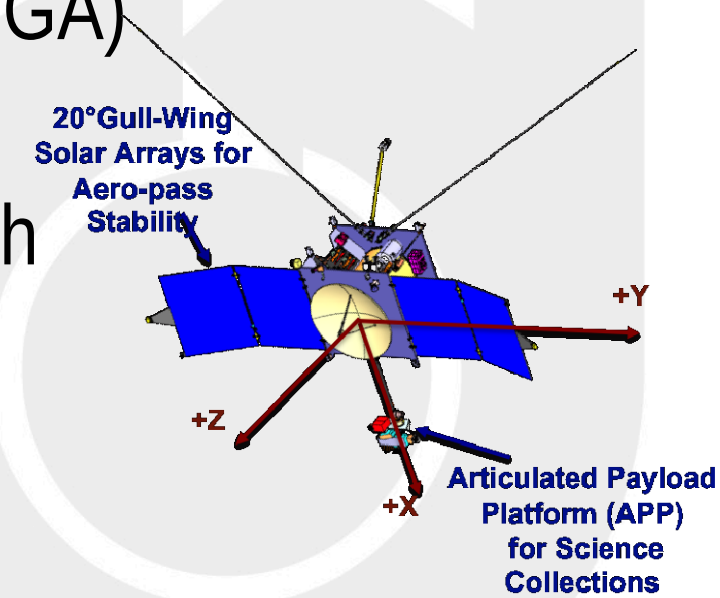
- Purpose: Study the atmosphere of Mars
- Spacecraft Orbit
  - Similar to a light aerobraking orbit.
  - Eccentric orbit to get atmosphere measurements at a low periapsis (~150 km) and high apoapsis (~6200 km) altitude.
  - Orbit period is 4.5 hours.
  - Orbit is inclined 74 degrees so periapsis naturally rotates through all local solar times and most latitudes.
  - Periapsis altitude is controlled to stay within a given density corridor. (0.05–0.15 kg/km^3)
  - Deep Dips: Periodically decrease altitude to go to a deeper density corridor for 5 days. (2.0–3.5 kg/km^3)

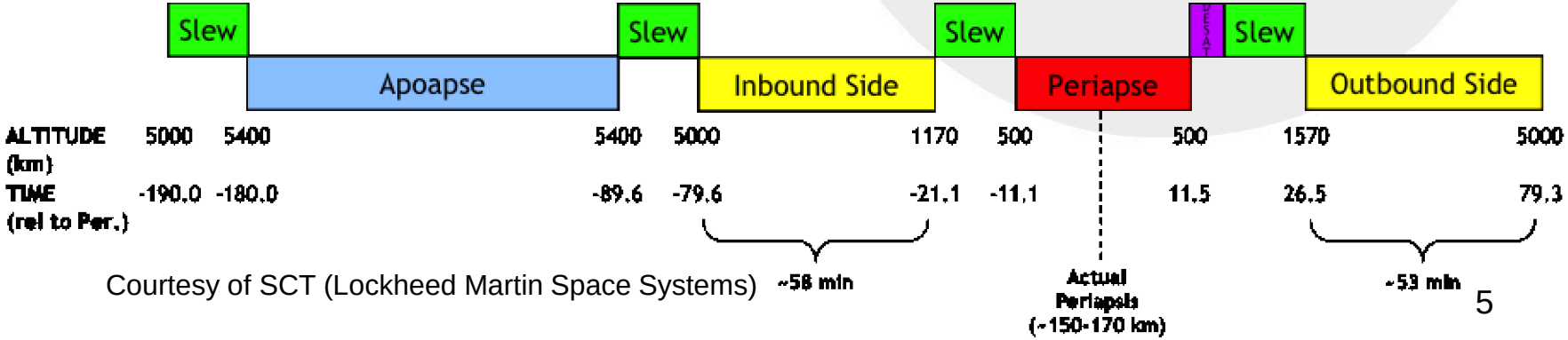
Navigation Requirements

- Positional knowledge of the orbiter shall be reconstructed to within 3 km (3-sigma, 3D), excluding DSN tracking gaps and atmospheric blooming events.
- Shall predict the periapsis uncertainty to less than 20 seconds of periapsis passage time for the first orbit of each new mapping ephemeris loaded on-board.
- Less stringent prediction requirements on the other five orbital elements.
- *Navigation has met all requirements.*

Spacecraft

- Has fixed High Gain Antenna (HGA) and solar arrays.
- Has four orientations during each orbit.
- Can be in any of four different attitudes around periapsis.

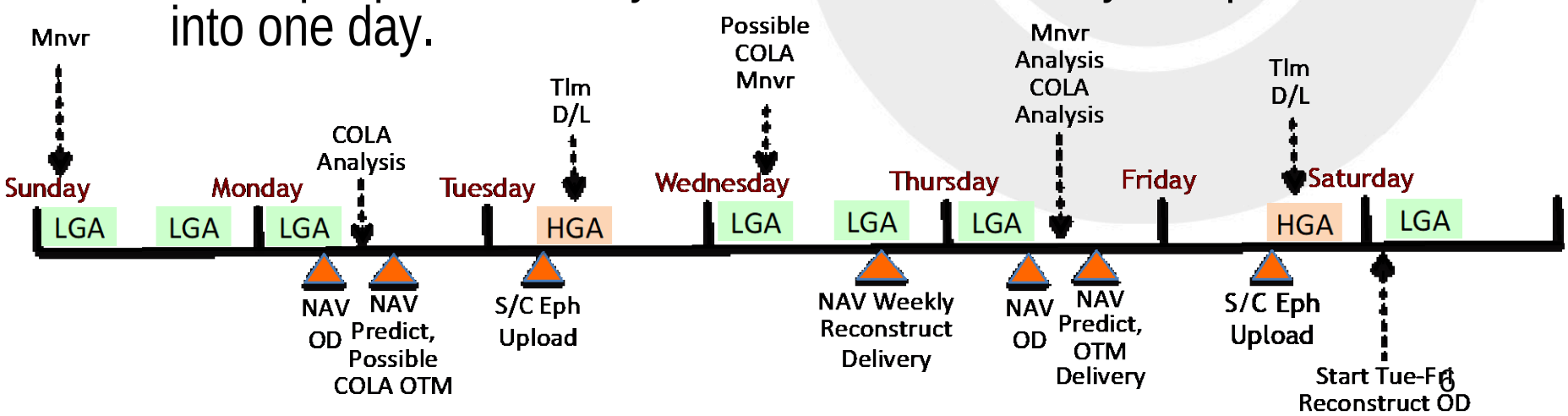




Courtesy of SCT (Lockheed Martin Space Systems)

Navigation Operations

- Have at least daily 2-way Doppler from DSN.
  - Needed to meet trajectory reconstruction requirements, density trending.
- Deliver predictions twice per week (Monday, Thursday).
- Deliver reconstructions once per week (Wednesday).
- Orbit Trim Maneuvers (OTMs) nominally available every weekend.
- In deep dips the weekly schedule is essentially compressed into one day.



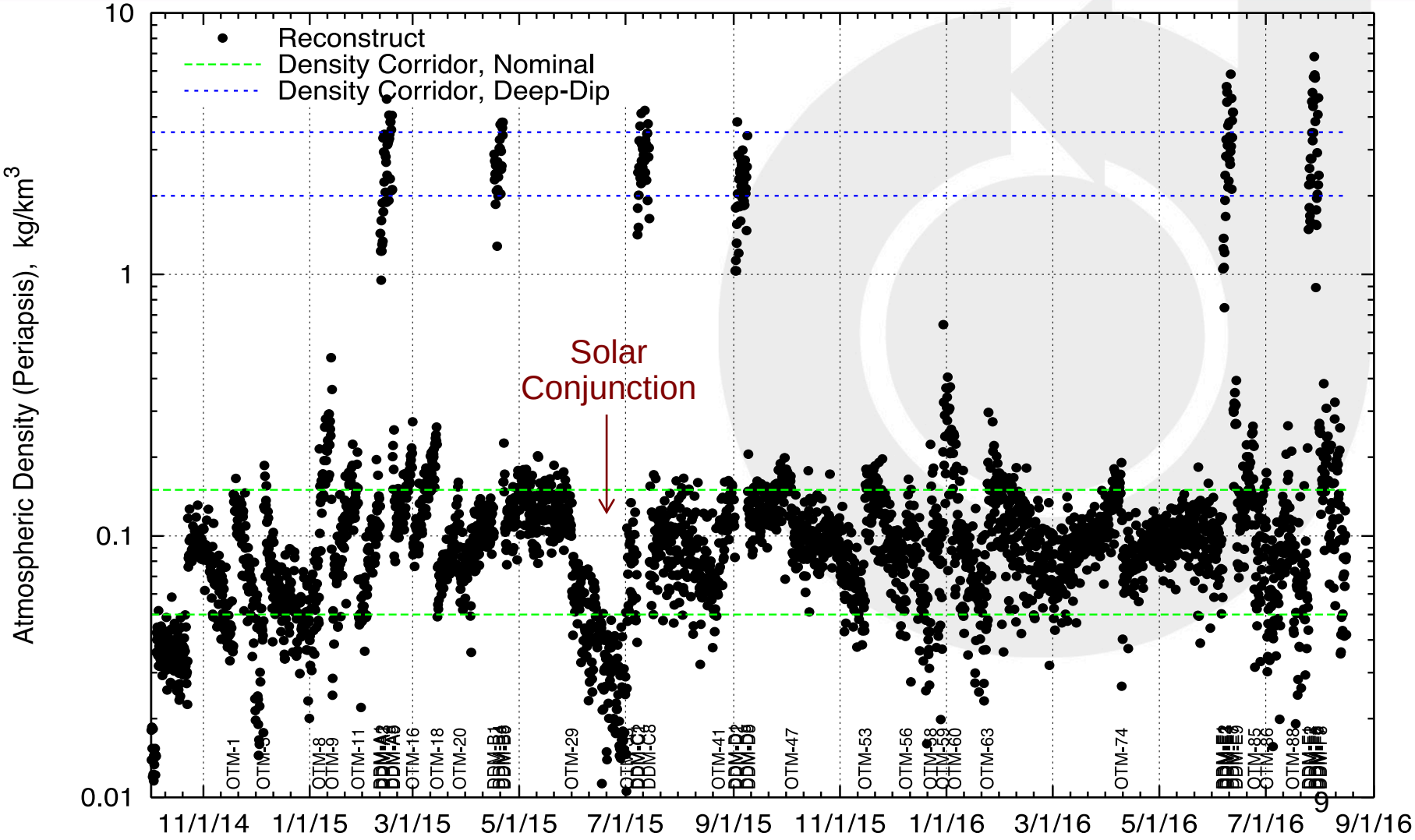
Maneuvers

- Almost all maneuvers are Orbit Trim Maneuvers (OTMs).
- The purpose of an OTM is to keep the spacecraft within the density corridor.
- OTMs are also used to avoid possible collisions with other bodies around Mars. (ODY, MRO, MEX, MOM, Phobos)
- OTMs nominally occur on the weekend, with the OTM decision on the preceding Thursday.
- OTMs are picked from a pre-defined set of ΔV values between 0.2 m/s and 6.0 m/s, and are executed in the (+/-) velocity direction at apoapsis.

Atmospheric Density

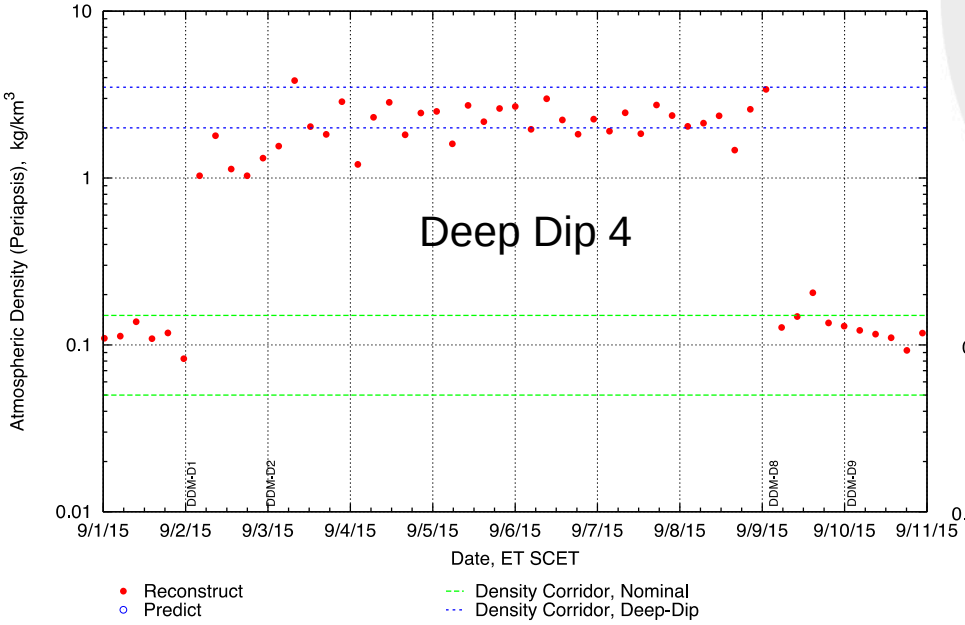
- Mars-GRAM 2005 (MapYear 0) [MG] is used as the atmosphere model.
- Navigation estimates for a scale factor on MG for each orbit.
  - Navigation essentially estimates for the total ΔV effect (or period change) of a drag pass.
  - Navigation process assumes MG shape of the density profile.
- Actual density profile can have a very different shape than MG, with the maximum density occurring in a very different location relative to periapsis.
- The density profile can change significantly from orbit to orbit. Some profiles can look quite strange.
- Both the density behavior and the periapsis altitude trend affect corridor control and OTM decisions.

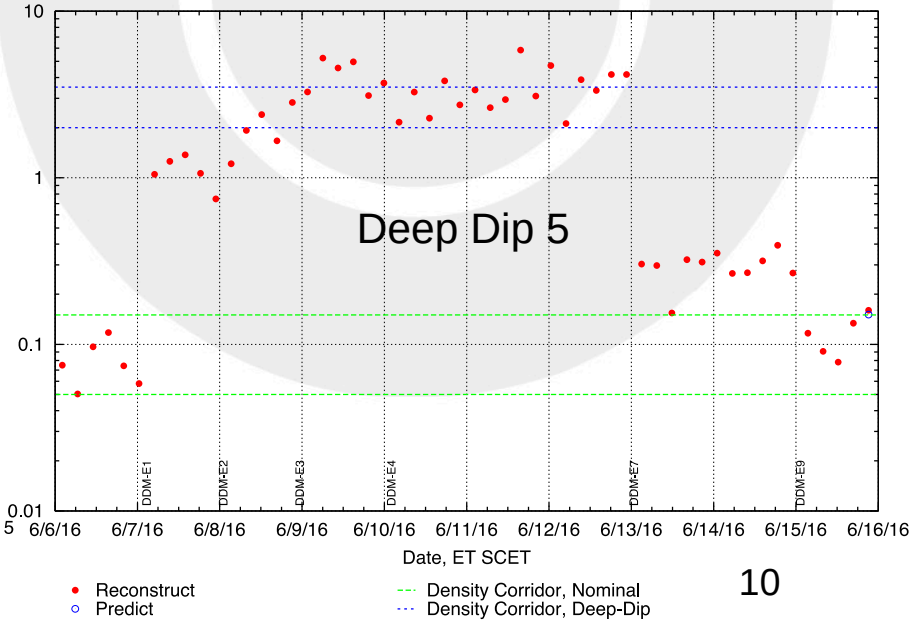
Periapsis Density Over First Mars Year



MAVEN Deep Dips 4 & 5

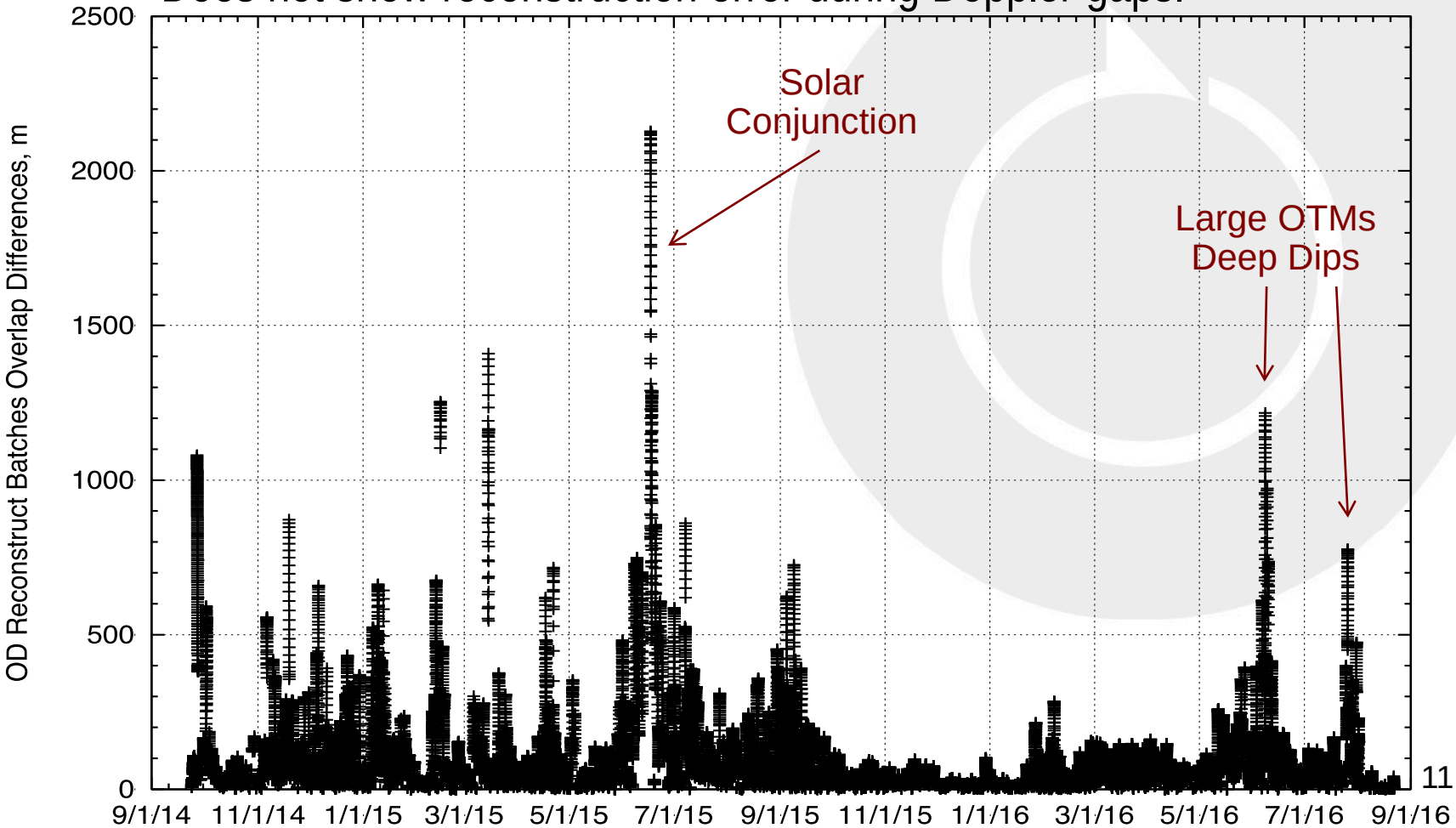
- First four deep dips went well.
- Deep dips 5 & 6 were more difficult.
  - Never assume things will go fine since they have in the past.
- Deep dip 4 (left plot) was nominal.
- Deep dip 5 (right plot) had difficulties due to density variability and density scale height uncertainty.





Trajectory Reconstruction Accuracies

- Reconstructions within 3 km
- Does not show reconstruction error during Doppler gaps.

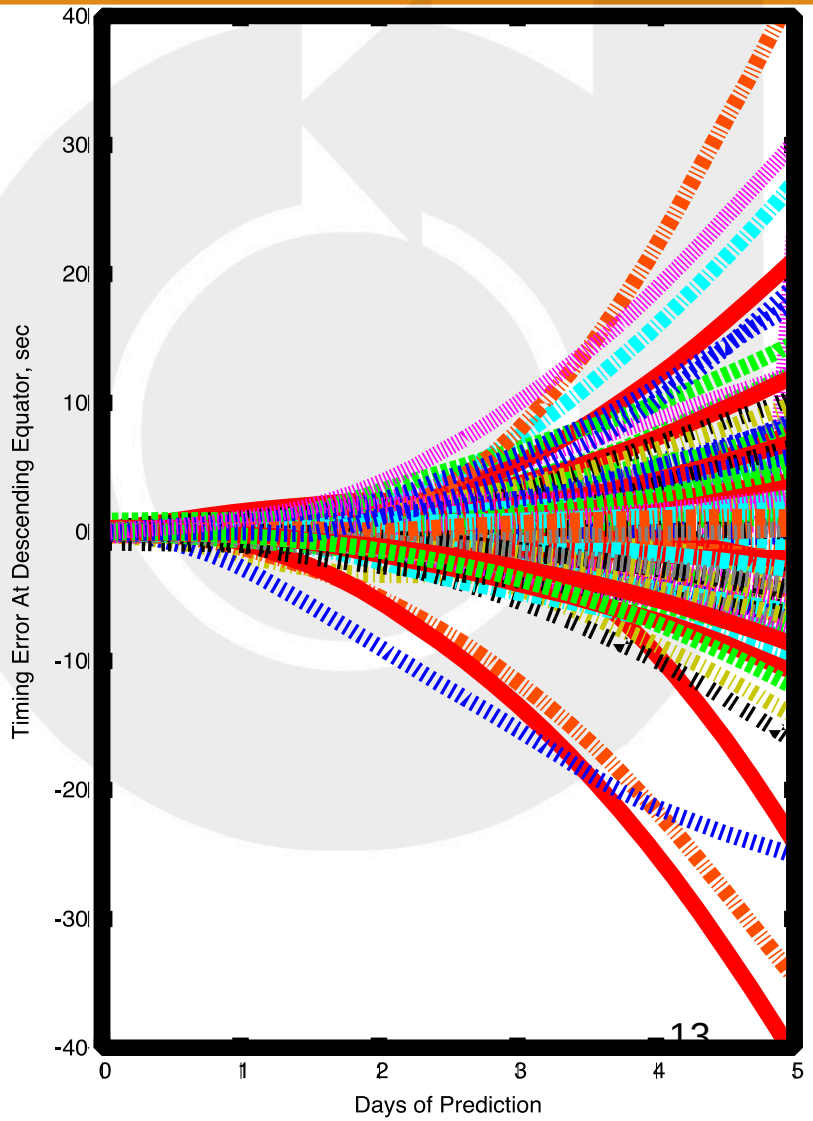


MAVEN Trajectory Prediction Accuracies

- Three prediction time intervals are important for MAVEN
  1) 0-2.5 days: Project requirement is for a 20 second prediction accuracy for spacecraft ephemeris and science instrument pointing.
  2) 2.5-10 days: Prediction interval applicable for OTM decisions to avoid collisions with other bodies around Mars.
  3) 22-30 days: Prediction accuracy used by Mars lander teams for scheduling relay passes.

Trajectory Prediction Accuracies (Short Term)

- MAVEN's requirement is to be able to predict the down-track timing within 20 seconds.
- Pre-operations analyses showed that this accuracy could be maintained within 2.5 days.
- In operations the Nav predictions have remained within 20 seconds for 3.6 days.



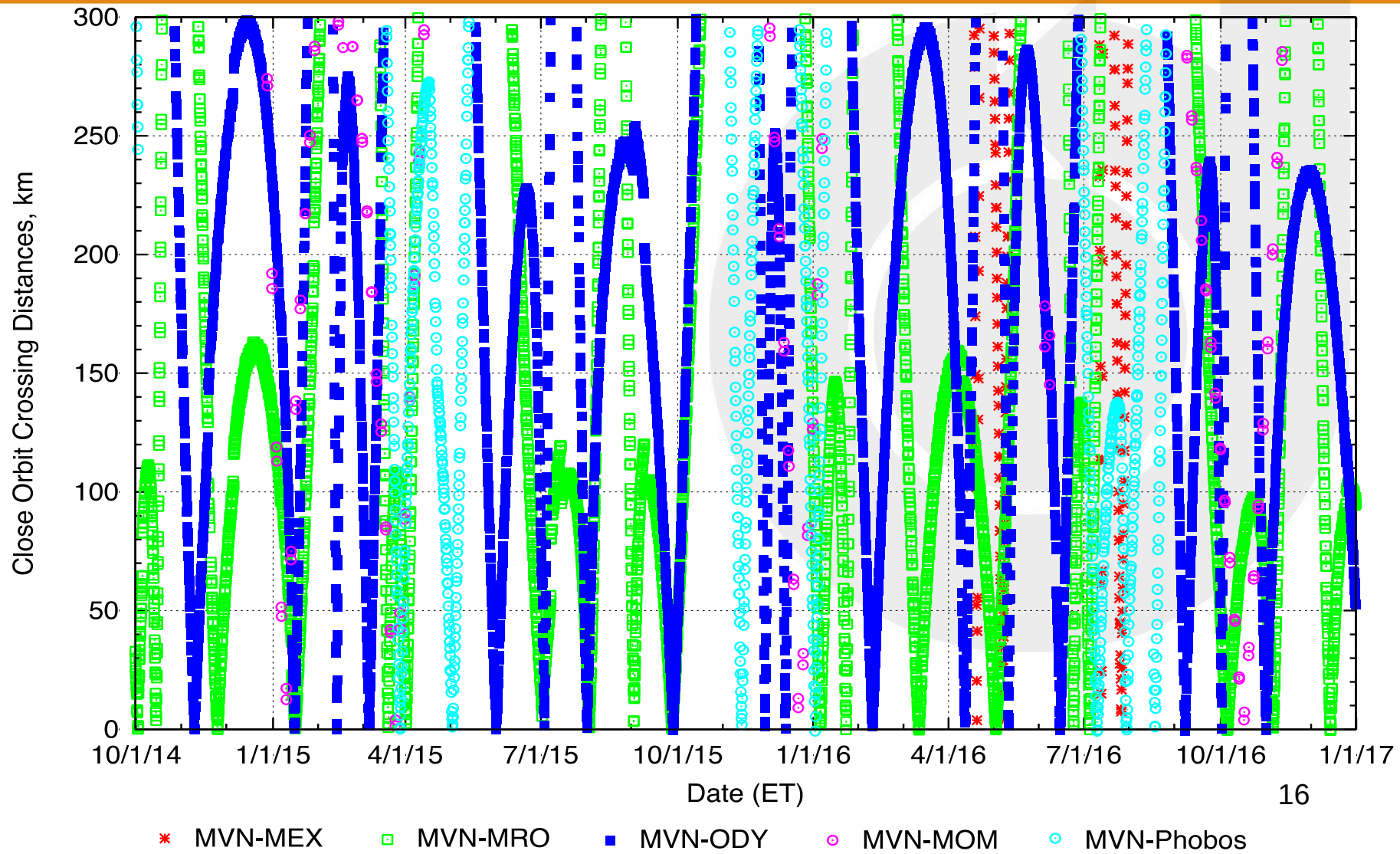
Collision (Conjunction) Avoidance [COLA]

- There are currently several bodies around Mars: MAVEN, ODY, MRO, MEX, MOM, Phobos.
  - Defunct spacecraft for which the orbits are poorly known are ignored.
- MAVEN has nominally taken the responsibility to avoid possible collisions with other spacecraft.
  - MAVEN has the lowest periapsis altitude, and thus the most significant drag perturbations.
  - MAVEN's trajectory predictions are the least accurate.
  - Thus MAVEN's analyses and accuracies drive any collision avoidance decisions which involve MAVEN.
  - MAVEN has a streamlined maneuver process and frequent maneuver capability.

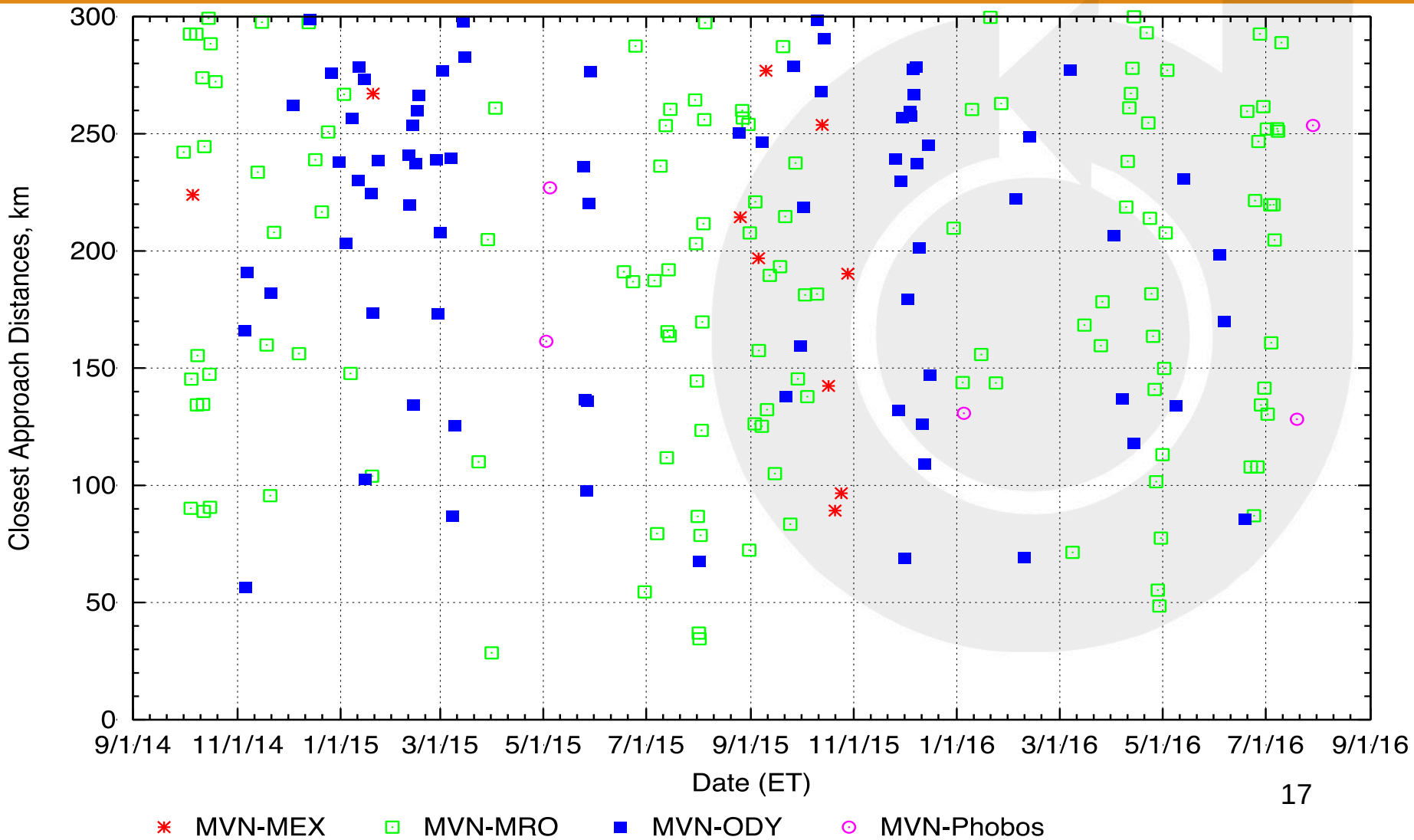
COLA Process

- COLA “seasons” are calculated well into the future.
  - Only involves stable orbit geometries.
  - Look at when the orbits cross each other.
- As a COLA season approaches, one checks whether the two bodies (e.g. spacecraft) are both near to the orbit crossing at the same time.
- OTM decisions for collision avoidance are made 2.5-10 days before a possible event.

COLA Seasons



Actual Closest Approaches



Mars Lander Relay Support

- Lander relay support planning looks at MAVEN trajectories predicted ~25 days into the future.
- Since MAVEN's periapsis is at low altitudes, its prediction accuracy is much worse than for other orbiters.
- For a 25 day prediction (OPS predictions through 2015)
  - 89% of the predictions were within 20 minutes
  - 58% of the predictions were within 10 minutes
- For a 25 day prediction around Mars perihelion (e.g. ExoMars 2016 EDM relay period), it is estimated that
  - 76% of the predictions will be within 20 minutes
  - 48% of the predictions will be within 10 minutes

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