NAVIGATION CHALLENGES IN THE MAVEN SCIENCE PHASE

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Introduction to MAVEN

- MAVEN = Mars Atmosphere and Volatile EvolutioN Mission
  - NASA Mars orbiter scout mission
  - Project management by GSFC, Navigation by JPL
- Purpose: Explore the planet's upper atmosphere, ionosphere and interactions with the sun and solar wind.
- Primary Science Phase:
  - One Earth year
  - Eccentric orbit with 4.5-hour period, 75 degree inclination
    - Periapsis naturally progresses over most of the planet ($\pm$75 deg latitude)
  - Periapsis altitude is controlled within a given density corridor.
    - Nominal orbit: maximum (mean) density kept between 0.05 kg/km^3 and 0.15 kg/km^3.
    - Deep-Dip orbit: maximum (mean) density kept between 2.0 kg/km^3 and 3.5 kg/km^3.
      - Five brief deep-dips during the primary mission.
      - Each deep-dip has five days of science at a lower periapsis altitude.
      - Total length of a deep-dip, including maneuver walk-in & walk-out, is eight days.
- High degree of Mars Reconnaissance Orbiter [MRO] inheritance.

Navigation Summary, Challenges

- The MAVEN science phase may be described as a light aerobraking phase with science requirements and limited DSN tracking data. This results in some significant differences from MRO Navigation.
  - NAV operations process is similar to MRO aerobraking, but with much smaller accuracy requirements.
  - NAV product delivery schedule is similar to the (less frequent) MRO science schedule.

- Navigation Challenges
  - Much tighter accuracy requirements than on previous Mars orbiters with significant atmosphere perturbations
    - Science while “aerobraking”
  - Quick prediction deliveries
    - Five hours for all Navigation analyses and final delivery
  - Determination of density behavior
    - Limited DSN tracking and thus limited density information
    - Affects quality of Navigation prediction model
    - Affects accuracy of delivered predicted trajectory
  - Necessity for quick maneuver designs, validations and uploads to the spacecraft
    - Mostly solved with “OTM” capability similar to MRO, ODY & MGS
  - Relatively quick deep-dip walk-in and walk-out with poor density information

JPL

Navigation Requirements

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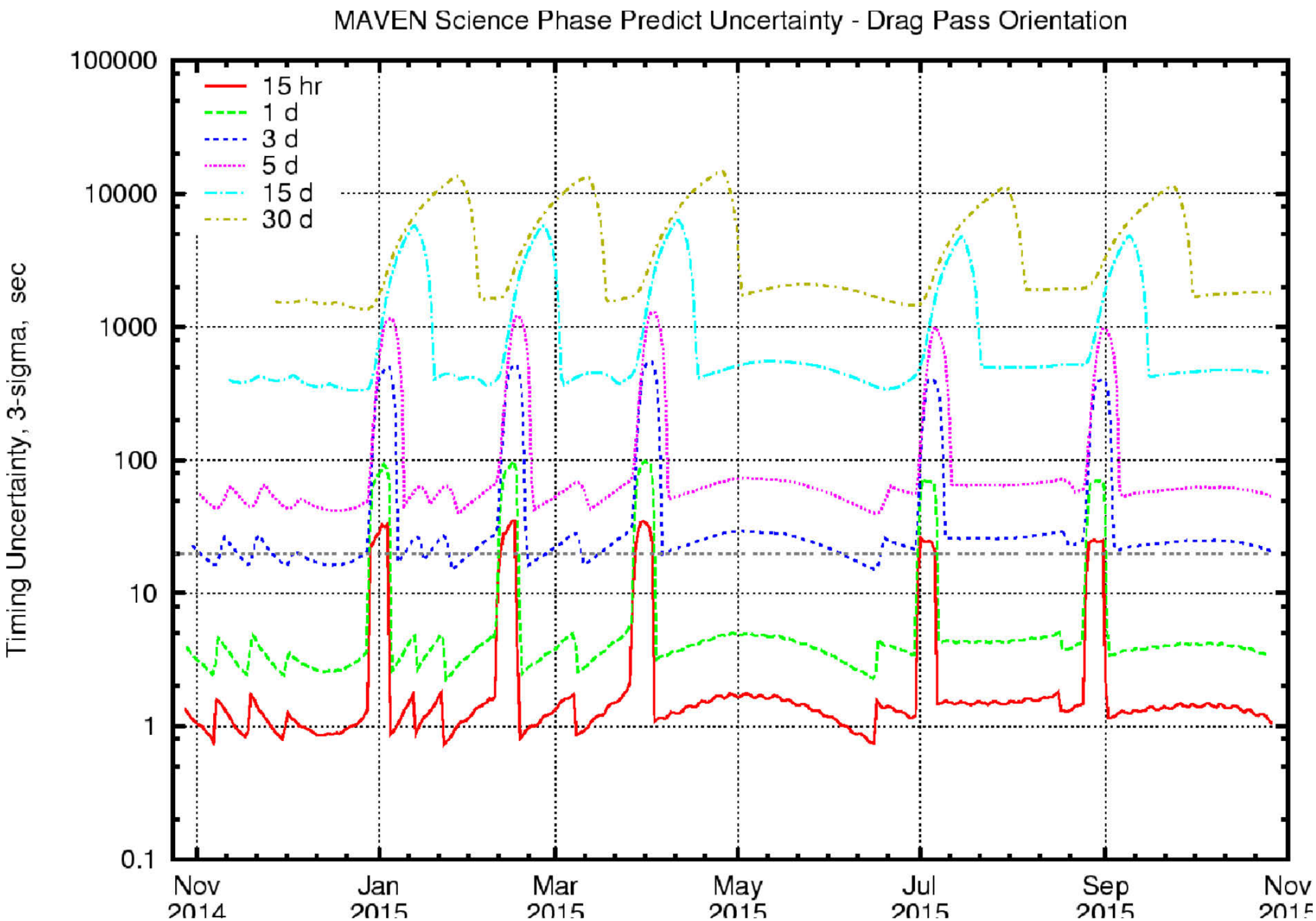
- Prediction accuracies are given in terms of orbital elements, and divided into two types.
  - Orbit shape and orientation, which does not change quickly with time and is relatively well known.
  - Location (timing) within the orbit, which has a degraded accuracy due to the atmosphere uncertainty.
- Requirements on Navigation accuracies
  - Reconstruction: Trajectory accuracies are to be within 3 km.
    - Navigation meets requirement with all DSN daily pass scenarios.
  - Prediction:
    - Navigation shall predict the periapsis uncertainty to less than 20 seconds of periapsis passage time.
    - Navigation shall predict the orbital elements to the following accuracies for at least 9.5 days in the nominal orbit and 2.8 days in the deep-dip orbit.
      - Semi-major axis: +/- 50 km
      - Eccentricity: +/-0.025
      - Inclination: +/-0.20 deg
      - Longitude of Ascending Node: +/-0.04 deg
      - Argument of periapsis: +/-0.3 deg
    - Predict requirements designed to allow for contingencies (e.g. missed DSN passes and/or uplinks).
  - Major error source is density. (3-σ errors: 40% mean, 105% orbit-to-orbit)

Predict Capabilities, Timing Error



JPL Requirements Affecting OPS Timelines

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- Navigation predict requirements
  - Nominal Orbit
    - Timing requirement: Predict (down-track) timing error must be within 20 seconds at first periapsis after onboard ephemeris upload.
      - ≤ 2.5 days (60 hours)
    - Science requirement: Specifies required accuracies of 5 orbital elements. (PTE controls 6^{th} element – true anomaly.)
      - ≤ 9.5 days
  - Deep-Dip
    - Timing requirement: Predict (down-track) timing error must be within 20 seconds at first periapsis after onboard ephemeris upload.
      - S/C ephemeris must be uploaded before third predicted periapsis after orbit determination [OD] Doppler arc.
      - < 3 periapses
    - Science requirement: Specifies required accuracies of 5 orbital elements over 2.8 days. (PTE controls 6^{th} element – true anomaly.)
      - ≤ 2.8 days
- PTE = Periapse Timing Estimator. Onboard (LM) software which keeps the timing error within 20 seconds after ephemeris upload.
- Above prediction accuracies determine work schedule and contingency scenarios.

JPL Nominal Orbit Weekly NAV OPS Timeline

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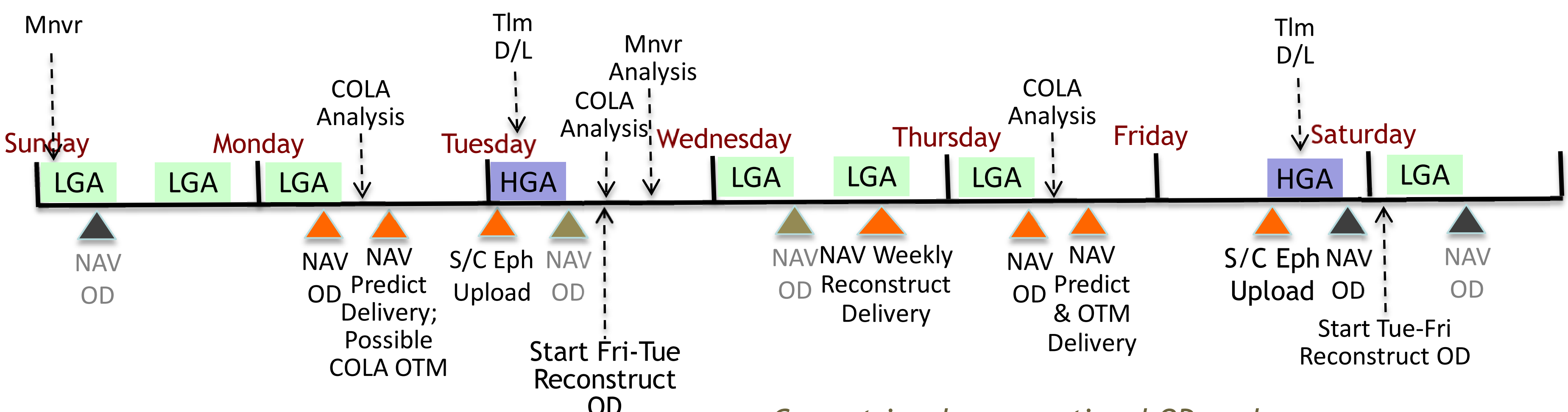
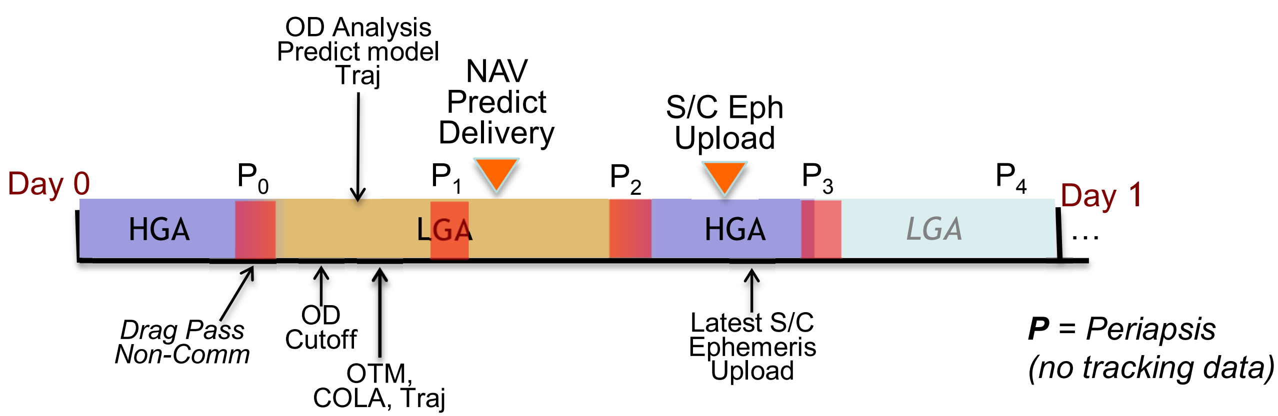
- 8-hour DSN pass per day, with extra pass on Sunday & Wednesday
  - All passes use Low Gain Antenna [LGA], except
  - Tuesday & Friday "HGA" pass, which has 5 of 8 hours on High Gain Antenna [HGA]
- OTM maneuver slot once per week – before OD prime/backup data arcs
- NAV analysis nominally uses LGA pass preceding HGA pass.
  - Thus Monday & Thursday LGA pass nominally used for NAV predict delivery
  - NAV predict delivery may involve: OD analysis, update of NAV predict models, trajectory run out, OTM design, trajectory run out, COLA analysis, final trajectory run out, delivery to project.
- Predicted ephemeris uploaded via HGA on Tuesday & Friday.
  - Minimal team timeline allocation:
    - NAV: 5 hours
    - MSA (SCT): 7 hours
- Contingency/backup scenario: Use 2nd or 3rd LGA pass before HGA pass
  - Also may be used to optimize work schedule
  - Second contingency scenario: skip predict delivery



Green triangles are optional OD analyses.

Deep-Dip NAV OPS Timeline

- 24 hour DSN coverage for 8 day deep-dip period.
  - Walk-in (2 days) and walk-out (1 day) are on HGA
- During 5 days of deep-dip science:
  - First and fourth orbit (<9 hours total) are on HGA.
  - Rest of DSN communication is on LGA.
  - No Doppler during drag pass (45-50 minutes).
- NAV predict ephemeris must be uploaded before third periapsis after OD data. Team timeline work allocation:
  - NAV: 5 hours
  - MSA (SCT): 6 hours
- Contingency case: skip predict delivery



Maneuvers

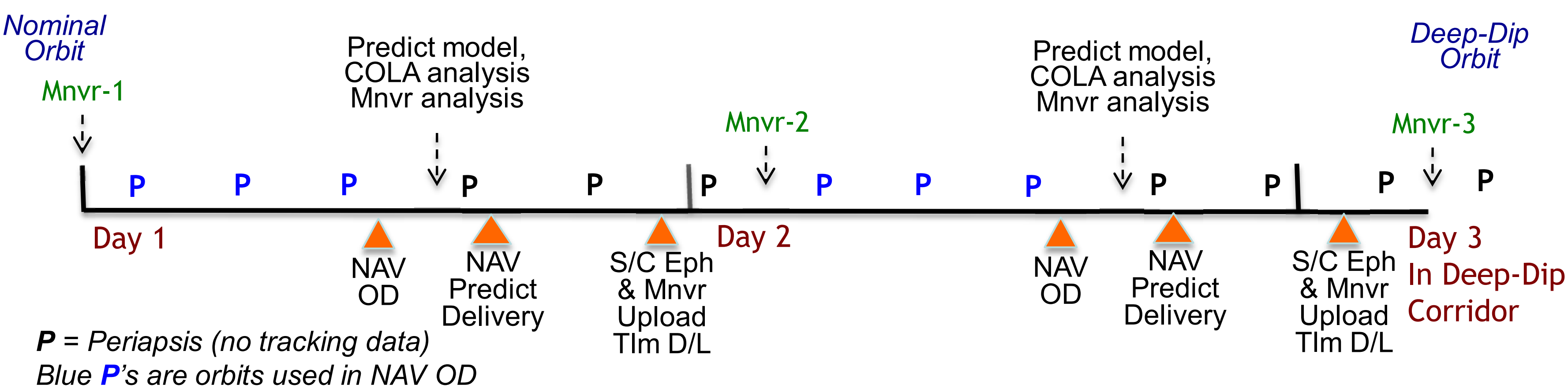
Science Phase Maneuvers

- The science phase orbit is defined to stay within a density "corridor".
- However, large atmosphere perturbations and uncertainty require a short maneuver process time.
- Thus most science phase maneuvers are executed as "Orbit Trim Maneuvers" [OTMs]
  - Greatly decreases operations design & sequence verification time.
  - Used for MRO, ODY & MGS aerobraking.
- An OTM is defined by:
  - *Magnitude*: OTM ΔV magnitude is picked from a ΔV menu.
    - ΔV menu is delivered by NAV before launch.
    - ΔV menu allows maneuvers to be pre-certified.
  - *Epoch*: OTM is executed at apoapsis, as determined by PTE.*
  - *Direction*: Two choices for OTM direction.
    - UP: velocity direction, increasing altitude
    - DOWN: anti-velocity direction, decreasing altitude
- Maximum OTM frequency
  - Nominal orbit OTMs: once per week
  - Deep dip orbit OTMs: once per day

** PTE = Periapse Timing Estimator (LM)*

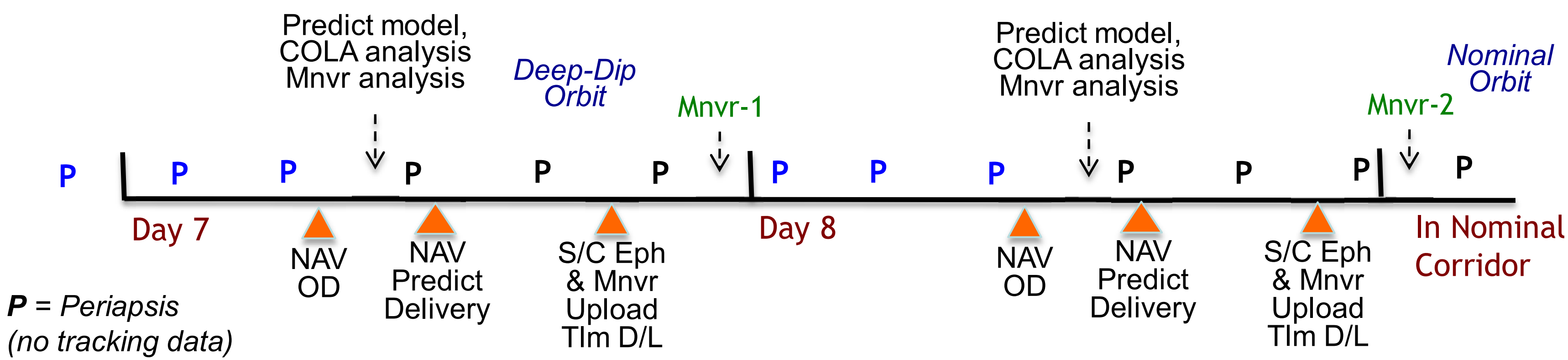
Deep-Dip Walk-in

- Deep-dip corridor: 2.0-3.5 kg/km^3
- 24-hour HGA DSN coverage.
- Mnvr-1 targets to ≤2 kg/km^3
  - Density predictability at significantly different altitudes is poor.
  - Only have two days to get down to deep dip density corridor.
  - Must not violate S/C and instrument safety requirements (≤7 kg/km^3 mean density).
- NAV analyzes 3 orbits after maneuver to get an estimate of the mean density (MG05 scale factor) at the new altitude.
- Use the deep dip strategy for uploading a NAV predict ephemeris: upload before third periapsis after the orbit determination [OD] Doppler data arc.



Deep-Dip Walk-out

- Science phase corridor: 0.05-0.15 kg/km^3
- 24-hour HGA DSN coverage.
- Mnvr-1 targets to >0.15 kg/km^3
  - Density predictability at significantly different altitudes is poor.
  - However, assume density behavior has not changed greatly in the past 7 days, so NAV can get back to the nominal orbit in only one day.
- NAV analyzes 3 orbits after maneuver to get an estimate of the mean density (MG05 scale factor) at the new altitude. (But 3 orbits do not give a good mean.)
- Use the deep dip strategy for uploading a NAV predict ephemeris: upload before third periapsis after the OD Doppler data arc.



Summary

- Navigation can meet all of its requirements.
- Some enhanced processes have been established to reduce Navigation operations analysis & delivery time.
- Almost all science phase maneuvers will be executed as OTM's because of the necessity of reducing maneuver operations process times due to atmospheric drag uncertainty.
  - Method previously used for MRO, ODY and MGS aerobraking.
- Operations timelines have been created for Navigation analyses and deliveries for nominal orbit, deep-dip orbit science, and deep-dip orbit walk-in and walk-out.
- Contingency timelines have been identified.

Backup

NAV Summary, Comparison to MRO

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MRO Aerobraking

- Purpose: <u>Orbit change</u>
- Drag Pass ΔV: 3 m/s
- Accuracy Requirements
  - Trajectory: 225 sec
  - Science: None
- Tracking Data (Doppler)
  - Continuous (HGA)
- Delivery Schedule
  - Multiple per day (4.5-hr orbit)
  - (Science: 2/week [predict])
- Density modeling – predict model
  - Doppler atmosphere estimate for every orbit.
  - S/C orientation is the same for each drag pass.
  - S/C component shadowing is the same for each drag pass. (No shadowing.)

MAVEN Primary Mission

- Purpose: <u>Science</u>
- Drag Pass ΔV: 0.006 m/s
- Accuracy Requirements
  - Trajectory: 20 sec
  - Science: *Yes*
- Tracking Data (Doppler)
  - 7 hours / day (mostly LGA)
- Delivery Schedule
  - 2/week (predict), 1/week (reconstruct)
  - Deep-Dip: 1/day
- Density modeling – predict model
  - Doppler atmosphere estimate for only 20% of the orbits.
  - S/C orientation changes with periapsis passes.
  - S/C component shadowing varies with periapsis passes. (Shadowing exists.)