Jet Propulsion Laboratory
California Institute of Technology

Dawn Safing Approach to Ceres Re-Design

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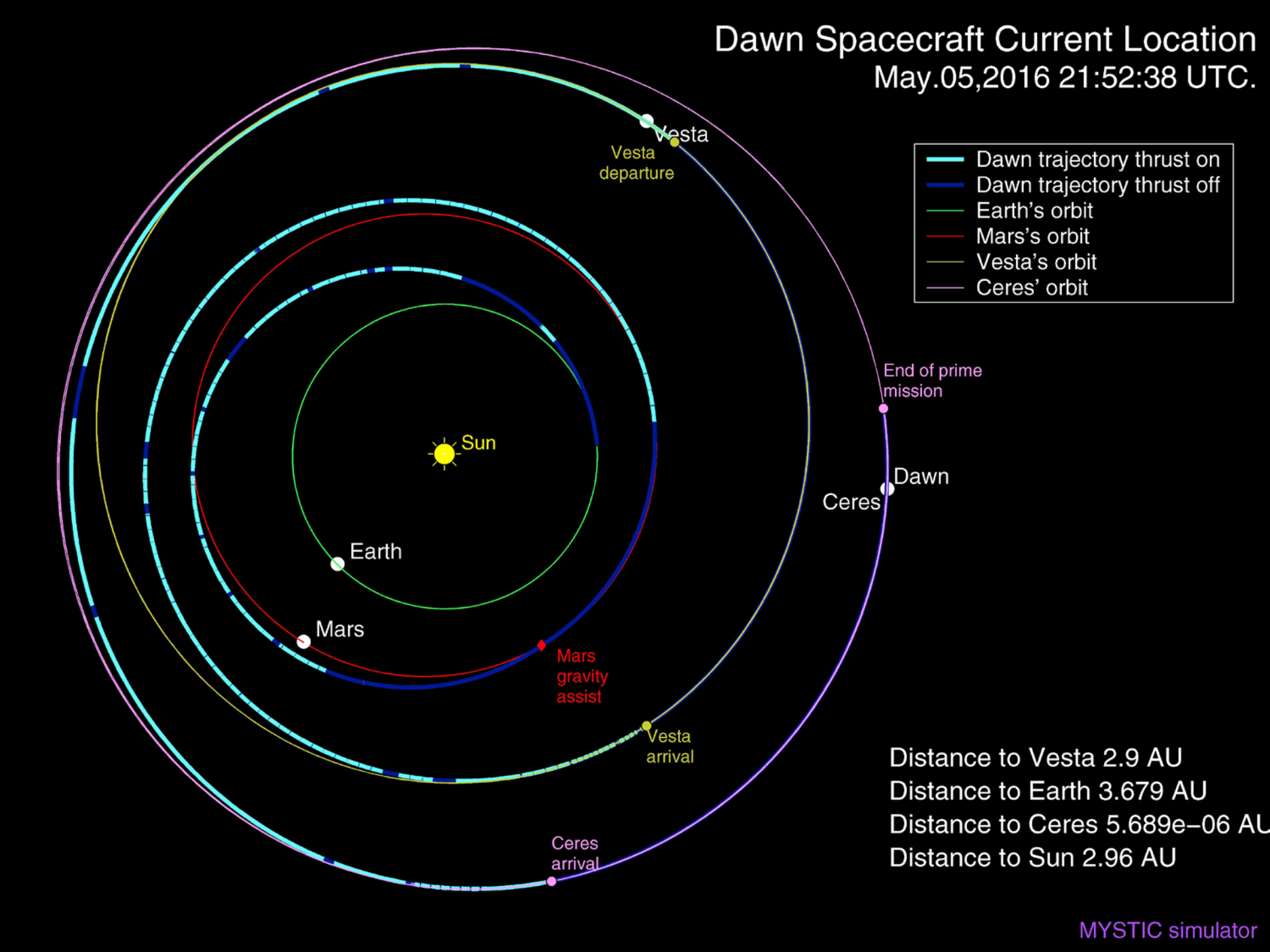
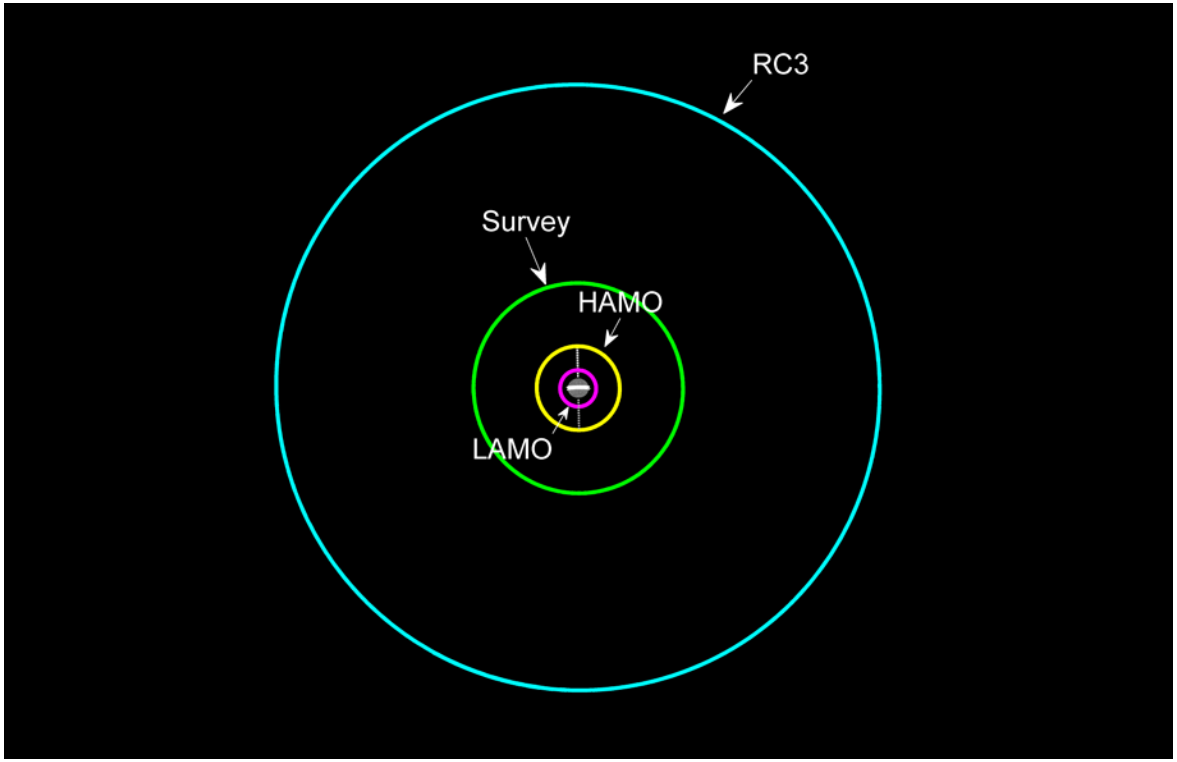

Dawn Spacecraft Current Location
May.05,2016 21:52:38 UTC.
Dawn trajectory thrust on
Dawn trajectory thrust off
Earth's orbit
Mars's orbit
Vesta's orbit
Ceres' orbit
Vesta
Vesta departure
Sun
Earth
Mars
Mars gravity assist
Vesta arrival
Ceres arrival
End of prime mission
Dawn
Ceres
Distance to Vesta 2.9 AU
Distance to Earth 3.679 AU
Distance to Ceres 5.689e−06 AU
Distance to Sun 2.96 AU
MYSTIC simulator

Ceres Approach

- Approach is the transition from interplanetary cruise to the highest science orbit around Ceres, RC3
  - RC3 orbit: 5º beta angle, +AM node, polar, circular, radius 14,000km



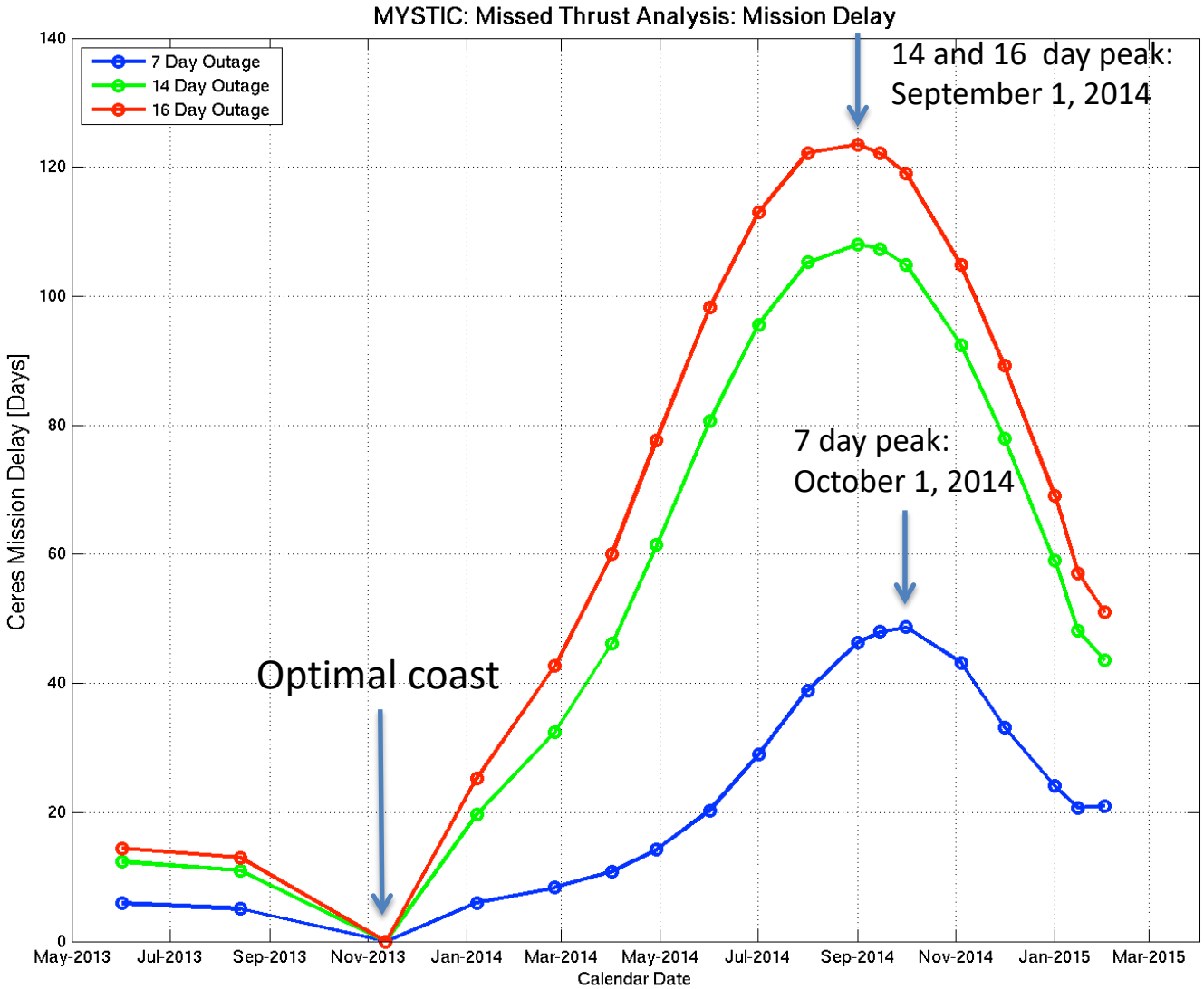
Dawn

Challenges of Ceres Approach

Dawn

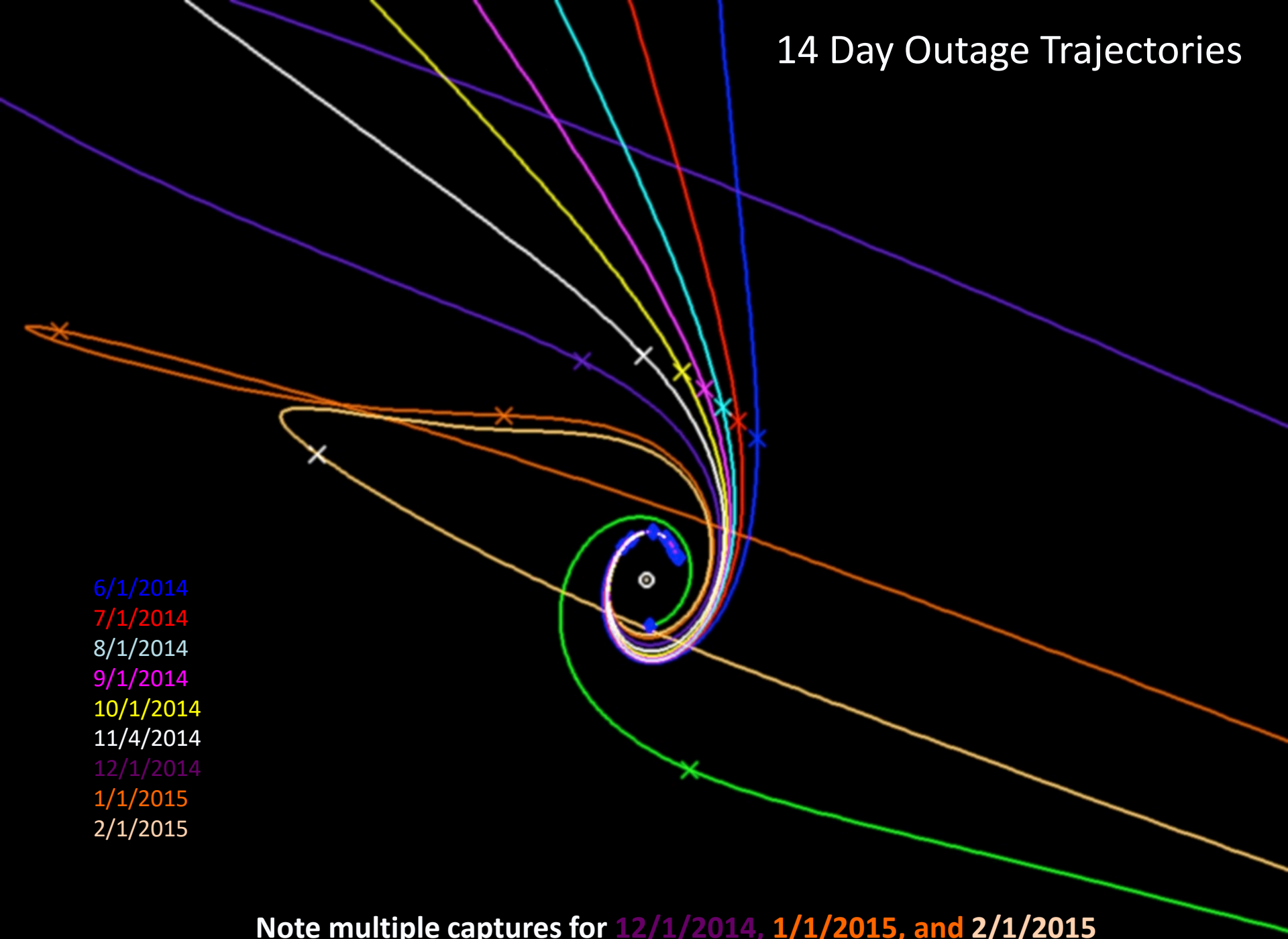
- Uncertainty in Ceres parameters
  - Ceres ephemeris, gravity, rotation rate, pole
- Optical navigation (opnav)
  - Range, phase, and number of opnavs
- Uncertainty in spacecraft parameters
  - Orbit determination, low-thrusting spacecraft, RCS impulses, etc.
- Dawn specific
  - Two of four RWAs failed
    - Attitude controlled with RCS thrusters, hydrazine limited, minimize coasting
    - Reduce number of opnavs to bare minimum
  - DSN booked months in advance
  - Safe mode just before approach
    - Adversely affected phase of planned opnavs, re-design
    - Planned architecture was broken, needed new architecture
    - Sensitive trajectory necessitated new way to fly the spacecraft into orbit around Ceres: waypoint targeting

Missed Thrust Analysis



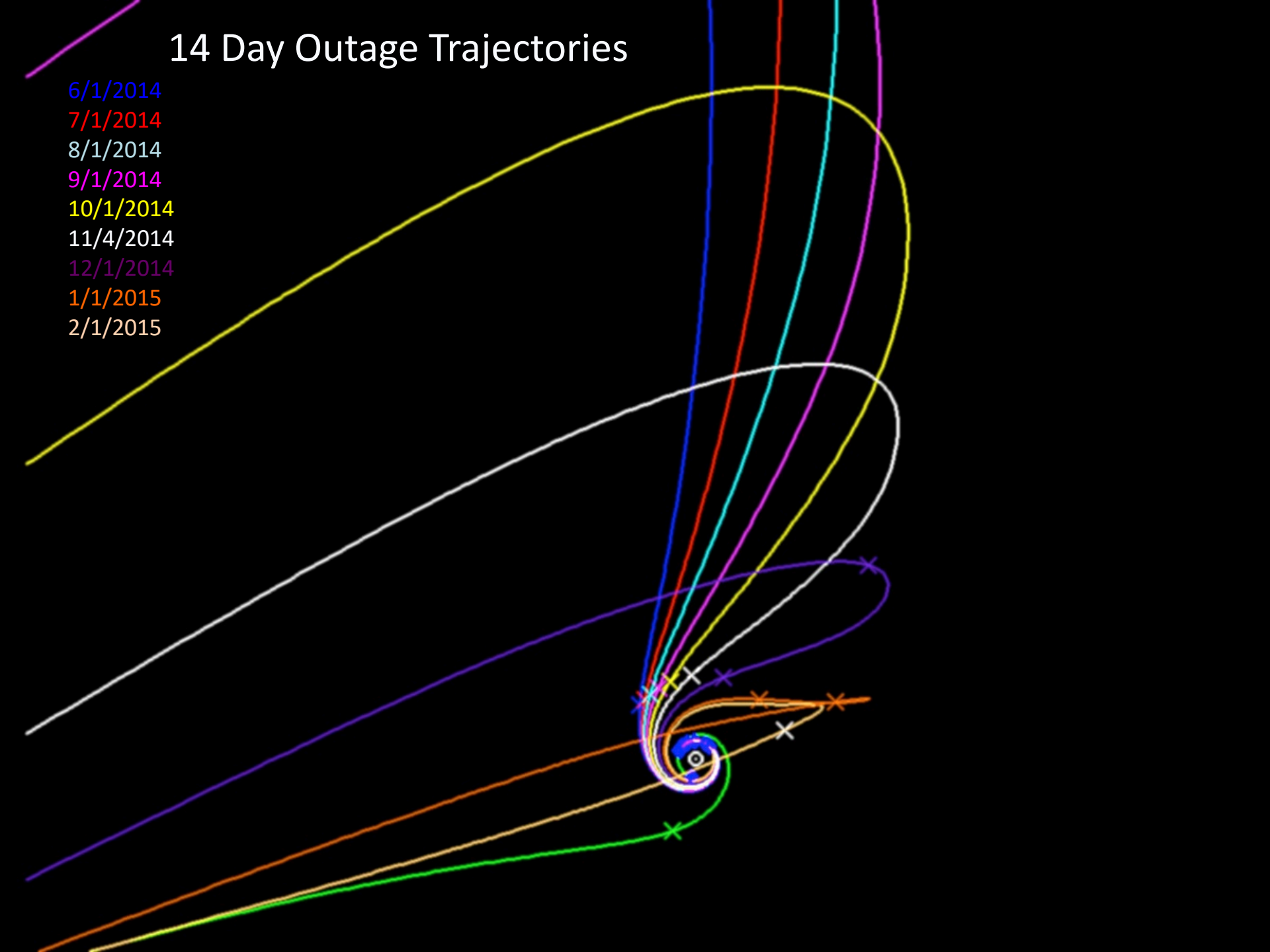
Dawn

14 Day Outage Trajectories



Note multiple captures for 12/1/2014, 1/1/2015, and 2/1/2015

14 Day Outage Trajectories



Safing & Approach Re-Design

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Discovered s/c in safe mode

Negotiated additional tracking

Re-design approach opnavs

Recovery maneuver designed for Monday uplink

Onboard flight computer rebooted

Further testing confirms s/c will respond nominally

Recovery maneuver uplinked to s/c

Thursday 9/11/2014	Friday 9/12/2014	Saturday 9/13/2014	Sunday 9/14/2014	Monday 9/15/2014	Tuesday 9/16/2014

Nav sensitivity analysis:
Uplink 15th: 29-dy delay
Uplink 16th: 40-dy delay
Uplink 17th: 50-dy delay
Uplink 18th: 60-dy delay
Uplink 20th: 78-dy delay
Uplink 22nd: 95-dy delay

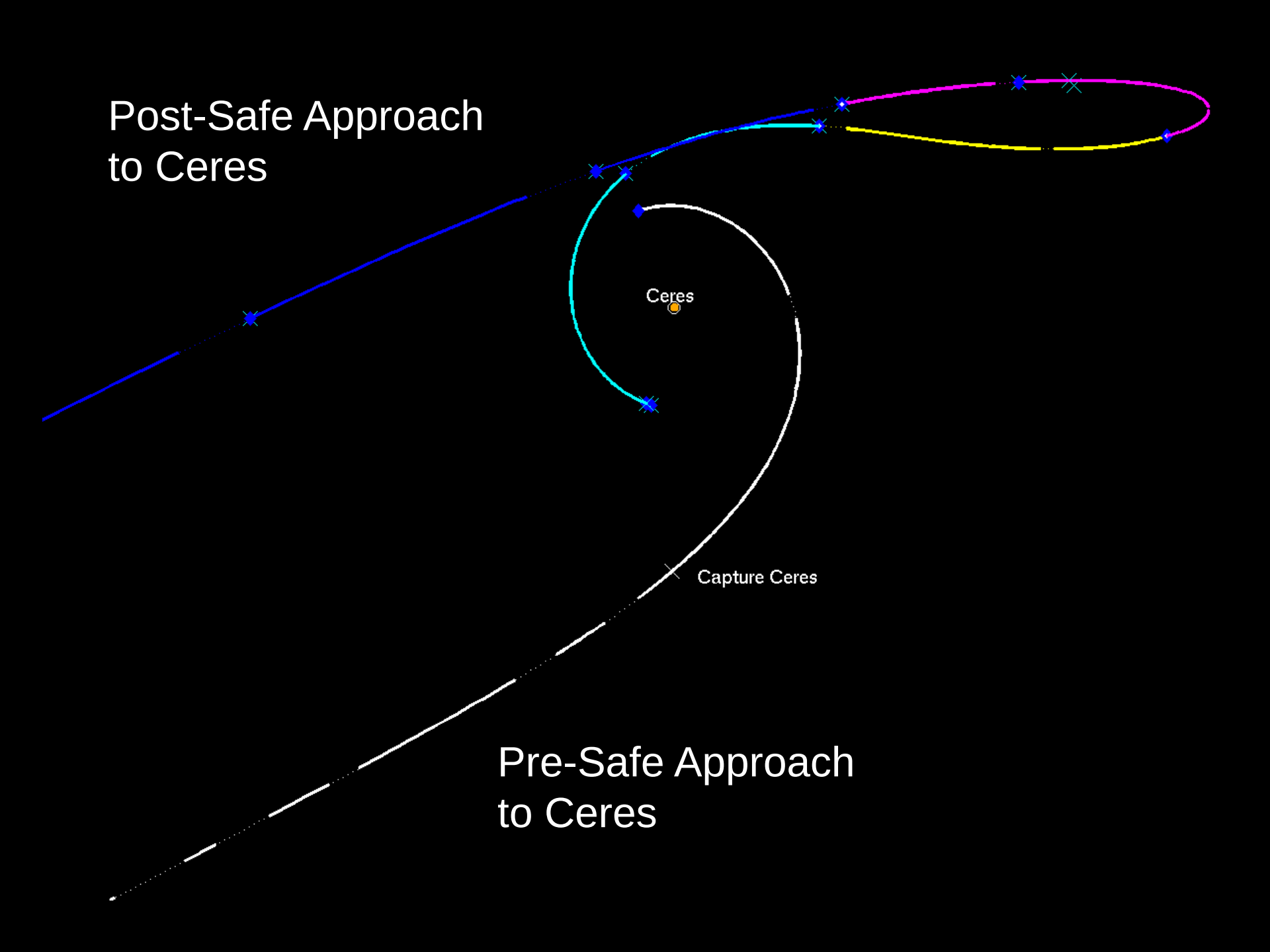
Decided likely switch thrusters

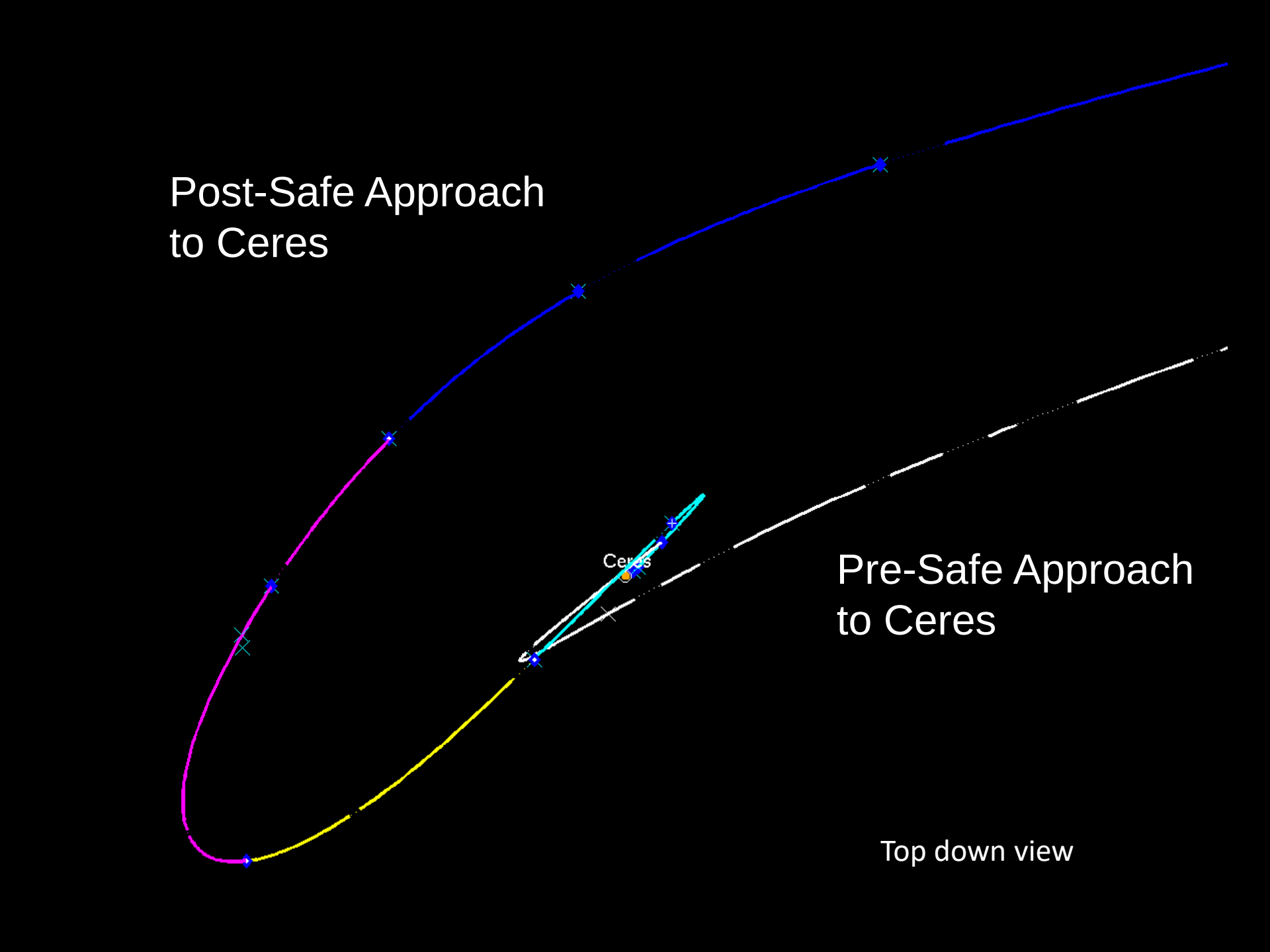
Problem still unknown

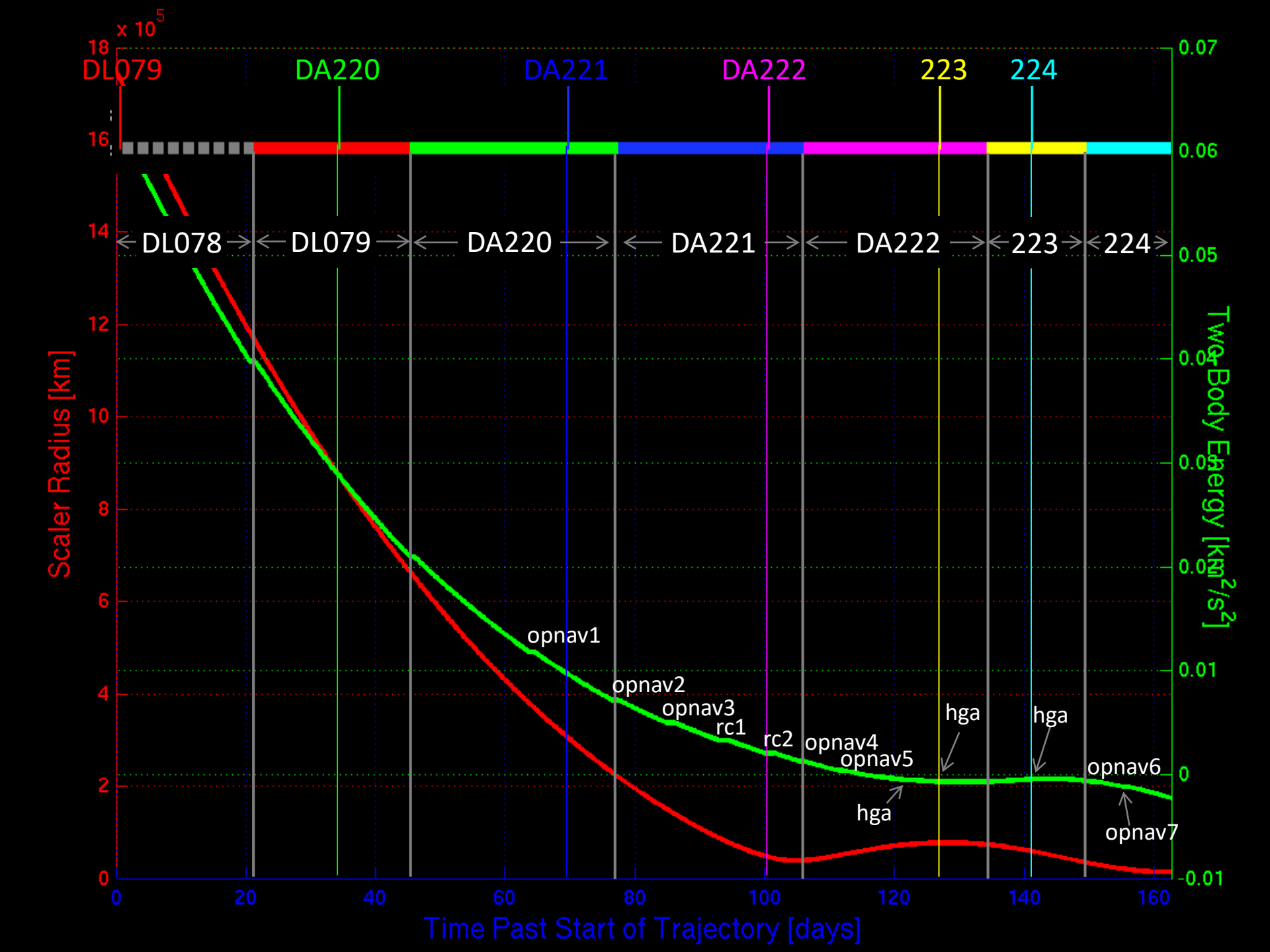
S/c commanded to turn HGA to Earth
No alarms

Cause of safe is disabled valve driver card for the IPS
Deemed SEU

Thrusting verified

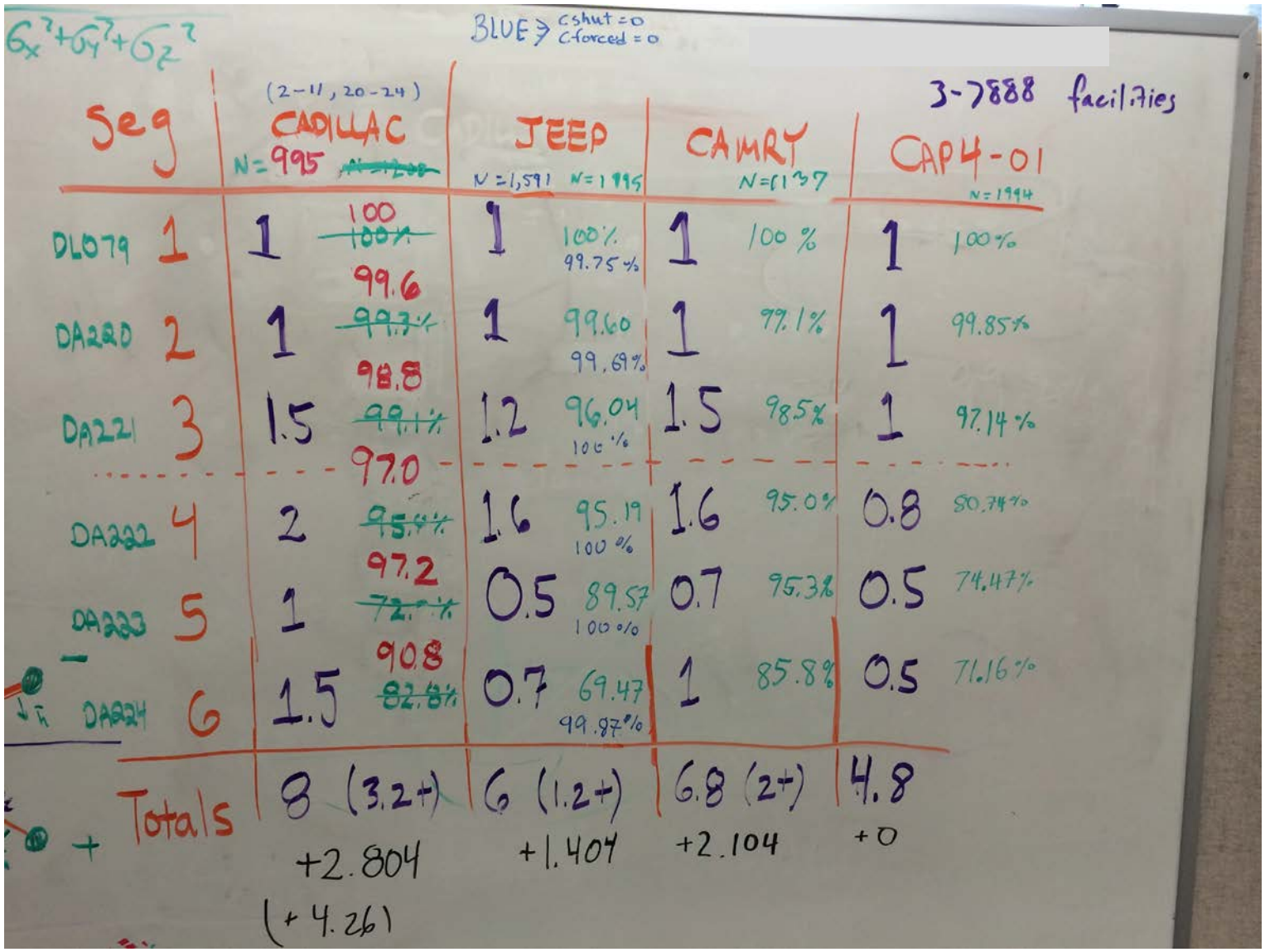

Post-Safe Approach
to Ceres
Ceres
Capture Ceres
Pre-Safe Approach
to Ceres


Post-Safe Approach
to Ceres
Ceres
Pre-Safe Approach
to Ceres
Top down view

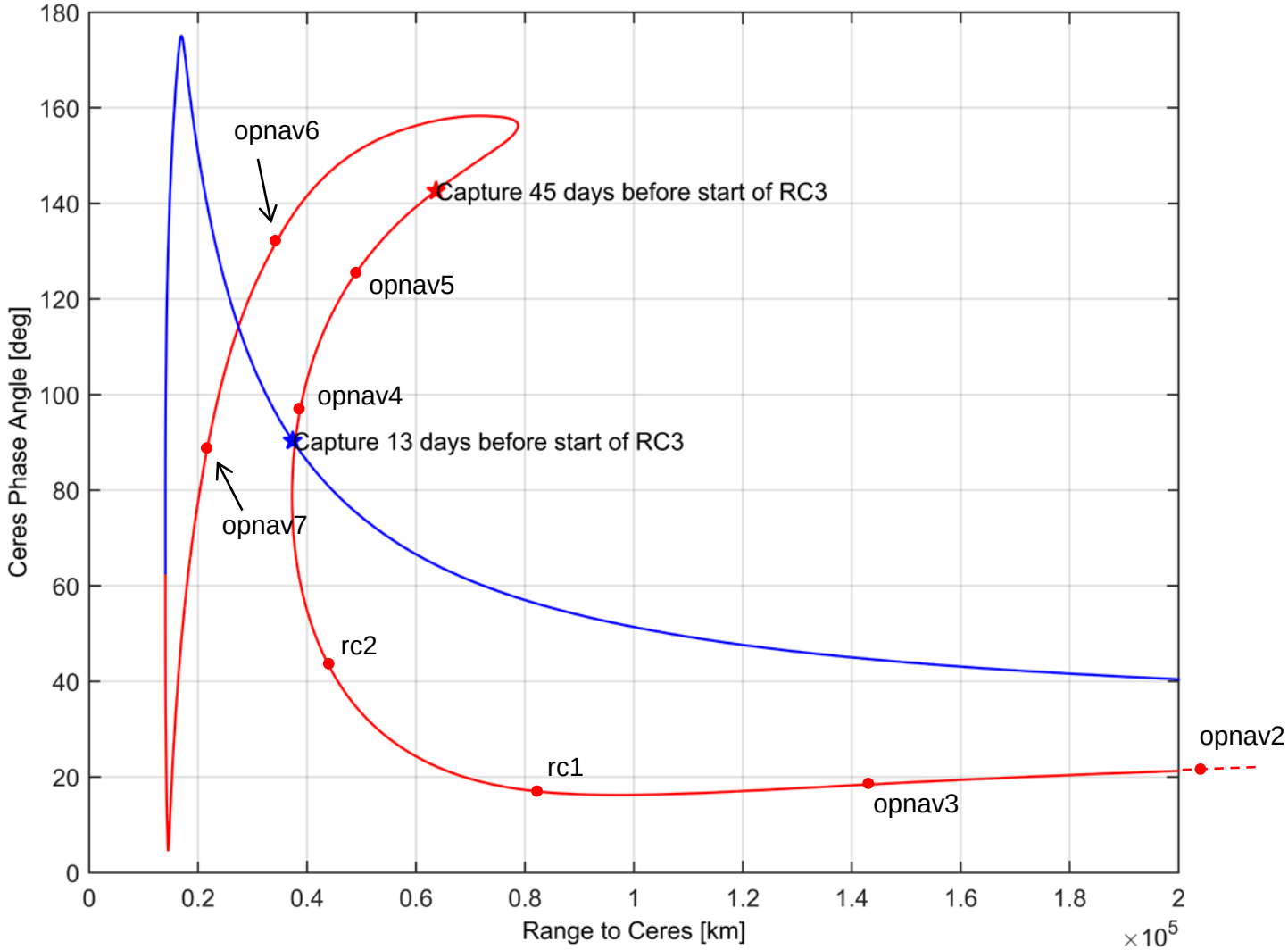

x 10^5
DL079
DA220
DA221
DA222
223
224
DL078
DL079
DA220
DA221
DA222
223
224
Scaler Radius [km]
Two-Body Energy [km^2/s^2]
Time Past Start of Trajectory [days]
opnav1
opnav2
opnav3
rc1
rc2
opnav4
opnav5
hga
hga
hga
opnav6
opnav7
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100
120
140
160
-0.01
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07

Veil Architecture Studies

Dawn



Approach Phase Angle



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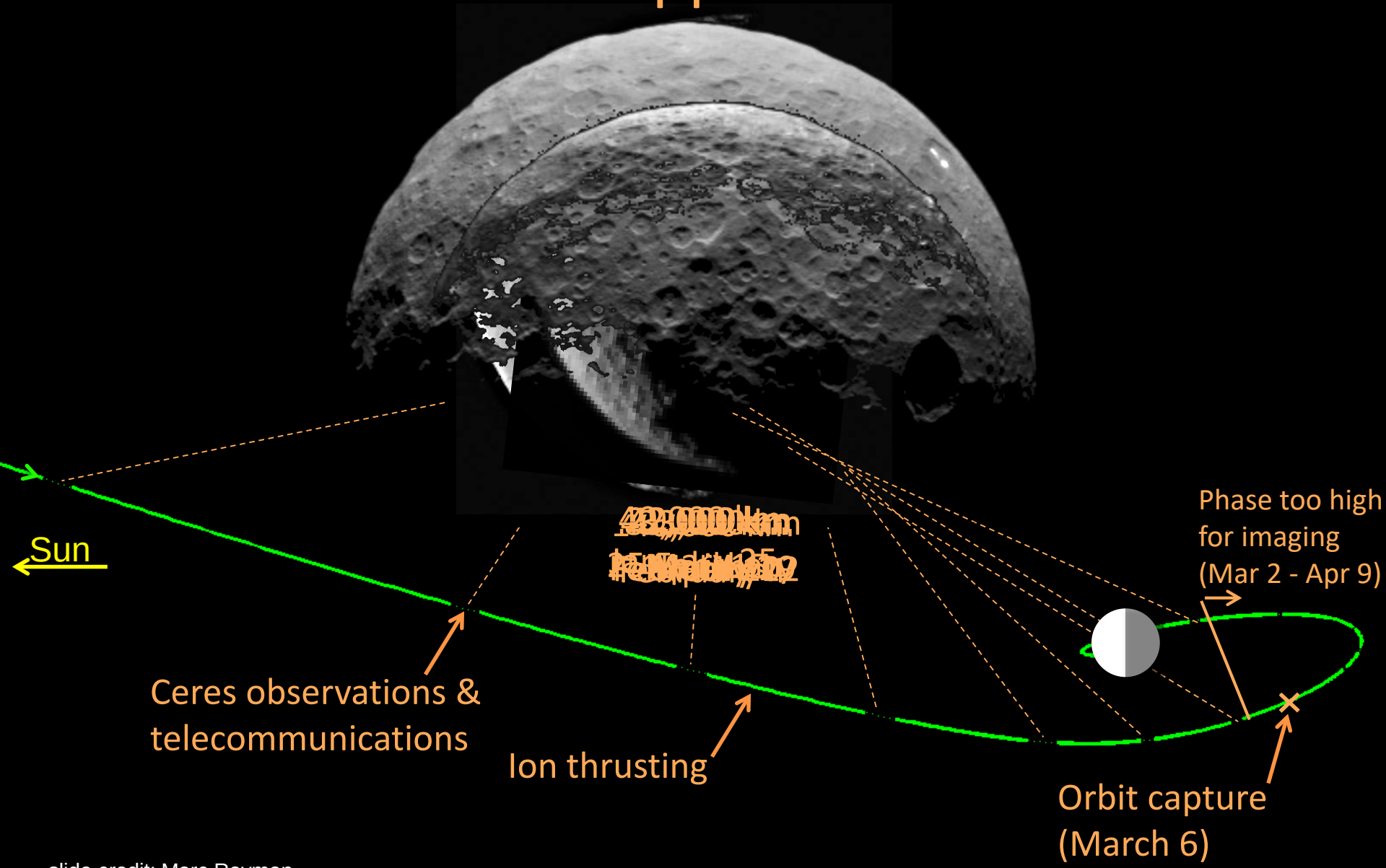
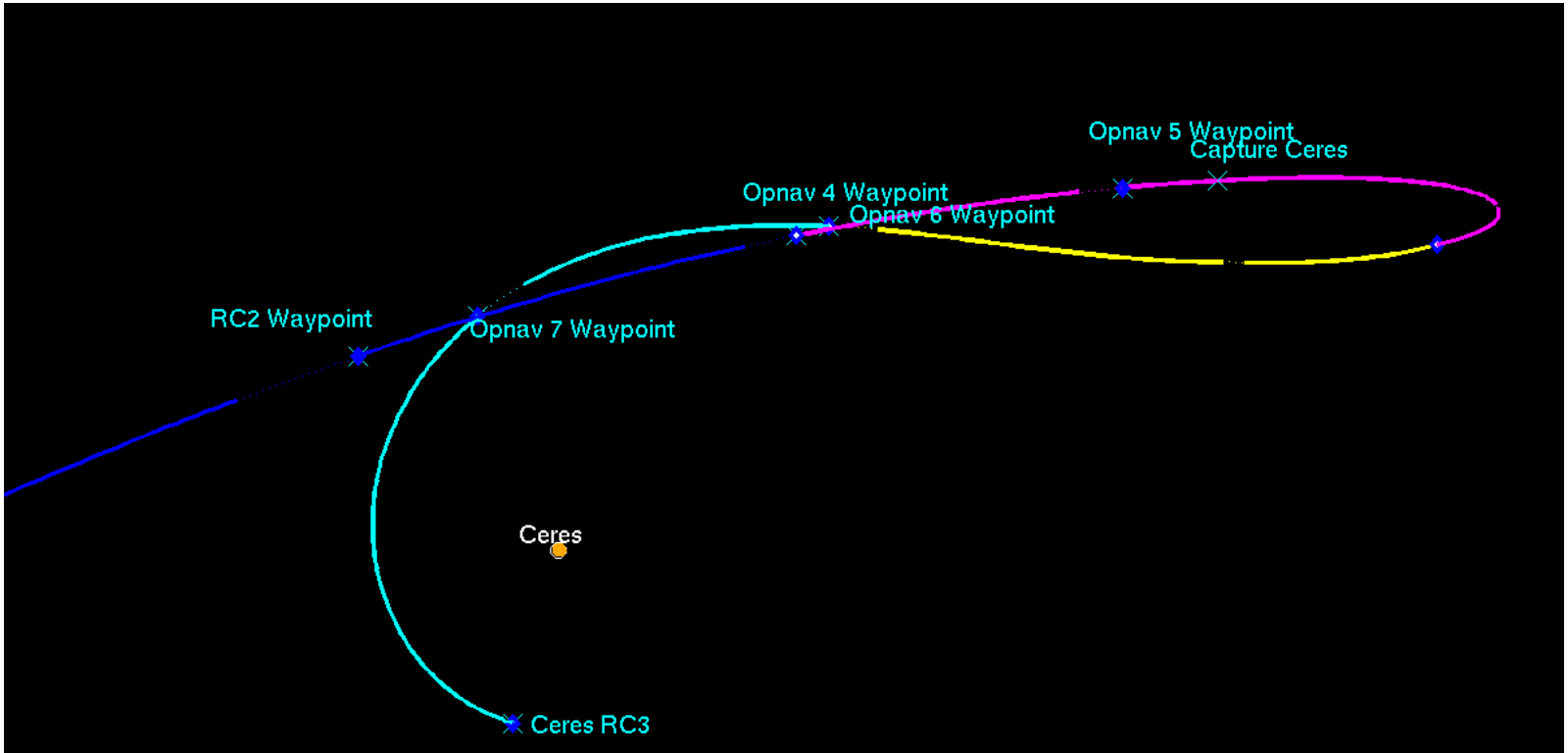
Dawn Approaches



slide credit: Marc Rayman

Waypoint Targeting

To preserve approach geometry, six-states were targeted on the way in to Ceres to guide the trajectory along the planned course



From Veil analysis, 1σ uncertainty for opnavs range < 2,000 km, phase < 4º

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Conclusion

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- Safing event on September 11, 2014 occurred when IPS thrusting was most effective
- This significantly altered our approach strategy
  - New trajectory flies past Ceres, turns around, and approaches Ceres from the dark side
  - Re-design opnav campaign
  - Pre-safing architecture for approach was broken, necessitating new architecture studies
  - Very sensitive approach required new strategy to preserve geometry via waypoint targets
- Dawn successfully inserted into RC3 on April 24, 2014
  - Just 4 days in missed thrust resulted in 33 days of delay to RC3
  - Insertion error was sub-sigma: 205 km, 61 cm/s
- Comment on versatility of IPS