Mars Reconnaissance Orbiter:
Aerobraking Sequencing Operations and Lessons Learned

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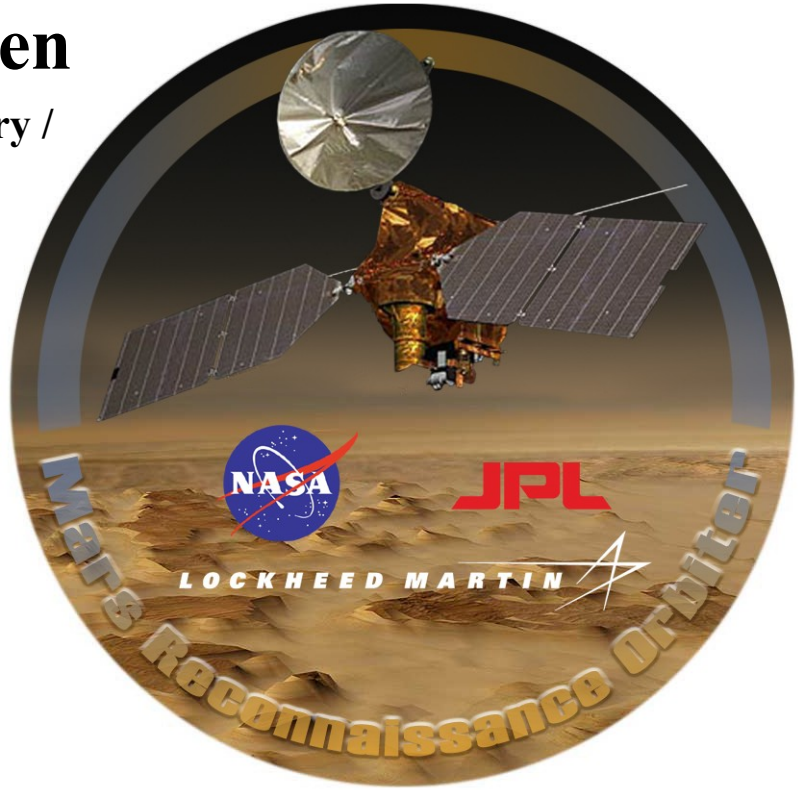
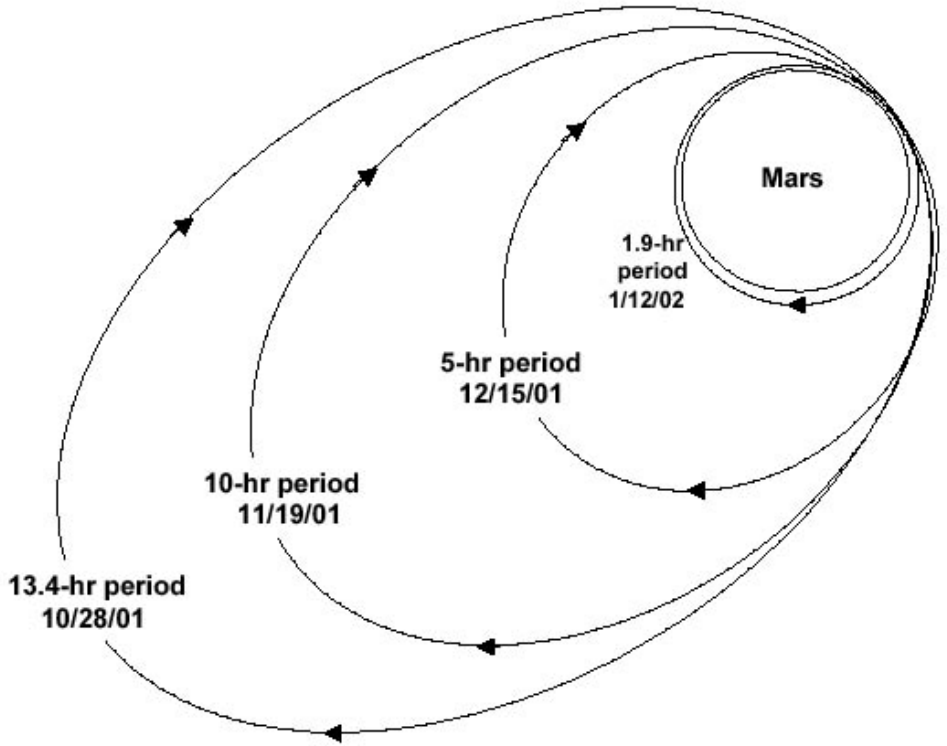
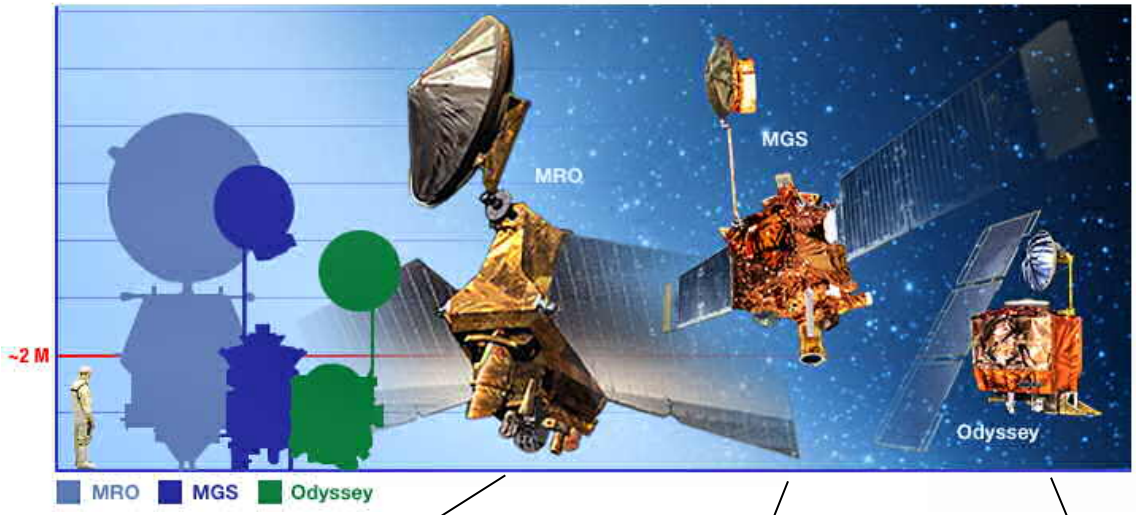


What is Aerobraking?

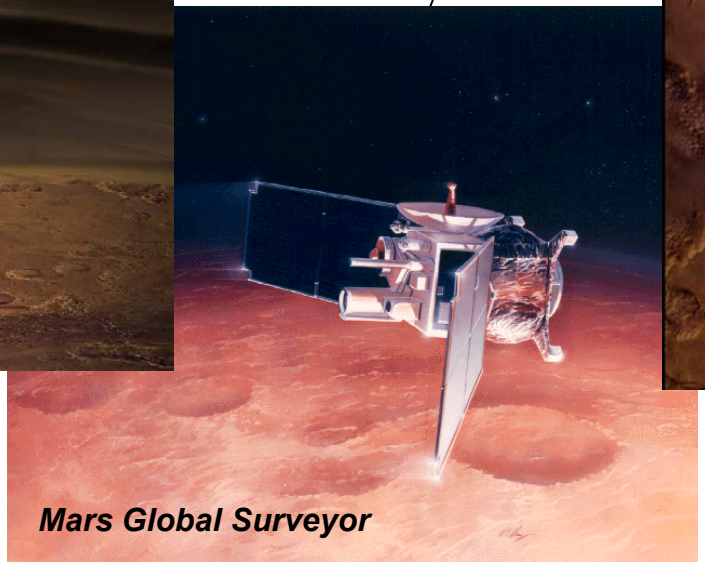
- **Aerobraking is a spaceflight maneuver performed by a spacecraft near a planet with an atmosphere.**
- **It is used to reduce the orbital period of a spacecraft by passing it through the upper levels of the atmosphere of a planet.**
- **The heat generated by the friction of the spacecraft against the atmosphere dissipates the kinetic energy of the spacecraft, thus imparting a change in velocity, or delta-V.**
- **The spacecraft radiates this heat to space between successive passes through the atmosphere, thus reducing its specific mechanical energy.**



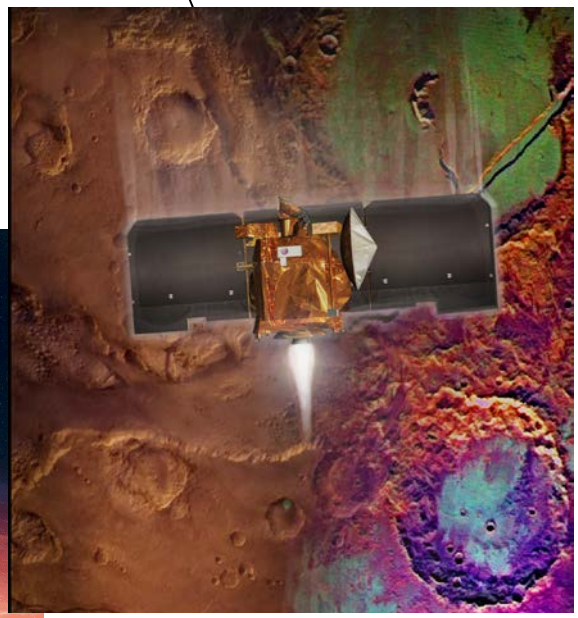
Aerobraking orbits



Mars Reconnaissance Orbiter



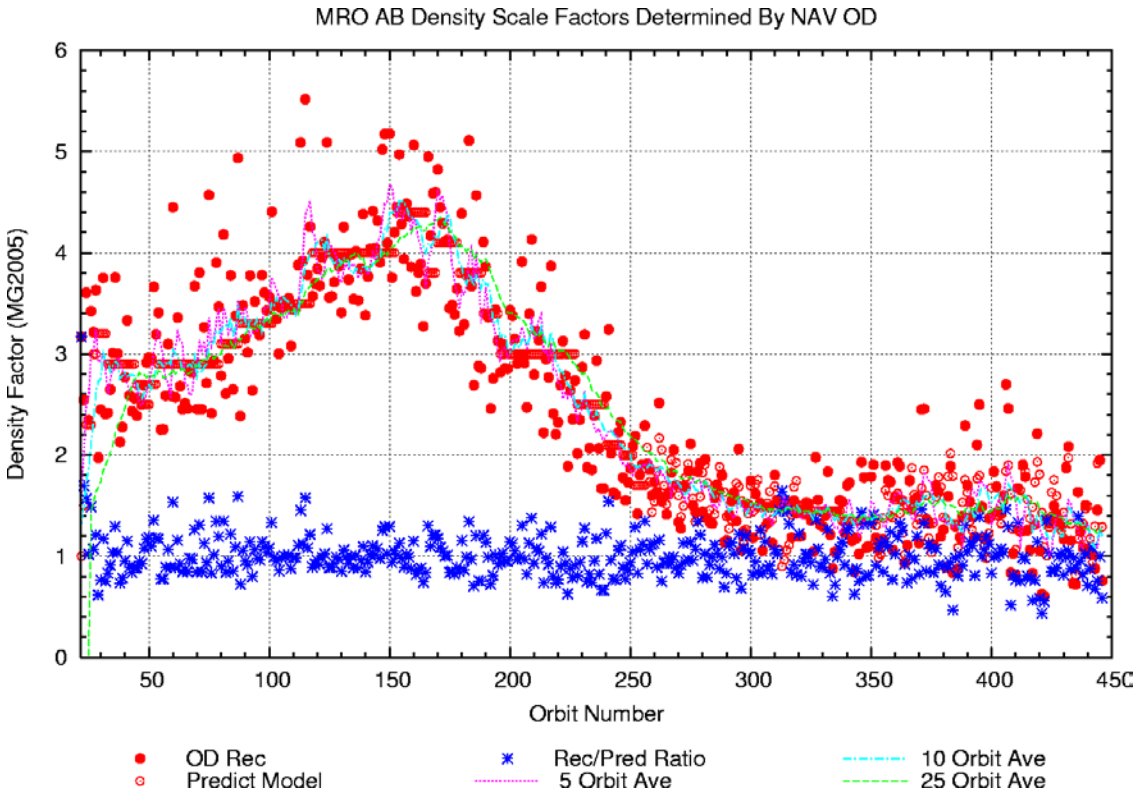
Mars Global Surveyor



Mars 2001 Odyssey

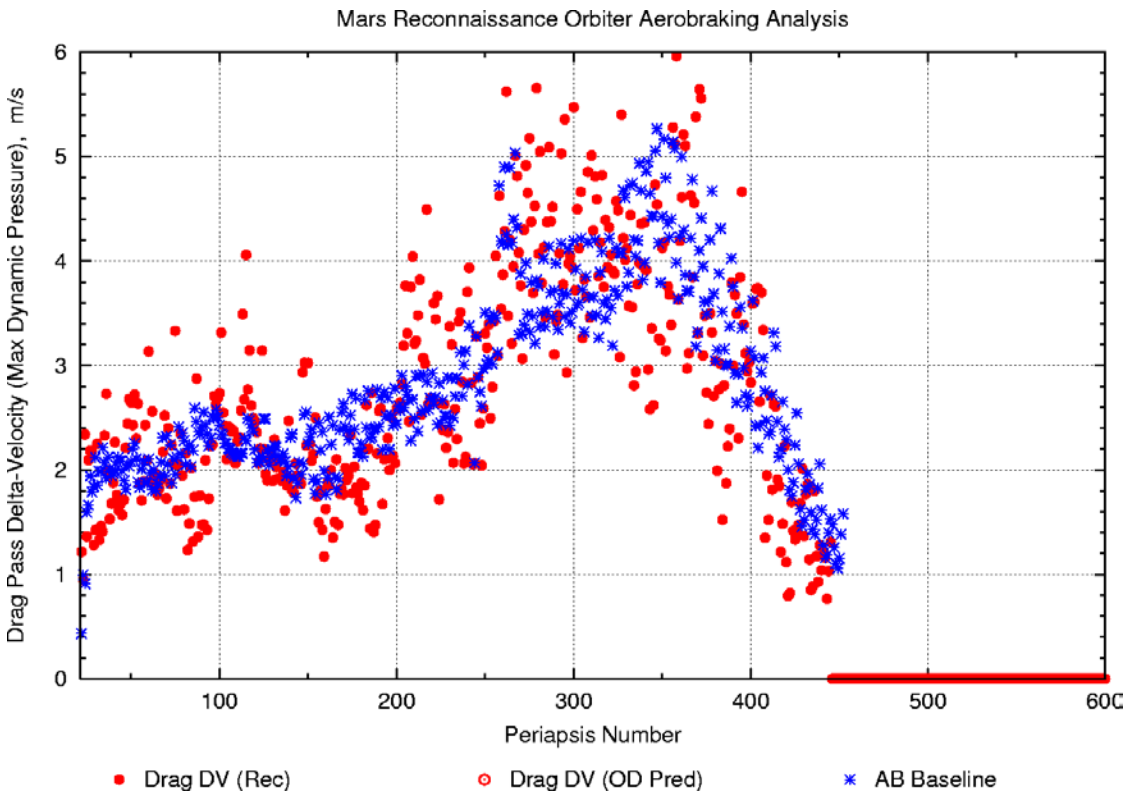
The Challenge of Aerobraking

- The density of the atmosphere at Mars is never certain.
- This makes it difficult to predict how much delta-V (and change in orbital period) would be imparted on each successive pass through the atmosphere.
- This is particularly challenging during the shorter orbits when several orbits would elapse before a new set of commands could be uploaded to the vehicles.
- The vehicles do not autonomously account for this change in velocity.

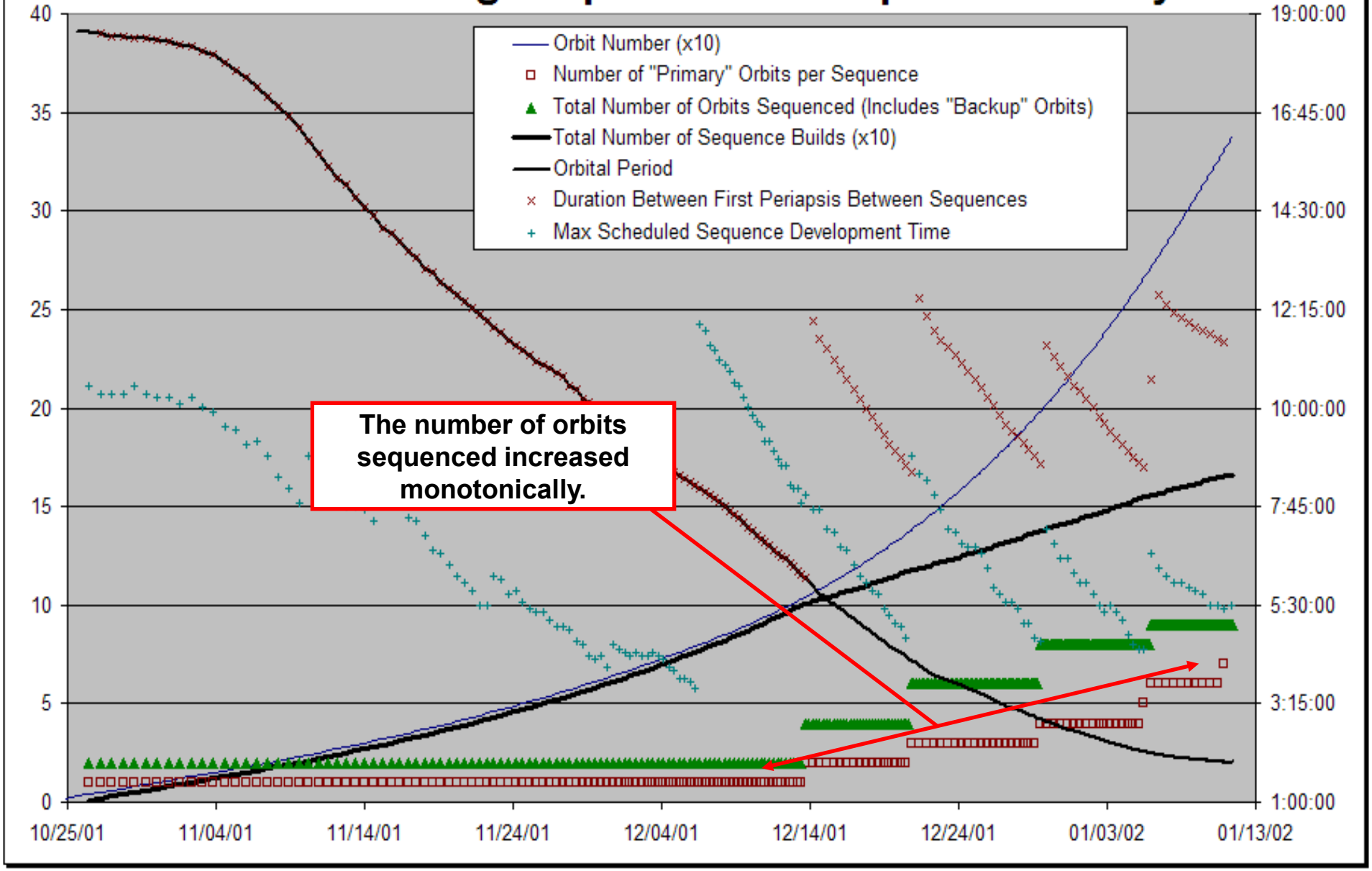


Sequence Shifting

- **Odyssey included the ability to shift the commands for the next orbit based upon the detected change between the predicted periapsis for the last orbit and the periapsis it believes it experienced.**
- **This compensated for the previous orbit's offset, but failed to address the effect of the delta-V on the orbital period.**
- **MRO augmented this sequence-shifting capability by measuring the approximate delta-V on each drag pass and predicting the time of the next periapsis passage.**



Mars 2001 Odyssey
Aerobraking Sequence Development History



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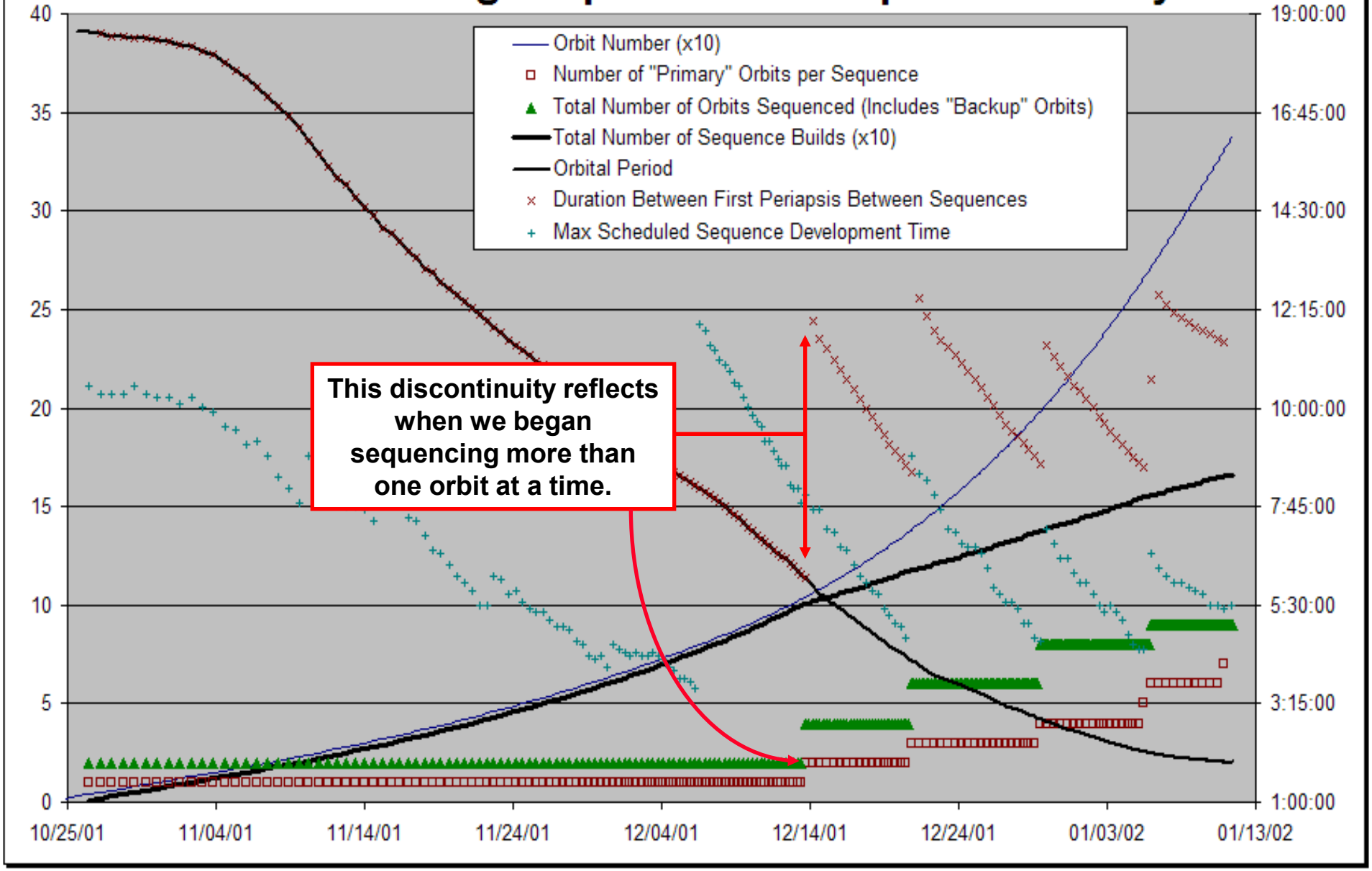

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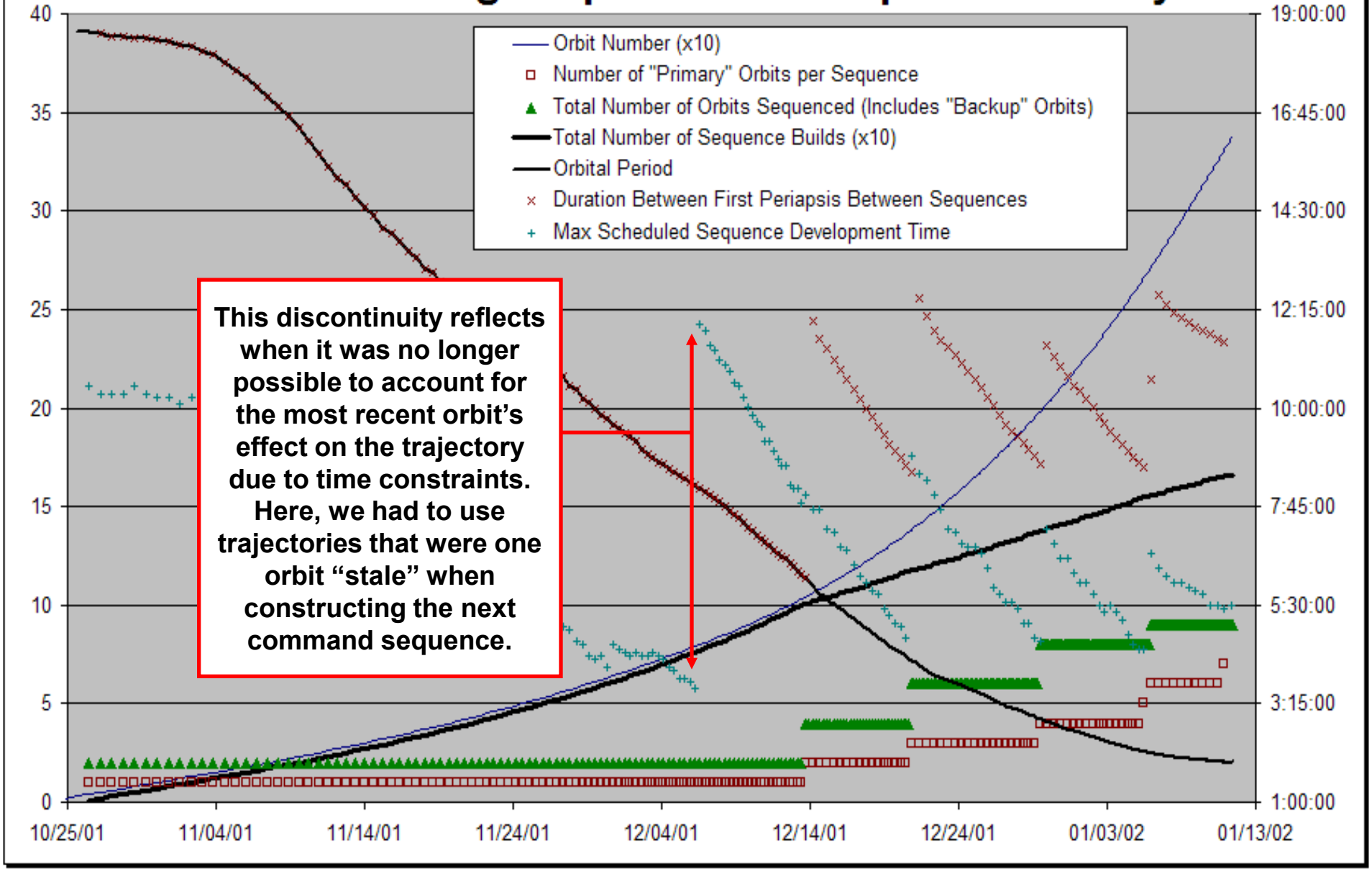

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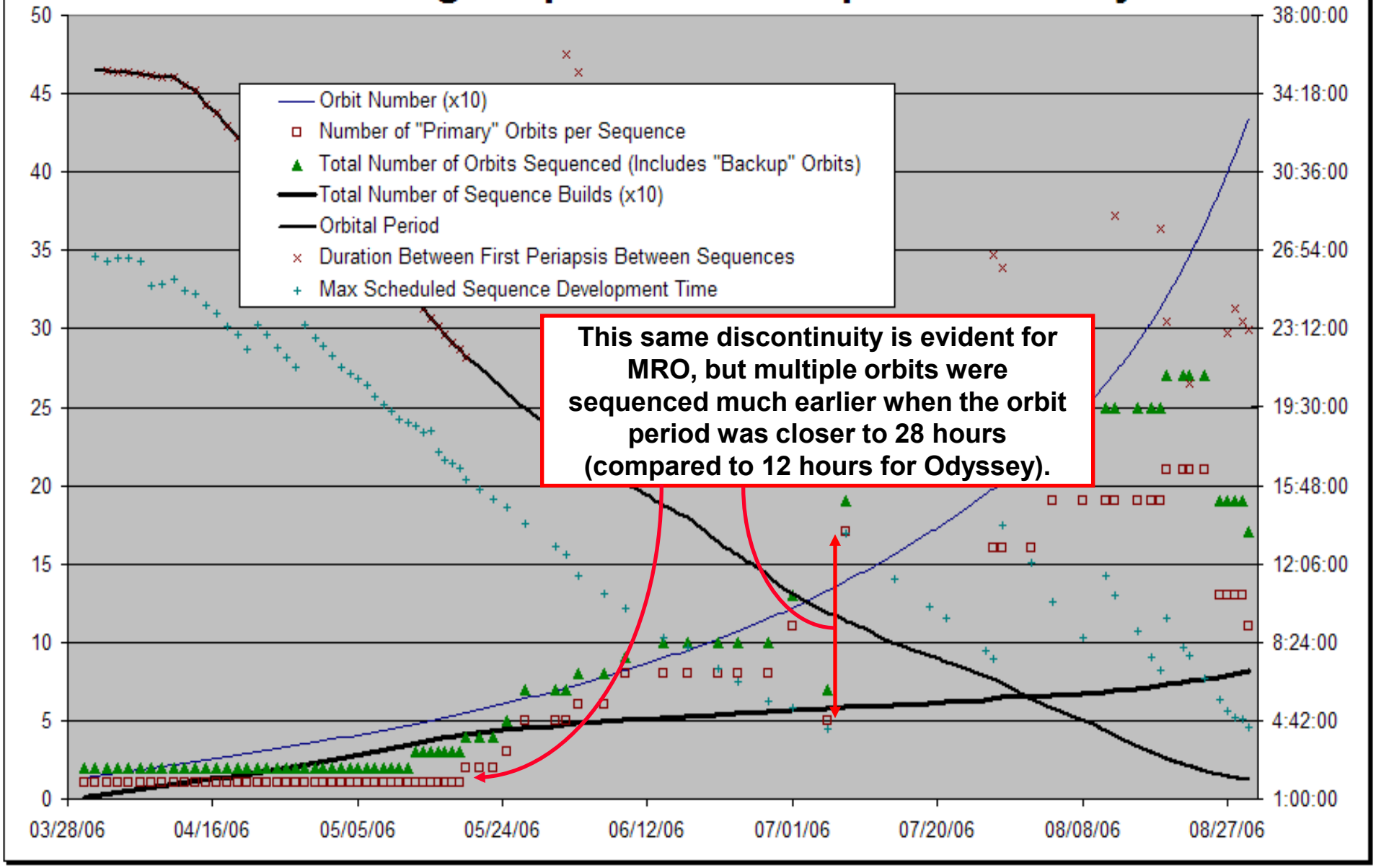

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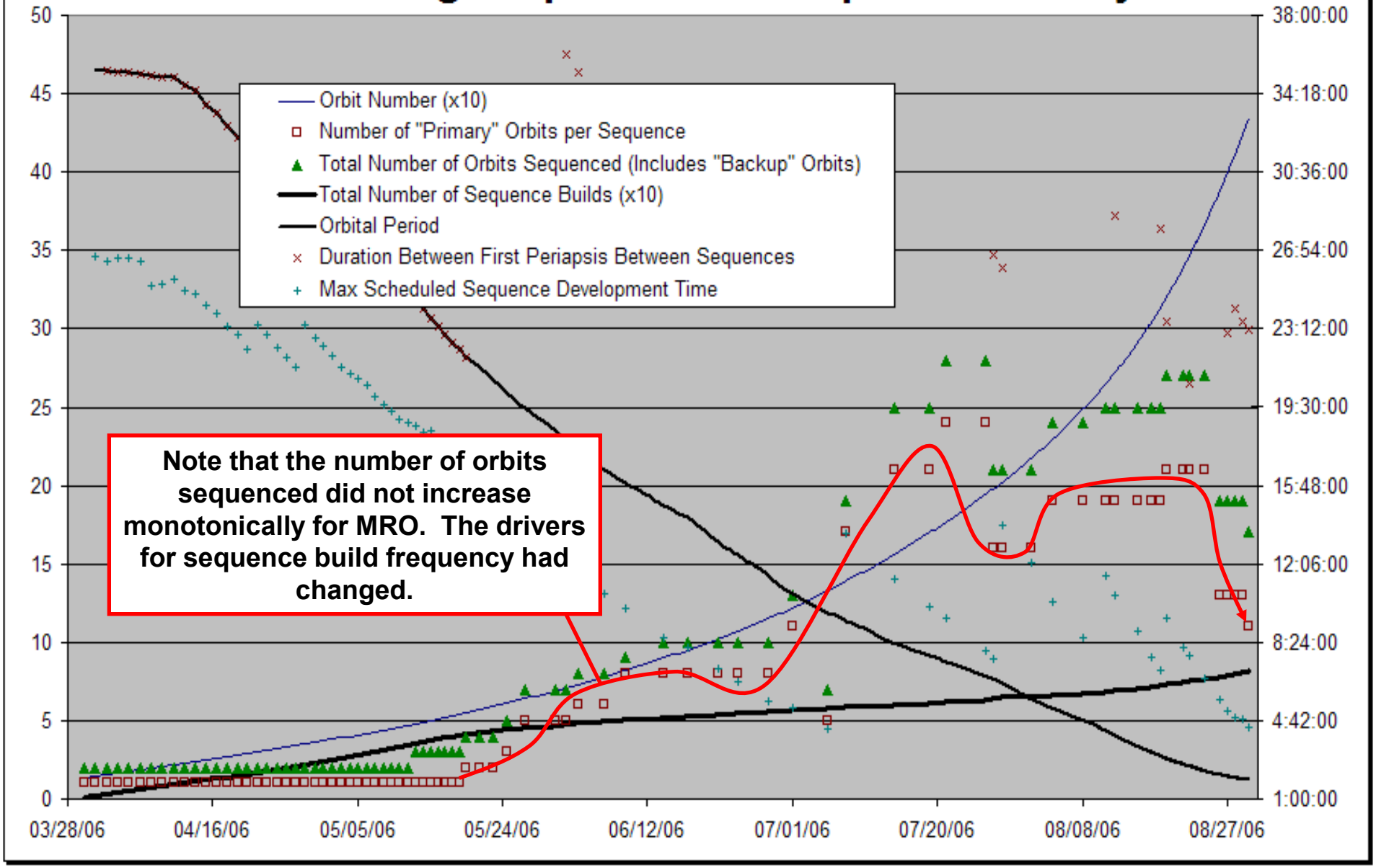
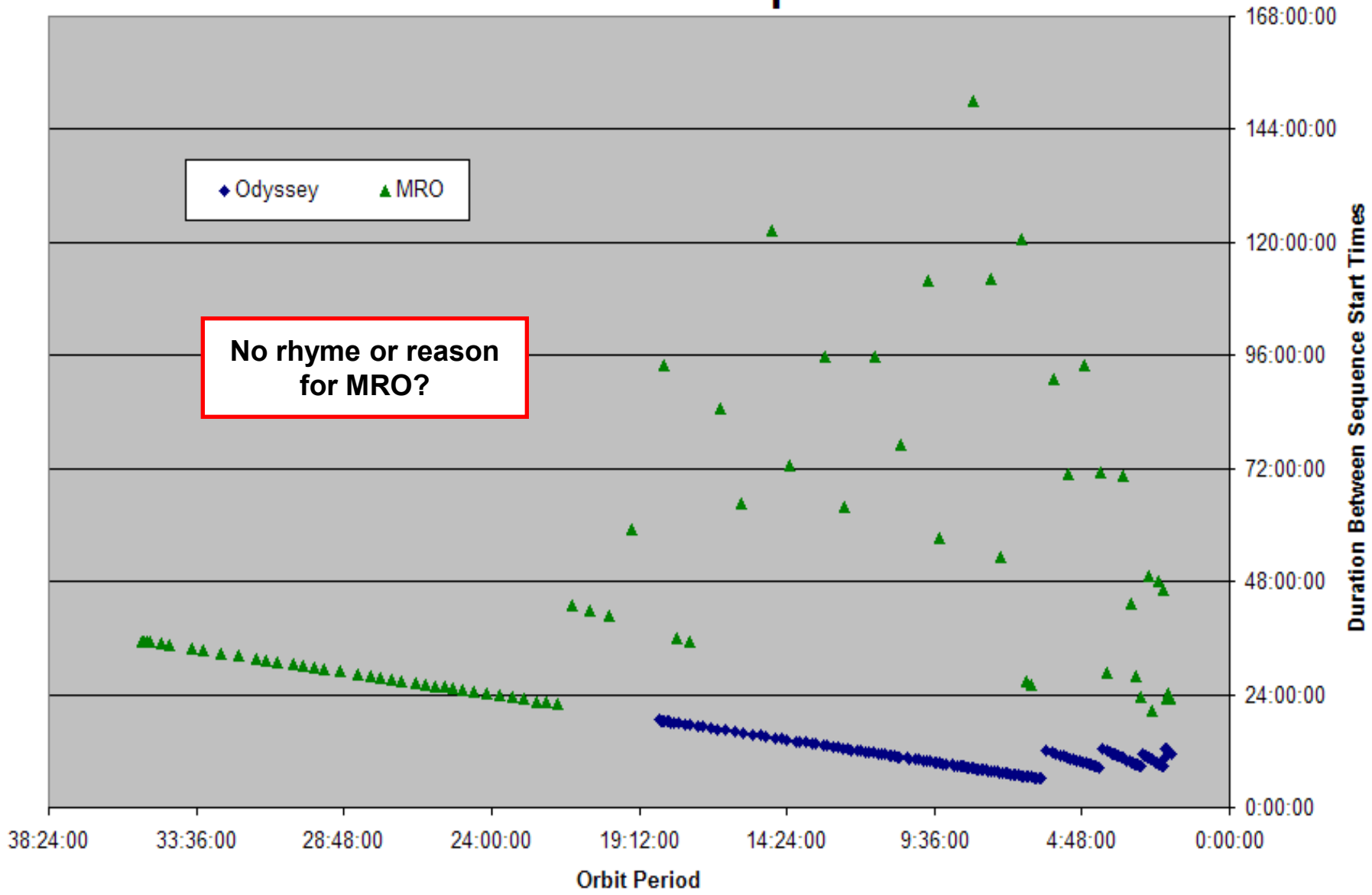
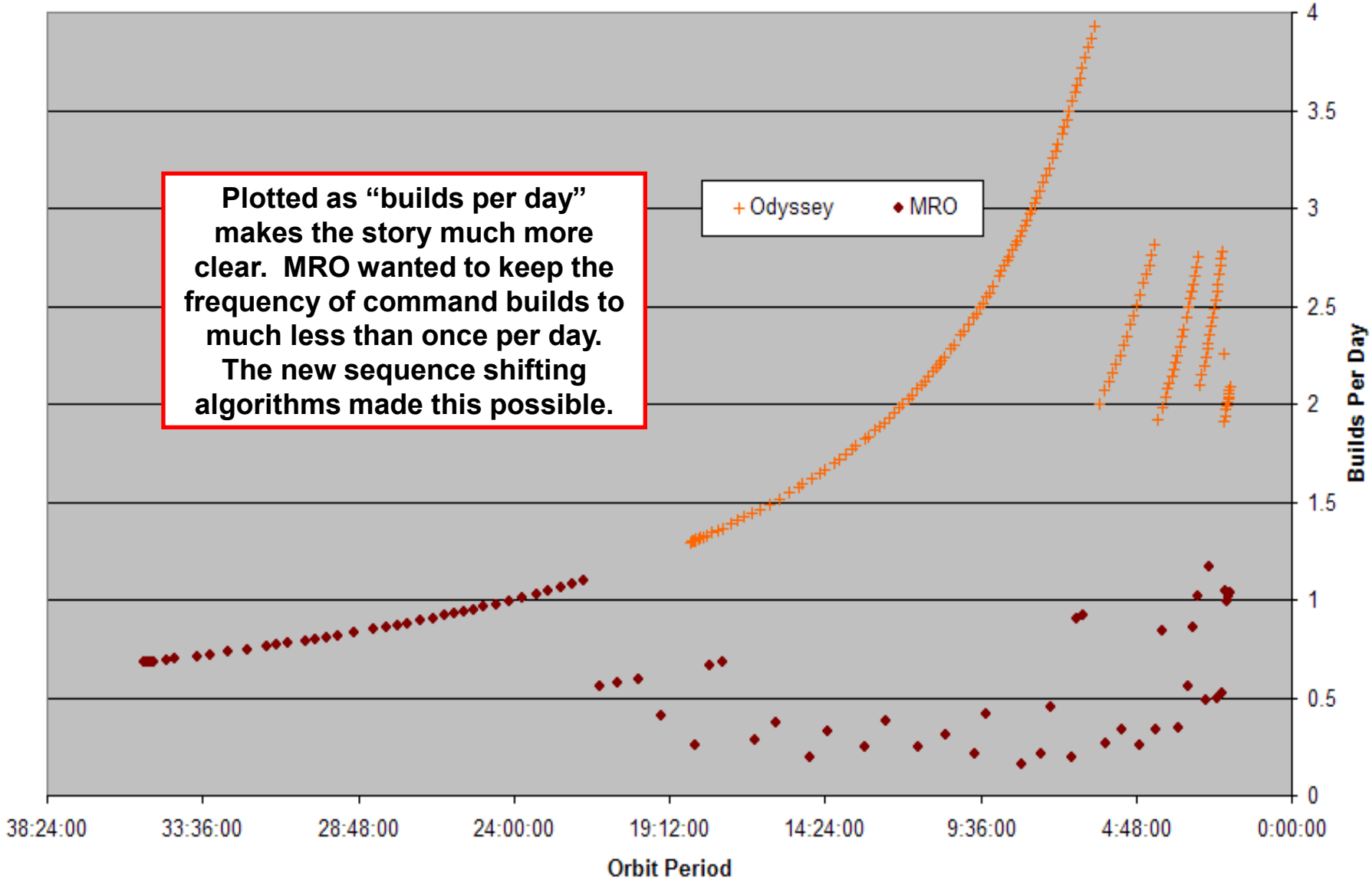


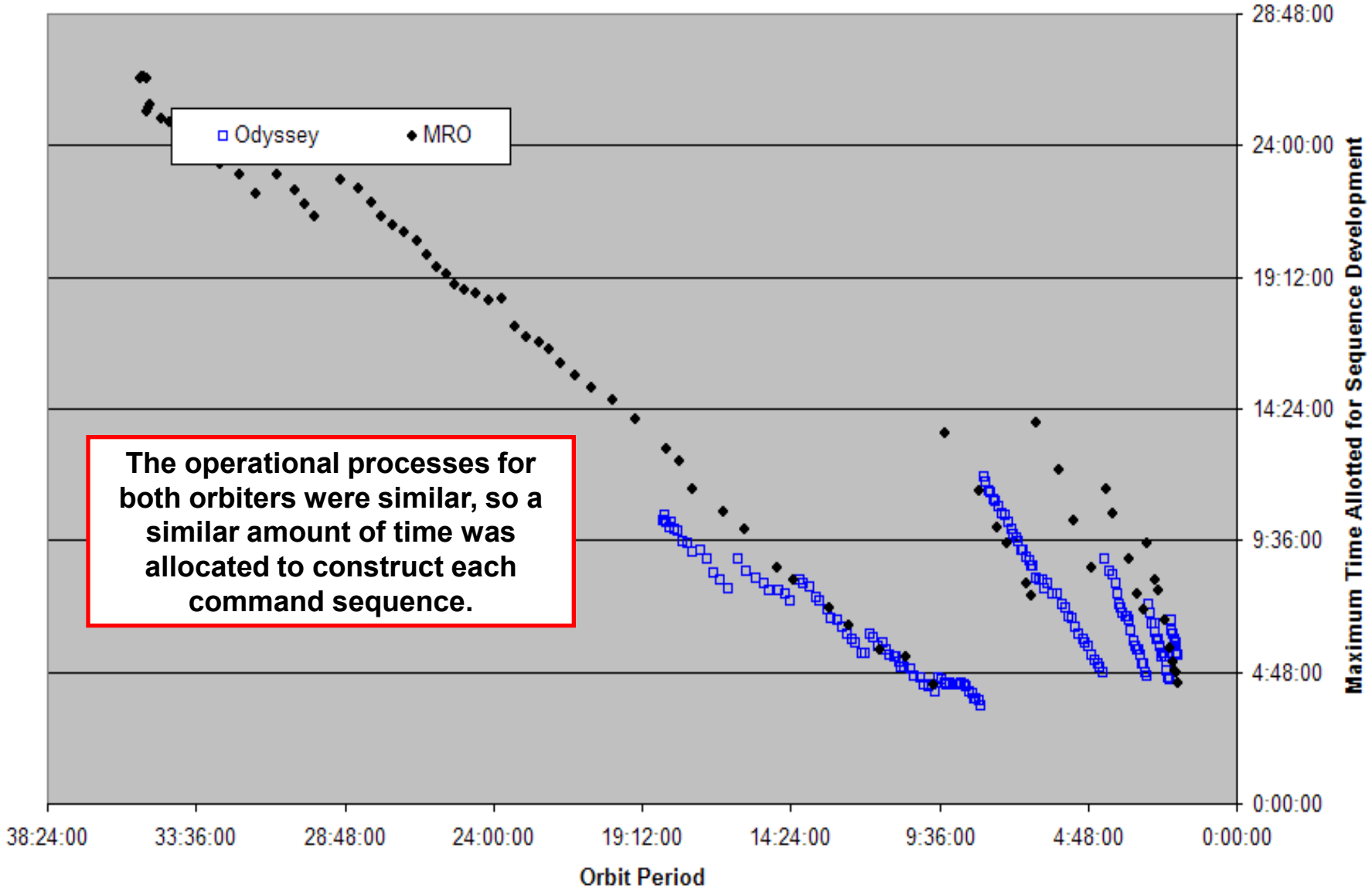
MRO and Odyssey Aerobraking Durations Between Sequence Starts



MRO and Odyssey Aerobraking Sequence Builds Per Day

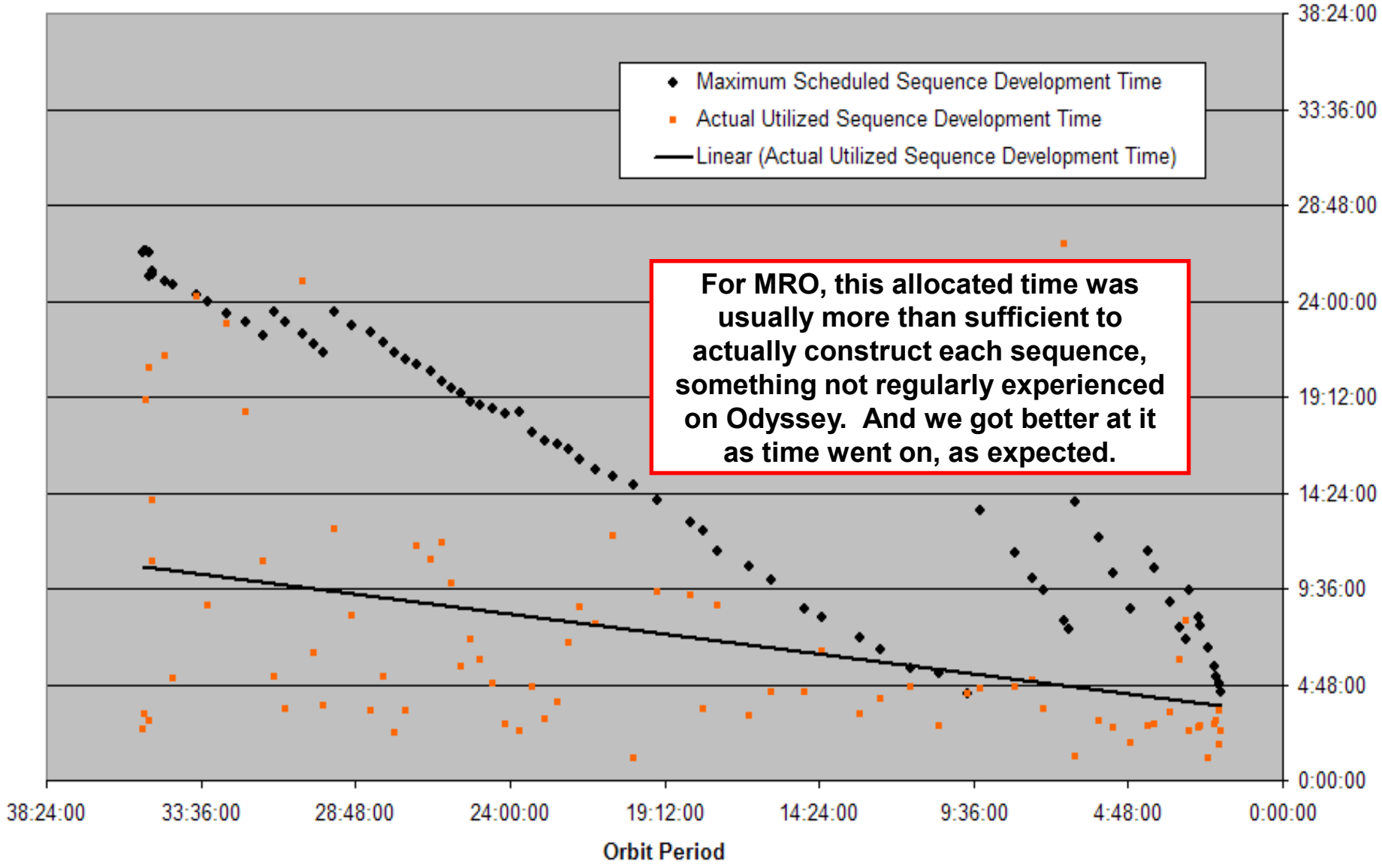


MRO and Odyssey Aerobraking
Maximum Time for Sequence Development



The operational processes for both orbiters were similar, so a similar amount of time was allocated to construct each command sequence.

MRO Aerobraking Sequence Development Times



For MRO, this allocated time was usually more than sufficient to actually construct each sequence, something not regularly experienced on Odyssey. And we got better at it as time went on, as expected.

Additional Comparisons

Feature	Odyssey	MRO
Allocated Time to Aerobrake	3 months	6 months
Sequence Shifting Paradigm	Corrected for time offset from previous orbit	Correct for delta-V offset from previous orbit
Mechanical Design	Not primarily designed for aerobraking operations	Designed for aerobraking operations with aero-stable configuration
Inheritance	Inherited processes, procedures, and personnel from MGS	Inherited processes, procedures, and personnel from Odyssey and MGS

- **The MRO mission design allowed for a more relaxed approach to aerobraking. Sequences were constructed during day shifts during the work-week by fewer people.**
- **The improved algorithms on MRO for sequence shifting were more accurate and provided a greater level of flexibility for sequencing the vehicle. Sequence builds could be delayed or moved to earlier orbits if needed.**
- **With higher thermal and temporal margins, operating MRO was a less tense experience, despite aerobraking for nearly twice as long.**
- **The depth of aerobraking experience of the operations teams made aerobraking seem routine.**

Final Words

- **The MRO project was able to improve aerobraking operations from the Odyssey experience in nearly every way, in itself an improvement over MGS.**
- **It is anticipated that these lessons will be carried forward to the next aerobraking vehicle to again simplify the process, improve the onboard software and the operational software, and to make aerobraking operations a more human-friendly experience while achieving mission objectives.**

Questions?

Many thanks to all the fine people who made these numbers look so good!

Both the Mars 2001 Odyssey spacecraft and the Mars Reconnaissance Orbiter are managed by the Jet Propulsion Laboratory, a division of the California Institute of Technology, Pasadena, for the NASA Science Mission Directorate, Washington, DC. Lockheed Martin Space Systems, in Denver, CO; is the prime contractor for the projects and built the spacecraft.

The work described in the subject paper was performed at the Jet Propulsion Laboratory (JPL), managed by The California Institute of Technology (CalTech), under contract to the National Aeronautics and Space Administration (NASA).

Additional information is available in: "AUTOGEN: The Mars 2001 Odyssey and the 'Autogen' Process", AIAA/USU Small Satellite Conference, Logan, UT, August 2002. R. Gladden.