# An End-to-End Trajectory Description of the LISA Mission


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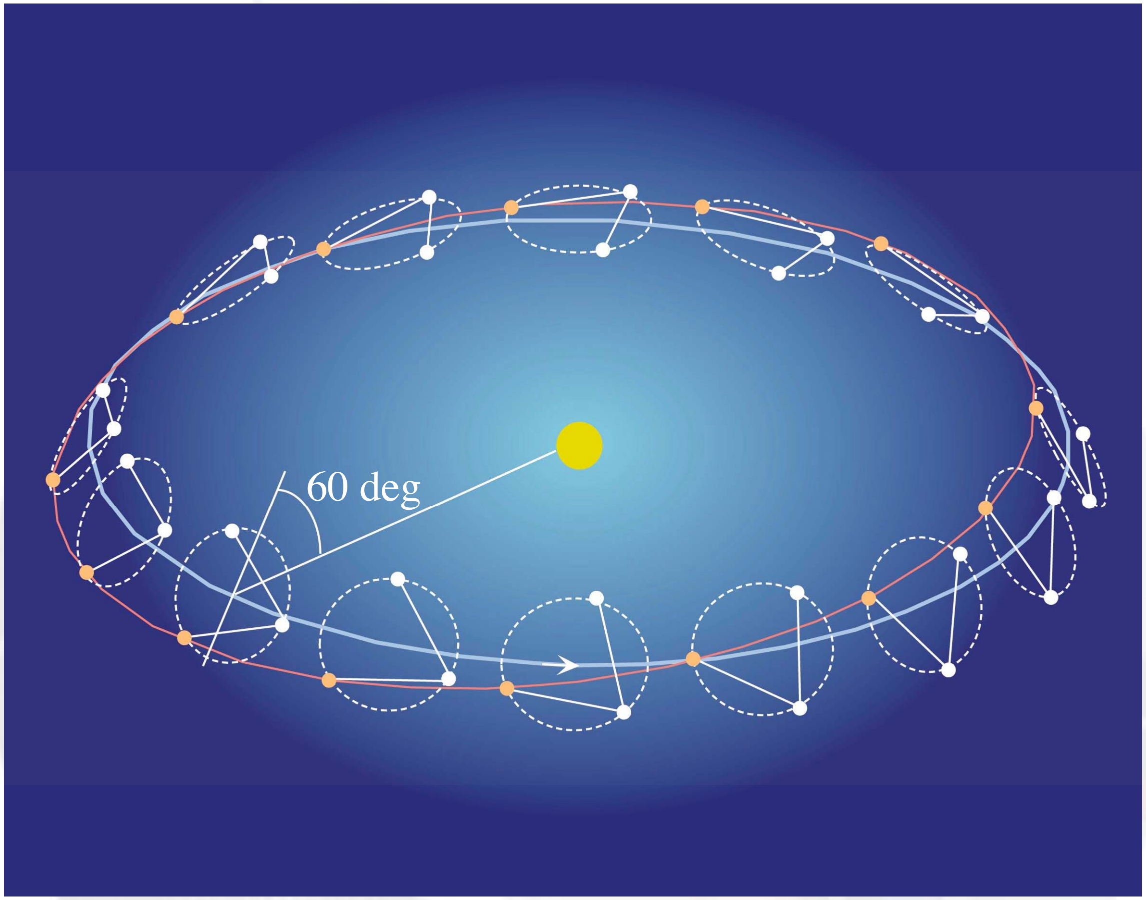
# My Three Main Points

- We'll look at how the orientation of the LISA constellation changes with time (it's probably not what you thought)
- The most important factor in the delivery of the spacecraft to their nominal orbits is the heliocentric period of each delivered orbit
- We should have a requirement for delivery accuracy that reflects the science needs of the mission, e.g., that the delivered orbits not increase the range rate along the arms by more than 3 m/s over the range rates in the nominal design

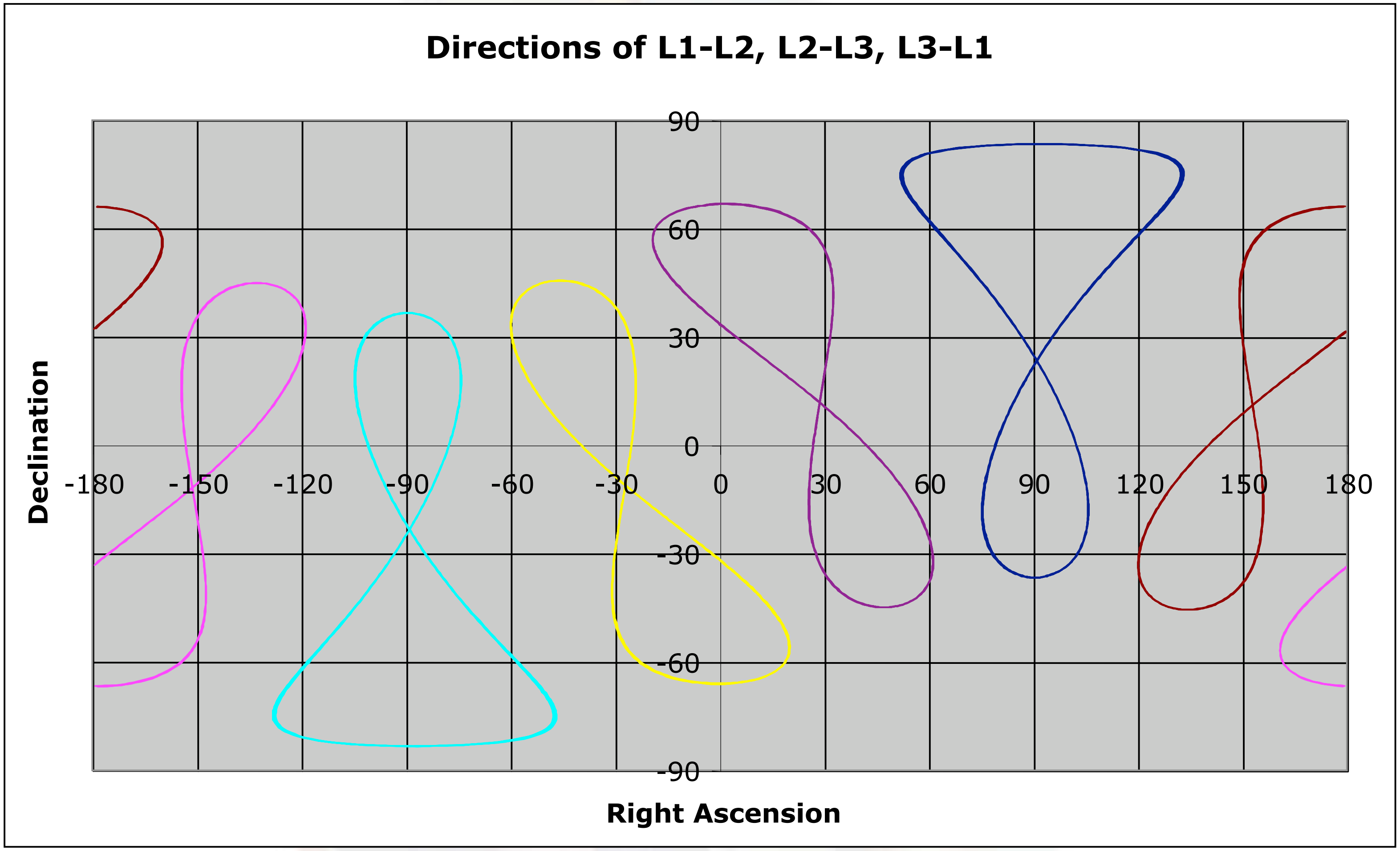
# Baseline 1.0 Operations Orbit

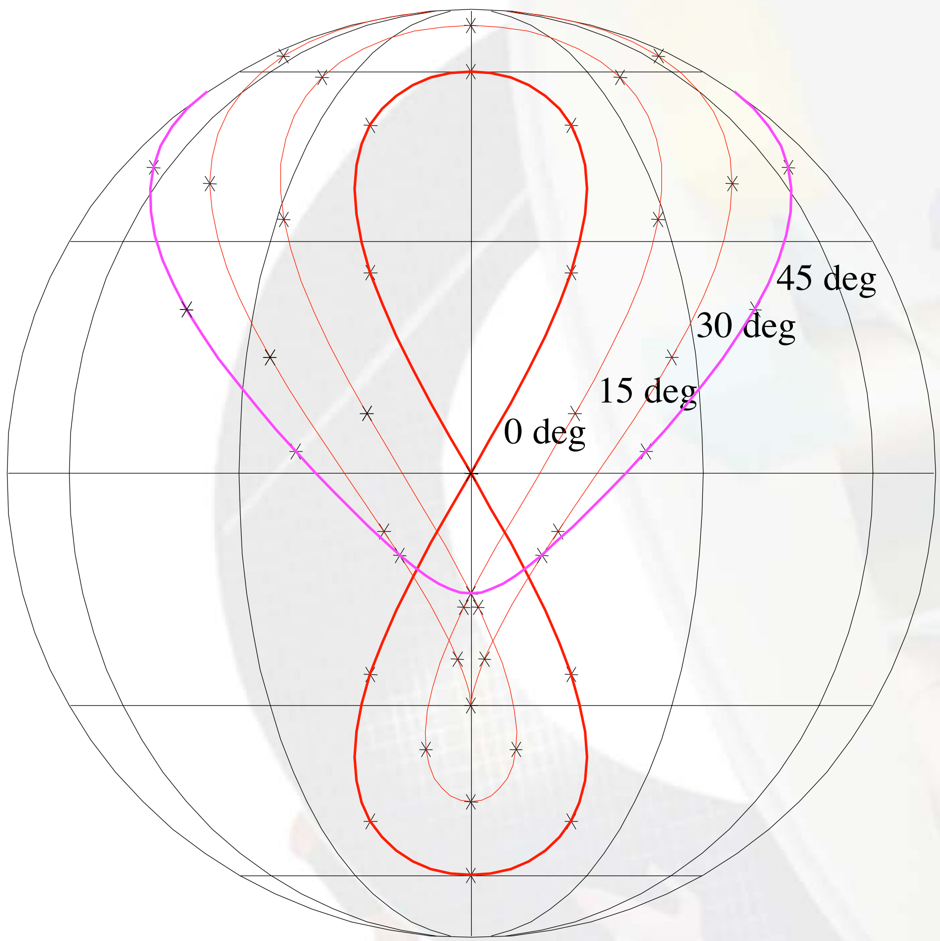





An inertial view of the LISA constellation in its motion around the Sun. (Note that the size of the constellation is greatly exaggerated relative to the distance from the Sun.)

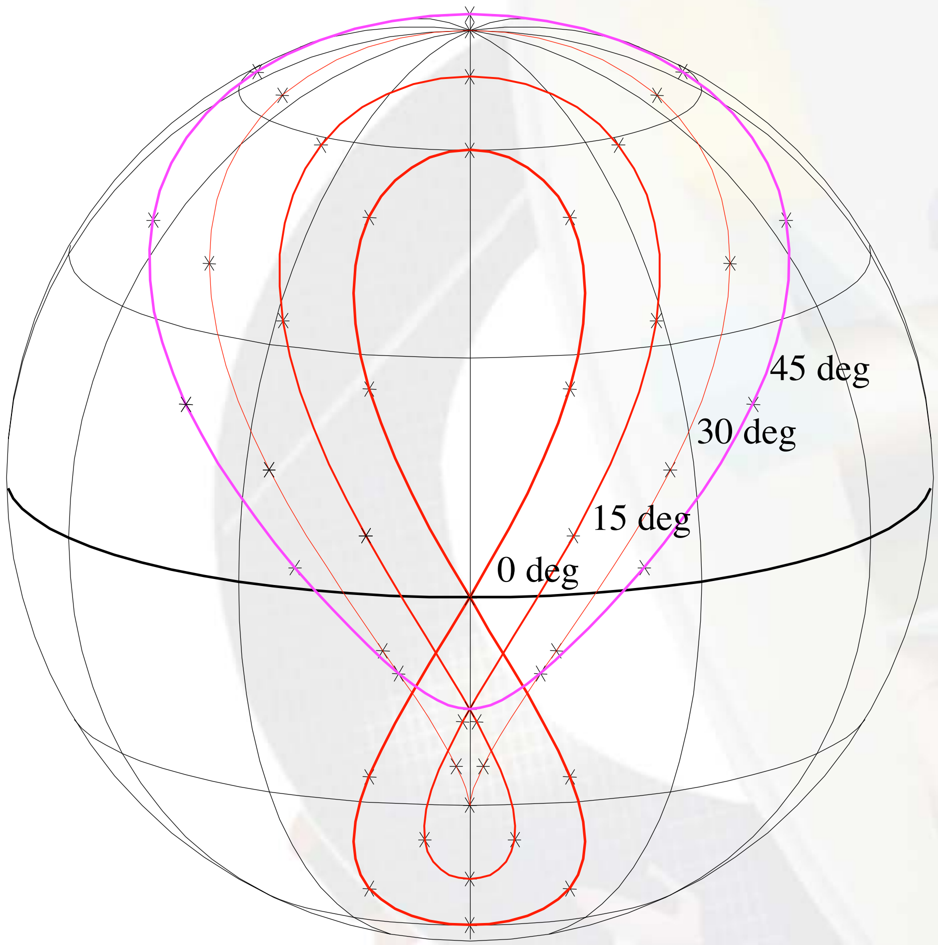
# Directions of LISA Arms





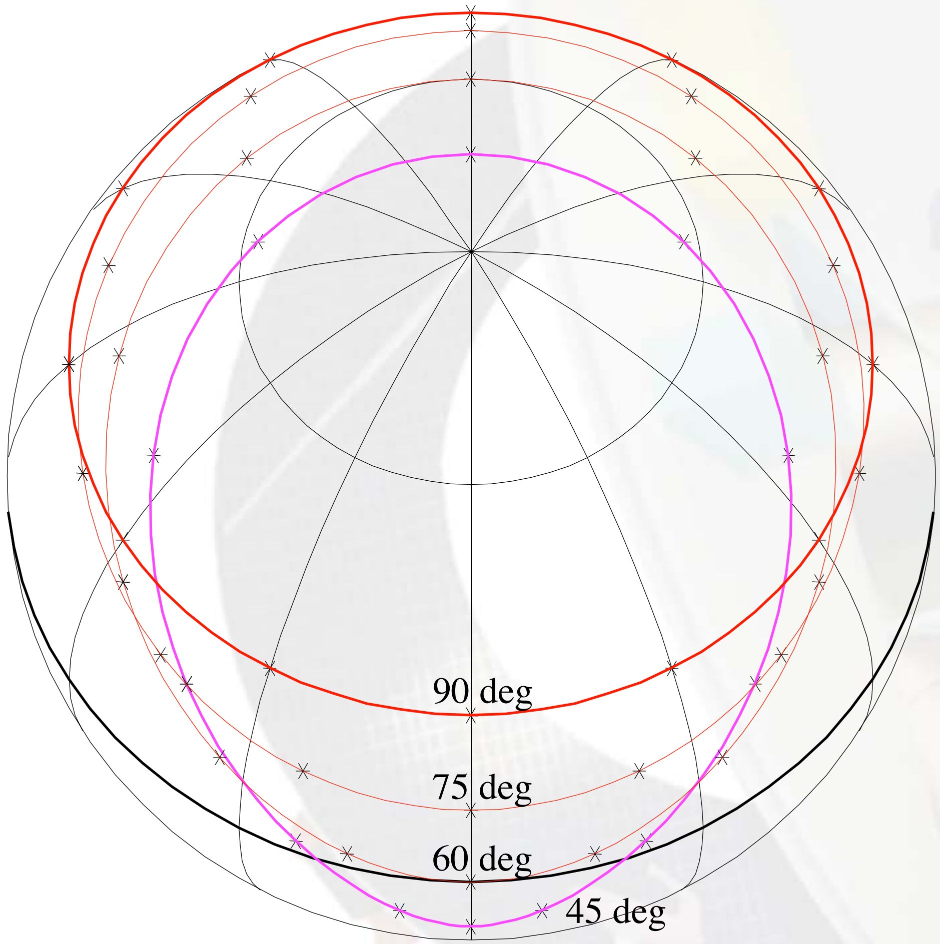

- This is one hemisphere of a latitude/longitude sphere for a LISA constellation-fixed frame
- The track of each source is labelled by the ecliptic latitude of the source
- Half the sky is between ecliptic latitudes –30 deg and +30 deg
- Tics are 1/12 year apart
- Grid interval is 30 deg

# Motion of GW Sources in LISA Coordinates




- This view of the LISA latitude/longitude sphere is from slightly farther north
- The track for each source is labelled by the ecliptic latitude of the source
- Tics are 1/12 year apart
- Grid interval is 30 deg
- Viewpoint at 15 deg latitude

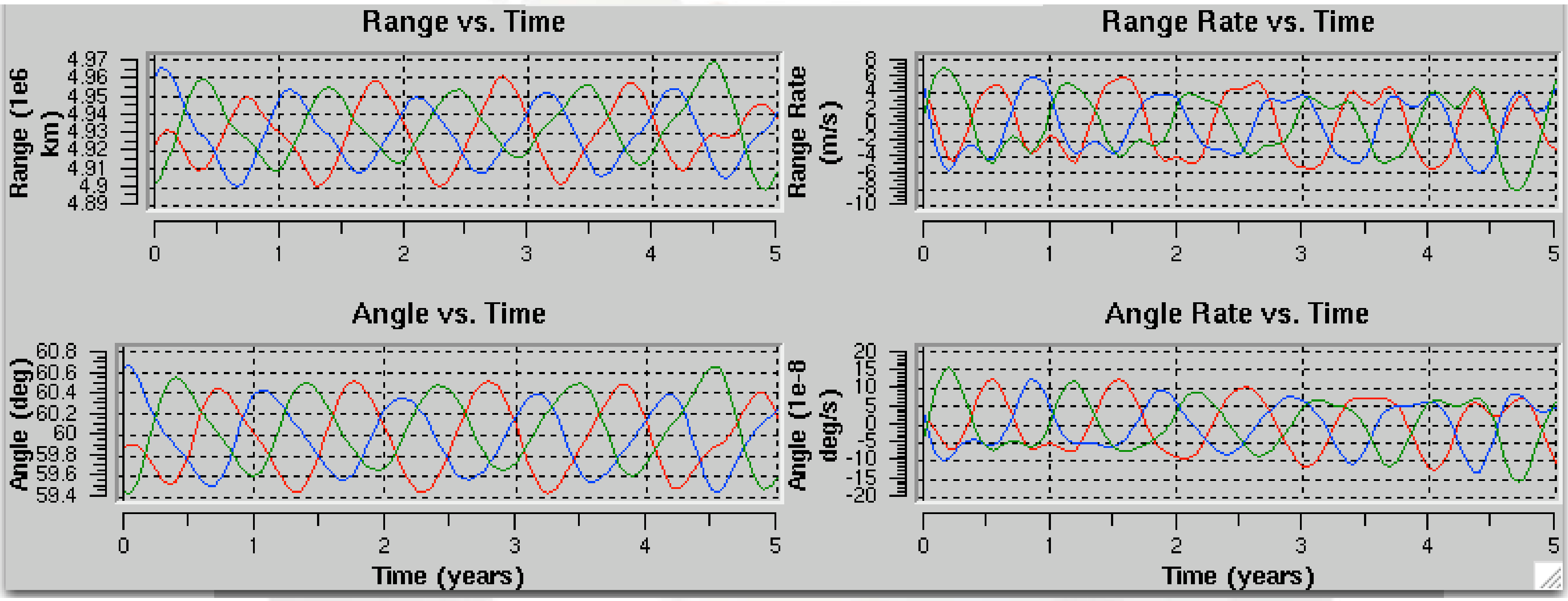
# Motion of GW Sources in LISA Coordinates




- This view of the LISA latitude/longitude sphere is from much farther north
- The track of each source is labelled by the ecliptic latitude of the source
- Tics are 1/12 year apart
- Grid interval is 30 deg
- Viewpoint at 60 deg latitude

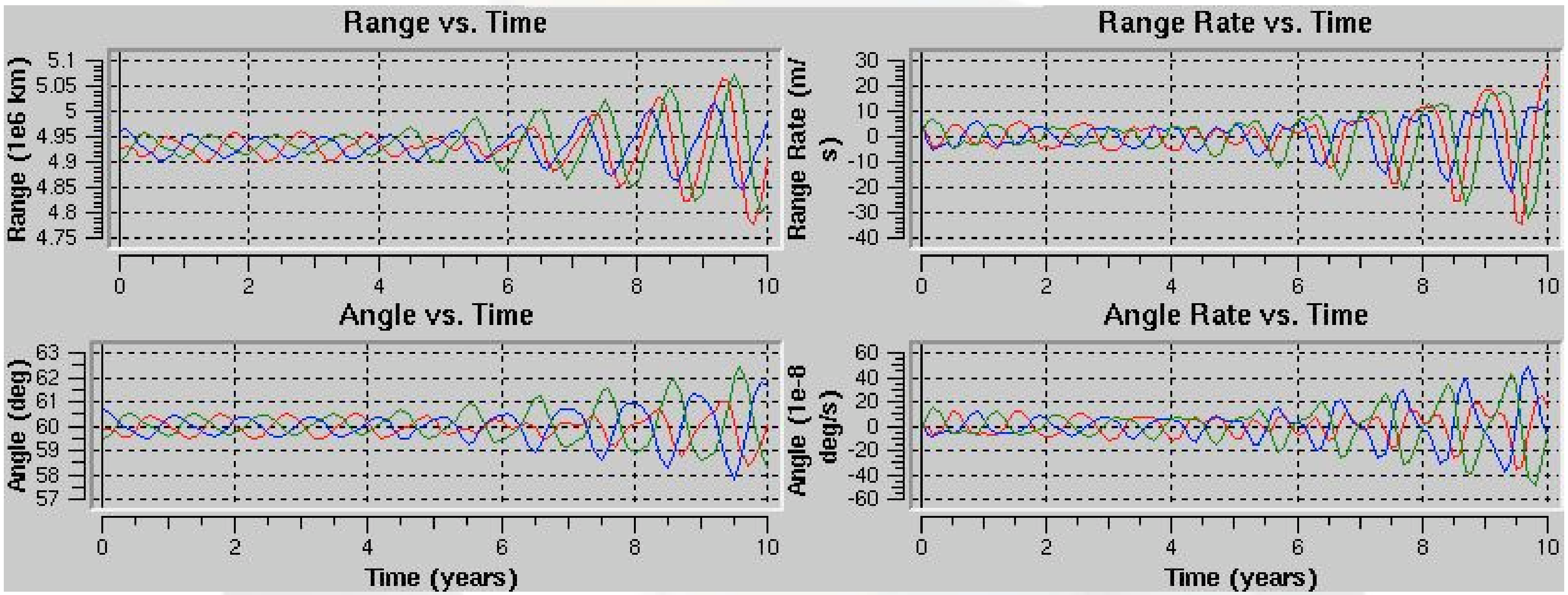
# Current Baseline Trajectory Characteristics





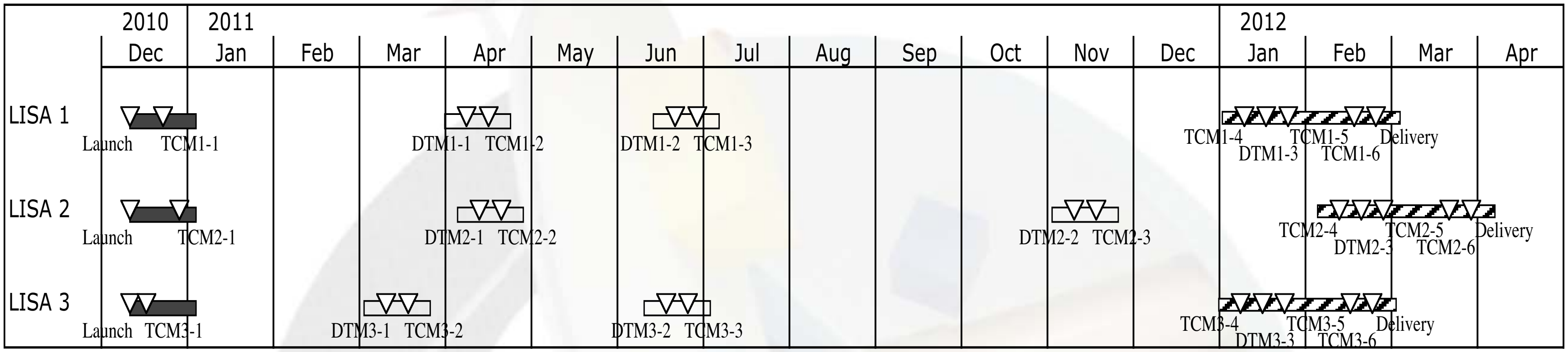

This trajectory was optimized to minimize the average range rate along the three arms of the LISA constellation over the 5-year mission (from initial conditions for 2012-01-01 in Table 11 of S. Hughes, "Preliminary Optimal Orbit Design for the Laser Interferometer Space Antenna (LISA)," 25th Annual AAS Guidance and Control Conference, BreckenRidge CO, Feb. 2002).

# Current Baseline Trajectory Characteristics




The current baseline does not meet requirements for an extended mission and will have to be reoptimized to do so. One way to meet the requirements would be to shift the “flat” region of the ranges, etc., later in the mission.

# Baseline 1.0 Delivery Plan




A timeline showing maneuvers and communications modes for the three LISA spacecraft from launch through delivery to the operations orbits. Except as noted there would be one four-hour pass per week with each spacecraft. Horizontal bars show the time periods when more frequent communications are taking place with a spacecraft; a filled bar indicates continuous coverage available, an open bar indicates daily passes, and a striped bar indicates daily passes [possibly including ΔVLBI].

| Maneuver | Date | S/C 1 ΔV (m/s) | S/C 2 ΔV (m/s) | S/C 3 ΔV (m/s) |
|---|---|---|---|---|
| DTM3-1 | 2011-03-10 | | | 149 |
| DTM1-1 | 2011-04-07 | 489 | | |
| DTM2-1 | 2011-04-11 | | 184 | |
| DTM3-2 | 2011-06-18 | | | 86 |
| DTM1-1 | 2011-06-22 | 50 | | |
| DTM2-2 | 2011-11-05 | | 252 | |
| DTM3-3 | 2012-01-07 | | | 832 |
| DTM1-3 | 2012-01-08 | 559 | | |
| DTM2-3 | 2012-02-12 | | 465 | |
| | Total ΔV: | 1096 | 900 | 1067 |

Deterministic maneuvers that provide optimal transfers of the three LISA spacecraft to their respective operations orbits.

# Effects of Final Delivery Error

- Effects of delivery error are dominated by any error in heliocentric period, which leads to a secular change in position (increasing with time)
- State component errors which affect period have twenty times greater effect on LISA at the end of five years than other component errors do
  - Heliocentric period is affected by radius and speed (magnitude of the velocity vector)
  - Period is not affected by position errors out-of-plane or along the orbit track
  - Period is not affected by cross-track velocity error (either in/out or up/down)
- An error in radius of 100 km has the same effect on LISA as an error in speed of 2 cm/s over the five year baseline lifetime
  - Differences in range to other spacecraft grows to almost 9000 km
  - Differences in range rate to other spacecraft grows to almost 1.7 m/s
  - Total effect on maximum range and range rate variations may be less because of differences in the phases of oscillations in these values

# Requirements for Final Delivery



- We should state a requirement for final delivery of the spacecraft to the constellation in terms which can be derived from the science that LISA will do. For example,

    *Deliveries of the LISA spacecraft to their design orbits shall be sufficiently accurate that the actual range rates along the arms of the constellation shall have < 1% chance of differing by more than 3 m/s from the range rates of the design.*

- Such a requirement could be met in a traditional way:
    - Each spacecraft shall have a pre-separation position error < 50 km (3 $\sigma$)
    - Each spacecraft shall have a pre-separation velocity error < 0.01 m/s (3 $\sigma$)
    - Separation will be at 3 cm/s and will have error < 2% (3 $\sigma$)
- Alternatively we could tune our requirements to the dynamics of LISA:
    - Each spacecraft shall have a pre-separation position error < 500 km (3 $\sigma$)
    - Each spacecraft shall have a pre-separation velocity error < 0.1 m/s (3 $\sigma$)
    - Each spacecraft shall have a pre-separation period error < 38 s (3 $\sigma$)
    - Separation will be at 3 cm/s and will have error < 20% (3 $\sigma$)
- Either set of derived requirements would meet the primary requirement with 33% margin.