Mini-ASTROD: Mission Concept

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Mini-ASTROD: Mission Concept

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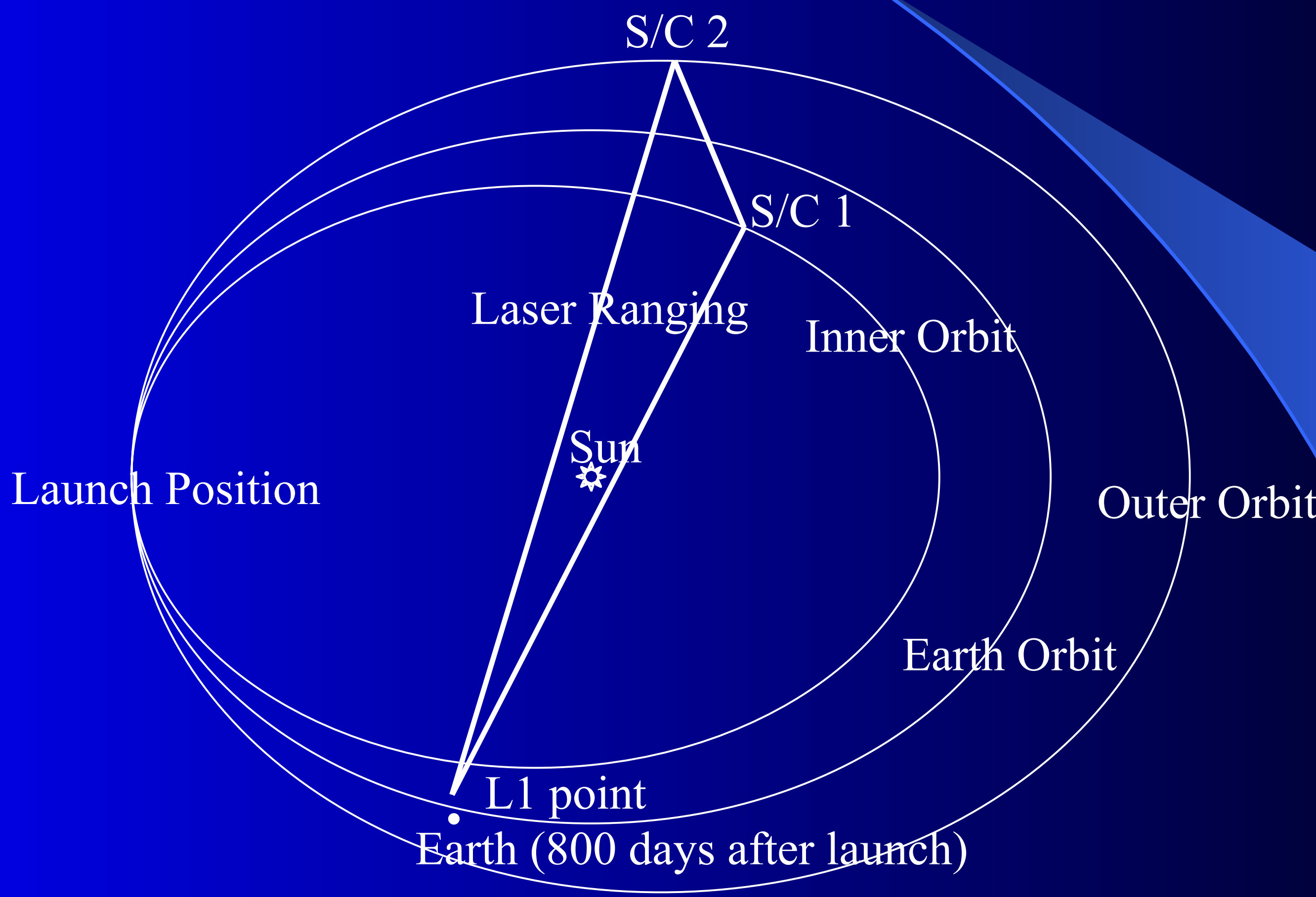
- 20.Nihon Fukushi University, Aichi
- 21.University of Duesseldorf, Duesseldorf
- 22.Observatoire de la Cote D'Azur, Glasse
- 23.Universitaet Konstanz, Konstanz
- 24.Max-Planck-Institut fuer Gravitationsphysik, Garching)
- 25. Hang-Ten Tsinghua, Beijing

ASTRODynamical Space Test of Relativity using Optical Devices



OBJECTIVE

ASTROD

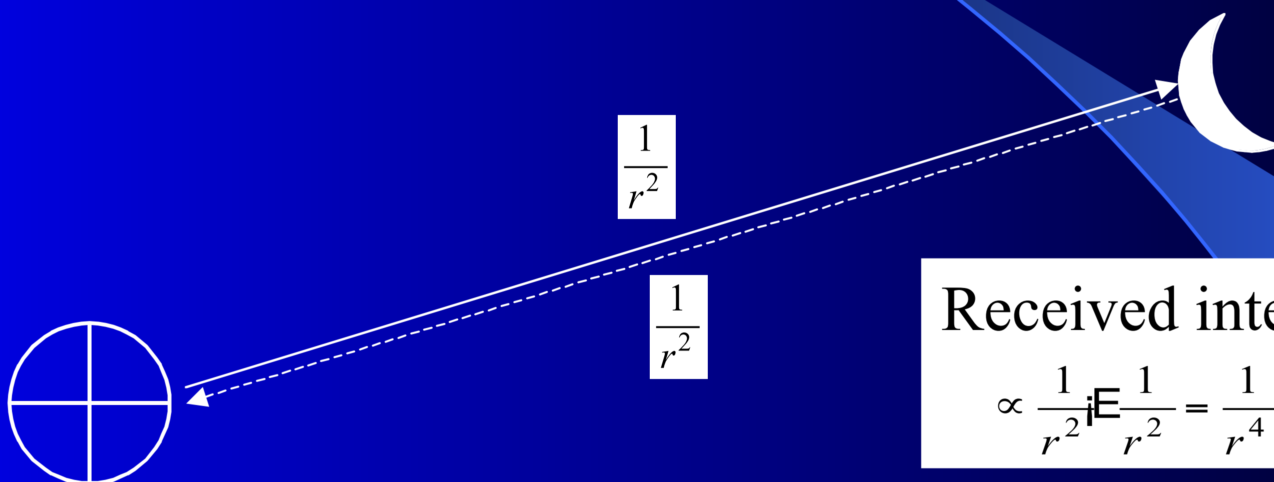
- Testing relativistic gravity and the fundamental laws of spacetime with more than three-order-of-magnitude improvment in sensitivity;
- Improving the sensitivity in the 5 μHz - 5 mHz low frequency gravitational-wave detection by several orders of magnitude as in LISA but shifted toward lower frequencies;
- Revolutionize the astrodynamics with laser ranging in the solar system, increasing the sensitivity of solar, planetary and asteroid parameter determination by 3 orders of magnitude.

OBJECTIVE

Mini-ASTROD

- Testing relativistic gravity and the fundamental laws of spacetime with three-order-of-magnitude improvment in sensitivity;
- Improving the sensitivity in the 5 μHz - 5 mHz low frequency gravitational-wave detection by several times to one order of magnitude;
- Initiating the revolution of astrodynamics with laser ranging in the solar system, increasing the sensitivity of solar, planetary and asteroid parameter determination by 1-3 orders of magnitude.

Lunar Laser Ranging



Received intensity

$$\propto \frac{1}{r^2} \times \frac{1}{r^2} = \frac{1}{r^4}$$

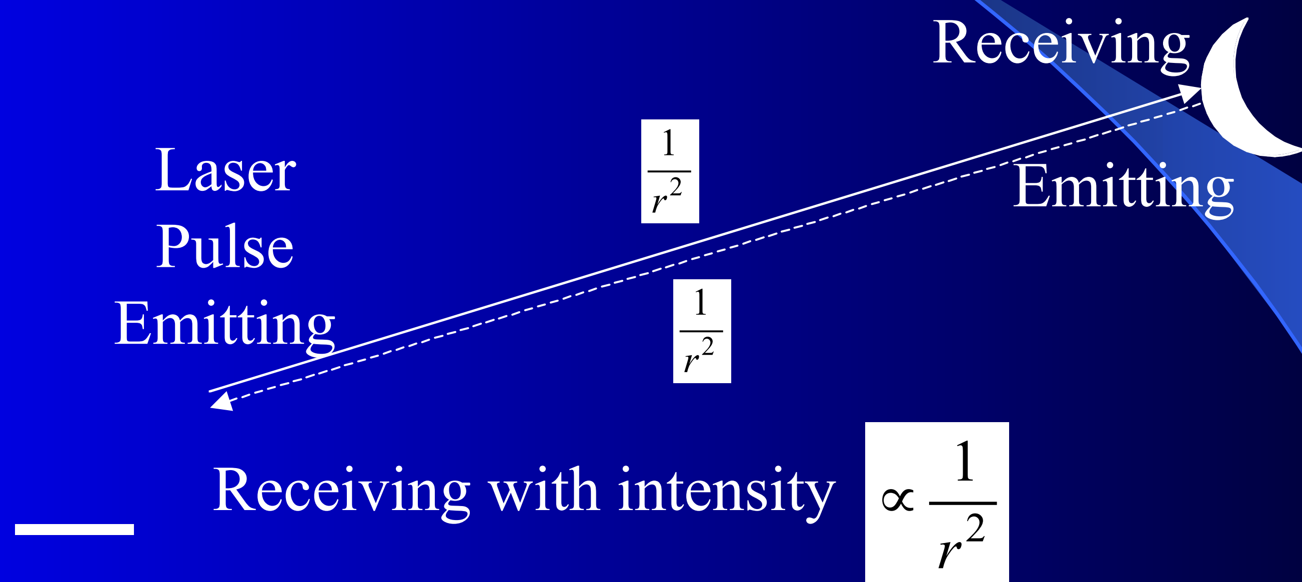
Receiving < 1 photon/pulse

($\langle n \rangle_{\text{received}} \sim 0.01$)

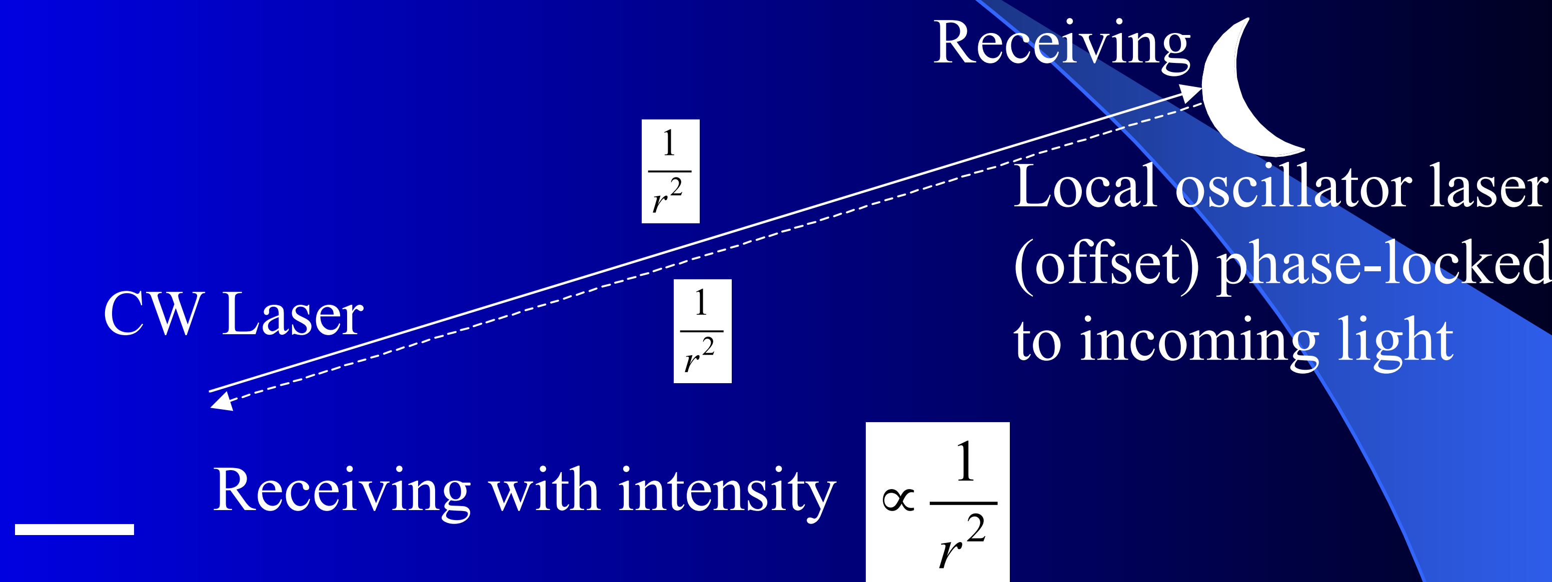
10 pulses/s

Round trip time ~ 2.5s

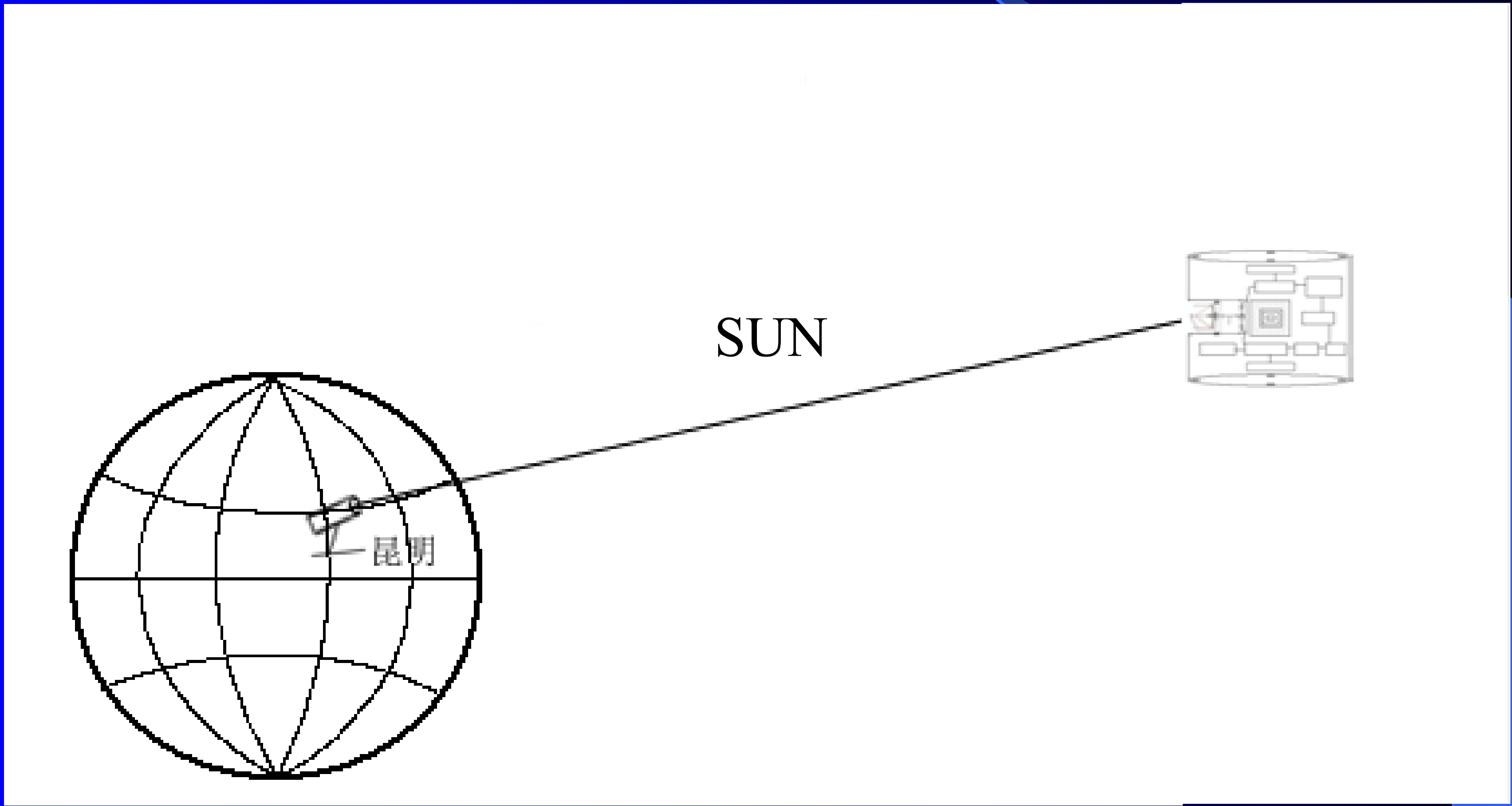
Pulse Transponding



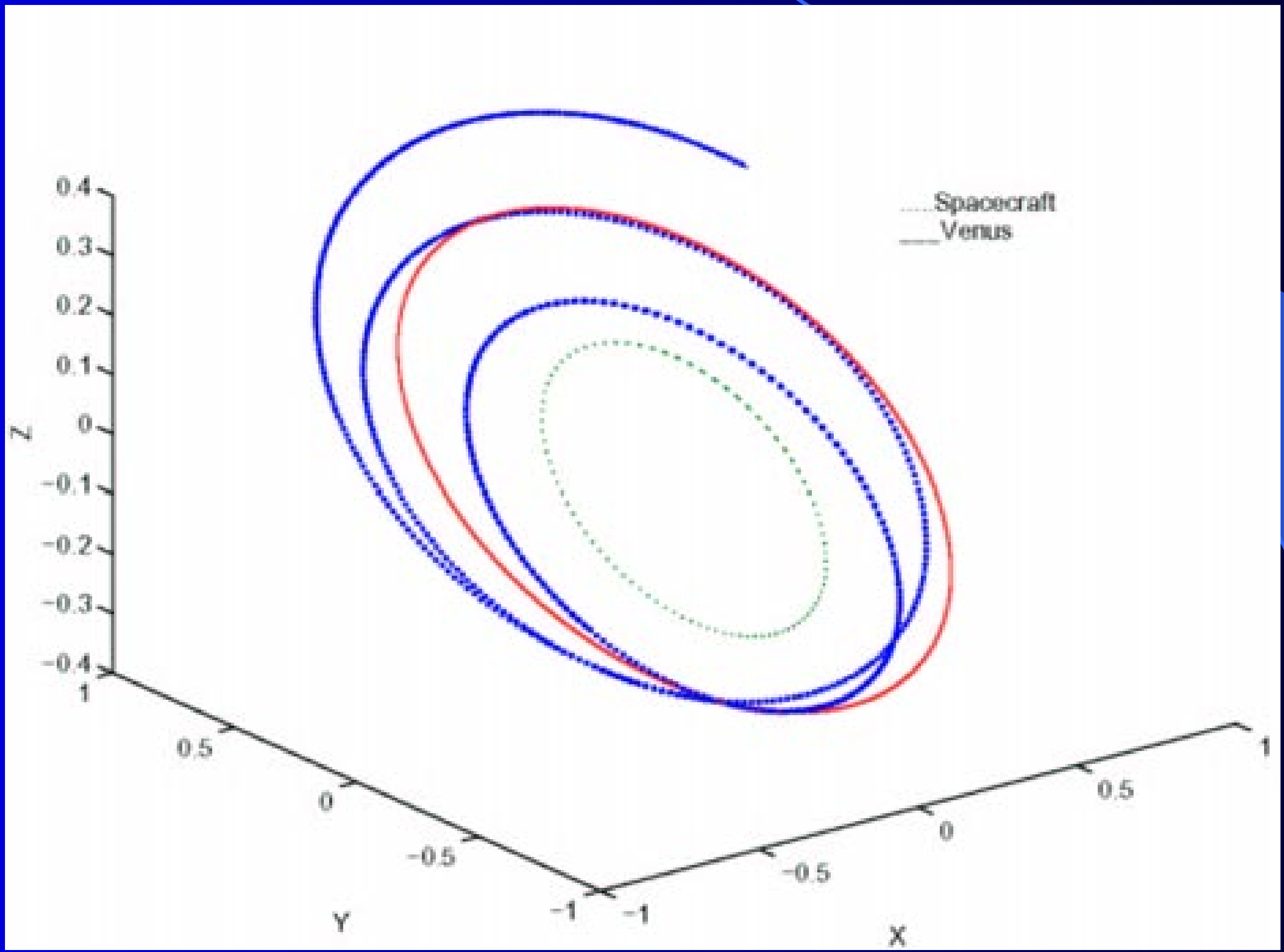
Interfermetric Transponding



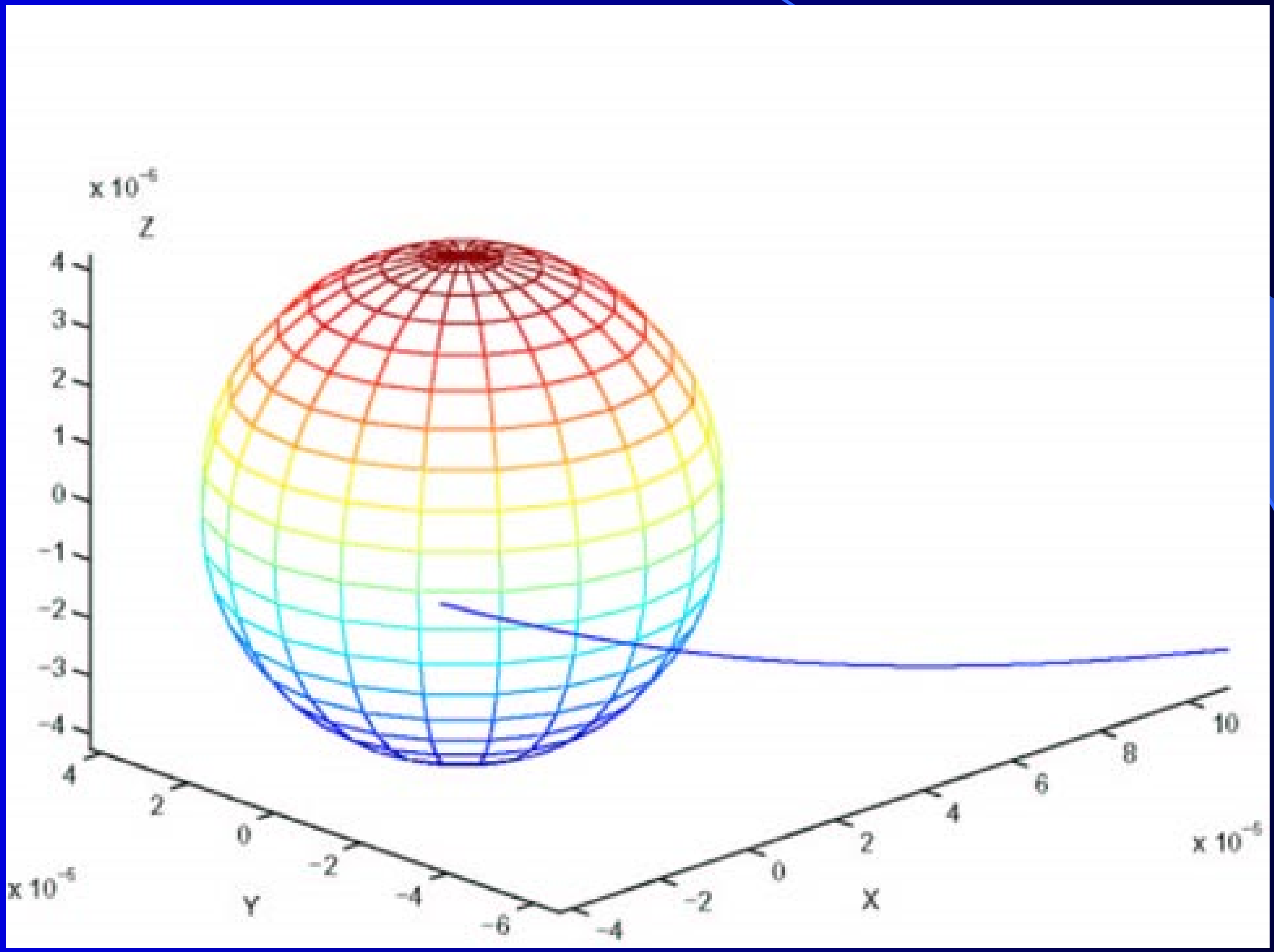
Two-Way Interferometric and Pulse Laser Ranging between Spacecraft and Ground Laser Station



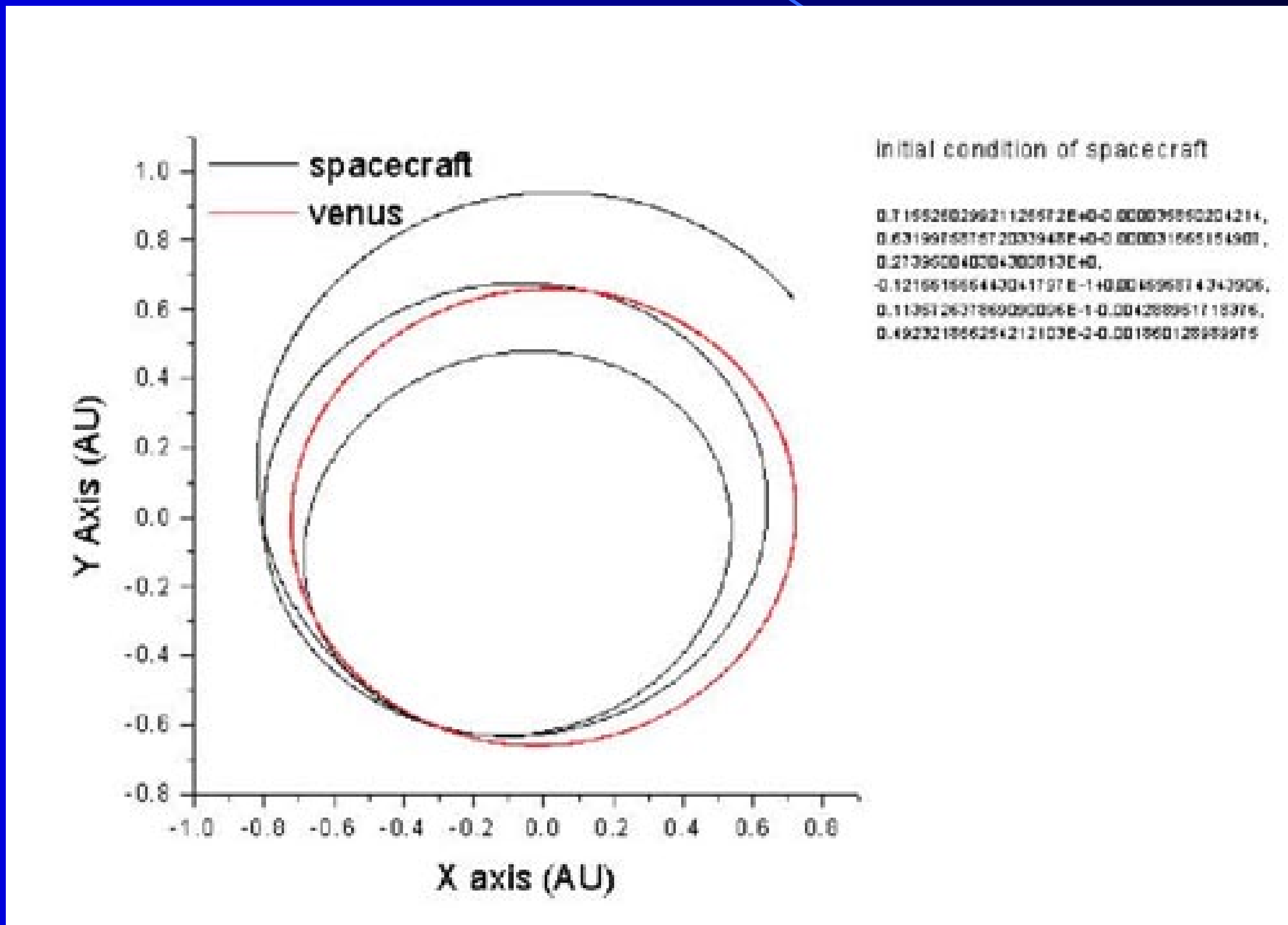
Typical Orbit Configuration of the Mini-ASTROD Spacecraft



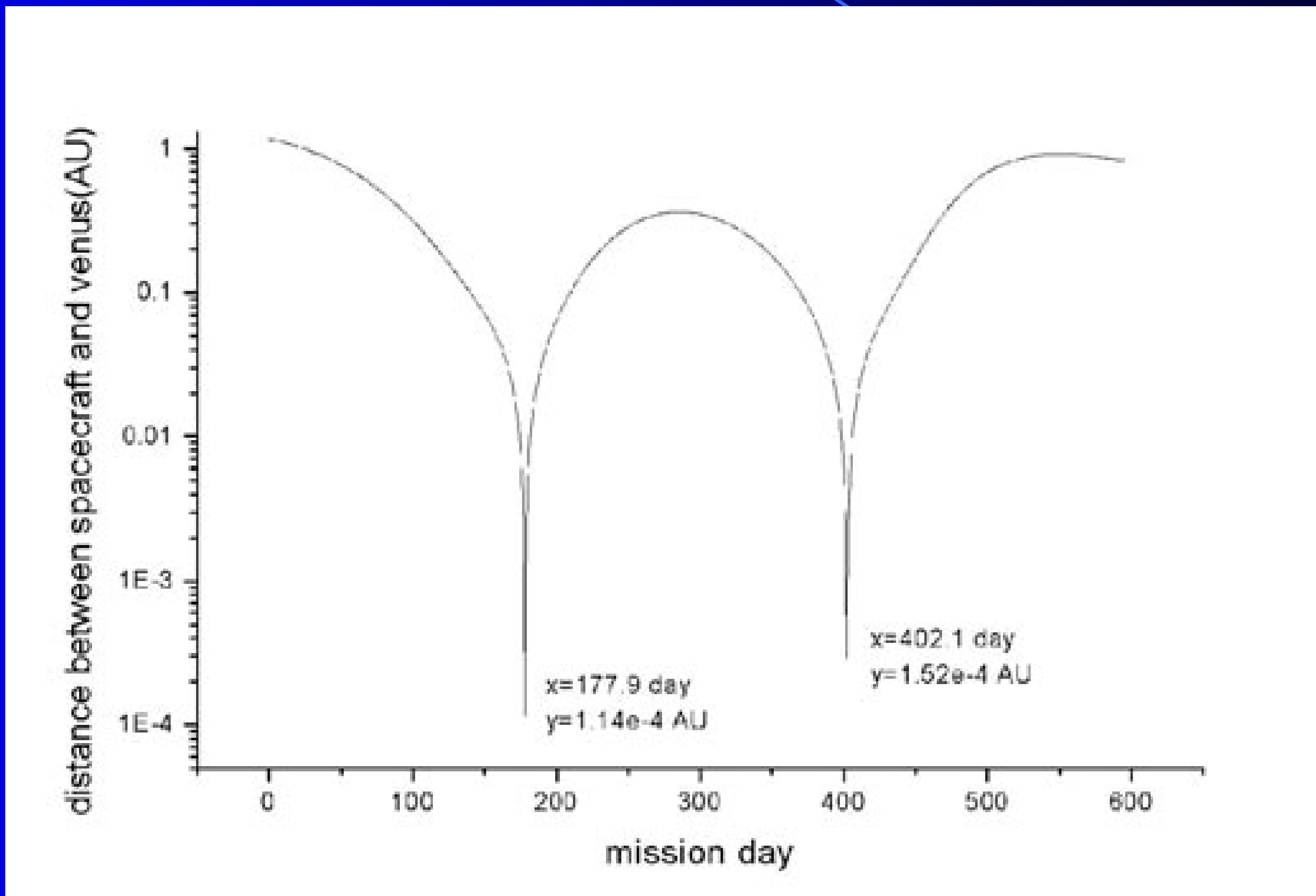
Typical Launch Trajectory



Spacecraft Trajectory



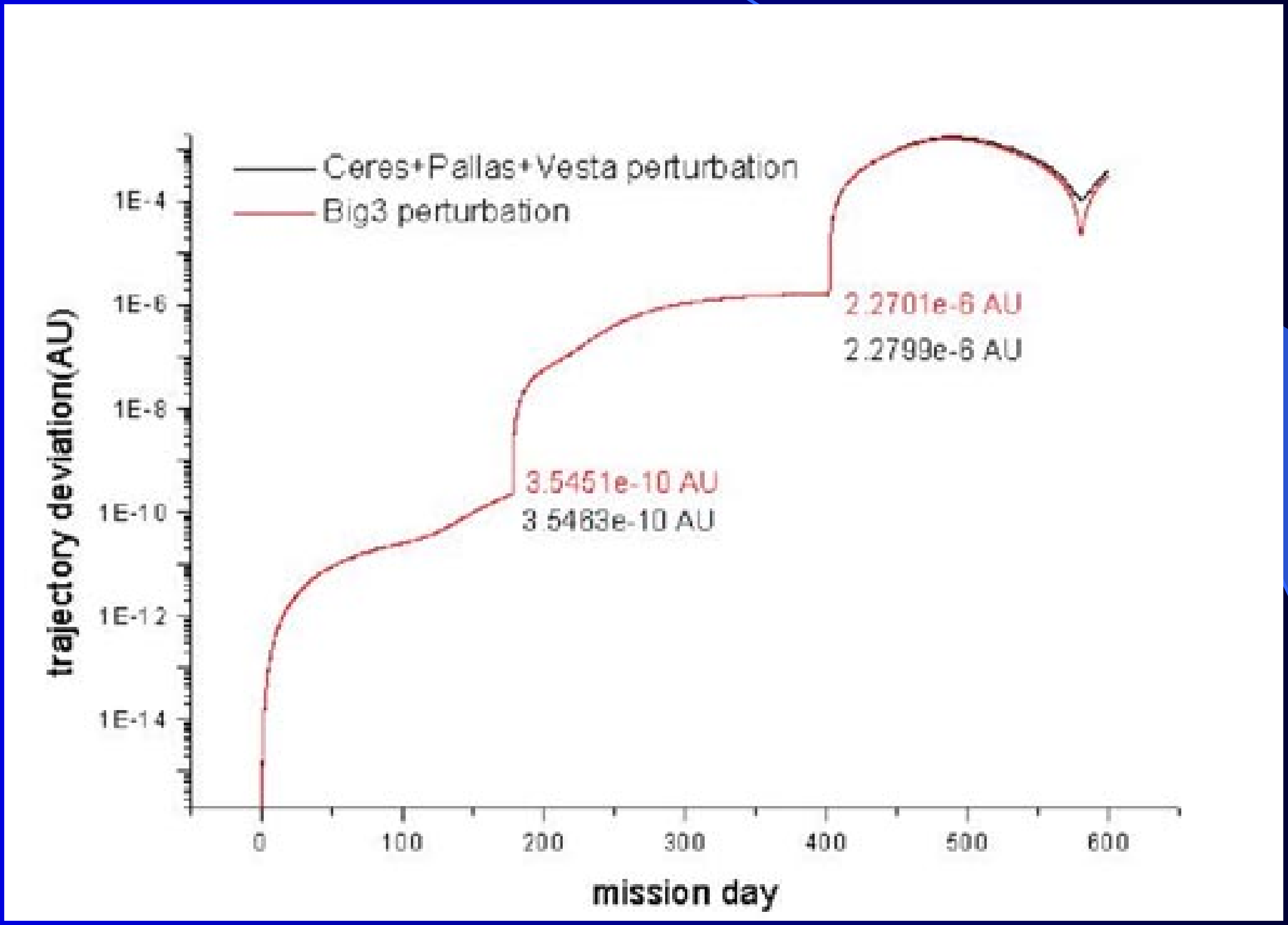
Spacecraft-Venus Distance



Orbit Discription

- Launch via low earth transfer orbit to solar orbit with orbit period 300 days
- First encounter with Venus at 178 days after launch; orbit period changed to 225 days (Venus orbit period)
- Second encounter with Venus at 402 days after launch; orbit period changed to 178 days
- Opposition to the Sun: shortly after 400 days, 700 days and 1100 days

Asteroid’s Perturbations



Orbit Simulation Assumptions

- (1) The uncertainty due to the imprecision of the ranging devices:

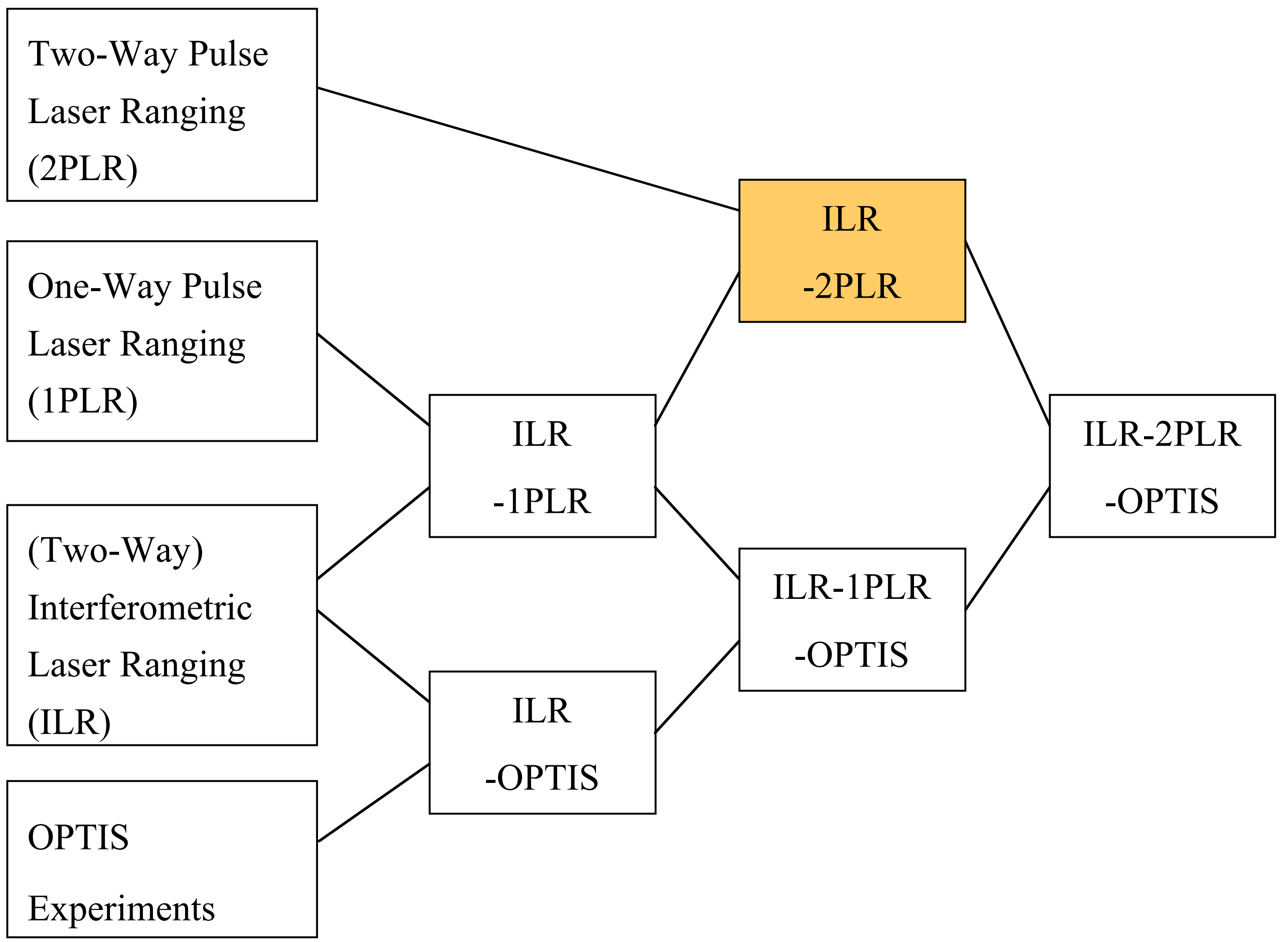
  5 ps one way (Gaussian)

- (2) Unknown acceleration due to the imperfections of the spacecraft drag-free system:

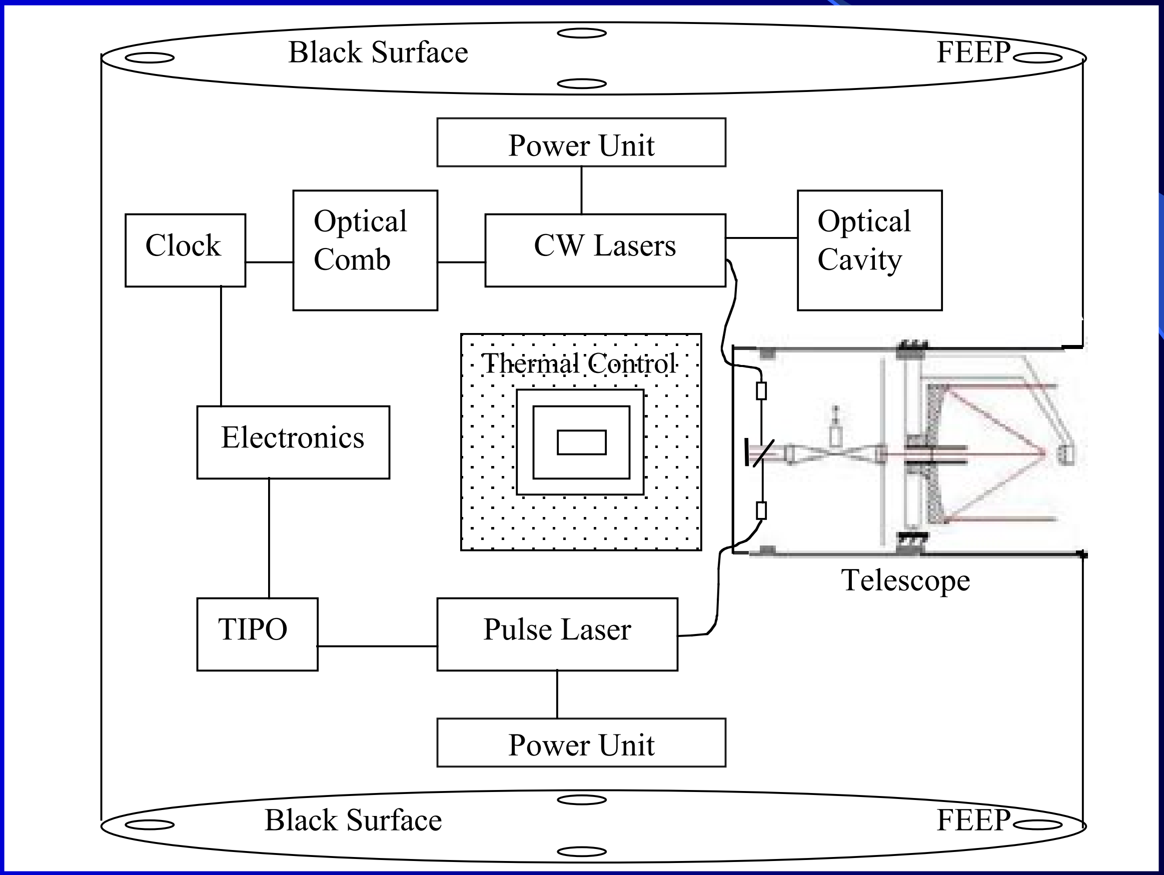
  10^{-15} m/s^2 & change direction randomly every 4 hr ($\sim 10^4$ s)

  [This is equivalent to $(10^{-15}\,\mathrm{m/s^2}) \times (10^4\,\mathrm{s})^{1/2} = 10^{-13}\,\mathrm{m/s^2(Hz)}$ – at 10^{-4} Hz]

Various Alternatives of Mini-ASTROD with OPTIS



Schematic Diagram of the Mini-ASTROD Spacecraft



Schematic Diagram of the Mini-ASTROD Spacecraft:

- (i) Cylindrical spacecraft with diameter 2.5m, height 2m and surface covered with solar panels,
- (ii) In orbit, the cylindrical axis is perpendicular to the orbit plane with the telescope pointing toward the ground laser station. The effective area to receive sunlight is about $5m^2$ and can generate over 500 W of power.
- (iii) The total mass of spacecraft is 300-350 kg. That of payload is 100-120 kg.
- (iv) Science data rate is 500 bps. The telemetry rate is 5 kbps for about 9 hours in two days.

Payload

(1) Laser systems for interferometric and pulse ranging

(i) 3 (plus 1 spare) diode-pumped Nd:YAG laser (wavelength 1.064 μm, output power 1 W) with a set of 2 perpendicular Fabry-Perot reference cavities: 2 lasers locked to 2 Fabry-Perot cavities, the other laser pre-stabilized by one of them and phase-locked to the incoming weak light.

(ii) 1 (plus 1 spare) pulsed Nd:YAG laser with transponding system for transponding back the incoming laser pulse from ground laser stations.

(2) Quadrant photodiode detector

(3) 380-500 mm diameter f/1 Cassegrain telescope (transmit/receive), $\lambda/10$ outgoing wavefront quality

Payload

(4) Coronagraph

(5) Drag-free proof mass (reference mirror as one face of it):

$50 \times 35 \times 35$ mm^3 rectangular parallelpiped;

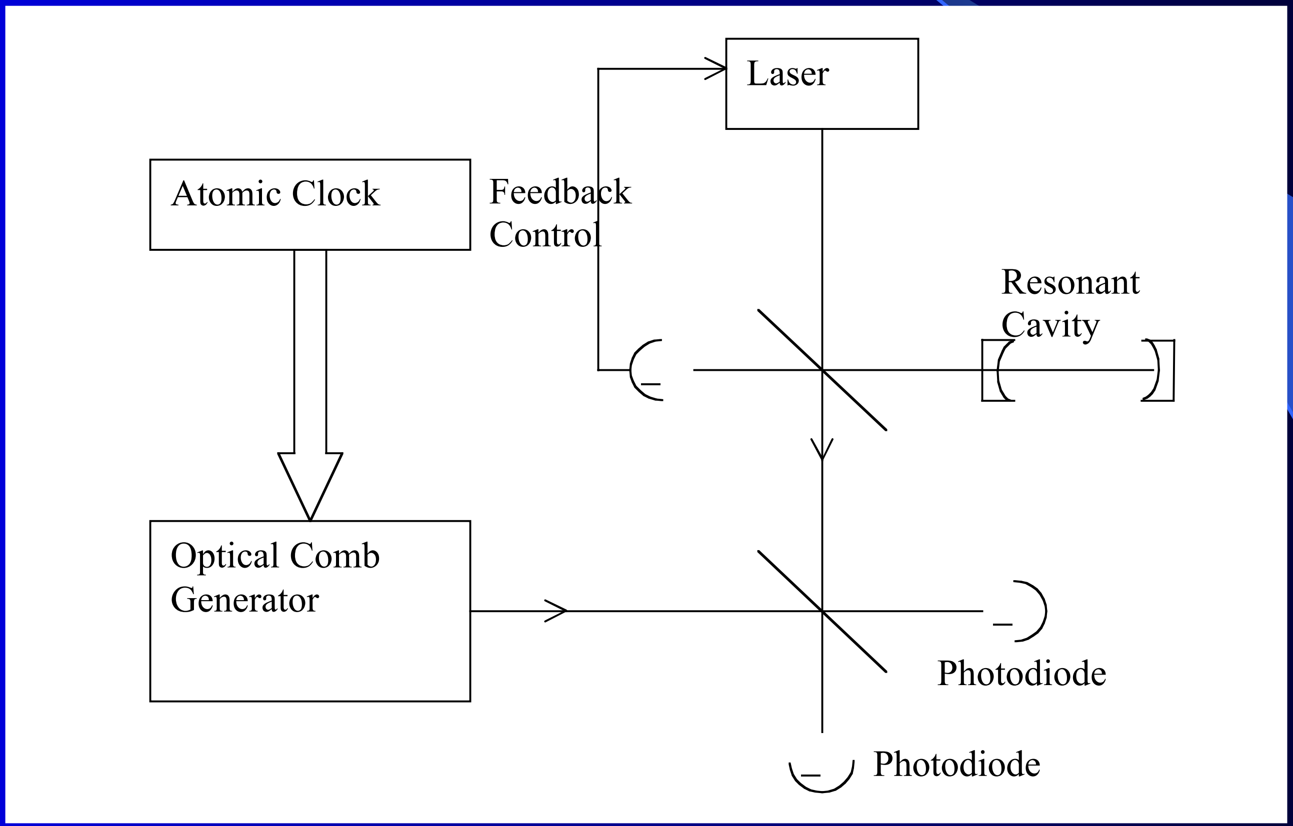
Au-Pt alloy of extremely low magnetic usceptibility ($\chi<10^{-6}$);

Ti-housing at vacuum 10^{-6} Pa ; six-degree-of-freedom capacity sensing.

(6) Cesium clock

(7) Optical comb

Comparison of the cesium clock frequency and the laser frequency



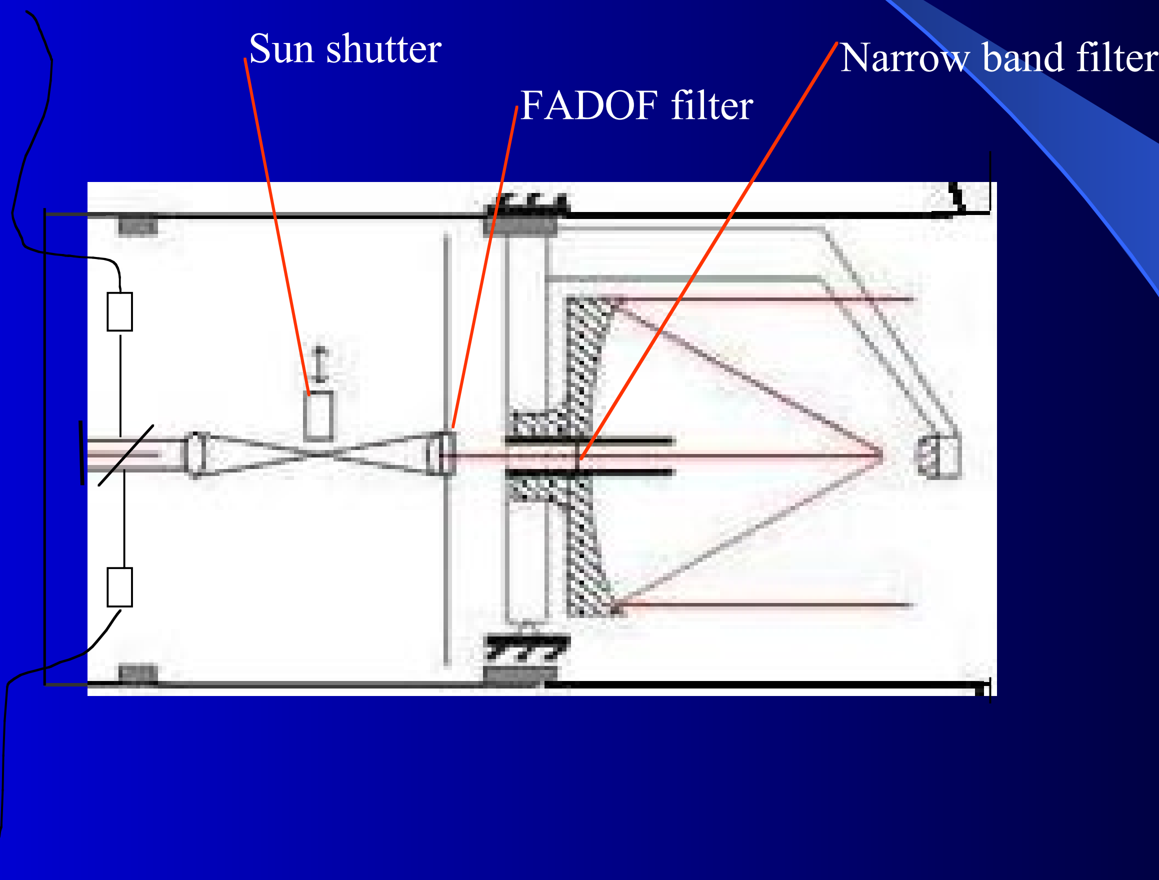
Crucial Technology

- 100 fW weaklight phase locking
- Design and development of coronagraph
- Design and development of drag-free system

Weaklight Phase Locking

- Requirement: phase locking to 100 fW weak light
- Achieved: phase locking of 2 pW weak light with 200 μW local oscillator
- With pre-stabilization of lasers, improving on the balanced photodetection and lowering of the electronic circuit noise, the intensity goal should be readily be achieved
- This part of chanllenge should be focussed on offset phase locking, frequency-tracking and modulation-demodulation to make it mature experimental technique (also important for deep space communication

Coronagraph Design



Coronagraph Design

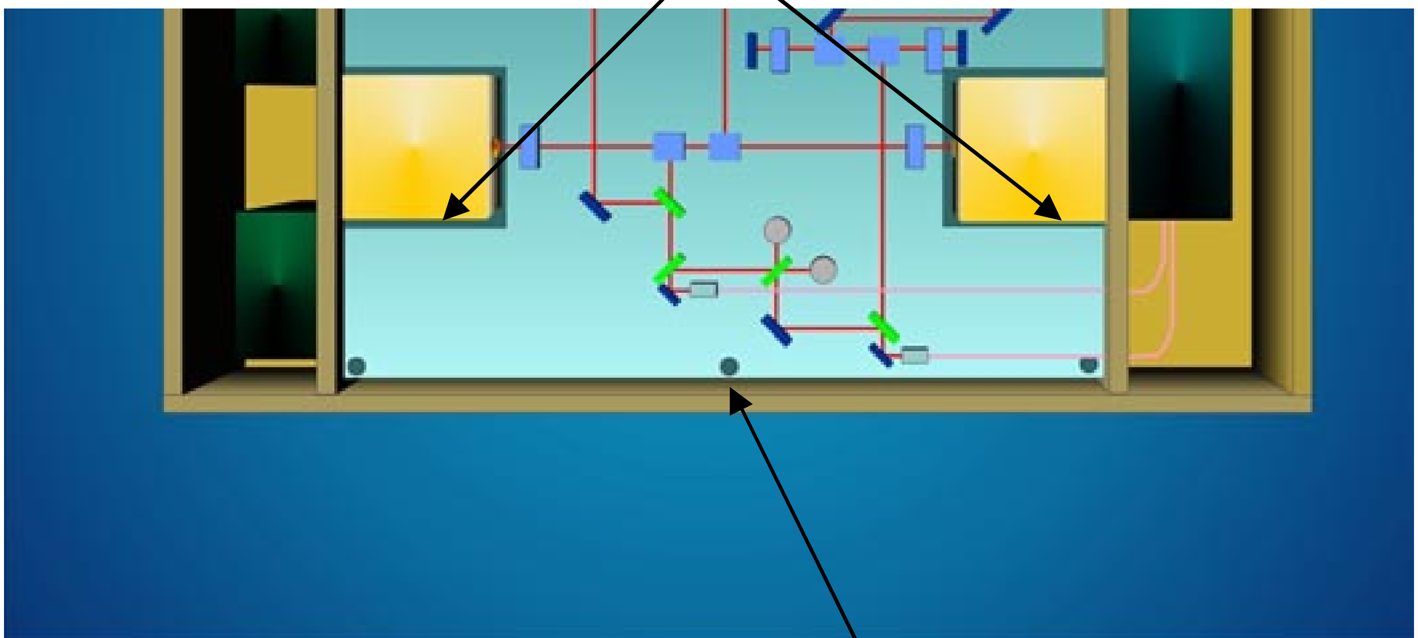
- The coronagraph consisits of a narrow-band interference filter, a FADOF (Faraday Anomalous Dispersion Optical Filter) filter, and a shutter
- The narrow-band interference filter reflects most of the Sun light directly to space
- The bandwidth of the FADOF filter can be 0.6-5 GHz
- With the shutter (coronagraph), the Sun light should be less than 1 % of the laser light at the photodetector

Drag-free System R & D

- Consists of a high-precision accelerometer/inertial sensor to detect non-drag-free motions and micro-thruster system to do the feedback to keep the spacecraft drag-free
- Looking for collaboration with ONERA and Trento to learn the R & D they have for LISA/SMART 2
- Collaboration with ZARM, Bremen University for feedback control and propulsion system

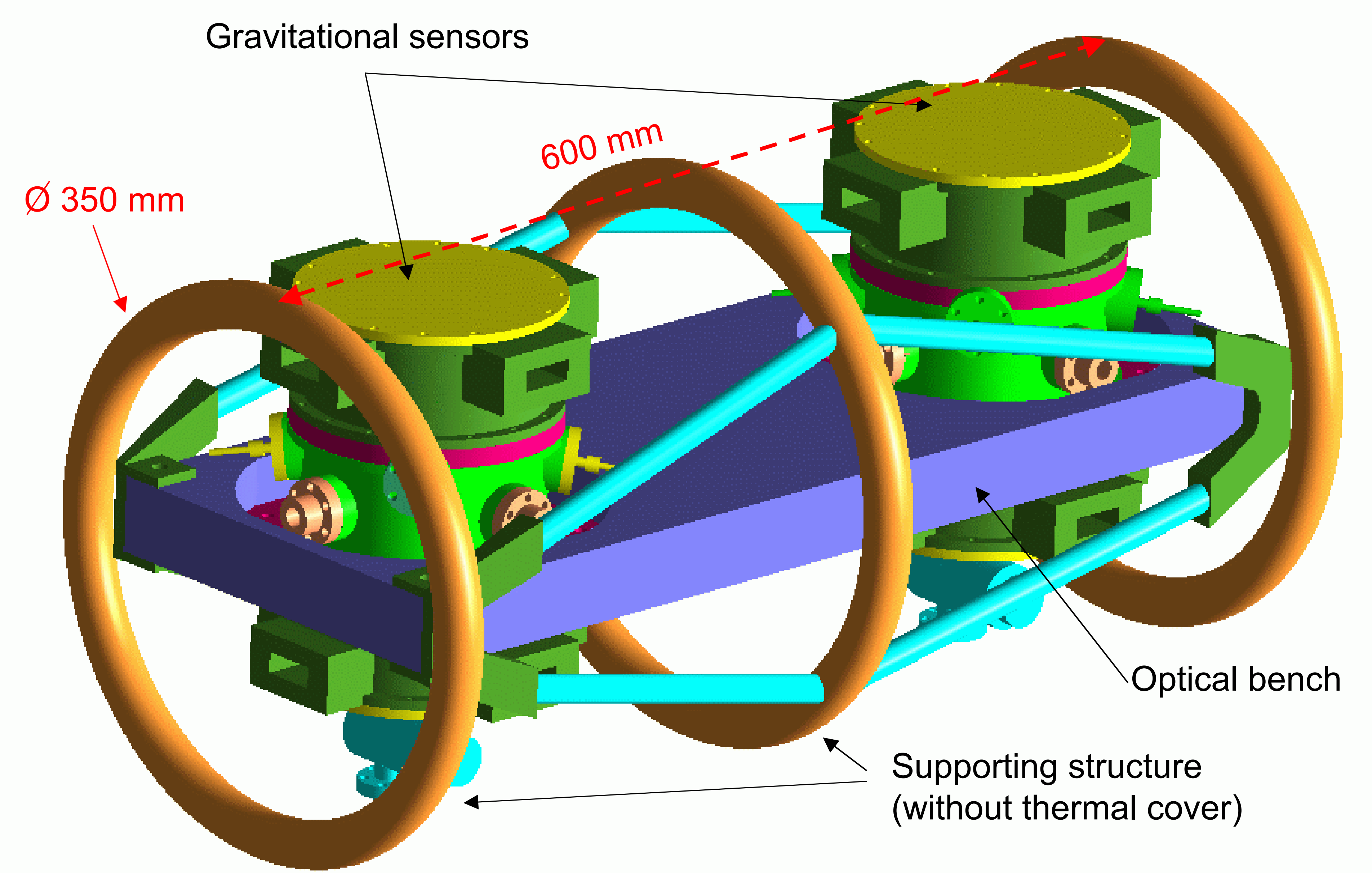
The LTP architecture and main subsystem

Test-masses
(gravitational sensor)



Interferometer

Current design of the LTP



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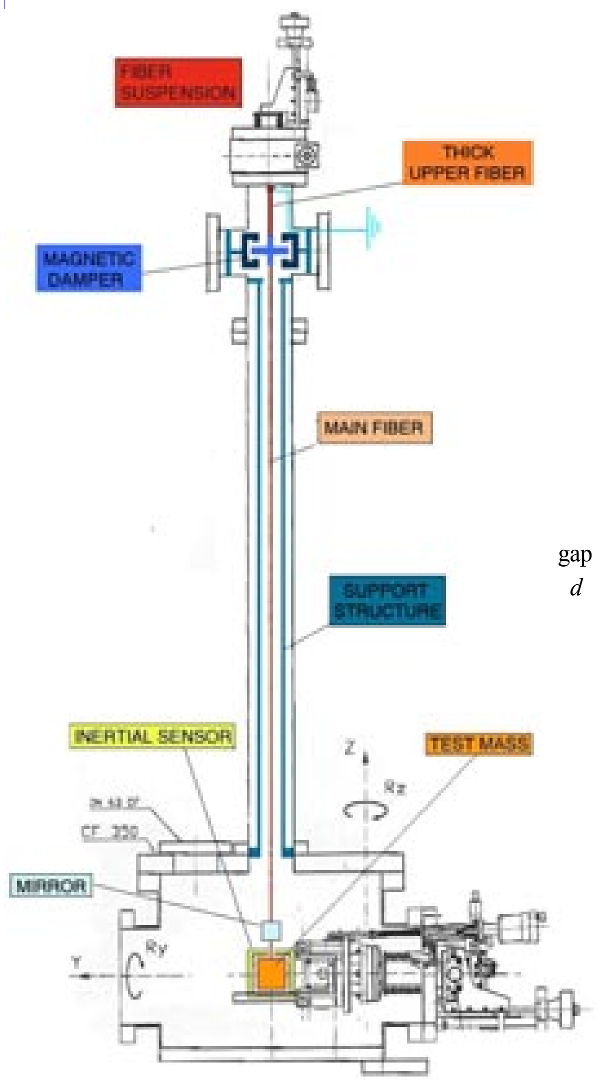
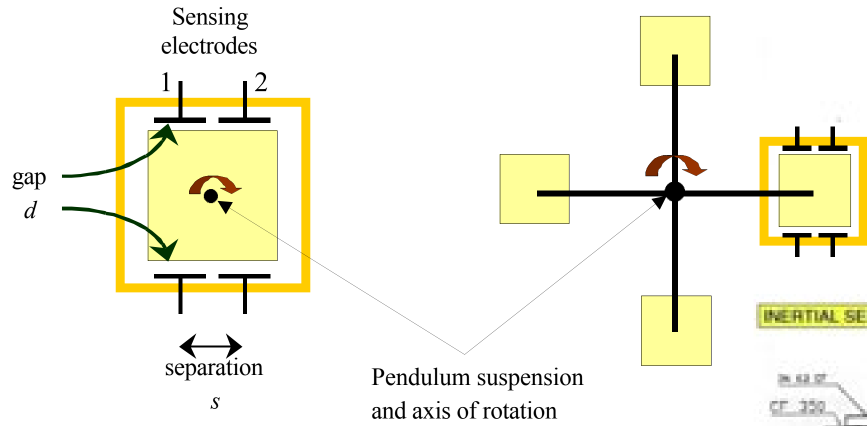
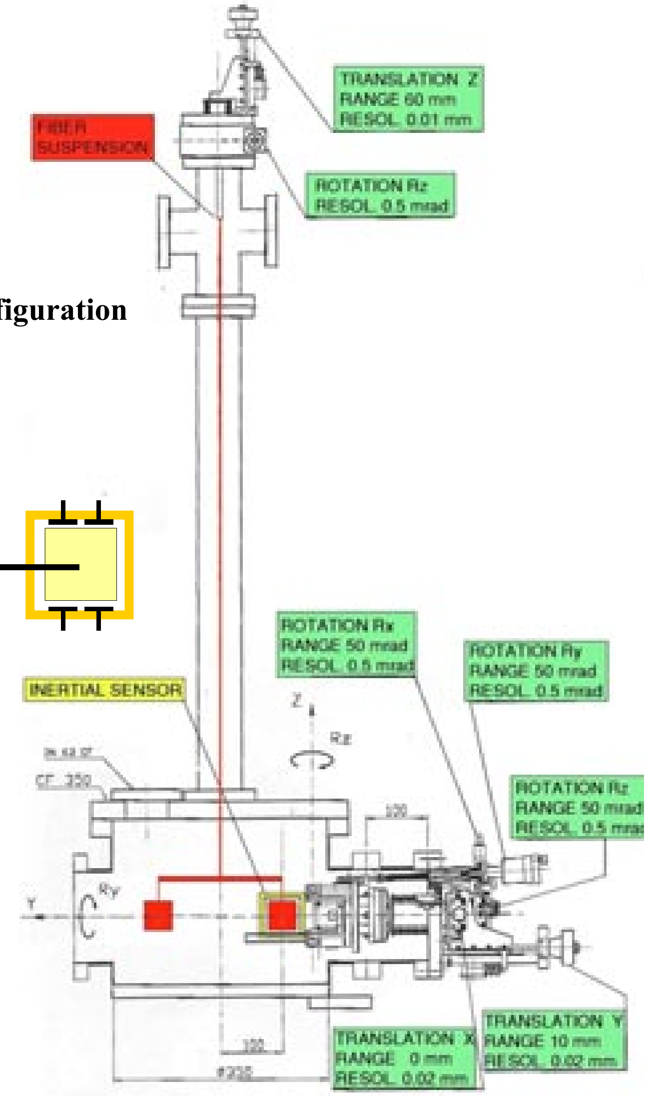


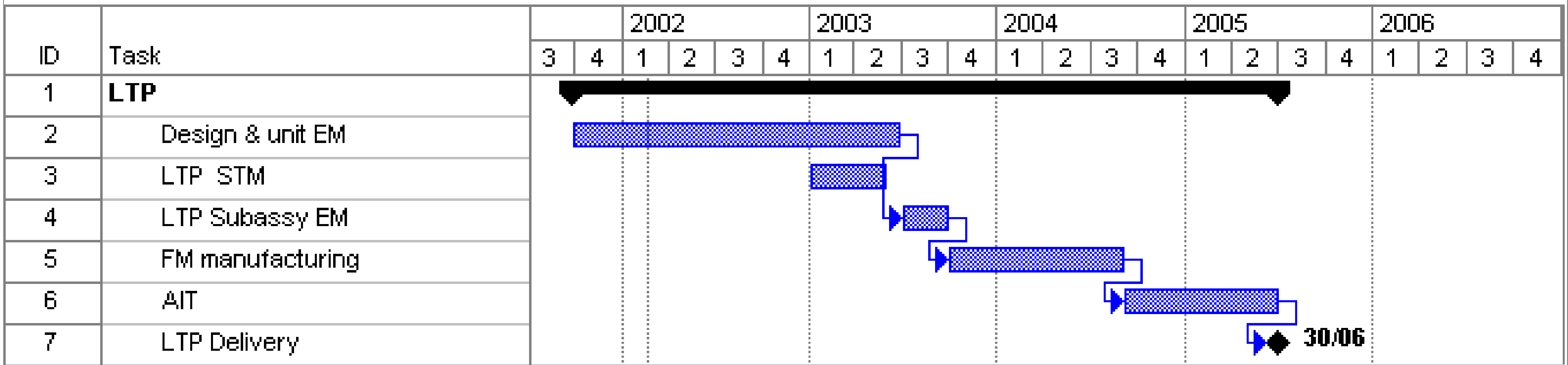
One mass configuration **Four mass configuration**





SMART-2 Launch 8-2006

LTP



Launcher and Mission Lifetime

- Launcher: Long March IV B (CZ-4B)
- Mission Lifetime:

  3 years (nominal)

  8 years (extended)

PHASE A STUDY

- Topical reports: due November, 2002
- Preliminary version: due January, 2003
- Presentation: March, 2003

OUTLOOK

Mini-ASTROD

- Testing relativistic gravity and the fundamental laws of spacetime with three-order-of-magnitude improvement in sensitivity; gamma to 10^{-7} or better, beta to 10^{-7}, J_2 to 10^{-8}, asteroid masses to 10^{-3} fraction
- Improving the sensitivity in the 5 μHz - 5 mHz low frequency gravitational-wave detection by several times to one order of magnitude;
- Initiating the revolution of astrodynamics with laser ranging in the solar system, increasing the sensitivity of solar, planetary and asteroid parameter determination by 1-3 orders of magnitude.
- Optimistic date of launch: November, 2002