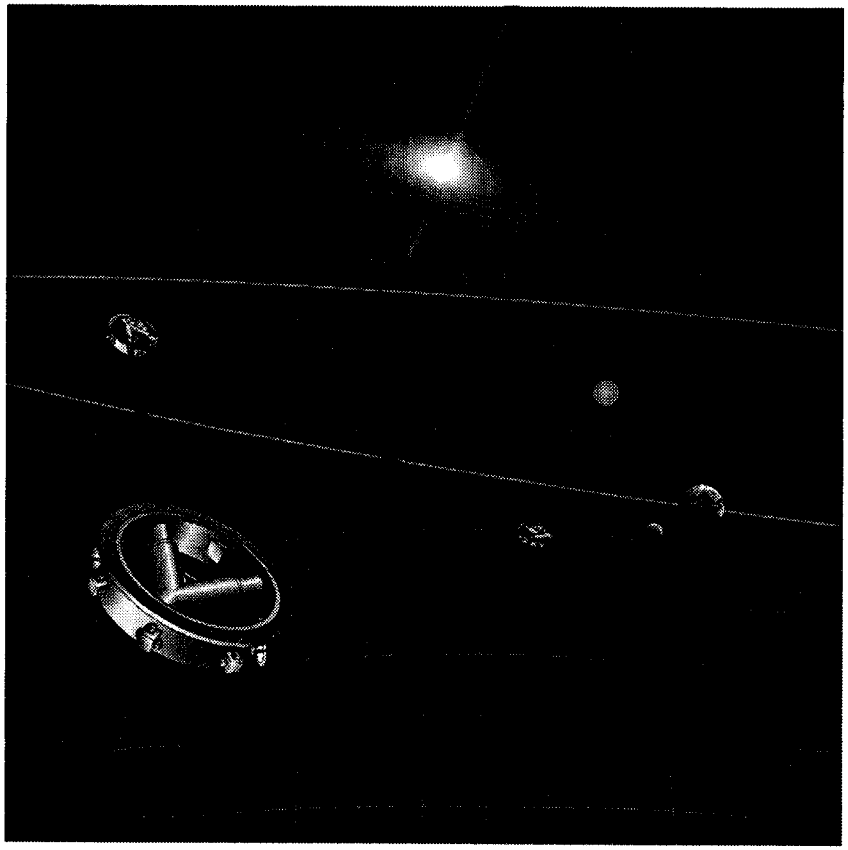
Space Technology Demonstrations for Gravitational-Wave Detection



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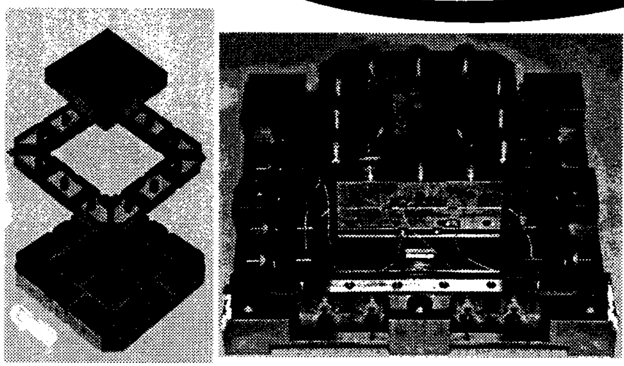
LISA Technology Needs

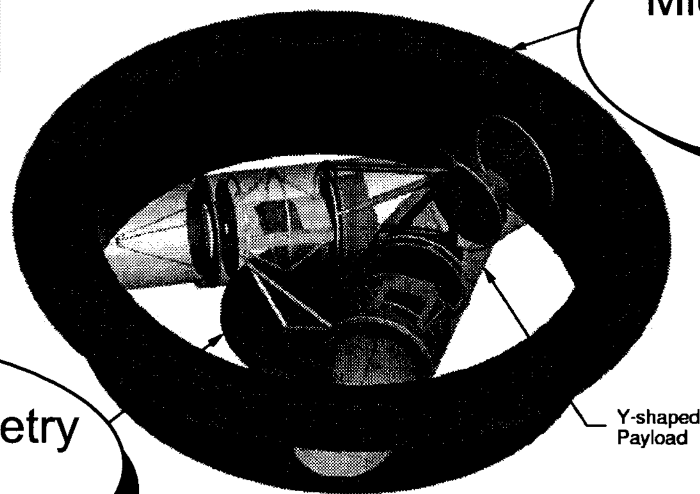
- Inertial sensors
  - Test masses with noise accelerations < 3×10^{-15} m/s^2/√Hz
    - Spurious motions < 20 pm/√Hz
  - Test masses must be shielded from noise forces
    - External (solar radiation pressure, magnetic, charged particle)
    - Spacecraft interactions (magnetic, electrostatic, gravitational)
  - Spacecraft position w.r.t. must be measured and controlled
    - Position electrostatically measured to <10 nm/√Hz
  - **Inertial sensor cannot be operated on Earth**
- Micronewton thrusters
  - Needed to control spacecraft position to required accuracy
- Laser interferometery
  - Measure separation between test masses to 10 pm/√Hz
    - ~One million times less sensitivity than LIGO, VIRGO, etc.
    - But ~one million times lower frequency

LISA Technologies

Inertial sensors
Noise < 10^{-16} g
rms for 1000 s average

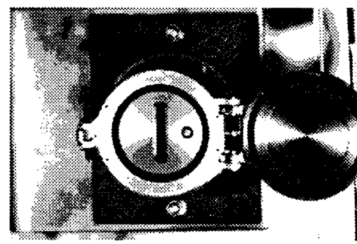


ONERA

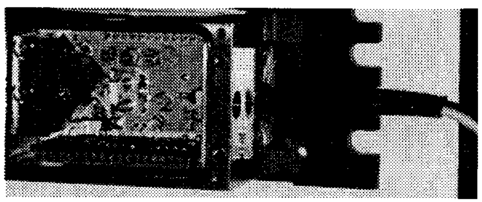


Micronewton thrusters
Range 1-100 μN
Noise <1 μN

Picometer interferometry
Accuracy < 1 pm
rms for 1000 s average
1 W laser

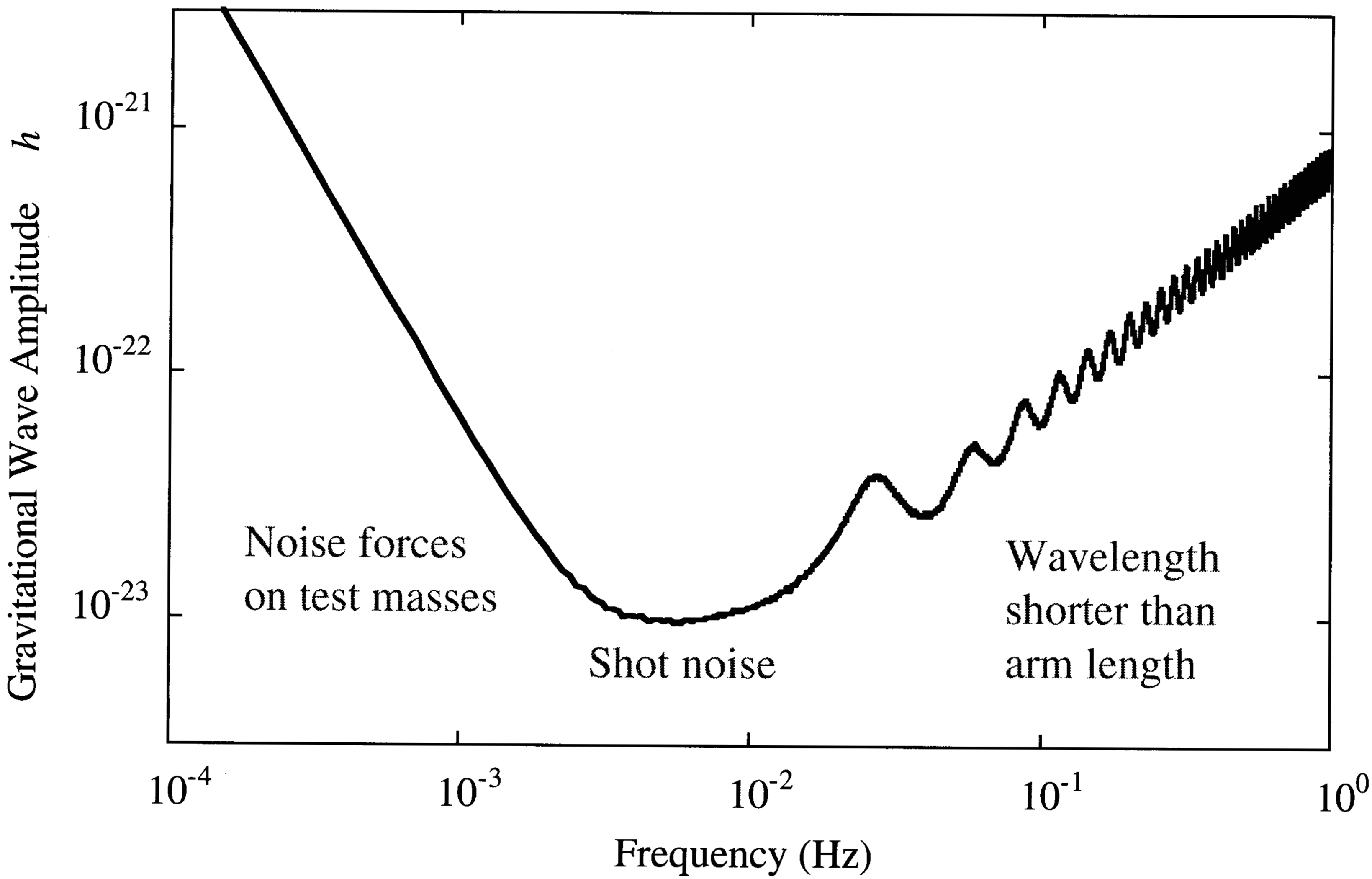


Centrospazio



JPL

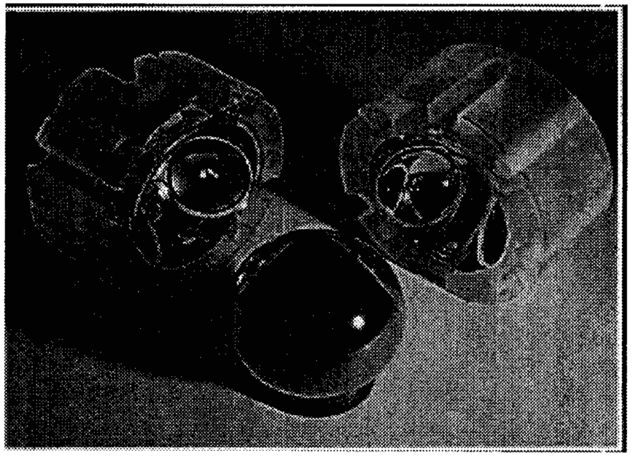
LISA Sensitivity



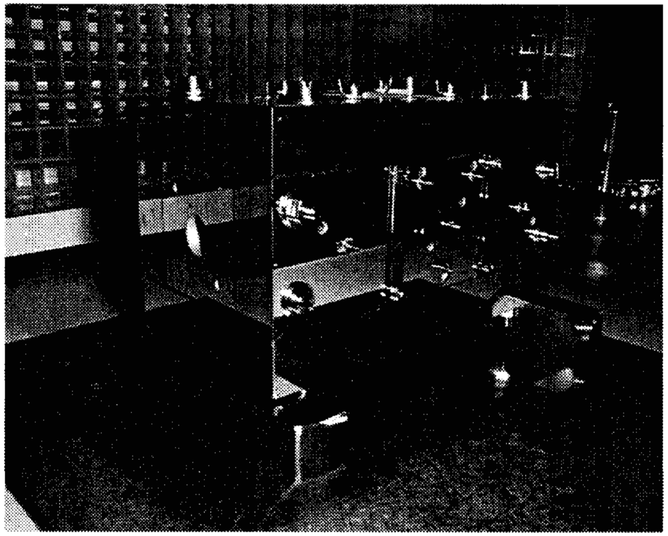
Design sensitivity for one year integration and signal-to-noise ratio of 5

Inertial Sensors

- An Inertial Sensor consists of;
  - Freely-floating test mass
  - Position measurement w.r.t housing
- Test mass must be isolated from;
  - Solar magnetic field
  - Solar radiation pressure
  - Residual gas pressure
  - Thermal radiation pressure
  - Cosmic rays
  - Spacecraft self-gravity
  - Spacecraft magnetic fields
  - Spacecraft electric fields
- Space heritage;
  - TRIAD (Stanford/APL, 1972)
  - GRADIO (ONERA, 1999)
  - CHAMP (ONERA, 2000)
  - GRACE (ONERA, 2001)
  - GP-B (Stanford, 2000)



Stanford University



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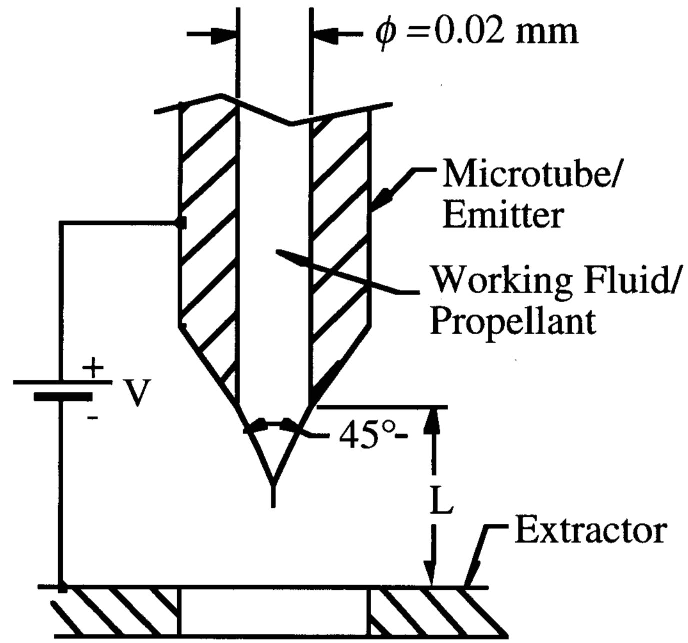
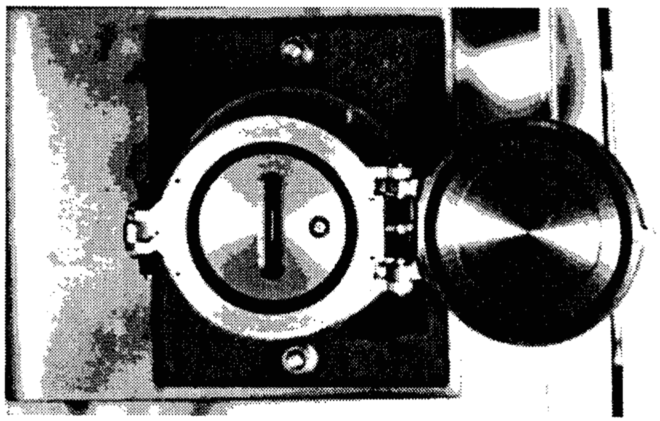
Micronewton Thrusters

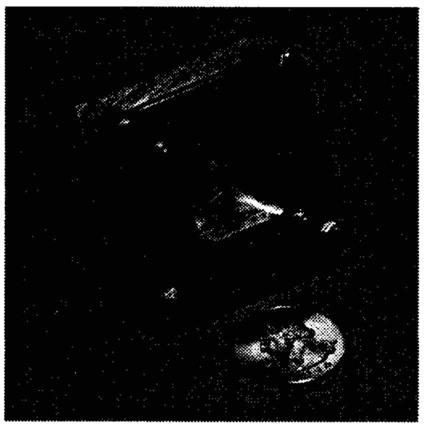
- Miniature ion thrusters
  - Eject, accelerate droplets of fluid
    - Cesium, indium, formamide
  - Thrust range set by solar pressure
    - Thrust 1-20 μN
    - Thrust noise <0.1 μN
  - Neutralizer needed to balance charge

Control s/c position to < 10nm



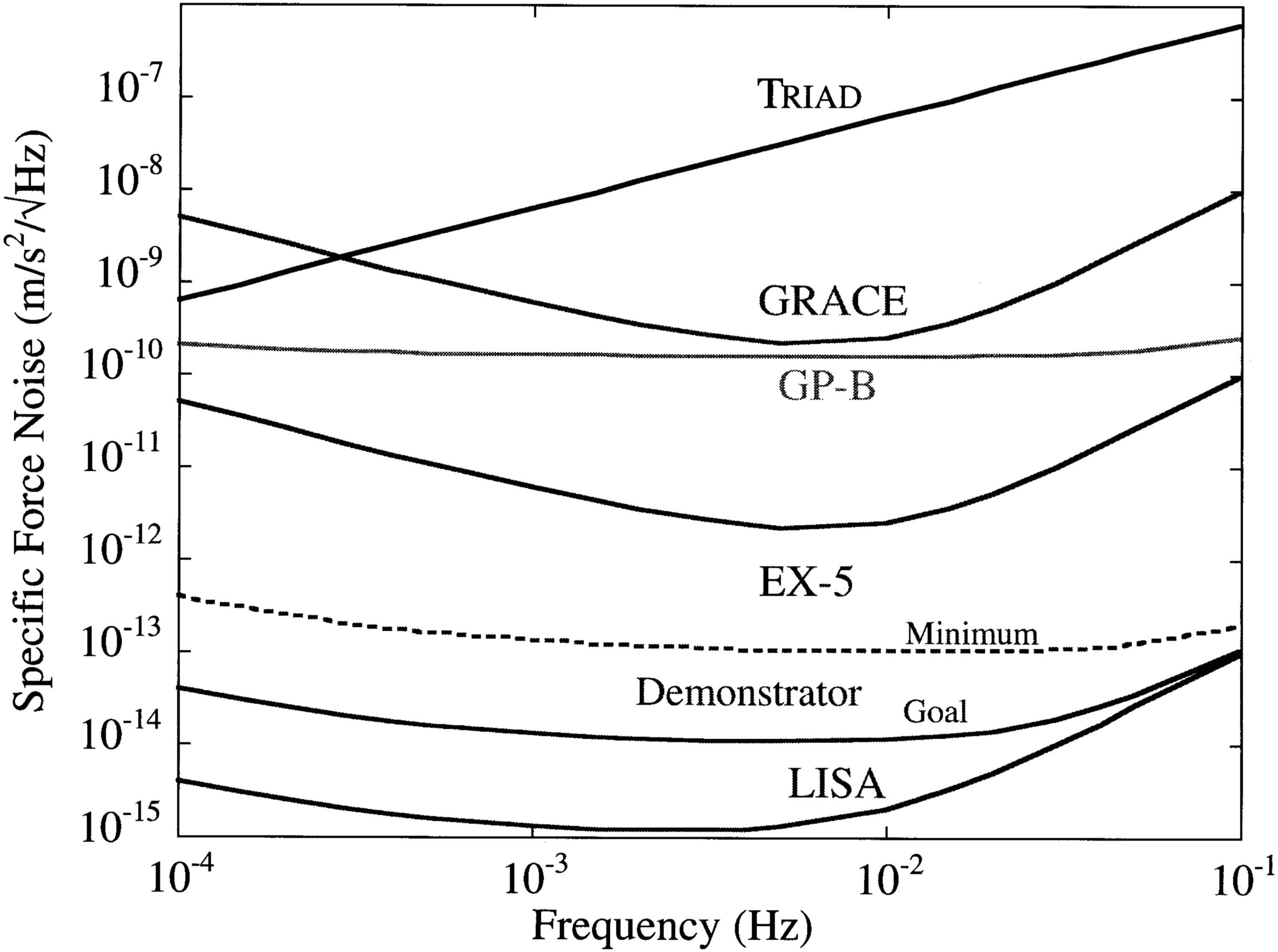


Centrospazio

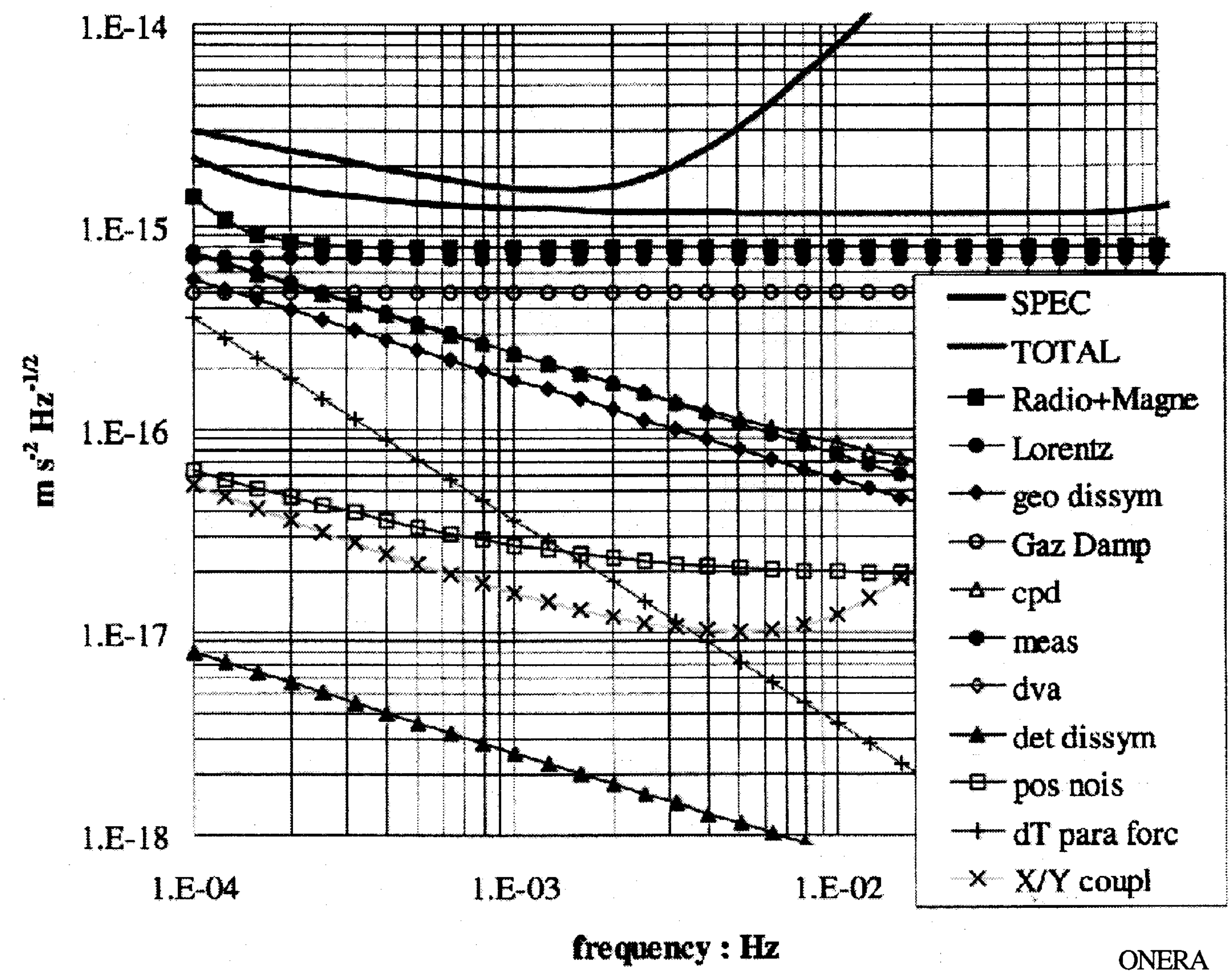


Busek Corp.

Inertial Sensor Performance



Expected Inertial Sensor Performance



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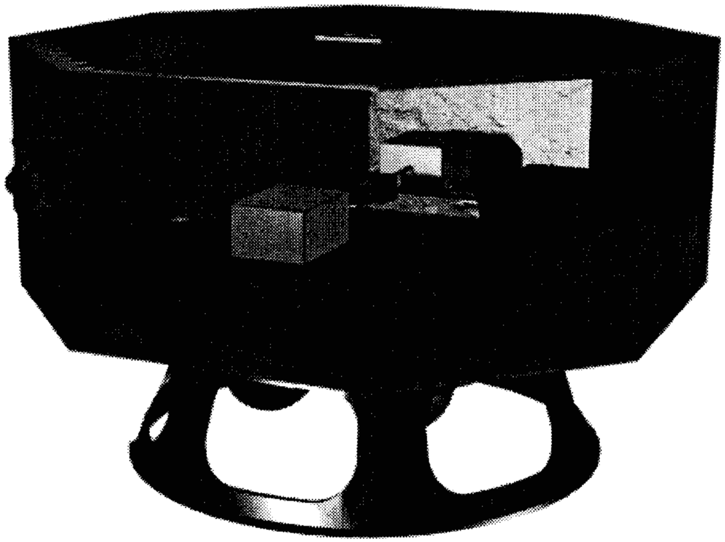
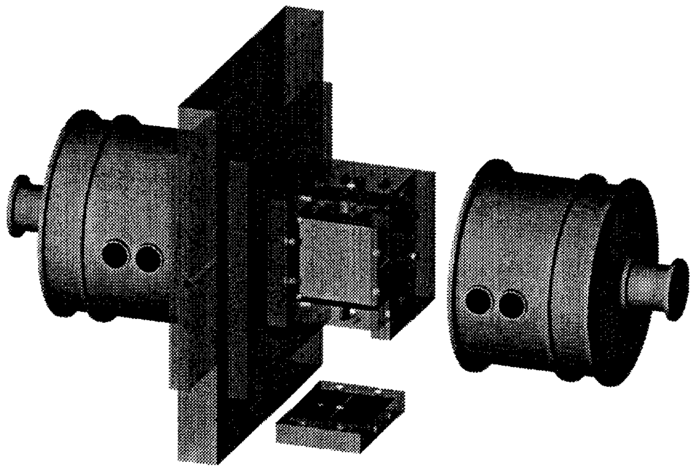
Flight Demonstration Concept

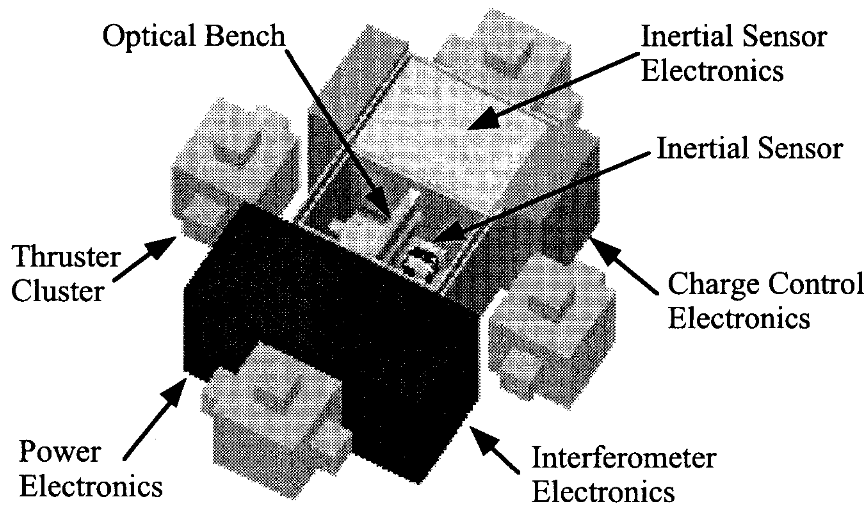
- Verify absence of noise forces by comparing two freely-floating test masses
  - Laser interferometer used to measure changes in separation
- Both test masses must be shielded from external forces by a spacecraft
  - Single spacecraft can house both
- Spacecraft must fly 'drag-free'
  - Micro-thrusters used to counteract solar radiation pressure
- Spacecraft must be far from radiation and gravitational tides
  - Need high-Earth or Earth-escape orbit



Instrument Configuration

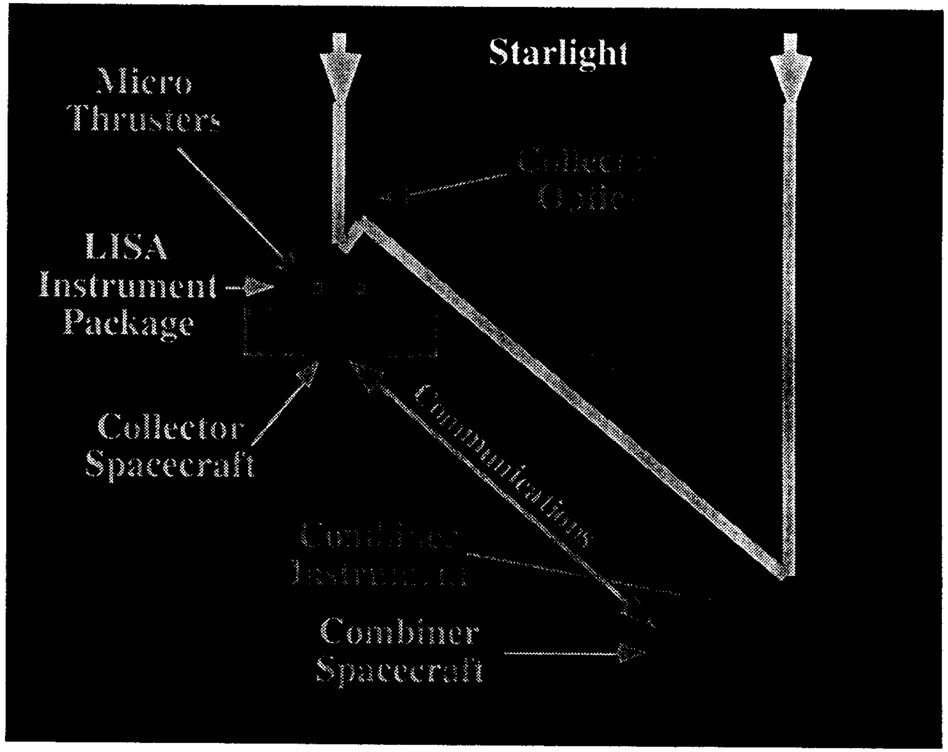
- Two inertial sensors, individual vacuum housings.
- Sensors integrated with interferometer
- 2-stage thermal isolation assembly





Flight Demonstration with ST3

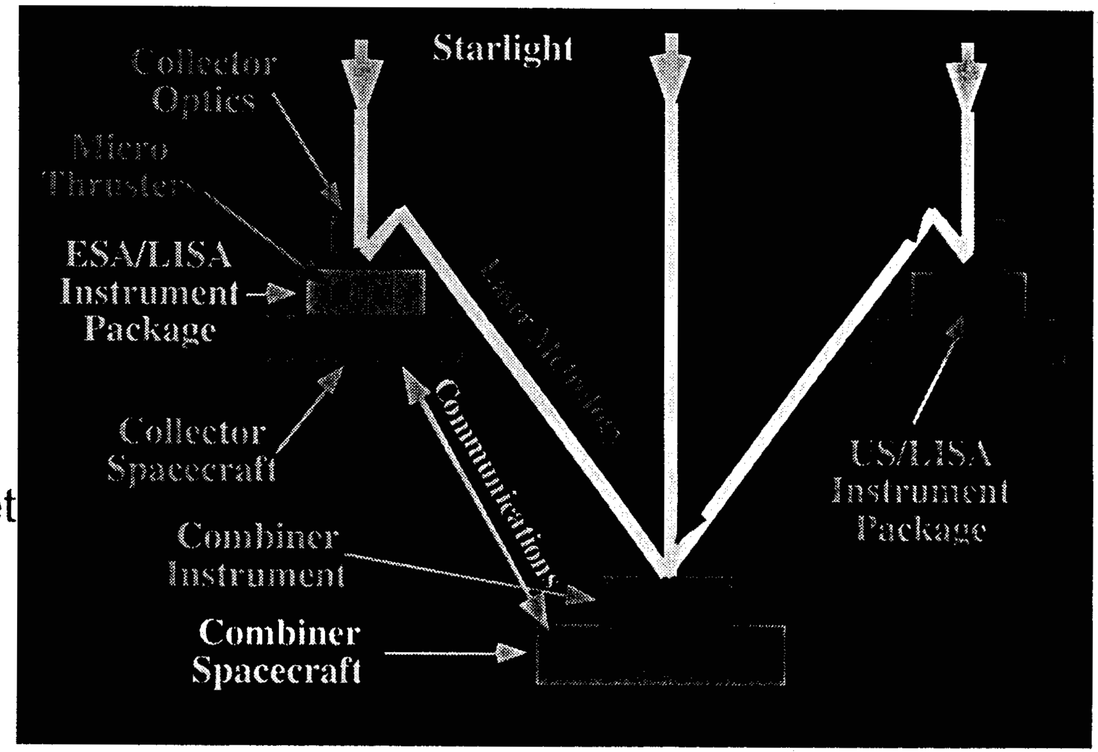
- Advantages;
  - Saves ~$40M for LISA test launch
  - Saves ~$20M for LISA test s/c
  - Adds mass margin for ST3
  - Enables more interferometer tests
    - No delay-line
    - Observe-on-fly
- Disadvantages
  - Ties schedule for ST3/LISA test
    - Schedule is fast for LISA test
  - Requires longer mission
  - Requires significant funding soon



Flight Demonstration with ST3/Smart II

- ESA SMART II mission is to test technologies for LISA and for separated-spacecraft interferometry (DARWIN/IRSI)
- A possible sharing between SMART II and ST3 is being explored
  - ESA would provide two spacecraft, one with a European LISA test package
  - Second ESA spacecraft could carry a US LISA test package

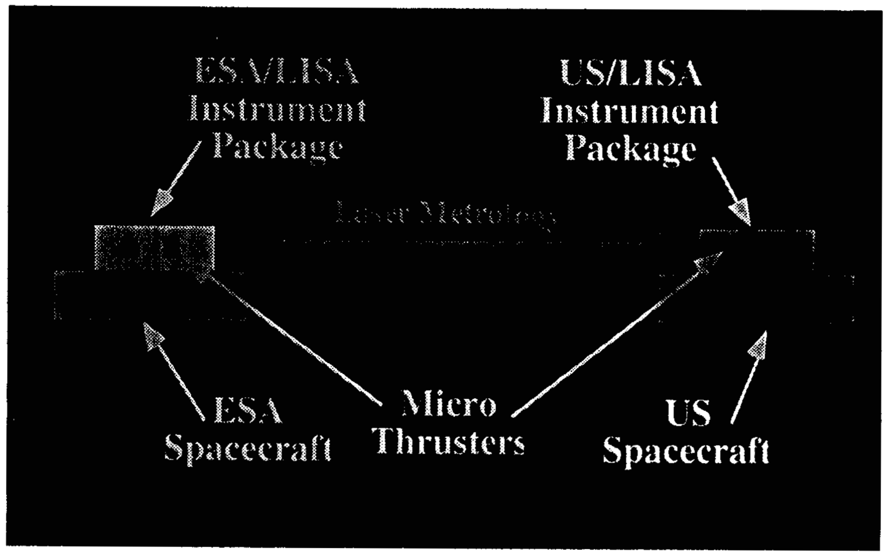
- Advantages
  - Tests 3 s/c formation
  - Better fringe visibility
  - More formation modes
  - Platform for LISA test
- Disadvantages
  - ESA/NASA schedule offset
  - Complex interfaces



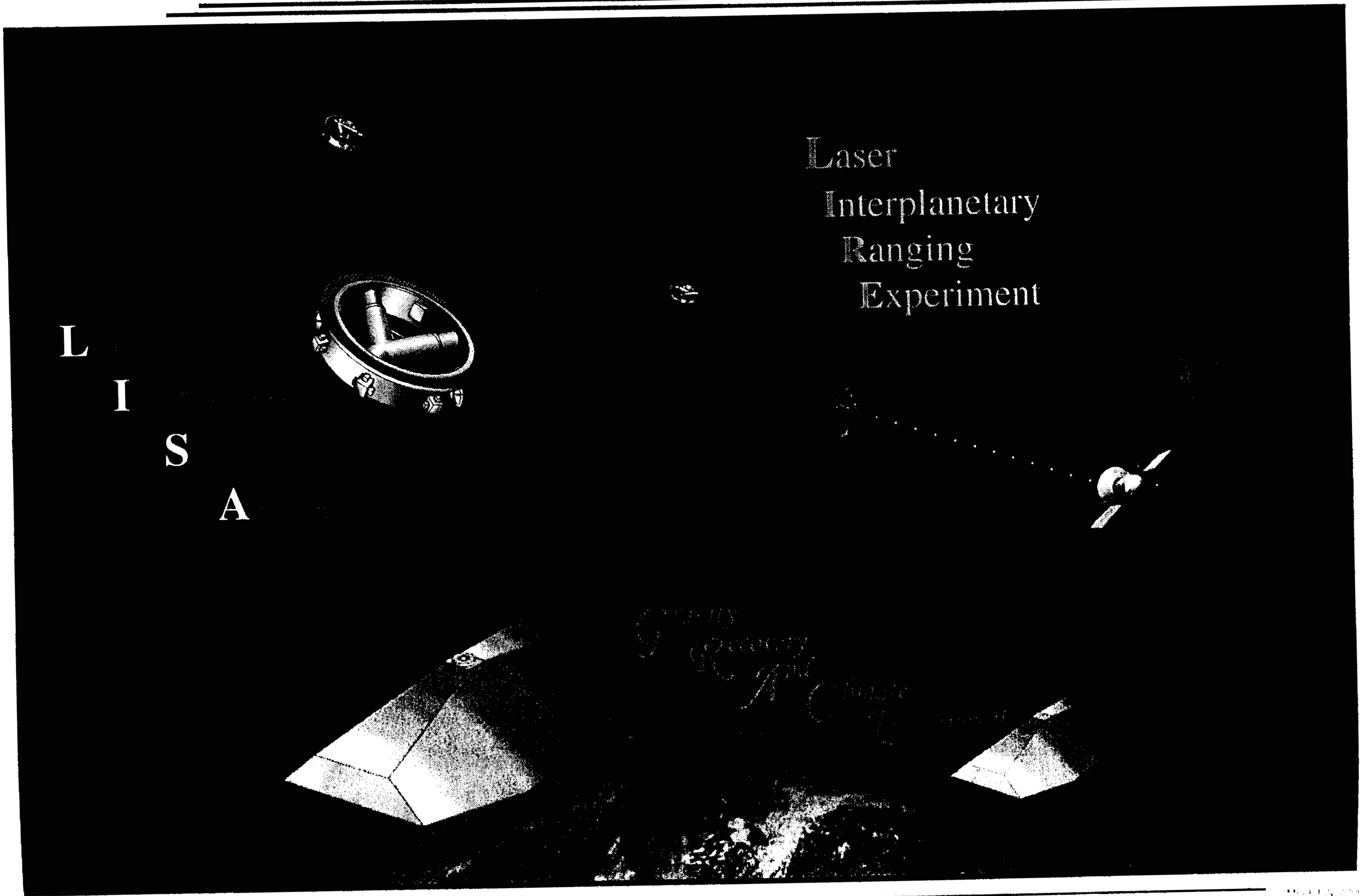
Flight Demonstration with ST6/SMART-II

- ST6, if approved, would start Phase A studies in March 2001
- One candidate mission would satisfy LISA test needs
  - Could be partnered with ESA EMART II
  - Could have one ESA s/c, one US s/c, each with separate test packages
  - Inter-spacecraft ranging could be part of ESA package

- Advantages
  - Separate ESA/NASA LISA tests
  - Clean interfaces
  - ESA/NASA schedules closer
  - Satisfies ESA formation flying
- Disadvantages
  - Subject to competition
  - Launch vehicle not identified
    - > Shared launch?
    - > Ariane 5 secondary launch?



Related Missions



Summary

- A test flight to demonstrate inertial sensor performance
  - Is highly desirable
  - Has strong support form NASA and ESA
  - Is synergistic with other flight demonstrations/science missions
  - Will probably launch in 2005/2006 time frame