US Micro-Thruster Development

J. Mueller and J. Ziemer

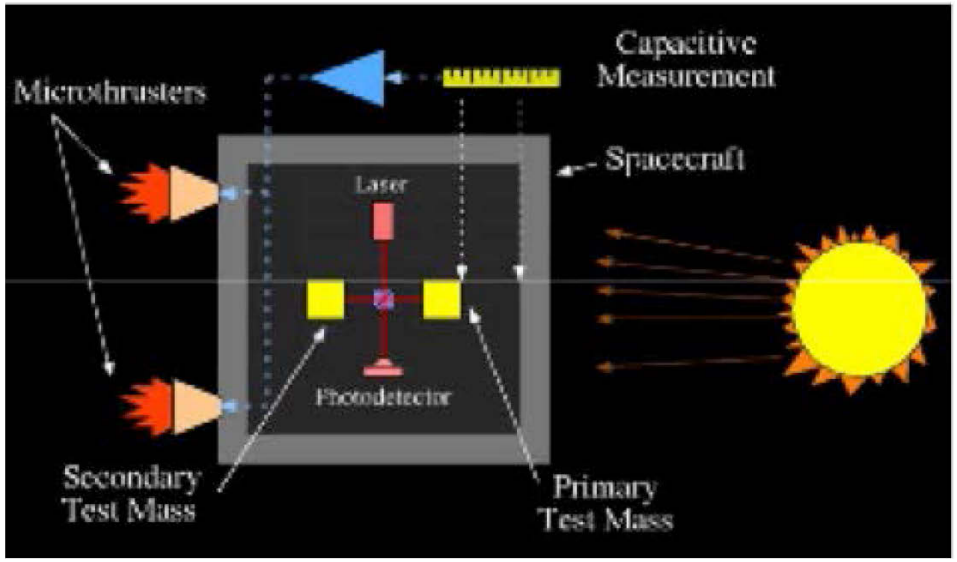
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Presented at the 'Science of Measurement' Working Group of the LISA Consortium
Max Planck Institute of Gravitational Physics/Albert-Einstein Institute
Hannover, Germany
January 28-29, 2013

Introduction:

Micro-Thruster Function and Role in the Flight System

- Micro-Thrust propulsion is required for all future space-based gravity wave observatory (SGO) missions.
- Negate orbital disturbances other than due to gravitational waves, mostly solar pressure induced.
- The spacecraft will follow an array of proof masses within approx 10 nm through micro-thruster action, canceling out environmental disturbances.



Micro-Thruster Requirements

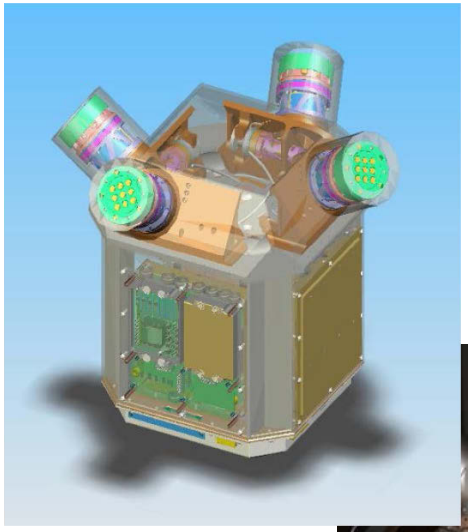
Past and Future Mission Scenarios

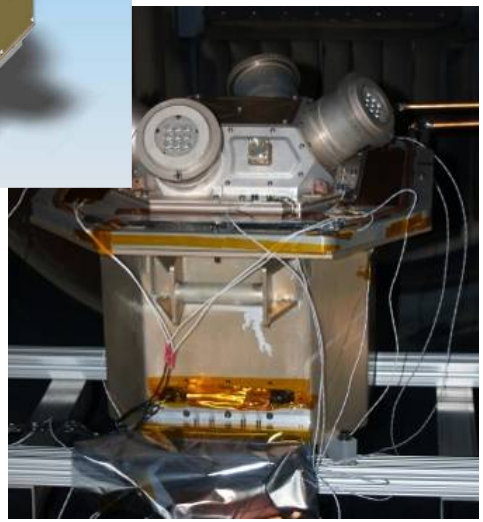
Requirement	ST7	LISA	SGO - Mid
Thrust Range	5 to 30 μN	4 to 30 μN	4-150 μN
Thrust Precision	< 0.1 μN	< 0.1 μN	< 0.1 μN
Thrust Noise	< 0.1 μN/√Hz (5 Hz control loop)	< 0.1 μN/√Hz (5 Hz control loop)	< 0.1 μN/√Hz (5 Hz control loop)
Thrust Command Rate	10 Hz (< 0.1 s latency)	TBD	TBD
Thrust Range Response Time	< 100 s	TBD	TBD
Specific Impulse (30 μN point)	> 150 s	TBD	TBD
Specific Impulse (6 μN point)	> 275 s	TBD	TBD
Operational Lifetime	> 2,200 hours	> 55,000 hours	> 8,000 hours
Plume Half Angle	< 35o (95% beam current)	TBD	TBD

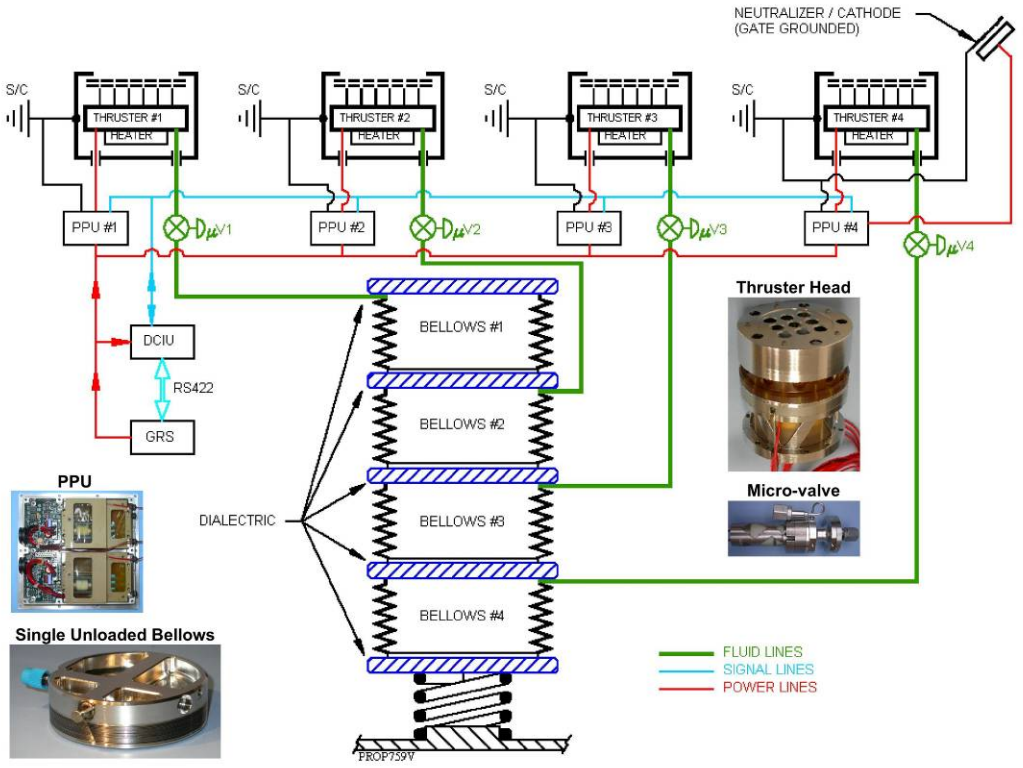
- Biggest difference between ST7 LISA Pathfinder and LISA is operational life.
- Future SGO mission scenarios will also require larger thrust range, possibly extending to 150 micro-N.

Thruster Development Status

ST7 Cluster with 4 Thruster Systems





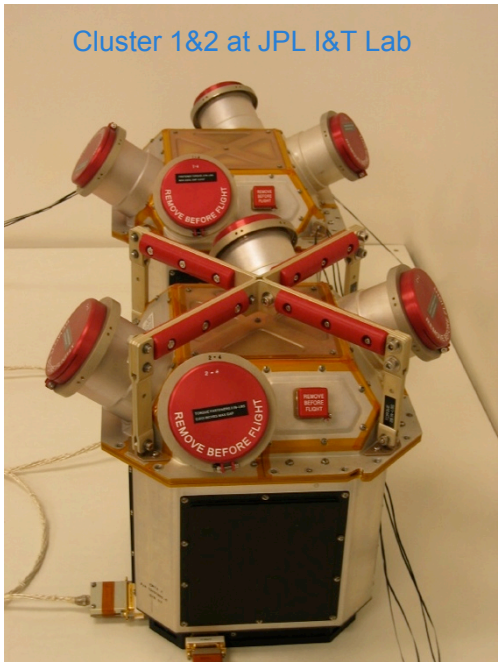


- ST7-DRS has 2 clusters with 4 thrusters per cluster
- All 8 thruster systems are identical
- There is one DCIU and neutralizer per cluster
- Thrust range: 5-30 μN from each thruster head

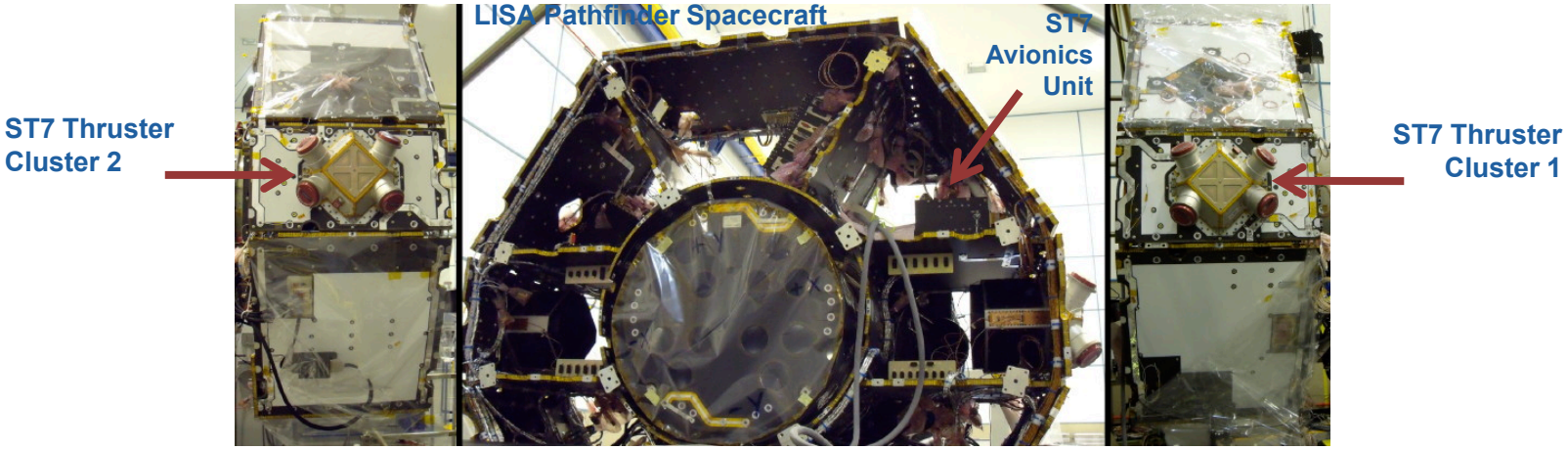
A single thruster sub-system includes:

- Thruster Head (including heater)
- Microvalve (precision flow control)
- Bellows (propellant storage)
- PPU (high-voltage converters)

Thruster Development Status – cont'd



- Busek Co. delivered two flight-qualified ST7 Colloid Thruster Clusters to JPL in early 2008
- Complete ST7 flight hardware and EM testbed units were delivered to ESA in July 2009
- All functional tests were successfully completed at Astrium UK in September 2009
- ST7 integration onto LISA Pathfinder Spacecraft was completed in November 2009



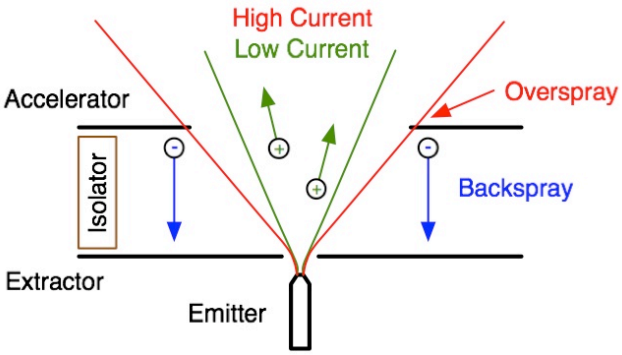
Thruster Development Status – cont'd

- LISA Pathfinder Demonstrated Performances:
  - 4.35 – 35.8 micro-N (> 36 micro-N for short durations)
  - 0.08 micro-N thrust precision (measured), 0.01 micro-N (calculated).
  - 3,460 hrs of lifetime, incl. 2,160 hrs using an expected thrust profile.

- LISA Micro-Thruster Technology Program (performed in parallel to ST7):
  - Failure mechanisms identified through analysis & test
  - 3,000 hr test of six single emitter thrusters in parallel, validating failure mode identification and feed system cleanliness and contamination requirements
  - Shorting due to propellant loading of grids was identified as highest lifetime risk.
  - Limits on propellant loading of grids were established, and design changes explored (frit materials, plume modeling).
  - Lifetime models and estimation tools were developed, estimating thruster lifetime at 40,000 hrs with 40% uncertainty due to facility effects (backspray).
  - Only single emitter tests under steady state conditions were performed - multi-emitter thrusters and time-varying conditions remain to be evaluated.

Future Technology Development Areas

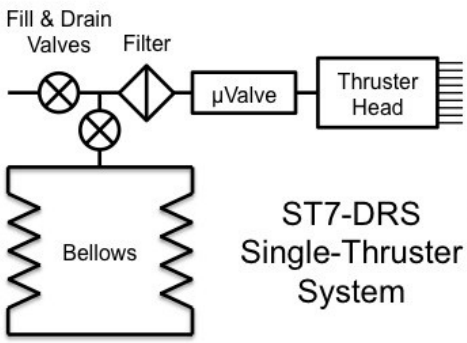
- **Lifetime:** A more detailed understanding, modeling and measuring of thruster "overspray" (small fractions of the beam current, < 1% of the exhaust at the outer edge, impinging on electrodes), which may lead to electrical shortening, reducing thruster lifetime.
- **Extended microvalve range and reliability**, including extended flow rate capability and cycle life without developing leakage over time.
- **Scaling up thruster system** through a combination of increased number of emitters, emitter size (current/emitter), increased microvalve flow capability, increased neutralizer currents, and increased propellant storage volume.



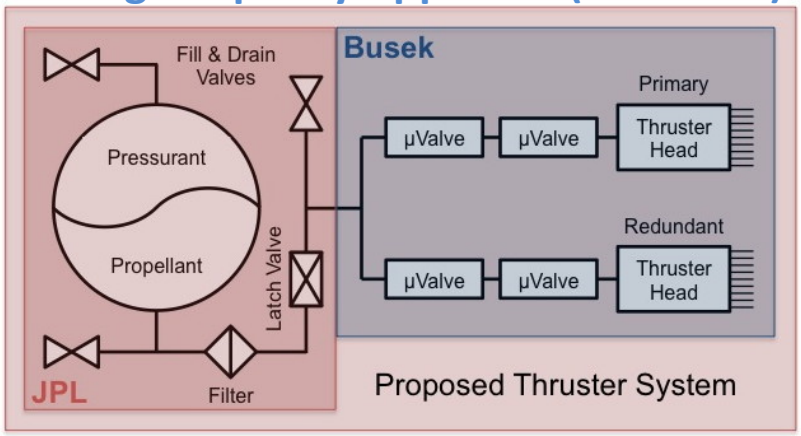
PCOS Technology Development

The NASA Physics of the Cosmos (PCOS) Strategic Astrophysics Technology (SAT) program is currently funded and was kicked off Dec 10, 2012 to increase propellant capacity of future micro-thruster systems.

ST7 System Concept:



New High Capacity Approach (PCOS SAT):



- The ST7-DRS propellant feed system includes
  - Bellows tank, 100 mL
  - Spring pressurized
  - Microvalve flow control
- Issues:
  - Not enough capacity
  - Heavy (scaled bellows)
  - Microvalve manufacturing
  - Single string
- Solutions:
  - Spherical metal diaphragm blow-down tank
  - New microvalve (Busek)
  - Dual string configuration

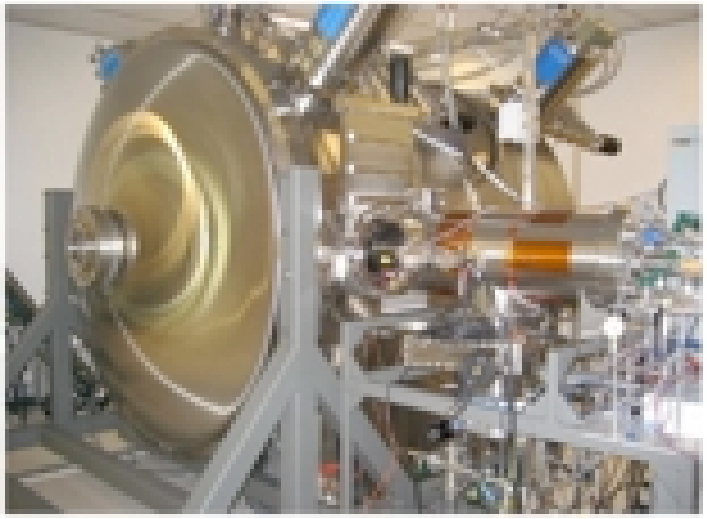
Proposed Development Tasks

- **Thruster Lifetime Evaluation:**
  - Physics-based modeling of overspray and condensed propellant migration across insulators and other thruster surfaces.
  - Model verification in short duration (1000 hrs) lifetests.
  - Accelerated life testing: using pre-deposited electrode and insulator surfaces (as determined by modeling) study failure modes at end of life.
  - 8,000 hr lifetest – run in parallel to previous tasks.
  - Extended thruster lifetest – extend the 8,000 hrs test, funding permitted, as long as desirable or thruster operation permits, addressing even the most severe lifetime requirements
- **Microvalve Lifetime:**
  - Currently qualified for 90-day operational lifetime for ST7.
  - Extend to desired operating life through functional testing at full propellant through-put, valve cycle life, incl. long-term propellant compatibility of soft-goods and leakage rates after extended operation.
- **Thrust Range Extension to 150 micro-N**
  - Through increasing number of emitters and possibly increased emitter size.
  - Must include scaled-up valve to handle required flow rates
- **Thruster Feed System Scaling:**
  - This project is underway using NASA PCOS SAT funding.
  - To replace ST7 bellows assembly with higher capacity metal-diaphragm tanks and increased valve redundancy.
  - PCOS SAT program does not allow for integrated thruster testing. Subsequent thruster integration required.
  - Future tasks also to include COTS valve component redesign for high-voltage isolation
- **Utilize JPL facilities & expertise to evaluate of competing thruster technologies. Track record for other US and European thruster concepts exists.**

JPL Unique Facilities for Micro-Thruster Evaluation

- JPL has a set of unique facilities and skills utilized in the ST7 micro-thruster development and evaluation.
- JPL has previously tested other micro-thrusters, both from the US and Europe.
- Facilities and skills could be utilized to evaluate alternative thruster concepts.

JPL Micro Thrust Propulsion Laboratory (MPL)



- 1000 sq ft, Class 10-100 certified clean room
- 2 m diameter UHV test chamber with simulated space environment capability
- μN thrust test stand with < μN resolution
- Plume diagnostics including Faraday cup probe stage and time-of-flight
- 6 inch thruster testing vacuum cube with thruster emission uniformity characterization diagnostics