<table>
<thead>
<tr>
<th>Name of Technology (256 char)</th>
<th>Laser</th>
<th>Phasemeter System</th>
<th>Alignment Sensing</th>
<th>Telescope</th>
<th>Gravitational Reference Sensor</th>
<th>Thrusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>LISA technology</td>
<td>LISA laser requires power of P=2W in a linearly polarized, single frequency, single spatial mode. It requires fast actuators (BW &gt; 10kHz) for intensity and frequency stabilization to enable laser phase locking and relative intensity noise of &lt;10^-9. Lifetime &gt; 10yrs. Shotnoise limited at 1mW laser power above 2GHz. Potential laser types: Diode pumped solid lasers Diode pumped fiber lasers Extended cavity diode lasers.</td>
<td>The phasemeter measures the phase of laser beat signals with uc/cy/Hz sensitivity. It is the main interferometry signal for LISA. The phasemeter consists of a fast photo receiver which detects the beat signal, an ADC, which digitizes the laser beat signal, and a digital signal processing board which processes the digitized signals.</td>
<td>Alignment sensing in interferometric space missions like LISA or formation flying missions is required to maintain the alignment between the individual spacecraft. This is done with differential wavefront sensing between a local and the received laser beam. The laser is a four element fast, non-dispersive photo detector.</td>
<td>LISA and also formation flying missions require telescopes to exchange laser fields for position and alignment sensing. The requirements for these telescopes include unusual length and alignment stability requirements at the pm/yr level.</td>
<td>Gravitational Wave detectors (LISA and LISA follow-on missions) as well as other fundamental physics missions require gravitational reference sensors. For LISA, the residual acceleration of the GRS has to be in the sub-uc/ryHz range.ESA has developed a gravitational reference sensor for the LISA pathfinder and will test it in flight in the upcoming years.</td>
<td>Thrusters for in-space operation with very low noise, tunable thrust, long lifetime (&gt;5 years) are required for LISA, LISA follow-on missions, and for formation flying missions. LISA needs low noise with less than 100m thrust.ESA needs more thrust but can also tolerate more noise compared to LISA.</td>
</tr>
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</table>

**Goals and Objectives (1024)**

The goal is to reach TRL 6 in 2015 with a laser system that meets NASA requirements. Frequency Comb has nothing to do with the LISA laser. Low noise or Ultra-low noise is not necessary because of active stabilization. The laser is at the beginning of the optical train and the required modulation, fibers, optical components, etc depend on the laser type. A change to a different laser system later could require a complete redesign of large portions of the optical system.

The goal is to reach TRL 6 by 2015 with the phasemeter system that meets LISA requirements. This system is essential to support tests of other subsystems at the uc/cy/Hz level and should be developed as soon as possible. Should be developed with Alignment sensing photodetector.

The goal is to reach TRL 6 by 2016 with the alignment sensing system. It should be developed together with the phasemeter system. Understanding the capabilities and the sensitivity of the alignment sensing system enables more targeted technology developments for LISA and allows to develop realistic designs for formation flying mission.

The initial goal has to be to support the LISA pathfinder and to import the technology to learn as much as possible from the pathfinder. This could raise the TRL well above 6 immediately. Future R&D in this direction has to depend on the outcome of the pathfinder mission. The lessons learned should help to evaluate how far this technology can be pushed or if radically new ideas should be investigated.

**TRL**

4 TRL is between 4 and 5. Requires no efforts towards future qualification and testing in relevant environment.

5 The phasemeter has been demonstrated but only with single element photodetectors and most of the components are not space qualified.

4 This might just be testing commercially available quadrant detectors and identifying one that meets the requirements.

4 for length and alignment stability 2 for backscatter.

Pathfinder GRS: TRL > 6 | Colloids: TRL 6 |

**Tipping Point (100 words or less)**

Laser meeting these requirements exist already. Several designs have reached TRL 4. A focused effort could increase this to TRL 6 or at least identify the issues in a fairly short time.

A survey of the available quadrant detectors and simple tests of the most promising ones might be sufficient to get this to TRL 6. Length and alignment stability: This requires to build a real LISA telescope and test it. Note that a 40cm telescope is not a gigantic investment but developing the measurement capabilities requires some funding. The coherent backscatter and an initial minor investment would make a huge difference.

This would be an ongoing effort.

**NASA capabilities (150 words)**

NASA's capabilities in this area appear to be restricted to testing and space qualification. Commercially or in-house built on-axis telescopes would not be useful for other laser interferometric missions such as formation flyers, multiple-aperture missions, or Gravitational Wave missions.

NASA has the capability to build a 40cm LISA telescope but the capabilities to measure the length and alignment variation need to be developed. NASA (and many others) could analyze and test the backscatter.

ESA is building it and collaborates with NASA on the pathfinder. Well within NASA capabilities.

**Benefit/Ranking**

It would allow to define the interfaces between the laser and all other subsystems in LISA. This simplifies and in some cases enables R&D on other important components. The laser system itself can become the core for other laser interferometric missions such as formation flying missions, multiple-aperture missions, or Gravity follow-on missions.

The capability to measure noise at the uc/cy/Hz level is essential for the R&D on many other components. Having well defined phasemeter system would enable this work and accelerate the R&D in general.

The telescope is another key part of LISA and formation flying missions. Off axis telescope with additional interferometer to control length and yaw of the telescope as well as other developments that could be used in an alternative but would increase mass and complexity. Yes. A gravitational reference sensor with sub-fs residual acceleration is critical for gravitational wave missions. Making sure that NASA has access to this technology should be one of the top priorities.

ESA is not a key part of LISA and formation flying missions. Off axis telescope with additional interferometer to control length and yaw of the telescope as well as other developments that could be used in an alternative but would increase mass and complexity.

Yes, if NASA can take advantage of the LISA pathfinder.

**NASA needs/Ranking**

LISA is the main customer but other interferometric space missions are planning to use similar phasemeter. Having a completely characterized system with uc/cy/Hz sensitivity would meet many NASA needs.

LISA and also formation flying missions. Having a completely characterized system with uc/cy/Hz sensitivity would meet many NASA needs.

Well within NASA capabilities.ESA has to import the LISA and formation flying missions. Off axis telescope with additional interferometer to control length and yaw of the telescope as well as other developments that could be used in an alternative but would increase mass and complexity.

LISA and LISA follow-on missions depend on it. | Formation flying would be a game changer. Thrusters are only a part of this. On going effort.

**Non-NASA but aerospace needs**

Formation flying might have commercial and national security applications in the form of smaller satellite missions. | Required for LISA and formation flying missions. Having a completely characterized system with uc/cy/Hz sensitivity would meet many NASA needs. | Would significantly simplify LISA and formation flying missions. | LISA and LISA follow-on missions depend on it. | Formation flying would be a game changer. Thrusters are only a part of this. On going effort. |

**Non aerospace needs**

Non, Non space-qualified lasers which meet the requirements are commercially available. | Formation flying might have commercial and national security applications in the form of smaller satellite missions. | LISA and also formation flying missions require telescopes to exchange laser fields for position and alignment sensing. The requirements for these telescopes include unusual length and alignment stability requirements at the pm/yr level. | Gravitational Wave detectors (LISA and LISA follow-on missions) as well as other fundamental physics missions require gravitational reference sensors. For LISA, the residual acceleration of the GRS has to be in the sub-uc/ryHz range.ESA has developed a gravitational reference sensor for the LISA pathfinder and will test it in flight in the upcoming years. | Formation flying might have commercial and national security applications in the form of smaller satellite missions. | Formation flying might have commercial and national security applications in the form of smaller satellite missions. | No non-NASA needs as far as I know | No non-NASA needs as far as I know | |
### Technical Risk

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<tr>
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<th>Main Challenge</th>
<th>ESA Responsibility</th>
<th>Ranking</th>
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<td>The technical risk is low. Several commercial systems exist that meet the requirements except space qualification. No commercial company will space qualify a LISA laser to commercialize it. Ranking ii.</td>
<td>Technical risk is low. The main challenge is to get the temperature dependent dispersion under control. Ranking ii</td>
<td>Technical risk for the longitudinal and alignment stability is low. Materials have been tested at the sub-pm level. The main challenge appears to be to develop the capabilities to perform the experiments.</td>
<td>ESA is taking most of the financial risk right now. If the pathfinder reaches the performance, technical risks for NASA are minimal. Ranking: ii (although the definitions for the rankings are not really applicable)</td>
<td>Continuous development. Technical risk low</td>
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### Sequencing/Timing

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<td>Should come as early as possible. The development of many other components depends on the specific laser system. Ranking iv.</td>
<td>Requires phasemeter. Should start before phasemeter development is finished and should be finished 1-2 years after phasemeter is at TRL 6. Ranking: iv</td>
<td>Length and alignment. The current status is sufficient for planning purposes. Tests on real models should start 2017. Backscatter: Start immediately as small effort. Ranking: iv</td>
<td>The timing is set by ESA. Ranking: iv</td>
<td>Continuous development.</td>
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### Time and Effort to achieve goal

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<td>3 year collaboration between industry and NASA. Ranking: iii.</td>
<td>2 year collaboration between academia and NASA, Ranking iv</td>
<td>3 year academia project Ranking: iv</td>
<td>Effort and time depends on form of collaboration with ESA. Ranking: iv (because of ESA lead)</td>
<td>Continuous development.</td>
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### Comment from me

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<td>Clarifies specs in TABS. Wavefront sensing in TABS is more adaptive optics related and not alignment related. LISA cares mainly about maintaining alignment. Telescopes for multi-S/C interferometric missions have different requirements than big optical telescopes. This is not reflected in the TABS.</td>
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<td>Telescopes for multi-S/C interferometric missions have different requirements than big optical telescopes. This is not reflected in the TABS.</td>
<td>I don’t think NASA needs to do anything in this area right now except make sure that they know how the LISA pathfinder works. And please forget the atomic interferometry for the next 10 years.</td>
<td>Continuous development. Technical risk low</td>
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[OK, atomic interferometry is a real near term project compared to the quantum vacuum drive proposed in this TABS...]

[Clarifies specs in TABS. Wavefront sensing in TABS is more adaptive optics related and not alignment related. LISA cares mainly about maintaining alignment. Telescopes for multi-S/C interferometric missions have different requirements than big optical telescopes. This is not reflected in the TABS. I don’t think NASA needs to do anything in this area right now except make sure that they know how the LISA pathfinder works. And please forget the atomic interferometry for the next 10 years. It is essentially covered. Maybe not really in the context of formation flying missions. OK, atomic interferometry is a real near term project compared to the quantum vacuum drive proposed in this TABS...]

[Continuous development. Technical risk low]