Idea I-2025-06920: Improving a mature Alexandrite laser in the UV region and demonstrating the suitability of monitoring reentered space debris with in situ resonance lidar measurements

Status Community Discussion

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Picture

Abstract

In times of "New Space" with increasing space activities and an unparalleled rise of objects in orbit, the clean-space initiative is important to guarantee mankind's access to space. Removing non-operational spacecrafts by controlled reentering in the atmosphere and the consequently burning up in high altitudes is the most efficient and only realistic way of limiting the number of objects. The problem is that satellite deorbiting may have polluting effects on the middle atmosphere. Recent measurements of the ratio of metals in stratospheric sulfuric acid particles suggest that a significant portion originates from reentering space debris [1]. Several different metals were clearly connected to the space debris origin. Recent studies indicate that the atmospheric effects of re-entering spacecraft could be significant [2]. There is very little data on the environmental impact (e.g. atmospheric

	chemistry) of de-orbiting and in-situ data collection in the respective altitude is practically impossible. Therefore, it requires continuous investigation over extended time scales. Measuring metals from ablated debris with resonance lidar is the solely solution for high sensitivity, continuity and efficiency. Measuring metal layers like Potassium, Sodium and Iron in the Mesosphere and lower Thermosphere (MLT) with resonance lidars is well-known. Though currently, the necessary laser and lidar technology is not mature enough for autonomous operation and involves high personnel effort. Furthermore, the detection of space debris might require the focus on other tracer metals that deviate from the natural composition and are representative for man-made space objects. The idea is to use the upcoming novel technology based on Alexandrite lasers for compact, autonomous and maintaining-free resonance lidars, demonstrated for Potassium, and demonstrate the extension to resonance wavelengths of potentially relevant metals from space debris in the lab.
Implementation Scheme	Early Technology Development
Ready for evaluation	Yes - ready for evaluation
Acceptance of Cooperative Agreement and General Conditions	I/We confirm
ESA Entity Code	1,000,002,131
Prime Contractor	Fraunhofer Institute for Laser Technology ILT
Prime Contractor Address	Steinbachstr. 15, 52074 Aachen, Germany
Country	Germany
Arbitration tribunal city and country	München, Germany
Subcontractor 1	Name:: Leibniz Institute of Atmospheric Physics (IAP) Code:: 1,000,032,043 Country:: Germany Share:: 25'000 €
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Start Date	01-12-2025
Duration	10 months
State of the Art	In the time of "New Space" the increasing number of anthropogenic objects in near-Earth space presents significant challenges, particularly concerning the

environmental impacts associated with the reentry of these objects. As satellites and rocket bodies reach the end of their operational life, their inevitable reentry into the Earth’s atmosphere leads to fragmentation in the mesosphere - an altitude range between 60 and 100 km - where a substantial portion of their mass disintegrates. This process introduces a variety of materials into an atmospheric layer that is already undergoing changes due to climatic change, raising concerns about the long-term implications for atmospheric chemistry, cloud formation, and radiative balance. Current international initiatives, such as the ESA's Zero Debris Charter and NASA's Space Sustainability Strategy, primarily focus on mitigating space debris within Low Earth Orbit (LEO). While these programs are important, they largely overlook the consequential atmospheric pollution that arises from the vaporization of reentering debris. The upcoming scientific community that is investigating the atmospheric effects of reentering space debris is still building, and significant knowledge gaps remain regarding the development of reentry aerosols and their influence on global atmospheric processes [1,2].

Sounding rockets that measure in-situ are only possible with huge effort and are respectively seldom. Ground-based resonance and aerosol lidars are currently the only existing methodologies for monitoring aerosols and metals in the mesosphere on a regular base [3-5]. But so far, for the injection by burnt-up space debris, no systematic and continuous observation exist for the spreading and development over short-, mid- and long-time scales . The overall impact on chemistry and dynamic of the upper atmosphere is unknown and models of the transport into the lower atmosphere (stratosphere) are highly speculative due to the lack of basic data like the chemical composition and physical behavior of reentry debris.

While resonance fluorescence and aerosol lidars have advanced our understanding of the upper atmosphere, the existing technology still requires substantial personnel involvement and is not yet optimized for autonomous and continuous operation. The measurements of aerosols in the mesosphere is mainly limited by the necessary power in traditional lidar systems, that lack the necessary spectral resolution of laser and filters for efficient detection of aerosol scattering. For resonance measurements, the addressing and stabilization on the specific atomic line increases the complexity and requires a tunable laser covering the relevant spectral range. Many of the relevant metals have resonance wavelengths in the ultraviolett region.

Currently, resonance measurements in the mesosphere focus on deriving wind and temperature in altitude of 80-120 km by probing natural metal layers, e.g. potassium, sodium and iron, which are produced by meteoroids. Beside a few attempts on other metals, no systematic evaluation of observable species have been conducted. A dedicated measurement campaign for the distinguishment between natural and anthropological origin has never been addressed so far.

Given these challenges, innovative novel measurement technologies are required. This proposed project aims to leverage advanced and mature resonance lidar technology [6-10] to facilitate high-sensitivity detection of metals associated with reentering space debris. By focusing on the development of solid-state lasers based on diode-pumped Alexandrite, we take the first step towards a future autonomous and maintenance-free resonance lidar for long-term monitoring of metals originating from space debris. The reliable and efficient diode-pumping combined with an sophisticated resonator design overcomes the susceptibility to environmental changes and aging of component. The capability for autonomous measurements ensures continuous data sets without the high personnel requirements of conventional resonance lidars. The compact design allows for high mobility and flexible measurements at sites with high relevance for reentering space debris.

The laser technology is developed and verified for potassium resonance lidars in the infrared region [6,7] and first lab experiments demonstrated the possibility for an efficient frequency-conversion to the ultraviolett region [9].

Implementing this technology will not only help filling critical knowledge gaps but also contribute to the responsible management of Earth's atmospheric resources as we continue to expand our activities in space. Understanding the atmospheric pollution resulting from reentering space debris is essential for maintaining the integrity of climate systems. By focusing on the unique capabilities of lidar technology, this project supports ESA's commitment to advancing sustainable practices in space exploration.

In summary, addressing the atmospheric impacts of reentering space debris is essential for the future of sustainable space operations. The proposed project represents a crucial step toward developing the necessary tools to monitor and mitigate the effects of human activities in the atmosphere, ensuring that we can responsibly manage both our planetary environment and our endeavors in space.

References

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Proposed solution

The overall goal is the autonomous and continuous long-term monitoring of metals from burnt up space debris with a novel resonance lidar system based on mature solid-state laser (e.g. diode-pumped Alexandrite laser) to gain data on the impact on the atmosphere. The diode-pumped Alexandrite laser is the key-component of the novel resonance lidar and is the optimal emitter with its extremely narrow linewidth, wide tunability, high efficiency and maintenance-free operation over long periods.

Compared to state-of-the-art lasers for lidar applications for resonance or Mie scattering with aerosols, the pulse energy is rather low (~1 mJ vs. ~100 mJ) but compensated with a higher repetition rate (~750 Hz) to yield the same average power. This drastically reduces the fluence on the optics and thereby the risk of laser-induced damage. To preserve the same signal-to-noise ratio, the background has to be efficiently suppressed. For that goal, the linewidth of the laser and the filters of the receiver are matched in their absolute wavelength on the species' resonance wavelengths and an extremely narrow linewidth (<10 MHz). With a potassium resonance lidar, the proof-of-concept was demonstrated by measuring the potassium layer in 80-110 km altitude during daylight [7].
The intended narrow linewidth requires a relatively long pulse length (~ 1 µs) that reduces the peak power of the laser pulse. For the frequency-conversion that is challenging as the conversion-efficiency depends on the peak power. To yield high pulse energy in the UV-region an innovative approach of intra-cavity frequency-conversion is implemented. By careful design of the conversion parameters, the output pulse energy in the UV is nearly the same as for the IR while avoiding the typical high optical load on the nonlinear crystal. A novel injection-seeding scheme allows for a single-longitudinal mode operation with comparable narrow linewidth <10 MHz with only slight changes of the wavelength control technique.
For addressing the different wavelengths within the tuning range of the laser, the alignment of wavelength-selective components in the resonator and the operation parameters have to be adapted carefully. When the dependencies and correlations are well-understood, the change of wavelength can be done remotely and without exchanging any components. This allows not only for a versatile laser platform but for a single laser source for the measurement of different species.
The objective of the development within this proposal is therefore the proof-of-concept by addressing different resonance wavelengths of suitable metals in the UV (370 - 400 nm) with a single laser platform in the lab. The relevant tracer metals and their resonance wavelengths are identified with support of an ongoing activity by John Plane and are planned to be verified within near-future research by proof-of-concept measurements in the atmosphere with a resonance lidar based on a dye laser.

Start TRL 3

Target TRL 4

Expected Outcome

1. Identify suitable metals originating from space debris within tunable spectrum of Alexandrite laser
2. Demonstrate the fulfillment of the energetic, spatial and temporal requirements on the laser transmitter for a future lidar and deepen the understanding of dependencies and derived process for switching wavelengths
3. Address multiple specific wavelengths and proof spectral suitability of the laser in the lab
4. Develop a roadmap to achieve long-term monitoring of the pollution of the mesosphere by residue of space debris
5. Deepen the understanding and maturing of the whole laser and lidar platform for other applications

These results provide a clear route for the long-term monitoring of the impending pollution of the mesosphere caused by space debris. Based on the heritage of a mature technology of resonance lidars based on diode-pumped solid-state lasers with Alexandrite, the long development towards high TRL for autonomous operation is significantly shortened. The addressing of different wavelengths with a single laser and lidar allows for monitoring different tracers with a single instrument. Further applications that are relevant for the space sector, e.g. real-time wind measurements throughout the whole atmosphere before and during a rocket launch, would also benefit from the overall maturing of the technology.

Expected next steps Follow-up ESA activity

	Other publicly funded follow-up activity Scientific publication of results
Key Performance Indicators	1. **Identification of Suitable Metals**: • **KPI**: Successfully identify at least 3 suitable metals for detection within the tunable spectrum of the Alexandrite laser (370-400 nm and 740-800 nm) through literature review and analysis. • **Rationale**: This ensures that the project has a clear target for the subsequent experimental work and aligns with atmospheric chemistry considerations. • **Laser Specification Derivation**: • **KPI**: Develop a comprehensive list of laser specifications (including resonance wavelengths, backscatter coefficients, and atmospheric transmission) required for lab experiments, completed within the timeline of WP1. • **Rationale**: Establishing clear specifications is crucial for guiding the experimental setup and ensuring that the laser can meet the necessary requirements for resonance lidar applications. • **Proof-of-Concept Demonstration**: • **KPI**: Achieve a successful proof-of-concept demonstration of all non-spectral laser specifications (e.g., pulse energy, repetition rate) required for atmospheric resonance lidar measurements within the timeline of WP2. • **Rationale**: This serves as a critical milestone to validate the laser's potential for remote sensing applications. • **Resonance Wavelength Addressing**: • **KPI**: Successfully address at least 2 specific resonance wavelengths through injection-seeding and demonstrate the capability of the Alexandrite laser to achieve a narrow linewidth (<10 MHz) in the lab by the end of WP3. • **Rationale**: Demonstrating the ability to target specific resonance wavelengths is essential for the future application of the lidar system in detecting metals from space debris. • **Roadmap Development**: • **KPI**: Produce a detailed roadmap outlining the necessary next steps for future atmospheric measurements and long-term monitoring of reentered space debris, completed by the end of WP4. • **Rationale**: A well-defined roadmap will guide future research efforts and facilitate the transition from laboratory experiments to field applications.
Workpackage Description	**WP1: Identify suitable tracers for reentered space debris** [2 months] WP1.1: Identify suitable metals to be measured within the tunable spectrum of the laser (370-400 nm and 740-800 nm) by reviewing literature about earlier remote sensing and analysing materials used for spaceborne objects and with plausible atmospheric chemistry for the occurrence of free metal atoms [IAP; 1 months] WP1.2: Check specific resonance wavelengths of the identified metals from WP1.1 as well as backscatter coefficient, atmospheric transmission and solar background [IAP; 0.5 months] WP1.3: Derive suitable laser specifications for lab experiments based on data from WP1.2 [IAP and ILT; 0.5 months] Output from WP1: List of requirements for laser experiments (MS1) **WP2: Demonstrate all non-spectral laser specifications at fixed wavelength in UV** [2 months] Input to WP2: List of requirements for laser experiments (WP1) WP2.1: Adapt UV laser setup in the lab to requirements from WP1 [ILT; 0.5 months]

WP2.2: Check dependencies and connections between laser parameters and identify suitable working point for stable UV operation
[ILT; 1 months]
WP2.3: Demonstrate all specifications (with reduced power) required for atmospheric resonance lidar measurements with a diode-pumped Alexandrite laser at a fixed wavelength in the UV region as proof-of-concept
[ILT and IAP; 0.5 months]
Output from WP2: Proof-of-concept report including measured UV pulse energy (target ≥1.5 mJ, threshold =1 mJ), 1-hour stability test, intra-cavity SHG behaviour and operating parameters (angle/temp), and an updated risk & procurement log. Base for decision for further continuation of experiments with wavelength tuning and addressing resonance wavelengths (MS2).

WP3: Address different resonance wavelengths [4 month]
Input to WP3: Design of and first experience with diode-pumped Alexandrite laser in the UV for a resonance lidar. The IR seeded linewidth control is verified and the measurements equipment (wavemeter and suitable FPI) is available.
WP3.1: Investigation of the possible tuning range and extrapolated laser performance in the IR and UV
[ILT; 2.5 months]
WP3.2: Specifically address dedicated resonance wavelengths by injection-seeding of adapted seedlaser for suitable narrow laser linewidth
[ILT; 1.5 months]
Output of WP3: Proof-of-concept for addressing different respective resonance wavelengths (absolute and linewidth) in lab with the diode-pumped Alexandrite laser and experience with currently possible performance

WP4: Roadmap towards future long-term monitoring of reentered space debris [1 month]
Input to WP4: Data from the lidar analysis from WP1 and the experiments
WP4.1: Analyse experimental results from Alexandrite laser and requirements from more detailed lidar analysis for most promising tracers
[IAP and ILT; 0.5 months]
WP4.2: Asses necessary next steps for a future demonstration of measurements in the atmosphere with this technology and potential long-term monitoring
[ILT and IAP; 0.5 months]
Output of WP4: Roadmap towards a resonance lidar system able to monitor space debris residue in the atmosphere

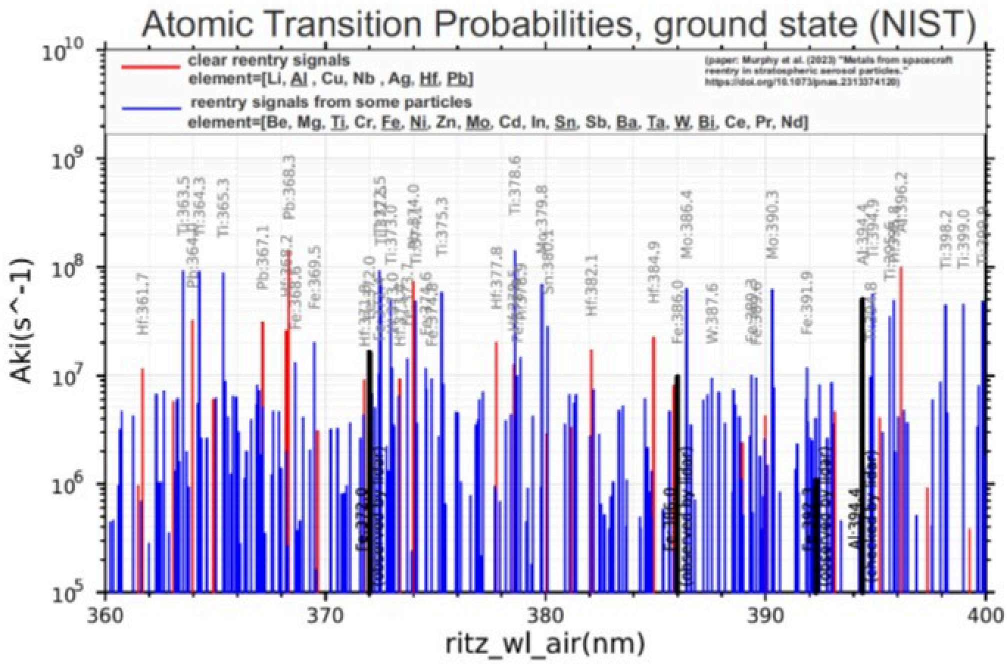
Problem areas & Risks

Covering the spectral region below 400 nm that is interesting due to the many resonance lines of potential tracer materials of space debris requires for a frequency conversion of the Alexandrite laser in the UV region. As the conversion efficiency is proportional to the intensity and the pulse energy in the infrared is relatively low and the pulse lengths long, conventional conversion schemes behind the laser resonator are not suitable. By using **intra-cavity frequency conversion**, the required conversion efficiency is equal to the outcoupling degree of the infrared laser to guarantee the same operation point. For Alexandrite lasers with low gain, the desired conversion is as low as 3 % and achievable without tight focusing. The intra-cavity enhancement allows for even lower intensities or larger beam diameters reducing the danger of laser induced damage or high susceptibilities to misalignment.
The tuning range in the UV is determined by the **tuning range** of the fundamental laser in the IR and the spectral acceptance of the frequency conversion process. With the diode-pumped Alexandrite lasers developed at ILT, tuning ranges over >50 nm were demonstrated without a change of optics. The conversion process is designed to be widely tolerant for different wavelengths by angle adjustments or temperature changes.
The **narrow linewidth operation** of the laser at an absolute wavelength that is necessary for resonance lidars is achieved by injection-seeding of the Alexandrite laser resonator with a cw-seed diode laser with narrow linewidth and the designated absolute wavelength. A cavity-control method for setting and stabilizing the linewidth

and wavelength of the pulsed laser was proven for the Alexandrite laser operating in the IR. The method is modified to allow for a seeding and stabilizing in the IR while emitting in the UV. This reduces the complexity significantly and the experience and development of the method for the IR can be used for a focused adaption for the UV operation.
The high requirements on spectral control will rise issues with environmental disturbance like air-flow in the lab experiments that limit wavelength stabilization. The reduced spectral performance does not limit the validity of the principle dependences and relations of laser parameters, processes and performance. For the experiments to address the resonance lines, a **housing to minimize fluctuations** is necessary.
The **measurement of the envisaged narrow linewidth** requires suitable equipment and synchronized spectral control. The partners provide wavemeters for the absolute resonance wavelength and customized Fabry-Perot-Interferometers with matched bandwidth and synchronized stabilization with an proprietary control software for the linewidth.

Preliminary analysis

Regular long-term remote monitoring of different metal layers in altitudes of 80-120 km with resonance lidars are performed for over 30 years by the partner Leibniz IAP [3-6]. For those measurements flashlamp-pumped Alexandrite lasers and dye lasers are used to address the resonance wavelengths of the respective metals. These lasers provide higher pulse energies (10s of mJ) but lower repetition rates (10s of Hz) that result in average powers of up to 3 W.
The lidar technology from IAP bases on a combination of lasers and filters with matched extremely narrow bandwidths that blocks the solar background almost completely. The operation within Fraunhofer lines that are a consequence of the resonance wavelength reduces the solar background even further. Therefore, the average power is the relevant parameter that determines the signal strength because the ratio to noise is independent from the background. The diode-pumped Alexandrite lasers yield comparable average powers but with lower pulse energies (mJ) and higher repetition rates (100s of Hz). With the detection and monitoring of the Potassium layer at night- and even daytime with a resonance lidar with a diode-pumped Alexandrite laser [7, 10] it was demonstrated that the results are comparable.
1. Therefore, the principle feasibility of resonance lidars based on diode-pumped Alexandrite lasers for monitoring metal layers in high altitude is expectable.
By analysing the atomic transition probabilities of different metals with clear and occasionally reentry signals identified in stratospheric particles [2] a first estimation of expectable signal strengths can be gained. Noticing the probability for iron (Fe @ 386.0 nm) that has been measured over decades with resonance lidars [4, 5] and comparing it to that of other potentially relevant tracers indicate a high probability of sufficient backscattered signal.
2. The evidence of materials from reentered space debris in stratospheric particles and a first analysis of resonance wavelengths and backscatter probabilities within the expected tuning range of a frequency-converted Alexandrite laser result in a high probability that metals are identified that can be detected with a lidar system based on a diode-pumped Alexandrite laser and originate from reentered space debris.



The parameters that are demonstrated in first experiments in the lab with a frequency-converted Alexandrite laser [9] are, except of the linewidth, comparable to those of the flashlamp-pumped laser that was used to monitor the iron layer [4]. The laser setup is currently in a different configuration for other experiments with higher repetition rates. It is expected that a working point with 750 Hz and up to 2.5 mJ and therefore 1.9 W average power can be achieved, but the reset to the original design as baseline is also possible.

For long-term monitoring of relevant metal layers a stationary lidar with a large aperture mirror is probably preferable. The current development to very compact and mobile systems limits the available average power of the laser and the mirror size. These limitations are, in contrast to the ability for autonomous operation, not relevant in a stationary installation with a focus on higher spatial and temporal resolution with higher average power and mirror sizes. A plausible outcome of the roadmap for future developments include therefore a power scaling of the diode-pumped Alexandrite laser. During the development of the current technology there were already two power scaling included, based on the available diode-pump power. For a stationary system a further scaling is advantageous and Fraunhofer ILT has already assessed designs for a moderate energy scaling solely of the laser oscillator or higher energy scaling based on a Master Oscillator Power Amplifier (MOPA) setup.

3. Based on the preliminary results with the frequency-converted Alexandrite laser and the parameters from proven resonance measurements of iron layers, it is expected that the laser can fulfill the requirements for remotely measuring metals in the UV.

The envisaged tuning range of the several 10 nm were demonstrated with a emission in the IR and first calculations show that the acceptance of the conversion process is sufficient to cover the tuning range by adapting the angle and/or temperature of the nonlinear crystal. For a continuous tuning of the wavelength without spectral jumps or cross-effects on the overall alignment of the resonator, a novel approach with a simple 1-dimentional alignment of a combination of customized resonator components is envisaged. In combination with a process for safely "tuning in" the UV conversion without loosing the necessary outcoupling channel, tuning of the wavelength in the UV is likely achievable over the designated range.

4. The already demonstrated tuning range in the IR and preliminary calculations on the conversion process indicate a sufficient tuning range in the UV.

Reaching the narrow linewidth operation at a designated resonance wavelength is achieved by injection-seeding with a suitable seedlaser. For the frequency-converted laser the injection scheme of the IR laser does not work anymore because of the

necessary change of a key component. A novel injection concept that is feasible for the UV laser ensures a sufficient seeding and consequent narrow linewidth operation. The concept was tested with a laser operating in the IR and offers additional advantages also for a lidar system operating in the IR. An adaption and application for the frequency-converted laser with a direct narrow linewidth emission in the UV is expected.
5. A novel method for injection-seeding to guarantee narrow linewidth and absolute wavelength stabilization is demonstrated in the IR and a direct transfer to the UV is likely possible.

Risk analysis

Risk	Likelihood	Impact	Mitigation (short)	Owner
Insufficient intra-cavity SHG conversion at operational pulse length/intensity	Medium	High	Perform early intra-cavity SHG tests at reduced power; optimize cavity outcoupling; iterate angle/temp and beam diameter; if needed, sketch plan for MOPA follow-on.	ILT
UV output drops or is unstable when switching from free-running to seeded narrow-line operation or linewidth transfer to UV fails or broadens beyond resonance tolerance	Medium	High	Verify energy within tuning range and characterize dependency in free-running operation; test seeding with reduced energy. Modify cavity-control method	ILT+ IAP
Environmental disturbances (air flow, temperature) degrading spectral stability	High	Medium	Build environmental housing for resonator; perform short reference tests without airflow in the lab.	ILT
Laser-induced damage or sensitivity to misalignment in intra-cavity SHG configuration	Low–Medium	High	Adapt to larger beam diameters with modified intra-cavity design; use safety-outcoupling channel in the IR; have spare optics and alignment procedures.	ILT
Lack/late availability of equipment or components	Low	Medium	Confirm partner inventory; order missing items at project start;.	IAP+ ILT

Market Assessment

The monitoring of the impact of reentered space debris on the upper atmosphere is essential for sustainable space operation and an institutional interest for the society. The quantification of the impact and measures for mitigation is the key factor for ensuring a fair participation of the cause of those pollutions.
The technology presented here is uniquely developed by the two partners and due to its relative high TRL well suited for a near-term commercialization. The capabilities of such lidars goes way beyond the monitoring of metal concentration in the upper atmosphere but also includes the measurement of temperature and 3D-wind-fields from the troposphere up to the mesosphere and lower thermosphere with unrivalled resolution. This potential is highly relevant for weather forecast services, climate monitoring and in support during commercial rocket launches at space ports.
The technology is also part of two ongoing R&D projects for the lower atmosphere with two consortia consisting of important stakeholders. Also there were first assessments for the compatibility with the platform for spaceborne lasers and optics developed by ILT and the potential for a spaceborne wind lidar mission based on this technology [10].
Furthermore, the technology platform of a daylight-capable lidar system with customized laser and matched filter technology that ensure solar-blindness is also very interesting for the 24h-detection of space debris still in orbit.
The development within this project further matures and opens up additional opportunities for this technology platform. Based on these results of this project, further activities are planned for the other applications.

Letter of Interest from User

	Name	Creation Time	Size	Created By
	LOI TOPTICA Projects 2025...	Aug 26 at 03:47 PM	413.82 kB	Michael Strotkamp
	LOI ESA Zero Debris.pdf	Aug 26 at 04:07 PM	427.78 kB	Michael Strotkamp

Idea Evaluator Feedback

- Evaluator's Feedback 1: The idea is interesting and relevant. The innovation potential needs to be clearly highlighted, it is understood that the activity is not about the laser development (which is already at TLR3), but on testing the laser for new application areas, in this sense tit is unclear whether the Study scheme or the ETD scheme is the most appropriate. The title should be simplified and clearly show what is innovative in the proposed activity.

- Response Feedback 1: We clarified that we are planning an ETD with proof-of-concept by substantial hardware experiments and expansion of the current capabilities.
  The title is now simplified and innovation clearly named: Improving a mature Alexandrite laser in the UV region and demonstrating the suitability of monitoring reentered space debris with in situ resonance lidar measurements

- Evaluator's Feedback 2: The impact on the atmosphere of products of the demise of re-entering launcher stages and spacecraft has been recently identified as a potential concern. There are scientific studies addressing the issue. The availability of data of products resulting of the demise of the vehicles is essential, The proposed development of a promising laser technology would be a novel way of acquiring data. The outline proposal is interesting. The proposing team is very strong.
- Response Feedback 2: Thank you, we fully agree ;)

Team (relevant expertise)

1. **Name:** Dr. Michael Strotkamp, Senior Scientist
2. **Company:** Fraunhofer ILT
3. **Time dedicated:** 2.5 months
4. **Experience:**
   - Working in laser development for 19 years with a focus on tunable lasers for ground-based, airborne and spaceborne lidars
   - Driving the development of diode-pumped Alexandrite lasers for lidar applications since 2012
   - Managed several R&D and technology transfer projects and coordinating EU-funded project to develop atmospheric lidar systems

1. **Name:** Dr. Alexander Munk, Expert Scientist
2. **Company:** Fraunhofer ILT
3. **Time dedicated:** 4 months
4. **Experience:**
   - Working in laser development for 13 years with focus on diode-pumped Alexandrite lasers
   - PhD on development of diode-pumped Alexandrite lasers for lidar applications
   - Built so far seven prototypes in five generations of Alexandrite lasers for resonance lidars since 2015

1. **Name:** Dr. Josef Höffner, Senior Scientist
2. **Company:** Leibniz IAP
3. **Time dedicated:** 3 months
4. **Experience:**
   - Developing, building and operating Doppler lidars (Mie, Rayleigh and resonance) based on Alexandrite lasers for over 30 years
   - Invention and maturation of method for wavelength control and stabilization
   - Experience of remotely monitoring and investigating the metal layers upper atmosphere

Consortium Composition Rational

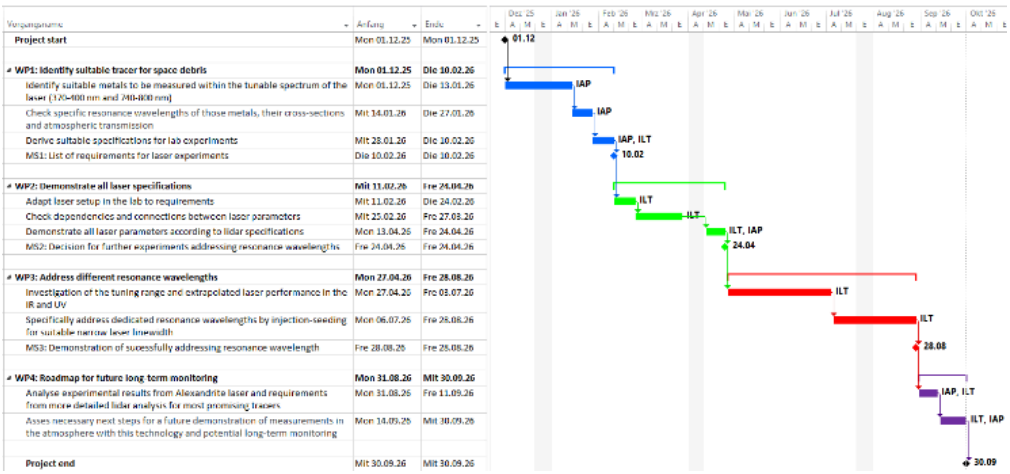
- **ILT:** The Fraunhofer Institute for Laser Technology (ILT) is one of the leading institutes for the development of tailored laser sources for ground-based, air- and spaceborne applications. The experience covers solid-state, diode and fiber lasers and successive NLO wavelength-conversion. The development of beam sources for atmospheric lidars (for

DIAL, Doppler and resonance) became a rising field within the last 15 years.

- **IAP:** The Leibniz Institute of Atmospheric Physics (IAP) is one of the leading institutes for research in the Mesosphere and lower Thermosphere. Over more than 30 years experts from IAP develop, build, and operate ground-based resonance lidars in compact, mobile and stationary systems. Besides the measurements of atmospheric parameters like wind and temperature, one focus is the monitoring of metals, e.g. K [3], Fe [4] and Ca, in MLT region by resonance lidars over long periods or during special events like during meteoric reentries [5].
- In the last 13 years a **inter-institutional group from Fraunhofer ILT and Leibniz IAP** (see team description above) joint their expertise for the development and building of novel, compact resonance lidars [6] enabled by diode-pumped Alexandrite lasers [7] to replace flashlamp-pumped systems. The prototypes of these lidar systems are 50x more compact and 100x more efficient compared to the old systems [8] and measure with up to five fields of view the potassium layer in 80 to 120 km altitude. Due to the strongly reduced effort for building such systems and the ability for autonomous operation, the building of a lidar network is currently investigated. Furthermore the versatility of the technology is explored by extending the operation wavelength to the resonance of iron in the UV [9]. The achievable efficiency, compactness and the optical concept with low necessary fluences make even a spaceborne application of the technology feasible [10].

Proposed Schedule

- The **start of project** could be as soon as possible due to availability of hardware and resources of personell at both partners (**December 25**).
- Within the project plan, **holidays** around Christmas, Eastern and summer (two week each) are **taken into account**.
- The **availability** for all team members and equipment is **checked** as far as possible.
- An **important meeting** is scheduled for the end of WP2 (End of April 26, mid-term) where the results of the experiments and the plans for addressing resonance wavelengths of dedicated tracers are revised and the **decision for further experiments** is taken.
- The **milestones**are intended at the end of each WP (including mid-term report with decision of continuation) and at project's end (Roadmap based on all results)



Reporting I/We confirm the list of mandatory reports

Budget 175,000 €

Company Contribution 0 €

Company Contribution Description	ILT: Providing full hardware for Alexandrite laser demonstrator in the lab including replacements during the project duration (~250 k€) IAP: Providing hardware for high-resolution spectral control and characterization of Alexandrite laser (~150 k€) and potentially access to a resonance lidar based on dye laser
Expected impacted sector	Institutional space activities (ESA, other European or national)
Your Activity in 2 Phrases	As space activities increase, we need to safely remove old satellites from orbit to prevent overcrowding, but this process may pollute the atmosphere with metals. The idea is to develop advanced laser technology that can autonomously measure these metals in the atmosphere, helping us understand the environmental impact of space debris.
Expected next steps	Follow-up ESA activity Other publicly funded follow-up activity Scientific publication of results Follow up research project (e.g. Grant application)
Tags	laser lidar remote sensing environmental space debris atmosphere aerosols resonance-lidar Sustainable Space lidar network

Details

ID	I-2025-06920
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Strategic Innovation Area	Discovery
Lead Author - new	Michael Strotkamp