

REQUIRED TECHNICAL SPECIFICATIONS

In French = CAHIER DES CLAUSES TECHNIQUES PARTICULIERES (CCTP)

Consultation n°202609

This project is a procurement operation led by the PhLAM laboratory and aligns with the objectives of the PEPR Origins project (as well as the CPER Wavetech@HdF project). Funding for this portion is provided by the PEPR Origins μ L2-HRMS project. The main objective of these projects is to characterize natural and/or anthropogenic samples using mass spectrometry for applications in paleontology, cosmochemistry, and environmental science.

Definitions and useful references:

- HESI heated electrospray ionization
- APPI atmospheric pressure photoionization
- APCI atmospheric chemical ionization
- CID collision-induced dissociation
- HCD higher-energy collisional dissociation
- UVPD ultraviolet photon dissociation

OBJETIVE OF THE PROCUREMENT OPERATION

The objective of this call for tenders is to acquire a laser desorption-ionization source with a laser post-ionization system and microscopic visualization of samples. A system for transferring the ions generated by this source to the ultra-high-resolution mass spectrometer available at PhLAM must be provided. The mass spectrometer in question is a Thermo Scientific™ Orbitrap Eclipse IC Ready model (described below). Control systems that allow the operation of the laser desorption-ionization source, of the laser post-ionization, of the transfer and injection of ions from this source into the mass spectrometer, must be provided. These systems must allow laser-desorption-ionization mass spectrometry with laser post-ionization to be carried on single spots and in mass spectrometric imaging mode, as described below. The “solution” refers to the sum of the systems that are to be proposed to achieve these objectives.

TECHNICAL SPECIFICATIONS

General considerations

In the following, Z represents the optical axis that is perpendicular to the sample surface. X and Y represent the horizontal and vertical axes parallel to the sample surface, and orthogonal to Z.

The coupling of the following instrumentation should be performed to a Thermo Scientific™ Orbitrap Eclipse IC Ready mass spectrometer (in PhLAM) that has 1 million mass resolution, ultra-violet laser photodissociation (UVPD) for multi-stage mass spectrometry (for MSⁿ), atmospheric pressure ionization sources Thermo Scientific™ Optamax NG™, and internal calibrant source Thermo Scientific™ Easy-IC™. The mass spectrometer is placed on an optical table of model OptoSigma OSDVIO-B-3015M-300t(900H), raised by 21 cm above the surface of the table. The laser desorption-ionization system provided should be able to stand on the optical table, in front of the spectrometer, on a free area 57.5 cm deep and as wide as the spectrometer (see details in figures 1 and 2 below).

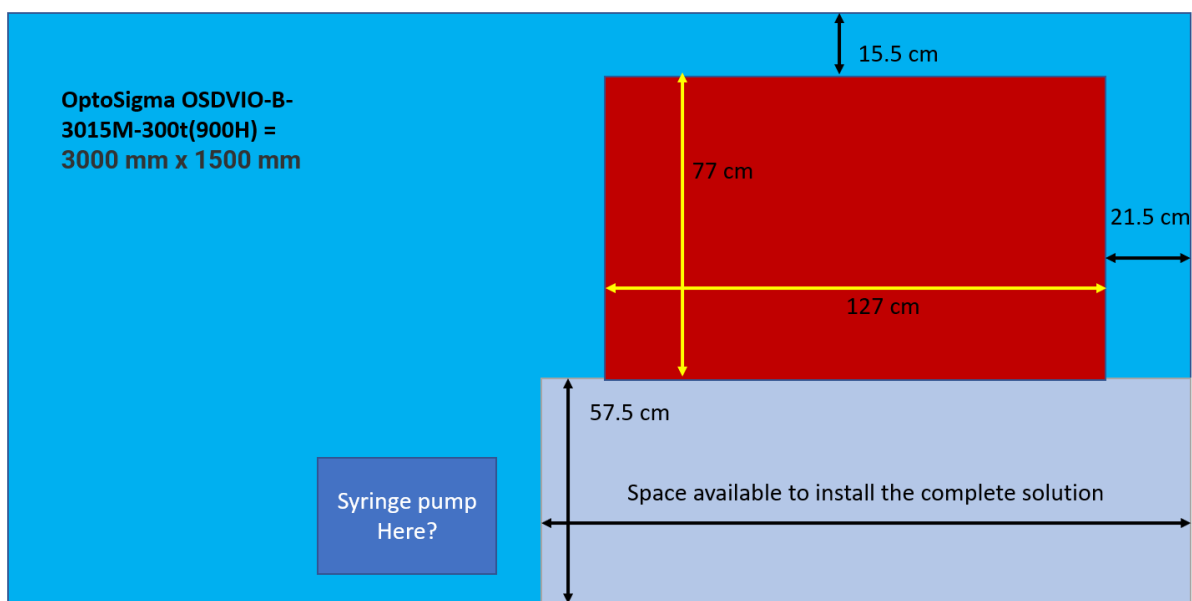


Figure. 1. Top view of the positioning of the Orbitrap™ Eclipse spectrometer (in red) on the optical table (in blue) of model OptoSigma OSDVIO-B-3015M-300t(900H). The relative scales are respected. The area available for the installation of the proposed solution is shown in grey.

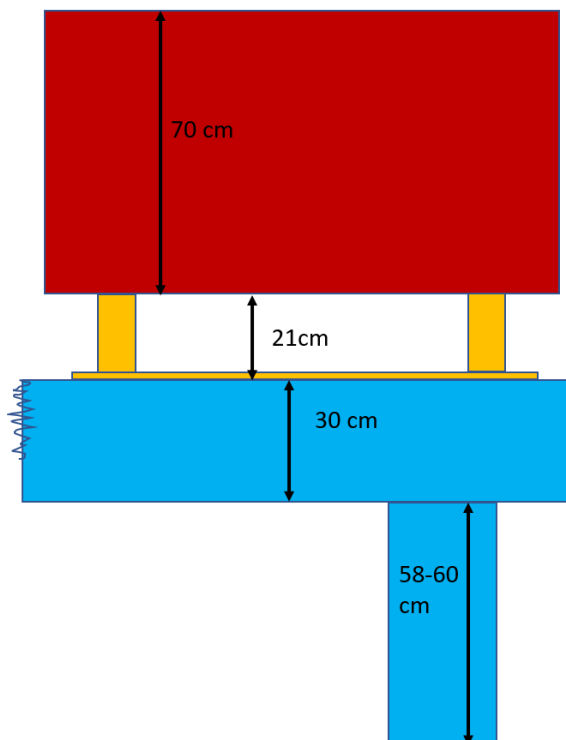


Figure. 2. Partial front view of the spectrometer on the optical table, in a raised position 21 cm above the table surface. The table surface itself, mounted on pneumatic feet, lies ~90 cm from the ground.

The proposed solution should be able to perform laser desorption-ionization with beams as small as 10 μm in “reflected” mode, and as small as 1 μm in “transmitted” mode. The proposed solution should enhance ionization efficiency using a post-ionization laser operating at 266 nm. The proposed solution should be able to transfer and inject 90 or more percent of the ions thus generated into the mass spectrometer.

Laser desorption-ionization system

“reflected” mode laser desorption capabilities

A first mode of operation of the desorption-ionization system should allow laser desorption with a laser spot in “reflected” mode (in incidence from above the sample surface) where the laser beam is oriented at a fixed angle (lying between 25 to 38°) relative to the normal to the sample surface. Manual adjustment of reflected laser spot size at the sample surface between 10 and 500 μm in diameter should be possible by use of an adjustable optical element. A correlation table between a set of positions of this optical element and the laser spot diameters at the sample surface should be provided.

In the “reflected” mode, laser desorption should be operated with laser beams focused to a spot down to 10 μm in diameter with the smallest of the laser wavelengths used. In the “reflected” mode, the ion

source and associated optics should allow desorption with two laser wavelengths: **A) 349 or 355 nm**, for this one laser should be provided that should already be integrated with the proposed ion source), and **B) 1064 nm**, for this, a laser available in PhLAM should be integrated with the ion source.

A desorption laser operating at 349 or 355 nm should be provided with the ion source, which should have the following specifications:

- $M^2 < 1.2$
- operate in TEM₀₀ spatial mode
- Laser pulse repetition rate: single shot to at least 1 kHz
- Laser pulse energy >100 µJ at 1 kHz
- Laser pulse duration between 1 and 10 nanoseconds.
- Long term (ca. 6 hours) pulse energy stability <6 % rms.
- The laser cooling system should not generate vibrations (e.g., using fans) that may affect the position of the sample and/or laser beam.
- Includes a means to control the laser pulse energy (within 1-100 % of the maximal/nominal laser output) and to measure this pulse energy, either directly as part of the laser source and/or using a combination of motorized attenuator(s) and calibrated energy sensor(s).

The desorption at 1064 nm should be carried with a laser of model Crylas-DSS1064-450 (with synchronization module) already available at PhLAM laboratory. This laser should be adapted to the laser optics and control systems of the provided ion source, and synchronized with the post-ionization and ion transfer systems of the complete solution upon installation onsite.

Imaging of the sample

In the position adequate for reflected- (described above) and transmitted-mode (described below) laser-desorption, the sample should be imaged with a 10X magnification objective operating at a working distance >30mm in transmitted light, as well as with a 50X magnification long working distance objective in transmitted light. The sample should also be imaged in reflected light using the reflected mode laser desorption light path and focusing systems. A high intensity visible light source illuminates the sample for both transmitted and reflected light imaging.

Two cameras are needed, one for the transmitted light and one for the reflected light. The camera for the transmitted light should be able to operate at low light regimes, and must thus have a low read noise of less than 2 e⁻ RMS. The latter camera may operate in monochrome in order to be able to image samples in the lowest possible light conditions. Both cameras should be able to operate at 20 frames per second or more at full resolution. Both cameras should have at least 2 million pixels.

An additional 50X (long-working distance) objective should be available to replace the 10X objective in the “transmitted” mode.

The objective holder should be mounted on a motorized stage that allows focusing. This motorized stage should have step resolution of less than 1 µm and reproducible translation of the light-transmission objectives over total travel of at least 5 mm (+/- 2.5 or more mm from the standard focus surface, see explanatory example in Figure 3 below).

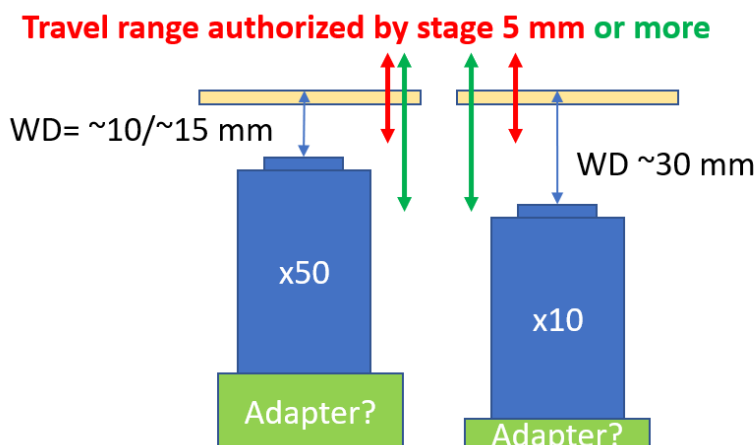


Figure. 3. Examples of positioning for the 10X and 50X (blue) objectives with respect to the surface of samples (in yellow), and as a function of the working distances (WD) of the objectives. The total travel distances of the stage are illustrated by arrows: a) in red, the minimum desired travel: 2.5 mm on each side of the

sample surface in focus with the objective lens, and b) in green, a wider travel range for the objective (if permitted by the supplied motorized stage and the objective adapter sizes), with a travel distance above the sample in focus that does not need to exceed 2.5 mm and which could be longer on the objective side (in order to defocus the desorption lasers in "transmitted" mode, in particular). Schematics are not to scale in this figure.

Laser beam delivery

The 10X objective used for sample imaging is compatible with focusing of the 1064 nm laser. The 50X objective used for sample imaging is compatible with focusing of the 349 or 355 nm desorption laser. Both are compatible with 532 nm wavelength.

All optical elements in the optical path of the lasers mentioned above are able to withstand repeated shots of unfocused, 100 μ J pulses of those lasers.

A first beam-combiner dichroic mirror should allow laser desorption at 349 or 355 nm combined with (and at the same time with) visible-light imaging of the sample. A second beam-combiner dichroic mirror should allow desorption at 1064 nm combined with (and at the same time with) visible-light imaging of the sample.

Using the 50X objective, the "transmitted" mode should thus allow desorption with a laser beam focused through the samples with ≤ 1 μ m laser spot size at 349/355 nm.

Using the 10X objective, the "transmitted" mode should allow laser desorption with a laser beam focused through the samples with 5-10 μ m laser spot size at 1064 nm.

Controlled focusing and defocusing of the lasers with motorized travel along the Z axis should be possible in "transmitted" mode.

All laser-focusing lenses for the "reflected" and "transmitted" modes of desorption should be anti-reflection coated (for the appropriate wavelength: 349/355 nm and 1064, respectively) and aspheric.

Post-ionization capabilities

A second laser should enhance the production of ions through post-ionization. This post-ionization laser should intercept the molecular plume desorbed from the sample in a direction parallel to the sample surface, at a distance of 0.25 to 5 mm above the sample surface.

A viewport should allow transmission of 266 and 213 nm lasers. The viewport window should be at least 12 mm in diameter. The viewport can be exchanged for another one allowing vacuum ultra-violet (118, 157 and 193 nm) transmission.

The system geometry should allow the delivery of a laser beam above the sample. This laser beam can be 1) focused as a 30 μm – 1 mm spot, but also 2) shaped into a lightsheet up to 2 mm in thickness and 10 mm in width oriented in a position parallel to the sample (that is, orthogonal to the desorption plume expansion direction). The center of these laser beams can be placed at a distance adjusted between 0.25 to 5 mm above the sample surface (3.5 mm for the largest, 2 mm-thick lightsheet).

The laser provided to perform the “post-ionization” should have the following characteristics:

- 266 nm wavelength
- Pulse repetition rate: single shot to at least 60 Hz
- Laser pulse energy >200 μJ at 20 Hz
- Laser pulse width between 1 and 10 ns
- Laser beam divergence <5 mrad
- long term pulse energy stability (6 hours) < 6% rms
- Laser beam diameter <2 mm at laser exit
- is associated with a means to control the laser pulse energy (within 1-100 % of the maximal/nominal laser output) and to measure this pulse energy, either directly as part of the laser source and/or using a combination of motorized attenuator(s) and calibrated energy sensor(s).

The post-ionization laser pulses should be synchronized to be emitted alternately with each desorption laser pulse, with a delay that can be adjusted by the user. Such synchronization should be provided for both the 349 nm (or 355 nm) laser provided with the ion source and the 1064 nm laser available in PhLAM.

The system should allow, in the future, to use a post-ionization laser with a “large-beam”, shaped as 8x2 mm lightsheet passing 2 to 3 mm above the sample, and to synchronize the pulses of the desorption lasers with those of this additional post-ionization laser. The latter would be operated at 1 to 200 Hz using single pulse energies ranging between 1 and 7 mJ at 266 nm and <10 μJ at 118.33 nm (generated as 355nm /3).

Sample environment

The laser desorption-ionization source and the system transferring ions to the mass spectrometer should include oil-free, dry pump(s) whenever necessary. The pump(s) should lie on the floor of the room, not on the optical table, so that vibrations associated with the pumping system should not generate vibrations of amplitude larger than 1 μm of the laser and sample positions.

It should be possible to back-fill the laser-desorption chamber with N₂, Argon, Helium, or Xenon using a leak (fine-needle) valve and associated pressure controller.

A gate/slide valve allows to isolate the mass spectrometer when opening the sample environment for sample loading without modification of the pressure in the mass spectrometer.

The laser desorption-ionization source should be cleanable by the users (who should receive adequate training), in particular to remove contamination generated by vertically-positioned samples, such as fallen particles.

Sample holder and sample positioning stage

The included sample holder should be able to carry ITO-coated glass slides 75x25 mm large, ca. 1-2 mm in thickness. Other types of samples holder, made of conductive metal (such as Cu) can also be carried in the sample holder.

The sample holder mechanical design should allow visualization and laser-desorption (post-)ionization of the sample, in transmitted and reflected light, over a zone at least 40 x 25 mm large (at the center of the 75x25 mm sample holding slide).

Two exchangeable sets of sample-positioning stages for X/Y travel in the plane parallel to the sample surface should be provided that have the following properties:

both sets of stages have:

- travel distances of 50x25 mm or more
 - No use of grease
 - backlash (reproducibility of displacement to a given position for millimetric travel) smaller than 2 µm
 - response time of the sample stage to a displacement command shorter than 50 ms
- One set of X-Y sample positioning stages that has a travel speed of at least of 2.5 mm/s and a resolution of displacement better than 100 nm is required. This set of stages should be used to operate the solution in laser desorption-ionization (in both transmitted and reflected modes) and sample visualization (also in transmitted and reflected modes).
 - A second set of X-Y sample positioning stages operating at least at 7 mm/s with a resolution of displacement better than 1.5 µm is required. This set of sample positioning stages may operate only in the reflected mode of operation for sample visualization and laser desorption-ionization.

System to transfer and inject ions from the laser desorption-(post-)ionization source into the mass spectrometer

A system should be provided to transfer the ions generated by laser desorption laser (post)ionization events in the provided ion source to the mass spectrometer (Thermo Scientific™ Orbitrap Eclipse IC Ready). This ion injection system should be compatible with the ion optics of the mass spectrometer in terms of vacuum quality, electronics, data acquisition triggering and any other feature required to operate the mass spectrometer using laser desorption-ionization and other ionization schemes (HESI, APCI, APPI).

The system should be able to operate in both negative and positive ion polarities.

Transmission efficiency of the positive and negative ions generated by laser-desorption laser (post)ionization to the first vacuum stage of the mass spectrometer should be over 90% over the m/z range 50 - 2000. Transmission of positive and negative ions with m/z between 2000 and 4000 should also be possible.

The system allows the accumulation of ions generated by laser desorption laser (post)ionization for a duration that can be as high as the maximum injection time of eight seconds allowed for a single scan spectrum acquisition in the Orbitrap™ cell of the mass spectrometer.

The system transferring ions produced by laser desorption laser (post)ionization events to the mass spectrometer should be compatible with the transfer of ions generated by HESI-, APCI- and APPI- ion sources to the mass spectrometer. The ion transfer system includes orthogonal injection of HESI-, APCI- and APPI-generated ions with an interface that can accommodate the available HESI-, APCI- and APPI-ion source (Thermo Scientific™ Optamax NG™). This interface allows for operation of the Thermo Scientific™ Optamax^{NG} ion source with all its functions.

When the provided laser desorption (post)-ionization source and the provided ion transfer system are attached to the mass spectrometer, it remains possible to run the calibration routine, as defined in the Thermo Scientific™ Tune software, for the Eclipse mass spectrometer using the HESI source (Optamax NG) with Flexmix standard, as well as the bake-out of mass spectrometer.

The geometry of the ion transfer system should favor the removal of neutral particles/molecules emitted by laser desorption events and infusion events into the HESI/APCI/APPI source.

The maximum mass resolution (1 million in $m/\Delta m$ FWHM at m/z 200 u.) and the accuracy (<1 ppm, with internal calibration) of the mass spectrometer should be preserved in mass spectra acquired on ions generated by laser desorption-ionization (with or without post-ionization), and orthogonally-injected ions that have been generated by the HESI-, APCI- and APPI- ion source.

The complete solution proposed should allow performance of the internal calibrant source of the mass spectrometer (Thermo Scientific™ Easy-IC™).

It should be possible to clean contaminants deposited onto parts of the ion transfer system during laser desorption or HESI/APCI/APCI experiments. Training should be provided to users to such cleaning operation during the initial installation and/or initial training session.

Using the provided complete solution, variations of sample topography <200 µm do not influence mass resolution, precision and ion transmission.

Removability

The systems provided here, including the laser desorption-(post-)ionization source and the system used to transfer the ions formed by this source and inject them into the Orbitrap™ mass spectrometer can be cleaned of atmosphere- and/or sample-derived contaminants. In order to perform such cleaning, these systems can be removed by the trained user. Adequate training is provided to remove the proposed systems (from the mass spectrometer) and clean the systems. Protocol to clean such contaminations, including physical and chemical treatments, is provided. The complete proposed solution can be removed in order to restore the Orbitrap™ Mass Spectrometer and the Optamax™ NG ion source to their initial configuration, and adequate training is provided. The complete proposed solution can also be re-installed on the Orbitrap™ Mass Spectrometer and coupled with the Optamax™ NG ion source by the trained user, and adequate training is provided.

Control system

Controls of the ion source (including triggering of the desorption and post-ionization lasers, sample positioning, sample visualization) and of the ion transfer system, and their coupling with the mass spectrometer should be operated on a single computer that is provided along with adapted software, and including the following features:

- The operating system is Microsoft Windows 10 LTSC or Windows 11 LTSC.
- The connectivity with the Orbitrap™ Eclipse mass spectrometer must allow for acquisition of full scan mass spectra as well as multi-stage (MS^n , generated using HCD, CID and/or UVPD dissociations) mass spectrometry data on i) ions generated by the laser desorption-(post)ionization events (on single spots and for automated acquisition of sample-raster mass spectrometric imaging datasets) and ii) ions generated by the HESI/APCI/APPI source.
- Readout and control of the parameters relevant to the transfer and injection in the mass spectrometer of the ions generated by the laser desorption-(post-)ionization events and the HESI/APCI/APPI source are required.
- Control of the synchronization of the laser desorption with the ion transfer system and mass spectrometer data acquisition is required.
- Control of the gate/slide valve protecting the vacuum quality in the mass spectrometer during sample exchange is required.
- Readout of the pressure(s) in the sample environment and in the ion transfer system (if different) should be provided.
- Readout of the desorption laser energies and readout of the post-ionization laser energy should be included.

- The computer can control the laser pulse rates for laser desorption and for laser post-ionization, as well as the number of laser shots at each pixel for single-spot analyses or for mass spectrometric imaging.
- The software provided can control the delays between the pulses of the desorption and post-ionization lasers.
- The light source used for sample visualization can be switched on/off from the control computer.
- Sample visualization on the transmitted- and reflected-light cameras and recording of images from each camera can be performed on the control computer.
- The provided measurement acquisition software can configure and control sample stage positions, speeds and accelerations.
- The measurement acquisition software includes a “bulk analysis” mode with the possibility to analyze multiple spots of the sample surface with displacement of the XY stages during the time required to inject ions in the Orbitrap™ Eclipse mass spectrometer. This mode allows for analysis of ion produced by laser desorption over multiple spots of the sample in a single scan mass spectrum and in multi-spectra datasets. For this “bulk analysis” mode, sample displacement can operate i) as line profiles along a single X or Y direction, positioned on the camera image, or ii) at random positions (without repeated targeting of a given coordinate) within a rectangle defined by the user on the camera image.
- The measurement acquisition software includes mass spectrometric imaging protocols, that comprise means of programming i) one or more series of X-Y translation steps performed by the sample stage and ii) the pixel number. In turn, this enables automated acquisition of mass spectrometry imaging datasets over user-selected areas of the sample. Different modes of displacement of the sample during acquisition of the maps include:
 - a “*line mode*” that is moving the sample from left-to-right direction (X direction), then moving to next Y coordinate, then returning to the leftmost X coordinate and starting next line of pixels by moving the sample in the same direction.
 - a “*snake/meander mode*” that is moving the sample from left-to-right direction (X direction), then moving to next Y coordinate, then starts acquisition of the next line of pixels by moving the sample in the opposite direction (relative to that used for the previous line)
 - A possibility to fractionate a X-Y sample displacement pixel into 9 sub-pixels for acquisition of mass spectrometry imaging where at each pixel are recorded a full scan and up to 8 MS² mass spectra; in this case the full scan mass spectrum and the MS² are recorded on sub-pixels that are near-adjacent within the main pixel, but not overlapping.
- Planes of reference Z coordinates can be generated from a series of user-defined Z-motor (carrying transmitted-light objectives) positions. These reference Z coordinates can be used to optimize the laser desorption focus at/near the sample surface. This is performed using automated Z-positioning along these reference Z coordinates during automated mass spectrometry imaging acquisition in transmitted laser desorption mode.

- Software is provided to process mass spectrometry imaging datasets. This software performs: export to .imzML format, generation of maps of the abundances of selected ions using user-selected m/z windows, and batch internal recalibration of all spectra in the map using a user-defined list of exact m/z values to search as internal calibrants in each spectra.

DELIVERY AND INSTALLATION

Full installation of the system should be provided, including laser alignments.

Delivery should take place 18 weeks after notification of this public market. Installation is 1 month.

An operation manual (in English) is required.

Training should be provided for 5 users (in English), covering operation of the complete solution, laser alignments, cleaning of the systems, and removal/reinstallation of the complete solution from the Orbitrap™ Eclipse.

WARRANTY AND MAINTENANCE

Two-year warranty, including labor, travel of the service engineer, and replacement parts are required.

It is mandatory for the candidate to propose the first of the following two options for preventive and curative maintenance plans. These maintenance plans should include labor, travel and replacement parts (with the exception of lasers).

- First option (mandatory) should be for such a maintenance plan of 2 years starting at the end of the initial 2-year warranty,
- And another option for such a maintenance plan of 3 years starting at the end of the initial 2-year warranty.