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PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022
Prot. 2022CCWJYL

PART A

1. Research project title

Near-Infra-Red Astrocomb for Earth-like exoplanet detections "NIR-Astrocomb"

2. Duration (months)

24 months

3. Main ERC field

PE - Physical Sciences and Engineering

4. Possible other ERC field

5. ERC subfields

1. PE9_13 Astronomical instrumentation and data, e.g. telescopes, detectors, techniques, archives, analyses
2. PE2_14 Lasers, ultra-short lasers and laser physics
3. PE9_3 Exoplanetary science, formation and characterization of extrasolar planets

6. Keywords

n°

Testo inglese

1. Near-infrared astrocomb

2. Astronomical and astrophysical instrumentation
3. Laser physics and technology
4. Infrared radial velocity spectroscopy
5. Absolute spectrograph calibration
6. Exoplanet research and characterization

7. Principal Investigator

LAPORTA (Surname)	PAOLO (Name)
Professore Ordinario (Qualification)	
18/11/1954 (Date of birth)	LPRPLA54S18G482T (Personal identification code)
Politecnico di MILANO (Organization)	
02 2399 6096 (Phone number)	paolo.laporta@polimi.it (E-mail address)

PI - Certified E_mail (CEM)

plaporta54@pec.it

Age limits derogation

The PI and/or the substitute PI are over 40 and they don't intend to benefit from derogations to the age limits for the amount allocated to under 40 PI;

8. List of the Research Units

n°	Associated Investigator	Qualification	University/ Research Institution	Registered office (address)	Operating office (address)	e-mail address
1.	LAPORTA Paolo	Professore Ordinario	Politecnico di MILANO	Piazza Leonardo da Vinci, 32 - MILANO (MI)	City: Milano (MI) Address Piazza Leonardo da Vinci 32	paolo.laporta@polimi.it
2.	LEONE	Professore	Università	P.zza	City: Catania	fleone@oact.inaf.it

	Francesco	Associato confermato	degli Studi di CATANIA	dell'Università, 2 - CATANIA (CT)	(CT) Address Piazza dell'Università 2	
3.	COSENTINO Rosario	Ricercatore astronomo confermato	Istituto Nazionale di Astrofisica	Viale del Parco Mellini, 84 - Roma (RM)	City: Brena Baja Santa Cruz de Tenerife, Spain Address Rambla José Ana Fernández Pérez, 7	rosario.cosentino@inaf.it

9 - Substitute Principal Investigator (To be identified among one of the associated investigators participating in the project).

LEONE (Surname)	FRANCESCO (Name)
Professore Associato confermato (Qualification)	
02/03/1961 (Date of birth)	LNEFNC61C02H163V (Personal identification code)
Università degli Studi di CATANIA (Organization)	
0957332229 (Phone number)	fleone@oact.inaf.it (E-mail address)

Substitute PI - Certified E_mail (CEM)

francesco.leone.1961@pec.it

10. Brief description of the proposal

A fundamental question of the human race, whether life exists on other planets, has brought huge interest in searching for Earth-like extrasolar planets (exoplanets), especially in the “habitable zone” where the orbital distance allows the presence of liquid water on the planet’s surface. The most refined technique for discovering and characterizing planets beyond our solar system relies upon Doppler spectroscopy, i.e. high-resolution spectroscopic measurements of the radial velocity (RV) of host stars induced by the orbiting bodies. To this aim, a recent fundamental advance has been the introduction of optical frequency combs (OFCs) as wavelength calibrators in the visible range of astronomical spectrometers. Frequency combs produce a series of equally-spaced reference frequencies offering extreme accuracy and spectral grasp. While the RV technique has been used extensively, the highest precision measurements have been restricted to the visible region of the spectrum, mainly due to the more mature technology available. Thus a substantial fraction of the stars in our galaxy, long-lived M-dwarfs, which primarily emit in the near-infrared (NIR), has largely been outside the efficient spectral grasp of the current generation of RV instruments. Moreover, stellar convection and magnetic activity can mask the small RV signature of terrestrial planets, but many of these noise sources are suppressed or mitigated in the NIR compared to visible.

Here we propose a joint project exploiting the long lasting experience and the complementary expertise of three research units located, respectively, at the Physics Department of Politecnico di Milano (PoliMI), at the Department of Physics and Astronomy of University of Catania (UniCT) and at the INAF-Catania Astrophysical Observatory which is tightly linked to the Fundación Galileo

Galilei (INAF-FGG) hosting the Telescopio Nazionale Galileo (TNG) in the Canary Islands. The ambitious goal of the project is a disruptive technology for the realization of a laser comb source with an exceptionally wide spectral coverage in the NIR from 1.1 to 2.4 μm and a fractional frequency accuracy of 10^{-12} on a scale of years (NIR-Astrocomb), to be used as a high-accuracy wavelength calibrator of high-resolution astronomical spectrographs in the NIR for exoplanets characterization. The new concept of laser comb is based on a 10-GHz-repetition rate mode-locked Er-Yb solid-state laser, frequency stabilized against an atomic clock, amplified in an Er-fibre amplifier and spectrally broadened in a suitable non-linear device. Calibration of the TNG high-resolution astronomical spectrograph GIANO-B by means of the NIR-Astrocomb will be improved by more than one order of magnitude, providing a unique instrument with a potential RV precision of 1-2 m/s. This new frequency comb platform in the NIR will be tested on-sky by observing stars hosting exoplanets with a known radial velocity amplitude.

11. Total cost of the research project identified by items

Associated Investigator	item A.1	item A.2.1	item B	item C	item D	item E	sub-total	Total
LAPORTA Paolo	68.814	25.000	56.288	15.000	0	33.000	198.102	198.102
LEONE Francesco	22.719	25.000	28.631	0	0	7.000	83.350	83.350
COSENTINO Rosario	61.016	0	36.610	0	0	23.000	120.626	120.626
Total	152.549	50.000	121.529	15.000	0	63.000	402.078	402.078

N.B. The Item B and TOTAL columns will be filled in automatically

- item A.1: enhancement of months/person of permanent employees
- item A.2.1: cost of contracts of non-employees, specifically to recruit
- item B: overhead (flat rate equal to 60% of the total personnel cost, A.1+A.2.1, for each research unit)
- item C: cost of equipment, tools and software products
- item D: cost of consulting and similar services
- item E: other operating costs

PART B

B.1

1. State of the art

The photonics community has driven the majority of astrocomb development, and a number of competing approaches have been advanced in parallel, separated by different choices of laser technology and operating wavelength regions. The first implementation of an astrocomb was based on spectral filtering of hundreds-MHz visible frequency combs by using Fabry-Perot cavities to thin out the required comb tooth spacing [1,2]. This approach is intrinsically narrowband, restricting the range over which a spectrograph can be calibrated. Alternative and more interesting broadband approaches are based on the generation of frequency combs with large comb-line spacing (>10 GHz), such as electro-optic (EO) combs [3], Kerr combs or micro-combs [4,5], and high-repetition rate mode-locked solid-state lasers [6, 7]. Parametric comb generation using EO modulators or micro-resonators offers a way to easily produce combs with 10-100 GHz line spacing. However, the formation of stable high-power femtosecond pulses and the supercontinuum broadening are less straightforward than with mode-locked lasers. EO combs, for example, show severe linewidth broadening in the wings of very broadband spectra due to the phase noise inherent to the microwave modulation source, introducing another source of unwanted line shifts and systematic errors. Micro-resonator combs require locking of a high-coherence parametric pump laser (single-spatial mode and single-optical frequency) to a high-Q resonator. On the other hand, in mode-locked lasers - both Kerr-lens and semiconductor saturable absorber mirror mode-locked lasers - the pulse train in the time domain and the spectral comb structure are intrinsically linked via Fourier transformation, and the intense output pulses are well suited to subsequent nonlinear frequency conversion, allowing for ultra-broadband supercontinuum generation from visible to mid-infrared spectral region [8]. Nevertheless, the best results so far obtained show a line spacing below 10 GHz and one octave bandwidth mainly in the visible, with the redward wavelength edge hardly exceeding $\sim 1.1 \mu\text{m}$.

b) RV detection of exoplanets in the habitable zone

The current set of 4940 confirmed exoplanets and 8709 candidates is expected to keep rapidly growing with the next future space missions, such as PLATO. A wide wavelength spectroscopic follow up is indeed required to discriminate false positives and to evaluate the candidate mass. The RV approach requires a wide wavelength range facility available, from visible (VIS) to near infrared (NIR). The most advanced VIS spectrograph equipped with an astrocomb is ESPRESSO, fed with 4x8.2m-telescopes and covering the 378-789 nm range with a resolving power $R=190000$, which measures RVs with an accuracy of 0.5 m/s over several months [9]. Yet,

this accuracy is not enough to detect an Earth-like planet in the habitable zone around a solar-type star, in which case RV measurements at 9 cm/s over a time scale of years are required. Being the current generation of instrumentation well below the sufficient precision to detect terrestrial planets in the habitable zone around Sun-like stars, the astronomical community is increasingly focusing on detecting exoplanets in this zone around low-mass stars. These are less luminous and the habitable zone is closer to the star, so that gravitational effects of the planet on the star are greater; their orbital periods are shorter than one year and red dwarfs make up the bulk of the Milky Way's population, about 73%. Detection of terrestrial planets in the habitable zone of low-mass stars, achievable with a RV accuracy of the order of 1 m/s [10], still presents significant challenges. Low-mass stars have surface temperatures from 3800 to 600 K, are faint in the VIS with their spectral-distribution peaks from 0.7 to 4.8 μm . Among the many high-resolution spectrographs operating in the NIR, only the "Habitable-Zone Planet Finder" (HPF) [11] at the McDonald Observatory, with $R=53000$, is presently equipped with an astrocomb in the 0.8-1.7 μm range, featuring a RV accuracy of 2.8 m/s. Just a few new astrocomb-calibrated NIR spectrographs are expected in the close future, like NIRSP@ESO and SPIRou@CFHT. False positives can be due to magnetic activity [12], and hence the stellar Magnetic Field (MF) has to be monitored as well during the exoplanet search. Direct measurements of stellar MF in late-type stars from high-resolution spectroscopy of visible spectral lines are rather difficult [13]. In the NIR, owing to λ^2 dependence of Zeeman line broadening, the measurements of MFs are much less critical [14]. After Johns-Krull [15] the most accurate information on stellar MF of cool stars is provided by the very magnetic sensitive metal lines at 2.2 μm , currently well beyond the longer wavelength limit of HPF.

2. Detailed description of the project: methodologies, objectives and results that the project aims to achieve and its interest for the advancement of knowledge, as well as methods of dissemination of the results achieved

Objectives and motivations

High resolution spectroscopy underpins most fields of astrophysics and has enabled major progress in multiple areas, such as the initial discovery of a planet orbiting a solar-type star [16] which led to the characterization of an exoplanet atmosphere [17], the study of metal-poor stars [18], as well as the chemical evolution of the Galactic bulge [19]. A wide range of scientific challenges encountered by modern astronomy is driving the construction of huge, up to 40 m, telescopes and a large number of satellite missions. The next generation of spectrographs is required with very broad spectral range and extremely accurate and stable wavelength reference, to address some of the most fundamental concepts in physics and cosmology, including the search for habitable exoplanets.

Optical frequency combs [20] provide the precision needed by future high-resolution spectrographs in the form of a broadband, exactly-calibrated spectral "ruler", whose absolute traceability allows for comparisons of observations made on timescales from days to years, even at different observatories [21, 22]. While the potential for such astrocombs to have a major impact on the astronomy community has been widely heralded [23], multiple technical challenges stem from the conflicting requirements of providing very large comb-line spacing in the 5-50 GHz range across an extended wavelength bandwidth from 380 nm (Ca II H and K lines) to 2.4 μm (CO band at 2.3 μm). Several well-known motivations push toward the use of NIR spectroscopy. Stellar convection and magnetic activity (e.g. granulation and starspots) which represent consistent noise sources that are noticeably attenuated in the NIR compared to visible. RV high precision measurements of bright stars in the visible will benefit from complementary RV high precision NIR observations that better discriminate stellar activity from real planet signals [24]. Due to their proximity, abundance, small radius and mass, M-dwarfs and K-dwarfs, which primarily emit in the near infrared, are indeed very attractive targets - as compared to Sun-like stars - in the search for habitable-zone rocky planets. So far, the highest precision measurements of the periodic Doppler shift of a star to provide evidence of an orbiting exoplanet by the radial velocity technique, have been limited to the visible region of the spectrum (< 700 nm), due to the better performance of silicon detectors as well as the availability of comb calibrators in this spectral interval.

The aim of this project is the development of a novel paradigm of compact and fully transportable astrocomb able to operate for the first time over an ultra-broad spectral range in the near infrared up to 2.4 μm - the NIR-Astrocomb - with a fractional frequency accuracy of 10^{-12} over an operation time scale of years, limited by the adopted radio-frequency Rb standard referenced to GPS, and the application of this specially-designed wavelength calibrator to exoplanet observation, that should push the precision of NIR RV measurements to 1-2 m/s over months-long time scale. The project involves the realization of a prototype of astrocomb operating in the wavelength range from 1100 to 2400 nm with comb-line spacing larger than 10 GHz, based on a robust passive mode-locked Er:Yb solid-state laser, the subsequent installation at the TNG and the validation by on-sky stellar observations of stars with known orbiting planets. Indeed, tested with an astrocomb in the 1.4-1.8 μm range, the wavelength solution of GIANO-B showed a precision of 25 cm/s [25]. It is worth noting that this measurement addresses the precision of the astrocomb calibration, and not the stability of the spectrograph. Currently, the only operative NIR spectrometer HPF certifies a RV accuracy of 2.8 m/s on the sky [11].

As active participant in the project, the TNG Director endorses the installation of the NIR-Astrocomb calibrator at the telescope (see endorsement letter below). Nights for tests will be taken from the TNG budget of technical time, without affecting the one available to the astronomical community.

After such a calibration upgrading, the TNG is expected to become the leading facility worldwide for exoplanets detection and observation in the habitable zones.



Fundación Galileo Galilei INAF, Fundación Canaria - Telescopio Nazionale Galileo

Breña Baja, March 24th, 2022

TO WHOM MAY CONCERN

This letter endorses the content of the project *Near-Infra-Red Astrocomb for Earth-like exoplanet detections "NIR-Astrocomb"* led by Prof. Paolo Laporta (Politecnico di Milano), to be submitted to the MUR call *PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE Bando 2022*.

Telescopio Nazionale Galileo (TNG) hosts the near-infrared spectrograph GIANO-B, currently used for observational studies at the frontiers the exoplanetary science. The TNG staff has a wide expertise in the use and maintenance of wavelength calibrator like emission lamps, Fabry-Perot systems and laser combs. About the latter, we are hosting a laser comb in the visible and we tested some infrared prototypes in the past.

The project is aimed at developing a new technology for the realization of a laser comb source. The application to the observations made with GIANO-B is quite straightforward. An accurate and precise wavelength calibrator is mandatory to detect exoplanets really similar to our Earth. Therefore, we are interested to collaborate to the development of this innovative technology, by putting our manpower and knowledge into the project. Technical nights will be offered to test the "NIR-Astrocomb" on sky. The expected superior performances will allow us to improve the GIANO-B results, warranting us to push forward the TNG in the context of the characterization of exoplanets.

Therefore, TNG strongly supports the full development of the proposed technology to realize a new astrocomb calibrator in the infrared.

Sincerely yours,

A handwritten signature in black ink that reads 'Ennio Peretti'.

Dr. Ennio Peretti

Director of the Telescopio Nazionale Galileo
Fundación Galileo Galilei-INAf

Fundación Galileo Galilei – INAF, Fundación Canaria

Dirección

C.I.F.: G-38783312 Rambla José Ana Fernández Pérez, 7 - 38712 Breña Baja, TF - Spain
Tel.: +34 922 433666 Fax: +34 922 42 05 08

Methodology

The prototype of NIR-Astrocomb, specifically designed for astronomy applications, will be carried out by PoliMI RU and is based on a novel paradigm exploiting a robust and compact solid-state femtosecond oscillator passively mode-locked by a saturable absorber mirror (SESAM), producing a mode spacing larger than 10 GHz, followed by a diode-pumped high-power fibre amplifier to generate a supercontinuum spectrum in a properly designed non-linear device. This astrocomb will be calibrated against a primary frequency standard (atomic clock) through both a fibre and a satellite link. Figure 1 shows the NIR-Astrocomb architecture. A compact solid-state Er-Yb:glass laser produces sub-ps pulses at 1550 nm by means of a passive mode-locking operation obtained with a SESAM. The diode-pumped resonator, <10 mm in length, generates longitudinal mode spacing larger than 10 GHz with average optical power of 50 mW. Tuning of the pulse repetition frequency and carrier offset frequency is obtained through a piezoelectric (PZT) transducer acting on the resonator length and the pump power current modulation, respectively. A diode-pumped large-mode area Er-doped fibre amplifier increases the average output power up to ~10 W. A critical issue is the design of the non-linear optical broadening system. After a proper pulse compression with a pair of Volume Bragg Gratings (VBG), the pulse train is coupled to a highly-non-linear fibre and then to a waveguide in a specially designed Periodically-Poled-Lithium Niobate (PPLN) crystal for the ultra-broadband supercontinuum (SC) generation from 1100 to 2400 nm. Additional non-linear structures, such as SiN₄-based waveguide, will be investigated in parallel to further extend the SC spectral coverage. Self-frequency locking of the OFC against an atomic frequency clock is achieved by the detection of the comb offset frequency in a compact common path f-2f interferometer (fed by a small portion of the SC) and controlling both the repetition and offset frequencies with a servo electronics acting on the PZT and on the diode pump current, respectively. Spectral flattening of the generated SC in the NIR spectral region will be obtained by combining spatial light modulator and multi-dielectric reflective filters.

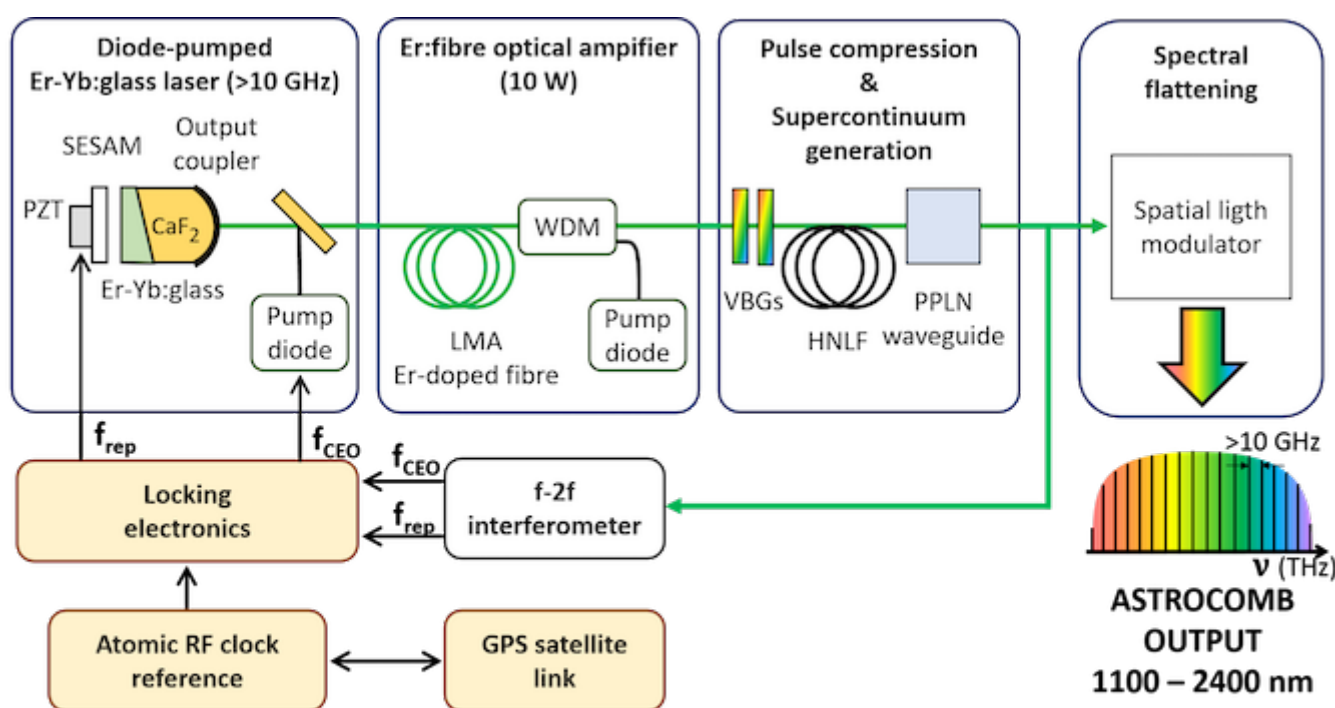
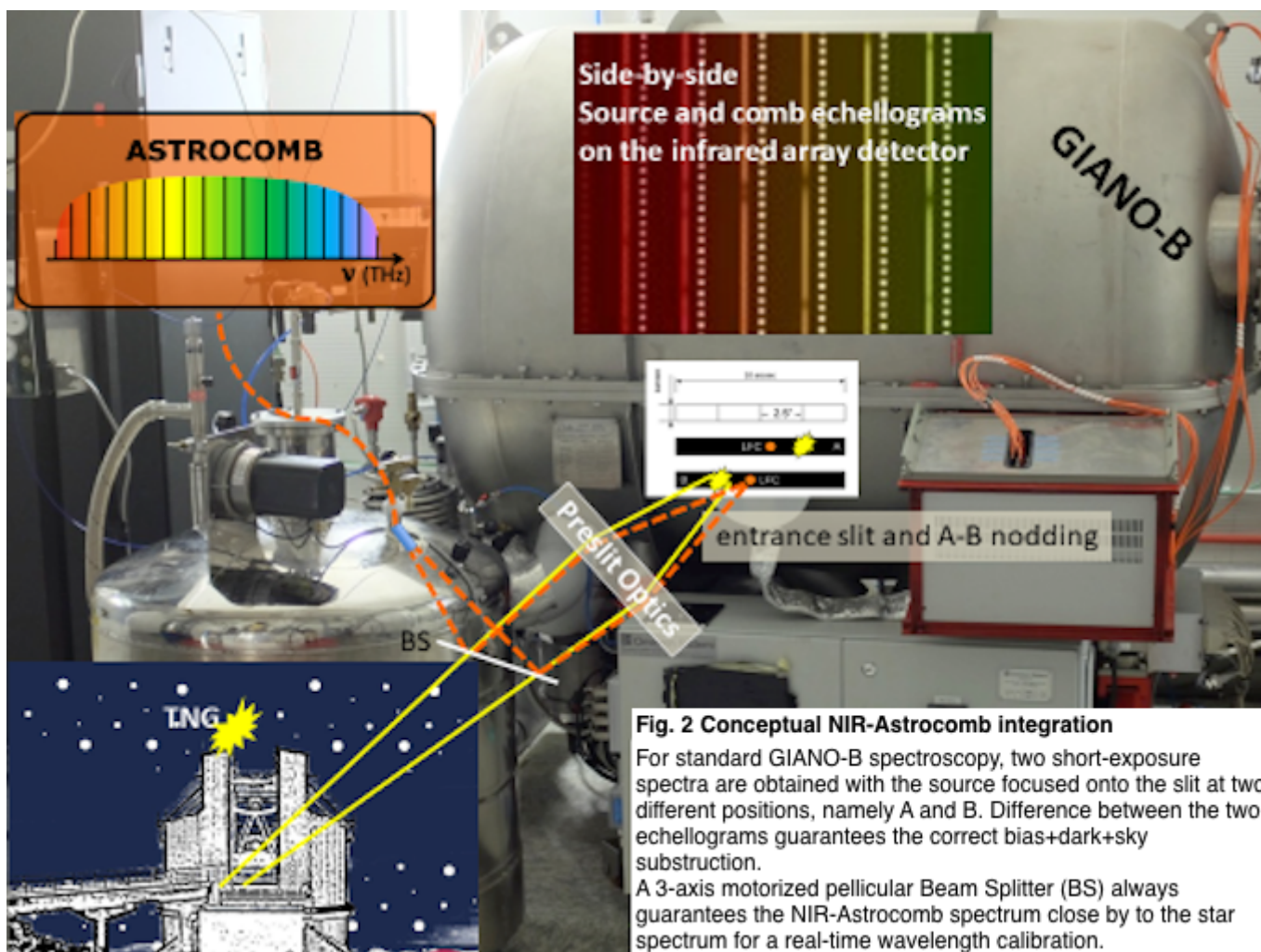


Fig. 1 NIR-Astrocomb architecture. PZT: Piezoelectric Transducer; SESAM: Semiconductor saturable absorber mirror; LMA: Large Mode Area; WDM: Wavelength Division Multiplexer; VBG: Volume Bragg Grating; HNLF: Highly Non-Linear Fibre; PPLN: Periodically Poled Lithium Niobate; RF: Radio Frequency; GPS: Global Position System; f_{rep} : repetition frequency; f_{CEO} : Carrier-Envelope Offset frequency.

The NIR-Astrocomb will be installed at TNG by INAF-FGG researchers. GIANO-B is collocated at a Nasmyth focus of the TNG and fed by an opto-mechanical system, including lenses and mirrors (the Front End Unit). A Calibration Unit disposes of lamps for the calibration of the spectra (U-Ne, Halogen, Fabry Perot, LEDs). The NIR-Astrocomb will be referenced to a GPS-disciplined rubidium standard available at TNG with fractional uncertainty of 10^{-12} for time scales longer than few tens of seconds up to months/years. The output of the astrocomb will be fibre-coupled and connected directly to the Front End Unit with a custom optical relay that feeds the light towards the spectrograph with a proper convergence in order to reimagine the fibre core onto the slit. The possibility/utility to implement a fibre scrambler could be easily taken into account to reduce speckle noise due to multimode fibres. Figure 2 shows the conceptual integration of the NIR-Astrocomb prototype at TNG. The comb light will be imaged onto the slit to produce a complete echellogram close-by the stellar one for a simultaneous wavelength calibration. A motorized system will guarantee the position of the NIR-Astrocomb spectrum during the telescope nodding. Unlike the U-Ne lamp whose strongest spectral lines persist on the infrared detector array even for many hours, thus preventing the possibility of collecting spectra of the calibration lamp during the night, the NIR-Astrocomb emission will be reasonably flattened and adjusted to match the stellar flux distribution level.



UniCT researchers will provide off-line tests of NIR-Astrocombs and develop numerical codes for data processing and retrieving of differential stellar RVs, will be in charge of all the day-time/night-time tests of the astrocomb for checking its stability in time, and will perform subsequent RV measurements of M-dwarfs with known orbiting planets to assess the ultimate RV precision of the NIR-astrocomb calibrated system. Moreover, UniCT will systematically acquire NIR spectra of Hollow Cathode Lamps to provide a list of wavelengths and spectral line intensities for neutral and slightly ionized species in the GIANO-B range. This information is fundamental to define the stellar spectral templates (or masks, [26]) used to measure the RVs with the Cross-Correlation Method. More in general, NIR lines are still scanty even in the NIST atomic database and this extended set of spectral lines will give a much better comprehension of stellar spectra. Following the successful completion of the project, the NIR-Astrocomb will remain permanently installed at TNG observatory, improving the ultimate absolute spectral calibration of GIANO-B spectrograph [27] in the NIR by more than one order of magnitude.

Expected results

Following the successful completion of the project activities, the main expected results are the following: 1) NIR-Astrocomb with >10 GHz comb mode spacing, spectral coverage from 1100 to 2400 nm, average output power of ~1 W (approximately 15 μ W per comb mode); 2) improvement of wavelength calibration accuracy of GIANO-B spectrograph in the NIR by more than one order of magnitude. In this regard, it is important to underline that the NIR-Astrocomb will remain permanently installed at TNG observatory; 3) development of numerical code for data analysis and RV retrieving from the comb-calibrated GIANO-B spectrograph; 4) demonstration of differential radial velocity measurements below 2 m/s over months-long time scale by on-sky tests with NIR-Astrocomb-calibrated GIANO-B spectrograph at TNG; 5) a legacy of new atomic data for NIR spectral lines necessary to efficiently exploit the past, present and future (Extremely Large Telescope) high-resolution spectroscopic observations; 6) publications in high impact scientific journals and communications in major international conferences; 7) patenting and technology transfer; 8) recruiting and training of young researchers and PhD students; 9) outreach and public dissemination of the main scientific results.

Resources required for project implementation

The total cost of the RUs, per single item, including personnel, is reported in part A, section 11. Materials, instrumentation and miscellaneous referred to therein are detailed as follows:

-*Equipment, tools and SW products (item C)*: Diode-laser current drivers; spatial light modulator, servo-locking electronics.

-*Other operating costs (item E)*: (a) Er-Yb:doped laser crystals, SESAMs, PZT, mirrors, active fibres, nonlinear optical fibres, nonlinear optical waveguides (PPLN, SiN₄), general purpose electronics, optical components, photodiodes, mechanics, consumables; (b)

management, missions, workshops and conferences, open-access publications.

Interest for the advancement of knowledge

An optical frequency comb is a discrete array of millions of evenly spaced narrow optical lines with known frequencies at a fractional level up to 10^{-16} [20]. The traditional implementation of an OFC is through the generation of femtosecond pulse trains from a passive mode-locked laser with a repetition frequency given by the inverse round-trip time of the pulse in the laser cavity. The corresponding Fourier spectrum is constituted by a discrete array of equidistantly spaced, sharp frequency components, whose frequency f is given by the comb equation $f(n)=nf_r+f_0$, where n is a large integer, f_r is the repetition frequency, and f_0 is the carrier-envelope offset frequency. When both the radio-frequencies f_r and f_0 are stabilized by referencing to a frequency standard, the laser source assumes the properties of an OFC, resulting in a comb spectrum with stable and absolutely known optical frequencies [20]. An astrocomb should provide a broad wavelength coverage in the whole spectrograph operating interval, with comb spacing tailored to match the spectrograph resolving power R .

With accurate identification of the comb lines on the detector of the spectrograph, a precise wavelength solution for the spectrograph can be constructed. The resolving power of a modern high-resolution spectrograph is typically $R>50,000$, with corresponding optimal mode spacing $f_r>10$ GHz, the exact choice being wavelength dependent. This line spacing is not readily obtainable from typical femtosecond laser systems, being the laser pulse repetition rate f_r equivalent to the mode spacing of the comb, typically well below 1 GHz and thus not resolvable by an astronomical spectrograph. Different approaches have been proposed to overcome this challenge. The most widely-adopted solution has been spectral filtering the modes of a lower repetition frequency laser ($f_r<1$ GHz) via cascaded Fabry-Perot cavities, which allows thinning out of the dense line spacing, but imperfect filtering and non-linear optical effects can effectively shift the apparent frequency of the transmitted lines and can lead to systematic errors [28]. Another approach is based on electro-optically modulated continuous-wave (CW) lasers. Also in this case for broadband spectra Fabry-Perot filter cavities are required to suppress linewidth degradation and related calibration errors [29]. Different types of micro-resonator frequency combs, with intrinsically large line spacing, have been proposed as an alternative solution, yet it has been so far challenging to achieve broadband combs with suitable line spacing [30], even if recent advances have shown that this solution may become a promising one [25].

Our NIR-Astrocomb addresses all this challenges, through notable advancements in comb technology that will be exploited to extend the basic knowledge of exoplanets. In particular, unlike all previous approaches, the NIR-Astrocomb is realized by generating sub-ps pulse trains with a fundamental repetition frequency >10 GHz by a properly designed diode-pumped passively mode-locked Er-Yb:glass laser operating at 1550 nm emission wavelength. Such a high fundamental repetition frequency of the laser source is obtained adopting a compact and robust linear resonator (~ 10 mm), which allows to overcoming the complexity of additional Fabry-Perot filtering cavities and the related spectral narrowing due to the limited bandwidth of mirrors coatings. It is worth emphasizing that this novel paradigm of OFC with line spacing >10 GHz is a powerful tool not only for the calibration of astronomical spectrographs, but it finds useful applications in arbitrary waveform generation and microwave photonics, terabit optical transmission systems, high-resolution spectroscopy and other applications that require easy access to the individual comb lines. A second major advancement that will be achieved is the extremely wide spectral coverage in the NIR, from 1100 nm to 2400 nm, corresponding to more than an octave, obtained by using a robust high-power Er-doped fibre amplifier coupled to a highly-non-linear-fibre followed by a properly designed waveguide in periodically-poled lithium niobate. The unique features above described will allow to use the NIR-Astrocomb for the calibration of several astronomical spectrographs with very high-resolution and extremely extended wavelength coverage in the near infrared spectral interval. Besides GIANO-B (900-2450 nm with $R > 50,000$) we mention, as a further examples of high-resolution échelle spectrographs, SPIRou, @CFHT; iSHELL@IRTF and NIRSP@3.6mESO. The pitfall of the RV method to measure the Doppler wobble of host stars due to the presence of a planet is the stellar jitter due to the activity of the star (hence its magnetic field). Stellar surface inhomogeneities like spots, plagues and granules, induce RV jitter that hides the planetary signal. One way to discriminate between stellar and planetary RV signal is by observing candidates in the NIR, where the impact of the activity on RVs is expected to be typically 3 times lower than in the visible [31]. In this way it is possible to discriminate between the stellar activity signal (reduced amplitude in the NIR) from the planetary signal (no variation at all). To achieve the requested precision for the detection of Earth-like planets in the habitable zone it will be necessary to adopt a high accuracy wavelength calibrator in the NIR, where the RV jitter due to spurious effects is minimized. In this region conventional calibrators show definitely unsatisfactory performance, because U-Ne lamp spectra do not assure a precise calibration due the poor density of lines, insufficient wavelength coverage, and small wavelength shifts in line position; also telluric lines achieve a precision of tens of m/s, still below requirements. To this aim, the use of our specially designed NIR-Astrocomb will enhance the ultimate absolute spectral calibration of GIANO-B (and possibly of other astronomical spectrographs) in the NIR. In fact, the equally spaced lines of our comb extend over an extremely wide spectral interval, from 1100 to 2400 nm, providing an almost complete coverage of the spectral range of GIANO-B spectrometer and thus making it possible ultra-precise wavelength calibration.

A complementary and ideal way to unmask false positive induced by stellar activity is to measure stellar magnetic fields. Such detection is rather challenging because the expected global fields are very weak (a few tenths of gauss for stars similar to the Sun). The sensitivity of spectral lines to the magnetic fields quadratically increases with the wavelengths and in the K-band the effects are so large that the signature of magnetic fields, if any, is unquestionable on spectral line profiles [15]. The extremely wide spectral range of our NIR-Astrocomb thus provides an additional positive impact on the ability to observe and characterize exoplanets in dubious conditions.

Methods of dissemination of the results achieved

Scientific communication and dissemination make culture, thought and scientific knowledge accessible to the general public through

the use of adequate communication strategies and a readable, understandable and meaningful language for non-specialized recipients. Communication and dissemination of science are also of great importance for the future of scientific and technological development, since they show that research funds are always a good investment for the development and well-being of society and contribute to increasing the influence of scientists, allowing them to achieve more visibility and recognition, opening them the doors towards new funding and potential collaborations.

The PI intends to underline the expertise of the group to timely disseminate the scientific results, the technical achievements and the knowledge generated, through an effective communication strategy to engage with the public. A series of communication initiatives will be planned, whose primary objective is to bring and make known technology and science connected to the Near-Infra-Red-Astrocomb for Earth-like exoplanet detection to society and professional groups potentially interested. Appropriate and efficient exploitation of the knowledge and technology generated by a project that wants to improve our studies on extra solar planets will be pursued through a strategy which identifies the main target groups and selects key events for dissemination opportunities. Specific actions will cover: scientific and marketing literature, press release, participation in leading international conferences and exhibitions, and organization of workshops at specific milestones (mid-term, project end). A special effort will be made to publish in peer-reviewed scientific journals. In particular, high-impact journals in the fields of Astrophysics (Nature Astronomy, Astrophysical Journal, Monthly Notices of the Royal Astronomical Society, Astronomy and Astrophysics), laser and photonics (Nature Photonics, Optica, Photonics Research, APL Photonics, Optics Letters, Optics Express) and advanced communications (Nature Communication, Scientific Reports) will be targeted.

The PI will also be responsible of an exhaustive website for the project, where the highlights will be advertised and the main underlying ideas will be popularized to target a wider audience. Following dissemination, several EU companies will be also contacted directly in view of possible technology transfer. In this regard, publication and dissemination will be carefully balanced against the need of Intellectual Property (IP) rights protection. Any major scientific and technological advance will be protected by patenting according to EU standards and each Research Unit owns its own generated IP; when this IP is generated in cooperation, the different units will jointly own the IP. In addition, Technology Transfer Office and Incubators of each partner will be involved in all stages of IP.

Regarding data management, all the participants to the NIR-Astrocomb project will adhere the rules of good scientific practice. In particular, the experimental data will be available to all the RUs and will be stored for a period of 10 years. Datasheets and other data summaries will be made accessible for verification and re-use via the project webpage. All other data, except for data on pending patent applications, will be made available upon request. Preprint of articles will be posted before publication in an online repository (e.g., <http://arxiv.org>).

3. Project development, with identification of the role of each research unit, with regards to related modalities of integration and collaboration

To achieve the ambitious objectives of the project, the three research units (RUs) will tightly interact with each other in carrying out the different activities. The project includes a number of work packages (WPs) and tasks strictly interconnected, as illustrated in the flow chart in Fig. 3 below. A PhD student of PoliMI and a PhD student of UniCT will be deeply involved in the project.

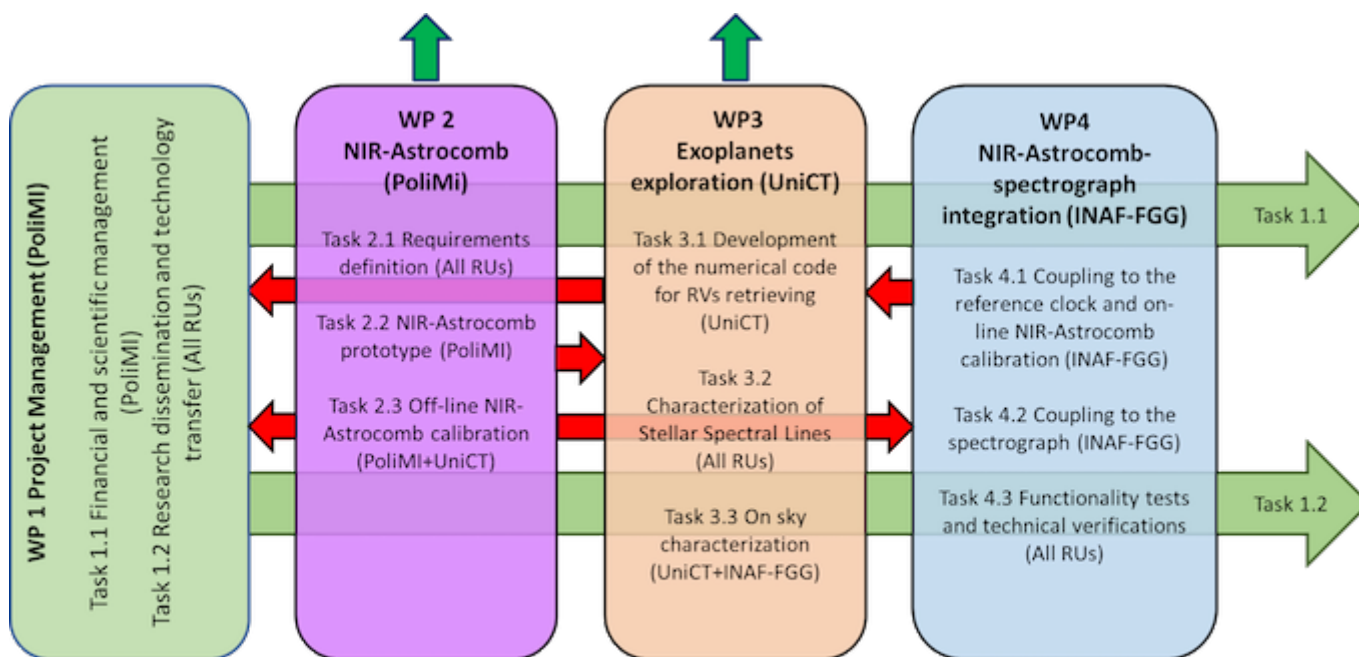


Fig. 3 Flow chart diagram showing the interconnections among WPs and the participation of the RUs to different tasks. Red and green arrows represent, respectively, WPs' inputs and outputs.

WP1 Project Management (PoliMI)

This WP, coordinated by PoliMI, is devoted to management and coordination activities. It covers the entire duration of the project, and includes all the activities required to ensure efficient management of financial, administrative, scientific and risk aspects of the project, as well as research dissemination and outreach, technology transfer, and training. The following two tasks have been identified.

Task 1.1 Financial and scientific management (PoliMI)

The principal Investigator (PI) bears the overall responsibility for the smooth and timely development of the project. The finance management will be carried out with the objective of organizing the whole financial regime in a transparent and satisfactory way. The scientific management has the main purpose of coordinating and synchronizing the research activities of the different WPs, ensuring a high quality of the scientific work. To minimize risks and maximize chances of innovation succeeding, in cooperation with the associated investigators, PI will monitor the achievement of the milestones and deliverables of the project and promptly address any problem that may arise. Our research proposal is highly innovative and thus has a certain level of risk. Table 1 reports the envisaged risk mitigation measures for a proper implementation of the project.

Task 1.2 Research dissemination and technology transfer (PoliMI)

Appropriate and efficient exploitation of the knowledge and technology generated by the project will be pursued through a strategy, which identifies the main target groups and selects key events for dissemination opportunities (scientific and marketing literature, press release, participation in conferences and exhibitions, and organization of workshops); a special effort will be made to publish in high-impact scientific journals. The PI will also be responsible for an exhaustive website for the project. Several EU companies will be also contacted directly in view of possible technology transfer. Publication and dissemination will be carefully balanced against the need for Intellectual Property (IP) rights protection. Any major scientific and technological advance will be protected by patenting according to EU standards.

Table 1. Critical risks and corresponding mitigation measures

Description of risks (Low/Medium/High)	Verification time /milestone	Risk mitigation measures
Repetition rate of the mode-locked laser <10 GHz (Medium)	T0+ 6 months	Adoption of a FP filter with a suitable finesse and FSR for thinning out comb teeth with suitable repetition frequency >10 GHz. Decreasing the repetition rate to ~5 GHz, a FSR of 10 or 15 GHz could be adopted, with a Finesse of ~1000.
Limited spectral coverage of supercontinuum radiation (Medium/High)	T0+12 months M1	Substitution of the PPLN waveguide with SiN-high nonlinear waveguide
Inadequate spectral flattening and intensity equalization of the astrocomb radiation on Giano-B infrared detector (Medium)	T0+ 18 months M4	Additional spatial light modulator stage to spectrally reshape the astrocomb; customized broadband spectral filters for tailoring astrocomb radiation
Limited comb optical bandwidth effectively coupled to GIANO-B spectrometer (Low/Medium)	T0+18 months M4	SW will include telluric spectral lines to improve wavelength calibration in the missing part of the astrocomb spectrum

WP2 NIR-Astrocomb (PoliMI)

This WP is under the responsibility of PoliMI RU and deals with the construction of a compact optical frequency comb synthesizers operating in the NIR spectral range from 1100 to 2400 nm, with a comb mode spacing >10 GHz. At the end of this activity a fully characterized prototype of the NIR-Astrocomb will be available. WP2 is divided into three different tasks that will be developed sequentially.

Task 2.1 Requirements definition (All RUs)

This task will be performed at the beginning of the project when a set of requirements for the NIR-Astrocomb will be listed on the basis of science requirements coming out from the main scientific case of the project, i.e. detection of exoplanets in the habitable zone around M-dwarfs. This task requires strong collaboration among all RUs.

Task 2.2 NIR-Astrocomb prototype (PoliMI)

This activity concerns the realization and characterization of a prototype of NIR-Astrocomb. The set-up (see methodologies), assembled on a fully transportable compact breadboard, is based on: (i) a compact SESAM passive mode-locked diode-pumped compact Er-Yb:glass laser, generating sub-ps pulse trains at the emission wavelength of ~1550 nm and with >10 GHz repetition rate; (ii) a diode-pumped Er-doped fibre amplifier with average output power of 10 W; (iii) a supercontinuum generation stage (> 1 octave) from 1100 to 2400 nm in a highly non-linear device; (iv) frequency locking electronics for the control of mode spacing and comb offset frequency; (v) a spectral flattening system in the range from 1100 to 2400 nm.

Task 2.3 Off-line NIR-Astrocomb calibration (UniCT + PoliMI)

This activity is devoted to metrological calibration of the NIR-Astrocomb in the laboratory environment, before transferring to the TNG, and will be carried out by UniCT RU. The comb, referenced to a GPS-disciplined Rb standard, will be calibrated and the comb noise will be characterized by comparison with the hydrogen masers used at the INAF Radio Telescope in Noto (SR), with the aim of achieving an uncertainty of 10^{-12} over time intervals greater than a few tens of seconds (of the order of typical exposure times). The astrocomb will be further characterized using Fourier-Transform spectroscopy, enabling comb mode orders to be identified.

WP3 Exoplanets exploration (UniCT)

The scope of this WP, jointly performed by UniCT and INAF-FGG, is the development of software tools necessary to measure stellar radial velocity with the accuracy necessary for detecting exoplanets orbiting within the habitable zone of cool stars.

Task 3.1 Development of the numerical code for RVs retrieving (UniCT)

Software for infrared-detector data extraction from the NIR-Astrocomb spectra is fundamental for optical alignments, flattening in wavelength the flux distribution according to the spectral type of the observed star, and checks scrambling effect and spectral resolution. The GIANO-B reduction software [32] will be updated to include a wavelength calibration system based on the NIR-Astrocomb teeth. The standard routine locating the U-Ne hollow cathode lamp spectral lines to define a wavelength scale will be replaced and every tooth will be located on the infrared array detector measuring its variation with position across the detector and upon changing line intensity. Distortion of tooth profiles due to spectrograph and detectors will be quantified by computing position, width, and skewness. The resulting 2D model of distortions will be applied to the adjacent stellar spectrum to achieve the ideal photon noise level.

Task 3.2 Characterization of Stellar Spectral Lines (All RUs)

To provide accurate stellar radial velocities, in addition to the technological effort to build a NIR-Astrocomb, it is also necessary a good dataset of laboratory wavelengths. Unfortunately, even the NIST atomic database is rather scanty in the NIR. We plan an experimental campaign to record with GIANO-B the spectra of neutral or slightly ionized atoms as they are emitted from single-element Hollow Cathode Lamps; acquisition of these spectra is strategic, due to the low temperature of M-dwarfs considered. NIR spectral emission of chemical elements will be systematically examined for decreasing cosmic abundances.

Task 3.3 On sky characterization (UniCT + INAF-FGG)

The aim of this task is to perfect a verification plan and to realize it through the on-sky tests in both the commissioning and science verification phase. In the verification plan, there will be a list of science tests to be performed on-sky and the catalogue of relevant objects at this scope.

WP4 NIR-Astrocomb-spectrograph integration (INAF-FGG)

The aim of this WP, coordinated by INAF-FGG with the involvement of all the RUs, is manifold: it takes care of the verification of the scientific requirements and performance of NIR-Astrocomb built in the framework of WP2, coordinates and performs the installation of NIR-Astrocomb prototype at TNG and its integration with GIANO-B, performs all the functionality tests and technical verification tests. The WP is subdivided in three tasks with different timings.

Task 4.1 Coupling to the reference clock and on-line NIR-Astrocomb calibration (INAF-FGG)

Following opto-mechanical coupling to Rb reference available at TNG, continuous calibration of the reference clock by satellite techniques for time and frequency transfer (Geodetic GPS) will be implemented. This calibration with respect to GPS is necessary as the intrinsic accuracy and stability of rubidium clocks are insufficient for exoplanet detections over the year time scale.

Task 4.2 Coupling to the spectrograph (INAF-FGG)

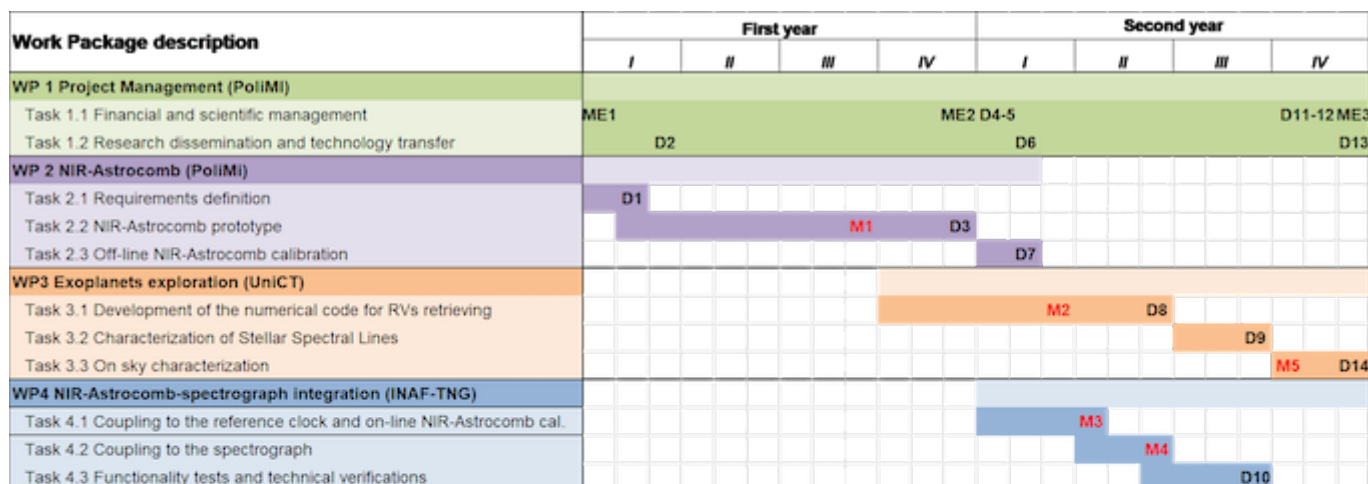
To achieve the necessary accuracy in the wavelength calibration of stellar spectra, the NIR-Astrocomb pattern has to be acquired with GIANO-B simultaneously to the spectrum of the star hosting the exoplanet. We plan the design of an optical relay able to feed GIANO-B with the NIR-Astrocomb light transmitted in an optical fibre. An active mirror, able to follow the telescope nodding, will redirect the astrocomb light onto the GIANO-B slit close by to the stellar light.

Task 4.3 Functionality tests and technical verifications (All RUs)

Following the integration, the NIR-Astrocomb will be extensively tested to assess its reliability and to demonstrate the improvement on the spectrograph RVs measurements. Tests include: (i) comparison with the wavelength solution obtained with the other available reference systems (U-Ne lamp, telluric lines, Fabry-Perot, absorbing cells); (ii) measurements of instrument stability; (iii) measurements of RVs using standard stars with simultaneous comb light injection into the slit; (iv) measurements of RVs on extended objects by bracketing the NIR-Astrocomb spectra before and after exposures.

As already pointed out, the activities of the different RUs are strictly correlated and, in addition to the joint experiments, a continuous exchange of information will be pursued throughout the project. Timing of the activities, with milestones, deliverables

and meetings indicated, is reported in the GANTT in Fig. 4.



ME = Meeting; M = Milestone; D = Deliverable

ME1: kick-off meeting (T0); ME2: intermediate meeting (T0+12 months); ME3: final meeting (T0+24 months).

M1: Spectral coverage of the NIR-Astrocomb (T0+9 months); M2: Validation of the software for RVs retrieving (T0+15 months);

M3: Installation of NIR-Astrocomb at TNG (T0+16 months); M4: NIR-Astrocomb coupling to GIANO (T0+18 months);

M5: Operation of the NIR-Astrocomb at TNG (T0+22 months).

D1: NIR-Astrocomb requirements (T0+2 months); D2: website (T0+3 months); D3: NIR-Astrocomb prototype (T0+12 months);

D4: Intermediate financial report (T0+13 months); D5: First scientific report (T0+13 months);

D6: Collection of dissemination, exploitation, and communication activities (T0+14 months); D7: NIR-Astrocomb off-line calibration (T0+14 months);

D8: Software package for RVs retrieving (T0+18 months); D9: Characterization of stellar spectral lines (T0+21 months);

D10: Functionality tests (T0+21 months); D11: Final scientific report (T0+24 months); D12: Final financial report (T0+24 months);

D13: Workshop on frequency comb for astronomy (T0+24); D14: Exoplanet observation (T0+24 months).

Fig. 4 GANTT of the project

4. Possible application potentialities and scientific and/or technological and/or social and/or economic impact

The novel paradigm of a portable OFC based on a robust and compact solid-state laser with line spacing >10 GHz and ultra-broadband spectral coverage in the NIR from 1100 to 2400 nm, turns out to be crucial not only for the calibration of astronomical spectrographs but, more in general, also for a variety of applications in all the scientific and technological fields that require the unique identification of the individual comb line. Among these, we mention high-resolution broadband direct-comb spectroscopy (dual-comb and Fourier transform methods) in an important part of the fingerprint region, where several molecules exhibit their strongest absorption features, optical coherence tomography, arbitrary waveform generation and microwave photonics, and terabit optical transmission systems, just to name a few.

In our framework we tackle the realization of the NIR-Astrocomb starting with a practical need, i.e., the request to have such an innovative calibrator at the Telescopio Nazionale Galileo (TNG), having in mind as well to develop the know-how to extend its application to other astrophysical cases. One of the most important characteristics of the TNG is to observe in the near infrared. Photometry, low- and high-resolution spectroscopy are currently requested answering the different calls for observing time. In particular, the GIANO-B instrument is performing high-resolution (resolving power $R \sim 50000$) spectroscopy in the near infrared (0.9-2.45 μm) with a single exposure. Unlike other infrared spectrographs (like CARMENES) it covers the K-band. Several teams of astrophysicists have obtained relevant results by studying not only the atmospheres of stars, but also those of the extrasolar planets. In the former case, GIANO-B has been used to study the different stellar populations of our Galaxy and to highlight differences in the stellar components of open clusters [33]; the species abundances are now combined with the precise astrometry provided by the Gaia mission [34]. In the latter case, we can say that GIANO-B pioneered the use of the technique of the transmission spectroscopy in the infrared [35] after the great successes achieved in the visible by HARPS at ESO [36], and HARPS-N at the TNG [37]. In the infrared some of the results are uncertain due to lack of a reliable and stable calibration system, being GIANO-B equipped with a U-Ne lamp. To sketch the most obvious drawback, the persistence of the U-Ne ghost images on the infrared detector array hampers to take spectra during the night, just one U-Ne calibration spectrum can be taken at the end. The possibility to take more astrocomb calibration spectra during the night will greatly improve the fine corrections of the instrumental drifts. In turn, the possibility to map the line structures to put in evidence winds moving blueward or redward without ambiguity can be done in presence of a well-sampled set of reference lines that only a laser comb can supply. These kinds of investigations are at the frontiers of exoplanetary studies and they strongly support the achievement of the technological goal of the project. The potentialities of the HeI 1083-nm line have been just explored in the stellar astrophysics [38]; a more powerful calibration system could open new possibilities, like the careful study of atmospheric dynamics [39]. Therefore, the idea to develop a spectral calibrator with an extended spectral coverage in the NIR matches the interests of the TNG, being the TNG the obvious laboratory for a careful testing and being strongly interested in a straight application.

In addition, the availability of the NIR-Astrocomb at the TNG could also attract the interests of the other telescopes of the

Observatorio de Roque de los Muchachos asking for high-precision reference-comb spectra. This could also open other future technological challenges linked with its portability. Moreover, another very important potential of this technology is its application to the next generation of extremely large (30-40 m diameter class) telescopes, like the European Extreme Large Telescope and the North American Thirty Meter Telescope. Indeed, the proposed NIR-Astrocombs and observational methodologies could pave the way for other applications, such as the direct measurement of the acceleration of the cosmic expansion and the investigation of the potential cosmic variability of fundamental constants. Both these topics must rely on a precise and accurate measurements of line shifts observed with telescopes having a very large collecting area.

Immediate impacts from the project breakthrough technologies and methodologies will be publications in the highest impact factor journals and participations for researchers in the leading international conferences. This will raise the profile of Italian R&D and promote cutting-edge collaborations with other Italian and foreign partners.

We also foresee that our project will impact the industry, as it will allow going beyond the establishment of the present laser comb technology, which was supported by previous EC Framework programs and gave rise to a number of new European manufacturers and commercial systems (e.g. MenloSystem, Toptica, IRSweep); these systems are now routinely supplied for applications across a number of industrial sectors ranging from industrial process monitoring and pharmaceutical quality control (QC) to non-destructive testing and materials analysis. Our project pursues the ambitious objective of a disruptive technology for high-repetition-rate (>10 GHz) mode-locked solid-state lasers at the forefront of the research and, in this context, particular attention will be devoted to the promotion of the technological transfer, also exploiting the business incubators at partner premises (PoliMi, UniCT) to seize the opportunity and tackle the challenge to start a new spin-off company.

Finally, it is worth mentioning that the realization of an instrument able to facilitate the understanding of other worlds can attract a very high level of public attention. The search of habitable planets in the Galaxy has social implications that would bring humanity to reconsider its place in the cosmos. It is expected to be similar to other great scientific revolutions of the past, such as the Copernican Revolution or Darwinism. Thus, given the potential societal consequences of the topics addressed in this proposal and the fascination they hold for the general public, we will take care of their dissemination. In such a context, beside the website of the project, it is worth mentioning that the TNG has already well consolidated channels (social media, institutional webpage, local media, MediaINAF, ...) to inform the public audience of its technological and scientific achievements. From an educational point of view, the public outreach activities of the project will no doubt have a potentially high impact. They will serve as a way to gain the attention of young students, attracting them to scientific and technological research, encouraging them to build an interest towards broader science subjects, and emphasizing the crucial role that an interdisciplinary approach like that proposed in this project plays in modern-day science.

5. Financial aspects: costs and funding for each research unit

n°		Total cost (euro)	Co-funding (item A.1) (euro)	MUR funding (other items) (euro)
1.	LAPORTA Paolo	198.102	68.814	129.288
2.	LEONE Francesco	83.350	22.719	60.631
3.	COSENTINO Rosario	120.626	61.016	59.610
	Total	402.078	152.549	249.529

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B.2

1. Scientific Curriculum of the Principal Investigator

Education and career development

Paolo Laporta graduated with first class honours (Italian "Laurea", integrated 5-years BSc and MSc degree, summa cum laude) in Nuclear Engineering at Politecnico di Milano in 1979. Following two-year post-laurea specialization internship in laser physics at the Department of Physics - Politecnico di Milano, he joined the Italian National Research Council as staff Researcher (1981-83) and, subsequently, Politecnico di Milano as Professor Assistant (1983-86). From 1986 to 1991 he was Associate Professor of Optoelectronics at Tor Vergata University of Rome. From 1991 to 1999 he was Associate Professor of Optics at Politecnico di Milano. Since 2000 he is Full Professor of Physics at Politecnico di Milano and Associate Scientist of the Institute for Photonics and Nanotechnologies - Italian National Research Council (IFN - CNR).

Research activity

Paolo Laporta (PL) has been actively involved for over 40 years in laser physics, optics, integrated photonics, and

spectroscopy. Since 1992 PL is the group leader of the "Solid-State Lasers and Photonics Devices" group at the Department of Physics, Politecnico di Milano. His main contributions to scientific research cover many thematic areas, and are briefly illustrated below.

(i) Diffraction-limited lasers and optical resonators.

In this area, PL made important and pioneering studies widely recognized at international level (1985-90). In particular, PL deeply investigated the problem of thermal lensing of solid-state lasers, considering the dynamic stability of laser resonators and made important contributions to the study of the unstable resonator with radially variable reflectance mirrors (European patent).

(ii) Diode-pumped erbium-ytterbium laser and innovative near-infrared solid-state lasers.

PL and co-workers provided between the mid and the late 90s major contributions to the design and realization of compact Er:Yb:glass laser sources for applications to optical communications, Lidar, and spectroscopy. These include the demonstration of single-mode narrow-linewidth microchip lasers, compact cavity single-frequency tunable lasers (USA patent), and high-repetition-rate mode-locked lasers at 1.5 micron. For such major achievements, PL in 1992 was awarded the Philip-Morris prize for scientific and technological research, and in 2000 was a co-winner of Italian Prize ITALGAS 2000 for Research and Technology Innovation (ITC section). Recently the focus moved to the demonstration and characterization of new solid-state and fibre lasers in the 2-3 micron region, based on Tm- and Ho-doped fluoride materials, Cr-doped ZnSe/S crystals, and Dy-doped fluoride fibres, in different settings and operational regimes for applications to optical radar for remote sensing of atmosphere and high-resolution spectroscopy.

(iii) Waveguide writing and micromachining by ultrashort laser pulses.

Femtosecond writing is a powerful technique which allows to modify the refraction index of transparent materials. In this field PL and his research group provided major pioneering contributions with the fabrication of novel integrated waveguide lasers and amplifiers, couplers and interferometers. This research activity led to several highly-cited articles and highlights at international level and was funded by three European projects (FP7).

(iv) Waveguide photonic devices and nano-optics.

Important results in this area concern the design and fabrication of special fiber Bragg gratings for applications to optical communications (optical filters for reshaping of pulse profile and multiplication of pulse repetition rate). The study of optical-quantum analogies in wave-guided photonic structures has been used as a laboratory tool for the investigation of 'hard-to-observe' quantum phenomena in the matter, including optical single-particle dynamics of strongly-driven electrons in atoms and solids. In the opposite way, the application of methods and protocols of quantum physics led to the design of integrated optical couplers for robust light transfer and splitting, by control of photonic tunneling. More recently, the scientific interest focussed on plasmonics applications and nanooptics.

(v) Frequency comb generation, precision spectroscopy and metrology.

The most recent research activities concern frequency metrology and molecular spectroscopy in the near infrared using fibre lasers and amplifiers, quantum-cascade-lasers and optical frequency combs. It is worth mentioning the development of an optical frequency standard in the near-IR with 10⁻¹³ stability based on semiconductor laser stabilized against acetylene and water sub-Doppler lines, and a frequency standard in the mid-IR range with 10⁻¹² stability based on quantum cascade laser stabilized against fluoroform sub-Doppler lines. Further important results concern the development of an optical frequency comb at 2-3 μm with average output power of 1 W and synthesis of a broadly tunable difference frequency generation comb in the mid-IR spectrum from 8 to 14 μm. Novel spectroscopic systems and techniques based on frequency comb in the infrared have been proposed and demonstrated, achieving important milestones. Major results have been the determination of the Boltzmann constant by Doppler broadening thermometry based on precision laser spectroscopy and comb-assisted precision spectroscopy in the mid-infrared region.

Publications and Bibliometrics

The intense research activity by PL and his personal contributions are documented by:

- over 240 papers published in high-impact peer-refereed ISI-indexed international journals;
- over 120 proceedings in international conferences and contributions to scientific books;
- over 140 contributions to international conferences (39 invited talks);
- 4 international patents.

Bibliometric Data (March 2022)

Scopus: H-index: 50; sum of total citations: 8729

Google Scholar: H-index: 57; sum of total citations: 11320

Teaching, academic supervision and outreaching activities

Broad teaching experience in university courses at undergraduate and graduate level including: General Physics,

Optoelectronics, Optics, Experimental Physics, Principles and Applications of Lasers, Electromagnetism and Optics, Advanced Optics and Lasers. Supervisor ("relatore") of more than 70 MSc and PhD thesis in Laser Physics and Engineering, Optics and Photonics. Author or coauthor of several scientific reviews and dissemination contributions, including a number of contributions/entries to several editorial series of Treccani Italian Encyclopedia Institute, to Encyclopedia of Condensated Matter Physics (Elsevier) and to Materials Science and Materials Engineering Handbook (Elsevier).

Commissions of trust and coordination activities

2008-2014 "Full Member" in the Board of Quantum Electronics and Optics Division (QEOD) - European Physical Society (EPS)

2004-2007 "Coopted Member" in the Board of Quantum Electronics and Optics Division (QEOD) - European Physical Society (EPS)

2002- 2015 Member of the Advisory Board of the Institute for Photonics and Nanotechnologies (IFN) of the Italian National Research Council (CNR)

Institutional responsibilities

2021-present - Deputy Director of the Physics Department, Politecnico di Milano

2007 -present - Faculty member of PhD School in Physics (Collegio di Dottorato), Politecnico di Milano.

2008-present - Member of the MSc in Engineering Physics Admission Committee, Politecnico di Milano

2004-2010 - Elected member of the Body for Coordination of Teaching and Education, Politecnico di Milano.

2000-present - Member of the Advisory Board for the Studies (Consiglio di Corso di Studi) in Electronics Engineering, Politecnico di Milano.

1993-present - Faculty Member of the School of Industrial and Information Engineering, Politecnico di Milano.

1987-1992 - Member of the Engineering Faculty, University of Rome "Tor Vergata".

Referee service

PL has served as referee for the most important international journals in the area of physics and optics and for more than 15 national and international research projects. Since 2000 has served continuously as referee for the LaserLab Europe (the Integrated Initiative of European Laser Research Infrastructures) and since 1988 as scientific expert of MIUR (Italian Ministry of Education, University, and Research) for the evaluation of industrial research projects.

National and international grants (as Principal Investigator)

2010-2012 - Italian MIUR PRIN 2008 "Amplification of Frequency Combs in the Near Infrared for Direct Multispectral Spectroscopy in the Near Infrared" [Grant Euro 151 k€].

2004-2005 - Italian MIUR PRIN 2003 "Novel Solid-State Laser Materials and Optical Frequency References for Metrology and High Resolution Spectroscopy in the Near Infrared" [Grant Euro 164 k€]. 2007-2008 - Italian MIUR PRIN 2006 "Spectroscopic Determination of Boltzmann Constant" [Grant Euro 163 k€].

1999-2001 - Italian Space Agency - ASI-ARS "Eye-Safe Coherent Sources at 2 μm for airborne meteorology" [Grant Euro 196 k€].

1999-2000 - European Space Agency Project "The identification and suitability assessment of solid-state laser components and materials" (No. 12658/97/NL/MV) [Grant Euro 100 k€].

National and international acknowledgments

2012 - Scientific qualification by ANVUR as member of national committee for awarding professional qualification to the functions of university full professor in the scientific sector 02/B1 - Experimental Physics of Matter.

2000 - National Italian Prize ITALGAS 2000 for Research and Technology Innovation (ITC section) - Project "Novel Lasers for Optical Communications" (co-winner).

1992 - Philip Morris Prize for Scientific and Technological Research- Project "Erbium-Ytterbium laser for optical communications" (co-winner).

2. Scientific Curriculum of the associated investigators

1. LEONE Francesco

Francesco Leone Curriculum Vitae (March 2022)

Education and career development

- 1985 Degree in Physics at the Catania University
- 1987 - 2005 Staff Astronomer at the Catania Astrophysical Observatory
- 2006 - Associated Professor at the Physics and Astronomy Department of the Catania University
- 2017 "Abilitazione Scientifica Nazionale" a Professore Ordinario nel SSD FIS05
- 2022 Selected for a Full Professor position in Astrophysics at the Catania University

Institutional responsibilities

- Since 2008, Directory of "Sezione Astrofisica del Dipartimento di Fisica e Astronomia dell'Università di Catania".
- 2011-2015 Director of the Catania University Section of the University Net for Astronomy and Astrophysics

Teaching, academic supervision and outreaching activities

- 1996 - 1999 Course of Stellar Spectroscopy for PhD students
- 2006 - 2007 Course of Physics of Space, Astronomy and Physics
- 2008 - 2009 Course of Physics of Space and Laboratory for Astrophysics
- 2009 - Courses: Astrophysical Laboratory I and II.
- 2009-2017 Member of PhD Board at the Physics and Astronomy Department of the Catania University.

Tutor of 8 Bachelor, 23 MA and 11 PhD thesis in Astrophysics.

Member of Doctorate Board for National and International Institutions.

Research activity

Research field is mainly in the study of stellar atmospheres by comparison of theoretical computation and high resolution spectroscopic data. Particular interest is devoted to reconstruction of magnetic fields. The approach is three-fold:

- numerical codes to solve the radiative transfer in presence of magnetic fields, both Zeeman and Paschen-Back regime have been investigated. Latest version in Stift & Leone (2017, ApJ 83, 24)
- including magnetic field effects in atomic physics (Zhang et al. 2020 ApJ 902, 7; Giarrusso et al. 2020 JPPH 86, id.845860502; Leone et al. 2018 MNRAS 480, 1656; Leone et al. 2017, ApJ 848, 107)
- instrumentation for the Catania Astrophysical Observatory and Telescopio Nazionale Galileo (Leone et al 2003, SPIE 9908, 7; Covino et al. 2014 AN 335, 117; Leone et al. 2016, AJ 355, 315; Leone et al. 2016 SPIE 9908, 7; Ghedina et al. 2018 SPIE 10702, 5).

Projects relevant for this proposal

- 2020 LAPSUS (Munari et al. 2021 SPIE, 1876E..0M)
- 2018 MAPS-3D (Giarrusso et al. 2018 JInst 13, 1020)
- 2018 SIFAP2@TNG (Ghedina et al. 2018 SPIE 10702, 5)
- 2012 HARPS-North@TNG polarimeter (Leone F. et al. 2014 SPIE 9147, 2)
- 2012 Catania Astrophysical Observatory Spectropolarimeter (Leone F. et al. 2016 AJ 151,116)
- 2011 DOLORES@TNG polarimeter (Covino et al. 2014 AN 335, 117)
- 2004 GIANO@TNG NIR-spectrograph (Oliva et al. 2012 SPIE 8446,3)
- 2003 High-resolution spectropolarimetry @TNG (Leone et al. 2003 SPIE 4843, 465)

Collaborations

Km3Net <https://www.km3net.org/>

CTA <https://www.cta-observatory.org/>

MAGIC <https://magic.mpp.mpg.de/>

LSST <https://www.vro.org/>

PLUS <https://www.afs.enea.it/project/astro/> (Board member)

Publications

Citation metrics from ADS

Refereed papers = 216

Citations = 4695

h-index = 34

Duties:

- MIUR – Referee for the Evaluation of Research Quality, a)VQR 2004-2010 b) Research Projects of National Interest c) Future in Research 2013 d) Scientific Independence of young Researchers 2014
- INAF committee member for competitive examinations for staff positions at different levels.
- Referee for the Evaluation of Research Quality for the Ministry of Research of Romania and Polonia.

Referee service

- Referee for the most important international journals in the area of Astrophysics and national and international research projects.
- Member of Allocation Committee dell'European Southern Observatory

National and international grants

Year Financing Institution Project POSITION

2021 Consorzio DTT Passive Spectroscopy (TASK number 4.10.4.112.14_001) Esterno ENEA

2020 UniCT ASTRI PI

2019 ASI LAPSUS - progetto UV Spectroscopy of Laboratory Plasma for Solar Physics, graduatoria SOLE

<http://studioss.iaps.inaf.it/StudioSSgraduatorie.html> co-PI

2019 UniCT CHANCE PI

2018 INFN MAPS-3D co-PI

2017 INAF SKA-CTA co-PI

2016 INFN PANDORA co-PI

2014 UniCT Stellar Abundance of light elements: merging stellar models and nuclear experimental reactions. PI

2012 MIUR – Progetti premiali T-REX Italian Technology for E-ELT co-I

2011 MIUR – Progetti premiali T-REX Italian Technology for E-ELT co-I

2010 INAF Asteroseismology co-I

2009 INAF A polarimetric module for DOLORES@TNG. co-I

2009 INAF Millisecond ASIC for the Readout of CCDs co-I

2. COSENTINO Rosario

Education and career development:

Graduated in physics in 1989 in Catania University

Navy officer in Italian Navy from 1990 to 1991

Electronic technician from 1991 to 1993

Staff astronomer at the Catania Astrophysical Observatory from 1993

Staff astronomer at Telescopio Nazionale Galileo (FGG-INAF) from 2000

Research activity:

From 1993 to 1999:

Development of the Catania Astrophysical Observatory facility for UV CCD characterization.

Electro-optic characterization of CCD detectors.

Participation in the "CCD WORKING GROUP" in the development of the CCD controller for the "Telescopio Nazionale Galileo" (TNG) and in the CCD's characterizations.

Implementation of a CCD camera based on SITE 1024X1024 CCD, for the Echelle spectrograph of "Serra La Nave" and development of acquisition software.

Participation in the development of the high-resolution spectrograph for Galileo (SARG).

In 1999, I began working in the TNG observatory. My responsibilities include the development and maintenance of CCD detectors and control electronics. At same time, I was collaborating with OACT on various activities.

In this period, I have been working on:

Participation at astronomical activities at TNG

Participation in the commissioning phases of the TNG, OIG and the high-resolution spectrograph (SARG).

The study of new generation CCD controller, participation in the realization of the imaging camera (OIG) for TNG and participation in the development of high-resolution spectro-polarimeter for TNG.

In 2001, as well as my previous responsibilities, I started working as responsible of development and maintenance of the high-resolution spectrograph SARG at TNG.

From 2001 I was involved in the following activities at TNG:

The testing of the prototype of new generation CCD controller and development of its acquisition software.

Development of the new auto-guide system, based on new generation CCD controller, at the TNG.

Development and testing of new detectors (CCD, SPAD, CMOS-APS) and control electronics, at Astrophysical Observatory of Catania (OACT).

Detectors and CCD controller upgrade at TNG and development of a new instrument control system for SARG and Dolores spectrograph .

Responsible of SARG, the High-resolution spectrograph at the TNG, from the beginning of operations to the decommissioning of the instrument.

Participation in the development of X-Shooter spectrograph

Participation of the study of a large robotic telescope (Codevisir)

Participation in the instrument control system for the European Solar Telescope (EST)

From 2012 to now the main activities carried out have been:

Responsible of the Instrument Control Unit of PLATO space observatory (ESA M3 mission in the Cosmic Vision 2015-2025 program).

Instrument scientist of the High Accuracy Radial velocity Planet Searcher (HARPS-N) spectrograph at the TNG telescope.

Collaboration with the HARPS-N Consortium GTO in the discovery and characterization of terrestrial exoplanets.

Collaboration with GAPS, an Italian national project that investigates several open issues in the field of exoplanetary science by making use of HARPS-N.

Study of a multi-object low resolution spectrograph based on Digital Micromirror Device (DMD)

Responsible of the detector system of the VIS arm of the SOXS spectrograph, a unique spectroscopic facility for the ESO NTT telescope able to cover the optical and NIR bands.

Collaboration with the INFN and Catania University in the PANDORA experiment, for what concern the implementation of the SARG spectrograph at INFN and regarding the acquisition system, based on CCD detectors.

Publications and Bibliometric:

Scientific papers, published in international journals and various technical documentation and user manuals of astronomical instruments, document the research activity.

Bibliometric Data (March 2022)

Google scholar: H-index:41; i10-index 105; sum of total citations: 5617

Scopus: H-index 31; sum of total citations: 3515

ADS: H-index 31; sum of total citations: 4122

3. Main Principal Investigator's scientific publications (Max. 20)

1. Molteni L. M., Canella F., Pirzio F., Betz M., Vicentini E., Coluccelli N., Piccinno G., Agnesi A., Laporta P., Galzerano G. (2021). Low-noise Yb:CALGO optical frequency comb. OPTICS EXPRESS, vol. 29, p. 19495-19505, ISSN: 1094-4087, doi: 10.1364/OE.428603 - **Articolo in rivista**
2. Gotti R., Puppe T., Mayzlin Y., Robinson-Tait J., Wojtewicz S., Gatti D., Alsaif B., Lamperti M., Laporta P., Rohde F., Wilk R., Leisching P., Kaenders W. G., Marangoni M. (2020). Comb-locked frequency-swept synthesizer for high precision broadband spectroscopy. SCIENTIFIC REPORTS, vol. 10, p. 1-10, ISSN:

2045-2322, doi: 10.1038/s41598-020-59398-1 - **Articolo in rivista**

3. Lamperti M., Gotti R., Gatti D., Shakfa M. K., Cane E., Tamassia F., Schunemann P., Laporta P., Farooq A., Marangoni M. (2020). Optical frequency metrology in the bending modes region. COMMUNICATIONS PHYSICS, vol. 3, p. 1-7, ISSN: 2399-3650, doi: 10.1038/s42005-020-00441-y - **Articolo in rivista**

4. Leonov S. O., Wang Y., Shiryayev V. S., Snopatin G. E., Stepanov B. S., Plotnichenko V. G., Vicentini E., Gambetta A., Coluccelli N., Svelto C., Laporta P., Galzerano G. (2020). Coherent mid-infrared supercontinuum generation in tapered suspended-core As₃₉Se₆₁ fibers pumped by a few-optical-cycle Cr:ZnSe laser. OPTICS LETTERS, vol. 45, p. 1346-1349, ISSN: 0146-9592, doi: 10.1364/OL.386429 - **Articolo in rivista**

5. Schirato A., Maiuri M., Toma A., Fugattini S., Proietti Zaccaria R., Laporta P., Nordlander P., Cerullo G., Alabastri A., Della Valle G. (2020). Transient optical symmetry breaking for ultrafast broadband dichroism in plasmonic metasurfaces. NATURE PHOTONICS, vol. 14, p. 723-727, ISSN: 1749-4885, doi: 10.1038/s41566-020-00702-w - **Articolo in rivista**

6. Wang Y., Jobin F., Duval S., Fortin V., Laporta P., Bernier M., Galzerano G., Vallee R. (2019). Ultrafast Dy³⁺:Fluoride fiber laser beyond 3 μm. OPTICS LETTERS, vol. 44, p. 395-398, ISSN: 0146-9592, doi: 10.1364/OL.44.000395 - **Articolo in rivista**

7. Lamperti, Marco, Alsaif, Bidoor, Gatti, Davide, Fermann, Martin, Laporta, Paolo, Farooq, Aamir, Marangoni, Marco (2018). Absolute spectroscopy near 7.8 μm with a comb-locked extended-cavity quantum-cascade-laser. SCIENTIFIC REPORTS, vol. 8, p. 1-7, ISSN: 2045-2322, doi: 10.1038/s41598-018-19188-2 - **Articolo in rivista**

8. COLUCCELLI, NICOLA, CASSINERIO, MARCO, Redding, Brandon, Cao, Hui, LAPORTA, PAOLO, GALZERANO, GIANLUCA (2016). The optical frequency comb fibre spectrometer. NATURE COMMUNICATIONS, vol. 7, p. 12995, ISSN: 2041-1723, doi: 10.1038/ncomms12995 - **Articolo in rivista**

9. GAMBETTA, ALESSIO, CASSINERIO, MARCO, GATTI, DAVIDE, LAPORTA, PAOLO, GALZERANO, GIANLUCA (2016). Scanning micro-resonator direct-comb absolute spectroscopy. SCIENTIFIC REPORTS, vol. 6, p. 35541-35548, ISSN: 2045-2322, doi: 10.1038/srep35541 - **Articolo in rivista**

10. COLUCCELLI, NICOLA, CASSINERIO, MARCO, GAMBETTA, ALESSIO, LAPORTA, PAOLO, GALZERANO, GIANLUCA (2015). Frequency-noise measurements of optical frequency combs by multiple fringe-side discriminator. SCIENTIFIC REPORTS, vol. 5, p. 16338-16347, ISSN: 2045-2322, doi: 10.1038/srep16338 - **Articolo in rivista**

11. GAMBETTA, ALESSIO, M. Cassinerio, COLUCCELLI, NICOLA, E. Fasci, A. Castrillo, L. Gianfrani, GATTI, DAVIDE, MARANGONI, MARCO ANDREA, LAPORTA, PAOLO, G. Galzerano (2015). Direct phase-locking of a 8.6 μm quantum cascade laser to a mid-IR optical frequency comb: application to precision spectroscopy of N₂O. OPTICS LETTERS, vol. 40, p. 304-307, ISSN: 0146-9592, doi: 10.1364/OL.40.000304 - **Articolo in rivista**

12. GATTI, DAVIDE, SALA, TOMMASO, GOTTI, RICCARDO, Lorenzo Cocola, Luca Poletto, Marco Prevedelli, LAPORTA, PAOLO, MARANGONI, MARCO ANDREA (2015). Comb-locked cavity ring-down spectrometer. THE JOURNAL OF CHEMICAL PHYSICS, vol. 142, p. 074201-1, ISSN: 0021-9606, doi: 10.1063/1.4907939 - **Articolo in rivista**

13. CASSINERIO, MARCO, GAMBETTA, ALESSIO, COLUCCELLI, NICOLA, LAPORTA, PAOLO, GALZERANO, GIANLUCA (2014). Absolute dual-comb spectroscopy at 1.55 μm by free-running Er: fiber lasers. APPLIED PHYSICS LETTERS, vol. 104, p. 231102-231105, ISSN: 0003-6951, doi: 10.1063/1.4882862 - **Articolo in rivista**

14. GAMBETTA, ALESSIO, COLUCCELLI, NICOLA, CASSINERIO, MARCO, GATTI, DAVIDE, LAPORTA, PAOLO, GALZERANO, GIANLUCA, MARANGONI, MARCO ANDREA (2013). Milliwatt-level frequency combs in the 8-14 μm range via difference frequency generation from an Er: fiber oscillator. OPTICS LETTERS, vol. 38, p. 1155-1157, ISSN: 0146-9592, doi: http://dx.doi.org/10.1364/OL.38.001155 - **Articolo in rivista**

15. L. Moretti, A. Castrillo, E. Fasci, M. D. De Vizia, G. Casa, GALZERANO, GIANLUCA, A. Merlone, LAPORTA, PAOLO, L. Gianfrani (2013). Determination of the Boltzmann Constant by Means of Precision Measurements

ofH2O18Line Shapes at 1.39 μm . PHYSICAL REVIEW LETTERS, vol. 111, p. 060803-1-060803-5, ISSN: 0031-9007, doi: 10.1103/PhysRevLett.111.060803 - **Articolo in rivista**

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16. COLUCCELLI, NICOLA, A. Lagatsky, A. Di Lieto, M. Tonelli, GALZERANO, GIANLUCA, W. Sibbett, LAPORTA, PAOLO (2011). Passive mode-locking of an in-band pumped Ho:YLiF₄ laser at 2.06 μm . OPTICS LETTERS, vol. 36, p. 3209-3211, ISSN: 0146-9592 - **Articolo in rivista**
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17. T. Toney Fernandez, S. M. Eaton, DELLA VALLE, GIUSEPPE, MARTINEZ VAZQUEZ, REBECA, M. Irannejad, G. Jose, A. Jha, CERULLO, GIULIO NICOLA, OSELLAME, ROBERTO, LAPORTA, PAOLO (2010). Femtosecond laser written optical waveguide amplifier in phospho-tellurite glass. OPTICS EXPRESS, vol. 18, p. 20289-20297, ISSN: 1094-4087, doi: 10.1364/OE.18.020289 - **Articolo in rivista**
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18. DELLA VALLE, GIUSEPPE, OSELLAME, ROBERTO, LAPORTA, PAOLO (2009). Micromachining of photonic devices by femtosecond laser pulses. JOURNAL OF OPTICS. A, PURE AND APPLIED OPTICS, vol. 11, p. 013001-1-013001-18, ISSN: 1464-4258, doi: 10.1088/1464-4258/11/1/013001 - **Articolo in rivista**
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19. G. Galzerano, E. Fasci, A. Castrillo, N. Coluccelli, L. Gianfrani, P. Laporta (2009). Absolute frequency stabilization of an extended-cavity diode laser against Doppler-free H₂17O absorption lines at 1.384 μm . OPTICS LETTERS, vol. 34, p. 3107-3109, ISSN: 0146-9592 - **Articolo in rivista**
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20. D. GATTI, G. GALZERANO, D. JANNER, S. LONGHI, P. LAPORTA (2008). Fiber strain sensor based on a π -phase-shifted Bragg grating and the Pound-Drever-Hall technique. OPTICS EXPRESS, vol. 16, p. 1945-1950, ISSN: 1094-4087 - **Articolo in rivista**
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4. Main scientific publications of the associated investigators (Max. 20, for each research unit)

1. LEONE Francesco

1. Ambrosino F., Miraval Zanon A., Papitto A., Coti Zelati F., Campana S., D'Avanzo P., Stella L., Di Salvo T., Burderi L., Casella P., Sanna A., de Martino D., Cadelano M., Ghedina A., Leone F., Meddi F., Cretaro P., Baglio M. C., Poretti E., Mignani R. P....(2021). Optical and ultraviolet pulsed emission from an accreting millisecond pulsar. NATURE ASTRONOMY, ISSN: 2397-3366, doi: 10.1038/s41550-021-01308-0 - **Articolo in rivista**
2. Acciari V. A., Ansoldi S., Antonelli L. A., ArbetEngels A., Baack D., Babic A., Banerjee B., Barres deAlmeida U., Barrio J. A., BecerraGonzalez J., Bednarek W., Bellizzi L., Bernardini E., Berti A., Besenrieder J., Bhattacharyya W., Bigongiari C., Biland A., Blanch O., Bonnoli G....(2019). Teraelectronvolt emission from the γ -ray burst GRB 190114C. NATURE, vol. 575, p. 455-458, ISSN: 0028-0836, doi: 10.1038/s41586-019-1750-x - **Articolo in rivista**
3. Acciari V. A., Ansoldi S., Antonelli L. A., Engels A. A., Baack D., Babic A., Banerjee B., Barres de Almeida U., Barrio J. A., Gonzalez J. B., Bednarek W., Bellizzi L., Bernardini E., Berti A., Besenrieder J., Bhattacharyya W., Bigongiari C., Biland A., Blanch O., Bonnoli G....(2019). Observation of inverse Compton emission from a long γ -ray burst. NATURE, vol. 575, p. 459-463, ISSN: 0028-0836, doi: 10.1038/s41586-019-1754-6 - **Articolo in rivista**
4. Ansoldi, S., Antonelli, L. A., Arcaro, C., Baack, D., Babić, A., Banerjee, B., Bangale, P., Barres De Almeida, U., Barrio, J. A., González, J. Becerra...(2018). The Blazar TXS 0506+056 Associated with a High-energy Neutrino: Insights into Extragalactic Jets and Cosmic-Ray Acceleration. THE ASTROPHYSICAL JOURNAL LETTERS, vol. 863, p. 1-10, ISSN: 2041-8205, doi: 10.3847/2041-8213/aad083 - **Articolo in rivista**
5. Leone F., Gangi M., Giarrusso M., Scalia C, Cecconi M., Cosentino R., Ghedina A., Munari M., Scuderi S. (2018). The solar-like 'Second Spectrum' and polarized metal lines in the emission of the post-AGB binary 89 Herculis. MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY, vol. 480, p. 1656-1665, ISSN: 0035-8711, doi: 10.1093/mnras/sty1882 - **Articolo in rivista**
6. Leone, Francesco, SCALIA, CESARE, GANGI, MANUELE ETTORRE MICHEL, GIARRUSSO, MARINA, Munari, Matteo, SCUDERI, ANTONINO SALVATORE, Trigilio, Corrado, Stift, Martin J. (2017). A Method to Measure the Transverse Magnetic Field and Orient the Rotational Axis of Stars. THE ASTROPHYSICAL JOURNAL, vol. 848, ISSN: 0004-637X, doi: 10.3847/1538-4357/aa8d72 - **Articolo in rivista**
7. LEONE, Francesco, Avila G., Bellassai G., Bruno P., Catalano S., Di Benedetto R., Di Stefano A., Gangi M., Giarrusso M., Greco V., Martinetti E., Miraglia M., Munari M., Pontoni C., Scalia C., Scuderi S., Spanó P. (2016). A Method to Calibrate the High-resolution Catania Astrophysical Observatory Spectropolarimeter. THE ASTRONOMICAL JOURNAL, vol. 151, p. 116-125, ISSN: 0004-6256, doi: 10.3847/0004-6256/151/5/116 - **Articolo in rivista**
8. M. Bellazzini, Bragaglia A., Carretta E., Gratton R. G. Lucatello S., Catanzaro G., Leone F (2012). Na-O anticorrelation and HB. IX. Kinematics of the program clusters A link between systemic rotation and HB morphology?. ASTRONOMY

- & ASTROPHYSICS, vol. 538, ISSN: 0004-6361, doi: 10.1051/0004-6361/201118056 - **Articolo in rivista**
9. LEONE, Francesco, Gonzalez MJM, Corradi RLM, Privitera G, Sainz RM (2011). NON-DETECTION OF MAGNETIC FIELDS IN THE CENTRAL STARS OF THE PLANETARY NEBULAE NGC 1360 AND LSS 1362. THE ASTROPHYSICAL JOURNAL LETTERS, vol. 731, ISSN: 2041-8205, doi: 10.1088/2041-8205/731/2/L33 - **Articolo in rivista**
 10. Carretta E, Bragaglia A, Gratton RG, Lucatello S, Bellazzini M, CATANZARO, GIOVANNI, LEONE, Francesco, Momany Y, Piotto G, D'Orazi V. (2010). Detailed abundances of a large sample of giant stars in M 54 and in the Sagittarius nucleus. ASTRONOMY & ASTROPHYSICS, vol. 520, p. 95-115, ISSN: 0004-6361, doi: 10.1051/0004-6361/201014924 - **Articolo in rivista**
 11. Carretta E, Bragaglia A, Gratton RG, Lucatello S, Bellazzini M, CATANZARO, GIOVANNI, LEONE, Francesco, Momany Y, Piotto G, D'Orazi V. (2010). M54+SAGITTARIUS = omega CENTAURI. THE ASTROPHYSICAL JOURNAL LETTERS, vol. 714, p. L7-L11, ISSN: 2041-8205, doi: 10.1088/2041-8205/714/1/L7 - **Articolo in rivista**
 12. Carretta E, Gratton RG, Lucatello S, Bragaglia A, CATANZARO, GIOVANNI, LEONE, Francesco, Momany Y, D'Orazi V, Cassisi S, D'Antona F, Ortolani S. (2010). ABUNDANCES FOR A LARGE SAMPLE OF RED GIANTS IN NGC 1851: HINTS FOR A MERGER OF TWO CLUSTERS?. THE ASTROPHYSICAL JOURNAL LETTERS, vol. 722, p. L1-L6, ISSN: 2041-8205, doi: 10.1088/2041-8205/722/1/L1 - **Articolo in rivista**
 13. LEONE, Francesco, Bohlender DA, Bolton CT, Buemi C, CATANZARO, GIOVANNI, Hill GM, Stift MJ (2010). The magnetic field and circumstellar environment of the helium-strong star HD 36485= δ Ori C. MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY, vol. 401, p. 2739-2752, ISSN: 0035-8711, doi: 10.1111/j.1365-2966.2009.15858.x - **Articolo in rivista**
 14. Carretta E, Bragaglia A, Gratton RG, Lucatello S, CATANZARO, GIOVANNI, LEONE, Francesco, Bellazzini M, Claudi R, D'Orazi V, Momany Y, Ortolani S, Pancino E, Piotto G, Recio Blanco A, Sabbi E. (2009). Na-O anticorrelation and HB VII. The chemical composition of first and second-generation stars in 15 globular clusters from GIRAFFE spectra. ASTRONOMY & ASTROPHYSICS, vol. 505, p. 117-138, ISSN: 0004-6361, doi: 10.1051/0004-6361/200912096 - **Articolo in rivista**
 15. LEONE, Francesco (2007). Magnetic intensification of the Li I λ 6708 line and the abundance and age spread in young cool stars. THE ASTROPHYSICAL JOURNAL, vol. 667, p. L175-L178, ISSN: 0004-637X, doi: 10.1086/522119 - **Articolo in rivista**
 16. Carretta E, Bragaglia A, Gratton RG, LEONE, Francesco, Recio Blanco A, Lucatello S. (2006). Na-O anticorrelation and HB I. The Na-O anticorrelation in NGC 2808. ASTRONOMY & ASTROPHYSICS, vol. 450, p. 523-U21, ISSN: 0004-6361, doi: 10.1051/0004-6361:20054346 - **Articolo in rivista**
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5. Main staff involved (max 10 professors/researchers for each research unit, in addition to the PI or associated investigator), highlighting the time commitment expected

List of the Research Units

Unit 1 - LAPORTA Paolo

Personnel of the research unit

n°	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	LAPORTA Paolo	Professore Ordinario	Politecnico di MILANO	paolo.laporta@polimi.it	6,0
2.	MANZOLLI Jacopo	Dottorando	Politecnico di MILANO	jacopo.manzolli@polimi.it	14,0

Possible sub-unit

Surname	Name	Qualification	e-mail address	Months/person expected

Unit 2 - LEONE Francesco

Personnel of the research unit

n°	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	LEONE Francesco	Professore Associato confermato	Università degli Studi di CATANIA	fleone@oact.inaf.it	3,0
2.	GIUSTOLISI Lorenzo	Dottorando	Università degli Studi di CATANIA	lorenzo.giustolisi@inaf.it	10,0

Unit 3 - COSENTINO Rosario

Personnel of the research unit

n°	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	COSENTINO Rosario	Ricercatore astronomo confermato	Istituto Nazionale di Astrofisica	rosario.cosentino@inaf.it	4,0
2.	PORETTI Ennio	Ricercatore astronomo confermato	Istituto Nazionale di Astrofisica	ennio.poretti@inaf.it	1,0
3.	ANDREUZZI Gloria	Ricercatore astronomo confermato	Istituto Nazionale di Astrofisica	gloria.andreuzzi@inaf.it	2,0
4.	MUNARI Matteo	Tecnologo	Istituto Nazionale di Astrofisica	mmu@oact.inaf.it	4,0

6. Information on the new contracts for personnel to be specifically recruited

n°	Associated or principal investigator	Number of expected RTD contracts	Number of research grants expected	Number of PhD scholarships expected	Overall expected time commitment (months)
1.	LAPORTA Paolo	0	1	0	12
2.	LEONE Francesco	1	1	0	12
3.	COSENTINO Rosario	0	0	0	0
	Total	1	2	0	24

7. PI "Do No Significant Harm (DNSH)" declaration, in compliance with article n. 17, EU Regulation 852/2020. (upload PDF)

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