Towards the SKA and CTA era: discovery, localisation, and physics of transient sources

SKA-CTA joint project

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Abstract

From our Galaxy out to high redshift, beyond where we can observe any other object, transient sources are rich astrophysical laboratories and invaluable probes. Powered by strong gravity, accretion, and magnetic fields, transient multi-wavelength and/or multi-messenger emission can be observed (i) in Galactic binaries of all kinds (novae, millisecond pulsar binaries, micro-quasars, etc), (ii) across a large range in cosmic distances in supernovae, tidal disruption events, gamma-ray bursts, and (iii) in recently discovered phenomena as diverse as fast radio bursts (electromagnetic and unpredicted) and gravitational wave events (non electromagnetic, long sought, and only recently revealed). The challenges posed by all these sources are also very diverse. On the theoretical side, transients offer elements to constrain the final stages of stellar evolution, acceleration processes, physics of compact objects, and the properties of the surrounding environment and intervening medium. Observationally, great sensitivity and the highest time, space, and spectral resolution are required across several decades in wavelength to characterise the evolution of each event, and wide fields of view are also necessary to discover more, and possibly unexpected, events. The real time analysis for transient detection and alert system, and the management of rapidly growing databases and time series are also topics in which novel approaches are required.

Our current knowledge shows that the emission mechanisms at work in transient sources produce radiation of variable energy depending on the source type and on the event phase. Both the Square Kilometre Array (SKA) and the Cherenkov Telescope Array (CTA) are therefore fundamental and ideally suited to permit tremendous advancement in the field of transients: compared to existing instrumentation, they will offer order of magnitude improvements in field of view, sensitivity, frequency/energy range, and prompt reaction capability, which are all key elements for the discovery and understanding of transient sources. Even with the pathfinders, precursors, and prototypes, significant progress will soon be possible in many areas, from fast radio bursts, for which MeerKAT will determine a leap in the number of observed events, to high energy sources, for which MAGIC has already provided both detections (binaries) and important limits (gamma-ray bursts). A long list of multi-wavelength facilities is also involved in intensive follow-up projects and in the hunt for electromagnetic counterparts of gravitational wave events.

The Italian community is at the forefront in all the above described fields in the international context. Solid theoretical and observational expertise in transients has been acquired starting with Beppo-SAX through the Swift and *Fermi* missions. Many structures are involved in the activities of the transient science working group within both SKA and CTA consortia. In this project, we aim at consolidating Italy's role in this context, by merging the existing expertise of people within the consortia with that of the larger community currently working on transients at excellence level - yet somewhat less involved in the CTA/SKA activities. The proposing team is composed of more than 100 people from 10 INAF structures, including researchers, engineers, technicians, outreach specialists, and coordinated by a member of both CTA and SKA transient working groups. We have developed a set of 12 work packages in the theory, observation, development, and public outreach fields to tackle the main challenges presented by transients: develop consistent and detailed physical models for different objects; use transients as probes for astrophysical and fundamental physics problems; find counterparts to gravitational wave events and associate other short and poorly localised transients; increase the statistics and push limits for all classes; reveal fine structural and spectral details; develop procedures, pipelines, and tools required for the complex challenges involved in the real time detection of short signals, in the management of immense amount of information, and in the coordination of multiple facilities and groups. We have also developed a rich and flexible outreach project to facilitate the involvement of the general public. This proposal should be considered a key support for the INAF 'transients' community to work towards astrophysical breakthroughs promised by the SKA-CTA synergy in this field, in particular by involving young researchers through dedicated positions preparing for the long term development on theoretical, observational and computational grounds.

1. General science context

"Transient" sources are astrophysical objects that explode or flare up in violent and unpredictable way. They can be of galactic or extragalactic origin, can emit coherent or incoherent radiation and even non EM signals, and can be the result of thermal runaways, explosions, and particle acceleration. Variability time scales, released energy, wavelength of the emitted radiation can vary widely depending on the nature of the progenitor and of the physical process. In general, they are associated with catastrophic events involving compact objects, such as WDs, NSs, and BHs, and as such they offer the possibility to study the most extreme physical conditions in the Universe. Furthermore, their peculiar characteristics (eg FRB impulsive nature, GRB extreme luminosity) make them invaluable cosmic probes.

The study of transient astrophysical sources is now entering a golden age. Among the most cited astrophysics papers in the last year, we find the discovery of a $>5.1\sigma$ transient GW signal by adLIGO [1], with a plethora of follow-up interpretative and MWL observational papers; the debate about the first possible extragalactic localisation of a FRB [2, 3], as well as the discovery and identification of the first repeating FRB [4, 5]; the appearance of new theory- and observation-based population studies of TDE rates [6, 7]. In more developed fields, some truly remarkable events have also been reported, such as a giant flare of the XRB Cyg X-3 [8]. Each of these results has far-reaching implications both for the study of the physical processes at the origin of the transients themselves (the mass of the merging BHs in the GW event, the FRB luminosity and possible progenitor type, the temperature and density of TDE events) and for more general topics that can be probed through these discoveries (e.g., the rate of binary BH mergers and their formation from massive stars in low-metallicity environments, the average cosmic density of ionised baryons in the intergalactic medium, the supermassive BH mass function).

Radio waves and gamma rays are both crucial, in a complementary fashion, to the study of transient phenomena. Radio waves have the key advantages of measuring kinetic feedback in relativistically moving ejecta, of probing the properties of the intervening ionised media, and of a precise localisation across wide FOV [9]. Gamma rays on the other hand directly trace the highest energy particles, their acceleration and emission processes, and are probes of EBL and LIV. As progress is being made towards the construction of SKA and CTA, as well as the operation of their pathfinders, precursors, and prototypes, it is becoming increasingly clear how their characteristics will be of fundamental importance for the discovery, localisation, and understanding of transient sources. By comparison to the present day facilities at the same wavelength, both instruments will have orders of magnitude improvements in FOV, sensitivity, and capability of promptly react to triggers. These are all key features to dramatically increase the number of detected transients and the level of details in which they could be studied. Indeed, "transients" are one of CTA's key science projects and the prime subject of science WGs both in CTA and SKA consortia. Other wavelengths and MM observations will also contribute to the advance of this field. It is thus mandatory to start coordinating the national community with a comprehensive program based on the preparatory radio and gamma-ray facilities, on complementary EM and GW observatories, and on the theoretical, modelling, and numerical side.

Within the present proposal, we intend to develop a common framework to deal with the large variety of transient phenomena: depending on the type of progenitor, the energy band and type of radiation through which they were discovered, and the relative time and

List of acronyms - adLIGO Advanced Laser Interferometers GW Observatory; *adVirgo* Advanced Virgo; *BH* black hole; *CTA* Cherenkov Telescope Array; *DM* dispersion measure; *EBL* extragalactic background light; *EM* electromagnetic; *FOV* field of view; *FRB* fast radio burst; *GRB* gamma ray burst; *GW* gravitational waves; *LIV* Lorentz invariance violation; *MWL* multi-wavelength; *MM* multi-messenger; *NS* neutron star; *SKA* Square Kilometre Array; *SN supernova; TDE* tidal disruption event; *(V)HE* (very) high energy; *VLBI v*ery long baseline interferometry; *WD* white dwarf; *WG* working group; *WHIM* warm hot intergalactic medium; *WP* work package; *XRB* X-ray binary space frequency, our present understanding of the different types of transients varies broadly (having discovered over a thousand GRBs, we know a greater deal about them in comparison to the dozen or so FRBs, for which it is still debated whether they are of galactic or extragalactic origin). There are however strong observational and interpretative connections between the various areas: a better understanding of already well studied transients, like binaries and GRBs, can help localising and discovering the EM counterparts of GW events. Analogously, our understanding of orphan GRBs necessarily passes through a better modelling of known on-axis GRBs. Moreover, many strategies of localisation are common to both FRBs and GWs. Finally, the majority of the, intrinsically different, astrophysical transients emits over a broad range of wavelengths. Several scientists in our team are active in more than one of these fields and the composition of the team is balanced between people already involved in the science/technology development of SKA and CTA (as the PI) and those willing to contribute to and support the scientific exploitation of their data. The most efficient approach is thus to gather the community in a single comprehensive, coordinated proposal. In the following, we outline the state of the art for the main classes of transients (1.1), and the role of SKA (1.2) and CTA (1.3). In section 2, we will define the actual WPs and actions for our project, highlighting the synergies among groups and topics.

1.1 Targets of interest

September 14, 2015, marked the official start of the gravitational astronomy era, with the first detection of **GW** achieved by the LIGO/VIRGO Collaboration [10]. Realistic detection rate by 2020 is of dozens up to hundreds of GW sources per year in the high frequency range accessible to ground-based GW interferometers (10-1000 Hz), with sky localisations of the order of tens of deg^2 [11]. EM counterparts of GW sources will increase sky localisation accuracy and provide a wealth of additional/ complementary information on the source nature. Primary candidate GW+EM sources in the era of ground-based laser interferometers as adLIGO and adVirgo are coalescing binary systems of compact objects as stellar-mass BH and NS. These systems are also the best candidate progenitors of EM events as short GRBs [12]. Other sources, as core-collapsing SNe and instability phenomena from NS, may also be detected in the high frequency GW spectrum, although expected signals and detection rates are highly uncertain. Sources of unknown nature might be identified too.

GRBs, the most luminous transients detected up to extremely high redshifts, are characterised by a prompt highly variable emission at high energies, followed by a smoothly decaying afterglow observed down to radio wavelengths [13]. Increasing observational evidence corroborates the general picture of GRBs being the EM signatures of relativistic jets launched by BHs or massive, highly magnetised, NS. Observations from >10 GeV to the radio band have covered the prompt and the afterglow timescales; in particular, optical photometry and spectroscopy have demonstrated that long GRBs are tied to the death of massive stars and to a small fraction of very luminous core-collapse SNe. However, there is still uncertainty about the physical mechanisms at work in GRBs and on their origin. The search for and the study of **SNe** explosions themselves in general have focused on the observation and analysis of the spectral energy distribution in the optical range for decades; as observations at other wavelengths are becoming available, they contribute to the knowledge of the SN explosion mechanisms and the characterisation of the SN precursors, which in turn are critical for our understanding of the final evolution of SNe progenitors, of their recent history of mass loss, and of long GRBs. However, radio detections of both GRBs and SNe are rare (<30%), and neither class has been secured a detection above 100 GeV so far.

Similar to SNe, also **TDEs** are at present mainly discovered in the optical and X-rays, but future radio and VHE observations hold great potential for their study. TDEs are unique laboratories to study stellar dynamics and the physics of accretion onto supermassive BHs at the centre of galaxies while in action. Transient emission mainly in the optical to X-rays is produced when a star or gas cloud is gravitationally disrupted and swallowed by BHs through the formation of an accretion disk [14]. About

10% of TDE should also have a jet and share properties of other relativistic jetted sources. HE and VHE emission is expected for jetted and non-jetted TDEs [15] but such prediction is still to be tested. Open questions in this field are overwhelmingly more compelling due to the lack of MWL observations and the present small statistics of events.

As for GWs, the issue of localisation is crucial also in the case of **FRBs**, unpredictable GHz frequencies bursts characterised by millisecond duration and high DM. A large number of models have been proposed, both galactic and extragalactic, with the large DM favouring the latter scenario. As the events are short and unpredictable, they are generally detected with a large positional uncertainty and the debate about an accurate localisation has been one of the hottest threads over the last year [2, 3, 16]. The discovery of one repeating event has permitted to follow it up interferometrically, and at least in that particular case the event seems to be extragalactic and associated with a dwarf galaxy at $z \sim 0.2$ [5]. This has tremendous implications for the progenitor and for probing the cosmic density of ionised baryons. Many open questions remain however, such as whether repeating and non-repeating FRBs have the same origin or form two different classes, the nature of the progenitors, the presence of high energy emission. Given the large estimate of event numbers (up to 10^4/sky/day), there is huge space for discovery in this field.

Within our own Galaxy, transient emission is detected from many **binary systems**, both composed of two compact objects (millisecond pulsar binaries) or of one compact and one stellar object (novae, micro-quasars). Many of these sources have shown surprises: symbiotic and classical novae have been revealed as a new class of gamma-ray emitters by *Fermi* [17, 18], indicating that they are sites of particle acceleration, and interferometric radio observations have demonstrated the possibility to study the spatial and spectral evolution of the emitting region [19, 20]. Millisecond pulsar binaries accreting at very low rates have been recently found to surprisingly emit at radio and GeV energies and to transit from disk to disk-free states on months-yrs timescales [21, 22]; analogously, the unique WD binary AE Aqr has shown bright radio flares and a puzzling high energy behaviour, with both detections and upper limits [23]. Such systems in which accretion disks exist but are only partially feeding the accreting fast spinning compact object, as well as micro-quasars in which transient radio and gamma-ray emission is detected, are crucial in understanding the accretion/ejection coupling on much shorter timescales than those permitted by blazars. This includes the outstanding cases of Cyg X-1, Cyg X-3, V404 Cyg [24, 25], as well as the high mass X-ray binaries detected in the MeV-TeV energy band [26], which prove that an efficient, yet far from being understood, particle acceleration mechanism is in place. Current radiative models involve both leptonic scenarios (gamma-ray production from inverse Compton scattering between the jet electrons and stellar/synchrotron photons) and hadronic scenarios (from *p-p* interactions between relativistic jet hadrons and cold stellar wind protons or nuclei).

1.2 Transients & radio emission

All the above described classes of sources are radio emitters, so the impact of SKA1 and its precursors (MWA, MeerKAT, ASKAP) will be huge in all areas. The key elements will be the sensitivity, the wide FOV and frequency range, the highly advanced signal processing and data management techniques required to detect transients on very short time scales and with large DM, and the possibility to operate in VLBI mode for ultra-high angular resolution imaging capabilities.

SKA1-mid observations will systematically probe the GRB emission and the jet dynamical evolution until the latest epochs (years) post trigger, presently probed only for few events. Complemented by MWL follow up campaigns, the radio observations will constrain the physics of external shocks (particle energy distribution, build up magnetic field), the density profile of the external medium, and even cosmological parameters [27]. SKA&MWL will also help to differentiate GRB and SNe progenitors and potentially can track the elusive pop-III population at very high redshifts. Radio deep wide-field surveys can access the, yet undetected, population of off-axis ‘orphan’ afterglows and the emission of the dynamically ejected material during a NS-BH or NS-NS merger: these are among the most promising EM counterpart of 10-1000 Hz GW sources. In parallel, SKA1-mid will enable indirect detections of very low frequencies (nano-Hz) GW, like those emitted by the merger of supermassive BHs, by precisely measuring how the distances to pulsars in our Galaxy change.

With their wide FOV, beam-forming capabilities, and survey commensality, SKA1-low and -mid, and their precursors, are the ideal instruments to detect a big number of new FRBs [28] and to localise them precisely. This will allow us to perform MWL follow-ups to pinpoint FRB's hosts which, in turn, will enable us to exploit FRBs as cosmological probes. In particular, since early 2018, the approved *Trapum* project at the MeerKAT SKA1 precursor and *UTMOST* at the upgraded Molonglo interferometer will become world-leaders in the detection of FRBs. The direct involvement of some members of this proposal in *Trapum* and existing contacts with *UTMOST* will make easy the establishment of suitable agreements for FRB follow-ups with our facilities.

1.3 Transients & (very) high energy emission

The design of CTA offers several important characteristics that will greatly benefit the study of transients: great sensitivity over a broad energy range thanks to the three telescope sizes, capability of fast repointing, and a large area survey mode provided by divergent pointing observations. Moreover, the nature of the gamma-ray sky itself, with a paucity of sources with respect e.g. to optical sky, could play a crucial role in detecting the EM counterpart of a GW event: CTA could quickly (<1 ks) cover large regions of the sky by operating in survey mode with good sensitivity without being contaminated by thousands of false positives as in the optical [29]. CTA detection of the EM counterpart would enhance source localisation accuracy thus enabling further monitoring with telescopes at longer wavelengths. CTA detection of a short GRB associated with a GW signal from compact binary systems will directly confirm the progenitor nature of this class of astrophysical sources. At the same time, detection of unidentified VHE transient sources can be searched off-line on archival GW data by exploiting the known sky location and event time. This strategy is for example actually carried on by adLIGO/adVirgo teams to understand the nature of FRB.

High sensitivity and high temporal/spectral resolution studies by CTA will contribute to understand the emission mechanisms for many other transients which are anticipated to be detected above few tens of GeV: binaries, TDEs, GRBs. For GRBs in particular, the results by *Fermi* [30] indicate that CTA will be crucial to reveal the prompt emission radiation mechanism (leptonic vs hadronic), the energy dissipation site (internal/external), the jet composition (magnetic/baryons) and its acceleration and collimation mechanism (magnetic or stellar envelope), the total energy involved, the transition from the prompt to the afterglow phase. CTA will probe the role of GRBs as sources of ultra HE cosmic rays and neutrinos and will use GRBs to constrain the EBL at intermediate and high redshifts and to study LIV through the expected energy dependence of photon arrival times [31]. Some of these open issues are directly related to the nature of the progenitors and central engine of both long and short GRBs. Acceleration mechanisms will be probed by CTA in binaries as well.

Bibliography [1] Abbott et al., PhRevL, 2016, 116, [2] Keane et al., Nature, 2016, 530, [3] Williams & Berger, ApJL, 2016, 821, [4] Spitler et al., Nature, 2016, 531, [5] Chatterjee et al., Nature, 2017, 541, [6] Holoien et al., MNRAS, 2016, 455, [7] Stone & Metzger, MNRAS, 2016, 455, [8] Egron et al., ATel 9508, 2017, [9] Fender et al., AASKA14, 2015, [10] Abbott et al., PhRevX, 2016, 6, [11] Abbott et al., Living Reviews in Relativity, 2016, 19, [12] Berger, ARAA, 2014, 52, [13] Kumar & Zhang, Physics Reports, 2015, 561, [14] Komossa, JHEA, 2015, 7, [15] Chen et al., MNRAS, 2016, 458, [16] Giroletti et al., A&A, 2016, 593, [17] Abdo et al., Science, 2010, 329, [18] Ackermann et al., Science, 2014, 345, [19] Giroletti et al., EVN12, id.47. 2012, [20] Chomiuk et al., Nature, 2014, 514, [21] Papitto et al., Nature, 2013, 501, [22] Stappers et al., ApJ, 2014, 790, [23] Aleksić et al., A&A, 2014, 568, [24] Tavani et al., Nature, 2009, 462, [25] Loh et al., MNRAS, 2016, 462, [26] Paredes et al., APh, 2013, 43, [27] Amati et al., AASKA14, 2015, [28] Macquart et al., AASKA14, 2015, [29] Dubus et al., APh, 2013, 43, [30] Ackermann et al., ApJS, 2013, 209, [31] Inoue et al., APh, 2013, 43

2. Goals

The long term goal of this project is to maximise the science return from the participation of INAF to SKA and CTA consortia in the following areas: understanding the physics of known transients, discovering and recognising new classes of transients, and exploiting transients as probes of the Universe both locally and at high redshift. This can be achieved through the creation of a well coordinated science network, the development of excellence science activities in the theoretical and observational fields, and solid contributions to the technological challenges (data acquisition, analysis, and management). Communicating to the general public is also a fundamental step to improve the return for INAF.

Many different classes of transients present similar challenges (discovery and localisation), share common physical mechanisms (particle acceleration, compact objects), and display emission in many bands of the EM spectrum, and beyond. For this reason, this project is inherently multi-class, MWL&MM, multi-location, and multi-approach. For each approach (T: theory, O: observations, D: data analysis and technology; P: public outreach), we highlight in the following the main goals, actions, structures involved, and deliverables. In details, we define 12 WP as follows (the participation of individual members to the WPs is given in Sect. 3, Table 1):

T1) Radiation processes. Goals (G): constrain emission mechanisms, activity regions, acceleration processes in outstanding transients. **Actions (A):** Focusing on selected recent/future 'VIP' events, compare observations to hadronic/leptonic models; set constraints from variability time scales and spectra. Develop and test FRB progenitor models. **Structures (S):** S1, S4-5, S8-9

T2) A comprehensive model of GRBs. G: obtain a physically complete and consistent model for GRBs, both of the short and long type, on prompt and afterglow timescales, on- and off-axis. This will be relevant for studies of GW progenitors and for the final evolution of core-collapse SNe and super-luminous SNe. **A:** implementation of synchrotron self-absorption emission component and of inverse Compton in the Klein-Nishina regime in the GRB code available at the OABr group. Inclusion of off-axis effects and transition to the non-relativistic phase. **S:** S5, S8.

T3) Population models and simulations of radio and TeV emission. G: provide a list of SKA and CTA requirements (reaction time, localisation, energy/frequency range, configuration) for the final design of the detectors, possible strategies for the surveys, and use case revisions. **A:** Based on existing data, improve current population models or develop new ones as needed. Determine detection rates under different assumptions at various frequencies/energies, also exploring synergy with other facilities (Athena, LSST). Test on precursor data. Complementary to T2, this WP is based on more simplistic models but addresses many more classes (TDEs, SNe, FRBs, binaries of all kinds). **S:** S1/3/5/8-9

T4) Transients as probes. G: Exploit transient sources to constrain parameters of cosmological and fundamental physics importance. **A:** From observed DMs of impulsive radio transients of known distance, determine line of sight electron column density; separate the intrinsic/Galactic contributions through HI and metal absorption to constrain the cosmological mass density of intervening WHIM, which is predicted to host the majority of the, yet to be detected, baryons in the z<~2 Universe. From gamma-ray spectral properties of GRBs with known redshift, constrain the EBL at intermediate and high redshift. Use high redshift GRBs to probe star formation up to z~9-10. From time of arrivals of gamma-ray photons of different energies, study LIV of the speed of light. **S:** S1-3, S5, S7-9

O1) MWL searches for counterpart localisation. G: Search for the EM counterpart of GW events, determine distance/host galaxy of FRBs, associate new transients. **A:** maintain a channel of information exchange with adLIGO, adVirgo, and SKA/CTA precursors for GW/neutrino/other transients follow-up. Design MWL strategies and procedures for search and follow-up of counterparts: study the MWL light curves and spectra of current GW candidate counterparts, based on the available models of compact stellar mergers and of other explosive potential GW emitters (magnetars, SNe); activation of various GW/FRB follow-up approved programs at national and international optical and radio telescopes; real-time detection of GRB contemporary to GW alert with INTEGRAL, and immediate repointing for identification with <1' error box. **S:** S1-2, S5-9

O2) MWL studies exploiting sensitivity. G: improve knowledge of several transient classes through deeper observations. For many transient sources, the present facilities already provide the possibility to solve many puzzles, as the frequency of the relativistic SNe, the SNe rate in starburst galaxies (often hidden behind dust), physics of accretion on supermassive BH after TDE, the quenched activity states in binary, etc. **A:** selection of new, well localised MWL transients as SNe (also to search for orphan GRBs), TDE, GRBs, novae for follow up with sensitive radio arrays (JVLA, MeerKAT, ASKAP). Monitoring of binaries in different states, with single dish and interferometers. **S:** S1-2/5/7-9

O3) Radio imaging at very high angular resolution. G: Obtain direct imaging of ejecta in various classes of sources, constrain structural and positional evolution. **A:** Data analysis, interpretation, and publication of already available VLBI datasets on the first gamma-ray nova V407 Cyg, the XRB Cyg X-3 during 2016 giant flare, and two selected GRBs. Derive implications for circumstellar medium, energy density, GRB viewing angles. Promptly react to new transients exploiting real time correlation on flexible arrays based on Italian radio telescopes. **S:** S1, S4-6

O4) Gamma-ray observations. G: the number of transient sources observed at (V)HE gamma rays is relatively low. This WP aims at a characterisation of a few outstanding objects detected in these bands with the present facilities. **A:** observations of binaries, novae, GRBs, jetted TDEs with MAGIC, *Fermi*/AGILE, and, for outstanding outbursts, ASTRI prototype or (starting in 2018) mini array. Study of temporal evolution and spectral shape; connect to hard X-rays (INTEGRAL/Swift). **S:** S1-2/S4-7/S9

D1) Test capabilities of national facilities for transient discovery towards SKA. G: develop expertise in impulsive radio transient detections, discover new objects. **A:** develop analysis tools (software, firmware, backends) for possible exploitation of national instruments as radio transient detectors: Sardinia Radio Telescope, upgraded Northern Cross sections, Sardinia Array Demonstrator. Initial tests on known pulsars with suitable characteristics and repeating FRBs. Blind searches in transit mode. Possible spin-off for discovery and characterisation of near earth asteroids. **S:** S4, S6, S10

D2) Real-time analysis techniques & decision trees. G: Contribute to set strategies for CTA/ SKA reaction to transients and target prioritisation. **A:** Development of analysis techniques for the serendipitous discovery and/or identification during MWL/MM campaigns of gamma-ray transients at different timescales (minutes to days) for the real-time analysis of CTA, in particular with a focus on GW EM counterpart. Definition of decision trees for the management of science alerts based on figure of merit algorithms. Test by means of both the CTA and SKA precursors. Develop visualisation techniques of data analysed in real-time in the FOV of CTA with different sub-arrays. **S:** S1-2, S5-6, S9

D3) "Small big data": databases, archives, MWL. G: Develop new methods to extract and handle information from huge time series and data sets. **A:** implementation of procedures of automated screening and classification of new transients and their MWL counterparts. Production of simple interfaces to disseminate the data and the results to the scientific community at large. Implementation of existing and new algorithms to optimise MWL follow up strategies to transient alerts. **S:** S1-2, S9

P) Public outreach. G: Present CTA/SKA projects and transient phenomena to the general public, pointing out Italy's role and creating emotional involvement. **A:** set up one exhibit about SKA/ CTA and Italy's role; one documentary about the people involved in the SKA/CTA; three educational hands-on activities (for details, see cost breakdown section). Collaboration with SKA/CTA outreach and education offices and INAF communication office. Local activities. **S:** S4-5, S7-8, S10

Deliverables for the T/O-WPs are science papers in peer-reviewed international journals (at least 2/WP/yr, >32 in total) and contributions to international conferences. The D-WPs have technology and data oriented focus, aimed at preparing software/hardware resources to be exploited in the mid-long term: deliverables are pipelines, software, observational tests, tech reports and communications to international conferences in the technological/instrumental field. The P-WP will deliver outreach media as outlined in Section 4.

3. Personnel commitment

With 110 participants from 10 different INAF structures and several other Universities and research institutes, this project involves a large community across and beyond INAF structures, with a broad distribution in expertise, age, and background. There is a significant participation of personnel already involved in the SKA and CTA consortia activities and in particular in the transient WGs: the national science coordinator is a member of both the SKA and CTA transient science WGs, ~30 other members participate to either one, and several more are involved in other SKA or CTA WGs. An even larger fraction of participants consists of scientists who are getting involved in the two facilities through the present project. In this sense, this project largely fulfils the indication of the PRIN call of enhancing the involvement at large of the community.

In total, we are devoting 54 full time equivalents (FTE) to the project over the two years. As indicated by the call, over 50% of these FTEs (actually, 84% in our case) come from INAF personnel. As such, the budget request is largely justified (based on the guideline of 2FTE:100k€).

Of the 54 FTE, 33 come from permanent staff researchers, which also fulfils the threshold for the number of new positions requested. In Section 4, we detail our request for a total of 13 FTE, whereas we could in principle ask for as many as 22, based on the 1.5:1 FTE ratio indicated in the call.

In Table 1, we list the involved personnel from (or associated with) each INAF structure. For each participant, we indicate the qualification, the role in the project through the activity in one or more WPs, and the FTE per year. A numeric flag indicates whether the participant is (1) INAF permanent staff, (2) INAF temporary staff, (3) associate permanent staff, or (4) associate temporary staff.

Table 1 - List of personnel

Name	Affiliation	Qualification	WP	FTE/yr	Type
Angela Bazzano	IAPS	Pr. Ricerc.	O1, O2, O4, T1	0.3, 0.3	1
Fiamma Capitanio	IAPS	Ricerc.	O2, O4, D2	0.3, 0.3	1
Ettore Del Monte	IAPS	Tecnol.	O2, D2	0.2, 0.2	1
Alessandra De Rosa	IAPS	Ricerc.	T1, O2	0.2, 0.2	1
Marco Feroci	IAPS	Dir. Ric.	O2, D2	0.2, 0.2	1
Mariateresa Fiocchi	IAPS	Ricerc.	O1, O4	0.2, 0.2	1
Lorenzo Natalucci	IAPS	Ricerc.	O2, O3	0.2, 0.2	1
Luigi Pacciani	IAPS	Ricerc.	T3, O4	0.2, 0.2	1
Francesca Panessa	IAPS	Ricerc.	O1, O2	0.3, 0.3	1
Luigi Piro	IAPS	Dir. Ric.	O2, T4	0.2, 0.2	1
Paolo Soffitta	IAPS	Pr. Ricerc.	O2, D2	0.2, 0.2	1
Martina Cardillo	IAPS	Post-doc	T3, O4, D2	0.3, 0.3	2
Enrico Costa	IAPS	Assoc. Em.	O2, D2	0.2, 0.2	2
Imma Donnarumma	IAPS	Ricerc. TD	O2, O4, D2	0.3, 0.3	2
Yuri Evangelista	IAPS	Ricerc. TD	O2, D2	0.2, 0.2	2
Sergio Fabiani	IAPS	Post-doc	O2, D2	0.3, 0.3	2
Simone Lotti	IAPS	Ricerc. TD	O2	0.2, 0.2	2
Fabio Muleri	IAPS	Ricerc. TD	O2, D2	0.2, 0.2	2
Giovanni Piano	IAPS	Post-doc	O2, O4, D2	0.3, 0.3	2

Name	Affiliation	Qualification	WP	FTE/yr	Type
Pietro Ubertini	IAPS	Assoc. Em.	O1, T1	0.3, 0.3	2
Valerio Vittorini	IAPS	Ricerc. TD	T3, O4	0.3, 0.3	2
Ugo Zannoni	IAPS	Tecn. TD	D3	0.3, 0.3	2
Post-doc position being filled	IAPS	Post-doc	O2, O3	0.2, 0.2	2
Bruno Luigi Martino	IAPS	Assoc. Staff	D2, D3	0.2, 0.2	3
Elena Pian	IASF-Bo	Pr. Ricerc.	O1, O2, O4	0.3, 0.3	1
Lorenzo Amati	IASF-Bo	Pr. Ricerc.	T4, O2	0.2, 0.2	1
Luciano Nicastro	IASF-Bo	Pr. Ricerc.	O1, D2, D3	0.3, 0.3	1
Eliana Palazzi	IASF-Bo	Pr. Ricerc.	O1, O2, D3	0.4, 0.4	1
Nicola Masetti	IASF-Bo	Ricerc.	O1, O2	0.3, 0.3	1
Giovanni De Cesare	IASF-Bo	Tecn.	O1, D2	0.2, 0.2	1
Andrea Bulgarelli	IASF-Bo	Tecnol.	O1, D2, D3	0.3, 0.3	1
Mauro Dadina	IASF-Bo	Ricerc.	O1, D2	0.2, 0.2	1
Daniela Vergani	IASF-Bo	Ricerc.	O1	0.2, 0.2	1
Mauro Orlandini	IASF-Bo	Pr. Ricerc.	O1, O4	0.3, 0.3	1
Vito Sguera	IASF-Bo	Ricerc.	O1, O4	0.2, 0.2	1
Elisabetta Maiorano	IASF-Bo	Post-doc	O1, O2	0.2, 0.2	2
Filippo Frontera	IASF-Bo	Assoc. Em.	T4, O2	0.2, 0.2	4
Giulia Stratta	IASF-Bo	Post-doc	O1, O4, D2	0.4, 0.4	4
Ruben Salvaterra	IASF-Mi	Ricerc.	T3, T4	0.2, 0.2	1
Marcello Giroletti (CSN)	IRA	Ricerc.	O3, O4, D1	0.5, 0.5	1
Monica Orienti	IRA	Ricerc.	O3, O4	0.2, 0.2	1
Carlo Stanghellini	IRA	Pr. Ricerc.	O3	0.2, 0.2	1
Andrea Maccaferri	IRA	Tecn.	D1	0.2, 0.2	1
Tiziana Venturi	IRA	Pr. Ricerc.	O3, D1	0.2, 0.2	1
Stefania Varano	IRA	Tecnol.	P	0.3, 0.3	1
Matteo Stagni	IRA	Tecn.	O3, D1	0.3, 0.3	2
Gabriele Giovannini	IRA	Assoc. Staff	O3	0.2, 0.2	3
Rocco Lico	IRA	Post-doc	O3, O4	0.2, 0.2	4
Filippo D'Ammando	IRA	Post-doc	O4, T1	0.3, 0.3	4
Sergio Campana	OABr	Dir. Ric.	O1, O2	0.2, 0.2	1
Stefano Covino	OABr	Ricerc.	O1, O4	0.2, 0.2	1
Giancarlo Ghirlanda	OABr	Ricerc.	T2, T3	0.2, 0.2	1
Stefano Vercellone	OABr	Ricerc.	O4, D2	0.2, 0.2	1
Gabriele Ghisellini	OABr	Dir. Ric.	T1, T2, T4	0.2, 0.2	1
Gianpiero Tagliaferri	OABr	Dir. Ric.	O1, O2	0.2, 0.2	1

Name	Affiliation	Qualification	WP	FTE/yr	Type
Fabrizio Tavecchio	OABr	Ricerc.	T1, T4	0.2, 0.2	1
Paolo D'Avanzo	OABr	Ricerc.	O1, O2	0.2, 0.2	1
Patizia Romano	OABr	Ricerc.	O4, D2	0.2, 0.2	1
Tomaso Belloni	OABr	Pr. Ricerc.	O2, O3	0.2, 0.2	1
Stefano Sandrelli	OABr	Tecnol.	P	0.2, 0.2	1
Andrea Melandri	OABr	Post-doc	O1, O2	0.2, 0.2	2
Ilaria Arosio	OABr	Post-doc	P	0.2, 0.2	2
Lara Nava	OABr	Post-doc	T1, T2	0.2, 0.2	4
Om S. Salafia	OABr	PhD Stud.	T2, T3	0.3, 0.3	4
Alessio Pescalli	OABr	PhD Stud.	T1, T2	0.3, 0.3	4
Deborah Mainetti	OABr	PhD Stud.	O2	0.3, 0.3	4
Andrea Possenti	OACg	Pr. Ricerc.	O1	0.2, 0.2	1
Marta Burgay	OACg	Ric. Astr.	O1, D1, D2	0.2, 0.2	1
Alberto Pellizzoni	OACg	Ricerc.	O3, O1, D1, O4	0.3, 0.3	1
Elise Egron	OACg	Ricerc. TD	O3, D1, O1	0.3, 0.3	2
Sara Loru	OACg	PhD Stud.	O3, D1, O1	0.3, 0.3	4
Maria Teresa Botticella	OACn	Ricerc.	O1, O2	0.2, 0.2	1
Domitilla de Martino	OACn	Astr. Ass.	O2, O4	0.2, 0.2	1
Massimo della Valle	OACn	Dir. Ric.	O1, O2	0.2, 0.2	1
Massimo Dall'Ora	OACn	Ricerc.	O1, O2	0.2, 0.2	1
Aniello Grado	OACn	Ric. Astr.	O1, T4	0.2, 0.2	1
Chiara Badia	OACn	Tecnol.	P	0.2, 0.2	1
Andrea Pastorello	OAPd	Ricerc.	O2	0.2, 0.2	1
Massimo Turatto	OAPd	Astr. Ord.	O2	0.2, 0.2	1
Stefano Benetti	OAPd	Pr. Ricerc.	O2	0.2, 0.2	1
Lina Tomasella	OAPd	Ricerc.	O1, O2	0.6, 0.6	1
Riccardo Ciolfi	OAPd	Ricerc.	T1, T2	0.2, 0.2	1
Marina Orio	OAPd	Ric. Astr.	T3, O2	0.3, 0.3	1
Ulisse Munari	OAPd	Astr. Ass.	O1, O2	0.3, 0.3	1
Sheng Yang	OAPd	PhD Stud.	O1	1, 1	2
Paolo Ochner	OAPd	Tecn. TD	P, O2	0.4, 0.4	4
Enzo Brocato	OARm	Astr. Ass.	O1, D3, T4	0.3, 0.3	1
Piergiorgio Casella	OARm	Ricerc.	T1, O2, D3	0.3, 0.3	1
Andrea Rossi	OARm	Post-doc	O1, O2	0.2, 0.2	1
Gianluca Israel	OARm	Pr. Ricerc.	O1, D3	0.3, 0.3	1
Silvia Piranomonte	OARm	Ricerc.	O1, D3	0.2, 0.2	1

Name	Affiliation	Qualification	WP	FTE/yr	Type
Vincenzo Testa	OARm	Ricerc.	O1, D2, D3	0.2, 0.2	1
Luigi Pulone	OARm	Ricerc.	O1, D2, D3	0.2, 0.2	1
Luigi Stella	OARm	Astr. Ord.	O1, T4	0.2, 0.2	1
Angelo Antonelli	OARm	Pr. Ricerc.	O4, D2	0.2, 0.2	1
Matteo Perri	OARm	Tecnol.	O4, D2	0.2, 0.2	1
Fabrizio Nicastro	OARm	Pr. Ricerc.	T4	0.2, 0.2	1
Guillermo Rodriguez	OARm	Post-doc	O1, D2, D3	0.3, 0.3	2
Valerio D'Elia	OARm	Tecnol.	O2, O4, T4	0.2, 0.2	2
Saverio Lombardi	OARm	Post-doc	O4, D2	0.2, 0.2	2
Fabrizio Lucarelli	OARm	Tecnol.	O4, D2	0.2, 0.2	2
Giuseppe Altavilla	OARm	Tecnol.	O1, D2	0.2, 0.2	2
Federico Vincentelli	OARm	PhD Stud.	O2	0.2, 0.2	4
Stefano Ascenzi	OARm	PhD Stud.	O1, T3, T4	0.2, 0.2	4
Marica Branchesi	OARm	Ricerc. TD	O1, D2, T4	0.2, 0.2	4
Enrico Bozzo	OARm	Ricerc. TD	O4	0.2, 0.2	4
Gaetano Valentini	OATe	Tecnol.	D1, P	0.2, 0.2	1
Di Cecco Alessandra	OATe	Post-doc	D1	0.2, 0.2	2
De Luise Fiore	OATe	Ricerc. TD	D1	0.2, 0.2	2

Notes - Ricerc. Ricercatore/trice; *Ricerc. TD* Ricercatore/trice a tempo determinato; *Pr. Ricerc*. Primo/a Ricercatore/trice; *Dir. Ric.* Dirigente di Ricerca; *Ric. Astr.* Ricercatore/trice Astronomo/a; *Astr. Ass.* Astronomo/a Associato/a; *Astr. Ord.* Astronomo/a Ordinario/a; *Tecnol*. Tecnologo/a; *Tecn*. Tecnico/a laureato/a; *Tecn. TD* Tecnico/a a tempo determinato; *Post-doc* Post-doc/assegnista; *PhD Stud*. Dottorando/a; *Assoc. Staff* Ricercatore/trice o Professore/ssa associato/a; *Assoc. Em*. Associato/a in quiescenza.

4. Project cost breakdown

In Table 2, we report the share of costs. The largest fraction of requested funds is for the acquisition of new personnel. This is driven by two main reasons: on one hand, it is vital to train and support junior researchers from the early stages of their career in the field of SKA and CTA studies, as they will eventually be the prime users of these facilities. Moreover, although our group is large and diversified, many goals require the commitment that only a person devoting 100% of their time to the corresponding action can warrant.

Table 2: Cost breakdown

Reason	Requested funds (k€)
Overhead	120
Outreach	40
Hired personnel	490
Travel	150
Total	800

In Table 3, we provide a list of topics for the positions to be filled, accompanied by the type and duration of the contract, the host structure, the corresponding WP of activity, and any other structure whose activities will be coordinated with those of the post-doc.

In one case, we will offer a senior position (RTD, 52.5 k€/yr) to acquire at least one unit of personnel with an advanced formation; in all the other cases, we will offer standard INAF salaries (ADR, 35 k€/yr), which should still attract brilliant junior researchers, in particular for the longer positions (three 2-yr and two 1.5-yr contracts, one of which to be extended to 2-yr through external funds already granted). Comparatively shorter positions (1-yr) will be offered for two more focused projects on development of analysis techniques in gamma rays and radio, which might be then followed-up with local funds.

We do not allocate funds for publications and computing. While these are important activities, the formation of personnel and their mobility have higher priority in a context with limited resources. We expect that a sufficient share of the overhead funds will be available for these needs. As fostering the link among various location is one of our goals, we will also divide the resources for travel so that the structures that do not acquire new personnel will have the possibility to have more mobility - to encourage interaction and maximise the return of the work.

We are also committed to carry out an extensive program of outreach activities, for a total of 40 k€ (5% of the total budget). In details, we estimate the following costs and activities:

- an exhibition presenting SKA and CTA, with panels (Italian and English) showing: what SKA and CTA are, their position and configuration; what radio and high energy waves are, what they can reveal about the objects emitting them; how the two instruments can be jointly used in order to answer to some astrophysical big questions; how radio and gamma images are produced from the collected data; what the role of Italy has been, is and will be. Each panel will have a digital frame showing videos about the subjects. The exhibition will be completed by the accompaniment of a music, the "sonification" of radio waves and gamma rays obtained by actual observations of transient phenomena, arranged in order to produce a symphony. An exhibit at the end of the exhibition path will show how that sounds were produced and explain that, since the observed information are not visible, any "translation" into sensible inputs can work. The use of digital frames in the exhibition's panels will allow a great flexibility in order to include brand new discoveries or other currently unexpected contents related to this PRIN project. Costs: panels: 10k€, musical accompaniment: 5 k€, final exhibit: 5 K€
- 1 documentary in the style of "*Quelli che la Fisica*" (https://www.youtube.com/watch?v=Y0L8rfYz0WI) about the people involved in SKA and CTA, their work and expectations and about the social aspects related to the Italian role in the CTA and SKA projects. Cost: 10 k€
- 3 educational hands-on activities for different targets involving students from all school grade levels: i) showing the global coverage of the SKA and CTA observing facilities scaled to accessible dimensions, made up of simple materials, easy to build and to reproduce; ii) using music and sounds in order to explain what a transient phenomenon is in term of duration related to the typical timescales of the Universe, using music and sounds and engaging in the research of possible

Table 3: Personnel to be hired						
Topic	**Type**	**Duration (months)**	**Cost (k€)**	**Reference structure**	**WP**	**Other structs.**
MWL search and characterisation of unidentified high energy transients and GW counterparts	RTD	24	105	IASF-BO	O1	S9
New physical insights on GRBs and TDEs in the SKA and CTA era	ADR	24	70	OABr	T2, T3	S1
The unexplored extremes of the electromagnetic emission from SNe: from gamma rays to radio	ADR	24	70	OAPd	O2	S7
MWL analysis and data mining of transient events toward the CTA and SKA era	ADR	24	70	OARm	D2, D3	
Accretion- and ejection-powered Galactic transients and development of target prioritisation strategies	ADR	18	52.5	IAPS	T1, O4	S2, S6-9
Transient events follow ups and SKA/ CTA-Athena synergy	ADR	18	52.5	IAPS	O1, D3	
Studying transients through real time imaging at the highest angular resolution with VLBI	ADR	12	35	IRA	O3, D1	S5, S6
Development of analysis techniques for high-energy transients identification and follow-up in the MM and MWL context	ADR	12	35	IASF-BO	D2	
Notes: RTD = Ricercatore a Tempo Determinato; ADR = Assegno di Ricerca						

explanations of the nature of these fascinating events. Costs: 6 k€ for the design and production of the 2 prototypes and their low cost reproducible version; 4 k€ for the production of roughly educational kits to be used in the involved structures.

All products will be designed in order to easily adapt to additional modular contents and to be easily adjustable within other contexts. All products will be available to be used within INAF Outreach and Educational activities at national and international level.

5. Resources from INAF research structures

5.1 Financial resources

IAPS 6 months co-funding for "Transient events follow ups and SKA/CTA-Athena synergy" position.

5.2 Instrumental resources

5.2.1 Radio

The following radio instrumentation is available through our structures and will be used for the activities in WPs T1, O1, O2, O3, D1:

- The **Northern Cross**, owned by the university of Bologna and operated by IRA, is one of the biggest radio telescopes in the world, with a total collecting area of about 30,000m^2. At present, a 1400m^2 part of the N-S arm (equivalent to a 42m parabolic dish), named BEST-2 (Basic Element for SKA Training), operates with 32 receivers able to generate 24 independent "electronic" beams within the antenna FoV. From 09/2017, the upgrade to BEST-4 will provide 2800m^2 collecting area (60m dish equivalent) with 64 receivers able to generate 48 independent beams inside the same BEST-2 FoV, combining high sensitivity and wide FoV at the same time. To exploit the characteristics of BEST-4 for survey observations (pulsar, FRB or transients) a dedicated back end is needed (WP D1).
- The **Medicina**, **Noto**, and (as soon as the extraordinary maintenance is completed) **Sardinia** radio telescopes, operated by IRA and OACg are available to follow up transients both as single dish instruments and as a **VLBI array**, within an ad hoc small and flexible networks that IRA coordinates through the **DiFX correlator** installed and run in Bologna. Data obtained from this resources during the 2016 Cyg X3 giant flare are the subject of WP O3, and will continue to be collected for future triggers.

5.2.2 Gamma rays

The following gamma-ray instrumentation is available through our structures and will be used for the activities in WPs T1, T4, O1, O2, O4, D2:

- Many structures within our group (S1-3, S5, S7-9) have greatly contributed to the design, development, and installation of the ASTRI dual-mirror small size telescope end-to-end prototype (**ASTRI SST-2M**). ASTRI SST-2M is installed at the Serra La Nave INAF observing station and it is currently performing commissioning and engineering tests. From Spring 2017, it will start acquiring scientific data on the Crab nebula and on a few variable sources, such as Mrk 421 and Mrk 501. The ASTRI SST-2M prototype is an important observing facility for INAF, the VHE community and our research group. Thanks to the end-to-end approach, it will allow scientists and technicians in our team to become acquainted with one of the CTA telescopes, its data collection and analysis. It will also be followed up by a nine-unit **mini array** which will start to be deployed in 2018 at the CTA southern site.
- OABr and OARm are also involved in **MAGIC,** the only experiment, among the present generation of Cherenkov instruments, able to respond to external triggers in real time. The fast reaction and the low energy (50 MeV) threshold make MAGIC a good performer in fast follow-up observations of extragalactic and galactic transients. As part of this project we are going to exploit the capabilities of MAGIC in observing non-thermal transient sources; moreover, activities carried on over the next two years will be aimed in testing the theoretical and observational background for CTA and its precursors, such as ASTRI SST-2M and mini-array.
- IAPS, IASFBO, IRA, and OACg personnel are members in the ***Fermi*-LAT** and **AGILE** collaborations, which provides our team the possibility of prompt reaction to gamma-ray transients

and to follow up with dedicated analysis tools and high-level expertise any transient reported at other wavelength.

5.2.3 MWL

The following MWL resources are available through our structures and will be used for the activities in WPs T1-4, O1, O2, O4, D2, D3:

- Our group (through OABr) is deeply involved from the design to the in-orbit operations in the **Swift** mission, actively participating to the scientific management of the mission. In the 11 years since launch, Swift's scientific program has expanded significantly beyond the realm of GRBs. Swift has become an unequaled Target of Opportunity (ToO) machine for the astronomical community. The rate of approved targets is now 4 per day, far exceeding any other mission. Thanks to its prompt reaction time, Swift provides the best suite of instruments, from optical/UV to hard X-rays, to follow-up and study newly discovered sources at other wavelengths.
- IAPS, IASF-Mi, and IASF-Bo have a significant participation in **INTEGRAL**, the wide field satellite observing the sky in hard X-rays/soft gamma rays since 2002. In 2017 and 2018, our group is leading (PI A. Bazzano) an INTEGRAL program to scan the galactic plane, for 2 Msec every year, and a ToO proposal for TDEs (PI F. Panessa).
- This project includes a large fraction of the Italian community (including the Italian PI) involved in the Imaging X-ray Polarimetry Explorer (**IXPE**) mission recently approved by NASA for a launch in 2020. Among the key science goals of the mission, there is the study of the boundary conditions of the jet launching mechanisms, including transients such as binaries and TDEs.
- Our team is also leading (at the level of PIship) many programs for space and ground-based follow-up of GRB, FRB and GW. A list is given in 5.4. We note here that in particular the INAF/OAPd optical telescopes in Asiago (Copernico 1.82m and Schmidt) are available through a guaranteed large program.

5.3 Computing resources

The following computing resources are available through our structures and will be used for the activities in WPs O1, O3, D1:

- IAPS has a BLADE architecture (UV 2000 SGI) for the processing of INTEGRAL data (WP O1), based on high speed storage and parallelisation of the data processing. The architecture uses both temporary RAMdisks and NVMe. At present, the BLADE AVES2 consists of 160 CPUs, 1TB available RAM, Numalink 6 connectivity and 2 x 48 TB Qsan F600Q-D316 SSD data storage units. The facility will be available for use within this project, if approved.
- IRA hosts and operates the software correlator for VLBI observations (WP O3) based on the Italian stations. It is currently composed of 4 "tanks" providing real-time acquisition capabilities for up to 5 stations transferring data at 1 Gbps rate, with a storage of 150 TB, and 24 cores. Flexbuff storage is being installed at the Mc and Nt stations, providing capability to simultaneously record and transmit voltage data.
- OACg has received 20 k€ funding from Sardinia government (*Bando capitale umano ad alta qualificazione annualità 2015*) to purchase by the start of this project a GPU cluster (two MB Supermicro super X9DRI-F and two VGA NVIDIA GTX980 TI, or similar), to be installed at SRT with software for real time FRB searches (WP D1).

5.4 Guaranteed time/collaborations/approved proposals

We recall here that many researchers from our project, through GRAWITA (the GRAvitational Wave INAF TeAm, PI Brocato), the space missions involved in this proposal, and the MAGIC collaboration, have signed a **Memorandum of Understanding with the LIGO/VIRGO Collaboration** to be alerted immediately after the gravitational signal is discovered. Thanks to these agreements, INAF researchers were able to promptly react to the GW events observed in 2015 showing that the Italian ‘transients’ community is extremely competitive in performing this kind of research and covering the full EM spectrum. The experience and know-how gained by the researchers of the present proposal represent a mandatory first step to develop new ideas and concrete data analysis to fully exploit the scientific outcome expected by SKA and CTA in the field of the transient sky. Thus, INAF has the unique opportunity of leading the growth of this community providing the needed human and financial support.

OAPd and OACn are members of **ePESSTO** (the continuation of PESSTO, Public ESO Spectroscopic Survey of Transient Objects; in particular S. Benetti is in the PESSTO Science Board), using the ESO New Technology Telescope and the EFOSC2 (optical) and SOFI (NIR) spectrographs. It is one of two currently running public spectroscopic surveys at ESO. OAPd personnel is also involved in **NUTS** (the NOT Unbiased Transient Survey). The membership in these two international collaborations offers the possibility of a priority access state of the art facilities of great relevance for many topics in our research project, such as SNe, TDEs, GRBs, and binaries.

Approved proposals with PI from our team for space and ground-based follow-up of GRB, FRB and GW:

GRB follow-up
- XMM-Newton (PI: D'Avanzo): 70 ks/year
- REM (PI: Melandri), 100 hours/semester
- TNG (PI: D'Elia), 10 hours/semester
- LBT (PI: D'Avanzo and Rossi): 6+16 hours/year
- ESO-VLT: (PI: D'Avanzo): 12 hours/semester
- ESO-VLT (PI: Pian): 6 hours/semester (GRB-SN)
- EVN (PI: Ghirlanda): 4x4hours/year

FRB follow-up
- REM (PI: Campana): 45 hours/semester

GW follow-up
- REM (PI: Campana): 10 hours/semester
- NOT (PI: Pian): 10 hours/semester
- ESO-VST (PI: Cappellaro, Grado): 30+30 hours/semester
- ESO-VLT (PI: Pian): 12 hours/semester
- ESO-VLT (PI: Covino): 6 hours/semester
- TNG (PI: Piranomonte): 40 hours/semester
- LBT (PI: Palazzi): 16 hours/year
- Campo Imperatore Schmidt (wide field) +AZT24 (NIR)(PI: Brocato): INAF/OAR-telescope priority for GW-ToO
- Asiago Schmidt + 1.82m (PI.: Tomasella, Pastorello, OAPd): INAF/OAPd telescope high priority for GW-ToO
- SRT (PI: Possenti, OACg): 75 hours/semester (year 2)
- ATCA (PI: Possenti): 120 hours/semester

Many members of our team are also involved in the ESO-VLT X-shooter program devoted to measure GRB redshifts (PI: J. Fynbo, DK) and in the NOT, TNG and ESO-VLT programs for the follow-up of FRB (PI; D. Malesani, DK). Many of the above programs have a long term status or are likely to be extended for the entire duration of the present research project.

6. Statements

This project has been received and approved by the Directors of all the participating INAF structures: IAPS, IASF-Bo, IASF-Mi, IRA, OABr, OACg, OACn, OAPd, OARm, OATe. All the relevant statements are annexed.

Io sottoscritto Marcello Giroletti, nato a Milano il 19/7/1975, residente a Bologna in via Ruggi 6, dipendente INAF presso la struttura Istituto di Radioastronomia, esprimo il mio assenso alla diffusione via Internet delle informazioni relative ai progetti finanziati e alla diffusione presso gli eventuali valutatori esterni, all'esclusivo scopo della valutazione stessa, delle informazioni riguardanti i progetti presentati; dichiaro inoltre ai sensi del D. Lgs. n. 196/2003 il mio consenso al trattamento dei dati sensibili e non.

Bologna, 12/1/2017,

Marcello Giroletti

Institute for Space Astrophysics and Planetology
Istituto di Astrofisica e Planetologia Spaziali

Roma 9 Gennaio 2017

Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma “CTA"

Il sottoscritto Fabrizio Capaccioni, direttore della struttura INAF-IAPS, dichiara di aver preso visione del progetto “Towards the SKA and CTA era: discovery, localisation, and physics of transient sources”, con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell’ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura.

Il Direttore IAPS-INAF
Dott. Fabrizio Capaccioni

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00133 Rome - Italy

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA - BOLOGNA

Il Direttore

Alla Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma "CTA"

Il sottoscritto Giuseppe Malaguti, direttore della struttura INAF IASF-Bologna, dichiara di aver preso visione del progetto "*Towards the SKA and CTA era: discovery, localisation, and physics of transient sources*", con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell'ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura, fatta salva, per il personale e i contrattisti a termine di qualunque tipologia, la verifica di compatibilità con il contratto stesso e con le norme di rendicontazione che lo regolano.

Bologna, 10 Gennaio 2017

Giuseppe Malaguti

ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA – BOLOGNA
Area della Ricerca di Bologna – via Piero Gobetti, 101 – 40129 Bologna – ITALY
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Istituto di Astrofisica Spaziale e Fisica Cosmica
Milano

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma "CTA"

la sottoscritta Patrizia Caraveo, direttrice della struttura INAF/IASF-MI dichiara di aver preso visione del progetto "Towards the SKA and CTA era: discovery, localisation, and physics of transient sources", con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell'ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura.

In fede,

Milano 10/1/2017

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INAF ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO DI RADIOASTRONOMIA

Bologna, 10/01/2017
Prot. n. 18/2017
Tit. 03 Cl. 02

Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma "CTA"

Il sottoscritto Dott. Steven Tingay, direttore della struttura INAF "Istituto di Radioastronomia", dichiara di aver preso visione del progetto "Towards the SKA and CTA era: discovery, localisation, and physics of transient sources", con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell'ambito del bando in oggetto (Decreto n. 70/2016). Dichiara inoltre di accettare tale progetto e che nulla osta alla partecipazione ad esso da parte del personale afferente alla struttura.

In fede,

Steven Tingay

Istituto Nazionale di Astrofisica
OSSERVATORIO ASTRONOMICO
DI BRERA

Prot. n. 21/2017

Titolo III Classe 02

Milano, 10/1/2017

Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma "CTA"

Il sottoscritto Gianpiero Tagliaferri, Direttore della struttura INAF – Osservatorio Astronomico di Brera, dichiara di aver preso visione del progetto "**Towards the SKA and CTA era: discovery, localisation, and physics of transient sources"**, con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell'ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura da me diretta.

Il Direttore
Dr. Gianpiero Tagliaferri

Oggetto: **Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma “CTA"**

Il sottoscritto Andrea Possenti, direttore della struttura INAF–Osservatorio Astronomico di Cagliari, dichiara di aver preso visione del progetto “**Towards the SKA and CTA era: discovery, localisation, and physics of transient sources**”, con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell’ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto del sottoscritto oltreché del personale afferente alla struttura: Alberto Pellizzoni, Marta Burgay, Elise Egron, Sara Loru.

Selargius, 11 gennaio 2017

In fede,

Napoli, 10 gennaio 2017

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma “CTA"

Il sottoscritto, Massimo Della Valle direttore della struttura INAF Osservatorio Astronomico di Capodimonte, dichiara di aver preso visione del progetto “Towards the SKA and CTA era: discovery, localisation, and physics of transient sources”, con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell’ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura:
Massimo Della Valle
Domitilla De Martino
Aniello Grado
Maria Teresa Botticella
Massimo Dall’Ora

In fede,

Il Direttore
Prof. Massimo Della Valle

P.I. : 06895721006 – C.F.: 97220210583
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ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

OSSERVATORIO ASTRONOMICO DI PADOVA

Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione a bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma “CTA"

Il sottoscritto Dott. Massimo Turatto, direttore della struttura INAF Osservatorio Astronomico di Padova, dichiara di aver preso visione del progetto “Towards the SKA and CTA era: discovery, localisation, and physics of transient sources”, con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell’ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura.

In fede,

Padova, 10 gennaio 2017

INAF

ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Osservatorio Astronomico di Roma
Direzione

PROT. N. 49 TITOLO III CLASSE 2 Monte Porzio Catone, 12.1.2017

Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini n.84
00136 Roma

Oggetto: partecipazione a bando competitivo per la selezione di programma di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma "CTA".

Il sottoscritto Dr. Fabrizio Fiore, Direttore della struttura INAF – OAR, dichiara di aver preso visione del progetto: "Towards the SKA and CTA era : discovery, localisation, and physics of transient sources" con coordinatore scientifico nazionale Dr. Marcello Giroletti, presentato nell'ambito del bando in oggetto (decreto n.70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura

In fede,

OSSERVATORIO ASTRONOMICO DI ROMA – ISTITUTO NAZIONALE DI ASTROFISICA – INAF

Prof. Fabrizio Fiore, Direttore

INAF

ISTITUTO NAZIONALE DI ASTROFISICA
OSSERVATORIO ASTRONOMICO DI TERAMO

Teramo, 11 gennaio 2017

Alla Direzione Scientifica
Istituto Nazionale di Astrofisica
Viale del Parco Mellini, 84
00136 Roma

Oggetto: Partecipazione al bando competitivo per la selezione di programmi di ricerca nel campo della radioastronomia "SKA" e astronomia a raggi gamma "CTA"

Il sottoscritto Prof. Roberto Buonanno, Direttore dell'INAF- Osservatorio Astronomico di Teramo, dichiara di aver preso visione del progetto "Towards the SKA and CTA era: discovery, localisation, and physics of transient sources", con coordinatore scientifico nazionale Dott. Marcello Giroletti, presentato nell'ambito del bando in oggetto (Decreto n. 70/2016) e che nulla osta alla partecipazione a tale progetto da parte del personale afferente alla struttura.

In fede,

IL DIRETTORE

Prof. Roberto Buonanno

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