ASTERICS Policy Forum

CTA Working Group

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Abstract

ASTERICS is an H2020 Research Infrastructure initiative to address cross-cutting synergies and common challenges shared by astro/particle ESFRI facilities (CTA, E-ELT, KM3NeT and SKA)

1 Introduction

The major objective of the ASTERICS initiative is to foster collaborations between ESFRI large installations (CTA, ELT, KM3NeT and SKA) to interoperate as a (virtual) integrated, multi-wavelength (MW) and multi-messenger (MM) facility. Within ASTERICS, we aim to discuss the common long-term strategies with the framework of a Policy Forum. Within CTA, we have identified three relevant topics:

- MW/joint time allocation on active galactic nuclei (AGN) and transients, e.g. gamma ray bursts (GRBs)/fast radio bursts (FRBs), between CTA, SKA and other observatories.
- MM campaigns between CTA and other facilities, in particular follow-up of gravitational wave (GW) events and neutrino telescope triggers.
- Galactic plane transients: given the large unexplored GeV (from $\sim$20 to $\sim$100 GeV) short-timescale transient space, many new phenomena may emerge, requiring simultaneous MW observations and follow-ups.

We defined three teams that worked on these three science cases from the CTA perspective. A special focus was put on the facilities mentioned above. In Section 3 we describe their main aspects, after briefly describing the CTA access and data rights model in the next section.

2 CTA Access and Data Rights

Three modes of access to the observation time of the CTA Observatory (CTAO) facility are envisaged:

- A Guest Observer (GO) Programme by which users can obtain access to proprietary observation time, submitting proposals in response to Announcements of Opportunity (AOs). Typical Guest Observer proposals will require between a few hours and 100 h of observation time.
- The Key Science Projects (KSPs) are large programmes that ensure that the key science issues for CTA are addressed in a coherent fashion, and that produce legacy data products; they require from several 100 h to beyond 1000 h of observation time.
- Director's Discretionary Time (DDT) represents a small fraction of observation time reserved for, for example, unanticipated targets of opportunity (ToOs).

The Observatory grants a 12-month proprietary period for science data delivered to the Principal Investigator (PI) of a proposal under each of these modes. The bulk of the CTAO observation time will be made available to Members of the Observatory and Associate Members. Part of the observation time may be made available to non-members. Sharing of and policies regarding observation time are decided by the Observatory Council. The Council may introduce additional time categories, with associated principles of access.

Modes of user access to CTAO data products include:

- delivery of science data to PIs of successful proposals under the access modes given above,
- archive access under which all CTA gamma-ray science data will be openly available after the proprietary period, and
- access to high-level data products such as catalogues, flux maps, light curves and spectra; these will be made openly accessible via Virtual Observatory tools.

CTA is designed for rapid reaction to external triggers and rapid generation of triggers, it is anticipated that a significant fraction of CTA proposals will be based on ToOs and that effective interaction with other major observatories will be essential to the scientific success of the facility. In the early phase of the project the KSPs are expected to form a large fraction of the observing time. Proposed KSPs with major MW/MM aspects are discussed in the sections below. A special program that foresees common time shared between large facilities is under discussion.

3 CTA MW/MW Science Cases

3.1 MW/joint time allocation of AGN and transients (GRBs/FRBs)

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3.1.1 CTA Science Case

The science involved in AGN and transients is the most clear case for which multi-wavelength campaigns play a crucial role, given the transitional nature of the observed radiation. In the following a summary of the main aspects of the science case for AGN, GRBs, and FRBs is outlined.

Concerning AGN, all the objects detected so far at VHE are so-called radio-loud AGN, in particular of the blazar type, whose relativistic jet points very near to our observing line of sight. Radio luminosity has been considered to be an important parameter determining the characteristics of the high-energy emission, and the connection between radio and gamma-ray emission has been the subject of several studies in the MeV/GeV band and the GeV/TeV band, with somewhat discrepant results depending on the considered energy band and type of source (e.g. flat spectrum radio quasars vs BL Lac type objects). The main limitation of present data is the selection bias for flaring episodes and high states, particularly in quasars, which often cannot be detected in quiescence. CTA is expected to dramatically change this picture, allowing us to obtain data from sources in quiescent states, from different spectral types, and maybe from new classes. The sheer number of observed sources will increase by orders of magnitudes, so that more types of objects will become regularly detected and, for some sources, regular monitoring will be available. Radio galaxies and radio-loud Narrow line Seyfert 1 galaxies (NLS1) are among the main classes that should accompany the large population of blazars detectable with CTA. An example of one aspect in particular where we expect to solve a currently open problem is the so-called Doppler factor crisis: TeV blazars displaying very short time scale variability (and hence are expected to have large Doppler and Lorentz factors) have only slow proper motions in their radio jets. Obtaining more radio data for these sources, and at the same time also obtaining VHE data for sources that do show superluminal motions in their jets, should indicate which are the parameters involved in this crisis: e.g. a jet transverse or radial velocity structure, the viewing angle, or something else.

GRBs are among the most energetic events in the universe. Thanks to their exceptional brightness they can be used as a unique tools to retrieve information on the high redshift universe. Forty years after their discovery, their origin and physics are yet to be fully understood. There are two main phases of the gamma-ray burst phenomenon: the prompt emission (occurring primarily at gamma-ray energies and lasting at most a few minutes), and the afterglow (a long-lasting, multi-wavelength emission which follows the main GRB event). The GRB emission is beamed in the direction of the jet motion; therefore, to observe the prompt GRB emission, our line-of-sight has to lie within the jet cone. However, as the jet is gradually decelerated over time, the beaming angle of the emission becomes wider allowing detection of the afterglow even for an observer not placed along the jet cone. Such an afterglow is called an orphan afterglow. In fact, on-axis GRBs are only the tip of the iceberg of the GRB population. For each GRB seen on axis, there should be hundreds of GRBs for which only the orphan afterglows can be detected. *Fermi*-LAT has been detecting GeV-band emission from GRBs at a rate of $> 10\ \mathrm{yr}^{-1}$ revealing a rich phenomenology. GeV emission is seen in both long and short GRBs and current observations are not inconsistent with the majority of GRBs possessing such high-energy emission. These observations indicate higher velocities of the emission zone than had been inferred previously, provide evidence for non-trivial mechanisms of emission and/or particle acceleration during the early afterglow, give constraints on the Extragalactic Background Light (EBL) at the highest redshifts so far, and lead to the strongest limits to date on the violation of Lorentz invariance. Nevertheless, in many cases, the limited photon statistics achievable with Fermi-LAT at tens of GeV have prevented firm conclusions, and many competing theoretical models remain viable. Although current ground-based telescopes have much higher photon statistics than *Fermi*-LAT, their sensitivities and energy thresholds imply a detection rate that is considerably less than one GRB yr^{-1}, and no GRB has clearly been detected so far despite efforts over the last decade. CTA will lead to a major breakthrough by detecting GRBs at an appreciable rate of $>1\ \mathrm{yr}^{-1}$ with far superior photon statistics compared to Fermi-LAT in the pivotal energy range above 10 GeV. Multi-wavelength and multi-messenger coverage of such CTA observations will be crucial to understand the engine behind these bursts.

Finally, FRBs represent one of the most mysterious astrophysical phenomena discover in recent years. They are bright, millisecond-duration transient phenomena detected in the radio waveband. The first FRB was detected in 2007 in archival data recorded as part of a 1.4-GHz survey for pulsars at the Parkes telescope. A few more than 20 have now been discovered in data from several wide field of view radio telescopes around the world, at 1.4 and 0.8 GHz frequencies. Similar to the radio signal from pulsars, the observed bursts are dispersed by the ionised plasma following the classical DM–f frequency-time relations, where DM (dispersion measure) represents the integrated density of free electrons aling the line-of-sight. The large DM values of FRBs seen so far range from about 300 cm^{-3} pc to well above 1000 cm^{-3} pc. Among other arguments, this suggests an extragalactic origin for the FRBs, although the exact phenomenon producing them is still actively debated (e.g. superflares from soft gamma repeaters, supergiant pulses from distant pulsars, Alfven waves from bodies orbiting a pulsar, or even neutron star-neutron star mergers).

Independently of their exact nature, the brightness and short durations of FRBs make them very useful astrophysical tools. For example, the DM of a large number of FRBs could be used to address the missing baryon problem in the low redshift Universe. The scattering-induced smearing of FRB signals could be used to probe the turbulent intergalactic medium. Another potential application of the detection of a population of FRBs with high measured redshifts is the study of the geometry of the Universe, via a model for the average electron density as a function of redshift. Some models for FRBs predict correlated VHE bursts on similar timescales, which would be testable only by simultaneous observations involving CTA and suitable radio facilities. CTA in connection to SKA will thus be important to constrain their nature either by direct detection or upper limits.

3.1.2 Which other facilities could bring unprecedented additional values to your science case?

Starting in the AGILE and *Fermi*-LAT era, a number of projects at the opposite end of the electromagnetic spectrum have been undertaken with radio facilities and continue to the present time. To list a few, there are VLBI projects such as MOJAVE[1], TANAMI[2], GENJI, the Boston University blazar monitoring[3], and single dish projects, e.g. in Italy (Medicina, Noto), Germany (Effelsberg), Finland (Metsahovi), and the USA (Owens Valley Radio Observatory). These monitoring projects have provided a wealth of information on the light curves of hundreds to thousands of blazars, and similar projects will certainly be very relevant in coordination with CTA activities. They have different features, as some of them provide direct images and evolution of the inner jet structure, some others are carried out with multi-frequency receivers, and some provide very densely sampled light curves (up to twice per week). The results have had great impact on the connection between emission at high energies and in the radio band, indicating some of the most important parameters driving the production of gamma rays and contributing to the debate on the exact location of the high-energy emission region. Some additional projects have been organised specifically to follow TeV sources, like in the case of M87, which has been the subject of several VLBI campaigns.

In the coming years, pathfinders and precursors of SKA, and eventually the SKA itself in its phase 1, will revolutionise radio interferometry, providing an incredible amount of data in terms of sensitivity, sky and frequency coverage. The current work has shown that connecting the properties

[1]http://www.physics.purdue.edu/astro/MOJAVE
[2]http://pulsar.sternwarte.uni-erlangen.de/tanami/
[3]http://www.bu.edu/blazars/VLBAproject.html

of (very) high-energy emission to the radio band usually is complicated by optical depth effects and by the presence of extended emission. Therefore, it is critical that the radio observatories continue and improve their monitoring projects and that they are coordinated with CTA operations. Alerts by external facilities at larger wavelengths (from radio to optical, X-rays and HE gamma-rays) will be used to trigger VHE CTA observations. In particular, instruments such i.e. SVOM for GRBs or Swift/XMM-Newton/Chandra for AGN are of great relevance for transients physics. These instruments are also of crucial for the alerts CTA will be producing as response of the CTA Real Time Analysis.

3.1.3 Specific needs for survey programmes and time synchronisation

Securing multi-wavelength observations, obtained with high angular resolution, multi-frequency (extending as high as possible, ideally to the mm-band) and with full polarisation for all the blazars that will be observed via the proposed CTA AGN Key Science Project is crucial to achieve the goals of this programme. *Zero-epoch* reference VLBI images and total flux densities are important, but also continued monitoring is needed, since variations in the radio light curve and jet structure often occur much later than the high-energy variations.

Besides the multi-wavelength connection, it will become increasingly important to consider AGN as sources of non-electromagnetic signals, including cosmic rays and neutrinos. In this multi-messenger (MM) framework, population studies are of utmost relevance for connecting cosmic rays and AGN on a statistical basis. Those population studies would benefit from the accessibility of large databases of AGN and gamma-ray blazars in particular. Moreover, for the neutrinos in particular, there are high expectations in order to put constraints on the emission models at very high energies, as highlighted by the recent first-time detection of VHE gamma rays by MAGIC from a direction consistent with an extremely high-energy neutrino event. Since MW coverage of this MM event has been vital to recognise the possible association, this will be fundamental also in future observations.

Real-time alerts of FRBs have begun to be issued only recently, with typical latency of a few hours. Follow-up observations were recently conducted by H.E.S.S., MAGIC and VERITAS (all CTA pathfinders), yielding the first upper limits on VHE afterglow emission from FRBs. CTA's superior sensitivity in particular for transients below 100 GeV will quickly improve on those results. Upcoming radio facilities with improved capabilities for FRB identification should allow more efficient follow-up for a larger number of events, critically constraining FRB models and helping to solve their mysterious origin.

3.1.4 VOTools and archival data access

Several VOTools/API/protocols are currently available (such i.e. SIMBAD, Vizier, X-match, VO-Events Alerts, etc). Those tools are definitely decisive for an efficient multi-wavelength and multi-messenger approach and maintaining them or any improved version is of great importance not only for this science case but also for the others described in this document. For the case of AGN and transients, several requirements should be pursued to understand the CTA observations: Access to archival data to obtain information about light curves and spectral energy distributions at lower energies is one useful tool in this context. The possibility to quickly browse over catalogs of known sources/galaxies as well as past archival images of the same sky regions is fundamental for transient source observations. Also, good spatial templates at other frequencies, with resolution of at least of the order of the CTA resolution (images in FITS format on different spatial scales, different frequencies, if possible also with spectral index and polarisation/rotation measure information) will be optimal. For alerts, a fast, standard protocol is also needed. Common development between facilities, e.g. such as a multi-facility scheduler, would be an improvement.

3.1.5 Modelling and numerical simulations

Modelling and numerical simulations aimed at characterising the accretion and ejection coupling, with 3D general relativity magneto-hydrodynamics simulations are, and will continue to be, essential to provide a framework against which observations from radio to very high energies will have to be tested. In particular for GRBs there is still a large suite of models which should be linked to population studies. The unknown nature of FRBs will definitely benefit of theoretical modelling to constrain the emission at very high energies.

3.1.6 Time request

The CTA Key Science Projects on AGN and Transients foresee a mean of 200 h/yrs observations devoted to those objects. The organisation of the MW observations can be roughly divided into two types of campaigns: long-term monitoring and targeted campaigns (both ToOs and pre-planned observations). For the latter, we envisage proposal-driven observatories and time granted via ToOs and memoranda of understanding (MoUs). To guarantee the long-term monitoring observations, proposal-driven observatories do not present a feasible option. In the optical band, dedicated automatic telescopes would be the best solution, while in the radio band, MoUs with existing telescopes (such as Metsähovi, Nancay, MWA, ...) could be sufficient. The possibility of long-term campaigns including X-ray facilities will need to be explored.

3.1.7 Operational Constrains

For all transients, a well organised coordinated alert system and, if possible, a common scheduling software for the involved facilities will be crucial. Fast reaction follow-ups are desirable to sample light curves of AGN with high precision. Strictly simultaneous observations are desirable but not essential.

3.2 MM campaigns between CTA and other facilities

Editors: Giulia Stratta & Sera Markoff

3.2.1 CTA Science Case

One of the main goals of multi-messenger observations is to provide a more complete phenomenological picture of several cosmic processes using information obtained from different probes. Indeed, gravitational waves (GWs) and high-energy neutrinos carry information about the sources which may be difficult to extract via electromagnetic observations alone. Specifically, GWs are produced by a non-axisymmetric mass distribution undergoing acceleration processes resulting in detectable distortions in spacetime, as for example two spiralling compact objects or the mass dynamics during collapse of a massive star. Contrary to electromagnetic emission that can suffer severe scattering effects (especially very high-energy photons), GWs can reach the observer almost unperturbed, thus carrying unique information on the matter distribution and dynamics of the innermost regions of the source. GWs that will be detected in the next two decades are confined in the high frequency range, namely from few up to few thousands of Hz, where ground-based interferometers as the current second-generation GW detectors (e.g. Advanced LIGO and Advanced VIrgo) but also the planned third one (e.g. the European "Einstein Telescope") are most sensitive. Several well known high-energy astrophysical sources that are expected to produce high-frequency GWs likely also drive relativistic outflows (e.g. gamma-ray bursts resulting from merging compact objects, core-collapse supernovae with rapidly rotating cores, flares from soft gamma repeaters), which can emit high-energy (GeV-PeV) neutrinos. Due to the small neutrino cross-section, their detection is expected to be nearly simultaneous with the GW event. The neutrino energy and spectrum (assuming we get higher statistics) will give a much more reliable view of the "parent" hadronic population than leptons, which may include both primaries and secondaries. Huge developments are ongoing in these years also on the AGN/blazar connection between gamma rays and neutrinos, making these sources another interesting target for combined VHE/neutrino detections. While the AGN-high energy neutrino connection has not been established yet, there are tantalizing hints, with two blazars flares occurring at the same time and position as two very high energy neutrino events seen by IceCube. With the low probability of detection, we do not expect to see neutrinos coincident with flares at all times, as a quiescent but high fluence source has a higher neutrino detection probability than short flares from fainter sources. We expect that obtaining CTA fluxes for a large number of AGN, either through the AGN monitoring KSP, the snapshort KSP, or the extragalactic survey will be crucial in constraining the high-energy SED to estimate whether the source has the capability to produce neutrinos, through physical modelling as well as through calculations from a particle physics point of view.

Another important goal of multi-messenger observations is the possibility to increase the detection confidence that can be obtained compared to using only one probe. For example, the sky position and the time of a GRB and/or a neutrino event can be used as priors in the challenging search of low signal-to-noise GW events.

3.2.2 Which other facilities could bring unprecedented additional values to your science case?

The search for common sources of GWs, electromagnetic radiation and high-energy neutrinos has recently become possible with the construction and upgrade of new generation observatories. Beside the incredibly powerful electromagnetic telescopes that will be available in the next years such as SKA, ELT, and CTA, GW second-generation detectors will form a world-wide based network including the two advanced LIGOs, advanced Virgo, KAGRA in Japan and I-LIGO in India. The GW detector network is expected to routinely detect GW events with a rate of tens up to hundreds per year, and with a sky localisation uncertainty of the order of tens up to few square-degrees. High-energy neutrino observatories currently in operation include IceCube, a cubic-kilometer detector at the geographic South Pole, and ANTARES in the Mediterranean sea. The multi-cubic-kilometer detector KM3NeT in the Mediterranean sea is currently under construction. The Baikal Neutrino Telescope, operating in southern Siberia, is also planned to be upgraded to a km^3 volume in the future. The main targets of these facilities include high-frequency GW sources (see above) as well as AGN and several class of Galactic transients.

3.2.3 Specific needs for survey programmes and time synchronisation

The GW sources that will be detected in the next years are those emitting at high frequencies in the GW spectrum, i.e. a few up to a few thousand Hz. Indeed, this is the frequency range to which ground-based interferometers are sensitive. The most promising high frequency GW sources are compact binary coalescences, core collapsing massive stars and flaring isolated neutron stars – in other words, transient sources. GW and neutrino detectors can be considered as all-sky monitors, with high duty cycle (80%–99%). Together with other electromagnetic survey telescopes, these facilities will provide alerts of possible new candidate detections. Given the transient nature of these sources, with still very uncertain timescales but possibly of the order of seconds or minutes, fast follow-ups are required with CTA, SKA, etc. The possibly large sky error box obtained from the GW source detections if, for example, only two interferometers are observing, could in principle be monitored by both CTA sites simultaneously.

CTA transient source detections (e.g. AGN flares, GRBs, etc.) will trigger follow-up campaigns with other large facilities that will be available in the 2020s (e.g. SKA, ELT, etc.) via Real Time Analysis (RTA) mode. Neutrino telescopes as IceCUBE and KM3NeT will analyse offline data taken in a temporal window centered at the time of the event. A very useful technique, already applied for fast radio transients, is the possibility to follow the CTA pointing simultaneously with optical or radio telescopes in order to be able to: 1) provide a multi-wavelength coverage of very fast transients and 2) enhance the detection confidence of low signal to noise threshold sources.

3.2.4 VOTools and archival data access

The possibility to quickly browse over catalogs of known sources/galaxies as well as past archival images of the same sky regions is fundamental for transient source observations. Up to now, new transient data in many bands are managed individually or by disconnected small groups. Effective VO tools including interoperating data archives and shareware are critical to support this kind of science.

3.2.5 Modelling and numerical simulation

Several sources requiring a multi-messenger approach are still poorly understood and to plan and optimise observational strategies, both modelling and numerical simulations are needed. For example, the expectation to observe GW sources such as neutron star mergers in the electromagnetic spectrum, as well as for example the association of a short gamma-ray burst or an *orphan afterglow* with such mergers, is fully based on modelling and numerical simulations. In general, simulations require massive amounts of CPU hours. So far, the EU is lagging the US in state-of-the-art high-performance computing. An effective funding programme on this issue has to be part of the overall approach in order to support the development of theoretical models of relativity and accretion/jet production.

3.2.6 Time request

A very rough estimate may be driven by the expected annual rate of GW sources. For example, for neutron star-neutron star mergers (the most promising GW sources for electromagnetic observations), a realistic estimate is 40 events per yr. Assuming that a 10% can be followed up with CTA and considering a minimum of five hours of exposure each, we estimate a few tens of hours on this type of events per year. A round up number of ∼50 h per year is obtained when including other kind of GW sources.

3.2.7 Operational constraints

It is possible that several transients may be very fast, on second-long timescales. Very fast reaction (<=20s) to follow-up GW event candidates/short GRBs/neutrino events/fast radio bursts is mandatory.

3.3 Galactic Plane transients

Editors: Alessandro Papitto & Emma de Oña Wilhelmi

3.3.1 CTA Science case

Observing the VHE emission from Galactic compact objects is crucial to understand the processes responsible for particle accelerations, as they offer the closest and *cleanest* available experimental set-up for this purpose. Accreting stellar-mass black holes and neutron stars, either isolated or in binary systems, are capable of launching relativistic jets and winds of particles which subsequently convert their energy into high-energy particles and photons. A large fraction of these systems exhibits transient activity at all wavelengths. This peculiarity offers unprecedented opportunities as the timescales of variability and the recurrence times (from years to less than a second) can be used to probe the physical and geometrical conditions of the emitter. The variability of Galactic accreting black holes duplicates, on time-scales accessible to humans, the accretion and jet phenomena seen from active galactic nuclei. The correlation observed between the black hole mass and the radio and the X-ray luminosities (the so-called fundamental plane of black holes) suggests that the accretion and ejection processes are scale invariant. Observations of Galactic accreting black holes are then crucial to understand accretion and ejection of mass at much larger scales, that likely play a crucial role in Galaxy formation and evolution. Time variability of Galactic transients is a powerful tool to understand these objects that requires dedicated observing strategies.

Predicted transient Galactic VHE emitters include (i) flaring pulsar wind nebulae, (ii) microquasars (accreting black holes or neutron stars that tear off matter from either a high or a low mass companion star), and (iii) rotation-powered pulsars in binary systems. Additional candidate VHE transient emitters include (iv) flaring highly-magnetised neutron stars (magnetars), (v) thermonuclear explosions on compact object surfaces (such as novae on accreting white dwarfs), (vi) tidal disruption events, (vii) the supermassive black hole at the Galactic centre, (viii) colliding wind binaries (such as Eta Carinae), and (ix) serendipitous sources.

3.3.2 Which other facilities could bring unprecedented additional values to your science case

Alerts by external facilities at larger wavelengths (from radio to optical, X-rays and HE gamma-rays) will be used to trigger VHE CTA observations. In addition, coordinated multi-wavelength observations will be crucial to address the nature of the emitting objects and to give constraints on the processes responsible for the VHE emission through, e.g., multi-band spectral energy distribution modelling. For example, the detection of coherent pulsations at radio or X-ray wavelengths identifies the compact object as a neutron star, while the multi-band spectral energy distribution measures the overall energy budget and allows for model fitting. On the other hand, the unprecedented CTA sensitivity will allow us to search for VHE emission of known and new transients discovered at lower energies (e.g. in X-rays and lower gamma rays), to characterise the highest energy radiation processes. Also considering the relatively poor angular resolution of CTA compared to radio or X-ray facilities, observations at almost every wavelength will be useful. These will include:

- GeV gamma rays (mainly from continuous Fermi-LAT all-sky coverage) and MeV gamma rays (INTEGRAL IBIS and Swift BAT for the brightest events, and possibly future missions, like proposed ESA M5 mission eASTROGAM),
- X-rays (relevant current missions are XMM–*Newton*, especially to look for spectral and timing features, e.g. X-ray pulsations from neutron stars, *Chandra*, for detection of faint sources and imaging capabilities, *Swift* for monitoring studies. In the 2020s NASA-IXPE will open X-ray polarimetry science, supported by the ESA-XIPE if approved, and in the 2030s, Athena will provide the most sensitive X-ray instrument ever flown with a high spectral resolution).
- optical (photometry and spectroscopy, e.g. for the identification of binary companions and the presence of accretion disks, including ESO e-ELT for single-object observations), and
- radio (searches for pulsations and/or jet signatures, including obviously the advent of the SKA in the future).

Possible coordination with multi-messenger facilities is foreseen related to neutrino alerts. Indeed, neutrino detectors such IceCube are routinely sending alerts not only to optical, X-ray and hard X-ray telescopes, but also to high and very high-energy ones. Neutrino fluxes should be accompanied by a detectable gamma-ray flux in the VHE range which should be detectable by CTA.

3.3.3 Specific needs for survey programmes and time synchronisation?

Monitoring gamma-ray and X-ray observations, as well as those simultaneous to CTA pointing, will have a key role as the timescales of variability are expected to be similar to those in the VHE regime (hours to weeks for pulsar wind nebulae flares, days to months for changes of state of micro-quasars). While Fermi-LAT performs continuous observations of the gamma-ray sky, X-ray and radio observations are pointed and require dedicated observing strategies. These include anticipated target of opportunity observations to follow predictable events (e.g. related to the orbital motion of gamma-ray binaries), to monitor the evolution of outbursts of micro-quasars (in coordination with radio observations), or to follow unpredictable events (e.g. flares from pulsar wind nebulae, novae or giant flares from magnetars). Wide field optical surveys (such as those provided by LSST) will be crucial to classify the nature and time-scales of variability, while strict simultaneity will be less compelling for observations related to classification purposes (e.g. optical photometry and spectroscopy). Proposals for anticipated target of opportunity observations should be submitted in response to the announcement of opportunity of the various observatories by existing teams of experts. A common programme to share time between the large facilities in particular objects will also be ideal.

3.3.4 VOTools and archival data access

Access to archival data is crucial to identify and classify flaring events in the CTA field-of-view. Confronting gamma-ray sources lying within the large field-of-view covered by CTA ($\sim 10^{o}$) with archival observations at low energies will allow us to 1) identify the accelerator/emitter and 2) optimise the best follow-up strategy.

3.3.5 Modelling, and numerical simulations?

Tools to model the spectral energy distribution (SED) of the above-mentioned known sources will help to constrain the physical parameters. The development of magneto-hydrodynamic (MHD) simulations will also help to understand the mechanisms behind fast flaring in objects such pulsar wind nebulae.

3.3.6 Time request

The amount of CTA time needed for multi-wavelength coverage of Galactic transients will crucially depend upon the flux and duration of the events. The CTA science case document estimates a total of 150 hr/yr/site during the early, commissioning phases of CTA and 30 hr/yr/site during the first two years of full operations.

3.3.7 Operational constrains

The identification and modelling of Galactic transients will greatly benefit from follow-up observations in the time range of hours to days as well as an efficient system of alerts.

3.4 Summary

Table 1: Summary of the MW/MW CTA Science Cases

	MW AGN & Transients	MM Campaigns	GP Transients
Physics Case	Flat spectrum radio quasars, BL Lacs, Radio galaxies, radio loud narrow line Seyfert 1 galaxies; prompt and afterglow emission in GRBs; FRBs	Gravitational waves and high-energy neutrinos from hadronic accelerators	Flaring pulsar wind nebulae, microquasars, pulsar binary systems, magnetars, novae, tidal disruption events, Galactic Centre, colliding wind binaries, and serendipitous source
Facilities	Monitoring facilities, SKA and precursors; AGILE, Fermi-LAT and X-ray satellites	SKA, ELT, GW second generation detectors: LIGO, VIRGO, KAGRA, I-LIGO, IceCube & KM3NeT, Baikal	Fermi-LAT, INTEGRAL IBIS, Swift BAT, eASTROGAM, XMM-Newton, Chandra, IXPE, XIPE, Athena, optical TLCs and SKA
Surveys/Time synchronisation	Monitoring and ToOs	Alerts of the order of secondsminutes following CTA observations	Simultaneous X-ray (similar timescale variability); ToO observations for MW follow-ups and shared time
VOTools / Archival Data	Fundamental to obtain information about light curves and SEDs	Crucial for localisation and identification	Fundamental for source identification and observation strategy optimisation
Modeling/Numerical Simulations	3D MHD & GRB modeling	VHE predictions; high-performance computing	SED and MHD simulations
Requested Time	∼100 h/yr	∼50 h/yr	∼150 h/yr