Macón Ridge Astronomical Site
The ABRAS and TOROS projects

Thematic Areas:
Astronomy and Astrophysics
Cosmology
Gravitational waves

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ABSTRACT
This white paper describes the first stage in the development of a new astronomical site in Argentina at the Macon Ridge. In its initial phase the development consist of two projects: the ABRAS project and the TOROS project. Both are complementary in nature and require a common infrastructure, which is at an advanced stage of development but will require additional funding to be completed and to be able to sustain regular operations.

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1 Introduction

The first detection of gravitational waves (GW) emitted by the merger of a Binary Black Hole (Abbott et al. 2016b) is probably the most important scientific discovery of the century, and heralded the start of the gravitational-wave astronomy era.

On October 20, 2017, Edo Berger (Harvard) wrote in the introduction to a special issue of the Astrophysical Journal Letters: “It is rare for the birth of a new field of astrophysics to be pinpointed to a singular event”[1]. The entire astronomical community has agreed with this statement: the simultaneous first detection of a binary neutron star merger using gravitational wave detectors —and telescopes covering the entire range of the electromagnetic spectrum— constitutes the beginning of Multi-messenger Astronomy (Abbott et al. 2017f). It is precisely this new window into the Universe, highly anticipated but with an uncertain start time, that prompted an announcement in 2016 by NSF[2]. Dr. France Córdova, NSF Director, unveiled at the time a research agenda intended to shape the agency’s next few decades formulated around six “big ideas”. One of them is: “Windows on the universe: multimessenger astrophysics”, building on the detection of gravitational waves. The combination of these detections with electromagnetic-wave astronomy and the study of high-energy particles enables us to probe the universe in a manner that we could not before. Each of these regimes provides a different perspective that combine to give a richer and more comprehensive view of the universe. Multi-messenger astronomy allows us to study matter, energy, and the cosmos with a new transformational methodology.

2 Scientific Context

Advanced LIGO (Aasi et al. 2015; Harry & LIGO Scientific Collaboration 2010), Advanced Virgo (Accadia et al. 2012; Acernese et al. 2015, 2009) and KAGRA (Aso et al. 2013; Somiya 2012) are kilometer-scale gravitational-wave (GW) detectors that are sensitive to GWs with frequencies of $20 - 2000$ Hz.[3] The era of GW astronomy began with the detection of GW150914 (Abbott et al. 2016b), a signal from the coalescence of a binary black hole (BBH). On August 17 2017 the first confirmed multi-messenger counterpart to a GW event was associated with GW170817 (Abbott et al. 2017e), a signal from a binary neutron star (BNS) coalescence which was accompanied by detections across the electromagnetic spectrum (Abbott et al. 2017f) .

Although the full science of ground-based GW detectors is broad (Abbott et al. 2016b) in this white paper we concentrate solely on GW transient events and in particular in the coalescence of BNS systems, which are the GW source for which electromagnetic follow-up is most promising (Metzger 2017; Metzger & Berger 2012; Paschalidis 2017; Patricelli et al. 2016; Rosswog et al. 2017). It is important to remember that BBHs have been the

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[1] E. Berger, Focus on the Electromagnetic Counterpart of the Neutron Star Binary Merger GW170817, http://iopscience.iop.org/journal/2041-8205/page/Focus_on_GW170817

[2] http://www.sciencemag.org/news/2016/05/nsf-director-unveils-big-ideas-eye-next-president-and-congress

[3] LIGO is short for Laser Interferometer Gravitational-Wave Observatory. KAGRA is an abbreviation for KAmioka GRavitational-wave Antenna.

most commonly-detected source thus far (Abbott et al. 2016a, 2017a). Despite that no electromagnetic emission is expected for vacuum BBH mergers (Centrella et al. 2010), there could be exceptional scenarios involving surrounding material (Schnittman 2013), that could have been produced by mass loss from the parent star (Janiuk et al. 2017; Perna et al. 2016) or if the binary was embedded in a circumbinary disc or a common envelope (Bartos et al. 2017; Stone et al. 2017; Woosley 2016).

There are still clear uncertainties as to the frequency of these events and the improvements in search methods and the progress in the commissioning and final operation of the detectors undergoing through the planned upgrades. The standard figure of merit for detector sensitivity, is the range, the volume- and orientation-averaged distance at which a compact binary coalescence consisting of a particular mass gives a matched filter signal-to-noise ratio (SNR) of 8 in a single detector (Abbott et al. 2018; Finn & Chernoff 1993).

The past and anticipated strain sensitivities for aLIGO, AdV and KAGRA are shown in Fig. 1.

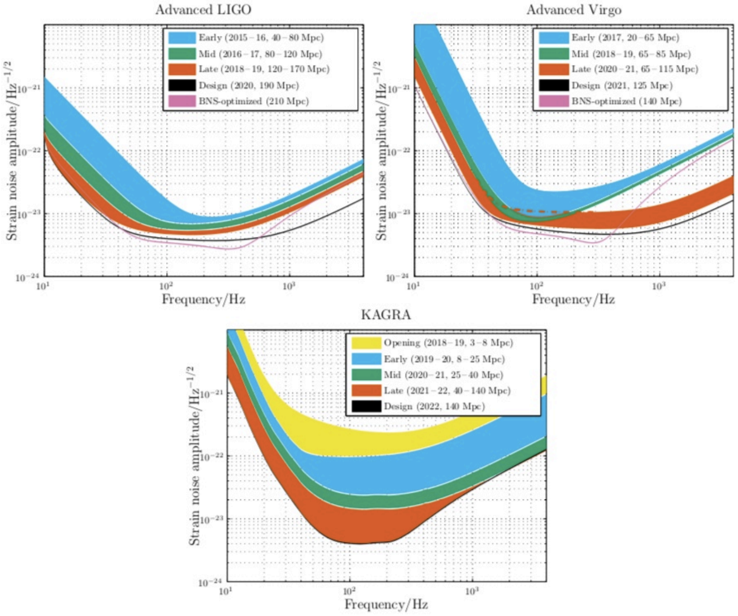
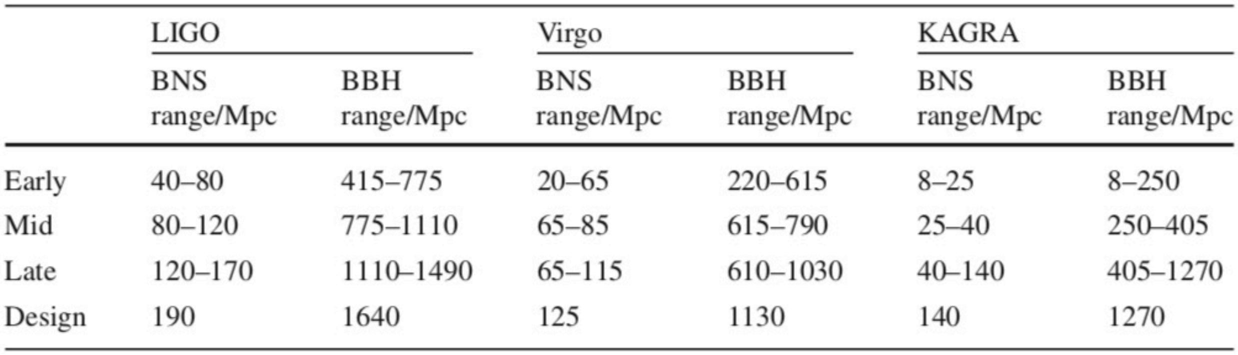


Figure 1: aLIGO (top left), AdV (top right) and KAGRA (bottom) past and future strain sensitivities as a function of frequency. The binary neutron star (BNS) range is given in units of megaparsecs (Abbott et al. 2018).

The BNS ranges, assuming two $1.4M_{\odot}$ neutron stars, for the various stages of the expected evolution are provided in Fig. 1 and the BNS and BBH ranges are quoted in Fig. 2.

It is estimated that the expected number of BNS coalescence detections using the inferred 90% credible range for the BNS source rate density, is between $320 - 4740\ Gpc^{-3}yr^{-1}$ (Abbott et al. 2017e).

The O1, O2 and O3 electromagnetic follow-up programs were great exercises to point out all the challenges and peculiarities associated with searching for counterparts. It proved the practicability to identify and send out gravitational-wave candidates within 30 minutes and



	LIGO		Virgo		KAGRA	
	BNS range/Mpc	BBH range/Mpc	BNS range/Mpc	BBH range/Mpc	BNS range/Mpc	BBH range/Mpc
Early	40–80	415–775	20–65	220–615	8–25	8–250
Mid	80–120	775–1110	65–85	615–790	25–40	250–405
Late	120–170	1110–1490	65–115	610–1030	40–140	405–1270
Design	190	1640	125	1130	140	1270

Figure 2: The different phases of aLIGO, AdV and KAGRA, matching the sensitivities shown in Fig. 1. In the case of aLIGO, "Mid" refers to the O2 run (already completed) and "Late" to the O3 run (ongoing). AdV and KAGRA timelines are shown in Figure 1. The range is the average distance to which a signal could be detected, for a $1.4M_{\odot} + 1.4M_{\odot}$ binary neutron star (BNS) system and a $30M_{\odot} + 30M_{\odot}$ binary black hole (BBH) system.(Abbott et al. 2018).

to obtain prompt electromagnetic observations.

GW150914 (the first GW detection) was followed up by 25 teams (including our TOROS collaboration) which operated ground- and space-based instruments spanning 19 orders of magnitude in electromagnetic wavelength (Ackermann et al. 2016; Annis et al. 2016; Brocato et al. 2018; Connaughton et al. 2016; Copperwheat et al. 2016; Díaz et al. 2016; Evans et al. 2016; Hurley et al. 2016; Kasliwal et al. 2016; Kawai et al. 2017; Lipunov et al. 2017; Morokuma et al. 2016; Palliyaguru et al. 2016; Savchenko et al. 2016; Smartt et al. 2016; Soares-Santos et al. 2016). No significant electromagnetic counterpart was found. The TOROS collaboration has also participated in the O2 observational campaign, following up several BBH mergers (Artola et al. 2019).

GW170817 was the first GW transient for which a firm electromagnetic counterpart was discovered (Abbott et al. 2017e). On 2017 August 17 12:41:06 UTC, Fermi-GBM triggered on the short GRB 170817A (Goldstein et al. 2017), and a GCN was sent after 14 s. About 6 min later, a GW trigger was identified; the signal was consistent with a BNS coalescence (Abbott et al. 2017d) occurring ∼1.7 s before the GRB 170817A (Abbott et al. 2017c), and a GCN was issued at 13:08:16 UTC. A three-detector GW localization was issued within 11 h of detection. An extensive observing campaign was launched, leading to the discovery of the bright transient AT 2017gfo at the 1-m Swope telescope (Coulter et al. 2017), and confirmed by other teams within the hour. The TOROS collaboration obtained photometry for two nights following the event (Díaz et al. 2017). The multimessenger observations conducted allowed for different studies ranging from astrophysics to fundamental physics and cosmology. An overview of the extensive multi-messenger observations is given in Abbott et al. (2017f). The GW and gamma-ray data show that the BNS coalescence and the GRB are associated (Abbott et al. 2017c). The time delay of ∼1.7 s between the two places a constraint on the size and bulk Lorentz factor of the emitting region; furthermore, this delay constrains the difference between the speed of light and the speed of gravity, places new bounds on the violation of Lorentz invariance, and tests the equivalence principle by constraining the Shapiro delay between gravitational and electromagnetic radiation (Abbott et al. 2017b). These results limit the range of potential viable alternative theories of gravity (e.g., Arai & Nishizawa (2018); Baker et al. (2017); Boran et al. (2018); Creminelli & Vernizzi (2017); Ezquiaga & Zumalacárregui (2017); Sakstein & Jain (2017)). Furthermore GWs can be used as standard sirens for cosmological measurements (Schutz 1986). Combining the inferred GW distance with the redshift of the host galaxy enabled a determination of the Hubble constant (Abbott et al. 2017b); this technique should be competitive with traditional methods (Planck Collaboration et al. 2015; Riess et al. 2016) once ~ 50 events are characterized.

Starting with O3 in April 2019, information on significant gravitational-wave candidate events started to be released publicly with a few minutes of latency to any interested observatory. Following the detection of a GW transient, posterior probability distributions for the position are constructed following a Bayesian framework (Abbott et al. 2016c; Cornish & Littenberg 2015; Singer & Price 2016; Veitch et al. 2015), with information for the sky localization coming from the time of arrival, plus the phase and amplitude of the GW. The probable localization is constructed essentially performing a triangulation using the observed time delays between sites. Providing prompt localizations for GW signals helps to maximize the chance that electromagnetic observatories can catch a counterpart. Localizations are produced at several different latencies, with updates coming from more computationally expensive algorithms that refine our understanding of the source.

The median localization was shown to be $\sim$100-200 sq.deg. for a two-detector network in O1 and $\sim$ 60-110 sq.deg. for a three-detector network in O2. A high mass BBH like GW150914 (Abbott et al. 2016b), could be detected by both burst and CBC analyses. In this case, we expect that the CBC localization, which makes use of the additional information available from constraining signals to match waveform templates, is more accurate than the burst localization (cf. Vitale (2016)).

The inclusion of the third detector to the network enhances localization whether or not it detects the signal, provided that it could do so, as the observed amplitude constrains the source position. As a result of being observed with a three-detector network, and its high SNR, GW170817 has the best GW localization to date.

O3 is envisioned to be a year long-run with three detectors. The aLIGO and AdV sensitivities will be similar to the late -and mid- bands of Fig. 1 respectively, with BNS ranges of 120-170 Mpc and 65-85 Mpc, and burst ranges of 75-90 Mpc and 40-50 Mpc for $EGW = 10^2\ Mc^2$. This gives an expected range of 1-50 BNS detections. Both the maximum distance and the accuracy in sky localization should increase relative to the 2016-2017 run.

Presently, GW detections are promptly communicated to the astronomical community using the Gamma-ray Coordinates Network (GCN) system, already widely used for the multiwavelength follow-up of gamma-ray bursts.[4] Messages are sent as machine-readable GCN Notices and as prose GCN Circulars, and astronomers communicate the results of observations using GCN Circulars. A shared infrastructure, including a database of results, allows observing

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[4] Details about the GCN system are available from http://gcn.gsfc.nasa.gov

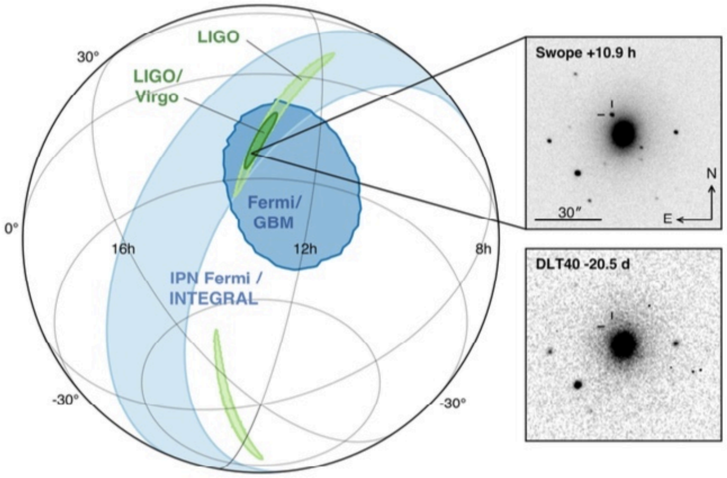

Figure 3: Localization of the gravitational-wave, gamma-ray, and optical signals for GW170817. The left panel shows an orthographic projection of the 90% credible regions from LIGO (190 sq.deg.; light green), the initial LIGO-Virgo localization (31 sq.deg.; dark green), IPN triangulation from the time delay between Fermi and INTEGRAL (light blue), and Fermi-GBM (dark blue). The inset shows the location of the apparent host galaxy NGC 4993 in the Swope optical discovery image at 10.9 hr after the merger (top right) and the DLT40 pre-discovery image from 20.5 days prior to merger (bottom right). The reticle marks the position of the transient in both images -reproduced from Abbott et al. (2017f)-

partners to announce, coordinate and visualize the coverage of their observations.

As evidenced by the observation of GW170817, the localization of gravitational waves by the network of three detectors is expected to be of a few tens of square degrees (Fig 3). Thus the electromagnetic observations need to deal with a rather large positional uncertainty. Figure 4 shows the expected light curve of the EM counterpart of a BNS merger at a distance of 200 Mpc, as well as the signal-to-noise ratio of the resulting TOROS photometry.

2.1 Objectives

These considerations have driven us to design a system with the largest possible aperture within the budget restrictions (primary mirror diameter of 0.6m) and a large field-of-view (10 sq.deg.) camera with a very broad bandpass ($0.4 - 0.9$ μm, equivalent to a combination of the Sloan *griz* filters). The system, currently under development, will be installed atop Cordón Macón in the Argentine portion of the Atacama Plateau. This dedicated instrument to follow-up candidate events in the Southern Hemisphere will fill a niche and offer extended coverage of the southern skies. Further description of the site can be found in the existing facilities description.

The telescope (Planewave CDK24 with LT500 mount: see Figure 5) and its dome (Ashdome Lanphier type) have been already purchased with funds provided by the USA National Science Foundation (NSF) and have been already installed at the site. NSF approved in July of

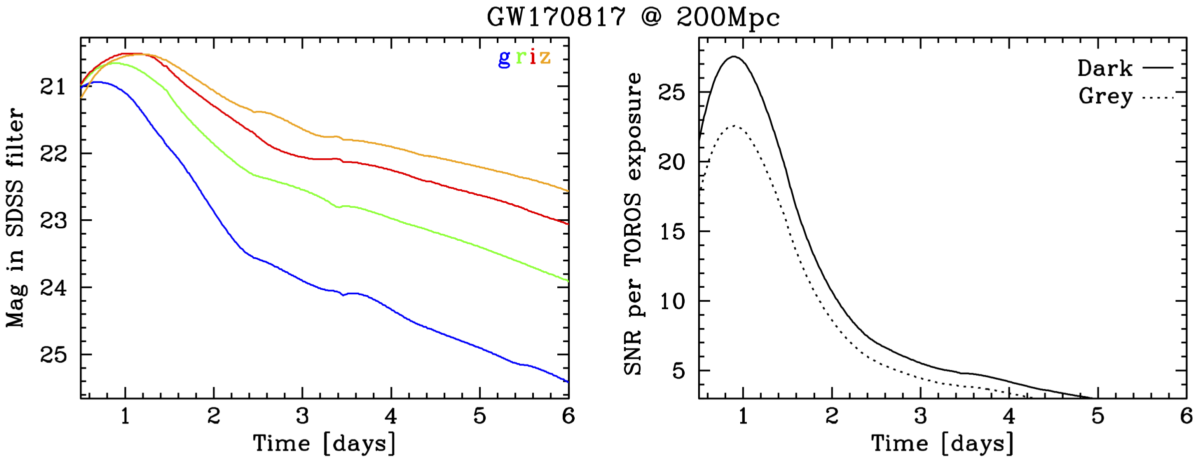

Figure 4: Left: light curves of GW170817 (Cowperthwaite et al. 2017) shifted to a distance of 200 Mpc. Right: expected SNR of TOROS photometry of such an event. “Dark” and “grey” refer to typical sky brightness values associated with the new and quarter Moon, respectively. Even in the most pessimistic case, TOROS remains sensitive (SNR> 3) to kilonova events for at least 4 days.

2019, under the program Windows on the Universe, funds for the purchase of the camera (based on a $10K \times 10K$ backside-illuminated STA1600LN CCD) and the manufacture of the prime-focus corrector to maximize the field of view of the telescope. Both of them are already under construction with commissioning expected by December 2020.

The TOROS telescope with its detector at design sensitivity will find an ideal complement in the neighboring ABRAS telescope. The Argentina-Brasil Astronomical Center (ABRAS) is a project involving both Latin-American countries. The main institutions behind the project are the IATE, from Argentina, and the IAG (Instituto de Astronomía, Geofísica e Ciencias Atmosféricas), from Sao Paulo, Brasil, while the funding institutions are the Ministerio de Ciencia, Tecnología e Innovación Productiva and the University of Sao Paulo (Universidade de Sao Paulo, USP). The infrared-optimized 1 meter telescope was delivered to Córdoba (Argentina) in late 2015, and the dome was built on Cerro Macón in 2012. ABRAS will be able to carry out both near-infrared imaging and optical spectroscopic follow-up characterization of transients idenditifed by TOROS. The main objective of both projects at this stage is to finish installation at the site and secure regular operations of both facilities (ABRAS and TOROS).

2.2 Methodology

TOROS will be a fully robotic facility, driven by a priority-based intelligent agent/scheduler. We currently envision three modes of operation in decreasing order of priority: (1) follow up of gravitational-wave triggers; (2) follow up of short-duration γ-ray bursts that will serve as LIGO triggers; (3) baseline imaging of the entire surveyable area.

The area of extragalactic sky accesible to TOROS on any given night ($\delta < 35°, |b| > 15°$, elevation$> 30^\circ$ for > 3 hrs) is $7 - 11 \times 10^3$ sq.deg. depending on the time of the year. This implies an observable trigger rate of $0.1 - 1$ per month for the three-interferometer case.

We plan to obtain 5-minute exposures so that we can complete three full searches of the median localization area even in the shortest nights of the year, while obtaining a sufficient SNR for the EM counterpart of a GW event at the maximum expected distance of 200 Mpc. Our exposure time calculations predict a $> 15\sigma$ detection at peak luminosity under grey sky conditions (first or last-quarter Moon); this improves to $> 20\sigma$ under dark sky conditions. Taking overheads into account (90s for readout & offset), our system will be capable of covering the entire median localization area for a two-interferometer scenario detection (250 sq.deg. or 26 pointings) in < 3 hours. We plan to repeat observations on a nightly basis to obtain a minimum of 4 epochs, but we will provide an initial list of possible counterparts once the first night of observations is completed, based on an automated pipeline processing using our baseline imaging (see §2.2.2).

In the event of a detection by both LIGO and AdVIRGO (such as the case of GW170817) we will be able to cover the median localization area in just two pointings, increasing our cadence by 13×. Hence, the co-added nightly imaging will have 3.6× higher SNR and we will be able to release an initial list of possible counterparts after only 3 hrs. of observations.

We will promptly release coordinates of potential transients through the GCN circular method, and stacked images to the entire astronomical community. Additionally, we plan to execute our own photometric and spectroscopic followup. The photometric followup will make use of the Bosque Alegre 1.5-m telescope in Córdoba and additional resources from the members of the TOROS collaboration in Chile and Argentina (CASLEO observatory in San Juan, Argentina and the Mammalluca observatory from La Serena University in Chile). The spectroscopic followup will be conducted using the ABRAS telescope but also the Gemini, Gran TeCANVLT 8-m telescopes, through target-of-opportunity time to be obtained via the US share of Gemini, and by our Chilean and Mexican collaborators with access to the other facilities.

2.2.1 Follow up of short-duration γ-ray bursts

In the absence of ongoing gravitational-wave triggers, the next highest priority of TOROS will be the follow up of γ-ray bursts. GRBs will be used as triggers to search for gravitational-wave signals in aLIGO & AdVIRGO (Abadie et al. 2010; Kelley et al. 2013). The *Fermi* GBM alert rate is ~ 200 events/year (source: NASA/Fermi data center).

The *Fermi* satellite GRB monitor (GBM) provides alerts within 15s of an event with initial localization uncertainties very similar to the ones associated with GW events (e.g., hundreds of square degrees). Thus GBM GRBs afterglows are not typically searched for by optical telescopes. Only in the last few years the Palomar Transient Factory and the Zwicky Transient Facility started to perform this search in the Northern hemisphere (Laher 2018; Singer et al. 2013). We plan to follow-up GBM events by performing a similar strategy used to detect the GW counterparts.

2.2.2 Baseline imaging survey

In order to facilitate a prompt, high SNR detection of GW and GRB counterparts, it is critical to have previous imaging of any region of interest using the same instrument. Furthermore, it is highly desirable to have previous knowledge of the rates of transients and variable sources with similar temporal characteristics, in order to be able to estimate the foreground/background contamination rate from other astrophysical events.

To this end, at the start of TOROS operations we will begin to survey the entire observable sky away from the Galactic plane ($\delta < 35°, |b| > 15°$), consisting of $\sim 24,690$ sq.deg. that can be covered in 2,560 pointings. We will obtain two images per pointing for cosmic-ray rejection and reach the same effective depth as our GW/GRB observations (18 minutes of telescope time, including overheads). This will require 752 hrs of telescope time to complete. For comparison, the number of potentially useful hours of telescope time per year (defined as all hours between evening and morning 18-degree twilight with the Moon below the horizon, or with the Moon above the horizon and an illumination fraction below 50%) is ~ 2006 (not taking weather losses into account). Given the extremely high fraction of cloudless nights at Macón $> 90\%$ (Renzi et al. 2009), we will easily complete the baseline imaging within the first year of operations.

3 Current Status

3.1 The TOROS telescope

The TOROS system will be comprised of a commercial-off-the-shelf (COTS) mount, main telescope optical tube, and CCD system and a custom wide-field corrector, which will be custom designed and built. A custom interface between the telescope and the corrector/CCD system will also be required.

The preliminary COTS components selected are: (1) a PlaneWave 24-inch CDK Optical tube[5]; (2) an LT 500 Direct drive mount[6]; and (3) a STA, Inc. STA1600 CCD system[7]. This optical tube provides a 610mm aperture using a prolate ellipsoid primary mirror and it is sufficiently lightweight to be held by the LT500 mount. The STA1600 is the largest format CCD system currently available (10560x10560 pixels). We have specific cost quotes for these components that are shown in the budget.

As described in §2, TOROS requires a ~ 10 sq.deg. field-of-view and $\sim 1''$ image quality; there are no commercially available telescope systems (or specific corrector optics) that can meet these requirements. Therefore, a custom corrector optical assembly will replace the secondary structure on the optical tube and will provide the interface between the primary mirror and the CCD focal plane. The system will be a "prime focus" imager with a 4-element corrector; given the STA1600 pixel size of 9 μm, we require an optical system with a focal length of ~ 1815 mm that functions with good image quality at $f/3$. The left panel of Figure 5

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[5] http://planewave.com/products-page/telescopes/24-inch-cdk-optical-tube-assembly/

[6] https://planewave.com/products-page/mounts/l-500-mount/#.W94pAC-ZMpQ

[7] http://www.sta-inc.net/product-1

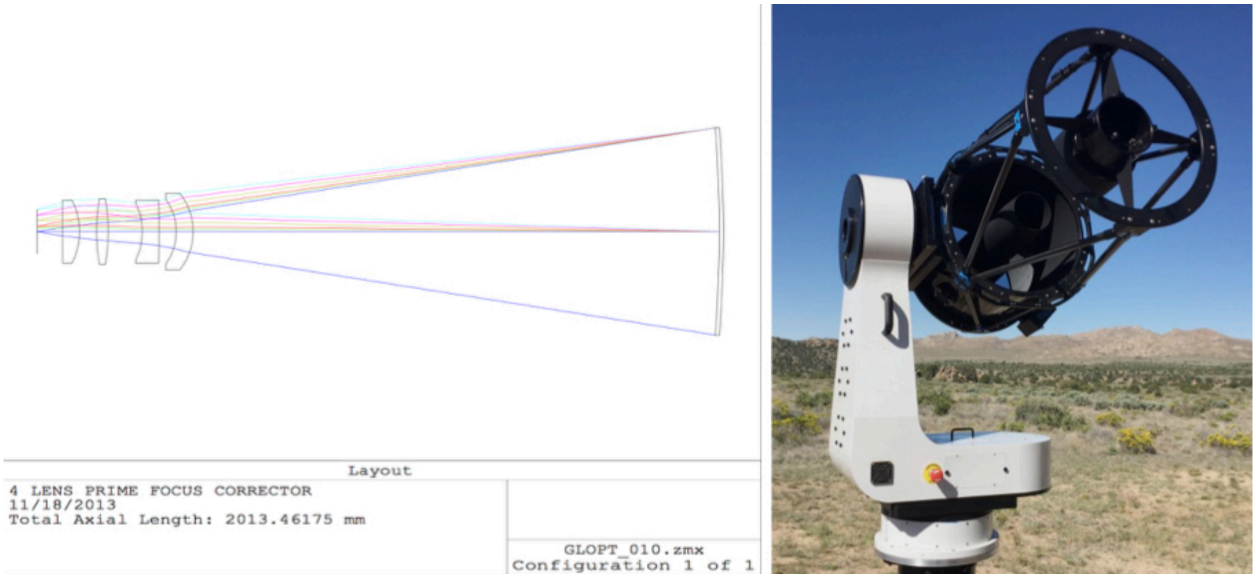
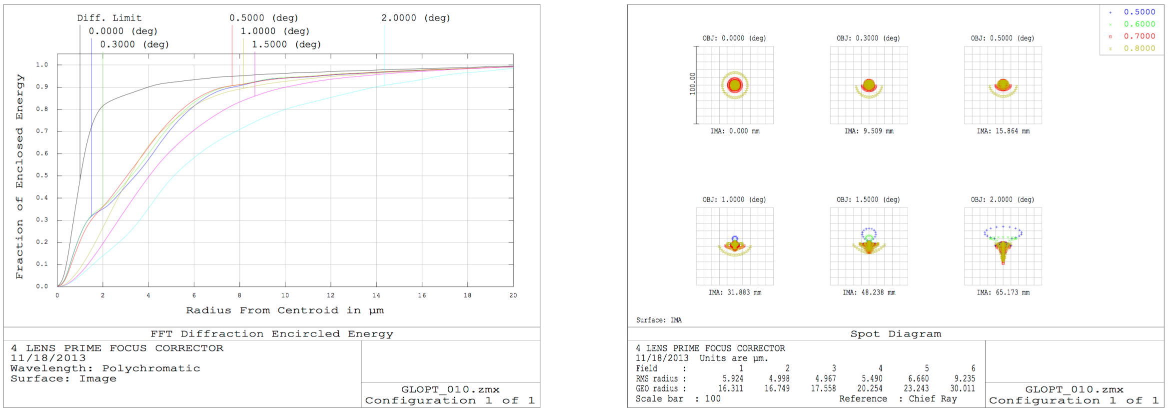


Figure 5: Optical layout for a nominal TOROS system. The prime focus corrector is composed of four elements of available glasses and all spherical surfaces (left figure). Image of the PlaneWave telescope with the LT 500 mount (right).



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4 LENS PRIME FOCUS CORRECTOR
11/18/2013  Units are µm.
Field      :         1         2         3         4         5         6
RMS radius :     5.924     4.998     4.967     5.490     6.660     9.235
GEO radius :    16.311    16.749    17.558    20.254    23.243    30.011
Scale bar  : 100                 Reference  : Chief Ray
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Figure 6: Encircled energy (left) and spot diagrams (right) for a nominal TOROS optical design including COTS telescope and custom prime focus corrector. 80% encircled energy diameter is 1” over the field for polychromatic images.

shows the optical layout of the prime-focus corrector, while Figure 6 shows the resulting encircled energy and spot diagrams. The focal corrector is currently under construction and the CCD has already been purchased with expected delivery october 2020.

3.2 Facilities and Resources

The northwest corner of Argentina, between S 23°15′ and S 24°30′ latitude and W 65°30′ and W 67°30′ longitude, is part of the Atacama Plateau shared with Chile. Given its average elevation of 3750 m and its dry and cloud-free climate (average annual precipitation below 5 mm, clear skies over 90% of the time) the area exhibits optimal conditions for the installation of large astronomical facilities. Several sites within the region were considered for the location of the European Extremely Large Telescope, including a site on the Macón Ridge in Argentina at an elevation of 4560 m. The site was extensively surveyed between 2008 and 2011 by personnel from ESO and the Astronomical Observatory of Córdoba (OAC in Spanish). Figure 7 shows the geographical location of the region in reference to Córdoba and to Buenos Aires, the capital city of Argentina and several well known sites in Chile.

Figure 7: Northern Salta with respect to Buenos Aires and Córdoba cities and other astronomical sites in Chile.

The mean and median of the seeing measurements obtained at Macón are 0.70 arcseconds and 0.55 arcseconds, respectively (Renzi et al. 2009). Light pollution is negligible in the area of interest (less than 400 inhabitants within 100 km) and it is not expected to change significantly in decades. Clear skies exceed 95% of the nights per year. In addition to these surveys, a relatively recent study modeling data from IASI (Infrared Atmospheric Sounding Interferometer) on the Metop-A satellite to retrieve water vapor profiles, determined that potentially interesting new sites are precisely Macón in Argentina and Summit in Greenland, both exhibiting similar conditions as Mauna Kea (Tremblin et al. 2012).

The Macón Ridge Astronomical Site and Dark Sky Preserve was established on August 15th 2011 by the Governor of Salta Province through Decree number 3728. The preserve, which covers over 2500 hectares, is managed by IATE. The provincial government constructed a road from Highway 27, which joins Tolar Grande with San Antonio de los Cobres highway, to the Macón ridge. The road is maintained by the Tolar Grande municipality. Electricity is provided efficiently by a solar cell array (4.5 kW). Internet access is available via high speed microwave link to the base camp at Tolar Grande.

Figure 8: The domes of TOROS (foreground) and ABRAS (background) at the Macón Ridge.

Telescopes at the Macón site can be remotely controlled year-round by operators living in the nearby village of Tolar Grande, with a direct view of the summit (9 kms distance along the line of the sight). There is strong local support by the community and governmental authorities for astronomical development in the area, including participation in the construction phase and contributions to the outreach center. The local infrastructure, logistics and operation will be provided by the Institute for Theoretical and Experimental Astrophysics (IATE). IATE/OAC will provide for 2 FTEs to secure the maintenance and operation of the proposed instrument.

A 3000-sqft building that will provide lodging for the operators, a clean room for maintenance and servicing of astronomical instrumentation, electronic shop and a dedicated room to house a computer center to handle local data reduction, analysis and storage has already been constructed. The computer center will consist of a system of 2 redundant 64-core computer servers with up to 1 Tb RAM and 8Tb RAID disks. Housing will be complemented additionally by the local municipality lodge. This is a recently-built, modern and comfortable "bed-and-breakfast" type of hotel.

Figure 9: The ABRAS dome and its telescope.

4 The TOROS scientific collaboration and interested scientists in the community

In 2011, scientists from the Center for Gravitational Wave Astronomy (CGWA) at The University of Texas Rio Grande Valley (formerly UT Brownsville) and the Observatorio Astronómico de Cordoba (OAC) and Instituto de Astronomía Teorica y Experimental (IATE) (both affiliated with the National University of Córdoba in Argentina) established a collaboration to develop an astronomical facility for optical followup of GW transients visible from the Southern Hemisphere. In addition to the general scientific motivation outlined in the previous section, we were driven by the limited number of southern facilities with wide fields of view that would be capable of dedicated searches for aLIGO and adVIRGO released triggers during their first years of operation. The first step in our partnership was the establishment of a Memorandum of Understanding between the University of Texas at Brownsville (now UTRGV) and the University of Córdoba. The MoU established a collaboration to nucleate enough expertise and manpower to enable such a project, which was named Transient Optical Robotic Observatory of the South (TOROS). The collaboration held its first meeting, entitled "The first international TOROS workshop", in Salta, Argentina on 2013 June 27-28. Approximately forty astronomers and physicists from North & South America and Europe discussed issues related to this project. Currently this is the list of scientists who are members of the TOROS Collaboration:

In Argentina:

From IATE: Diego Garcia Lambas, Dario Graña, Marcelo Lares, Sebastian Gurovich, Mariano

Figure 10: Operations and EPO building. On the left, perspective of the building. Right: view of the control room and laboratory.

Dominguez, Horacio Dominguez, Victor Renzi, Federico Stasyszyn. CASLEO: Sergio Aldo Cellone (not a member of TOROS but a scientist who expressed interest) In Chile:
Universidad de La Serena: Jose Nilo Castellon, Amelia Ramirez, Hector Cuevas
Pontificia Universidad Catolica: Nelson Padilla.
In the USA:
Duke University: Bruno Sanchez.
Texas A&M University: Darren DePoy, Lucas Macri, Jennifer Marshall.
University of Texas Rio Grande Valley: Mario Diaz, Juan Madrid, Martin Beroiz.
In Mexico:
Instituto Nacional de Astrofisica, Optica y Electronica: Omar Lopez Cruz.
In Poland:
National Centre for Nuclear Research: Adam Zadrozny.

5 Estimated Budget

Current investment at Cordon Macon exceeded $2,500,000 in US dollars. About $500,000 was provided by the Brazilian funding agencies, about $750,000 was provided by Argentine provincial and national agencies and $1,000,000 has been provided by the National Science Foundation of the USA. The projected estimated investment to fully complete the project (completion of construction inside ABRAS dome, ABRAS telescope installation, spectrograph for ABRAS, additional solar panels and batteries) is about $250,000 in US dollars. This includes also the purchase of 4x4 vehicles for permanent operation at the site. Regular operation will require an annual budget for 2 FTEs (technical personnel) plus about $25,000 for regular operations.

6 Timeline

The TOROS telescope is ready to start operations. If funding is secured, the ABRAS telescope could start operations by mid-2020.

7 Computing requirements

Most of the computing requirements are already covered by funding from Universidad Nacional de Córdoba.

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