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The Transient Sky Observed from Mexico

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Abstract

The Observatorio Nacional de San Pedro Mártir (OAN-SPM) is located in Ensenada, México. Nowadays, it has three robotic telescopes dedicated to the study of transient events such as gamma-ray flashes and gravitational waves: COATLI, RATIR and DDOTI. This review will provide a general image of the astronomical site and a brief summary of the characteristics of each of them, as well as the achievements of the team over the years and future prospects.

Keywords: RATIR, COATLI, DDOTI

Introduction

Each time that we look at the sky in the middle of the night, we can appreciate stars whose bright is almost constant through the time. On the other hand, there are many other phenomena which have a different luminosity over a time interval. We call *variable* to these events [see e.g.][]2011avsa.book. W. Finally, since some decades, astronomers have observed a set of objects labelled as *transients* [see e.g.][]2012ratu.book. V.

Differences between a variable object and a transient object lie in the unpredictable nature as well as the origin of the phenomenon. Observationally, it is possible to appreciate a periodical shape in the light curve of a variable object, whereas a transient source will disappear after a period of time (typically days).

Transient sky includes supernova explosions, tidal disruption events, gamma-ray bursts and gravitational wave events. All of them, originated by the violent end of (at least) an energetic source.

This review is divided in four sections. § **??** briefly describes gamma-rays burst and gravitational waves. § describes Observatorio Astronómico Nacional de San Pedro Mártir and the designed instruments to observe the transient universe: RATIR, DDOTI and COATLI.

Transients

Gamma-ray bursts

Among the transient events are gamma ray flashes, which typically have a duration between 20 and 30 seconds. They were discovered in the 1960s and remain a mystery in many ways to astronomers due to their short-lived nature.

The study of these phenomena is motivated by the desire to understand more about their progenitors, the emission processes involved and the environment in which they evolve. It is noteworthy that the energy released by a flash of gamma rays is comparable to that emitted by all the stars in the galaxy to which these phenomena belong, being the brightest objects known to date being the brightest events in the universe up to today.

We currently know that there are two different populations of gamma ray bursts 1993ApJ...413L.101K. Long gamma-ray bursts, lasting more than 2 seconds, are associated with the death of massive stars Woosley1993,MacFadyen1999ApJ,Hjorth2012, while short gamma-ray bursts, whose measured duration is less than 2 seconds, are the consequence of the collapse of two compact objects such as black holes or neutron stars [e.g.][]Eichler1989,Narayan1992,Ruffert1998,Rosswog2002,Giacomazzo2011,Lee2007.

Gravitational waves

Predicted by Einstein in 1916, gravitational waves are disturbances in space-time caused by violent and energetic processes in the Universe. These perturbations travel through the space-time similarly as a wave produced by a fallen rock into the water, in all directions away from the source with the same speed as the light one. Gravitational waves carrying with them information about their origins, as well as clues to the nature of gravity itself.

Astronomers verified the Einstein's theory was only 6 years ago, on September 14, 2015, when the LIGO collaboration detected perturbations produced in space-time caused by gravitational waves generated by two colliding black holes 1.3 billion light-years away Abbott2016a,Abbott2016b. This achievement has been one of humanity's greatest scientific breakthroughs. Two years after, on August 17, 2017, the simultaneous detection of a gravitational wave and a short gamma-ray burst, opened the window to the multi-messenger era in astronomy. From this day, it is possible to study an object using not just the light, but the perturbations in the space-time produced by the source.

Observatorio Astronómico Nacional San Pedro Mártir

In the middle of a national park in Baja California, three-hours from Ensenada city, at 2,830 meters above sea level, the Observatorio Nacional de San Pedro Mártir (OAN-SPM) is located. This is one of the two observatories in charge of Universidad Nacional Autónoma de México (UNAM) (https://www.astrossp.unam.mx/index.php/es/).

San Pedro Mártir is a beautiful place on its own: it is a mountain range lined by pine trees, where the landscape is covered with snow when the temperature drops and the height creates truly spectacular panoramas (see Figure 1). But what is exceptional is that it meets the perfect conditions for observing the night sky. In fact, it is the best place in Mexico to see the stars , and also one of the best in the world due to its climatic natural condition, clear nights most of the year (about 290 clear nights per year) and low luminous pollution 2009PASP..121.1151S,2004PASP..116..682A. In addition, the state of Baja California has legislation to protect the night sky, which became the first at national level and unique around the world (http://leydelcielo.astrosen.unam.mx/index.php/en/

Nowadays, the OAN-SPM has three telescopes designed to observe transient phenomena: RATIR, COATLI and DDOTI.

RATIR

Starting operations in 2012, the Reionization and Transient Inrared Optical Project (RATIR) (http://ratir.astroscu.unam.mx/) was designed for follow-up observations of the afterglows of gamma-ray bursts (GRBs) detected by the Neil Gehrels Swift Observatory, but is also used for other science. RATIR is a four-channel simultaneous optical and near-infrared imager mounted on the 1.5 meters Harold L. Johnson Telescope at the Observatorio Astronómico Nacional in Sierra San Pedro Mártir in Baja California, Mexico. RATIR responds autonomously to GRB triggers from the Swift satellite and obtains simultaneous photometry in *riZJ* or *riYH* 2012SPIE.8446E..10B,2012SPIE.8444E..5LW. Figure 2 shows an example of how is detected a GRB, in this case GRB 130327A in comparison with an image after 24 hours.

RATIR was designed for follow-up observations of the afterglows of gamma-ray bursts detected by the Neil Gehrels Swift Observatory, but is also used for other science. The advantage of this telescope in the fields of transients is the depth of its observations, reaching until an AB magnitude about 23 in two hours of exposure. RATIR contributes to observe the optical counterpart of gamma-ray bursts since minutes and up to hours after the trigger. Moreover, the infrared camera installed in RATIR, facilitates the determination of colour of the source, observations of host galaxies and photometric redshift associated.

COATLI

One of the biggest challenges they present is their detection, since it is difficult to design a telescope that reacts before the burst has finished. Thus, it was born the idea of installing the Cámara de Óptica Adaptiva Tilt Límite de difracción, COATLI (http://coatli.astroscu.unam.mx/), a 50 cm diameter robotic telescope, located at the National Astronomical Observatory in the San Pedro Mártir (Fig. 3). Installed in 2016, COATLI has the main purpose of monitoring the optical counterparts of gamma-ray bursts 2018RMxAA..54. 5F.

Catching early optical emission from GRBs is not an easy task. The short duration of these events, combined with telemetry delays and the response time of ground telescopes and satellites, present a challenge. For these reasons, our understanding of the earlier phases of GRBs continues to be incomplete compared to our understanding of later afterglows (occurring minutes after the trigger) for which we have a sample of hundreds of observations. COATLI, in comparison to large diameter telescopes, has the advantage of a rapid mount which allows it to point to any point of the sky in less than 10 seconds, allowing us to study the inner processes involved in a gamma-ray burst production 2019ApJ...872..118B.

DDOTI

The the Deca-degree Optical Transient Imager (DDOTI) (http://ddoti.astroscu.unam.mx/) is a wide-field, optical, robotic imager located at the Observatorio Astronómico Nacional (OAN) on the Sierra de San Pedro Mártir in Mexico 2016SPIE.9910E..0GW.

DDOTI has an ASTELCO Systems NTM-500 mount with six Celestron RASA 28-cm astrographs each with an unfiltered Finger Lakes Instrumentation ML50100 front-illuminated CCD detector, an adapter of our design and manufacture that allows static tip-tilt adjustment of the detector, and a modified Starlight Instruments motorized focuser (see Figure 4). Each telescope has a field of about 3.4 ×3.4 deg with 2.0 arcsec pixels. The individual fields are arranged on the sky in a 2 3×grid (nominally 6.8 deg E-W and 10.2 deg N-S) to give a total field of 69 deg^2. Thisis a great advantage regarding that the maps of probabili- ties sent by the LIGO/Virgo collaborations includes up to 1000 deg^2 and, therefore, cover a region like that would be impossible with telescopes with smaller fields of view.

Operating since 2018, the main science goals of DDOTI are the localization of the optical transients associated with GRBs detected by the GBM instrument on the Fermi satellite and with gravitational-wave transients.

Achievements

RATIR has produced more than three hundred of GCN/TAN circulars with photometric information of gamma-ray burst event followed-up whereas COATLI has 60. COATLI has observed the early stage of around ten GRBs. About scientific production, RATIR data has appeared in 60 papers, whereas data from COATLI has been published in 3 articles 2019ApJ...887..254B,2019MNRAS.484.1031P,2019ApJ...872..118B and have two more in preparation (http://ratir.astroscu.unam.mx/publications.html).

On the other hand, DDOTI has two papers related to individual gravitational wave follow-up and has another one in preparation about the response during the O3 run of the LIGO/Virgo Campaign 2020MNRAS.492.5916W,2020MNRAS.499.3868T.

Future

Bearing in mind the subsequent mission to explore the universe, for example the SVOM mission (https://www.svom.eu/en/) and Vera C. Rubin Telescope (https://www.lsst.org/), and the continuos improvements to LIGO/Virgo (and in the future KAGRA) interferometers (which translates in better localizations and therefore, more probabilities of detection of an electromagnetic counterpart), the future in this field is exciting and for sure, there will be extraordinary news for all the astronomers.

Summarizing, the OAN-SPM is an exceptional place to do astronomy. We have, undoubtedly, taken advantage of this great opportunity and for almost a decade, the instruments that have been placed have been mostly for the search and study of the transitory events of the universe. Finally, the following year will be the date of installation of COLIBRÍ (https://www.colibri-obs.org/), a telescope that will combine speed in its mount and great sensitivity due to its primary mirror of 1.3 m in diameter, thus allowing it to continue within the groups that lead the field of transients observable in the optical. In conclusion, the rise of this science is just beginning and at OAN-SPM we have all the tools and equipment to face the challenges ahead.

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Figura 1
2.1 m telescope, the largest one at OAN-SPM is placed in the highest point of the mountain. Credits: Ilse Plauchu Frayn

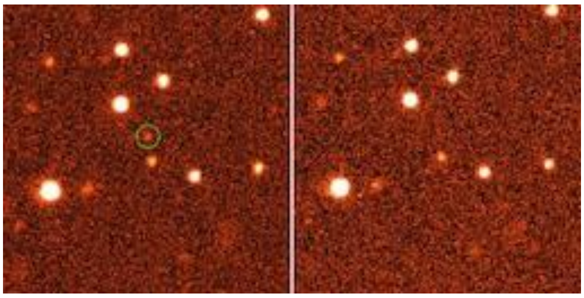

Figura 2
Images above show the fading afterglow of GRB 130327A. The image on the left was taken with RATIR 1.7 hours after the GRB was detected by Swift. The image on the right was taken about 24 hours later.

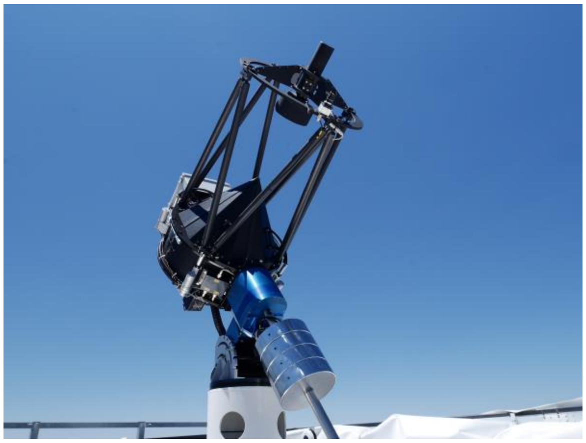

Figura 3 *COATLI telescope*

Figura 4 *DDOTI telescop*