Working Paper 28

Extragalactic Astronomy and Cosmology at UNAM´s Instituto de Astronomía

by

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August 2024

All titles are available on the PUEAA website: http://pueaa.unam.mx/observatorio-asia-africa/working-paper

Working paper PUEAA No. 28. Extragalactic Astronomy and Cosmology at UNAM’s Instituto de Astronomía

DOI: xxxxxxxxxx

Publication Date August 2024

Programa Universitario de Estudios sobre Asia y África
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04360, Copilco Universidad
Coyoacán, Ciudad de México

Mechanical Editing Andrea Reyes, Anaelia Lazcano y Yuliemy Carmona. Composition: Andrea Reyes. Cover design: Yussef A. Galicia Galicia.

Made in Mexico / Hecho en México

Abstract

An overview of UNAM's Instituto de Astronomía teaching and research resources is presented. Undergraduate studies in Physics at Facultad de Ciencias are followed by Graduate Studies in Astrophysics supported by three institutes with astronomical researchers. Extragalactic and cosmology groups both in Mexico City and Ensenada are presented, followed by some recent research highlights and ongoing projects. Finally, the major observing facilities at the National Astronomical Observatory in Baja California, Large Millimeter Telescope Alfonso Serrano (LMT) and High Altitude Water Cherenkov (HAWC) observatories in Puebla, together with international facilities as Gran Telescopio Canarias (GTC) and Sloan Digital Sky Survey (SDSS), are observing resources for extragalactic and galactic studies.

Resumen

Se presenta una visión general de los recursos docentes y de investigación del Instituto de Astronomía de la UNAM. Los estudios de licenciatura en Física en la Facultad de Ciencias son seguidos por estudios de posgrado en Astrofísica apoyados por tres institutos con investigadores astronómicos. Se presentan los grupos extragalácticos y de cosmología tanto en la Ciudad de México como en Ensenada, seguidos de algunos puntos destacados de investigación reciente y proyectos en curso. Finalmente, las principales instalaciones de observación del Observatorio Astronómico Nacional en Baja California, el Gran Telescopio Milimétrico Alfonso Serrano (GTM) y el High Altitude Water Cherenkov (HAWC) en Puebla, junto con instalaciones internacionales como el Gran Telescopio Canarias (GTC) y el Sloan Digital Sky Survey (SDSS), son recursos de observación para estudios extragalácticos y galácticos.

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Graduate and undergraduate studies

The School of Science (Facultad de Ciencias, FC) at UNAM has several undergraduate programs Actuary, Biology, Computer Science, Earth Science, Environmental Science, Mathematics, Applied Mathematics, **Physics**, Biomedical Physics and Sustainable Coastal Zones: Overall 9380 undergraduate students are registered and **~2000 are in the Physics** (1500 men & 500 women) program (Stern, 2020).

The **Physics Faculty** consists of 316 professors, researchers, assistant professors, part-time professionals, teaching assistants and technicians. This faculty includes 62 full-time professors associated to FC and ~200 full-time researchers in 10 research institutes in Mexico City and 4 campuses (Facultad de Ciencias, 2020).[1]

UNAM´s Graduate Program in Astrophysics (MSc & PhD), accepts undergraduate students in Physics, Mathematics, Computer Science, Engineering from any Mexican or foreign University (all with scholarships). The program has 4 fields: Theoretical Astrophysics, Observational Astrophysics, Fields & Particles, and Instrumentation. It relies on researchers and professors from 4 academic institutions: Instituto de Astronomía, Instituto de Radioastronomía y Astrofísica, Instituto de Ciencias Nucleares and Facultad de Ciencias. In 2020 the graduate program had 196 professors and 120 students. Postdocto-

[1] Detailed information for students and professors on UNAM's Facultad de Ciencias is on the Web page http://www.fciencias.unam.mx/

ral and pre-doctoral positions abroad are highly recommended to the students to promote international collaboration at an early stage (Graduate Program in Astrophysics, 2011).[2]

Research group

UNAM's Instituto de Astronomia has two main research locations: Mexico City, where the main campus is located (Ciudad Universitaria, CU), and Ensenada in Baja California. The academic group includes 89 Astronomy and Physics professors (53 CU & 36 Ensenada); 68 Engineers & technicians (instrumentation, computing & services), 16 postdocs, 160 students (60 graduate), and 116 administrative & maintenance staff. Details of IAUNAM can be found in the recent Director Report (González, 2020).

The Extragalactic and Cosmology group includes researchers (e-mail in parenthesis @astro.unam.mx) in both **Mexico City**: Vladimir Avila-Reese (avila), Jorge Barrera-Ballesteros (jkbarrerab), Erika Benitez (erika), Luc Binette (binette), Mariana Cano-Diaz (mcano), Irene Cruz-Gonzalez (irene), Jose A. de Diego (jdo), Deborah Dultzin (deborah), Jesus Gonzalez (jesus), Hector Hernandez-Toledo (hector),Yair Krongold (yair), Anna Lia Longinotti (alonginotti), Marco Matos (marco), Luis Martinez-Medina (lamartinez), Alenka Negrete (alenka), Aldo Rodriguez-Puebla (apuebla), Elfego Ruiz (elfego), Sebastian Sánchez (sfsanchez), Octavio Valenzuela (octavio); **and Ensenada**: Hector Aceves (aceves), Luis Aguilar (aguilar), Miguel A. Aragon (maragon), Elena Jimenez-Bailon (elena), Takamitsu Miyaji (miyaji), Aida Wofford (awofford), Michael Richer (richer), Tomas Verdugo (tomasv) (Instituto de Astronomía, 2012).[3]

[2] Information on the Graduate Program in Astrophysics is on the Web page https://www.fisica.unam.mx/coordinacion_docente/licenciatura_y_posgrado.php?lang=en

[3] Information on their research can be found at the main Web page: http://www.astroscu.unam.mx/

The extragalactic groups are involved in several large projects which include: GAIA, SDSS IV (MaNGA, eBOSS), SDSS V, and projects in development as JWST, DESI, SPM6.5m, ToLTEC/LMT. Full access to SPM, GTC & LMT observing is available to the Mexican community.

Recent research highlights

International partnerships in Gran Telescopio Canarias (Spain, Mexico & U. Florida; GTC), SDSS IV (MaNGA, eBOSS) & V, HAWC, Gaia, DESI, and full access to the LMT has notably strengthen our research in astrophysics. A gallery of recent results from the extragalactic astronomy researchers is presented below.

There is a group involved in chemical evolution of galaxies projects using integral field spectroscopy (IFS) galaxy surveys as CALIFA (Sánchez *et al*., 2012); MaNGA (Bundy *et al*., 2015; Blanton *et al*., 2017); AMUSING++ (López-Cobá *et al*., 2020), among others. A review of various results is presented by Sánchez (2021).

On the Star Formation Main Sequence (SFMS) a study by Cano-Diaz *et al*., (2019), of ~2000 galaxies show the SFMS in log >SFR vs. log M_* that separates passive (retired) from actively forming stars galaxies. They show that IFS allow to go from global galaxy properties to local ones, up to kpc scales. Stellar and gas cubes are recovered using Pipe3d software (Sánchez et al., 2012). Another approach of the SFMS in 8,400 galaxies of MaNGA survey is presented using the densities SFR and $M_{baryonic}$ at kpc scales by Barrera-Ballesteros et al. (2021).

Among the recent PhD thesis stands out the work of Carlos López-Cobá with S. F. Sánchez as supervisor. The AMUSSING++ Nearby Galaxy Compilation (López-Cobá *et al*., 2020) is worth mentioning, where outflows or galactic winds of 800 galaxies with IFS in an unbiased sample (no bias to starburst, Active Galactic Nucleus (AGN) or mass) are studied, which allows spatial information to trace ionization extensions. Outflows are driven by star formation and AGN activity, the gas is out of the disk at kpc scales with a wind velocity of 1000 km/s and produce conical or collimated gas structures. The warm outflow component is traced by optical emission lines. Important results: a) Outflows are a low frequency phenomenon <10% in the Local Universe. b) Outflows are not exclusive of high-SF galaxies, outflows occur in all types of galaxies. c) Outflows span masses $9.0 < \log M_{*}/M_{\odot} < 11.5$. d) 3% of the outflows are SF-wind driven produced by supernovas and stellar winds, they show conical/biconical structure, and excess in [NII]. e) 5% are AGN-wind driven produced by accretion of material to the supermassive black hole, they show typically collimated/filamentary structures, and excess in [OIII].

Several papers have been published by the EDGE-CALIFA survey. Here we just mention one by Sánchez *et al.* (2021), that involves local and global relations between the stellar, star formation rate and molecular densities that regulate star formation. The molecular mass was obtained from CO observations from CARMA (spatially resolved 125 galaxies) and APEX (512 galaxies in 23.2 arcsec beam). For CALIFA galaxies they used the relation from Barrera-Ballesteros *et al.*, (2021) between Σ_{mol} and A_V. They show that surface densities Σ_{*}, Σ_{SFR} & Σ_{mol} are tightly correlated with each other, describing not only a set of relations between any pair of them, but also are tightly correlated in 3D space, following a single linear relation (in log scale).

Rodríguez-Puebla *et al.*, (2020), present an analytical approach to study the evolution of the star-forming (SF) galaxy main sequence (MS) and the contribution of dust obscured star formation for z~0 to z~4 redshifts from the far-ultraviolet plus infrared luminosity functions.

The SFMS is not a power-law at all M_* but bends around $M_* \sim 5 \times 10^8$ $M_\odot$, and that the dust-obscured fractions depend strongly on M_* and show almost no dependence with z above z~1.25. High-mass galaxies below z~0.75 are more transparent compared to their high redshift counterparts.

Galaxy classification on deep blind surveys OTELO and COSMOS with deep learning algorithms is presented by De Diego et al. (2020). OTELO is a very deep blind survey performed with the red tunable filter OSIRIS instrument of the 10.4 m GTC (Bongiovanni *et al.*, 2019). Images in 36 adjacent narrow bands (FWHM 12 Å) covering a window of 230 Å around λ = 9175 Å. OTELO catalog includes ancillary data ranging from X-rays to far-IR of 11237 galaxies. Furthermore, OTELO-SP (Sérsic index and photometry) sample: 1834 (99 early-type, ET, and 1735 late-type, LT) galaxies at z ≤ 2, and OTELO-CP (concentration and photometry) sample consists of 2292 galaxies (114 ET and 2178 LT).

Classified galaxies with deep learning algorithm: (a) Strateva u-r color discriminant, (b) linear discriminant analysis (LDA) using the u-r color, and the Sérsic or the concentration indexes, and (c) dense neural network (DNN) using photometric colors and either the Sérsic or the concentration indexes. The authors show that the best statistics are obtained with deep learning DNN, and that using the same DNN on COSMOS survey shows similar results on the galaxy classification.

Search for dual AGN, merging galaxies (both AGN) with < 10 kpc separation (binary AGN < 100 pc separation), has been. Although hundreds of galaxy pairs have been discovered, only a few kpc-scale dual AGN are confirmed (e.g. Rubinur *et al.*, 2019). Benítez *et al.*, (2019), present a multiwavelength study of the triple-peaked source Mrk 622. The 76 pc-scale separation observed with ISIS/WHT in [OIII] was observed with CanariCam/GTC, but source was not resolved at 0.5 arcsec. In radio, evidence for an elongated source suggests more than one core in the nucleus. Radio interferometric observations are needed to resolve the nuclear region and confirm the possibility of a dual AGN system in the obscured object Mrk 622.

Obscured active galactic nuclei are being studied at mm wavelengths with Large Millimeter Telescope (LMT) spectrographs. The ULIRG and CTAGN UGC 5101 study at 3mm of its molecular torus is presented in Cruz-González *et al*. (2020).

National Astronomical Observatory

The main optical-infrared (OIR) facilities are located in the Baja California Peninsula, in the San Pedro Mártir (SPM) National Park. SPM is a protected region of incredible natural beauty plus biological and geological diversity. As an astronomical site SPM is among the best astronomical sites on the planet. SPM location is longitude 115º 27' 49'' West and latitude 31º 02' 39'' North at an altitude of 2830 m. Astronomical site testing studies and information of San Pedro Mártir is reviewed in Tapia *et al*. (2007a, b).

The National Astronomical Observatory (OAN) OIR telescopes, both operational and under construction, plus the SPM6.5m that is on final design phase, are of two types: for general science and international robotic dedicated (gamma ray bursts, gravitational waves, supernovas, exoplanets, transneptunian objects). These telescopes are presented in Figure 1. It is important to note that the allocation of time in most telescopes is available to astronomers in all Mexican institutions, and that in a few telescopes the allocation is limited to members of the funding collaboration. For details on telescopes, instrumentation and time allocation see San Pedro Martir National Astronomical Observatory (2021).[4]

[4] OAN Web page: https://www.astrossp.unam.mx/index.php/en/

High-Altitude Water Cherenkov Observatory (HAWC) and Large Millimeter Telescope (LMT) Observatory

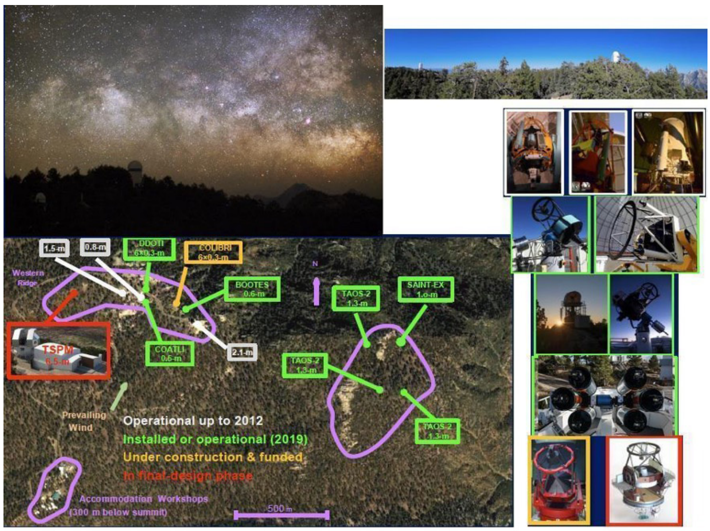
HAWC is a facility designed to observe gamma rays and cosmic rays between 100 GeV and 100 TeV located in the volcano Sierra Negra, Puebla. It is run by an international collaboration between more than thirty institutions in Mexico, the United States, Europe, South America, and Asia. The Mexican collaboration is headed by groups at INAOE, and UNAM's IA, IF and ICN. Information on HAWC and published articles can be found in HAWC (2021).[5] The LMT Alfonso Serrano is a 50 m single-dish steerable telescope designed for observations in the 0.85 to 4 mm wavelength range. LMT represents the largest and most complex scientific instrument constructed in Mexico through a binational collaboration between the United States and Mexico, headed by the University of Massachusetts and INAOE. Information on LMT instrumentation, time allocation and publications can be found at Large Millimeter Telescope Alfonso Serrano (2021). Astronomers in Mexican institutions have full access to LMT observations and are actively participating in its science observations calls.

Final remarks

The recent results and astronomical facilities described above show that international collaborations are essential for extragalactic studies. We hope to motivate future joint projects not only between the University of Tokyo and UNAM, but between Japan and Mexico institutions in all fields of astronomical research.

[5] HAWC Web page: https://www.hawc-observatory.org/publications/#articles

Figure 1. National Astronomical Observatory at San Pedro Mártir, Baja California[6] Source: González (2020). Instituto de Astronomía, UNAM.



[6] North is at the top and West to the left. Telescopes in operation, under construction and in the final design phase are shown. In white are marked the locations in the summit of the general science telescopes, in green dedicated science robotic telescopes, in yellow under construction and in red the TSPM 6.5m telescope on design phase. The accommodation facilities and workshops are located 300 m below the summit. The prevailing wind direction is marked as a green arrow (lower left). (SPM National Astronomical Observatory, 2021).

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