Astronomy in Mexico

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Why astronomy and astrophysics?

- Astronomy and astrophysics are basic frontier science, and Mexico has a long tradition in this area.
- Astronomy is being transformed by projects directed towards multi-wavelength integration, large data sets, the variable and transient sky and multi-messenger interpretations. Technology and computing are playing a big role in these developments along with traditional tools and methodologies.
- Countries with privileged sites, such as Mexico, have a strategic advantage.
- Astronomy is an attractive element towards science in society.

Tradition

- Long history of observatories: Observatorio Astronómico Nacional (1887), Tacubaya (1909-1960), Tonantzintla (1940s), San Pedro Mártir (1960s-1970s); Observatorio Astrofísico Nacional (Tonantztintla (1940s), Cananea (1970s); Sierra Negra (2000s).

- Modern astrophysics begins in the 1950s-1960s in Mexico, has grown considerably into the 1990s and is undergoing a substantial renewal.

- Astronomy and astrophysics in Mexico have given rise and/or been heavily involved in the creation of groups and institutions in optics, topography, scientific photography, electronics and control, precision mechanics, satellite technology and the internet in Mexico, among others.

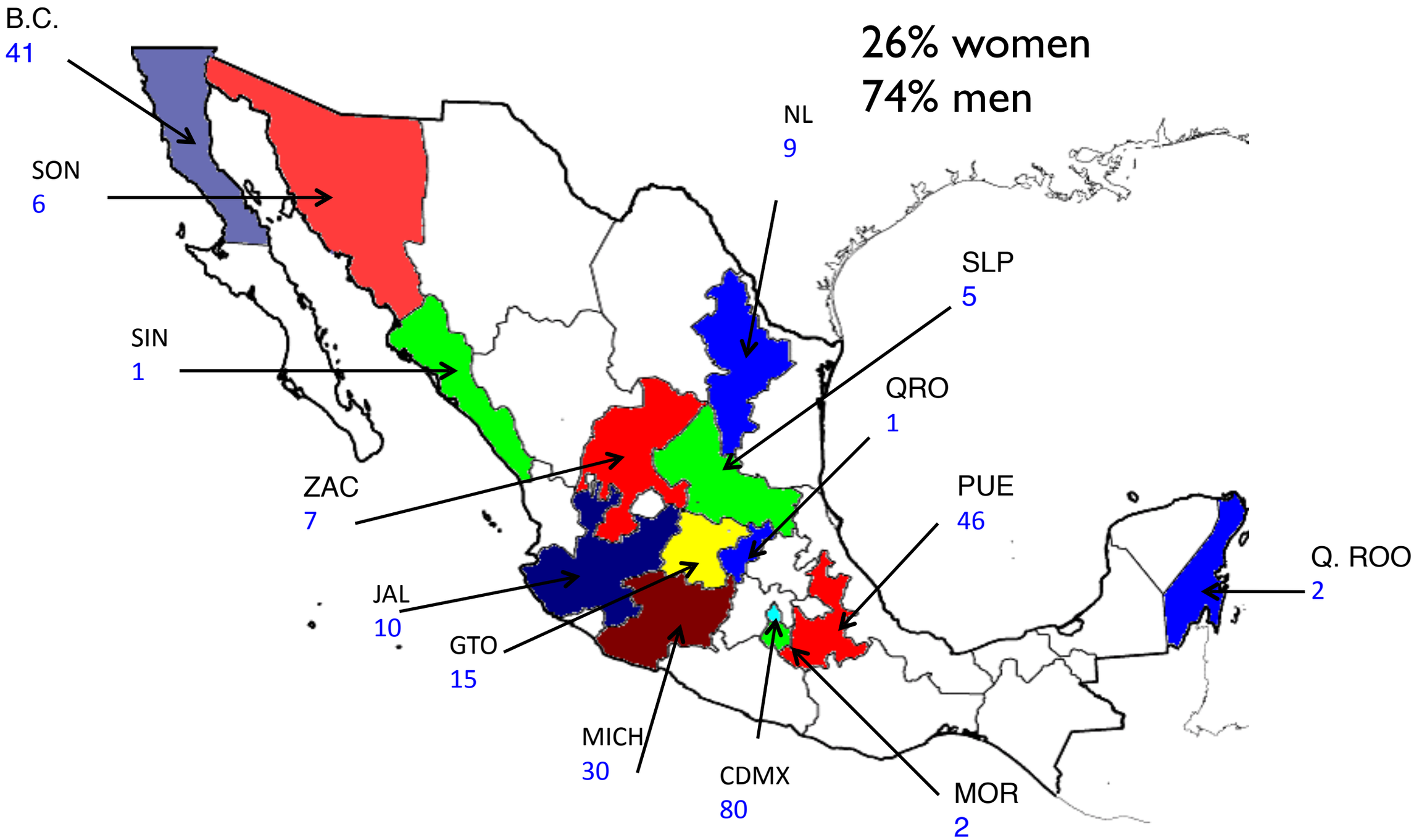
- Mexico was the 8th country to join the IAU 100 years ago.

- IA-UNAM publishes the highest I.F. journal in Latin America.

- Astronomy in Mexico is the most productive science and highest ranked in terms of impact over the last 40 years.

- It contributes 4% of papers in the most highly ranked journals (Q1), with roughly the same proportion of citations.

Mexican community in astronomy and astrophysics



TOTAL

242 researchers

19 institutions

4 members of El Colegio Nacional

TOTAL including institutions in physics

~500 researchers

50 institutions

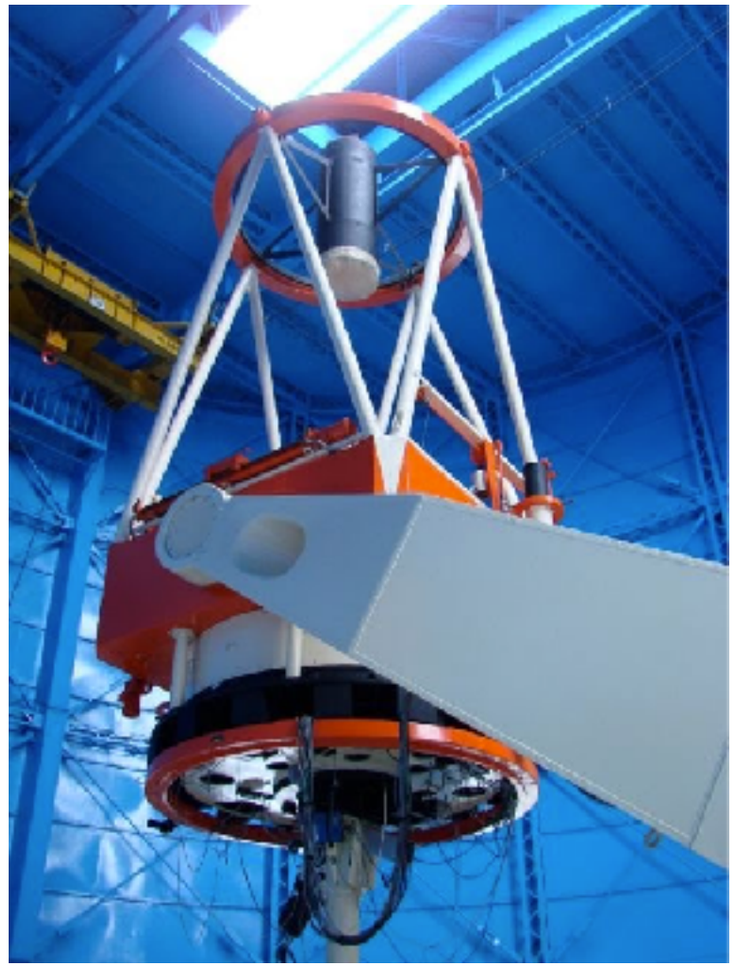
~700 refereed papers/year

Sites - 1: Sierra Negra, Pue.

- It has become an excepcional site for the development of international infrastructure for astronomy.
- Within the Pico de Orizaba National Park.
- The high transmission at mm and sub-mm wavelengths favored the construction of the Large Millimeter Telescope-Alfonso Serrano, the largest single-dish mm antenna in the world (50m), 4600m above sea level. The infrastructure for the LMT was a major factor in the choice of the site for the High Altitude Water Cerenkov observatory (HAWC).
- Service infrastructure: roads to the summit of Sierra Negra, power lines, pressurized spaces with oxygen at the summit, optical fiber to the telescopes, offices at Atzitzintla and base camp at Ciudad Cerdán.

Sites - 2: Observatorio Astrofísico “Guillermo Haro”, Cananea, Son.

- Inaugurated september 8, 1987, from the Observatorio Astrofísico Nacional de Tonantzintla.
- Sierra de la Mariquita, 13km from Cananea, 2480m above sea level. Some light pollution from mining activity in Cananea and the surrounding area.
- A 2.12m telescopio and a 14” seeing monitor.
- Instrumentation: CANICA (IR camera), Boller & Chivens spectrograph, CanHis (high resolution spectrograph), direct camera for visible photometry.
- OAGH is a national facility that is open to the Mexican community.



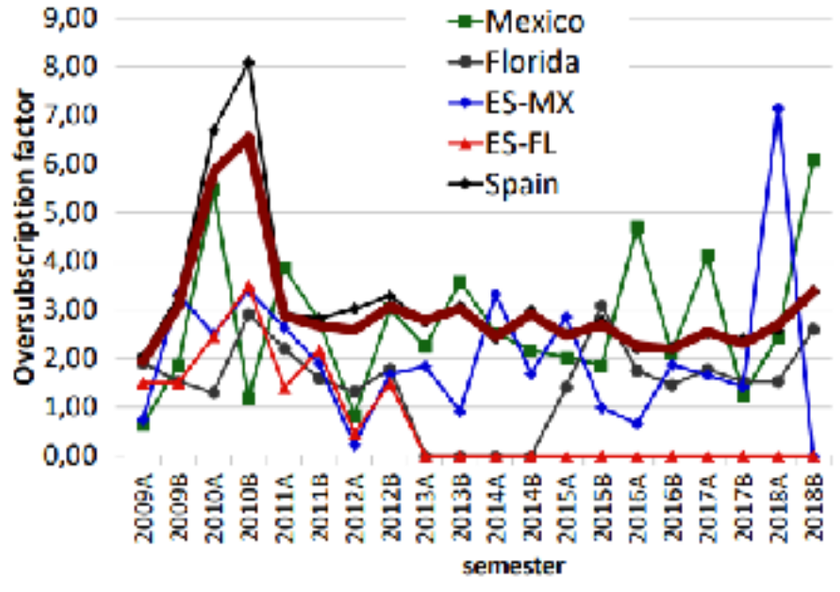
Sites - 3: San Pedro Mártir, B.C.

- Operated by Instituto de Astronomía at UNAM, and a National Lab under the CONACyT call since 2010.
- One of the top 4 sites for OIR astronomy in the world, in terms of darkness and atmospheric quality. A light pollution law is in effect in Baja California since 2009.
- Within the National Park Sierra de San Pedro Mártir, 2830m above sea level. A general agreement with the national environmental authority allows for the installation of scientific infrastructure for astronomy.

- Access road is fully paved, currently power is generated on site. A power line and optical fiber line are under construction and are scheduled to be completed in 2020.
- 3 telescopes until 2010: 2.12m, 1.5m, 0.84m, installed in the 1970s.
- Renewal under way with international partners for key programs, since ~2010.
- In 2017-2018: +80 refereed papers, +70 students, +70 press notes

GTC - Gran Telescopio Canarias

- GTC is the largest OIR telescopio in the world, 10.4m on La Palma, operated by Instituto de Astrofísica de Canarias (IAC).
- Through a collaborative agreement (2009) between Spain and Mexico, the entire Mexican astronomy community has access to GTC time at 5% through a direct contribution, and a time-exchange program between GTC and the LMT is in effect.
- The contribution from Mexico is shared between IA-UNAM and INAOE 50/50.
- The largest over-subscription comes from the Mexican community.

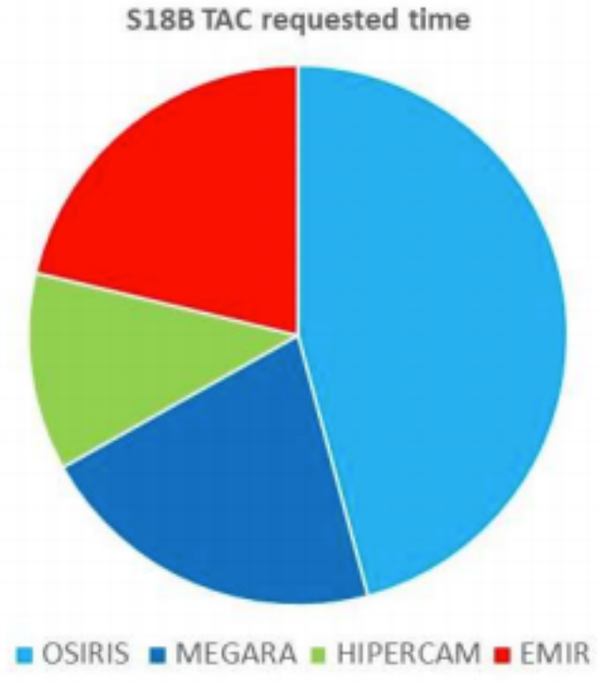


GTC - Gran Telescopio Canarias

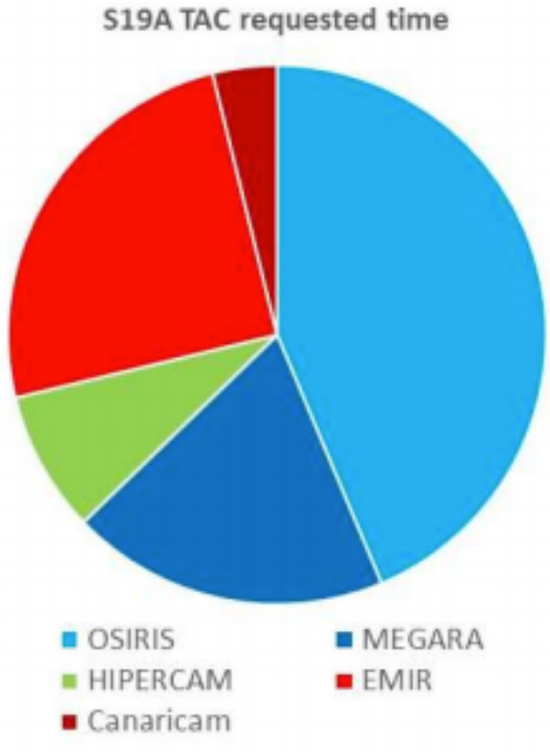
- Mexico participated in the design, development and construction of instruments for GTC: commissioning camera (2004), OSIRIS (2006), MEGARA (2018).

- Currently FRIDA is under development and led by Mexico.

- Until february 2019, 429 published papers with GTC data: 189 correspond to Spain, (44%), 22 to Mexico (5%) and 16 to UF (3.7%). OSIRIS data have been used in 386 papers, and 2 papers with MEGARA data are already published.



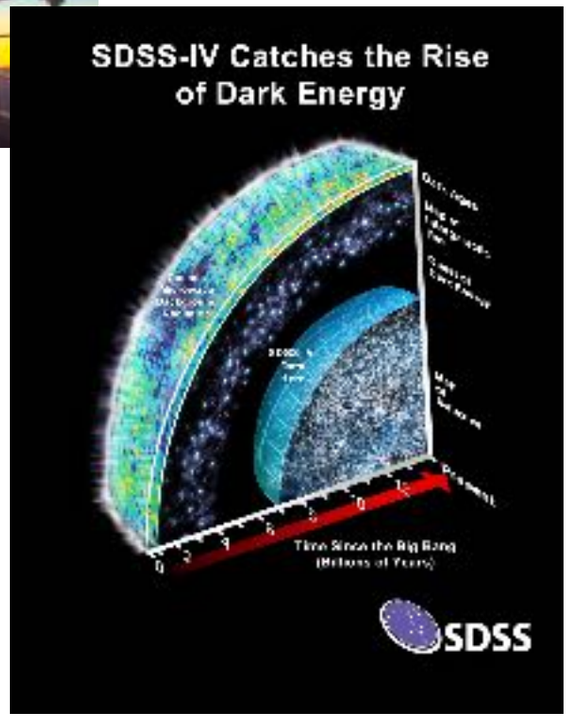
TOTAL = 1938 h



TOTAL = 1957.4 h

SDSSIV and SDSSV

- UNAM agreed to enter SDSS in the IVth stage in 2012.
- 2.5m de Apache Point Observatory, USA, ~40 international institutions
- UNAM/Astrophysics Research Consortium (ARC) agreement in 2013
- SDSS closeout in 2020
- UNAM participation in APOGEE-2, MaNGA and eBOSS surveys
- Will now participate in SDSSV



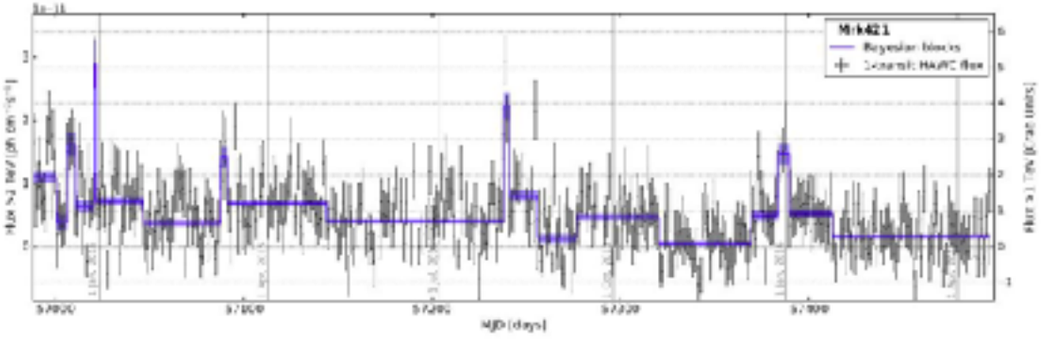
HAWC - High Altitude Water Cerenkov Observatory

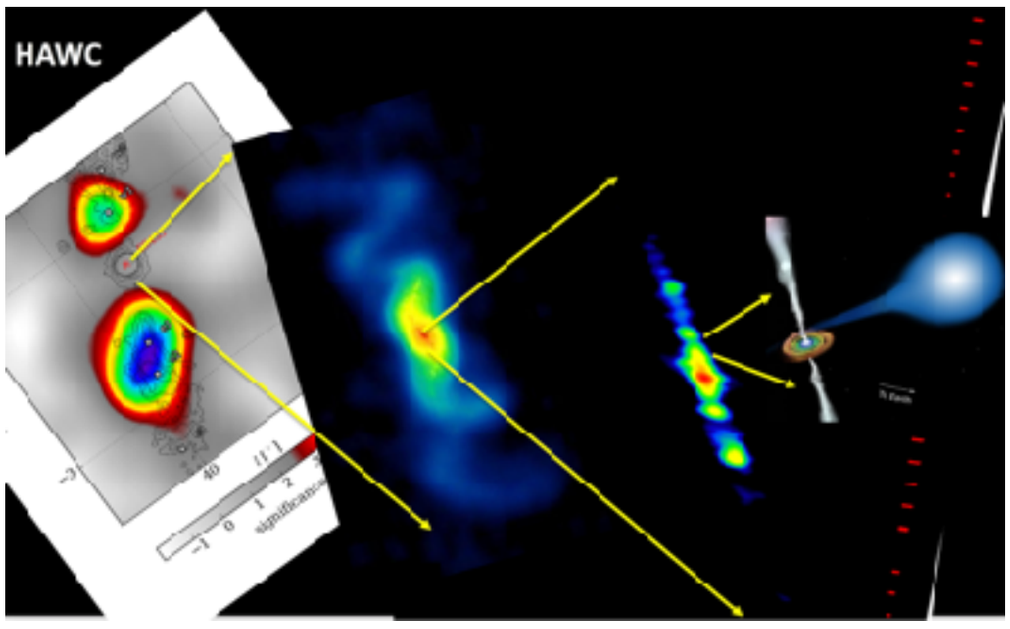
HAWC - High Altitude Water Cerenkov Observatory

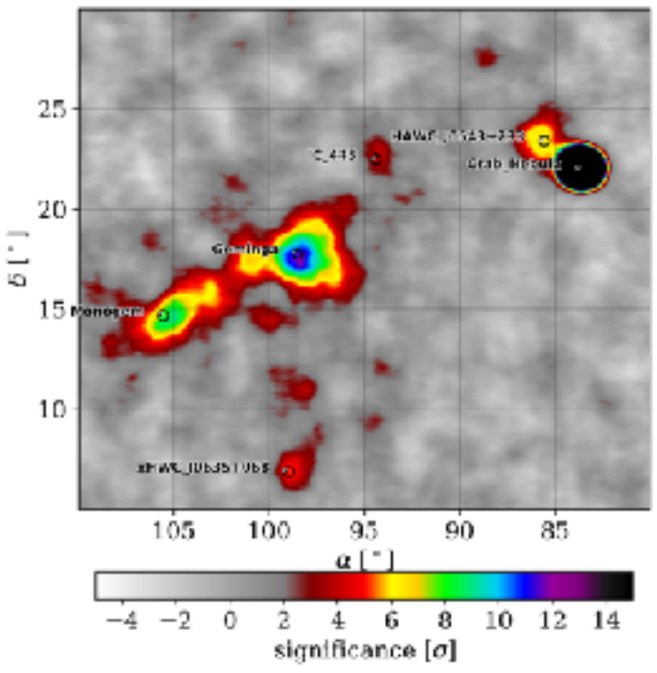
- Gamma-ray observatory for the most energetic events in the universe.
- US-Mexico collaboration (13 Institutions from México, 110 members from México, 8 graduate programs), plus a dozen more institutions from the US.
- A unique, cutting-edge instrument for Mexico and CONACYT.
- 2007 – site selection; 2011 – funding (NSF, CONACyT, DoE); 2011-2015 – construction; March 2015. – Inauguration
- Total investment for construction: USD $15 million - 1/3 Mexico, 1/3 NSF and 1/3 DoE.
- 25,000 events/second = 2TB/day. Largest scientific computing center (ICN-UNAM) in Mexico with 7PB storage and 1,500 processors.
- Agreements with international instruments for gravitational waves, neutrinos, X-rays and cosmic rays
- 2017 - 2019: 22 papers, one in Nature and three in Science, 2015 - 2019: ~20 graduate students, 40 undergraduates
- High impact outreach work, press conferences, youtube, Facebook, etc.

HAWC - High Altitude Water Cerenkov Observatory

- **NSF and DoE evaluated HAWC in november 2018 and decided to continue funding for 5 more years:**
- "The panel unanimously praised the HAWC Collaboration for its cutting-edge contributions to VHE gamma-ray astronomy, including its active and central participation in multi-messenger observations, for its highly efficient operations, and for its evidence of and strong commitment to inclusive excellence. The panel strongly recommends running HAWC through at least 2023, during which time the experiment will have much of the discovery space above 10 TeV all to itself. Near the end of that period, a reassessment of the scientific and broader impacts should be made."





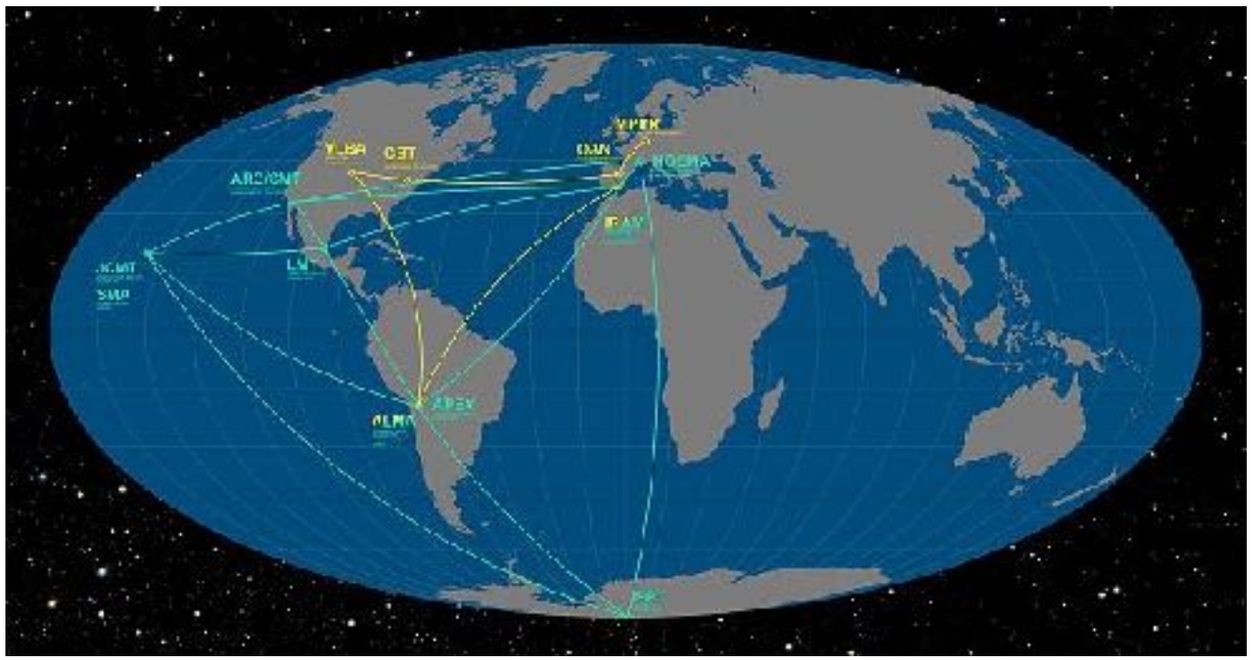


Radioastronomy

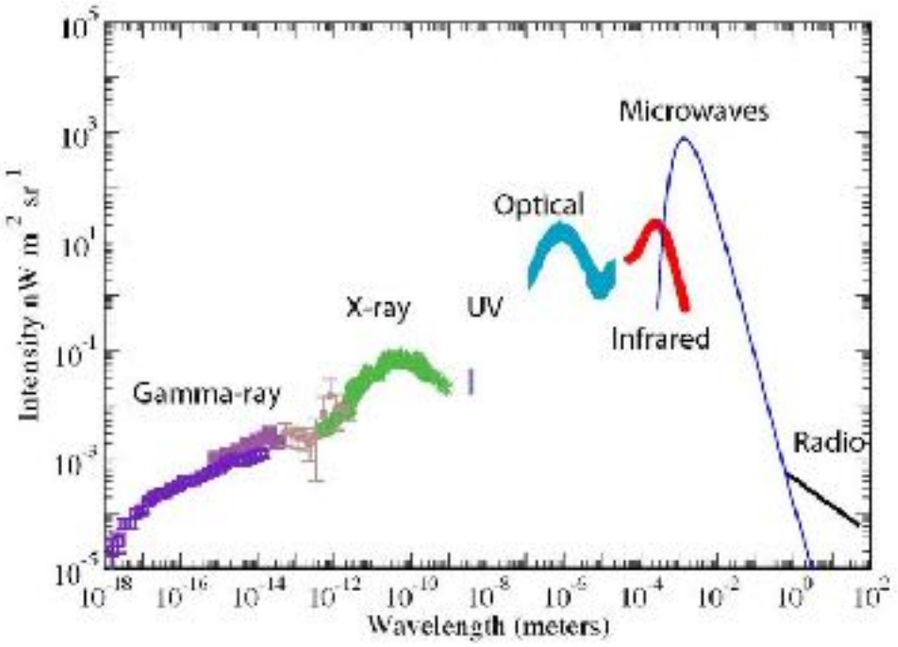
- **Infrastructure projects**
- **In progress**: reconfiguration of telecom antenna in Tulancingo, Hgo.
  - 50/50 funding from Newton Fund, UK, and Estado de Hidalgo (total 20 Mpesos), for reconversion.
- **Under consideration**: Possible participation in the Next Generation Very Large Array (ngVLA), NM, EUA.
  - 10x the collecting area and angular resolution of VLA.
  - Cost ~ 2,000 MUSD (2000USD/hour of operation). Key to participate through the construction and location of some antennae in Mexico
  - NRAO (National Radio Astronomy Observatory, EUA) is in principle open to Mexican companies participating.

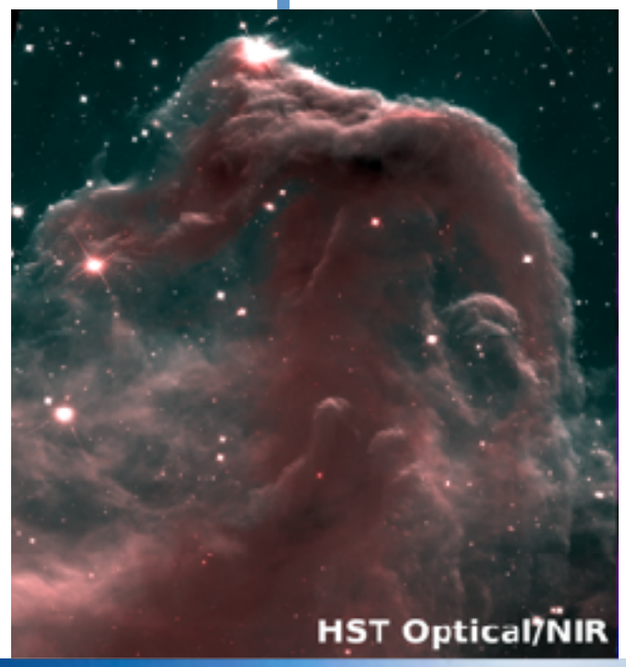
Radioastronomy

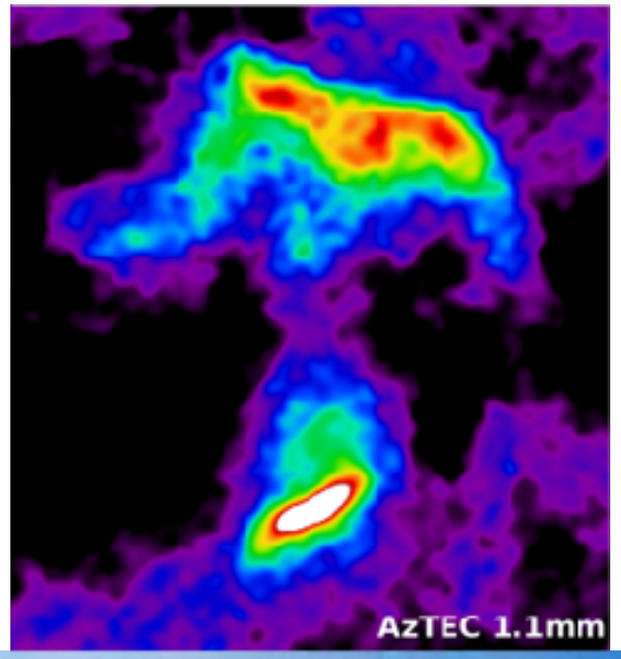
- **Collaborative projects:**
  - **GOBELINS**. Ultraprecise distances to star forming regions using VLBA (Very Long Baseline Array).
  - **Event Horizon Telescope:** observations of the black hole in SgrA* and M87.
  - **Future**: possibilty to install a decomissioned CARMA antenna at SPM.



Large Millimeter Telescope - Alfonso Serrano







- comets
- asteroids
- planets
- proto-planetary disks
- proto-stars
- molecular gas and dust in star forming galaxies
- galaxy formation
- galaxy clusters

Large Millimeter Telescope - Alfonso Serrano

- The LMT is the largest single-dish mm antenna
- Observations at mm wavelengths trace star formation through the history of the universe
- This complements other and future infrastructure projects in Mexico in gamma-rays, optical, IR, mm and radio.

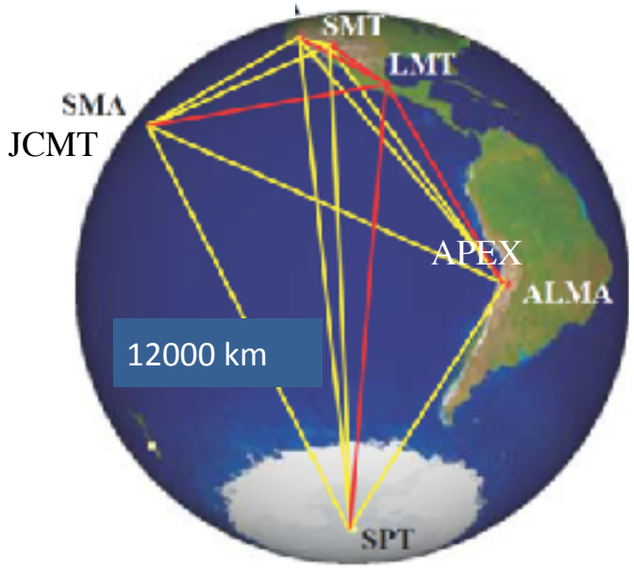
- **Bi-national project** (>1994) between Mexico (CONACYT) and the US (University of Massachusetts), 100 researchers, engineers and technical staff
- **Site selection del sitio** (1997) Sierra Negra, Puebla - 4600m above sea level
- **Construction start** (>1998)
- **LMT 32-m: first light** (2011)
- **Termination plan**(2013-2018): LMT 32-m to LMT 50-m
- **Primary reflector at 50m** *(~75 μm r.m.s.)*
- **Active control system for** primary reflector for thermal and gravitational effects
- **LMT50-m** – optimization and scientific operation (> 2018)
  observing range: 1.1-4mm
  angular resolution (FWHM): 5´´ - 18´´
- +20 publications with 300 researchers (30% from Mexico) at 100 institutions
- 10 PhD thesis + 2 M.S. thesis; 10 more PhD+M.S. in progress

Large Millimeter Telescope Alfonso Serrano

- **Observing time:** México (70%), UMASS (30%)

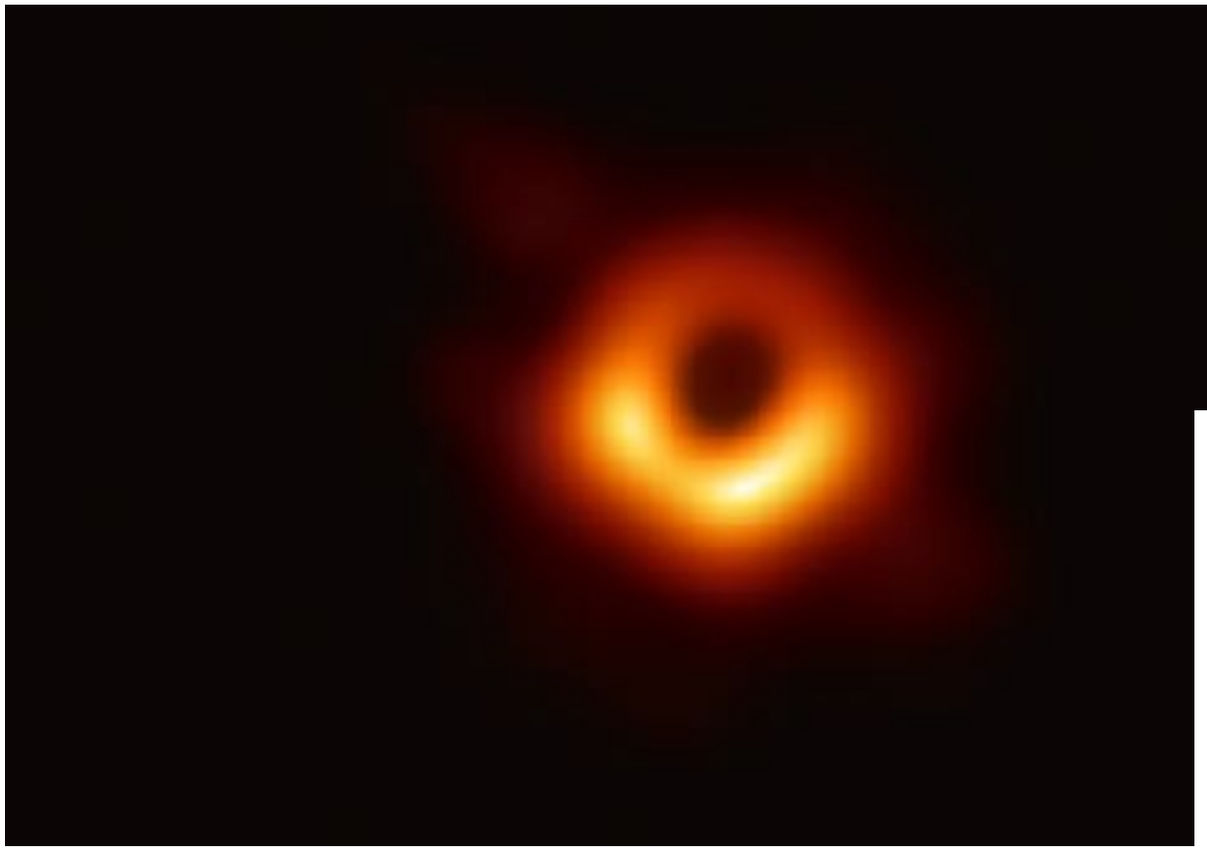
- **Development of scientific instrumentation**
- RSR, AzTEC, SEQUOIA, B4R, EHT VLBI, MUSCAT, TolTEC, SuperSpec
  - **Mexico $ 20 MdP** (CONACYT FONCICYT y FORDECYT)
  - **UK $ 13 MdP** (RCUK-Newton Fund)
  - **Japan $ 30 MdP** (Japanese Society for the Promotion of Science)
  - **USA $250 MdP** (UMASS; NSF: MSIP, ATI; Caltech, Colorado, Chicago, NIST)

- **Event Horizon Telescope (VLBI 1.3mm – GTM + ALMA, APEX, SPT, JCMT, SMA, SMT, GLT, IRAM y NOEMA)**
  - collaboration > 300 people; 100 institutions
  - first image of a black hole
  - fundamental physics and GR tests in the strong field regime



Event Horizon Telescope/LMT

Event Horizon Telescope/LMT



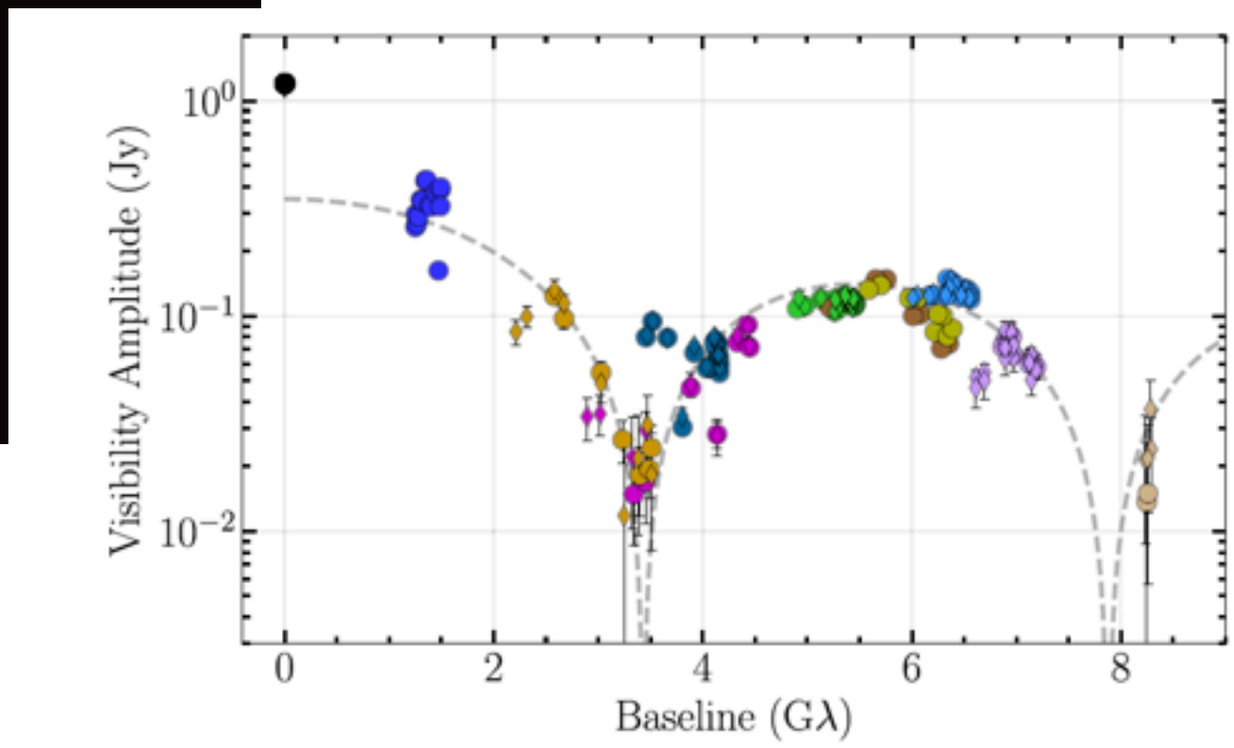


Figure 2. Top: (u, v) coverage for M87*, aggregated over all four days of the observations. (u, v) coordinates for each antenna pair are the source-projected baseline length in units of the observing wavelength λ and are given for conjugate pairs. Baselines to ALMA/APEX and to JCMT/SMA are redundant. Dotted circular lines indicate baseline lengths corresponding to fringe spacings of 50 and 25 μas. Bottom: final calibrated visibility amplitudes of M87* as a function of projected baseline length on April 11. Redundant baselines to APEX and JCMT are plotted as diamonds. Error bars correspond to thermal (statistical) uncertainties. The Fourier transform of an azimuthally symmetric thin ring model with diameter 46 μas is also shown with a dashed line for comparison.

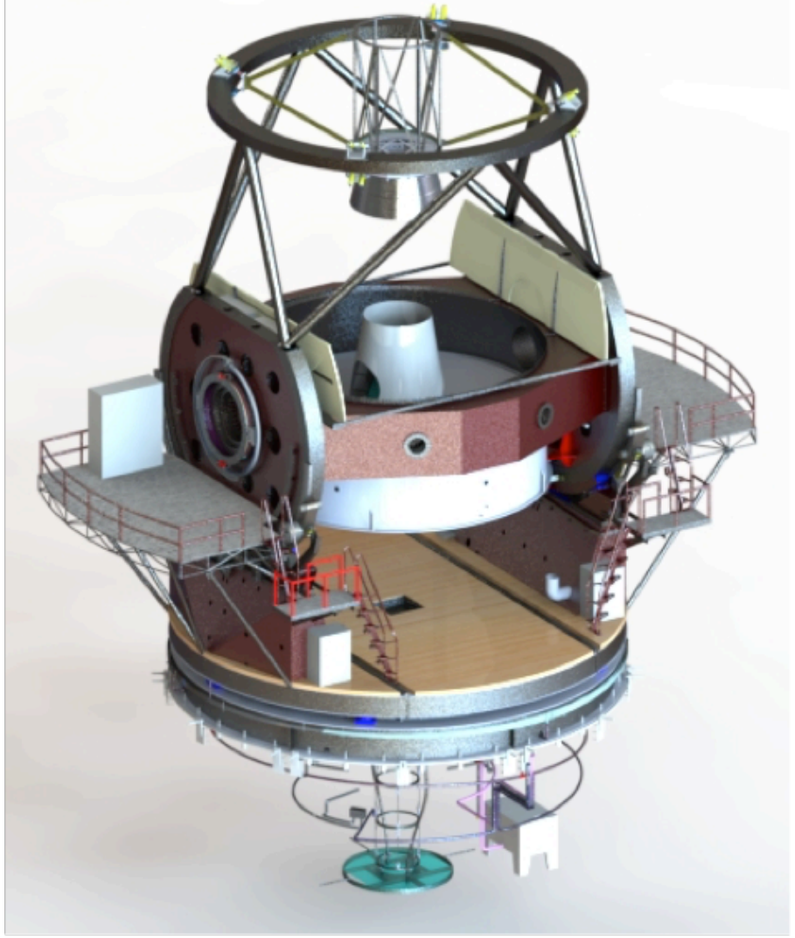
Internationalization and development at OAN-SPM, 2010-

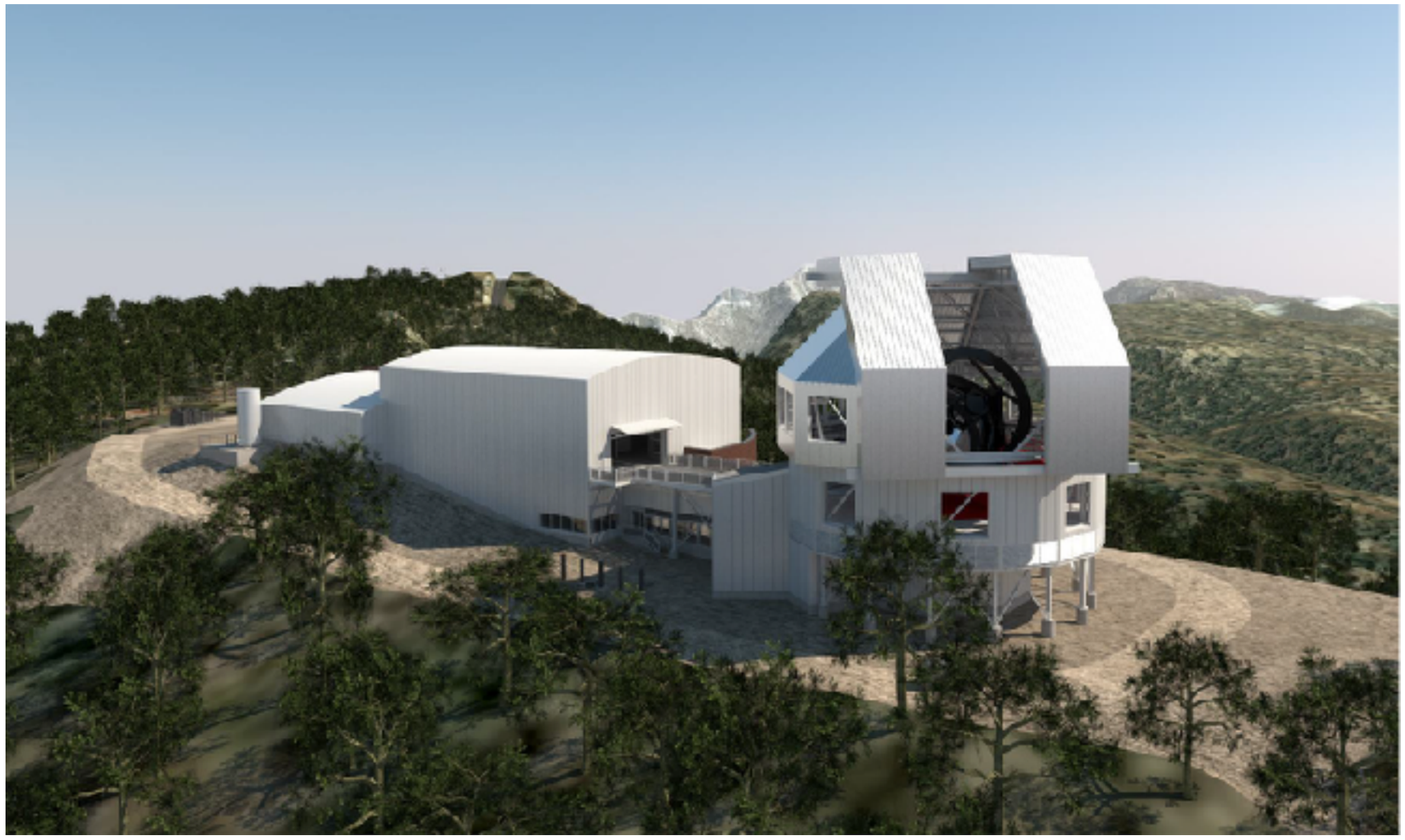
Project	Infrastructure	Key project	Partners	Funding	Operation**
RATIR	Rob. Tel. 1.5m	Transients*, general science	EEUU-NASA/GSFC/ASU (80%) UNAM (20%)	1.3 MUSD	2012-2021
Bootes-5	Rob. Tel. 60cm	Transients*, general science	Spain-CSIC (60%) UNAM (40%)	0.7 M€	2017-25
TAOS-II	3 Rob. Tel. 1.3m High speed cameras	Trans-Neptunian objects and NEOS	Taiwan-ASIAA (92%) UNAM (8%)	16 MUSD	2019-2029
SAINT-EX	Rob. Tel. 1m	Exoplanets	Switzerland-Bern/Geneva and UK-Cambridge (100%) UNAM (<1%)	1.15 M€	2019-
COATLI	Rob. Tel. 0.5m	High resolution imaging	CONACyT (75%) UNAM (25%)	0.2 MUSD	2017,20-
DDOTI	Rob. Tel. wide field	Transients*	EEUU-NASA/GSFC/UMD/ ASU (21%) CONACyT (62%) UNAM (17%)	0.1 MUSD	2017,19-
COLIBRI	Rob. Tel. 1.3m O/IR instrumentation	Transients*, general science	France-CNRS/CNES (50%) UNAM and CONACyT (50%)	3 M€	2020-**

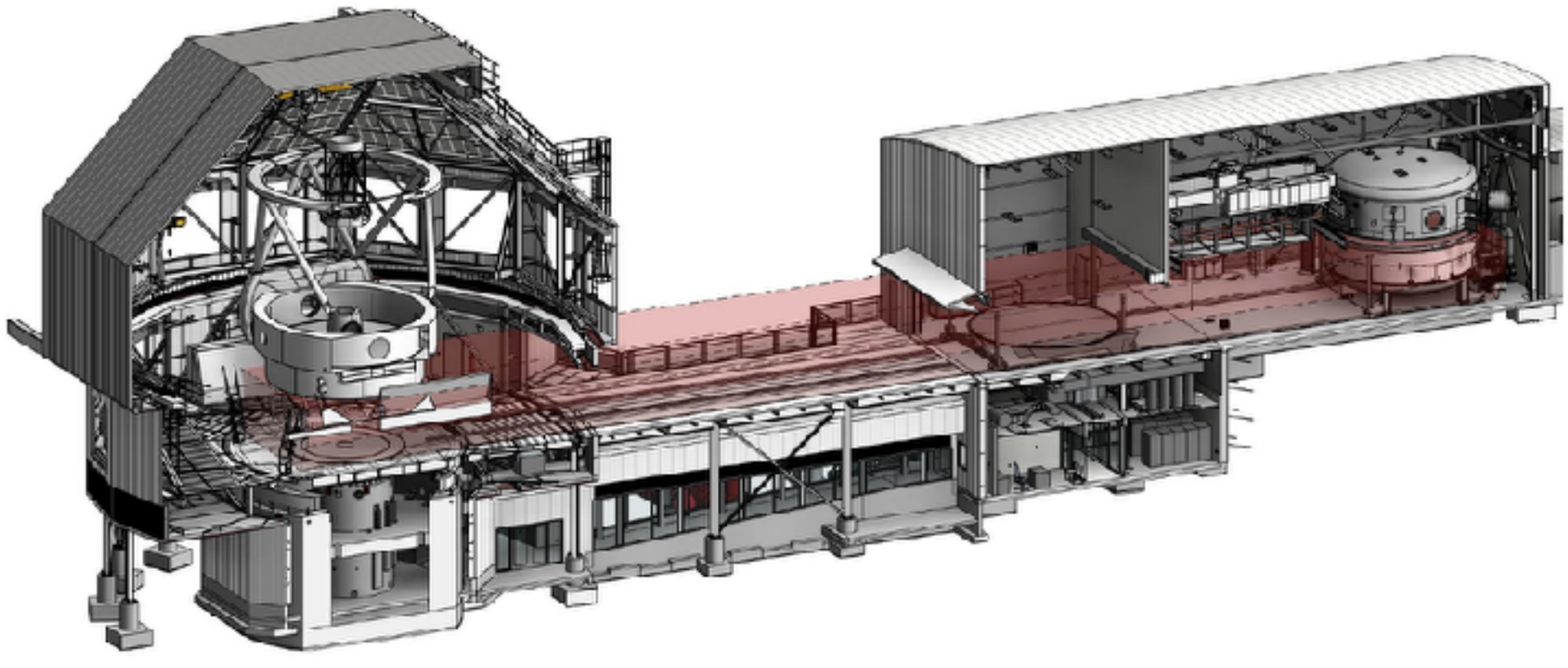
* Transients: Gamma ray Bursts (GRB), Gravitational wave sources (GW) and Supernovae, among others
** Under construction

TSPM - Telescopio San Pedro Mártir

- 6.5m telescope for OIR at SPM
- Letter of intent between UNAM, INAOE, University of Arizona (UA) and Smithsonian Astrophysical Observatory (SAO) in 2012.
- Goal: to operate the new TSPM at OAN-SPM jointly with the MMT UA y SAO) at Mt Hopkins, Arizona as a binational astrophysics lab open to the entire mexican community.
- Develop the TSPM where appropriate and possible in Mexico
- Contributions (****: existing elements)***
    - Mexico: site at SPM, project management, support and services buildings, telescope structure, ***co-ownership of the primary optics system, 6.5m****
    - UA and SAO: ***co-ownership of the primary optics system, 6.5m*; secondary mirror, corrector, instruments, MMT telescope at Mt Hopkins, Arizona (UA/SAO)* Design work began in 2013***
- Telescope structure, buildings and project management - Mexico
- Two international external reviews: PDR for enclosure and services in 2016; CDR for enclosure and services, and PDR for telescope and optics in 2017.
- Construction requires 100MUSD in 5 years.







Public outreach

- The community in Mexico has pioneered outreach efforts and public knowledge in astronomy for the general public.

- Since 2009, we carry out the largest public outreach event in science in Mexico: la Noche de las Estrellas, directly related to the Nuit des Étoiles which has been organized in France for over 25 years.

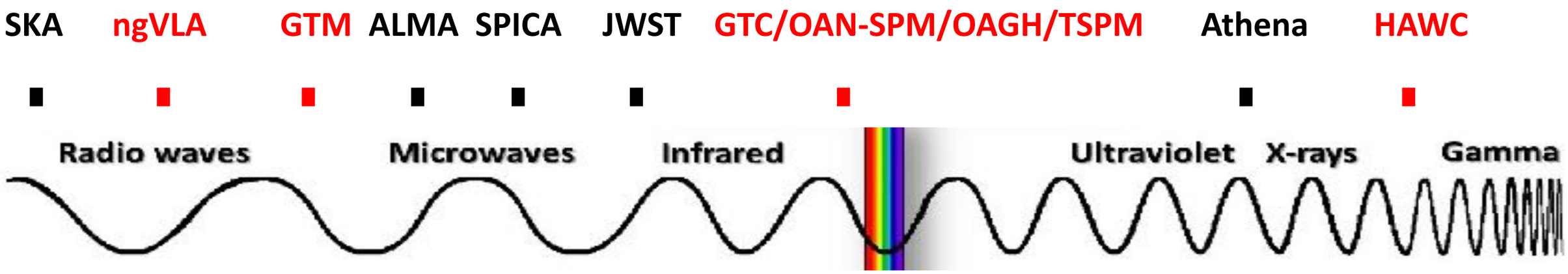
- Today, NdE happens in over 100 locales around the country and in every state, with collaboration with Colombia, China, Costa Rica, Puerto Rico, Argentina, Guatemala and Brasil.

- Directed at the general public and in particular to children.

- Talks, workshops, hands-on experience and interaction with astronomers

Opportunities

- Many of these projects are complementary and give Mexico a wide range of possibilities for astronomy and astrophysics today and for the next decades throughout the electromagnetic spectrum, from gamma rays, optical, infrared, millimeter and radio, and in gravitational waves.



- 3 National Laboratories under CONACyT: LN-SPM, LN-HAWC, LN-GTMAS
- Multi-frequency capability from Mexico and in international observatories (e.g. SDSS, GTC, ngVLA)
- Responsible development of unique sites within national parks
- High added value technological development
- Qualified human resources development

Merci!