Large Facility Workshop

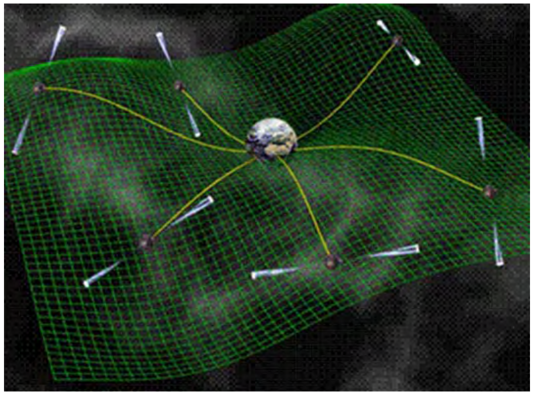
May 12, 2015

ARECIBO OBSERVATORY
PUERTO RICO
SRI • UMET • USRA

Welcome to Arecibo Observatory

Background, and what to expect

- Brief History of Arecibo Observatory (AO)
  - A "Space Race" facility, conceived in 1958
  - 1963 inauguration, major upgrades 1973, 1994, 2015
- AO is an interdisciplinary federal facility
  - Radio Astronomy, Planetary Science, Space Science
  - Nested instrumentation
  - Users
  - Some science highlights
  - Education and public outreach
  - Staffing
- AO is an industrial site
  - A steel suspension bridge in the tropics
  - Precise motion control and RFI quiet requirements
  - High-power transmitters
  - Safety
  - Deferred maintenance challenges
- Logistics



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- Became operational in 1963.
- It is the largest single dish radio telescope in the world.
- Research in atmospheric science, astronomy, & Planetary Sci.

- The Arecibo telescope was conceived by Cornell Engineering Professor Bill Gordon in 1958, and construction began in the Spring of 1960. Purpose: Incoherent Scatter Radar studies of the ionosphere.

=> Arecibo Ionospheric Observatory, "AIO" funded by Advanced Research Projects Agency (ARPA) at roughly $9M. Inauguration on November 1, 1963.

- Its potential for radio and radar astronomy was recognized by Cornell Professor Tommy Gold..

- Cornell University managed the Arecibo Observatory from 1963 - 2011, first under cooperative agreement with ARPA, and subsequently under cooperative agreement with the NSF.

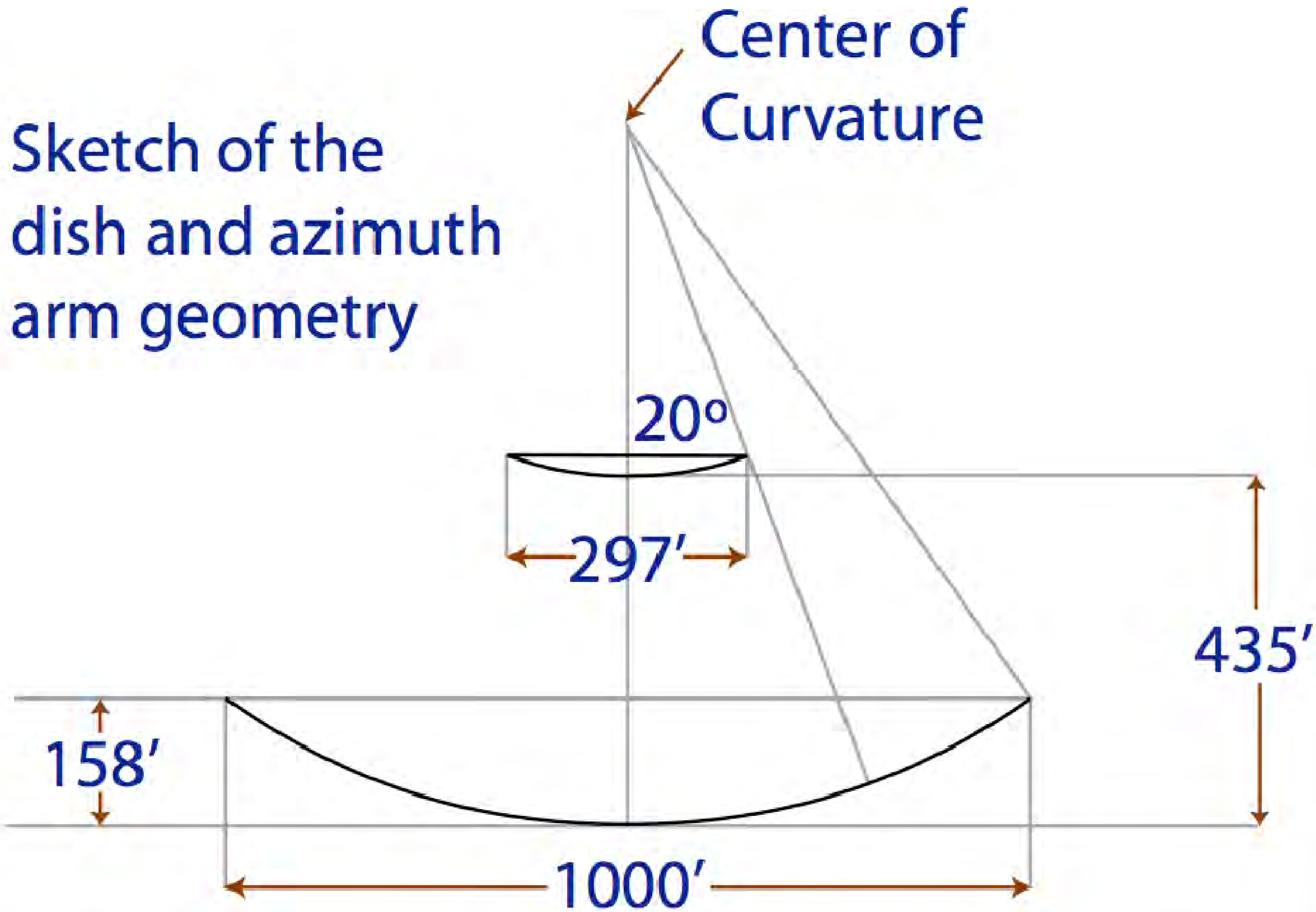
Karst Topography

Arecibo: June 1960

Arecibo: June 1962

Arecibo: Aug 1963

Sketch of the dish and azimuth arm geometry



430 MHZ TRANSMITTER

(STILL THE ORIGNAL)

The 430 Antenna

- 96 ft. in length.
- It receives and transmits radio waves of 430 MHz.
- Main instrument used to study the ionosphere.

Main facilities: control room, electronic and computer departments, scientific office space

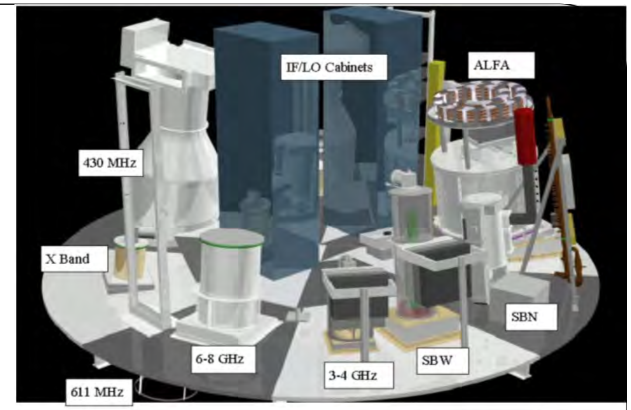
The Arecibo Observatory is now 50 years old, but the Telescope and nested instrumentation are NOT!

- Passive optical instruments for study of the upper atmosphere began to be added in 1965
- Surface upgrade completed in 1973 allowed frequency response to 2 GHz
- “S-band” 2380 MHz (13 cm) transmitter added in 1973 permits radar studies of planet surfaces
- High power lasers (“LIDAR”) added for studies of the middle and upper atmosphere in 1995
- Major upgrade completed in 1997 converted line focus of the spherical reflector to a point focus, using “Gregorian optics”.
- Ground-screen added in 1997 lowers edge spillover losses, and reduces RFI reflection from the surrounding mountains.
- “S-band” transmitter upgraded to a 1 MW system in 1997
- Visitor Center outreach and education facility added in 1997
- A radio “camera” permitting broad sky coverage and imaging completed in 2004
- A High Frequency transmitter and a mesh secondary antenna is being added in 2014 for active plasma experiments in the Earth’s Ionosphere

1973 - A New Primary Reflector

- 38,000 aluminum panels
- It is suspended above ground by a cable network.
- Each panel is individually adjusted in order to maintain the spherical curvature (~2.5 mm).

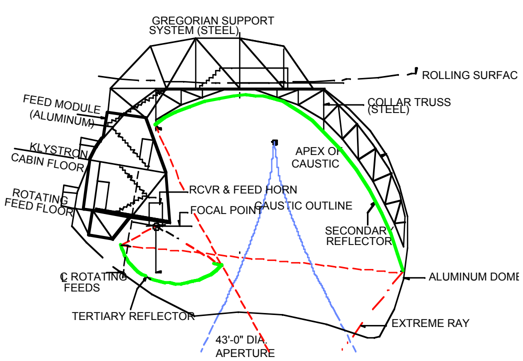
1997 Upgrade



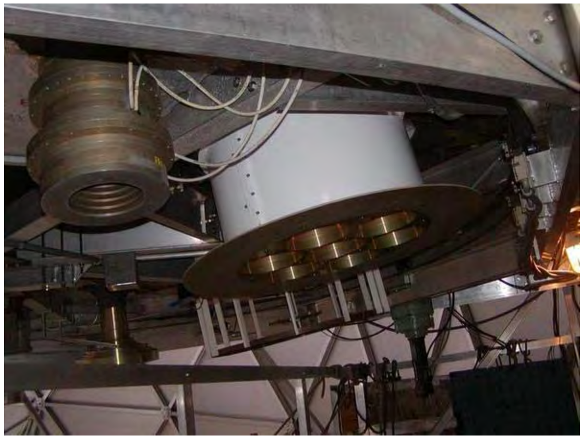
Rotary floor simulation of topside showing receivers and IF/LO cabinets where the downconversion stages for all the receivers is performed.

Ground Screen
Cable Strengthening
Gregorian Dome
New S-band Transmitter

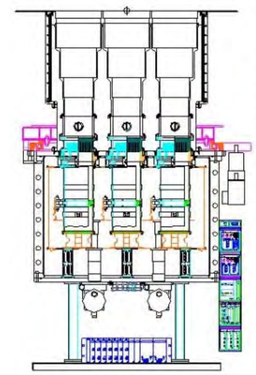
- Upgrade allowed for operation at frequencies as high as 10 GHz.
- Created a dual beam Incoherent Scatter Radar
- A vast increase in the number and complexity of the receiver and signal processing systems.



2004: ALFA - A Camera for Arecibo



- Installed 2004 Apr
- Surveys initiated Feb 2005
- 7 beams x 2 pol (linear) = 14 “pixels”
- 1225-1525 MHz full range
- Unmatched sensitivity (SEFD = 2.4 to 3 Jy)
- 3.3’ x 3.8’ beams on 11’ X 13’ ellipse
- Unprecedented capability for mapping the sky
- Survey consortia self-organized by community




CSIRO

Instrumentation at Arecibo Observatory

Radio frequency instrumentation:

305 m diameter spherical reflector radio telescope
HF – 10.2 GHz response
12-m steerable S/X band radio telescope. Slew rate is LEO capable.
Transmitters:
430 MHz 2.5 MW pulsed transmitter, 6% duty cycle
2380 MHz 1 MW CW transmitter
46.8 MHz 40 kW pulsed transmitter, 2% duty cycle
6 100 kW HF transmitters, crossed dipoles
tuned to 5.1 and 8.2 MHz, series operation at 600 kW CW,
for ionospheric modification experiments

Other:

3 GPS receivers (UTD Dallas, Miami Univ. Ohio, and Univ. of Turabo)
digital ionosonde (Canadian Advanced Digital Ionosonde [CADI], in repair)
digital ionosonde (GIRO network, in Cayey PR, PR
San Juan Magnetic Obs., UMASS Lowell)
standard riometer (30 MHz, Takushoku Univ.,
South America Riometer Network [SARINET]. Japan funded)
riometer-polarimeter (Takushoku Univ., SARINET, Japan funded)
UHF dipole receiver (in planning)

Optical and near-infrared instrumentation:

Nd:YAG Rayleigh Lidar
Alexandrite Doppler Resonance Lidar
Two Dye-lasers (Resonance Lidars)

Fabry-Perot Interferometer (red line dedicated; SSI)
Fabry-Perot Interferometer (green line dedicated; SSI)
Fabry-Perot interferometer (low resolution,
844.6 nm, 732. nm, 1083.0 nm configurable; SSI/AO)
Fabry-Perot interferometer (medium resolution, H-alpha; SSI)

1-m Ebert-Fastie Spectrometer (plans to convert to a an imaging spectrograph system)
Two Tilting-Filter Photometers w/ multiple filter stock

All sky imager, 4-inch, multi-channel system with filter wheel
(Boston Univ.)
All sky imager, 2-inch, single wavelength (SSI/AO)
All sky imager, 4-inch, multichannel system (Penn State Univ.;
currently being refurbished)
Narrow field imager, 4-inch, multichannel (Penn State Univ.
currently being refurbished)

2 solar radiometers (vis – IR)
2 cloud sensors (IR)

Other:
Lightning detector (electric field sensor)
A microbarograph (Penn State University)
Accelerometer
Atomic clock, active hydrogen maser w/ GPS clock check
NIST Time Measurement Analysis Service (TMAS) receiver

Today, Arecibo Observatory is involved in three core scientific research areas:

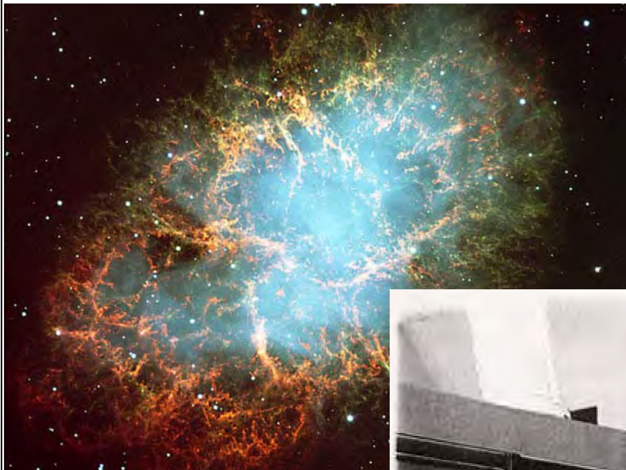
Astronomy **Planetary Science** **Space Science**

- No other observatory can match the proficiency, the breadth, nor the accomplishments of Arecibo Observatory in these combined efforts.

- No other astronomical telescope, (excepting "Goldstone"), transmits to its targets as well as passively samples.

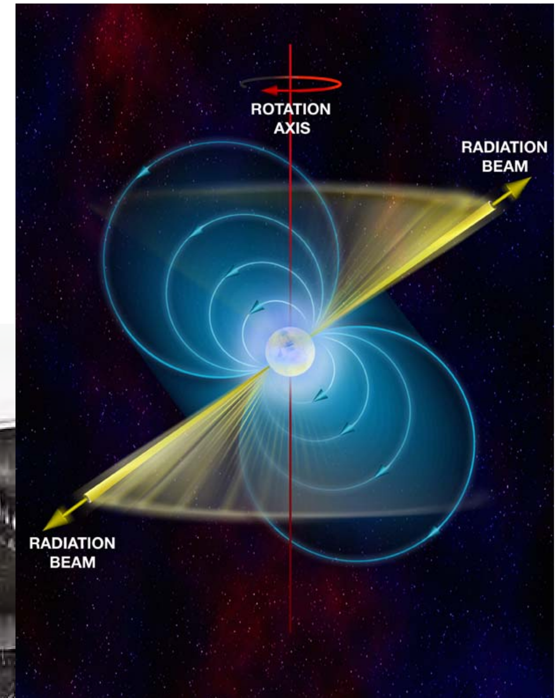
- Cutting-edge research at Arecibo Observatory applies directly to four identified natural threats – Gamma Ray Bursts, Asteroid or comet impact, Space Weather, and Global Climate Change. No other observatory can claim that breadth of significance to modern civilization.

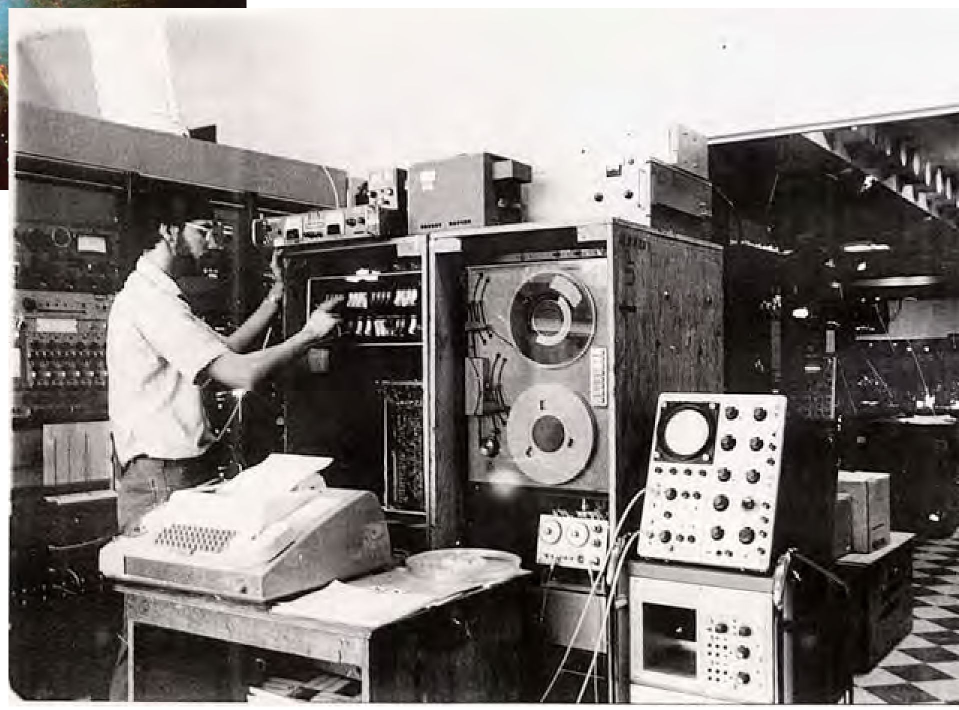
Today, AO is formally recognized as an "Electrical Engineering Milestone" by the IEEE, and a "Mechanical Engineering Landmark" by the IMSE. AO is also a "National Historical Landmark".

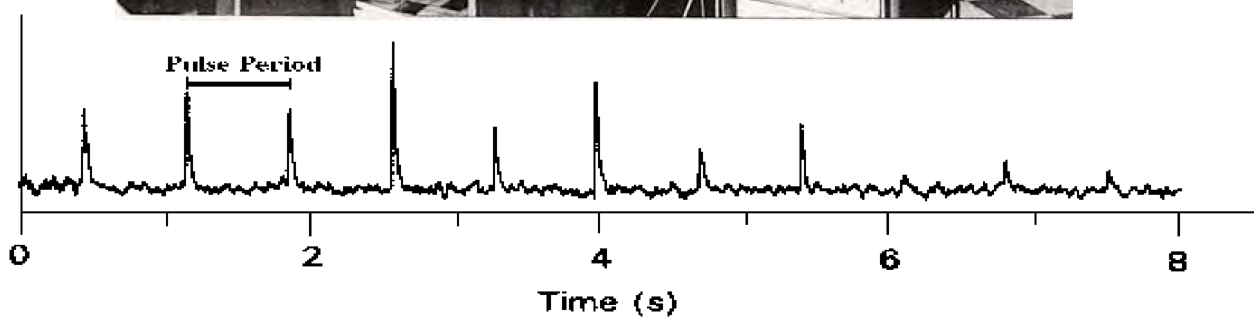


Pulsars

- Bell & Hewitt, 1967 (LGM-1)
- Hulse & Taylor 1974 (binary)
- Backer 1982 (millisecond pulsars)
- Wolsczam 1993 (extrasolar planets)



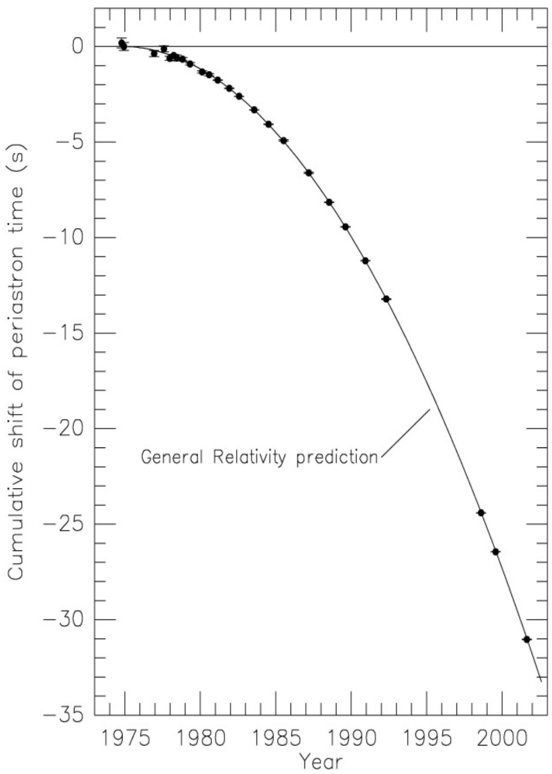




The Binary Pulsar

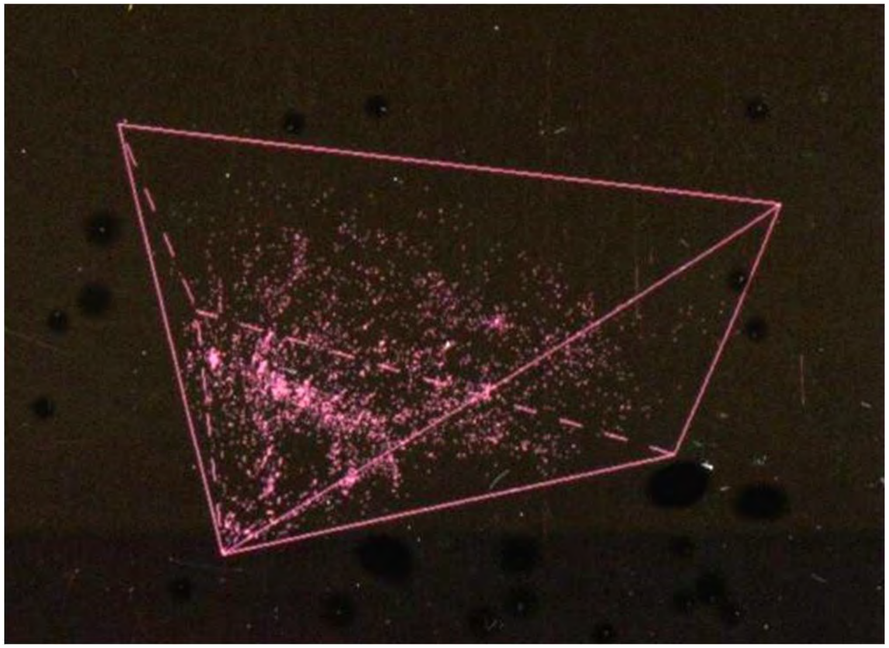
PSR B1913+16

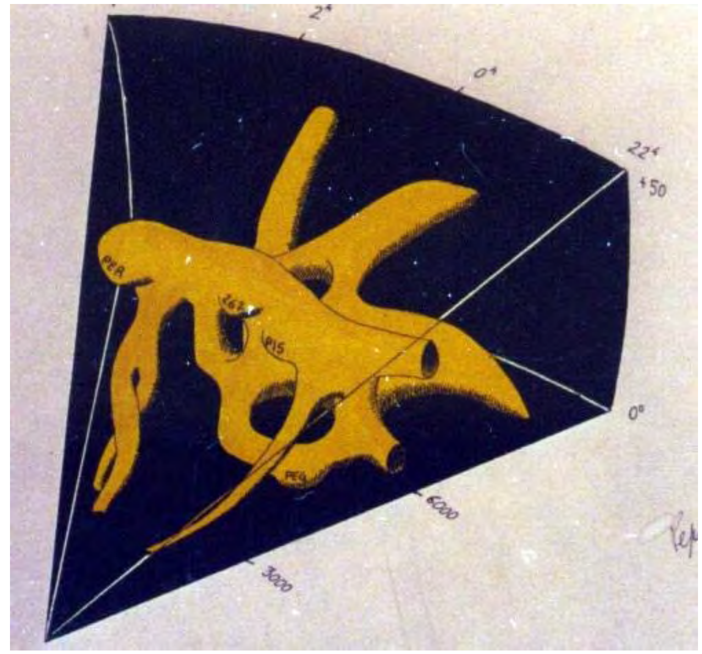
In 1974, Russ Hulse and Joe Taylor discovered the binary motion of PSR 1916+13 revealing evidence that the system is losing energy by the emission of gravitational radiation, just as predicted by Einstein's theory of General Relativity.



In 1993, Hulse and Taylor received the Nobel prize in physics for "the discovery of a new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation."

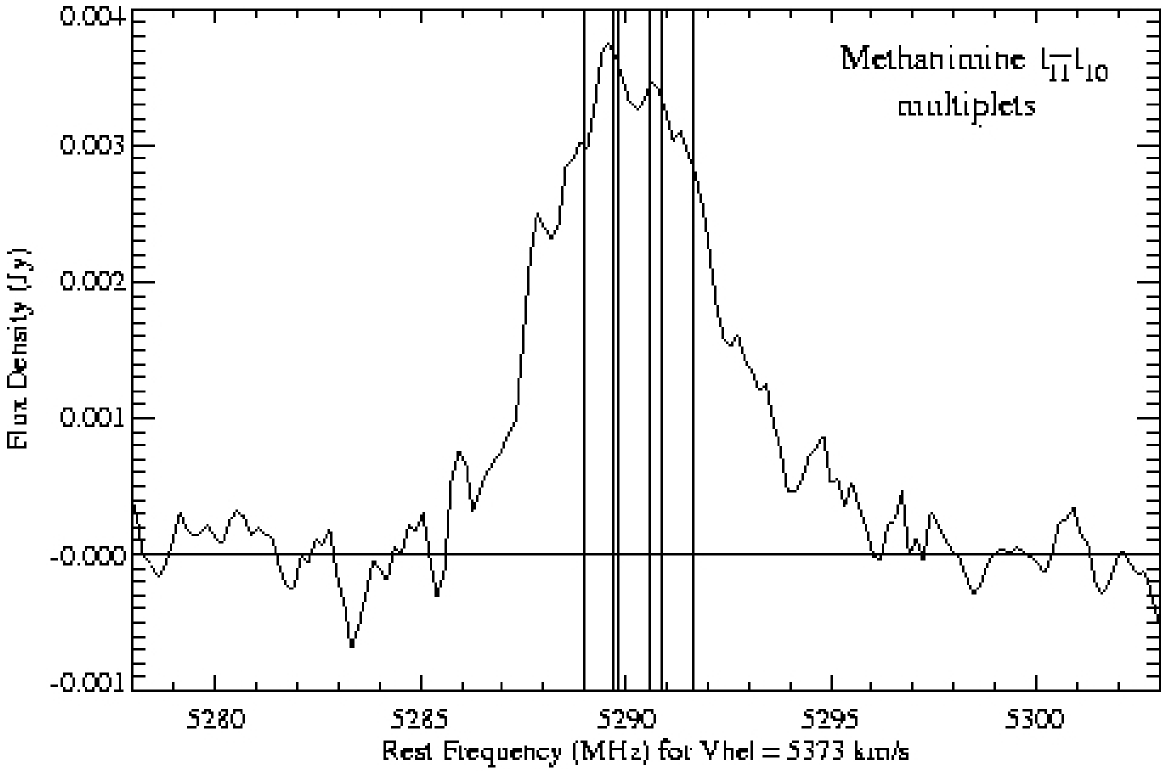
Arecibo as a Redshift Machine





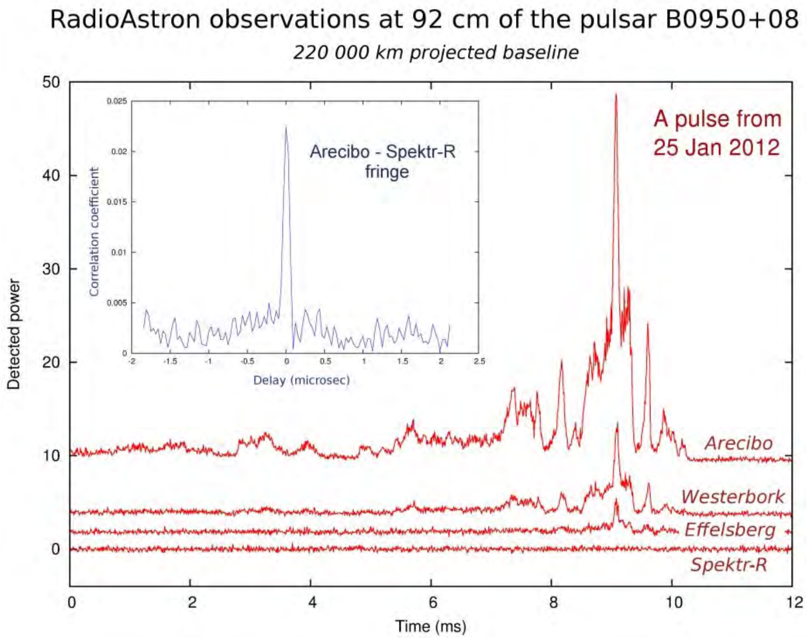
In 1989, the Henry Draper Medal of the National Academy of Sciences was awarded to Riccardo Giovanelli and Martha Haynes for their work demonstrating the filamentary nature of the Pisces-Perseus Supercluster which exploited Arecibo's high sensitivity spectroscopic and signal processing capabilities.

Using an 800 MHz bandwidth, allowed by the new dual "WAPP" configuration, a dozen molecular lines are resolved in the starburst galaxy ARP 220 – including the 1st evidence of the organic molecule methanimine outside our galaxy. CH_2NH combines with HCN (also detected) in the presence of water to produce the simple amino acid glycine. The organic chemistry giving rise to life on Earth is present in its constituent form outside the Milky Way.



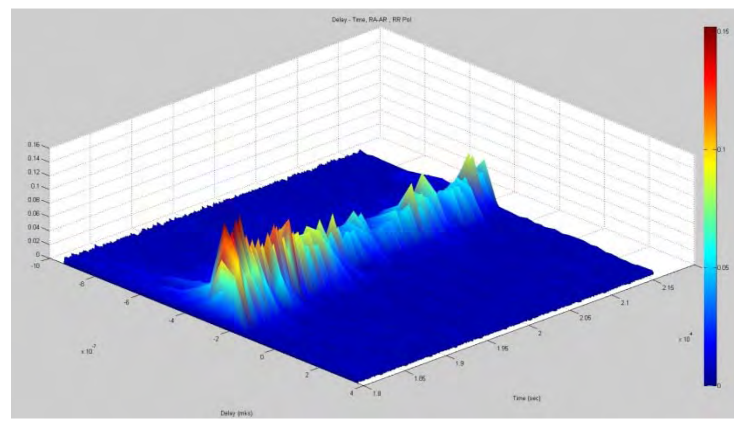
Russians, Americans and Europeans work together to set records for celestial detail.

Records were made this January when the *RadioAstron* satellite was joined by ground-based telescopes, forming a radio telescope 220,000 km across – roughly 20 times larger than the Earth.



Profiles of a single pulse from the pulsar B0950+08 detected individually (in red) by the three ground telescopes and *RadioAstron*. The inset presents the interferometer signal between *RadioAstron* and Arecibo for this single pulse. (*Image credit:Yuri Kovalev, Lebedev Physical Inst.)*

The *RadioAstron* orbital antenna (10-meter diameter); the Arecibo *William E. Gordon Telescope* (305-m diameter); the Westerbork Synthesis Radio Telescope (14 × 25-m diameter antennas), and the Effelsberg dish (100-m diameter). (*Images from http://asc-lebedev.ru,* www.naic.edu, www.nentjes.info/Kijkers/telescopes-a.htm, *and credit: N. Tacken, MPIfR)*

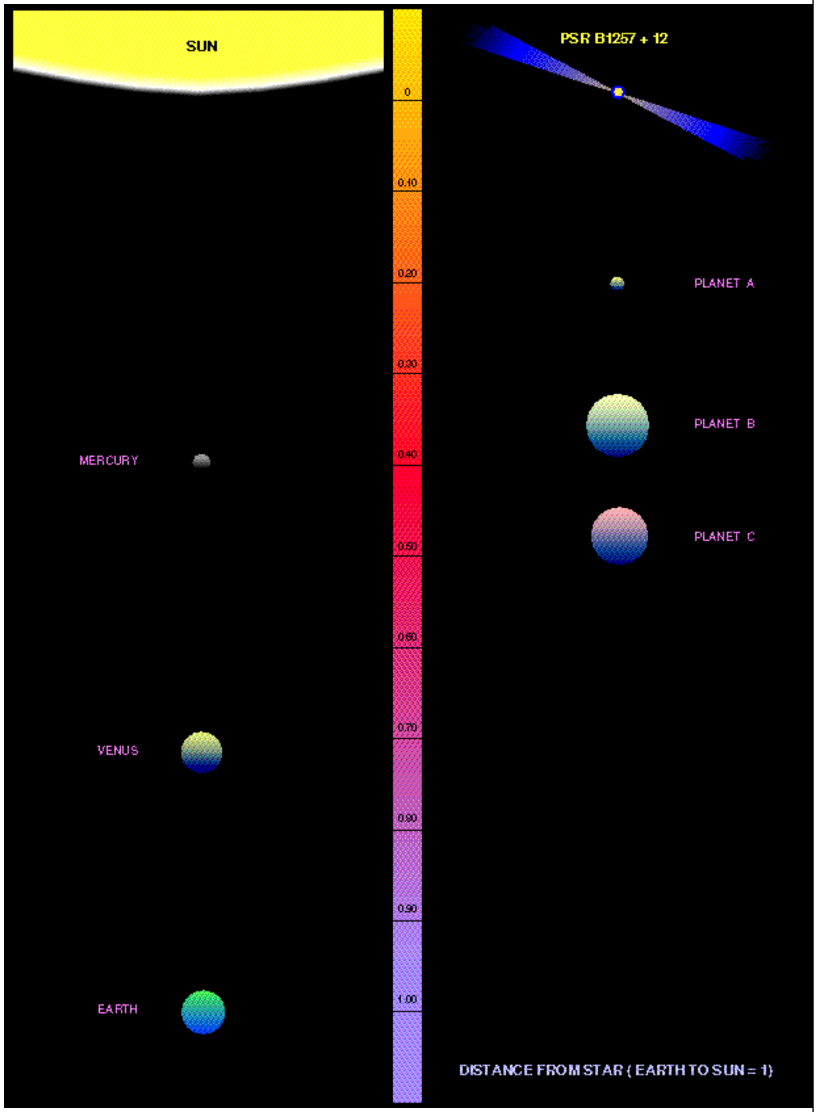


The interferometer signals between *RadioAstron* and Arecibo for the pulsar B0950+08 for the full one hour long session. On the axes: time (sec), interferometric delay (sec), and the interferometer signal I n color. The signal variations in time are due to interstellar s cintillations of the pulsar emission.
(*Image credit: Yuri Kovalev, Lebedev Physical Inst.)*

The First ExtraSolar Planets

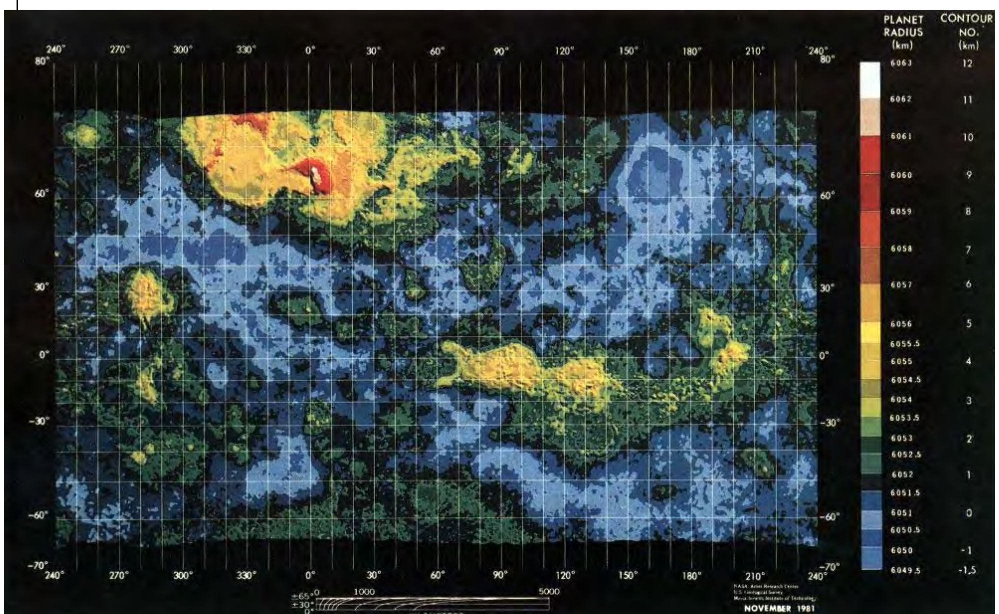
In 1992, Alex Wolszczan and Dale Frail used precise pulsar timing measurements to detect the first ExtraSolar planetary system. The pulsar's motion can be explained by the presence of at least 3 planets in tight orbit around the pulsar.

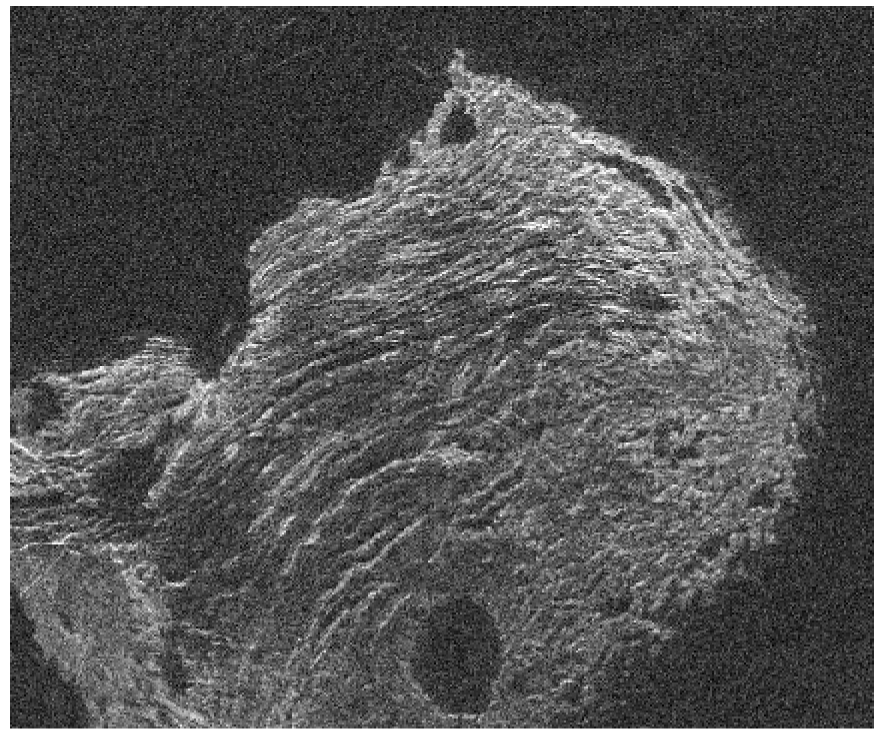
The 1996 Beatrice Tinsley Prize of American Astronomical Society was awarded to Wolszczan for his precision timing of the pulsar planets.



Venus

The first geologic maps of Venus were published in 1981, after being mapped by the Observatory S-band Radar, that was established during the 1974 upgrade.





This “same sense circular polarization Tx/Rx” (SC) image shows a portion of Maxwell Montes, spatially averaged to 1.2 km resolution.

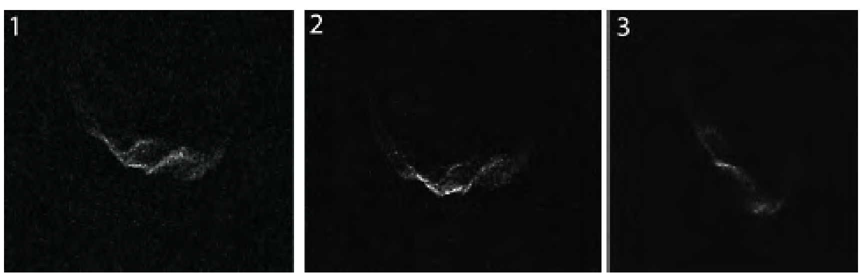
PLANETARY RADAR SCIENCE

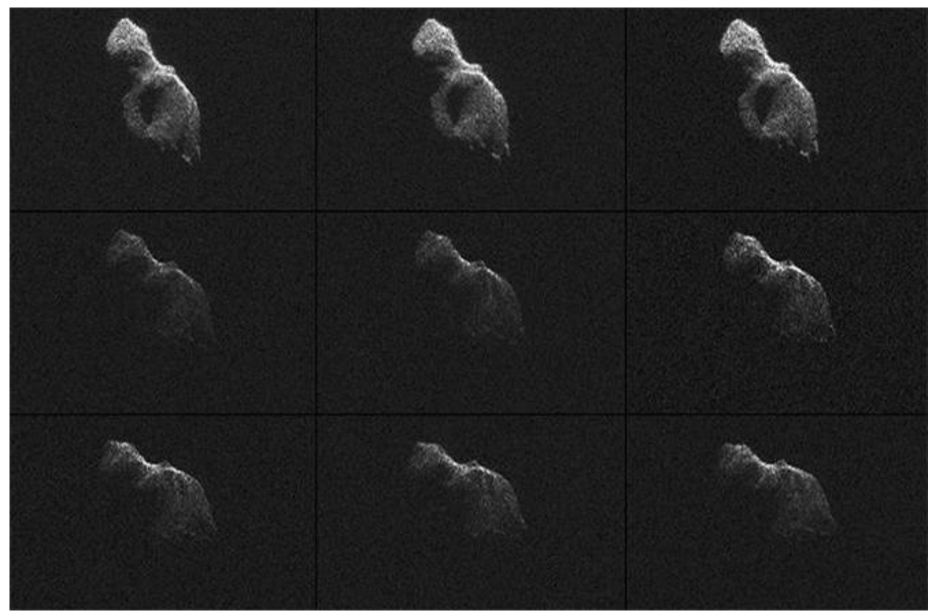
Comet 209P/Linear

- May 23 – May 27, 2014
- 1.2 x 1.5 miles in dimension
- 25' resolution
- 4th nucleus imaged from Earth (7 have been imaged)

Asteroid 2014 HQ124

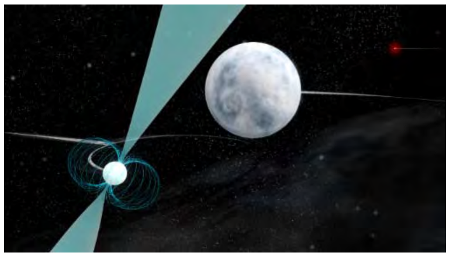
- June 8, 2014
- 800,000 miles from Earth (3 lunar distances)
- About 1,200 feet across
- 12 ' resolution



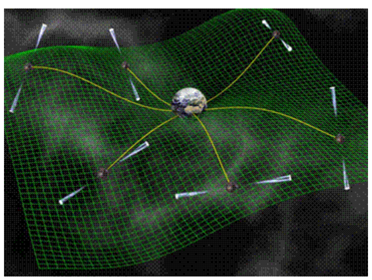


RADIO ASTRONOMY

What is the nature of gravity ?

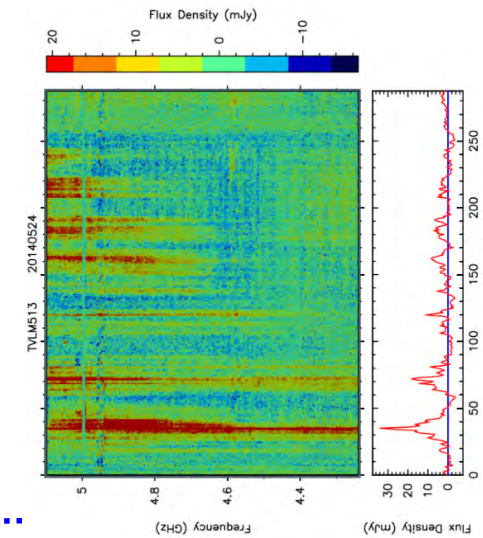


A Pulsar in a stellar triple system makes a unique cosmic gravitational laboratory. Orbital decay will test the Einstein "equivalence principle" – which suggests that the binding energy will react to gravity as though it were mass.



An array of pulsars is being developed to allow detection of "gravitational waves".

Strong Radio pulses from the magnetospheres of brown dwarfs



Unexplained radio bursts….

McGill

FOR IMMEDIATE RELEASE
Montreal, xxxxxx xx, 2014

July 10, 2014

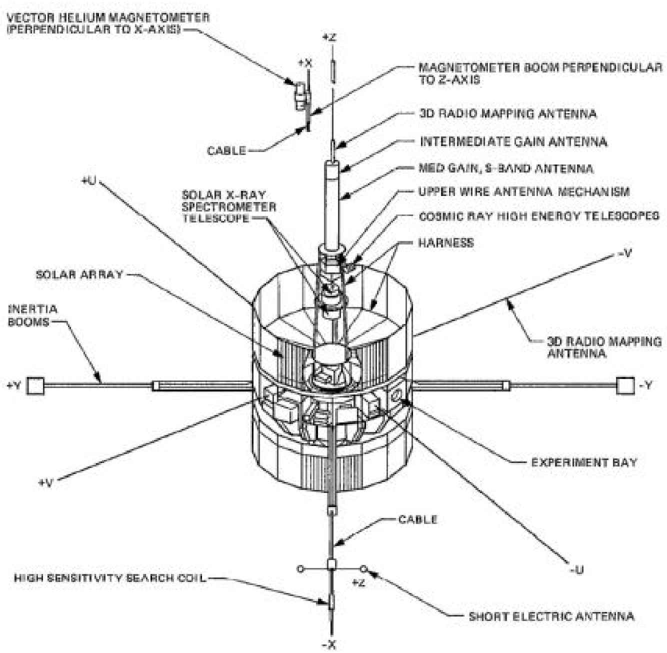
Radio-burst discovery deepens astrophysics mystery

- Discovered at Parkes, Australia, 2007
- 5 more discovered at Parkes since (2013)
- Few ms pulse. – BRIGHT
- Dispersion indicates extra-galactic source (3 bLY [Milky Way 100,000 LY diameter])
- 11/2/2012 PALFA survey at AO sees another example!
- 10,000 every day, across the sky …

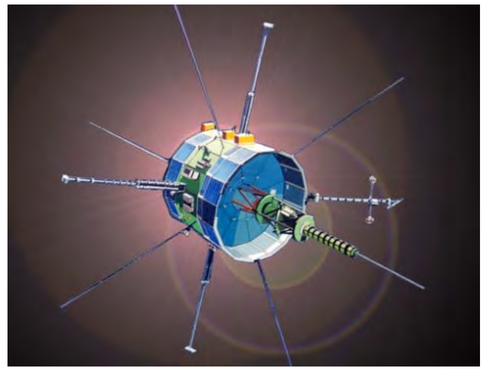
- WHAT **IS** THIS PHENOMONON ?

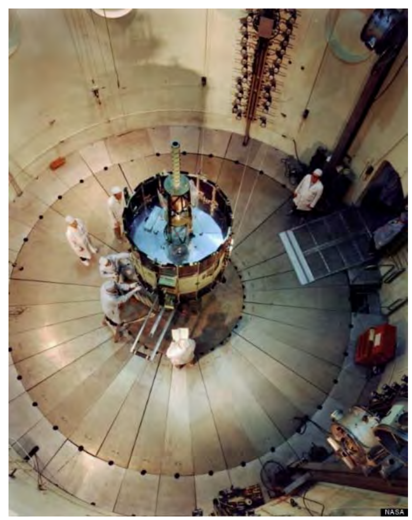
REBOOTING A SATELLITE

International Sun-Earth Explorer ISEE-3

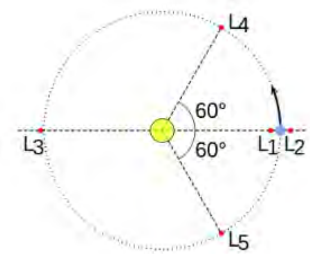


ICE spacecraft

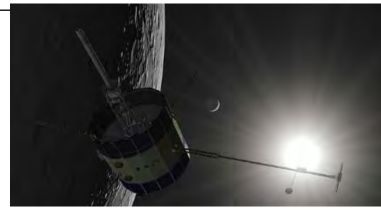




- 8/12/78 Launch. Cape Canaveral. 390 kg
- 1st International mission (NASA/ESA)
- 1st craft in "Halo" orbit



- 6/10/82 Redirected for comet encounter (ICE)
- 12/12/83 119.4 km from Moon surface
- 1984 heliocentric orbit established
- 9/11/85 7800 km from Giacobini-Zinner
- 1st craft to encounter a comet
- 3/86 28 million km from Comet Halley
- 5/5/1997 NASA decommissioning
- 1999 DSN contact, ISEE donated to Smithsonion
- 9/18/2008 DSN contact. 12/13 instruments operating.



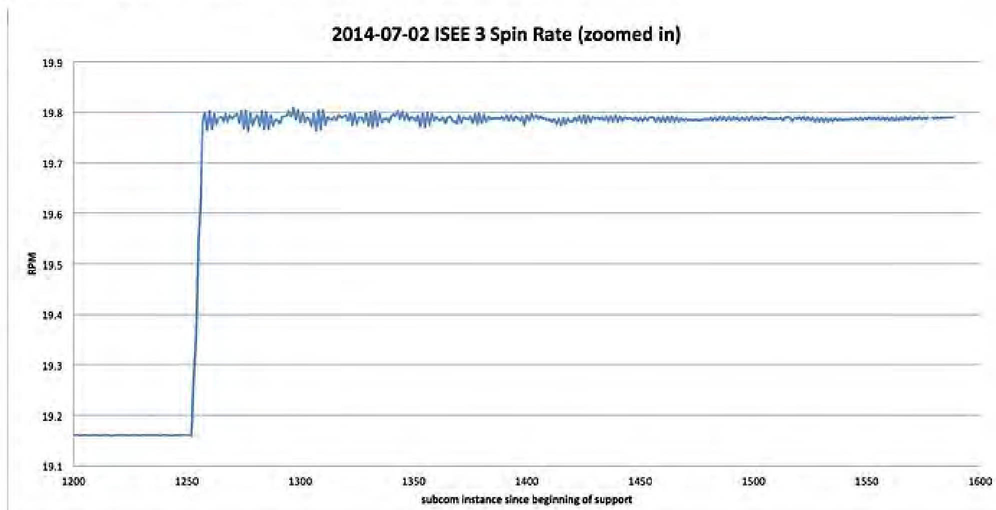
2014 Arecibo and Citizen Scientists (SkyCorp) re-establish control

- "Handshaking" with ISEE-3 from Arecibo established 5/29/14
- Coverage by BBC, FOX, NBC, NY Times, Sky & Tel., Huffington Post, etc.
- 6/5/14: Demodulated telemetry indicating +28 W power, ALL instruments responding
- 6/20/14: "Coherent" mode ranging established
- 7/2/14: Successful "spin-up"
- Improved ephemeris for Moon maneuver back to L1 ?
- 1st Citizen/NASA cooperation for NASA satellite "hand-off"

http://spacecollege.org/

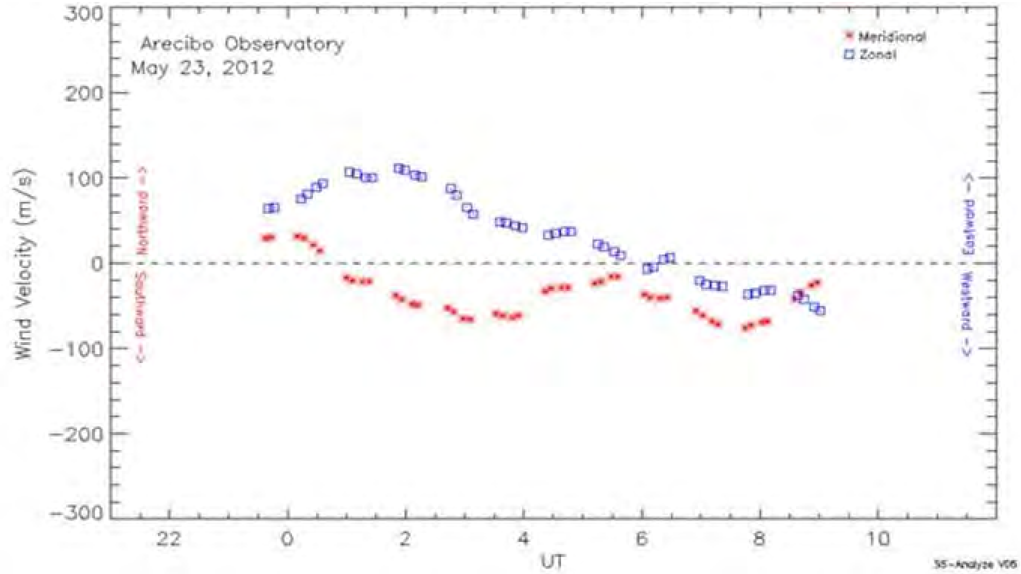
Additional ISEE-3 Spin-up Confirmation

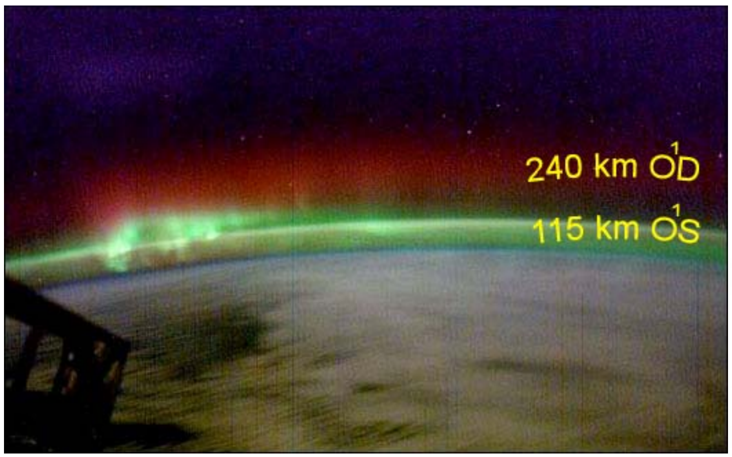
By Keith Cowing on July 3, 2014 12:17 PM

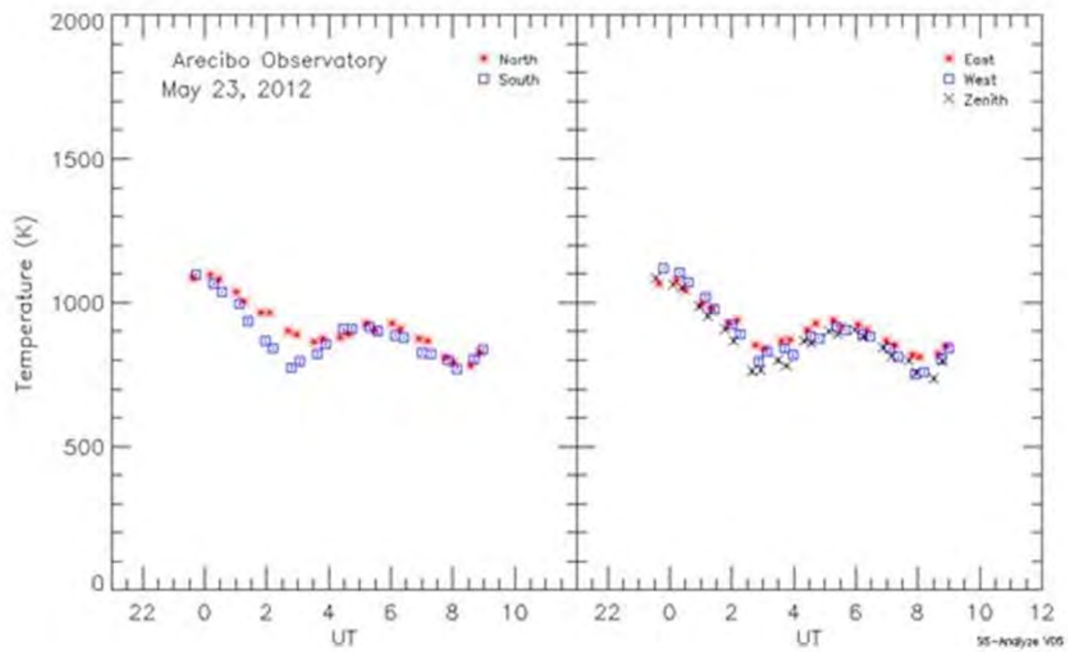


Further confirmation of the ISEE-3 spin-up burn yesterday. Before the burn (actually 11 pulses on the spacecraft's hydrazine thrusters) the spin rate of ISEE-3 was 19.16 rpm. After spin-up burn it was 19.76 rpm. The original mission specifications for ISEE-3 called for a spin rate of 19.75 +/- 0.2 rpm. Bullseye.

We now publish neutral winds and temperatures At LEO altitudes each morning, from the night previous.







Long-term changes in the thermospheric neutral winds over Arecibo

Arecibo science highlight #3 – a consequence of AO's long term ISR and optical database

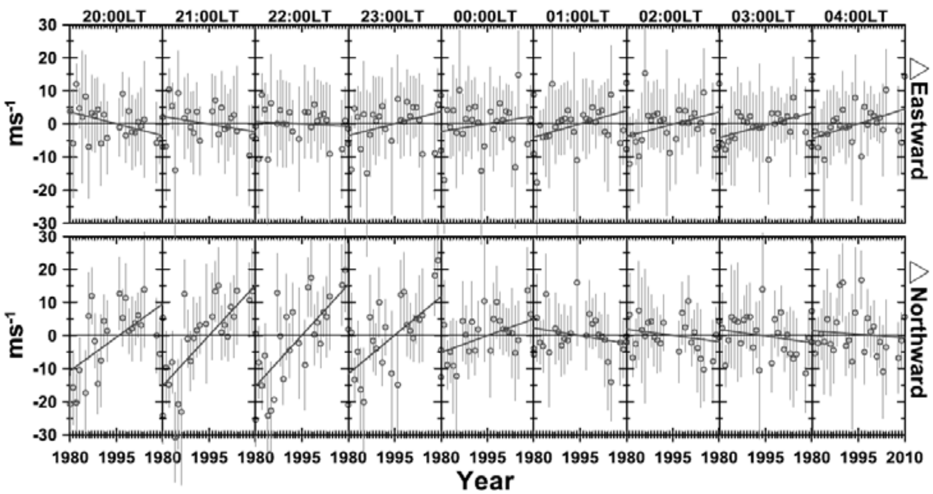


Fig.1. Linear fits to the 30 year trend observed in the zonal and meridional neutral wind component residuals relative to an empirical solar wind model (top and bottom panels, respectively) for nine different LT bins (±30 minutes). The slope of the linear fit establishes the temporal trend (m/s per year) in the change of the wind vectors. Error bars are +/- 0.5 *SD*. (Brum et al, 2012)

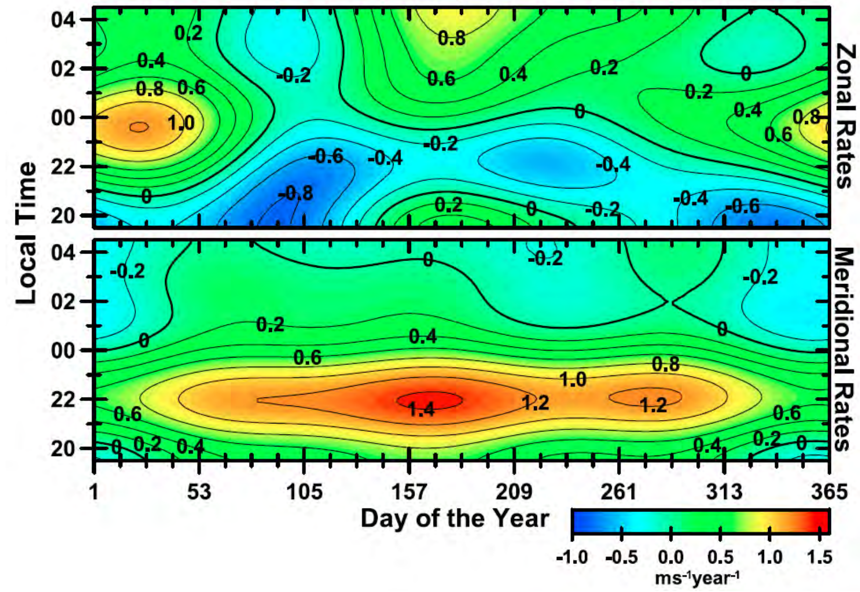


Fig.2 - Contour plots of the long-term trend rates based on year by LT and DOY for both zonal and meridional components (top and bottom panel, respectively). Contour intervals are 0.2 $ms^{-1}year^{-1}$. (Brum et al, 2012)

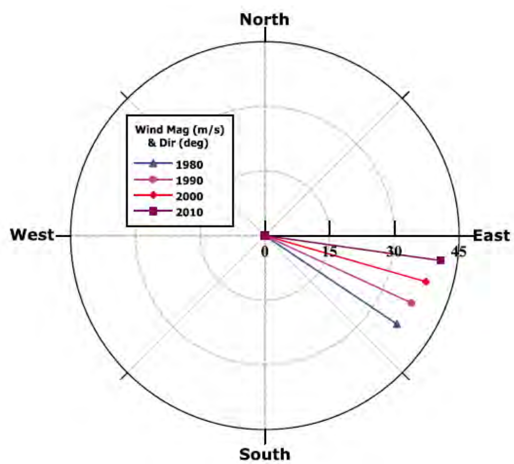


Fig.3 - Variation of the vector component of the thermospheric neutral wind derived from the trends shown in Figure 1. **Over 30 years, the vector direction has rotated counterclockwise by approximately 26°** while its magnitude has only slightly increased, maintaining an average value of roughly 40 m/s. (Tepley et al, 2011)

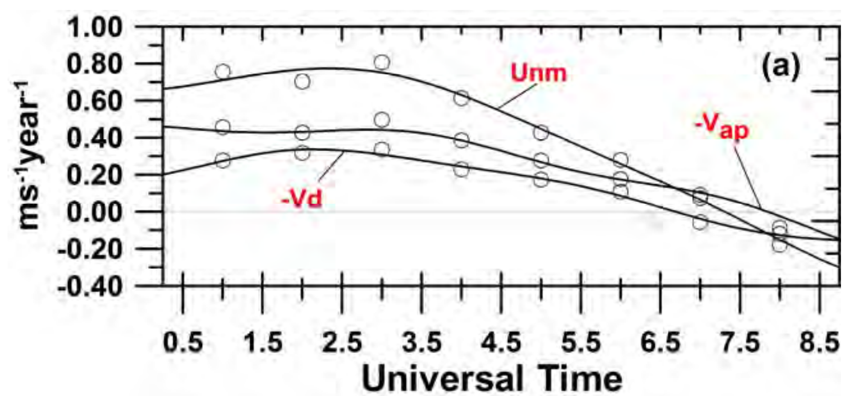


Fig.4 - Anti-parallel plasma drift (Vap) and the antiparallel diffusion velocity of O^+ (Vd) trends derived from ISR data are compared to the neutral winds along the magnetic field (Unm), during the same time period of Figure 1. **Plasma drift velocity have changed in a manner very similar to the neutral winds at Arecibo Observatory.** (Santos et al, 2011)

Formal Education Development

Pre-School:	The AO mascot
K-12:	Saturday Academy (H.S.) High School Vocational students (H.S.) ECOAME (K-12)
Undergraduate:	REU IAU Aguadilla Interns National University interns Study Abroad
Graduate:	Ph.D. granting program at Univ. of Granada

Staffing demographics

Business Admin.	10
Maintenance, Visitor Service	38
Electronics	17
IT	4
Telescope Ops.	7
SAS	11
PRS	8
AST	5
EPO	7

Admin./Business	7
HR	1
EHS	1
Media Specialist	1
Site Maintenance	16
Platform Maint.	10
HF	5
Kitchen, VSQ, Ware.	7 (1 temp.)
Electronics	17 (1 PT)
Tel. Ops.	7
SAS	11 (3 PT)
PRS	7 (1 PT)
	4 AOSA
AST	5
IT	4 (1 PT)
EPO	7

Partner	employees
UMET	55.5 (1 temp/PT) (plus 17 guides)
USRA	36 (7 PT)
SRI	18.5 (4 PT)
TOTAL:	109 (plus 17 guides)

ARECIBO OBSERVATORY
PUERTO RICO
SRI • UMET • USRA

Scientific and technical staff -today

SAS

Sulzer (ISR)
Friedman (lidar) [PT]
Raizada (lidar)
Aponte (ISR) [PT]
Terra-Santos (analysis)
Brum (analysis)

Robles (airglow data)
Cabassa (data handling)
Santoni (transmitters)
Garcia (optics tech) [PT]
Iguina (transmitters) [PT]

- Research Scientist
- Technician

AST

Salter
Ghosh
Minchin
Seymour
Hernandez
- Director

PRS

Nolan
Howell
Taylor
Richardson
Rivera-Valentin
Ford (data analyst)
Zambrano (data analyst)

Negron (transmitter)
Lebron (transmitter)
Bague (transmitter)
Marrero (transmitter)

Electronics

17 (1 PT)

IT

Venkataraman
Gomes
Shankaran [PT]
- Software

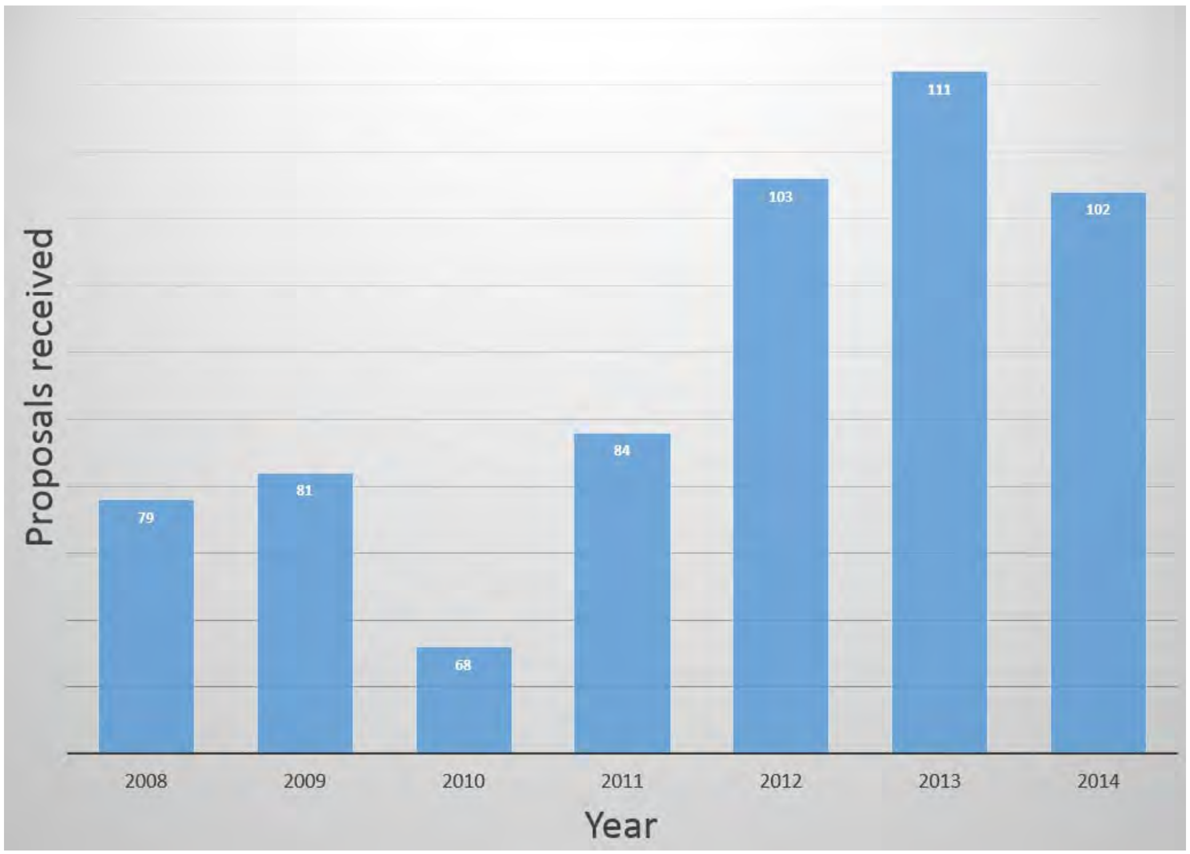
Green indicates open position to be filled.

Diversity

- 76% of the AO workforce is Hispanic
- 22% of the AO staff are women
- Of our 30 scientific staff members, 8 are female, 10 are Hispanic, and at least two are persons with disabilities.
- In our astronomy program, the breakdown of the 95 PIs that used the Gordon telescope in PY 2014 is as follows:
  Female PIs in Radio Astronomy: 38%
  Female PIs in Pulsar Astronomy: 38%
  Female PIs PRS: 45%
- However, women get the bulk of scheduled telescope time:
  Woman PI telescope use in Radio Astronomy: 54%
  Woman PI telescope use in Pulsar Astronomy: 50%
  Woman PI telescope use in PRS: 59%
- Nearly every student that we train in our formal education programs is Hispanic

➢ **AMT is committed to workforce and user diversity at AO. AMT is also committed to improving diversity in the science disciplines within which we operate through the STEM education and training programs that we provide in Latin America.**

Gordon Telescope proposal pressure

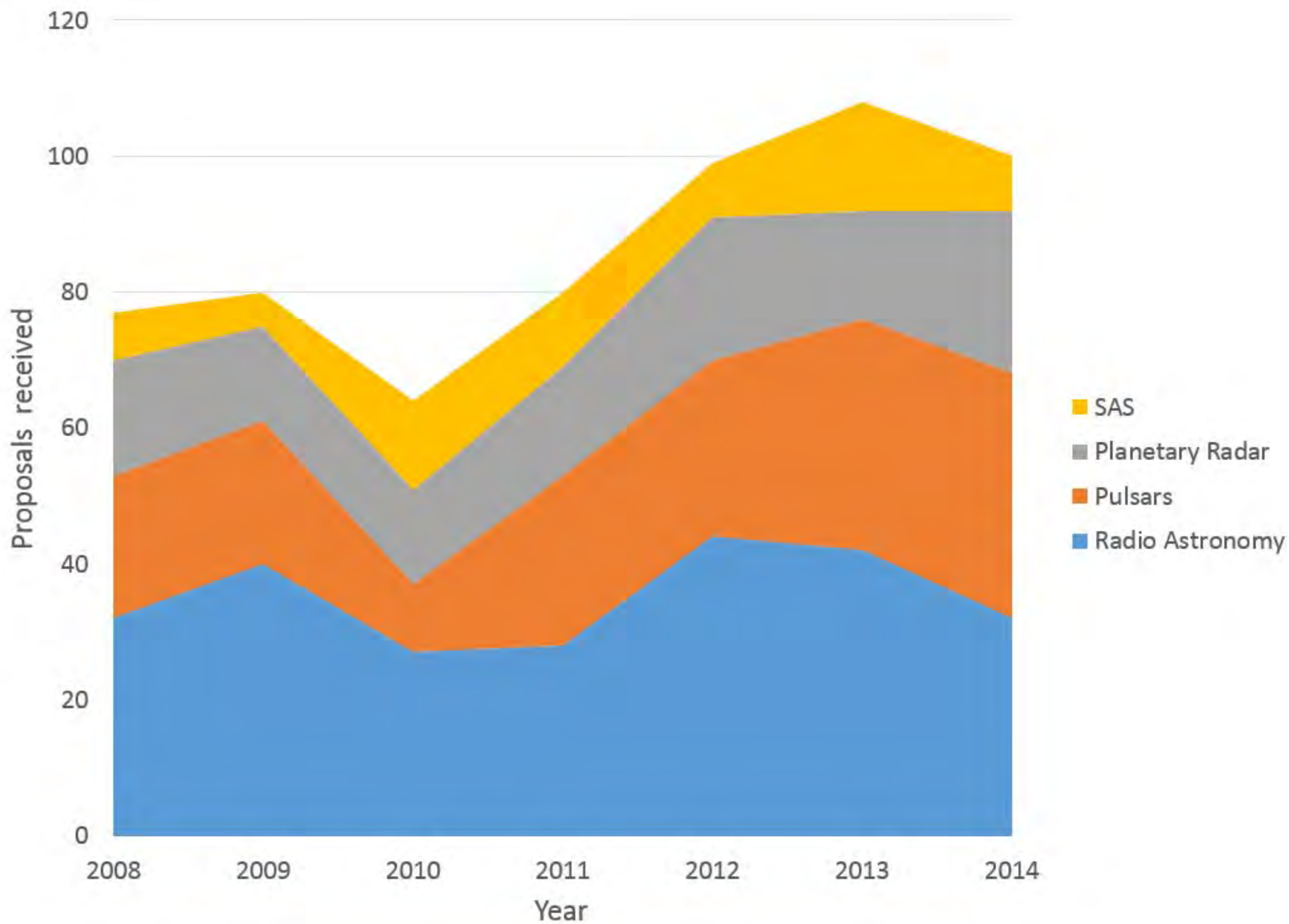


These are proposal ALL submitted proposals, by Number, not by hours requested.

Why the large increase?

- Surveys ramp to end ?
- New proposal periods ?
- New capabilities ?

Proposal pressure by discipline



New pressure for pulsar timing (NANOGrav), expanded NEW program, and the Heating facility.

Users of Arecibo Observatory

Users of Arecibo Observatory in the past five years[1]

	User and data type	**AO total users**	**Space Physics specific**
1	Telescope proposal authors, PIs and 1st Co-Is only	310	56
2	Extrapolated number of all proposal authors	489[2]	64[3]
3	Refereed publications using AO data[4]	398	89
4	Publication authors (all authors)	1592[5]	327[6]
5	Scientist users, telescope users & authors[7]	2090	379[8]
6	Formal Ed. Programs sponsored by AO	730	
7	Formal Ed. Programs sponsored outside of AO	642	
8	Citizen science users (SETI & Einstein@Home)	151,247	
9	Tourists and media	340,040	
	Total[9]	**494,749**	

[1]items in green are rough estimates

[2]based on known number of telescope use co-authors on urgent proposals in the last 5 years, extrapolated to all proposals

[3]very conservative extrapolation of all telescope proposal authors based on known co-authors on urgent proposals in the last 5 years, extrapolated to all proposals. Urgent proposals are not common in Space Physics.

[4]probably not an exhaustive number. Some publish AO data without attribution.

[5]This is a VERY rough estimate of an average of 4 total co-authors per publication.

[6]This is an exact number, assuming all publications have been identified. Space Physics publications averaged 3.7 authors per publicatiom – no individual author is counted twice in this total, though they may appear on multiple publications.

[7]Scientist users are here defined as individuals authoring proposals to use the telescope, plus authors of refereed publications using AO data

[8]some scientists authored both observing proposals and refereed publications, so they are not counted twice. This is our best estimate for the total number of AO scientific users in the past five years.

[9]Totals lines 5-9. Relative to other NSF/AGS upper atmospheric facilities, the 494,749 users of AO rival the combined populations of Greenland and Alaska.

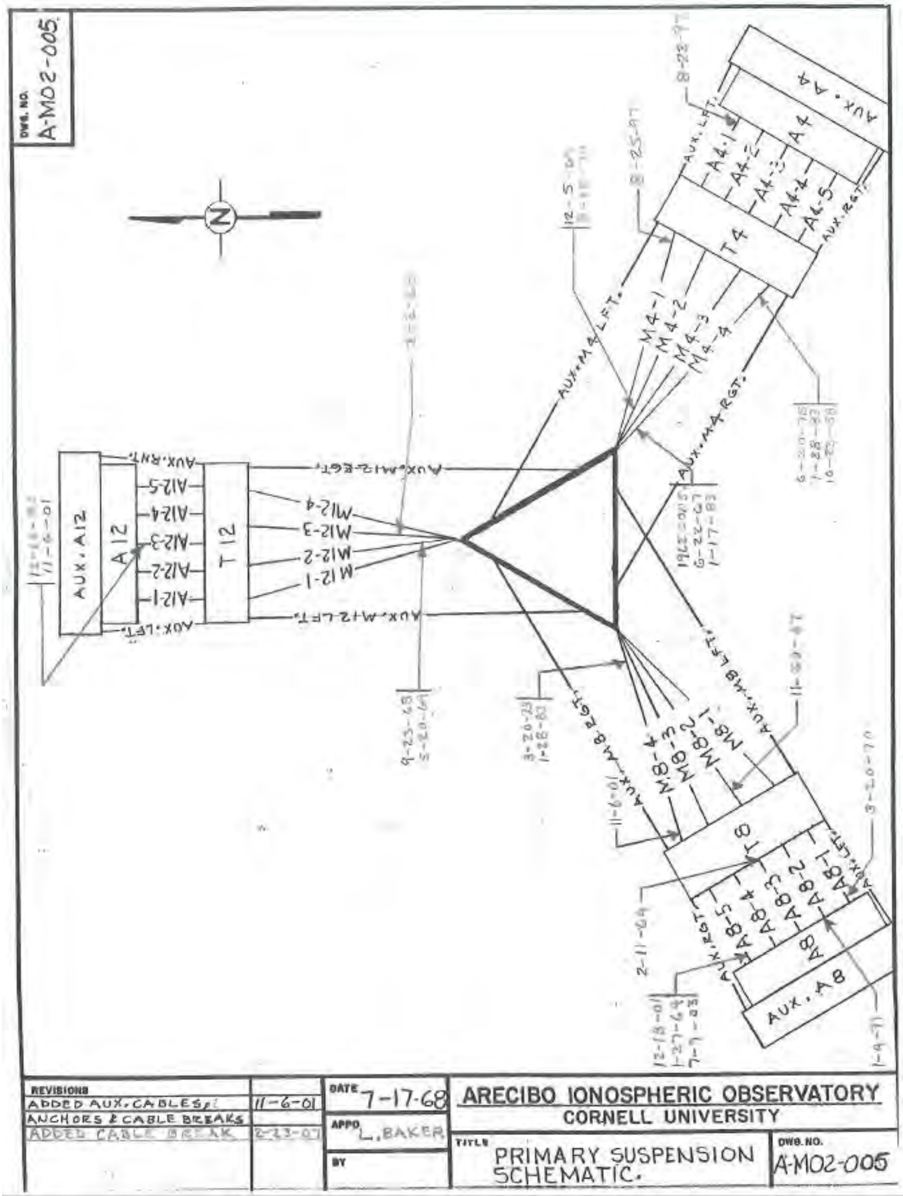
Table as supplied to the NSF/AGS Portfolio review panel.

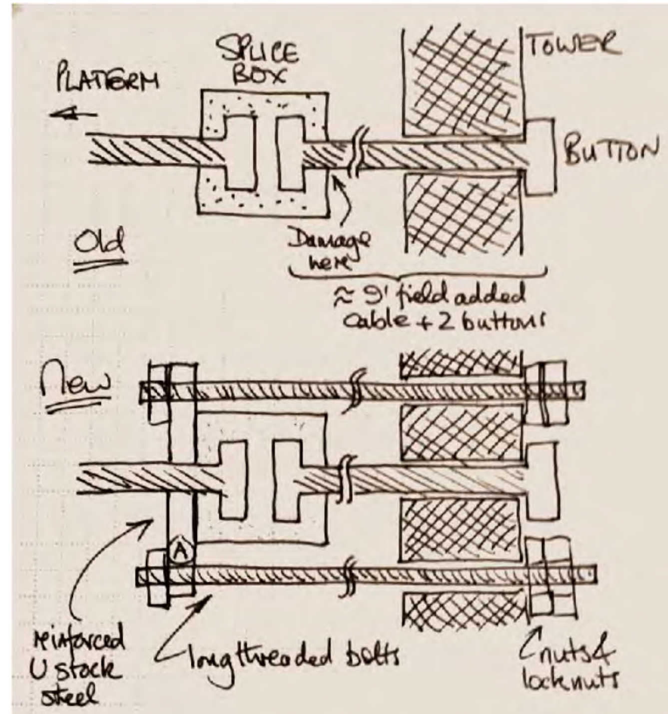
ARECIBO OBSERVATORY
PUERTO RICO
SRI • UMET • USRA

Arecibo Observatory is an industrial and public site, with multiple safety challenges

- Fall Safety
- High power electrical safety
- Workplace environmental safety
    - hazardous chemicals
    - radiation
    - shop machinery
    - "struck-bys" (rocks falls, platform drops
- Public Safety (90,000 visitors/year)
    - traffic safety
    - slip and fall
    - lost children
    - harassment and assault
- Natural Disaster preparedness
    - hurricanes
    - earthquakes
- Security
    - large cash business
    - terrorism
- Environmental
    - Sink Holes & water quality
    - Pb paint, asbestos, air quality, waste





REVISIONS
ADDED AUX. CABLES, ANCHORS & CABLE BREAKS 11-6-01
ADDED CABLE BREAK
DATE 7-17-68
APPD L. BAKER
BY
ARECIBO IONOSPHERIC OBSERVATORY
CORNELL UNIVERSITY
TITLE PRIMARY SUSPENSION SCHEMATIC.
DWG. NO. A-M02-005


PLATFORM
SPLICE BOX
TOWER
BUTTON
Old
Damage here
≈ 9' field added cable + 2 buttons
New
A
reinforced U stock steel
long threaded bolts
nuts & locknuts


TATA

Technical development
Leaning Forward

- HF
- ISR analysis
- Culebra (ROF)
- Lidar lab
- Automated Optical lab
- UHF downlink antenna
- Octave bandwidth C-band receiver (90%, test & install)
- IF/LO upgrade (75%)
- 12m antenna (85% - control software)
- AO-40 technical development