The Status and Future of the Arecibo Atmospheric and Geologic Radars

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Arecibo Observatory
prior to August 2020

Arecibo Observatory had three core science areas

Atmospheric and space geophysics
Instrumentation: Pulsed 430-MHz radar, 5 and 8-MHz transmitter, optical

Planetary geology
Instrumentation: CW S-band (2-GHz) radar

Astronomy
Instrumentation: Wideband (0.3 to 10 GHz) radio telescope

No observatory could match Arecibo in these areas

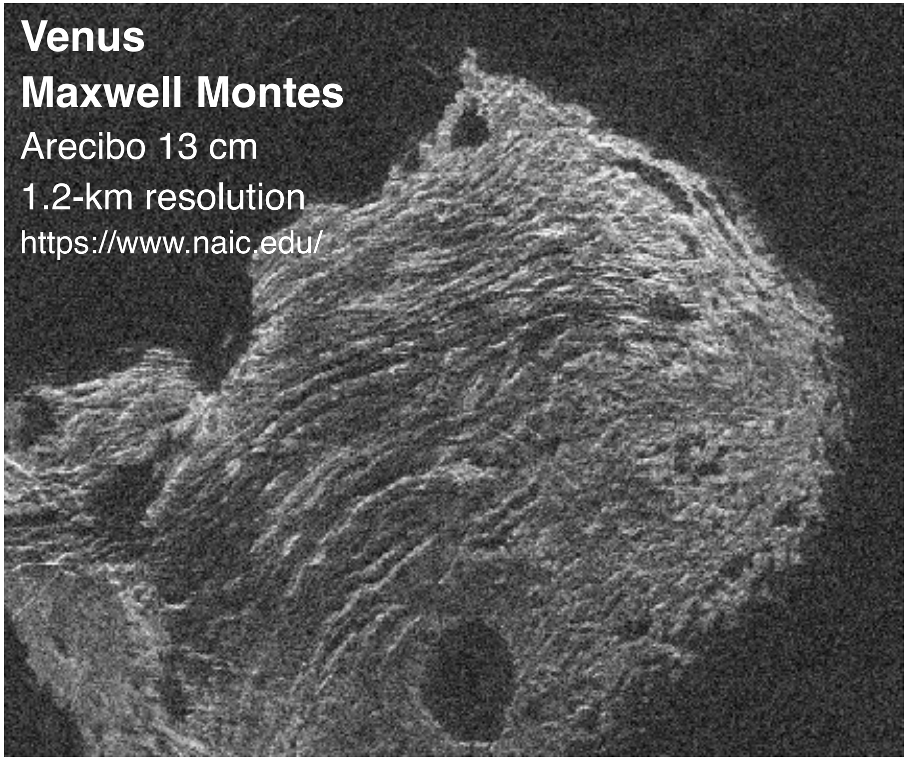
The enormous dish provided unrivaled receiving sensitivity

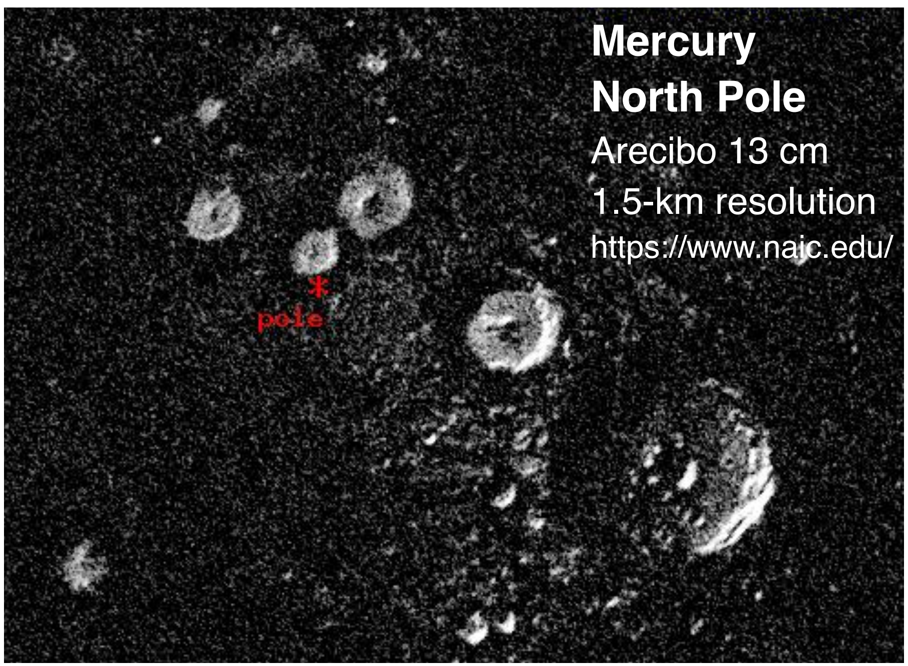
The radar systems were unique in the world

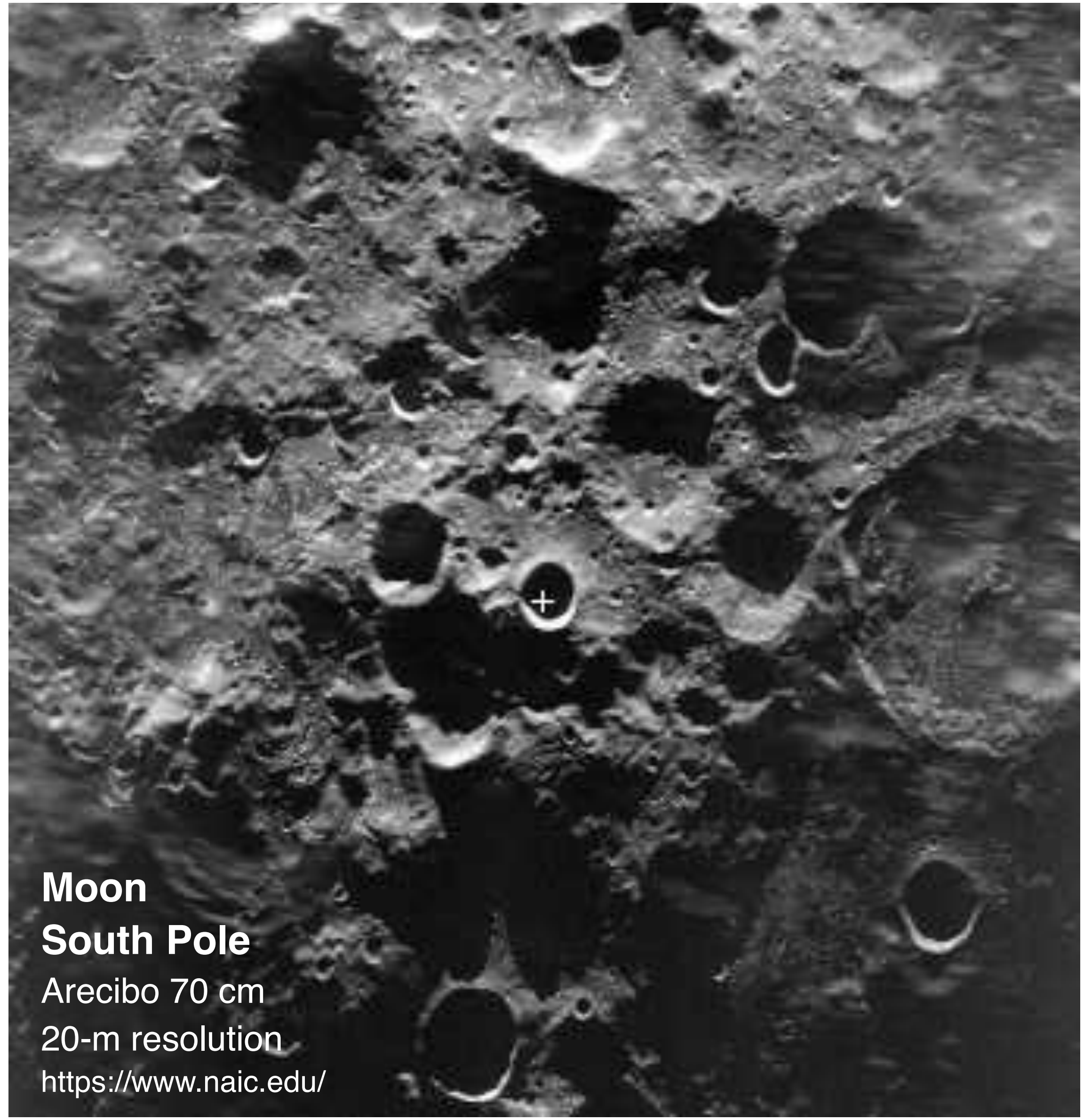
The Arecibo geophysical radars point up

Geology of planets and asteroids

Geophysics of the atmosphere








Arecibo Observatory
March 2021

The collapse of the Arecibo telescope has sparked significant activity towards reinvigorating radio and space science in Puerto Rico

All Geophysical Radar and Radio Science

The Next Generation Arecibo Telescope (NGAT) (white paper on arXiv, February 2021)
Radio science center at UPR Mayagüez (NSF, funded October 2021)

Atmospheric and Space Geophysics

High-frequency coherent radar (NSF, submitted January 2021)
Imaging array and instrumentation site (DoD, submitted July 2021)
Acquisition of a new atmospheric radar (NSF, submitted September 2021)
Arecibo high-frequency transmitter restoration (NSF, partially funded)

Atmospheric, Space, and Planetary Geophysics

Design of a geophysical/planetary/solar radar (DARPA, to be submitted May 2022)

Radio Astronomy

Acquisition of an ngVLA antenna for the VLBA (NSF, submitted September 2021)
Acquisition of an 8-element ngVLA phased array (NSF, submitted September 2021)

Proposed new Arecibo (NGAT) geophysical radar systems

Atmospheric and space geophysics
Increase pulsed radar power to 10 MW at 430 MHz
Potentially also at 220 MHz

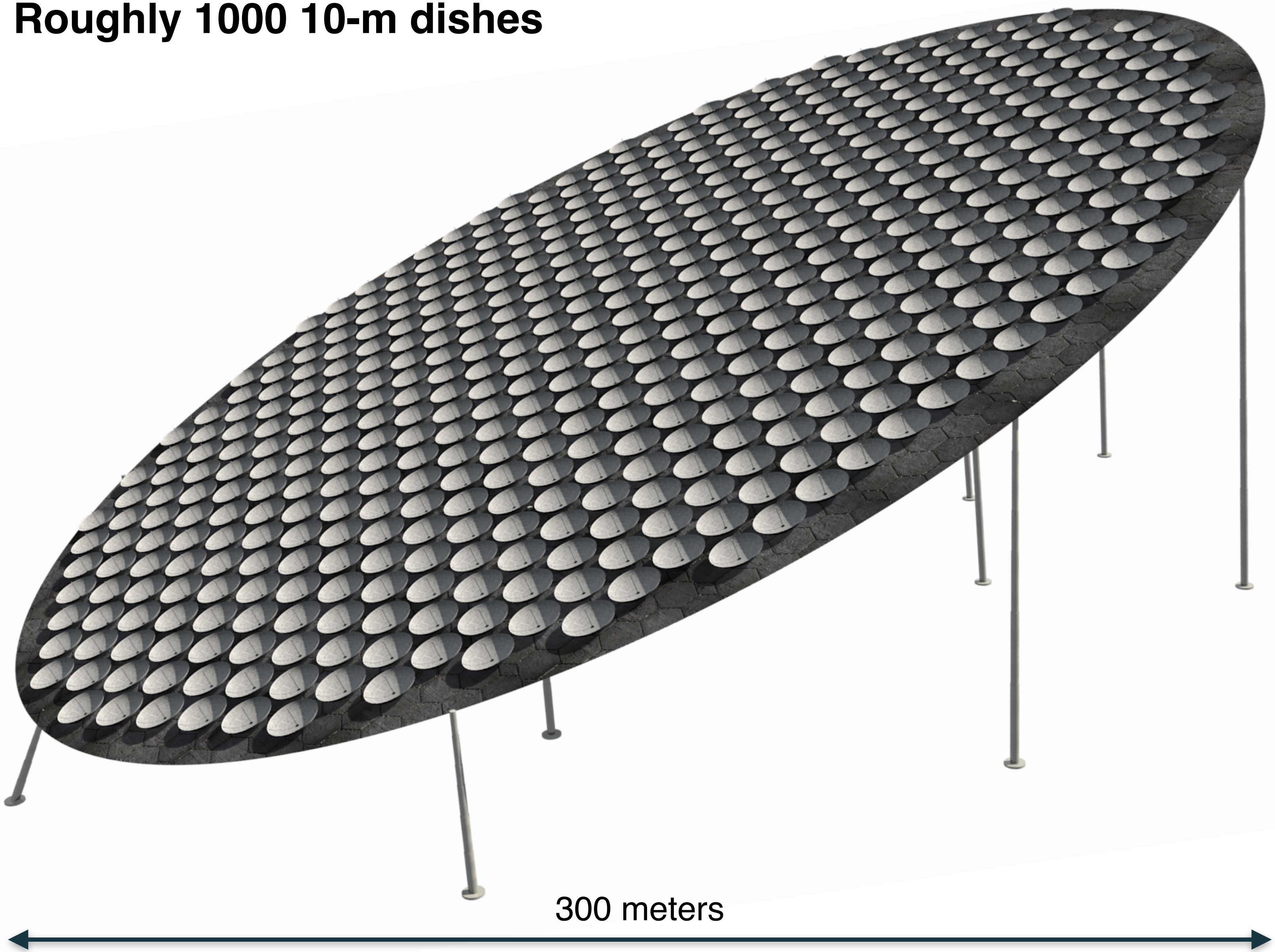
Planetary geology
Increase CW radar power to 5 MW at 2 GHz

Increased transmitter power
Greater sensitivity and greater range

Increased maximum zenith angle
Up to 45 degrees
Versus 20 degrees for the legacy Arecibo radar

Reference:
The Future of the Arecibo Observatory: The Next Generation Arecibo Telescope
Roshi et al. (2021)
https://arxiv.org/abs/2103.01367

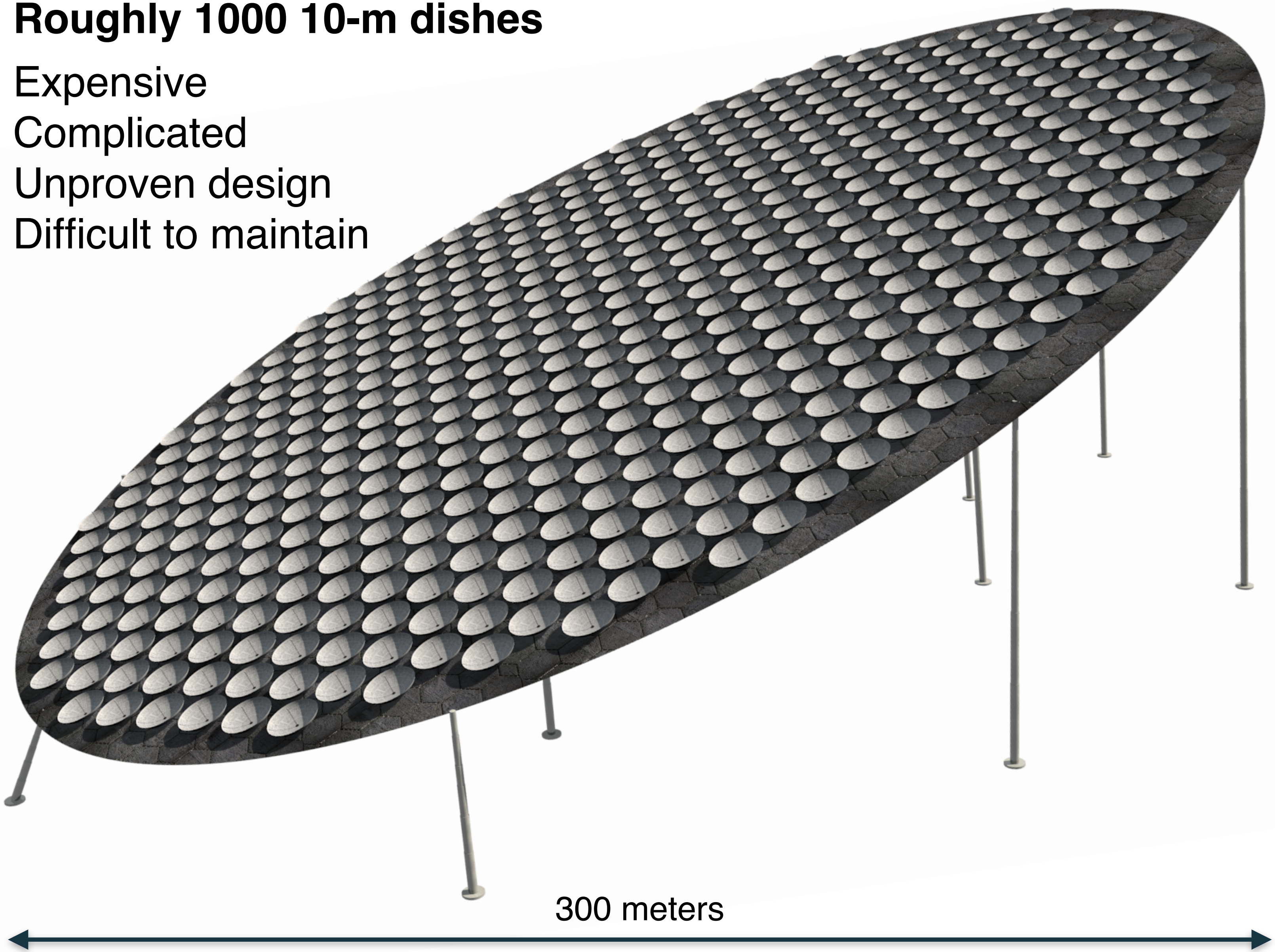
Proposed Arecibo array
Roughly 1000 10-m dishes



Roshi et al., 2021 (https://arxiv.org/abs/2103.01367). Figure by Rhys Taylor, 2021.

Proposed Arecibo array
Roughly 1000 10-m dishes

Expensive
Complicated
Unproven design
Difficult to maintain



Roshi et al., 2021 (https://arxiv.org/abs/2103.01367). Figure by Rhys Taylor, 2021.

Advantages of single dish

Design
Proven design
Well-suited to the existing site
Full science operations within five years
Much better possibilities for new state-of-the-art and experimental equipment
Much greater flexibility to accommodate user-developed equipment

Cost
Reasonable construction cost
Lower operational cost

Technical goals
Factor of three increase in performance (sky coverage and collecting area)
Based on lessons learned over 50 years combined with modern technology

Science goals
The science case is the same for a dish vs an array
See NGAT white paper (https://arxiv.org/abs/2103.01367)

A new Arecibo dish

Larger zenith angle pointing

15 to 20 degrees for legacy dish
25 degrees via increased curvature
35 degrees may be possible
45 degrees more difficult
Greater sky coverage, geomagnetic field
Longer planetary tracking
Southern astronomical objects

Greater sensitivity

Larger dish
300-meter illuminated area would double sensitivity and equal FAST

Much lighter instrument platform

High-performance waveguide
Allows planetary radar transmitter to be on the ground

Active secondary reflector
Focus point at the ground
In addition much easier maintenance

New single dish
323-meter diameter
25° zenith pointing

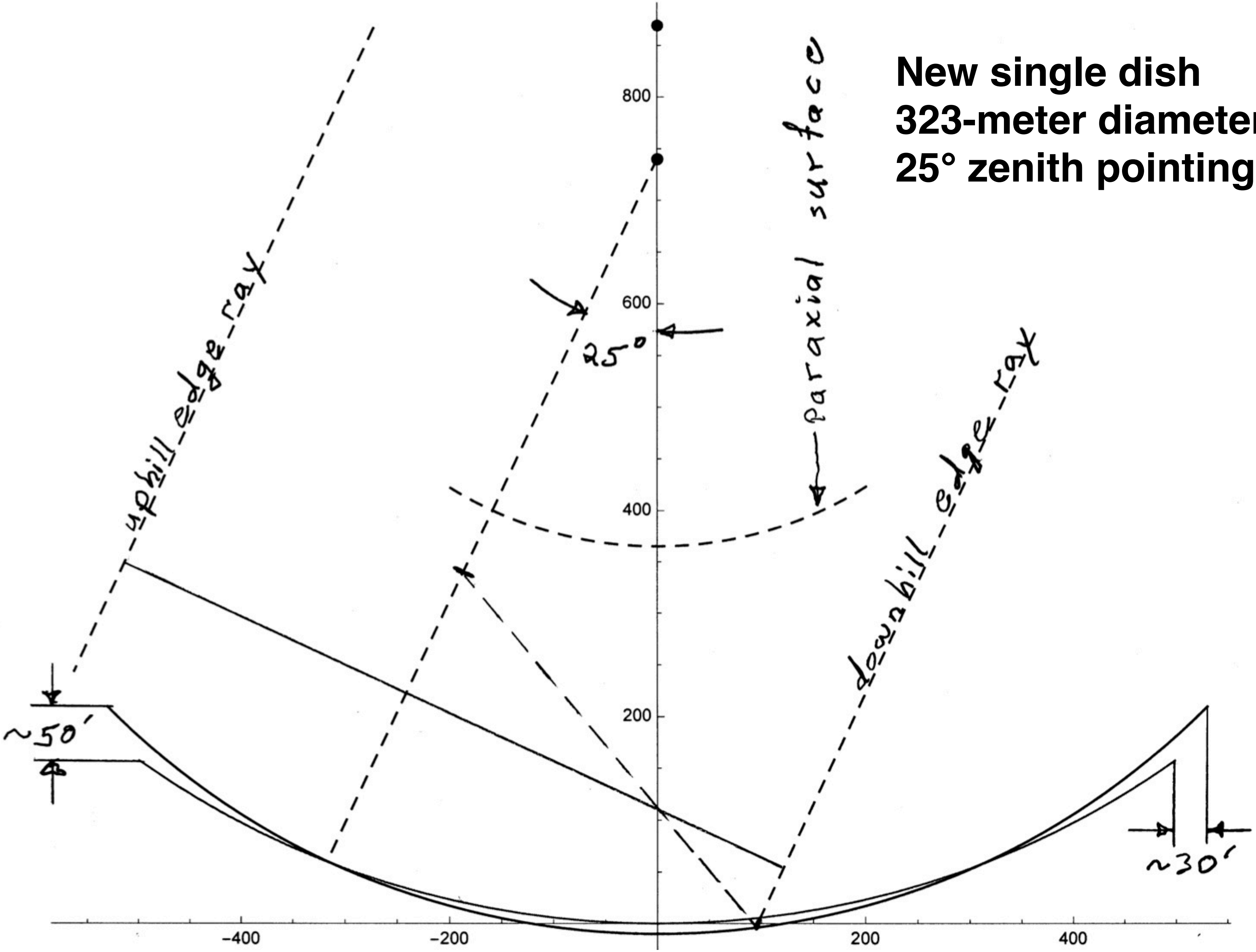


Figure courtesy of Cornell University.

New single dish
366-meter diameter
35° zenith pointing

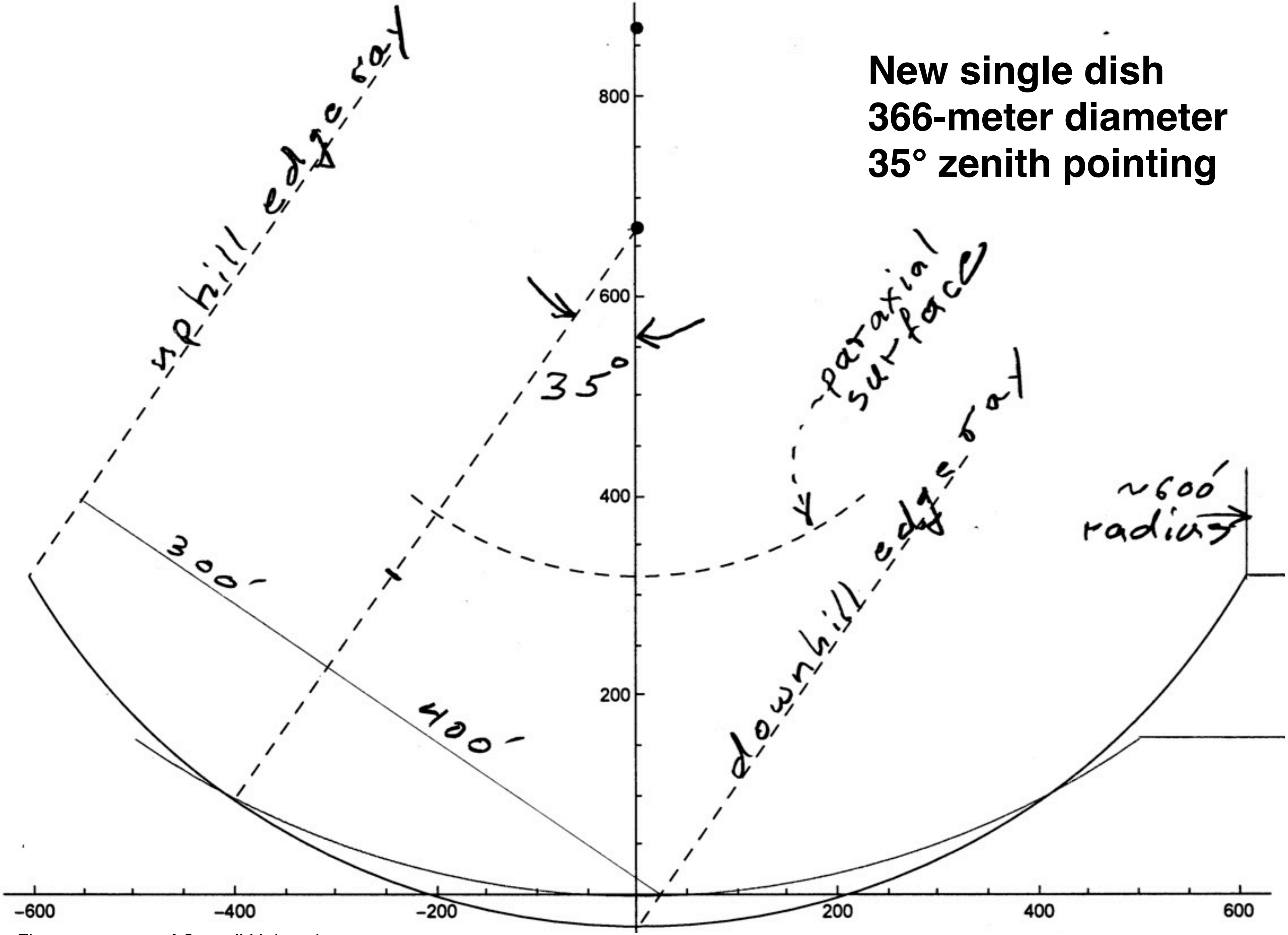
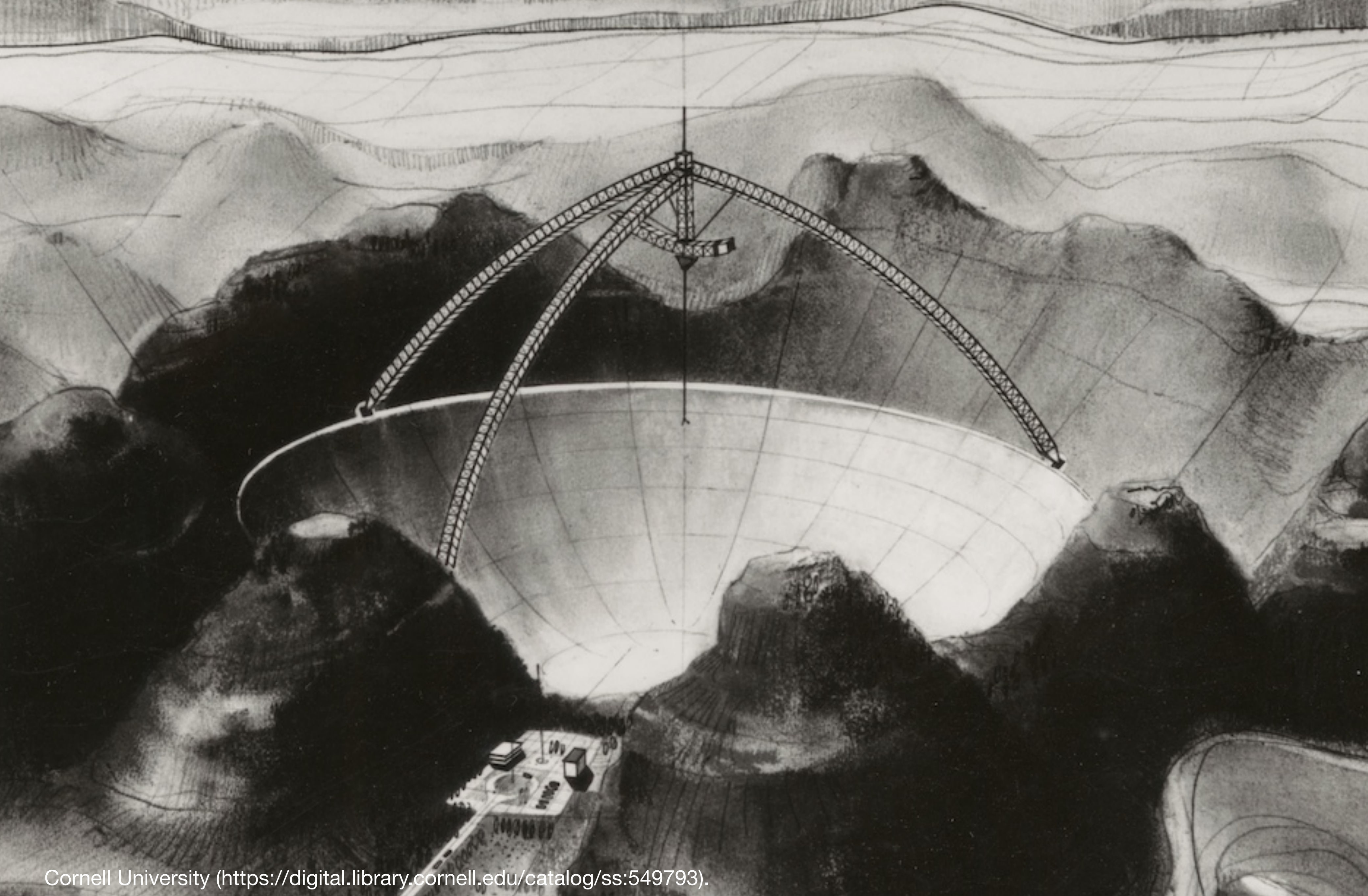


Figure courtesy of Cornell University.

Arch alternative to towers and cables



Cornell University (https://digital.library.cornell.edu/catalog/ss:549793).

Innovative science
Discovery science
Clues from the legacy Arecibo system

Legacy Arecibo 430-MHz pulsed radar
Designed for atmospheric and space geophysics
Yet used for:
– The first maps of Venus
– The rotation rate of Mercury

Legacy Arecibo 2.4-GHz CW radar
Designed for planetary geology
Yet used for:
– The highest-ever-resolution observations of the stratosphere

What if all Arecibo radars were designed for all geophysical purposes?

The platform collapse is an opportunity for out-of-box thinking

Many capabilities could potentially be included into AO2 radar systems

Simultaneous collinear operation of all radars

Selectable radar frequencies within wide bandwidths

Operation of each radar at simultaneous multiple frequencies

Wide instantaneous bandwidth (range resolution, multi-frequency)

Multiple radar beams (local area and mesoscale measurements)

Variable beam width (beam widening and shaping)

Continuous transmission bistatic operation at all radar frequencies

These would allow all Arecibo radars to be used for all geophysical studies

Don't let past practice limit new instrumentation

Do let science and flexibility drive the technology

Capabilities that might be included for new Arecibo geophysical radars in addition to the main dish

Multiple receiving sites
Vector velocities
Interferometry
Aperture synthesis imaging
Improved spatial resolution

Multiple transmitting sites
Continuous transmission (CW) as alternative to pulsed radar
MIMO

Broader range of radar and radio frequencies
2 MHz to 20 GHz

These would be significant improvements over the legacy Arecibo systems

Lessons from EISCAT in Scandinavia
– Tristatic vector measurements
– Dual k vectors

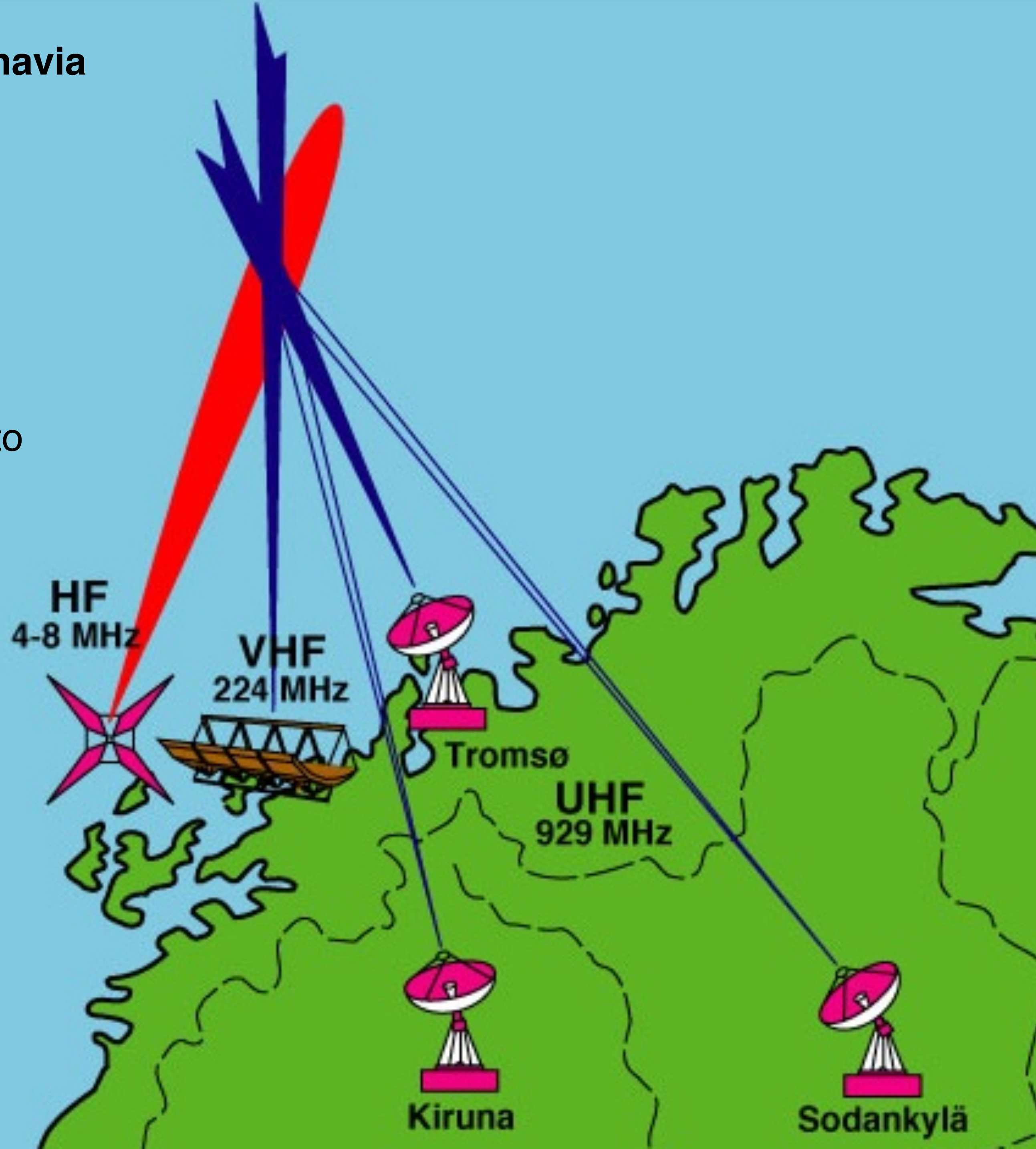
EISCAT initially had
– Limited bandwidth
– Limited dynamic range

Both of which when expanded led to fundamental discoveries in ionospheric physics

All can be done better now

There will be technology limits and tradeoffs

It's worth pushing the envelope



A strategy for a new Arecibo Observatory

Receive-only dish
For all frequencies
Larger than 305-meters (compete with FAST)
Lightweight secondary, perhaps prime focus under dish
Challenge: 45-degree pointing
Receiving rings for high spacial resolution?

Separate continuous transmission (CW) sites
2-10 GHz (S, C, X-band) – planetary and atmospheric small scale lengths
200-800 MHz (UHF) – planetary and atmospheric medium scale lengths
40-160 MHz (low VHF) – solar radar, planetary and atmospheric long scale lengths
2-20 MHz (HF) – ionosphere and very long scales

Additional receiving sites
Atmospheric radar vector measurements (all frequencies)
Solar radar imaging (low VHF)
Sensitivity for radio astronomy (low VHF)
Critical plasma level imaging of the ionosphere (HF)

Towards a new Arecibo Observatory

Collaborators welcome in all areas

Science

Geoscience of the atmosphere and ionosphere
Planetary geology and geophysics
Space science
Astronomical science

Technical

Technical design
Site selection

Funding

Funding proposals for design, siting, and construction

Current status

Several proposals submitted for new auxiliary instrumentation
Design and funding proposals for main Arecibo geologic radar systems in development

Contact

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Related Publications

The Future of the Arecibo Observatory: The Next Generation Arecibo Telescope
Roshi et al. (2021)
https://arxiv.org/abs/2103.01367

A Short History of Geophysical Radar at Arecibo Observatory
Mathews (2013)
https://doi.org/10.5194/hgss-4-19-2013

The Case for Combining a Large Low-Band Very High Frequency Transmitter with Multiple Receiving Arrays for Geospace Research: A Geospace Radar
Hysell et al. (2019)
https://doi.org/10.1029/2018RS006688

Radio Studies of Solar-Terrestrial Relationships
Thidé et al. (2002)
http://doi.org/10.13140/RG.2.2.16990.54084

HiScat International Radio Observatory
Thidé, Boström, et al. (1994)
http://doi.org/10.13140/2.1.3915.8560

Thank you!

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