A Meeting to Celebrate the 70th Birthday of Miller Goss

Radio Astronomy & the ISM

May 18-20th, 2011
Durango, Colorado

The Colgate Paramp

&

Its Impact on Radio Astronomy

Bob Hayward
Senior Engineer
NRAO – Socorro, NM

In Collaboration with **The Man of the Hour** Himself
Miller Goss

Setting the Scene
A Letter Printed in *Science Magazine*, Jan 1972

SCIENCE
7 January 1972
Vol. 175, No. 4017
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Radar System Dismantled

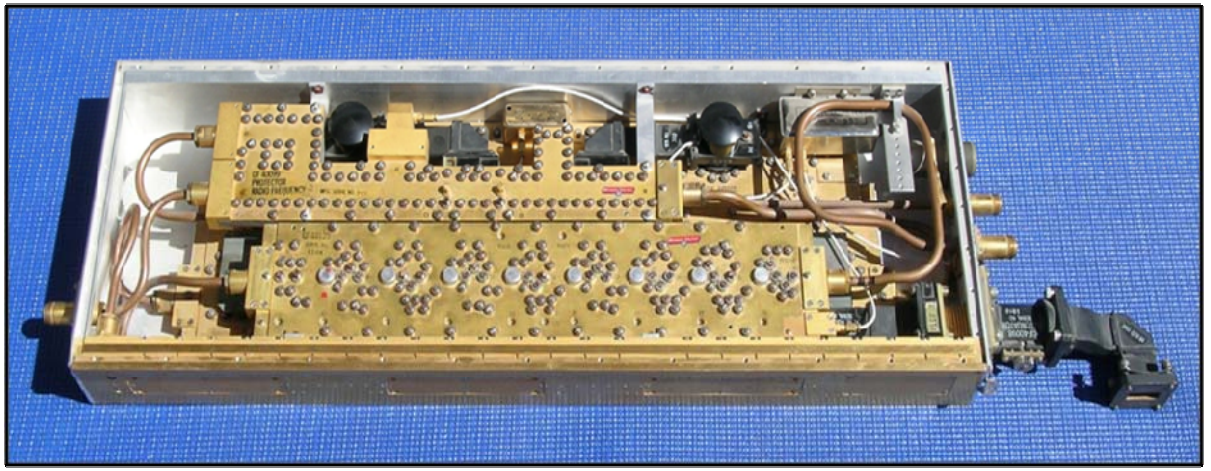
An extraordinarily complex radar system called MAR (multiple array radar) became operational in 1964 at White Sands Missile Range; it was designed to detect incoming missiles for national defense. The receiver of this radar was made up of approximately 2500 separate, circularly polarized, switched elements, each with its own wide-band, low-noise, parametric amplifier. Beam switching by means of aperture synthesis was completely controlled by computer. Such arrays are usually switched manually and never include the luxury of a low-temperature front end.

The aggregate cost of this radar was approximately $160 million. It was an incomparable instrument, operating near the 21-centimeter line for beam-switched observations of distant radio sources and possibly even of supernovas in distant galaxies. Its cost was greater than all the radio astronomical facilities that have been built in this country and possibly in the world. It was three times as expensive as the VLA (very large array), the largest radio astronomy telescope ever proposed.

The MAR radar was dismantled before a proper evaluation could be made of its astronomical capability. Regretfully, we at the New Mexico Institute of Mining and Technology performed the dismantling and salvage without access to the specifications of the ability of the whole system. It is a tragedy indeed that such a short-term military experiment could not have been made available to astronomers who could have made measurements that now may not be made for many decades. Fortunately, 2000 parametric amplifiers were salvaged, and 280 have been presented for use by radio telescopes throughout the world. These alone significantly improve the quality of many instruments.

STIRLING A. COLGATE
New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801

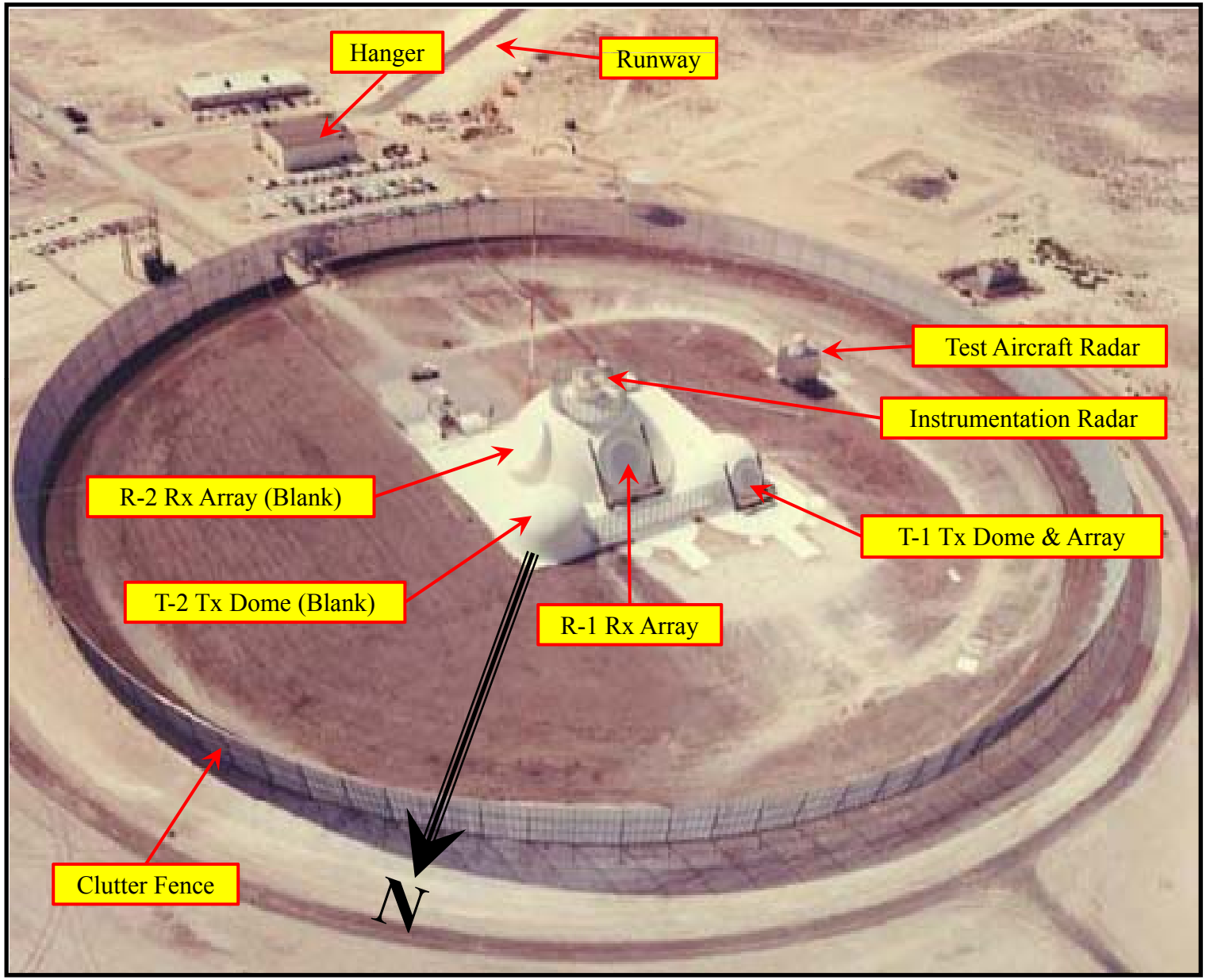
One of the over 2000 MAR *Western Electric Preamplifiers* (Model GF-40096) which came to be known as the "*Colgate Paramp*"



- Talk Overview:
  - Introduction to the Colgate Paramp story.
  - Where did the ~2000 paramps come from?
  - What was Stirling Colgate's interest in them?
  - Where did the 280 paramps go and what were they used for?
  - What happened to the rest of the paramps?

  - **Acknowledgements:**
    - **Doyle Piland (WSMR Archivist)**
    - **Bruce Blevins, Steve Hunyady & Joe Martinec (former NMT students)**
    - **Paul Krehbiel, John Reiche & Bill Winn (NMT)**
    - **Vestal Fulp & Bob Gamboa (former MAR-I employees)**
    - **Stirling Colgate (LANL & NMT)**

Nike-X Prototype *Multifunction Array Radar* (MAR-I)



(Aerial View 1965 - Photo courtesy of Doyle Piland)

The large dome was 120 ft in diameter & 45 ft high.

Most of the 195 x 155 ft structure is underground and extends 42 ft below the surface.

It had 2 floors underground and 2 floors in each of the domes.

It had a total interior floor space of 90,000 sq ft.

Western Electric (WECo) was the primary contractor while Bell Labs was responsible for the overall design.

The site was salvaged by NMT in 1970-71.

Over 200 truckloads of material was hauled back to Socorro.

MAR-I Receiver Array Face

Receiver Array Face Diameter ~25 ft

Antenna Element Field of View > 90°

Phased-Array Beamwidth ~1.8°

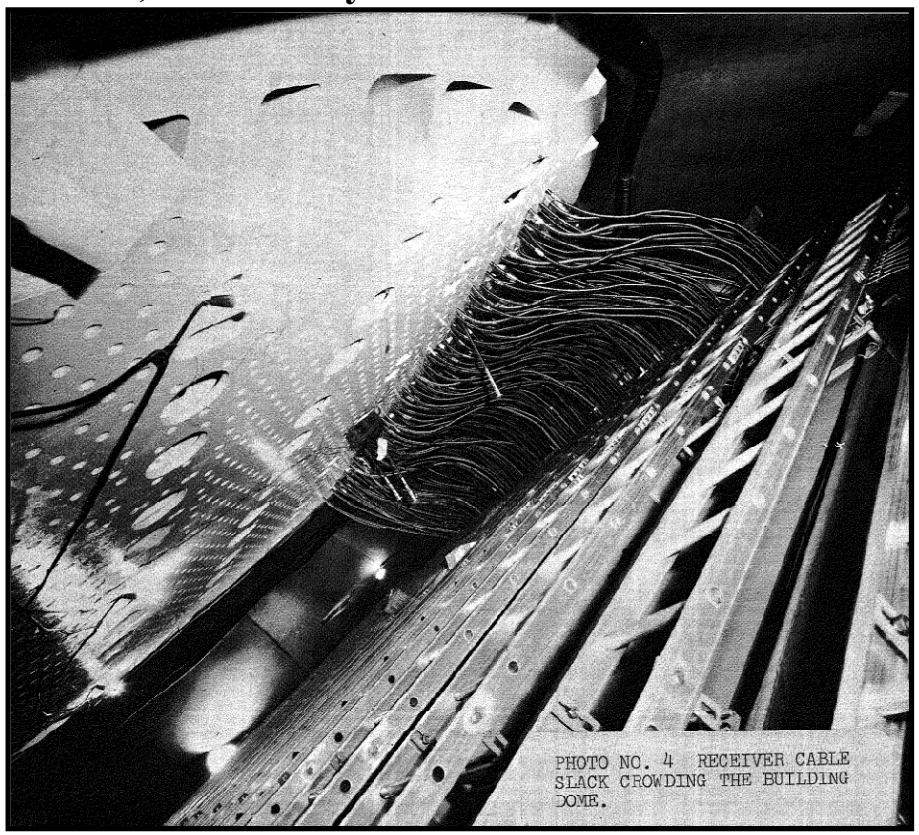
Number of Antenna Elements = 2077 Active + 168 Passive = 2245

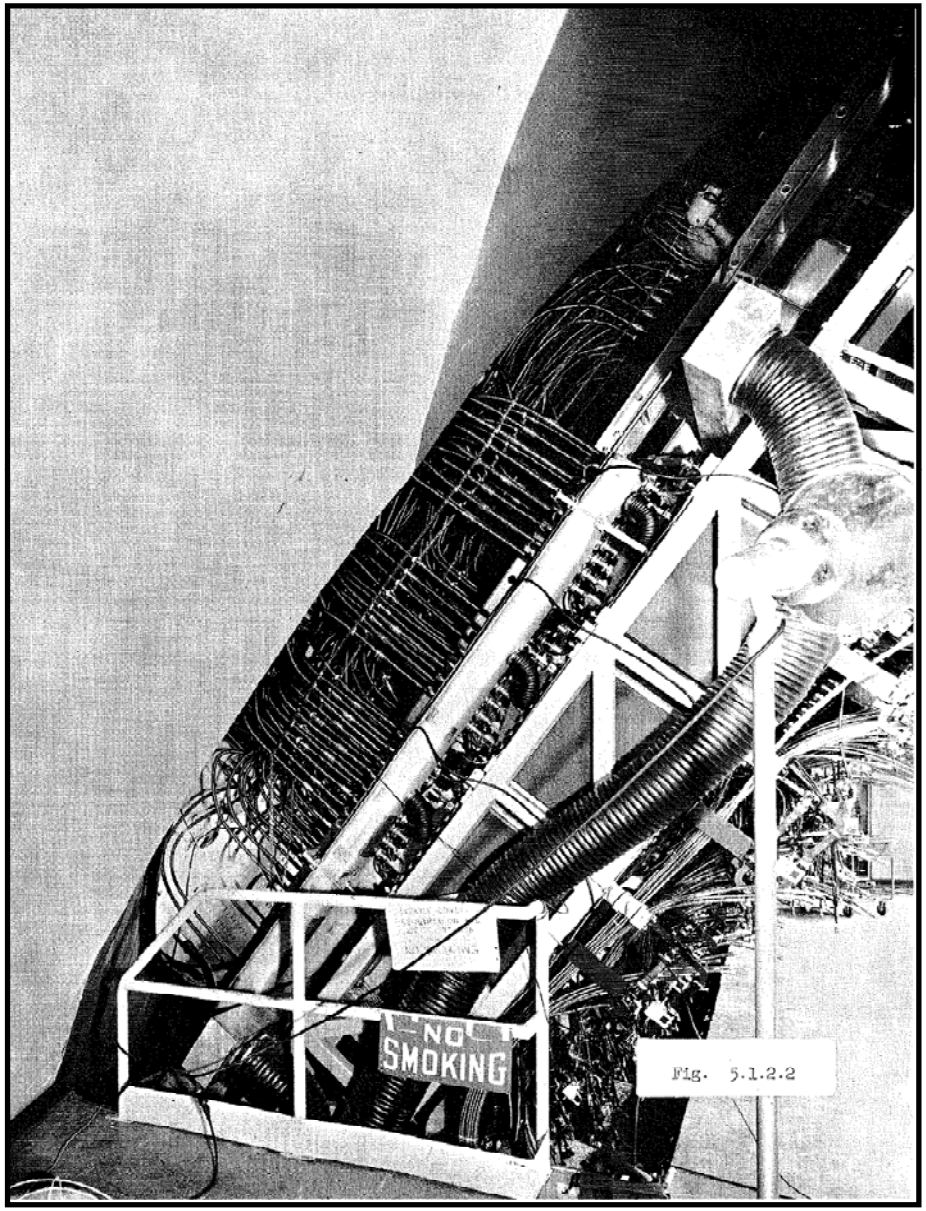
(Photo courtesy of Doyle Piland)

Inside the MAR-I Receiver Dome

Views of the ~2000 cables running between the Antenna Elements and the Paramps in the 45 ton *Preamplifier Structure*.

Picture below shows the start of the installation from the *Lower Dome Level*; the right shows the final cabling configuration from the *Upper Dome Level*, with nearly 4 miles of 7/8" Heliax cable.

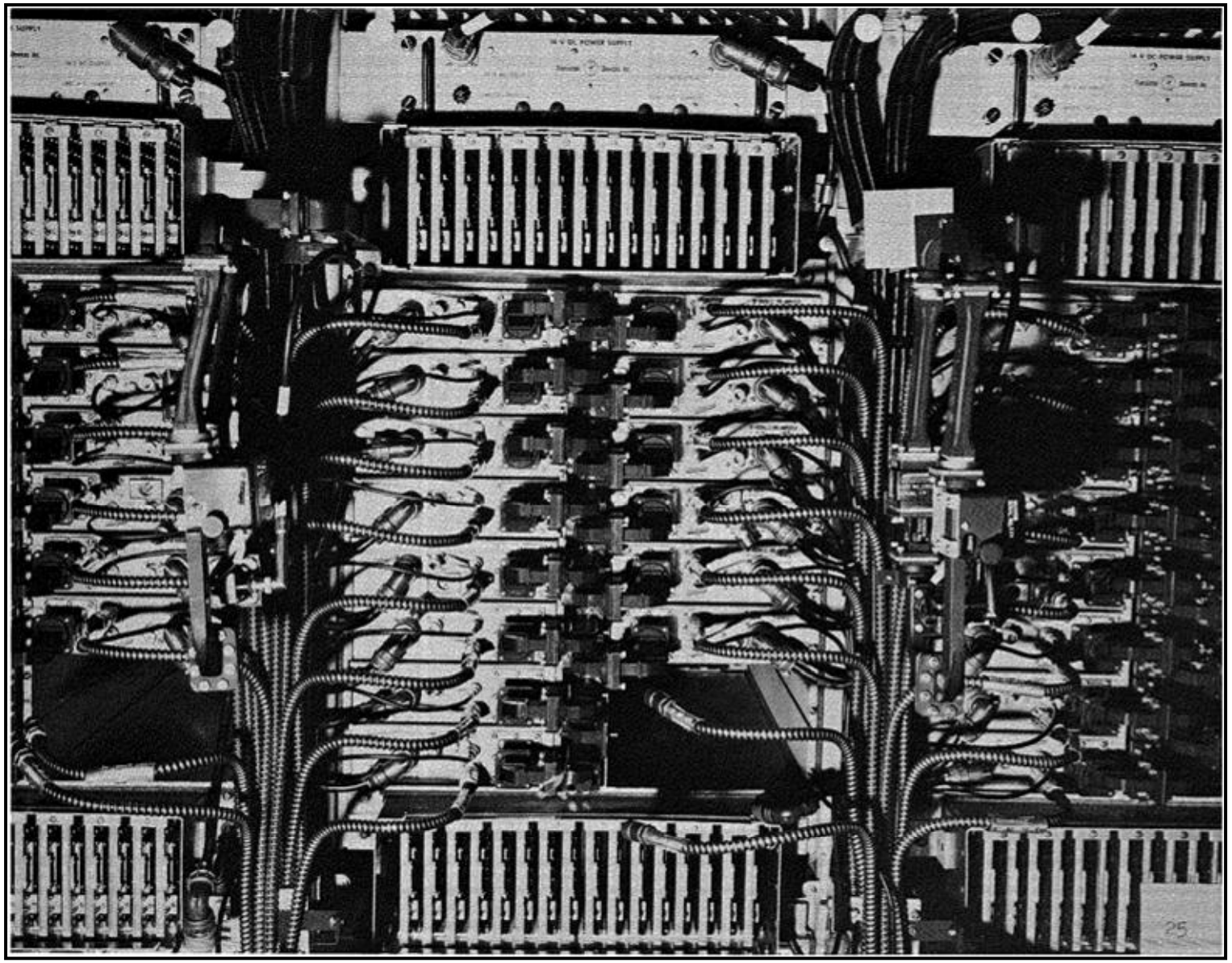




Review of mechanical Problems Associated with the Multi-Function Array Radar (MAR-I), G.R. Tobias, BTL Report, 5 June 1964
MAR I Critique (Preliminary), BTL Report, W.G. Graves II & W.E. Kelley, 15 June 1964

View of the Back of ~2 Dozen of the 2000 Preamps

Note 11 GHz Pump Input Waveguide, 3/8” Output Heliax & Varactor Bias Circuits



MAR I Critique (Preliminary), BTL Report, W.G. Graves II & W.E. Kelley, 15 June 1964

Main Floor "Beta" (Elevation) Delay-Racks

Length of precut 3/8" Heliax Cables > 27 Miles

(Photo courtesy of Doyle Piland)

MAR-I

By the Numbers:

Electronic Racks
~ 200

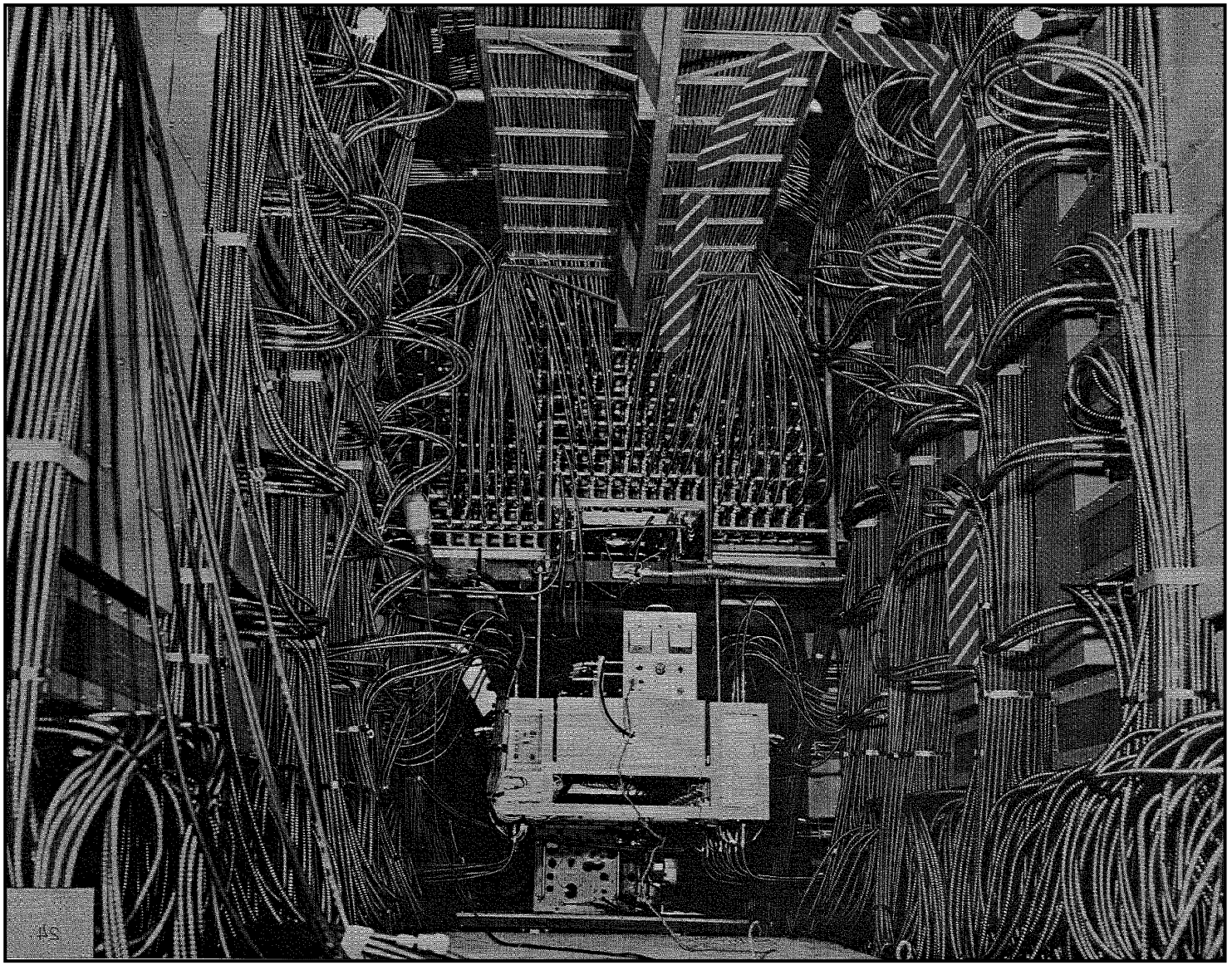
Cables
~ 30,000

Wiring List
~ 7,000 pages

First project to successfully use a computer to pre-route and pre-calculate cable lengths.

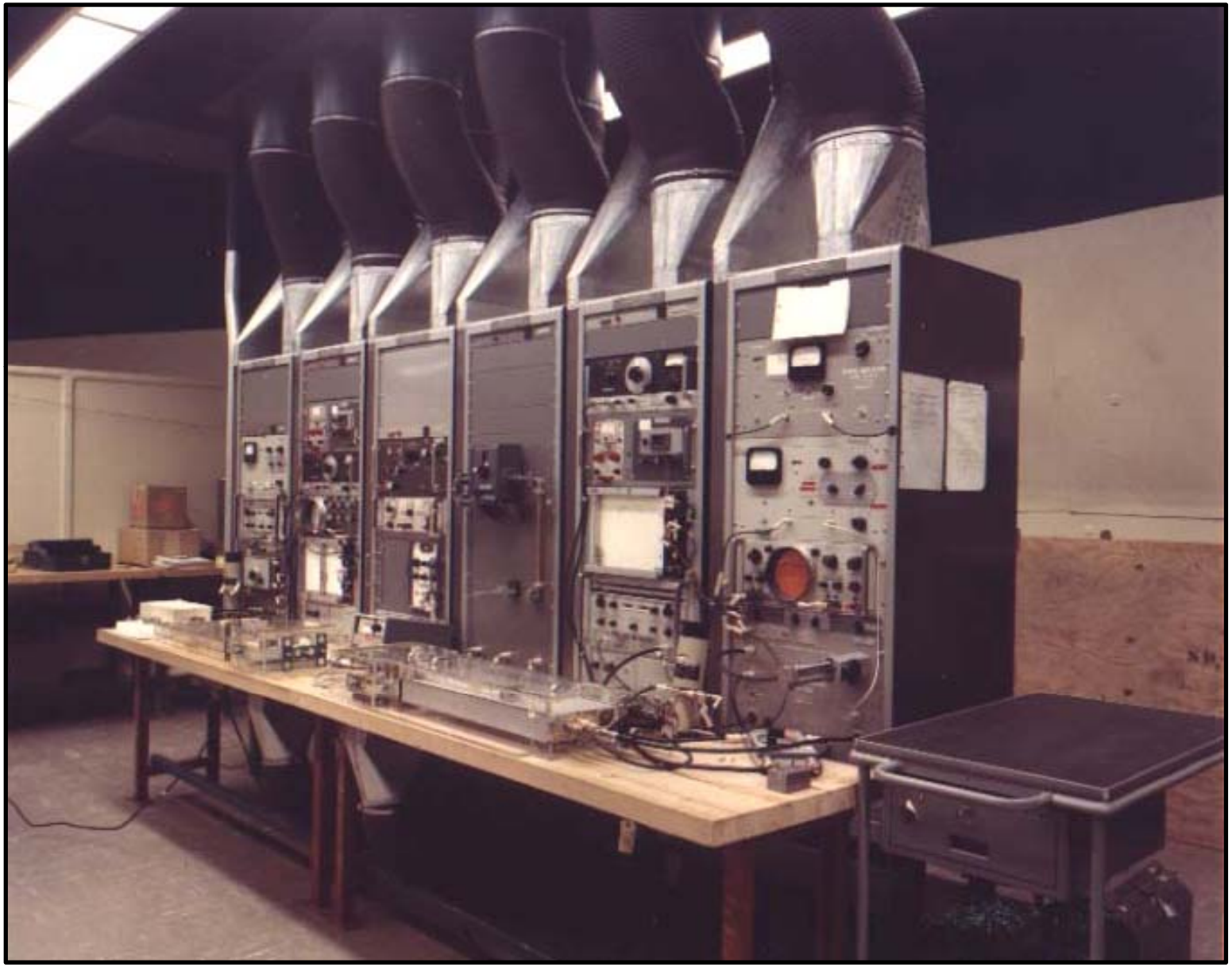
MAR-I Beam-Former

Miles of 3/8” Heliax cables feed the 12-to-1 signal combiner, a critical portion of the beam-former.



MAR I Critique (Preliminary), BTL Report, W.G. Graves II & W.E. Kelley, 15 June 1964

MAR-I Preamplifier Test Area



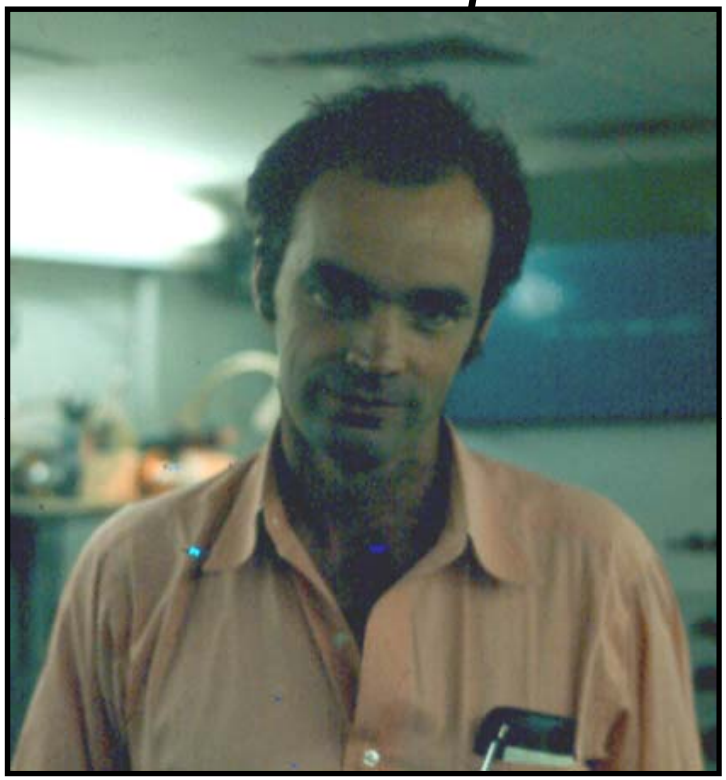
(Photo courtesy of Doyle Piland)

Abbreviated MAR-I Timeline

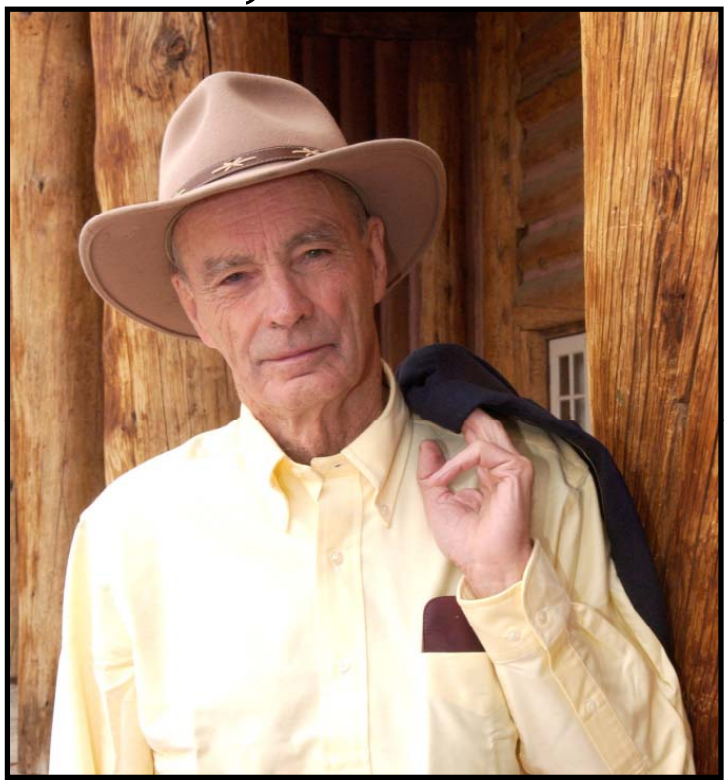
1960	**Engineering studies & conceptual designs for a multifunction array developed at BTL.**
June 1961	**WECo authorized to proceed with the design of a prototype phased-array radar. BTL was responsible for supervising the design. Sylvania selected as major subcontractor for the detailed design & fabrication of the prototype model to be built at WSMR.**
1961 - 1962	**Proposals for the MAR-I system were solicited and the final design of the MAR-I completed.**
1962 - 1963	**Many of the numerous electronic components of the MAR-I were manufactured.**
March 15, 1963	**Groundbreaking for the MAR-I at WSMR.**
December 1963	**Construction of the MAR-I building and facilities completed.**
January 1964	**Installation of electronic equipment on the MAR-I begins.**
June 15, 1964	**Installation of the MAR-I completed and the power is turned on for the first time.**
September 11, 1964	**MAR- I successfully tracked a real target - a balloon - for the first time, following it for 50 minutes while intentionally dropping and automatically re-establishing lock several times. The balloon was successfully handed over in the automatic mode, which included transfer from search to verification, to acquisition track, and target lock-on.**
1964 - 1967	**MAR-I undergoes long series of characterization tests**
September 30, 1967	**MAR-I test program terminated.**
1968 - 1969	**MAR-I continues at reduced level as a *Sentinel* Evaluation Agency training facility.**
May 1969	**MAR-I site placed in care-taker status.**
Nov 1969 -1981 (?)	**The unused MAR-I facility is identified as the main fallout shelter area for all 5,800 dependents of the military staff assigned to Holloman Air Force Base, located 24 miles away.**
Late '70 / Early '71	**Electronic equipment and hardware salvaged from the MAR-I site by New Mexico Tech.**
1981 to 1984	**Construction of the High-Energy Laser Test Facility (HELSTF) at the MAR-I site, representing a ~$800 million investment over several decades.**
September 6, 1985	**HELSTF becomes operational when the Mid-Infrared Advanced Chemical Laser (MIRACL), the first megawatt-class, continuous wave, chemical laser built in the free world, was used to destroy a Titan missile booster in a static test.**

Stirling Colgate

President of New Mexico Tech, 1965-1975



Inside the SNORT Trailer (~1973)
(photo courtesy of Bruce Blevins)



Los Alamos National Lab (recent photo)
http://www.lanl.gov/news/albums/people/Stirling_Colgate.jpg

- **Considered one of the foremost diagnosticians of thermonuclear weapons.**
- **In 1956 he became interested in supernovae after investigating the theoretical radiation and debris that would be produced by a hydrogen bomb exploded in space.**
- **In the late 1960's he theorized the possibility of dispersed electromagnetic pulses arising from supernovae.**
- **This led to the SNORT experiment to detect "Extragalactic Whistlers".**
- **Left NMT in 1975 and joined the Los Alamos National Laboratory (LANL) where he has continued his research into supernovae to this day.**

Abstract for the "SNORT" Paper Presented at the Radio Astronomy Commission V Meeting of the International Union of Radio Science (URSI) held in Socorro Jan 1973.

(Bulletin of the American Astronomical Society, Vol. 5, p. 284, 1973)

04. Supernova Observational Radio Telescope.
S. A. COLGATE and B. A. BLEVINS, New Mexico Institute of Mining & Technology, Socorro, NM. - We propose to search for dispersed electromagnetic pulses from distant supernovae with a 20-beam radio telescope at 1.4 x 10^9 Hz and antenna gain of 100 x 4 . On the basis of the expected magnetic field of pulsars and the frequency of supernova, we expect about 1 event per month from galaxies at 70 Mpc. The coordinate in the sky should be deduced to a 3-degree solid angle (10^{-2} of the array area). The expected number of galaxies that could have contained such an event at 70 Mpc is 12. The size and distance of such galaxies is roughly 1 minute of arc at 70 Mpc. This number of galaxies at this size can be searched conventionally for a supernova that would rise to optical maximum in a week to ten days. Each of the right circularly polarized feeds (7 to a parabolic dish) feeds a 2-stage parametric amplifier, 50MHz bandwidth, and then various stages of postamplification before being mixed with itself delayed by 4 meters equivalent. Dispersed pulses then appear on oscilloscopes as low frequency oscillations corresponding to the varying frequency of the signal.

Bruce Blevins
BSc '72 & MSc '75 from NMT,
PhD '78 from NMSU

Super Nova Observational Radio Telescope

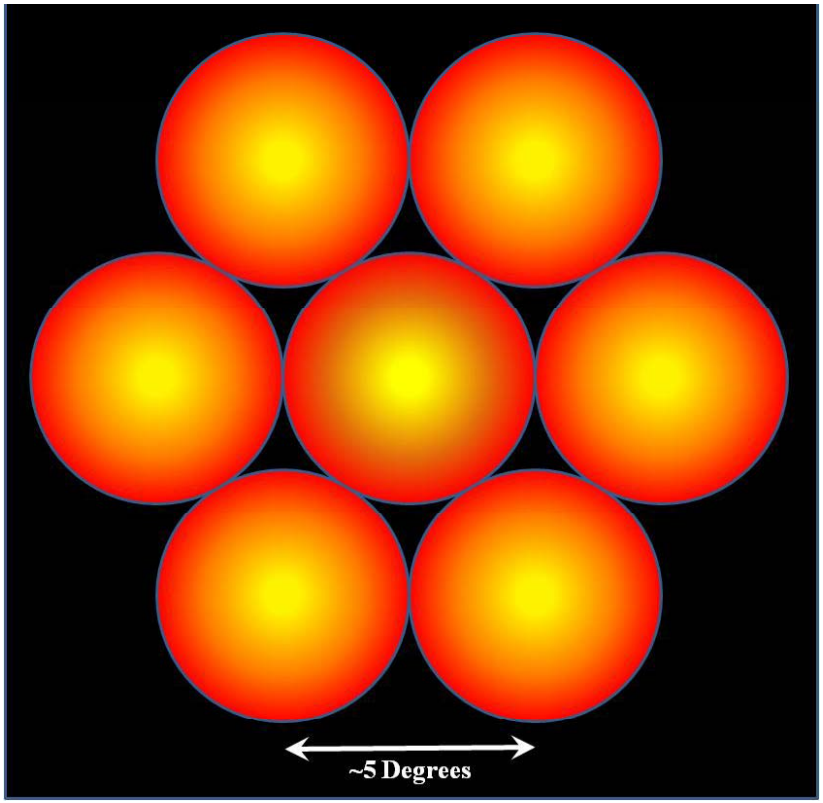
A picture of SNORT from the roof of an adjacent building on the New Mexico Tech campus in the early 1970's (photo courtesy of Bruce Blevins).

The SNORT Experiment

A close-up picture of the SNORT experiment's trailer and its three 7-beam telescopes which yielded 21 separate beams on the sky searching for a microwave pulse from an exploding star

(photo courtesy of Bruce Blevins)

SNORT



The reception pattern of the 7 beams of a single SNORT antenna. The 21 feeds would have a total field of view of about 420 square degrees.

A photo of most of the 11 Tektonix 551 dual-beam oscilloscopes used to display possible pulses coming from a supernova when transiting the array's field of view.

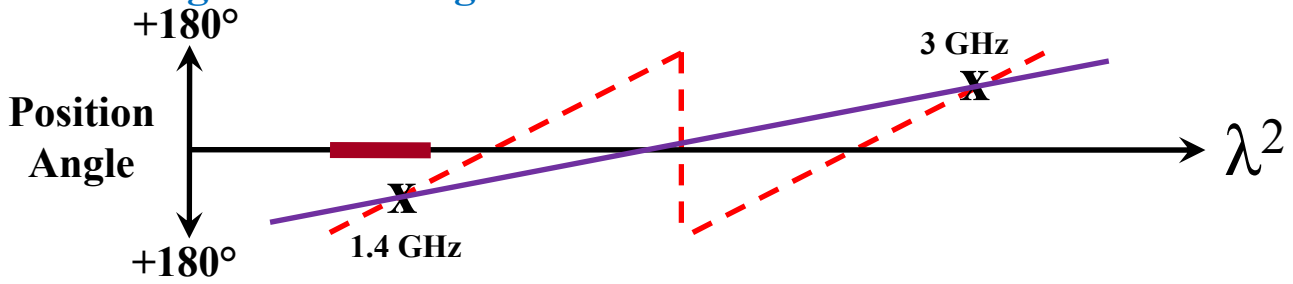
Gary Schwede & SNORT 1974-75

BSc '73 & MSc '76 from NMT, PhD '83 from U.C. Berkeley

- **On the SNORT Concept:**
  - ***"If there was a pulse, and if there was enough matter between the galaxies, and if we happened to be gathering radio waves when the pulse arrived here, we might catch a dispersed pulse."***
- **On SNORT's Paramps:**
  - ***"Stir would occasionally fiddle one to his satisfaction, while I watched. Then I'd try, but the next one refused to play along. I didn't really know how these amplifiers worked. Beautiful, shining, overbuilt & expensive."***
- **On SNORT after transferring to Computer Science for his MSc:**
  - ***"I don't think anyone ever got the whole array running."***
- **In 1975, Colgate & the NMT Regents came to a "parting of the way" and he left to join LANL. It is uncertain whether this was the reason SNORT died, or whether a reanalysis of his EMP theory was less encouraging for success, or perhaps it was the adverse RFI environment at L-Band.**
- ***"Stirling, for all his intelligence, ego, and drive, always put Tech's students first. This is so unusual, and such a marker of a great mentor! I was privileged to sweat it out in the SNORT trailer. May he live long and prosper in the dimensions he loves."***

The Colgate Paramp & Green Bank

- **NRAO obtained ~10 of the paramps from Stirling Colgate and while they were no where near as sensitive as the cryogenically-cooled paramps which were being used on the Green Bank 140 foot telescope, the room-temperature 2-stage amplifier had a much wider bandwidth.**
  - **Over 200 MHz compared to a few 10's of MHz for the existing receivers.**
- **In 1972 NRAO built a receiver using the Colgate Paramp for S. J. Goldstein and F. S. Gauss that exploited its unusually wide bandwidth to study the effect of Faraday Rotation on several extragalactic sources.**
  - **Faraday rotation arises when electromagnetic waves propagate through a medium in the presence of a strong magnetic field. Such an interaction will rotate the plane of linear polarization. By measuring the polarization angle at a number of wavelengths, the Rotation Measure can be determined which then allows one to estimate the average magnetic field along the line of sight.**



- **In the early days of linear polarization measurements relatively widely spaced frequencies between 1 and 3 GHz were looked at. There was some concern that the values of the Faraday Rotation could be in error because an integral number of "half-turns" in the rotation angle might have been missed. This would mean that the RM might have been underestimated.**
  - **Since radio telescopes in those days were rarely outfitted with more than one low-noise receiver at a time and since the front-end could usually only be tuned across a narrow range, these observations at different frequencies were often made months apart. As many extragalactic sources have time variable emission, and time-varying polarization, the previous observations could be prone to error.**

The Goldstein Receiver

What was needed to eliminate any RM ambiguity was a set of observations done with a receiver that had a much wider instantaneous bandwidth than had ever been used before.

This was a perfect role for the wideband Colgate Paramp, as it covered the 1250-1445 MHz band and perfectly matched the 200 MHz bandwidth of the facility spectrometer used on the 140-ft (40 x 5 MHz channel filter bank).

Thanks to this extra bandwidth, the *Goldstein Receiver* was able to observe 8 extragalactic sources in Jan & April of 1972 and determined an accurate value of the RM without having to be worry that the rotation angle frequency curve was being under-sampled.

Goldstein and Gauss were able to confirm that the previous polarization measurements did indeed agree well with their values, thus removing all questions about half-turn ambiguities.

MULTIFREQUENCY POLARIZATION OBSERVATIONS OF EIGHT EXTRAGALACTIC SOURCES

F. STEPHEN GAUSS* AND SAMUEL J. GOLDSTEIN, JR.
Department of Astronomy, University of Virginia
Received 1972 July 20; revised 1972 August 14

ABSTRACT

Observations of linear polarization in forty 5-MHz bands between 1250.4 and 1445.4 MHz show the expected linear relation between position angle of the polarized vector and wavelength squared for eight sources. Seven of the sources have Faraday rotations in agreement with values in the literature obtained at higher frequencies. Upper limits to the difference in Faraday rotation of the two components of five double sources are derived.

III. RECEIVER AND REDUCTION TECHNIQUES

The receiver begins with a diode switch which compares the power from a linearly polarized feed antenna to that from a room-temperature load. The first amplifier is a two-stage paramp followed by a bandpass filter and broad-band transistor amplifier.

We acknowledge with thanks the skilled assistance of the staff of the National Radio Astronomy Observatory. We thank R. J. O'Connell for reading a preliminary manuscript, and S. A. Colgate for arranging the transfer of the surplus military parametric amplifier that was the first stage in our receiver.

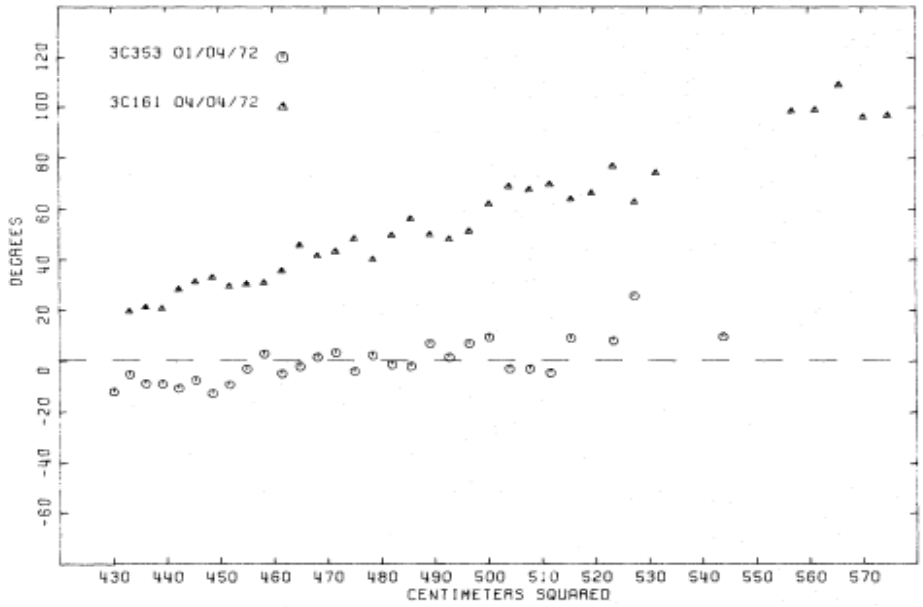
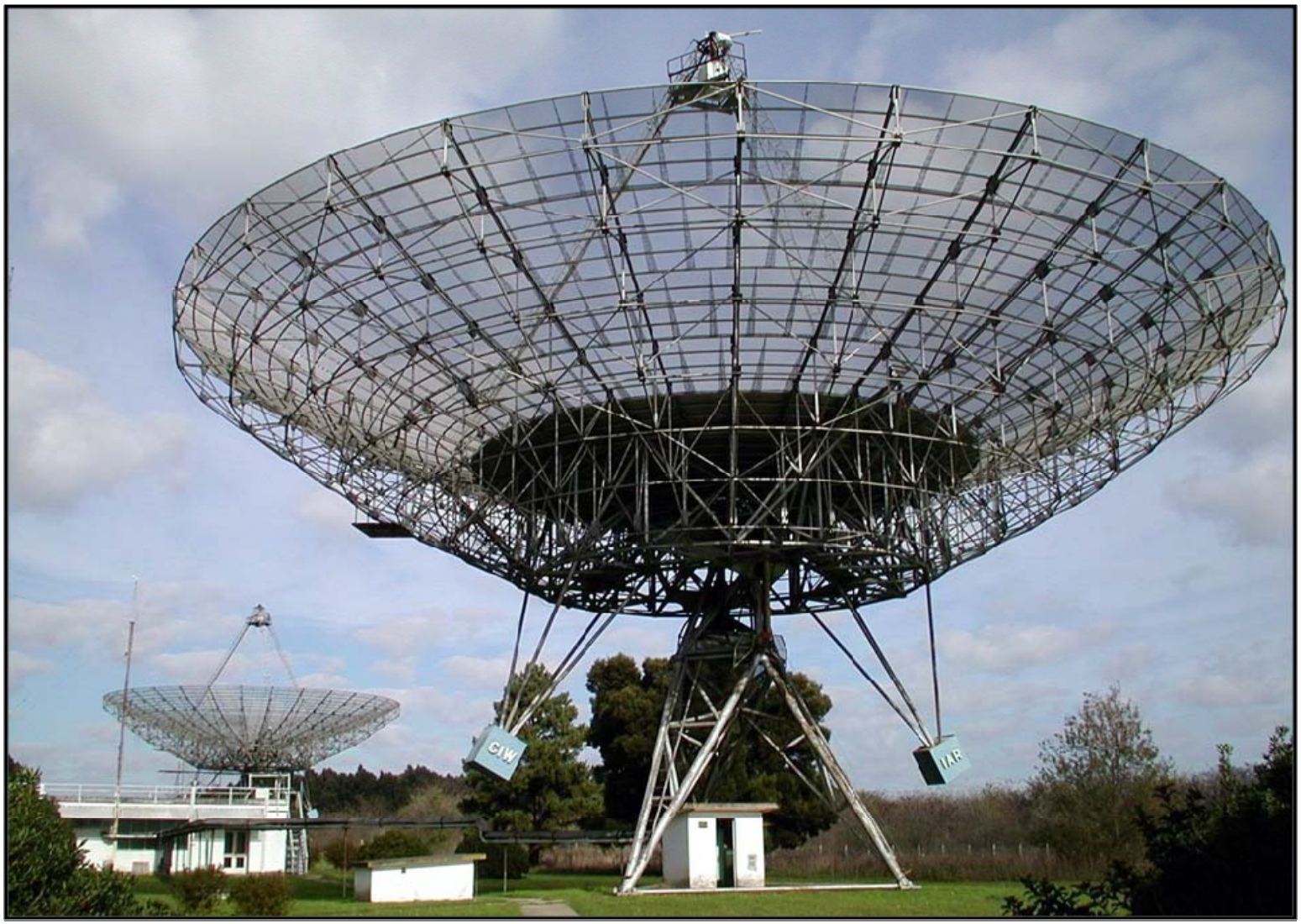


FIG. 1.—Position angle of the linearly polarized radiation from 3C 161 and 3C 353 plotted against wavelength squared. The estimated angular error for each point is about 6°.

The Colgate Paramp & Argentina

30-meter Antenna-I near La Plata



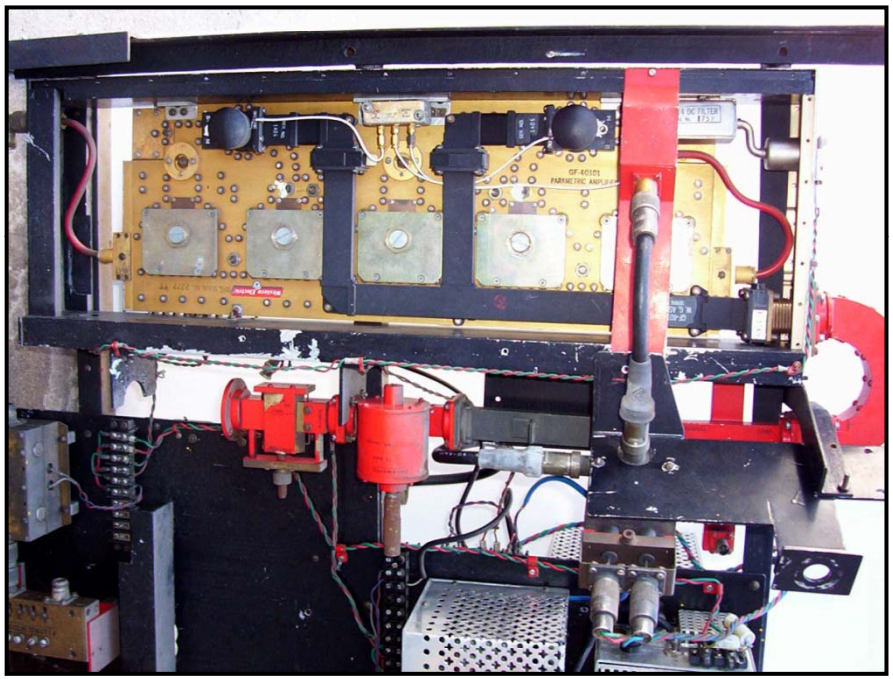
http://www.iar.unlp.edu.ar/images/imagenes/a-034.jpgevins)

Argentina & Radio Astronomy

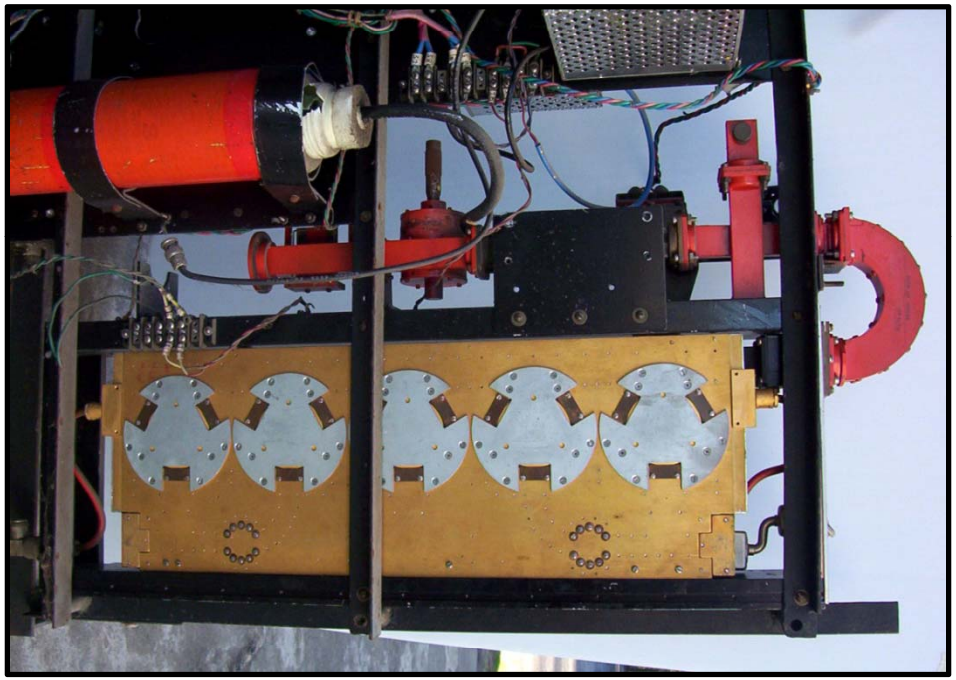
- **In 1962, the *Instituto Argentino de Radioastronomia* (IAR) was created. Its primary purpose was to promote and coordinate scientific research and technical development in the field of radio astronomy.**
- **In 1963, with funds from the Carnegie Institution of Washington (CIW) and the National Science Foundation, construction began on a 30-m antenna located 20 km from the city of La Plata.**
  - **The CIW collaboration included the provision of a 21 cm receiver.**
  - **On 11 April 1965, *Antenna I* detected its first line of neutral hydrogen emission.**
  - **A few years later, construction started on the 2nd 30-meter telescope, *Antenna II*.**
  - **The original receiver on *Antenna I* was replaced by a more modern system utilizing a parametric amplifier, also provided by CIW, dropping the system temperature from 800°K to 300°K.**
- **In 1972, a receiver utilizing a Colgate Paramp was installed on Antenna I which resulted in a T(sys) of 200°K.**
  - **A new receiver was installed on Antenna I in 1992 which was built at the MPIfR, by IAR engineers. This system was cryogenicly cooled to reduce internal noise."**

The Colgate Paramp & the IAR 21-cm Rx

Front



Back



Front and back views of the receiver showing the bright gold stripline parametric amplifier circuit board that had been removed from the WECo Preamplifier used on the MAR-I and donated to the IAR by Stirling Colgate.

IAR 30m L-Band receiver picture (photo courtesy of Gloria Dubner & Juan Carlos Olalde)

The IAR 30-Meter L-Band Receiver

- **Recollections from Tomas Gergely, who in the 1970's worked at the IAR 30-m. He is now the NSF Spectrum Manager:**
  - ***"I do remember that at about that time the engineers at the IAR were quite excited about receiving what they called the "parametricos".***
- **Recollections from Gloria Dubner, currently the head of the Radio Astronomy Group at the Institute of Space Research, Argentina:**
  - **She was a graduate student who used the IAR 30m L-Band receiver in the 1970's.**
  - **"*When I worked with the 30m dish, I was a student that, I must admit, was little concerned with most of the technical details of the telescope, being focused on the astronomical subjects.*"**
  - **"*What I remember from those years is that I was impressed with the handsome appearance of Stirling Colgate!*"**
  - **"*I first met Colgate in 1978 in Italy during a supernovae workshop, where I met Miller Goss too.*"**
  - **"*It seems that my thesis, and many more, were carried out using those amplifiers.*"**

List of IAR 30-m papers which acknowledged the Colgate Paramp

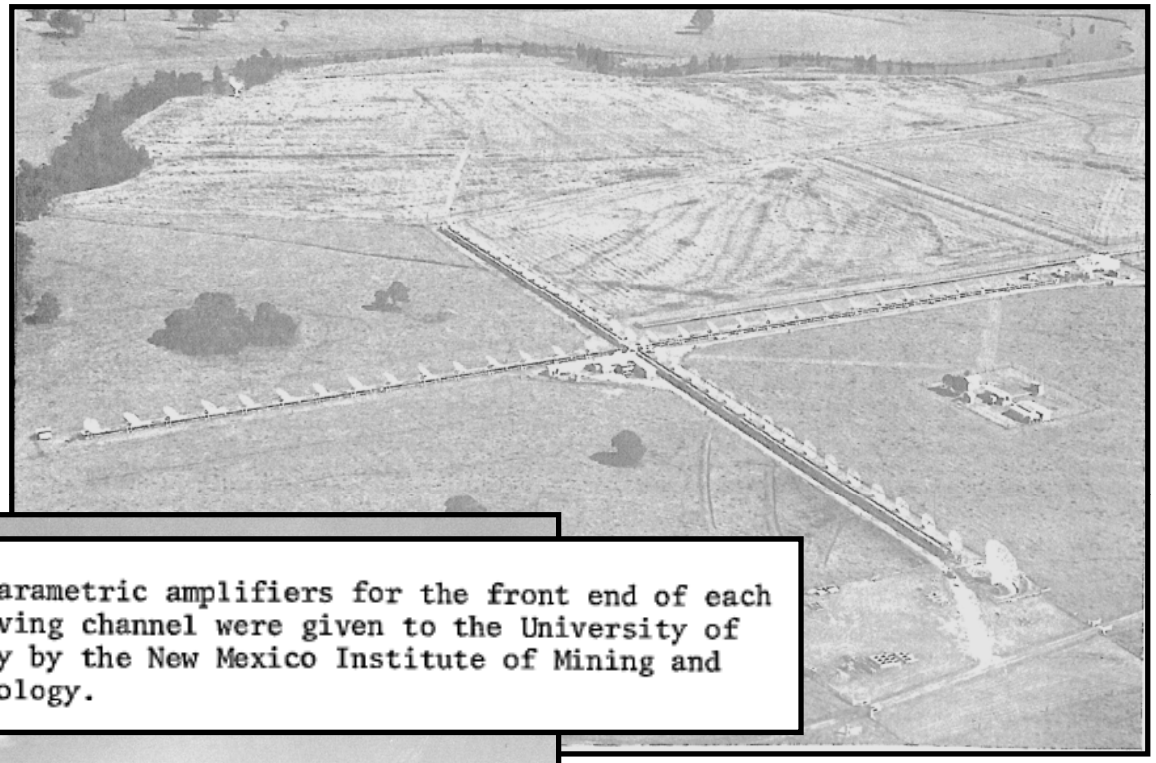
1) ***A Search for Neutral Hydrogen Remnants of Strong Tidal Disruption of the Small Magellanic Cloud***
   Mirabel & K.C. Turner, Astron. Astrophys., Vol 22, pg 437-440, 1973
2) ***Study of the Outer Galactic Structure for 288° ≤ l ≤ 310°, -7° ≤ b≤ 2°***
   S.L. Garzoli& I.F. Mirabel, Astrophysics & Space Science, Vol 25, Issue 1, pg 207-216, 1973
3) ***An Anomalous Velocity Neutral Hydrogen Structure Near the Galactic Center***
   I.F. Mirabel & K.C. Turner, Astrophysics and Space Science, Vol 3, pg 381-394, 1975
4) ***Observations of the 21-cm Hydrogen Emission Line in the Direction of 23 Southern Pulsars***
   F.R. Colomb & I.F. Mirabel, Astron. Astrophys., Vol 47, No. 1, pg 157-159, 1976
5) ***A Peculiar HI Feature at l = 285°, b = ~18°***
   E. Bajaja, F.R. Colomb & M. Gil, Astron. Astrophys., Vol 49, pg 259-262, 1976
6) ***A Survey of Neutral Hydrogen in the Region 290° ≤ l ≤ 314° -32° ≤ b ≤ -17°***
   F.R. Colomb, M. Gil & R. Morras, Astron. Astrophys Suppl Series, Vol 26, pg 195-206, 1976
7) ***21cm Line Observations in the Region 348° ≤ l ≤ 360°, -22° ≤ b ≤ -1°***
   I.F. Mirabel, Astronomy & Astrophysics Supplement Series, Vol 28, pg 327, 1977
8) ***Galactic HI at |b|>=10 - I. Preliminary Presentation of Part of the Southern Sky Area***
   F.R. Colomb, W.G.L. Poppel and C. Heiles, Astron. Astrophys. Sup., Vol 29, pg 89-101, 1977
9) ***Neutral Hydrogen Associated with Southern Supernovae Remnants***
   F.R. Colomb and G.M Dubner, Astron. Astrophys., Vol 82, pg 244-248, 1980)
10) ***HI 21 cm Line Observations at Low Galactic Latitudes in the Southern Hemisphere***
    E. Bajaja & R. Morras, Astrophysics and Space Science, Vol 41, pg 121-128, 1980

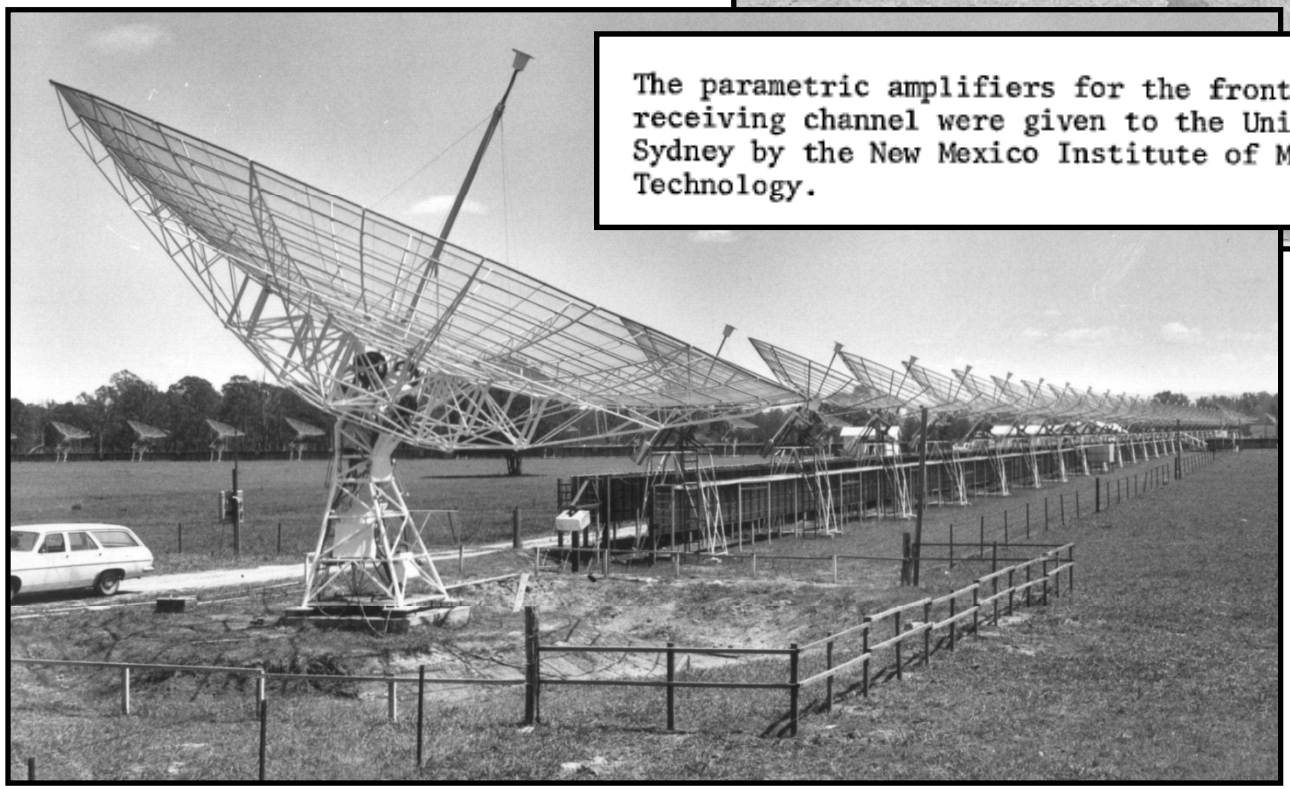
The Fleurs Synthesis Telescope (University of Sydney)

W. N. CHRISTIANSEN*
Fellow, I R E E

Proceedings of the I R E E
September 1973

Fleurs was the site of the Mills, Shain & Chris Crosses. The FST operated at 21-cm and had a resolving power of 20".





The parametric amplifiers for the front end of each receiving channel were given to the University of Sydney by the New Mexico Institute of Mining and Technology.

East-West array of 32 x 5.7-m dishes

North-South array of 32 x 5.7-m dishes

Beyond the ends of the E-W & N-S arrays were 4 x 13.7-m dishes

Max Baseline of 1.6 km

FST Recollections

- **Kelvin Wellington worked on the design of the FST, as later worked at the Westerbork Synthesis Radio Telescope and the CSIRO's Div. of Radiophysics.**
  - **"*I'm pretty sure they were never used at Fleurs. They didn't come with a pump oscillator which would have been a pretty expensive addition so I don't think they even went on the 13.7m dishes.*"**
- **Bob Frater was the Director of the FST in 1980, Chief of the CSIRO Div. of Radiophysics, 1981 – 1988 and Deputy Chief Executive of CSIRO, 1997-1999.**
  - **"*I really only remember the big load of boxes arriving and wondering what we were going to do with them. I had no idea the paramps would be the size they were.*"**
  - **"*They were too heavy for our 5.7m & not that comfortable for our 13.7m antennas.*"**
  - **"*I found myself calculating the value of the gold!*"**
- **John Bunton worked at the FST. From 1986 to 1988, he was Engineer-in-Charge with responsibility for all aspects of telescope operation.**
  - **There were enough to outfit 32 of the smaller 5.7m dishes & possibly all 64 of them. "*They use to live under the stairs down to the courtyard at the School of Elect Eng.*"**
  - **"*No one ever figured out how to tune them to 1.4 GHz.*" [WECo had originally tuned the MAR-I paramps for 1150-1375 MHz so they would need to be tweaked to access 1420 MHz on the FST, an unappetizing prospect for up to 64 antennas.]**
  - **"*They were beautifully made with lots of gold plating.*"**
- **While the FST seemed to have acquired enough Colgate Paramps to populate the entire array, they never ended up being used for a number of reasons.**
  - **By the mid 1980's, low-noise GAsFET amps had been added ahead of the crystal mixers to lower the system noise from 800°K down to about 170°K.**

Distribution of the 280 Colgate Paramps

Organization	Min	Max	Used	Contact
New Mexico Tech (NMT)	21	21	SNORT	S. Colgate, B. Blevins
	3	3	3-Element Lightening Array	B. Winn
California Inst of Technology	1	2	Laboratory evaluation	A. Moffet (1971 letter)
CSIRO	2	6	Several from Univ. of Sydney, never used	M.Sinclair, B.Cooper (1973 letter)
Goddard Institute Space Studies	2	6	Unknown (a few)	A. Kerr
Instituto Argentino de	1	1	Disassembled to see how it worked	G. Dubner, J.Olalde,
Radioastronomia (IAR)	1	1	Used on 30-meter Antenna I	E.Filloy, T. Gergely
	2	2	Unknown	
Massachusetts Institute of Tech	6	10	Perhaps used in Microwave	P. Crane, P. Myers, J. Barrett
National Radio Astronomy	1	1	Polarization experiment on 140 ft	M. Ballister
Observatory (NRAO)	9	9	Never used	
National Research Council	2	2	Ottawa & ARO - Never used	K. Tapping, T. Legg
of Canada	1	2	Penticton & DRAO - Never used	T. Landecker
New Mexico State University	1	1	Disassembled	C. Seeger (1971 letter)
(NMSU)	6	6	Unknown	
Ohio State University	2	3	Never used on the “Big Ear”	R. Dixon
Rutherford Appleton Lab, UK	1	2	Unknown	K. Tapping
University of Groningen, NL	?	?	Student telescope	R. Allen, M. Goss
University of Sydney, Australia	68	80	Considered for use on the FST	C. Christiansen (1973 paper)
			(only 2 of the 13.7m may have used	R. Frater & K. Wellington
Others to England & Sweden		?	?	According to John Reiche
Sub-totals	130	158		

The Story of the Remaining Paramps

- **The paramps that weren't used – probably close 2000 - were stored away in the NMT corporate "Bone Yard" for the next 10 years.**
- **It was known that the paramp components where heavily gold plated.**
  - **When the MAR-I was salvaged in 1970, the price of gold was only ~$50/oz.**
  - **The price of gold would climb through the rest of the 70's and would peak at about $850/oz in 1980.**
- **John Reiche, the NMT Instrumentation Manager at the time, did the first assay of the paramps himself and was flabbergasted to find that there was well over 1 ounce of gold in each paramp module.**
- **At that point they realized they literally had a goldmine on their hands.**
- **Late in 1980, almost exactly a decade after the MAR-I site had been salvaged, the remaining amplifiers were driven in two trucks to the Sabin Metal Corp in NY where the gold was reclaimed and, amazingly, netted the university…**

$941,966 → ~$2.5M today

- **The proceeds of the reclaimed gold were used to construct a new wing on the *Workman Center* building.**
- **Although the official name was the "*Workman Addition*", it has since become known as the *Gold Building*.**

The *Gold Building* on the NMT Campus

Now the Bureau of Geology "Mineral Museum"

The Last Surviving Colgate Paramp ?

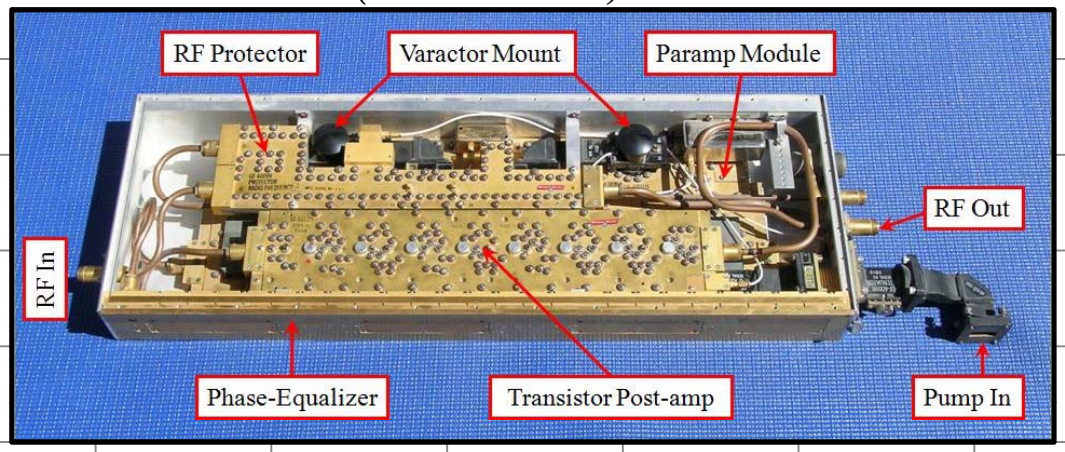
- **After spending much of 2009 researching the Colgate Paramp, we hoped to find one of the units to look at but with little success.**
  - **Upon hearing that would be passing through Socorro, Paul Krehbiel arranged for a lunch-time meeting John Reiche at a local restaurant (where John described the *Gold Building* story).**
  - **As luck would have it, Paul told his wife, Kay, about the upcoming lunch. She said, "*By the way, you know that we have one of these things in Archive at the Tech Library*". She retired as the Director of the NMT Library in 2003.**
- **Bob and Paul Krehbiel examine the Colgate Paramp in the Skeen Library.**
- **And so, we were able to sign out a Colgate Paramp on a 6 month loan.**

(Pictures by Miller Goss, 1 Sept 2009)

RF Tests on the NMT Library Colgate Paramp

WECo Preamp Module S/N 930 - Pump = 11,092 MHz @ +21.8 dBm

(RHH : 7 Nov 2010)



Receiver Temperature (K)

1000
900
800
700
600
500
400
300
200
100
0

BW = 200 MHz

1050 1100 1150 1200 1250 1300 1350 1400 1450 1500

Frequency (MHz)

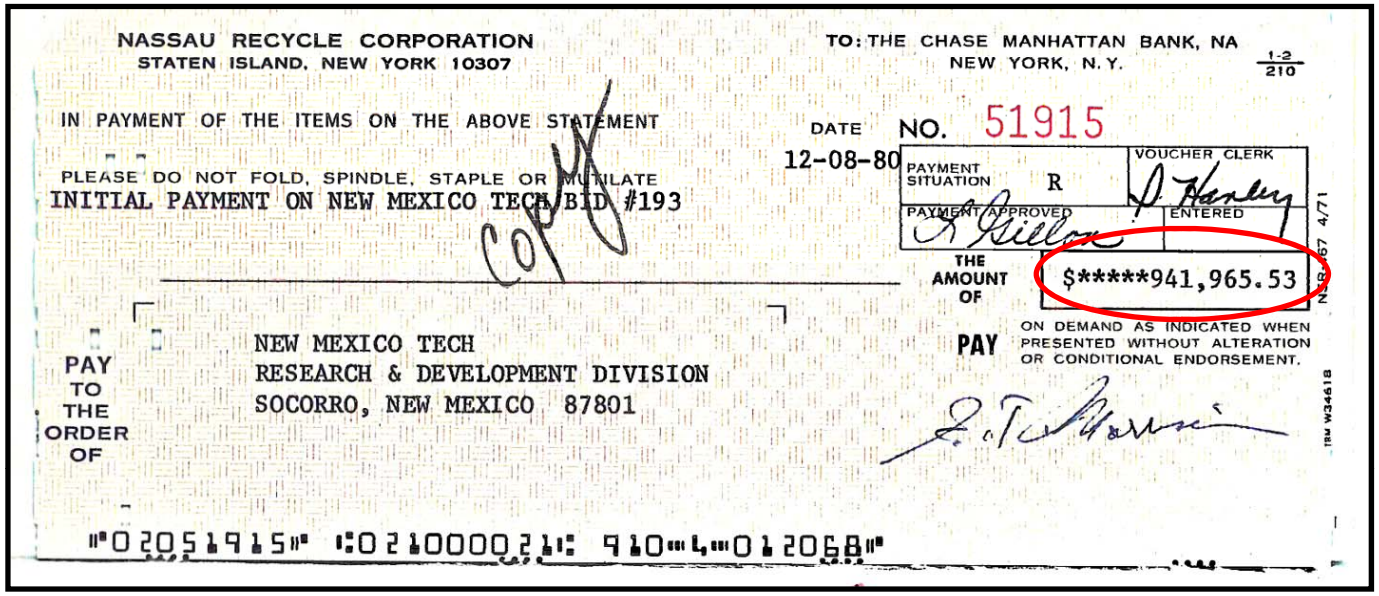
Without the losses in the RF Protector Module, the minimum noise temperature of the stripline Paramp would be < 125°K. A cooled InP HEMT amplifier today would be about 3°K.

Conclusions

- **Of the over 2,000 paramps that Colgate had harvested from the MAR-I in 1970, we now know where most of them ended up.**
- **We've managed to track down about half of the ~280 paramps donated to observatories & science organizations around the world.**
  - **Several national observatories used them to do interesting or unique radio astronomy projects (Polarization studies on the Green Bank 140 ft & HI observation of the southern sky with the IAR 30-m**
  - **Several observatories acquired them with specific plans for their use which, alas, never panned out (FST, MOST & Parkes).**
  - **Numerous institutions acquired small quantities of the paramps but they never ended up putting them to use (ARO, CIT, DRAO, GISS, MIT, NMSU, OSU, RAL).**
- **The Colgate Paramp's most novel feature was its extraordinary 25% bandwidth ratio at a time when most units typically only had about 5%.**
- **When the MAR-I paramp was first developed in 1963 by Bell Labs and then mass produced by WECo in 1964, its performance was competitive with any low-noise, room-temperature microwave amplifier then in existence.**
- **Had the MAR-I paramp been made available to the scientific community in the mid to late 60's, rather than the early 70's, its impact on the field of radio astronomy would certainly have been even more significant.**
- **After sitting in the Tech Bone Yard for nearly a decade, the gold in the ~2000 surviving paramps was reclaimed, providing NMT with a $1M windfall in 1980.**
- **The contribution of the Colgate Paramp to science & technology continues to live on some 40 years later in the *Gold Building* on the Tech Campus.**
- **Finally, one can truthfully say that the *Skeen Library* at NMT is probably the only library in the world where you can check out a 45 year old fully functional parametric amplifier !!!**

The End

The Gold Check
(courtesy of Paul Krehbiel)


NASSAU RECYCLE CORPORATION
STATEN ISLAND, NEW YORK 10307

TO: THE CHASE MANHATTAN BANK, NA
NEW YORK, N.Y.
1-2
210

IN PAYMENT OF THE ITEMS ON THE ABOVE STATEMENT

PLEASE DO NOT FOLD, SPINDLE, STAPLE OR MUTILATE
INITIAL PAYMENT ON NEW MEXICO TECH BID #193

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DATE 12-08-80

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THE AMOUNT OF $*****941,965.53

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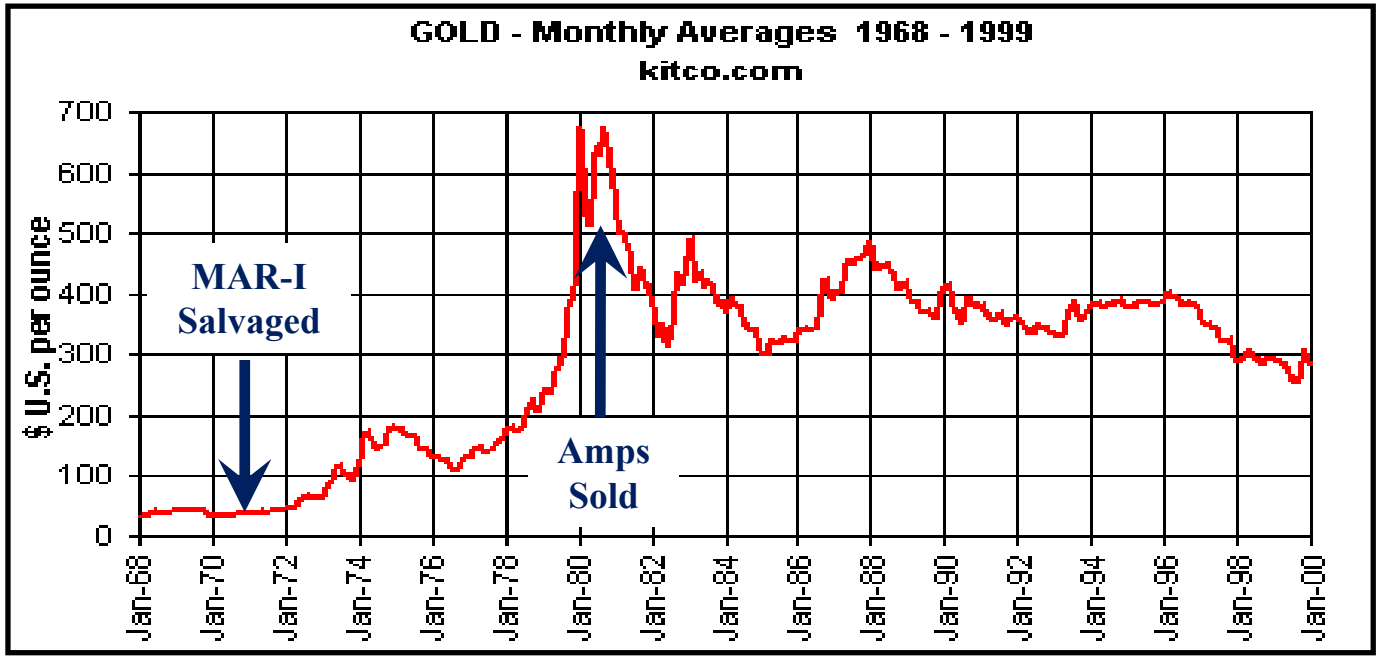
⑈02051915⑈ ⑆021000021⑆ 910⑈4⑈012068⑈

Monthly gold prices from Jan 1968 to Jan 2000



Backup Slides

The Source of the "Colgate Paramps"
Multifunction Array Radar (MAR-I)

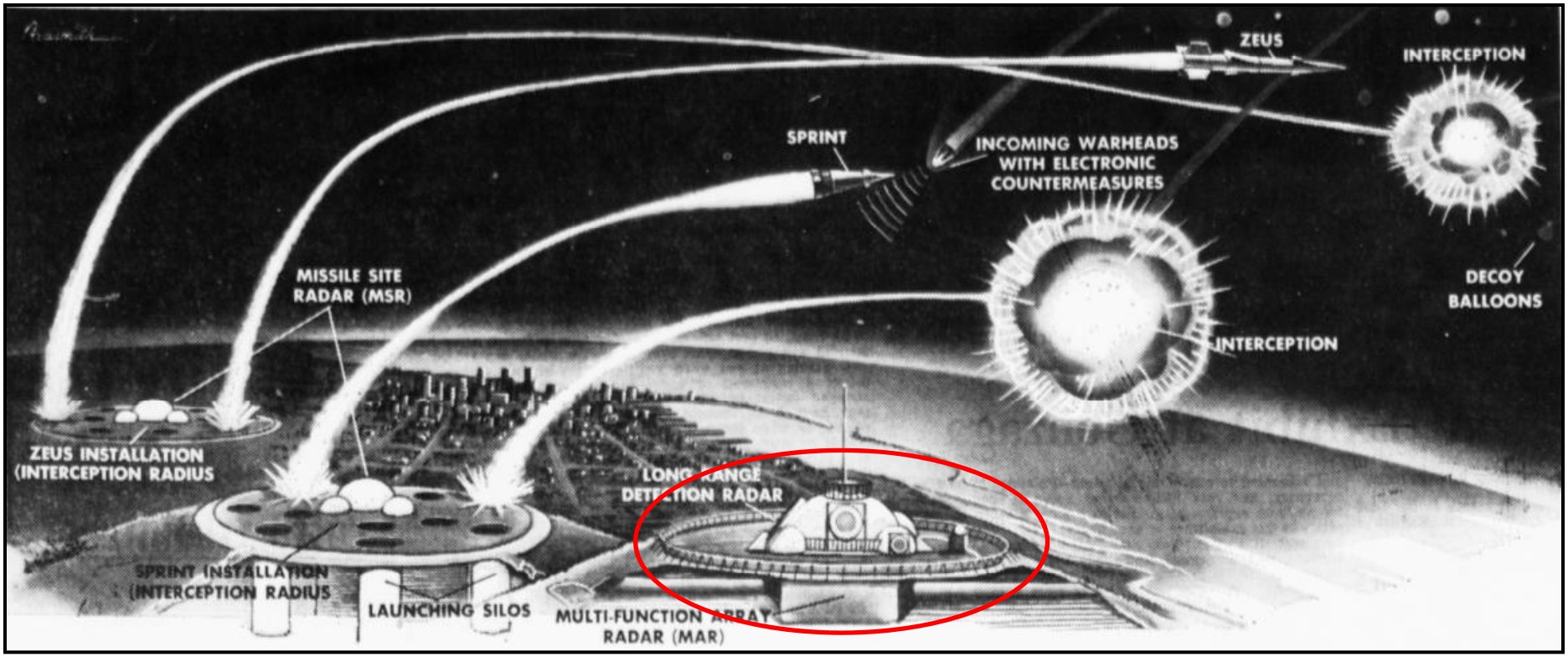
Aerial view of the prototype Nike-X *Multifunction Array Radar* (designated "*MAR-I*") built on the White Sands Missile Range (WSMR) in the mid 1960s for evaluating anti-ballistic missile (ABM) defense.

Western Electric was the primary contractor while Bell Labs was responsible for the overall design.

The MAR-I was salvaged by New Mexico Tech in 1970-71. Over 200 truckloads of material was hauled back to Socorro.

(Photo courtesy of Bob Gamboa)

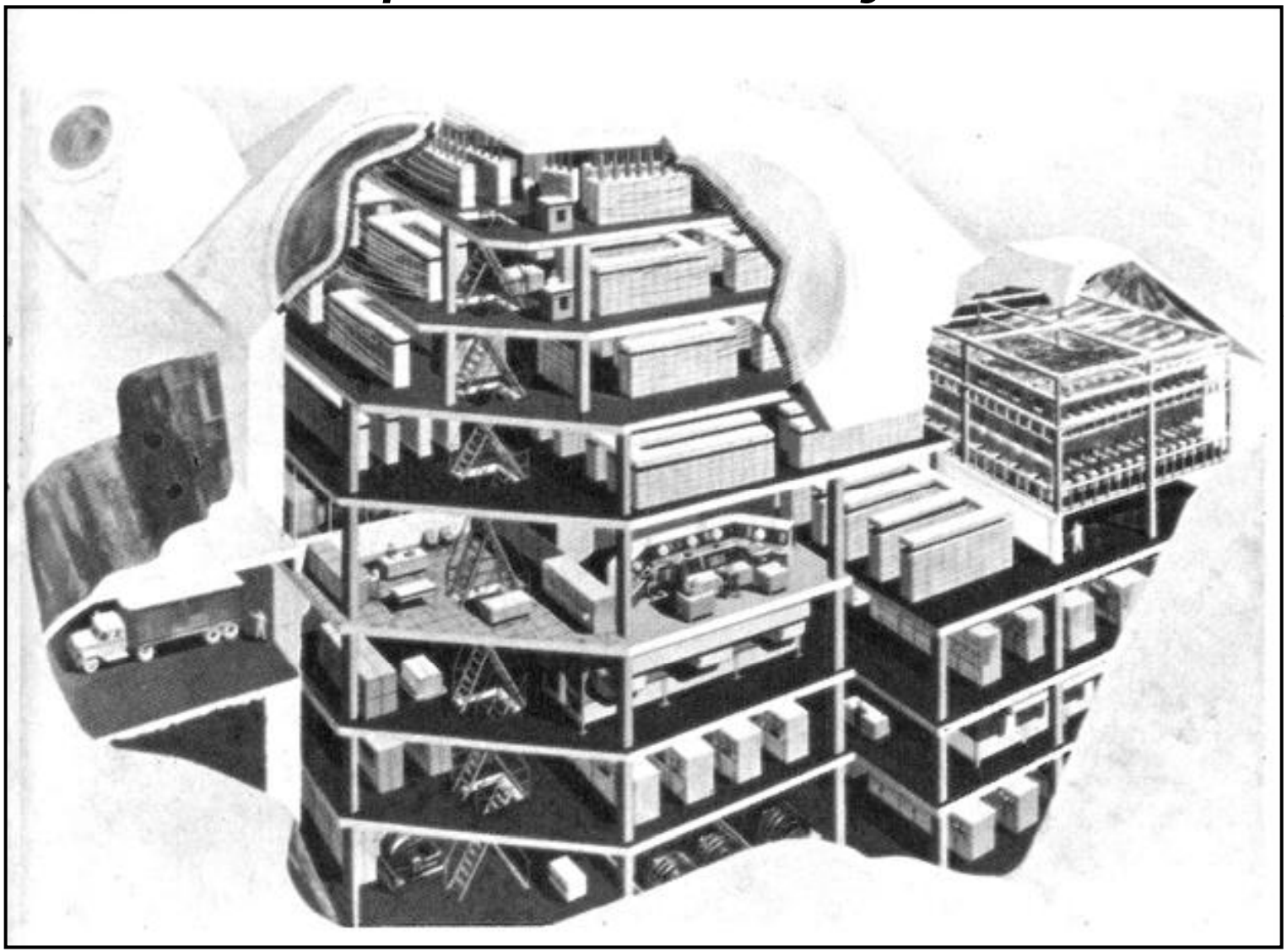
The *Nike-X* Anti-Ballistic Missile (ABM) Defense Concept of the Mid 1960s



"*Nike*" was the Greek Goddess of Victory

(from The Spokesman-Review Newspaper, Spokane, WA – 7 Jan 1967)

Cutaway Drawing of the Proposed Nike-X *Multifunction Array Radar*



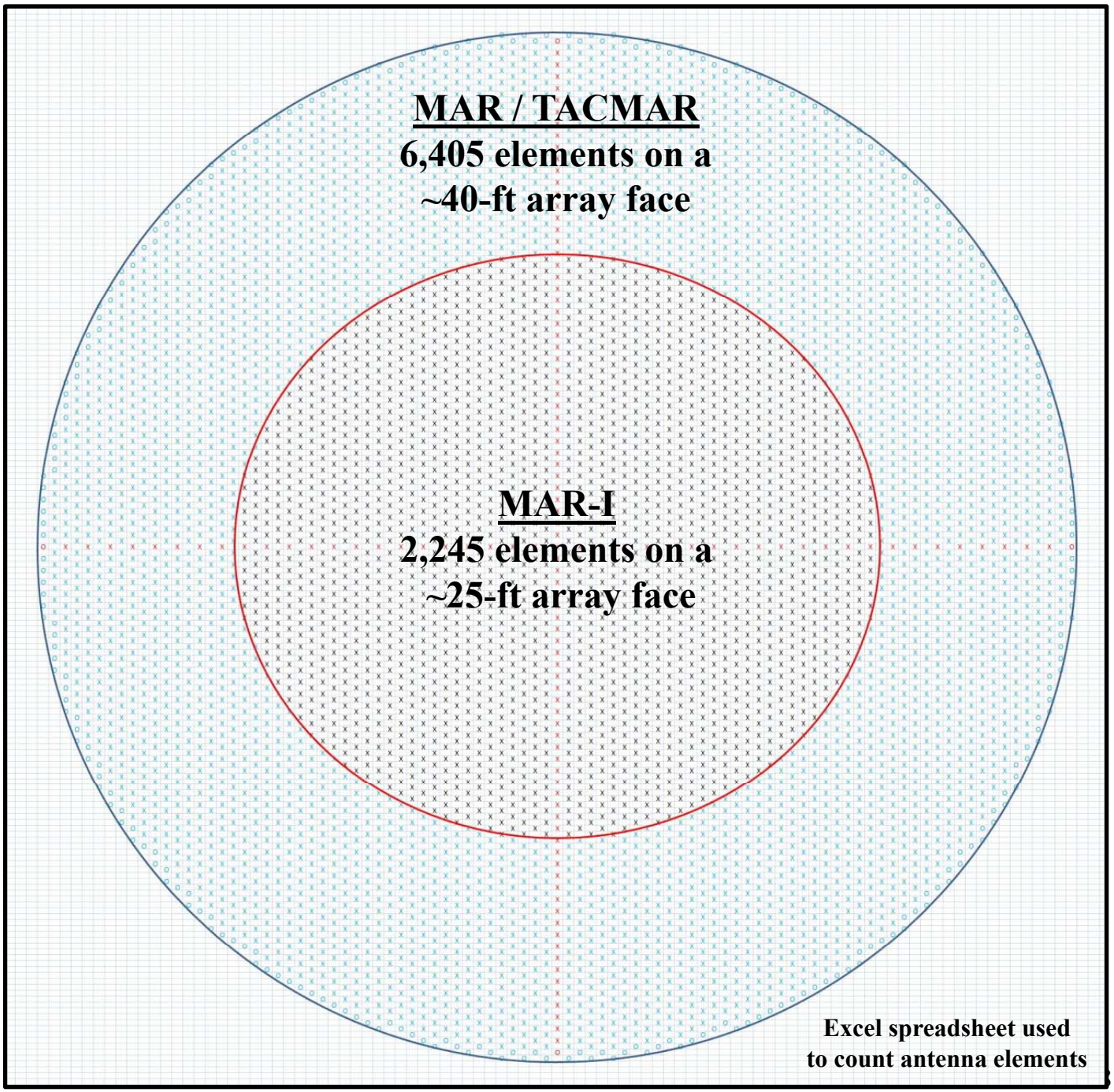
A full MAR would have all 4 quadrants fully populated, while the cheaper, less powerful TACMAR would have had half the number of active Tx & Rx modules.

A heavy defensive system to protect the 50 largest cities against a Soviet attack called for 8 MARs and 3 TACMARs costing about $3.2B (or $21.5B in 2010).

Had the entire *Nike-X* program gone ahead, it would have cost ~$20B (or $125B today) and would have rivaled the national effort that the Apollo program required to land a man on the moon.

Bids Due Soon on New Nike-X Radar, Missiles and Rockets, May 30, 1966, p 14-15

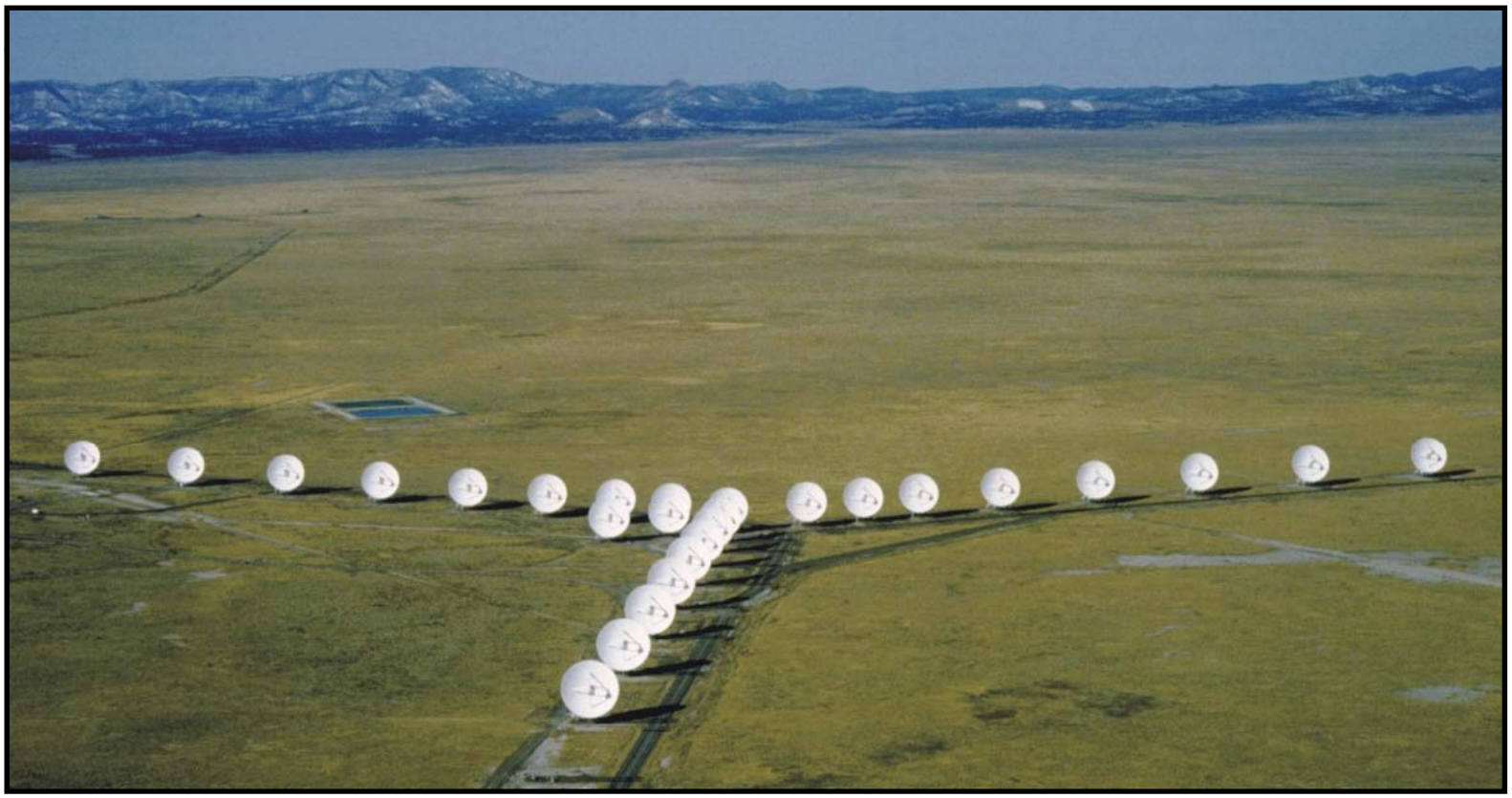
The MAR vs. the MAR-I Rx Array



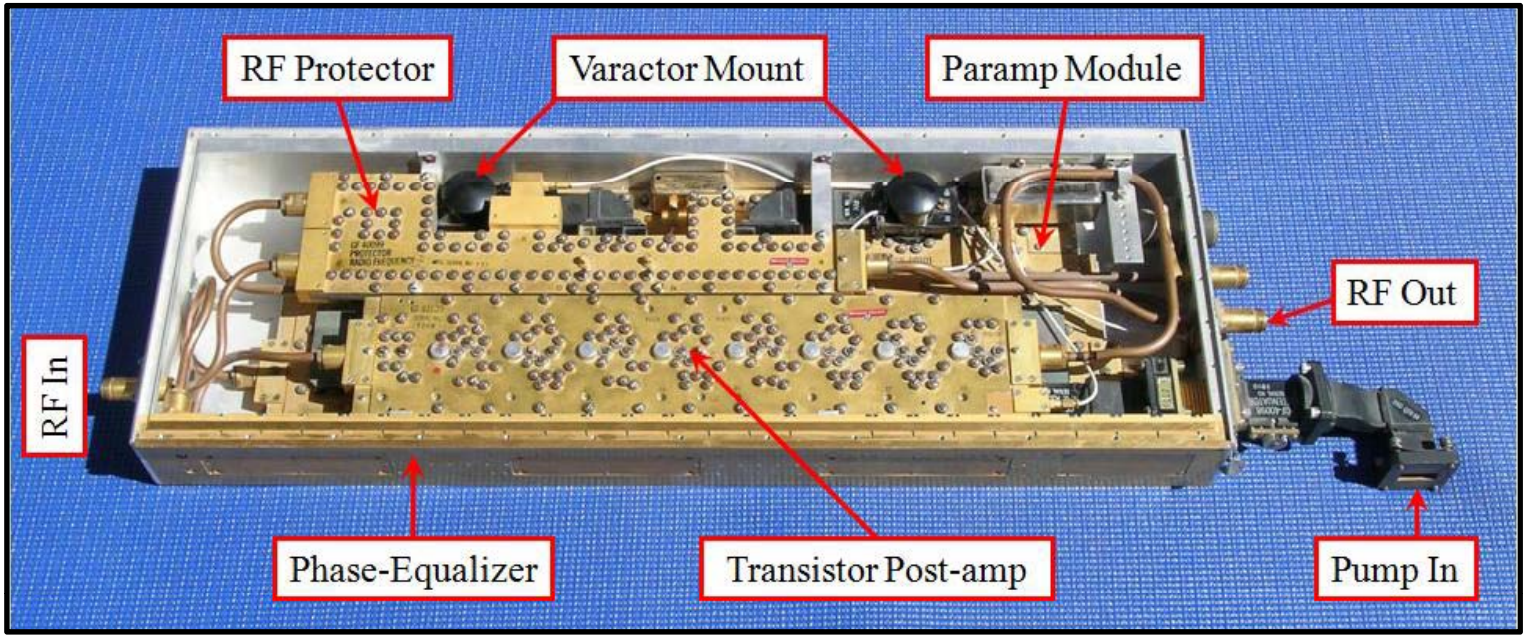
The MAR's four Receiving Arrays would have utilized 25,620 paramps

Paramps on the Very Large Array

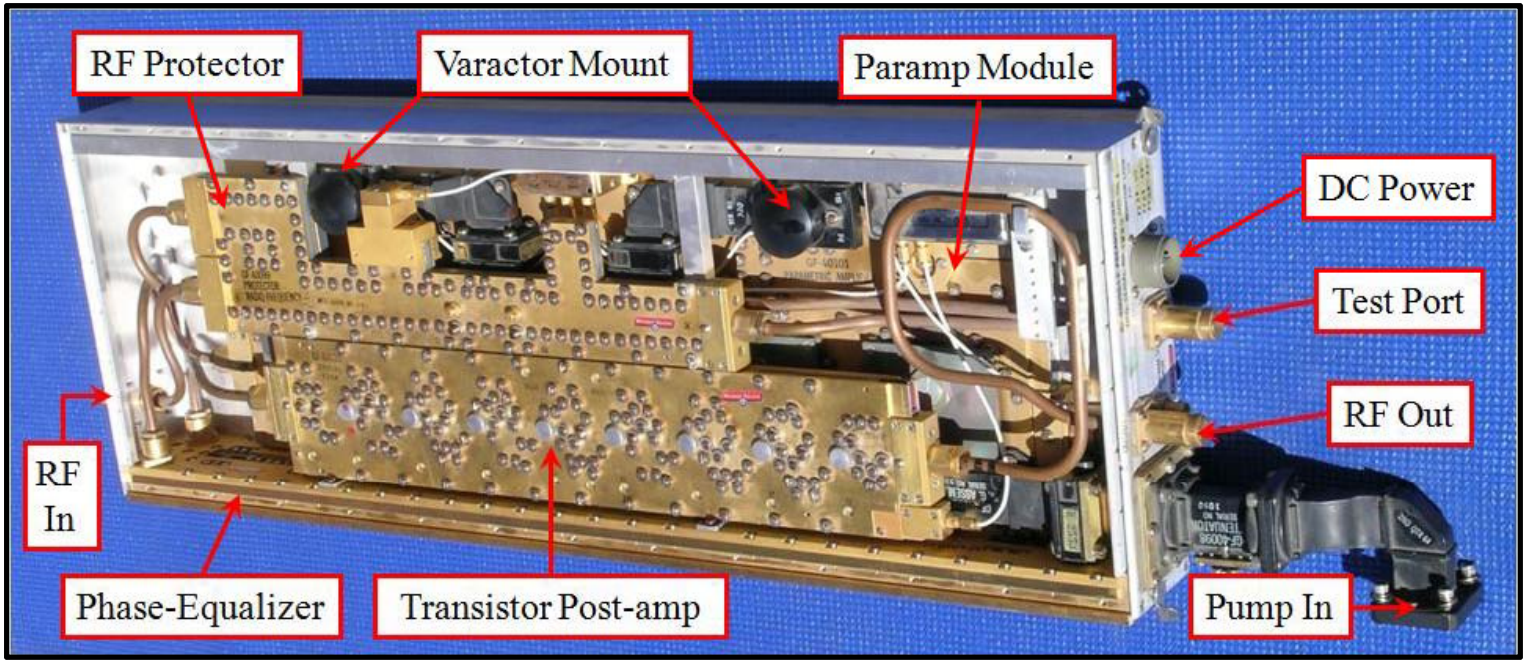
- **Original VLA design, carried out in the mid 1970's, called for:**
  - **28 cooled "L-Band" (1.3-1.7 GHz) parametric up-converters.**
  - **28 cooled "C-Band" (4.5-5.0 GHz) three-stage parametric amplifiers.**
  - **For a total of 112 cryogenic operational paramp stages !!**
  - **The MAR-I had 4490 room temperature paramp stages !!!!!**
- **Until the mid 1980's, paramps were more sensitive than transistor amps, albeit less stable and much more difficult to work with.**



http://images.nrao.edu/object/index.php?id=307



WECo Preamplifier, Model GF-40096-L2, Serial Number 930



The MAR-I as an Astronomical Instrument ?

The MAR radar was dismantled before a proper evaluation could be made of its astronomical capability.

It is a tragedy indeed that such a short-term military experiment could not have been made available to astronomers who could have made measurements that now may not be made for many decades.

It was an incomparable instrument, operating near the 21-centimeter line for beam-switched observations of distant radio sources and possibly even of supernovas in distant galaxies.

- Stirling Colgate, in his 1972 letter to *Science*, suggested the MAR-I would have made a great astronomical telescope.
  - Pro's: - With retuning, it could access the 21-cm Hydrogen Line.
    - Field of View > 90° with a phased-array beamwidth of ~1.8°
  - Con's: - Smallish Aperture of about 25 ft.
    - System Temperature of Antenna Element & Paramp > 300K
    - Its single Receiving Array Face points to the Northwest.
    - The maintenance of over 2000 paramps is more than scary.
- So it was probably rather marginal as an astronomical instrument.
  - Except, perhaps, for surveying the Northern Sky for Supernovae.
- The astronomical community certainly wouldn't say no to a portion of its cost ($160M or $1.1B today ≈ ALMA) nor the speed of its construction (groundbreaking to turn-on took only 15 months).