MARTIN SCHWARZSCHILD’S
DIFFRACTION LIMITED IMAGERY
FROM THE STRATOSPHERE

Blair D. Savage
University of Wisconsin-Madison

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<th>Stratoscope I</th>
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<td>(12” SOLAR)</td>
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At an early 1950s lunch with Lyman Spitzer, James Van Allen, and Martin Schwarzschild, it was agreed that a diffraction limited solar telescope was needed to make progress in understanding convective processes in the solar photosphere.

Spitzer was into fusion research.
Van Allen was into upper atmosphere particle research.

“They both looked at me. That is how I became involved with Stratoscope!”
12 inch mirror, 8 foot focal length
25x enlarging lens, 200 foot effective focal length
1000’ 35 mm film, 8000 exposures/flight
\( \lambda = 5400\pm400 \) Å, 2 msec exposure time

FWHM = 0.38” = 0.112 mm on film
= 275 km on the sun.

Stratoscope I
350 pound telescope
1400 pound system
TECHNICAL ISSUES

The thermal design to minimize mirror distortions and convection at altitude.

The pointing system needed to achieve < 0.1 arc sec blurring over 2 msec exposure time.

Successively operating a robotic observatory at 80,000 ft in the stratosphere where the ambient temperature is -50 C.

Two scientific flights during the summer of 1957

Solar granulation, pores, limb

2x10^6 ft^3 polyethylene balloon to 82,000 feet
“The bright granules, ranging in diameter from ~300 to ~1800 km, are of highly irregular, often polygonal, shape and are separated from one another by dark, often narrow lanes.”

“The granulation has the character of non-stationary convection.”

“This result came as a surprise, at least to this author (Schwarzschild 1959).”
Four Flights in 1959 with a TV system to locate solar magnetic regions and obtain photographic images.

"The penumbra is resolved into a complex array of radial bright filaments having widths of < 300 km and length of ~5000 km. "Bright dots are observed in sunspot umbras" (Danielson 1963)
Some years after the flights of Stratoscope I, Don Morton remembers Martin saying:

“The most significant result of those flights was to simulate ground based solar observers to devise the techniques to obtain sharper images from the ground.”
STRATOSCOPE II
started in 1960

Martin Schwarzschild
Robert Danielson

Fused quartz 36” primary mirror
1/50 λ rms surface accuracy

Photographic camera at f/100 final focus.

TV acquisition cameras

3200 kg observatory

Mirror pre-cooled to -50 C

Alti-azimuth mount with mercury azimuth bearing.

Angular resolution ~ 0.2 arc sec

rms pointing stability ~ 0.02 arc sec
36 inch f/4 primary mirror

Final focus at f/100

Imaging onto 70 mm film.

Integrating intensified TV system was considered too risky for the science detector.

Magnetically suspended 2.5 power transfer lens for image stabilization with error signals derived from guide stars.

TV acquisition system for locating the guide stars and the scientific targets.
Heavy Lift Balloon

Launch balloon  \( 3.05 \times 10^5 \text{ ft}^3 \)

Main balloon  \( 5.3 \times 10^6 \text{ ft}^3 \)

0.35 mil mylar/ dacron mesh

660 ft tall at launch
monitor observatory status
unlatch telescope at altitude
open mirror door
move to correct azimuth and elevation
balance the telescope
find the guide stars
establish servo system guide star lock
focus and align the optics
record scientific images
move to the next object
etc.
close mirror door
latch telescope
Release He for controlled decent
1963, 1964 IR Flights

0.8-3.1 μm SPECTRA OF THE MOON, PLANETS AND STARS

IR Spectrum of Mars

The IR spectrum of Sirius reveals the stratosphere above 80,000 is very dry and a good site for IR astronomy.

Wolff, Schwarzschild & Rose (1964)

The 3.1 μm H₂O Ice feature was not detected in the spectrum of μ Cep. No more than 25% of interstellar reddening is due to ice.

Danielson, Woolf & Gaustad (1965)

There is < 40 μm of H₂O in the atmosphere of Mars

Danielson, Gaustad, Schwarzschild, Weaver & Woolf (1964)
After flight failures in 1965, 1966, and 1967 due to mechanical problems, Stratoscope II underwent environmental testing at Valley Forge, PA in 1967-68.
Result from the 1968 imaging flight
(residual seeing in the main telescope tube)

An Upper Limit to the Angular Diameter to the Nucleus of NGC 4151
Danielson, Savage & Schwarzschild (1968)

half intensity angular diameter $< 0.18$ arc sec

Results from the 1970 flight (NGC 4151 and Uranus)

An Upper Limit to the Angular Diameter to the Nucleus of NGC 4151
Schwarzschild (1973)

half intensity angular diameter $< 0.08$ arc sec

“The inferred stellar collision rate is so high it provides a strong indication of the
extraordinary conditions apparently prevailing within the nuclei of Seyfert
galaxies.”
No evident surface features with $> 5\%$ contrast. Limb darkening is apparent.
Limb darkening is consistent with a finite Rayleigh scattering H\textsubscript{2} Atmosphere (\(\tau \sim 0.5\)) over a cloud deck (likely methane ice).

\[D_{eq} = 51,800 \pm 600 \text{ km} \quad \text{vs} \quad 51,118 \pm 4 \text{ km from Voyager}\]

Flattening = 0.01\pm0.01 \quad \text{vs} \quad 0.0229\pm0.0008 \text{ from Voyager}
Last flight of Stratoscope II in 1971

The Nucleus of M31
Light, Danielson & Scharzschild (1974)
direct 24 min exposure 0.2 arc sec resolution

"The SS II observations appear to have fully resolved the nucleus of M 31. The size of the nucleus is 0.28 arc sec. The offset with respect to the outer portions of the nucleus is puzzling."

HST Planetary Camera

Planetary Camera Observations of the Double Nucleus of M31
Lauer et al. (1993)
deconvolved image
NAS Astronomy Survey Committee (Greenstein 1972)

“The committee feels that the LST has extraordinary potential for a wide variety of astronomical uses and should be a major goal in any well-planned program of ground and space based-astronomy.”

History of the LST (Spitzer 1974)

“It is no coincidence that these strong recommendations came at a time when large optical space instruments were achieving important scientific results. The Stratoscope II 36-inch balloon telescope had very successful flights in 1970 and 1971, achieving photographs of planets, satellites and galactic nuclei with an instrumental profile of about 0.2 arc sec.”
THANK YOU MARTIN FOR LEADING US DOWN THE PATH TO MAJOR ASTRONOMICAL OBSERVATORIES IN SPACE!
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