



Up, Up, and Away - Chasing the Umbra Into the Stratosphere (and Beyond)



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<http://nicmosis.as.arizona.edu:8000>

GENISIS: 1918 PROPOSAL TO USNO by Col. John Millis: *ECLIPSE OBSERVATIONS FROM AIRPLANES*

1st Flight: TSE 08 June 1918, Fort Sill, Oklahoma, USA

Scientific American, Oct. 19, 1918

(Prescience, or Pre-Science?)

“If it develops nothing else of novelty, the recent solar eclipse can fairly lay claim to be *the first astronomical event to be observed from an airplane*.

Although the flight and observation made at Fort Sill, Okla., were not undertaken with any serious scientific objective in view, it was at least demonstrated that *we may eventually look to the aviator for work of value in connection with eclipses.*”

GENISIS: 1918 PROPOSAL TO USNO by Col. John Millis: *ECLIPSE OBSERVATIONS FROM AIRPLANES*

1st Flight: TSE 08 June 1918, Fort Sill, Oklahoma, USA

Scientific American, Oct. 19, 1918

(Prescience, or Pre-Science?)

“While most of the undertakings of eclipse time call for a solid foundation, which can hardly be looked for even in the plane of the future, *the aviator can at least free the astronomer from his complete subjection to clouds and other superficial weather phenomena.*

We may, therefore, look for *more general use of planes in connection with subsequent eclipses.*”



Reasons for Employing Aircraft To Observe Total Solar Eclipses



1. Deployment/Relocation

TSE 22 December 1870 - Jules Jannsen escapes the siege of Paris by balloon to observe eclipse in Algeria.

2. Cloud obscuration avoidance

Stratosphere: Virtually assured; Polar Stratosphere: 99.99%

3. Totality Prolongation

Record (by far) to date: TSE 1973 - Duration ~ 74 minutes

4. Sky Transparency

Improved (Reduced Particulate Scattering)

5. Sky Darkness

Improved (Higher Contrast Coronal Visibility to Larger Radii)



Reasons for Employing Aircraft To Observe Total Solar Eclipses



6. Astronomical Seeing

Improved (“r_naught” decreases with increasing altitude)

7. Atmospheric Turbidity

Reduced (Vorticity & Shear decline in power with altitude)

8. Panchromatic Visibility

Improved (IR and UV “windows” open up)

9. Unparalleled Horizon Reach and Observational Vista

Apparent Horizon 367 km (228 miles) distant @ 35,000 ft

10. It's just plain neat (cool, keen, fun, da bomb [oops]...)

If you haven't done one yet...what are you waiting for???

... and think of those frequent flyer miles.

FOLLOWING 1st FLIGHT - MORE TSE FLIGHT PROPOSALS TO USNO:

1919 - Prof. D. P. Todd: aircraft observations

1923 - Col. J. Millis (retired): aircraft observations

Cpt. Albert William Stevens (1886-1949), U.S. Army officer



- pioneer aerial photographer
- “father of airborne astronomy”
- early balloon-borne aeronaut*
- *in situ* tropopausal temperature measurement
- 1st photograph of Earth’s curvature(1930)
- record balloon ascent Explorer II 72,395 ft with Cpt. O. Anderson at Rapid City, S.D. (11 Nov 1935)

*Stevens, W. S., National Geographic, Dec 1926, 755:
“*Exploring the Earth’s Stratosphere*”

De Havilland DH-4B



TSE: 10 September 1923

US Navy - 16 Aircraft

Altitudes: 5,500 - 16,500 ft

Deployment: Along Path

Objective: Determine Centerline Location from Air

Method: Aerial Eclipse Photography, 30 photographs exposed

Result: none successful in imaging the eclipse

Synopsis: “no valuable results were secured”

-F.B. Little, 1925, Popular Astronomy, 33, 239

Albert William Stevens

**1st (in a series) of
airborne eclipse flights**



FOLLOWING 1st FLIGHT - MORE TSE FLIGHT PROPOSALS TO USNO:

1919 - Prof. D. P. Todd: aircraft observations

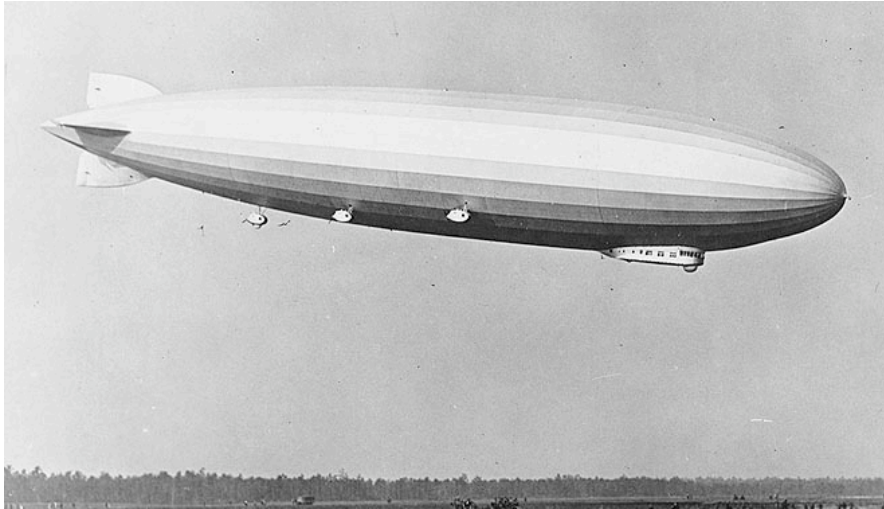
1923 - Col. J. Millis (retired): aircraft observations

1925 - Col. J. Millis: dirigible* observations

*“It was the idea of Colonel Millis that the **TOP** of the airship could be used as a platform for apparatus and observers...*

Much skepticism was evinced as to the desirability of attempting so unusual a method of observing the eclipse as a serious scientific undertaking...”

- F. B. Little, USN



TSE: 24 January 1925

US Navy Airship "Los Angeles"

Altitude: 4,500 ft.

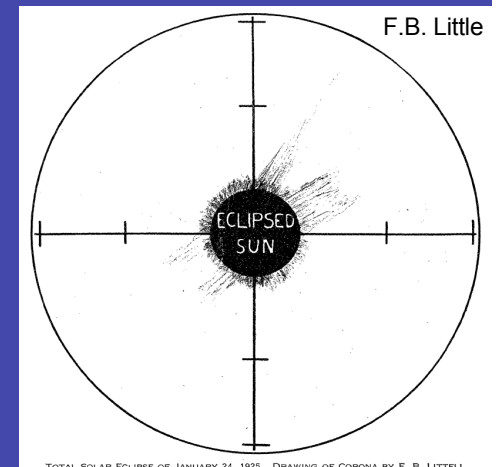
Deployment: 41.0°N, 71.5°W

100 mile E of Montauk Pt., NY

DISADVANTAGE: Inability to ascend high to "over-ride" clouds.

Objectives:

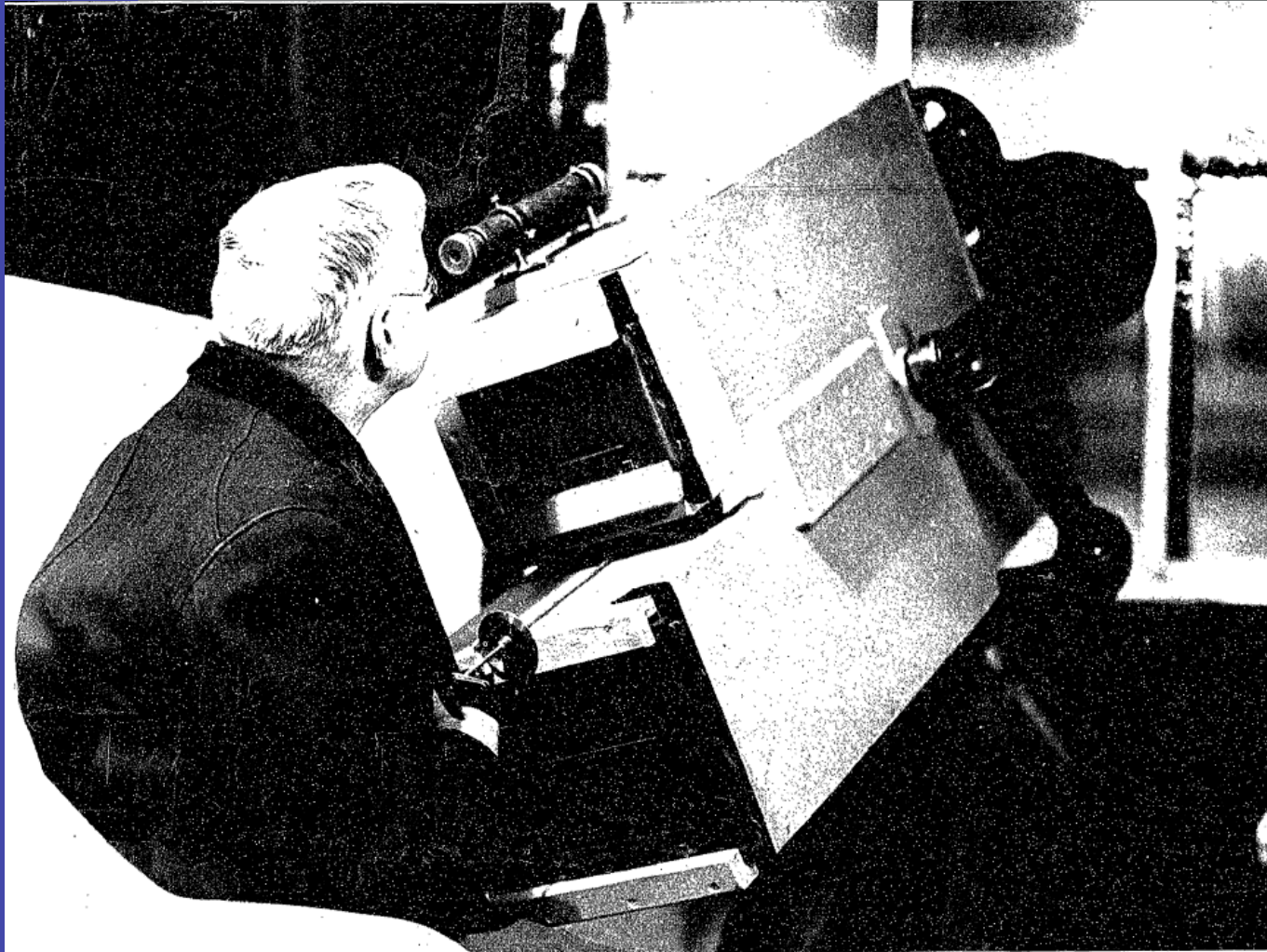
- Secure Photographs & Drawings of Solar Corona***
- Obtain Spectroscopic Observations (Bureau of Standards)***
- Record Contact Timings***
- Observe and Document Color Effects***
- Observe Shadow Bands***
- Observe "possible comets & other objects"***
- Observe "any other unusual appearances"***



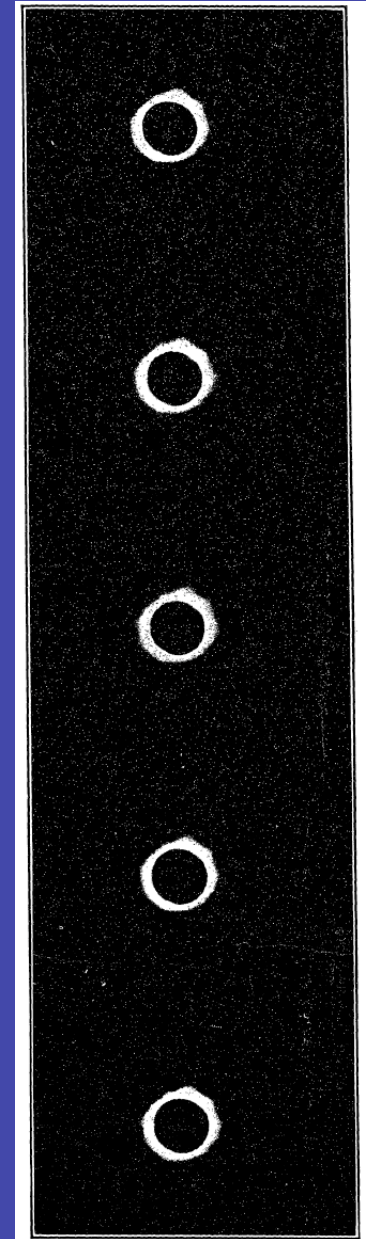
TSE: 24 January 1925

US Navy Airship “Los Angeles”

“upon consultation with those familiar with the the construction and use of airships, it became immediately evident that the **top** surface is not a suitable place for... apparatus... {or} personnel”.



“As it was, the one person assigned to duty in the cockpit has his *face and fingers frozen* while securing pictures of the eclipse.”

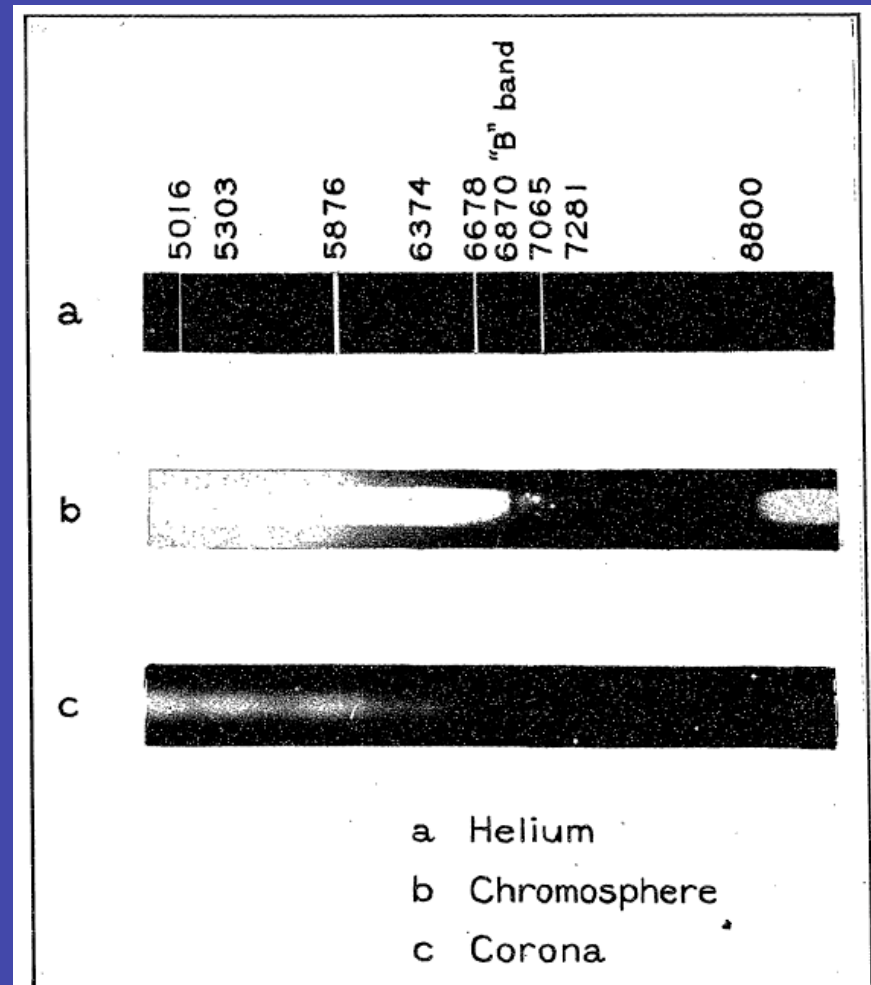
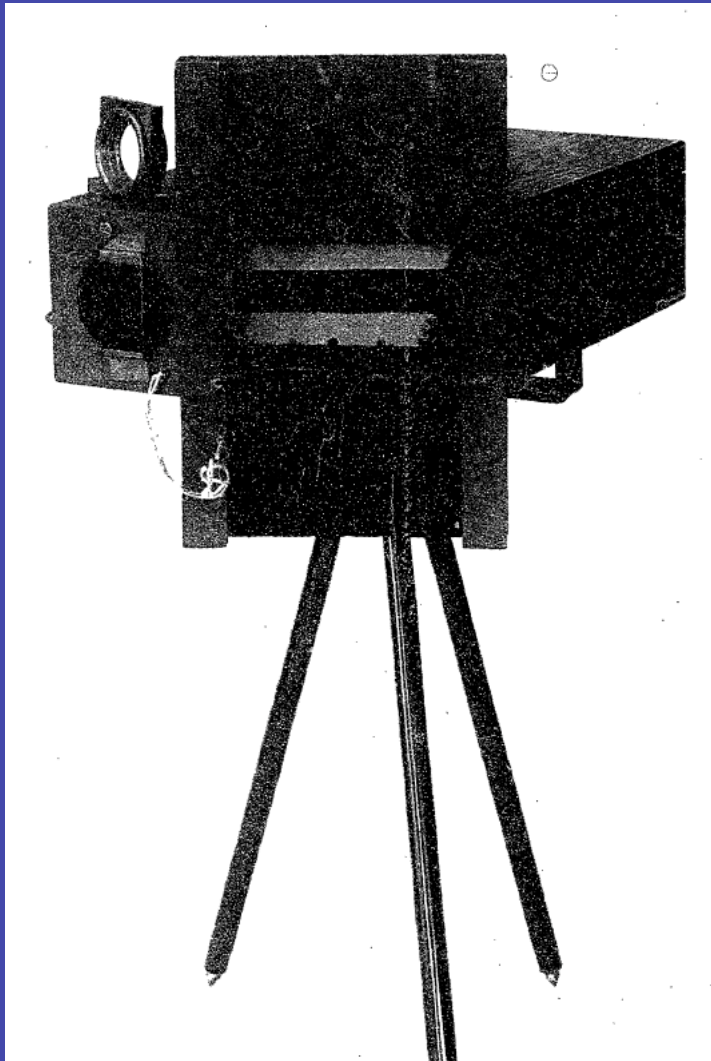


TOTAL SOLAR ECLIPSE OF JANUARY 24, 1925. PHOTOGRAPH OF CORONA WITH MOVING-PICTURE CAMERA

TSE: 24 January 1925

US Navy Airship "Los Angeles"

SPECTROGRAPHIC CAMERA

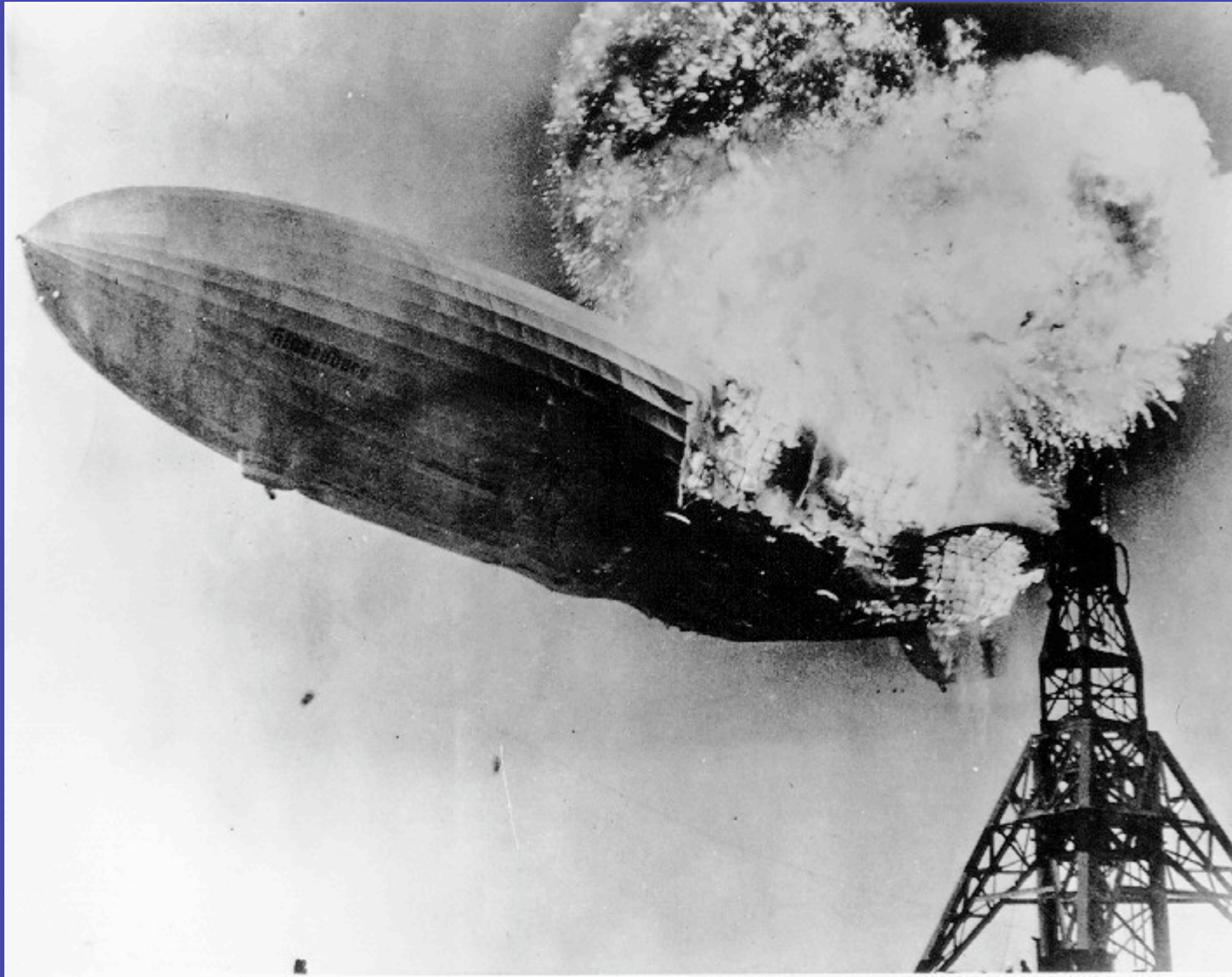


TOTAL SOLAR ECLIPSE OF JANUARY 24, 1925. SPECTROGRAM OF CHROMOSPHERE AND CORONA

06 May 1937

LZ 129 Hindenburg

The Tragic End of the Dirigible Eclipse Observing Concept



TSE 28 Apr 1930, Northern California

Jeffers, W.H., PASP, (Nov) 1930, 42, 141.

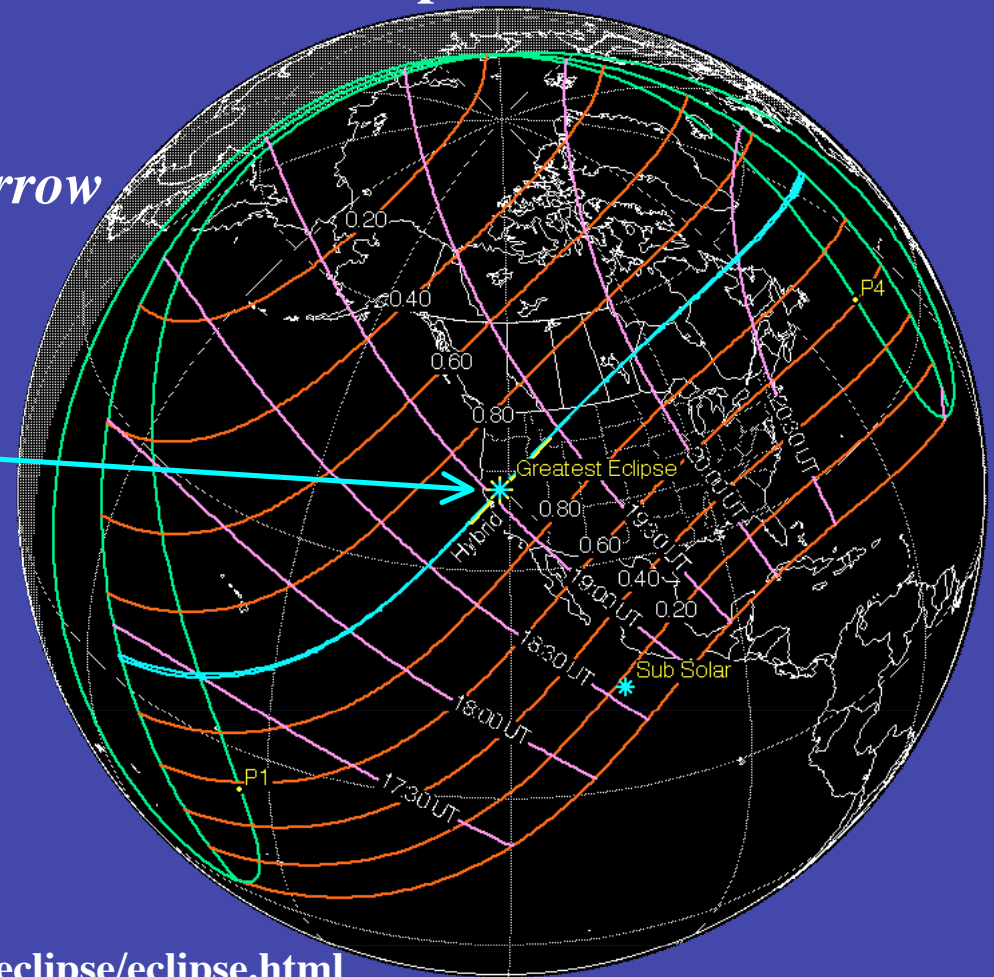
The Observation of the Eclipse by Airplane [Napa, Sonoma]

“...the eclipse ... so *near the border line between annular and total* it appeared well worthwhile... to observe from an airplane at considerable altitude.

“...the *shadow track was so very narrow* its exact location was in doubt.

Greatest Eclipse:
29.6°N, 121.2°W
Path Width*: 1.1 km
Duration*: 1.4 sec

*no limb corrections



TWO AIRCRAFT @ 10,000 ft

TSE 28 April 1930

- 1) Lt. W. Bobzien, Pilot (CMD)
Sgt. S. Bush, Photographer
SUN: 20" EFL f/3.5 K-6 Camera

Army Air Corps Expedition
Napa/Sonoma, California

- 2) 1st Lt. H. Wallace, Pilot
M. H. Jeffers, Photographer
SHADOW: 3.5" EFL f/1.85 box camera



“...it was possible the advancing shadow cone would be seen many miles away, and the pilot of a plane might have time to *alter the line of flight* so as to get into the shadow...”

“...a photograph of the corona... would suffer less from scattered light... at high altitude {due to} *less air, dust, and water vapor* between Sun and camera.

“...airplane would afford {a} point of vantage from which to effectively *observe the Moon's shadow on the ground.*

TSE 28 Apr 1930, Napa, Sonoma, California

Jeffers, W.H., PASP, (Nov) 1930, 42, 141.
The Observation of the Eclipse by Airplane

“Two minutes before totality was due... the region over the Pacific to the SW as getting very dark...”

“At this time the visual search for the expected half-mile wide umbral shadow was begun. This was *unsuccessfully* looked for up to the moment when it was realized that the eclipse was central, and that the shadow, *what there was of it*, was at hand.”

“It seems safe to say, now, in the Sonoma region the umbra did not exist.”

Vought O2U-1 Corsair



Copyright 1999 Brian Johannesson

TSE 28 April 1930
USNO Eclipse Expedition
Honey Lake, California
Duration of Totality: 1.4 s

Akeley "Pancake"
35mm Hand-Crank
Motion Picture
Camera



***Objective: Determine exact
Centerline of eclipse.***

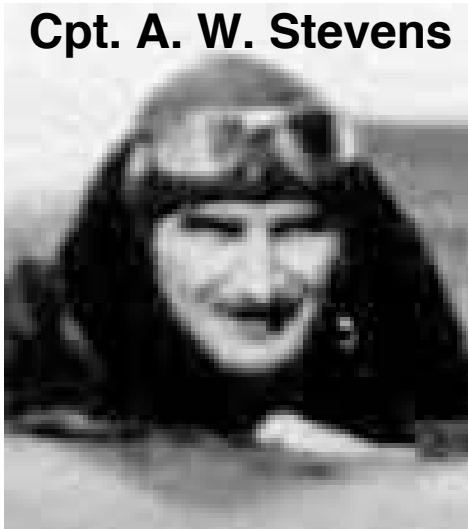
***Method: Cinematography of
Shadow***

***Result: Recorded Approach
Of Lunar Shadow***

***Application: Corrections to
Lunar Almanac***



Cpt. A. W. Stevens



3rd Airborne TSE

TSE: 31 August 1932

Army Air Corps/NGS Expedition

27,000 ft over New Hampshire, USA

OPERATED THREE CAMERAS

- + Obtained time-resolved series of approaching lunar shadow
- + Obtained *IR filtered* images of solar corona
- One camera tangled in Oxygen hose

"From Five Miles Above the Earth's Surface, the National Geographic Society-Army Air Corps Survey Obtained Successful Photographs of the Moon's Shadow."*

Stevens, A. W., National Geographic, (Nov) 1932, 62, 581.

Photographing the Eclipse of 1932 from the Air

*During the Total solar Eclipse of 28 April 1930

TSE: 9 July 1945

Millman, P.M., *Sky & Telescope*, 1945, 4 (47), 3.
RCAF Operation Eclipse

Royal Canadian Air Force/Canadian Radio Wave Propagation Cmte. :

- 4 Aircraft: Spitfire, Mitchell, Anson(2)
- 17,000 ft. to 34,000 ft.
- 7 Aerial Cameras (6 automated operation) + 1 motion picture camera
- Aircraft fitted with special (plate glass) windows
- *Visual & Infrared* photographs of corona & prominences
- *Spectroscopic & Polarization* measurements
- First spectroscopic observations from heavier-than-air aircraft



Multi-Spectral, Multi-Modal, Temporal
PHYSICAL SCIENCE

Blackwell, 1954, MNRAS, 115, 629.

TSE: 30 June 1954

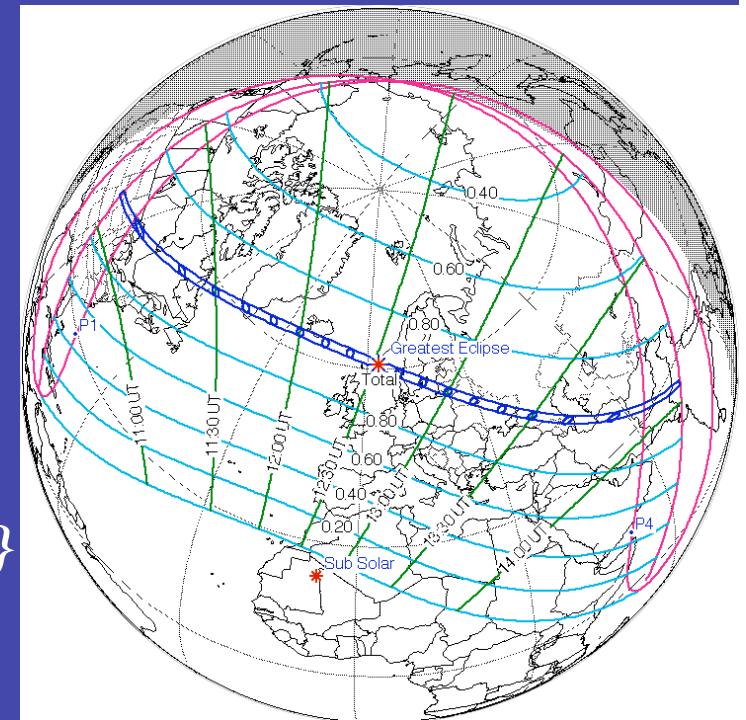
A Study of the Outer Corona from a High Altitude Aircraft at the Eclipse of 1954 June 30

“Observations should be made in an *open aircraft*, not through an aircraft window... extra light scattering at the window will entirely vitiate the advantage of high altitude observations.

In making the observations... if was found most convenient to fold the aircraft door back and *mount the camera in the open doorway*.

The aircraft used was a special Lincoln capable of flying to an altitude of 43,000 ft.

Physiological difficulties made it *inadvisable* {!} to attempt observations from this height ... 30,000 ft was chosen to give the best compromise between sky darkening... aircraft stability and observer alertness...



Blackwell, 1954, MNRAS, 115, 629.

TSE: 30 June 1954

Eclipse Observations: Lat = 61° 23.9'N, 1° 34.6'W



404 mm EFL Multi-Lens Occulting/Baffled Camera

8 images on one 12"-sq. Ilford HP3 plate.

4 for direct intensity measurements:

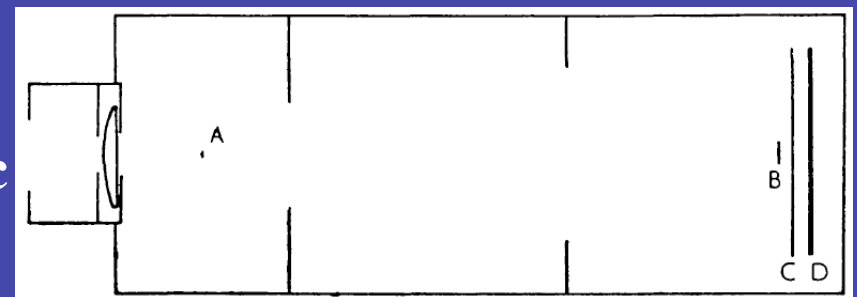
f/9 (14° x 28° FOV), f/20, f/49, f/130

4 for polarization: 2-f/9, 2-f/20

quad pol. 2 cm in front of film

parallel & perpendicular to ecliptic

Exposure time: 1 min., start CII + 30s
for darkest sky



ONE OF EIGHT

Guiding Error: 10' over 1m exposure.

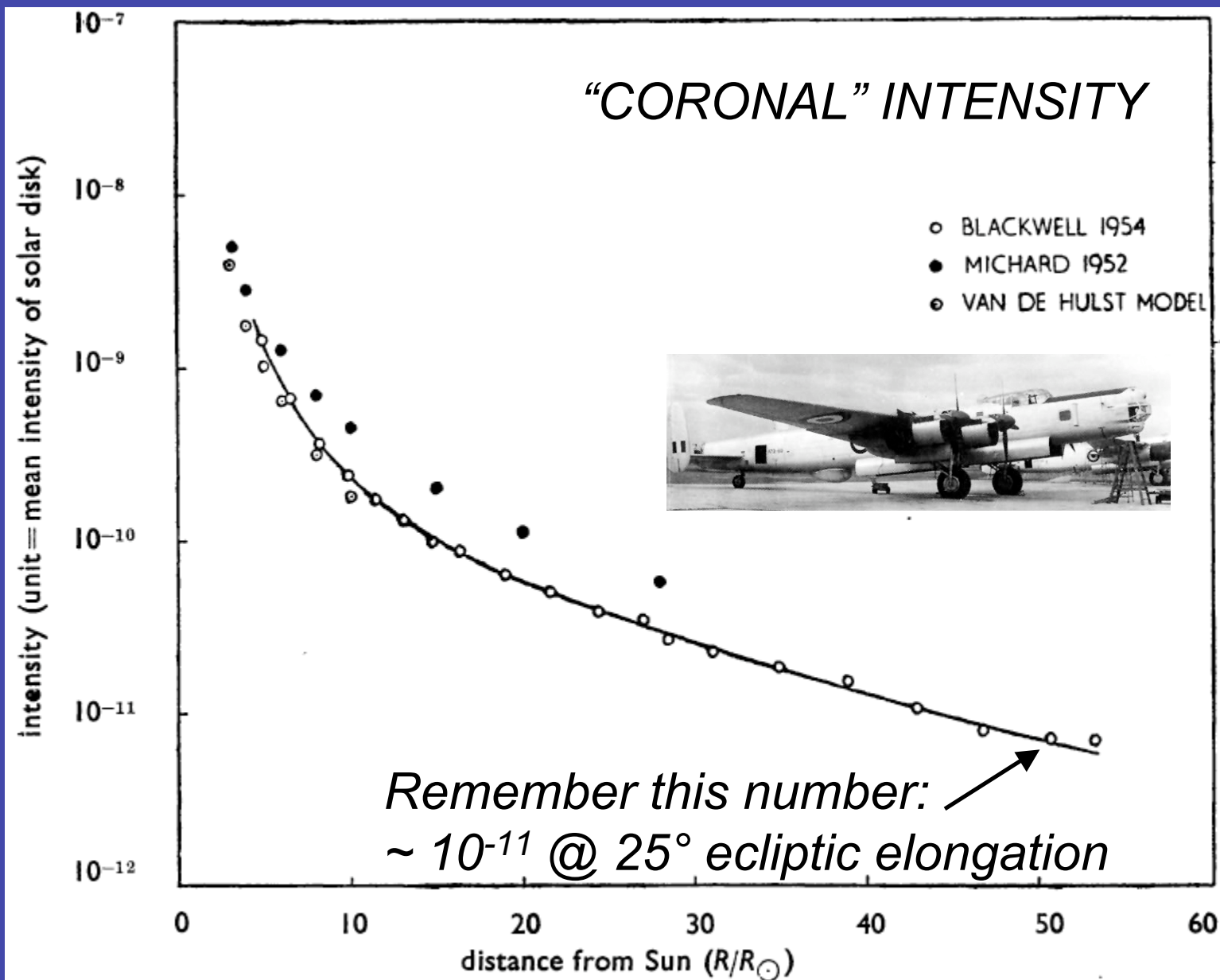


FIG. 6.—Brightness variation of solar corona along ecliptic (which is practically coincident with solar equator).

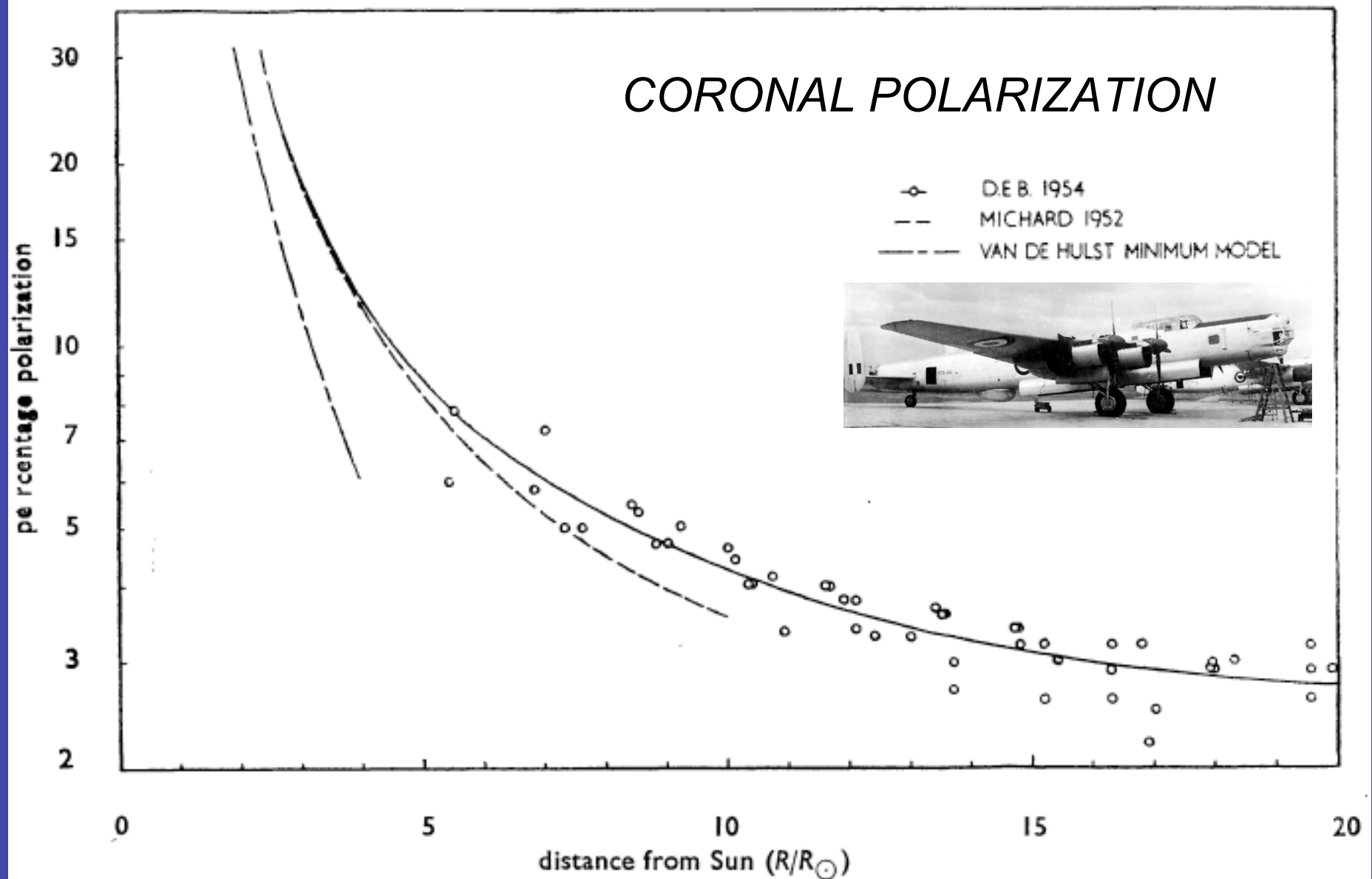


FIG. 9.—Polarization of the solar corona. The measures refer to those parts of the corona within 20° of the ecliptic.

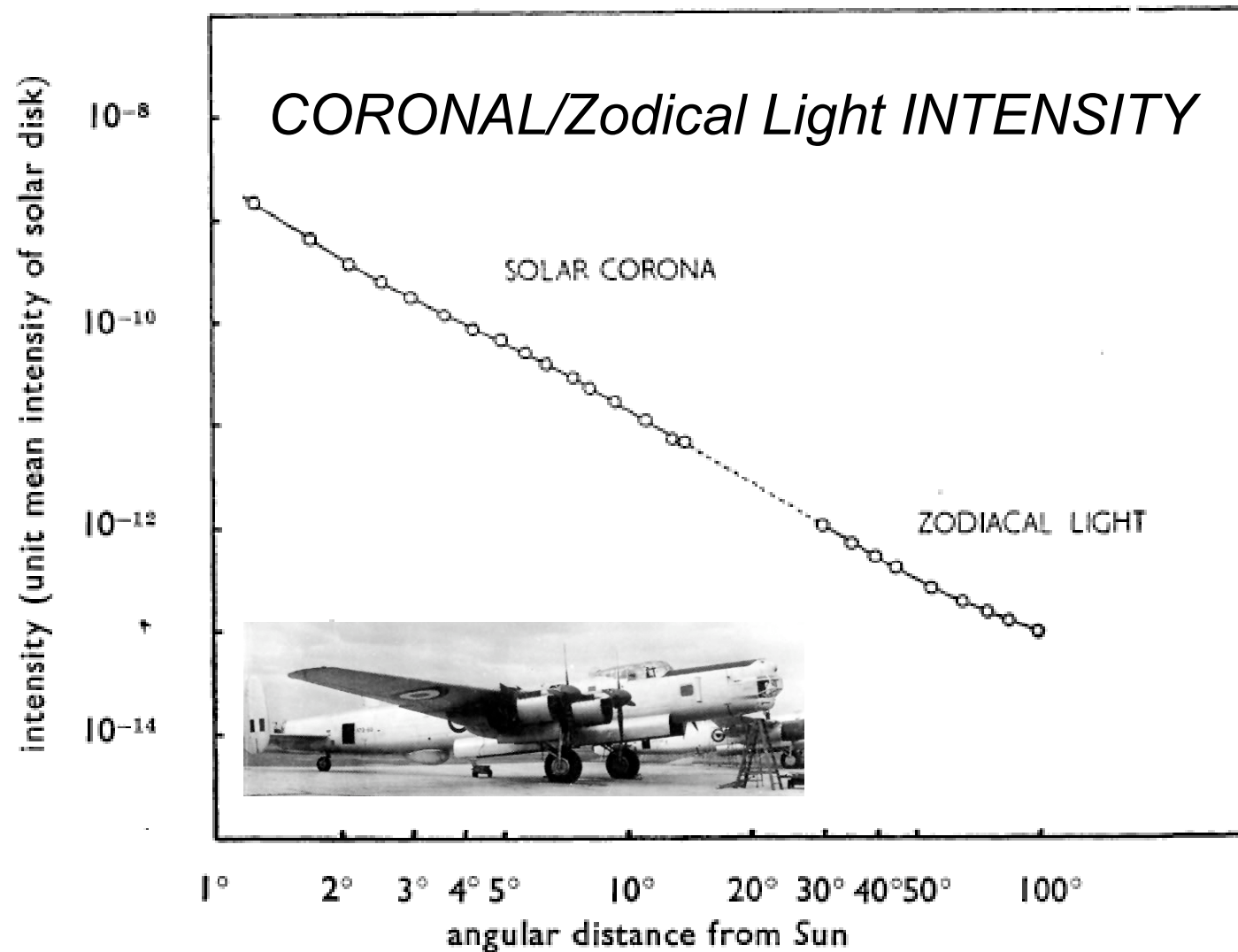
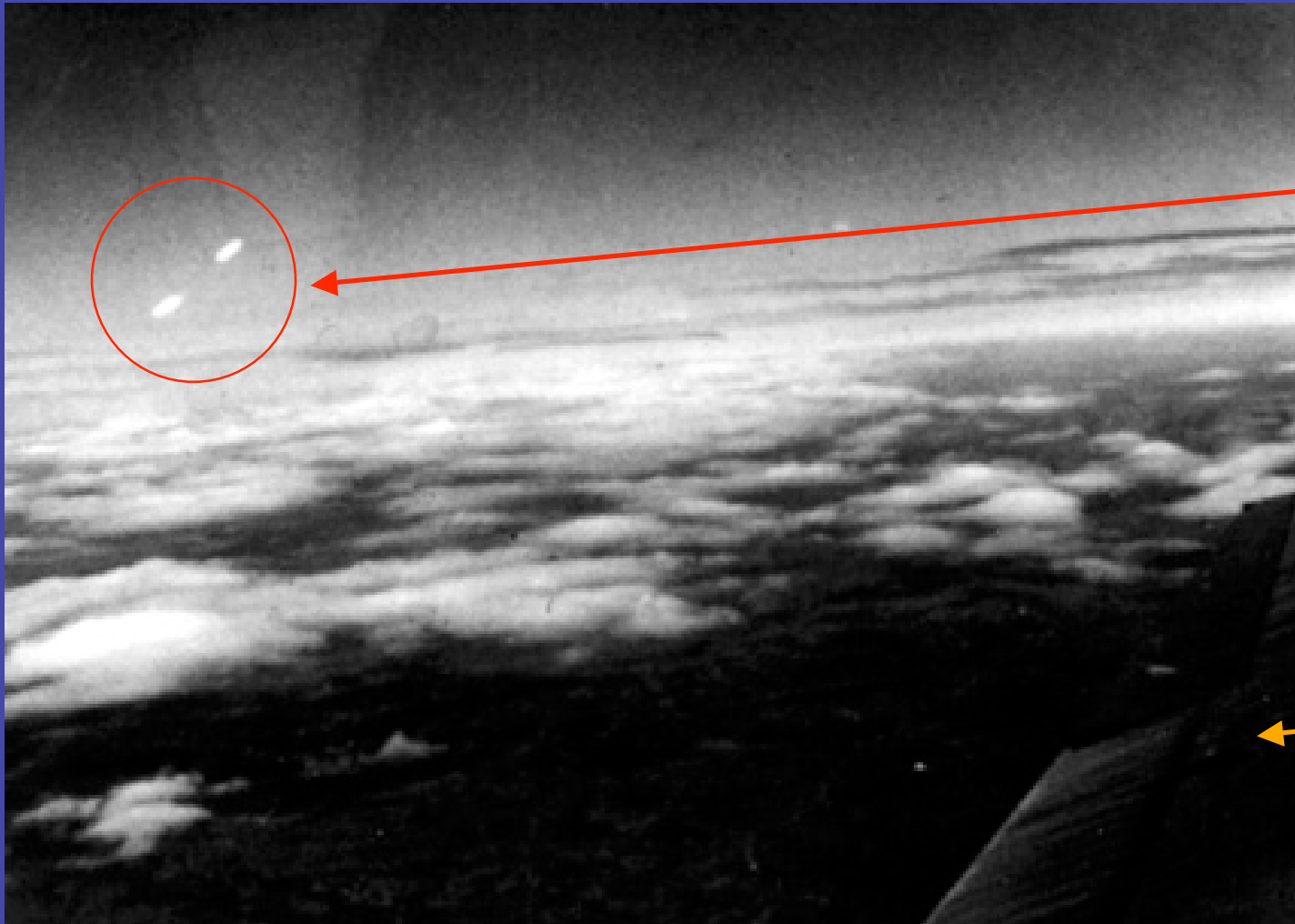


FIG. 10.—*Variation of brightness of solar corona and zodiacal light with distance from the Sun. The zodiacal light data are taken from the work of Roach et al.*

On the Lighter Side...

TSE: 30 June 1954

<http://www.ufo.se/blogg/index.php?entry=entry061006-010324>



*Claim
Of
"UFO"*

*Lunar
Umbral
Shadow
On
Clouds*

**Scandinavian Airlines "Torolf Viking" at 15,000 ft
near Lifjell in Telemark in the south of Norway
"Anti-Sun Side" - Johnny Björnulf, Raun Conradi**

20 June 1955: First Dedicated Eclipse “Chase” With A Jet Aircraft

- T-33 Jet (Trainer)
- Totality Ground Duration: 7m 09s (Philippines)
- Aircraft Ground Speed ~ 600 mph
- Totality Duration from Air: 12m 15s



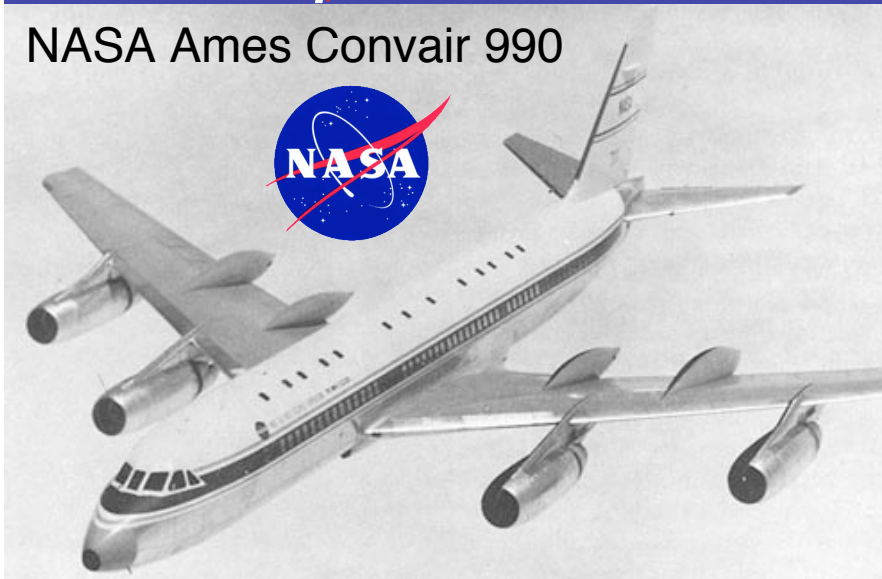


NASA/Ames's Sheldon Smith (Physics Branch) & Ray Torrey (Guidance & Control Systems Branch) built *a gyro-stabilized camera** for airborne (DC-8) observations of TSE 1963, shown here on the Ames Convair 990 "Galileo" (one of 13 experiments) carried to TSE 1965 in the South Pacific.

*Smith, et al, 1964, ISA Transactions, "A Stabilized Automated Camera for Airborne Eclipse Photography"

1918: ~~"a solid foundation, which can hardly be looked for even in the plane of the future"~~

NASA Ames Convair 990



A large, powerful nuclear explosion is shown, with a massive, billowing mushroom cloud rising into the sky. The cloud is bright yellow and orange at the base, transitioning to a lighter, almost white, top. The background is a dark, hazy sky. In the bottom right corner, four men in military uniforms are visible, wearing goggles and looking towards the explosion.

*The Cold War:
A Golden Age
For Airborne
Coronaphiles*

The Tragic Beginning of the
USAF/AEC Eclipse
Observing Concept

5 Aug 1963	Nuclear Test Ban Treaty Signed by “Original Parties”: US, UK, USSR
24 Sept 1963	Ratified by Senate in U.S.
10 Oct 1963	Entered into Force

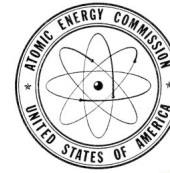
PROHIBITS: “Nuclear weapons test or any other nuclear explosion in the atmosphere, in outer space, or under water.”

U.S. CONGRESS AUTHORIZES 4 Part “Test Readiness Program” including: “improvement of monitoring capability vis-à-vis Sino-Soviet Nuclear technology.”

LEADS TO the acquisition of three AEC partnered USAF NC-135 (modified B707) aircraft operated by Los Alamos, Sandia, and Lawrence Livermore research facilities as “flying laboratories.”



AEC 1964 REPORT: Weapons test diagnostics from aircraft were so successful ground facilities on Eniwetok and Christmas Island were obviated.



SCIENTISTS LOBBIED AEC to obtain permission to use aircraft also to study ionospheric E and B fields, cosmic rays, and *SOLAR ECLIPSES*, arguing such missions would augment the TRP simulation exercises.

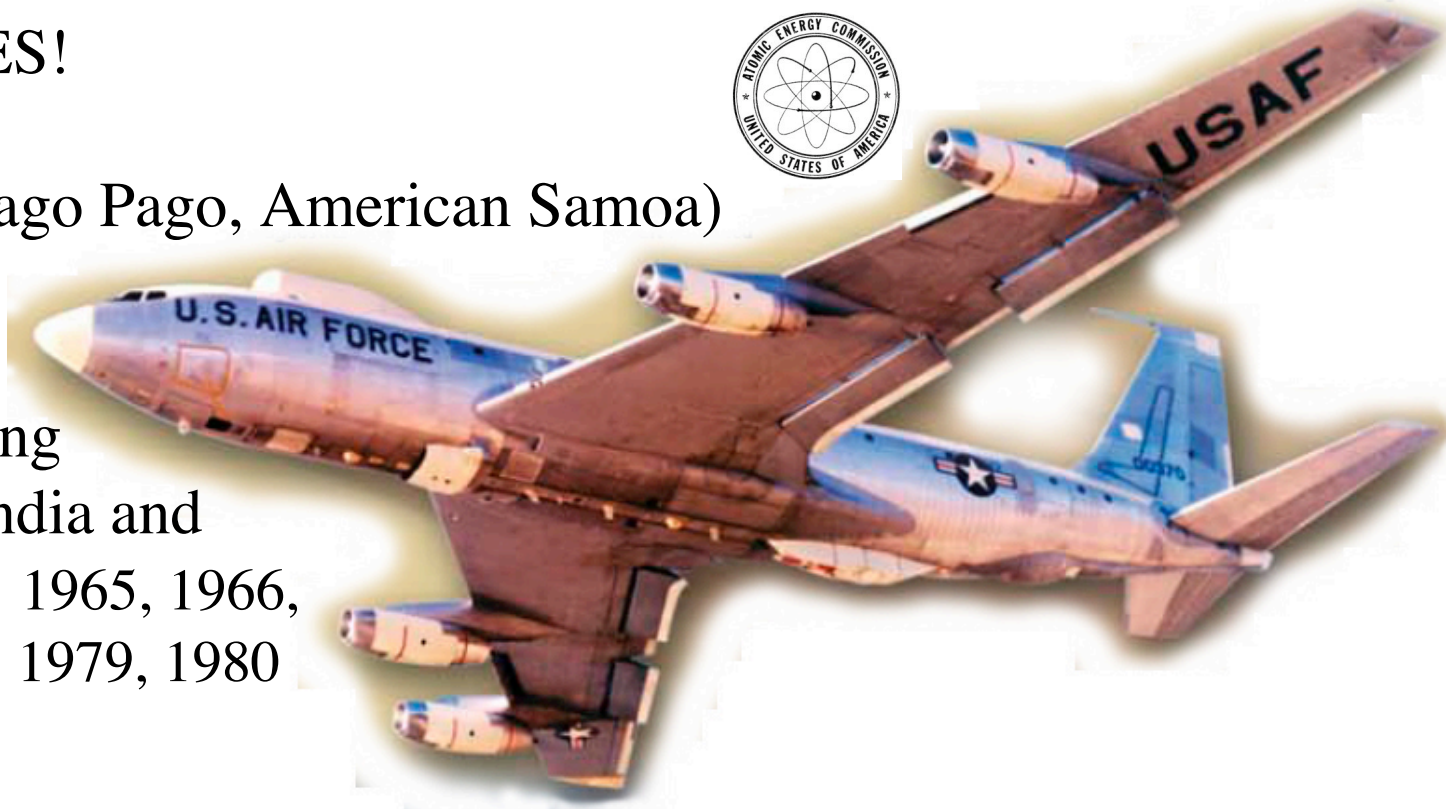
High-flying, long-range jet aircraft ... could be used as observation stations for extraterrestrial phenomena and would have a tremendous advantage over ground facilities.

Jet aircraft capability would place researchers above the clouds that often negate ground observation, and above 80% of the earth's atmosphere, whose dust and water vapor scatters light and degrades data.

For instance ... meaningful measurements of the solar corona, which are impossible from the ground because of water vapor that blocks the infrared end of the solar spectrum, could be made from the aircraft.

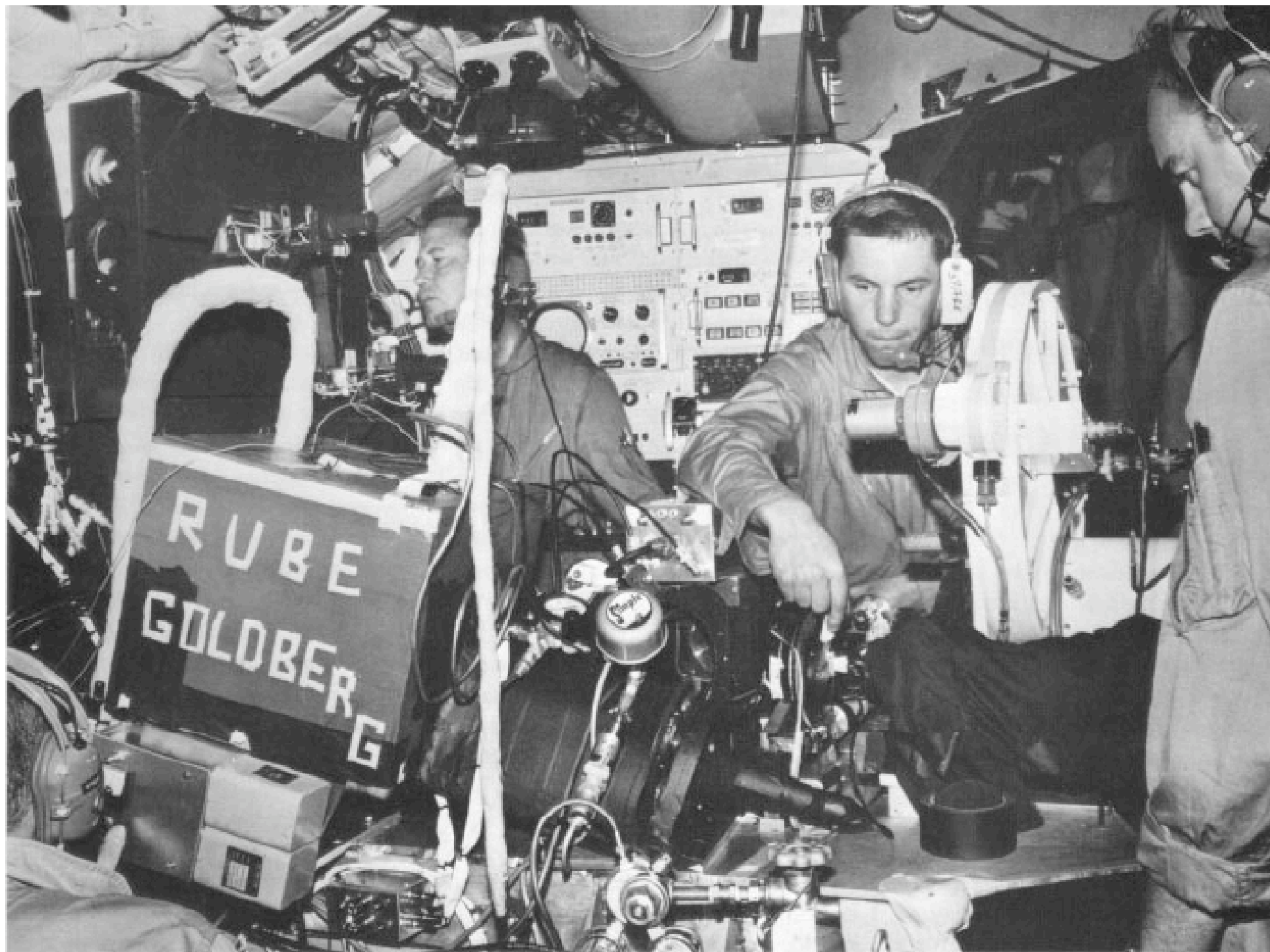
AEC APPROVES!

30 May 1965 (Pago Pago, American Samoa)
1st of 7 airborne
solar eclipse
missions involving
Los Alamos, Sandia and
Livermore Labs: 1965, 1966,
1970, 1972, 1973, 1979, 1980



Ken Williamson, Don Liedenbergh, Walt Wolff of Los Alamos Lab operating the **“The Rube”** - a multi-function telescopic imager, photometer, and interferometer over the South Pacific during the 30 May 1965 TSE.



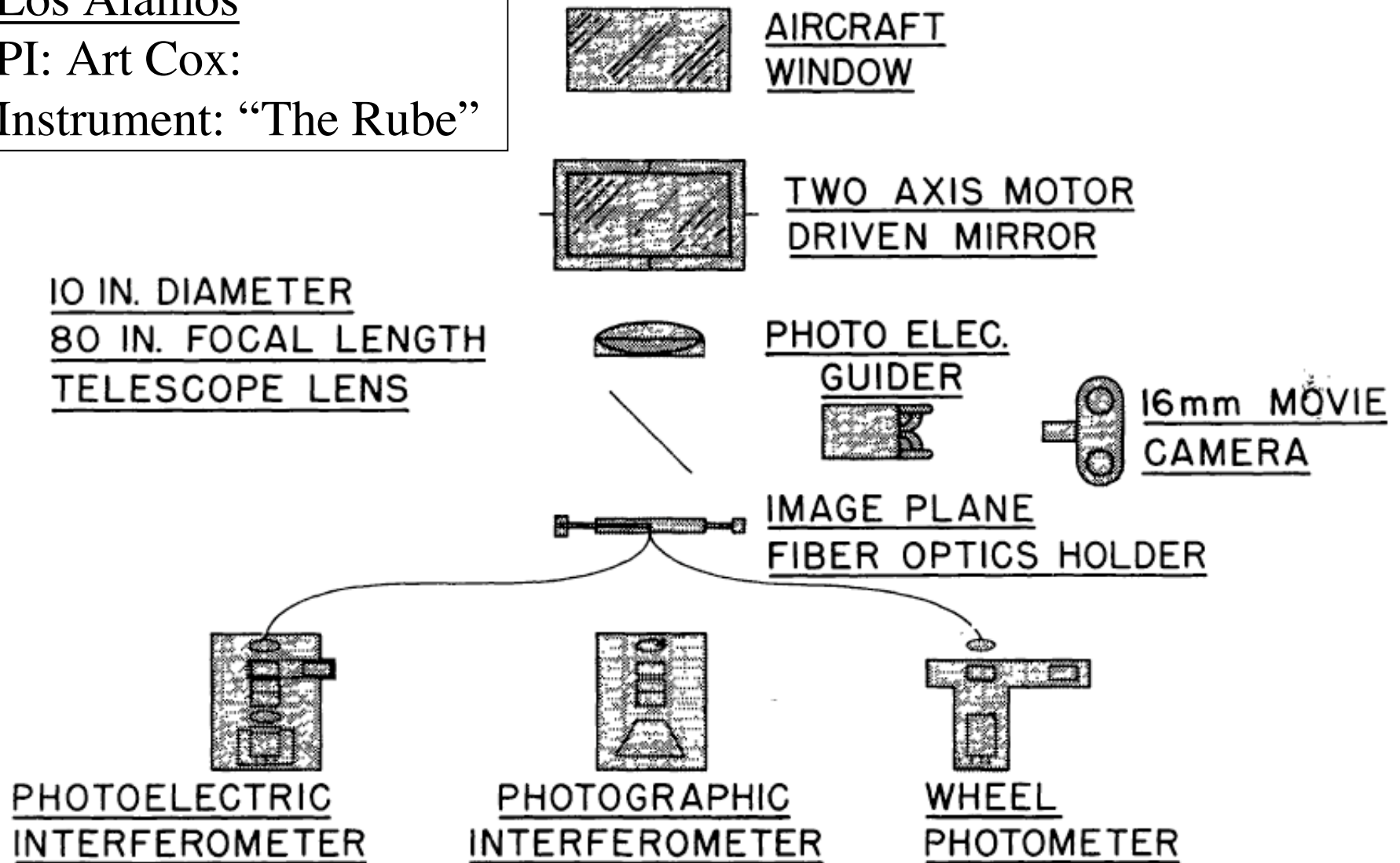


Liebenberg, 1975, Solar Physics, 44, 33.

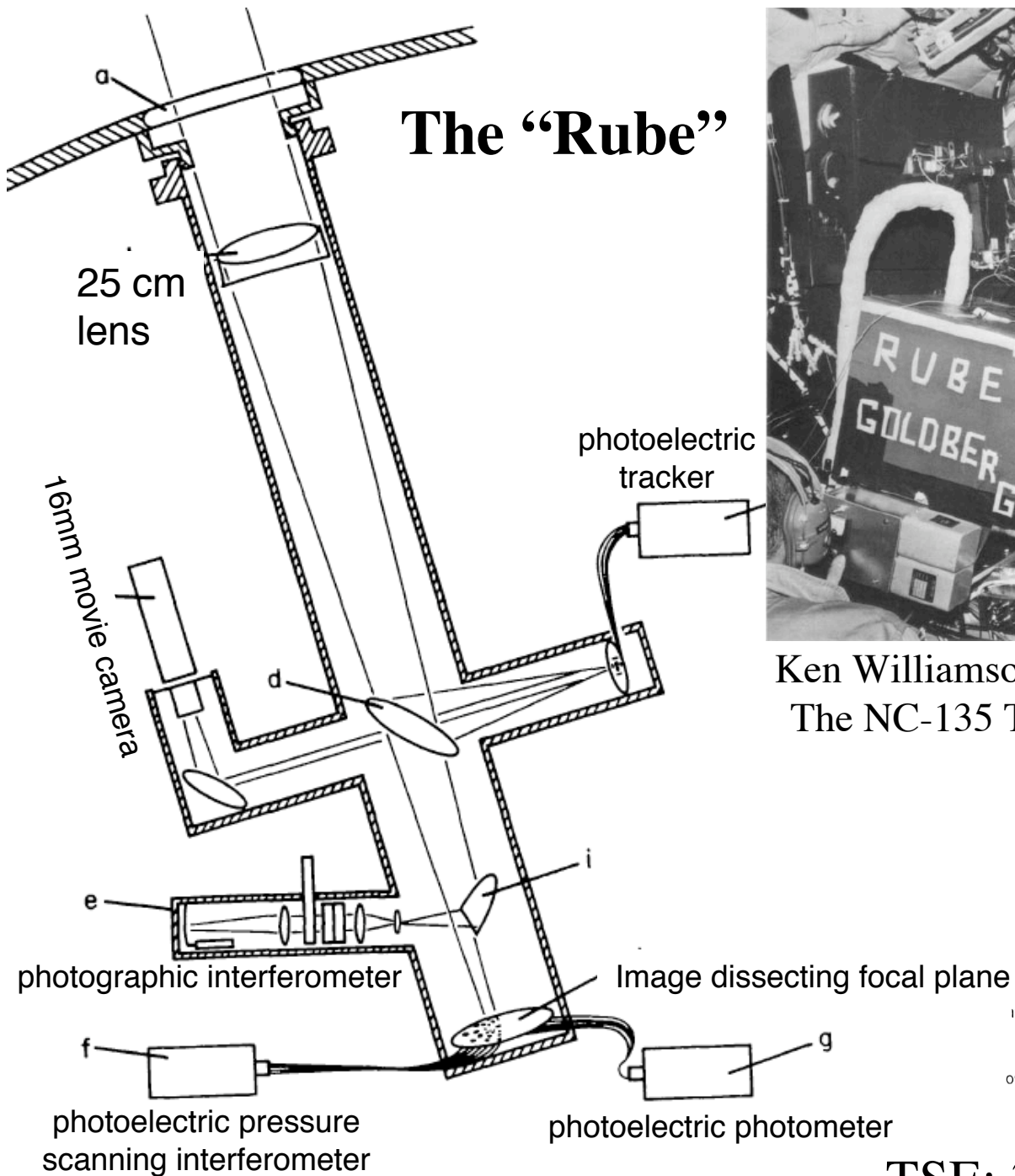
Los Alamos

PI: Art Cox:

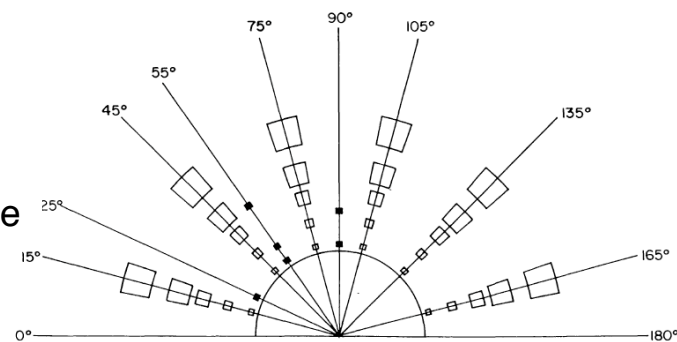
Instrument: "The Rube"



TSE: 30 May 1965/ 12 Nov 1966



Ken Williamson, Don Lidenberg, Walt Wolff on
The NC-135 TSE 1965 American Samoa Flight



TSE: 30 May 1965/ 12 Nov 1966

AEC APPROVES!

30 May 1965 (Pago Pago, American Samoa)

1st of 7 airborne

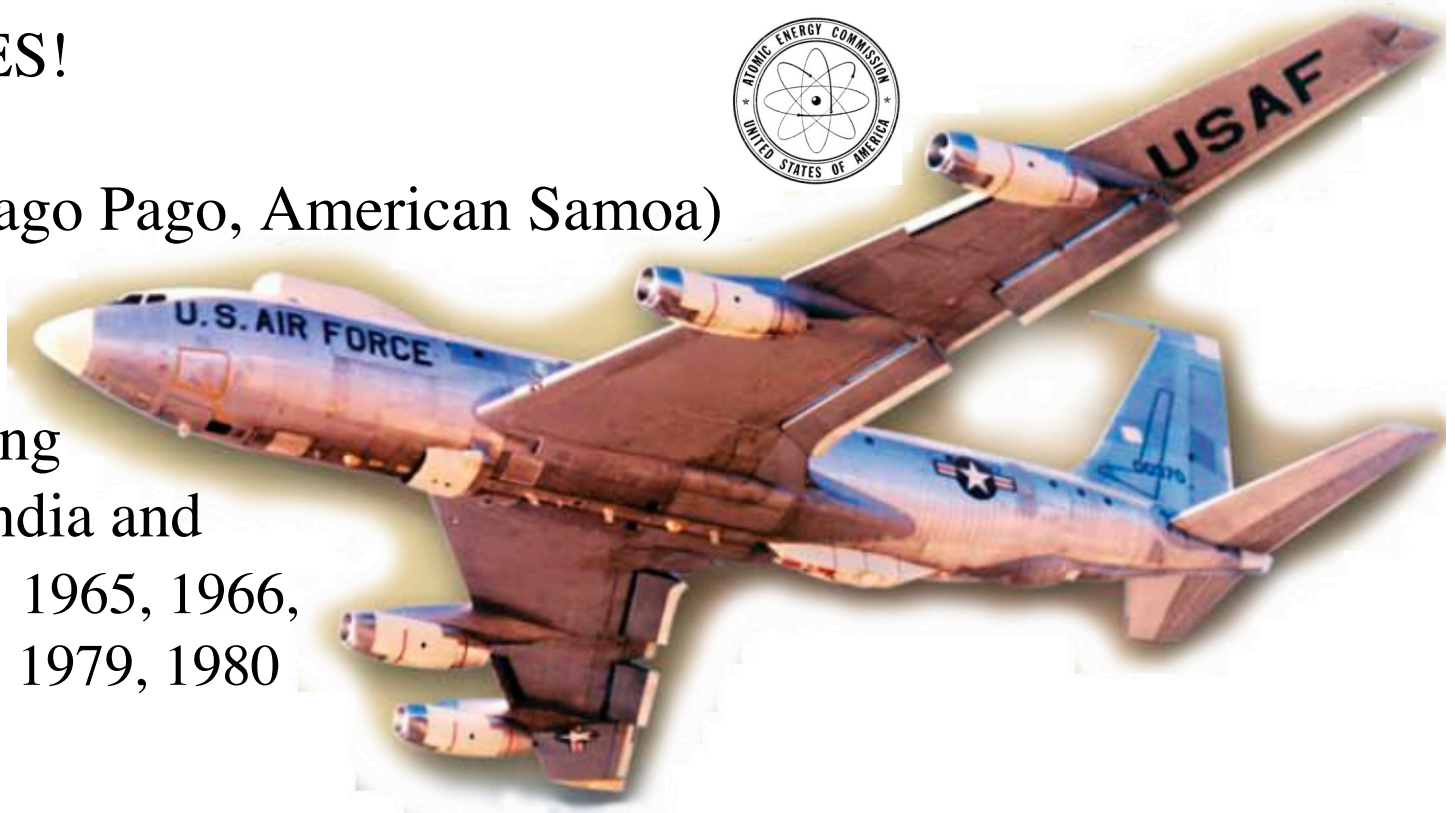
solar eclipse

missions involving

Los Alamos, Sandia and

Livermore Labs: 1965, 1966,

1970, 1972, 1973, 1979, 1980



John Kuruzovich, Jose Llamas, John Barsic & Lyle Porter of Sandia National Lab operating the **“Holy Cow”** manual tracking infrared spectrograph over the South Pacific during the 30 May 1965 TSE.



Solar Physics, 1975, 44, 33.

**CORONAL EMISSION LINE PROFILE OBSERVATIONS
AT TOTAL SOLAR ECLIPSES**

*I: Airborne Instrumentation and Results**

D. H. LIEBENBERG

LASL, University of California, Los Alamos, N.M. 87545, U.S.A.

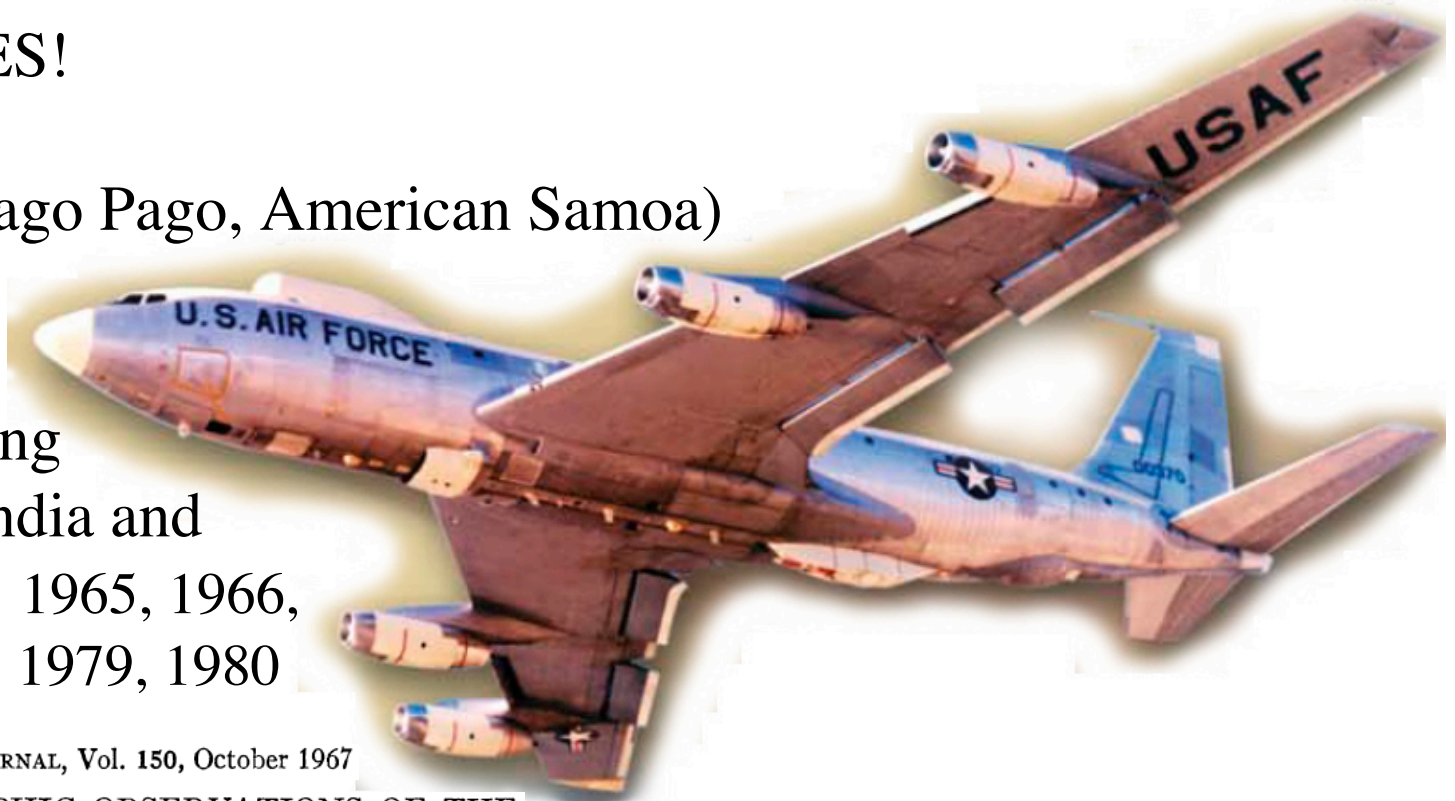
(Received 7 July, 1975)

“A 25-cm aperture f/8.0 telescope was operated aboard a U.S. Air Force - Energy Research and Development Administration aircraft at the 30 May 1965 and 12 November 1966 total solar eclipses...

TSE: 30 May 1965/ 12 Nov 1966

AEC APPROVES!

30 May 1965 (Pago Pago, American Samoa)
1st of 7 airborne
solar eclipse
missions involving
Los Alamos, Sandia and
Livermore Labs: 1965, 1966,
1970, 1972, 1973, 1979, 1980



THE ASTROPHYSICAL JOURNAL, Vol. 150, October 1967

AIRBORNE SPECTROGRAPHIC OBSERVATIONS OF THE SOLAR ECLIPSE OF NOVEMBER 12, 1966*

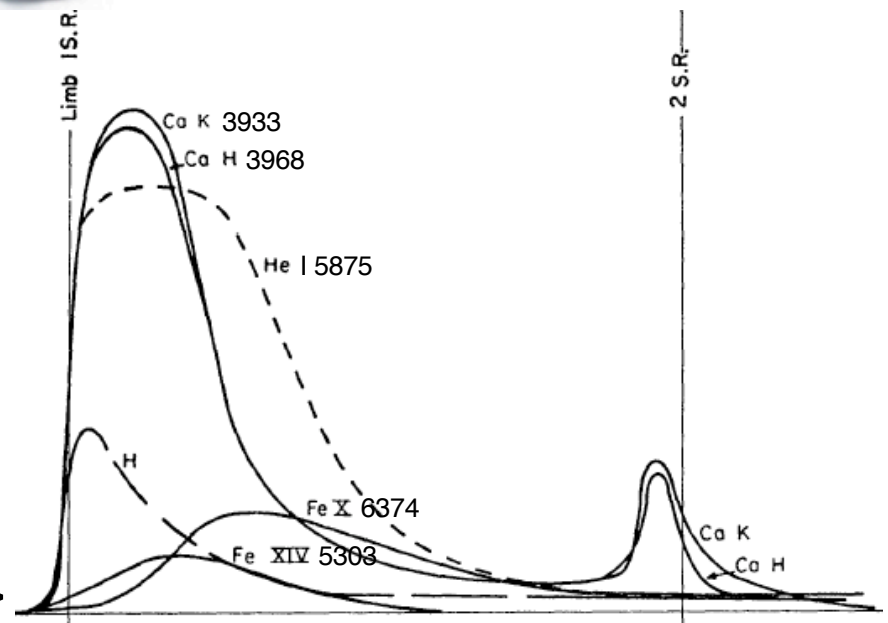
JOHN G. CONWAY

Lawrence Radiation Laboratory, University of California, Berkeley

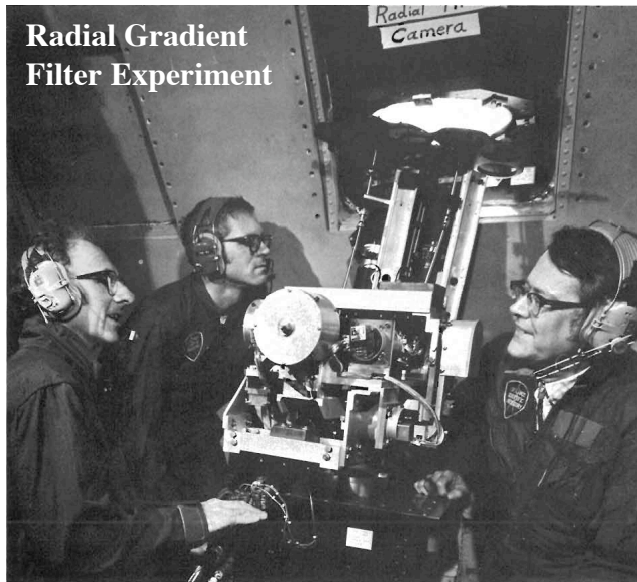
WILLIAM F. MORRIS AND C. FREDERICK ANDREWS

Lawrence Radiation Laboratory, University of California, Livermore

Two spectrographs were flown.
Ca II, H & K lines observed at 2 R_{sun}.
 $T(5303; \text{Fe XIV}) = 2.5\text{MK}$
 $T(6374; \text{Fe X}) = 1.8\text{MK}$,
Limb-to-corona intensity profiles ----->



TSE 1973 (Sahara, 13m Totality)



**Radial Gradient
Filter Experiment**

Sid Stone, Darell Call & Bill Regan



Coronal Camera

Bob Straight, Joe Montoya & Charles Keller

"As the mission proceeded, those on the 135 watched in disbelief as the SST streaked by and above at 55000 ft."

**TSE 1980: Bob Jeffries, Charles Keller,
Brook Sanford, Paul Mutschlener,
Joe Montoya & Carl Lilliquist**



**The RGFE camera used again for TSE 1980
"produced a marvelous photograph of a
hydrodynamic eruption from the sun's surface
that formed a huge bubble in the corona."**

TSE 1979: Charles Keller



**"We mounted a quick & dirty mission...
intensity data out to 20 solar radii were
collected." (37,000 ft. over North Dakota)**

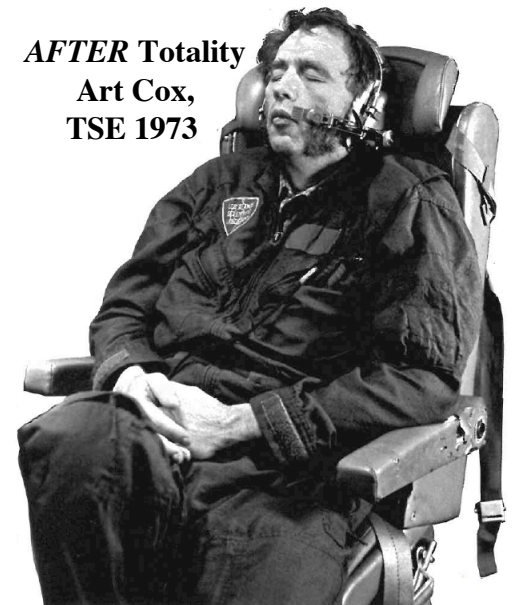


TSE 1980: Bill Regan

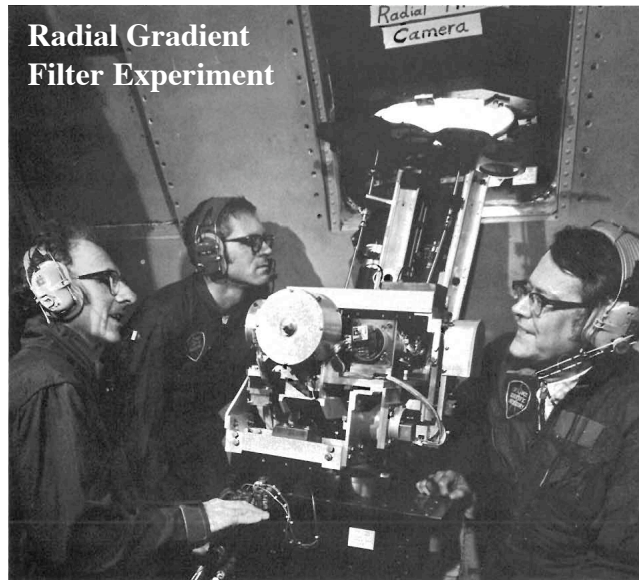


**"Lilliquist was on his back,
still struggling to center the
disk as totality approached..."**

**AFTER Totality
Art Cox,
TSE 1973**

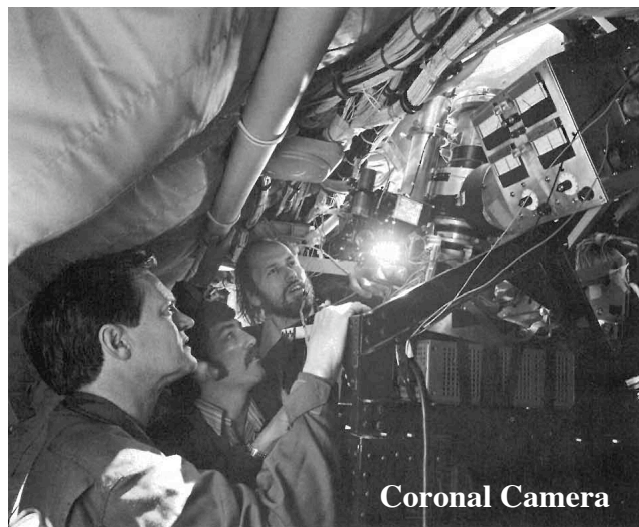


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TSE 1980: Bob Jeffries, Charles Keller, Brook Sanford, Paul Mutschlener, Joe Montoya & Carl Lilliquist



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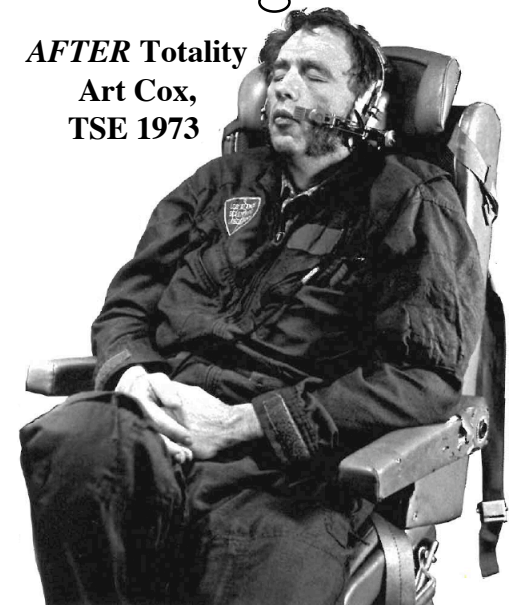
TSE 1979: Charles Keller



“We mounted a quick & dirty mission... intensity data out to 20 solar radii were collected.” (37,000 ft. over North Dakota)



AFTER Totality
Art Cox,
TSE 1973



Contemporaneous with the USAF/AEC Eclipse mission (TSE 1966):
Gemini 12 was launched on 11 November 1966 at 20:46:33 UT and inserted into a 160.8 x 270.6 km Earth orbit at 20:52:40. *Two phasing maneuvers using the Gemini Agena Target Vehicle secondary propulsion system were accomplished* allowing the spacecraft to rendezvous *with the November 12 total eclipse* over South America at 9:20 a.m. EST with the crew taking pictures through the spacecraft windows.

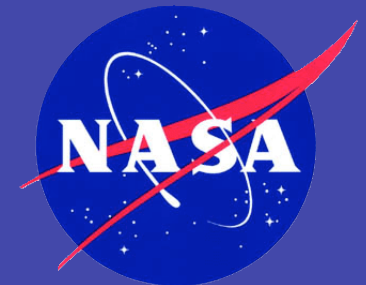
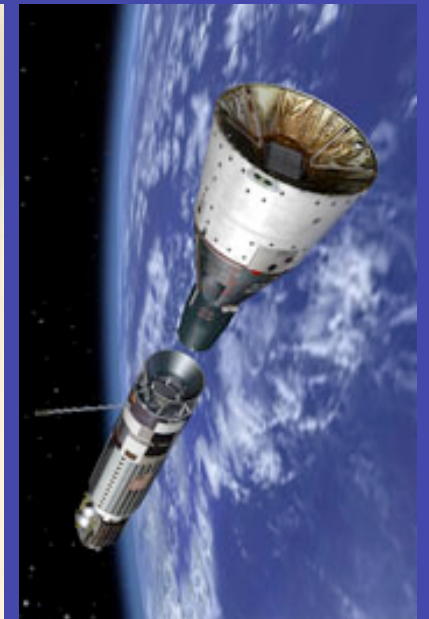


Aldrin



Lovell

NASA Photo ID: S66-63415





TSE: 30 JUNE 1973
Concorde 001 F-WTSS/375
Mach 2.05 @ 16.2—17.7 km
Las Palmas to Ft. Lamy
74 minutes of totality!

Special Purpose Windows:

- crystal quartz
- composite Intran-2
- (2) fused quartz





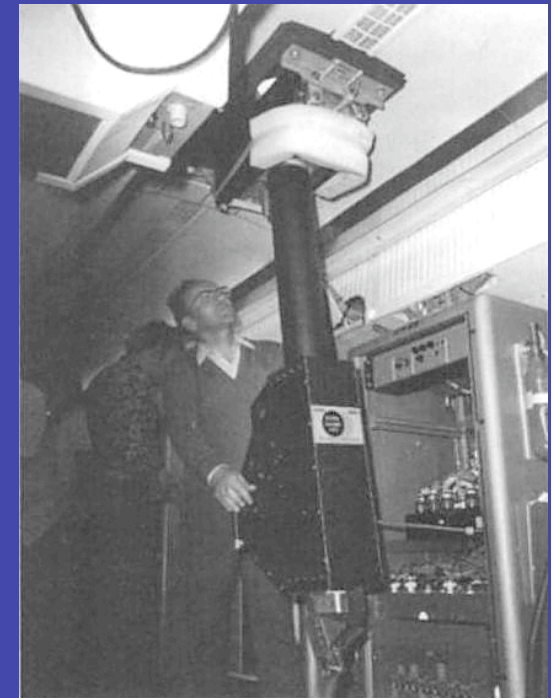
TSE: 30 JUNE 1973

Concorde 001 F-WTSS/375
Mach 2.05 @ 16.2—17.7 km
Las Palmas to Ft. Lamy
74 minutes of totality!

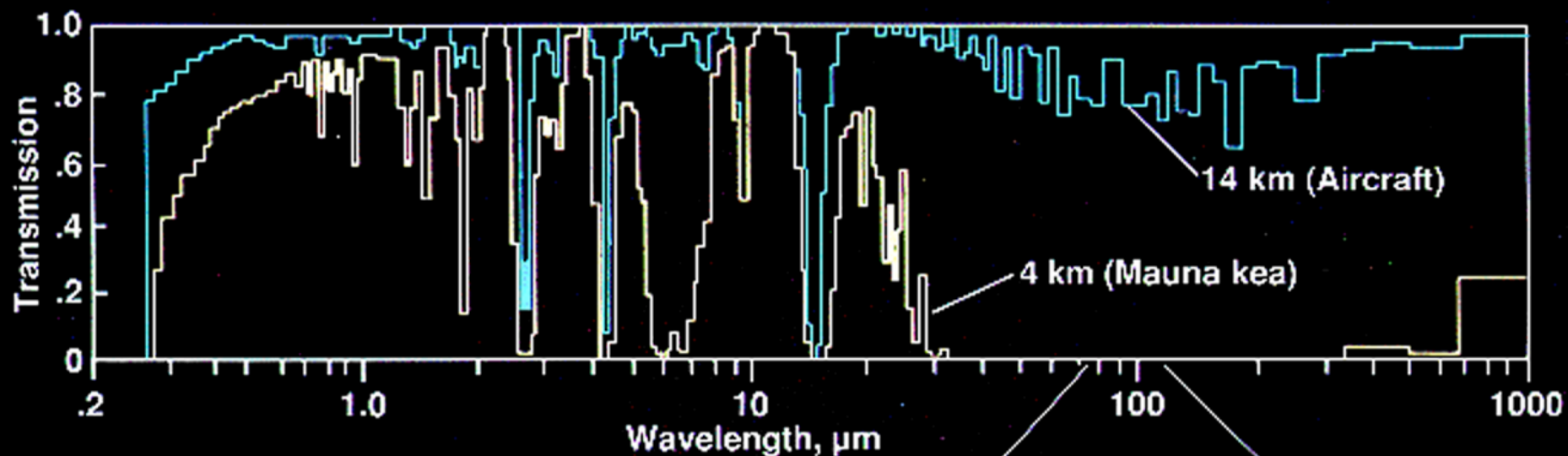
Special Purpose Windows:

- crystal quartz
- composite Intran-2
- (2) fused quartz

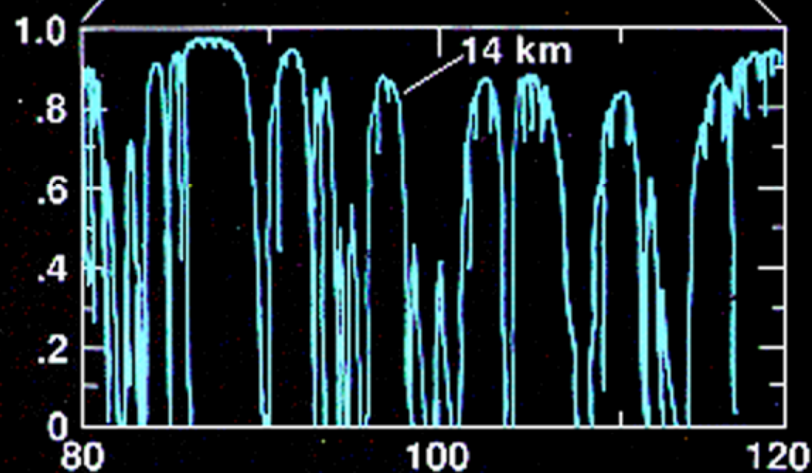
- *Far-IR Chromospheric Emission (250 μm to 2 mm)*
 Michelson spectral interferometer,
 liquid-He cooled InSb detector
- *Coronal near/mid- IR Emission (2-3, 4-5, 9-13 μm)*
 liquid-N₂ cooled InSb photoconductive detectors,
 liquid-He cooled Ge bolometer
- *Time-Resolved Coronal Imaging (<1.4R_{*}, <15R_{*})*
 Film cameras with 180mm, 1.52m, 3m EFL
- *High Resolution Coronal 5303Å Emission Line Imaging*
 FP pressure-scanned (0.05Å) interferometer - vidicon

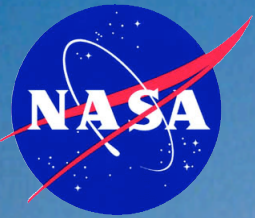


ATMOSPHERIC TRANSMISSION VERSUS WAVELENGTH



- Many wavelength bands obscured from earth are accessible from aircraft





NASA's Learjet Observatory*

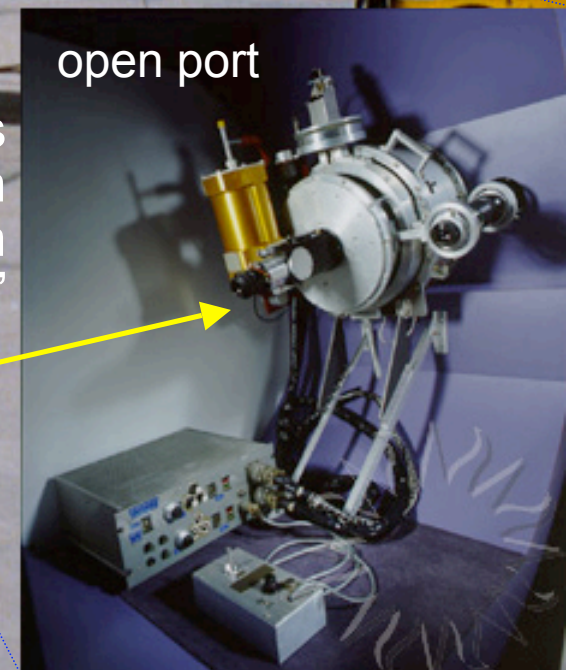
* 45,000 ft standard operation



1954: "Observations should be made in an *open aircraft*, not through an aircraft window..."



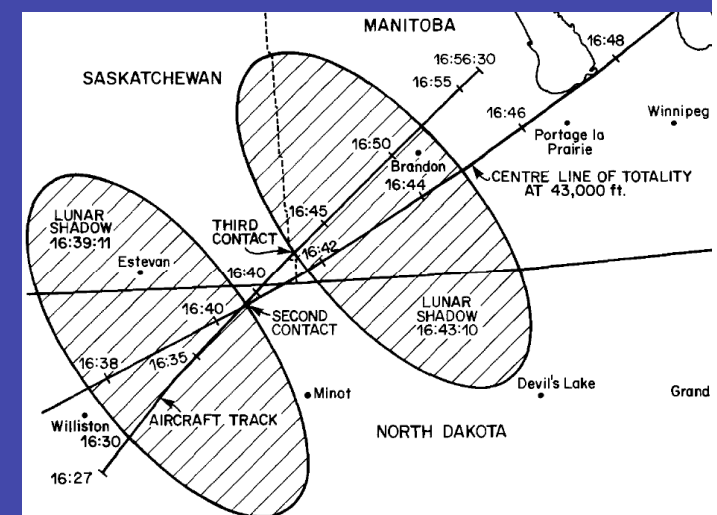
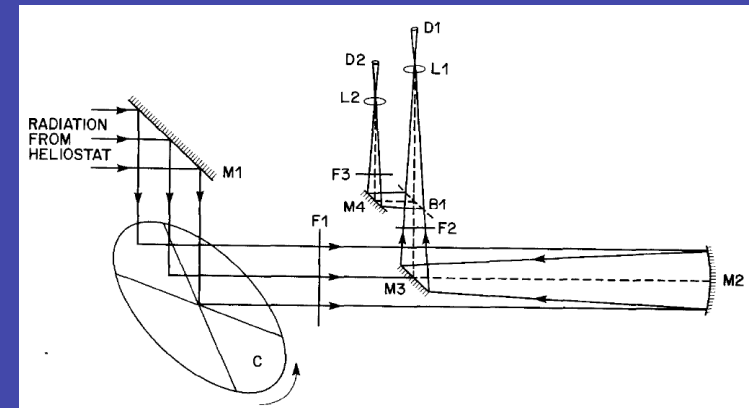
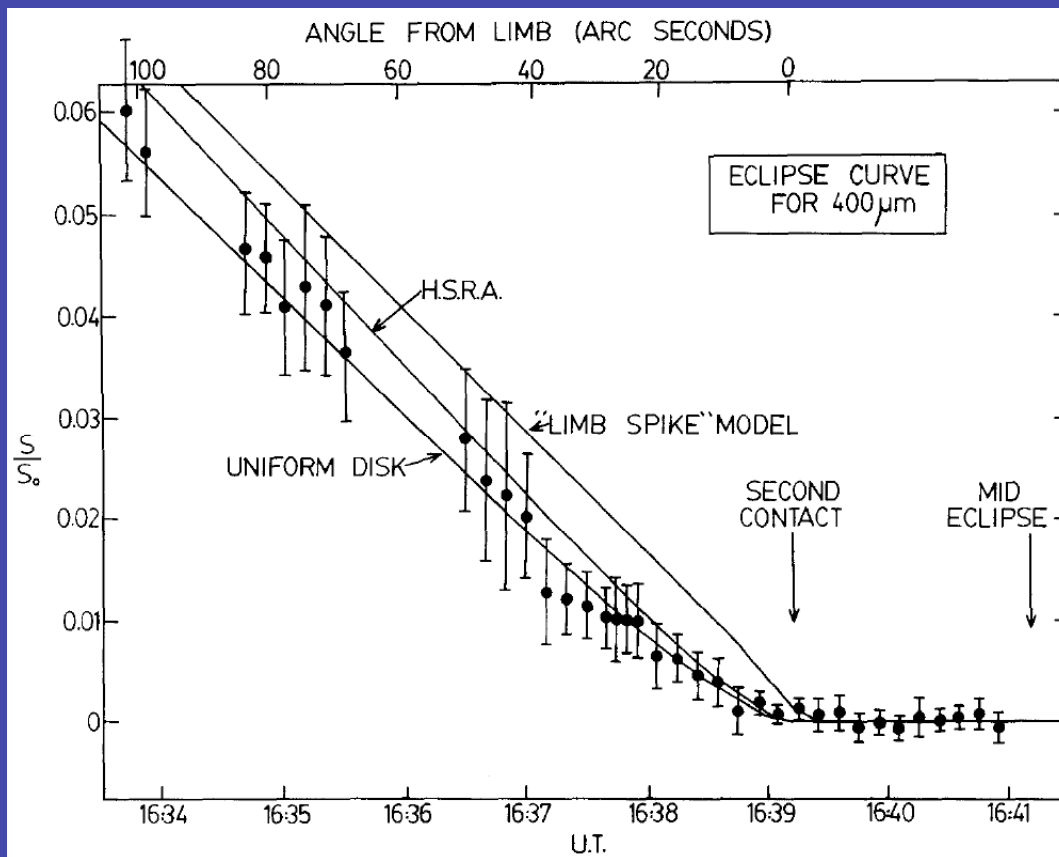
29 cm IR Telescope built by Frank Low (used multiple times in late 1960's-70's)



open port

TSE 26 February 1979 - AIRBORNE OBSERVATIONS OF THE EXTREME SOLAR LIMB AT $400\ \mu\text{m}$ WITH THE NASA LEARJET OBSERVATORY @ 13 km*

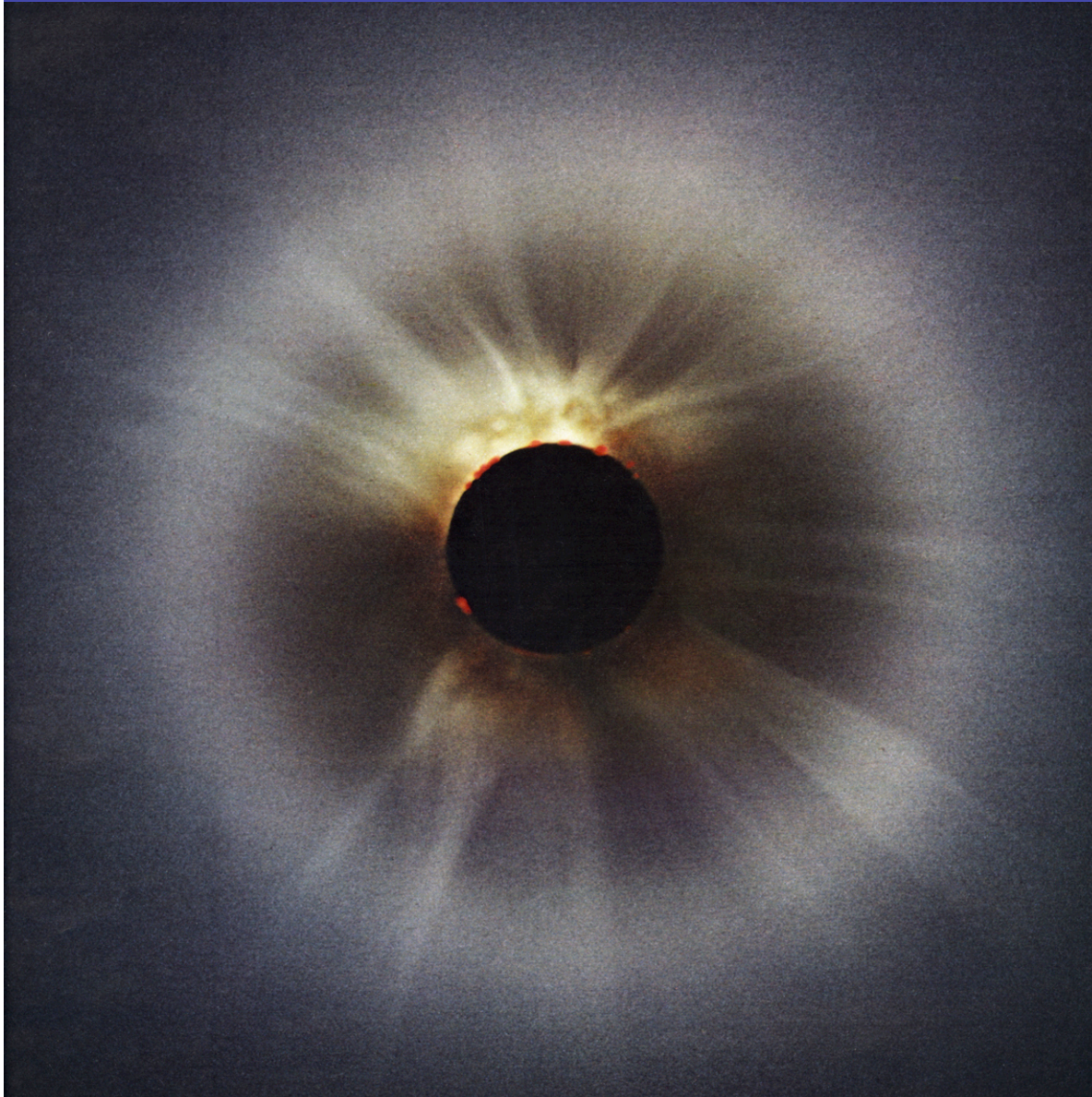
Demonstrated likelihood of significant inhomogeneities
in the lower chromosphere with size scales $\sim 1000\ \text{km}$



* Clark & Boreiko, 1982, 76, 117.

TSE 26 February 1979 - AIRBORNE OBSERVATIONS

Los Alamos Scientific Laboratory — Radial Gradient Filter Camera @ 40,000 ft



KC-135



“At least 1,000 planes were in the air along the path of totality; some airports were so jammed that a number of eclipse viewers never got off the ground in time.”

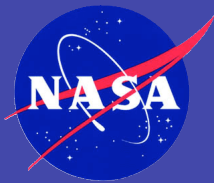
- Life (Apr 1979)

TSE 26 February 1979 - AIRBORNE OBSERVATIONS



NASA astrophysicist astronauts (then candidates) Sally Ride & Steve Hawley photograph TSE 1979 from a T-38 @ 43,000 ft.

"We thought up the trip as a good training opportunity to do science in an operational environment - like we hoped to get to do on Shuttle one day."



1918: "Although the flight... not undertaken with any serious scientific objective...demonstrated

-S. Hawley 17 JUL 2007



that we may... look to the aviator for work of value in connection with eclipses".

In flight photo by Steve Hawley

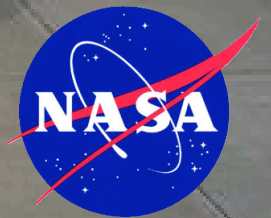


NASA's Kuiper Airborne Observatory*

C-141A Aircraft, 14 km ceiling, 6,000 mile range



92 cm telescope
1 to 500 μm spectral range



*1974 — 1995

NASA's Kuiper Airborne Observatory far-IR/sub-mm Observations of TSE 31 July 1981



THE ASTROPHYSICAL JOURNAL, 264:L25–L30, 1983 January 1

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SUBMILLIMETER EXTENSIONS OF THE SOLAR LIMB DETERMINED FROM OBSERVATIONS OF THE TOTAL ECLIPSE OF 1981 JULY 31

C. LINDSEY, E. E. BECKLIN, J. T. JEFFERIES, AND F. Q. ORRALL

Institute for Astronomy, University of Hawaii

M. W. WERNER

NASA Ames Research Center

AND

IAN GATLEY

United Kingdom Infrared Telescope

Received 1982 July 7; accepted 1982 September 10

“We present the first results of a lunar occultation of the solar limb made from the Kuiper Airborne Observatory in the 30, 50, 100, and 200 μm continuum during the total solar eclipse of 1981 31 July.

We find the solar limb to be extended at the longer wavelengths up to 1000 km higher than predicated from smooth plane-parallel chromosphere models.

Results at both 2nd and 3rd contact show the infrared limb extensions to be approximately 0.8”, 1.5”, 2.5”, and 3.0” above the visible limb in the 30, 50, 100, and 200 μm bands, respectively.

A possible interpretation proposes chromospheric fine-structure inhomogeneities of greater density than presently incorporated in models of the middle chromosphere.”

NASA's Kuiper Airborne Observatory far-IR/sub-mm Observations of TSE 31 July 1981



“We dedicate this work to **David A. Barth**, the chief pilot for the KAO during the eclipse observation, who tragically lost his life while test-flying an aircraft a few weeks after the successful completion of our program. Our observations required operation of the KAO aircraft at its performance limit, and we therefore depended very much on his skill. We were very fortunate not only in having the benefit of his outstanding ability, but also for the real pleasure of his personal acquaintance during his involvement with our program.”

The 1970's - Egalitarian E-Flights

TSE 1972 - RELOCATION

*paradigm
shift* →

TSE 1974 -
In Situ
OBSERVING



“Then you flew your Lear jet up to Nova Scotia to see the total eclipse of the sun”

Ansett Airlines Eclipse Flight - Perth, Australia



Images Courtesy of Wendy Carlos

CANON OF SOLAR ECLIPSES

Meeus, Grosjean and Vanderleen

No. 7604		1986 October 3				rt		
k	m	*	*	*	*	m	s	h-m
18	56.0	+ 26.17	+ 25.89	+66.53	0.0	0	06	59
18	57	+ 31.90	+ 31.62	+65.47	2.4	0	03	30
19	00	+ 36.00	+ 35.72	+63.38	4.4	0	01	10
19	03	+ 37.47	+ 37.19	+61.60	5.3	0	00	1
19	06	+ 37.81	+ 37.53	+59.99	5.6	0	00+	2
19	09	+ 37.34	+ 37.06	+58.52	5.4	0	00+	2
19	12	+ 36.08	+ 35.80	+57.18	4.8	0	00	5
19	15	+ 33.60	+ 33.32	+55.98	3.3	0	02	20
19	17.1	+ 27.96	+ 27.68	+55.47	0.0	0	06	51

"t"SE 1986 would be my 12th Total Solar Eclipse - but would it be Total?

GREENLAND

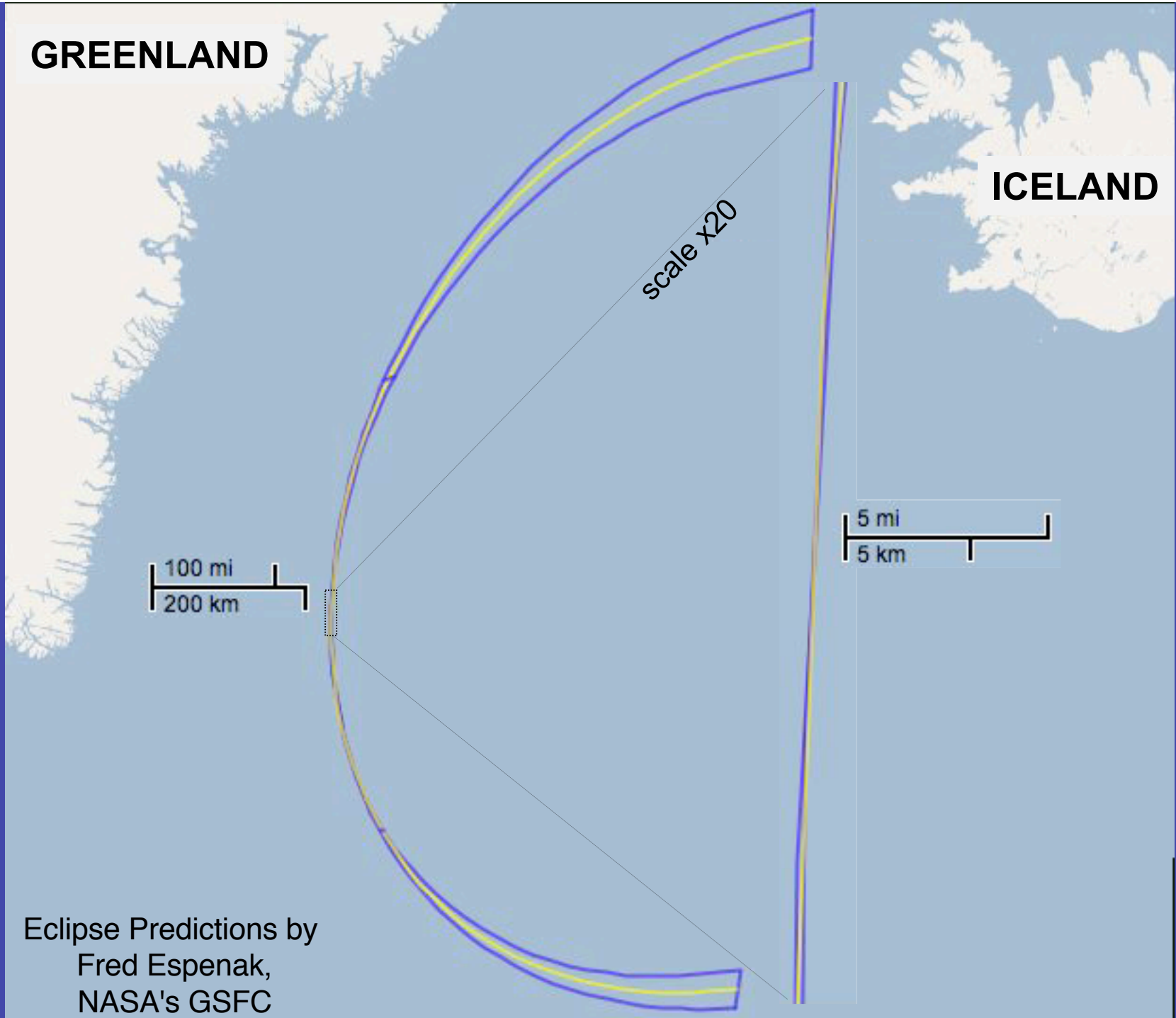
ICELAND

scale x20

100 mi
200 km

5 mi
5 km

Eclipse Predictions by
Fred Espenak,
NASA's GSFC





hSE 28 Apr 1930
California
1.4 s Totality



Vought O2U-1 Corsair

Copyright 1999 Brian Johannesson

“the eclipse ... so near the border line between annular and total it appeared well worthwhile... to observe from an airplane at considerable altitude.

“...the shadow track was so very narrow its exact location was in doubt.

- W. H. Jeffers (1930)

A PERSONAL “FIRST FLIGHT”:

Cessna Citation II



hSE 03 October 1986 (19:05:19.0 UT)

“Gang-of-Nine” Eclipse Expedition

North Atlantic, southwest of Iceland

Stationary Observer Totality Duration:

0.0 s MAX (Meeus 1966) @ Sea level*

-0.2 s (Espenak 2001) @ 44,000 ft/19:05:19

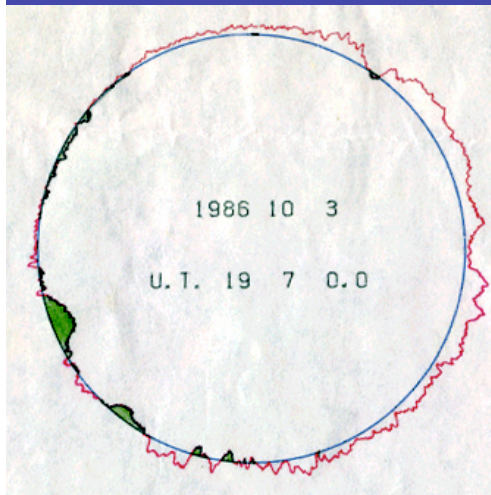
*@ max eclipse, altitude = 6°

@ 44 kft/max ecl., d(moon) + 0.7” wrt MSL

hSE 03 October 1986 (19:05:19.0 UT)

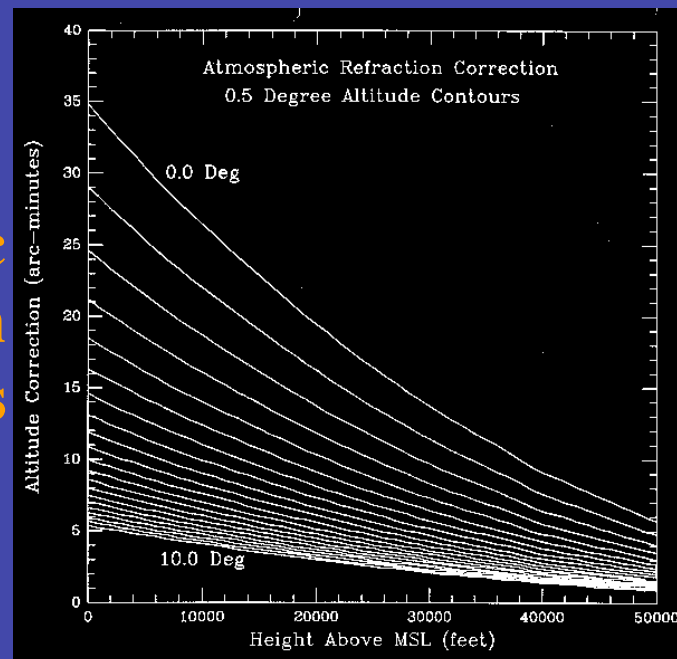
“Gang-of-Nine” Eclipse Expedition
North Atlantic, southwest of Iceland

1985 - “CENTERLINE” S/W



**Topocentric
Lunar
Limb
Corrections
(Data: A. Fiala)**

**Atmospheric
Refraction
Models**



*PREDICTION ISSUES
circa 1985-86:
Pre-Computation*

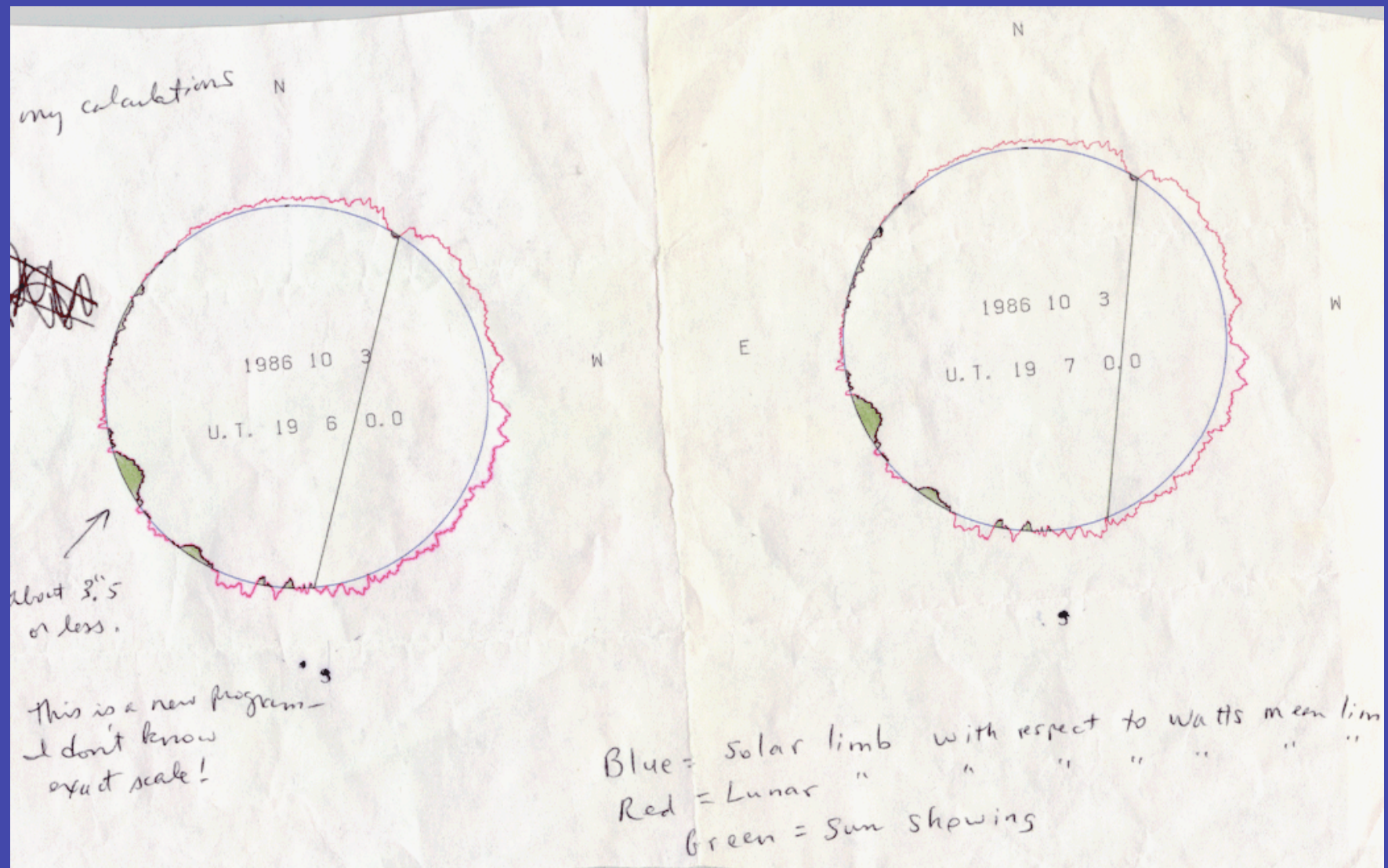
VAX/11-750 RSX APL11



(not exactly portable...)

hSE 03 October 1986 (19:05:19.0 UT)
“Gang-of-Nine” Eclipse Expedition
North Atlantic, southwest of Iceland

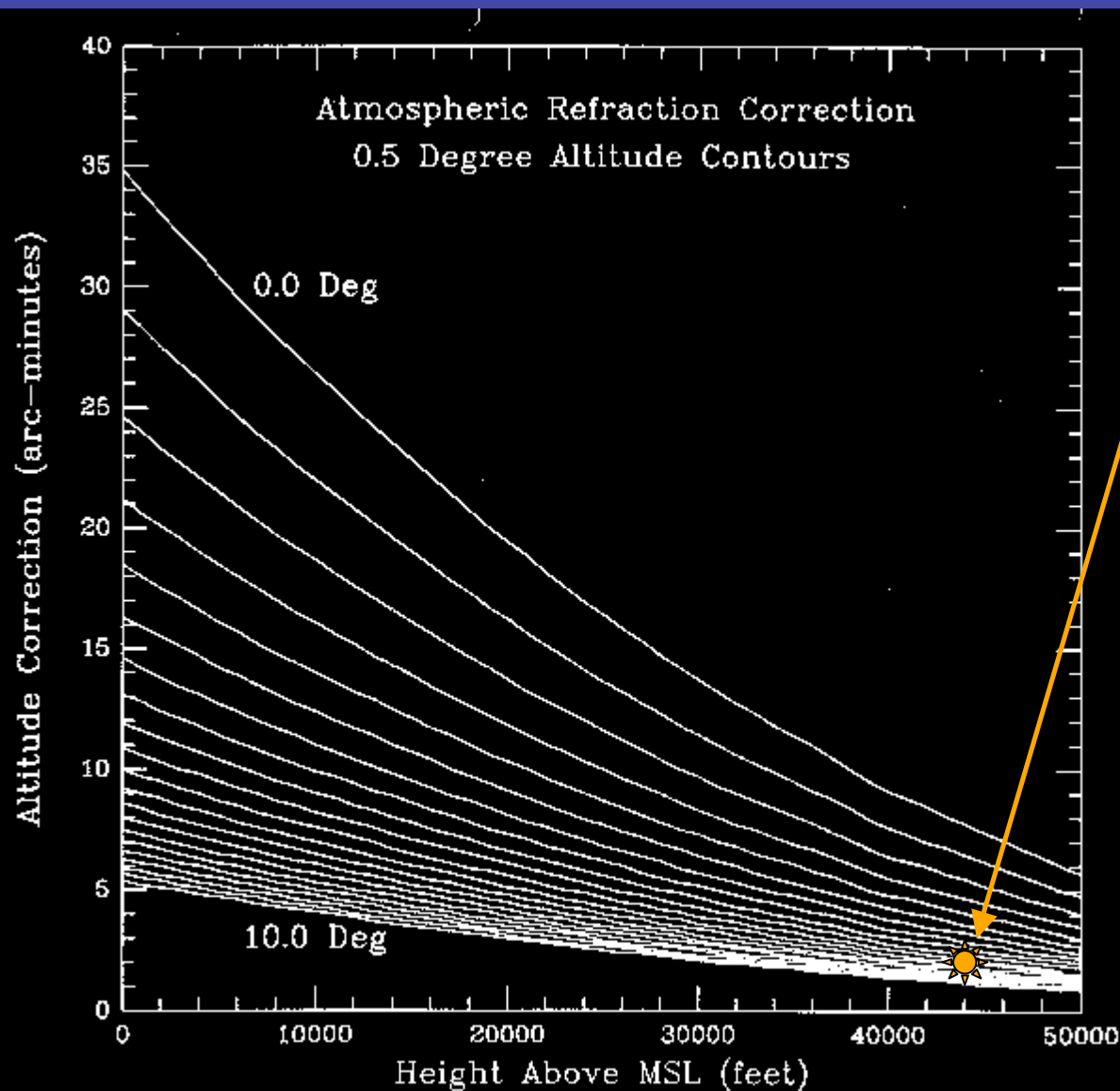
*PREDICTION ISSUES
circa 1985-86:
LIMB PROFILE*



A. Fiala (USNO): This is a new program - I don't know exact Scale!

hSE 03 October 1986 (19:05:19.0 UT)
“Gang-of-Nine” Eclipse Expedition
North Atlantic, southwest of Iceland

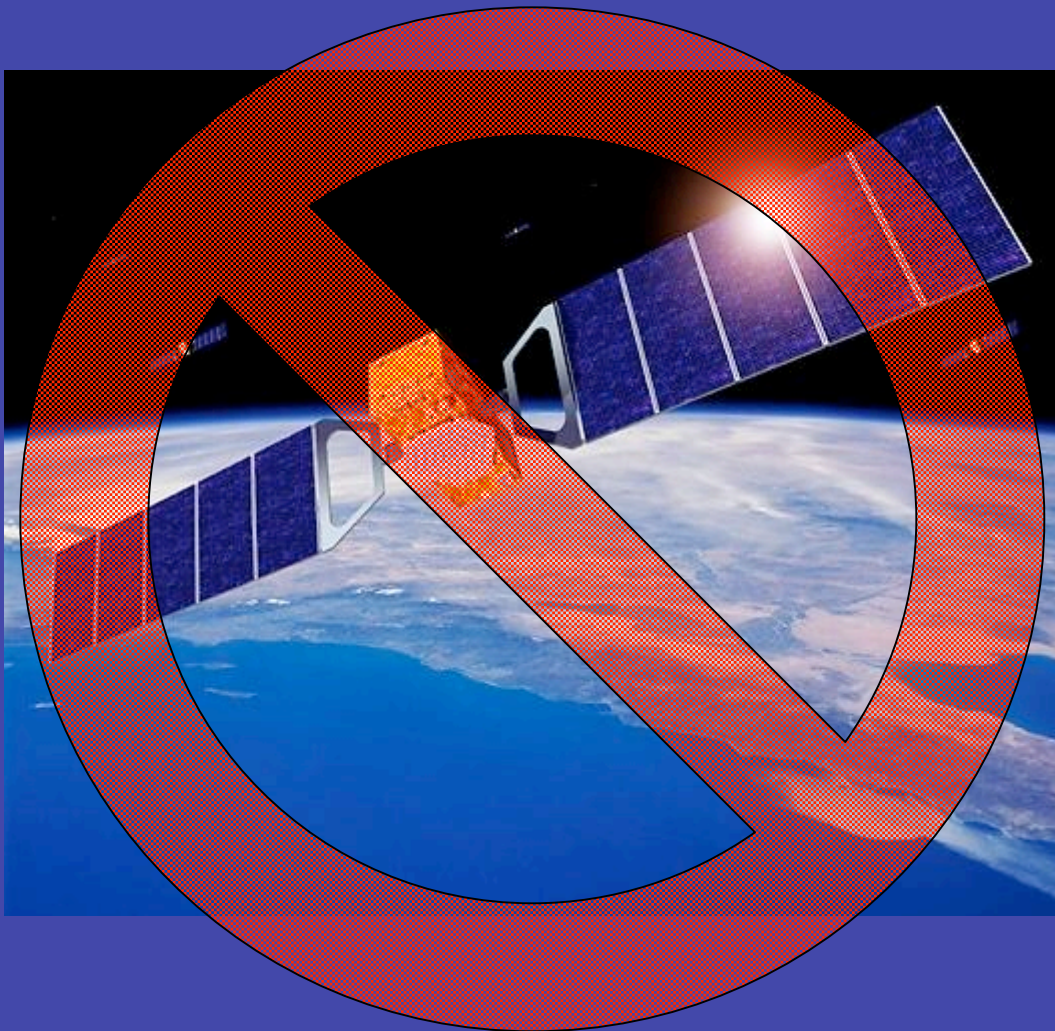
PREDICTION ISSUES
circa 1985-86
ATMOSPHERIC
REFRACTION



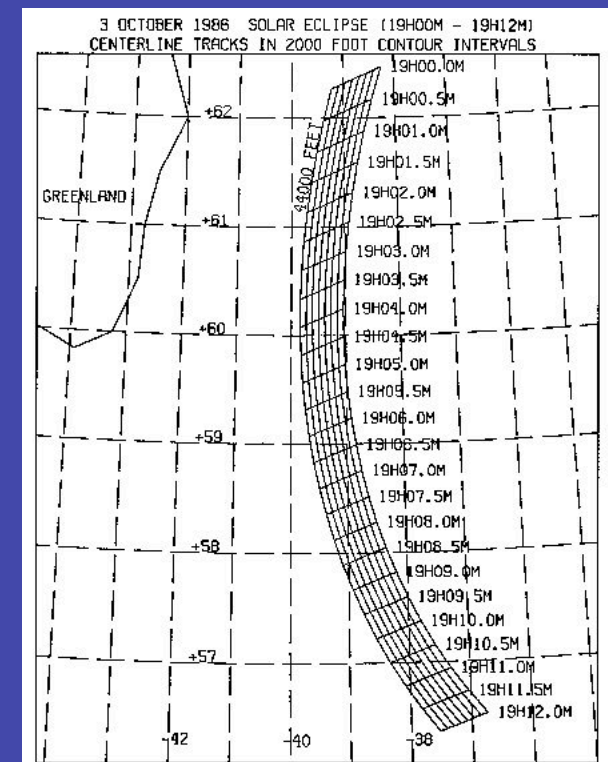
1.9' but model dependent

hSE 03 October 1986 (19:05:19.0 UT)
“Gang-of-Nine” Eclipse Expedition
North Atlantic, southwest of Iceland

PREDICTION ISSUES
circa 1985-86
PRE-GPS

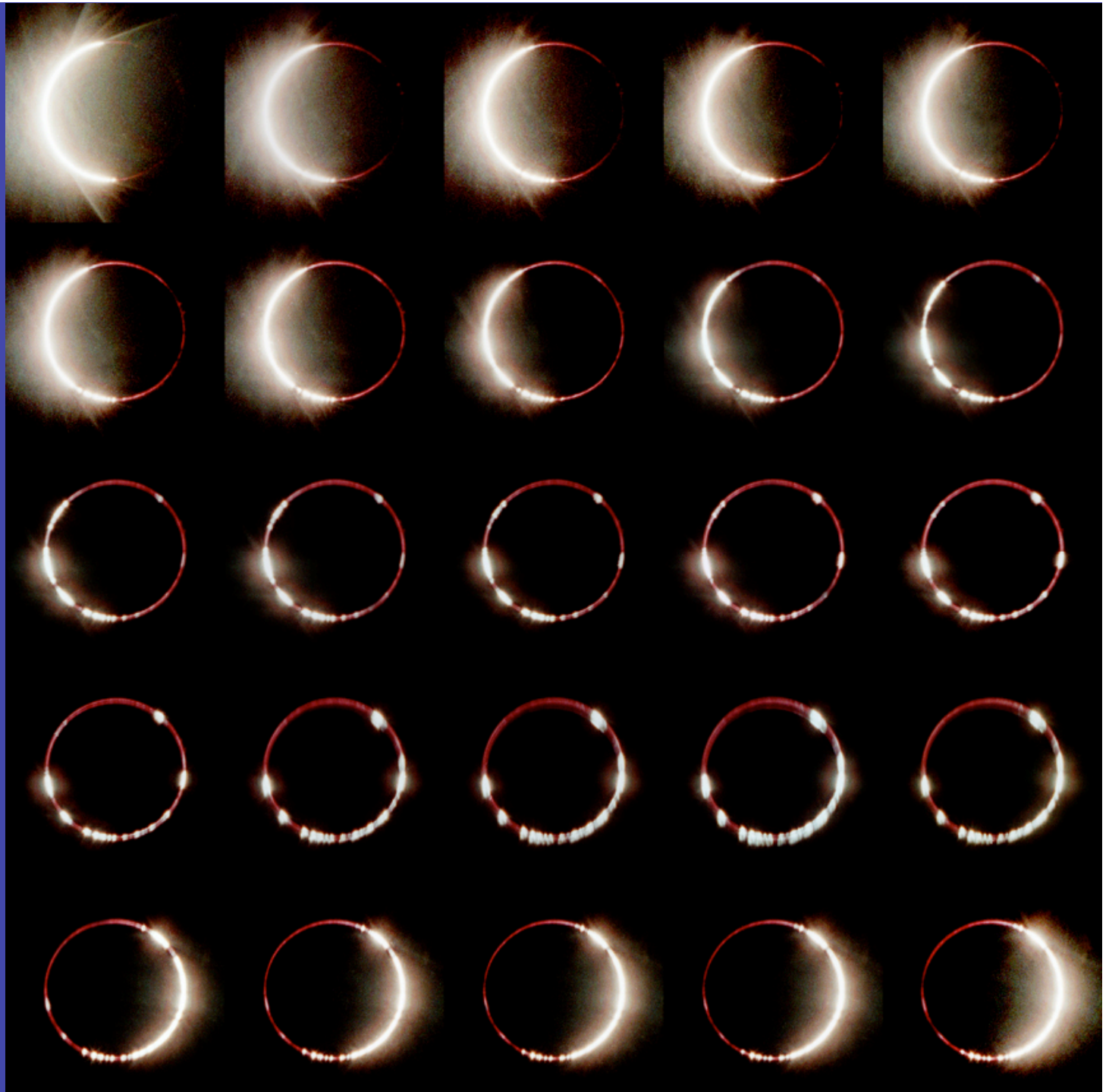
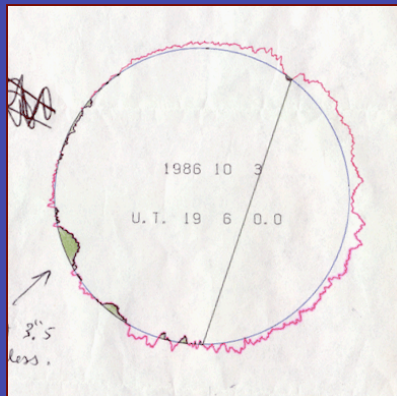


Inertial Navigation
Gyro Bias Error
Secular Accumulation:
~ 1 per 1000 km of flight



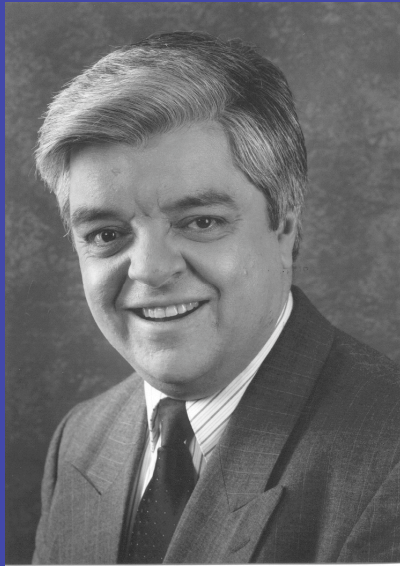
*So,
How Did
We Do?*

Top Left to
Bottom Right
19:05:14.33 -
19:05:22.33
(3 fps)



TSE: 22 July 1990

Joe Rao's coup d'air
Trans-Air Airlines 403
L-1011: Honolulu-> S.F.



41 min. "delay"
nets 360 PAX 71s Totality



32,000 ft, Finnair DC-9
Over Joensuu, Finland



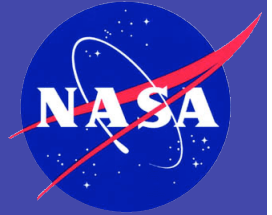
80 s of totality, 90 PAX on-board



Photos: Fred Espenak

NASA's Hubble Space Telescope

"Observes" TSE 11 July 1991



1m 04s of Totality from 602 km AMSL

@ Maximum Eclipse:

Magnitude = 1.0351

$r_{\text{moon}}/r_{\text{sun}} = 1.0746$

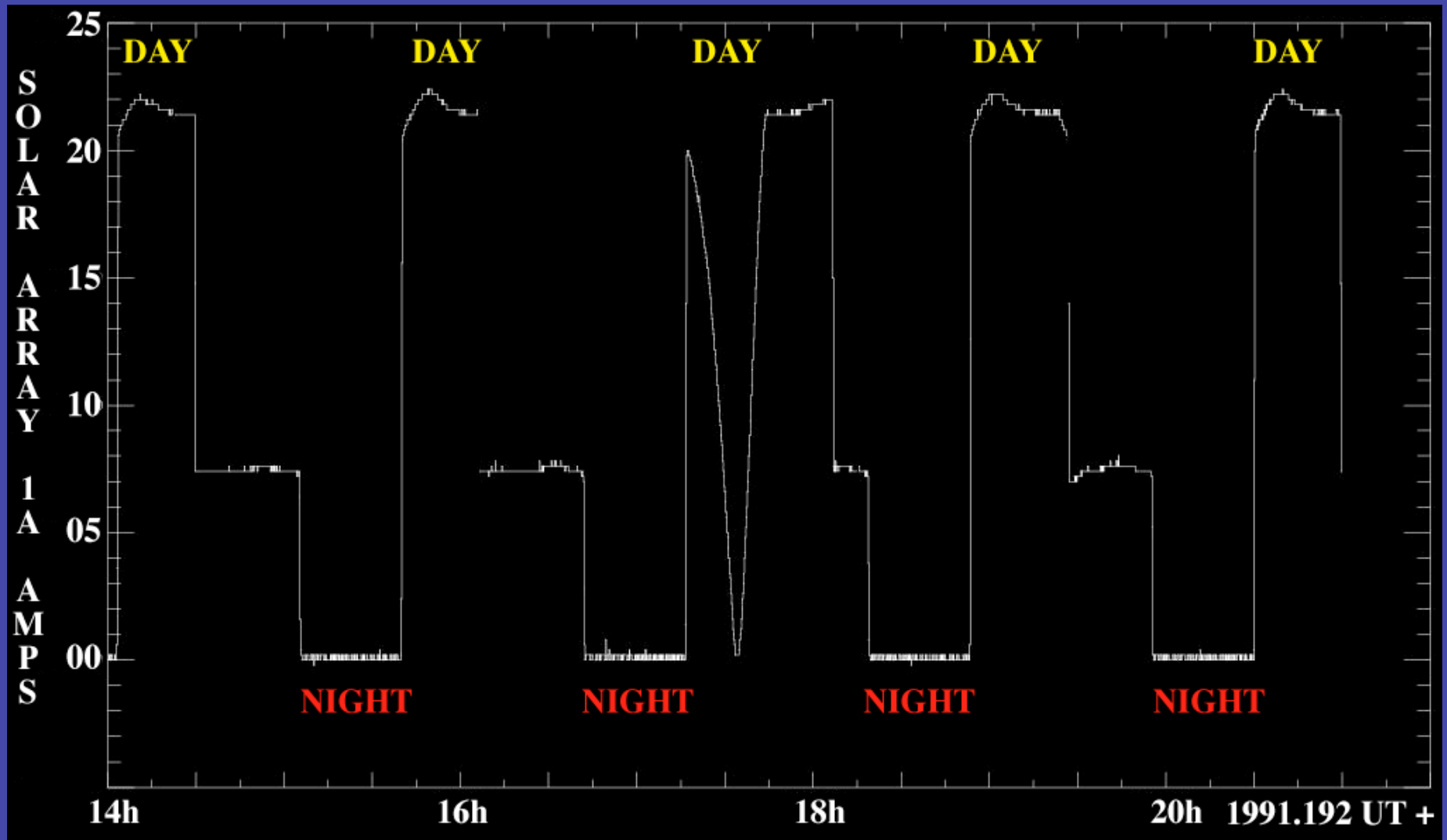
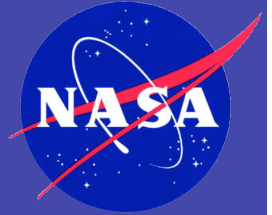
"Antumbral" depth = 95.4%



<u>EVENT</u>	<u>HH:MM:SS</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>
C2:	17:33:48	24.110 N	142.478 W
MAX:	17:34:19	23.574 N	140.649 W
MID:	17:34:20	23.559 N	140.527 W
C3:	17:34:52	22.971 N	138.595 W

HUBBLE SPACE TELESCOPE -- *IN THE UMBRA!*

NASA's Hubble Space Telescope "Observes" TSE 11 July 1991

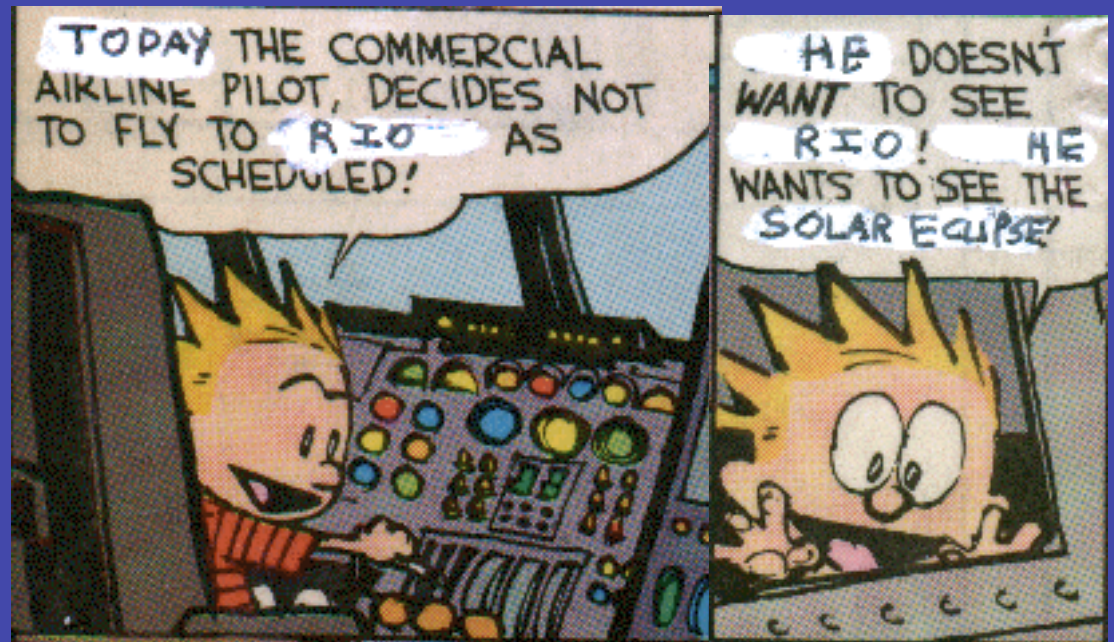


TSE: 30 June 1992 - South Atlantic

Only landfall: Coastal Uruguay With Sun on Horizon

Unobscured Viewing Probability: $\leq 5\%$

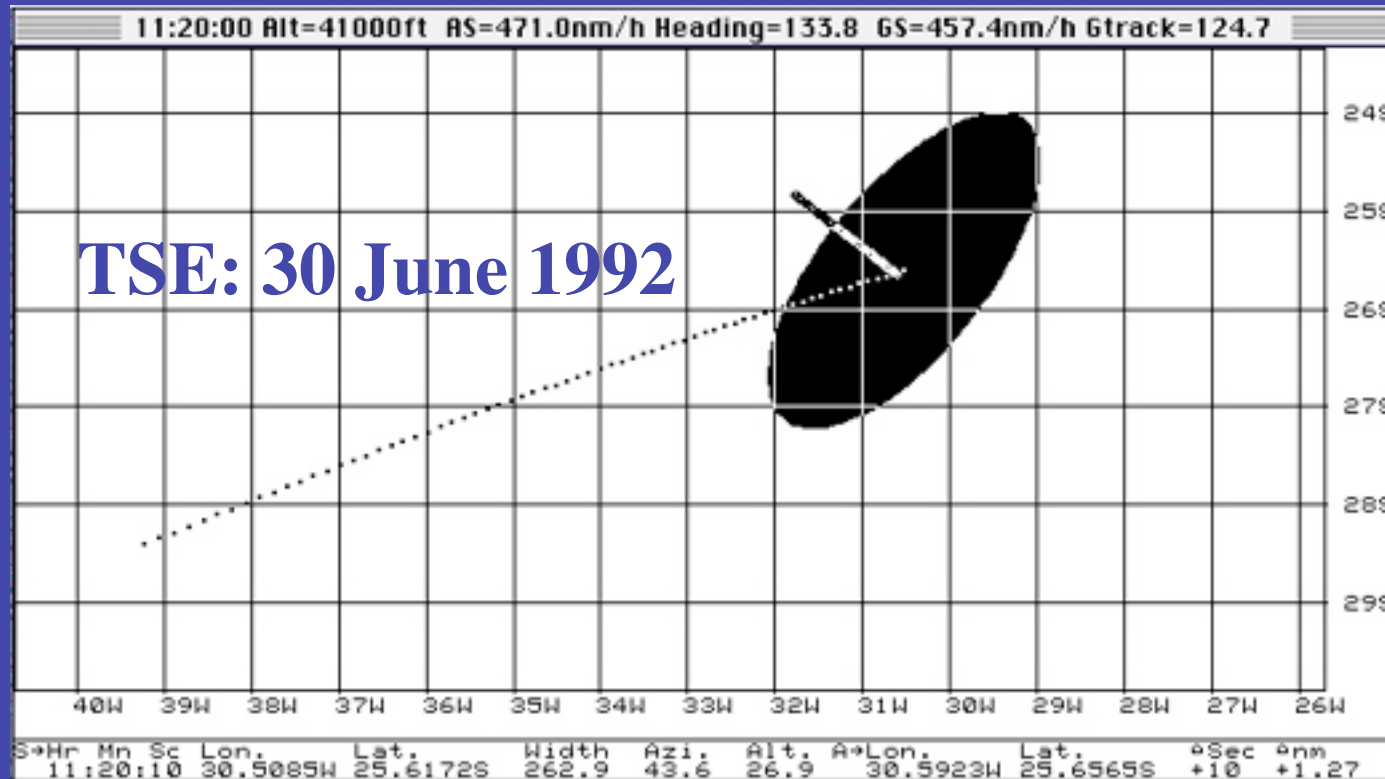
What to DO?...



1992 - EFLIGHT S/W (*UMBRAHILE/CENTERLINE* derivative) Eclipse Flight/Shadow Intercept & Real-Time Navigation

*High Precision “Moving Platform” Dynamical Computation
of TSE Ephemerides, Global & Local Circumstances.*

- Topocentric Lunar Limb Corrections
- Atmospheric Refraction Models



1st Implementation: Mac PB 170 MacOS 7 APL/68000

Digression: The Evolution of “EFLIGHT”

In Situ OPERATIONAL PEDIGREE:
TSE 30 June 1992
DC-10 Eclipse Flight



Digression: The Evolution of “EFLIGHT”

In Situ OPERATIONAL PEDIGREE:

TSE 30 June 1992

DC-10 Eclipse Flight

6m 15s @ 41,000 ft
(Ground Duration: 4m 37s)



Digression: The Evolution of “EFLIGHT”

In Situ OPERATIONAL PEDIGREE:

TSE 30 June 1992

DC-10 Eclipse Flight



2001, 2003, 2008...



...Into the Wild Blue Yonder!

SUPERSONIC



FASTER!, HIGHER!, LONGER!





TSE 24 October 1995
Indian Air Force
Gp Capt S. Mukherjee
Wg Cdr Y.S. Babu
south-west of Kanpur

MIG-25
80,000 ft.
Mach 2.5



"Our attention was focused on flying... when the red glow of the instruments panel filled the cockpit that we realised that the sunlight had gone. It had become a dark night and the sky was filled with stars all round... At 80,000 feet... the sky appears grey... because of the absence of dust, air and water molecules. But this time, during totality, the sky suddenly turned inky dark without notice..."

At a speed of Mach 2.5, we got to see about 90 seconds of totality, while those on ground got to see only 55 seconds."

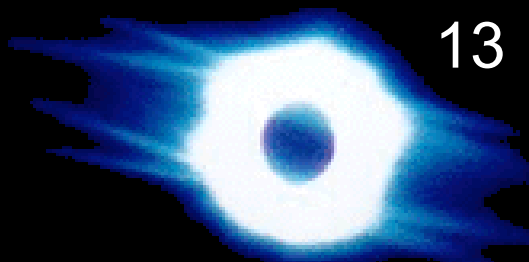


TSE 11 August 1999
MIG-21
13,000 m, 1650 kph

Yavor Shopov
(U. of Sophia)

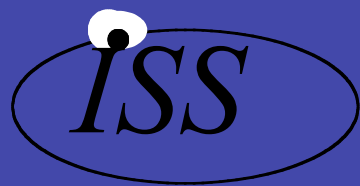
Coordinated Air + Ground Photographic Program

nIR corona (EIR + yellow blocker; 630 - 930 nm) to 18 solar radii
82 film rolls, 1184 frames: 15 VIS&IR spectral regions
761 frames of eclipse 13 IR films
423 calibration frames

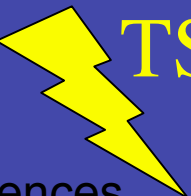


Registered Coronal Images to 23 R(sun)





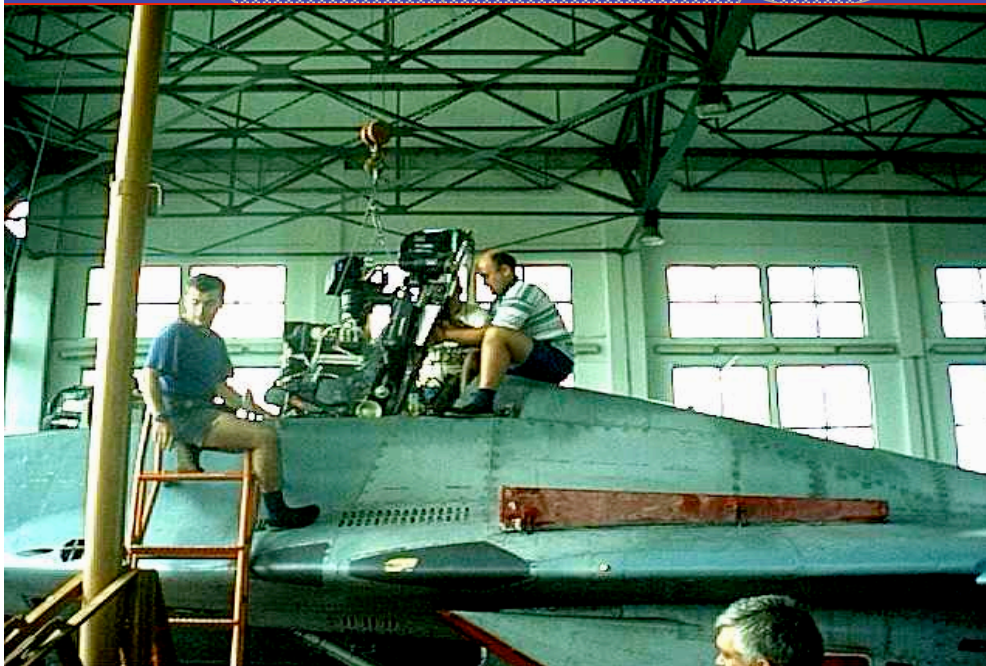
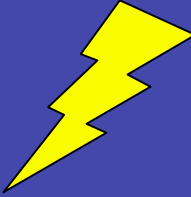
Institute for Space Sciences
Bucharest, Romania

 TSE 11 August 1999
and a MIG-29
(0 m, 0 kph)

“experiments ... were not possible ... due to weather conditions (the MIG-29 was stopped by the control tower during take off, not because it could not take off, but because that, if something wrong happened, it could not land safely nowhere in the area).”

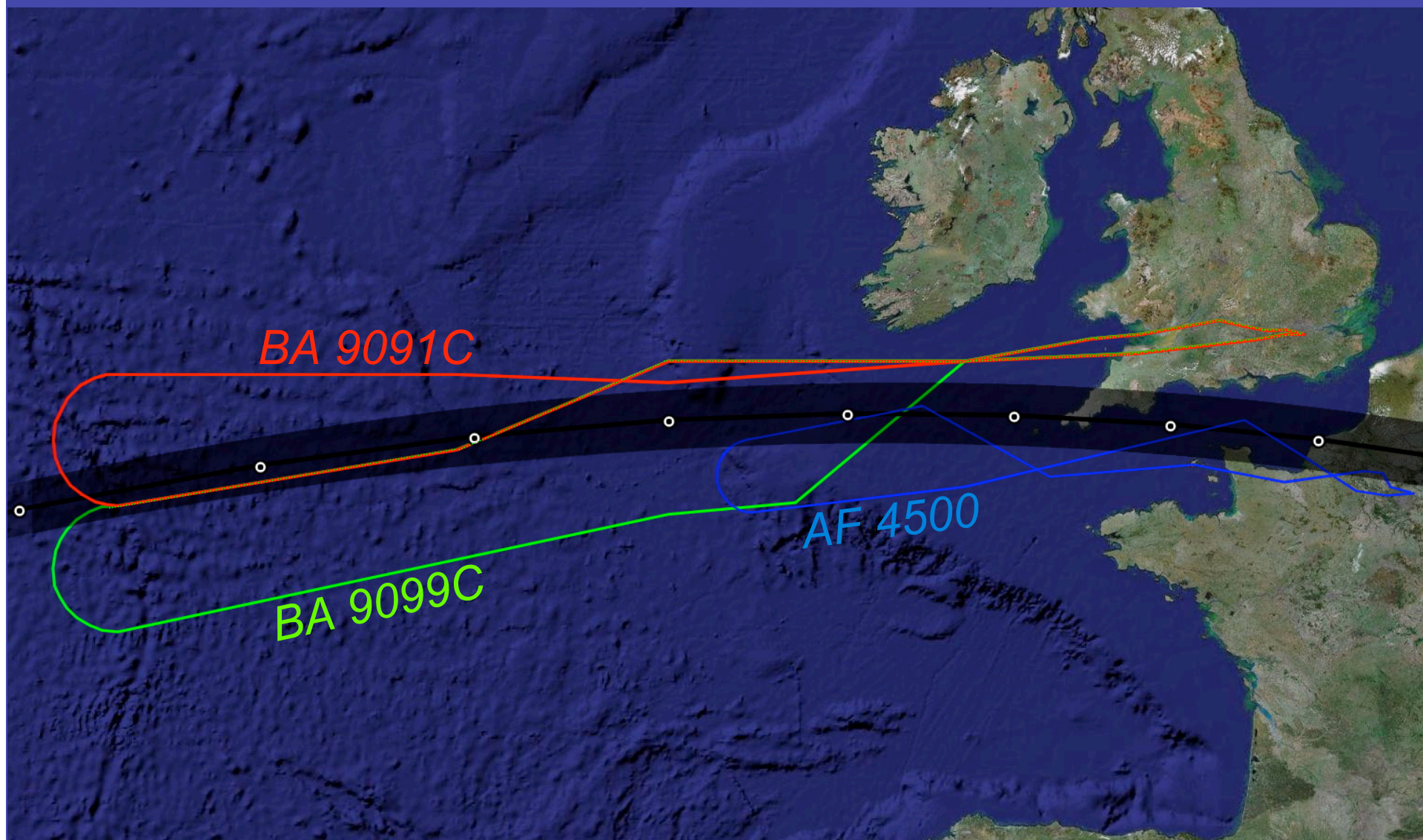
-Vlad Popa, 17 July 2007

PROJECT
Neutrino
Oscillation with
Telescopes
during the
Total
Ecclipse





TSE 11 August 1999 and a Flock of Concordes



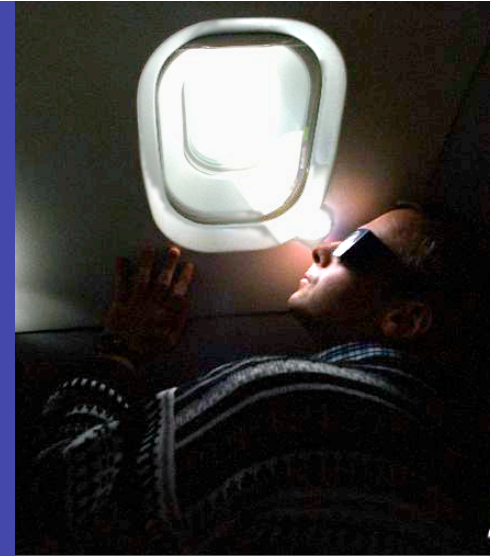
Christine McGourty, BA 9091:

“Before take-off there was a rehearsal of the seat-switching that had to be performed to get those on the left hand side of the plane over to the right and back twice during totality.”

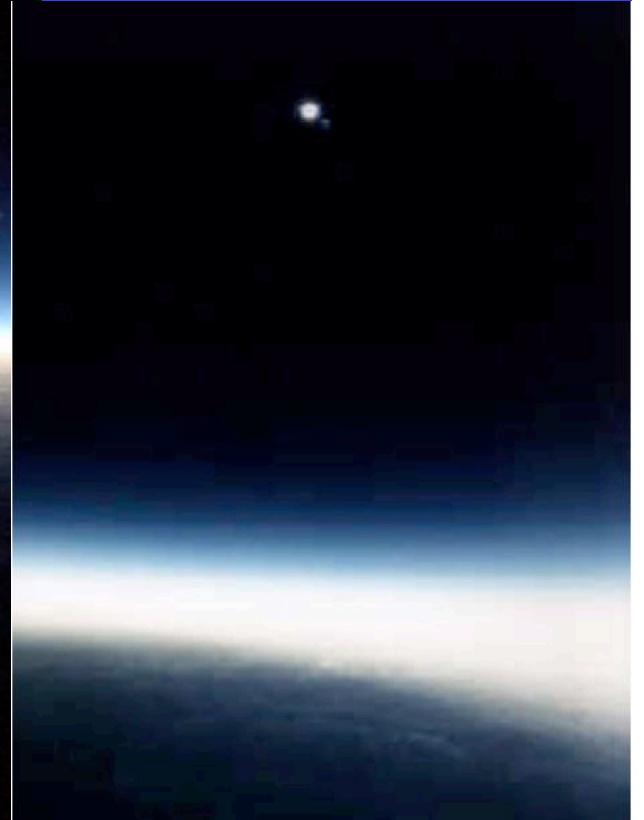


AF4500 Wide-Field View from the Cockpit – Vincent Coude du Foresto

“There was a stunning view of the partial eclipse. But it wasn't easy to see, appearing quite small and so high in the sky that many people were on their knees between their own seat and the one in front, twisting their necks round and peering up out of the tiny window. *Totality was something it seemed only the lucky ones were able to witness.*”

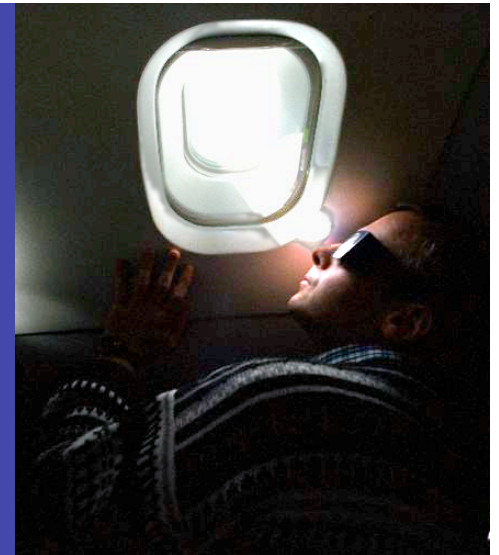


AF 4500 Wide-Field View from the Cockpit

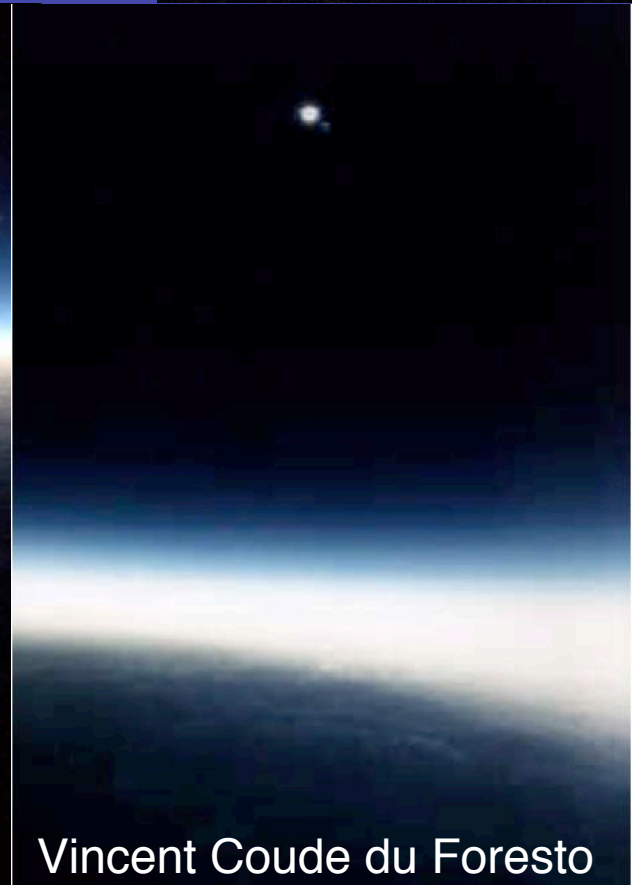


Vincent Coude du Foresto

John Beckman: "Because of the small windows and the angle, you could never get your eye in the right position to see totality while the plane was in level flight. It was only when it did a few wiggles in the air that you could see totality... *I saw about 10 seconds of totality. It was obviously disappointing and I'd hoped to see several minutes.*"



AF 4500 Wide-Field View from the Cockpit



Vincent Coude du Foresto



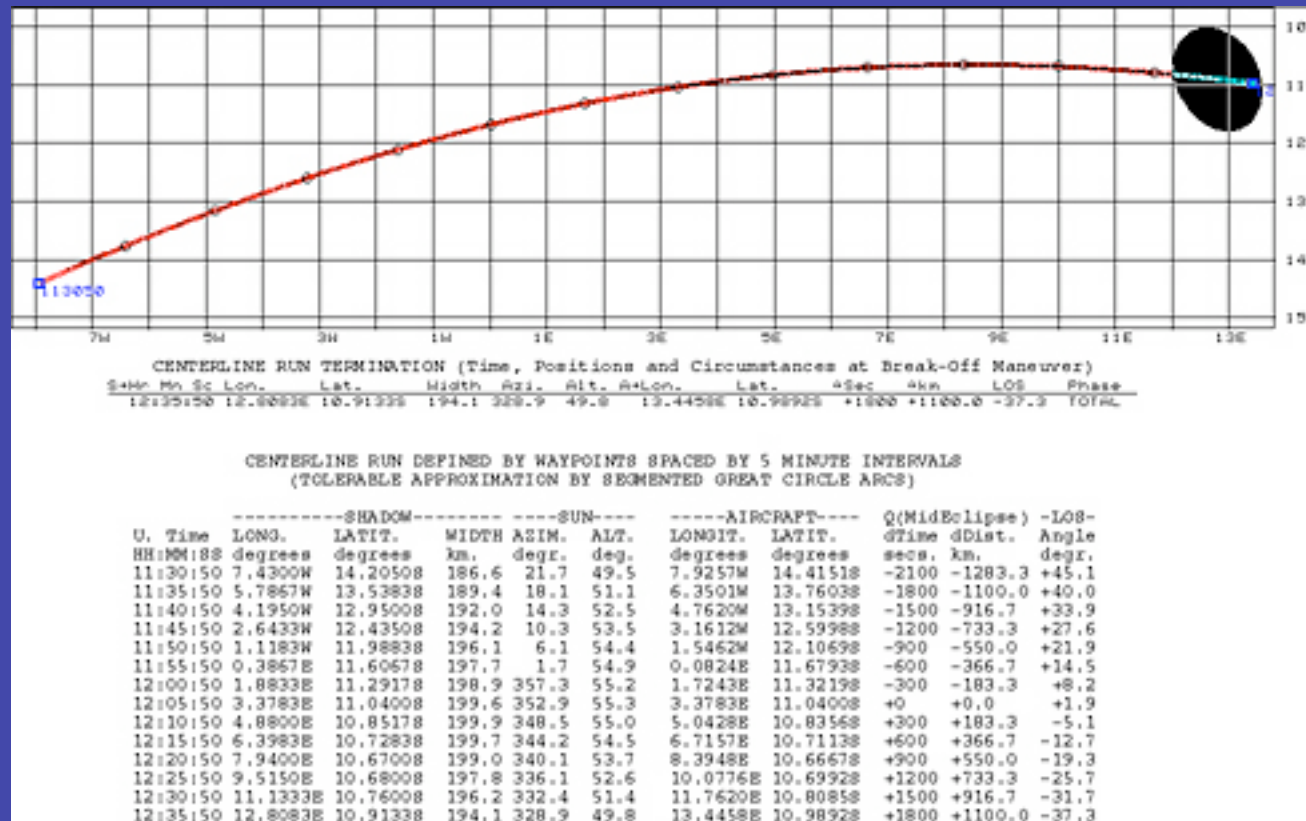
EFLIGHT SS 2001

Modifications for $V_{\text{aircraft}} > V_{\text{umbra}}$

2001 - EFLIGHT SS (for TSE 21 June 2001)

Modified for Concorde/Supersonic Flight Intercept

PowerMac PB/G3-G4 MacOS 9 APL/Level II



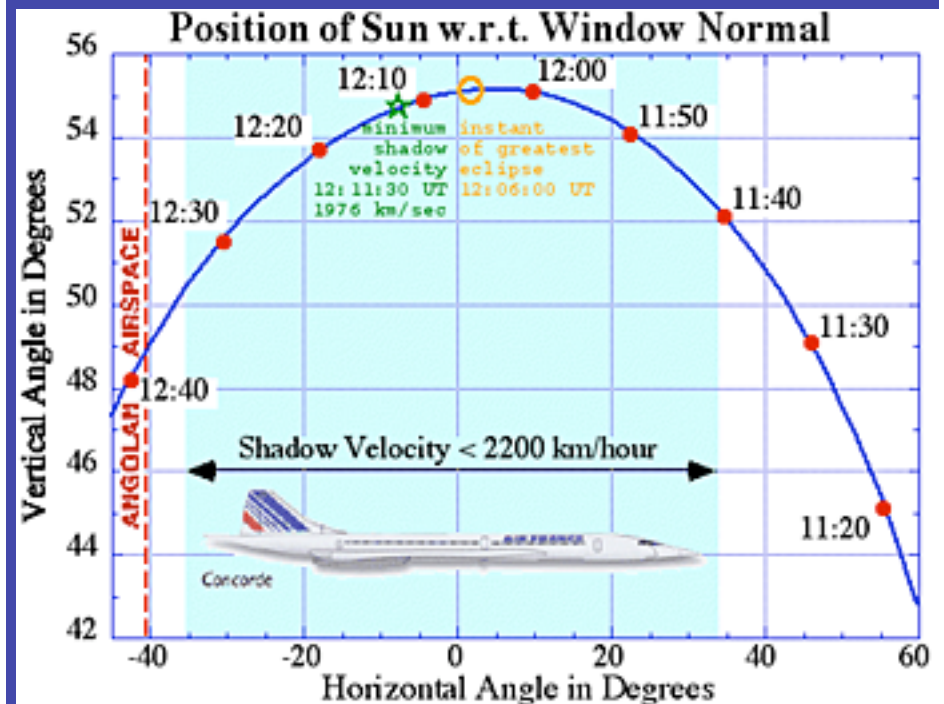
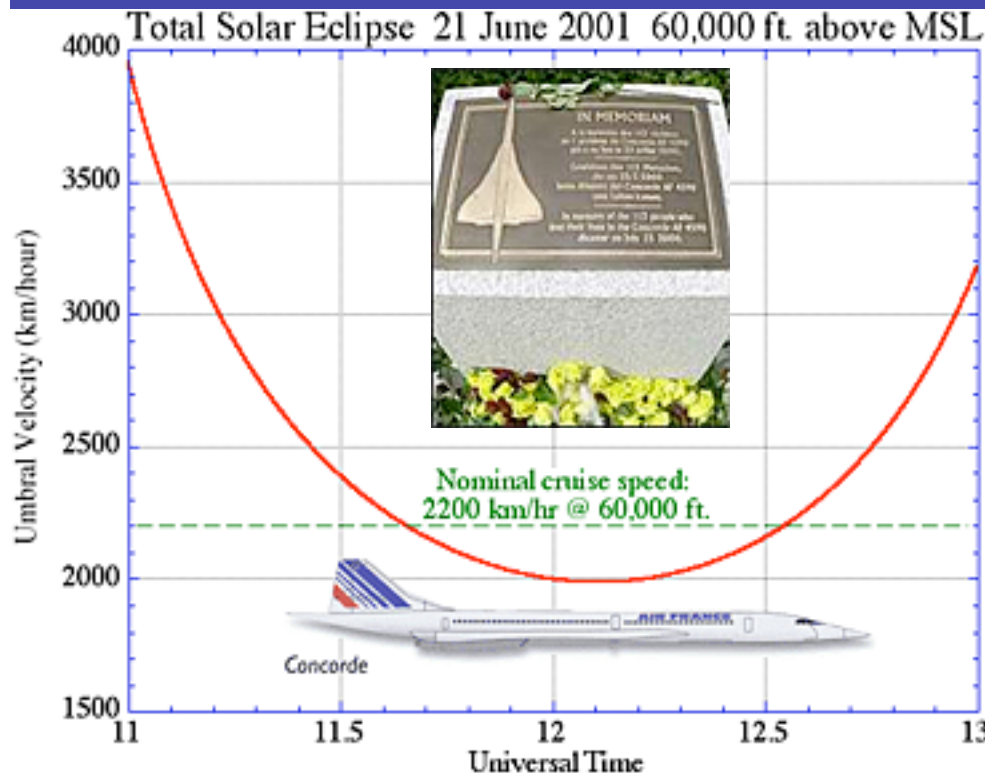
EFLIGHT SS 2001

Eclipse Circumstance Calculator and Aircraft Navigation Aide

Specifically designed to address the problem optimally intercepting the moon's shadow from a moving aircraft.

PEDIGREE:

- 21 June 2001 Planned 1 Hour Totality With Ill-Fated AF Concorde



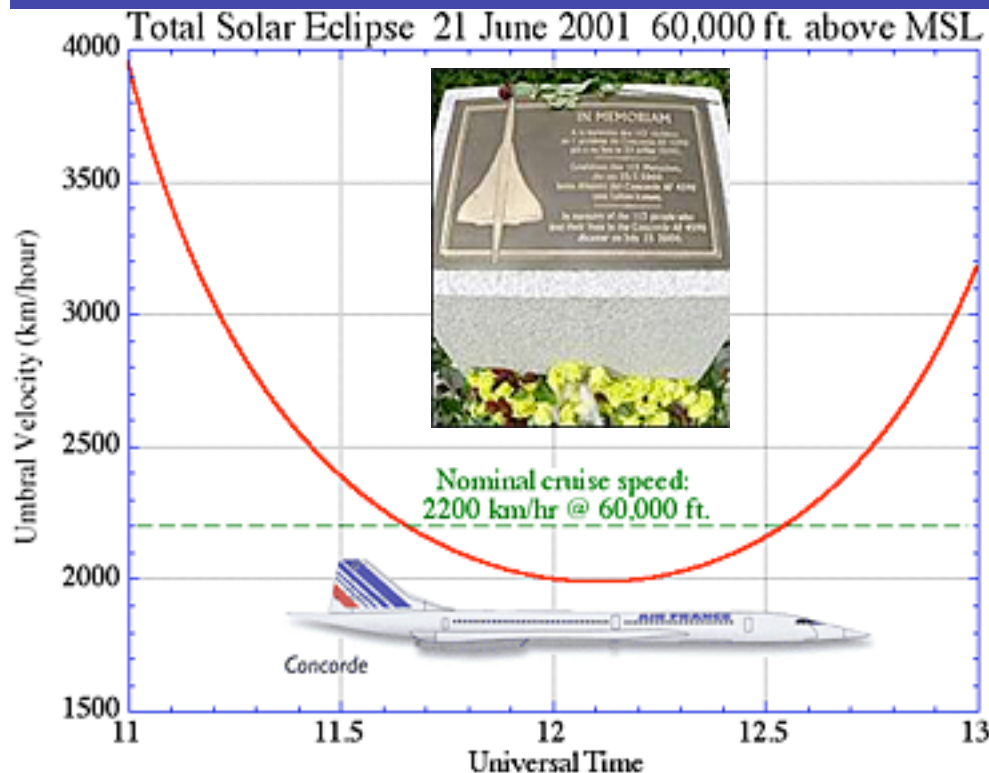
EFLIGHT SS 2001

Eclipse Circumstance Calculator and Aircraft Navigation Aide

Specifically designed to address the problem optimally intercepting the moon's shadow from a moving aircraft.

PEDIGREE:

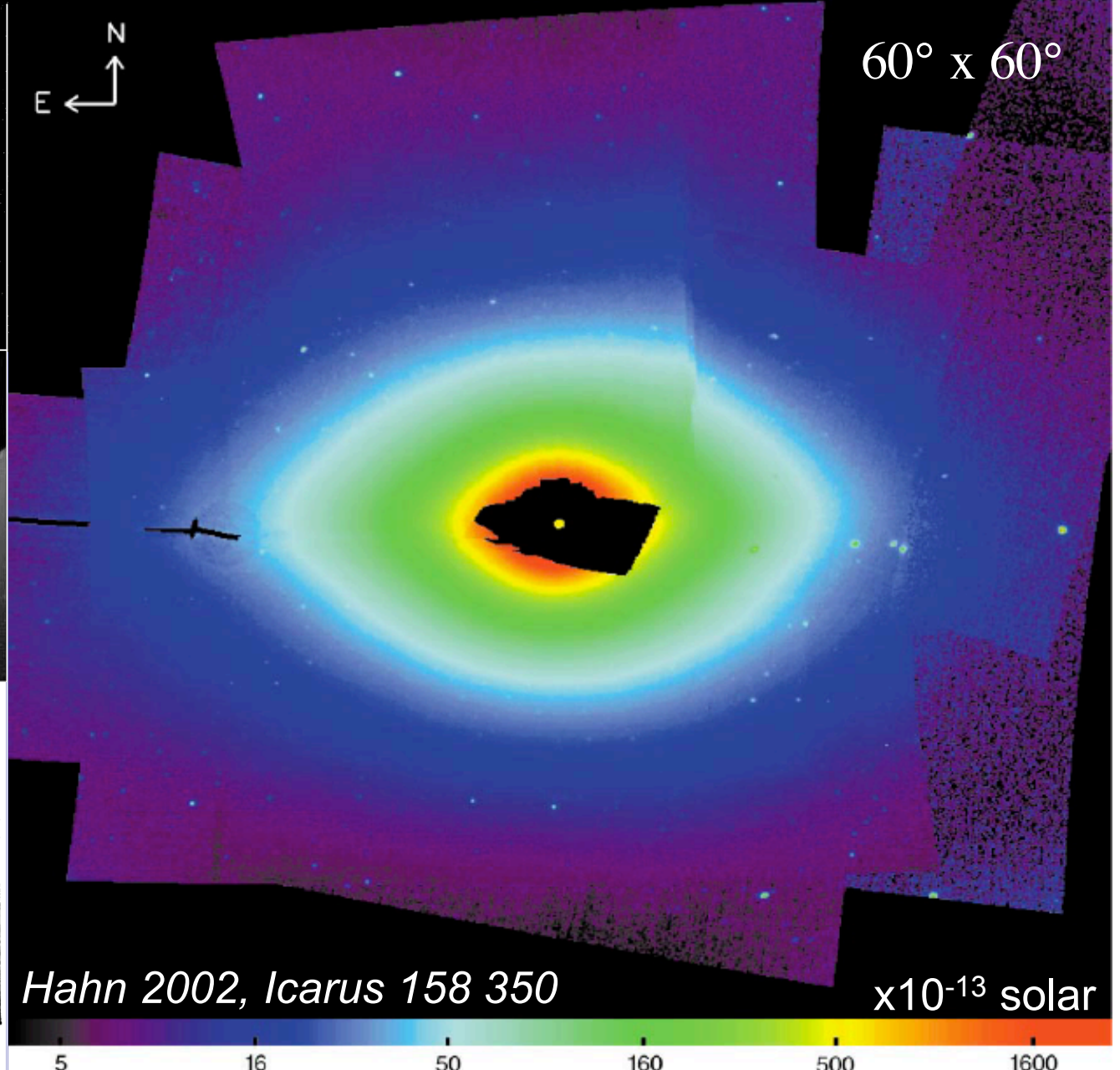
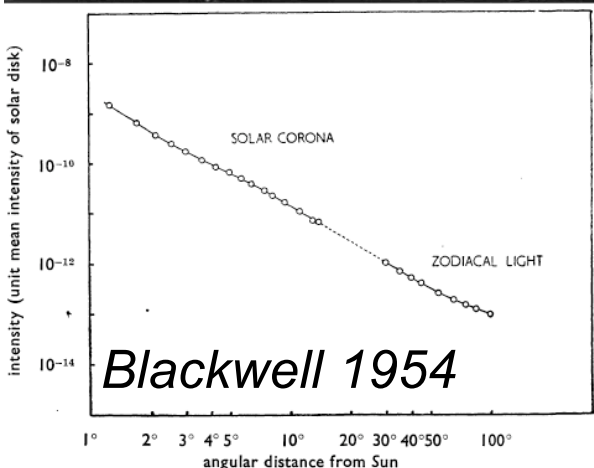
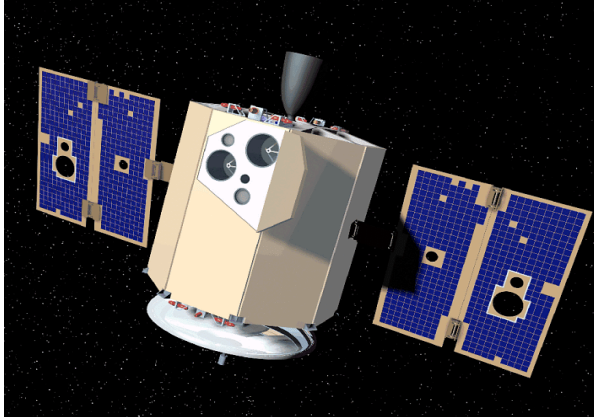
- 21 June 2001 Planned 1 Hour Totality With Ill-Fated AF Concorde



The Tragic End of Concorde Eclipse Observing Concept



Clementine Lunar-Orbital Circum-Solar Imaging While In Moon's Shadow



EFLIGHT 2003 X (MacOS X)

Fully Integrated for TSE 23 Nov 2003...

Fully compliant with CDU I/O & FMS interface requirements of modern aircraft systems

PowerMac PB G4 MacOS X APL X



Boeing 747-400 ER



EFLIGHT 2003 X (MacOS X)

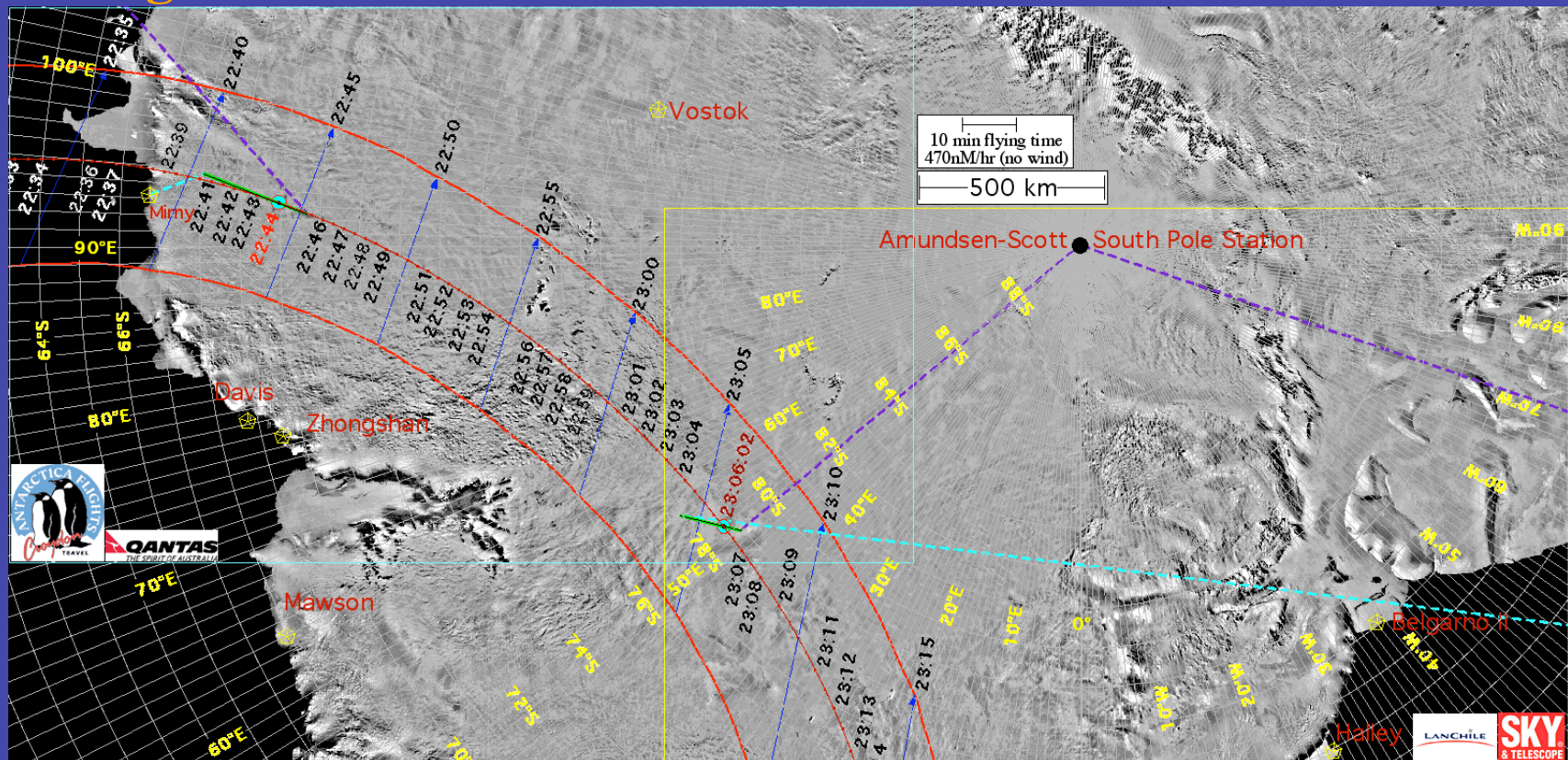
Eclipse Circumstance Calculator and Aircraft Navigation Aide

Specifically designed to address the problem optimally intercepting the moon's shadow from a moving aircraft.

23 November 2003 - ANTARCTICA:

Planning and Real-Time Navigation Croydon/QANTAS QF 2901

Planning S&T/Lan Chile LC 8001



EFLIGHT X Parametric Inputs

U. T. Mid-Eclipse = hhmmss

Intercept CL ☐ km ☐ mi toward Sun ☒ nm

Time Window = Min.

True Air Speed = /hr

☐ Fly Aircraft Heading = Deg.
☒ Fly Perpendicular to Sun
☐ Fly Parallel to Shadow

Altitude in feet AMSL =

WIND from Deg., Speed =

Autoscale + Deg

Display Time Resolution:
☐ 1s ☒ 5s ☐ 10s ☐ 30s

Display Frame Delay = s

☐ Export Waypoint Table
☐ RT SIMULATION

Graphics Scale = °/°

Start Time HHMMSS.f

End Time HHMMSS.f

Increment HHMMSS.f

Altitude meters

☐ Read Data File

☐ Use System Clock Time hhmmss
☒ Set EFLIGHT Clock U.T. =

EFLIGHT X Tabular Output

Co-Moving “Local Circumstances” from Moving Aircraft



EFLIGHT03:TABULATE TOTALITY RUN

U.T. Intercept: 22:44:00 | TOTALITY DURATION = 2m 34.7s
Flight Altitude: 35000ft |
Heading: 198.80° | Cnt hh:mm:ss.f Alt° Az° P° Cnt hh:mm:ss.f Alt° Az° P°
Air Speed: 470.0nm/h | 2ND 22:42:43.1 +14.8 109.0 109.3 3RD 22:45:17.8 +15.0 108.6 289.7
Wind Speed: 0.0nm/h | LATITUDE: -069° 49' 24.2'' LATITUDE: -070° 08' 32.0''
Wind Direction: 0.0° | LONGITUDE: +093° 09' 44.5'' LONGITUDE: +092° 50' 52.3''

HHMMSS	Umbra Long	Umbra Lat	WidKM	Uaz°	Ual°	AirCr Long	AirCr Lat	MidAT	MidAD	LOS	Bearng	ACaz	ACal
223200	9422.514E	6239.618S	535.1	111.9	11.8	9423.086E	6829.493S	-720s	-94.0nm	+0.3	197.52	108.5	14.7
223205	9423.657E	6243.010S	534.8	111.8	11.8	9422.551E	6830.114S	-715s	-93.3nm	+0.3	197.52	108.5	14.7
223210	9424.773E	6246.395S	534.6	111.8	11.8	9422.015E	6830.736S	-710s	-92.7nm	+0.3	197.53	108.5	14.7
223215	9425.863E	6249.772S	534.4	111.7	11.9	9421.479E	6831.357S	-705s	-92.0nm	+0.3	197.54	108.5	14.7
223220	9426.927E	6253.143S	534.2	111.7	11.9	9420.942E	6831.978S	-700s	-91.4nm	+0.3	197.55	108.5	14.7
223225	9427.964E	6256.506S	533.9	111.7	12.0	9420.405E	6832.599S	-695s	-90.7nm	+0.3	197.56	108.5	14.7

KB: Non-APL

Time Correlated Aircraft Track, Centerline, and Umbra Intercept Data



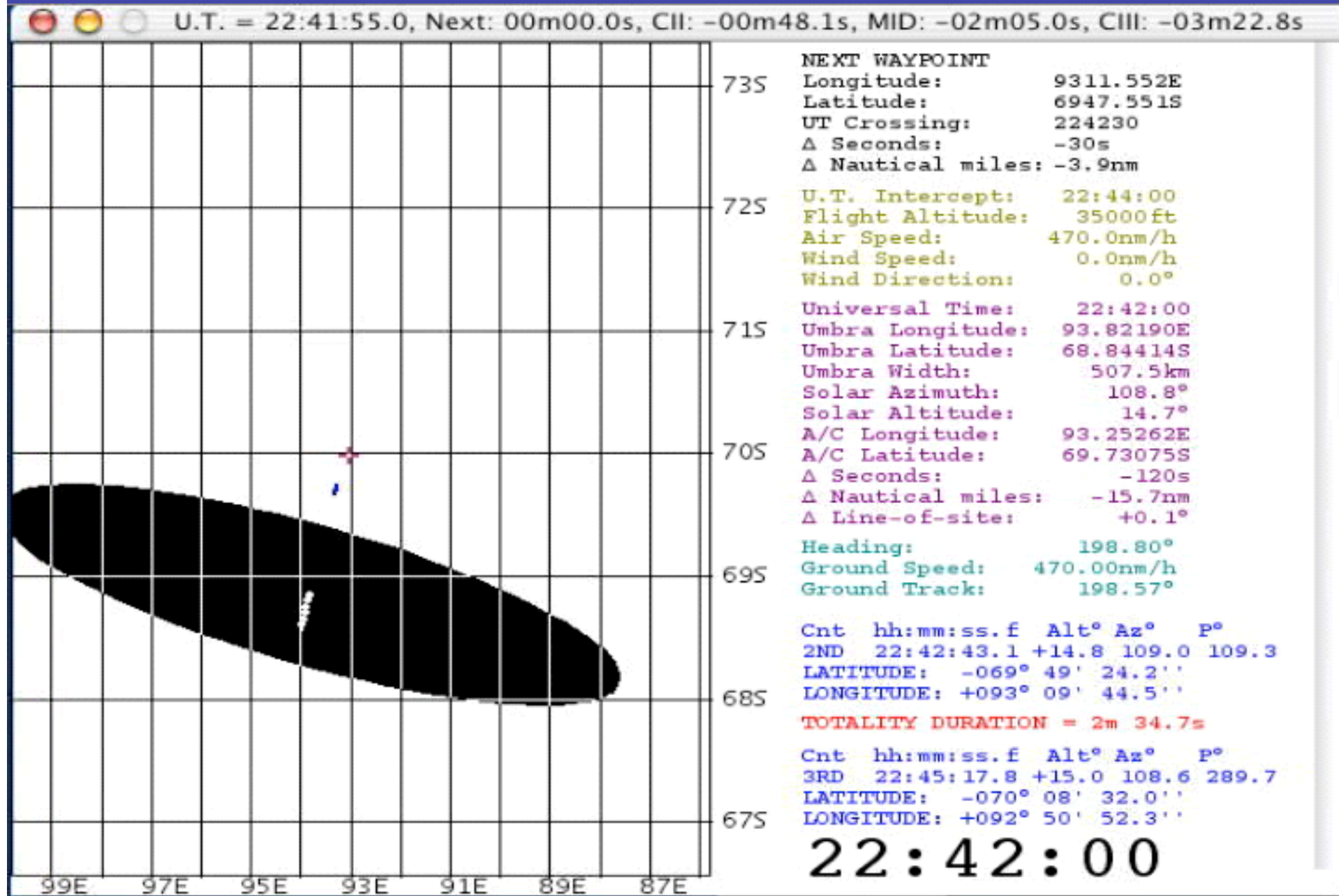
Selected WAYPOINTS

#	HHMMSS	Umbra Long	Umbra Lat	WidKM	Uaz°	Ual°	AirCr Long	AirCr Lat	MidAT	MidAD	LOS	Bearng	ACaz	ACal
A	223200	9422.514E	6239.618S	535.1	111.9	11.8	9423.086E	6829.493S	-720s	-94.0nm	+0.3	197.52	108.5	14.7
B	223600	9449.442E	6515.523S	523.8	110.1	13.3	9356.833E	6859.287S	-480s	-62.7nm	+0.2	197.92	108.6	14.8
C	224000	9422.996E	6740.906S	512.7	109.0	14.3	9329.370E	6929.011S	-240s	-31.3nm	+0.1	198.35	108.7	14.9
D	224400	9300.609E	6958.660S	502.7	108.8	14.9	9300.609E	6958.663S	+0s	+0.0nm	-0.0	198.88	108.8	14.9
E	224800	9030.598E	7209.511S	494.5	109.6	15.2	9231.848E	7028.309S	+240s	+31.3nm	-0.1	197.54	108.9	15.0

FMS INPUT

“READ-BACK”

EFLIGHT X Dynamic Display



TSE 23 November 2003

70°S @ 35,000 ft

THE UMBRAL SHADOW APPROACH RECESSION

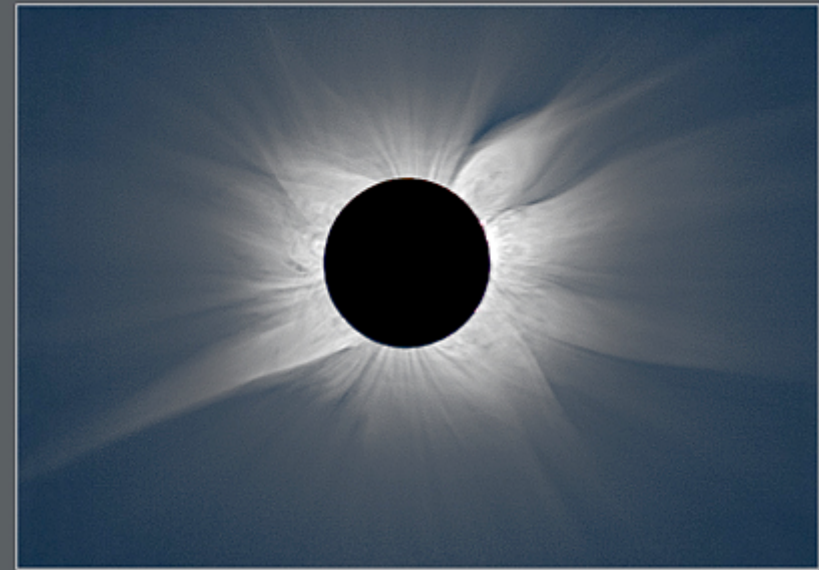
Carter Roberts



Jay Pasachoff



APEX/MID-ECLIPSE



Total Solar Eclipse 2003

© 2003 David Finlay © 2005 Miloslav Druckmüller

D. Finlay & M. Druckmüller

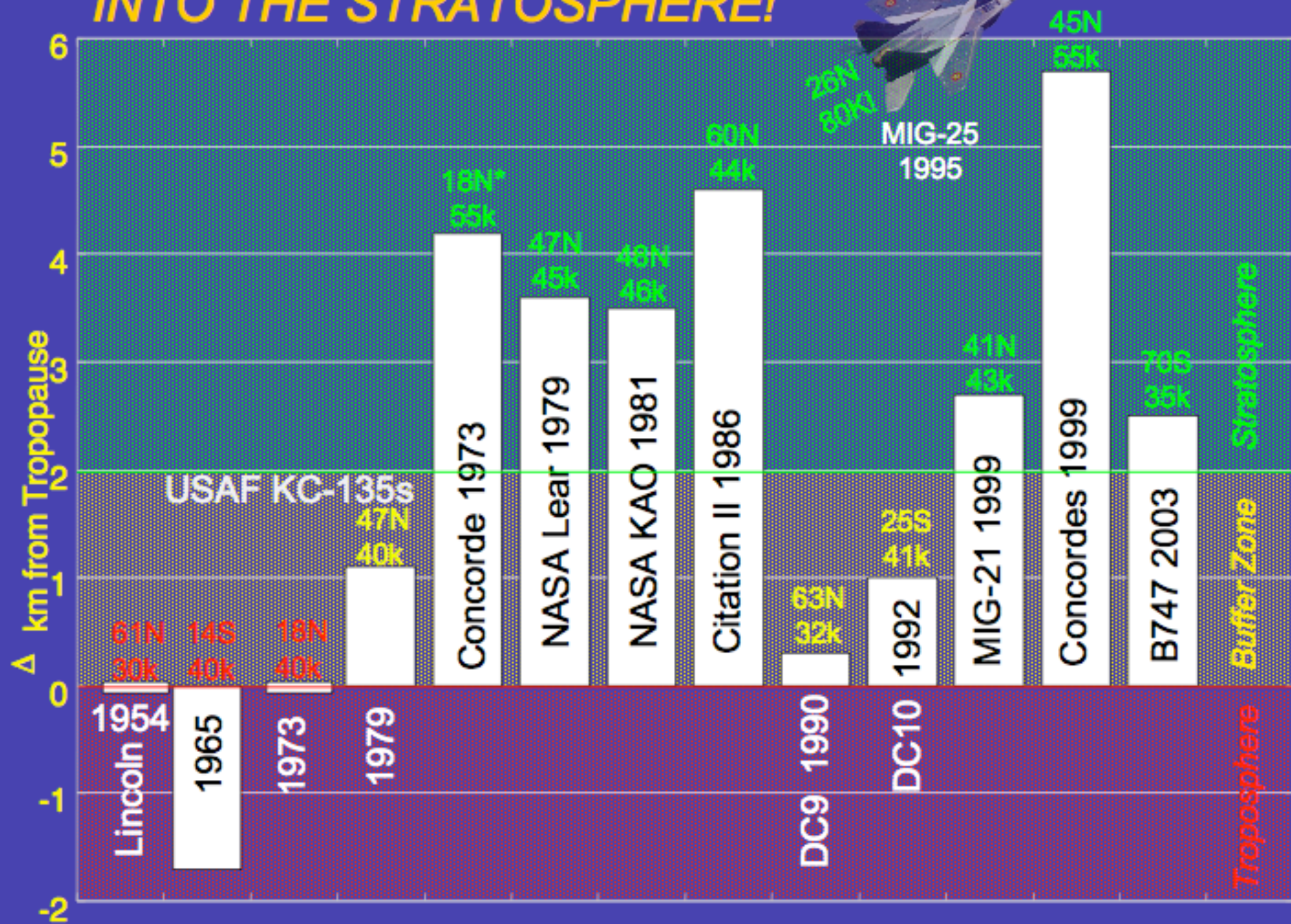




NHK (Japan) Real-Time HDTV



INTO THE STRATOSPHERE!

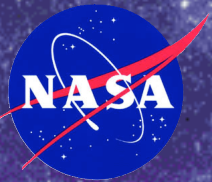
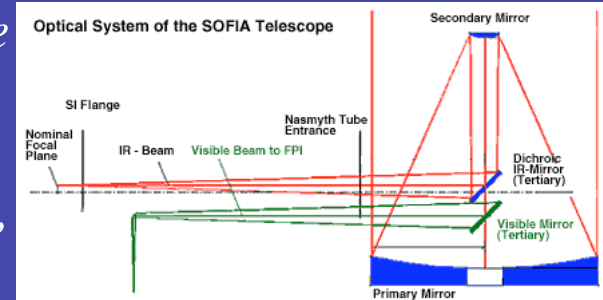


What's Next? -- NASA/DRL SOFIA

Stratospheric Observatory for Infrared Astronomy

The SOFIA Telescope has a 2.5 m diameter clear aperture (comparable in size to the Hubble Space Telescope's 2.4 m)

The SOFIA Aircraft will operate from 39,000–45,000 ft, 3–4 8hr flights per week over 20 years. Mission deployable



Boeing 747-SP



Prof. Eric Becklin
(UCLA), SOFIA
Chief Scientist, was
on Aloha Airlines
243...

USRA receiving Federal Aviation
Administration's Part 145 Repair
Station Certification, April 27, 2005



4-28-1988 After 89,090 flight cycles on a 737-200, metal fatigue lets the top go in flight.



The Tragic End of the SOFIA Eclipse Observing Concept??



National Aeronautics and Space Administration President's FY 2007 Budget Request



Budget Authority (\$ millions)	FY2005	FY2006	Change	FY2007	FY2008	FY2009	FY2010	FY2011
Hubble Space Telescope	302.6	268.6	68.1	336.7	302.2	161.4	120.3	138.5
Stratospheric Observatory for Infrared Astronomy (SOFIA)	71.5	48.0	-48.0					
Gamma-ray Large Space Telescope (GLAST) Program	111.4	125.9	-40.5	85.4	25.2	28.8	29.3	30.4

FY 2008 Budget Estimates



REPRIEVE!!

Budget Authority (\$ millions)	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012
Stratospheric Observatory for Infrared Astronomy (SOFIA)	90.8	--	77.3	89.1	88.6	89.9	92.1



SOFIA
1st Flight
04/26/2007
Successful



1st Science Operations -- 2008-9?
But Not (yet; 2010-11?) Solar Enabled...



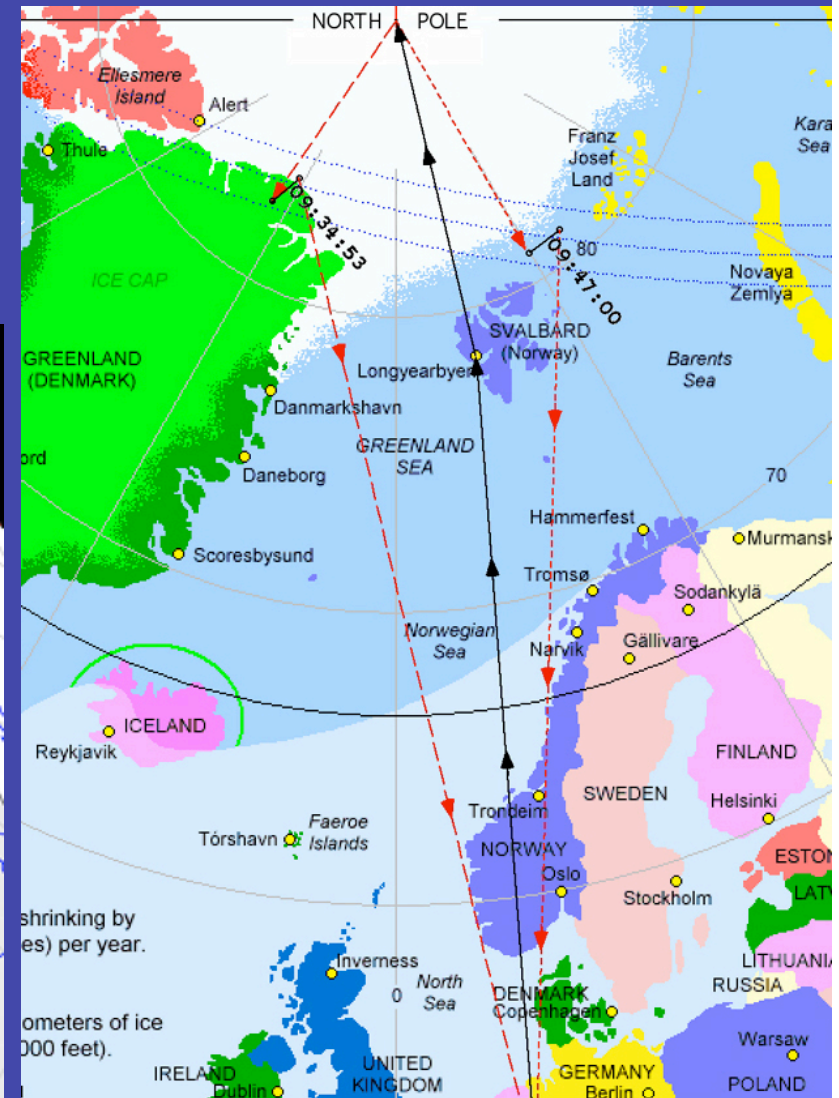
But FIRST! -- TSE 01 August 2008

2m 51s +/-10s of Totality

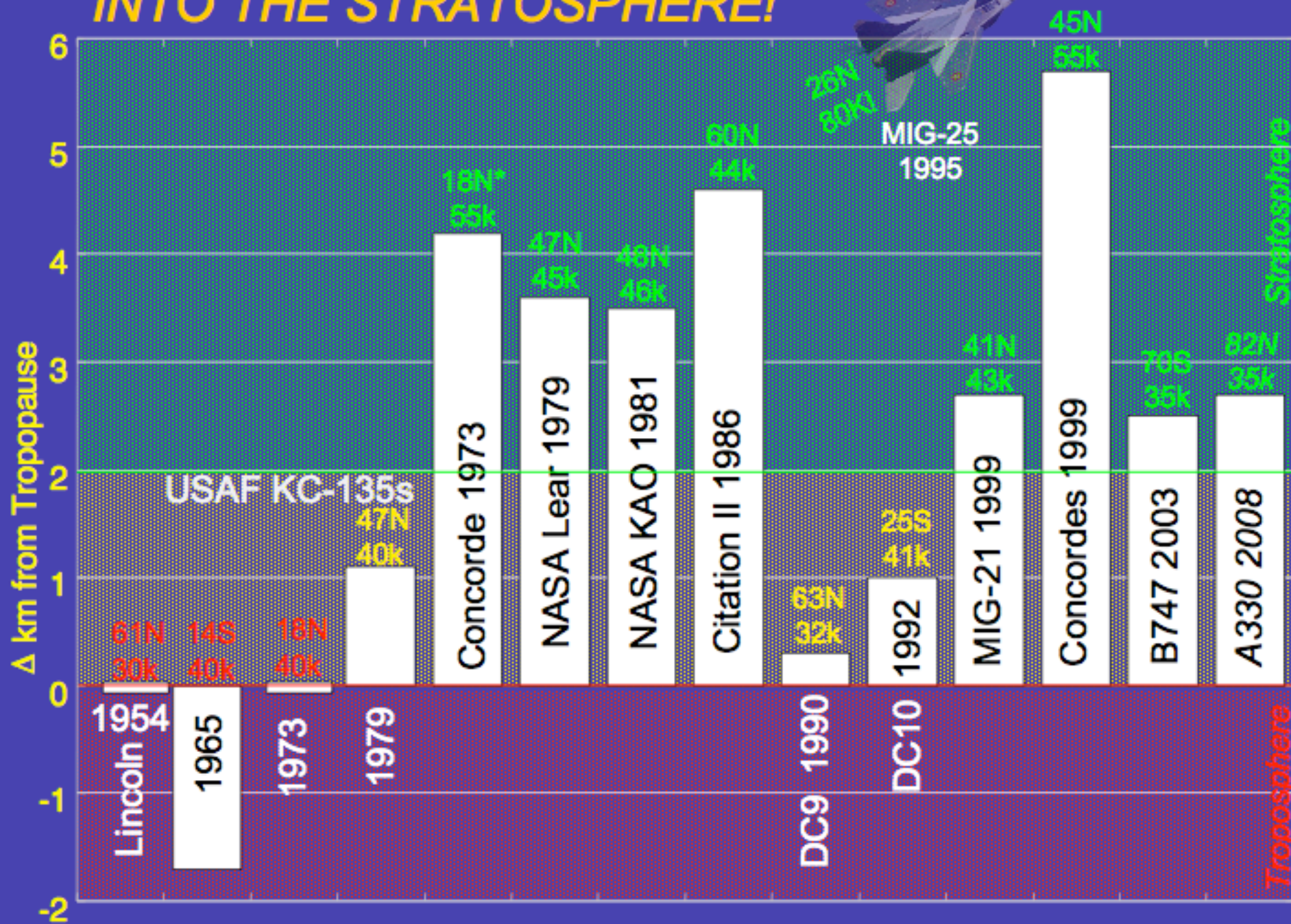
From the Pristine, Clear, and Particulate Free Skies
of the High Polar (81° – 83°) North from 35,000+ feet



Airbus 330-200



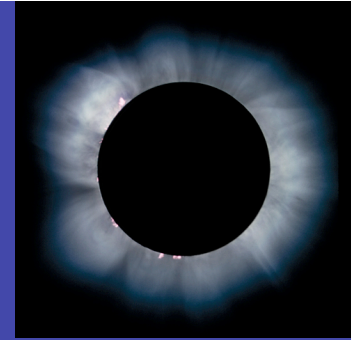
INTO THE STRATOSPHERE!



But FIRST! -- TSE 01 August 2008

2m 51s +/-10s of Totality

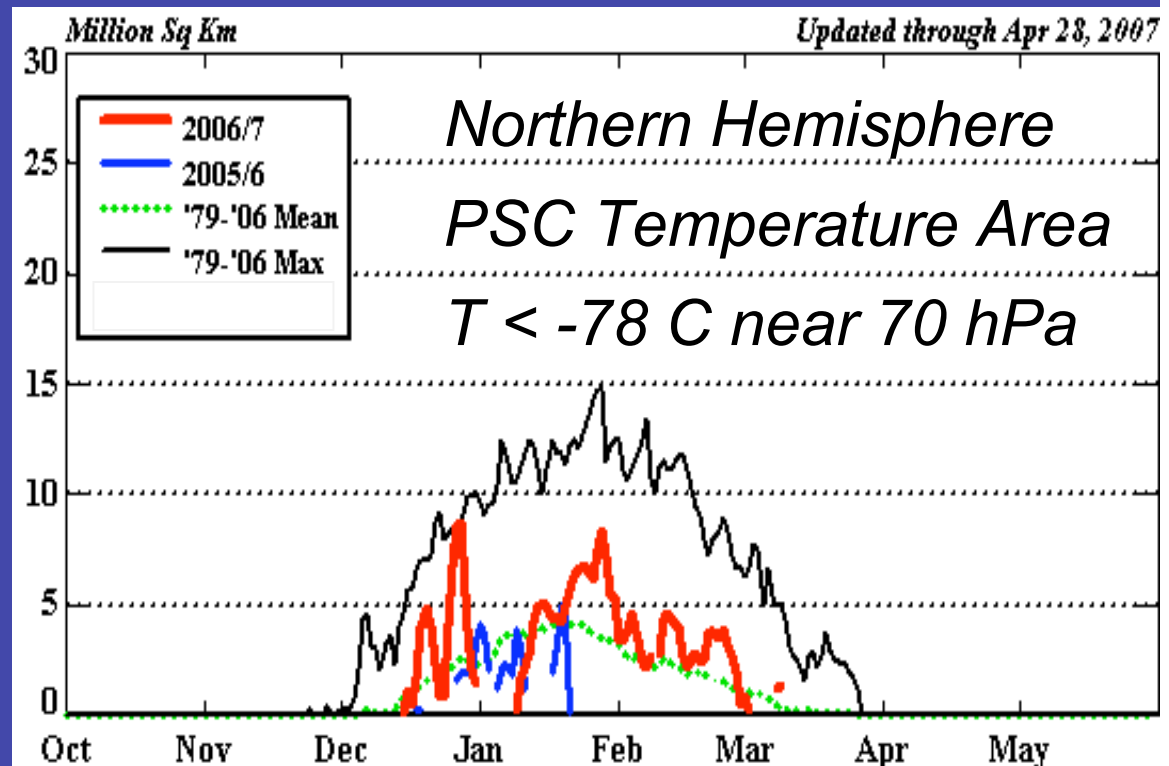
From the Pristine, Clear, and Particulate Free Skies
of the High Polar (81° – 83°) North from 35,000+ feet



At high polar latitudes, the tropopausal boundary between the troposphere below (where "*weather occurs*") and the stratosphere is only 6–9 km AMSL (compared to 12–17 km at mid and low latitudes).

Polar stratospheric clouds
can only form at $< -78^{\circ}\text{C}$,
i.e., during the polar winter,
**making the probability of
cloud-free eclipse viewing
nearly 100%.**

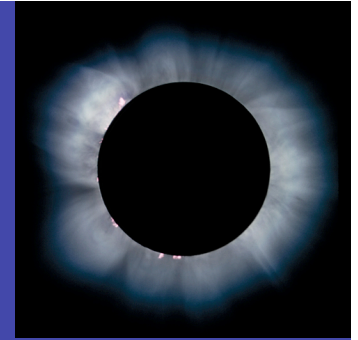
C. Long, NOAA/NWS ->



But FIRST! -- TSE 01 August 2008

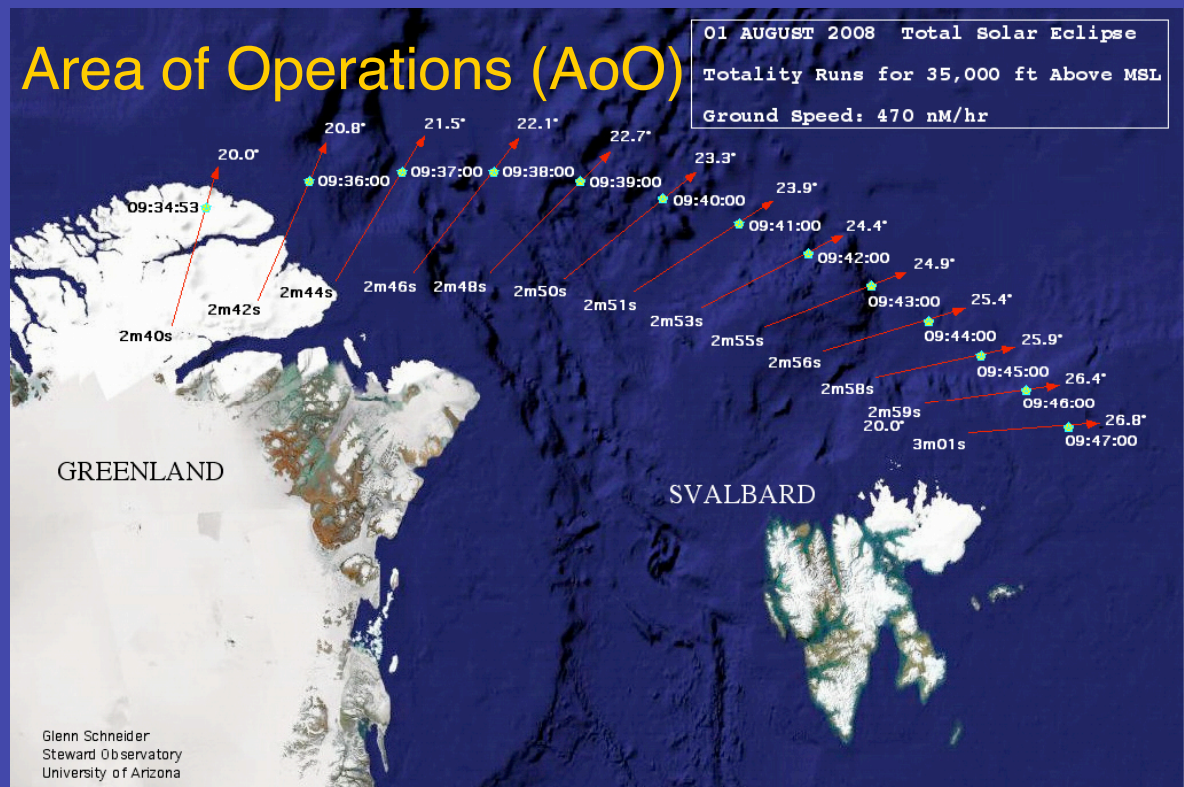
2m 51s +/-10s of Totality

From the Pristine, Clear, and Particulate Free Skies
of the High Polar (81° – 83°) North from 35,000+ feet



In the AoO, aerosol scattering of sunlight by airborne particulates is *extremely* low, resulting in **exceptionally dark skies** during totality, enabling eclipse viewing with significantly enhanced image contrasts.

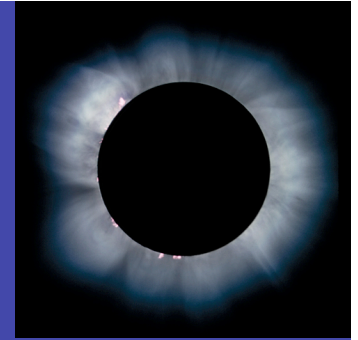
Moreover, the airmass along the line-of-sight to the Sun is significantly reduced (by $\sim 75\%$), resulting in **exceptional sky transparency**, greatly reduced atmospheric turbidity, and significantly **better astronomical "seeing"**.



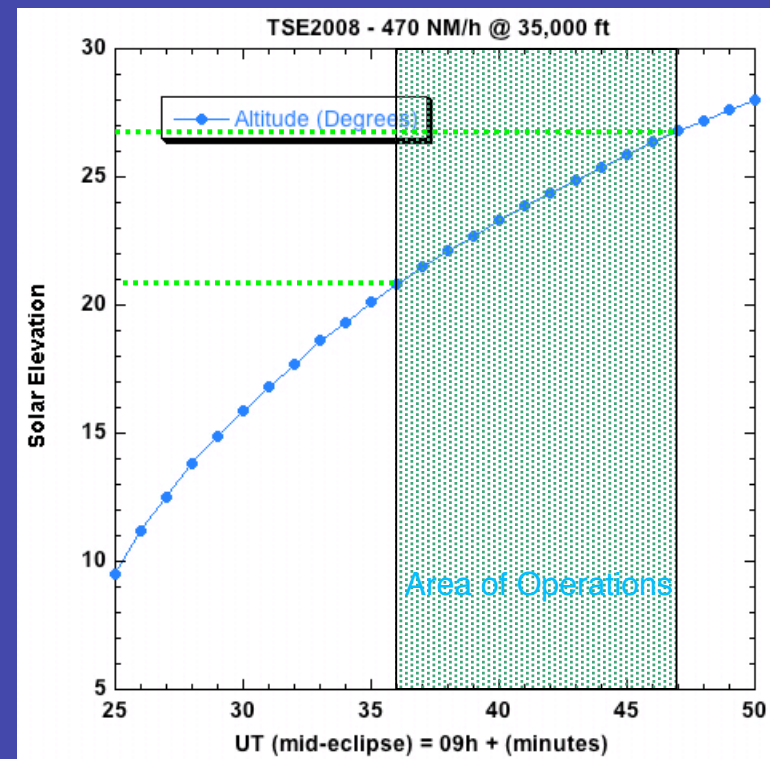
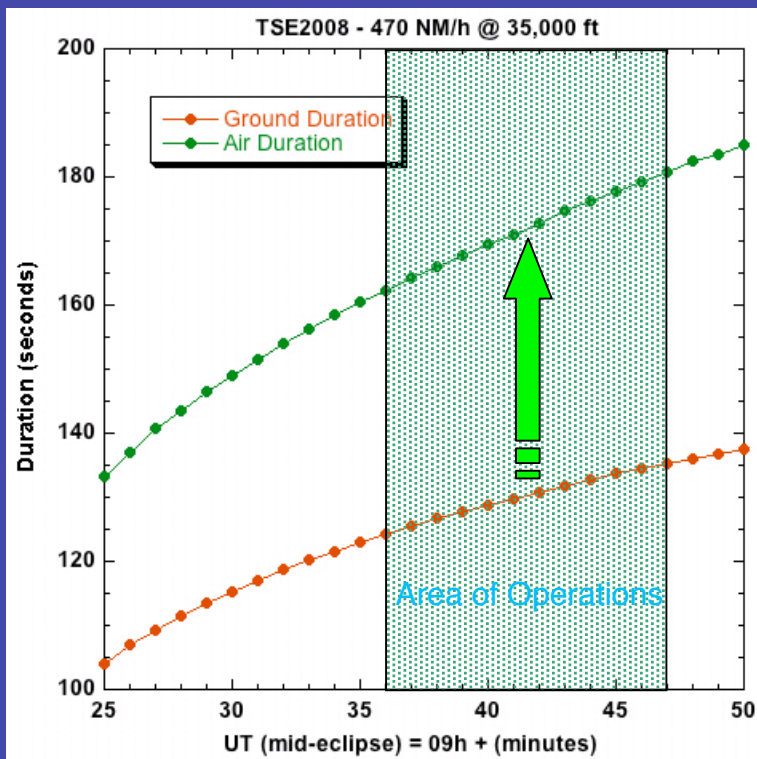
But FIRST! -- TSE 01 August 2008

2m 51s +/-10s of Totality

From the Pristine, Clear, and Particulate Free Skies of the High Polar (81° – 83°) North from 35,000+ feet



In the AoO, the duration of totality will be increased by appx. 40s over the “ground”, with the Sun comfortably positioned and optimally oriented for observations on the starboard side of the aircraft.



But FIRST! -- TSE 01 August 2008

2m 51s +/-10s of Totality

From the Pristine, Clear, and Particulate Free Skies
of the High Polar (81° – 83°) North from 35,000+ feet

[http://nicmosis.as.arizona.edu:8000/
ECLIPSE_WEB/ECLIPSE_08/TSE2008_EFLIGHT.html](http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_08/TSE2008_EFLIGHT.html)

[http://www.tq-international.com/
NorthPoleFlight2008/NPFlighthome.htm](http://www.tq-international.com/NorthPoleFlight2008/NPFlighthome.htm)

