How We Talked from the Moon

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NN4NT

NASA Marshall Space Flight Center

GNU Radio Conference 2019

APOLLO 50

NEXT GIANT LEAP

POWERED BY THE ROCKET CITY

HUNTSVILLE, ALABAMA

How they got the sounds and videos back to Earth

The sounds of Apollo

The key is USB

Extreme SWL

Lots of options for comms

In living color - eventually

We’re gonna do it again

The iconic “beeps” were used to push-to-talk from Mission Control to the ground stations

The Quindar tones were used to command ground stations into transmit and back to receive over phone line from Mission Control

Intro 2525 Hz
transmit

Outro 2475 Hz
listen

Constant S-band carrier was sent to the spacecraft for tracking

PRN code from ground was returned by spacecraft and range was determined

The Apollo Snoopy Cap carried the headphones and microphones

The magic is USB – Unified S-Band System

APOLLO UNIFIED
S-BAND SYSTEM CAPABILITIES

GROUND TO SPACECRAFT

1. VOICE
2. DIGITAL COMMANDS
3. RANGING SIGNALS

SPACECRAFT TO GROUND

1. VOICE
2. TELEMETRY
3. TELEVISION
4. BIOMEDICAL DATA
5. RANGING
6. EMERGENCY VOICE
7. EMERGENCY KEY

Figure 1. Apollo Unified S-Band System Capabilities

SPACECRAFT COMMUNICATED WITH
VIA UNIFIED S-BAND SYSTEM

1. COMMAND MODULE
2. LEM
3. SATURN S-IVB

Figure 4. Spacecraft Communicated with Via the Unified S-Band System

NASA TM X-55492 1966

Unified S-band System

https://www.ab9il.net/images/apollo-usb-transponder.jpg

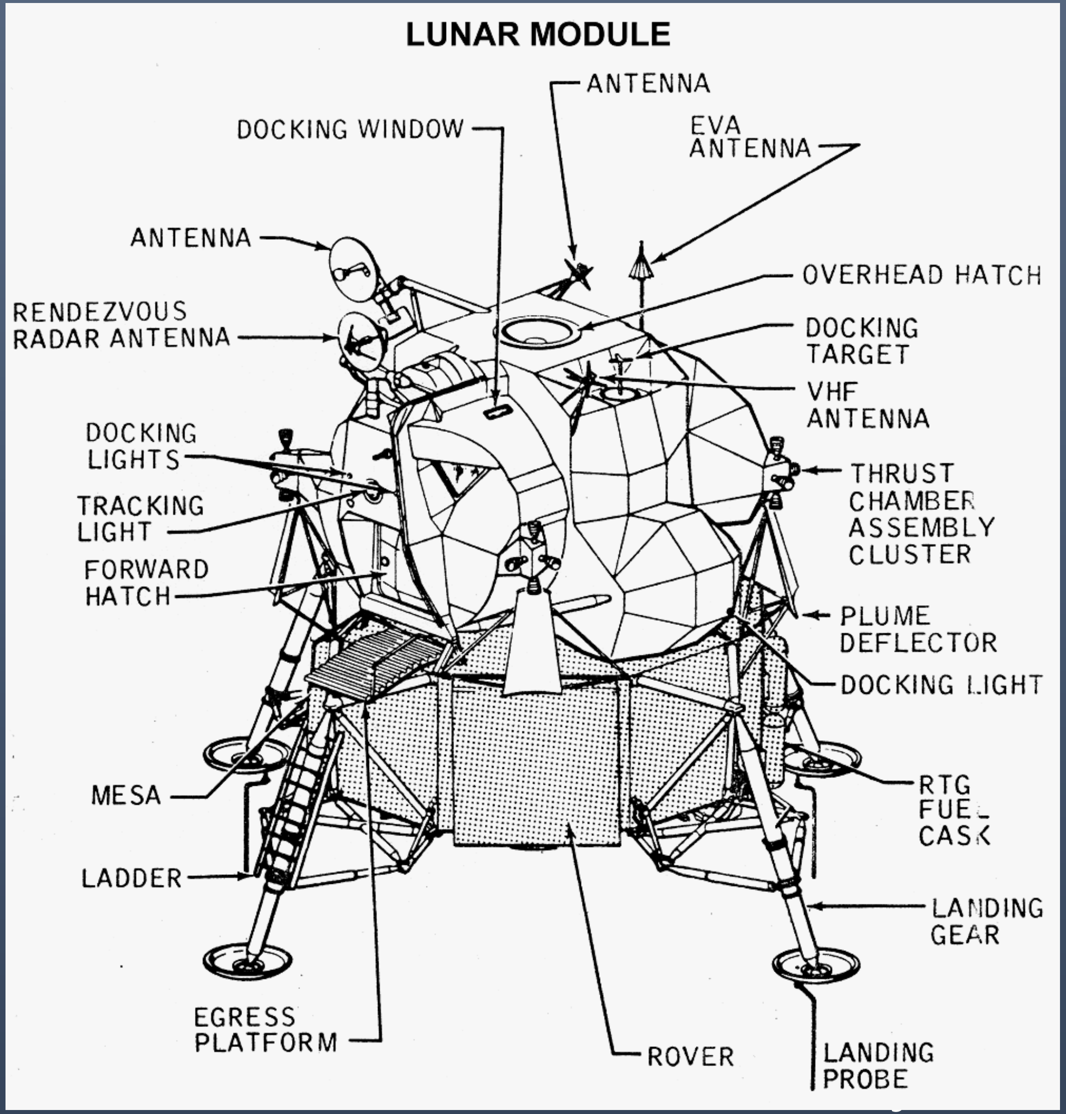
Both spacecraft had numerous antennas for S-band and VHF

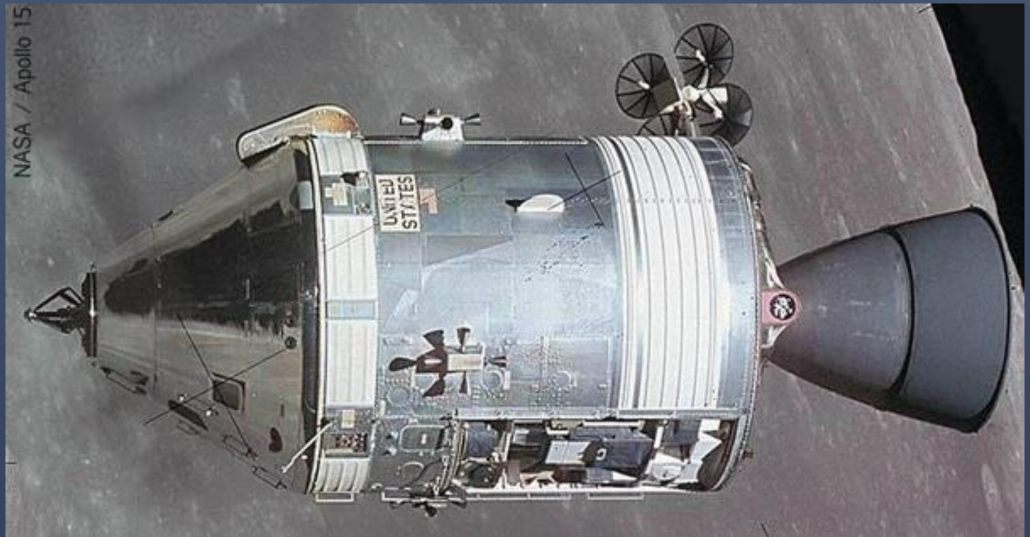
Command Service Module

- 4 omni antennas were body-mounted
- 4 dish High Gain Antenna

Lunar Module

- 2 omni antennas
- 2 VHF + 1 for linking EVA crew to Earth
- 1 S-band high gain and 1 radar dish





GROUND ANTENNAS

1. 30 FOOT PARABOLA WITH CASSEGRAIN FEED SYSTEM:
2. 85 FOOT PARABOLA WITH CASSEGRAIN FEED SYSTEM:

GROUND SYSTEM CHARACTERISTICS

1. POWER AMPLIFIER - KLYSTRON

   POWER OUTPUT - 20 kw cw

2. PREAMPLIFIER - PARAMETRIC AMPLIFIER

   GAIN - 20 db

   NOISE FIGURE - 1.7 db

   BANDWIDTH - 30 Mc

3. CARRIER FREQUENCIES - UPLINK

   2106.4 Mc COMMAND MODULES

   2101.8 Mc LEM OR S-IVB

4. VOICE SUBCARRIER

   FREQUENCY - 30 kc

   FM MODULATION - 100 cps TO 3 kc

5. UPDATA SUBCARRIER

   FREQUENCY - 70 kc

   MODULATION - 1 kc SYNC TONE; 2 kc SINE WAVE BI-PHASE MODULATED AT 200 cps

6. RANGE CODE

   LENGTH OF SHORT CODE - L_1 - 70 MILLISEC

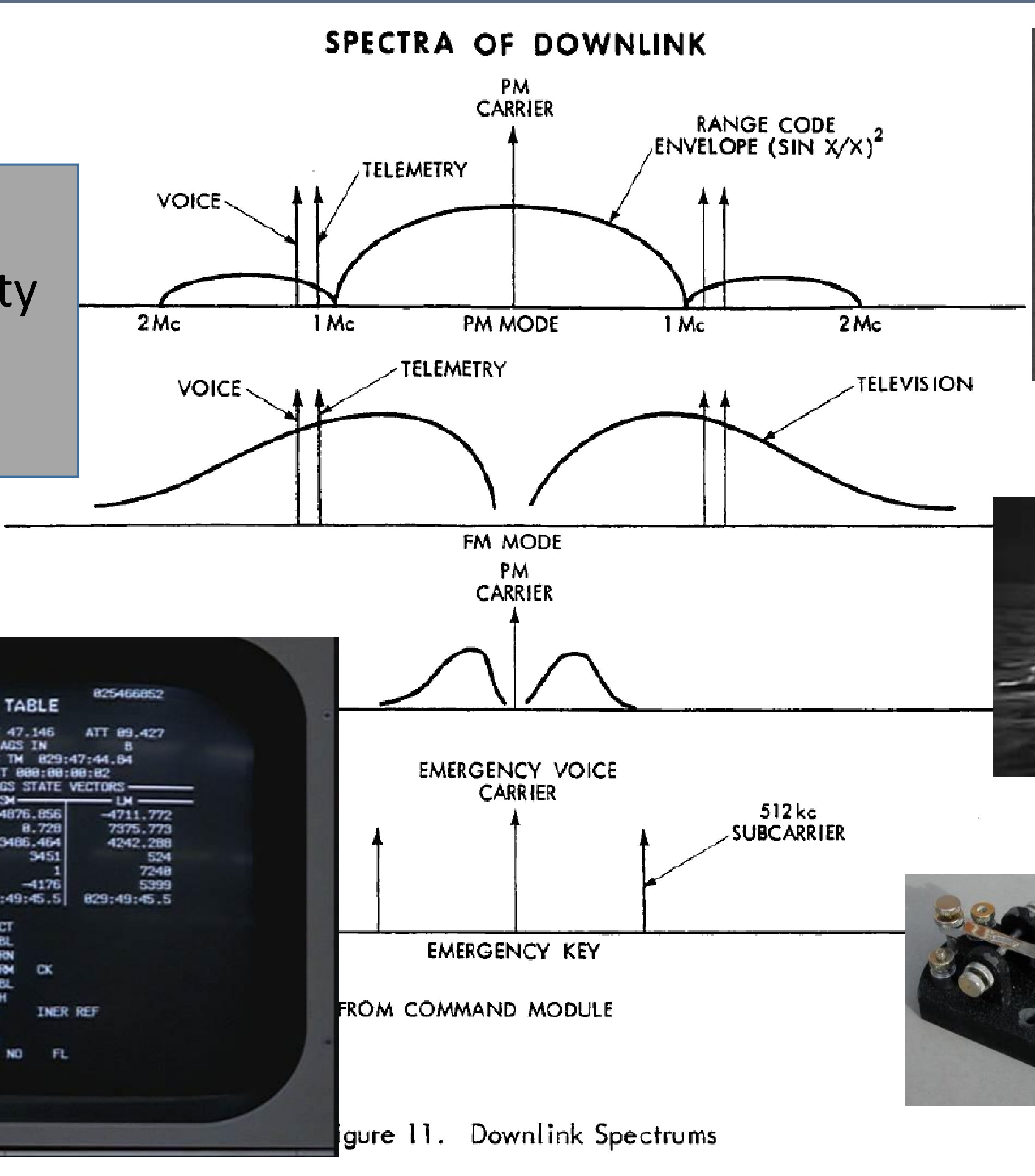
   LENGTH OF LONG CODE - L_2 - 5.4 SECONDS

NASA TM X-55492 1966

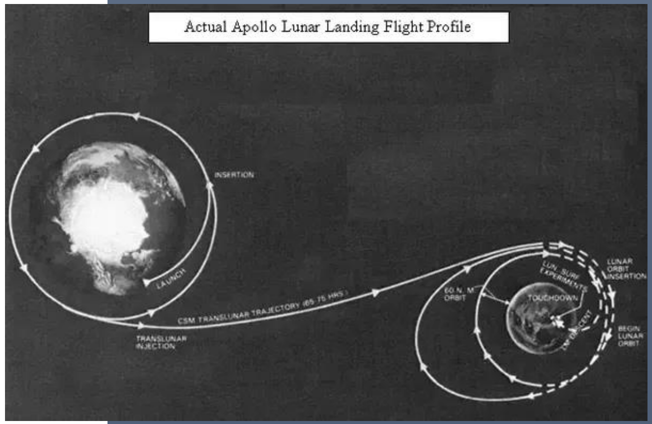
Figure 7. Ground System Characteristics

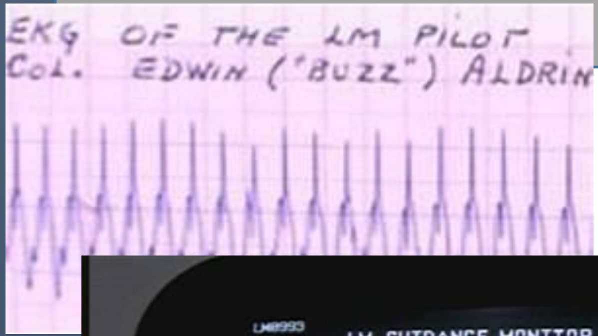
85 foot dish at Honeysuckle Creek Australia
https://www.honeysucklecreek.net/station/index.html

"Houston, Tranquility Base here…"



gure 11. Downlink Spectrums





NAS

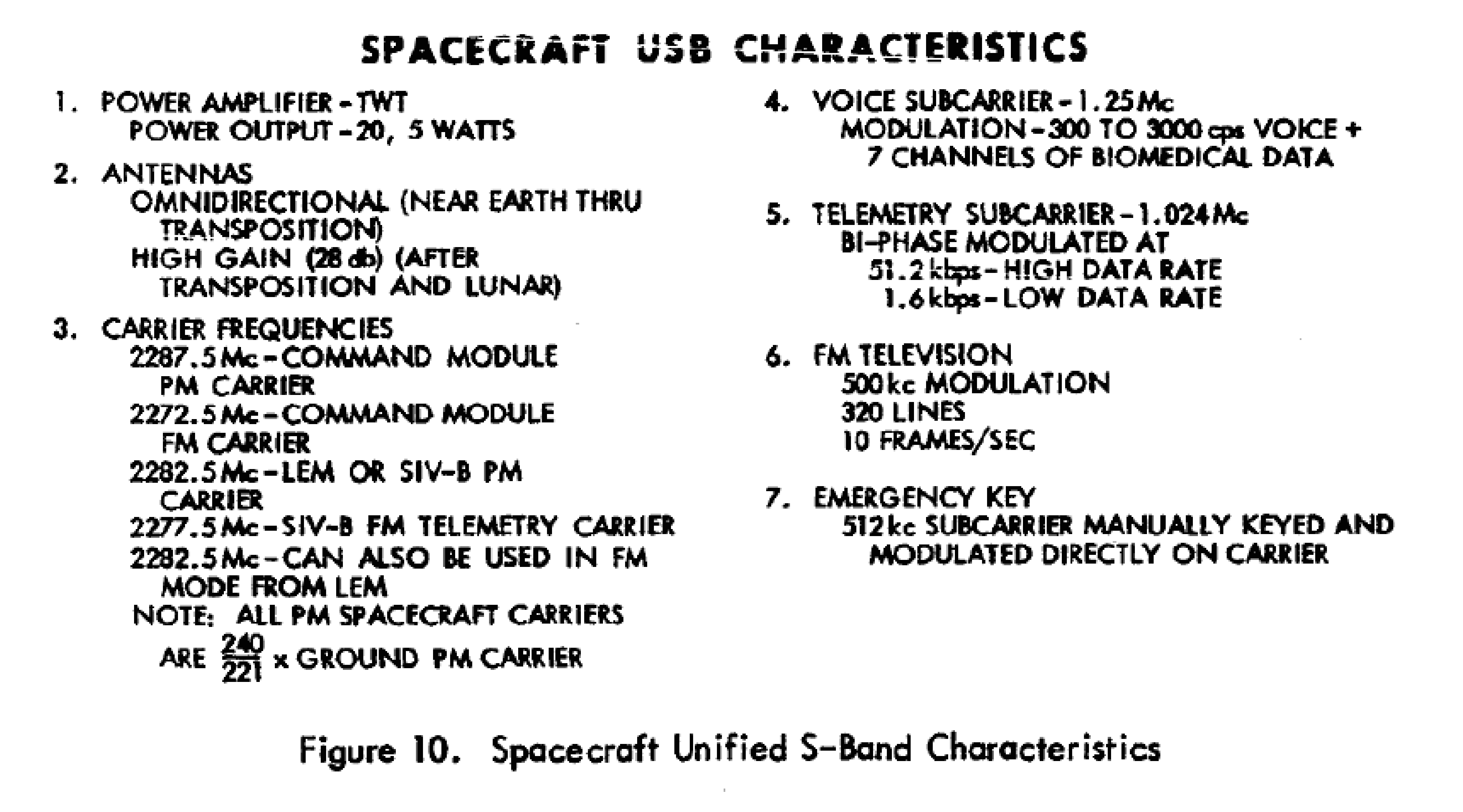


Figure 10. Spacecraft Unified S-Band Characteristics

NASA TM X-55492 1966

Hams received some S-band from the CSM in lunar orbit

"Houston, This is Apollo . . ."

BY PAUL M. WILSON,* W4HHK AND RICHARD T. KNADLE, JR.,** K2RIW

EQUIPMENT ORIGINALLY BUILT by W4HHK for 2304-MHz EME and tropo scatter experiments has been successfully used to receive 2287.5-MHz signals from Apollo 10, 12, 14 and 15 spacecraft in lunar orbit.[1,2,3,4] It was not until the Apollo 15 mission, however, that successful reception of voice transmissions from the Command Service Module (CSM) was achieved. This occurred at 0026 GMT on the morning of August 1, 1971, when the partially quieted fm receiver suddenly quieted completely and the voice of CSM pilot Al Worden was heard loud and clear from the speaker! Unprepared for this reception, I was caught without the tape recorder connected to the receiver. It was an exciting moment I shall always remember. Minutes later the signal cut off sharply as the spacecraft went behind the moon. Initial reception of the Apollo 15 CSM had been made the previous day at 2121 GMT. Unlimited monitoring of the Apollo 15 mission (and others) was not possible because of a regular work schedule and the changing lunar position. The

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** 816 Vanderbilt Parkway, Dix Hills, NY 11746

[1] Tilton, "To the Moon and Back — on 2300 MHz," *QST*, July, 1969, p. 54.
[2] Wilson, "A 2.3-GHz Crystal-Controlled Converter," *QST*, April, 1971, p. 34.
[3] Smith, "The World Above 50 Mc.," *QST*, December, 1970, p. 92.
[4] Fisk, "Parametric Amplifiers," 73, 1964, p. 58.

The lunar exploration which the Apollo astronauts are currently undertaking is one of the most exciting technical events of the decade. For amateurs who wish to take part in these events and learn much about modern space communications networks, direct reception of the Apollo transmitter while it is in lunar orbit is possible for the dedicated amateur, using mostly amateur equipment. This article describes two quite different equipment setups; according to NASA, they are one of the first independent stations in the world which have demodulated the Apollo S-band voice signals from a lunar distance.

Apollo 16 took off on April 16; Apollo 17 (which may be the last manned mission) is scheduled for December 9, 1972. The equipment that amateurs assemble for these missions will not gather dust, because it will have the possible capability of receiving Pioneer F and G (1973 Jupiter fly-bys), Helois (1974 sun probe) and Viking (1975 Mars lander) probes, since they all will transmit between 2265 and 2300 MHz. Also tropo and EME experiments in the 2300-2450 MHz amateur band are possible the year round, as W4HHK has discovered.

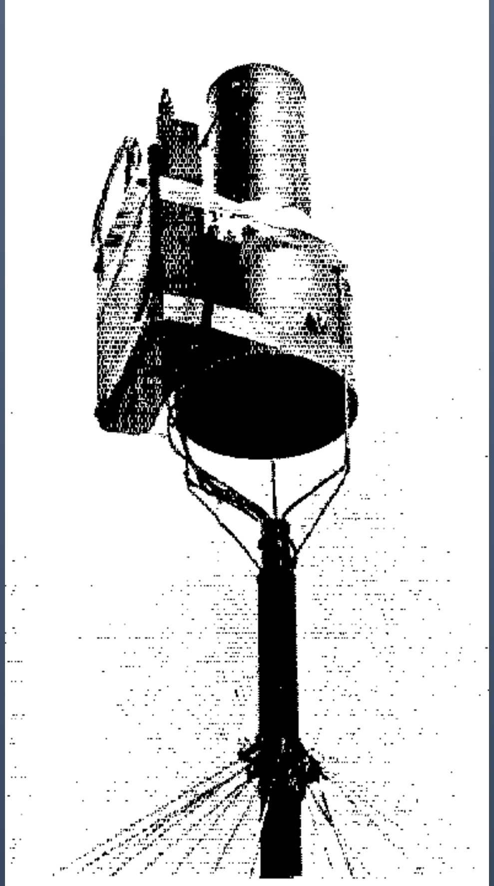
The first section of this article, by W4HHK, describes the use of a commercially manufactured 18-foot diameter dish and a homemade receiver which have been used to receive signals since Apollo 10 and which achieved voice reception of Apollo 15, as well as the first 2300-MHz EME QSO. The second section, by K2RIW, describes the use of a home-constructed 12-foot diameter dish combined with a receiver, made up of commercially manufactured amateur equipment and laboratory instruments which recorded 3-3/4 hours of voice reception from the Apollo 15 astronauts. This accomplishment resulted in K2RIW's visit to the NASA Manned Spacecraft Center in Houston.

From QST June 1972


APOLLO 15
SCOTT WORDEN IRWIN


HATCH ADAPTER COVER

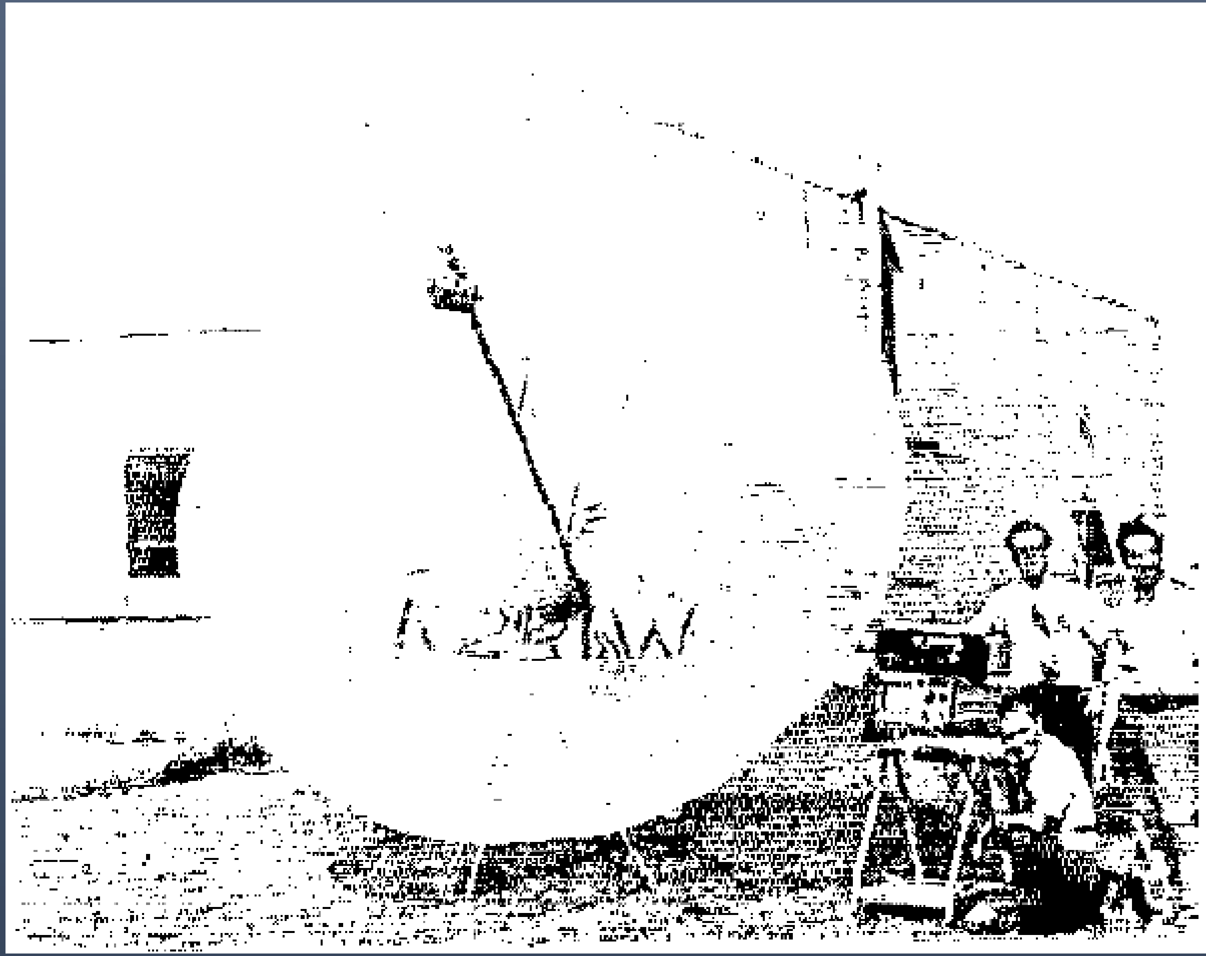
Richard Knadle K2RIW and Paul Wilson W4HHK independently received the Apollo 15 signals



Heard Al Worden in
Apollo 15 CSM
in lunar orbit and crew
during return cruise.
13.2 w 2287 MHz

K2RIW Feed horn made from American paint can and Scottish oatmeal can

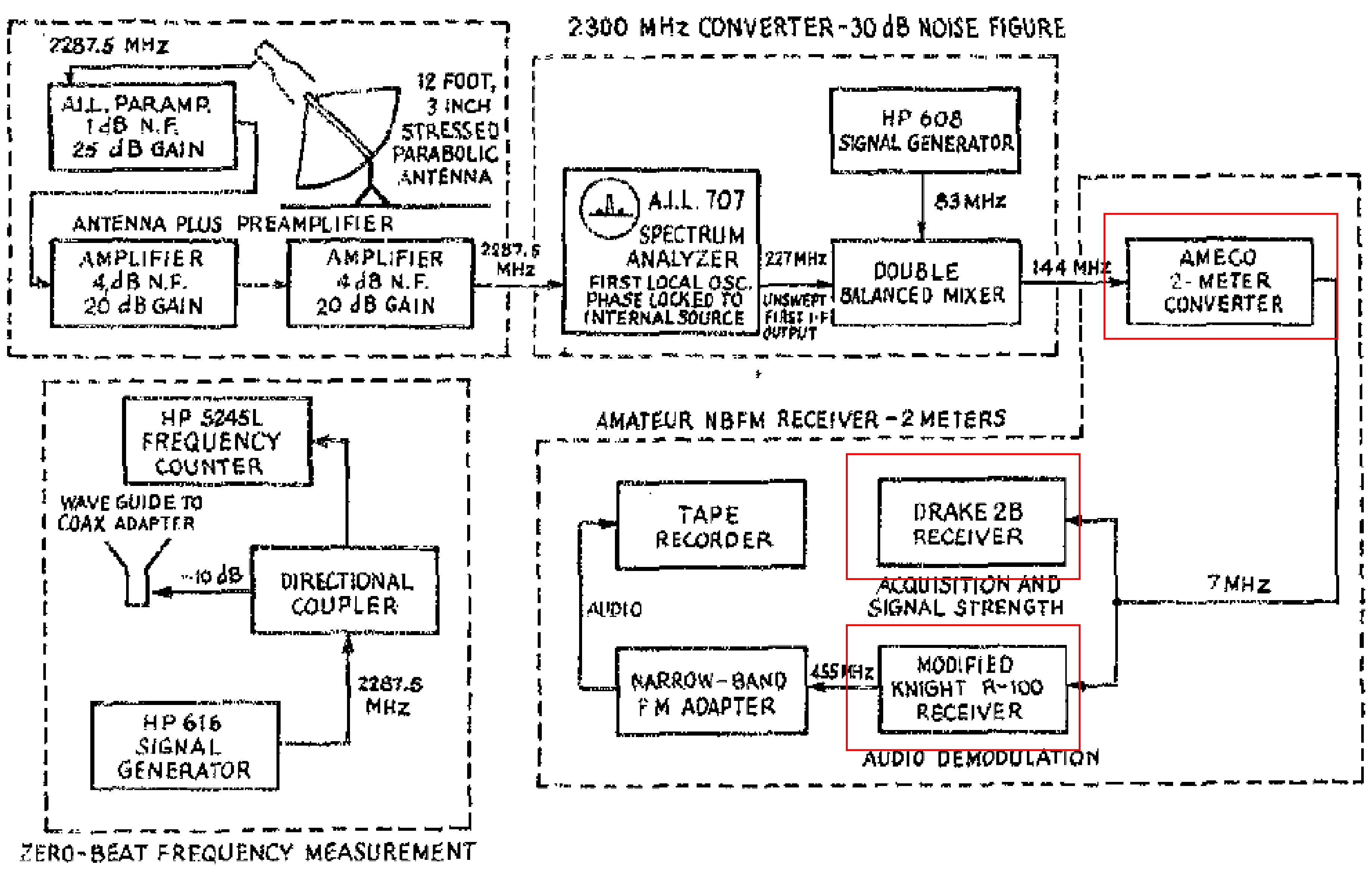
From QST June 1972



12 ft diameter wire mesh dish

K2IRW's system used some amateur radio components

Richard is still active
on 10 GHz and VHF/UHF



AUDIO DEMODULATION

Fig. 3 — (A) Apollo 15 reception system used by K2RIW. (B) Phase-locked loop system used to receive Apollo signals on the return trip from the moon.

There were better results with Apollo 16

Detected Lunar Module carrier and from doppler could see touchdown

Detected Earth-based uplink via EME

Detected 1W signals from ALSEP scientific packages

to Apollo 15. Results with Apollo 16 were even better. Dick and his associates have about ten hours of voice tape of the Command Service Module (CSM). They listened to the carrier of the Lunar Module (LM) but could not get the audio, the signal being too weak because of failure of the LM's high-gain antenna system. By observation of the Doppler they were able to tell when the LM landed on the moon's surface.

Dick had asked Houston for the frequencies used for talking to the mission, in the hope that they might be able to hear Houston by EME. Houston supplied the frequencies (2106.4 MHz for the CSM uplink, 2101.8 for the LM uplink) but doubted that EME reception would be possible. Both were received, with interesting and potentially useful characteristics. The level varies widely, but the frequency remains almost constant. Some of the LM uplink phone (30-kHz subcarrier) during the time of LM liftoff from the moon is readable. The tapes show all the EME qualities that 2300-MHz moonbouncers will have to cope with.

Next, they found the 1-watt signals from all four ALSEP packages, left on the moon by Apollo missions. These are on 2278.5 (Apollo 12), 2279.5 (14), 2278.0 (15), and 2276.0 MHz (16). At some 3 dB above the receiver threshold, they are probably the best weak-signal sensitivity testers we're likely to have for 2300-MHz work, sinc e they are nuclear-powered, presumably for some 10 years of life. They run 24 hours per day, and are available whenever you can see the moon. If your antenna gain minus system noise figure is 32 dB, you can hear ALSEP -- and you have enough for voice reception from the lunar vehicles, CSM, LM, and Lunar Rover. You have until December to find out!

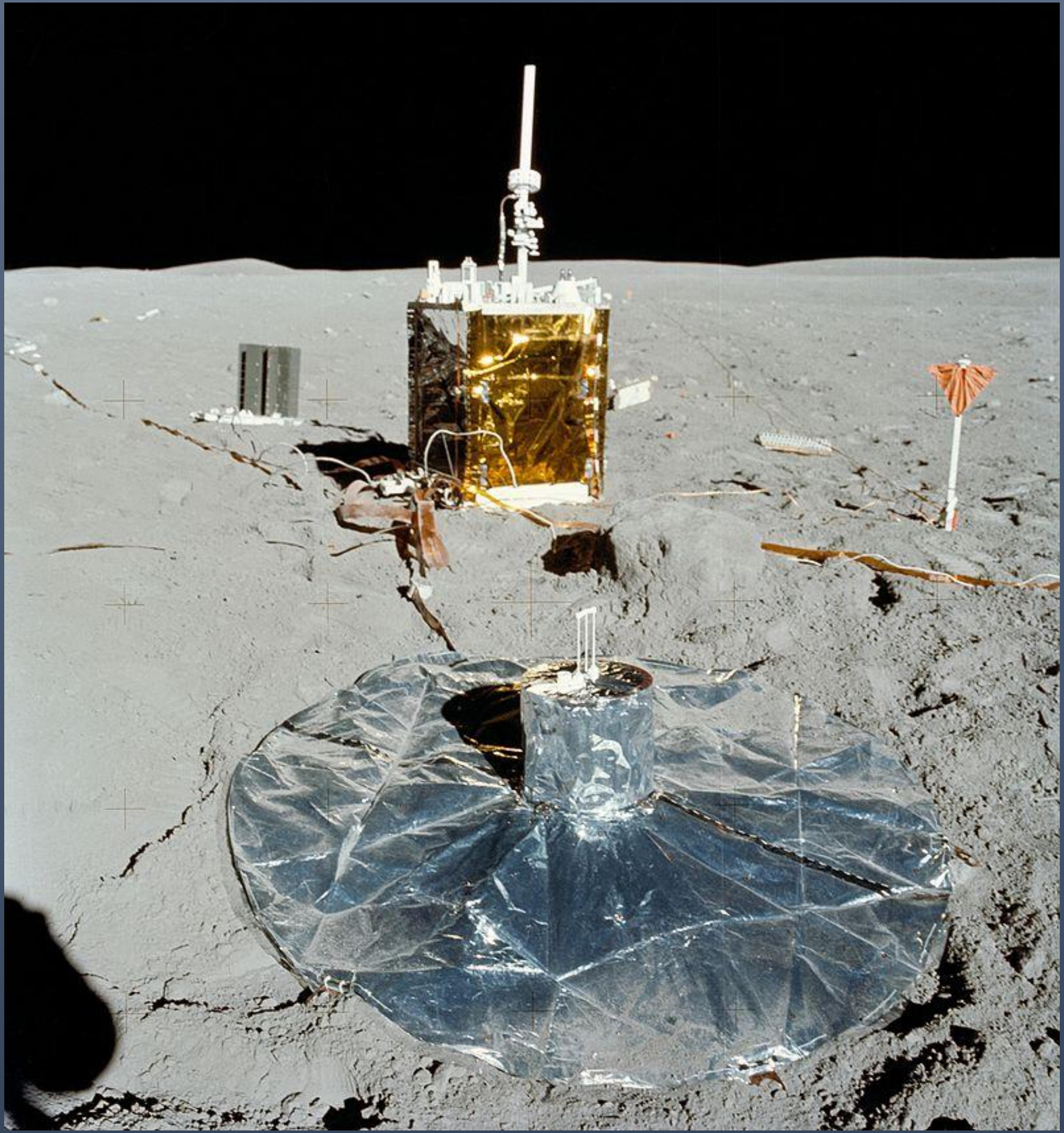
From QST July 1972, World Above 50 MHz

Apollo 16 ALSEP

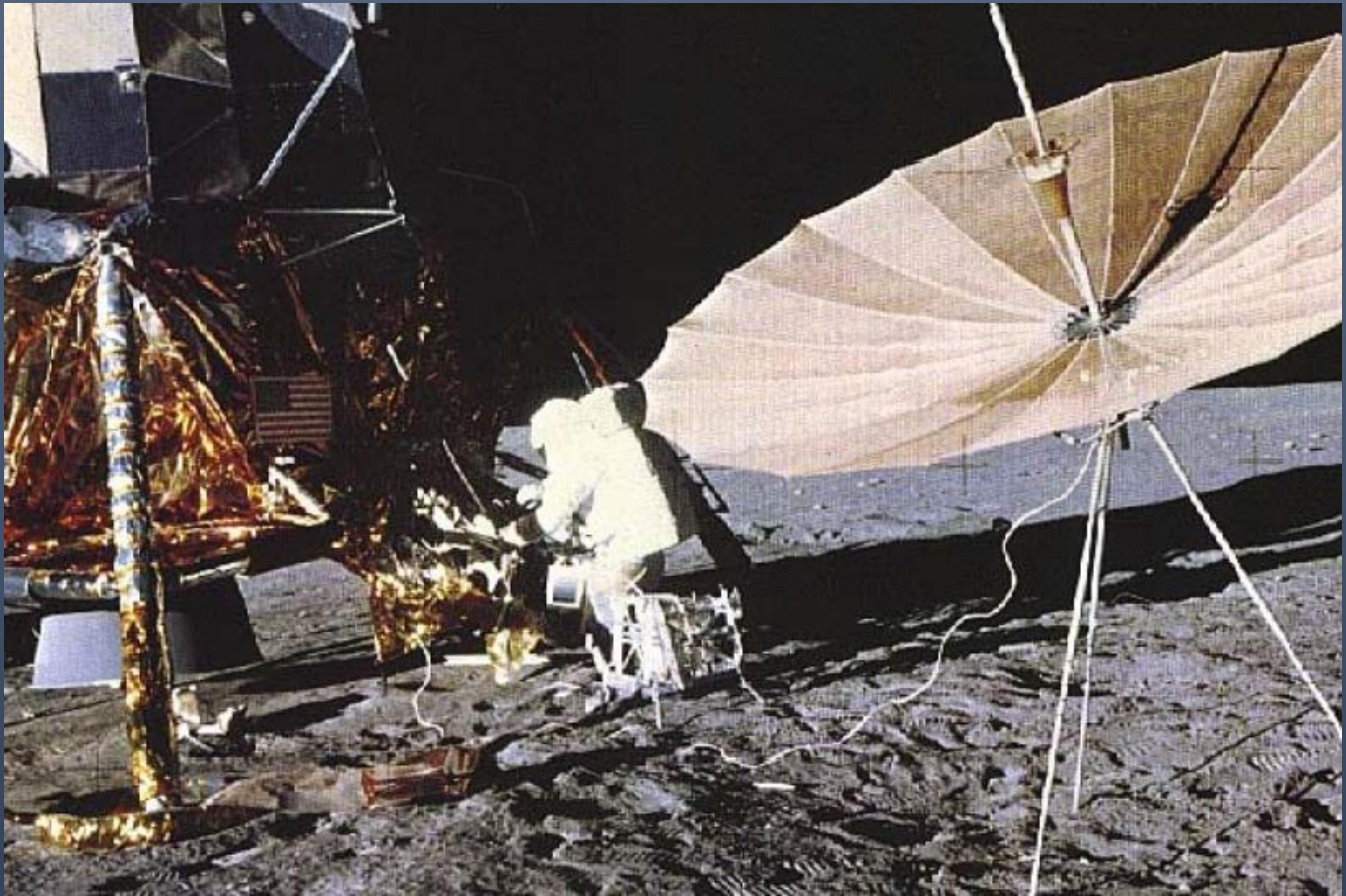
Apollo Lunar Surface Experiments Package

1W S-band

Passive Lunar Seismic Experiment
Lunar Tri-axis Magnetometer
Medium-Energy Solar Wind
Suprathermal Ion Detection
Lunar Heat Flow Management
Low-Energy Solar Wind
Active Lunar Seismic Experiment
SNAP-27 isotopic power system

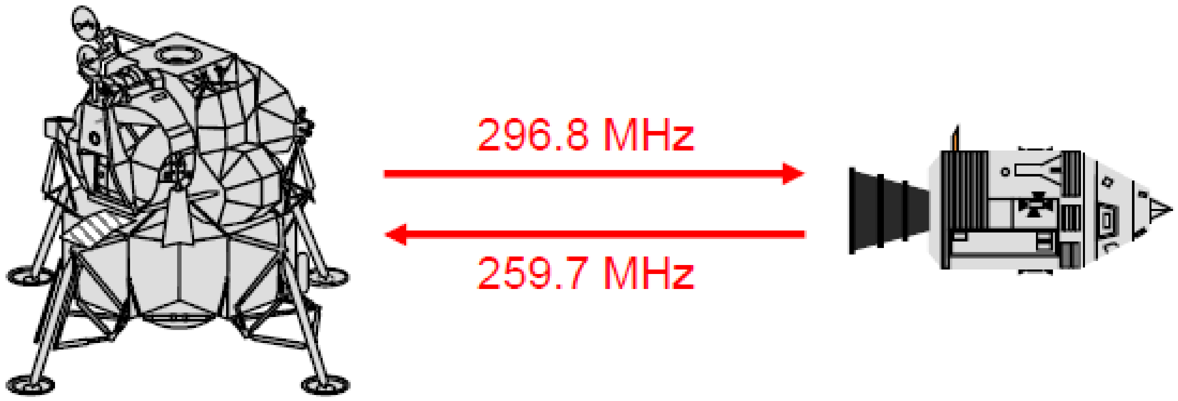


The S-band and VHF systems allowed various direct and relay configurations



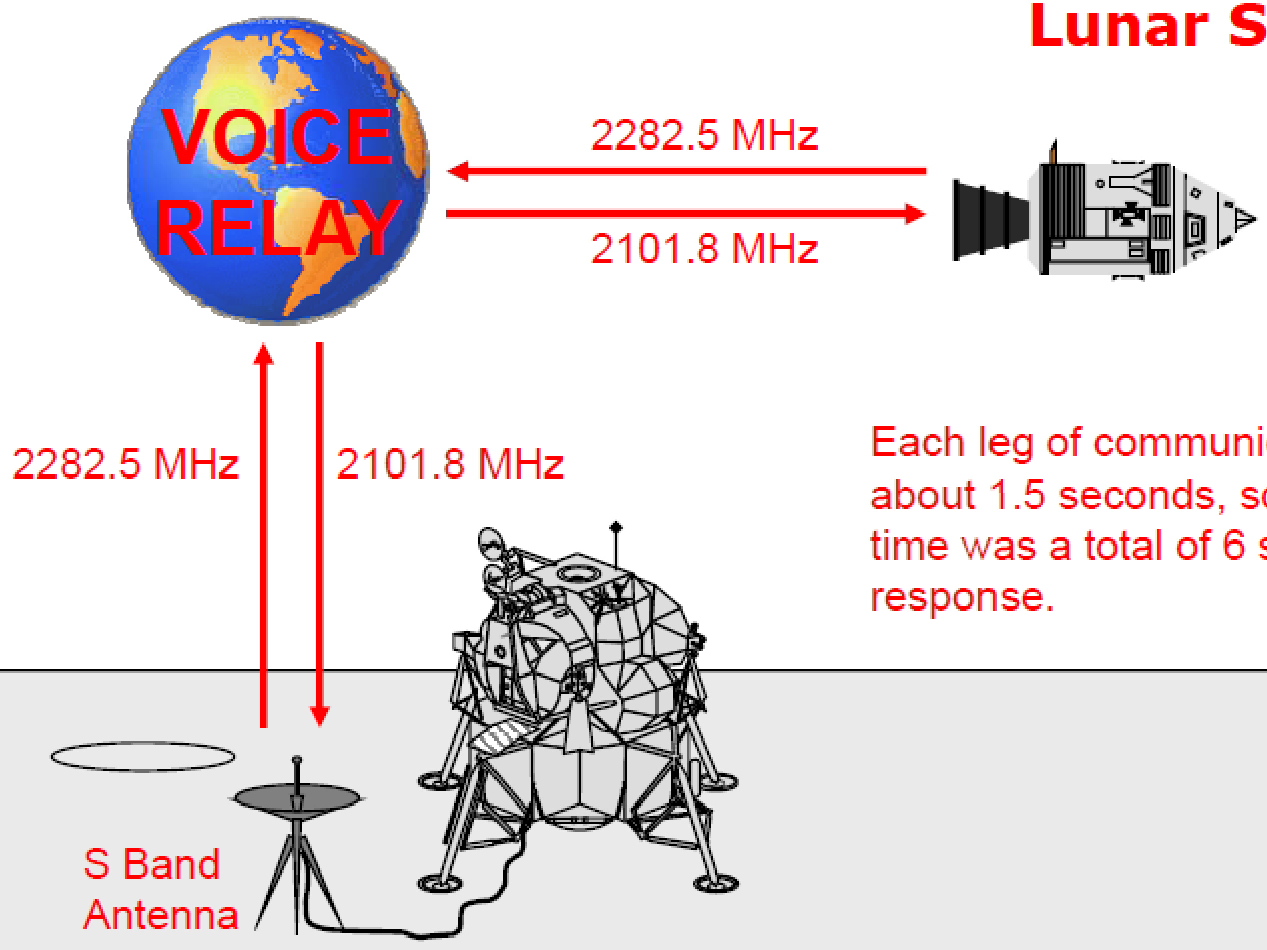
Earth Line of Sight Comm

Note:
296.8 MHz = VHF Channel A
259.7 MHz = VHF Channel B



Duplex Operations = Transmit and Receive on different frequencies
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090015392.pdf

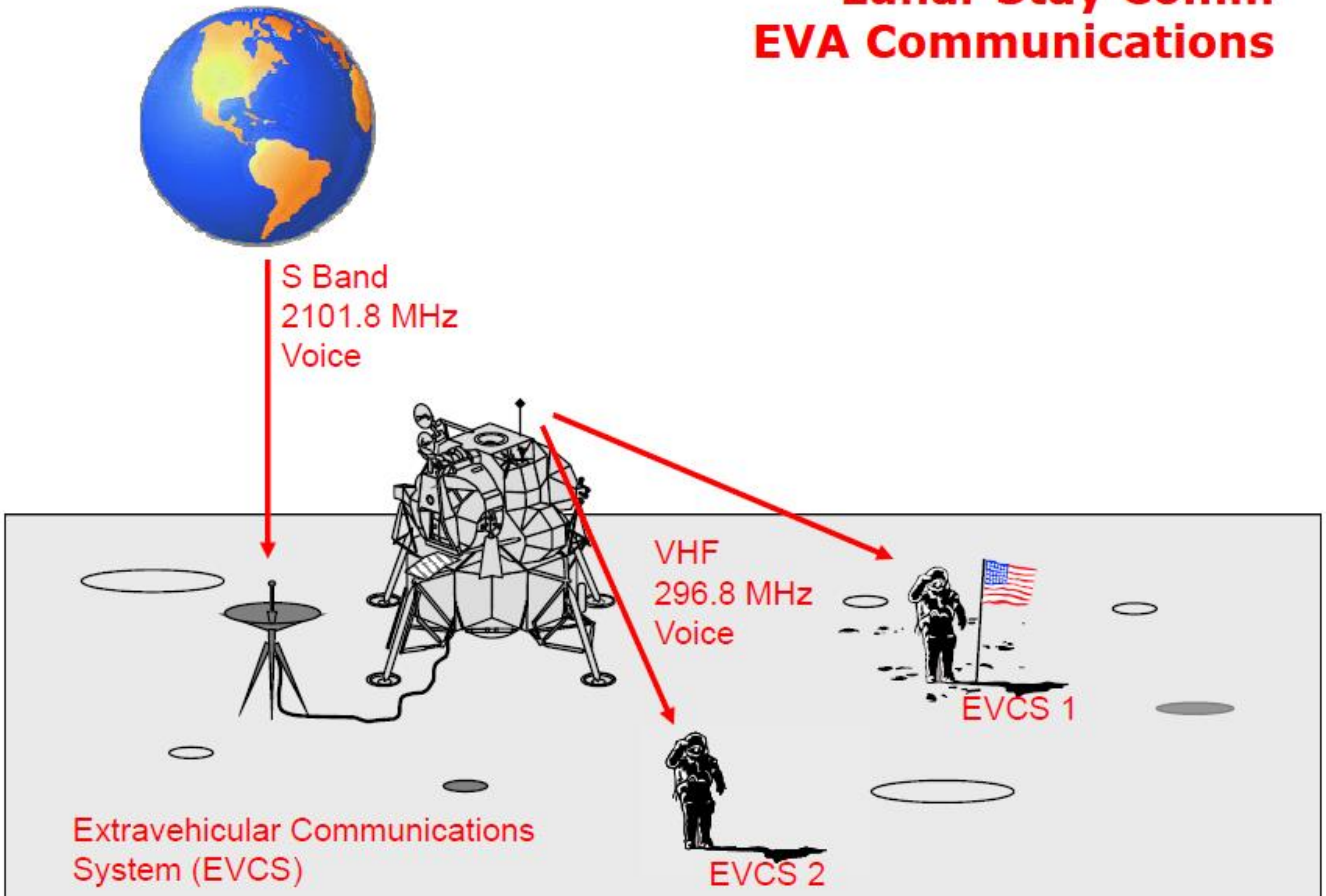
Lunar Stay Comm



Each leg of communications took about 1.5 seconds, so turnaround time was a total of 6 seconds for response.

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090015392.pdf

Lunar Stay Comm
EVA Communications



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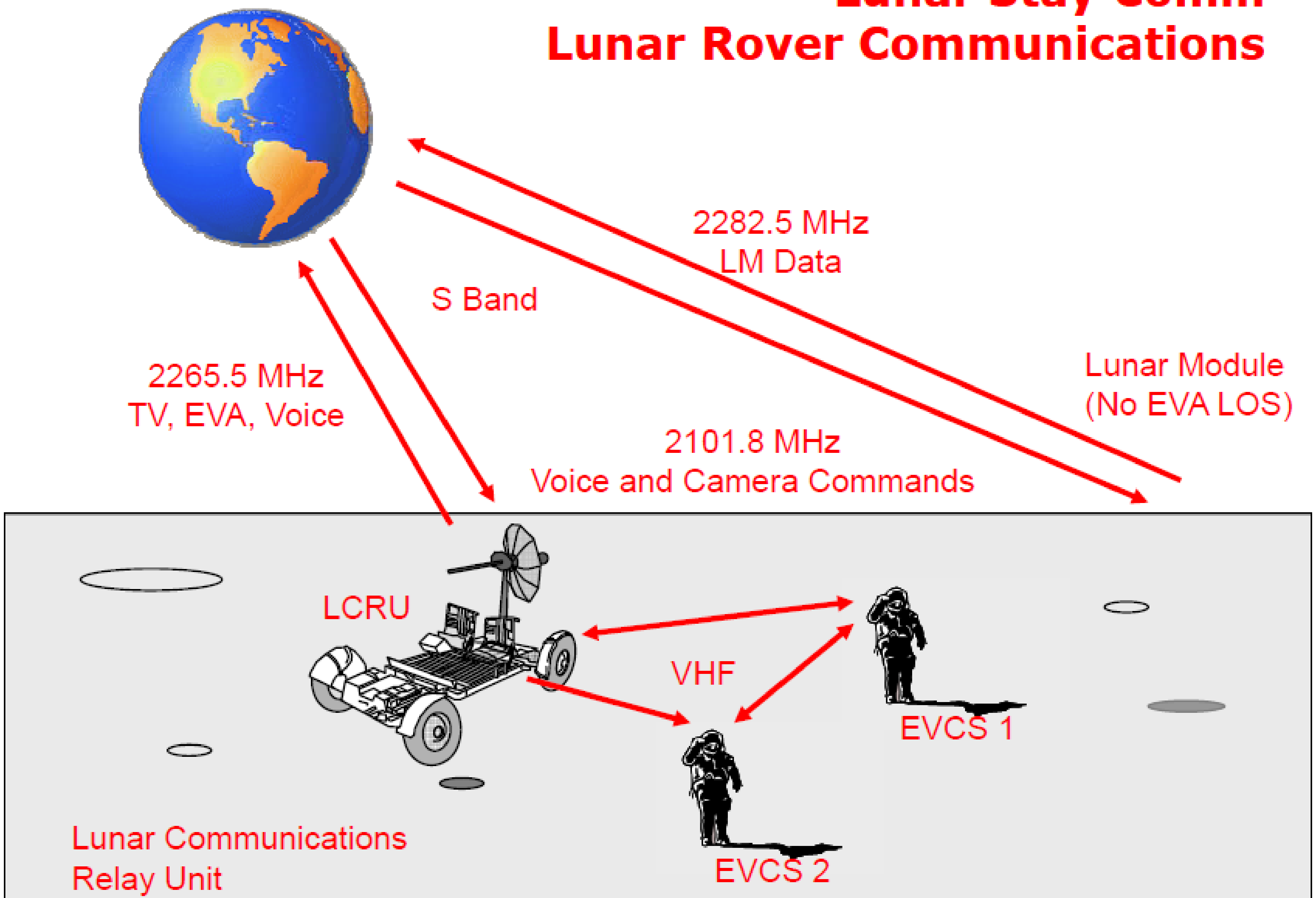
Lunar Stay Comm
Lunar Rover Communications



https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090015392.pdf

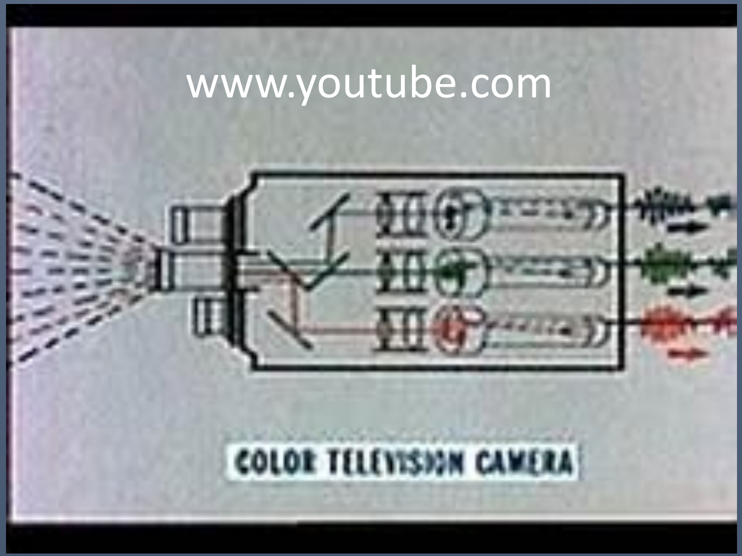
Television used B&W vidicon detectors

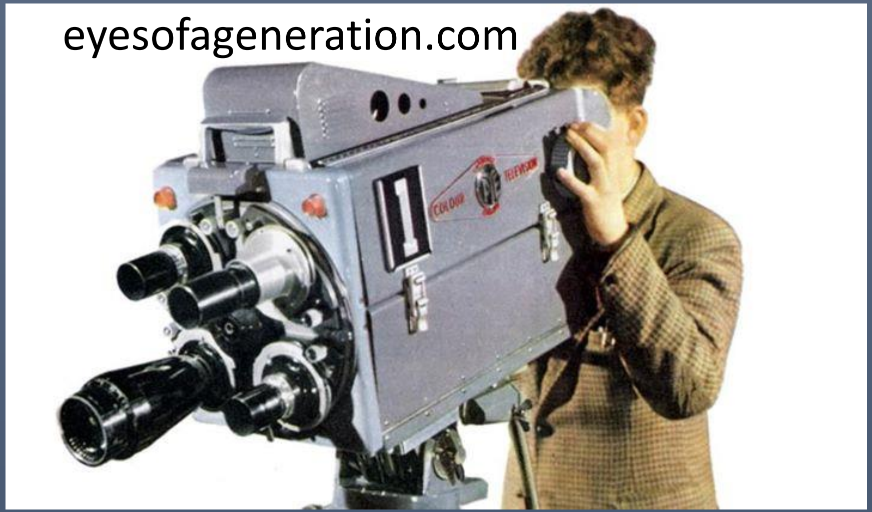
Video used S-band auxiliary signal bandwidth ~ 0.4 MHz (broadcast TV uses 6 MHz)

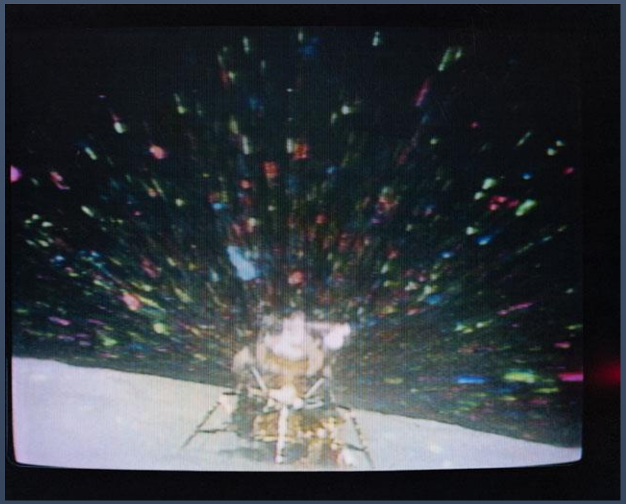
Black and white was 10 frames per second of 320 lines

Standard video was generated at the ground station by pointing a camera at a 10 fps screen, recording that to a magnetic disk and replaying that frame 5 times to create 30 fps (60 fields/sec)

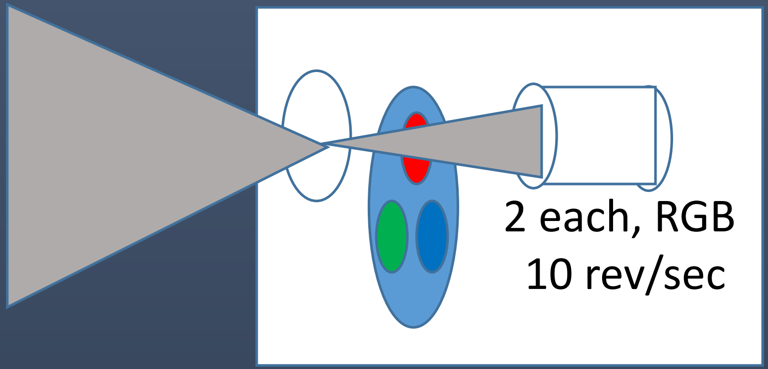
How to get color TV from a B&W vidicon







spaceflight.nasa.gov



200 lines, 60 fields per second = 2 MHz bandwidth signal which required significant filtering to avoid interference from other S-band components

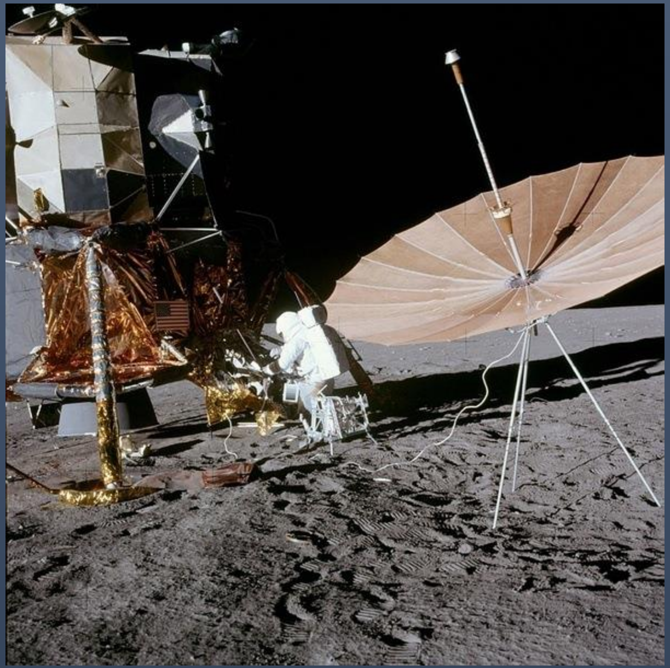
Video tape was used to correct video sync for doppler

A magnetic disk recorder spinning at 3600 rpm (1/60 sec) recorded RGB on 6 separate tracks which were read simultaneously with multiple heads and combined to produce a standard color video signal

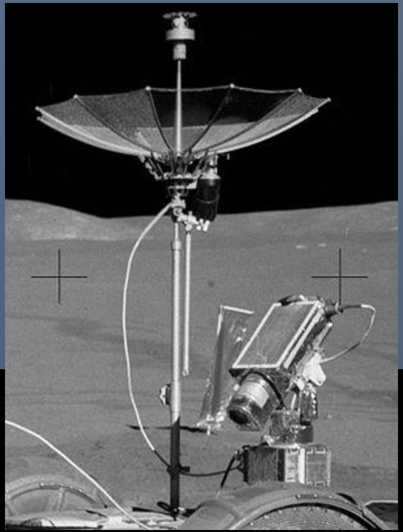
S-band antennas enabled color video

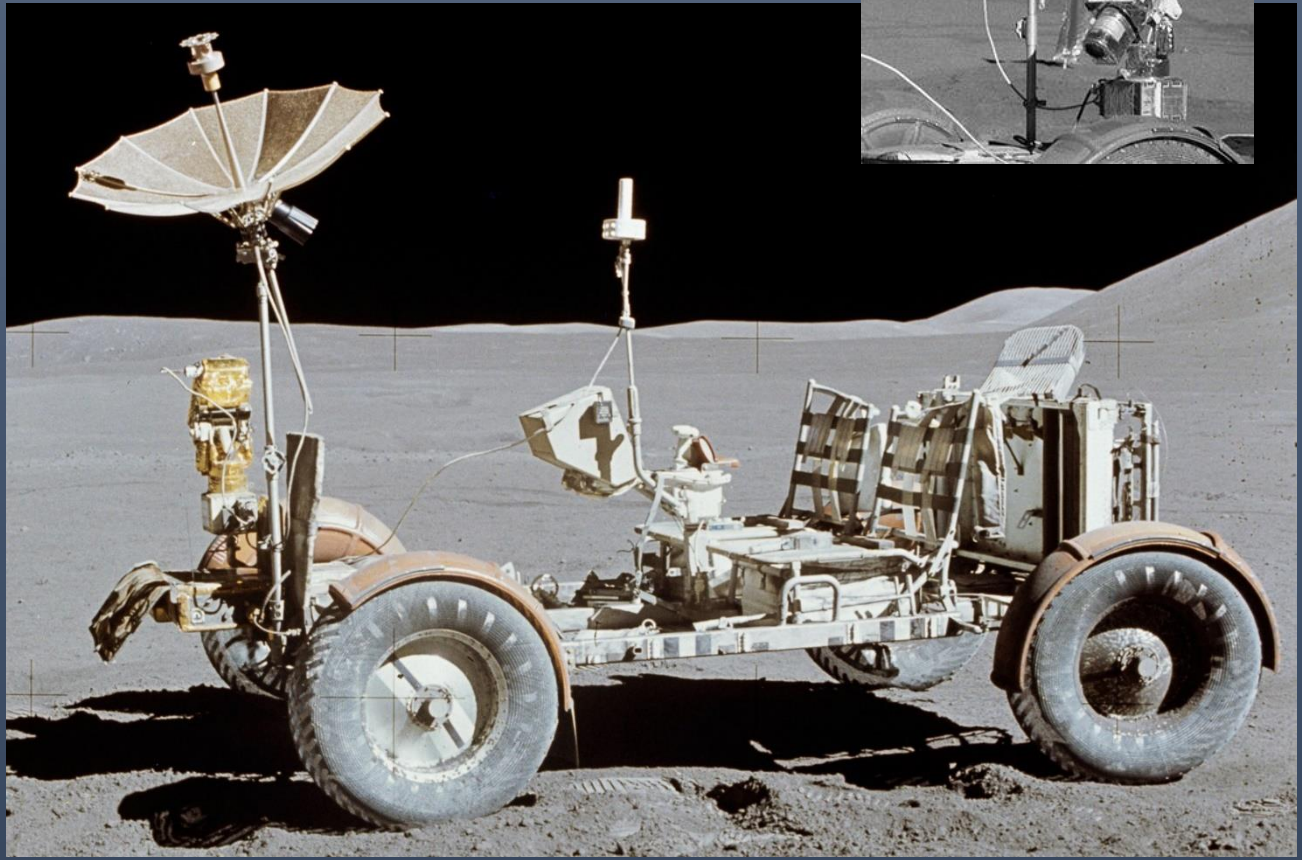
Apollo 11 used LM dish for B&W video

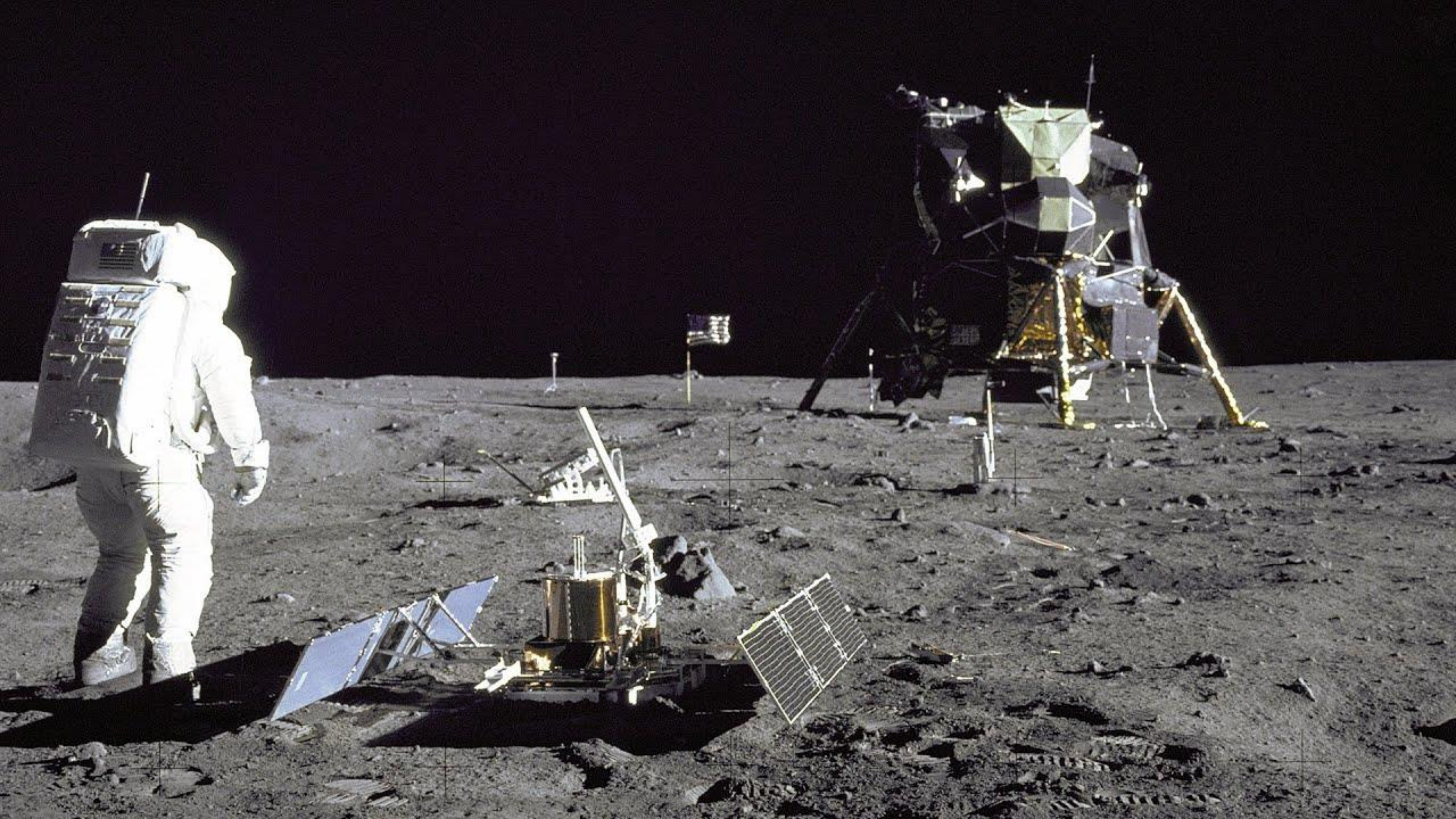
Apollo 12 and 14 used fixed cameras and dishes



Apollo 15, 16, and 17 had pan/tilt/zoom camera and dish antenna on lunar rover








HERE MEN FROM THE PLANET EARTH
FIRST SET FOOT UPON THE MOON
JULY 1969, A.D.
WE CAME IN PEACE FOR ALL MANKIND


HERE MAN COMPLETED HIS FIRST
EXPLORATIONS OF THE MOON
DECEMBER 1972, A.D.
MAY THE SPIRIT OF PEACE IN WHICH WE CAME
BE REFLECTED IN THE LIVES OF ALL MANKIND
EUGENE A. CERNAN
ASTRONAUT
RONALD E. EVANS
ASTRONAUT
HARRISON H. SCHMITT
ASTRONAUT
RICHARD NIXON
PRESIDENT, UNITED STATES OF AMERICA

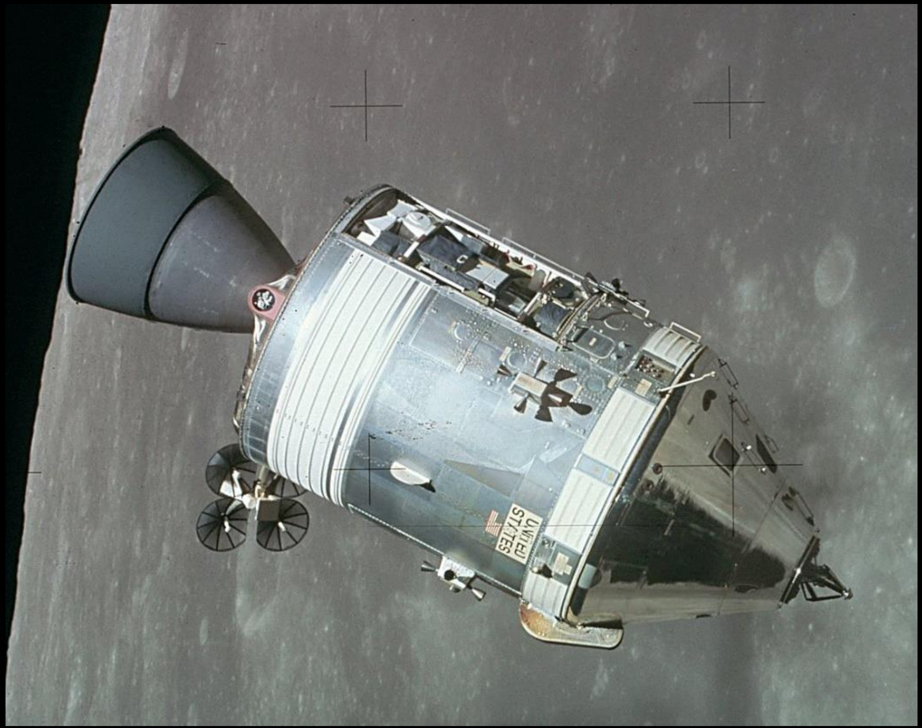
Artemis
Return to the Moon

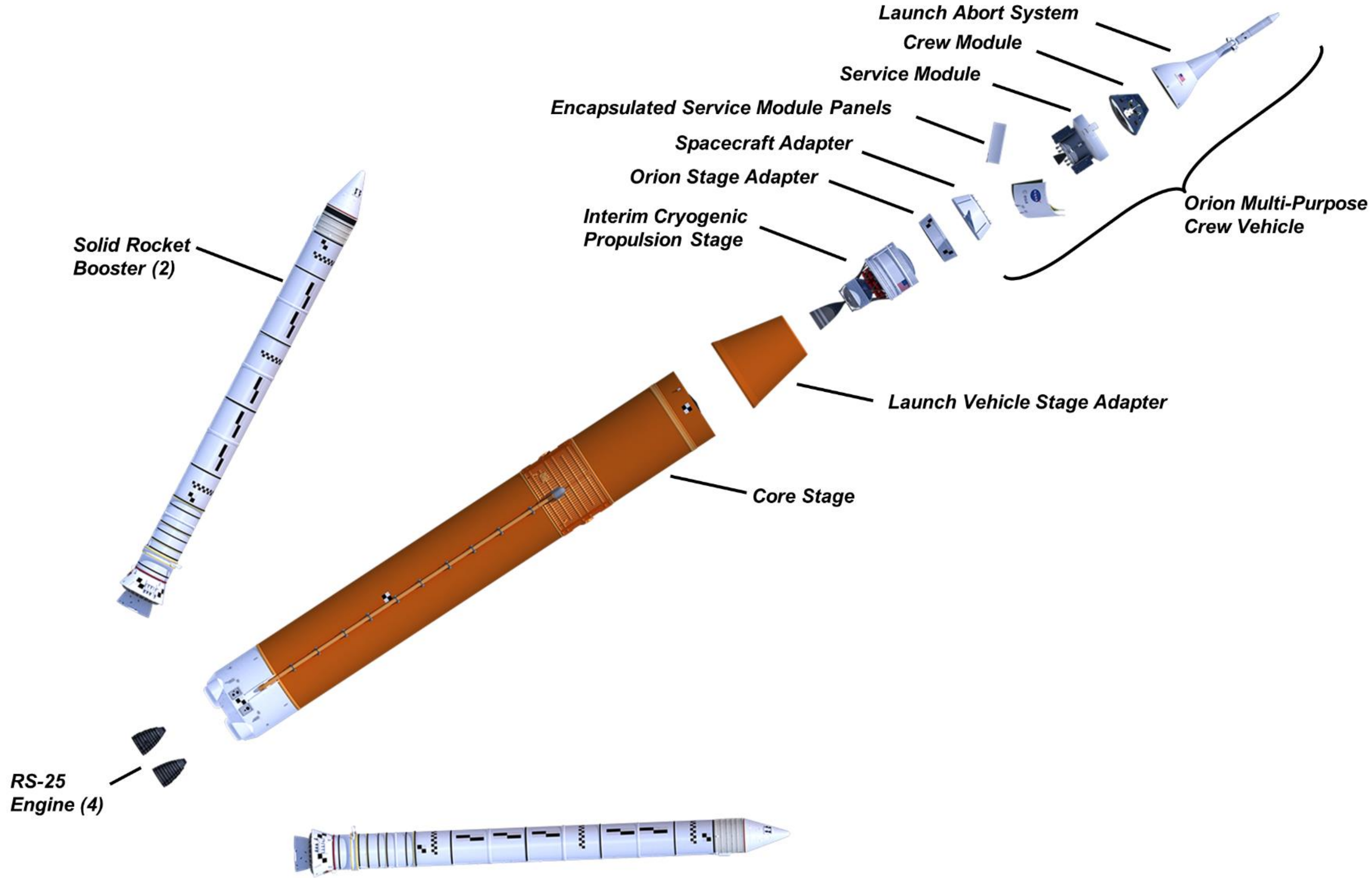
Boots on the Moon by 2024

- Space Policy Directive 1 (Dec. 2017) – return to the Moon and on to Mars
- In March VP Pence directed NASA to land humans near the lunar south pole by 2024. Original planning was for 2028.
- Sustainable lunar exploration will be done with Gateway and the Human Landing System (transfer, descent and ascent elements)
    - HLS elements will be aggregated at Gateway and Ascent Element will be reused
- Space Launch System (SLS) and Orion will ferry the crew and some of the hardware
- Commercial launches will transport some of the hardware and logistics

Apollo

Command/Service Module (with crew) and Lunar Module were launched together on Saturn V

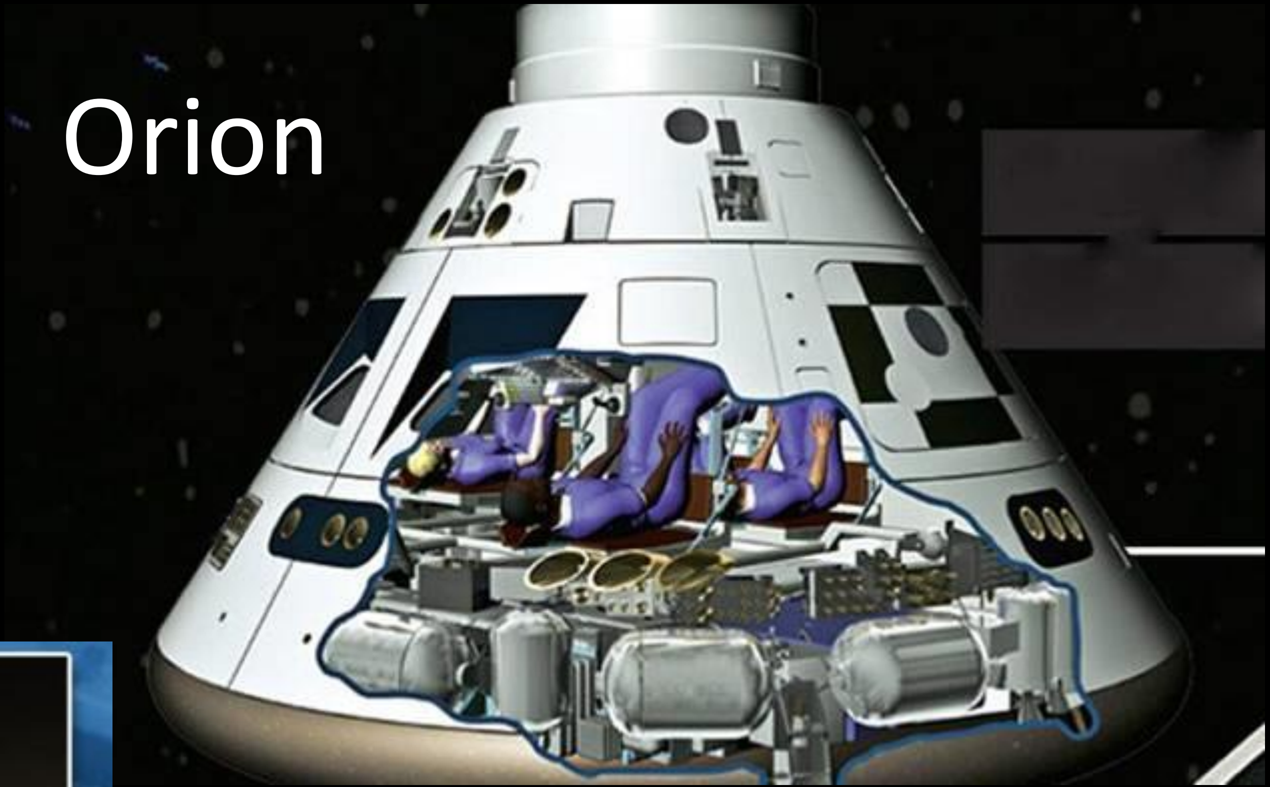


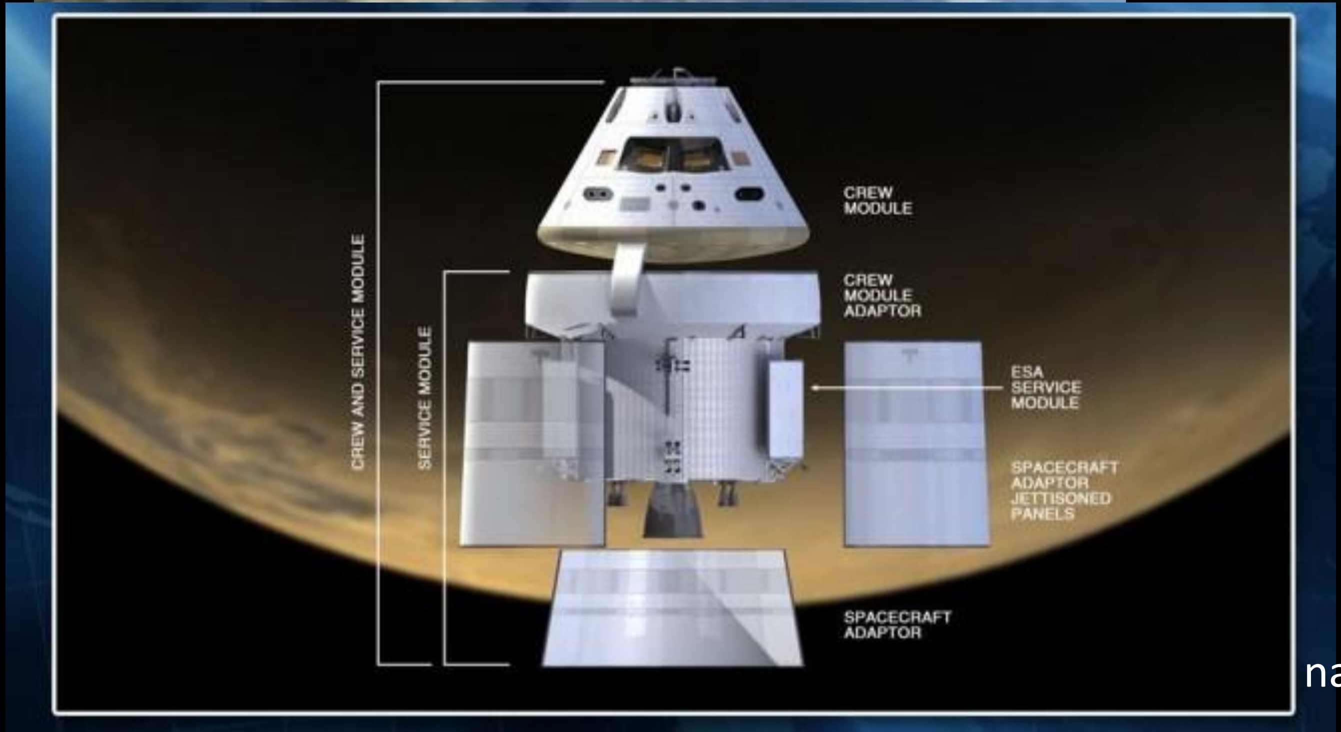


Launch Abort System
Crew Module
Service Module
Encapsulated Service Module Panels
Spacecraft Adapter
Orion Stage Adapter
Interim Cryogenic Propulsion Stage
Orion Multi-Purpose Crew Vehicle
Solid Rocket Booster (2)
Launch Vehicle Stage Adapter
Core Stage
RS-25 Engine (4)

nasa.gov

Orion





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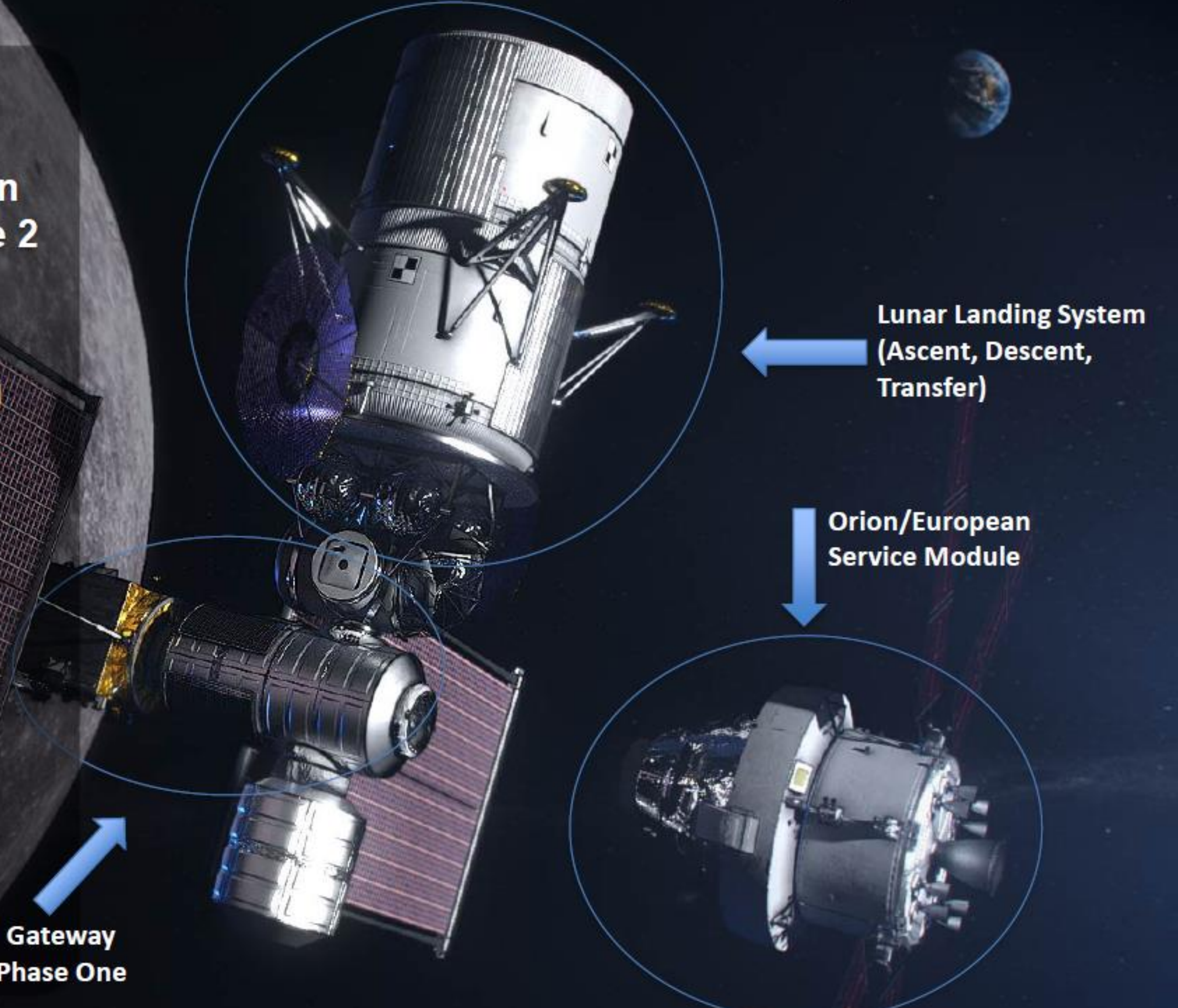
Gateway is Essential for 2024 Landing

- Initial Gateway focuses on the minimum systems required to support a 2024 human lunar landing while also supporting Phase 2
- Provides command center and aggregation point for 2024 human landing
- Establishes strategic presence around the Moon – US in the leadership role
- Creates resilience and robustness in the lunar architecture
- Open architecture and interoperability standards provides building blocks for partnerships and future expansion



Gateway Phase 2

US and international partners

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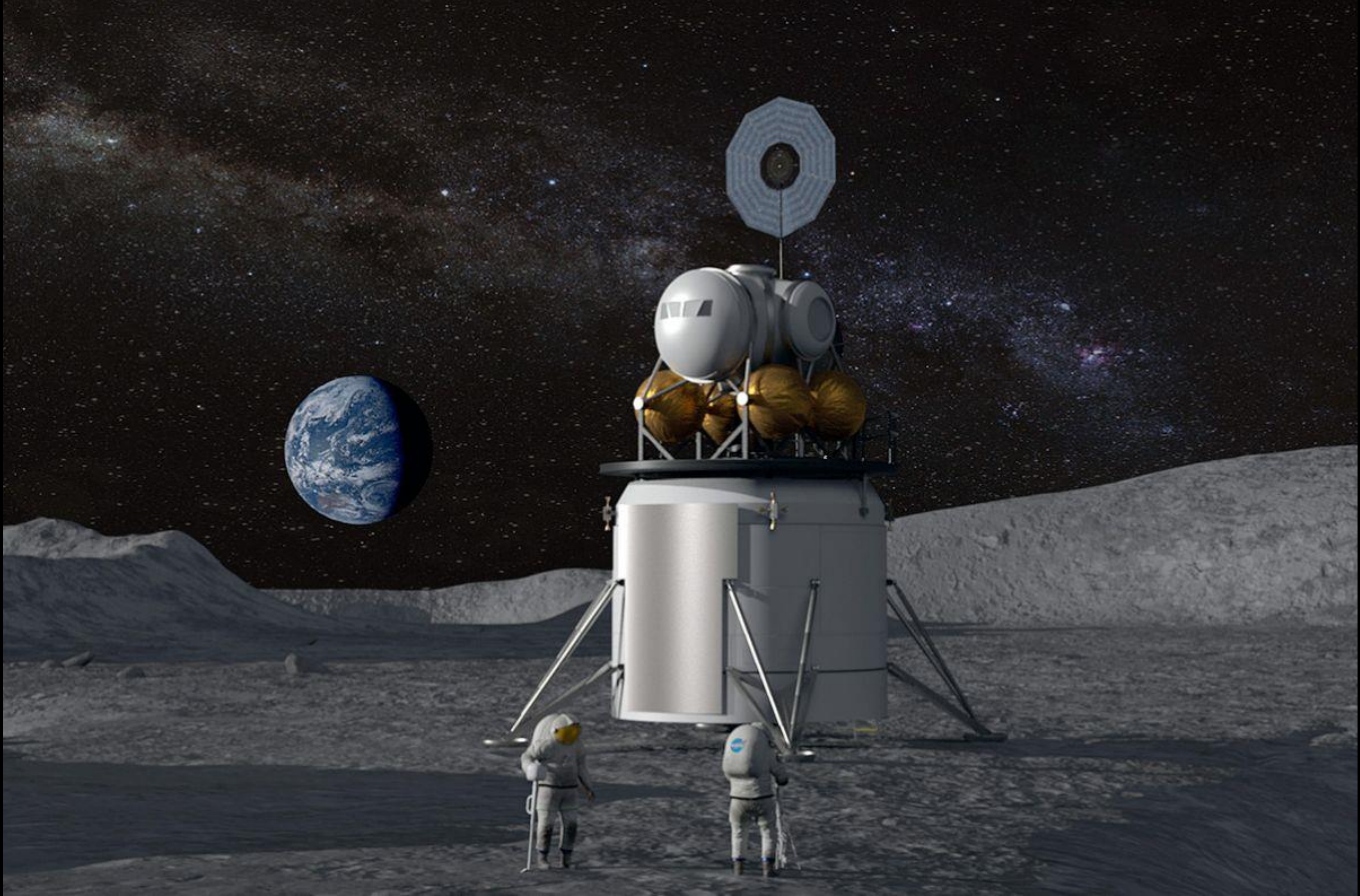

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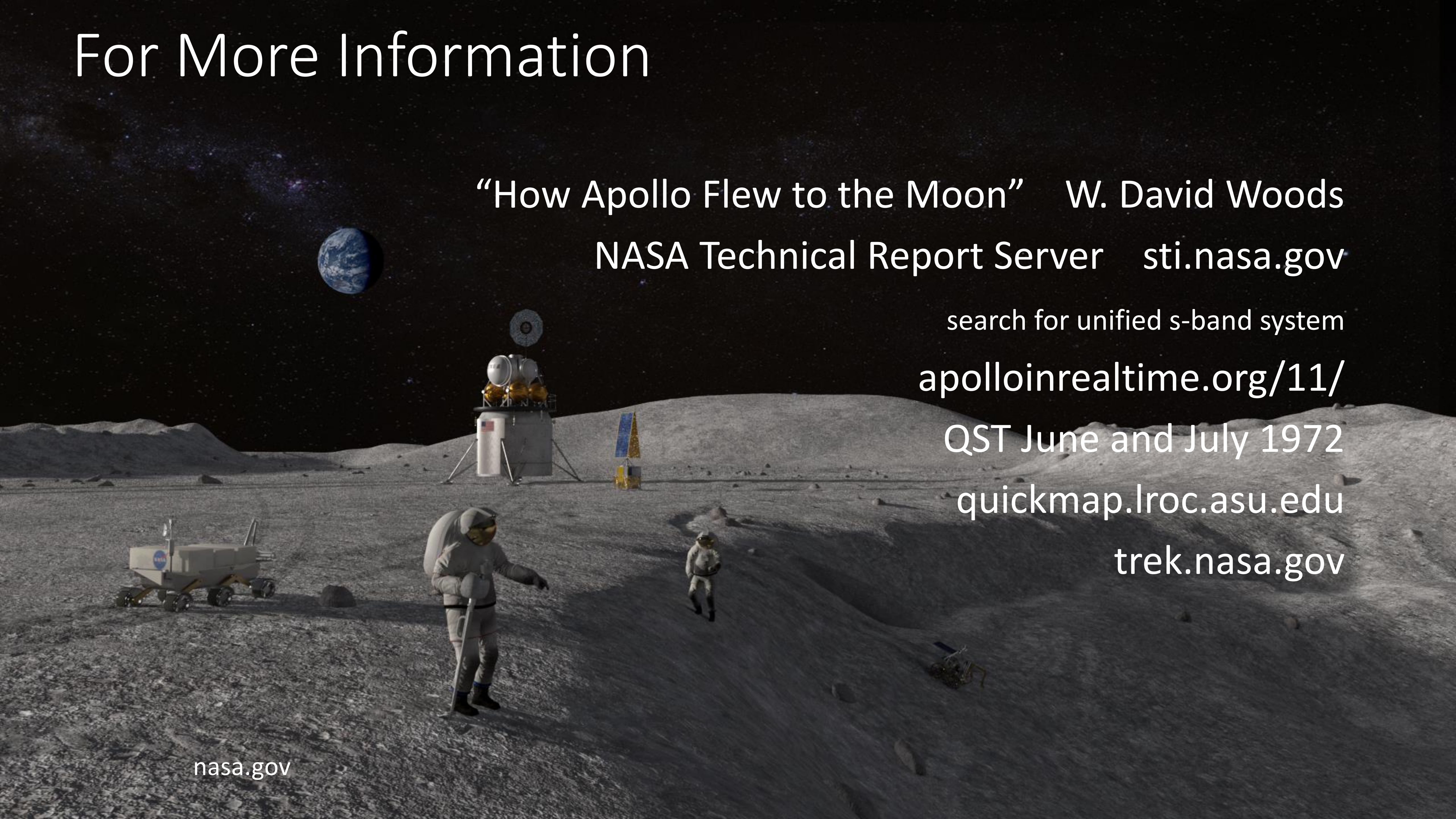
Lunar south pole illumination map

https://quickmap.lroc.asu.edu/layers?extent=-112.4216008,-84.630363,117.5697916,-83.4670082&proj=17&layers=NrBsFYBoAZIRnpEB2Bb4F0saA

For More Information



"How Apollo Flew to the Moon" W. David Woods

NASA Technical Report Server sti.nasa.gov

search for unified s-band system

apolloinrealtime.org/11/

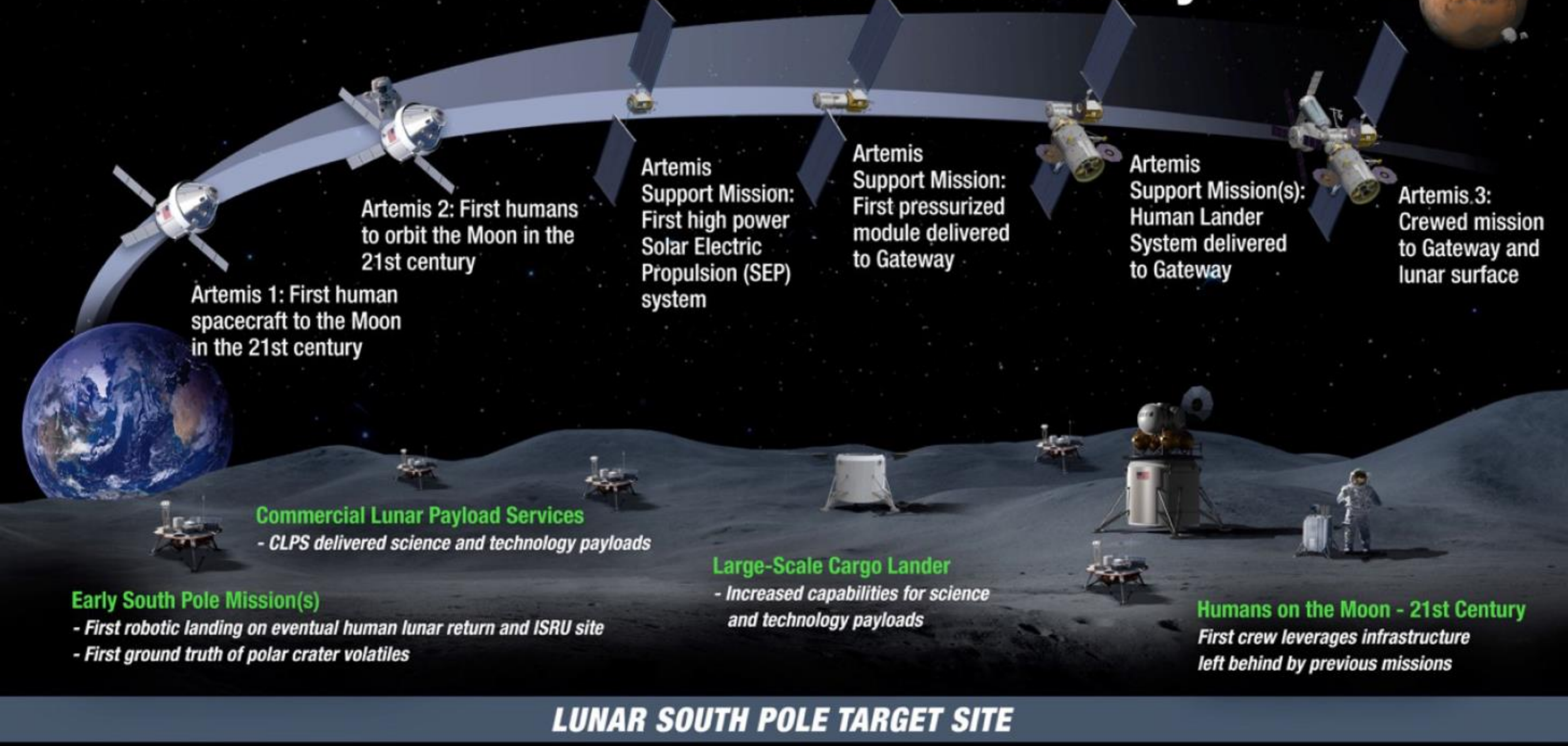
QST June and July 1972

quickmap.lroc.asu.edu

trek.nasa.gov

nasa.gov

Artemis Phase 1: To the Lunar Surface by 2024



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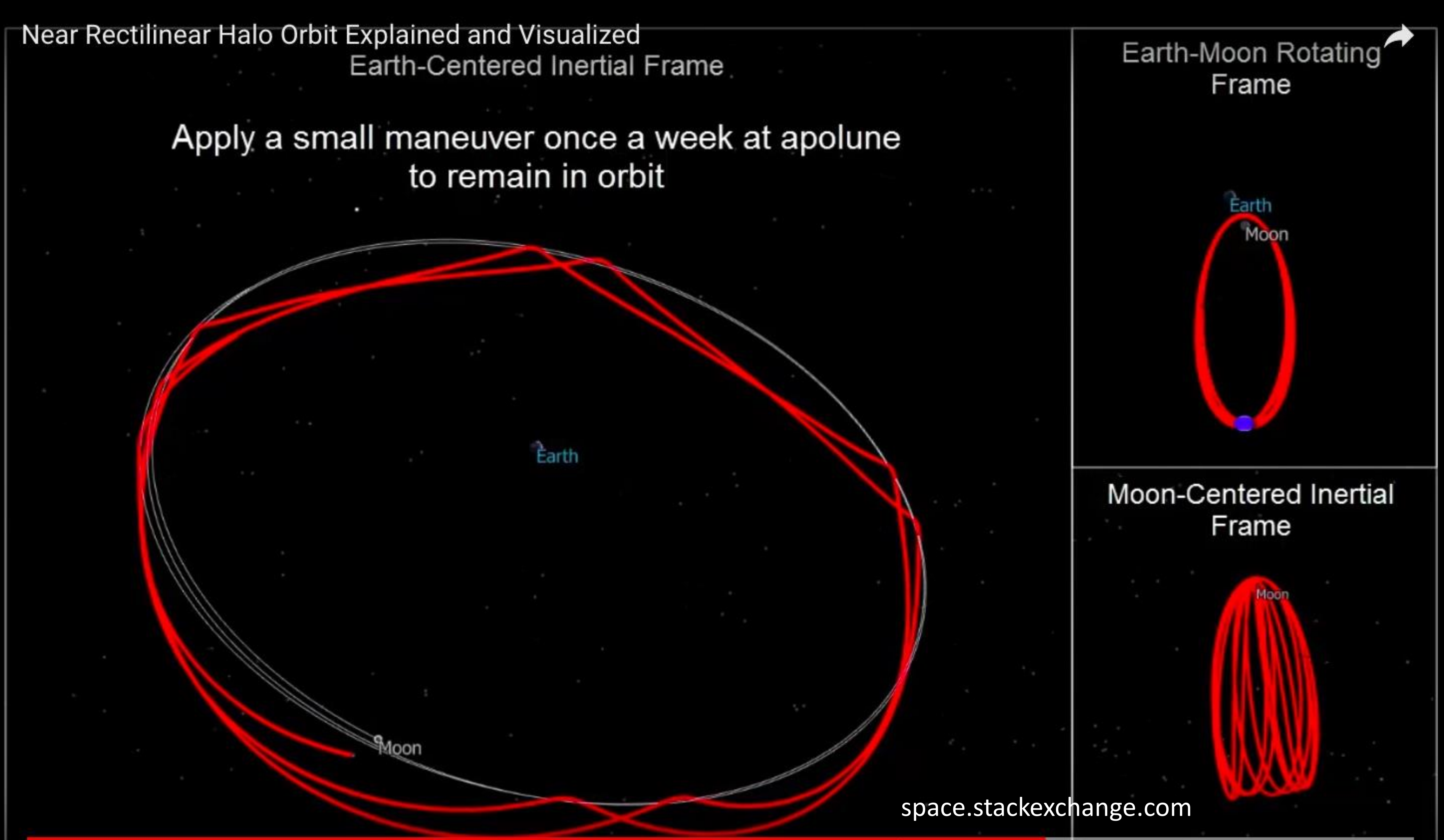
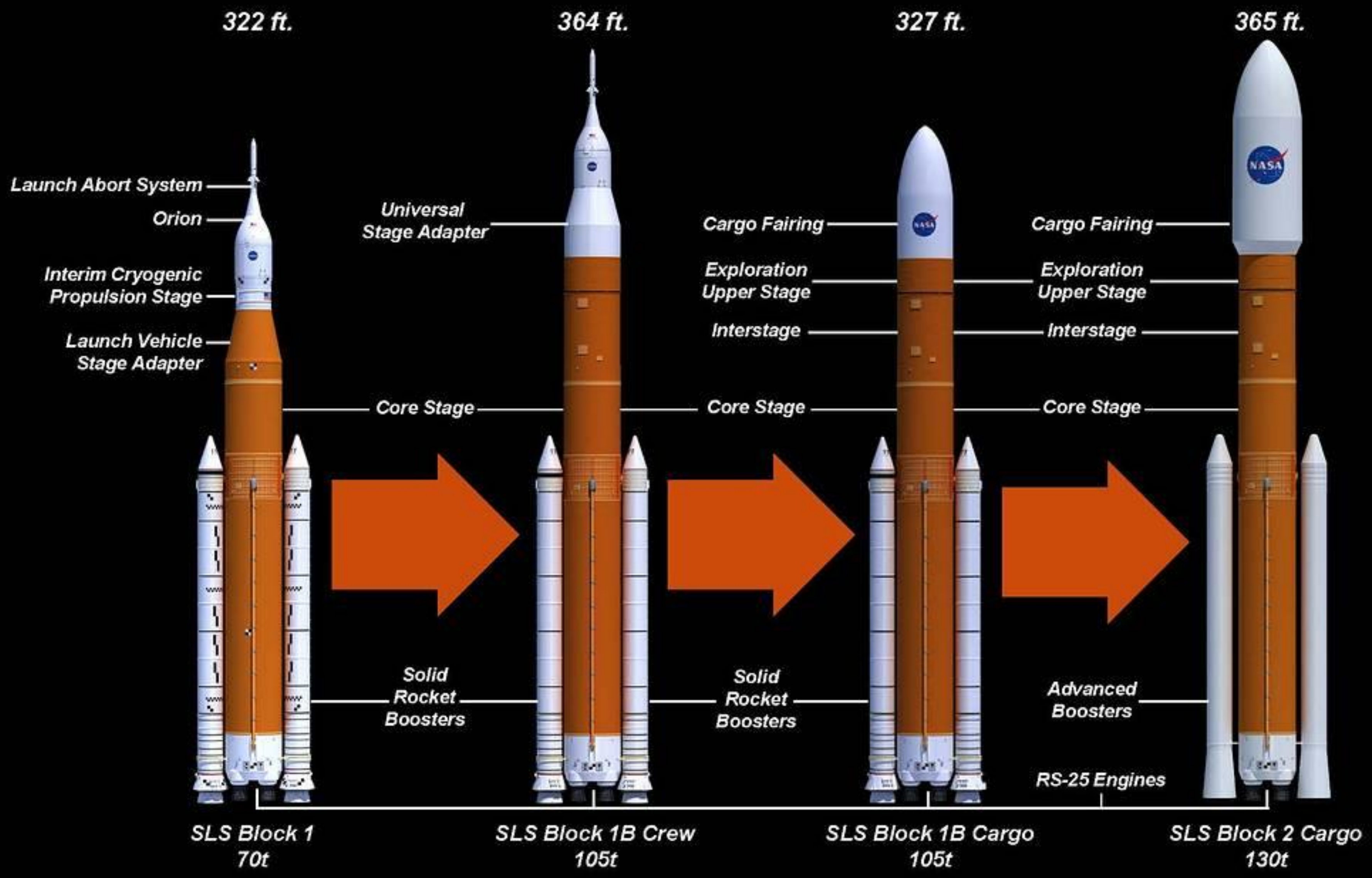


space.stackexchange.com



322 ft.
364 ft.
327 ft.
365 ft.
Launch Abort System
Orion
Interim Cryogenic Propulsion Stage
Launch Vehicle Stage Adapter
Universal Stage Adapter
Cargo Fairing
Exploration Upper Stage
Interstage
Cargo Fairing
Exploration Upper Stage
Interstage
Core Stage
Core Stage
Core Stage
Solid Rocket Boosters
Solid Rocket Boosters
Advanced Boosters
RS-25 Engines
SLS Block 1
70t
SLS Block 1B Crew
105t
SLS Block 1B Cargo
105t
SLS Block 2 Cargo
130t

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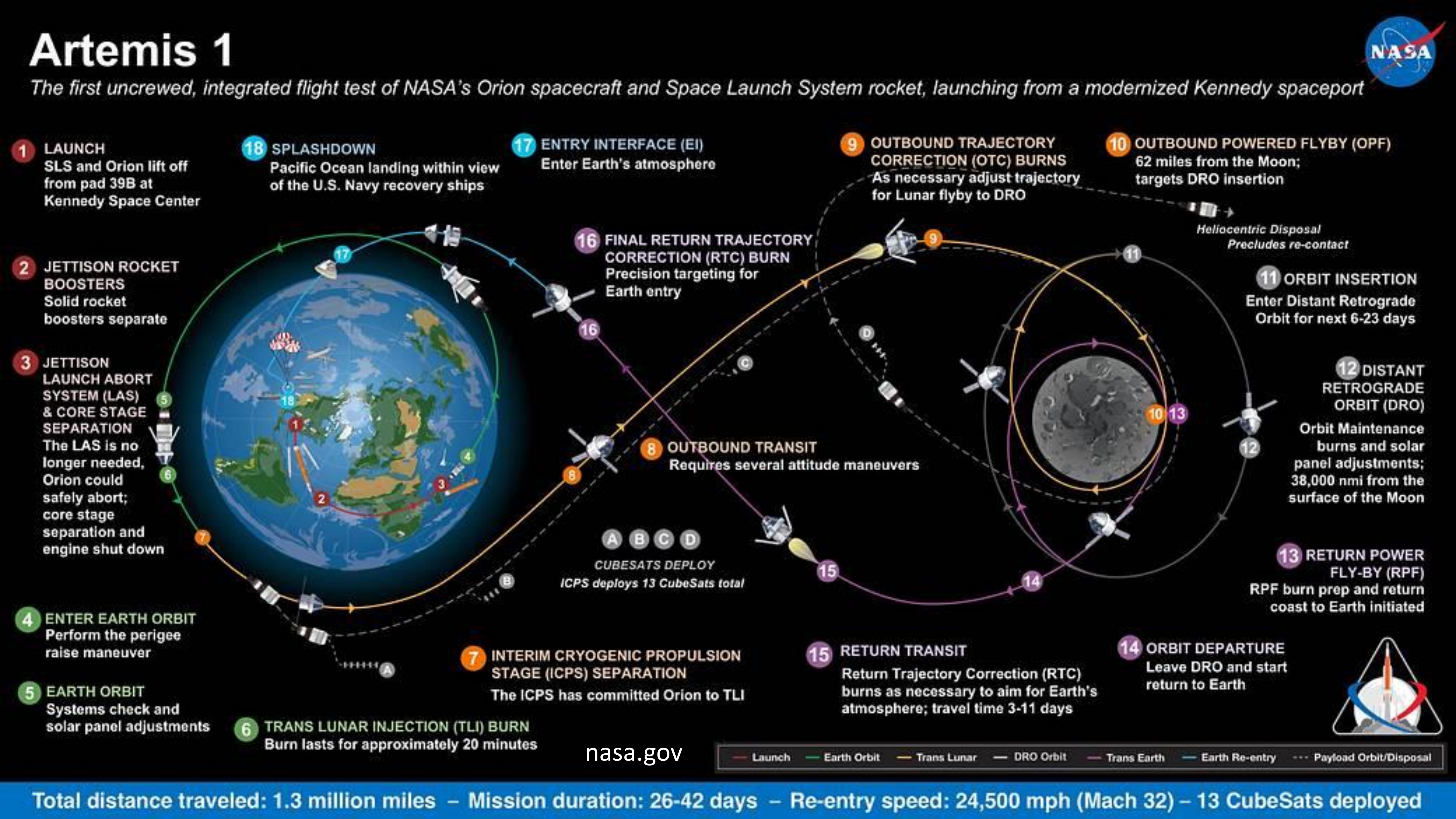
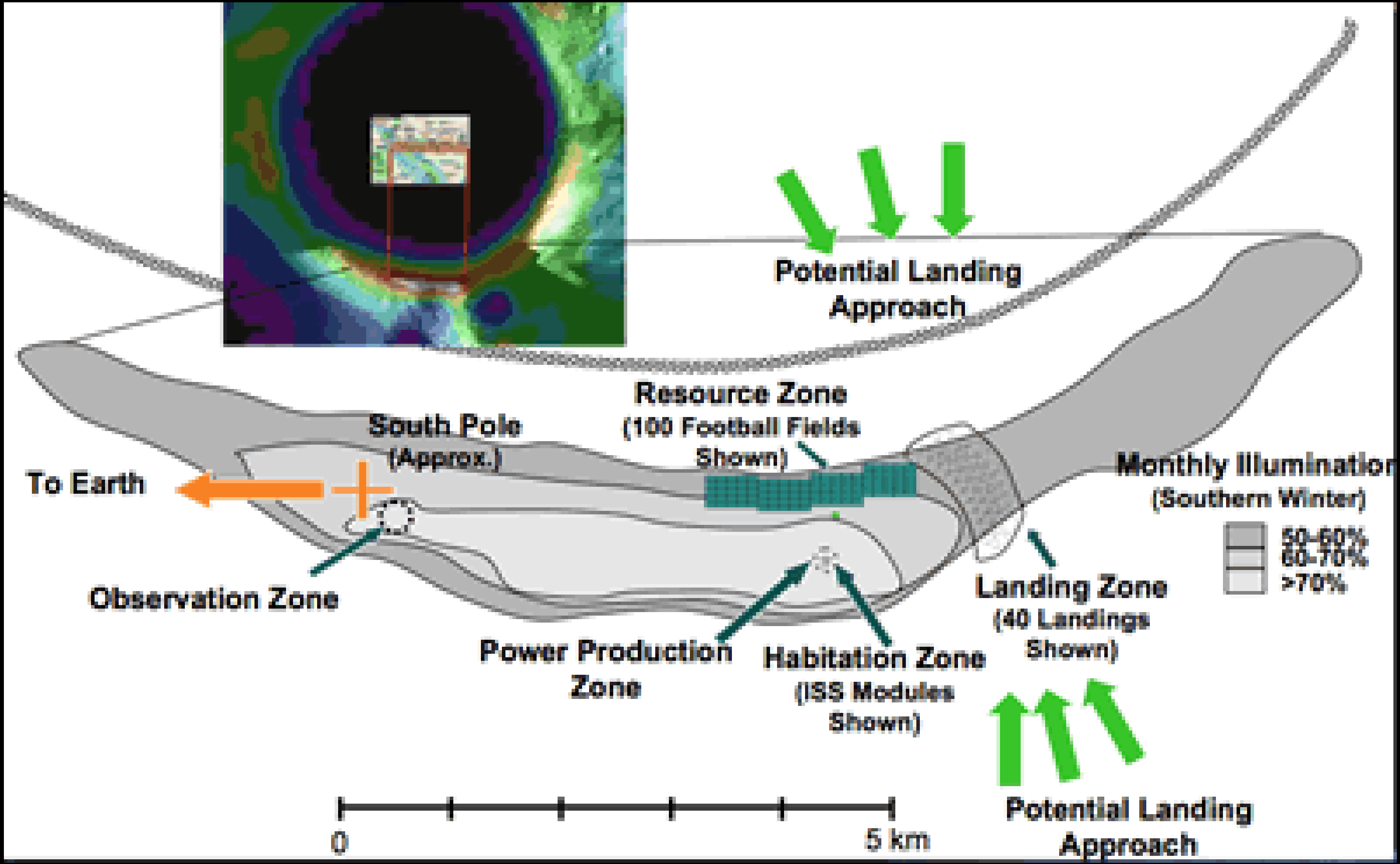
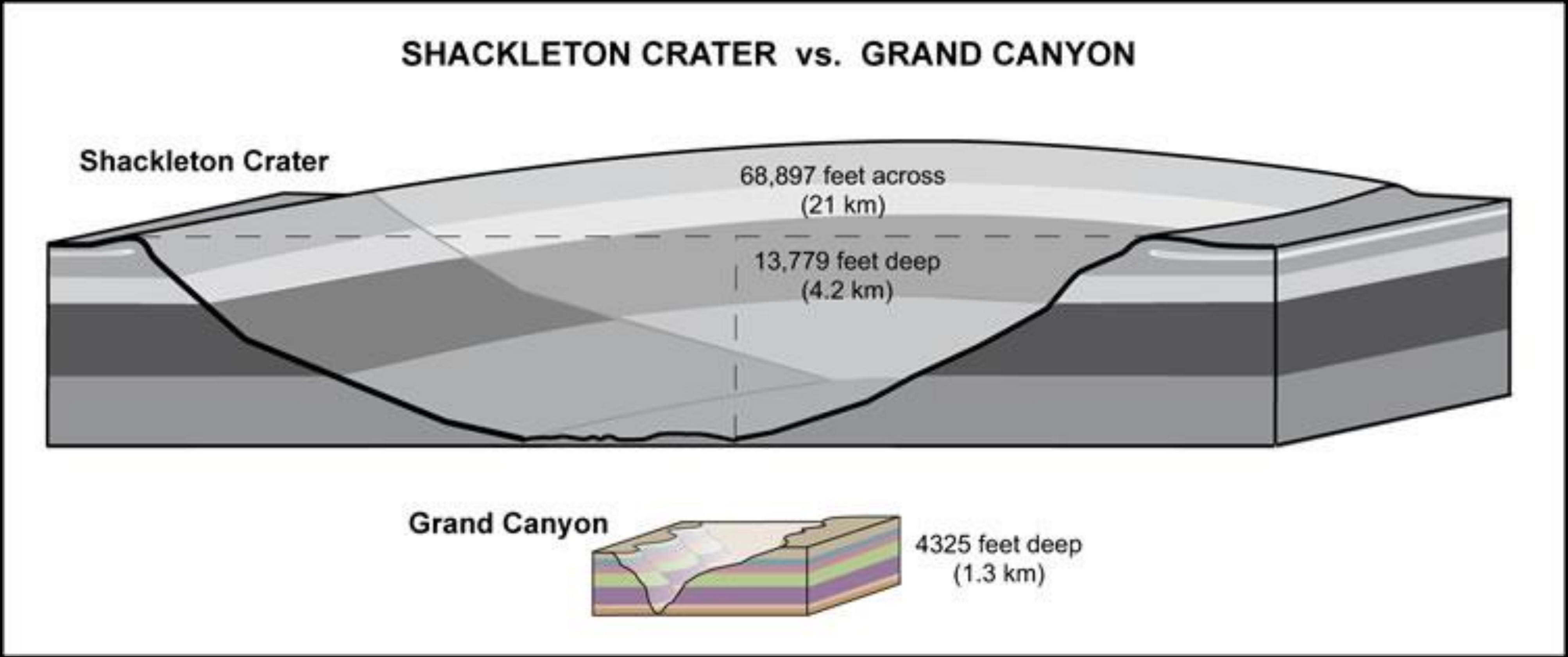

Artemis 1
The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport
NASA
1 LAUNCH
SLS and Orion lift off from pad 39B at Kennedy Space Center
2 JETTISON ROCKET BOOSTERS
Solid rocket boosters separate
3 JETTISON LAUNCH ABORT SYSTEM (LAS) & CORE STAGE SEPARATION
The LAS is no longer needed, Orion could safely abort; core stage separation and engine shut down
4 ENTER EARTH ORBIT
Perform the perigee raise maneuver
5 EARTH ORBIT
Systems check and solar panel adjustments
6 TRANS LUNAR INJECTION (TLI) BURN
Burn lasts for approximately 20 minutes
7 INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION
The ICPS has committed Orion to TLI
8 OUTBOUND TRANSIT
Requires several attitude maneuvers
9 OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS
As necessary adjust trajectory for Lunar flyby to DRO
10 OUTBOUND POWERED FLYBY (OPF)
62 miles from the Moon; targets DRO insertion
Heliocentric Disposal
Precludes re-contact
11 ORBIT INSERTION
Enter Distant Retrograde Orbit for next 6-23 days
12 DISTANT RETROGRADE ORBIT (DRO)
Orbit Maintenance burns and solar panel adjustments; 38,000 nmi from the surface of the Moon
13 RETURN POWER FLY-BY (RPF)
RPF burn prep and return coast to Earth initiated
14 ORBIT DEPARTURE
Leave DRO and start return to Earth
15 RETURN TRANSIT
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time 3-11 days
16 FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN
Precision targeting for Earth entry
17 ENTRY INTERFACE (EI)
Enter Earth's atmosphere
18 SPLASHDOWN
Pacific Ocean landing within view of the U.S. Navy recovery ships
A B C D
CUBESATS DEPLOY
ICPS deploys 13 CubeSats total
Launch
Earth Orbit
Trans Lunar
DRO Orbit
Trans Earth
Earth Re-entry
Payload Orbit/Disposal
Total distance traveled: 1.3 million miles – Mission duration: 26-42 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed
nasa.gov


Potential Landing
Approach
Resource Zone
(100 Football Fields
Shown)
South Pole
(Approx.)
To Earth
Monthly Illumination
(Southern Winter)
50-60%
60-70%
>70%
Observation Zone
Landing Zone
(40 Landings
Shown)
Power Production
Zone
Habitation Zone
(ISS Modules
Shown)
0
5 km
Potential Landing
Approach



www.lpi.usra.edu

Voice and telemetry subcarriers

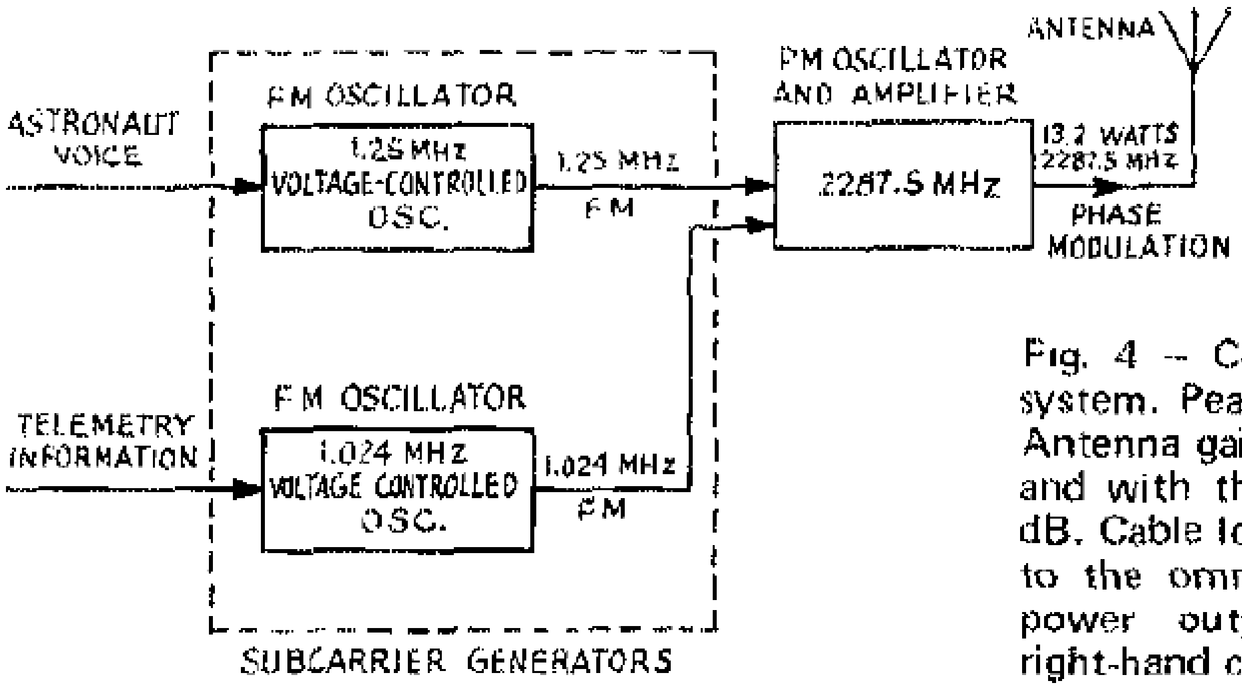


Fig. 4 -- Command Service Module S-band voice system. Peak subcarrier fm deviation is ± 7.5 kHz. Antenna gain with the high-gain antenna is 26.3 dB and with the omnidirectional antenna is -6 to +6 dB. Cable loss to the high-gain antenna is 5 dB, and to the omni antenna is 2.5 dB. The transmitter power output is 13.2 watts. Polarization is right-hand circular.

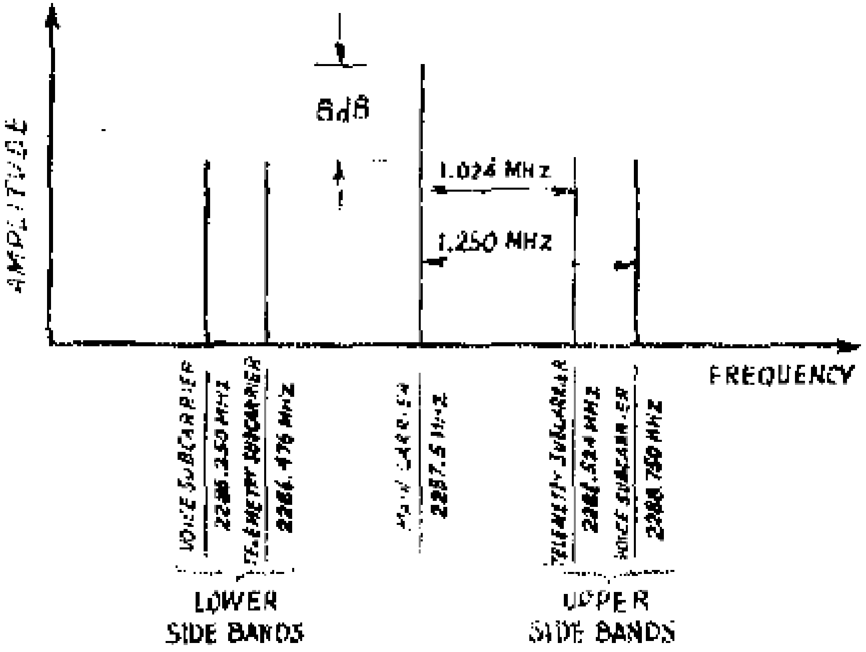


Fig. 5 -- Resultant transmitted signal from CSM.

From QST June 1972

TABLE I

Apollo Frequencies (extracted from information received from NASA.)

Command and Service Module (CSM)
Vhf: 296.8 or 259.7 MHz (a-m voice).

Unified S-Band (usb): on Main carrier: 2287.5 MHz
Fm Voice subcarrier: 1.25 MHz

CSM Backup Voice: on Main carrier: 2287.5 MHz
(fm)

Lunar Module (LM) usb: Main carrier: 2282.5 MHz
Fm Voice subcarrier: 1.25 MHz

LM Backup Voice: on Main carrier: 2282.5 MHz
(fm)

Lunar Communications Relay Unit (LCRU):
2265.5 MHz
Fm Voice subcarrier: 1.25 MHz

LCRU Backup Mode: Voice on Main carrier:
2265.5 MHz
(fm)

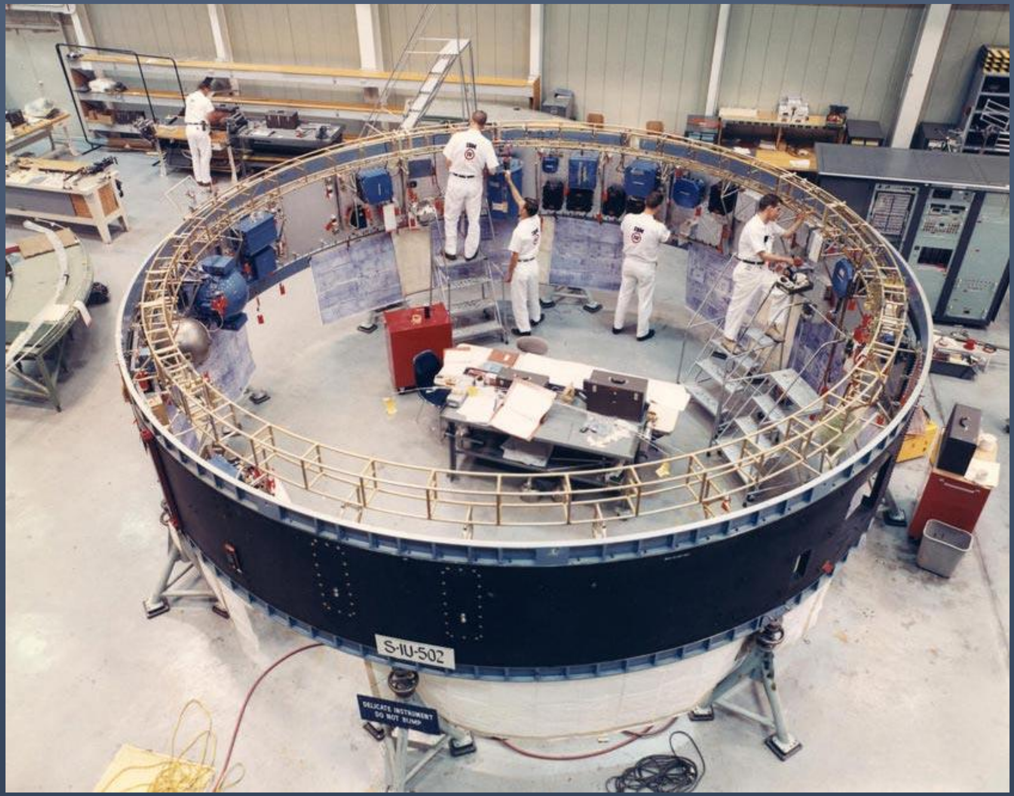
Signal loss at 2287.5 MHz and 240,000 Nautical Miles: —213 dB.

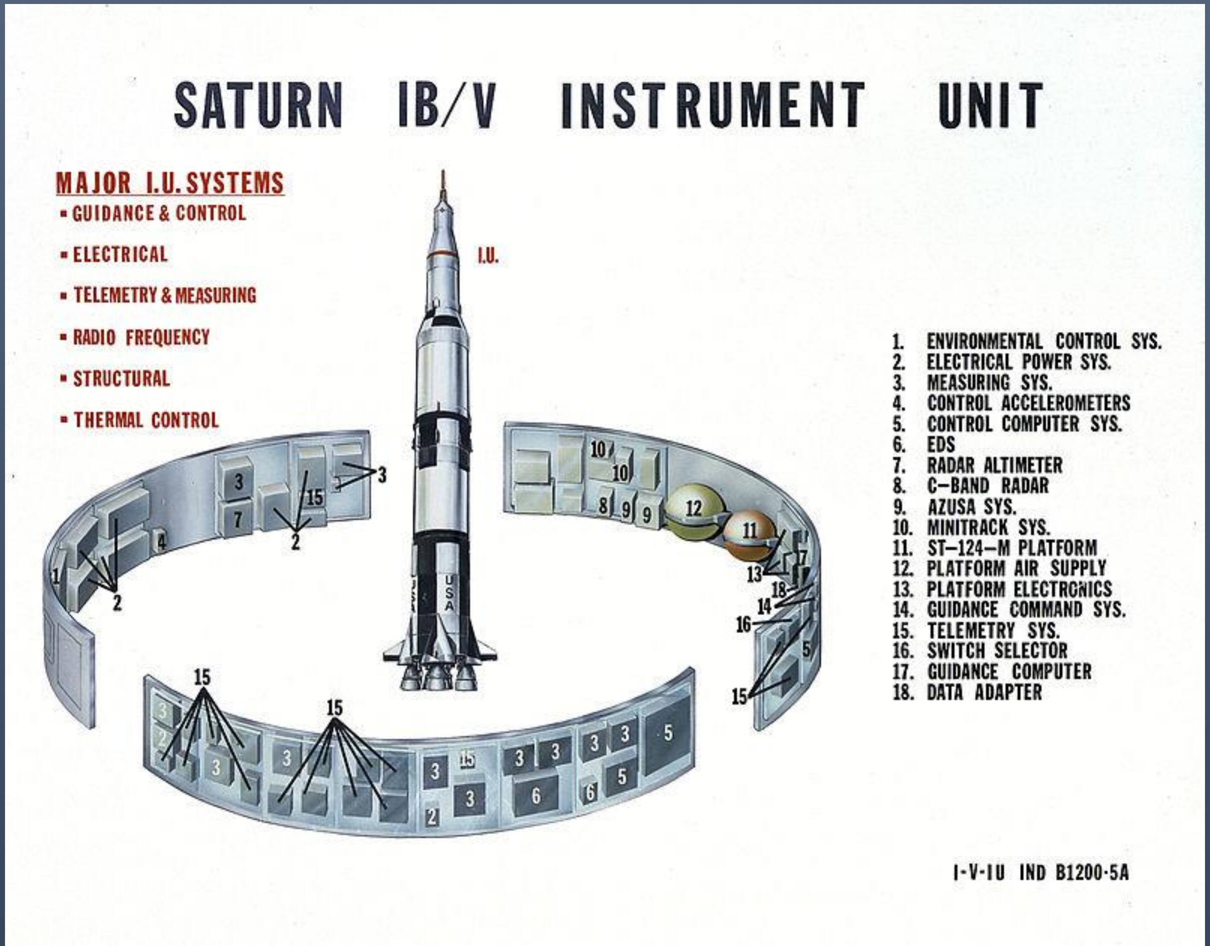
From QST June 1972

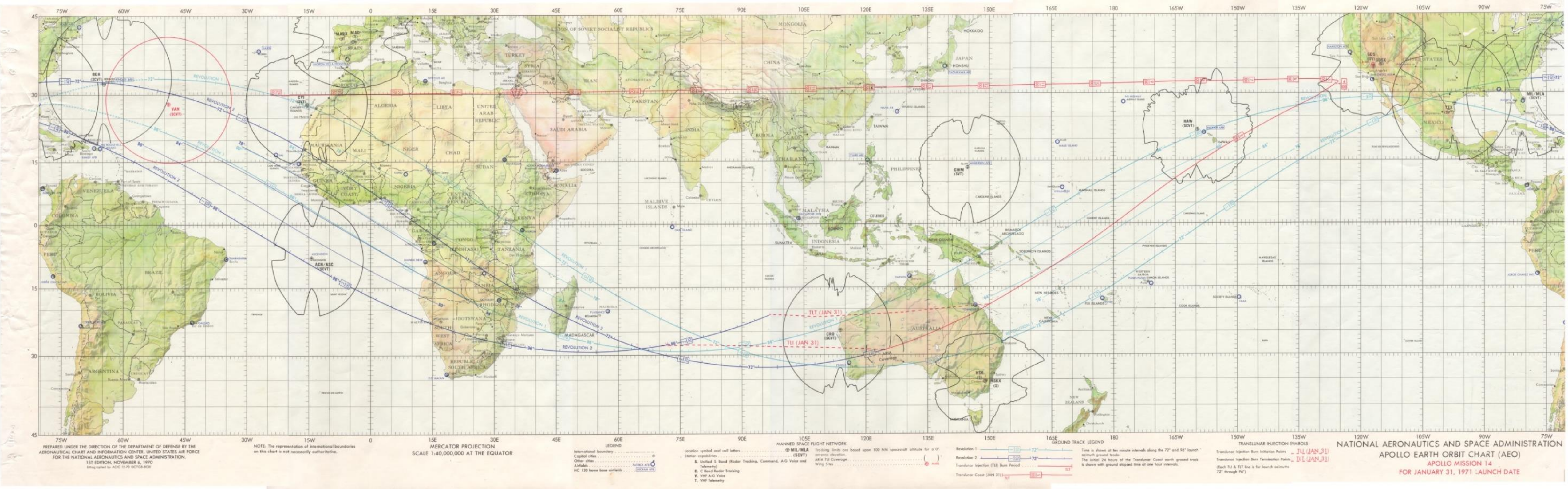

Gateway 2024 concept
nasa.gov

Saturn Telemetry

- C-band transponder on Instrument Unit – 5400-5900 MHz, 10 MHz bandwidth
- 700 W nominal transmit power







Manned Space Flight Network
Apollo 14 stations
https://www.honeysucklecreek.net/msfn_missions/MSFN/index.html

W4HHK's system also used some amateur components

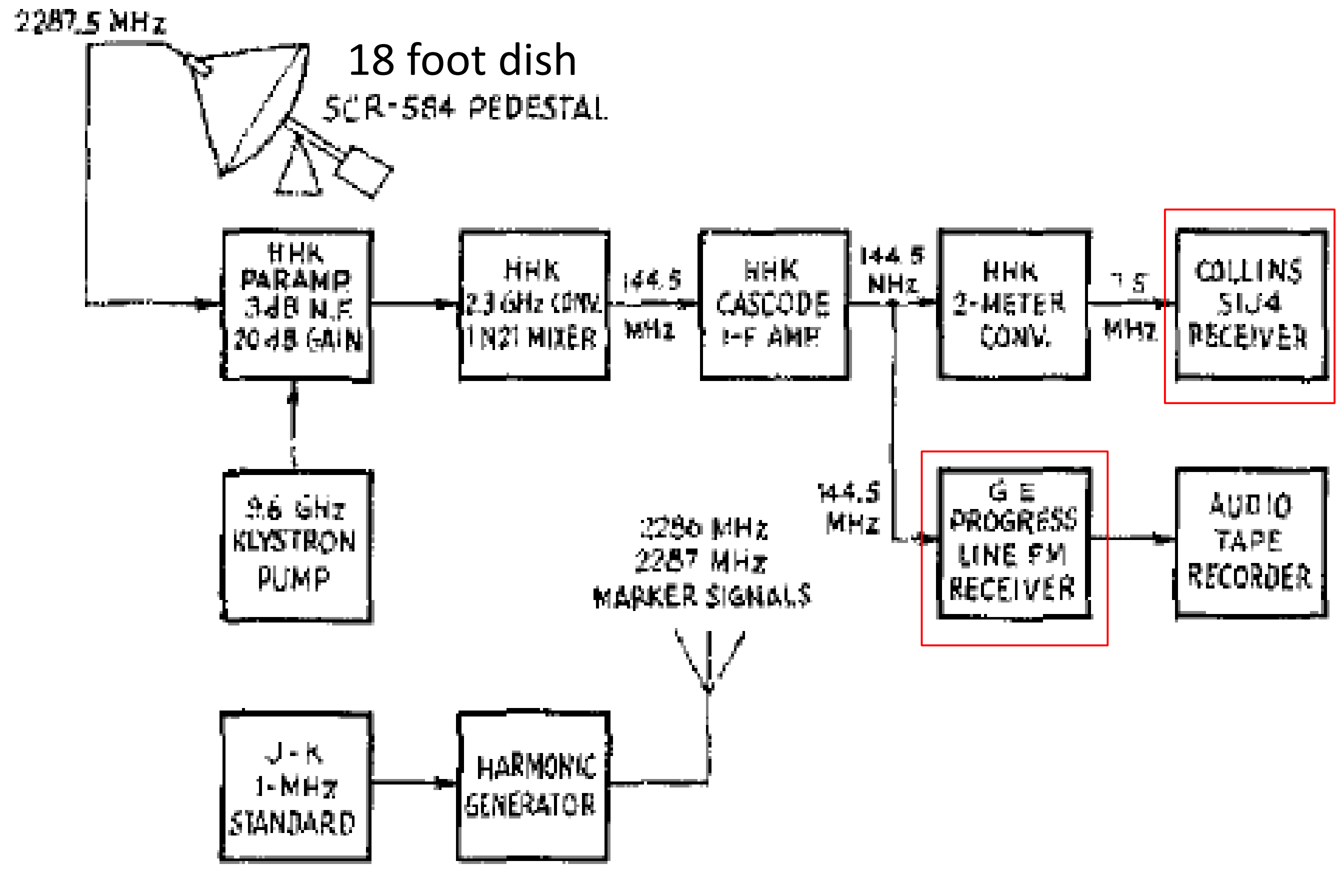


Fig. 1 — Block diagram of the S-band receiver system used to receive Apollo 15 at W4HHK.

W4HHK became a Silent Key in 1999. Call is now held by Collierville Millimeter Wave Society

THE VOICE, UPDATA AND BINARY RANGING CODE ARE COMBINED AND THE RESULTANT PHASE MODULATES THE S-BAND CARRIER TO FORM THE FOLLOWING SPECTRUM FOR UPLINK TRANSMISSION

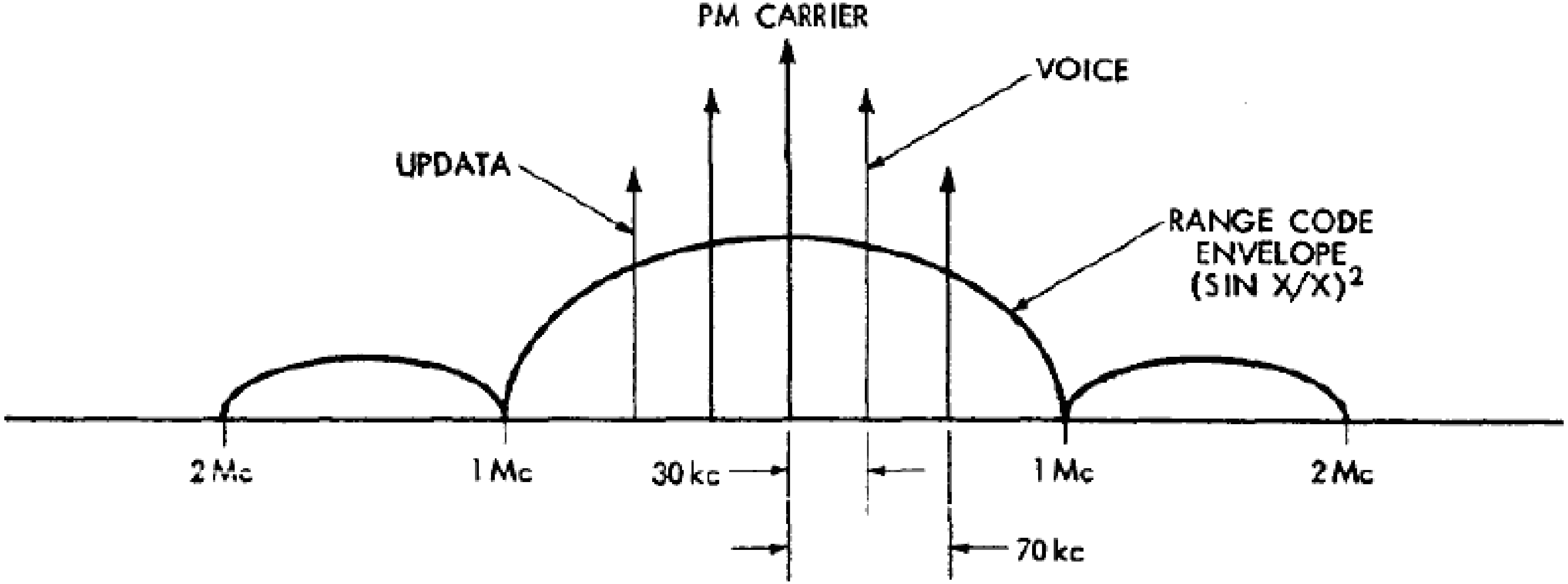


Figure 8. Uplink Spectrum

NASA TM X-55492 1966