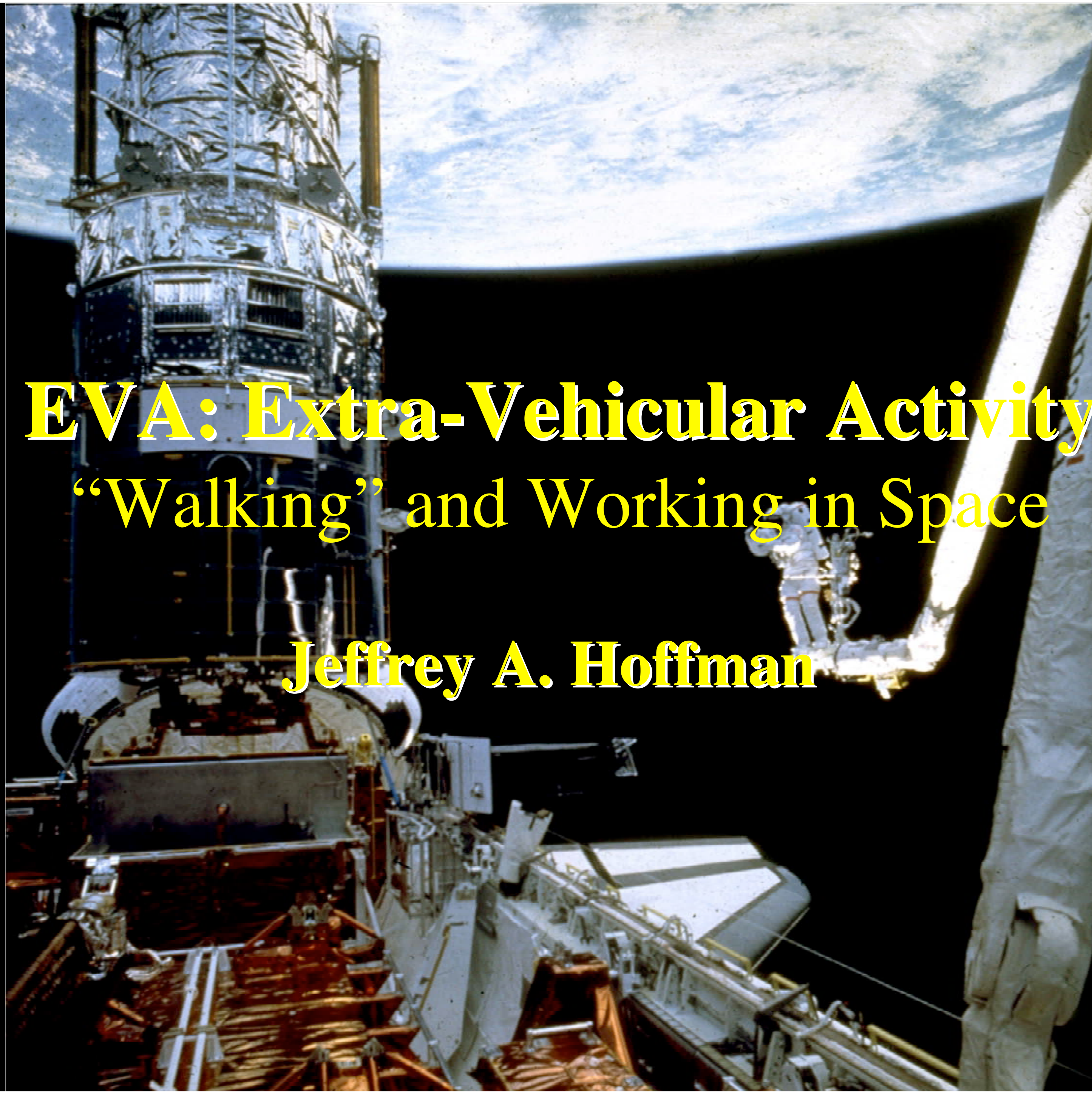
EVA: Extra-Vehicular Activity

"Walking" and Working in Space

Jeffrey A. Hoffman



What do you need to survive in space?

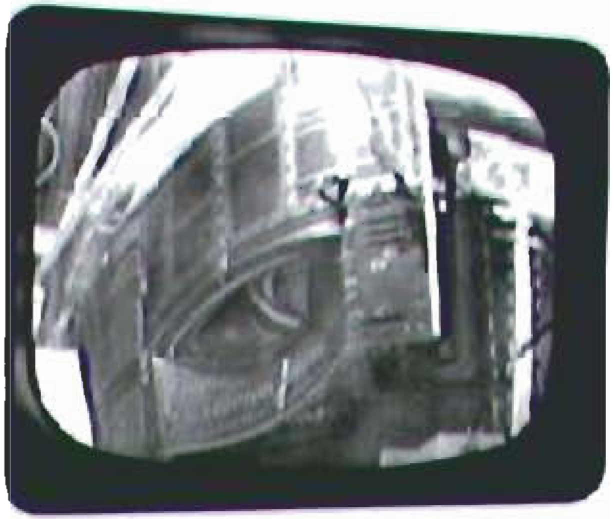
- Oxygen
- Pressure

NASA S-65-4196

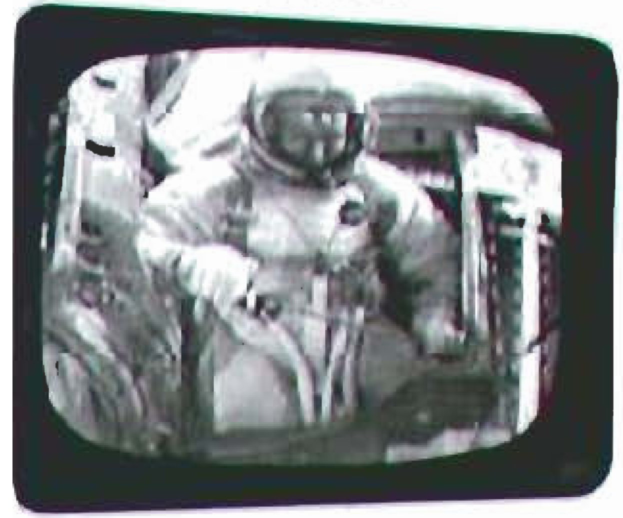
EVA AT SIMULATED 150,000 FEET

MAC PRESSURE CHAMBER - 3/24/65

HATCH OPENING



STAND UP

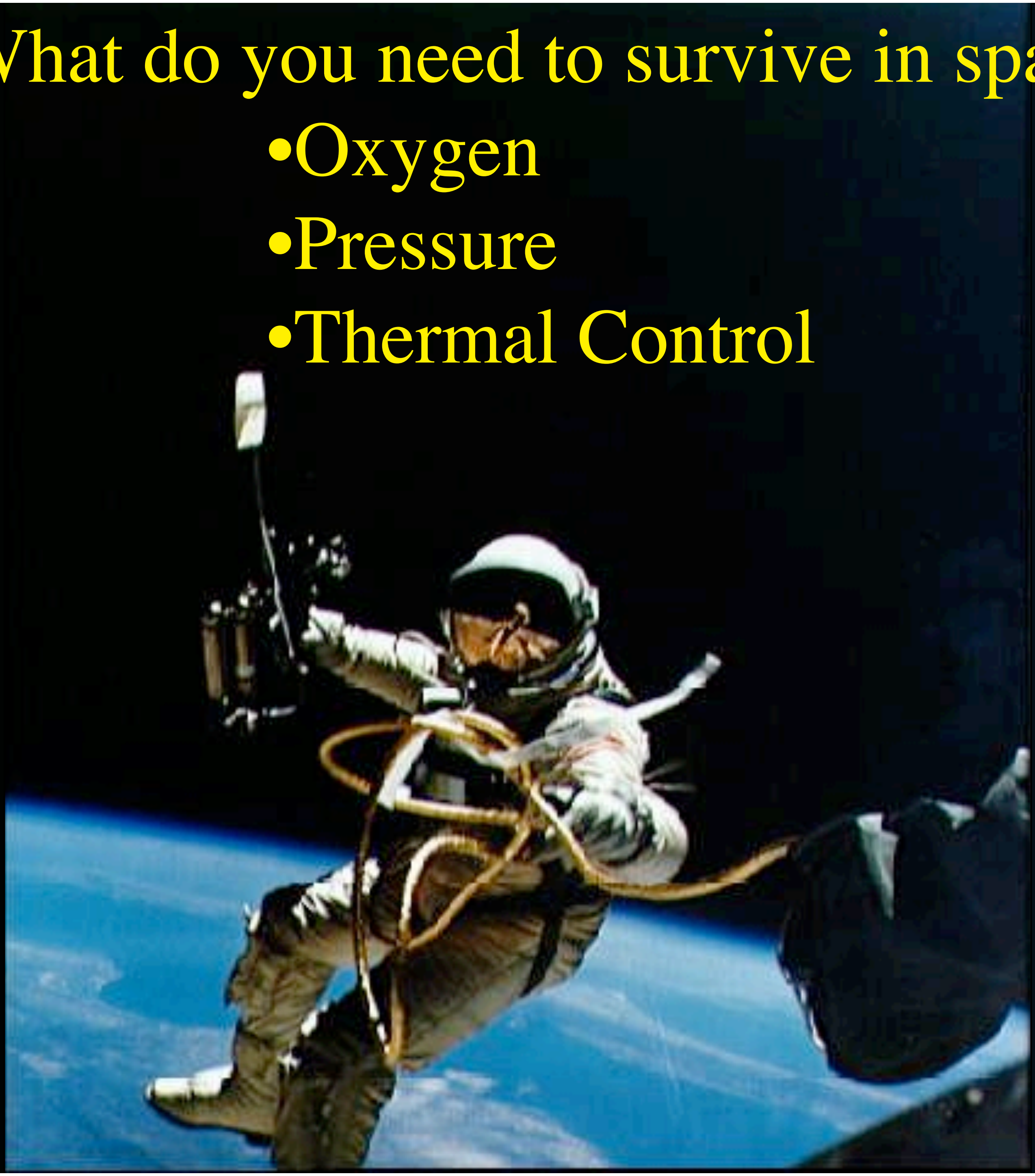


EQUIPMENT OPERATION

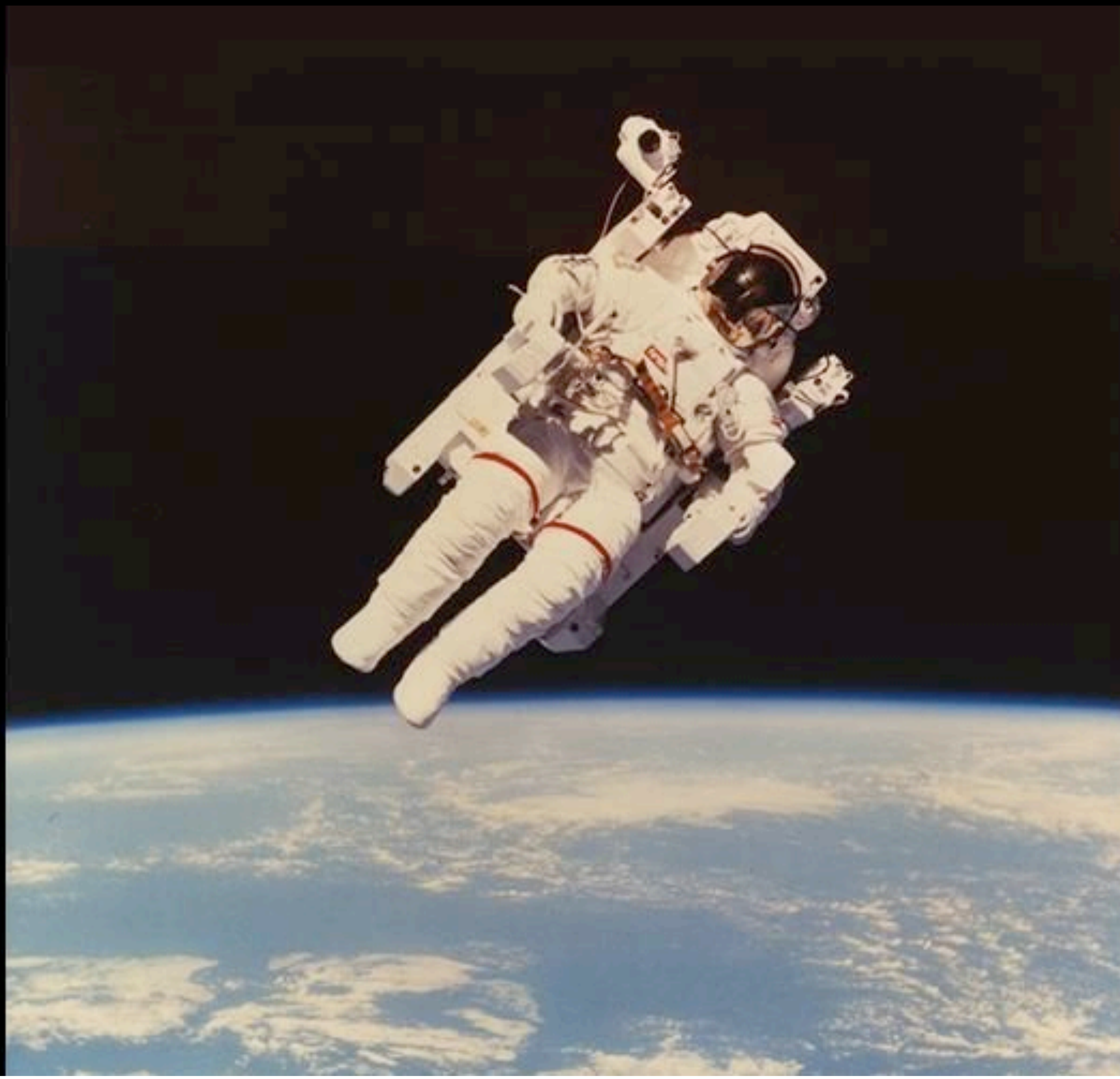
HATCH CLOSING

What do you need to survive in space?

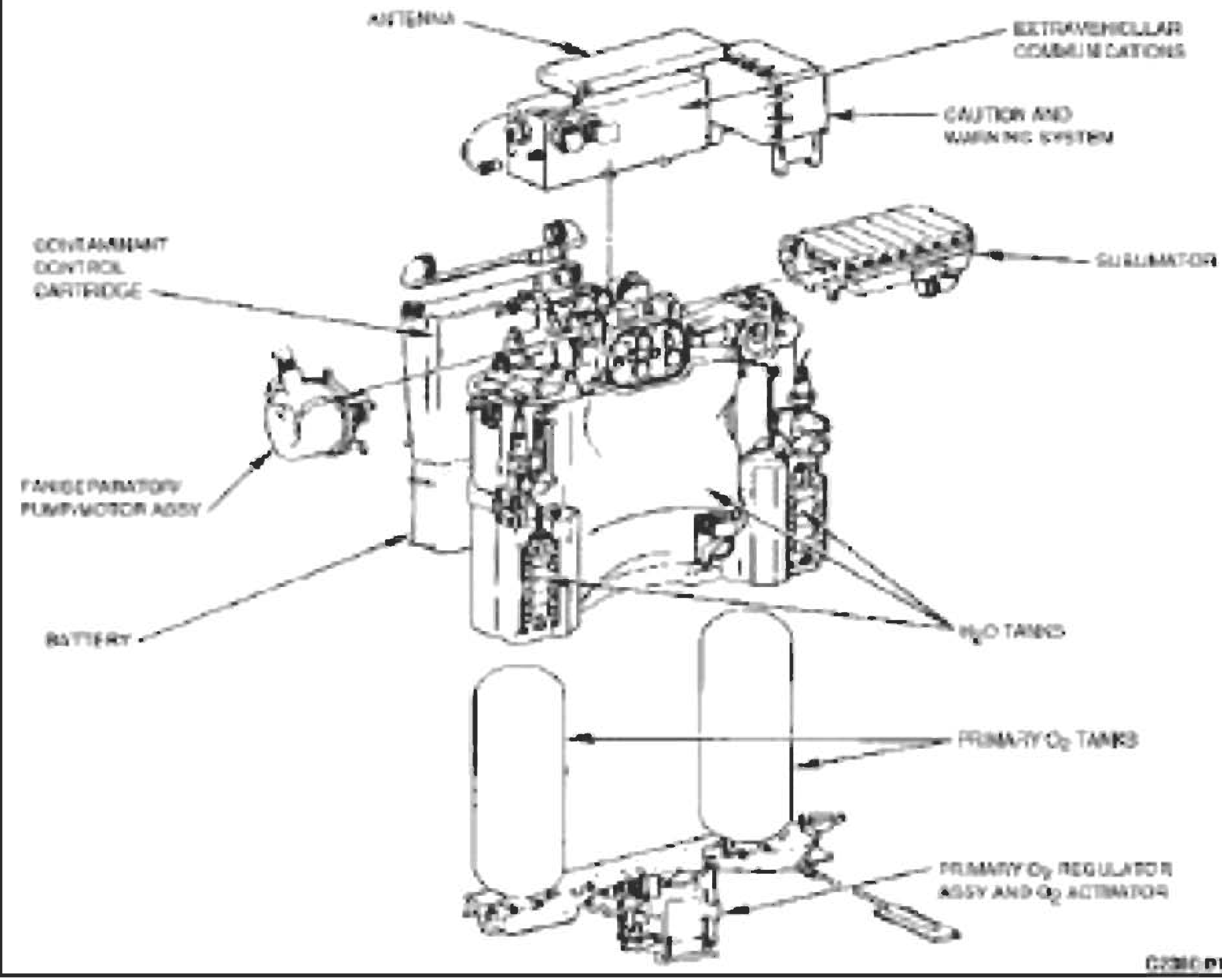
- Oxygen
- Pressure
- Thermal Control

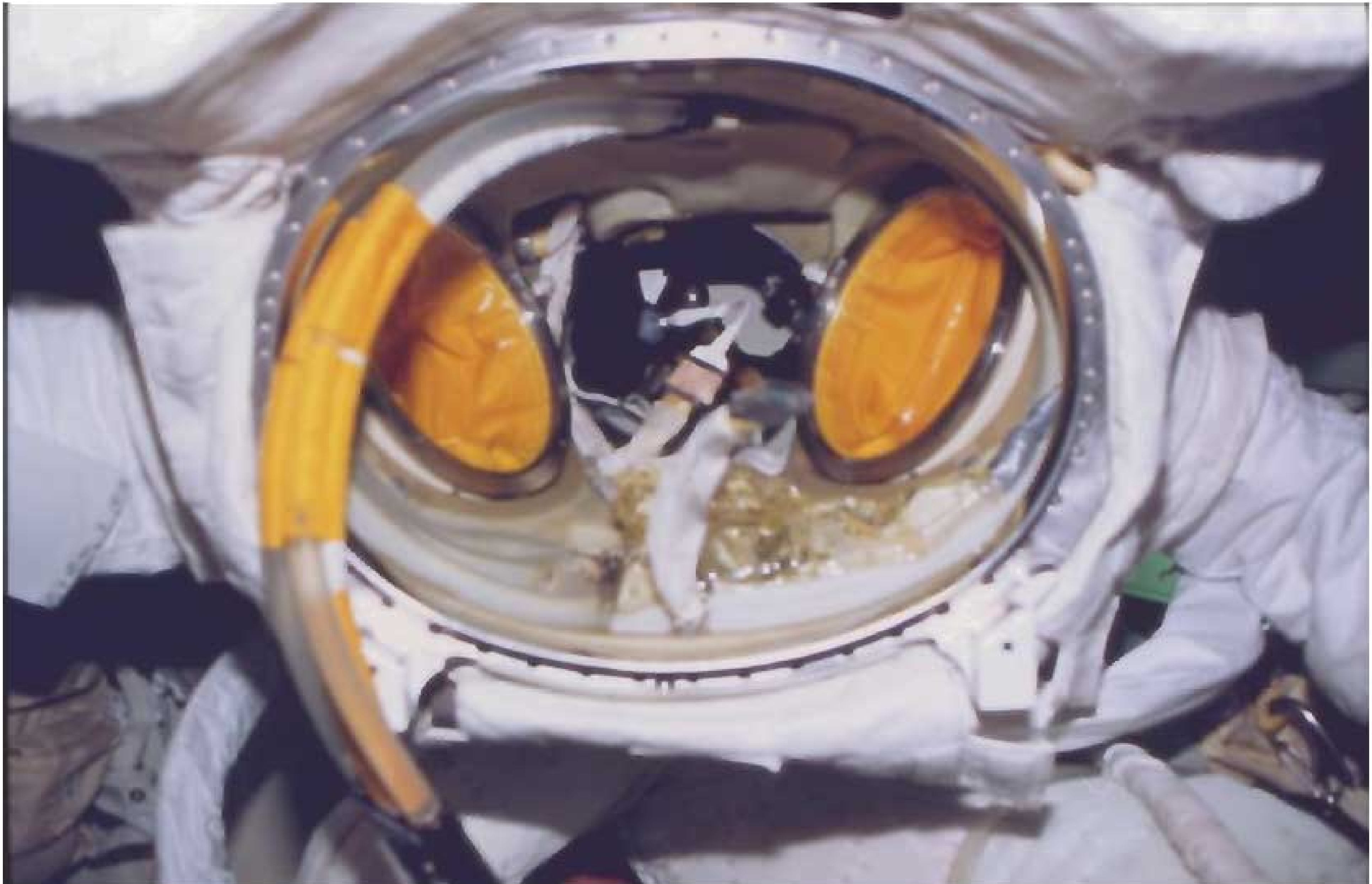


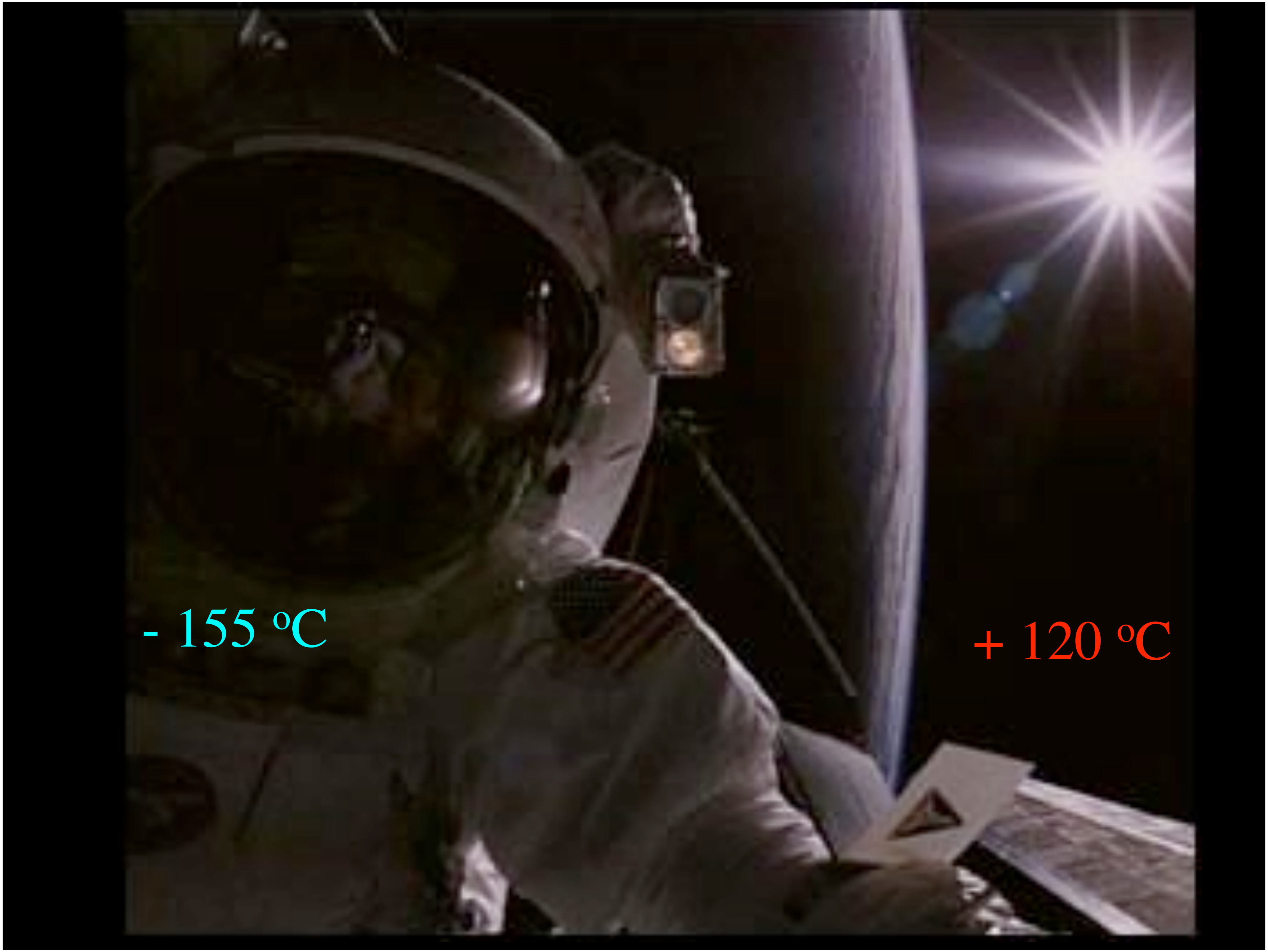
What is the temperature of space?

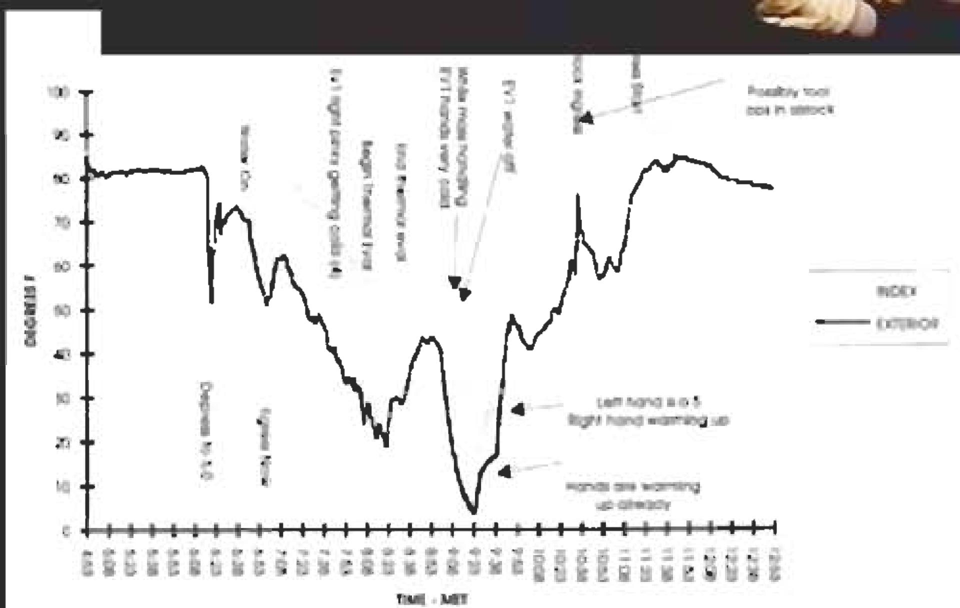



+ 120 ºC


ANTENNA
EXTRAVEHICULAR COMMUNICATIONS
CAUTION AND WARNING SYSTEM
CONTAMINANT CONTROL CARTRIDGE
SUBLIMATOR
FAN/SEPARATOR/ PUMP/MOTOR ASSY
BATTERY
H_2O TANKS
PRIMARY O_2 TANKS
PRIMARY O_2 REGULATOR ASSY AND O_2 ACTUATOR

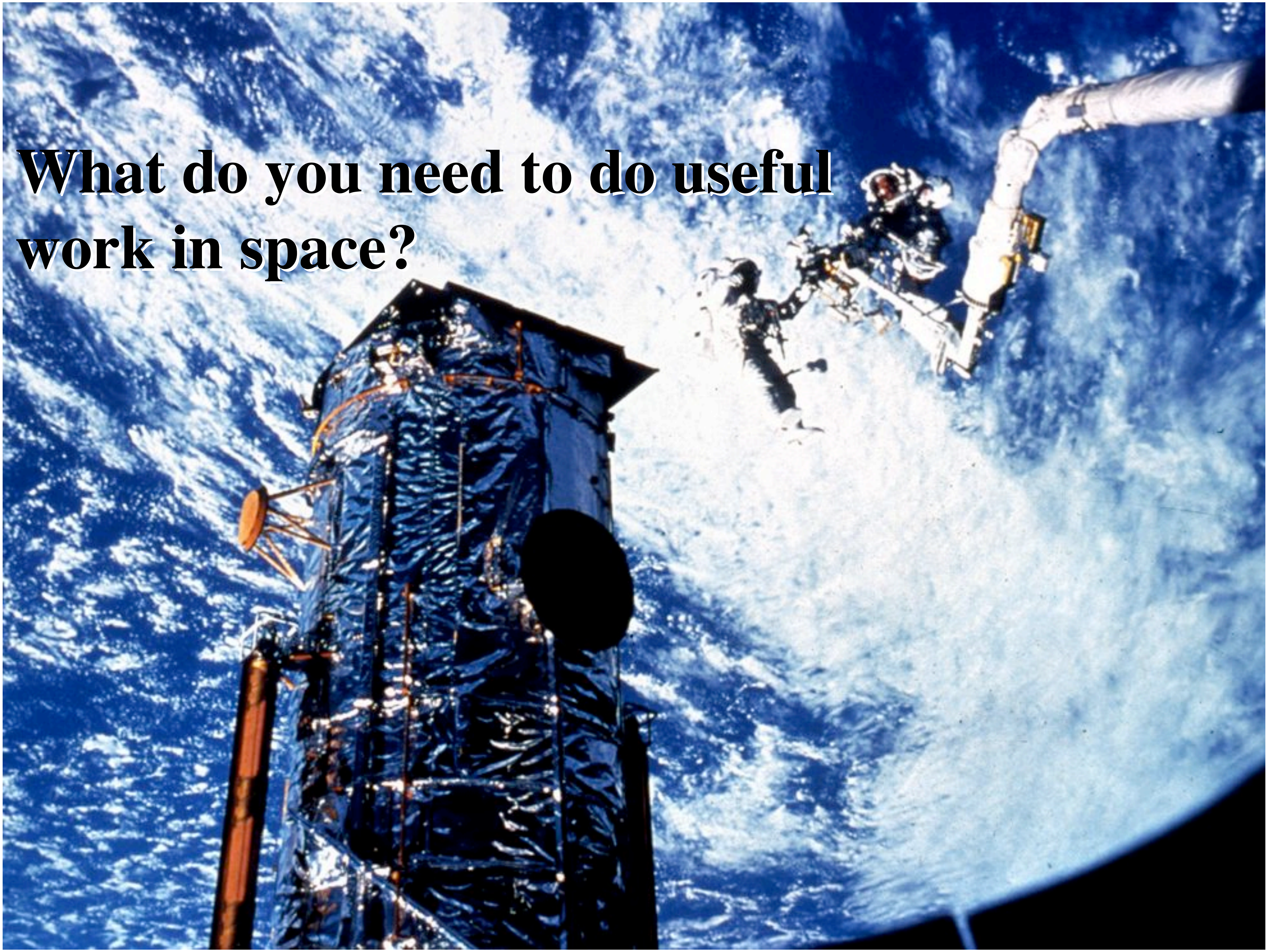



- 155 ºC
+ 120 ºC


DEGREES F
TIME - MET
0
10
20
30
40
50
60
70
80
90
100
Possibly tool box in airlock
INDEX
EXTERIOR
Left hand is a 5
Right hand warming up
Hands are warming up already

What do you need to survive in space?

- Oxygen
- Pressure
- Thermal Control
- Water and Food

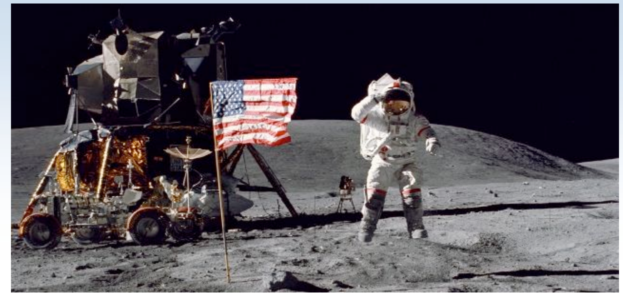

What do you need to do useful work in space?


What do you need to do useful work in space?
•Flexibility


Launch and Entry Suits


Mercury Suits

Historical Cabin and Spacesuit Atmospheres



Program	Cabin Pressure, kPa (psia)	Cabin Oxygen Concentration, volume %	EVA Suit Pressure,(1) kPa (psia)	EVA O_2 Pre-breathe Time, minutes	EVA Prebreathe Conditions
Mercury	34.5 (5)	100	-	-	-
Gemini/Apollo	34.5 (5)	100	25.8 (3.75)	0	-
Skylab	34.5 (5)	70	25.8 (3.75)	0	-
Shuttle	70.3 (10.2)	26.5	29.6 (4.3)	40	In-suit (after 36 hours at 70.3 kPa)
	101.3 (14.7)	21	29.6 (4.3)	240(3)	In-suit
ISS/US	101.3 (14.7)	21	29.6 (4.3)	120-140	Mask and in-suit; staged w/exercise
				240(3)	In-suit
Salyut, Mir, ISS/Russian	101.3 (14.7)	21	39.2 (5.7)(2)	30	In-suit

References: Carson (1975), McBarron (1993), Waligora (1993), NASA (2002), NASA (2003).

(1) 100% oxygen.

(2) Can be reduced to 26.5 kPa (3.8 psia) for short-duration work regime.

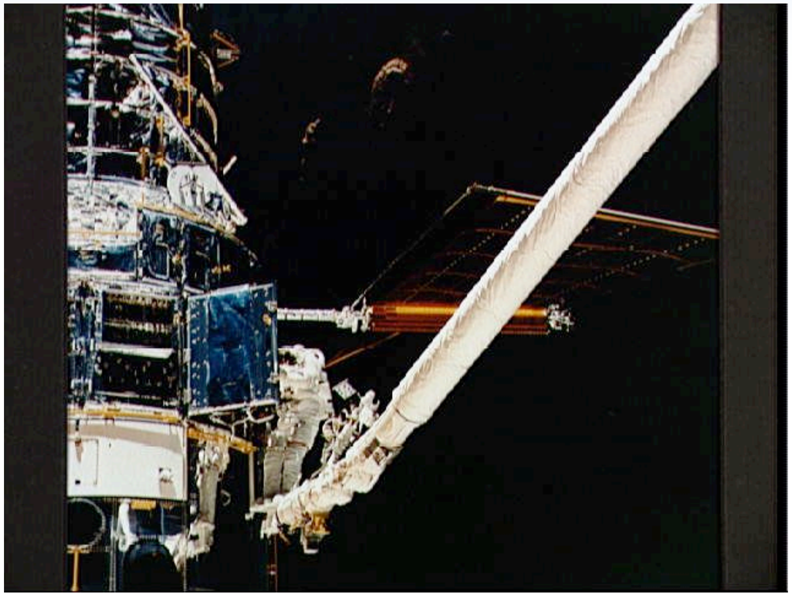
(3) Under emergency conditions, a minimum of 150 minutes of unbroken prebreathe is recommended.

What Drives Cabin Atmosphere Selection?

- **Crew Health and Safety Requirements**
  - Crew Physiology
  - Decompression Sickness Prevention
  - Emergency EVA Capability
  - Rapid Cabin Decompression Response
- **Materials Requirements**
  - Materials Flammability and Offgassing
- **Science Requirements**
  - Microgravity and Partial-Gravity Physiology Studies

    (Critical for ISS)
- **Program Requirements**
  - Mission Segments and Durations
  - EVA Frequency
  - Cross-Vehicle Atmosphere Compatibility
- **Mission/Vehicle Optimization**
  - Structure, Equipment, and Consumable Mass
  - Thermal Control Power Requirements
  - Crew Time
  - Crew Comfort and Performance
  - Cost

Shuttle has variable pressure capability



- 10.2 psi

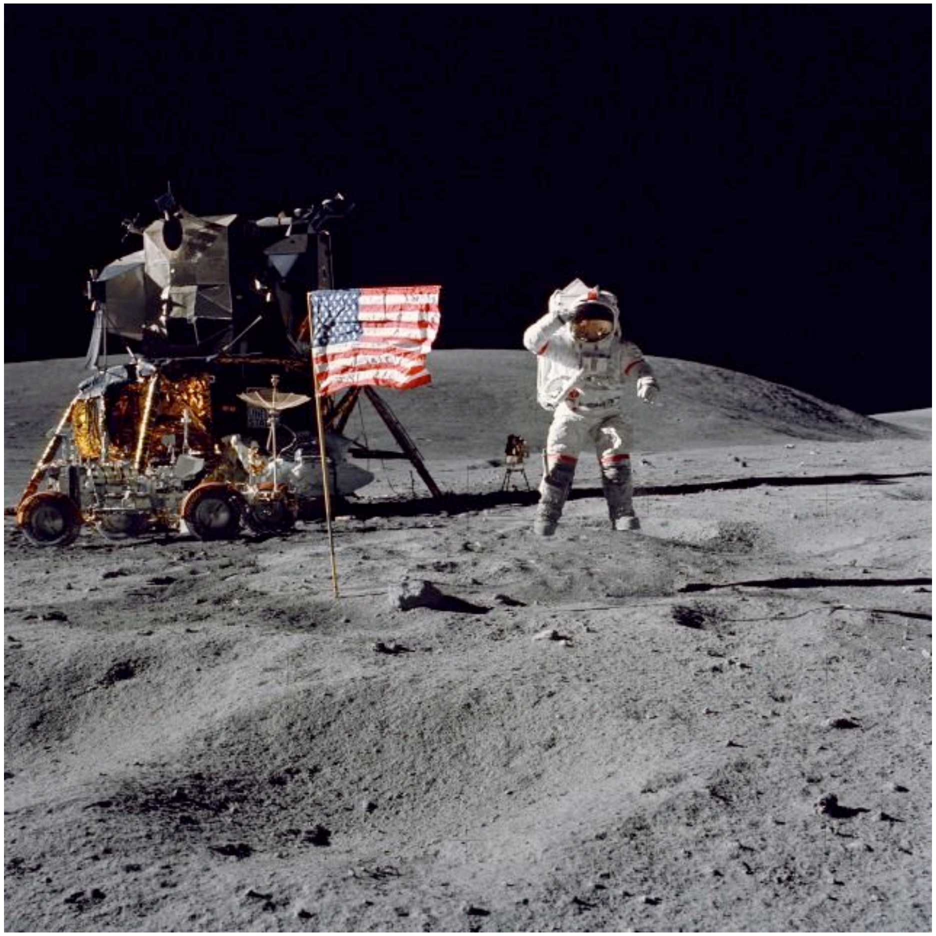
(Shuttle-only EVAs)

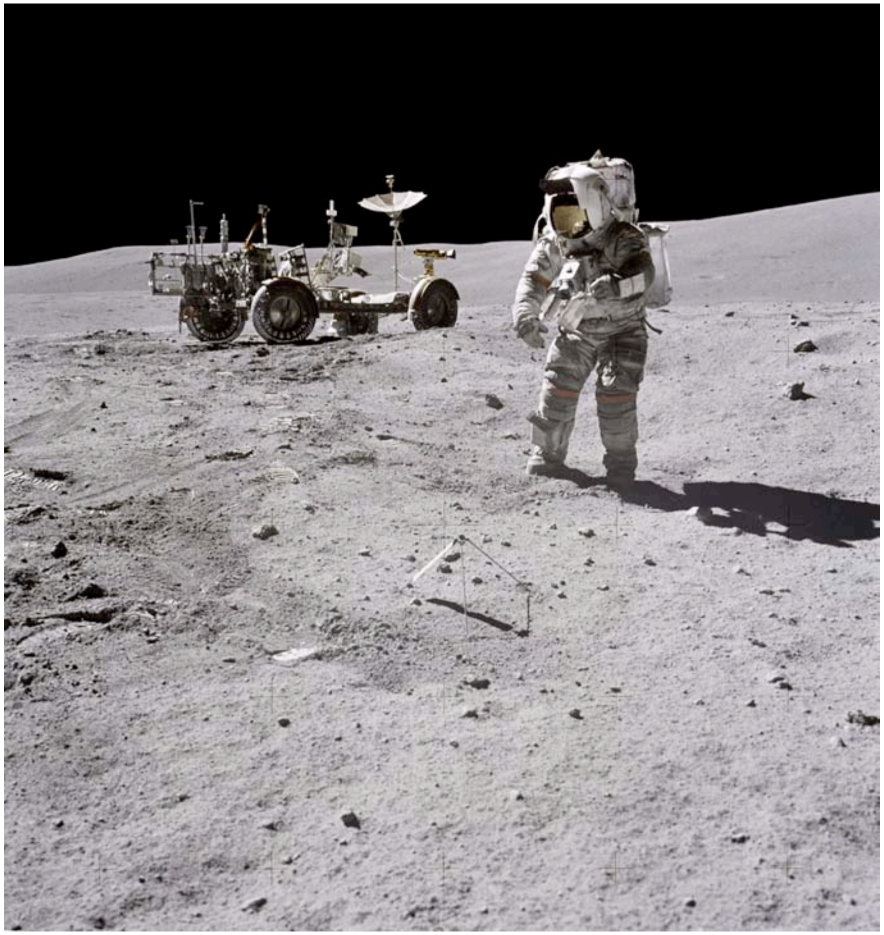
- 14.7 psi

(ISS EVAs)

Critical Issue for Exploration

- Planetary surface exploration by humans is EVA!





Physiological Requirements
(NASA (1995))

- Provide sufficient total pressure to prevent vaporization of body fluids (> 6 kPa (0.9 psia)).
- Provide sufficient oxygen partial pressure for adequate respiration.
  - Determined by partial pressure of oxygen in the alveoli of the lung.
  - Oxygen partial pressure must not be so great as to induce oxygen toxicity.
- Provide a physiologically inert gas for long durations (in excess of two weeks) to prevent atelectasis.
  - Absorption Atelectasis: collapse of obstructed alveoli due to complete gas absorption (see West (1990)).

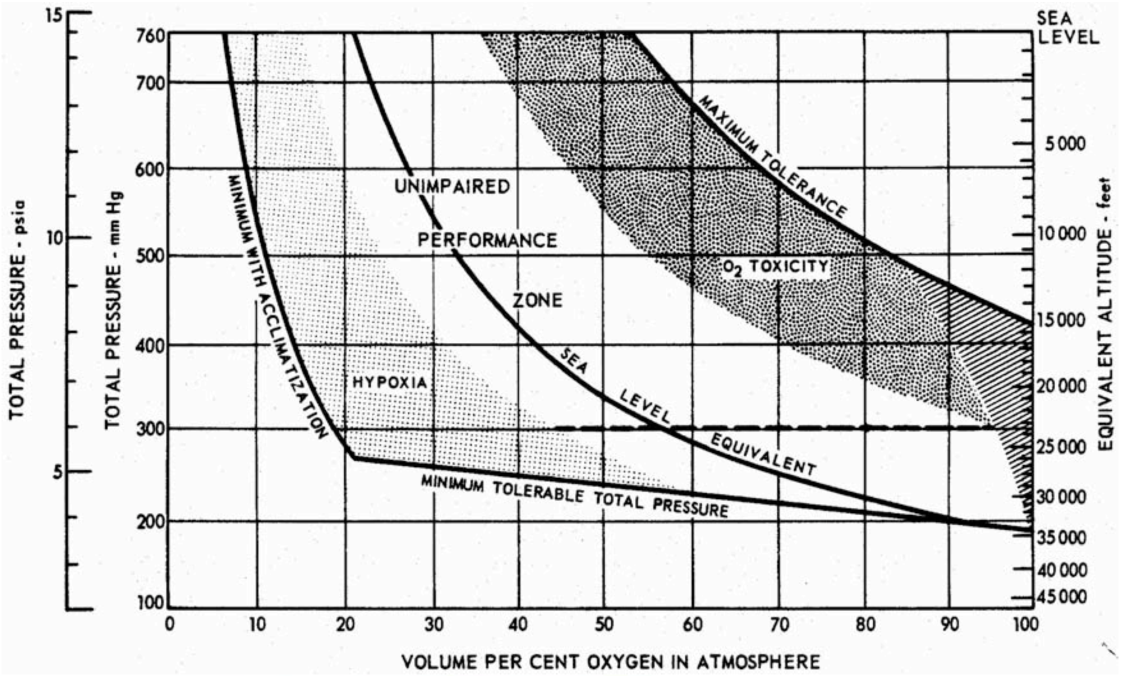
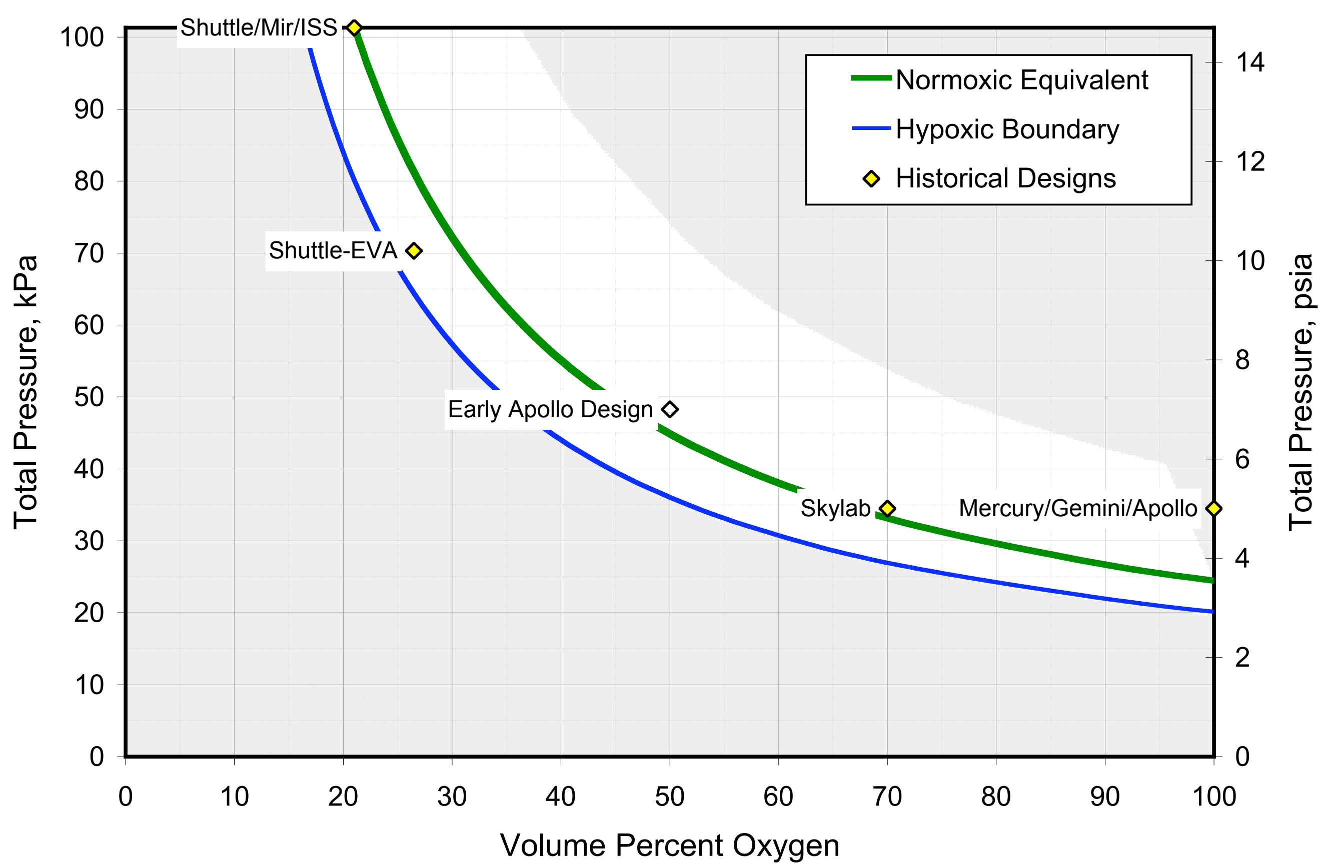


Figure: Webb (1964) (also NASA (1995)).

Assumed Physiological Bounds

- Normoxic equivalent corresponds to sea-level alveolar pAO2 of 13.9 kPa (104 mm Hg).
- Hypoxic boundary corresponds to alveolar pAO2 of 10.3 kPa (77 mm Hg) for which “acclimation can be nearly complete” according to Waligora (1993).
- Assumes more conservative “textbook” conditions.



Decompression Sickness (DCS)

- *Decompression sickness takes place when the inert gas (generally nitrogen) that normally is dissolved in body tissues at one pressure forms a gas phase ("bubbles") at a lower ambient pressure, when the the tissues become supersaturated with nitrogen.* [Powell (1993)]
  - Important consideration for mixed cabin atmospheres when extravehicular activities (EVA) are performed in lower-pressure spacesuits, and when changes in cabin pressure can occur as a result of planned activities and emergencies.
  - DCS symptoms can include pain ("bends"), chokes, skin manifestations, circulatory collapse, and neurological disorders (NASA (1995)).
  - DCS can be prevented or minimized by prebreathing 100% oxygen to wash out nitrogen from body tissues prior to depressurization (see photo).

R-Value and DCS

- DCS occurrence and severity depend on the ratio, *R*, of the partial pressure of inert gas in equilibrium with body tissue to the final ambient pressure.
- *R* is known as the tissue ratio or bends ratio, frequently referred to a tissue with a 360-minute time constant for change in the inert gas content to half of the difference between the initial and final equilibrium states.

$$R = \frac{\text{Tissue } p_{N2}}{\text{Final Ambient (Suit) Pressure}}$$

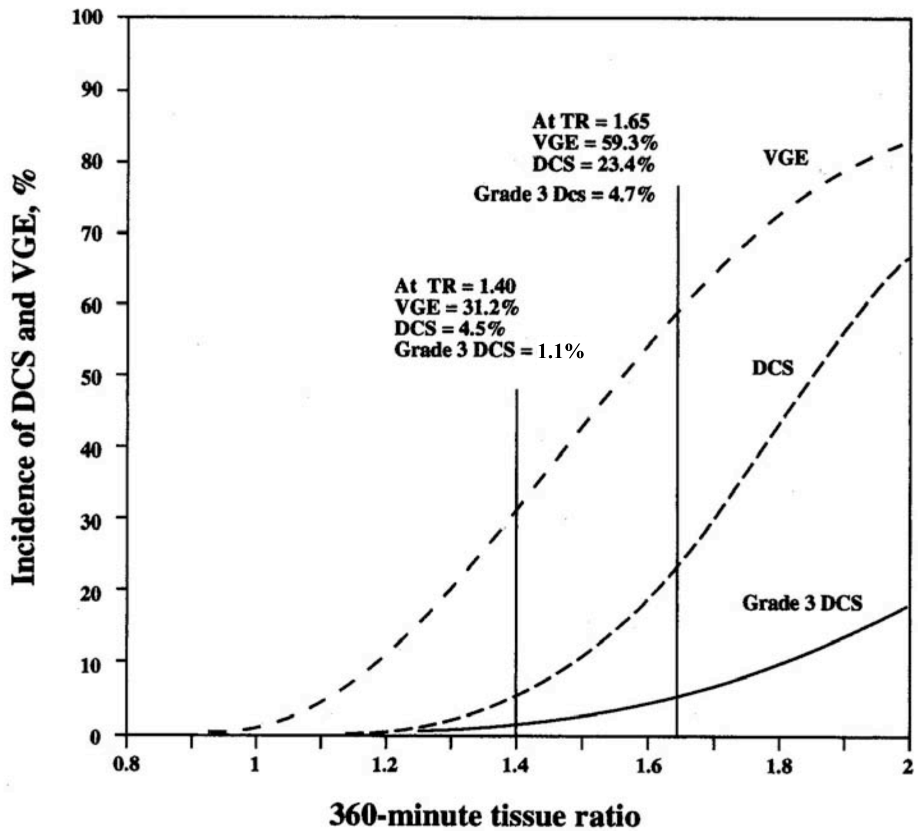


Figure Source: Horrigan (1993)
VGE = venous gas emboli

Other DCS Factors

- DCS also depends on the duration at reduced pressure, and the degree of physical activity at reduced pressure.
- Test data suggest that at the same *R* value, a higher spacesuit pressure will result in a lower probability of DCS (Conkin, et al. (1996)).
- Exercise increases the formation of gas bubbles.

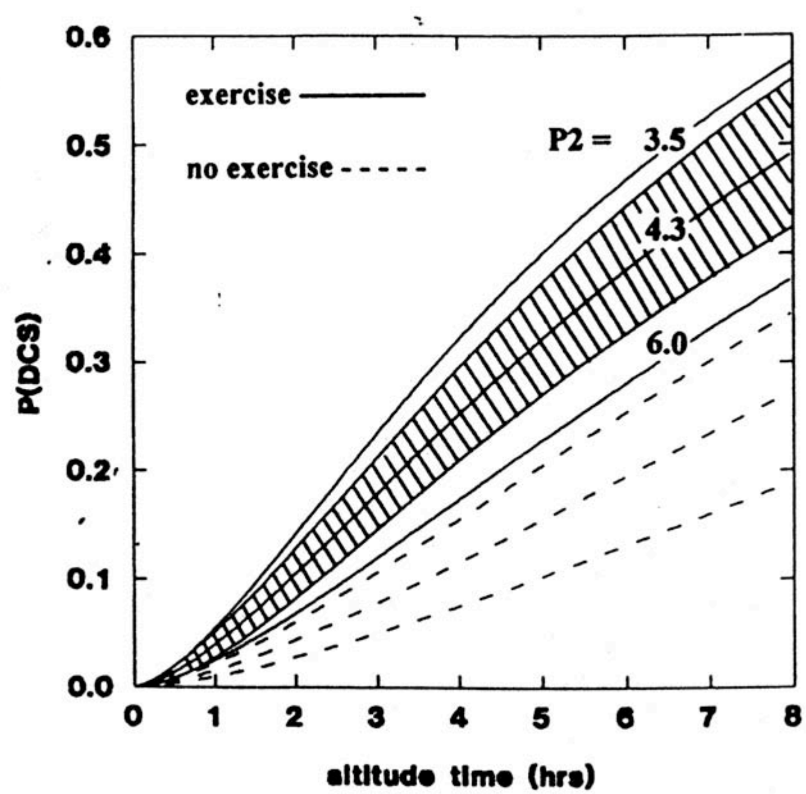


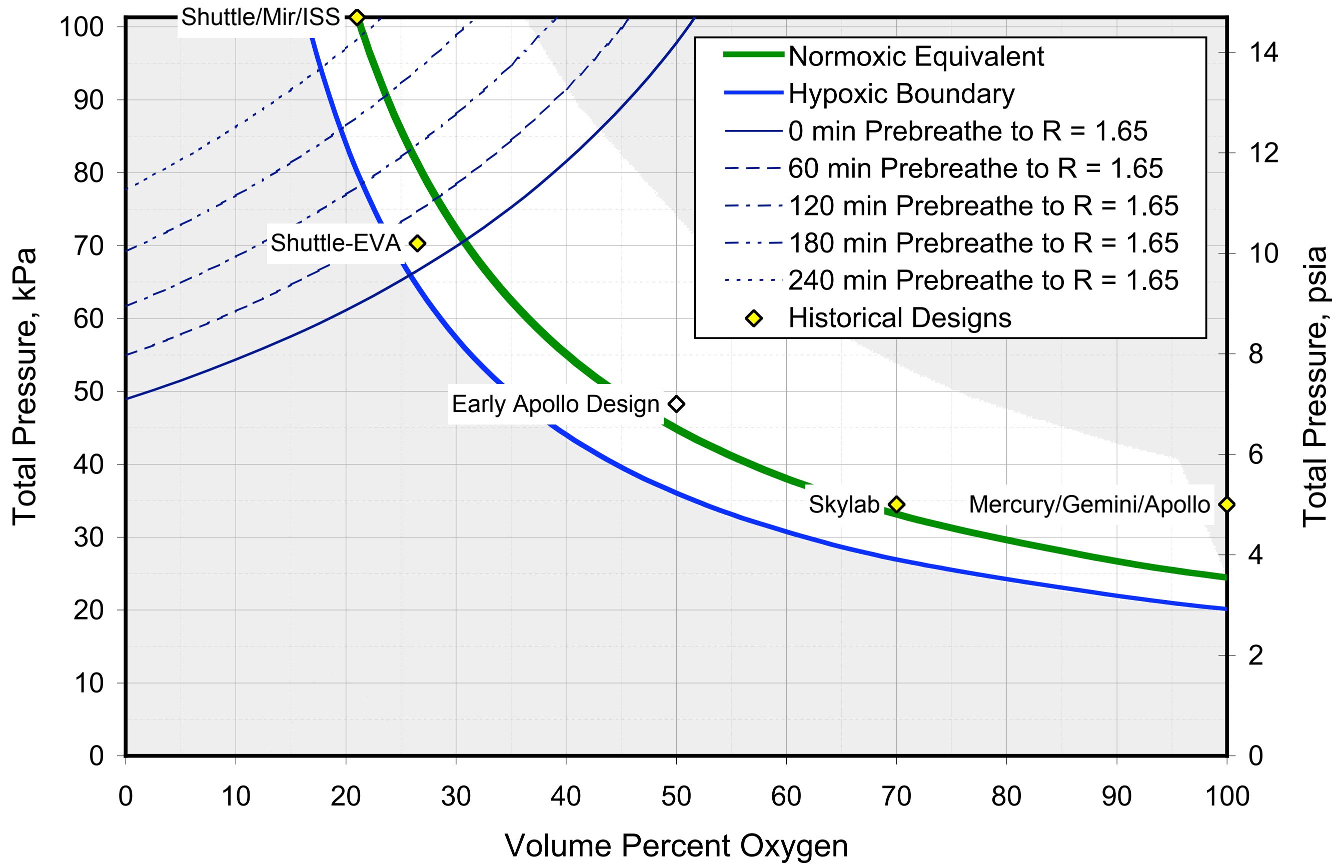
Fig. 3. The P(DCS) at either 3.5, 4.3, or 6.0 psia with (solid line) or without (dashed line) exercise at a particular time after decompression. The ratio of $P1N_2$ to P2 (TR) in Eq. 5 was 1.65 for each curve, but notice the P(DCS) increases as P2 decreases at any particular time after decompression. The 95% confidence interval is provided for the curve specific to the 4.3 psia exposure that included exercise.

Figure source: Conkin, et al. (1996).
P(DCS) = calculated probability of DCS from statistical model
P2 = final ambient (suit) pressure, psia
R = 1.65

Current Microgravity EVA Prebreathe Protocols

29.6 kPa (4.3 psia) Spacesuit

- Shuttle and ISS/US prebreathe protocols are based on a final calculated *R* value of 1.65-1.68 after oxygen prebreathe (see Horrigan (1993), and NASA (2002, 2003)).
- Actual *R* values during Shuttle flights are frequently lower.
- Calculated prebreathe times assume an exponential-decay tissue half-time of 360 minutes (see Conkin (1987)).



Prebreathe Bounds for Surface Exploration EVAs

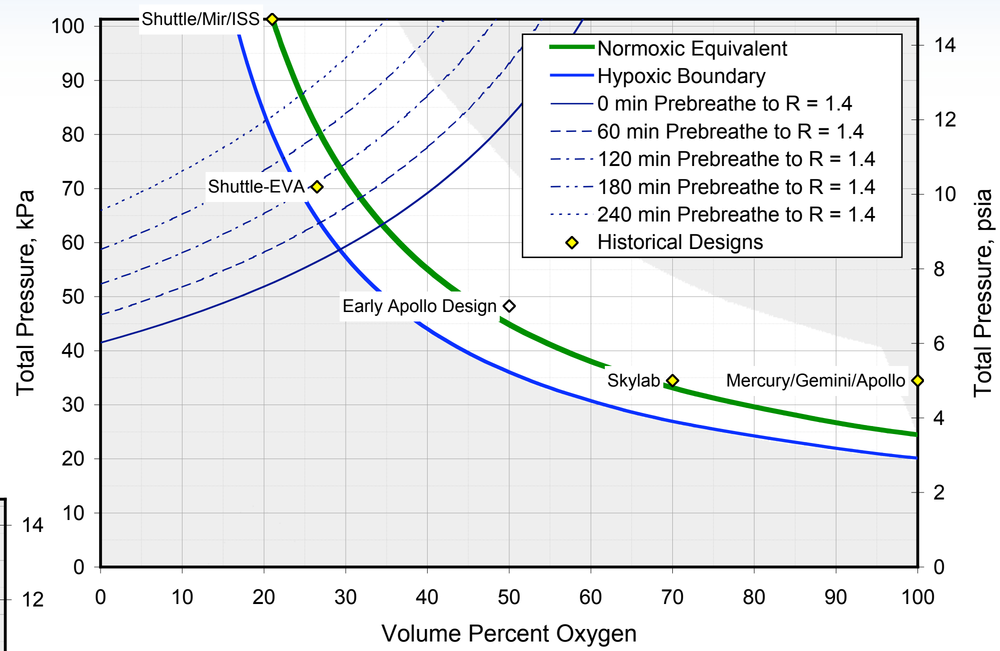
- The quantification of DCS risks and the development of prebreathe protocols for partial-gravity surface exploration EVAs require additional research.
- The acceptable level of DCS risk for surface exploration EVAs has also not been established.
- Higher physical loads imposed by partial gravity suggest higher DCS risk than in microgravity.
- The need to treat DCS problems locally without the option for a quick return to Earth is also a consideration.
- A final *R*-value of 1.3-1.4 is considered a reasonable starting point for analysis (Conkin (2004)).
- When performing EVAs from an atmosphere containing nitrogen, an oxygen prebreathe time of approximately 1 hour is desirable to denitrogenate the brain and spinal cord in order to prevent the occurrence of serious (Type II) DCS symptoms (Gernhardt (2004)).

Prebreathe Bounds for Surface Exploration EVAs

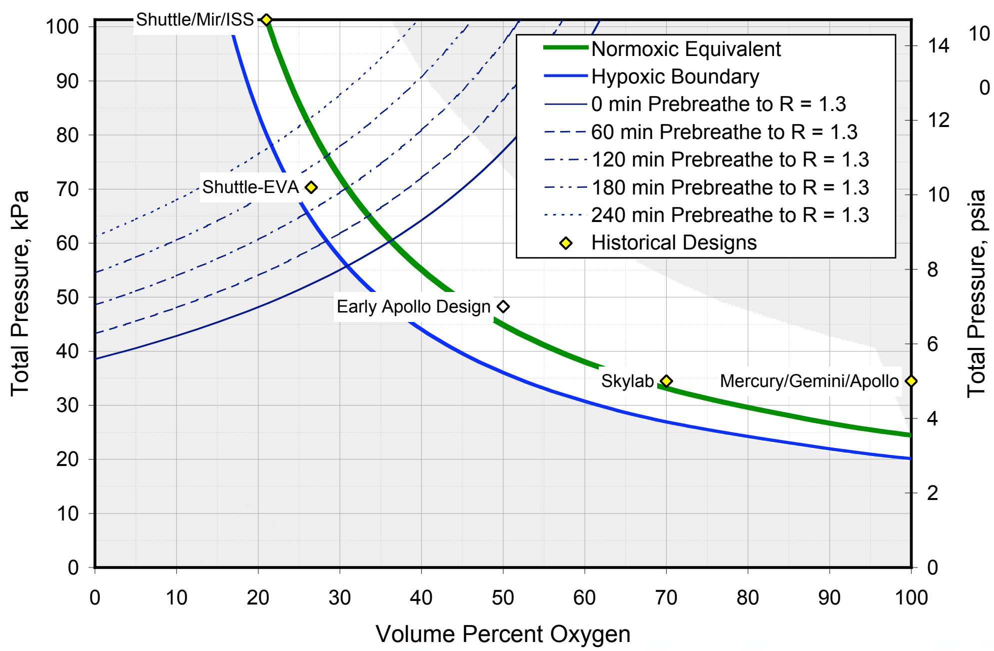
Current Spacesuit Pressure

29.6 kPa (4.3 psia) Spacesuit

R = 1.4



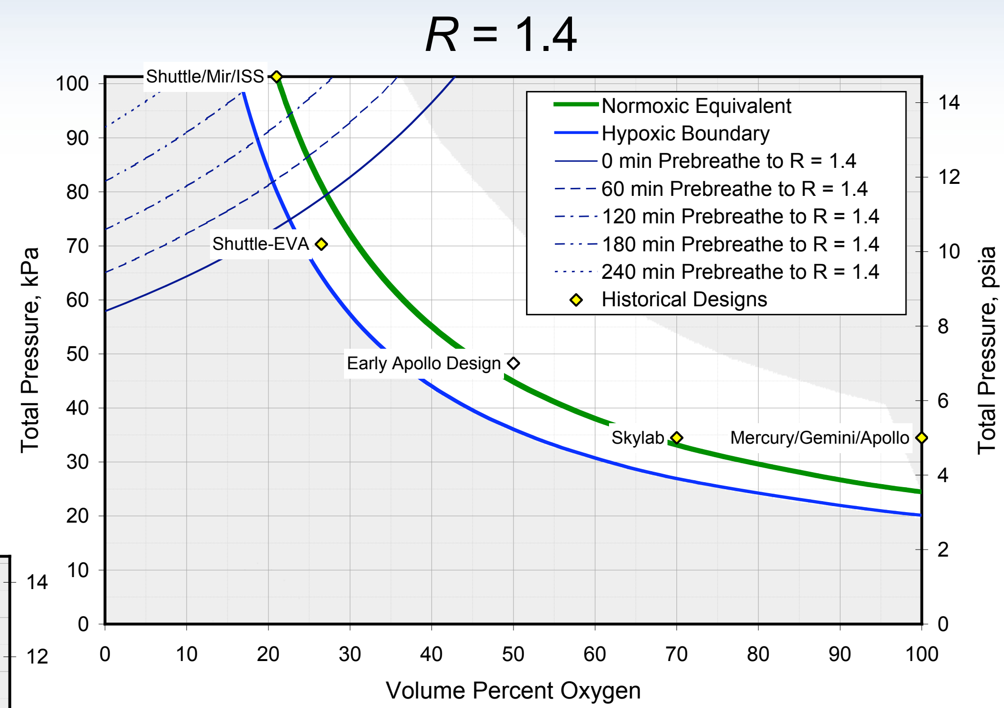
R = 1.3

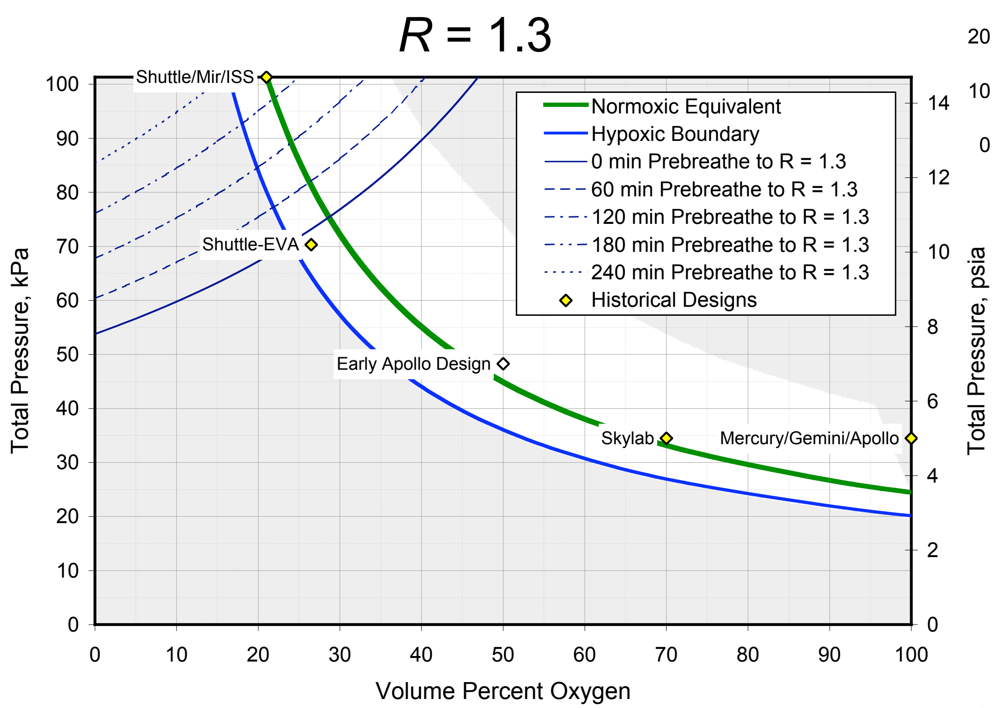


Prebreathe Bounds for Surface Exploration EVAs

Higher Spacesuit Pressure

41.4 kPa (6 psia) Spacesuit

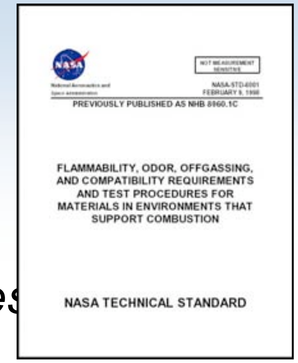




Materials Selection for Future Space Missions

- High oxygen concentrations, such as employed in the Skylab program (70%), would require extensive use of metallic materials.
- Research in deep-space ionizing radiation has found that metals are much poorer than hydrogen-containing materials in shielding the crew from high-energy particles associated within Solar Particle Events (SPE) and Galactic Cosmic Radiation (GCR):
  - *Aluminum has been found to be a poor shield material when dose equivalent is used with exposure limits for low Earth orbit (LEO) as a guide for shield requirements. Because the radiation issues are cost related—the parasitic shield mass has high launch costs—the use of aluminum as a basic construction material is clearly not cost-effective and alternate materials need to be developed*. [Wilson (1997)]
  - *Shielding against the radiation environment involves the entire spacecraft, meaning that apparently simple design choices (e.g., aluminum structures as opposed to polymer composites) can have adverse effects on radiation exposures. Shielding during every aspect of the mission is necessary to ensure crew safety, health, and performance.* [Allen (2003)]

Materials Flammability Requirements



- *Spacecraft fire control is based on minimizing potential ignition sources and “eliminating materials that can propagate fire.”*
  - *This means controlling quantity and configuration of flammable materials to eliminate potential fire propagation paths and ensure any fire would be small, localized, isolated and would self-extinguish without harm to the crew.* [Griffin (2001)]
- Flight hardware must comply with NASA-STD-6001, “Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion” (NASA (1998)).
  - Describes required flammability tests.
  - Requires a system flammability evaluation for materials that fail.
- Flammable materials of limited size and quantity can be used by isolating from ignition sources and by eliminating or restricting fire propagation paths (Friedman (1999), Griffin (2001)).
  - Approaches include enclosing in nonflammable containers and covering with nonflammable materials or coatings.

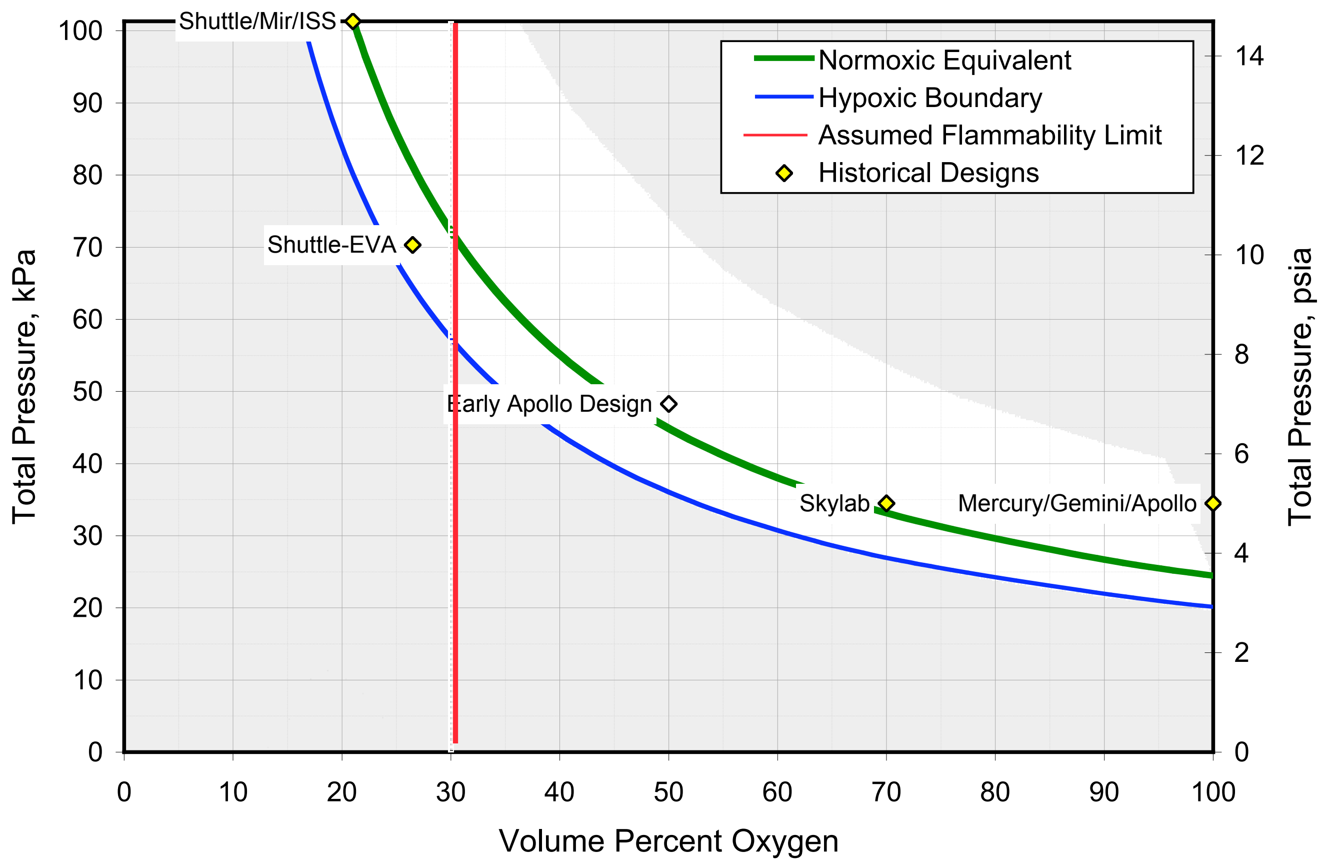
Materials Flammability

Effect of Oxygen Concentration and Atmosphere Pressure

- Materials flammability is strongly dependent on oxygen concentration (volume percent) and to a lesser extent on total pressure.
  - Increasing oxygen concentration at constant atmosphere pressure decreases the minimum ignition energy, increases the flame spread rate, and increases the amount of extinguishant required to put out a fire (NFPA (2004), Beeson (1997)).
  - Increasing the atmosphere pressure at constant oxygen concentration has also been found to increase the flame spread rate of nonmetallic materials (NFPA (2004)).
- The number of non-metallic materials that pass NASA flammability tests falls off rapidly above 30% oxygen.

Flammability Bound

- Limit oxygen concentration to 30% or below based on an expected increased use of non-metallic materials for future missions to reduce mass and optimize radiation shielding.
- An extensive database of flammability test results exists at 30% oxygen and 70.3 kPa (10.2 psia).
- For constant oxygen concentration, a small reduction in flammability risk is expected as the pressure is reduced.

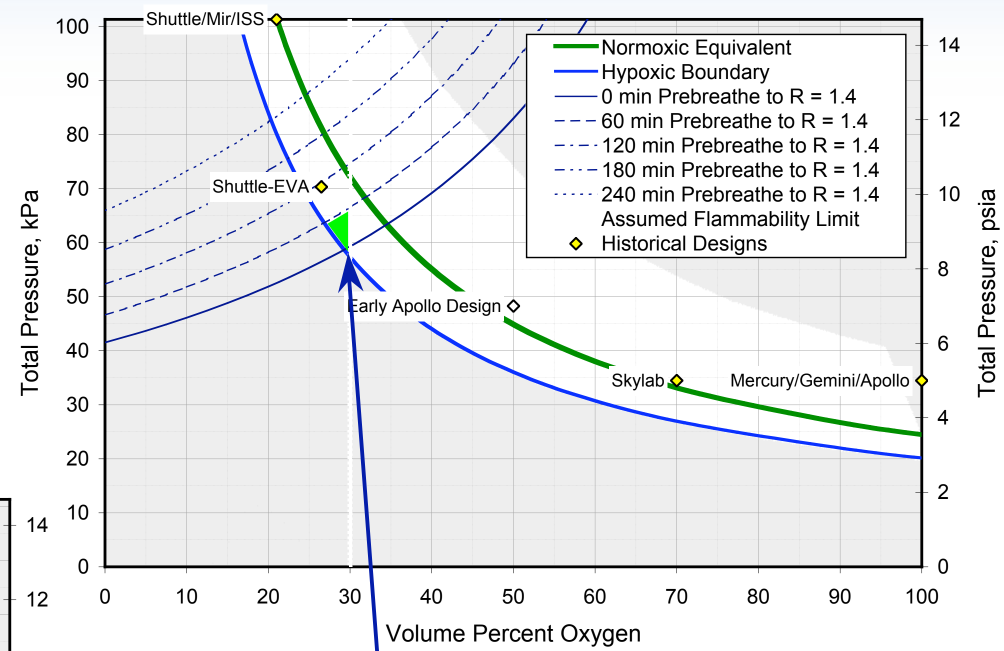


Combined Results and Initial Bounded Design Space

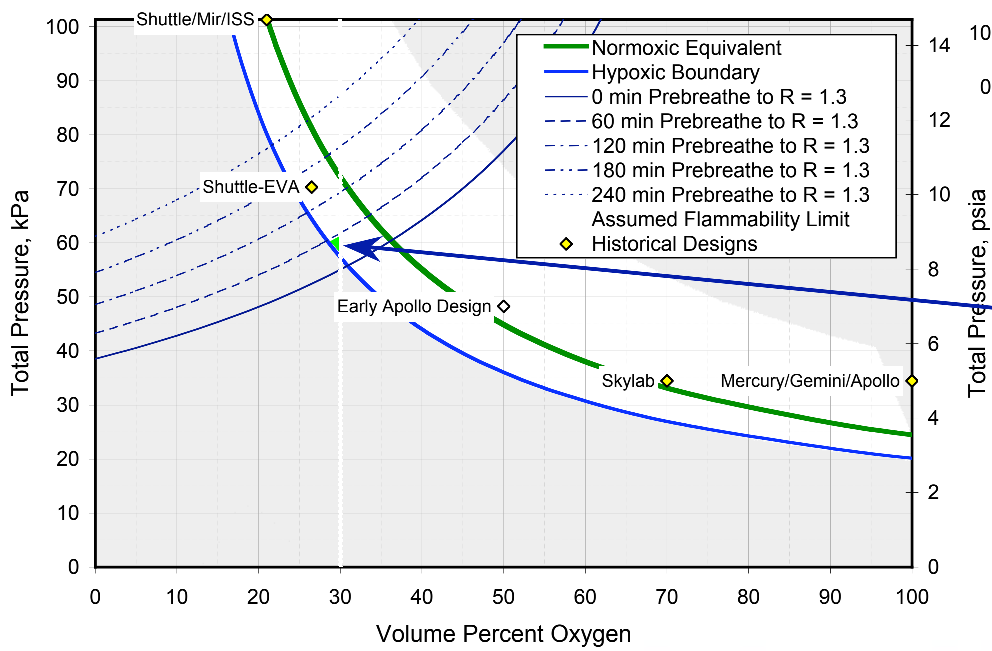
Current Spacesuit Pressure

29.6 kPa (4.3 psia) Spacesuit

R = 1.4



R = 1.3

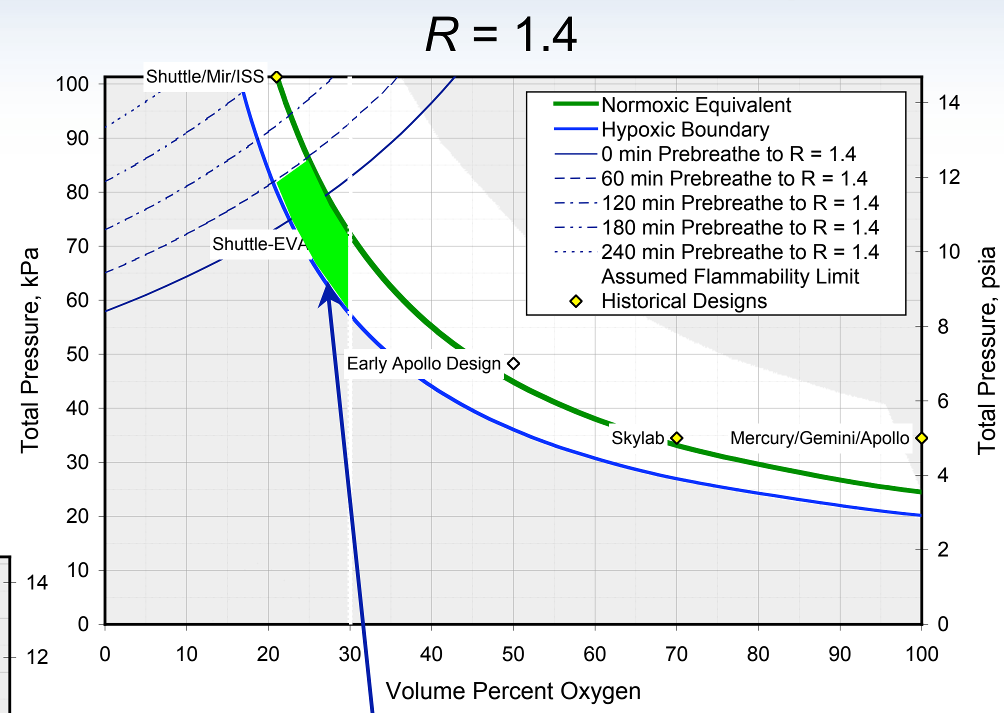


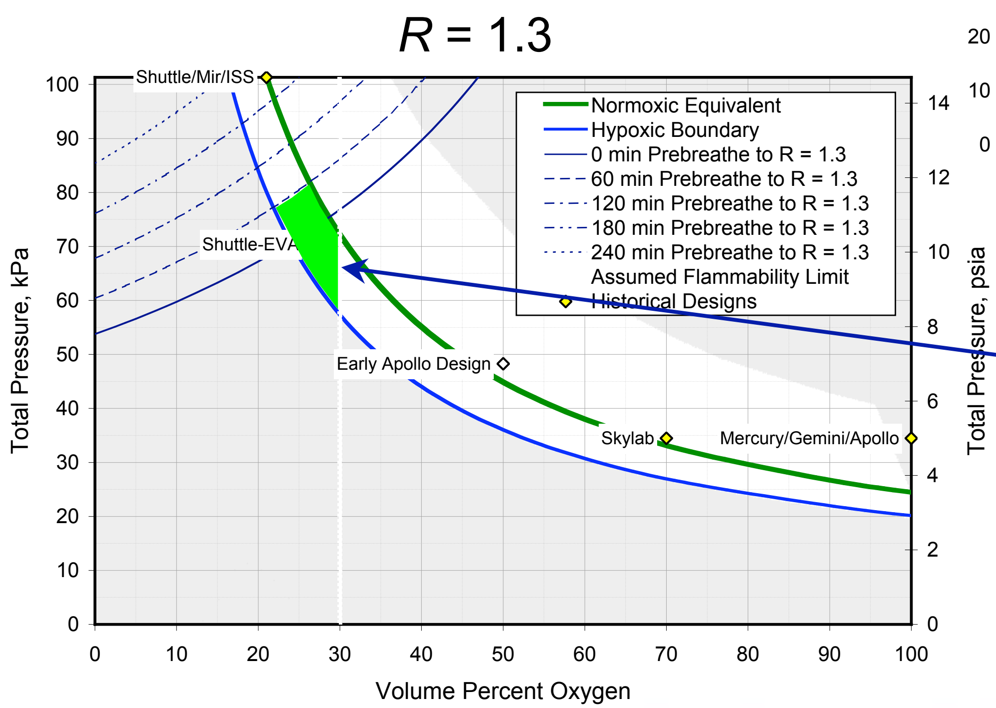
Initial Design Space (1 hour or less required prebreathe)

Combined Results and Initial Bounded Design Space

Higher Spacesuit Pressure

41.4 kPa (6 psia) Spacesuit





Initial Design Space (1 hour or less required prebreathe)

Considerations for Lunar Prebreathe Predictions

- **It is not clear at this time whether the lunar environment can be considered approximately equal to the micro-gravity environment**
  - Model predictions should consider a range from 1-g to micro-gravity
- **Current exercise prebreathe models are all calibrated with 14.7 psi protocols:**
  - It is not clear that they can be extrapolated with any confidence to lower saturation pressures
- **Additional research is planned:**
  - Any lunar prebreathe protocol will have to be tested against a prospective acceptance criteria
- **Any model predictions at this time will have low confidence levels**
- **Lunar EVAs in Apollo were easy (100% 02 cabin). Lunar EVAs from a 8-12 psi habitat are going to be challenging.**
  - We can systematically provide a solution.
  - Important to have strong communications between suit development and prebreathe research

Summary and Conclusions

- The design of habitat atmospheres for future space missions is driven primarily by physiological, safety, and materials requirements.
- Future spacecraft designs will likely incorporate more composite and polymeric materials both to reduce structural mass and to optimize crew radiation protection. Materials need to be compatible with a 30% Oxygen environment.
- Based on the assumed bounds and the current spacesuit pressure of 29.6 kPa (4.3 psia), a small atmosphere design range is found that can provide an *R* value of 1.3 with 1 hour or less of prebreathe for surface EVAs.
  - An atmosphere pressure of 60 kPa (8.7 psia) at 28-29% oxygen would appear to be a good starting point for detailed design studies.

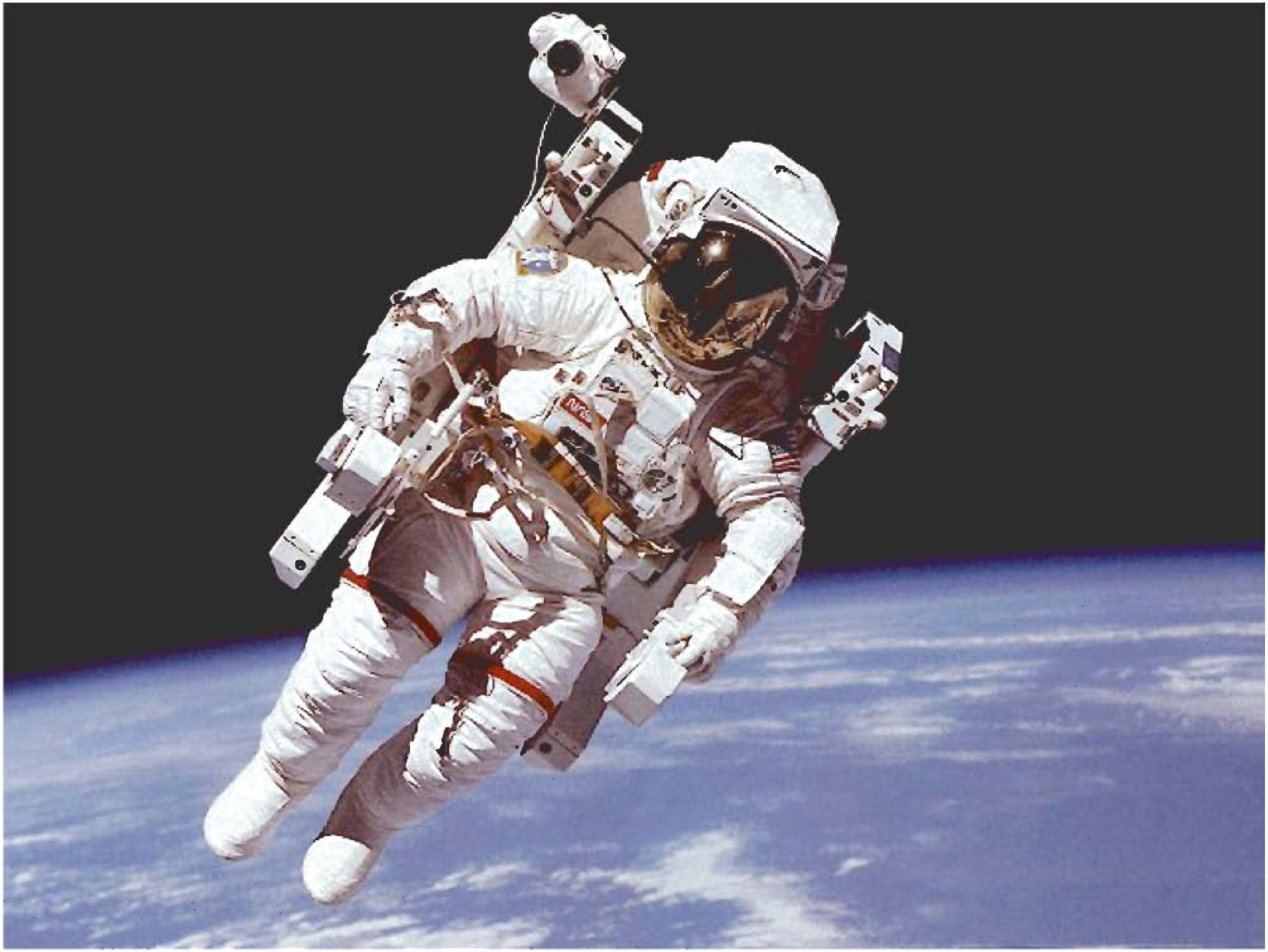
Summary and Conclusions
(continued)

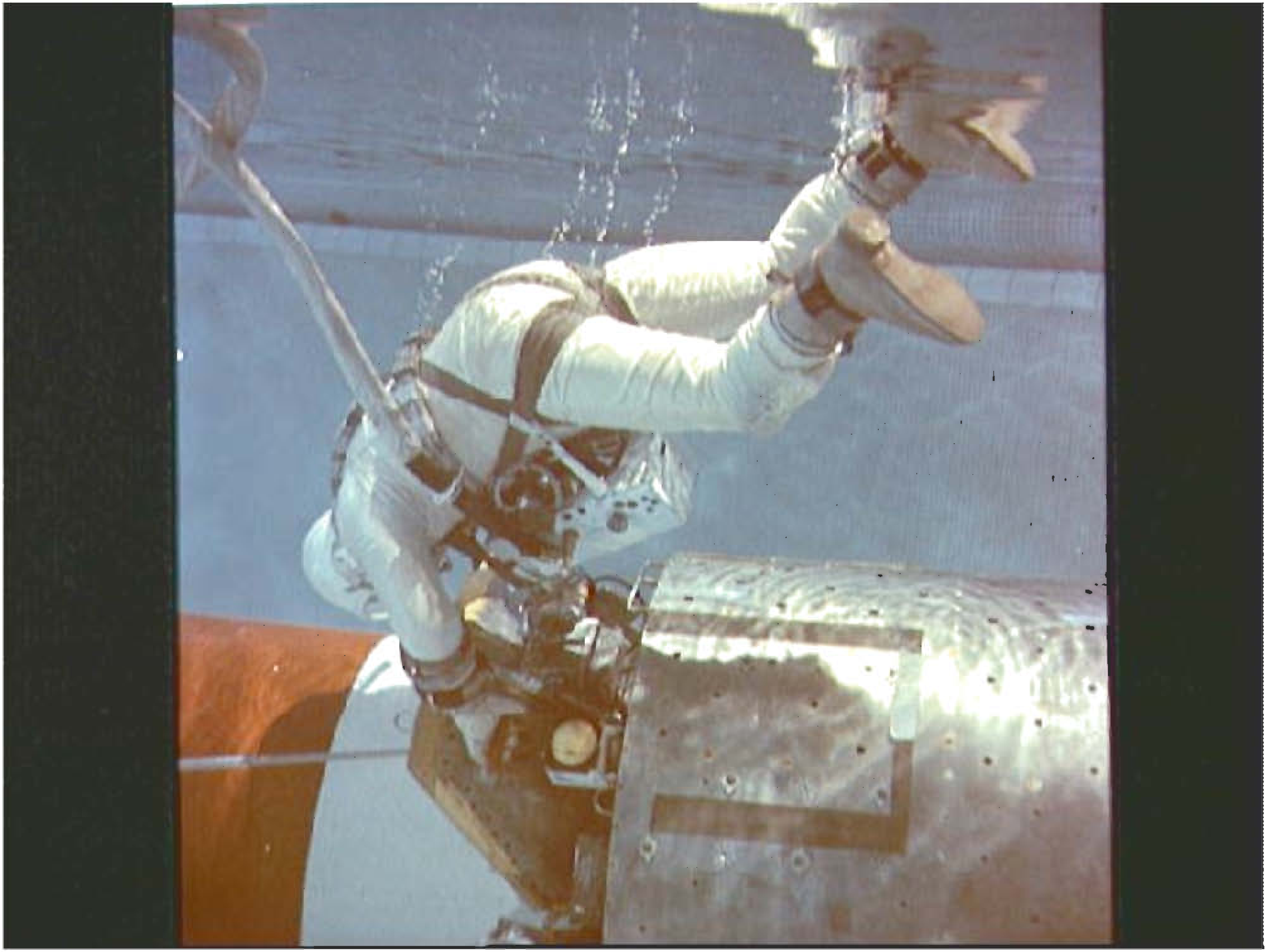
- If a lower oxygen concentration is needed based on materials considerations, a higher space suit pressure of up to 41.4 kPa (6 psia) can provide a much wider range of atmosphere solutions, but impacts to spacesuit mass and glove dexterity must be considered.
- For vehicles that dock with the International Space Station, the ISS (Earth normal) atmosphere conditions must be included in the design space.
- For transit vehicles with few EVAs, the potential atmosphere design space extends between the normoxic equivalent and hypoxic boundary curves below 30% oxygen.
  - A detailed mission definition and detailed design studies will be required to optimize the vehicle atmosphere.

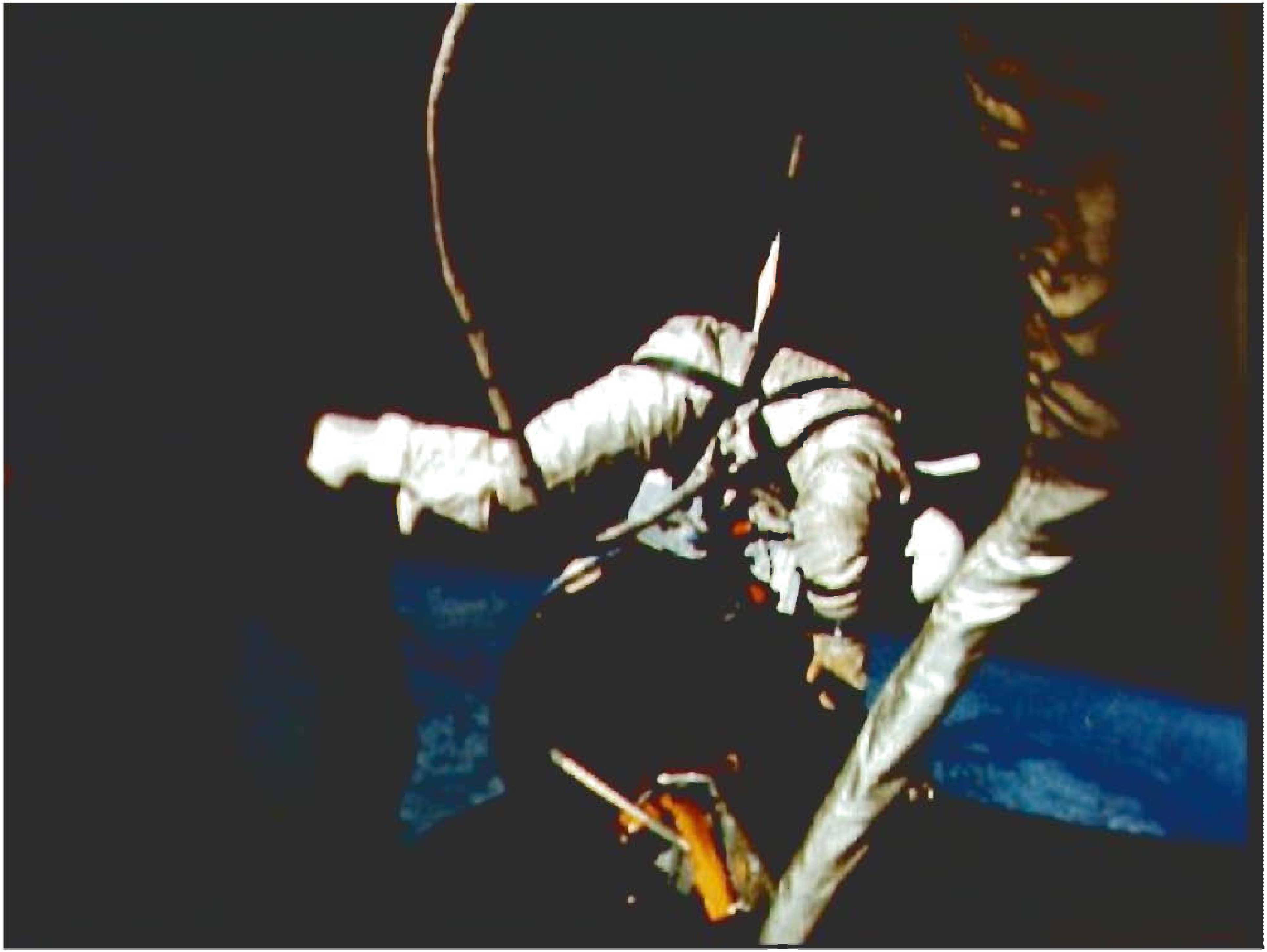

What do you need to do useful work in space?
•Flexibility
•Visibility

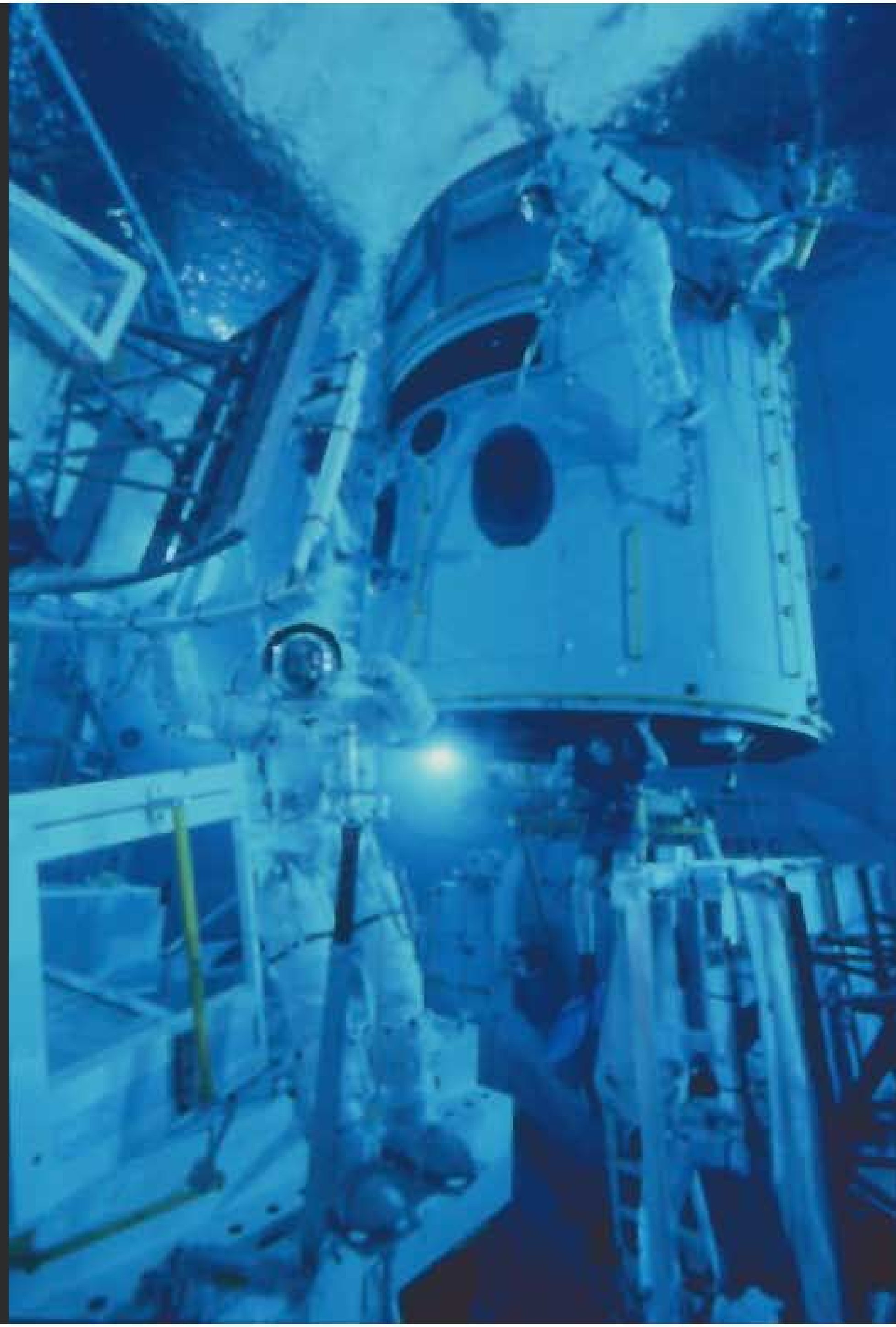

What do you need to do useful work in space?
•Flexibility
•Visibility
•Tools

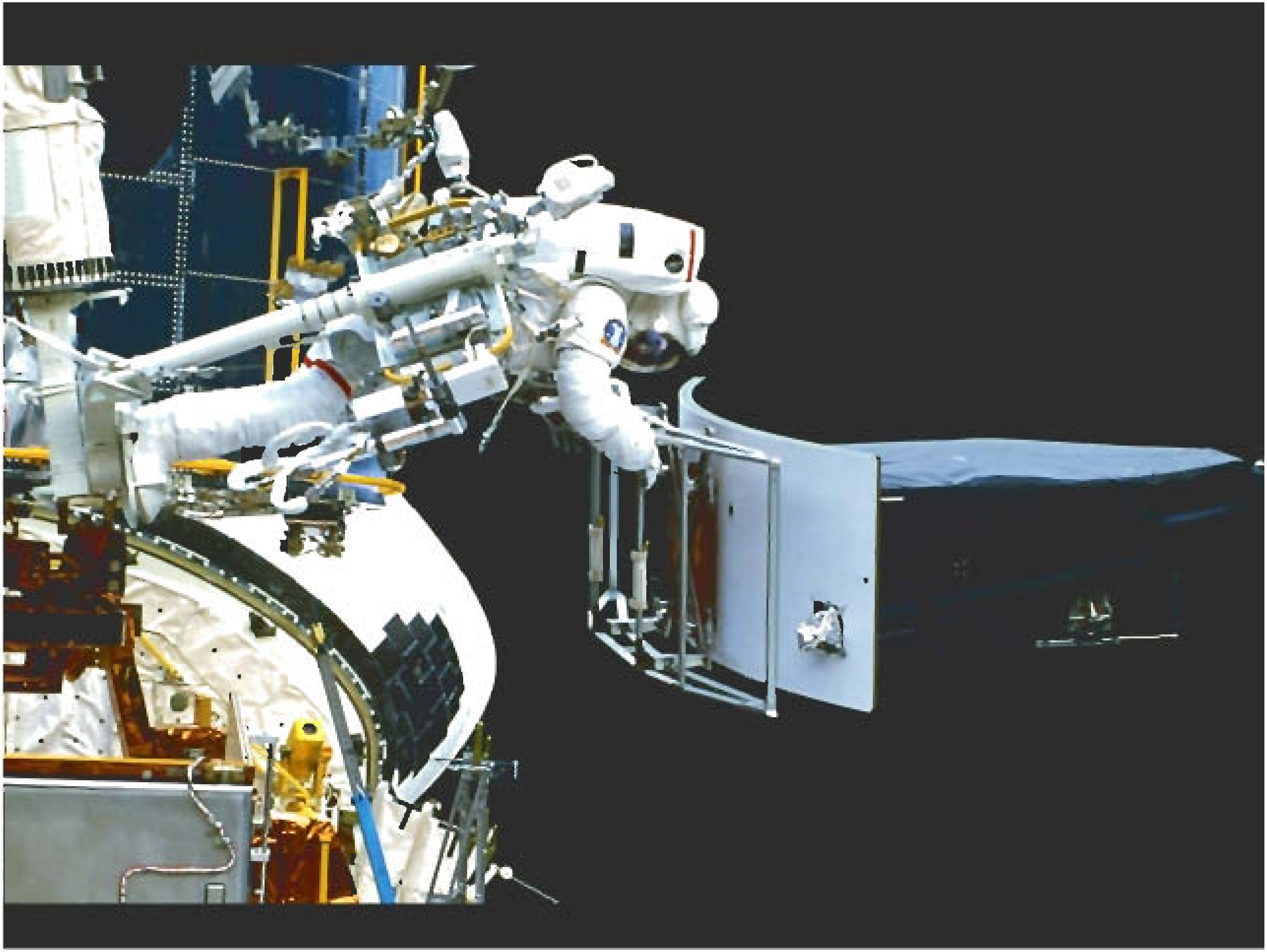

What do you need to do useful work in space?
•Flexibility
•Visibility
•Tools
•Stability

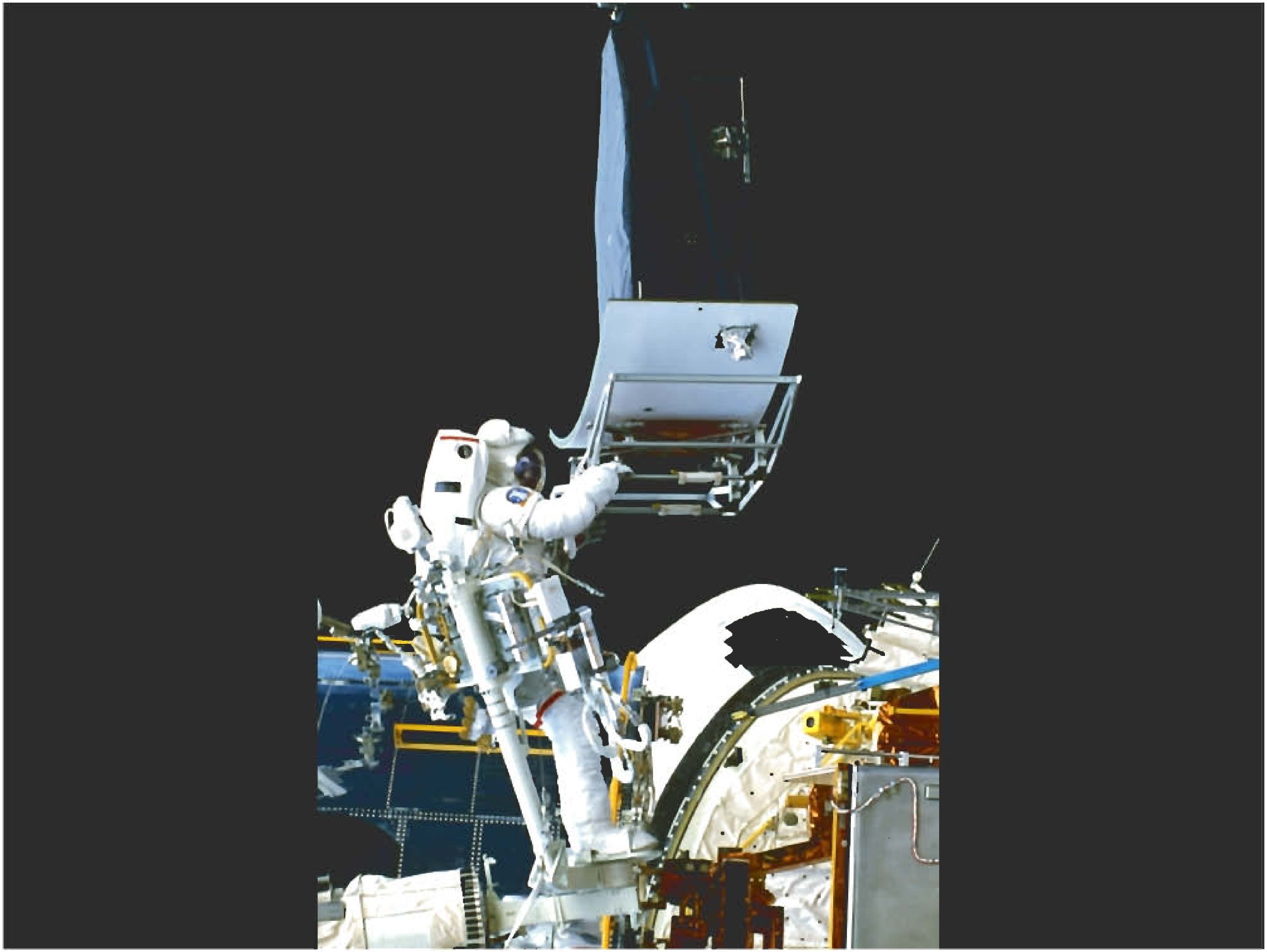




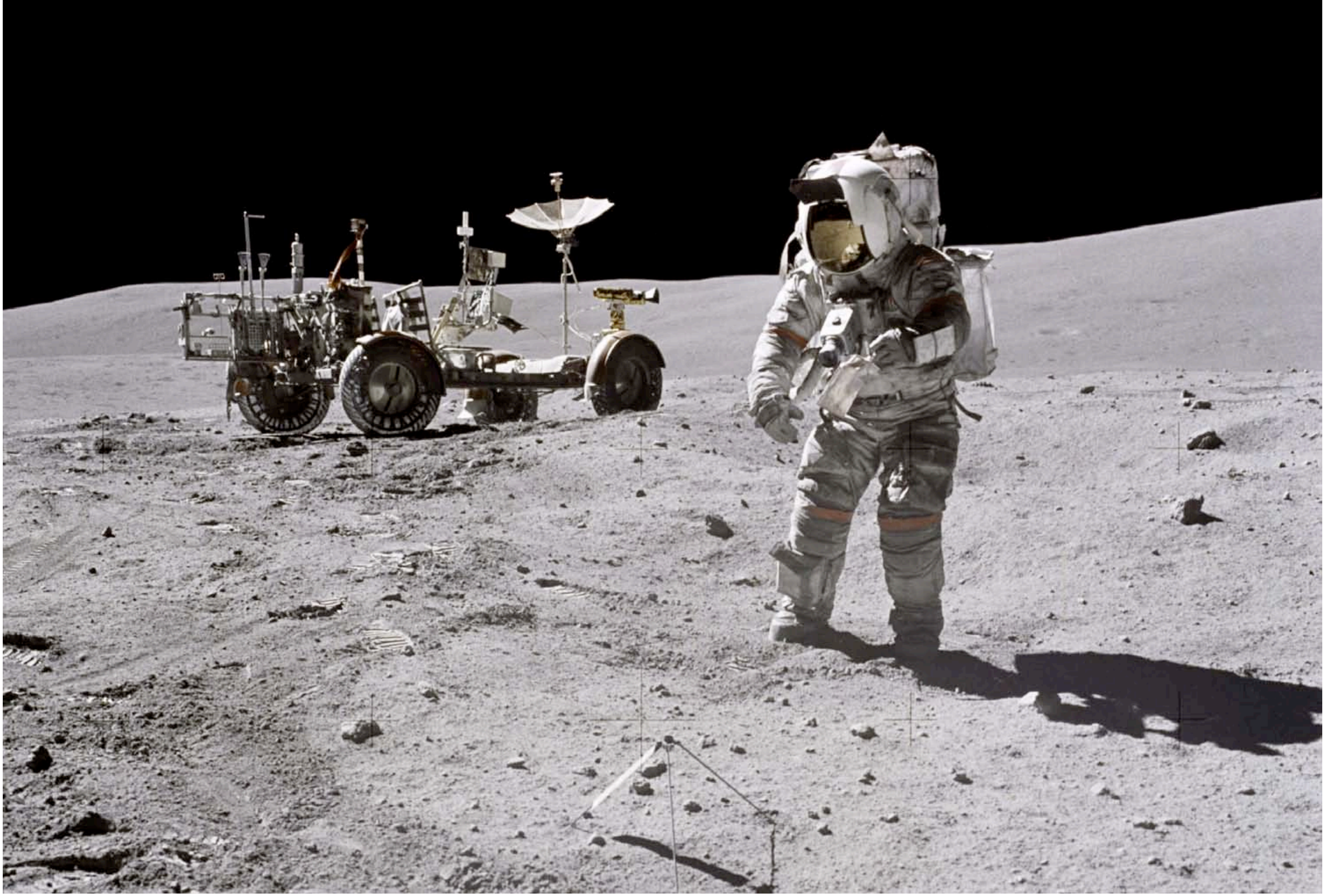






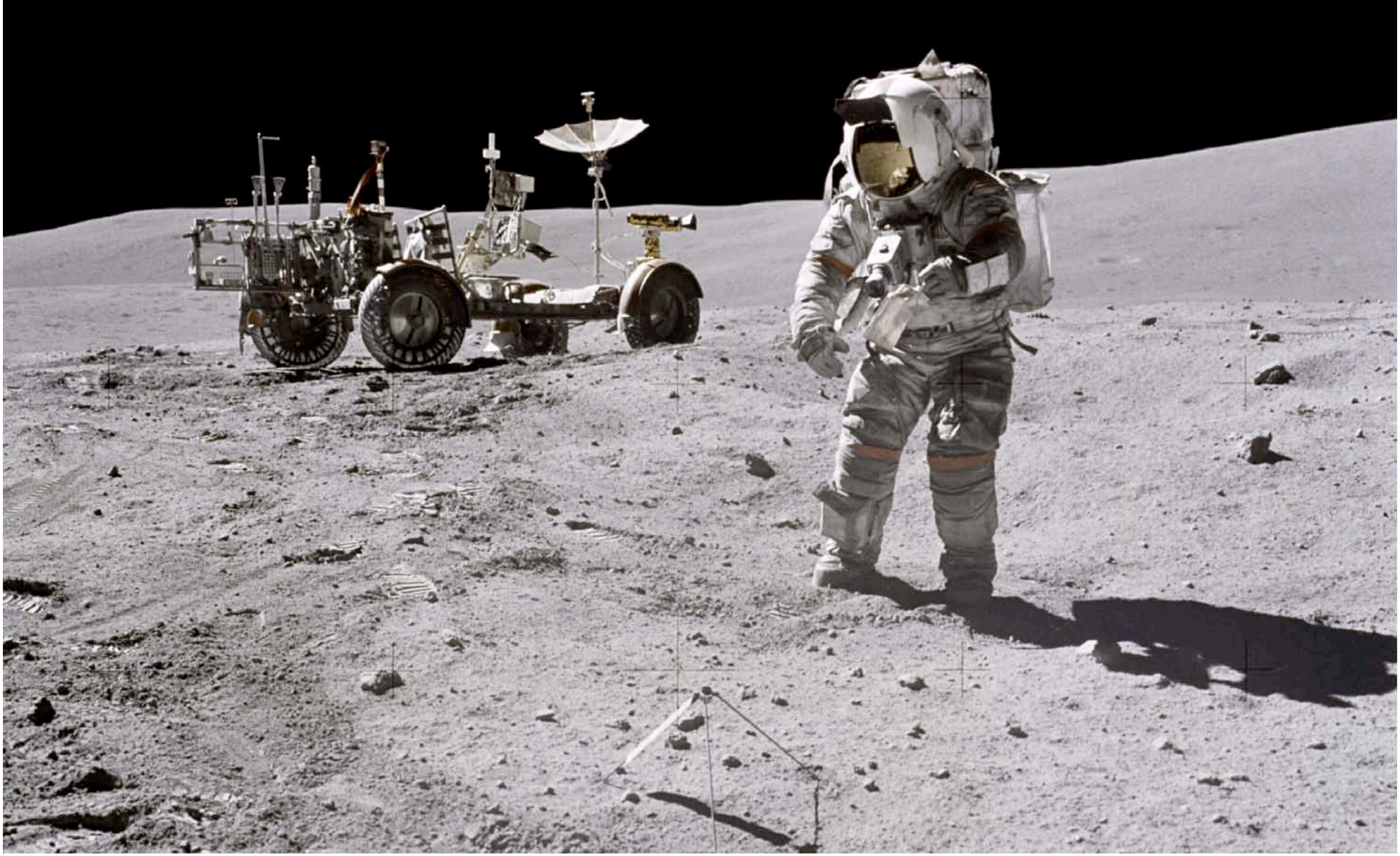


On planetary surfaces, you need <u>mobility</u>!



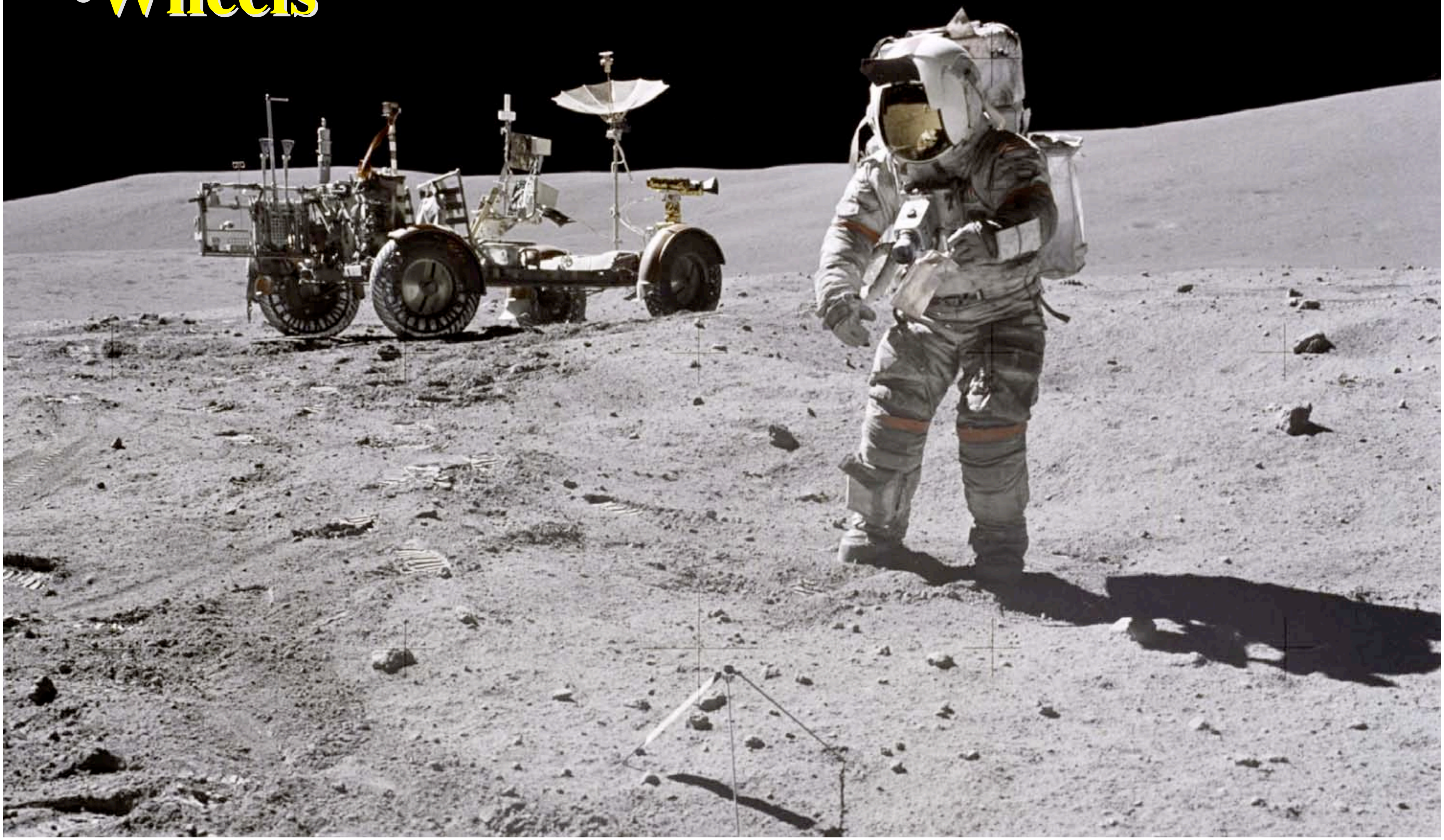
On planetary surfaces, you need <u>mobility</u>!

- Weight



On planetary surfaces, you need mobility!

- Weight
- Wheels



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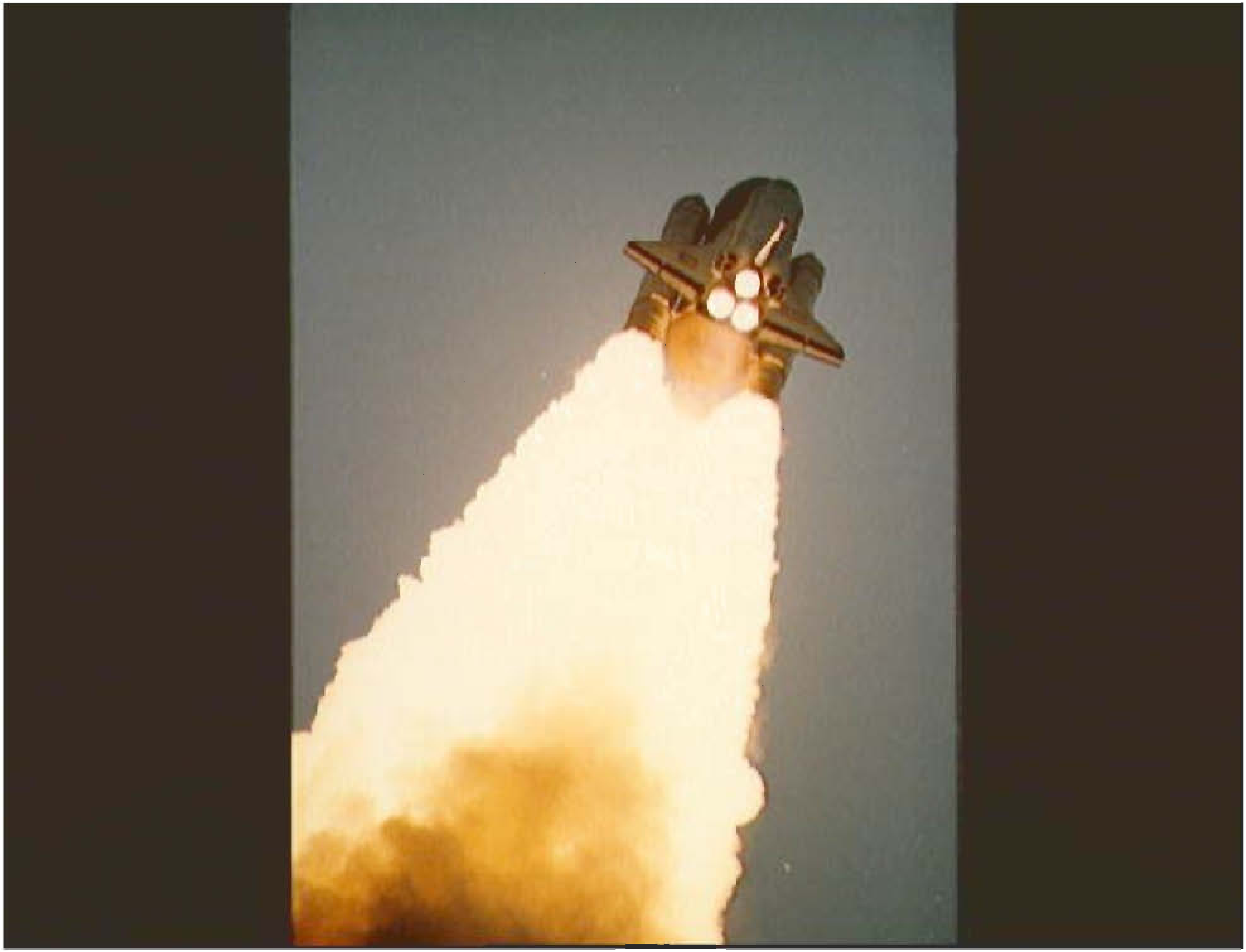

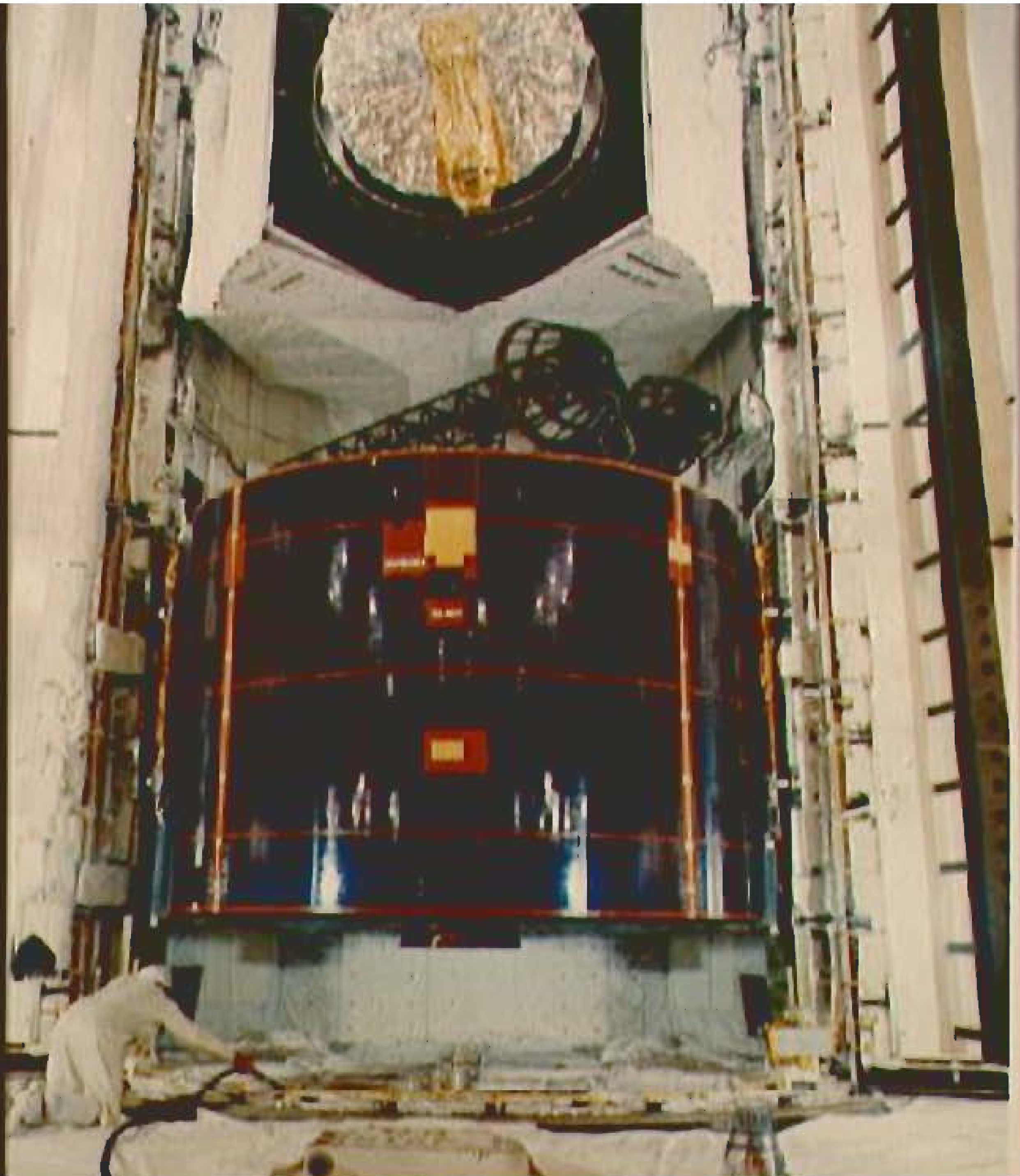

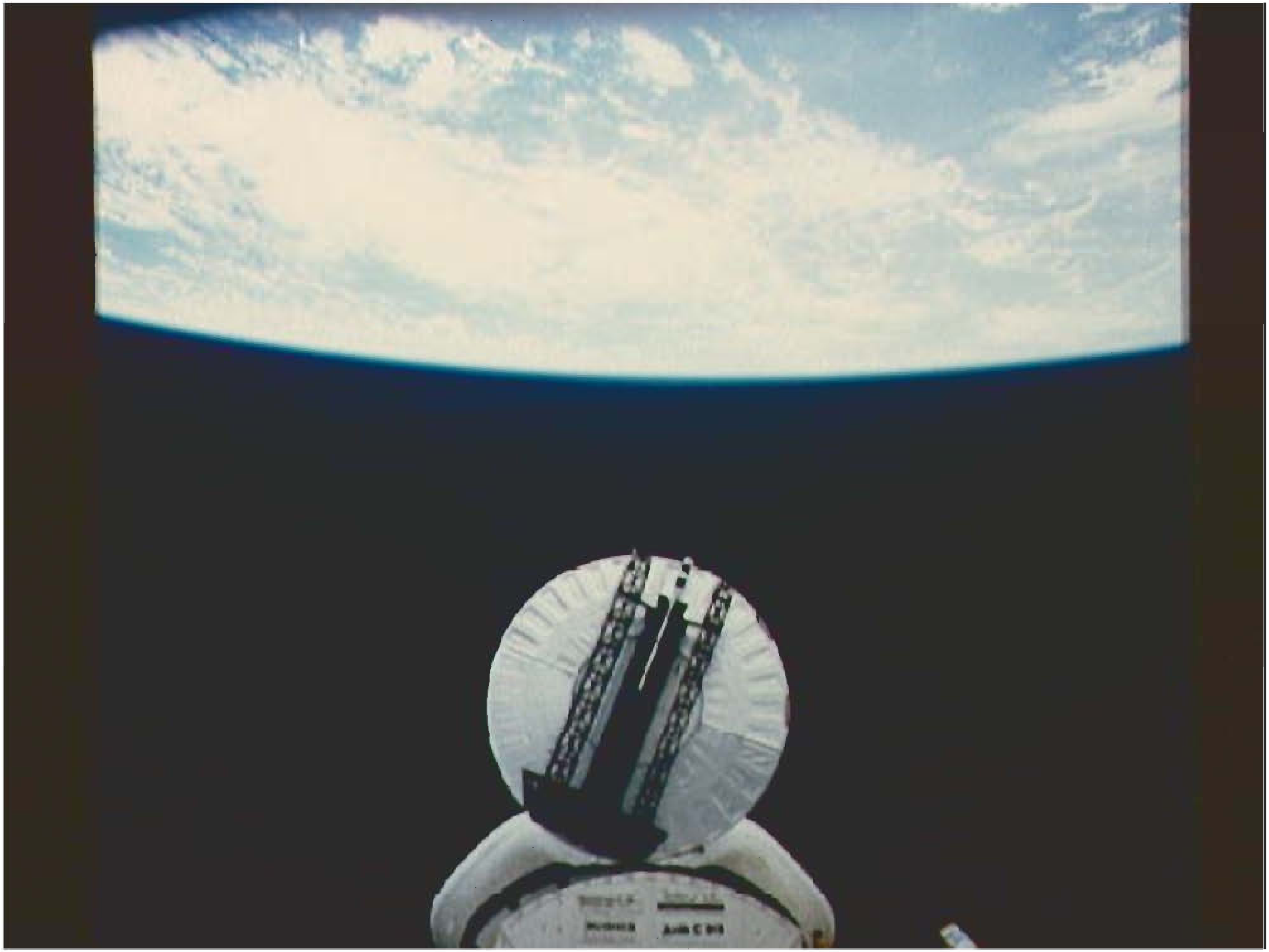

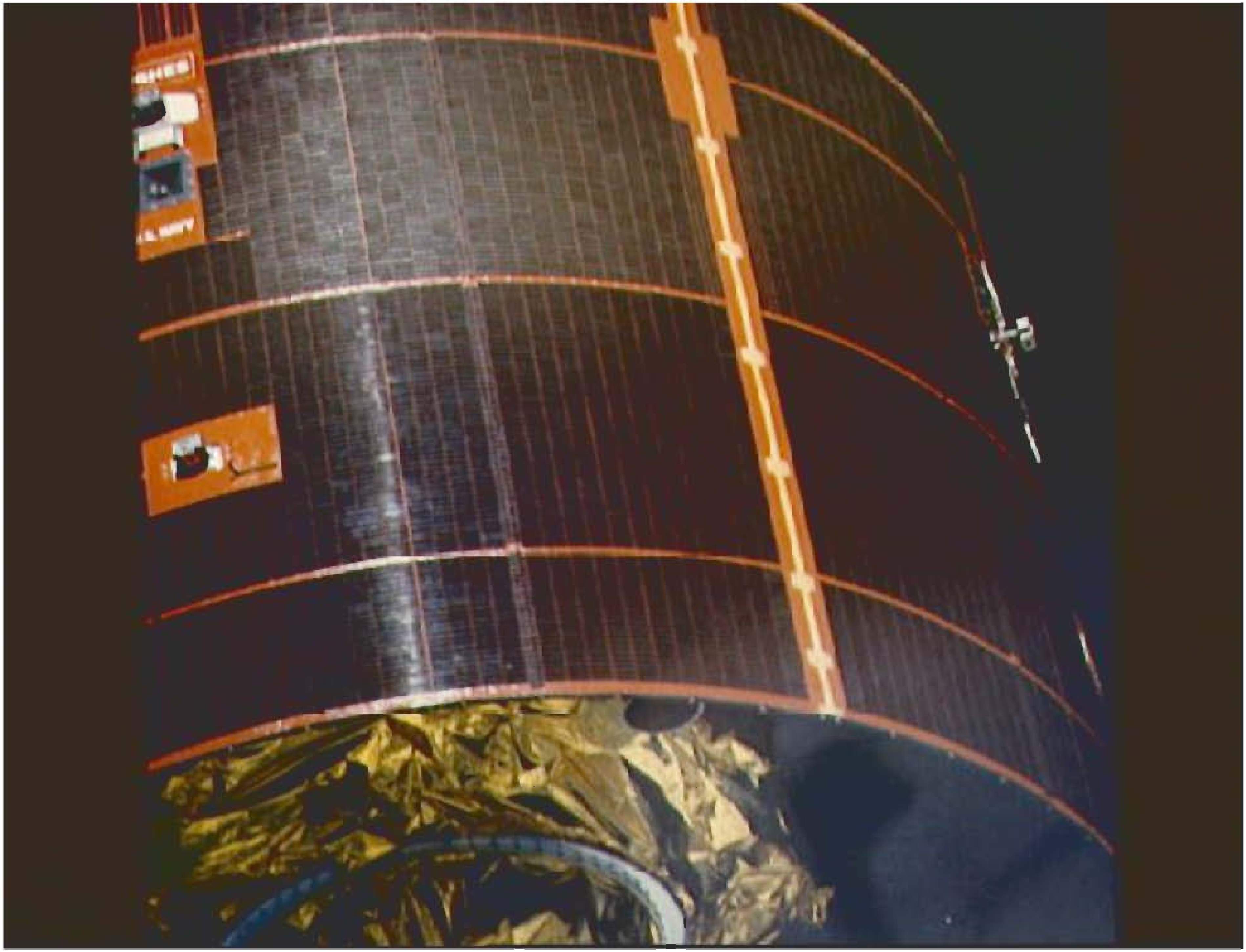

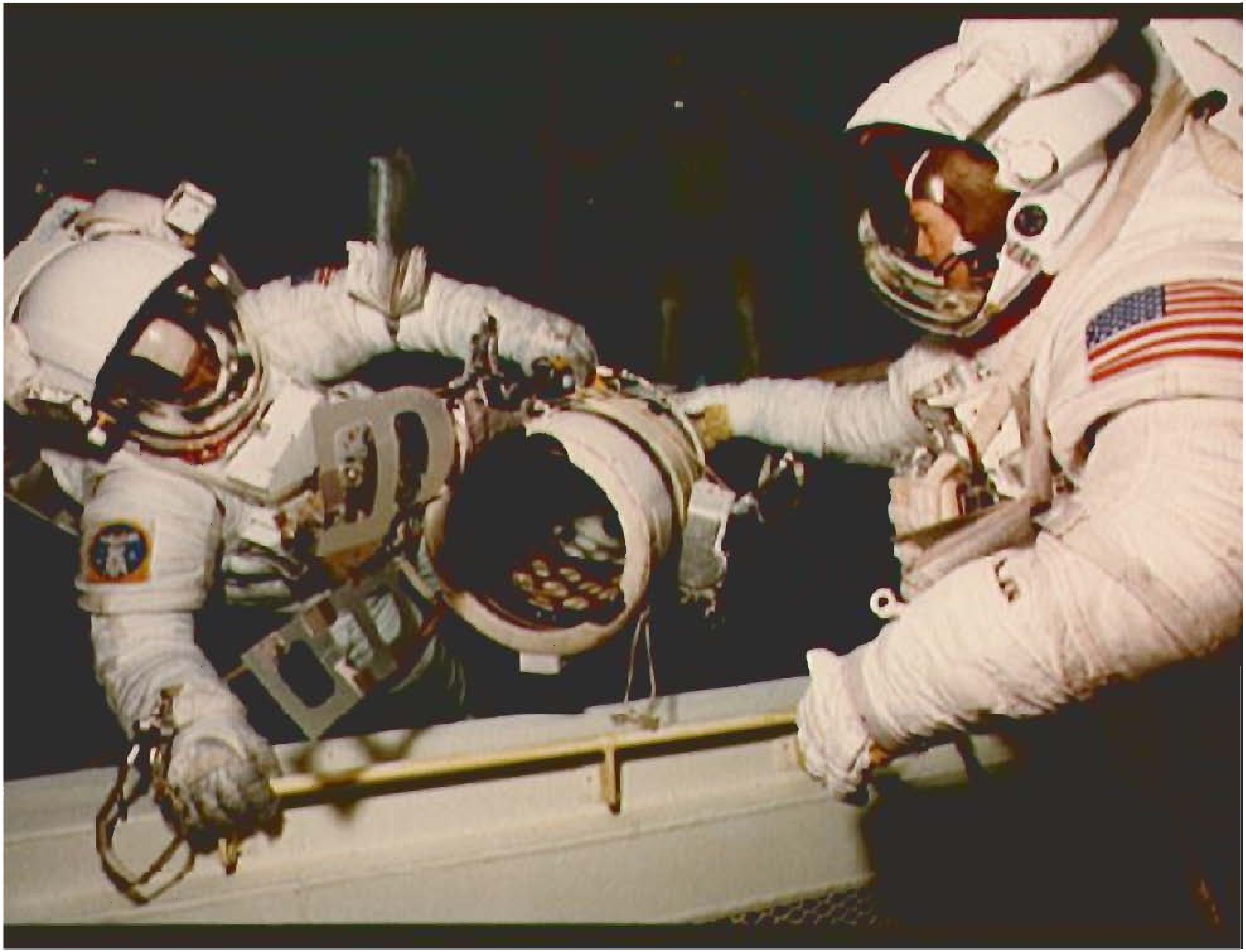

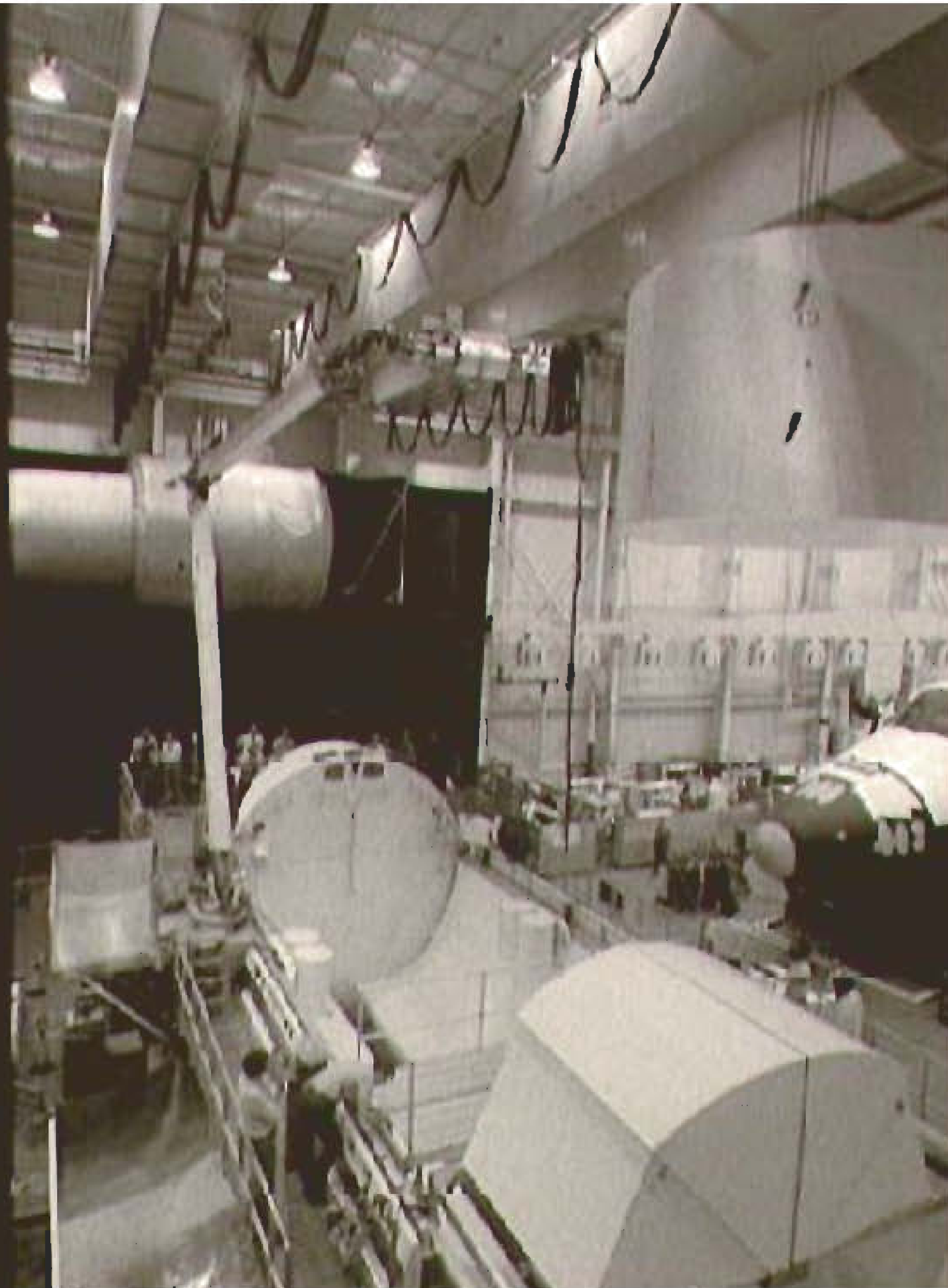

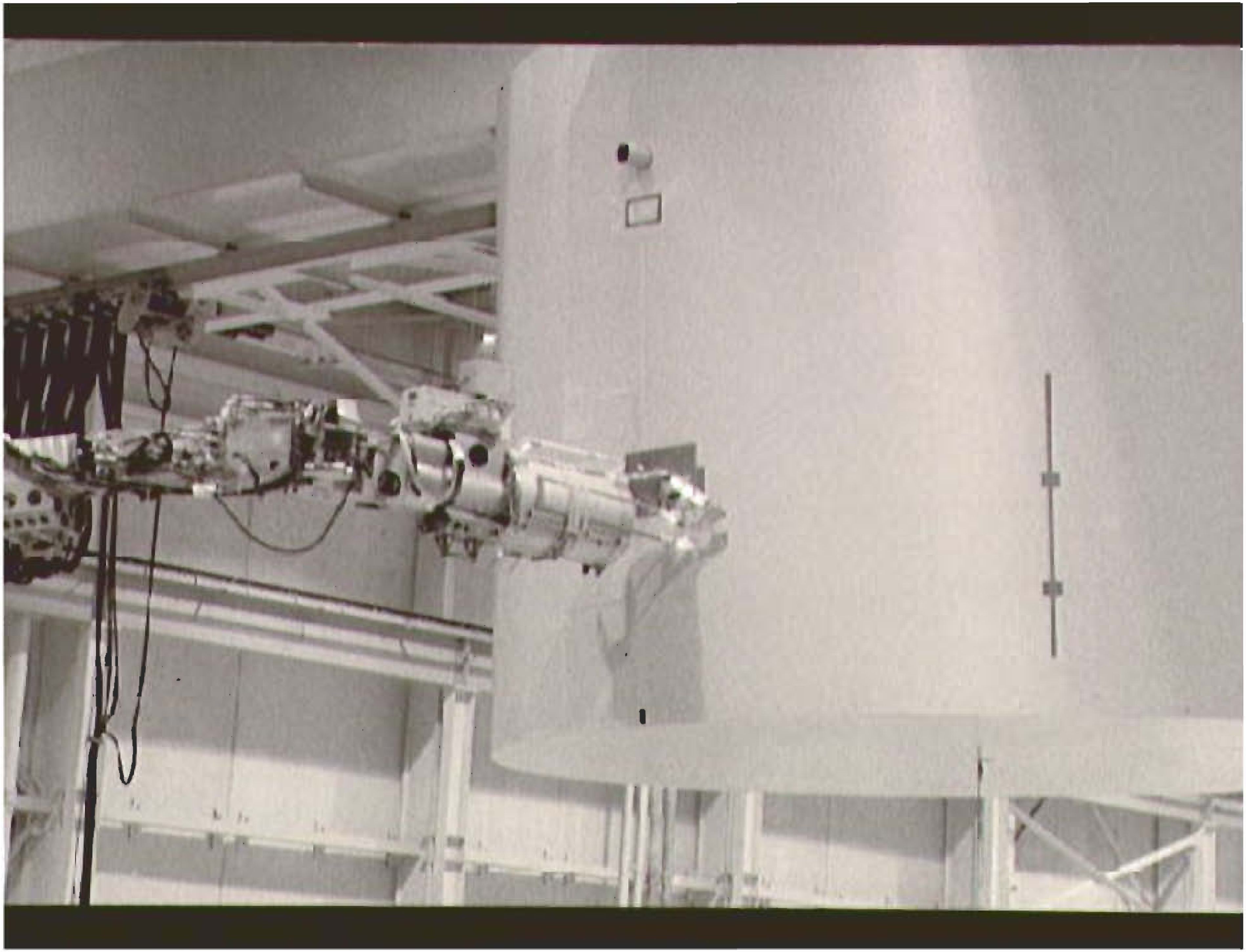

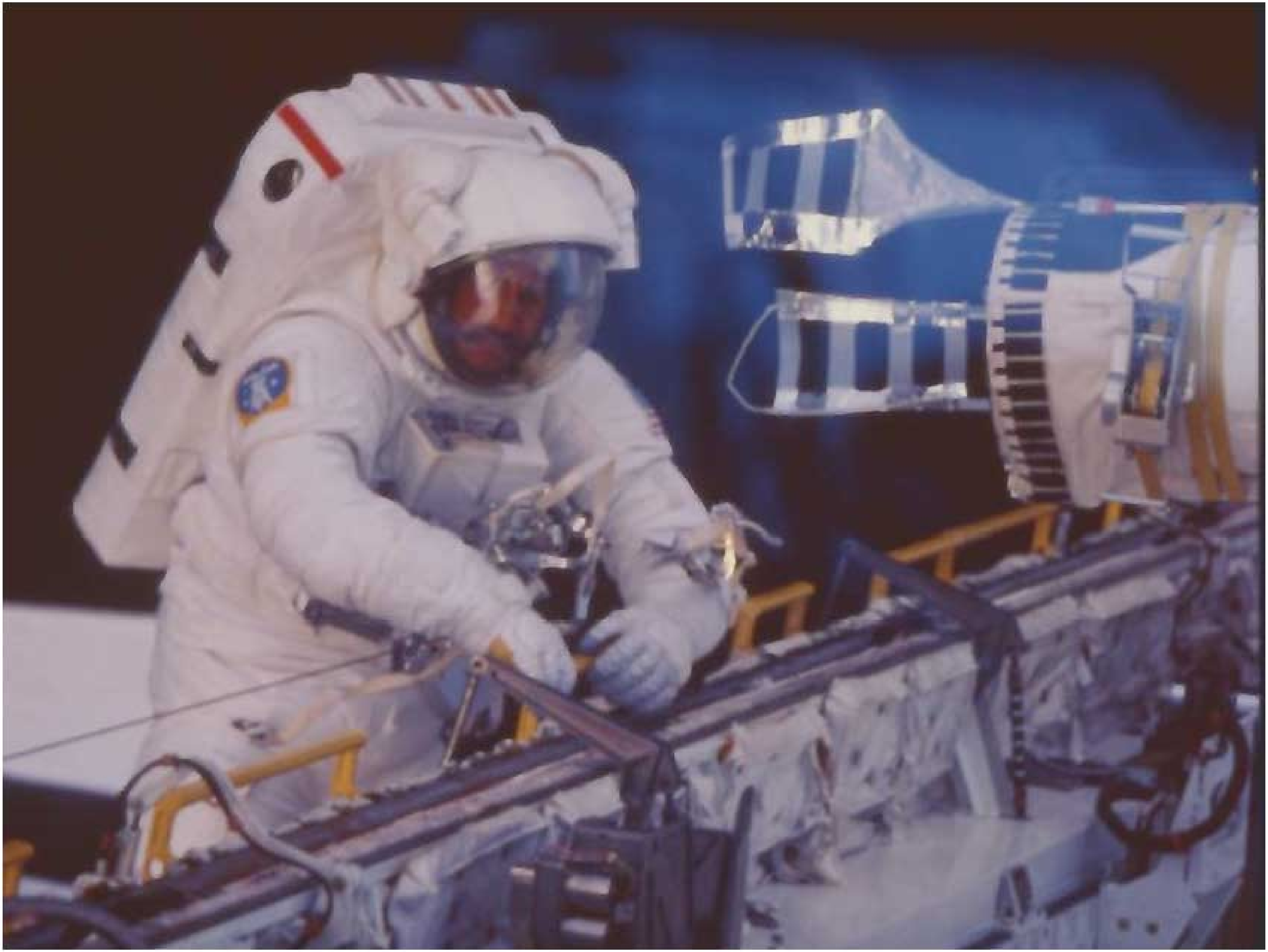

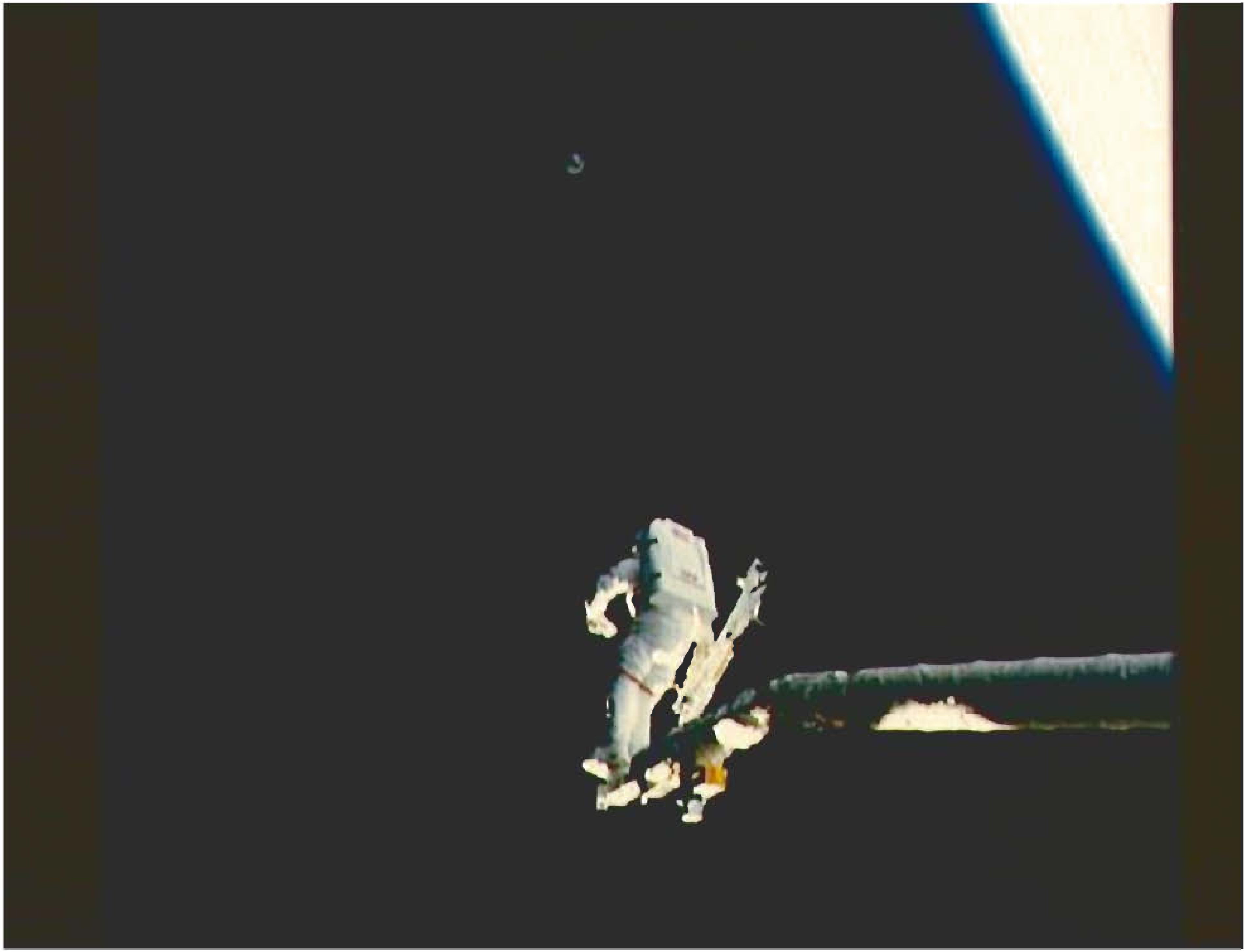

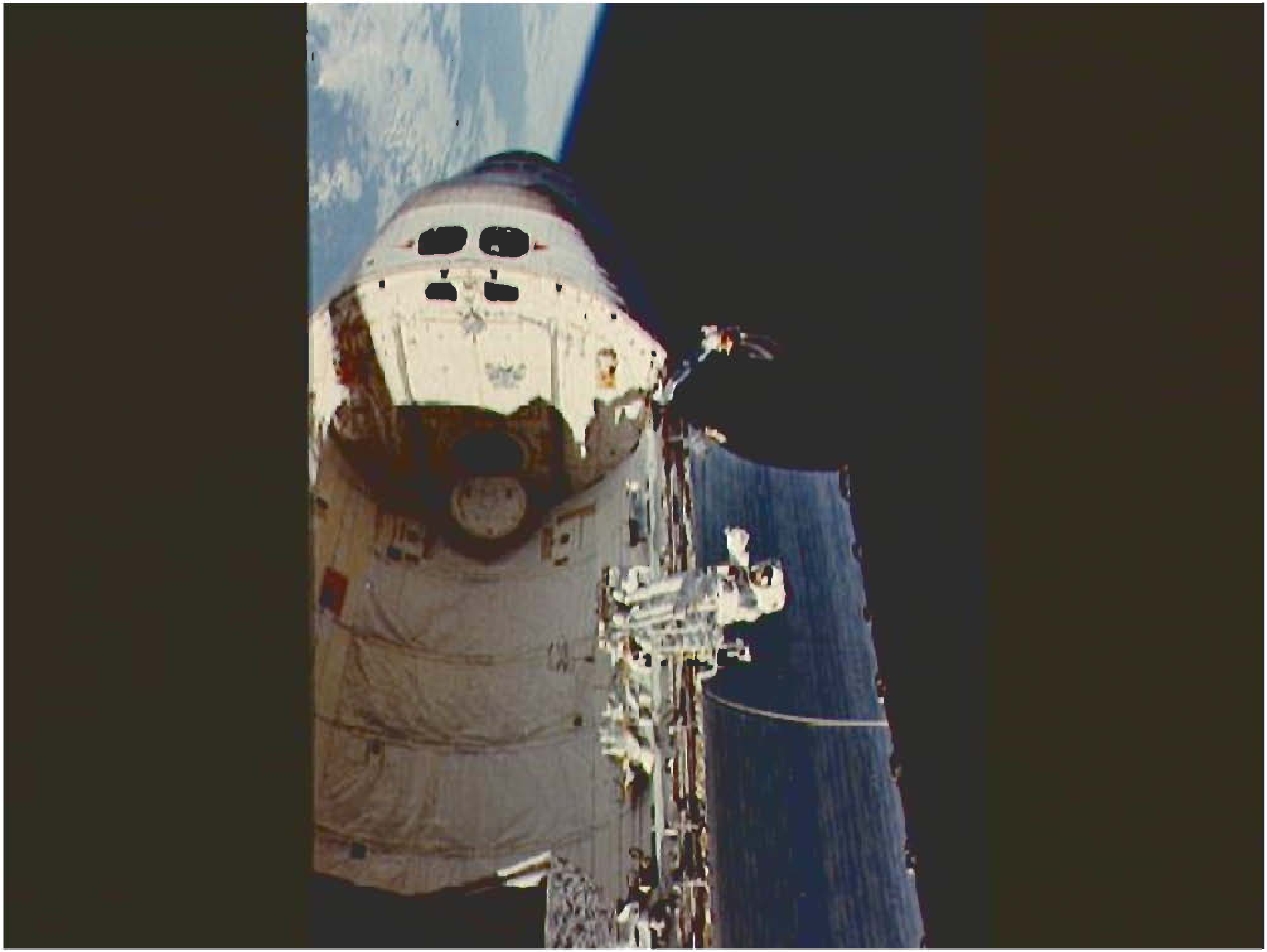

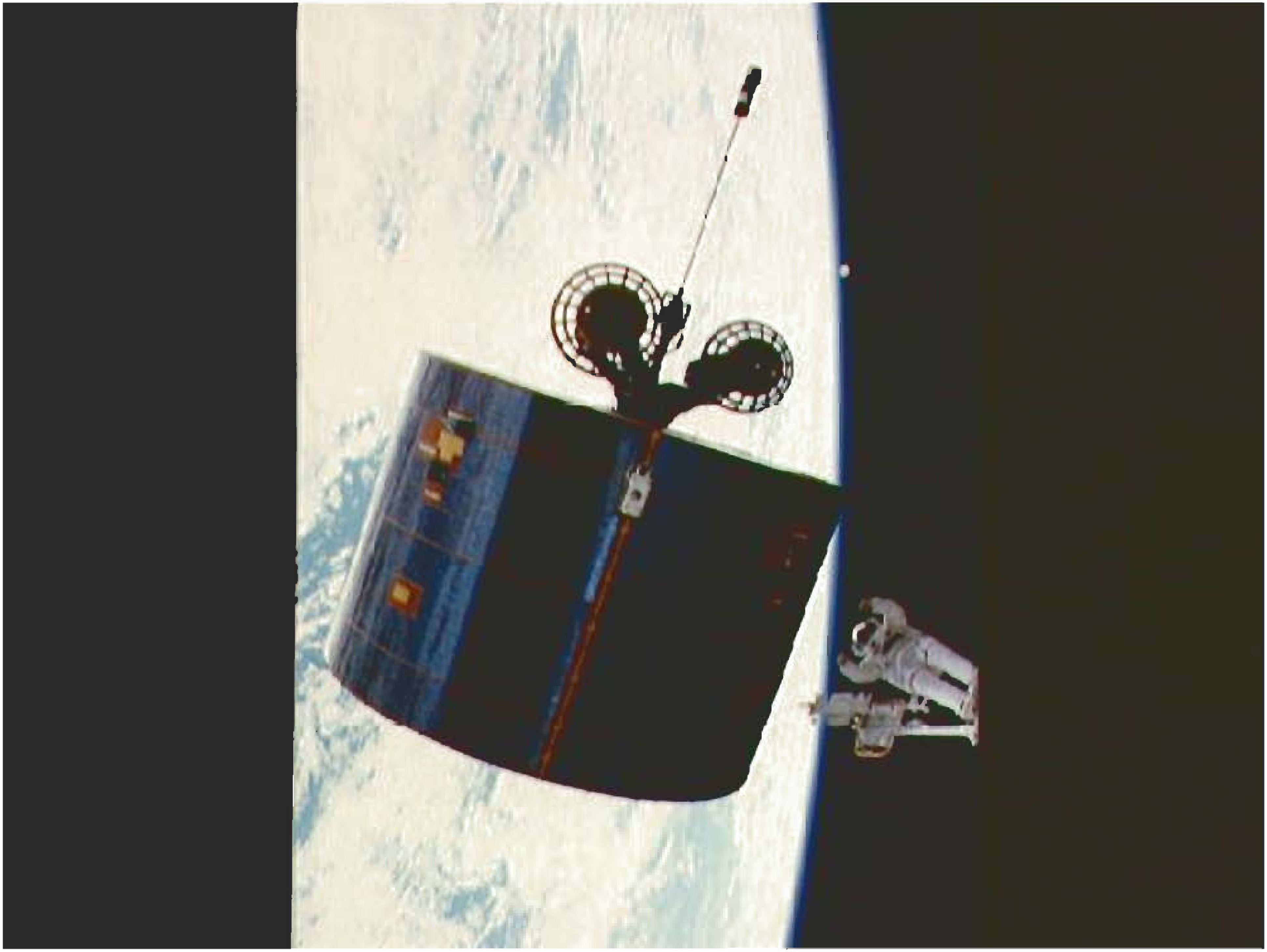

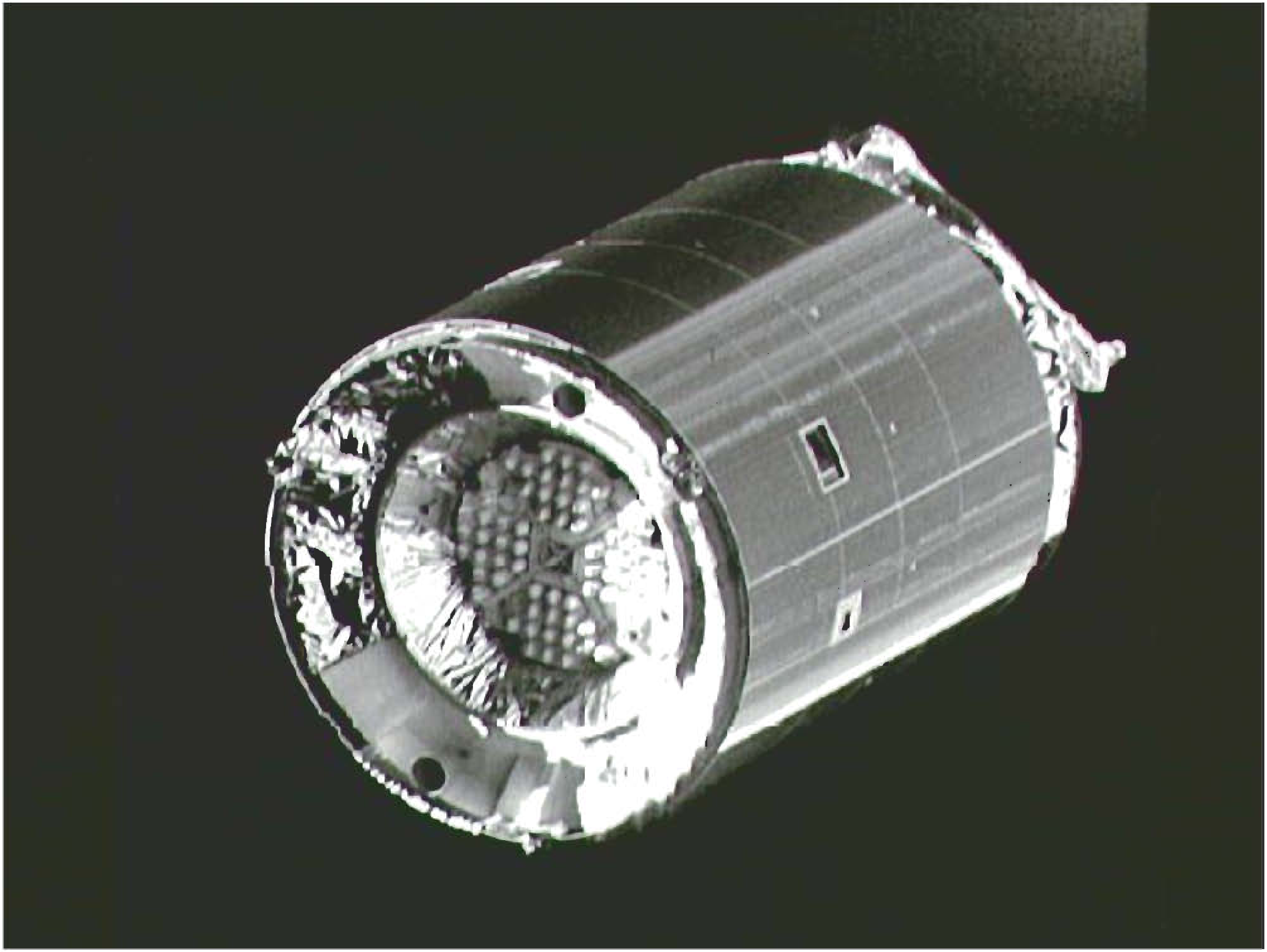

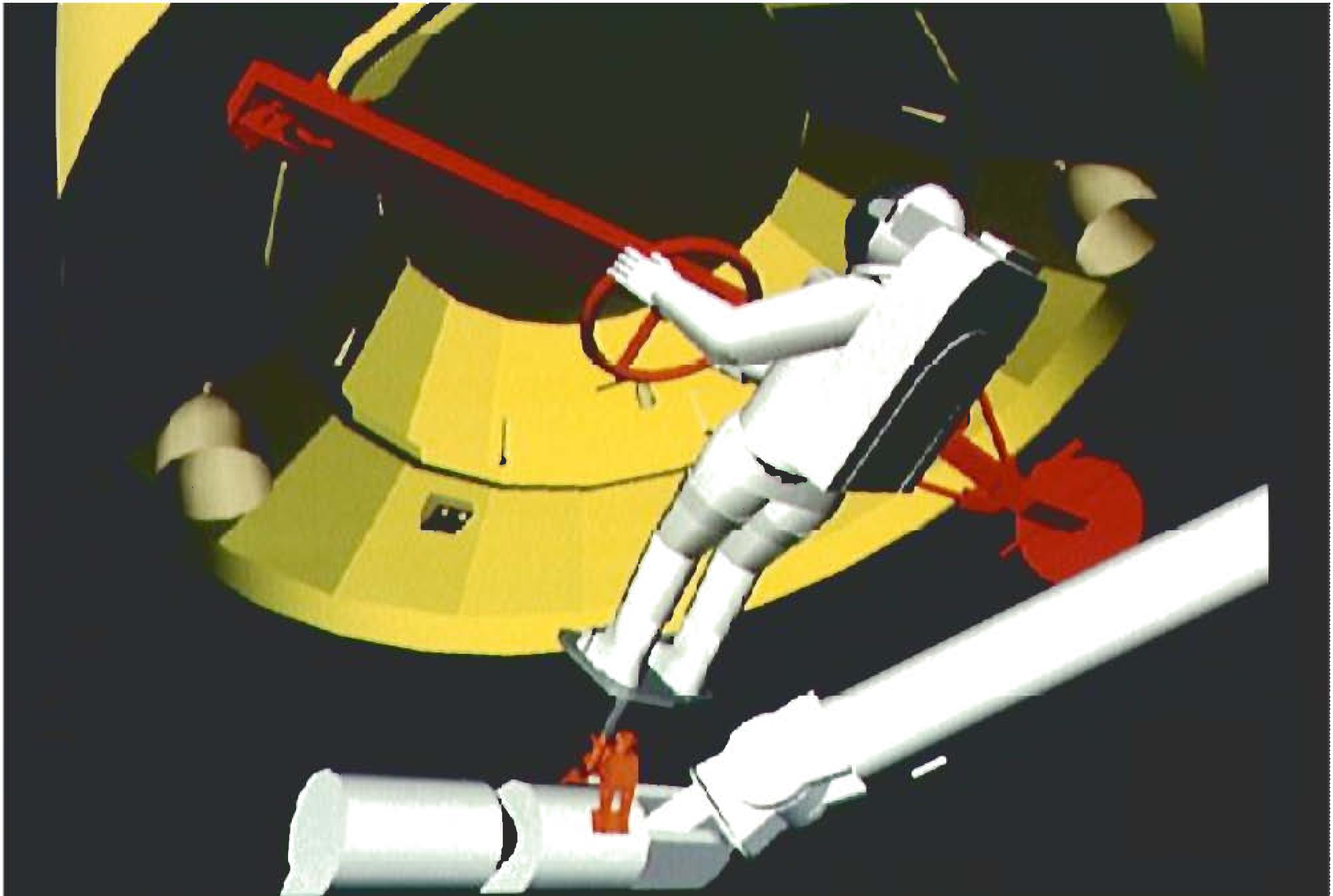

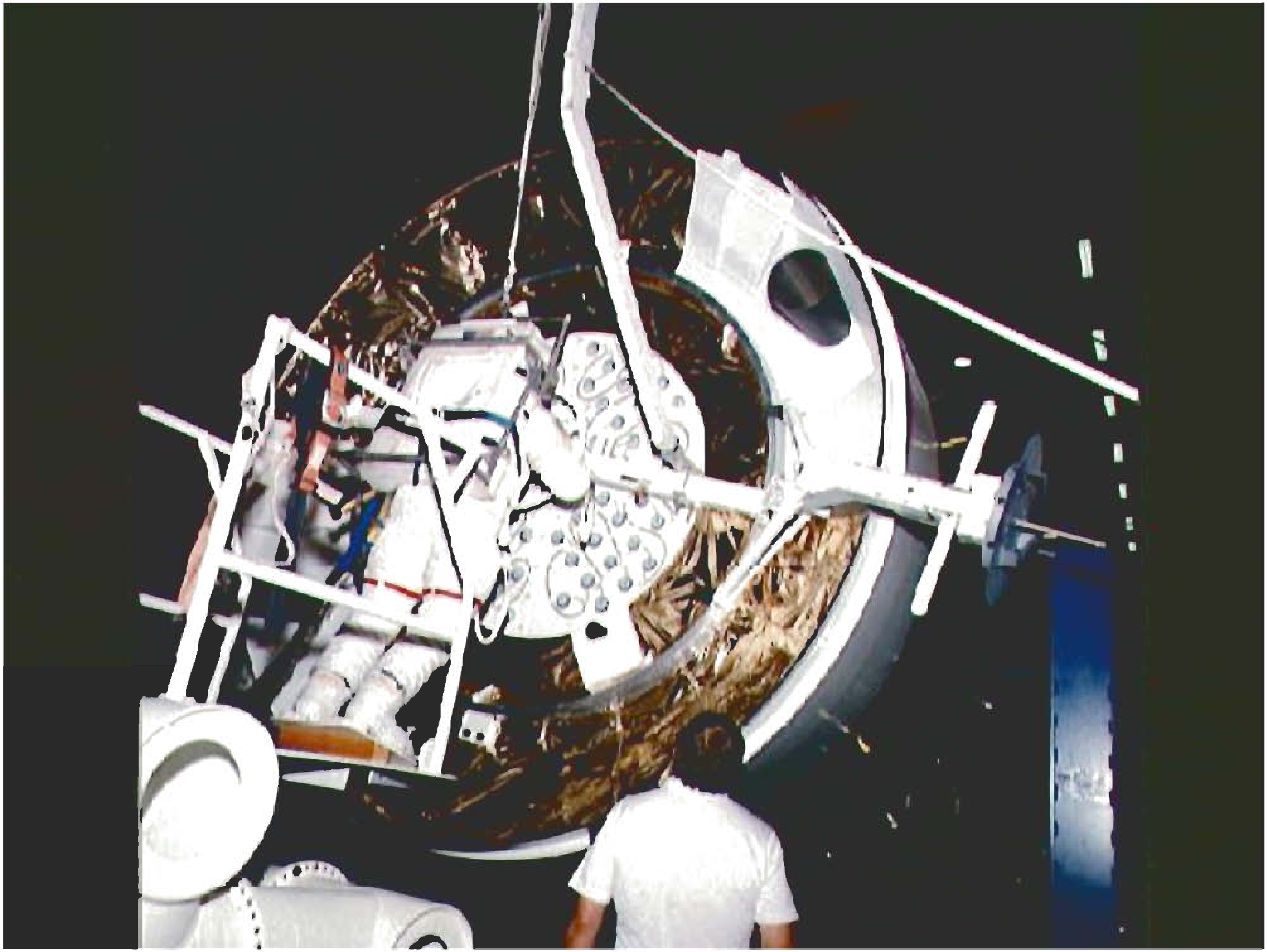

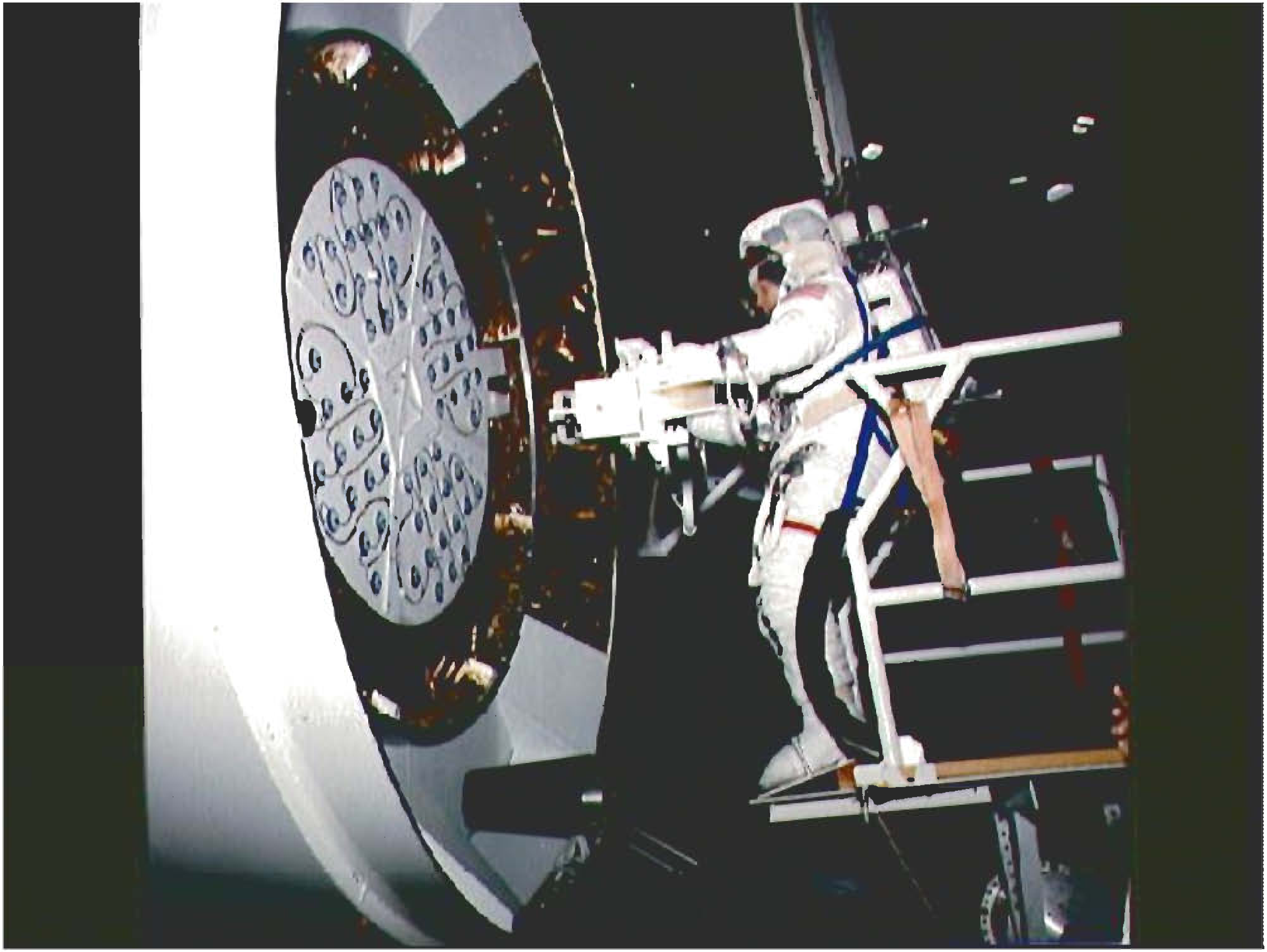

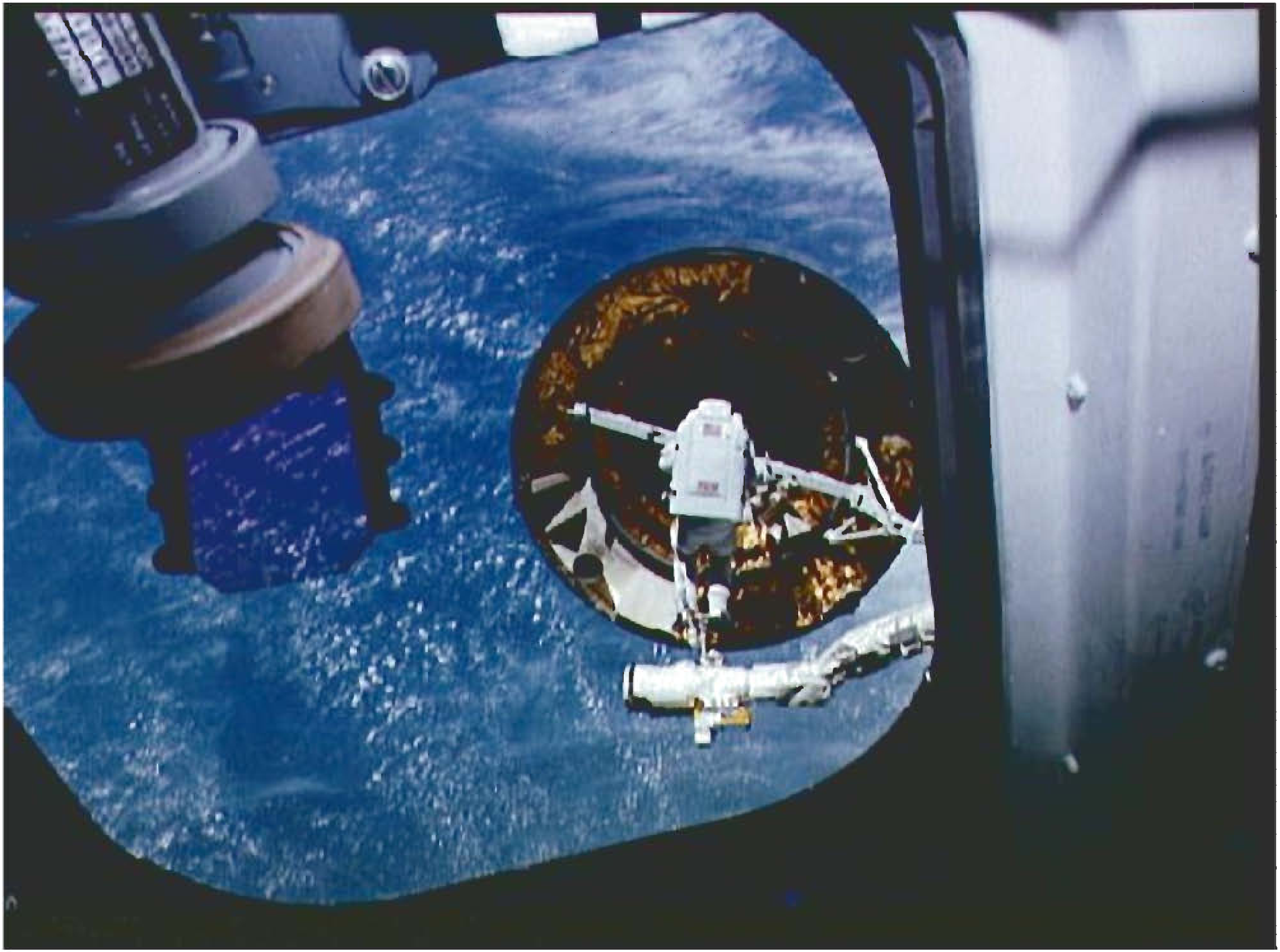

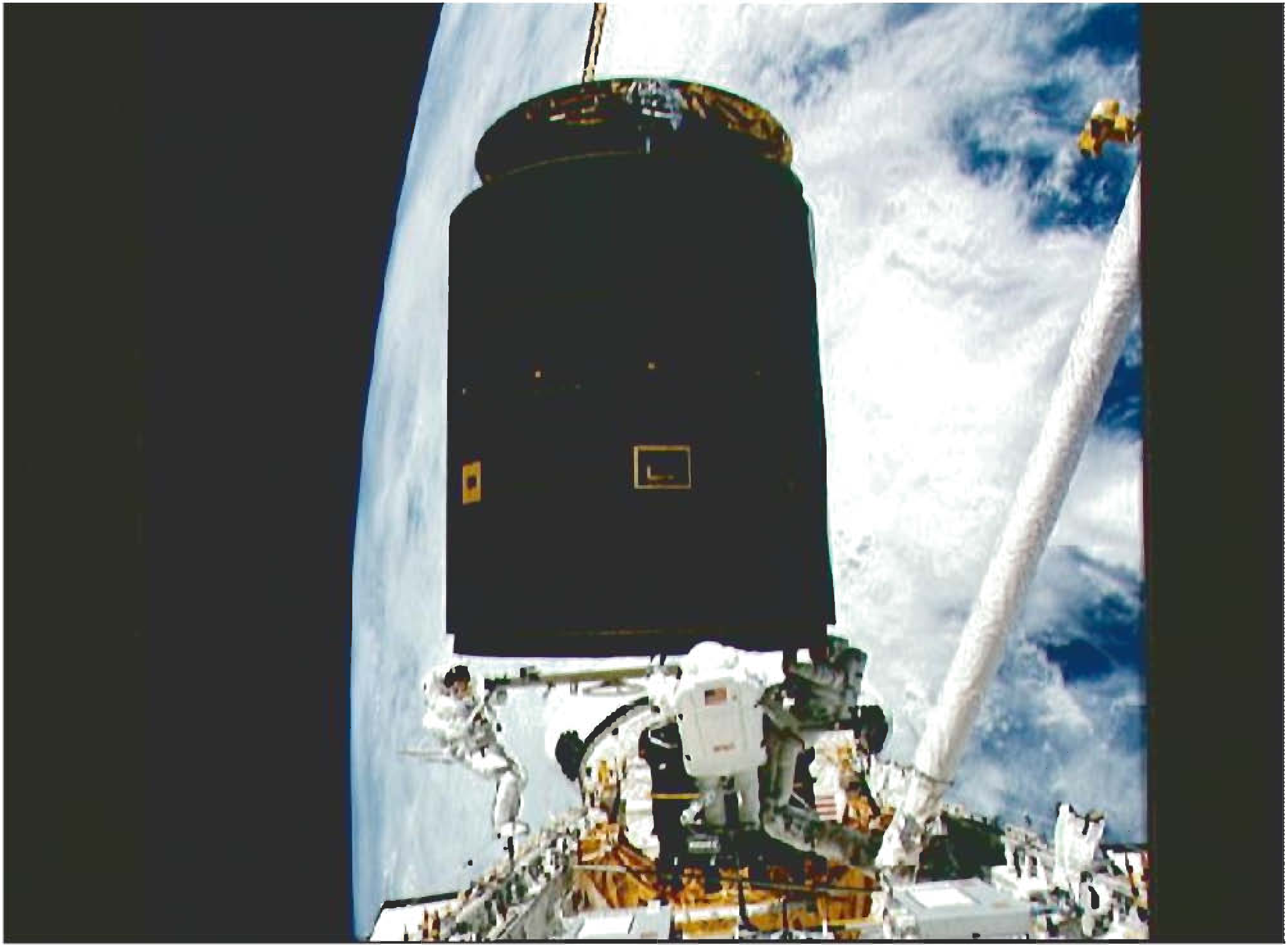

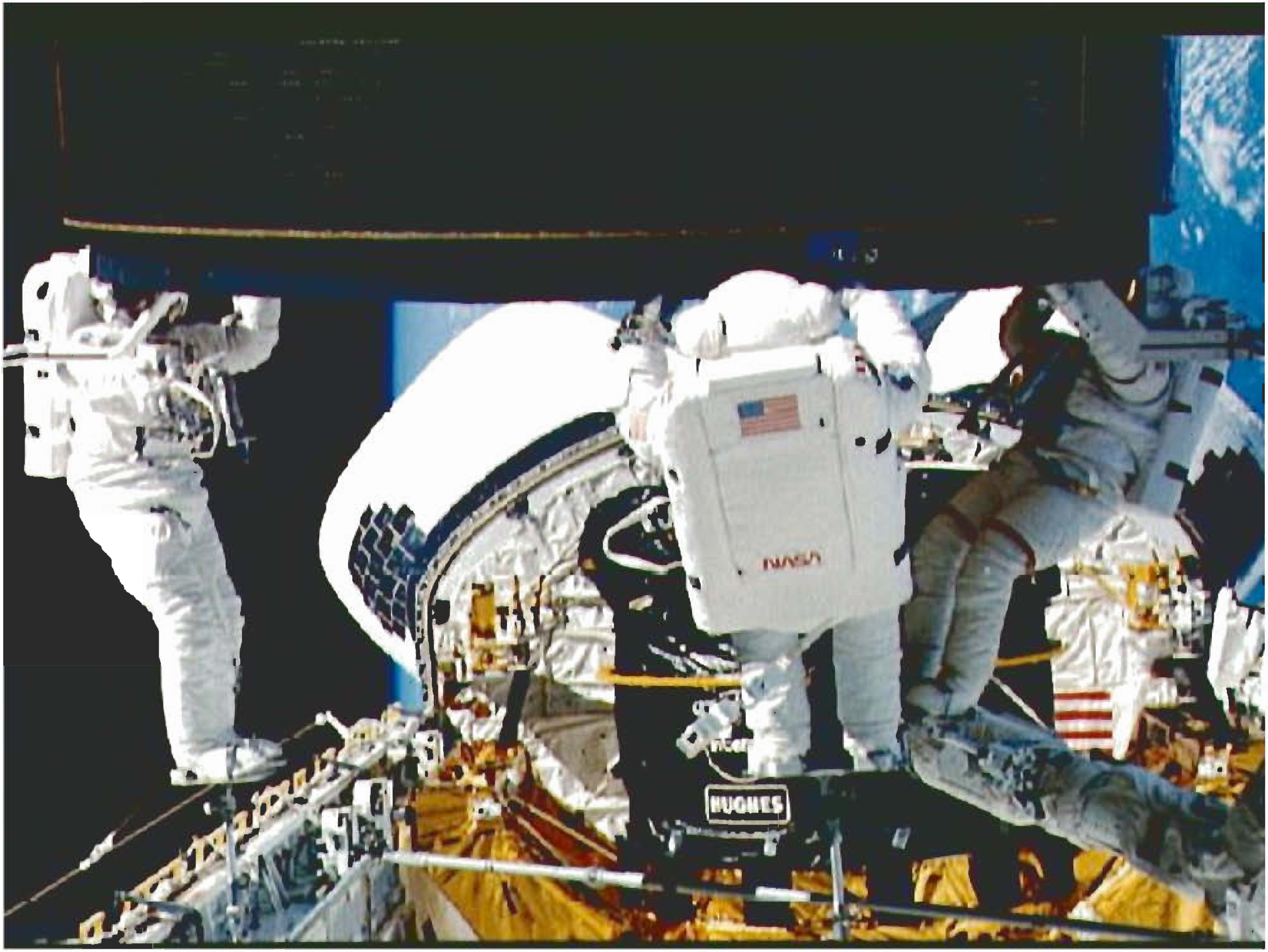
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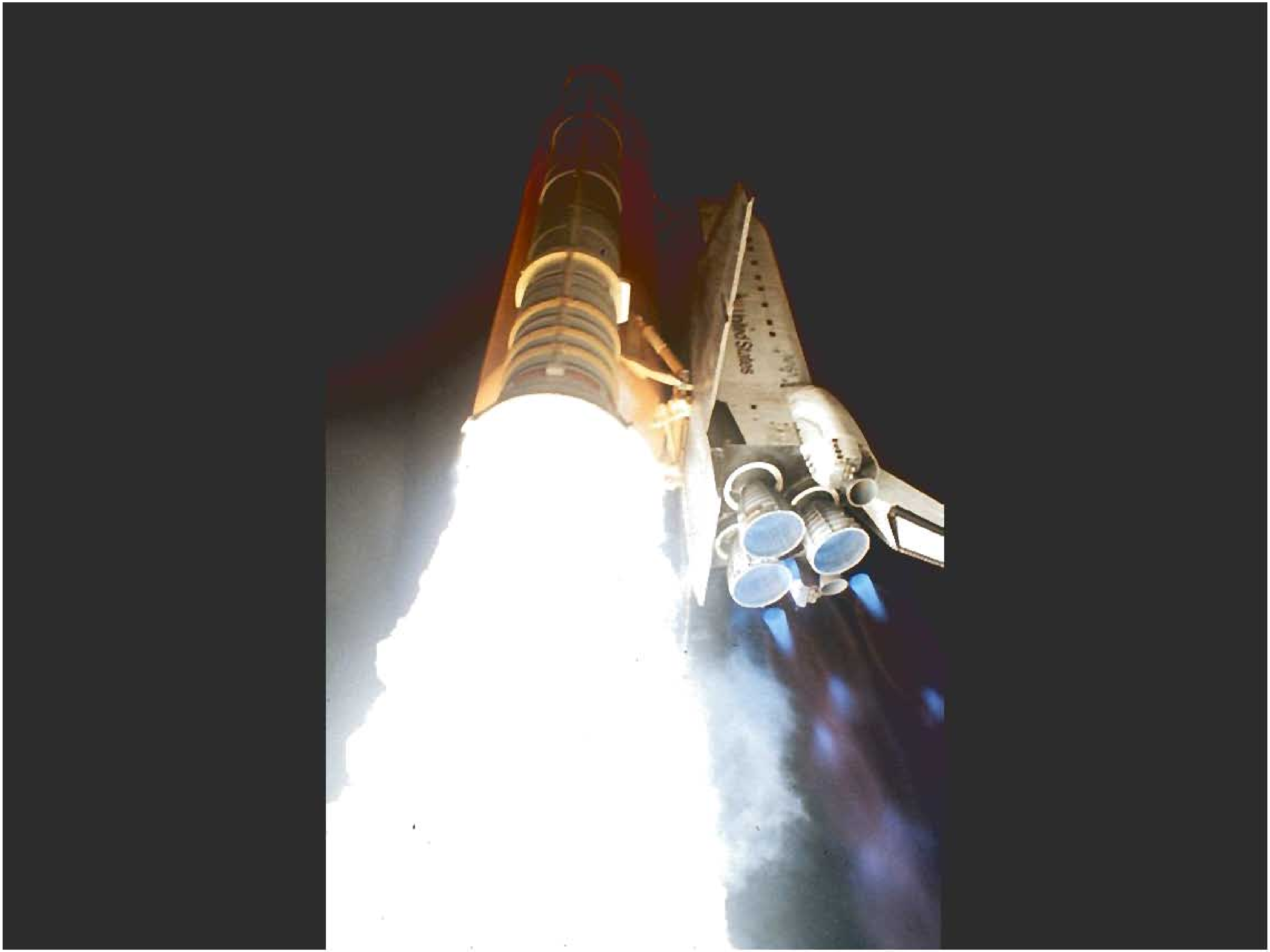

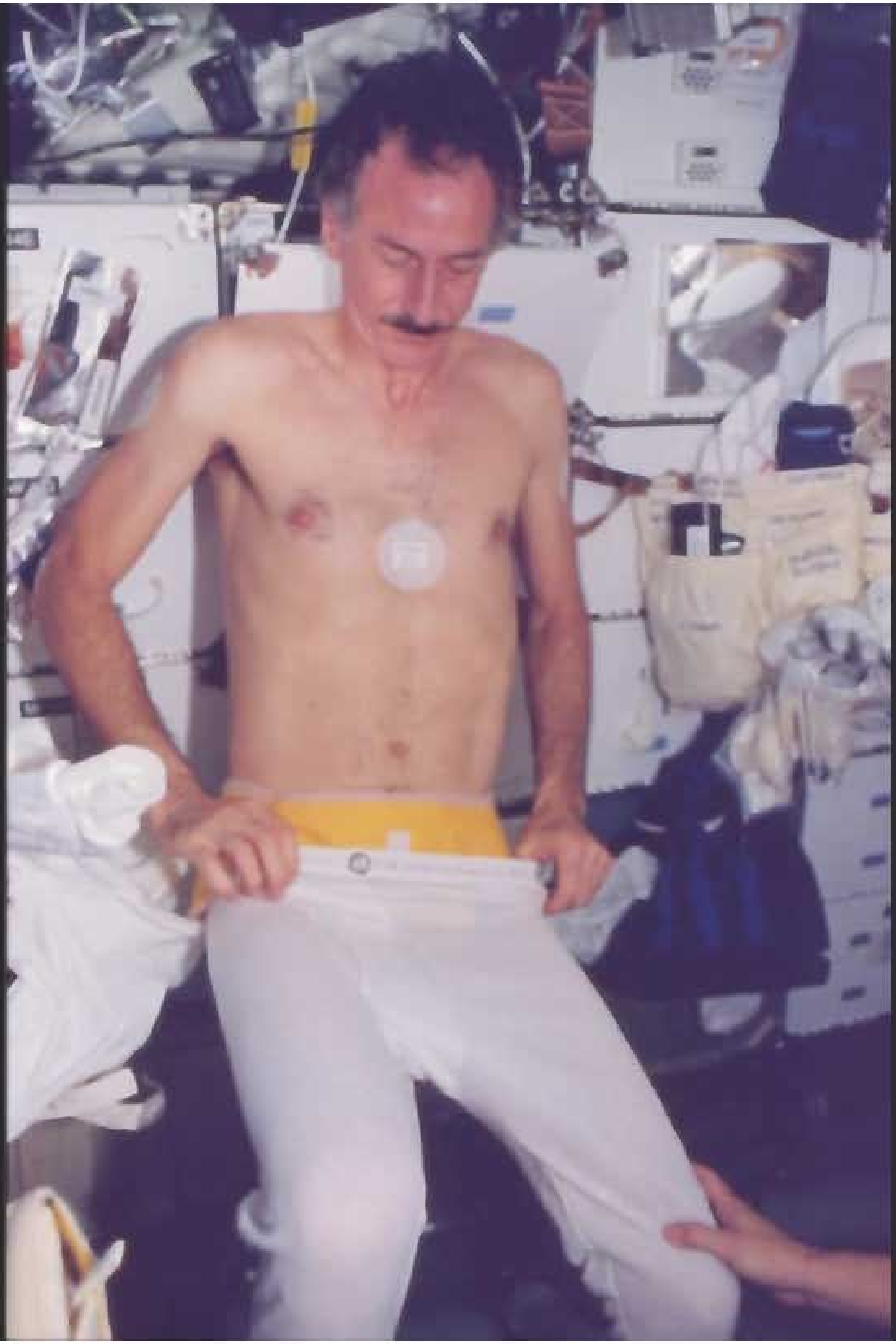

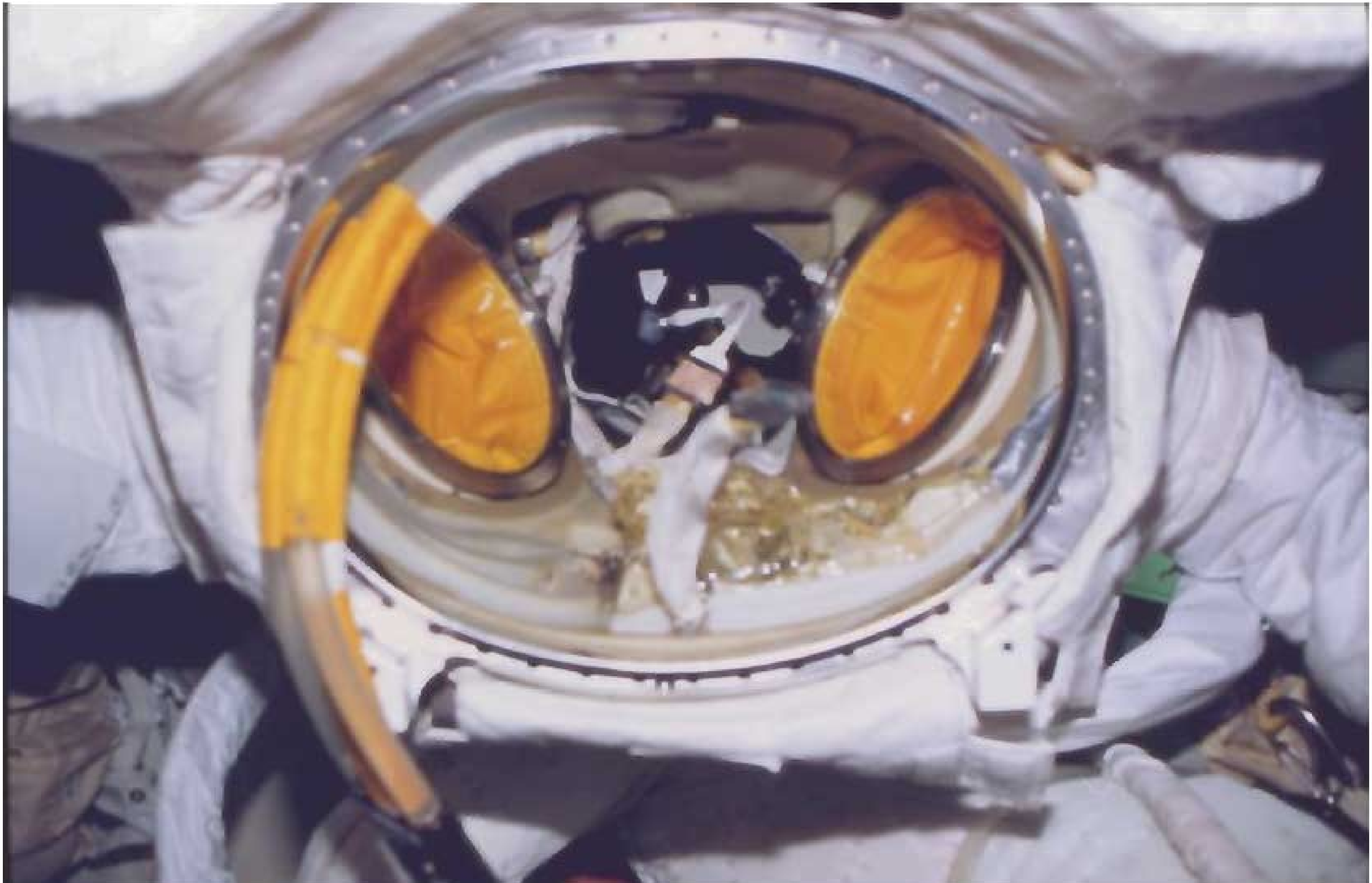

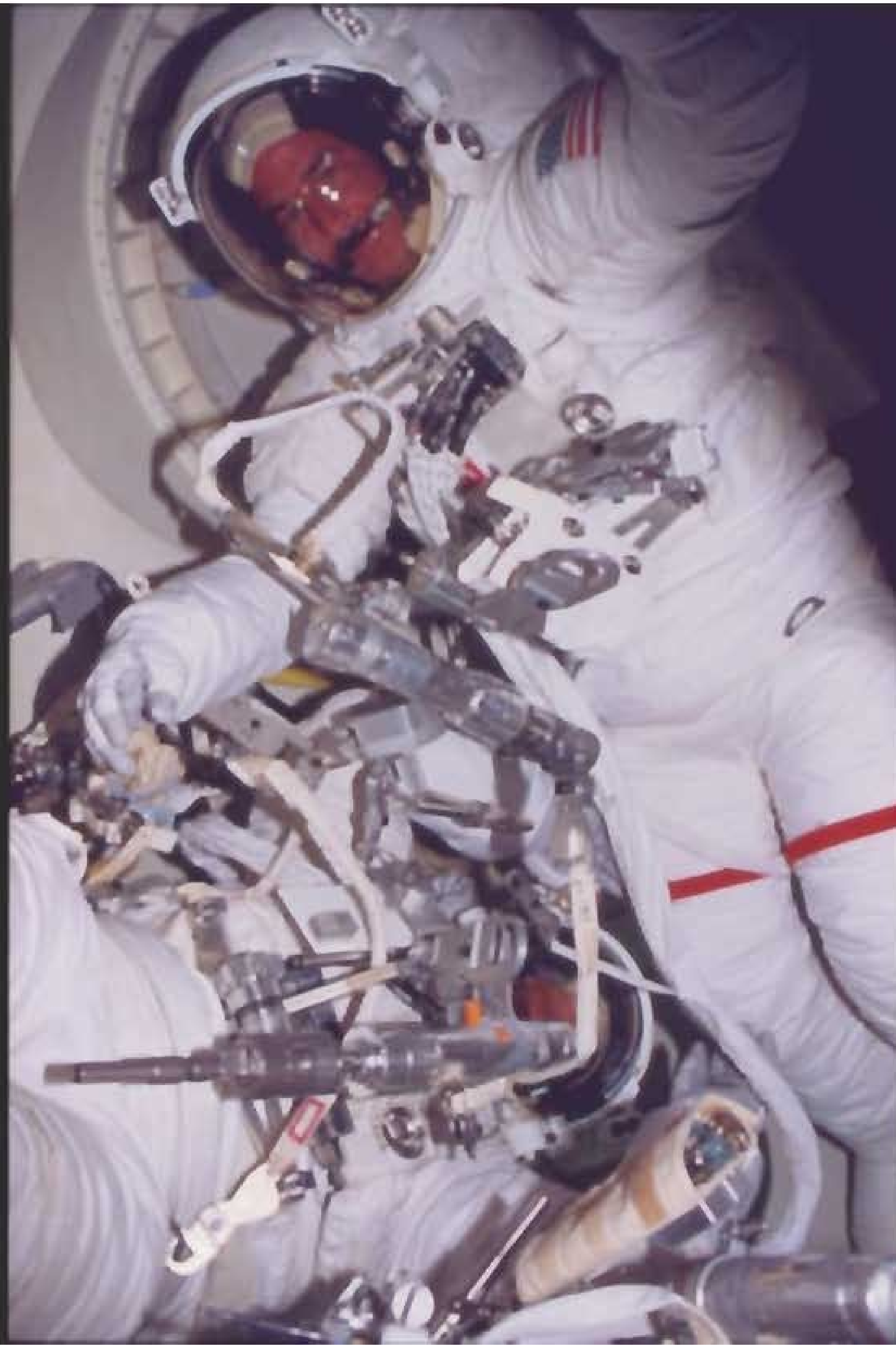

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