Moon to Mars:
Exploration Atmosphere

Trilateral Safety and Mission Assurance Conference
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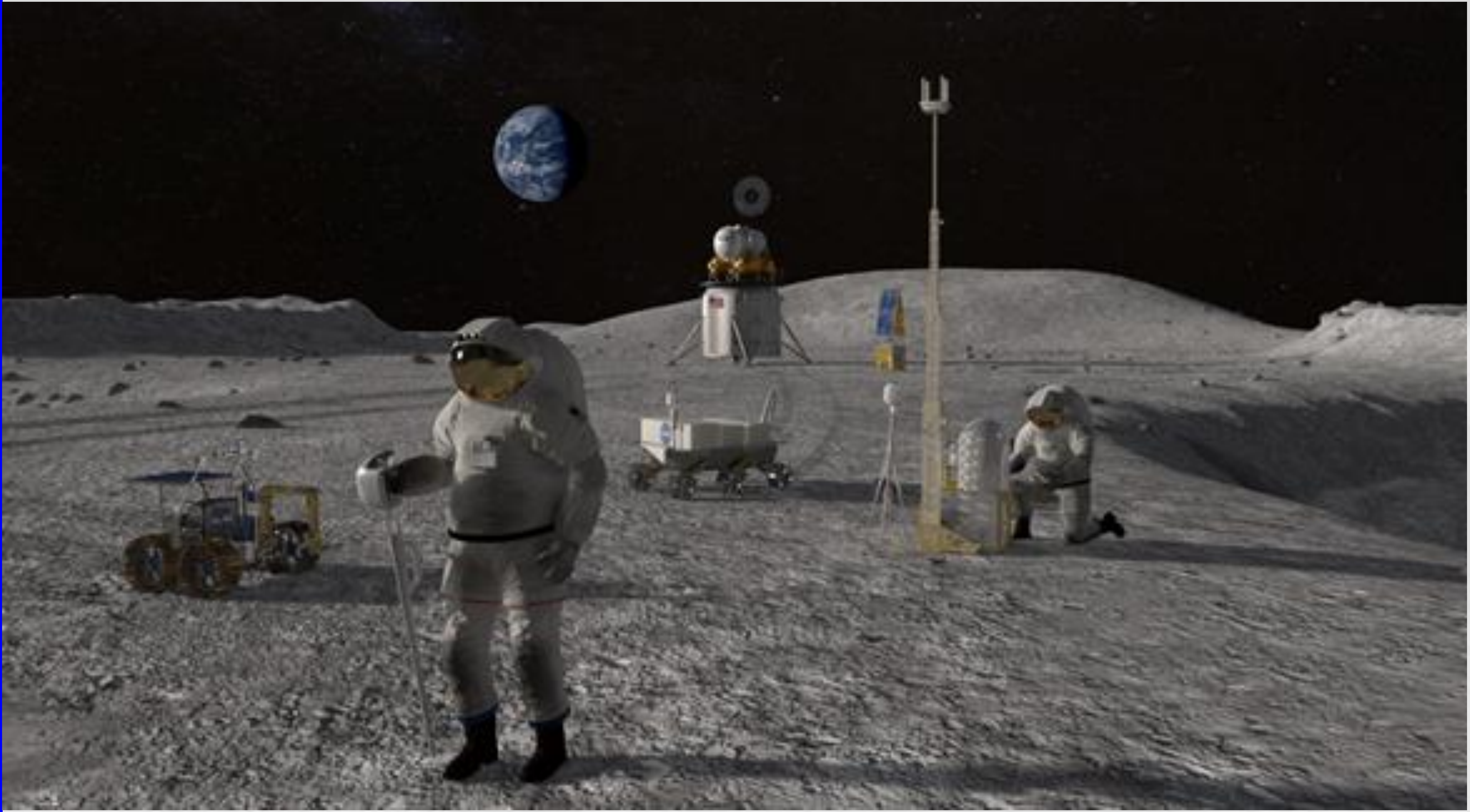
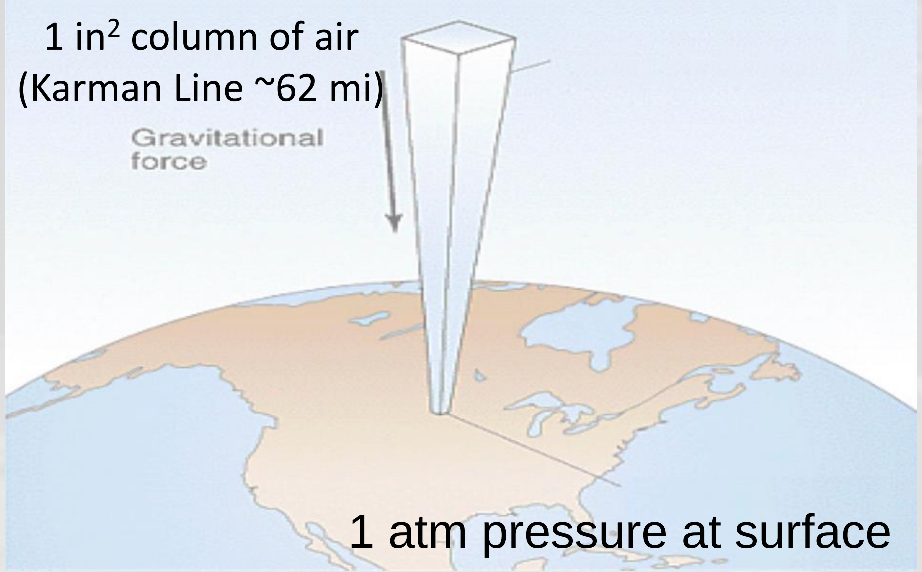
Marlei Walton, PhD, MSE
marlei.walton@nasa.gov
Jason Norcross, MS

Moon to Mars: Exploration Atmosphere



Atmospheric Composition



Atmospheric pressure (1 atm) is:

- 14.7 psi
- 101.3 kPa

Atmospheric Composition

- 21% O_2, 78% N_2, 1% Ar & trace

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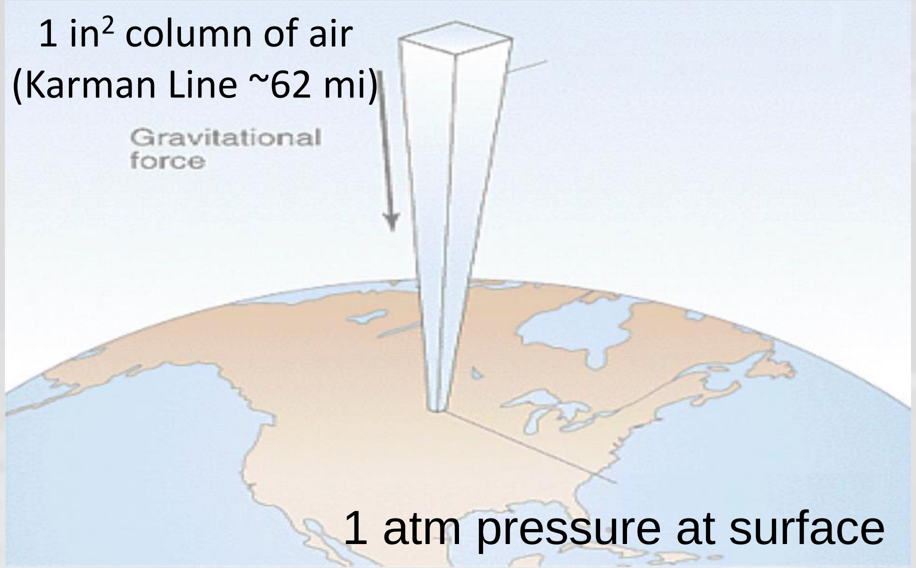

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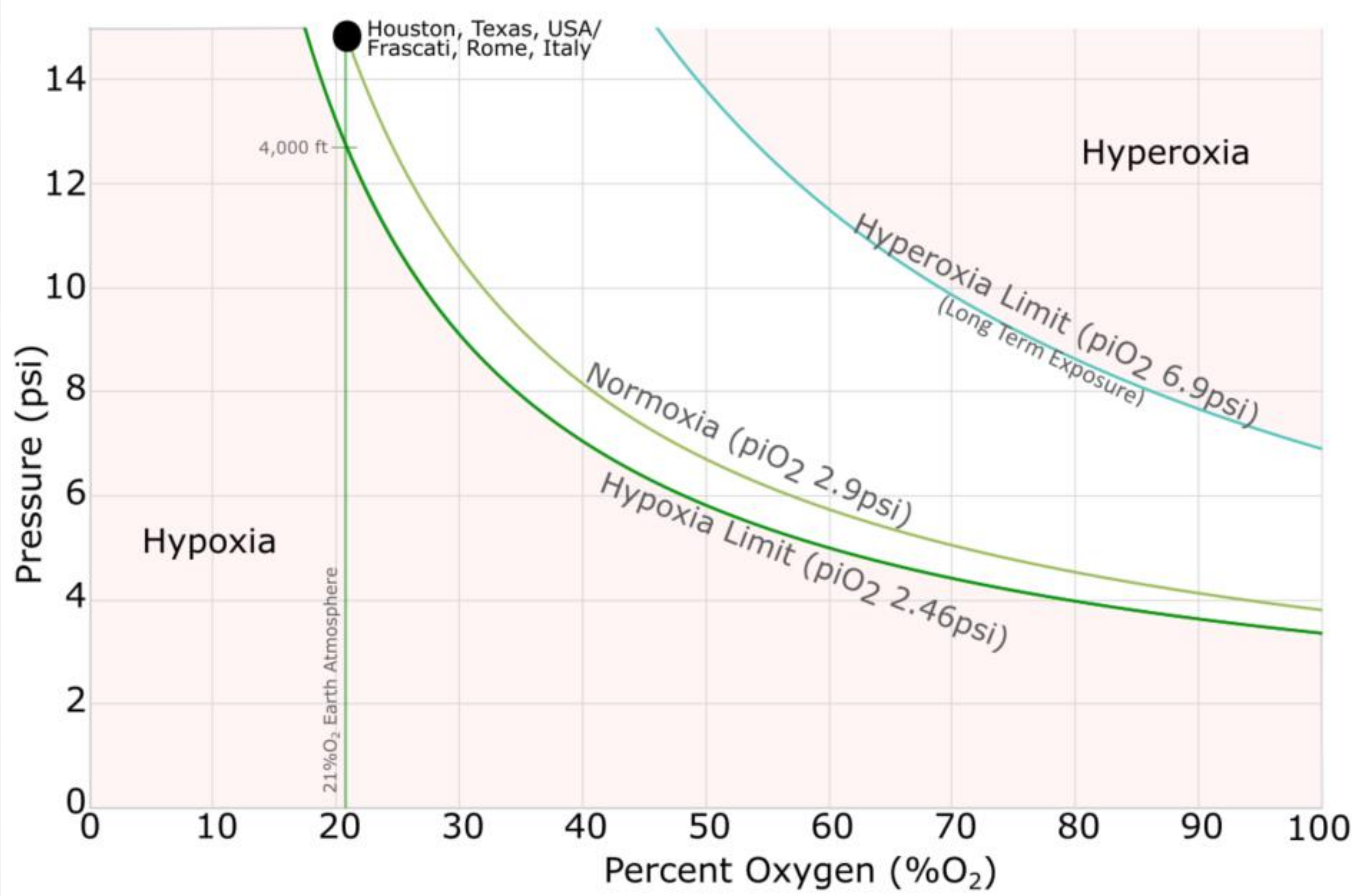
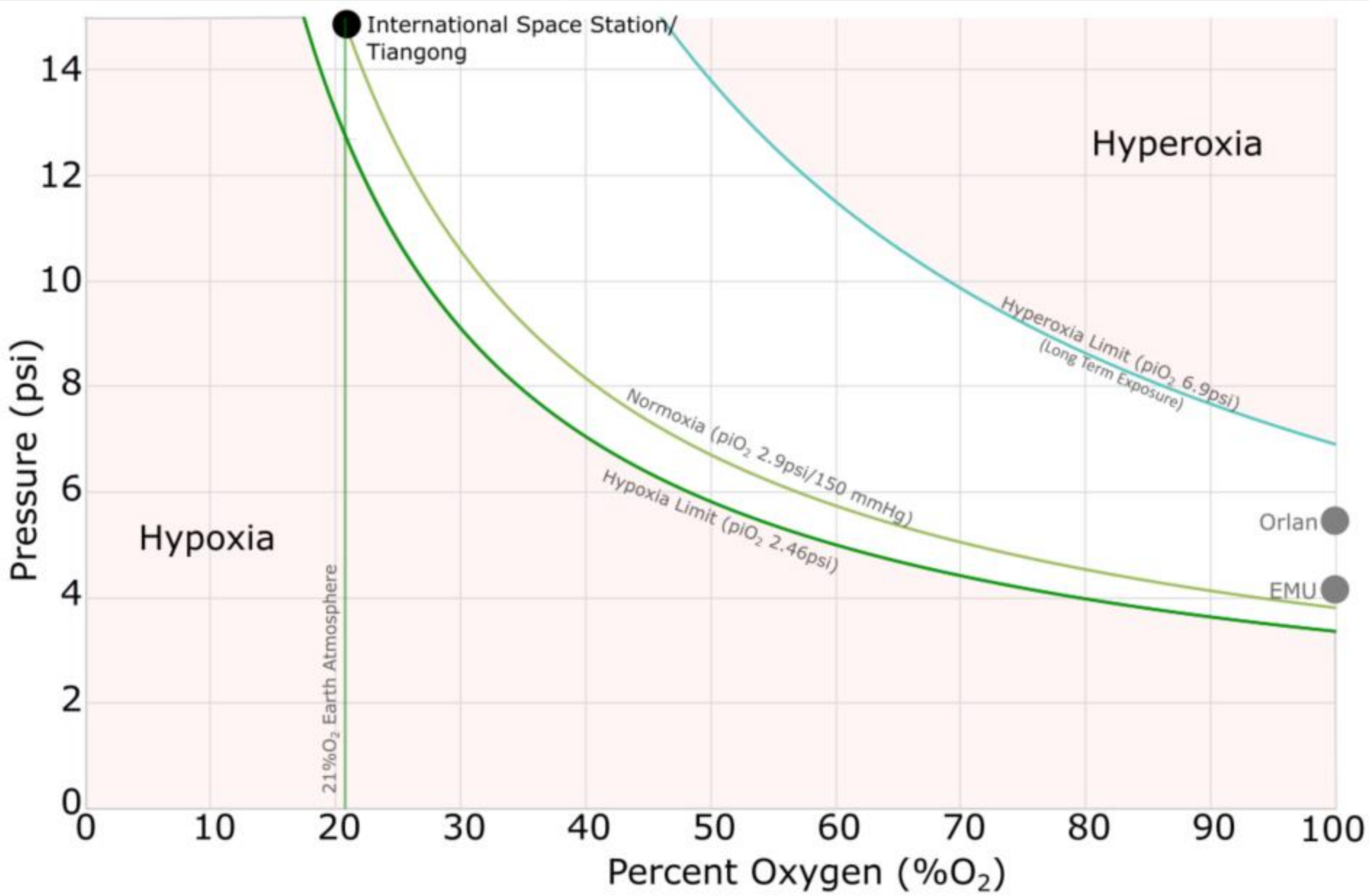


Current: Vehicle and Suit Atmosphere

ISS

14.7 psia / 21% O_2 / 79% N_2 Cabin

Suit pressure - 4.3 psid (EMU), 5.8 psid (Orlan)



Conditions for Decompression Sickness (DCS)

- Decrease in Pressure
- Change in Phase State

Supersaturation

- Tissue pN_2 > Ambient Pressure

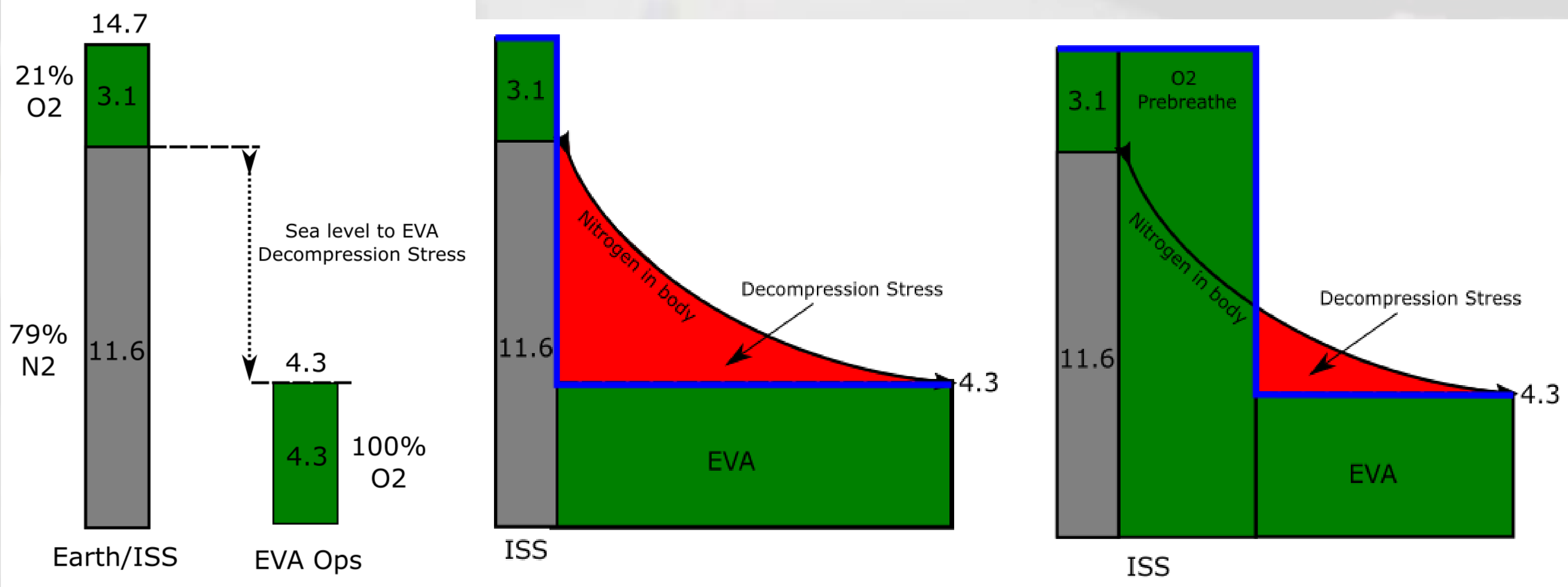
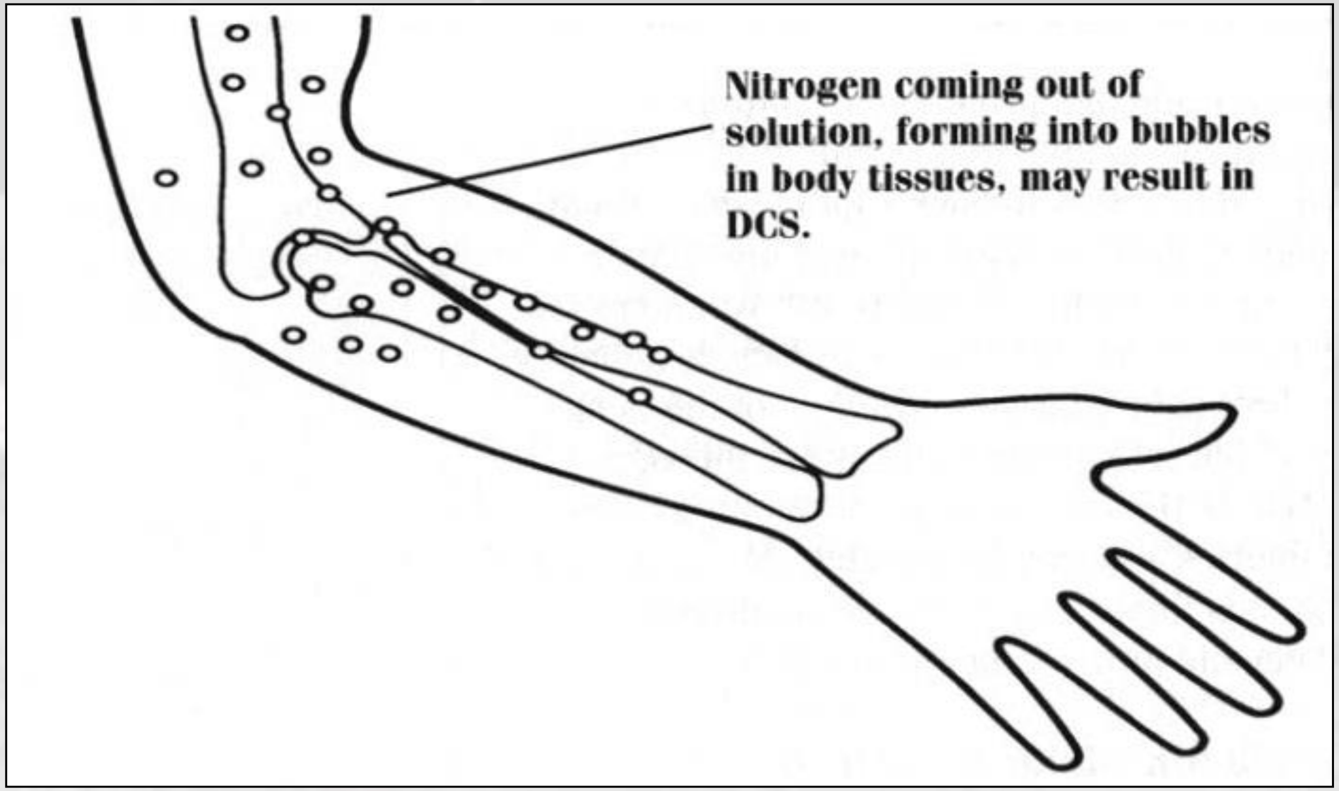


Figure: Alejandro Garbino, MD, PhD

Moon to Mars: Exploration Atmosphere

Decompression Sickness (DCS)

- **Health risk** - Overarching medical and operational philosophy is that it is always better to **prevent** DCS than to treat DCS
- **Mission Risk** - DCS symptoms would most likely occur during an EVA and result in EVA termination, additional crew time/resources to treat DCS, and subsequent loss of mission objectives



Prebreathe (PB): Moving from Vehicle to Suit

ISS

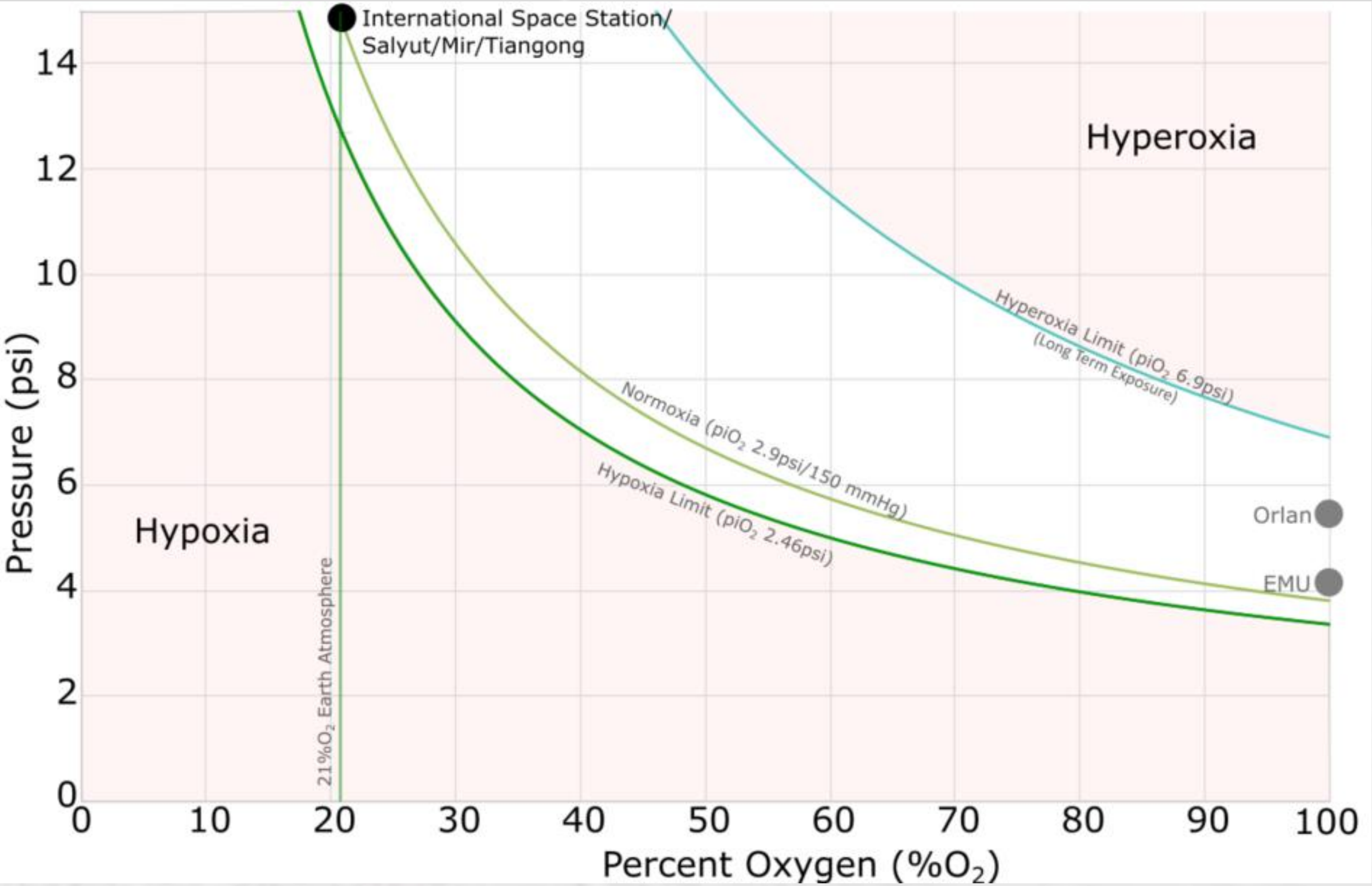
14.7 psia / 21% O_2/ 79% N_2 Cabin

Suit pressure - 4.3 psid (US EMU)

- Complex operational protocols require mask PB, airlock isolation, exercise, ground support
- 5-6 hours total prep time (2.5-3 hours dedicated to PB) prior to EVA

Suit Pressure – 5.8 psid (Russian Orlan)

- Similar EVA prep procedures but use of higher pressure reduces PB time to 30-40 min



History: Vehicle and Suit Atmosphere

Apollo

16 psia/60% O_2 on Pad

3-hr PB on launch pad

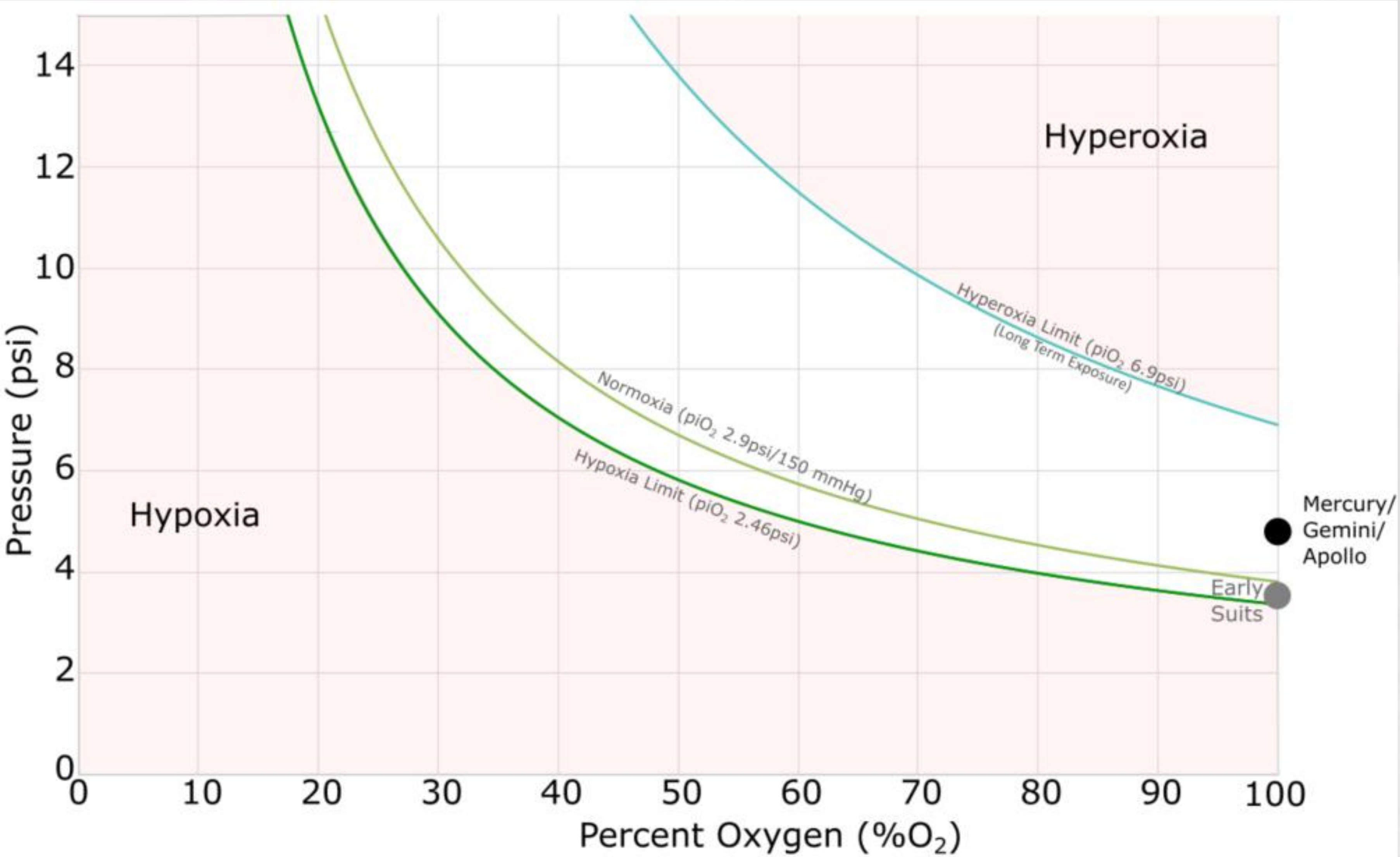
Aerospace Med 1970; 41:1162-5.

*DCS - experienced in transit

5 psia / 100% O_2 Cabin

3.7-4.0 psid suit pressure

- Minimum pressure to avoid hypoxia
- *No EVA DCS risk = No PB*



History: Vehicle and Suit Atmosphere

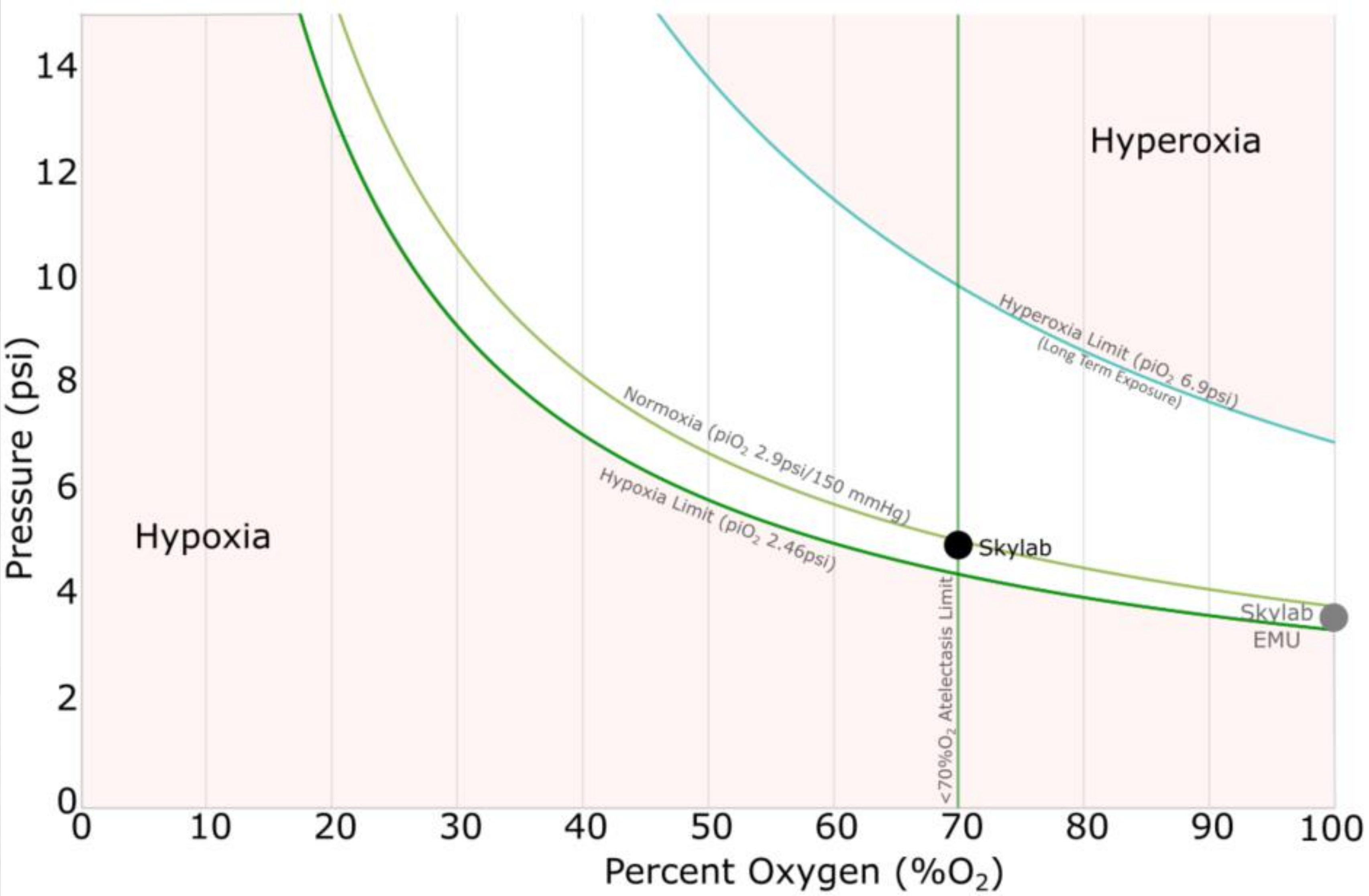
Skylab

5 psia / 70% O_2 Cabin

- Maintains P_IO_2 = 150 mmHg for normoxic environment
- Inclusion of 30% N_2 prevents atelectasis and was needed due to increased mission duration

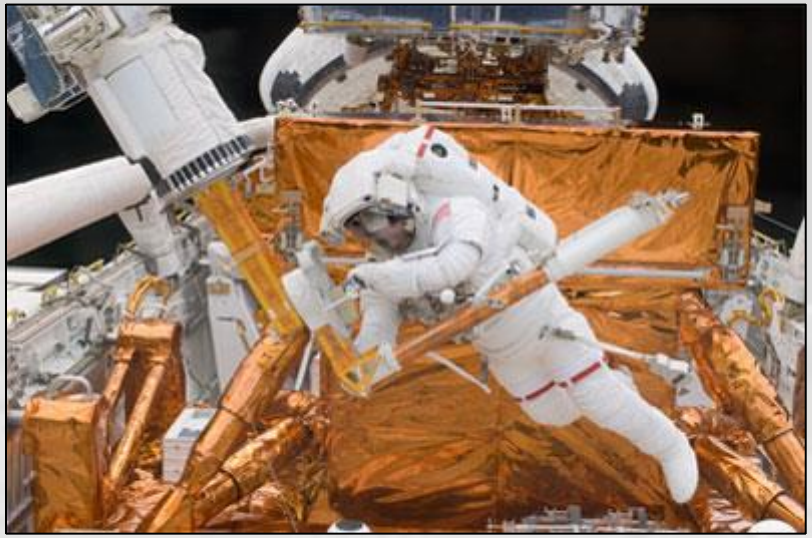
3.7-4.0 psid suit pressure

- *No EVA DCS risk = No PB*



History: Vehicle and Suit Atmosphere

Shuttle

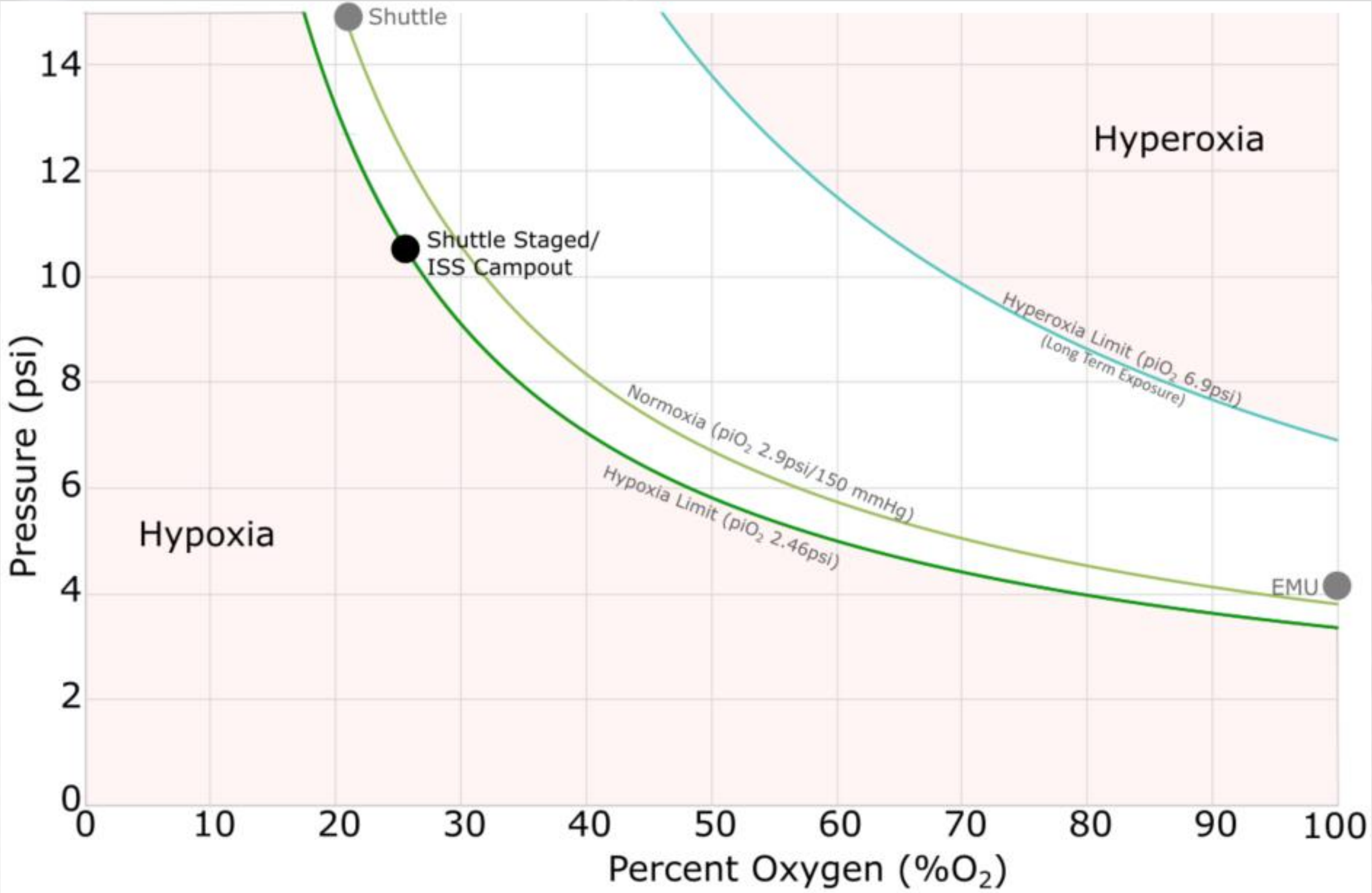


14.7 psia / 21% O_2 Cabin
Suit pressure increased to 4.1-4.3 psid
4-hour pre-EVA PB required

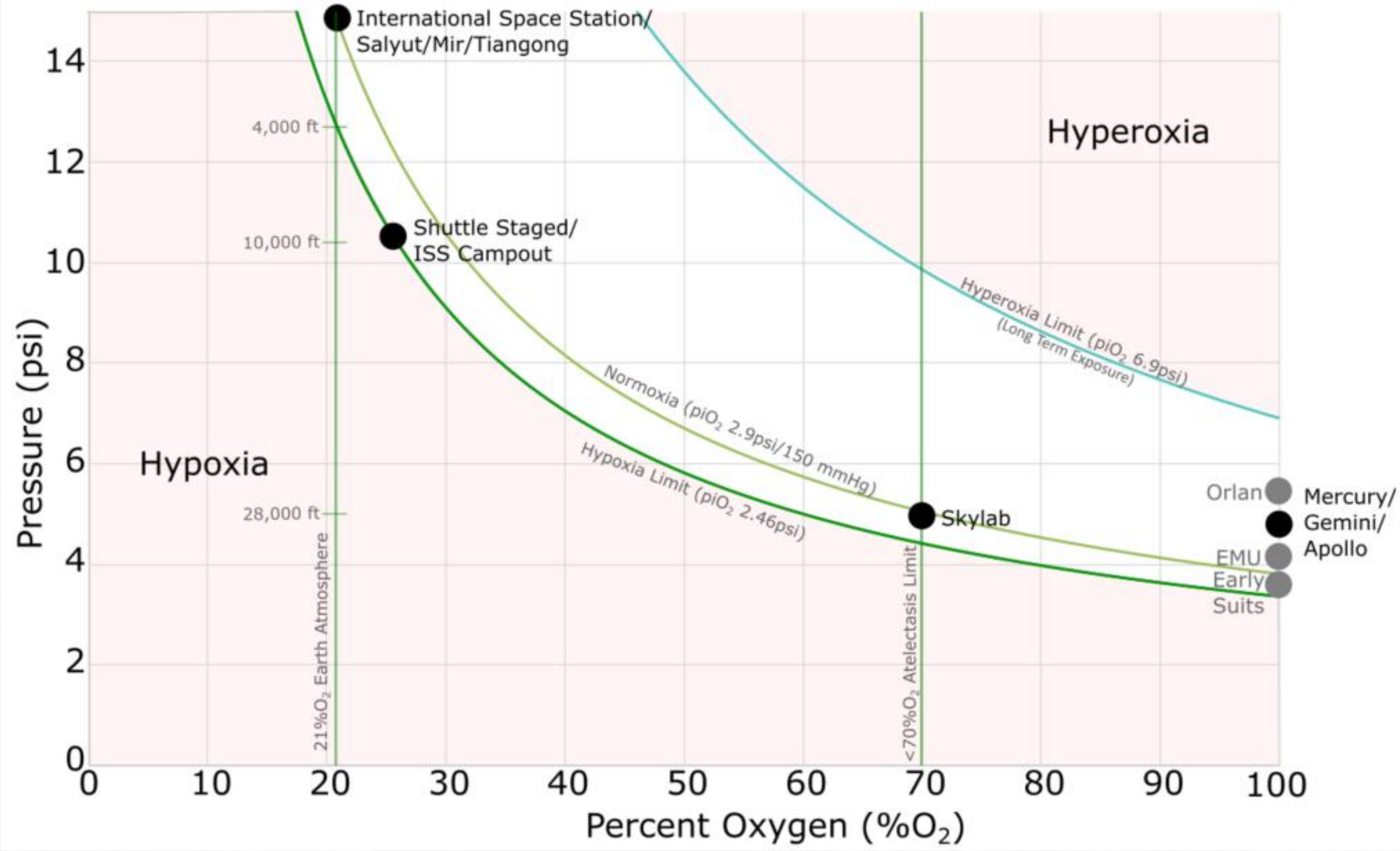
- Used only 6 times due to crew dislike

Shuttle retroactively certified to
10.2 psia / 26.5% O_2 Cabin
40-70 min in-suit PB pre-EVA

- *Efficient mitigation of DCS risk*

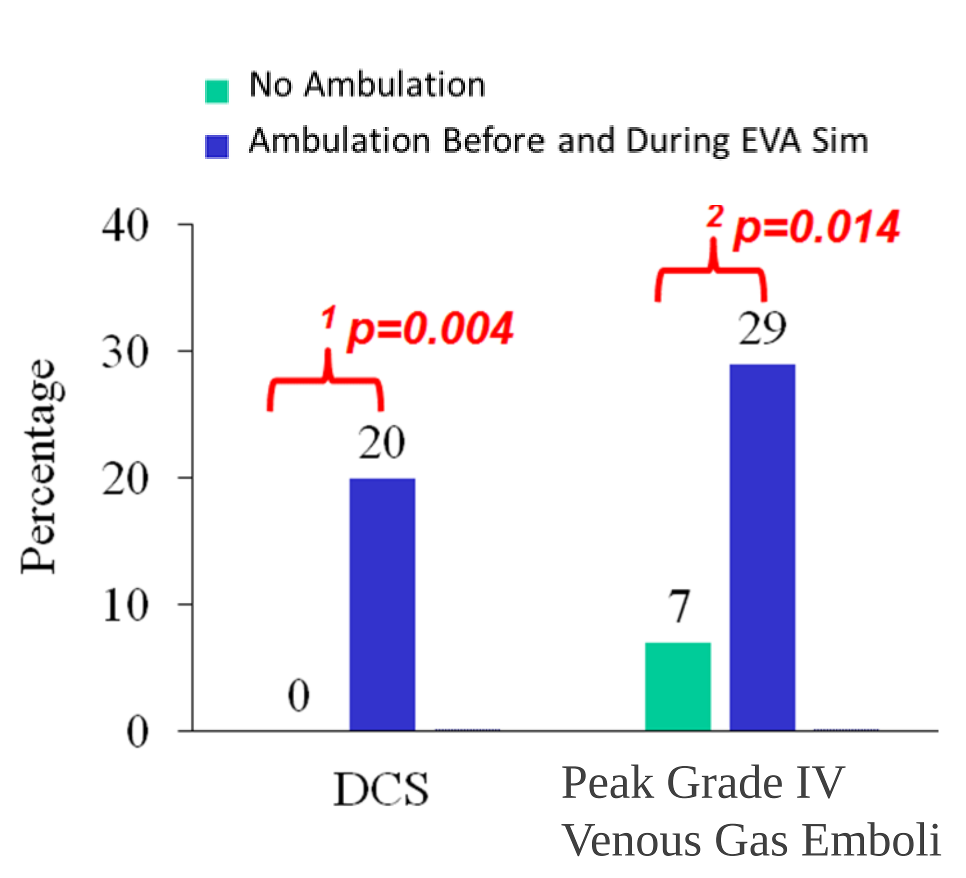


Vehicle and Suit Atmosphere to Date



Micro- Versus Partial-gravity DCS Risk

- No ***reported*** cases inflight to date
  - Michael Collins on Gemini X & Apollo 11 believed he had symptoms of pain-only DCS in his left knee that eventually resolved (Biomedical Results of Apollo)
- Apollo had no risk during EVA
  - Denitrogenation on launch pad
  - 100% O_2 Cabin – Fire risk too great
  - Not an option for Artemis
- Shuttle/ISS has risk but no cases
  - Microgravity- upper body activity
  - Transition to ops increases safety margin
- Artemis (Lunar) *will be* ambulatory
  - Greater metabolic and joint forces
  - Transition to ops does not guarantee increased safety



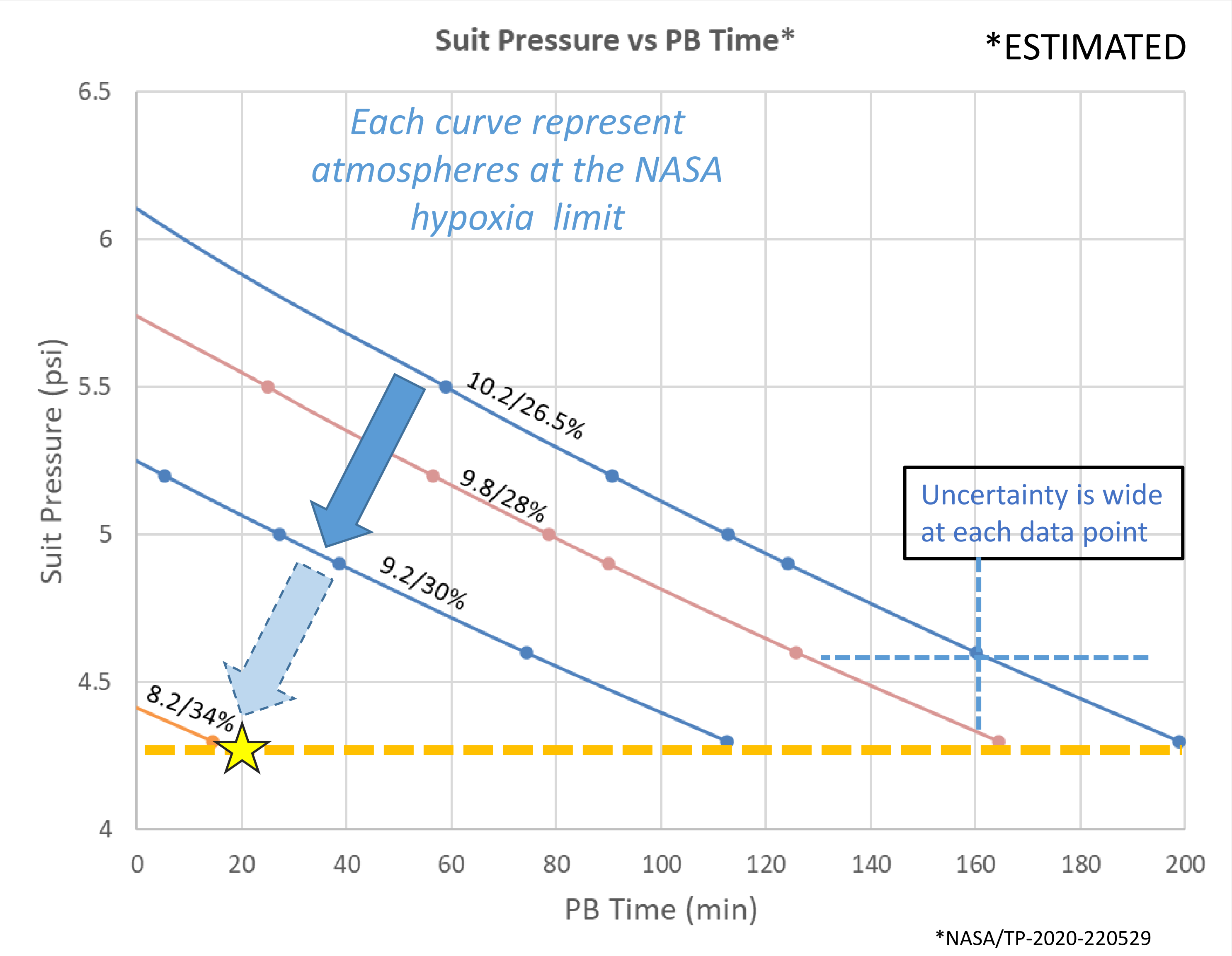
Conkin J, Pollock NW, Natoli MJ, Martina SD, Wessell JH III, Gernhardt ML. Venous gas emboli and ambulation at 4.3 psia. Aerosp Med Hum Perform. 2017; 88(4):370–376.
Webb JT, Krock LP, Gernhardt ML. Oxygen consumption at altitude as a risk factor for altitude decompression sickness. Aviat Space Environ Med 2010; 81:987-92.
Webb JT, Morgan TR, Sarsfield SD. Altitude Decompression Sickness Risk and Physical Activity During Exposure. Aerosp Med Hum Perform. 2016: 87(6):516-20.

Atmospheric Impacts on Suit Pressure and PB Time
(estimated)

Model* estimates to achieve 3% per person per EVA DCS Risk

Any movement toward the origin
- optimizes timeline efficiency
- minimizes consumables
- decreases human workload

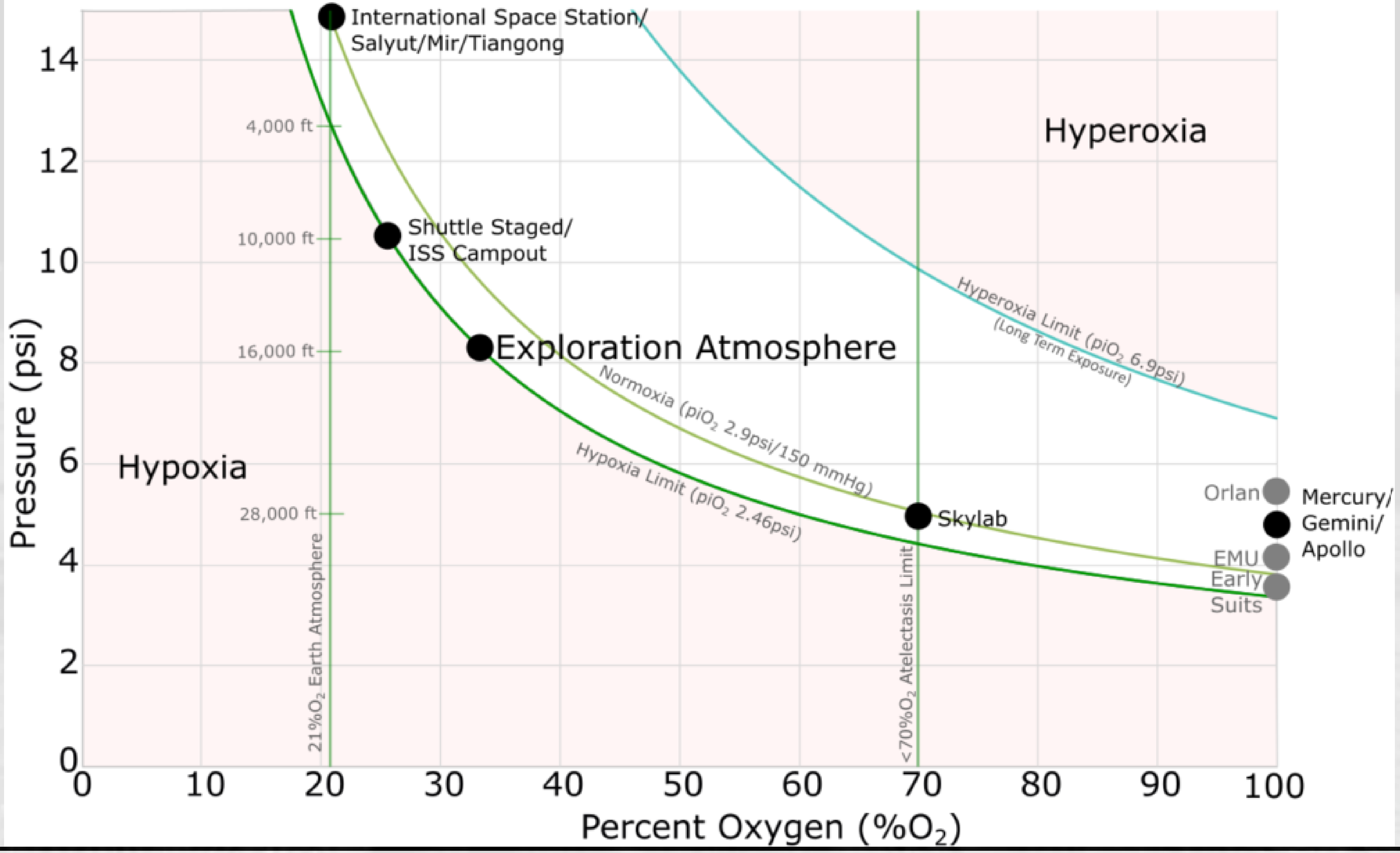
Every incremental increase in O_2% drives us down and left towards less suit pressure and shorter prebreathe duration



★ Validated test point

Abstract 12 - AsMA Annual Conference, 2024.

Exploration Atmosphere



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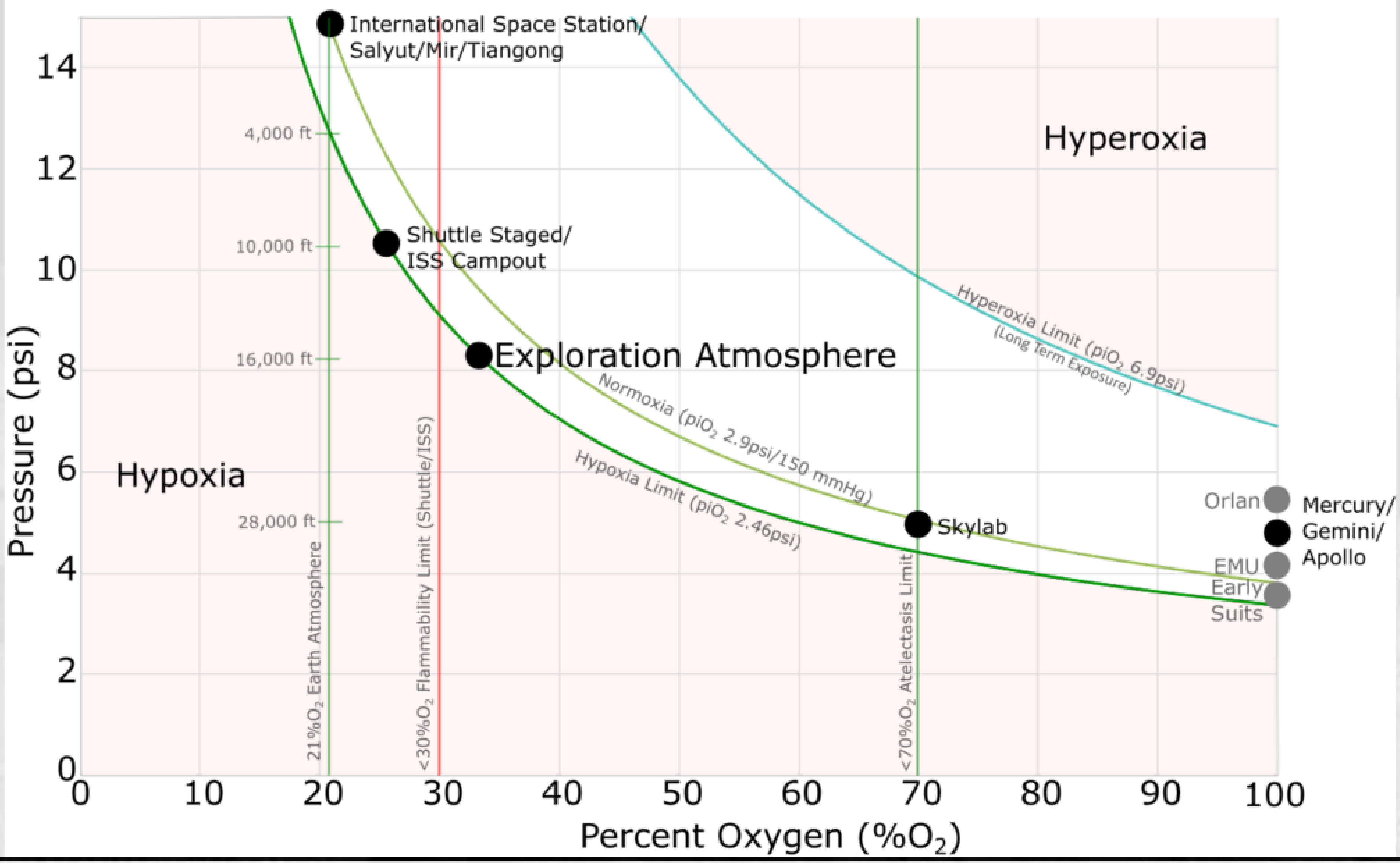

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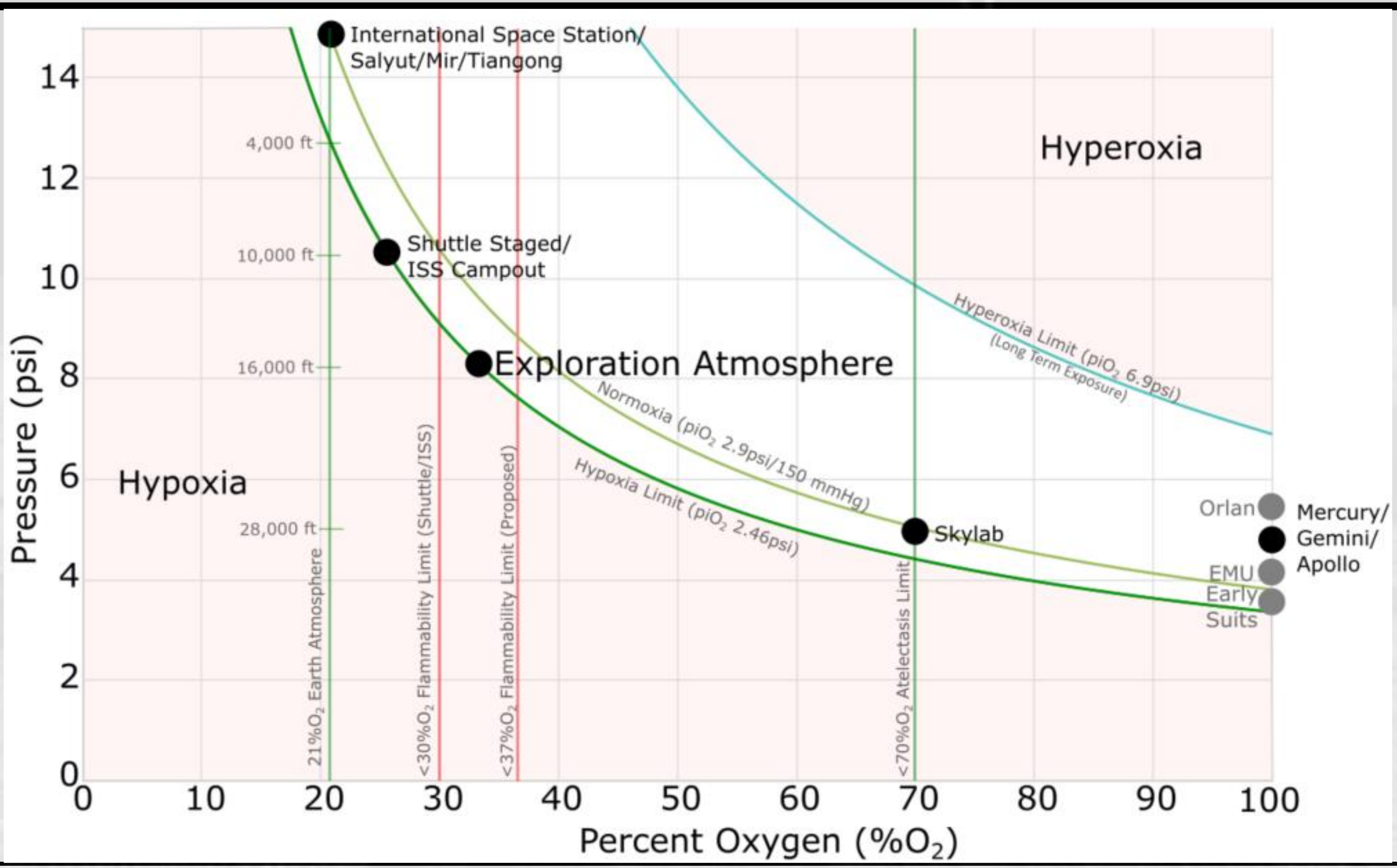


Historical Lessons Learned from Apollo I

In a **post Apollo I mockup test**, fire spreads rapidly through the command module cabin in pure oxygen at 16.7 psi

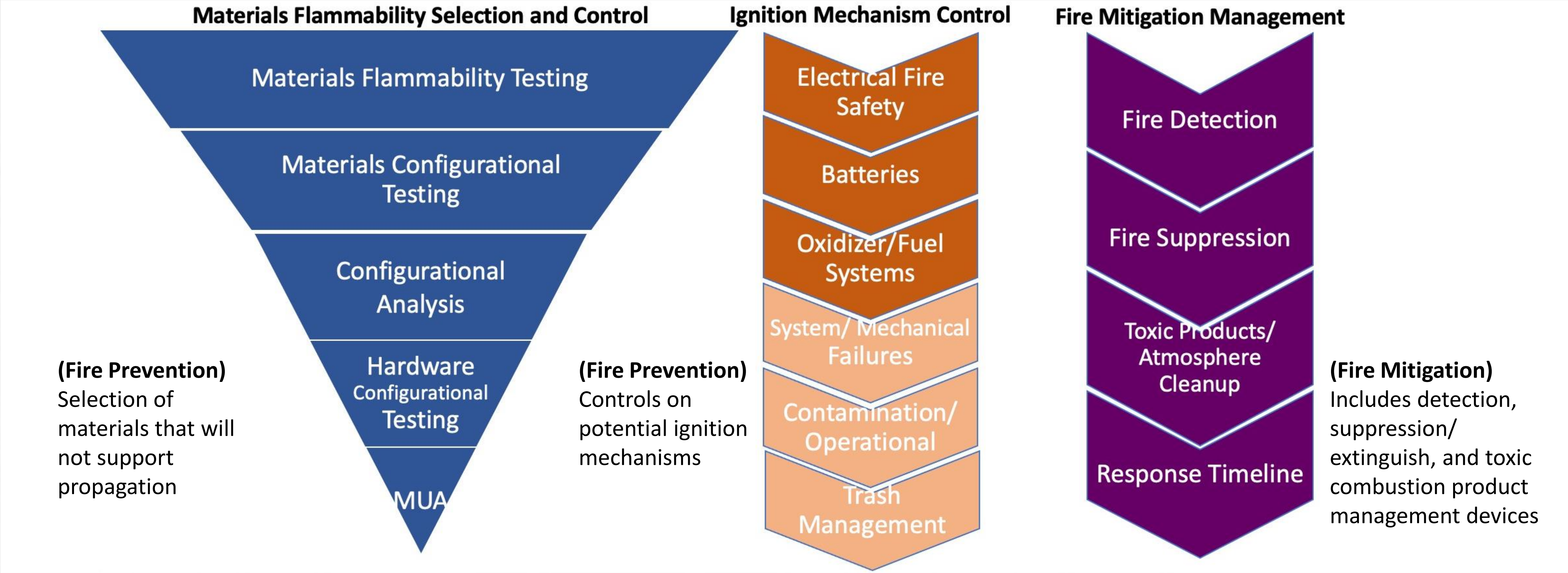
Note the explosive burning of Velcro attached to cabin walls, which helped spread the blaze.

- **Oxygen-enriched flammability testing was not standardized by NASA before the Apollo program**
- Manned Spacecraft Center laboratories began looking into test method standardization for elevated oxygen environments;1964 workshops identified key criteria:
  - Need for non-metallic materials flammability screening test
  - Clear acceptance / rejection criteria
  - Generation of list of acceptable/ not acceptable materials
- Apollo 1 fire occurred January 27, 1967; in 1968, NASA announced 60%O_2@16 PSI launchpad ops, Apollo program continued with 100% O_2 in flight at 5 psia
- *"It soon became apparent that so many tests of a highly varied nature were being run at different locations that it was not possible to correlate the results of these tests, and it was decided that it would be* ***necessary to establish a standard set of test methods and criteria****" – Johnston & Pippen, 1970*

NASA Fire Safety Approach

Three-pronged approach - provides robust spacecraft fire safety management plan

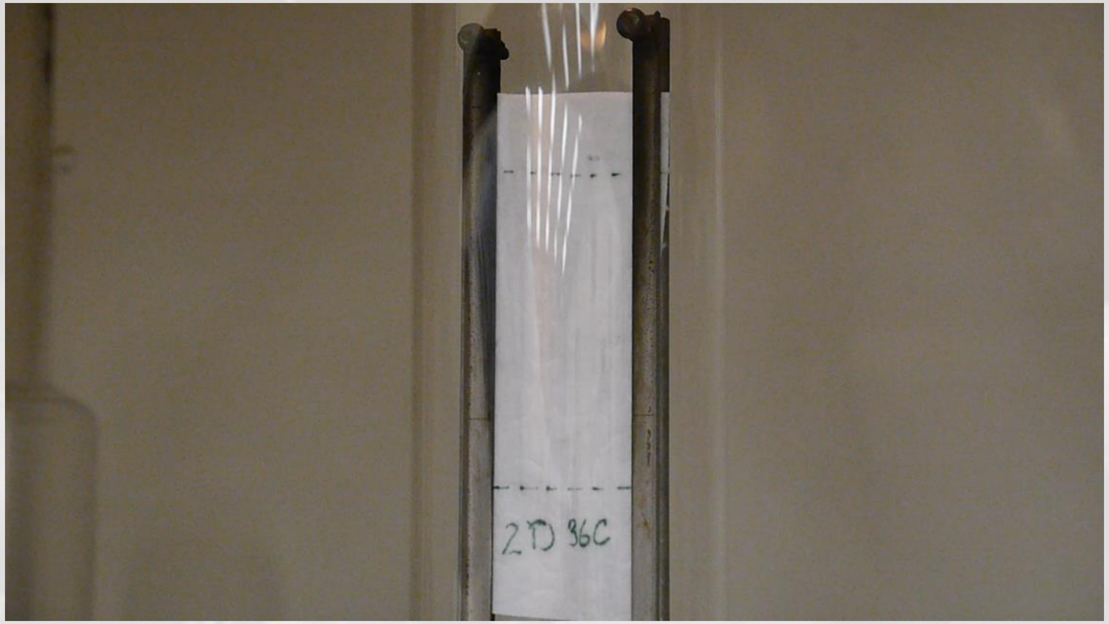
- Misses or weaknesses in one component → compensated for on others, safeguarding against an overall system failure
- Each component - intended to be fully independent, cannot be waived based on the execution of others



Dried Hygiene Wipe Comparison

21% O_2, 14.7 psi

36% O_2, 14.7 psi



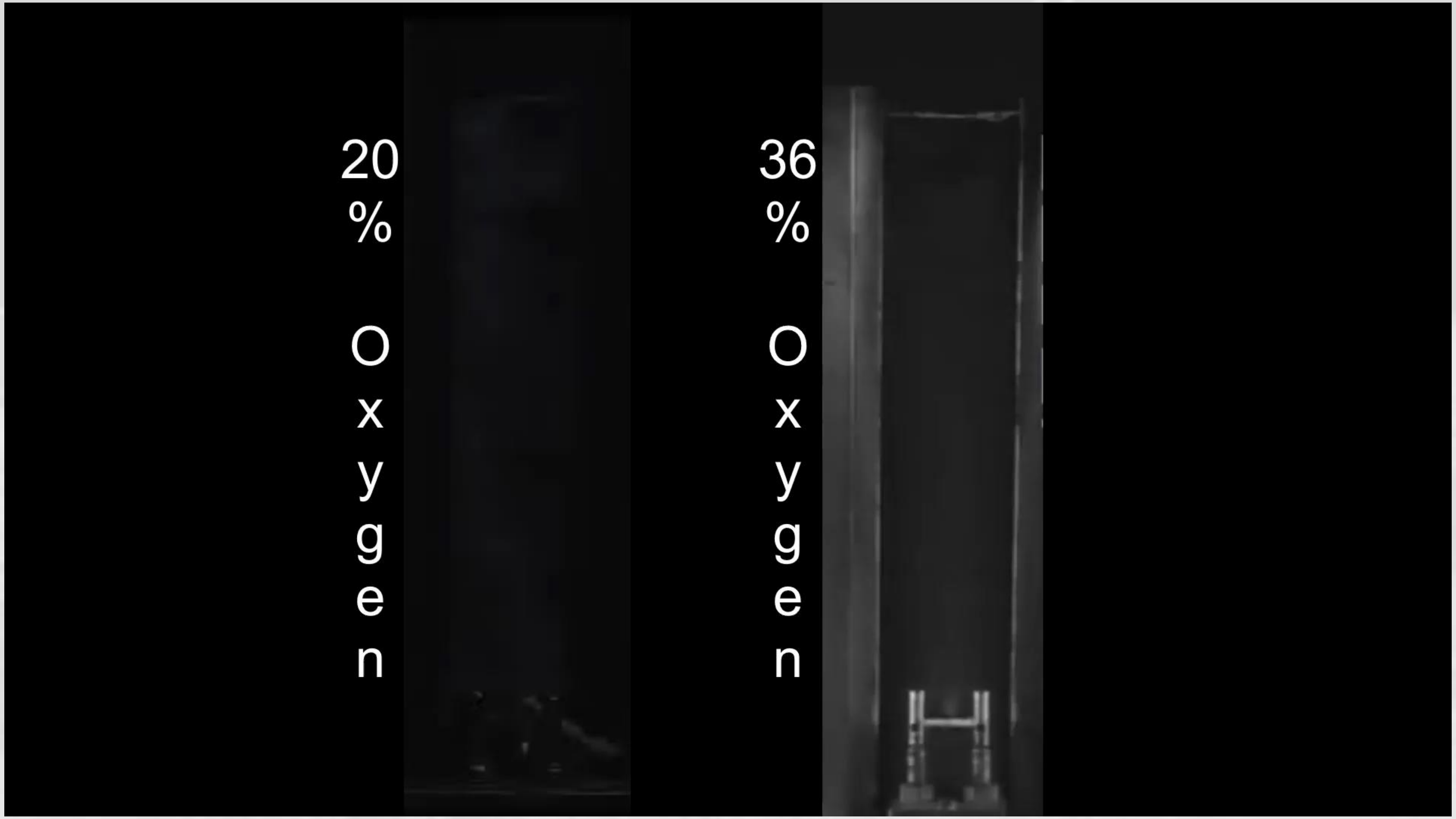
Ignition time and flame spread occur rapidly at 36% oxygen.

Flammability data from ignition of flammable materials provides guidance for flammability configuration analyses required to justify the use of flammable materials in spacecraft flight hardware and operational controls.

JSC Advanced Materials Lab

Cotton Sweatshirt Comparison

20% O_2
14.7 psi

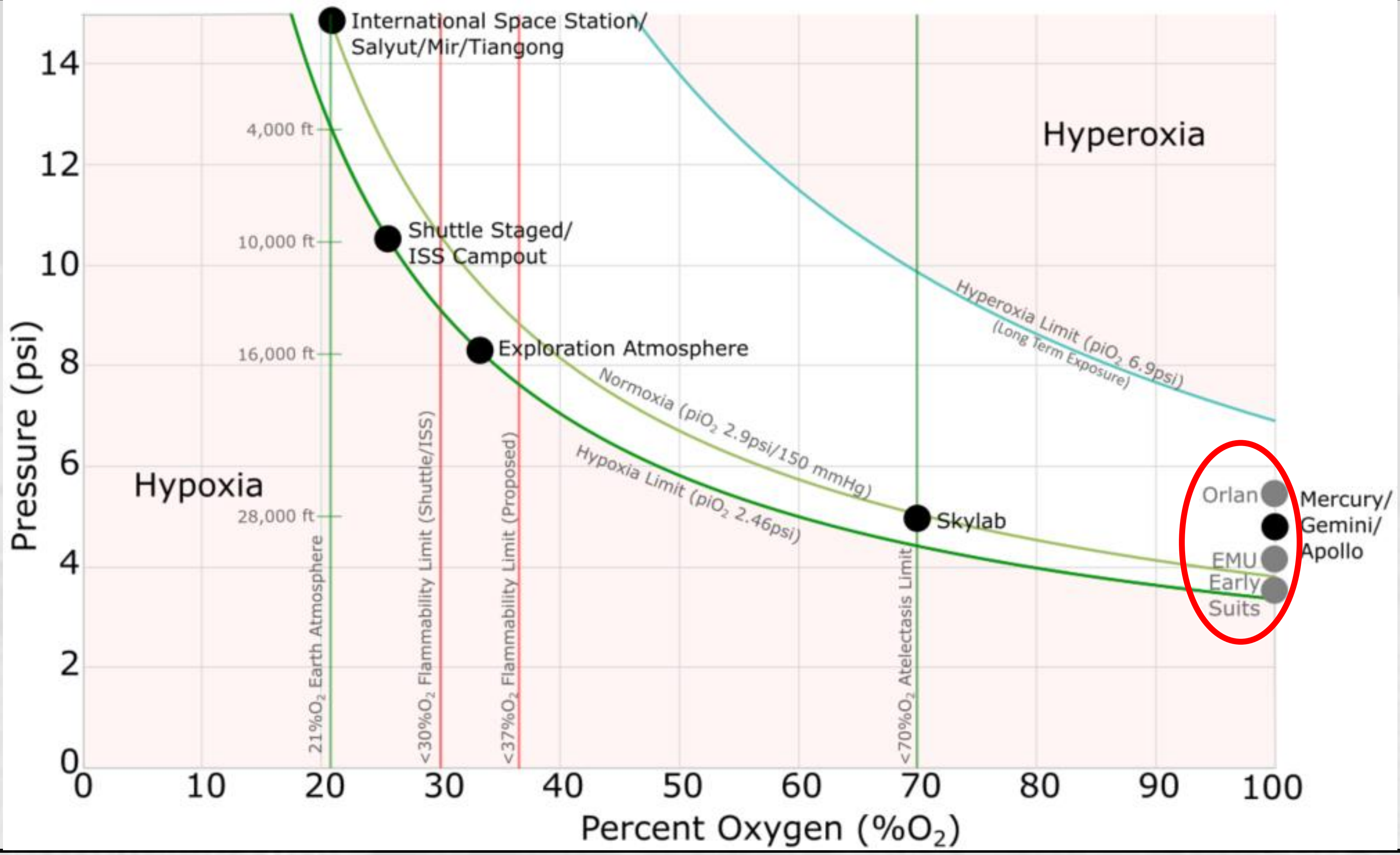


36% O_2
8.2 psi

Due to desired properties of cotton, it will likely be used for underwear and towels. Though flammable in air, ignition and propagation occurs more readily in oxygen-enriched exploration atmospheres.

Susana Harper, White Sands Test Facility

Suit Pressure and Physiologic Responses



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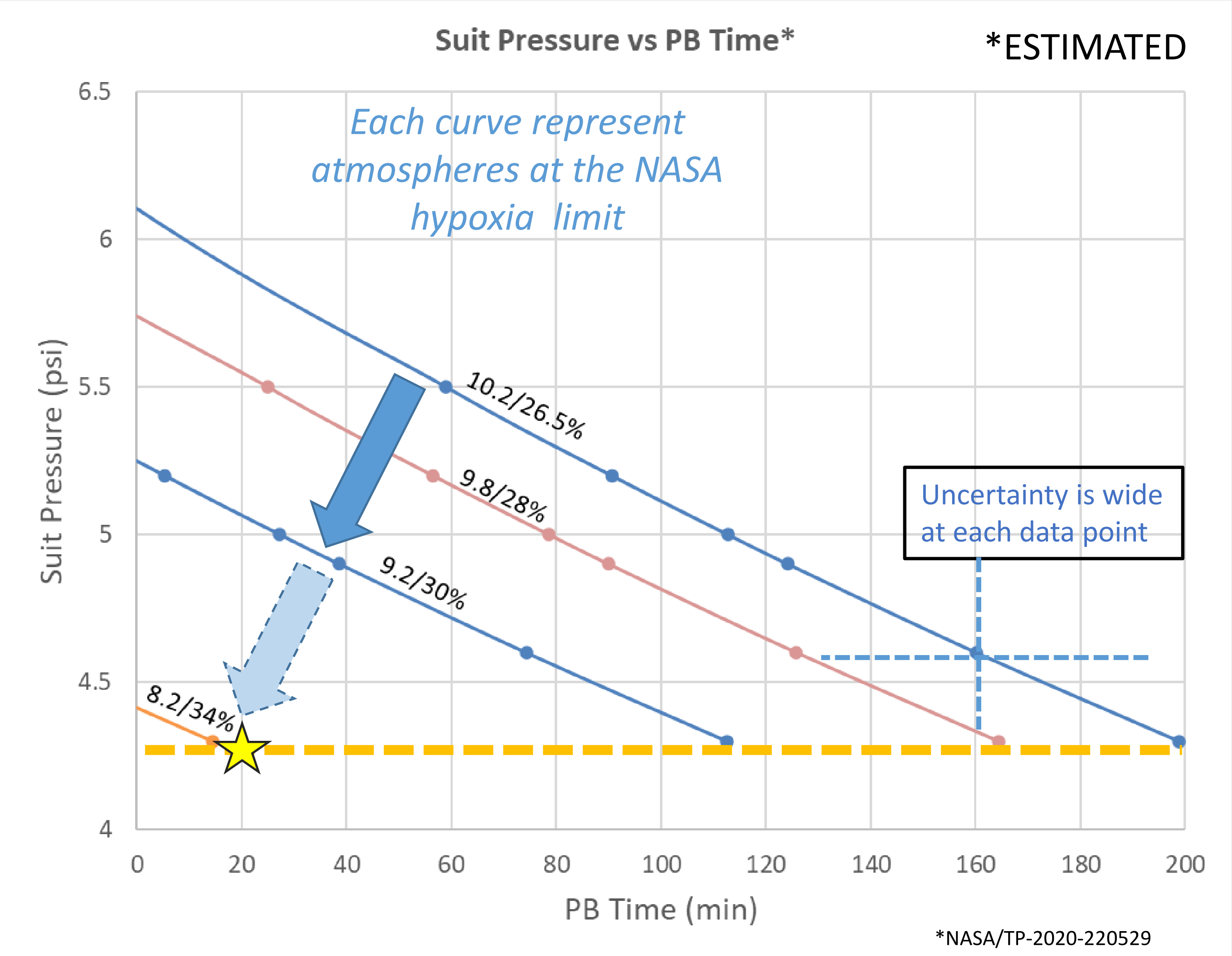


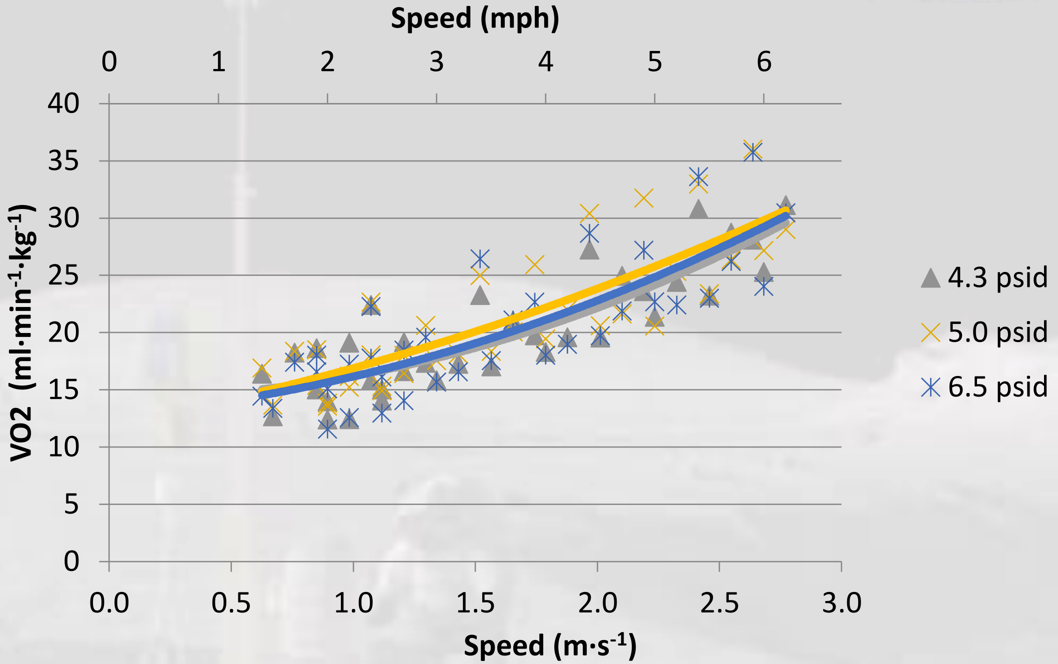
*NASA/TP-2020-220529

☆ Validated test point

Abstract 12 - AsMA Annual Conference, 2024.

Data with Suit Pressures > 4.3 psid

- Metabolic rate not affected by suit pressures from 4.3-6.5 psid in Artemis-like Lunar suit with treadmill ambulation using overhead partial gravity offload (NASA/TP-2010-216115)
- Short durations at 8.0 psid during NBL testing using xEMU early prototype provided positive feedback
  - Gloves primary discernable difference between 4.0 psid and 8.0 psid (ICES-2018-71)
- 15 US Crew have done EVA (some several) in 5.8 psid Russian Orlan
- Planetary EVA is full body vs all upper body microgravity EVA
  - Hand/forearm fatigue may be most impacted
  - Crew can be trained to prepare for these impacts
- Data is very limited on human performance implications



Russian Orlan Suit @ 5.8 psia

Exploration Atmosphere Considerations

Moon to Mars: Exploration Atmosphere

Exploration Atmosphere – Start with Engineering Solutions

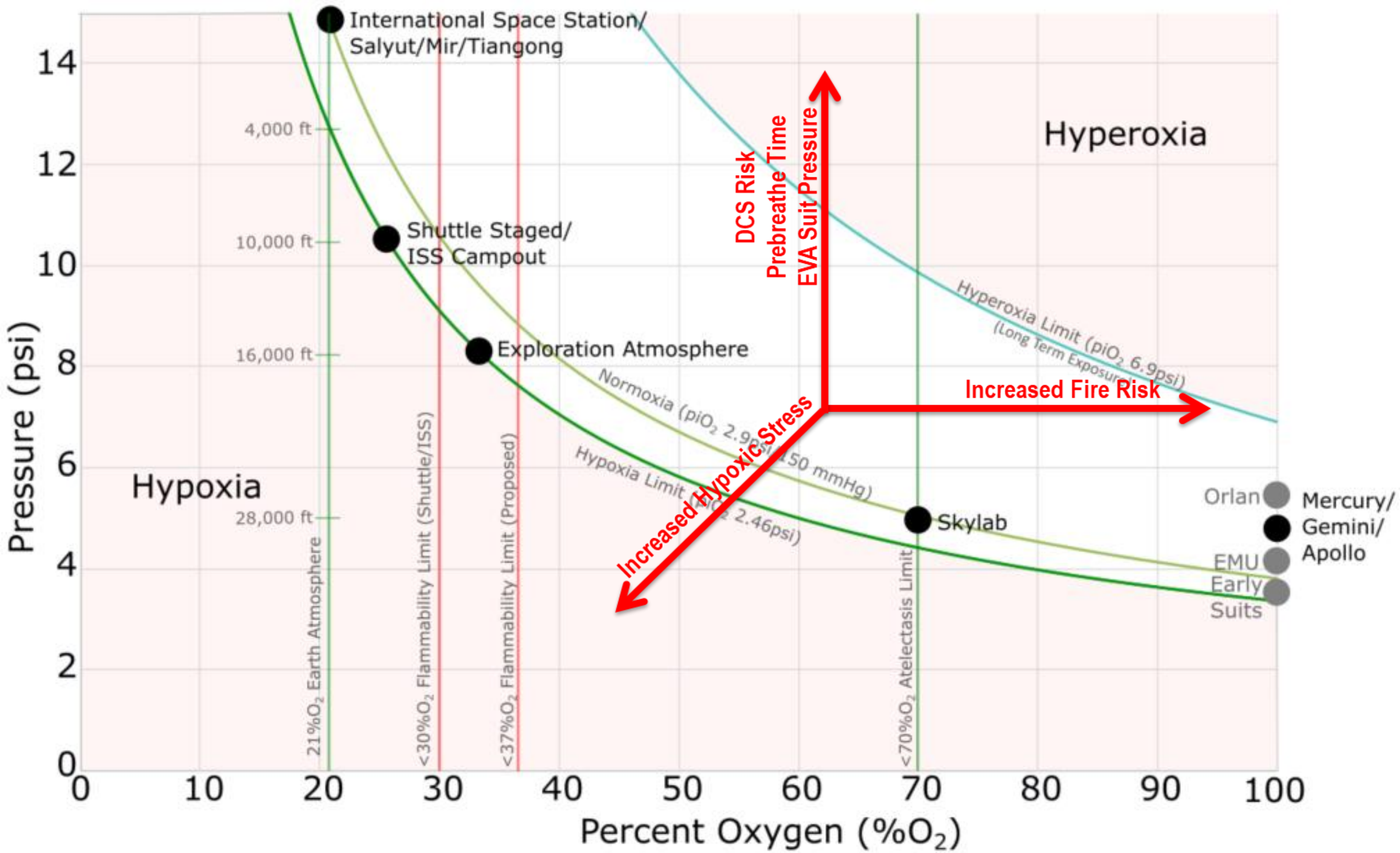
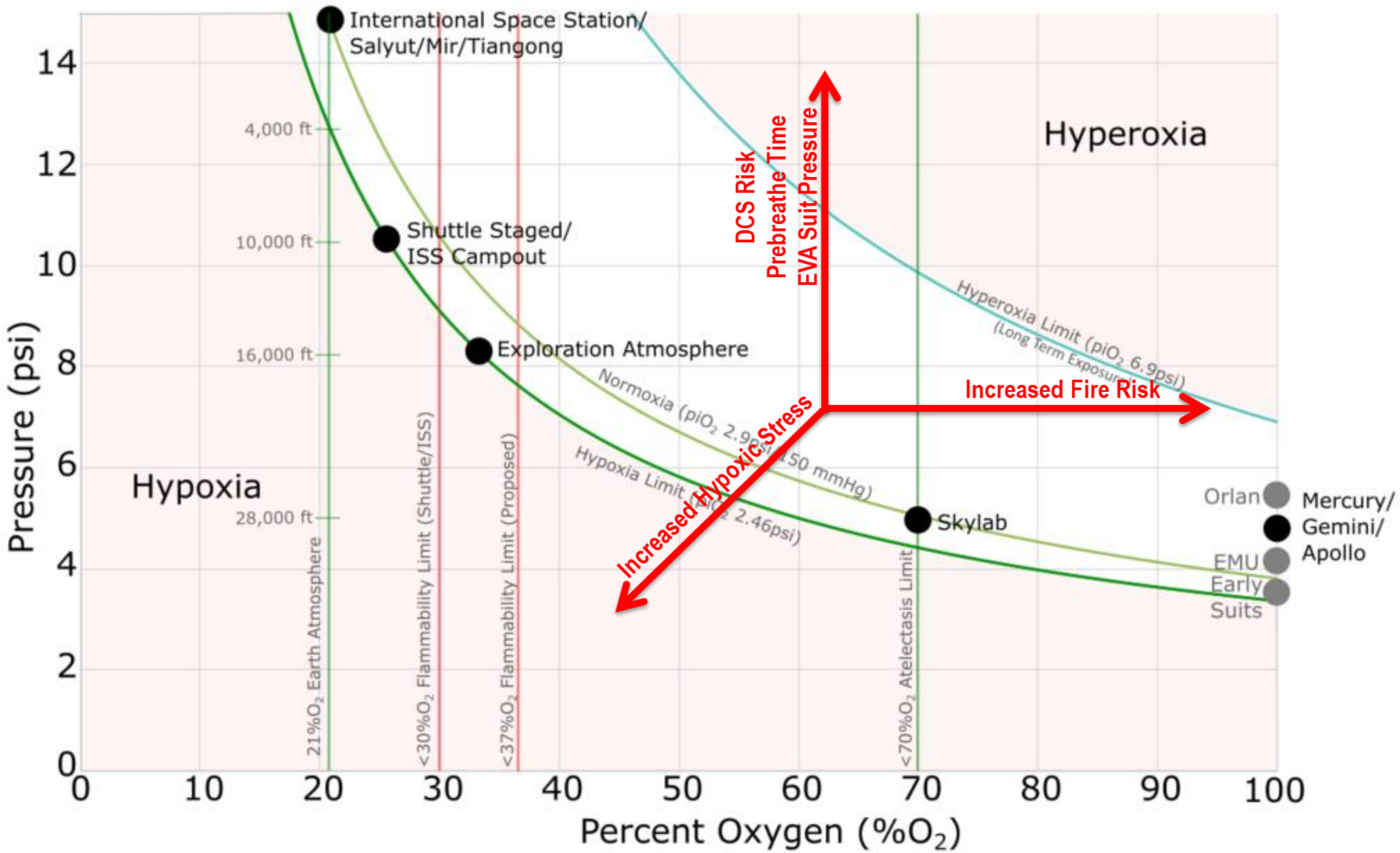


Figure: Alejandro Garbino, MD, PhD, modified by M. Walton

Exploration Atmosphere Considerations

- Significantly higher EVA frequency during Artemis versus ISS
  - Artemis includes back-to-back EVAs and multiple EVAs per person per week
  - ISS EVA is infrequent so 5-6 hours of EVA prep time considered acceptable
- Limited validated prebreathe protocols exist for planetary EVA
  - Apollo used 5 psia / 100% O_2 cabin to eliminate DCS risk during EVA
  - 20 minute protocol – valid only at 8.2 psia / 34% O_2
- Engineering solutions required to achieve mission success
  - Exploration Atmosphere
  - Variable Pressure EVA Suit



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Thank you!

Questions?