HOW DO HUMANS SLEEP IN SPACE?

WHAT WE KNOW AND WHAT WE NEED TO KNOW BEFORE WE GO TO THE MOON AND MARS?

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Photo credit: www.nasa.gov

Society for Light Treatment and Biological Rhythms Conference
May 30, 2023
Lausanne, Switzerland

10 NASA Centers

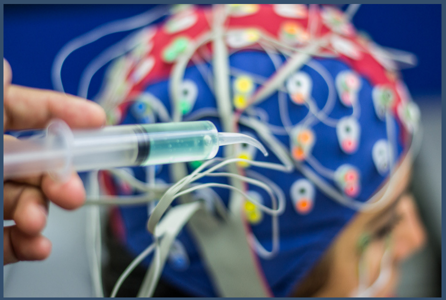

Photo credit: www.nasa.gov

What do we do in the Fatigue Countermeasures Laboratory?

SPACEFLIGHT RESEARCH

AERONAUTICS RESEARCH

LABORATORY RESEARCH



Three Research Areas

Photo credit: www.canva.com

What will I share today?

Results from new and old studies in space

What is it like to sleep in space?
- Sleep environment issues

How does sleep in space compare to sleep on Earth?
- Evaluation of sleep duration and circadian misalignment in space

Is sleep architecture different in space?
- Sleep staging comparisons
- Sleep spindle analysis

What do we need to know before we travel further?
- Space vehicle/mission considerations

What is it like to sleep in space?

Photo credit: www.nasa.gov

EXTERNAL CAUSES OF SLEEP DISRUPTION

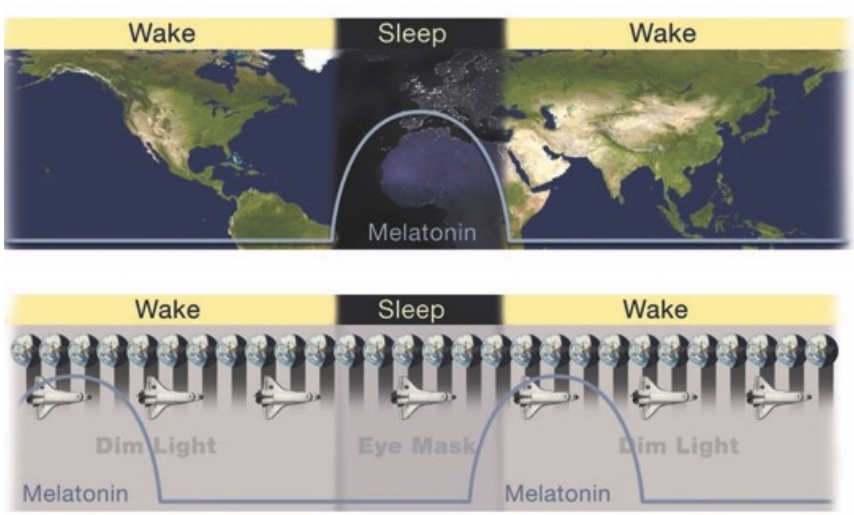
- Noise
- Temperature
- Poor air quality
- Light pollution
- Insufficient lighting
- Schedule creep
- Stress
- Psychosocial issues

The Spaceflight Sleep Environment

Photo credit: www.nasa.gov

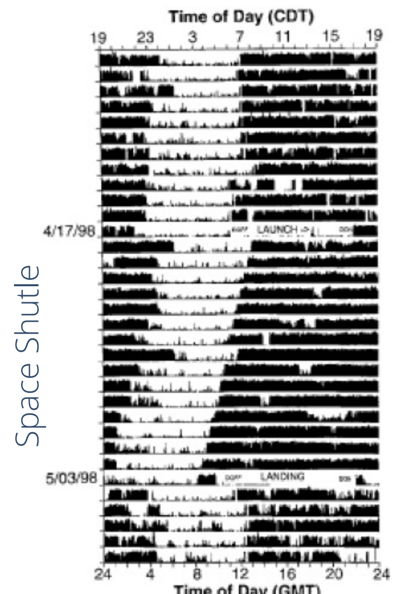
Potential for Circadian Misalignment

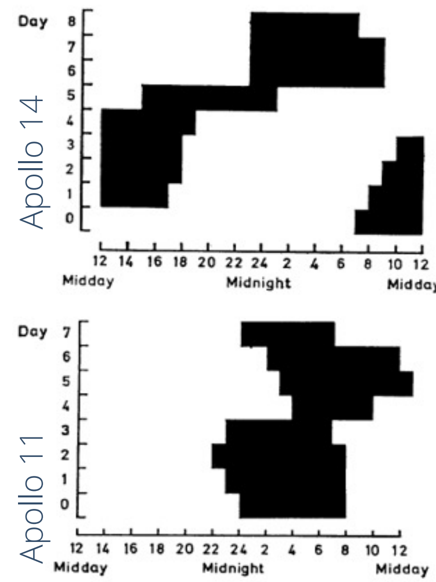
Inappropriate/Insufficient Light Exposure

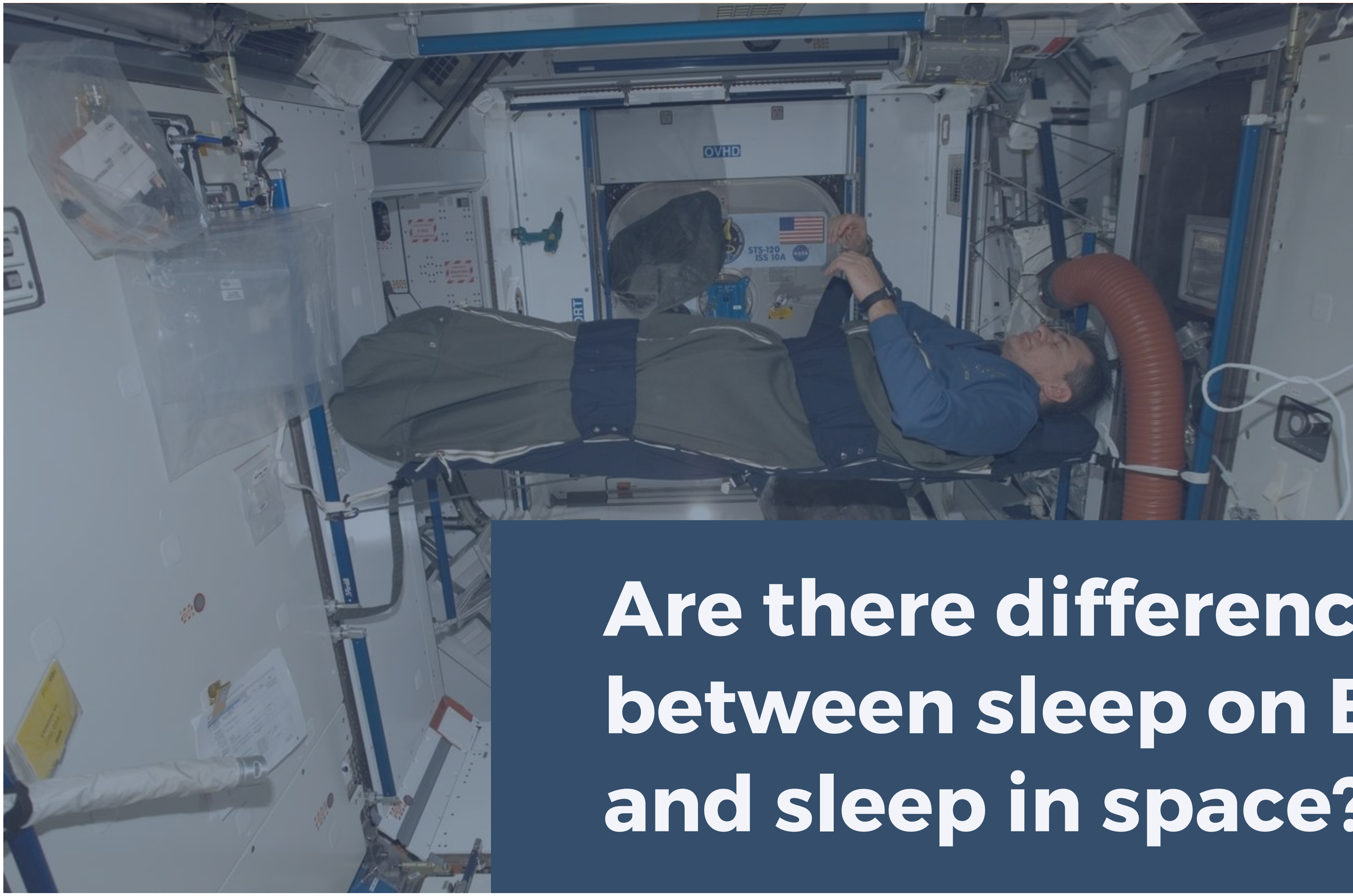


Dijk *et al.* 2001 *AJP RICP*, Nicholson 1972 *Proc Roy Soc Med*

Schedule-induced



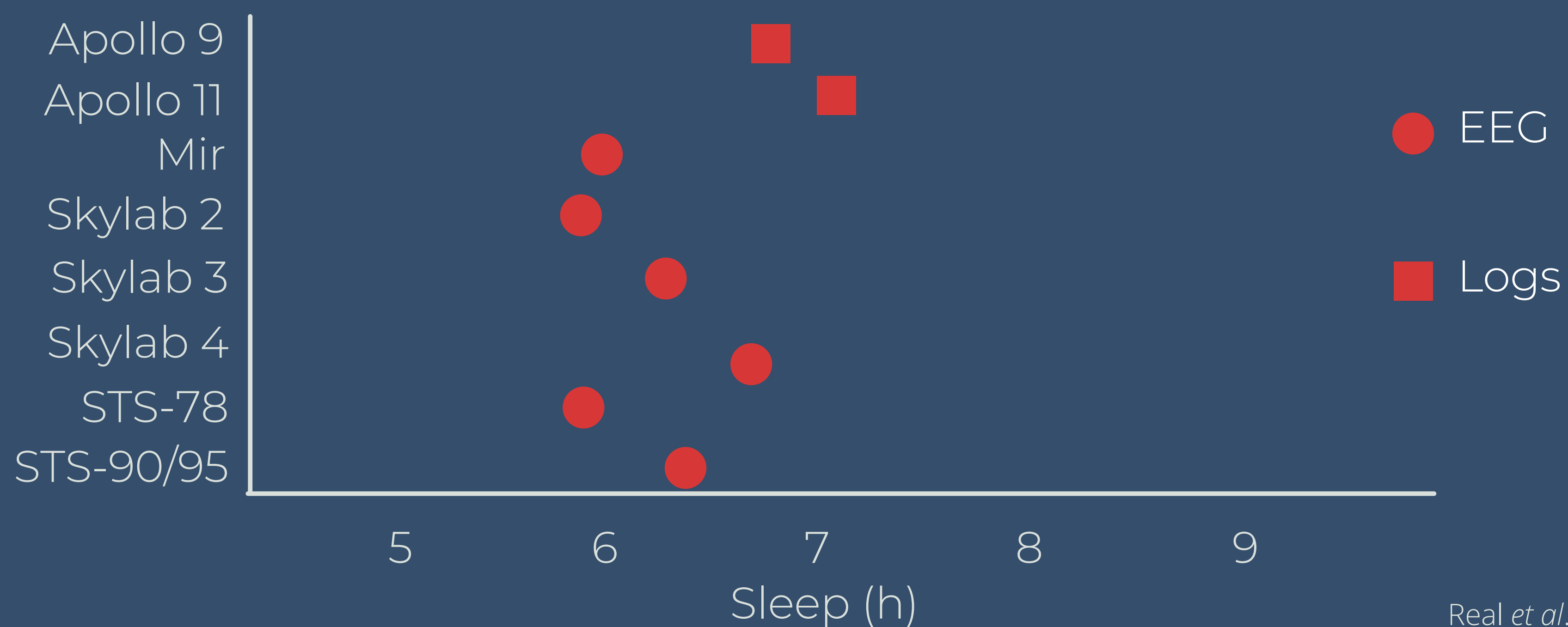




Are there differences between sleep on Earth and sleep in space?

Photo credit: www.nasa.gov

Houston, we have a sleep problem!



Real *et al.* 2016

Spaceflight Actigraphy Study

Background Methods Results Conclusions

WE AIMED TO:

- Compare sleep duration in space to sleep duration on Earth
- Determine what countermeasures (if any) astronauts use in space
- Compare sleep duration on short duration missions to long duration missions
- Assess the influence of circadian misalignment on sleep outcomes

Evaluation of short and long-duration spaceflight

- Space shuttle (short)
- International Space Station (ISS; long)

Measures

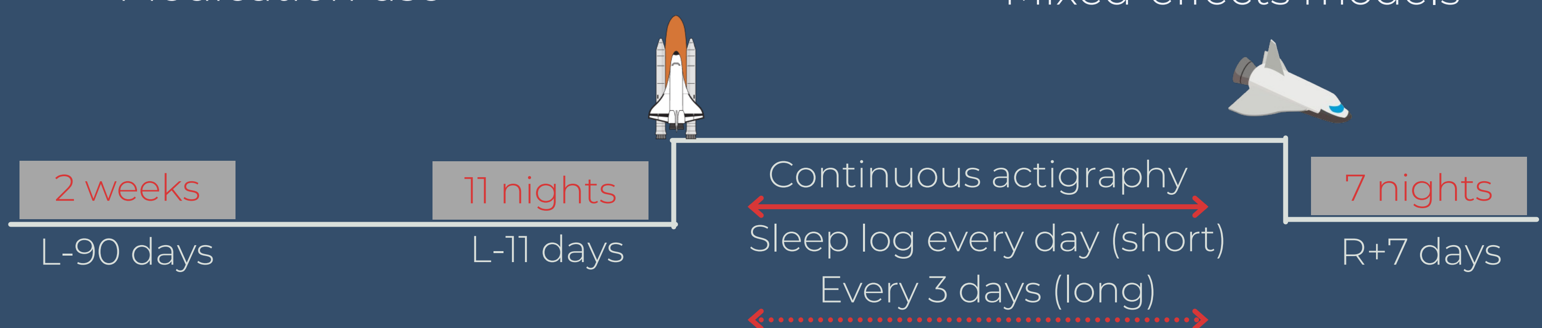
- Actigraphy
- Sleep logs
  - Medication use

Circadian phase estimation

- Circadian performance simulation software (CPSS)
  - Estimate of CBTmin
  - Actigraphy/light input
  - Jewett-Kronauer model

Analysis

- Mixed-effects models



Spaceflight Actigraphy Study

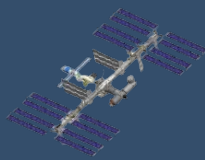
Background **Methods** Results Conclusions

SHORT DURATION CREW PARTICIPATION

n = 64 Crewmembers (10F)
n = 26 Flights
n = 4,173 Nights of data collection

Mean age: 46.4 +/- 4.5 y

Average inflight nights per crewmember 13.2 +/- 1.7



LONG DURATION CREW PARTICIPATION

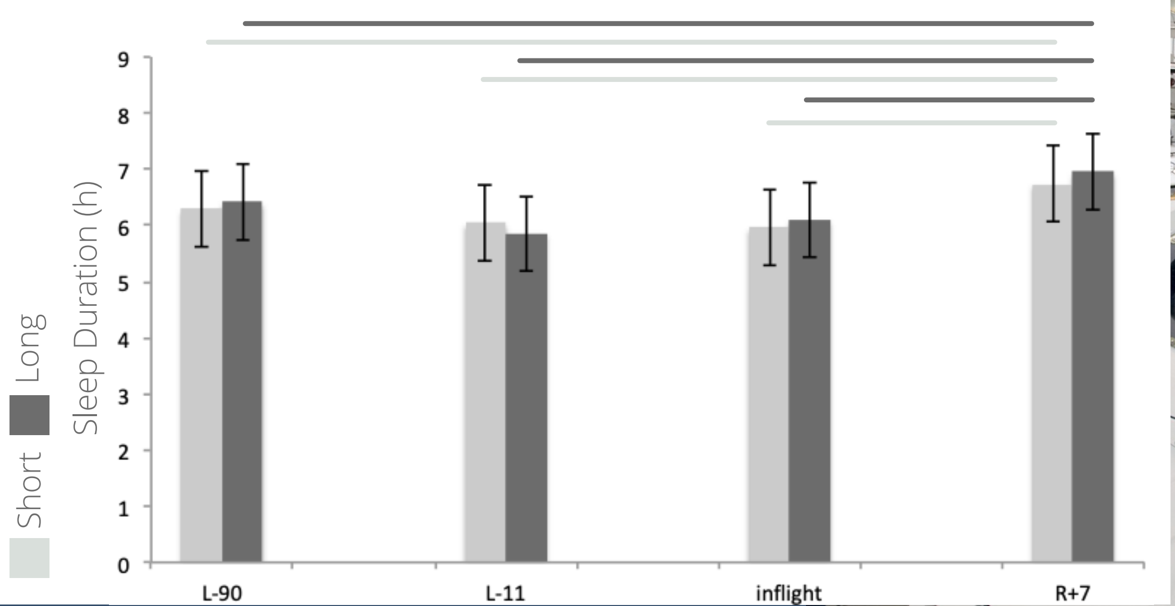
n = 21 Crewmembers (6F)
n = 13 Flights
n = 3,248 Nights of data collection

Mean age: 46.7 +/- 3.9 y

Average inflight nights per crewmember 155 +/- 39

Note: Crews scheduled for 8.5 h sleep

Sleep duration is shorter in space relative to on Earth

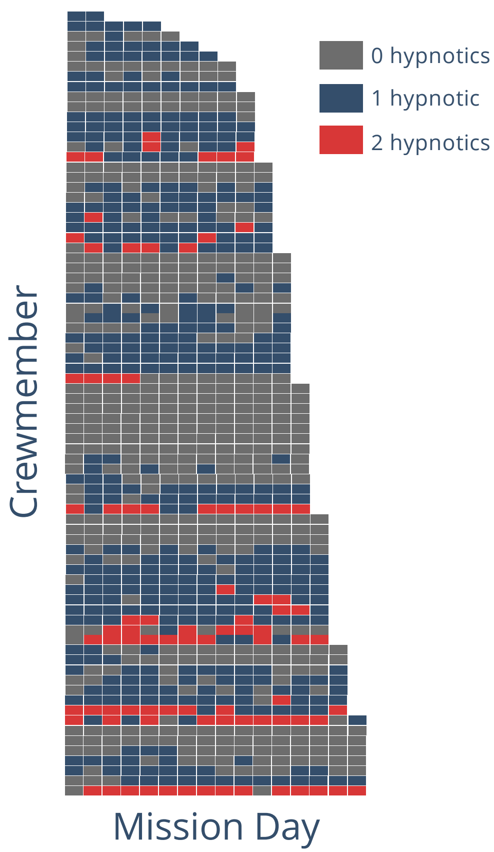


Barger *et al.* 2014 *Lancet Neurology*

Spaceflight Actigraphy Study

Background Methods Results Conclusions

Photo credit: www.nasa.gov



Hypnotic use

- **78% of participants used hypnotics at least once**
- **Hypnotics used on 52% of all nights in flight**
- **Crew used more than one dose on 18% of nights**

Barger *et al*. 2014 *Lancet Neurology*

Spaceflight Actigraphy Study

Background Methods Results Conclusions

Photo credit: www.canva.com

Effect of hypnotic use on sleep outcomes

	Nights with Hypnotics	Nights without Hypnotics
Sleep duration (h)	6.0 (0.6)	5.8 (0.9)
Latency (m)	22 (17)	33 (27)
Alertness	66 (16)	58 (20)
Sleep efficiency (%)	88 (6)	87 (7)
Sleep quality	66 (14)	58 (20)

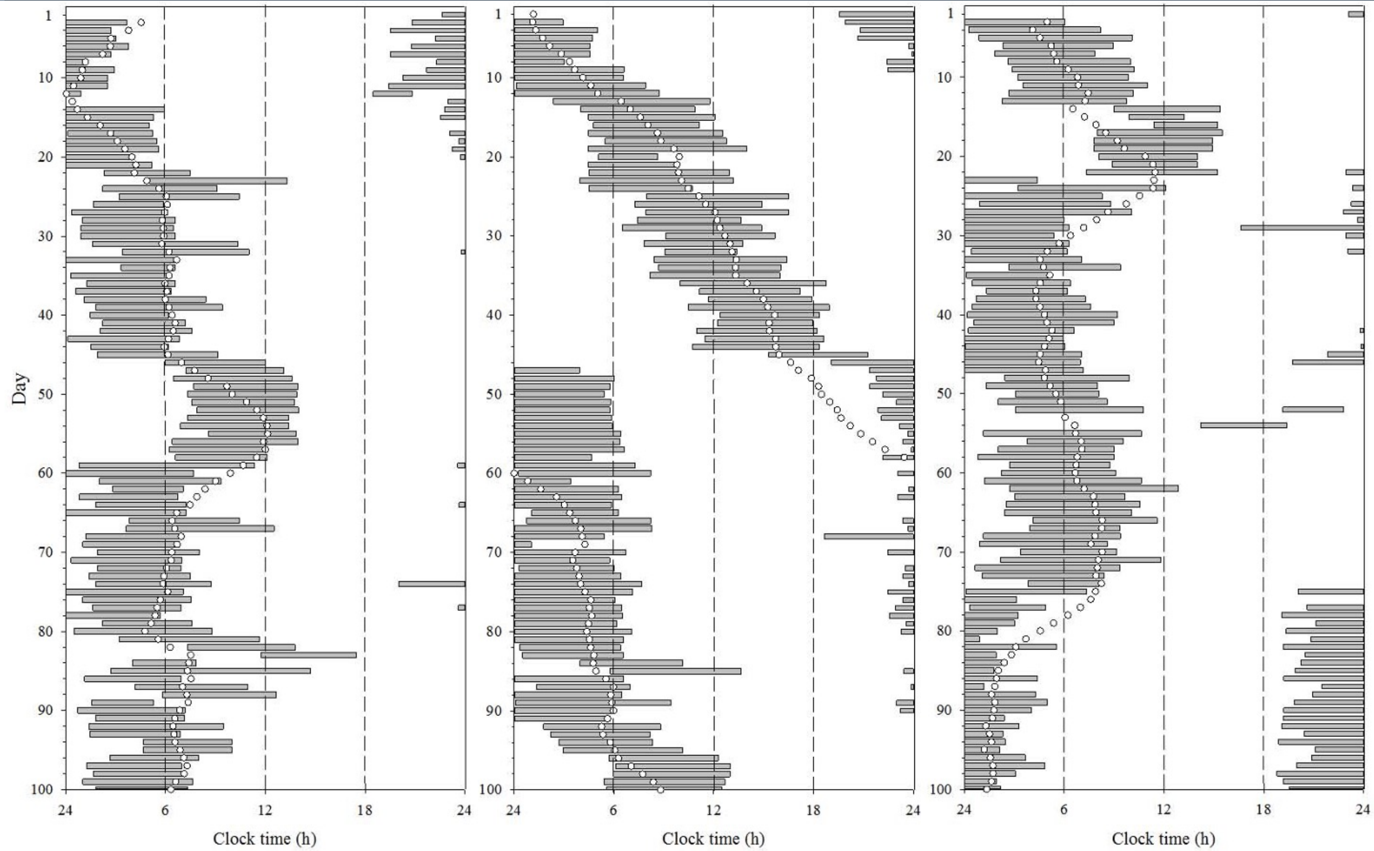
Barger *et al*. 2014 *Lancet Neurology*

Spaceflight Actigraphy Study

Background Methods Results Conclusions

Photo credit: www.nasa.gov

Circadian Misalignment during 20% of Nights



Spaceflight Actigraphy Study

Background Methods **Results** Conclusions

Consequences of Circadian Misalignment

	Aligned	Misaligned
Sleep duration (h)	6.4 (1.2)	5.5 (1.2)
Latency (m)	10 (15)	13 (25)
# wakings	1.7 (1.9)	1.8 (1.8)
Sleep efficiency (%)	89 (7)	90 (7)
Sleep quality	67 (18)	60 (21)

Flynn-Evans *et al*. 2016 *Nature Microgravity*

Spaceflight Actigraphy Study

Background Methods Results Conclusions

Photo credit: www.nasa.gov

Medication use Increased during Circadian Misalignment

- **Sleep medication reported on 24% of misaligned nights and 11% of aligned nights**
- **Any medication reported on 63% of misaligned nights and 49% of aligned nights**

Are humans capable of achieving sufficient sleep in space?

Photo credit: www.nasa.gov

Recent changes to spaceflight sleep

Sleep stations (crew quarters)

- Light and sound attenuation
- Some temperature control
- Airflow
- Privacy

Scheduling

- Nominal schedule 2130-0600 GMT, "fixed sleep"
- Restrictions on shifting schedules
- Weekends off, "free sleep"

Fatigue Management Office

- Sleep hygiene training
- Ground-based hypnotic trials

Photo credit: www.nasa.gov

KEY QUESTIONS:

Are humans capable of averaging more than 6 hours of sleep per night in space when the sleep environment is improved?

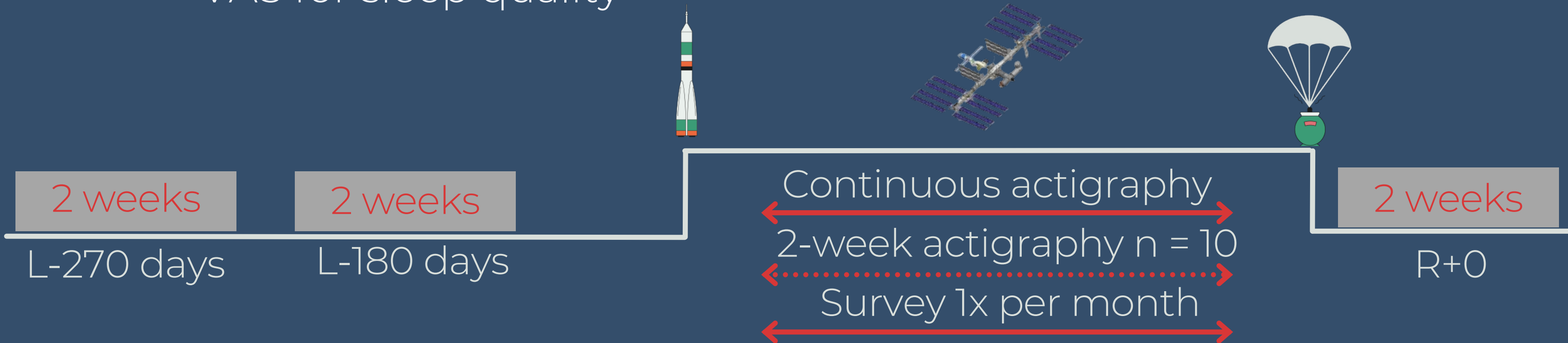
How much influence do schedule changes have on sleep duration?

Measures

- Actigraphy
  - Continuous
  - 2 weeks every 2 months
- Surveys
  - VAS for sleep quality

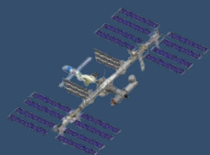
Analysis

- Mixed-effects models
- Analyzed until day 200



Spaceflight Actigraphy Study 2

Background **Methods** Results Conclusions



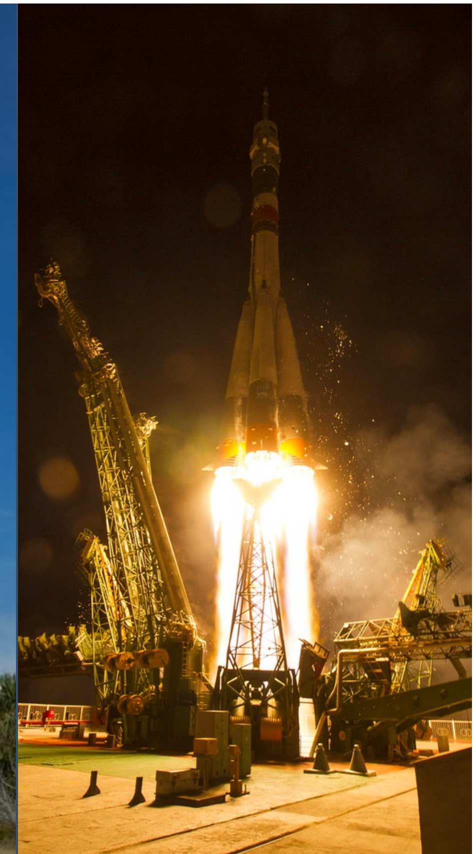
CREW PARTICIPATION

n = 19 Crewmembers (7F)
n = 2,137 Nights of data collection

Mean age: 45 +/- 7 y

Average mission duration 208 +/- 49

10 launched from Kazakhstan
9 launched from Florida



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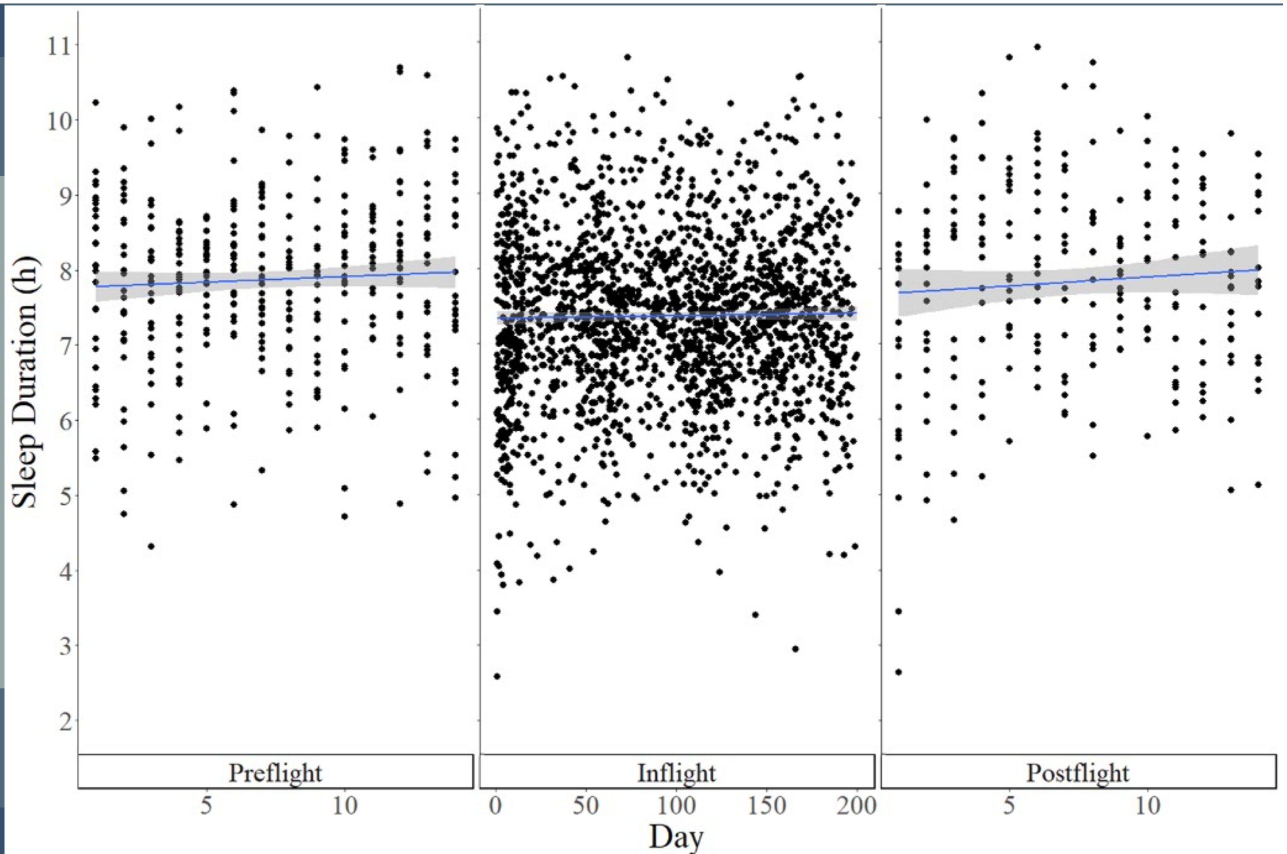
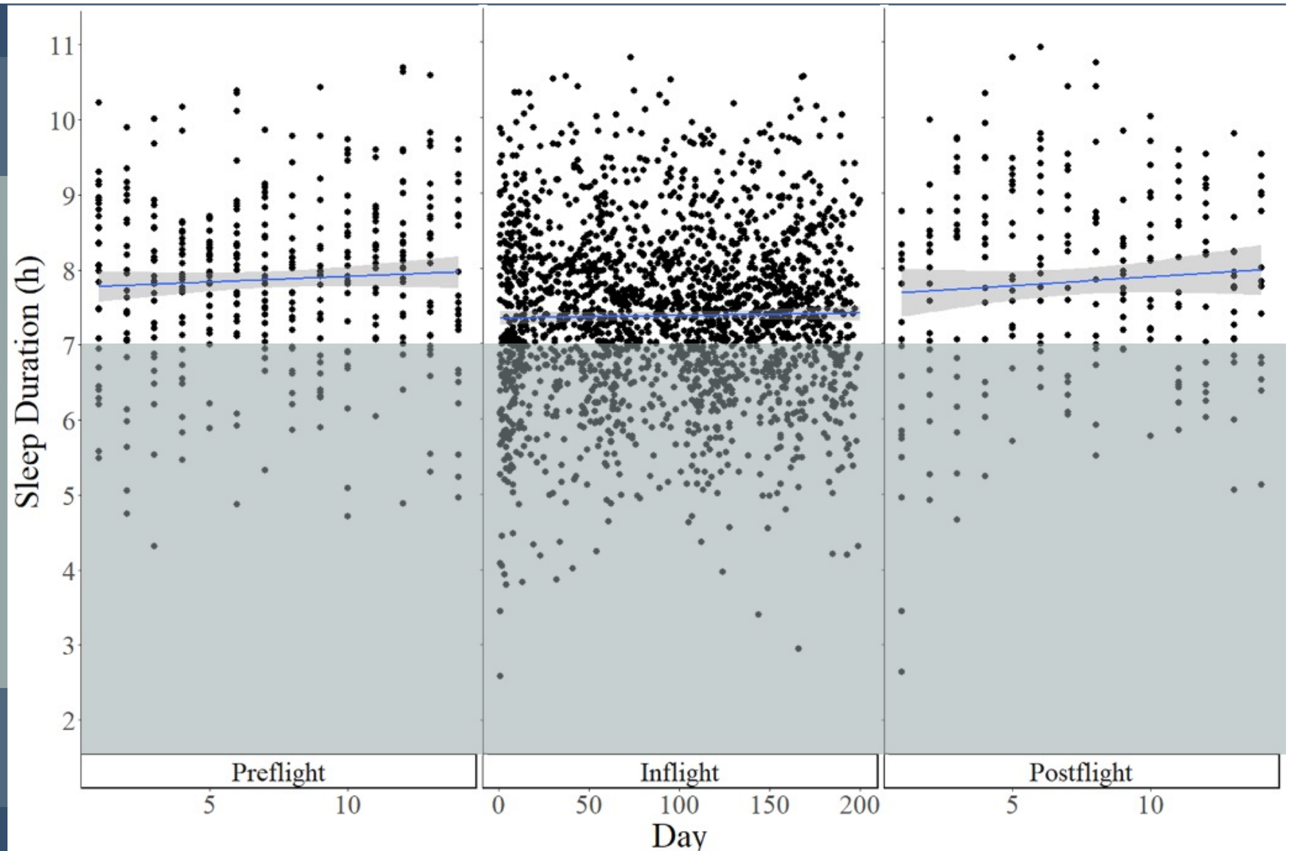
Humans can achieve recommended amounts of sleep in space



Spaceflight Actigraphy Study 2

Background Methods Results Conclusions

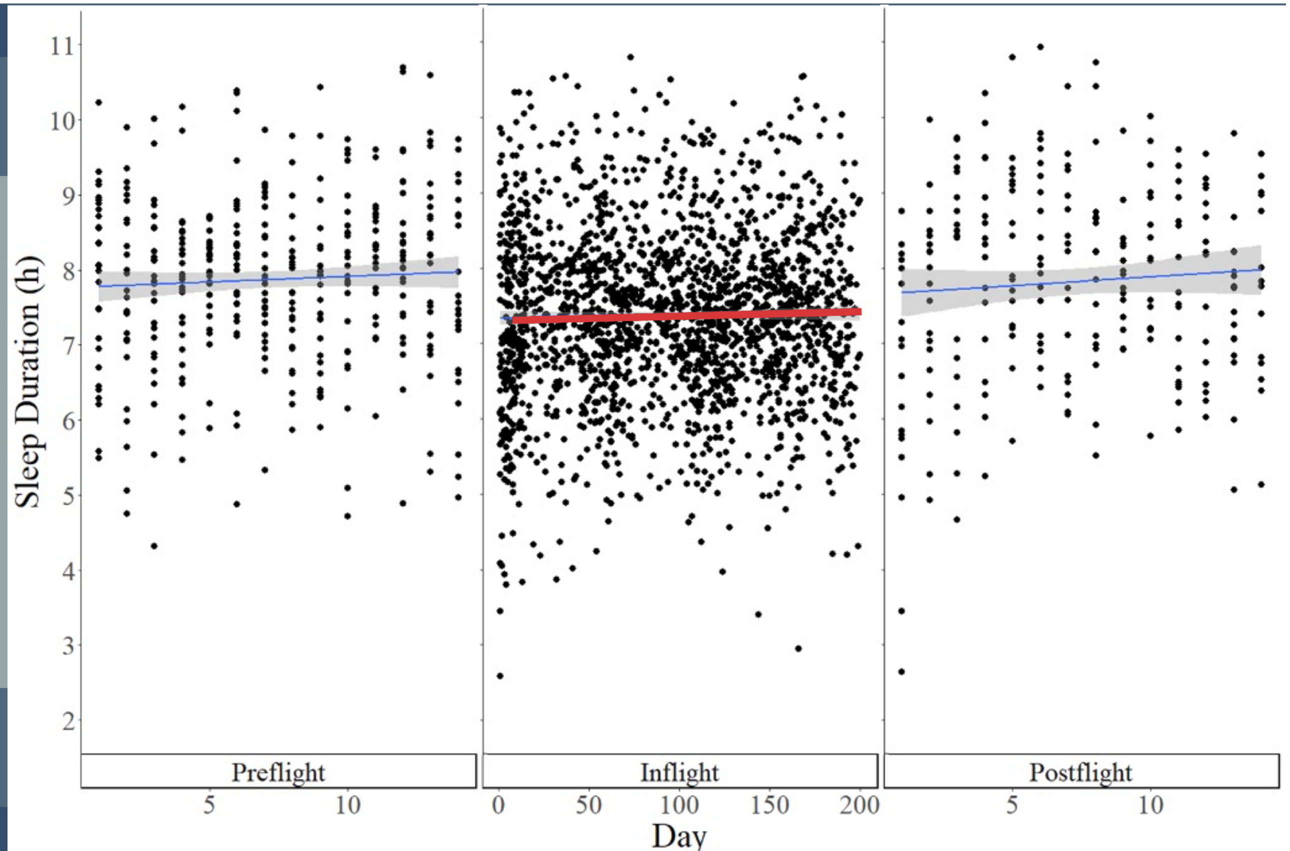
Humans can achieve recommended amounts of sleep in space



Spaceflight Actigraphy Study 2

Background Methods Results Conclusions

Sleep duration is stable over time with appropriate countermeasures



Spaceflight Actigraphy Study 2

Background Methods Results Conclusions

Changes in Sleep Outcomes

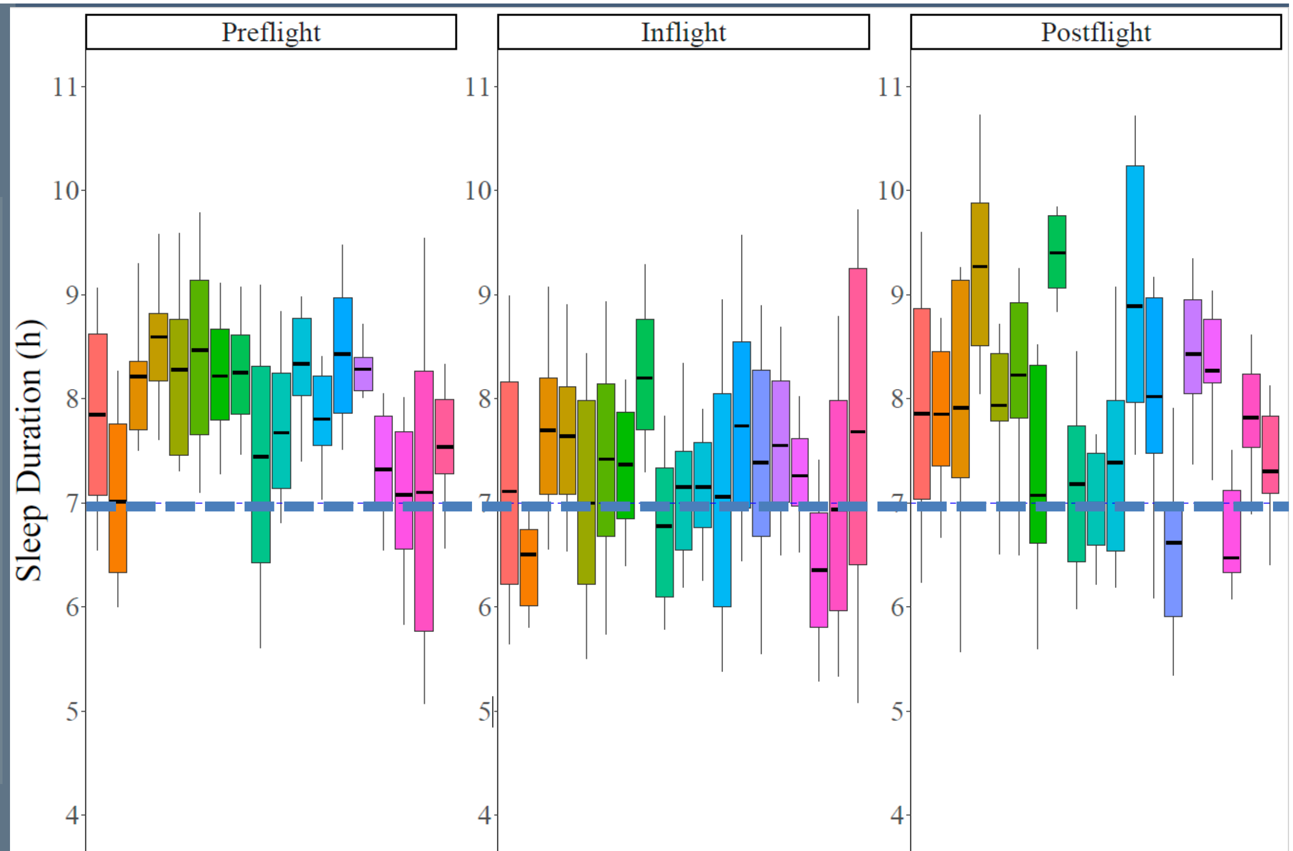
	Preflight	Inflight	Postflight
Latency (m)	11 (9)	8 (6)	9 (7)
WASO (m)	46 (16)	30 (8)	49 (16)
# wakings	29 (9)	16 (3)	28 (8)
Sleep efficiency (%)	85 (6)	89 (3)	84 (6)
Sleep quality	27 (14)	27 (16)	26 (15)

Spaceflight Actigraphy Study 2

Background Methods Results Conclusions

Photo credit: www.nasa.gov

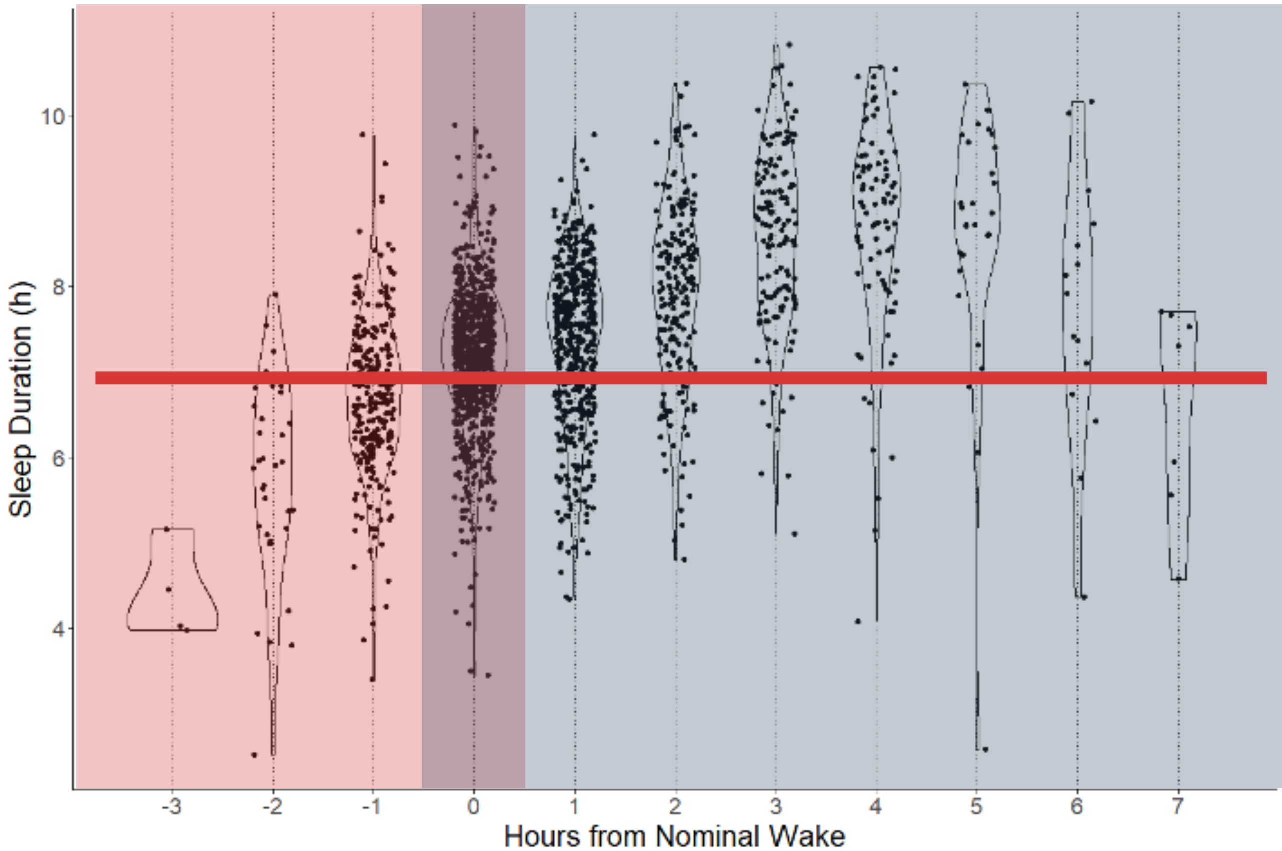
Habitual sleep duration is >7 h per night



Spaceflight Actigraphy Study 2

Background Methods Results Conclusions

Impact of shifting sleep timing



Spaceflight Actigraphy Study 2

Background Methods Results Conclusions

Evidence of abnormal entrainment?

	Weekdays	Weekends
Sleep duration	7.1 (0.5)	7.6 (0.06)
Wake time (hh:mm)	6:39 (0:41)	7:40 (0:59)
Latency (m)	9 (6)	8 (6)
WASO (m)	29 (8)	32 (9)
Sleep efficiency (%)	89 (3)	89 (3)

Photo credit: www.nasa.gov

Actigraphy Study Conclusions

HUMANS CAN ACHIEVE RECOMMENDED AMOUNTS OF SLEEP IN SPACE

Appropriate sleep environment
Stable schedules

NEED TO UNDERSTAND HOW SLEEP RELATES TO OTHER OUTCOMES

Performance and sleepiness

- Jones et al. 2022 tie shorter sleep to poorer performance

Medication use

OUTSTANDING QUESTIONS

Do astronauts achieve stable phase entrainment with appropriate lighting (Lockley, Brainard)?
Does sleep architecture change in space?

Is sleep architecture different in space relative to on Earth?

Photo credit: www.nasa.gov

Prior studies reported mixed results

REM

- One study suggested REM increases in space (Frost et al. 1978)
- One found an increase in eye movements during REM in space (Quadens and Green 1984)

Slow wave sleep

- Two studies found increased SWS in space (Frost et al. 1978, Monk et al. 1998)
- Two studies found decreased SWS in space (Gundel et al. 1997, Dijk et al. 2001)

Three studies found a redistribution of REM/SWS (Gundel et al. 1993, Gundel et al. 1997, Stoilova et al. 2000)

*All small sample sizes

Re-analysis of Two Studies

Mir

- Data previously collected, but not analyzed
- REM/NREM over long-duration spaceflight

Space Shuttle (Neurolab)

- Sleep architecture characteristics published previously
- Sleep microarchitecture not previously explored

Evaluation of sleep architecture changes during long-duration spaceflight

Sleep assessed with NightCap (EOG, EMG)

- Assessment of REM/NREM

Re-analysis of Mir data, N = 5

- Participants spent ~179 days in space
- Mean age 43.5 (39.3 – 49.6)
- n = 113 nights preflight, 68 nights inflight, 61 nights post-flight

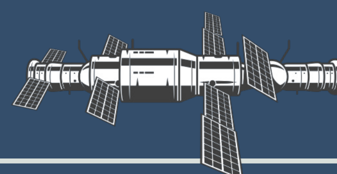
NightCap System

Robert Stickgold
Harvard Medical School

Oliver Piltch
Harvard College
Columbia Medical School

Analysis

- Mixed-effects models



~11 nights each	~11 nights each	~11 nights each	~11 nights each	~11 nights n=2	~11 nights each	~11 nights n=2
L-140-199	L- 42-161	Nights 23-51	Nights 79-135	Nights 163-174	R+ 3-17	R+ 43-99

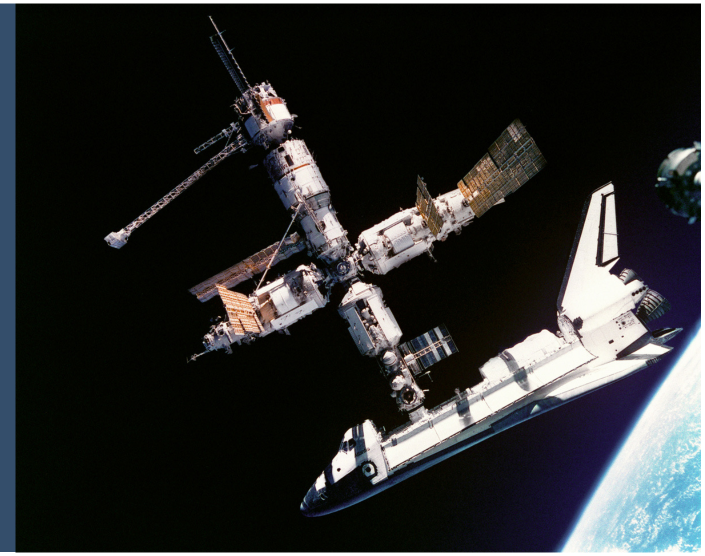
Spaceflight Sleep Architecture

Background **Methods** Results Conclusions

Photo credit: www.nasa.gov

Mir Re-analysis

- Fairly stable schedules
- Large number of nights inflight
- Individual differences apparent



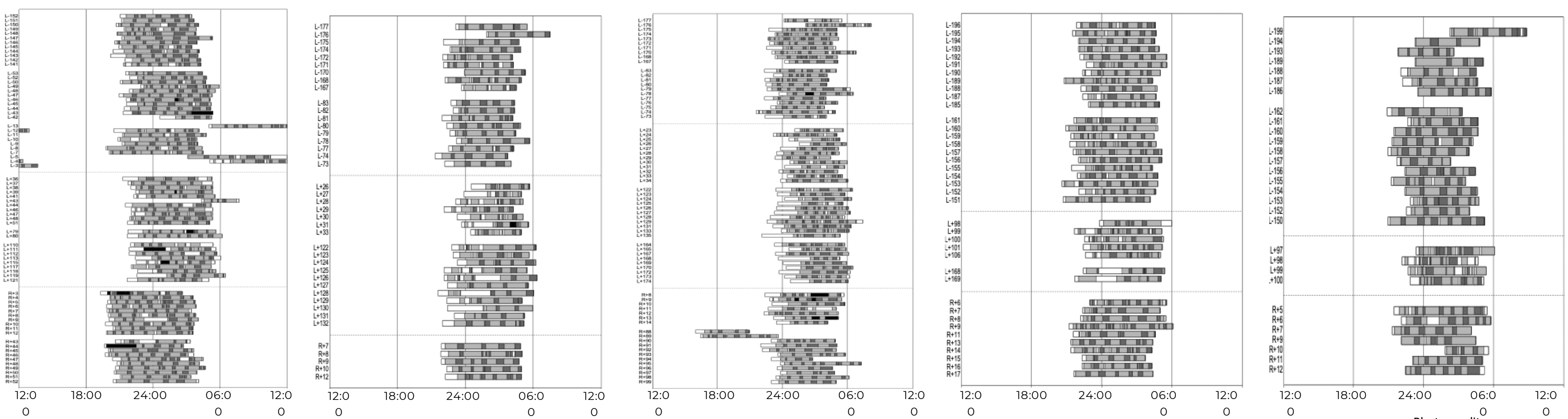
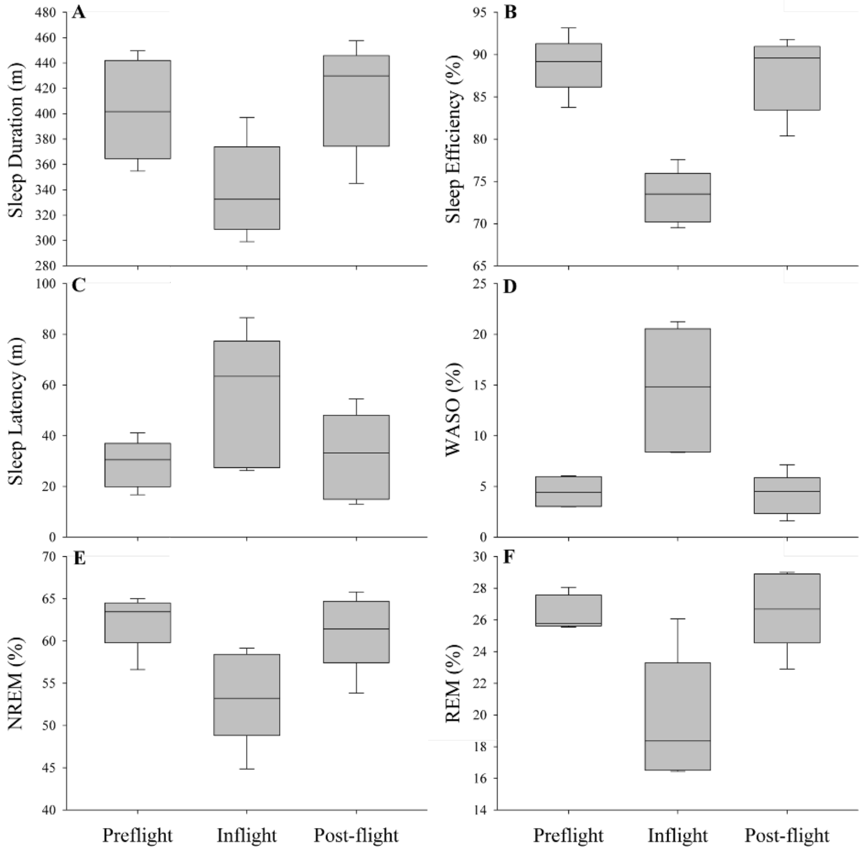


Photo credit: www.nasa.gov

Changes in sleep during spaceflight

- Sleep opportunity was the same on Earth compared to in space



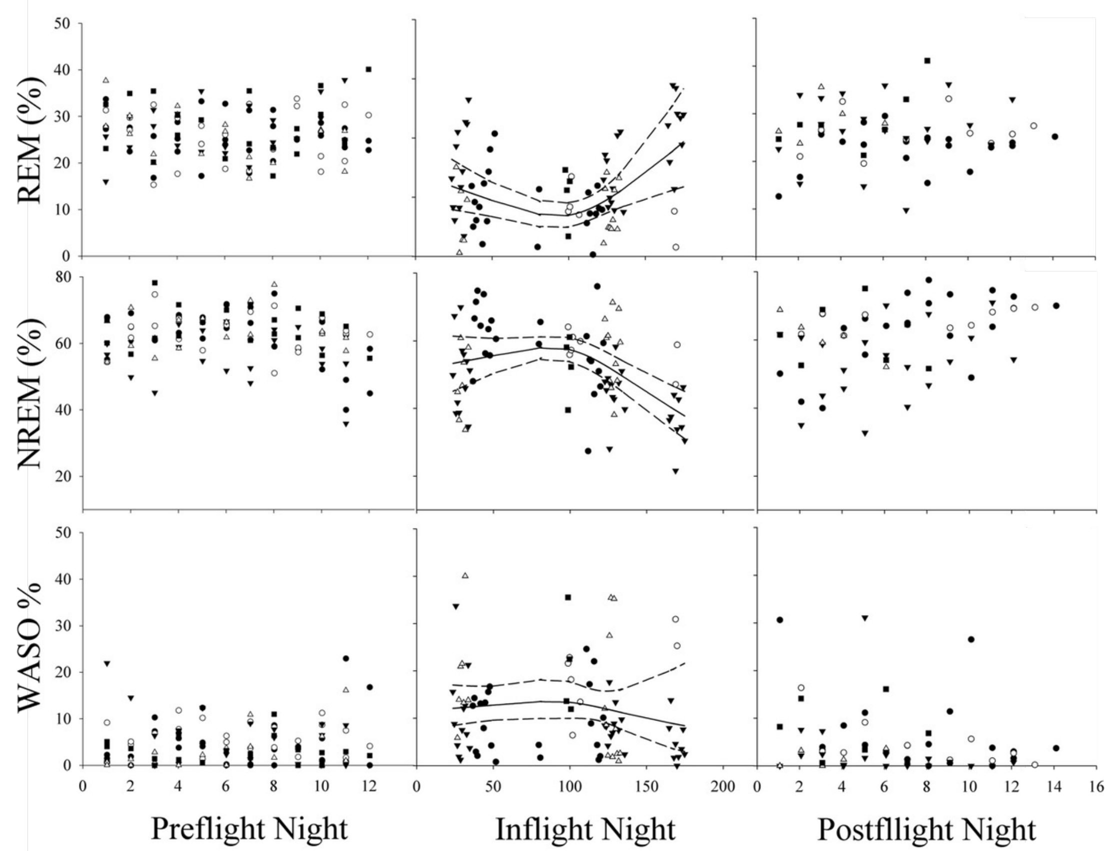
Spaceflight Sleep Architecture

Background Methods **Results** Conclusions

Photo credit: www.nasa.gov

Longitudinal changes over time in space

- Sleep opportunity increased during spaceflight
- Sleep latency increased during spaceflight
    - Reduced sleep efficiency over time
- REM recovers to near preflight levels at the expense of NREM
    - Potential for REM homeostasis?



Spaceflight Sleep Architecture

Background Methods **Results** Conclusions

Hypothesis: Sleep spindle density and slow wave amplitude in N2/N3 will be decreased in space compared to on Earth

- Data mining of Neurolab missions (Dijk et al. 2001)

Am J Physiol Regulatory Integrative Comp Physiol
281: R1647–R1664, 2001.

Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights

DERK-JAN DIJK,[1] DAVID F. NERI,[1,2] JAMES K. WYATT,[1] JOSEPH M. RONDA,[1] EYMARD RIEL,[1] ANGELA RITZ-DE CECCO,[1] ROD J. HUGHES,[1] ANN R. ELLIOTT,[3] G. KIM PRISK,[3] JOHN B. WEST,[3] AND CHARLES A. CZEISLER[1]
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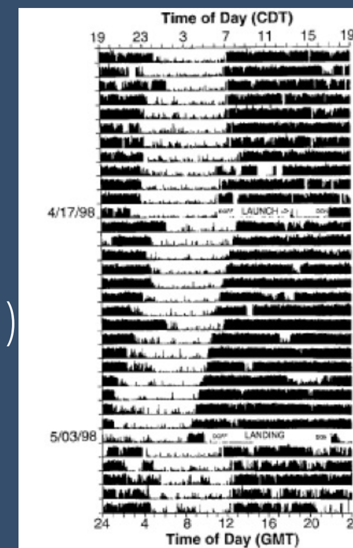
Spaceflight Sleep Architecture

Background Methods Results Conclusions

Standard Polysomnography

- Spindle characteristics (e.g., frequency, density)
  - Slow spindles 9-12 Hz (associated with word-pair retention)
  - Fast spindles 12-15 Hz (associated with motor learning)
- Slow wave characteristics (e.g., amplitude, density)



Analysis

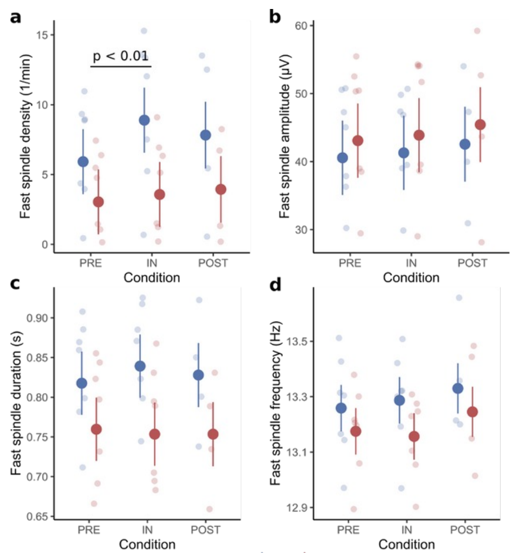
- Mixed-effects models

n = 4

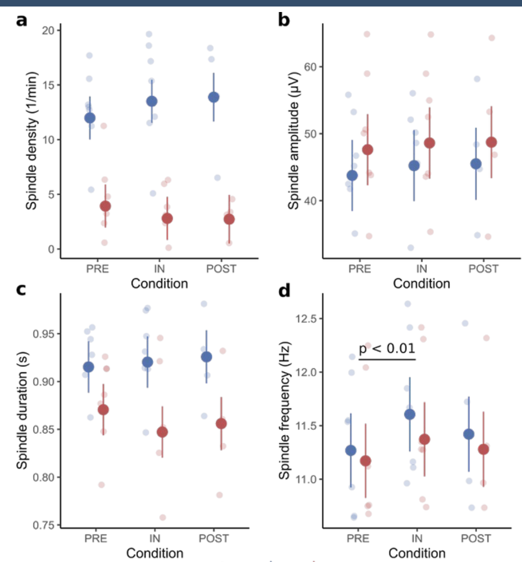
Spaceflight Sleep Architecture

Background **Methods** Results Conclusions

Fast spindle density increased
Slow spindle frequency increased



Fast Spindles



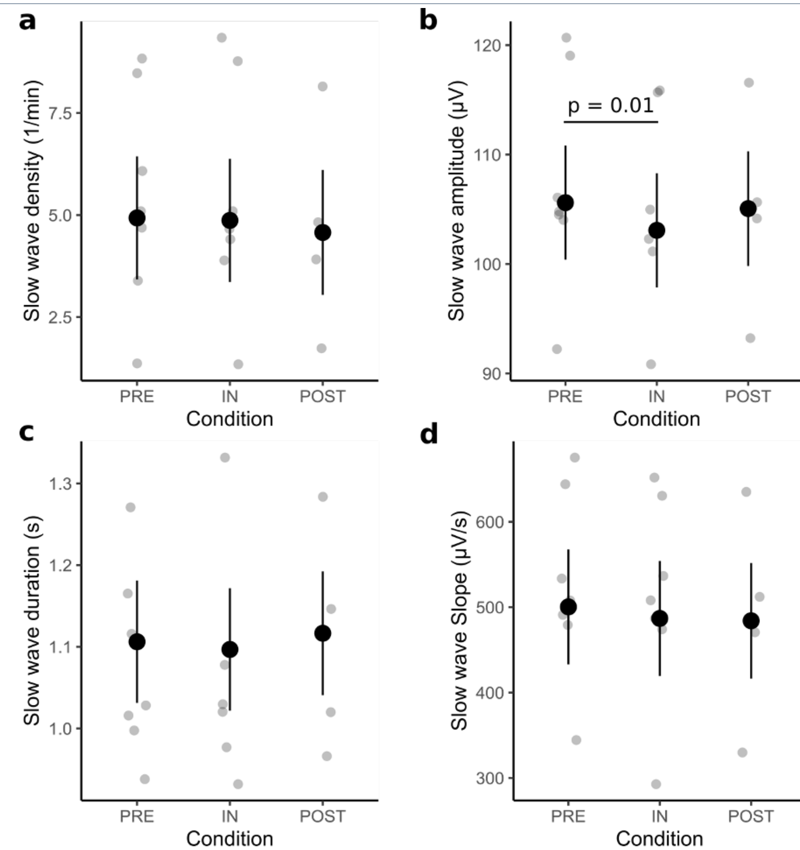
Slow Spindles

Koller *et al. Nature Microgravity* 2021

Photo credit: www.nasa.gov

Slow wave amplitude decreased during spaceflight

Koller *et al. Nature Microgravity* 2021



Spaceflight Sleep Architecture

Background Methods Results Conclusions

Photo credit: www.nasa.gov

Sleep Architcture Conclusions

REDUCED SLEEP DURATION IN SPACE

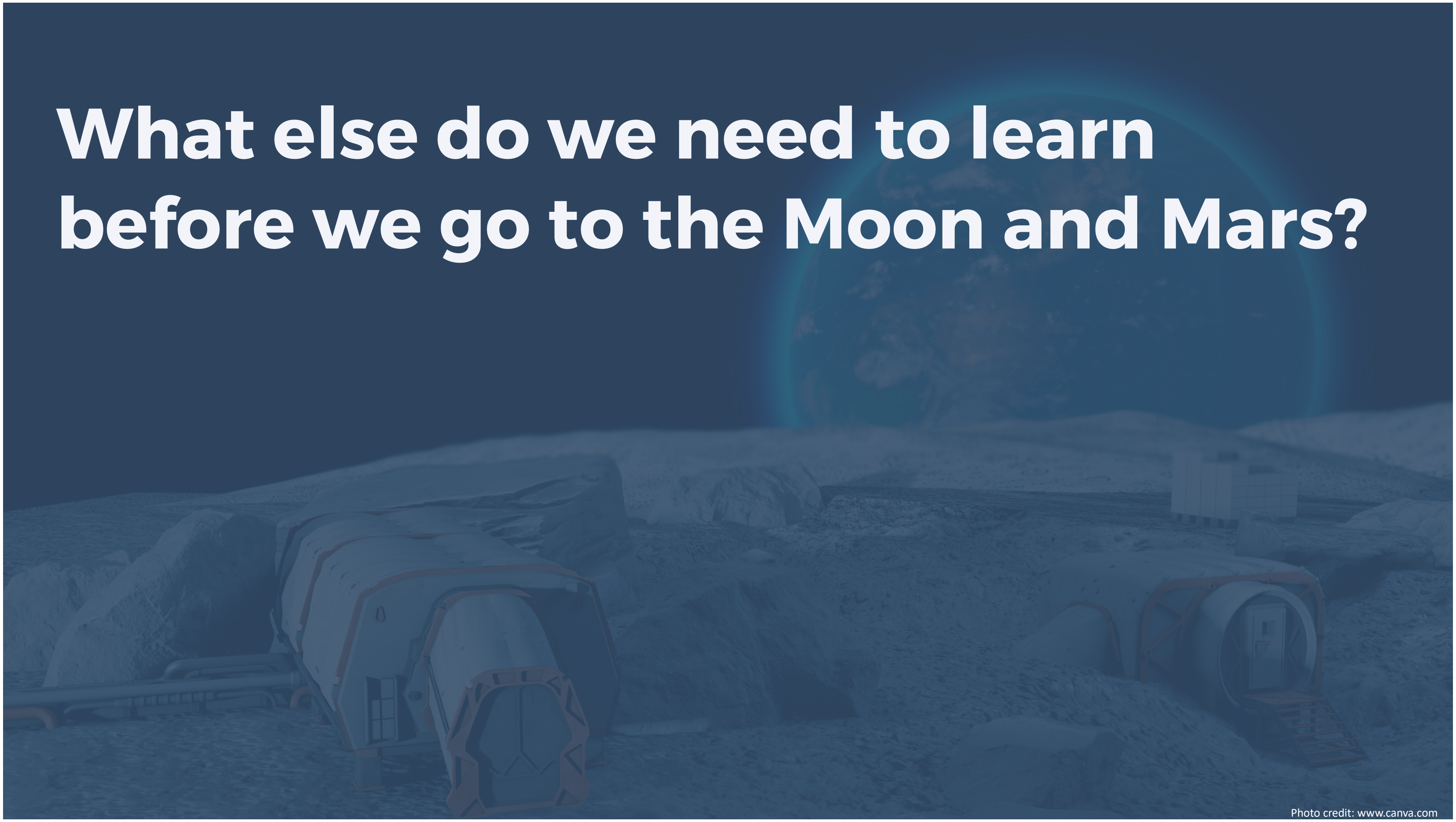
Associated with a reduction in REM and NREM sleep
Recovery of REM sleep with (long) time

SLEEP MICRO-ARCHITECTURE ALTERED IN SPACE

Increased fast spindle density could relate to learning new motor skills while in space
Reduced slow wave amplitude may reflect changes in the glymphatic system during spaceflight

MORE STUDIES NEEDED

Require studies in environments that are not stressful
Studies in environments that have optimized sleep environment and stable schedules


What else do we need to learn
before we go to the Moon and Mars?
Photo credit: www.canva.com

From Low-Earth Orbit to the Moon to Mars

INTERNATIONAL SPACE STATION

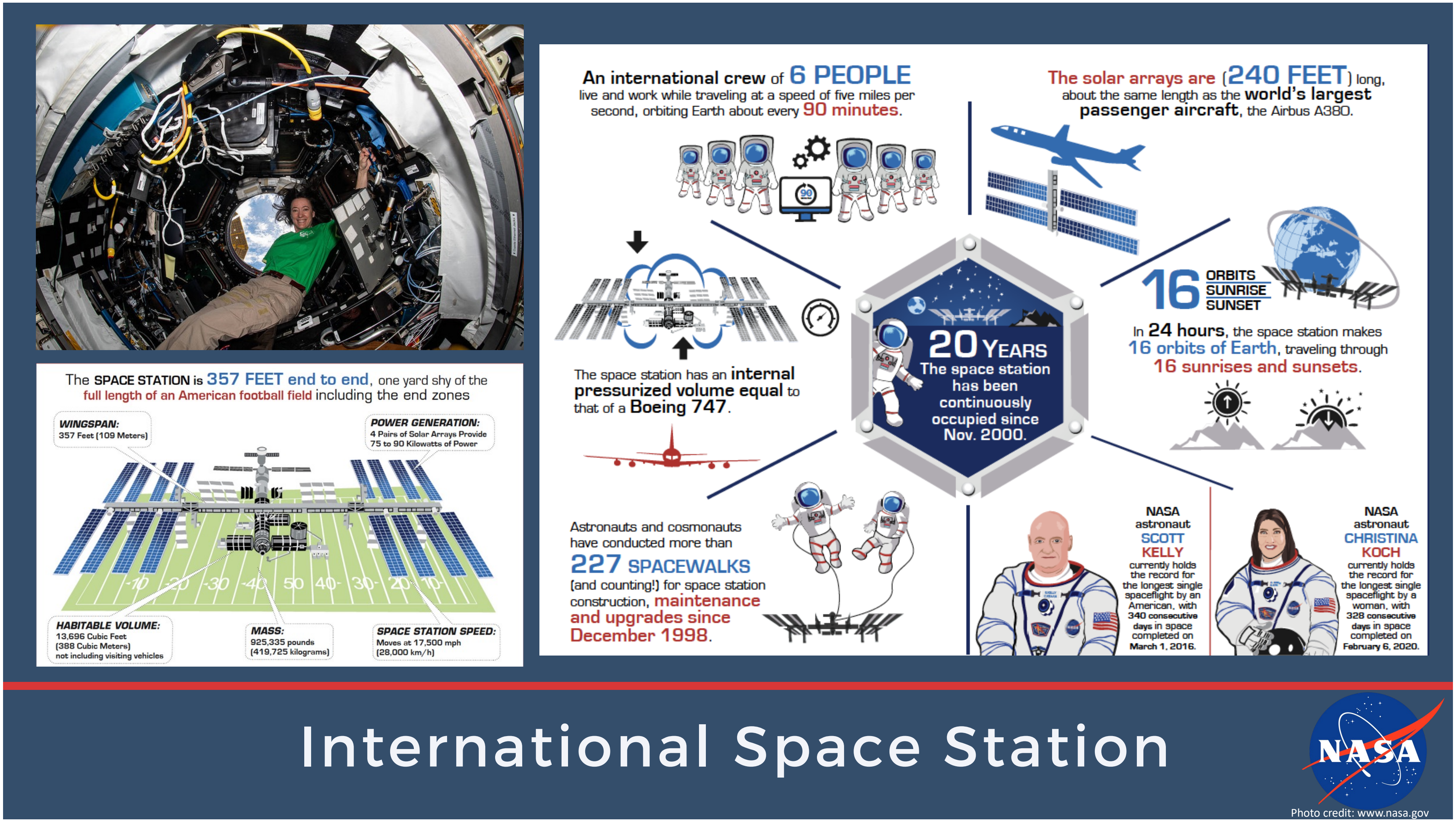
ARTEMIS LUNAR EXPEDITIONS

MARS MISSIONS

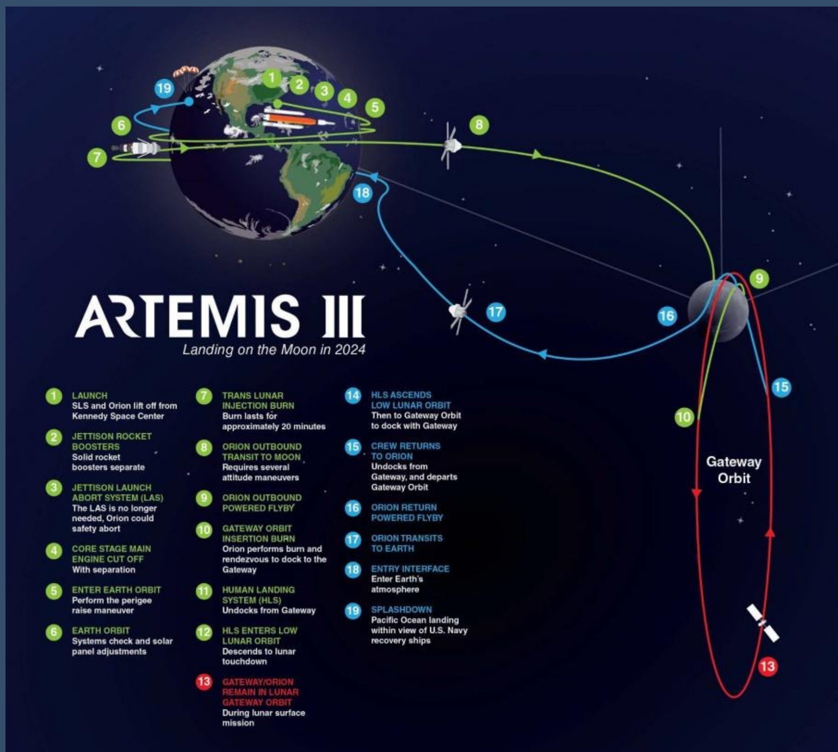
NASA Spaceflight Missions

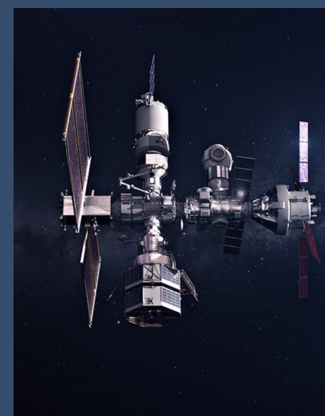
NASA

Photo credit: www.nasa.gov



The SPACE STATION is 357 FEET end to end, one yard shy of the full length of an American football field including the end zones
WINGSPAN: 357 Feet (109 Meters)
POWER GENERATION: 4 Pairs of Solar Arrays Provide 75 to 90 Kilowatts of Power
HABITABLE VOLUME: 13,696 Cubic Feet (388 Cubic Meters) not including visiting vehicles
MASS: 925,335 pounds (419,725 kilograms)
SPACE STATION SPEED: Moves at 17,500 mph (28,000 km/h)
An international crew of 6 PEOPLE live and work while traveling at a speed of five miles per second, orbiting Earth about every 90 minutes.
90
The solar arrays are (240 FEET) long, about the same length as the world's largest passenger aircraft, the Airbus A380.
The space station has an internal pressurized volume equal to that of a Boeing 747.
20 YEARS
The space station has been continuously occupied since Nov. 2000.
16 ORBITS SUNRISE SUNSET
In 24 hours, the space station makes 16 orbits of Earth, traveling through 16 sunrises and sunsets.
Astronauts and cosmonauts have conducted more than 227 SPACEWALKS (and counting!) for space station construction, maintenance and upgrades since December 1998.
NASA astronaut SCOTT KELLY currently holds the record for the longest single spaceflight by an American, with 340 consecutive days in space completed on March 1, 2016.
NASA astronaut CHRISTINA KOCH currently holds the record for the longest single spaceflight by a woman, with 328 consecutive days in space completed on February 6, 2020.
International Space Station
NASA
Photo credit: www.nasa.gov





GATEWAY

Space station orbiting the moon

HUMAN LANDING SYSTEM

Lunar lander transporting crews between Gateway and the lunar surface

SURFACE OPERATIONS

Lunar base

Artemis III: Lunar Surface

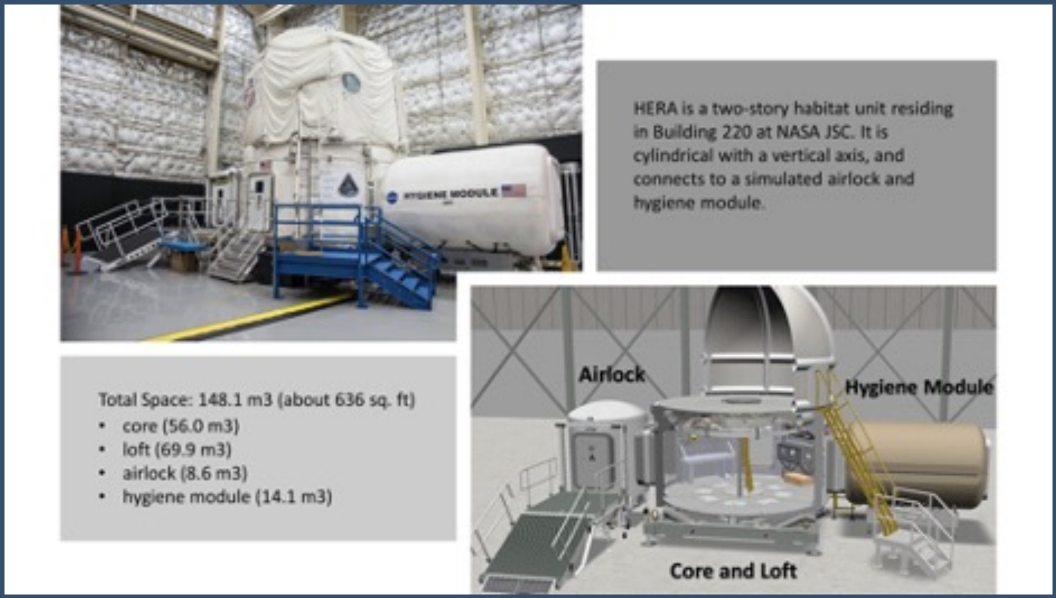
Photo credit: www.nasa.gov

Human Exploration Research Analog (HERA)

Analog Studies

-What characteristics are associated with resilient performance?

-How well do biomathematical models predict alertness and performance in an operational environment?



Flynn-Evans *et al*. 2020 *Sci Reports*

How do we prepare for Lunar Missions?

Photo credit: www.nasa.gov

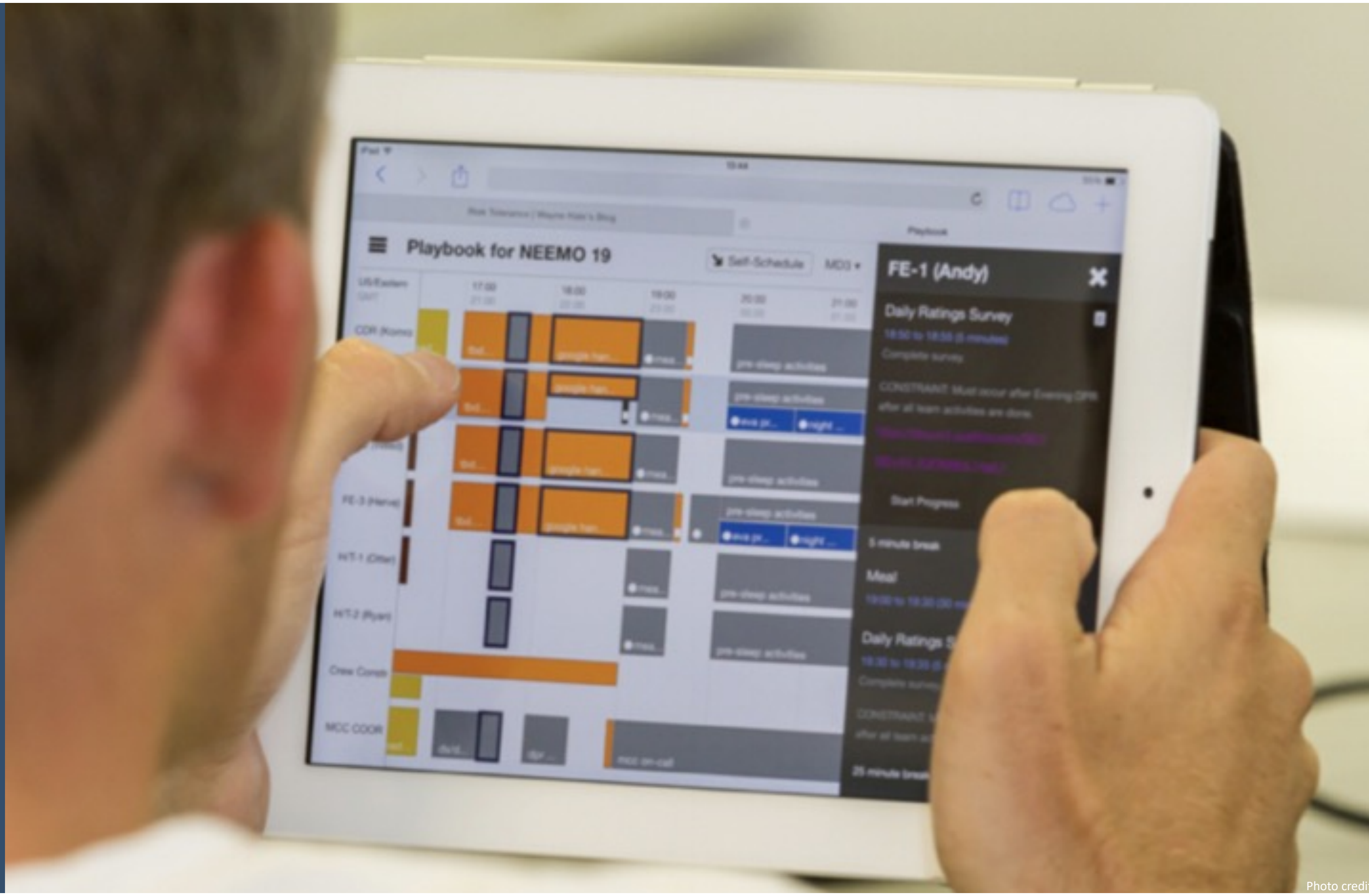


Photo credit: www.nasa.gov

Lunar Sleep and Performance Conclusions

POTENTIAL TOOL FOR DISCRIMINATING RESILIENT FROM NON-RESILIENT

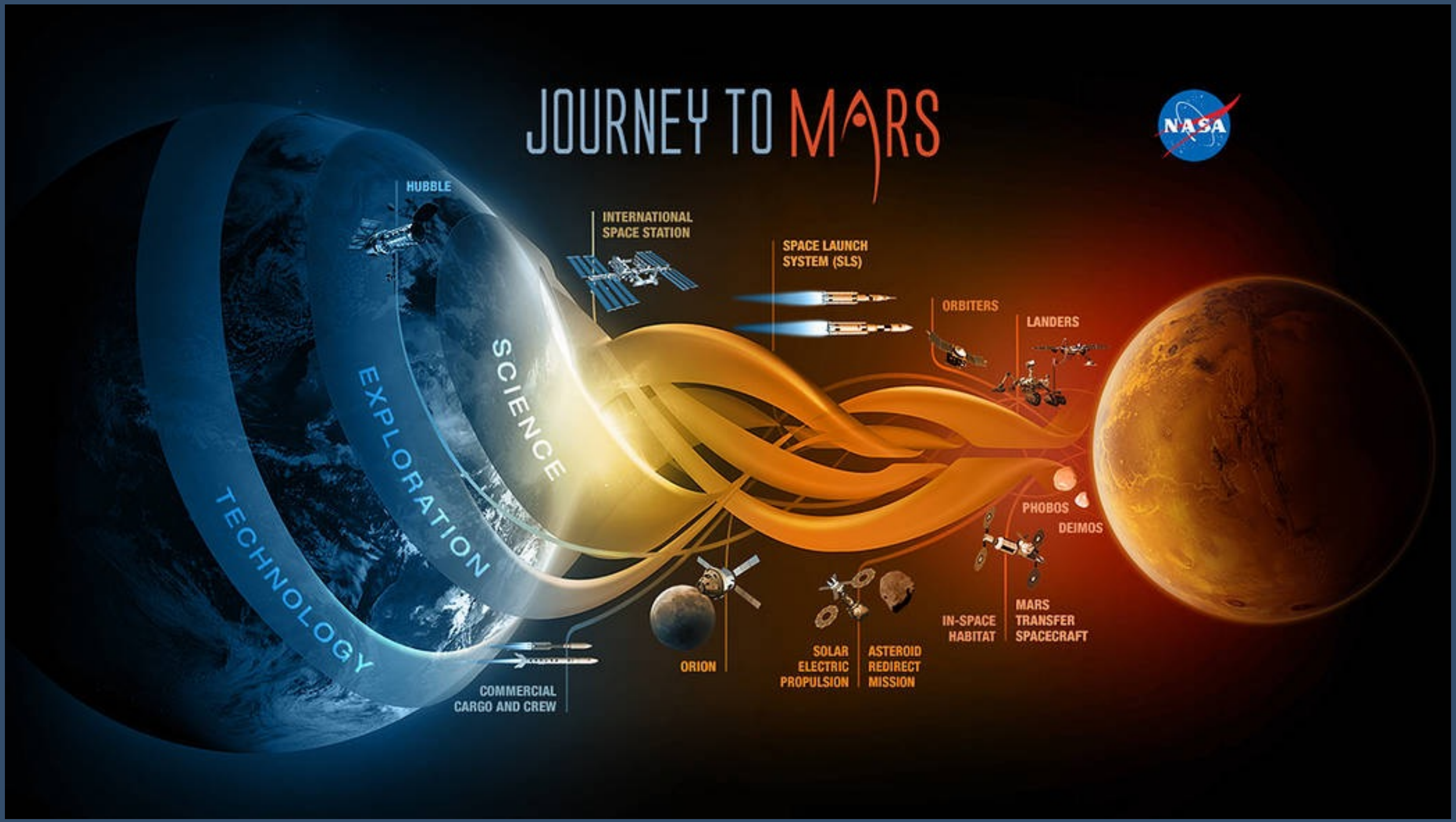
- May help operational personnel identify those at most risk of performance impairment due to chronic sleep loss

CONSIDERATIONS AND LIMITATIONS

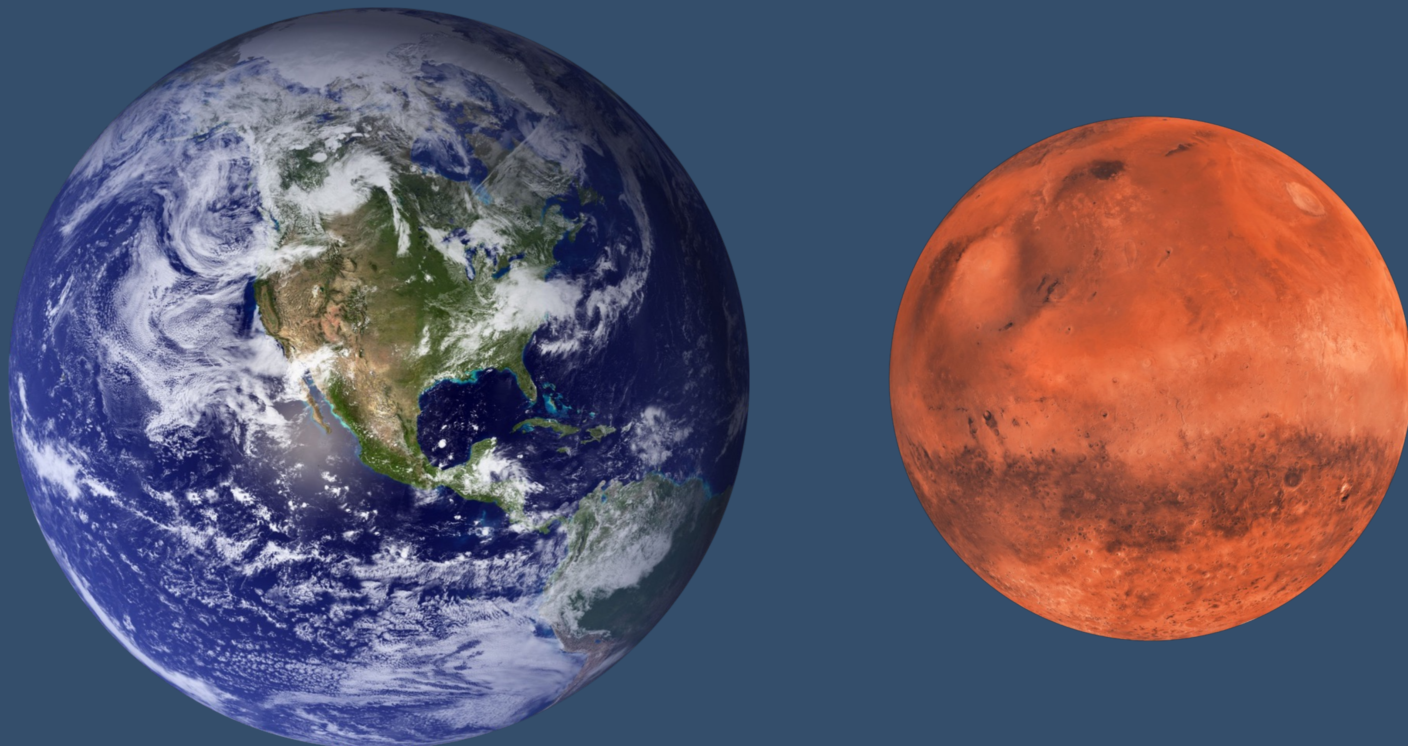
- Additional operational data needed
  - Additional mission scenarios
  - Larger n needed
  - Apply/compare to other cognitive domains-

-Models are reasonable at discriminating resilient and vulnerable overall, but daily/hourly predictions inaccurate

-Approach better at identifying resilient individuals, many "average" individuals included in "non-resilient"

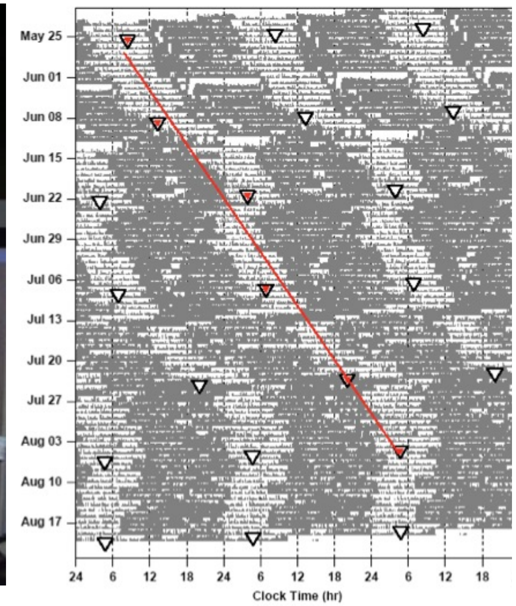


Mars Missions

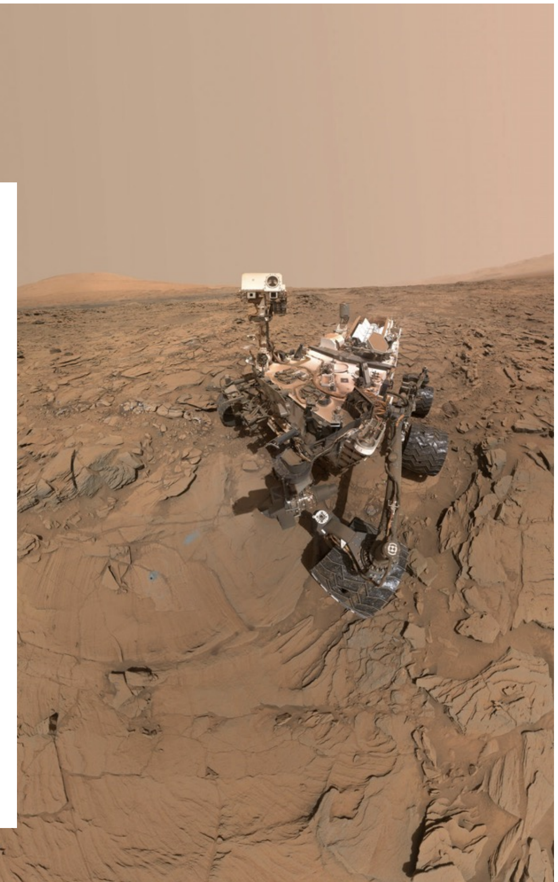


How do we prepare for Mars Missions?

We can shift to Mars time!



Barger *et al*. 2012 *SLEEP*



Circadian phase shifting studies

Photo credit: www.nasa.gov

What else are we studying?

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Future directions

ASSESS SLEEP ARCHITECTURE IN A LARGER SAMPLE

- More data needed to confirm spaceflight insomnia and to understand its consequences
- Assess sleep in a quality sleep environment without circadian misalignment
- Quantify impact of sleep quarters

ASSESS COUNTERMEASURES

- Scheduling interventions to minimize misalignment (Brainard, Lockley)
- Lighting on ISS to mitigate circadian misalignment
  - Assess adaptation to Mars Sol in space

ASSESS PERFORMANCE INFLIGHT

Is sleep loss associated with poorer performance?

THANK YOU!

Photo credit: Erin Flynn-Evans

THANK YOU!

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