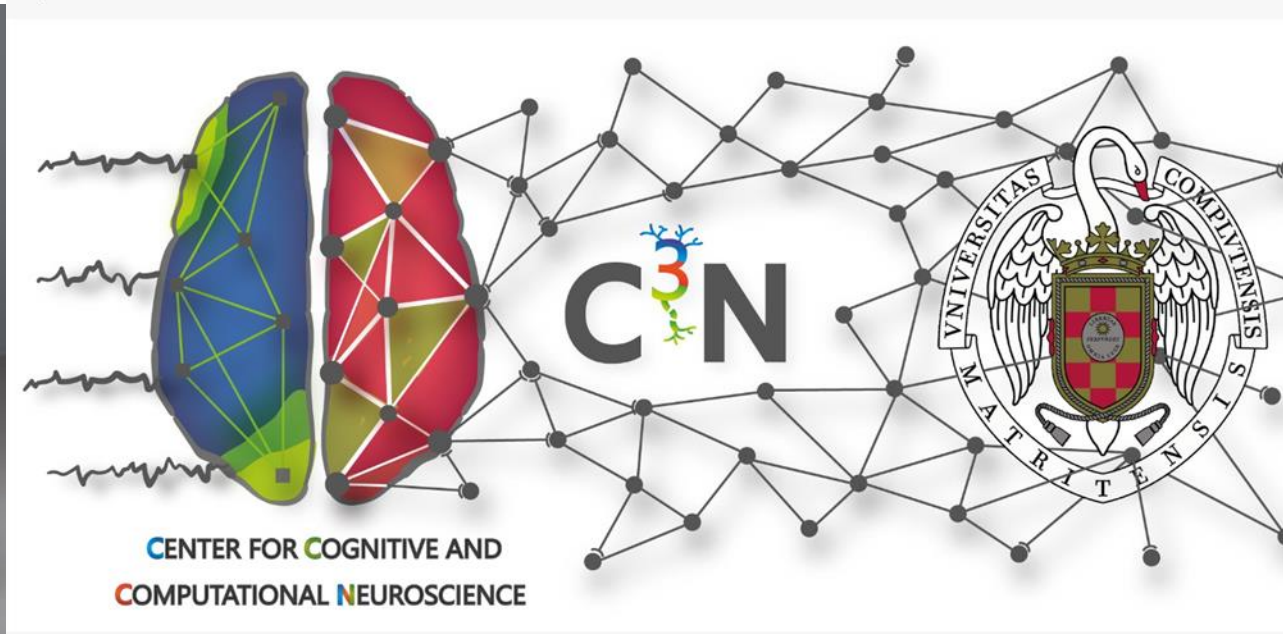


# Brain Anatomico-Functional Changes Associated with Spaceflights



Fernando Maestú PhD

Director of the Center for Cognitive and Computational Neuroscience





## Risk factors associated with Spaceflights

1. Isolation, Radiation, Microgravity
2. SANS / Cognitive performance

## Brain Morphological and functional Changes associated with Spaceflights

1. Volumetric Changes
2. Structural connectivity changes
3. Functional MRI

## Brain Oscillatory activity changes

1. Brief history of EEG in the Space
2. Potential Technical Issues
3. Alpha power and connectivity changes after spaceflights
4. New avenues and analysis





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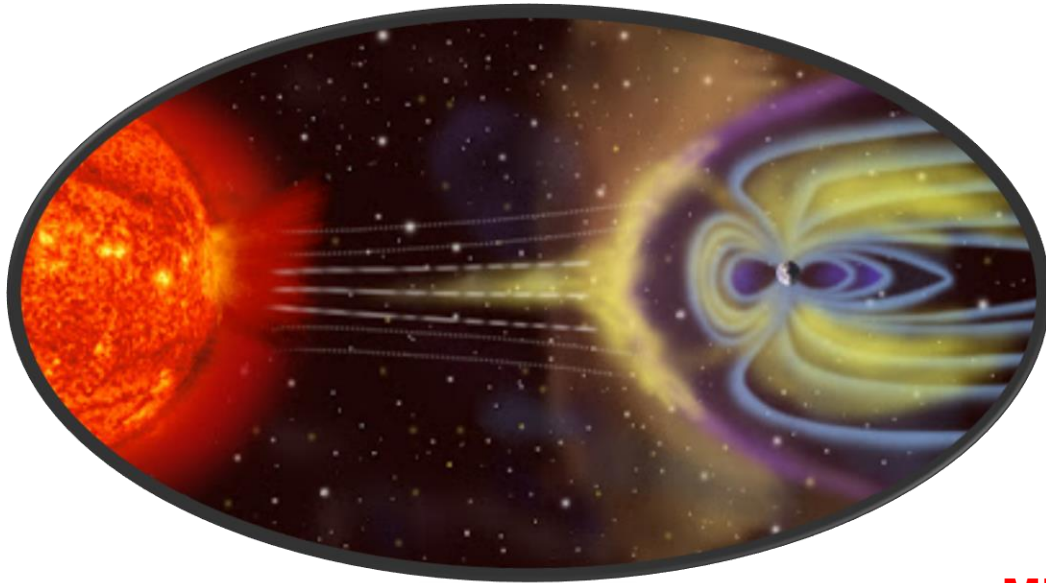
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## RISK FACTORS

### RADIATION



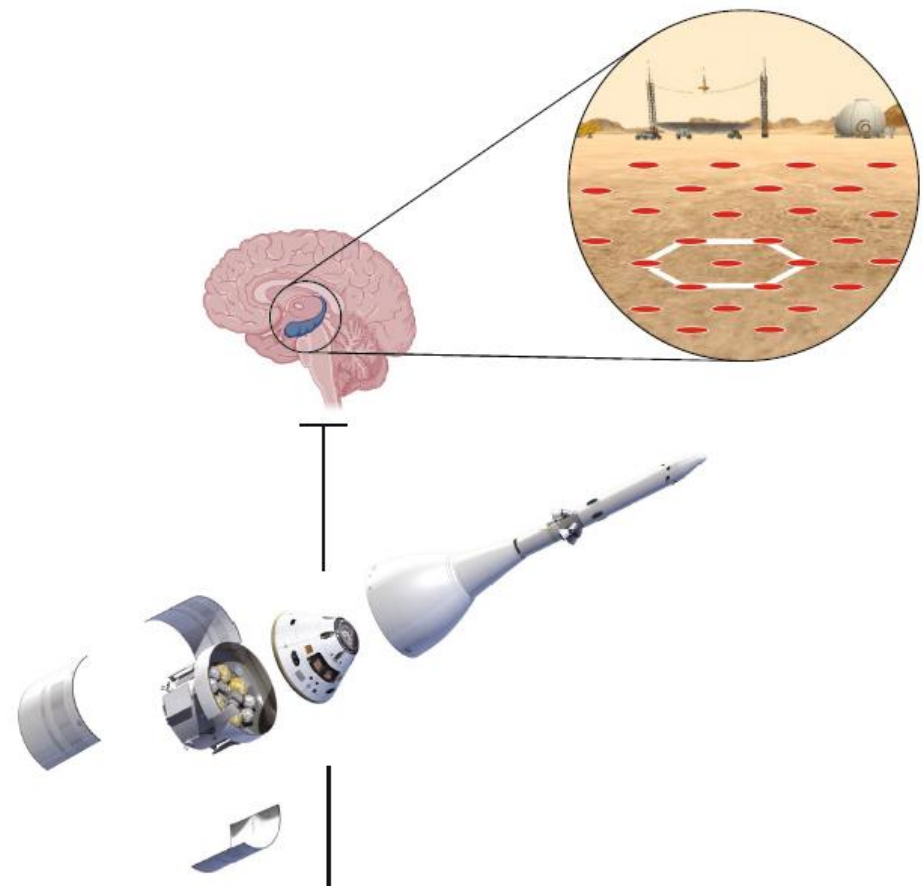
### ISOLATION



### MICROGRAVITY

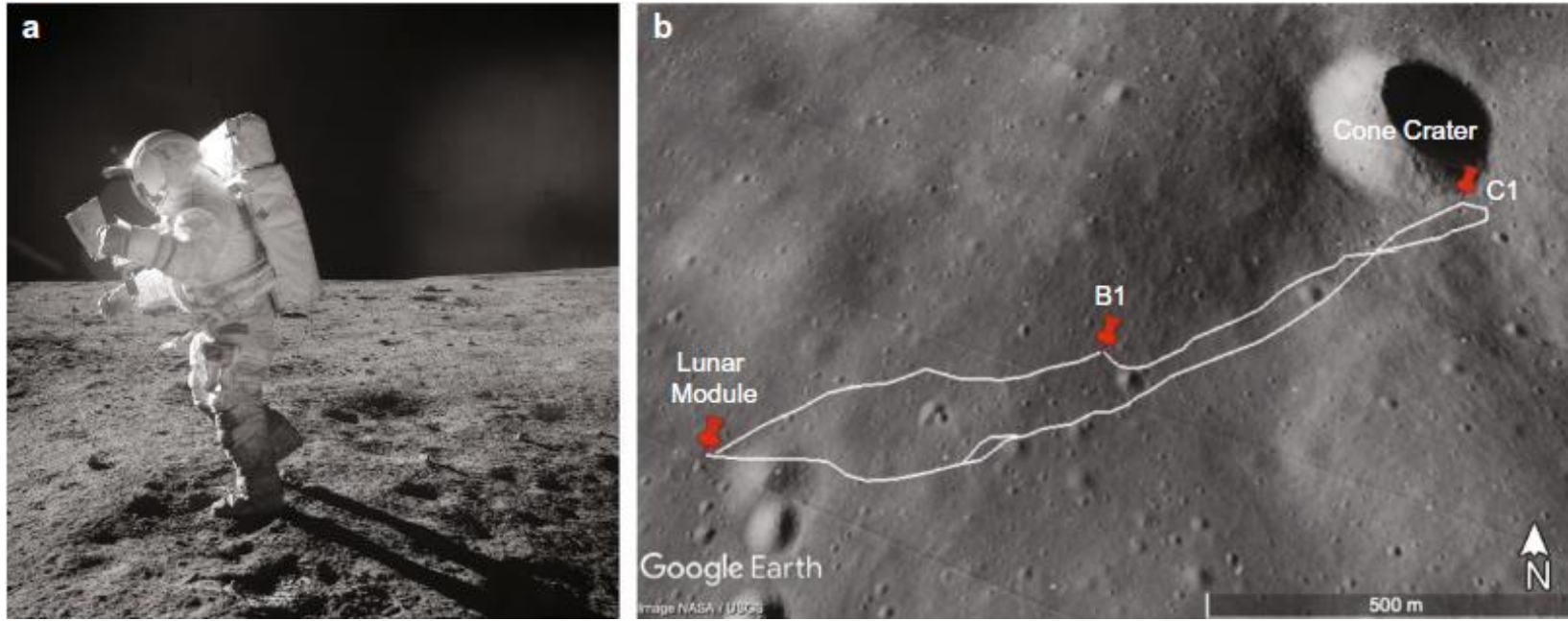


## SANS



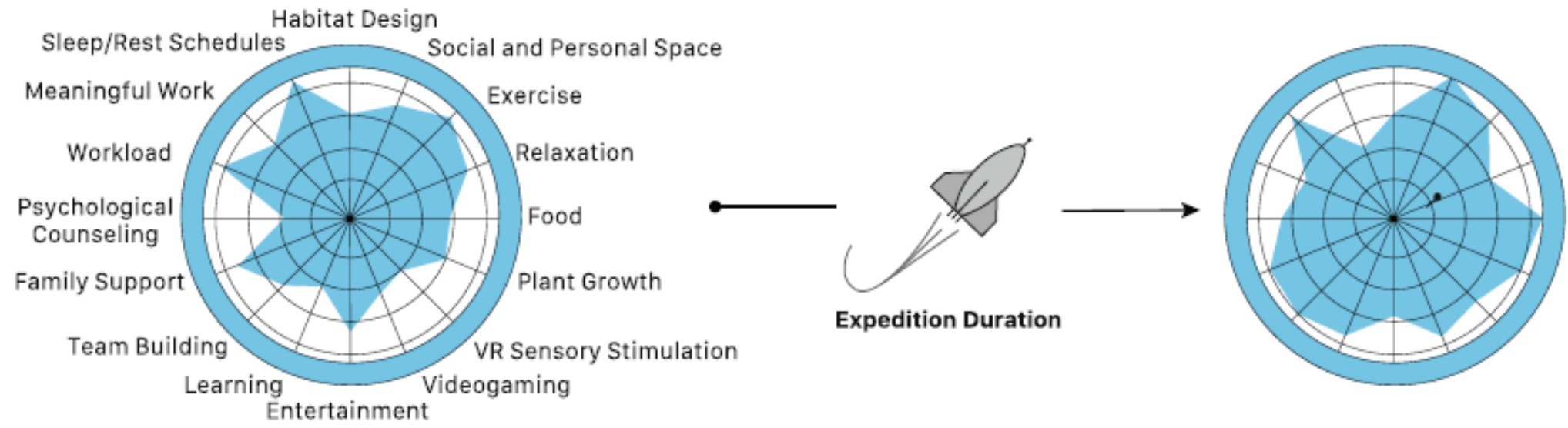
- Radiation
- CO<sub>2</sub>
- Weightlessness & Body Unloading
- Non-24h Day/Night Cycles
- Isolation & Confinement
- Sensory Deprivation

(Stahn and Kühn, 2021)

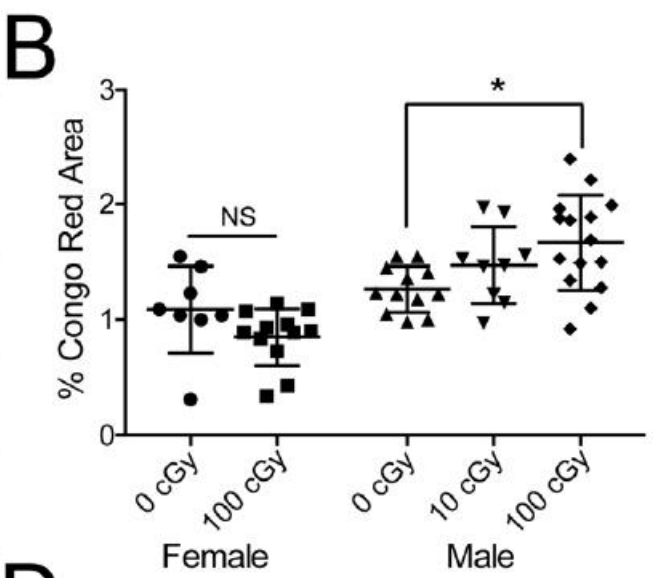
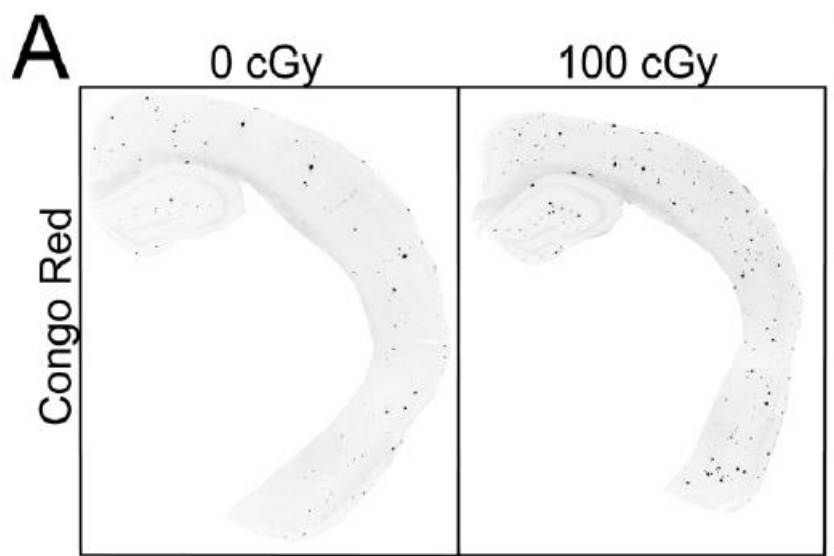


Astronauts Ed Mitchell and Alan Shepard had to walk to a crater located within a mile from their landing module. Having nearly reached the target destination, they had to abort the assignment because of spatial disorientation. They were just 30m away from the target crater.

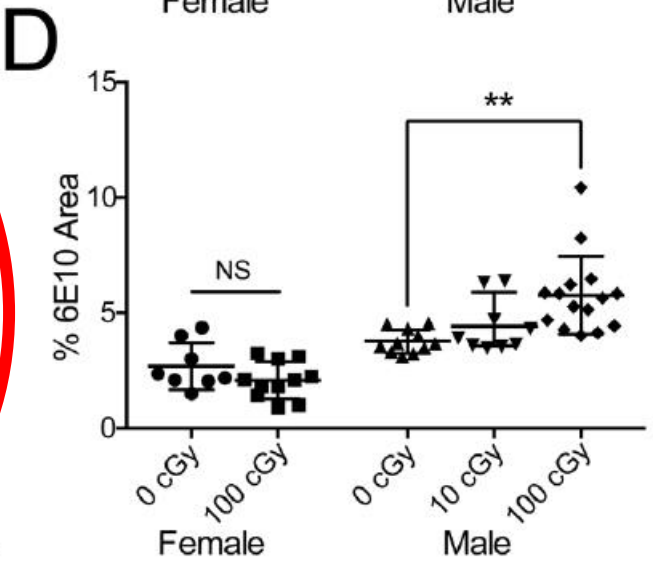
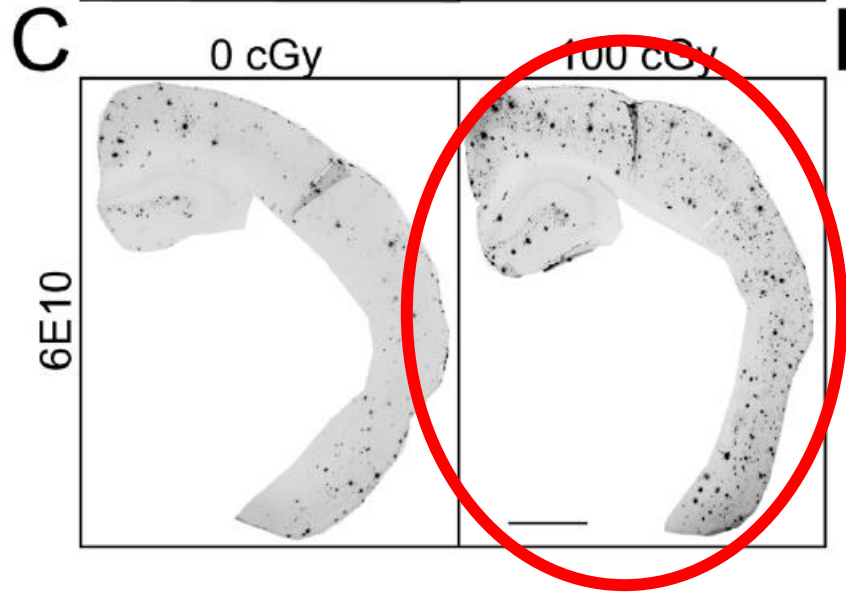
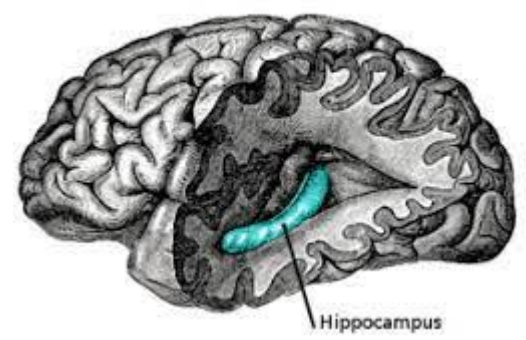
(Stahn and Kühn, 2021)



(Stahn and Kühn, 2021)

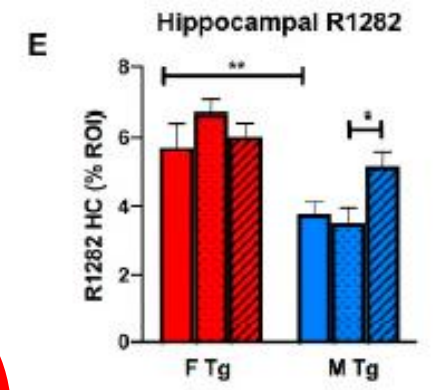
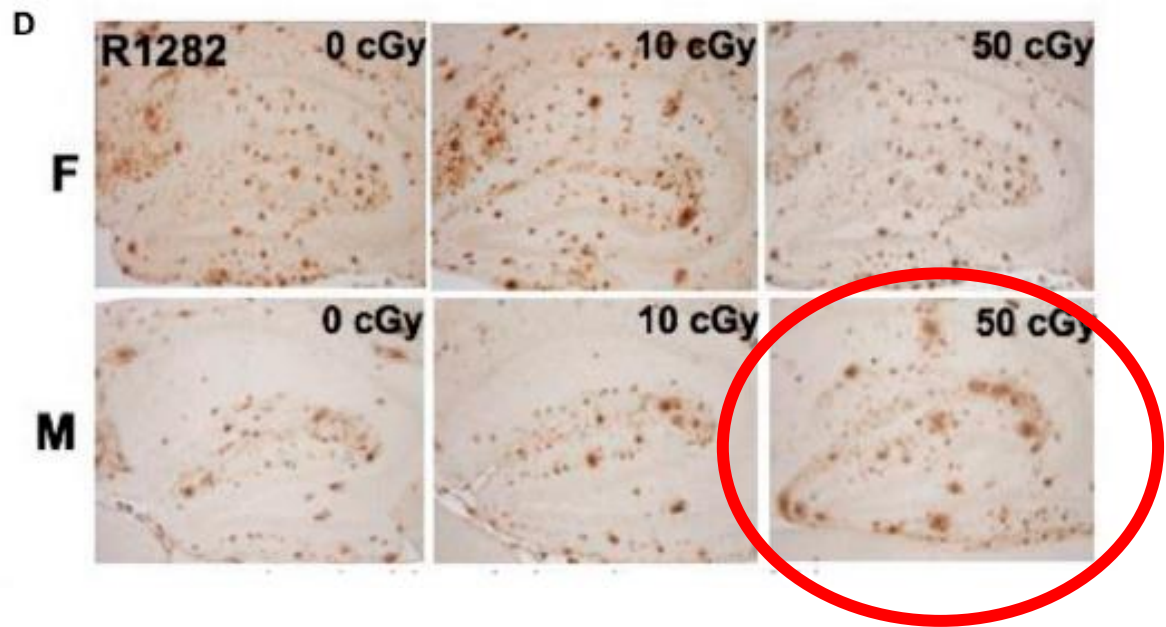
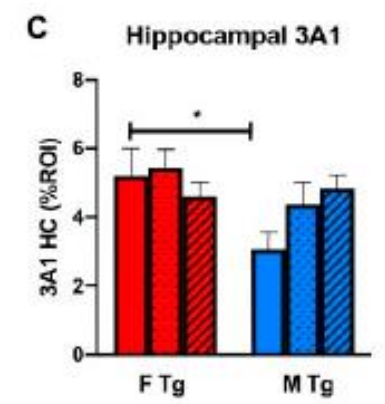
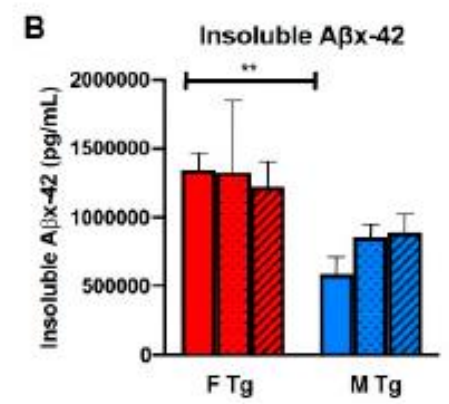
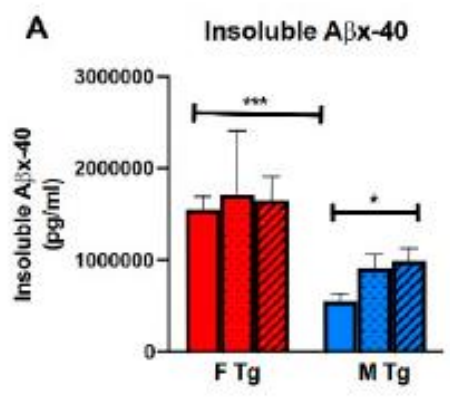


**Male animals  
 increased amyloid deposition**

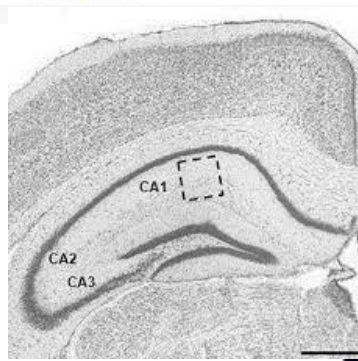


(Cherry et al, 2012)

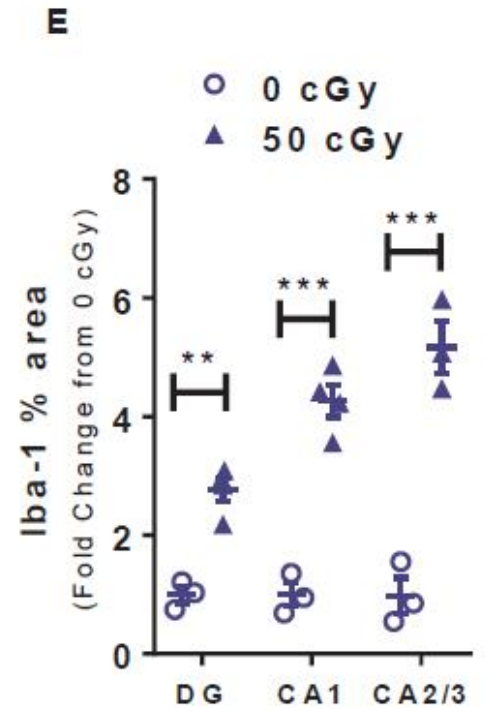
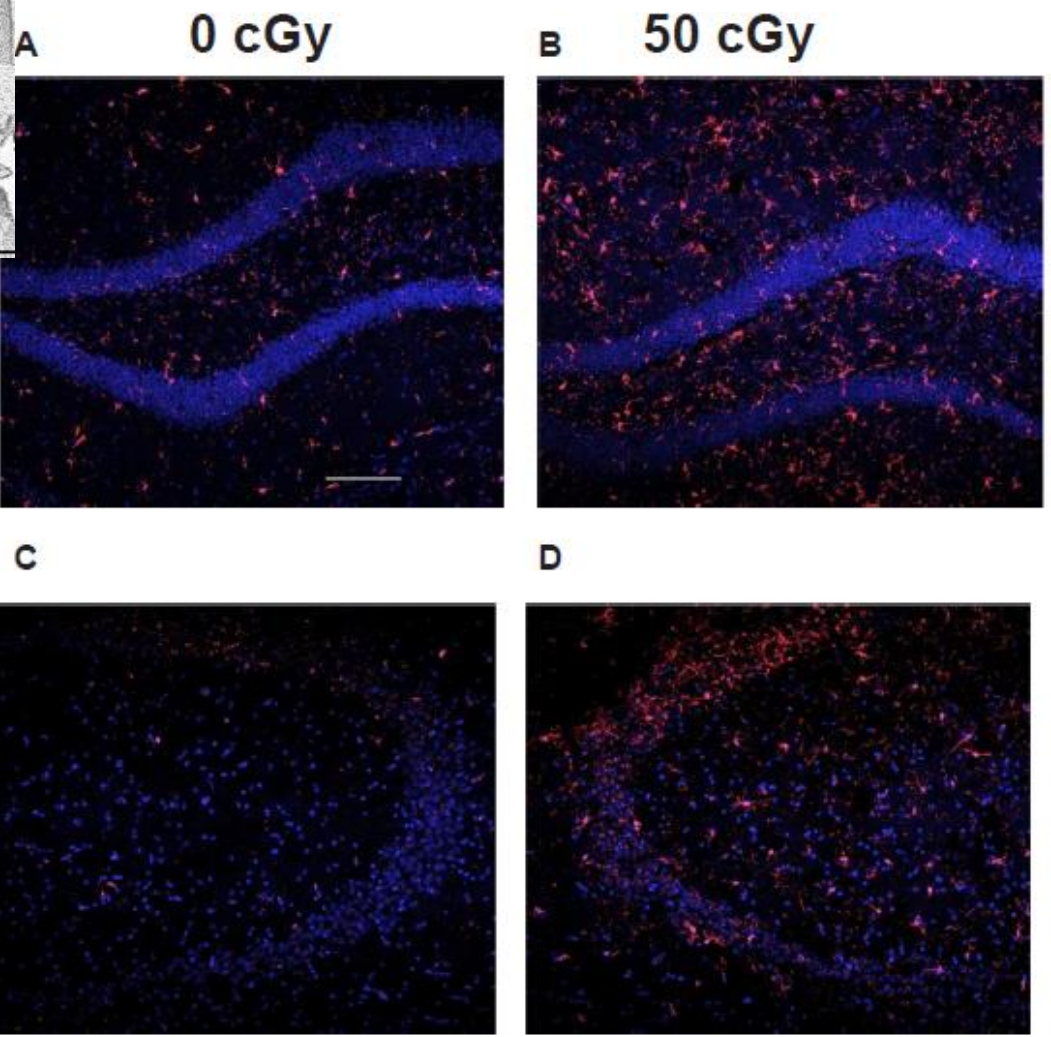




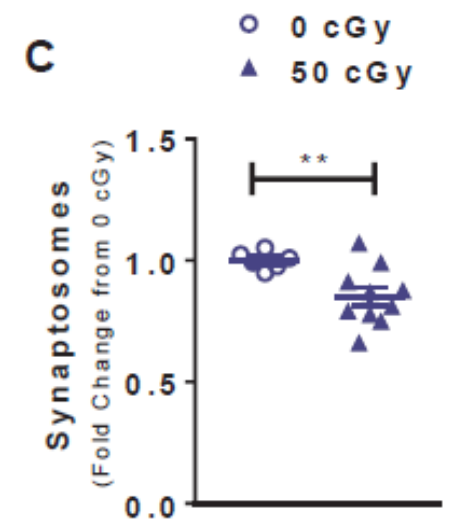
(Schroeder et al, 2021)



Hippocampus



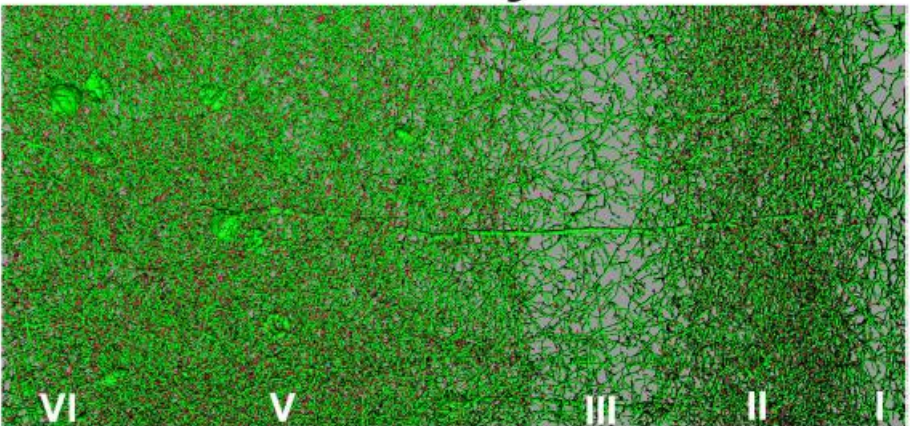
**Just in male animal**  
 diminished social interaction,  
 increased anxiety-like  
 impaired recognition  
 memory



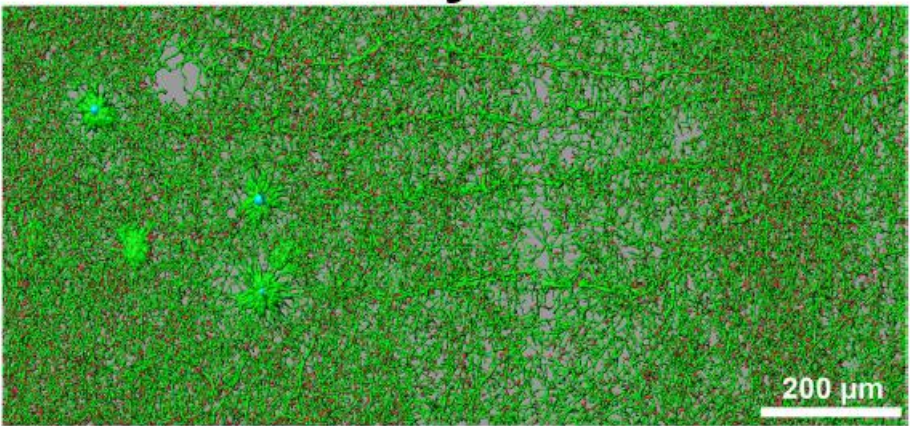
(Krukowskia et al, 2018)

# Radiation: dendritic complexity

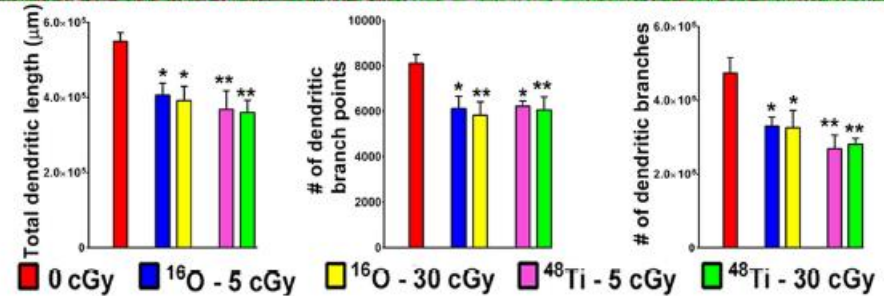
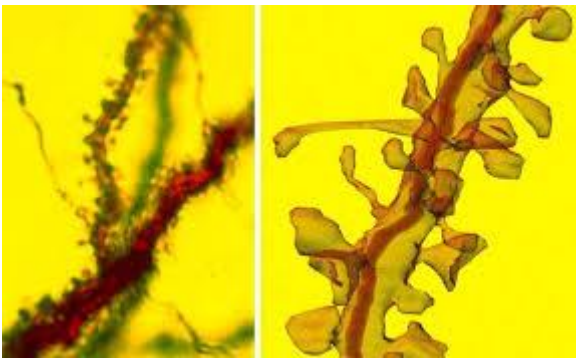
0 cGy



30 cGy <sup>48</sup>Ti



Reduced dendritic complexity



(Parihar, et al, 2016)



## Risk factors associated with Spaceflights

1. Isolation, Radiation, Microgravity
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# Brain Morphological Changes

Narrowing of the central sulcus occurred in 17 of 18 astronauts after long-duration flights and in 3 of 16 astronauts after short-duration flights

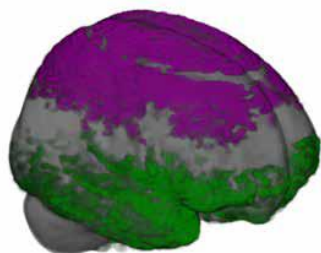


18 Astronauts Long duration

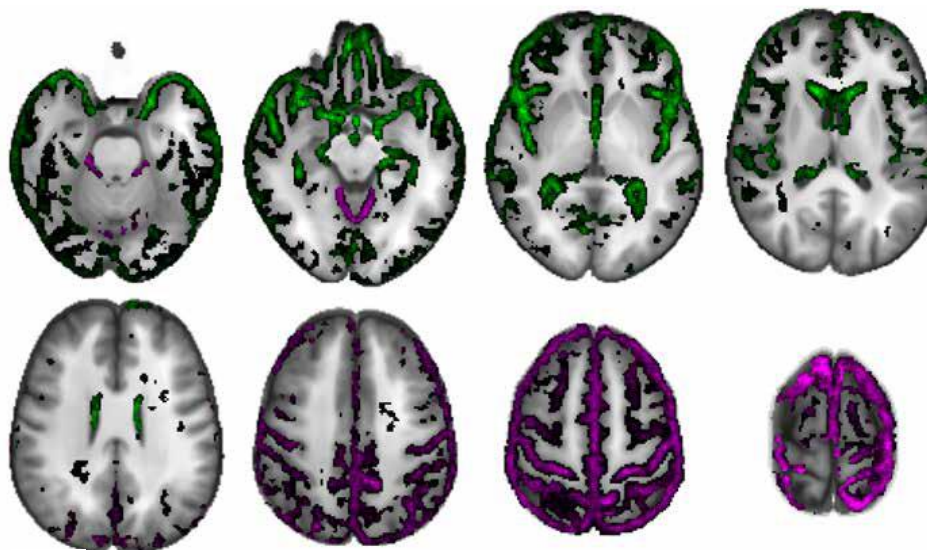
16 short Duration

(Roberts et al, NEJM, 2017)

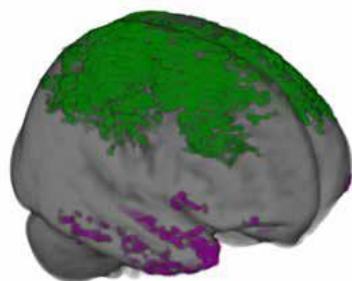
**Microgravity-induced  
upward brain shift inside the skull**



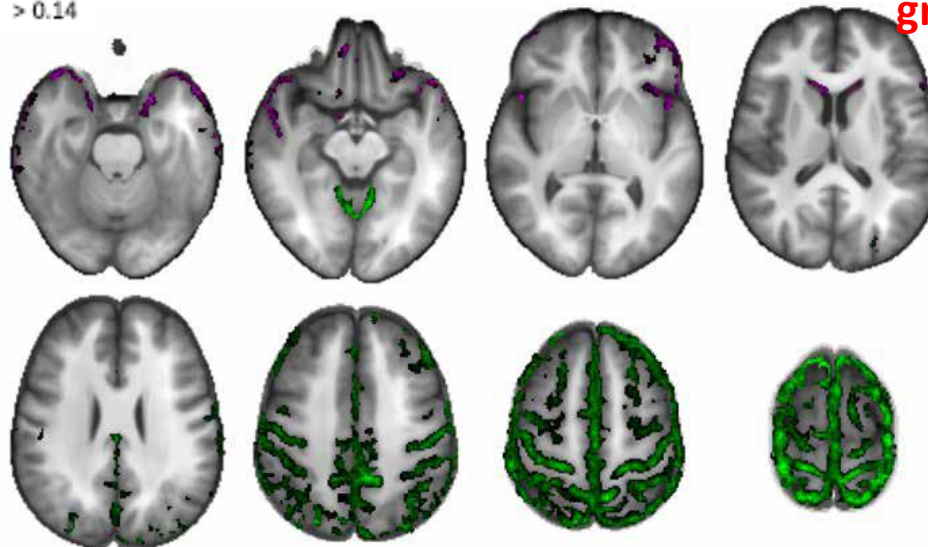
## Preflight - postflight



## Follow-up - Postflight



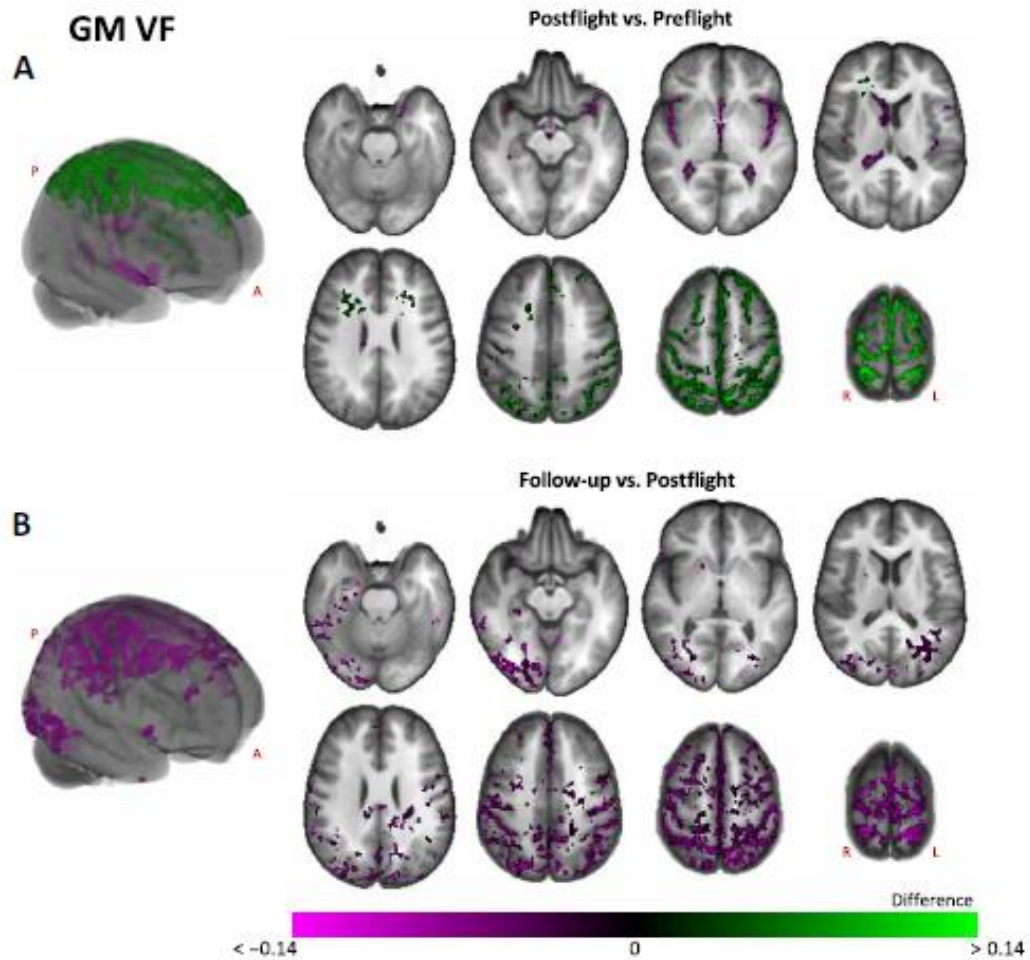
**7 months after landing on earth  
gradual recovery of CSF distribution**



(Jillings et al, 2020)

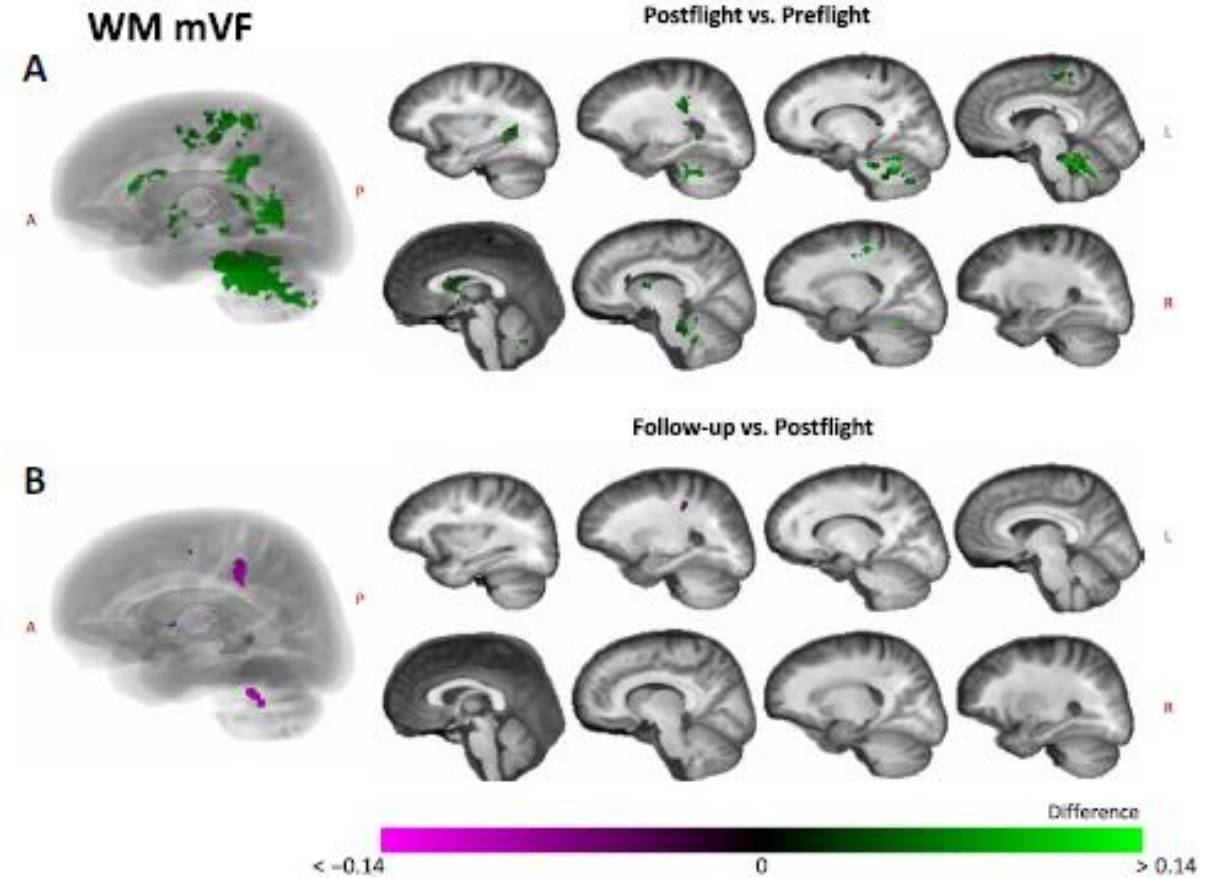


## Grey Matter Changes



**CSF volume decrease in superior region, cause crowding of the GM tissue along the interface with the sulci**

## White Matter Changes

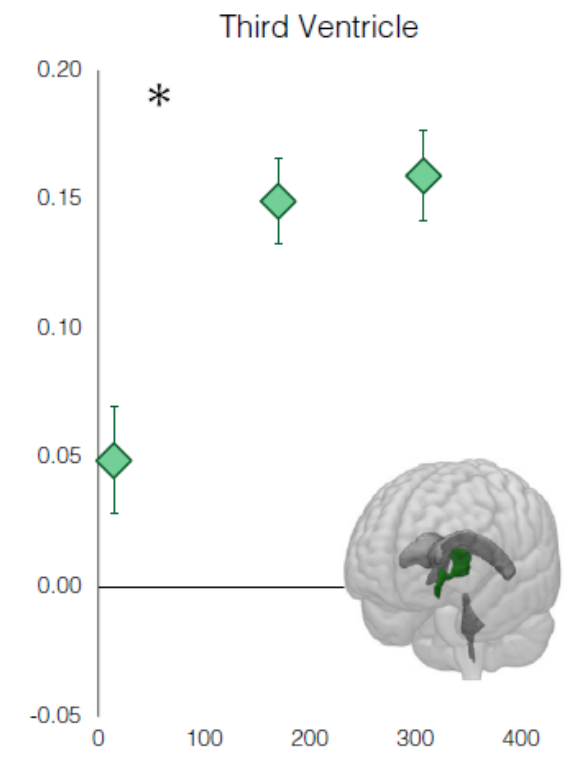
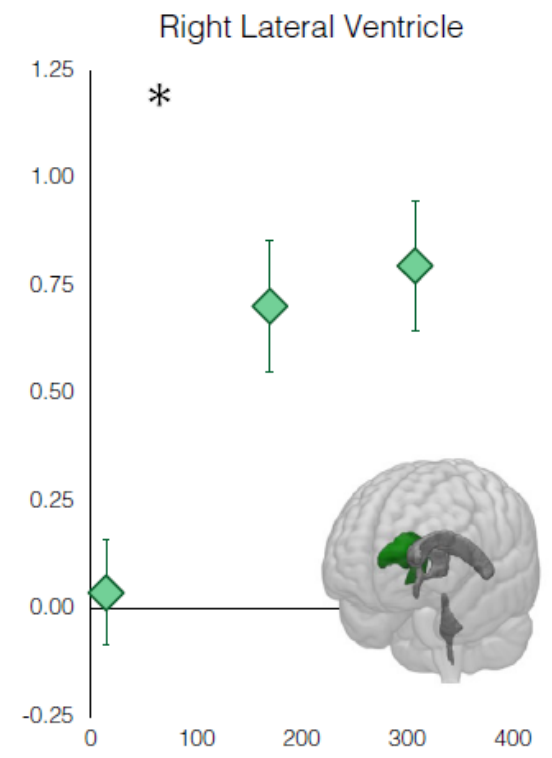
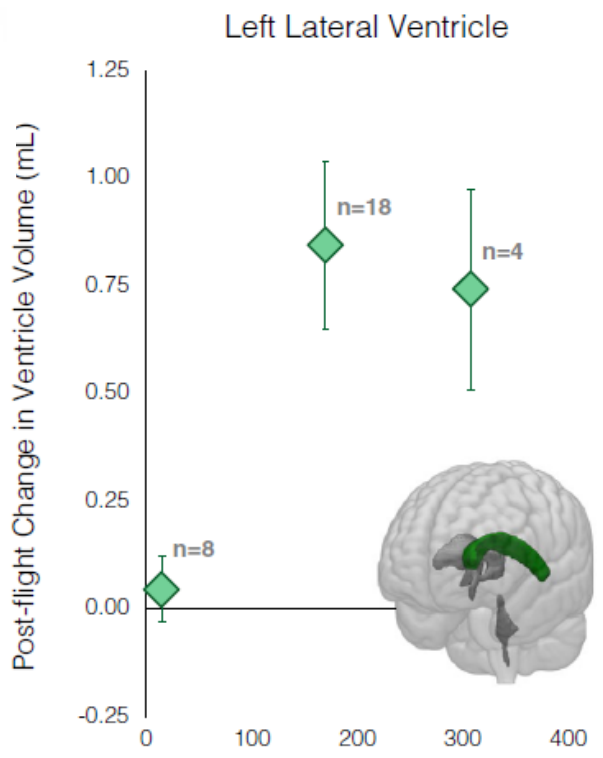
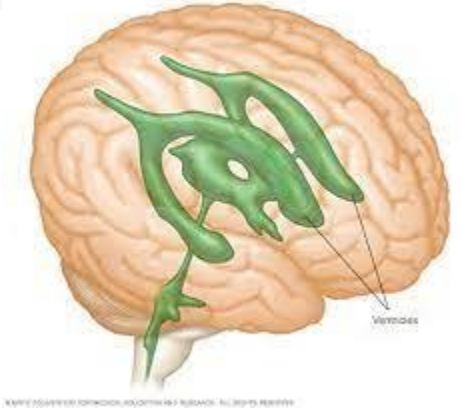


**Cerebellar and motor areas plasticity**

(Jillings et al, 2020)



# Volumetric changes: effects of flight duration and previous flights

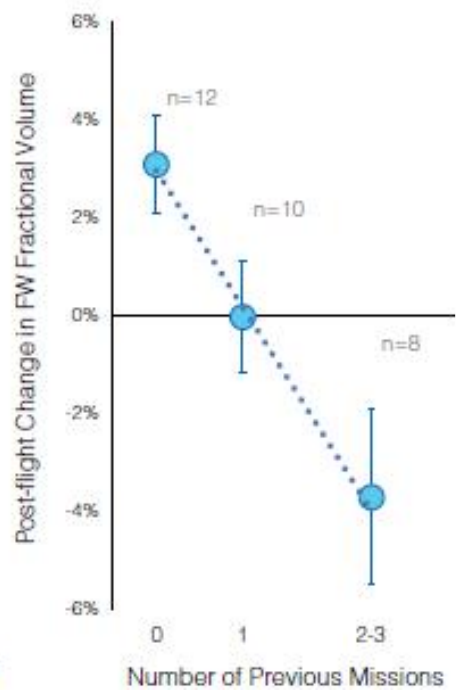
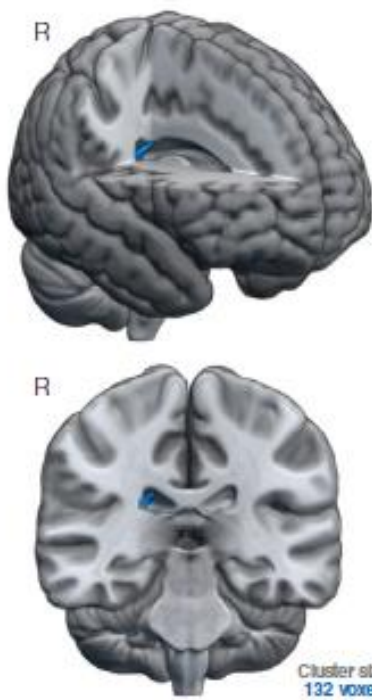


Current Mission Duration (days)

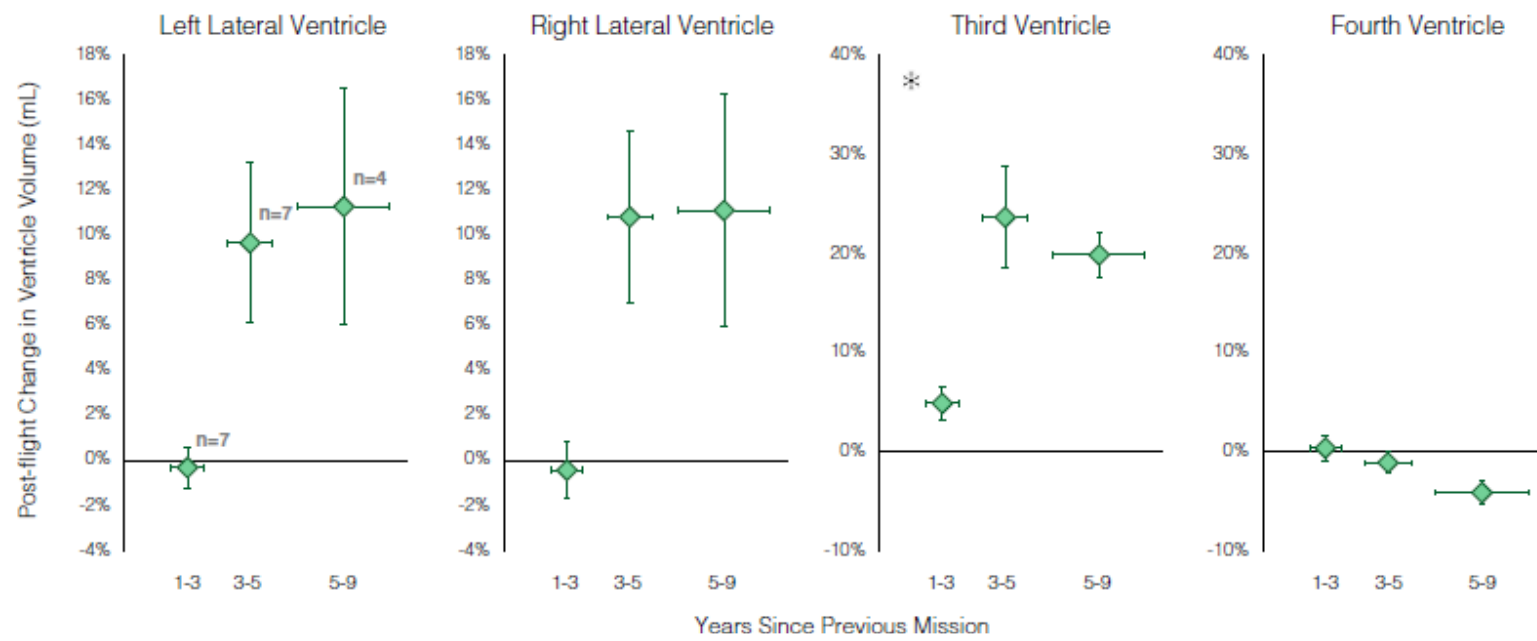
(McGregor et al, 2023)



# Volumetric changes: effects of flight duration and previous flights



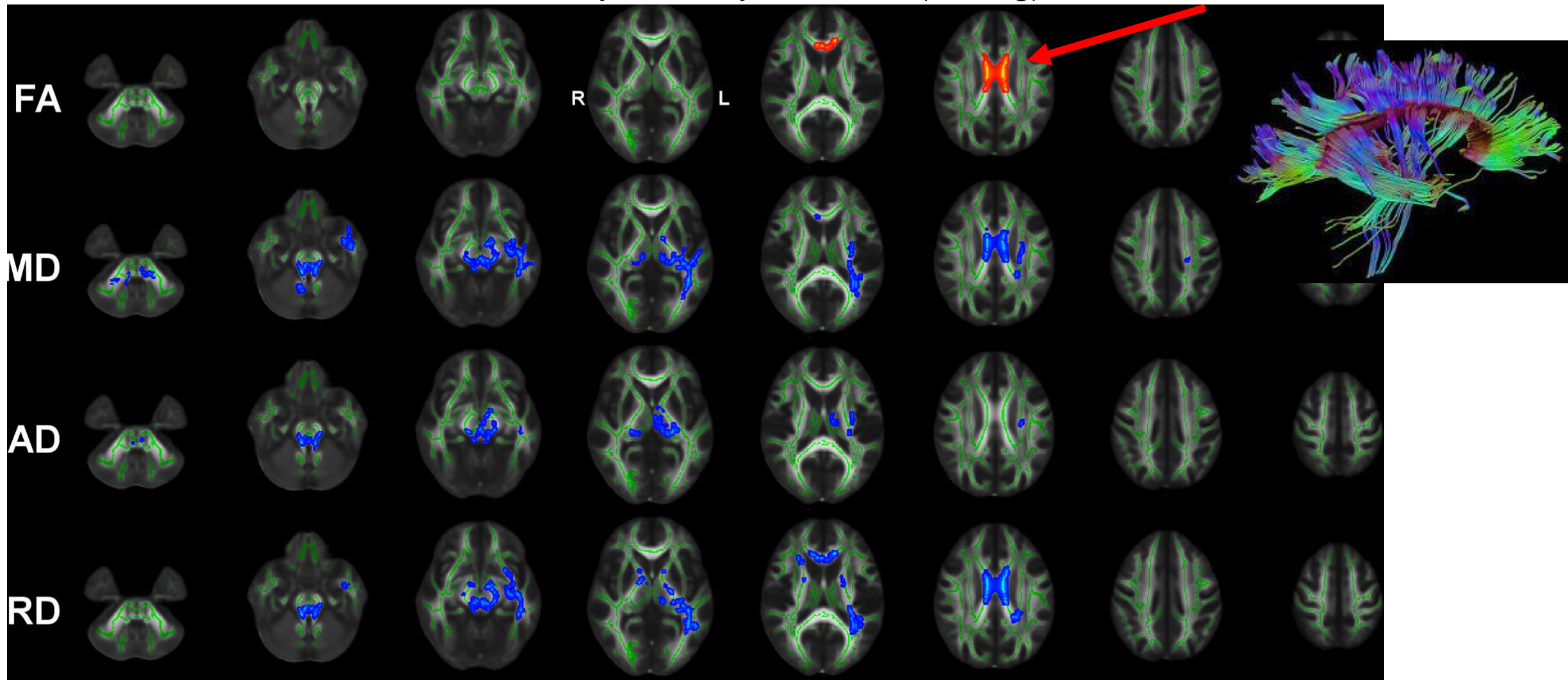
No further increase of volume as a function of previous missions



Crewmembers who had 3 years or longer to recover following their previous mission showed ventricular expansion following the current mission



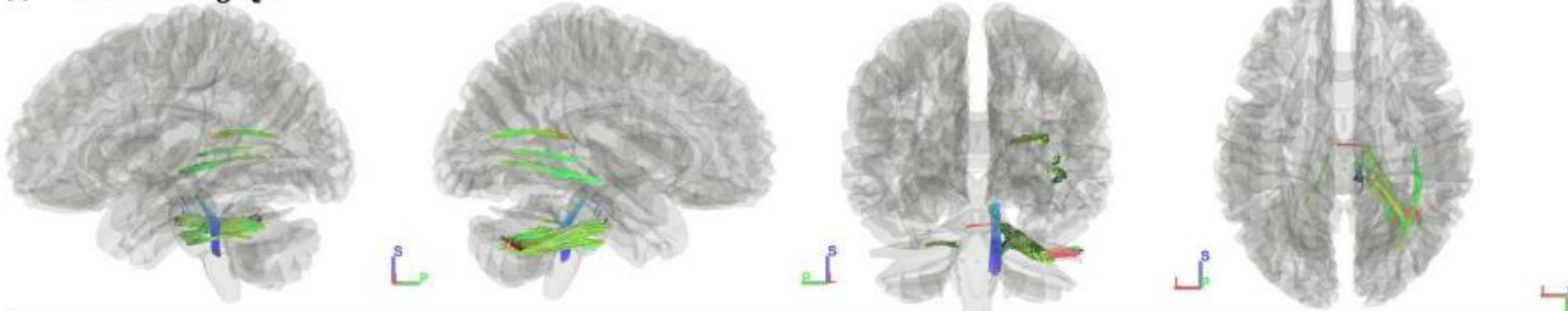
Structural connectivity: 520 days isolation (analog) **Reduction of FA values**



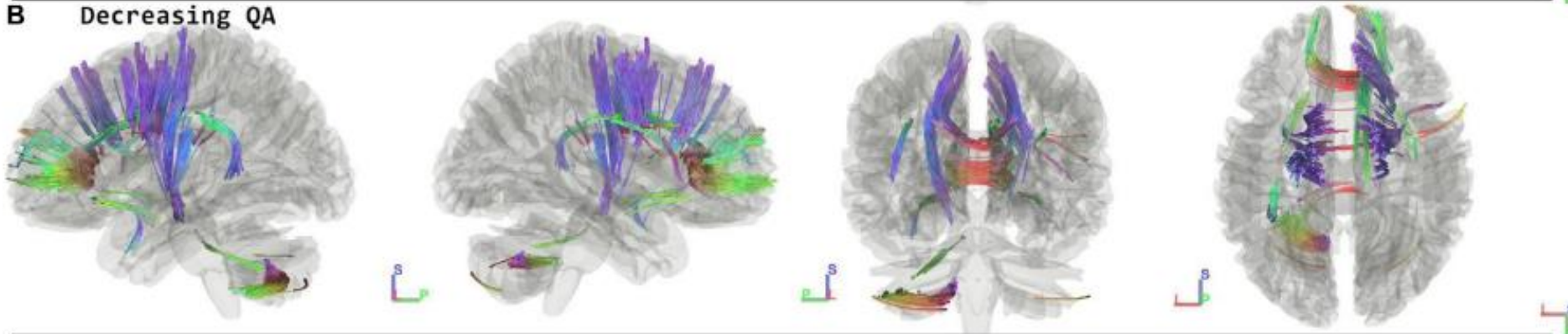
Structural connectivity in 12 Cosmonauts: Six months at ISS

Pre/Post Flight

A Increasing QA

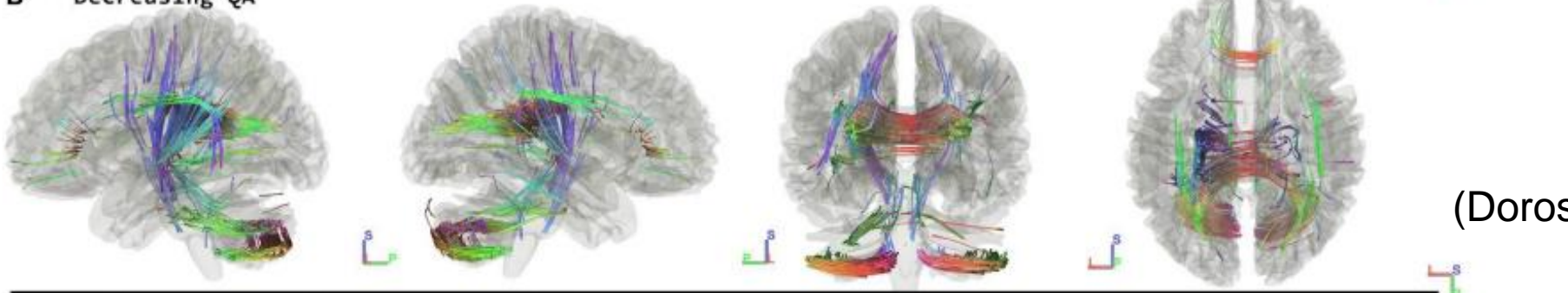


B Decreasing QA



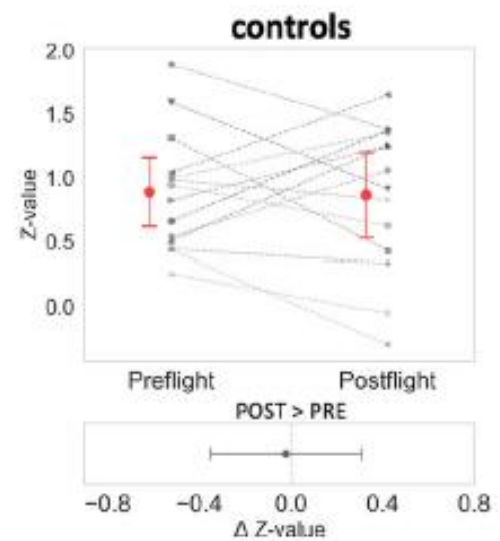
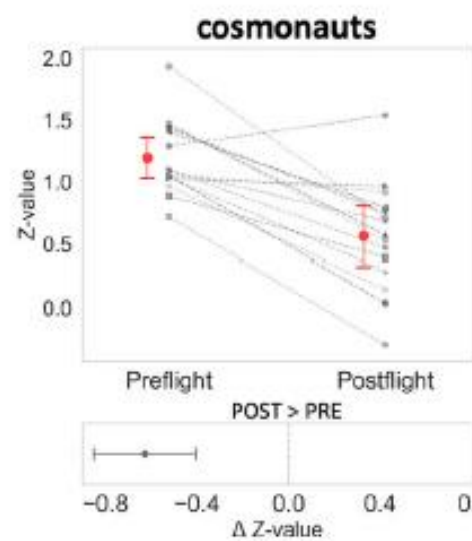
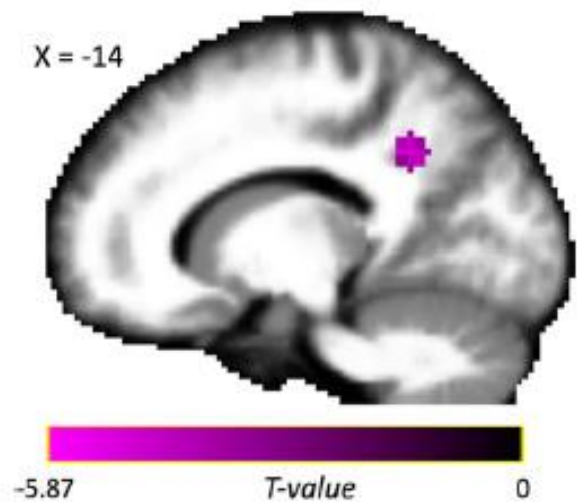
Pre/Follow-up

B Decreasing QA

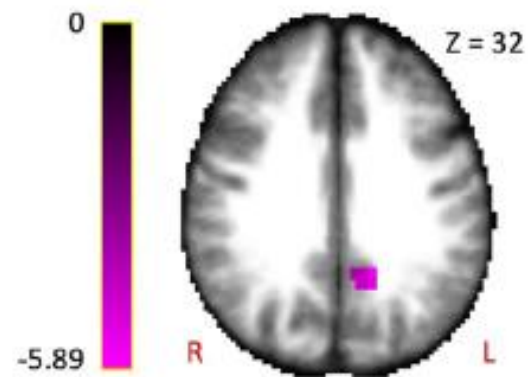


(Doroshin et al, 2022)

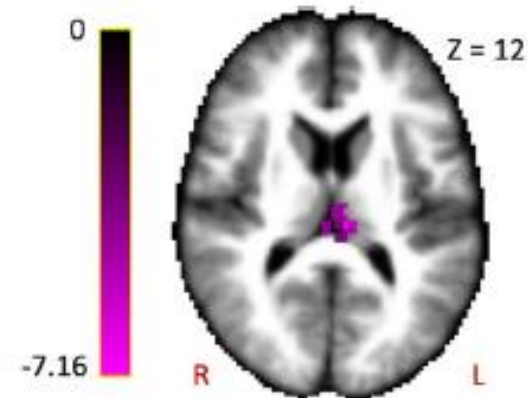
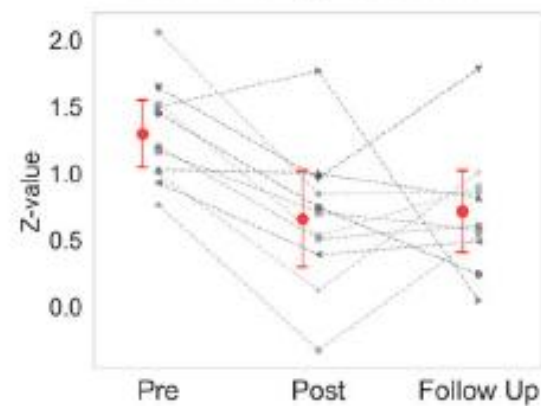
Posterior Cingulate Cortex decreased connectivity postflight



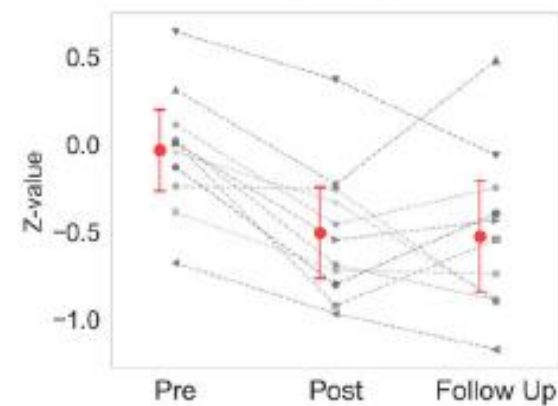
Posterior Cingulate Cortex and Thalamus decreased connectivity 7 months after landing



Posterior cingulate cortex



Thalamus





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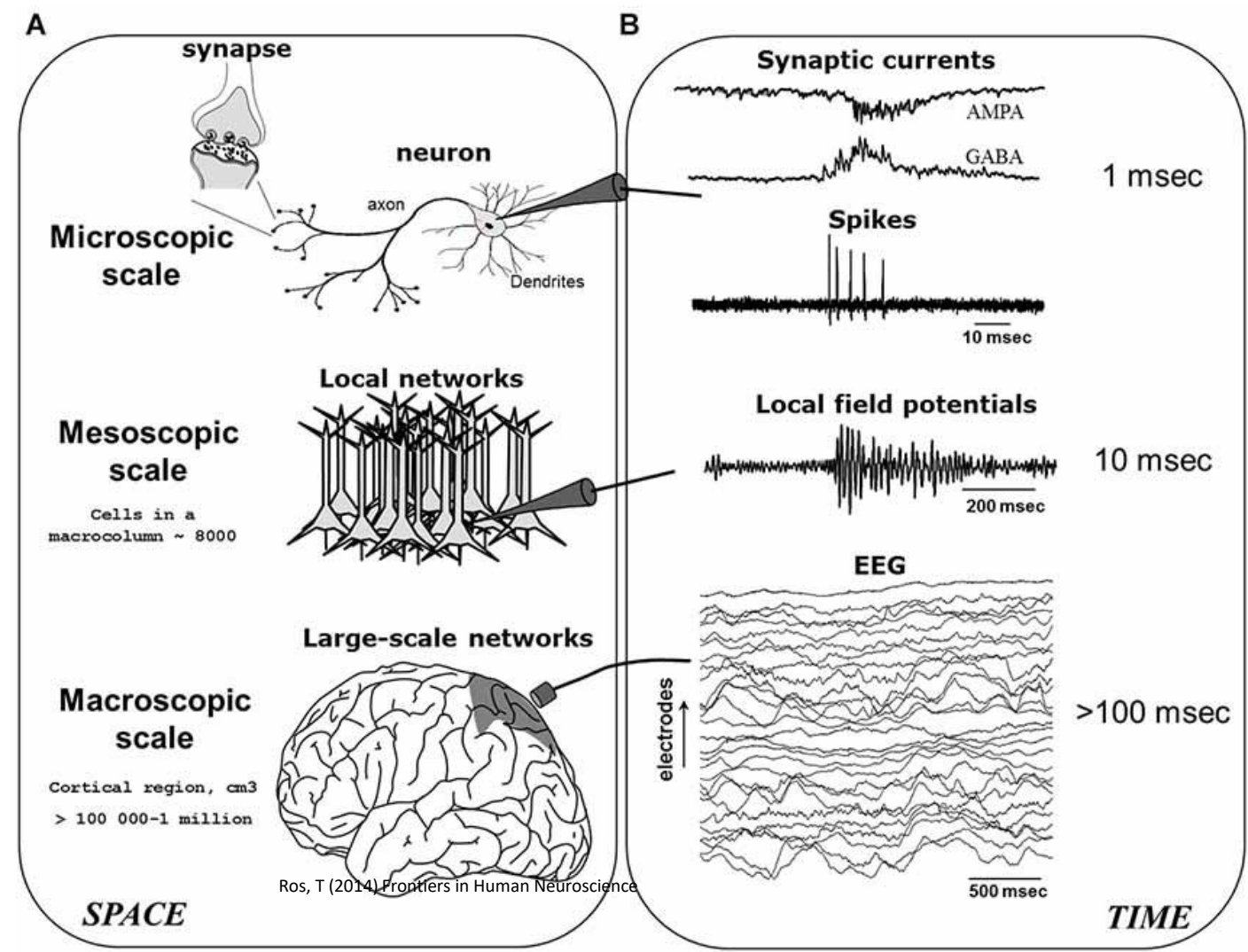
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# Generación de la actividad cerebral



Ros, T (2014) Frontiers in Human Neuroscience



# Oscilaciones y ritmos cerebrales

Amplitud



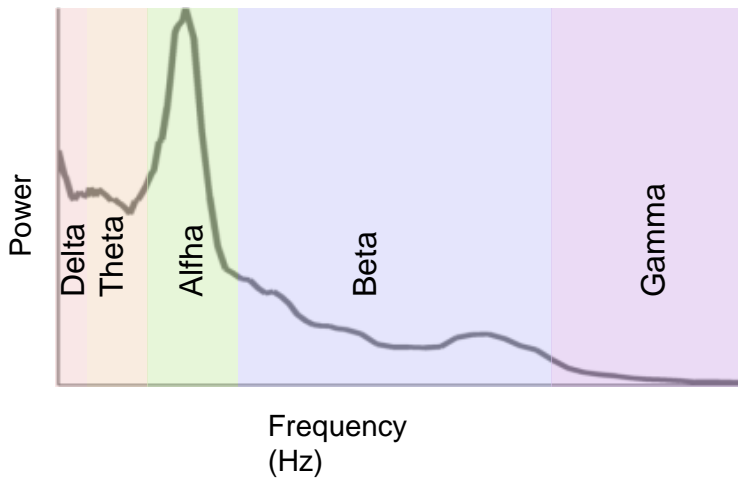
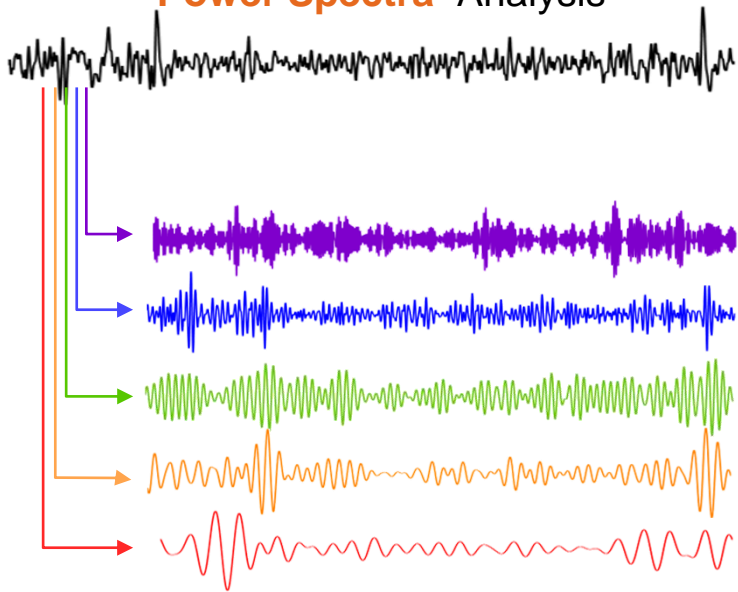
Tiempo

- Amplitud: Es la amplitud máxima que alcanza el oscilador desde el punto de reposo
- Periodo: Es el tiempo que tarda el oscilador en completar un ciclo completo, es decir, en ir desde un punto cualquiera, hasta volver al mismo punto tras completar una vuelta entera.
- Fase: Es la posición de la oscilación en un momento de tiempo cualquiera



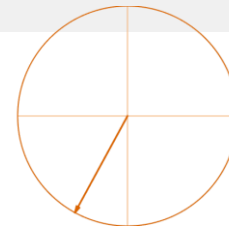
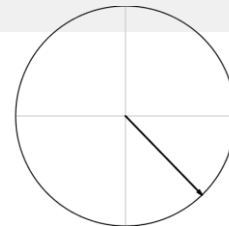
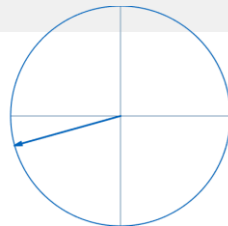
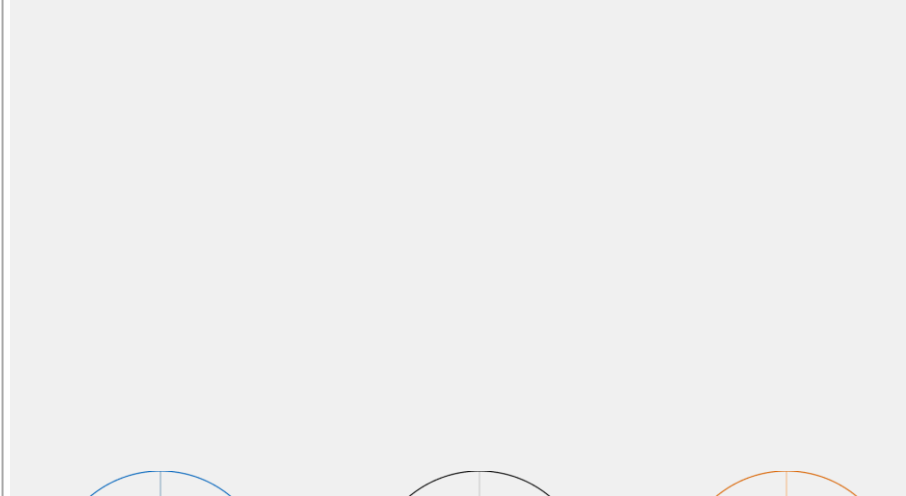


**Power Spectra** Analysis



**Functional Connectivity** Analysis

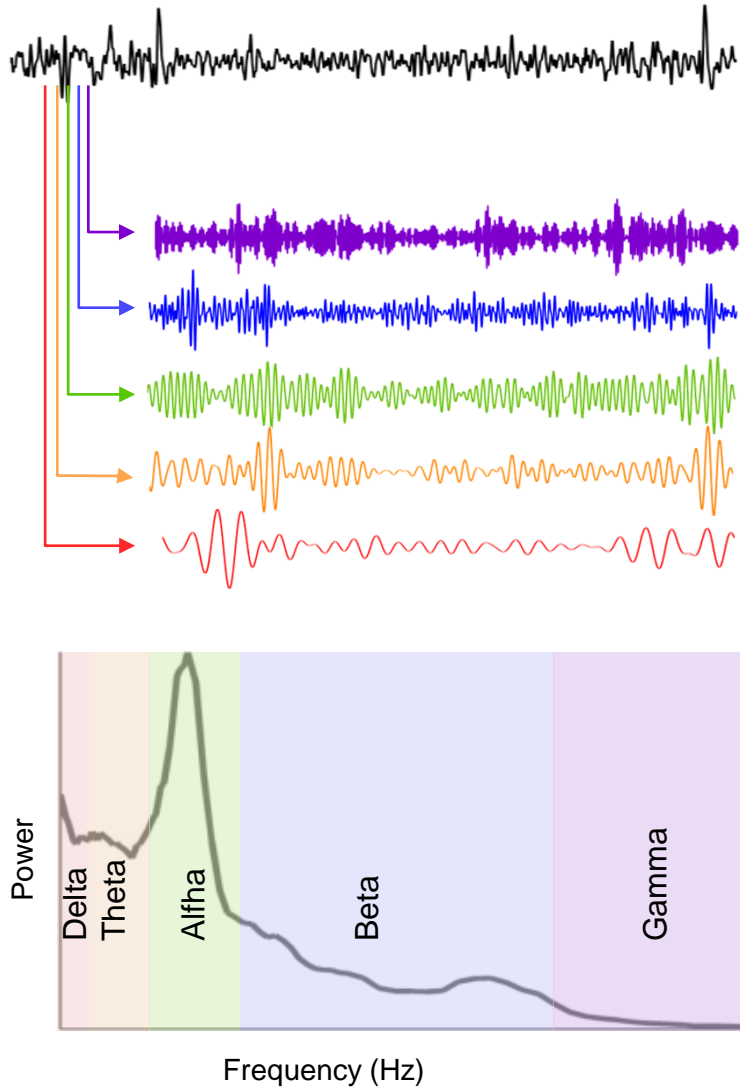
- Phase** Synchronization
- Amplitude** Synchronization



**Network** Analysis

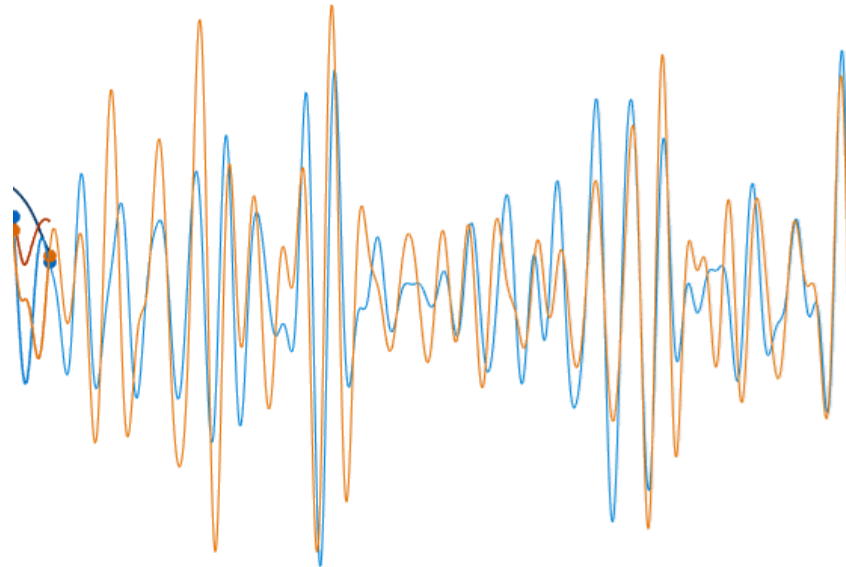


## Power Spectra Analysis

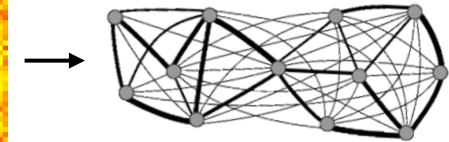
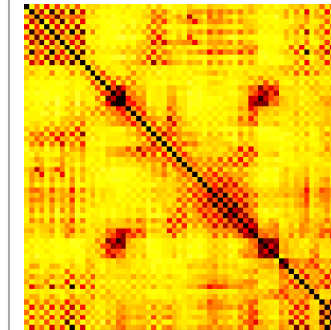


## Functional Connectivity Analysis

Phase Synchronization  
Amplitude Synchronization



## Network Analysis



Include **all edges** between nodes with their respective **weights**

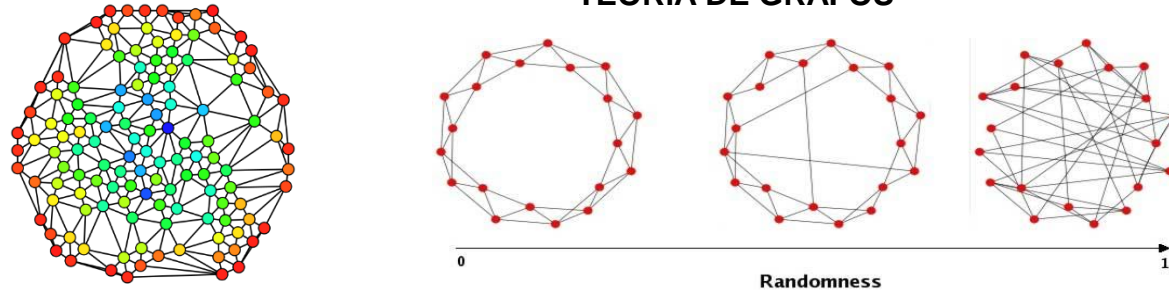
Binarization



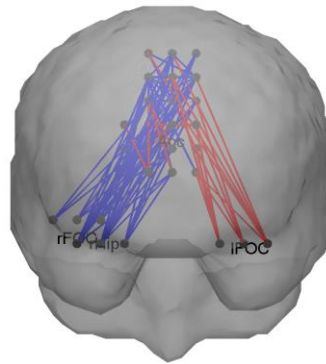
Includes just the **most relevant edges** between nodes **without weights**



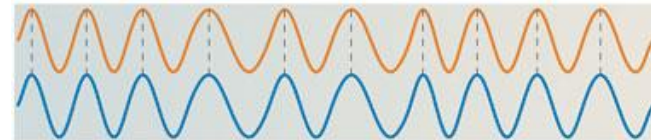
## TEORÍA DE GRAFOS



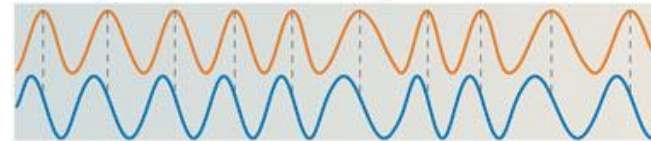
## CONECTIVIDAD FUNCIONAL Y EFECTIVA



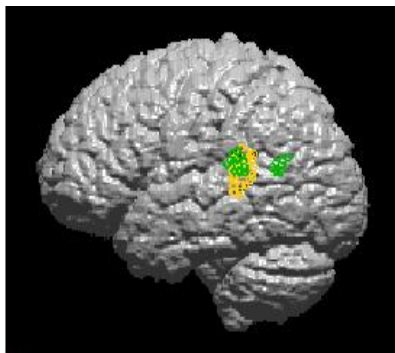
Phase synchronization: phase lag = 0°



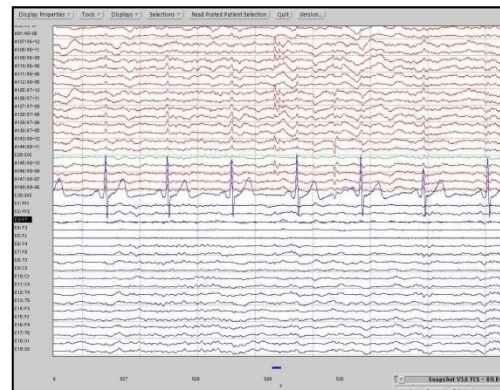
Phase synchronization: phase lag ≠ 0°



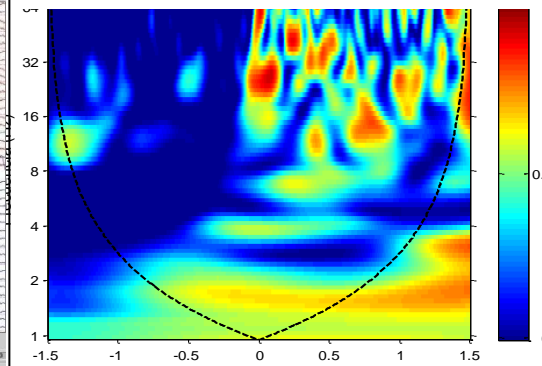
## ESPACIO



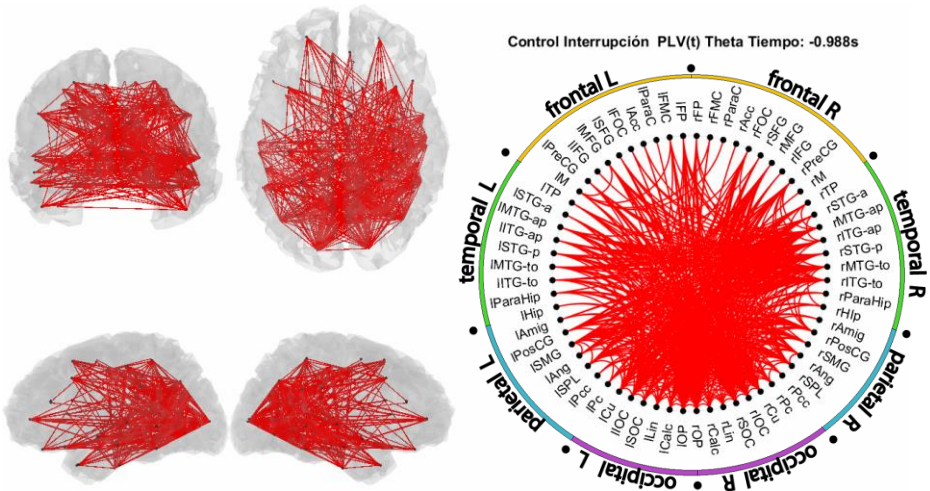
## TIEMPO



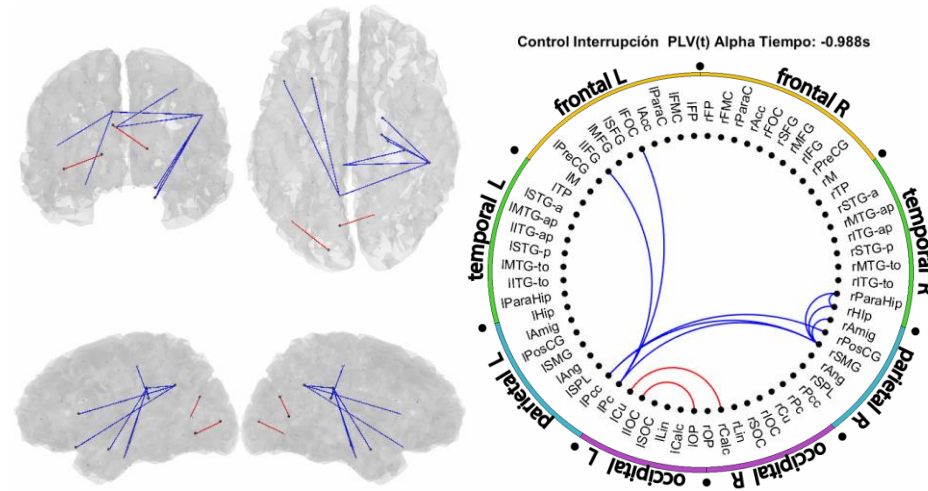
## FRECUENCIA



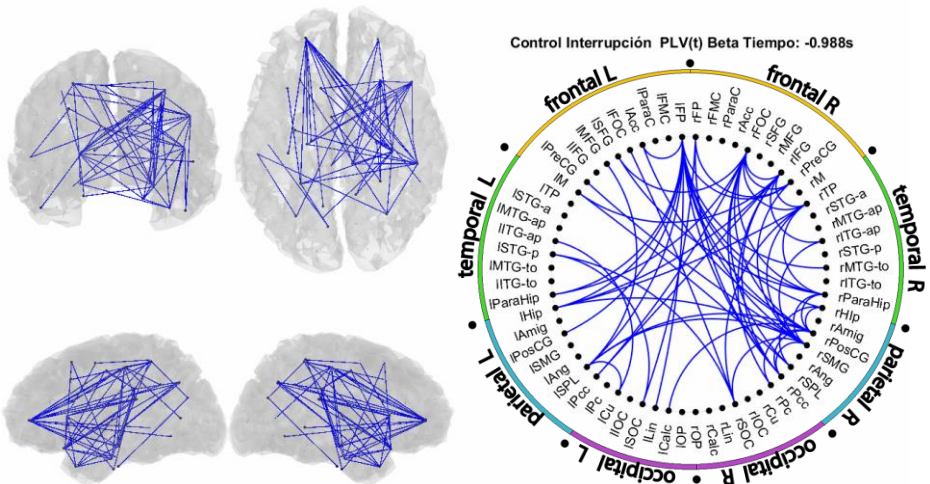
# Theta



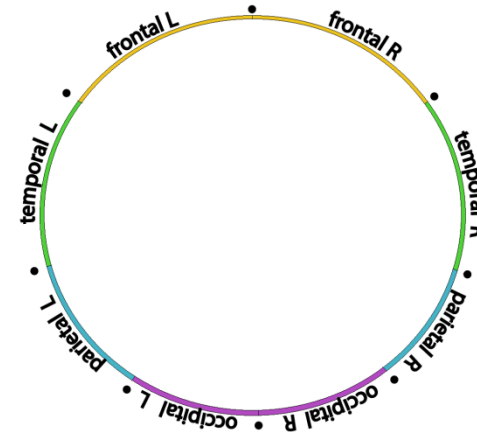
# Alpha



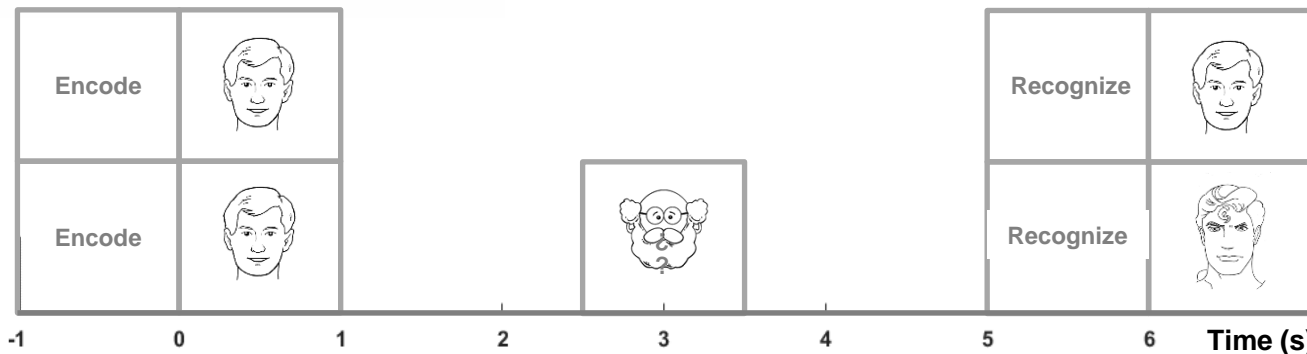
# Beta

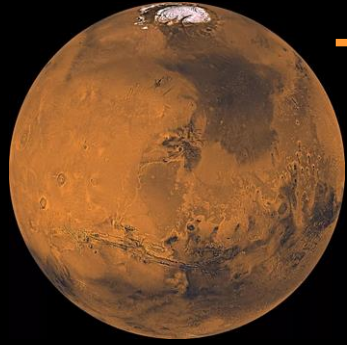


# Gamma

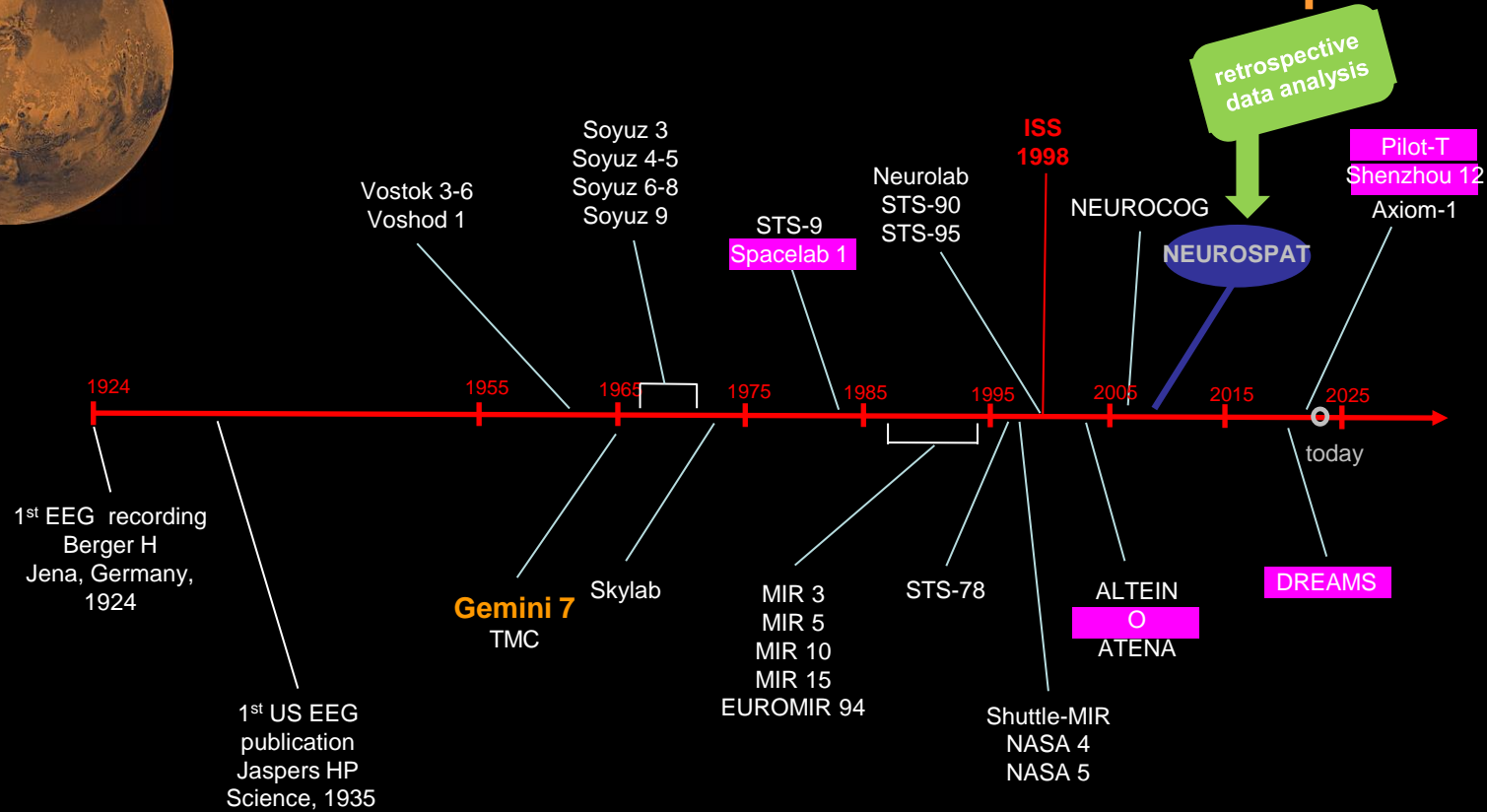


WM Retroactive  
 Theta            Alpha  
 Beta            Gamma





# TIMELINE - EEG in Human Spaceflight



(Funke et al, in progress)

\* EEG experiments without reported EEG results in literature

# EEG Space recordings timeline

1961

1964

1965

1966

1973

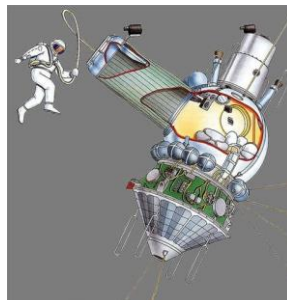
Vostok

Voskhod

Gemini VII

Soyuz

Skylab





# First EEG Recording in Spaceflight, August 1962

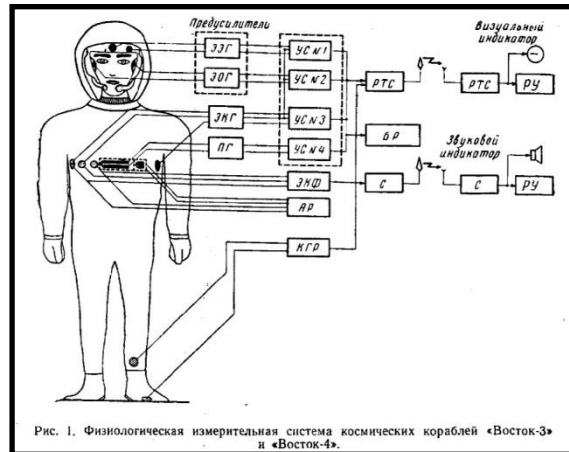
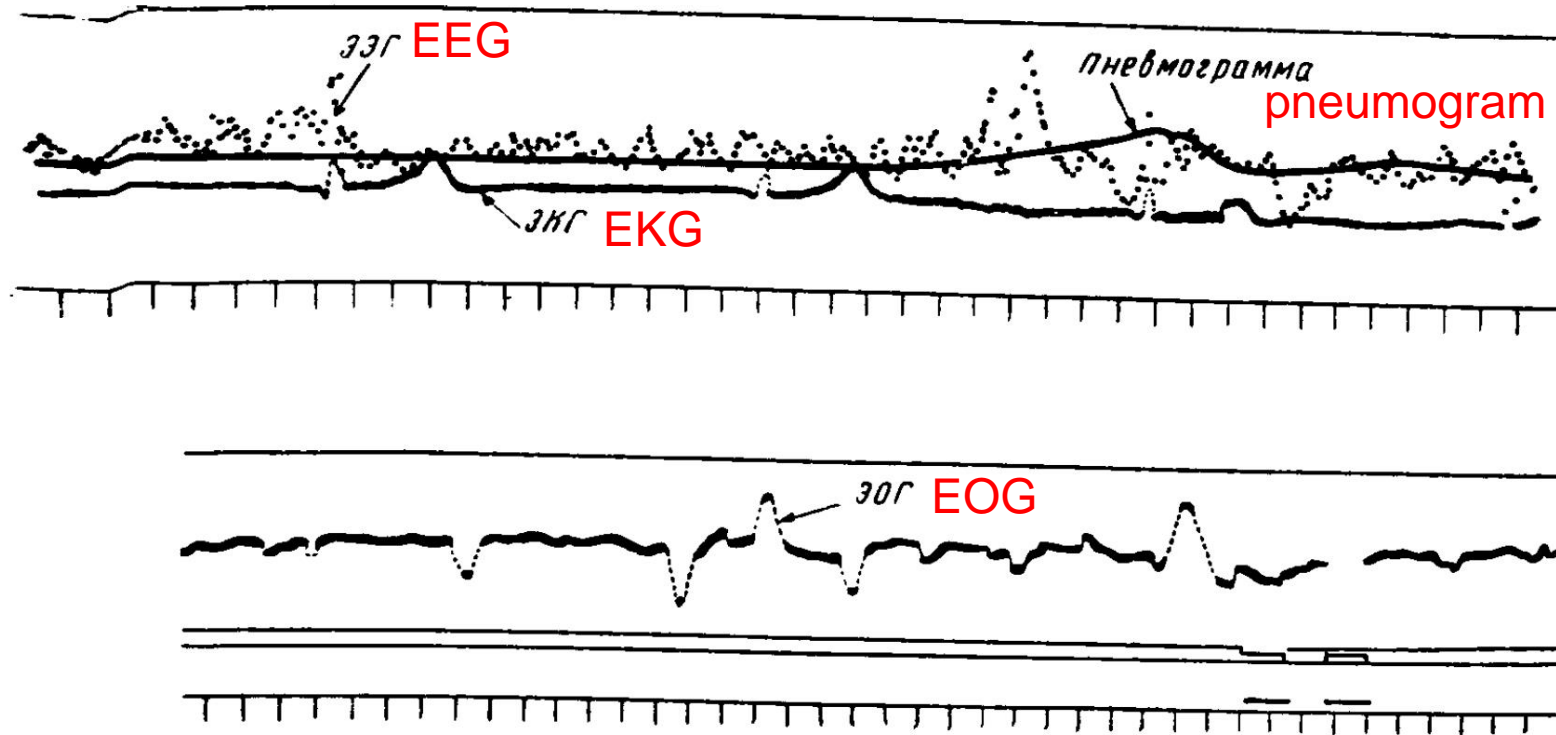


Рис. 1. Физиологическая измерительная система космических кораблей «Восток-3» и «Восток-4».

физиологических показателей, полученных во время полета А. Г. Николаева.

Akulinichev and Baevsky, 1964



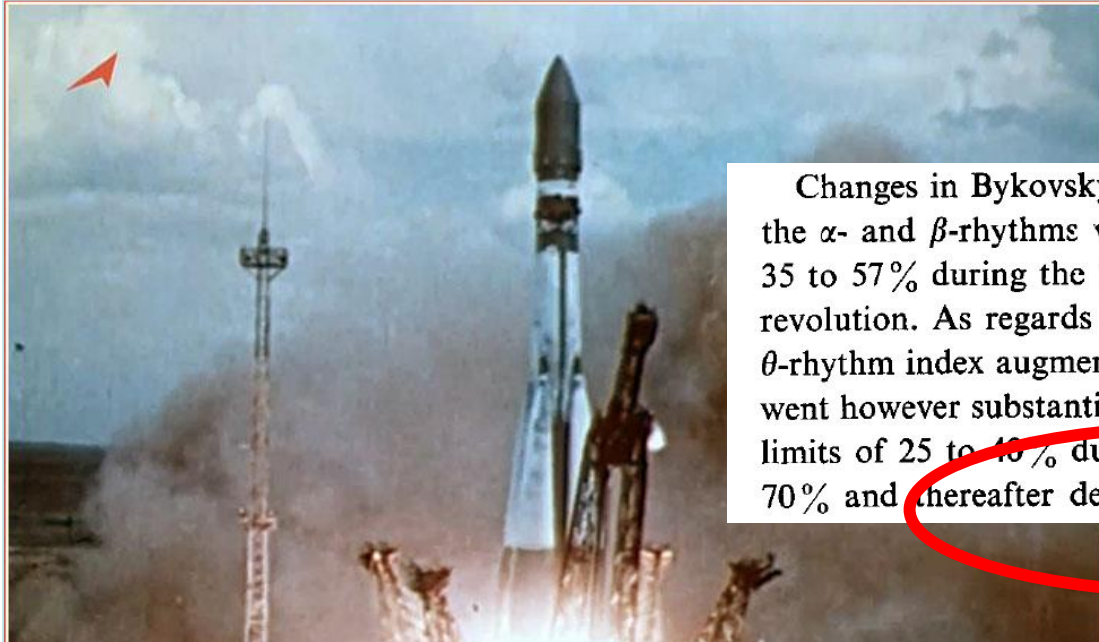
ИТАР-ТАСС



TABLE 2  
Methods of recording of physiological parameters during flights of Soviet and American spaceships

Astronauts	Physiological parameters							Arterial blood pressure	Body temperature
	ECG	Pneumogram	Kinectocardiogram	EEG	PGR	EOG	SCG		
Glenn	+	+	-	-	-	-	-	+	+
Carpenter	+	+	-	-	-	-	-	+	+
Schirra	+	+	-	-	-	-	-	+	+
Cooper	+	+	-	-	-	-	-	+	+
Gagarin	+	+	-	-	-	-	-	-	-
Titov	+	+	+	-	-	-	-	-	-
Nikolayev	+	+	-	+	+	+	-	-	-
Popovich	+	+	-	+	+	+	-	-	-
Bykovsky	+	+	-	+	+	+	+	-	-
Tereshkova	+	+	-	+	+	+	+	-	-



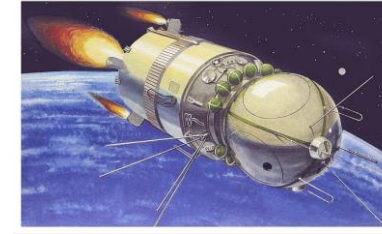


Changes in Bykovsky's encephalogram were rather equivocal. Indices of the  $\alpha$ - and  $\beta$ -rhythms varied substantially, e.g. the  $\alpha$ -rhythm index ranged 35 to 57% during the 1st to 4th revolutions and reached 85% at the 51st revolution. As regards Tereshkova, her  $\beta$ -rhythm index lowered while the  $\theta$ -rhythm index augmented during the weightless state. Both indices underwent however substantial deviations. The  $\alpha$ -rhythm index ranged within the limits of 25 to 40% during the first two days, then increased up to 50 to 70% and thereafter decreased up to 35 to 38% by the end of the flight

Parin et al., 1965



# Vostok (1961-1963)



Vostok 1- Yuri Gagarin

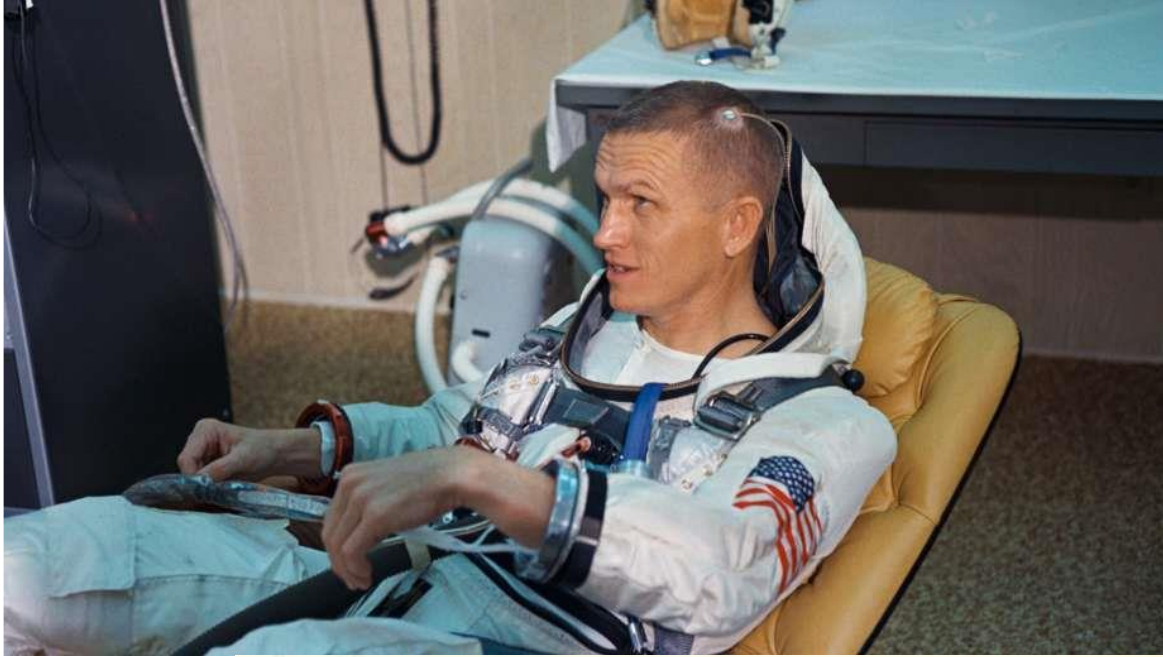


Vostok 2- Gherman Titov

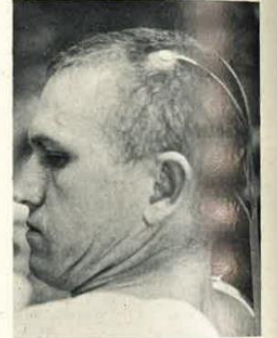
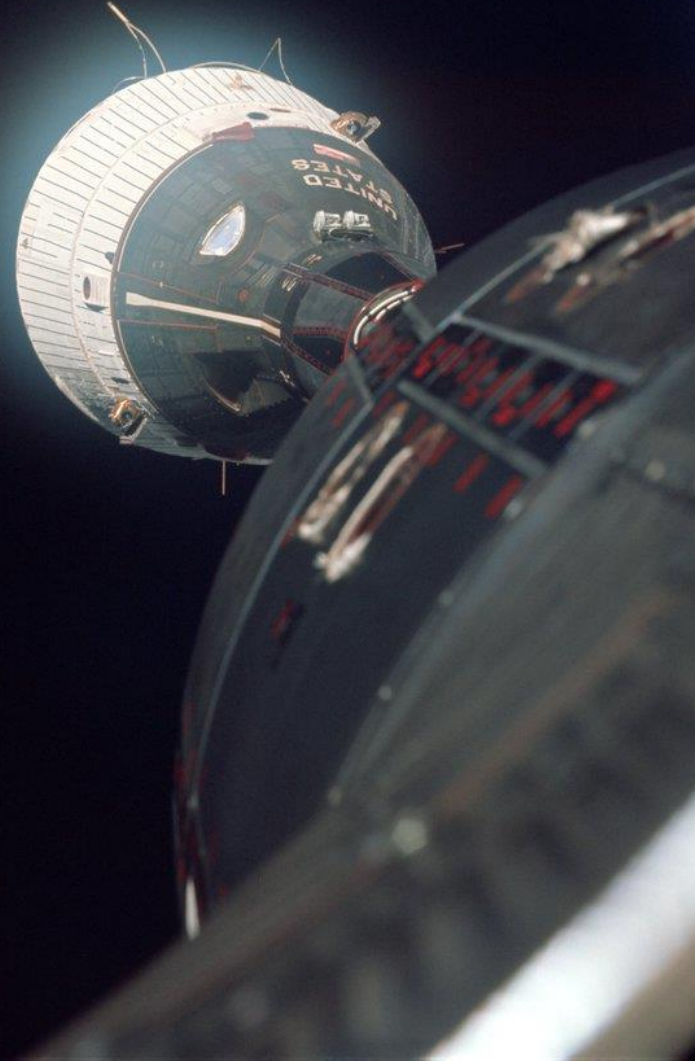


Vostok 6- Valentina Tereshkova

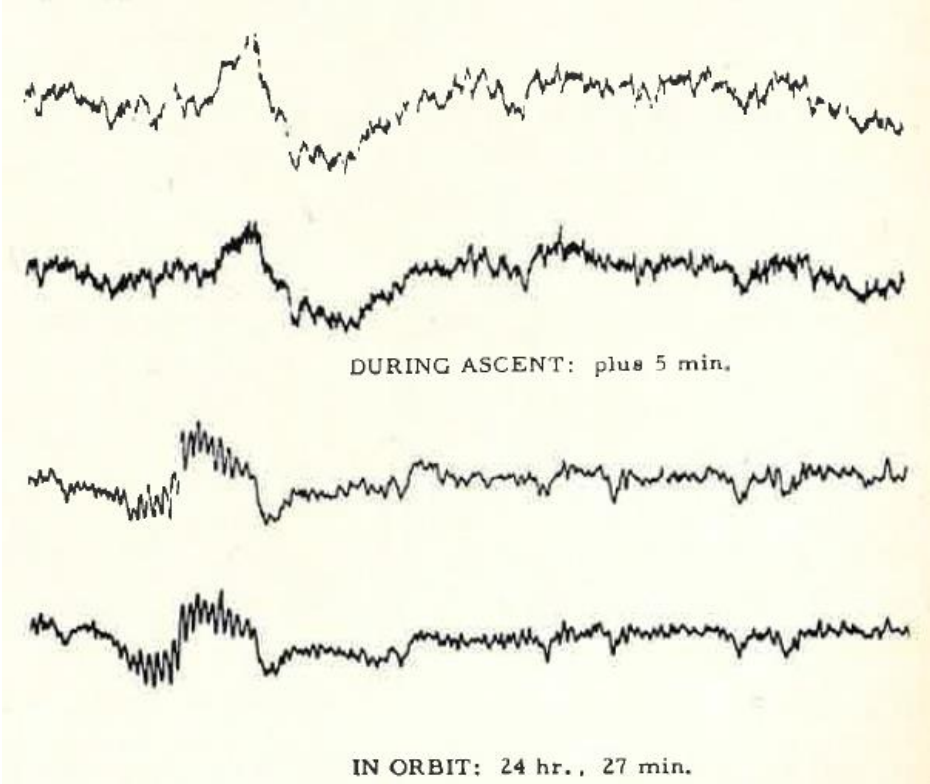




# Gemini 7, 1965

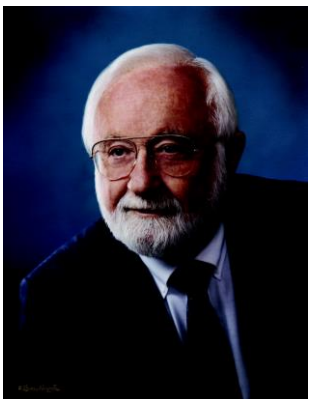


Figs. 1 and 2. Photographs of Command Pilot Frank Borman showing EEG electrodes attached to scalp (NASA photos).





# Gemini VII (1965)



Dr. Peter Kellaway

## GEMINI PROGRAM MISSION REPORT

### GEMINI VII

(U)

(NASA-TM-X-62892) GEMINI PROGRAM MISSION REPORT, GEMINI 7 (NASA) 395 p

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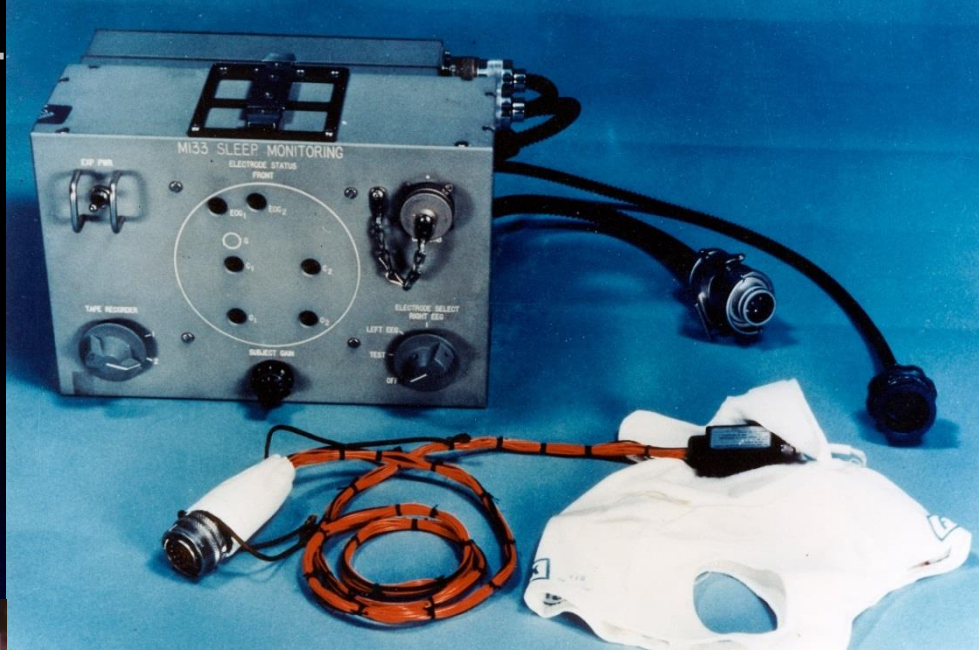
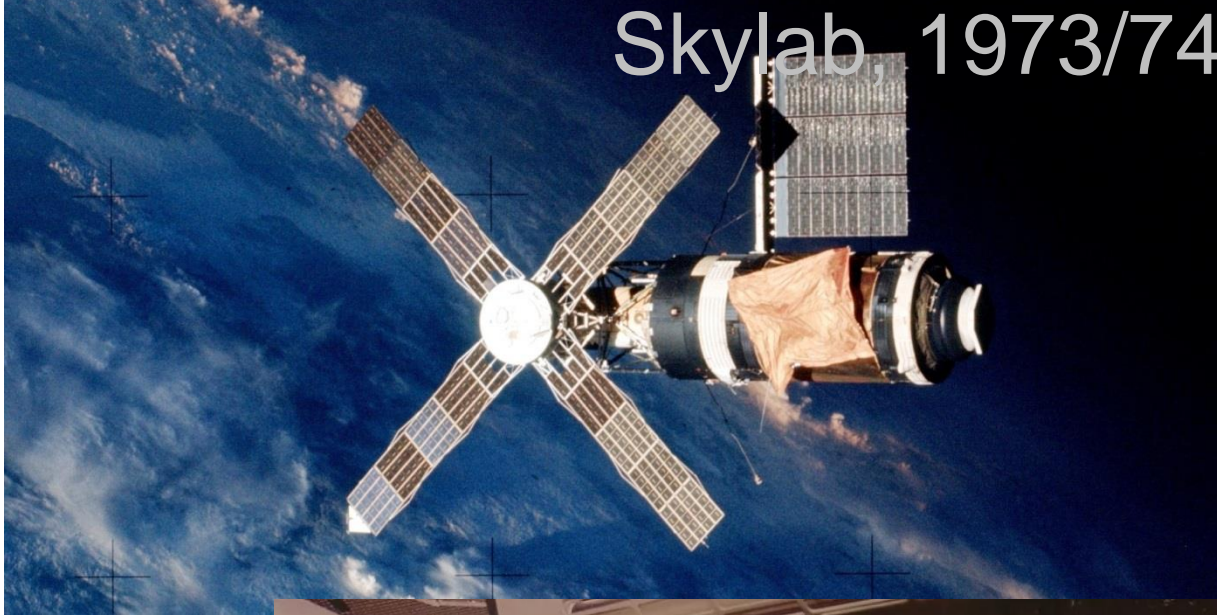


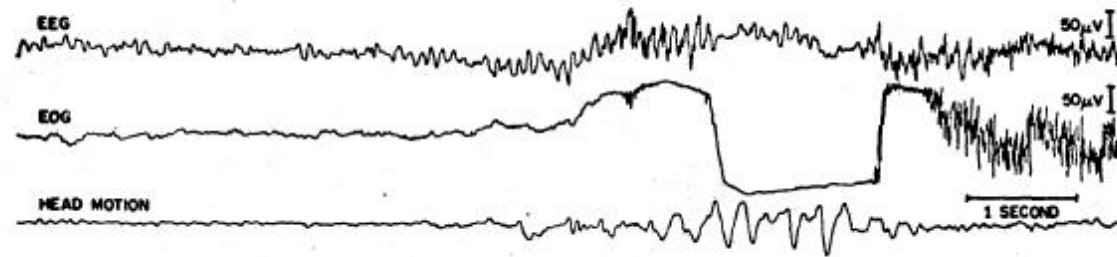
7.2.2.1.5 Other physiological data measurements: The EEG and phonocardiogram records were recorded on the inflight biomedical recorder only. The EEG was to be recorded continuously for 96 hours (4 days). During the first day of flight, one lead was detached inadvertently, despite the fact that the command pilot wore his helmet continuously to protect the sensor and leads. During the second day of flight, the remaining three leads became snagged on the ejection seat back and were detached. An attempt by the crew to replace the sensors was unsuccessful.

#### 8.10.4 Results

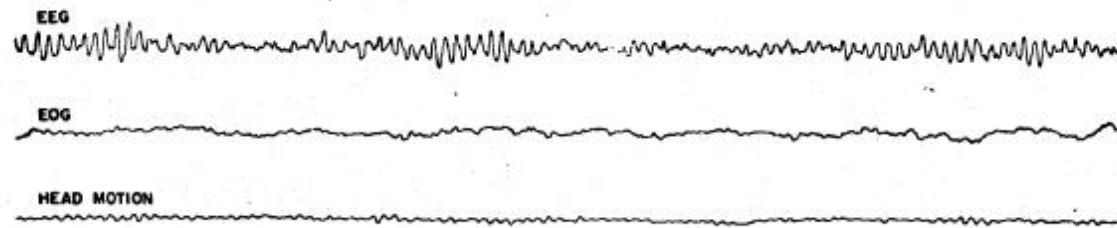
The experiment was terminated by the command pilot at 55:10 hours ground elapsed time after the accidental removal of all of the electrodes. A "quick-look" examination of the tapes has shown that usable EEG data were obtained during the 55-hour duration of the experiment. Analysis of the data is continuing.

# Skylab, 1973/74

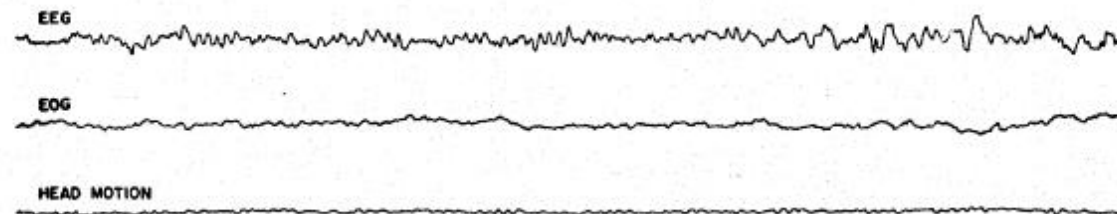




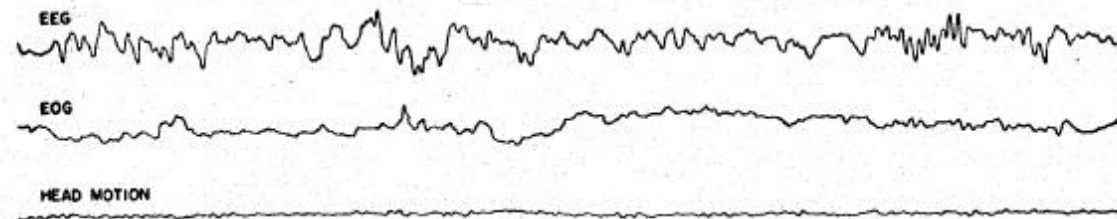
A. AWAKE, MOVING



B. AWAKE, RELAXED



C. STAGE 1

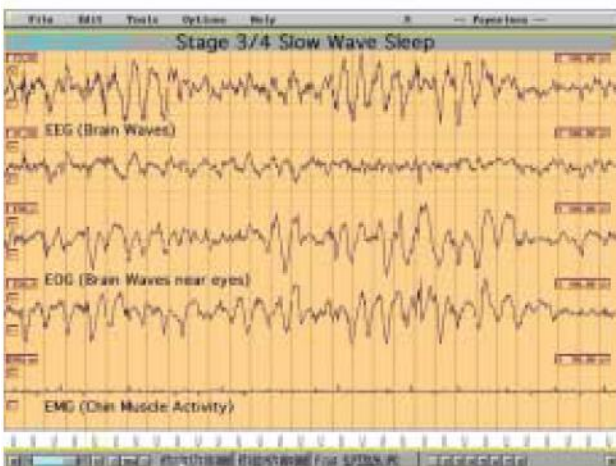
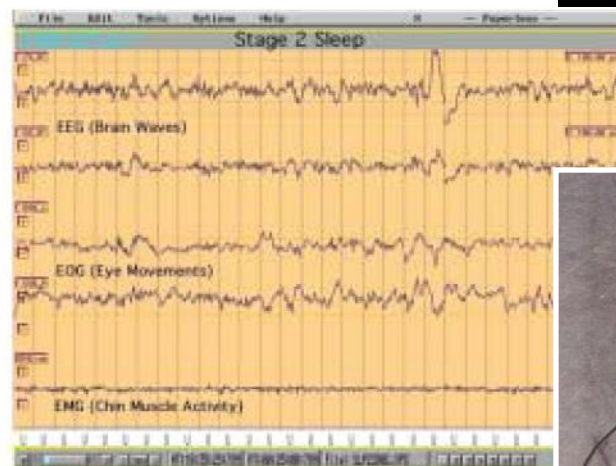
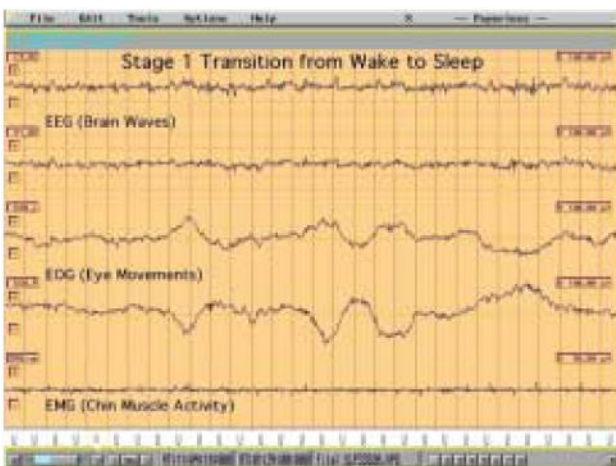
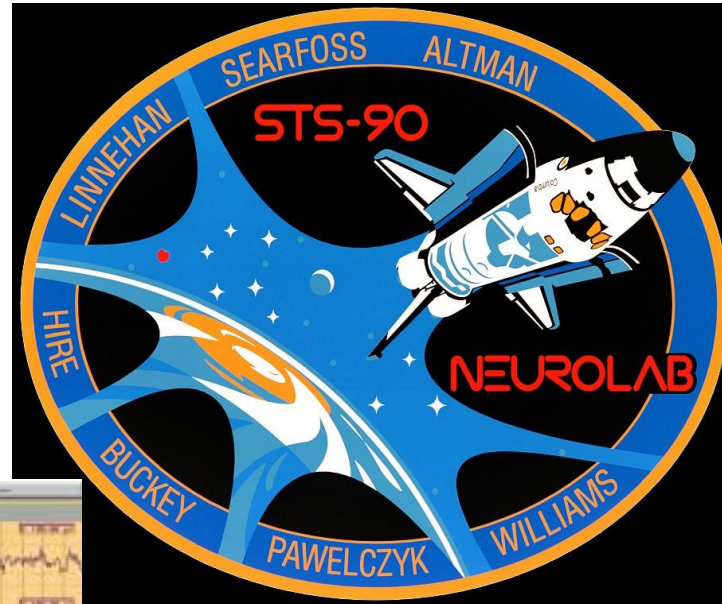




Blood Collection Belt Medilog Sleep Research Recorder (MSRR)



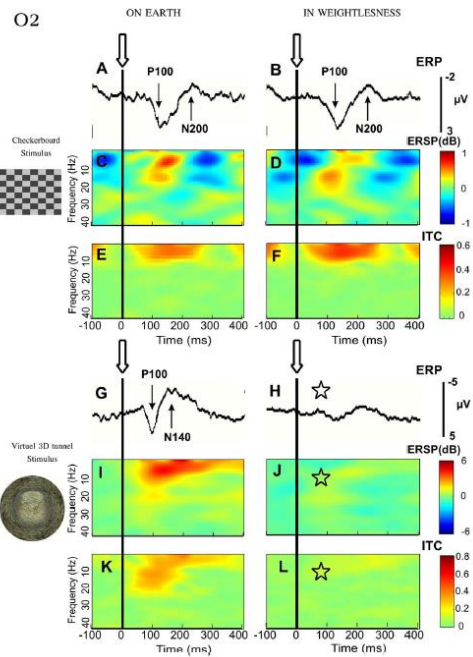
9301104  
PI: Czeisler (USA)  
1998





# NEUROCOG/NEUROSPAT (ESA)

PI: Dr. Cheron (BE)





# ALTEINA/ALTEA (IT/RU)

PI: Dr. Narici (IT)

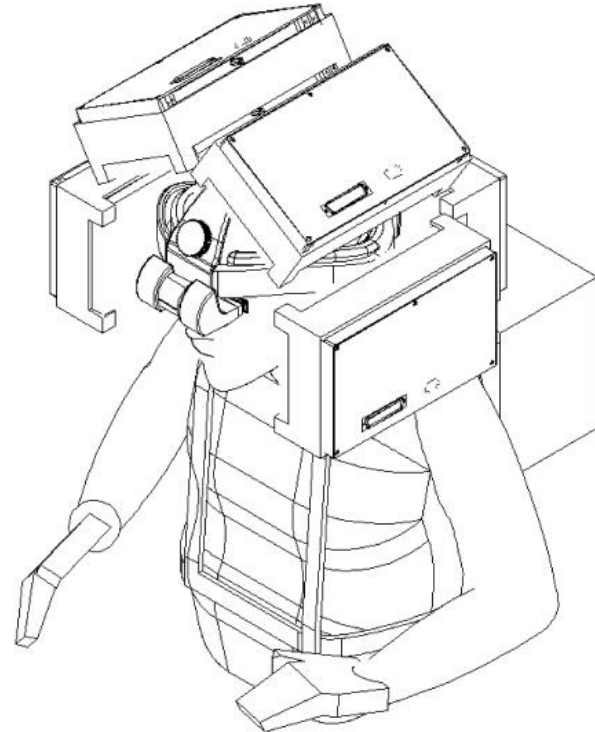
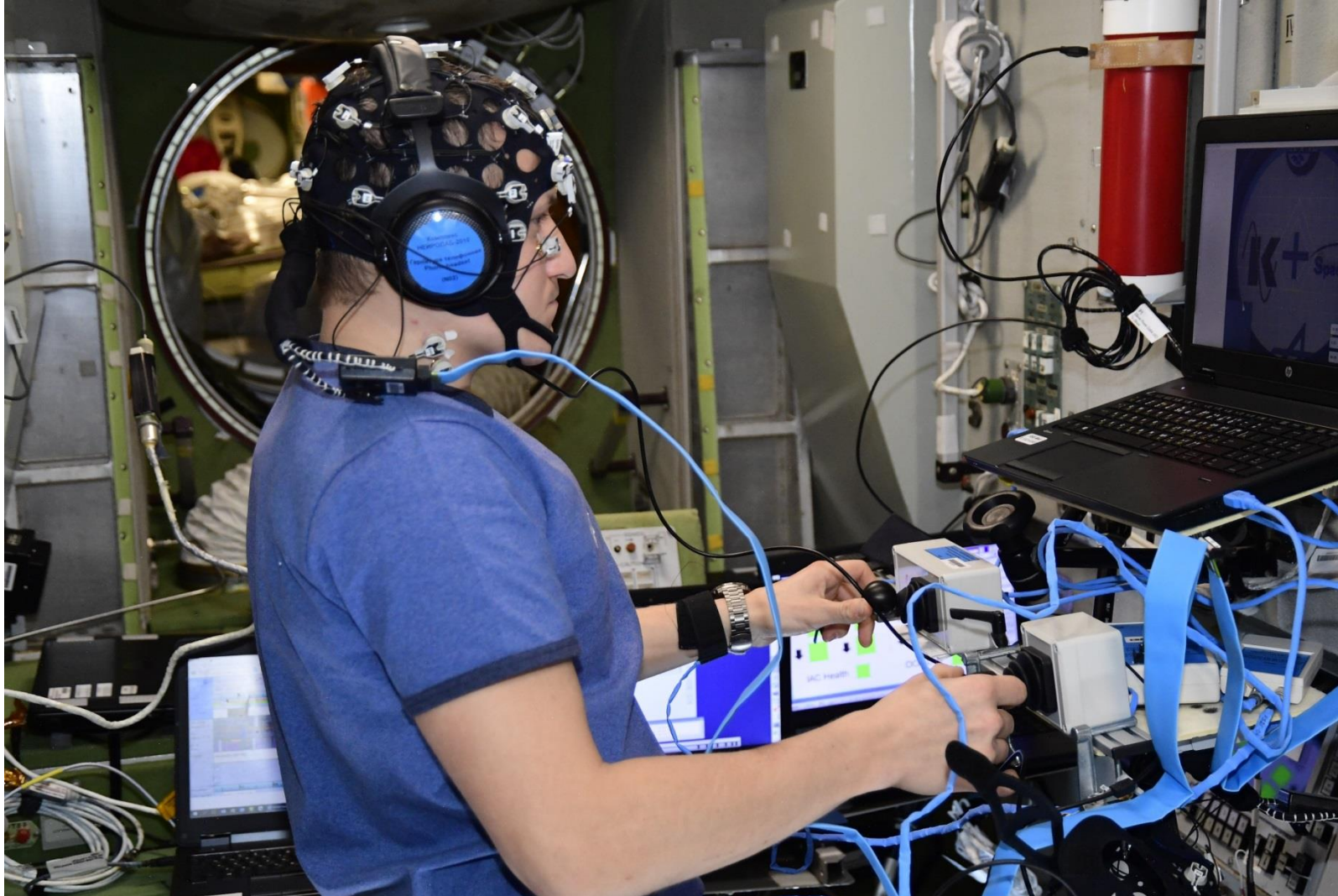


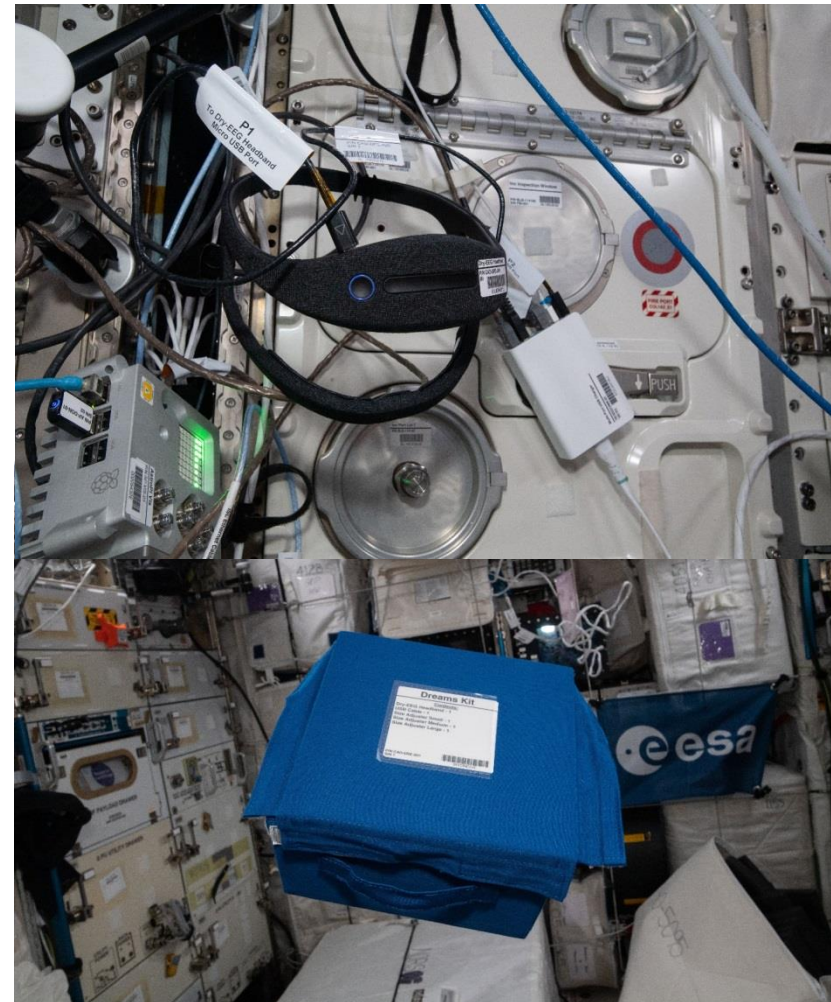
Fig. 1 – A schematic view of the astronaut with the ALTEA system (frontal Silicon Telescopes box not shown).



# PILOT-T (ROSCOSMOS/DLR)

PIs: D. Schastlivtcheva (RU), B. Johannes (GE) 2015



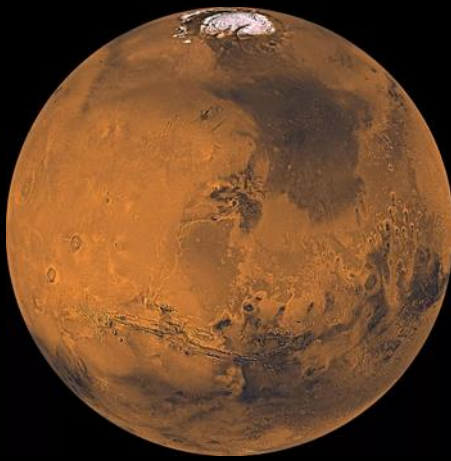


# TIANHE (CNSA)



# AXIOM-1 (Commercial Mission)





# Data Quality

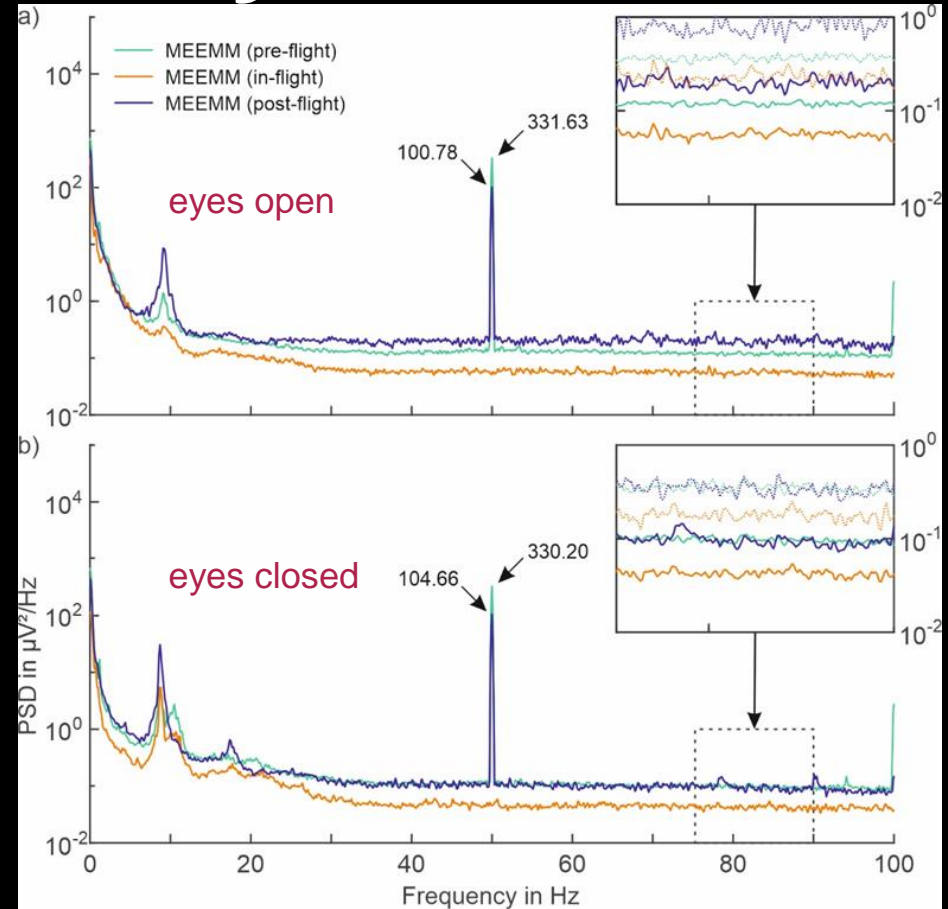
**EEG in-flight recording (orange) of superior quality compared to ground recordings.**

Average EEG power spectra of resting-state EEG data recorded with the MEEMM system during ground-level (pre- and post-flight) and in-flight conditions.

Solid lines represent mean; dotted lines represent mean + standard deviation

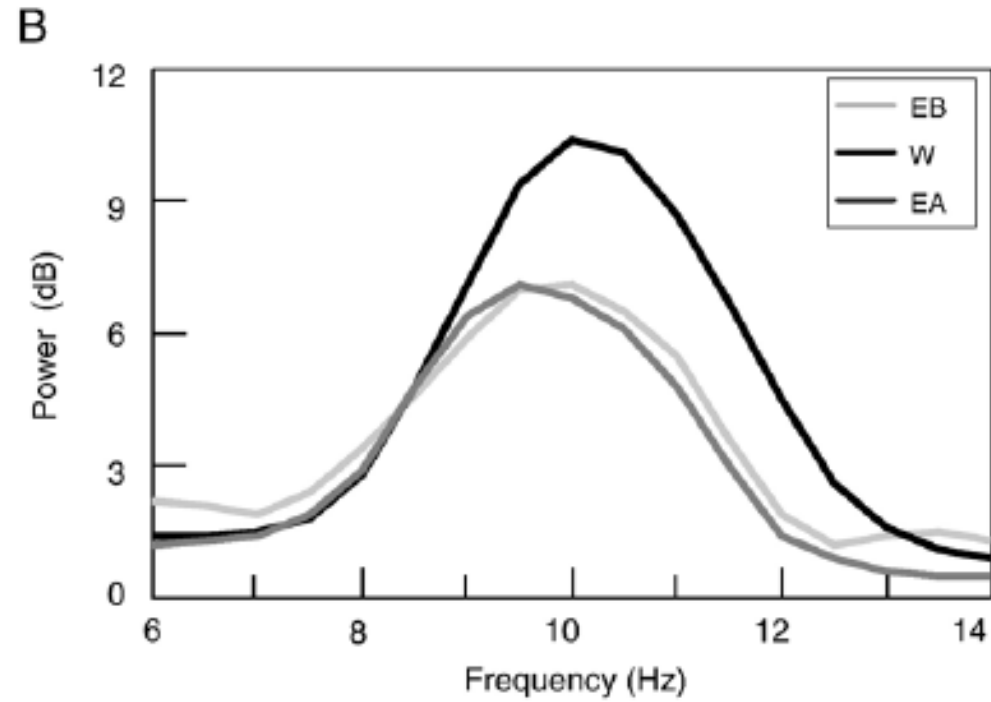


Fiedler et al., 2023, Plos One



Grand average power spectra of 120 s of EEG data from 5 astronauts pre-flight, inflight, and postflight.

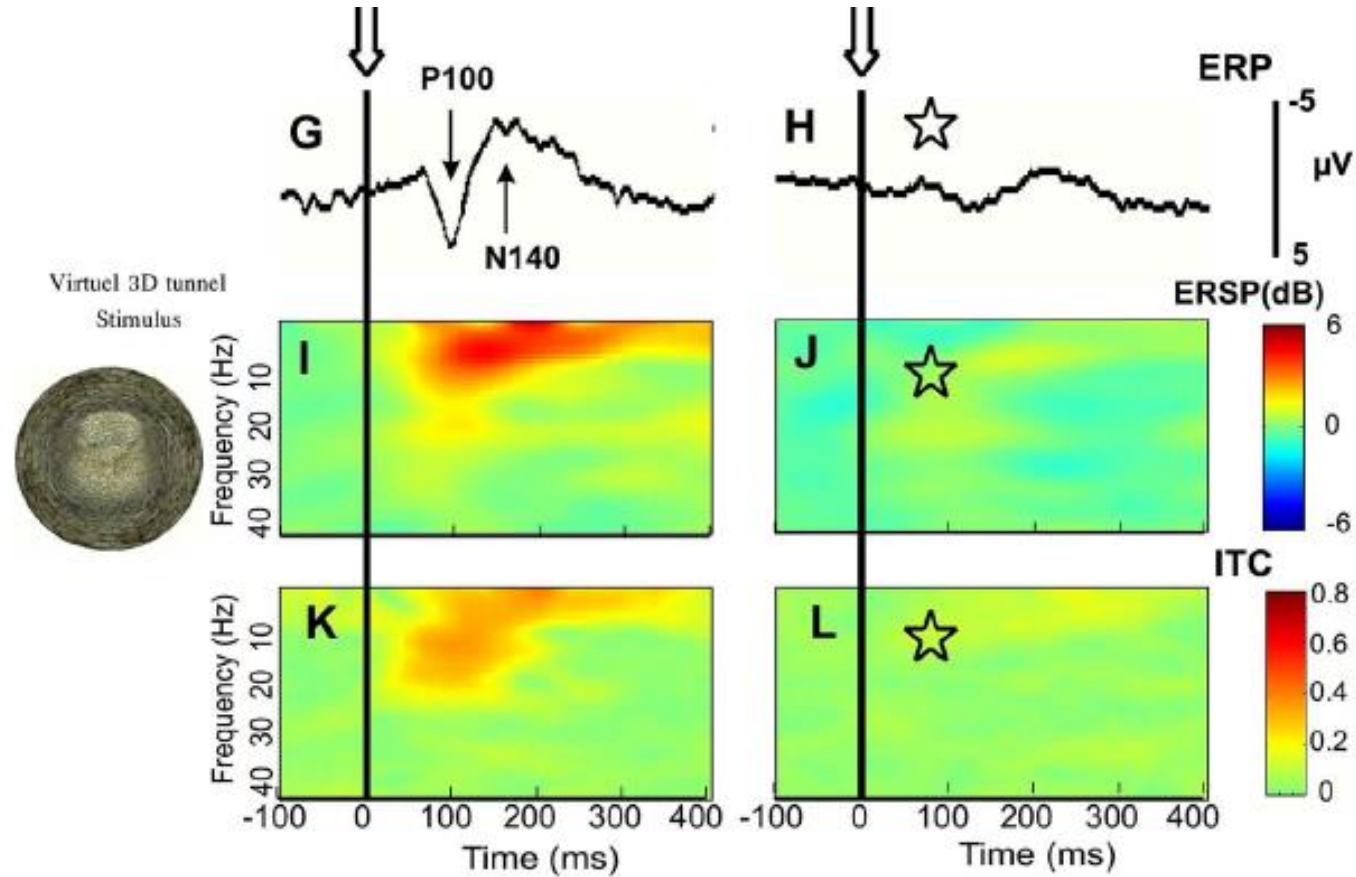
Differences between eyes close and open



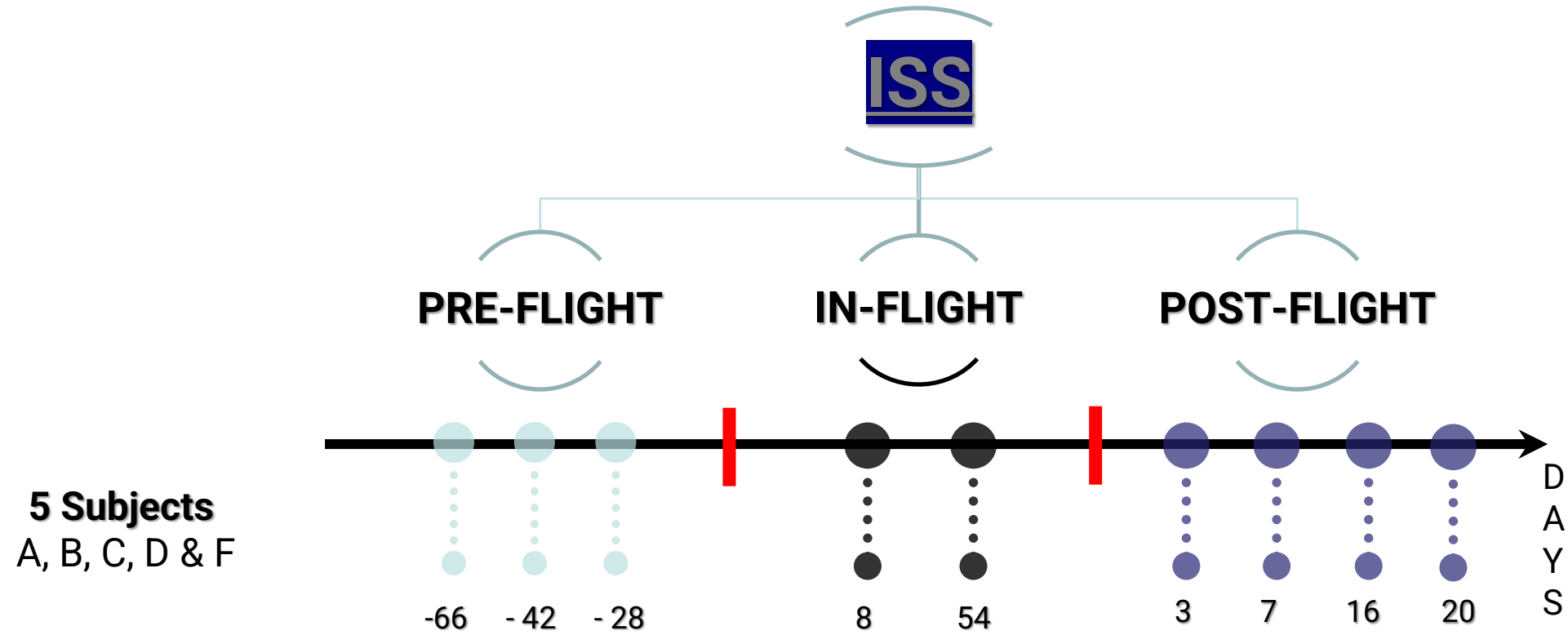
(Cheron et al, 2006)



phase-locking of theta-alpha oscillations was suppressed in weightlessness



(Cheron et al, 2014)



**5 Subjects**  
A, B, C, D & F

**Eyes closed**

**Measures**

Source space (eloreta)  
Alpha peak  
Power (AVG - DMN)  
FC (PLV) – Strength (AVG - DMN)

**Frequency Bands:**

Delta: 2-4Hz  
Theta: 4-8Hz  
Alpha: 8-12Hz  
Beta: 12-30 Hz  
Gamma: 30 -45 Hz

(Cheron et al, 2014)  
(Pusil et al, 2023)



16 subjects (8 in the morning 8 in the afternoon)

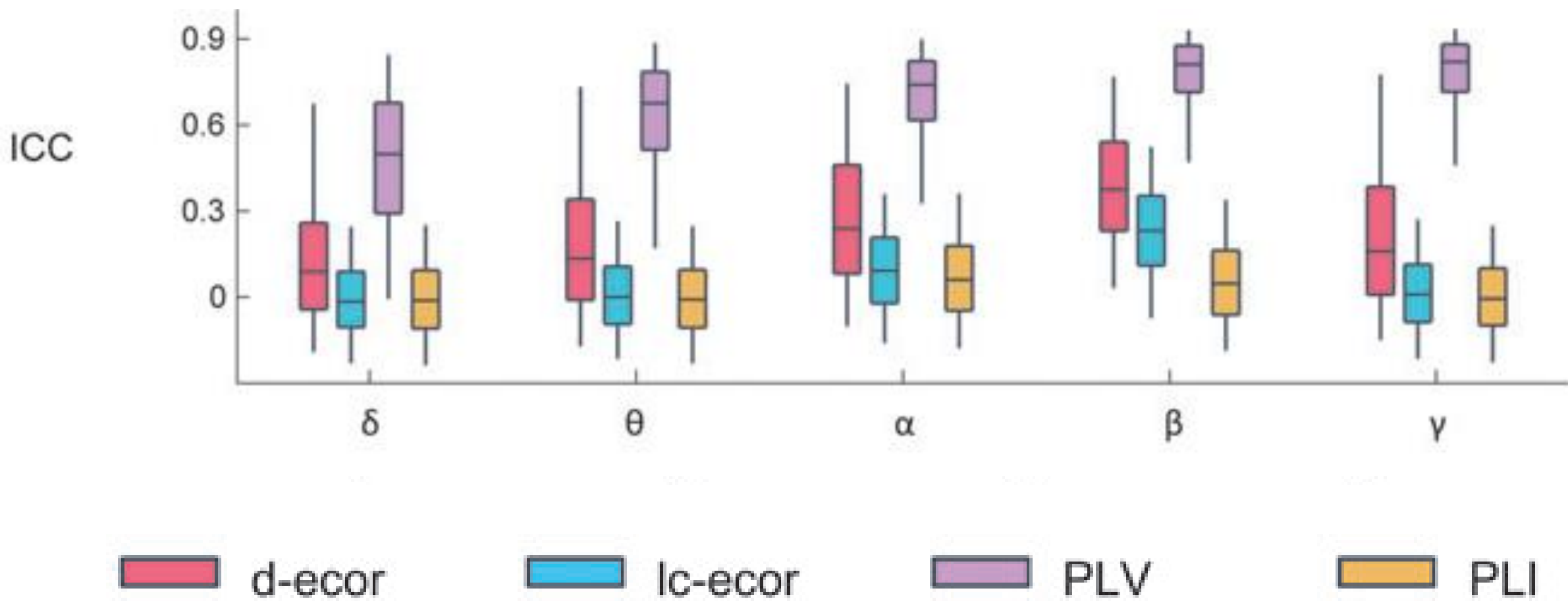


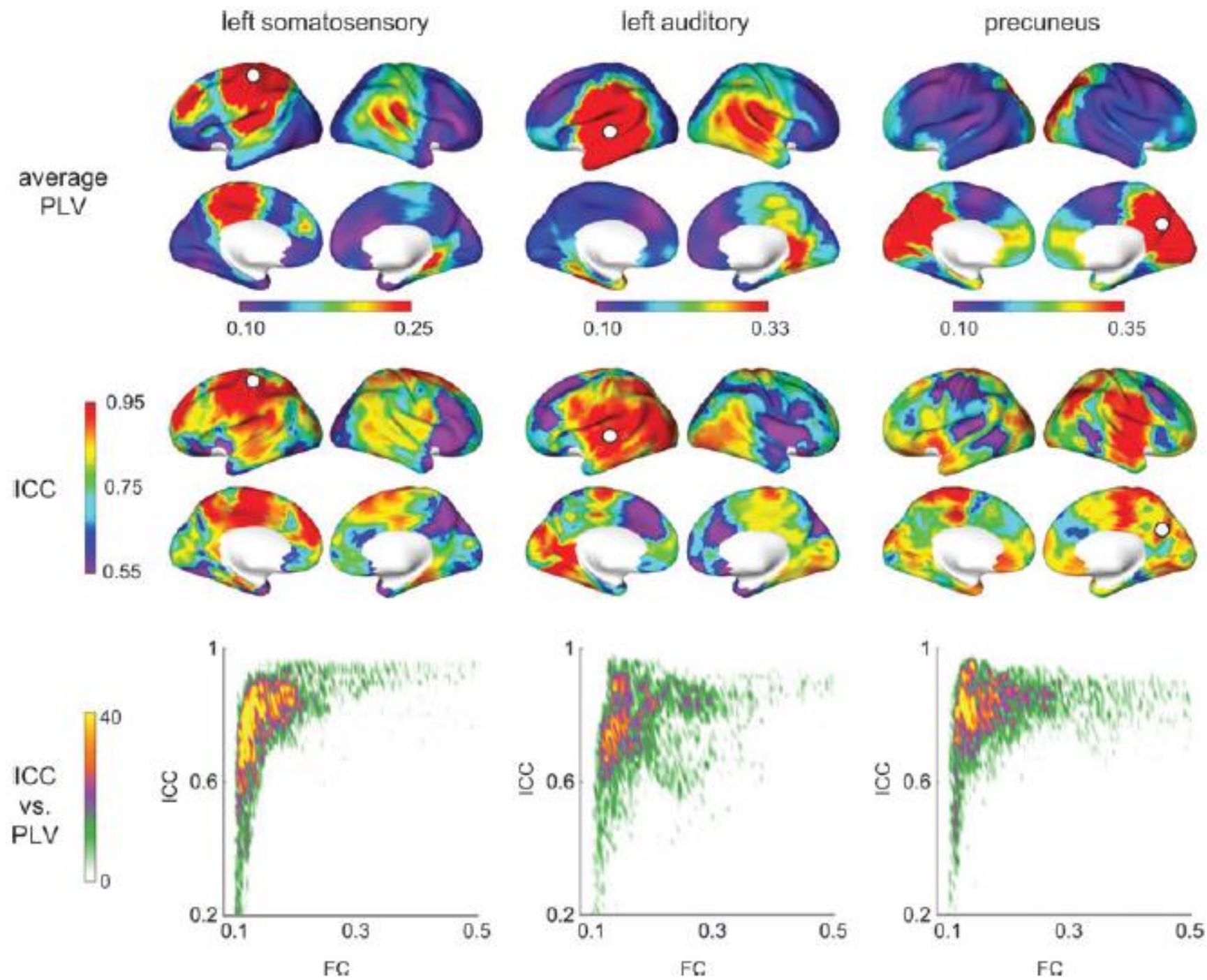
One week

One week

Time

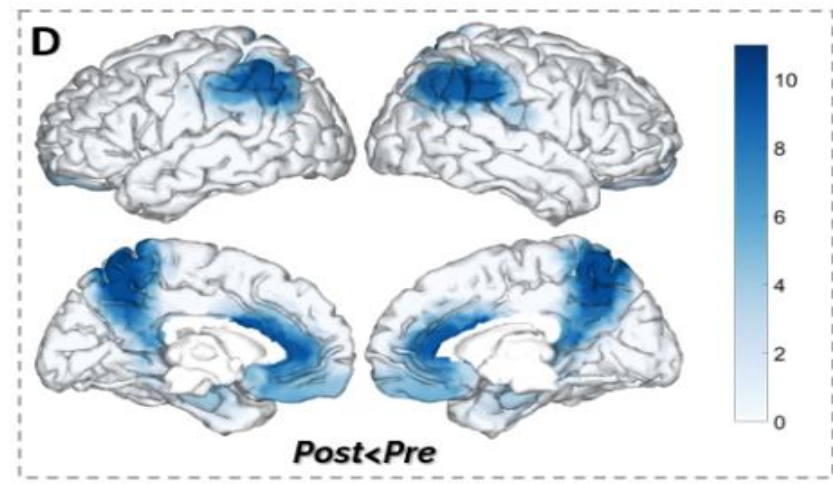
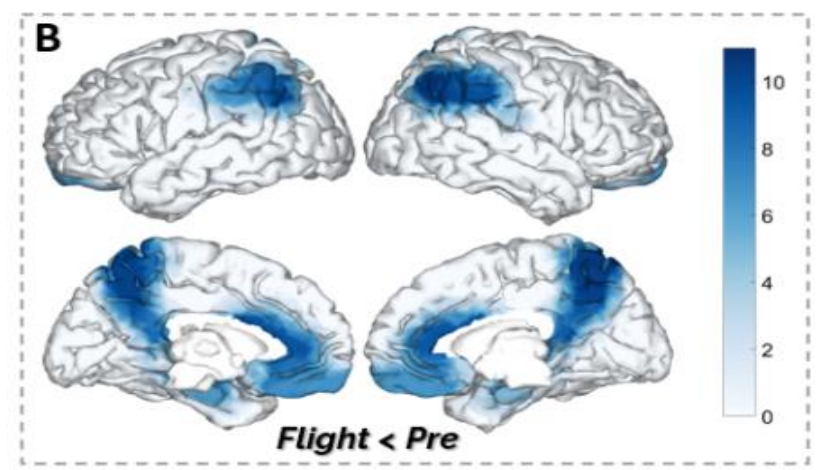
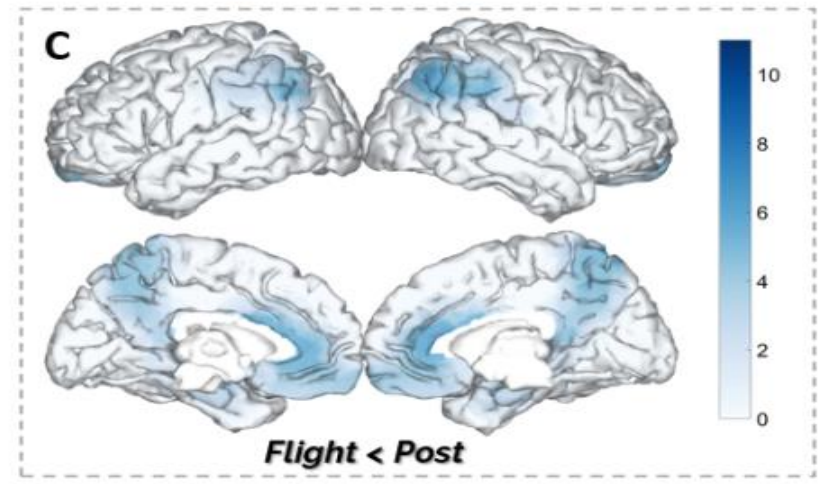
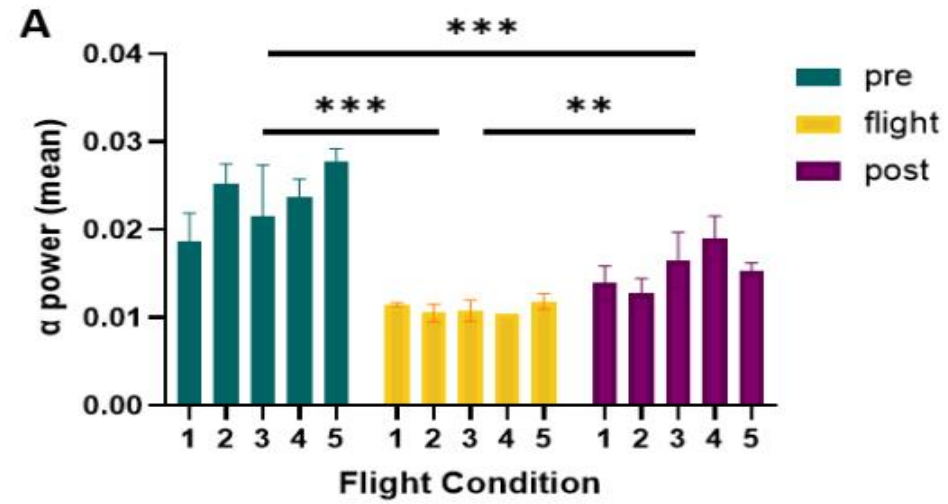
(Garces et al, 2016)





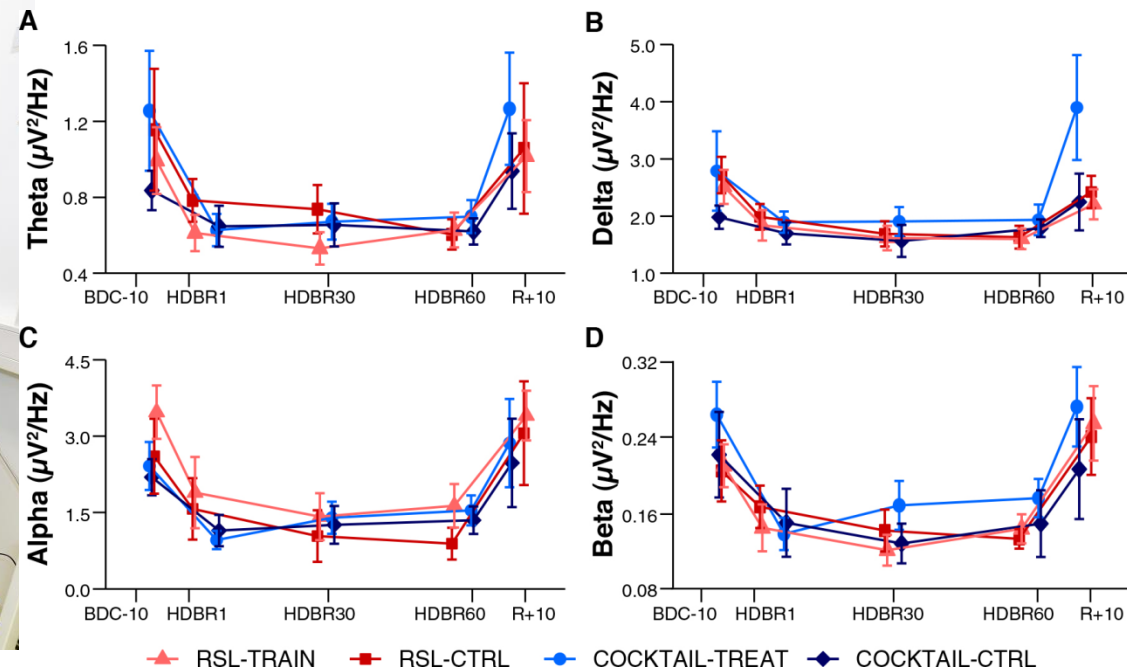
(Garces et al, 2016)

## Changes in DMN Alpha band power (eyes closed) between flight conditions



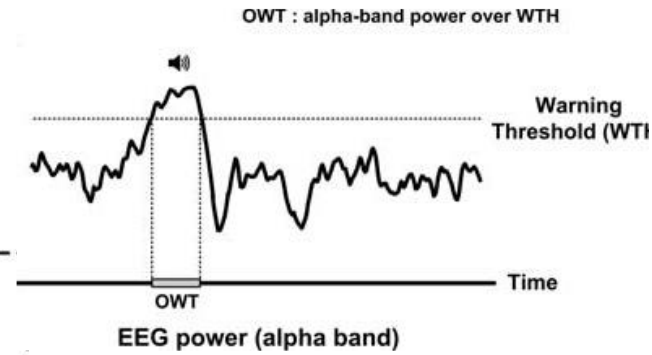
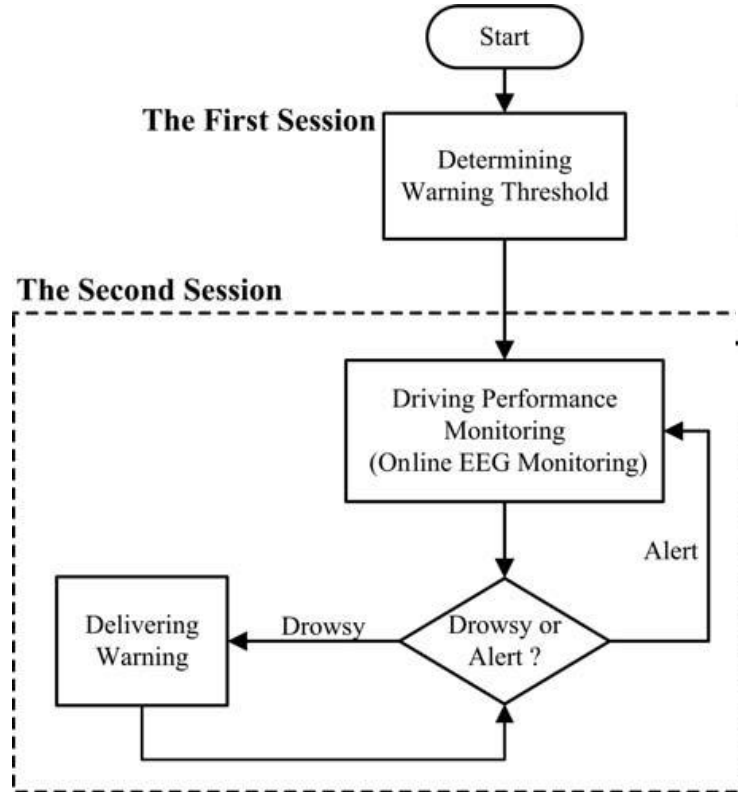
(Pusil et al, 2023)

## Bed-Rest Dataset

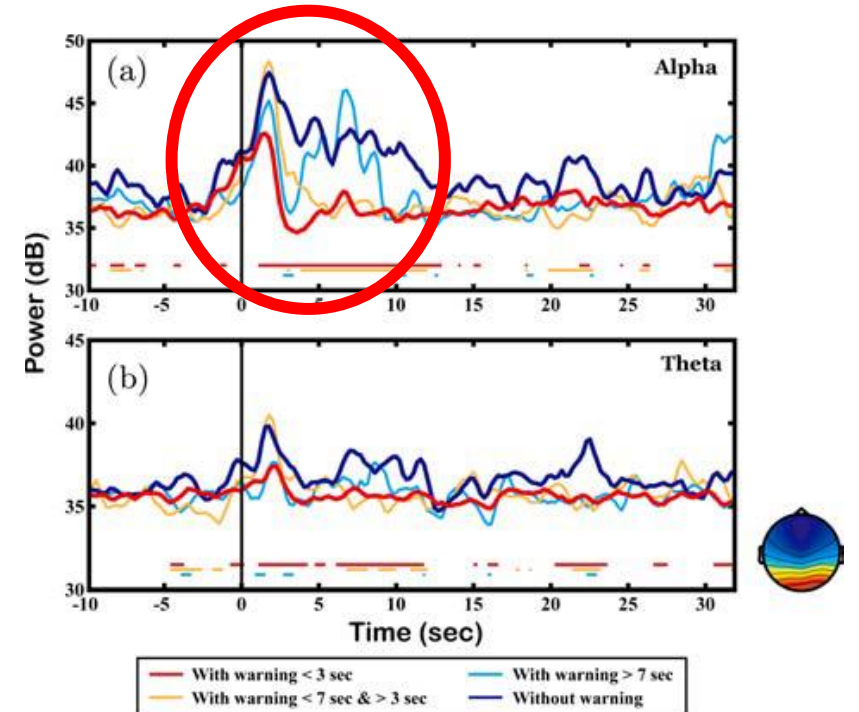


(Brauns et al, 2021)

# Fatigue



Alpha threshold



(Huang et al, 2016)





## CONCLUSIONS

1. Functional and anatomical changes after spaceflights
2. Cognitive and motor performance could have a physiological EEG equivalent
3. Changes in power and connectivity during flight conditions
4. More data and research needed

To: Prof. Fernando Maestú and the team of the Laboratory of Cognitive and Computational Neuroscience at the Complutense University of Madrid, Spain

# Best Wishes from Orbit & Happy 2022!



Anton Shkaplerov  
Soyuz MS-19/ISS-66



*Regis Chan*  
*Mattias M*  
*M. J. ...*  
*Tom ...*

