NATIONAL
SPACE ACADEMY

Astro Academy: Principia - physics from the ISS

NATIONAL SPACE CENTRE

Science & Technology Facilities Council

UK SPACE AGENCY

esa

CATAPULT Satellite Applications

Lloyd's Register Foundation

Title: 'Teaser'
Edit: 07
Duration: 01m 27s
Market: United Kingdom
Product: NSA Educational Content
Client: National Space Academy
Date: 07.09.16
Job: NSA1506001

CRAFT 7-11 Herbrand Street London WC1N 1EX / +44 (0) 20 7961 2000 / craftww.com

Who qualifies for astronaut/cosmonaut status?

- FAI (Karman line) – 100 km (328 000 ft)
- USAF – 50 miles (80 km…..264 000ft)

Why dream of space?

- Definition – a propulsion system containing both fuel and oxidiser
- First true rockets – Chinese “fire arrows” (13th Century)

<u>Solid fuels</u>

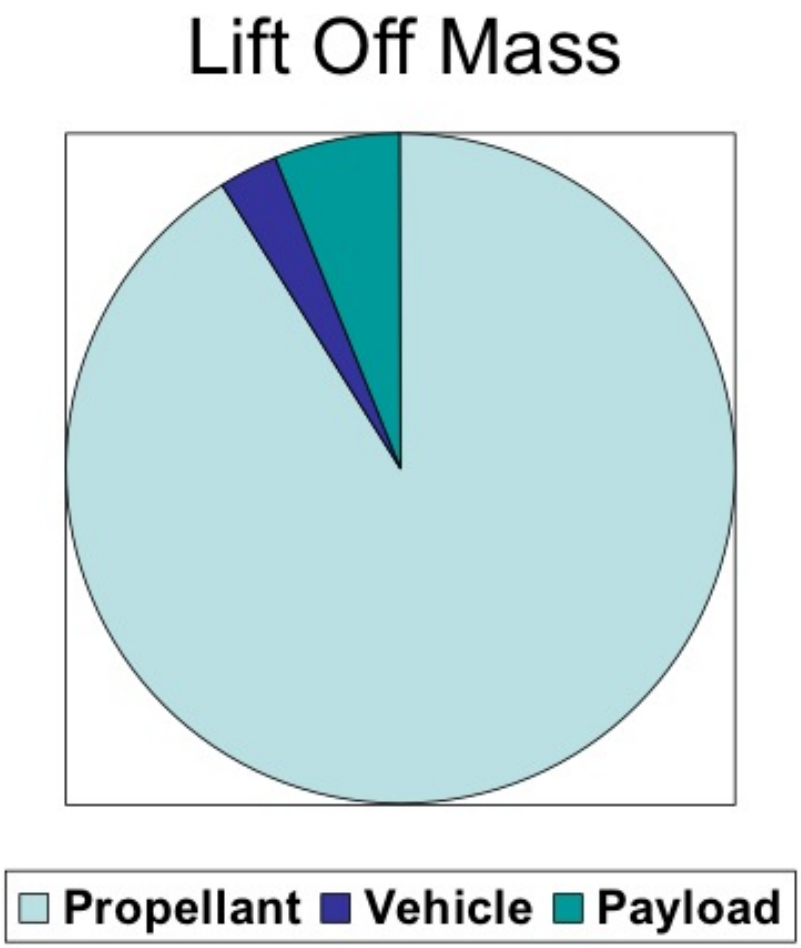
☺ Simple, stable, can store for a long time

☹ Cannot stop them once ignited

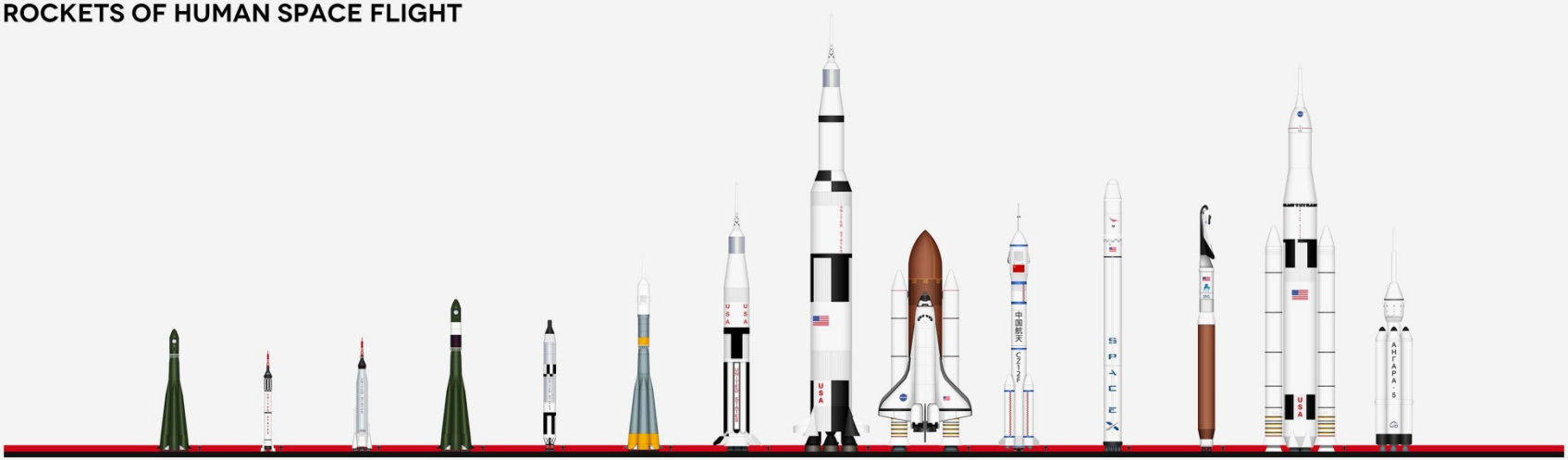
<u>Liquid fuels</u>

☺ Throttle-able, high “specific impulse”

☹ Low temperatures (cryogenic – 90K for LOX, 20K for LH2), complex engineering systems, possible toxicity issues



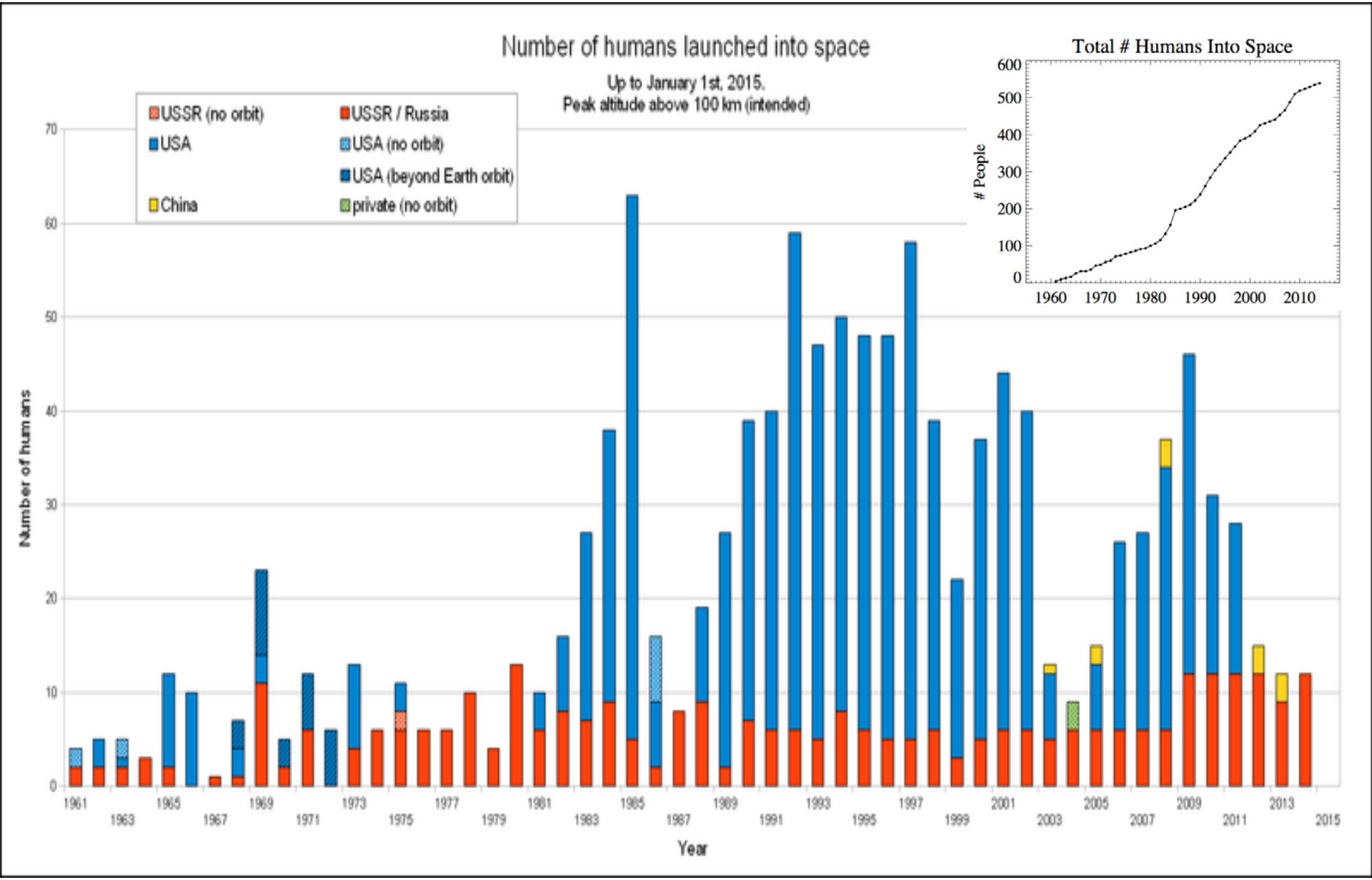
ROCKETS OF HUMAN SPACE FLIGHT

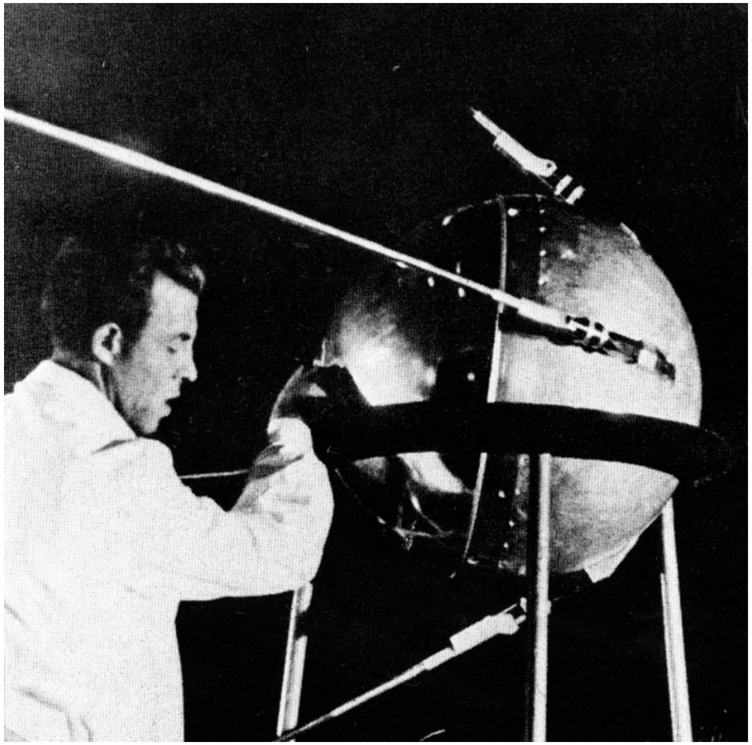


1961 VOSTOK-K	1961 MRLV	1962 ATLAS LV-3B	1964 VOSKHOD	1965 TITAN II GLV	1967 SOYUZ	1968 SATURN 1B	1968 SATURN V	1981 STS	2003 LONG MARCH 2F	FALCON 9	ATLAS V DREAM CHASER	SLS	ANGARA-A5P
Payload to Low Earth Orbit													
4752 KG	SUBORBITAL	1360 KG	5900 KG	3600 KG	7100 KG	46000 KG	120000 KG	24000 KG	8400 KG	13150 KG	10470 KG	70000 KG	

average hieght of a person

2013 SKRABEK


Number of humans launched into space
Up to January 1st, 2015.
Peak altitude above 100 km (intended)
USSR (no orbit)
USSR / Russia
USA
USA (no orbit)
USA (beyond Earth orbit)
China
private (no orbit)
Number of humans
Year
Total # Humans Into Space
People



"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

NEW YORK, SATURDAY, OCTOBER 5, 1957.

FIVE CENTS

SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

HOFFA IS ELECTED TEAMSTERS HEAD; WARNS OF BATTLE

Defeats Two Foes 3 to 1 —Says Union Will Fight 'With Every Ounce'

COURSE RECORDED

Navy Picks Up Radio Signals—4 Report Sighting Device

560 MILES HIGH

Visible With Simple Binoculars, Moscow Statement Says

Device Is 8 Times Heavier Than One Planned by U.S.

FAUBUS COMPARES HIS STAND TO LEE'S

Says He Will Remain Loyal to People of Arkansas— All Is Quiet at School

Flu Widens in City; 18% Rate Predicted; 200,000 Pupils Out

ARGENTINA TAKES EMERGENCY STEPS

State of Siege Proclaimed in Buenos Aires Region —Arrests Reported

SATELLITE SIGNAL BROADCAST HERE

Ex-Premier Mollet Accepts Bid To Form a New French Cabinet

City Suits Charge That Schupler, Brooklyn Councilman, Sold a Job

Warsaw Crushes New Protest; Clubs, Tear Gas Rout Students

The Huntsville Times

Man Enters Space

'So Close, Yet So Far,' Sighs Cape

U.S. Had Hoped For Own Launch

Soviet Officer Orbits Globe In 5-Ton Ship

Maximum Height Reached Reported As 188 Miles

Hobbs Admits 1944 Slaying

To Keep Up, U.S.A. Must Run Like Hell

Praise Is Heaped On Major Gagarin

'Worker' Stands By Story

First Man To Enter Space Is Pf. Married, Father Of Two

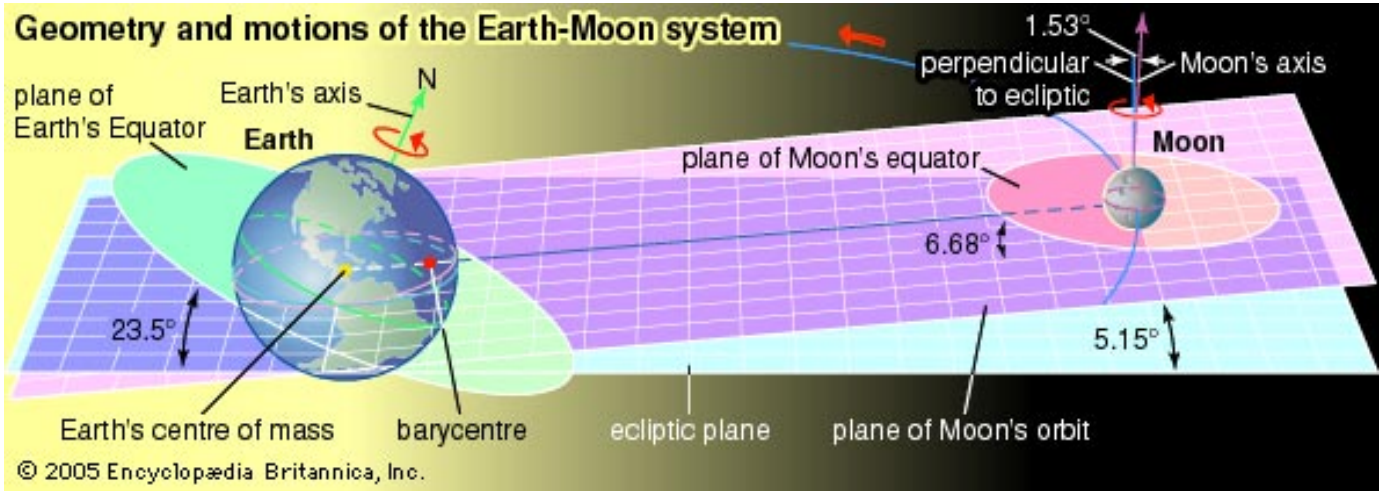
Reds Decry Spacemen Have Died

Reds Win Running Lead In Race To Control Space

“ I believe that this nation should commit itself, before this decade is out, to putting a man on the Moon and returning him safely, before this decade is out”

What the maths really tells us……the view from DSCOVR

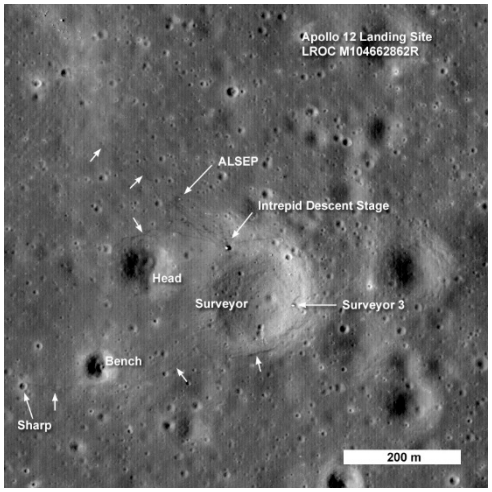
- **Earth diameter = 12 800 km**
- **Moon diameter = 3 460km**
- **Earth-Moon distance = 384 000km**

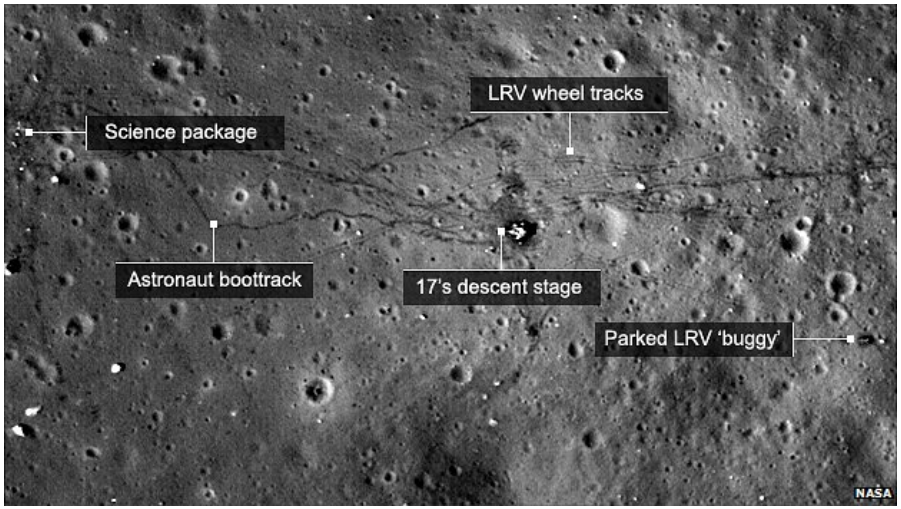


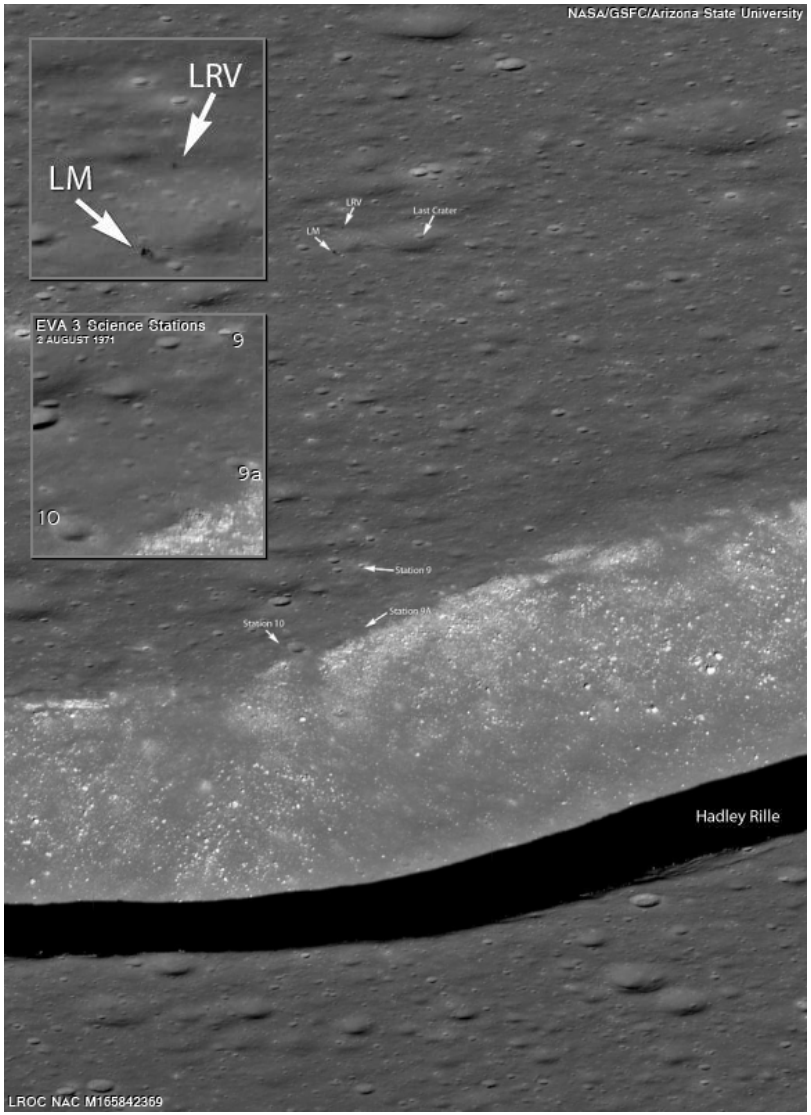
1963-65.....The Soviets still getting ahead?

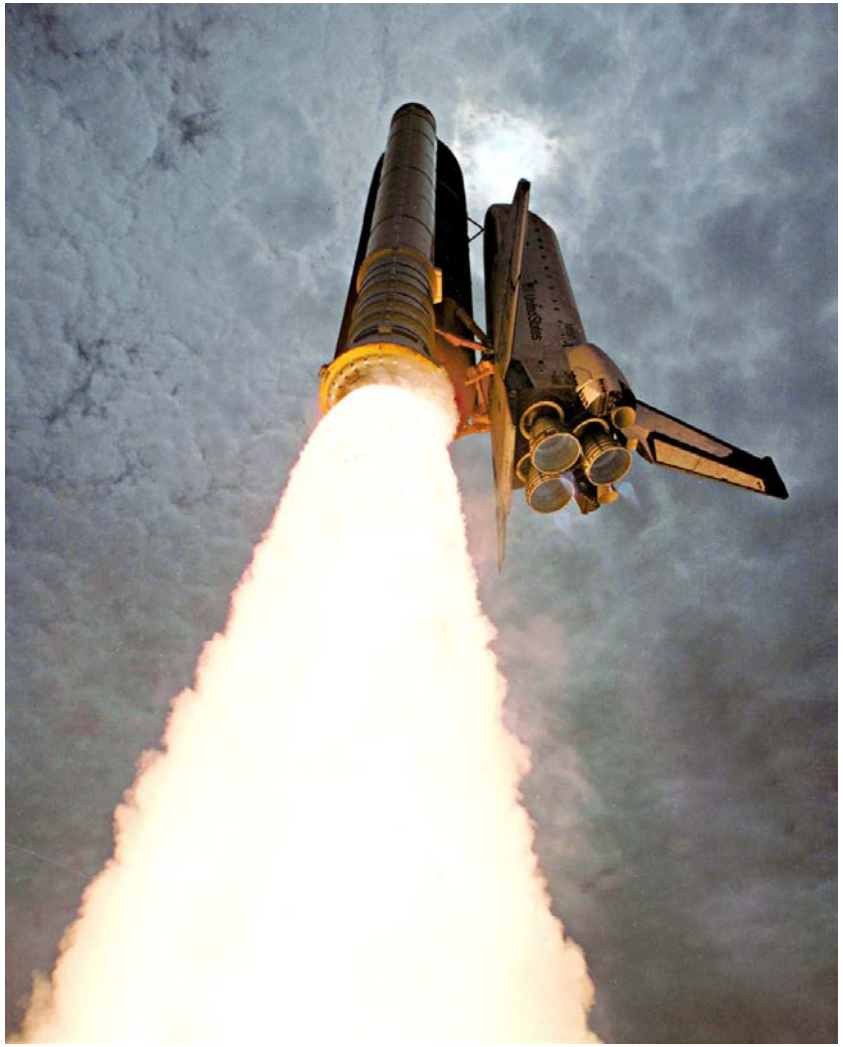
Project Apollo – the pinnacle of exploration

- 1968-1972
- 9 lunar missions
- 24 humans ventured into deep space – 12 landed
- 6 successful landings and one “magnificent failure”

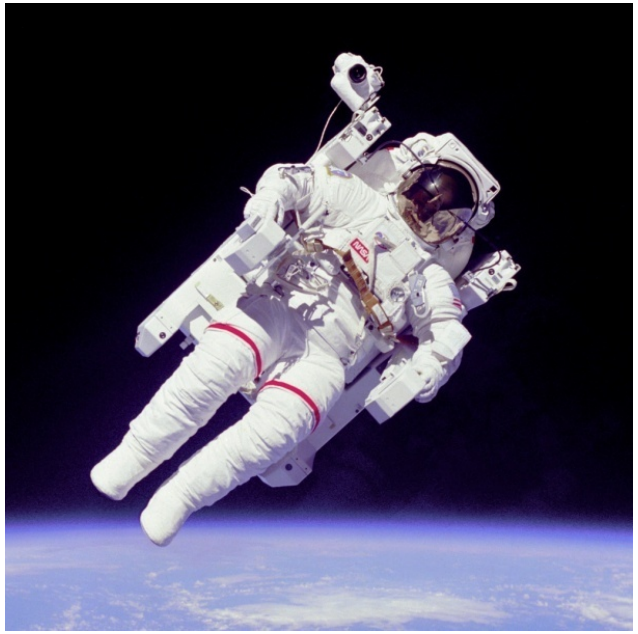

Apollo 12 Landing Site
LROC M104662862R
ALSEP
Intrepid Descent Stage
Head
Surveyor
Surveyor 3
Bench
Sharp
200 m

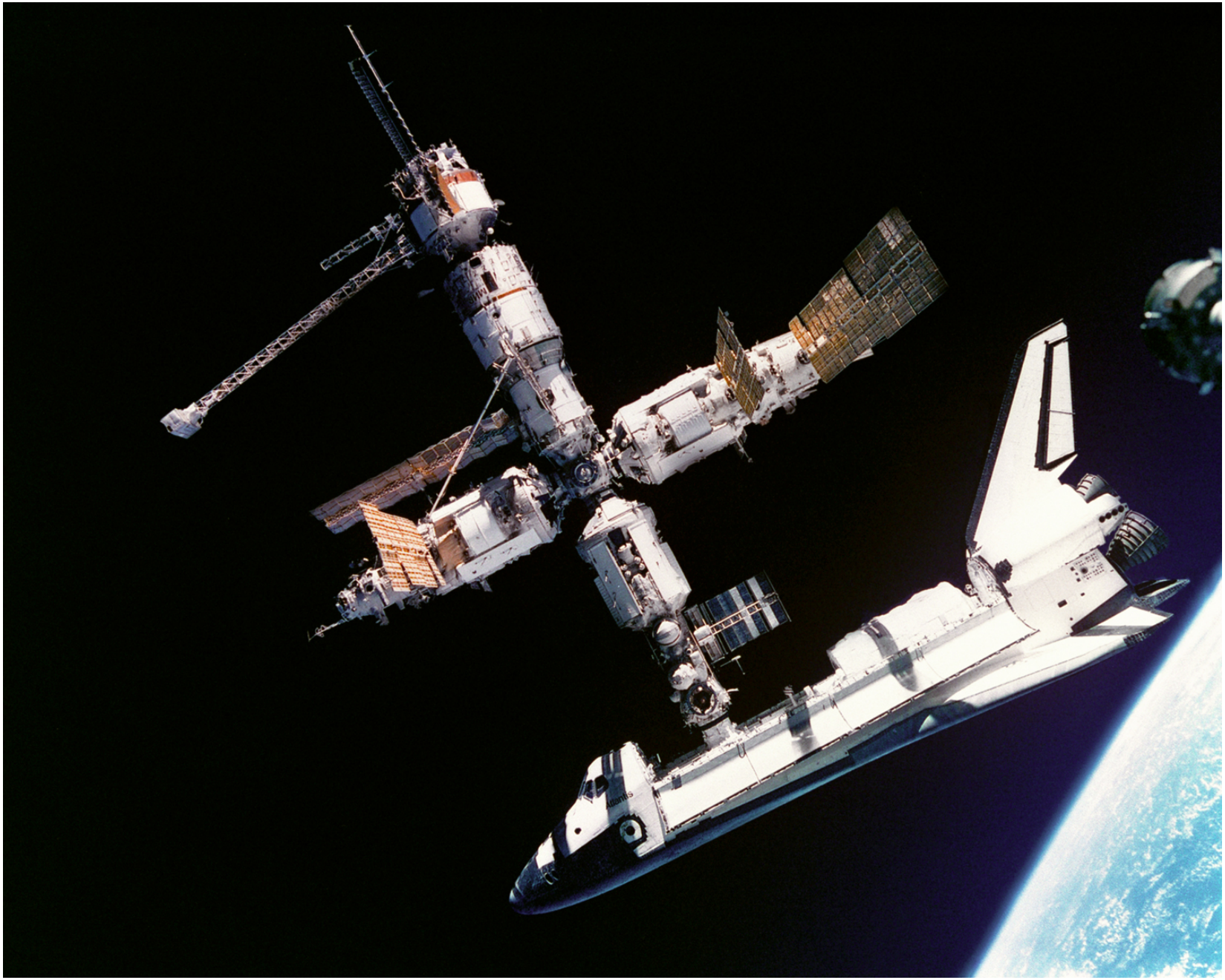

LRV wheel tracks
Science package
Astronaut boottrack
17's descent stage
Parked LRV 'buggy'
NASA


NASA/GSFC/Arizona State University
LRV
LM
EVA 3 Science Stations
2 AUGUST 1971
9
9a
10
Station 9
Station 9A
Station 10
Hadley Rille
LROC NAC M165842369



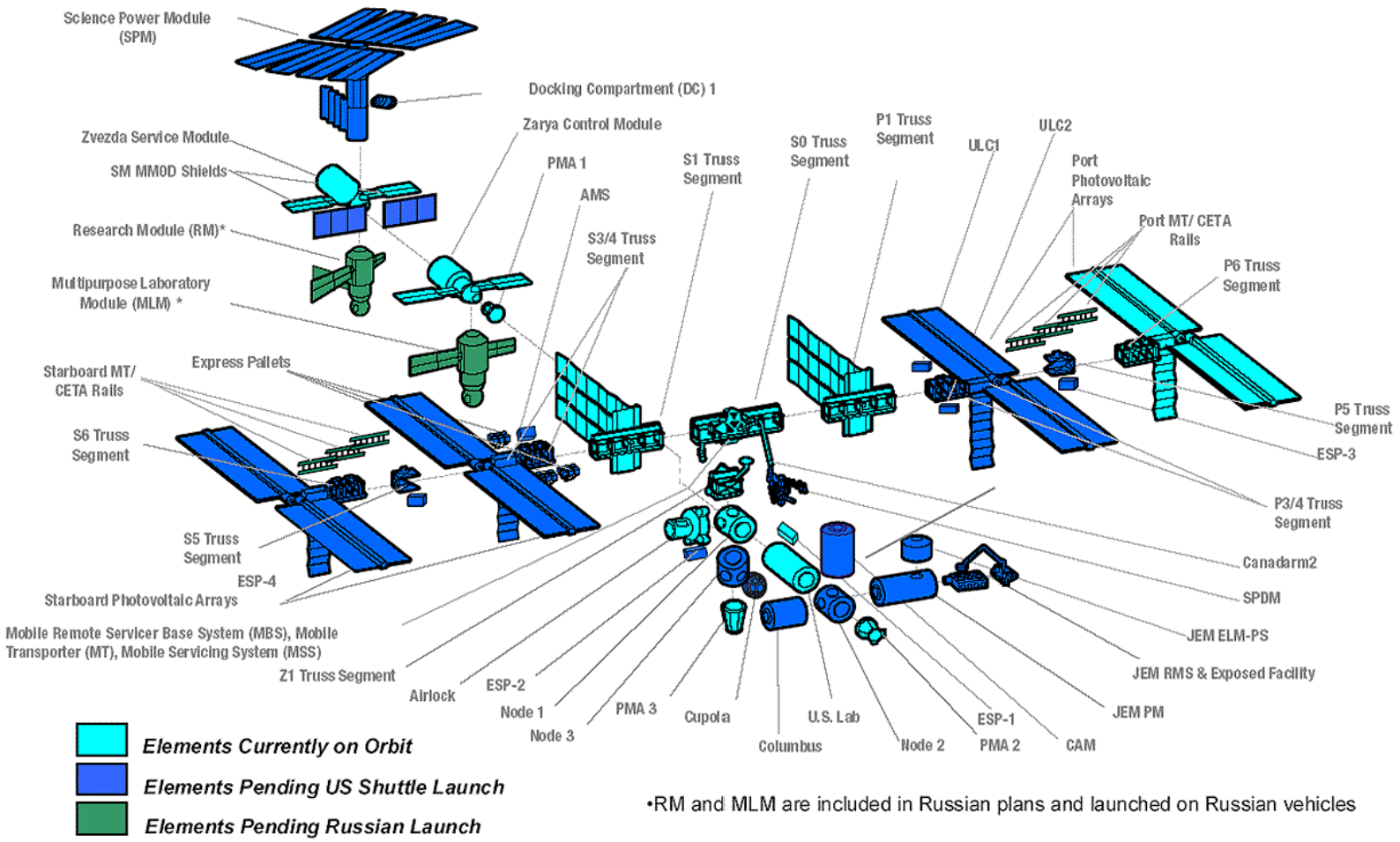

SCIENCE PHOTO LIBRARY



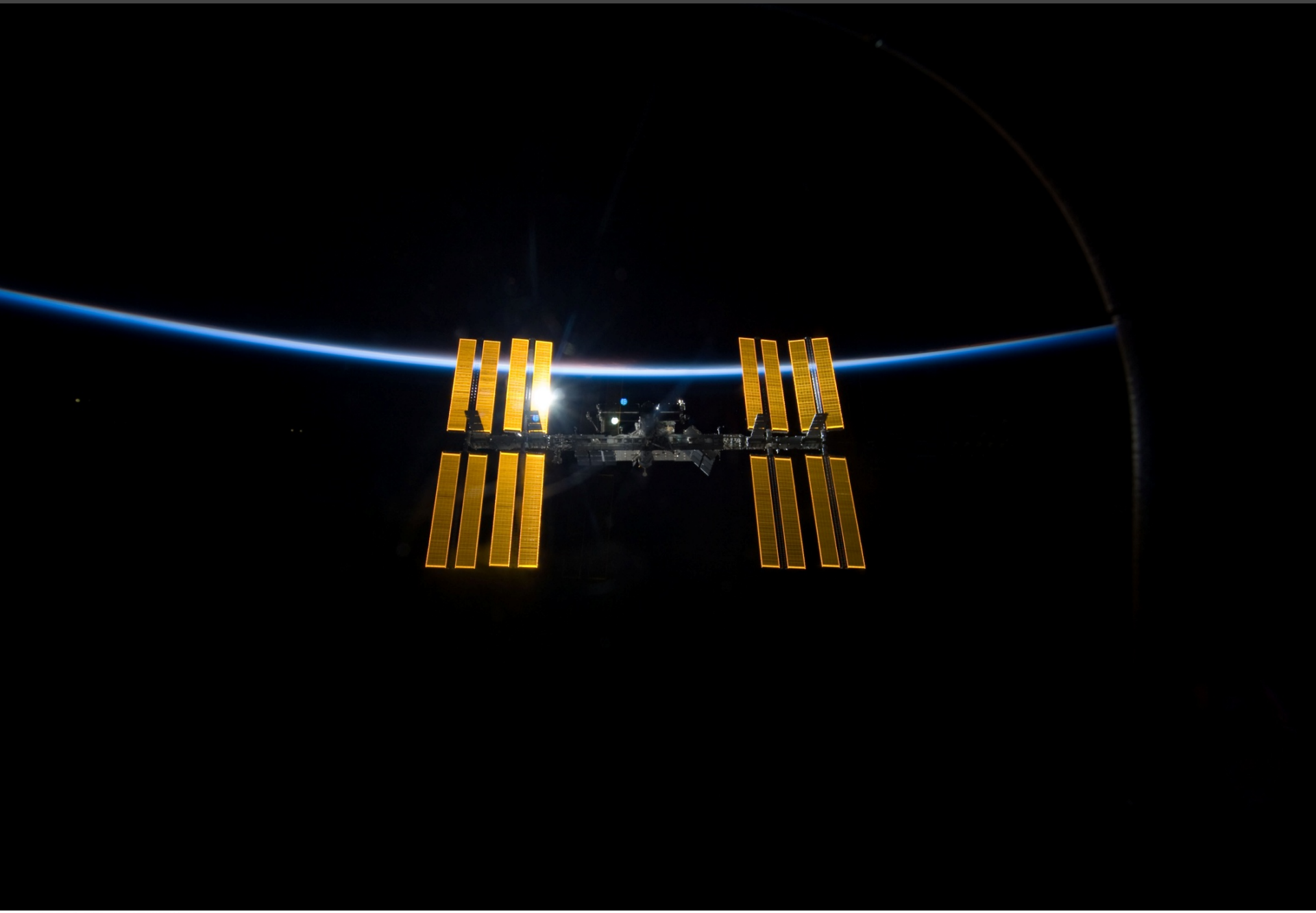


ISS Technical Configuration

Endorsed by ISS Heads of Agency on July 23, 2004

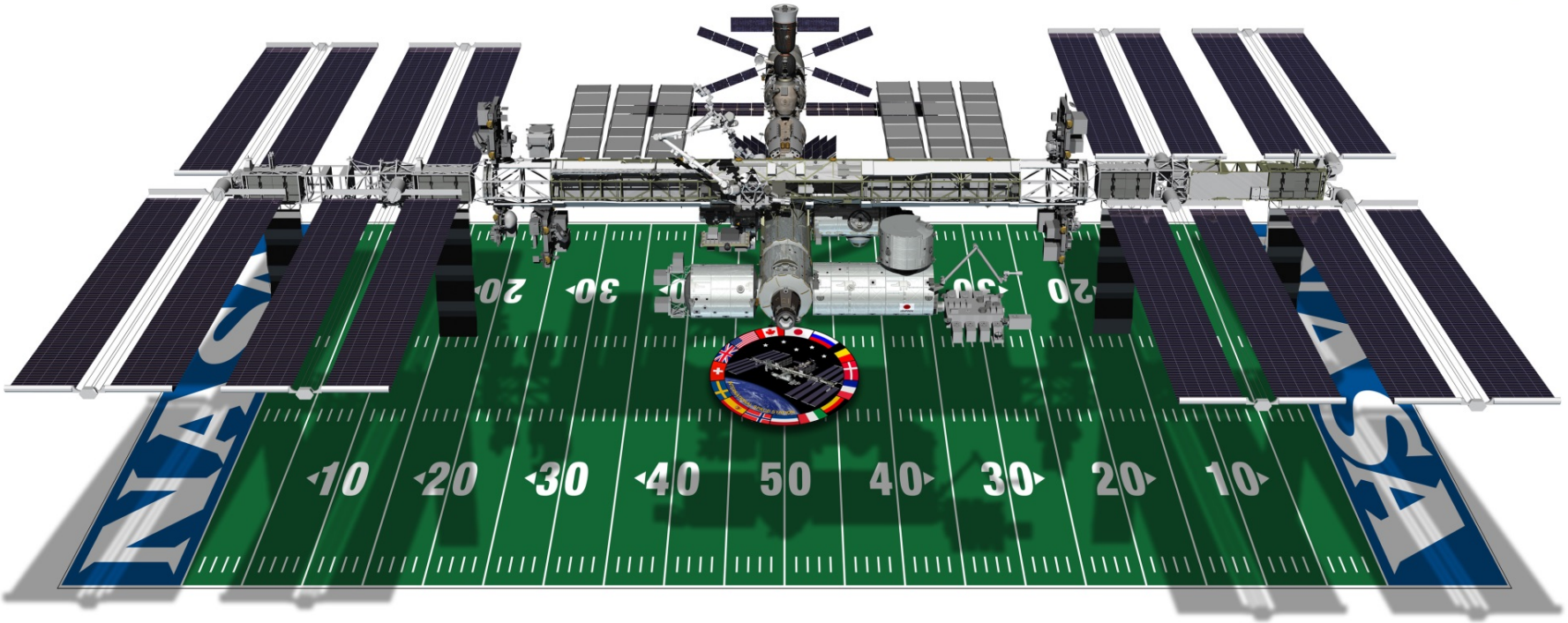


•RM and MLM are included in Russian plans and launched on Russian vehicles

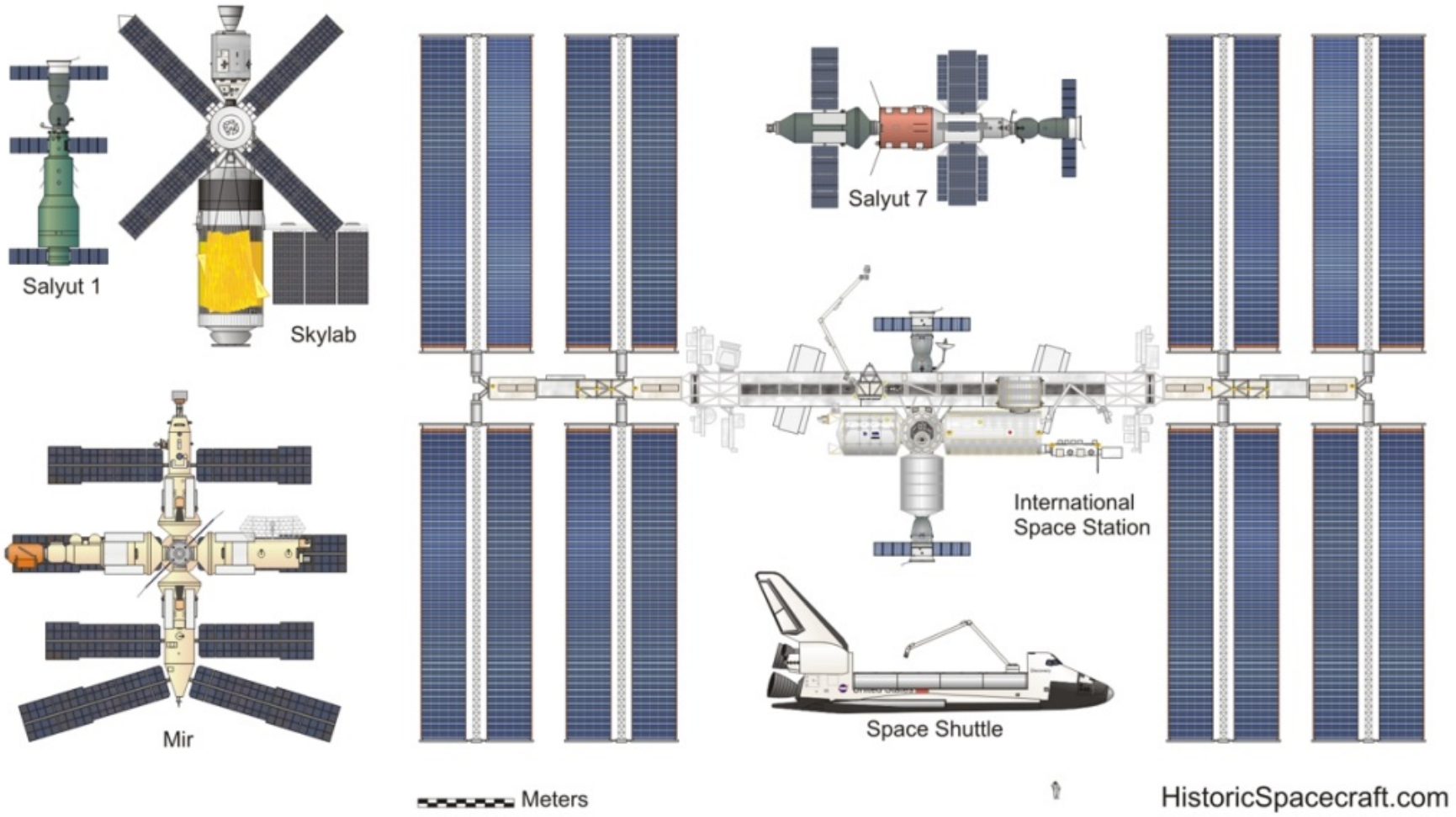


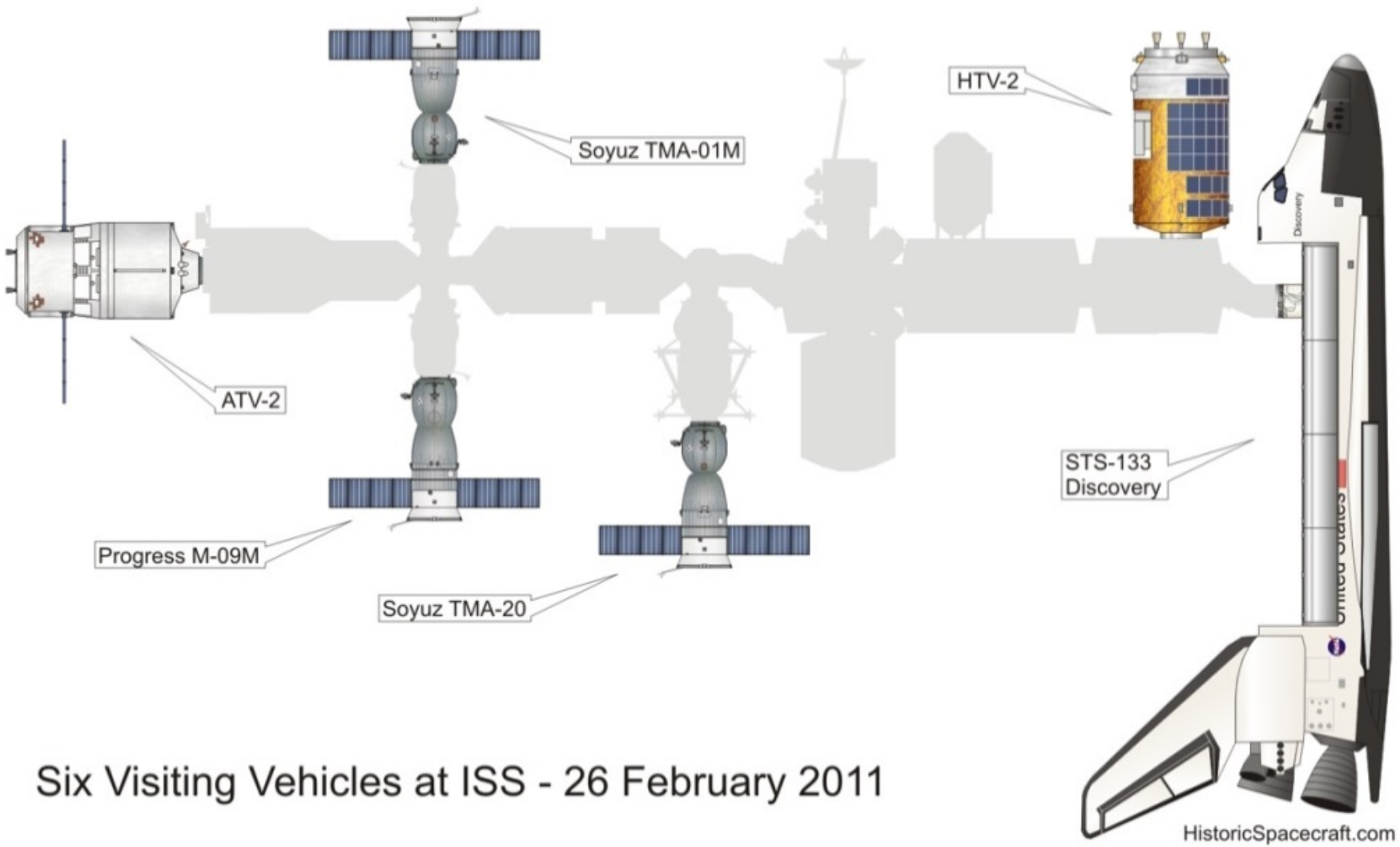
S119E010500

National Aeronautics and Space Administration



www.nasa.gov


Salyut 1
Skylab
Salyut 7
Mir
International
Space Station
Space Shuttle
Meters
HistoricSpacecraft.com



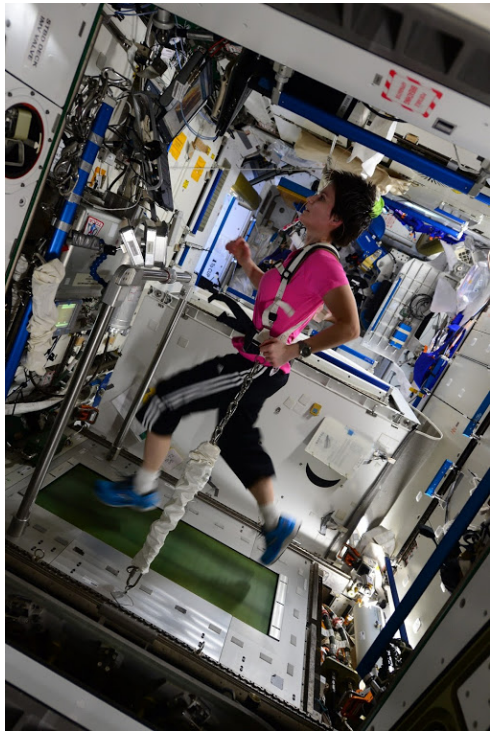
Six Visiting Vehicles at ISS - 26 February 2011

ISS023E023513

ESA- class of 2009

What was Tim doing for 186 days?

- Microgravity countermeasures
- Station upkeep and maintenance
- Science (https://principia.org.uk/the-mission/experiments-in-space/)



Inc 45 & 46 Investigation List

Biology & Biotechnology

Animal Biology	
Rodent Research-3-Ell	SpX-8 (↑↓)
Micro-10	SpX-8 (↑↓)
Embryo Rad	SpX-8 (↓)
Mouse Epigenetics	SpX-9 (↑↓)
Space Pup	SpX-10
CYTOSKELETON	SpX-8 (↑↓)
Cellular Biology	
Cell Science-01	SpX-9 (↑↓)
Heart Cells	SpX-9 (↑↓)
OsteoOmics	SpX-9 (↑↓)
Stem Cells	SpX-9 (↑↓)
SPHEROIDS	SpX-8 (↑↓)
Macromolecular Crystal Growth	
CASIS PCG-5	SpX-10
NanoRacks PCG	SpX-9, SpX-10
CASIS PCG 4	SpX-8 (↑↓)
PCG Crystal Hotel Validation	
JAXA PCG	
JAXA PCG Demo	SpX-8 (↑↓)
Microbiology	
(RJR) Microbial Sampling	SpX-8 (↑↓)
Microbial Observatory-1	SpX-9 (↑↓)
Microbial Observatory-2	SpX-9 (↑↓), SpX-10
BRIC-NP	SpX-9 (↑↓)
Microbe-IV	SpX-8 (↓), SpX-9 (↑)
Myco (for 1YM)	
Plant Biology	
APEX-04	SpX-10 (↑)
Plant RNA Regulation	SpX-9 (↑↓)
Auxin Transport	SpX-9, SpX-10
Plant Rotation	

Physical Science

Combustion Science	
FLEX-2J	
BASS-M	SpX-8
ATOMIZATION	
Group Combustion	HTV5
Complex Fluids	
ACE-H2	SpX-8
ACE-T1	SpX-9
LMM Biophysics 1	SpX-10
LMM Biophysics 3	SpX-10
PK-4	
Fluid Physics	
ARTE (Thermal Exchange)	SpX-9
PBRE	SpX-8
ZBOT	SpX-10
Dynamic Surf	
Marangoni-UVP	SpX-9 (↑↓)
Two-Phase Flow	SpX-10 (↑)
Fundamental Physics	
DOSIS-3D	
Materials Science	
MSL 2b - NASA SCA	SpX-9 (↑↓)
NanoRacks Module-40	
Interfacial Energy 1	
JAXA ELF	HTV5
EML Batch 1	
MSL Batch 2b	SpX-10

Technology Development

Air, Water & Surface Monitoring	
Personal CO2 Monitor	SpX-10
Avionics & Software	
SNFM	
Telescience Resource Kit	
Characterizing Expt Hardware	
POP 3D	Orb-4
ESA-Haptics-1	
MVIS Controller-1	
Communication & Navigation	
Maritime Awareness	SpX-9
OPALS (Ext)	
SCAN Testbed (Ext)	
Vessel ID System (Ext)	
Food & Clothing Systems	
Skinsuit	SpX-8 (↓)
Imaging Technology	
3DA1 Camcorder	
HDEV (Ext)	
ExHAM-Array Mark (Ext)	SpX-9 (↓)
Life Support Systems	
UBNT (RJR)	
Radiation & Shielding	
Radiation Environment Monitor	
Area PADLES	
PS-TEPC	HTV5
Radi-N2	
Repair/Fabrication Technologies	
3D Printing In Zero-G	
Robotics	
Robonaut (RJR)	
RRM-P2 (Ext)	
SUPVIS-E	
Small Satellites Technologies	
NanoRacks MicroSat Deployer	SpX-8
NanoRacks-MicroSat-SIMPL	SpX-8
NRCSD#6	HTV5
NRCSD#7	HTV5
NRCSD #8, 9, 10	Orb-4
Space Structures	
BEAM (Ext)	SpX-8
Spacecraft & Orbital Environmts	
ISS External Leak Locator	Orb-4
STP-H4 (Ext)	HTV5 (↓)
STP-H5 APS (Ext)	SpX-10 (↑)
Spacecraft Materials	
MISSE-8 FSE	SpX-10 (↓)
ExHAM-CFRP Mirror (Ext)	SpX-9 (↓)
ExHAM-MDM2 (Ext)	SpX-9 (↓)
ExHAM-PEEK (Ext)	SpX-9 (↓)
ExHAM-Solar Sail (Ext)	SpX-9 (↓)
TBD	
NanoRacks MicroSat - Kestrel Eye	SpX-9 (↑)
NanoRacks-Gumstix	SpX-8

Human Research

Bone & Muscle Physiology	
Bisphosphonates	
Hip QCT (P)	
Intervertebral Disc Damage (P)	
Sprint	
CARTILAGE (P)	
EDOS-2	
MUSCLE BIOPSY (P)	
Marrow	
Tbone (P)	
Cardiovascular & Respiratory Systems	
Cardio Ox	
IPVI	
IPVI for 1YM (P)	
AIRWAY MONITORING	
BP Reg	
Vascular Echo	
Crew Healthcare Systems	
Skin-B	
Habitability and Human Factors	
Body Measures	
Fine Motor Skills	
Habitability	
Human Behavior & Performance	
Cognition	
Journals	
Reaction Self Test	
Sleep ISS-12	
Synergy (P)	
Circadian Rhythms	
At Home in Space	
Human Microbiome	
Microbiome	
Immune System	
Salivary Markers	
Multi-Omics	HTV5, SpX-9
IMMUNO-2	
Integrated Physiology & Nutrition	
Biochem Profile	
Dose Tracker	
Field Test (P)	
Functional Task Test (P)	
Repository	
Telomeres	
Twins Study	
Biological Rhythms 48hrs	
Biological Rhythms 48hrs for 1YM	
Energy	SpX-9
Nervous & Vestibular Systems	
NeuroMapping	
V-C REFLEX (P)	
Straight Ahead in Microgravity (P)	
Space Headaches	
Vision	
Fluid Shifts	
Ocular Health	
Russian	
Interactions-2	
Pilot-T	

Earth & Space Science

Astrobiology & Astrophysics	
AMS-02 (Ext)	
CALET (Ext)	HTV5 (↑)
MAXI (Ext)	
MCE (Ext)	HTV5 (↓)
Earth Remote Sensing	
CATS (Ext)	
HREP-RAIDS (Ext)	
ISS RapidScat	
SAGE III-ISS (Ext)	SpX-10 (↑)
Heliophysics	
Solar-SOLACES	
Solar-SOLSPEC	
Near-Earth Space Environment	
SEDA-AP (Ext)	

Education & Outreach

Commercial Demonstrations	
JAXA-Commercial	HTV5
Cultural Activities	
NanoRacks Module-48	SpX-9 & SpX-10 (↑↓)
Educational Competitions	
SPHERES-Zero-Robotics (RJR)	
NanoRacks Module-9	
Educational Demonstrations	
(RJR) Sally Ride EarthKAM	
ISS Ham Radio	
Story Time From Space	Orb-4 (↑)
JAXA EPO	HTV5
Try Zero-G for Asia	
ESA-EPO-Peake	44S
Student-Developed Investigations	
Genes in Space-1	SpX-9 (↑↓)
NanoRacks Module-18, 20-22	SpX-8 (↑↓)

TBD Category

CASIS Dev 11	SpX-10
NanoRacks-SMiLE	SpX-9 (↑↓)
Payload Card Multilab-X	SpX-9 (↑↓)
Payload Card-X	SpX-10

Key

NASA	(P) = Pre/Post BDC only
JAXA	(Ext) = External
ESA	(RJR) = Russian Joint Research
CSA	(↑) = Launch only
	(↓) = Return only

Incr46-47 PRINCIPIA Science Complement

ESA Research Overview

ESA EXPERIMENTS	36+
HUMAN RESEARCH	11
BIOLOGY	5
FLUID PHYSICS	0
MATERIALS SCIENCE	8
SOLAR RESEARCH	2
RADIATION DOSIMETRY	2
TECHNOLOGY DEMONSTRATIONS	5
EDUCATION	3+

human spaceflight

Incr46-47 PRINCIPIA Science Complement

esa

HUMAN RESEARCH (11)

AIRWAY MONITORING
BRAIN-DTI (G,R + ESA)
CARTILAGE (G)
CIRCADIAN RHYTHMS
EDOS-2 (R)
ENERGY
IMMUNO-2 (R)
MUSCLE BIOPSY (G)
SKIN-B
SPACE HEADACHES
STRAIGHT AHEAD (G, other crew)

G: Ground experiment
R: Russian crew
New experiments are in yellow.

BIOLOGY (5)

EXPOSE-R2 (3)
Cytoskeleton (TBC)
Spheroids (TBC)

MATERIAL SCIENCES (8)

EML Batch 1 (5)
MSL Batch 2B (2)
PK4

SOLAR RESEARCH (2)

SOLSPEC, SOLACES

EDUCATION (3+)

EPO PEAKE

ESA Research Overview

RADIATION PHYSICS (2)

DOSIS-3D
EXPOSE-R2 (1)

TECHNOLOGY DEMONSTRATIONS (5)

3D-VIT
HAPTICS-1
INTERACT (TBC)
SUPVIS-E
VESSEL ID SYSTEM

FACILITIES

MARES CMP2 (backup)

AAP components

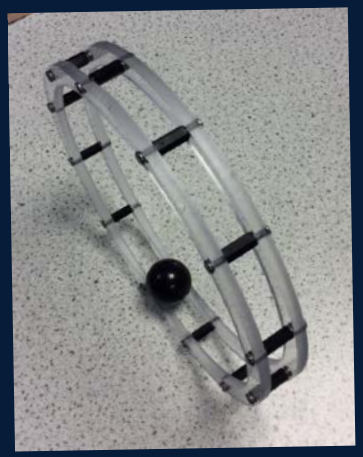
- 5 six-minute films on specific themes from HSF which also cover specific curriculum topics
- Films include ground-based experiments for students/teachers with orbital demos yielding different results
- Standalone clips of every orbital experiment – including extras not included in short films
- Teacher guides with all ground- and space-based experiment details, space/aerospace contexts and further links – including tracker guide

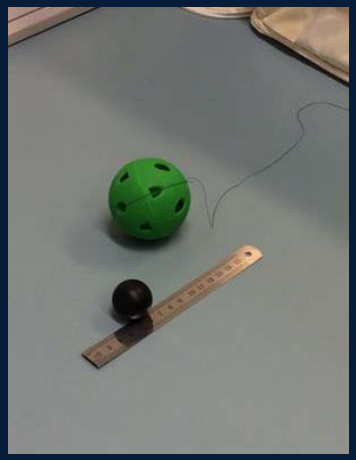
How do you get your experiments onto the ISS?

- Outgassing
- Shatterability
- Electrical requirements
- Thermal management
- Toxicity
- Flammability
- Acoustic vibration testing for launch
- Mass and stowage parameters
- Operations manual

Hardware Manufacture and Procurement

6 identical, flight ready sets of equipment were procured and manufactured.





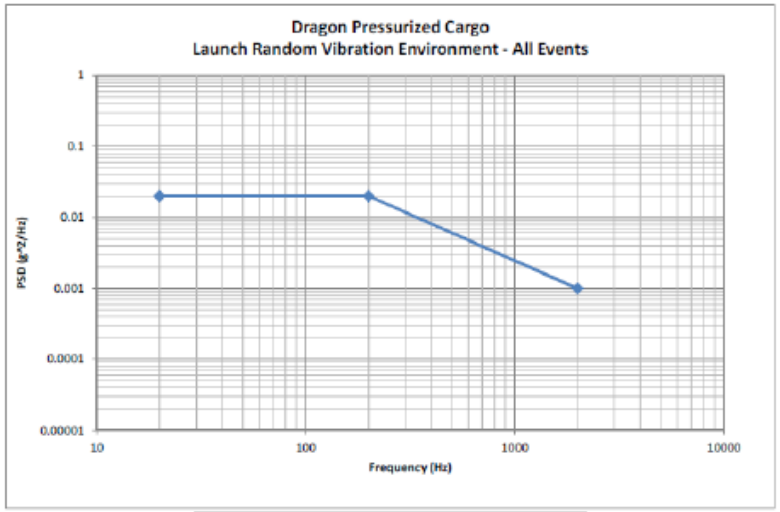

- Owing to scheduling issues, one set was sent to Turin for flight (on SpX-7), whilst a different set was vibration tested
- A third set had been kept safe as a Flight Spare

Vibration Testing

University of Leicester Space Research Centre conducted the testing on behalf of UKSA and National Space Academy on 15th April 2015

The experiments were packed into a cargo transfer bag (CTB) as shown: specification provided in the Space-X documentation.

The experiments packed within the CTB were subjected to tests in X,Y,Z axes by using a vibration test fixture mounted on both a slip table and directly on the vibration head. This test fixture was provided by Rutherford Appleton Laboratory



Frequency (Hz)	Dragon Pressurized Cargo Launch Vibration MPE - All Events (Rev11) - All Axes [g^2/Hz]
20	0.02
200	0.02
2000	0.001
GRMS	**3.2**
Duration	**60 sec/axis**

Random Vibration (LAUNCH – All Events)

Notes:

1. This random vibration environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.
2. Duration covers liftoff, ascent, Mvac burn, and reentry (abort).

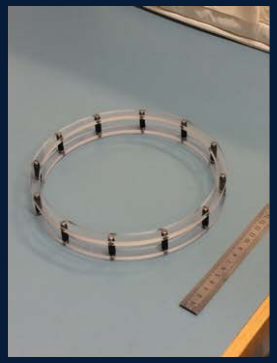
Figure 1: Random Vibration Specification Used in Testing

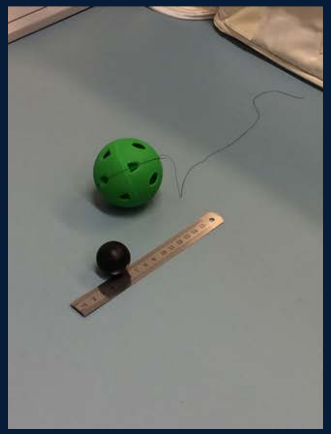
Figure 7: CTB Mounting Hardware Attached to Fixture on Slip Table (X axis configuration)

Figure 8: CTB Attached To Fixture on Slip Table (X axis configuration)

Vibration Testing Conclusion

There is no evidence of any damage or other effects of vibration on any of the experiment hardware. The packing scheme has been demonstrated to be fit for purpose. It is considered that the experiment hardware and the packing configuration are qualified for the vibration environment of Space-X 7.





FLIGHT SAFETY CERTIFICATE

I. Certificate Number – *Unique alpha-numeric identifier provided by the Cargo Item Provider.*	SPX7/ESA/TR1OP1/EPOPk-CVD-1

II. Cargo Item Provider – *The Cargo Item Provider is either the IP which owns the cargo or is the IP sponsoring the cargo on behalf of its nationals which own the hardware.*

☐ NASA ☐ FSA ☒ ESA ☐ JAXA ☐ CSA

III. Cargo Identification – *Official nomenclature and part number of the cargo item.*

Cargo Item Name *(Use an attachment for more items)*	**Part Number / Configuration Item No.**
For Classroom Video Demonstrations Items	
see attached item list	

IV. Transportation Safety Requirements – *The check marks below define the transportation vehicle(s) which will be used for the upload/download of the cargo item(s) together with the Process and Technical Safety Requirements which have been made applicable to the subject cargo item(s).*

Transport Vehicle	**Process Requirements**	**Launch Requirements**	☐**Return** ☒**Disposal Req.**
		Category: ☒1 ☐2	Category: ☒1 ☐2
☒ **Dragon** ☐ **Cygnus**	☒ SSP 30599 ☐ SSP 50146	☒ SSP 50021* ☐ SSP 51700*	☒ SSP 50021* ☐ SSP 51700*
☐ **Progress** ☐ **Soyuz**	☐ SSP 50146	☐ П32928-103	☐ П32928-103
☐ **HTV**	☐ JSX-2008041B (upload) ☐ JSX-2009059A (disposal)	☐ JMR-002B	☐ SSP 50021 ☐ SSP 51700
☐ **ATV**	☐ ESA-ATV-PR-13830	☐ ESA-ATV-1700.7b	Not Applicable

V. Operations/Stowage Safety Requirements – *the check marks below define the foreseen on-orbit operational/stowage location and the Process and Technical Safety Requirements which have been made applicable to the subject cargo item(s).*

ISS Segment	**Process Requirements**	**Stowage Requirements**	**Operations Requirements**
		Category: ☒1 ☐2	Category: ☒1 ☐2
☐ **NASA** ☐ **JAXA** ☒ **ESA** ☐ **FSA**	☐ SSP 30599	☒ SSP 41168 (Columbus) ☐ Choose Additional Document ☐ Choose Additional Document ☐ Choose Additional Document	☐ SSP 51700 ☐ SSP 41165 (JEM) ☒ SSP 41168 (Columbus) ☐ Choose Additional Document

Plan A: 28th June 2015


LIVE
T+ 00:02:11
CRS-7 TELEMETRY
SPEED
ALTITUDE
04052
km/h
38.4
km
UPCOMING
MECO
MAX-Q
FALCON IS CURRENTLY EXPERIENCING MAX-Q OR MAXIMUM DYNAMIC PRESSURE. THIS IS THE POINT WHERE THE LARGEST AMOUNT OF AERODYNAMIC STRESS IS EXERTED ON THE VEHICLE
LAUNCH: CRS-7
SPACE LAUNCH COMPLEX 40, CAPE CANAVERAL, FLORIDA, EARTH
GO/NO-GO POLL
DRAGON INTERNAL
STARTUP
PITCH KICK
MECO
NOSE JETTISON
DRAGON DEPLOY
TERMINAL COUNT
STRONGBACK LOWER
LIFTOFF
MAX-Q
SES-1
SECO-1
SOLAR ARRAY
SPACEX

Finally….

- The vibration tested kit now became the new flight kit. It has been inspected and it looks pristine.
- There is no difference between the 44S kit and the Spx-7 kit.
- No other testing was done during the original safety process (PRSP agreement). OCADs have been written for other possibilities.

Plan B: 2nd Sept 2015

Modelling kinetic theory of gases

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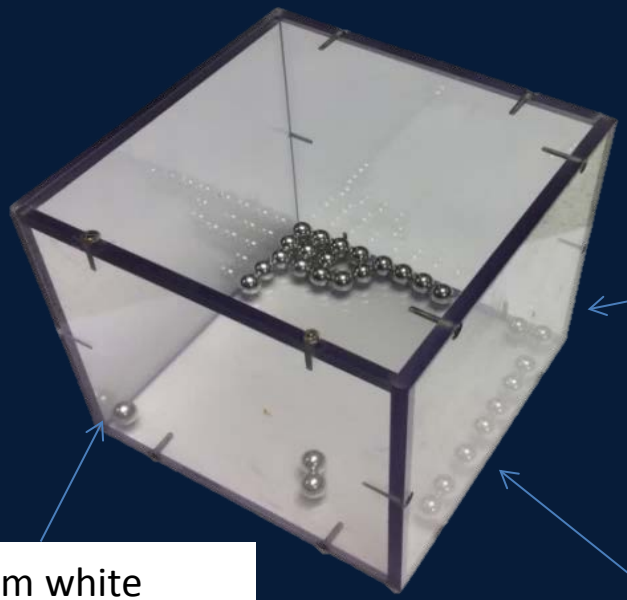
Models the particle motion and collisions for an ideal gas.



Lexan 9030 box of 120 mm internal width and 130 mm external, walls are 5 mm thick. All sides screwed together.

One 10mm white Delrin ball

45 hollow aluminium balls of mass 0.33 g and diameter 9.5 mm

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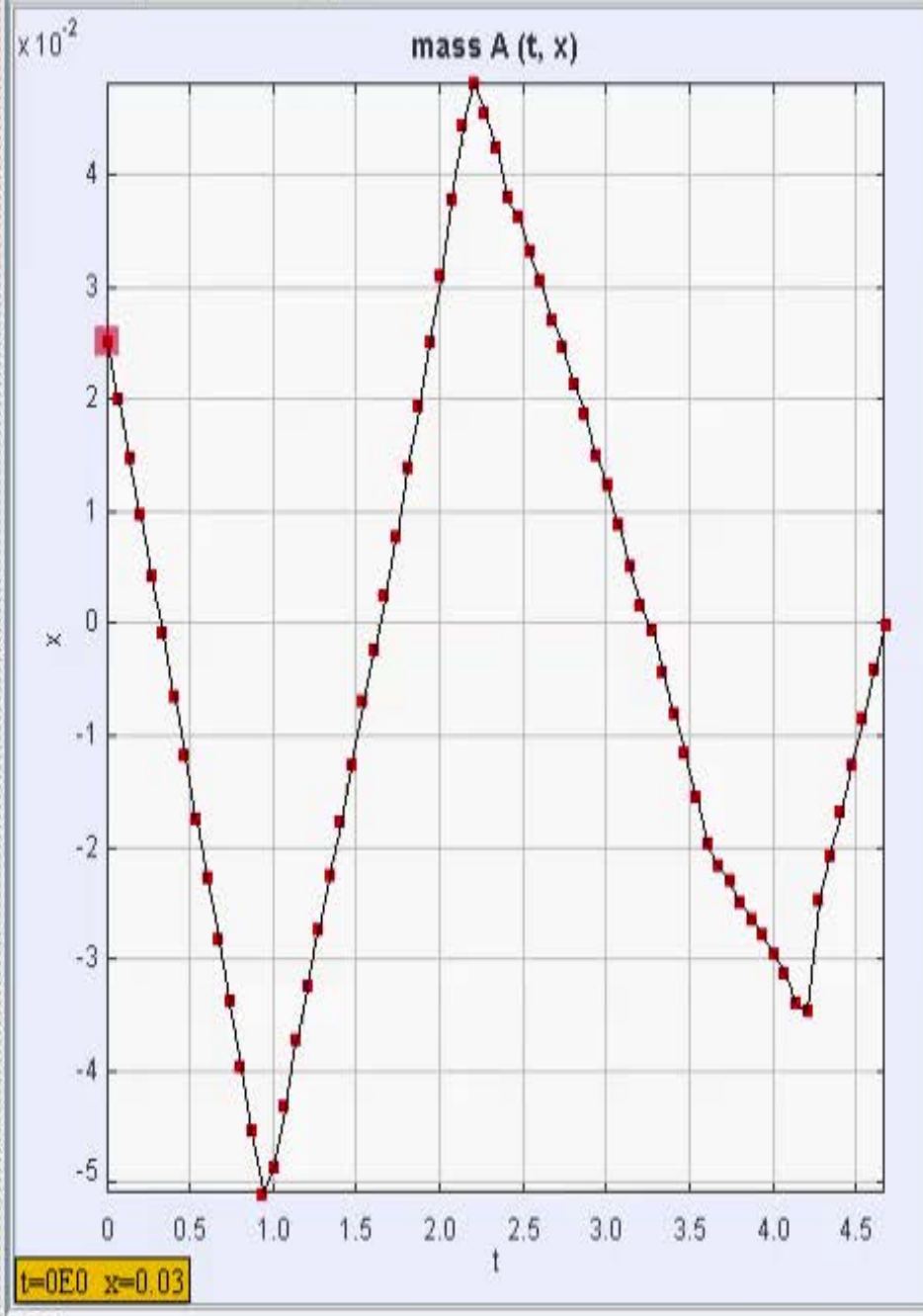
esa


023
100%
2

Plot
mass A


mass A (t, x)
x 10^-2
x
t
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
4
3
2
1
0
-1
-2
-3
-4
-5
t=0E0 x=0.03

Circular motion and centripetal forces

The demo introduces the concept of reaction forces providing centripetal force and the need for a force to produce acceleration as Newton's 2nd Law.
Since a single-plane analysis of circular motion behaviour yields SHM behaviour in that plane, this footage will be used to explore the relationship between SHM and circular motion.

Two Lexan rings (of diameter 20 cm) fixed together with nylon spacers.

30 mm diameter polypropylene ball

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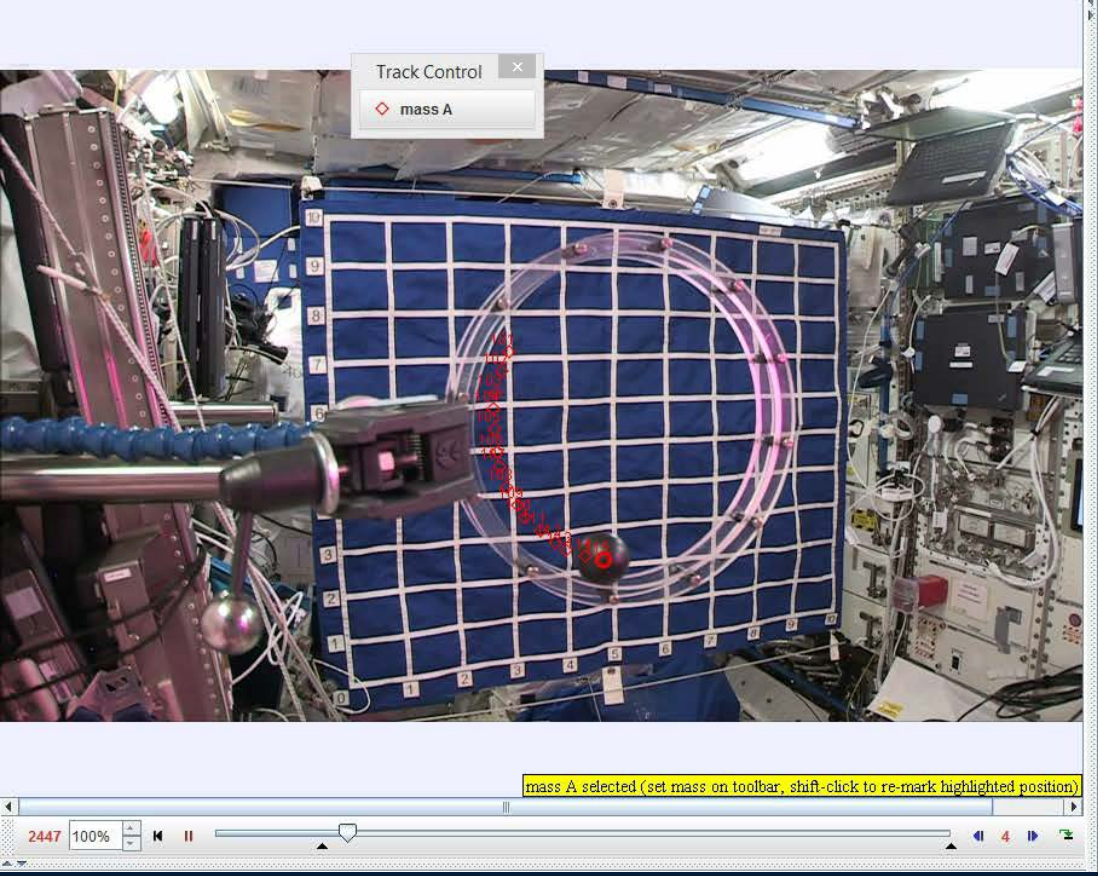

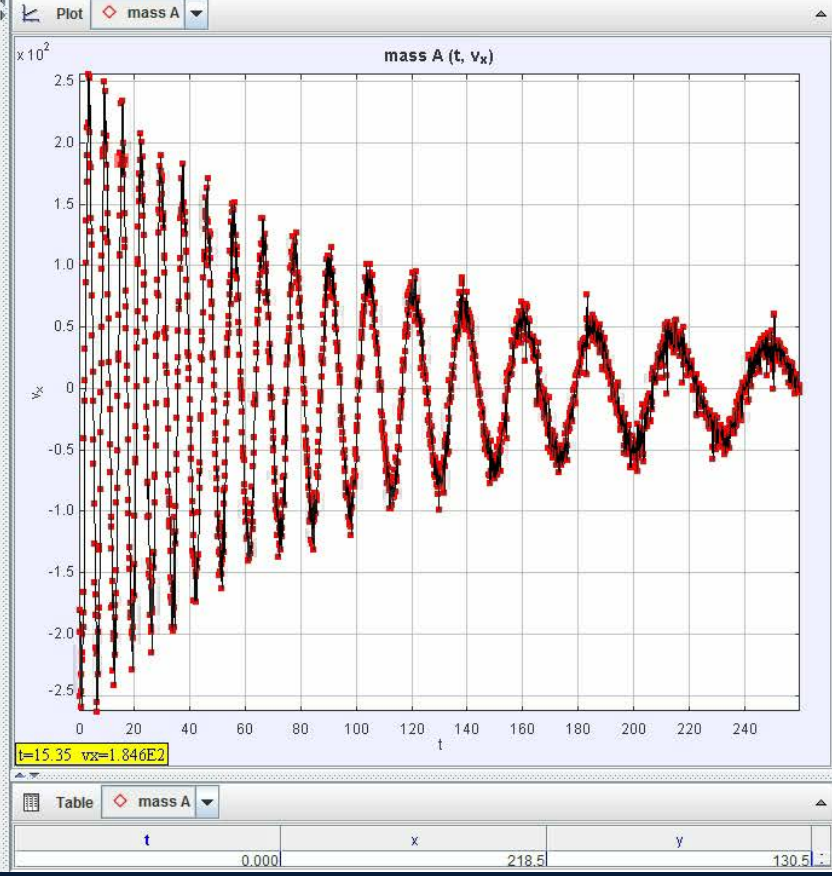

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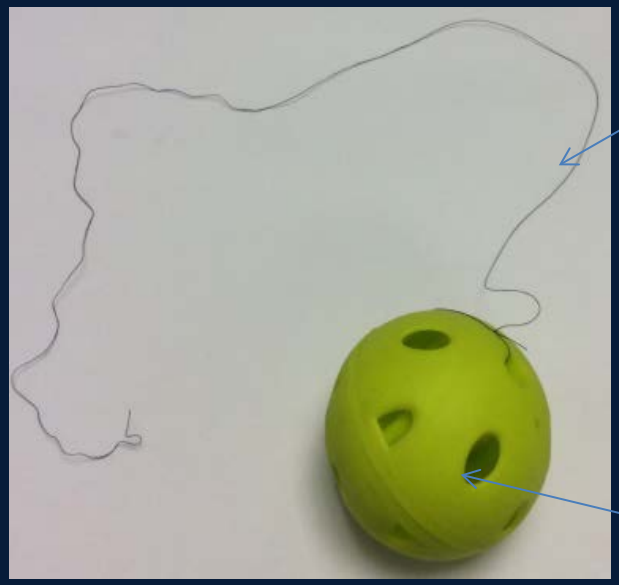
Circular motion and Centripetal Force

Introduces the idea of centripetal force and starts to model gravity as the centripetal force. The extension is the removal of the force (by letting go) and showing how the object moves at a constant velocity according to Newton's 1st Law.



30 cm length of polyester thread

Polypropylene ball 65 mm diameter and mass 21.5g

Simple Harmonic Motion and Modelling Molecules

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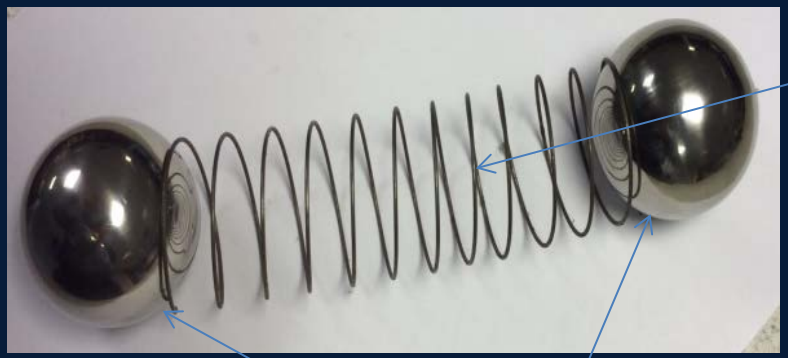
This model demonstrates SHM simple molecule vibration using equal masses on the ends of a spring to model a simple diatomic molecule.



180mm spring that is fixed to the balls with Kapton tape

Two 65 mm diameter hollow stainless steel balls each of mass 33 g. NOTE: these balls are also used in the collisions demo and will need the spring and tape removing before use in that demo

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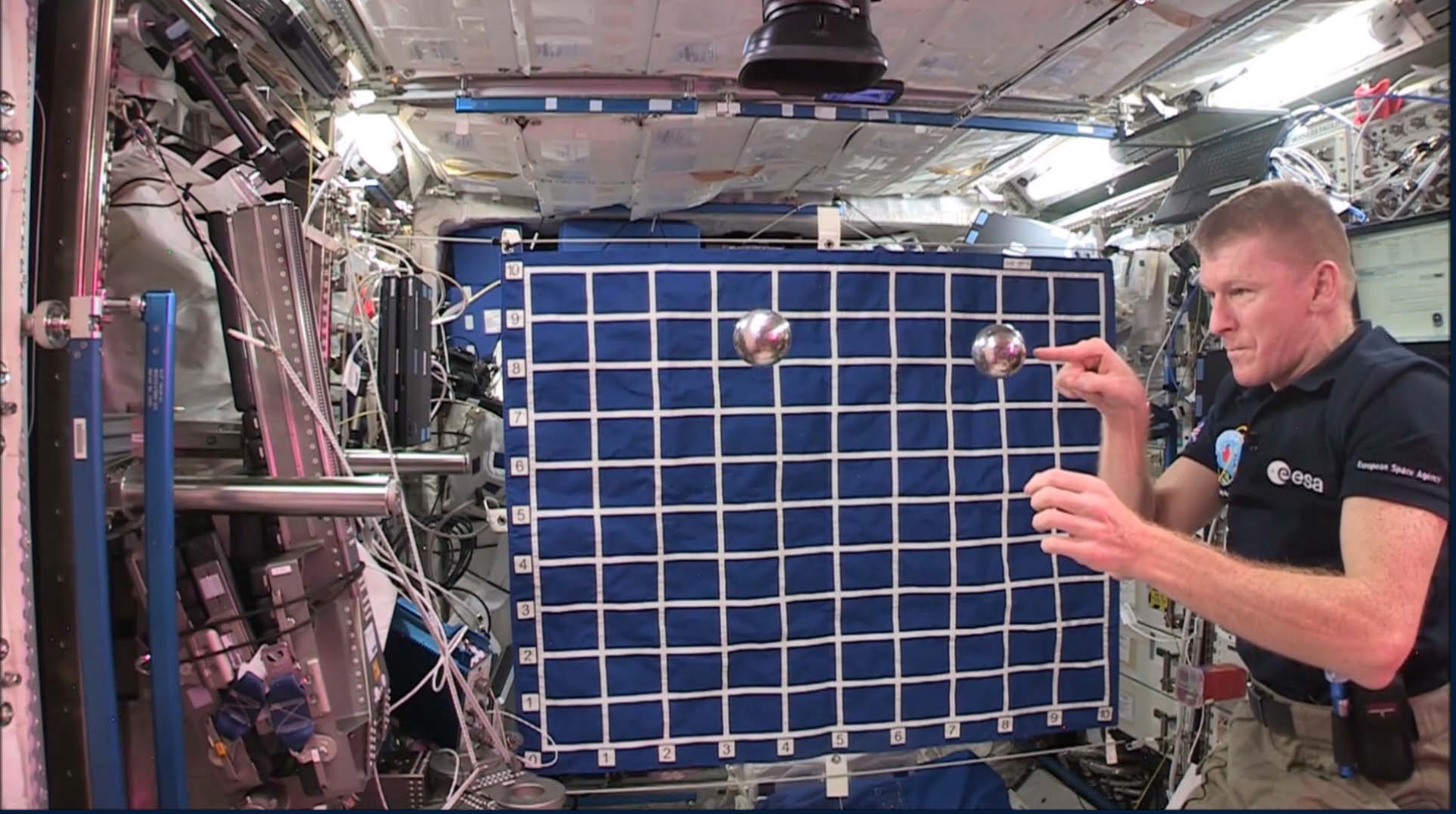
Conservation of momentum and the vector nature of momentum

Collisions are used to show the concept of momentum conservation, (nearly) elastic and plastic collisions and how momentum must be a vector nature to observe conservation laws.

Two 65 mm diameter hollow stainless steel balls each of mass 33 g. NOTE: these balls are also used in the Oscillating Molecule demo and will need the spring and tape removing before use in this demo.

One 9.5 mm hollow aluminium ball of mass 0.33 g



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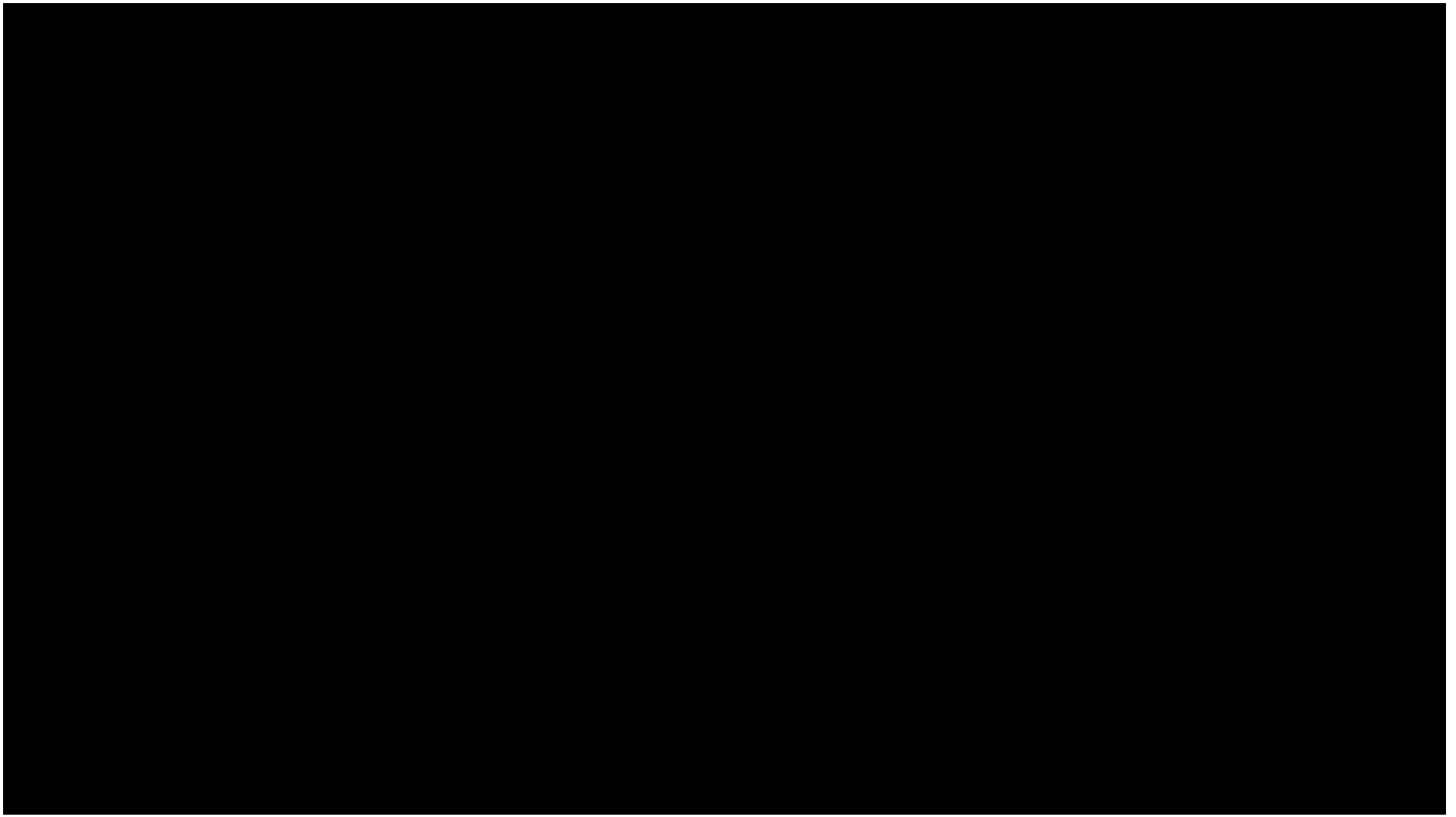
Oblique collision equal masses

Y-z plane collision with x plane tracking

Decaying velocity against time 1-d analysis

y, v and a modelling in one dimension – analogue of SHM dynamics



Kinetic theory of gases – tracking one atom through multiple collisions with walls of container

Diatomic harmonic oscillator showing translational motion also

Film	Curriculum topics	Ground-based experiments	Orbital demonstrations	Space Contexts
Introduction	• Gravitational fields and forces • Kepler's Laws • Ballistics modelling	• Gravity wells • Ballistics (IoP rocket launcher) • "Marble-ous ellipses"	• None	• Comet orbits • Kepler's Laws • Microgravity platforms (drop towers and parabolic flights) • ISS reboost
Momentum in collisions	• Conservation of momentum • Kinetic energy • Elastic and inelastic collisions • Oblique impacts, translational and rotational kinetic energy • Moments of Inertia	• Newton's Cradle • Various 1-d elastic collisions • Inelastic vs elastic collisions – rebounding balls and sand	• 2/3d modelling of Various elastic collisions • Inelastic collisions • Oblique collisions	• Neutron spectroscopy and detecting Mars' hidden water • Formation of Moon • Uranus' axial tilt
Circular motion	• Newton's First Law • Centripetal forces • Rotating frames of reference and pseudo-forces • Reaction forces	• Water in swinging cup • Vertical loop rollercoaster track	• Ball on tether • Centripetal loop – various demonstrations	• Aerospace centrifuges • Skylab orbital gymnastics • Hypergravity facilities on Earth • Gravity analogues in rotating space structures
Kinetic theory of gases	• P,V,T relationships • Ideal and non-ideal gases • Kinetic theory of gases • Exponential pressure drop in atmospheres with altitude • Degrees of freedom • Thermodynamic temperature • Induced dipole interactions	• Water and cup • Syringe experiments with marshmallows and hot water • Arm and leg inflatable splints • Mass on spring as harmonic oscillator	• Kinetic theory box • Electrostatic phenomena • Diatomic oscillator molecule • Circular motion in loop reduced to one plane of observation	• Effect on humans in vacuum • Comparison of atmospheric pressure on Mars, Venus and Earth • Isotopic analysis of water content of comets


ASTRO ACADEMY: PRINCIPIA
F=∂(mv)/∂t
Gm1m2/r²

Kinetic theory of gases – A level modelling

M and M sphere showing analogue for molecular rotation and translational motion

Where can I find everything?

- www.astroacademy.org.uk