Space engineering
Name of the course

Introduction to Space Science and Technology

CTU FEE
BEST Space Curse 2018

Rene Hudec

Course Organization

- Please do not hesitate to contact me in the case of any question
- Apologies if this lecture will be too easy or too difficult for you. I am not aware about level of your knowledge in this field
- **Your feedback is highly appreciated!**
- Preferably by email hudecren@fel.cvut.cz

Prague – historical city of astronomy: Tycho de Brahe, Kepler, Einstein, Doppler …








Important Note

- This course is Introduction to Space Science and Technology. The idea is to introduce you to this area. But, having just one week course, we cannot go into details and also are unable to cover the whole field.
- Note that e.g. Thermal issues of spacecrafts is a whole book…
- Full course will be given at the CTU FEE, winter semester

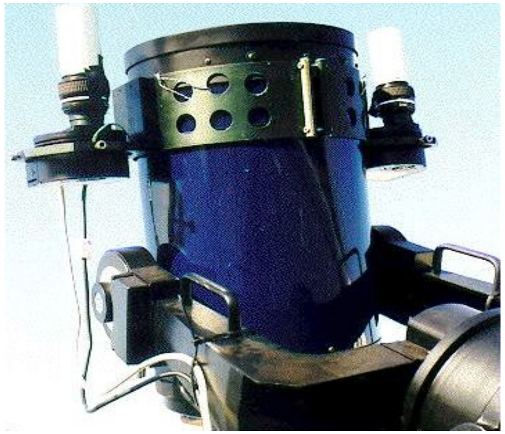
Past and recent projects: Overview

Department of Radioelectronics of CTU FEE and ASU AV CR: 1970-1990 participation in various and numerous efforts within the INTERKOSMOS program“ Vertikal, AUOS-S-IK, Fobos I, II, KORONAS (electronics, mechanical construction, designs, image detectors, image detectors, image analyses, control electronics)

FEL CVUT played an important role in the first 20 years on space research in the Czech Republic

1990-now participation of CTU in the BOOTES experiment in Spain (robotic telescopes) and ESA INTEGRAL satellite (data compressions and analyses, OMC test device, ground-based support)

Recently: ESA ATHENA, ESA SMILE, ESA LOFT, ESA THESEUS, ….

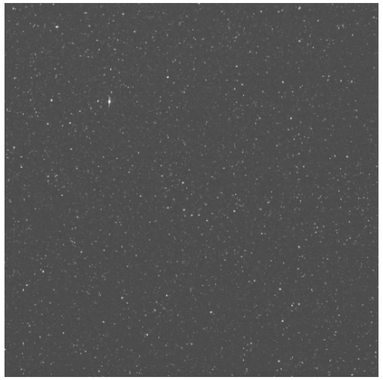


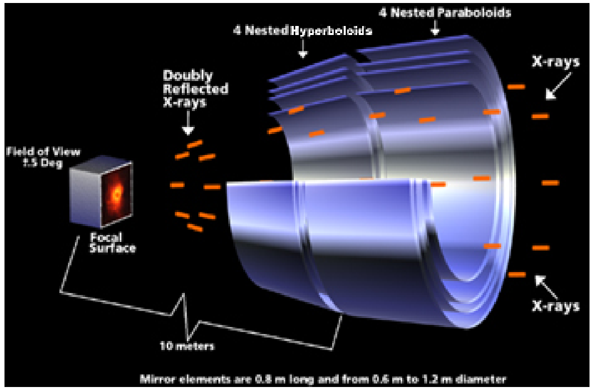
BOOTES

INTEGRAL

X-ray telescope TEREK. Fobos 1space probe,Hudec et al. SPIE Vol. 3766, p. 62-71, 1999.

OMC camera INTEGRAL - image





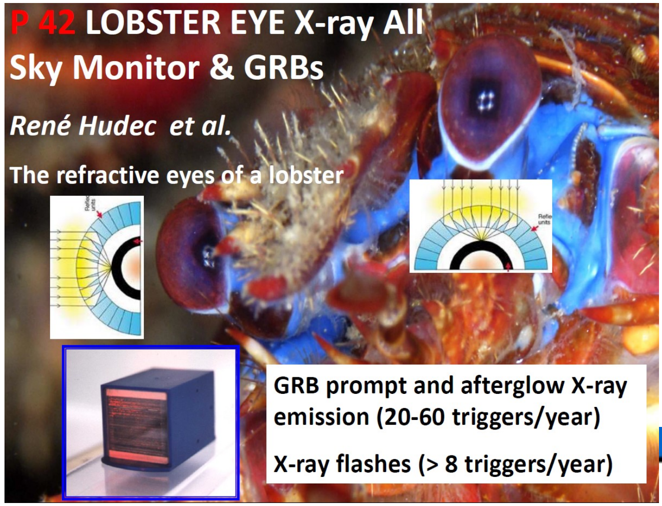
Space X-ray telescope: optics and detector

Just few examples ......

P 42 LOBSTER EYE X-ray All Sky Monitor & GRBs

René Hudec et al.

The refractive eyes of a lobster



GRB prompt and afterglow X-ray emission (20-60 triggers/year)

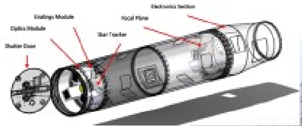
X-ray flashes (> 8 triggers/year)

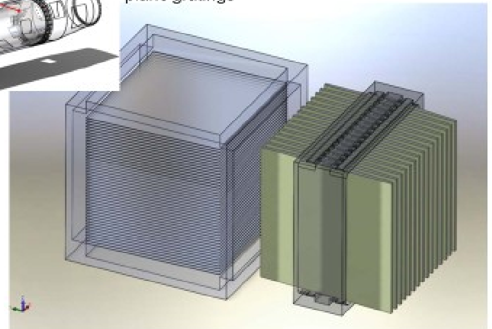
VZLUSAT Assembly (by CTU students)

Assembly take place many times during the functional testing. The reason is the difference between EGSE mounting and PFM mounting. Except platform (EPS, OBC, Radio and Antenna) all board was in-house developed.

NASA Rocket Proposal

A high resolution X-ray spectrometer utilizing Kirkpatrick-Baez optics and off-plane gratings





Delivered April 2009

R. Hudec co-I, participation of CTU

KB X-ray space telescope

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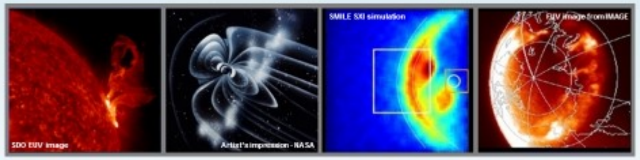
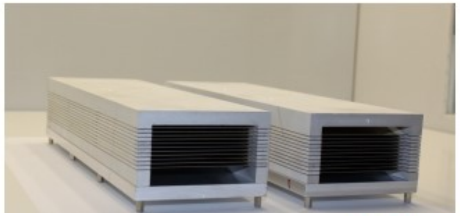
SMILE impact



- X-rays from the magnetosphere: from 'unwanted background' for X-ray astrophysical observatories to diagnostic tool of Sun-Earth relationships
- SMILE will trace and link processes of solar wind injection with those acting on charged particles precipitating into the cusps and the aurora
- Outreach: Captivate public to science (magnetic field) so far invisible
- Cooperation with China: SMILE is a showcase, building on Double Star experience

Kirkpatrick Baez X-ray test module 2

- Model based on ray-tracing (11 profiles)
- Two sets of mirrors from Si chips 100x100x0.525 mm
- Total optics length 600 mm, aperture 40x40 mm, f=20 m



esa

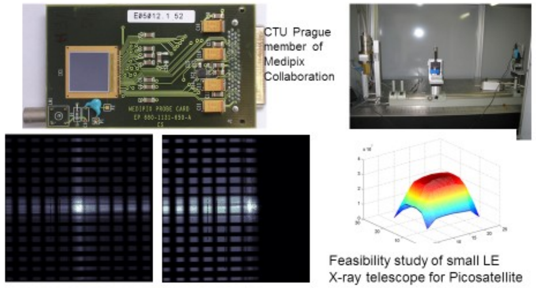
Shedding light on the Early Universe with THESEUS

Rene Hudec and Lorenzo Amati

on behalf of the THESEUS team

Lobster Telescope for Picosatellite

Tests with Lobster Eye X-ray Optics at 8 keV



CTU Prague member of Medipix Collaboration

Feasibility study of small LE X-ray telescope for Picosatellite

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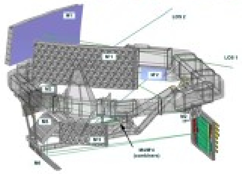
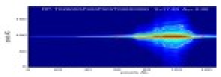
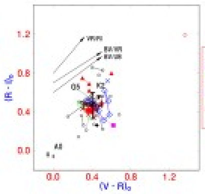
P39 ESA Gaia and GRBs

René Hudec et al.







The strength of Gaia for GRB study is the fine spectro-photometry

The OAs of GRBs are known to exhibit typical colors, distiguishing them from other types of astrophysical objects (Simon et al. 2001, 2004)

A realiable classification of OTs will be possible using this method

ESA INTEGRAL Gamma-ray observatory

Launch in 2002

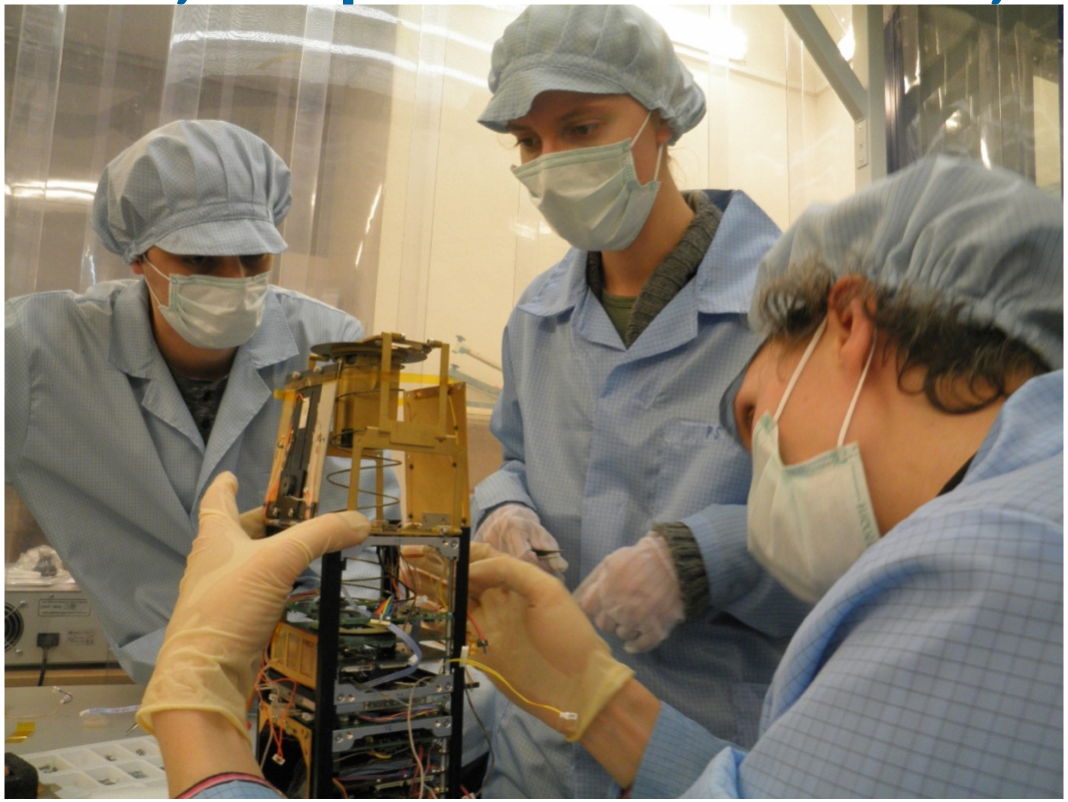
Recently approved for prolongati until at least 2012

R. Hudec co-I on onboard OMC experiment and of Integral Scien and Data Center ISDC

Participation of FEL CVUT

Ground-based segment: robotric telescopes/BOOTES

VZLUSAT nanosat assembly by CTU PhD Students, in space since June 23, 2017



Assembly take place many times during the functional testing. The reason is the difference between EGSE mounting and PFM mounting. Except platform (EPS, OBC, Radio and Antenna) all board was in-house developed.

Space

- High atmosphere < 100 km (difficult access)
- Near space (Earth orbits) > 100 km (most satellites)
- Interplanetary space (inside our planetary system) 100 000 km to 10 billion km, only few planetary probes
- Interstellar space (outside our solar system) > 10 billion km, very few extraplanetary probes

Space Systems

- **Space segment** (what is in the space i.e. satellite or spacecraft)
- **Ground segment** (what is on the ground i.e. tracking antennas, mission control and operational centers, test facilities etc and in addition serves as interface between satellites and end users)

Terminology

- Satellite: an object that orbits a more massive object
- Space Station: a satellite in which people can live and work for long periods
- Lander: craft designed to land a planet’s surface
- Probe: spacecraft that drops into a planet’s atmosphere & records data

Spacecrafts

- Spaceships and space shuttles are used to transport people into space
- space probes are used for ‘non-manned’ exploration of space – they carry instruments for recording info
  - e.g. Pioneer 11 – flyby of Jupiter and Saturn in 1974 - 79
  - e.g. Mars Pathfinder – landed on Mars in 2000

- space stations are orbiting spacecrafts that have living quarters, work areas, support systems… to allow for people to live and work in space for extended periods of time

- satellites (Earth orbit)
- moons stations etc. (future)

Satellites and Probes

- **natural satellites** such as the Moon
- **man-made satellites**
  - Communication satellites – “wireless” technologies
  - Observation and research satellites – weather, tracking systems (e.g. radar), scientific, astronomical, geophysical, ….
  - Remote sensing – imaging of earth surface
  - Global Positioning Systems

Orbiters

- Spacecraft collects data from a planet while moving around it.
- Can view most or all of a planet's surface over a longer period of time
- Sends pictures back to Earth and also takes temperature readings

Landers

- Spacecraft designed to land on a planet's surface
- Landers have been on Moon, Venus, and Mars
- Collects soil and rock samples, takes pictures, measures properties of atmosphere & surface
- Eg. Rovers SPIRIT & OPPORTUNITY

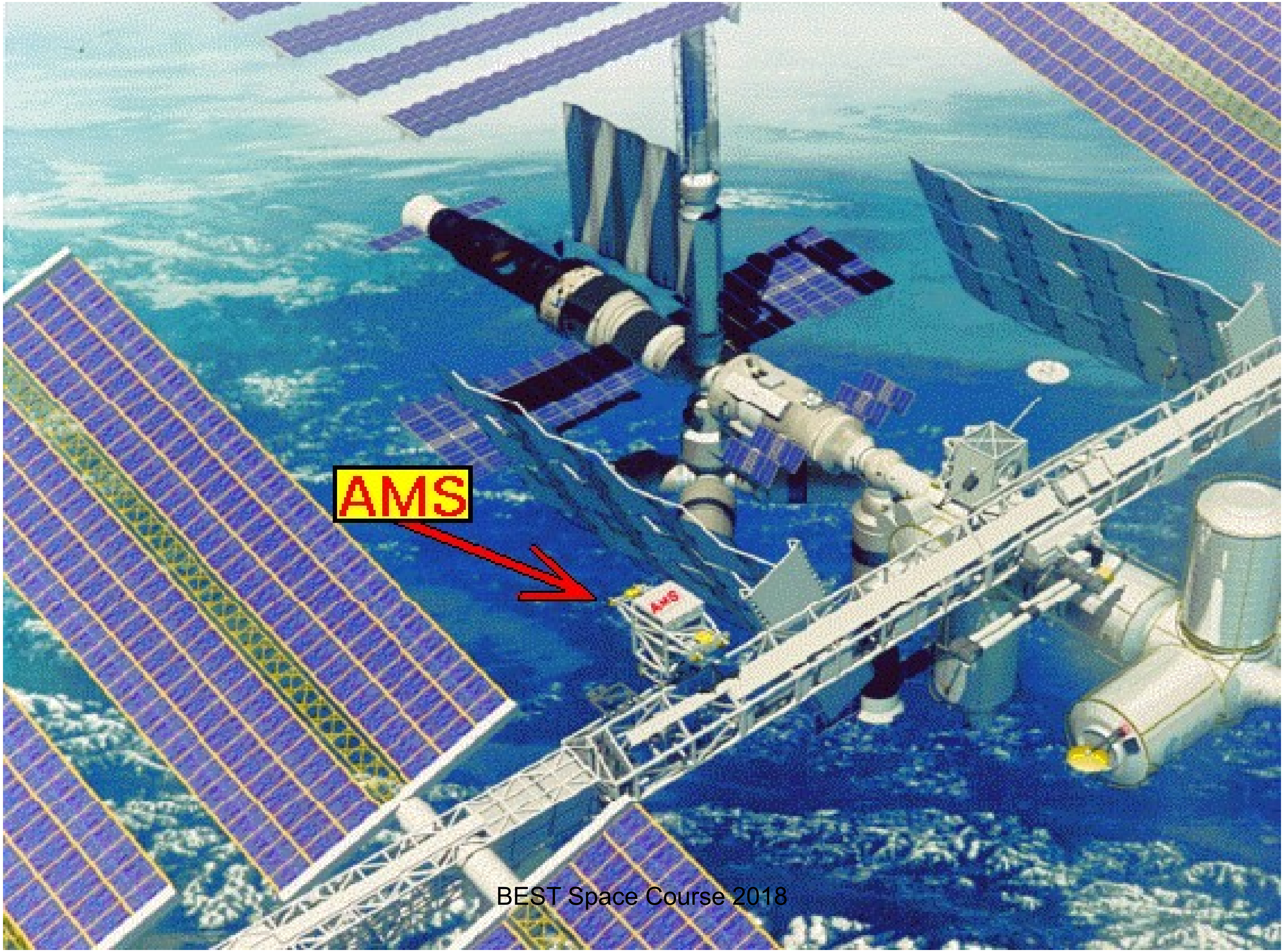
Probes

- Spacecraft that collects data from a planet as it drops into the planet's atmosphere
- Takes atmospheric pressure and temperature readings
- Work for a short period of time and are destroyed usually on impact
- Used to explore deep atmosphere of Jupiter

Space Environment

Space Environment Specifics

- Vacuum/outgassing
- Temperature Issues (high T gradients, bad heat transfer, cold/hot if illuminated by Sun, temperature cycles) …. SMILE CVUT role
- Radiation issues (from UV and X rays to particles)
- Missing protection by Earth atmosphere
- Solid particles impact danger (micrometeoroids, orbital debris)
- Low gravity
- All spacecraft and satellite systems must take this into account


AMS
AMS

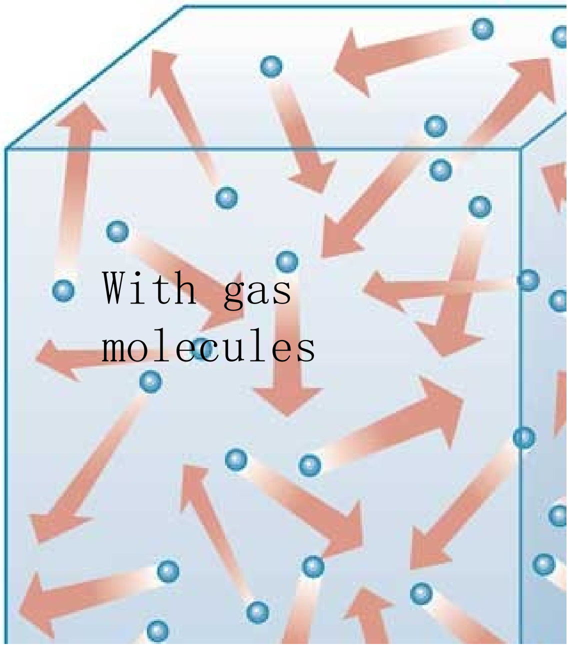
Space as Dynamic Place

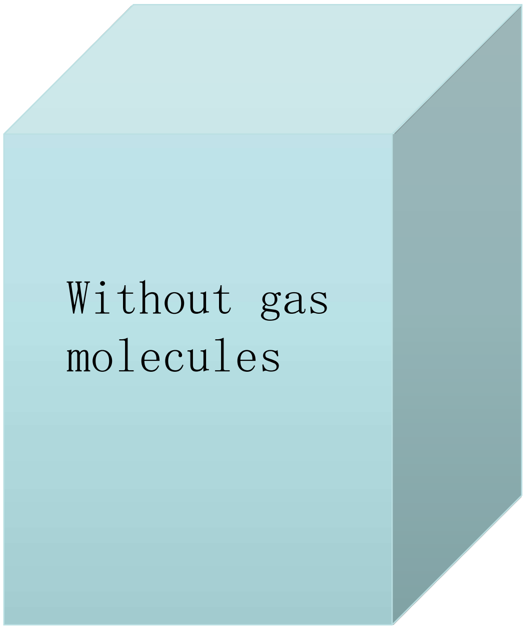
- Space is often incorrectly thought of as a vast, empty vacuum that begins at the outer reaches of the Earth's atmosphere and extends throughout the universe.
- In reality, space is a dynamic place that is filled with energetic particles, radiation, and trillions of objects both very large and very small.
- Compared to what we experience on Earth, it is a place of extremes. Distances are vast. Velocities can range from zero to the speed of light. Temperatures on the sunny side of an object can be very high, yet extremely low on the shady side, just a short distance away.

Vacuum

Vacuum environments

- A **pure vacuum**, by the strictest definition of the word, is a volume of space completely devoid of all material.





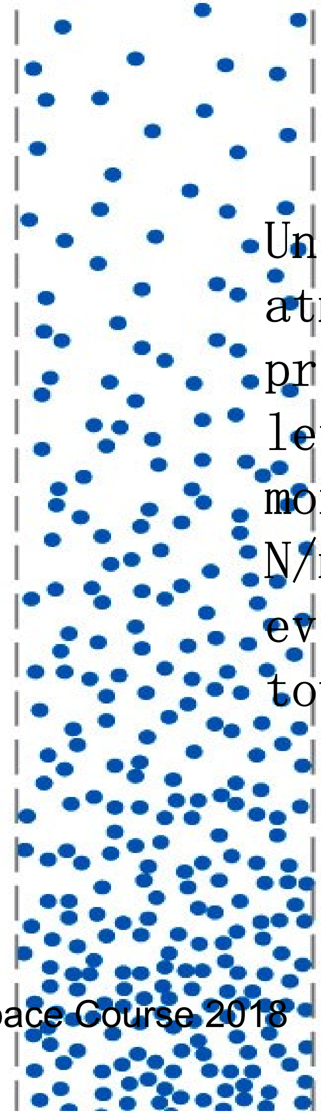
In practice, however a pure vacuum is nearly unattainable

- Even at an altitude of 960 km, we still find about 1,000,000 particles per cubic centimeter.

So when we talk about the vacuum of space, we're talking about a "near" or "hard" vacuum.

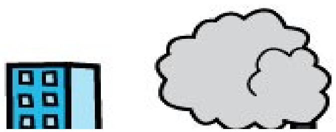
Earth Atmosphere

Atmospheric Density decreases with height

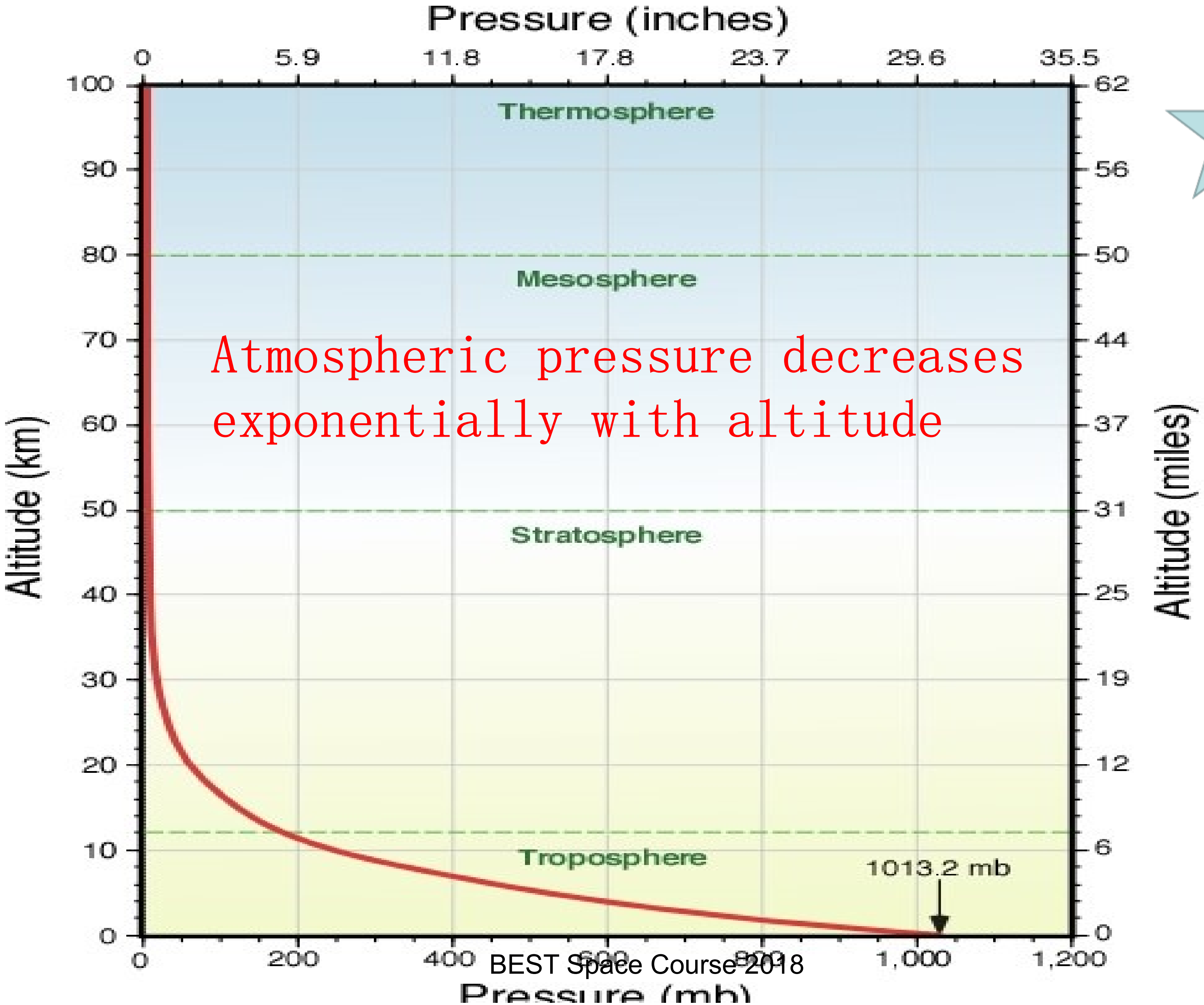


Atmospheric pressure represents the amount of force per unit area exerted by the weight of the atmosphere pushing on us.

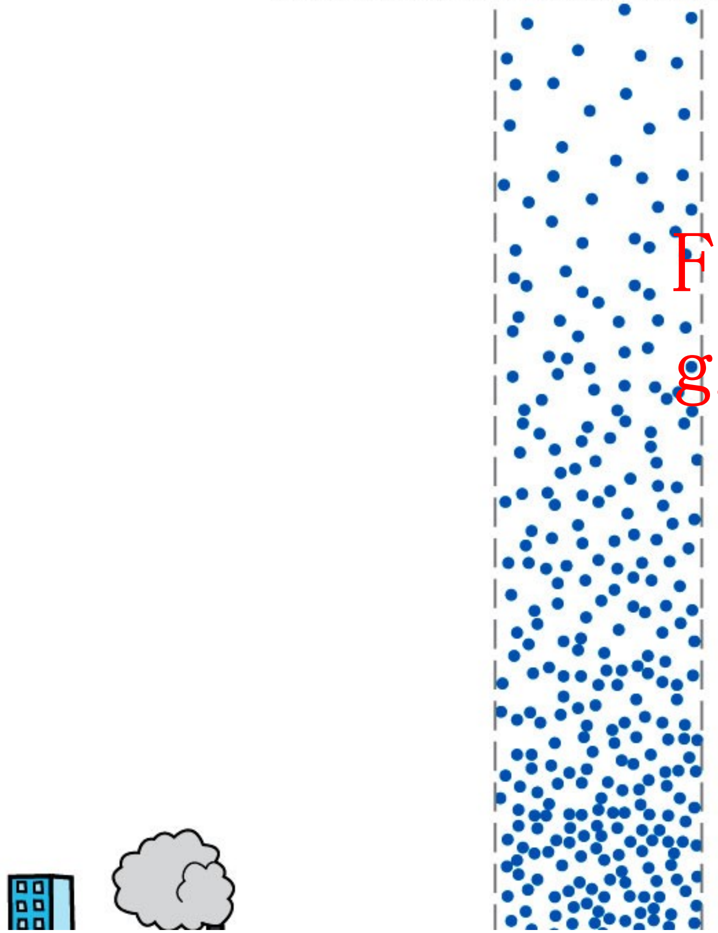
Under standard atmospheric pressure at sea level, air exerts more than 101,325 N/m² of force on everything it touches.



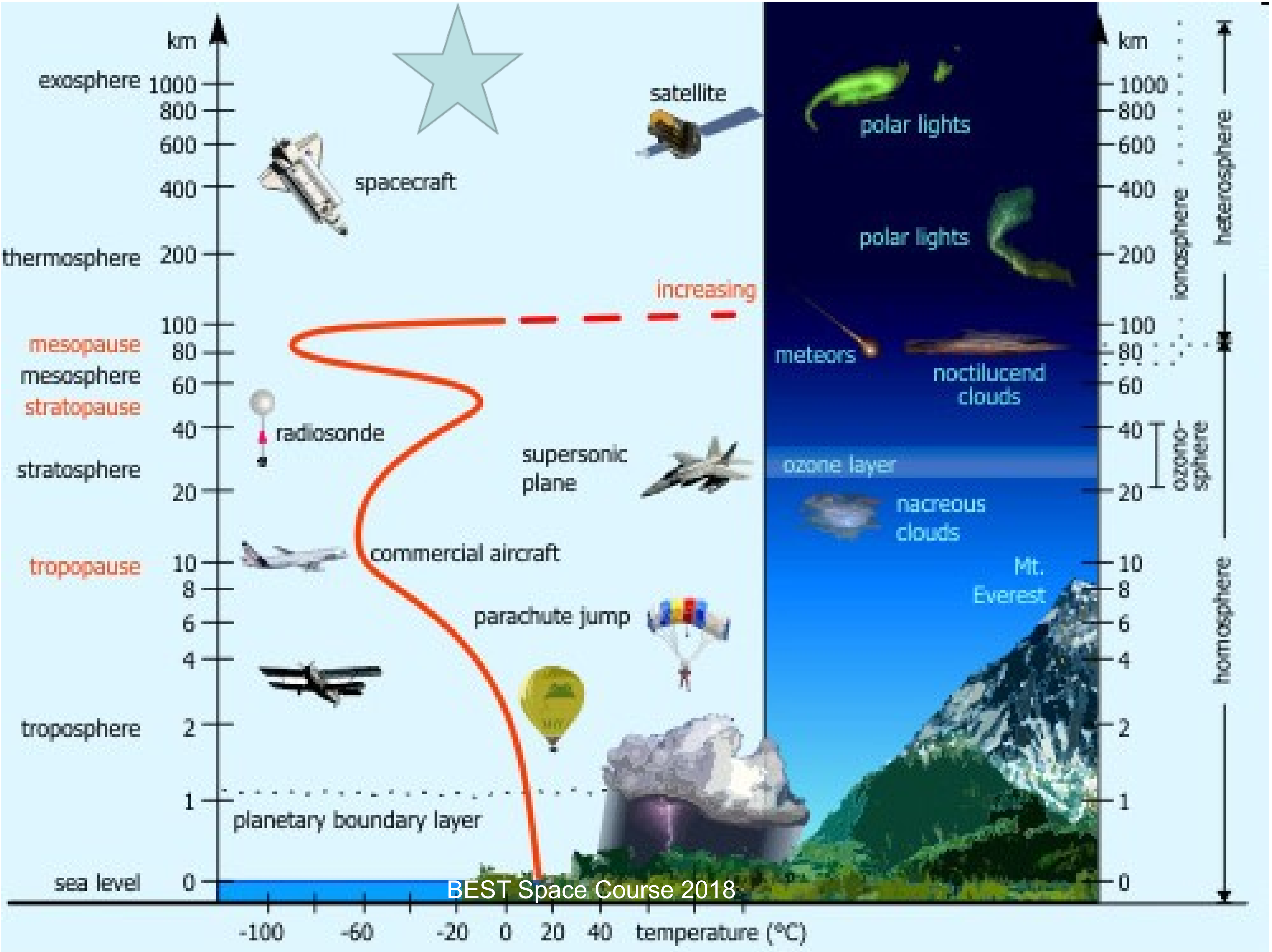
Atmospheric pressure decreases exponentially with altitude



What causes most of the atmosphere’s molecules to be close to the earths surface?



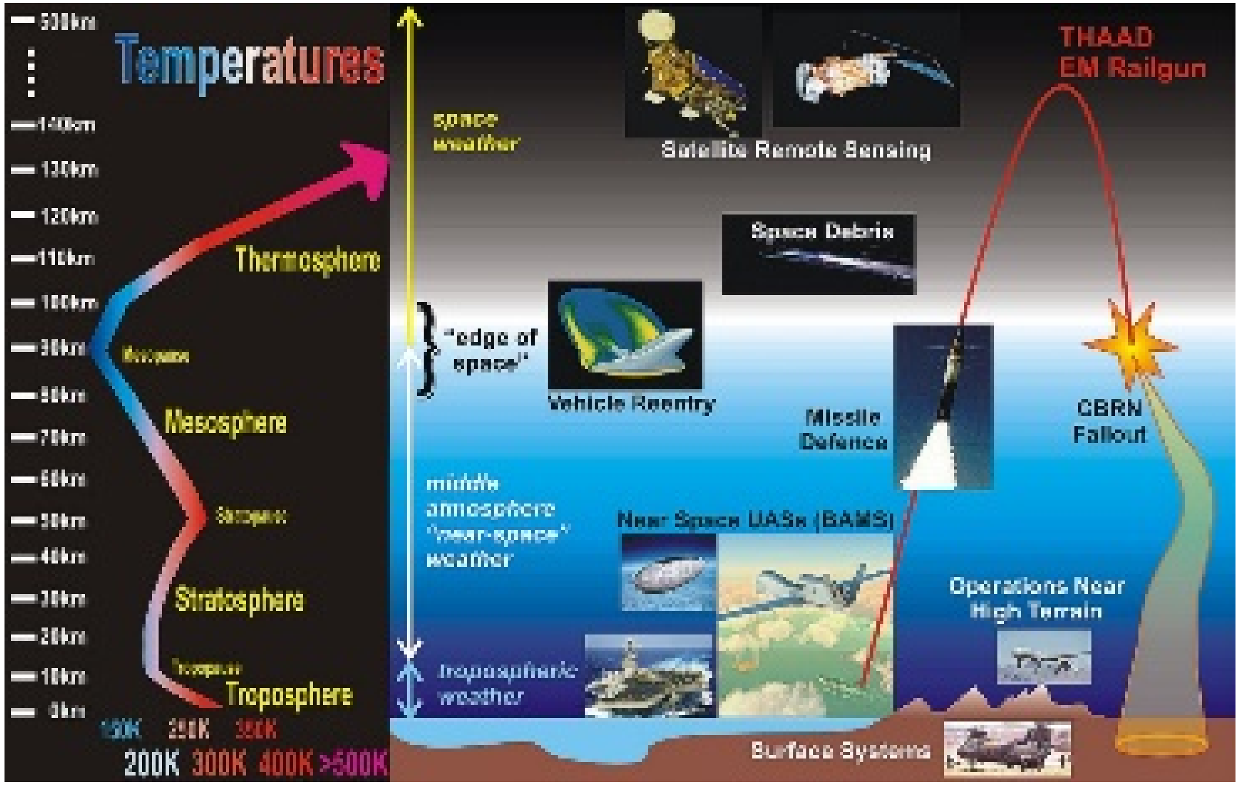
Force of gravity!!!


km
exosphere
1000
800
600
400
thermosphere
200
100
mesopause
80
mesosphere
60
stratopause
40
stratosphere
20
tropopause
10
8
6
4
troposphere
2
1
planetary boundary layer
sea level
0
spacecraft
satellite
increasing
radiosonde
supersonic plane
commercial aircraft
parachute jump
polar lights
polar lights
meteors
noctilucend clouds
ozone layer
nacreous clouds
Mt. Everest
ionosphere
heterosphere
ozono-sphere
homosphere
-100
-60
-20
0
20
40
temperature (°C)

So where space begin?

The atmosphere gradually thins with increasing altitude so there is no real boundary between Earth's upper atmosphere and Space.

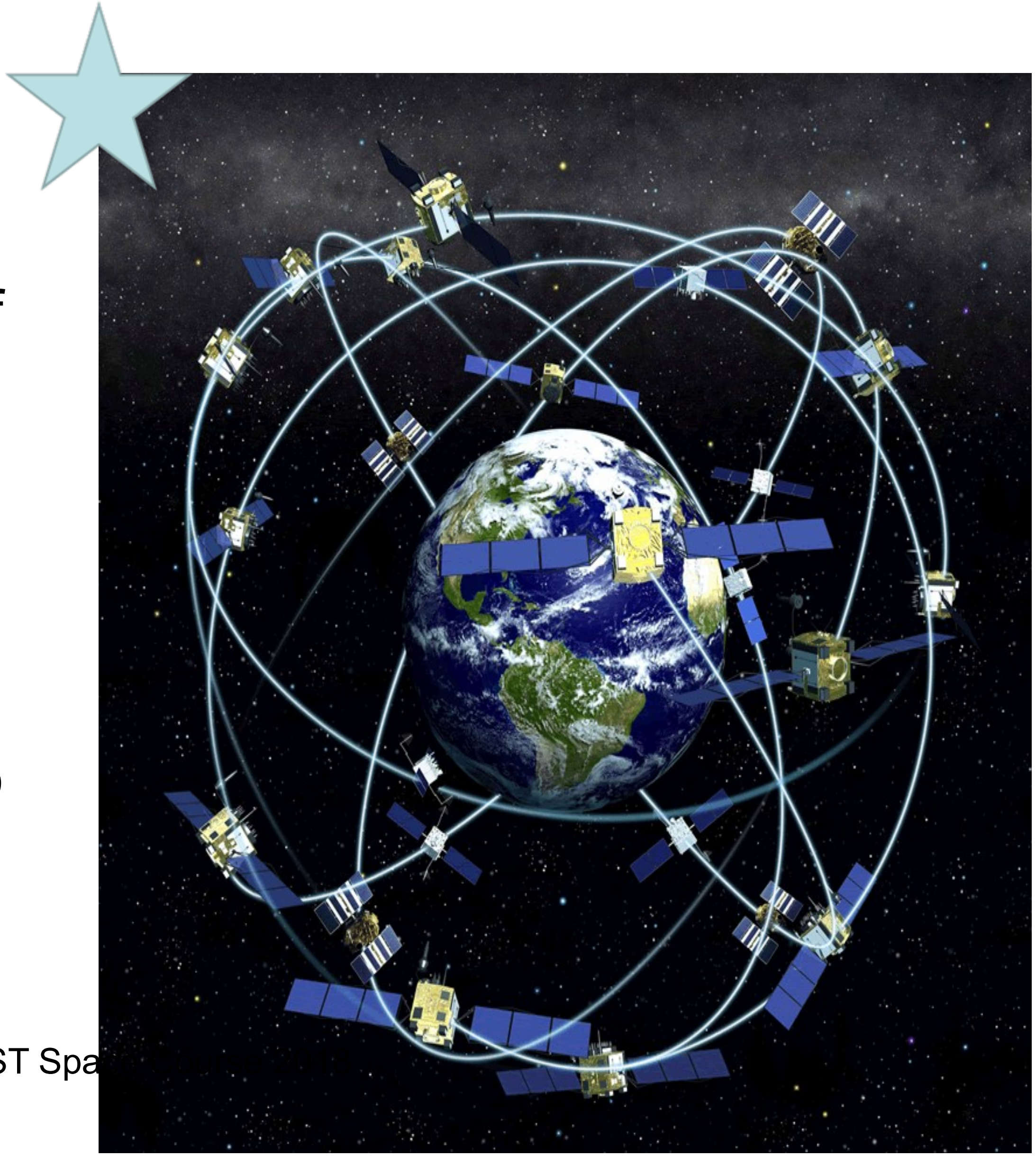
The most widely accepted altitude where Space begins is 100 kilometers



Link to altitude chart: http://www.spacetoday.org/SolSys/Earth/AltitudesChart.html

Outside the Earth's atmosphere it is the vacuum of space that challenge spacecraft engineers

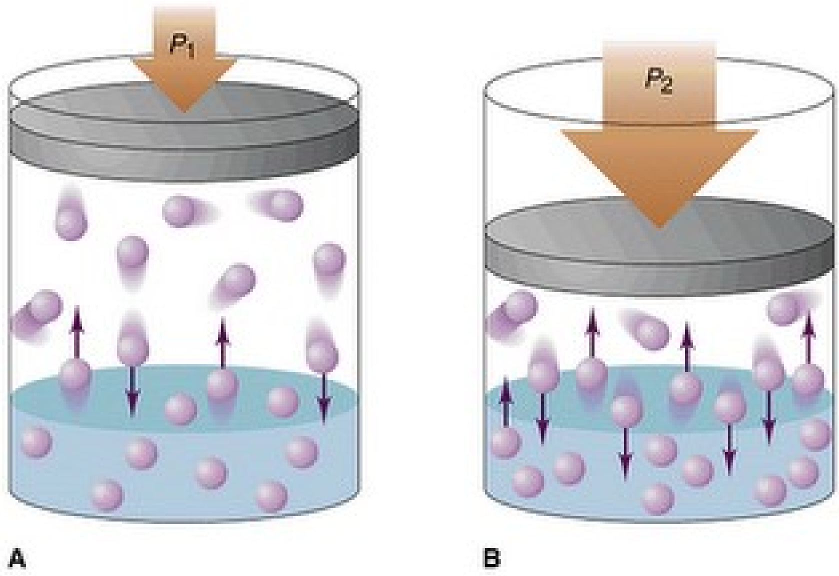
- Three potential problems for spacecraft are:
- Out-gassing = (release of gases from spacecraft materials)
- Cold-welding = (fusing together of metal components)
- Heat transfer = (limited to radiation) …. SMILE
- More details later



Out-gassing also known as “off-gassing”

- **Out-gassing** is the release of a gas that was dissolved, trapped, frozen, or absorbed in some material.
- **When you get into your car and it has that “new car smell” is a common real world example**

In a low pressure environment the problem of out-gassing increases



In space-based equipment, released gas can condense on such materials as mirrors and camera lenses, rendering them inoperative

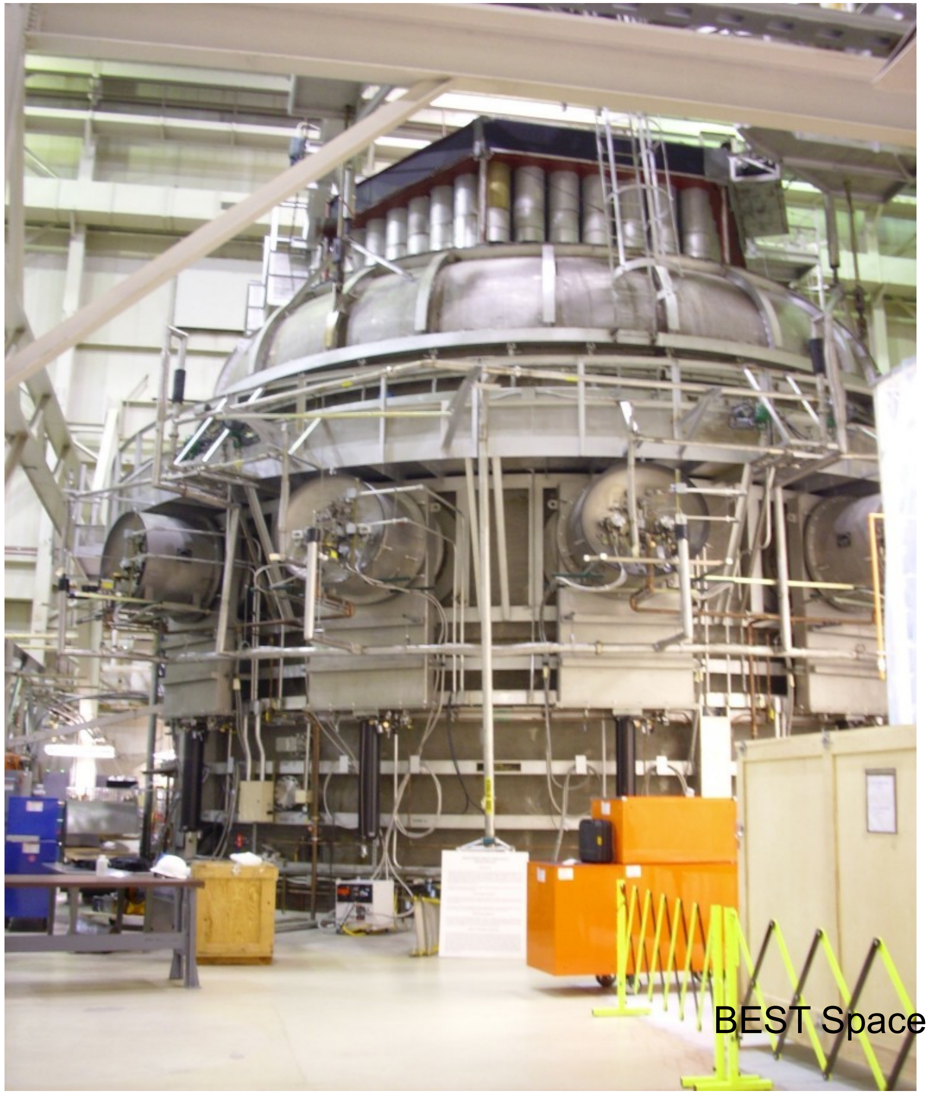
- Solutions:
- Laboratory testing to select materials that have low out-gassing properties in a “near” vacuum environment.
- Moisture sealants, lubricants, and adhesives are the most common sources, but even metals and glasses can release gases from cracks or impurities.

NASA Low Outgassing

The industry standard test for measuring outgassing in adhesives and other materials is ASTM E595. Developed by NASA to screen low-outgassing materials for use in space, the test determines the volatile content of material samples placed in a heated vacuum chamber.

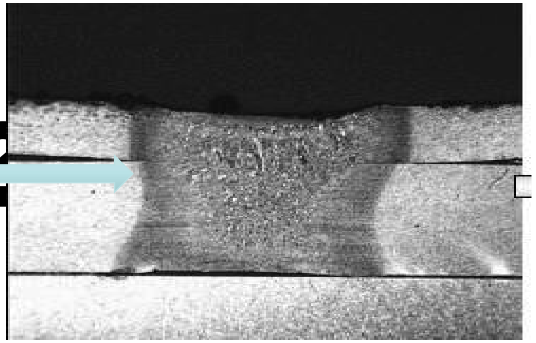
http://www.masterbond.com/certifications/nasa-low-outgassing

Before being put into orbit, spacecrafts are placed into a thermal-vacuum chamber for a process called “bake-out”.



Thermal Vacuum Chamber at NASA Goddard
By Corrie Davidson

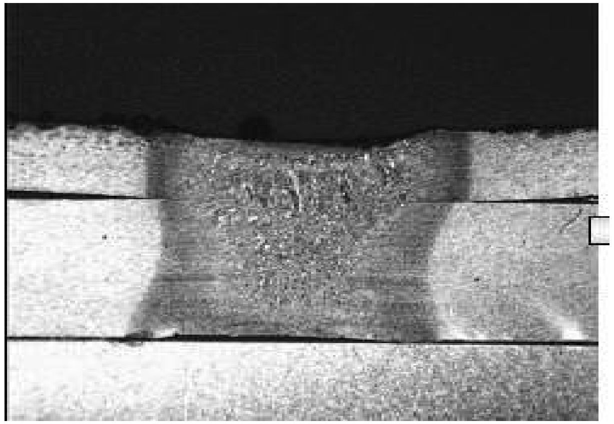
What is cold-welding?

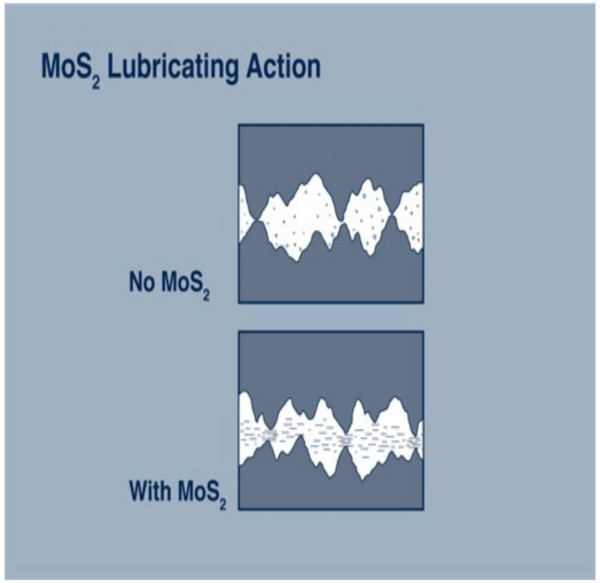


- Cold welding occurs between mechanical parts that have very little separation between them.
- Alternatively, cold welding will occur when the lubricant between moving mechanical parts outgas or evaporate.
- Important for satellites and spaceprobes as they include moving and rotating parts eg filter wheels
- Some space engineering approaches avoid moving parts using alternatives (eg. Gaia, BRITE)

Possible solution for cold-welding

- **Ground controllers must try different strategies to “unstick” the two parts.**
- **One strategy is to expose one part to the Sun and the other to shade so that differential heating causes the parts to expand and contract.**
- **Lubricants that don’t evaporate or outgas must be used. For example solid molybdenum-disulphide is an example of lubricant that will not evaporate or outgas.**



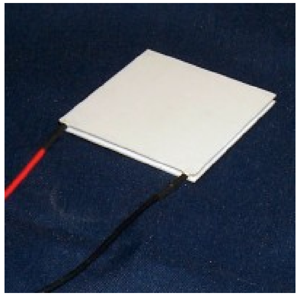


Heat management in space

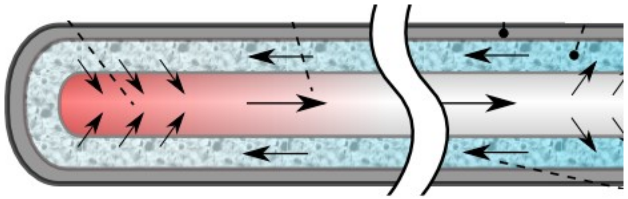
- Heat transfer in and out of a satellite is a unique problem in a near vacuum.
- Mechanical and electrical systems create heat that can degrade spacecraft systems.
- On the ground, e.g. in a laptop, fans are used to transfer heat out of the system. That is not possible in vacuum.

Heat transfer in the space environment

1. Conduction and radiation (convection ineffective)
2. Spot electrical cooling with devices such as peltrier coolers.



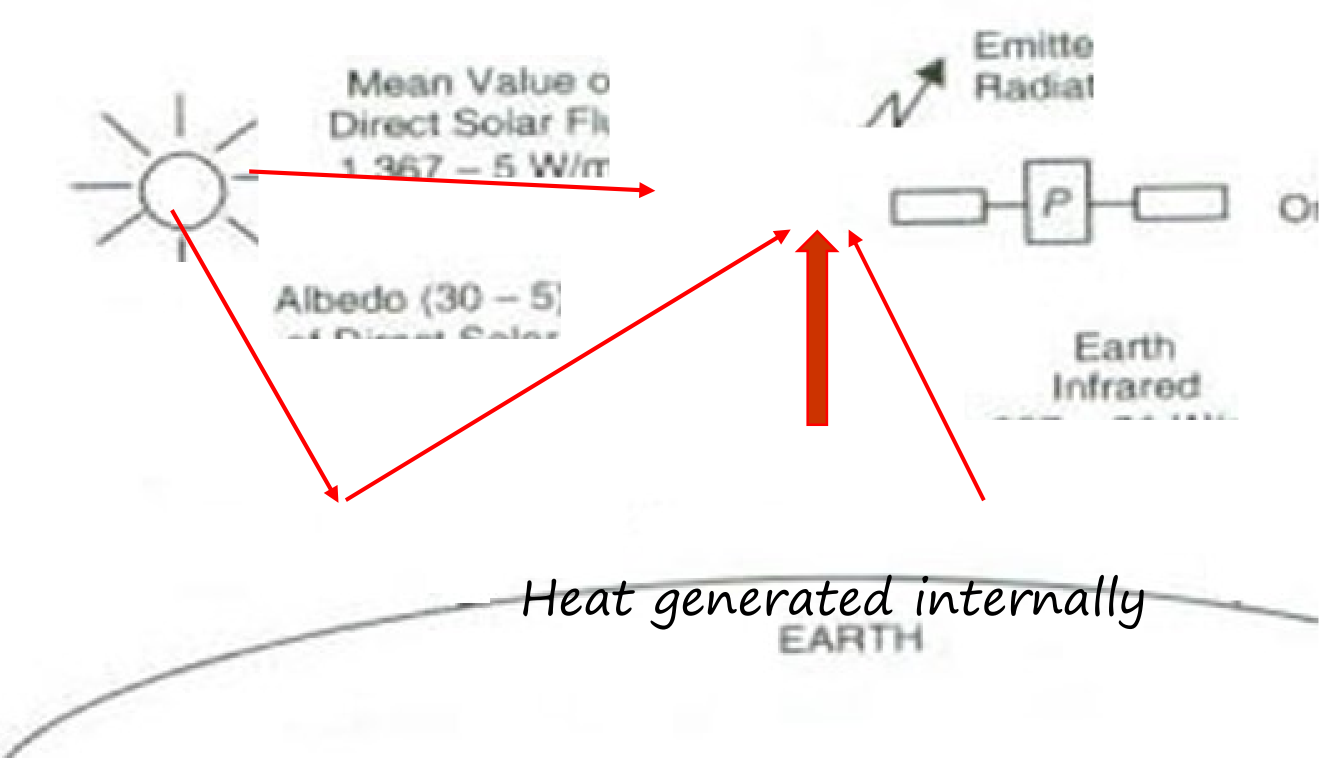
3. Move heat from hot areas to cool areas by conduction, fluids and heat pipes.



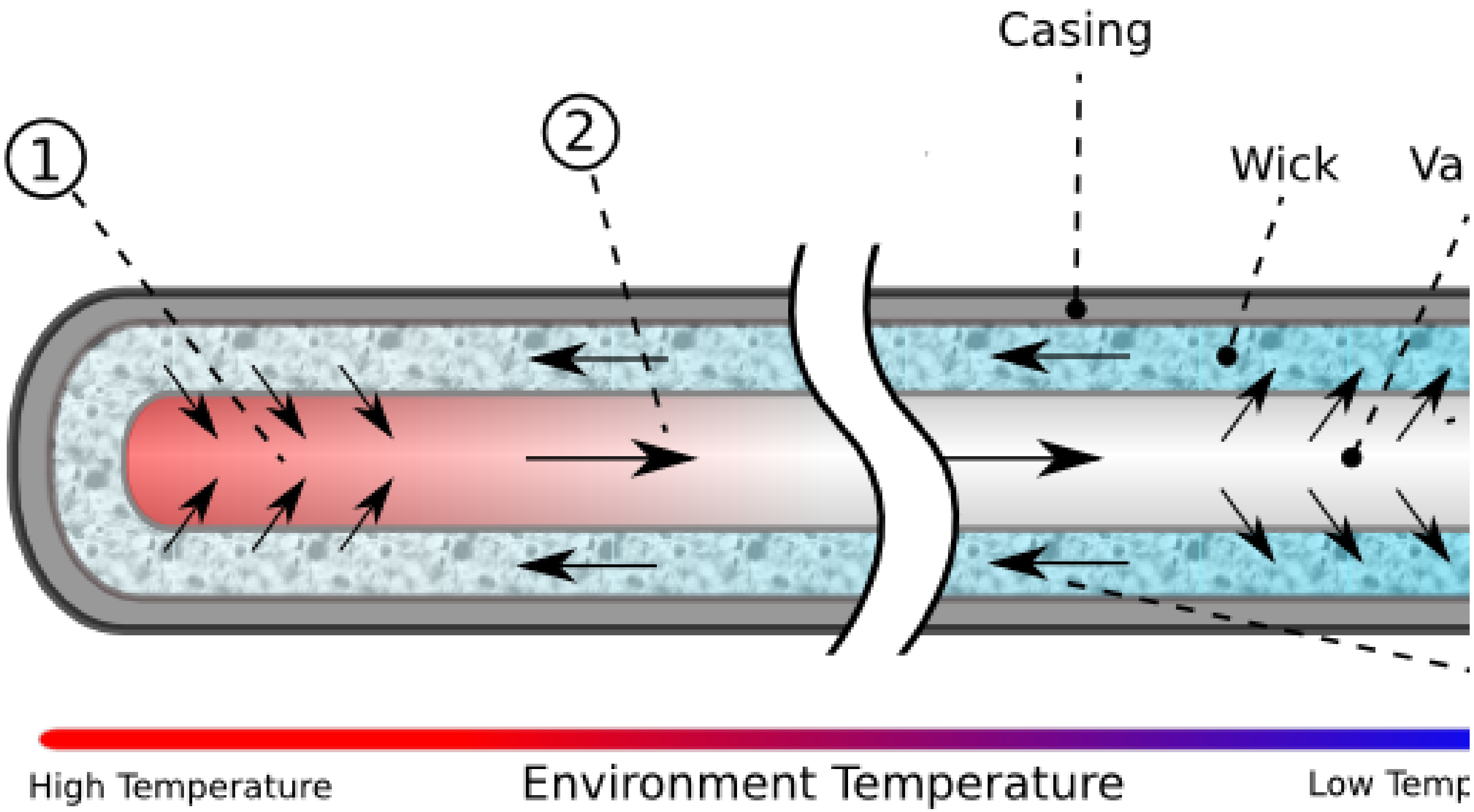
Heat & Space Environment

In: (where heat comes from)

Out: (where heat goes)



Passive Heat Pipes



Heat pipe thermal cycle

1) Working fluid evaporates to vapour absorbing thermal en

Debris and Micrometeoroids

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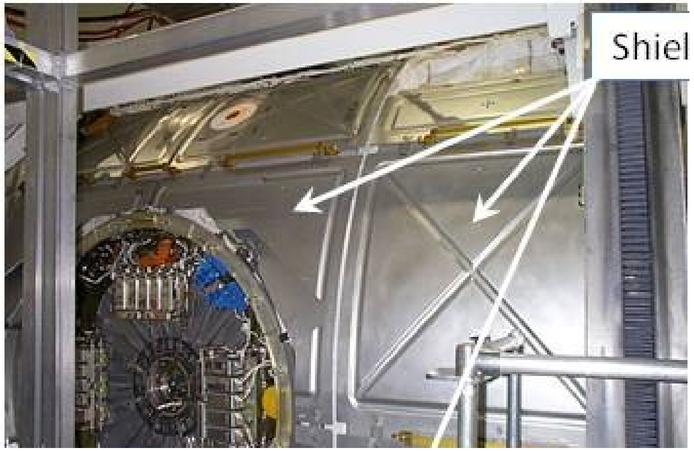
Space Debris

- Space debris is non-operational man-made object in space. The size varies from inoperative satellites and expended rocket bodies to small pieces.
- Of the more than 10,000 man-made items in space currently tracked and catalogued, only about 5% are operational space systems.
- The rest is space debris. Space debris smaller than approximately 2 cm cannot be detected and tracked reliably, so there probably are significantly more space debris (40-80 000) than we know about.
- The debris can hit satellites at high speed and damage them

Meteoroids

- It is estimated that approximately 20,000 tons of natural material is added to the Earth each year from impacts of meteoroids and asteroid fragments with the Earth's atmosphere.
- Most of these particles are the size of dust particles, however, some are much larger. When meteoroids enter the Earth's atmosphere they usually burn up due to the friction with the air molecules. Larger meteoroids generate enough light to be seen as meteors streaking across the night sky.
- Occasionally, larger objects don't completely vaporize. When a piece strikes the surface of the Earth it is called a meteorite.



- These particles represent a constant natural danger to satellites in orbit around the Earth.
- Most meteoroids are too small and traveling too fast to be detectable in time for satellite controllers to direct a satellite to change it's orbit to avoid collision.
- Shielding and other design considerations are the most effective means to protect satellites from catastrophic damage.

Radiation and Particles

Radiation and charged particles from the Sun and the universe can severely damage unprotected spacecraft

Cosmic Rays

- Cosmic rays originate from two sources: the Sun (solar cosmic rays), and other stars throughout the universe (galactic cosmic rays). This radiation is primarily high velocity protons and electrons. The galactic cosmic rays are extremely energetic, but do not pose a serious threat, due to the low flux, the rate they enter the atmosphere.
- The solar cosmic rays are not a serious threat to humans, except during periods of solar flare activity, when the radiation can increase a thousand-fold over short periods. Cosmic ray particles can also cause direct damage to internal components through collision. Cosmic rays have the most impact on polar and geosynchronous orbits. This is due to the fact that they are outside or near the edge of the protective shielding provided by Earth's magnetic field.

Radiation Environment: Galactic

- Primarily interplanetary protons and ionized heavy nuclei
  - 1 MeV $< E <$ 1 GeV per nucleon Cause Single Event Upsets (SEU)

- Sources are outside the solar system
  - other   solar flares
  - nova and supernova explosions
  - quasars

Radiation Environment: Solar

Solar Radiation:

Composition: Electromagnetic radiation, protons and electrons

Energy: Electromagnetic: 1 Å to 10^5 Å
Protons: 500 eV to 15 BeV; typically 20 to 500 MeV
Electrons: 1 eV to 100 MeV

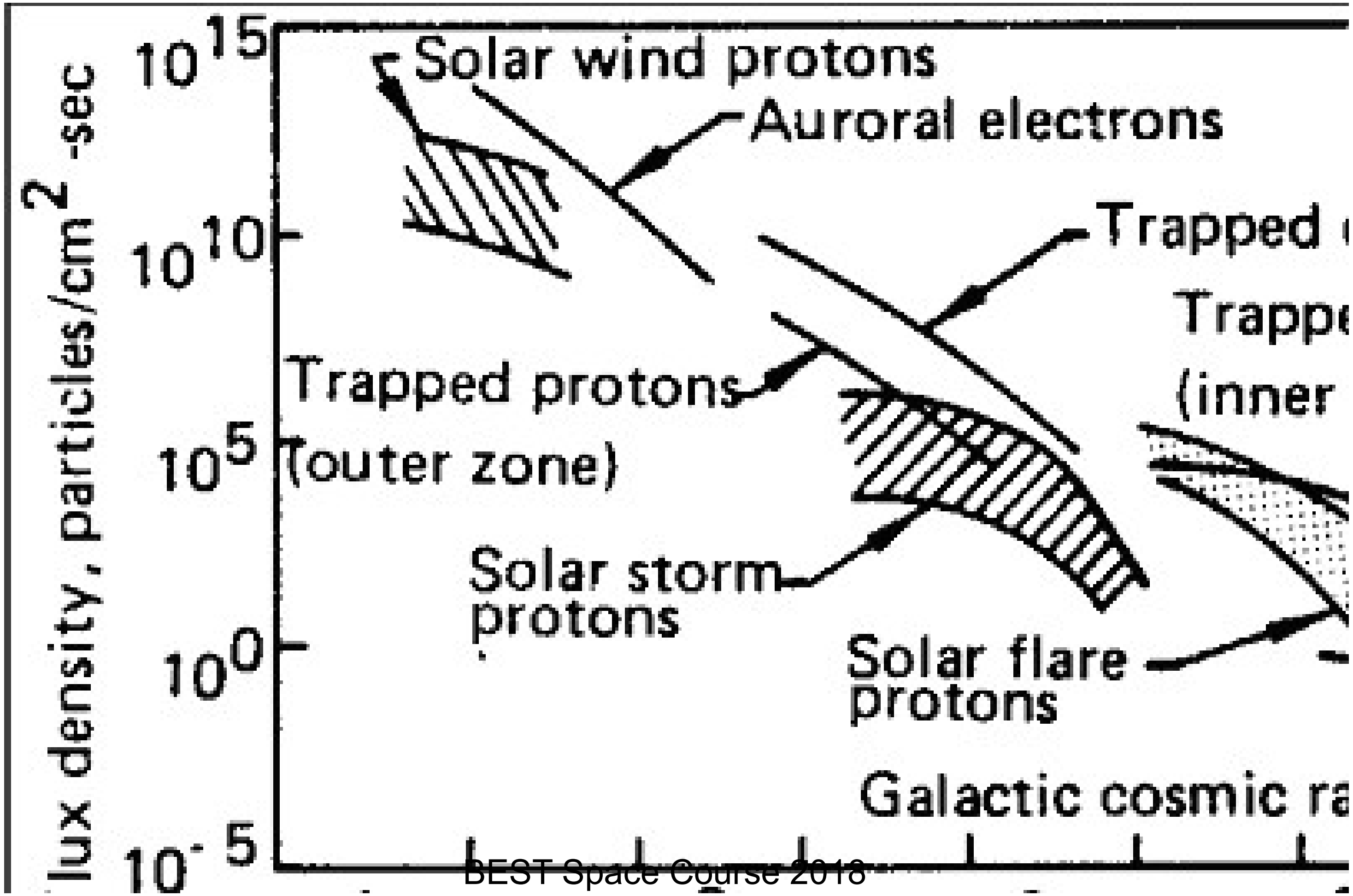
Intensity: Electromagnetic: 130 Watts/ft^2
Protons: 1 to 10^{12} particles/cm^2 sec; typically 10^4 particles/cm^2 sec during major flare
Electrons: Generally less than 10^2 particles/cm^2 sec; up to 10^7 particles/cm^2 sec

Spatial Distribution: Electromagnetic: $I = I_o (r_o/r)$ where r is distance from sun; I_o, r_o at sun
Protons: Nearly $1/r^2$
Electrons: Uncertain

Temporal Fluctuations: Electromagnetic: Nearly stable, low λ (x-ray) peak during 11 year cycle
Protons: Maximum during solar maximum; flare and CME dependent
Electrons: Same as protons

Earth Radiation Environment

Is extremely complex and very variable



Solar Wind

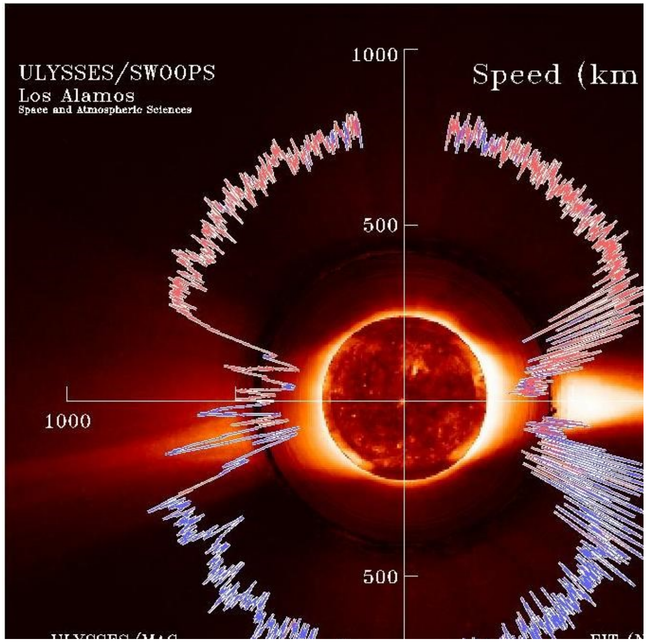
- Because of the high temperature of the Sun's corona, solar protons and electrons acquire velocities in excess of the escape velocity from the sun. There is a continuous outward flow of charged particles in all directions from the sun called the solar wind. By the time the solar wind reaches Earth's orbit, it is traveling at 300 to 700 km/sec. The density is 1 - to 10 particles per cubic centimeter. The velocity and density of the solar wind vary with sunspot activity.
- The total number of particles carried away from the Sun by the solar wind is about 1.3×10^{36} per second. Thus, the total mass loss each year is about $(2–3)\times10^{-14}$ solar masses, or about one billion kilograms per second.

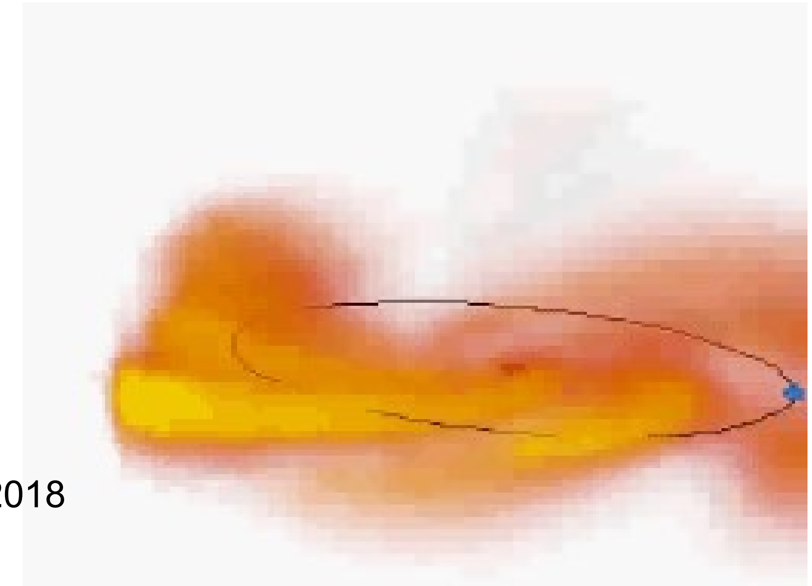
It Starts from the Sun…

Solar Wind Properties:

- Comprised of protons (96%), He^{2+} ions (4%), and electrons.
- Flows out in an Archimedean spiral.

- Average Values:
  - Speed (nearly Radial): 400 - 450 km/s
  - Proton Density: 5 - 7 cm^{-3}
  - Proton Temperature 1-10eV (10^5-10^6 K)

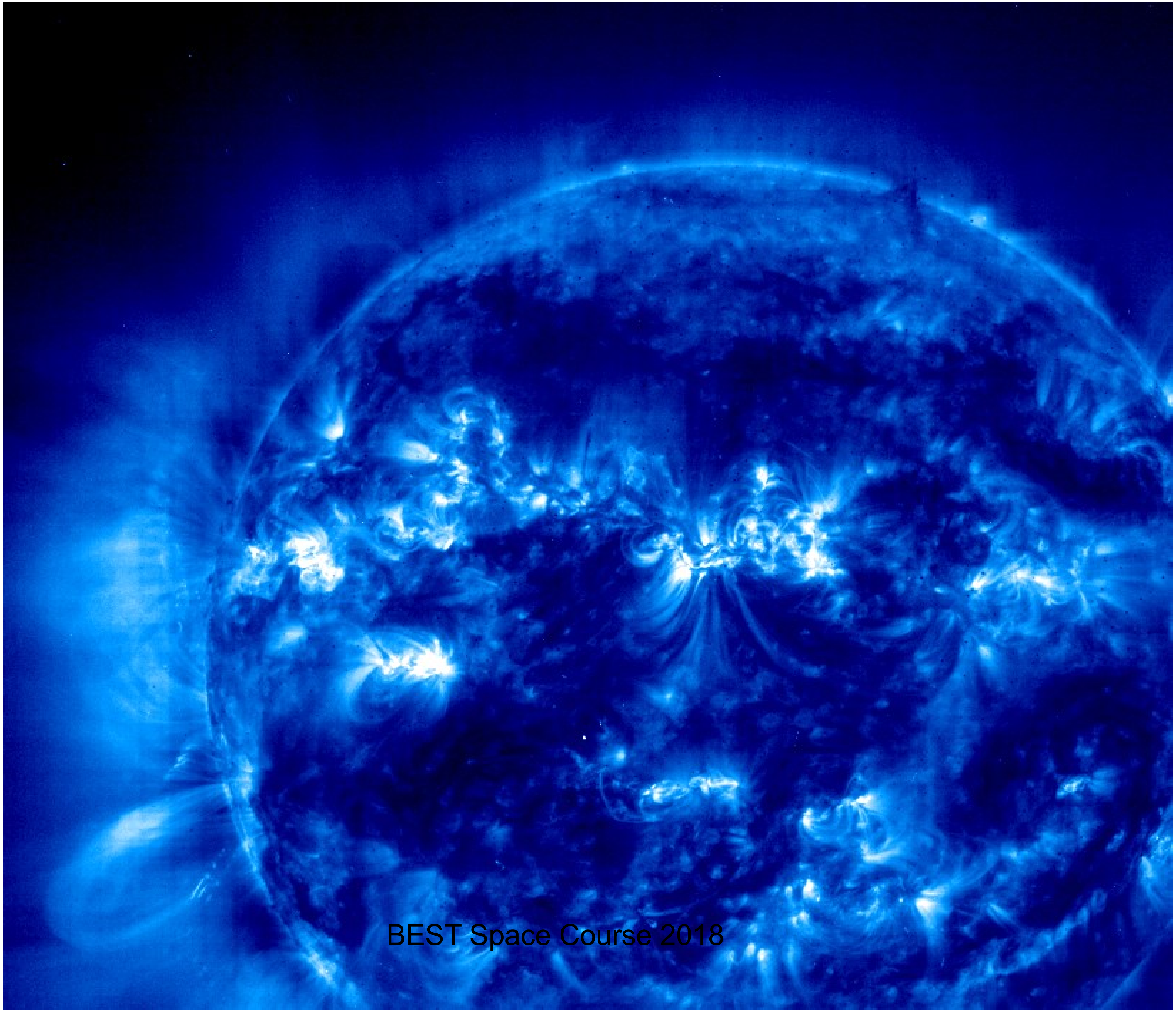




Solar Wind II

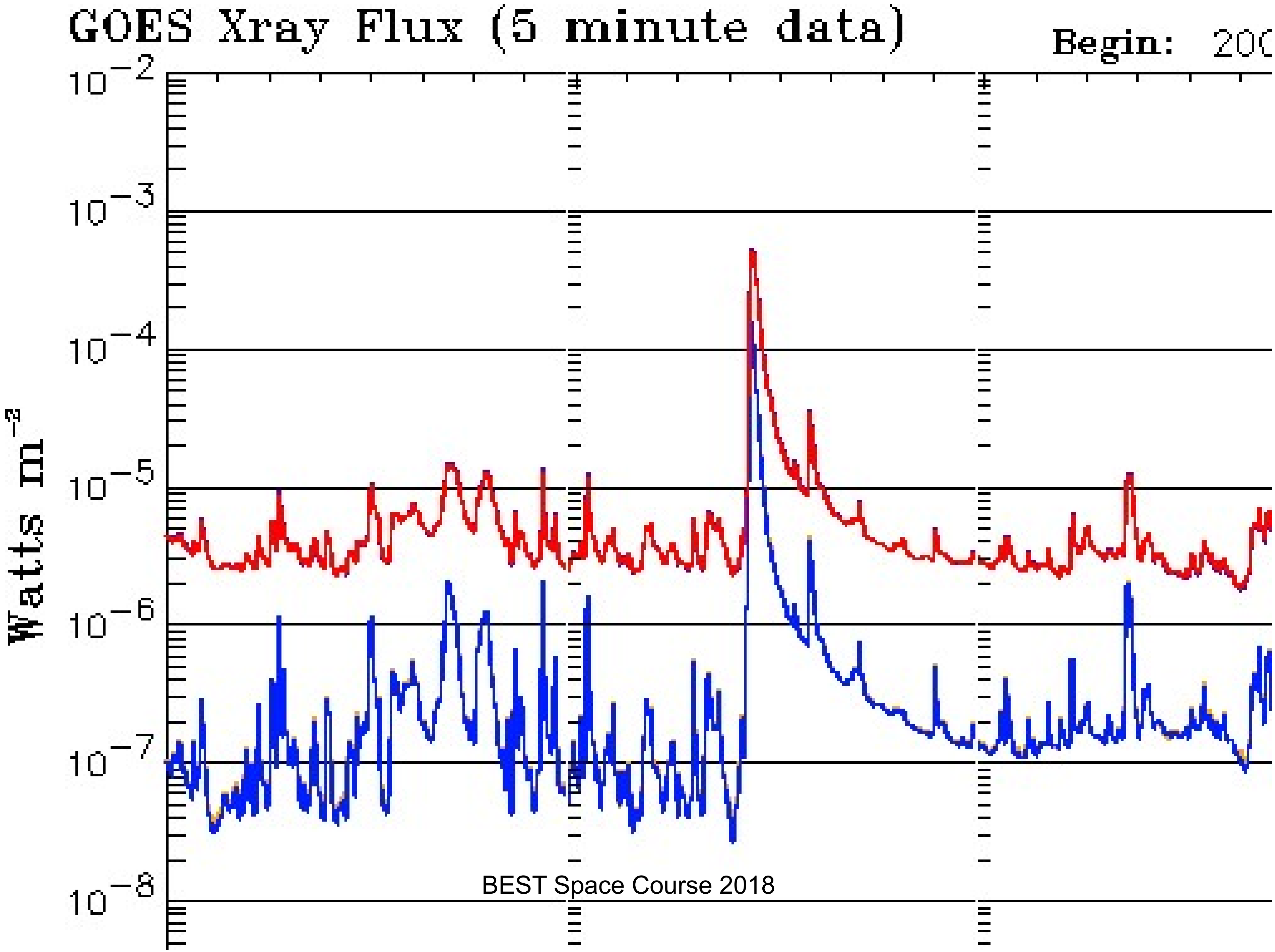
- The solar wind causes a **radiation pressure on satellites**. Radiation pressure is a source of perturbations, especially for satellites with large area to mass ratios e.g. with large solar panels Radiation pressure causes frictional drag. It is present only on the daylight side of Earth. The satellite is essentially shielded from solar wind when it is on the night side of Earth. This causes irregular perturbations of a satellite's orbital elements and corresponding ground traces.

SOHO-EIT, 2000/07/14 @ 07:00 UT



Solar Flares

- High speed solar protons emitted by a solar flare represent hazards to space flight. Flares are among the most spectacular disturbances seen on the Sun. A flare may last from several minutes to a few hours. There is a relationship between the number of sunspots and the frequency of flare formation, but the most intense flares do not necessarily occur at solar cycle maximum. There are many events that may occur on Earth following a solar flare e.g. a Sudden Ionosphere Disturbance (SID) in Earth's ionosphere. This causes short wave fade-out, resulting in the loss of long-range communications for 15 minutes to 1 hour. During the first few minutes of a flare, there may be a radio noise storm.


GOES Xray Flux (5 minute data)
Begin: 200
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
Watts m^-2
BEST Space Course 2018

Solar Activity

- Represents danger for spacecrafts and satellites
- It is not constant and good knowledge and predictions are extremely important

Solar activity II

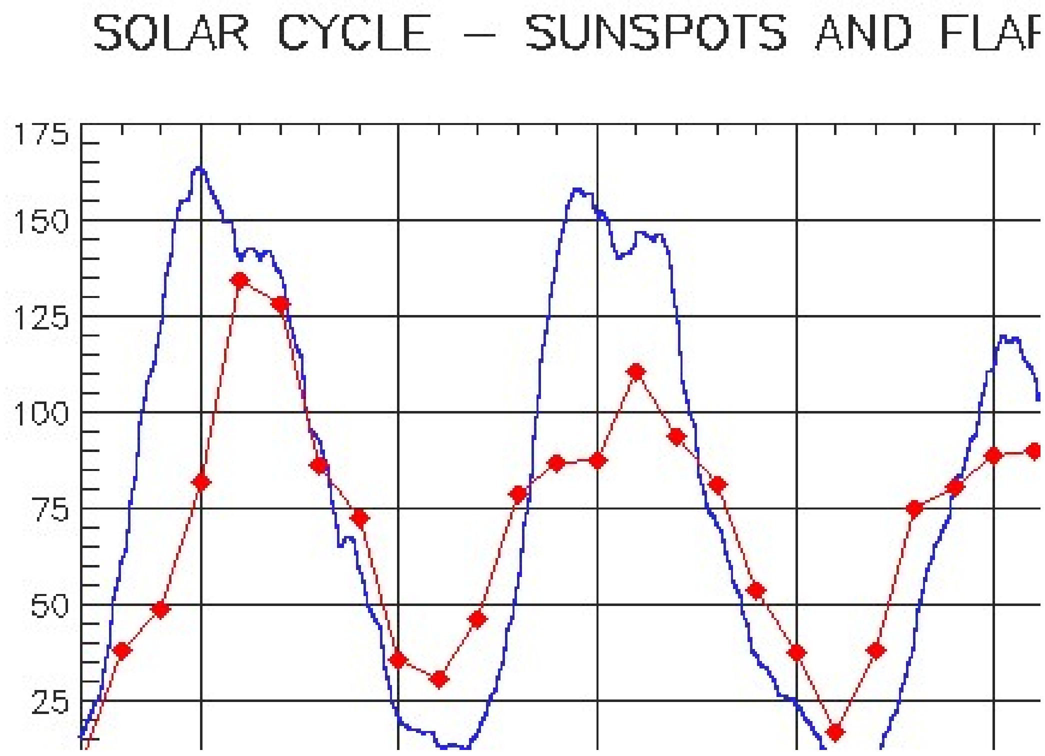
- Solar activity is also characterized by cycles of various lengths. The Sun has a rotation period of 28 days, which exposes Earth to the surface features of the Sun, such as sunspots. The number of sunspots is characterized by an 11-year cycle. Sunspots are normally associated in a complex, but not completely understood, way with solar flares, i.e., the more the sunspots, the more the solar flares. A change in polarity of the overall solar magnetic field is characterized by a 22 year cycle

WHAT IS A SOLAR CYCLE?

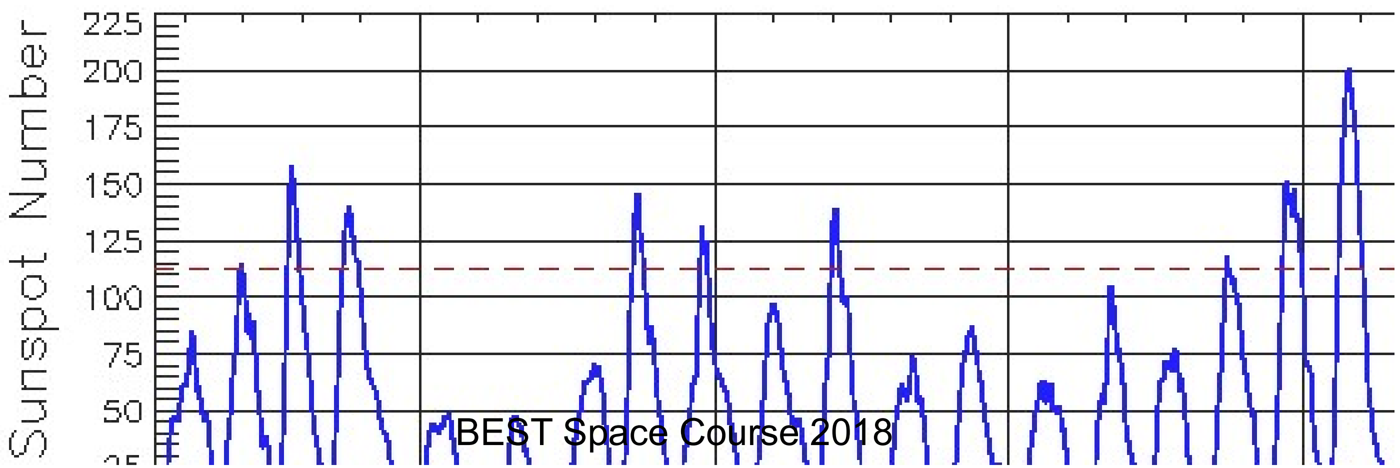
Solar activity rises and falls over an 11 year cycle

- **Can be shorter/longer**
- **Activity correlates with**

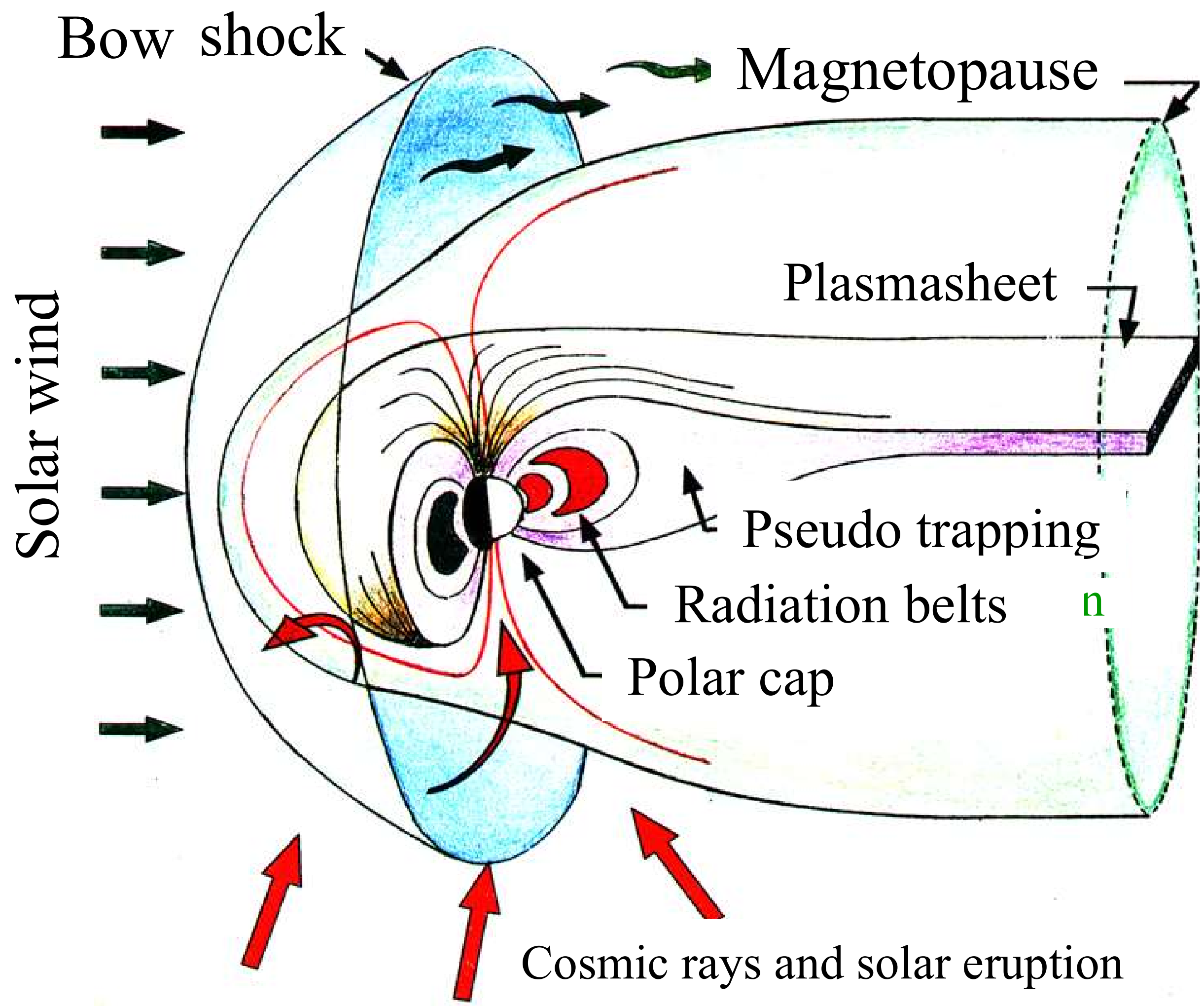
  Sunspot Number



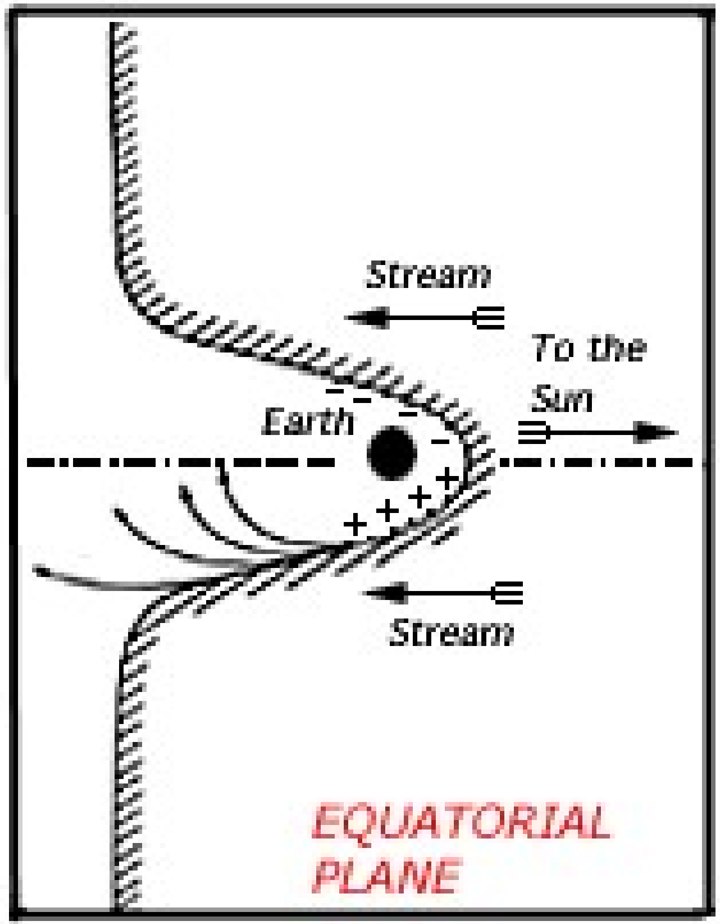
The Solar Cycle in Sunspot Number



Complex Near Earth Environment

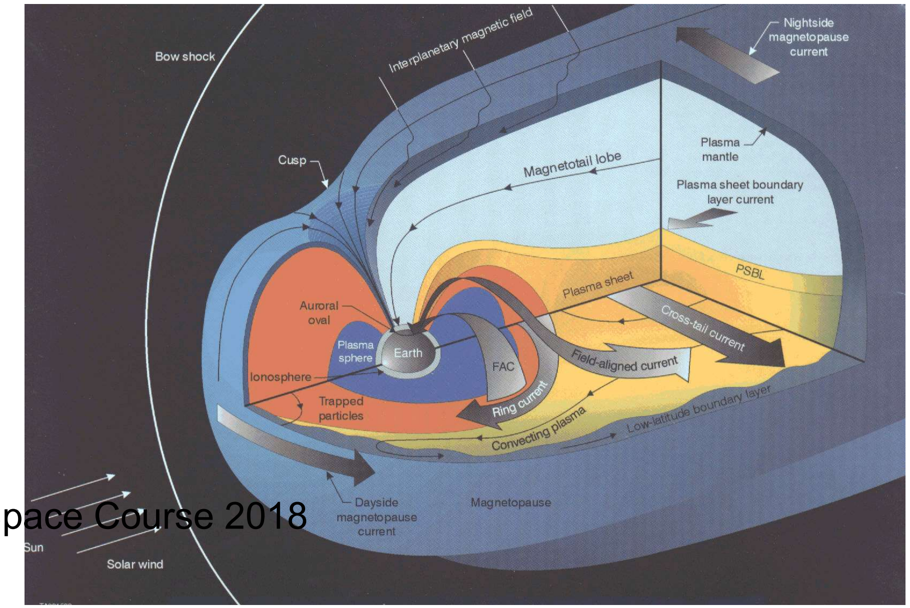


Shaping Earth's Magnetosphere



- Earth's magnetic field is an obstacle in the supersonic magnetized solar wind flow.

- Solar wind confines Earth's magnetic field to a cavity called the "Magnetosphere"

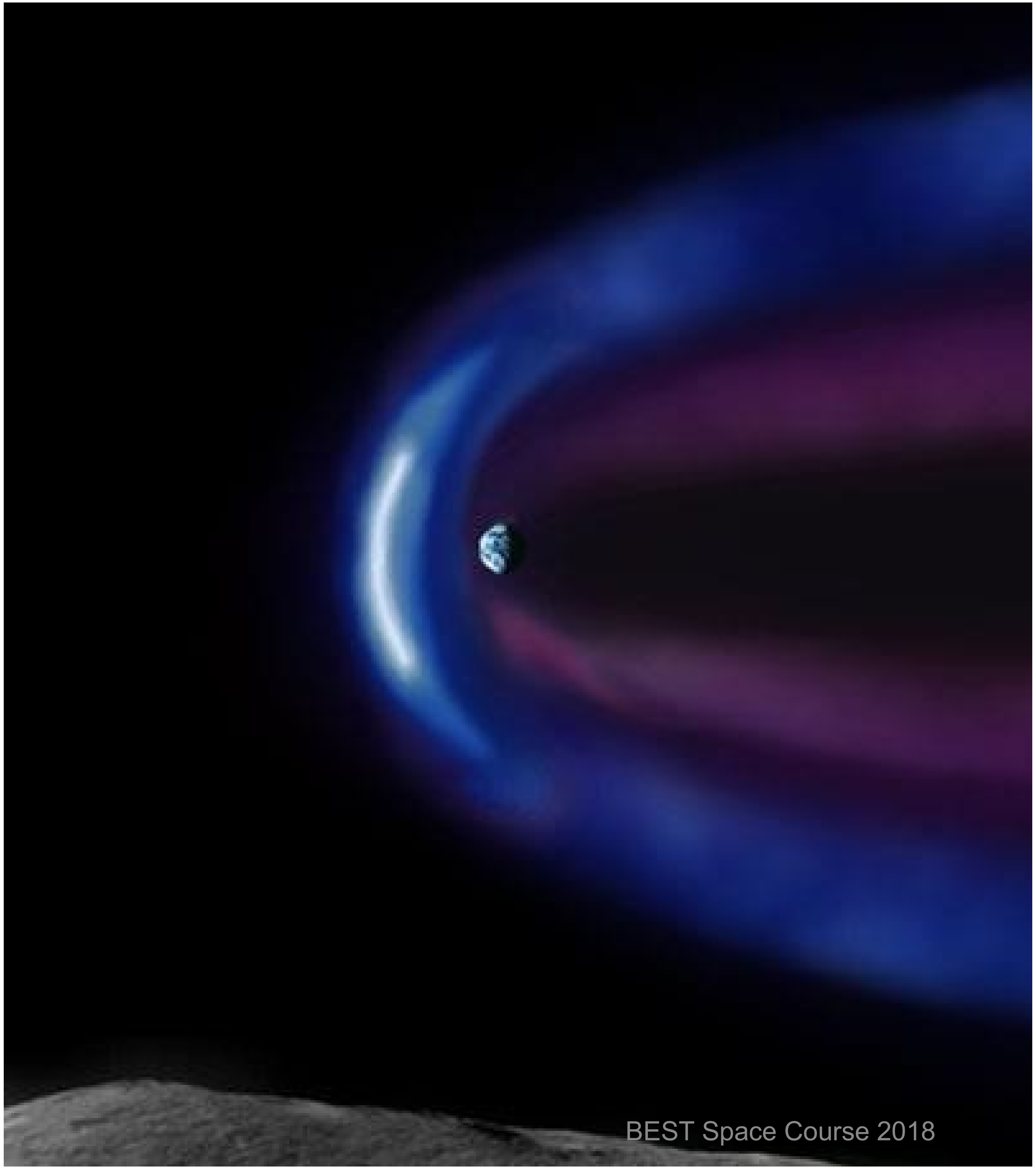


SMILE

Solar wind Magnetosphere Ionosphere Link Explorer

Rene ... dec, Graziella Branduardi-Raymont,
Steve S... nd Chi Wang

for the SMILE collaboration



This is an artist's concept of the magnetosphere's boundary as seen from the moon in soft X-rays emitted by solar wind charge exchange (SWCX).

Credit: NASA / Rob Kilgore

Radiation Environment: Trapped

Van Allen Radiation:

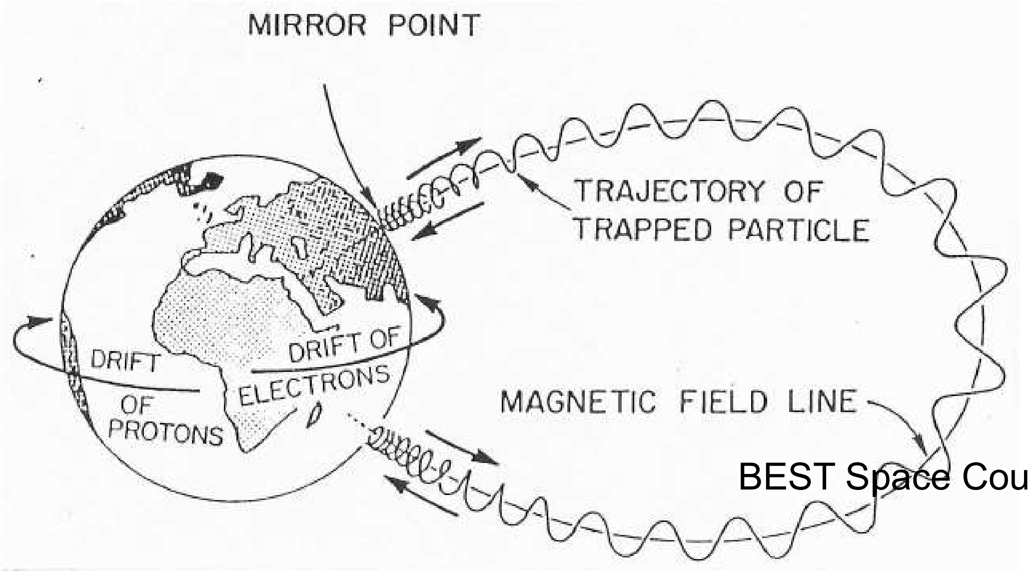
Solar protons and electrons trapped by Earth magnetic field

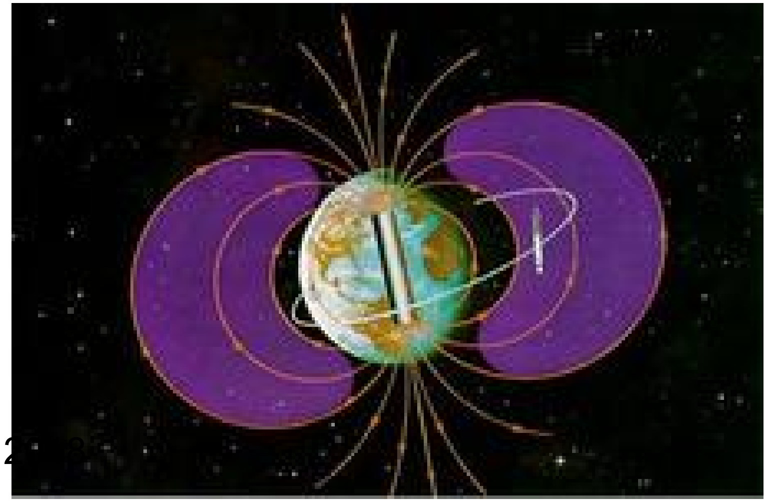
Composition: Protons and electrons
Energy: Protons: Up to several hundred MeV
Electrons: Up to about 5 MeV

Intensity: Protons: (E>30 MeV): 1 to 3 particles/cm^2 sec; up to 10^4 particles/cm^2 sec (inner zone)

Spatial Distribution: Protons: High flux between 600 and 6000 km; peak at about 3500 km
Electrons: Distributed throughout zone; peak near 20,000 km

Temporal Fluctuations: Protons: Inner zone fairly stable; fluctuations within factor of 3 evident
Electrons: Outer zone exhibits wide fluctuations with magnetic storms

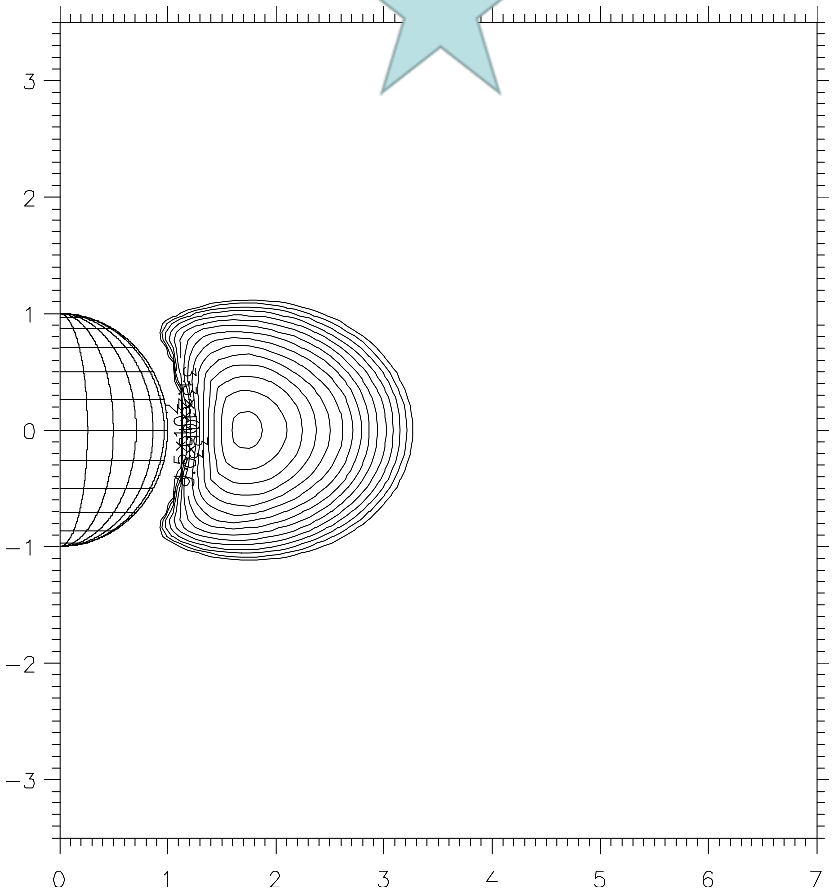




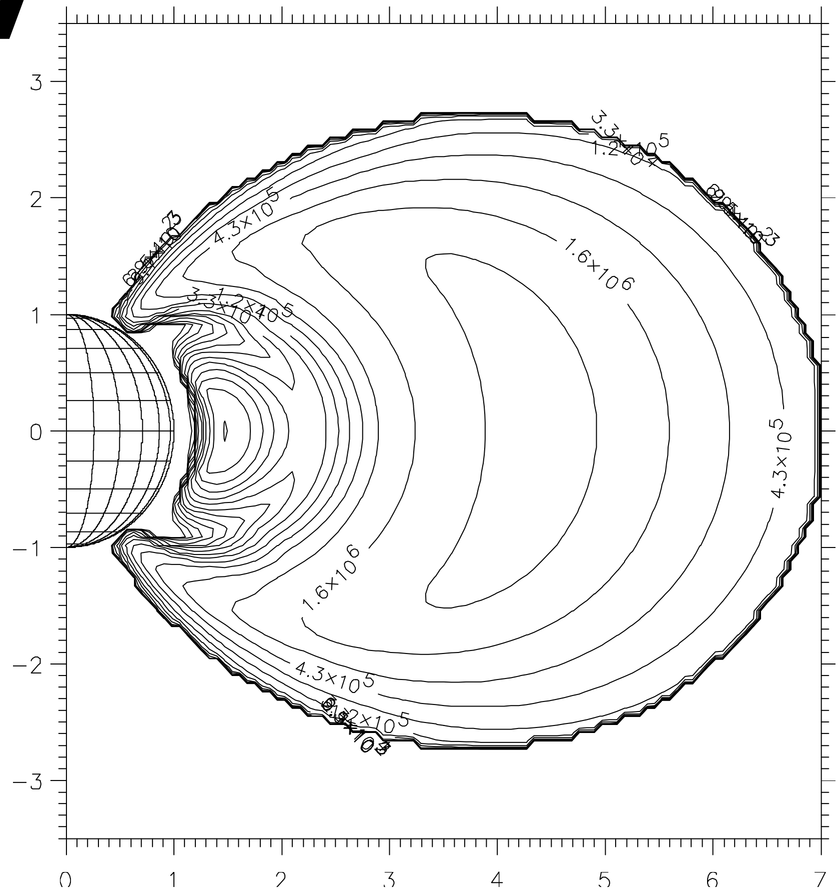
Van Allen Belts

- Torodial belts around the earth made up of electrons and ions (primarily protons) with energies > 30 keV.
- Two big zones
  - **Inner belt** ~ 1000 Km→ 6000 km altitude
    - Protons E > 10's of MeV
    - Electrons E ~ 1 - 10 MeV
  - **Outer belt** 10,000 - 60,000 km
    - Electrons E ~ 0.04 - 4.5 MeV

Van Allen Radiation belts IV



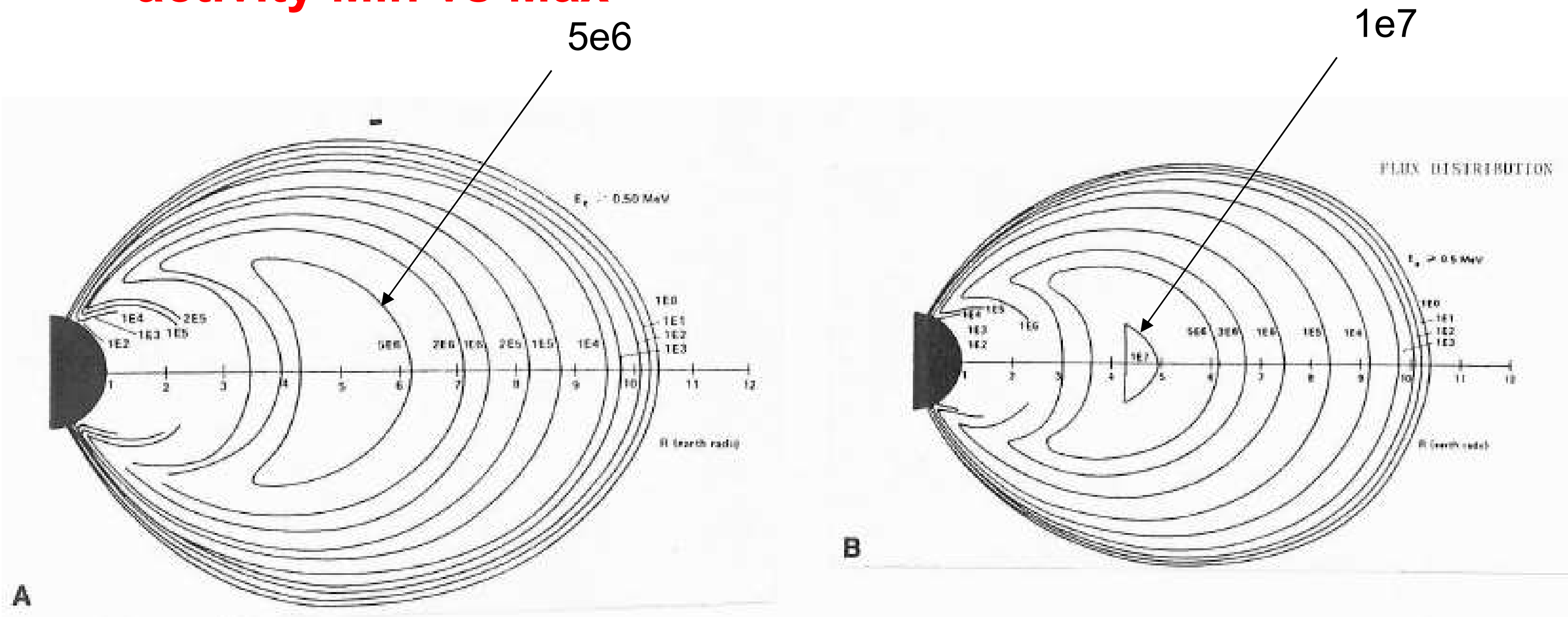
Proton radiation belt



Electron radiation belt

Van Allen Radiation Belts Variations

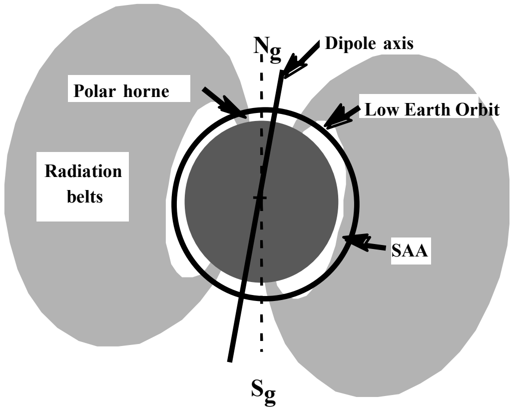
Large variations dependent of phase of solar activity Min vs Max

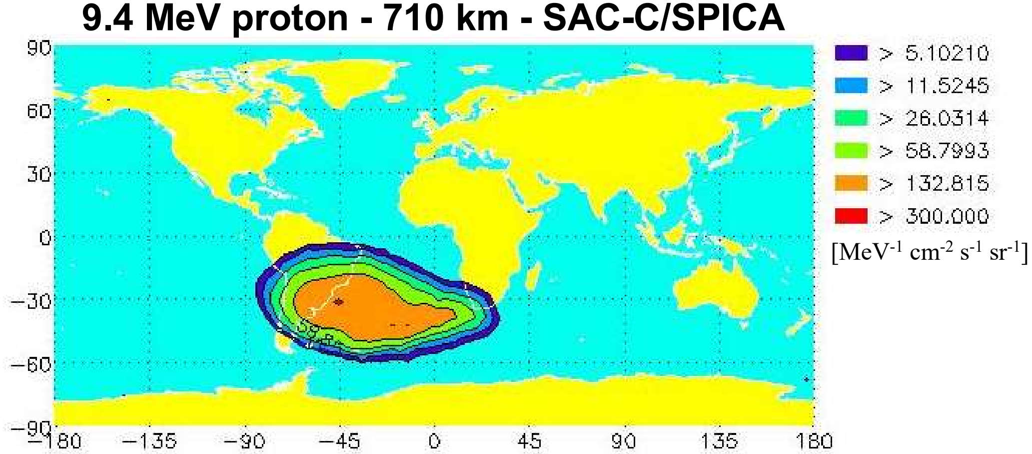


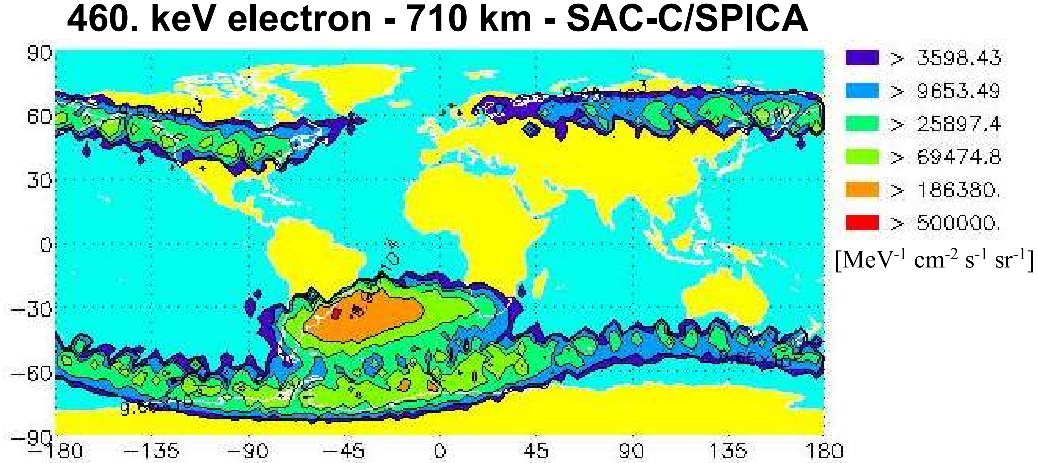
Solar Min

Solar Max

The radiation belts - The South Atlantic Anomaly







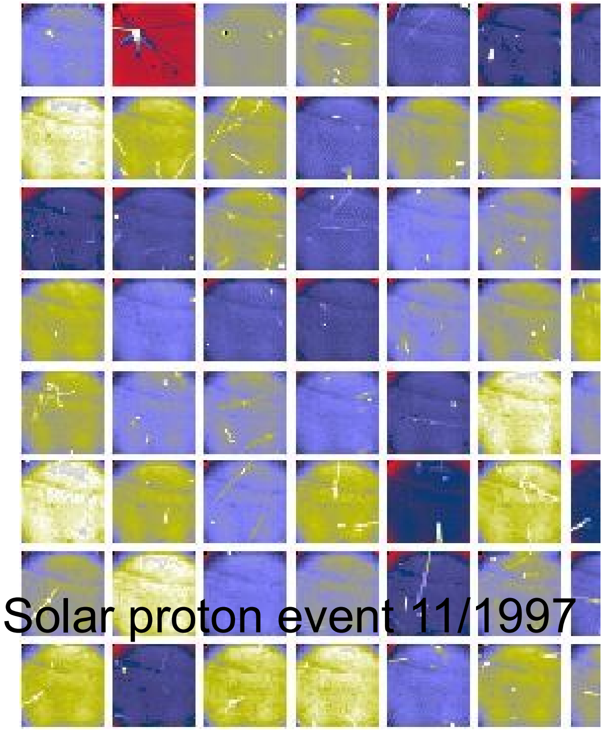
The South Atlantic Anomaly (SAA) is an area where the Earth's inner Van Allen radiation belt comes closest to the Earth's surface dipping down to an altitude of 200 km

Radiation Interactions

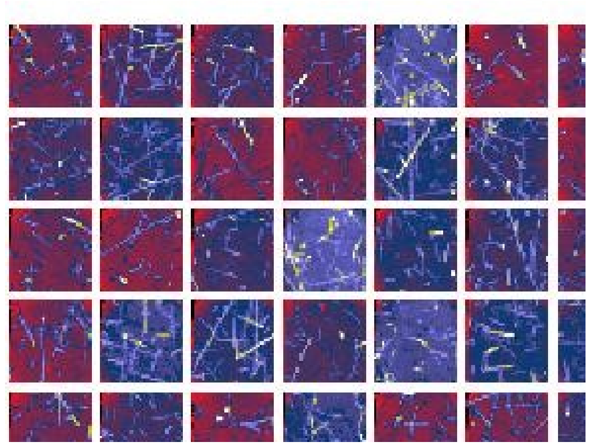
- **Permanent radiation effects**
  - Change in material that persists after material removed from radiation source
  - Typically caused by atomic displacements in the material
- **Transient radiation effects**
  - Change in material does not persist after material removed from radiation source
  - Alters material properties during exposure

Radiation Effects

- Degradation
  - Human
  - Optical Surfaces
  - Solar Arrays
  - Thermal Properties
  - Mechanical Properties
- Sensors and Processors
  - False readings
  - SEU
  - Latch ups



Solar proton event 11/1997

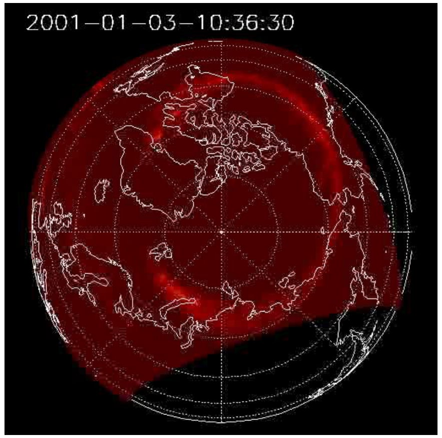


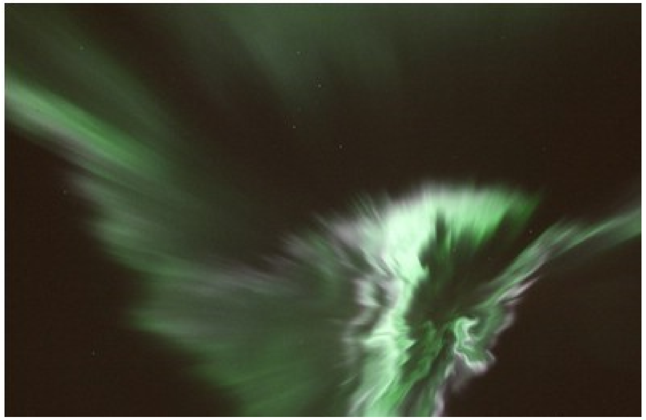
Plasma

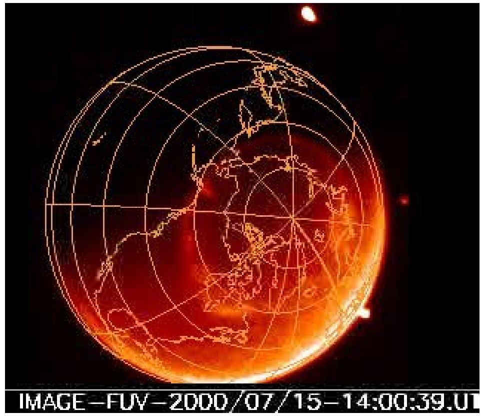
Space Plasma Physics

- Space physics is concerned with the interaction of charged particles with electric and magnetic fields in space.
- Space physics involves the interaction between the Sun, the solar wind, the magnetosphere and the ionosphere.
- Space physics started with observations of the aurorae.
  - Old Testament references to auroras.
  - Greek literature speaks of “moving accumulations of burning clouds”
  - Chinese literature has references to auroras prior to 2000BC

Auroral Displays: Direct Manifestation of Space Plasma Dynamics







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The Plasma State

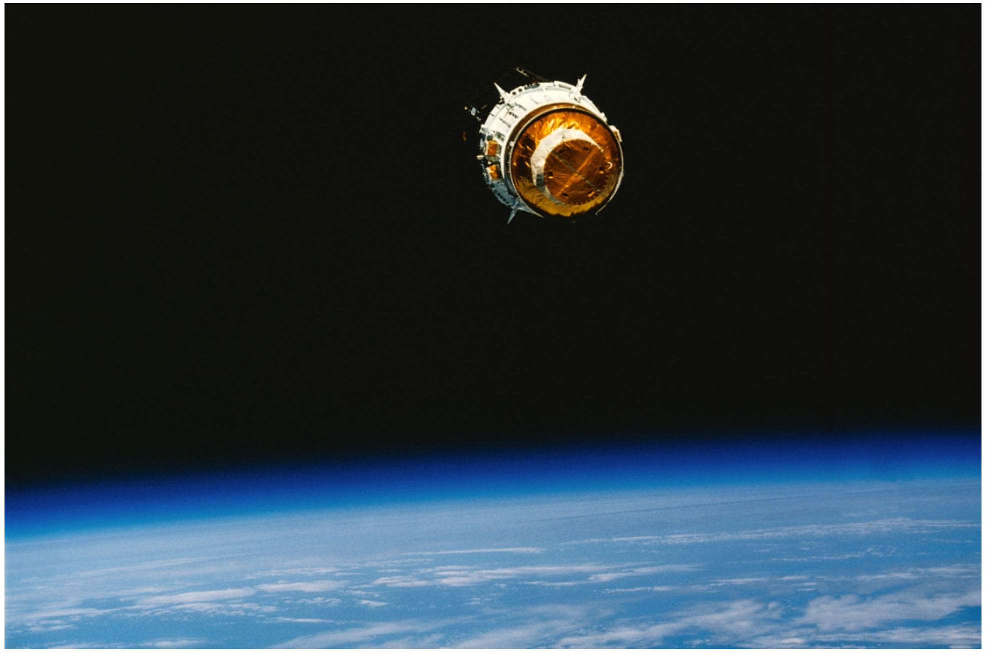
- A plasma is an electrically neutral ionized gas.
  - The Sun is a plasma
  - The space between the Sun and the Earth is “filled” with a plasma.
  - The Earth is surrounded by a plasma.
  - A stroke of lightning forms a plasma
  - Over 99% of the Universe is a plasma.
- Although neutral a plasma is composed of charged particles- electric and magnetic forces are critical for understanding plasmas.

Spacecraft's and Payloads

- Satellite (spacecraft) bus
- Payload (onboard instruments e.g. scientific)

Space-systems Engineering

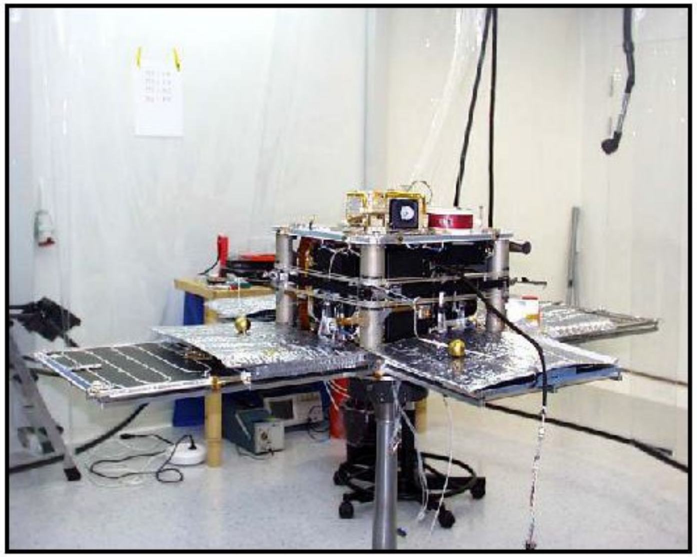
- Define payload.
- Explain how payload requirements affect spacecraft design.
- Describe the major spacecraft subsystems



Spacecraft and Payloads

- Environment
- Power
- Propulsion
  - Attitude Control
- Structure
- Thermal
- Communication
- Data handling
- System Budgets

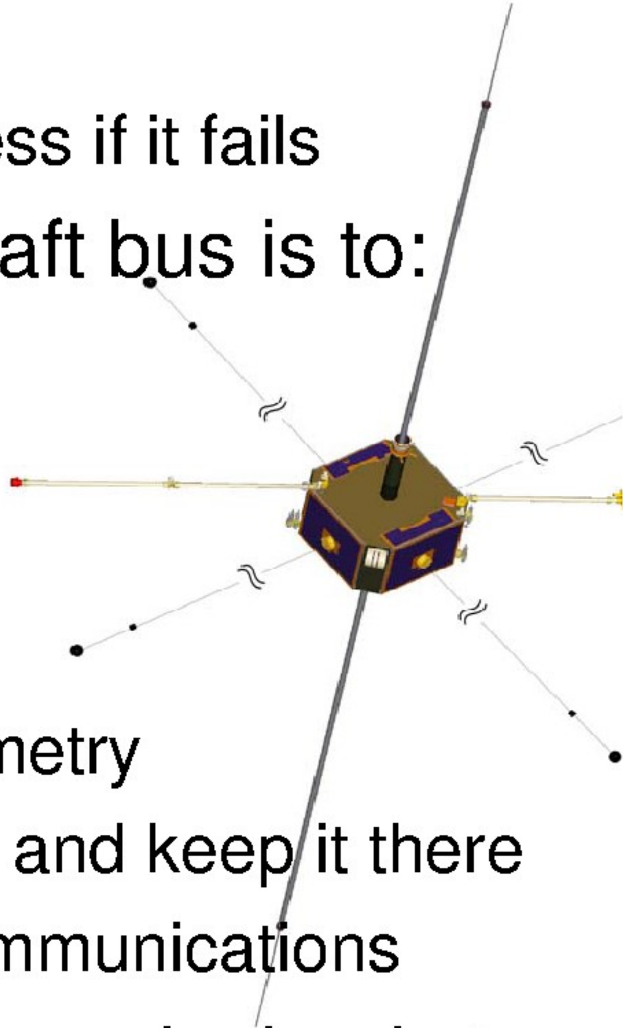
Themis vibration test, NASA Jet Propulsion Lab (JPL)



Astrid-2 in Swedish Space Corporation Cleanroom

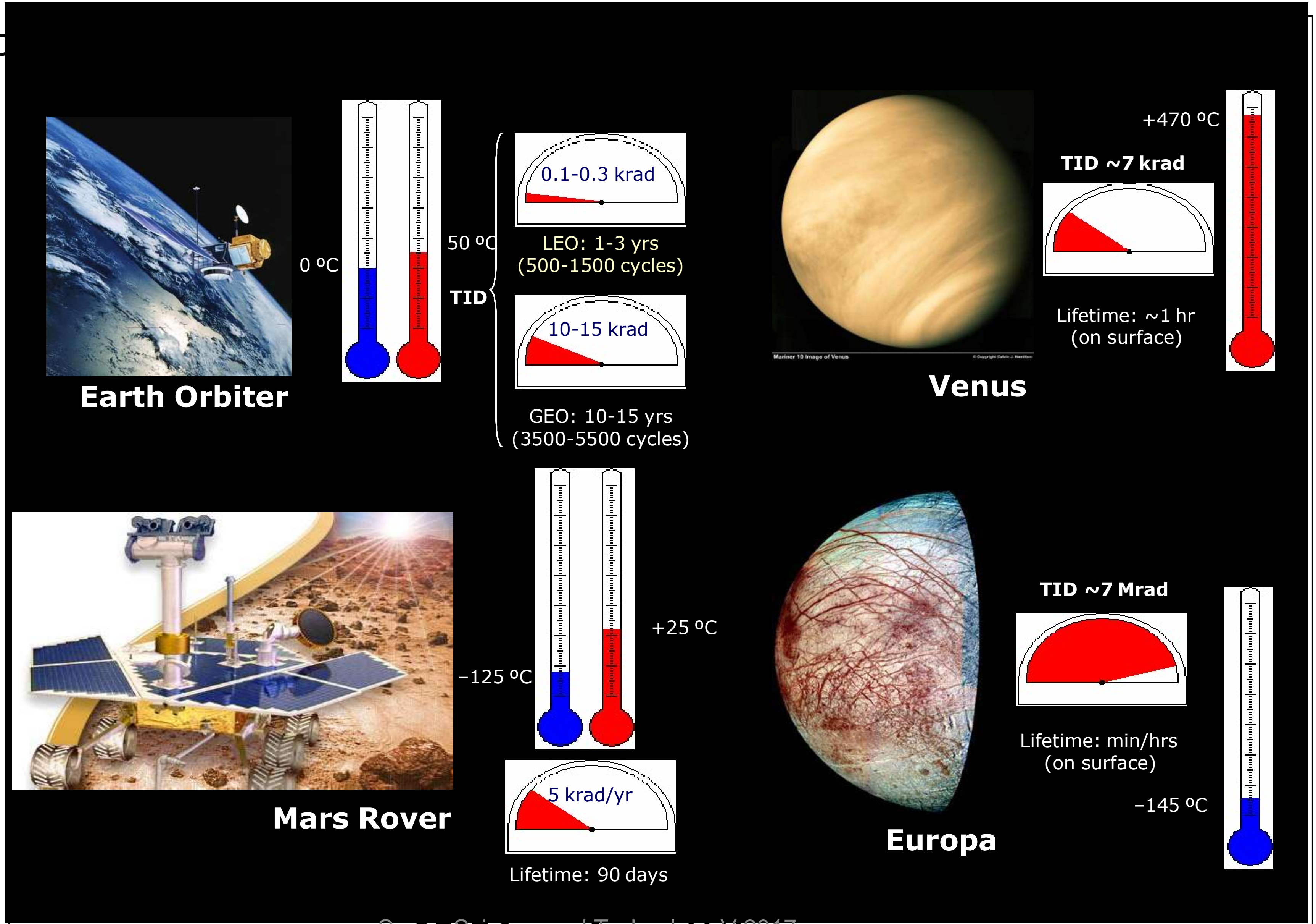
The Spacecraft Bus

- Basic issue:
  - Hostile environment, no access if it fails
- The function of the spacecraft bus is to:
  - Support the payload mass
  - Point it correctly
  - Keep it at right temperature
  - Provide electric power
  - Provide commands and telemetry
  - Put payload in the right orbit, and keep it there
  - Provide data storage and communications
- The goal of the spacecraft bus design is to achieve this at minimum cost and risk



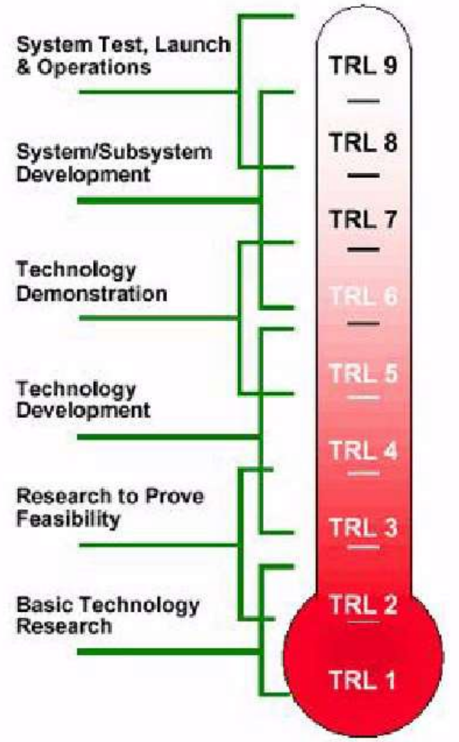
The rad is a deprecated unit of absorbed radiation dose,
defined as 1 rad = 0.01 Gy = 0.01 J/kg

Po



Design for Qualification

- **Space electronics is virtually never installed in a satellite and launched until it is "qualified"**
  – Confirmed high probability to meet operational requirements for period exceeding mission life
- **Can't put product in operational environment (in satellite, in space) for mission life, so:**
  – Develop data during design to gain confidence
  – Perform specific tests at selected conditions to verify expectations
- **Qualification should be hierarchical**
  – Verify underlying parts, materials, processes before moving to higher levels of assembly
  – Include design libraries, models and tools



Technology Readiness Level (TRL) scale (SOURCE: NASA)

NASA TRL scale is one of many tools in maturity assessment

Technology Readiness Levels

Table 19.14 Technology readiness levels

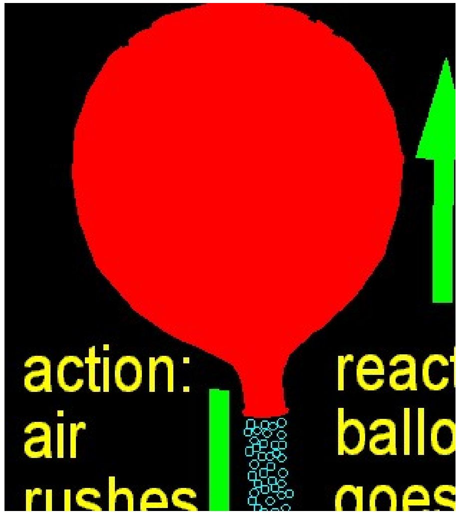
Technology readiness level	Description
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 8	Actual system completed and 'flight qualified' through test and demonstration (ground or space)
TRL 9	Actual system 'flight proven' through successful mission operations

Table 19.15 Technology development stages

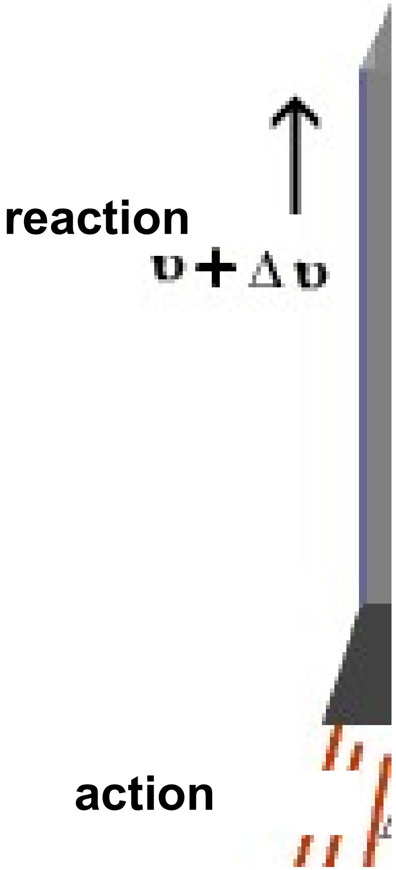
Development stage	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
Basic technology research.	■	■							
Research to prove feasibility		■	■	■					
Technology development.			■	■	■				
Technology demonstration.					■	■	■		
System/subsystem dev't.							■	■	
System test, launch and ops.								■	■

How to go there

- The vehicle/engine must work in vacuum



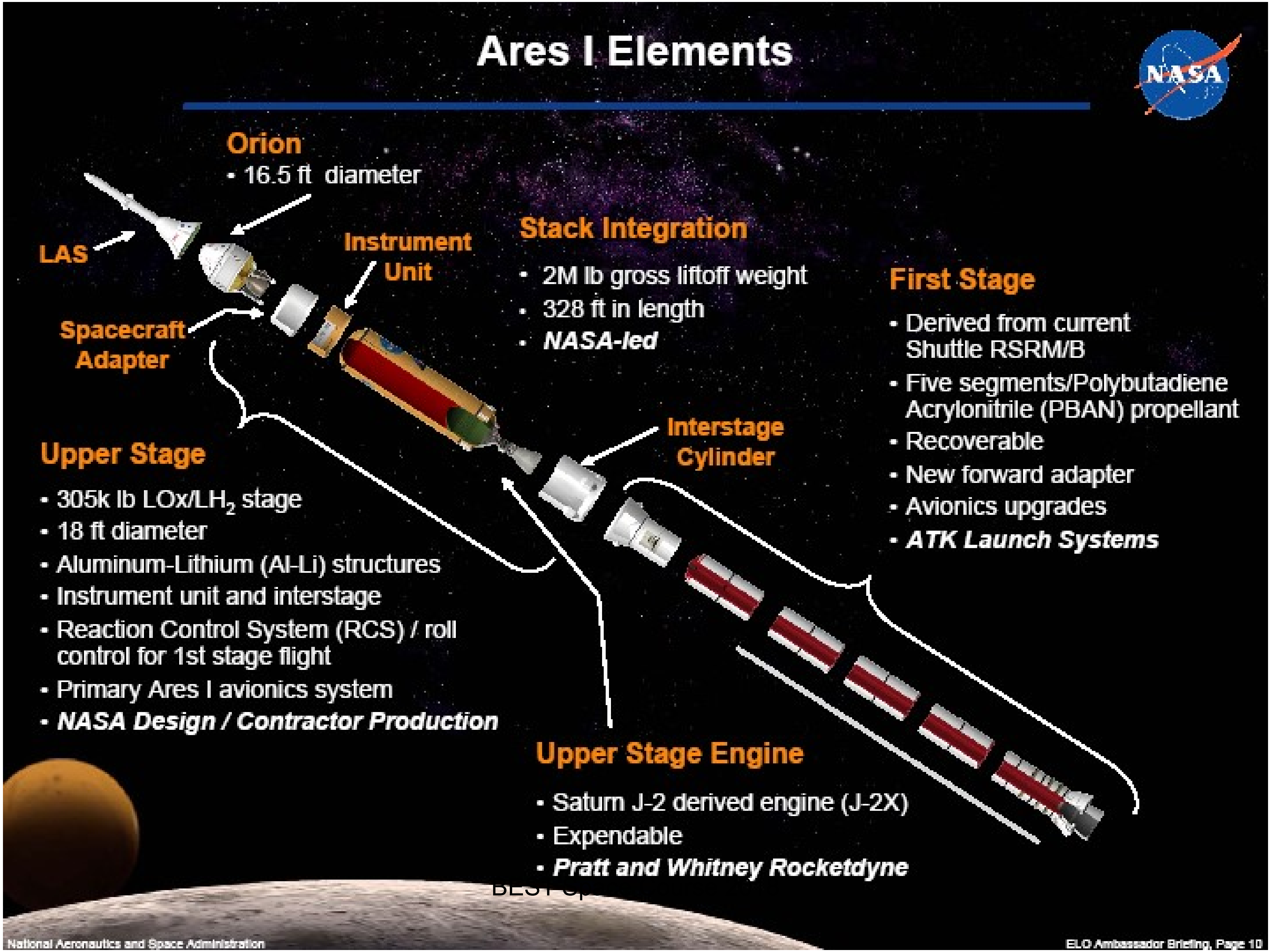
Rockets



- Newton's Third Law – for every action there an equal and opposite reaction
- rocket gas is under pressure in a tank
- when gas is released in a combustion reacti it produces a downward thrust
- then the rocket lifts upward and away from Earth in an opposite reaction
- rockets must reach an escape velocity of 28000 km/h to overcome Earth's gravity

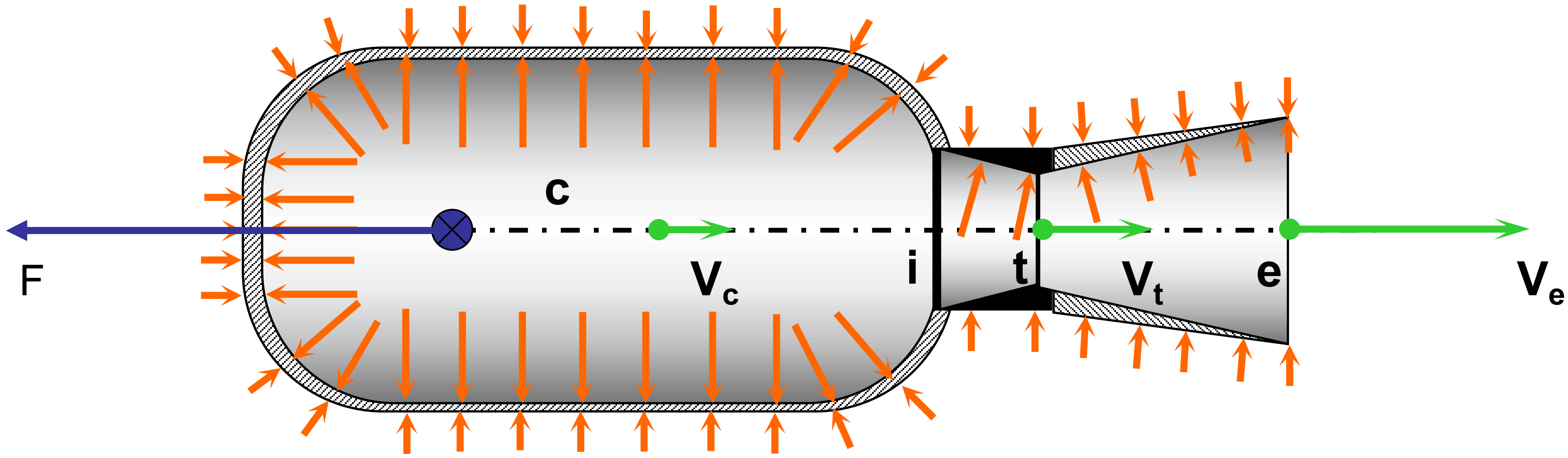
- There are 3 basic parts to a rocket
  - the structural and mechanical parts (engines, storage spaces, tanks, fins)
  - fuel (can be various materials such as liquid oxygen, gasoline or liquid hydrogen
  - payload – what is being transported by the rocket (people, food, water, air, cargo)

- Fins – are important because they stabililize the rocket (so it does not wobble) and make it more efficient
- designed in stages so empty fuel tanks can be dropped when the fuel is used up… this makes rockets more efficient



Ares I Elements
NASA
Orion
• 16.5 ft diameter
LAS
Instrument Unit
Spacecraft Adapter
Stack Integration
• 2M lb gross liftoff weight
• 328 ft in length
• NASA-led
First Stage
• Derived from current Shuttle RSRM/B
• Five segments/Polybutadiene Acrylonitrile (PBAN) propellant
• Recoverable
• New forward adapter
• Avionics upgrades
• ATK Launch Systems
Interstage Cylinder
Upper Stage
• 305k lb LOx/LH2 stage
• 18 ft diameter
• Aluminum-Lithium (Al-Li) structures
• Instrument unit and interstage
• Reaction Control System (RCS) / roll control for 1st stage flight
• Primary Ares I avionics system
• NASA Design / Contractor Production
Upper Stage Engine
• Saturn J-2 derived engine (J-2X)
• Expendable
• Pratt and Whitney Rocketdyne
National Aeronautics and Space Administration
ELO Ambassador Briefing, Page 10

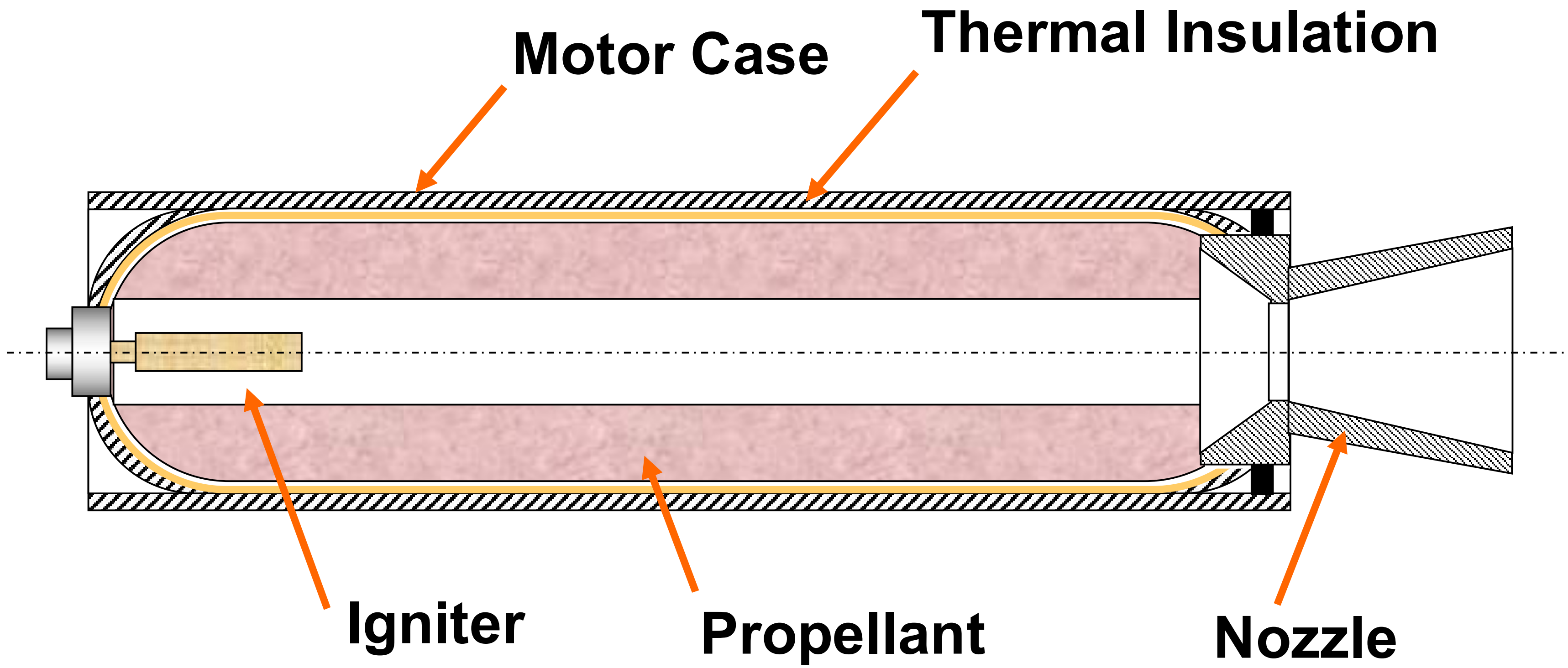
Rocket Elements – Main Parts



c : chamber
i : entrance
t : throat
e : exit
V: velocity

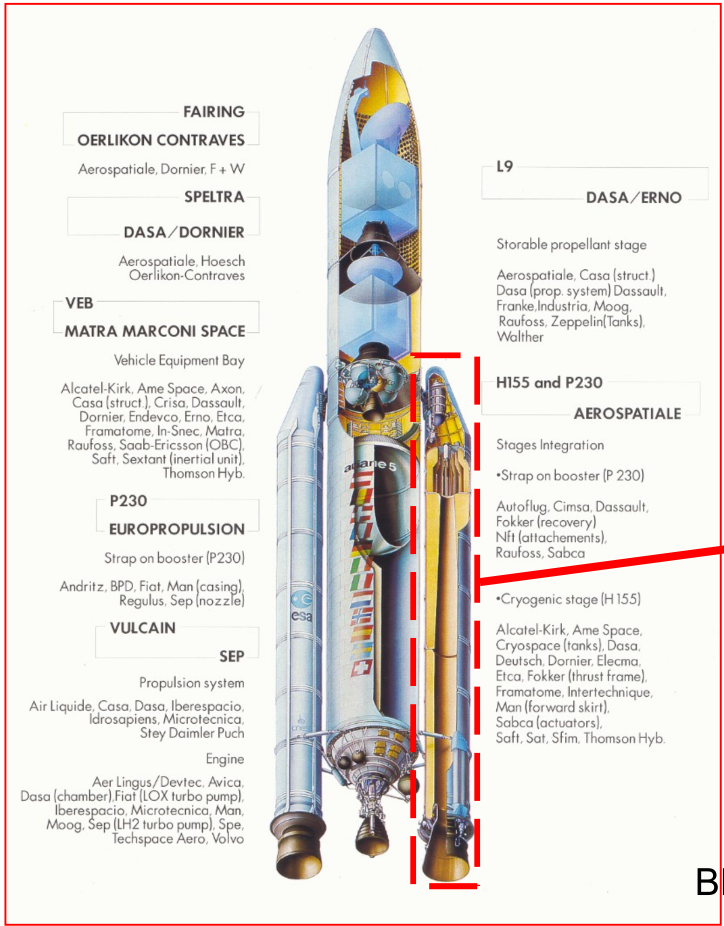
The Solid Propellant Rocket

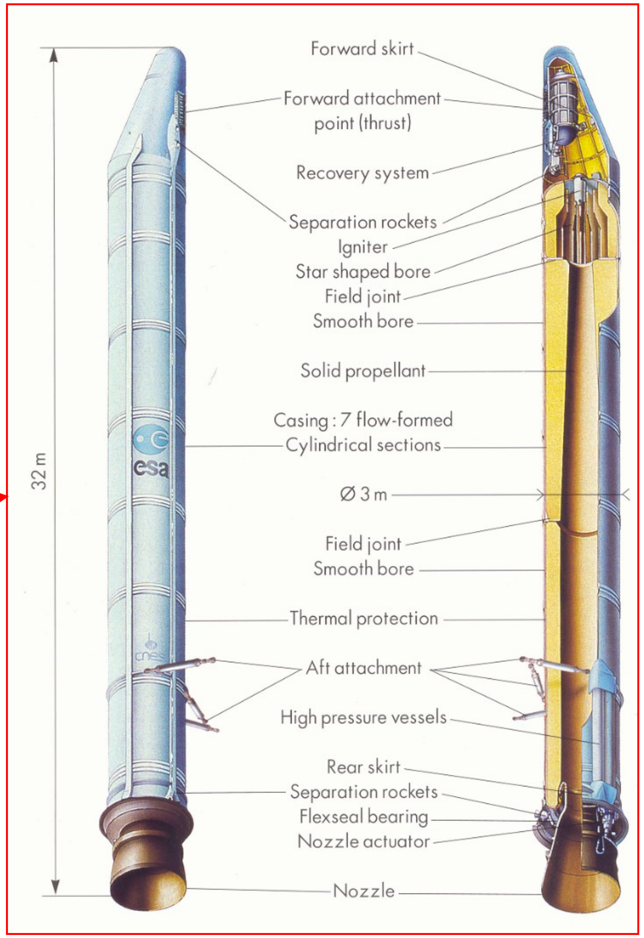
Construction:



The Solid Propellant Rocket

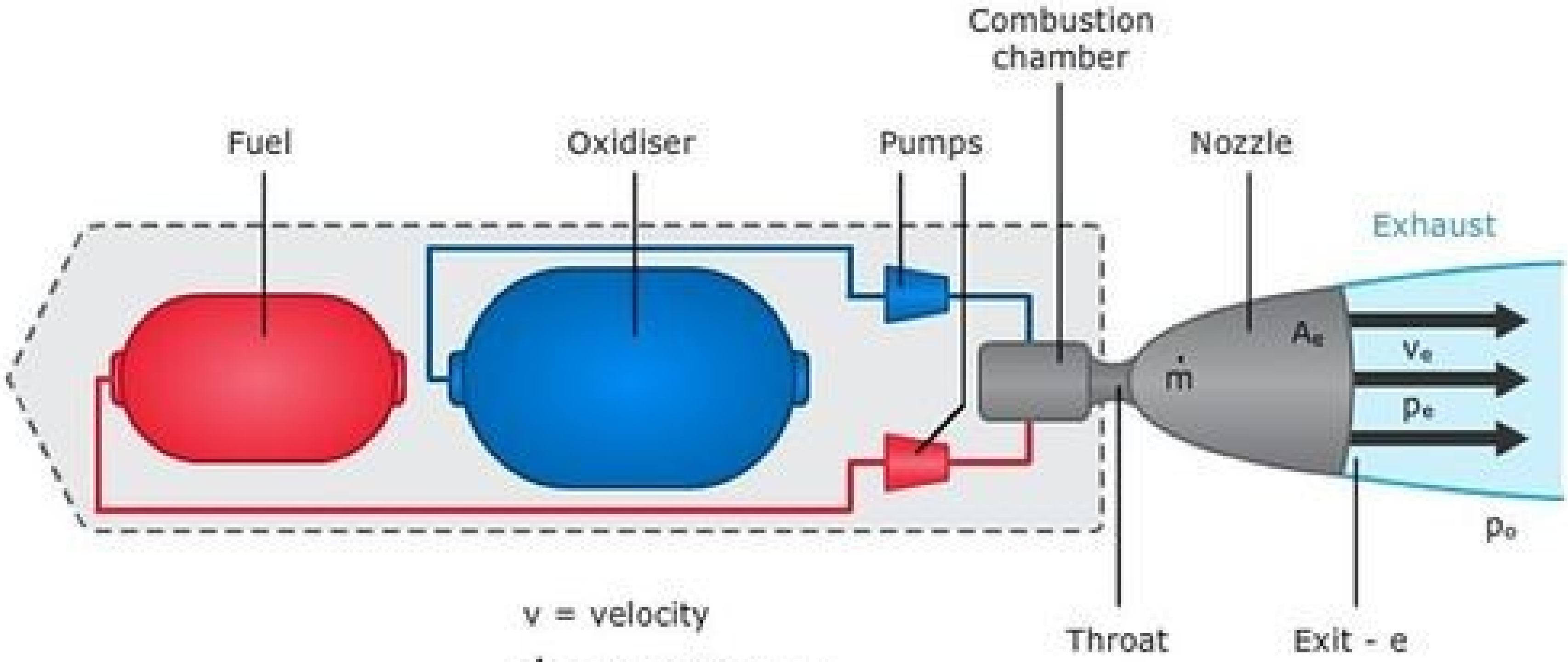
Ariane 5 Solid Rocket Booster:





<u>DATA for one SRB</u>
Propellant: HTPB
Propellant Mass: 237T (158 cars)
Motor Mass: 273T (182 cars)
Thrust: 5400kN (about 550T!!!!)
Burn Time: 130s (2.16min)
Mass Consumption: 1.82T/s
TVC: +/-6deg vectorable nozzle

Liquid rocket engine



v = velocity

$\dot{m}$ = mass flow rate

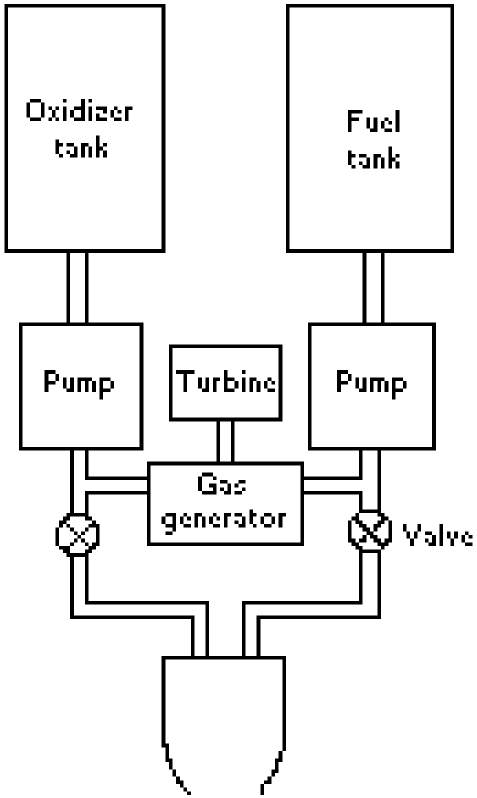
p = pressure

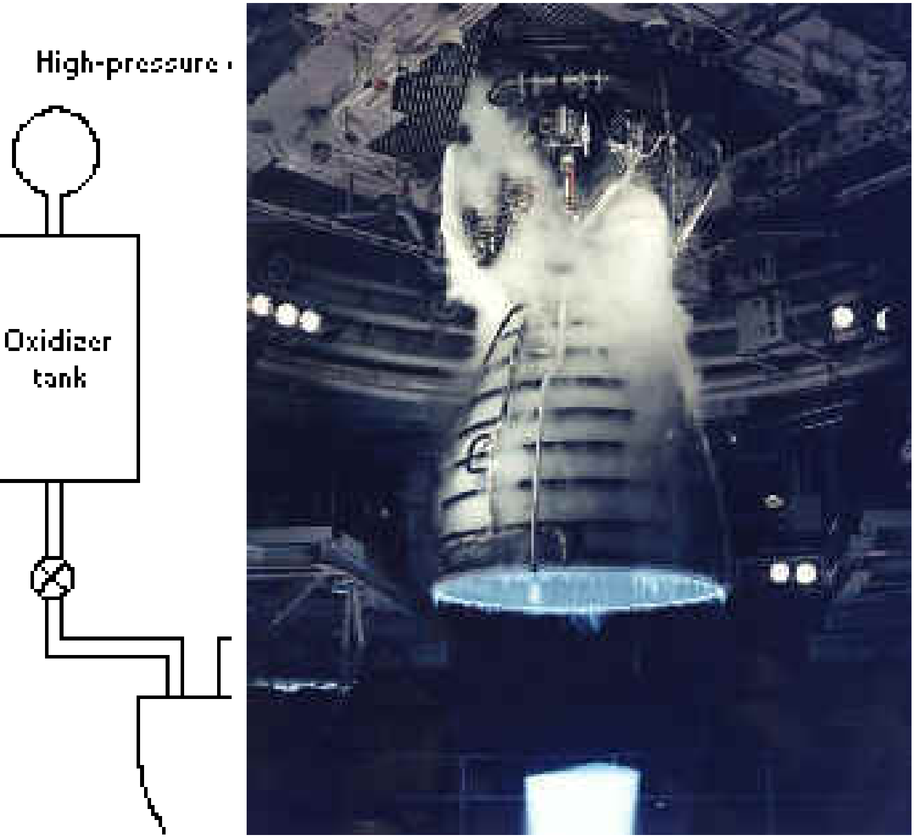
A = area

$$\text{Thrust} = F = \dot{m}\, v_e + (p_e - p_o)\, A_e$$

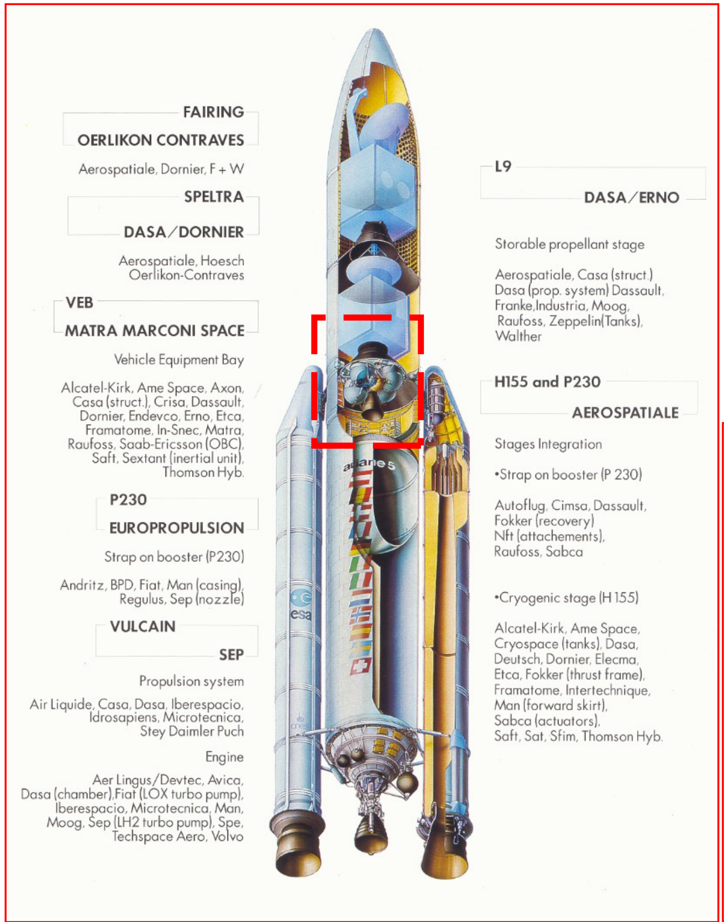
The Liquid Propellant Rocket

Constructions:





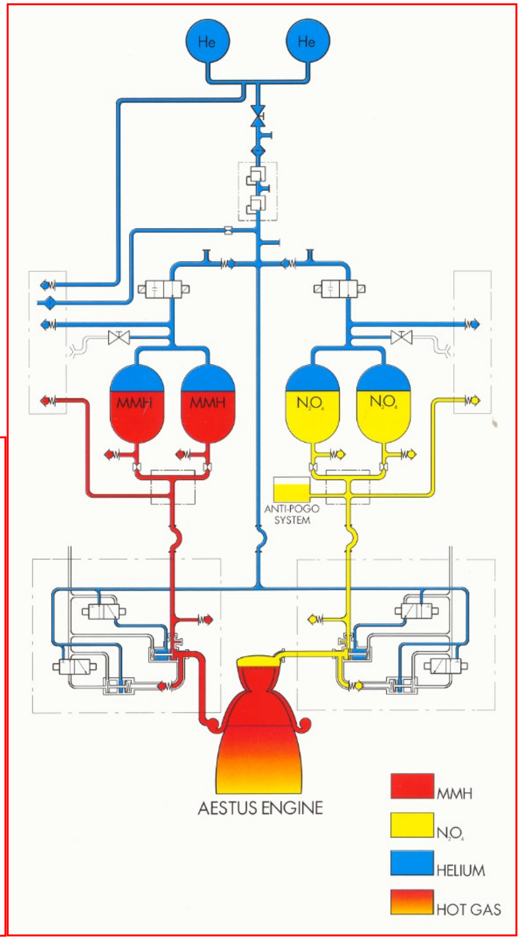
The Liquid Propellant Rocket



L9 UPPER STAGE: Propulsion system

Engine	: AESTUS, reignitable
Propellant	: Storable MMH/N2 O4, mission dependent loading
Propellant Mass (max)	: 9.7 T
Mass	: 10.9 T
Thrust	: 29 kN (VAC)
Specific impulse	: 324 s (VAC)
Mixture ratio	: 2.05
Chamber pressure	: 11 bar
Engine feed pressure	: 17.8 bar
Burn time	: 1100 sec.
Control	: ± 6 deg. hydraulic gimballing


The AESTUS engine



Advanced Technologies for Space Travel

(future .... theoretical propulsion systems)

- Ion drives
  - engines that use xenon gas instead of chemical fuel
  - xenon is electrically charged in the engine, accelerated, then emitted as exhaust
  - exhaust creates thrust which pushes spacecraft in opposite direction

- Solar Sails similar to wind pushing sailboats
  - solar sails collect electromagnetic energy from the Sun… when 'photons' hit the sail they transfer energy which causes the spacecraft to move forward

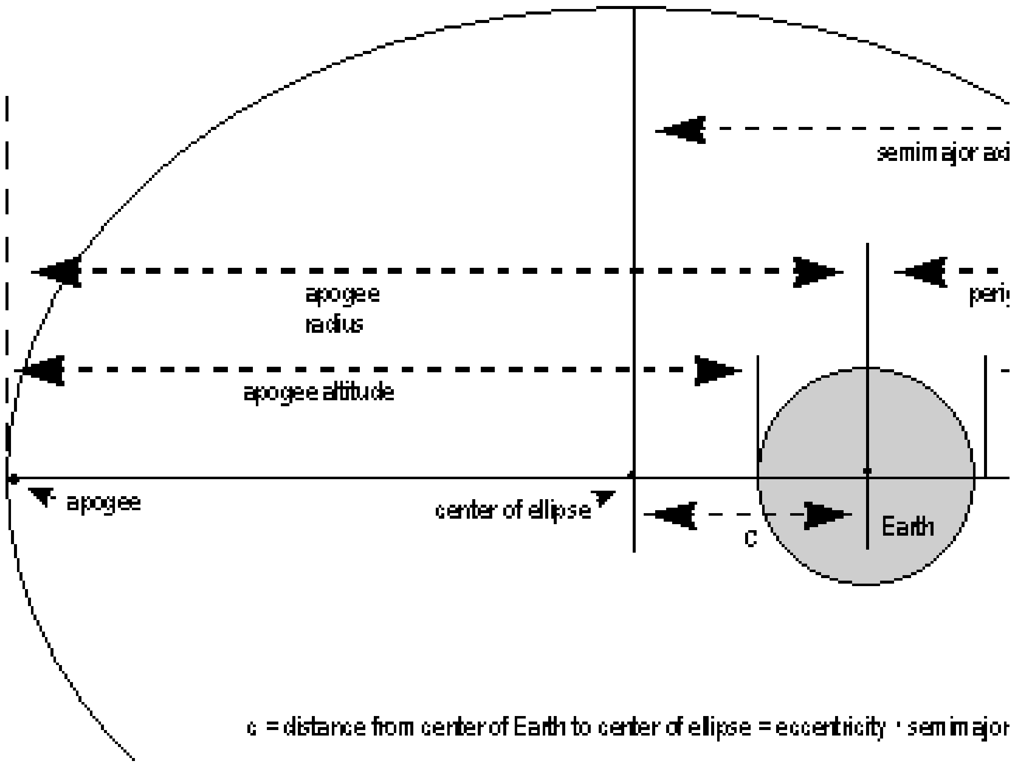
- Gravitational Assist
  - fly a spacecraft toward a planet or star, then at the last minute pull around it and away… creating a slingshot effect that shoots the craft forward in the desired direction

Satellite Orbits

Orbit Size and Shape

Parameter Definition

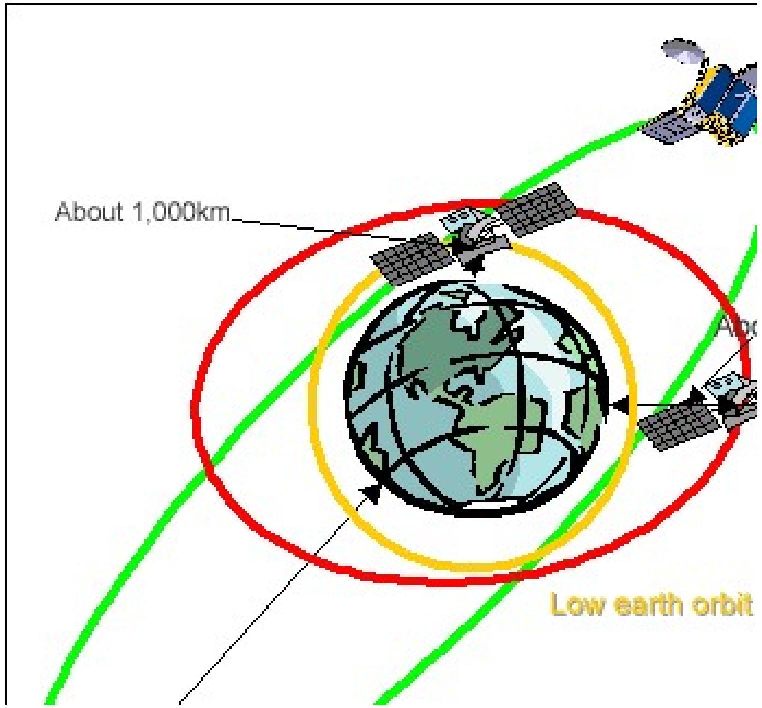
- **Semimajor Axis:** Half the distance between the two points in the orbit that are farthest apart
- **Apogee/Perigee Radius:** Measured from the center of the Earth to the points of maximum and minimum radius in the orbit
- **Apogee/Perigee Altitude:** Measured from the "surface" of the Earth (a theoretical sphere with a radius equal to the equatorial radius of the Earth) to the points of maximum and minimum radius in the orbit
- **Period:** The duration of one orbit, based on assumed two-body motion
- **Mean Motion:** The number of orbits per solar day (86,400 sec/24 hour), based on assumed two-body motion
- **Eccentricity:** The shape of the ellipse comprising the orbit, ranging between a perfect circle (eccentricity = 0) and a parabola (eccentricity = 1)

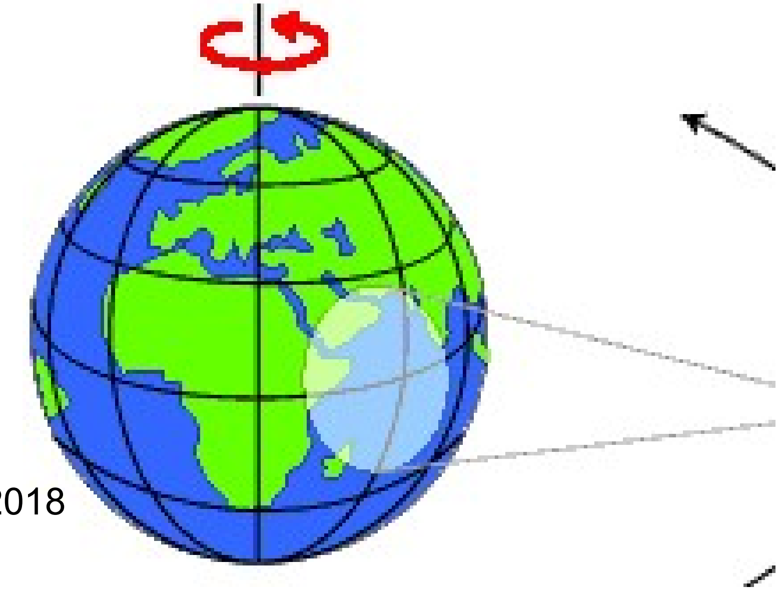


Satellite Orbits

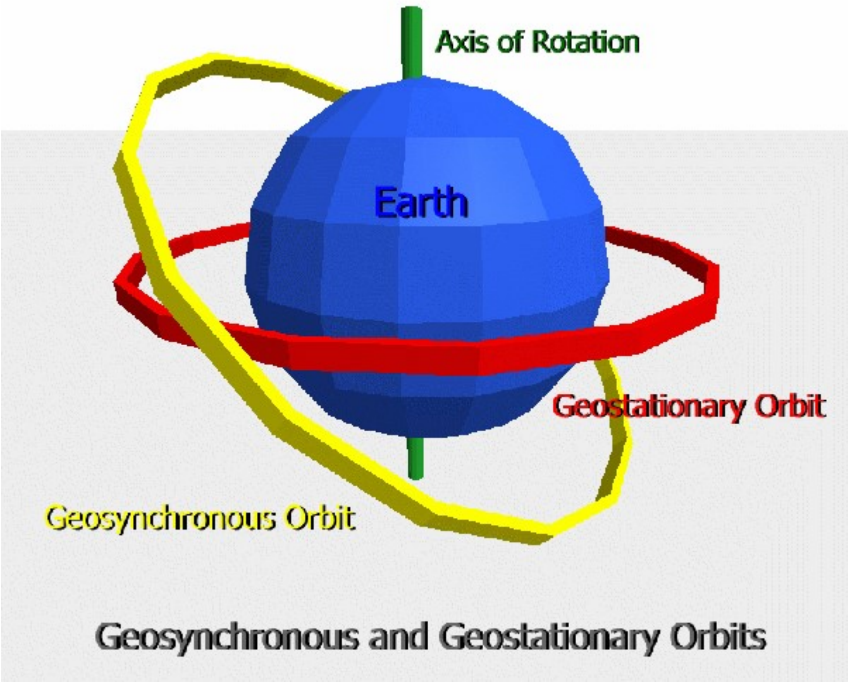
- **Low Earth Orbit**
  - 200 – 1000 km altitude
  - e.g. remote sensing satellites
- **Geosynchronous Orbits**
  - an orbit around the Earth with an orbital period of one sidereal day, intentionally matching the Earth's sidereal rotation period (approximately 23 hours 56 minutes and 4 seconds). Returns to the same point in the sky at the same time each day,
- **Geostationary Orbits**

  high Earth orbit 35800 km
  - An object in such an orbit has an orbital period equal to the Earth's rotational period (one sidereal day), and thus appears motionless, at a fixed position in the sky, to ground observers.
  - e.g. communication ad weather satellites
  - **Fixed on the sky (antenna fixed)**





Geosynchronous versus geostationary orbit



A special case of geosynchronous orbit is the geostationary orbit, which is a circular geosynchronous orbit inclined 0° to Earth's equatorial plane (that is, directly above the Equator). A satellite in a geostationary orbit appears stationary, always at the same point in the sky, to observers on the surface.

Geostationary Orbits II

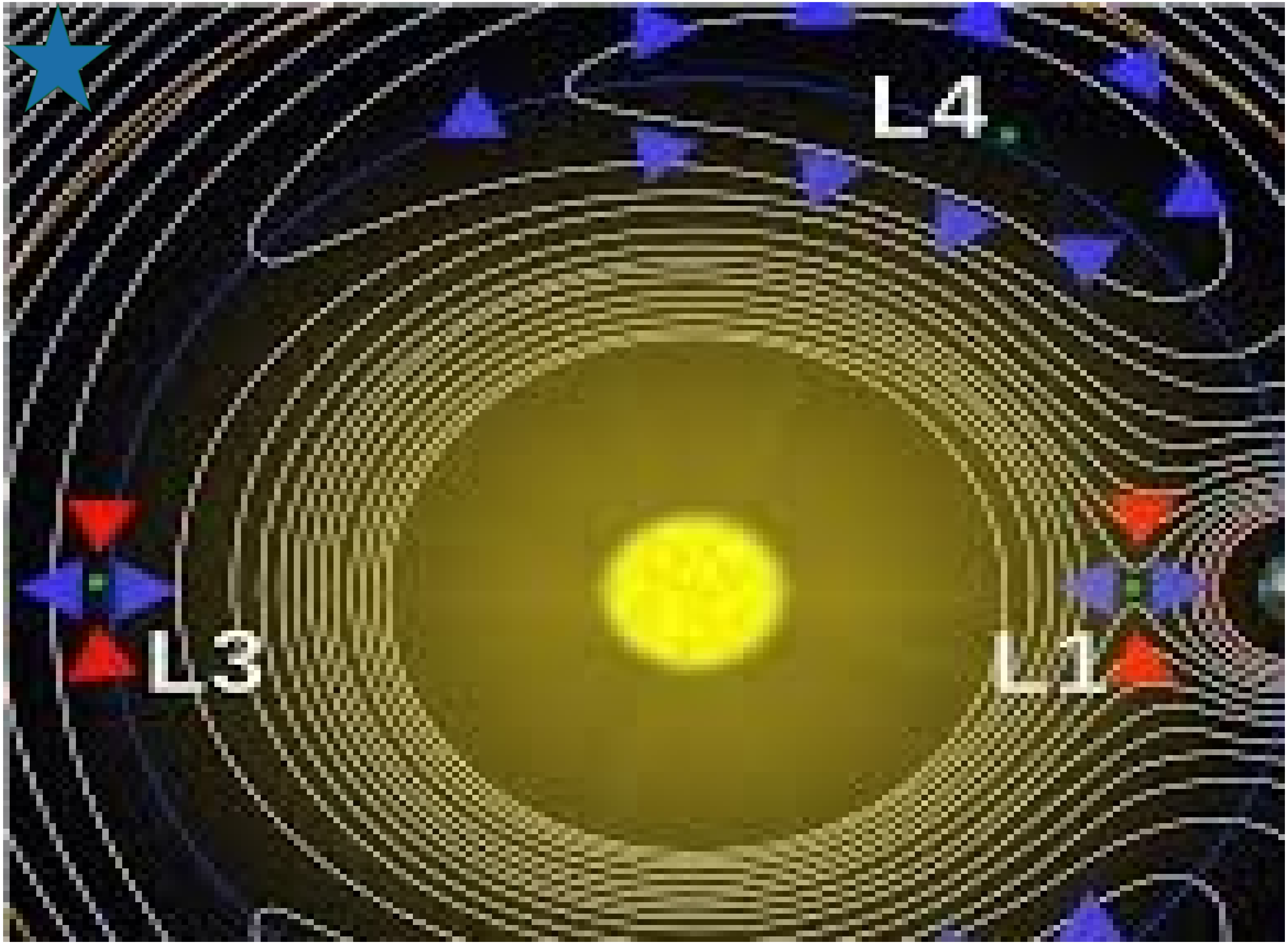
The geostationary orbit is useful for communications applications because ground based antennas, which must be directed toward the satellite, can operate effectively without the need for expensive equipment to track the satellite's motion.

Especially for applications that require a large number of ground antennas (such as direct TV distribution), the savings in ground equipment can more than justify the extra cost and onboard complexity of lifting a satellite into the relatively high geostationary orbit

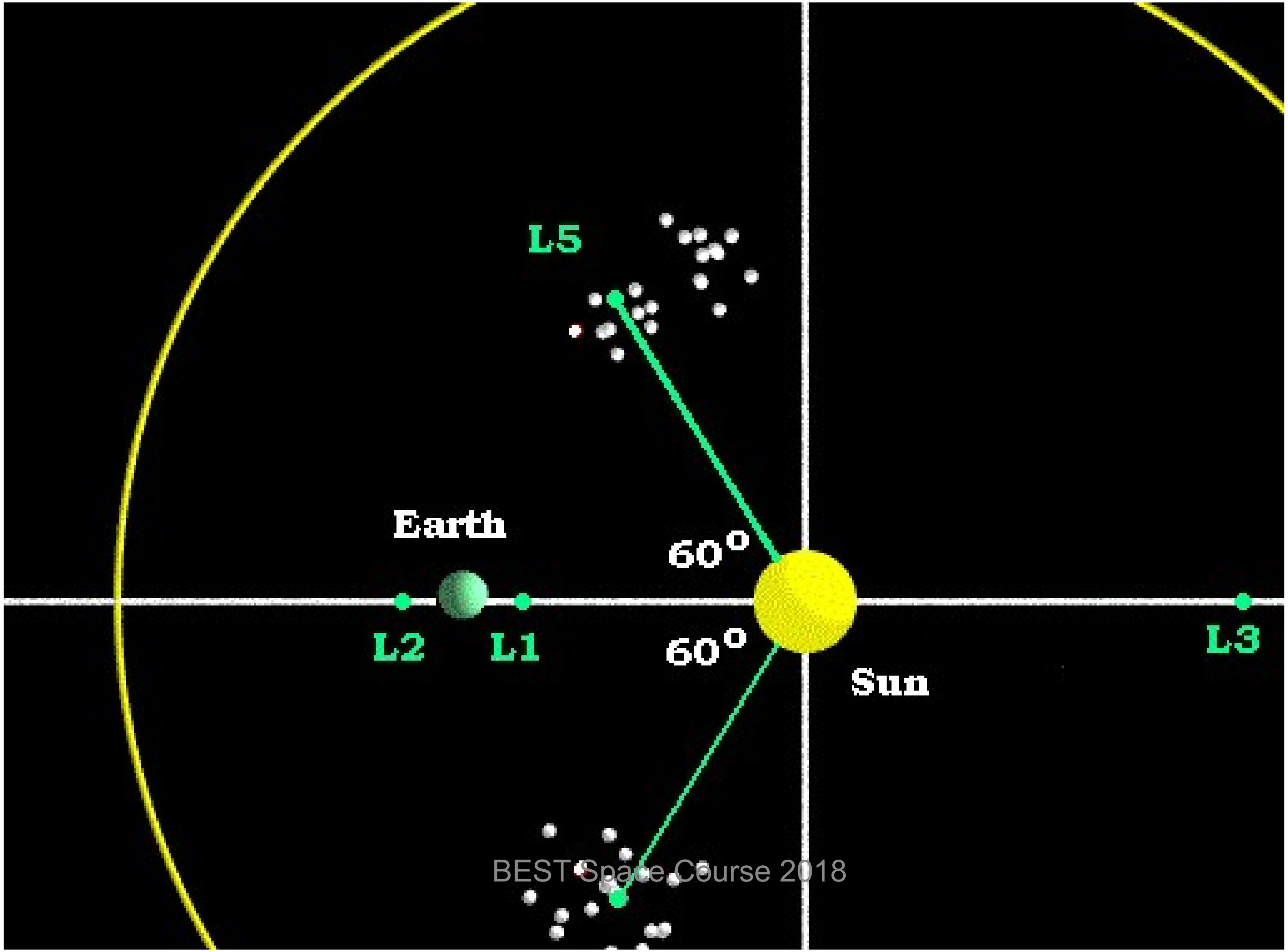
Lagrange Points

- Lagrange points are locations in space where gravitational forces and the orbital motion of a body balance each other.
- These points represent the five solutions by the mathematician Joseph-Louis Lagrange in the 18th century to the three-body problem. Lagrange was searching for a stable configuration in which three bodies could orbit each other yet stay in the same position relative to each other. He found five such solutions, and they are called the five Lagrange points in honor of their discoverer.

There are five Lagrangian points in the Sun-Earth system and such points also exist in the Earth-Moon system.
http://www.esa.int/esaSC/SEMM17XJD1E_index_0.html


L4
L3
L1

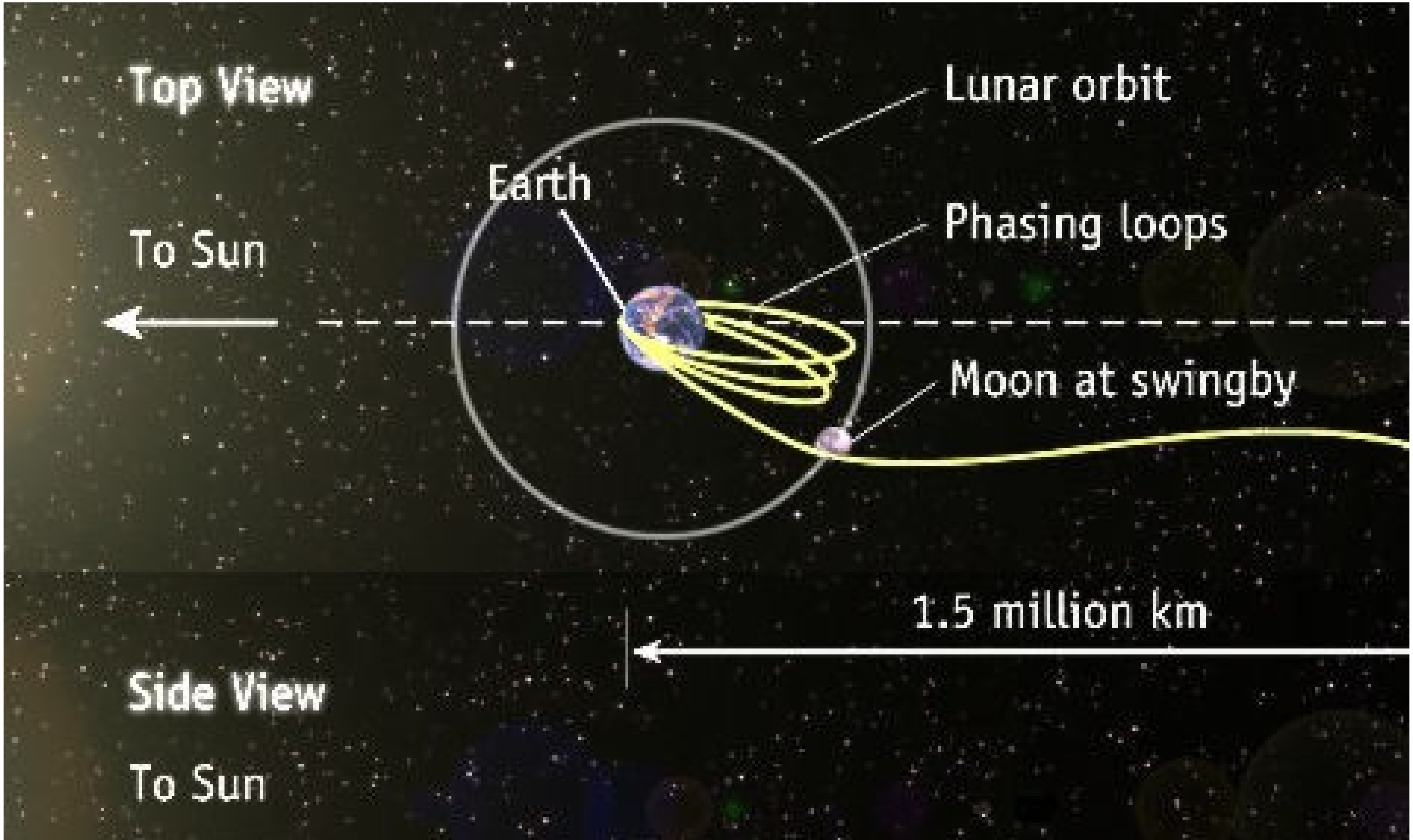
L1, L2 about 1.5 mil km from the Earth



L2 Orbits II

For scientific satellites with long lifetime, the increasingly promising orbit about the Sun-Earth is second Lagrange point (L2), approximately 1.5 million km from Earth, outside the orbit of the Moon. The region about L2 is a gravitational saddle point, where spacecraft may remain at roughly constant distance from the Earth throughout the year by small station-keeping maneuvers.

Transfer to L2



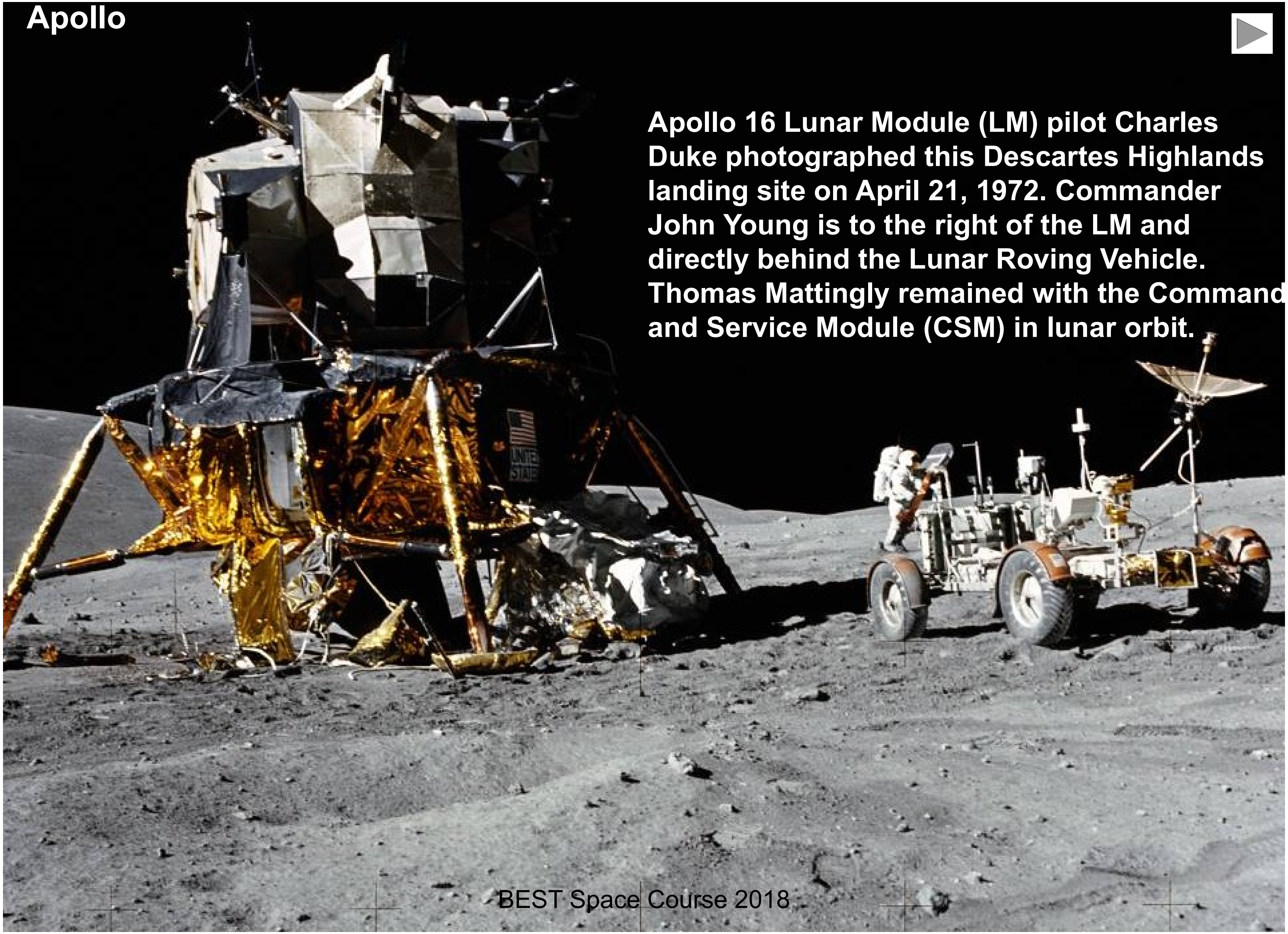
Human Spaceflight

- Special spacecrafts able to provide living and working conditions for humans (astronauts)
- Spaceships and space stations

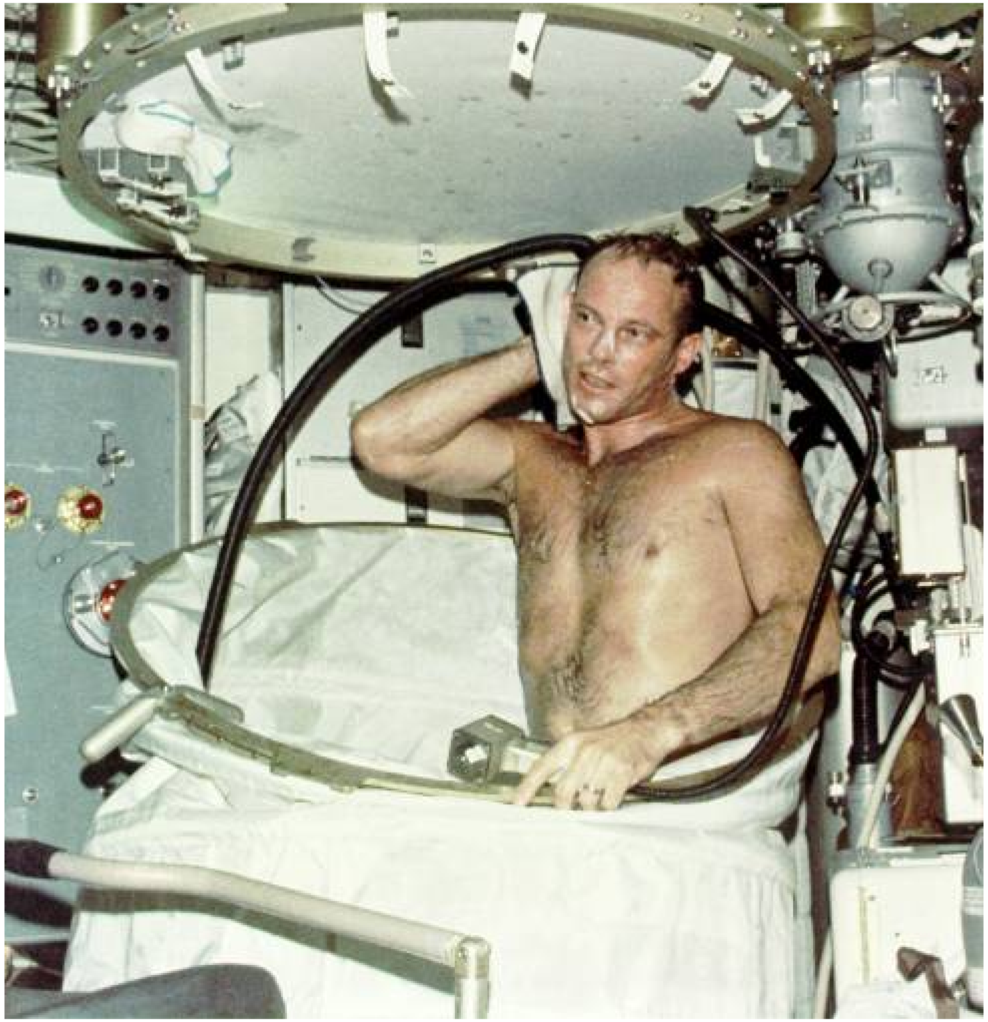
EVA Extra Vehicular Activity

Repairs, upgrades of Instrumentation etc

Apollo

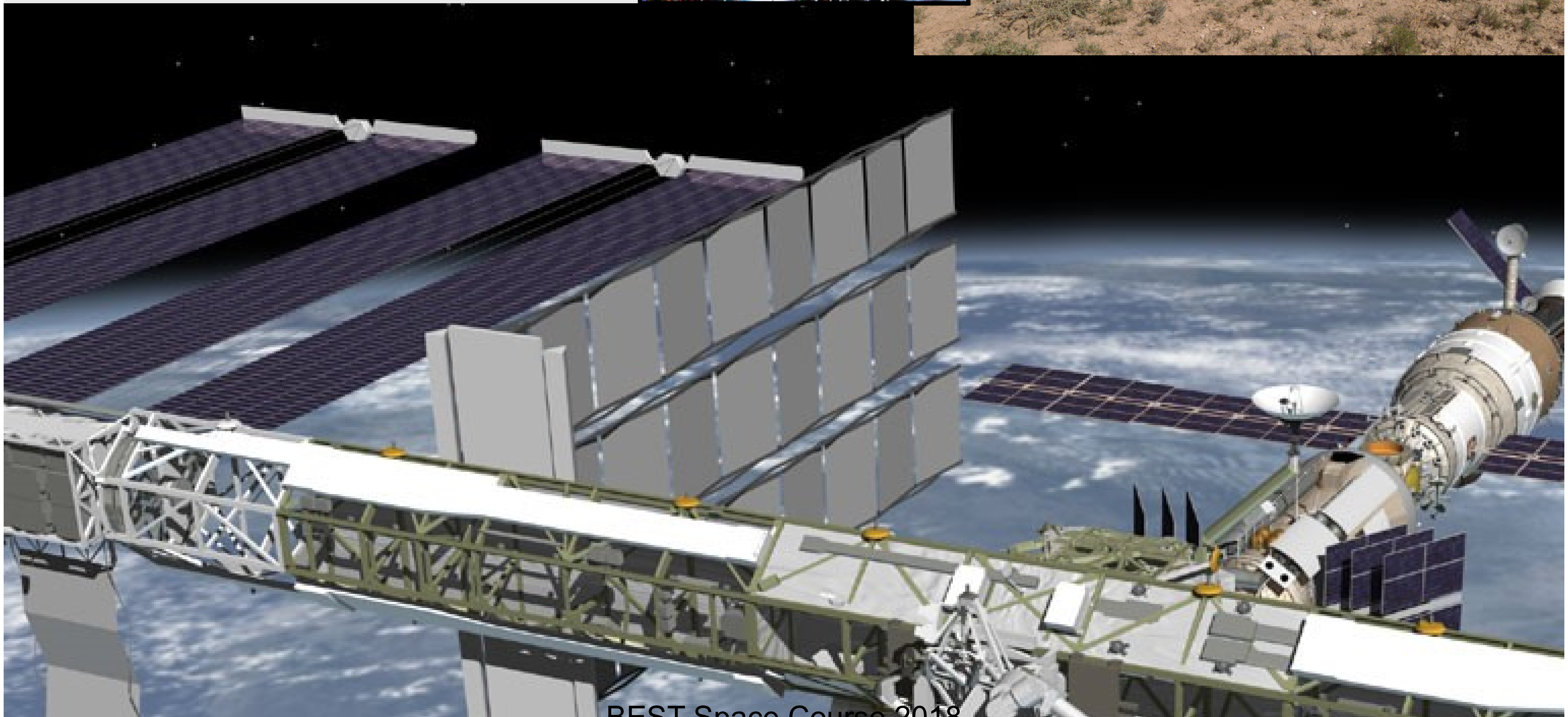


Apollo 16 Lunar Module (LM) pilot Charles Duke photographed this Descartes Highlands landing site on April 21, 1972. Commander John Young is to the right of the LM and directly behind the Lunar Roving Vehicle. Thomas Mattingly remained with the Command and Service Module (CSM) in lunar orbit.



Skylab 3 astronaut Jack Lousma takes a shower in the crew quarters of the Orbital Workshop (OWS) on July 1, 1973.
Skylab 4 astronauts Gerald Carr (right) and William Pogue are shown in the OWS on February 1, 1974.

Space exploration imposes new challenges on human systems and terrestrial life in general.



Challenges of human spaceflight

- Present
  - Orbital Missions
    - Known medical risks
    - Communications
    - Access to Earth
    - Minimum autonomy
- Future
  - Moon (Short duration)
    - Mostly known medical risks
    - Communications
    - 2-3 day to access Earth facilities
    - Greater autonomy necessary
- Future (con't)
  - Moon (Long duration)
    - Many known medical risks, others unknown but anticipated
    - Communication
    - 2-3 day to access Earth facilities
    - Greater autonomy necessary
  - Mars
    - Many medical risks (known, unknown, unanticipated)
    - Communications difficult
    - Probably no access to Earth facilities
    - Autonomous medical care absolutely required

Impacts of Extended Weightlessness

Physical tolerance of stresses during aerobraking, landing, and launch phases, and strenuous surface activities

Bone loss
- no documented end-point or adapted state
- countermeasures in work on ground but not yet flight tested

Cardiovascular alterations
- pharmacological treatments for autonomic insufficiency

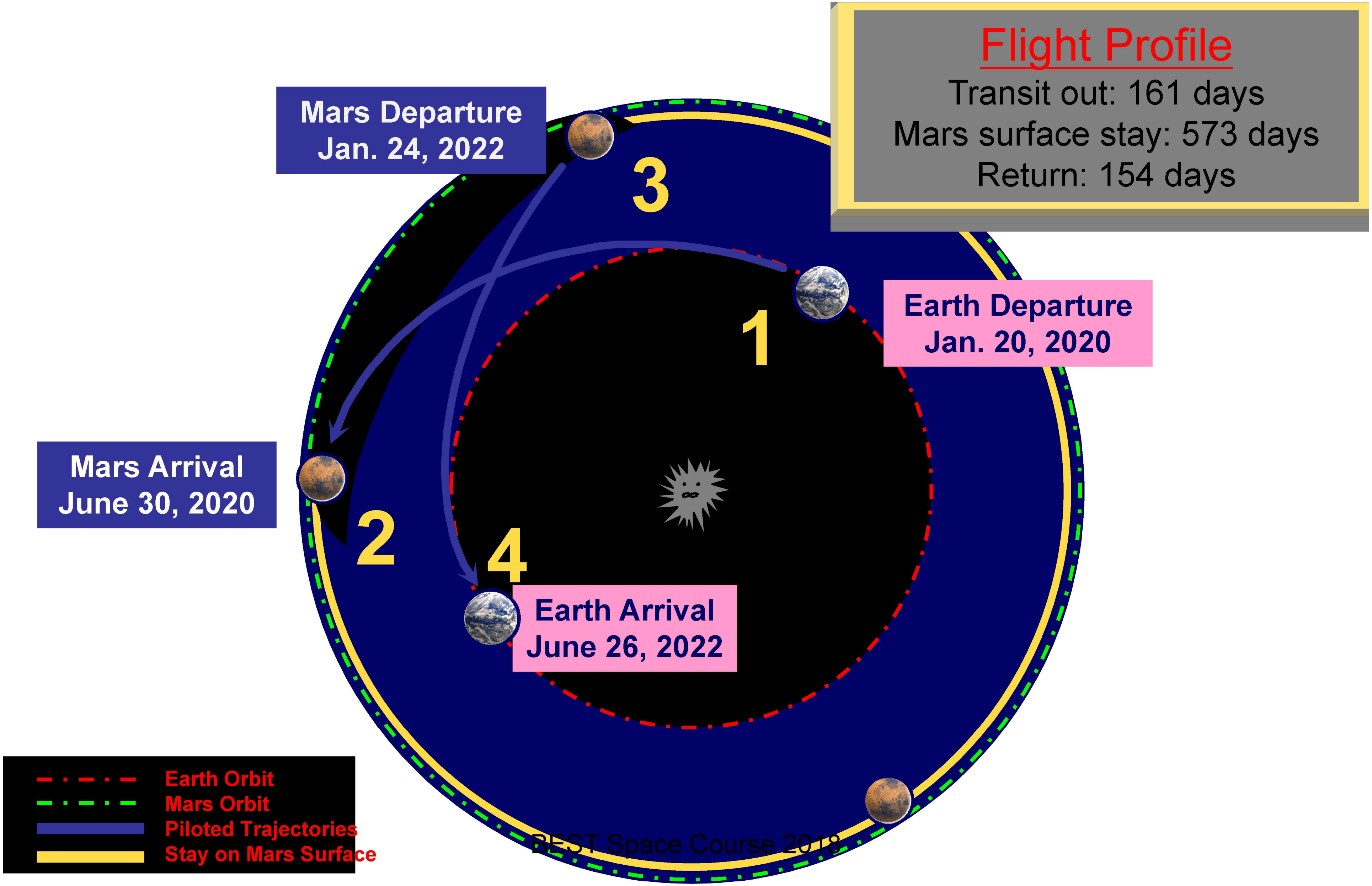
Muscle atrophy
- resistive exercise under evaluation

Neurovestibular adaptations
- vehicle modifications, including centrifuge
- may require auto-land capability

Risks to Humans in Microgravity

- Exposure to ionizing radiation
- Bone density decrease
- Muscle Atrophy
- Cardiovascular Deconditioning
- Psychosocial impacts
- Fluid Shifting
- Vestibular Dysfunction
- Hematological changes
- Immune Dysfunction
- Delayed wound healing
- Gastrointestinal Distress
- Orthostatic Intolerance
- Renal stones

Human Mars Mission Trajectory



Mars Transit Requirements

Facilities must be mostly autonomous
(one-way Earth-Mars communications time is 3-22 min.)

Health care functions

- Nutrition
- Exercise
- Psychological support
  - planned activities
    - entry/landing simulations
    - housekeeping
    - refresher training
    - cruise science (rover operations/site preparation, microgravity, astronomy, and biomedicine)
  - communications
    - reliable contact with mission control, family, & friends
- Health Care
  - autonomous care
  - telemedicine

Habitat facilities

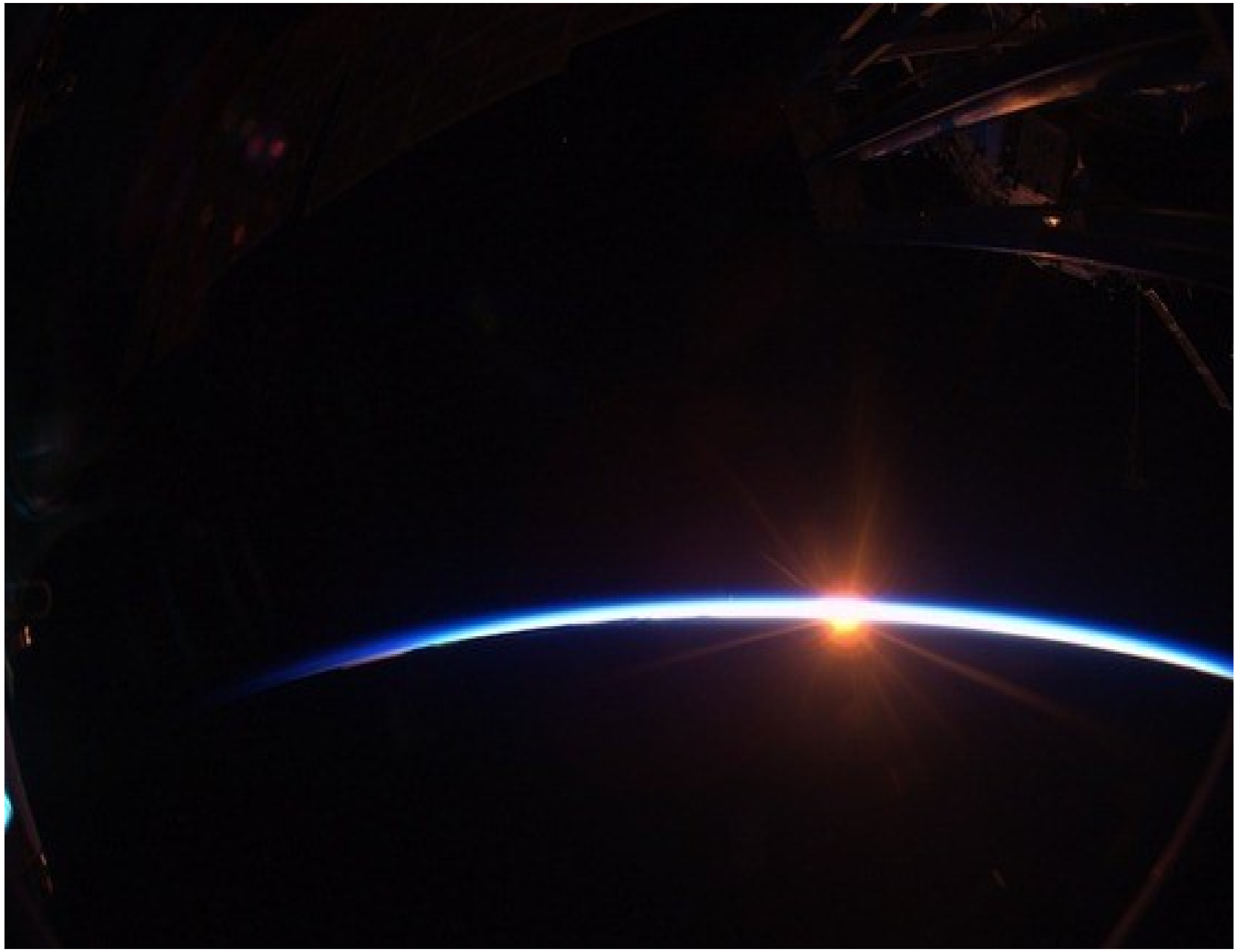
artwork from Constance Adams and Kris Kennedy for the JSC TransHab Team

Bed Rest Studies (on ground)

- 6^{o} head tilt down
- Remain in bed continually for various time intervals; i.e., 60 days
- Mimics many alterations that occur in microgravity due to fluid shift to head and lack of weight bearing lower limbs; i.e., bone loss & muscle atrophy
- Often involved in countermeasure testing

ESA, WISE

Another spectacular sunset. We see 16 such sunsets each day and each of them is really valuable.



In this time of year you can enjoy the beauty of the polar mesospheric clouds. With our high-angle illumination, we were able to capture a thin layer of noctilucent clouds at sunset.

Over the Sahara desert, approaching the ancient lands and thousand-year history. River Nile flows through Egypt by the Pyramids of Giza near Cairo . Further, the Red Sea, Sinai Peninsula, Dead Sea , Jordan River, as well as the island of Cyprus in the Mediterranean Sea and Greece on the horizon.

Night view of the River Nile, stretching like a snake through Egypt to the Mediterranean, and Cairo , located in the Delta. Far away in this picture, one can see the Mediterranean Sea

All the beauty of Italy , a clear winter night. You can see many beautiful islands that adorn the coast - Capri , Sicily and Malta . Naples and Mount Vesuvius are allocated along the coast.

A (very) brief history of the Universe

- Universe hasn’t always been the same: our Universe “started” about 14 billion years ago as pure energy
- After a few minutes, atoms were formed, but contents were very different: hydrogen, helium, bit of lithium and beryllium
- Early matter formed into stars
  - Stars are nuclear reactors: elements are changed into others by nuclear fusion in their cores, producing energy (light) in the process
  - Stars have lives and some, when their lives are done, explode!
- Material from inside the star is released and mixes with other gases

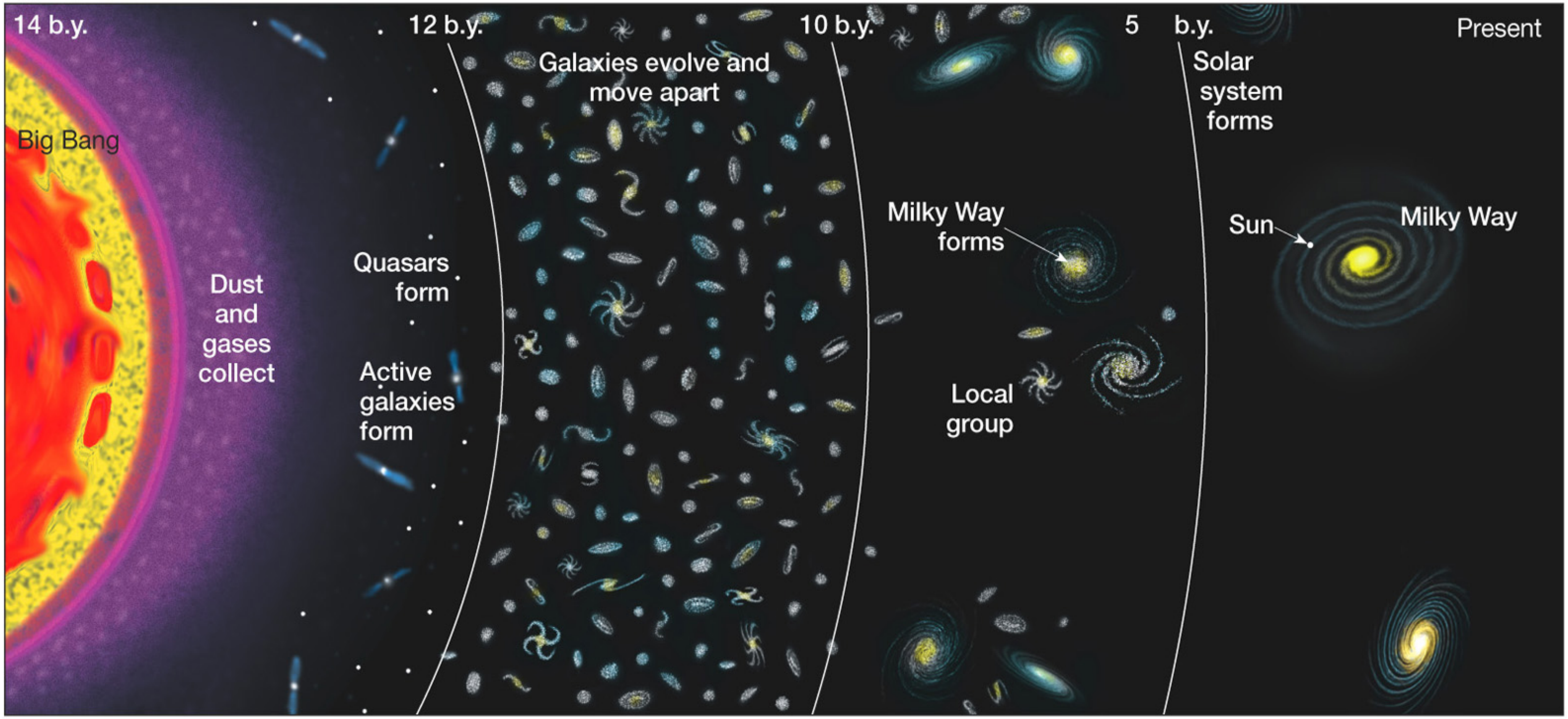
Cosmology -- the Origin and Structure of the Universe

Cosmological Principle – the Universe appears the same from all directions .

There is no preferred location.

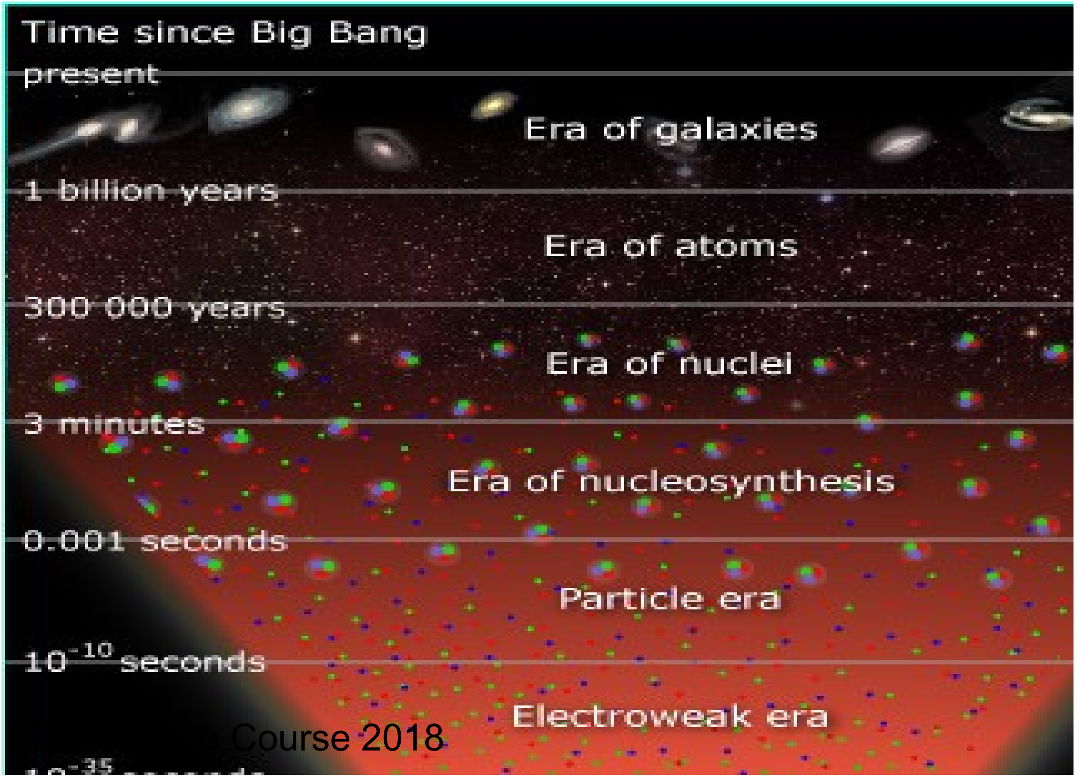
(The physical laws apply to the whole Universe).

The concise history of the Universe

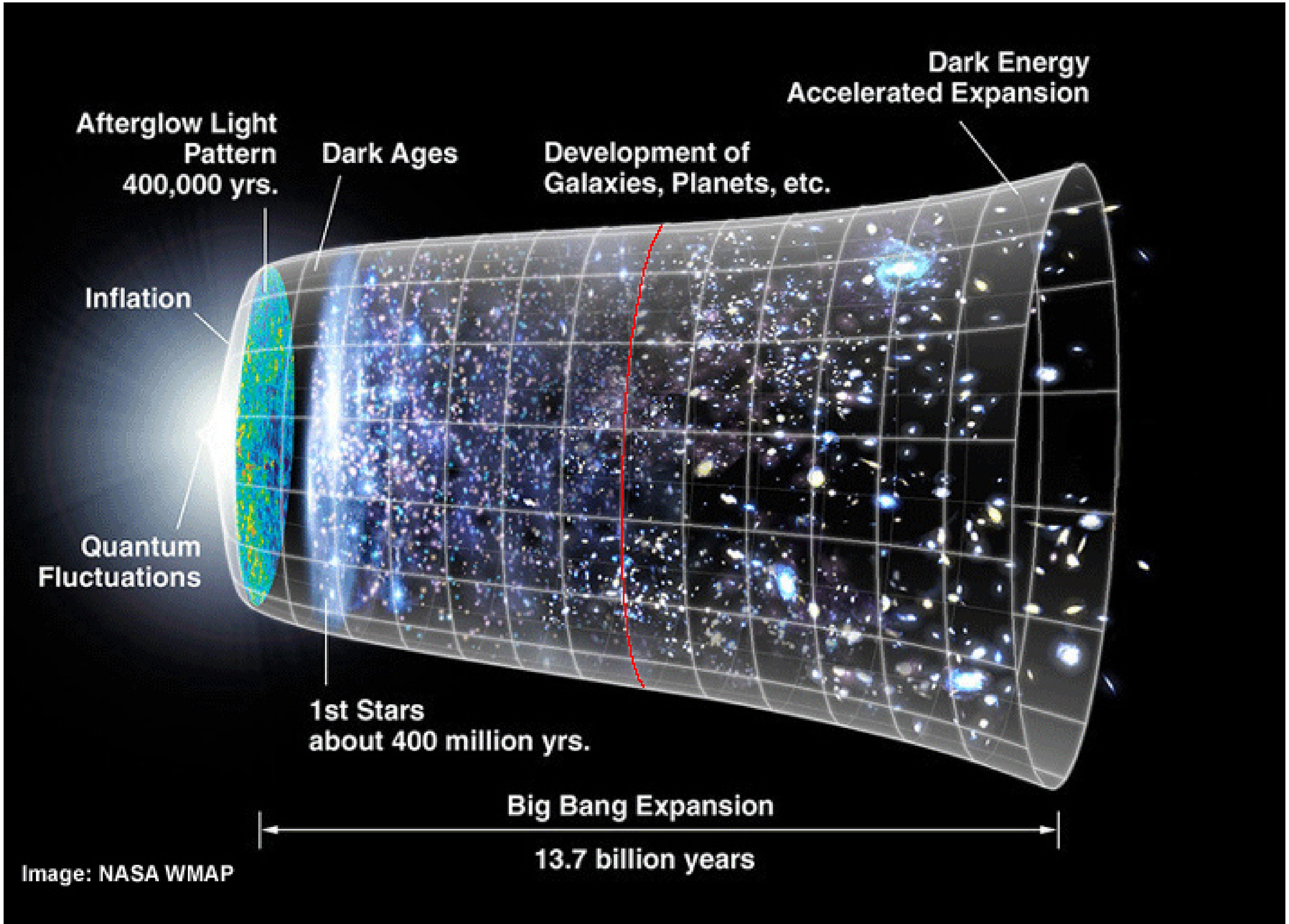


The Big Bang Theory

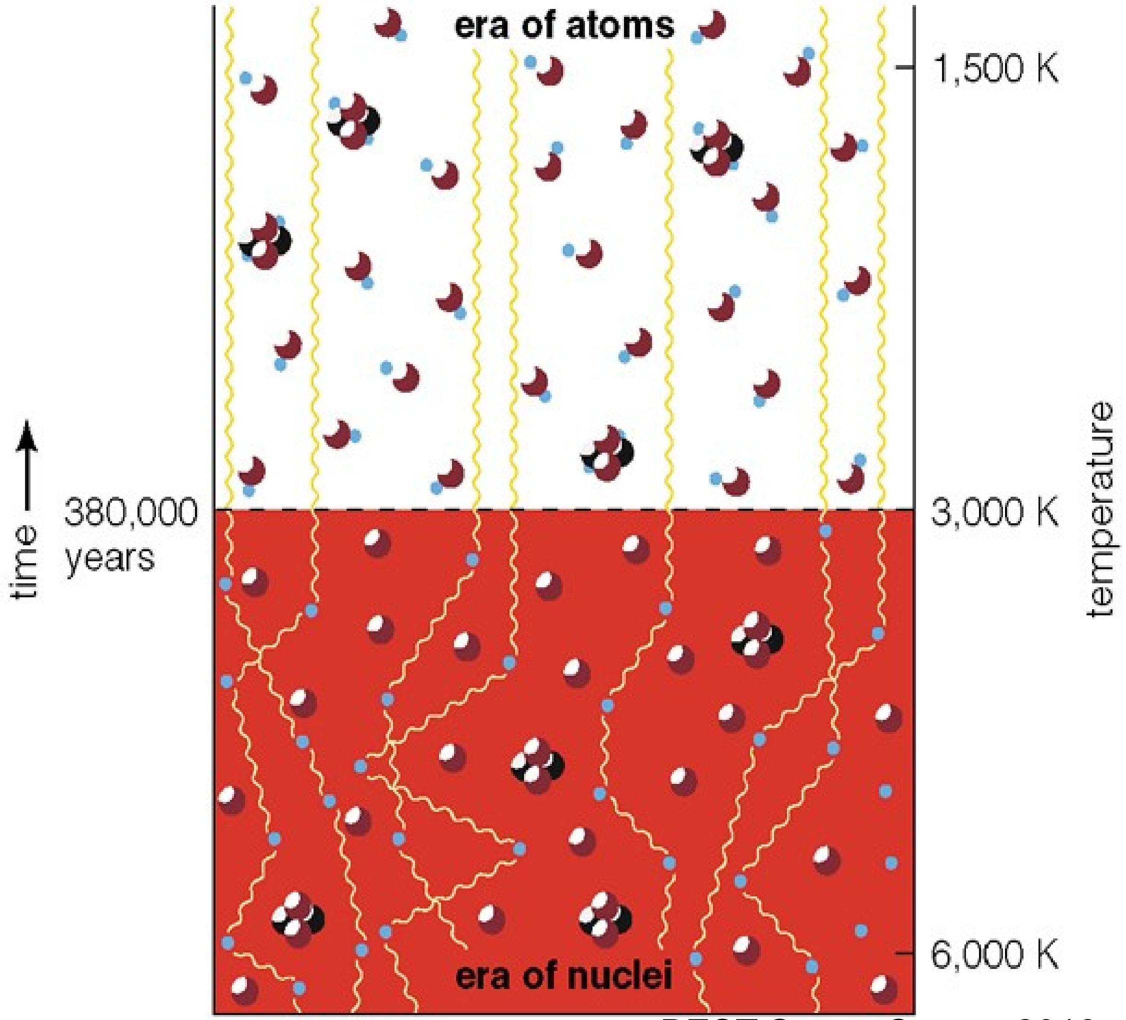
The theory holding that the universe originated from the instant expansion of an extremely small agglomeration of matter of extremely high density and temperature.



The Big Bang -- the standard model -- 13 – 15 x 10^9 yrs

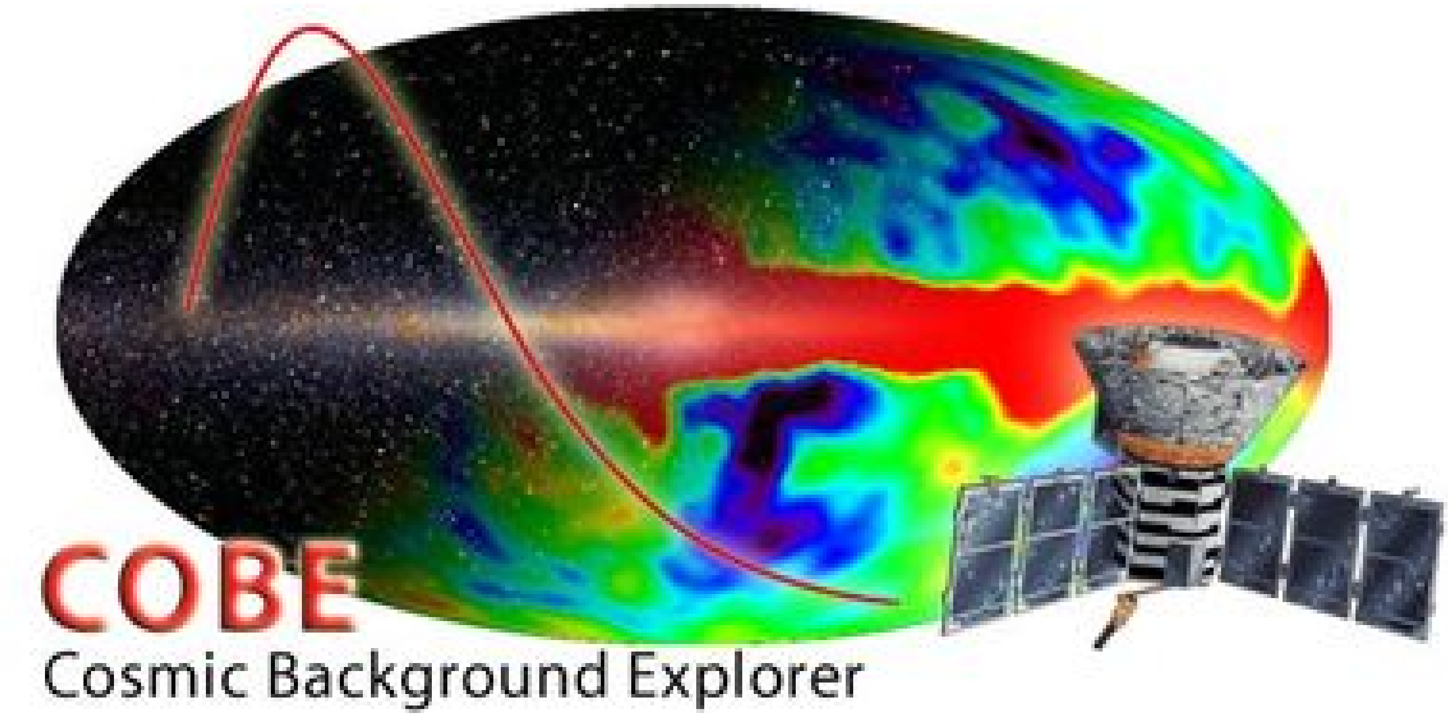


The Cosmic Background Radiation (Microwaves)



Background radiation from Big Bang has been freely streaming across universe since atoms formed at temperature ~ 3,000 K: *visible/IR*

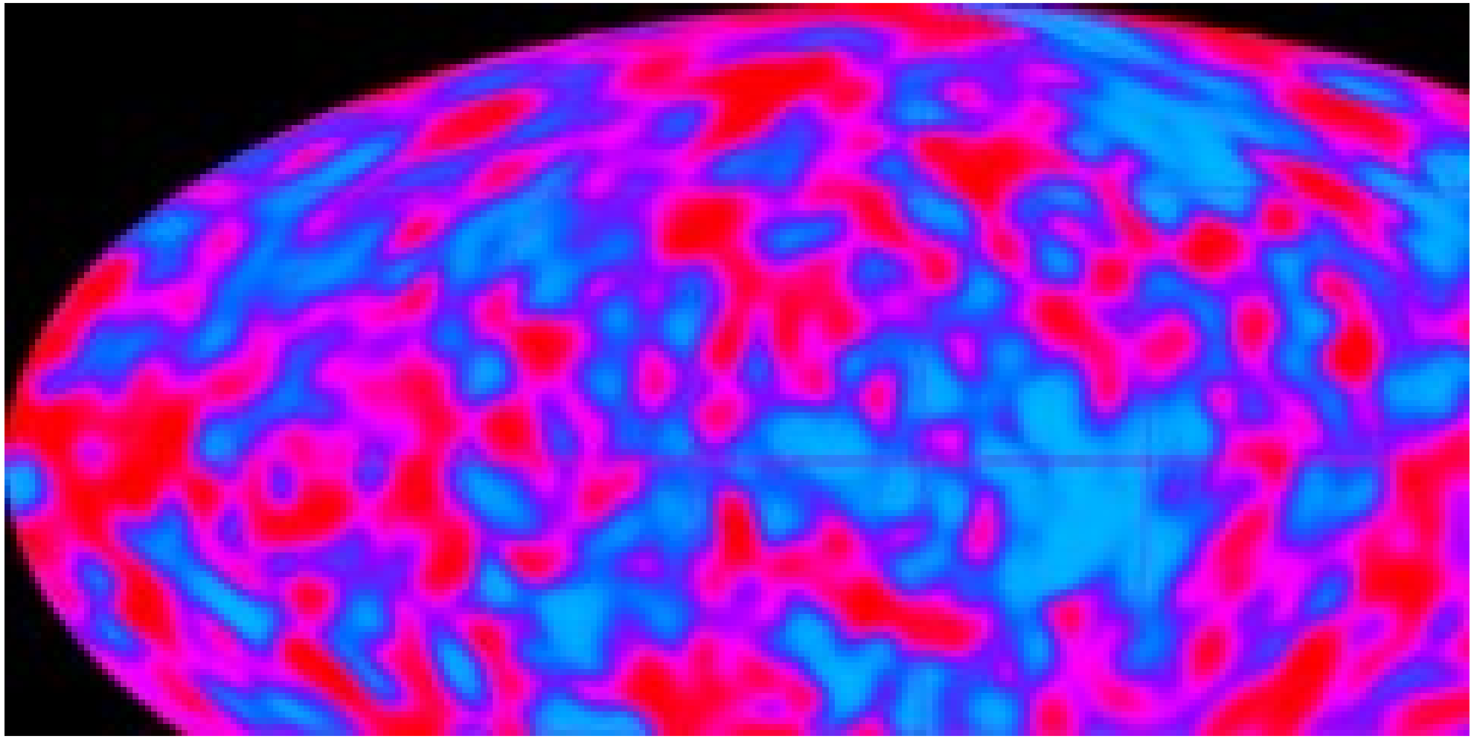
Cosmic Background Explorer



The first satellite built dedicated to cosmology. Its goals were to investigate the cosmic microwave background radiation (CMB) of the universe and provide measurements that would help shape our understanding of the cosmos.

Cosmic Background Explorer

13.799±0.021 ×10 9 years



The "famous" map of the CMB anisotropy formed from data taken by the COBE spacecraft.

Dark matter and dark energy

Dark Matter: An undetected form of mass that emits little or no photons, but we know it must exist because we observe the effects of its gravity

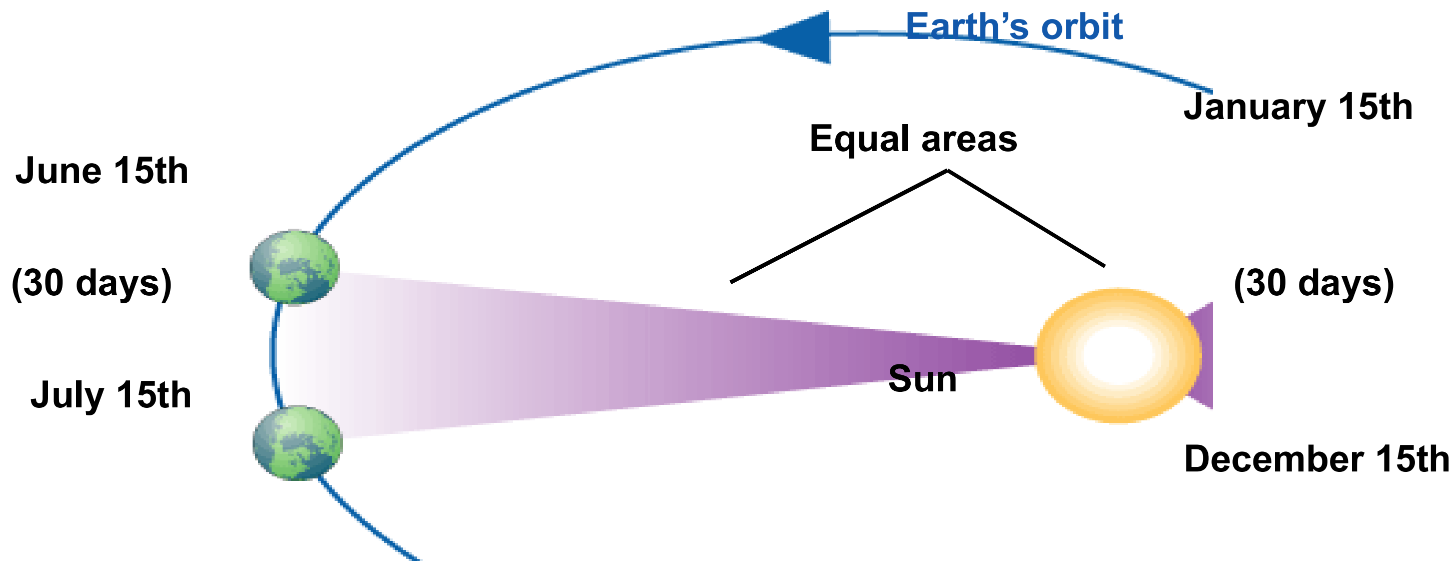
Dark Energy: An unknown form of energy that is causing the universe to expand faster over time

What is the Universe made of?

- “Normal” Matter: ~ 4.4%
  - Normal Matter inside stars: ~ 0.6%
  - Normal Matter outside stars:~ 3.8%
- Dark Matter: ~ 25%
- Dark Energy ~ 71%

Early Astronomy … and Prague

Johannes Kepler used Tycho Brahe’s data to develop three laws that explained the motions of the planets



KEPLER’S EQUAL AREA LAW states that a line connecting Earth to the sun will pass over equal areas of space in equal times. Because Earth’s orbit is elliptical, Earth moves faster when it is nearer to the sun.

Johannes Kepler – modern Astronomy begin in Prague

- **1599 – Kepler hired by Tycho Brahe**
  - Work on the orbit of Mars
  - Kepler worked in Prague 1600 to 1612

- **1609 – Kepler's 1st and 2nd Laws**
  - Planets move on ellipses with the Sun at one focus
  - The radius vector sweeps out equal areas in equal times

- **1618 – Kepler's 3rd Law**
  - The square of a planet's orbital period P is proportional to the cube of its semi-major axis R.

Kepler 1st and 2nd law discovered in Prague perhaps in relation to the elliptical church near the Prague Kepler house

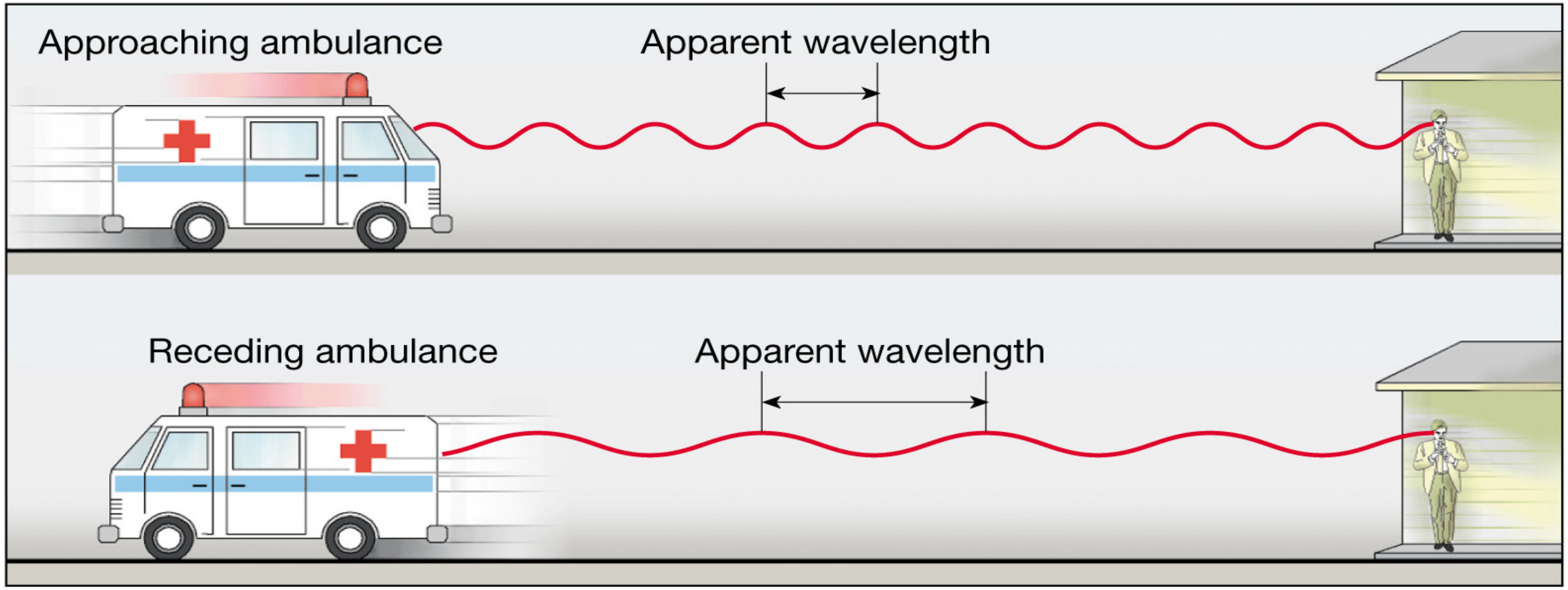
How Did Kepler discover his 1st and 2nd law?

The Wallachian (Vlašská) Chapel of the Assumption of the Virgin Mary
Křižovnické nám. 2, 110 00 Praha

It is speculated that the elliptical shape of the Wallachian Chapel of the Church of the Assumption of Virgin Mary (1590-1597) in Old Town's Charles Street inspired Johannes Kepler to think of the movement of Mars on an elliptical path (with a focus in the Sun). At that time, it was the only elliptical structure north of the Alps. Even in Italy, there were barely ten.

The Wallachian chapel was built in 1590 (consecrated by 1600) by Italian craftsmen from the Italian-Wallachian colony living in Prague, but still managed by the Italian state.

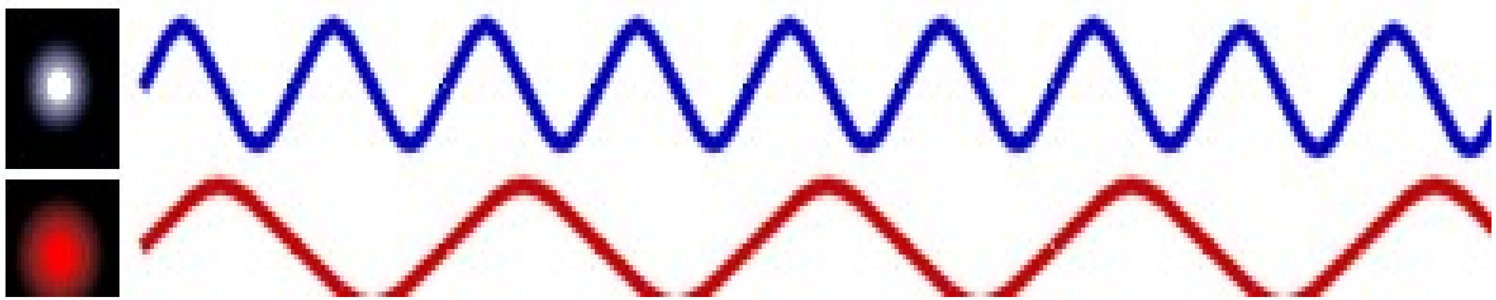
The Doppler effect



Originally discovered by the Austrian mathematician and physicist, Christian Doppler (1803-53), this change in pitch results from a **shift** in the frequency of the sound waves.

The Doppler effect

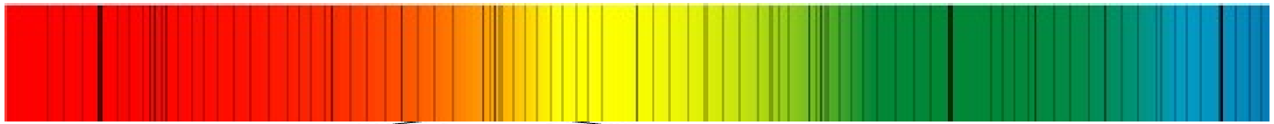
The electromagnetic radiation emitted by a moving object also exhibits the Doppler effect.

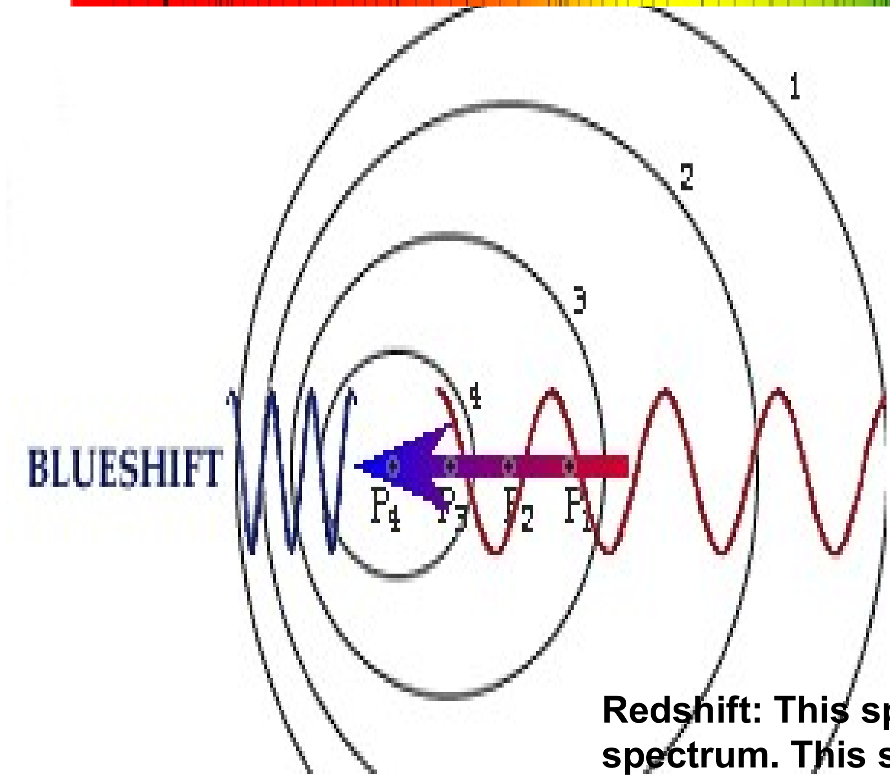


•Redshift, a phenomenon of electromagnetic waves such as light in which spectral lines are shifted to the red end of the spectrum.

The Doppler effect

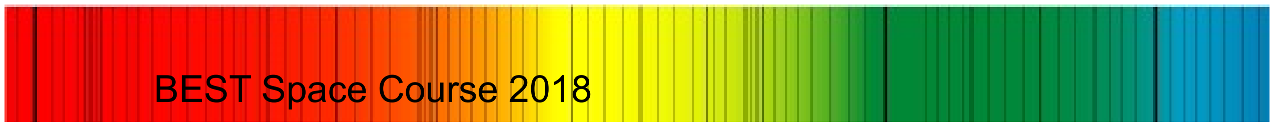
Blueshift: This spectrum shows hydrogen shifted to the blue end of the spectrum. This star is moving toward Earth.





The radiation emitted by an object moving toward an observer is squeezed; its frequency appears to increase and is therefore said to be **blueshifted**. In contrast, the radiation emitted by an object moving away is stretched or **redshifted**. Blueshifts and redshifts exhibited by stars, galaxies and gas clouds also indicate their motions with respect to the observer.

Redshift: This spectrum shows hydrogen shifted to the red end of the spectrum. This star is moving away from Earth.



Doppler Effect II

This simple phenomenon mean a tremendous advance in space exploration, allowing the determination of the radial velocities of the cosmic bodies, the speed of convection in the solar photosphere, the velocity and weight of the binary stars, the black hole mass, the search for extraterrestrial planets, the galaxies, it is essential in helioseismology and direct study of invisible solar interior

Doppler and Prague

Doppler House Prague
U Obecního dvora 799/7,
110 00 Staré Město

Professor in Prague 1835-1847

In 1843, at the proposal of František Palacký, he became a full member of the Royal Czech Society of Science. At the meeting of the science section of the Society, he lectured on May 25, 1842, "On the Color of the Binary Stars", where he described the so-called Doppler phenomenon. However, since he had no experimental evidence, the work did not receive too much attention

Places to see in Prague

- Kepler house and Kepler Museum inside
- Thumb of Tycho Brahe in Tyn church, Staromestske namesti
- Astronomical clock, old city hall Staromestske namesti
- Monument of Kepler and Brahe at Pohorelec, Tram station 22 near Prague castle
- Doppler House

Visit to Astronomical Prague

Belveder: Former Observing Place of Tycho de Brahe

Kepler House in Prague (and Kepler museum inside)

http://www.keplerovomuzeum.cz/en/

Tycho de Brahe Thumb

Astronomical Clock

Klementinum Old Prague Observatory

Jesuit College

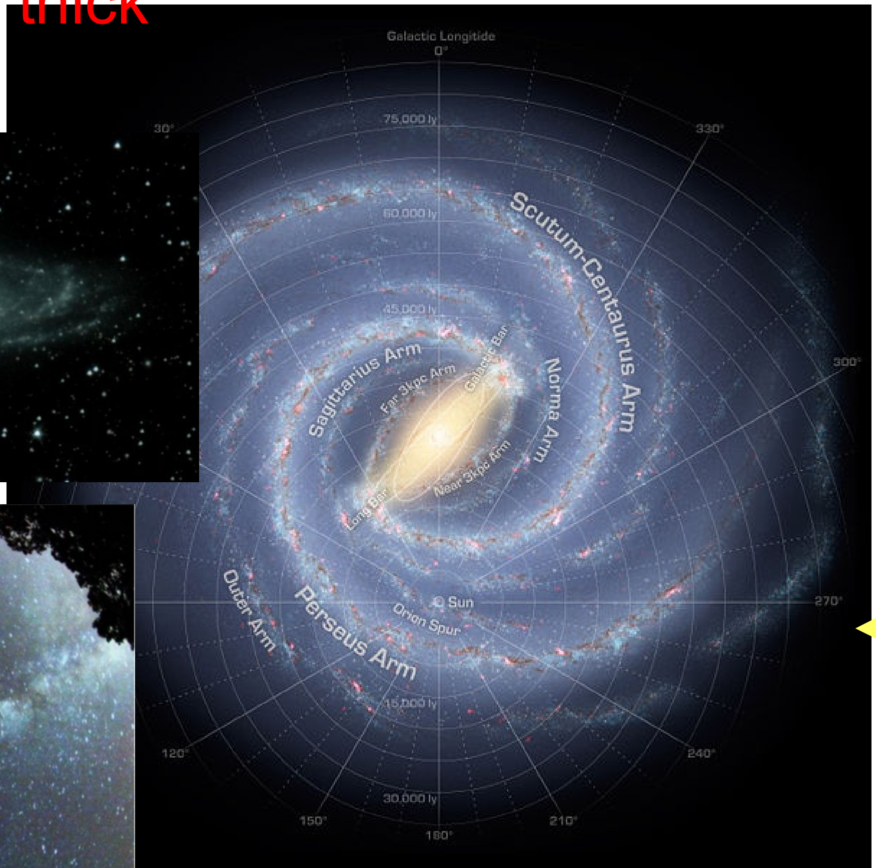
1st Prague Observatory
Observatory tower from 1722
Today National Library

Enjoy the space course ….
and Prague

The End

The Milky Way Galaxy

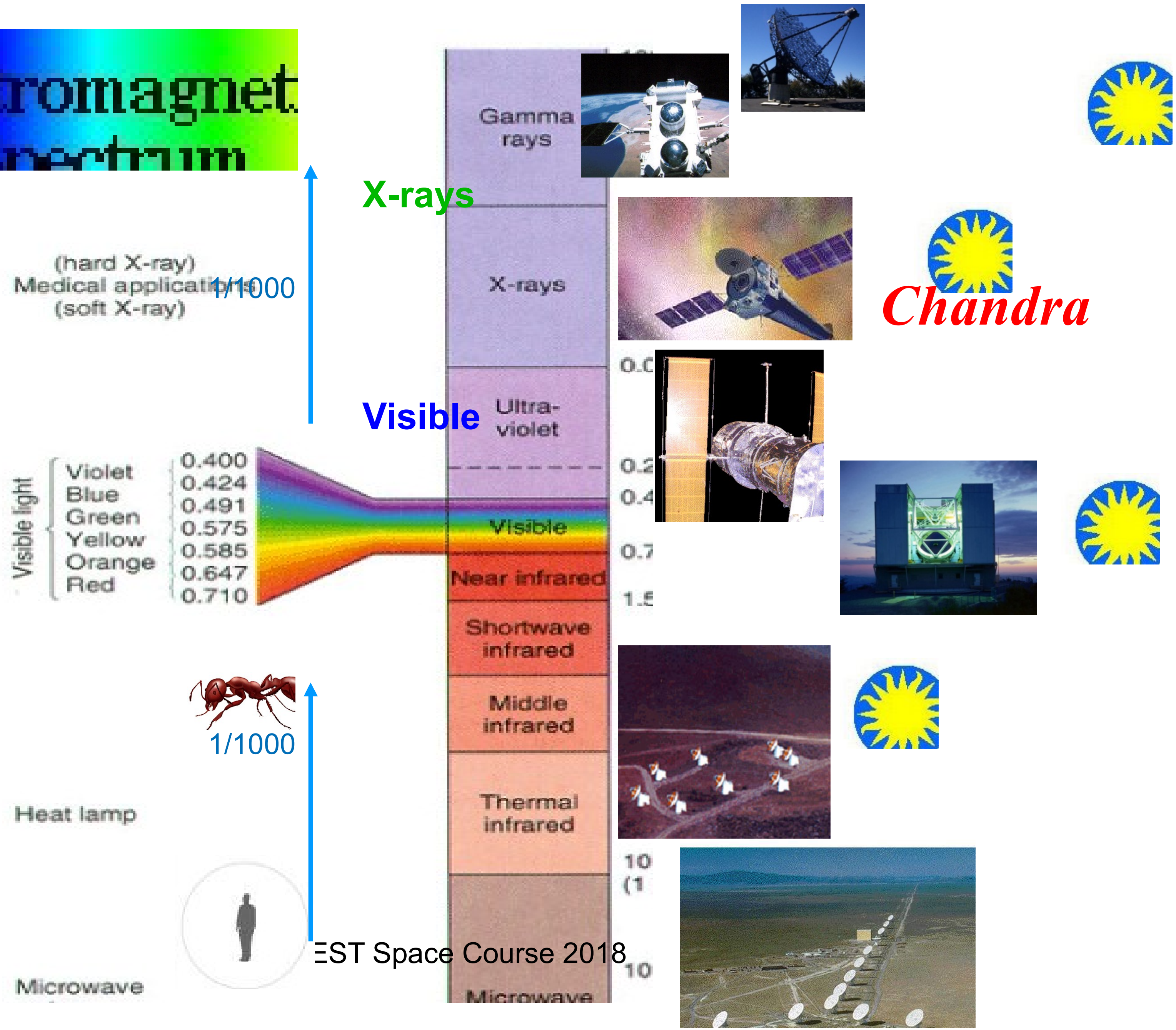
100,000 light years across
1,000 light years thick
200 billion stars

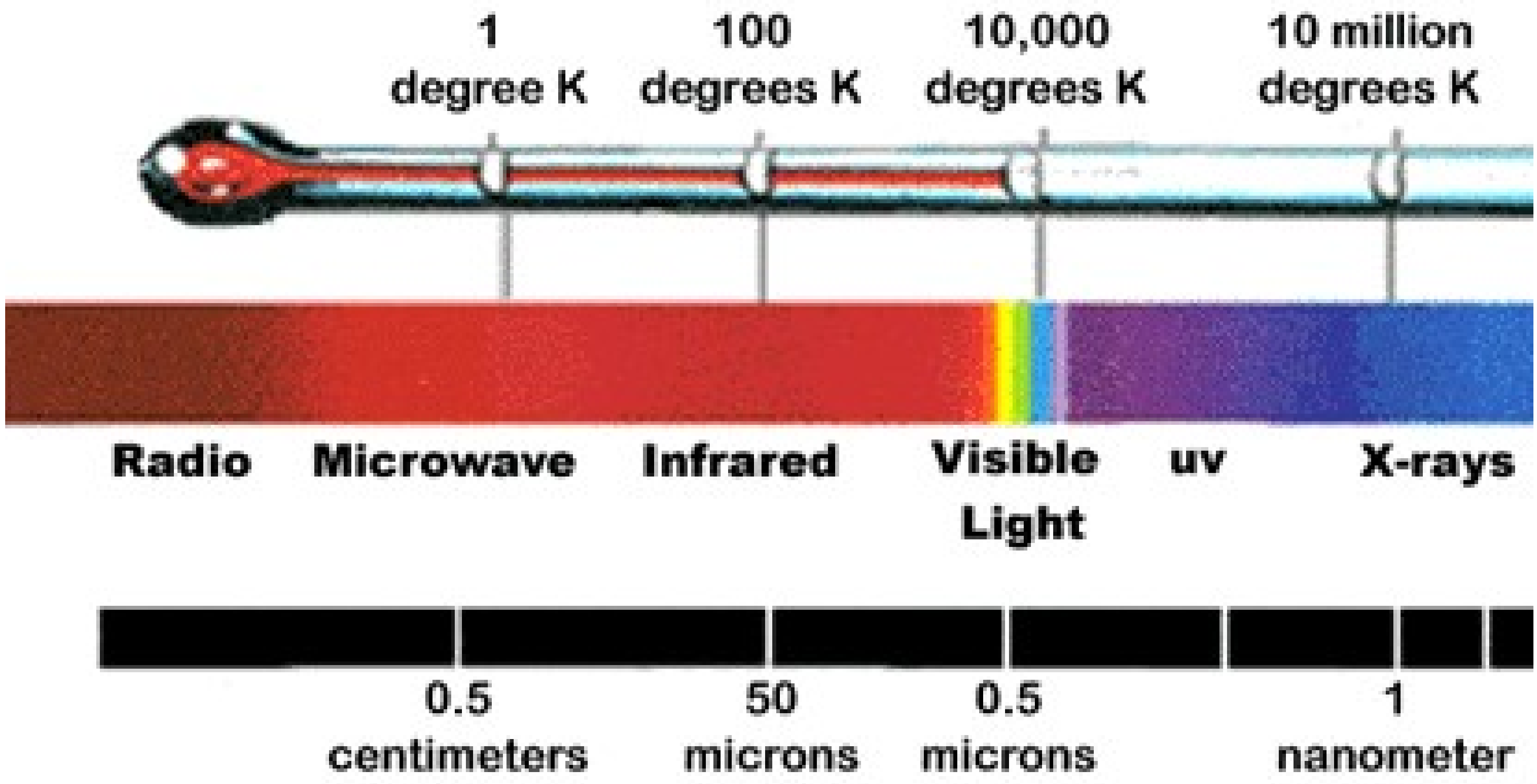


You are here

Electromagnet Spectrum

10^{15} rozsah ve vlnových délkách

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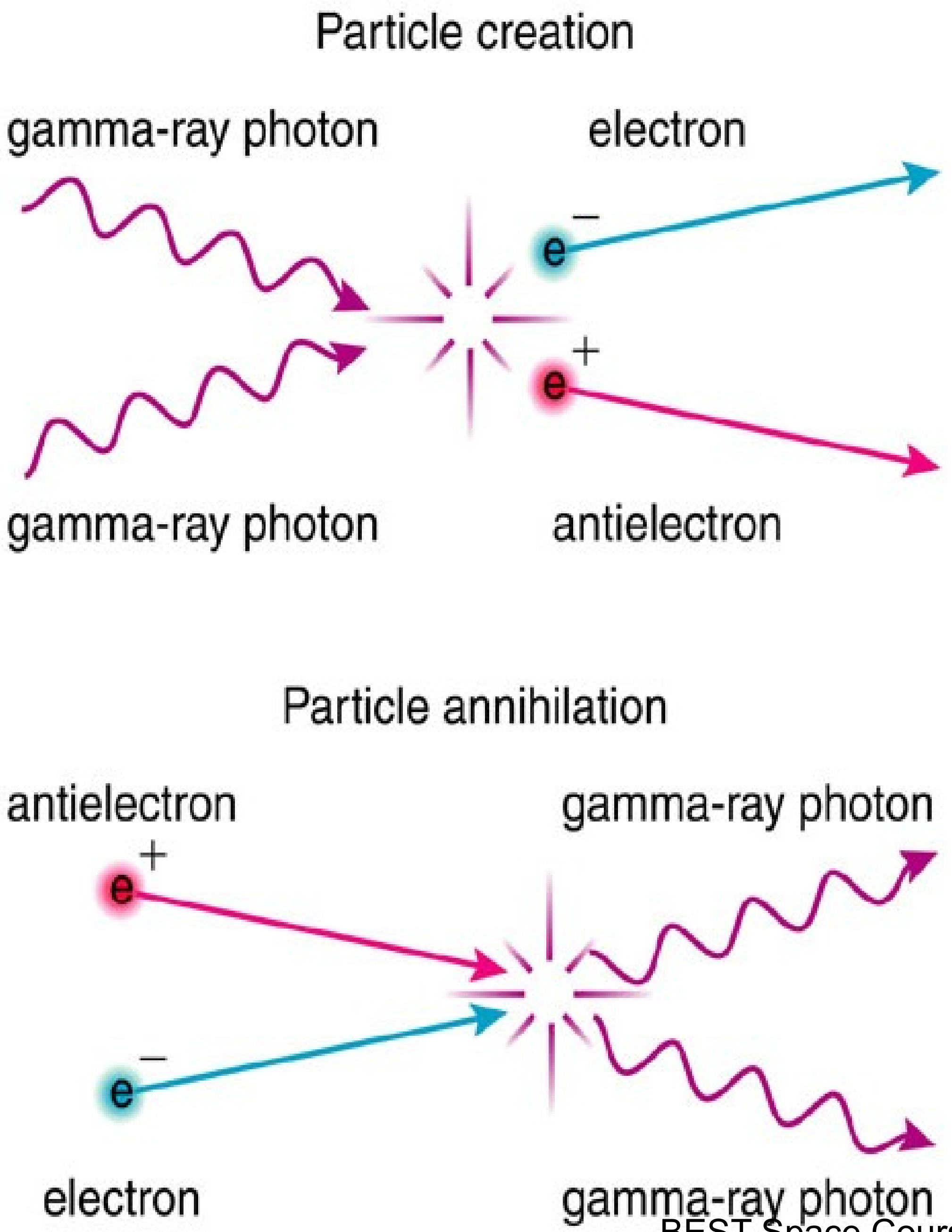

Photons converted into particle-antiparticle pairs and vice-versa

$$E = mc^2$$

Early universe was full of particles and radiation because of its high temperature

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Energetic particles in the Heliosphere and the Magnetosphere. Shri Kanekal LASP
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RM Johnson Earth and Space Science Education: Implications and Opportunities
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Space Systems Design

Satellite and Space Networks ÖMER KORÇAK, Marmara University

Department of Computer Engineering, Satellite Networks Research Laboratory (SATLAB), Department of Computer Engineering,

Boğaziçi University, Istanbul, Turkey

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Stanford University Matthew Peet Spacecraft Orbit design

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