BSS194

Threats from Outer Space

MAREK
DVORACEK

24. 3. 2020

European Space Agency

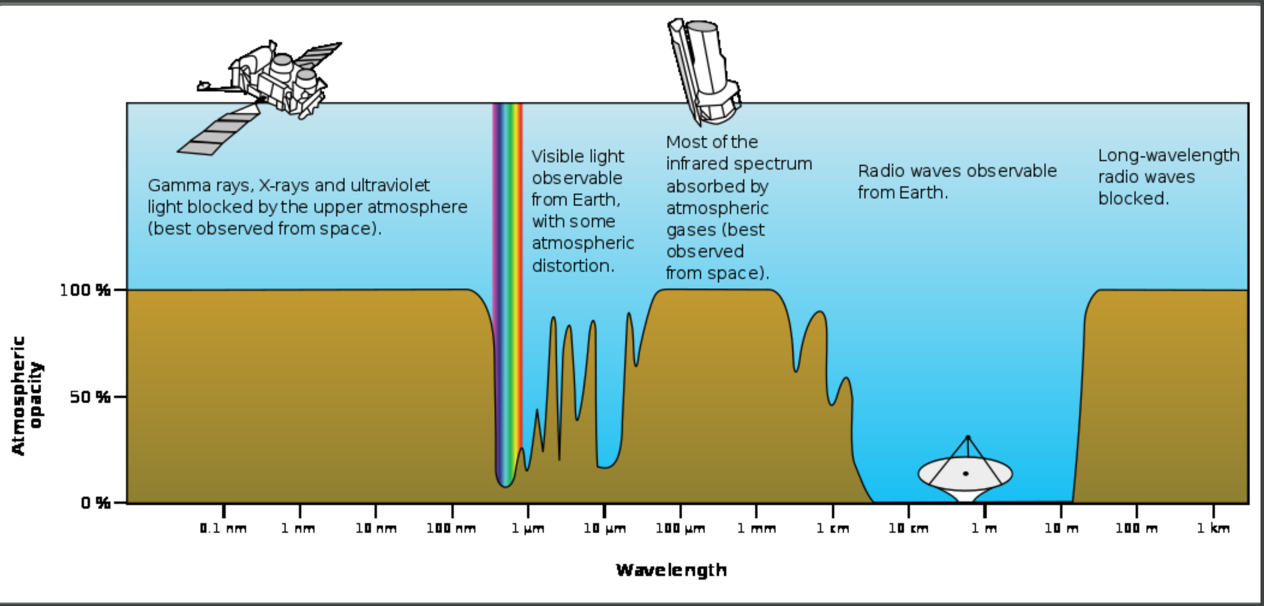
Content

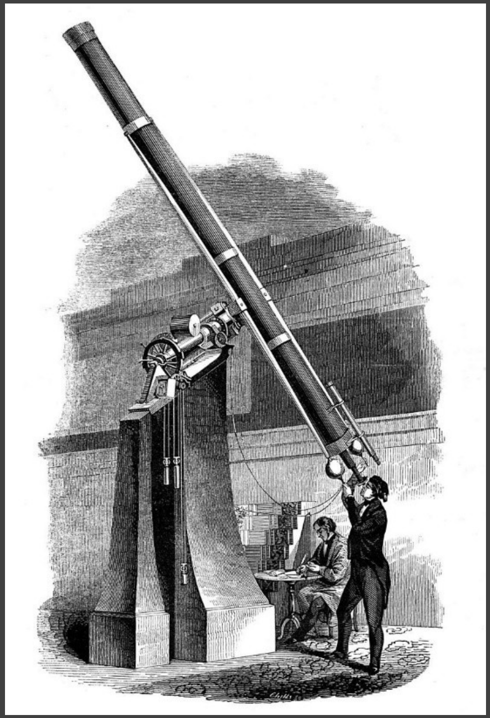
1) What is going on?
2) SST
3) NEOs
4) Weather
5) Others

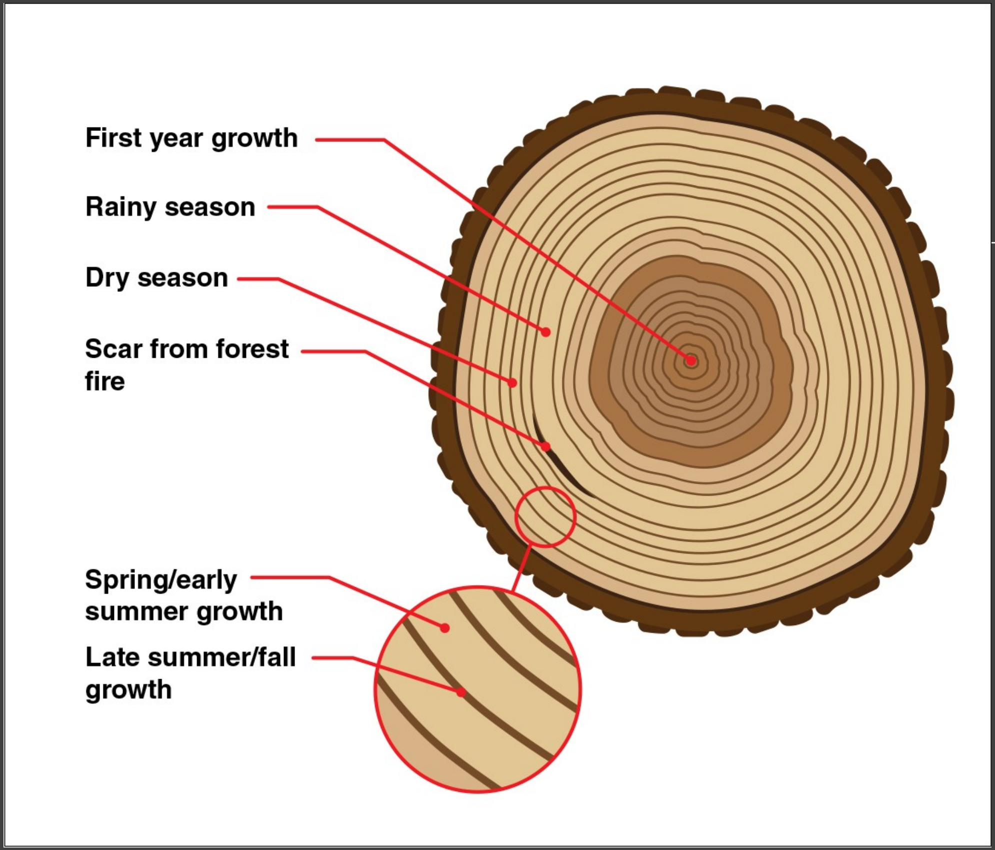
What is going on?

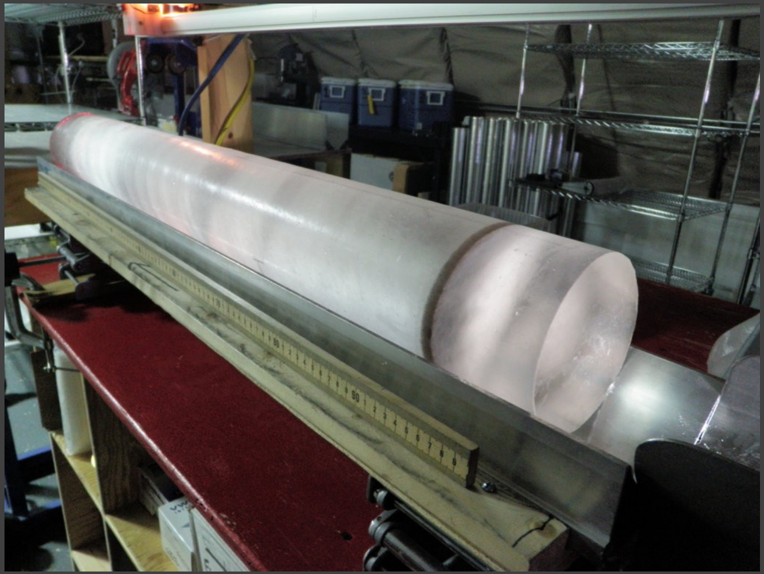
Planetary and Stellar unintentional and natural threats

1608 - Hans Lippershey patent for refracting telescope







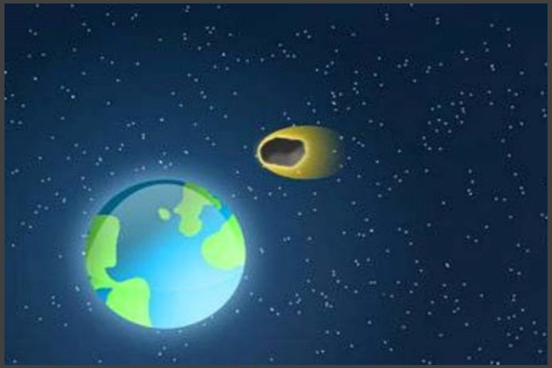


https://www.youtube.com/watch?v=odGrgsLkfUQ

Space Situational Awareness

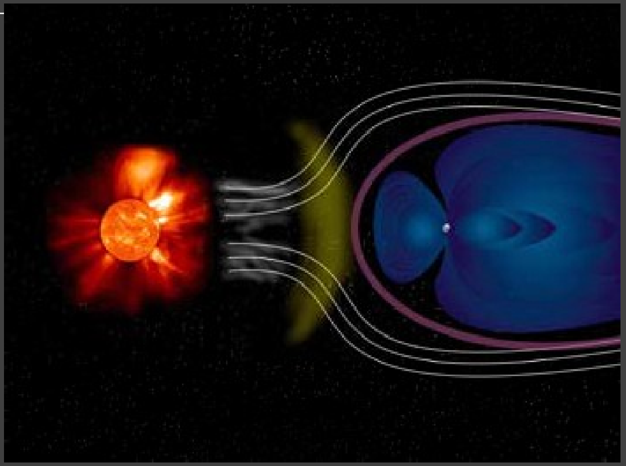
Space Surveillance and Tracking

Space Debris



Near-Earth Objects

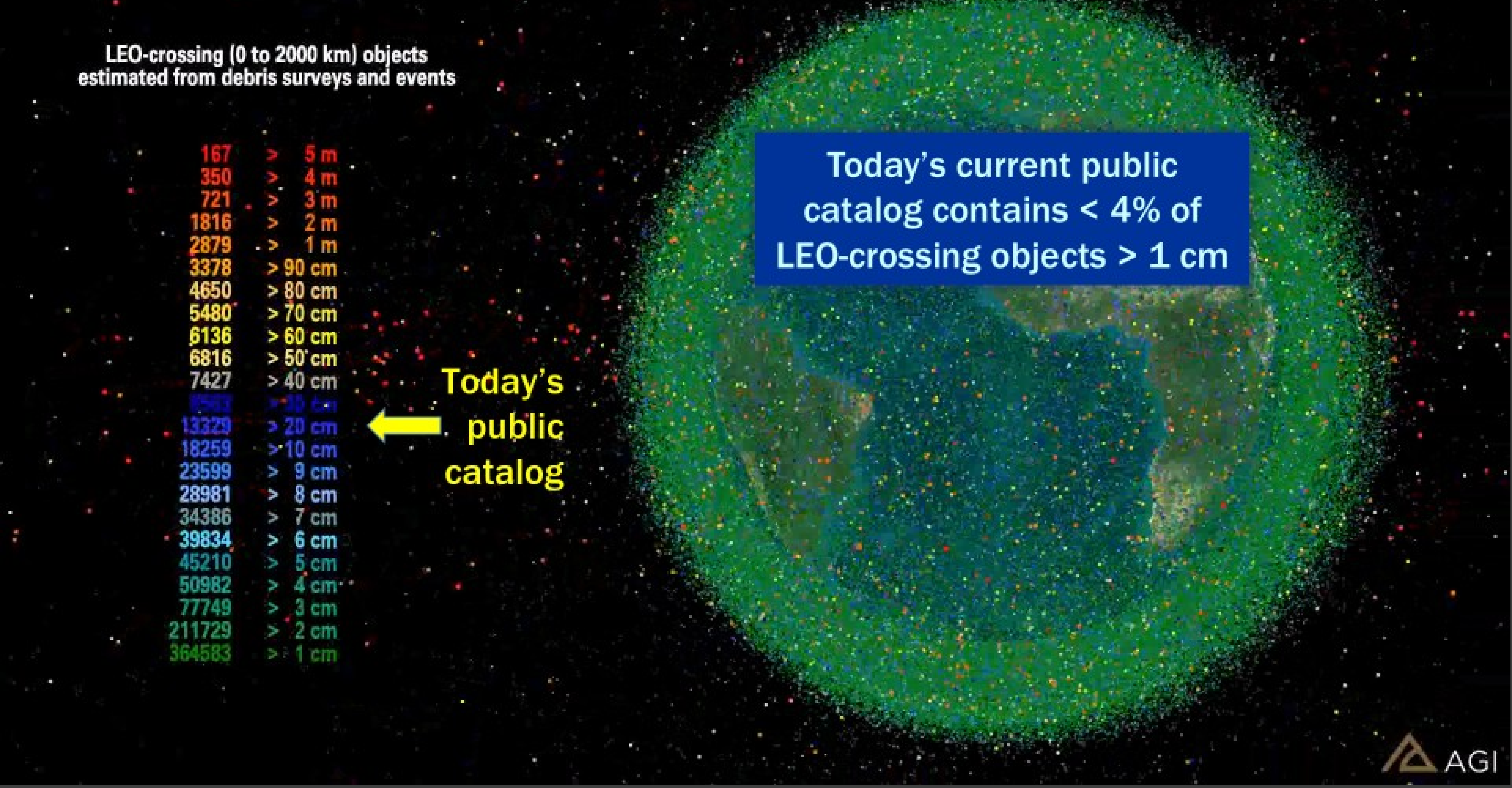
Asteroids



Space Weather

Sun-related Phenomena

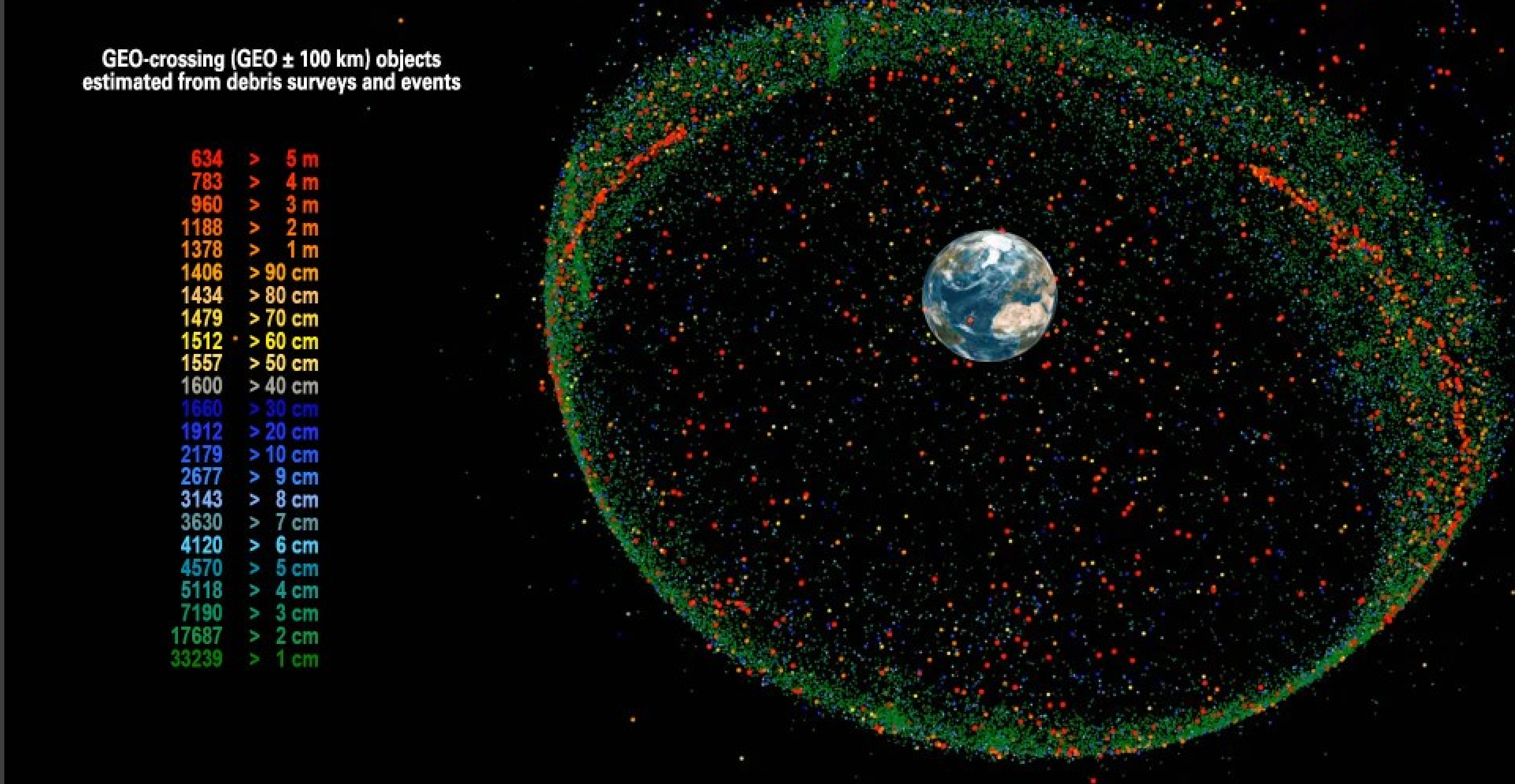
Small LEO space population largely unknown



Cislunar outer space is not an empty space. On the contrary it is becoming more „contested, congested, competitive“

Space Surveillance and Tracking (SST)

Small GEO space population especially unknown!



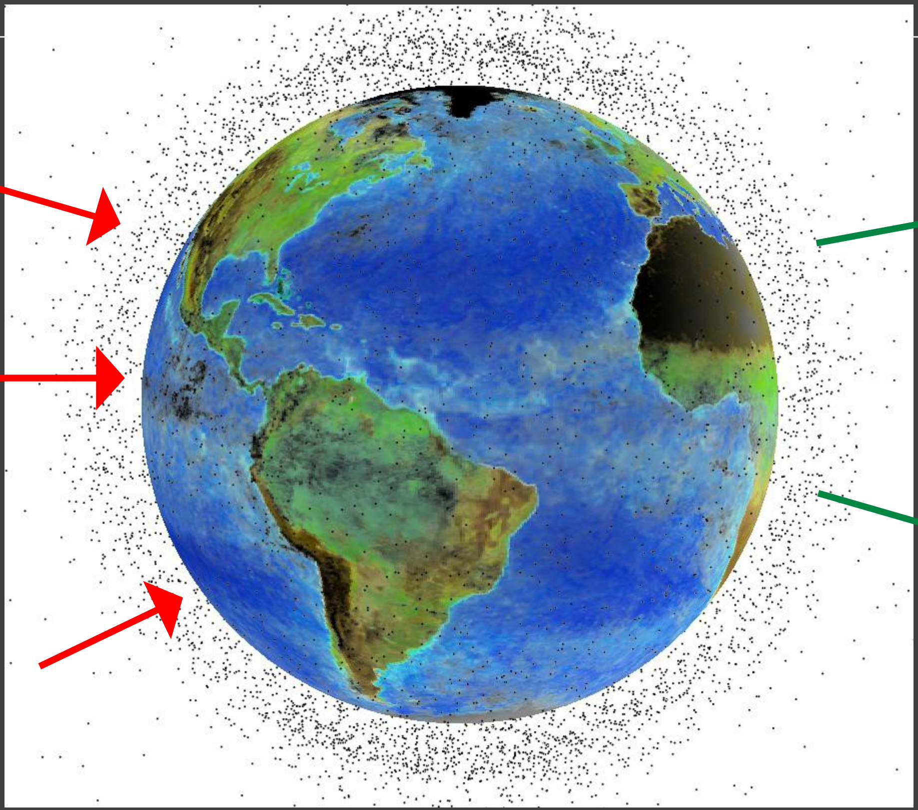
Sources and Sinks of Space Debris

Sources

Launches (rocket bodies, payloads, mission related objects)

Fragmentations (explosions, collisions)

Non-fragmentation debris (surface degradation, solid rocket motor particles)

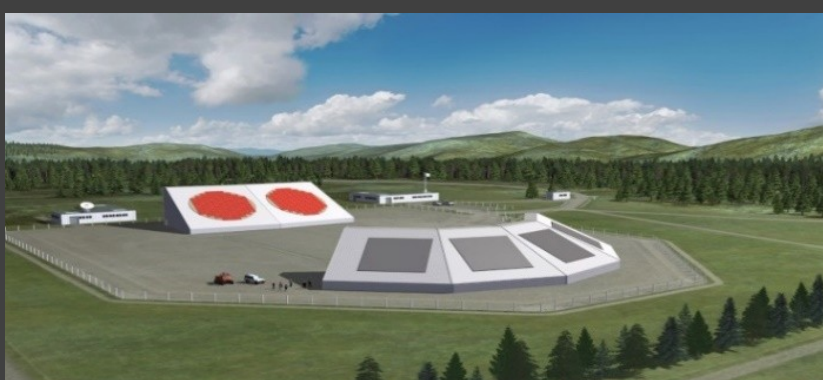


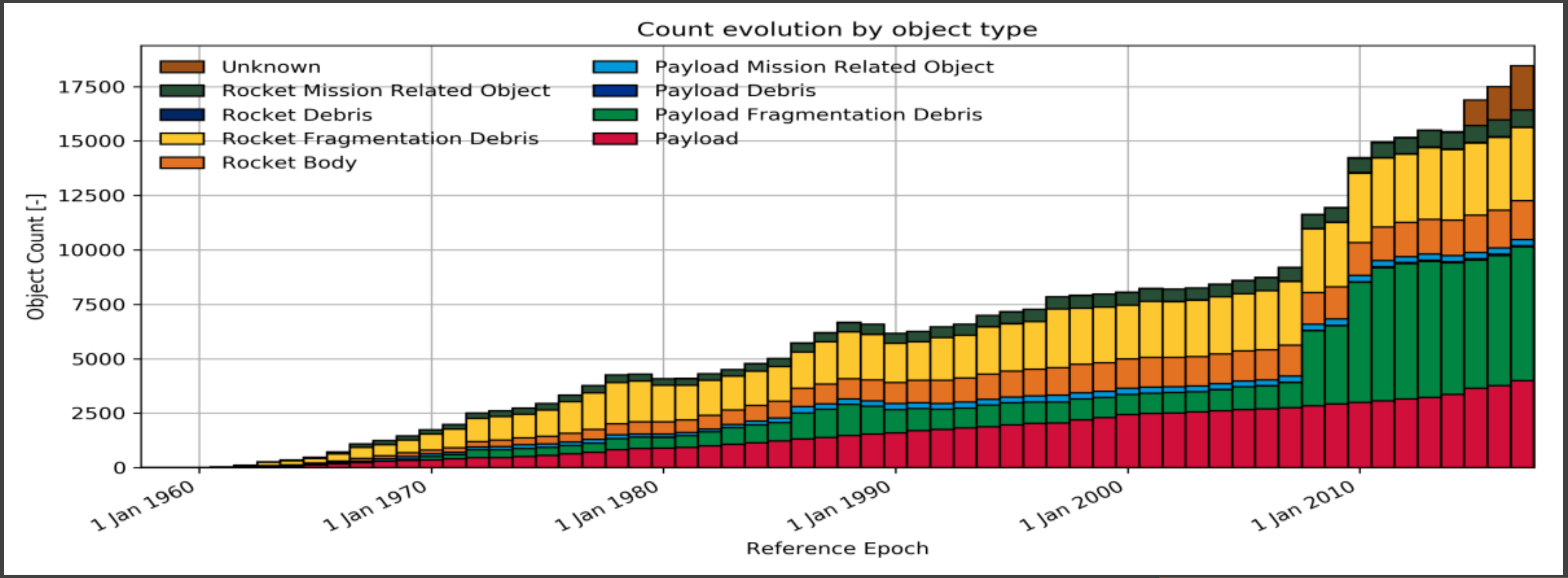
Sinks

Natural decay (atmospheric drag, solar radiation pressure, lunisolar perturbations)

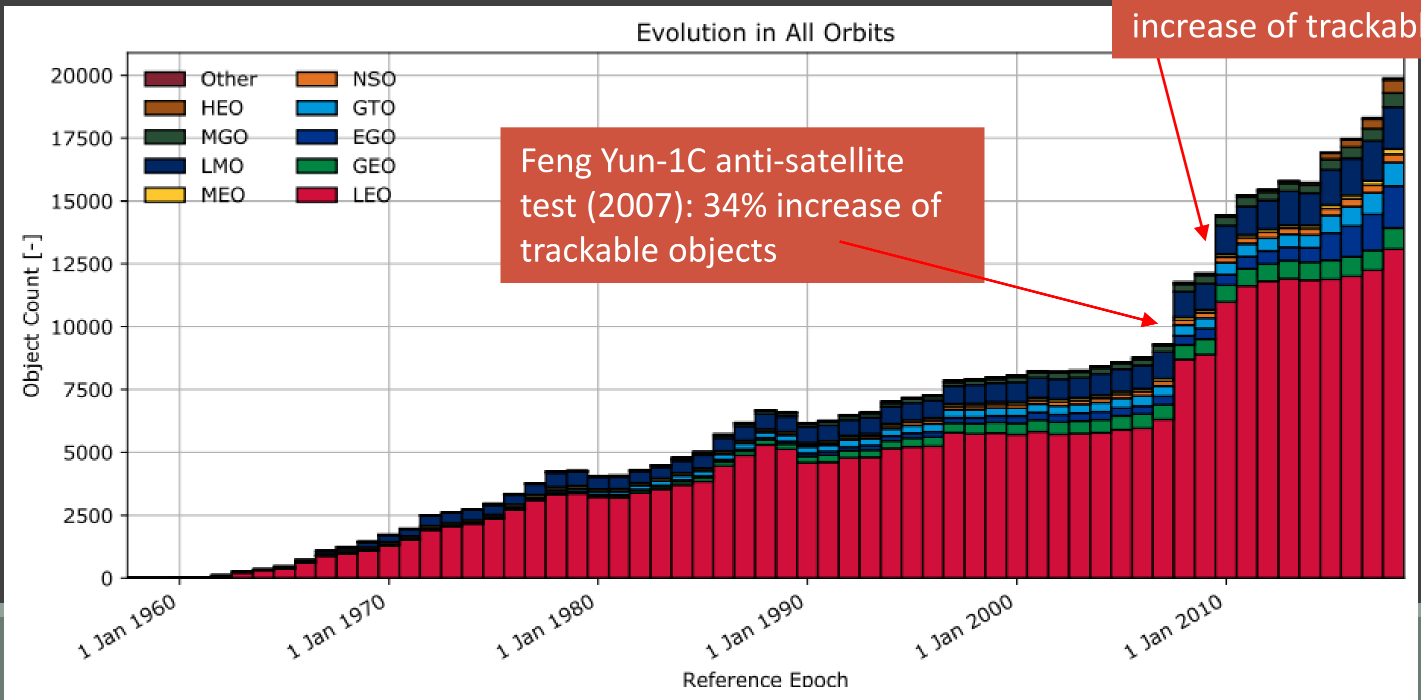
Active Removal (de-orbit, non-propulsive maneuvers)

Enhanced SST capabilities





Iridium-33 and Cosmos-2251 collision (2009): 17% increase of trackable objects



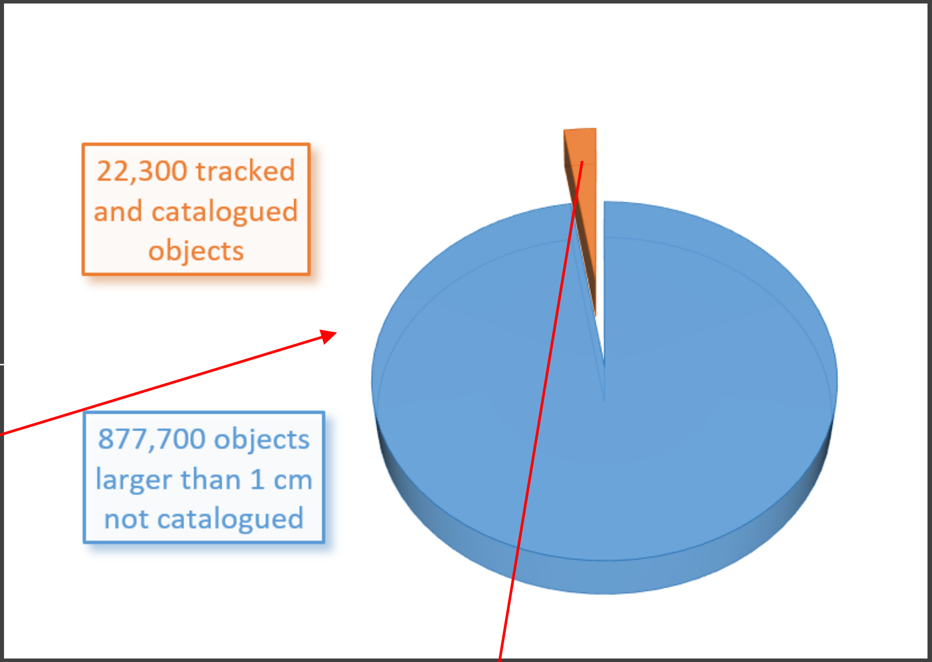
Feng Yun-1C anti-satellite test (2007): 34% increase of trackable objects

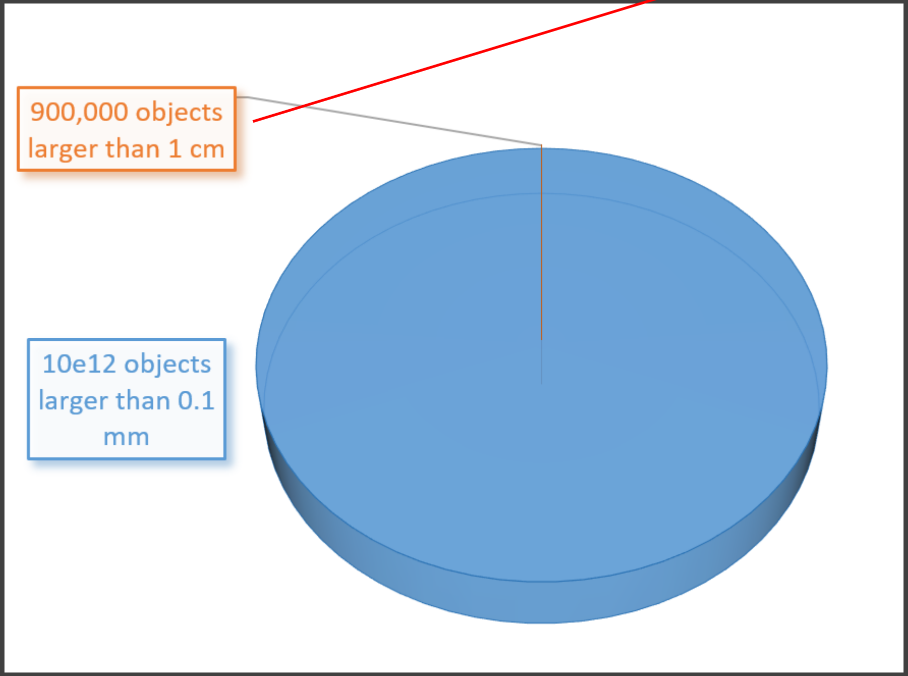
Debris Size	Similar in size to	Mass (g) aluminum sphere	Kinetic Energy (J)	Equiv. TNT (kg)	Energy similar to	Quantity	Trackable
1 mm	medium-grit sand or poppy seeds	0.0014	71	0.0003	Pitched baseball	Tens of millions	Can't be tracked
3 mm	smaller than BBs	0.038	1910	0.008	Bullets	Millions	Can't be tracked
1 cm	blueberries	1.41	70700	0.3	Falling anvil	Hundreds of thousands	Can't be tracked
5 cm	plum	176.7	8840000	37	Hit by bus	Tens of thousands	Most can't be tracked
10 cm	softball	1413.7	70700000	300	Large bomb	Tens of thousands	Most can be tracked
> 10 cm	basketball to football field	1400 to 500,000,000	Up to 1x10^13	Up to 3,000,000	Very large bomb	Thousands	Tracked and cataloged by the space surveillance network

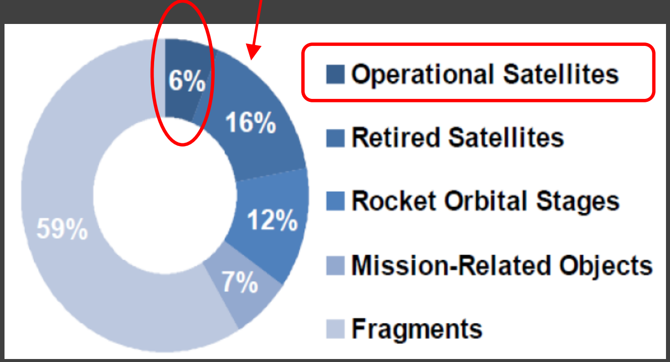
A summary of collision energies of various sized particles. Notice that tiny space debris can be deadly and are typically not trackable.

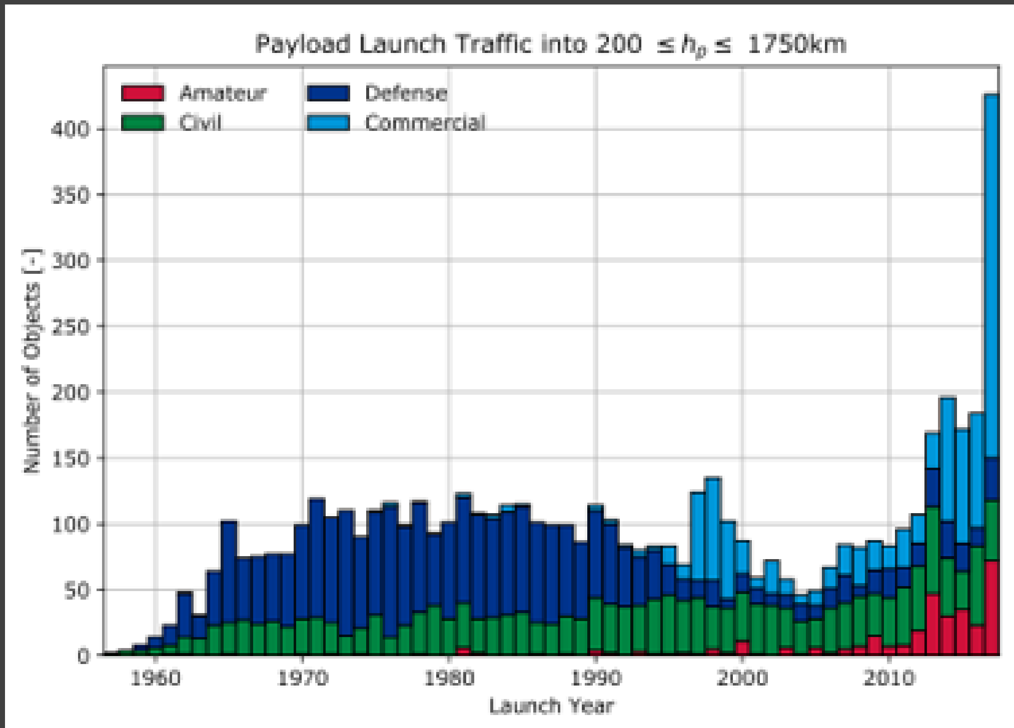
https://aerospace.org/story/space-debris-and-space-traffic-management

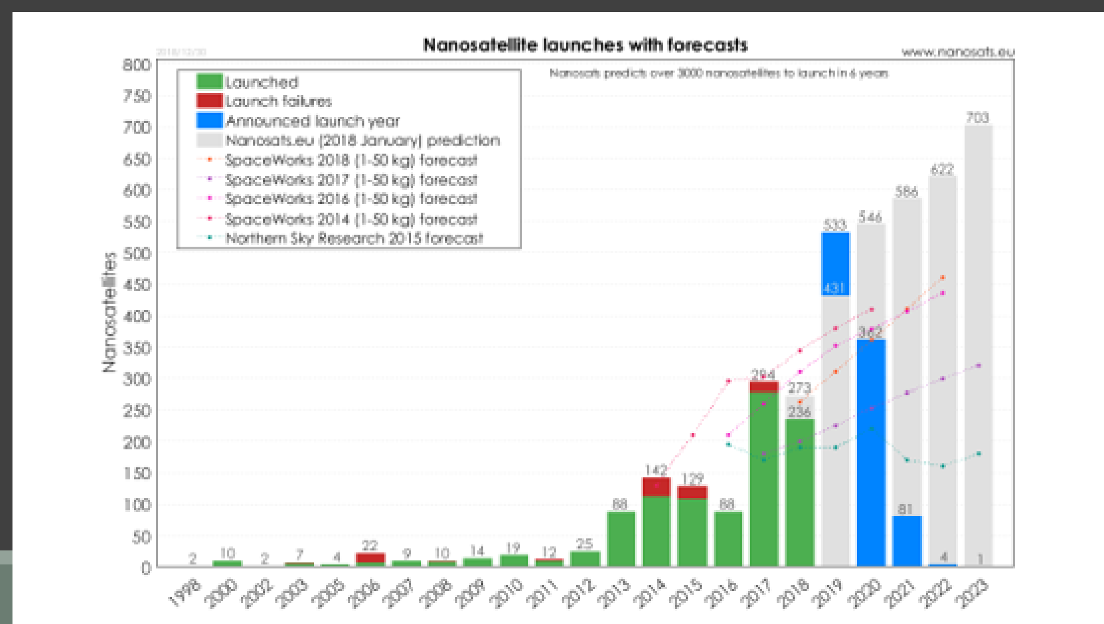
Why even care?











http://www.unoosa.org/res/oosadoc/data/documents/2019/aac_105c_12019crp/aac_105c_12019crp_7_0_html/AC105_C1_2019_CRP07E.pdf

What to do now?

Space Debris

man-made objects, *including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are* ***non-functional***[1]

Mitigation

the action of reducing the severity, seriousness, or painfulness of something[2]

Space Debris Mitigation

the action of reducing the severity, seriousness, or painfulness of space debris

Objectives

Space Sustainability

the ability to preserve and protect the outer space environment over long-term for use by future generations

Targets:

- *To prevent the "**Kessler Syndrome**", i.e. global amount and density of space debris in Earth orbit growing to a point where random collisions occur between objects in space (cascade effect) making orbits not longer exploitable*

Risk limitation

For risk relates to:

- *fatality,*
- *injury or occupational illness,*
- *pollution of the environment, atmosphere or outer space,*
- *damage to public or private property.*

Targets:

- *To minimize the risk for human population and Earth environment and damages to assets associated to a* ***re-entry***
- *To prevent* ***in-orbit collisions*** *by not polluting the outer space with debris*

References:
[1] IADC
[2] Oxford dictionary

NEOs

NEOs

Near Earth Objects

Asteroids or comets of sizes ranging from metres to tens of kilometres that orbit the Sun and whose orbits come close to that of Earth’s. Of the more than 600 000 known asteroids in our Solar System, more than 18000 are NEOs.

comprising natural objects that can potentially impact Earth and cause damage, and <u>assessing their impact risk</u> and potential <u>mitigation</u> measures

Less than 1% of NEOs (15 – 40m) discovered

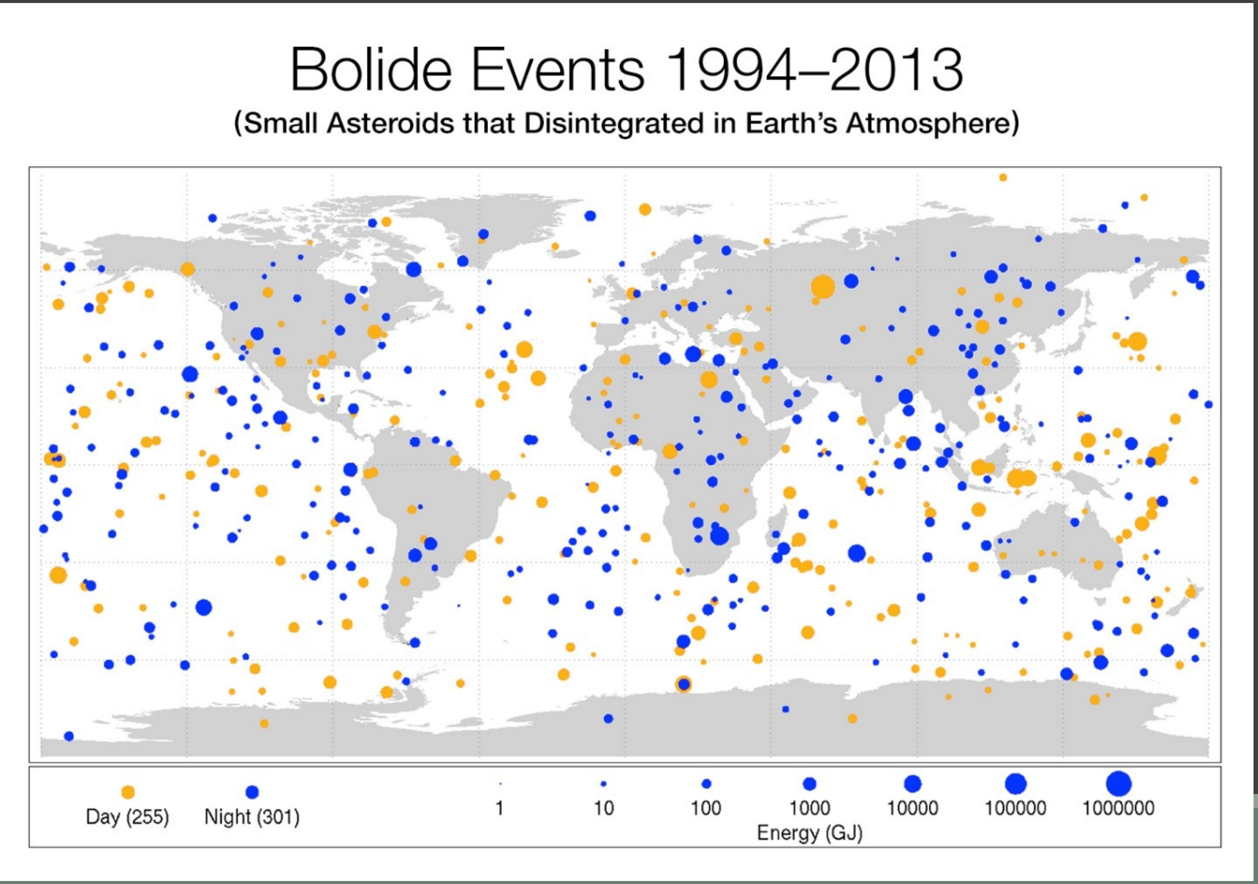
Average one impact every 10 years (Chelyabinsk type – 20m)

Stuff from space

https://www.youtube.com/watch?v=9q3uNcJh4pc

meteorites are everywhere

There are probably more than 500 000 fireballs a year (shooting star)



2018

*„Nearly **22.5 million observations** of asteroids and comets had been collected in **2018** by the worldwide network of astronomical observatories, based in 41 countries. It also noted that the number of known near-Earth objects had exceeded 19 574 as at 1 February 2019, of which 1 837 had been discovered in 2018, with 1 963 asteroids now catalogued whose orbits took them within 8 million kilometres of Earth's orbit.“*

http://www.unoosa.org/res/oosadoc/data/documents/2019/aac_105c_1l/aac_105c_1l_374add_2_0_html/AC105_C1_L374Add02E.pdf

More Hunting to Do

NASA's NEO Observations Program (asteroid surveys) is responsible for over 90 percent of near-Earth asteroid and comet discoveries. The discovery rate averages about *40 per week*.

NEO Observations Program - to discover 90 percent of the NEOs down to the much smaller size of 140 meters by the year 2020

These smaller asteroids may not present a threat of global catastrophe if they impact Earth, but they could still cause massive regional devastation and loss of life, especially if they occur near a metropolitan area

https://www.jpl.nasa.gov/news/news.php?feature=7194

https://www.youtube.com/watch?v=V_eEXScLFBA

https://www.vox.com/xpress/2014/9/8/6118717/interactives-calculator-asteroid-meteoroid-meteorite-comet-destroy

Impacts

- Siljan ring – 375 mil. years ago, 52km
  - largest crater in Europe
- Chicxulub crater - 66 mil. years ago, 150km, 11-80km diameter
  - killed dinosaurs
- Vredefort crater – 2 bil. years ago, 160 km
  - largest confirmed known crater on Earth


SKATTUNGEN
Orsa
ORSA-
SJÖN
Mora
Rättvik
SILJAN

Impact consequences

- instant destruction at the impact site
- firestorms, shockwave, tsunamis
- “impact winter” – dust and ash blocking sun
  - drop in temperatures, no photosynthesis
  - food chain collapse, extinction of species

Experience the Disaster that Wiped Out Dinosaurs

Impacts in the present

- Tunguska, 1908 – 30m in diameter
  - 10 megaton equivalent airburst
  - 80 mil trees damaged, no known victims
- Chelyabinsk, 2013 – 20m in diameter
  - 440 kilotons of energy
  - 1500 injured, thousands of buildings damaged
- Bering Sea, 2018
  - 173 kilotons of energy, 11x Little Boy
  - Remote area, unnoticed, ex-post
- small impacts and near misses are very common

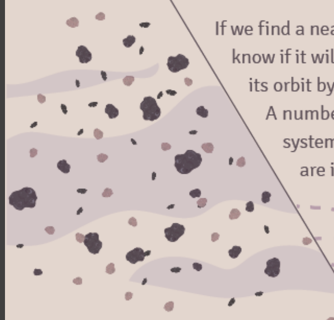
Asteroid / Planetary Defence

- by impact
  - kinetic
  - nuclear
- deflection
  - gravitational
  - solar
  - propulsion
  - laser

- crucial element: monitoring and early warning

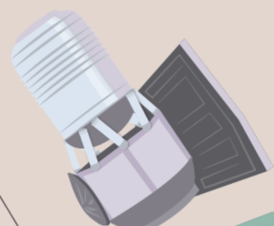
DEFENDING EARTH

With advanced planning and preparation, we could prevent a disastrous impact from an asteroid or comet. The Planetary Society breaks it down into these five steps for saving the world.



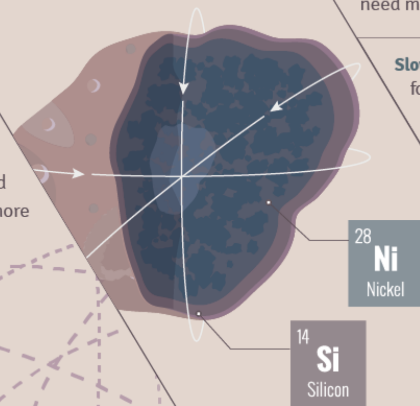
1. Find

Astronomers use ground- and space-based telescopes to spot NEOs and have found 90% of the largest ones. Infrared imaging also helps find objects that are too dark to see from their reflected light.



2. Track

If we find a near-Earth object, how do we know if it will hit Earth? We need to map its orbit by taking repeated observations. A number of missions, observatories, and systems track the orbits of NEOs, and more are in development.



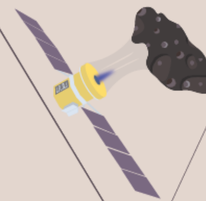
3. Characterize

By characterizing the spin rate, composition, and physical properties of potentially hazardous NEOs, we can better know how to deflect them. Awardees of The Planetary Society's Shoemaker NEO Grant Program are making tremendous contributions in this area.

4. Deflect

There is a variety of possible techniques for deflecting a potential impact, but all need more development and testing:

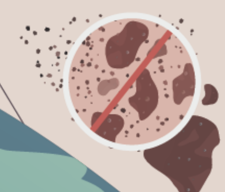
Slow gravity tractor: A massive spacecraft follows next to the near-Earth object and uses the spacecraft's gravity to pull the object off its collision course.



Kinetic impactor: A swarm of spacecraft slam into the object to knock it off course.

Laser ablation: A spacecraft uses lasers to vaporize rock on the object, creating jets that push it off course. The Planetary Society is researching this technique with the University of Strathclyde through their Laser Bees project.

What about the nuclear option? Detonating nuclear devices on or beside an asteroid may be the only viable technique we have today for deflecting an asteroid. But this comes with challenges, including political opposition and the danger of fragment impacts.



5. Coordinate and Educate

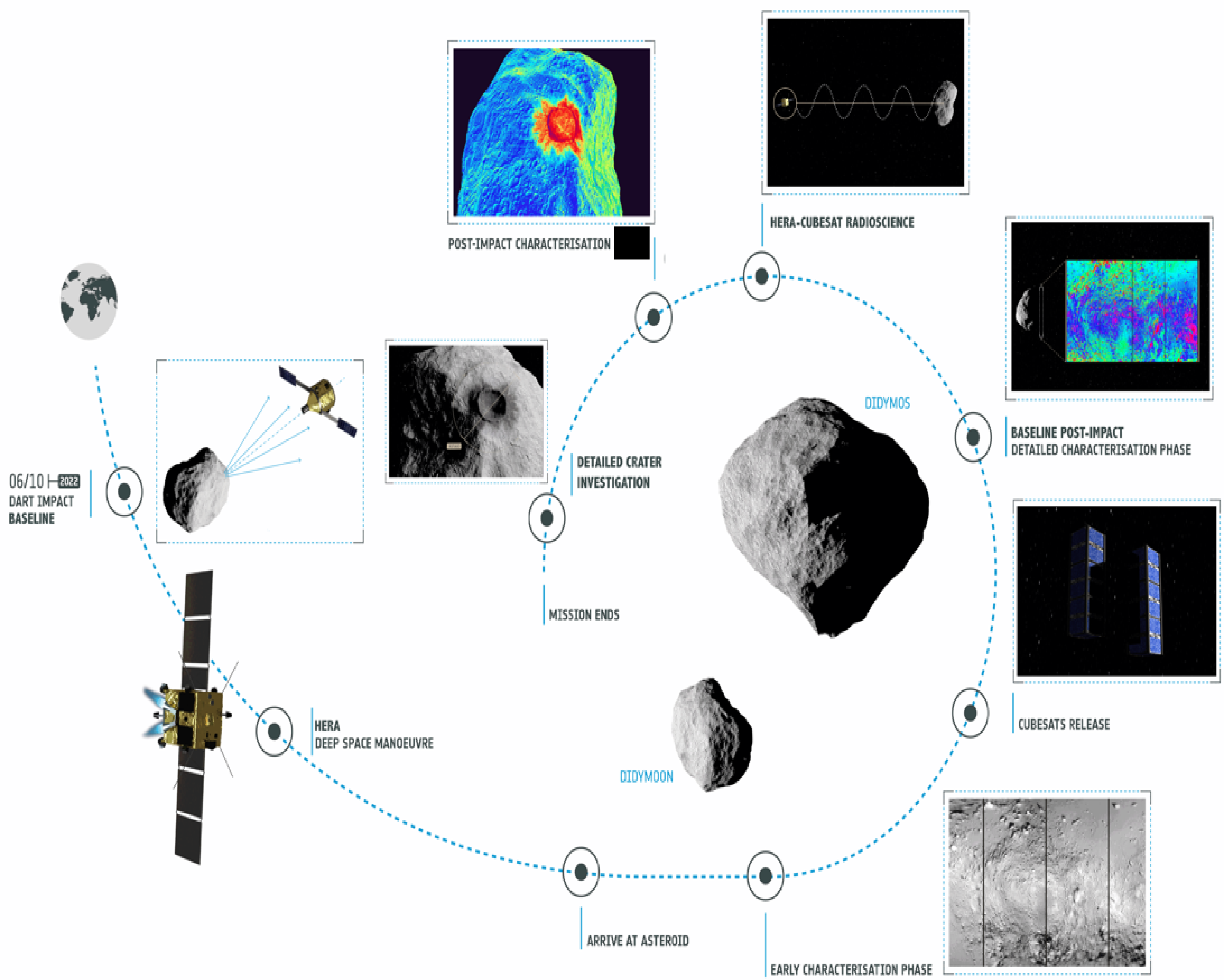
An asteroid impact is a worldwide issue that requires immense advance coordination and education. The Planetary Society is taking an active role by working with governments around the world, hosting conferences, doing public outreach, and supporting volunteer efforts.

THE PLANETARY SOCIETY

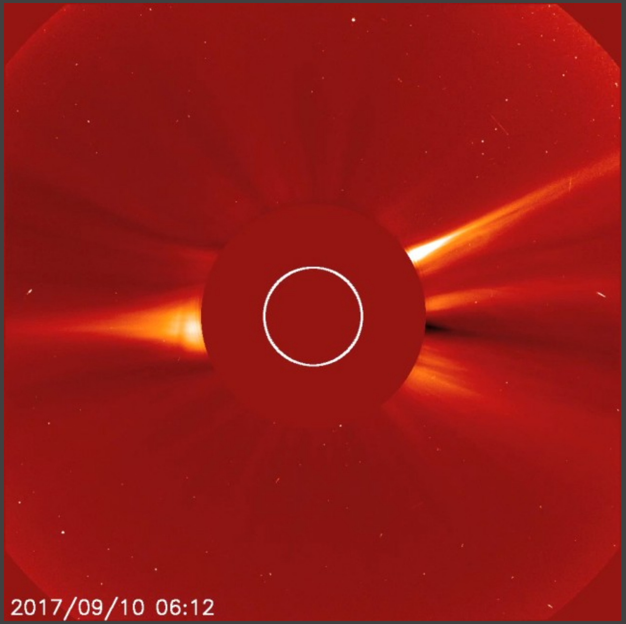
Find out more at **planetary.org/defense**

Redirection Test + ESA Hera experiment

- **First** precise measurement of deflection efficiency and **Planetary Defence capability**
- **First** binary asteroid and smallest asteroid ever visited
- **First** detailed measurement of small body cratering physics
- **First** deep-space CubeSat for very close asteroid inspection



Space Weather

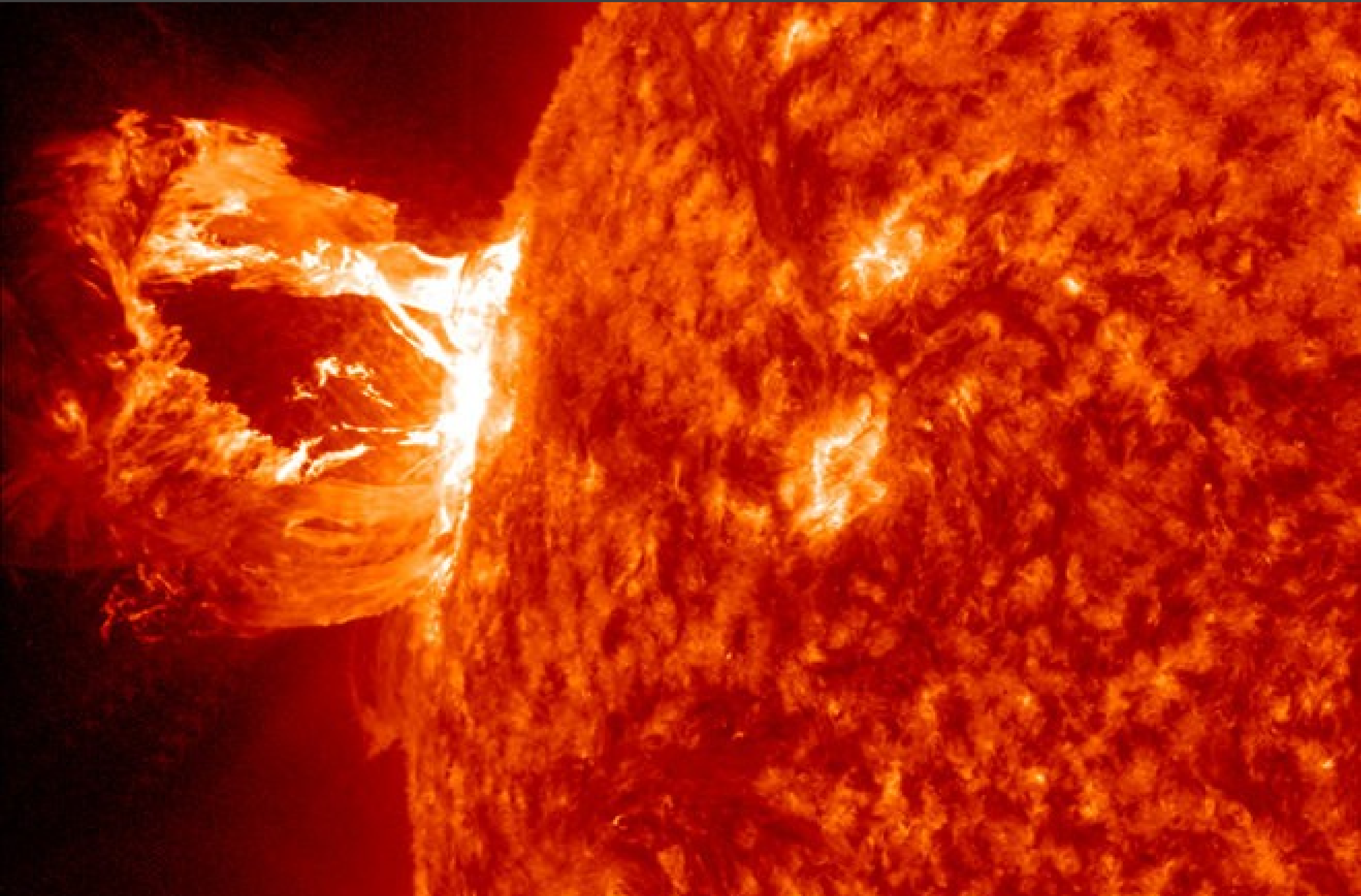


Space Weather

I) A **solar flare** is an eruption of radiation emitted from the energy accumulated in the sun's magnetic fields as they become increasingly unstable

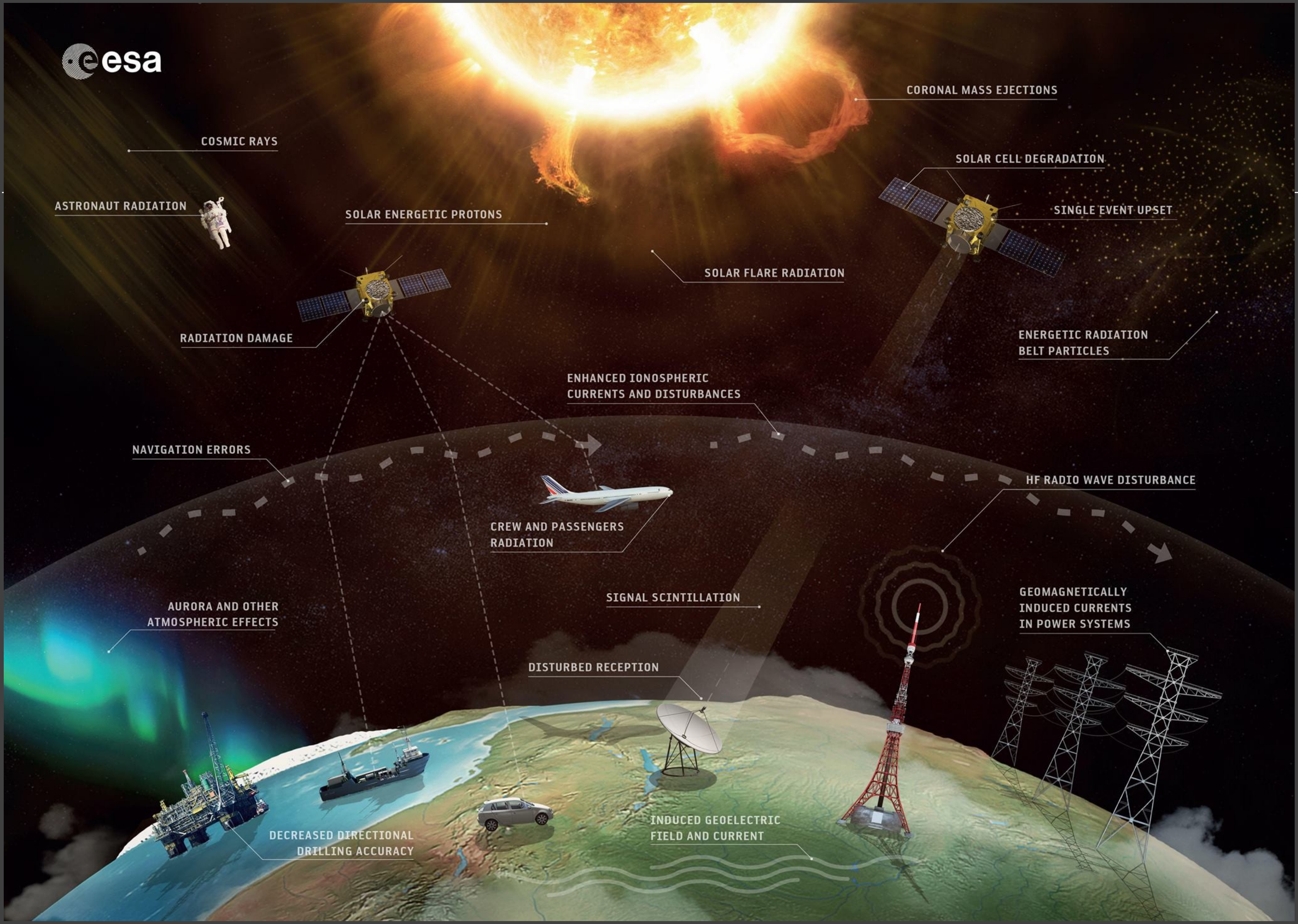
II) **Coronal Mass Ejections** are large expulsions of plasma and magnetic field originating from the Sun's coronal atmosphere

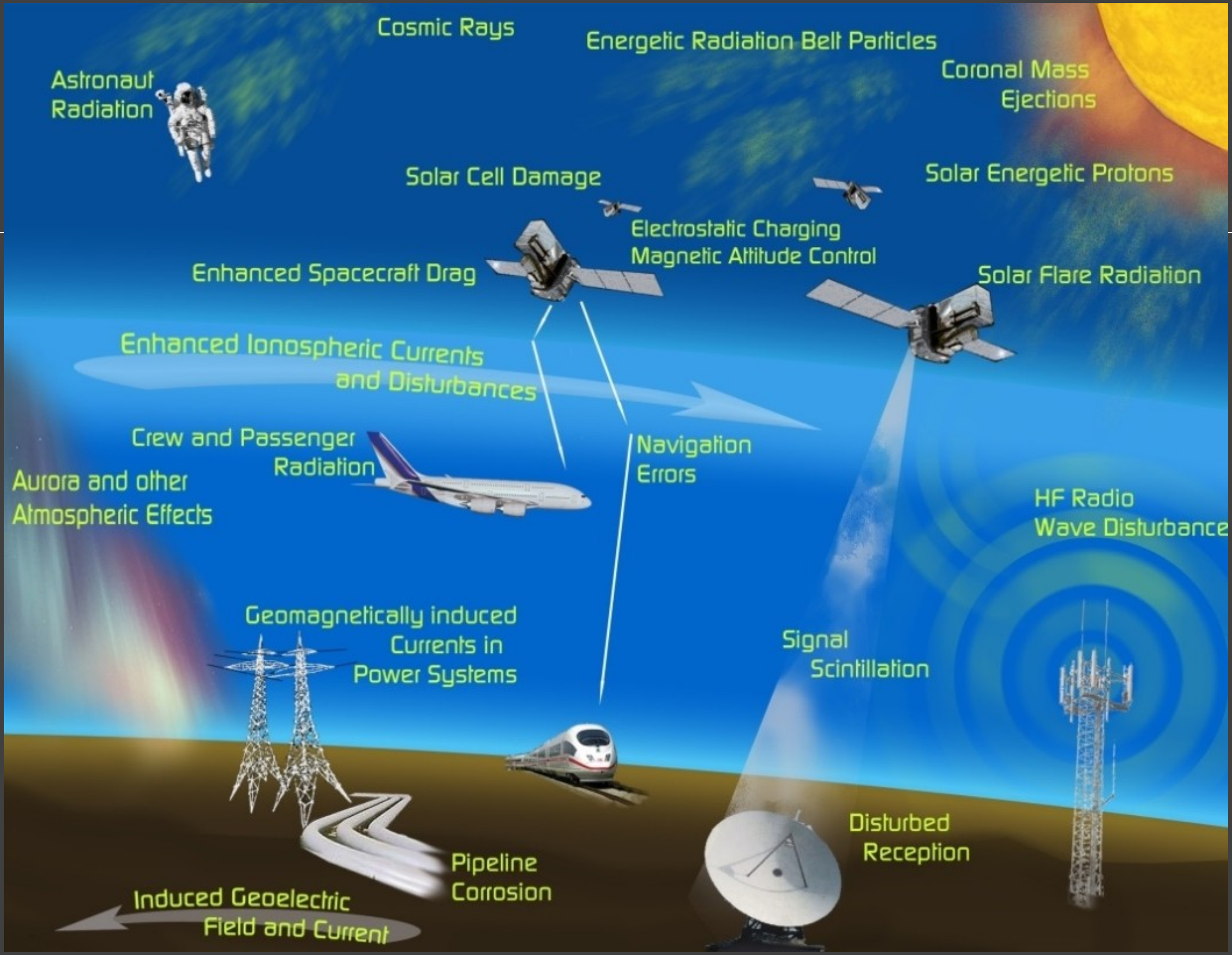
III) **Solar Energetic Particles,** are high energy charged particles accelerated by the Sun, a form of cosmic ray



Space Weather event

SWE event	Description
Geomagnetic Storm	Geomagnetic storms are strong disturbances in the Earth's magnetic field that occur when CMEs or solar wind streams interact with the geomagnetic field. As a result of this interaction, the Earth's magnetic field adjusts to this jolt of energy and is altered. **Frequency**: Most common during the solar maximum and during the declining phase, but can occur anytime during the solar cycle. **Duration**: From a few hours to a few days
Solar radiation storm	Solar radiation storm events occur when the near-Earth environment is immersed in large quantities of charged particles, primarily protons, which are accelerated by solar activity (solar flares). **Frequency:** Most common during the solar maximum years, but can occur at any stage of the solar cycle. **Duration:** Proportional to the magnitude of the solar eruption and received spectrum – from hours to a week.
Radio black out (Solar Flares)	Radio blackouts are the consequence of solar flares causing enhanced electron densities that ionise the sun-side of the Earth- disrupting radio waves as they pass through this region. **Frequency:** Very common – minor events occurring on average 2,000 times each solar cycle, most frequent during the peak years of the solar cycle, almost absent during solar minimum. **Duration:** Minutes to hours.


esa
CORONAL MASS EJECTIONS
COSMIC RAYS
SOLAR CELL DEGRADATION
ASTRONAUT RADIATION
SOLAR ENERGETIC PROTONS
SINGLE EVENT UPSET
SOLAR FLARE RADIATION
RADIATION DAMAGE
ENERGETIC RADIATION BELT PARTICLES
ENHANCED IONOSPHERIC CURRENTS AND DISTURBANCES
NAVIGATION ERRORS
HF RADIO WAVE DISTURBANCE
CREW AND PASSENGERS RADIATION
SIGNAL SCINTILLATION
GEOMAGNETICALLY INDUCED CURRENTS IN POWER SYSTEMS
AURORA AND OTHER ATMOSPHERIC EFFECTS
DISTURBED RECEPTION
INDUCED GEOELECTRIC FIELD AND CURRENT
DECREASED DIRECTIONAL DRILLING ACCURACY


Cosmic Rays
Energetic Radiation Belt Particles
Coronal Mass Ejections
Astronaut Radiation
Solar Cell Damage
Solar Energetic Protons
Electrostatic Charging
Magnetic Attitude Control
Enhanced Spacecraft Drag
Solar Flare Radiation
Enhanced Ionospheric Currents and Disturbances
Crew and Passenger Radiation
Navigation Errors
Aurora and other Atmospheric Effects
HF Radio Wave Disturbance
Geomagnetically induced Currents in Power Systems
Signal Scintillation
Disturbed Reception
Pipeline Corrosion
Induced Geoelectric Field and Current

Space Weather

- Carrington event (1859)
  - extreme aurora visible in the Caribbean, Africa
  - telegraph wires overloaded, fires, shocks, etc.

- SC 22 flare (1989, quite small)
  - auroras in Texas, blackout in Quebec
  - satellites failing, people panicking over WW3

- 2012 near miss, Carrington-sized

- we cannot really predict them

Space Weather

Modern society is totally dependent upon energy networks, and a repeat of the Carrington Event – a solar storm in 1859 that severely impacted the worldwide telegraph infrastructure – would have even more extreme consequences today

As a result of increased dependency on the systems that would be affected, with estimated losses of up to $2 trillion in the US alone

Not IF, but WHEN, with a similar level (or worse) event likely within the next *50 years*.

Contingency plans? Not yet. Duck and hope for the best.

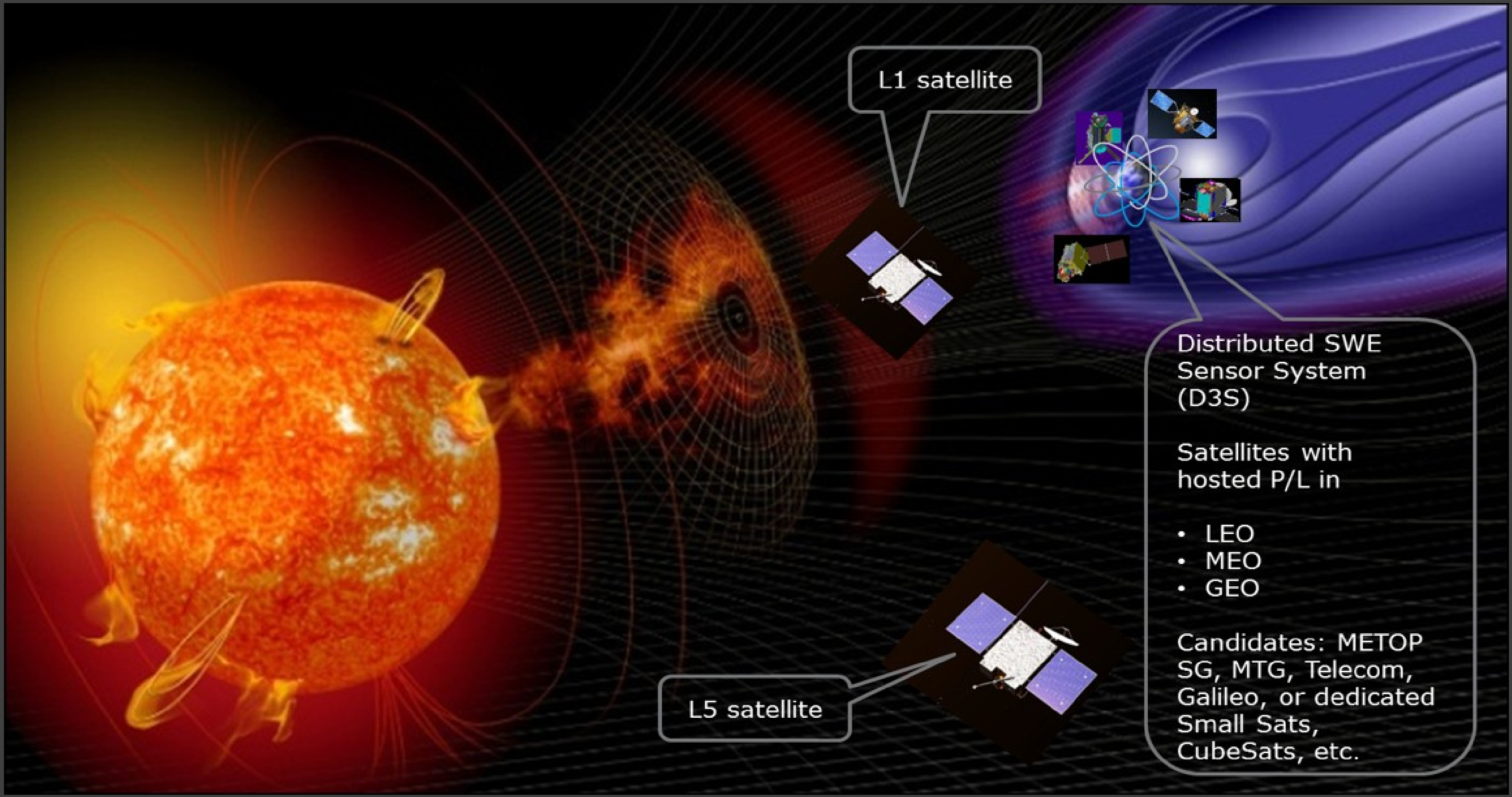
L1-L5 ESA Project

The L1 point is “located in the solar wind “upstream” from Earth, so measurements at L1 provide information about the space weather coming toward Earth”.

The L5 point, “located 60 degrees behind Earth, close to its orbit, will provide a way to monitor Earth-oriented coronal mass ejections (CMEs) from the 'side' so as to give more precise estimates of the speed and direction of the CME”.

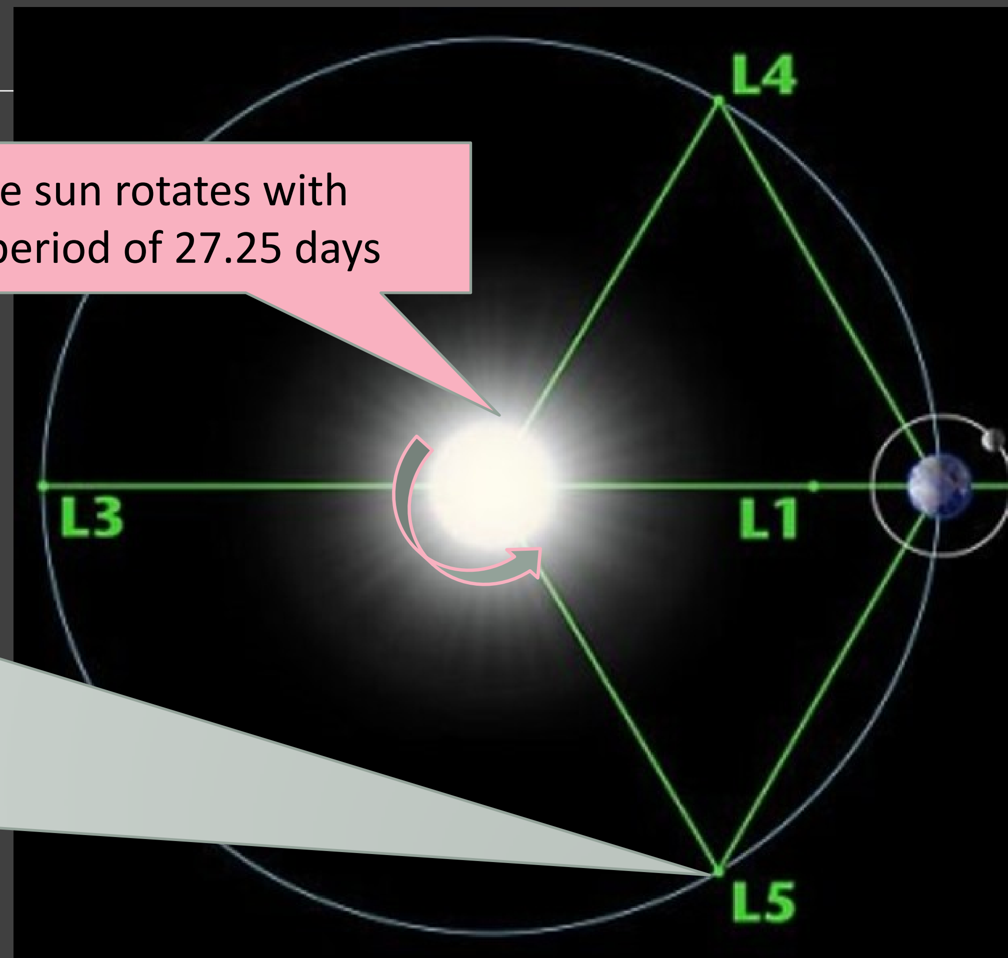
The primary objective of the L1 mission is “**to provide in-situ observations** of the interplanetary medium, including ***solar wind speed***, ***density***, ***temperature*** and ***dynamic pressure***, as well as characteristics of the charged particle environment and the direction and strength of the Interplanetary Magnetic Field (IMF). The L1 mission will also monitor the solar disc and solar corona and measure solar energetic particles that may be associated with solar flares and the onset of coronal mass ejections”.

The L5 mission objective is “to **complement measurements** made from L1 by providing a view of the Sun away from the direct Sun-Earth line. This gives visibility of the propagation of plasma clouds emitted by the Sun toward Earth, as well as views of the solar disk before it rotates into view from Earth.


L1 satellite
Distributed SWE
Sensor System
(D3S)
Satellites with
hosted P/L in
• LEO
• MEO
• GEO
Candidates: METOP
SG, MTG, Telecom,
Galileo, or dedicated
Small Sats,
CubeSats, etc.
L5 satellite

Development of SWE L5:

- Solar corona monitoring
- Heliospheric imaging
- Solar disc magnetic field
- EUV imaging
- In-situ measurements:
  - solar wind
  - magnetic field
  - charged particles
  - hot plasma
- Mission phases in SSA-P3
  - A/B1
  - Readiness for B2/C/D



Geomagnetic Storms			Kp values* determined every 3 hours	Nr. of storm events when Kp level was met; (nr. of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required; false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms; long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)

* The K-index used to generate these messages is derived in real-time from the Boulder NOAA Magnetometer. The Boulder K-index, in most cases, approximates the Planetary Kp-index referenced in the NOAA Space Weather Scales. The Planetary Kp-index is not yet available in real-time.** For specific locations around the globe, use geomagnetic latitude to determine likely sightings

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5-minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2}. Based on this measure, but other physical measures are also considered. ** These events can last more than one day. *** High energy particle measurements (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

NOAA Space Weather Scale for Radio Blackouts[307]

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning occur for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on the sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on the sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on the sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

others

- Supernovas
- Gamma-ray burst

- our Sun will turn into red giant in about 5e9 years
- Milky Way will collide with Andromeda in 4e9 years
- Earth will become too hot in 1e9 years (billion)
- heat death of the universe in 1e100 years

- ALIENS!

Aliens

*If aliens do exist, theoretical physicist Dr. Michio Kaku posits, why would they want anything to do with us? It would be like a hunter talking to a squirrel, he suggests. Hollywood and **science fiction novels** have conditioned us for years to believe that aliens either want to hang out on our intellectual level and learn from us... or destroy us.*

*If alien life really does have the technology and know-how to make it all the way here, perhaps we should just play it cool and not assume that we are the top species in the universe. Mankind's biggest folly, Kaku suggests, might just be in its insistence that we are an **exceptional species**.*

- Arrival, Annihilation, Expanse, Stanislaw Lem…

Some other video sources

https://www.youtube.com/watch?v=itdYS9XF4a0&t=308s

https://www.youtube.com/watch?v=OfvkKBNup5A

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