# Satellites for Earth Science

# Agenda

- Making of a Satellite
  - How do they work?
  - How much do they cost, when can I get mine and why does it only last 15 years ?
  - What are some of the design considerations and testing processes ?
- Launch vehicles
- Why different orbits are used
- How Satellites are used in science and geology

# Satellite Types

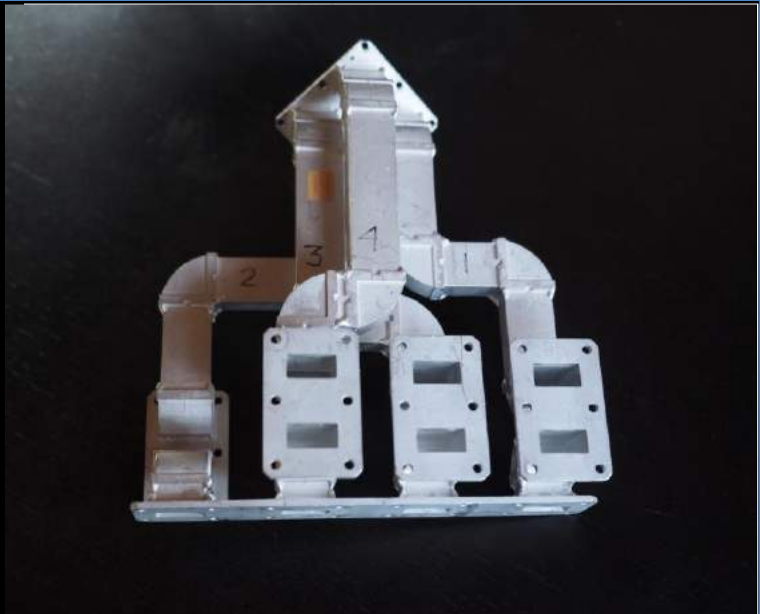
- Earth observation satellites
- Astronomical satellites
- Navigational satellites
- Communications satellites
- Reconnaissance (spy) satellites
- Biosatellites
- Tether Satellites

# How they work

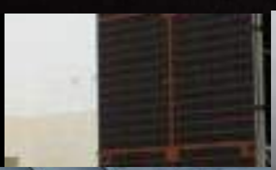
**Satellites receive (uplink) commands from ground stations through hi-gain antennas**

- Signals are reflected into feed horns and microwave energy is routed thru the satellite using waveguide

**Satellites transmit (downlink) signals to user**







# Who builds them

ASI - Agenzia Spaziale Italiana

CNES - Centre National d'Etudes Spatiales (France)

CNSA - China National Space Administration

CSA - Canadian Space Agency

DLR - German Aerospace Center

ESA - European Space Agency

ISRO - Indian Space Research Organization

JAXA - Japan Aerospace Exploration Agency

KARI - Korea Aerospace Research Institute

NASA - National Aeronautics and Space Administration

SSAU - State Space Agency of Ukraine

ROSCOSMOS - Russian Federal Space Agency

UK - Space Agency

## Companies to Call

Space Systems/Loral US

Boeing Defense, Space & Security

Lockheed Martin

Orbital ATK

Airbus Defence & Space Europe ( Fr/ Gr/ Sp/ UK)

Thales Alenia Space Europe ( Fr/ It)

JSC Information Satellite Systems Russia

Doosti Satellite (Iranian Space Agency)

# Modern Satellite Classes

- Micro satellites

  <500 kg (1,000 lb) generating <1 kw power

- Low power series

  1,000 kg (2,200 lb) generating 1-2 kw power

- Mid-size

  2,000 kg (4,400 lb) generating 3-8 kw power

- Large platform (communications and television)

  6,000+ kg (13,000+ lb)  with 6-15 kw power

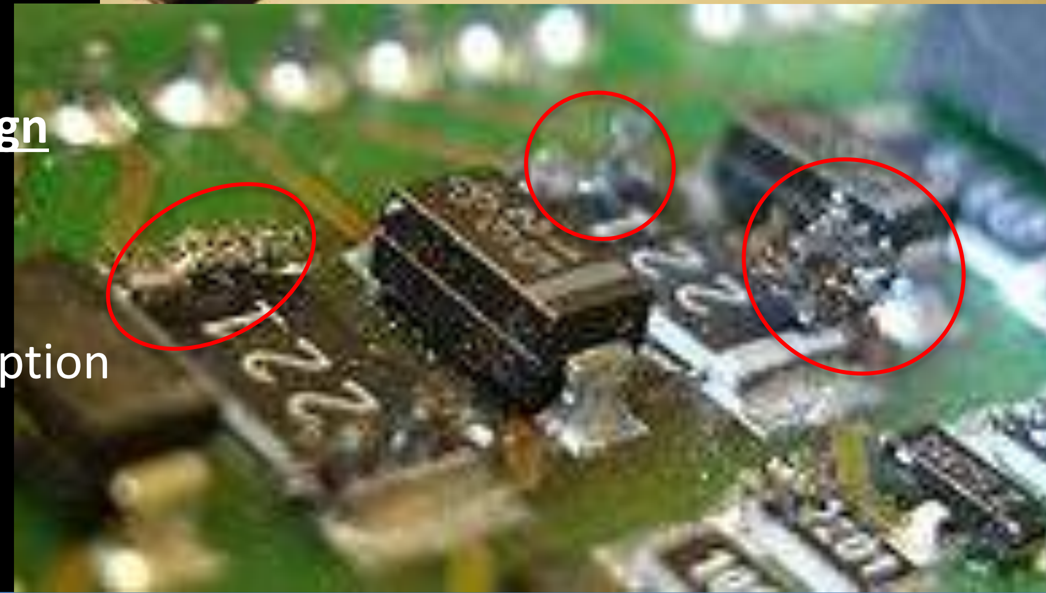
# Satellite Orders

- Every satellite order is custom …
- Contracts are (usually) for 2-4 satellites
- New satellite development & delivery is 24-36 mos
- Satellite cost range is $50M to >$300M each
- Contracts are signed with <u>completely</u> different companies for launch services @ $70-400M

# Some Design Considerations

**<u>Surviving launch and space</u>**

- Loads, Vibration & Acoustic
- Thermal, Radiation, Solar flares
- Micrometeoroids
- Prohibited material (e.g.- Tin plating)
- Grounding, Venting



**<u>The three unwritten rules s/c design</u>**

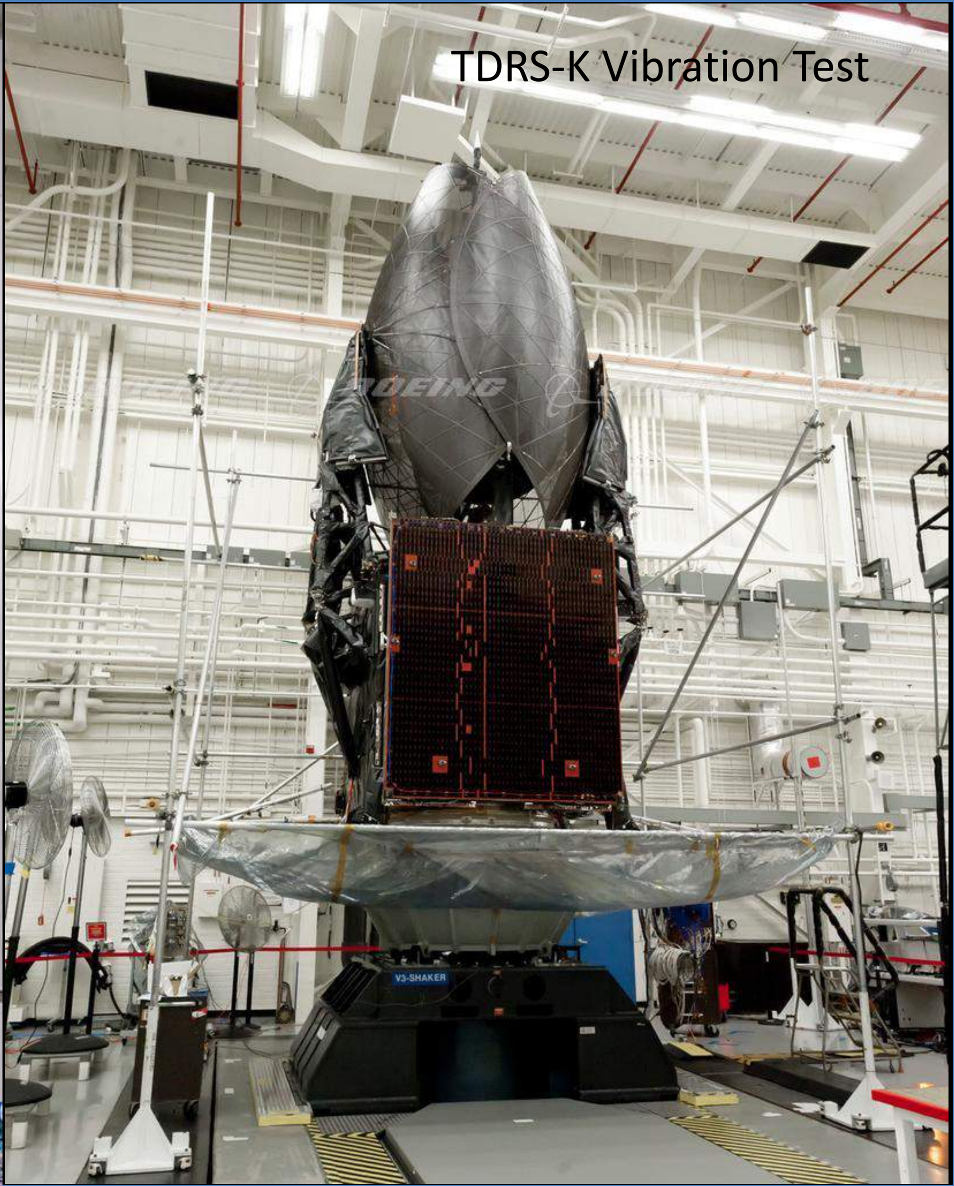
- You can't bring it back
- Mission Failure: not an option
- Missing a launch date: not an option

# Satellite Component Testing

# Antenna Pattern Testing

# Final Vibration Testing

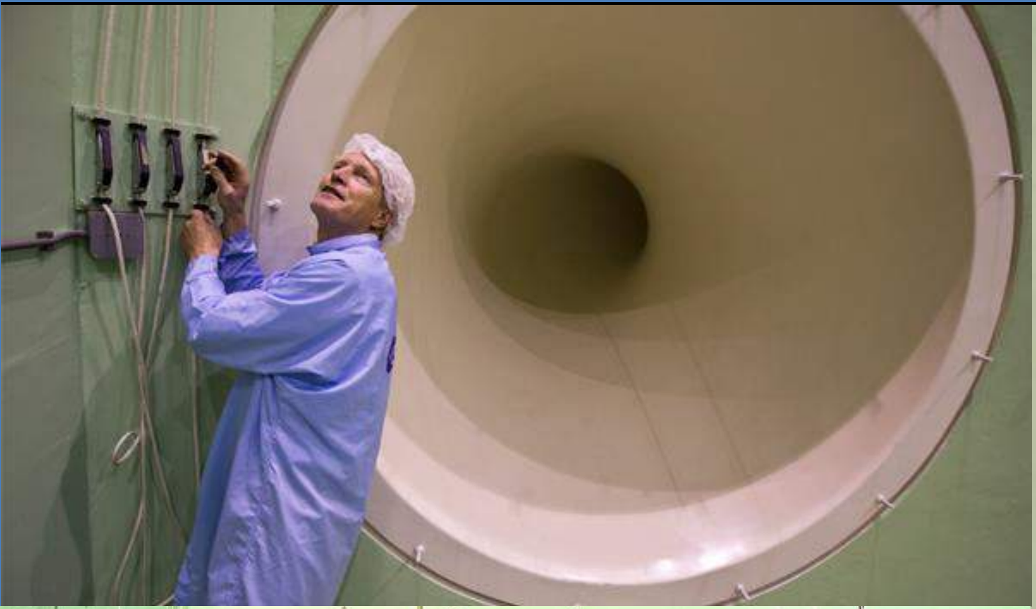
Eutelsat-8 Vibration Test



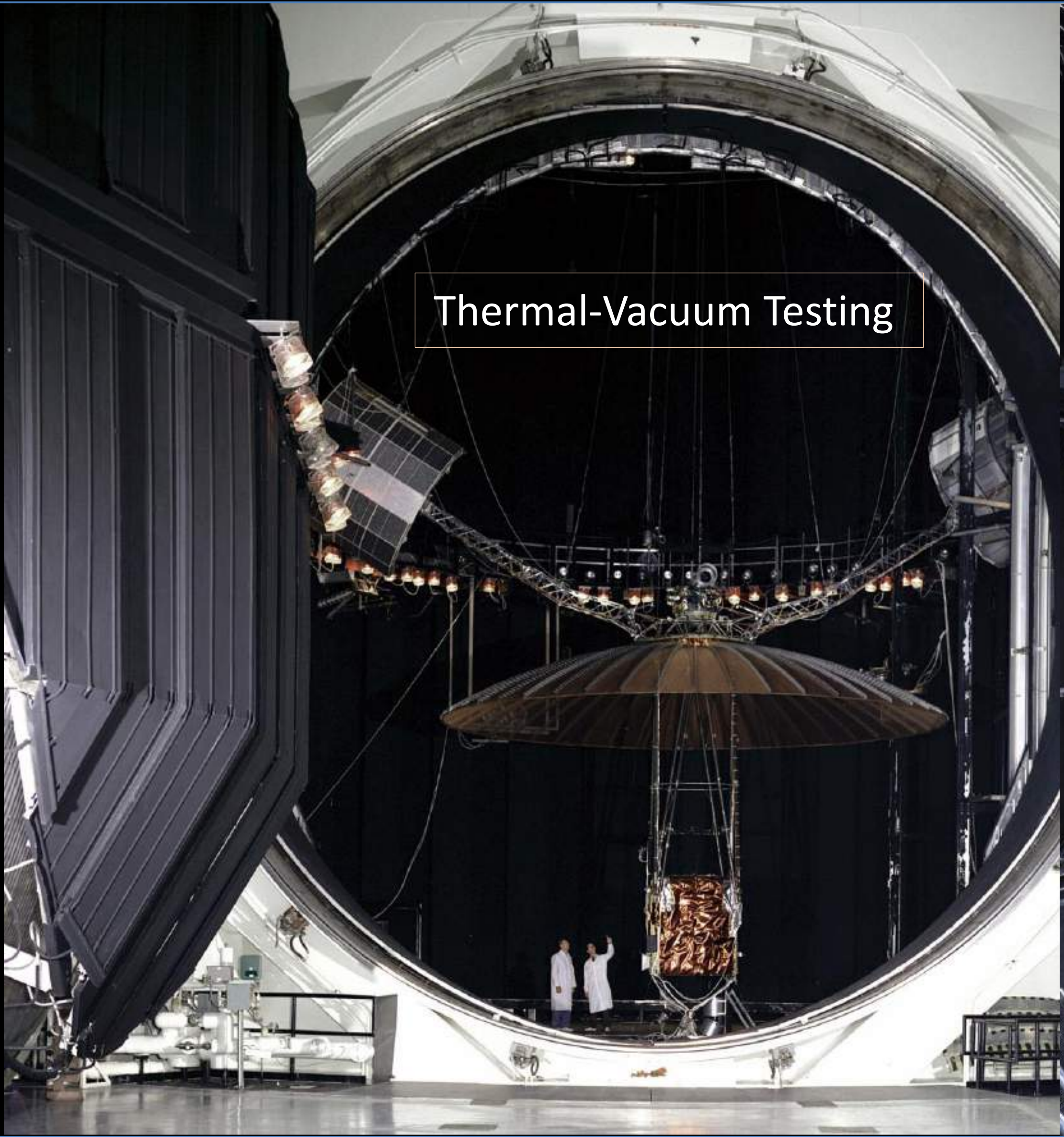

TDRS-K Vibration Test

# Full Scale Vibration Testing

# Acoustic Testing



# Satellite Thermal-Vacuum Testing




# Ready for Launch

- Satellites are shipped in large containers to the launch site and mated to the booster.
- A protective faring is installed and launch vehicle (LV) is moved to the launch pad.
- Just prior to launch, the satellite is powered up and is communicating via telemetry and command (T&C) antennas.
- During that period, the satellite manufacturer maintains constant communication (comm) with the satellite.
- When the launch fairing is blown-away, the T&C system is the primary means of comm during orbit raising, solar panel and antenna deployment.
- Initial On-orbit Testing (IOT) lasts several weeks wherein all systems are verified before turning over service to the customer.

LV Fairing

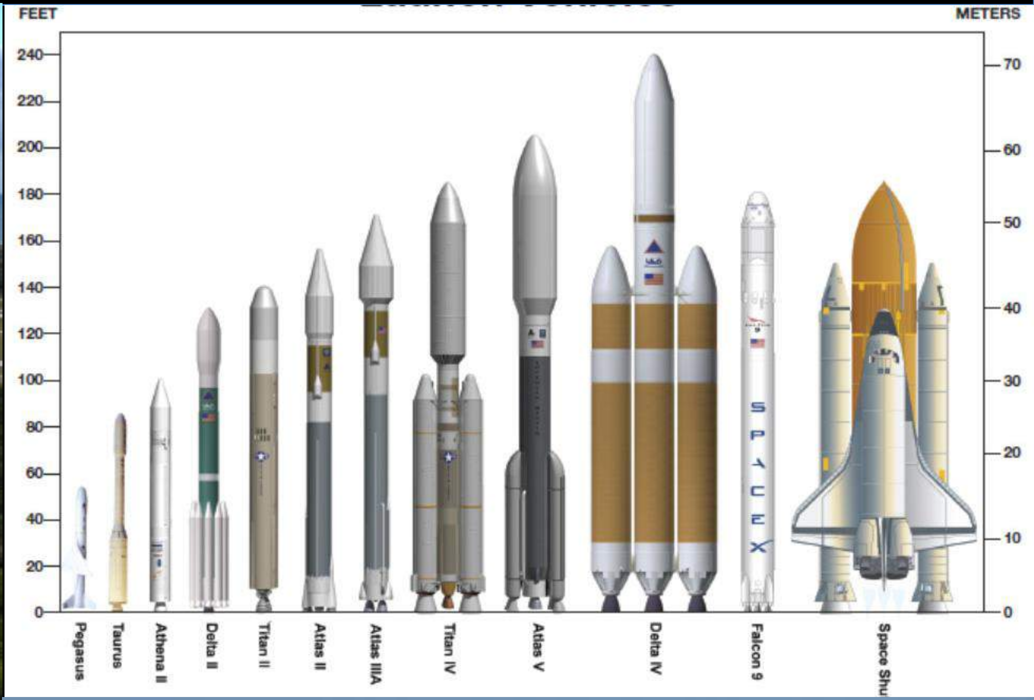

LV being moved to the launch pad

# Commercial Launchers – Sea Launch (US)

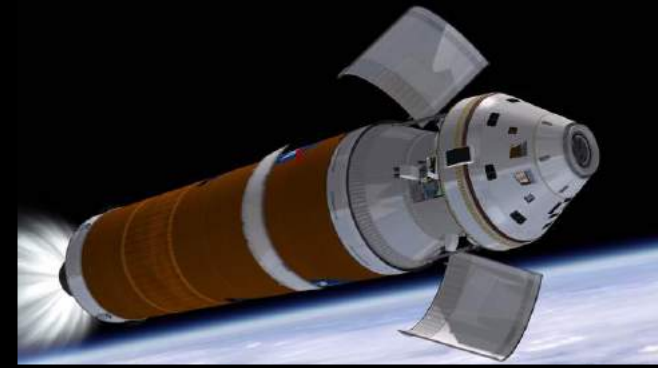

Geo-stationary lift capabilities are increased dramatically the closer you launch to the equator. This platform was operational from 1999-2014.

Oil Drilling Platform converted to mobile launch site

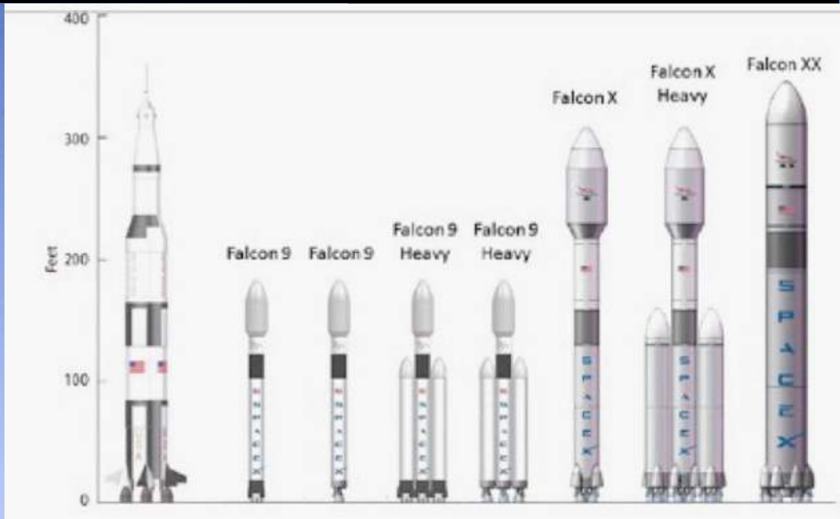
# Commercial Launchers – Atlas (US)


# Commercial Launchers – Delta (US)

# Commercial Launchers – SpaceX (US)




# Commercial Launchers – Ariane (France)



# Commercial Launchers – Proton (Russia)


# Where are they launched to?


**High Earth orbit (HEO):** Orbits at *or above* the altitude of 22,240 miles; at this particular altitude the orbital period is 24 hours.

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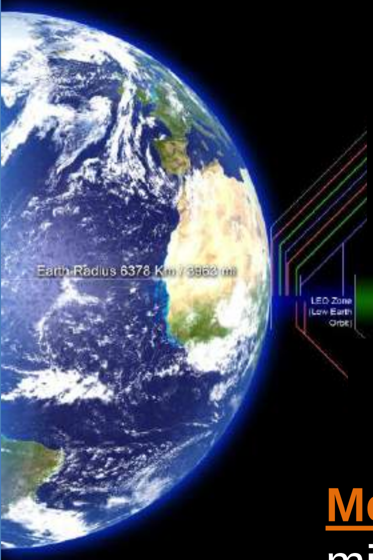
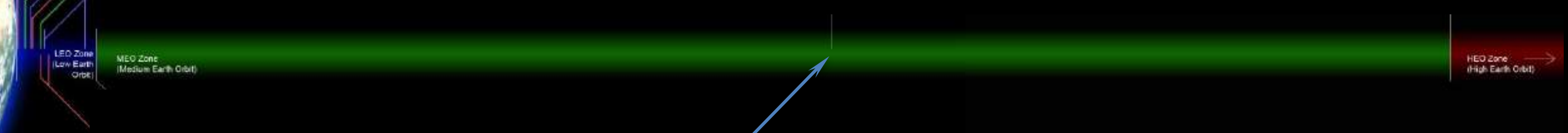


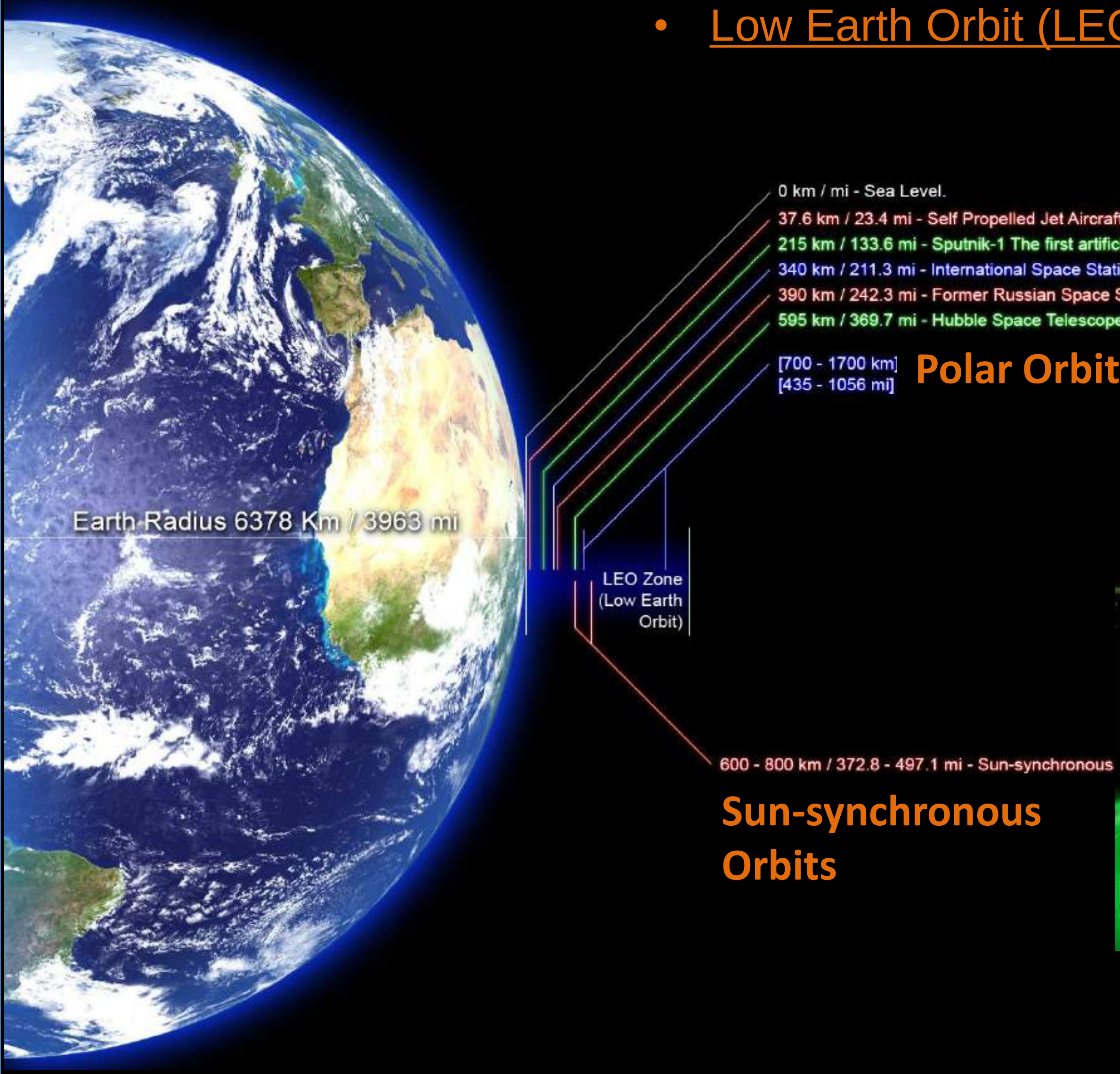
**Low Earth orbit (LEO):** Geocentric orbits with altitudes up to 1,240 miles with an orbital period of ~90 minutes.

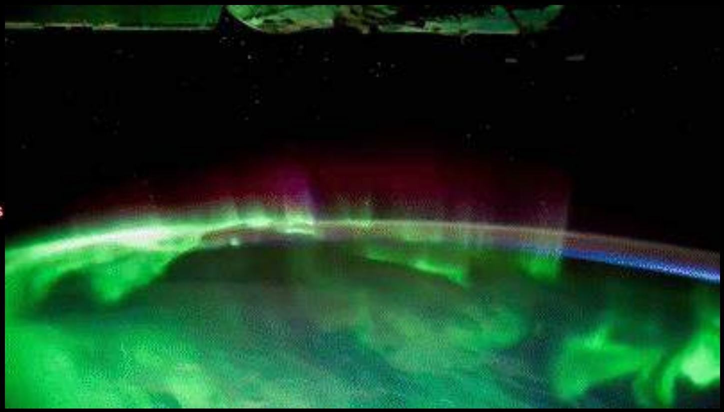



**Medium Earth orbit (MEO):** Geocentric orbits from 1,240 - 22,240 miles. These are most commonly used for GPS (~12,700 miles) with an orbital period of 12 hours.

# Low Earth Orbit (LEO)

- Low Earth Orbit (LEO): orbital period ~90min

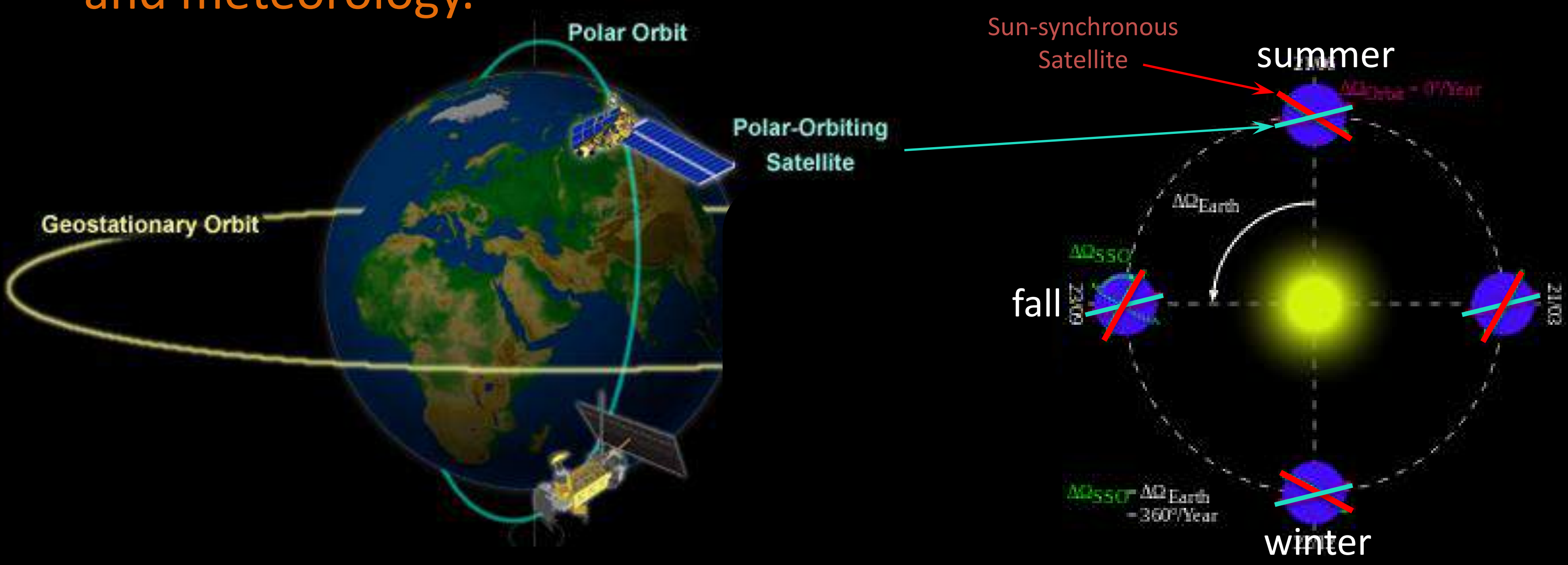


ISS footage in LEO of the northern lights

# LEO - Polar Orbits

- Polar orbit: These satellites orbit the Earth about the poles or slightly off-axis.
    - Sun-synchronous orbit (SSO): A special polar orbit, these satellites pass over any given point of the earths' surface at the same local solar time.
- These orbits are useful for imaging, mapping, earth studies, and meteorology.



# Landsat 8 (USGS)

- Launched into SSO Feb 2013; it is the eighth satellite in the Landsat program and the seventh to reach orbit successfully.
- Originally called the Landsat Data Continuity Mission (LDCM), it is collaboration between NASA and the United States Geological Survey (USGS).
- The USGS provides maintains ground systems and conducts on-going mission operations.
- Landsat 8 satellite images the entire Earth every 16 days in an 8-day offset from Landsat 7.
- Landsat 8 captures more than 700 scenes a day, an increase from the 250 scenes a day on Landsat 7.

# Other LEO Satellites


Terra/Aqua - Wildfire Monitoring

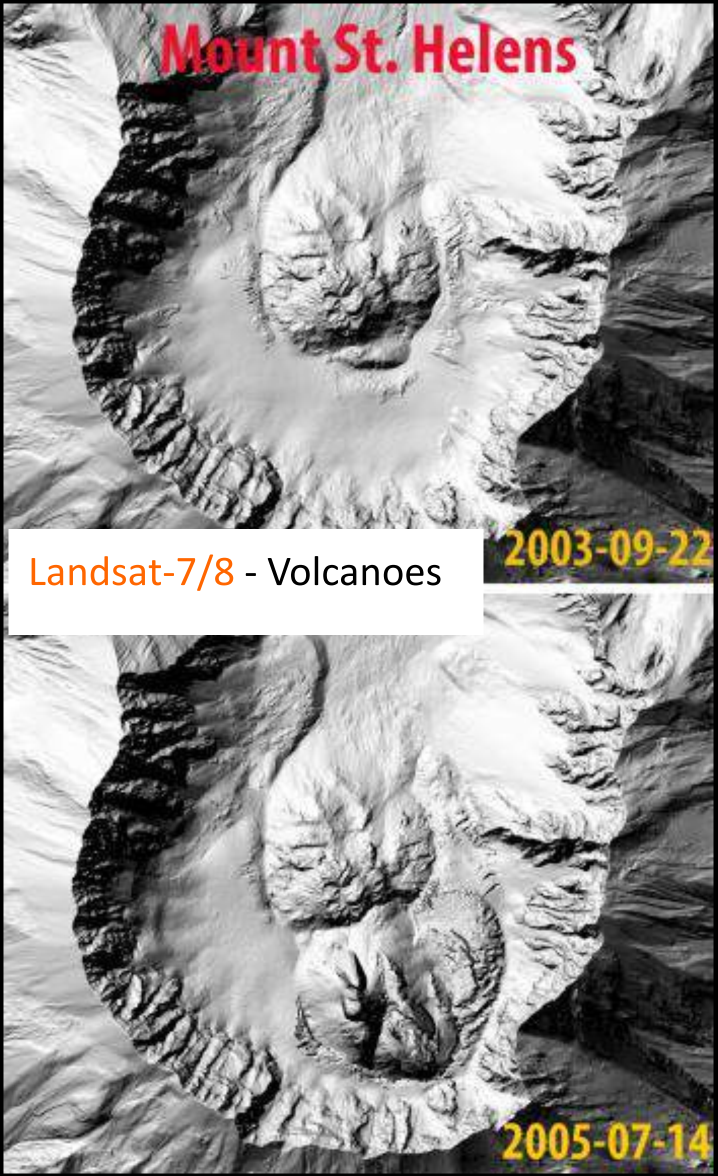
ICESat, LRO - Space-based Lidar

http://ssed.gsfc.nasa.gov/co2sounder/pdf/SpaceLidarXiaoliIeeeJSTAR5-29-2013.pdf

Jason-2/Aquarius - Ocean levels, salinity

Terra/TRMM - River mapping, rainfall

https://servirglobal.net/Global/Articles/Article/1375/satellites-hold-secrets-to-understanding-remote-rivers




Landsat-7/8 - Volcanoes

# Climate Science


OCO-2 (Polar Orbit; July 2014) – dedicated to studying $CO_2$ and characterizing sources and sinks with high precision and resolution

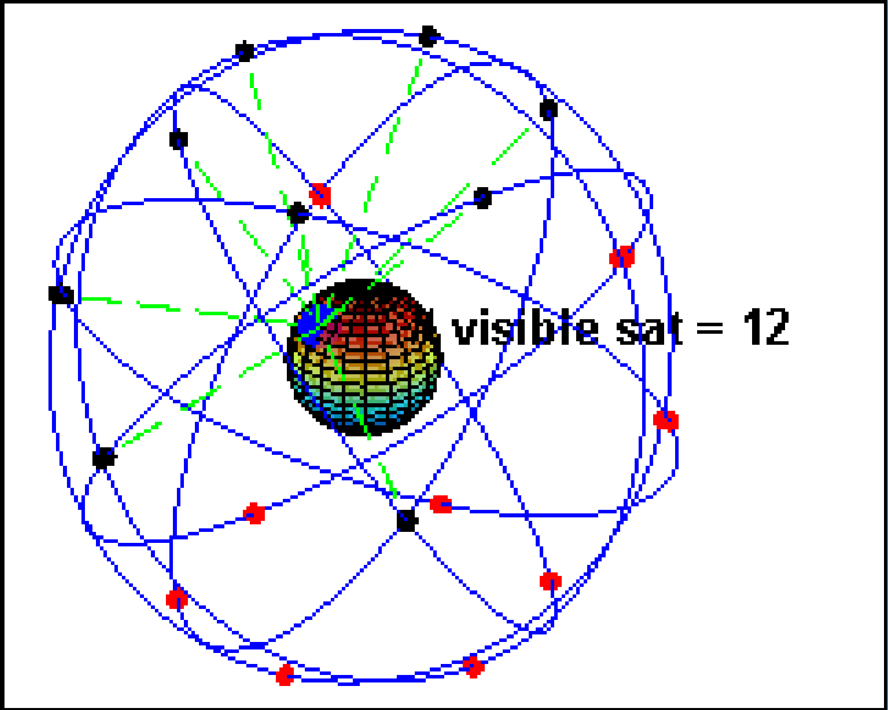
Gosat (LEO; Jan 2009) – monitors sources & sinks of $CO_2$ and methane

Aura (SSO; July 2004) – vertically resolved profiles for ozone and spatial sampling of $CO_2$

Aqua (LEO; May 2002) – measures water vapor and $CO_2$ circulation in the troposphere

# Medium Earth Orbit (MEO)


Global Positioning Satellites (GPS): are launched into a constellation with other GPS satellites on a Semi-synchronous orbit (SSO) at 12,550mi . . . meaning they orbit the earth in exactly 12 hours.

# Navigational Satellites

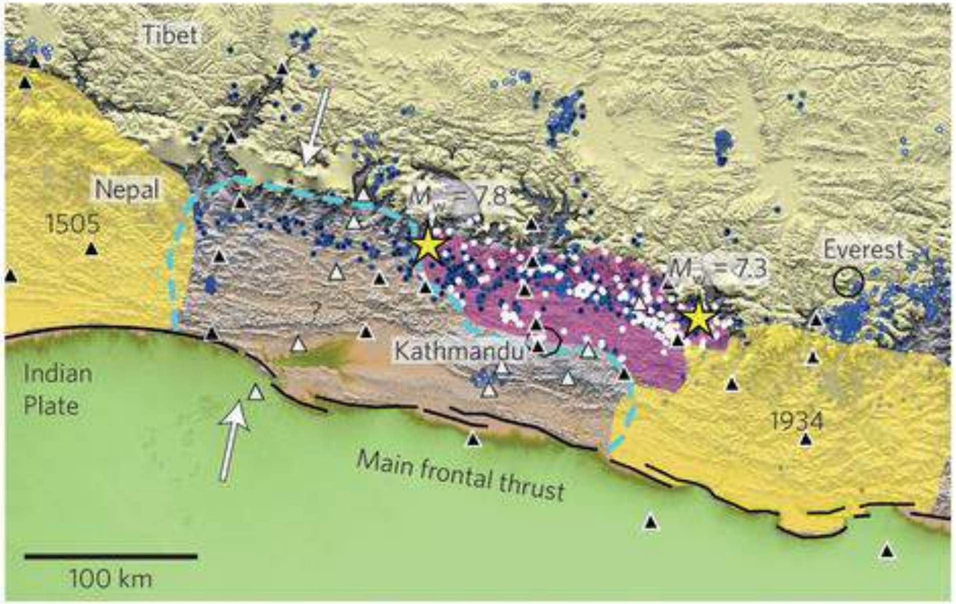
Navigational Satellites : there are several GPS systems in-orbit

- GPS - (US) 32 MEO satellites operational since 1978
- GLONASS - (Russia) 24 MEO satellites operational since 1995
- Galileo - (EU) 30 MEO satellites operational by 2020
- Compass - (China) 30 MEO satellites expanding into global service by 2020

# Continental Mega-thrust

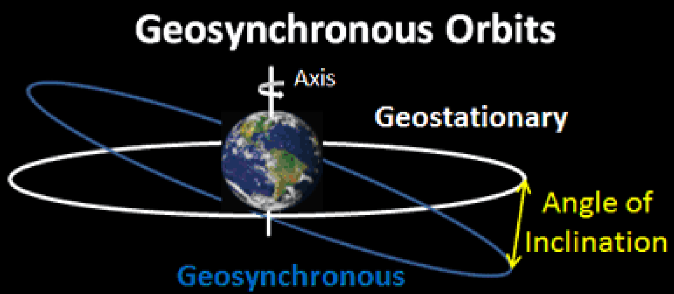
a

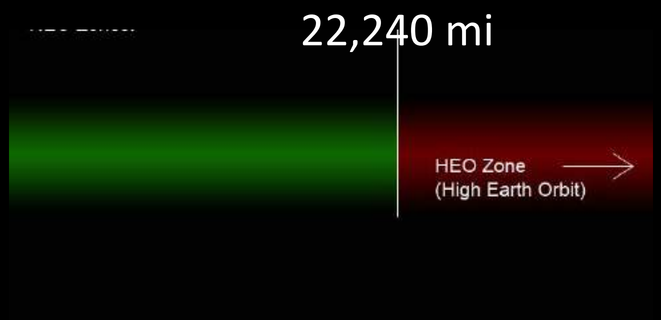

b




- Nepal (April 2015) – a magnitude 7.8 earthquake and $M_w$=7.3 aftershock was the first example of a large continental rupture to be captured by a GPS satellite network measuring ground motion.
  - Physical movement (shift) was measured using fixed GPS reference points
  - Relative plate movement was estimated at 3m while fixed GPS reference points moved only 1.5m. (The earth in this region is not done shaking!)

# High Earth Orbit (HEO)




Used for communication, television, and meteorological satellites

- At 22,240 miles, a GEO satellite orbits the earth once per day
- Geostationary orbit (GEO) is the most highly sought after and commercially utilized orbit
- Geostationary (circular) orbit stays exactly above the equator
- Geosynchronous orbit will swing north and south to cover more of the Earth's surface

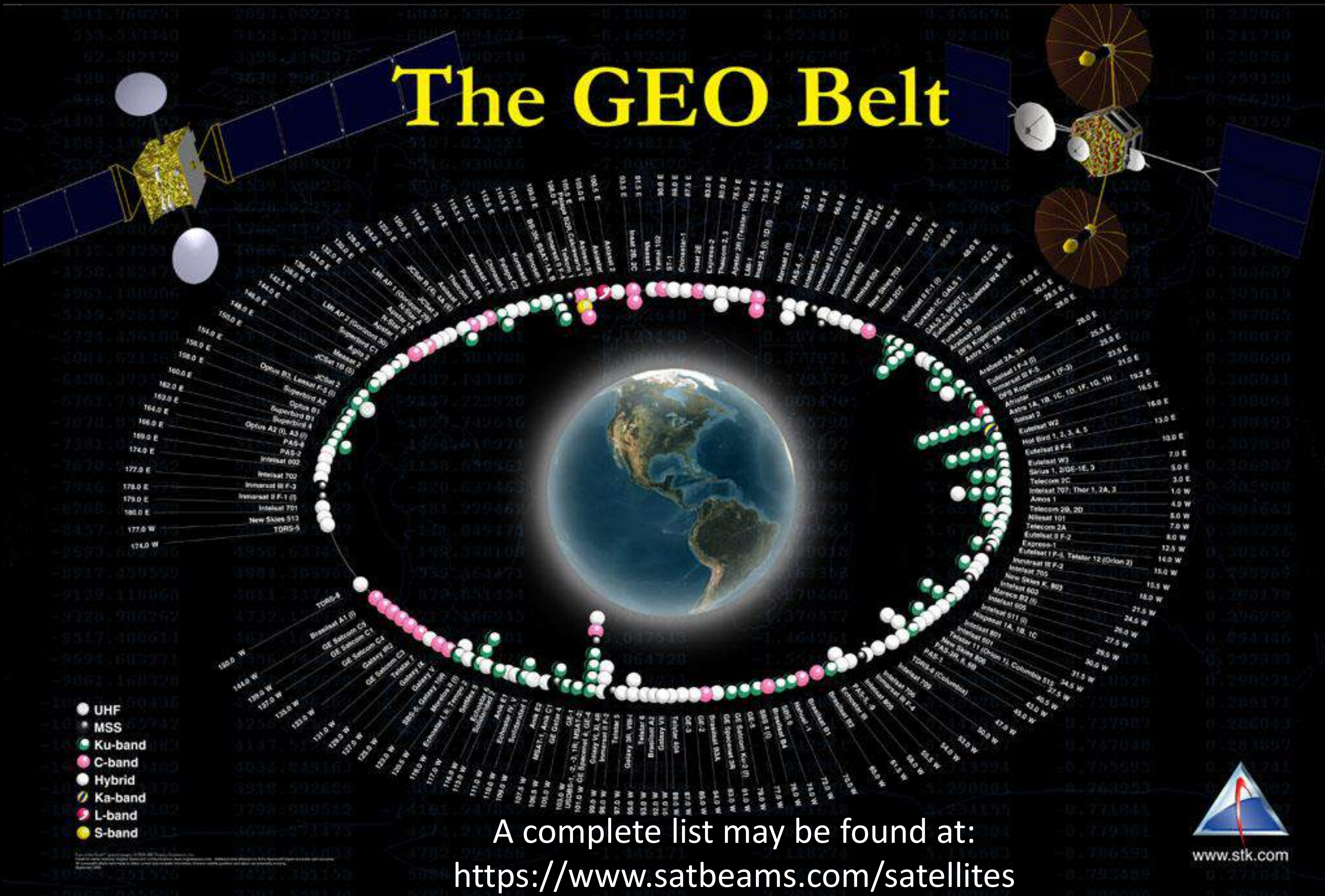
You can modify a satellite's orbit somewhat (e.g. – sun-synchronous). However, you cannot put a satellite into LEO then change it's orbit to HEO or vice versa.

# Geostationary Orbital Slots

- Satellites in these orbits must all occupy a single ring above the equator.
- Communications satellites must be spaced to avoid frequency interference/overlap.

  This means that there is a limited number of orbital slots available which has led to conflict between different countries wishing access to the same orbital slots (countries at the same longitude but differing latitudes).
- The International Telecommunication Union (ITU) allocates orbital slots and addresses disputes.
- Satellite operators may share slots with other spacecraft that they own & operate . . . or spacecraft from other operators. In these cases, station-keeping maneuvers are tightly coordinated.

# Geostationary Orbital Slots



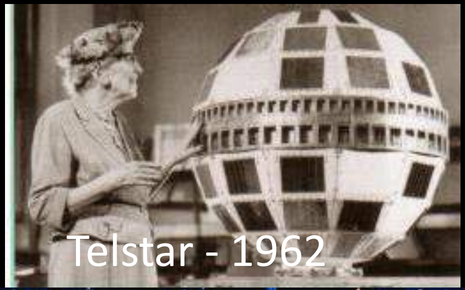

A complete list may be found at:
https://www.satbeams.com/satellites

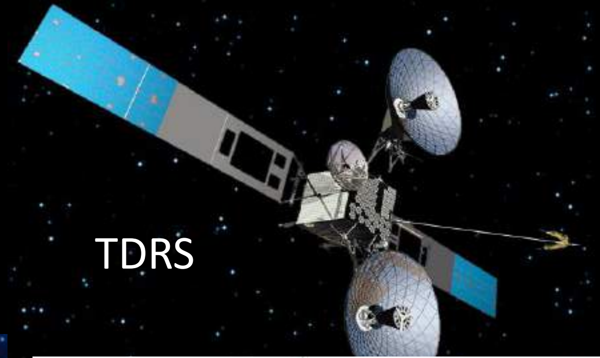
# Geostationary Orbital Slots

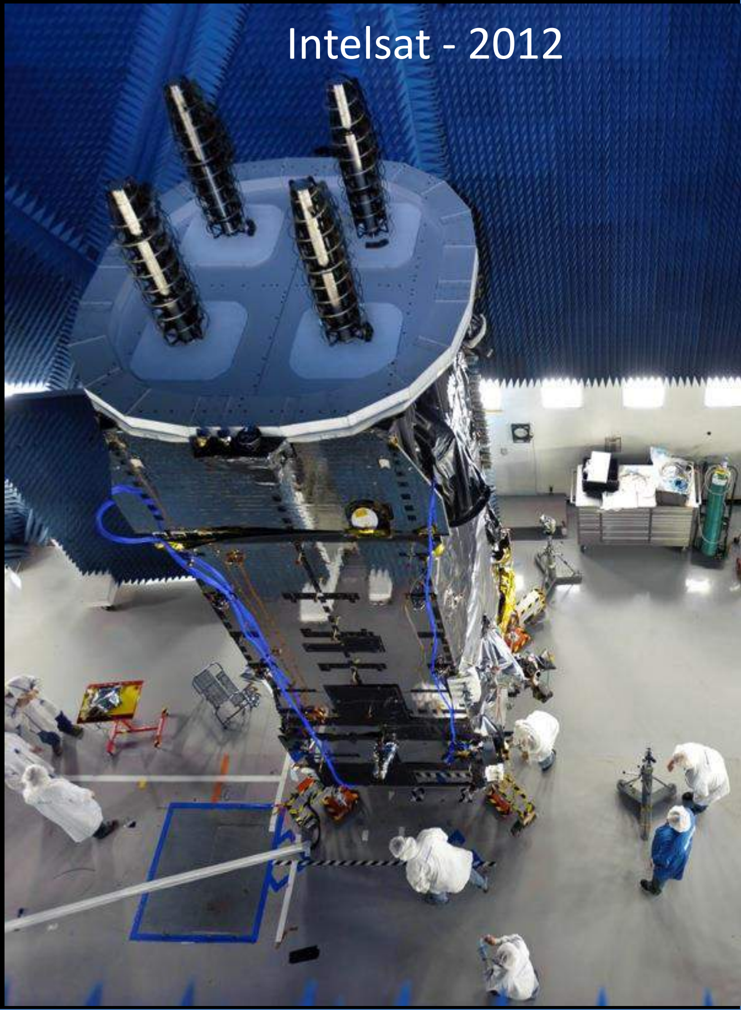
- Most geostationary satellites are kept within a very small operational window, about 0.5 degrees (200 miles) by firing onboard thrusters at the appropriate times to correct deviations also know as “wobble”.
  - The sun, moon and Earth’s flattening at it's poles . . . all cause some precession to occur. Additionally solar wind, sunlight and the unevenness of the Earth's equator all contribute to orbit instabilities.
- It requires added thrust to remain in a geostationary orbit due to this effect.
- ***Running out of stationkeeping fuel*** is a key reason all satellites are replaced. A modern geo-sat lifetime is 14-18 years.*
- A fuel reserve is held back - at the end of the satellite's life, it is boosted out of position and into the “geo-graveyard” so the orbital slot can be re-used.

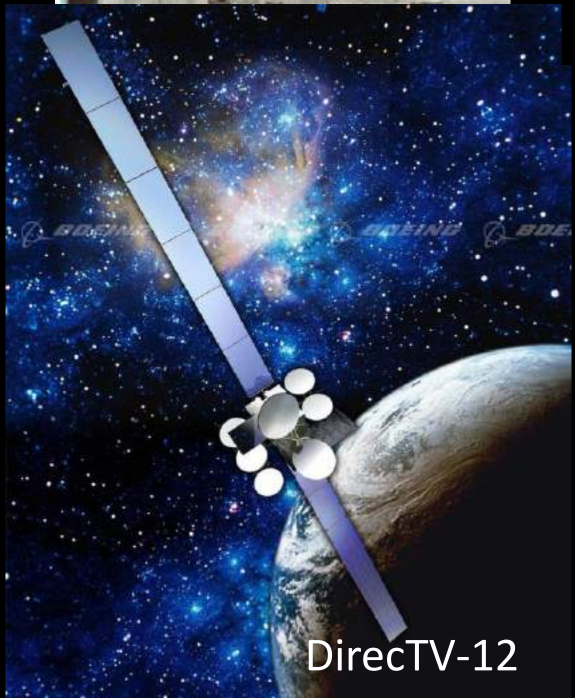
# Communication Satellites

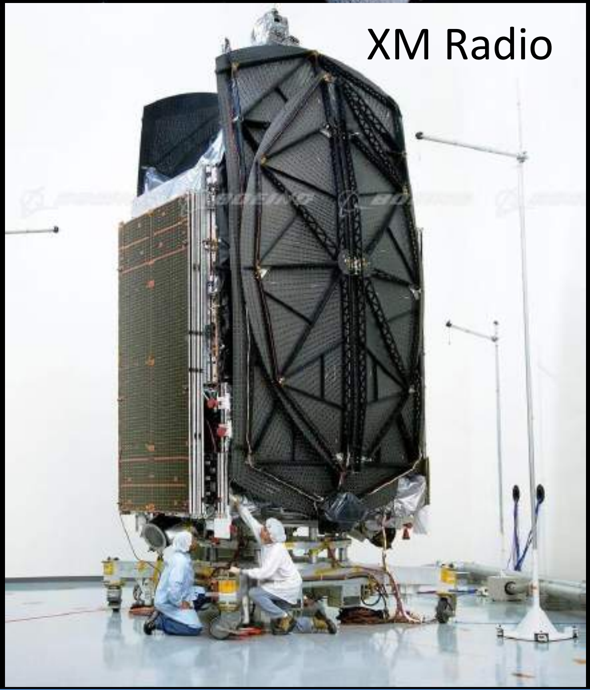
- **Communications satellites** are typically stationed in geostationary orbits for telecommunications – Intelsat, TDRS, DirecTV, XM Radio



# Astronomical Satellites

- **Astronomical satellites** are used for studying planetary geology, star and galaxy formation use *polar, sun-synchronous and Halo* orbits.

ames Webb Telescope (Halo-L2)

SWIFT - Gamma Ray Burst Mission (LEO)

Chandra X-Ray Observatory (Elliptical)

DSCOVR-1 (Halo-L1)

Gaia (Halo-L2)

WISE - Infrared Survey Explorer (SSO)

# Halo Orbits

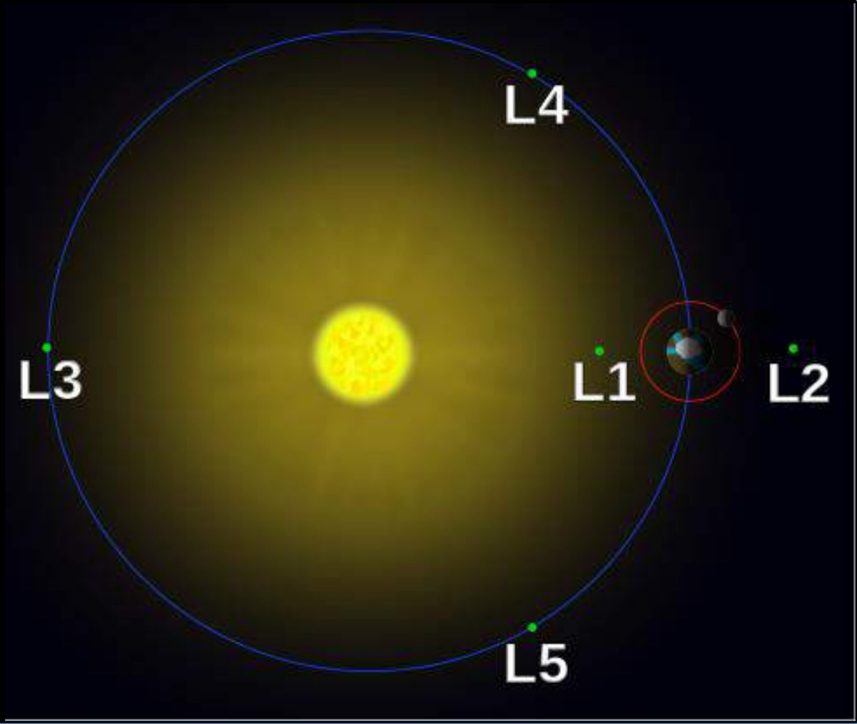
**Halo (Lissajous) Orbit:** Points L1 – L5 are stable orbits providing ideal locations for many astronomical missions.

**Satellites at L1** (932,000miles)

- Deep Space Climate Observatory (DSCOVR), studies the solar wind and its effects on Earth, capturing full-frame photos of the planet.

**Satellites at L2** (932,000miles)

- Gaia probe – ESA mission to make a 3-D map of the Milky Way galaxy
- James Webb Space Telescope (2018)
- WFIRST - Wide Field Infrared Survey Telescope (2024)

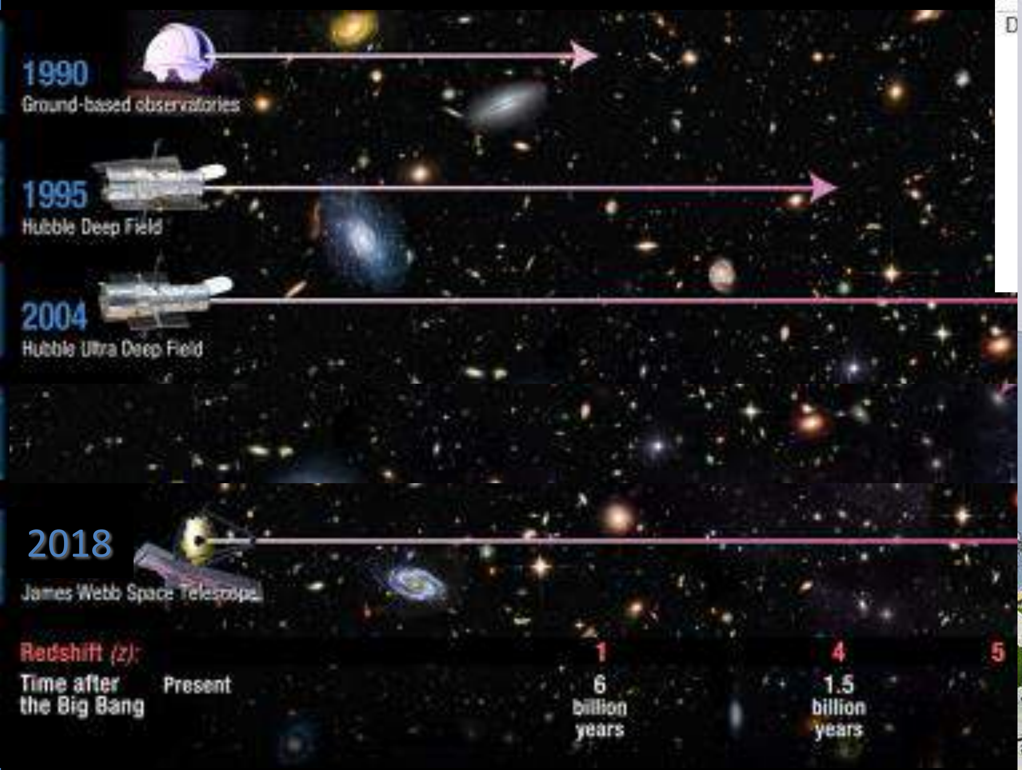


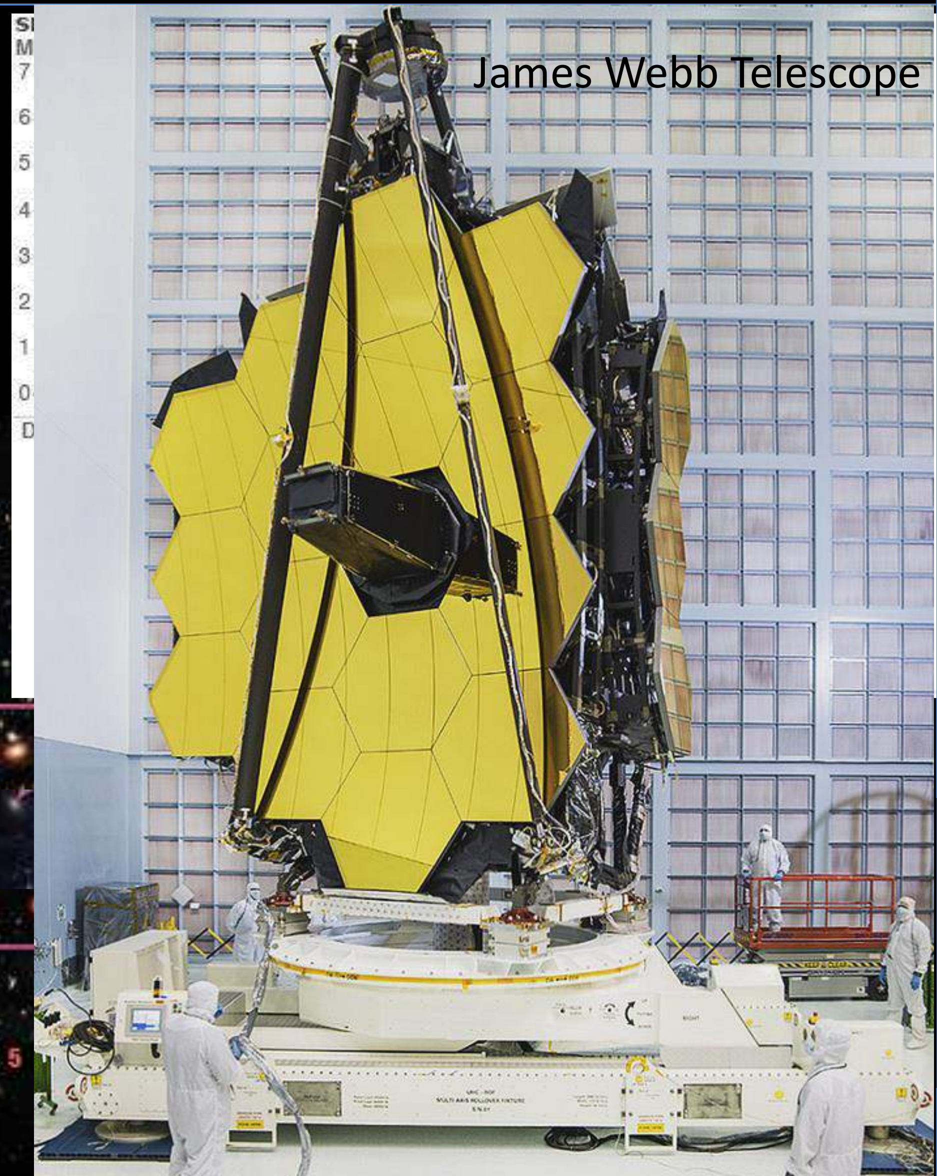
# Looking at the " Big Bang"

## James Webb Space Telescope (2018)

JWST mirror - 21'

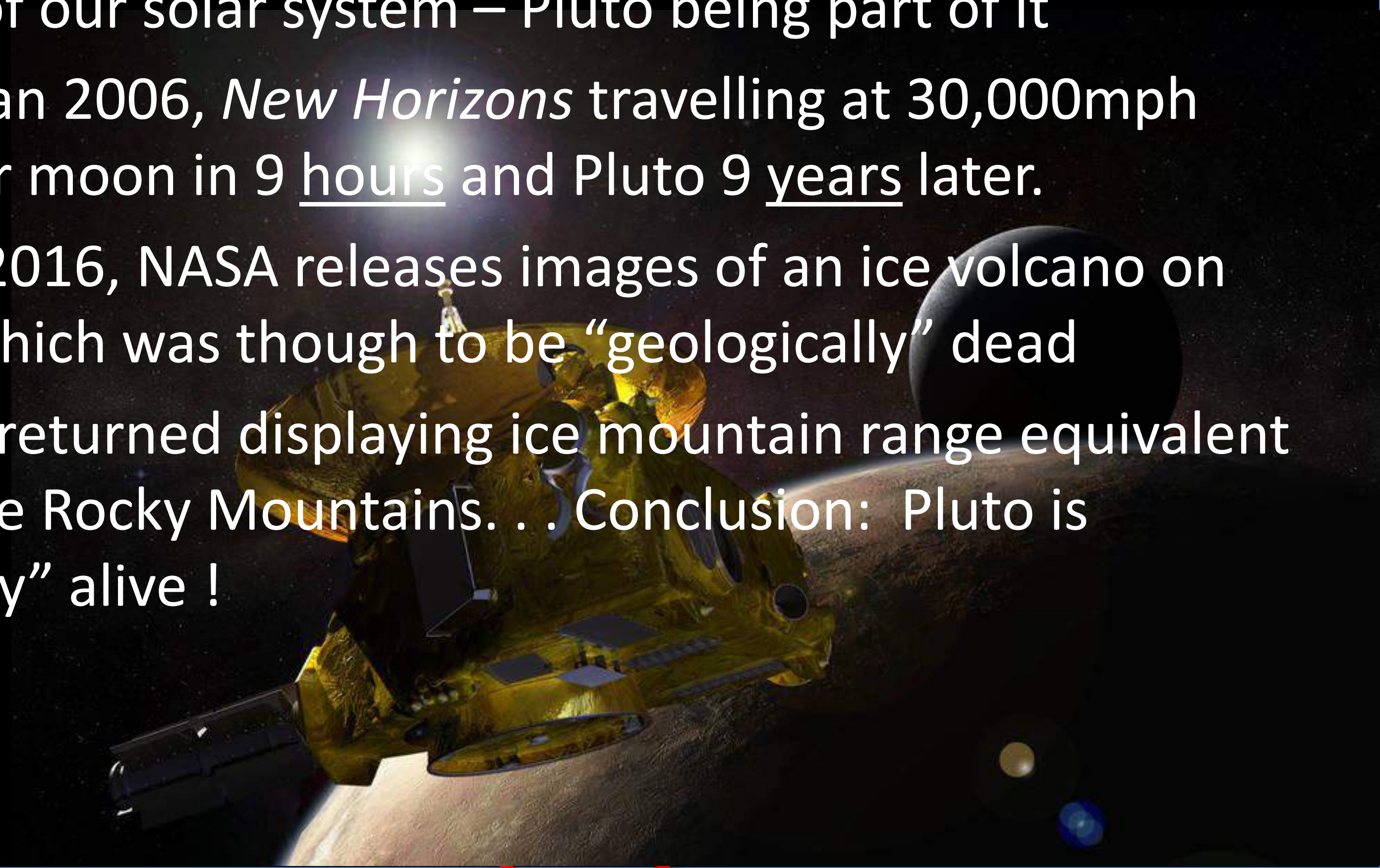
Hubble mirror – 8'



# Planetary Geology

- <u>**New Horizons**</u> – Pluto flyby & study of the Kuiper belt
  - The Kuiper belt is composed of "leftover objects" from the formation of our solar system – Pluto being part of it
  - Launched Jan 2006, *New Horizons* travelling at 30,000mph reached our moon in 9 <u>hours</u> and Pluto 9 <u>years</u> later.
  - In January 2016, NASA releases images of an ice volcano on Pluto . . . which was though to be "geologically" dead
  - Images are returned displaying ice mountain range equivalent in size to the Rocky Mountains. . . Conclusion: Pluto is "geologically" alive !



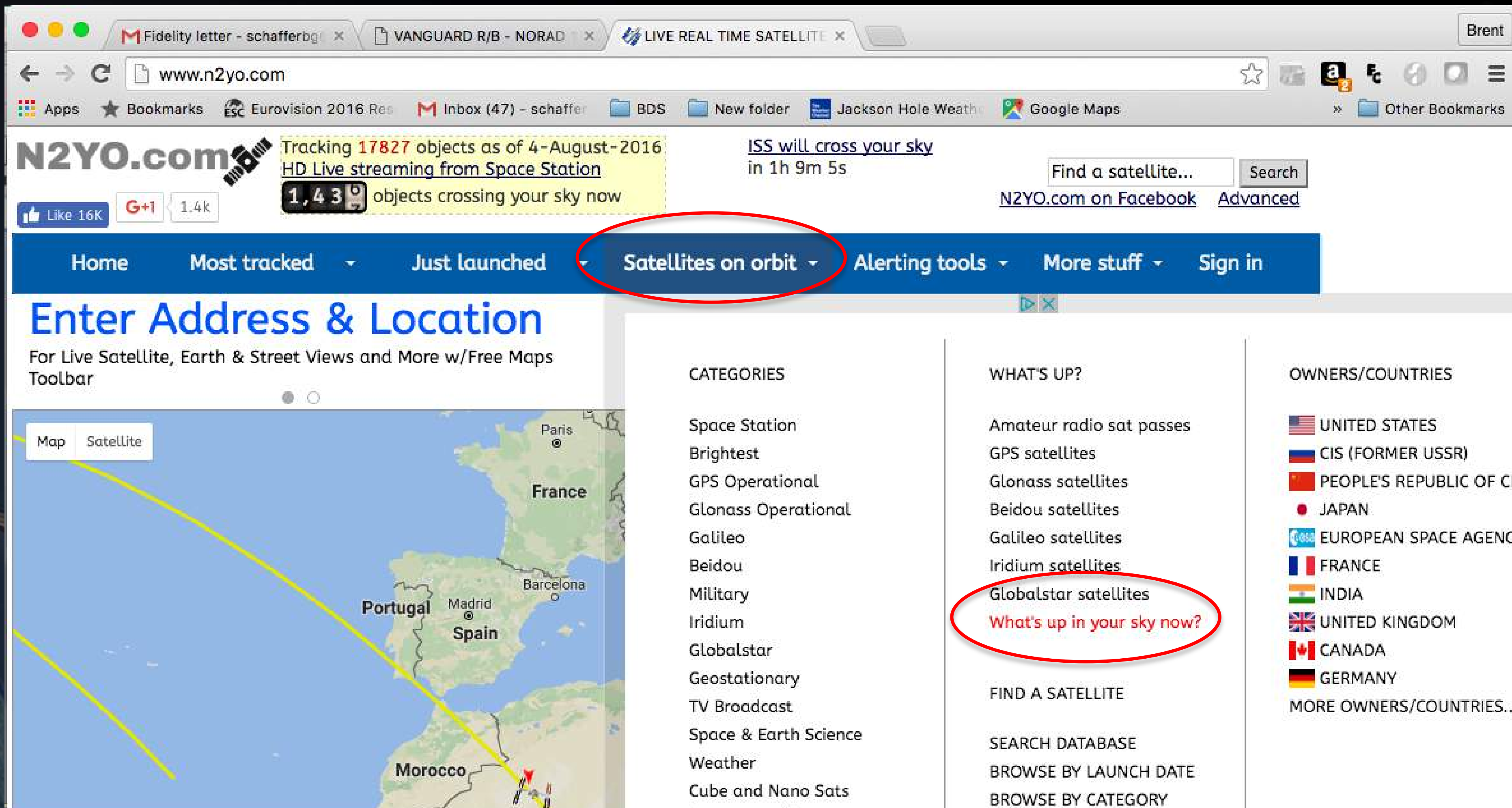
# Summary

- Satellites run out of fuel which limits their lifetime
- Orbits are mission specific: LEO - Landsats 7-8, MEO for Global Positioning Satellites, and GEO for communication satellites
- Satellites can weigh as much as 14,000 lbs and range in price from $50-300M+ . . . plus launch costs . . .
- Satellites are used extensively by geologists and scientists for research, imaging, GPS, map making, planetary geology, climate monitoring and more . . .

# Interesting Links

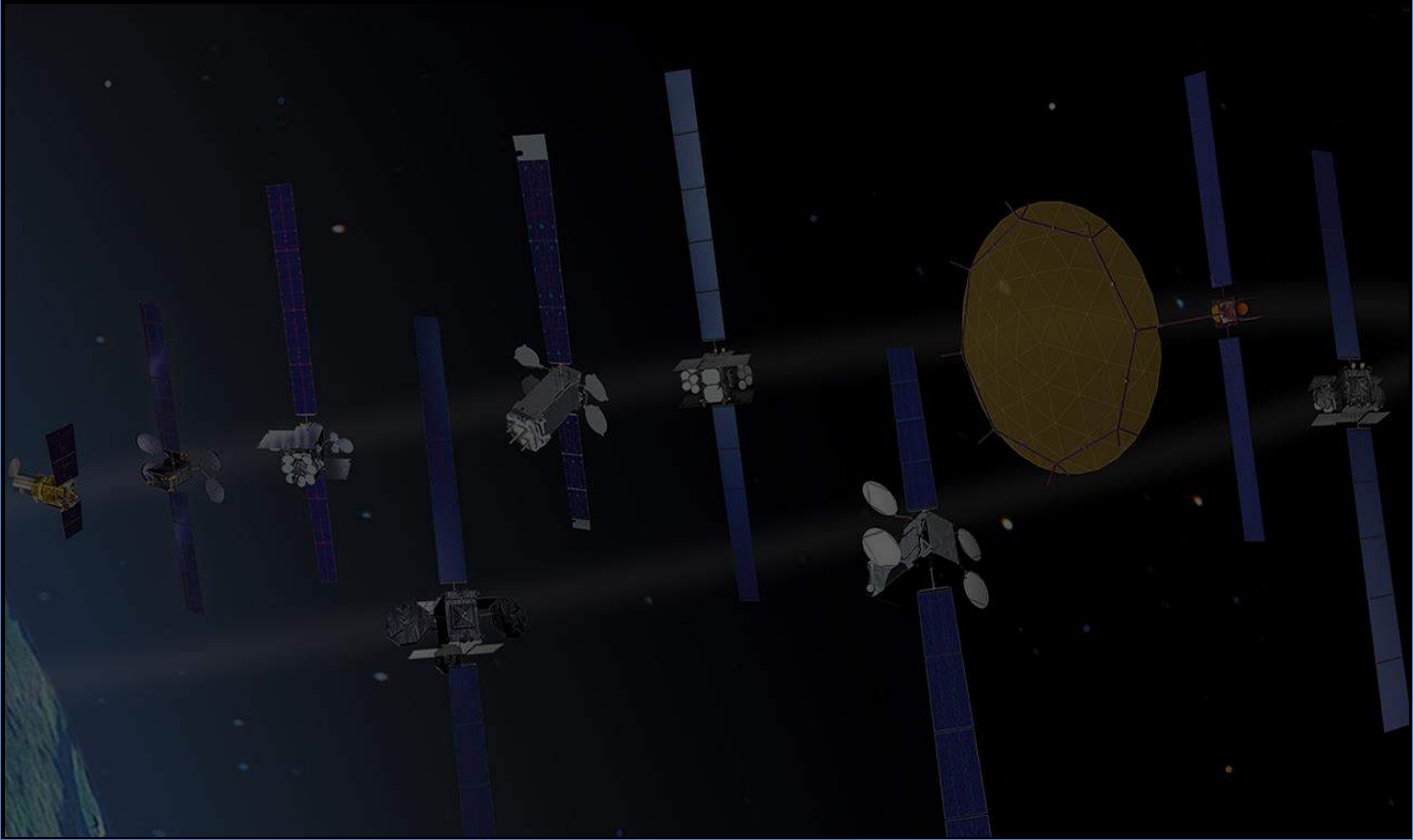
- Satellite tracking - What is up in the sky right now?
  - http://www.n2yo.com/ ; http://www.satview.org/
- Geo Satellites – complete listing, coverage (pattern) diagrams
  - https://www.satbeams.com/satellites
- Landsat 7-8 mapping
  - http://landsat.usgs.gov/
- NOAA Geostationary Satellite Server – weather images
  - http://www.goes.noaa.gov/
- Jackson Hole Weather – visible, IR, etc. satellite images
  - http://www.mountainweather.com/index.php?page=jackson_hole_forecast
- Climate Science
  - http://oco.jpl.nasa.gov/ ; https://co2.jpl.nasa.gov/
- Space-based Lidar
  - http://ssed.gsfc.nasa.gov/co2sounder/pdf/SpaceLidarXiaoliIeeeJSTAR5-29-2013.pdf
- River mapping
  - https://servirglobal.net/Global/Articles/Article/1375/satellites-hold-secrets-to-understanding-remote-rivers
- Tracking changes in Yellowstone's volcanic system
  - http://pubs.usgs.gov/fs/fs100-03/
- Global Fishing Watch – monitors fishing vessel activity
  - http://globalfishingwatch.org/

# N2YO.COM



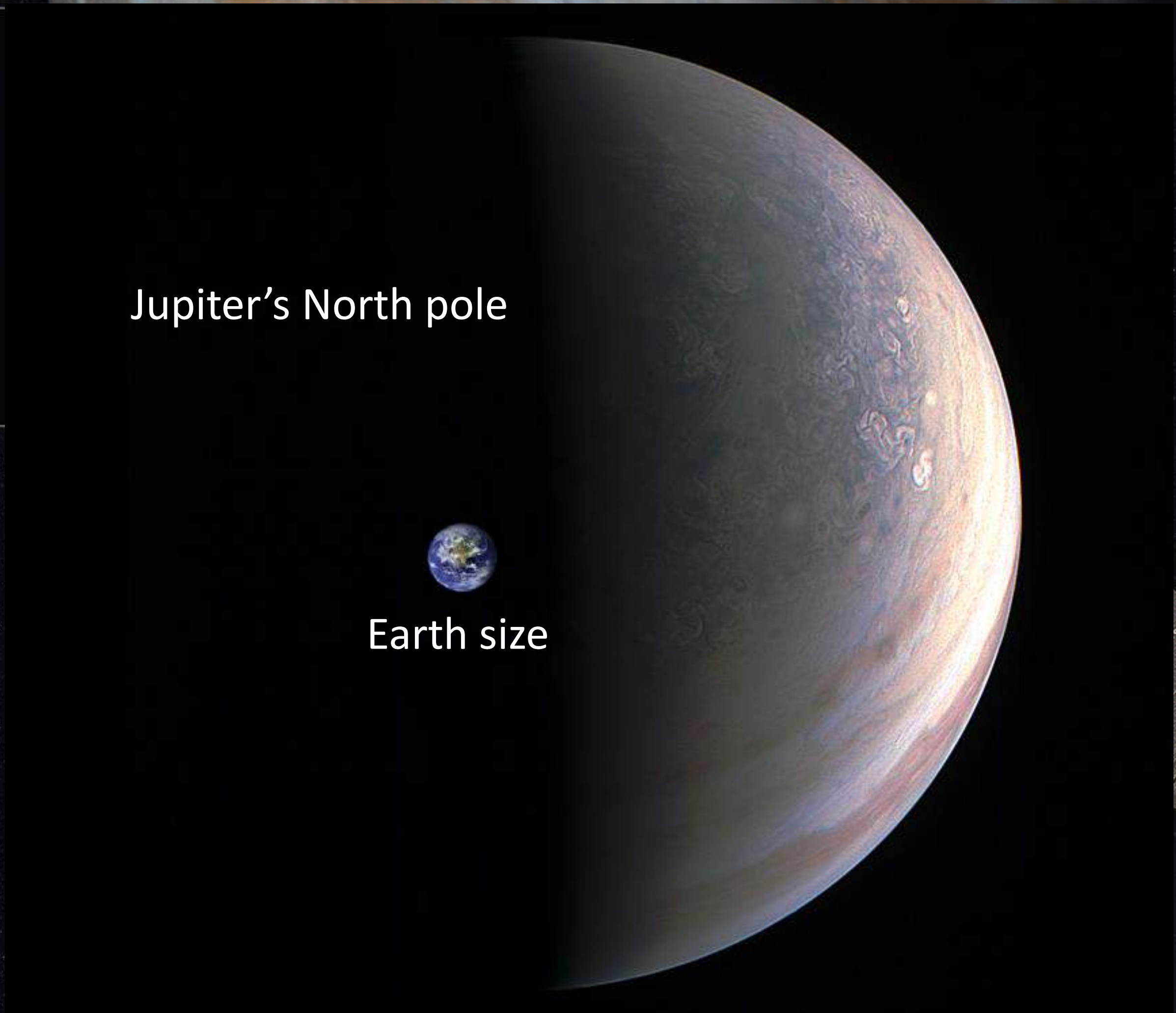
Fidelity letter - schafferbg
VANGUARD R/B - NORAD
LIVE REAL TIME SATELLITE
Brent
www.n2yo.com
Apps
Bookmarks
Eurovision 2016 Res
Inbox (47) - schaffer
BDS
New folder
Jackson Hole Weath
Google Maps
Other Bookmarks
N2YO.com
Tracking 17827 objects as of 4-August-2016
HD Live streaming from Space Station
1,43 objects crossing your sky now
ISS will cross your sky
in 1h 9m 5s
Find a satellite...
Search
N2YO.com on Facebook
Advanced
Like 16K
G+1
1.4k
Home
Most tracked
Just launched
Satellites on orbit
Alerting tools
More stuff
Sign in
Enter Address & Location
For Live Satellite, Earth & Street Views and More w/Free Maps Toolbar
Map
Satellite
Paris
France
Barcelona
Portugal
Madrid
Spain
Morocco
CATEGORIES
Space Station
Brightest
GPS Operational
Glonass Operational
Galileo
Beidou
Military
Iridium
Globalstar
Geostationary
TV Broadcast
Space & Earth Science
Weather
Cube and Nano Sats
WHAT'S UP?
Amateur radio sat passes
GPS satellites
Glonass satellites
Beidou satellites
Galileo satellites
Iridium satellites
Globalstar satellites
What's up in your sky now?
FIND A SATELLITE
SEARCH DATABASE
BROWSE BY LAUNCH DATE
BROWSE BY CATEGORY
OWNERS/COUNTRIES
UNITED STATES
CIS (FORMER USSR)
PEOPLE'S REPUBLIC OF CH
JAPAN
EUROPEAN SPACE AGENCY
FRANCE
INDIA
UNITED KINGDOM
CANADA
GERMANY
MORE OWNERS/COUNTRIES...

# Back-up



# Planetary Geology


National Aeronautics and Space Administration




**Juno’s Instruments**

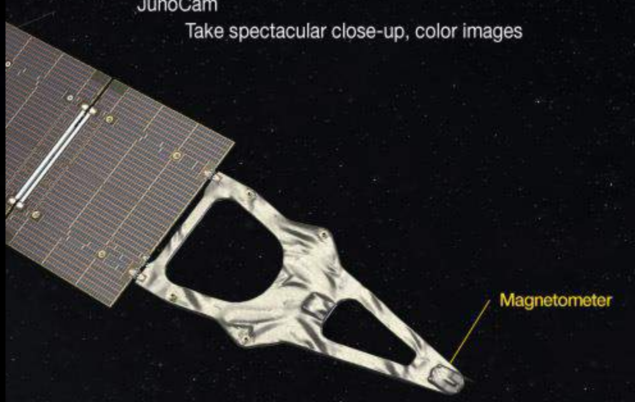
Gravity Science and Magnetometers
: Study Jupiter’s deep structure by mapping the planet’s gravity field and magnetic field

Microwave Radiometer
: Probe Jupiter’s deep atmosphere and measure how much water (and hence oxygen) is there

JEDI, JADE and Waves
: Sample electric fields, plasma waves and particles around Jupiter to determine how the magnetic field is connected to the atmosphere, and especially the auroras (northern and southern lights)

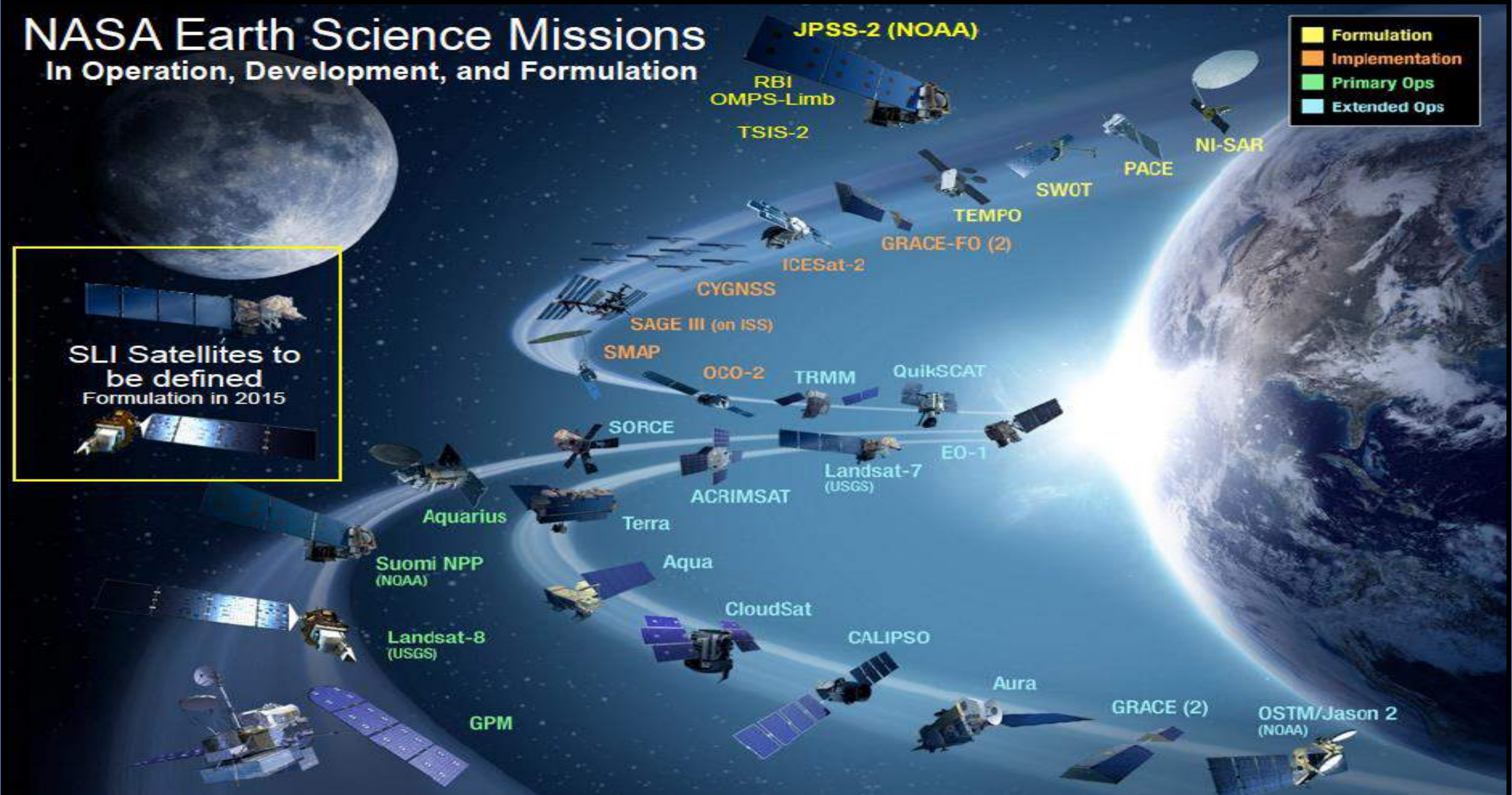
UVS and JIRAM
: Using ultraviolet and infrared cameras, take images of the atmosphere and auroras, including chemical fingerprints of the gases present

JunoCam
: Take spectacular close-up, color images



# Earth Observation Satellites

**Observation satellites** are used in geophysics, environmental monitoring, meteorology, map making etc. are typically stationed in *polar* or *sun-synchronous* orbits.

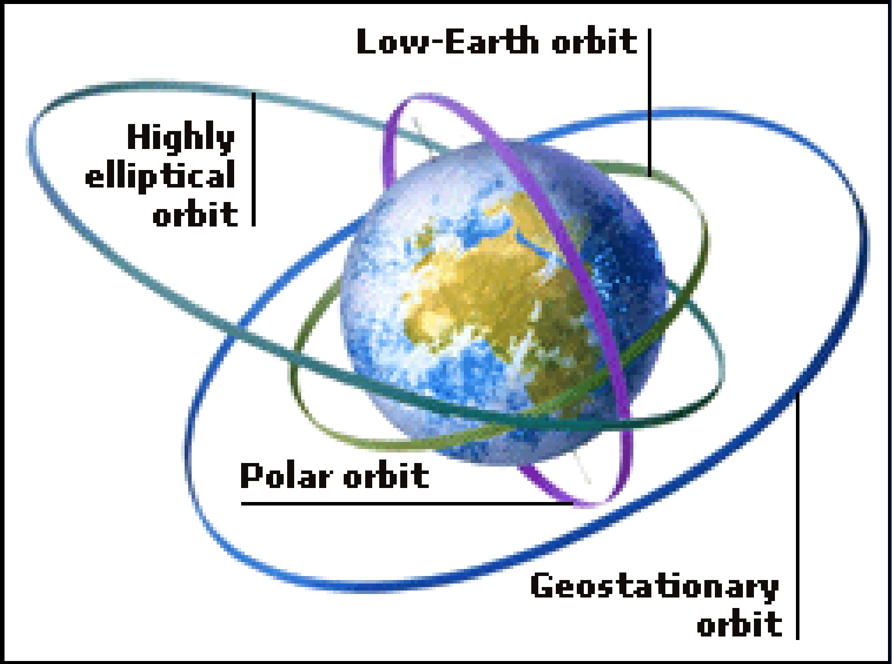


# Inclined Orbits

- **Molniya orbit:** is a highly inclined, elliptical orbit where satellites spend the great majority of their time over the far [northern] latitudes with the ground footprint moving only slightly.

- A period of 12 hrs, these satellites are available for operation over the targeted region for 6-9 hrs each day. Therefore, a three-satellite constellation can provide uninterrupted coverage.


- Sirius found this orbit to provide better coverage than XM Radio's geostationary satellites



# Space Junk: It's adding up . . .

- A few debris facts:
  - At any one time, ten million pieces of human-made debris are estimated to be in-orbit.
  - An average of one object/day has been dropping out of orbit for the past 50 years.
  - In 2007, China conducted an anti-satellite missile test, creating over 2,300 pieces golf-ball size, over 35,000 1 cm (0.4 in), and one million pieces 1 mm (0.04 in) debris.


  - The oldest debris still in orbit is Vanguard I, America's 2nd satellite launched in 1958.
  - Current space law retains ownership of all satellites (including leftover debris) with the original operators.

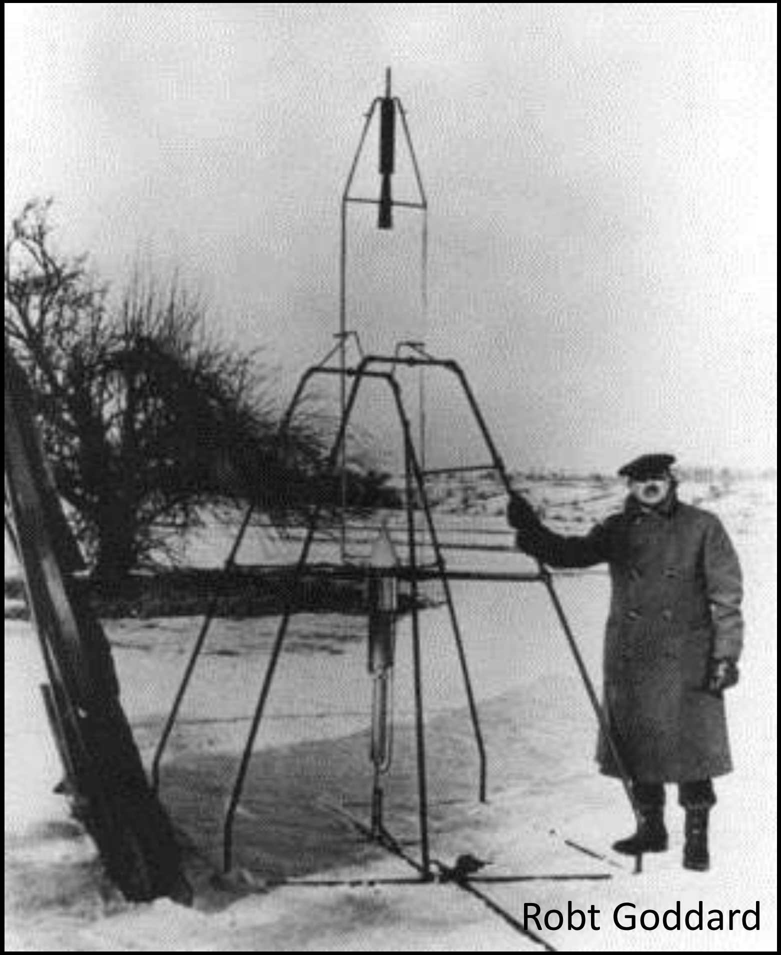
# Getting off the ground. . .

- **1926** Robert Goddard launches the first liquid fueled rocket demonstrating the ability to "throttle" launch vehicles

- Goddard proposes that rocketry could be used to put a man on the moon.

*The idea is thought to be utter nonsense and Goddard crazy.*

*They called him . . . "the moon man"*



Robt Goddard

# A boost in know-how. . .

- **After WW2** Wernher von Braun and other German scientists join the US space effort

- Between 1950 and 1956, von Braun led an rocket development team at the Redstone Arsenal in Huntsville for the Army, meanwhile the Navy is building Vanguard.
- Oct 1957 Russia launches Sputnik !!!
- Dec 1957 the Navy's new Vanguard rocket fails to launch America's first satellite.

  von Braun is asked for help

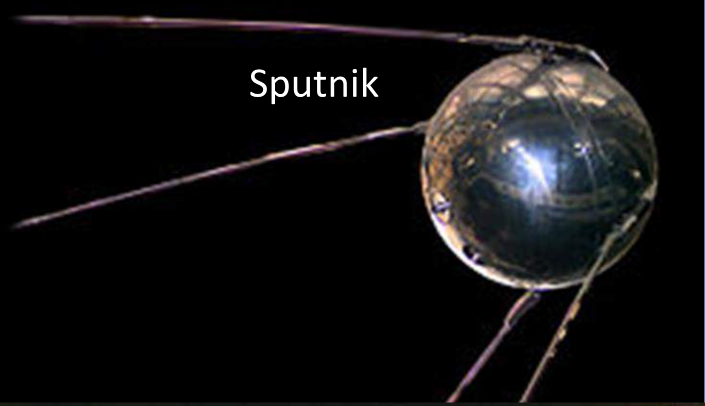
- Werner von Braun's Jupiter-C successfully launches the first US satellite Explorer 1 on January 31, 1958

Werner von Braun

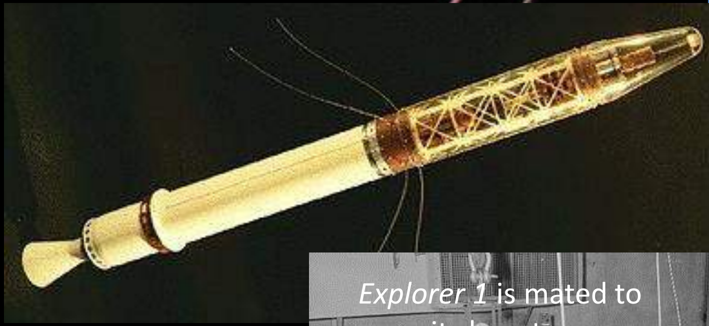
- This event signaled the birth of America's space program

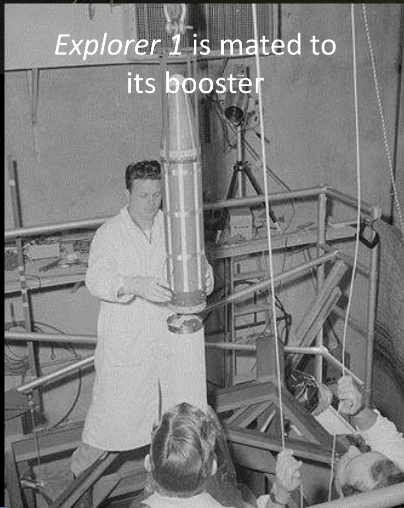
# The Russians were are ahead of us. . .

- **<u>Oct 4, 1957</u> <u>Sputnik</u>** – the first artificial satellite weighing 184 lbs, carried a radio beacon and thermometer into space orbiting at 134 miles




- **<u>Jan 31, 1958</u>** <u>Explorer 1</u> – launched by the Army, is the first American satellite weighing 31 lbs, orbiting at 1580 miles
  - Designed to study cosmic rays, it detected areas of intense radiation around the earth using a device created by scientist James Van Allen
  - These radiation areas trapped by the earth's magnetic field, became know as the Van Allen belts . . . The first discovery about our world from space . . .





*Explorer 1* is mated to its booster

- **<u>October 1, 1958</u>** - <u>NASA</u> is formed for "the peaceful exploration of space"

# The space race is on. . .

- **<u>April 12, 1961 –</u>** Soviets launch the first human into space 203 miles above the earth lasting 108 minutes

- **<u>May 5, 1961 –</u>** The US puts Alan Shepard (the second person and first American) in space 116 miles above the earth lasting 15 minutes

- **<u>Feb 20, 1962 –</u>** <u>John Glenn</u> orbits the earth 3 times becoming the first human satellite


Yuri Gagarin


The Huntsville Times

Man Enters Space

So Close Yet So Far Sighs Cape

Soviet Officer Orbits Globe In 5-Ton Ship

Praise Is Heaped On Major Gagarin

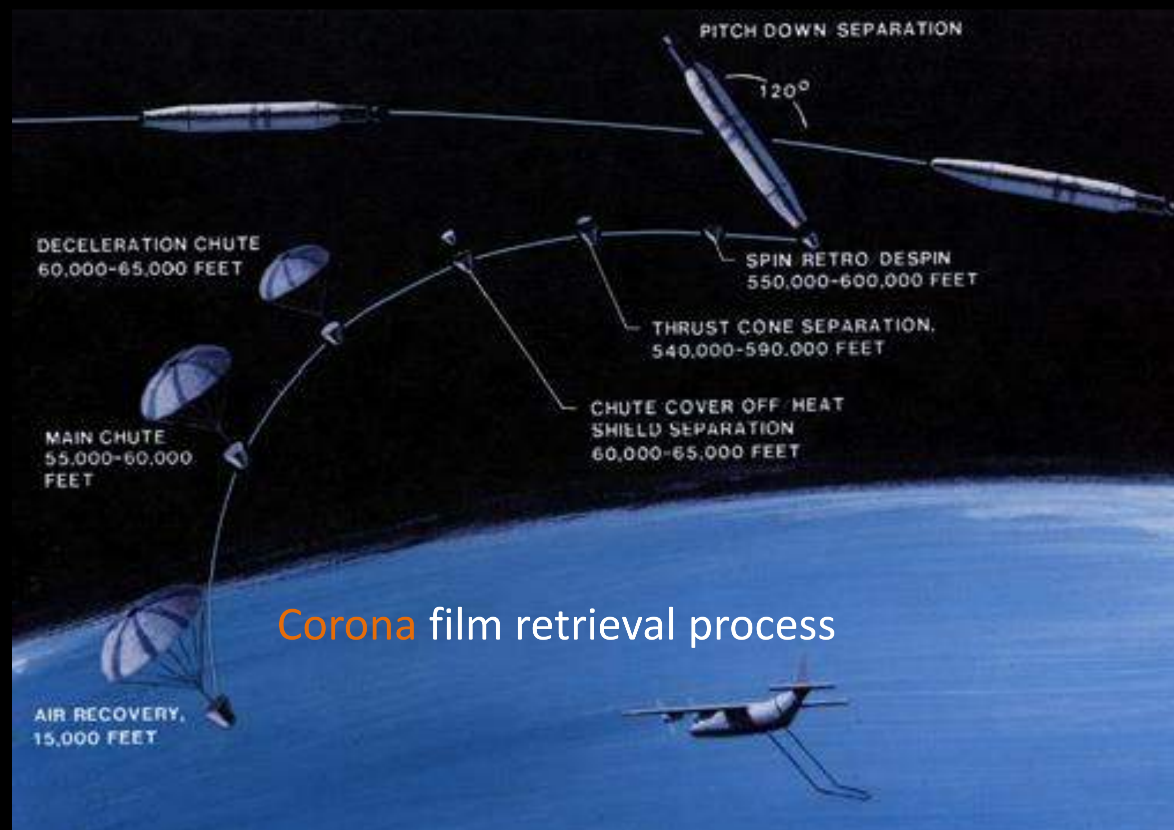
Reds Win Running Lead In Race To Control Space

John Glenn

# Meanwhile . . .

- The CIA funds technology and programs to take detailed pictures from space
- Feb 1959 - Discover I is launched part of a secret program aka- “Corona”
- Aug 1960 - the National Reconnaissance Organization (NRO) is formed
  ( if you asked
  . . . it did not exist)

- Technology spin-offs:
  - Digital imagery
  - Mapping Satellites
  - GPS – global positioning system




Corona film retrieval process