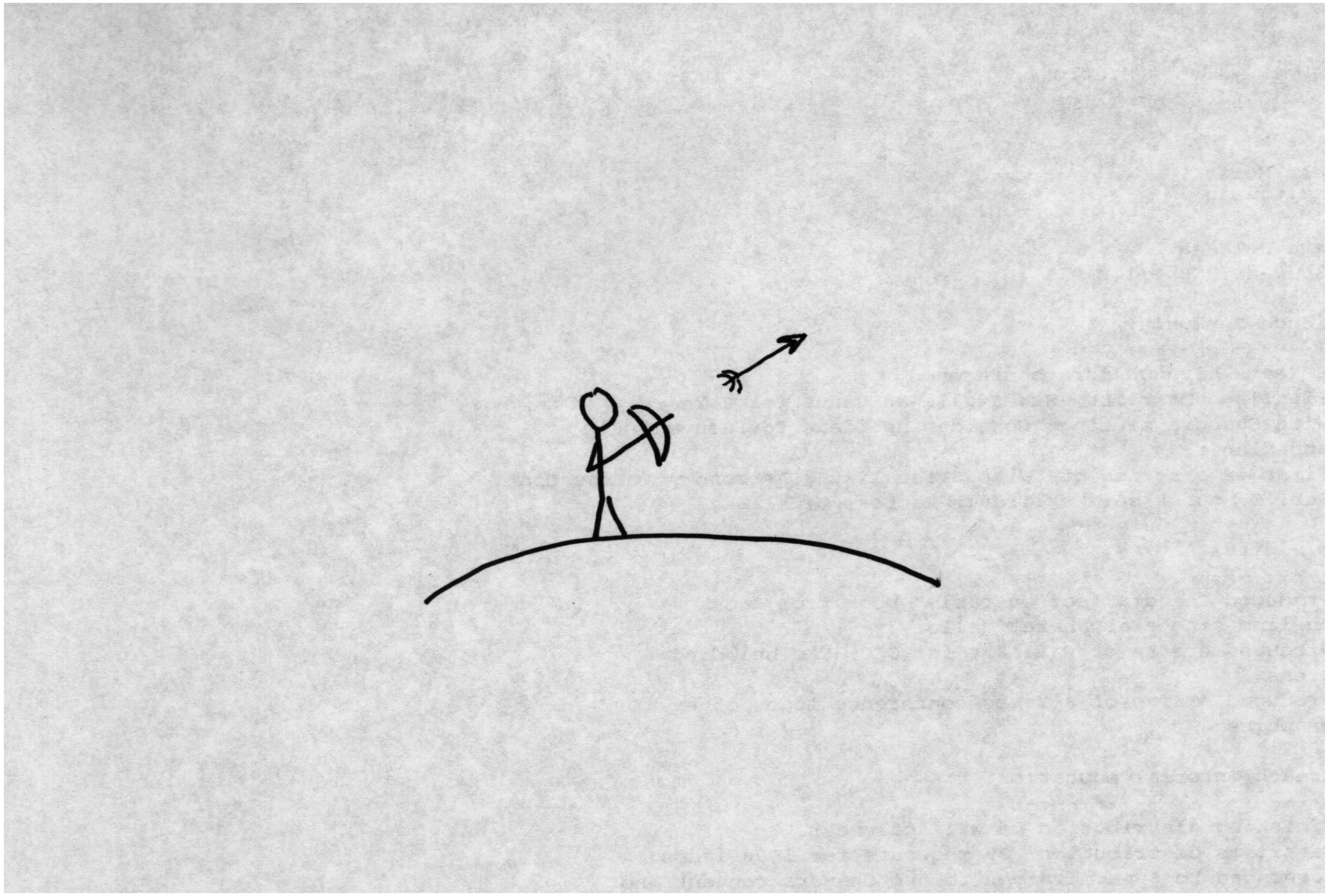
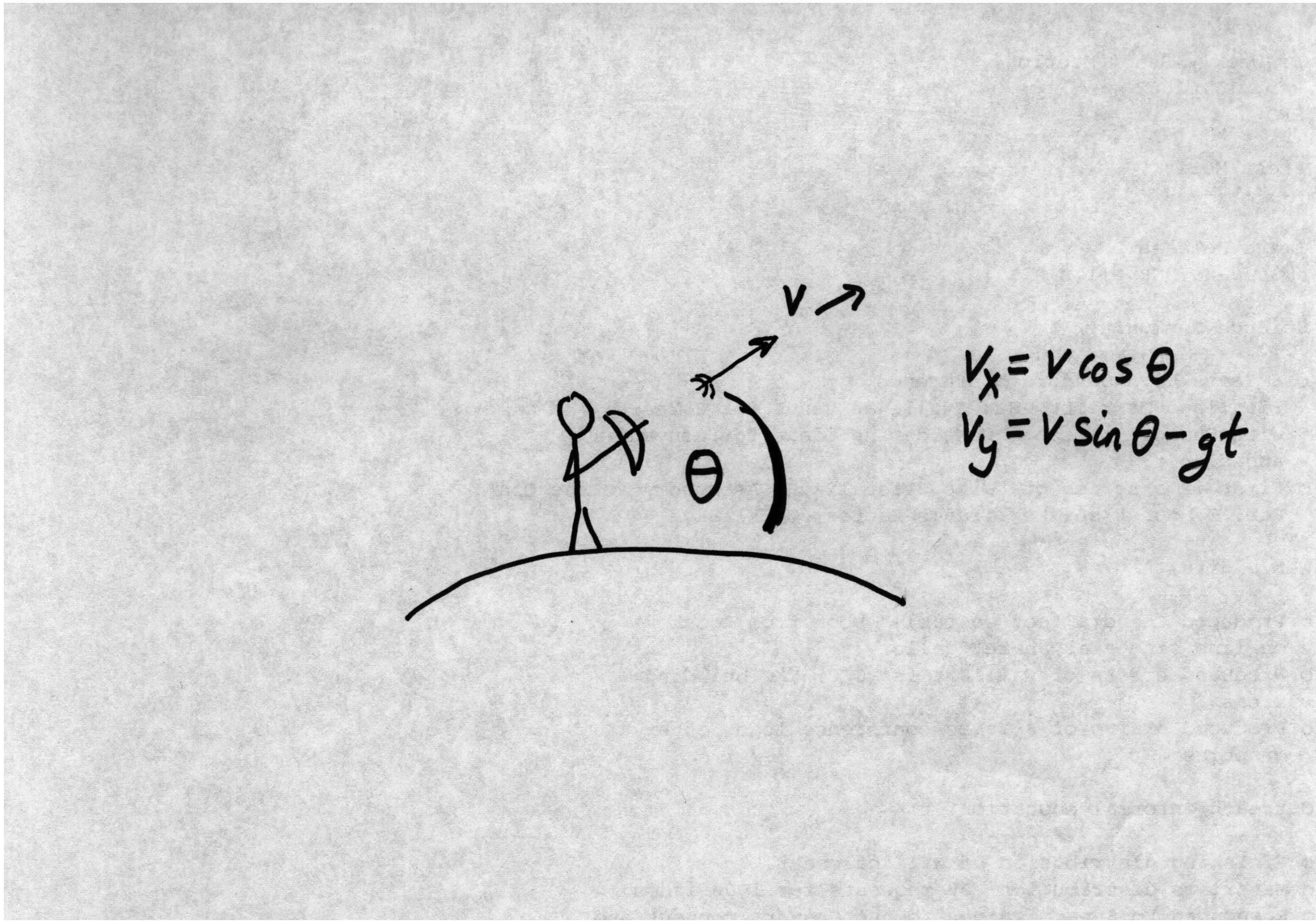


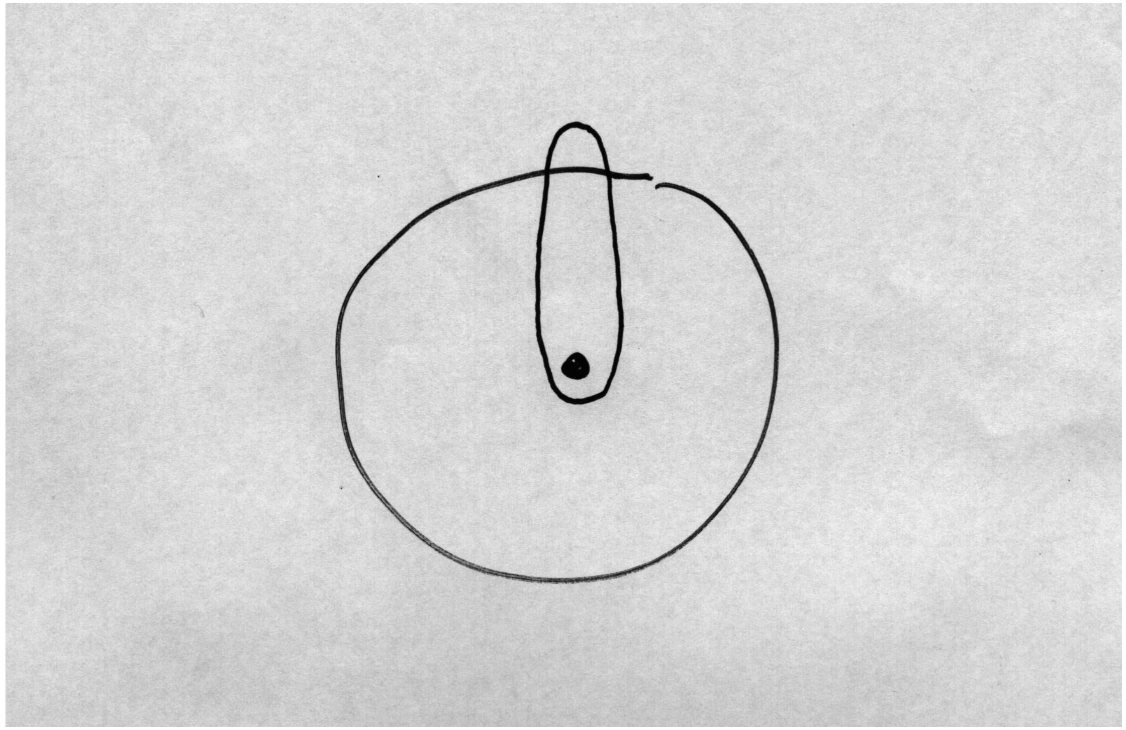
I shot an arrow in the air
It fell to Earth,
I knew not where

Orbits for poets - Longfellow



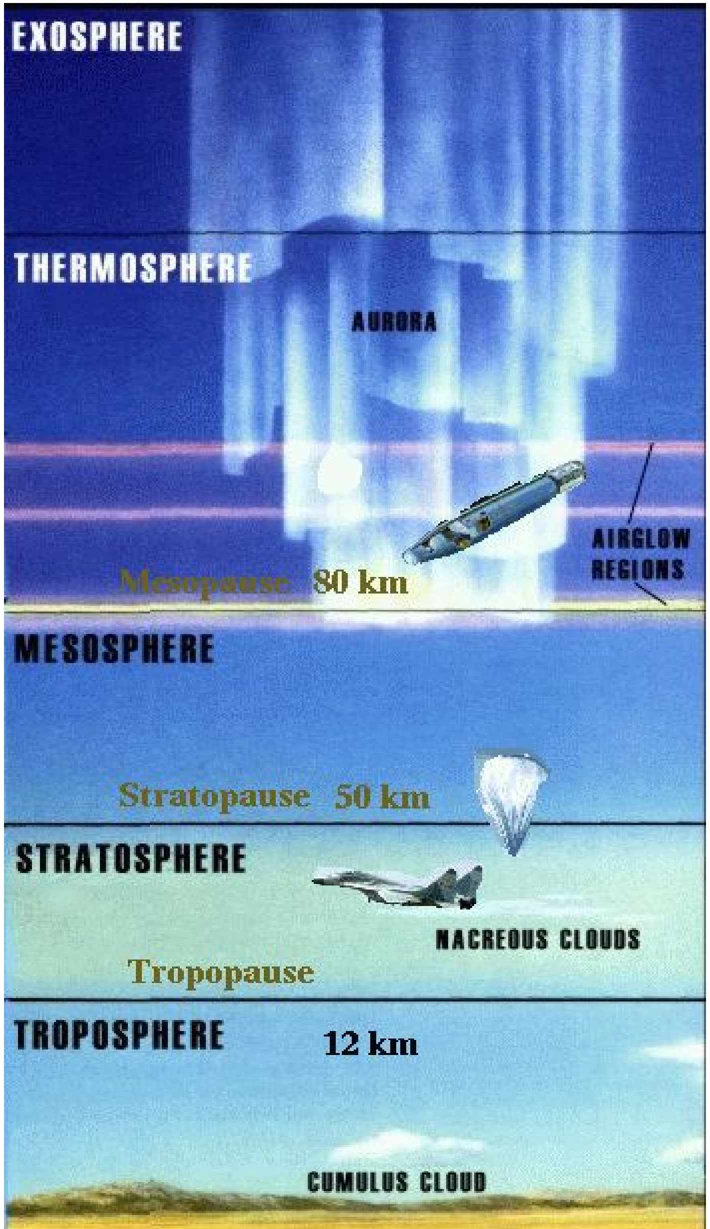
I shot an arrow in the air
It fell to Earth,
A distance v^2 sin 2 theta/g away

Orbits for physicists- Galileo



Shoot arrow at 75 m/s, at an angle of 45 deg up into air
(but ignore air resistance)
Goes 185 metres high
High school math: it's a parabola
Not quite! That ignores Earth curvature - really an ellipse with e=0.999955
Low point is 280m from center of Earth.
It's in orbit! - briefly....

THE EDGE OF SPACE



- Highest airplanes 38 km
- Highest balloons 51 km
- Lowest satellite perigees 90 km (high apogee or freq. reboost)
- Physics: highest transition layer is mesopause at nominal 80 km
- Tradition: USAF gave astronaut wings at 50 mi.=80 km
- I adopt 80 km as a natural boundary

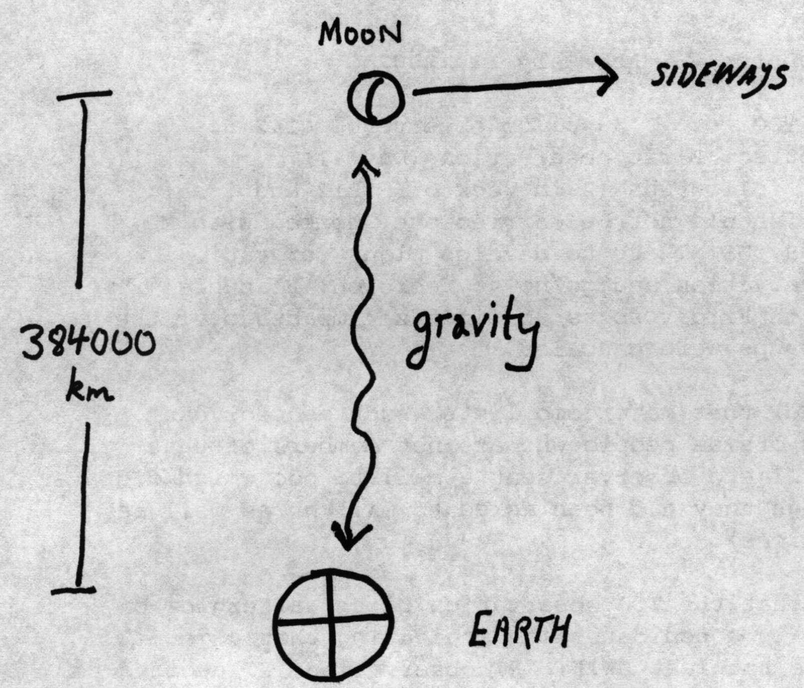
Early space launches (suborbital)

- Germany (Peenemunde): 1942 Oct 3 (or 1943 Mar 18?), V-2
- USA (White Sands): 1946 May 10, V-2
- USSR (Kapustin Yar): 1947 Oct 18, V-2
- France (Hammaguir): 1954 Feb 21 , Veronique
- UK (Woomera): 1957 Jul 23, Skylark
- Japan (Akita): 1960 Jul 11, Kappa-8
- Canada (Churchill): 1960 Oct 12, Black Brant 2
- China (Jiuquan): 1960 Nov, R-2 (V-2 derivative)
- Italy (Sardinia): 1961 Jan 12 with US Nike Cajun
- India (TERLS): 1963 Nov 21 with US Nike Apache

Getting to orbit

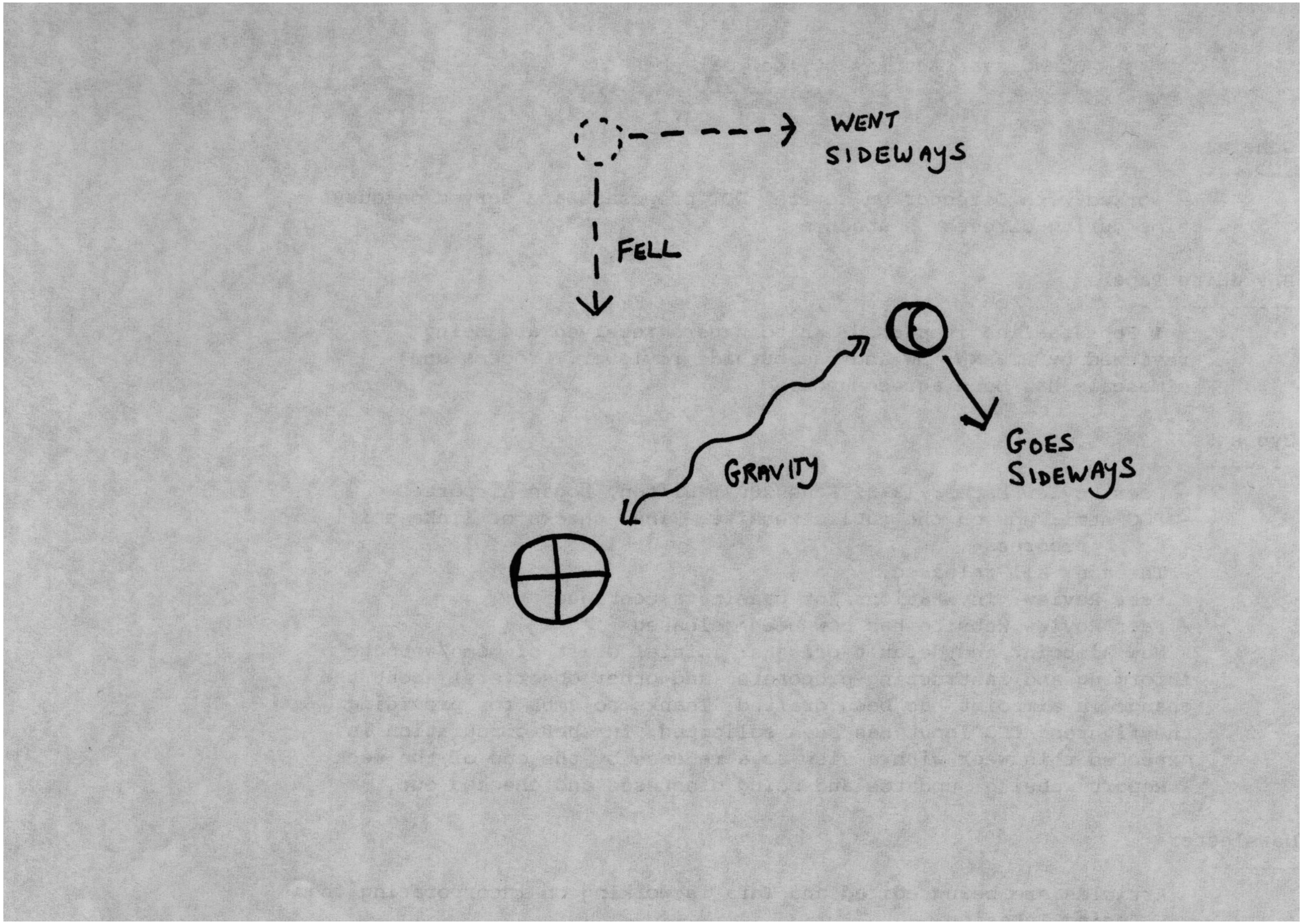
- Consider the “specific energy”(energy per unit mass, KE + PE) of an object in space relative to an inertial point on the Earth's surface
- The V-2, moving slowly at the edge of space, had E = 1.5 MJ/kg (1.1 to 2.1 for different launches)
- An orbiting satellite at the same altitude needs E=31.6 MJ/kg. Getting to orbit is MUCH harder! It took 15 more years...

HOW DOES THE MOON STAY UP?

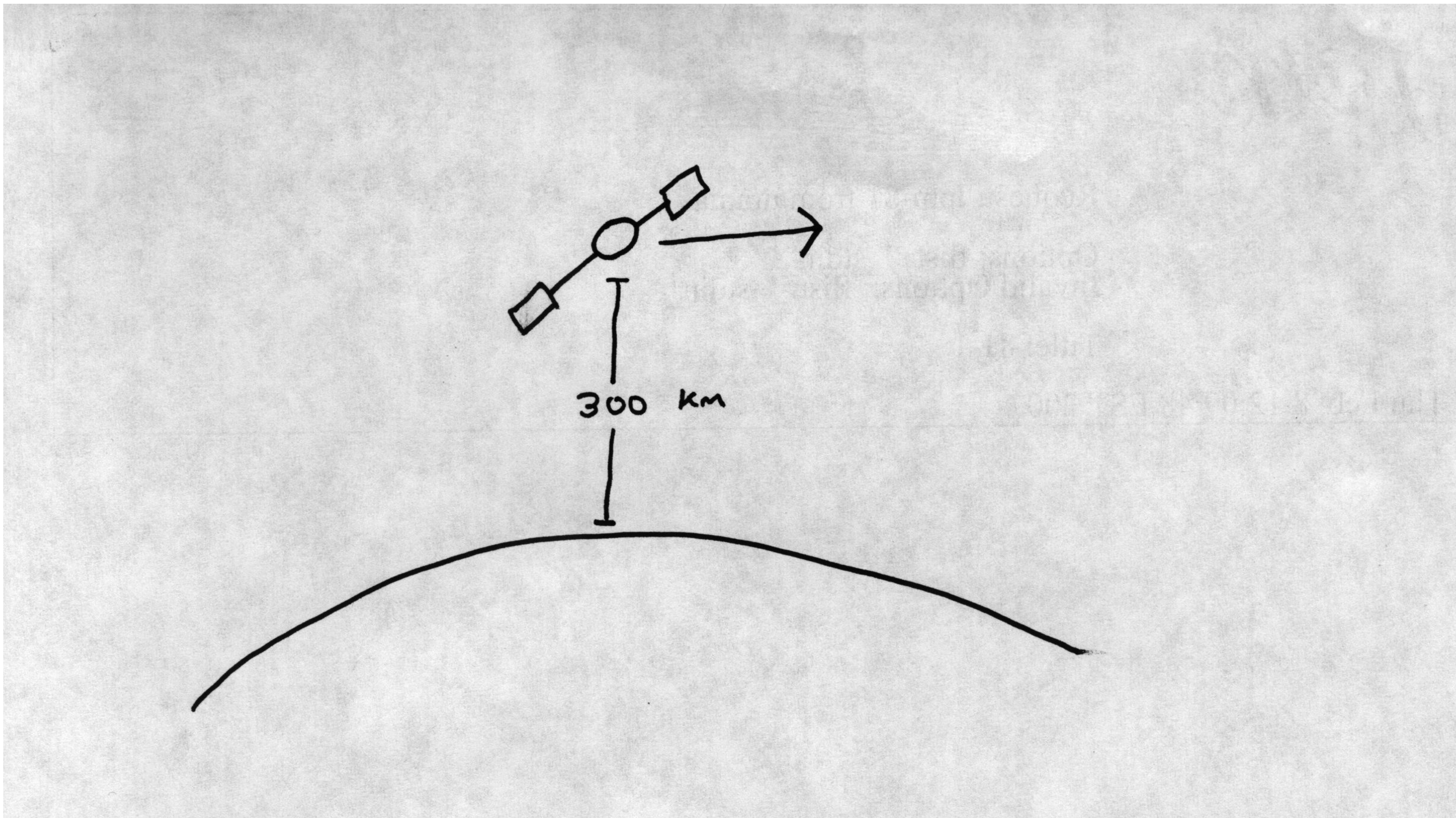


Here's the Moon whizzing sideways through space
at 1 km/s (2200 mph)
Earth's gravity makes it fall

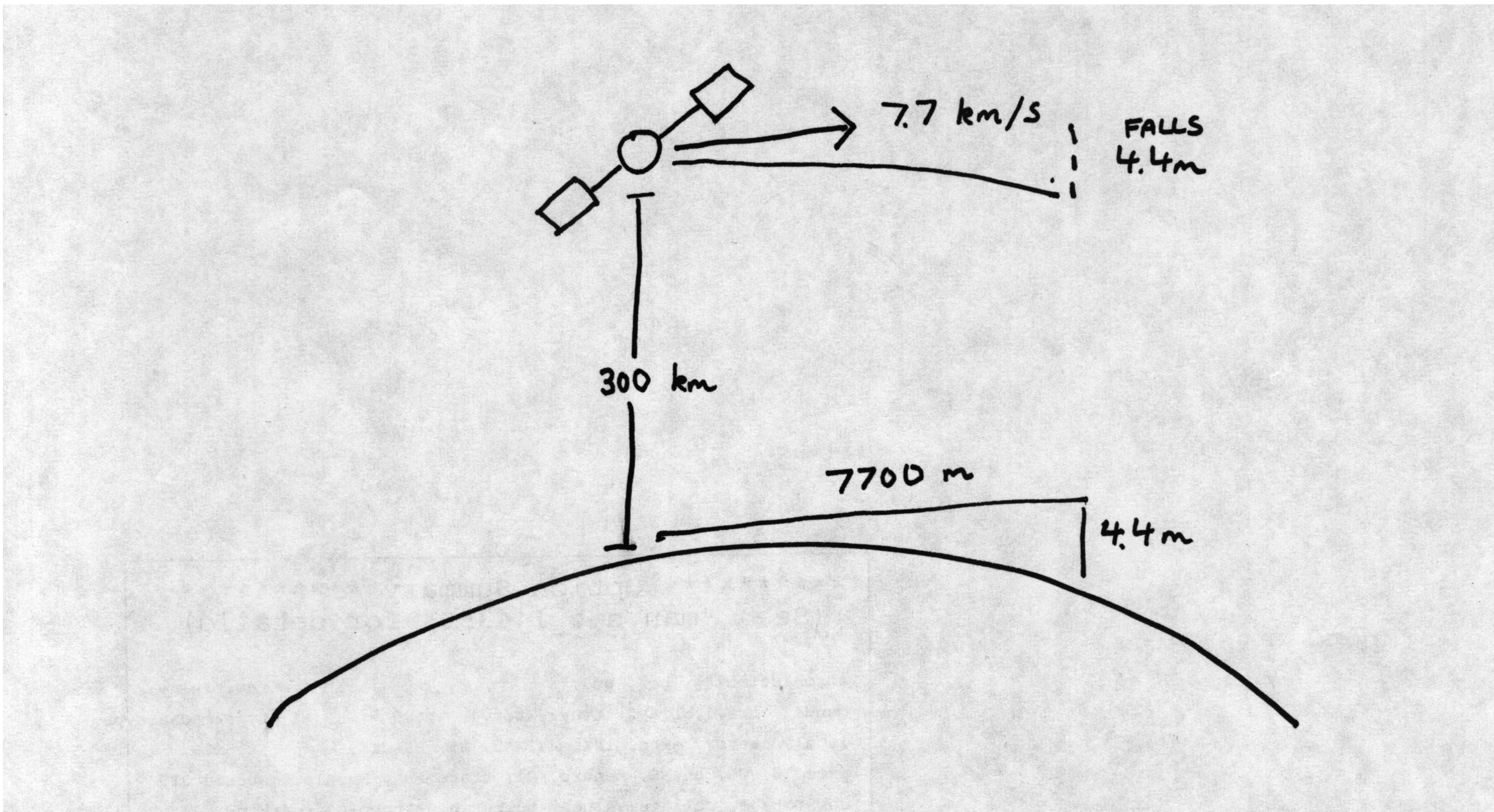
IT FALLS TOWARD THE EARTH BUT MISSES!



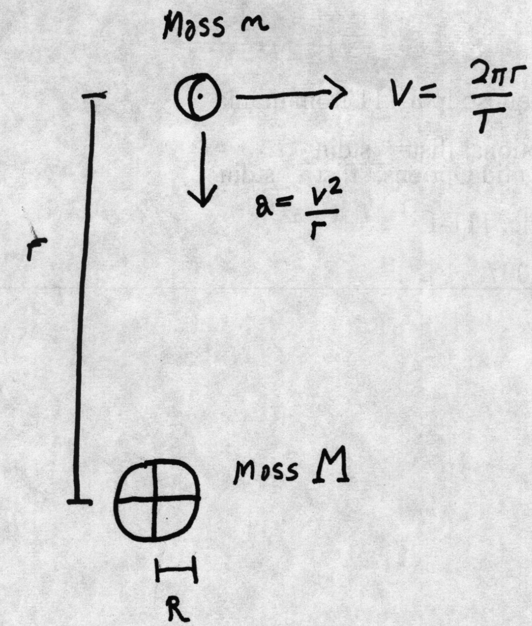
As it falls, the Moon is still moving sideways
Now Earth's gravity is pulling at it from a different angle
The old 'Sideways' speed getsslowed and stopped by Earth's gravity
But the speed it picked up in falling is now a 'sideways' speed!



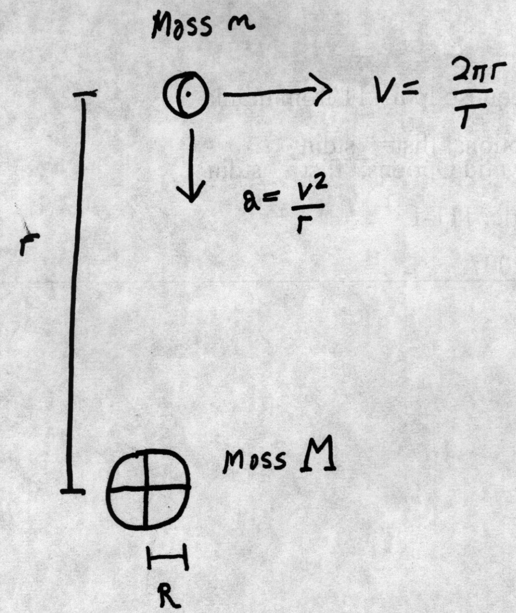
The same math applies to a satellite or spaceship orbiting 300 km above the Earth



The satellite is going sideways at the circular velocity of 7.7 km/s.
In one second it travels 7700 m sideways and falls 4.4 m
But in 7700 m, the Earth curves away from you 4.4m
So you haven't got any closer to the surface!



$$F = ma$$

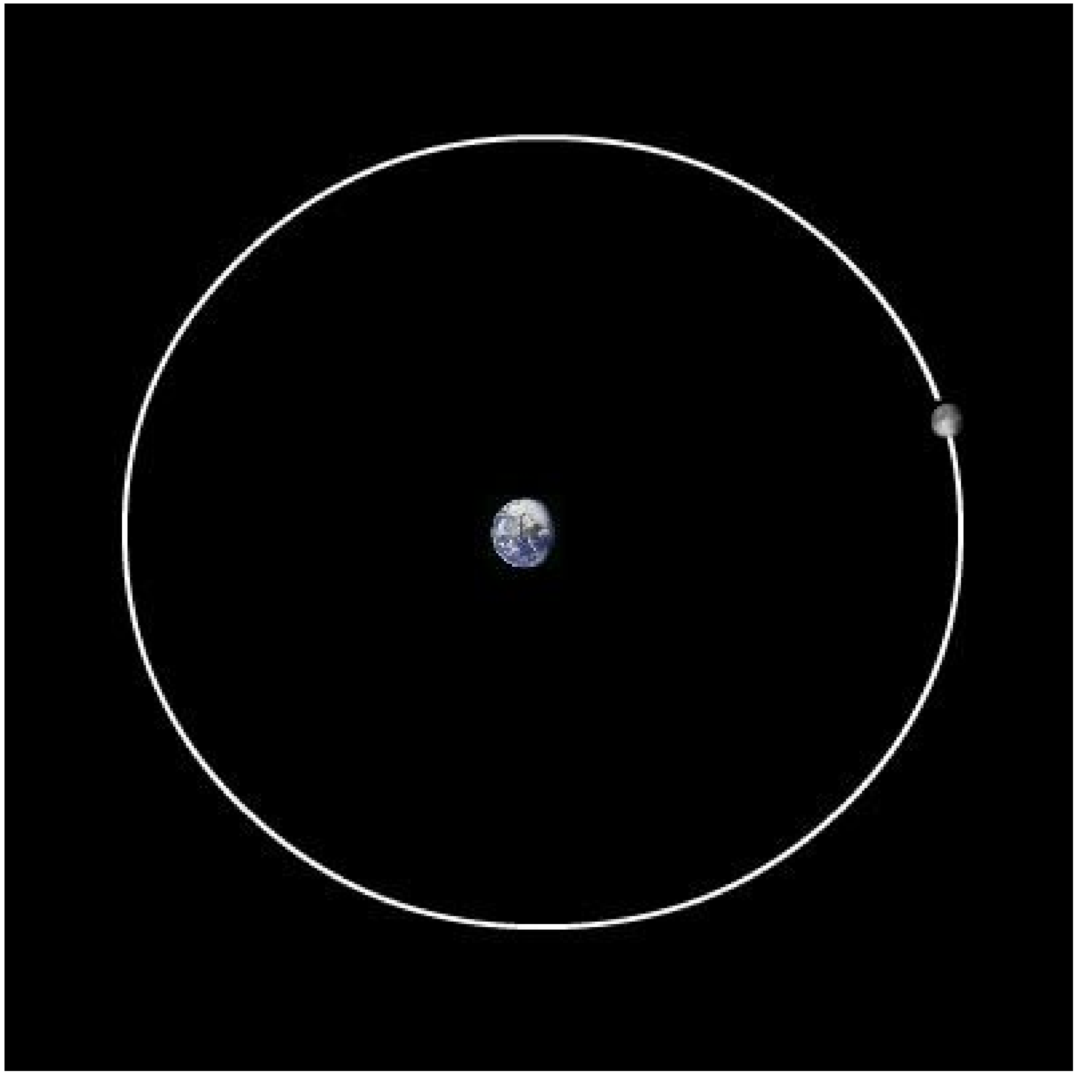


$$\frac{GMm}{r^2} = F = ma = mv^2/r$$

$$\Rightarrow \quad v^2 = GM/r = \left(\frac{2\pi r}{T}\right)^2 = \frac{4\pi^2 r^2}{T^2}$$

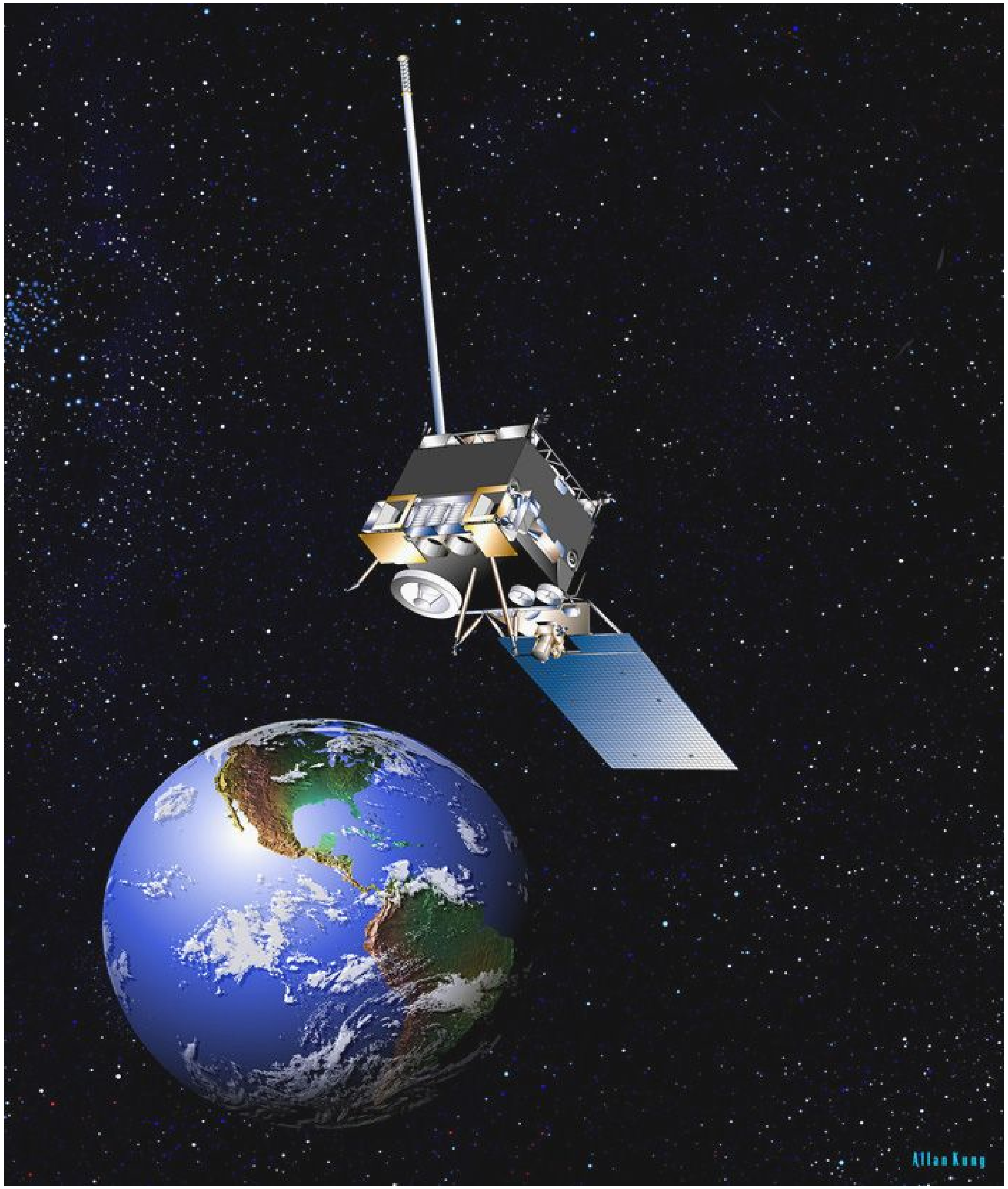
$$\Rightarrow \quad T^2 = \frac{4\pi^2}{GM} r^3$$

$$\left(\text{ORBITAL PERIOD}\right)^2 \propto \left(\text{HEIGHT}\right)^3$$



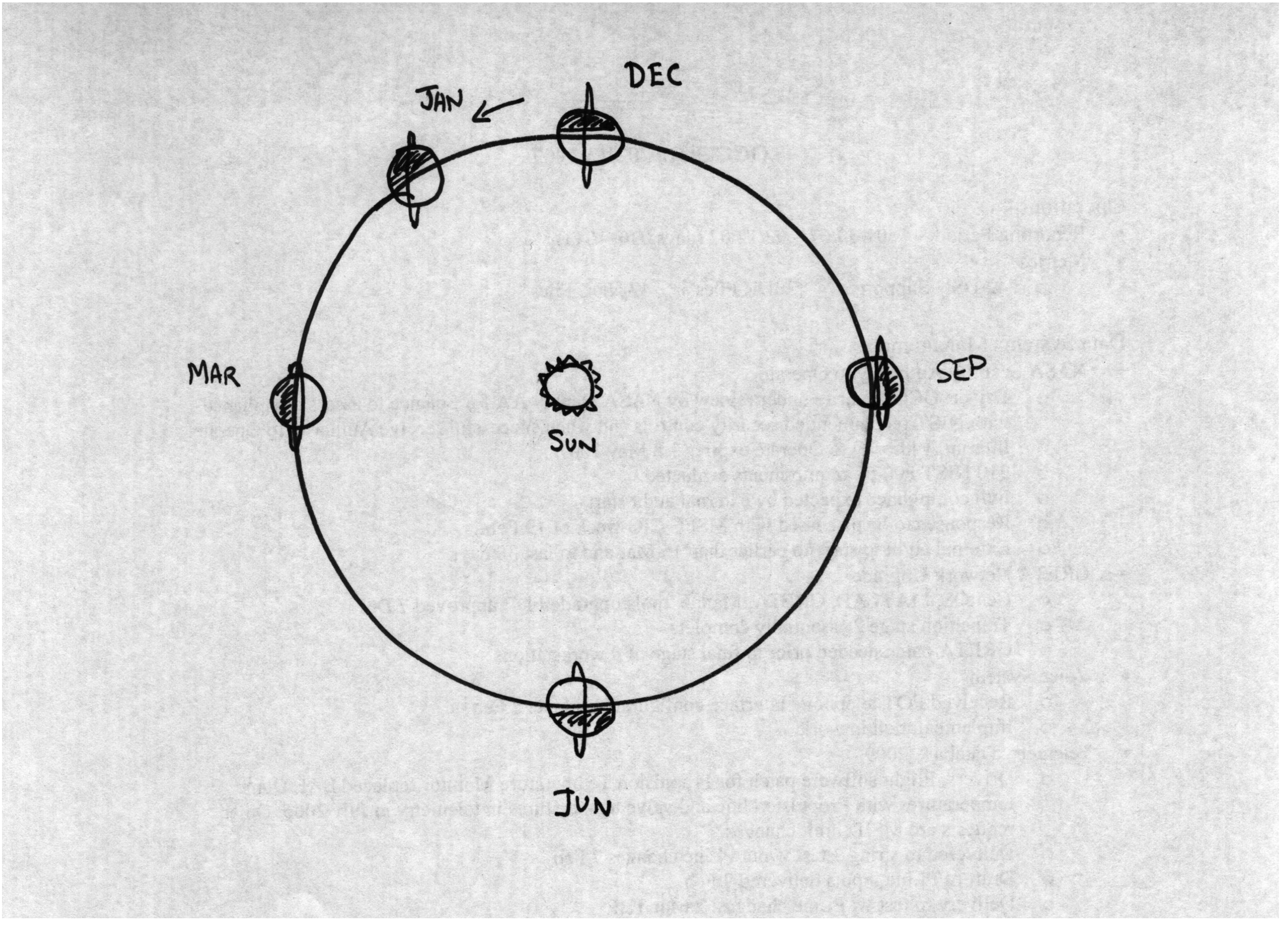
Lunar orbit: r=384000 km T= 27 days

Low Earth Orbit satellite: $R = 6378 + 560$ km, $T = 1$ hr 36 min



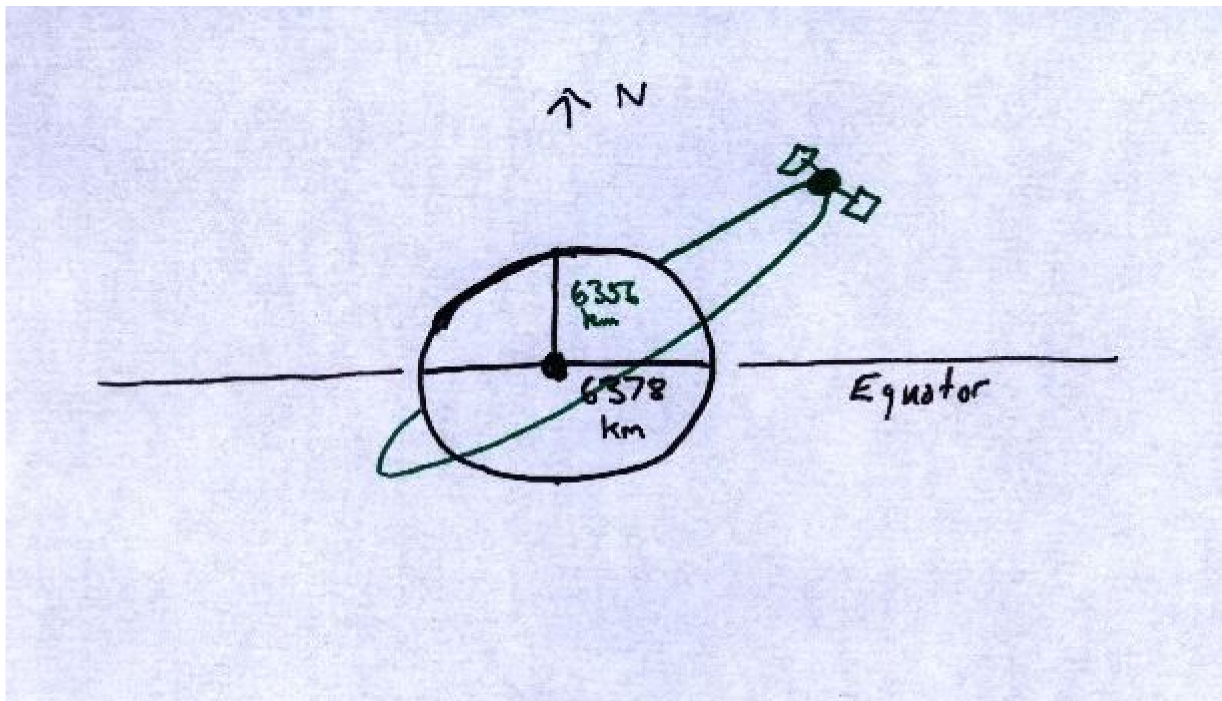
Geostationary orbit: R = 6378 + 35787 km, T = 23 h 56 min

ORBITAL PLANE



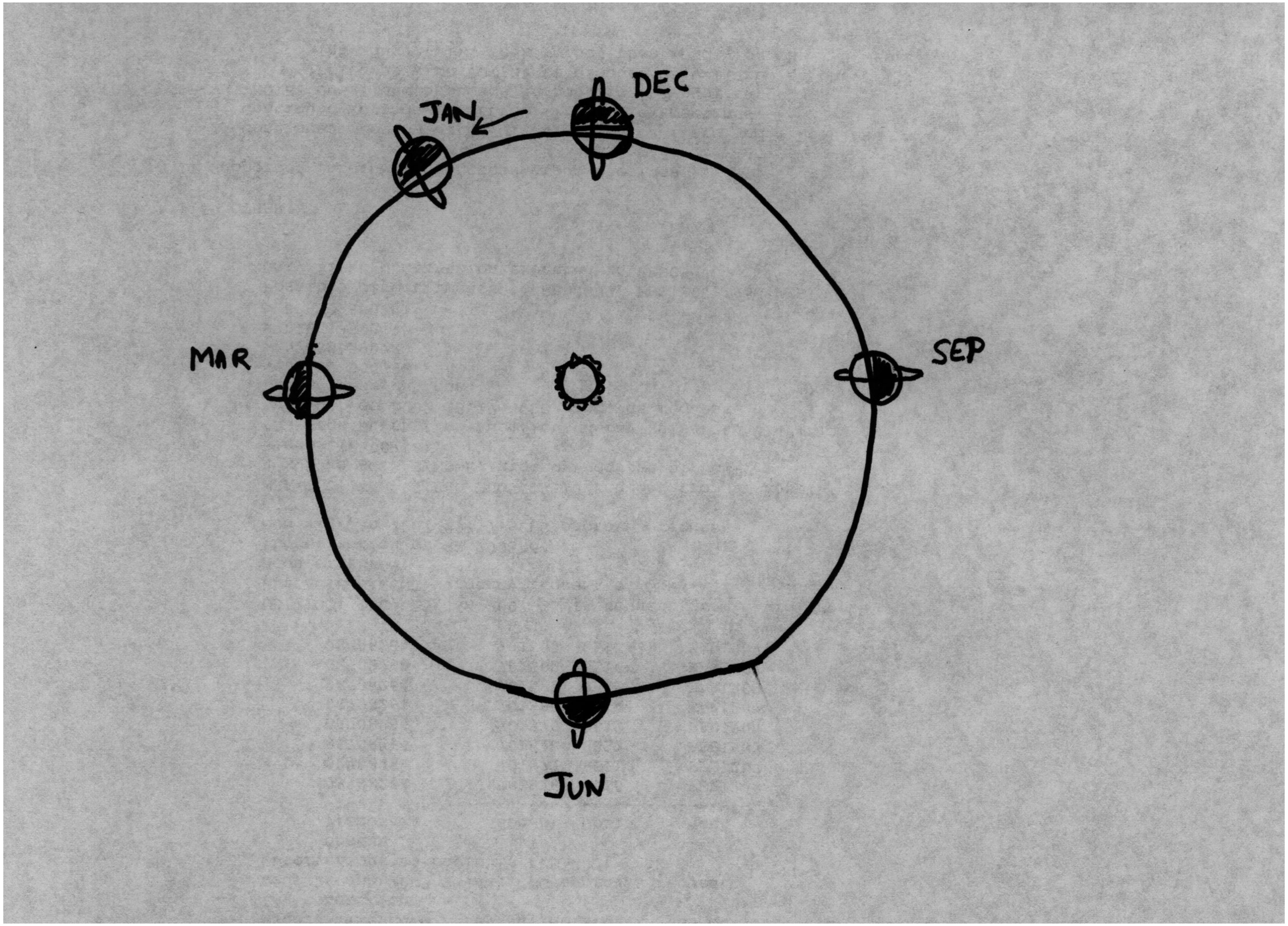
Orbital plane: For ideal planet, plane stays fixed relative to distant stars, not fixed relative to the Sun. In this example, satellite is permanently illuminated in Mar and Sep, but spends time in darkness in Dec and Jun

BUT - THE EARTH IS NOT ROUND!

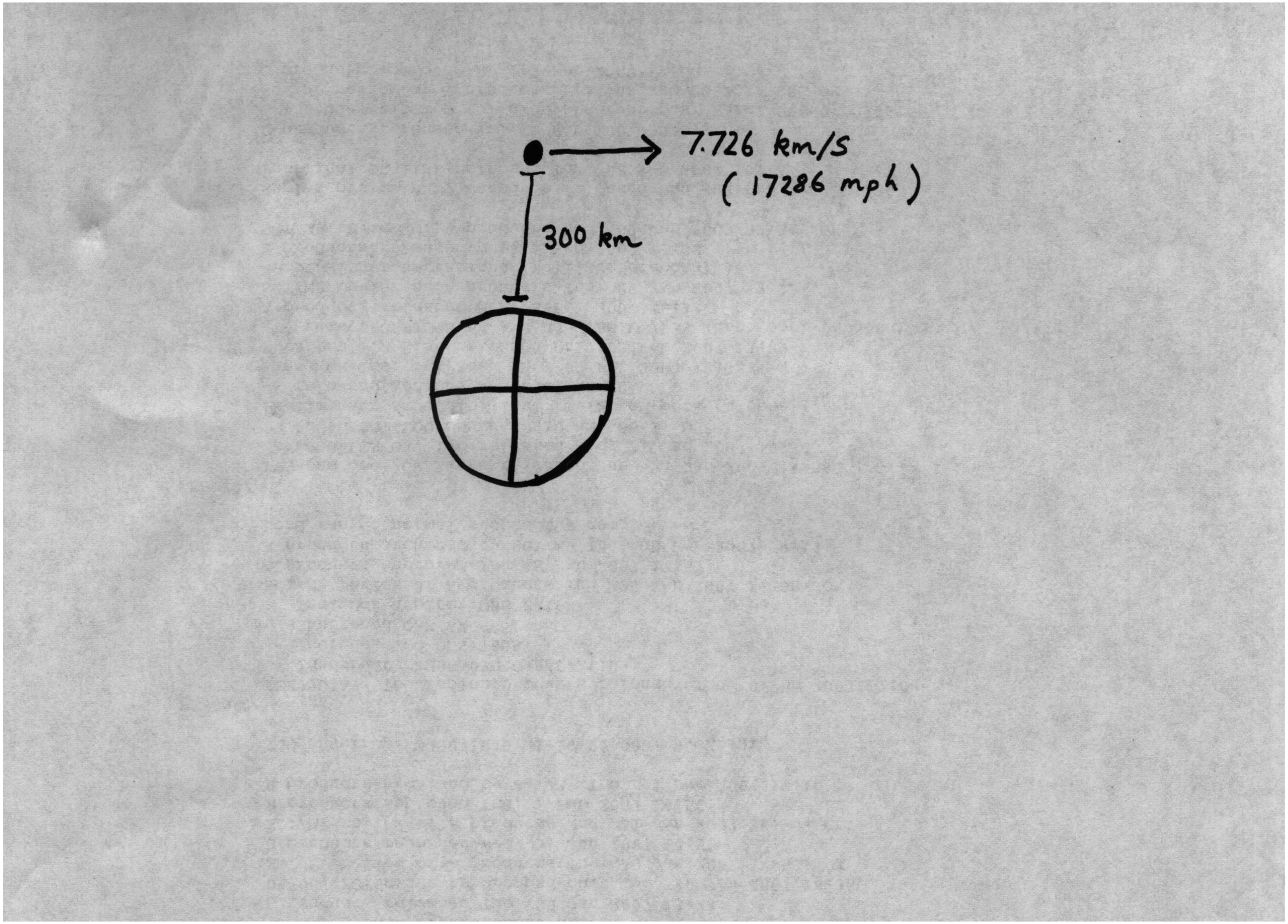


Satellite gets extra tug as it passes the fat equator
Causes Kepler ellipse to rotate in space
For low orbit satellites, this effect is a few degrees a day
Amount depends on inclination of orbit to equator

SUN-SYNCHRONOUS ORBIT

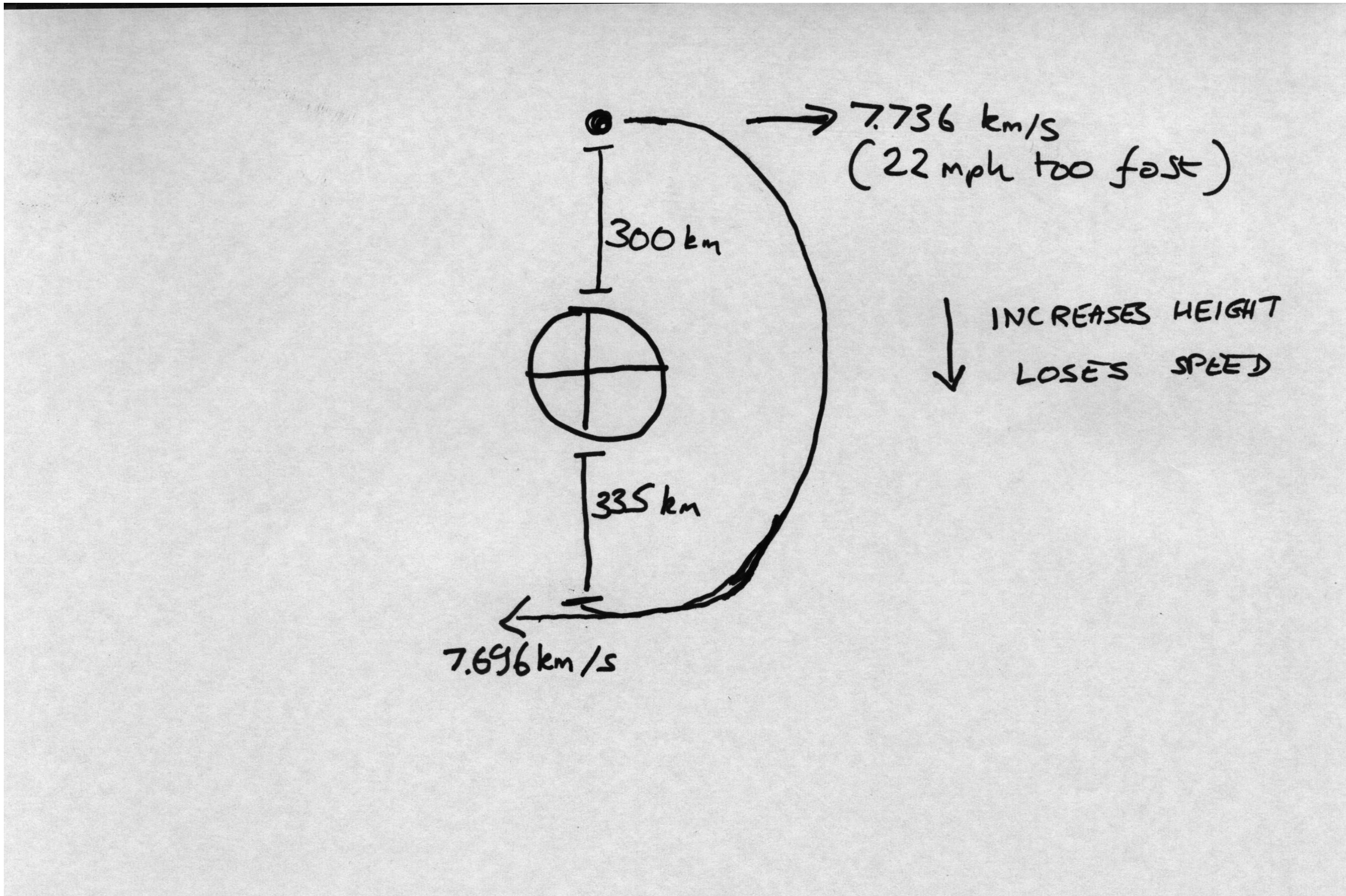


Orbital plane rotates at same rate Earth goes round Sun -
Angle of orbit to Sun stays the same - always same local time



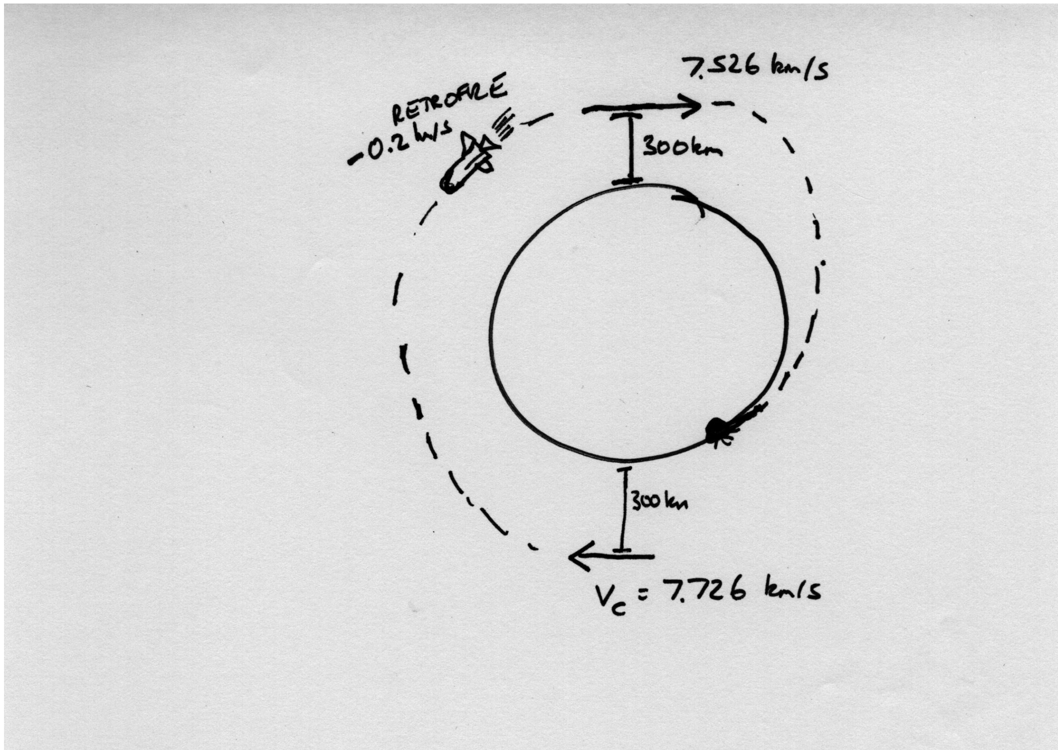
If you want to stay in circular orbit at 300 km you MUST go at exactly 7.726 km/s, the CIRCULAR VELOCITY. What if you speed up?

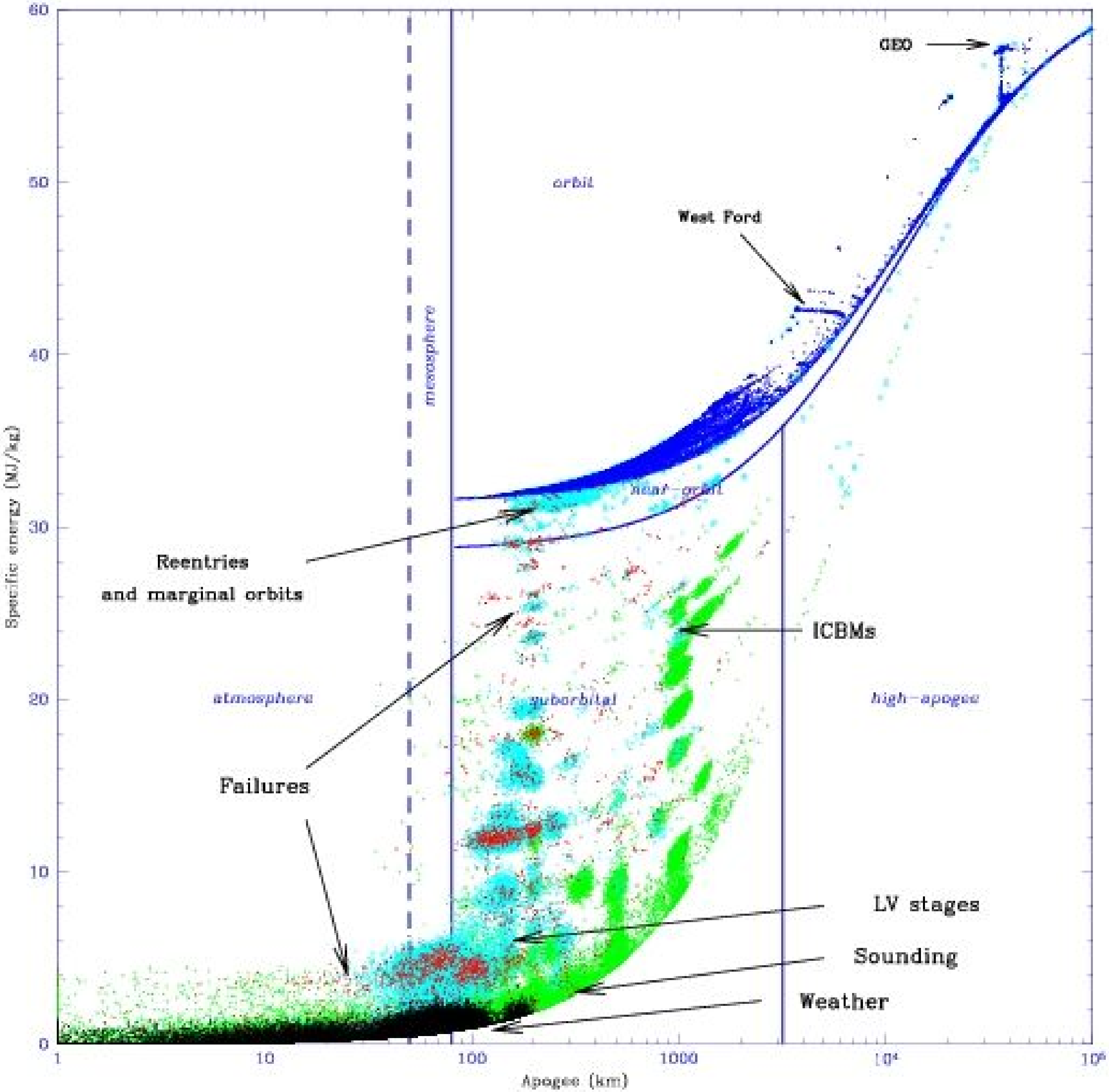
- Faster sideways
- Earth curves away more in a give time
- Go higher but lose speed



Go 0.01 km/s too fast - after 1/2 orbit, end up 35 km higher
but lose 0.04 km/s (89 mph) in speed: from 7.736 km/s to 7.696 km/s
At 335 km, circular velocity is less than at 300 km, but not that much less:
Vc = 7.706 km/s. We are going too slow to stay at 335 km!
Over next 1/2 orbit, fall back to 300 km and start again:
ELLIPTICAL ORBIT

What if you go too slow?
Say you are at 300 km/s and go 0.2 km/s too slow: 7.526 km/s
At opposite end of ellipse, end up 648 km lower
Oops! We started only 300 km above Earth surface...
CRUNCH!
This is how we do reentry





GEO
orbit
West Ford
mesosphere
near-orbit
Reentries
and marginal orbits
ICBMs
atmosphere
suborbital
high-apogee
Failures
LV stages
Sounding
Weather
Specific energy (MJ/kg)
Apogee (km)
0
10
20
30
40
50
60
1
10
100
1000
10⁴
10⁵

ENVIRONMENTAL THREATS IN SPACE - 1

RADIO FREQUENCY INTERFERENCE (RFI):

Communications satellites too close to each other, signals interfere

Russian GLONASS navigation satellites had leaky sidebands, interfere with radio astronomy.

LIGHT POLLUTION:

Large satellite constellations could mean there's always a bright satellite in any field of view of a telescope - makes astronomy difficult

Space advertising - large inflatable satellites or stationkeeping vehicles spelling out the name of your favorite soft drink

Russian proposal to use space mirrors to banish night from cities

RADIATION:

US nuke at 400 km high (STARFISH PRIME, July 1962) created new radiation belt which lastest years, damaged several science satellites

Soviet 'Upravleniye Sputnik' satellites with nuclear reactors contaminated LEO, intefered with gamma ray astronomy satellites

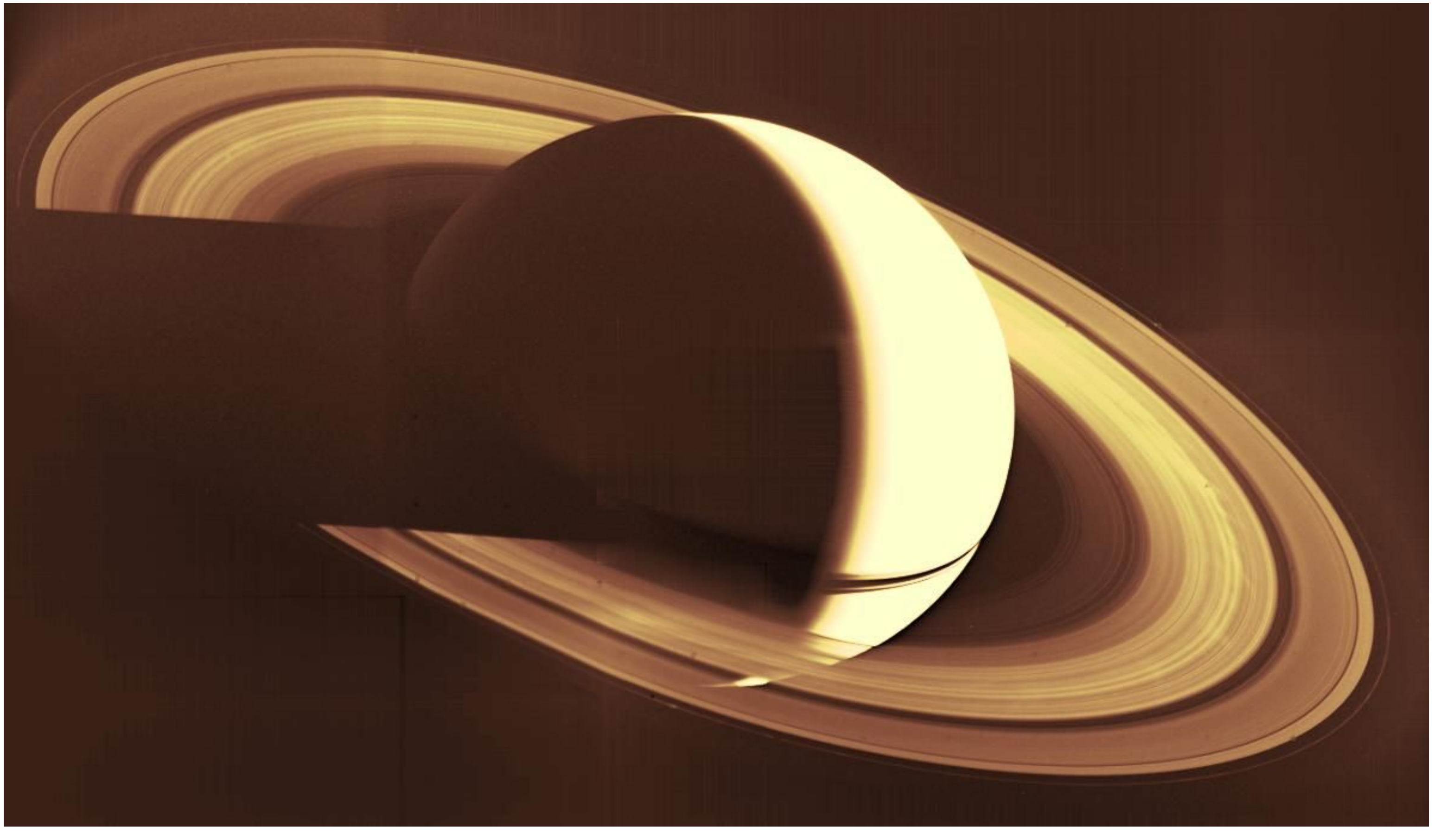
High energy radar pulses can modify ionosphere - effects on Earth environment are not clear. Magnetosphere protects us from solar flares

ENVIRONMENTAL THREATS IN SPACE - 2

DEBRIS

Natural micrometeorite threat worried early space pioneers - but flux is low

Artificial debris is a real concern



Saturn used to be the planet with the worst debris problem....

SPACE DEBRIS

Chinese FY-1C satellite in orbit 840 x 840 km high

Missile launch from Xichang enters -4000 x 840 km suborbital path

Hits FY-1C at apogee

100 kg at relative speed of about 7.5 km/s
$1/2\ mv^2$ = 2.8 gigajoules
Equivalent to 5000 tons at 70 mph or to 1 ton of TNT

Created 1000 pieces of debris bigger than 10 cm
Maybe 100000 pieces bigger than 1 cm?

Figure 2. Cloud of debris greater than 10 cm in size after 10 minutes.

Figure 3. Debris cloud after 10 days.

Figure 4. Debris cloud after 6 months.

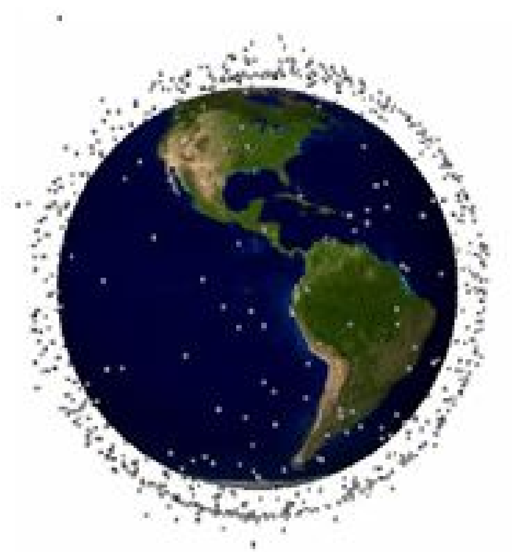


Figure 5. Debris cloud after 3 years.

David Wright and Wang Ting (UCS): FY-1C debris cloud

SOURCES OF SPACE DEBRIS:

- Lens caps, dropped astronaut cameras, yo-yo weights
- Defunct payloads
- Upper stages of launch vehicles

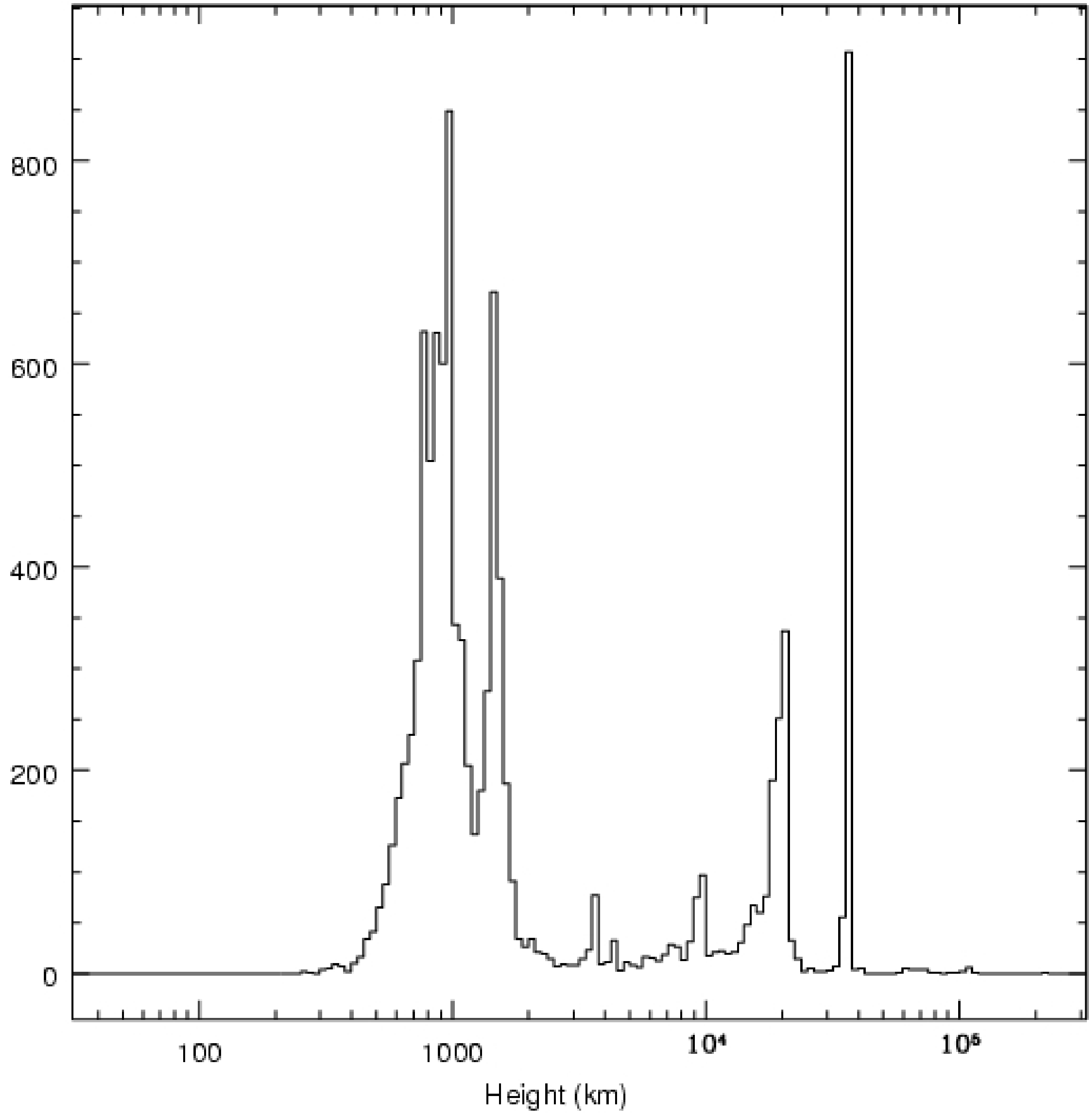
Solution: lens caps on hinges not ejected, etc.
Lower orbit of payload and upper stages after job is done; low orbit means reentry sooner

- Residual propellant. Upper stage still has propellant on board; years later, rubber joints erode away and fuel, oxidiser meet - BANG.
Solution: get rid of any extra fuel in a final 'depletion burn'.

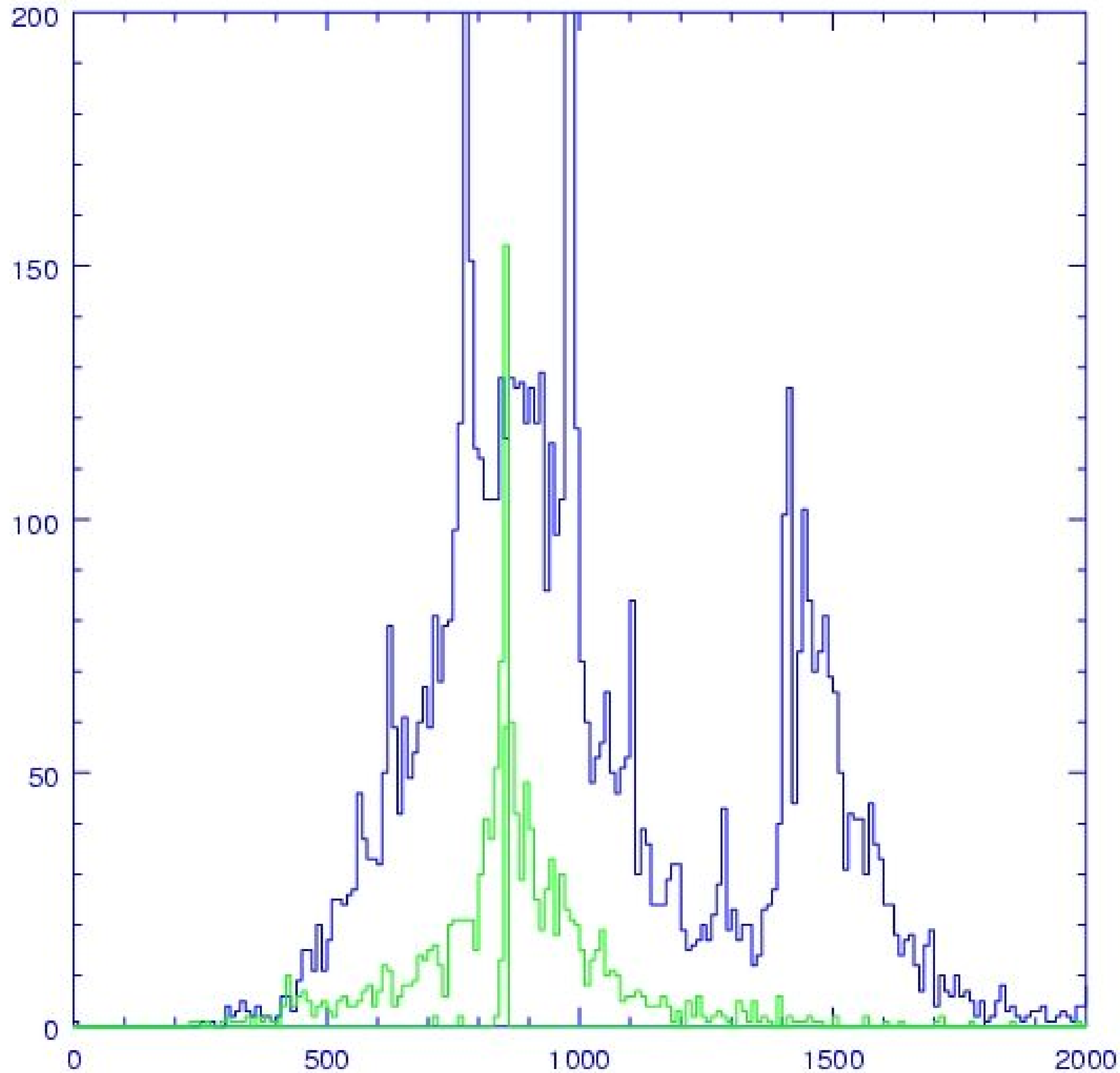
- Satellite-satellite collisions (accidental). Potential for chain reaction, but currently probability is low enough that only a few accidental cases are known.

- Satellite-satellite collisions (deliberate). BAD BAD BAD. Can cause a LOT of debris.

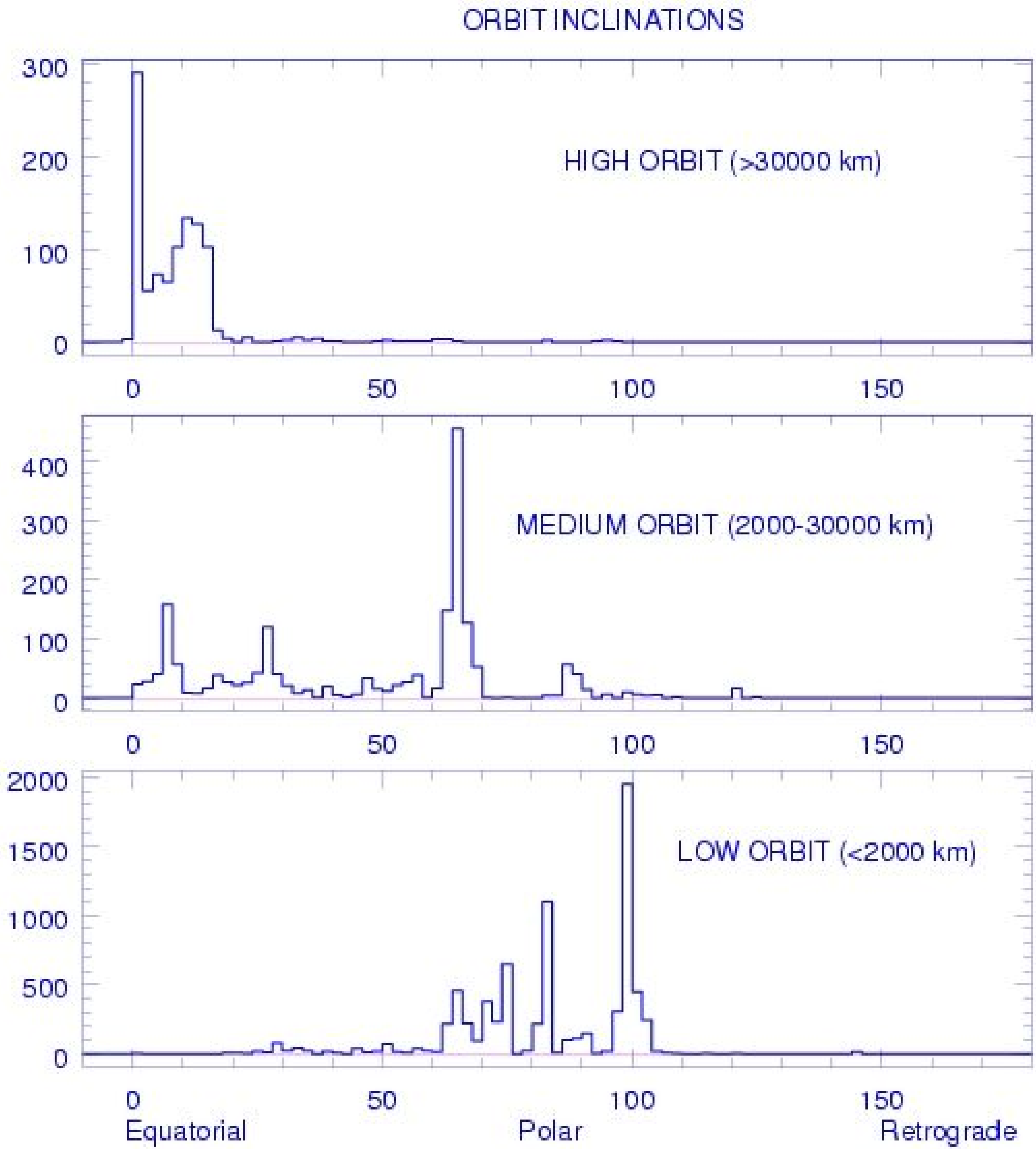
- On-board destruct with high explosive. Also bad. Mostly done with LEO sats, debris reenters quickly.



800
600
400
200
0
100
1000
10^4
10^5
Height (km)



200
150
100
50
0
0
500
1000
1500
2000



ORBIT INCLINATIONS
HIGH ORBIT (>30000 km)
MEDIUM ORBIT (2000-30000 km)
LOW ORBIT (<2000 km)
300
200
100
0
400
2000
1500
1000
500
50
150
Equatorial
Polar
Retrograde