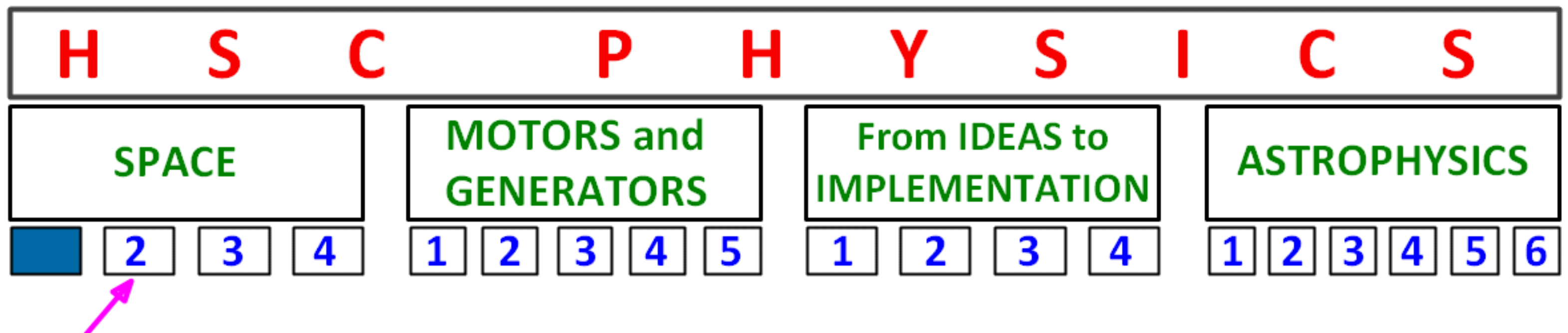


SPACE

1st Quarter; Module 1

PERIOD 15

Low Earth and Geostationary Orbits [LEOs and GOs]
Orbital Decay



SPACE 2

Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

Students learn to:

- describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components
- describe Galileo's analysis of projectile motion
- explain the concept of escape velocity in terms of the:
 - gravitational constant
 - mass and radius of the planet
- outline Newton's concept of escape velocity
- identify why the term 'g forces' is used to explain the forces acting on an astronaut during launch
- discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket
- analyse the changing acceleration of a rocket during launch in terms of the:
 - Law of Conservation of Momentum
 - forces experienced by astronauts
- analyse the forces involved in uniform circular motion for a range of objects, including satellites orbiting the Earth
- compare qualitatively low Earth and geo-stationary orbits
- define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods
- account for the orbital decay of satellites in low Earth orbit
- discuss issues associated with safe re-entry into the Earth's atmosphere and landing on the Earth's surface
- identify that there is an optimum angle for safe re-entry for a manned spacecraft into the Earth's atmosphere and the consequences of failing to achieve this angle

SPACE 2

Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

Students:

- solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using:

$$v_x^2 = u_x^2$$

$$v = u + at$$

$$v_y^2 = u_y^2 + 2a_y\Delta y$$

$$\Delta x = u_x t$$

$$\Delta y = u_y t + \frac{1}{2} a_y t^2$$

- perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis
- identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun
- solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using

$$F = \frac{mv^2}{r}$$

- solve problems and analyse information using:

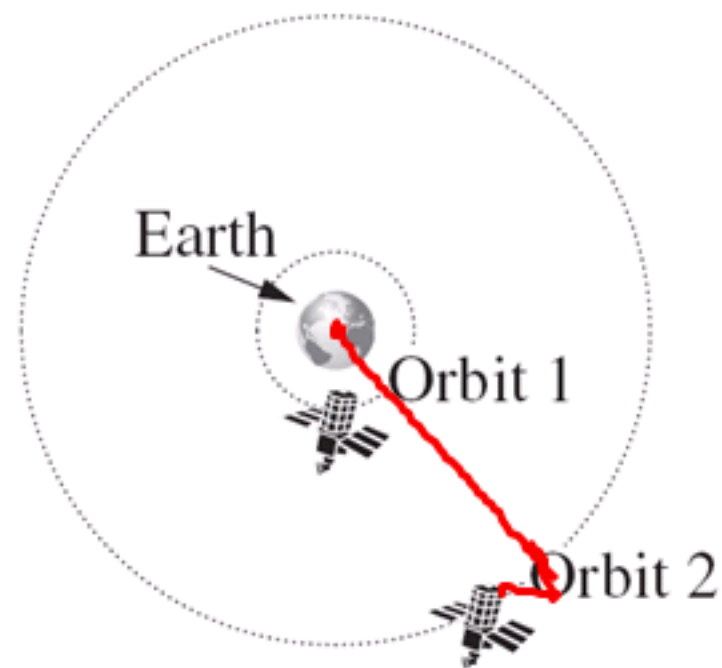
$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

COMPARISON OF COMMON CIRCULAR MOTIONS

MOTION	F_c PROVIDED BY ...
Whirling rock on a string	The string
Electron orbiting atomic nucleus	Electron–nucleus electrical attraction
Car cornering	Friction between tyres and road
Moon revolving around Earth	Moon–Earth gravitational attraction
Satellite revolving around Earth	Satellite–Earth gravitational attraction
Lady bug on a rotating disc	Friction b/w her hairy feet and the disc
Principal rotating the girl in the movie "Mathilda"	Tension in their arms
Playground swing	Tension in the rope
Vortex	Reaction force from the walls
Earth revolving around the Sun	Earth-Sun gravitational attraction

2008 HSC QUESTION

(b) A satellite is propelled from Orbit 1 to Orbit 2 as shown in the diagram.



$$\frac{mv^2}{r} = G \frac{mM}{r^2}$$

$$v = \sqrt{\frac{GM}{r}}$$

Orbit 2 has a radius of 27 000 km. What is the satellite's speed in this orbit?

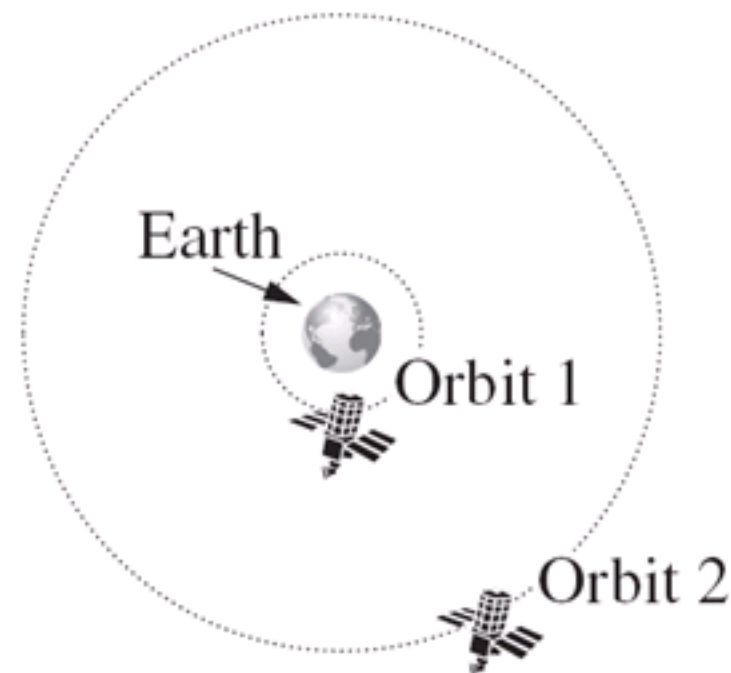
3

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{27 \times 10^6}} = 3800 \text{ m/s}$$

2008 HSC QUESTION

(b) A satellite is propelled from Orbit 1 to Orbit 2 as shown in the diagram.

$$\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$$



$$\frac{R_1^3}{T_1^2} = \frac{R_2^3}{T_2^2}$$

(c) The radius of Orbit 2 is four times that of Orbit 1. What is the ratio of the new orbital period to the original period?

2

$$R_2 = 4R_1$$

what is $\frac{T_2}{T_1} = 8$

$$\frac{R_1^3}{T_1^2} = \frac{(4R_1)^3}{T_2^2}$$

$$\frac{R_1^3}{T_1^2} = \frac{64R_1^3}{T_2^2} \Rightarrow$$

$$\sqrt{64T_1^2} = \sqrt{T_2^2}$$

$$T_2 = 8T_1$$

Types of Orbits: There are many types of orbits but we need to study only two:

$$R = 6780 \text{ km}$$

1. Low Earth Orbits (LEOs): > 250-1000 km from Earth's surface (radius of Earth is 6400 km)

Can you find the period of MIR space station - 380 km from Earth's surface?

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}} \approx 5500 \text{ s} \approx 1.5 \text{ hours}$$

$$v = \frac{2\pi R}{T} = 7600 \text{ m/s}$$

2. Geostationary Orbits (GOs): > orbits around the Earth in 24 hours.

Can you find the radius of orbit and altitude above earth for GOs?

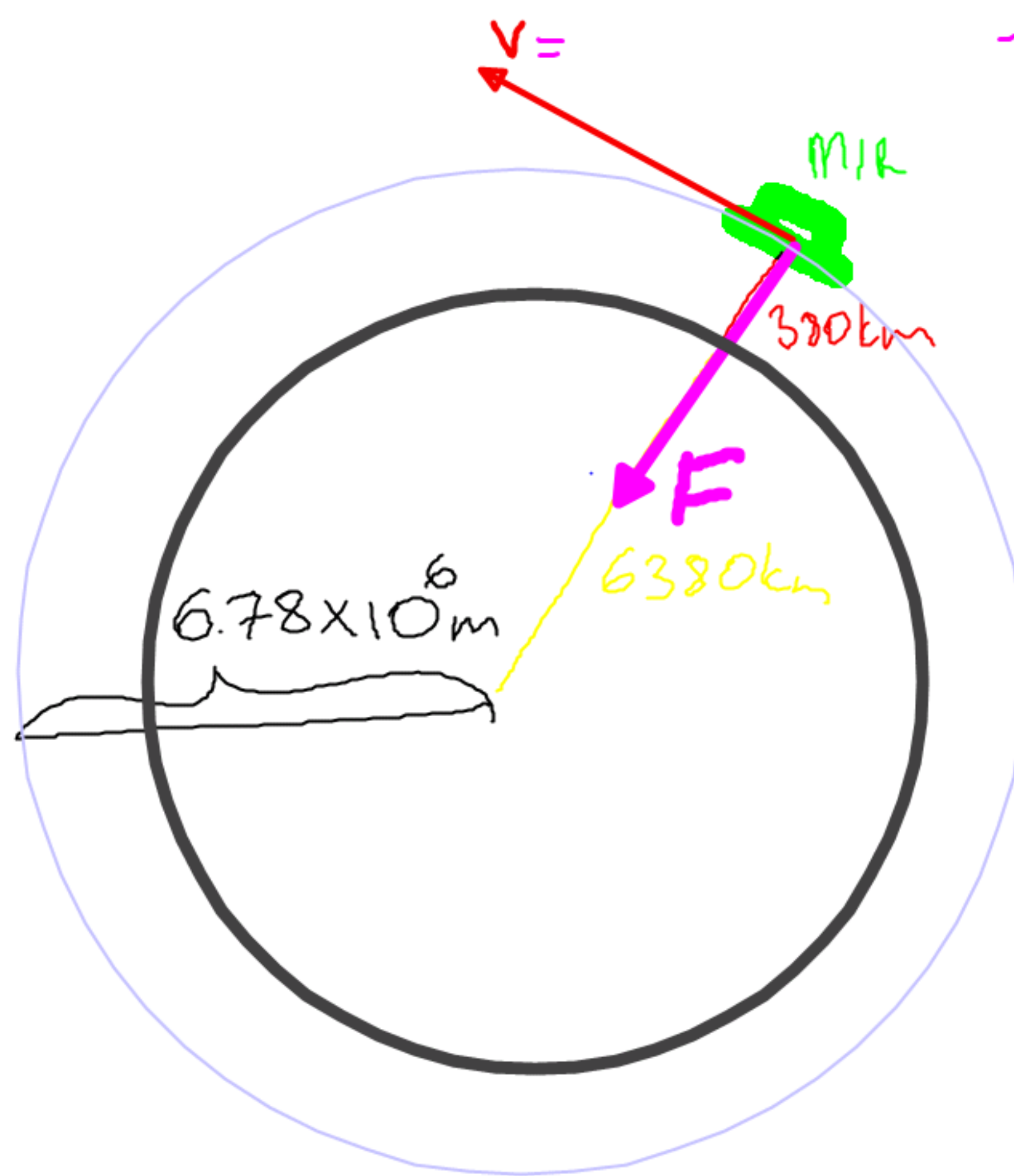
$$R = \sqrt[3]{\frac{GMT^2}{4\pi^2}} \approx 42000 \text{ km}$$

$$h \approx 36000 \text{ km}$$

altitude

$$= R_{\text{orbit}} - R_{\text{earth}}$$

$$v = \frac{2\pi R}{T} \approx 3000 \text{ m/s}$$



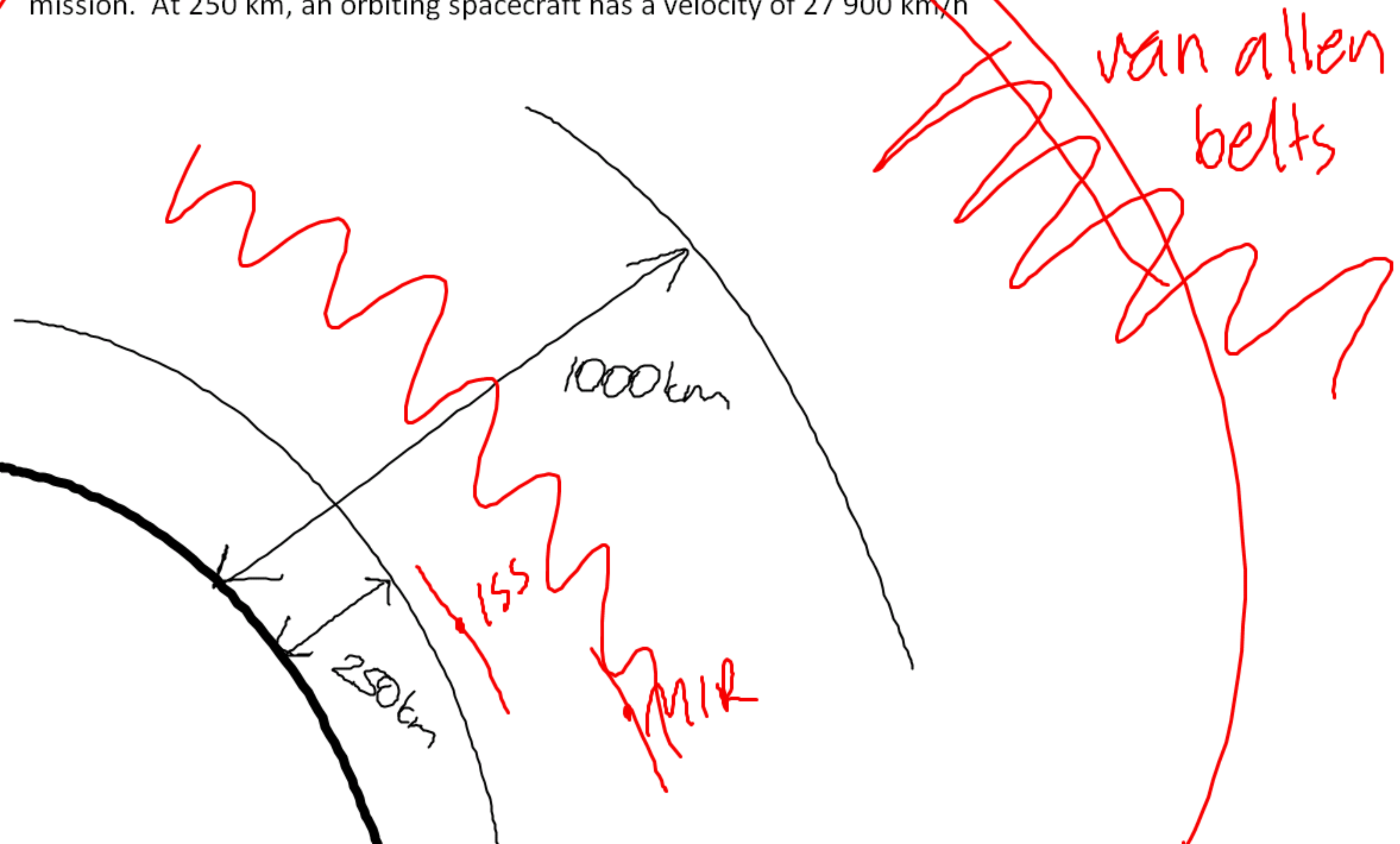
$$T = 5500s$$

LOW EARTH ORBITS

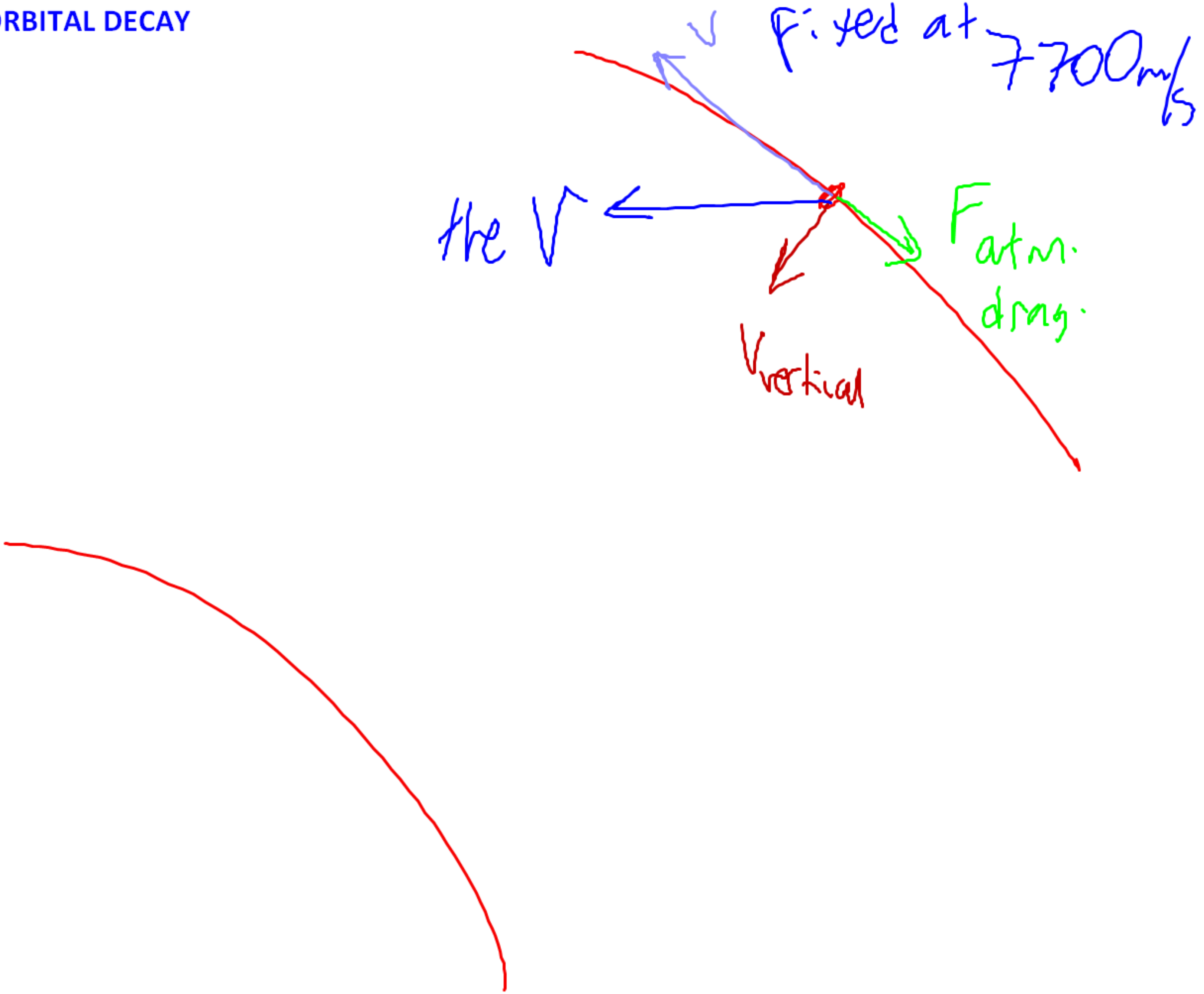
A **low Earth orbit** is generally an orbit higher than approximately 250 km, in order to avoid atmospheric drag, and lower than approximately 1000 km, which is the altitude at which the Van Allen radiation belts* start to appear.

*These belts are regions of high radiation trapped by the Earth's magnetic field and pose significant risk to live space travellers as well as to electronic equipment.

The space shuttle utilises a low Earth orbit somewhere between 250 km and 400 km depending upon the mission. At 250 km, an orbiting spacecraft has a velocity of 27 900 km/h



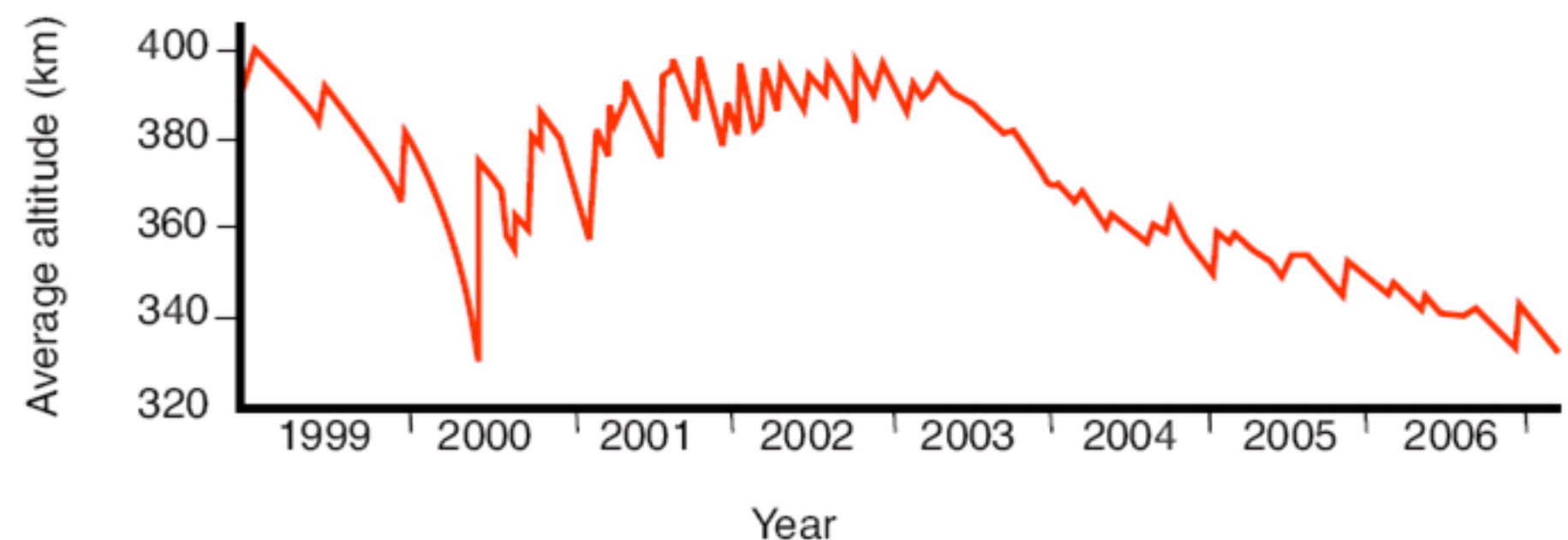
ORBITAL DECAY



ORBITAL DECAY

- a All satellites in low Earth orbit are subject to some degree of atmospheric drag that will eventually decay their orbit and limit their lifetimes.
- a Although the atmosphere is very thin 1000 km above the surface of the Earth, it is still sufficient to cause some friction with a satellite.
- a This friction causes a gradual ('nonimpulsive') loss of energy to heat.
- a A loss of orbital energy necessarily means a loss of altitude, so that this gradual loss of energy causes a low-orbiting satellite to slowly spiral back towards the Earth.
- a As the satellite descends atmospheric drag increases for two reasons:
 - The density of the atmosphere increases by a factor of almost 10^9 from an altitude of 150 km down to ground level.
 - As the satellite loses altitude some of its E_p is transformed into E_k and it speeds up \rightarrow it is literally starting to fall back to Earth. The drag force is proportional to the square of the velocity, so as the speed increases the drag increases much more sharply.
- a Designers plan for an expected satellite lifetime by building in small rocket boosters so that the satellite can be lifted periodically back up to its intended orbital altitude.

Figure 3.6 *Altitude changes of the International Space Station. The drops in altitude represent orbital decay due to atmospheric drag. The increases in altitude are lifts performed by visiting spacecraft.*

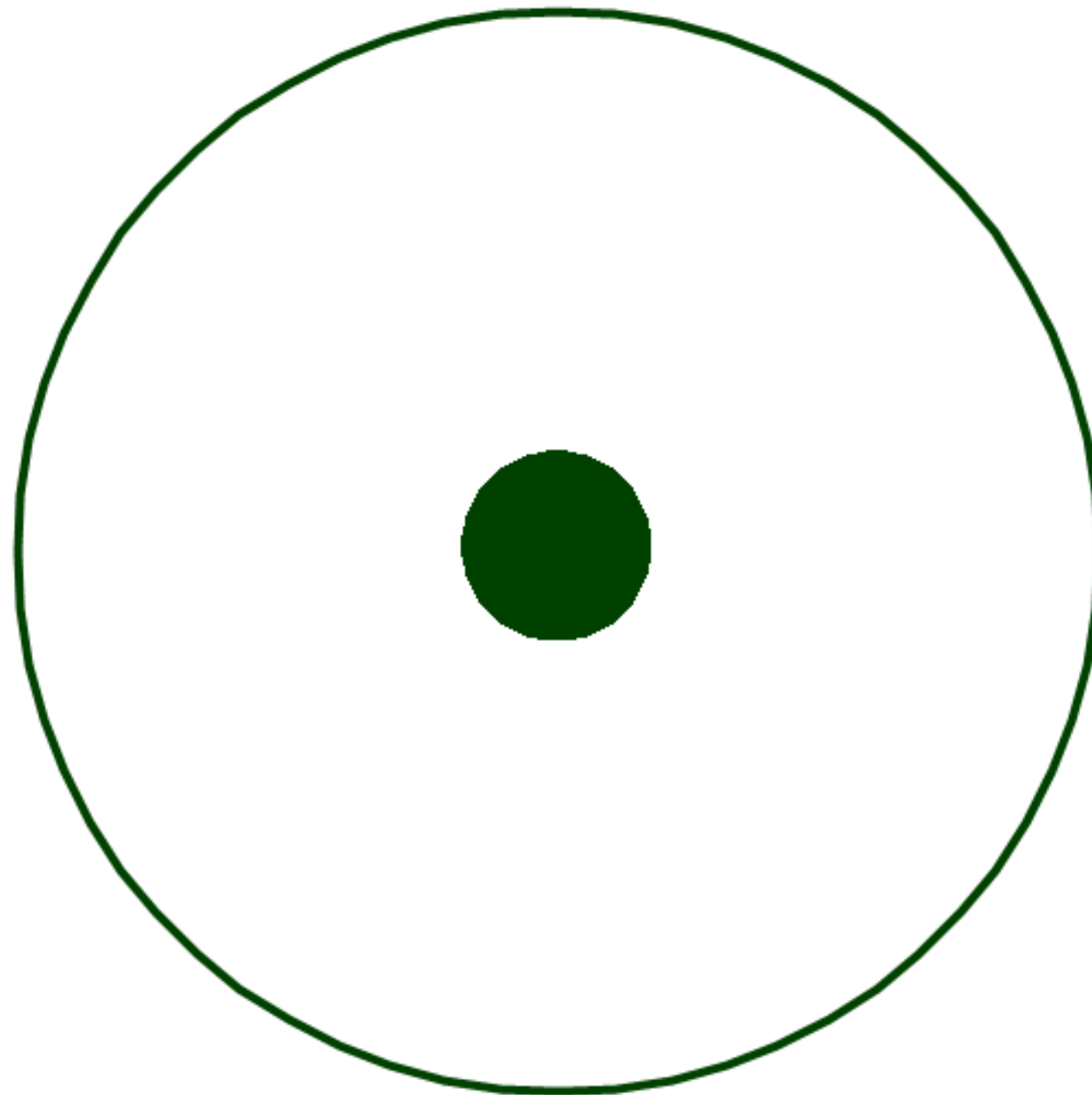


GEOSTATIONARY ORBIT

A **geostationary orbit** is at an altitude at which the period of the orbit precisely matches that of the Earth.

If over the Equator, such an orbit would allow a satellite to remain 'parked' over a fixed point on the surface of the Earth throughout the day and night. From the Earth such a satellite appears to be stationary in the sky, always located in the same direction regardless of the time of day. This is particularly useful for communications satellites because a receiving dish need only point to a fixed spot in the sky in order to remain in contact with the satellite.

This places the satellite at the upper limits of the Van Allen radiation belts and near the edge of the magnetosphere, making them useful for scientific purposes as well. Australia has the AUSSAT and OPTUS satellites in geostationary orbits.



COMPARISON OF LOW EARTH AND GEOSTATIONARY ORBITS

	LEO	GO
velocity	$\sim 7000 \text{ m/s}$	$= 3070 \text{ m/s}$
period	1.5 - 2 h	$= 24.00 \text{ h}$
altitude	250 - 1000 km	36000
orbital radius		
atmospheric drag		
purpose		

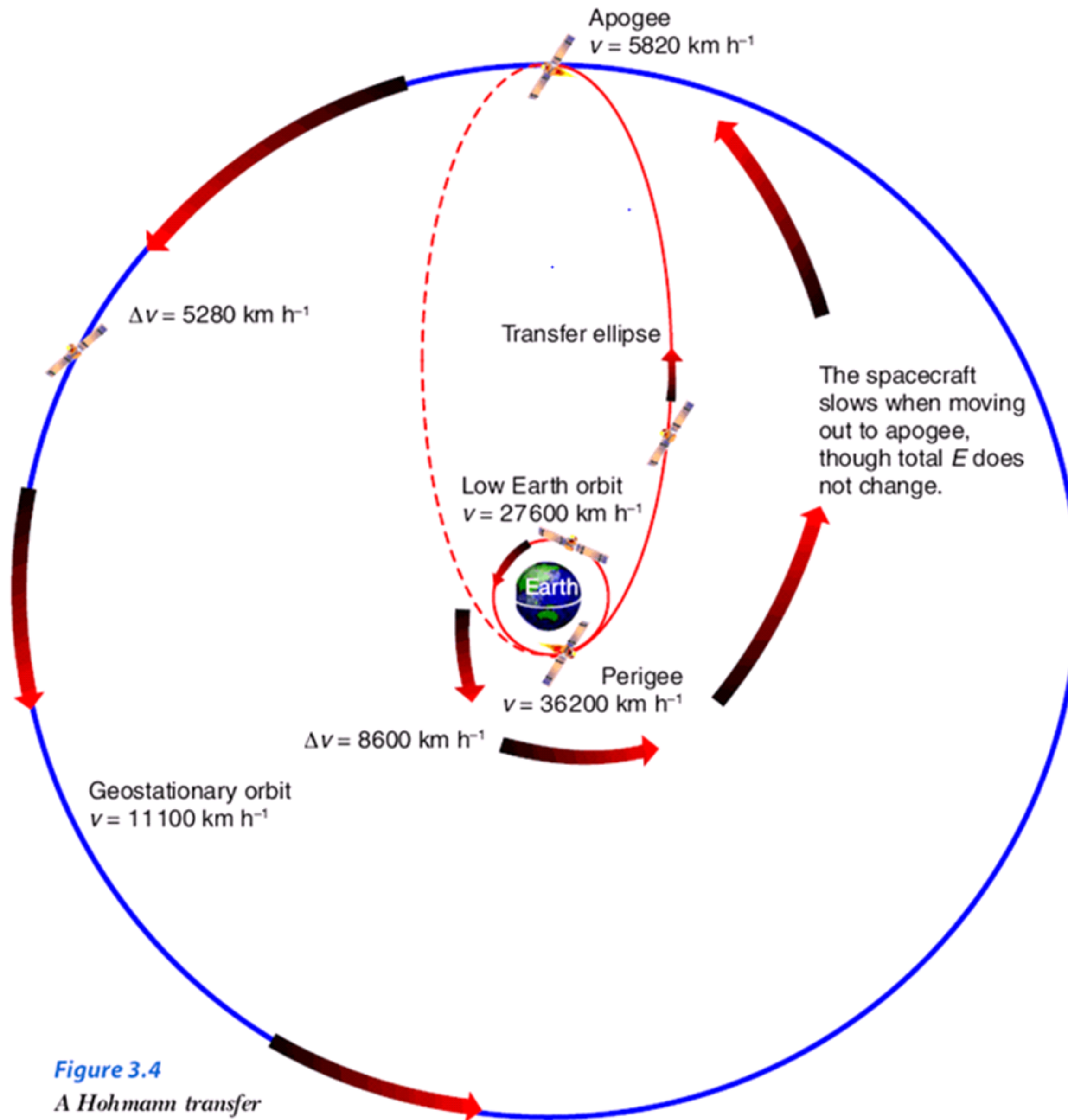


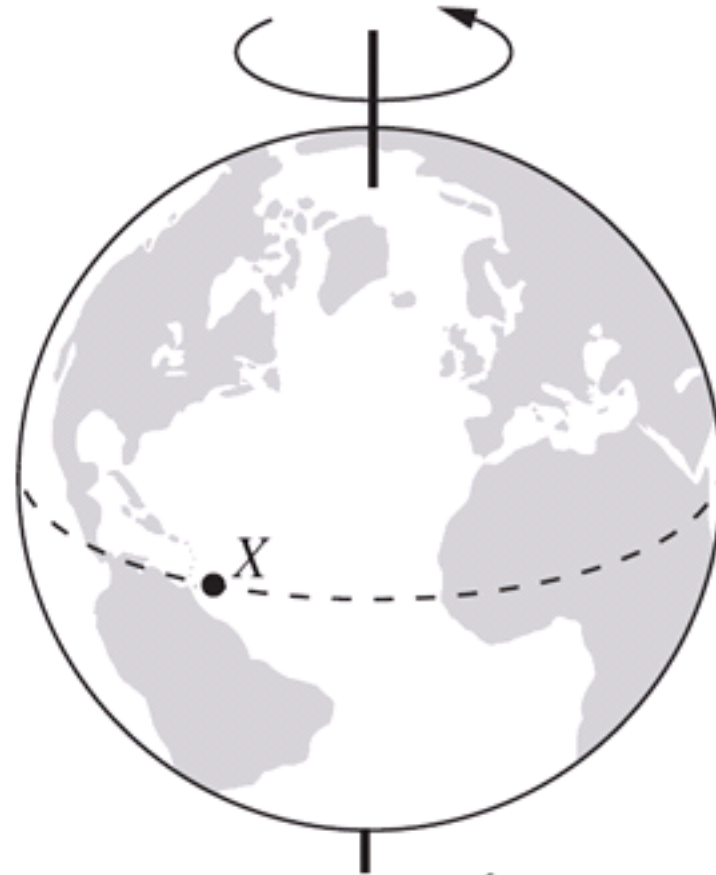
Figure 3.4

A Hohmann transfer orbit used to raise a satellite from a low Earth orbit of altitude 400 km up to a geostationary orbit of altitude 35 800 km

2007 HSC QUESTION

Question 17 (4 marks)

The diagram shows the position X on Earth's surface from which a satellite is to be launched into a geostationary orbit.



- (b) Given that the radius of Earth is 6.38×10^6 m, calculate the height of the satellite above Earth's surface.

3

HOMEWORK

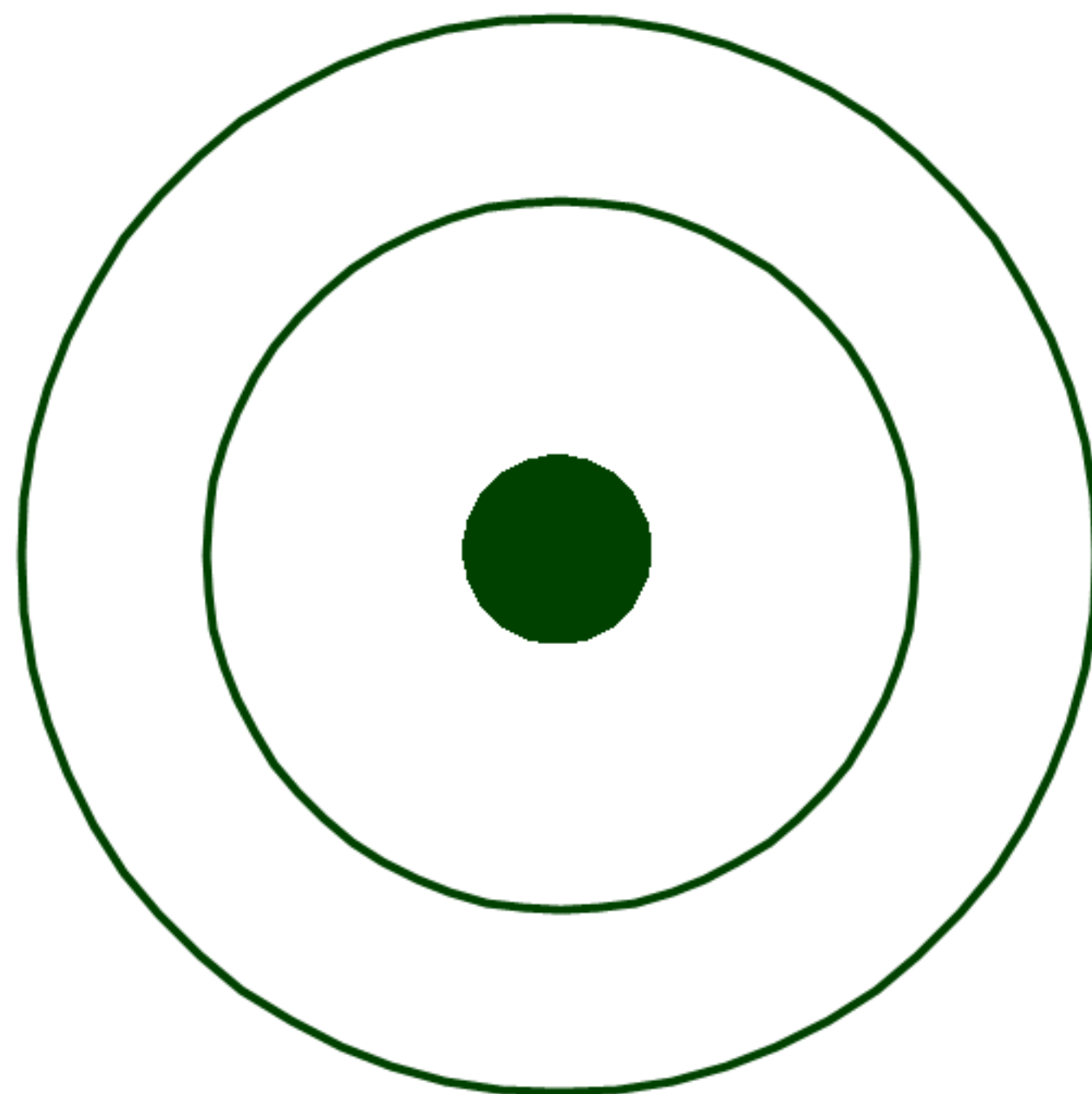
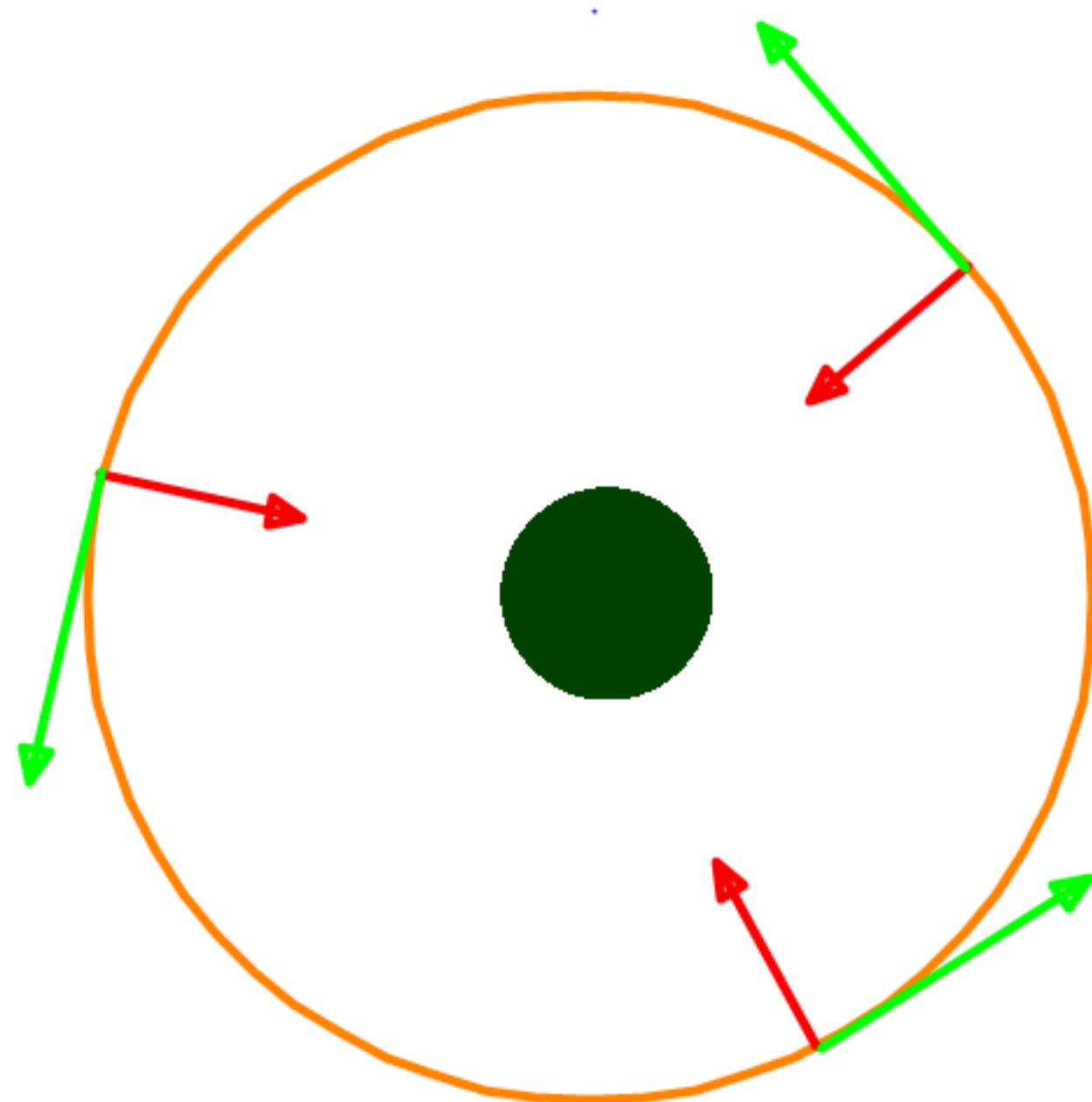
- ✦ Homework is an integral part of your "Learning Curve", take it seriously!
- ✦ Target minimum 1 hour of Physics everyday
- ✦ Divide your physics home study in three segments;
 - ✓ Revision (past)
 - ✓ Homework (present)
 - ✓ Tomorrow (future)
- ✦ Homework is due next period, unless otherwise stated
- ✦ If you cannot do all, at least do a few from each piece

*Apart from **reading the relevant pages from the textbook and solving the rest of the questions in this booklet** your homework is:*

1. Relevant pages in Multiple Choice Dot Points Book (DPB)
2. New 8 page booklet (pages 16-23)
3. Space 2 Past Year Questions
4. Chapter 3 all questions
5. Experiment 3 of the Practical Booklet
6. Old 8 page booklet (pages 8-15)

NEXT PERIOD > SAFE RE-ENTRY

	LEO	GO
Distance (relative to surface)	very close 250-1000km	not close $\sim 36'000\text{km}$
Period	much lower $\sim 1-2\text{hours}$	exactly 24h
Position relative to Earth's surface	constantly changing position.	always above the same point
Orbital velocity	faster for MIR = 7680m/s	not so fast $v \approx 3000\text{m/s}$
Atmospheric drag	significant	negligible



Steps in solving PM questions.

Step 1 > Read the question.

Step 2 > Understand the question.

Step 3 > Make sure you understand "What is given/provided" and "What is asked".

Step 4 > Draw a diagram.

Step 5 > Select your interval (A to B). Mark A and B on your diagram.

Step 6 > Draw the data table and fill in the details as much as you can. Mark unknowns.

Step 7 > Select the appropriate formula and solve it for unknowns.

