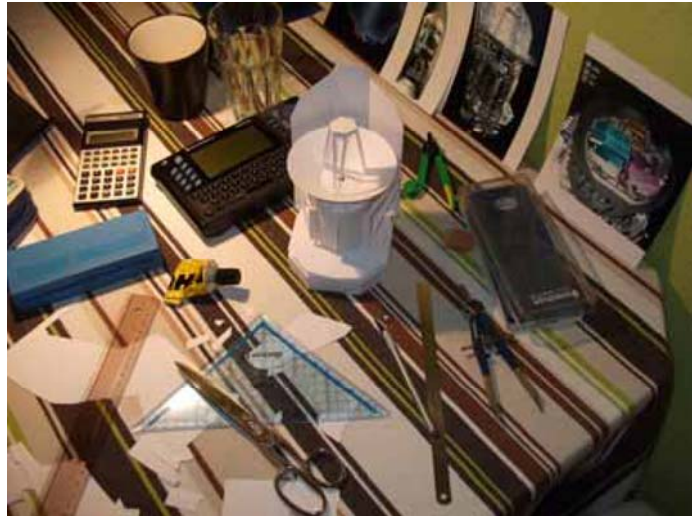


A model of the Herschel telescope

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1. Introduction

The Herschel telescope will mark a further milestone in the history of successful space telescopes. With its 3.5 metre primary mirror, the telescope will have the ability to make observations in the infrared and submillimetre range between 60 and 670 microns. There are three instruments available for this purpose, including two cameras which are able to picture spectroscopy (PACS and SPIRE) and a high resolution spectrometer (HIFI). Herschel will be able to make advances in the observation ranges that remained



hidden to all earlier space telescopes. The main scientific issues that Herschel will explore are

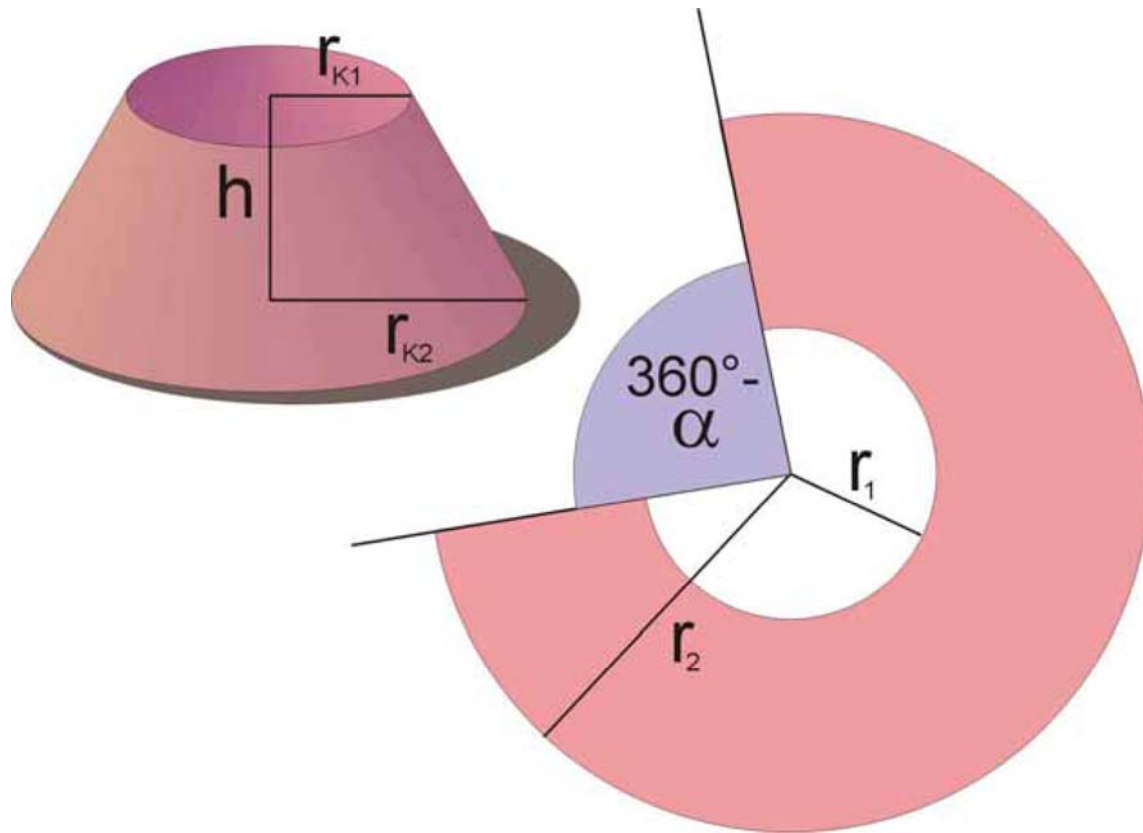
- the formation of the galaxies in the early universe and their subsequent development.
- the formation of stars and their interaction with the interstellar medium.
- the investigation of the chemical composition of atmospheres and surfaces of comets, planets and their moons.
- the investigation of the molecular chemistry of the universe.

The model, for which the assembly instructions and plan are introduced here, provides an authentic reflection of the appearance of the space telescope using a manageable number of individual parts. It is also simple to put together, even for inexperienced model builders. When planning this model it was important to limit ourselves to the essential parts to allow the mode of operation of this observation device to be understood in 3D. The primary mirror can be easily recognized, in the middle of which the inlet aperture through which the light beams enter the instrument bay can be seen. The entire upper part of the model, together with the primary mirror and the cover of the instrument bay, can be removed such that the three instruments arranged underneath become visible.

2. Classification and other disciplines covered

Physics	Mechanics	Gravitation, libration points
Astronomy	Space travel	Space telescope, Herschel satellite, spacecraft modules, Lagrange points
Related disciplines	Astro mathematics Astro equipment design	Truncated cones, model making and model design

3. Truncated cones



Three components of the model use segments of a circle which are shaped into truncated cones. These shapes can be covered in mathematics classes at intermediate level. You can start the assembly plan of the truncated cone while covering other bodies such as hexahedrons and pyramids. The theoretical concepts can quickly be tested in practice using paper, scissors and glue.

The issue of how the radii of the resulting cone (here: r_{K1} and r_{K2}) and its height are related to the corresponding radii of the sectors of the circle (here: r_1 and r_2) and its sector angle is rather more complicated.

Because the thickness of the boundary of the truncated cone corresponds to the difference of the segment radii $r_2 - r_1$, we can place a Pythagorean triangle on the sloping exterior of the cone:

$$(r_2 - r_1)^2 = (r_{K2} - r_{K1})^2 + h^2.$$

In addition, the following applies based on the theorems on bisecting lines:

$$\frac{r_1}{r_2} = \frac{r_{K1}}{r_{K2}}.$$

If we solve the second equation for r_1 and place this into the first, we can solve for r_2 to yield:

$$r_2 = \frac{\sqrt{(r_{K2} - r_{K1})^2 + h^2}}{1 - \frac{r_{K1}}{r_{K2}}}.$$

This yields the inner segment radius of

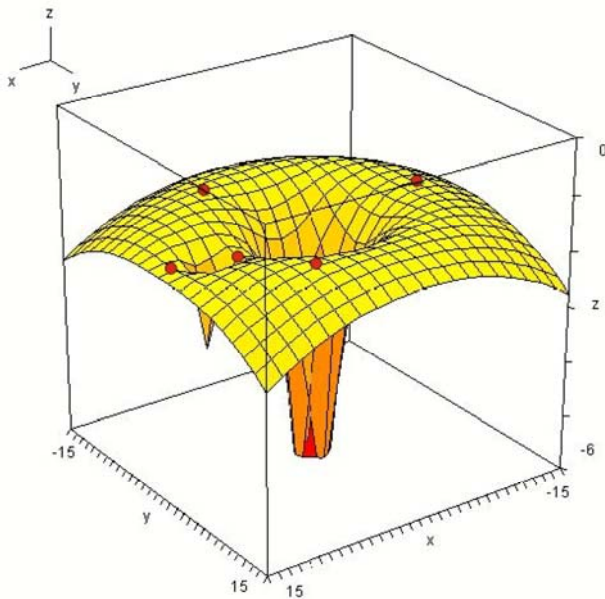
$$r_1 = \frac{r_2}{r_{K2}} \cdot r_{K1}$$

and the angle of the segment of the circle:

$$\alpha = 360^\circ \cdot \frac{r_{K1}}{r_1}.$$

Using this formula, a programme that enables the parameters required for the cone to be converted into the parameters for the segments of the circle (for a cut-out sheet) can be written quite quickly for use with the student calculators.

4. Effective potential and Lagrange points



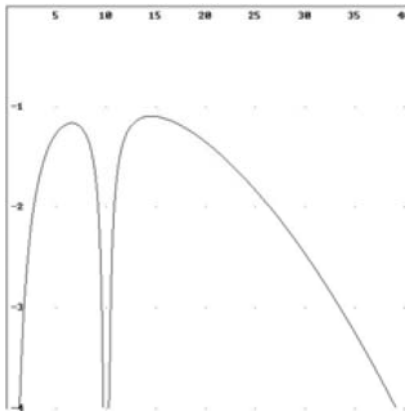
The topic of 'fields' is also dealt with in physics at this course level. If the electrostatic and magnetic fields are also addressed in the class, as is preferable, the topic of gravitational fields offers scope for considering analogies and interesting applications arising from space travel (e.g.: [GK07], p. 92ff.). The concept of potential can be introduced in connection with electrostatic fields and can easily be expanded to include gravitational fields. The concept of effective potential is interesting for space travel-related issues, the energy calculations of which not only provide the basis for gravitational forces of the celestial bodies involved, but also for the centripetal force that is required to keep a spacecraft (such as the Herschel telescope here) on a stable path with angular velocity ω . If we select the position of

the central celestial body (Sun) as the origin and the position of the other (Earth) at an interval of x_E on the x axis, the potential curve can be shown along the x axis. The following applies for the three forces that are to be added together

$$F(x) = G \cdot \frac{m \cdot M_S}{x^2} + G \cdot \frac{m \cdot M_E}{(x - x_E)^2} - m \cdot \frac{G \cdot M_S}{x_E^3} \cdot x.$$

For the angular velocity, which is supposed to correspond with that of the Earth, the following has been used:

$$\omega = \sqrt{\frac{G \cdot M_S}{x_E^3}}.$$



This then yields for the potential curve along the x axis

$$V(x) = \frac{1}{m} \cdot \int F(r) \cdot dr = -G \cdot \left(\frac{M_S}{x} + \frac{M_E}{|x - x_E|} + \frac{M_S}{2 \cdot x_E^3} \cdot x^2 \right).$$

The function graphs shown in this section using the programme Derive¹ are given as qualitative for $M_S = 5 \cdot M_E$. The gravitational constant was replaced by the dummy constant 1. The potential curve can be shown in the xy level accordingly:

$$V(x, y) = -G \cdot \left(\frac{M_S}{\sqrt{x^2 + y^2}} + \frac{M_E}{\sqrt{(x - x_E)^2 + y^2}} + \frac{M_S}{2 \cdot x_E^3} \cdot (x^2 + y^2) \right).$$

There is a corresponding illustration at the beginning of this section. The five libration points or Lagrange points, marked here using stable red balls, can be easily recognized. The ball to the left of the ‘terrestrial potential funnel’ is located on the Lagrange point L2, in which the Herschel telescope should also be positioned. This point is located in the two-dimensional function diagram at the position of the right local maximum, and the Lagrange point L1 is located at the position of the left local maximum.

5. Building a model of the Herschel telescope

As an attachment to this paper you will find the model template for the Herschel telescope, together with assembly instructions. The kit can be created by dividing the work among teams. You could for example pretend that the teams are different companies that have been commissioned to construct the telescope components and need to collaborate. The parts of the kit have been divided into four modules for this purpose.



Assembly module A comprises the basic frame with the solar cell shield, assembly module B the cooling system and the helium cryostat, assembly module C the instrument platform with the three instruments, and assembly module D the cover for the instrument platform with the mirror system. Each group of students could introduce their components to the class and also respond to some related questions posed by the teacher. The internet address [esa07] provided in the references can be used as one of many sources of information. ESA also has a webpage for students at primary level on its homepage. Questions related to the individual construction components could be for example:

¹ Derive™ 5.02 Copyright © 1988-2000 Texas Instruments Incorporated

Construction components	Possible related questions
A Base frame with solar cell shield	<ul style="list-style-type: none"> • What is concealed in the base plate of the telescope? • What functions does the solar cell shield fulfill?
B Cooling system (helium cryostat)	<ul style="list-style-type: none"> • Which parts of the telescope must be cooled? • How does a helium cooling system work?
C Instrument platform	<ul style="list-style-type: none"> • Which instruments can be found on board? • What are photometry and spectroscopy?²
D Mirror system	<ul style="list-style-type: none"> • What shape are primary and secondary mirrors? • What course does the optical path take in the mirror system?

6. Assembly instructions

The Herschel telescope kit has a scale of 1:34. If you copy the sheets onto A3 size paper (zoom factor 141%), you can compare the size by using Playmobil® figures. The kit components on the sheets are not ordered by assembly module and related numbers; they are ordered by colour. If you would like to make the kit in colour you can copy the templates onto coloured cardboard. Suggestions for colours can be found at the top of each sheet. It is generally advisable to score the edges to be folded. The following legend applies to the marking of the cutting lines and the folding lines:

Marking	Meaning
—————	Cutting line
.....	Fold backwards
- - - - -	Fold forwards
.....	Marking / positioning line

Before starting the assembly, please use the enclosed exploded drawing to get a general overview of the individual parts of the model. The part numbers are always located outside of the part. Smaller numbers on the parts indicate contact points with other corresponding parts. Complete all four assembly modules in order of the numbers.

Assembly module A:

Start with the component **A1**. Shape this into an octagonal prism and glue the side walls to the bottom (which has adhesive tabs). At this stage do not stick the top together (which has no adhesive tabs). First shape the stabilizing part **A2** into a square frame and glue it as centrally as possible inside the open octagon of part **A1**. Now close part **A1** by gluing it together. Next shape part **A3** into a cylinder and use it to connect parts **A1** and **A4**. Next cut out part **A5** and glue the square side of the resulting wedge onto part **A3** such that it points in the direction of the solar cell shield (**A6**).

² A good classification of the areas of astronomy can be found in the dtv Atlas zur Astronomie [Atlas of Astronomy] [He85].

Now attach the inner surface of the solar cell shield **A6** to the adhesive tabs of part **A4** such that there is a downward overhang of two millimetres. Then cover part **A6** with part **A7**. The two parts should meet together in alignment at the bottom, and there is a small overhang at the top and sides. Assembly module A is now complete.

Assembly module B:

This assembly module starts with the complicated part that is **B1**. Wedges must be folded within the basic cylindrical shape at three positions. Three small tabs close the holes located above. The cylinder, which is at first a little misshapen, is now brought into shape with the aid of the static support pieces **B1a** and **B1b**. The two parts are inserted into the cylinder from the bottom. The adhesive tabs each point downwards, part **B1a** should be glued in place one centimetre below the top edge of the cylinder and part **B1b** should be glued in place as low as possible. The conical component **B2** is now attached from below to the adhesive tabs of part **B1** and sealed using the circular part **B3**. Now the cryostat is complete except for the top cover from assembly module D. This cryostat is attached to the inner surface of the solar cell shield of assembly module A using three struts. The two symmetrical components **B4** and **B6** are attached to the two outer wedges on the cylinder of component **B1** using their adhesive tabs. The other side of each is stuck to the small outer tabs of part **A6**. The parts **B5a** and **B5b** are first glued to each other back to back and later serve as a vertical connection between the cryostat and part **A6**. Assembly module B is now complete.

Assembly module C:

The three instruments of the Herschel telescope are made individually and stuck to the instrument platform **C2**. Component **C3** is the SPIRE instrument (Spectral and Photometric Imaging Receiver), component **C4** is the PACS instrument (Photodetector Array Camera and Spectrometer), and component **C5** is the HIFI instrument (Heterodyne Instrument for the Far Infrared). The entire instrument platform is then stuck to the centre of the carrier part **C1** and placed inside the top opening of the cryostat (**B1**). When this has been done, the work for assembly module C is complete.

Assembly module D:

For this assembly group, begin with component **D1**. This component must later be able to be joined flush to the cryostat cylinder (component **B1**). Therefore when gluing it is extremely important to place this part **D1** around the top edge of component **B1** (caution: the two parts must not stick together!). Now place the cone from component **D2** onto part **D1** and close it using the ring **D3**. An additional cylinder (component **D4**) is glued to this ring. Now shape part **D5** into a 'bowl' and close it on both sides using the circular ring components **D6a** (from above) and **D6b** (from below). Now shape part **D7** into a cuff and glue this around the outside of the cylinder in part **D1**. Attach the three small adhesive tabs to the primary mirror (component **D5**). Now the mounting for the secondary mirror (component **D8**) still needs to be constructed. To do this, first make a hexagonal prism. The three holding struts have external notches to strengthen them. Use the adhesive tabs to stick the three holding struts to the triangular markings on component **D5**. As a final step, part **D9** is glued to part **D8** from above as a cover. When these steps have been completed, the model is ready.

7. Educational objectives

The students should...

- become acquainted with the design and mode of operation of the Herschel telescope.
- come to regard space telescopes as important technical instruments used to explore the galaxies, stars and celestial bodies in our Solar System.
- become acquainted with the mathematical formula for the truncated cone.
- work with and transpose formulae.
- become acquainted with a practical application of the concept of potential.
- Build a model of the Herschel telescope.

8. References

- [He85] Joachim Herrmann: *dtv Atlas zur Astronomie [dtv Atlas of Astronomy]*, 8th edition, Munich 1985
- [GK07] Joachim Grehn, Joachim Krause: *Metzler Physik [Metzler's Physics]*, Braunschweig 2007
- [esa07] Homepage of Herschel's telescope at esa:
<http://sci.esa.int/science-e/www/area/index.cfm?fareaid=16>