

Teaching Material for Schools

Eight teaching units for different school classes

The teaching material is a supplement to ESA's planetarium show "Journey to a Billion Suns. It has been created in cooperation with WiS [Science into Schools!] and made possible thanks to the generous financial support by AIRBUS Defence and Space (formerly Astrium). We thank the authors for their detailed handling of the topic and the sponsor for his kind support.



Introduction to the Gaia mission

Gaia design challenges

By Vincent Poinignoin, Gaia project manager at Astrium

Gaia, the most advanced space telescope ever built in Europe, will produce the most detailed map of our galaxy, the Milky Way, and reveal yet unknown areas. Gaia's mission has an even deeper purpose: to understand the origins and evolution of the Universe.

Gaia will map one billion stars at the heart of our galaxy, observing them approximately 70 times over the five years mission lifetime, recording their velocities and positions, including their distance from Earth, as well as their brightness.

Combining all these observations through a very complex ground processing, Gaia will finally offer extremely high precision measurements: from the moon, it would be comparable to measure the thumbnail of a person on Earth!

Using again the global astronomy concept successfully demonstrated by the Hipparcos spacecraft, built by Astrium and launched in 1989, the Gaia payload incorporates two large-scale telescopes observing simultaneously in 2 directions separated by the so-called "Basic Angle" of 106.5 deg. This optical concept, patented by Astrium, allows combining both optical paths towards a single focal plane where observed fields of view superimpose while being able to discriminate each star image incoming direction.

To cope with these overlapping optical beams, the first opto-mechanical challenges were to define adequate folding to contain the overall spacecraft diameter within the Soyuz launcher fairing, and to design a structure avoiding the optical beams. This has been achieved thanks to an original concept of the optical bench, where the 10 mirrors of the optical layout and the common focal plane are hanged to a toric structure. The Gaia instruments benefit from the unique in-house expertise in the field of silicon carbide (SiC) technology used on all telescopes or instruments developed and built by Astrium. All the mirrors, the focal plane structure, the detectors supports and the main primary structure are made of this SiC, the only condition to ensure the very stringent optical stability. An interferometric device is mounted on the telescopes to monitor permanently throughout the mission lifetime the Basic Angle stability with an accuracy of about 1 micro-arcsec.

Mixing the three different types of measurements for astrometry, photometry and spectroscopy for Gaia science needs, the focal plane is a gigantic one-billion pixels sensor, with 106 CCDs detectors of 9 million pixels each, distributed on a 1 m² focal plane area. Gaia will detect stars autonomously with a capacity of 10 000 stars/s, thanks to an on-board processing mixing hardware computing and a software power of 7000 Mips.

The Gaia spacecraft design is also driven by two major requirements.

The first one is to maintain the detectors temperature at -110 °C, which leads to a cool-down of the full payload about -150°C. This constraint is imposed to minimize the effects induced by the space radiations on the detectors, which are detrimental to the astrometric accuracy.

The second one is to maintain the stability of the angle between the two lines of sight, the "Basic Angle", within a few micro arcsec.

To reach such performances, the Gaia payload needs to be extremely stable from thermal and mechanical viewpoints, then isolated as much as possible from the external environmental disturbances.

An ultimate insulation from the solar flux is obtained by the cumulative effect of a deployable Sun-shield, maintaining the payload in the Sun shadow, a CFRP structure fully covering the payload and finally multi-layered insulation blankets on the entire payload structure. From a +70°C temperature on the sunny side of the sun-shield, the payload ambient temperature is about -150°C and is extremely stable within +/-5 micro °C. Then, thanks to the combination of a high thermal conductivity and a low thermal expansion of the silicon carbide, the mechanical stability of the opto-mechanical assembly is in the range of a few picometers allowing the required angular stability in the range of picoradians to be reached!

Besides, the payload is decoupled from mechanical and thermal disturbances of the other parts of the spacecraft, thanks to a very flexible iso-static glass-fibre link with glass-fibre bipods. As these ones cannot withstand the launch loads, they are reinforced by stiffer carbon fibre bipods releasable once in orbit.

Last but not least, another very strong need is to control the line-of-sight scanning speed with an accuracy down to the milli-arc-second/second, not to blur the star images on the detectors.

Not accessible with classical propulsion systems, the Gaia spacecraft embarks a low disturbance "micro-propulsion" attitude control device for the operational mode, based on cold-gas thrusters offering the micro-Newton accuracy. Any mobile part in the Gaia spacecraft has also been prohibited which imposes the use of an active antenna, which electronically steers the communication beam towards the Earth, describing a cone 45 deg apart of the Gaia spin axis. The science data transmitted to the ground stations at a daily average rate of 100 Go, will cumulate up to 1 Peta-octet (1000 To) after the 5 years of mission.

[2014]

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Vincent Poinignon is the project manager in charge at AIRBUS Defence & Space (formerly Astrium). Astrium has been commissioned by the European Space Agency (ESA) and was responsible for the development and the construction of the Gaia satellite. As prime contractor, Astrium coordinated over 50 suppliers all over Europe and managed a budget of approx. 500 million Euro. The Gaia satellite was manufactured at its Toulouse site and then tested at several locations, prior to being launched on the 19 December 2013 at 9:12 UTC from the European Spaceport Kourou (French Guyana).

Astrium was renamed as AIRBUS Defence and Space as part of a corporate restructuring on 1 January 2014.

Gaia - The Milky Way World Map is being revolutionised

With regards to a short message in and an on-line contribution from SuW 1/2014, furthermore with references to contributions in SuW 5/2013, SuW 6/2013 and SuW 10/2013 and based on the planetarium program on the Gaia mission.

Autors: Cecilia Scorza, Dirk Brockmann-Behnsen, Olaf Hofschulz, Olaf Fischer

If you compare today's world maps with those from the Middle Ages, you will see enormous changes. The accuracy of maps improved dramatically with the new positioning opportunities. Among other things, consider here the leap in accuracy that was possible due to the determination of longitude using a precise clock over a long time.

Similar progress was possible in the mapping of the Milky Way system. We are currently on the cusp of a revolution of our map of the Milky Way system. Space observatories such as Gaia make this possible.

The aim of the following WIS entry is to link selected aspects of the Gaia mission with educational content and to present them in an understandable manner with a multitude of activities for students.

Overview of references		
Physics	Mechanics, optics, quantum physics	Gravitational field, Central force , Gravitational force , Summation of forces , Lagrangian points , uniform linear motion , Mirror optical paths , Colour addition , Digital camera
Astronomy	History of astronomy, astronomy of position, solar system, stars, space travel, astropraxis	astronomical coordinates , star images , Stars (distances, Colours , Spectral types), Star clusters , Stellar evolution , Milky Way system (Structure , Components), identification of trigonometric distance , Standard candles , annual parallaxes , Astrometry , astronomical CCD camera , optical path Telescope , space telescopes and their positions
Link between topics	Astro Mathematics Astro Technology Astro - History	Coordinates , Area calculations , linear functions , inverse quadratic functions , intersections of functions , trigonometry , link between arc lengths and angle , parallaxes (relative and absolute) , CCD camera , Link between technological development, schools of thought and scientific data
Teaching in general	Competencies (transfer of knowledge and findings), teaching aids	Evaluation of image material , Assessment of scales, full-scale conversion , astronomical research methods, Work with software to simulate the view of the sky and fields depicted by the CCD camera , potential of satellite missions for acquiring knowledge, Sorting task , analogy observation , cloze text , craft work sheet , construction manual , Source for student papers



Gaia

The Milky Way world map is being revolutionised

1. History: [Milky Way world view through the ages](#)
2. Astronomy: [Distances in the Milky Way system - Travel to the stars](#)
3. Astronautics: [Lagrange 2 - Gaia's address in space](#)
4. Technology: [Gaia's optics in the model](#)
5. Technology: [Gaia's telescope system](#)
6. Technology / Computer Science: [Gigapixel camera](#)
7. Mathematics: [Calculation of distance - relative and absolute Parallaxes](#)
8. Astronomy: [Gaia and our knowledge of the stars](#)

Figure 1: The distant regions of the Mercator Europa map of 1589 differ from the current map of Europa. The current map of the Milky Way system is changing in the same way (images: Image map: Tartu University Library, Mercator, Gerardus, 1512-1594 Mercator, Rumold, 1545-1599; Image Gaia: ESA/C. Carreau).

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1. Milky Way conception through the ages

(Olaf Fischer)













Most of us as children, we experienced the world around us in different (false) dimensions. The world often seems much bigger in a child's eyes. Astronomers underwent and undergo the same experience when looking at the Milky Way system - our cosmic environment. This evolution is linked to the development of observational (technical measurement) capabilities, modern day mind-sets (paradigms) and breakthroughs in "thinking barriers". A historical section below shows some important stages in the acquisition of knowledge on the size and composition of our "Milky Way Galaxy" (sorting task). An additional section shows the difficulties of astronomers in describing the Milky Way system, which they have only been able to see from within (analogy observation).

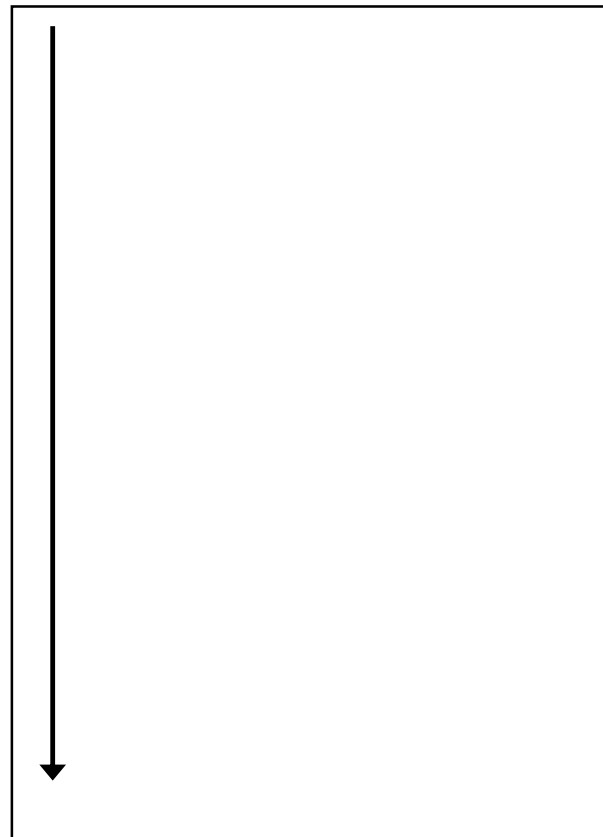
Sorting task

Sort the blocks of facts given below (times, persons, developments; see image below) in their chronological order and based on their connections (left: time; centre: if available, people; right: developments in technology, thinking and science).


Now draw a timeline on the left side of a blank A4 page, extending from top to bottom (see image below right). Now cut out all fact blocks (following page) for the sorting task. Then stick the blocks with the time details in the right sequence. Now comes the hard part. Put the times of the events and developments in the right order (glue them in). Search for important people who are linked to these developments. Check the order before you glue everything. At the same time, think about the context of the major findings and thinking in which the new knowledge on the Milky Way system could occur. This will also draw on your knowledge from the history lesson.







Blocks of facts for the sorting task

1838	from 1450	from 2005	1608	1728	from 1960s	1584	1712	1939-1945	
Mid 15 cent.	1920	1609	1618-1648	1543	1950s	From 1990s	1785	2010	
from 1992	Galileo Galilei 								
Giordano Bruno 	James Bradley	Friedrich Wilhelm Bessel 							
William Herschel 	Harlow Shapley Heber Curtis 	Nicolaus Copernicus 							
The Dutch spectacle maker Hans Lippershey builds the first telescope (Dutch telescope)				Use of moveable letters in metal for printing					
Using the Fermi space telescope two huge "energy bubbles" are discovered in the gamma ray wavebands, which project North-South from the middle of the Milky Way system 									
Beginning of the Industrial Revolution in Great Britain, first usable steam engine (Thomas Newcomen), many discoveries				Thirty Year's war.					
First telescopic observation shows that the Milky Way is made of stars. 			Development of radio location systems (RADAR) for military purposes (World War 2).						
The development of adaptive optics (for the military since the seventies makes high resolution astronomical observations possible (prevents "smearing of images" through atmospheric turbulence).			First measurement of a fixed star parallax for the star 61 Cygni.						
First time manufacturing of clear, transparent glass in Europe (Idea: Angelo Barovier)				Publication of the ideas about heliocentrism					
High resolution observations (using adaptive optics) from stars near the galactic centre in the near infrared region: Evidence of a super massive black hole in the centre of the Milky Way system. 									
Construction and use of large reflecting radio scopes: Milky Way system as a lensular collection of stars with the sun in the centre. 			Radio observations demonstrate the spiral structure of the Milky Way system 						
Analysis of the infrared shots of the Spitzer space telescope by astronomers at the University of Wisconsin-Madison show that the Milky Way system is a two-armed barred spiral galaxy (and not a "regular" spiral galaxy). 									
The development of sensors for infrared radiation (for the military since the fifties) leads to the development of infrared astronomy.									
Discovery of the directional deviation of the star light propagating at a finite speed from the moving earth (aberration) when searching for fixed star parallaxes.				Hypothesis: Space is infinite in size and unending and is not geocentric. The sun is no exception among the stars.					
Shapley: Milky Way system much larger than believed, sun not in centre, spiral clouds are gas clouds in this single giant galaxy, Curtis: Milky Way system (MWS) much smaller, spiral clouds are objects at great distances from each other like the MWS.									




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Exploration of the Milky Way system - an analogy observation

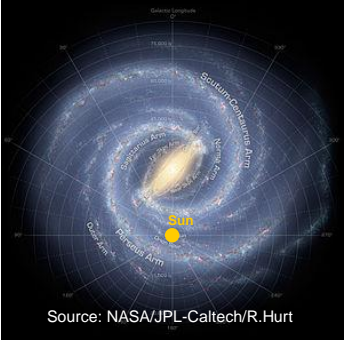
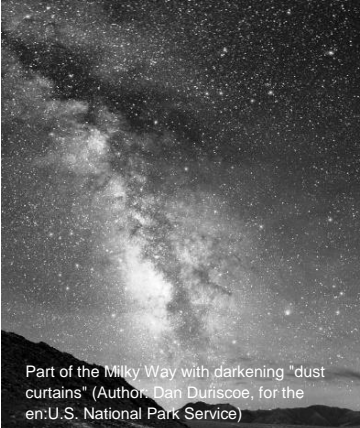
Exploration of the Milky Way system is impacted by the difficulty that it must be carried out from a fixed point (the location of the sun) from its interior. Compare this with the task of drawing a city plan from a place of residence without being able to visit the city or being able to see it from a bird's eye view.

An analogy observation is also used below which should show how the astronomers work like detectives to construct an "image" from clues. The analogy makes it easier for students to understand the information in a more realistic way and also makes it easier to memorise.

Task: Cloze text

Fill the gaps in the following analogy observations, by using your own experience to draw logical conclusions and referencing different sources (books, journals, Internet).

Supplement: Using your own school as a starting point, draw a city plan with dimensions, in order to show visitors to the school how to get to different places in the city.

City plan cartographer at the place of residence	Astronomer at the position of the sun
<p>Centre We assume here that the density of lamps (inside houses and outdoors) increases as you approach the town centre. If you count the number of lamps per directional area at night in a 360° view (not increased), it is possible to identify the direction to the town centre.</p>	<p>Astronomers assume that the quantity of [] increases as you approach the centre of the Milky Way system. By [] stars (number of stars per sky area) you receive initial indications of the decentralised location of the [] and the direction to the galactic centre in the [] .</p>  <p>Source: NASA/JPL-Caltech/R.Hurt</p>
<p>Perspective On foggy days, we can lose sight of distant environments and sometimes of the city centre. In near infrared regions the view is better.</p>	<p>Interstellar dust (dust between the []) impedes direct view of the galactic centre. To be able to look deeper into the galaxy, astronomers view the [] of the electromagnetic spectrum.</p>  <p>Part of the Milky Way with darkening "dust curtains" (Author: Dan Duriscoe, for the en:U.S. National Park Service)</p>

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City plan cartographer at the place of residence	Astronomer at the position of the sun
<p>Distances (with angles) To establish distances to different places in the city, without having to travel there, we use our knowledge of trigonometry. So for example we look towards the lightning conductor of the neighbouring house while standing to the left and right of our own house and see it from slightly varying directions. Using the angle between these two directions and the distance between our observation points we can calculate the distance to the conductor.</p> <p>Distances (with light sources) An illuminant (electric light bulbs, fluorescent lamps, etc.) with specified radiance (in Watts) appear to be dimmer the further away you go from it. If you know the brightness for a known distance, it is possible to calculate any distance that you want from the magnitude measurement. In the city there are many street lamps. We can therefore assume that these all contain standardised illuminants with defined light outputs. The radiance is also revealed by the type of light - e.g. by its red colour.</p> <p>Vision with radio emission Almost everyone owns a mobile or a laptop with wireless access. As a result, each of us represents a radio source, which could be "tapped" in order to find the sender's location and movements. (We know that radio emissions can pass through things that light is not likely to pass through).</p>	<p>To calculate the distances to the stars, you find the angle between two lines of sight to them, taken from two observation points from the earth on its journey around the . How this is done is explained later (see "Measurement of distance by angle measurement"). If this angle has a value of 1" (the part of a degree) and if both locations on orbit are at a distance of 1 astronomical unit (approx. 150 million km) from each other, the distance to the star is 1 parsec (pc).</p> <p>In the Milky Way system (and beyond) there are sources of luminosity that "are standardised in nature". Astronomers call these Standard Candles. The qualification of stars in terms of depends on how precisely you can determine their luminosity (radiance). Certain star types e.g. Delta Cephei stars are excellent standard candles. O and B spectral type stars are not as good but are still very useful, as they are extremely bright and can therefore be viewed at a greater . They were used to demonstrate the existence and position of the Milky Way system's spiral arms. How did that happen? The approximate luminosity of the O and B stars was known; and the minimum for one object was also known. Now you could use the measurements to find the unknown to the stars.</p> <p>A large amount of gas and some dust exist between the stars of the Milky Way system. Most of the gas consists of neutral hydrogen which emits emissions with a wavelength of 21 cm, allowing it to the interstellar in the galaxy. This interstellar hydrogen is "intercepted" by the radio-astronomers. Based on these observations they were able to reconstruct the spiral structure of the galaxy, where the interstellar material exists in greater density.</p> <div data-bbox="1037 1590 1388 1915" data-label="Figure"> </div> <p>Density distribution of neutral Hydrogen in the Milky Way plane (graphic: Oort, Kerr, Westerhout, 1958)</p>

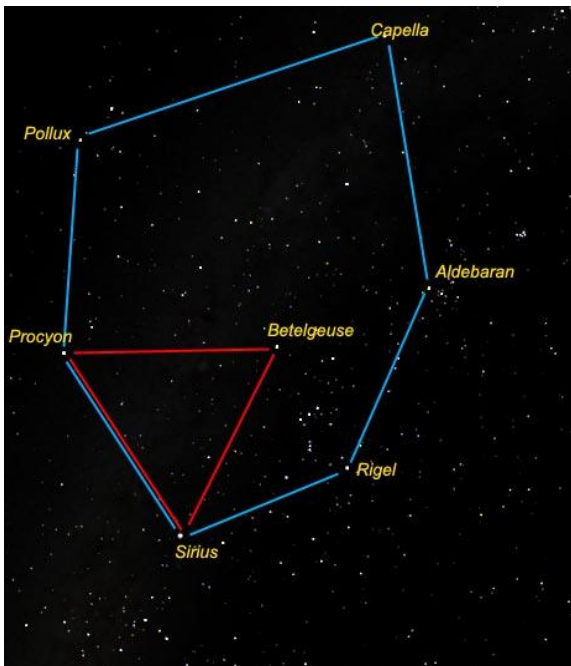
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2. Cosmic distances in the Milky Way - Journey to the stars

(Cecilia Scorza)

Looking at the winter sky

The star sky is never as full of bright stars at any other time of the year than in winter and it is at this time that it is the most beautiful to look at. If you look almost directly straight up towards 10p.m. (when in Germany) you discover a bright yellow star. It is called Capella and is the brightest star in the Auriga constellation. Together with Aldebaran in the Taurus constellation, Rigel in Orion, Sirius in Canis Major, Procyon in Canis Minor and Pollux in Gemini, Capella forms what is referred to as the Winter hexagon (fig. 2).



If we could travel at the speed of light towards the Winter hexagon, the first star we would arrive at, after an 8 year trip, would be Sirius. Next would be Procyon after another 11.2 years. A light year is the distance that light travels in one year (speed of light: approx. 300,000 km/s!) This corresponds to approx. 10 billion kilometres!

Closer examination of the main stars of the hexagon constellations reveals their different colours. Sirius, by far the brightest star in the night sky, is blue-white in colour, while Aldebaran in Taurus appears to be red. These different colours are due to the different surface temperatures of the stars. To understand this better, take the example of a glowing iron rod. If this is placed in a fire, it first turns red in colour. After a while, it radiates orange, yellow, white and finally, just before it melts, it turns bluish in colour.

Astronomers arrange stars based on their surface temperature in different "starlight types"

(the technical term is 'spectral type') denoted by the following letters: O, B, A, F, G, K, M. A funny rhyme to help remember this is: "Oh Be A Fine Girl, Kiss Me" or "Oh Be A Fine Guy, Kiss Me"!

In Table 1 the temperature ranges are listed in Kelvin and die star colours are listed that correspond to each of the spectral types (OBAFGKM).

Table 1: Surface temperatures and colours for stars of the different spectral types.

Surface temperature [K]	Colour of star	Colour
30000 – 60000	blue	
10000 – 30000	blue-white	
5000 – 10000	white	
3000 – 7500	yellow-white	
3000 – 6000	yellow	
5000 – 5000	yellow-orange	
3500	red	

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Task - Winter hexagon stars

1. What is a light year? Is it a unit of time or distance?
2. Using the colours of the stars in fig. 2 and the details in table 1, enter the temperature ranges of the main stars in the winter hexagon and their spectral types in table 2. Which is the coolest and which is the hottest star?
3. Enter the names of the hexagon stars in fig. 3. Complete the distance scale using the values from table 2 on the right side in fig. 3 and enter the stars per distance there on each sight line (broken line). Compare the actual distance ratios with your estimates and discuss the discrepancies.

Table 2: Data of stars
in the winter hexagon

	Distance [Lj]	Temperature	Spectral type	Radius [Solar radii]
	11.2			12
Aldebaran	70			25
Rigel	650			78
Sirius	8.6			1.7
Procyon	11.2			1.8
Pollux	33.7			8

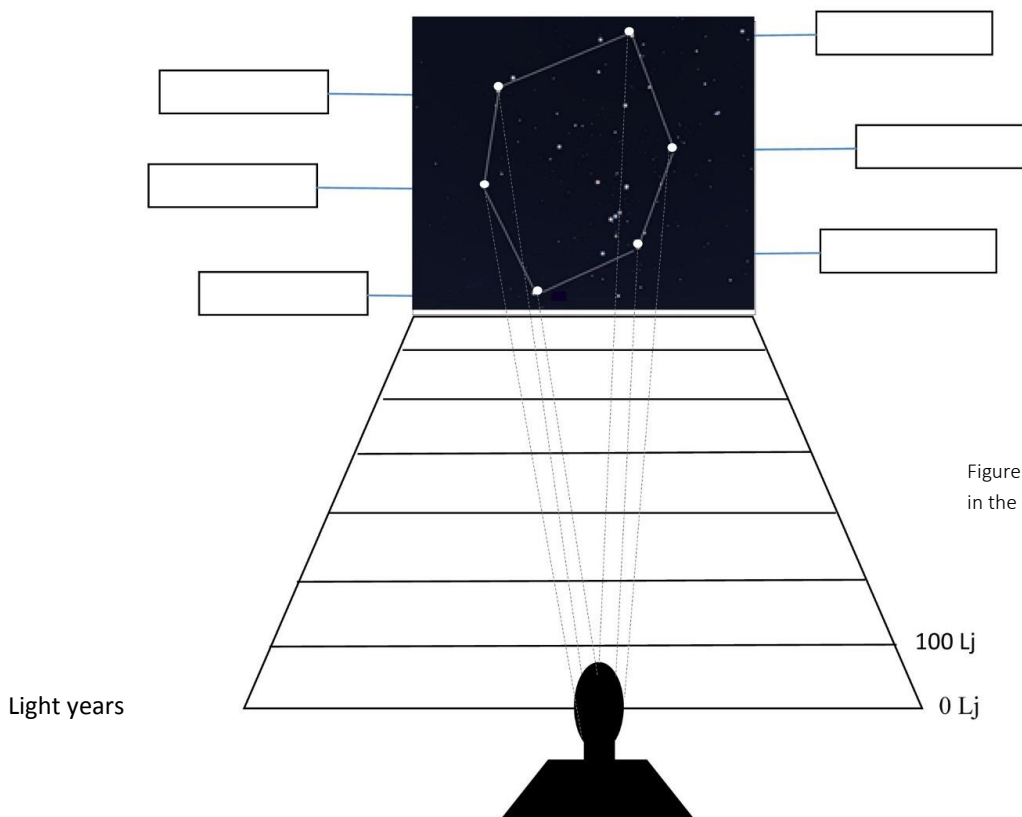


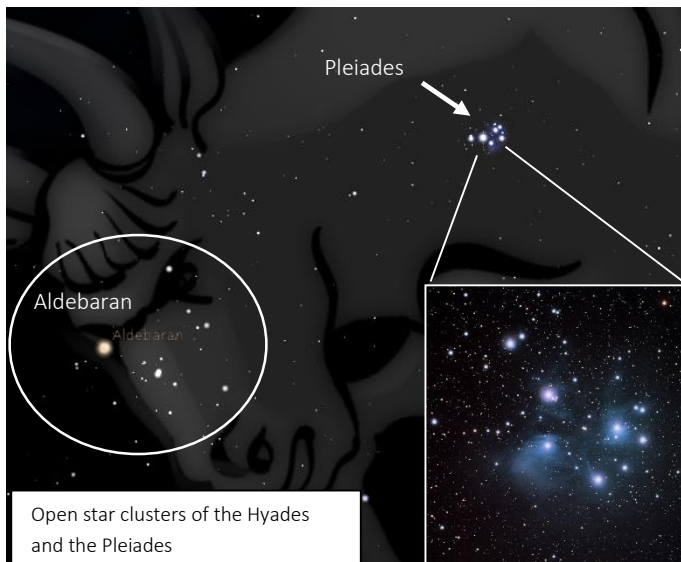
Figure 3: Distances of Stars
in the Winter Hexagon

4. Using the values for the star radii in table 2, draw the stars as circles. As far as possible, use the scale 1:700,000,000,000 (the radius of the sun (700,000 km) corresponds to 1 mm). Estimate how many times the earth fits into the Sun. The radius of the Sun is nearly 110 times the radius of Earth. Volume of the Sun is $1.412 \times 10^{18} \text{ km}^3$ and the volume of the Earth is $1.083 \times 10^{12} \text{ km}^3$. So dividing the volume of the Sun by the volume of the Earth give an answer of 1,300,000.

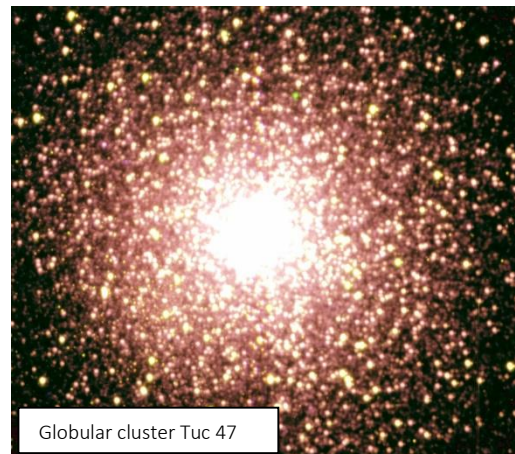
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View of two open star clusters

If we look at the Taurus constellation in detail, our eyes are drawn to a cluster of blue stars in it to the Northwest - the Pleiades. This beautiful star cluster are often in the sky and can be easily viewed with a telescope. A second star cluster, the Hyades is visible as a V shaped arrangement just beside the main Taurus star Aldebaran. However, Aldebaran is itself not part of Hyades. The stars in this cluster mostly belong together i.e. that first of all they are linked together by the force of attraction of their stars i.e. spatially they are located very close together and their arrangement is not merely simulated as the result of a projection against the sky.

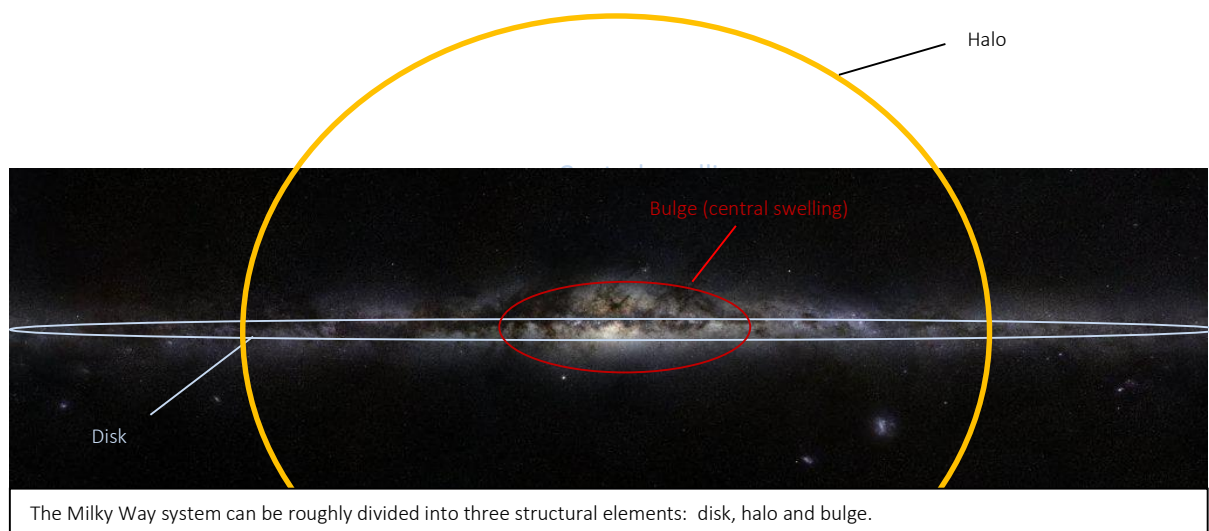


These types of star clusters have between 50 and 1000 younger stars that were created from a cloud of dust and gas millions of years ago. Since the stars within this cluster originated in the same location and at the same time, they are all of the same age. This fact makes them very suited to the research of how stars developed, as it is immediately noticeable that stars with different masses develop at different speeds.



Stars in open star clusters are more loosely distributed than stars in globular clusters. The latter are located in the halo of the galaxy and consist of many more stars (up to 100,000) which are considerably older and more closely linked than stars in open clusters (compared the globular cluster Tuc 47 right).

Nowadays, astronomers are of the opinion that open star clusters are important elements in our Milky Way system. It has been recognised that these clusters are dispersed in the disk planes of the Milky Way system over time, so that the disk of the galaxy is constantly expanding!

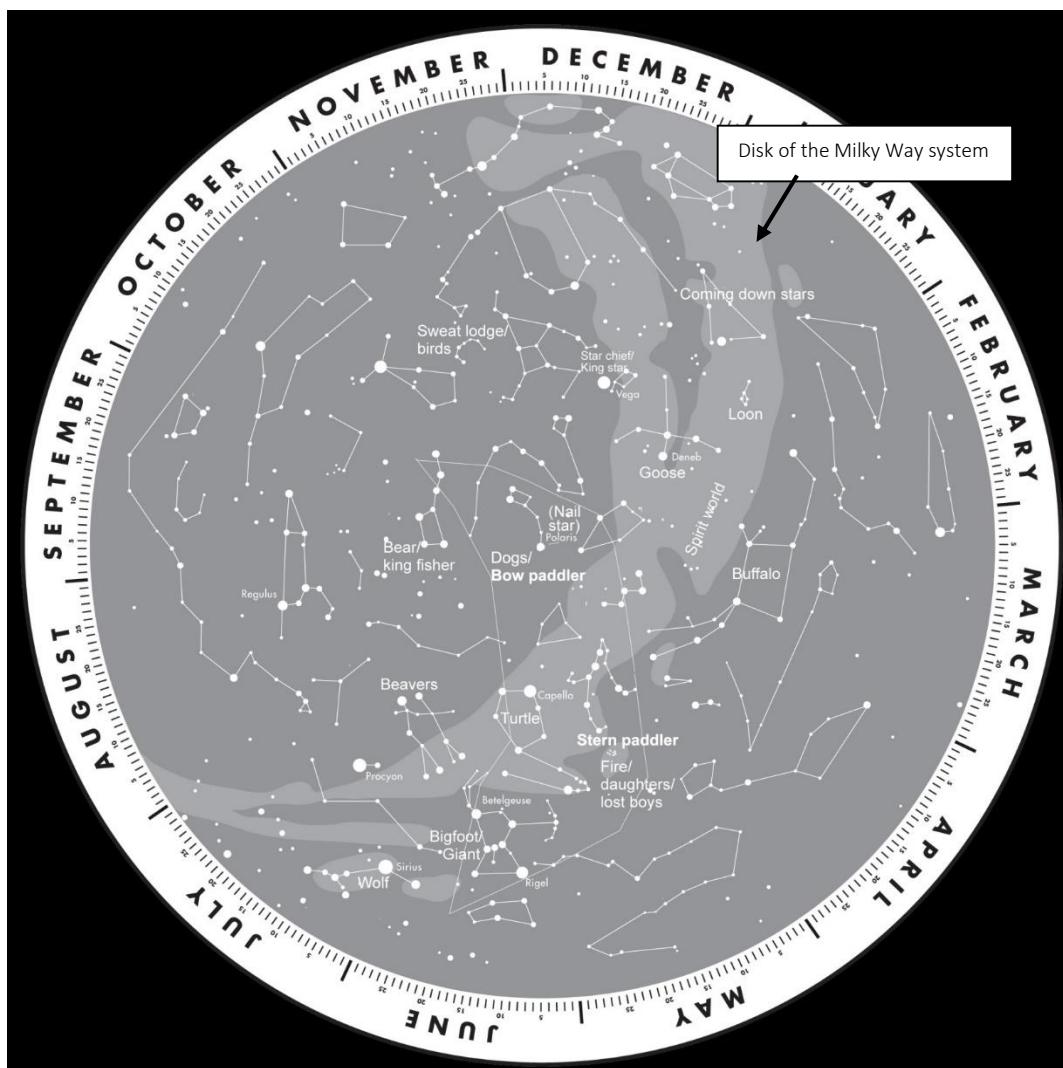
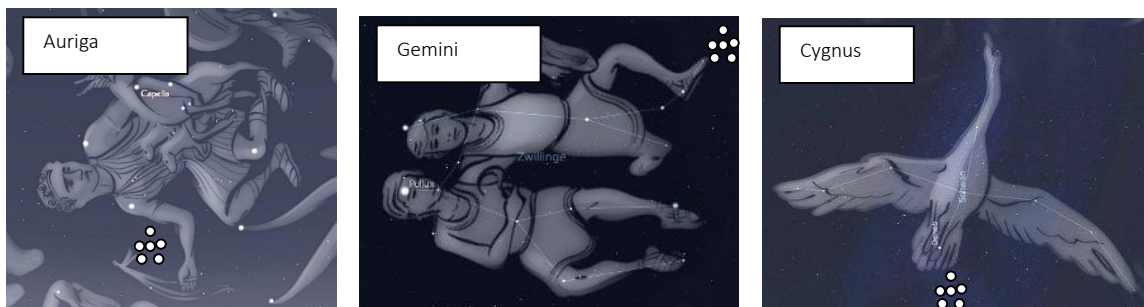


The Milky Way system can be roughly divided into three structural elements: disk, halo and bulge.

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Task - Star clusters

1. Enter the Hyades (distance: 153 ly) and the Pleiades (distance: 380 ly) as small points on the distance diagram of fig. 3 and compare their distances with those of the stars of the winter hexagon. Pay particular attention in the picture to the colours of the stars in this cluster. What are their temperatures?
- 2 Use a blue pen to highlight the locations of the Pleiades, the Hyades and the following three clusters on the star map in fig. 4, upon which the disk of the Milky Way is visible in the section as a dark band: M37 (Auriga), M35 (Gemini), M39 (Cygnus). What conclusions can you make about their location in relation to the disk of the Milky Way system? Why do you think that these young open star clusters are formed within the disk and not at a distance from it? Research.



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3. Lagrange 2 – Gaia's address in space

(Dirk Brockmann-Behnsen)

This section shows how it is possible to understand the effective potential using training materials: In a system with two bodies, where the gravity of one is dominant over the other, there are five places where a spacecraft can stay in position, so that it can maintain a relatively stable position in relation to both bodies without any significant propulsion. Three of these locations are along the length of the straight lines connecting the two bodies and comparatively they are easily found quantitatively using mathematical-physical school materials. At a minimum, it is possible to find good rationale for the two other locations based on vector geometry. The explanations in this section are suitable as the basis for texts for student presentations for example.

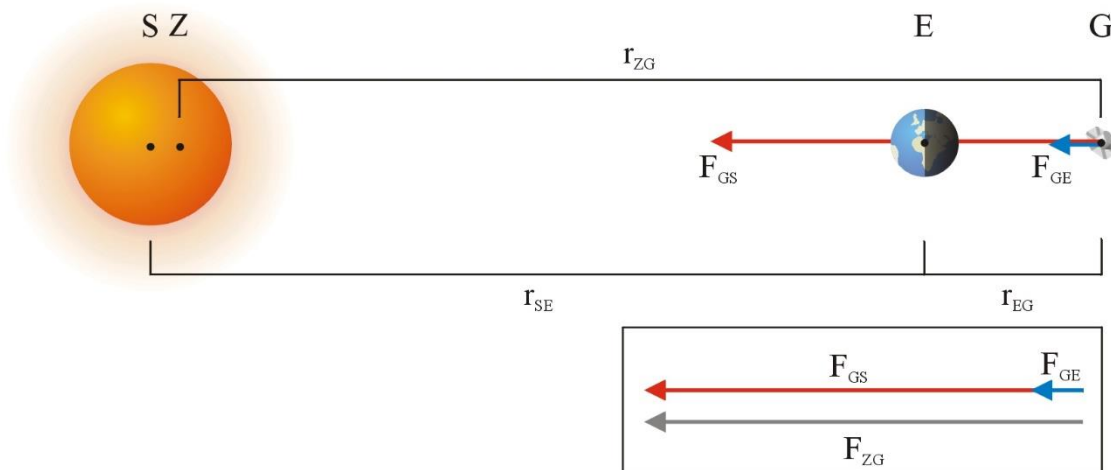
Background

If you want to position a spacecraft in outer space so that it maintains a relatively stable position to the earth and the sun, you must understand the concept of effective potential (cf. [6], P. 14f.), in which the energy calculations not only use the gravitational forces of the celestial bodies involved, but also the centripetal force required for the corresponding angular velocity of the earth..

The following considerations are based on the forces concept¹. Two forces are exerted on the Gaia (G) spacecraft, they are the gravitational forces of the sun (F_{GS}) and the earth (F_{GE}). When evaluated vectorially the total of these two forces (F_{ZG}) must produce a central acceleration of the spacecraft, which allows it to rotate around the common centre of gravity of the earth and the sun with the earth's angular velocity.

Where you limit it at first only to possible positions along the straight lines connecting the sun and the earth, you must differentiate between three possible cases (symbols explained at the end of this chapter):

Case 1: The earth is located between the spacecraft and the sun: Lagrangian point L2



In accordance with the third of Kepler's Laws, the spacecraft would have a longer round-trip time around the sun than the earth, so therefore a lower angular velocity. The central force and the angular velocity are increased by the earth's additional gravitational force. The following applies as an equation of condition for the forces:

$$m \cdot r_{ZG} \cdot \omega_E^2 = G \cdot \frac{m \cdot M_S}{(r_{SE} + r_{EG})^2} + G \cdot \frac{m \cdot M_E}{r_{EG}^2}.$$

¹ I would like to thank Dr. Christian Hohn for stimulating discussions on this topic.

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A good approximation would be where r_{ZG} is equated with $r_{SE} + r_{EG}$ and r_{ZE} is equated with r_{SE}^2 . The following is also used for the angular velocity, which should correspond to that of the earth around the common centre of gravity of the sun and the earth:

$$m \cdot r_{SE} \cdot \omega_E^2 \approx m \cdot r_{ZE} \cdot \omega_E^2 = G \cdot \frac{M_S \cdot m}{r_{SE}^2} \Rightarrow \omega_E \approx \sqrt{\frac{G \cdot M_S}{r_{SE}^3}}$$

This results in:

$$m \cdot (r_{SE} + r_{EG}) \cdot \frac{G \cdot M_S}{r_{SE}^3} \approx G \cdot \frac{m \cdot M_S}{(r_{SE} + r_{EG})^2} + G \cdot \frac{m \cdot M_E}{r_{EG}^2}$$

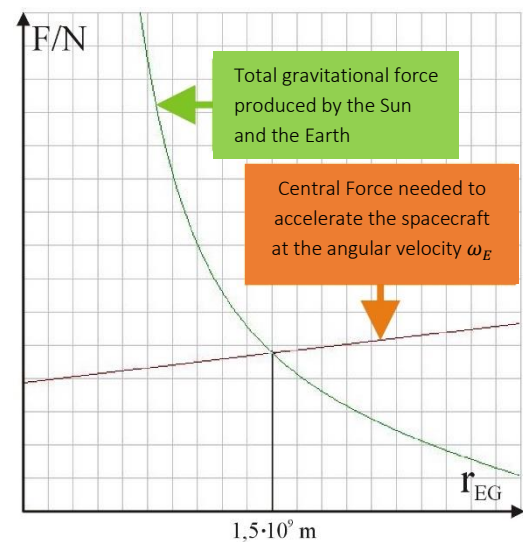
If you reduce the equation by m and G and insert all known values, you get:

$$(149,6 \cdot 10^9 \text{ m} + r_{EG}) \cdot \frac{1,989 \cdot 10^{30} \text{ kg}}{(149,6 \cdot 10^9 \text{ m})^3} \approx \frac{1,989 \cdot 10^{30} \text{ kg}}{(149,6 \cdot 10^9 \text{ m} + r_{EG})^2} + \frac{5,974 \cdot 10^{24} \text{ kg}}{r_{EG}^2}$$

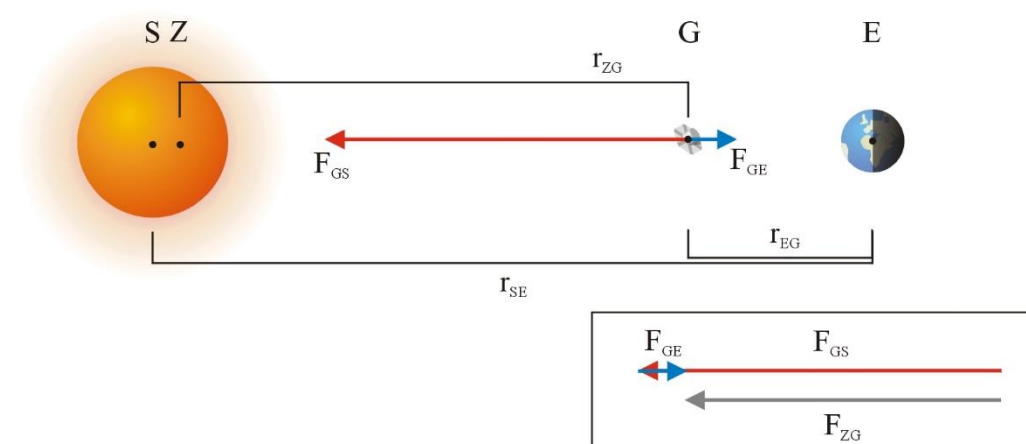
If you now want to find the distance of r_{EG} , that the Gaia spacecraft must be from earth, then you can solve the above equation.

This produces $r_{EG} = 1,48 \cdot 10^9 \text{ m}$.

However, alternatively you can also enter the left or the right side of the equation as functions of the respective forces depending on the distance from the Earth r_{EG} in a graphics compatible pocket calculator or a computer program and find the common point of intersection. The diagram on the right shows an illustration that was created with the program "derive 5". The point of origin of the x-axis corresponds to the location of the earth. r_{EG} was calculated via the coordinates of the point of intersection at approx. $1,5 \cdot 10^9 \text{ m}$. The Lagrangian point L2 is equal to approx. four times the distance of the moon from the earth.



Case 2: The spacecraft is located between the earth and the sun: Lagrangian point L



² The centre of mass Z of the sun and the earth is barely 500 km away from the centre of the sun S.

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In accordance with the third of Kepler's Laws, the spacecraft would have a shorter round-trip time around the sun than the earth, so therefore a higher angular velocity. However, the central force and therefore the angular velocity are reduced by the opposing gravitational forces of the sun and the earth. The following applies as an equation of condition for the forces:

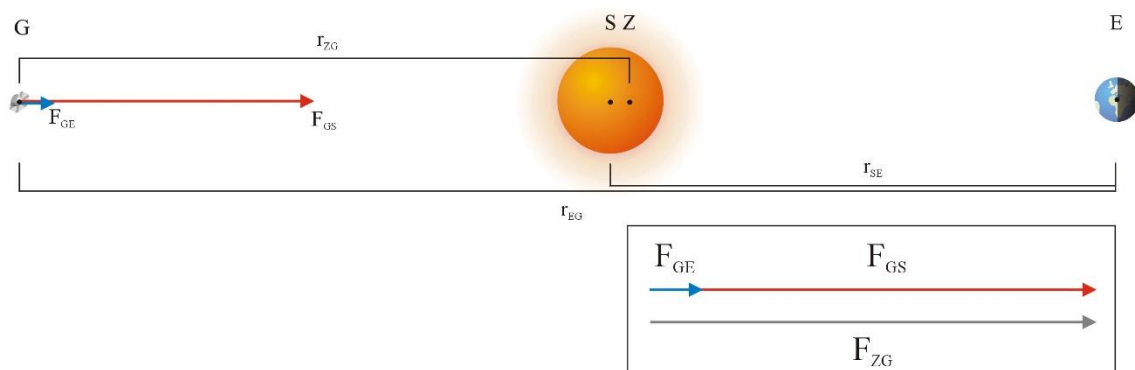
$$m \cdot r_{ZG} \cdot \omega_E^2 = G \cdot \frac{m \cdot M_S}{(r_{SE} - r_{EG})^2} - G \cdot \frac{m \cdot M_E}{r_{EG}^2}.$$

A good approximation would be where r_{ZG} is equated with $r_{SE} - r_{EG}$ and r_{ZE} is equated with r_{SE} . In keeping with Case 1 this produces:

$$m \cdot (r_{SE} - r_{EG}) \cdot \frac{G \cdot M_S}{r_{SE}^3} \approx G \cdot \frac{m \cdot M_S}{(r_{SE} - r_{EG})^2} - G \cdot \frac{m \cdot M_E}{r_{EG}^2}$$

The solution for this case is: $r_{EG} = 1,51 \cdot 10^9$ m, a spacecraft was located at Lagrangian point L1 or $149.60 \cdot 10^9$ m – $1.48 \cdot 10^9$ m = $148.12 \cdot 10^9$ m from the sun.

Case 3: The sun is located between the earth and the spacecraft: Lagrangian point L3



The gravitational forces of the sun and the earth continue to operate in a collinear manner, there is therefore an increased central force for the spacecraft. If Gaia is to orbit the sun solely with the angular velocity of the earth, the spacecraft must be located on the side that is away from the sun slightly outside the earth's radius:

$$m \cdot r_{ZG} \cdot \omega_E^2 = G \cdot \frac{m \cdot M_S}{(r_{EG} - r_{SE})^2} + G \cdot \frac{m \cdot M_E}{r_{EG}^2}.$$

A good approximation would be where r_{ZG} is equated with $r_{EG} - r_{SE}$ and r_{ZE} is equated with r_{SE} . Similarly to Cases 1 and 2 this produces:

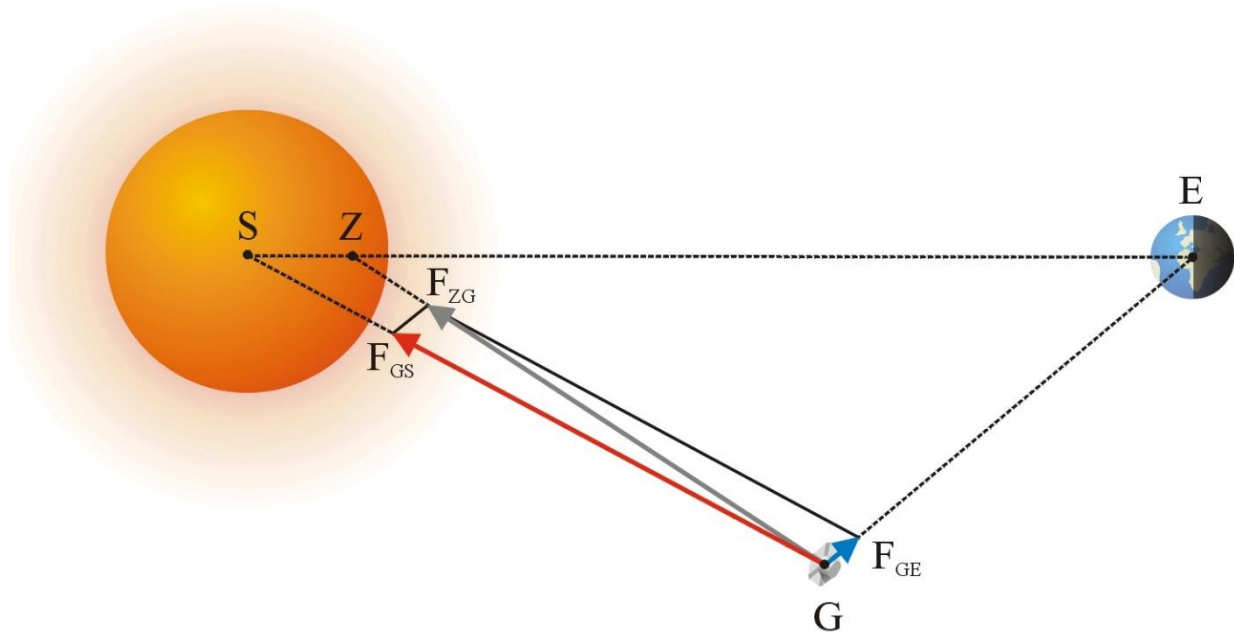
$$m \cdot (r_{EG} - r_{SE}) \cdot \frac{G \cdot M_S}{r_{SE}^3} \approx G \cdot \frac{m \cdot M_S}{(r_{EG} - r_{SE})^2} + G \cdot \frac{m \cdot M_E}{r_{EG}^2}.$$

The solution for this case is: $r_{EG} = 2.99 \cdot 10^{11}$ m, a spacecraft would be located at Lagrangian point L3 or at the opposite side of the sun at a distance of $299.13 \cdot 10^9$ m – $149.60 \cdot 10^9$ m = $149.53 \cdot 10^9$ m from it. The earth and the spacecraft are therefore opposite to each other in relation to the sun at almost the same distance.

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Beyond the connecting line between the sun and the earth, there are two additional locations where a spacecraft can orbit around the sun without propulsion using the angular velocity of the earth (more accurately it orbits around the common centre of gravity of the sun and the earth):

Cases 4 and 5: Sun, earth and spacecraft form a triangle: Lagrange 4 and 5.



The above diagram explains the Lagrangian point L4, the same applies for L5 but as a mirror image. Both of these cases must only be qualitatively discussed. Sun, earth and spacecraft orbit around the common centre of gravity Z from the sun and the earth with the angular velocity of the earth³.

Symbols:

S = Sun, **Z** = Gravity Centre (Central), **E** = Earth, **G** = Gaia (spacecraft)
r_{ZG} = radius of the (Sun's) gravity centre to the Gaia spacecraft
F_{GS} = Attraction force against the Gaia spacecraft from the Sun
F_{GE} = Attraction force against the Gaia spacecraft from the Earth
r_{SE} = radius Sun to Earth,
r_{EG} = radius Earth to Gaia spacecraft
F_{ZG} = Attraction force against the Gaia spacecraft from the Gravity
m = Meter
r = radius
 ω = angular velocity
M = mass
G = Gaia spacecraft
MS = mass of the Sun
ME = Mass of the Earth
r_{ZE} = radius of the (Sun's) gravity centre to the Earth

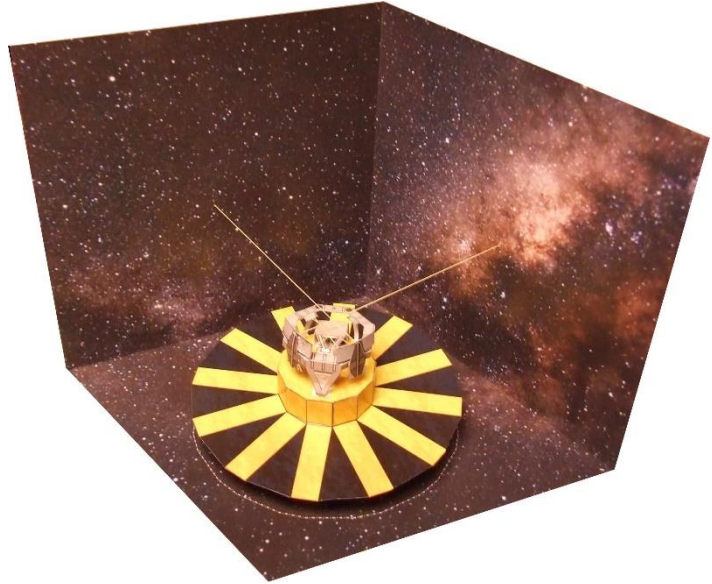
³ At the latest this demonstrates that the reduction performed to a two body problem (Gaia's mass can be omitted) is quite approximate, two other planets are located in the diagrams between the earth and the sun, one of which has the same mass as the earth.

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4. A model of Gaia's optics

(Dirk Brockmann-Behnsen)

The following article contains instructions on how to build a model of the Gaia spacecraft, where the optical path specifically illustrates its double telescope. There is a worksheet in the article and instructions including design proposals for the model. The course of the two part representative beams by the complicated mirror system of both telescopes is illustrated by two cords, which can be threaded into the cardboard model.



Background

In 2013, when the Gaia space telescope was launched into space with the help of a Russian Soyuz Fregat rocket, it marked the start of one of the most ambitious survey projects in the history of stellar cartography. The aim of the mission is to determine at least one percent of all stars within our galaxy (i.e. 10^9 stars!) with an accuracy of less than 24 micro-arc seconds and spontaneous movement vectors of the 150 million brightest stars. Supplemented by broadband photometric analyses in the wavelength range between 300 and 1000 nm and high-resolution spectra in the 847 to 874 range, Gaia will decisively shape our view of the development of our native galaxy and the processes of star formation.

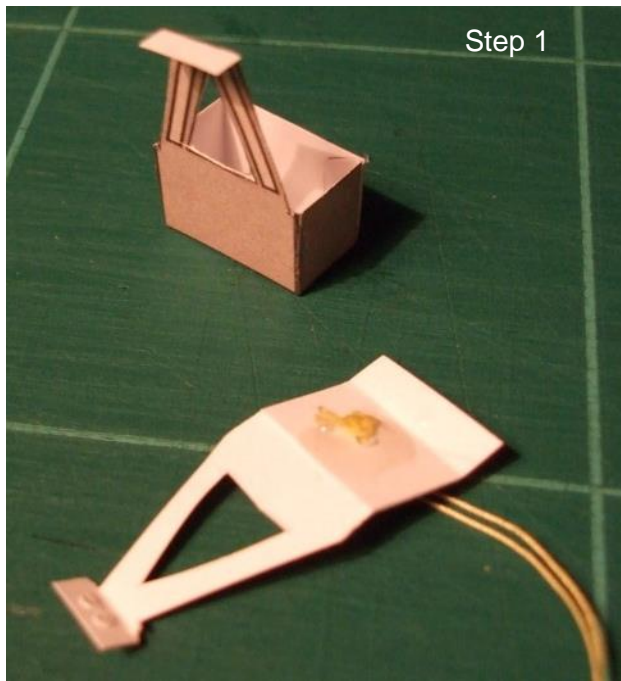
Other mission objectives are the discovery and trajectory data analyses of extrasolar planet systems, the search for additional small bodies in our solar system and distant quasars. Furthermore, Gaia's technology offers the option to perform numerous tests of the general theory of relativity and cosmological hypotheses.

Excellent optics are a prerequisite for these types of challenging objectives. Gaia consists of two identical telescopes, which are aligned with each other at a base angle of 106.5° . These telescopes consist of three-mirror anastigmats (TMA). Only three mirrors are enough to provide sufficient parameters in order to carry out appropriate image field corrections. Furthermore, three mirror systems allow the use of a broad spectral range (cf. [7], p. 96).

Task: Construct a model with optical path - instructions

The construction kit consists of four sheets (see extra file "Gaia worksheet"). A star background with an assembly frame is built from the first three sheets, and this can be used to display the model of the Gaia spacecraft (parts "Base 1" to "Base 3"). The fourth sheet contains the parts of the spacecraft (parts 1 to 7) and the base, which connects the frame with the spacecraft (part 8).

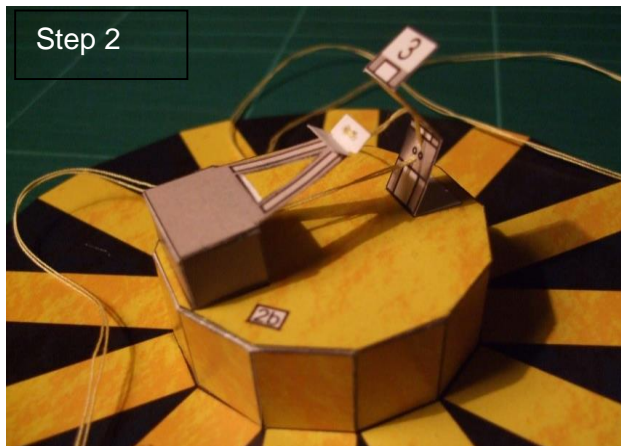
The optical path in the Gaia telescope can be threaded into the model using (yellow) thread. This requires a high level of construction skill and patience on the part of the model builder, but it produces a very clear and attractive result. You should consider carefully beforehand whether you want to build the model with or without an optical path. If you opt for one, prior to cutting out the shapes, use a needle and thread to punch through the holes that are drawn onto the base ("Base 1" and "Base 2" parts) on the mirror areas (parts 3, 4, 6b and 7) and the scientific detector (also part 6b). You can also decide whether the model should be displayed on the base in front of the star backdrop. In the latter case, you only print out sheet 4 and omit part 8. If you would like to build the frames as well, print out sheets 1 to 3 on 300g cardboard, but print sheet 4 on thinner cardboard (e.g. 160g).



Step 1

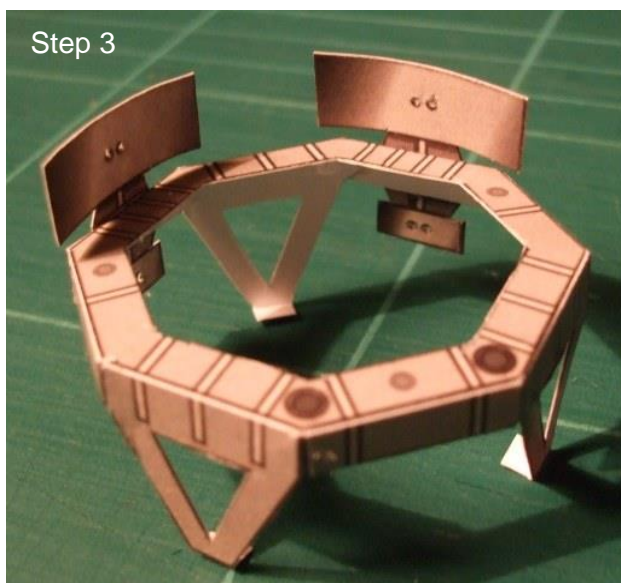
The following instructions are based on the assumption that thread is being used, if you prefer not to do so simply skip the relevant text. Parts 6a and 6b (scientific instrumentation) are built first. The thread is doubled, knotted at the end, pulled from behind in part 6b and stuck (see image in step 1). Only then is this part inserted in the completed part 6a. In so doing it must be ensured that the small flap with the M4 mirror from part 6b is first not yet glued by its back from part 6a, as the thread must still be pulled through there (see image from step 2).

Then glue parts 1 and 1R (solar shield) together. Put together the service module cladding using part 2 and glue it to the solar shield. The double mirror system is then glued to the service module cladding (flap with 2 downwards). The double thread is first pulled through the lower mirror (M6) then through the upper mirror (M5). The double thread is threaded in through the lower of the two holes and out through the upper hole for each mirror. Next the double thread is pulled through the double mirror M4 on the 6a/b component, mirror M4 and its back panel are still not glued together, as the double thread must still be tightened up later. The double thread divides into two from here.



Step 2

The octagonal frame, which supports the mirror pairs M1A/B, M2A/B and M3A/B, is built next. The image for step 3 shows the results. Both mirror systems M1A and M3A and M1B and M3B (two identical 4 components) plus their backs, the identical 5 components are already glued on. The M2A and M2B mirrors are already connected with part 2 according to the technical construction plan.



Step 3

The frames with the mirrors are now glued on the service module cladding. Afterwards one of the two individual threads is pulled through the M3A, M2A and M1A mirrors one by one, the other through the M3B, M2B and M1B mirrors. The image for step 4 shows an overview.

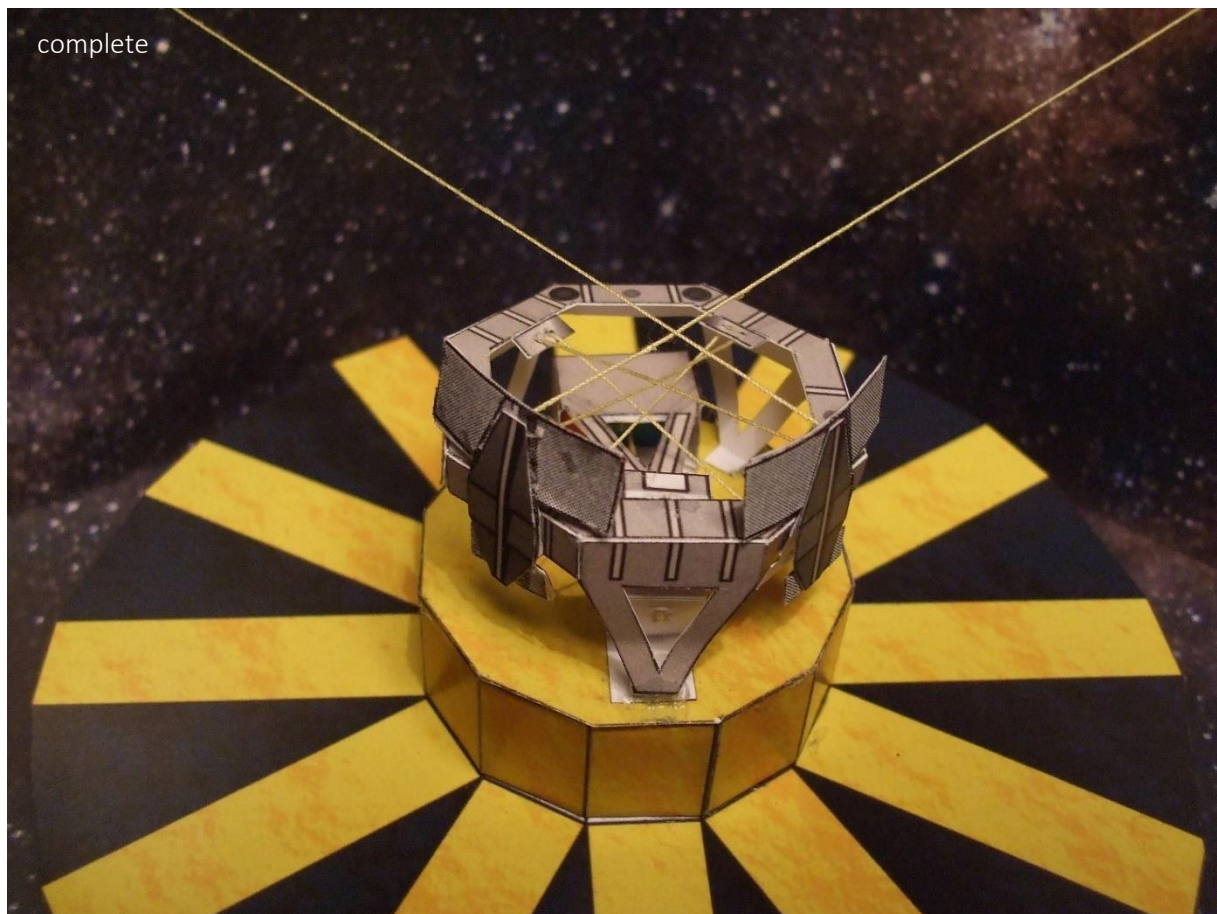
Finally, the spacecraft can be installed on the assembly frame using the base (part 8). In so doing, you should ensure that the instrument (part 6a/b) points exactly into the assembly frame.

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Finally, both threads protruding from the mirrors M1A and M1B are threaded through the holes of the sides of the assembly frames opposite the mirrors and are secured to the backs, after the entire thread system has been carefully tightened, if necessary with a pair of tweezers. Only now may mirror M4 from part 6b and its back from part 6a be glued together. The backs of the assembly frames can be further reinforced using black cardboard.

The finished model shows the optics and instrumentation of GAIA in the upper section. In reality, this upper section of the spacecraft is covered by thermal cladding, which has been omitted here for educational purposes.



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5. Gaia's Telescopic System

(Olaf Hofschulz)

Gaia has 2 telescopes. Both of its rectangular main mirrors have an area of 1.45 m x 0.5 m, the optical axes are at an angle of 106.5° . This makes it possible to simultaneously examine objects in 2 different directions. It is possible to measure angle distances very accurately and Gaia's precise orientation in space can be ensured. A system of several additional mirrors ultimately guides the path of both telescopes in the common focal plane, where the CCD camera is located.

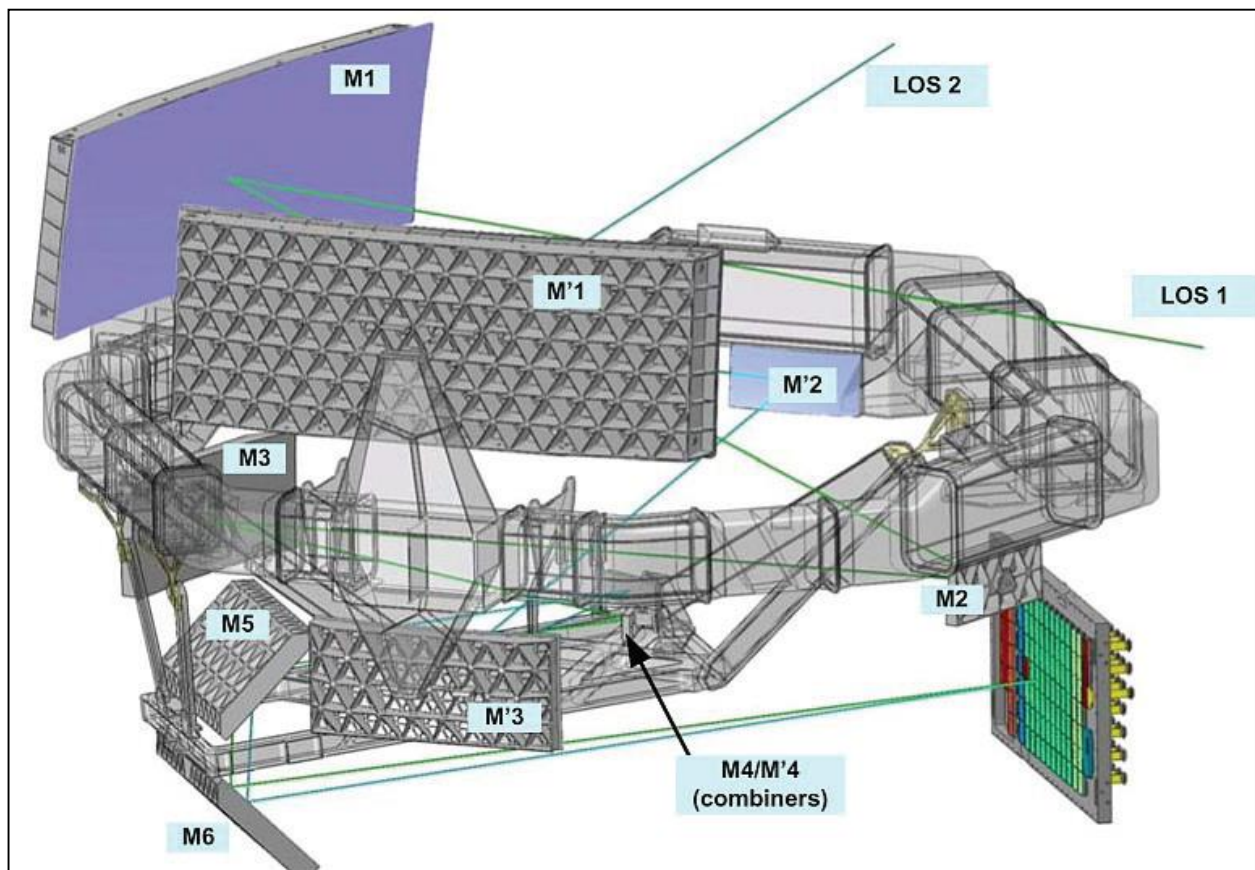


Figure 5: Gaia's optical set-up with both main mirrors M1 and M'1.

Source: ESA (http://www.rssd.esa.int/SA/GAIA/docs/flyers/Gaia_flyer_2012_ge.pdf).

Tasks: "The more accurate Gaia telescope"

1. Describe the optical path in the Gaia telescope based on fig. 5. (You can also use the model described in chapter 4 "Gaia's optics".)
2. The dimensions of the rectangular main mirror are equal to 1.45 m x 0.5 m. What diameter must a coextensive circular main mirror have?

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3. Define a new combination from the telescope and the camera chip with the Gaia data in the Stellarium program. (In so doing, use the diameter of the coextensive circular mirror, therefore use $d = 0.96$ m and $f = 36$ m as well as chip measurements of 104 cm \times 42 cm).
Now "start" up different celestial bodies with your "Gaia-Simulator". Save a "shot" as an image and finally print out the result.

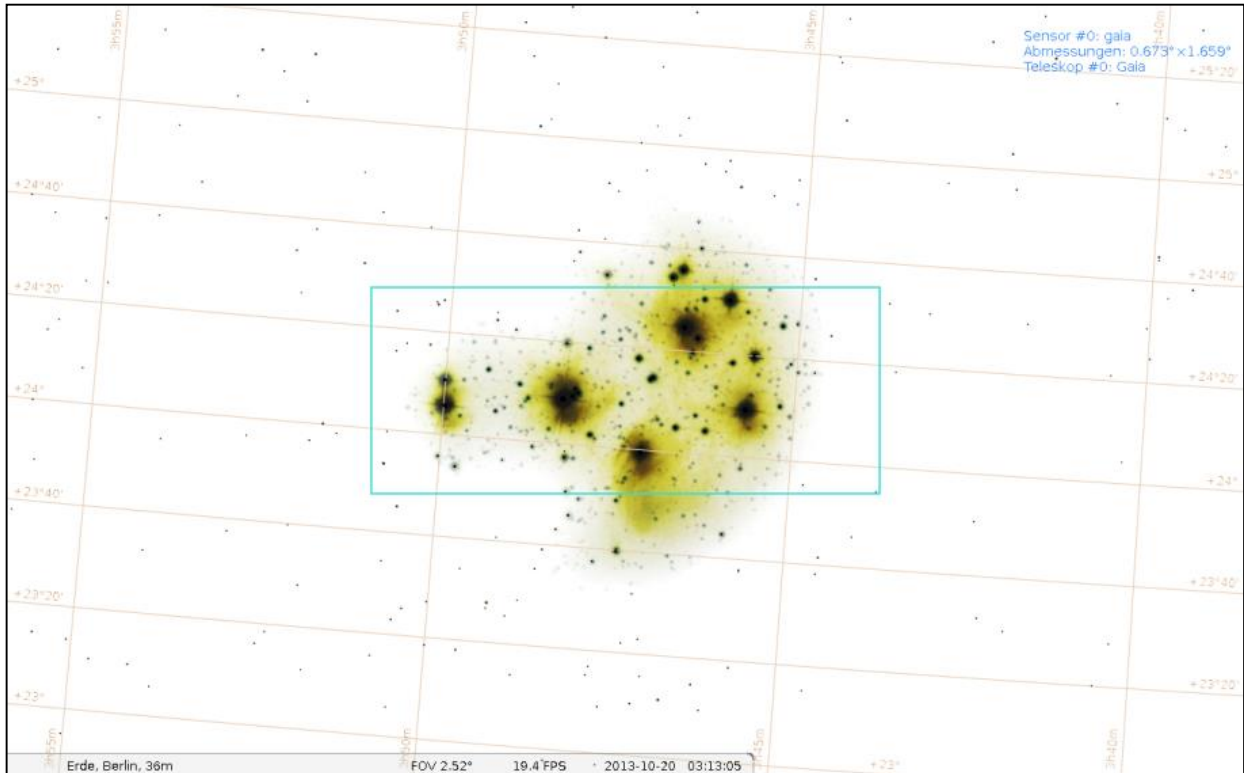


Figure 6: Pleiades with the "Gaia CCD camera". Created using Stellarium.

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6. Gaia – The Gigapixel camera

(Olaf Hofschulz)

CCD cameras are an essential tool for astronomers. They allow them to record the information generated from the emissions of the observed objects and therefore makes it possible to analyse them.

Gaia has the largest CCD camera ever built for use in outer space. It has approx. a thousand million pixels. The camera is composed of 106 individual CCD chips, which complete different tasks when combined in groups. The rotation of the satellites means that the stars move over the CCD field in a uniform linear motion. As a result, they pass through the different regions.

First, the stars that enter the view field shift through the "sky mapper" CCD field. Pre-selection occurs here, information on the position and magnitude of the objects are defined, so that window regions can subsequently be defined, which can be exported from the subsequent CCDs. This makes it possible to reduce the enormous quantity of data.

Columns in the area of the pre-defined window are exported following a time-delay, precisely synchronised with the motion of the satellites, while traversing the 62 astrometric CCDs. This is how the actual shot is created for later determination of positioning (astrometry). Each region will be observed approx. 70 times during the time that Gaia will be in use. This will permit precise parallax calculations.

The following blue and red photometer CCDs are used to determine magnitude. Spectra of brighter stars are created in the radial speed spectrometer using a grid, so that classification in a spectral class is possible.

The remaining CCDs are used for technical purposes, such as focusing and positional control.

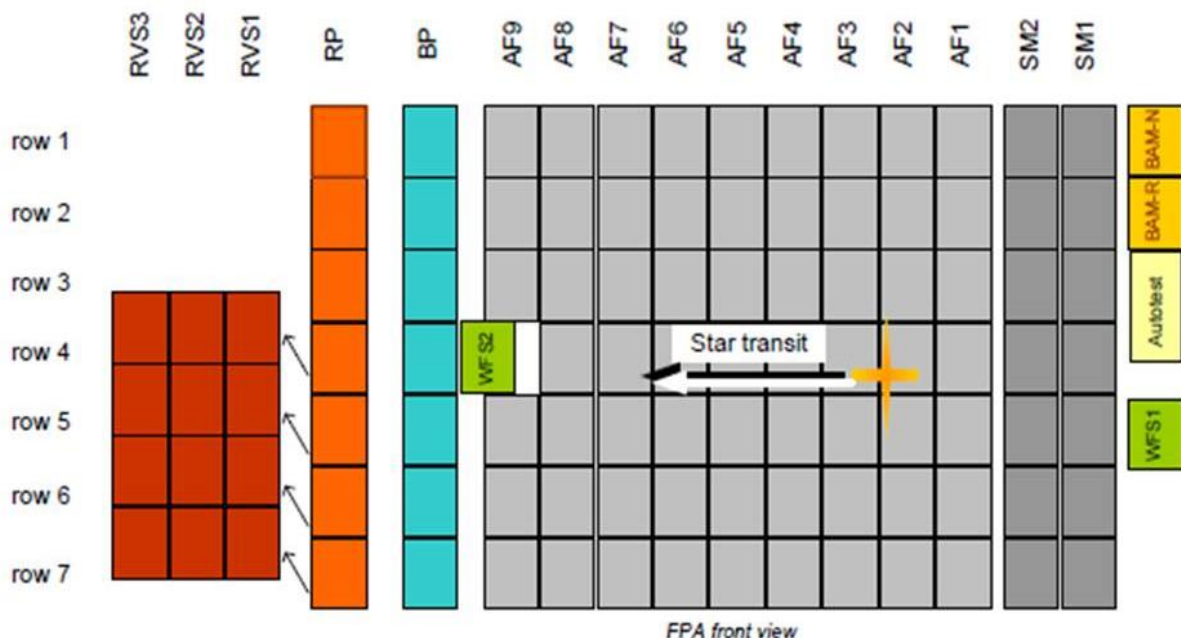
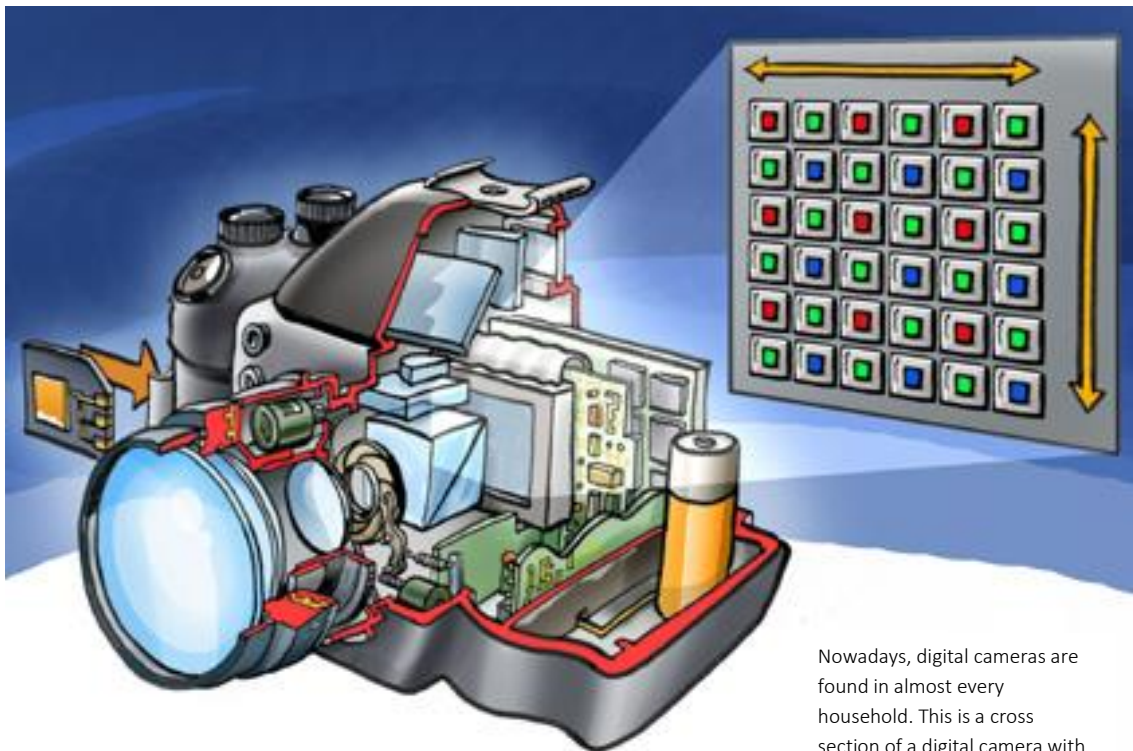


Figure 7: CCD Camera from Gaia. Source: ESA

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Tasks: "Pixellated images - Gaia's CCD Camera"

1. Gaia's gigapixel CCD camera has 106 CCDs each with 4500 x 1966 pixels. Calculate the total number of pixels.
2. Compare the number of pixels with those of a commonly used digital camera nowadays.
3. In professional astronomy, almost only SW-CCD cameras are used. Colour shots are often not at all important for scientific purposes. However, if colour images are required, for example where three shots are produced consecutively using a red, green and blue filter (RGB) and added or mixed subsequently to a colour composite image.
 - a) Explain the principle according to which three monochrome shots (RGB) of the colour composite images are created.
 - b) Investigate what is understood by a Bayer matrix.
 - c) What advantage do black and white CCD cameras have compared with colour cameras?
4. Due to the rotation of the sensor, the stars have covered a distance within 30 s that corresponds to the full-scale arrow length in fig. 7 above. Calculate the speed with which the stars drift over the CCDs.
5. List the tasks of the individual CCD fields.
6. The exposure time is specified by the transit time of a star by a pixel or a CCD. A pixel is 10 micrometres wide. Calculate the exposure time for a pixel or a total CCD chip.



Nowadays, digital cameras are found in almost every household. This is a cross section of a digital camera with RGB CCD image sensors (Source: Wikimedia Commons, Author: Welleman)

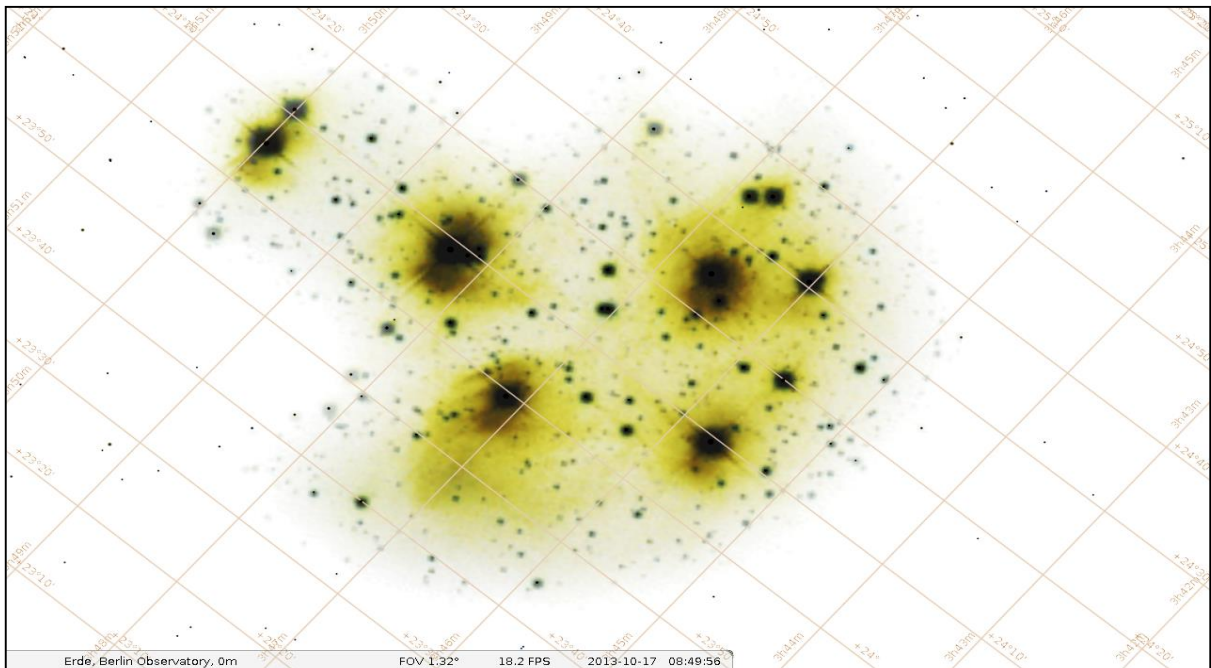
The following worksheet should explain the essential tasks / job steps in the evaluation of the Gaia shots...

WORK SHEET 1

1. Identify the coordinates (right ascension and declination) of 6 bright stars from the shot taken of the Pleiades. Also use the section of the sky map in the figure below, in order to read the coordinates as accurately as possible. Enter your results in the following table.



Pleiades (M45 open star cluster in Taurus). Shot with refractor ($D = 85 \text{ mm}$, $f = 450 \text{ mm}$) and Canon 1000D.



Star map with coordinate lines from the Pleiades region. Created using Stellarium.

WORK SHEET 2

2. Start the Stellarium program, which was used to create the star map. Find Pleiades in the Taurus constellation and check the coordinates of the stars that you have selected using the program.
3. Use Stellarium to continue to identify the names or the labels of the stars and their apparent magnitudes.
4. How far away from us are the Pleiades on average? Calculate the average distance of the brightest Pleiades stars. (In Stellarium both distance and parallaxes are displayed for the brighter stars).

Number	Name	Right ascension	Declination	Apparent Magnitude
1				
2				
3				
4				
5				
6				

5. The following figure shows the spectra of the Pleiades stars. Explain why the brightest cluster stars appear blue, so that they are very similar in their properties. How can you explain this? Also take into consideration the images of the Pleiades shown above.

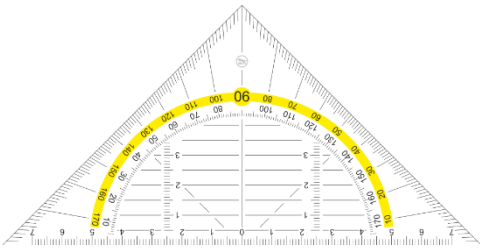


Pleiades (left in image) and associated spectra. Refractor 60/360 with blazed grating and Canon 1000Da, exposed for 30 s at ISO 1600.

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7. Determination of distance – relative and absolute parallaxes

(Olaf Fischer)

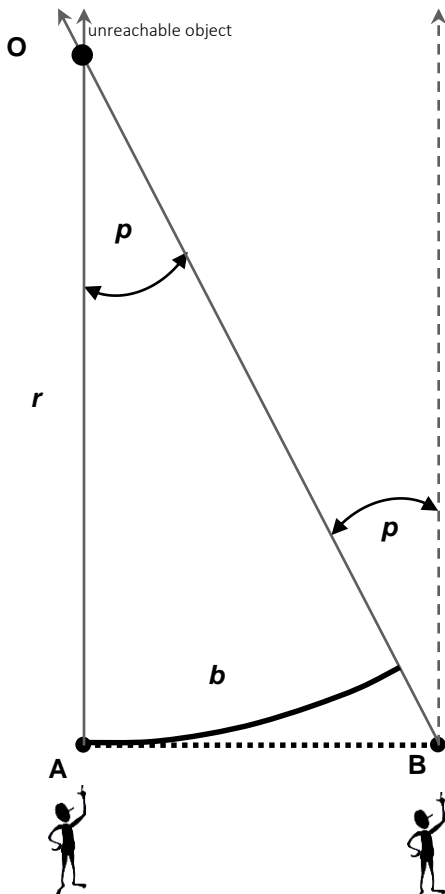
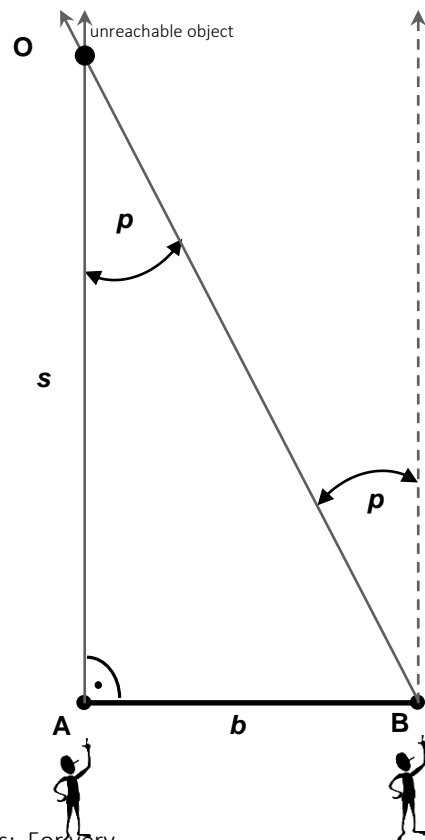


Determination of distance through angle measurement – the trigonometric parallaxes

The method for determination of the distance to a (currently) unreachable object using the triangle originates with the ancient Greeks.

The basic idea is the following: A baseline $AB = b$ is specified perpendicular to a connecting line (unknown length s) from the observer to the object (the observer sits at the end point of this line – in the photo on the right: in A). Now the observer moves to the other end point of the baseline (B) and targets the object again. The direction has changed by the angle p , which we refer to as **parallax**.

The parallaxes p are identified once more in the ABO triangle as an alternate angle. It is therefore possible to calculate the length s in the right angle triangle based on length b and the given angle p . Details and calculations in different examples in [3] demonstrate this.



It is also possible without using triangles: For very large distances, the base length AB should be viewed as part of a circle (the **arc length** b) around point O with the radius r (the distance that you are looking for). The following simple proportion can be used to calculate r :

$$\frac{u}{b} = \frac{360^\circ}{p} \Rightarrow \frac{2\pi \cdot r}{b} = \frac{360^\circ}{p} \cdot b.$$

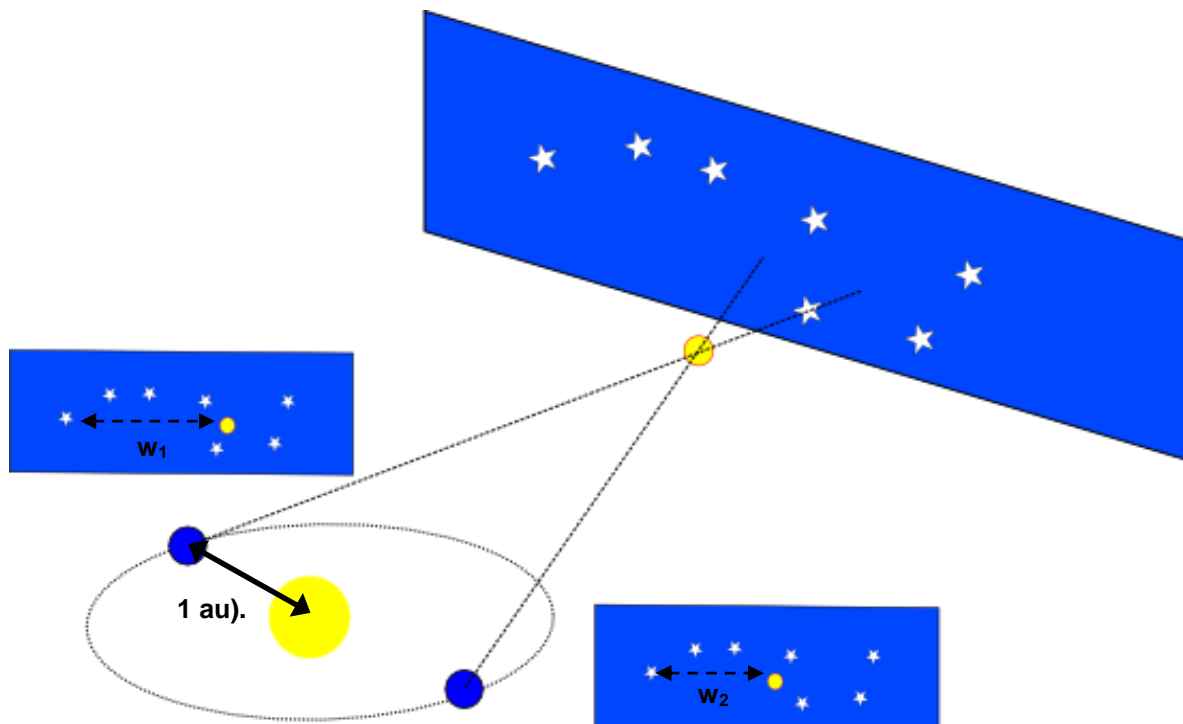
Although the basic idea appears simple, where angles are very small problems can occur (omitted for educational purposes). These depend on (see image) how precisely the direction from AO (reference direction for the angle measurement) can be defined in B. See also the following.

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Annual parallaxes - relative and absolute

If the base line is extended by the orbit of the earth around the sun, then we refer to annual parallaxes. For definition purposes we refer to the average distance of the earth to the sun (an astronomical unit: 1 au). You can imagine how difficult it is to find a reference direction again that was specified six months previously in outer space.

In the era where only earth bound astronomy was possible, they relied on a particular trick. Astronomers searched for a reference object that is much further away (preferably a quasar) in the vicinity to the object, whose distance was to be found, which established the reference direction. In the erect telescopic image or on a sky shot taken with the telescope, you can measure the parallaxes p relative to the reference object. This is referred to a relative annual parallax.



Annual parallaxes (Author/Source: WikiStefan for de.wikipedia). The parallax p is found by $w_1 - w_2$.

Observation from the earth's surface determines the thresholds of measurement accuracy (atmosphere, gravitational force). Space astronomy opens up new opportunities for astrometry (angle measuring astronomy). The following [tasks 1 and 2](#) demonstrate this in a concrete way for the Gaia space observatory.

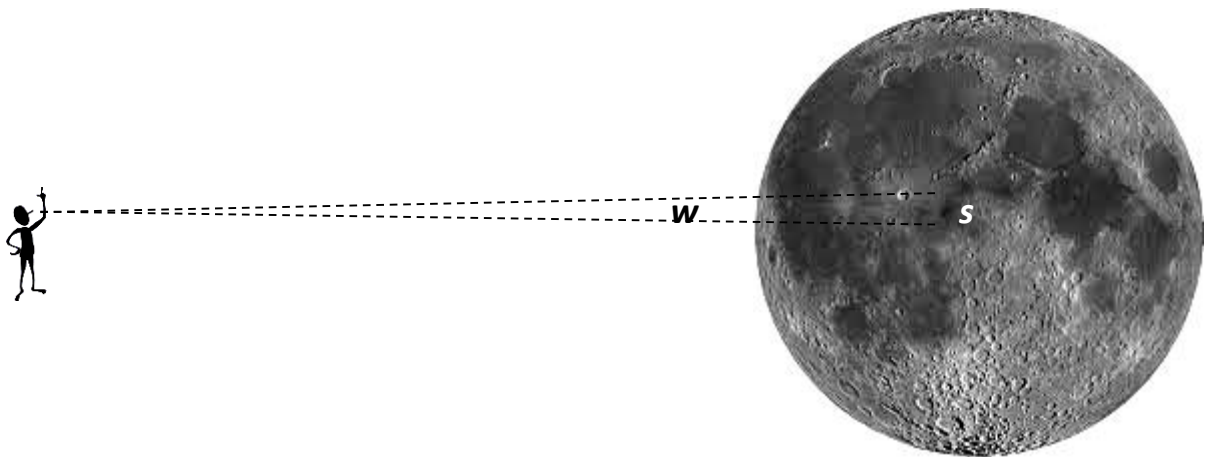
In [task 3](#) it is obvious that even quasars are not enough as reference objects for Gaia accuracy. You should be made aware that in addition to the annual parallax motion of the stars in the sky (an apparent motion), internal (true) motion and the motion of the sun in the Milky Way system (effectively another parallax) are superimposed on top of it.

All of this makes it necessary to find a fixed reference direction in the sky, from which you can measure the absolute annual parallaxes. This can only be done on the basis of stars surveyed over the entire sky.

In contrast to the conventional earth-based astrometry, where observation only records a small section of the sky, orbiting space observatories make it possible to record complete circuits of the celestial sphere by scanning in a short period of time. Furthermore, an idea to increase accuracy was made a reality, whereby two areas of the sky located far apart from each other are observed simultaneously with two telescopes. [Tasks 4 and 5](#) provide an initial view of this.

Tasks - Parallaxes and Angle measurement

- 1.) Gaia should be measured with an accuracy of 20 micro-arcseconds. What part of a degree does this angle correspond to? What straight length s on the surface of this moon spans this angle w ? You have two possible solutions:
- You can define the straight length that you are looking for as an arc segment of a circle, where its radius represents the distance that you are looking for.
 - You can also use an angle function.

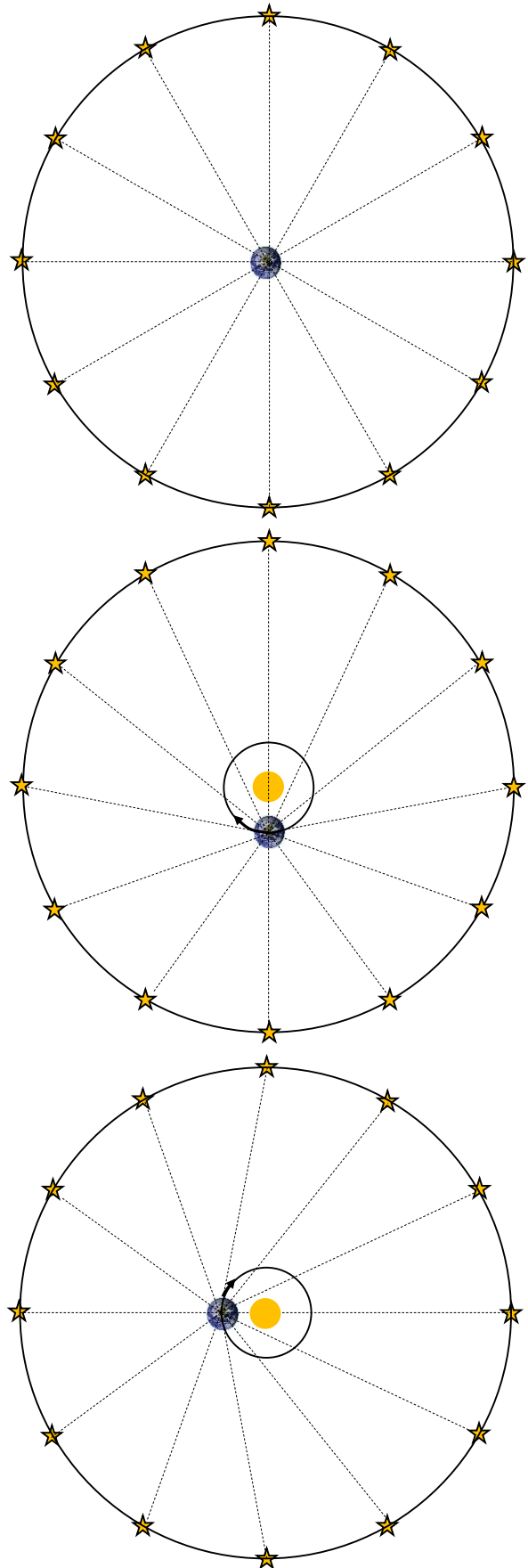


- 2.) How far away is a star (in light years), where the annual parallax has a value of 100 micro-arcseconds (5 times the measurement accuracy of Gaia)? 1 light year is equal to approx. $9,461 \times 10^{15}$ m. Consider in the solution that the specified parallaxes represent the difference between the directions, in which a star in the distance that you are searching for, is observed from two points on the earth's orbit. These two points are 1 au apart ($1 \text{ au} = 149,597,871 \text{ km} = 150 \cdot 10^6 \text{ km}$).
- 3.)
- What annual parallax does a quasar have when used as a reference object, where it is located 10 billion light years away?
 - Quasars are identified as nuclei of galaxies, which are active and therefore extremely luminous. Galaxy nuclei have a diameter in the region of several light years. The position in the galaxy nucleus of the very bright region of the quasar can shift [5].
It is assumed that the position of an extremely bright area of a quasar, 10 billion ly away, shifts by 5 ly within the nucleus of the galaxy during the course of a year. What does this angular displacement represent in the sky?
- 4.) How can accuracy be improved by receiving angle data for stars from a complete circuit of the sky instead of from a small section (on a photograph of a sky)?
To answer this question you must first think about how the identification of the relative parallaxes depend on a photograph of the sky, and it must be said that the absolute star positions normally exist at an accuracy in the tenth arc second range.

- 5.) Below the parallactic shift of the fixed stars should be taken into consideration for examples of two positions of the earth where the stars are located in the celestial sphere, at the level of the earth's orbit (in the ecliptic). This produces a systematic behaviour of all stars, which can be used in order to define a reference direction.

3 images are provided (Note: high level of simplification!). The top image shows fixed stars around an earth that is staying still. In the middle and bottom images, you again see fixed stars, only this time around an earth in two different positions as it is itself moving around the sun.

- Measure the angle distances between the stars, as they can be measured from the earth.
- What is the value of the angles and how can you verify this result?
- What conclusions can be made about the systematic change of the angle distances between the fixed stars in relation to the position of the earth?
- How are angle distances distributed in reality i.e. if the distance between the earth and the sun is much smaller than the distance between the earth and the stars?



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8. Gaia and our knowledge of the stars

(Cecilia Scorza)

The more precisely the distance to a star is known, the more accurately it can be physically described. Gaia's results will therefore contribute considerably to enhancing our understanding of the origin, formation and death of stars. Considerations in relation to the motion of the stars (in binary star systems or around the black hole in the centre of the Milky Way system) will lead to considerably more accurate results. The following section contains activities to encourage discussion about stellar evolution and the black hole in the centre of the galaxy.

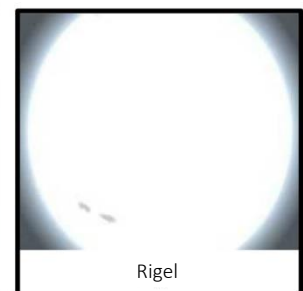
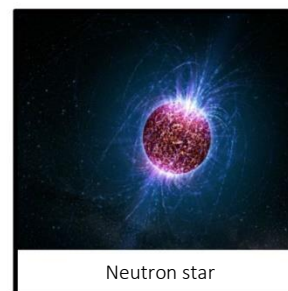
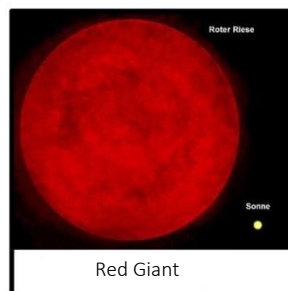
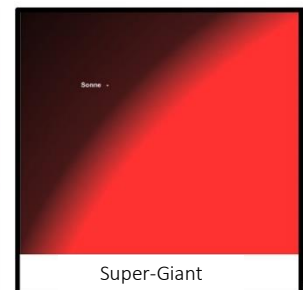
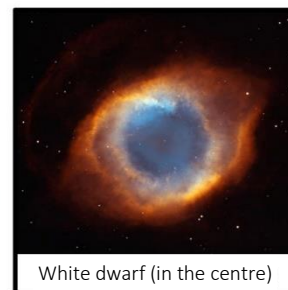
Of pulsars, black holes and dark matter in the Milky Way system

All stars are born within gas and dust clouds that are distributed in the disk of the Milky Way (see right: Photograph of a star-forming region). In these gas clouds, the gas density (in particular hydrogen) is much higher than in the environment. The power of attraction of its own mass compressed parts of the clouds, and stars grew from these "gas clumps". The mass of a star at its beginning determines its subsequent formation.



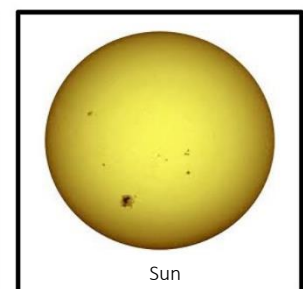
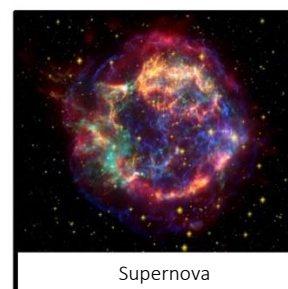
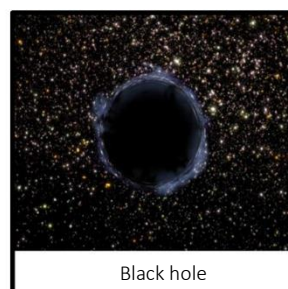
High-mass stars such as Rigel, with more than 10 sun masses live for a short time (a few million years) and "burn off" their "energy matter" (hydrogen) very quickly. When they age, they expand and become Red Super Giants. Finally, they explode as supernova (SN) where their cores collapse violently under the power of attraction. All that remains of them are neutron stars (much harder than diamonds!). However, if the star originally has a mass greater than 30 sun masses, then a black hole occurs after the supernova explosion!

Stars such as the sun or low mass stars live for a very long time (up to 15 billion years!), as they burn their "energy matter" slowly. When they age, they expand, become Red Giants and finally shed their external shells. The core then contracts under the pressure of self-gravity and becomes a White Dwarf.



Task - The lives of the stars

Arrange these photos in two sequences: Formation of high-mass and low-mass stars.



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A dead star in the Taurus constellation?

We have already found two star nurseries in the Taurus constellation (the Pleiades and the Hyades). Now let's look for the remainder of a supernova! It is easy to find this slightly above the right tip of the horns of the bull at a distance of approx. 6300 ly from us! Since its discoverer thought that the shape of its nebula looked like a crab it called it the "crab nebula".



In the centre of this supernova remainder, a neutron star was discovered, that rotated very quickly: 30 times per second. It has a very powerful magnetic field and emits radio waves, which were originally interpreted as signals from an intelligent civilisation! These neutron stars with a strong radio wave signal are described as radio pulsars.

Tasks: "The crab nebula and its pulsar"

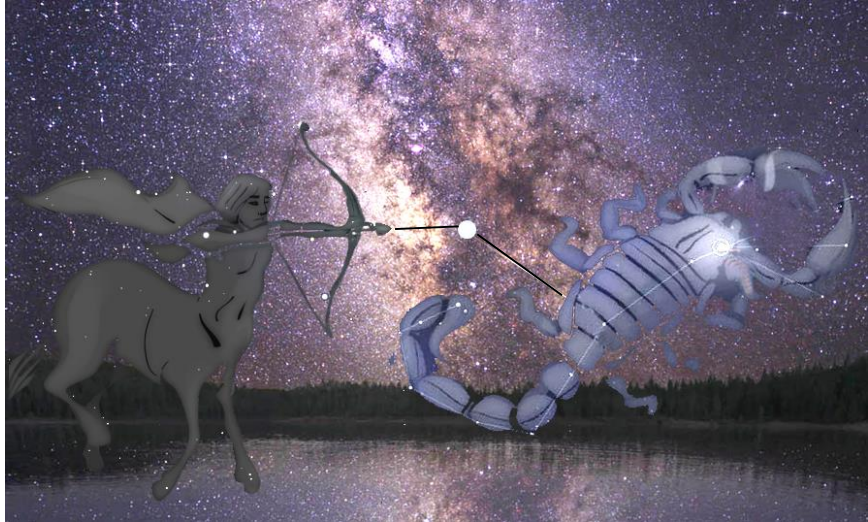
- 1.) What was the mass of the original star at the centre of the crab nebula before it exploded?
- 2.) How often does a pulsar rotate per hour?
- 3.) How long does it take a radio signal from the crab nebula to reach earth?

[\(→back to Start\)](#)

The supermassive black hole between Sagittarius and Scorpio

Similarly to the crab pulsar, astronomers have received radio signals from the central region of the Milky Way, which is located between the Sagittarius and Scorpio constellations. These were so strong that for a long time it was suspected that there was a black hole there. However, this area of our galaxy is filled with thick dust clouds - the ash from dead stars - which absorbs the light of central stars.

However, using infrared astronomy, astronomers were able to see through the dust clouds, as the stars infrared radiation were better able to penetrate the dust barriers. This made it possible to follow the motion of a star in a period of 12 years! The star is rotating around something that is not visible. It's very high orbiting speed (18 million km/s) shows that it is subject to enormous gravitational force (otherwise it would have flown away a long time ago!). In addition, what can simultaneously exert such an unbelievably strong power of attraction and be invisible? The answer has to be: A black hole!



Tasks: "Speeding stars in the Milky Way"














- 1.) Take a remote control, your camera phone and a coke bottle. Ask a friend to operate the remote control (press on any key). Look at it directly with your camera phone. What do you see? Now place the coke bottle in front of the remote control: What happens? This is exactly how astronomers can see through dust clouds!
- 2.) Take a wooden ball with holes in it and pull a thin cord through it. Tie a large knot on the end so that it is well secured! Take the other end and swing the cord quickly so that the wooden ball spins around it. Now accelerate the rotation and find out at what point you must pull the cord towards you so that the ball does not fly away, during a slow or a fast rotation? Can you explain this analogy in relation to the black hole?

[\(→back to Start\)](#)

Sources

- [1] Bastian, Ulrich: Gaia Project: The hexagonal Milky Way, part 1: Why and for what purpose was Gaia built, *Sterne und Weltraum (Stars and Space)* 5/2013, p. 36-44
- [2] Bastian, Ulrich: Gaia Project: The hexagonal Milky Way, part 2: Where, when and how Gaia should work, *Sterne und Weltraum (Stars and Space)* 5/2013, p. 48-55
- [3] Hennig, Reiner: Stars are far away - how far in fact?, Article in the portal "Science in Schools"(WIS 9/2013), <http://www.wissenschaft-schulen.de/alias/material/sterne-sind-weit-weg-wie-weit-eigentlich/1156161>
- [4] Reffert, Sabine: Astrometric Measurement Techniques, *New Astronomy Reviews*, March 31, 2009
- [5] Bastian, Ulrich: Correspondence in July 2013
- [6] Brockmann, D. (2008): A model of the Herschel telescope, in: Staude, J. & Landeau-Constantin, J. (Hrsg.): *Sterne und Weltraum / esa The Planck and Herschel space observatories* , p. 16 – 25, Heidelberg
- [7] Laux, U. (1999): *Astrooptik (Astro optics)*, 2nd updated and extended edition, Publishers Sterne und Weltraum, Heidelberg
- [8] ESA: http://www.rssd.esa.int/SA/GAIA/docs/flyers/Gaia_flyer_2012_ge.pdf (accessed on 27.10.2013)
- [9] Stellarium: <http://www.stellarium.org/de/> (accessed on 27.10.2013)

Solutions

from 1450	Use of moveable letters in metal for printing
Mid 15 cent.	First time manufacturing of clear, transparent glass in Europe (Idea: Angelo Barovier)
1543	Nicolaus Copernicus  Publication of the ideas about heliocentrism
1584	Giordano Bruno  Hypothesis: Space is infinite in size and unending and is not geocentric. The sun is no exception among the stars.
1608	The Dutch spectacle maker Hans <u>Lipperhey</u> builds the first telescope (Dutch telescope)
1609	Galileo Galilei  First telescopic observation shows that the Milky Way is made of stars. 
1618 - 1648	Thirty Year's War.
1712	Beginning of the Industrial Revolution in Great Britain, first usable steam engine (Thomas <u>Newcomen</u>), many discoveries
1728	James Bradley Discovery of the directional deviation of the star light propagating at a finite speed from the moving earth (aberration) when searching for fixed star parallaxes.
1785	William Herschel  Construction and use of large reflecting tele scopes: Milky Way system as a lenticular collection collection of stars with the sun in the centre. 
1838	Friedrich Wilhelm Bessel  First measurement of a fixed star parallax for the star 61 Cygni.
1920	Harlow Shapley  Heber Curtis  Shapley: Milky Way system much larger than believed, sun not in centre, spiral clouds are gas clouds in this single giant galaxy, Curtis: Milky Way system (MWS) much smaller, spiral clouds are objects at great distances from each other like the MWS
1939- 1945	Development of radio location systems (RADAR) for military purposes (World War
1950s	Radio observations demonstrate the spiral structure of the Milky Way system 
from 1960s	The development of sensors for infrared radiation (for the military since the fifties) leads to the development of infra-red astronomy.
From 1990s	The development of adaptive optics (for the military since the seventies makes high resolution astronomical observations possible (prevents "smearing of images") through atmospheric turbulence).
from 1992	High resolution observations (using adaptive optics) from stars near the galactic centre in the near infra-red region: Evidence of a super massive black hole in the centre of the Milky Way system. 
from 2005	Analyses of the infrared shots of the Spitzer space telescope by astronomers at the University of Wisconsin-Madison show that the Milky Way system is a two-armed barred spiral galaxy (and not a "regular" spiral galaxy). 
2010	Using the Fermi space telescope two huge "energy bubbles" are discovered in the gamma ray wavebands, which project North-South from the middle of the Milky Way system 

Solution to the cloze text

Centre: Stars, counting, sun, Milky Way; *Perspective:* Stars, infra-red region; *Distances (with triangles):* Sun, 3600th, earth's...; *Distances (with standard candles):* Standard candle, distance, distance, luminosity..., distances; *Vision with radio emissions:* Radio radiation, penetrate, dust

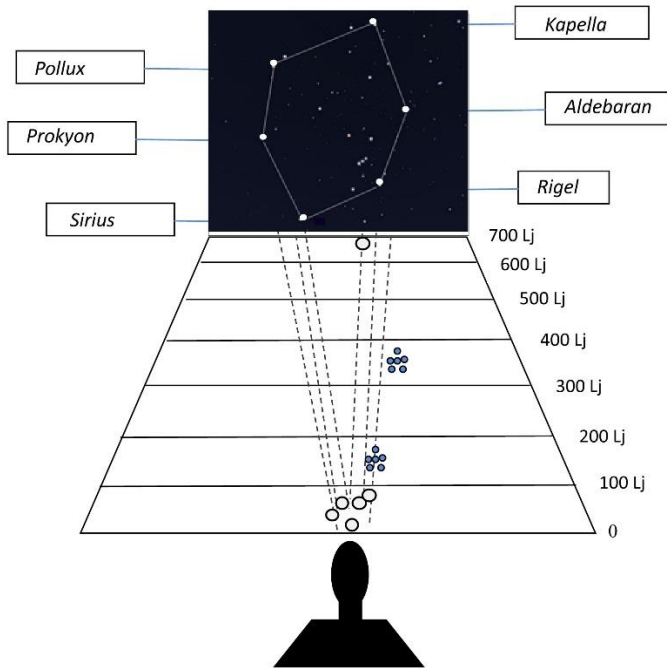
Solutions to "winter hexagon stars"

1. A light year is a unit of distance and is equal to approx. 10 billion km,

2. The coolest stars in the winter hexagon are Aldebaran and Pollux and the hottest star is Rigel.

Star	Distance [ly]	Temperature	Star type	Radius [Solar radii]
Capella	42.2	5000-6000	G	12
Aldebaran	70	3500-5000	K	25
Rigel	650	10000-30000	B	78
Sirius	8.6	7500-10000	A	1.7
Procyon	11.2	6000-7500	F	1.8
Pollux	33.7	3500-5000	K	8

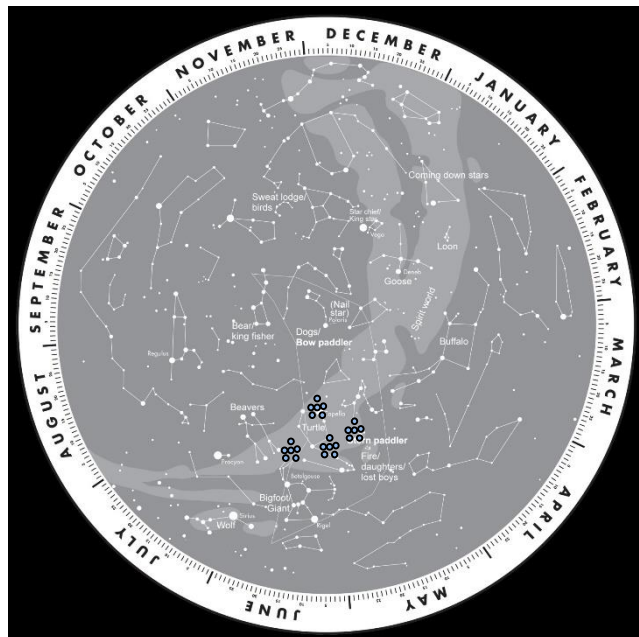
3+ 4.



Solutions to "Star clusters"

1. See diagram above with distances of the Hyades and Pleiades provided.
2. Hyades: 7500-1000 K, Pleiades: 10000-30000 K
3. Position of the open star cluster: all open star clusters are located within the disk of the Milky Way. They originate there, because the building material of stars (gas and dust clouds) exist in the disk.

Solutions to the "The more accurate Gaia telescope"



- The light falls on the two rectangular main mirrors M1 and M'1, is then reflected to each of the mirrors from M2 to M5, so that finally it enters the focal level on the CCD camera. These many reflections result in the large focal length of 6 m. Up to M5 all mirrors are duplicated.

The following animation can also be used for demonstration purposes:

Link: http://www.rssd.esa.int/SA/GAIA/images/image_gallery/290_BANC_02_410x230p.mov

(accessed on 27, 10. 2013)

- $A = 1.45 \text{ m} \times 0.5 \text{ m} = 0.725 \text{ m}^2 \rightarrow d = \sqrt{\frac{4A}{\pi}} = 0.96 \text{ m}.$
- Use the shortcut <Alt+O> and Configure Ocular point \rightarrow to enter the appropriate menu. This is where the telescope ($d = 0.96 \text{ m}$, $f = 36 \text{ m}$ for Gaia) and chip (104 cm \times 42 cm) are configured. The field that shows the chip in the field of view then appears and celestial objects can be moved into it. Use the shortcut <Ctrl+S> to take a "photo" of the current view.

Solutions to "Pixellated images - Gaia's CCD Camera"

- 937,782,000 Pixels
- e.g. 5 MP \rightarrow Gaia has approx. 188 times more pixels
- Explain the principle of colour mixing
 - Explain the set-up and how to use a Bayer matrix (RGGB).
 - Greater sensitivity, higher resolution
- Based on the measurements from the diagram, the distance is approx. 32 cm, which moves a constellation in 30 s. Consequently $v = 1.07 \text{ cm/s}$.
- Tasks are organised according to the information in the introduction.
- $t = \frac{s}{v} = \frac{1 \times 10^{-5} \text{ m}}{0.0107 \text{ m/s}} = 9.35 \times 10^{-4} \text{ s}$ for one pixel. Since a CCD chip has a width of 4500 pixels, the time for an individual CCD chip is approx. 4.2 s.

Solutions / Notes on the Worksheet

Basic terms such as astronomical coordinates and apparent magnitude should first be explained and taught appropriately.

- The coordinates are calculated approximately by taking a reading and entering the values in the table.
- The solutions to tasks 2 and 3 are stored in the table e.g.

Number	Name	Right ascension	Declination	Apparent Magnitude
1	Merope (23 Tau)	3 h 47 min	+23° 44'	4.1 m
2	Electra (17 Tau)	3 h 45 min	+24° 09'	3.7 m
3	Alcyone (η Tau)	3 h 48 min	+24° 08'	2.85 m
4	Maia (20 Tau)	3 h 46 min	+24° 24'	3.85 m
...				

- The distances provided for the stars listed in the table are:

380.14 ly, 404.66 ly, 403.16 ly, 383.26 ly → average distance: 392,8 ly
 0.00858"; 0.00806"; 0.00809"; 0.00851" → average parallax: 0.00831"

4. All spectra show a brightness focal point in the blue to violet range. As already demonstrated in figure 2, the stars appear blueish in colour. The stars were formed at the same time and due to their common origins they have the same chemical composition. The brightest cluster stars have a comparable mass and are therefore at a similar stage of development.

The Stellarium freeware program can be downloaded at the following link:

<http://www.stellarium.org/de/>

Prior to carrying out the task, the functions of the program should be explained.

Solutions - Parallaxes and Angle measurement

- 1.) 20 microarc seconds correspond to approx. 5 billionths of a degree:

$$0.000020'' = 0.0002'' \times \frac{1^\circ}{3600''} \approx 5.55 \times 10^{-9} \text{ degrees}$$

In the middle distance of the moon (384,400 km) a distance of $b \approx 4$ cm spans this angle.

Without trigonometry, this angle can be calculated from observations on the circle. The distance sought represents an arc segment with a radius r of the average distance to the moon (and the circumference $C = 2\pi \cdot r$).

$$\frac{b}{u} = \frac{5.55 \times 10^{-9} \text{ degrees}}{360^\circ} \Rightarrow b = \frac{5.55 \times 10^{-9}}{360} \cdot 2\pi \times 384,400 \text{ km} \approx 4 \text{ cm}$$

Using the angle functions b can be calculated as follows:

$$\tan p = \frac{b}{r} \Rightarrow b = \tan 5.55 \times 10^{-9} \text{ degrees} \times 384,400 \text{ km} \approx 4 \text{ cm}$$

- 2.) The solution considered an arc segment $b = 1$ au in the required distance r where this occurs at an angle of 100 micro-arc seconds.

$$\frac{u}{b} = \frac{360^\circ}{p} \Rightarrow 2\pi \times r = \frac{360^\circ}{p} \times b \Rightarrow r = \frac{1}{p} \times \left(\frac{360^\circ}{2\pi} \times 1 \text{ AE} \right) = \frac{1}{\frac{0.0001''}{3600''/^\circ}} \times \frac{360^\circ}{2\pi} \times 150 \times 10^6 \text{ km} \approx 3,1 \times 10^{17} \text{ km}$$

$$1 \text{ Ly} \approx 9.461 \times 10^{15} \text{ m results in } r \approx 33,000 \text{ Ly (light years).}$$

- 3.) a.) A quasar at a distance of 10 billion ly ≈ 3.07 billion pc (1 pc is equal to approx. 3.26 ly) has an annual parallax of approx. 0.00000000326". Considered as a point, the quasar would be very well suited for absolute parallax measurement using Gaia but: see b.).

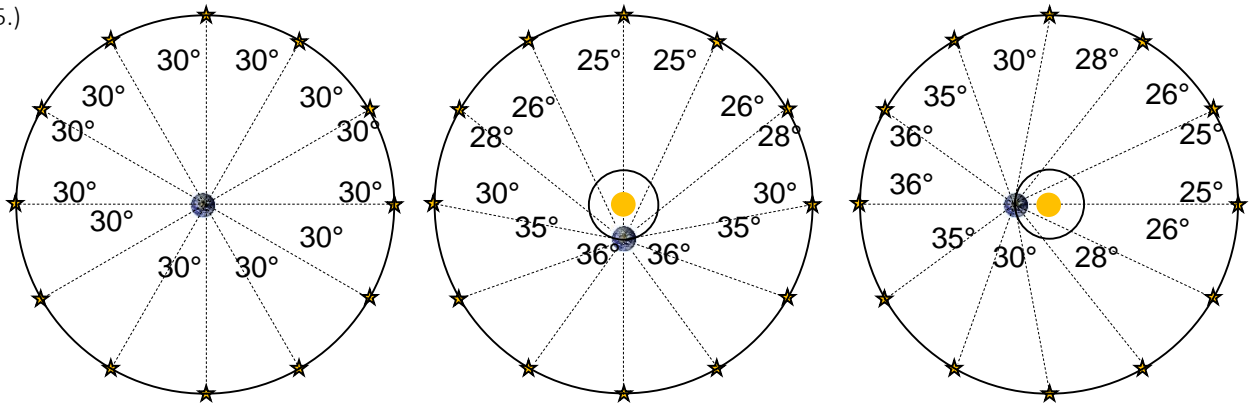
- b.) Quasars are not point-like and can significantly change their location in the galaxy core:

If the bright region of the quasar located at 10 billion ly shifts by 5 ly, this represents an angular displacement of approx. 100 micro-arc seconds in the sky (and Gaia measures more accurately).

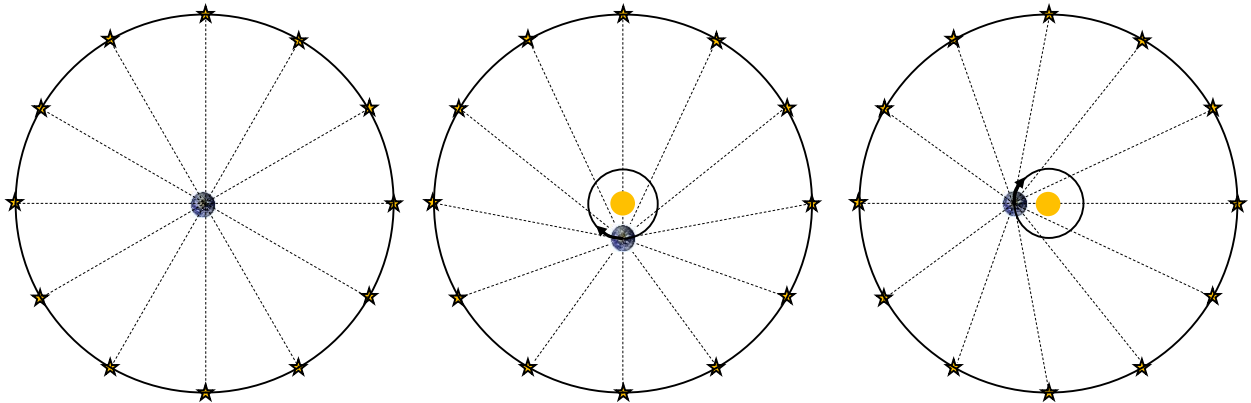
$$\frac{p}{360^\circ} = \frac{5 \text{ Lj}}{2\pi \cdot 10^{10} \text{ Lj}} \Rightarrow p = \frac{5}{2\pi \cdot 10^{10}} \cdot 360^\circ \approx 0.0001''$$

- 4.) To measure angles from only a photo of the sky (to calculate relative parallaxes), the details of which linear measure on the photo corresponds to which angular scale in the sky (magnification) is required. This information can be derived from the intervals between the stars on the photo. The accuracy of the star positions limits the accuracy of the magnification and thereby the accuracy of the measurement of the relative parallaxes. In the case of the sky circuit, the "angular length" of the photo was preset. 360° and therefore is provided with an opportunity to more accurately define the magnification.

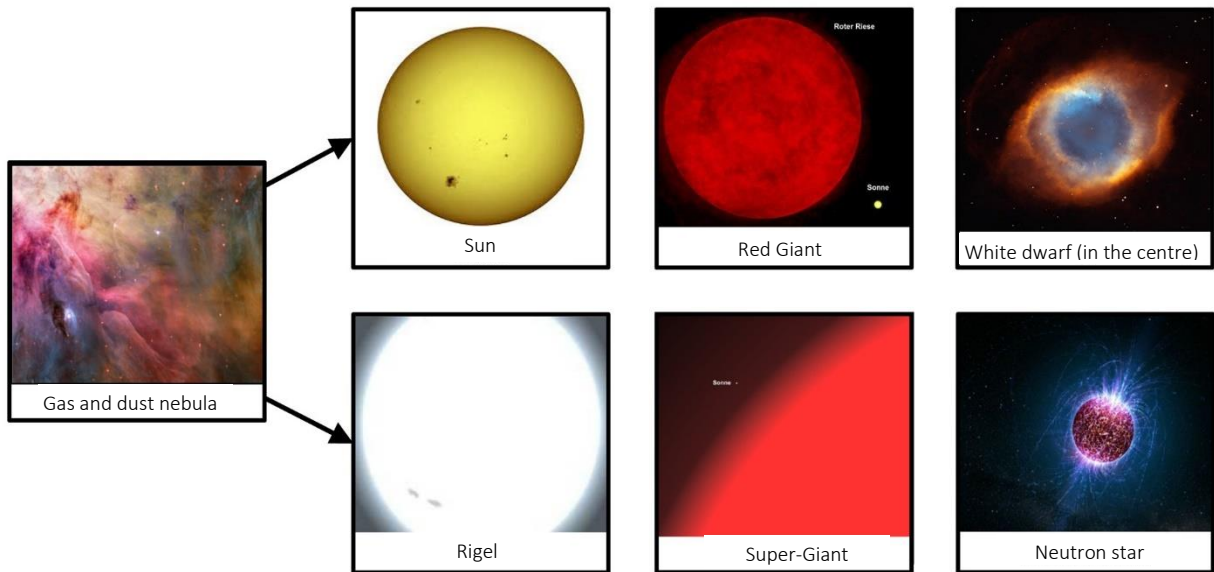
5.)



The angular accuracy can be tested by its 360° total. The (intrinsically fixed) angular intervals apparently change due to different earth orbit positions (displacement due to parallax). In reality, the largest displacement occurs perpendicular to the connecting line between earth and sun and no displacement occurs along this connecting line.



Solution to "Lives of the stars"



Solutions to "The crab nebula and its pulsar"

- 1.) Between 12 and 13 solar masses
- 2.) 108000 times per hour
- 3.) 6300 years

Solutions to "Speeding stars in the Milky Way"

- 1.) Remote control experiment: You can see the remote control signal through the coke with the digital camera.
- 2.) More tension occurs in the cord during a fast rotation. In exactly the same way, the stars "are pulled" more by the "invisible gravitational cord" to the black hole, when their orbit nears the hole where the orbiting speed is the highest.

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