Theoretical round. Sketches for solutions

Note. The given sketches are not full; the team leaders have to give more detailed explanations to students. But the correct solutions in the students' papers (enough for 8 pts) may be shorter.

Note. Jury members should evaluate the student's solutions in essence, and not by looking on formal existence the mentioned sentences or formulae. The formal presence of the mentioned positions in the text is not necessary to give the respective points. Points should be done if the following steps de facto using these positions.

αβ-1. Double star. (Common part for both **α** and **β**).

As the components move in circular orbits around their common center of mass, the distance between them does not change. Therefore observed from Earth, the angular distance between them can be changed only due to the fact that we see the orbits of the stars inclined.

The angular distance between the stars becomes maximum (2.2″) when the line connecting them is perpendicular to the direction to the Earth (see figure). This situation take place twice during one period T_Σ of rotating the stars, so $T_\Sigma = 2\tau = 79.2$ years. The total mass of the system M_Σ (in solar masses) is equal to $M_\Sigma = 1.11\ M_\odot + 0.93\ M_\odot = 2.04\ M_\odot$.

In the system of units $M_\odot$ – year – au the Kepler's third law may be expressed as

$$a^3 / T^2 \cdot M = 1.$$

Therefore, in this binary system the semimajor axis of the relative orbit (in this case, the distance between the components) will be equal to

$$a_\Sigma = (T_\Sigma^2 \cdot M_\Sigma)^{1/3} \approx 23.4 \text{ au}.$$

As follows from the problem situation these 23.4 au are visible from the Earth as an angle of 2.2″, therefore,…

α-1. Double star. (Continue for **α**).

… the distance (in parsecs), at which this double star is located, will be:

$$L = 23.4 / 2.2 \approx 10.63 \text{ pc} \approx 10.6 \text{ pc}.$$

Answer: about ten and a half parsecs.

β-1. Double star. (Continue for **β**).

… parallax of the double star equals to

$$p = 2.2'' / 23.4 \approx 0.094''.$$

(You can also find the distance at which the double star is located, in parsecs

$$L = 23.4 / 2.2 \approx 10.63 \text{ pc} \approx 10.6 \text{ pc}.\ )$$

By comparing the components with the real α Centauri **A** and α Centauri **B**, which have parallax 0.747″ and magnitudes -0.01^m and 1.34^m, we get:

$$m_1 = m_{\alpha CenA} - 5^m \cdot \lg(p/p_{\alpha CenA}) = -0.01^m + 5^m \cdot \lg(0.747/0.094) = -0.01^m + 4.48^m \approx 4.5^m,$$
$$m_2 = m_{\alpha CenB} - 5^m \cdot \lg(p/p_{\alpha CenB}) = 1.34^m + 5^m \cdot \lg(0.747/0.094) = 1.34^m + 4.48^m \approx 5.8^m.$$

(The difference $+4.48^m$ can be also found through the ratio of distances, first by calculating the distance to α Centauri as 1/p, 1 / 0/747 = 1.34 (parsec):

$$\Delta m = +5^m \cdot \lg(L_1/L_{\alpha Cen}) = +5^m \cdot \lg(10.6/1.34) \approx 4.49^m).$$

The total magnitude of the two components will be equal to

$$m_{1+2} = -2.5^m \cdot \lg(10^{-m1/2.5} + 10^{-m2/2.5}) \approx 4.2^m.$$

(One can also first find the total magnitude of both components of α Centauri as

$$m_{\alpha Cen(A+B)} = -2.5^m \cdot \lg(10^{-m\alpha CenA/2.5} + 10^{-m\alpha CenB/2.5}) \approx -0.28^m,$$

and then add to it the difference of $+4.48^m$ and get the same 4.2^m).

Answers: $m_1 \approx 4.5^m$, $m_2 \approx 5.8^m$, $m_{1+2} \approx 4.2^m$.

α-2. Extraterrestrial summit.

The minimum distance between native stars of Bear and Penguin will be in the case when the distances between these stars and the venue of the summit also will be minimum. At the minimum possible distance that satisfies the conditions of the problem may be brown dwarfs with apparent magnitude of 1^m, and absolute one of 16^m. Accordingly, the distance to a brown dwarf anyway

$$r = 10^{[0.2(m-M+5)]} \approx 0.01 \text{ pc}.$$

The distance between two such stars can be found, having considered the equilateral triangle, length of base equal to

$$L = r_B \, 2\sin\beta/2$$

$$L = 0{,}01 \text{ pc} \times 2\sin 15° \approx 0.005 \text{ pc} \approx 1000 \text{ au}.$$

(more precise value here does not make sense).

Answer: **about 0,005 pc or 1000 a.u.**

To find the maximum distance between the stars we have to consider several options, which, however, will be calculated using the maximum distance from the summit to the stars of Penguin or a Bear. In order that the star was as far as possible, observer must see it as a faint object (star of 6^m), and it should have high luminosity (the star of the class A0 with an absolute visible magnitude of about 0.5^m). Then, using the formula for the absolute magnitude will get:

$$R = 10^{[0.2(m-M+5)]} \approx 126 \text{ pc}.$$

Now consider two options for a possible maximum distance:

1. We have two different stars: a brown dwarf and a main sequence star of spectral class A. The first one is on minimum possible distance, the second – on highest possible distance. The distance between them is calculated in this case by theorem of cosines:

$$L_I = [r^2 + R^2 - 2rR\cos\beta]^{1/2}.$$

If you take the r for a brown dwarf (the value of which we found earlier), due to the small values of r compared to R in the formula L_I it can be neglected. And then the distance between stars would actually be equal to the distance from the summit to the star of spectral class A0.

2. If we have two stars of the main sequence spectral class A, then the distance between them is given by the same theorem of cosines, but in a slightly simplified form:

$$L_{II} = R \cdot [2(1-\cos\beta)]^{1/2} = 2R \cdot \sin\beta/2.$$

We get an isosceles triangle while the third side will be less than the first two (β < 60°), this formula will not give the maximum distance. However, when our triangle to turn into an equilateral (β = 60°) and the angle at the apex will continue to increase (β > 60°), the distance between the stars will also increase, which cannot be said about the first the case.

From the task we have the angle $\beta = 30°$, so the second of the options considered, we are not automatically perfect. Accordingly, the maximum distance between the stars is approximately 130 pc (more precisely to say here does not make sense).

Answer: **about 130 pc**.

β-2. Extraterrestrial summit. (Common part for both **α** and **β**).

The minimum distance between native stars of Bear and Penguin will be in the case when the distances between these stars and the venue of the summit also will be minimum. At the minimum possible distance that satisfies the conditions of the problem may be brown dwarfs with apparent magnitude of 1^m, and absolute one of 16^m. Accordingly, the distance to a brown dwarf anyway

$$r = 10^{[0.2(m-M+5)]} \approx 0.01 \text{ pc}.$$

The distance between two such stars can be found, having considered the equilateral triangle, length of base equal to

$$L = r_B\, 2\sin\beta/2$$

A common solution based on the minimal distance from β is determined by the formula:

$$L = 0{,}02 \text{ pc} \times \sin\beta/2 \approx 4000 \text{ au} \times \sin\beta/2$$

In the context of our problem it is from 0.005 to 0.015 pc or from 1000 au to 3000 au (more precise values here does not make sense).

Answer: **determined by formula $L = 0{,}02 \text{ pc} \times \sin\beta/2 \approx 4000 \text{ a.u.} \times \sin\beta/2$**.

To find the maximum distance between the stars we have to consider several options, which, however, will be calculated using the maximum distance from the summit to the stars of Penguin or a Bear. In order that the star was as far as possible, observer must see it as a faint object (star of 6^m), and it should have high luminosity (the star of the class A0 with an absolute visible magnitude of about 0.5^m). Then, using the formula for the absolute magnitude will get:

$$R = 10^{[0.2(m-M+5)]} \approx 126 \text{ pc}.$$

Now consider two options for a possible maximum distance:

1. We have two different stars: a brown dwarf and a main sequence star of spectral class A. The first one is on minimum possible distance, the second – on highest possible distance. The distance between them is calculated in this case by theorem of cosines:

$$L_I = [r^2 + R^2 - 2rR\cos\beta]^{1/2}.$$

If you take the r for a brown dwarf (the value of which we found earlier), due to the small values of r compared to R in the formula L_I it can be neglected. And then the distance between stars would actually be equal to the distance from the summit to the star of spectral class A0.

2. If we have two stars of the main sequence spectral class A, then the distance between them is given by the same theorem of cosines, but in a slightly simplified form:

$$L_{II} = R\cdot[2(1-\cos\beta)]^{1/2} = 2R\cdot\sin\beta/2.$$

We get an isosceles triangle while the third side will be less than the first two ($\beta < 60°$), this formula will not give the maximum distance. However, when our triangle to turn into an equilateral ($\beta = 60°$) and the angle at the apex will continue to increase ($\beta > 60°$), the distance between the stars will also increase, which cannot be said about the first the case.

In the end, while the angle between the directions to the home stars Bear and Penguin will not exceed 60° the maximum possible distance between them would be approximately 130 pc. n the problem we are given a maximum angle of 90°. Thus, at angles from 60° till 90° the answer will be formula $L_{II} = 2R\cdot\sin\beta/2$, and when angle is maximal 90° is the distance to the root 2 times more calculated 130 pc, that is, approximately180 pc.

Answer: if $30° < \beta < 60°$ – **about 130 pc.**
if $60° < \beta < 90°$ – **determined by formula $L \approx 252$ pc × sinβ/2.**

αβ-3. Mirror and plate. The observer sees the combined light from parallel rays A1, A2, A3, A4,.. in the direction B. Every beam AN once passed through the plate (losing K%), then successively reflected from the mirror (without losing intensity) and from plates (each time losing (100-K)% of the light), with N reflections from mirrors and N-1 reflections from the plate.

```
                     B
                    /
                   /
            ---------------------------------------- Mirror
              / \ / \ / \ / \ / \ / \
Observer O * ------------------------------------- Plate
              \   \   \   \   \   \   \
               \   \   \   \   \   \
                \   \   \   \   \
                 A  A1  A2  A3  A4
```

As the star is at a very large distance, all the rays AN are coming from the mentioned star 2^m. Therefore, the observer sees in the direction "B" a single star, the intensity of which we need to calculate as the sum of the series:

$$P_0 \cdot k + P_0 \cdot (1-k)k + P_0 \cdot (1-k)^2 k + P_0 \cdot (1-k)^3 k + P_0 \cdot (1-k)^4 k + P_0 \cdot (1-k)^5 k + \ldots$$

where P_0 is the flow of light from the star 2^m, and k is the fraction of the transmitted light from the plate (i.e., k = K/100).
The sum of the series $1+(1-k)+(1-k)^2+(1-k)^3+(1-k)^4+(1-k)^5+\ldots$ is equal to 1/k. Accordingly, the sum of our series is

$$P_0 \cdot k \cdot (1+(1-k)+(1-k)^2+(1-k)^3+(1-k)^4+(1-k)^5+\ldots) = P_0 \cdot k \cdot 1/k = P_0.$$

Paradoxically, the fact! Regardless of the value of K the observer would see the only one star in the direction "B", and its magnitude is 2^m.
So the numerical answer in the both cases: 2^m.

α-4. Eclipse in USA.

4.1. Let us analyze the ellipse of the Moon's shadow on the Earth's surface to calculate the altitude **h** of the Sun. If the diameter of the Moon's shadow near the Earth is denoted by **D**, the lengths of these axes equal to:

in the azimuth direction, where the Moon and the Sun are: A = **D**/sin**h**,

in the direction perpendicular to this azimuth: B = **D**.

Thus, from these two equations: sin**h** = B/A.

Measuring lengths of the axes of the shadow "2" on the given map, we get:

sin**h** = 26 mm / 39 mm.

h = arcsin(2/3) = 41.8°.

Answer: about 42°.

Note. In reality, the height of the Sun during the totality phase in Oregon was from 39° (in the West part) to 45° (in the East part), and in the selected for measurement place "2" it was 41.9°.

4.2. The size of the eclipsing shadow along the central line of the path is the speed of the shadow multiplied by the duration of the total phase, and the difference in the positions of shadows "1" and "2" is the speed of the shadow multiplied by the time that we need to find.

The duration of the totality can be obtained by analyzing pictures 2 and 4. Both of them demonstrate the so-called "diamond ring", a unique phenomenon, lasting a few seconds only. It is seen that images of approximately symmetrical in shape, and were shorted about 3-4 seconds before the second contact and after 3-4 seconds of the third one. In addition, from the fact that the points of the second and the third contacts are almost symmetric, it can be concluded that the Bulgarian-Russian group observed the central eclipse and, therefore, was located about in the middle of the totality path. Thus, it is possible to obtain the totality duration at the middle of the path $\tau = 2^m04^s$ by calculating the time difference of the dating of these images.

Note. The above few seconds before the second contact and after the third one is a very delicate moment. It should not be considered an error if a participant will not take it into account and use the value $\tau = 2^m11^s$.

Making the necessary measurements on the map, we get:

$$t = \tau \times (42.5 \text{ mm} / 30 \text{ mm}) = 176 \text{ s} \approx 180 \text{ s}.$$

Answer: about 180 seconds.

Note. In reality, 180 seconds is the interval between the positions of the shadow on the map.

β-4. Eclipse in USA.

4.1. At first, we have to calculate the speed of the shadow on the Earth's surface. The speed of the Moon in its synodic movement around the Earth is

$$V_1 = 2\pi R_{moon}/T_{moon} = (6.28 \cdot 384\,400\,000 \text{ m}) / (29.53 \cdot 24 \cdot 60 \cdot 60 \text{ s}) = 947 \text{ m/s}.$$

The same speed would have the speed of the Moon's shadow on perpendicular to the Sun direction unmoving surface. To take into account the inclination of the territory of Oregon during the eclipse to the perpendicular unmoving surface, we should divide V_1 by the sine of some angle $\mathbf{h}_E$, which is defined as

$$\mathbf{h}_E = \arctan(\tan\mathbf{h}/\sin\chi),$$

where χ is the angle between the direction to the South and the azimuth of the Sun, in our case it is 59,5°.

$$V_2 = V_1 / \sin\mathbf{h}_E = V_1 / \sin(\arctan(\tan\mathbf{h}/\sin\chi))° = 1313 \text{ m/s}.$$

And to take into account moving of the territory of Oregon due to sidereal rotation of the Earth we should substrate synodic (!) speed V_φ of a point at latitude $\varphi = 45°$ from V_2

$$V_\varphi = V_E \cdot \cos\varphi = 2\pi R_E/T_E \cdot \cos\varphi = (6{,}283 \cdot 6378\,000 \text{ m} / (24 \cdot 60 \cdot 60 \text{ s}) \cdot 0{,}707 = 328 \text{ m/s}.$$

$$V_3 = V_2 - V_E = 1313 \text{ m/s} - 328 \text{ m/s} \approx 985 \text{ m/s}.$$

As we consider the pass of the eclipse was going along the geographical parallel, the other corrections should be not taken into account. So the speed of the Moon's shadow on the territory of Oregon was about 985 m/s, and it is the answer to the first part of the problem.

Note. The real value of the speed of the shadow in that area was 1001 m/s.

4.2. The size of the eclipsing shadow on the Earth is determined by the projection of the Moon's shade diameter **D** of the on Earth's surface. This is usually an ellipse with axes equal to:

in the azimuth direction, where there are the Moon and the Sun: $A = \mathbf{D}/\sin\mathbf{h}$,

in the perpendicular to this azimuth direction: $B = \mathbf{D}$.

It is more complicated to calculate the size of the shadow in other directions, but for ellipses with small eccentricities it is possible to use the approximation formula:

$$L = B + (A-B) \cdot \cos\alpha,$$

where α is the angle between the direction of measuring and the semi-major axis of the ellipse. The semi-major axis of the ellipse is directed to the Sun and the Moon. Therefore, is it also at an angle $\chi = 59{,}5°$ to the direction of the South in this configuration. One can write the approximate relations for the size of the shadow on the Earth's surface:

in the direction North-South: $L_{NS} = B + (A-B)\cdot\cos\chi = \mathbf{D} + (\mathbf{D}/\sin\mathbf{h} - \mathbf{D})\cdot\cos\chi$,

in the direction West-East: $L_{WE} = B + (A-B)\cdot\sin\chi = \mathbf{D} + (\mathbf{D}/\sin\mathbf{h} - \mathbf{D})\cdot\sin\chi$,

Substituting the numerical values of the angles, we get:

$$A \approx 1.5\ B,\quad L_{NS} \approx 1.25\ B,\quad L_{WE} \approx 1.43\ B,\quad L_{NS} \approx 0.87\ L_{WE}.$$

We need the width of track that is the size of the shadow in the direction perpendicular to the movement of the shadow that is approximately the direction North-South in our case, L_{NS}. And the size of the shadow in the direction of its movement, L_{WE}, approximately West-East, can be calculated as the speed of the shadow multiplied by the duration of the total phase of the Eclipse:

$$L_{WE} = V\cdot\mathbf{T},$$

The duration of the totality can be obtained by analyzing pictures 2 and 4. Both of them demonstrate the so-called "diamond ring", a unique phenomenon, lasting a few seconds only. It is seen that images of approximately symmetrical in shape, and were shorted about 3-4 seconds before the second contact and after 3-4 seconds of the third one. In addition, from the fact that the points of the second and the third contacts are almost symmetric, it can be concluded that the Bulgarian-Russian group observed the central eclipse and, therefore, was located about in the middle of the totality path. Thus, is possible to obtain the totality duration at the middle of the path $\mathbf{T} = 2^{M}04^{c}$ by calculating the time difference of the dating of these images.

Note. The above few seconds before the second contact and after the third one is a very delicate moment. It should not be considered an error if a participant will not take it into account and use the value $\mathbf{T} = 2^{m}11^{s}$.

Thus, the size of the shadow on the Earth's surface in the direction of its motion is equal to:

$$L_{NS} = V_3\cdot\mathbf{T} = 985\ \text{m/s} \times 2^{M}04^{c} \approx 120\ \text{km},$$

and the size in the perpendicular direction:

$$L_{NS} = 0{,}87\ L_{WE} = 0{,}87\cdot120\ \text{km} \approx 105\ \text{km}.$$

Thus, the width of the path of the totality was equal to approximately 105 km.

Note. The real value of the width of the path in that area was 102 km.

α-5. Whirlpool galaxy.

5.1. (Method of solution 1, without explanations).

$$S = \alpha = 13^{h}29^{m}56^{s} = 202.483° = S_0 + (T_c - 8^{h}) \times (1+1/365.2422) + 122.05°,$$

$$S_0\ (^{d}) \approx 93^{d},\quad S_0(°) = 93^{d} \times (360°/365.2422^{d}) = 91.67°$$

$$\rightarrow\ T_c = -11.2° + 120° = 108.8° = 7.25^{h} = 07^{h}15^{m}.$$

Answer: 07:15.

5.1. (Method of solution 2, with explanations). The upper culmination of a celestial body occurs when its sidereal time equals to its right ascension. It is ≈ $13^{h}\ 30^{m}$ for NGC 5194. Sidereal time is equal to mean solar time at the date of autumnal equinox, and then begins to outstrip it with speed $1^{d}/365.2422$ per day (about $3^{m}\ 56^{s}$ per day).

Note. Strictly speaking, the sidereal time is equal to mean solar time about two days earlier, but we are not going to account for this subtle effect.

93 days passed since September 22/23 (autumnal equinox) till December 24/25 (the observation was made). The difference between mean solar time and sidereal time at the night of observations is:

$$24^{h}\ 00^{m} \times 93^{d}/365.2422^{d} = 6^{h}\ 07^{m}$$

So on December 24/25 sidereal time $13^{h}\ 30^{m}$ corresponds to

$$13^h\,30^m - 6^h\,07^m = 7^h\,23^m \quad \text{of mean solar time.}$$

Weihai is located in 2.05° East from the meridian of 120° (base meridian for Beijing time UT+08), so the mean solar time here ahead the Beijing time by $2.05° \times 4^{m/°} = 8.2^m \approx 8^m$. So to get answer according to time UT+08 we have to subtract these 8^m, and we have

$$7^h\,23^m - 0^h\,08^m = 7^h\,15^m \quad \text{Beijing time.}$$

Answer: 07:15.

5.2. FoV = 2048 × 13.5 μm × 206265″ / 8 m = 712.85″ = 11.88′, so measured from the Figure, the angular size in diameter is $\beta \approx 55$ mm / 116 mm × FoV ≈ 5.6′.

5.3. $L = D / \beta(\text{rad}) \approx ½ \times 0.03 \text{ Mpc} / (5.6' / 3438^{\text{rad}/'}) \approx 9$ Mpc.

5.4. Type = spiral.

β-5. Seyfert galaxy.

5.1. (Method of solution 1, without explanations)

$$S = \alpha = 23^h04^m57^s = 346.238° = S_0 + (T_c - 8^h) \times (1+1/365.2422) + 117.575°,$$

$$S_0 \approx -8^d = -8^d \times (360°/365.2422^d) = -7.9°$$

$$\rightarrow \; T_c = -123.5° + 120° = -3.5° = -0.23^h \;\rightarrow\; 23.77^h = 23^h46^m.$$

Answer: 23:46.

5.1. (Method of solution 2, with explanations). The upper culmination of a celestial body occurs when its sidereal time equals to its right ascension. It is $\approx 23^h\,05^m$ for NGC 7479. Sidereal time is equal to mean solar time at the date of autumnal equinox, and then begins to outstrip it with speed $1^d/365.2422$ per day (about $3^m\,56^s$ per day).

Note. Strictly speaking, the sidereal time is equal to mean solar time about two days earlier, but we are not going to account for this subtle effect.

8 days to be passed till September 22/23 (autumnal equinox) since September 14/15 (the observation was made). The difference between mean solar time and sidereal time at the night of observations is:

$$24^h\,00^m \times -8^d/365.2422^d = -31.5^m$$

So on September 14/15 sidereal time $23^h\,05^m$ corresponds to

$$23^h\,05^m - (-31.5^m) = 23^h\,36.5^m \quad \text{of mean solar time.}$$

Xinglong Station is located in 2.425° West from the meridian of 120° (base meridian for Beijing time UT+08), so the mean solar time here behind the Beijing time by $2.425° \times 4^{m/°} = 9.7^m \approx 10^m$. So to get answer according to time UT+08 we have to add these $9.7^m \approx 10^m$, and we have

$$23^h\,36.5^m + 0^h\,09.7^m = 23^h\,46.2^m \approx 23^h\,46^m \quad \text{Beijing time.}$$

Answer: 23:46.

5.2. Maximum of the Hα emission line is observed at $\lambda_{obs} = 6614$ Å, while its laboratory wavelength is known as $\lambda_0 = 6563$ Å. So the redshift of NGC 7479 is

$$z = (\lambda_{obs} - \lambda_0) / \lambda_0 = (6614 \text{ Å} - 6563 \text{ Å}) / 6563 \text{ Å} = 51 \text{ Å} / 6563 \text{ Å} \approx 0.0078.$$

Note. Real value from literature is z = 0.007935 ± 0.000017.

5.3. $D = v/H_0 = zc/H_0 = 0.0078 \times 300000$ km/s / 68 Mpc/(km/s) ≈ 34 Mpc.

5.4. Measured from the spectrum, FWHM(Hα) = 10 Å, so in units of km/s,

$$\text{FWHM(H}\alpha) = 10 \text{ Å} / 6563 \text{ Å} \times 300000 \text{ km/s} \approx 460 \text{ km/s}.$$

5.5. Type = Seyfert-II.

Theoretical round. Basic criteria. For work of Jury

Note. The given sketches of solutions are not full; the team leaders have to give more detailed explanations to students. The correct solutions in the students' papers (enough for 8 pts) may be shorter.

Note. Jury members should evaluate the student's solutions in essence, and not by looking on formal existence the mentioned sentences or formulae. The formal presence of the mentioned positions in the text is not necessary to give the respective points. Points should be done if the following steps de facto using these positions.

Note. Jury members should elaborate more detailed criteria, and also create criteria for other correct ways of the student's solutions.

α-1. Double star.

Understanding effect is due to the orbits of stars inclined – 2 pt.
$T_\Sigma = 2\tau = 79.2$ years – 1 pt.
$a_\Sigma = (T_\Sigma^2 \cdot M_\Sigma)^{1/3} \approx 23.4$ au – 2pt.
Understanding relations between **a** and L (using parallax) – 1 pt.
L ≈ 10.5 pc – 2 pt.

β-1. Double star.

Understanding effect is due to the orbits of stars inclined – 1,5 pt.
$T_\Sigma = 2\tau = 79.2$ years – 1 pt.
$a_\Sigma = (T_\Sigma^2 \cdot M_\Sigma)^{1/3} \approx 23.4$ au – 2pt.
Understanding relations between using parallaxes and distances – 1 pt.
Correct formula or analogous relations to calculate magnitudes – 1 pt.
Correct calculation of $m_1 \approx 4.5^m$, $m_2 \approx 5.8^m$, $m_{1+2} \approx 4.2^m$ – 1,5 pt (0,5 pt each).

α-2. Extraterrestrial summit.

Minimum distance – 3 pt, including:
- Understanding brown dwarf stars, 16^m abs, 1^m apparent – 1 pt.
- Formula and result ~0.01 pc till the stars – 0.5 pt.
- Geometry and calculation distance between the stars – 1 pt.
- Correct number of significant digits (not more than 2) – 0.5 pt.

Maximum distance – 4 pt, including:
- Understanding A0 star, 0.5^m abs, 6^m apparent – 1 pt.
- Formula and result ~130 pc till A0 stars – 0.5 pt.
- Analysis for two A0 stars – 0.5 pt.
- Analysis for brown dwarf and A0 star – 0.5 pt.
- Issue to take into account brown dwarf and A0 star – 0.5 pt.
- Geometry and calculation distance between the stars – 0.5 pt.
- Correct number of significant digits (not more than 2) – 0.5 pt.

Picture of animals – 1 pt.

β-2. Extraterrestrial summit.

Minimum distance – 2.5 pt, including:
- Understanding brown dwarf stars, 16^m abs, 1^m apparent – 1 pt.
- Formula and result ~0.01 pc till the stars – 0.5 pt.
- Geometry and calculation distance between the stars – 0.5 pt.
- Correct number of significant digits (not more than 2) – 0.5 pt.

Maximum distance – 4.5 pt, including:
- Understanding A0 star, 0.5^m abs, 6^m apparent – 0.5 pt.
- Formula and result ~130 pc till A0 stars – 0.5 pt.
- Analysis for two A0 stars – 0.5 pt.

Analysis for brown dwarf and A0 star – 0.5 pt.
Issue to take into account brown dwarf and A0 star – 0.5 pt.
Geometry and calculation distance between the stars – 0.5 pt.
Understanding difference $\beta<60°$ and $\beta>60°$ – 0.5 pt.
Geometry and calculation distance between the stars for $\beta<60°$ – 0.5 pt.
Geometry and formulae for distance between the stars for $\beta>60°$ – 0.5 pt.
Correct number of significant digits (not more than 2) – 0.5 pt.
Picture of animals – 0.5 pt.

αβ-3. Mirror and plate.
Correct picture of reflections (or logic explanation) – 1.5 pt.
Issue the only one star visible – 2 pt.
Understanding about series, calculation intensity of star B as sum of series – 2 pt.
Issue the result is not depend on K – 1 pt.
Final answer – 1.5 pt.

α-4. Eclipse in USA.
4.1. – 3 pt, including:
Understanding shadow ellipse parameters depend on the altitude – 0.5 pt.
Formulae A = **D**/sin**h**, B = **D**, sin**h** = B/A – 1 pt.
Measurements of axis – 0.5 pt.
Calculations and answer – 0.5 pt.
Correct number of significant digits (not more than 2) – 0.5 pt.
4.2. – 5 pt, including:
Understanding to use times of 2 and 4 as duration – 1 pt.
Calculation of duration using photos – 1 pt.
Understanding the size of shadow along the path is $V\tau$ – 0.5 pt.
Ratio between the size of shadow along the path and distance between 1 and 2 – 0.5 pt.
Measurements of size and distance – 0.5 pt.
Calculations and answer – 1 pt.
Correct number of significant digits (not more than 2) – 0.5 pt.

β-4. Eclipse in USA.
4.1. – 4 pt, including:
Using synodic system of all corrections in sidereal system – 1 pt.
Speed of Moon – 0.5 pt.
Taking into account inclination of the Earth's surface – 0.5 pt.
Correct using the azimuth and altitude of the Sun – 0.5 pt.
Taking into account rotation of the Earth, subtraction speed of rotation – 0.5 pt.
Calculation of the speed of shadow – 1 pt.
4.2. – 4 pt, including:
Understanding shadow ellipse parameters depend on the altitude – 0.5 pt.
Formulae A = **D**/sin**h**, B = **D**, approximation formula for other directions – 0.5 pt.
Formulae for L_{NS} and L_{WE}, and their ratio – 0.5 pt.
Understanding the size of shadow along the path is $V\tau$ – 0.5 pt.
Understanding to use times of 2 and 4 as duration – 1 pt.
Calculation of duration using photos – 0.5 pt.
Calculations and answer – 0.5 pt.

α-5. Whirlpool galaxy.
5.1. – 2.5 pt.
5.2. – 2.5 pt.
5.3. – 2 pt.
5.4. – 1 pt.

β-5. Seyfert galaxy.
5.1. – 2.5 pt.
5.2. – 1.5 pt.
5.3. – 1.5 pt.
5.4. – 1.5 pt.
5.5. – 1 pt.