GeCAA – Theory

Final Question Sheet

(Total 150 points)

1. Astrophotography

An astrophotographer, based on the Equator, uses a good digital camera on a tripod, but with no tracking. The camera has a telescopic lens with focal length of 150 *mm* and aperture (objective diameter) of 84 *mm*. The sensor has an effective light collecting diameter of 22.5 *mm*. The photographic target is a star field at the observer's Zenith.

a) **(2 points)** Calculate the field of view (the angular width of the image) which can be captured on the sensor using this equipment.

b) **(5 points)** The pixels in the camera's sensor are separated by a distance of 3.23 μm . What is the maximum possible exposure time for a single frame, so that no star trails appear on the exposed image?

c) **(3 points)** For a better-quality image of the star field, the photographer decides to take multiple shots at the exposure time calculated in b) and then to stack them together. The total time for all these shots is 30 seconds (ignore any time taken to write data to the memory card) What proportion of the total field of view is possible at the higher signal to noise ratio?

2. Flat Earth

(10 points) A new model of the world is gaining in popularity among some people. These people believe in the “Flat Earth” view of the world, where the Earth is not a spheroid, but rather a circle with radius $R_{\oplus}$. The central axis of the Earth (normal to the circle passing through its centre C) passes through the observer's zenith.

This model must at least remain consistent with the observed phenomena, as listed below:

- ❏ The value of the solar constant is $S_{\odot} = 1366\ W/m^2$.
- ❏ The Earth's central axis precesses in a circle with a period 25800 years.
- ❏ The radius of the precession circle is 23.5°.

Assume that (1) the Earth is a perfect blackbody radiator and the Sun is sufficiently far away such that all solar rays are parallel and (2) the Sun's current (initial) location is at the zenith,

Determine how many years it will take for the Earth's equilibrium temperature to decrease by 1°C.

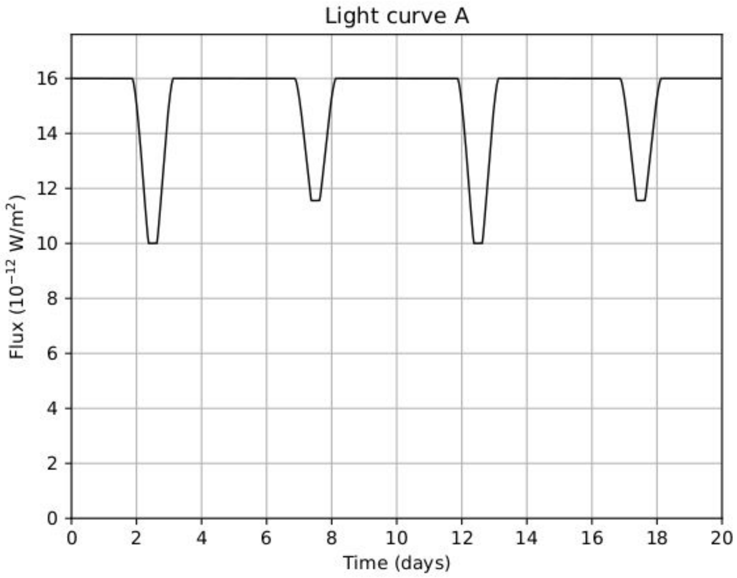
3. Mirror

A bored cosmologist comes up with a thought experiment to determine the Hubble constant (H_0) for his model of a Steady-State-Universe. In this experiment, a large, fully reflecting flat mirror - carrying several gyroscopes that would maintain its spatial orientation in the same plane - would be placed at a distance D from the Solar System in a region without gravitational influences. From the Earth, a laser beam would be directed towards that region for a long period of time. After a time T, the radiation would return and be detected, allowing the determination of the fixed constant H_0.

a) **(7 points)** Find an expression for H_0 as a function of D, c (speed of light) and T.
   Consider that the separation S between the Solar System and the mirror increases only due to the expansion of the universe according to the law $S = s \cdot e^{H_0 t}$, where s is the initial separation. You may use $e^x \approx 1 + x$ for $x \ll 1$, if necessary.
b) **(3 points)** Imagine that such a mirror is located in the vicinity of the star Vega (which also features on the logo of the 1st GeCAA). Vega was the first star outside the Solar System to be photographed and one of the first stars whose parallax ($p = 0.125"$) was accurately measured in 1840 by G. W. von Struve.
   Estimate the total duration of this H_0 measurement experiment.

4. Light Curves

The light curve A shown below, shows a fictional edge-on eclipsing binary system containing stars X (radius r_X , luminosity L_X) and Y (radius r_Y , Luminosity L_Y) . Assume that star X is



brighter, but star Y is hotter.

a) **(1 point)** Which of the two stars is likely to be on the main sequence? (Write ``X'' or ``Y'')

b) Based on light curve A, estimate:

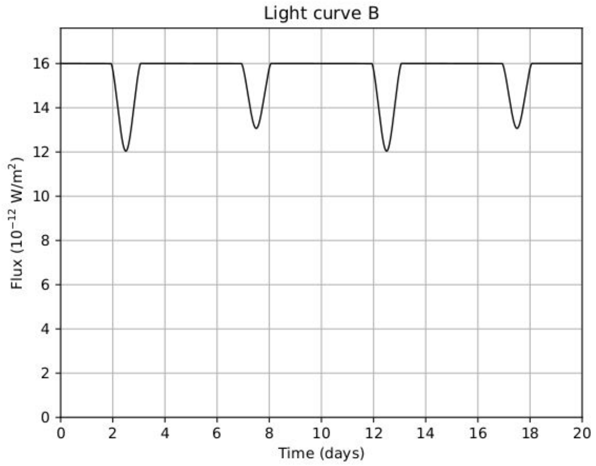
(I) **(2 points)** $\frac{r_X}{r_Y}$, the ratio of the radii of the two stars.

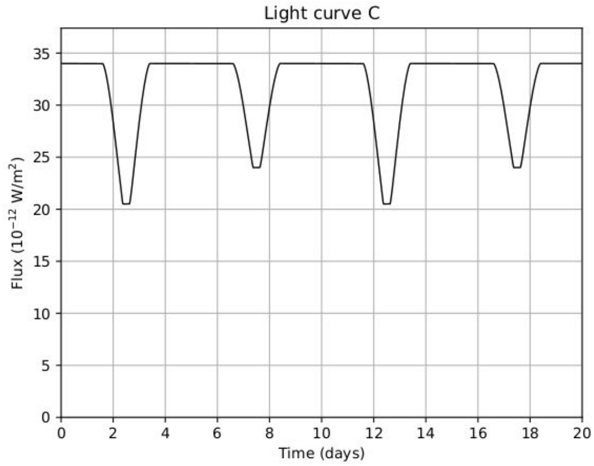
(II) **(2 points)** $\frac{L_X}{L_Y}$, the ratio of the Luminosity of the two stars.

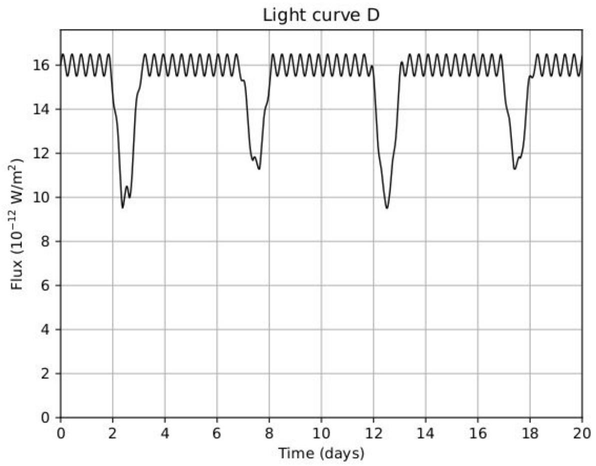
c) **(15 points)** For light curves B to F, in each case only one parameter of the binary system has been changed from the case in light curve A.
For each case, choose the description from the following list that best corresponds to the change (Write the appropriate roman numeral in the answer sheet).

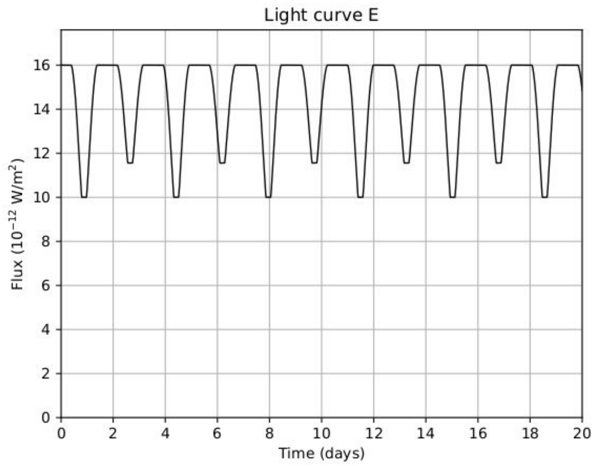
i) Star X increased in size.
ii) Star X increased in luminosity.
iii) Star X decreased in size.
iv) Star X decreased in luminosity.
v) Star Y increased in size.
vi) Star Y increased in luminosity.
vii) Star Y decreased in size.
viii) Star Y decreased in luminosity.
ix) Star X is a variable star.
x) Star Y is a variable star.
xi) The inclination of the system relative to the Earth has changed.

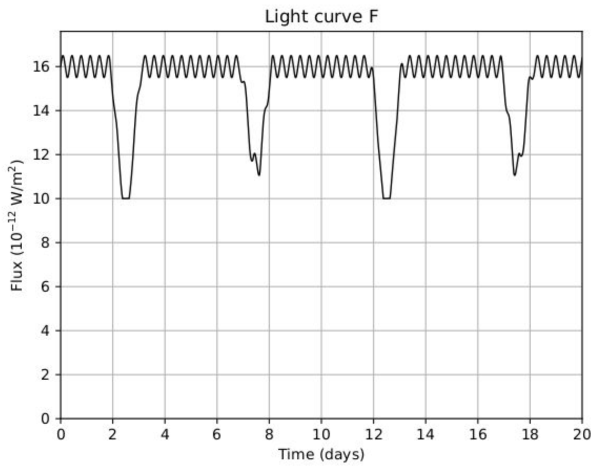
xii) The distance of the system from the Earth has decreased.
xiii) The distance of the system from the Earth has increased.
xiv) The orbital period of the system increased.
xv) The orbital period of the system decreased.











5. HII region

Luminous Blue Variables (LBV) are massive, unstable, supergiant stars that can undergo episodes of very strong mass loss, due to an instability in their atmospheres. After such an event, a dense nebula is formed around the star. LBV are also very hot stars and produce a large amount of high-energy photons that are able to ionise hydrogen atoms ($E_{ph} > h\upsilon_0 = 13.6\ eV$) creating a roughly spherical region of ionized hydrogen (HII region).

In this problem, we consider a static, homogeneous, pure hydrogen nebula with a concentration of $n_H = 10^8/m^3$ and temperature $T_{HII} = 10^4 K$, ionized by photons from a single LBV star with a stable rate of ionizing photons $Q = 10^{49} ph/s$. Assume that each photon can ionise only one hydrogen atom. At a particular location within an HII region, the rate of photoionization is balanced by the rate of recombination per unit volume. This sets the radius of the fully ionized region and this region is called the Stromgren sphere with the radius R_S.
The total number of recombinations per volume is proportional to the concentration of protons n_p, the concentration of electrons n_e and the recombination coefficient for hydrogen $\alpha(T_{HII}) = 10^{-19} m^3/s$. For simplification, ignore the fact that the process of recombination can also release ionising photons.

a) **(5 points)** Derive an algebraic expression for the radius of the Stromgren sphere and calculate its value for the given parameters. Express your answer in units of parsecs (pc).
b) **(3 points)** The photoionization cross-section of H-atoms in the ground state encountering photons with frequency υ_0 is equal to
$$\sigma \approx 10^{-21} m^2$$
Calculate the mean-free path l_{υ_0} of an ionising photon. Compare l_{υ_0} to R_S to determine if this ionized nebulae is sharp-edged or not? (answer "YES" or "NO")
c) **(4 points)** On what timescale (in years) do you expect the Stromgren sphere to form?
d) **(4 points)** Radiation from an ionized hydrogen cloud (HII region) is often called free-free emission because it is produced by free electrons scattering off the ions without being captured: the electrons are free before the interaction and remain free afterwards. In this process, the electron retains most of its pre-scattering energy.
An electron, while passing by a much more massive singly ionized hydrogen atom, produces a radio photon of $\upsilon = 10 GHz$. Calculate the mean electron thermal energy in the HII region, for the given temperature of the Stromgren sphere. Is this an example of free-free emission? (answer "YES" or "NO")

e) **(4 points)** Since the HII region is in local thermodynamic equilibrium, one can calculate the absorption coefficient that is proportional to the optical depth $\tau_\upsilon \propto \upsilon^{-2.1}$ and it turns out that at sufficiently high radio frequencies, the hot plasma is nearly transparent and hence $\tau_\upsilon \ll 1$.
The flux density of photons has power-law spectra of the form $S_\upsilon \propto \upsilon^\beta$.
Find β for the radio frequencies.

6. Occultation of an X-ray Source

Consider a satellite observing x-ray sources, while orbiting the Earth in the equatorial plane with orbital radius r, and orbital time period P. Assume that this satellite is pointed in one fixed direction in space for a given length of time. Take the radius of the Earth as R.

When the satellite moves 'behind' the Earth in its orbit, the x-ray source is 'occulted' and the measured x-ray flux from the source drops to zero. However, due to Earth's atmosphere, this drop is gradual. If the line of sight to the source passes through the atmosphere, the extent of the attenuation depends on the air-mass (i.e. length of air column) along the line of sight.

a) **(1 point)** Let us assume that the satellite is pointing towards a fixed source at 0° declination. We consider that the source is occulted when 50% of the light coming from the source gets attenuated due to the atmosphere. Let us say that this happens when the minimum height of the line of sight from the surface of the Earth is h.

   If θ_0 is the angle between the direction of the source and the direction of the Earth, as measured from the spacecraft, find an expression for θ_0.

b) **(4 points)** The time duration Δt between the source getting attenuated from 90% of the pre-occultation flux to 10% is defined as the 'occultation time' for the source. Assume the flux attenuates to 90% when the minimum height of the line of sight $(h + 0.5\Delta h)$ and similarly the flux attenuates to 10% at $(h - 0.5\Delta h)$, where $\Delta h \ll R$.

   Find the expression for Δt in terms of r, P, Δh and θ_0.

c) **(15 points)** If the satellite was pointing towards a source at an arbitrary declination β instead (where β is not too large), what will be the expression for Δt?

Note: If the satellite was not in the equatorial plane, then the problem could have been simply rephrased by assuming the satellite's orbital plane to be the equatorial plane. In that case, β becomes 'relative declination'.

7. Radiant of a Meteor Shower

A stargazer in Chiayi, Chinese Taipei (23.5°N, 120.4°E, GMT+8) saw two meteors streaking through the sky at 21:00 (Chinese Taipei time) on 25th September 2020. One of the meteors originated directly above the northern horizon at 15° altitude and streaked to meet the horizon exactly due east. The second meteor originated at an altitude of 23.5° and an azimuth of 210° and ended at an altitude of 75° and an azimuth of 255°.

a) **(6 points)** What is the Local Sidereal Time (LST) at the time of observation?
b) **(16 points)** Find the alt-az coordinates of the apparent radiant of the two meteors.
c) **(6 points)** Find the equatorial coordinates of the apparent radiant.
d) **(2 points)** Which of the following constellations is closest to the radiant?
   Crux / Dorado / Pavo / Tucana / Triangulum Australes
   (choose one and write the same name in the answer box)

Notes:

- ❏ Azimuths are measured from the North (0°) towards the East.
- ❏ The Greenwich Sidereal Time (GST) at 00:00 UT on 1st January 2020 is $6^h\ 40^m\ 30^s$.

8. Jupiter's Great Red Spot

In the following problem, the fluid mechanics of Jupiter's Great Red Spot (GRS) is studied based on the velocity field data. The diagram on the next page shows a map of relative velocity for GRS and the surrounding region. The arrows are oriented and scaled as per the directions and magnitudes of winds at different points.

Due to the combined effects of gravity and rotation, Jupiter is slightly flattened at its poles. The equation of a spheroid approximating for the shape of Jupiter can be stated as:

$$\frac{x^2+y^2}{R_e^2} + \frac{z^2}{R_p^2} = 1$$

where $R_e = 7.15 \times 10^7 m$ is the equatorial radius of Jupiter, and $R_p = 6.69 \times 10^7 m$ the polar radius. The radii of curvature of this spheroid in any direction can be calculated by the following equations ($\varepsilon = \frac{R_e}{R_p}$):

$$r(\phi) = R_e(1 + \varepsilon^{-2} tan^2 \phi)^{-1/2}$$

$$R(\phi) = R_e \varepsilon^{-2} \left(\frac{r(\phi)}{R_e cos\phi}\right)^3$$

where $r(\phi)$ and $R(\phi)$ are the zonal (aka in the zone of a particular latitude) and meridional (aka longitudinal) radii of curvature, respectively, as a function of planetographic latitude ϕ. The sidereal rotation period of Jupiter is $P = 3.57 \times 10^4 s$.

a) **(4 points)** Calculate the zonal and meridional radii values ($\overline{r}$ and $\overline{R}$ respectively) at the location of the centre of the GRS.

b) **(5 points)** Estimate the eccentricity of the GRS.

c) **(6 points)** 'Vorticity' at any point is a measure of local spinning of the fluid as measured by an observer situated in the reference frame of the fluid. Mathematically, it is calculated as 'curl' (vector derivative product) of the velocity field. In this case, the average relative vorticity may be estimated by the equation:

$$\xi = \frac{V_w L_{GRS}}{A_{GRS}}$$

where V_w is the maximum value of winds as per the velocity field, L_{GRS} is the length of the circumference of the GRS and A_{GRS} is the area of the GRS.

Estimate average relative vorticity of the GRS.

Hint: The circumference of an ellipse is well approximated by an average of circumferences of the corresponding auxiliary and minor circles.

d) **(2 points)** Find the absolute vorticity $\xi_a = (\xi + f)$ by adding the Coriolis parameter

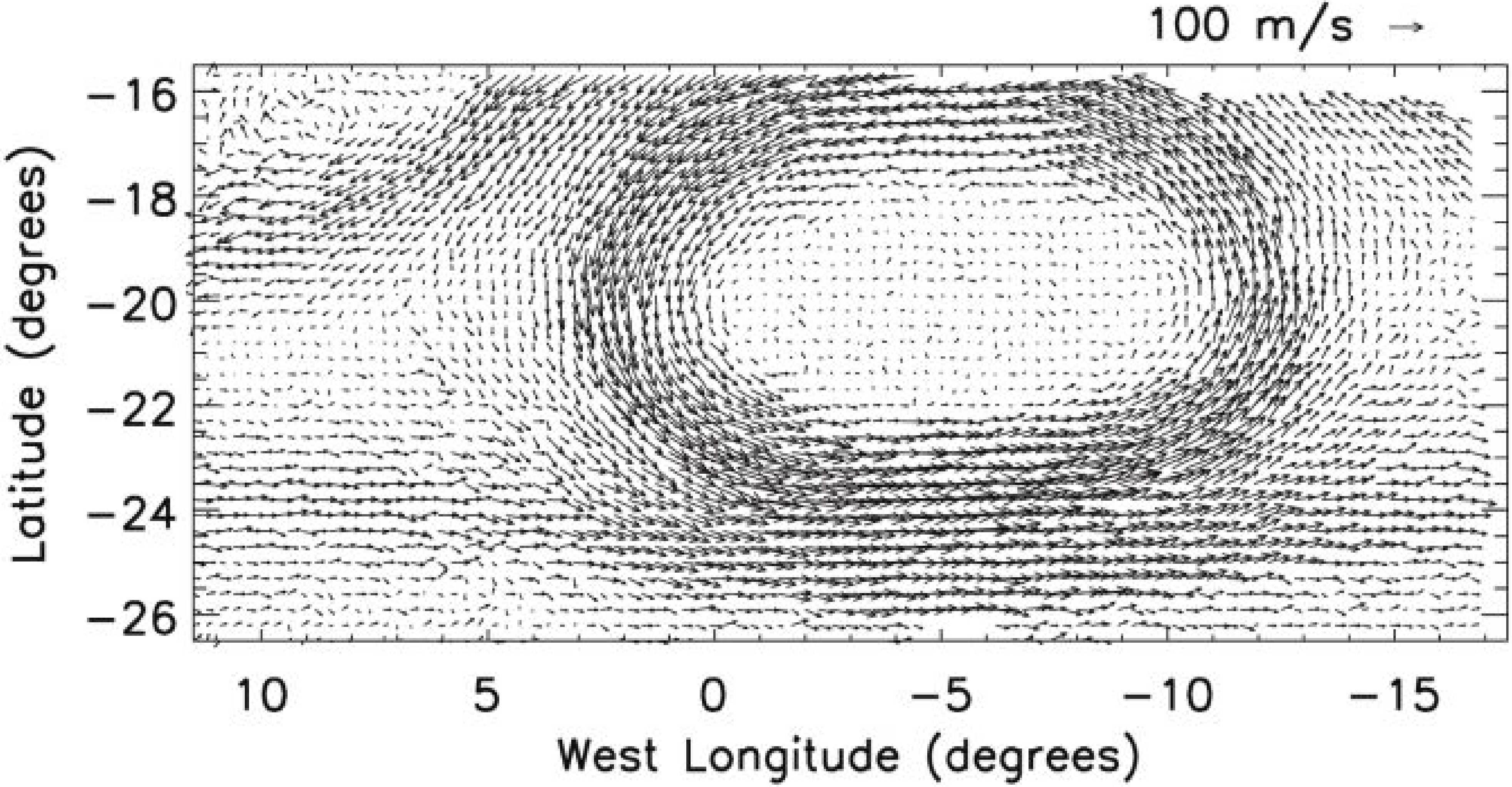
$$f = 2\Omega sin\phi$$

where Ω is the angular velocity of the Jupiter (due to axial rotation) and ϕ is the appropriate latitude.

e) **(1 point)** If the absolute vorticity has the same sign as the latitude, we call the storm a 'cyclonic storm'. If they have opposite signs, the system is 'anticyclonic'. Is the GRS cyclonic or anticyclonic?

f) **(12 points)** Imagine that the GRS moves to another latitude ϕ_1, where the absolute vorticity changes the sign (changes from anti-cyclonic to cyclonic or vice versa). Assuming minimum possible displacement of the GRS, at what value of ϕ_1 do we expect this change?

In your analysis, assume that the GRS at the new location would occupy the same angular span in latitude, as well as have the same wind velocities and eccentricity as the original.


100 m/s
Latitude (degrees)
−16
−18
−20
−22
−24
−26
10
5
0
−5
−10
−15
West Longitude (degrees)

GeCAA – Data Analysis

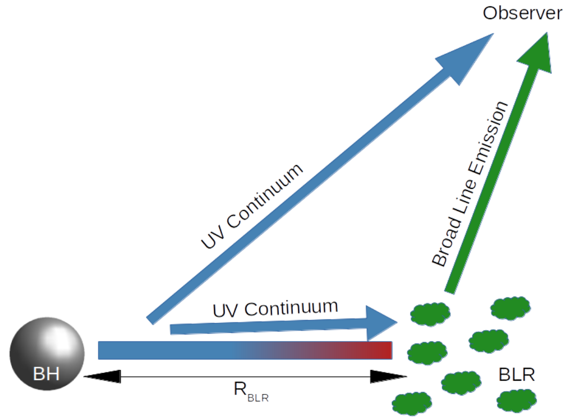
Final Question Sheet

(Total 120 points)

1. AGN

It is believed that the accretion disc around supermassive black holes (BH) at galactic centres gives rise to UV thermal emission. This emission is associated with Active Galactic Nuclei (AGNs).

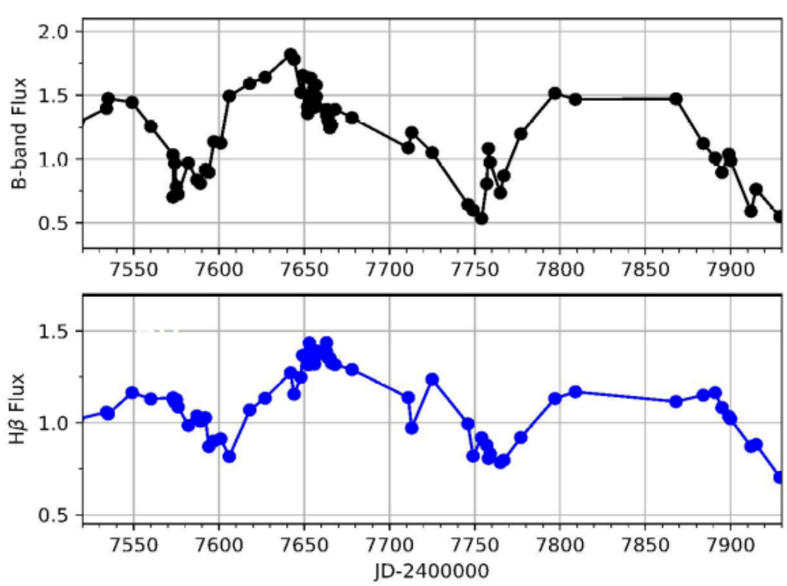
The optical spectra of bright AGNs show additional bright broad emission lines. Those emission lines arise from the dense gas in the Broad Line Region (BLR), which is ionized by the UV photons from the accretion disc. See the sketch to visualise this model.



We can assume that the flux of broad emission lines varies in response to the variation of the UV continuum with a time delay. This time delay should be proportional to the separation R_{BLR} between the BH and the BLR.

Assume that the size of the accretion disc is negligible as compared to R_{BLR}.

a) **(1 point)** Estimate the time lag (days) between the B-band continuum and broad emission line (H_{β}) using the light curves shown below. The x-axis is in reduced Julian Dates (JD).



b) **(3 points)** Estimate R_{BLR} in parsecs (*pc*).

c) **(2 points)** Estimate the angular separation of this region θ_{BLR} (in arcsec) from the blackhole, if this AGN is *100 Mpc* away from us.

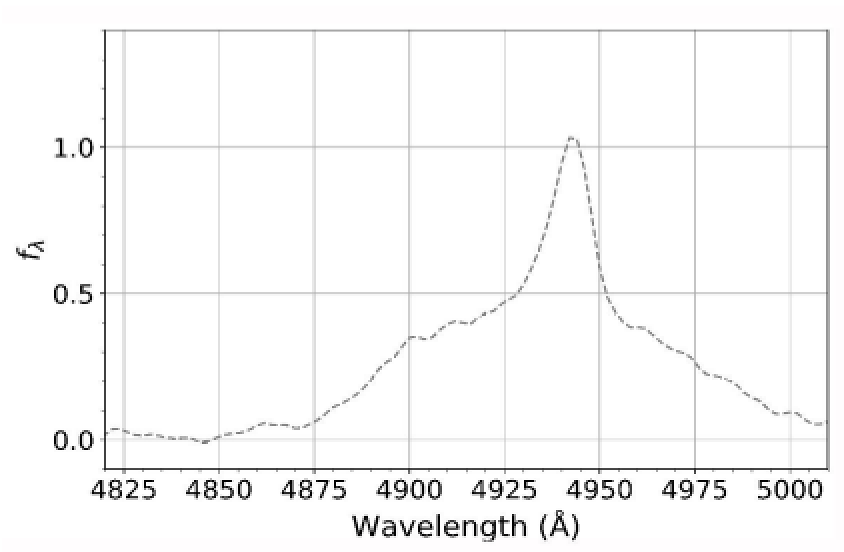
It is possible to estimate the mass of the system using the Virial theorem, if the velocity dispersion of the gasses in theBLR and the size of the system are known. Assume that the masses of the accretion disc and broad line region are negligible, as compared to the black hole.

The velocity dispersion v_σ may be estimated from the broadening of the given emission line. We will take the corresponding wavelength dispersion to be

$$\sigma = \frac{FWHM}{2.35}$$

where FWHM is the full width at half maximum of the broad emission line.

d) **(5 points)** Calculate the velocity dispersion v_σ in units of km s^{-1}, from the spectral line shown below.



e) **(4 points)** Calculate the mass of the central BH ($M_{vir,BH}$) in units of $M_\odot$.

2. Minor Planet

Table 1 gives the ecliptic longitude (λ) and parallax (*p*) at different times (*t*), for a certain hypothetical minor planet. The baseline for the parallax measurement is the diameter of the earth. The time is expressed in years and, for your reference, the ecliptic longitudes of the Sun ($\lambda_{\odot}$) for the same dates are also given the table. Let us assume that the orbital inclination of this minor planet, with respect to the ecliptic, is negligible and the eccentricity of the Earth's orbit is negligible.

a) **(38 points)** Calculate the coordinates of the minor planet in the heliocentric polar coordinate system and put them in an approximately sketched polar plot. The x-axis in the plot should be directed towards the initial position of the minor planet. Draw the major axis of the orbit of the minor planet.
Identify erroneous observation(s), if any.

b) **(6 points)** Assuming the heliocentric orbit of the minor planet to be elliptical, determine
   i) the semi-major axis length a_p.
   ii) eccentricity *e*.
   iii) the period *P*.

c) **(6 points)** Estimate the errors in the values of *P*, a_p, *e* and the solar mass.

Table 1: Minor planet data.

t [year]	λ [°]	$\lambda_{\odot}$ [°]	*p* [″]
2012.3	336.73	40.95	3.82
2012.6	3.44	134.83	7.24
2012.9	50.71	242.08	7.09
2013.4	94.52	64.84	2.40
2013.6	121.40	134.59	2.16
2013.9	154.31	241.82	2.75
2014.2	25.33	353.29	3.16
2014.5	148.51	99.04	1.99
2014.8	176.26	205.45	1.83
2015.0	216.33	280.19	2.03
2015.3	187.5	28.55	2.897

3. Hypervelocity Stars

In recent years, a new field of research has emerged, that of Hypervelocity Stars (HVS for short). These are stars in our Galaxy (mostly at its outskirts), which are moving with excessive velocities and may be escaping from the Milky Way.

In this question, you will use spectroscopic and astrometric measurements in order to calculate the velocity of one such star, called “HVS1”, consider its origin and whether it may escape the Galaxy.

Figure 1 shows a spectrum of HVS1 in the blue to UV part of the spectrum:

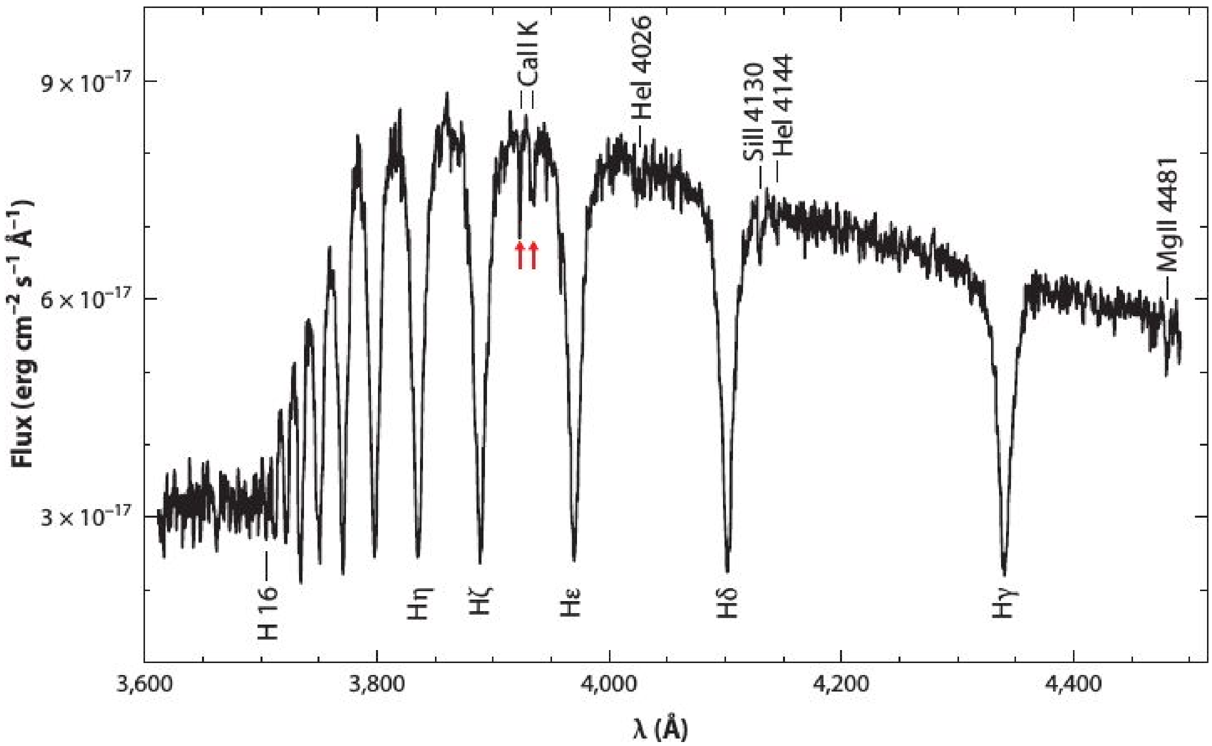


Figure 1. The spectrum of HVS1 shifted to the rest frame of the star (i.e., there is no Doppler shift due to the motion of the star along the line of sight).

a) **(7 points)** Determine the spectral type of the star using the standard spectra in Appendix 3 and the absorption lines identified on the spectrum of HVS1. (Note that the spectrum above contains both stellar and interstellar absorption lines.)

b) **(18 points)** Detailed modeling of the spectral lines places the star between luminosity classes V (Main Sequence) and IV (subgiant).

i. The apparent magnitude of the star in the visual band is m_V = 19.84. Find the absolute magnitude M_V of the star using Appendix 1 for the two possible luminosity classes.

You may ignore the uncertainty in m_V, since the uncertainty in your calculation will be dominated by the uncertainty in M_V.

ii. For both these possible luminosity classes, calculate the star's distance from the Sun, ignoring interstellar extinction.

iii. The Galactic coordinates of HVS1 are $\ell = 227.33537267°$, $b = 31.33199386°$. Is the assumption of ignoring interstellar absorption justified? Write "YES" or "NO".

iv. The Gaia mission of the European Space Agency has been mapping the Milky Way since 2014, measuring the parallax and proper motion of 1.5 billion stars to an accuracy between 0.04 and 0.1 milliarcseconds (mas).
Could Gaia have measured the parallax of HVS1,
A) if it is a MS star? Write "YES" or "NO".
B) If it is a subgiant? Write "YES" or "NO".

For the rest of this question, adopt the larger of the two distances you have calculated above.

v. Assume that the distance of the Sun from the Galactic center is $R_{\odot}=8.0\ kpc$.
Make a roughly proportionate sketch of the relative positions of HVS1, the Sun and the Galactic center. Use it to calculate the distance (*r*) of HVS1 from the Galactic center.

c) **(17 points)** Here, you will calculate the actual velocity of HVS1.

i. The spectrum in Fig1 shows two absorption lines due to Ca II. One is caused by the atmosphere of the star and the other is due to the interstellar medium. The shift of this line is due to the motion of the star with respect to the interstellar medium.
Measure this Doppler shift and calculate the radial velocity of HVS1 with respect to the Sun.

ii. We are interested in the velocity with respect to the Galactic center. For this, we first need to take into account the velocity of the Sun due to the rotation of the Galaxy. The following equation transforms the velocity of a star with heliocentric radial velocity v_{hc} to one in the Galactic rest frame (rf), v_{rf}:

$$v_{\mathrm{rf}} = v_{\mathrm{hc}} + 11.1 \cos \ell \cos b + 247.24 \sin \ell \cos b + 7.25 \sin b$$

where the speeds are measured in km s^{-1}.
Find v_{rf} for HVS1.

iii. HVS1's proper motion has been measured as:

$$(\mu_{\alpha}, \mu_{\delta}) = (+0.08 \pm 0.26, -0.12 \pm 0.22) \text{ mas yr}^{-1}$$

Calculate the tangential velocity component (in km s^{-1}) of HVS1. (You may ignore the correction for declination as the star is near the celestial equator).

iv. Calculate the velocity (v_T) of the star with respect to the Galactic center (magnitude measured in km s^{-1} and angle with respect to direction of the Galactic center).

v. Assuming this star was born within the Galactic disc, use your calculation of the velocity to estimate where in the Galactic disc it is more likely to have come from:
A) near to the Galactic center
B) further out in the Galactic disc

d) **(6 points)** From the energy considerations,

i. Give an expression for the escape speed (v_{esc}), as a function of the distance from the Galactic center and the enclosed mass of the Galaxy.

ii. Calculate the mass of the Galaxy (in solar masses) within the radius of the distance of HVS1.

$$M(r) = 4\pi\rho_0 r_c^2 \left[r - r_c arctan\left(\frac{r}{r_c}\right)\right]$$

Where $r_c = 8\ pc$ and $\rho_0 = 1.396\text{x}10^4\ M_\odot\ pc^{-3}$ are constants of the equation.

iii. Calculate the magnitude of the escape velocity at the distance of HVS1.

iv. Is this a runaway star? Write “YES” or “NO”.

e) **(2 points)** How long has it taken for HVS1 to reach this position?

f) **(3 points)** On the basis of the spectral type and the luminosity class of this star, estimate the age of HVS1 and compare this with your result in the previous part. Which one of the following statements about the origin of the star is true:
(A) the star was ejected when or shortly after it was formed
(B) the star was ejected mid-way through its time on the Main Sequence
(C) the star was ejected towards the end of its time on the Main Sequence

g) **(2 points)** Astronomers looking for HVS-s start by finding a sample of stars in the Galactic halo which are of a spectral type similar to that of HVS1. Explain why by choosing which one of the following statements is true:
(A) Stars of this spectral type are young and so belong to the native population of the halo
(B) Stars of this spectral type are old and so belong to the native population of the halo
(C) Stars of this spectral type are young and so **do not** belong to the native population of the halo
(D) Stars of this spectral type are old and so **do not** belong to the native population of the halo

Appendix 1: Spectral types, luminosity class and absolute magnitude M_v

Classification and absolute magnitude of stars (M_v)

	Supergiants		Bright giants	Giants	Sub-giants	Main sequence dwarfs	ZAMS[(a)]	White dwarfs	Population II		
Sp	Ia	Ib	II	III	IV	V	V	VII	Sub-dwarfs VI	Red branch	Horiz. branch
O5	−6.4			−5.4		−5.7					
B0	−6.7	−6.1	−5.4	−5.0	−4.7	−4.1	−3.3	+10.2			
B5	−6.9	−5.7	−4.3	−2.4	−1.8	−1.1	−0.2	+10.7			+2.3
A0	−7.1	−5.3	−3.1	−0.2	+0.1	+0.7	+1.5	+11.3			+0.8
A5	−7.7	−4.9	−2.6	+0.5	+1.4	+2.0	+2.4	+12.2			+0.5
F0	−8.2	−4.7	−2.3	+1.2	+2.0	+2.6	+3.1	+12.9			+0.4
F5	−7.7	−4.7	−2.2	+1.4	+2.3	+3.4	+3.9	+13.6	+4.8	+4.8	+0.4
G0	−7.5	−4.7	−2.1	+1.1	+2.9	+4.4	+4.6	+14.3	+5.7	+4.1	+0.3
G5	−7.5	−4.7	−2.1	+0.7	+3.1	+5.1	+5.2	+14.9	+6.4	+2.0	−0.1
K0	−7.5	−4.6	−2.1	+0.5	+3.2	+5.9	+6.0	+15.3	+7.3	−0.2	−0.6
K5	−7.5	−4.6	−2.2	−0.2		+7.3	+7.3	+15	+8.4	−2.2	−2.2
M0	−7.5	−4.6	−2.3	−0.4		+9.0	+9.0	+15	+10	−3	−3
M2	−7		−2.4	−0.6		+10.0	+10.0		+12		
M5				−0.8		+11.8	+11.8		+14		
M8						+16			+16		

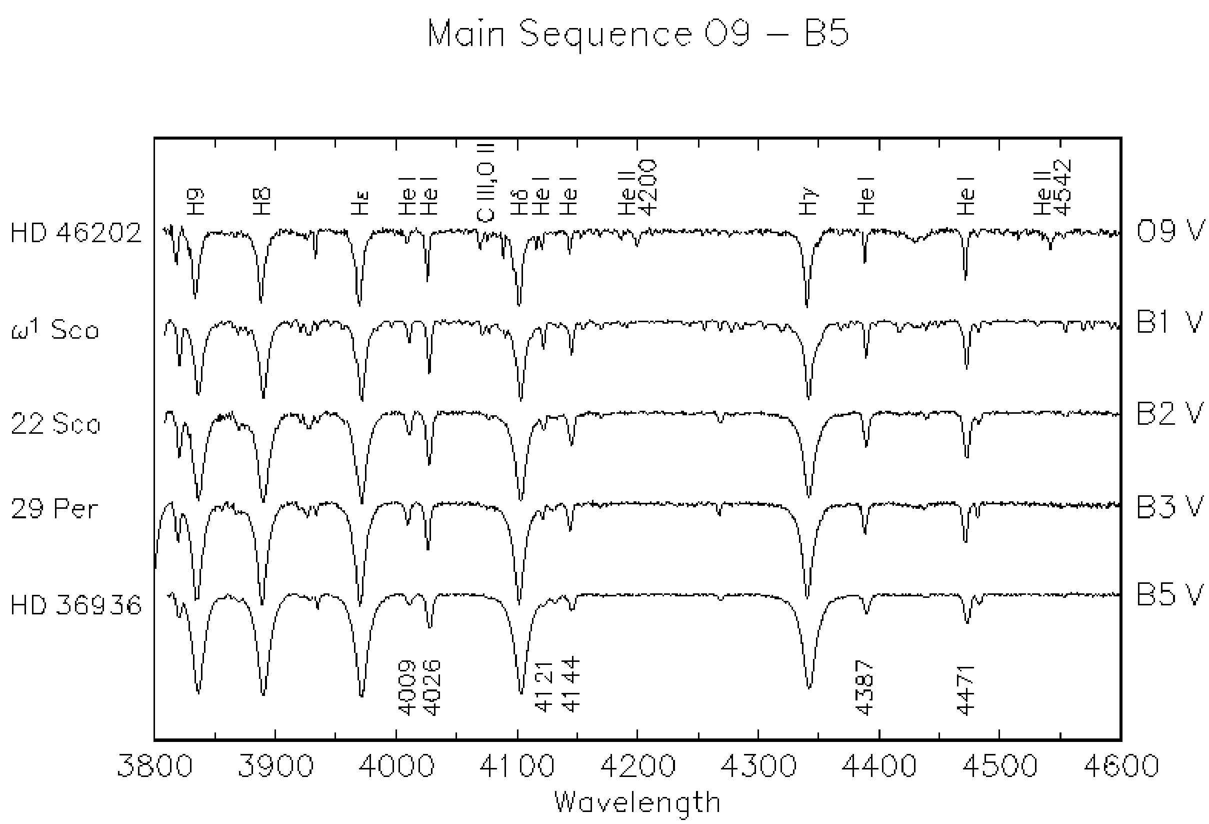
Appendix 2: Spectral Lines

Spectral lines useful in the spectral characterization of low resolution stellar spectra of different stars.

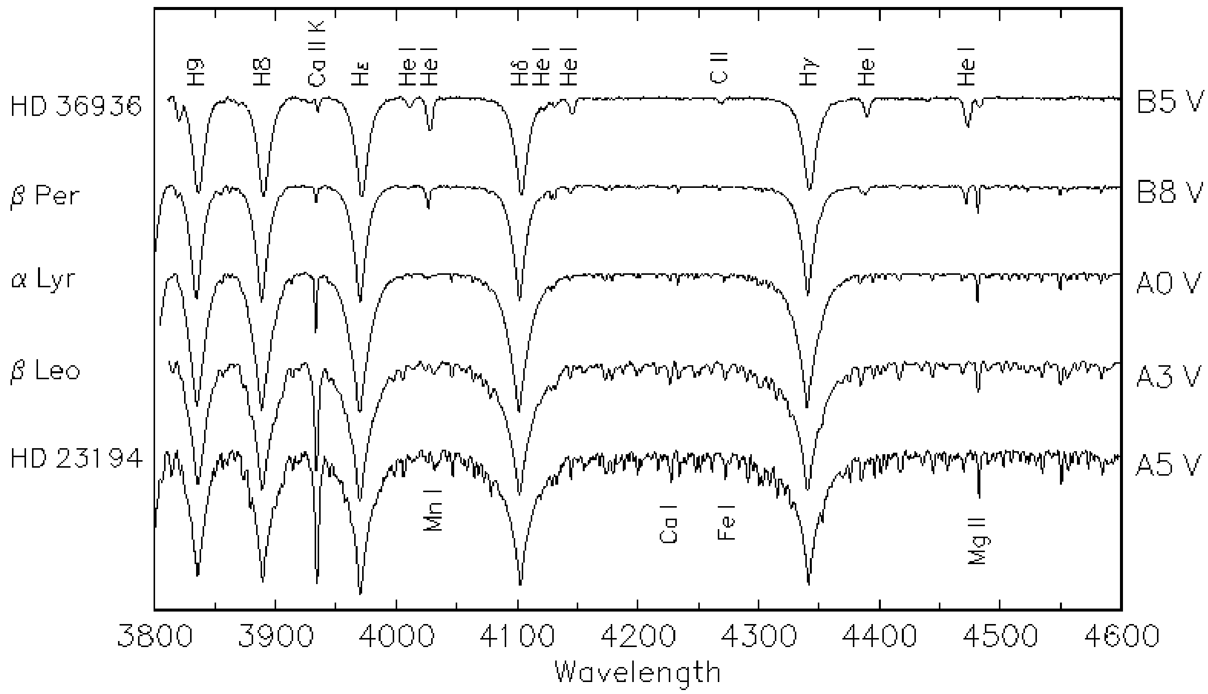
Species and ionization	Identification	Wavelength/nm		Species and ionization	Identification	Wavelength/nm
Ca II	K	393.4		TiO		545–570
Ca II	H	396.8		Na I	D doublet	589.0,589.6
H I	Balmer Hε	397.0		TiO		590–610
Fe I		404.6		CH_4	methane band	619
H I	Balmer Hδ	410.1		TiO		620–640
Ca I	g	422.7		H I	Balmer Hα	656.3
CH	G	430–432.5		TiO		665–700
H I	Balmer Hγ	434.0		O_2	B (telluric band)	686.7
He II		454.2		H_2O	a (telluric band)	716.0
TiO		475–490		CH_4	methane band	725
H I	Balmer Hβ	486.1		H_2O	(telluric band)	732–738
TiO		495–510		O_2	A (telluric band)	759.4
[O III]	oxygen	495.9		H_2O	Z (telluric band)	790–840
[O III]	oxygen	500.7		CH_4	methane band	798
TiO		515–540		CH_4	methane band	887–911

Appendix 3: Absorption spectra typical of different spectral classes[3]

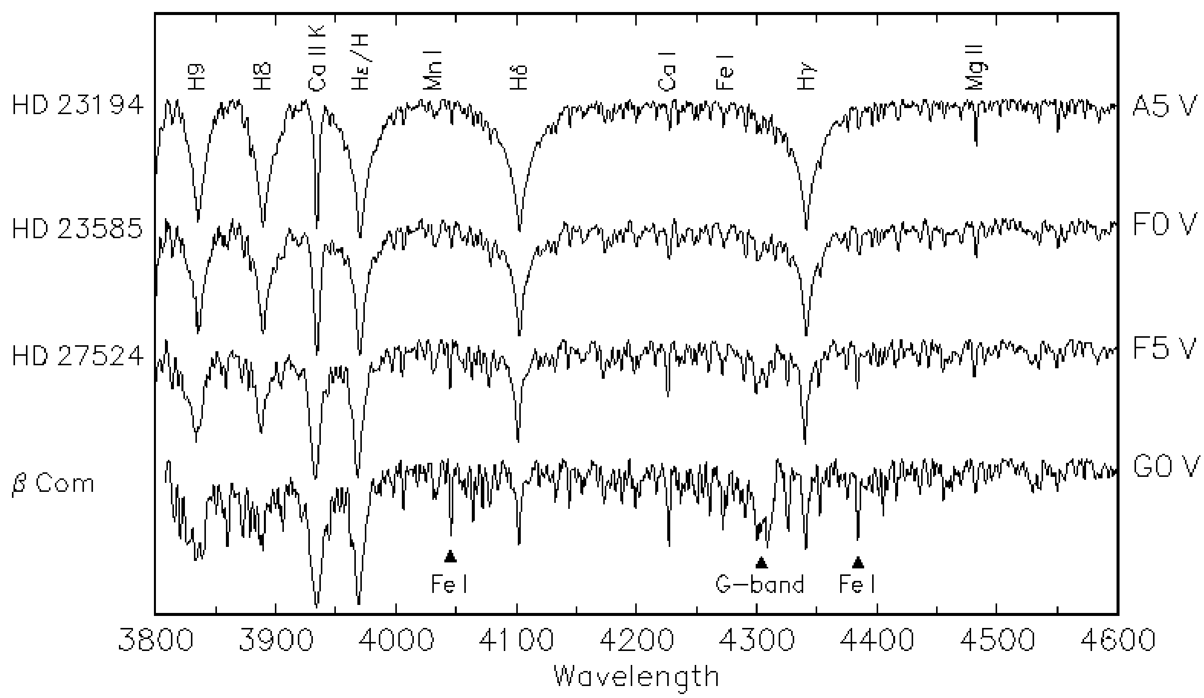
Spectra of main sequence stars of different spectral classes, at the blue end of the spectrum (where there are many absorption lines due to atomic transitions). The spectra have been divided by the respective continuum so that the lines are more easily discernible. The first six panels correspond to MS stars. The seventh panel shows how the lines change for different luminosity classes for the same spectral type.



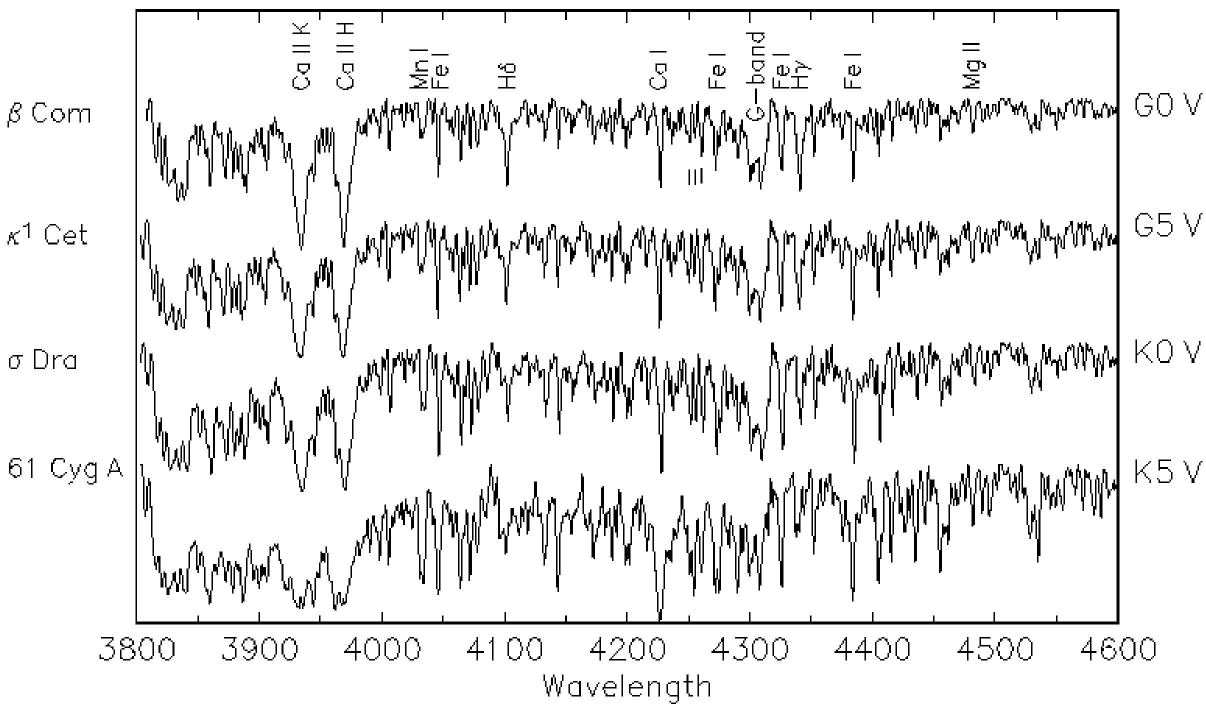
Main Sequence B5 – A5



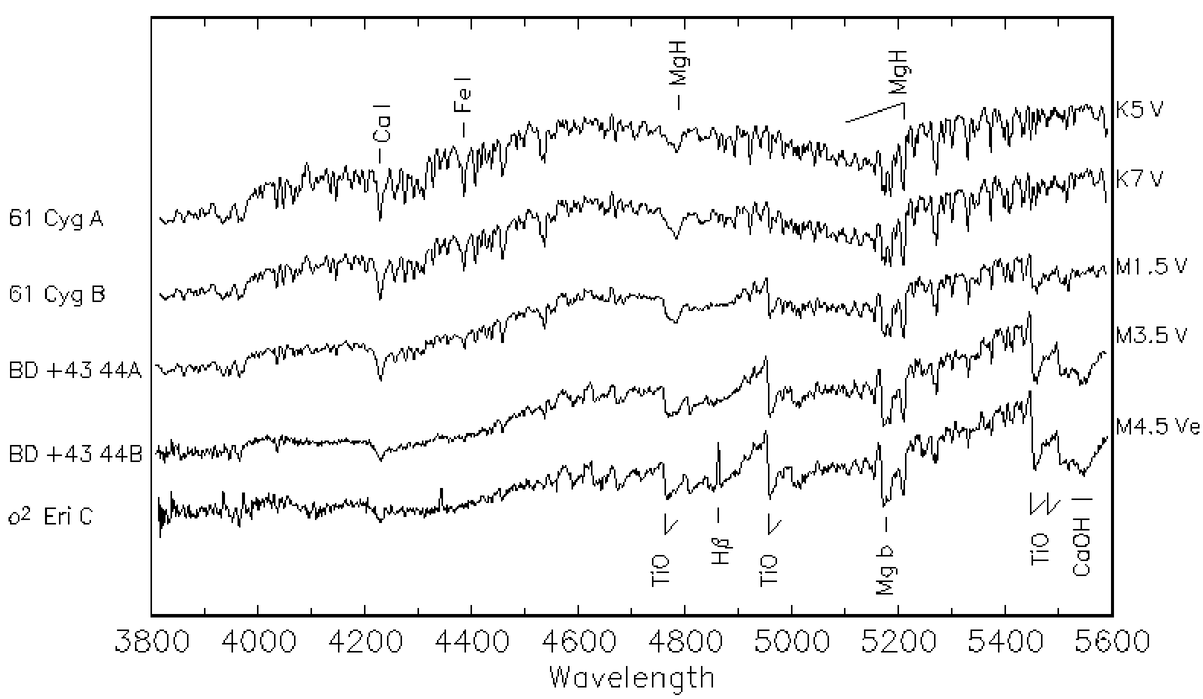
Main Sequence A5 – G0



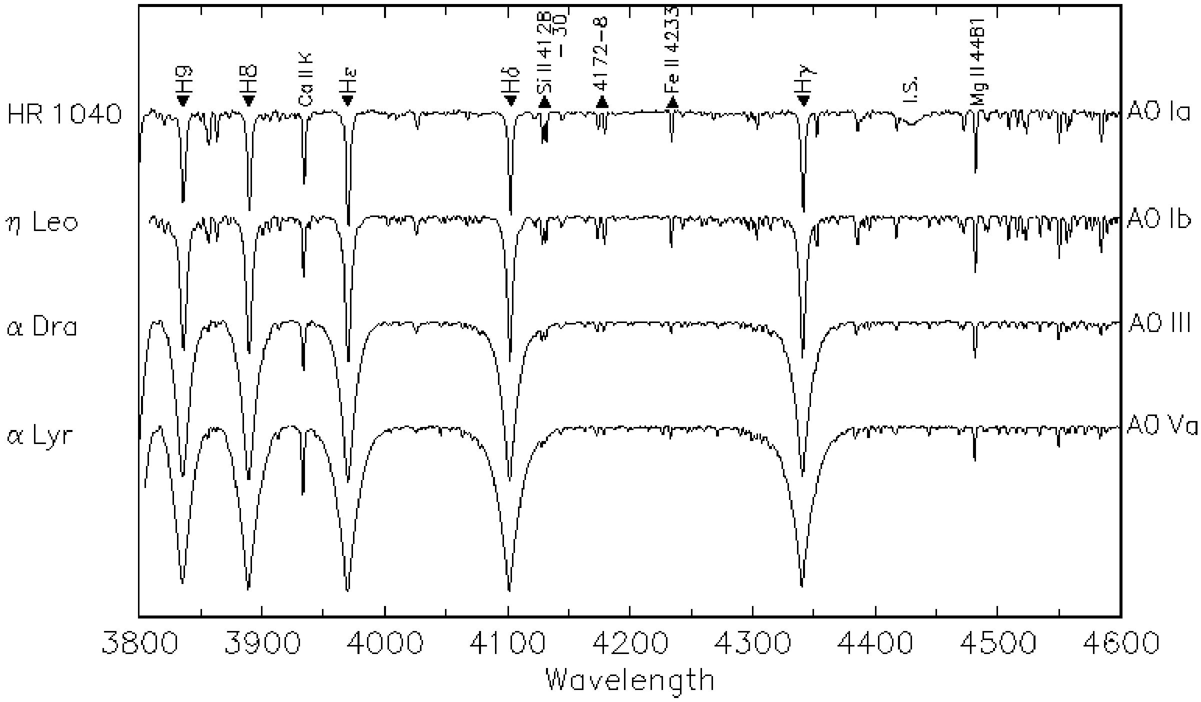
Main Sequence G0 – K5



Main Sequence K5 – M4.5
Normalized Flux



Luminosity Effects at A0



GeCAA - Observation

Constants and materials

Here we provide all links that are inserted for the student:

In theory round there are 4 questions with a sum of 80 points, point value of question should be in accordance with question difficulty level. Solving time is 1:30h
Points for questions are:

1. 15 points
2. 10 points
3. 40 points
4. 15 points

Correct answers in bold

Comets in the “air”

(5 points) The figure below shows a star chart of the night sky. The location of comet C/2020 F3 Neowise on July 31st, 2020 is marked by a red dot.

Name the five brightest stars in the field shown. Please use IAU star names in your answer (i.e. like Sirius or Rigel).

The brightest stars[5]

Sort the brightest stars visible on the figure in descending order of brightness.

A. **1st brightest - Arcturus**
B. **2nd brightest - Regulus**
C. **3rd brightest - Pollux**
D. **4th brightest - Spica**
E. **5th brightest - Capella**

[CATEGORIES]

1. Achernar
2. Acrux
3. Aldebaran
4. Altair
5. Antares
6. Arcturus
7. Canopus
8. Capella
9. Fomalhaut
10. Hadar
11. Pollux
12. Procyon
13. Regulus
14. Shaula
15. Spica

Where is the Sun? [2]

(2 points) Write the latin name abbreviation (you can find accepted abbreviated names here: https://en.wikipedia.org/wiki/IAU_designated_constellations) of the constellation in which the Sun is present on 31st July 2020.

(Cnc)

Point on chart[3]

(3 points) Mark the position of the Sun on the chart, in case it is not present on the chart, mark the direction to the Sun at the edge of the image.

[CANVAS] - not graded

1. {"name":"Sun","x":0.57899,"y":0.91937”}

Tail of the comet Neowise [2]

(2 points) Mark which line on the chart corresponds most accurately to the position of the comet’s gas tail (1, 2, 3 or 4 as indicated on Figure). Write the correct number as your answer.

[4]

In which constellation is comet Neowise [3]

(3 points) Name the constellation in which the comet is seen in Figure 1. Write the answer using the IAU abbreviation

Com

Neowise with MAGIC

The Figure shows the Astronomy Picture of the Day on July 24, 2020 (image credit & copyright: Urs Leutenegger, https://apod.nasa.gov/apod/ap200724.html) taken near the MAGIC telescopes at European Northern Observatory. Comet C/2020 F3 Neowise is visible in the image.

Photographer's location [5]

Estimate the latitude of the telescope's location. (5 pts)
[NUMBER: 30 (10%)]

When was this picture taken? [3]

(**3 points**) Is this picture taken in the morning, evening or midnight sky

A. Morning sky
B. Evening sky
C. Midnight

Comet tails[2]

(**2 points**) Two tails of the comet are visible in Figure 2. Which tail is the gas and which one is the dust tail?

A. The Dust tail is on the left and the gas tail is one the right of the image.
B. The Gas tail is on the left and the dust tail is on the right of the image.

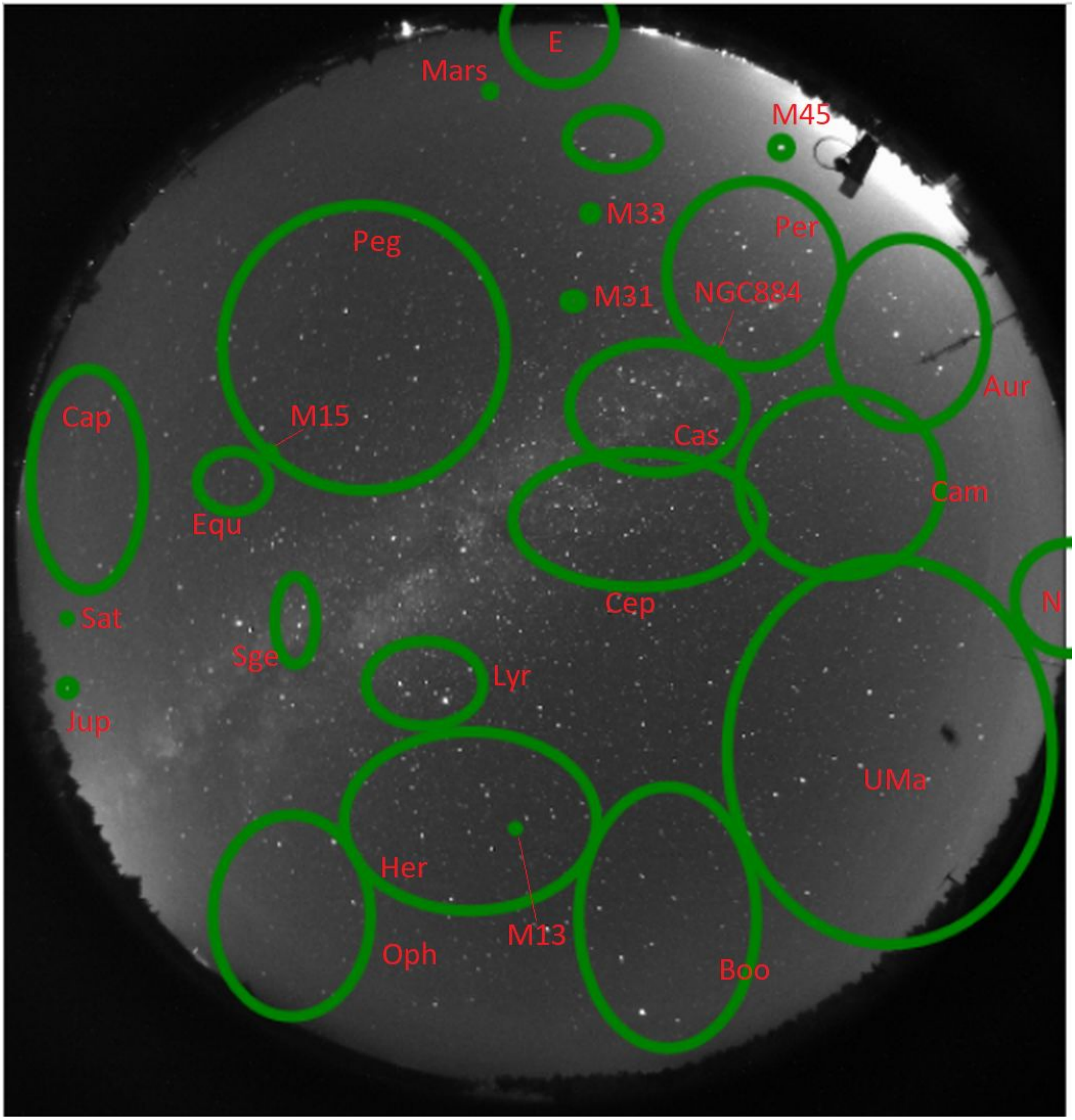
All sky

The Figure shows an all-sky image taken somewhere at local midnight.

Directions in the sky

(**26 points**) In this question you are asked to mark the following visible objects or directions

- Mark north and east directions on the horizon by clicking with the mouse. (4 pts)
- Mark all Solar System objects that are visible (3 points)
- Identify and mark on the all-sky image the following deep-sky objects: M31, M13, NGC 884, M45, M33, M15 (6 pts)
- Identify and mark the following constellations by clicking on their approximate center: Pegasus, Ophiucus, Ursa Major, Cepheus, Capricornus, Camelopardalis, Cassiopeia, Lyra, Sagitta, Perseus, Equuleus, Aries, Hercules, Bootes, Auriga (15 pts)



1.

Geographic latitude of an observatory [4]

(**4 points**) Estimate the geographic latitude of the site where the image was taken. The right ascension of Altair and Capella are $19^h\ 51^m$ and $5^h\ 17^m$, respectively. Write the latitude in integer format.

[**58 (accepted error 5%)]**

Sidereal time [4]

(4 points) Estimate the approximate sidereal time when the image was taken. The right ascension of Altair and Capella are $19^h\ 51^m$ and $5^h\ 17^m$, respectively. Please give your answer using the format HH:MM !

Answer: **20:21 - 20:51 (20:36 +- 15 min)**

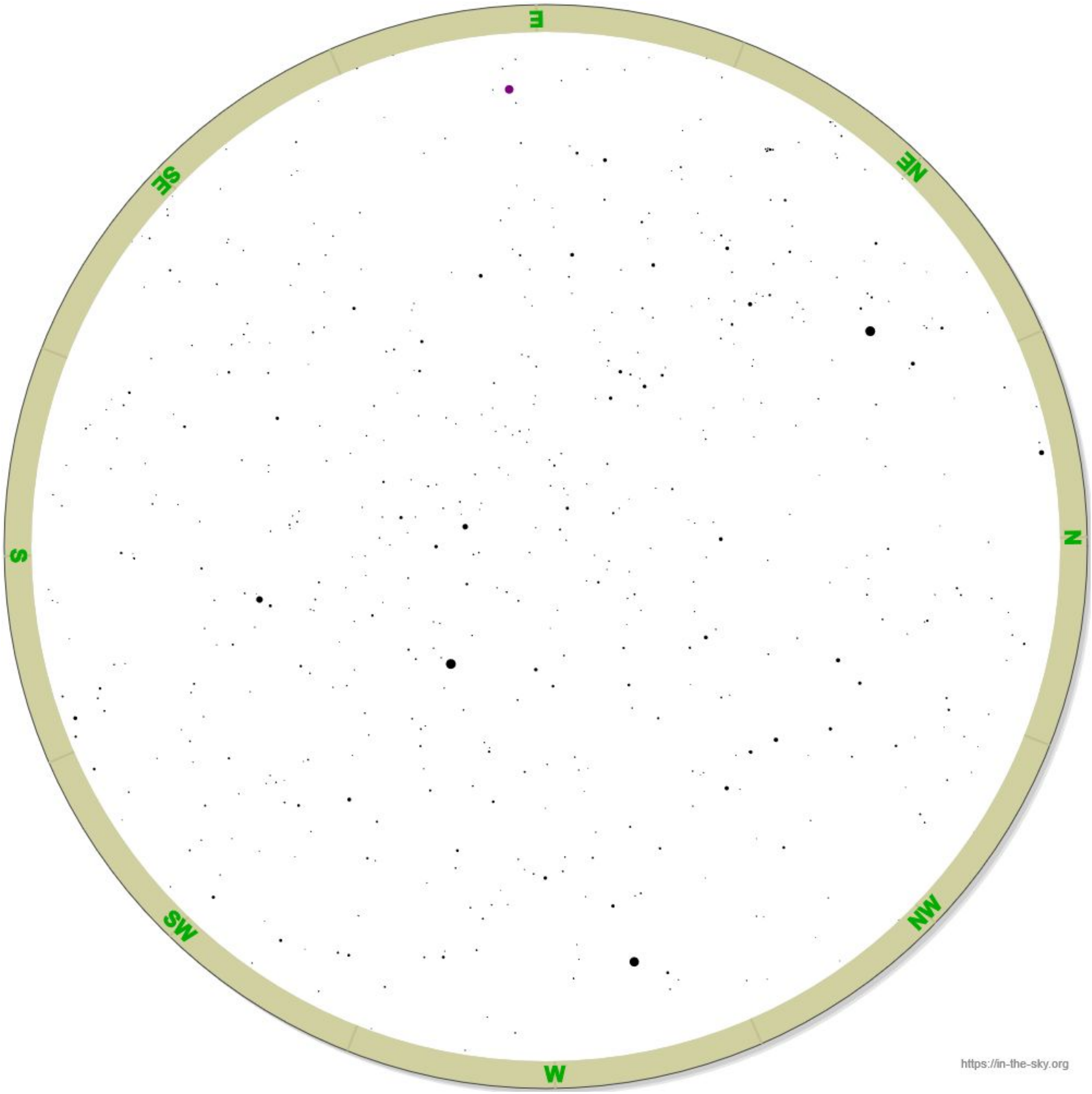
Galactic equator [6]

(**6 points**) On the Figure, the Galactic Equator passes through 12 constellations. Mark all the constellations that are on the Galactic Equator in this Figure.

Galactic equator: **Aquila, Auriga, Camelopardalis, Cassiopeia, Cepheus, Cygnus, Perseus, Sagitta, Sagittarius, Scutum, Taurus, Vulpecula**

Skymap

On the Figure, a star chart is shown for Tallinn, Estonia (Lat 59.43 N, Long: 24.75 E) on 14th September 2020 at 22:00 (UTC+3). The chart is not distorted and shows all altitudes from 0^o to $+90^o$. Stars to magnitude $+4.7^m$ and one planet are shown.



Planets [4]

(**4 points**) Four relatively bright (about 1.5^m - 3.5^m) stars in well-known constellations or asterisms are missing. Identify them (in any order) using the Bayer classification.

Mark all the planets that should be visible at this time on this chart. Mars is marked as a red dot:

A. Mercury
B. Venus
C. Earth
D. Jupiter
E. Saturn
F. Uranus
G. Neptune

NB! Marking Earth was penalized -2 p and Venus and Mercury -1point, minum score was 0

Missing stars[8]

(8 points) Mark the missing stars indicating their rank order as greek letter with IAU Designation

epsilon Cassiopeiae, gamma Pegasi, beta Tauri, delta Ursa Majoris

Mars [3]

(**3 points**) What is the RA of Mars (to nearest 10 minutes, **write in format HH:MMm, where H and M-s are replaced with correct numbers, round answer to nearest 10 minutes, so it must end with “0” for example 12:10**)?

01:40 - 02:00 (01:50+- 10m).