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UNIVERSITY OF CAPE TOWN
EXAMINATION ANSWER BOOK

All answer books must be numbered

Number of books handed in	1
Number of this book	1

EMPL ID

1	7	1	4	6	9	7

Date: 20/06/25

Degree/Diploma/Certificate for which you are registered (e.g. BA BSc): NASSP - MSc

Course code and description: ACB
(to be copied from the heading on the Examination Paper)

Paper No: 1
(to be copied from the heading on the Examination Paper)

Venue: CHO
(e.g. Jameson Hall)

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1	2	3	4
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1	1		
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2	4		
Examiner's Initials			

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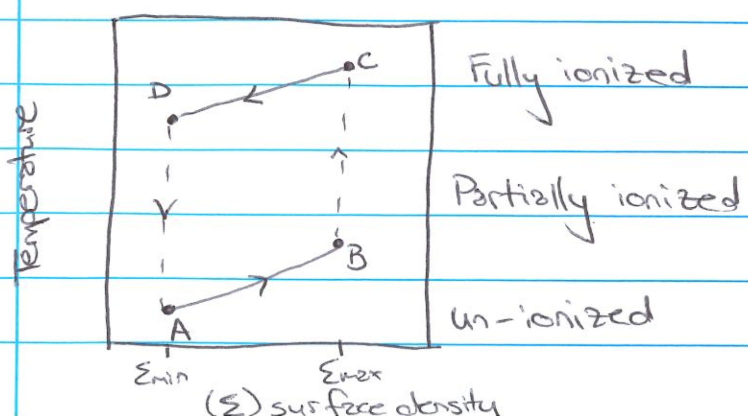
Question 1

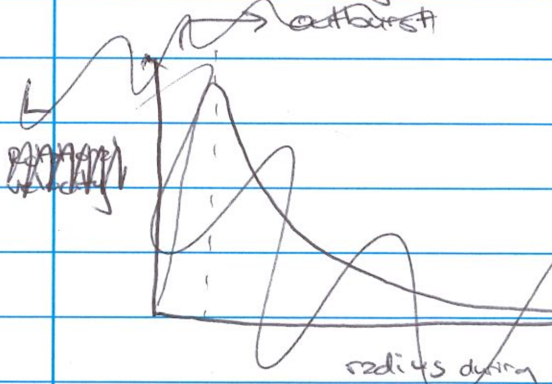
There was an ongoing debate between Bath and Osaki on the origin of the dwarf-nova outbursts witnessed. Bath suggested using a model which described small outbursts of material from the secondary star at the L1 point of their equipotentials, which led to the outbursts seen. Osaki suggested a disk-instability model where instabilities in the disk lead to outbursts. Osaki's theory was substantiated by 2 points. Firstly, if an outburst of mass was coming from L1, the bright spot would have proportionally increased in brightness, however the bright spot is actually outshone by the accretion disk. Bath's model also suggested that the disk shrinks during outburst and expands during quiescence, however the opposite is observed.

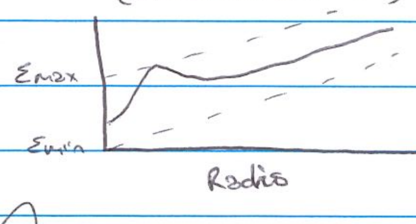
~~Viscosity is~~ The different layers of the disk are moving with different velocities (differential rotation) ∴ the inner part is moving faster. This causes a friction between the layers (known as viscosity). (∴ falling inwards) This loss of energy causes parts of the disk to accrete closer to the white dwarf (WD) surface. In order to conserve angular momentum the outer layers are pushed outwards, ~~and~~ ultimately forming a disk. In accretion disks magnetic turbulence is another form of viscosity. When an element of material at low radii, is connected to another element at larger radii by a magnetic field lines. As the inner element rotates faster, the magnetic field line is stretched ∴ becomes stronger. This could eventually reach the Balbus-Hawley instability and cause the material to break into clumps which then transport the angular momentum.

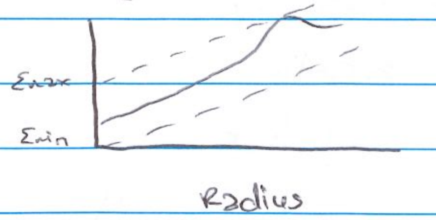
The thermal instability within a disk can be described using the following plot. At point 'A', the disk is in equilibrium. Once matter starts accreting, the surface density increases from Σ_{min} to Σ_{max}, this causes more collisions between particles ∴ temperature rises. This causes the ionization fraction to increase and become partially ionized

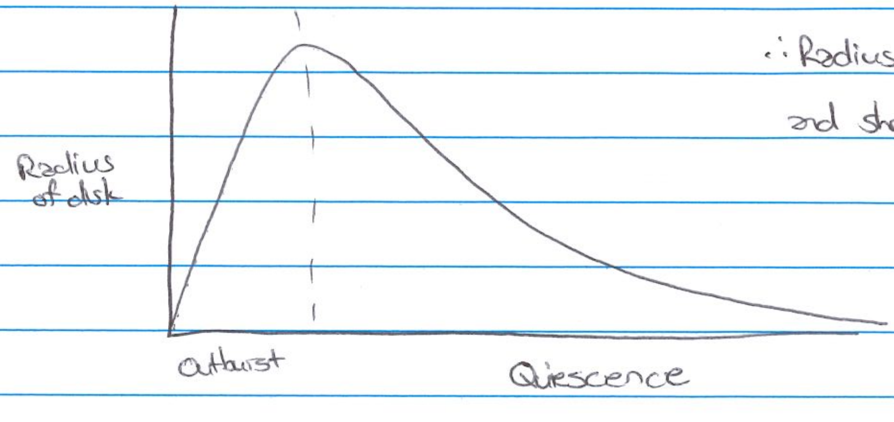


In a partially ionized state, the opacity of the material is very sensitive to changes in temperature, Therefore, any slight increase in temperature, will cause the disk material to become opaque. This traps all the heat trying to radiate away and the temperature rises very quickly to point 'C' where it tries to reach a new equilibrium with all the material ionized. The opacity is no longer sensitive to the temperature when the material is completely ionized ∴ the material is no longer opaque ∴ the radiation can escape, lowering the surface density and temperature until it reaches point 'D' where the material is no longer fully ionized ∴ the partial ionization leads to a high opacity material once again. Because of this, the surface temperature can no longer be maintained ∴ the temperature drops rapidly to begin again at point 'A'. If the accretion rate is low, this Σ_{max} will first occur at the inner radii as the material can dissipate through the disk (known as an inside-out outburst). At high accretion rates the material builds up on the outer disk and the outburst begins there in an outside-in outburst. The cooling wave that brings the system out of outburst always starts from the outside and works its way inwards.









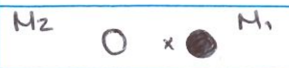
∴ Radius increases during outburst and shrinks during quiescence.

Novalike variables are ones in which the accretion rate keeps it in a constant state of outburst. A Z-Cam variable is one which experiences smaller outbursts until eventually resulting in a full outburst. The outburst obviously could not be sustained throughout the disk until multiple tries laid the groundwork to allow for a full outburst.

Angular Momentum = $J = mvr$

Question 2

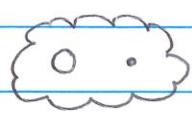
<u>Origin of a CV</u>



Starting with 2 main-sequence stars, M_1 is much more massive than M_2 ∴ $M_1 > M_2$
Because of its massive size, M_1 evolves quickly and expands into a red giant. This red giant can now fill its Roche Lobe.

Once it fills its Roche Lobe matter is expelled off the M_1 star and travels towards M_2 to be accreted. However, because the centre-of-mass is closer to the more massive star (M_1), the expelled material has to travel further away from the centre-of-mass.

This material has to gain angular momentum to do so. Therefore the system decreases the seperation between M_1 and M_2 to conserve angular momentum.
Even though M_1 is losing mass which should ~~shrink~~ expand its Roche Lobe and stop mass transfer, the decrease in seperation caused the Roche Lobe to shrink and therefore allow mass transfer.
This mass-transfer is a runaway process as it always leads to more mass transfer. That is until all the outer layers of the ~~red giant~~ M_1 are expelled and M_2 cannot take on this much mass ∴ forming a common envelope around M_2 and the now exposed core of M_1, the white dwarf.



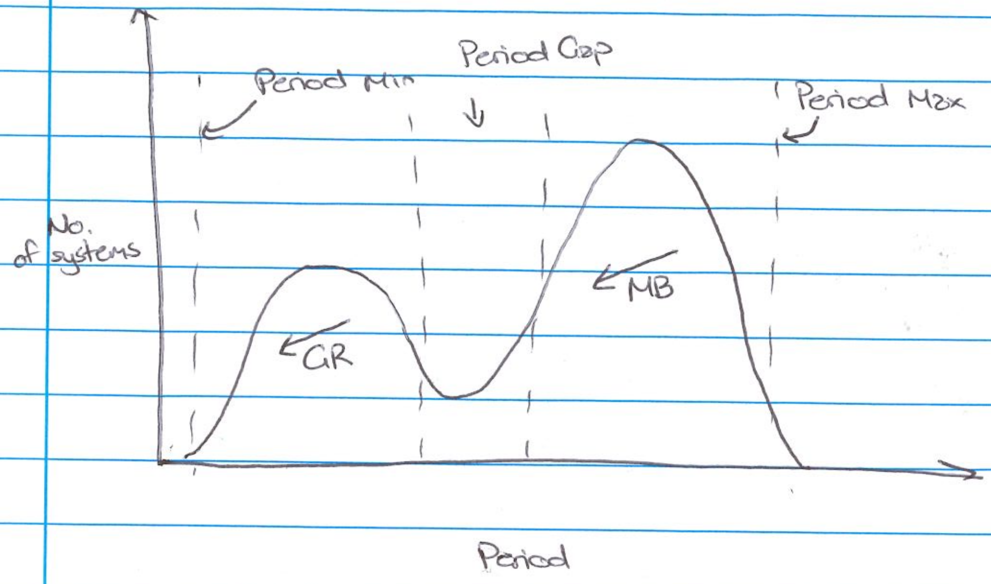
These 2 stars are still orbiting each other through this envelope of material ∴ causing a lot of friction ∴ this lost energy is supplied by the gravitational potential energy when the 2 stars move closer together. This decrease in angular momentum causes the common envelope to expand to larger radii.

Evolution of a CV

At this point, M_2 is not massive enough to evolve on these timescales ∴ it will not expand into a red giant to trigger mass transfer. Instead the seperation ~~size of the Roche Lobes~~ needs to be decreased to shrink the Roche Lobe and allow for mass transfer. Once this happens you have a cataclysmic variable star defined as the flow of material in an unresolved binary system where mass from the red dwarf (M_2) is accreted onto a white dwarf (M_1) in a stable way.

These systems evolve to smaller periods due to their seperation decreasing. However, an important difference between the mass transfer that gave birth to the CV was a 'runaway' process where as the transfer of mass from M_2 leads to the Roche Lobes increasing, halting mass transfer ∴ the only way to continue transferring mass is by reducing their seperation.

Period Distribution of CV



The period distribution of the known systems shows how these systems evolve to smaller periods through either magnetic breaking (at higher periods). Magnetic Braking (MB), is when a strong magnetic field pushes material out to large radii along field lines, in order to conserve angular momentum, the seperation decreases. The other dominant driving mechanism for mass transfer is gravitational radiation which is energy radiated from the quickly orbiting system as gravitational waves in spacetime. This loss in energy leads to the seperation decreasing, ~~in order to supply energy through~~ this energy is supplied through the loss of gravitational potential energy. There is a distinct feature known as the period gap which is a range of periods for which neither magnetic braking nor gravitational radiation mechanisms are active. The reason this is not an empty region is due to some systems starting their evolution in this period gap and therefore need time to evolve.

~~The other~~ Another dominant feature is the period max. This boundary on the size of the period is determined from the orbital period relation. $P_{orb}^2 = \frac{4\pi^2 a^3}{G(M+m)}$, this shows that large periods, require large seperation (a), mass transfer can only occur at the large seperations if the masses are large enough. However, there is a limit on the mass of ~~the~~ M_1 and M_2. In order for M_1 to evolve into a white dwarf it must remain below $1.4 M_\odot$ (the Chandrasekhar Limit) otherwise it will collapse further into a neutron star supported by neutron-degeneracy pressure from the Pauli Exclusion Principle which doesn't allow the charged particles to occupy the same space at the same time. If the mass limit on M_1 is $1.4 M_\odot$, then M_2 must be even less massive, as $M_1 > M_2$. Therefore, the mass limit introduces a limit on the period of the orbiting system. The other prominant feature is the period minimum. This is caused by the stars becoming degenerate past this point. When this occurs, the mass transferred from M_2 causes it to increase in size rather than decrease (like the non-degenerate case). This causes the period to increase with this mass loss and so the systems evolve to higher periods past this point. Interestingly AM Cvn stars which are composed mostly of Helium rather than Hydrogen can evolve to lower periods due to their increased density, however they too reach a period minimum caused by degeneracy.

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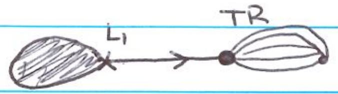
Question 4

AM Her stars are magnetic cataclysmic variables with a magnetic field strength of around 10-100 MG. Once the seperation between the strongly magnetic white dwarf and the slightly less strong magnetic red dwarf, decreases, mass transfer can begin. Mass is liberated from the surface of the red dwarf at the L_1 point on the equipotential surfaces. From here the material falls ballistically (virtual free fall) towards the white dwarf.



The materials falls in free-fall until it experiences the magnetic field of the white dwarf. This region is known as the threading region. It is where the material in the stream is re-directed along the magnetic field lines converging on accretion regions on the white dwarf surface. This process of redirecting material along the field lines is very turbulent due to the different densities of material needing to be redirected and the chaotic motions lead to shocks within the threading region (TR). The threading region is also not a point in space but rather covers a distorted portion of space due to the differing material densities being threaded onto magnetic field lines at different positions. This material is then funnelled along the field lines producing cyclotron emission where the field lines eventually converge near the white dwarf surface causing material to slam onto the white dwarf surface in accretion regions. These accretion regions are also elongated (as the threading region) around the magnetic poles in arc shapes. This is again due to different density of material entering the threading region and making it's way to the (elongated) accretion regions.

The accretion regions in these magnetised systems are also affected by the density of the material in the way that this material is accreted, and observed. The diffuse material is funnelled until is hits the white dwarf surface where its kinetic energy is converted to thermal energy causing the region to heat up. This diffuse material expands into a hot, dense accretion column which is bombarded by more accreted diffuse material and produces shocks on the surface of the accretion column. Therefore, the

accretion column emits hard-X-ray emission. A large portion of this emitted X-ray radiation is reabsorbed by the white dwarf surface where the surface acts as a blackbody re-emitting this energy in the UV, these are known as soft-x-rays.
When a dense blob of material is funnelled towards the white dwarf surface, it has enough angular momentum to plunge deeper into the surface of the white dwarf. Their kinetic energy is quickly dissipated within the white dwarf and re-emitted as a blackbody in the UV (soft x-rays)

~~The magnetic~~ Ionized plasma (charged particles) moving perpendicular to a field line experience a perpendicular force, causing them to spiral down the field line. This is known as cyclotron emission. The emission line could be broadened by faster motion. This cyclotron emission gives rise to 2 polarizations. Linearly polarized (when viewing the field line side-on) , the particle appears to move up and down as it travels down the field line. Circularly polarized (when viewing down the field line) ⊗, the particle appears to be travelling in a circle around the field line. Thus, ~~there~~ cyclotron emission is a strong indicator of a magnetic field. The peak of the broadened cyclotron hump could be used to determine magnetic field strength. The polarization observed could be compared with models in order to determine the field strength. Zeeman splitting is the ~~observation~~ effect that a strong magnetic field will split a spectral line, The degree of splitting ∴ the spacings between the split lines can be used to estimate magnetic field strength.

Synchronous rotation is a hallmark of the generic picture of an AM Her or magnetic cataclysmic variable. It is a consequence of the interaction between the strong magnetic field of the white dwarf and the weaker magnetic field of the red dwarf. This causes the WD to change its spin rate to match the orbital spin in order to ensure the WD and the RD are tidally locked ∴ the same face of each always faces the other. Systems such as these can easily be thrown out of synchronicity, either due to too large an angular seperation or too weak of a magnetic field. This creates what is known as an asynchronous polar which produces a 'beat' cycle as the spin and orbit are no longer synchronized. This may lead to one magnetic pole being preferentially close to the threading region during different phases of orbit. This may cause the accretion stream to oscillate between accreting onto the North magnetic pole versus the South magnetic pole.