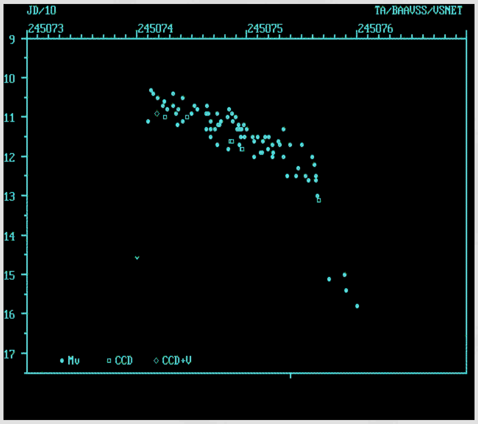
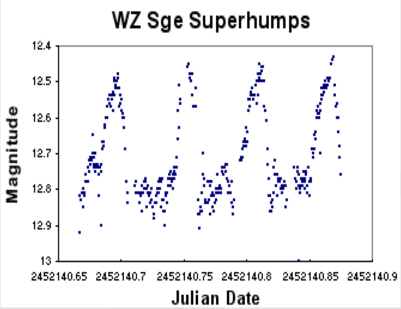
Superoutbursts & Superhumps



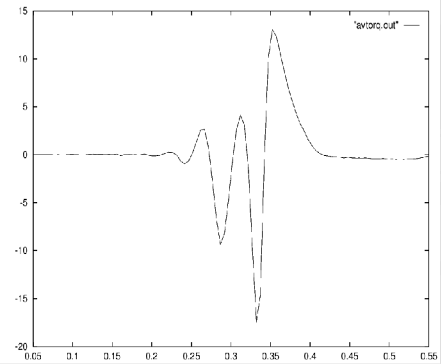
20 - 30 days



$P_{orb} \leq P_{sh} \leq 1.1P_{orb}$

Tides

Mass is transported inwards through a disc, so angular momentum must be transported outwards.
So what happens to the a.m. at the outer edge?



Resonances

Gas returns to same position relative to the secondary star every orbit if:

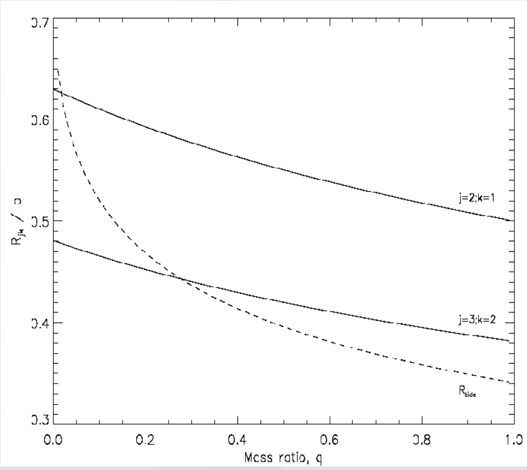
$$j(\Omega - \Omega_{orb}) = k\Omega_e$$

Kepler's law then gives the positions of the resonances:

$$R / a \quad (1+q)^{-1/3}$$

j=3,k=2 resonance is available to dwarf novae with q< 0.3 !

“3:1 resonance”



Resonances

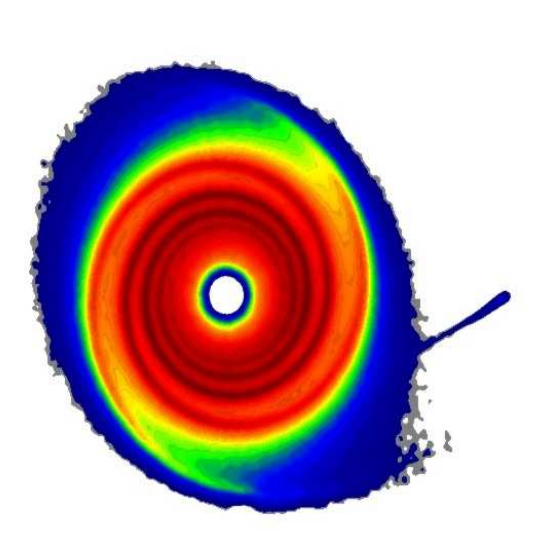
The Roche potential can be expressed as a set of functions:

$$\phi(\rho,\theta,t) = \sum \phi_m(r) \cos[m(\theta - \Omega_{orb}t)]$$

Each normal mode m generates a response

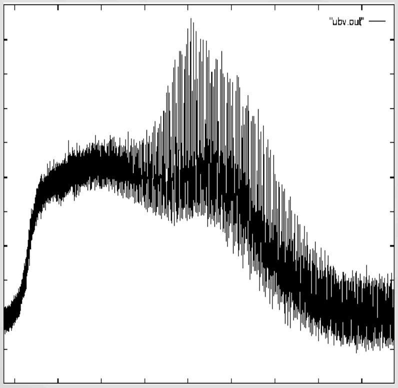
$$\exp[i(k\theta - l\Omega_{orb}t)]$$

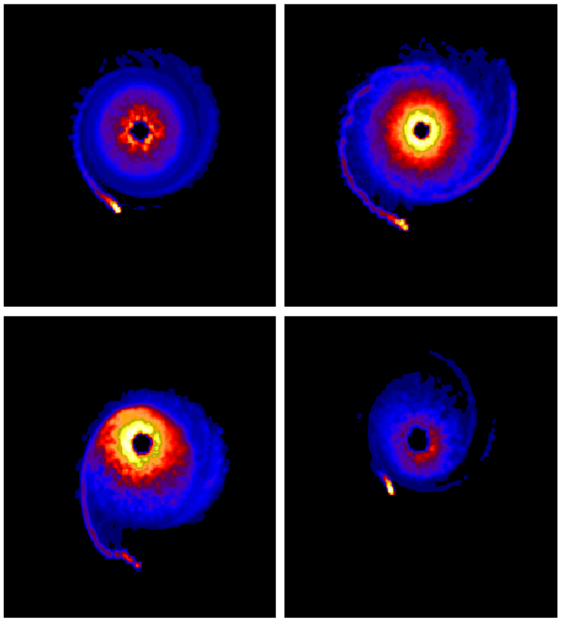
The (k,l) = (1,0) mode is eccentricity
The (k,l) = (2,3) mode is a two-armed travelling spiral wave



Superoutburst model

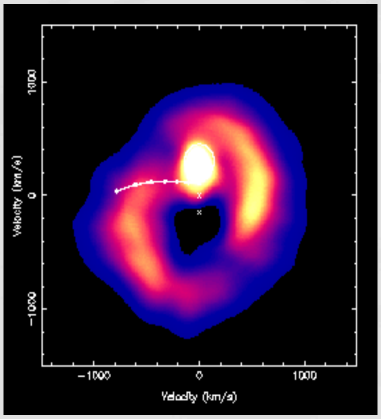
1. Outburst starts in normal way
2. Disc expands past 3:1 radius
3. Eccentricity: superhumps appear
4. Enhanced tidal heating drives more gas in and prolongs the outburst.



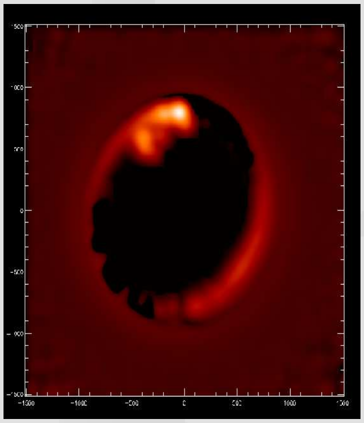


Spiral waves: observations

Doppler tomogram : map of accretion disc in velocity space derived from doppler shifts of spectral lines

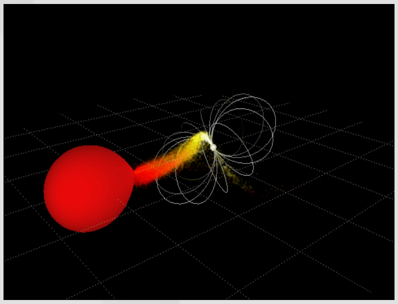


Observed (IP Pegasi)



Simulated

Magnetic accretion



Observational signatures:

- Strong X-ray emission
- Large linear and circular polarization
- Periodicity of the WD spin period

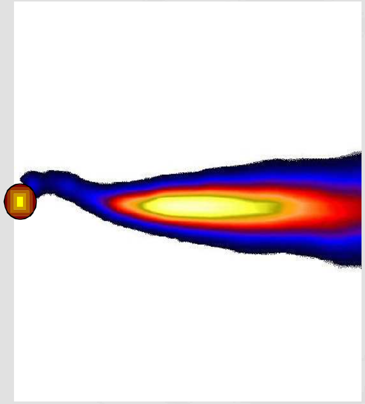
Pressure balance defines the inner edge of the accretion disc:

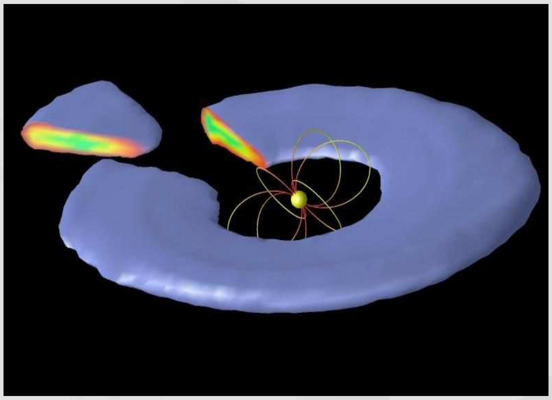
$$\frac{B^2}{8\pi} \sim \rho(r) v^2(r)$$

For polars (AM Her systems), $B_{star} \sim 10^7$ G $R_\mu \sim 10^{11}$cm ~ a **NO DISC!**

For intermediate polars, $B_{star} \sim 10^5$ G $R_\mu \sim 10^{10}$cm **TRUNCATED DISC**

Intermediate polar





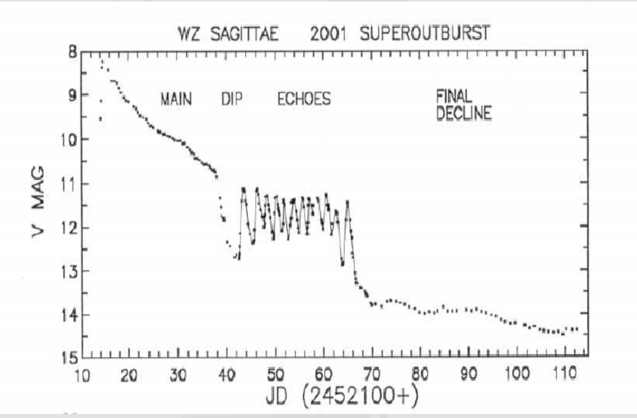
We define the corotation radius as the point at which the disc corotates with the magnetic field.

This is usually near the inner edge of the disc, which we call the magnetospheric radius.

TOADs

Tremendous
Outburst
Amplitude
Dwarf Novae

- Long superoutbursts
- No normal outbursts
- Very long recurrence times (decades!)
- Most famous is WZ Sagittae, which had outbursts in 1913, 1946, 1978 and 2001.



Accretion disc time-scales

Dynamical time-scale (orbiting) : $t_\phi \sim \Omega^{-1}$ [secs - mins]

Viscous time-scale (accretion) : $t_{visc} \sim R^2 / \nu = R^2\Omega / \alpha c_s^{\,2}$ [days - weeks]

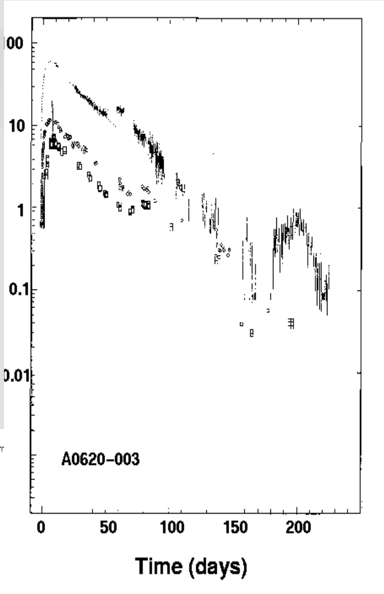
Thermal time-scale (heating/cooling) : $t_{th} \sim (\alpha\Omega)^{-1}$ [mins - hours]

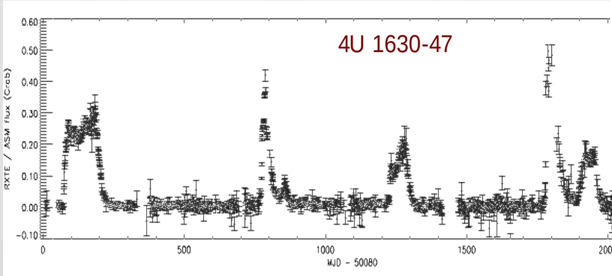
Long recurrence times:

- Very small viscosity ?
- Missing inner parts of the disc?

X-ray transients

- Low-mass star + ns / bh
- P_{orb} ~ $2^h – 33.5^d$
- Bright X-ray outbursts last 3 months – several years
- Recurrence times 1 year - centuries!





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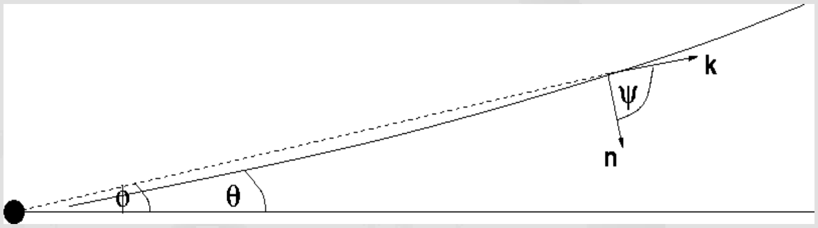
$M_1 \sim 4M_\odot$ (black hole!)
$P_{orb} \sim 7.75$ h (short!)
$q = 0.07$ (tides!)

- Very bright in soft X-rays during outburst
- Outbursts last more than a year
- No superhumps

?

Self-irradiation



Irradiating flux $F = L_X(1-\beta)\cos\psi / 4\pi r^2$

$$\cos\psi = \sin(\theta-\phi) = \cos\theta\cos\phi\,[\tan\theta - \tan\phi] \simeq dH/dr - H/r$$

$L_X = \eta c^2 dM/dt$ and $F = \sigma T_{irr}^4$

$$R_{irr}^2 = \{\eta c^2(1-\beta)[dH/dr - H/r] / 4\pi\sigma T_H^4\}\, dM/dt$$

Summary

Accretion discs in interacting binaries show time-variability because...

CAUSE	EFFECT
Geometry and viewing angle	Eclipses, dips and humps
Ionisation instability	Outbursts
Tidal forces	Superhumps, superoutbursts, spiral waves
Magnetic fields	Truncation, polarisation, warps
Irradiation	Truncation, long outbursts, warps

and we didn't even mention...

Nuclear burning of hydrogen on the primary	X-ray bursts
General relativistic effects	Quasi-periodic oscillations, warps

Further reading............

Accretion Power in Astrophysics 3rd ed.(chapters 5 and 6)
Frank, King & Raine, Cambridge University Press, 2002
Cataclysmic Variable Stars
Warner, Cambridge University Press, 1995
Exploring the X-Ray Universe
Charles & Seward, Cambridge University Press, 1995
Images of accretion discs I- the eclipse mapping method
Horne, Monthly Notices of the Royal Astronomical Society, 1985, 213, 129
The accretion disc limit cycle model
Cannizzo, Astrophysical Journal, 1993, 419, 318
Spiral structure in the accretion disc of the binary IP Pegasi
Steeghs, Harlaftis & Horne, MNRAS, 1997, 290, L28
On the nature of superoutbursts in dwarf novae
Truss, Murray & Wynn, MNRAS, 2001, 324, L1

Animations: **http://www.ukaff.ac.uk/movies.shtml**
http://star-www.st-and.ac.uk/~mrt2/Welcome2.html