Modelling Flares in the Jet Emission from Microquasar GRS 1915+105

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Abstract

Observations of large-amplitude flares in the infrared and millimetre light-curves of GRS 1915+105 are believed to be indicative of fluctuations in the unresolved inner-most stream of the system's relativistic jet. We have analysed these observations by modifying the Blandford & Königl jet emission model to include time dependent variations in the jet flow. For the assumed jet inclination and distance values, we conclude that the observations are inconsistent with the jet model, which requires unphysically high electron densities to reproduce the observed flare amplitudes and time-lags.

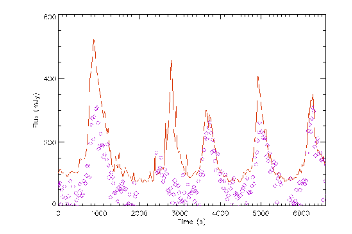


Figure 1 – **Observations of large-amplitude flares from GRS 1915+105** – the red line indicates the infrared emission (2.2 μm, IRCAM) and the purple diamonds indicate the millimetre emission (1.3 mm, SCUBA), taken from Fender & Pooley (2000). Note that the variation in flux between the two wavebands is very small indicating a flat spectrum, and that the time-lags between flux peaks are very short.

Our Time-Dependent Jet Emission Model

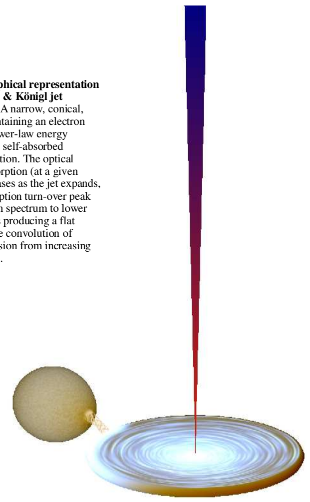
A self-absorbed synchrotron emission model for a jet has two free parameters; the optical depth normalisation and the flux normalisation, which we denote as *a* and *b* respectively. Both parameters are physically dependent upon the magnetic field strength, but only *a* depends upon the electron density within the jet plasma.

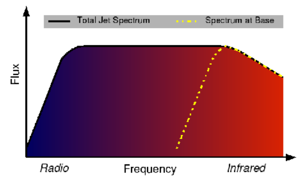
Physically we believe that the flares are more likely to be caused by an increase in the injected electron density. Therefore, we make the model time-dependent by varying the parameter *a*, following a Gaussian distribution with time.

The fixed parameters of the model are the length of the jet ($\sim 10^{11}$m), which is constrained by the flare rise time and the jet speed (assumed to be 0.6 c). The opening angle of the jet (< 4°), which is constrained by observations (and for reasonable values has little impact upon the results). The inclination of the jet to our line-of-sight (~70°), which is determined by previous observations of superluminal ejecta, and the distance to GRS 1915+105 (11 kpc).

In the time-dependent model the peak value of *a*, a_0, directly determines the predicted time-lag between the infrared flare reaching peak flux and the millimetre flare reaching peak flux. We have found that this model predicts a relationship between this time-lag and the ratio of the two peak fluxes, which is consistent with the observations. This is a good indication that the fixed parameters, relevant to this relationship, are correct. The constant value of *b* then controls the peak flux of the flare.

Figure 2 – **A graphical representation of the Blandford & Königl jet emission model.** A narrow, conical, relativistic jet containing an electron plasma with a power-law energy distribution emits self-absorbed synchrotron radiation. The optical depth to self-absorption (at a given frequency) decreases as the jet expands, shifting the absorption turn-over peak of the synchrotron spectrum to lower frequencies. Thus producing a flat spectrum from the convolution of synchrotron emission from increasing radii along the jet.





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Our Paper

Collins, Kaiser & Cox, 2003, MNRAS, 338, 331

Jet Emission Animations

www.astro.soton.ac.uk/~rsc/ckc02.html

Result

A series of models were calculated for different values of the free parameters. This resulted in a relationship between the time-lag predicted by the model and the peak flux of either waveband (since the flux ratio is fixed by the time-lag, see previous section), which is shown in figure 4.

The observations shown in figure 1, reveal time-lags of less than 50s, with peak millimetre fluxes being a few 10^2 mJy. Taking the upper-limit, a time-lag of 50s, we calculate the corresponding value of a_0. By scaling *b* such that the predicted millimetre flux agrees with the observations the required magnetic field strength and peak electron density maybe determined. We have found that for our model to be consistent with the observations at this limit we require an unphysically high peak injected electron density of 10^{40} m^{-3}.

Observations

The microquasar GRS 1915+105 has a persistent, *steady* jet, in addition to the transient ejection of superluminal blobs for which it is famous. The existence of this steady jet is confirmed by its flat radio spectrum and it is resolved in milli-arcsecond scale radio images.

Quasi-periodic oscillations in the emission intensity from GRS 1915+105 are observed at all wavelengths. Recent observations in the millimetre and infrared wavebands by Fender & Pooley have revealed repeated large-amplitude flares (see figure 1). The flux from these flares are approximately the same in both wavebands indicating that these are observations of a flaring flat spectrum, and hence the emission originates in the jet.

A flat spectrum is the result of the Blandford & Königl jet emission model, which is graphically explained in figure 2. However, this emission model only predicts a 'steady-state' solution for the jet emission spectrum. In order to confirm the jet origin theory for the emission flares shown in figure 1, we have developed a time-dependent version of the basic Blandford & Königl jet emission model.

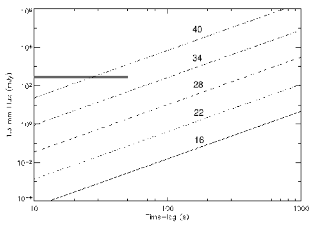

Figure 4 – **Time-dependent emission model constraints** – This plot shows the relationship of the time-lag between flux peaks at the two wavebands against the corresponding millimetre peak flux predicted by our model for different peak injected electron density values, from 10^{16} m^{-3} (bottom, solid line) to 10^{40} m^{-3} (top, triple dot-dashed line), in equal steps. Clearly for the observed time-lags marked in the plot by the grey rectangle, unphysical electron densities of the order of 10^{40} m^{-3} must be invoked.

Discussion

To make the model agree with the observations the predicted peak flux amplitudes must be 10^4 times greater. The failure of the model may be due to incorrect assumptions for some of the fixed parameter values, even though the predicted flux-ratio versus time-lag relationship is correct.

Is the jet at a shallower inclination? There is strong evidence for jets to be inclined at a wide variety of angles with respect to the system's accretion disc as well as observations of jets precessing with time (e.g. SS 433 and Cyg X-1). A significant change in the jet angle towards the observer would increase the amount of Doppler beaming in the jet emission. This would mean the intrinsic jet emission is weaker and hence our model would then agree with the observations for lower electron densities. Is this the first observation indicating that the GRS 1915+105 jet precesses?

Is the distance estimate wrong? The distance to GRS 1915+105 is based upon absorption estimates, which are notoriously inaccurate (Hipparcos moved Cyg X-1 40% closer to us!). However, the order of magnitude change of the flux required is so great that this possibility is not a solution.

Figure 3 – **Stills from our time-dependent jet emission animation** – Each frame shows the variation in electron density along the jet (on a logarithmic scale), the spatial extent of the radio emission (on a linear scale), the light-curve of five wavebands (2.2 μm infrared, 1.3 mm millimetre, 15 GHz, 8.3 GHz, and 2.3 GHz radio), and the broadband spectrum.

In this animation a quiescent, steady jet undergoes a burst of increased injected electron density. The first frame shows the epoch where the infrared emission peaks, this is coincident with the peak of the injected electron density, and a fully extend flat spectrum has been formed. In the next frame the injected electron density is decreasing, so the high frequency emission is weakening, but the low frequency emission increases as the jet plasma reaches greater radii.

The injected electron density returns to its quiescent level in the last two frames, so the denser plasma moves out of the conical jet and becomes a discrete blob of plasma, which fades as it moves away from the steady jet (c.f. radio images by Dhawan, Mirabel & Rodrigeuz 2000). The emission from this dense plasma is now just a single self-absorbed synchrotron emission spectrum, superimposed upon the underlying quiescent flat spectrum, which moves to lower frequencies as the plasma expands.