N72-33815

STELLAR X-RAY TEMPORAL VARIATIONS

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At the lowest level of what we mean by the understanding of an X-ray source is the qualitative nature of the emission process (whether synchrotron or thermal bremsstrahlung, for example), and we can usually get a handle on this from the shape of the X-ray spectrum. If we want to dig a little deeper into the problem and determine from where the energy comes, we find that the shape of the spectrum is no help at all. But the temporal behavior of the source may give us a hint.

For example, consider the Crab Nebula, the archtype synchrotron source. It has a featureless power law spectrum, and we know that the magnetic field must be there from the Crab's radio emission. But if we construct a synchrotron model from the observational parameters, we find that it has only enough energy for 1 yr of operation. As you know, we found out where the energy to keep the Crab going came from when we found pulsed emission from the source. The pulsed power itself is very small, but the interpretation of the periodicity in terms of a rapidly rotating central object which can transfer rotational kinetic energy to relativistic electrons in the far reaches of the nebula completely satisfies the overall energy requirements. That's a 2-yr-old story, I would like to tell you now about some temporal studies we have performed this year.

The first is on Sco X-1, where the spectral shape indicates thermal emission. But the observational parameters in this case indicate a lifetime much smaller than 1 yr; in fact, smaller than 100 ms. So we looked for a pulsar in our rocket data for Sco X-1, and we could not find one. We also looked for nonperiodic fluctuations and we could not find them, either. In Figure 1 we present 5σ upper limits to the pulsed fraction for those conditions under which fluctuations would be the most difficult to detect; that is, when each pulse is smeared out over half the interval between pulses. Thus these are very conservative upper limits.

We get about 1 percent for periodic fluctuations (independent of period) in the range 3 to 300 ms, and let me remind you that the Crab would be at 33 ms and it would have about 15 percent pulsed fraction in this energy band. We get somewhat larger limits for fluctuations that are not periodic but which have the average time scale of the abscissa between bursts. In the 2 full minutes we spent looking Sco X-1 straight in the eye, we could not find any variations in excess of Poisson statistics whatsoever. And this,

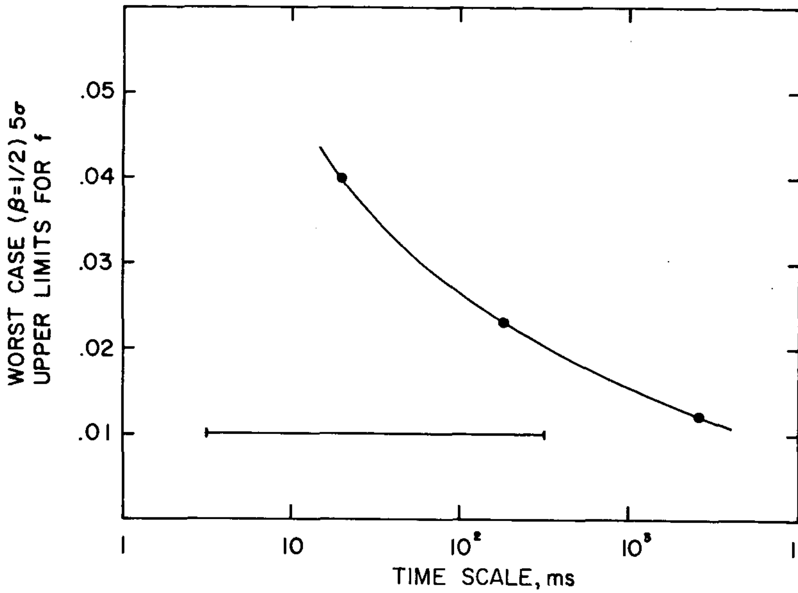

Figure 1–Upper limits to the pulsed fraction for those conditions causing the most difficult detection of fluctuations.

remember, when we calculated a lifetime for Sco X-1 of less than 100 ms. The conclusion we are forced to is that the energy input must be essentially continuous on this time scale.

At least two separate detailed theoretical models of X-ray sources have been proposed this year based on the premise that a pulsar can be hidden underneath a thick plasma cloud (so that you cannot see the pulsed component of the radiation), and the X-ray emission would come secondarily from the pulsar energy incident from the cloud from underneath. It is important to remember that the loss of rotational kinetic energy from a pulsar is continuous, not pulsed. In the Crab, the pulsed component is a minuscule fraction of the energy, and is important only because it tells us where to find all the continuous energy input. In this case we cannot find the pulsed part so we cannot make a positive identification of the pulsar origin for the Sco X-1 energy input. However, the lack of nonperiodic variations demands a continuous energy source, and that in itself rules out lots of other possibilities. So a pulsar in Sco X-1 is not only consistent with our data, it is also, I think, the most reasonable explanation for it, even if a pulsed component is never detected.

Are all X-ray sources driven by pulsars, then? Some direct evidence for another X-ray pulsar was offered by the experimenters on Explorer 42 (SAS A) this year who reported a 73-ms period for Cyg X-1, which could also have been 4 times 73 or 292 ms owing to their 96-ms sampling time. We looked at a 5-s exposure to Cyg X-1 in our rocket data for conformation and we found some very surprising results. We found nothing at 73 ms but lots of variations in excess of Poisson statistics. Figure 2 is our power density spectrum for Cyg X-1, with a whole multitude of seemingly unrelated peaks of high statistical significance; this means either that there is no real periodicity (just aperiodic bursts), or a combination of separate harmonic components. Alpha and beta are two components that, if modulating each other, explain most of our peaks and are also consistent with the original Explorer 42 results, as alpha is about 290 ms.

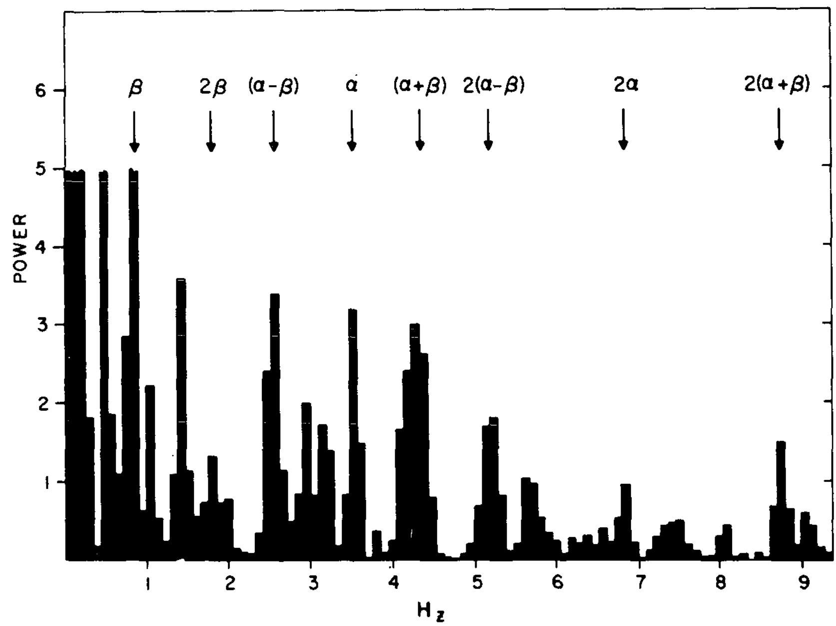

Figure 2—Power density spectrum for Cyg X-1.

In Figure 3 you can see the source of the power spectrum. The overall triangular pattern is the collimator response as the source moves across our field of view, and it does not take too much imagination to see an amplitude modulation of the basic 290-ms periodicity, at least during the first half of the exposure. During the second half we seem to lose phase, although the average separation between these minima is still about 290 ms.

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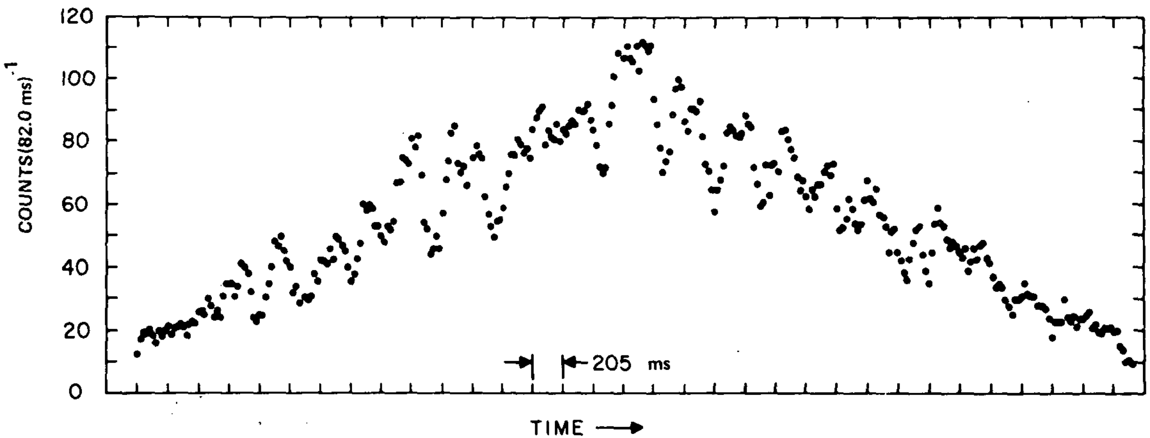

Figure 3–Source of power spectrum.

Subsequent investigations from Explorer 42 and from rockets indicate that this sort of pseudoperiodic behavior, where harmonic components seem to come and go with characteristic times of less than 10 s, seems to be the rule for Cyg X-1. This is definitely not what you would expect from a pulsar, and I wish I could tell you what it is.

So you might say that we win one and we lose one, in the sense that of the two temporal studies that I have discussed, we can at least reconcile one with a respectable model on an energetics basis now in addition to just identifying the emission mechanism. As far as Cyg X-1 is concerned, however, it appears that our analysis has raised more questions than it has answered. Perhaps someone on next year's program can come up with a believable explanation for what we have found.