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# DETECTING GRAVITY WAVES FROM BINARY BLACK HOLES

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One of the most attractive possible sources of strong gravitational waves would be a binary system comprising massive black holes (BH). The gravitational radiation from a binary is an elliptically polarized, periodic wave which could be observed continuously - or at intervals whenever a detector was available. This continuity of the signal is certainly appealing compared to waiting for individual pulses from infrequent random events. It also has the advantage over pulses that continued observation can increase the signal-to-noise ratio almost indefinitely. Futhermore, this system is dynamically simple; the theory of the generation of the radiation is unambiguous; all characteristics of the signal can be precisley related to the dynamical parameters of the source.

The difficulty is that there is no clear observational evidence for their existence. The best evidence for the existence of any black holes comes from 3 or 4 binary systems which contain a normal star and a compact object whose mass apparently exceeds the limiting masses of white dwarfs and neutron stars. It is, of course, possible that some binaries do exist in which both stellar components have evolved into compact objects or black holes.

The lowest shaded band in Figure 1, labeled CLOSE - NORMAL, includes these possible BH binaries of normal stellar mass.

Astrophysical theory appears to require supermassive black holes to power active galactic nuclei (AGN) and quasars. The most detailed models invoke a single supermassive ($10^8$ - $10^9$ $M_\odot$), spinning BH to explain the dynamics and configuration of the active nuclei. Evidence is accumulating that even normal galaxies may have a black hole in their nuclei; cusps in the central light emission, and rotational velocity profiles and velocity dispersions which rise within the central ~100 pc. could be explained by black holes of $10^6$ - $10^7$ $M_\odot$. There is some evidence that our own galaxy may contain a supermassive object, but conflicting interpretations lead to estimated masses from as low as 100 $M_\odot$ to as high as 3 x $10^6$ $M_\odot$.

It has also been proposed that massive binary BH may occur quite frequently in galactic nuclei as a consequence of merging of galaxies. It has been estimated that roughly 1 in 300 galaxies could contain massive binaries and might show periodic electromagnetic emission. So far, however, periodicity has not been found observationally.

The top shaded band in Figure 1, labeled AGN, is intended to cover these possible supermassive binaries in galactic nuclei.

Another speculation on the existance of massive BH is related to the missing mass problem in galaxies. Dynamical observations of stars imply that there must be as much dark matter present in galactic disks and haloes as can be seen. It has been proposed that primordial, or pre-galatic, BH may have formed at the same time as the globular clusters and with approximately the same range of masses (~$10^6$ $M_\odot$) and spatial distribution. If enough of them formed to explain the mass deficit,they could be expected to have effects on stellar dynamics similar to those observed. It is not unreasonable to assume that some of them would have formed binary systems.

The center shaded band in Figure 1, labeled HALO, includes possible BH binaries of about globular cluster mass.

In **summary**, the current situation is that while there is no observational evidence as yet for the existence of massive binary BH, their formation is theoretically plausible, and within certain coupled constraints of mass and location, their existence cannot be observationally excluded. Detecting gravitational waves from these objects might be the first observational proof of their existence.

Figure 1 shows the range of possible binary BH with masses between $2M_\odot$ and $2 \times 10^9$ $M_\odot$ and with seperations from 1 lt.-sec. to $10^8$ lt.-sec. (~1pc.). The shaded bands indicate those mass ranges which have been suggested as theoretically plausible, but are not meant to imply that other mass values are impossible. The diagram can be used to distinguish the regions of likely detection.

The two dashed lines (L=30 yrs and L=$10^{10}$ yrs) give the remaining lifetime of binaries located along those lines, based on energy loss to gravitational radiation only. Detecting a binary to the left of the L=30 yrs line, i.e., during the last 30 yrs of its lifetime, would be extraordinarily fortunate. Only the portion of the diagram to the right of this line presents reasonable probabilities of detection.

The three dotted lines (P=1000 sec, P=12 days, P=30 yrs) give the period of the binaries located along these lines, assuming a circular orbit. Periods longer than 30 yrs would require very long observation times, more than 300 yrs to detect just 10 periods of the signal. From practical considerations alone, it is not unreasonable to exclude the portions of the diagram to the right of this line.

A different problem arises in the bottom shaded band of stellar mass binaries. Any signal from a BH binary in this region is likely to be overwhelmed in the confusion of comparable signals from the multitude of ordinary, and other compact, binary systems.

These considerations serve to delimit a quadrilateral of detectability in the middle of the figure which includes the central parts of the AGN and HALO bands.

The set of eight solid lines in Figure 1 gives the amplitude of the gravitational waves from equal mass binaries located along these lines at two particularly relevant distances: first, $10^4$ pc (typical distance in our galaxy), and second, 10 Mpc (distance to the Virgo cluster). It is worth noting that a gravitational wave sensitivity of H = $10^{-17}$ is sufficient to explore most of the detectable HALO band within our galaxy, and all of the detectable AGN band out to the Virgo cluster. However, this exploration requires detectors capable of responding to very long period waves - from hours to years.

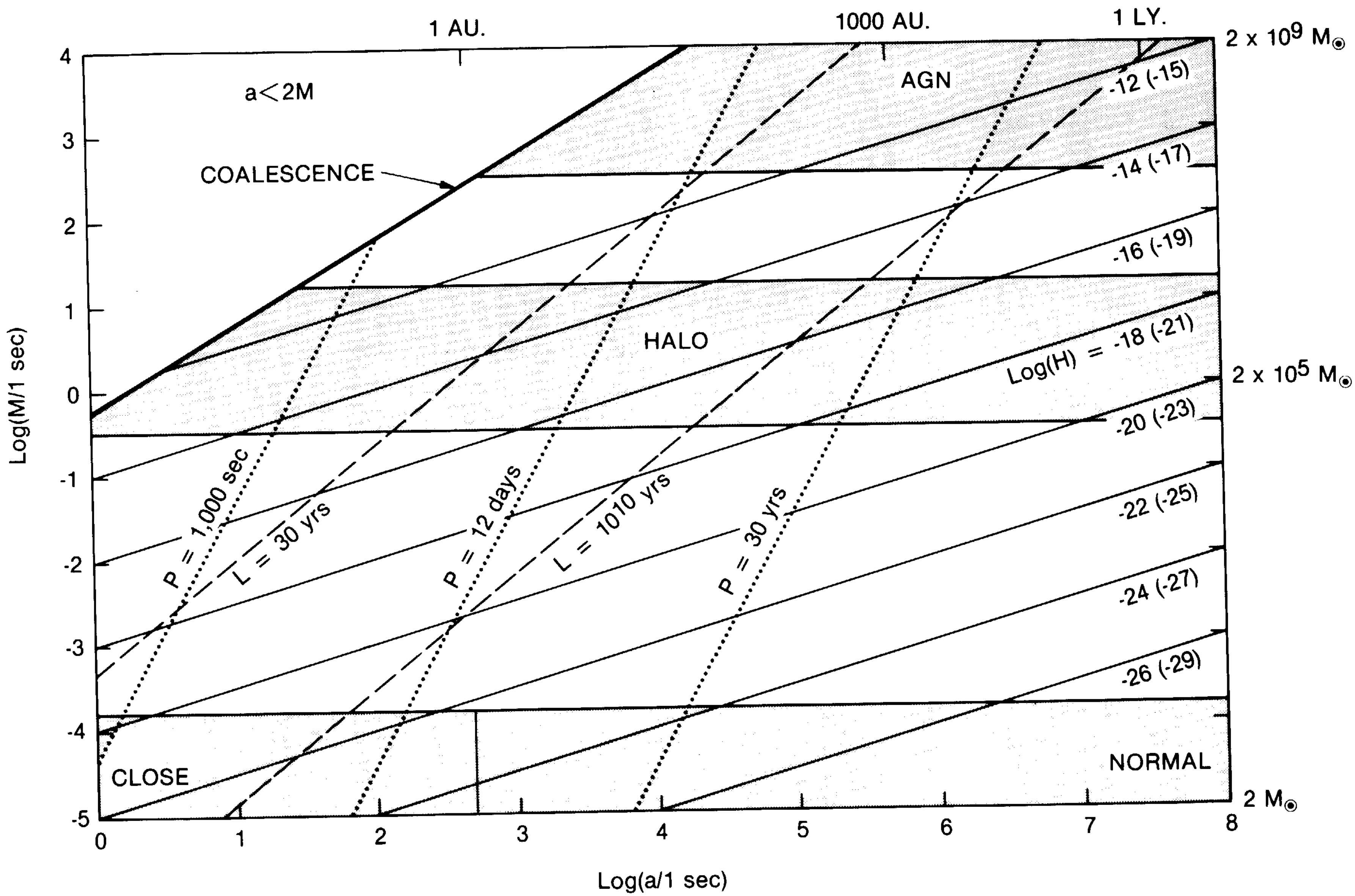


Figure 1. Possible black hole binary systems ranging in mass (M) and separation (a).

DISCUSSION

SONNABEND: It seems to me that binary B.H. of $\sim 10^5 M_\odot$ each would be rare compared to binaries with $\sim 10^5 M_\odot$ to $\sim 1\ M_\odot$, thus populating the region below the galactic halo band in your slide.

WAHLQUIST: I don't want to discourage looking for such objects, but there are plausible scenarios in which binaries of globular cluster mass form.

TAYLOR: Don't be too quick to rule out as inaccessible the region of your overlaid diagram around P $\sim 10^8$ sec. For the larger black hole masses, at least, this region is probed by millisecond pulsar timing observations.

WAHLQUIST: I concur - and will expand the detectable region in the published paper.

HELLINGS: For halo objects ($\sim 10^5\ M_\odot$), it is reasonable to look for sources in our galaxy, but for nuclear objects ($\sim 10^7$ - $10^9\ M_\odot$), since we only have one galaxy, it is probably statistically preferable to look for sources outside our galaxy.

WAHLQUIST: Yes. These supermassive binaries can be detected even out to Virgo with moderate sensitivity.