UPPER LIMIT TO RADIATION OF MASS ENERGY DERIVED FROM EXPANSION OF GALAXY

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Loss of mass energy from the galaxy, whether by gravitational radiation or otherwise, should cause the galaxy to expand. Observations of stellar motions near the sun imply that the rate of radiation averaged over the last ~10^8 yr must be less than $200M_\odot$ yr^{-1}. Studies based on the 21-cm line have already yielded some evidence for galactic expansion, which could be a consequence of mass loss.

If gravitational radiation[1] or any other radiation of mass energy from the galaxy[2] had anything like the level indicated by Weber,[1,2] it would have serious astronomical consequences. We derive here from astronomical data a limit on the loss of mass energy from the galaxy. An upper limit follows from considerations of stellar dynamics, because the mass loss $\dot{M}$ due to gravitational radiation would cause the galaxy to expand with a radial velocity Π given by

$$\Pi/\omega = |\langle\dot{M}\rangle|/M_E. \quad (1)$$

Here ω is the radial coordinate and M_E is an effective mass roughly equal to the mass of the galaxy. $\langle\dot{M}\rangle$ denotes the mass loss averaged over a characteristic dynamical time scale of ~10^8 yr, and (1) applies if $M/|\langle\dot{M}\rangle| \gtrsim 10^8$ yr. M_E would exactly equal the mass of the galaxy if all the mass were concentrated at the center. The expansion would be manifested by nonzero values of the quantities[3]

$$K = \frac{1}{2}\left(\frac{d\Pi}{d\omega} + \frac{\Pi}{\omega}\right), \quad C = \frac{1}{2}\left(\frac{d\Pi}{d\omega} - \frac{\Pi}{\omega}\right), \quad (2)$$

which can in principle be determined, assuming axisymmetry, by analysis of stellar motions near the sun ($\omega = 10$ kpc). In order to calculate the values of Π and $d\Pi/d\omega$ to be expected, one must adopt a model of the distribution of mass and mass loss. From a simple model which fits the known values of Θ, ω, and $d\Theta/d\omega$ (Θ = rotational velocity), and in which the mass loss is concentrated at the galactic center, we find that

$$M_E \simeq 2\times10^{44}\text{ g}, \quad K \simeq 0.9\Pi/\omega, \quad C \simeq -0.1\Pi/\omega. \quad (3)$$

Stars as a whole do not possess a detectable K term.[4,5] The corresponding upper limit is

$$K \lesssim 2\text{ km sec}^{-1}\text{ kpc}^{-1} = 2\times10^{-9}\text{ yr}^{-1}, \quad (4)$$

and, from Eq. (3),

$$|\Pi/\omega| < 2\text{ km sec}^{-1}\text{ kpc}^{-1}. \quad (5)$$

If our model is correct, this implies $|C| < 0.2$. An estimate of C based on the difference in longitude of the apparent center of rotation[6] from that of the radio source Sag A, presumed to be at the center of the galaxy,[7] yields $C = 1.3 \pm 0.7$. The discrepancy is not significantly larger than the errors.

From (1), (3), and (5) we obtain an upper limit on $\langle\dot{M}\rangle$ consistent with these considerations:

$$|\langle\dot{M}\rangle| \lesssim 1.3\times10^{28}\text{ g sec}^{-1} = 200M_\odot\text{ yr}^{-1}. \quad (6)$$

If we assume that the sources of radiation lie at the galactic center, (6) implies that the mean mass flux at the earth, averaged over the last ~10^8 yr, is $F \lesssim 1.1\times10^{-18}$ g cm^{-2} sec^{-1}. This flux is comparable with the flux of gravitational waves reported by Weber, if it is assumed that this radiation is broad band.

Relation (6) is astronomically nontrivial, since there is sufficient material within ~1 kpc of the galactic center to maintain a mean annihilation rate as great as $200M_\odot$/yr for ~10^8 yr. If the efficiency could be so high that all but a small fraction of the original mass were radiated away, the amount of material at the galactic center may once have been many times higher, and the radiation could have continued for longer than 10^8 yr. It is not yet known what radiative efficiencies are possible.[8]

There is, in fact, some evidence from 21-cm studies that the galaxy may indeed be expanding, although not at the ~20 km sec^{-1} permitted by (5). Kerr[9] has proposed that the local standard of rest (defined by the mean motion of young stars in the solar neighborhood) moves outward from the center with $\Pi \simeq 7$ km sec^{-1}. Such a velocity would account for the observed difference of the galactic rotation curve on opposite sides of the sun-center line. Because no radial motion of the interstellar gas and young stars relative to old stars is observed,[10,11] all the material in our vicinity must be moving outward at $\simeq$7 km sec^{-1} if Kerr is correct. Although Kerr's proposal is still controversial[10,12] it is interesting that a mass-loss model meets this requirement. Kerr's original conjecture that $\Pi \propto \omega^{-2}$ (which would have fitted the ~60-km-sec^{-1} expansion of the 3-kpc arm) has been disproved[13]; our calculations suggest instead that, for steady mass loss, $\Pi \propto \omega^{0.8}$, and this seems not to contradict known data.[13] Schmidt has stressed that if the expansion were real, agreement between the local velocities of gas and different types of stars would be understandable only if the gravitational potential varies. Further, "it would have to vary with a characteristic time of about one billion years, which seems quite improbably short." We therefore view Kerr's proposal in a new light. We suggest that the galaxy may suffer a mean mass loss of ~$70 M_\odot$ yr^{-1}, over the last 10^8 yr at least, as a result of radiation or otherwise, and that this accounts for the ~7-km-sec^{-1} expansion proposed by Kerr. If this rate of mass loss has continued for longer than 10^9 yr, one would not expect the galaxy to contain stars with bound orbits of period exceeding ~10^9 yr. An analysis of velocity data to be published elsewhere[14] indicates that this requirement may be satisfied, although possibly for other reasons.

If the above hypothesis should prove to be essentially correct, there would be considerable ramifications for other problems in astronomy. Some of these consequences, which include the breaking of rotational symmetry in the galaxy, with resulting selection between leading and trailing spiral arms,[15] the large extent of certain galaxies like M87,[16] the existence of ring galaxies, and the dynamics of clusters of galaxies, will be discussed elsewhere.

Since the high rate of mass loss indicated by Weber's experiments is not ruled out by direct astronomical considerations discussed here, it would clearly be desirable for these experiments to be repeated by other workers.

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