THE OPTICAL AND X-RAY LUMINOSITY (MULTIPLICITY) FUNCTION OF GALAXY SYSTEMS.

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Abstract: The luminosity function of galaxy systems - from single galaxies and small groups to rich clusters - is determined. I first determine the rich-cluster luminosity function, then a "groupings" luminosity function, which includes all systems from small groups to rich clusters, and finally, I estimate a general luminosity function of all galaxy systems (AGS), from single galaxies to rich clusters. The catalogs of Abell (rich clusters) and Turner and Gott (groups, singles) are used. The AGS luminosity function is found to be a smooth and steeply decreasing function of number density with luminosity; it spans over twelve decades of number densities in the observed five-decade range of luminosities ($\sim 10^9$ to $10^{14}\ L_\odot$). The function exhibits an exponential cutoff in the rich-cluster luminosity domain, a power law dependence over most of the intermediate luminosity range, and a flattening of slope below the characteristic galactic luminosity, L*. A smooth transition between the groups and rich-clusters occurs near $\sim 10^{13} L_\odot$. The groupings LF (i.e., groups to rich-clusters) can be represented well by a Schechter-type analytic form $\eta(L)=\eta_o(L/L_o)^{-\alpha} \exp(-L/L_o)$, where $\eta(L)$ is number of systems per unit volume per unit luminosity. The best-fit parameters are $\alpha=2.0 \pm 0.1$, $L_o=1.0 \pm 0.2\times10^{13} L_\odot$, and a normalization $\eta_o=1.6 \times 10^{-7}$ systems $Mpc^{-3}\ (10^{12}L_\odot)^{-1}$. The "break" at $L_o \simeq 1 \times 10^{13} L_\odot$ occurs at the typical luminosity of rich Abell-type clusters. The slope α is found to depend on the density enhancement factor with which the groups are selected, but the dependence is relatively weak. The exponential decay at the bright end (rich clusters) has an equivalent power-law slope of approximately -5, i.e., $\eta(L) \propto L^{-5}$. The functional form of the LF is consistent with the Press-Schechter (1974) model of galaxy formation, and with the recent Silk-White (1978) model (predicted slope of -2.0). When single galaxies are added to the groupings luminosity function, the luminosity function of all galaxy systems (AGS) can be roughly described as $\eta(L)=1.6 \times 10^{-7}\ (L/L_o)^{-2} e^{-L/L_o} (1 + 1.6 \times 10^{10}/L)^{-0.75} Mpc^{-3} (10^{12}L_\odot)^{-1}$ with $L_o=1 \times 10^{13} L_\odot$. This function approaches Schechter's field galaxy luminosity function at low luminosities, and the groupings function at high luminosities. Comparisons of the LF with the LF of galaxies and X-ray clusters of galaxies are discussed, and an estimate of $\mathcal{L}(B(0)) \simeq 10^8 L_\odot(B) Mpc^{-3}$ is given for

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the observed luminosity density in the universe.

The above luminosity function of galaxy systems could be compared with high redshift cluster data, when available, and thus shed light on possible evolutionary processes.

The X-ray luminosity function of clusters of galaxies is calculated using the general LF of optical clusters above and a relation between X-ray and optical luminosity based on a thermal bremmstrahlung model. The derived X-ray LF applies to clusters whose X-ray emission is mostly due to thermal bremmstrahlung from a smooth, hot intracluster gas. The main features predicted by the LF are a change of slope in the log η_X -log L_x plane at $L_x \sim 10^{44}$ ergs/s, a moderately steep slope of -2.5 at high luminosities ($\sim 10^{44}$-10^{46} ergs/s), and a flatter slope of ~-1.3 below 10^{44} ergs/s (down to $\sim 10^{42}$ or 10^{43} ergs/s, where the smooth thermal bremsstrahlung may not dominate the total X-ray emission). Simple analytic expressions of the LF are given for various X-ray energy bands. X-ray data from Uhuru and Ariel-5, available for the 10^{44}-10^{46} ergs/s luminosity range (including upper limits in the 10^{45}-10^{46} range), agree well with the LF calculated here. The present calculations suggest that at least to $L_x \sim 10^{46}$ ergs/s the X-ray LF does not decay faster than $\sim L_x^{-2.5}$ (for a wide enough energy band). It is also suggested that fewer faint X-ray clusters than previously expected may exist (and be detected by the Einstein satellite).

DISCUSSION

Jaffe: The breaks in the slope of your optical luminosity function occur at the points where you changed catalogs (Abell to Gott-Turner; Gott-Turner to single galaxies). Do you think that the different selection criteria in different catalogs cause the change in slope, or did the changes in slope provide natural limits where the catalog compilers stopped counting?

Bahcall: No. The flattening in the luminosity function near $L_O \sim 1 - 2 \times 10^{13}$ $L_\odot$ occurs even when the Abell catalog is used by itself, independent of any group catalog. The flattening at the fainter end occurs without any change of catalogs; both the groups and the "single" galaxies used are the entire complete sample given by the same Turner-Gott catalog. The uncertainties at the faint end, however, are large, but the agreement with the standard field galaxy luminosity function is apparent.

Perrenod: Your optical cluster luminosity function has an exponential tail and your X-ray luminosity-optical luminosity relation is a power law. Shouldn't your X-ray luminosity function have an exponential to a weak power law in it?

Bahcall: Yes. If expressed as an exponential $\eta_X(L_X)$ would roughly satisfy $\sim e_X^{-1/3}$ at the bright end. This is a very weak exponential, roughly equivalent to the $\sim L_X^{-2.5}$ power law for $L_X \lesssim 5 \times 10^{45}$ ergs/s.