# SOME CONSTRAINTS ON QUASAR PROGENITORS AND QUASAR EVOLUTION

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There is strong evidence that quasars are powered by the gravitational energy released by in fall of matter into a compact supermassive object which is most likely a black hole with mass $M>10^6$ to $10^9 M_O$. The question then arises as to how such massive black holes came to be formed. What sort of objects were the progenitors? While looking for an answer we have to bear in mind another bit of intriguing evidence that even high Z quasars show lines of heavier elements (Oxygen, magnesium, etc) with solar abundances, strongly suggesting that matter had already undergone nuclear processing at even earlier epochs. Again even the oldest stars in our galaxy show evidence of metal content. All this suggests that atleast part of the metal content could have been generated by pregalactic supermassive stars, sometimes referred to as Pop.III objects. Such stars with masses ranging from $10^2$ - $10^6$ $M_\odot$ could have formed in clusters consisting of about a few hundred or thousand of these objects at $Z \simeq 10$. Now objects $>10^6$ $M_\odot$ would have central temperatures not high enough for nuclear reactions the reason being a well known instability of general relativistic origin which is reached when $GM/R \approx 9c^2/16\ (M_O/M)^{\frac{1}{2}}$ ; $M_O \approx M_\odot$ giving rise to a maximum central temperature $T_c$ reached at the instability, i.e. just before collapse. This is given by $T_c = 2 \times 10^{13}/(M/M_O)$ giving $T_{max} = 10^7$ K (necessary for CNO reactions) for $M \simeq 10^6 M_O$ and for $M > 10^6$ $M_\odot$, $T_c$ is too low. It is believed that $10^{-5}$ of the primordial material might have been processed in Pop III objects which would have undergone nuclear reactions and evolved over some fraction of a Salpeter time, $c\sigma_T/4\pi G m_p \simeq 10^8$ yrs; ($\sigma_T$ = Thompson cross section, $m_p$ is proton mass)., producing heavier elements in the process. It turns out that objects of mass $M < 300$ $M_\odot$ can explode and scatter the heavy elements. For instance a 116 $M_\odot$ oxgen core of a $200 M_O$ object can completely disrupt and the evolution of such objects can explain anomalies like the O/Fe enrichment in metal poor stars and the G dwarf problem. Again there can be substantial mass loss from these superstars (a typical empirical relation like $M \simeq (t_D/t_kH)^{\frac{1}{4}}$. L/GM/R (where $t_D$ is the dynamical time, and $t_kH$ is the Kelvin-Helmholtz scale, L is the luminosity) predicting $\dot{M} \simeq 10^{-3} M_O/yr$) again leading to enrichment of the medium. Stars $>300$ $M_O$ do not explode but would collapse. The relaxation time scale for a cluster of these objects is again $5 \times 10^8$ to $10^9$ yrs,

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so that they would all collapse to form a central black hole of $M \sim 10^8 - 10^9 M_\odot$, the surrounding earlier ejected matter enriched in heavier elements being now accreted onto it. There would have been atleast a few times $10^8$ of these black holes formed. Assuming near Eddington luminosity the rate of accretion given by $\dot{M}(t) \simeq 8\pi GM(t)/kc \simeq 16\pi G^2 M^2(t) X \rho(t) V/c^4$, $\rho(t)$ being a function of Z) would put a constraint on when Pop III stars formed and accreted enough matter to trigger quasar activity as quasars do not seem to be present before $z = 4$. This gives the result that they could not have formed before $z \simeq 8-10$. Another possibility of forming a central black hole is by the collapse of a dense star cluster (consisting mainly of neutron stars or white dwarfs), the central relaxation time is $t_R \sim V_C^3 / m_c^2 \ln(0.4\, N_C) \sim 10^9$ yr. One obtains the result that for a core of compact stars to evolve to a relativistic state in a Hubble time it should have a minimal velocity dispersion given by $V_C\,(\min) \simeq 10^3 (m_C)^{(1-A/B)\,(7-3A/B)}$ km/s, A, B are constants. This corresponds to clusters roughly having $10^7 - 10^9$ compact stars and the gravitational collapse of such a cluster would then lead to black holes in the required mass range. An observed example is the central 3.5 pc core of NGC 4151 which has a mean stellar density of $2 \times 10^8$ M $\mathrm{pc}^{-3}$ corresponding to $V_c \simeq 10^3$ km/s. As the central black hole grows the relative tidal force decreases and quasar activity can stop when the hole can no longer break up stars. (Tidal break up is also producing and scattering heavy elements.) For a central black hole accreting white dwarfs $M < 10^6 M_\odot$ and for it to break up neutron stars $M < 2 \cdot 10^3 M_\odot$. The break up of a neutron star by such a hole would give a burst of energy $\sim 10^{52}$ ergs/sec which has so far not been recorded in any quasar or AGN, the upper limit to the luminosity being $\sim 10^{49}$ ergs/s. This may be indirect evidence that the mass of the central black hole is well above $10^4\, M_\odot$ in all cases. It is a pleasure to thank Professor Martin Rees for valuable discussions.