A simple model for quasar density evolution

Hannes Horst\textsuperscript{1,2} and Wolfgang J. Duschl\textsuperscript{2,3}

\textsuperscript{1} European Southern Observatory, Casilla 19001, Santiago 19, Chile
\texttt{hhorst@eso.org}

\textsuperscript{2} Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, 69120 Heidelberg, Germany
\texttt{wjd@ita.uni-heidelberg.de}

\textsuperscript{3} Steward Observatory, The University of Arizona, 933 N. Cherry Ave, Tucson, AZ 85721, USA

\textbf{Summary.} It is widely agreed upon that AGN and Quasars are driven by gas accretion onto a supermassive black hole. The origin of the latter however still remains an open question. In this work we present the results of an extremely simple cosmological model combined with an evolutionary scenario in which both the formation of the black hole as well as the gas accretion onto it are triggered by major mergers of gas-rich galaxies. Despite its very generous approximations our model reproduces the quasar density evolution in remarkable agreement with observations.

\section{1 Introduction}

While it is widely agreed upon that galaxy-galaxy interactions and, in particular, mergers play a crucial role for the growth of supermassive black holes in quasars and also for providing the fuel for quasar activity, there is still dispute whether these black holes are of primordial nature or not. N-body simulations (e.g. by [1]) show that the tidal forces in interacting galaxies can trigger strong gas inflows towards the center of the merger. The mass of this gas is sufficient to build a supermassive BH of $10^7 \cdots 10^{10} M_\odot$ and provide enough fuel for quasar activity. On the basis of the $\beta$-viscosity model by [3] calculations by [4] show that it takes less than $10^9$ a from the merger to form a fully developed quasar even if no primordial supermassive BH was originally present. This model can be tested by comparing the resulting co-moving space density of quasars to those derived from observations (e.g. [5]).

\section{2 Outline of the model}

Based on results by [4] we assume an average time delay of $5 \cdot 10^8$ a between the merger and the peak quasar activity. The individual values of this delay depend, of course, on details like the size ($s_{\text{disk}}$) and initial mass ($M_{\text{disk}}$) of
the disk. Estimates of the relevant (viscous) timescale show its dependence
\( \propto s_{\text{disk}}^{3/2} M_{\text{disk}}^{1/2} \). This leads to the – at first glance surprising—finding of the faster formation of the more massive black holes. For our present purpose, however, an average value of this delay serves its purpose. For more details of this model, we refer the reader to the contribution by Duschl and Strittmatter in this volume and in [4].

For our purpose it is sufficient to use a “test universe” comprised of 50 000 galaxies. This test universe is expanding according to an Einstein-de Sitter-cosmology with a Hubble constant of \( H_0 = 72 \frac{\text{km}}{\text{Mpc}} \). Our galaxies are treated as particles with a finite cross section and a thermal velocity dispersion of \( v_s = 300 \frac{\text{km}}{\text{s}} \). In this framework we compute the merger rate for each simulated time bin \((10 \cdot 10^6 \text{a})\) by taking into account two different processes: Direct geometrical hits and gravitationally driven mergers. For the first process we assume every galaxy to have a spherical cross section with a radius of 15 kpc. For the second process the cross section radius is \( r_{\text{cs}} = 2G\ast M v_{\text{rel}}^{-2} \), with \( M \) being the mass of one galaxy and \( v_{\text{rel}} \) being the relative velocity between both. We assume a delay between the merger and the onset of the quasar phase of \( 5 \cdot 10^8 \text{a} \) for the geometrical hit and \( 1 \cdot 10^9 \text{a} \) for the gravitationally driven merger. The quasar phase in turn is assumed to last for another \( 5 \cdot 10^8 \text{a} \).

In our model the Universe is treated in very simple manner: As an expanding spherical box. The size of this box is determined by deriving today’s matter density from the assumed Hubble constant \( (\frac{5}{3}\pi G\ast \rho_0)^{1/2} = H_0) \) and then using the Friedmann-Lemaître-equation to calculate the according radius at any given time. We completely neglect structure formation and start our simulation with large galaxies \((M = 10^{11} M_\odot)\) already in place \( 2 \cdot 10^8 \text{a} \) after the Big Bang. To account for the formation of galaxies we increase their number over the first \( 5 \cdot 10^8 \text{a} \) of our simulation until the final number of 50 000 is reached (see fig. 1 for the effect of this procedure).

Fig. 1. Co-moving space density of quasars as computed by our simulation. In panel a) all galaxies are in place at the start of the simulation. In panels b) and c) the number of galaxies is gradually increased over the first \( 5 \cdot 10^8 \text{a} \). In panel b) a constant galaxy formation rate and in panel c) a Gaussian formation rate were used – the resulting co-moving space density of quasars is almost exactly the same.
3 Results

The comparison between our model results and observational data compiled by [5] is shown in fig. 2. The quasar density evolution at lower redshifts and the position of the peak at $z \approx 2.5$ match very well. Please note that the X-ray selected sample contains lower luminosity AGN in addition to quasars. In this respect it is natural that our results resemble the 2dF curve (from [2]) better than the data from [5]. At higher redshifts the deviation between simulated and observed co-moving spatial density is increasing. In our model we clearly miss the earliest quasars which arise from exceptionally fast evolving mergers. Despite this shortcoming of our results their overall agreement with observational data is remarkable.

![Fig. 2. Comparison of our simulated quasar density evolution with observational results. The broken line is the same as in panel b) of Fig. 1, while the underlying graph has been taken from [5]. The theoretical curve has been scaled to match the 2dF results.](image)

References

1. J. E. Barnes, L. E. Hernquist: ApJ 471, 115 (1996)
2. S. M. Croom, et al.: MNRAS 349, 1397 (2004)
3. W. J. Duschl, P. A. Strittmatter, P. L. Biermann: A&A 357, 1123
4. W. J. Duschl, P. A. Strittmatter: in prep. (2006)
5. J. D. Silverman, et al.: ApJ 624, 630 (2005)