Unified Modeling of Quasar, Black Hole, and Spheroid Evolution in Galaxy Mergers

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Hopkins et al. 2005a, ApJL, 625, 71
Hopkins et al. 2005e (astro-ph/0506398), 2005f, in preparation
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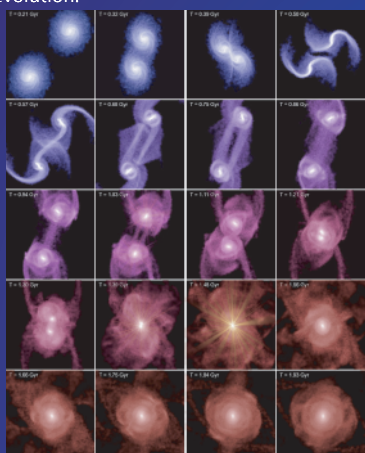
Abstract

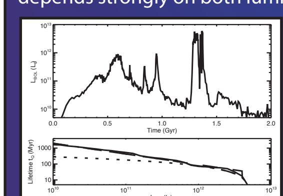
We develop a model of the co-formation of quasars, supermassive black holes (BHs), starbursts, and spheroids in major galaxy mergers. We utilize high-resolution merger simulations, including the effects of radiative cooling, a multi-phase dynamically star-forming interstellar medium, black hole (BH) accretion based on the surrounding gas properties, and feedback from BH growth and star formation (Springel et al. 2002, 2005b). These simulations allow us to self-consistently track simultaneous BH and galaxy evolution.



A typical simulation. Brightness shows density, color shows gas fraction (increasing red to blue). Rays show quasar luminosity.

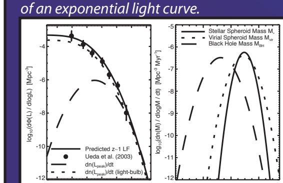
Quasars Spend Different Times at Different Luminosities, with More Time in Dimmer Phases: the Quasar Lifetime is *Luminosity-Dependent*

We measure the quasar light curve, calculating column densities along all sightlines to the quasar through the merger. The quasar light curves are quite complex, with periods of activity on first passage of the galaxies, and an extended period of rapid obscured growth, until a critical BH mass/luminosity is reached and feedback from accretion heats and unbinds nearby gas, leaving a BH in an elliptical with hot X-ray gas (Cox et al. 2005) on the M-sigma relation (Di Matteo et al. 2005). The resulting optical quasar lifetime is ~10^7 yr at bright luminosities (in good agreement with observations, see e.g. Martini 2004), but depends strongly on both luminosity and waveband, in a very different manner than with traditionally assumed lifetimes (where quasars turn on/off or follow exponential light curves). Quasars spend more time at luminosities below their peak than they do at their brightest luminosities, and this has important consequences.

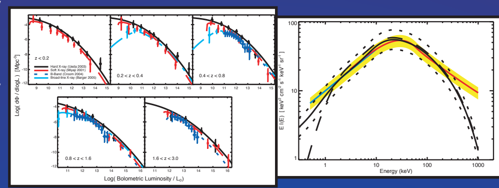


Typical simulated quasar light curve and lifetime (solid lines). Dashed line is our analytical fit, dotted line is the prediction of an exponential light curve.

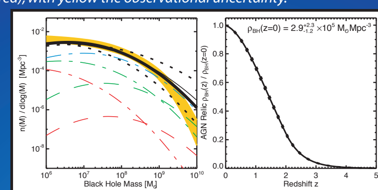
From our column density calculations, we find that the obscuration evolves dramatically during the merger, as the violent gas inflows driving BH/quasar evolution imply rapidly evolving columns. The obscuration does depend on angle (especially in relaxed systems), but the distribution across bright systems is dominated by different phases of evolution, not different viewing angles.



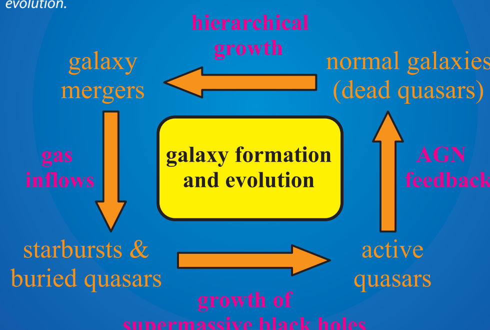
Quasar LF (circles & solid) and corresponding formation rate vs. peak luminosity distribution in our model (dashed) and traditional light curve models (dotted). Associated BH and host galaxy mass formation rates shown on right.



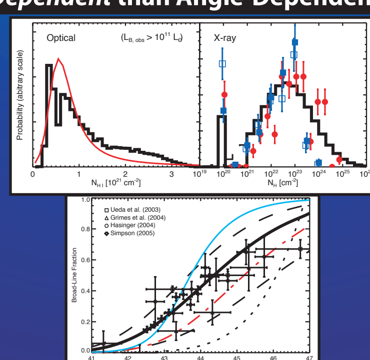
Predicted quasar LFs in hard X-ray (black), soft X-ray (red) and optical (blue), and the resulting cosmic X-ray background (solid, dotted lines show uncertainty). Colored lines show the observations from Barcons et al. 2000 (blue) and Gruber et al. 1999 (red), with yellow the observational uncertainty.



Predicted BH mass function (solid) and uncertainty (dotted), compared to the observations (yellow, Marconi et al. 2004). Colored lines show predictions at higher redshifts. Right panel shows the total z=-0 BH mass density and fractional evolution.



Quasar Obscuration Evolves Strongly in Mergers: It Can Be More *Time-Dependent* than Angle-Dependent



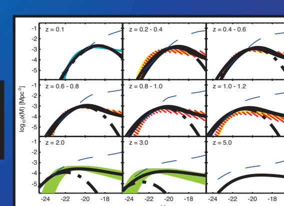
Predicted column density distributions (upper histograms, compared to observations of Hopkins et al. 2004 (red line), Triester et al. 2004 (blue), and Mainieri et al. 2005 (red circles)), and predicted broad-line fraction vs. luminosity (solid black line, dashed lines show uncertainty, dotted line an exponential light curve prediction, and blue line the best-fit receding torus model).

Physical Quasar Lifetimes Yield a New Interpretation of the QLF: the Observed Break is Determined by the *Peak* in the Active BH Mass Distribution

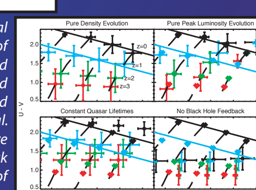
By de-convolving our quasar lifetimes and the observed luminosity function (QLF), we find that the rate at which BHs of a given final mass/luminosity are created is peaked at the break in the observed LF (a feature unique to our modeling). This gives an immediate physical motivation for the break, and the faint-end slope, and resolves several observational conflicts. Further, this allows us to accurately predict a large number of observations: the BH mass function, X-ray background, broad-line fraction vs. luminosity, column density distributions, QLF vs. waveband, Eddington ratio distributions, and active BH mass functions. Strong tests, such as the clustering of quasars as a function of luminosity (Lidz et al. 2005) distinguish our modeling from that based on traditional models of quasar light curves. Anti-hierarchical BH and galaxy growth is a natural consequence of this model, most simply a result of the QLF break luminosity moving to lower values at low redshift.

Modeling the Quasar Lifetime + Quasar-Host Galaxy Relations in Simulations Predicts the Red/Elliptical Galaxy Population Properties

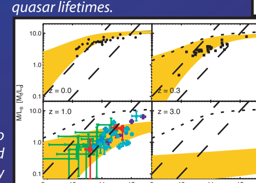
Finally, we can combine this with the BH-host galaxy scaling relationships (M-sigma, BH-bulge mass, fundamental plane) derived in our simulations (Di Matteo et al. 2005, Robertson et al. 2005) to predict the properties of spheroids/red ellipticals formed in these mergers. BH feedback is critical in rapidly terminating star formation and allowing these to redden (Springel et al. 2005a). From our modeling and the QLF, we can accurately predict elliptical and red galaxy LFs in many wavebands and redshifts, the color-magnitude relations and their evolution with redshift, mass-to-light ratios and luminosity-size relations, and age distributions.



Red/elliptical galaxy luminosity functions (solid lines) at many redshifts. Shaded areas are observations, from (Madgwick et al. 2002, blue, Faber et al. 2005, yellow and red, Giallongo et al. 2005, green). Blue dashed lines show the prediction assuming an "on/off" or exponential light curve model of quasar evolution.



Color-magnitude relations at several redshifts, and tracks (dashed lines) of populations of ellipticals of fixed stellar mass (10^9-10^{12} M_{sun}). Solid lines show observations for z=0 and z=0.5 (Bell et al. 2004, Giallongo et al. 2005). Different models are considered - neglecting BH feedback or the luminosity-dependence of quasar lifetimes.



Mass-to-light ratios vs. mass, at several redshifts (yellow ranges). Dotted line shows the z=0 relation in each panel for comparison. Points show observations (Jorgensen et al. 1995,1996, Kelson et al. 2000, van der Wel et al. 2005, Holden et al. 2005, van Dokkum & Stanford 2003, Wuyts et al. 2004, and di Serego Alighieri et al. 2005).

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