Major Galaxy Mergers and the Growth of Supermassive Black Holes in Quasars

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Abstract

Despite observed strong correlations between central supermassive black holes (SMBHs) and star-formation in galactic nuclei, uncertainties exist in our understanding of their coupling. We present observations of the ratio of heavily-obscured to unobscured quasars as a function of cosmic epoch up to $z\sim3$, and show that a simple physical model describing mergers of massive, gas-rich galaxies matches these observations. In the context of this model, every obscured and unobscured quasar represent two distinct phases that result from a massive galaxy merger event. Much of the mass growth of the SMBH occurs during the heavily-obscured phase. These observations provide additional evidence for a causal link between gas-rich galaxy mergers, accretion onto the nuclear SMBH and coeval star formation.

Space Density of Obscured AGN

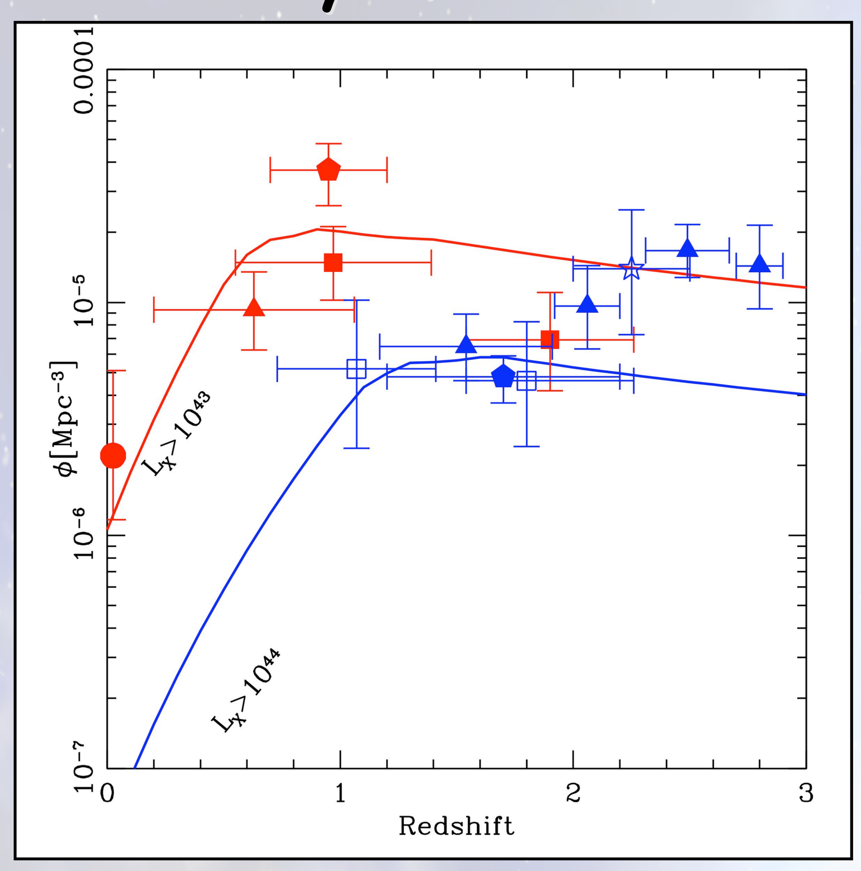


Figure 1: Space density of heavily-obscured AGN as a function of redshift. *Filled triangles* show the measurements of Treister et al. (2009). *Squares*: space density from the work of Tozzi et al. (2006). *Star*: Measurement by Alexander et al. (2008). *Pentagons*: Values reported by Fiore et al. 2009. *Solid lines* show the expected space density of Compton thick AGN from the luminosity function of Della Ceca et al. (2008). *Red symbols* show measurements and expectations for $L_X>10^{43}$erg/s sources, while the *blue symbols* are for $L_X>10^{44}$erg/s. The new measurements seem to indicate as strong increase in the number of high-luminosity heavily-obscured sources at $z>2$.

The Model

We propose a simple scenario in which every obscured quasar is triggered by the gas-rich merger of two massive galaxies. This can be converted into a equation describing the evolution of the ratio of obscured to unobscured quasars as follows:

$$\frac{N_{obsc}}{N_{Unobsc}}(z) = \frac{\Delta t \frac{d^2 merger}{dtdN} N_{gal}(>M_{\min}(z)) f_{gas}(z)}{N_{Unobsc}(z)}$$

The redshift evolution of each of these terms can be independently constrained observationally:

- $d^2merger/dtdN$ is the major merger frequency per galaxy per unit time. We use the parametrization of this fraction given by Hopkins et al. (2009), which was obtained from models constrained by observations.
- $N_{gal}(>M_{min}(z))$ corresponds to the space density of massive galaxies, with M_{min} being the minimum mass for ULIRGs, as determined by Kartaltepe et al. (2010) from observations in the COSMOS field. N_{gal} was then obtained from the stellar mass function of Marchesini et al. (2009).
- Rather than directly estimate the gas content of high redshift galaxies, which is currently observationally impossible at these redshifts, we used the average star formation rate as a proxy for the fraction f_{gas} of gas-rich galaxies.
- The space density of unobscured quasars, N_{unobsc} has been measured by both X-ray (e.g., Hasinger et al. 2005) and optical (e.g., Richards et al. 2006) surveys, and consistent results are found with these two methods.
- Δt (the time required to convert an obscured quasar into an unobscured one) can be determined as a free parameter. The redshift dependence of each of these components is shown below.

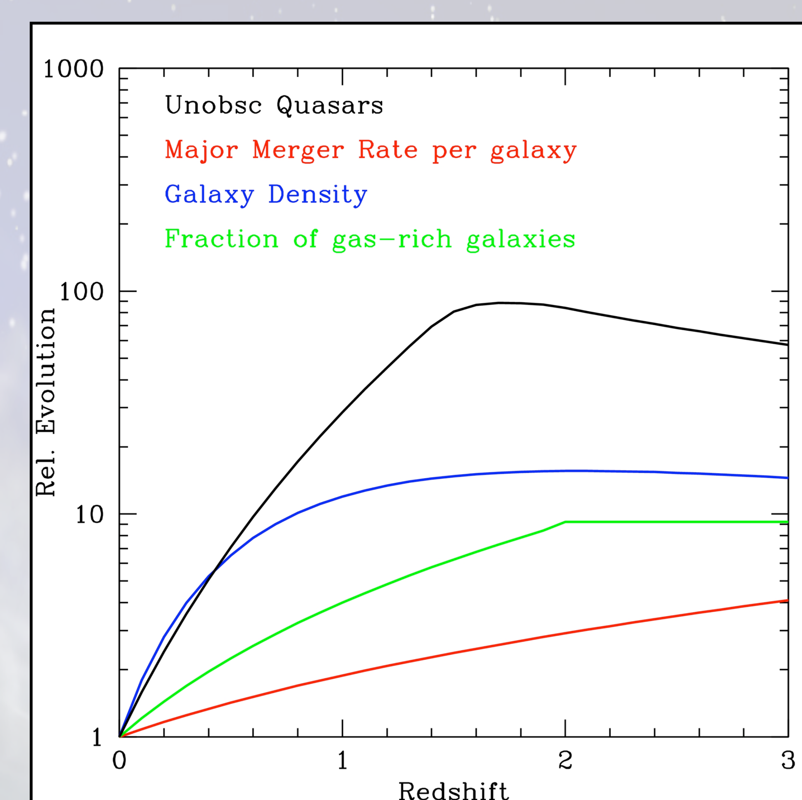
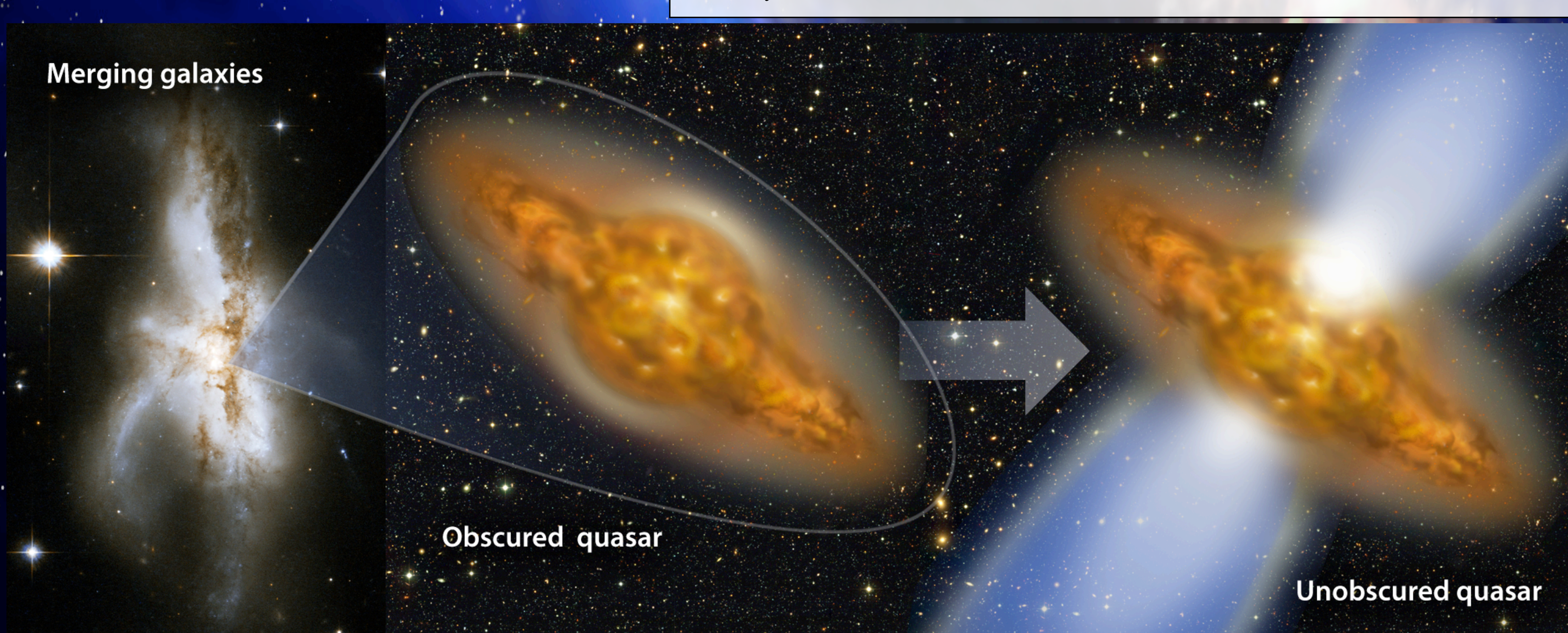


Figure 2: Redshift evolution for the model components described above. Each component was individually normalized to its value at z=0.



Obscured Quasars Evolution

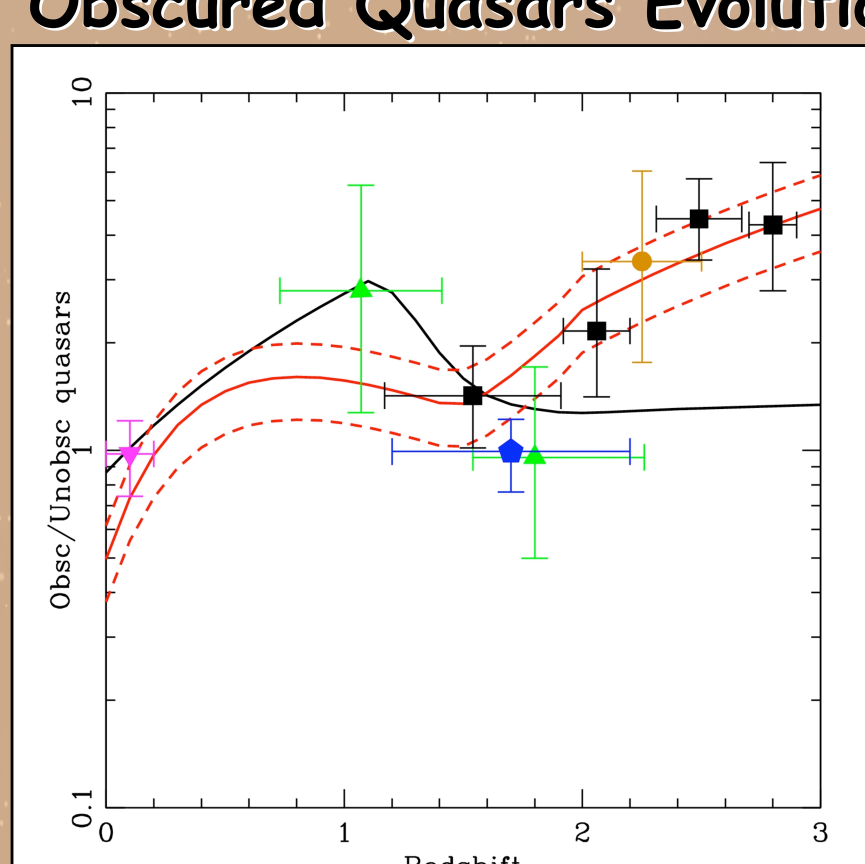


Figure 3: The ratio of heavily-obscured to unobscured quasars as a function of redshift. Measurements of the space density of obscured quasars at high redshift were obtained from X-ray - *green triangles*; Tozzi et al. (2006) - and mid-IR imaging - *blue pentagon*; Fiore et al. (2009) and *black squares*; Treister et al. (2009) - and spectroscopy - *brown circle*; Alexander et al. (2008) - selection techniques. For the $z\sim0$ measurement we used the luminosity function of local Ultraluminous IR galaxies (ULIRGs; Kim & Sanders 1998), assuming that each ULIRG is either a heavily-obscured or an unobscured quasar. The *solid black line* shows the heavily-obscured to unobscured quasar ratio expected from AGN luminosity functions derived from hard X-ray observations (Della Ceca et al. 2008). The *red solid line* corresponds to the ratio obtained if every gas-rich major merger of two massive galaxies generates a heavily-obscured quasar, which after a time Δt=96 Myrs becomes unobscured. *Dashed lines* show the uncertainty in this relation, at the 90% confidence level.

RESULTS

- **We found a steep increase in the number of heavily-obscured (Compton-thick) quasars at $z>2$.**
- **This increase is consistent with a simple model in which quasars are triggered by the gas-rich merger of two massive galaxies. The resulting quasar is originally heavily-obscured but after ~100 Myrs it becomes unobscured.**
- **Given the intrinsic luminosities and the duration of this phase, it is possible for a quasar to build most or all of the black hole mass in a single event.**
- **The integrated black holes growth in the obscured quasar phase is $1.3\times10^5 M_\odot Mpc^{-3}$, or ~30% of the total black hole mass density at z=0.**

References

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Host Galaxy Morphologies

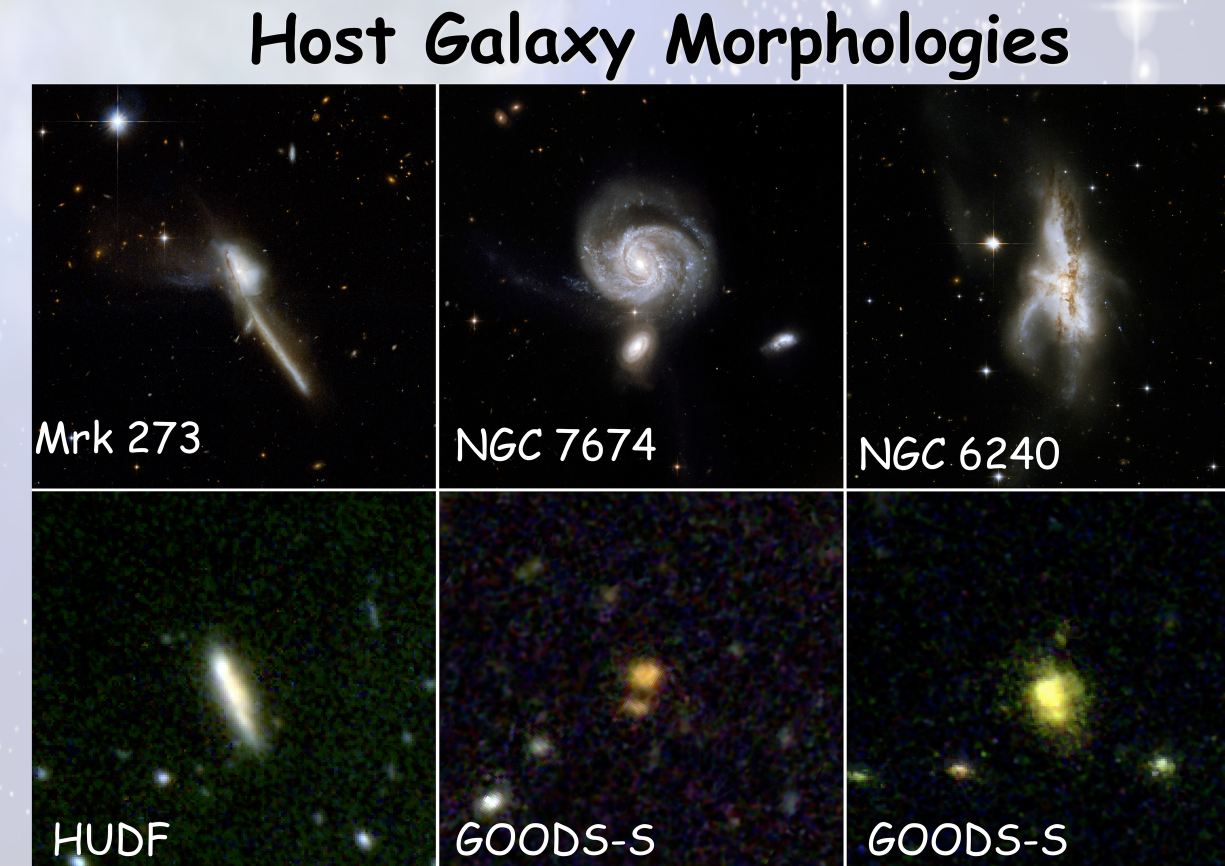

Figure 4: Examples of strongly-interacting/merging galaxies containing a heavily obscured growing supermassive black hole observed by the Hubble Space Telescope. The top panels show examples in the nearby Universe, while the bottom panel show galaxies at $z\sim1$-2. For the first 10-100 Myrs after the merger, the growing black hole remains highly obscured, after which it becomes an optically bright quasar that shines again for another 10-100 Myrs before it likely reaches its upper limit.