# Covering factor in AGNs: evolution or selection

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## Abstract

Recent studies have reported a possible evolution of the **covering factor (CF)** with redshift (Fig. 1). An important question arises: **Is CF evolution real or do selection effects play an important role?**

Based on a sample of over 17,000 quasars, two separated redshift bins were created – low-$z$ and high-$z$. **CF estimation** used in our work was calculated from the **ratio** between dusty torus **infrared luminosity ($L_{IR}$)** and the accretion disk **optical luminosity ($L_{AGN}$)**; see Fig. 2. The accuracy of the WISE W4 was found to be problematic - Spitzer MIPS 24 $\mu$m should be used when possible. Luminosity evolution with redshift for $L_{IR}$ and $L_{AGN}$ was confirmed through the Efron & Petrosian test.

The low-z and high-z samples follow a similar correlation between $L_{AGN}$ and $L_{IR}$. The relation between $L_{IR}$ and $L_{AGN}$ is slightly different than the 1:1 scaling (Fig. 3), hinting at a more complex relationship between CF and $L_{AGN}$, affected by possible contaminations. No evolution of the CF is detected based on the subsample within the high super massive black hole (SMBH) mass bin (Fig. 4).

## Active Galactic Nuclei

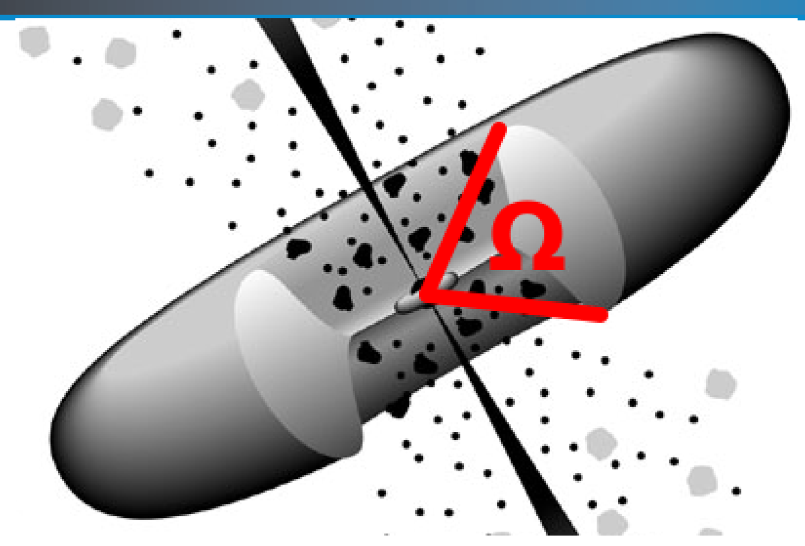
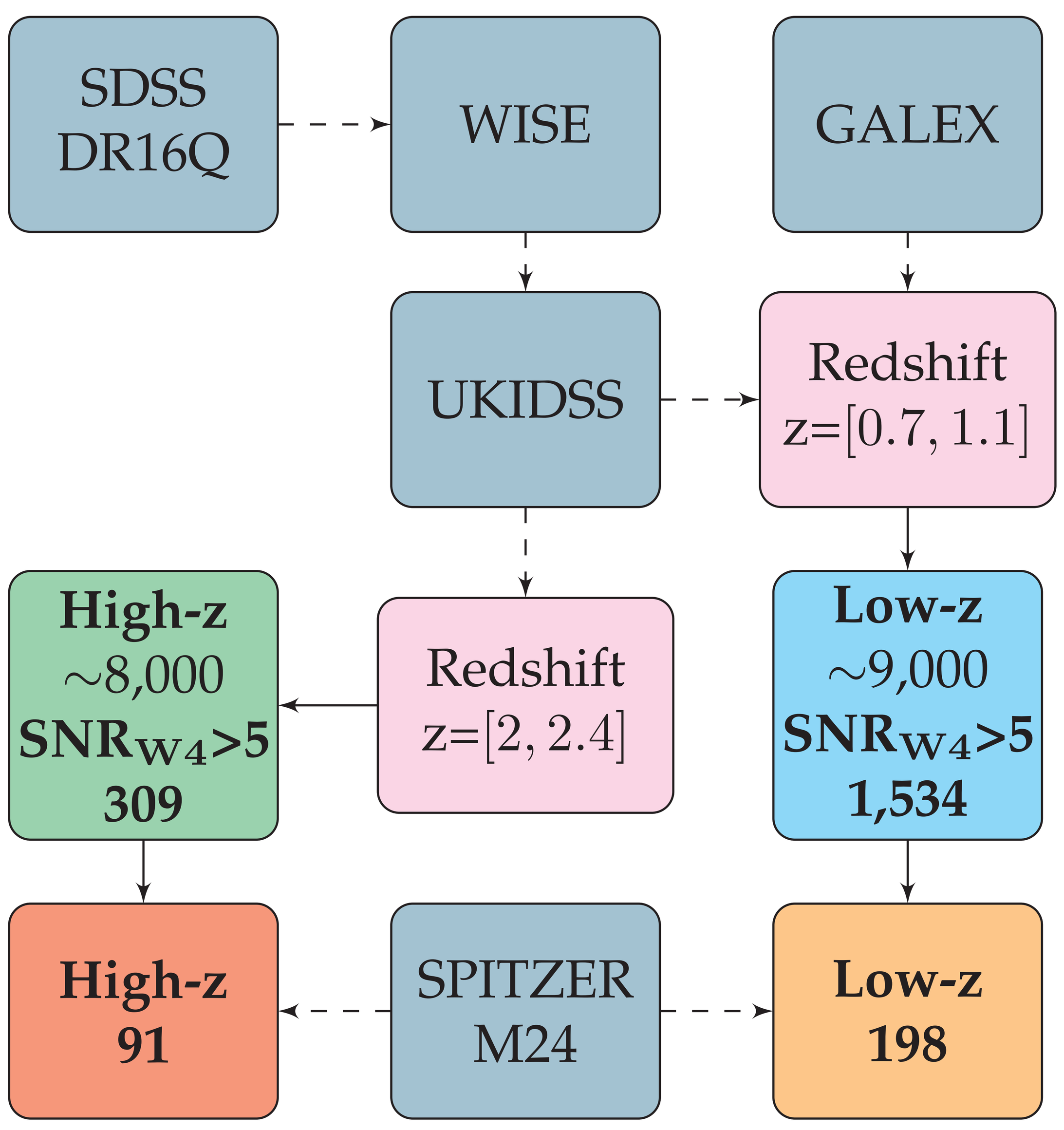



**Figure 1.** The schematic view of the AGN, based on the unification scheme (CREDIT [1]). **The dusty torus** is shape around the supermassive black hole (SMBH). The solid angle **Ω** between the SMBH and the torus is used to **define the CF.**

## Data

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## Covering Factor (CF)

The CF describes the fraction of **obscuration** of the quasar SMBH **by the dusty torus**. First studies defined it as the ratio of the solid angle between SMBH and torus to $4\pi$ (CF = $\Omega/4\pi$). Currently an estimation of the CF defined as **ratio between $L_{IR}$ and $L_{AGN}$** is used, as it is easier to calculate from photometry.

$$\mathbf{CF = L_{IR}/L_{AGN}}$$

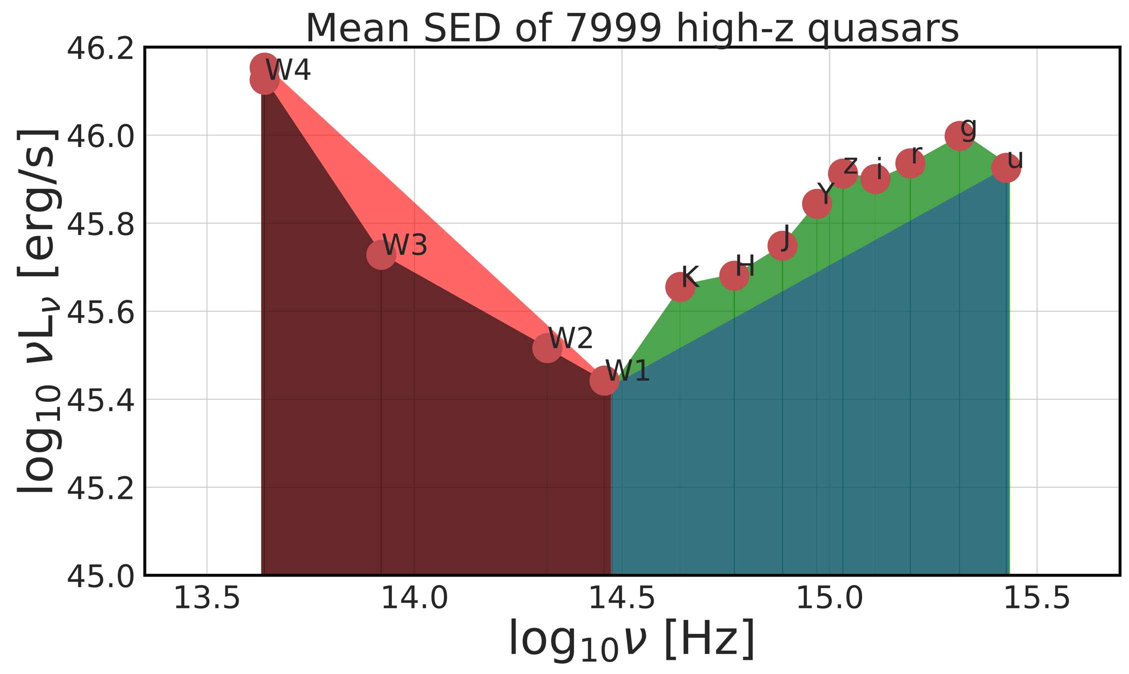


**Figure 2.** The mean spectral energy distribution (SED) of the high-z quasars. Coloured regions mark **areas integrated** for $L_{IR}$ (black) and $L_{AGN}$ (green) **luminosities**. With the red and blue colours the method from the literature [3] is shown.

## Methodology

1. The check for possible **selection effects**. We focused on the IR quality and found that the selection of data with $SNR_{W3\&W4} > 5$ we get good agreement with the SPITZER M24 data, but after the detailed comparison we concluded that *whether possible M24 should be used instead*.
2. Fitting the **Bayesian regression between $L_{IR}$ and $L_{AGN}$** (Fig. 3) for both low-$z$ and high-$z$. We used additional statistical weights to account for largely different sample sizes.
3. Calculation of the CF with the estimation based on the $L_{IR}/L_{AGN}$ ratio.
4. **Selection of the objects with similar physical properties** based on the same SMBH masses ($M_{SMBH}$>8.5 [$M_\odot$] from spectroscopic VAC [2]).

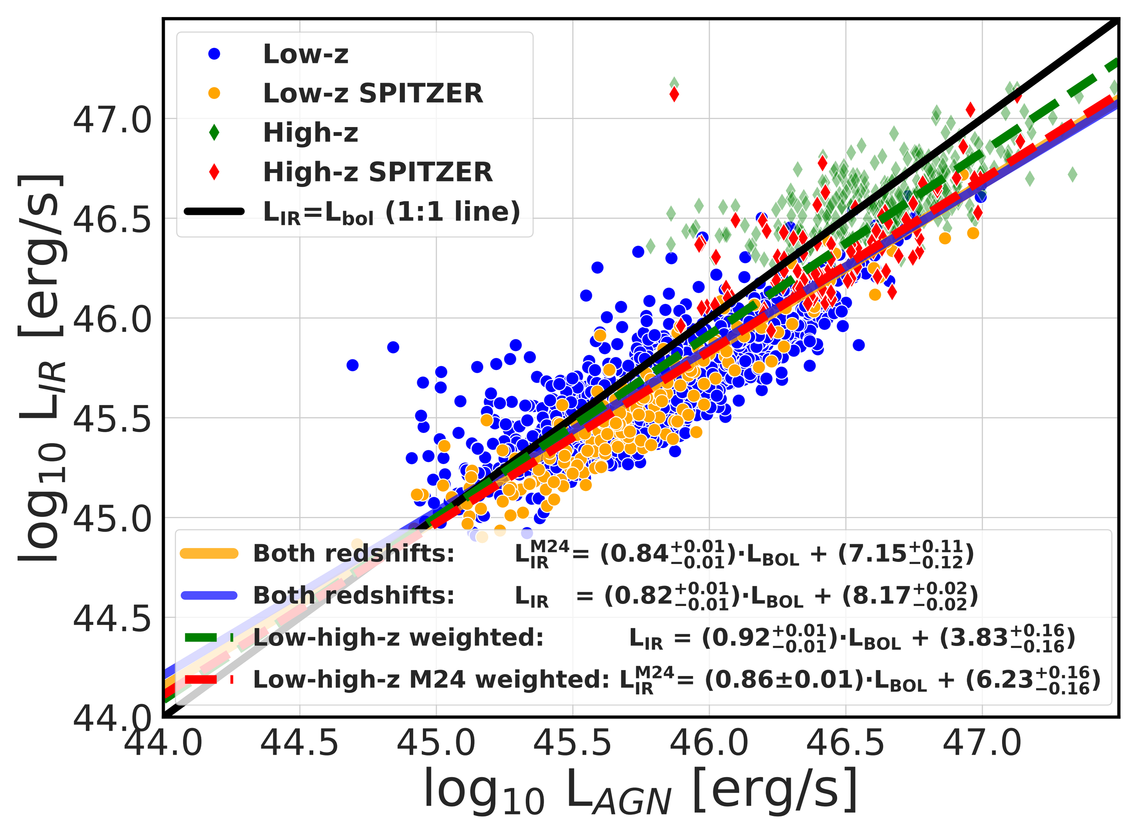


**Figure 3.** The relation between the $\log_{10} L_{IR}$ vs $\log_{10} L_{AGN}$. Only sources with $SNR_{W3\&W4} > 5$ are showed. The Bayesian regressions were fitted for low-$z$ and high-$z$ samples combined.

## Results

The calculated estimations of CF median values for the samples are:

- **SNR$_{W3\&W4}$>5:**
  $\log_{10}$CF(low-$z$) = $-0.18\pm0.10$,
  $\log_{10}$CF(high-$z$) = $-0.05 \pm 0.13$.
- **With SPITZER M24:**
  $\log_{10}$CF(low-$z$) = $-0.19\pm0.11$,
  $\log_{10}$CF(high-$z$) = $-0.17\pm0.11$.

To further study the CF evolution the *Efron&Petrosian test for luminosity evolution* [4], was performed. The result stated that the redshift evolution of the $L_{IR}$ and $L_{AGN}$ is observed.

The Bayesian regressions between $L_{IR}$ and $L_{AGN}$ show a difference from the 1:1 scaling (regression slopes $\sim$ 0.85). This can **suggest that contaminations** such as polar dust (especially for low-$z$ sources) and torus dust (for high-$z$) or data limitations **can play an important role.**

The Kolmogorov-Smirnov test for the CF estimator (within the same $M_{SMBH}$ bin) stated that low-$z$ and high-$z$ samples may be drawn from the same distribution. **No CF evolution is detected.** This result is also visible in Fig. 4.

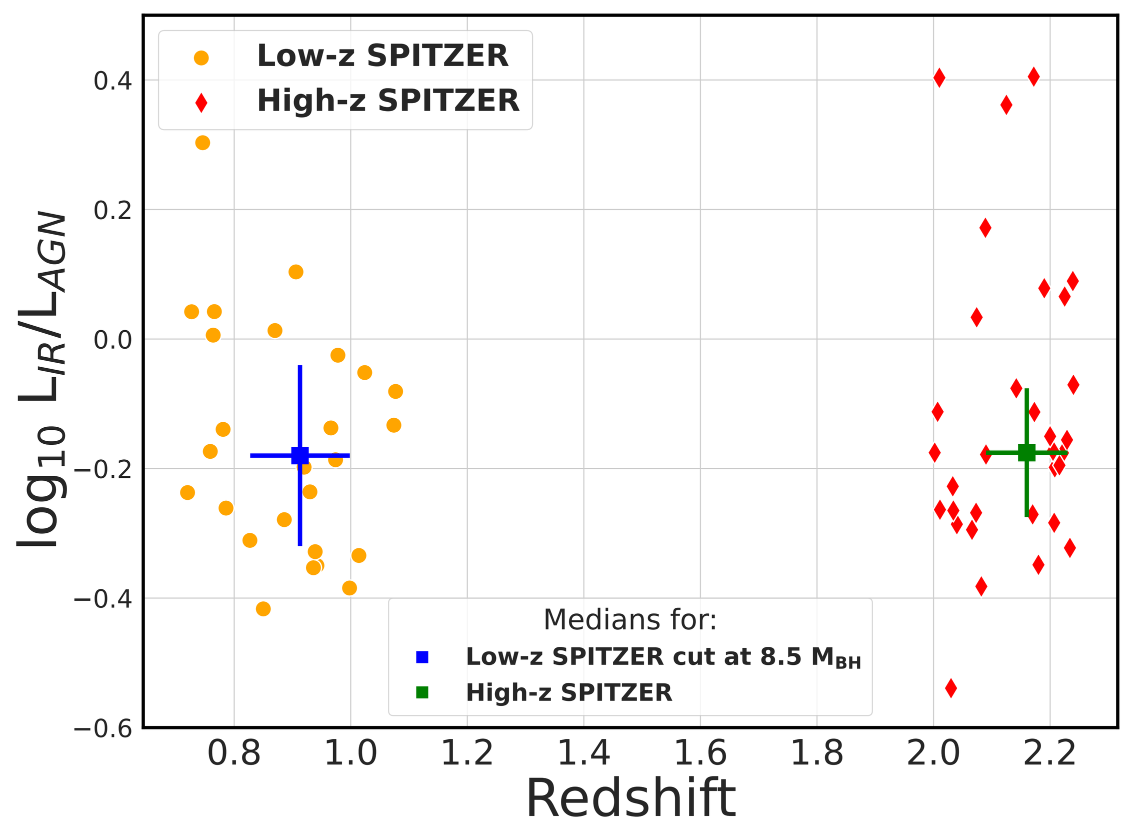


**Figure 4.** $\log_{10}$ CF estimation vs redshift for both low-$z$ and high-$z$ samples. With blue and green points the medians with errors for low-$z$ (after the cut at 8.5 $M_{SMBH}/M_\odot$ ) and high-$z$ are shown respectively.

## Ongoing/Future Research

- Study of possible contaminations that can influence the $L_{IR}$ vs $L_{AGN}$ relation. The SED fitting technique with CIGALE code is being used. In this way one can estimate components from AGN (accreation disk, torus, polar dust) and host galaxy (stellar light, cold dust).

  SED fitting can be also used for more accurate estimation of CF as a function of $L_{IR}/L_{AGN}$.
- Machine learning technique.

## References

[1] Torres D. F., Anchordoqui L. A., 2004, Rep. Prog. Phys., 67, 1663
[2] Kozłowski, S. 2017, ApJS, 228, 9
[3] Gu, M. 2013, ApJ, 773, 176
[4] Efron, B. & Petrosian, V. 1992, ApJ, 399, 345