Quasar Lensing

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Summary

Lensing of quasars (via magnification bias) provides an alternative and independent method to galaxy lensing for estimating the masses of foreground galactic structures and, potentially, the cosmological parameters. Moreover, lensing of the CMB {by quasars provides a powerful route to study the masses and bias of the host galaxies.

Here, we first present results on lensing of quasars from the cross correlation of the VST ATLAS quasar catalogue with galaxy and galaxy cluster catalogues.

Then we present results on lensing by quasars of the CMB from cross-correlating the same ATLAS catalogue with Planck CMB maps.

Finally we propose to use the Vera Rubin LSST to search for dark matter haloes via quasar variability caused by lensing and we present a pilot study using data from a new CTIO DECam survey.

Data:

VST-ATLAS survey

- Survey imaging ≈ 4700 deg^2 of the Southern sky in the optical $ugriz$ bands to similar depths as SDSS

neoWISE

- Publicly available unwise catalogue (Shlafly et al., 2019) observed by NASA's Wide-field Infrared Survey explorer (WISE), most recent iteration is called neo6
- We create bandmerged *u+g, riz* catalogues and include infrared information from the W1 and W2 bands

Cross-correlation of VST ATLAS quasar catalogue with galaxy catalogue

Myers et al (2005) and Mountrichas & Shanks (2007) find observational results which imply a strong anti-bias, i.e. b=0.1 (or a high Ω_M?) – inconsistent with standard ΛCDM model

SDSS work from Scranton et al. (2005) finds results compatible with standard ΛCDM model (b=1.0)

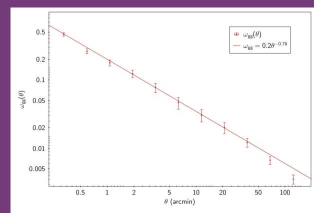
We use the VST-ATLAS Quasar Catalogue (Eltvedt et al, in prep) and generate a galaxy catalogue from the VST ATLAS data to cross-correlate and measure an anti-correlation, which we then fit to a bias value with our selected model

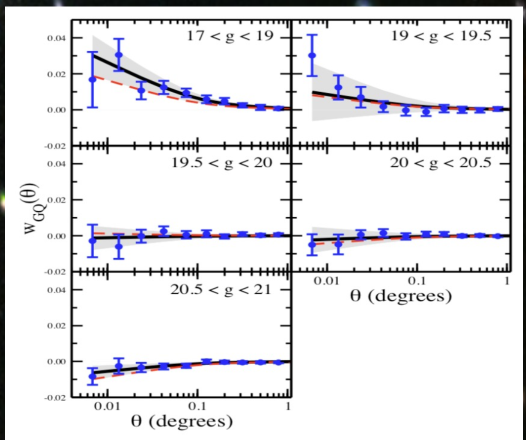
QSO-galaxy cross-correlation model:

Williams & Irwin model to describe the correlation between our quasar sample and foreground galaxies

$$\omega_{gq}(\theta) = (2.5\alpha - 1)\frac{2\bar{\kappa}}{b}\omega_{gg}(\theta),$$

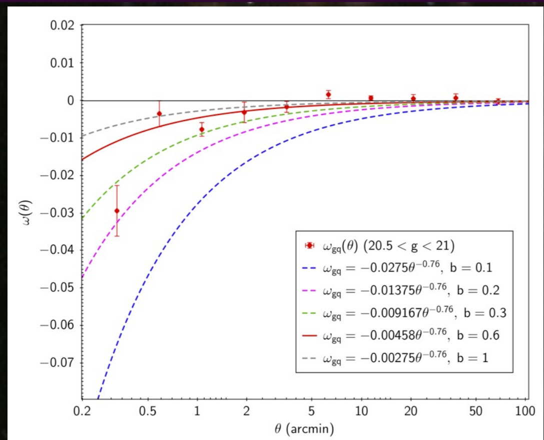
Using our galaxy sample auto-correlation, we fit a power law to the data which gives us $\omega_{gg} = 0.2\theta^{-0.76}$





<- SDSS result from Scranton et al. (2005)

Our result->



Conclusions from QSO-galaxy lensing:

- We find a negative correlation at quasar magnitudes of g > 20 and a positive correlation at brighter magnitudes
- Improved agreement with the SDSS result of Scranton et al. (2005) but still some possible discrepancy
- we find a quasar bias of b = $0.6^{+0.18}_{-0.1}$, and therefore reject the b = 1 value assumed by Scranton the ΛCDM model at the 2.2σ level.

Cross-correlation of VST ATLAS quasar catalogue with galaxy cluster catalogue

We use the VST-ATLAS Quasar Catalogue (Eltvedt et al, in prep) and the VST ATLAS Southern Galaxy Galaxy cluster catalogue (Ansarinejad et al, in prep)

We introduce similar selections as Myers et al. (2003) into our galaxy cluster catalogue in order to compare our result

Weak lensing model:

We assume lensing caused by a singular isothermal sphere (SIS)

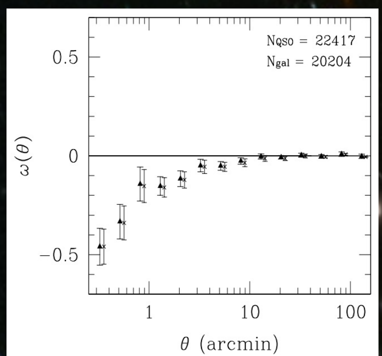
Amplification of a background source due to a SIS:

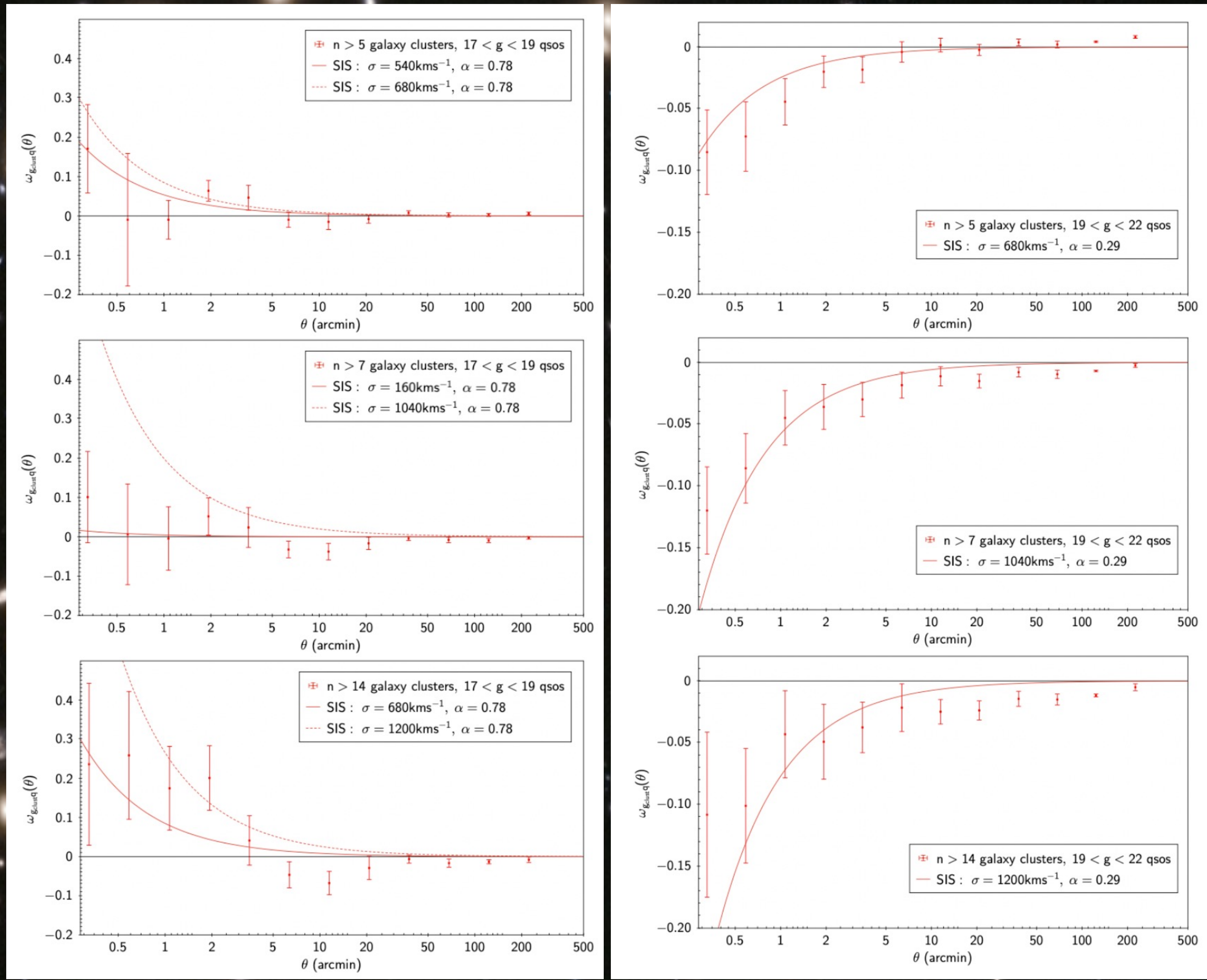
$$A = \left| \frac{\theta}{\theta - 4\pi(\frac{D_{ls}}{D_s})(\frac{\sigma}{c})^2} \right|$$

We relate the angular cross-correlation to the amplification factor through:

$$\omega(\theta) = A^{2.5\alpha - 1} - 1$$

previous work by Myers et al, 2003 (below), our results (right)





Conclusions from QSO-galaxy cluster lensing:

- We show a clear anti-correlation at faint quasar magnitudes ($19 < g < 22$), and a positive trending correlation at bright quasar magnitudes ($17 < g < 19$)
- derive a model for the lensing of background quasars by foreground galaxy clusters

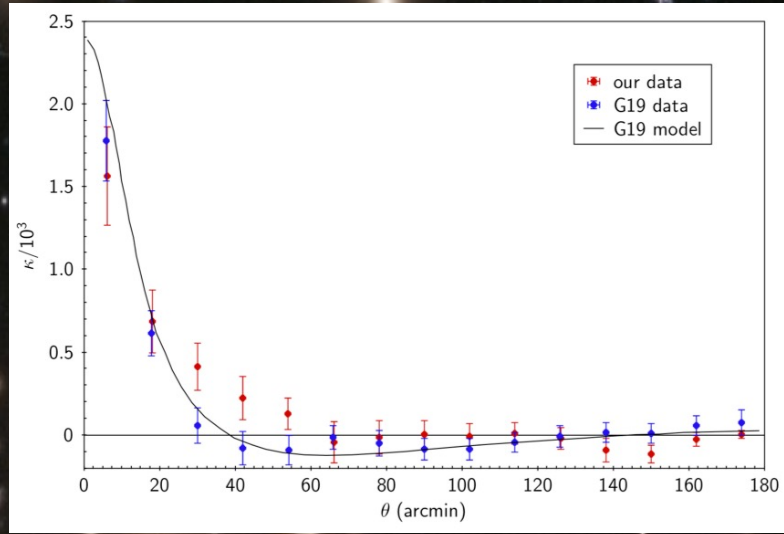
Cross-correlation of VST ATLAS quasar catalogue with Planck CMB lensing catalogue

Following works of Han et al. (2019) and particularly Geach et al. (2019)

They argue that the QSO-CMB lensing map cross-correlation is a more precise way of measuring the quasar bias than the more commonly used two-point auto-correlation function for QSO samples

Data used:

- VST-ATLAS Quasar Catalogue from Eltvedt et al, in prep
- 2018 release of the Planck lensing convergence baseline map, using the CMB-only minimum variance estimates of the lensing signal to scales of *l* = 4096



Our results compared to the Geach et al. (2019) data and model

QSO-CMB lensing cross-correlation model:

As we are using the same CMB lensing data catalogue and similar quasar samples as Geach et al. (2019), we perform our analysis using the model described in their work

1-Halo term:

$$\kappa_1(R) = \frac{\Sigma(R)}{\Sigma_{crit}}$$

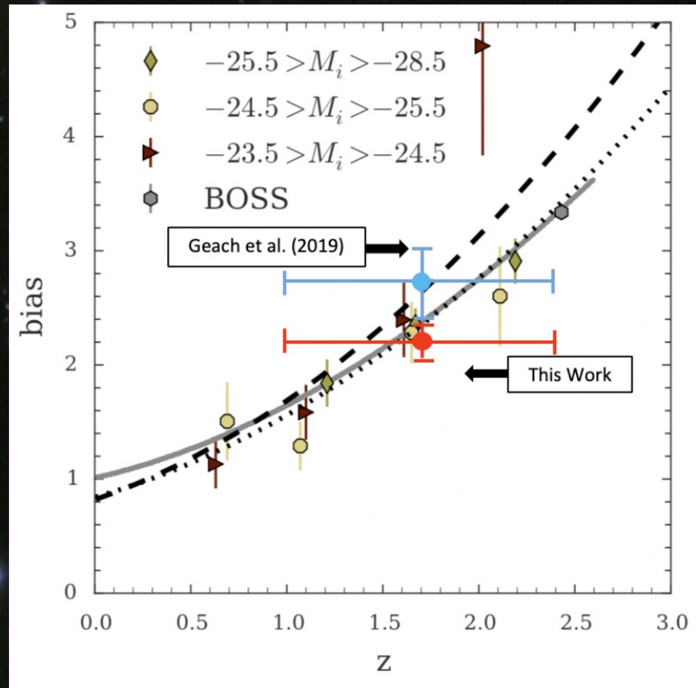
2-Halo term:

$$\kappa_2(\theta) = \frac{\bar{\rho}(z)}{(1+z)^3 \Sigma_{crit} D^2(z)} \int \frac{l dl}{2\pi} J_0(l\theta) b_h \triangle(k,z)$$

Final lensing convergence

$$< \kappa > = \int dz(\kappa_1 + \kappa_2) dn/dz$$

In good agreement with previous measurements from direct quasar clustering analyses (e.g. Chehade et al., 2016)



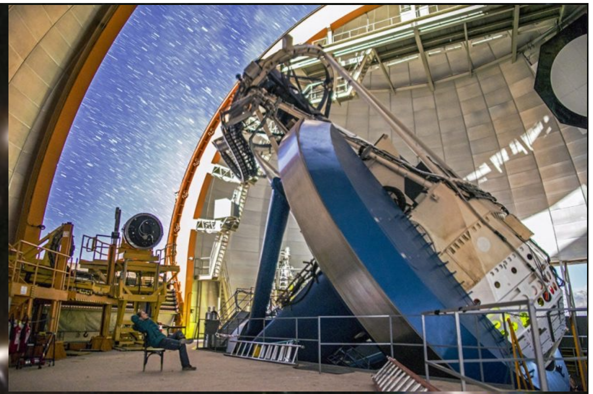
Conclusions from CMB-QSO lensing:

- find good agreement between our data and the Geach et al. (2019) data
- measure a quasar halo bias of b_q = 2.0 ± 0.12 at an average redshift of z = 1.7

2dfquasar.org

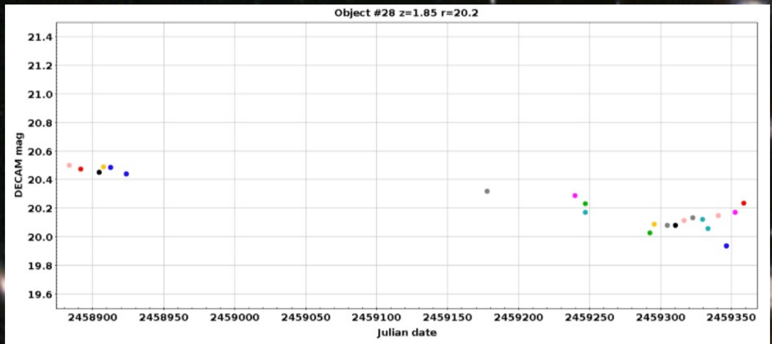
Reverberation Mapping:

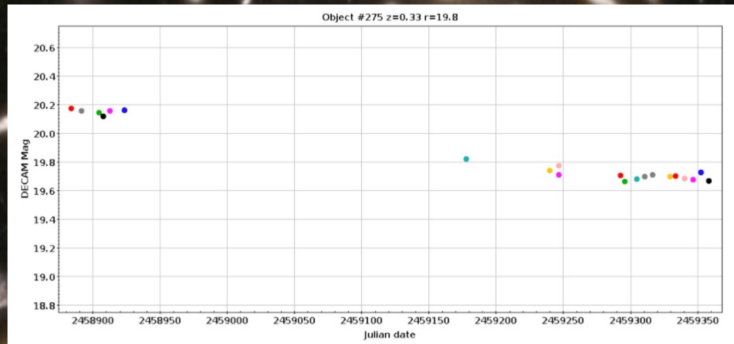
- cross-correlations in time looking at X-ray (via eROSITA) and optical bands to measure the size of the accretion disk
- If the accretion disk flares due to X-rays, it can flare up the broad line region after a certain time delay
- We can measure mass of black hole through virial theorem as we measure the size of the accretion disk as well as the FWHM of the emission line
- Also looking for ‘changing look’ quasars with larger variability amplitudes

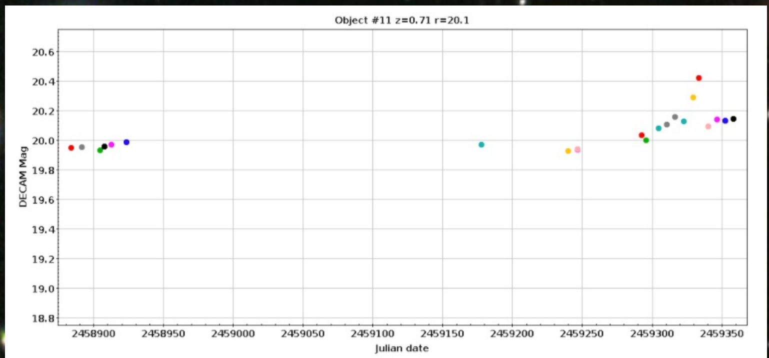


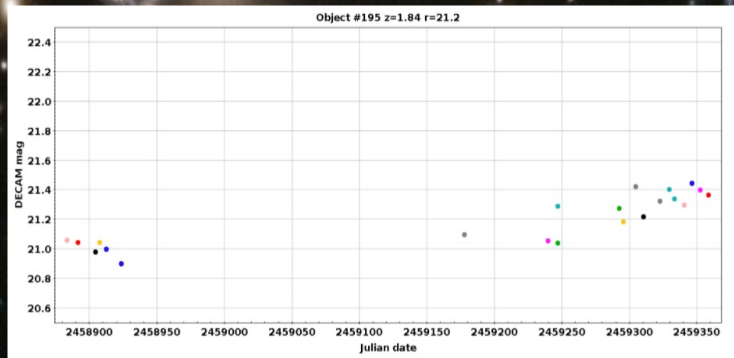
darkenergysurvey.org

Here we present example light curve results from a pilot study using quasar variability data from a new CTIO DECam survey.









New QSO Lensing route to Dark Haloes?

Can these DECam data be used to search for dark haloes by looking for the effect of lensing on the QSO light curve when a dark halo crosses a QSO sight line?

Still very speculative but if our pilot study produces such events then exciting opportunities with LSST!

References:
The VST-ATLAS Quasar Survey I: Catalogue (Eltvedt et al, in prep)
The VST-ATLAS Quasar Survey II: Weak Gravitational Lensing Analyses (Eltvedt et al, in prep)
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