Estimating dust extinction in distant galaxies using quasars

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Based on the paper:

"Extinction properties of lensing galaxies"
Östman, Goobar, Mörtsell 2008, A&A to be published
2007 ArXiv e-prints 711

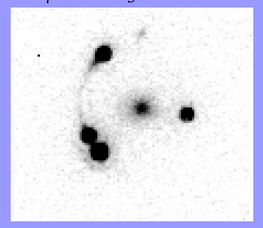
See also the paper:

"Looking at quasars through galaxies"
Östman, Goobar, Mörtsell 2006, A&A, 450, 971

Our data set

In our data set there are 21 quasars with foreground galaxies. Out of these we have
- 15 strongly lensed quasars with several images
- 3 quasars where a foreground galaxy was found due to absorption features detected in the quasar spectrum
- 3 quasar-galaxy systems found by coordinate matching (Östman, Goobar, Mörtsell 2006, A&A, 450, 971)

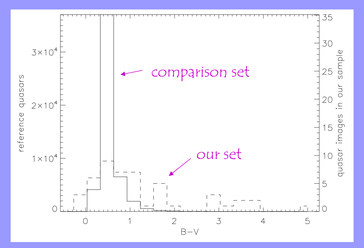
At a total we have 48 quasar images.



Test of data

The rest frame B-V for our set of quasars is significantly redder than a comparison sample of quasars without resolved foreground galaxies. This implies that the colours of the quasars in our set are affected by the foreground galaxy.

In the figure below, the rest frame B-V for our quasar images (dotted lines) is shown together with the rest frame B-V for the comparison sample (solid lines).



Our method - step by step

1. Quasars with a foreground galaxy are found by…
   a) identifying multiply imaged quasars where the lensing object is a galaxy
   b) matching the coordinates of quasars with those of galaxies from a catalogue
   c) looking for absorption features, originating from an intervening galaxy, in quasar spectra

We require the following for the systems:
   a) spectroscopically determined redshifts for both the quasar and the galaxy
   b) observations in at least four broad band filters for the quasar

2. We assume dust in the intervening galaxy with different values of the two dust parameters R_V and E(B-V) and calculate what colours that would lead to using a template

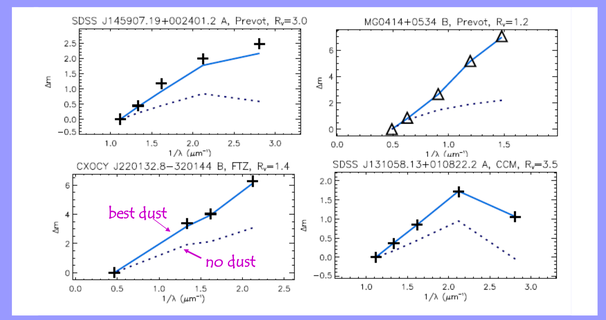
3. These synthetic colours for different R_V and E(B-V) are then compared with the observed colours using the χ^2-method.

In the χ^2-test, we use a covariance matrix containing the observational uncertainties and the uncertainties of the template colours (corresponding to the variations between different quasars and effects from host extinction). These latter uncertainties are found using a reference set of quasars without foreground galaxies.

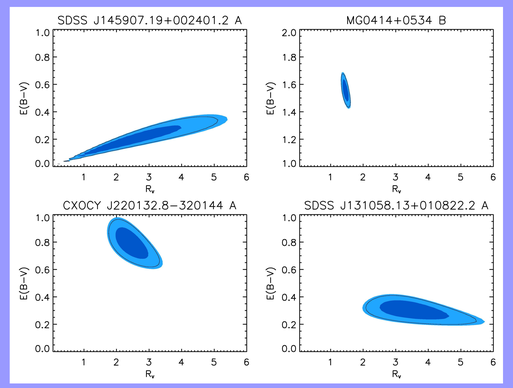
4. Using the χ^2-test we find what values of R_V and E(B-V) best describe the observed colours.

Examples of fits for dust extinction

Some of the cases where a dust reddened template could explain the observed quasar colours are shown below. The plus signs and triangles show observed colours, the dotted lines show the expected colours if no dust is present and the solid lines show the best colours obtained with dust extinction by varying R_V and E(B-V). For many cases dust extinction is able to explain the observed colours, when a template without dust is not.



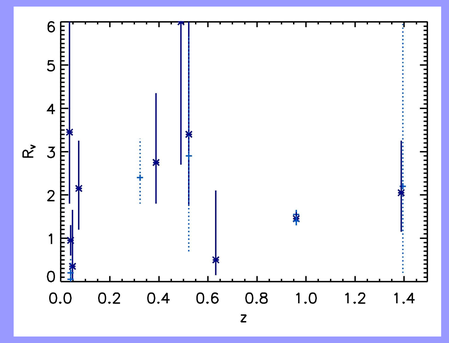
The confidence levels for some of the quasar images that we could fit by dust extinction is shown below. The levels correspond to 1σ for one parameter (black line) and 68% (dark blue region) and 90% (pale blue region) for two parameters.



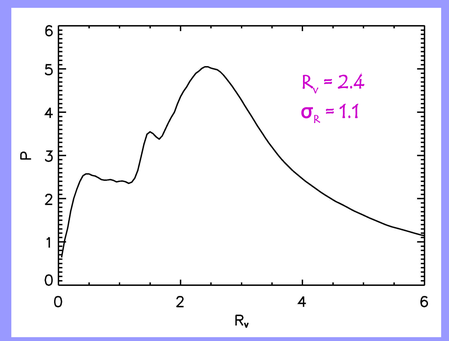
Results

We found 22 quasar images whose colours could be explained by dust extinction in the foreground galaxy. These came from 13 different quasar-galaxy systems.

The distribution of R_V as a function of redshift for these systems are shown below. The solid lines correspond to fits with a higher probability. No clear trend can be observed.



The added probability distribution of R_V for dust extinction in an intervening galaxy is shown below. A most probable value of R_V of 2.4 was found.



Conclusions

- We find R_V values that agree both with the mean R_V found in the Milky Way (R_V =3.1) and with the low R_V values found for supernovae
- Assuming R_V = 3.1 for all galaxies could be a bad assumption
- There seem to be a big spread in R_V between galaxies, but not so much within galaxies