Investigating dust extinction using background quasars

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Some important parameters

- Extinction in the V-band $A_V$
- Colour excess
  \[ E(B - V) = (B - V)_{\text{obs}} - (B - V)_{\text{intr}} \]
- Total-to-selective extinction ratio
  \[ R_V \equiv \frac{A_V}{E(B - V)} \]
Idea

- Dust extinction affects the colour differently depending on $R_V$ and $E(B-V)$
- Knowing the intrinsic colour, we can constrain the dust extinction
- Quasars have fairly homogeneous colours
Method

• Identify quasars with the line-of-sight passing through the dust content of a galaxy

• To a quasar spectral template, we add dust extinction [with different $R_V$ and $E(B-V)$] at the galaxy redshift and compute the resulting colours

• By comparing these simulated colours with the observed colours we learn about the properties of the dust extinction.

• Requirements: $z$ (galaxy, quasar), photometry of the quasar
Finding pairs

- Coordinate matching
- Lensing
- Spectral identification
Choice of colours to compare

1) No redundant comparisons
2) Maximise the probability to detect dust extinction
3) Minimise the use of the photometry with large uncertainties

Maximising

\[ Q = \sum \frac{[E(i - j)]^2}{\sigma_{ij}^2} \]

e.g. \( i,j = u,g,r,i,z \)
Error estimates

- Uncertainty in the observed magnitudes of the quasar
- Uncertainty in the template colours
  - From colours of SDSS quasars with $z \pm 0.05$
  - Include intrinsic colour variations
Example system:

- SDSS J084957.97 +510829.0 (z=0.6)
- 2MASX J08495751+5108416 (z = 0.07)
Dust extinction outside the petrosian radius of a galaxy

- Coordinate matching of SDSS Quasar catalogue DR 3 with NYU-VAGC

- (1) $\chi^2$ for no dust worse than 90% random quasars without foreground galaxies

- (2) $\chi^2$ for dust better than 90% random quasars with mock galaxy.

→ 2 quasars-galaxy pairs

<table>
<thead>
<tr>
<th>Fitzpatrick</th>
<th>Separation</th>
<th>Petrosian radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_V = 3.4 \left(2.4 - 4.7\right)$</td>
<td>15 kpc</td>
<td>10 kpc</td>
</tr>
<tr>
<td>$R_V = 2.2 \left(1.5 - 2.9\right)$</td>
<td>19 kpc</td>
<td>16 kpc</td>
</tr>
</tbody>
</table>

Östman, Goobar & Mörtsell 2006 A&A 450, 971
Added probability distribution for $R_v$

$R_v = 2.4$

$\sigma R_v = 1.1$

Dust in intervening galaxy following the Fitzpatrick parameterisation

Östman, Goobar & Mörlset 2008 A&A 485, 403
**MG0414+0534**
- a system with 4 images

- Quasar $z = 2.64$, galaxy $z = 0.96$
- Early type galaxy

<table>
<thead>
<tr>
<th>Image</th>
<th>$R_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1.5 (1.4–1.6)</td>
</tr>
<tr>
<td>A2</td>
<td>1.5 (1.5–1.7)</td>
</tr>
<tr>
<td>B</td>
<td>1.5 (1.3–1.6)</td>
</tr>
<tr>
<td>C</td>
<td>1.4 (1.3–1.5)</td>
</tr>
</tbody>
</table>
Limiting the effects from intergalactic dust using quasars

- Using SNOC (Goobar et al. 2002 A&A 392, 757), the mean colours for redshift bins of size 0.05 are simulated.
- Vary $R_v$ and the interaction length $D_{0V}$.
- Two different models for the evolution of the dust density:
  - $A$: $\rho = \rho^0(1+z)^3$
  - $B$: $\rho = \rho^0(1+z)^\alpha$
    - $\alpha = 3$ for $z < 0.5$
    - $\alpha = 0$ for $z > 0.5$
For Milky Way like dust ($R_V < 4$)

Dimming < 0.03 mag in the B-band for a SN Ia at $z=1$

Yellow to red: 68%, 90%, 95%, 99% confidence level from $\chi^2$ analysis

Black lines: B band attenuation in magnitudes for a SN Ia at $z = 1$
Allowing for grey dust ($R_v > 4$)
Dimming $< 0.2$ mag in the B-band for a SN Ia at $z=1$
In progress...