Extinction curves in AGN

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Dust plume rising to 1,500 m elevation in San Joaquin Valley, Calif., s.e. of Bakersfield, December 1977. (Wilshire et al., 1996; photo by Sam Chase)
Extinction curve - definitions

Extinction at a specific wavelength $\lambda$ is defined as

$$A_\lambda = m_\lambda - m_{0,\lambda}$$

where $m$ is the observed magnitude and $m_0$ is the magnitude in the absence of dust.

Extinction curve is introduced to characterize the wavelength dependence of $A_\lambda$ on $\lambda$ in a universal way (i.e. relatively independently from the amount of dust along the line of sight).

A few different normalizations are typically used.

Magnitudes:

$$m = -2.5 \log F + \text{const}$$

$$F_{\text{obs}} = F_{\text{int}} \exp(-\tau)$$

so

$$A_\lambda \sim \tau$$

Extinction curve can be defined as:

$$A_\lambda / A_I$$

see Draine (2003), ARA&A
Extinction curve - definitions

Extinction is closely related to the reddening (or color excess) defined as

\[ E(X-Y) = A_X - A_Y \]

where \( X \) and \( Y \) are two bands.

Therefore, for historical reasons, extinction curve is also frequently defined either as:

\[ \frac{A_\lambda}{E(B-V)} \]

or

\[ \frac{(A_\lambda - A_V)}{E(B-V)} \]

The slope of the extinction curve, \( R_V \), is defined as:

\[ R_V = \frac{A_V}{A_B - A_V} = \frac{A_V}{E(B-V)}. \]

For our Galaxy, the typical value is \( R_V = 3.1 \) (Schultz & Wiemer 1975). Another useful relation is

\[ N_H = 1.79 \pm 0.03 A_V \times 1.e21 \]

(from ROSAT study, Predehl & Schmidt 1995).

see Draine (2003), ARA&A
How we derive it?

“The extinction is most reliably determined using the pair method – comparing spectrophotometry of two stars of the same spectral class; if one star has negligible foreground dust while the second star is heavily reddened, comparison of the two spectra, together with the assumption that the dust extinction goes to zero at very long wavelength, allows to determine the extinction $A_\lambda = 2.5 \log(F_\lambda^0/F_\lambda)$, as a function of wavelength.”

from Draine (2003), ARA&A
MW

Fig. 1.—The observed mean value for interstellar extinction. *Large solid dots:* mean values for interstellar extinction and their mean errors for up to five pairs of stars as a function of inverse wavelength. *Open circles:* Boggess and Borgman (1964). The point marked "H" is from Alexander et al. (1964). The points marked "C" are from Chubb and Byram (1963). All values are normalized to $B - V = 1$ and $V = 0$.

2175 A feature - Stecher (1965)
Figure 1. The UV extinction $X(x) = A_\lambda / E_{B-V}$ against $x = 1/\lambda$ with $\lambda$ in microns. + OAO-2 data of C76 (Code et al. 1976); • TD-1 data of N75 (Nandy et al. 1975); ○ TD-1 data of N76 (Nandy et al. 1976). The full line curve is from the fits of Table 2.

Seaton 1979

<table>
<thead>
<tr>
<th>Range of $x$</th>
<th>Expression for $X(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2.70 \leq x \leq 3.65$</td>
<td>$1.56 + 1.048x + 1.01/((x - 4.60)^2 + 0.280)$</td>
</tr>
<tr>
<td>$3.65 \leq x \leq 7.14$</td>
<td>$2.29 + 0.848x + 1.01/((x - 4.60)^2 + 0.280)$</td>
</tr>
<tr>
<td>$7.14 \leq x \leq 10$</td>
<td>$16.17 - 3.20x + 0.2975x^2$</td>
</tr>
</tbody>
</table>
What if AGN spectrum is corrected for MW-type dust?

The HST + background spectrum of PG1211+143 (Dobrzycki; Kuraszkiewicz)
In very old papers the 2175 Å feature was used to put an upper limit on the amount of dust in quasars and Seyfert galaxies (e.g. McKee & Petrosian 1974, Mushotzky 1984).
SMC and LMC

**LMC:**

stars away from 30 Doradus region – extinction similar to MW

Stars in 30 Doradus region – 2175 A feature much weaker

**SMC:**

Stars in the bar region – no 2175 A feature!

Fig. 1. SMC extinction curve (present work) compared to Hutchings (1982) and Bromage and Nandy (1983) results. The Galactic mean curve (Savage and Mathis, 1979) as well as the LMC mean extinction (average of Nandy et al. (1984) and Koenigl and Code (1981) results) are shown for comparison.

SMC – Prevot et al. (1984)
SMC and LMC

Hutchings and Giasson (2001), from FUSE
LMC and SMC

Differences among the individual lines of sight; Cartledge et al. (2005), from FUSE
Taurus dark cloud with dense molecular clump TMC-1

Line of sight through the TMC-1 clump shows weak or absent 2175 Å feature (Whittet et al. 2004).
Fig. 21.—The extinction law derived in this work (eq. [25], continuous line) is compared with the Milky Way (dashed line) and the LMC (dot-dashed line) extinction laws. The extinction law derived by Kinney et al. (1994b) is also shown (dotted line). The zero point of the four curves is arbitrary and has been chosen to be the value $Q(5500) = 0.0$. 

Calzetti et al. 1994
Dust in the intervening systems

1 < \( z_{\text{abs}} \) < 2

York et al. (2006)
Lensing galaxies

Eliasdottir et al. 2006
the AGN dust does not have to follow the standard MW curve with 2175 feature …
Non-standard dust in AGN – early considerations

Czerny et al. 1992

Loska et al. 1993

Dust model without silicates
Non-standard dust in AGN – early considerations

Laor & Draine (1993)

Dust model with modified chemical composition and sizes!
AGN spectrum corrected for circum-nuclear dust

Assumed extinction; best fit model for large carbon grains (0.01 – 0.5), $E_{(B-V)} = 0.4$

Czerny et al. (1995)

<table>
<thead>
<tr>
<th>curve</th>
<th>$E(B-V)_{\text{circ}}$</th>
<th>starlight$^1$</th>
<th>$E(B-V)_{\text{nuc}}$</th>
<th>en. index</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaton</td>
<td>0.1</td>
<td>$0.6864^{+0.0}_{-0.03}$</td>
<td>$0.3^{+0.3}_{-0.3}$</td>
<td>$0.4^{+0.9}_{-0.7}$</td>
<td>7.1</td>
</tr>
<tr>
<td>C:0.001-0.5</td>
<td>0.1</td>
<td>$0.6864^{+0.06}_{-0.0}$</td>
<td>$0.3^{+0.1}_{-0.1}$</td>
<td>$0.4^{+0.3}_{-0.3}$</td>
<td>4.0</td>
</tr>
<tr>
<td>C:0.01-0.5</td>
<td>0.1</td>
<td>$0.6864^{+0.08}_{-0.0}$</td>
<td>$0.4^{+0.1}_{-0.1}$</td>
<td>$0.6^{+0.2}_{-0.2}$</td>
<td>2.5</td>
</tr>
<tr>
<td>AC/B/E</td>
<td>0.1</td>
<td>$0.6864^{+0.03}_{-0.0}$</td>
<td>$0.0^{+0.06}_{-0.0}$</td>
<td>$0.4^{+0.1}_{-0.1}$</td>
<td>7.4</td>
</tr>
</tbody>
</table>

$^1$ starlight normalization given as a fraction of starlight in the original spectrum at 5400 Å.
SDSS era – simple exercise

Richards et al. (2003) composites.
SDSS era – simple exercise

The 'Best Fit' line shows the favoured model extinction curve:

AC amorphous carbon grains, amin= 0.016 μm, amax= 0.12 μm, p= 3.5.

Czerny et al. (2004)
Radio louds from continua


Slide from Martin Gaskell
More advanced studies:

Willott (2005) corrected for bias in composite spectra

His conclusion: SMC better than more grey extinction curve
More advanced studies

Hopkins et al. (2004), SDSS data but based on individual spectra analysis
support for SMC extinction curve
Best-Determined Individual Extinction Curves

Gaskell & Benker (2006)

Slide from Martin Gaskell
Less Certain Extinction Curves

Gaskell & Benker (2006)

Slide from Martin Gaskell
Gaskell & Benker (2006)

Mean Extinction Curve (radio-quiet)

Note: very similar to Czerny et al. (2004) curve from SDSS

Slide from Martin Gaskell
High redshift AGN

Maiolino et al. 2004; Maiolino et al. 2006

Similar results by Hirashita et al. 2005

Fig. 7. Extinction curve observed in the QSO SDSS J1049+46 at z=6.2 (solid curve and shaded area) compared with the SMC curve (dotted line), which applies to QSOs at z<4, and with the extinction curve expected for dust produced by SNe (dashed line, adapted from Maiolino et al. 2004)
Our recent results

Individual spectra in UV, dispersion in optical.
Our recent results

Extinction curve based on extreme spectra
Our recent result:

Averaged extinction curve from individual spectra, weighted mean:

More like Seaton, flatter in far UV than SMC?
Our recent result:

Averaged extinction curve from individual spectra, weighted mean:

More like Seaton but flatter in far UV?

**NO**
IT WAS JUST A WARNING!
Our recent results – what data we used …

Intrinsic time delays, Sergeev et al. (2005)

Mrk 335

<table>
<thead>
<tr>
<th>band</th>
<th>peak</th>
<th>centroid</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>0.43(+0.83,-0.81)</td>
<td>0.86(+0.56,-0.97)</td>
</tr>
<tr>
<td>R</td>
<td>2.36(+0.74,-0.85)</td>
<td>2.44(+0.67,-1.07)</td>
</tr>
<tr>
<td>R1</td>
<td>2.30(+0.44,-1.76)</td>
<td>1.45(+0.94,-1.26)</td>
</tr>
<tr>
<td>I</td>
<td>2.33(+0.30,-1.86)</td>
<td>1.74(+0.78,-1.25)</td>
</tr>
</tbody>
</table>

The effect is intrinsic – at least in optical band. It is well modelled by the irradiation of the outer disk due to scattering of the inner disk radiation by the disk corona…

There may be dust effect in the far UV part but we did not model it yet.
It is definitively hard to go beyond the statement made by Richards et al. (2003), which is

„It is likely that dust reddening plays some role in the color differences between the composites 1-4 but the reddening alone cannot be the cause of significant trends in emission line properties from composite 1 to composite 4”.
Physical conditions in AGN dust

- Metallicities
- Radiation field
- High density

AGN: estimated density n about $10^7$ cm$^{-3}$ (Akylas et al. 2002) from variability of Sy 2 object Mrk 348; dust clump size of a few light days)

Density in dense molecular clump of Taurus dark cloud TMC-1: $n = 10^4 - 10^5$ (Turner et al. 2005)

Therefore, an extinction like in TMC-1 is rather expected: lower or absent 2175 feature, grayer in UV than SMC
Summary

Spectra should be deredened using an extinction curve without 2175 Å feature

Grey or SMC? I would think it’s grey but more studies are needed
- taking into account possible intrinsic effects
- using info from the IR dust emission
- trying to apply the dust formation theory