Extinction curves in AGN

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)

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Extinction curve - definitions

Extinction at a specific wavelength **λ** is defined as

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

where **m** is the observed magnitude and $\mathbf{m_0}$ is the magnitude in the absence of dust.

Extinction curve is introduced to characterize the wavelength dependence of $\mathbf{A_\lambda}$ on **λ** 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:

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

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

$$\mathbf{A_\lambda} \sim \tau$$

Extinction curve can be defined as:

$$\mathbf{A_\lambda / A_I}$$

see Draine (2003), ARA&A

Extinction curve - definitions

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

$$E(X\text{-}Y) = A_X - A_Y$$

where **X** and **Y** are two bands.

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

$$A_\lambda/E(B\text{-}V)$$

or

$$(A_\lambda - A_V)/E(B\text{-}V)$$

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

$$R_V = A_V/A_B - A_V) = A_V/E(B\text{-}V).$$

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

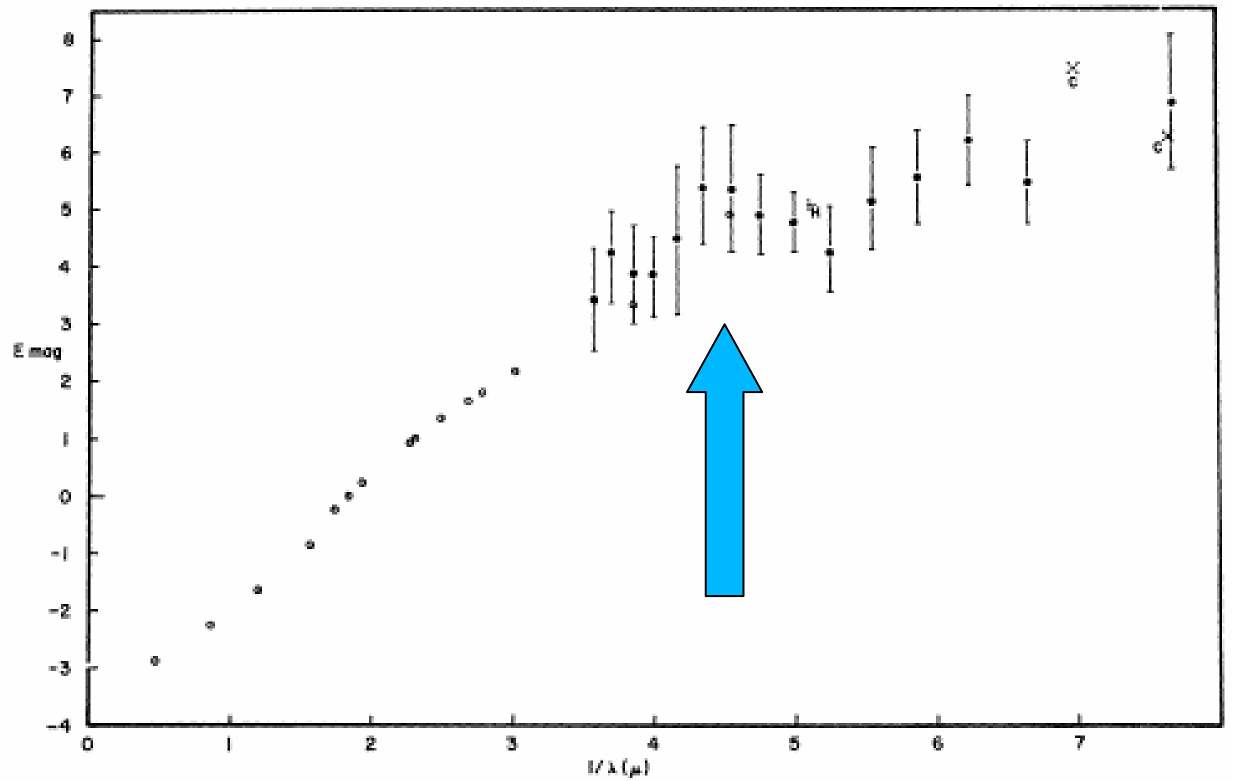


FIG. 1.—The observed mean value for interstellar extinction. *Large solid dots:* mean values for interstellar extinction and their mean errors for up to five pairs of stars as a function of inverse wavelength. *Open circles:* Boggess and Borgman (1964) The point marked "*H*" is from Alexander *et al.* (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)

MW

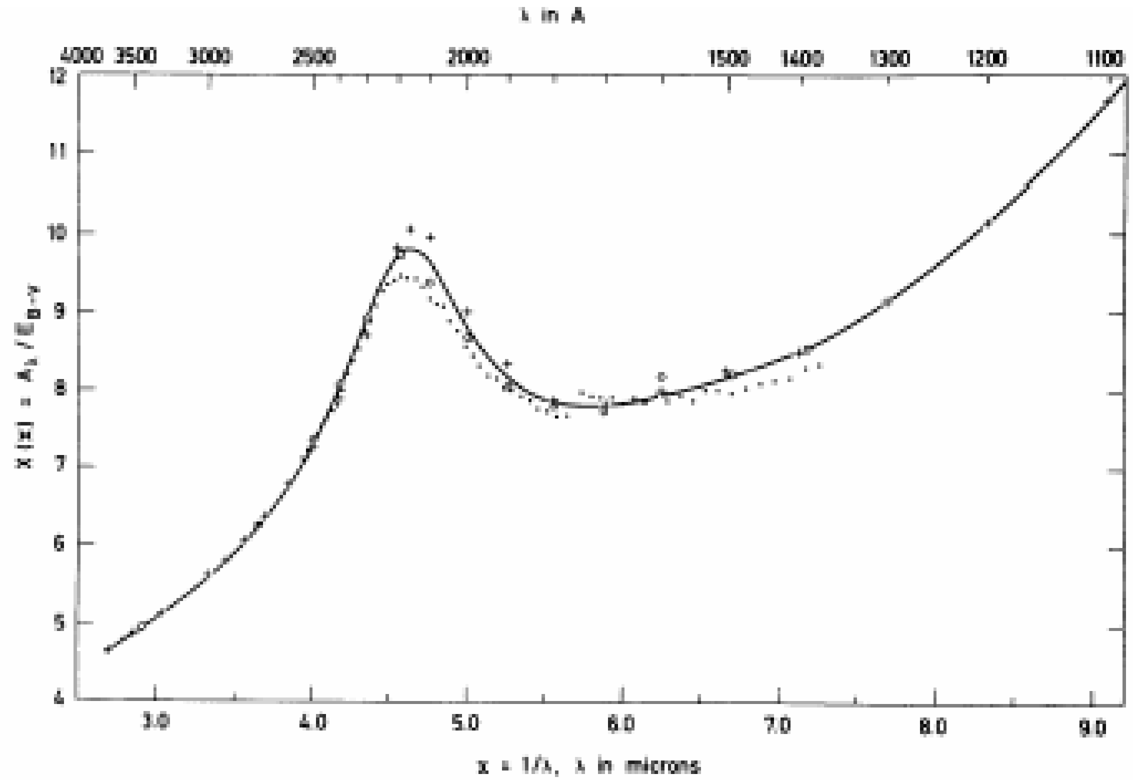
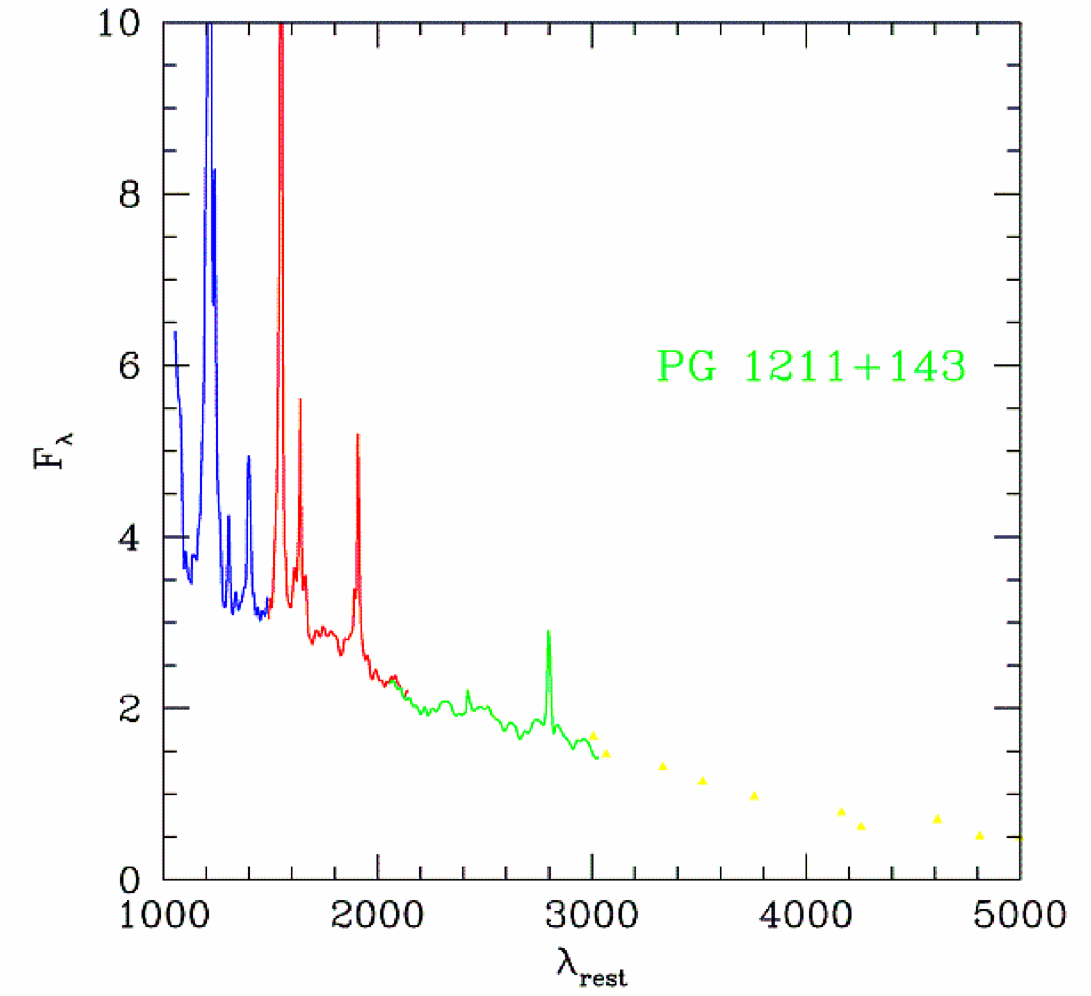


Figure 1. The UV extinction $X(x) = A_\lambda/E_{B-V}$ against $x = 1/\lambda$ with λ in microns. + *OAO-2* data of C76 (Code *et al.* 1976); · *TD-1* data of N75 (Nandy *et al.* 1975); ○ *TD-1* data of N76 (Nandy *et al.* 1976). The full line curve is from the fits of Table 2.

Seaton 1979

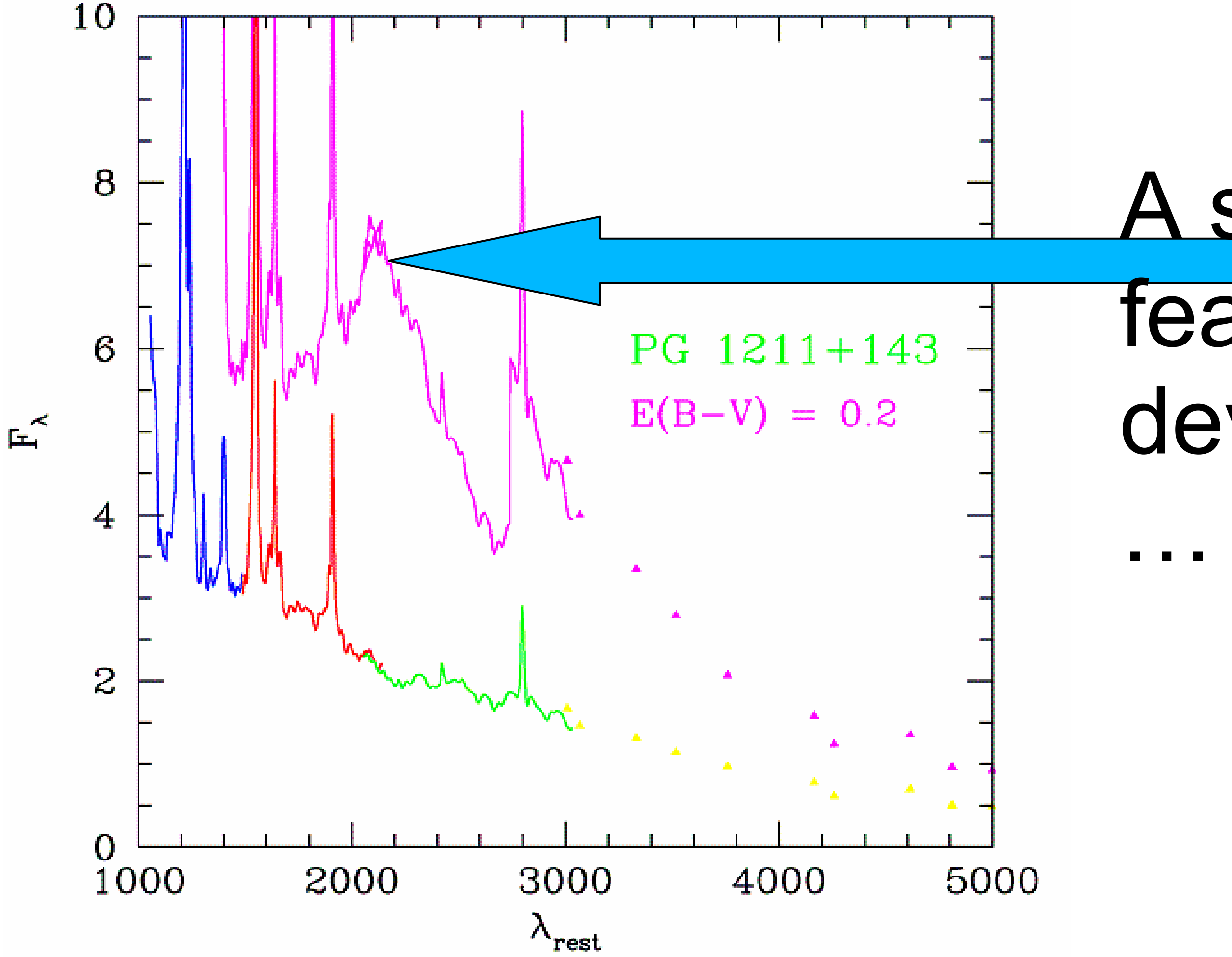
Range of x	Expression for $X(x)$
$2.70 \leq x \leq 3.65$	$1.56 + 1.048x + 1.01/\{(x - 4.60)^2 + 0.280\}$
$3.65 \leq x \leq 7.14$	$2.29 + 0.848x + 1.01/\{(x - 4.60)^2 + 0.280\}$
$7.14 \leq x \leq 10$	$16.17 - 3.20x + 0.2975x^2$

What if AGN spectrum is corrected for MW-type dust?



The HST + background spectrum of PG1211+143 (Dobrzycki; Kuraszkiewicz)

AGN spectrum corrected for MW



A strange feature developes …

In very old papers the 2175 A 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!

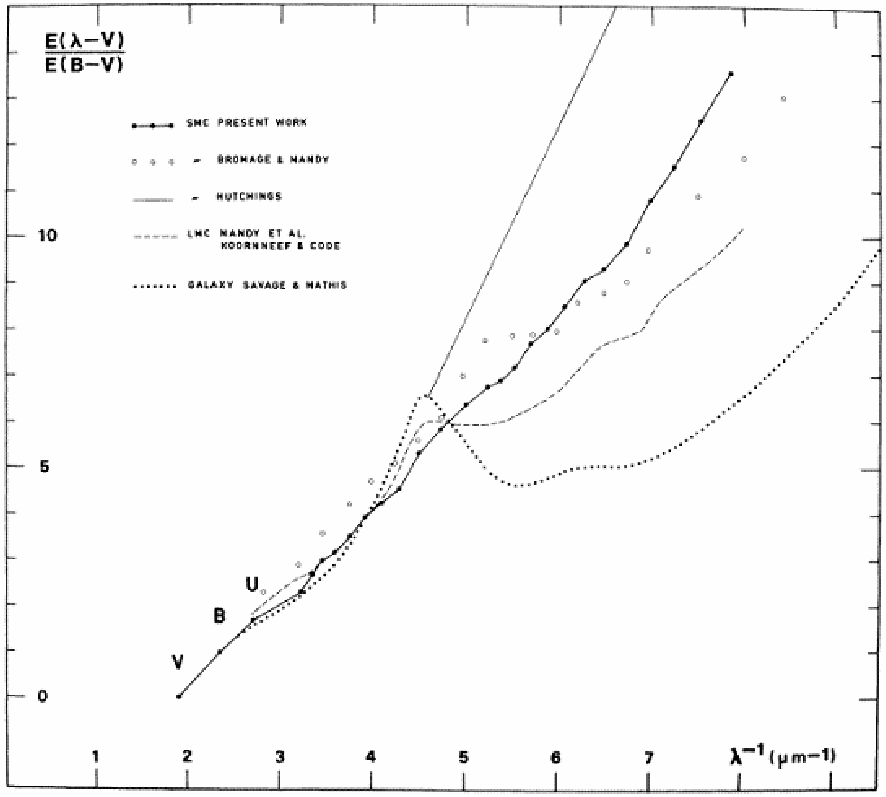
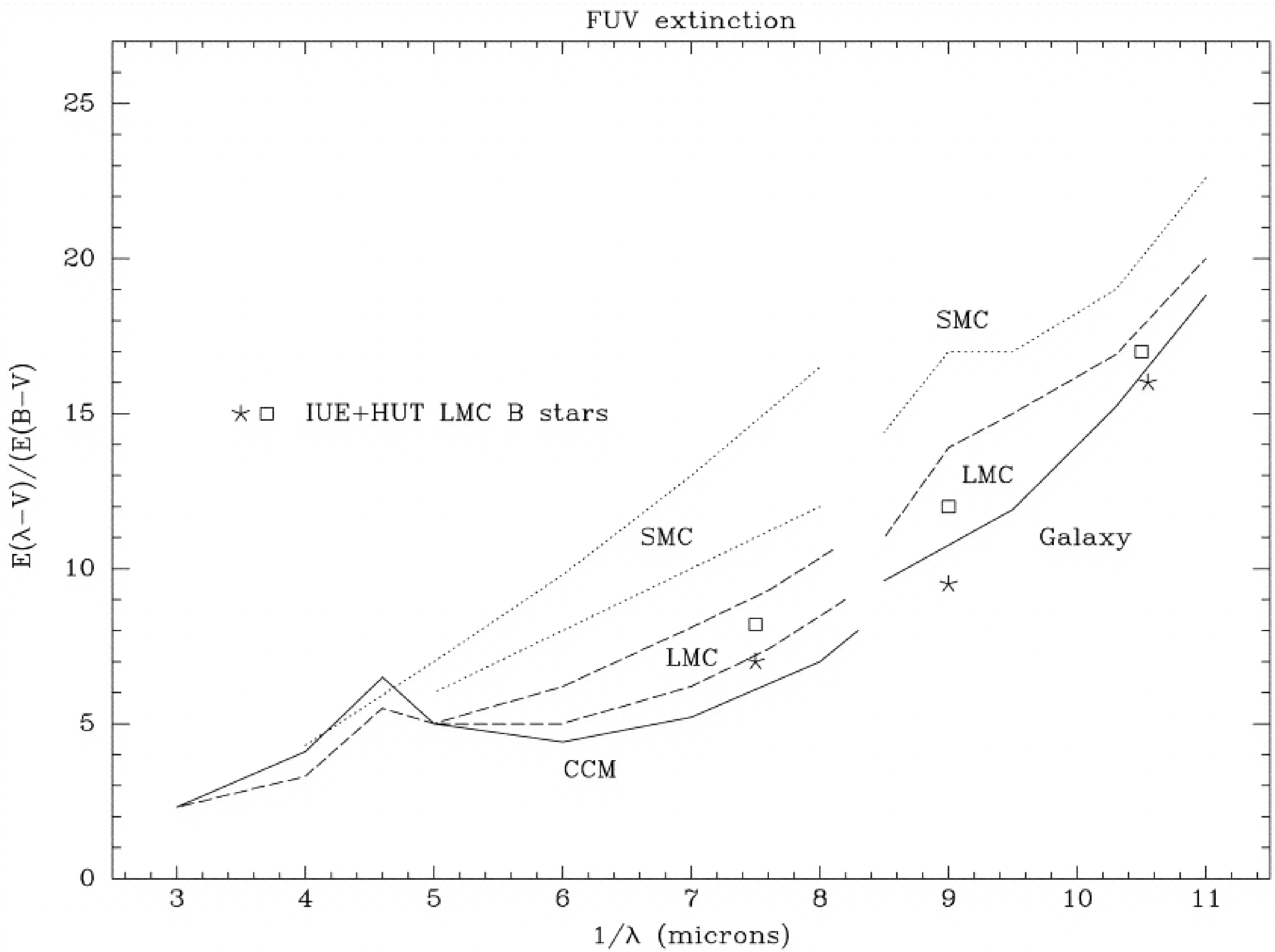


Fig. 1. SMC extinction curve (present work) compared to Hutchings (1982) and Bromage and Nandy (1983) results. The galactic mean curve (Savage and Mathis, 1979) as well as the LMC mean extinction [average of Nandy et al. (1981) and Koornneef and Code (1981) results] are shown for comparison

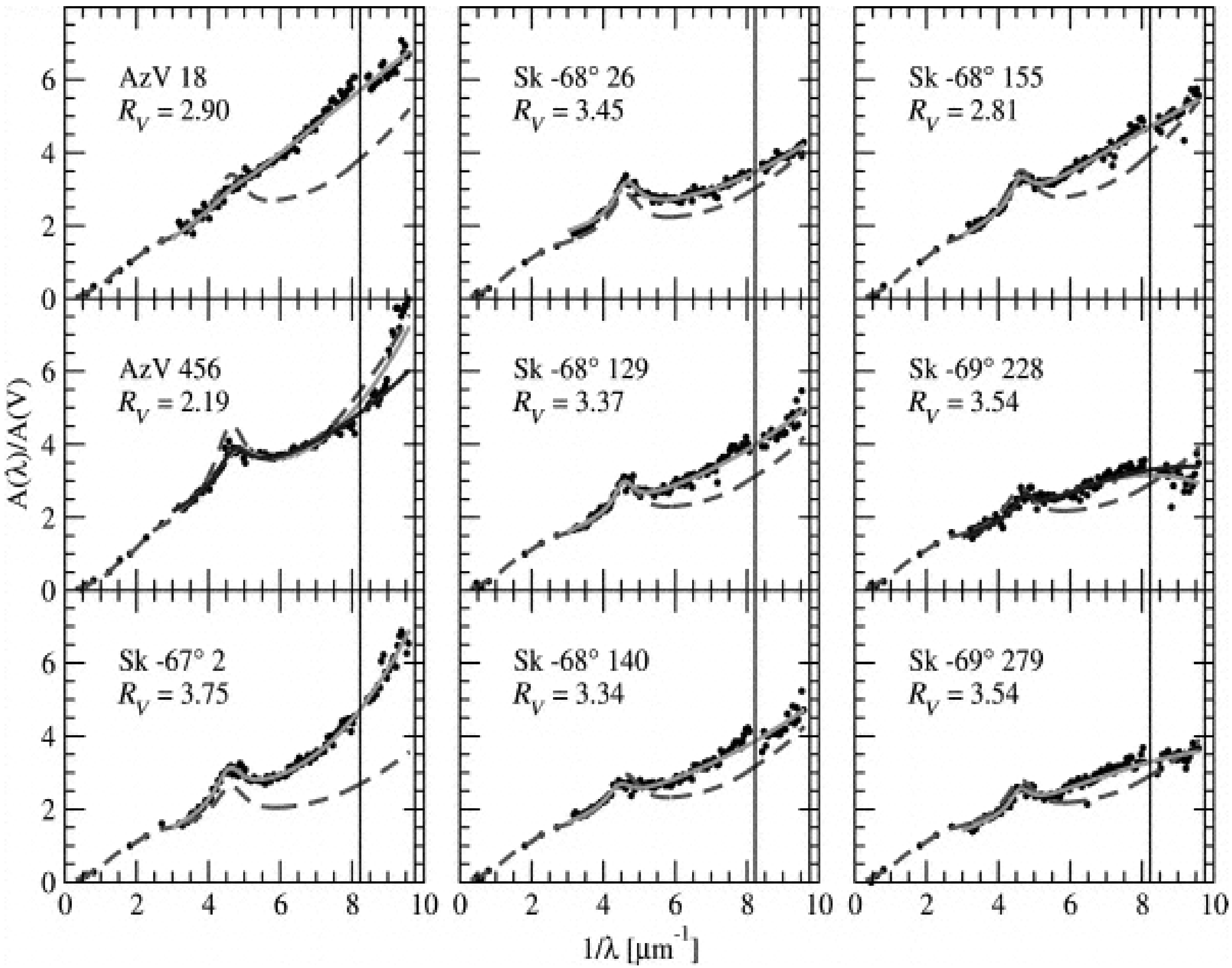
SMC – Prevot et al. (1984)

SMC and LMC



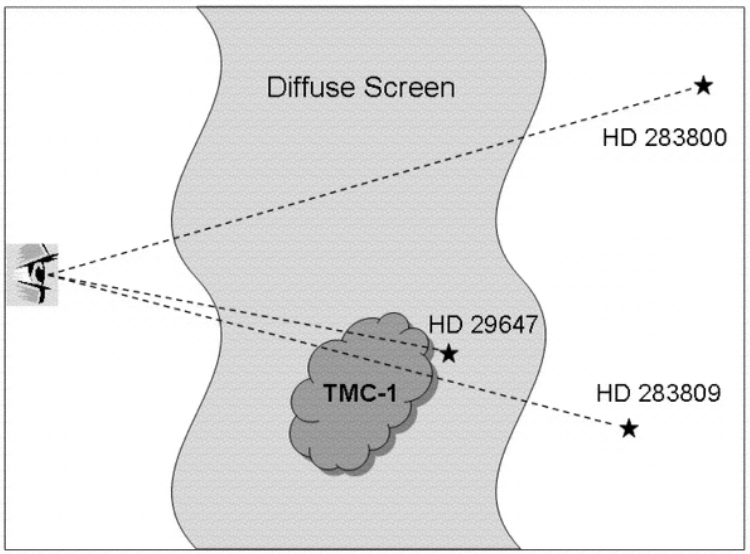
Hutchings and Giasson (2001), from FUSE

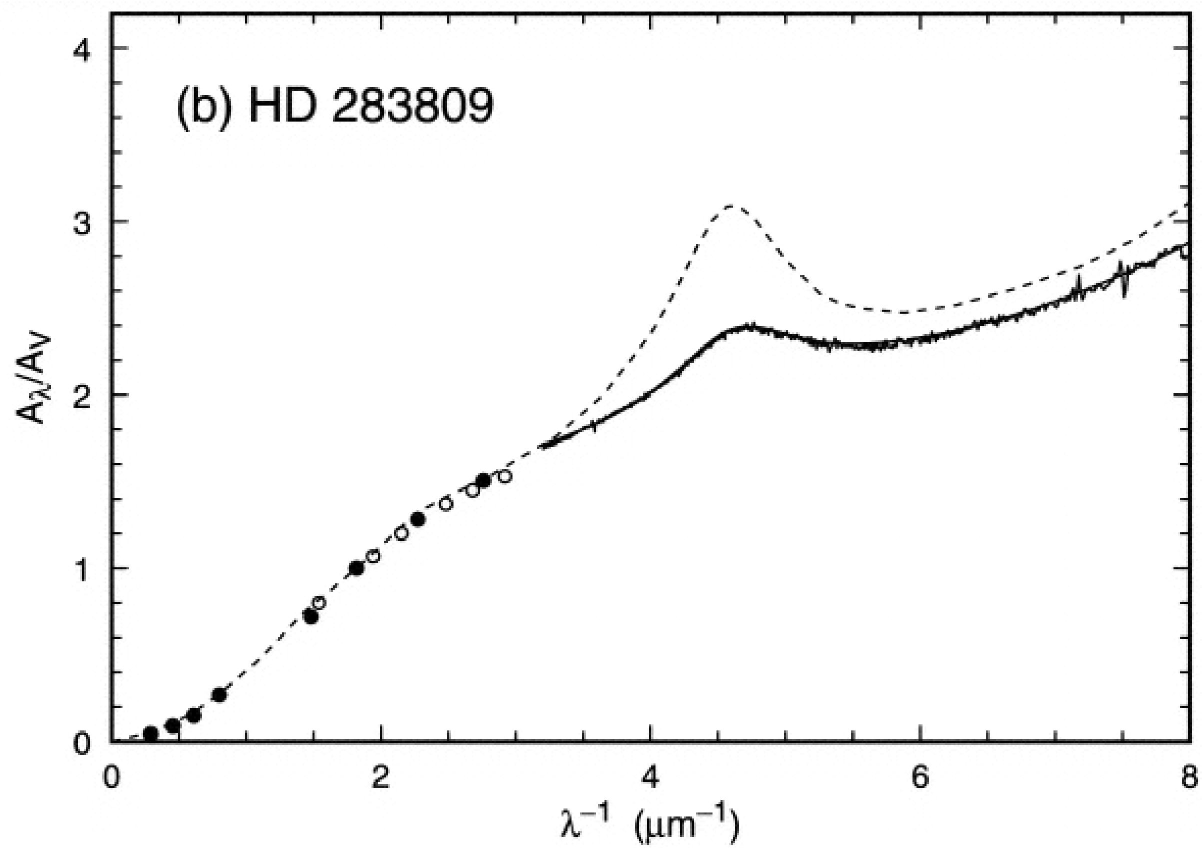
LMC and SMC



Differences amoung the idividual 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 A feature (Whittet et al. 2004).

Starburst galaxies

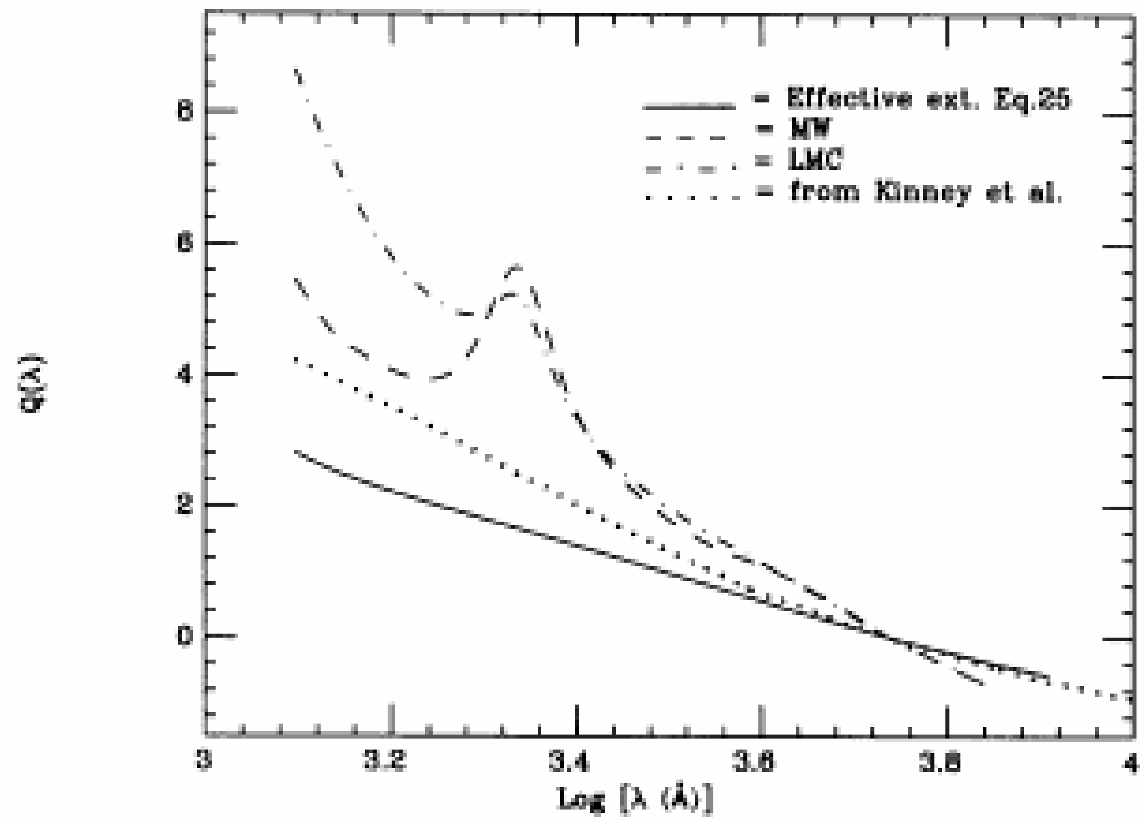
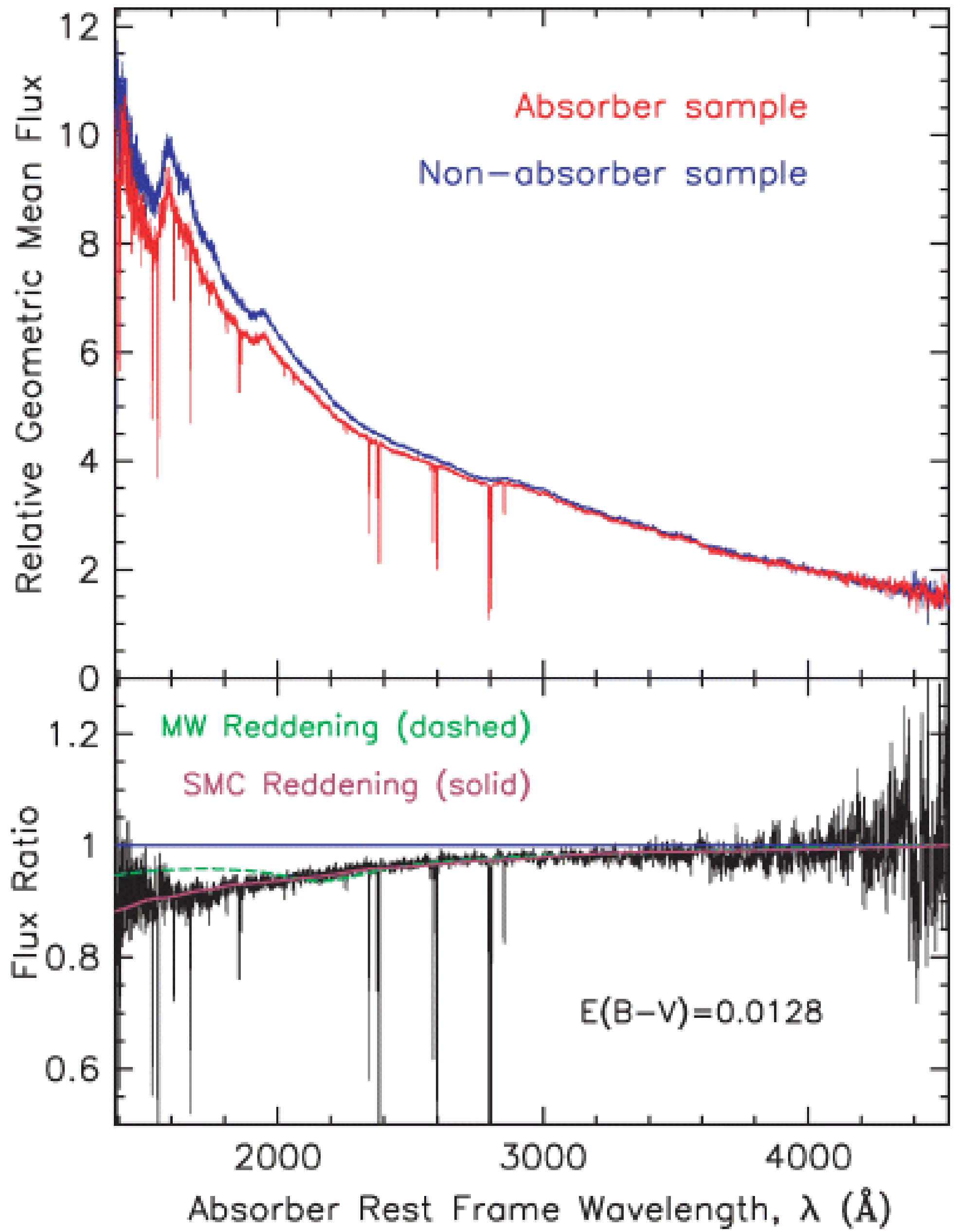


FIG. 21.—The extinction law derived in this work (eq. [25], *continuous line*) is compared with the Milky Way (*dashed line*) and the LMC (*dot-dashed line*) extinction laws. The extinction law derived by Kinney et al. (1994b) is also shown (*dotted line*). The zero point of the four curves is arbitrary and has been chosen to be the value $Q(5500) = 0.0$.

Calzetti et al. 1994

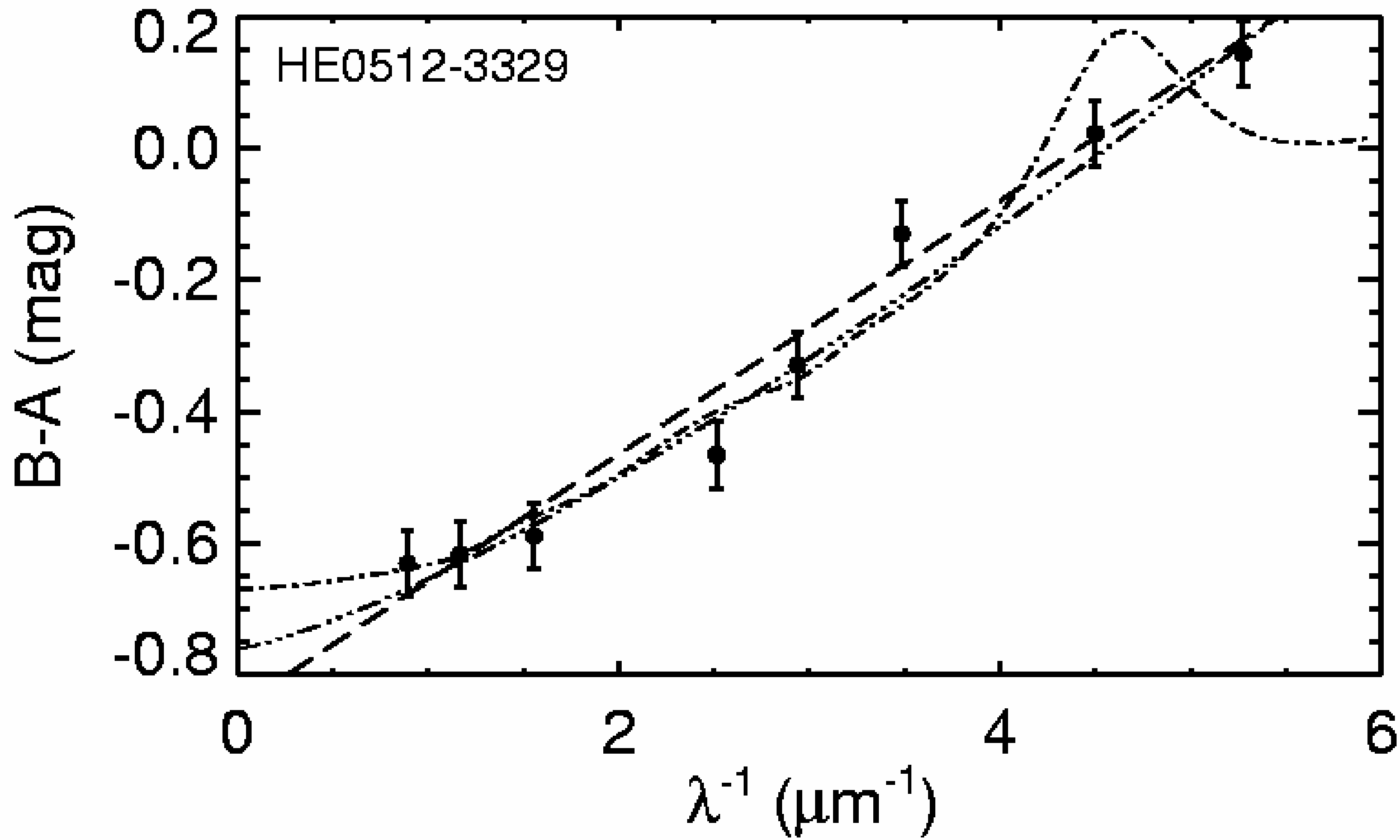
Dust in the intervening systems



$1 < z_{abs} < 2$

York et al. (2006)

Lensing galaxies

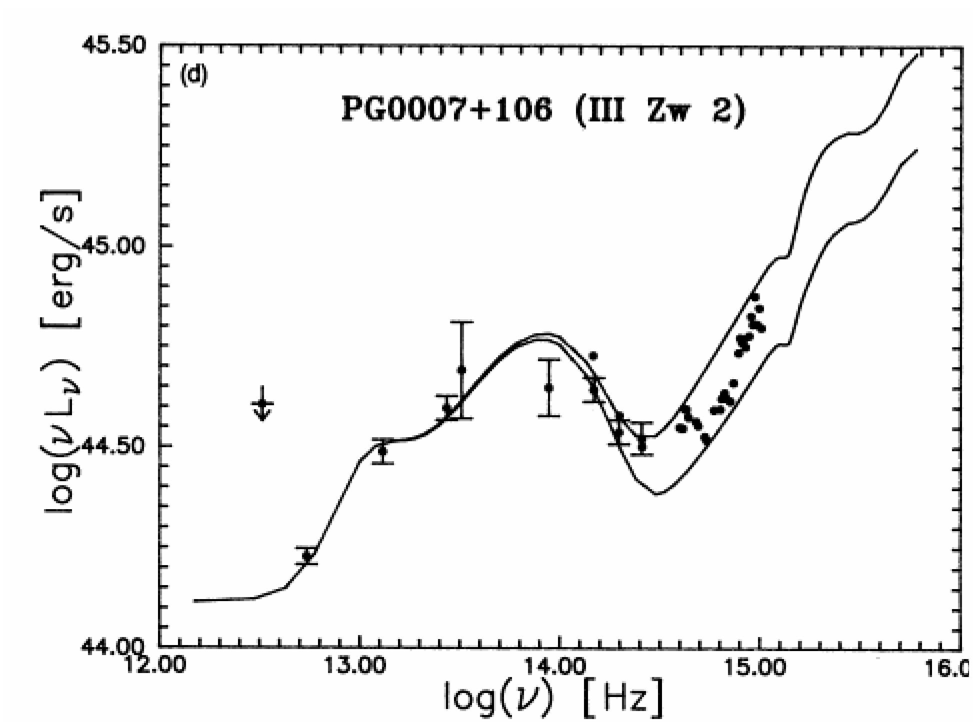


Eliasdottir et al. 2006

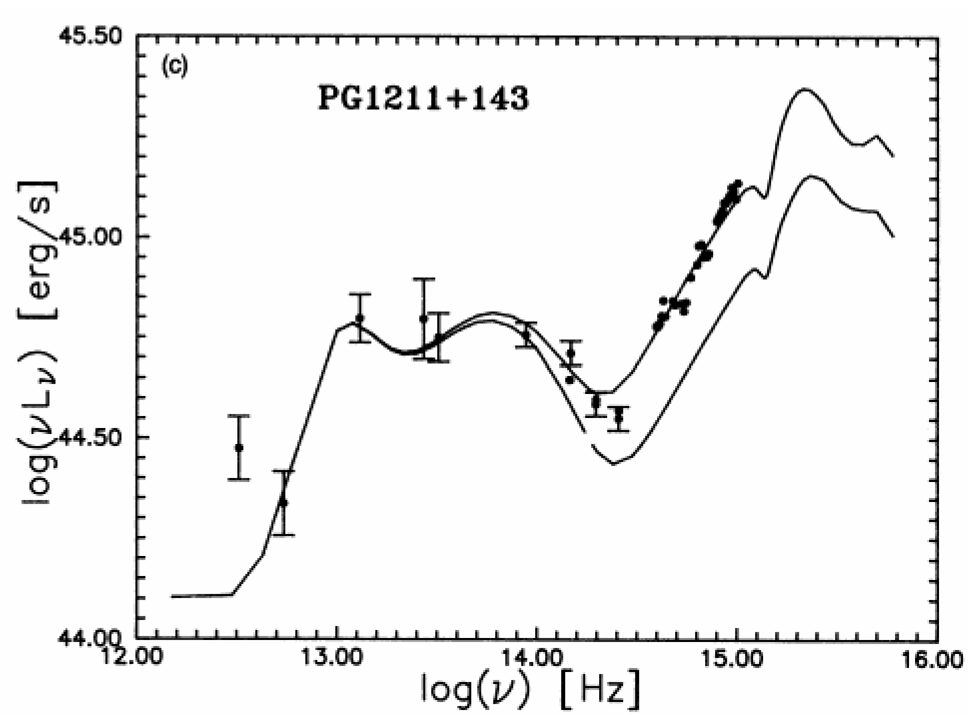
So …

the AGN dust does not have to follow the standard MW curve with 2175 feature …

Non-standard dust in AGN – early considerations



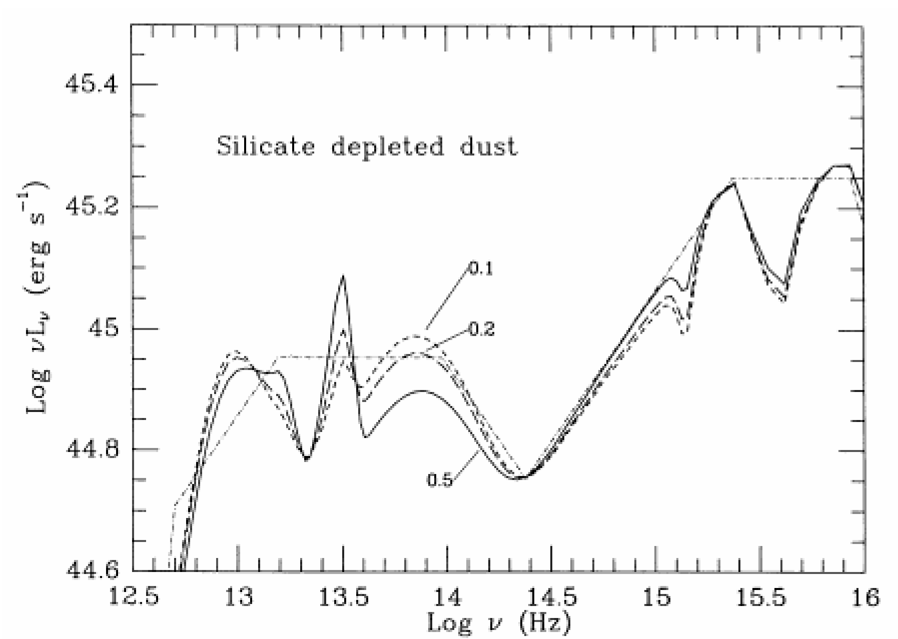
Czerny et al. 1992

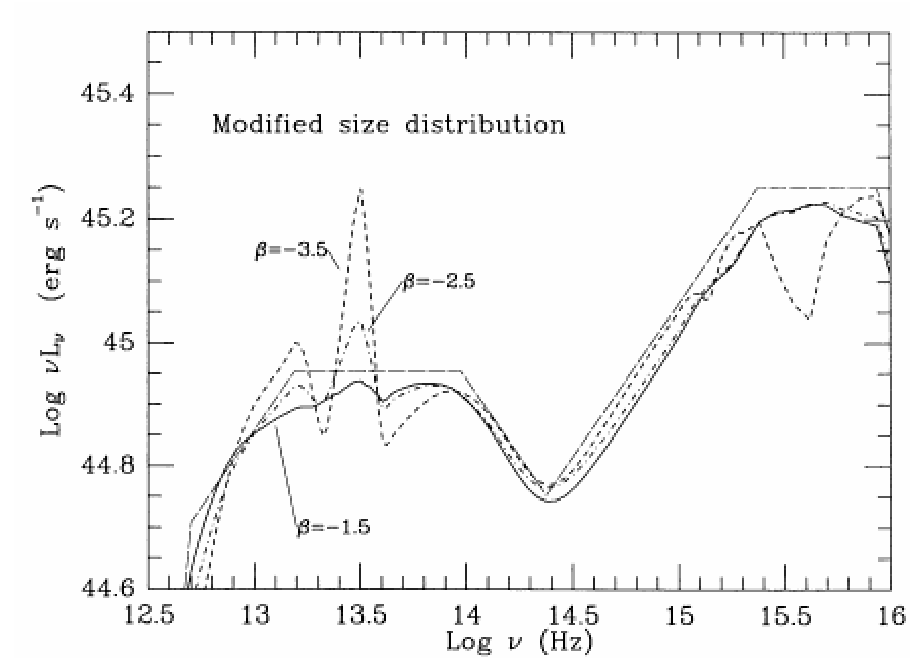


Loska et al. 1993

Dust model without silicates

Non-standard dust in AGN – early considerations

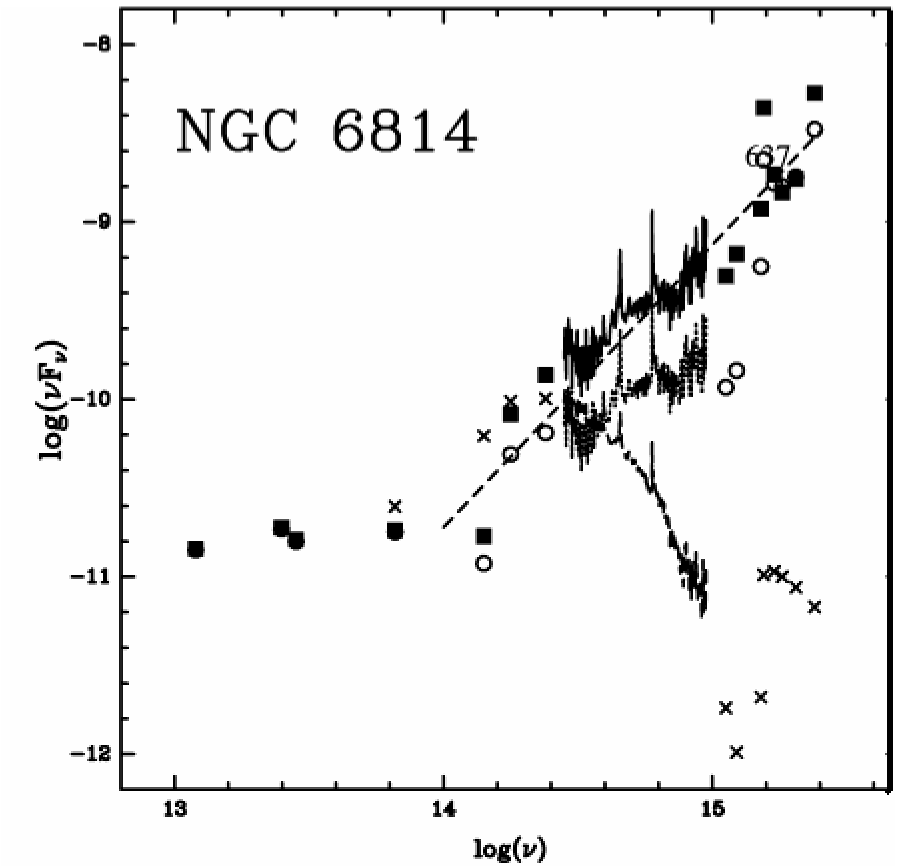




Laor & Draine (1993)

Dust model with modified chemical composition and sizes!

AGN spectrum corrected for circum-nuclear dust



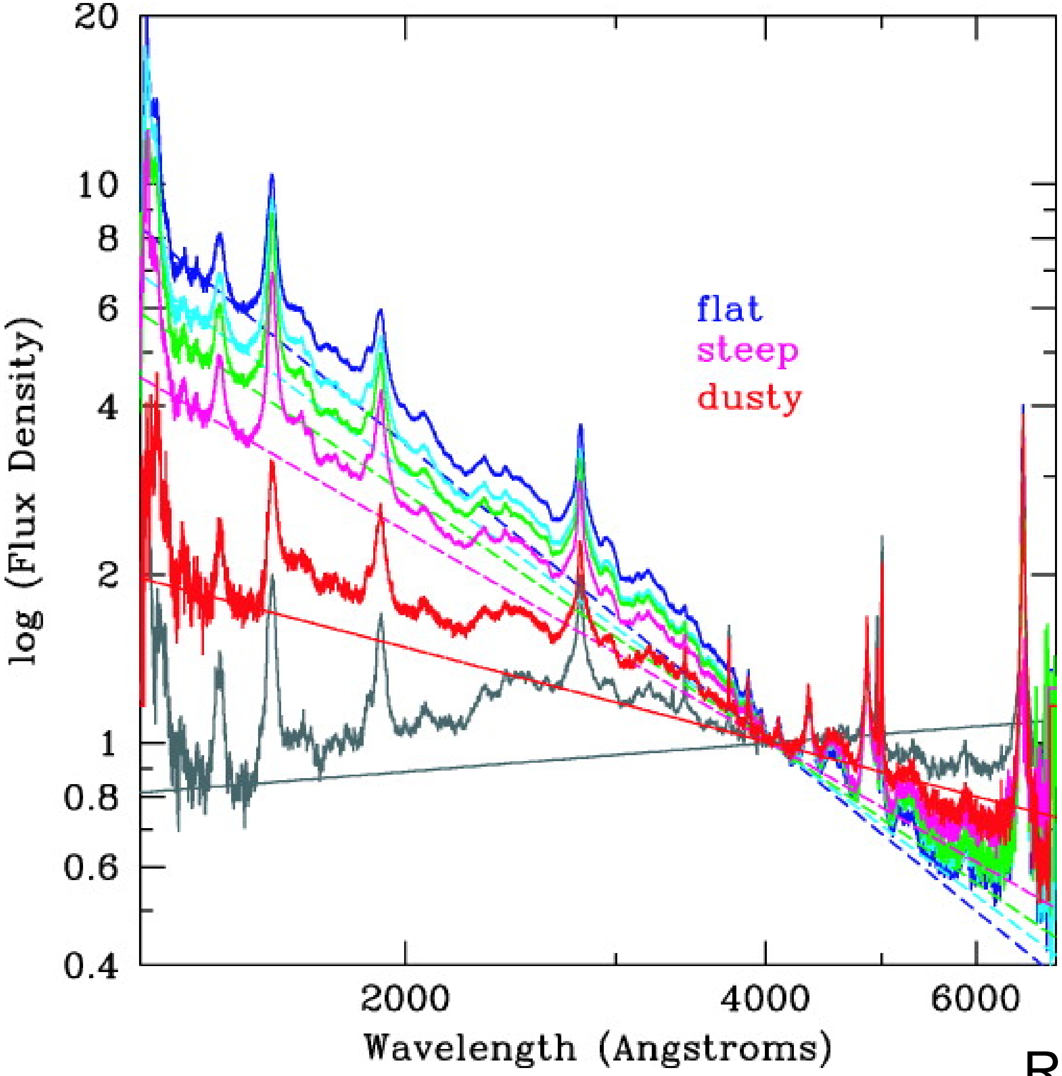
curve	$E(B-V)_{\rm cirrus}$	starlight[1]	$E(B-V)_{\rm nuc}$	en. index	χ^2
Seaton	0.1	$0.6864^{+0.0}_{-0.03}$	$0.3^{+0.3}_{-0.3}$	$0.1^{+0.9}_{-0.7}$	7.1
C:0.001-0.5	0.1	$0.6864^{+0.0}_{-0.06}$	$0.3^{+0.1}_{-0.1}$	$0.4^{+0.2}_{-0.3}$	4.0
C:0.01-0.5	0.1	$0.6864^{+0.0}_{-0.08}$	$0.4^{+0.1}_{-0.1}$	$0.6^{+0.2}_{-0.2}$	2.5
AC/BE	0.1	$0.6864^{+0.0}_{-0.03}$	$0.0^{+0.006}_{-0.0}$	$0.4^{+0.1}_{-0.1}$	7.4

[1] starlight normalization given as a fraction of starlight in the original spectrum at 5400 Å.

Czerny et al. (1995)

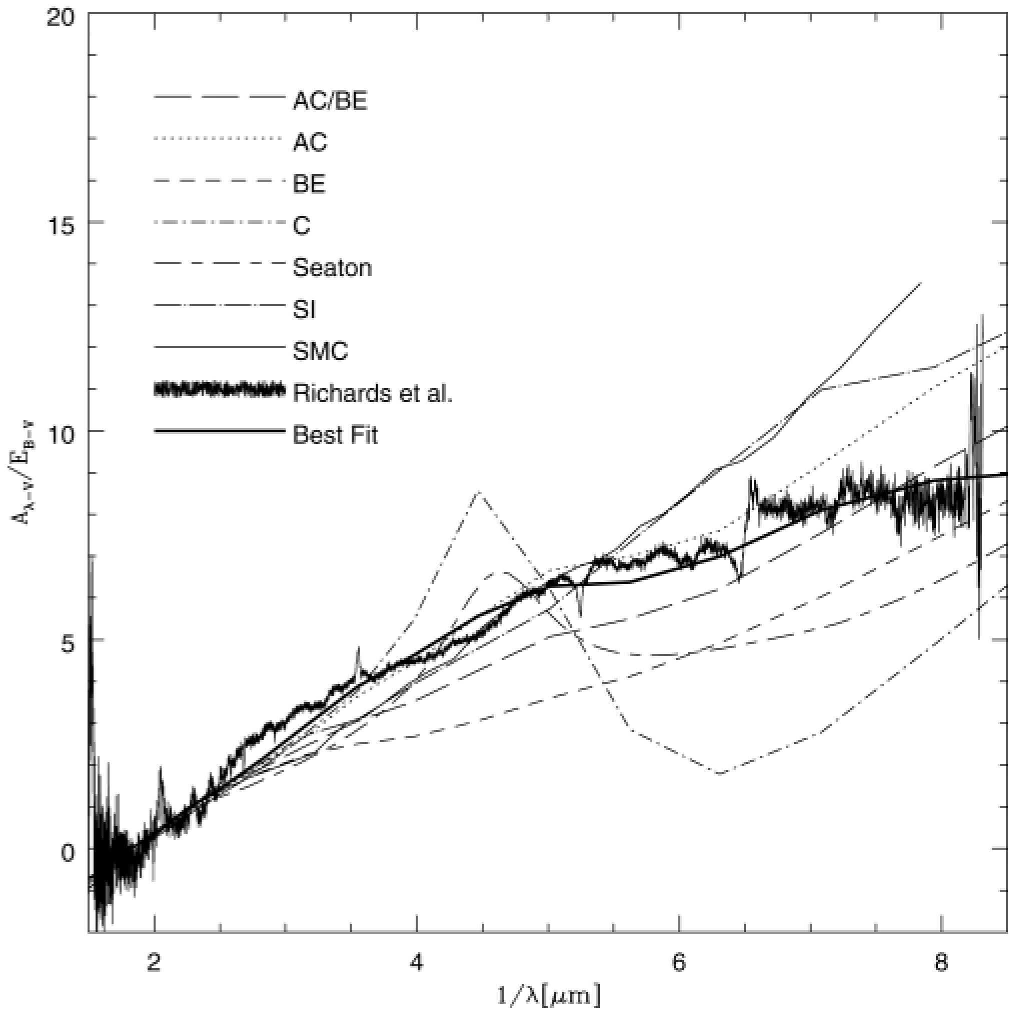
Assumed extinction; best fit model for large carbon grains (0.01 – 0.5), E_(B-V) = 0.4

SDSS era – simple excercise



Richards et al. (2003) composites.

SDSS era – simple excercise

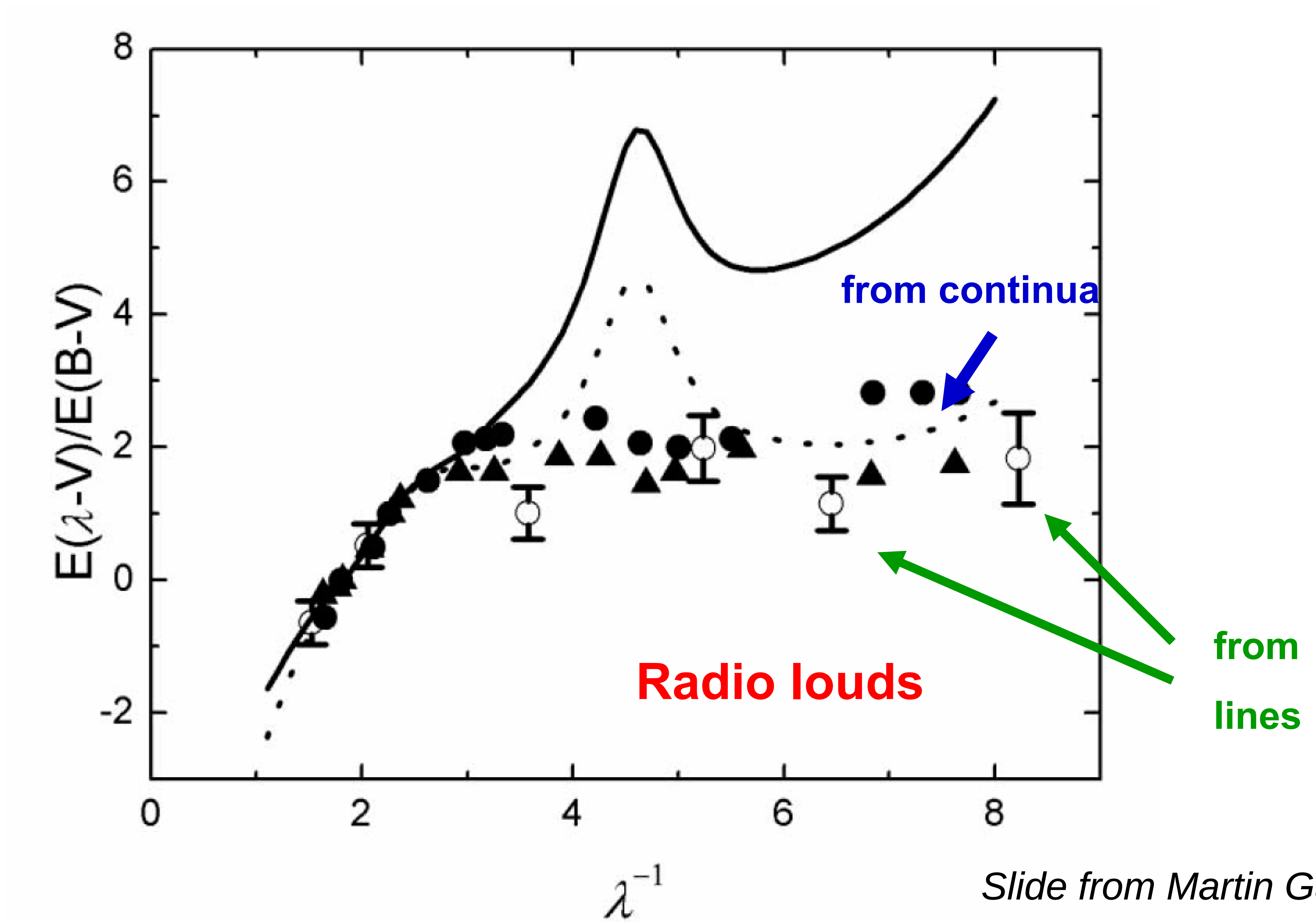


The 'Best Fit' line shows the favoured model extinction curve:

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

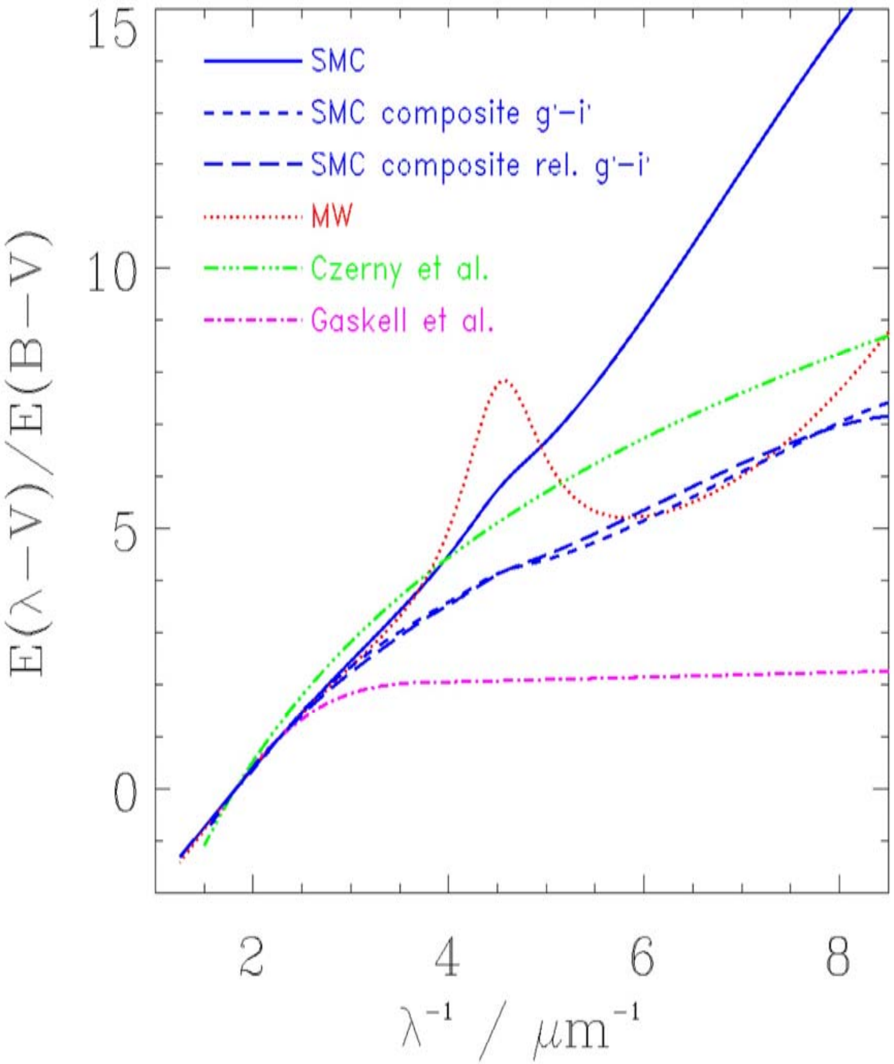
Czerny et al. (2004)

Gaskell, Goosmann, Antonucci, & Whysong (2004), *Ap.J*, 616, 147



Slide from Martin Gaskell

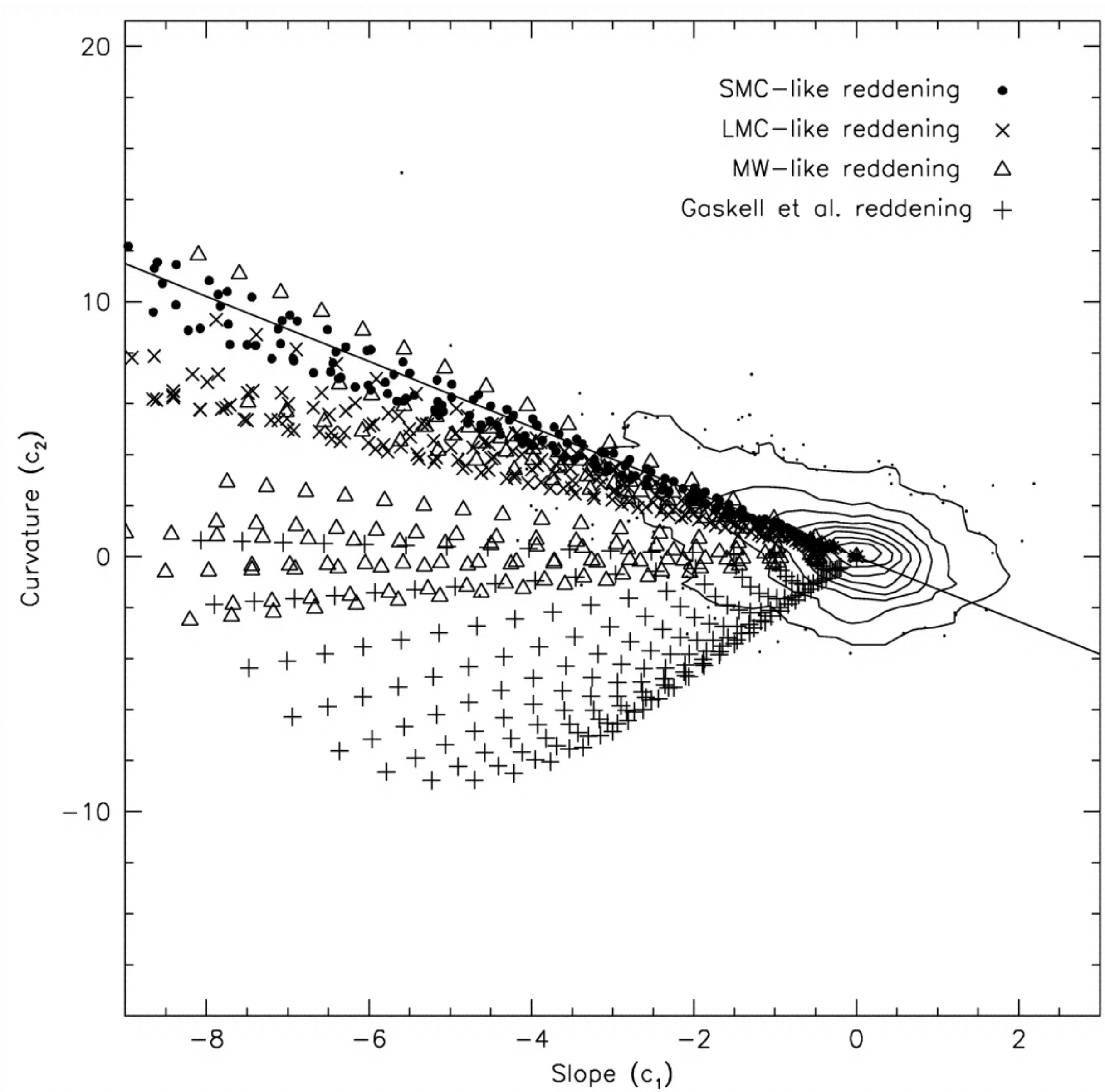
More advanced studies:



Willott (2005) corrected for bias in composite spectra

His conclusion: SMC better than more grey extinction curve

More advanced studies

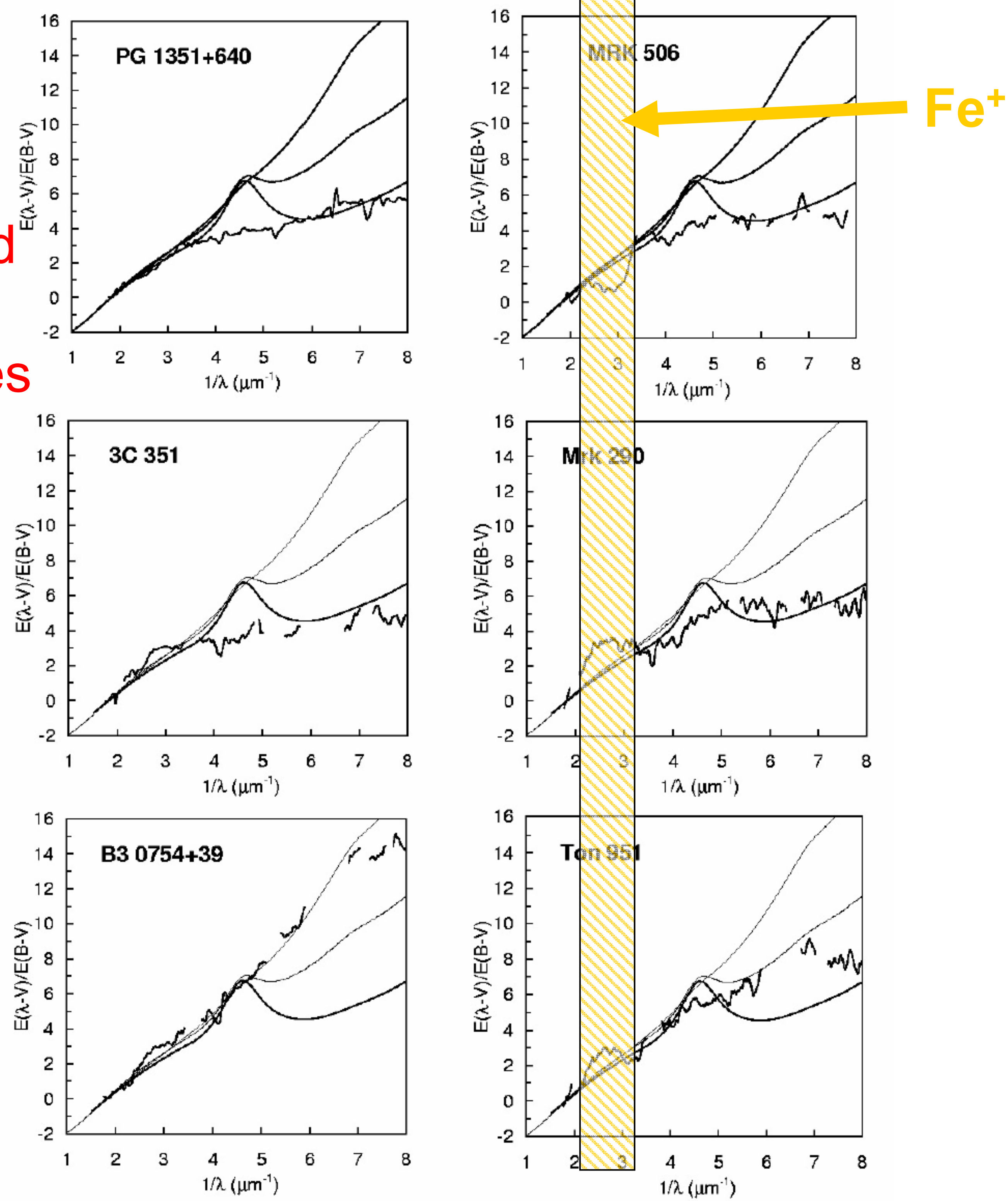


Hopkins et al. (2004), SDSS data but based on individual spectra analysis

support for SMC extinction curve

Best-Determined Individual Extinction Curves

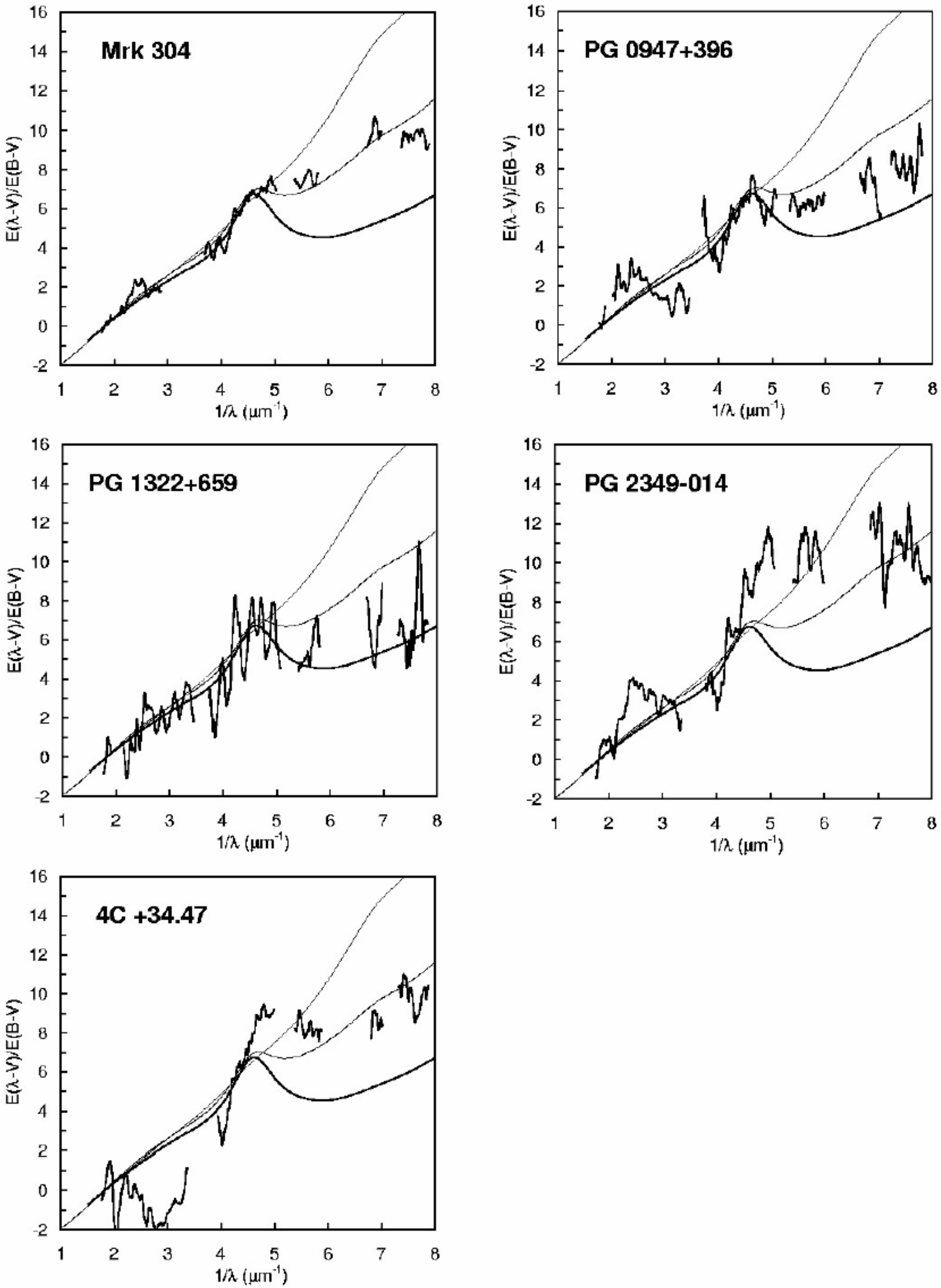
Gaskell & Benker (2006)



Slide from Martin Gaskell

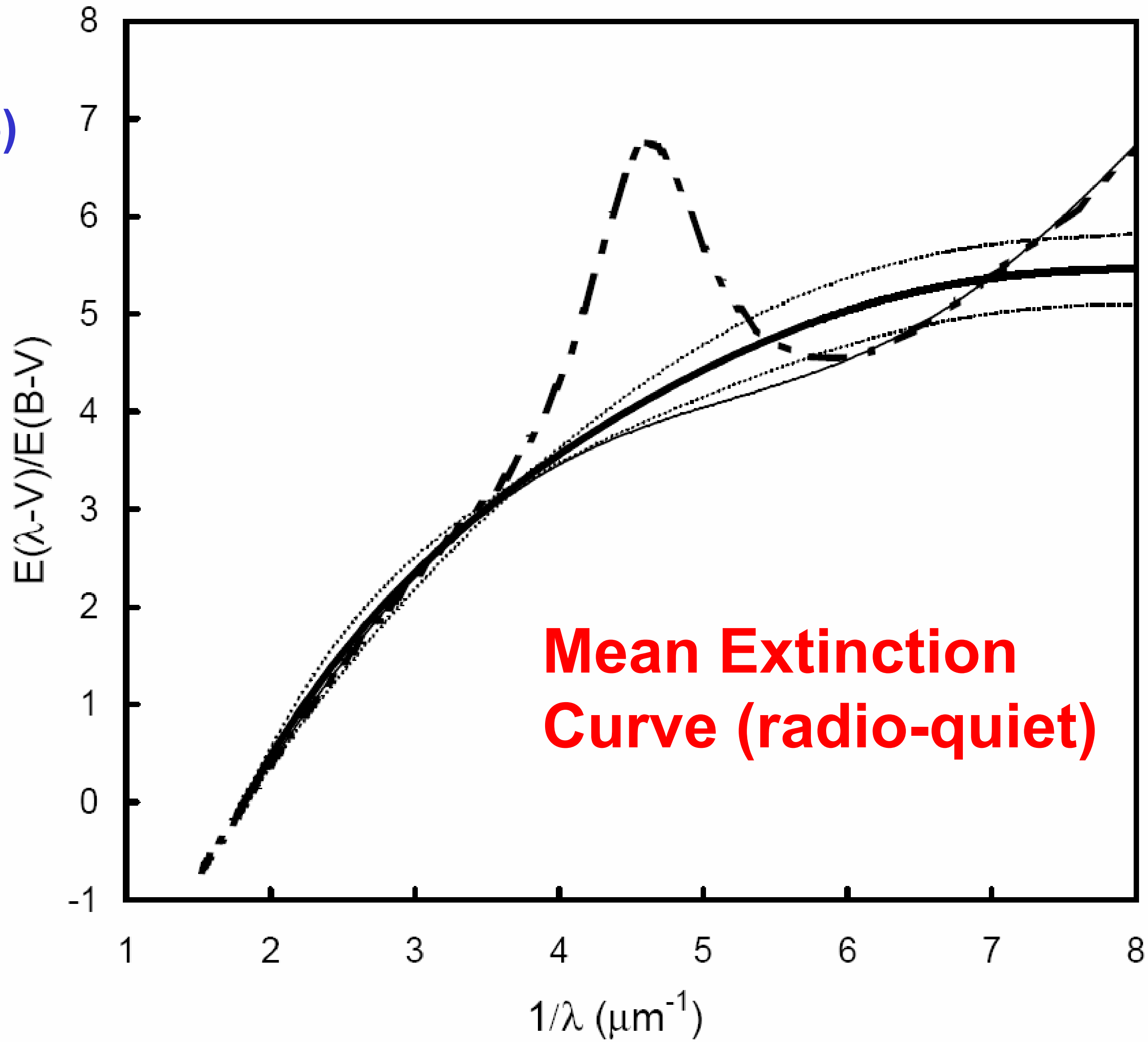
Less Certain Extinction Curves

Gaskell & Benker (2006)



Slide from Martin Gaskell

Gaskell & Benker (2006)



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

Slide from Martin Gaskell

High redshift AGN

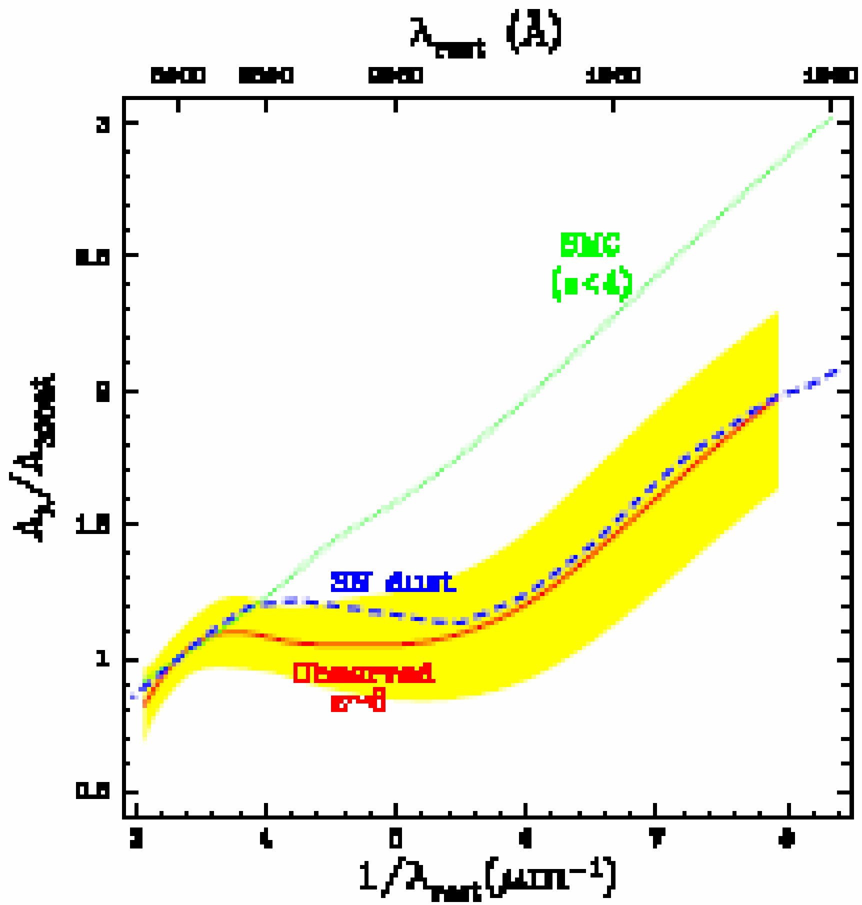
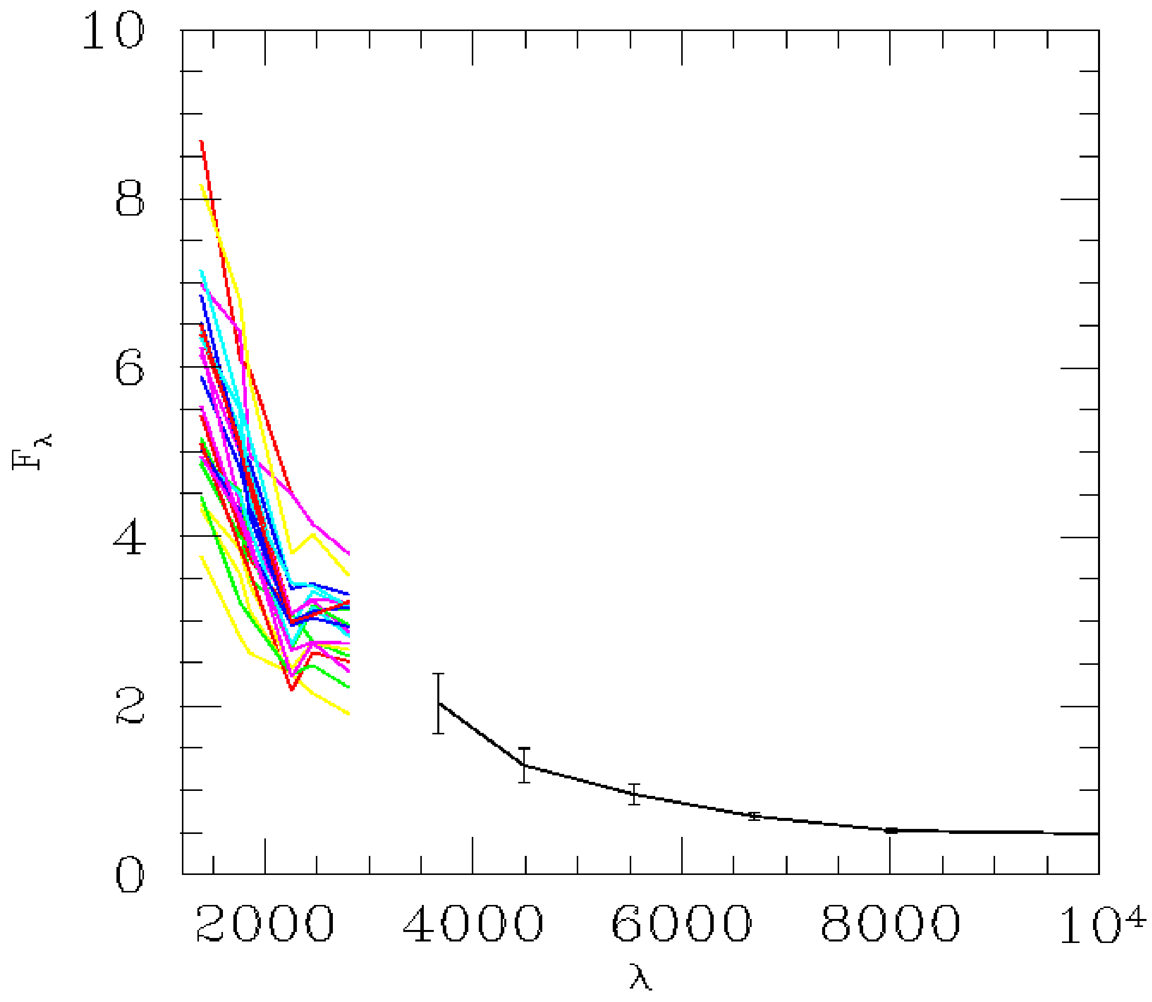


Fig. 7. Extinction curve observed in the QSO SDSSJ1049+46 at z=6.2 (solid curve and shaded area) compared with the SMC curve (dotted line), which applies to QSOs at z<4, and with the extinction curve expected for dust produced by SNe (dashed line, adapted from Maiolino et al. 2004)

Maiolino et al. 2004; Maiolino et al. 2006

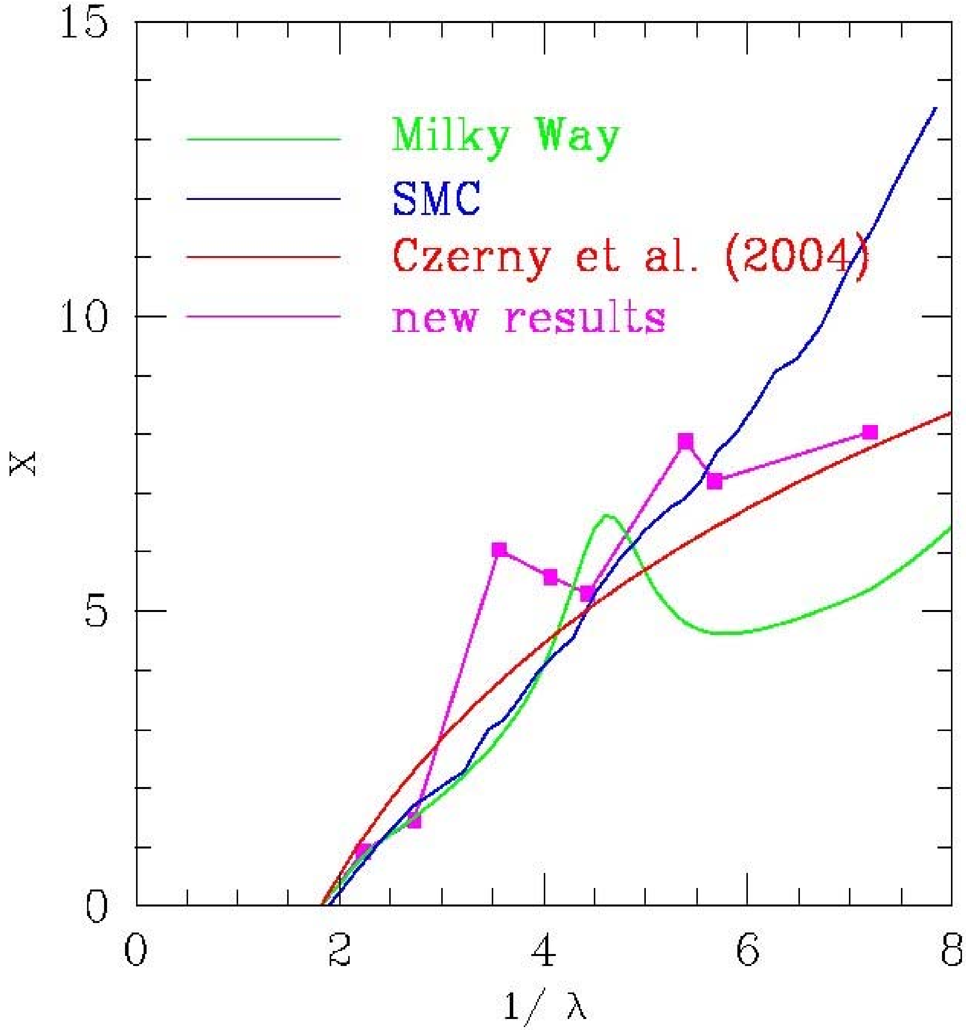
Similar results by Hirashita et al. 2005

Our recent results



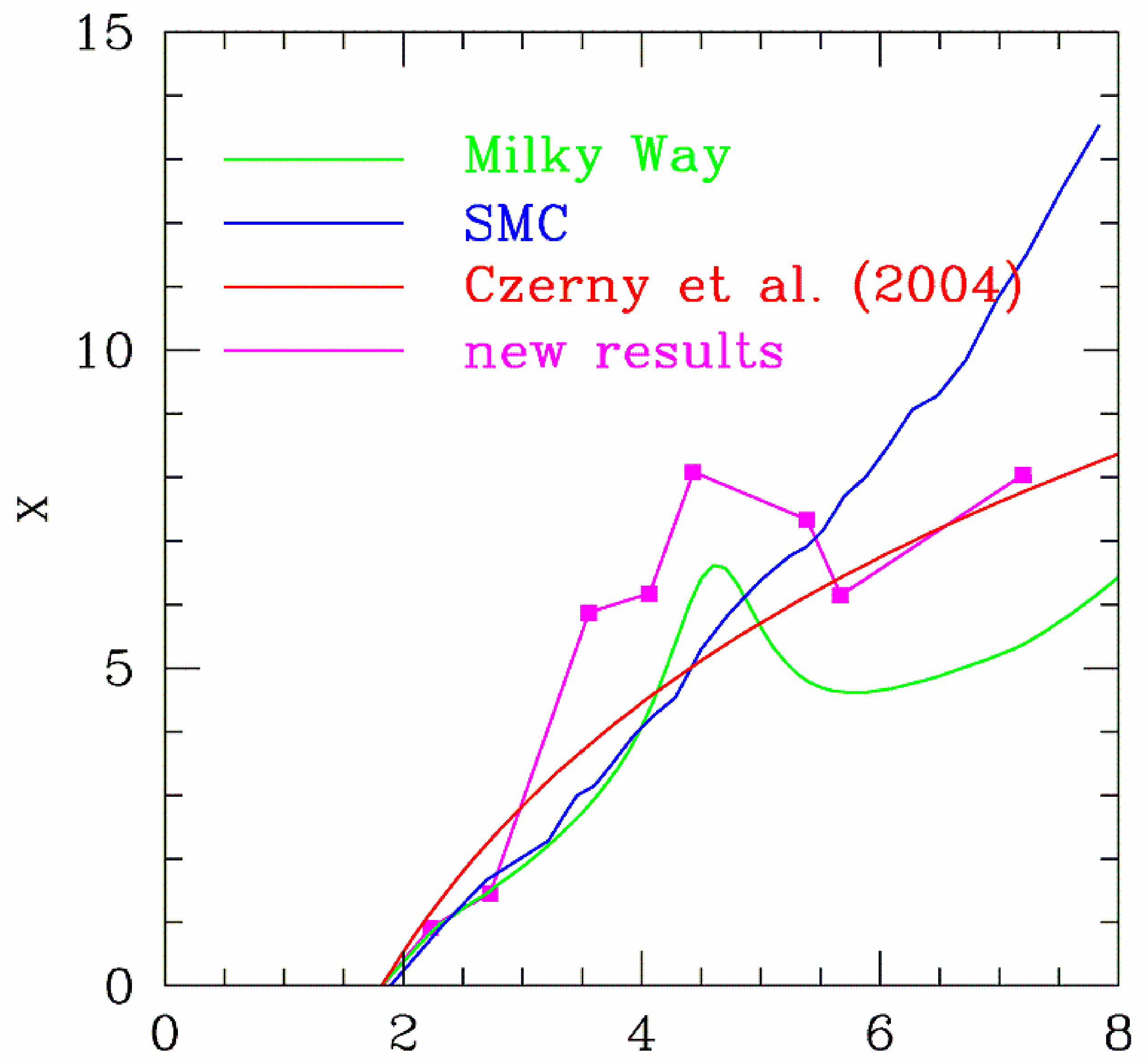
Individual spectra in UV, dispersion in optical.

Our recent results



Extinction curve based on extreme spectra

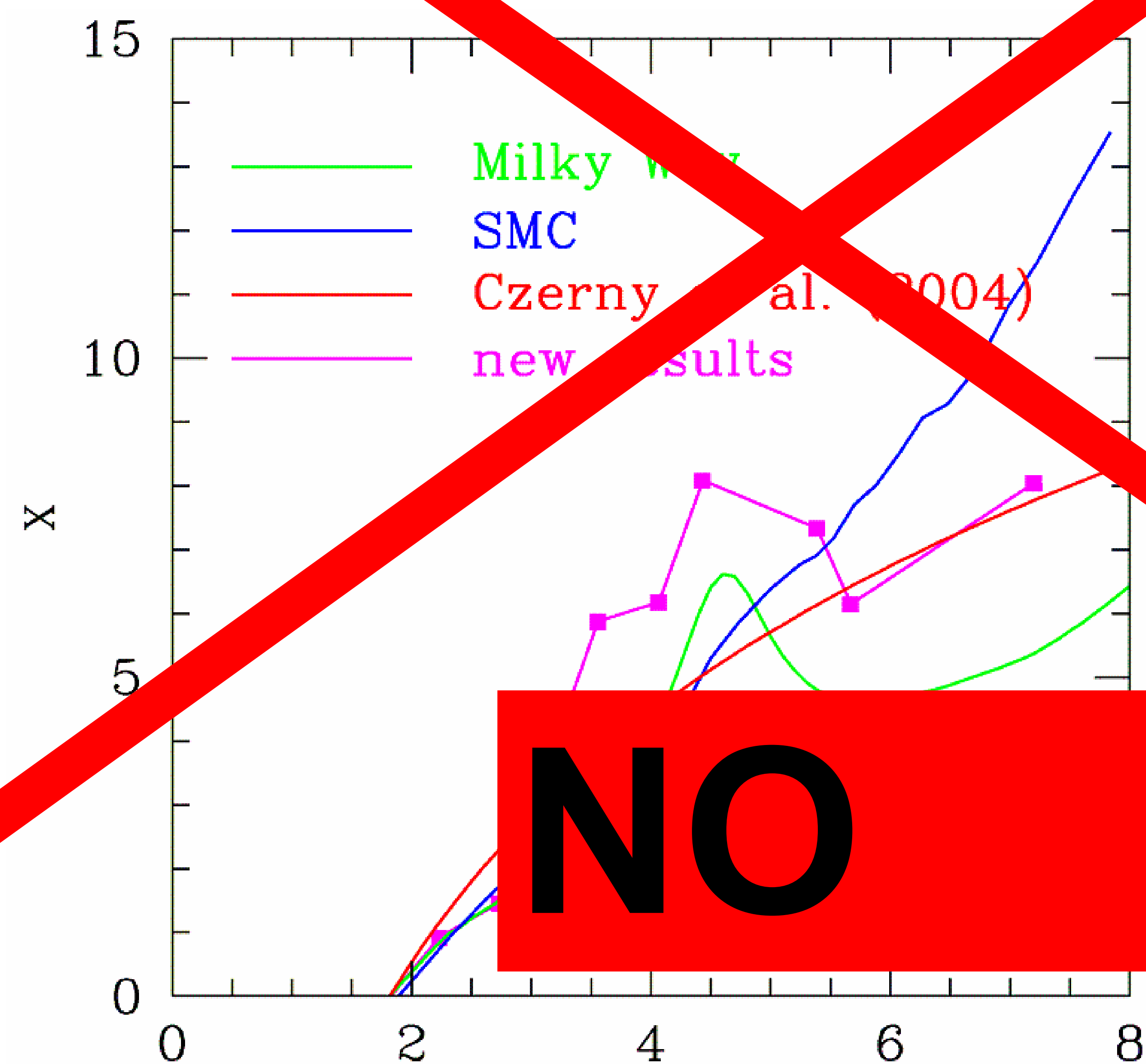
Our recent result:



Averaged extinction curve from individual spectra, weighted mean:

More like Seaton, flatter in far UV than SMC?

Our recent result:



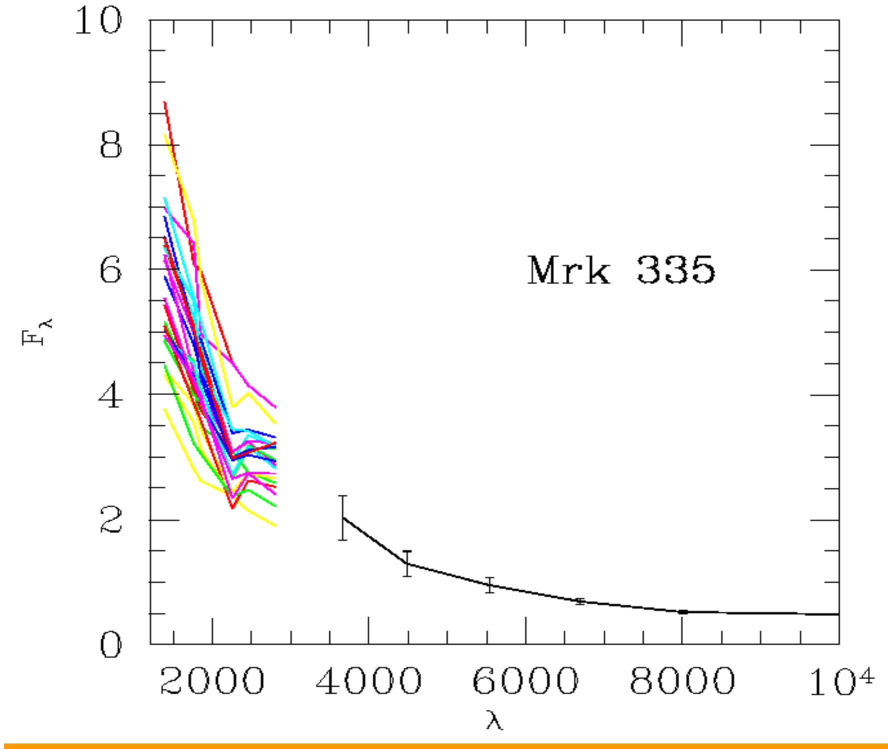
NO

Averaged extinction curve from individual spectra, weighted mean:

More like Seaton but [illegible]r in far UV?


IT WAS JUST
A WARNING !

Our recent results – what data we used …



Intrinsic time delays, Sergeev et al. (2005)

Mrk 335

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

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.

SDSS summary

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

- Metallicity
- 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 dereddened using an extinction curve without 2175 A 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