Meeting #12 AY208 v. Y2K

"Cleaning Up Dust"

Charlie Lada gave you:

History, Techniques, A_λ ← wavelength dep of extinction, E(B-V) [def. of color excess

Today:

Add "Theory" of $\underbrace{\text{Abs., Scatt,}}_{\Downarrow\ \text{Extinction}}$ Polarization

Give dust extra time in this course for ② reasons:

① Most important constituent of M.W. ISM for extragalactic obsv'ns, at many λ's

② AG likes it!

Astronomy 208 - Meeting #12

Interstellar Dust

The Basic Question:

"How much is there & where?"

Ⓐ Easiest Approach: Star-Counting, Extinction Studies (e.g. Barnard, Bok)

Ⓑ Less direct: Thermal Dust Emission (KAO, IRAS, SOFIA, SIRTF) mm, sub-mm

Ⓒ Even Less direct Approach: Reddening Studies

look @ effect of dust on ★ colors

Ⓓ Least direct Approach: Measure Gas, infer N_{dust} from "assumed" dust/gas ratio

Complications:

- Not all dust grains are the same.

PROPERTIES
- sizes
- composition
- shapes

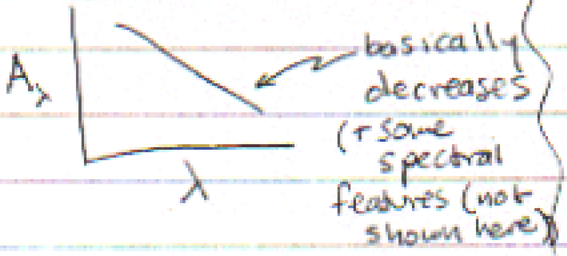
} vary w/local conditions

- Absorption, scattering & emission efficiency depends on "PROPERTIES" above. These efficiencies also vary as a function of λ.

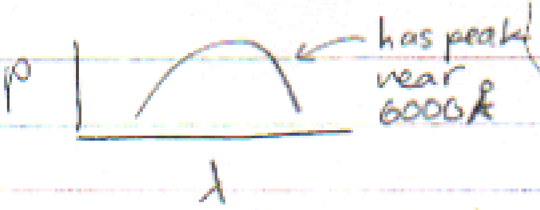
Two ways to look at the problem – they need to be connected for a full understanding...

Empirical

① • extinction vs. wavelength

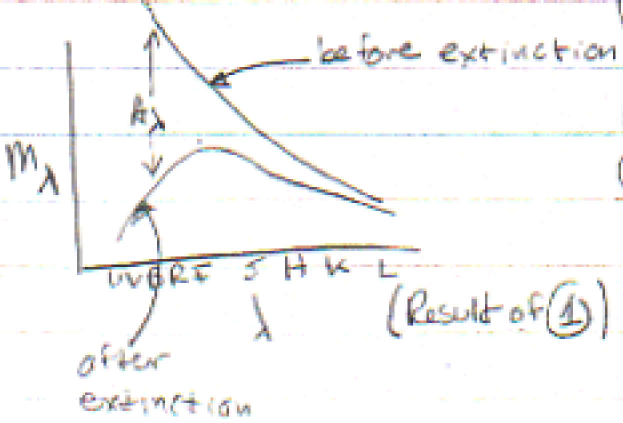


② • polarization vs. wavelength



③ • Star Color Changes as a funxn of Wavelength

aka "Selective Extinction" or "Color Excess"



Theoretical

photon encounters grain

(i) SIZE

Result of encounter depends most strongly on ratio $\frac{a}{\lambda}$.

$a \gg \lambda$ → "brick wall" all photons absorbed

$a \ll \lambda$ → very little effect photons "sneak around" grains

$a \simeq \lambda$ → need detailed scattering theory (e.g. Mie), but this is where grains have maximum effect

(ii) COMPOSITION

index of refraction determines scattering properties

(iii) SHAPE

- "fluffy" or fractal grains have pieces w/ size << a
- strong effect on polarizing properties

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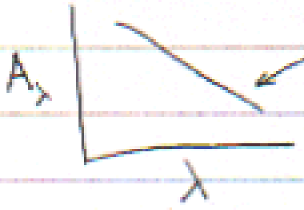
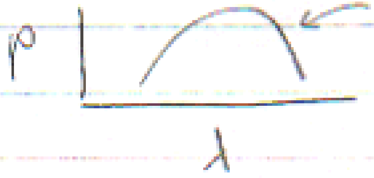


basically decreases (+ some spectral features (not shown here))

② • polarization vs. wavelength



has peak near 6000Å

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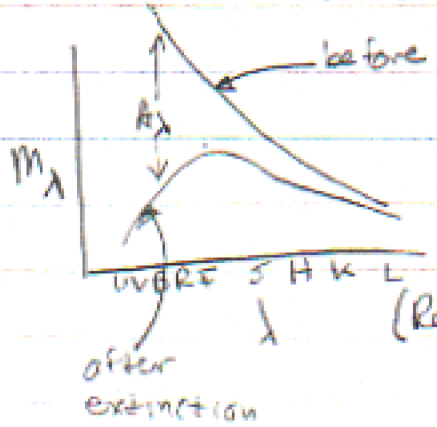

(Result of ①)

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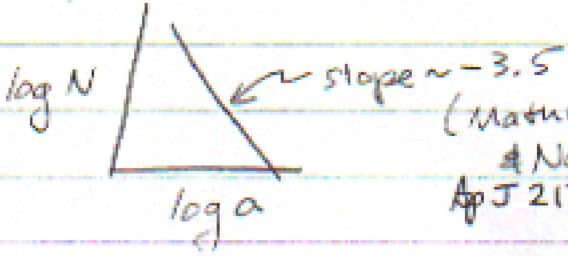
TWO Most fundamental Empirical ⇔ Theoretical Connections

Observed effects of dust depend critically on size distribution, N(a)



(Mathis, Rumpl & Nordseik 1977 ApJ 217, 425)

See Kim & Martin 1994

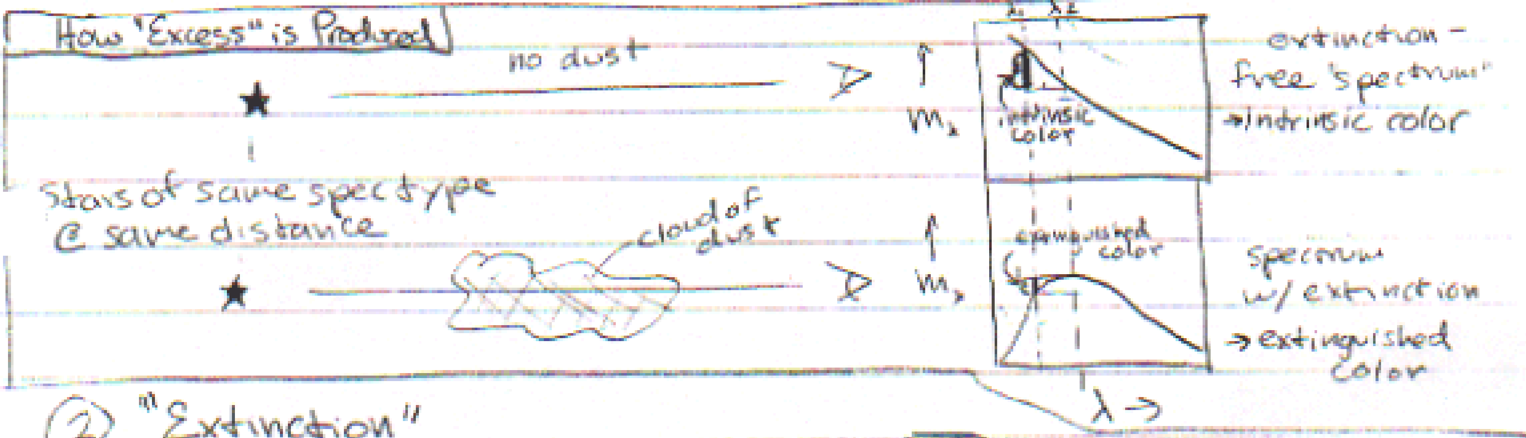
① Total # grains (in "relevant" size range) = $\int_{a_1}^{a_2} N(a)\,da$ related to magnitude of overall effects of dust (e.g. how much extinction, how much emission, etc.)

② Details of Size Distribution (N(a)) related to wavelength dependences of extinction, emission, scattering, polarization, etc.

Arcane Astronomical "Definitions" Related to Dust

① "Color Excess" = degree of reddening or "selective extinction"

$$\text{color excess} = \boxed{E_{\lambda_1-\lambda_2} = \underbrace{\overbrace{(m_{\lambda_1}-m_{\lambda_2})}^{\text{obs'd mags}}}_{\text{observed "color"}} - \underbrace{\overbrace{(m_{\lambda_1}-m_{\lambda_2})_0}^{\text{apparent mags w/o extinction}}}_{\text{"color" that would be observed w/o extinction}}}$$



② "Extinction"

$$\left[\underset{\substack{\uparrow\\ \text{apparent}\\ \text{mag @ }\lambda_1}}{m_{\lambda_1}} = \underset{\substack{\uparrow\\ \text{absolute}\\ \text{mag @ }\lambda_1}}{M_{\lambda_1}} + \underset{\substack{\uparrow\\ \text{extinction}\\ \text{@ }\lambda_1}}{A_{\lambda_1}} + 5\log \underset{\substack{\uparrow\\ \text{distance in pc}}}{d} - 5\right]$$

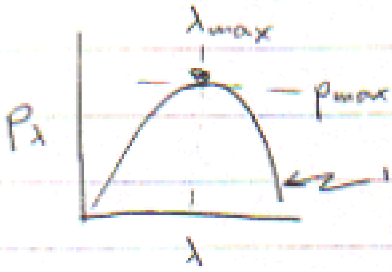
③ "Ratio of total-to-selective Extinction," R_{λ_2}

$$\boxed{A_{\lambda_2} = R_{\lambda_2} E_{\lambda_1-\lambda_2}}$$

$$\text{e.g. "}\underset{\substack{\uparrow\\ \text{extinction in the}\\ \text{V-band}}}{A_V} = \underset{\substack{\uparrow\\ \text{ratio for}\\ \text{V-band}}}{R_V}\, \underset{\substack{\nwarrow\ \text{color excess where}\\ \lambda_1 = B\\ \lambda_2 = V}}{E_{B-V}}\text{"}$$

(~ Part of § 3.3b)

④ Wavelength of Maximum Polarization



"Serkowski Law" $\frac{p_\lambda}{p_{max}} = \exp\left\{-K\ln^2\left(\frac{\lambda_{max}}{\lambda}\right)\right\}$

note: K actually can be a function of λ_{max}

MORE INFO: If grains all same size $\boxed{\lambda_{max} \simeq 2\pi a(n-1)}$

size ↗ (a) ↑ index of refraction (n)
$\simeq 1.6$ for silicates

More on why later.

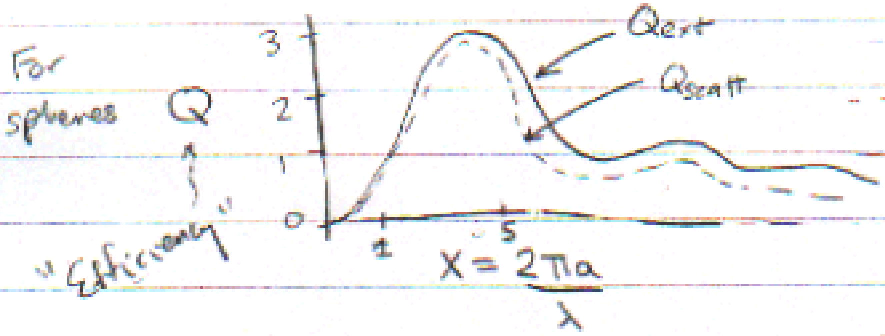
For now realize that this is where the grain size is ≈ wavelength & that tells you about the size distribution of (polarizing) grains.

Empirical claim: (Whittet & van Breda 1978) $\left\{\boxed{R_V = (5.6 \pm 0.3)\lambda_{max}}\right\}$ λ_{max} in μm

↑ (R_V) changes in this also related to changes in grain size distribution

Making the Observation – Theory Connection

All boils down to scattering theory. { Mie scattering theory / Discrete Dipole Approx (DDA) }



exact values depend on complex refractive index, $m = n - ik$

(for dielectrics, $k = 0$)

n, k called "optical constants"
(see work of Draine & Lee)

Extinction

$$Q_{ext} = \overset{\text{absorption}}{Q_{abs}} + \overset{\text{scattering}}{Q_{scatt}}$$ = photons removed from l.o.s.

see Whittet '92 p.58: $A_\lambda = 1.086\, N_d\, \pi a^2 Q_{ext}$ for one-size-fits-all dust

N_d: column density of dust ptcls — [illegible]

$$\boxed{A_\lambda = 1.086\,\pi \int a^2 Q_{ext}(a)\, N(a)\, da}$$ for distribution of N(a)

so if "optical constants" & N(a) are known, then A_λ can be predicted theoretically (e.g. handout from Mathis' review; see Cardelli, Clayton & Mathis 1989 ApJ 345, 245)

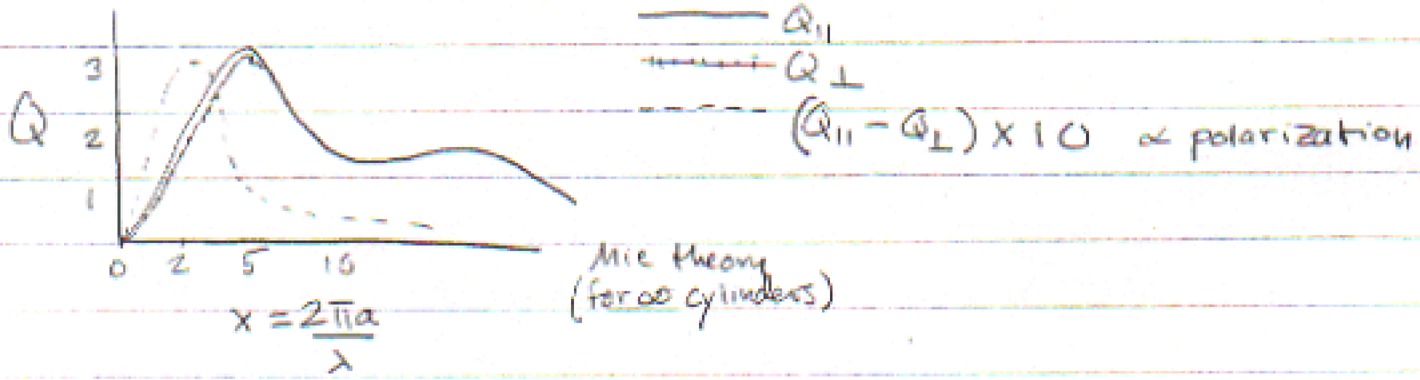
Fine Points:

Albedo $= \gamma = \frac{Q_{scatt}}{Q_{ext}}$ "How shiny?" Very relevant to KBOs

see Whittet '92 p. 61 for discussion of scattering.

Polarization

Efficiencies for extinction are ≠ ∥ & ⊥ to grain's short axis



$\sigma =$ x-secn'l area of grain in plane of wavefront $(\sim \pi \overset{\text{short axis}}{a} \overset{\text{long axis}}{b})$

$$A_\parallel = 1.086\, N_d\, \sigma\, Q_\parallel \;;\quad A_\perp = 1.086\, N_d\, \sigma\, Q_\perp$$

$$\boxed{\rho = \text{polarization} = A_\parallel - A_\perp = 1.086\, N_d\, \sigma (Q_\parallel - Q_\perp)}$$

for a given grain size

$$\boxed{\frac{\rho}{A} = 2\left\{\frac{Q_\parallel - Q_\perp}{Q_\parallel + Q_\perp}\right\} = \text{"polarization-to-extinction ratio"}}$$

Actual p_λ will depend on size distribution of <u>polarizing</u> grains.

See AG for discussion of $\boxed{\text{pol.ay208.jpg}}$ ← in this directory

(return to this in discussion of B-fields)