AST393F **Spring 2007**
Jaffe **February 16, 2007**

Class 12 Notes

1. Apai paper (Science)
   ? Evidence for evolution toward planetary systems – see figures 1 & 2
   claimed relation between flattering and crystallinity

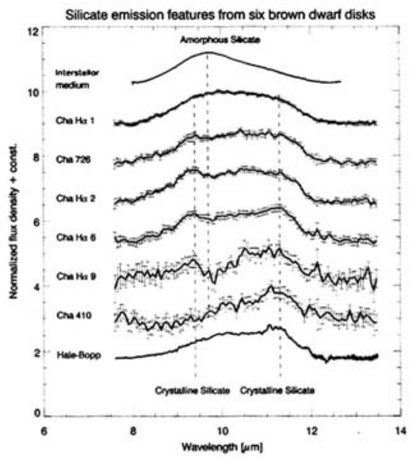


Figure 1
Apai et al. (2005) *Science*

Continuum-subtracted and normalized silicate emission features from our targets. For comparison the spectra of the amorphous silicate-dominated interstellar medium and the crystalline-rich comet Hale-Bopp (*5*) are also shown. The 9.3 μm peak is mainly enstatite, the 11.3 μm peak is from forsterite.

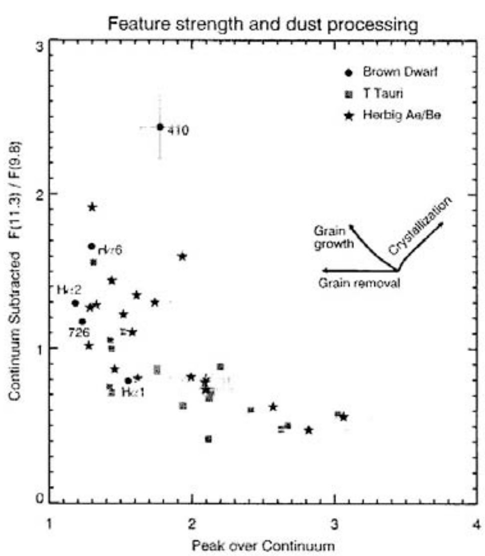


Figure 2
Apai et al. (2005) *Science*

Crystalline contribution to the silicate feature (flux at 11.3 μm over flux at 9.8 μm) as a function of the emission feature strength (peak flux over continuum flux). The correlation recognized for intermediate- and low-mass young stars (Herbig Ae and T Tauri) holds for brown dwarfs, but it is not linear.

2. Question: what is the difference between

(a) Extinction

(b) Absorption

(c) Scattering

Dust optical depth

$$\tau(\lambda) = \mathrm{n_d}\ \mathrm{C_{ext}}\ \mathrm{L}$$

$$\tau(\lambda) = 1.086 A_\lambda$$

Extinction efficiency $Q_{ext}(\lambda) = \dfrac{\mathrm{C_{ext}}(\lambda)}{\sigma_\mathrm{d}}$

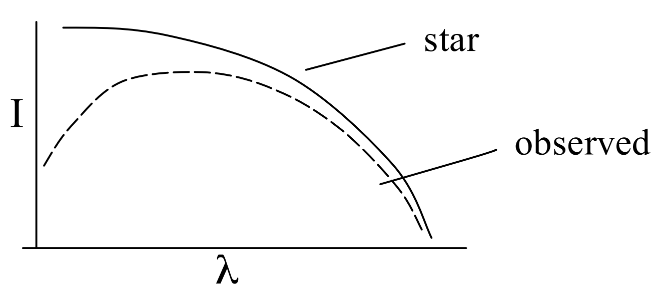
$$Q_{ext}(\lambda) = Q_{abs}(\lambda) + Q_{sca}(\lambda)$$

Albedo $\bar{\omega} = \dfrac{Q_{sca}(\lambda)}{Q_{ext}(\lambda)}$

= 1 for pure scatterers = 0 for pure absorbers

<u>Question:</u> In the large distance approximation for a/λ bigger lines λ, what is the albedo? Babinet's principle

Schematic of how you observe extinction:



Plot in logarithmic terms (magnitudes, apparent, with the zero suppressed), with the absolute stellar magnatude subtracted from each color to remove the stellar properties. See Figure 3

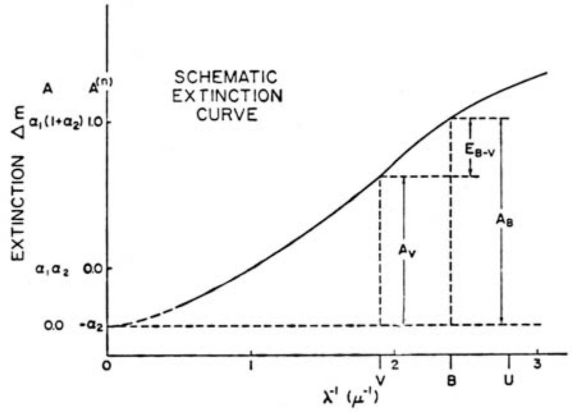


FIG. 1.—Schematic extinction curve

The schematic extinction curve (Fig. 1) conveniently illustrates some important astrophysical terms to which we shall refer. Note that Figures 1 in this and in the Johnson chapter are inverted with respect to each other and that, for theoretical reasons, the abrupt change in the slope[2] in the blue in Johnson's Figure 1 is replaced by the smooth

Apai et al. (2005) *Science*

What you measure easily is $E(\lambda_1 - \lambda_2)$

Question: (Always bluer color first, why?)
You can normalize to B – V and plot curve (Figure 4) – "2200 Å bump" – graphite

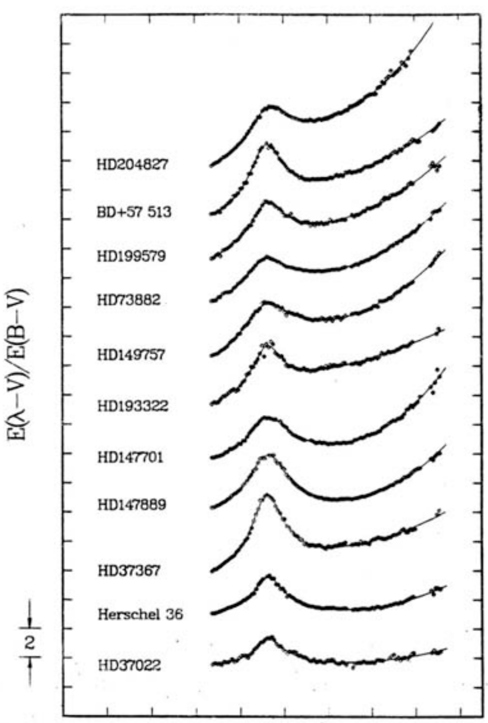


Figure 4a: Savage and Massa 1988, IAU 135

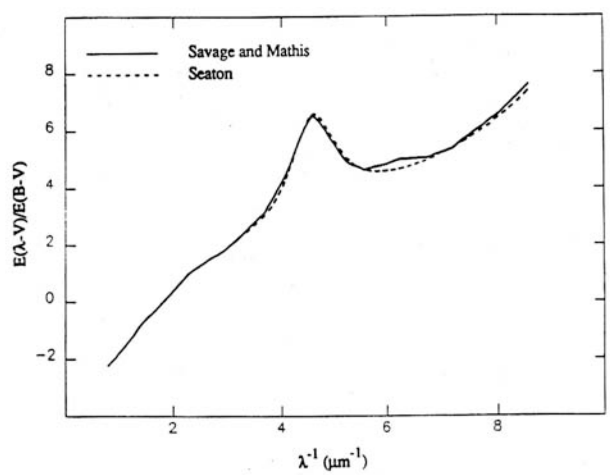


Figure 4b: Standard interstellar extinction curves by Savage and Mathis (1979 ARA[2], 17, 733), Seaton (1979, MNRAS 187)

. **2.** **Two average interstellar extinction curves are illustrated in a plot of $E(\lambda - V)/E(B-V)$ us λ^{-1} in μm^{-1}. The curves are from Savage and Mathis (1979) and Seaton (1979). The age and Mathis curve contains a spurious artifact near $\lambda^{-1} = 6.3\ \mu m^{-1}$ which is the result of minosity mismatch error in the average TD-1 satellite survey data used to produce the average 'e.**

<u>Question:</u> How do you tell what $A_\lambda / E(\lambda_1 - \lambda_2)$ is?

(a) Observe star of known color of known distance
(b) Observe at a long wavelength where $A_\lambda = 0$ and the bootstrap excesses.

TABLE 12

COLOR-EXCESS RATIOS FOR VAN DE HULST'S CURVE NO. 15*

Curve	$\frac{E_{U-V}}{E_{V-K}}$	$\frac{E_{B-V}}{E_{V-K}}$	$\frac{E_{V-R}}{E_{V-K}}$	$\frac{E_{V-I}}{E_{V-K}}$	$\frac{E_{V-J}}{E_{V-K}}$	$\frac{E_{V-K}}{E_{V-K}}$	$\frac{E_{V-L}}{E_{V-K}}$	$\frac{E_{V-M}}{E_{V-K}}$	$\frac{E_{V-N}}{E_{V-K}}$	$\frac{E_{V-O}}{E_{V-K}}$	$\frac{A_V}{E_{V-K}}$
No. 15	0.62	0.36	0.29	0.58	0.83	1.00	1.04	1.06	1.08	1.09	1.10
Curve	$\frac{E_{U-V}}{E_{B-V}}$	$\frac{E_{B-V}}{E_{B-V}}$	$\frac{E_{V-R}}{E_{B-V}}$	$\frac{E_{V-I}}{E_{B-V}}$	$\frac{E_{V-J}}{E_{B-V}}$	$\frac{E_{V-K}}{E_{B-V}}$	$\frac{E_{V-L}}{E_{B-V}}$	$\frac{E_{V-M}}{E_{B-V}}$	$\frac{E_{V-N}}{E_{B-V}}$	$\frac{E_{V-O}}{E_{B-V}}$	$\frac{A_V}{E_{B-V}} = R$
No. 15	1.71	1.00	0.80	1.62	2.30	2.78	2.91	2.95	3.01	3.02	3.05

* van de Hulst, 1949.

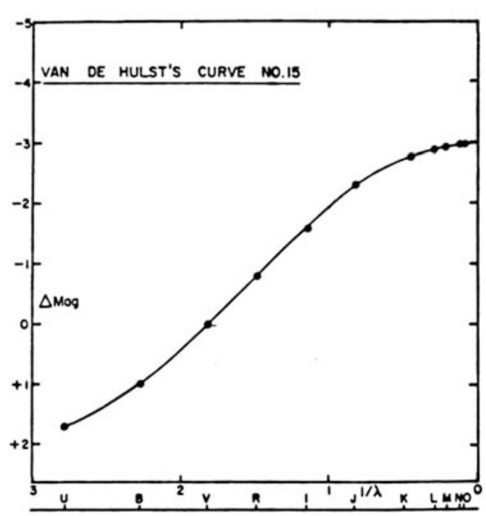
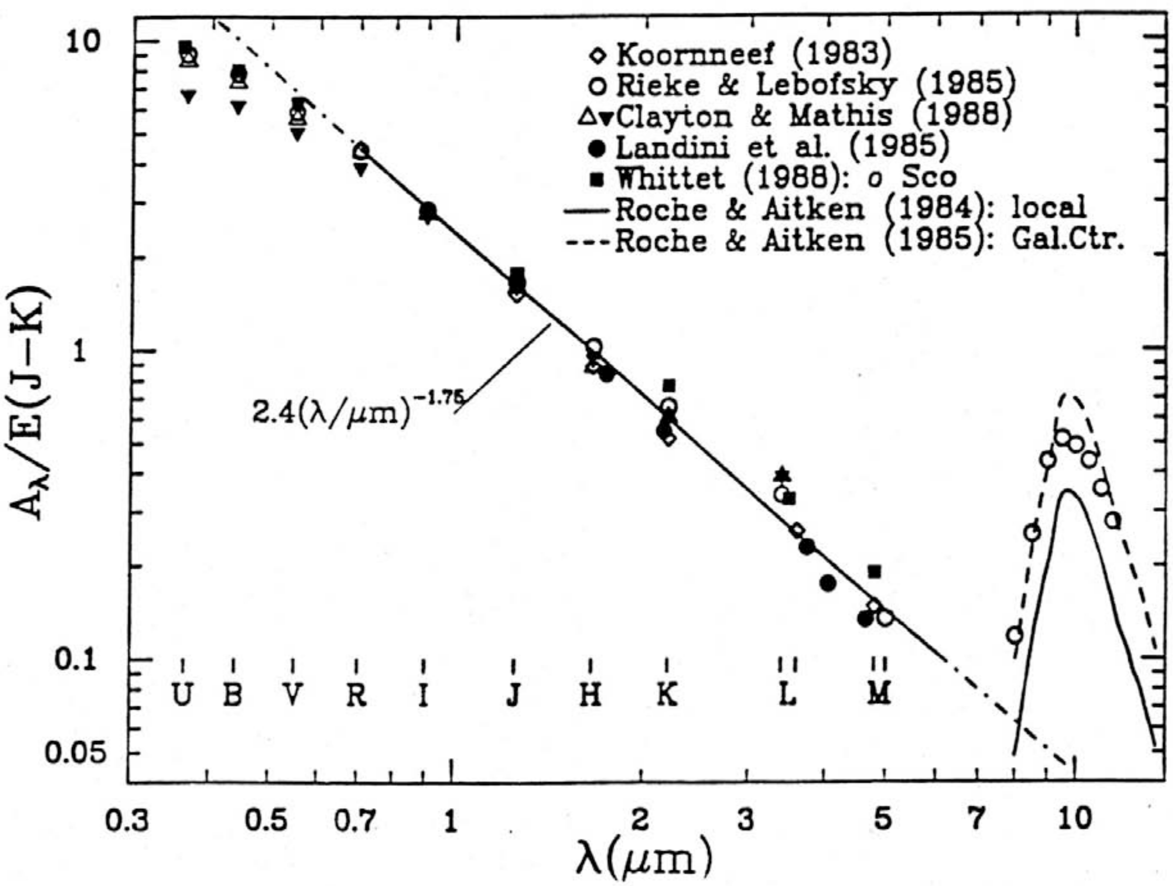


Figure 5 Van de Hulst

FIG. 23.—van de Hulst's theoretical curve No. 15

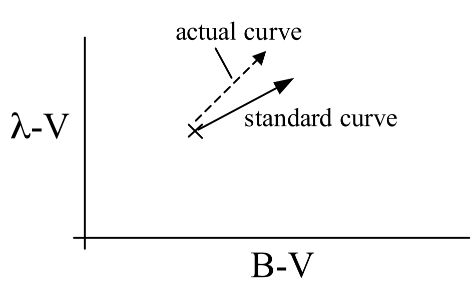
Figure 6 Silicate feature - note that it will appear in emission too!

Genzel (1991) In "The Galactic Interstellar Medium"



$$R = \frac{A_v}{E_{B-V}} \quad = 3 \text{ for standard curve.} \quad \text{It can } = 5 \text{ in dense clouds}$$

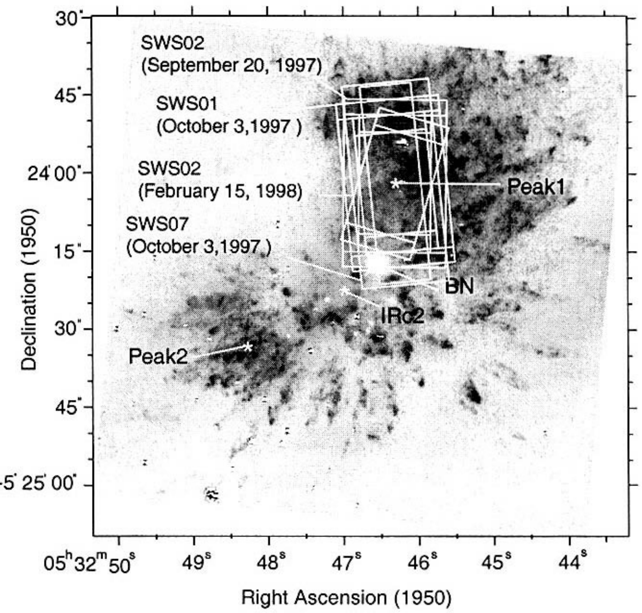
Question: How can we tell which curve to use?



<u>Question:</u> How else can we measure R_λ, apart from stars?

a) Nebular decrements – especially Balmer

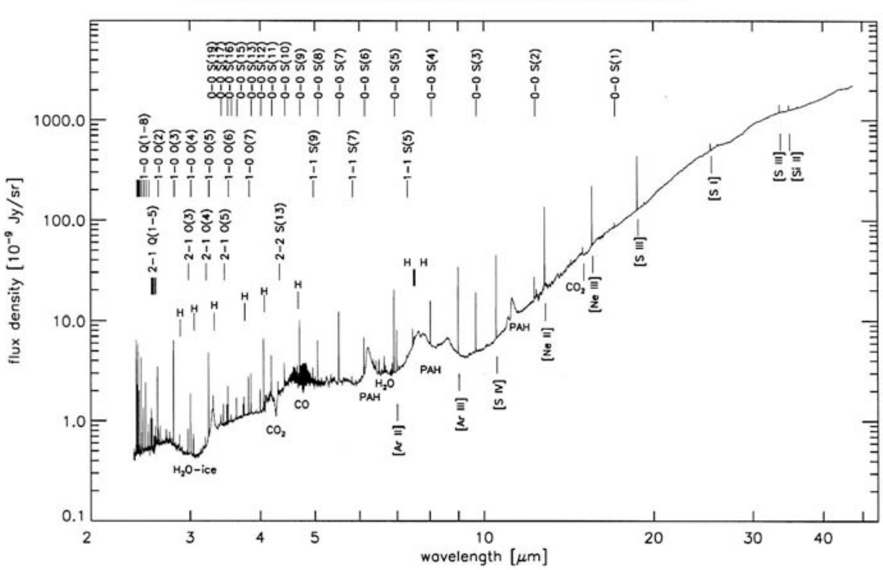
b) Hydrogen H_2 lines



Rosenthal, et al. (2000) *A&A*

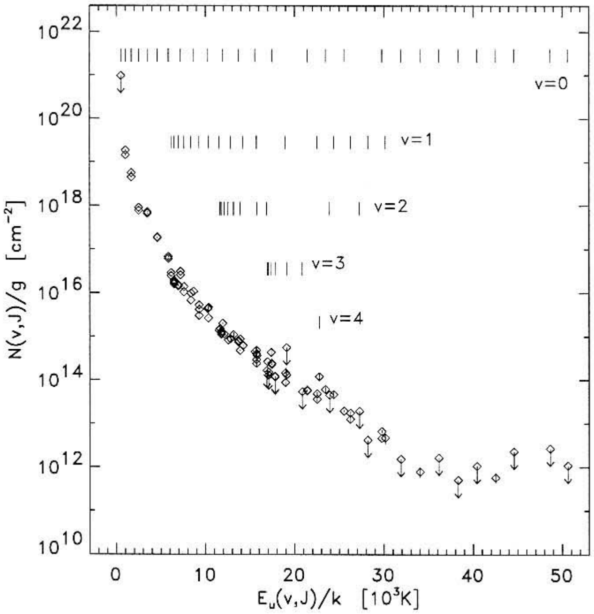
H_2 1-0 S(1) emission of the OMC-1 outflow as seen with the NICMOS camera aboard the HST (Schultz et al. 1999). Overlaid are the various apertures of our ISO-SWS observations, which were centered on $\alpha_{2000.} = 5^h35^m13^s\!.67$, $\delta_{2000.} = -5°22'8''\!.5$, with an aperture of $14'' \times 20''$ for $\lambda < 12\,\mu$m, $14'' \times 27''$ at 12 to 27.5μm, $20'' \times 27''$ at 27.5 to 29μm, and $20'' \times 33''$ at 29 to 45.2μm.

D. Rosenthal et al.: ISO-SWS observations of OMC-1: H_2 and fine structure lines

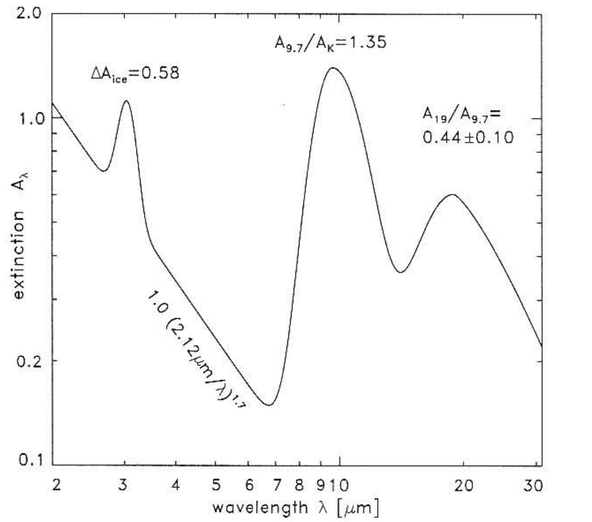


2.4–45 μm spectrum of Orion Peak 1 obtained in the SWS 01 grating scan observing mode. Some of the detected lines, bands and features are identified. The continuum levels of the individual bands, which differ due to aperture changes, were adjusted to make the spectrum appear continuous.

D. Rosenthal et al.: ISO-SWS observations of OMC-1: H_2 and fine structure lines



Excitation diagram of the H_2 level column density distribution toward Peak 1, plotting the observed level columns (not corrected for extinction, divided by the level degeneracy) against level energy.



Near- and mid-infrared extinction (Eq. 2) found from the relative intensities of the H_2 lines observed toward Peak 1. The curve was constructed using four free parameters for which values were derived that minimize the dispersion of the H_2 column density distribution (Fig. 5) for levels with $E/k < 16\,000$ K

Question: Why is this bullet proof as far as excitation goes? - Take pairs of lines arising for the same upper state.

Question: What complication might arise using extended emission line regions – clumpiness of τ. Why is this a problem?

For years, the game was to build models that take into account grain composition and size distributions and can account for extinction, scattering, and emission properties of dust.

Dust doesn't scatter isotropically, we describe the directionality with a cosine weighted integral of the angular scattering function $\frac{d\sigma(\lambda)}{d\Omega}$

$$g \equiv \; <\cos\theta> = \frac{1}{C_{sca}} \int_0^{2\pi} \int_0^{\pi} \frac{d\sigma(\lambda)}{d\Omega} \cos\theta \sin\theta \, d\theta \, d\varphi$$

for $2\pi a << \lambda$ $\qquad \frac{d\sigma(\lambda)}{d\Omega} = \frac{1}{2}\left(H \cos^2\theta\right)$

This has g = 0.

Radiation Pressure

$$F_{RP}(\lambda) = C_{RP}(\lambda) \frac{I(\lambda)}{c}$$

$$C_{RP} = C_{abs} + (1 - g)\, C_{sca}$$

i.e. less important for forward scattering

Question: Why do we care about radiation pressure?
1) Red giant winds
2) Migration of grains in protoplanetary disks

Measuring Extinction in extended regions:
1) Star counts – photographic materials – saturation
2) "Nice" method – works to higher A_v