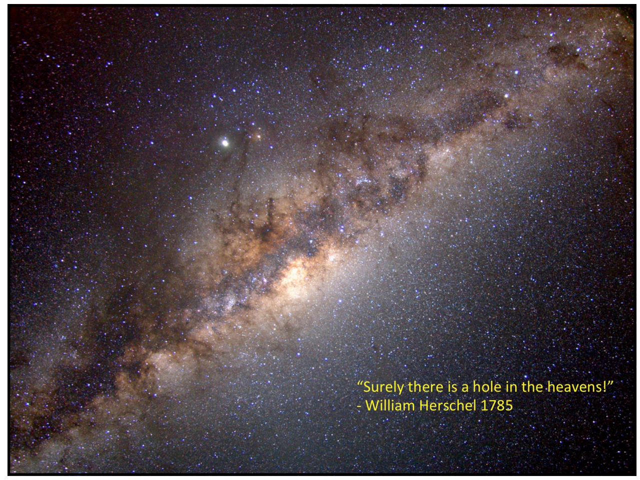
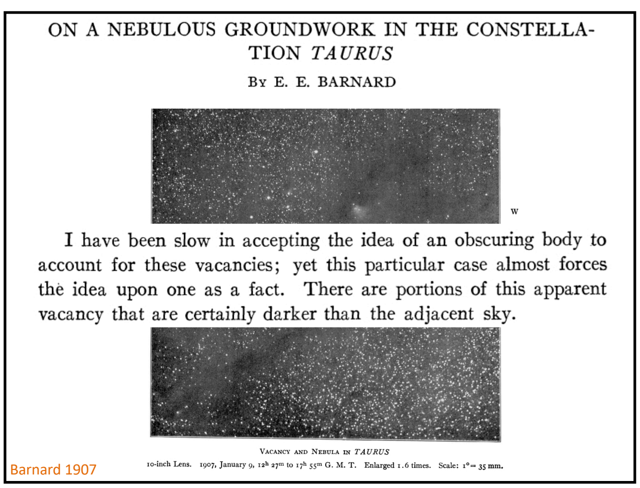



ON A NEBULOUS GROUNDWORK IN THE CONSTELLATION *TAURUS*

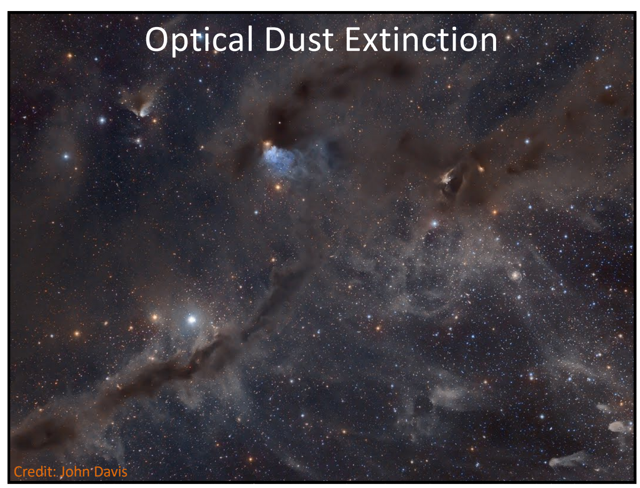
By E. E. BARNARD

I have been slow in accepting the idea of an obscuring body to account for these vacancies; yet this particular case almost forces the idea upon one as a fact. There are portions of this apparent vacancy that are certainly darker than the adjacent sky.

Vacancy and Nebula in *Taurus*

10-inch Lens. 1907, January 9, 12h 27m to 17h 55m G. M. T. Enlarged 1.6 times. Scale: 1° = 35 mm.

Barnard 1907

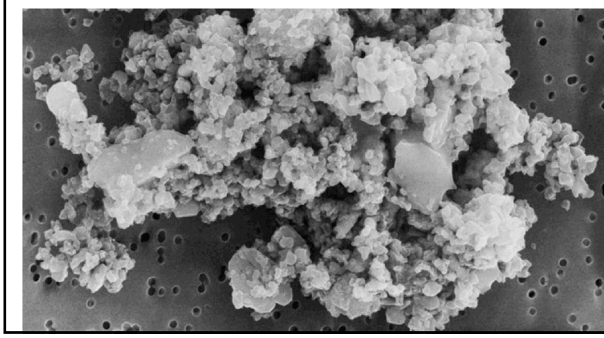


Recognizing Dust - History

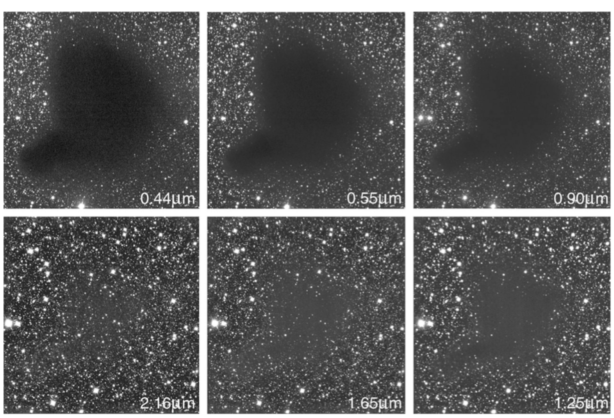
- As early as 1867 Wilhelm Struve found that the density of stars diminished with increasing distance from the Sun: "Stars are dimmed!"
- Jacobus Kapteyn 1904 derives an extinction value of ~ 1.6 mag kpc^{-1} (close to current value of 1.8). However, he didn't believe the result and didn't include it in later work.
- Robert Trumpler 1930 compared luminosity and size of open clusters assuming all their diameters were the same. Identified absorption and color excess with increasing distance.
- Rudnick 1936, Hall 1937, and Stebbins et al. 1939 derive the interstellar reddening law ~ λ^{-1}

Interstellar Dust Grains

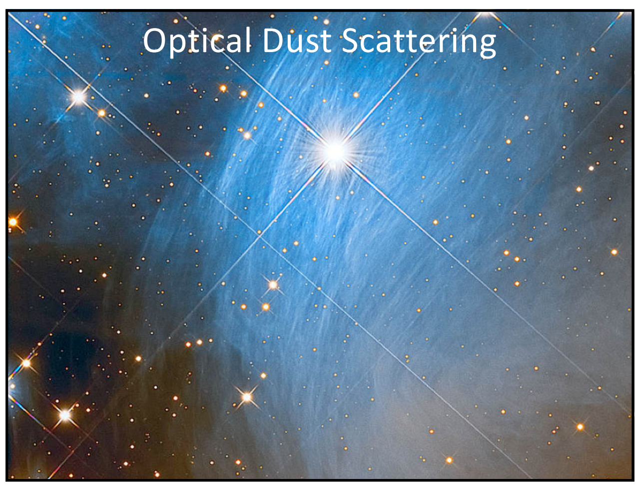
ISM dust sizes from a few atoms up to few μm sizes
can grow much larger in protoplanetary disks



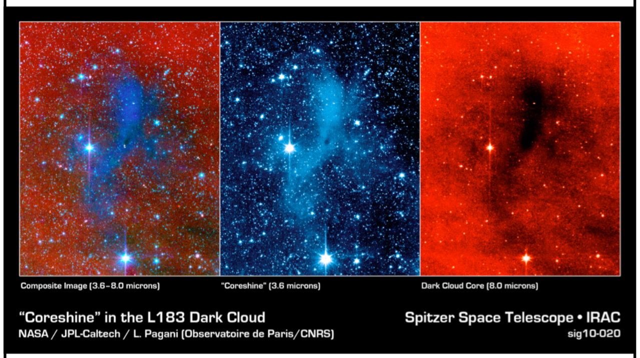
Dust Extinction (Absorption+Scattering)



Optical Dust Scattering



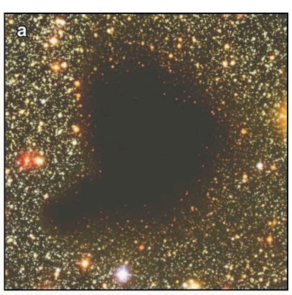
Infrared Dust Scattering – “CoreShine”



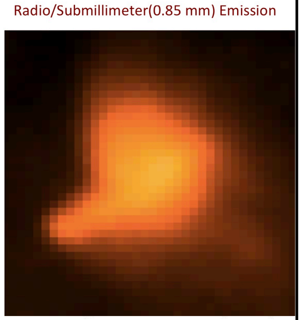
100 μm Dust Emission

Dust Extinction vs. Emission

Optical Absorption/Scattering



Radio/Submillimeter(0.85 mm) Emission



Bergin & Tafalla 2007 ARA&A

Dust Grains

Wavelength dependent extinction (absorption and scattering)
- Typically < 20 μm
- Polarization-dependent attenuation
- Scattered light result in reflection nebula
  - Small angle scattering of x-rays = x-ray scattering “halos”

Thermal emission
- Typically infrared through millimeter (radio)
- Opacity modified blackbody emission
- Microwave (cm-mm) emission from spinning dust grains

Sites of formation of H_2 molecules

Gas Phase Abundance of Diffuse Cloud

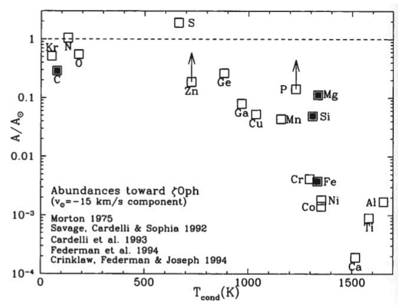


Figure 23.1 Gas-phase abundances (relative to solar) in the diffuse cloud toward ζ Oph, plotted versus "condensation temperature" $T_{\rm cond}$ (see text). Data from Morton (1975), Savage et al. (1992), Cardelli et al. (1993), Federman et al. (1993), Crinklaw et al. (1994). Solid symbols: major grain constituents C, Mg, Si, Fe. The C abundance has been calculated assuming $f(\text{C II}]2325\,\text{Å}) = 1.0 \times 10^{-7}$ (see text). The apparent overabundance of S may be due to observational error, but may also arise because of S II absorption in the H II region around ζ Oph.

Gas Phase Abundance of Diffuse Cloud

Table 23.1 Inferred Elemental Composition of Dust toward ζOph

X	$(N_X/N_{\rm H})_\odot$ [a] (ppm)	$N_{X,\rm gas}/N_{\rm H}$ [b] (ppm)	$N_{X,\rm dust}/N_{\rm H}$ (ppm)	$10^3 M_{X,\rm dust}/M_{\rm H}$
C	295 ± 36	135 ± 33 [d,e]	160 ± 49	1.92 ± 0.59 [e]
		85 ± 20 [d,f]	210 ± 41	2.52 ± 0.49 [f]
N	74.1 ± 9.0	78 ± 13 [g]	-14 ± 16	0
O	537 ± 62	295 ± 36 [d]	242 ± 72	3.87 ± 1.15
		[383] [c]	154 ± 8 [c]	2.46 ± 0.13 [c]
Mg	43.7 ± 4.2	4.9 ± 0.5 [g]	39 ± 4	0.94 ± 0.10
Al	2.8 ± 0.2	0.005 ± 0.001 [h]	2.8 ± 0.2	0.08 ± 0.01
Si	35.5 ± 3.0	1.7 ± 0.5 [i]	34 ± 3	0.95 ± 0.08
S	14.5 ± 1.0	28 ± 16 [j]	-14 ± 16	0
Ca	2.3 ± 0.2	0.0004 ± 0.0001 [k]	2.2 ± 0.2	0.09 ± 0.008
Fe	34.7 ± 3.3	0.13 ± 0.01 [g]	35 ± 3	1.96 ± 0.17
Ni	1.7 ± 0.2	0.0030 ± 0.0002 [j]	1.7 ± 0.2	0.10 ± 0.01
Total if $f(\text{C II}]2325) = 4.78 \times 10^{-8}$ (see text)				9.9 ± 1.3 [e]
Total if $f(\text{C II}]2325) = 1.0 \times 10^{-7}$ (see text)				10.5 ± 1.3 [f]
Total if $f(\text{C II}]2325) = 1.0 \times 10^{-7}$, $N_{\rm O,dust}/N_{\rm H} = 154$ ppm (see text)				9.1 ± 0.6 [c]

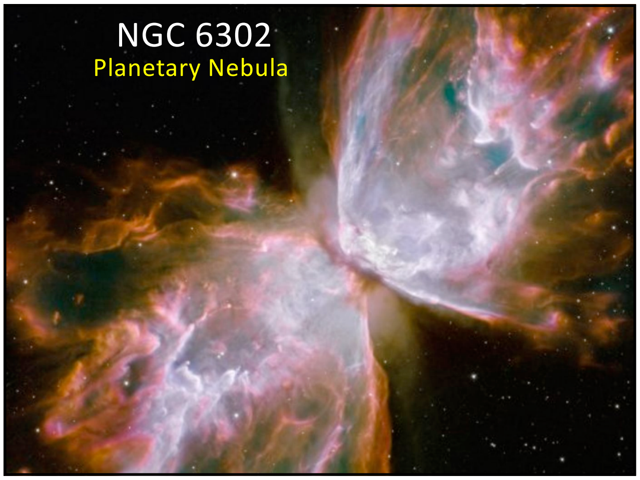
[a] Asplund et al. (2009).
[b] Assuming $N(\text{H})+2N(\text{H}_2)=10^{21.13\pm0.03}\,\text{cm}^{-2}$.
[c] Assuming $N_{\rm O,dust}/N_{\rm H} = 154$ ppm.
[d] Cardelli et al. (1993).
[e] If $f(\text{C II}]2325\,\text{Å}) = 4.78 \times 10^{-8}$ (Morton 2003).
[f] If $f(\text{C II}]2325\,\text{Å}) = 1.00 \times 10^{-7}$ (see text).
[g] Savage et al. (1992).
[h] Morton (1975).
[i] Cardelli et al. (1994).
[j] Federman et al. (1993).
[k] Crinklaw et al. (1994).

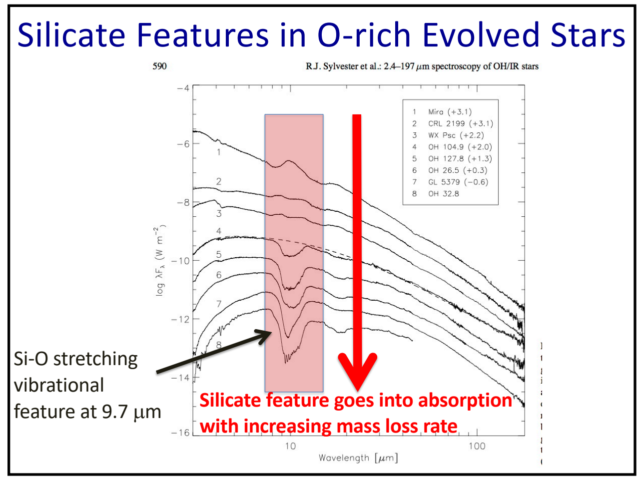
Abundance of Pre-solar Grains

Table 23.2 Types and Properties of Major Presolar Materials[a,b] Identified in Meteorites and IDPs.

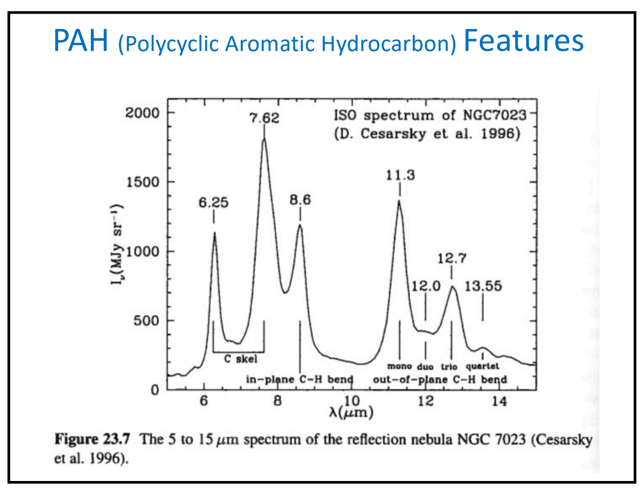
Material	Source	Grain Size (μm)	Abundance[c] (ppm)†
Amorphous silicates	Circumstellar	0.2–0.5	20–3600
Forsterite (Mg_2SiO_4) } Enstatite ($MgSiO_3$)	Circumstellar	0.2–0.5	10–1800
Diamond		~0.002	~1400
P3 fraction	Not known		
HL fraction	Circumstellar		
Silicon carbide	Circumstellar	0.1–20	13–14
Graphite	Circumstellar	0.1–10	7–10
Spinel ($MgAl_2O_4$)	Circumstellar	0.1–3	1.2
Corundum (Al_2O_3)	Circumstellar	0.5–3	0.01
Hibonite ($CaAl_{12}O_{19}$)	Circumstellar	1–2	0.02

[a] Other presolar materials include TiC, MoC, ZrC, RuC, FeC, Si_3N_4, TiO_2, and Fe-Ni metal.
[b] See Huss & Draine (2007) for details and references therein.
[c] Abundance in fine-grained fraction (= matrix in primitive chondrites).


NGC 6302
Planetary Nebula


Silicate Features in O-rich Evolved Stars
590
R.J. Sylvester et al.: 2.4–197 μm spectroscopy of OH/IR stars
1 Mira (+3.1)
2 CRL 2199 (+3.1)
3 WX Psc (+2.2)
4 OH 104.9 (+2.0)
5 OH 127.8 (+1.3)
6 OH 26.5 (+0.3)
7 GL 5379 (−0.6)
8 OH 32.8
log λF$_\lambda$ (W m^{-2})
Wavelength [μm]
Si-O stretching vibrational feature at 9.7 μm
Silicate feature goes into absorption with increasing mass loss rate


NGC 7023 Refelction Nebula
NOAO Kitt Peak 4m


PAH (Polycyclic Aromatic Hydrocarbon) Features
ISO spectrum of NGC7023
(D. Cesarsky et al. 1996)
7.62
6.25
8.6
11.3
12.7
12.0
13.55
C skel
in-plane C–H bend
mono duo trio quartet
out-of-plane C–H bend
I$_\nu$(MJy sr^{-1})
λ(μm)
Figure 23.7 The 5 to 15 μm spectrum of the reflection nebula NGC 7023 (Cesarsky et al. 1996).

Polycyclic Aromatic Hydrocarbons - PAHs

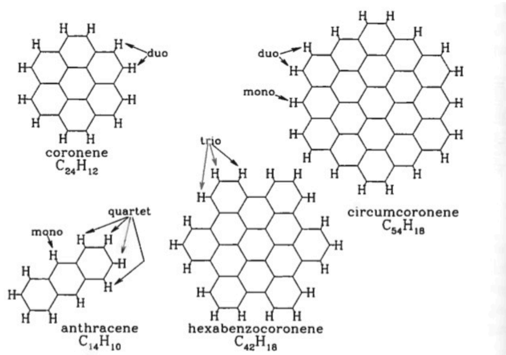
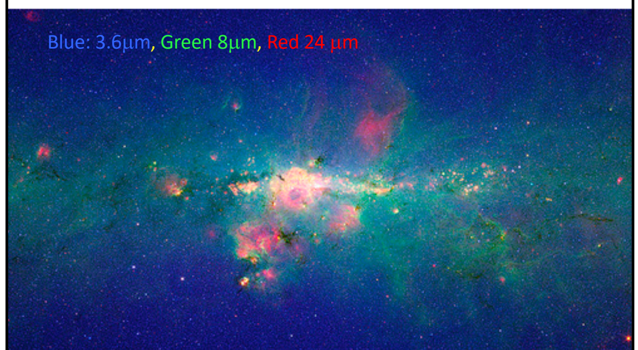


Figure 23.9 Structure of four PAHs. Examples of singlet, doublet, trio, and quartet H atoms are indicated.

Galactic PAH Emission – 8μm (Green)



Credit: GLIMPSE/MIPSGAL Team Spitzer Space Telescope