# Organic Molecules and Meteorites

Bro. Robert Macke SJ
Vatican Observatory

VATICAN OBSERVATORY

# Organics in Meteorites: Possible sources

Astrophysical / Interstellar formation

Protosolar Nebula

Parent body processes

Decreasing abundances with increasing C number indicate abiotic origin. (cf. Pizzarello et al. 2006, *Meteorites II*)

# Basic Meteorite Classification

## Irons and Mesosiderites

Dominated by metallic Fe-Ni
Formed in cores of differentiated parent body

## Achondrites

Formed from crustal material of differentiated parent body
Heavily processed

## Chondrites

Primitive material from undifferentiated parent body
Composed of refractory inclusions, chondrules (glassy melt droplets)
and intergranular matrix

# Carbonaceous Chondrites and Ordinary Chondrites

## Carbonaceous Chondrites

Probably formed further out in solar nebula.
Tend to be aqueously altered to unaltered.
CI, CM, CR, CV, CO, CK, CH

## Ordinary Chondrites

Probably formed closer in to Sun.
Tend to be thermally altered.
H, L, LL

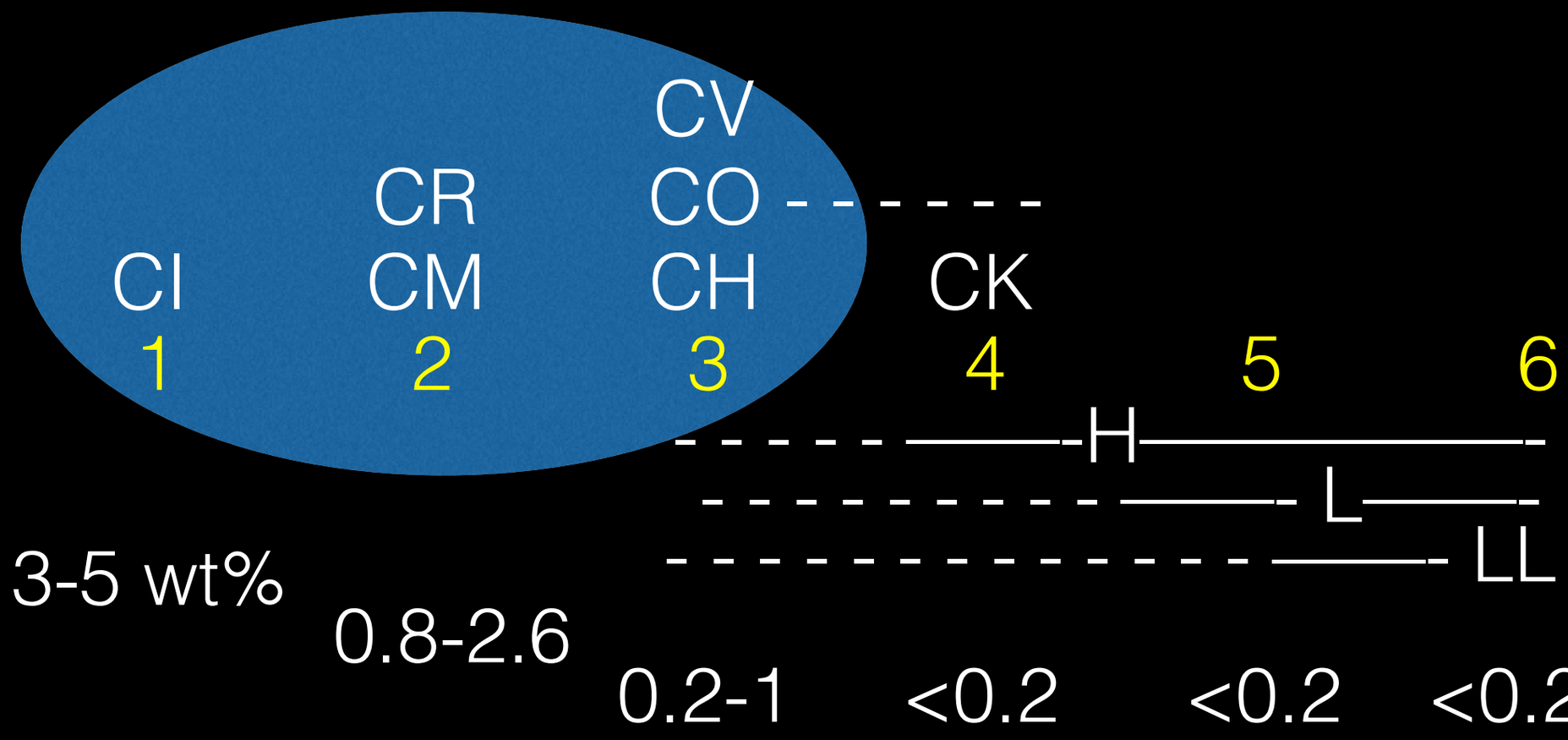
## Enstatite Chondrites

EH, EL

N.B. Carbonaceous Chondrites are not all carbon-rich.
Some have virtually no carbon and some
OCs have comparable C quantities.

# Petrographic Type

Type 3: Little to no alteration
Type 2 and 1: Predominantly aqueously altered
Types 4, 5, 6: Predominantly thermally altered




Carbon abundance also follows petrographic type

(Van Schmuss and Wood, 1967)

# Organics in Meteorites

Predominantly in Carbonaceous Chondrites

Why?

Low alteration or aqueous alteration

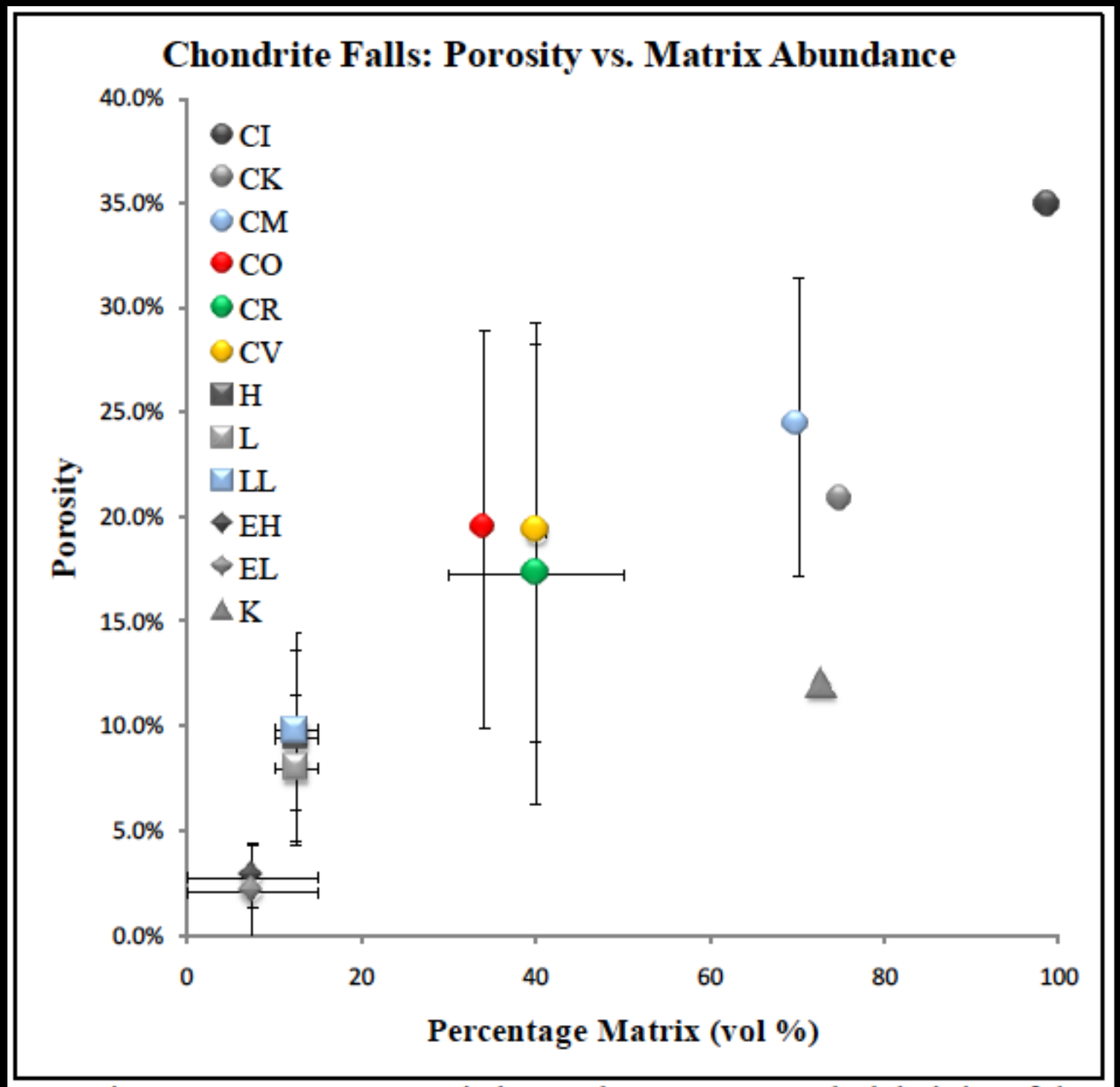
Also:

High temperatures destroy organics such as amino acids.

Chondrules and refractory inclusions formed
at high temperatures (>1000 K).

Matrix remained at low temperature.

# Porosity and Matrix




Data points are group averages, vertical "error bars" are one standard deviation of the population, and horizontal bars represent ranges given in Brearley and Jones (1988).

From Macke (2010)

**Table 1.** The abundances of insoluble and soluble organic compounds (in $\mu$g/g or ppm) found in carbonaceous chondrites. For the CMs, all data are from the Murchison CM2 meteorite, unless otherwise noted (updated from Botta & Bada 2002).

| | CI | CM | CR | Tag. Lake |
|---|---|---|---|---|
| Matrix (vol%) | 100 | ~50 | ~35 | ~80 |
| IOM | ~20,000 | ~10,000 | ~5,000 | ~18,000 |
| Amino acids | ~5[a] | 14-71[d] | 1-250[b] | 0.04-5.6[c] |
| Aromatic hydrocarbons | | 3[d] | 16[e] | |
| Aliphatic hydrocarbons | | >35 | | |
| Monocarboxylic acids | | >300 | 96[e] | 165-448[c] |
| Hydroxy- and dicarboxylic acids | | 14-15 | 212[e] | |
| Purines and pyrimidines | | 1.3 | | |
| Basic N heterocycles | | 7 | | |
| Amines | | 8 | 103[e] | |
| Alcohols | | 11 | | |
| Aldehydes and Ketones | | 27 | | |
| Sulphonic acids | | 68 | | |
| Phosphonic acids | | 2 | | |
| Polyols | | >8[f] | | |

*Notes:*
[a] Average for Orgueil and Ivuna (Ehrenfreund *et al.* 2001).
[b] Range from Martins *et al.* (2007).
[c] Herd *et al.* (2011).
[d] For Y-791198 (Naraoka *et al.* 1998).
[e] For GRA 95229 (Pizzarello *et al.* 2008).
[f] Lower limit of glyceric acid (Cooper *et al.* 2001).

Source: C. M. O'D Alexander (2011) *Proc. IAU Symp.* 280

# Amino Acids

More than 80 amino acid species,
both D and L enantiomers in near-racemic abundances.
(Terrestrial biological organics have 20, all L)

Slight L-enantiomeric excesses of some amino acids.

Some may be the result of terrestrial contamination.
Some may be the result of circularly-polarized UV radiation
in interstellar or protosolar ices.

(cf. Marcellus et al. 2011, ApJ Lett. 727:L27)

# Amino Acids

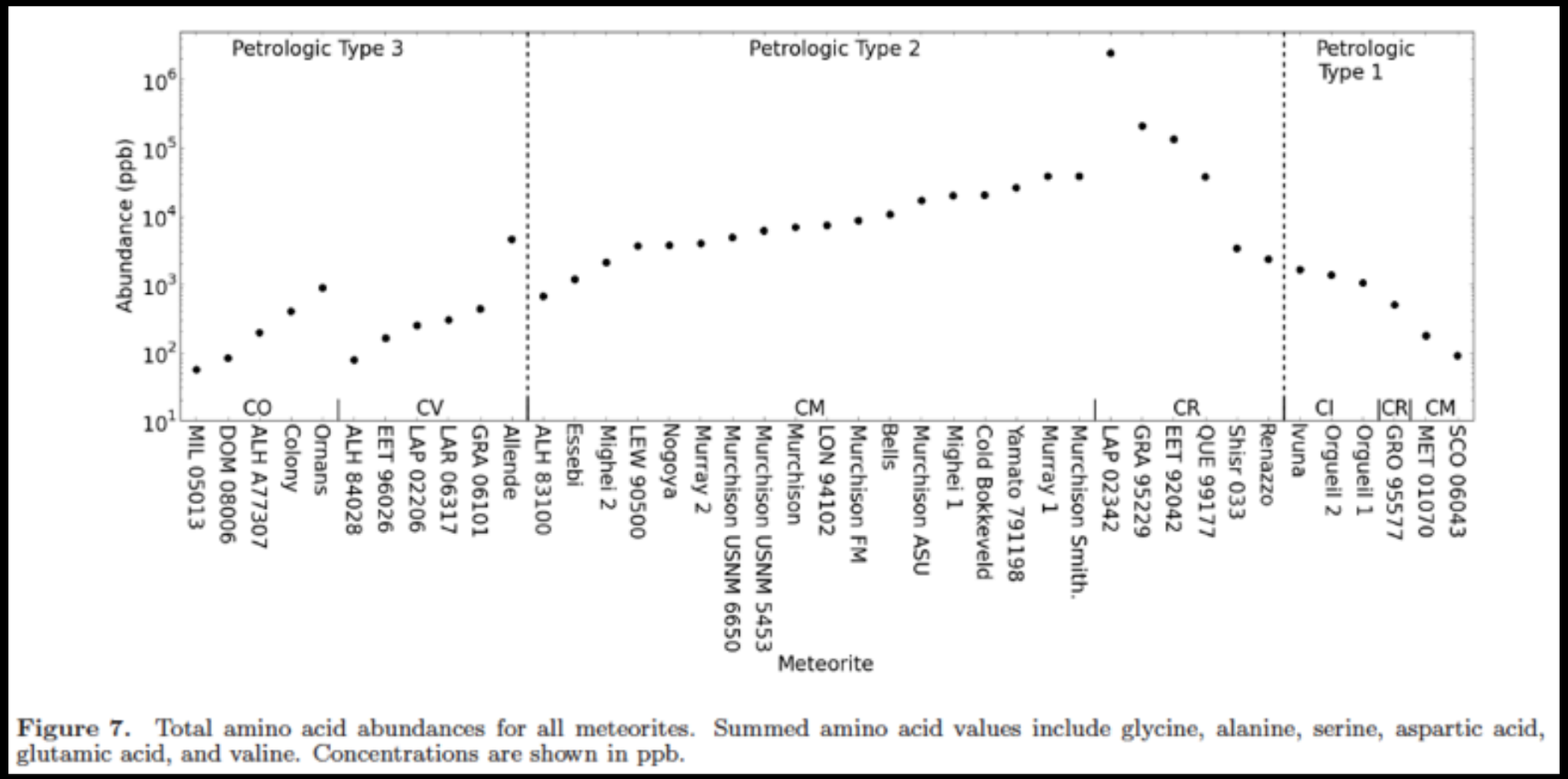



**Figure 7.** Total amino acid abundances for all meteorites. Summed amino acid values include glycine, alanine, serine, aspartic acid, glutamic acid, and valine. Concentrations are shown in ppb.

Source: Cobb and Pudritz (2014) *Ap.J.* 783

# Summary

- Matrix of Carbonaceous Chondrites is the best source for soluble organic material in meteorites.
- While insoluble organic molecules follow total C abundances, amino acids are more abundant in mildly-aqueously-altered (type 2; CR, CM) meteorites.
- Meteorites exhibit a wider variety of organic molecules and isomers than are found in terrestrial sources.
- Organics in meteorites exhibit both D and L enantiomers in near-equal quantities.  There is a slight L excess in some amino acid species.
- All of this is consistent with abiotic processes.