Large-scale Structure: the numerical version

Lecture 4:
Dark Energy and type Ia Supernovae. MCMC in practice (in numerical).

Dragan Huterer
ICTP Trieste/SAIFR Cosmology School
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Makeup of universe **today**

- **Dark Energy**
  - (suspected since 1980s, established since 1998)
  - 74% of universe

- **Dark Matter**
  - (suspected since 1930s, established since 1970s)
  - 22% of universe

- **Baryonic Matter**
  - (stars 0.4%, gas 3.6%)
  - 4% of universe

- Also:
  - radiation (0.01%)
Fine-tuning problem I: Coincidence problem

\[ \rho_{\text{mat}}(a) \propto a^{-3} \]
\[ \rho_{\text{rad}}(a) \propto a^{-4} \]
\[ \rho_{\text{DE}}(a) \propto a^{-3(1+w)} \approx a^0 \]

\( a \) is scale factor
\( a=0 \): Big Bang
\( a=1 \): today
\( a \equiv 1/(1+z) \)

Energy/volume

Time

Inflation
Nucleosynthesis
CMB
Now

10^{-35} \text{ sec} \quad 1 \text{ minute} \quad 380,000 \text{ yr} \quad 13.7 \text{ Gyr}
Type Ia Supernovae

A white dwarf accretes matter from a companion.
SNe Ia are “Standard Candles”

If you know the intrinsic brightness of the headlights, you can estimate how far away the car is (car headlights example)

A way to measure (relative) distances to objects far away
Standardizing the candles

Before correction

"Broader is Brighter"

After correction

Calan/Tololo SNe Ia

Kim, et al. (1997)
But how do you find SNe?

Rate: 1 SN per galaxy per 100 yrs!

Solution:
1. use world’s large telescopes,
2. schedule them to find, then “follow-up” SNe
3. put in heroic hard work

Motivation: to measure geometry of the universe
Supernova Hubble diagram
(binned; each error bar denotes ~20 SN)
Supernova Cosmology Project

No Big Bang

$\Omega_{DE} \equiv \frac{\rho_{DE}}{\rho_{crit}}$

$w \equiv \frac{p_{DE}}{\rho_{DE}}$
Supernova analysis - it’s simple!

The difference between the apparent and absolute magnitude is the *distance modulus*. So

\[
DM = m - M = 2.5 \log_{10} \left( \frac{L}{f} \right) + \text{const} = 5 \log_{10} \left( \frac{d_L}{10 \text{ pc}} \right)
\]

(590)

where, note, we have taken care of the constants correctly, so that DM = 0 at 10 parsecs.

This equation can be re-written as

\[
m = M + 5 \log_{10} \left( \frac{d_L}{1 \text{ Mpc}} \right) + 25
\]

(591)

\[
= M + 5 \log_{10}(H_0 d_L) - 5 \log_{10}(H_0 \times 1 \text{ Mpc}) + 25
\]

(592)

\[
\equiv 5 \log_{10}(H_0 d_L) + \mathcal{M}
\]

(593)

where the "script-M" factor is defined as

\[
\mathcal{M} \equiv M - 5 \log_{10}(H_0 \times 1 \text{ Mpc}) + 25.
\]

(594)

To summarize

\[
m = 5 \log_{10}(H_0 d_L) + \mathcal{M}
\]

(595)

Parameters are therefore: Omega_m, Omega_L (or w), etc, plus a single nuisance parameter $\mathcal{M}$.
Further reading

Popular articles:
“The Once and Future Cosmos”, Scientific American special issue, December 2002

Standard semi-technical review: