The impact of cosmic dust on cosmology with supernovae

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in collaboration with

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The opacity of the Universe

$$\tau_{obs}(\lambda, z) = \int_0^z \sigma n_0 \bar{\tau} \left( \frac{\lambda}{1 + z} \right) \frac{(1 + z)^2}{H(z)} \, dz$$

Tolman test (More et al. 09)
QSO color scatter (Moorsell & Goobar 05)
SNe Ia + H(z) (Avgoustidis et al. 09)
dust around galaxies (Menard et al. 09)
dust in MgII absorbers (Menard et al. 07)
The opacity of the Universe

\[ \tau_{obs}(\lambda, z) = \int_0^z \sigma n_0 \tau \left( \frac{\lambda}{1 + z} \right) \frac{(1 + z)^2}{H(z)} \, dz \]
Extracting cosmological parameters from supernova magnitudes

1: Correct for dust extinction due to our Galaxy

2: The distance modulus is described with an unknown stretch factor and an unknown extinction

\[ \mu_i = m_{\text{obs},i} - M + \alpha (s_i - 1) - \beta c_i \]

Assumption: \( \alpha \) and \( \beta \) are redshift independent

3: A chi-square is performed to extract the cosmology and the best stretch and extinction coefficients
Extracting cosmological parameters from supernova magnitudes

\[ \mu_i = m_{\text{obs},i} - M + \alpha (s_i - 1) - \beta c_i \]

The observed color excess \( c_i \) has several contributions:

\[ c_i = \sum_k c_{i,k} \]

Each of them should be corrected with the appropriate \( \beta \) or \( R_B \):

\[ \delta m_i = \sum_k \beta_{i,k} c_{i,k} \]

If not, a bias is introduced in the distance modulus estimate:

\[ \delta m_{\text{bias},i} = (\beta_d - \beta_0) c_d(z_i) \]
Effects on cosmological parameters

$$\mu_B = m_B^* - M + \alpha(s - 1) - \beta c$$
Effects on cosmological parameters

$$
\mu_B = m_B^* - M + \alpha(s - 1) - \beta c
$$
<table>
<thead>
<tr>
<th>Parameter</th>
<th>No Correction</th>
<th>High $A_B$ $\beta_d = 4.9$</th>
<th>High $A_B$ $\beta_d = 4.9 \pm 2.6$</th>
<th>Low $A_B$ $\beta_d = 4.9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda$CDM: $\Omega_M$</td>
<td>0.291$^{+0.032}_{-0.030}$</td>
<td>0.308$^{+0.034}_{-0.031}$ (0.55$\sigma$)</td>
<td>0.308$^{+0.039}_{-0.035}$ (0.55$\sigma$)</td>
<td>0.304$^{+0.033}_{-0.031}$ (0.42$\sigma$)</td>
</tr>
<tr>
<td>$w$CDM: $\Omega_b$</td>
<td>0.0457$^{+0.002}_{-0.002}$</td>
<td>0.046$^{+0.002}_{-0.002}$ (0.35$\sigma$)</td>
<td>0.045$^{+0.003}_{-0.002}$ (0.25$\sigma$)</td>
<td>0.045$^{+0.002}_{-0.002}$ (0.25$\sigma$)</td>
</tr>
<tr>
<td>$h$</td>
<td>0.695$^{+0.018}_{-0.017}$</td>
<td>0.687$^{+0.018}_{-0.017}$ (0.45$\sigma$)</td>
<td>0.688$^{+0.020}_{-0.019}$ (0.40$\sigma$)</td>
<td>0.688$^{+0.018}_{-0.017}$ (0.40$\sigma$)</td>
</tr>
<tr>
<td>$\Omega_M$</td>
<td>0.273$^{+0.017}_{-0.016}$</td>
<td>0.279$^{+0.017}_{-0.016}$ (0.36$\sigma$)</td>
<td>0.278$^{+0.018}_{-0.017}$ (0.30$\sigma$)</td>
<td>0.278$^{+0.017}_{-0.016}$ (0.30$\sigma$)</td>
</tr>
<tr>
<td>$-w$</td>
<td>0.968$^{+0.068}_{-0.061}$</td>
<td>0.940$^{+0.067}_{-0.061}$ (0.43$\sigma$)</td>
<td>0.944$^{+0.072}_{-0.067}$ (0.37$\sigma$)</td>
<td>0.944$^{+0.062}_{-0.066}$ (0.37$\sigma$)</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>all models</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$</td>
<td>$-19.31 \pm 0.03$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>$1.37 \pm 0.13$</td>
</tr>
<tr>
<td>$\beta$</td>
<td>$2.45 \pm 0.12$</td>
</tr>
</tbody>
</table>

$\sim 3\%$ (or $0.4 \sigma$) offset in $w$
SUMMARY

The current formalism used to make supernovae standard candles uses a unique $\beta$ (or $R_B$) coefficient to convert color change into magnitude change.

Current results indicate $\beta \approx 2$ ($R_V \approx 1$)

The presence of intergalactic breaks the above assumption.

Including its effects into the cosmological analysis changes $w$ by 3% (or 0.4$\sigma$ of the latest SNLS results).