Tests for the Expansion of the Universe

Martín López-Corredoira

Instituto de Astrofísica de Canarias
(Tenerife, Canary islands, Spain)

May 2015
Expansion of the Universe

1) $T_{\text{CMBR}}(z)$ test

Variation of microwave background radiation temperature with $z$. This temperature is obtained from its relationship with the excitation in atomic/molecular transitions due to the absorption of radiation.

- MacKellar (1941) detects with this method in Cyan molecules a background radiation temperature of 2.3 K

Static Universe:

Universe in expansion:

$T_{\text{CMBR}}(z)=2.73(1+z)$ K

$T_{\text{CMBR}}(z)=2.73$ K (local CMBR origin)

$T_{\text{CMBR}}(z)=2.73(1+z)$ K (distant CMBR origin with tired light)
Expansion of the Universe

1) $T_{\text{CMBR}}(z)$ test

$T_{\text{CMBR}}(z) = (2.725 \pm 0.002) \times (1 + z)^{1.007 \pm 0.027}$

Nonetheless, there are other results which disagree this dependence (Krelowski et al. 2012; Sato et al. 2013). There might be some excess temperature due to collisional excitation (Molaro et al. 2002) or bias due to unresolved structure in low space resolution mapping (Sato et al. 2013).

Noterdaeme et al. (2011): $T_{\text{CMBR}}(z) = (2.725 \pm 0.002) \times (1 + z)^{1.007 \pm 0.027}$
Expansion of the Universe

1) $T_{\text{CMBR}}(z)$ test

Luzzi et al. (2015): $T_{\text{CMBR}}(z) = T_{\text{CMBR},0} \times (1 + z)^{0.978 \pm 0.018}$

With thermal Sunyaev Zel’dovich effect
Expansion of the Universe

2) Time dilation test

Proposed by Wilson (1939)

Universe in expansion:

- Due to the motion, pulses of intrinsic period $T$ are observed with period $T(1+z)$.

Static Universe:

- Pulses of intrinsic period $T$, are observed with period $T$. 
Expansion of the Universe

2) Time dilation test

Results of the test:

- Goldhaber et al. (2001): in SNIa the periods are proportional in average to \((1+z)^{1.07\pm0.06}\) (photom.);
- Blondin et al. (2008): \((1+z)^{0.97\pm0.10}\) (with spectra)
- Hawkins (2010): in quasars, there is no time dilation
- Crawford (2009): in \(\gamma\)-ray bursts, there is no time dilation
Expansion of the Universe

2) Time dilation test

Skepticism on the result with SNIa:

- Leaning (2006): most (18/22) SNIa light curves can be fitted without time dilation by allowing a modificacion of zero-point of the calibration within the uncertainties (see also Brynjolfsson 2004).


- Other hypotheses without expansion (eg., variable mass [Narlikar & Arp 1997], cosmochronometry [Segal 1997], variable speed of light [Holushko 2012]) also predict a factor (1+z)

- Are not there variations of T due to evolution?
Expansion of the Universe

3) Hubble diagram test

Variation of apparent magnitude vs. $z$, up to high values of $z$

LaViolette (1986): cD galaxies and radiogalaxies; Solid line: static Universe
Dashed line: expanding Universe ($q_0=0.5$)

Today, the test favours the static rather than expanding Universe, but the **dark energy** and/or **evolution** of galaxies can solve the discrepancy with the expanding model.
Expansion of the Universe

3) Hubble diagram test

Variation of apparent magnitude vs. z, up to high values of z

With SNIa (supposed to be without evolution), the standard model works, but some static models also fit the data.

López-Corredoira (2010)
Expansion of the Universe 4) Tolman test

Proposed by Hubble & Tolman in 1935:
Surface brightness (flux per unit angular area)
proportional to \((1+z)^{-n}\), with \(z=\Delta \lambda/\lambda\) (redshift)

If AB magnitudes are used, the dimming factor is \((1+z)^{1-n}\)

Universe in expansion: \(n=4\)  Static Universe: \(n=1\)

- A factor \((1+z)\) due to the loss of energy in each photon.
- A factor \((1+z)\) due to the loss of energy in each photon.
- A factor \((1+z)\) due to time dilation.
- Two factors \((1+z)\) due to the increase of angular size in each direction.
Expansion of the Universe 4) Tolman test

No variation with redshift of NUV and FUV surface brightness (comparing the fluxes at rest) of disc galaxies with $M$ between 17.5 and 19.0.

This is consistent with a static Universe without evolution of galaxies; and would need a strong evolution to make it compatible with standard cosmology.

(Lerner et al. 2014)
Expansion of the Universe

5) Angular size test

The test favours the static rather than expanding Universe (with $\Omega_m=0.24$, $\Omega_\Lambda=0.76$).

Standard cosmology claims that evolution of galaxies size explains the discrepancy with the expanding model but this evolution is too strong.

López-Corredoira (2010)
Expansion of the Universe

5) Angular size test

The necessary evolution to make compatible the standard cosmology is too strong and it cannot be explained by:

- Early galaxy formation with much higher densities.
- Luminosity evolution.
- Merger ratio.
- Massive outflows due to a quasar feedback mechanism.

(López-Corredoira 2010)
Expansion of the Universe

6) UV Surface brightness limit

Dashed line indicates the maximum UV Surface brightness (Lerner 2006), which is exceeded for the expanding Universe but not for static one.

(López-Corredoira 2010)
Expansion of the Universe

7) Alcock-Paczynski test

Given an object with spherical symmetry, the radius along the line of sight is

\[ s_\parallel = \Delta z \frac{d(d_{\text{com}}(z))}{dz} \]

and the radius perpendicular to the line of sight is

\[ s_\perp = \Delta \Theta (1+z)^m d_{\text{ang}}(z) \] \[ m=1 \text{ with expansion, } m=0 \text{ for static} \]

We define the ratio:

\[ y \equiv \frac{\Delta z \ s_\perp}{z \Delta \Theta \ s_\parallel} \]

which is independent of the evolution and depends on the cosmological comoving distance \((d_{\text{com}}(z))\) and the angular distance \((d_{\text{ang}}(z))\)
Expansion of the Universe

7) Alcock-Paczynski test

With BAO peak data, $\Lambda$CDM with standard values of parameters is also excluded at 99.34% C.L. and static with tired light, but also an expanding Universe with $R_h=ct$ or $w$CDM with:

(Melia & López-Corredoira 2015)

SDSS-III/BOSS data
Confidence level contours of 68.3% C.L, 95.4% C.L., 99.73% C.L. The concordance $\Lambda$CDM in the cross.
<table>
<thead>
<tr>
<th>TEST</th>
<th>EXPANSION</th>
<th>STATIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{CMBR}(z)$</td>
<td>Good fit.</td>
<td>Tired light redshift of a CMBR coming from very high $z$.</td>
</tr>
<tr>
<td>Time dilation</td>
<td>Good fit for SNIa. Unexplained absence of time dilation for QSOs and GRBs.</td>
<td>Selection effects, or ad hoc modification of the theory or the zero point calibration, or evolution of SNIa periods.</td>
</tr>
<tr>
<td>Hubble diagram</td>
<td>Good fit but requires the introduction of dark energy and/or evolution of galaxies.</td>
<td>Good fit for galaxies. Good fit for SNIa with some models.</td>
</tr>
<tr>
<td>Tolman (SB)</td>
<td>Requires strong evolution of SB.</td>
<td>Good fit.</td>
</tr>
<tr>
<td>Angular size</td>
<td>Requires too strong evolution of angular sizes.</td>
<td>Good fit.</td>
</tr>
<tr>
<td>UV SB limit</td>
<td>Anomalously high UV SB at high $z$.</td>
<td>Good fit.</td>
</tr>
<tr>
<td>Alcock-Paczynski</td>
<td>Non-good fit for the standard model but good fit with other wCDM models</td>
<td>Good fit for tired light.</td>
</tr>
</tbody>
</table>