Stalking the Cosmic 3He Abundance

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Primordial Nucleosynthesis

Burles et al. (2001)
4He: Observations (optical recombination lines)

Metal poor blue compact galaxies

Izotov et al. (1999)
3He Experiment

4He: Results

<table>
<thead>
<tr>
<th>Yp [mass]</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2421 (0.0021)</td>
<td>Izotov &amp; Thuan (2004)</td>
</tr>
<tr>
<td>0.249 (0.009)</td>
<td>Olive &amp; Skillman (2004)</td>
</tr>
<tr>
<td>0.2371 (0.0015)</td>
<td>Peimbert &amp; Peimbert (2002)</td>
</tr>
</tbody>
</table>
7Li: Observations (resonance line)

Metal poor
Halo stars

Boesgaard et al. (2005)
7Li: Results (The Spite Plateau)

Log(7Li/H) + 12

Reference

2.09 (+0.19,-0.13) Ryan et al. (2000)
2.37 (0.1) Melendez & Ramirez (2004)
2.44 (0.18) Boesgaard et al. (2005)
Deuterium: Observations (Lyman series)

Q1243+3047

HS 0105+1619

Kirkman et al. (2003)  O’Meara et al. (2001)
Deuterium: Results

\[
\frac{D}{H} = 2.78 \pm 0.38 \times 10^{-5}
\]

Kirkman et al. (2003)
Steigman (2005)
"... the present interstellar 3He is more of stellar than primordial origin"

Rood, Steigman, & Tinsley (1976)

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3He: Galactic Evolution

The 3He survival fraction

Steigman & Tosi (1992)
3He: Observations

Solar System:
Meteorites (protosolar)—$^{3}\text{He}/\text{H} = 1.5 \pm 0.3 \times 10^{-5}$ (Bochsler & Geiss 1974)
Jupiter (Galileo Probe)—$^{3}\text{He}/^{4}\text{He} = 1.66 \pm 0.05 \times 10^{-4}$ (Mahaffy et al. 1998)

Local Interstellar Medium (LISM):
Ulysses Probe—$^{3}\text{He}/^{4}\text{He} = 2.2_{-0.6}^{+0.7} \text{(stat)} \pm 0.2 \text{(sys)} \times 10^{-4}$ (Gloeckler & Geiss 1996)
Mir—$^{3}\text{He}/^{4}\text{He} = 1.71_{-0.42}^{+0.50} \times 10^{-4}$ (Salerno et al. 2003)

Galactic:
$^{3}\text{He}$ Recombination Lines?
$^{3}\text{He}^+$ Hyperfine Line?
3He+ Hyperfine Line

N=3

N=2

N=1

F=0 Singlet

F=1 Triplet

$^2S_{1/2} \rightarrow F = 0 \rightarrow 1$

$\nu_{01} = 8665.65 \text{ MHz} \quad (3.46 \text{ cm})$

$A_{01} = 1.950 \times 10^{-12} \text{ s}^{-1} \quad (16,300 \text{ years})$
NRAO 140 Foot Telescope (HII Regions)

Galactic HII Regions
(1982 – 1999)
(~50)

Orion nebula (M42)
Eagle nebula (M16)
Rosette nebula
W49
S209
G0.60+0.32

HPBW = 3.5 arcmin
M16 (Eagle Nebula)

Hubble Space Telescope

NRAO Very Large Array

White et al. (1999)

Hester & Scowen

3He Experiment
HII Region 3He+ Spectra

Bania et al. (1997)
HII Region 3He+ Spectra

Bania et al. (1997)
HII Region Radio Recombination Line Spectra

Bania et al. (1997)

H91α  n = 92 → 91
H114β  n = 116 → 114
H130γ  n = 133 → 130

3He Experiment
HII Region Continuum

MPIfR 100m Telescope

NRAO Very Large Array

Balser et al. (1995)
HII Region Continuum

NRAO Very Large Array

3He Experiment
HII Region Models

Balser et al. (1999)
MPIfR 100 meter Telescope (PNe)


NGC 3242 (Ghost of Jupiter)
NGC 6543 (Cat’s Eye)
NGC 6720 (Ring)
NGC 7009 (Saturn)
NGC 7662 (Blue Snowball)

HPBW = 80 arcsec
NGC 3242 (Ghost of Jupiter)

Hubble Space Telescope

Balick et al.

3He Experiment
NGC 6543 (Cat’s Eye)

Hubble Space Telescope

Corradi & Tsvetanov

3He Experiment
Modeling of NGC 3242 indicates a halo.

Balser et al. (1997)
Results: Abundance versus [O/H]

\[ \frac{^{3}\text{He}}{\text{H}} = 1.5 \times 10^{-5} \]

Bania, Rood & Balser (2002)

\[ \uparrow \frac{\text{O}}{\text{H}} = 6.3 \times 10^{-4} \]
The 3He Problem

![Graph showing the abundance of 3He with time](image)

- **Meteorites**: Geiss (1993)
- **Jupiter**: Mahaffy et al. (1998)
- **HII regions**: Bania, Rood & Balser (2002)
- **Local ISM**: Gloecker & Geiss (1998)

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Extra-mixing Process (low-mass stars < 2 Msun)

“...meridional circulation driven by internal rotation might lead to the mixing of CNO-processed material ...of a red giant star.”

Sweigart & Mengel (1979)

96% of low-mass stars

Charbonnel & do Nascimento (1998)

Charbonnel (1995)
No Mixing in NGC3242

3He+ line at 8665 MHz

$^3\text{He}/H = 2 \times 5 \times 10^{-4}$

Main Beam Brightness Temperature (mK)

LSR Velocity (km/s)

Balser et al. (1999)

C III] multiplet near 1908 Å

$^{12}\text{C}/^{13}\text{C} > 38$

Palla et al. (2002)
12C/13C in Planetary Nebulae

Results: Abundance versus Rgal

Bania, Rood & Balser (2002)
Cosmic Microwave Background (WMAP)

\[ \Omega_b h^2 = 0.0223^{+0.0007}_{-0.0009} \]

\[ \eta = 6.0965 \pm 0.2055 \times 10^{-10} \]

Spergel et al. (2006)
Results: Primordial Abundances

Izotov & Thuan (2004)
Peimbert & Peimbert (2002)

Kirkman et al. (2003)
Bania, Rood, & Balser (2002)
Ryan et al. (2003)
Boesgaard et al. (2006)

Burles et al. (2001)
Spergel et al. (2006)
New Search for 3He in Planetary Nebulae

NRAO Very Large Array

NAIC Arecibo Telescope

NRAO Green Bank Telescope
PNe Sample

PNe progenitor stars with no extra mixing:

\[ ^4\text{He}/H \leq 0.125 \]
\[ [\text{N/O}] \leq -0.3 \]
\[ ^{13}\text{C}/^{12}\text{C} \text{ as low as possible} \]

Peimbert Class: IIb, III, IV (old population)

Helium is singly ionized
PNe Continuum Image

Balser et al. (2006)
$^3\text{He}/H = 1.9 \pm 3.8 \times 10^{-3}$

Balser et al. (2006)
PNe: J320

I \textit{3He Experiment}

Balser et al. (2006)

Halo detected
NRAO Green Bank Telescope 100 m (PNe)
GBT Clear Aperture Optics

3He Experiment
HII Region S206: 140 Foot versus GBT

140 Foot  March 1995

GBT  June 2004

33.1 hr

3.2 hr
GBT S209 HII Region: calibrated raw spectrum

14.5 hr integration
GBT S209 HII Region

14.5 hr integration 5 km/s resolution
NGC 7009: H91alpha (61.8 hr)
NGC 7009: H114beta (62.1 hr)
NGC 7009: H144delta (61.7 hr)

Reliability level of ~0.5 mK
NGC 7009: 3He+ (62.1 hr)
NGC 7009 + NGC 6543 + NGC 6826 (180.3 hr)
Arecibo 305 m Telescope (PNe)
Conclusions

• Detection of 3He in J320 with the VLA.

• Possible detection of 3He in NGC 7009 and NGC 6543 with the GBT.

• First epoch observations with Arecibo complete.

• Roughly 25% of PNe meet our selection criteria. To be consistent with chemical evolution models only 1/5 of these should show detectable 3He.

• It may be difficult to acquire enough telescope time to solidify these results.

• Observe a few select HII region to determine 3He gradient?

• The EVLA (10 times more sensitive than the VLA) has great potential.

• Magellanic Clouds using the Parkes 64m telescope is feasible.
Spectral Baseline Structure (NRAO 140 Foot)

Standing Waves
Spectral Baseline Structure (GBT)