Stalking the Cosmic 3He Abundance

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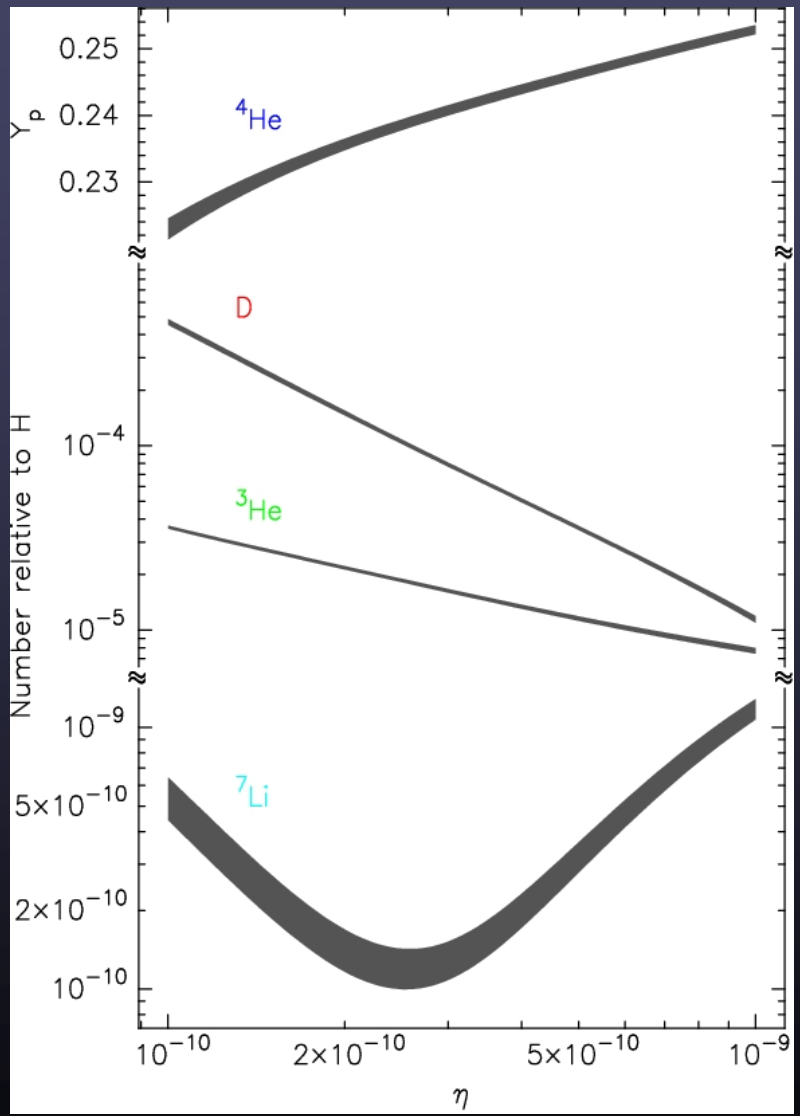
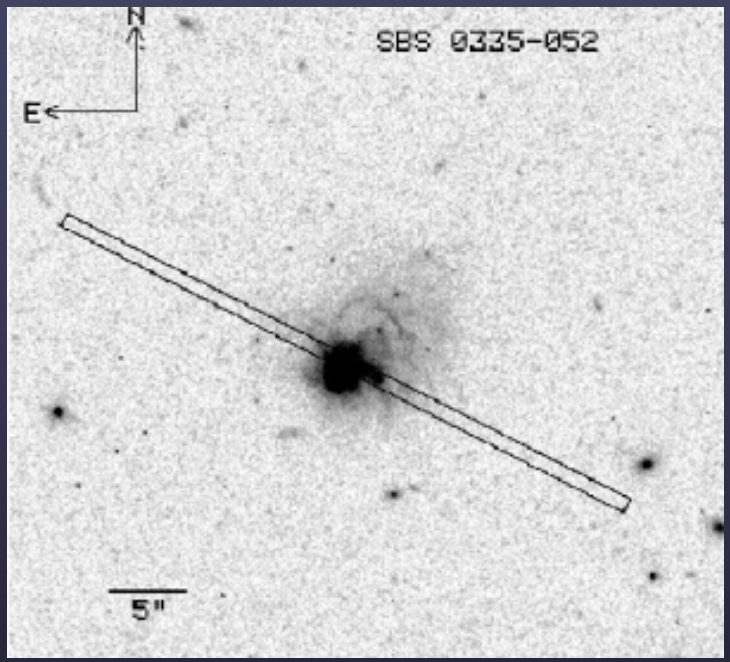
Primordial Nucleosynthesis



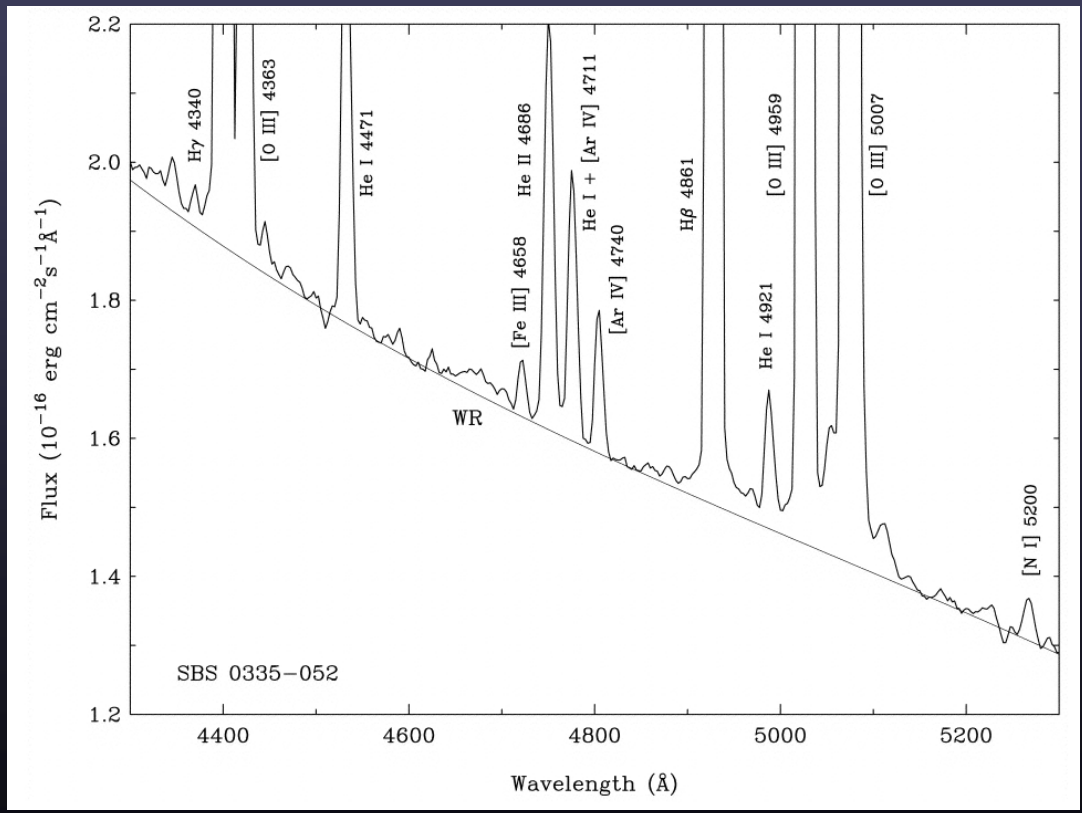
Burles et al. (2001)

4He: Observations (optical recombination lines)

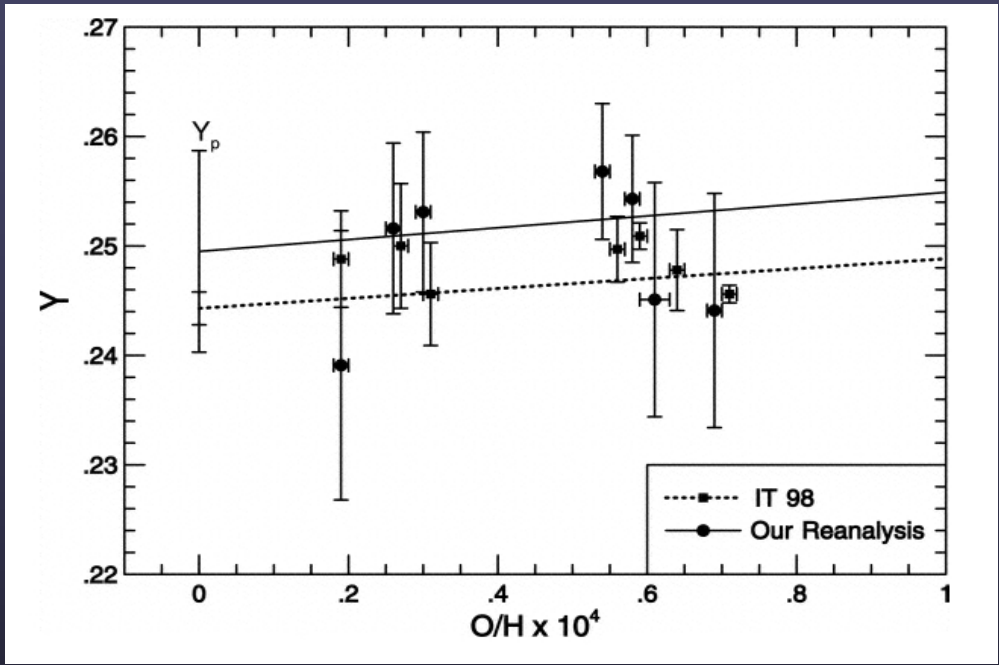


Metal poor blue compact galaxies

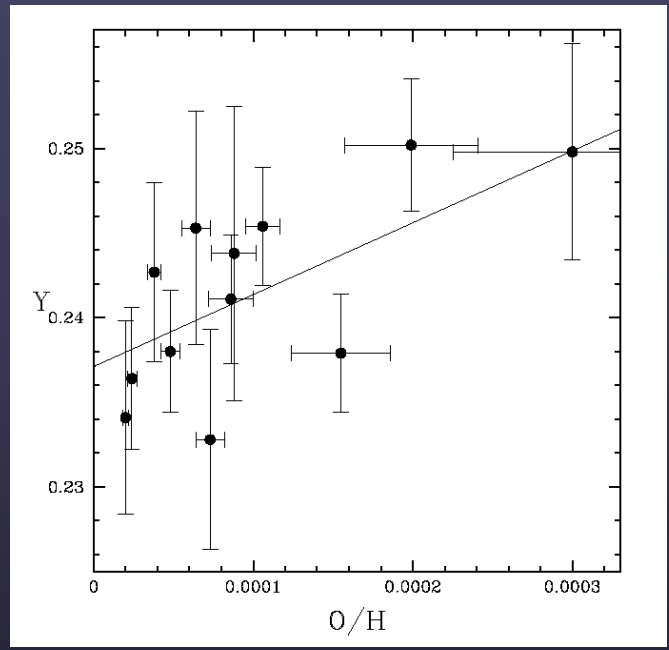
Izotov et al. (1999)



4He: Results



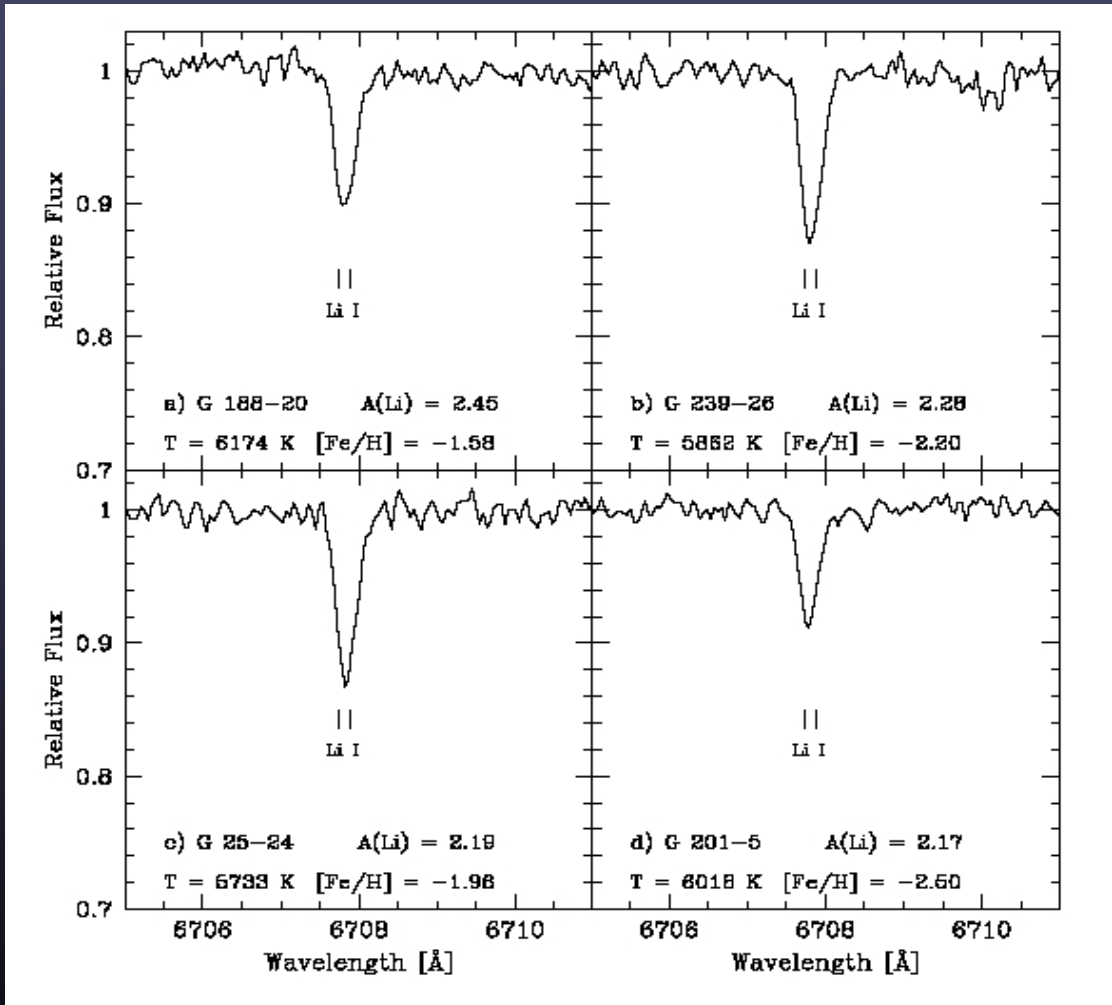
Olive & Skillman (2004)



Peimbert & Peimbert (2002)

Yp [mass]	Reference
0.2421 (0.0021)	Izotov & Thuan (2004)
0.249 (0.009)	Olive & Skillman (2004)
0.2371 (0.0015)	Peimbert & Peimbert (2002)

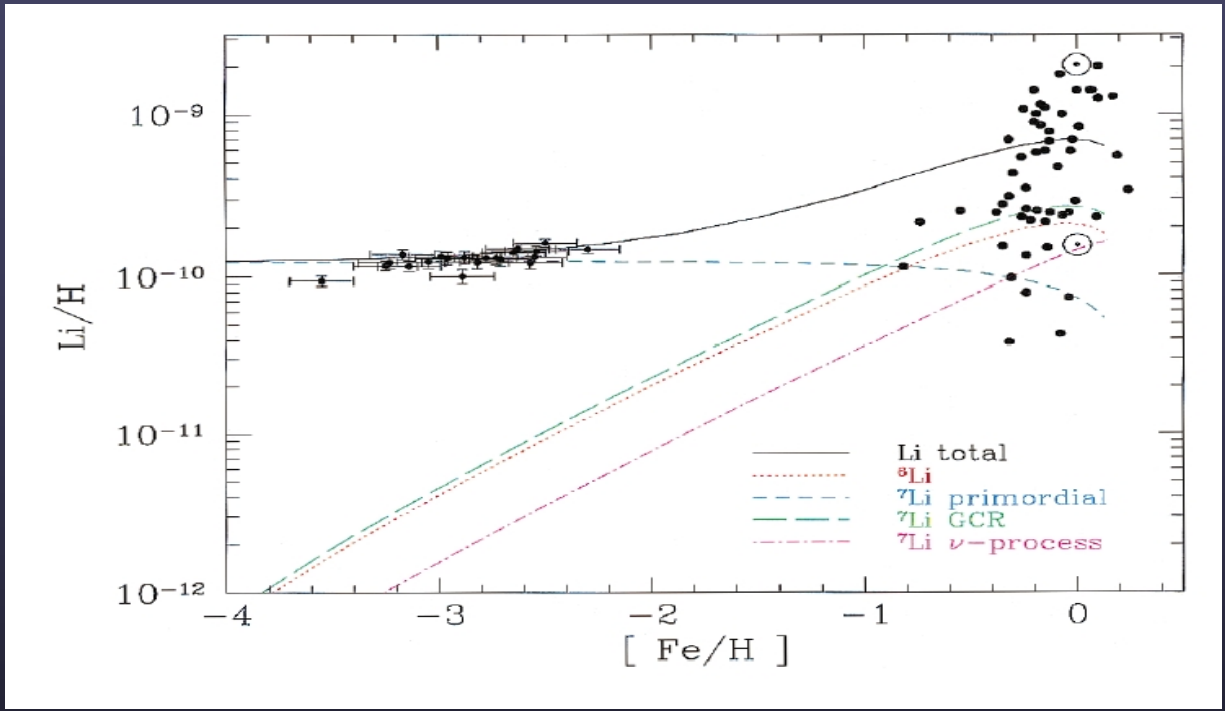
7Li: Observations (resonance line)



Metal poor
Halo stars

Boesgaard et al. (2005)

7Li: Results (The Spite Plateau)

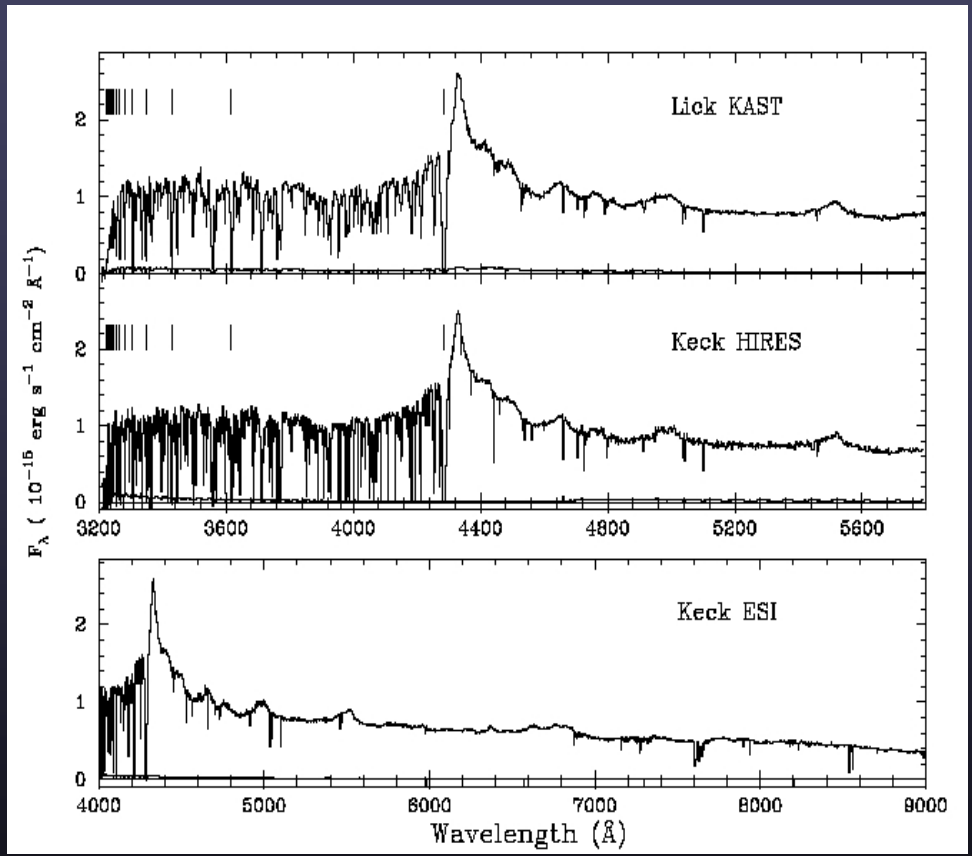


Ryan et al. (2000)

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)

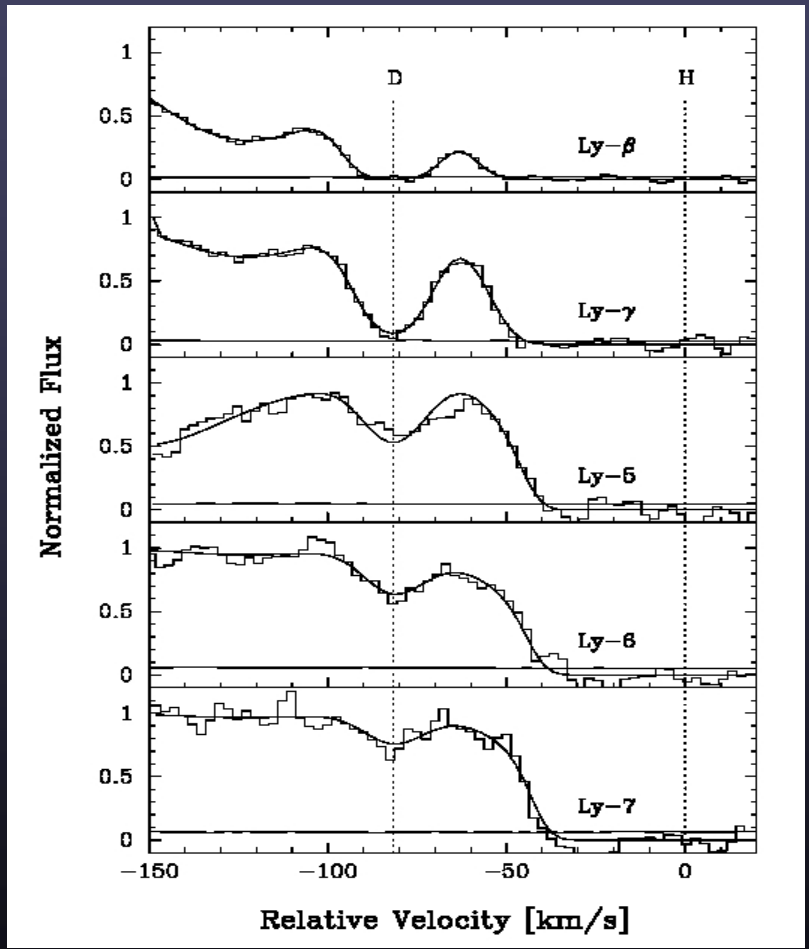
Deuterium: Observations (Lyman series)

Q1243+3047



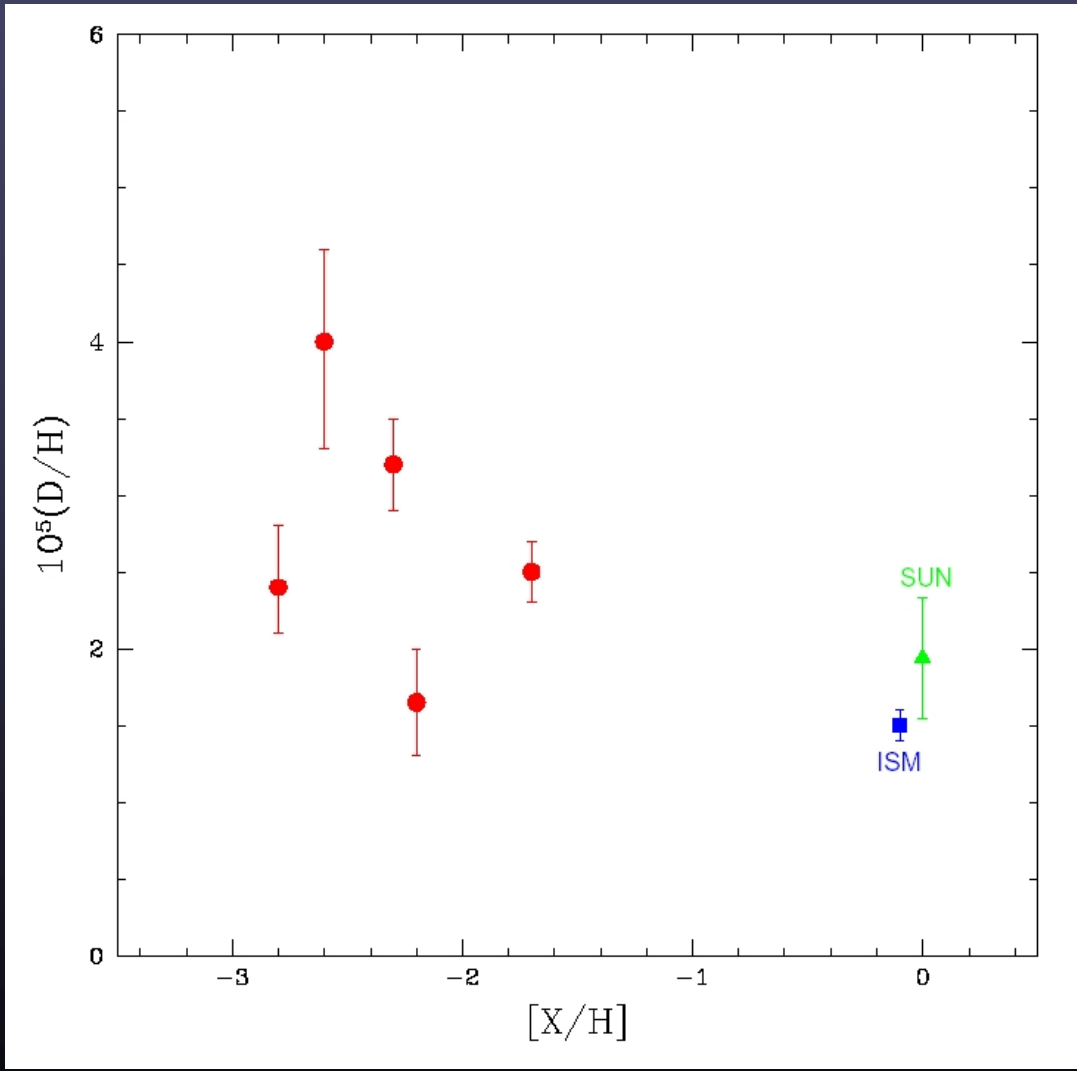
Kirkman et al. (2003)

HS 0105+1619



O'Meara et al. (2001)

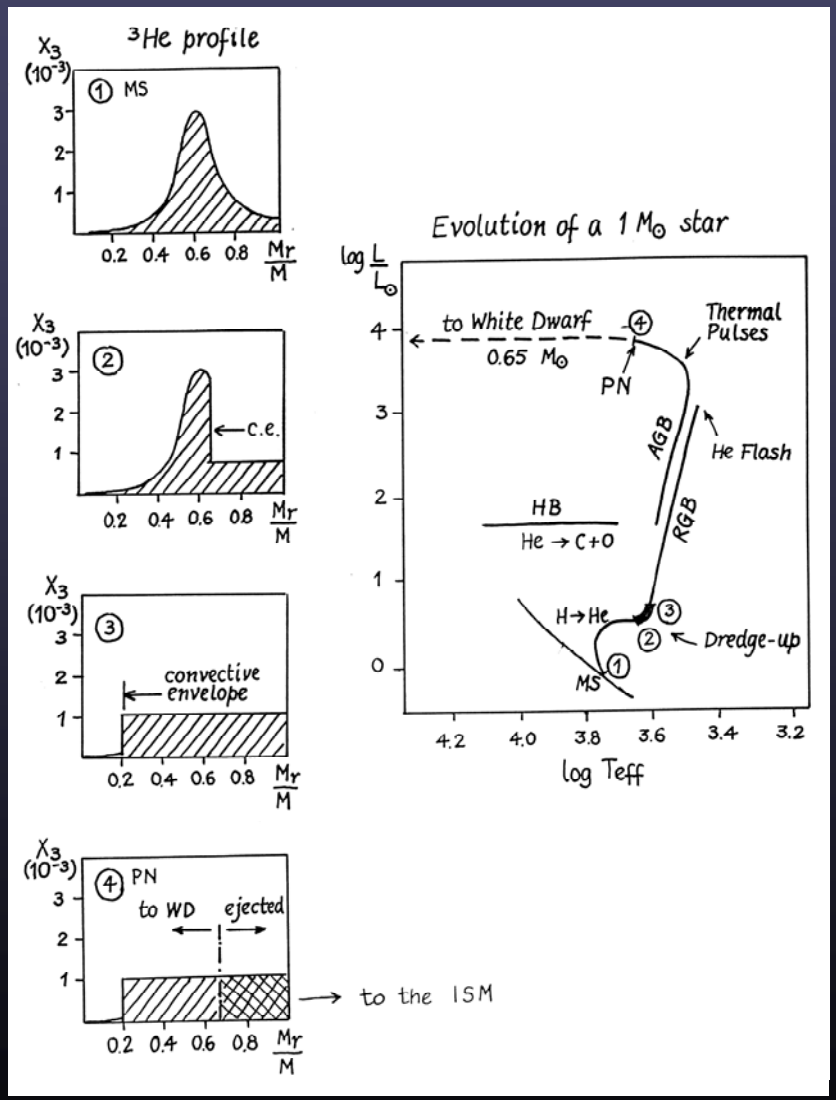
Deuterium: Results



$$D/H = 2.78\ ^{+0.44}_{-0.38} \times 10^{-5}$$

Kirkman et al. (2003)
Steigman (2005)

3He: Stellar Evolution



$^1H + {}^1H \rightarrow {}^2H + e^+ + \nu$	Production
$^2H + {}^1H \rightarrow {}^3He + \gamma$	$T > 6 \times 10^5$ K
$^3He + {}^3He \rightarrow {}^4He + 2p$	Destruction
$^3He + {}^4He \rightarrow {}^7Be + \gamma$	$T > 7 \times 10^6$ K

"… the present interstellar 3He is more of stellar than primordial origin"

Rood, Steigman, & Tinsley (1976)

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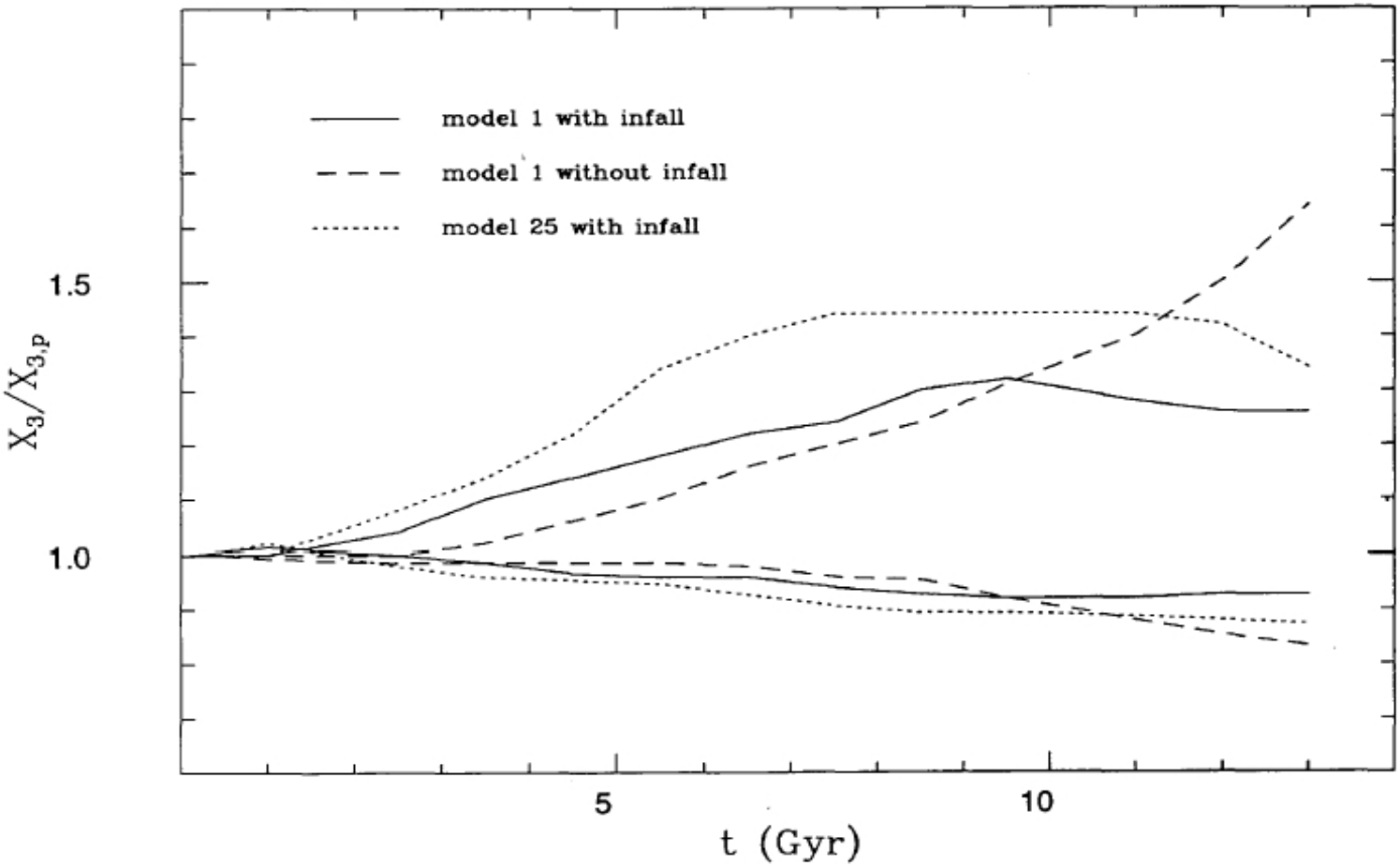
3He: Galactic Evolution



Steigman & Tosi (1992)

3He: Observations

Solar System:

Meteorites (protosolar)— $^3He/H = 1.5 \pm 0.3 \times 10^{-5}$ (Bochsler & Geiss 1974)

Jupiter (Galileo Probe)— $^3He/^4He = 1.66 \pm 0.05 \times 10^{-4}$ (Mahaffy et al. 1998)

Local Interstellar Medium (LISM):

Ulysses Probe— $^3He/^4He = 2.2^{+0.7}_{-0.6}(stat) \pm 0.2(sys) \times 10^{-4}$ (Gloeckler & Geiss 1996)

Mir— $^3He/^4He = 1.71^{+0.50}_{-0.42} \times 10^{-4}$ (Salerno et al. 2003)

Galactic:

^3He Recombination Lines?

$^3He^+$ Hyperfine Line?

3He+ Hyperfine Line

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

$A_{01} = 1.950 \times 10^{-12}\ s^{-1}$ (16,300 years)

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

NRAO 140 Foot Telescope (HII Regions)

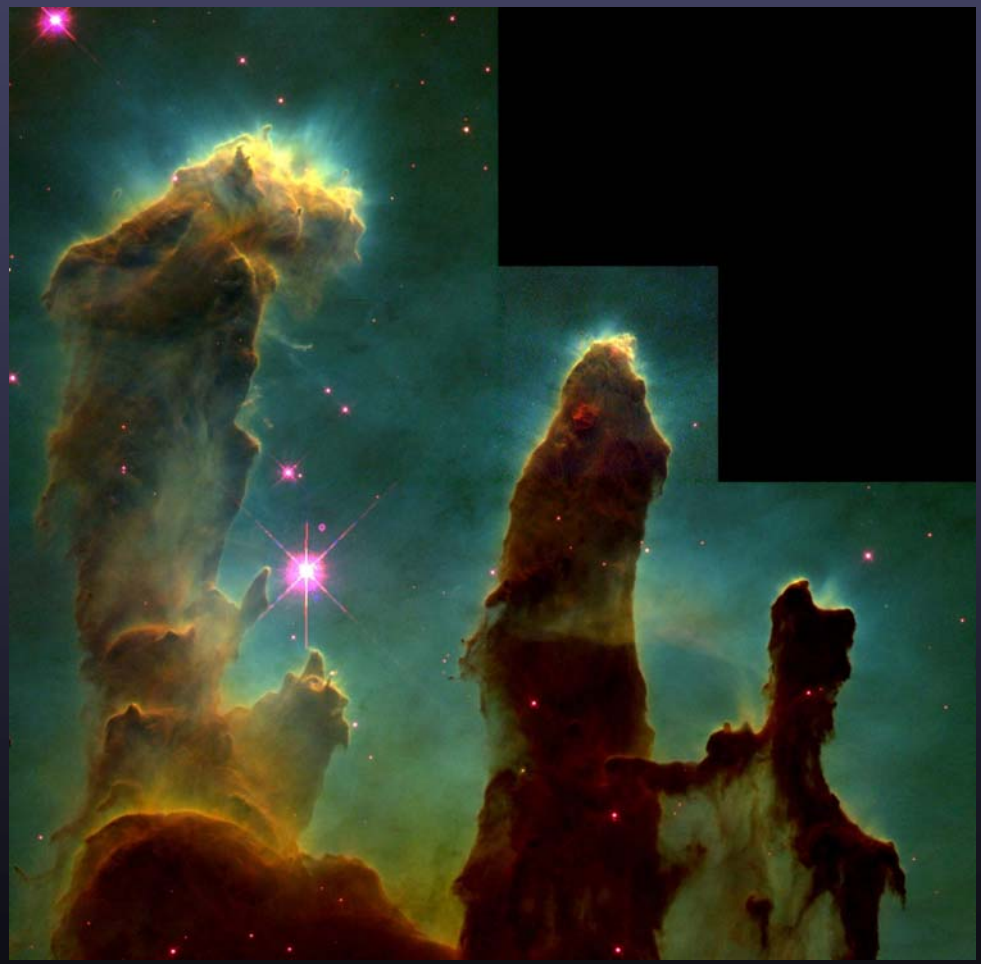
Galactic HII Regions
(1982 – 1999)
(~50)

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

HPBW = 3.5 arcmin

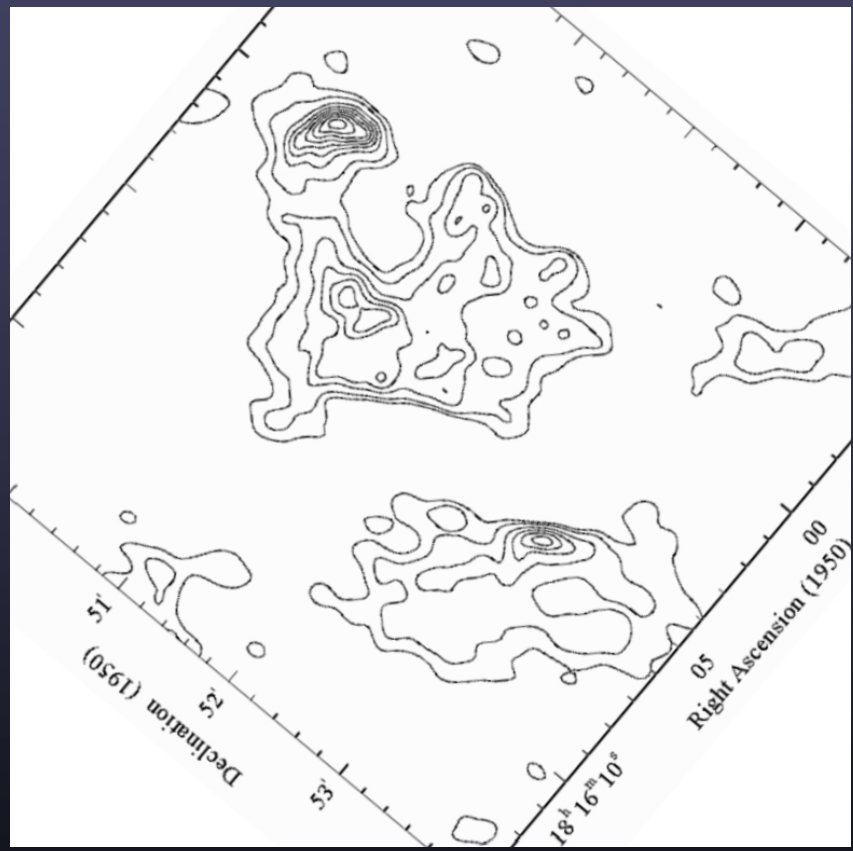
M16 (Eagle Nebula)

Hubble Space Telescope



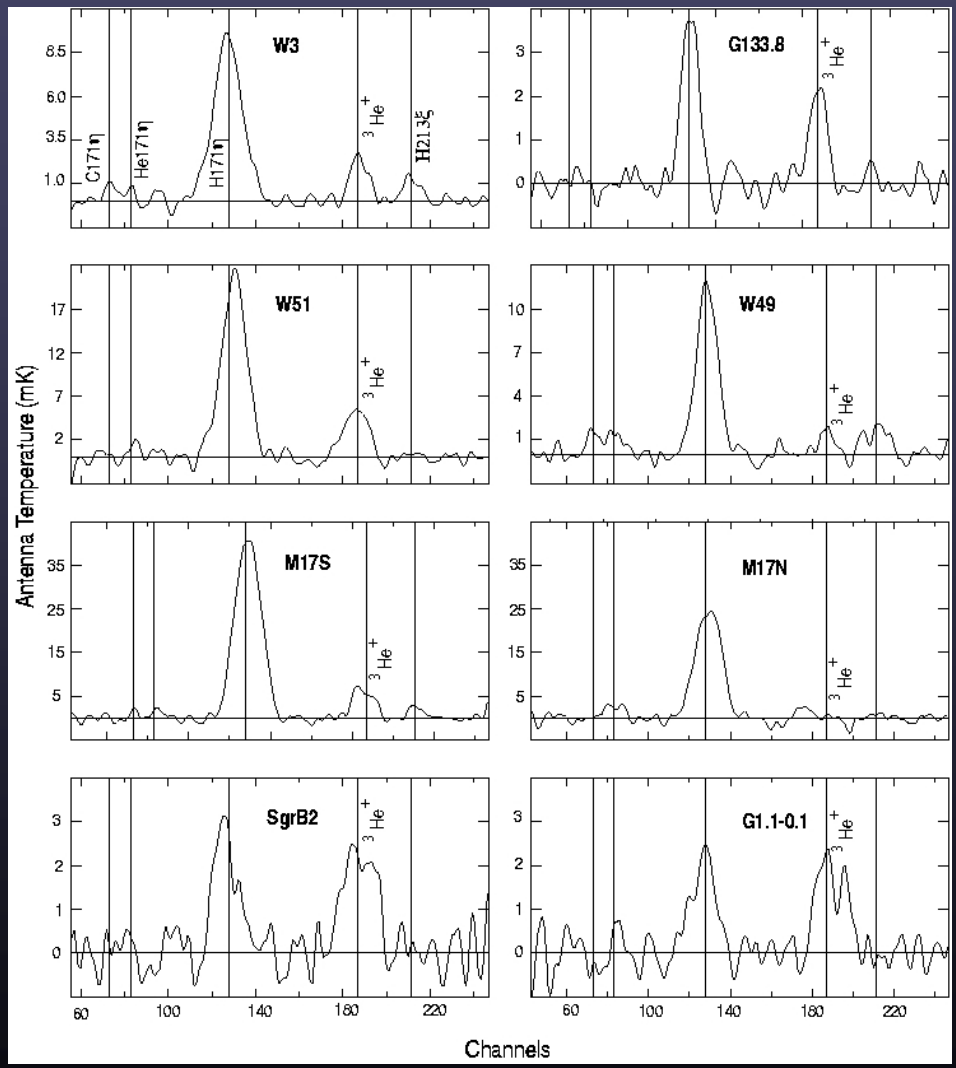
Hester & Scowen

NRAO Very Large Array



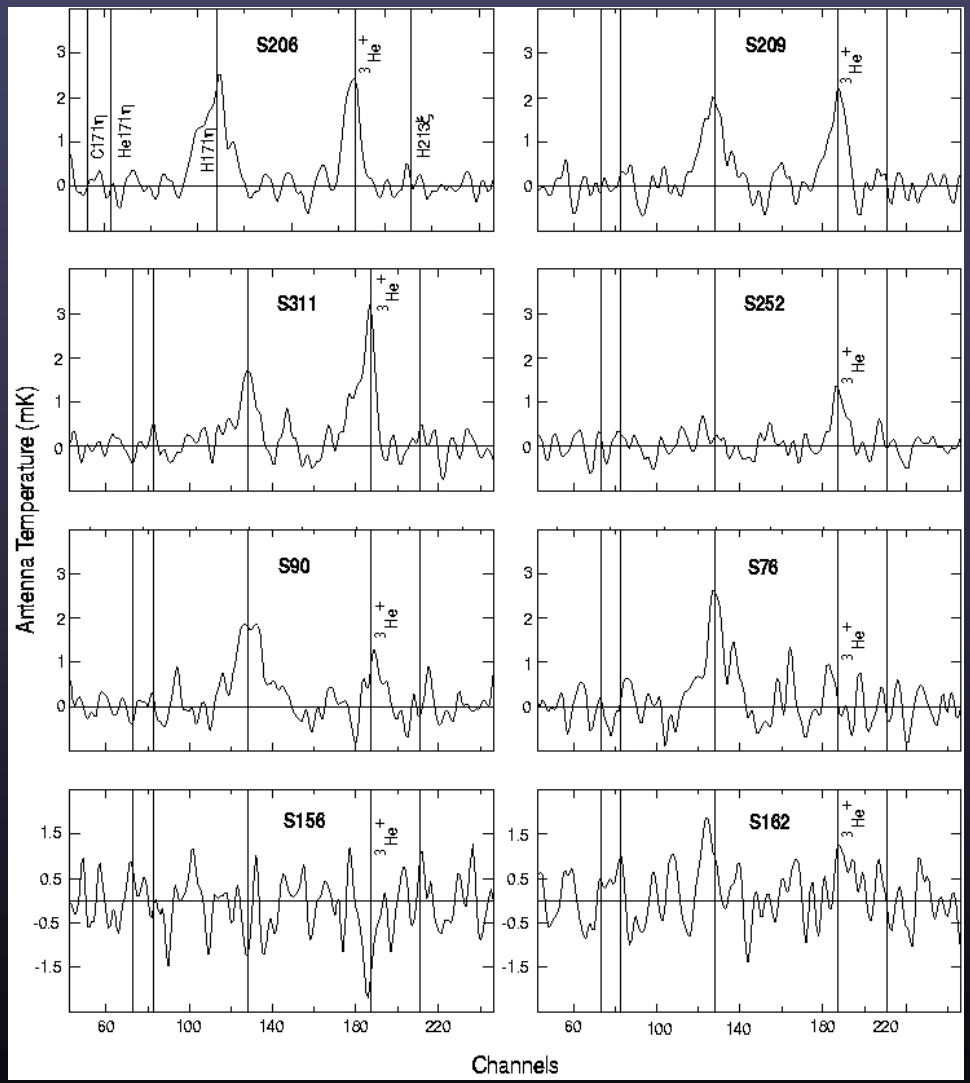
White et al. (1999)

HII Region 3He+ Spectra



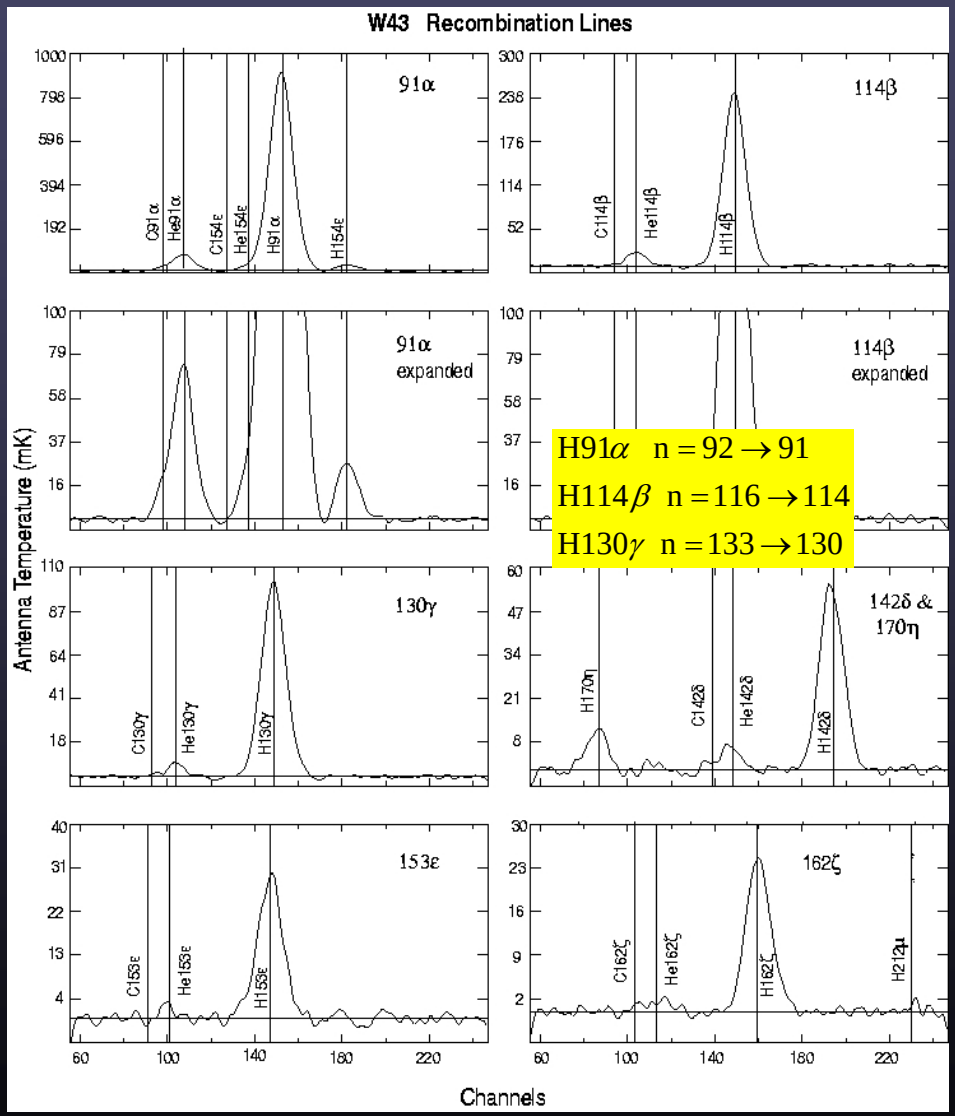
Bania et al. (1997)

HII Region 3He+ Spectra



Bania et al. (1997)

HII Region Radio Recombination Line Spectra



$H91\alpha \quad n = 92 \rightarrow 91$

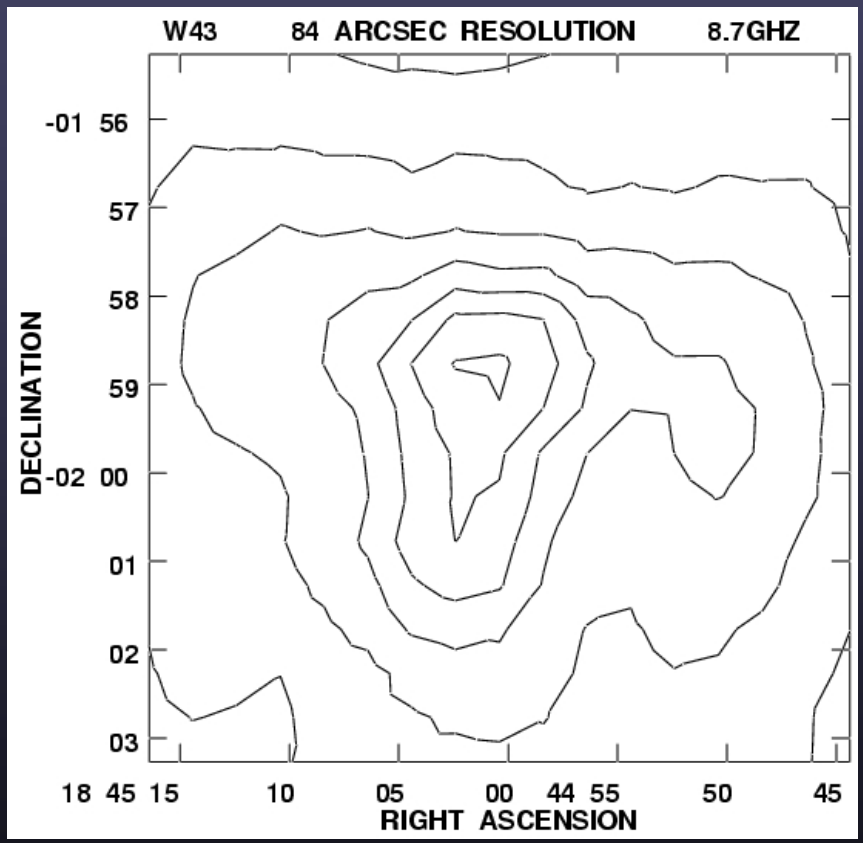
$H114\beta \quad n = 116 \rightarrow 114$

$H130\gamma \quad n = 133 \rightarrow 130$

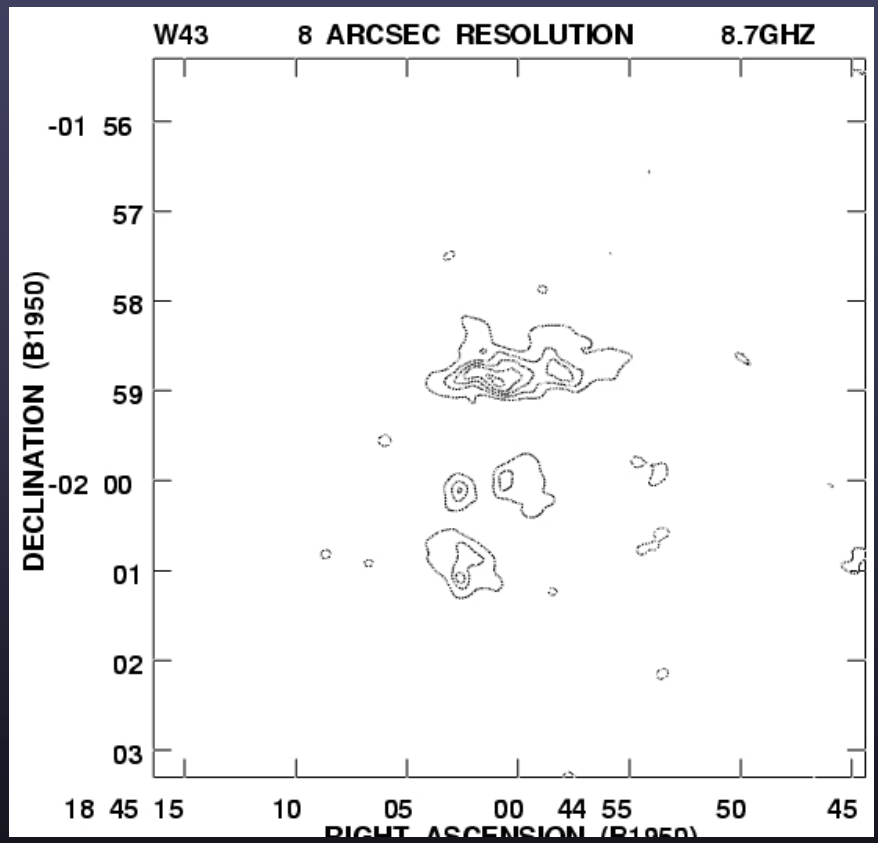
Bania et al. (1997)

HII Region Continuum

MPIfR 100m Telescope



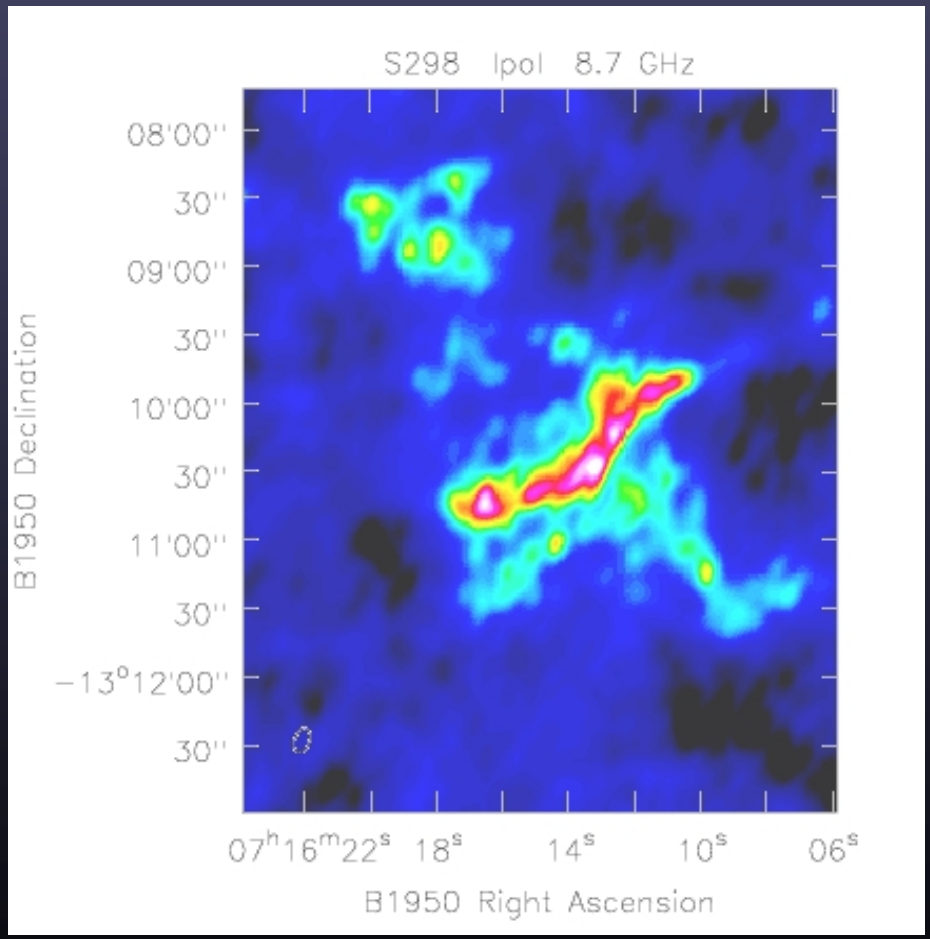
NRAO Very Large Array

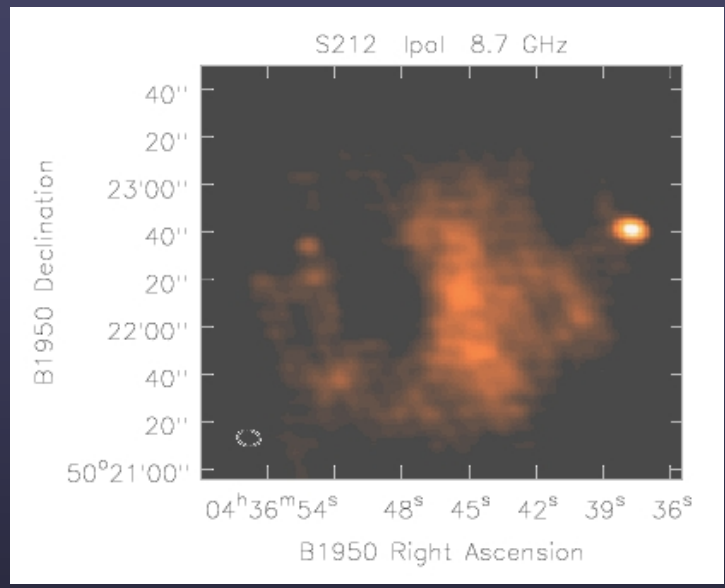


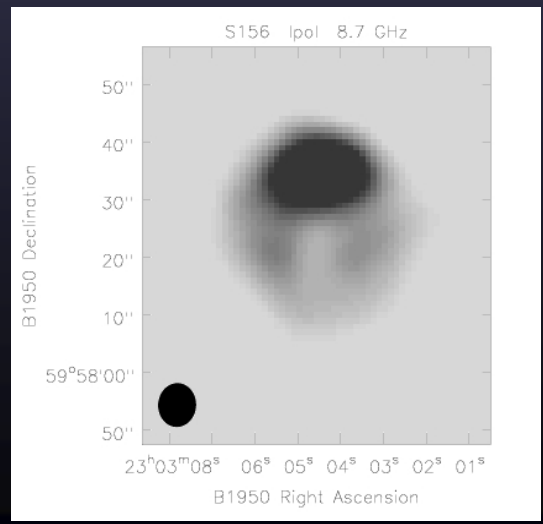
Balser et al. (1995)

HII Region Continuum

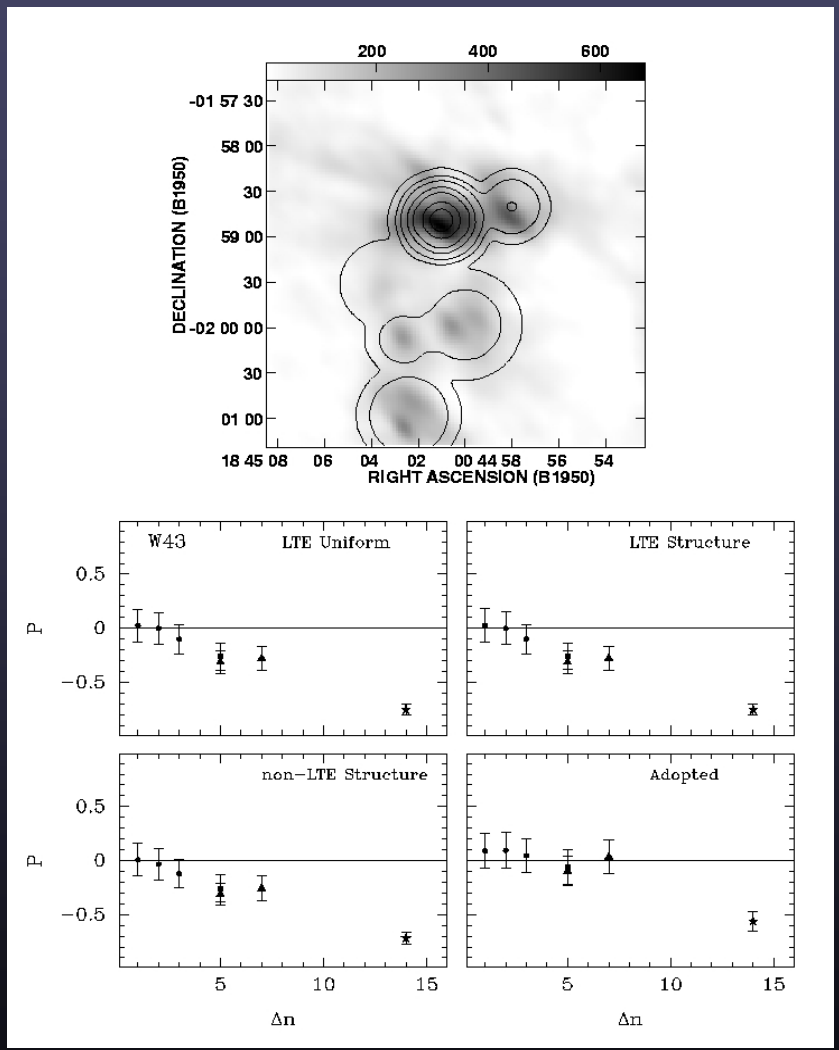
NRAO Very Large Array

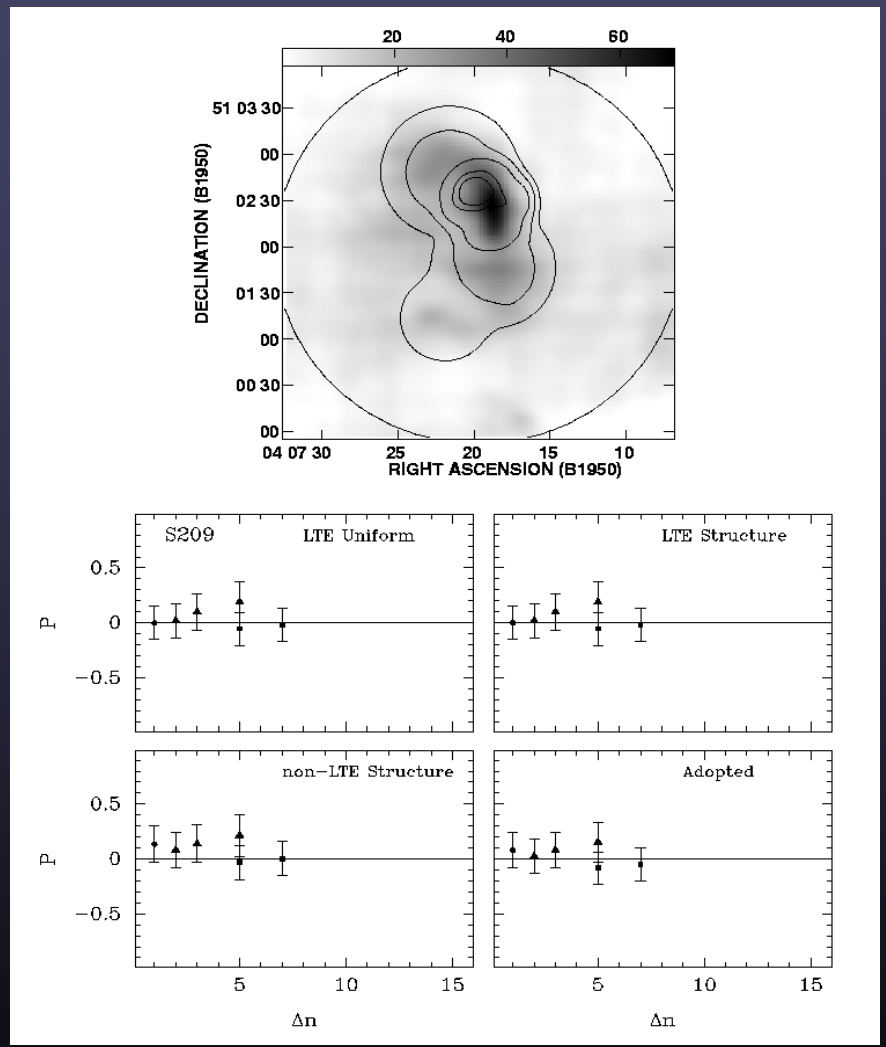






HII Region Models





Balser et al. (1999)

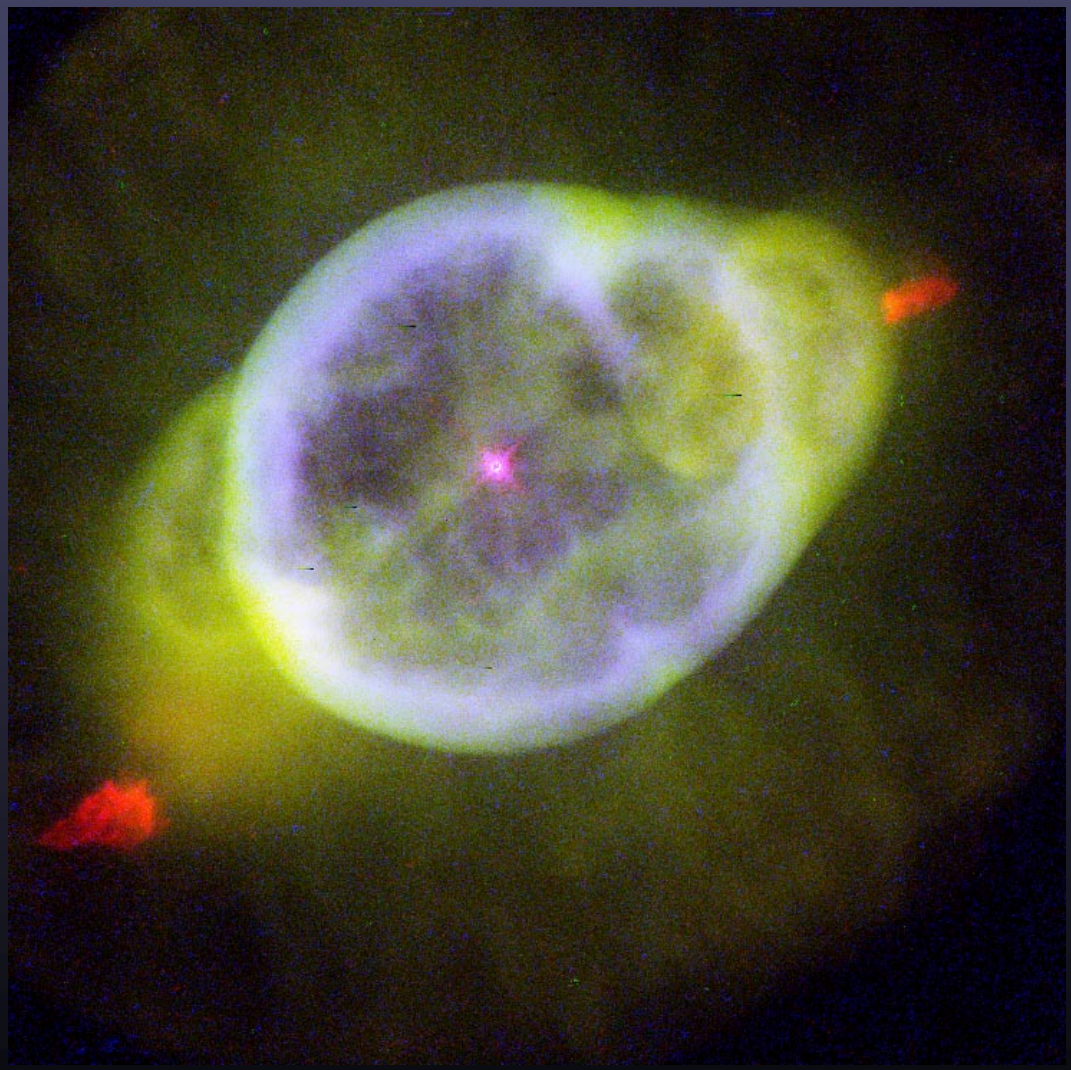
MPIfR 100 meter Telescope (PNe)

Galactic Planetary Nebulae
(1991 – 1995)

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

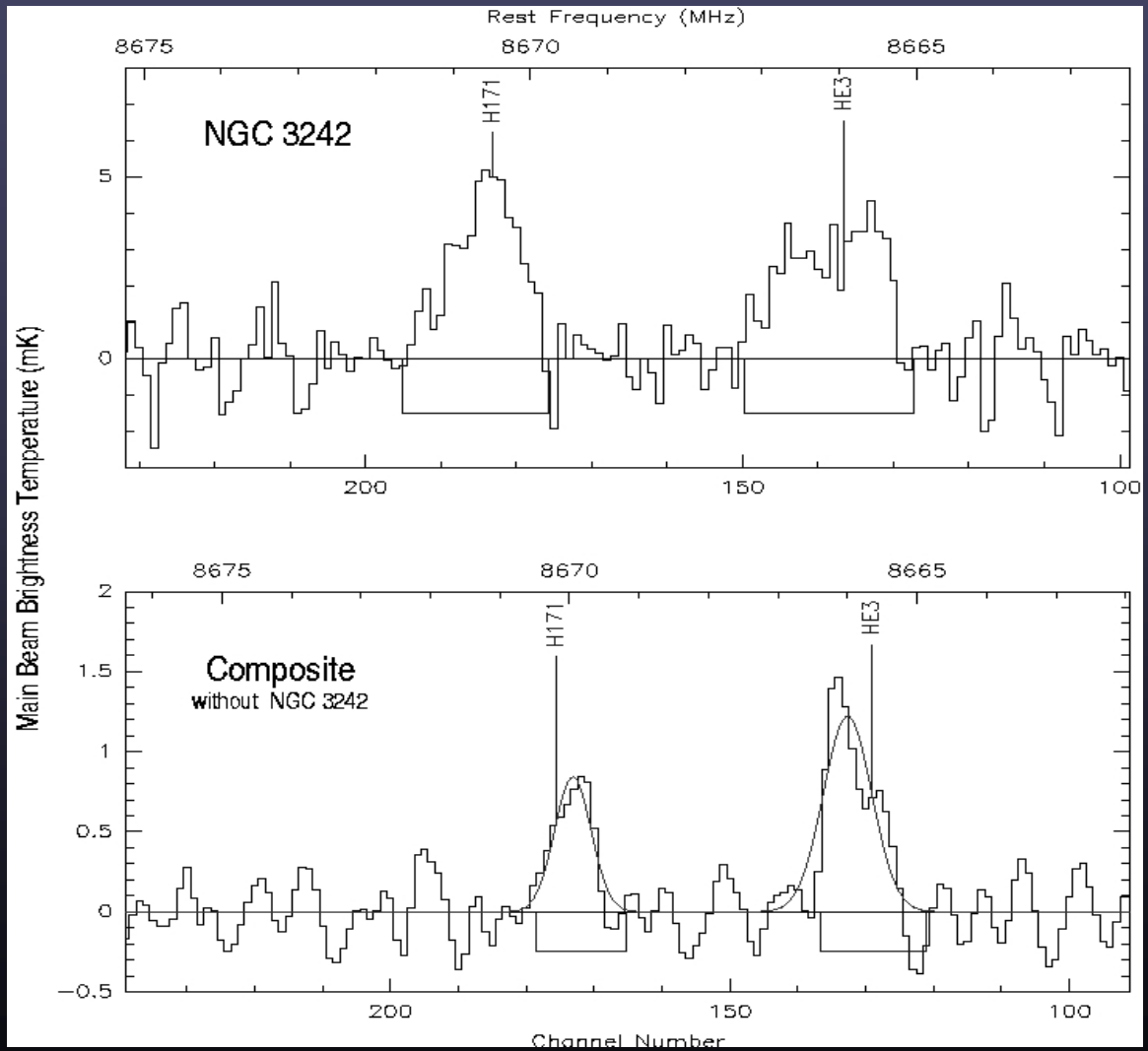
Balick et al.

NGC 6543 (Cat's Eye)

Hubble Space Telescope

Corradi & Tsvetanov

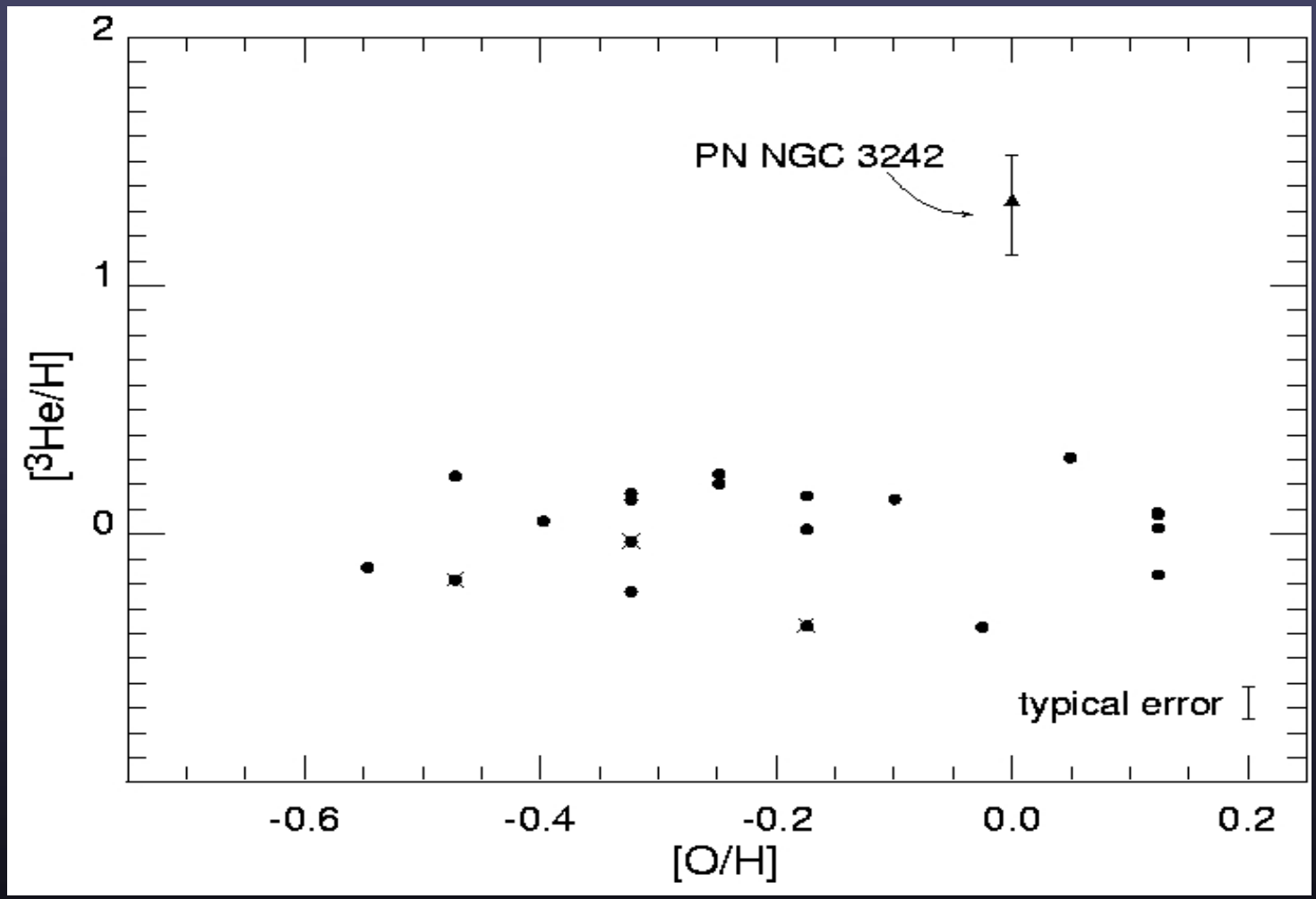
PNe 3He+ Spectra



Modeling of NGC 3242 indicates a halo.

Balser et al. (1997)

Results: Abundance versus [O/H]

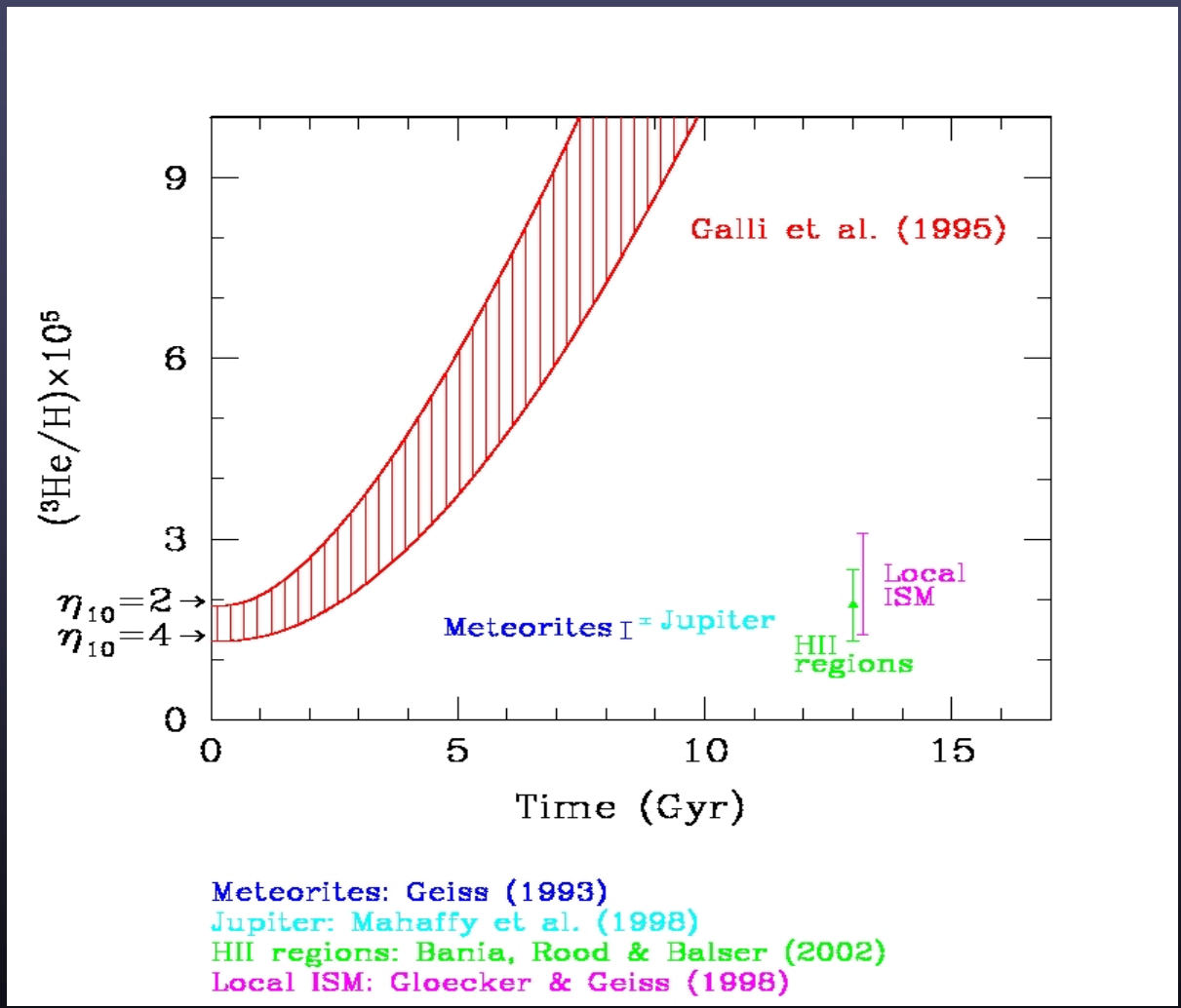


$\leftarrow {}^3\mathrm{He/H} = 1.5 \times 10^{-5}$

Bania, Rood & Balser (2002)

$\uparrow \mathrm{O/H} = 6.3 \times 10^{-4}$

The 3He Problem



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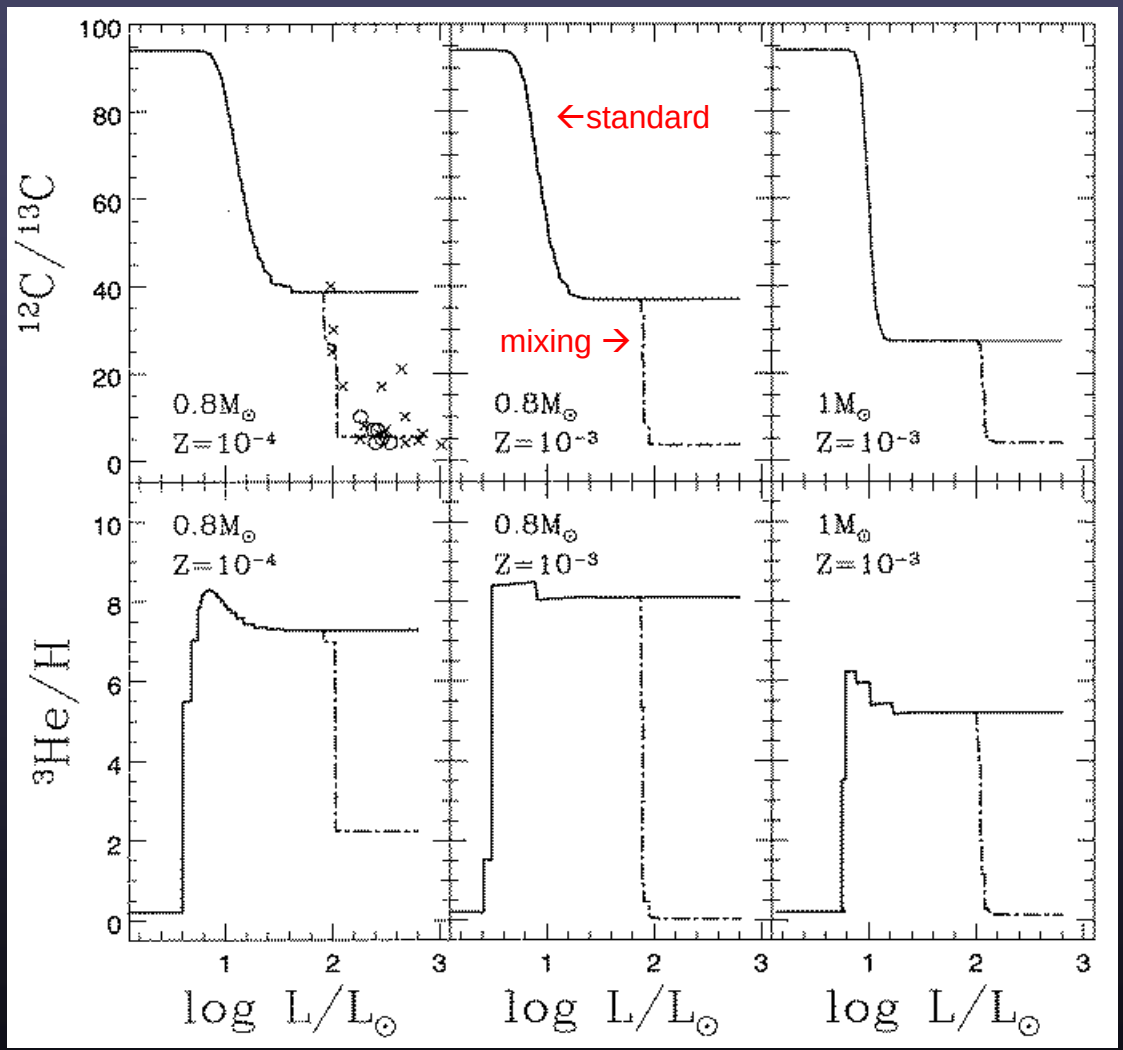
Extra-mixing Process (low-mass stars < 2 Msun)



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

Sweigart & Mengel (1979)

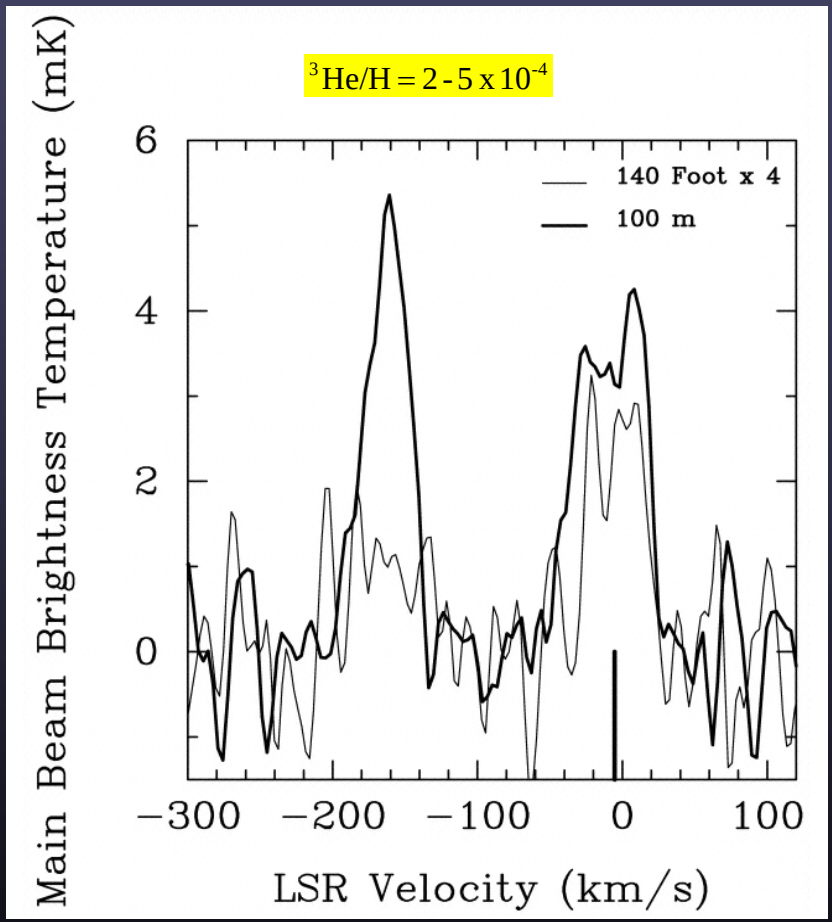
96% of low-mass stars

Charbonnel & do Nascimento (1998)

Charbonnel (1995)

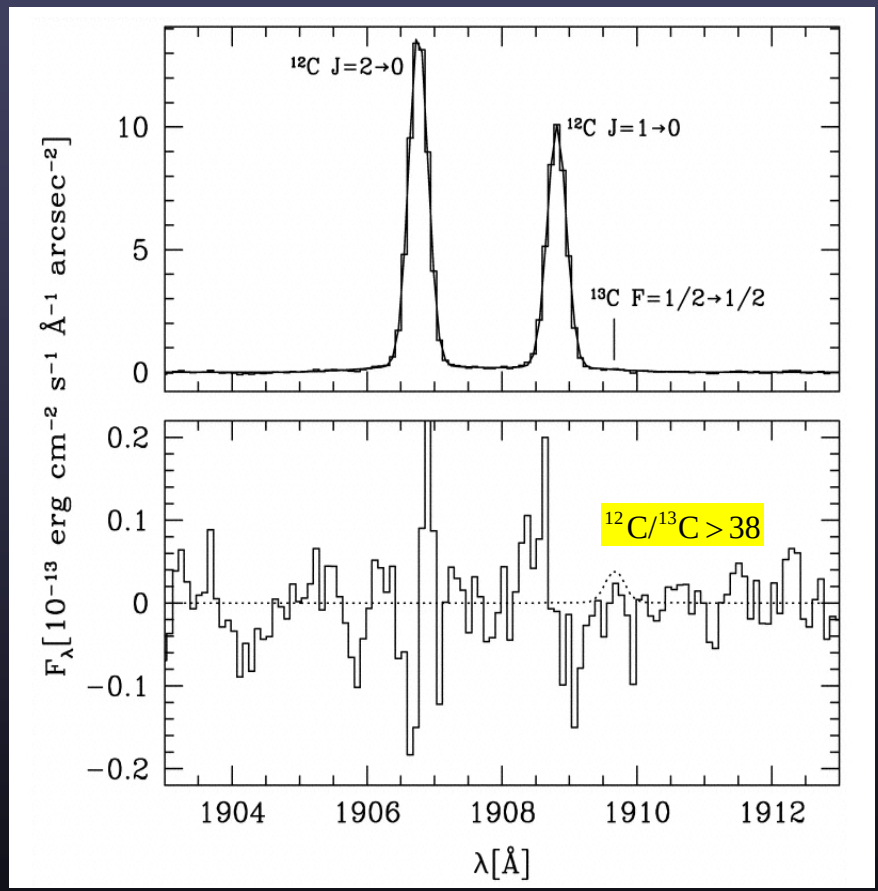
No Mixing in NGC3242

3He+ line at 8665 MHz



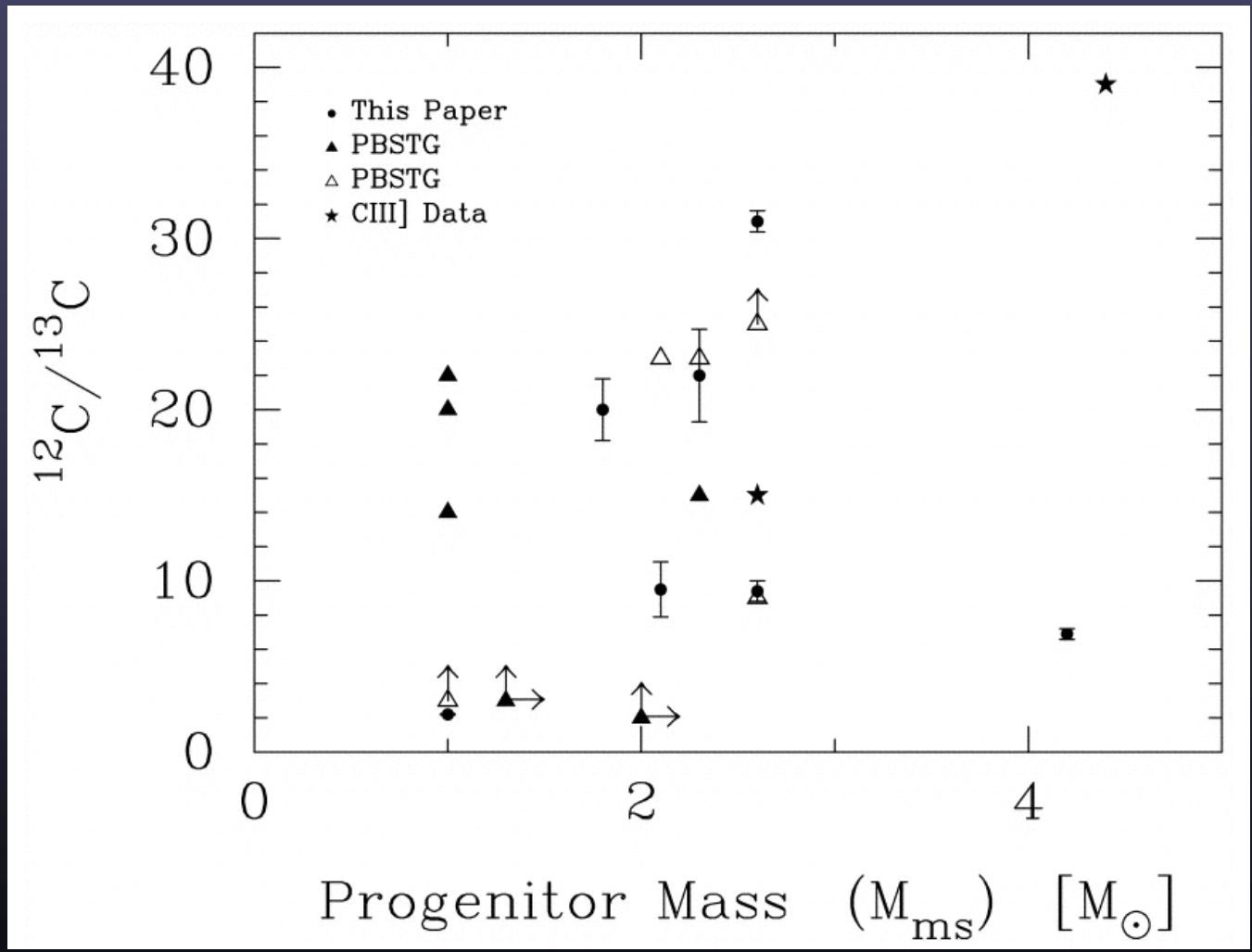
Balser et al. (1999)

C III] multiplet near 1908 A



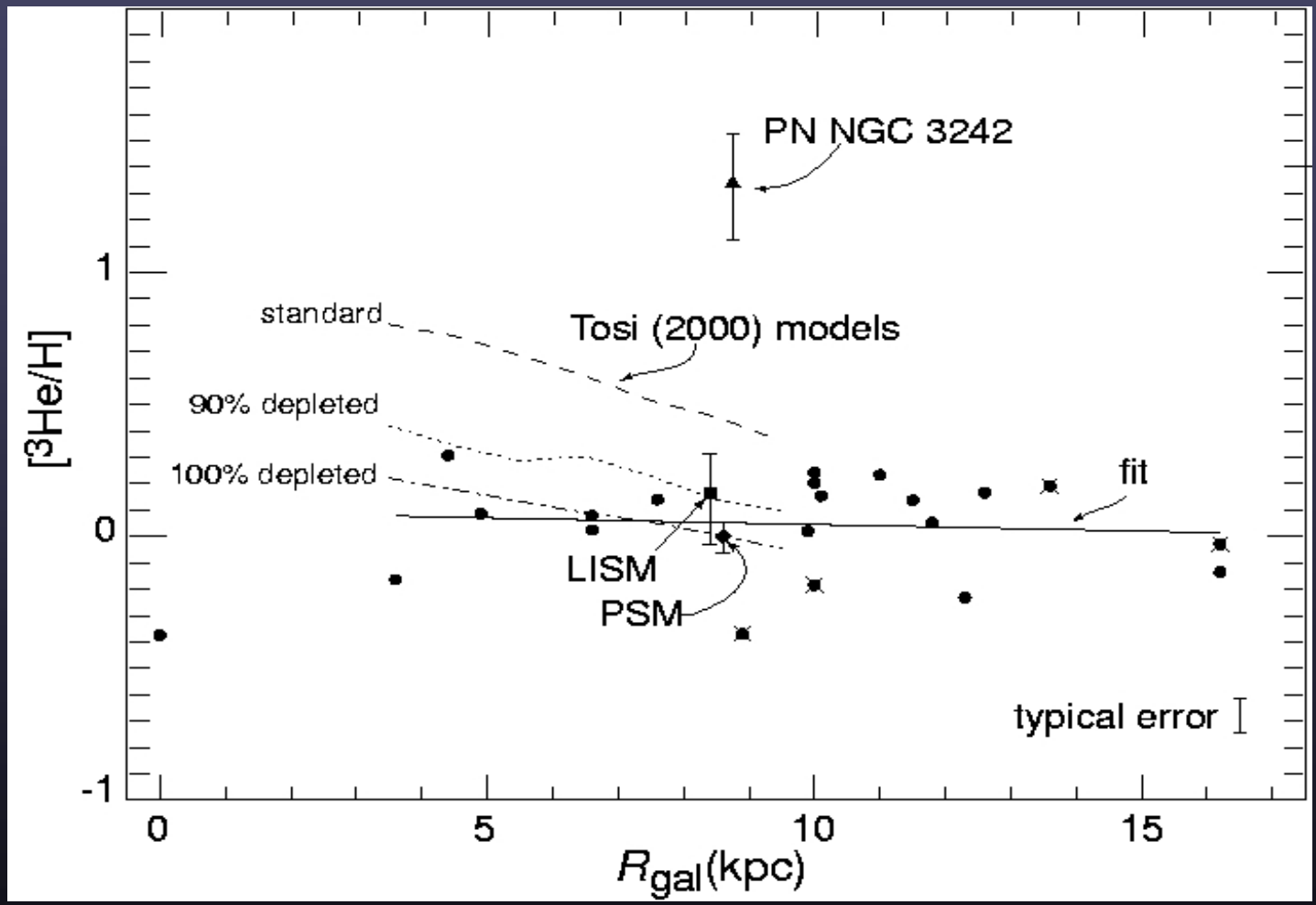
Palla et al. (2002)

12C/13C in Planetary Nebulae



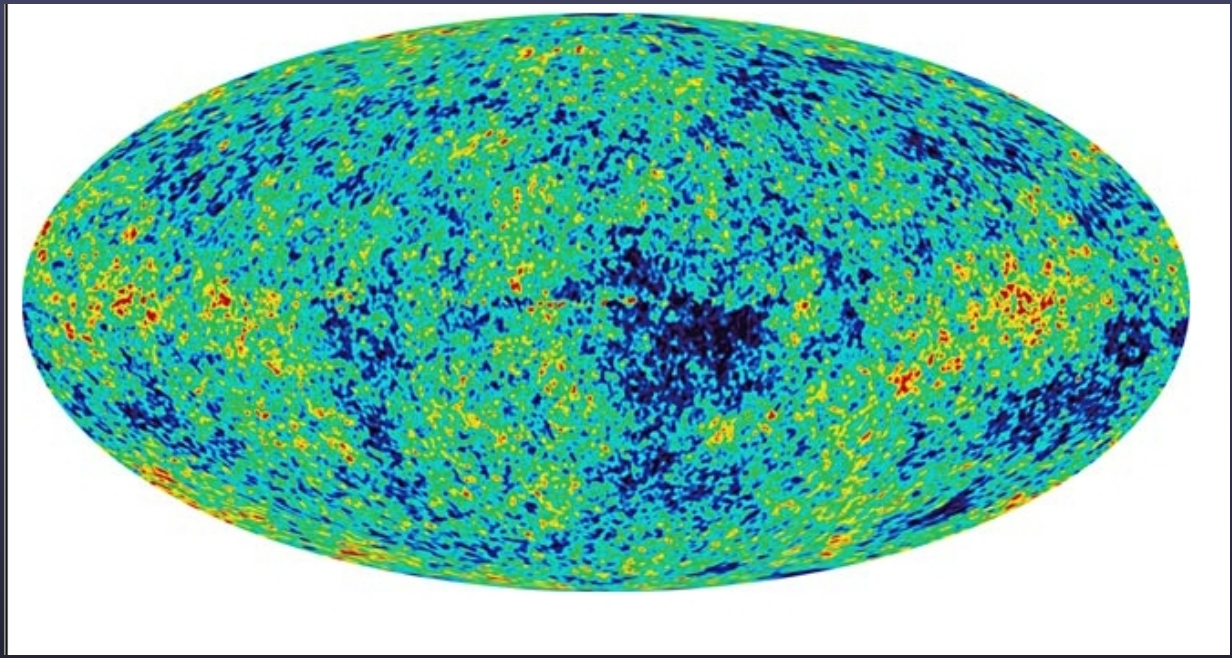
Balser, McMullin, & Wilson (2002)

Results: Abundance versus Rgal



Bania, Rood & Balser (2002)

Cosmic Microwave Background (WMAP)

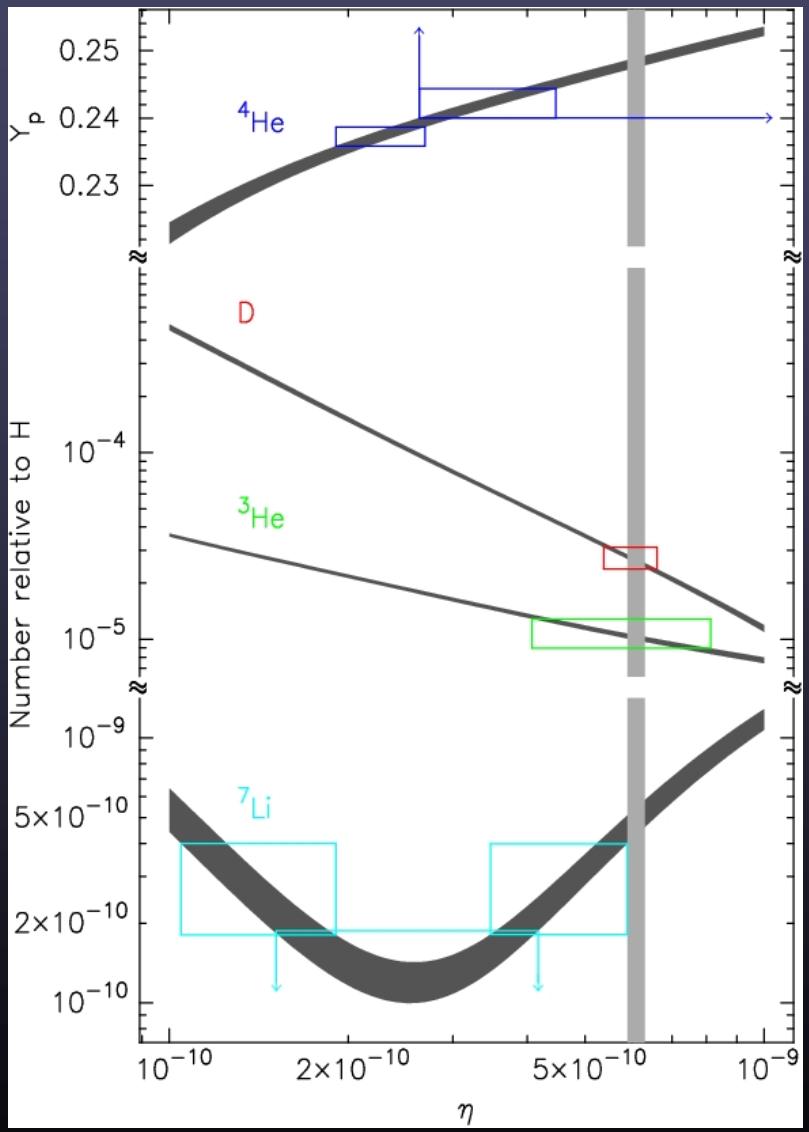


$$\Omega_b h^2 = 0.0223^{+0.0007}_{-0.0009}$$

$$\eta = 6.0965 \pm 0.2055 \; x \, 10^{-10}$$

Spergel et al. (2006)

Results: Primordial Abundances



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

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:

$$^{4}\mathrm{He/H} \leq 0.125$$

$$[\mathrm{N/O}] \leq -0.3$$

$$^{13}\mathrm{C}/^{12}\mathrm{C}\ \text{as low as possible}$$

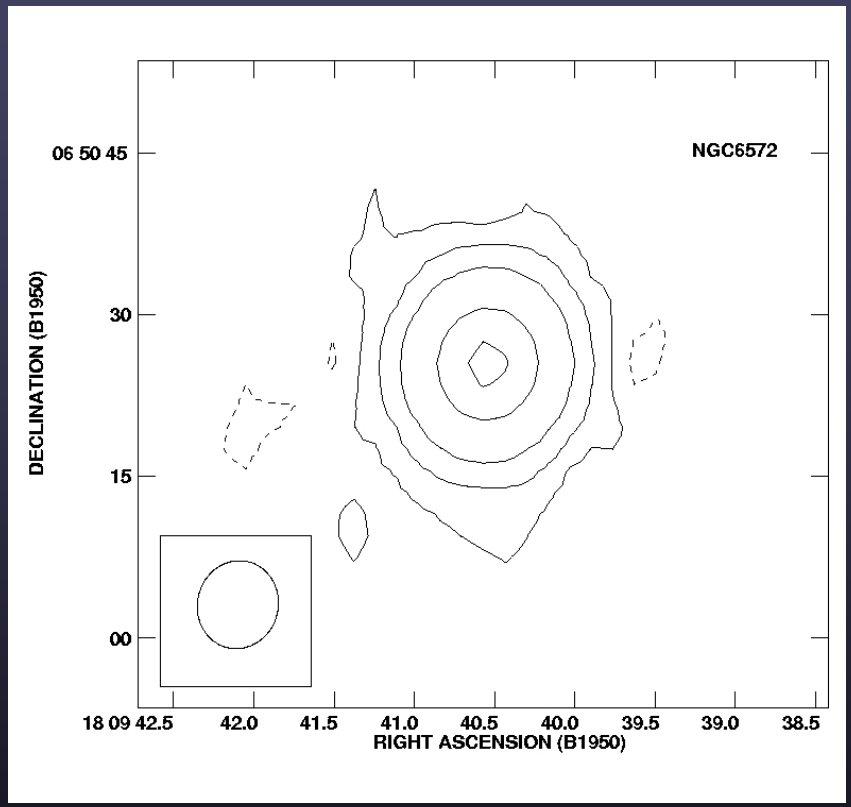
Peimbert Class: IIb, III, IV (old population)

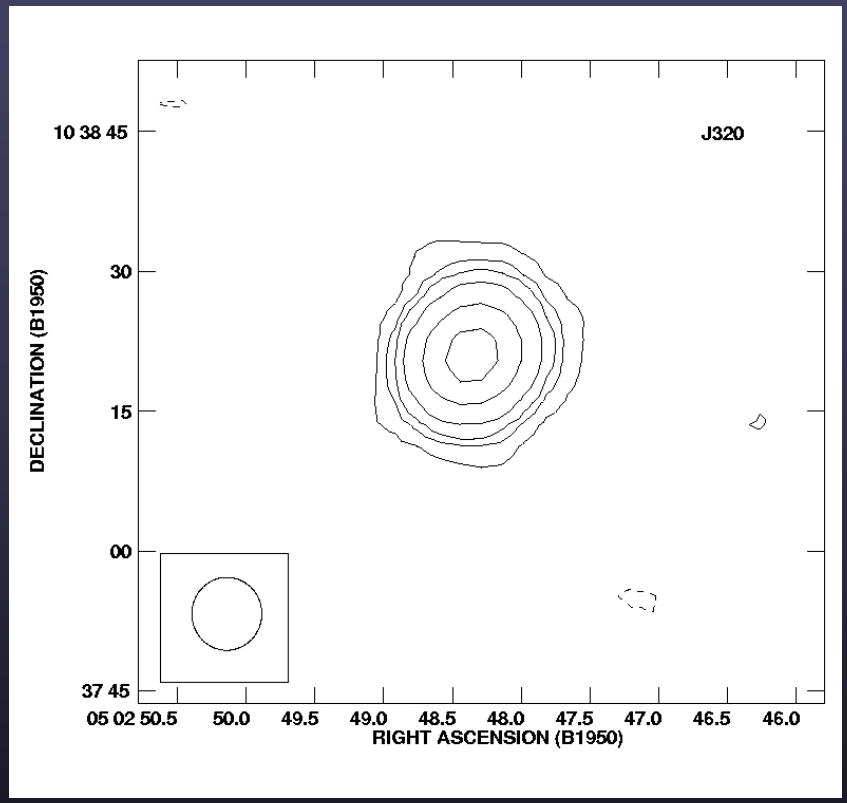
Helium is singly ionized

NRAO Very Large Array (PNe)

NGC 6572
J320

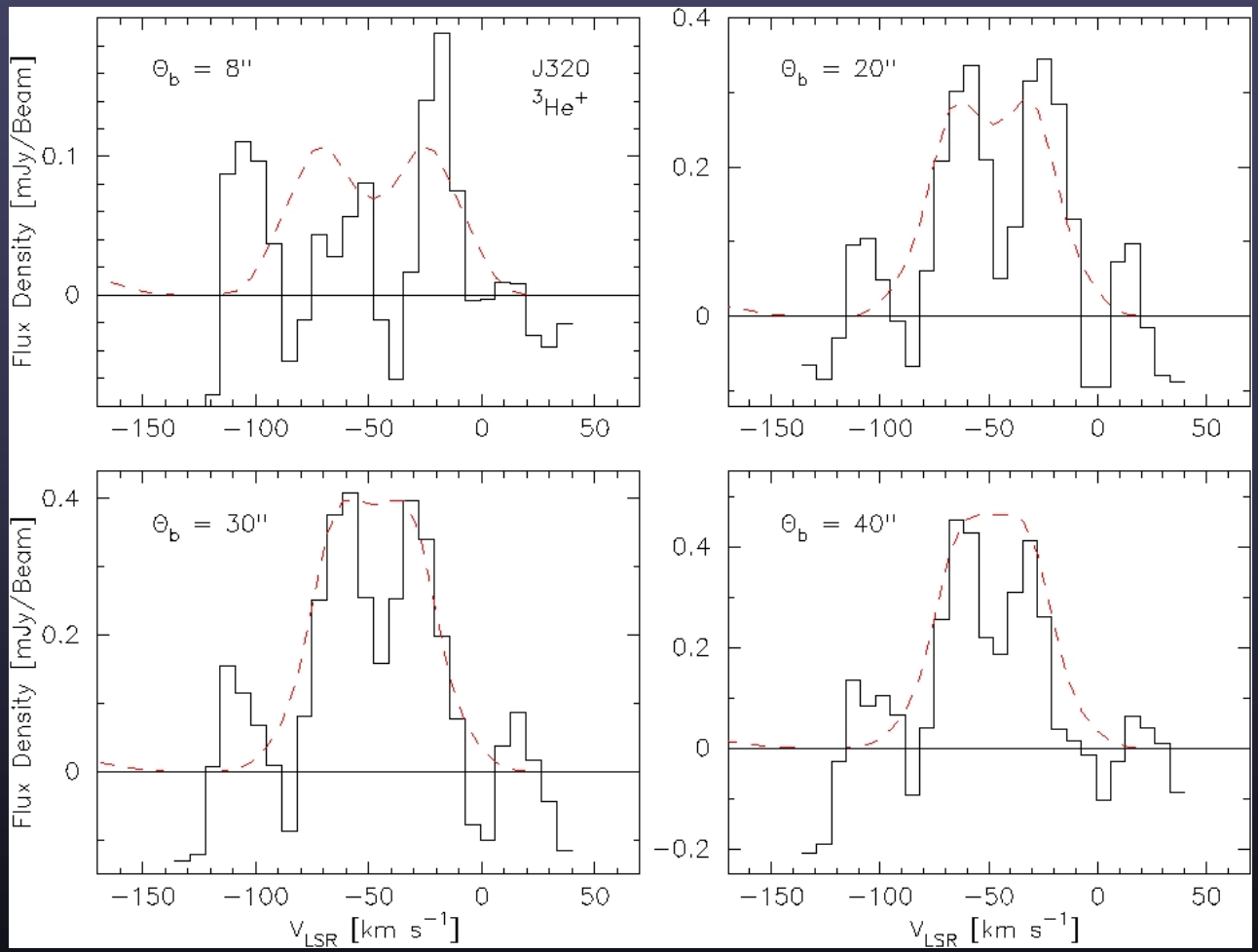
PNe Continuum Image





Balser et al. (2006)

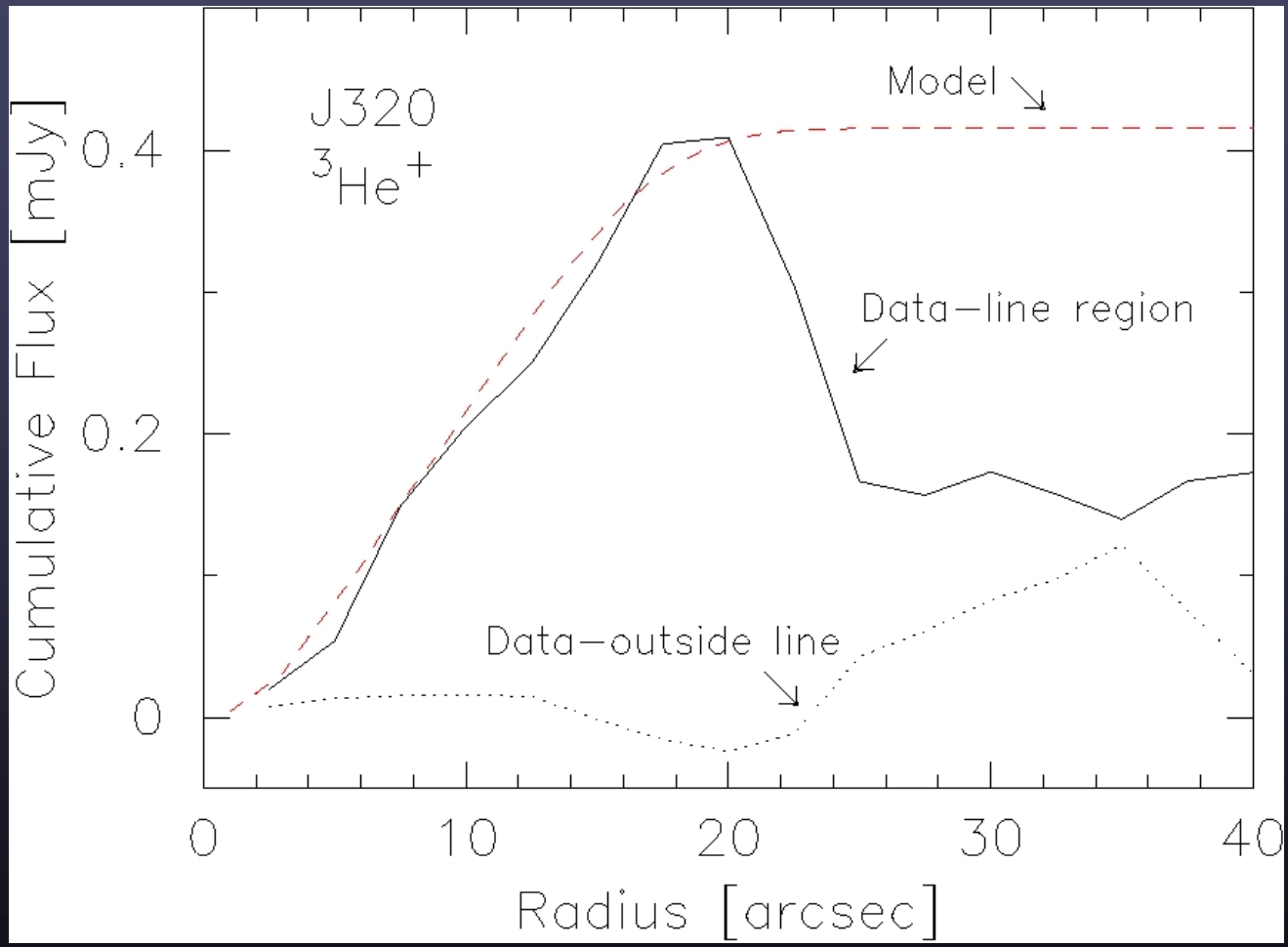
PNe Spectra: J320



$^{3}\mathrm{He/H} = 1.9 \pm 3.8 \times 10^{-3}$

Balser et al. (2006)

PNe: J320



Halo detected

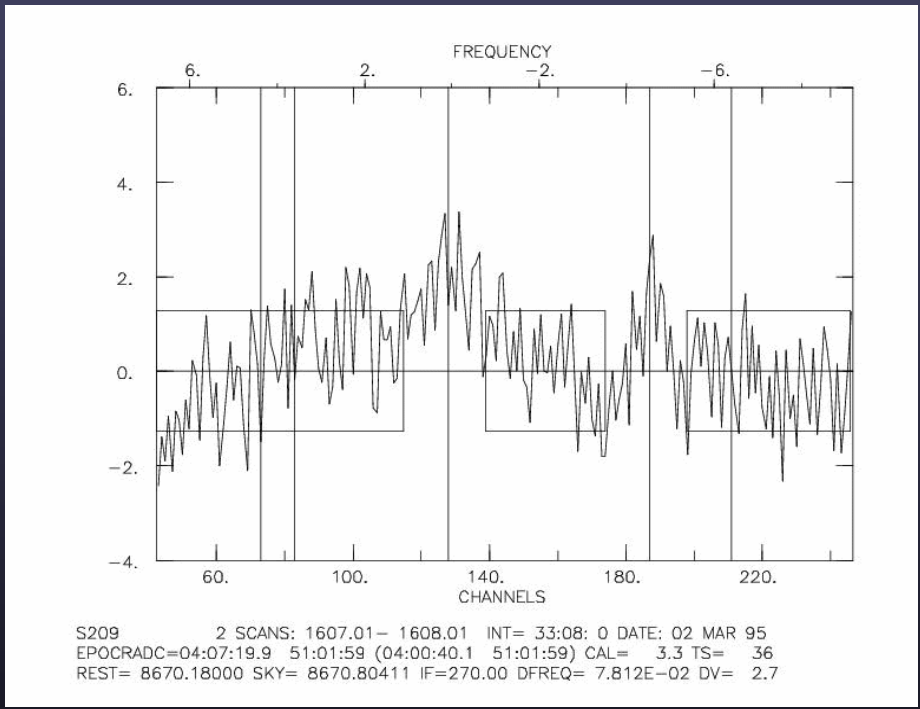
Balser et al. (2006)

NRAO Green Bank Telescope 100 m (PNe)

GBT Clear Aperture Optics

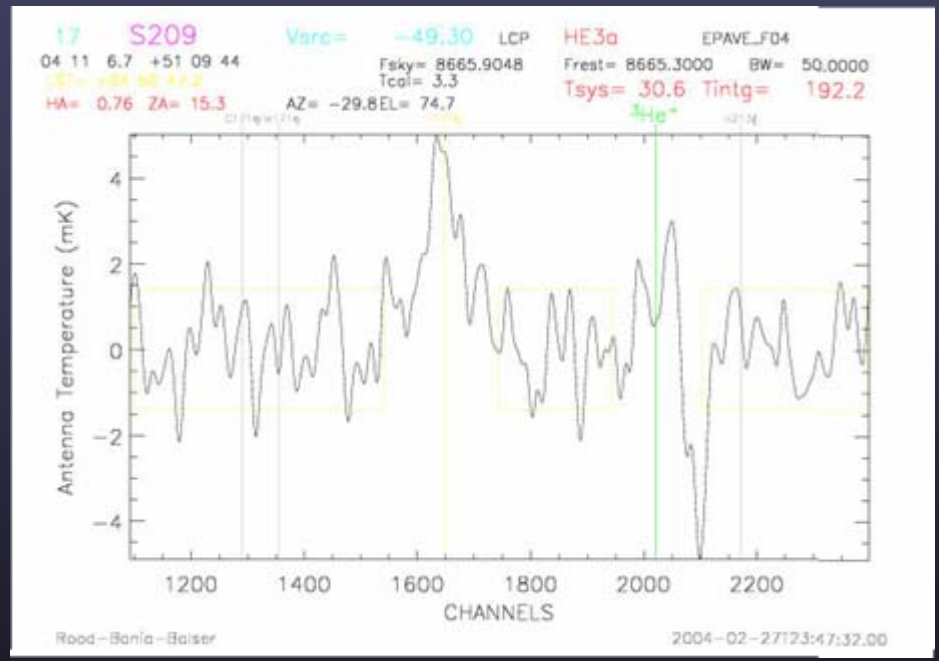
HII Region S206: 140 Foot versus GBT

140 Foot March 1995



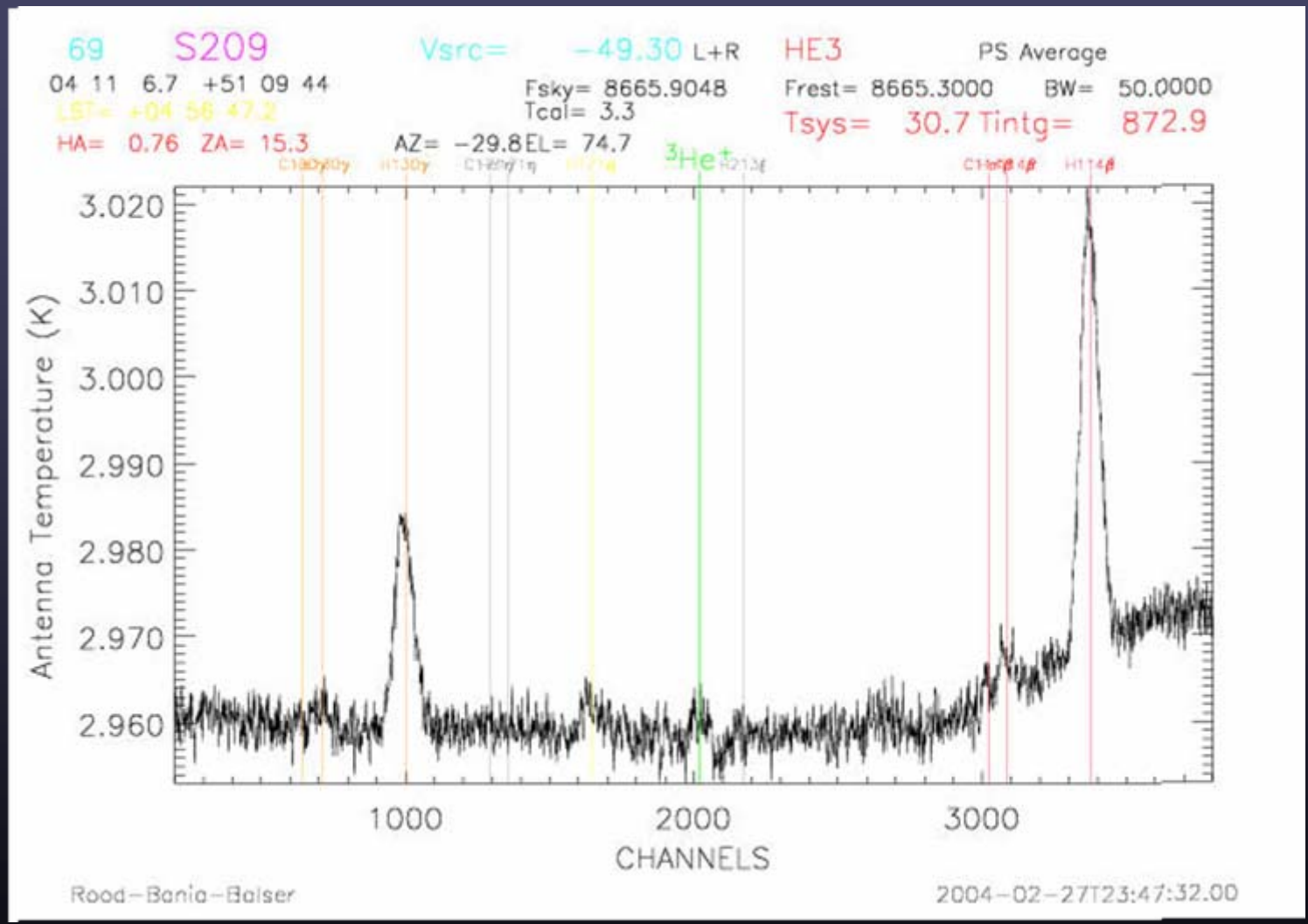
33.1 hr

GBT June 2004



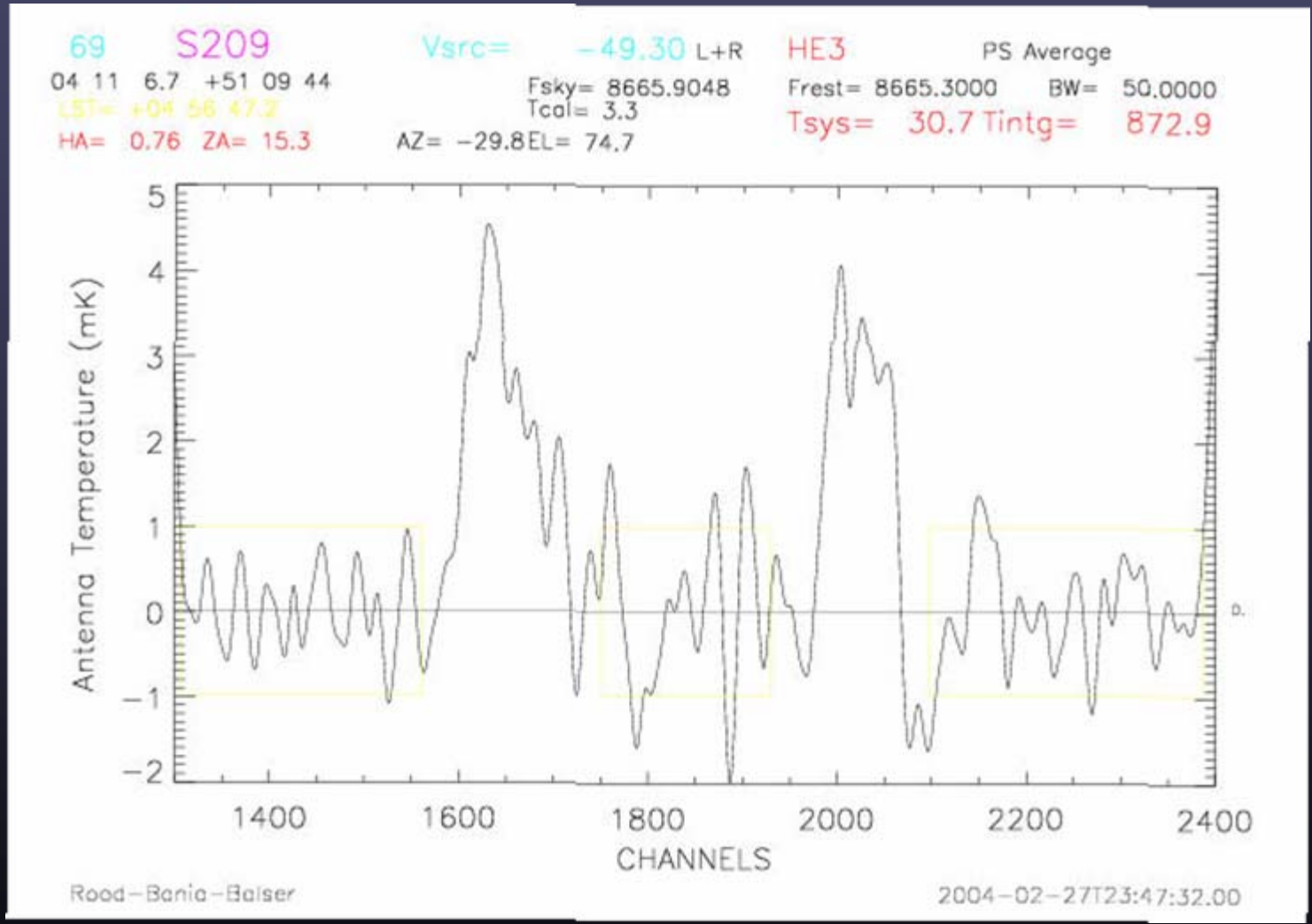
3.2 hr

GBT S209 HII Region: calibrated raw spectrum



14.5 hr integration

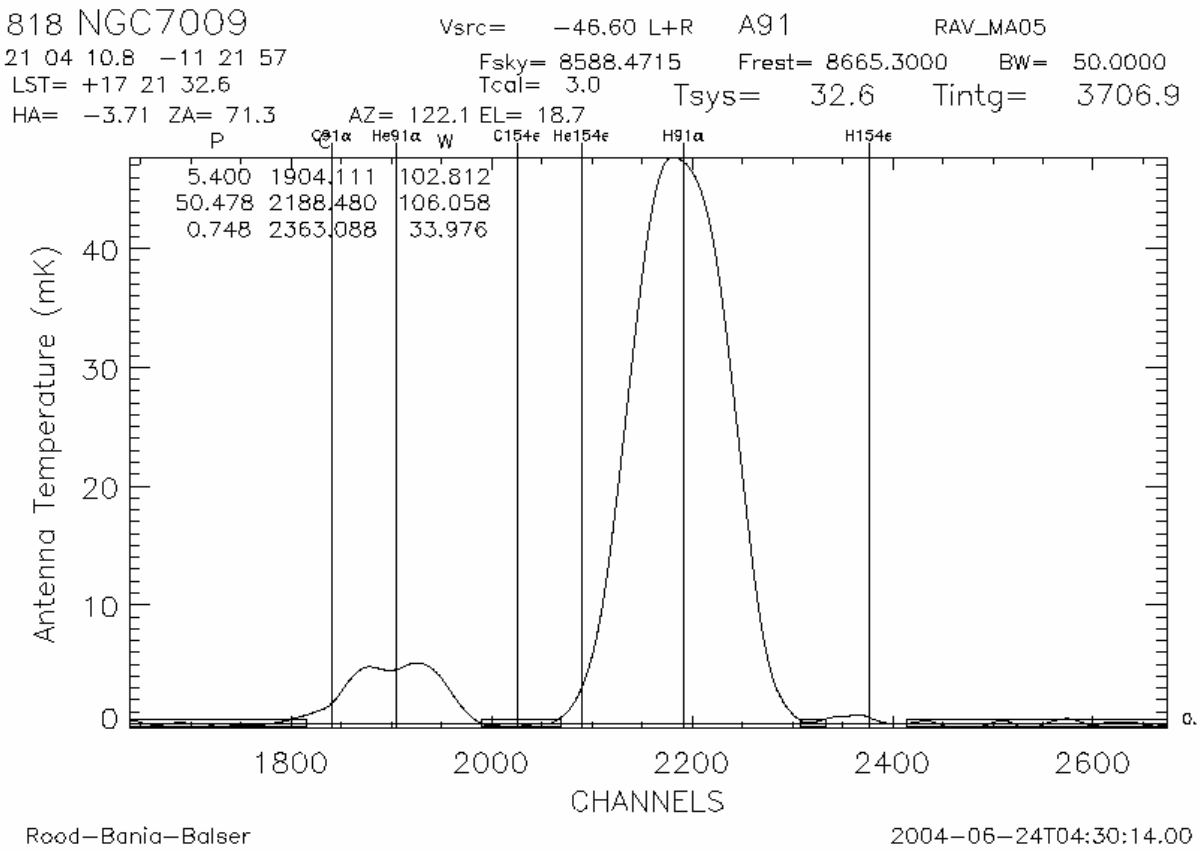
GBT S209 HII Region



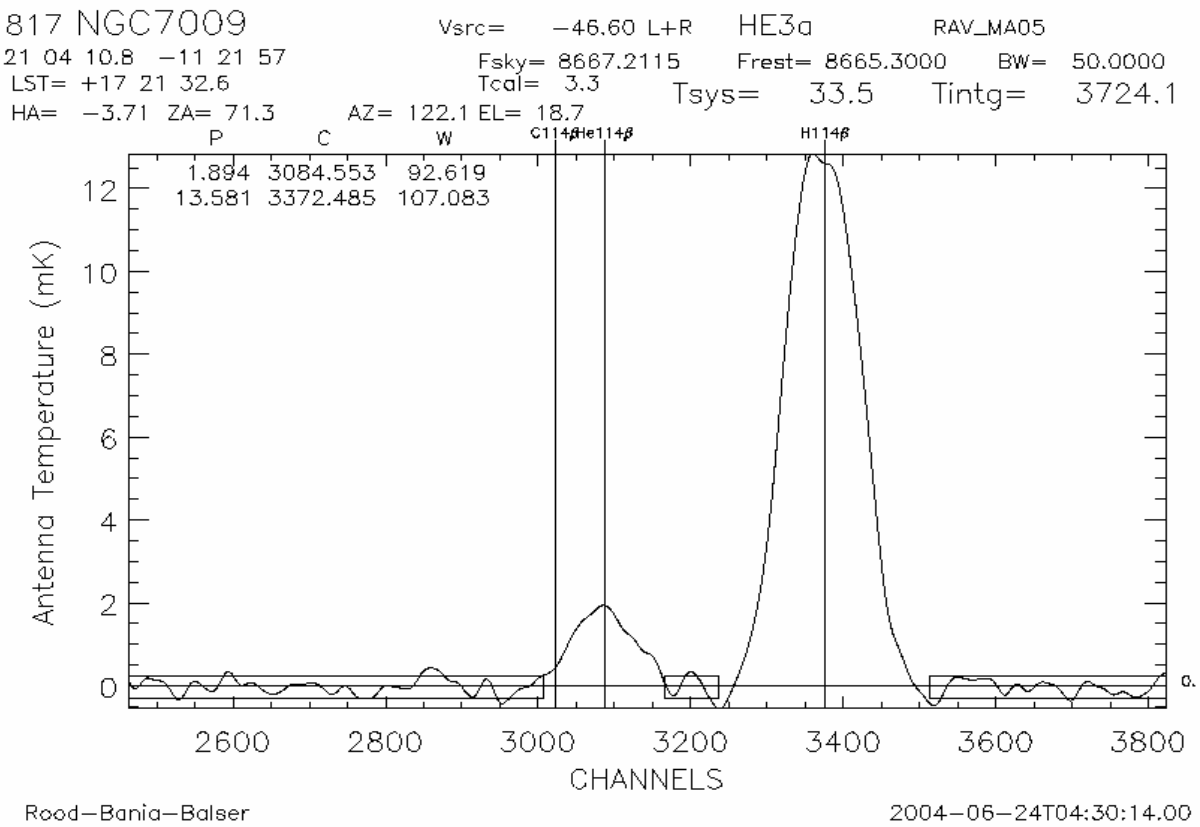
14.5 hr integration

5 km/s resolution

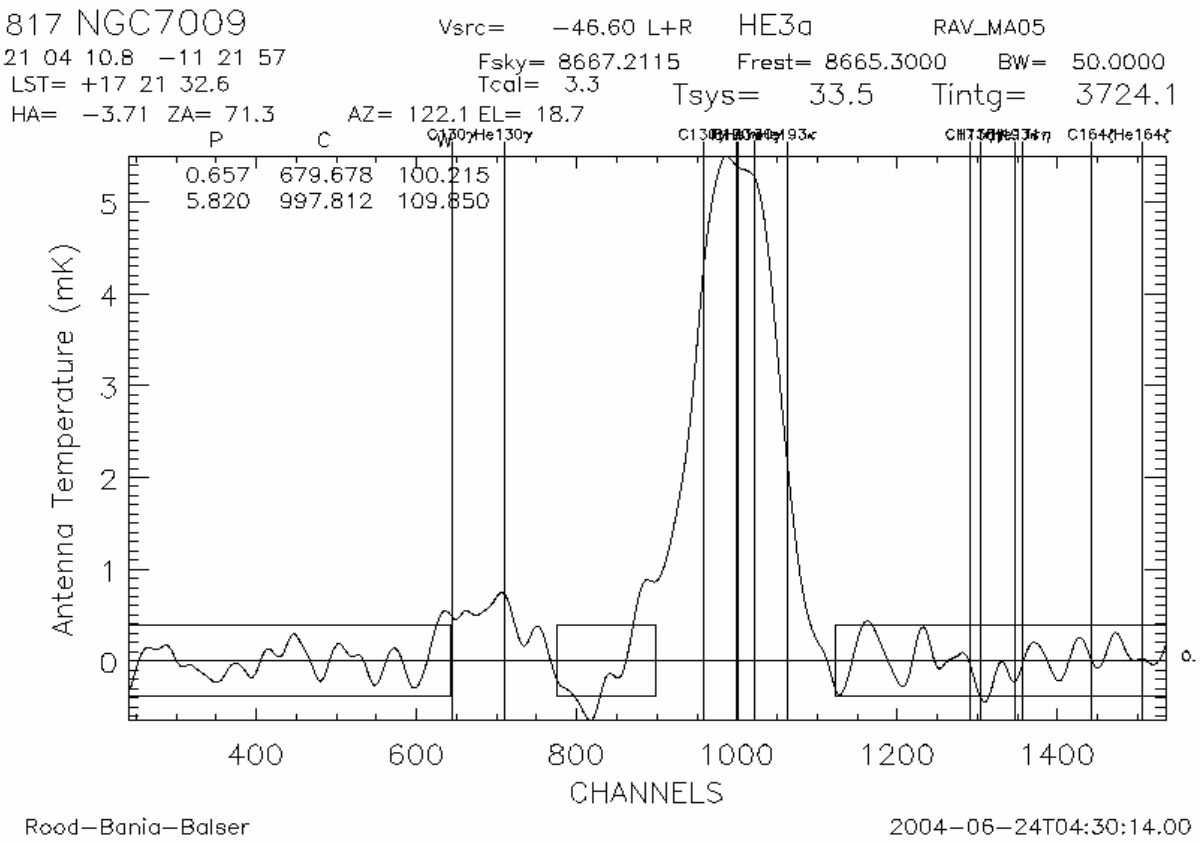
NGC 7009: H91alpha (61.8 hr)



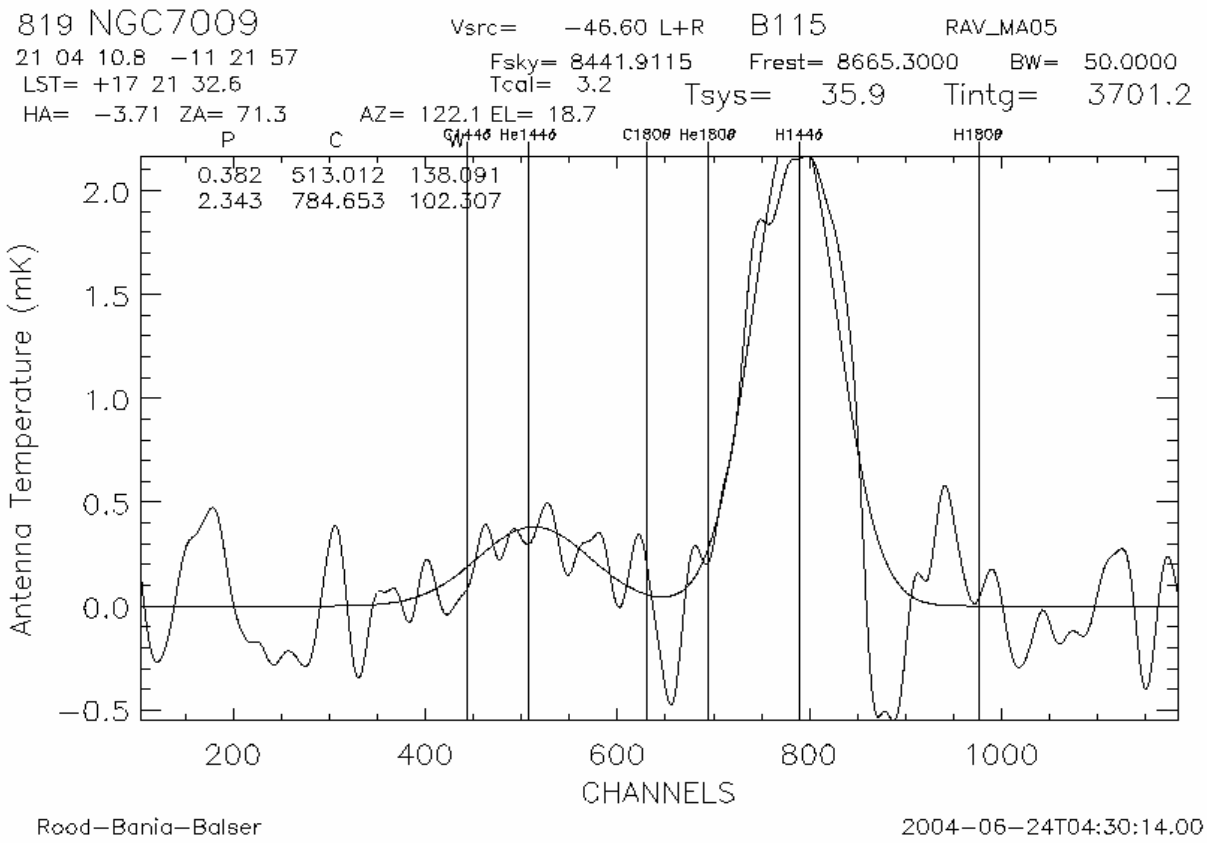
NGC 7009: H114beta (62.1 hr)



NGC 7009: H130gamma (62.1 hr)

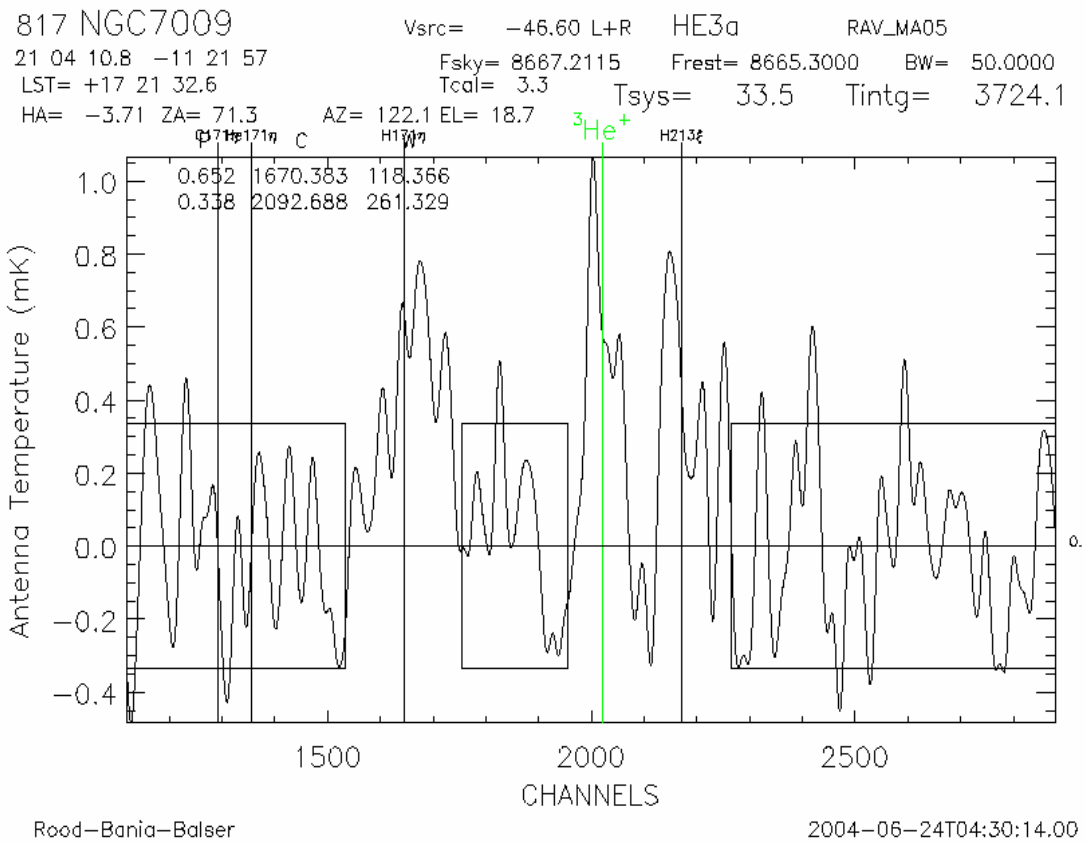


NGC 7009: H144delta (61.7 hr)

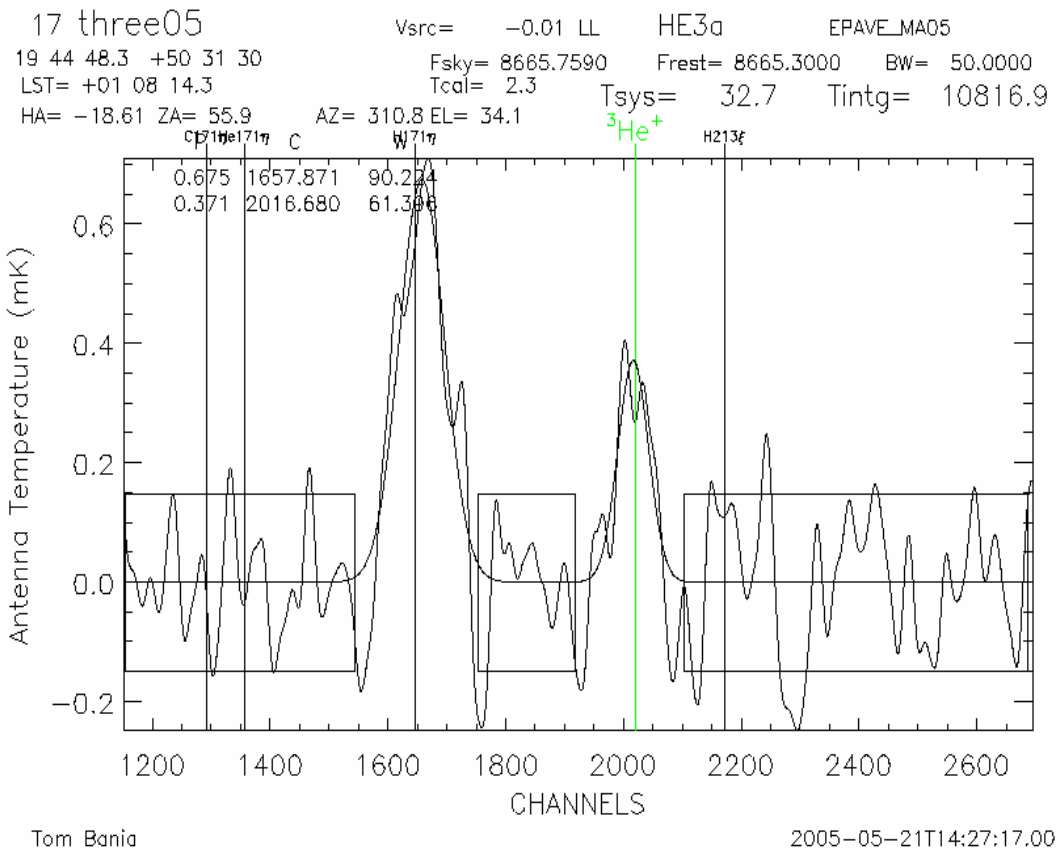


Reliability level of ~0.5 mK

NGC 7009: 3He+ (62.1 hr)



NGC 7009 + NGC 6543 + NGC 6826 (180.3 hr)

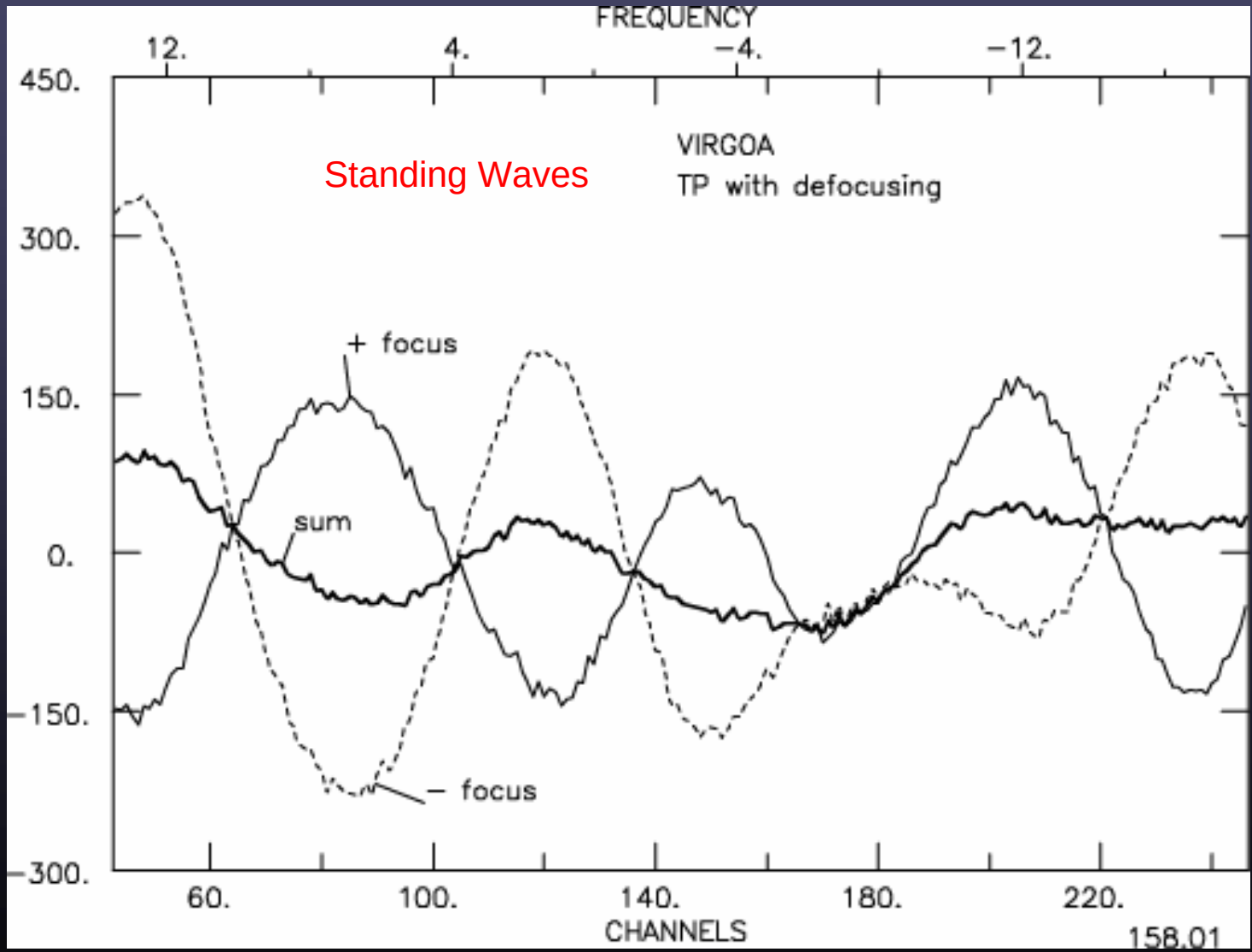


Arecibo 305 m Telescope (PNe)

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)



Spectral Baseline Structure (GBT)