The 3-Helium Problem: Constraining the Chemical Evolution of the Milky Way

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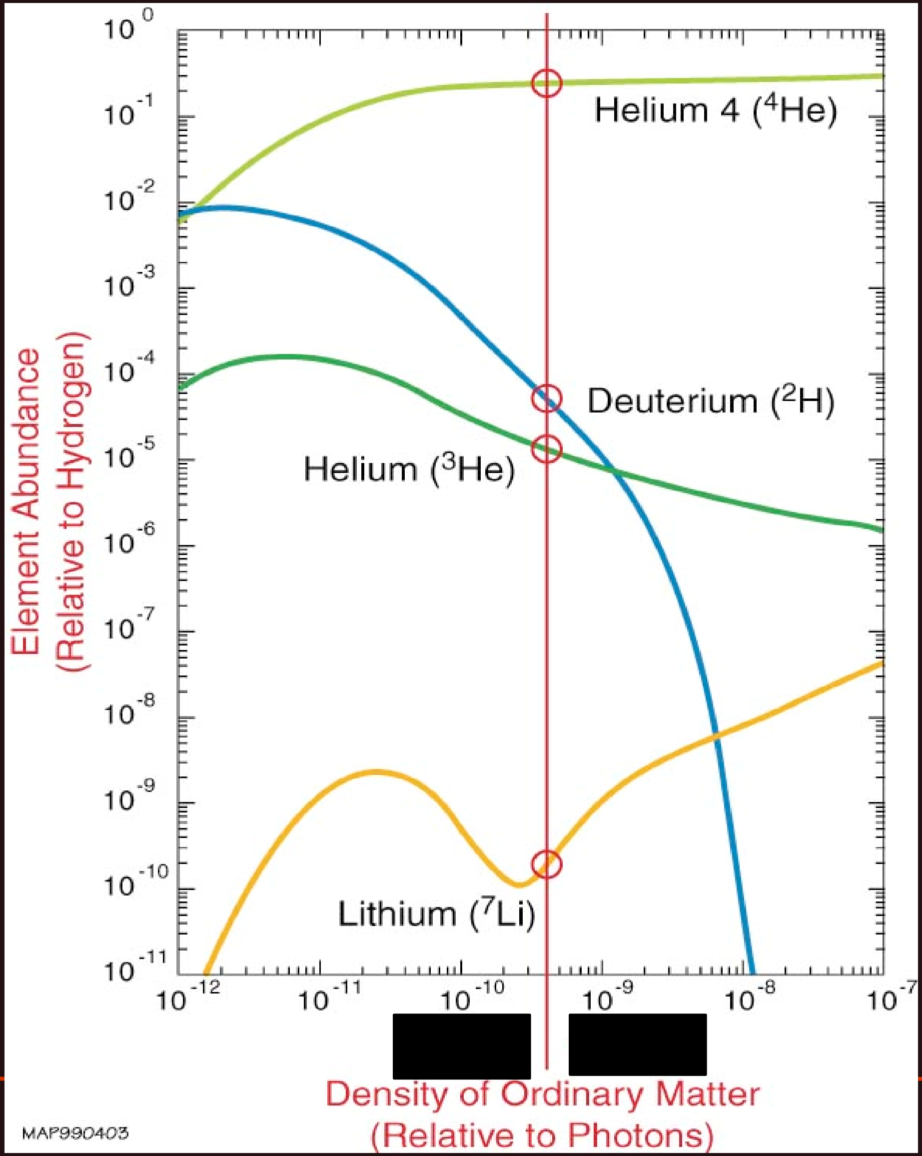
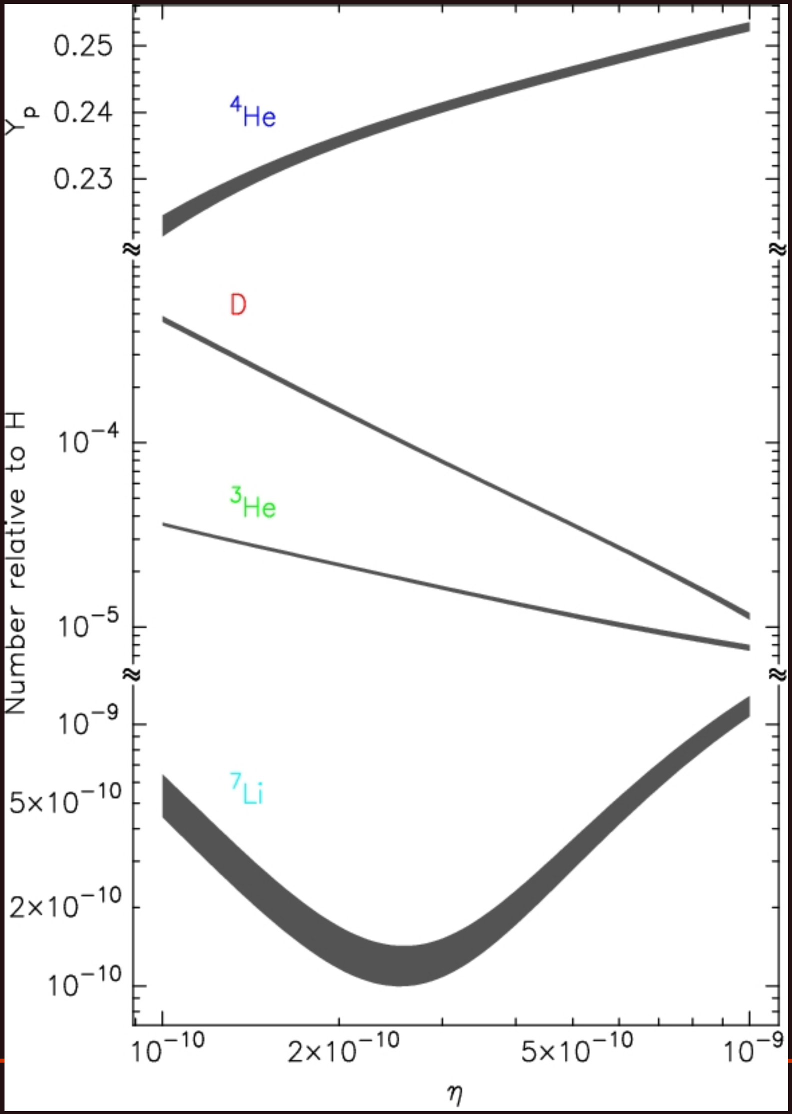
Light Elements as Baryometers

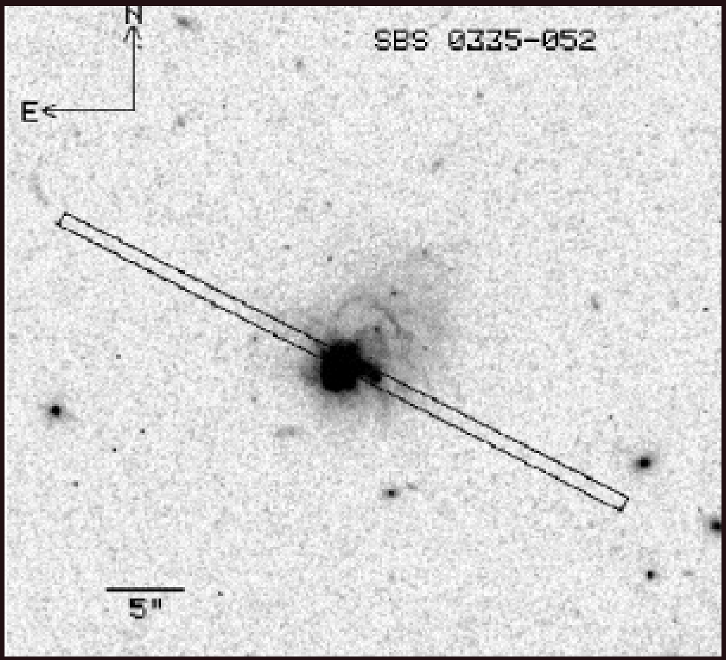


Primordial Nucleosynthesis: BBNS

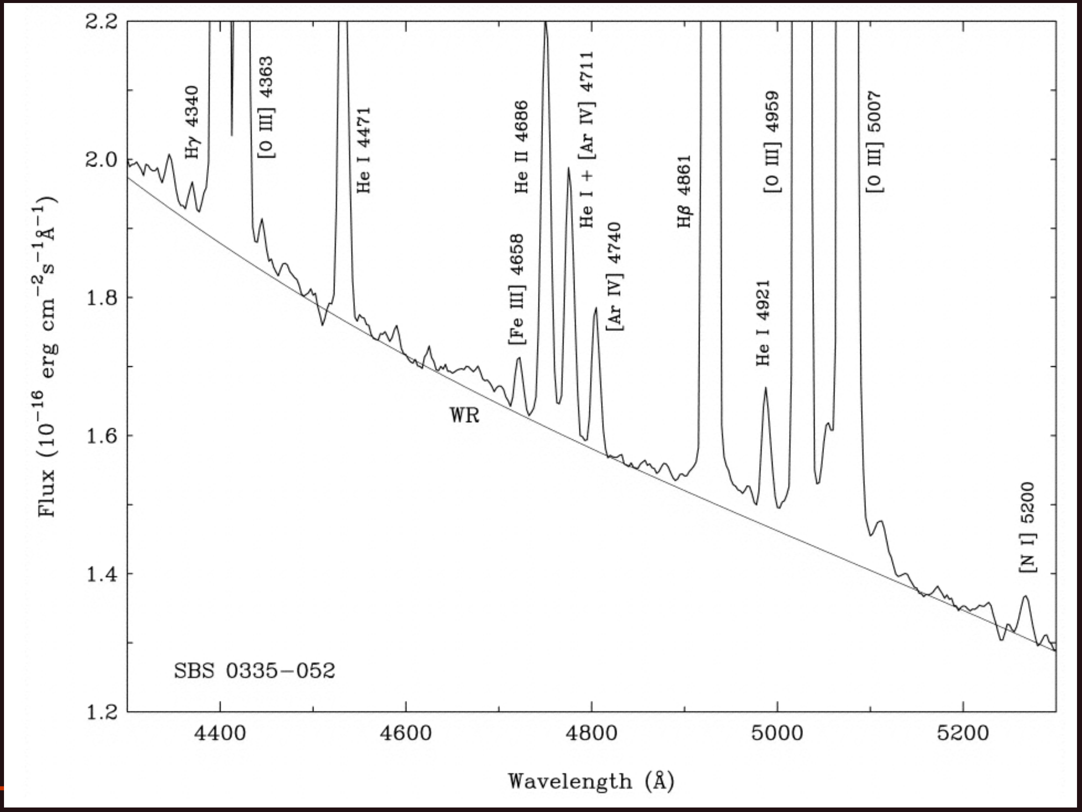


Burles et al. (2001)

^{4}He: Optical recombination lines

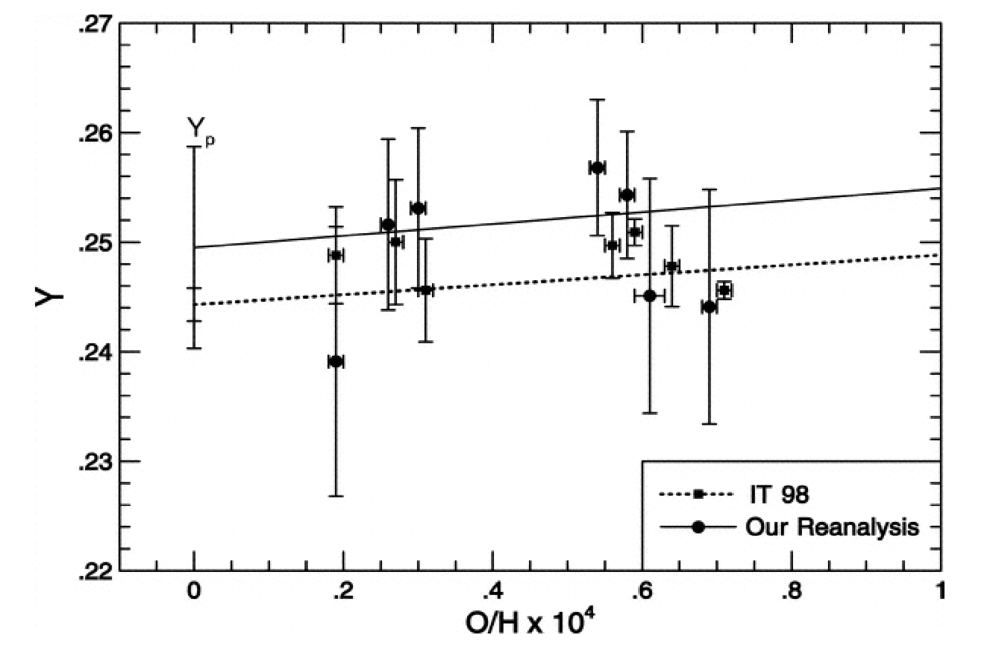


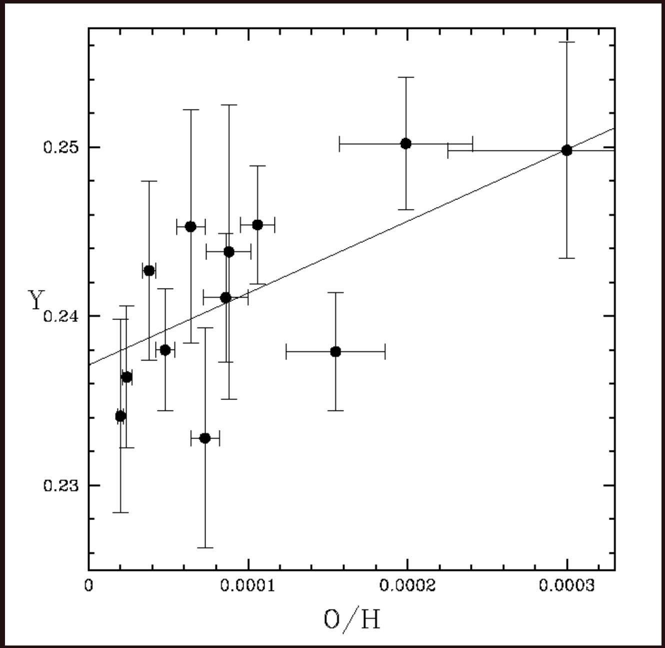
Metal poor blue compact galaxies



Izotov et al. (1999)

^{4}He Abundances



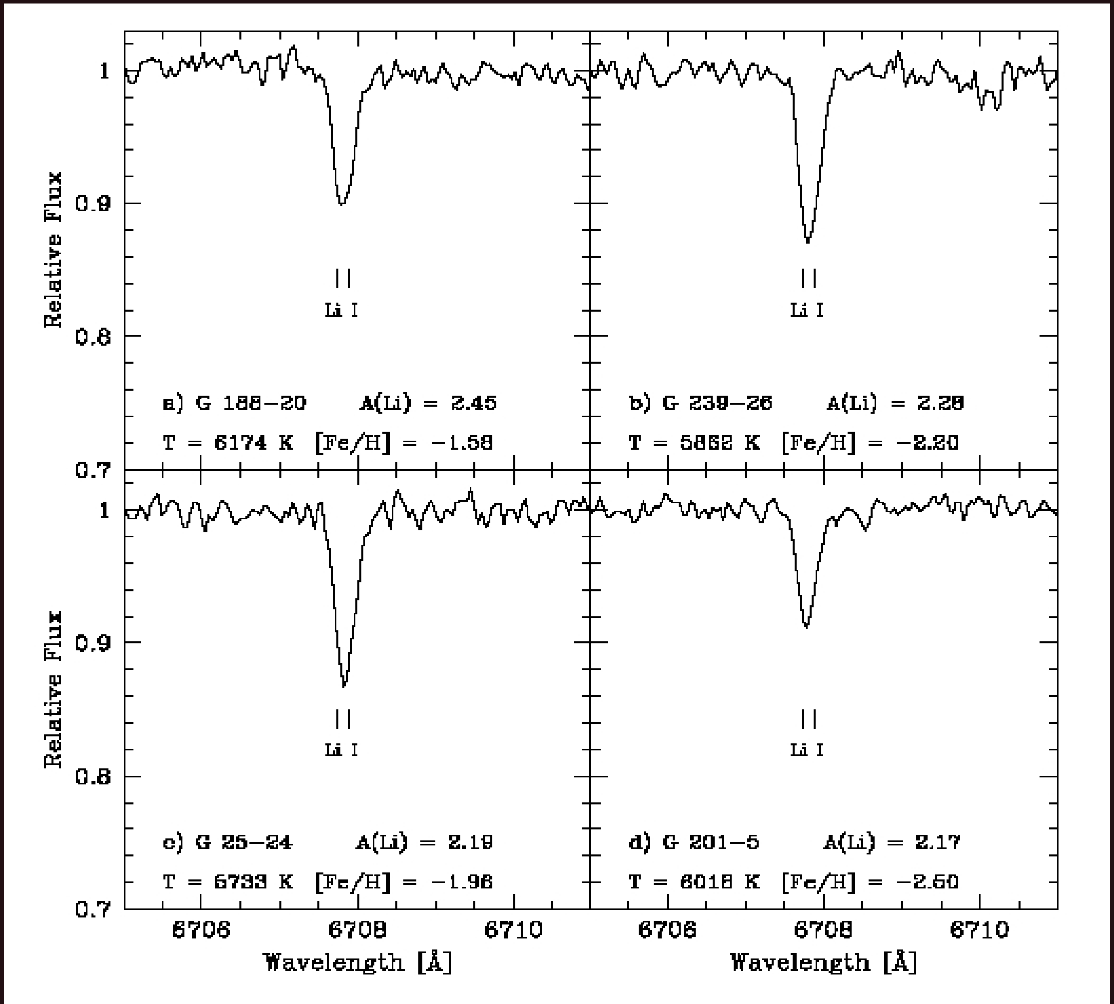


Olive & Skillman (2004)

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)

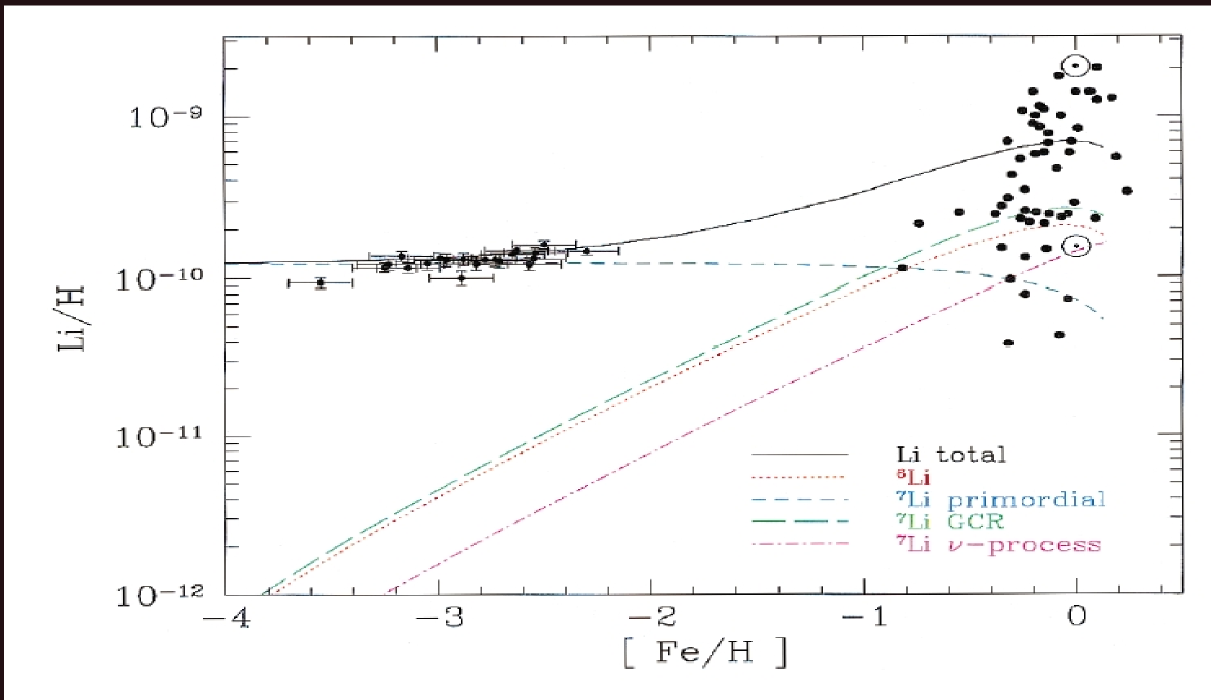
^{7}Li: Resonance Line



Metal poor
Halo stars

Boesgaard et al. (2005)

^{7}Li: The Spite Plateau



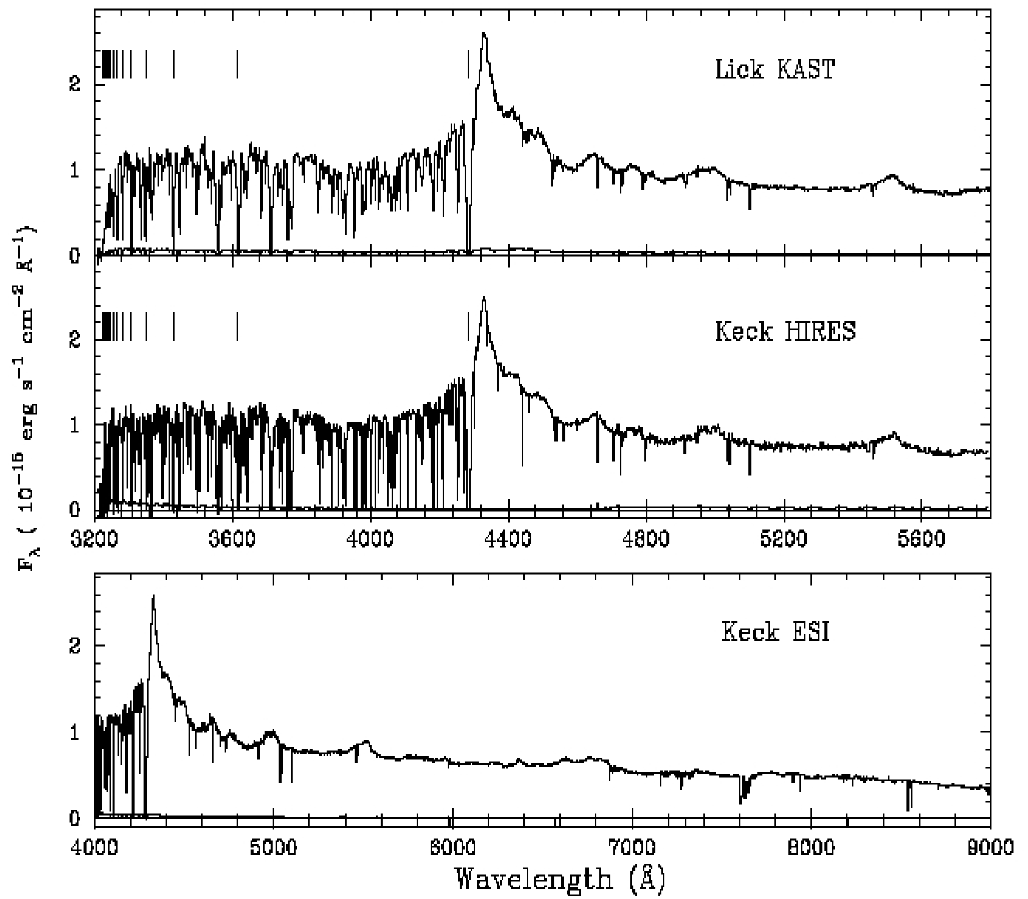
Ryan et al. (2000)

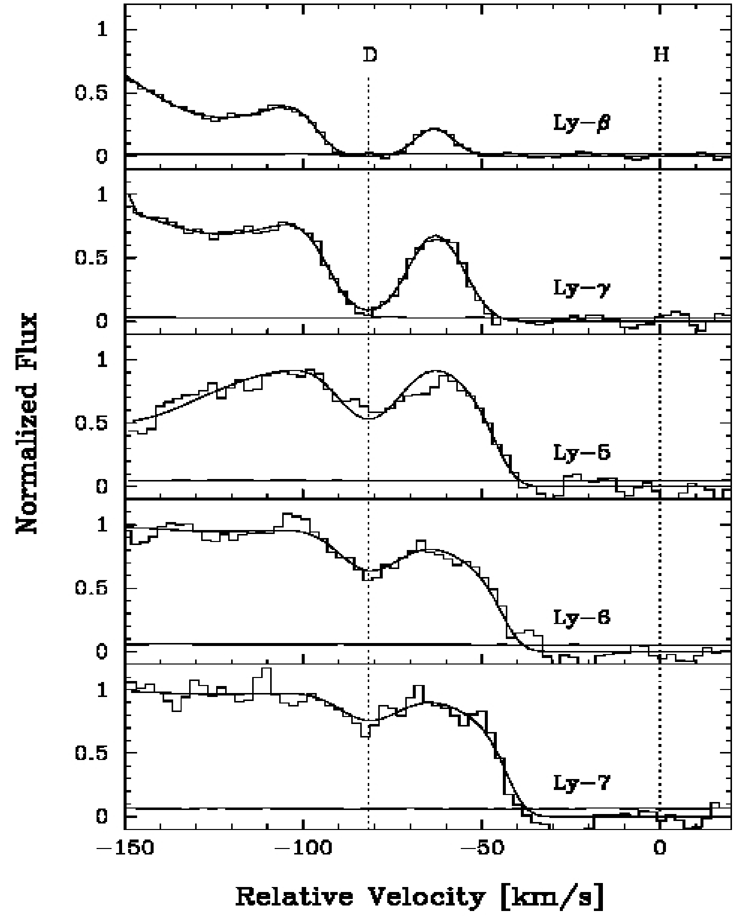
Log(7Li/H) + 12	Reference
2.09 (+0.19,-0.13)	Ryan et al. (2000)
2.37 (0.1)	Melendez & Ramirez (2004)
2.44 (0.18)	Boesgaard et al. (2005)

Deuterium: Lyman series

Q1243+3047

HS 0105+1619

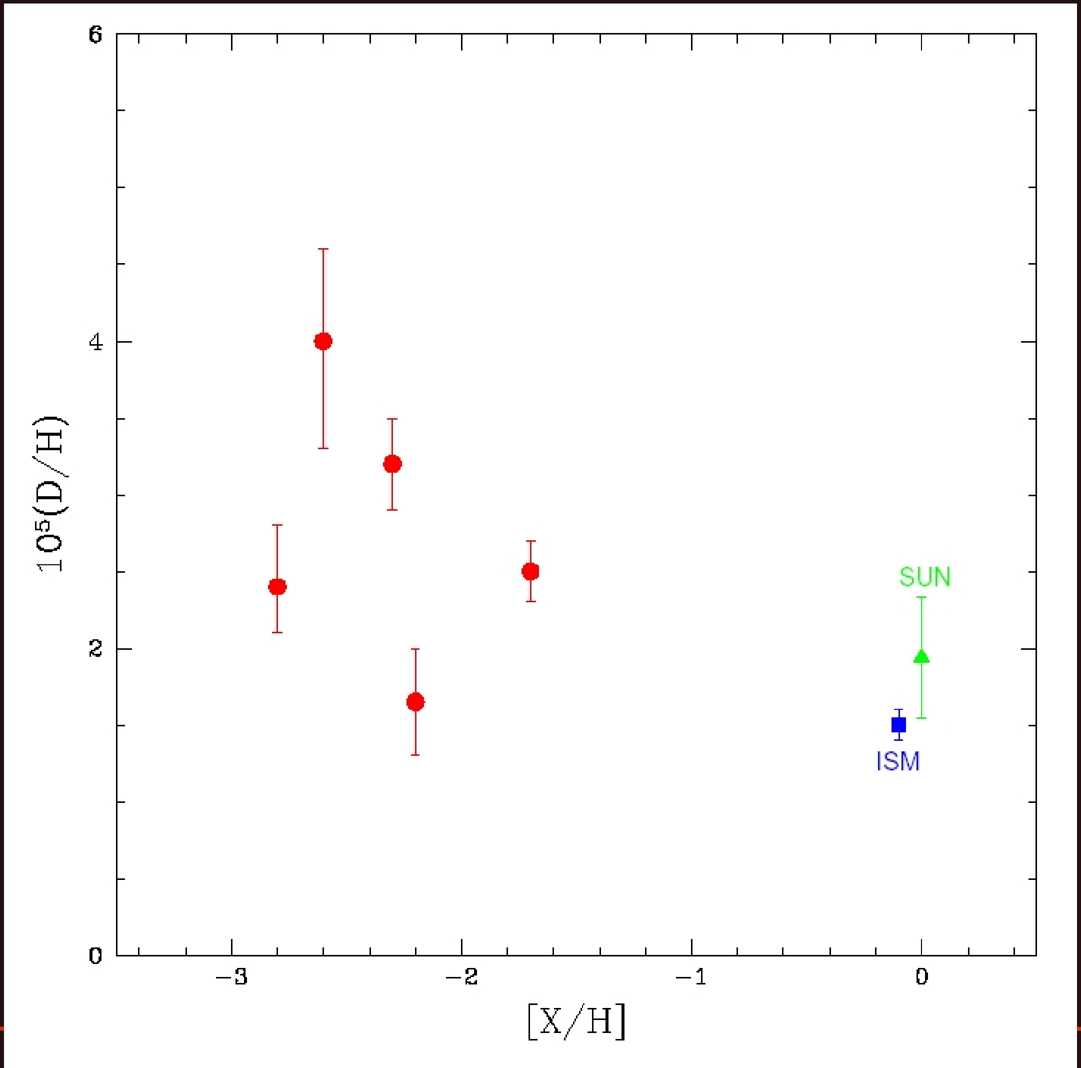




Kirkman et al.
(2003)

O'Meara et al. (2001)

Deuterium Abundances



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

Kirkman et al. (2003)
Steigman (2005)

The 327 MHz Deuterium Line

Rogers, Dudevoir, Carter, Fanous, Kratzenberg, and Bania
2005, ApJ, **630**, L41-44 (**RDCFKB**):
"Deuterium Abundance in the Interstellar Gas of the Galactic Anticenter from the 327 MHz Line"   92 cm wavelength

Overall view of the 25 5x5 crossed dipole stations of the Deuterium array

Haystack Observatory, Westford, MA

Array: 24 stations

Station: 24 crossed Yagis

Station Area: 12 m^2

Station Beam: 14^o

Beam Steering: +/- 40^o

Frequency: 327.4 MHz

Bandwidth: 250 kHz

Channels: 1024

Resolution: 244 Hz

Polarization: Dual Linear

System Temperature: 40 K + sky

Rx Ports: 48 x 24 = 1152

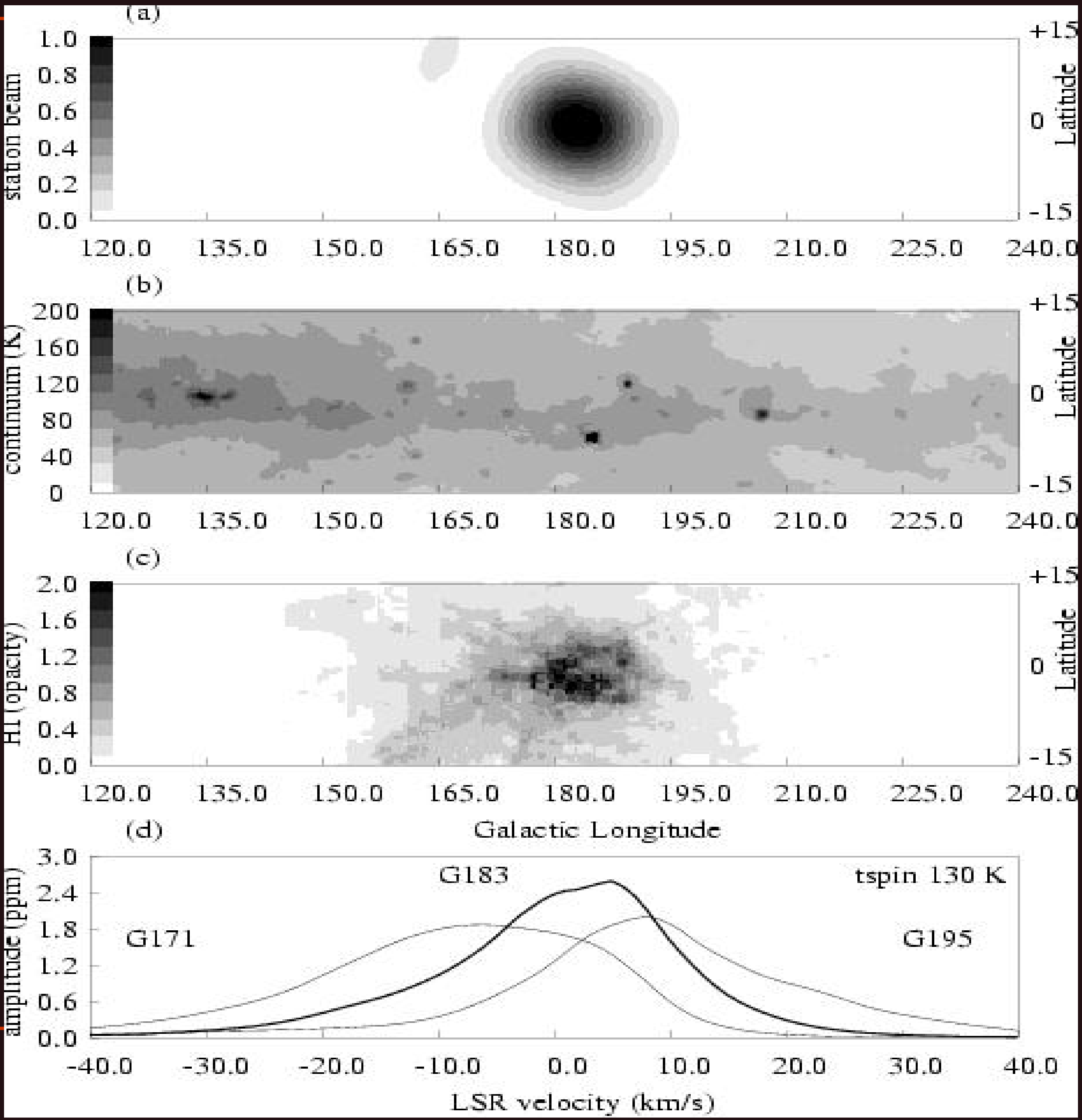
D I

Beam

Continuum

H I

Model D I Spectra

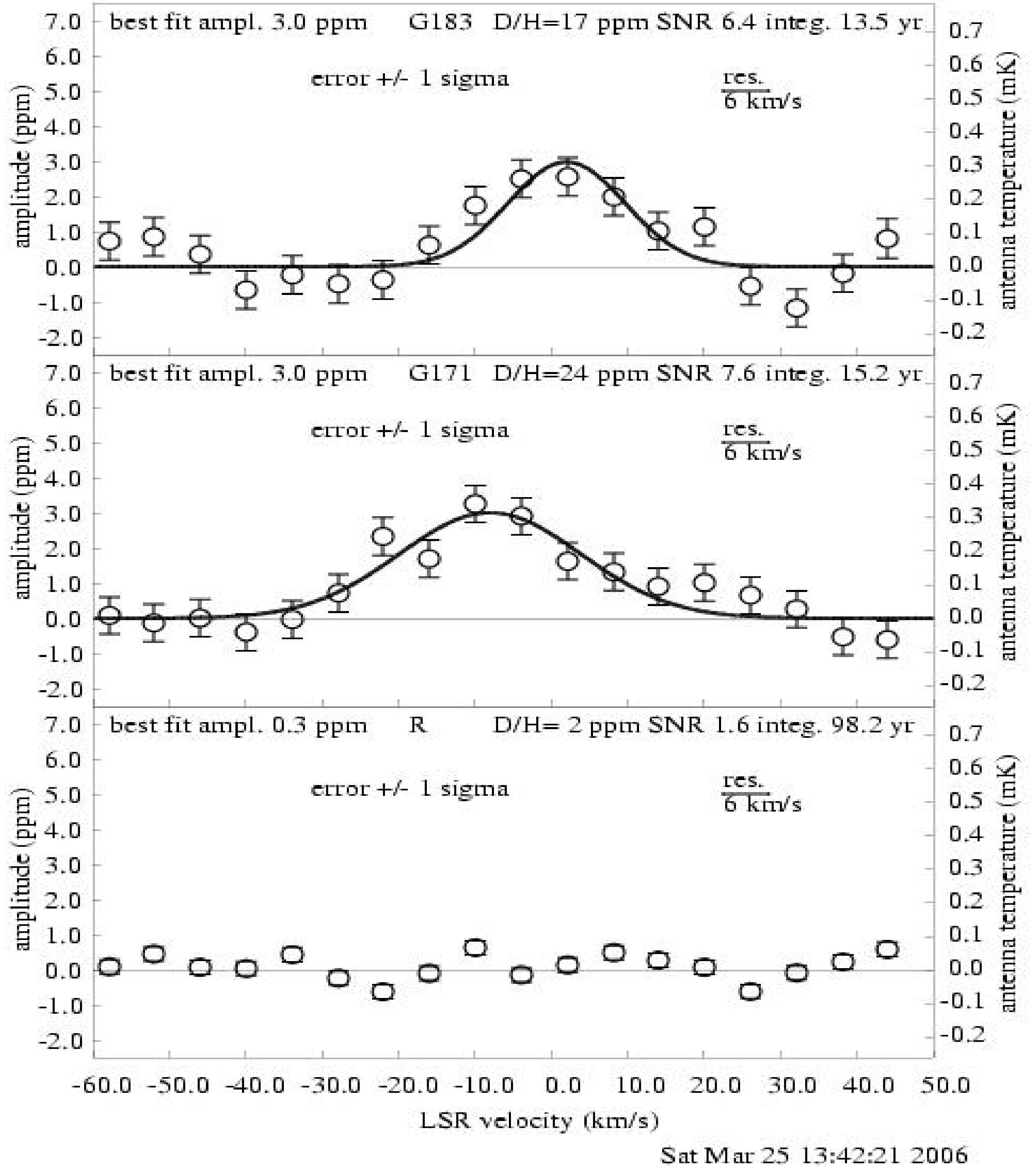


Mar 2006

L = 183°

L = 171°

Blank Fields



ANTICENTER D/H ABUNDANCE

* Spin Temperature Range: 100-150 K
* Continuum Uniformly Distributed Along Line of Sight
* 1 Sigma measurement errors

=> <D/H> = $(2.0 +/- 0.5) \times 10^{-5}$ <=

for Rgal = (10+/-1) kpc

I ♥ ^{3}He

Stalking the Cosmic ^{3}He Abundance

Tom Bania (BU),

Bob Rood (UVa),

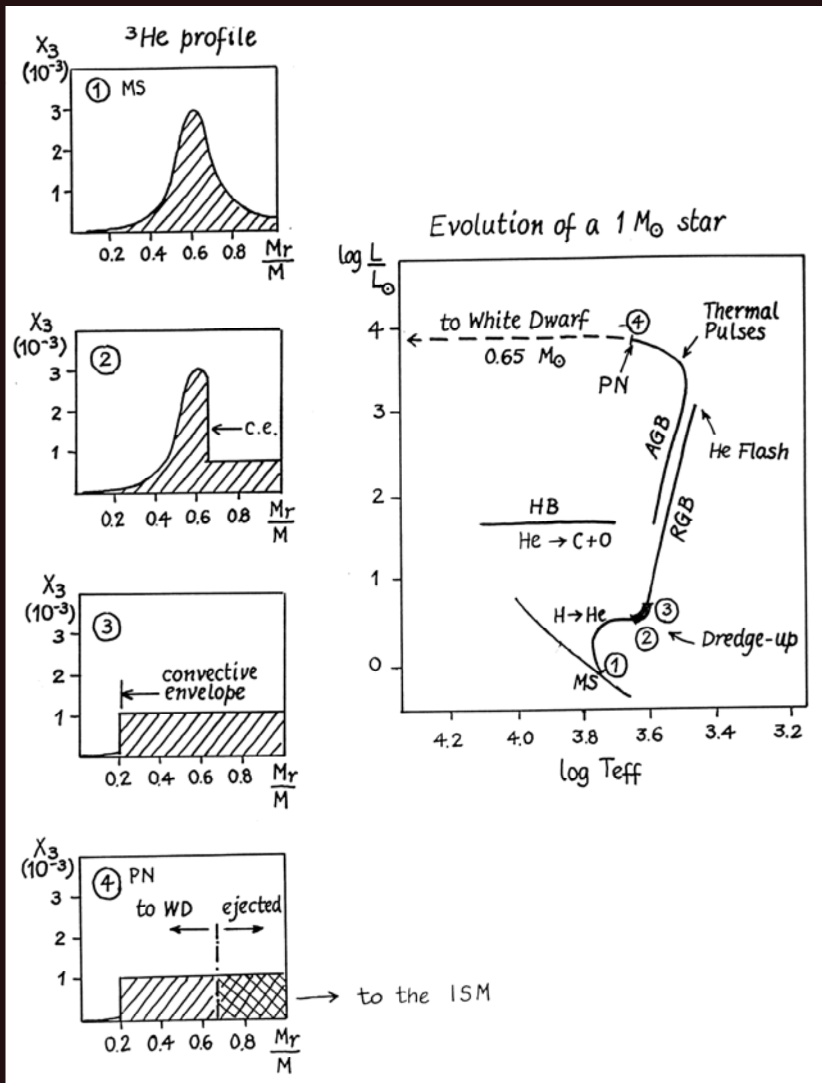
Dana Balser (NRAO),

Miller Goss (NRAO),

Cintia Quireza (ON, Brazil),

Tom Wilson (MPIfR)

^{3}He: Stellar Evolution



$^1H + {}^1H \rightarrow {}^2H + e^+ + \nu$ Production

$^2H + {}^1H \rightarrow {}^3He + \gamma$ $\quad T > 6 \, x \, 10^5 \, K$

$^3He + {}^3He \rightarrow {}^4He + 2p$ Destruction

$^3He + {}^4He \rightarrow {}^7Be + \gamma$ $\quad T > 7 \, x \, 10^6 \, K$

Daniele Galli

^{3}He: Observations

Solar System:

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

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

Local Interstellar Medium (LISM):

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

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

Galactic:

^{3}He Recombination Lines?

^{3}He$^+$ Hyperfine Line?

$^{3}He^{+}$ Hyperfine Transition

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

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

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

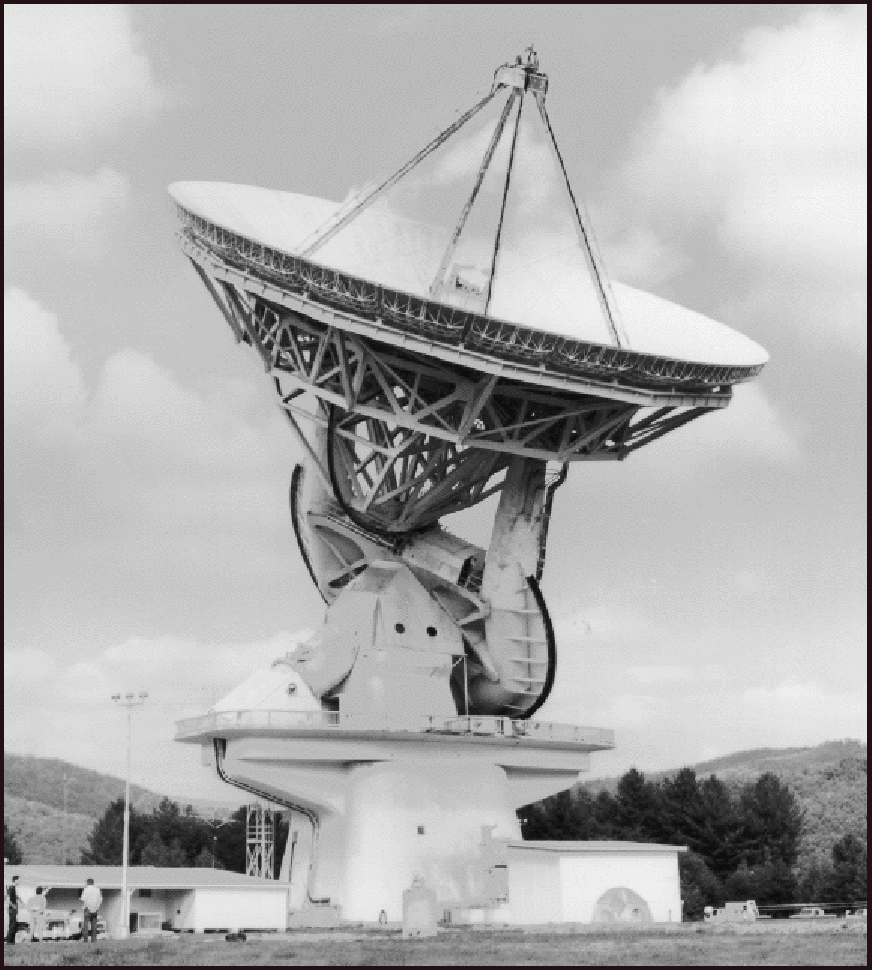
NRAO 140 ft

MPIfR 100 m

H II Regions

Planetary Nebulae (PNe)

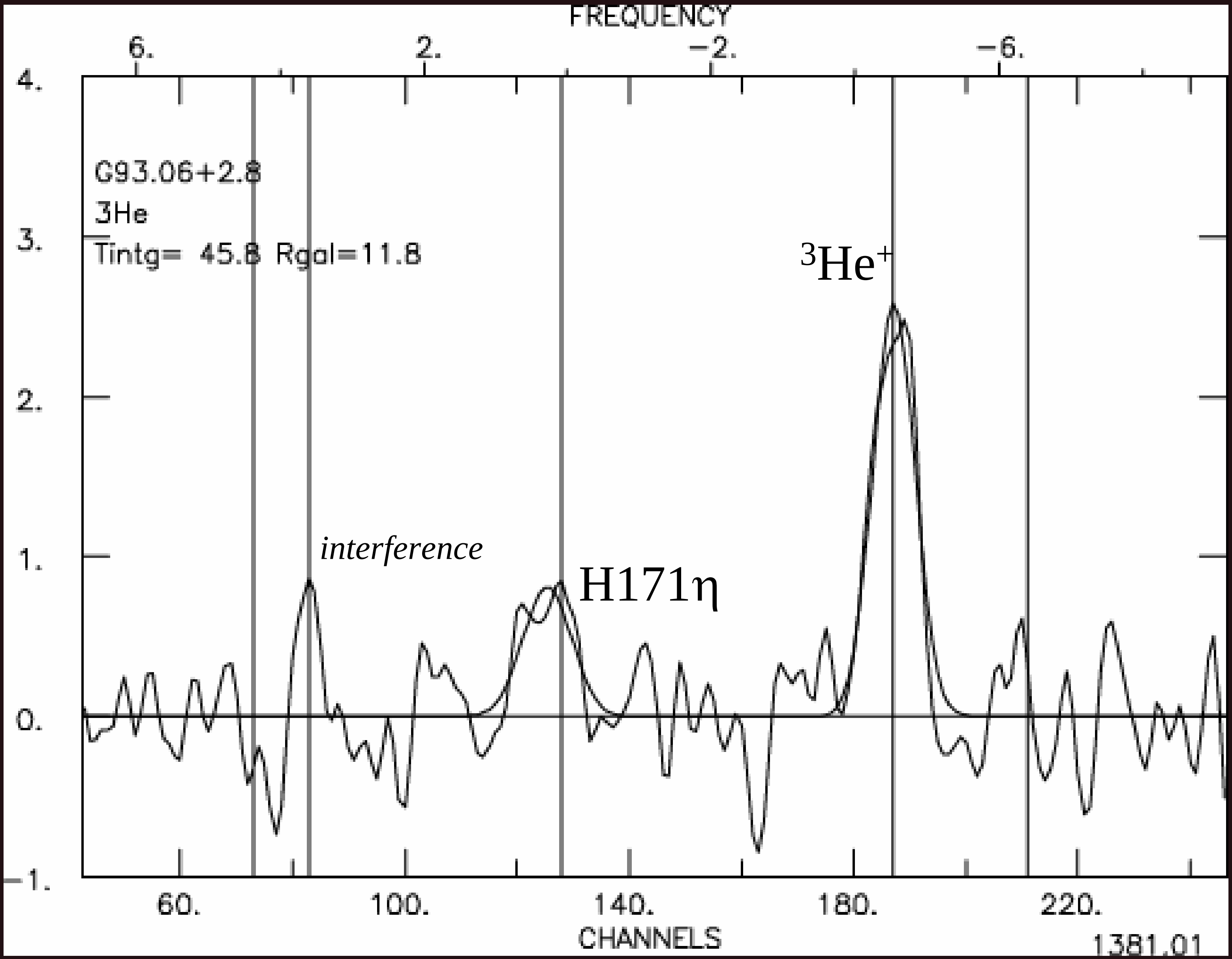
NRAO 140 Foot: HII Regions



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

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

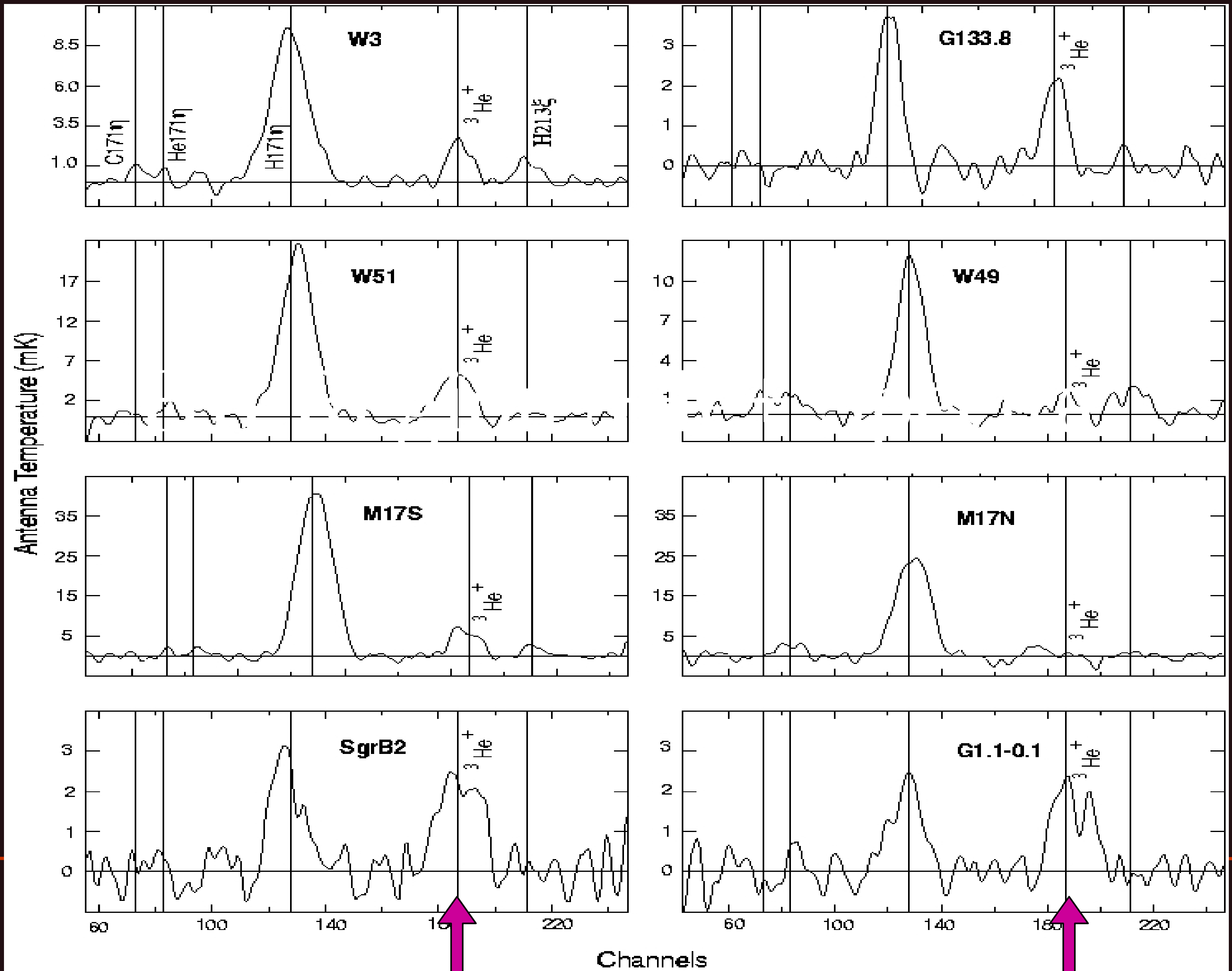
HPBW = 3.5 arcmin



G93.06+2.8 45.8 hr integration

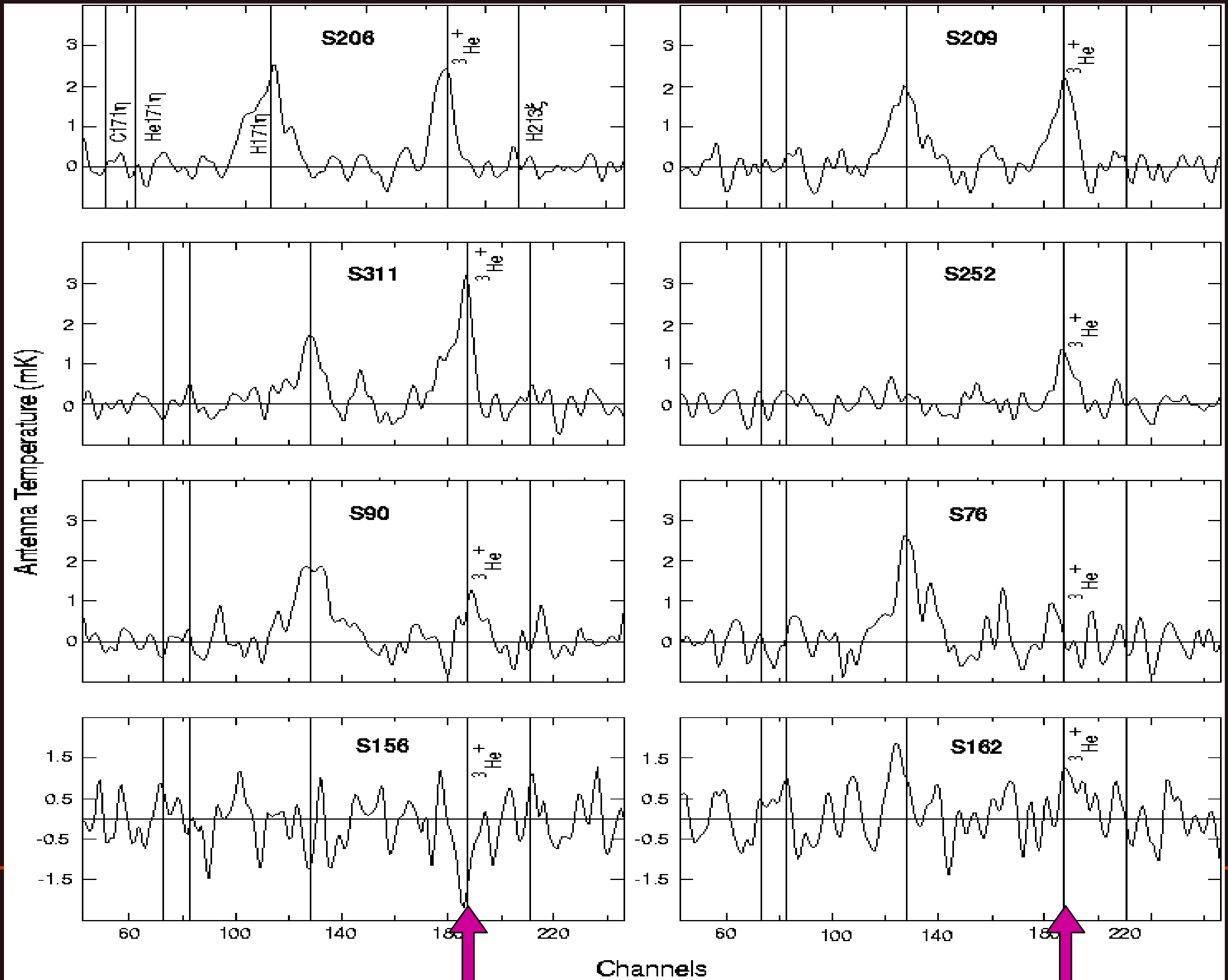
HII Region $^3He^+$ Spectra

Bania et al. (1997)



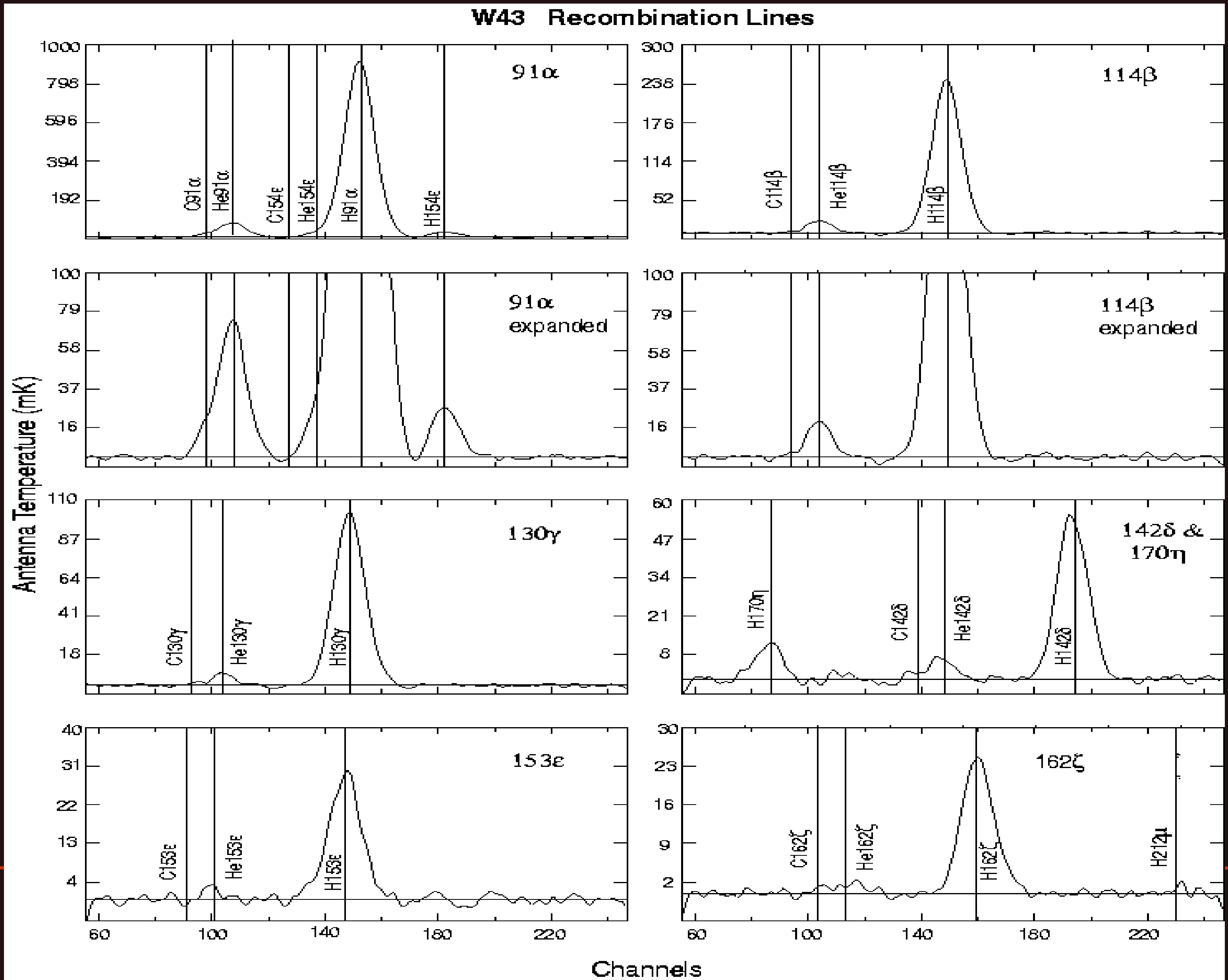
Sharpless HII Regions

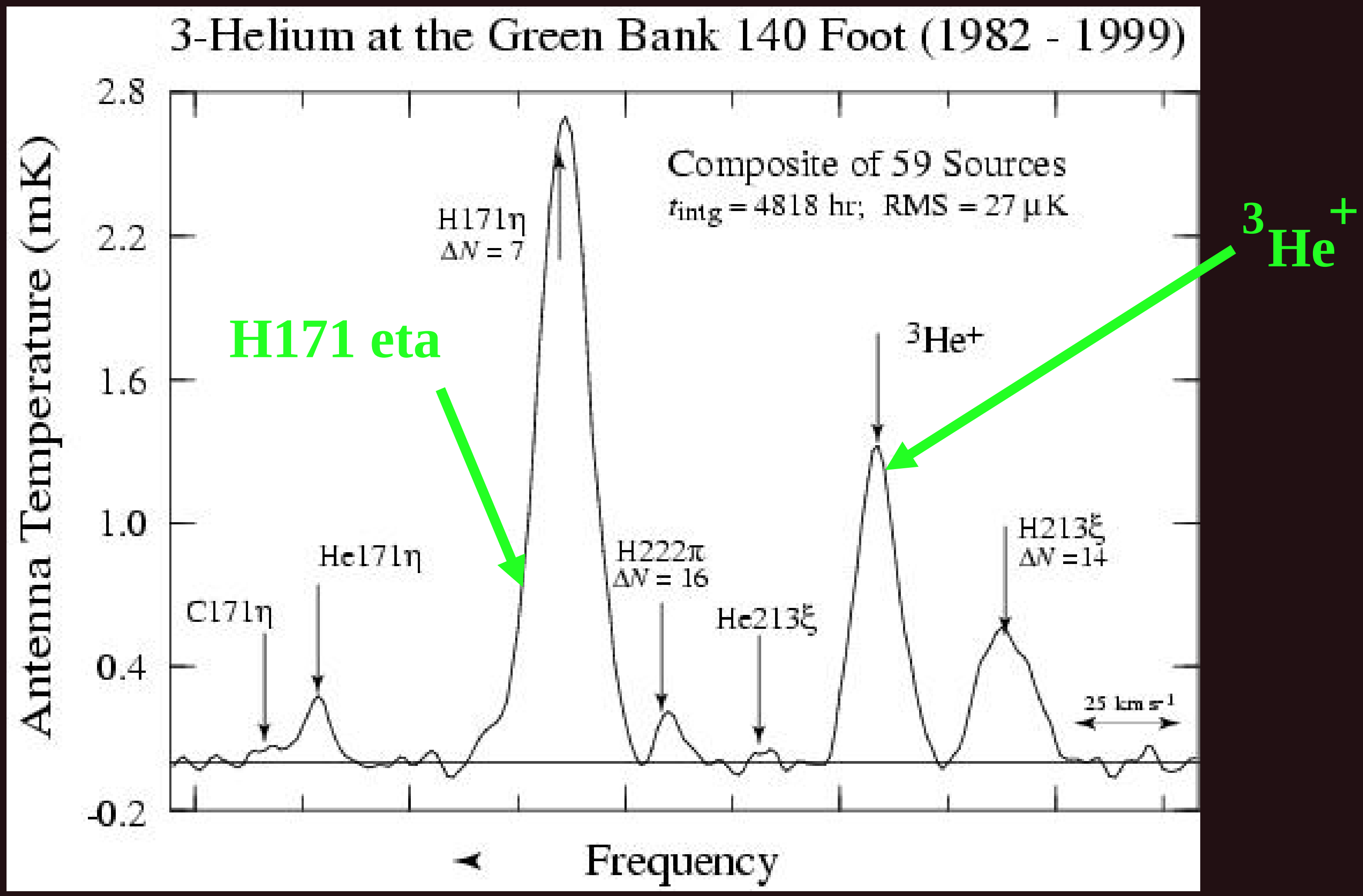
Bania et al. (1997)



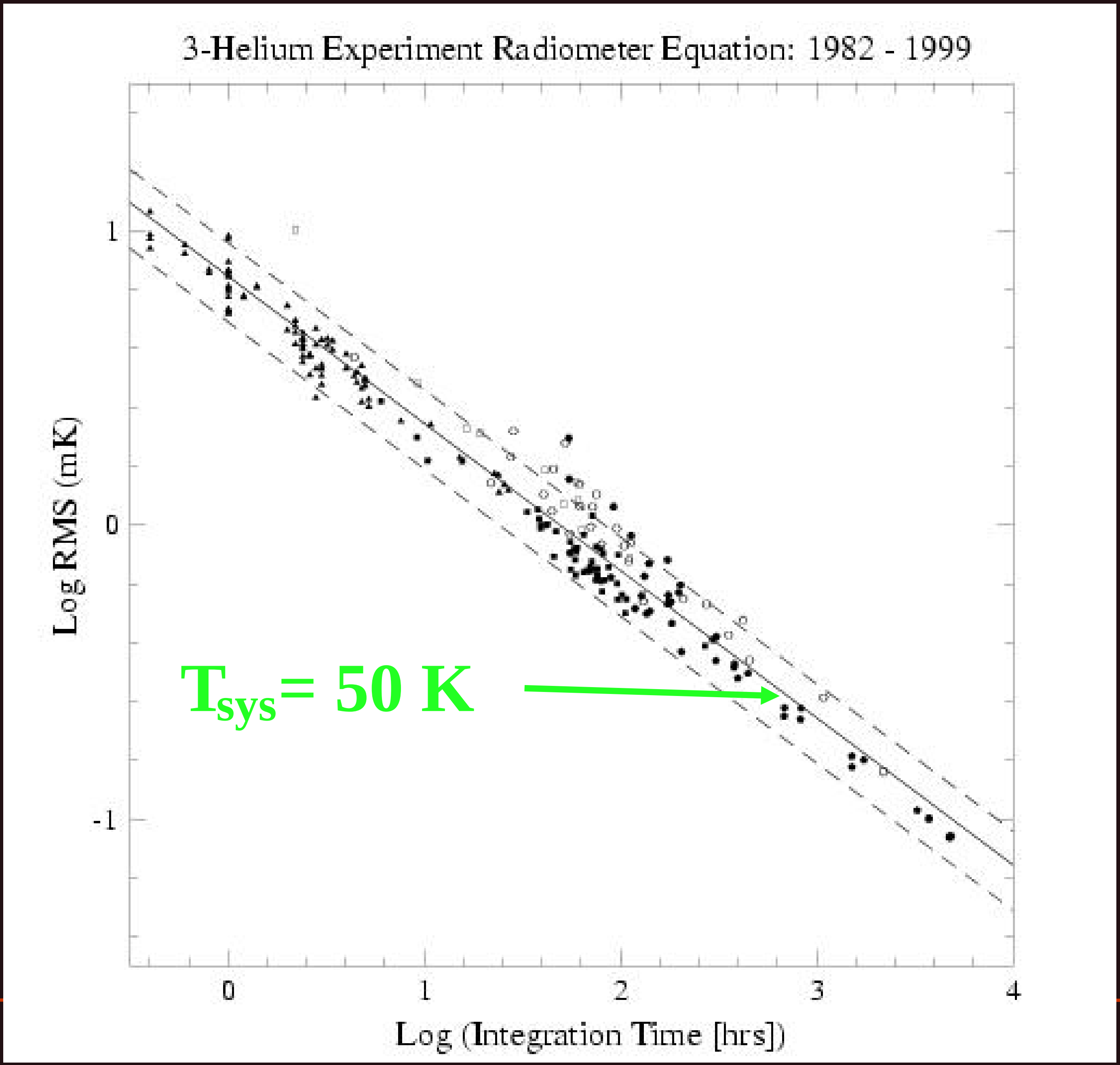
Radio Recombination Lines

Bania et al. (1997)





200 Day Integration: 27 microKelvin RMS


3-Helium Experiment Radiometer Equation: 1982 - 1999
Log RMS (mK)
Log (Integration Time [hrs])
1
0
-1
0
1
2
3
4
Tsys= 50 K

^{3}He Abundance Determination

OBSERVE THE EQUIVALENT WIDTH
DERIVE THE ABUNDANCE

For a uniform, isothermal, ionized nebula composed solely of hydrogen and helium the ($^{3}He^{+}/H^{+}$) column density ratio is

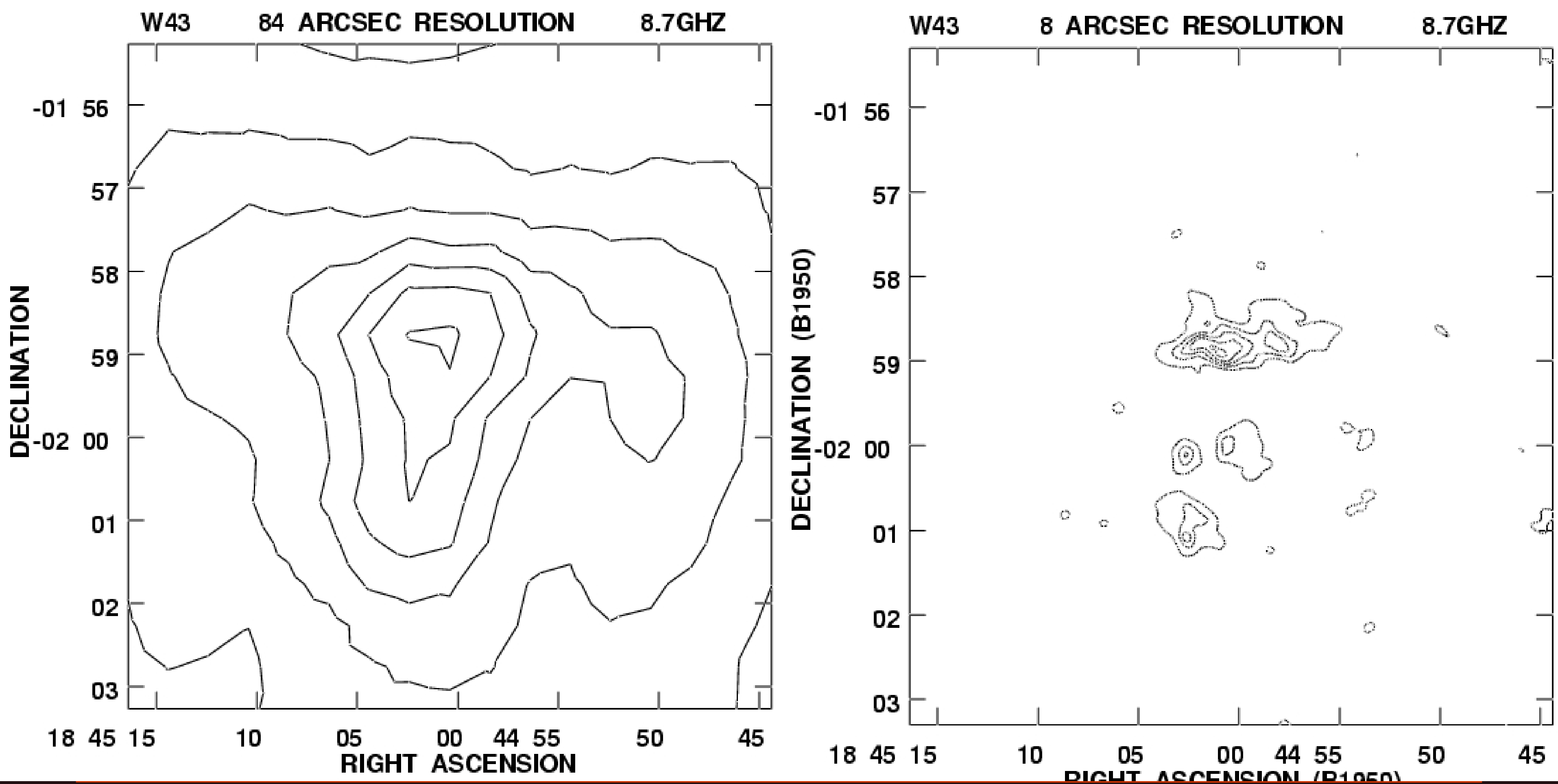
$$\frac{N(^{3}\mathrm{He}^{+})}{N(\mathrm{H}^{+})} = 3.873\times10^{-3}\,\frac{T_{\mathrm{L}}^{\mathrm{A}}(^{3}\mathrm{He}^{+})\Delta v(^{3}\mathrm{He}^{+})[\ln(5.717\times10^{-3}T_{\mathrm{e}}^{3/2})]^{1/2}\,\theta_{\mathrm{obs}}}{A\,(\eta_{\mathrm{b}}T_{\mathrm{C}}^{\mathrm{A}}D)^{1/2}\,T_{\mathrm{e}}^{1/4}\,(\theta_{\mathrm{obs}}^{2}-\theta_{\mathrm{a}}^{2})^{3/4}} \qquad (1)$$

where

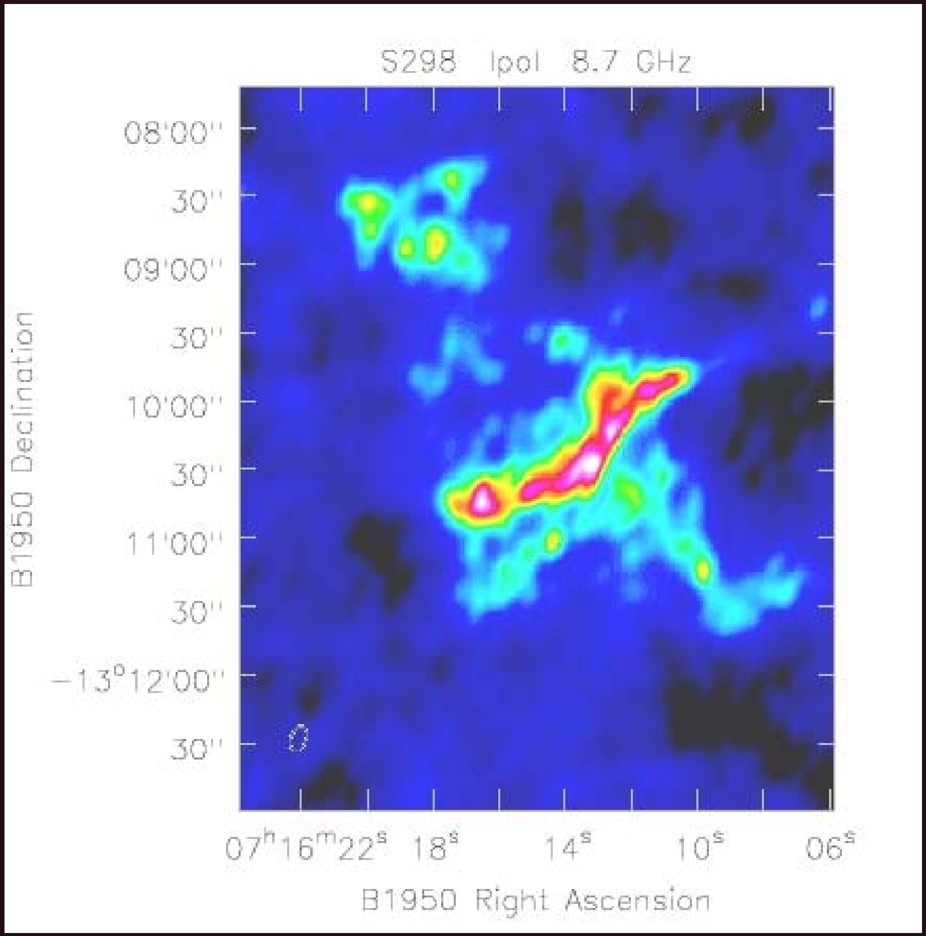
$$A^{2} = \left\{\left(1+\frac{n(\mathrm{He}^{+})}{n(H^{+})}+2\frac{n(\mathrm{He}^{++})}{n(\mathrm{H}^{+})}\right)\left(1+\frac{n(\mathrm{He}^{+})}{n(H^{+})}+4\frac{n(\mathrm{He}^{++})}{n(\mathrm{H}^{+})}\left[1-\frac{\ln(2)}{\ln(5.717\times10^{-3}T_{\mathrm{e}}^{3/2})}\right]\right)\right\}^{-1}. \qquad (2)$$

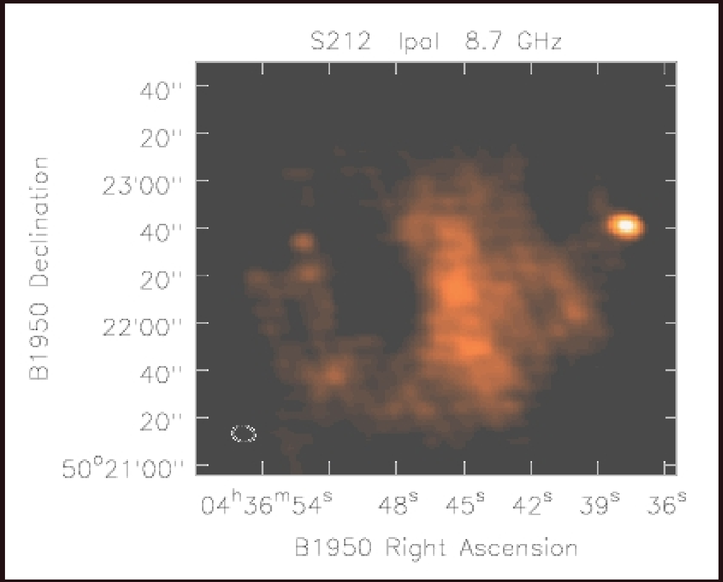
H II Region Continuum

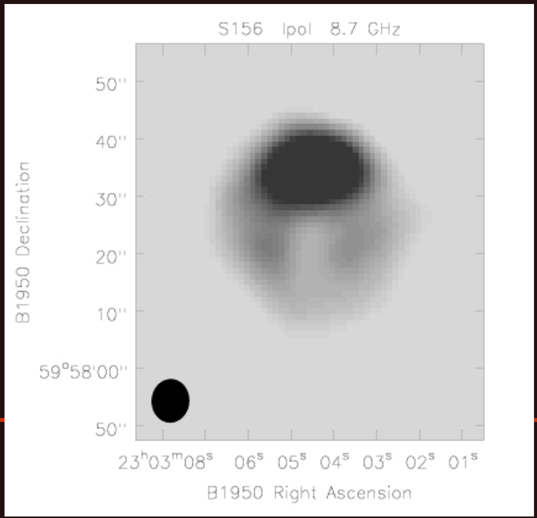
Balser et al. (1995)



H II Region Continuum



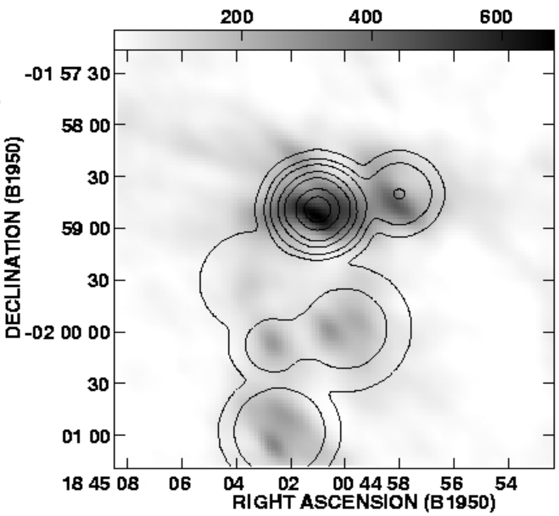


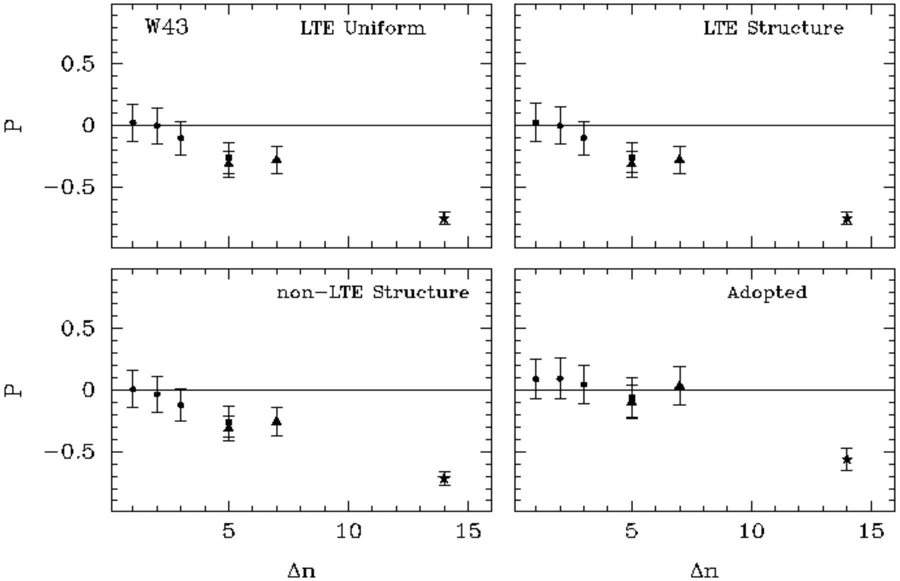


H II Region Models

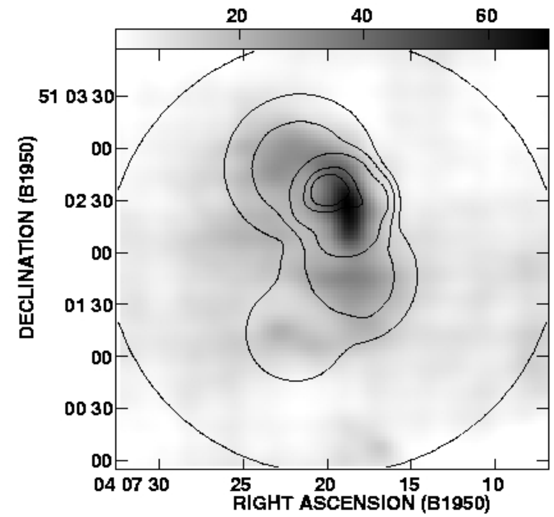
Balser et al. (1999)

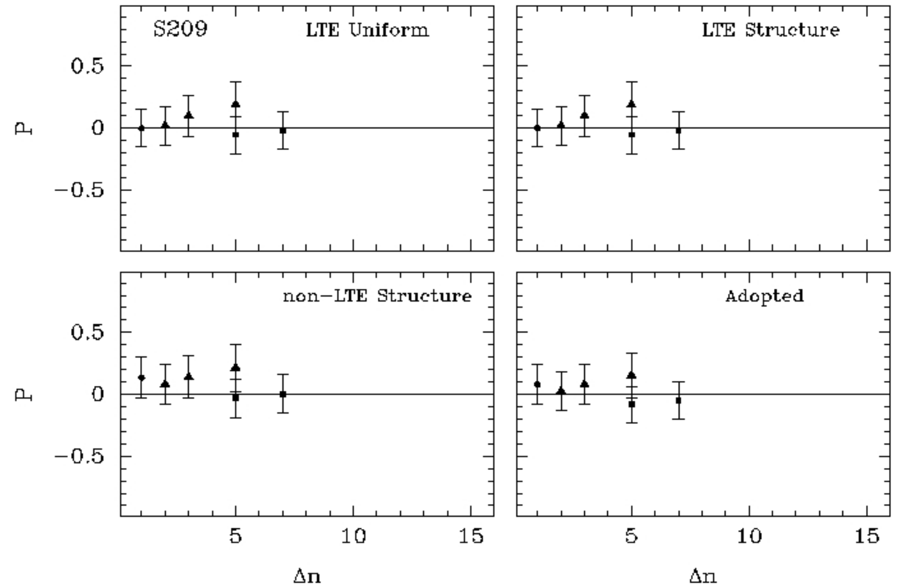
W43



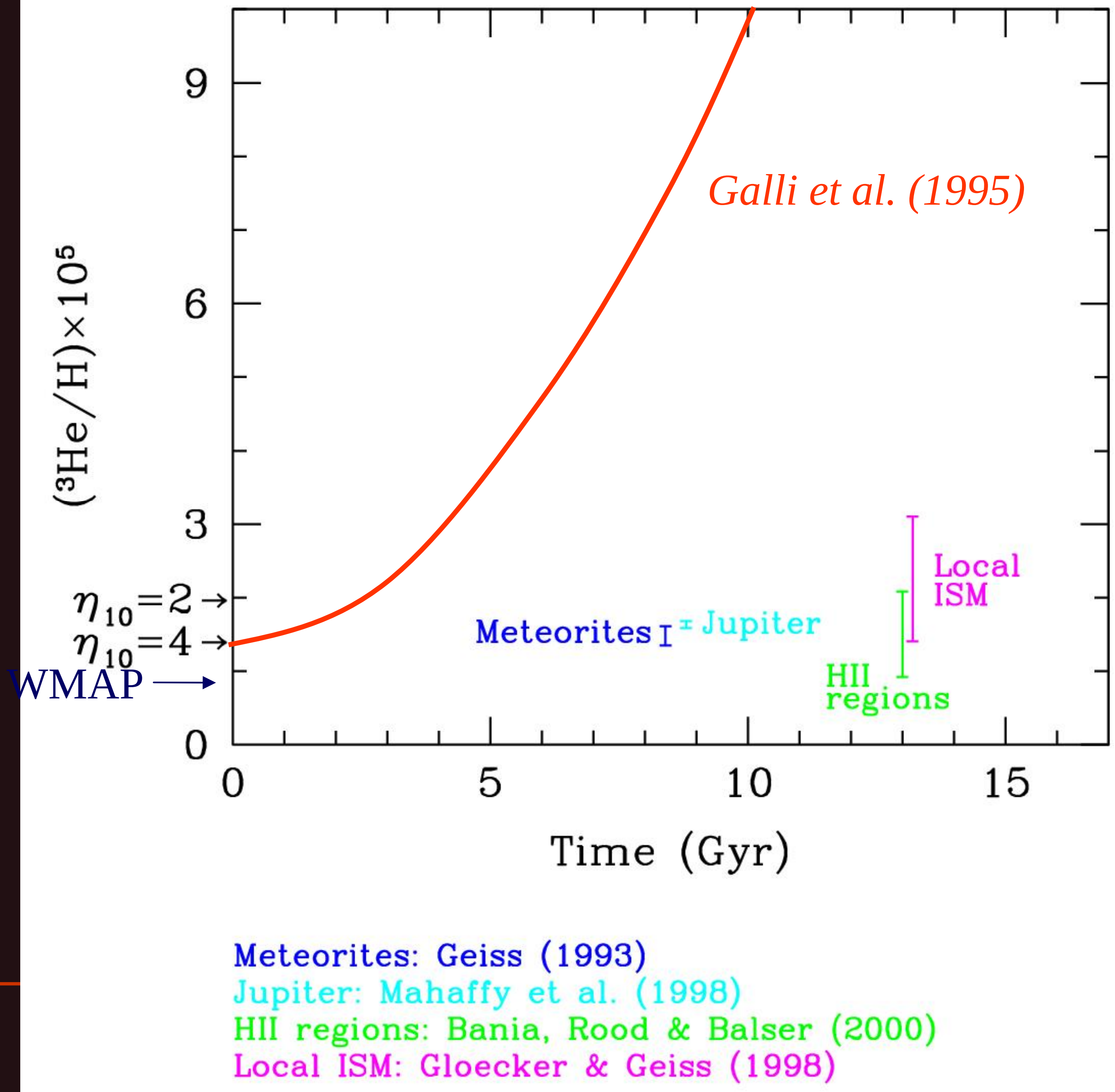


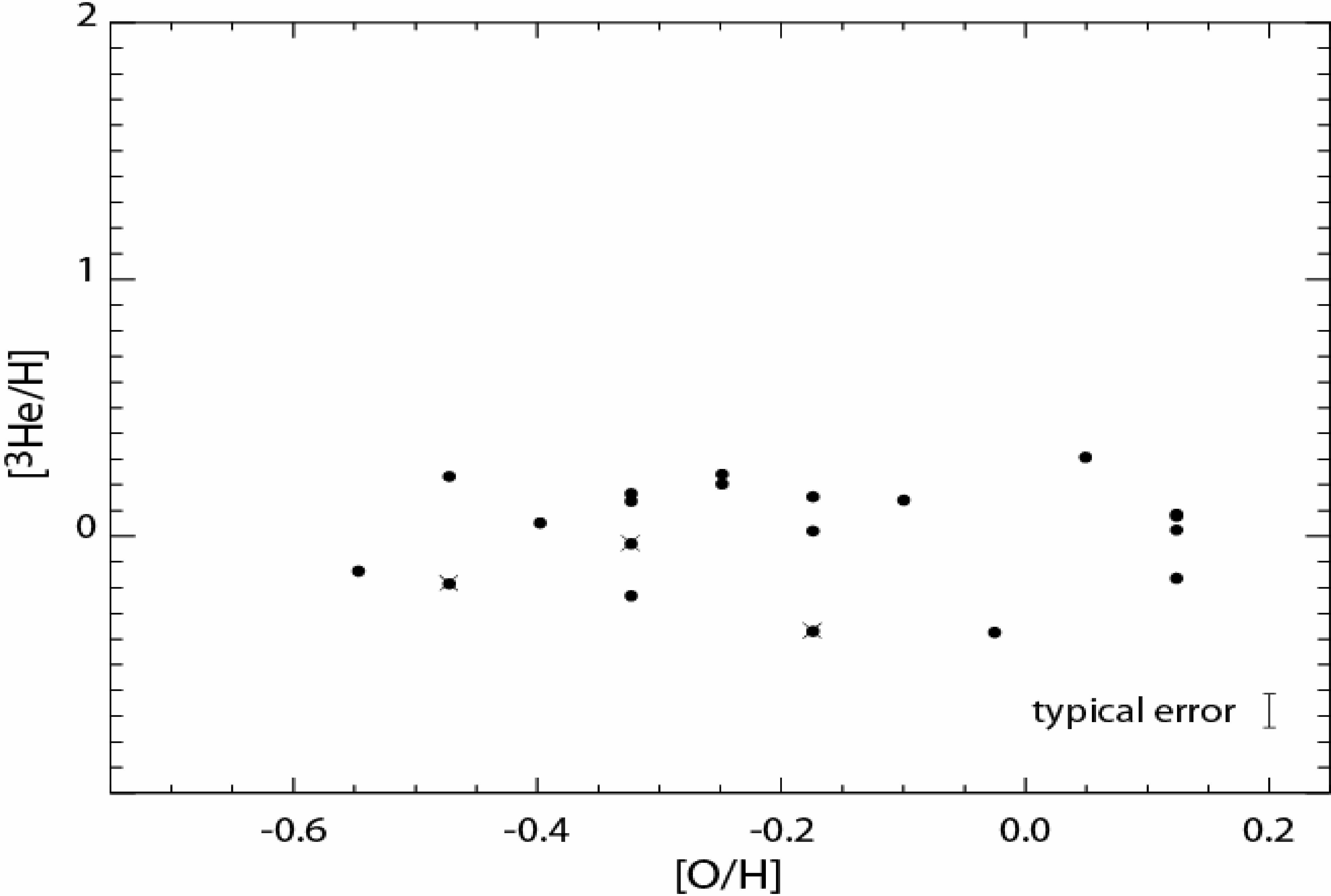
S209



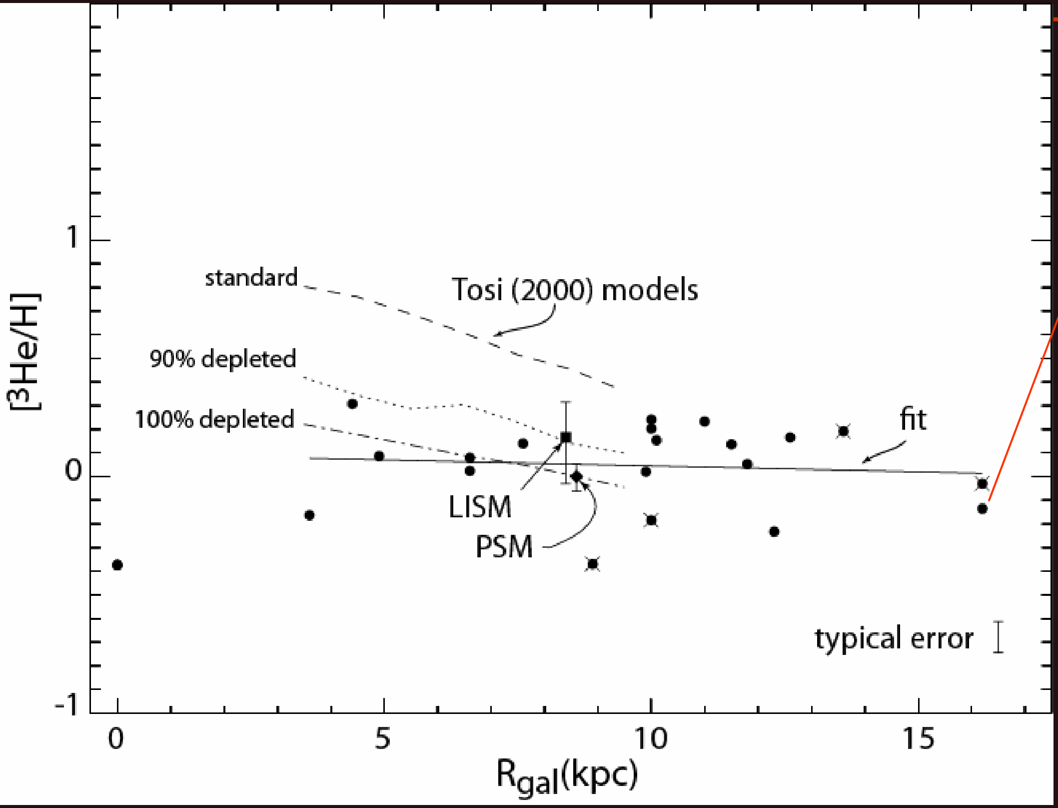


“The ^{3}He Problem”





“Simple” H II Regions



Bania, Rood, & Balser 2002

$\eta_{10} = 5.4^{+2.2}_{-1.2}$

$\Omega_B = 0.04$

Spergel et al. 2003, WMAP

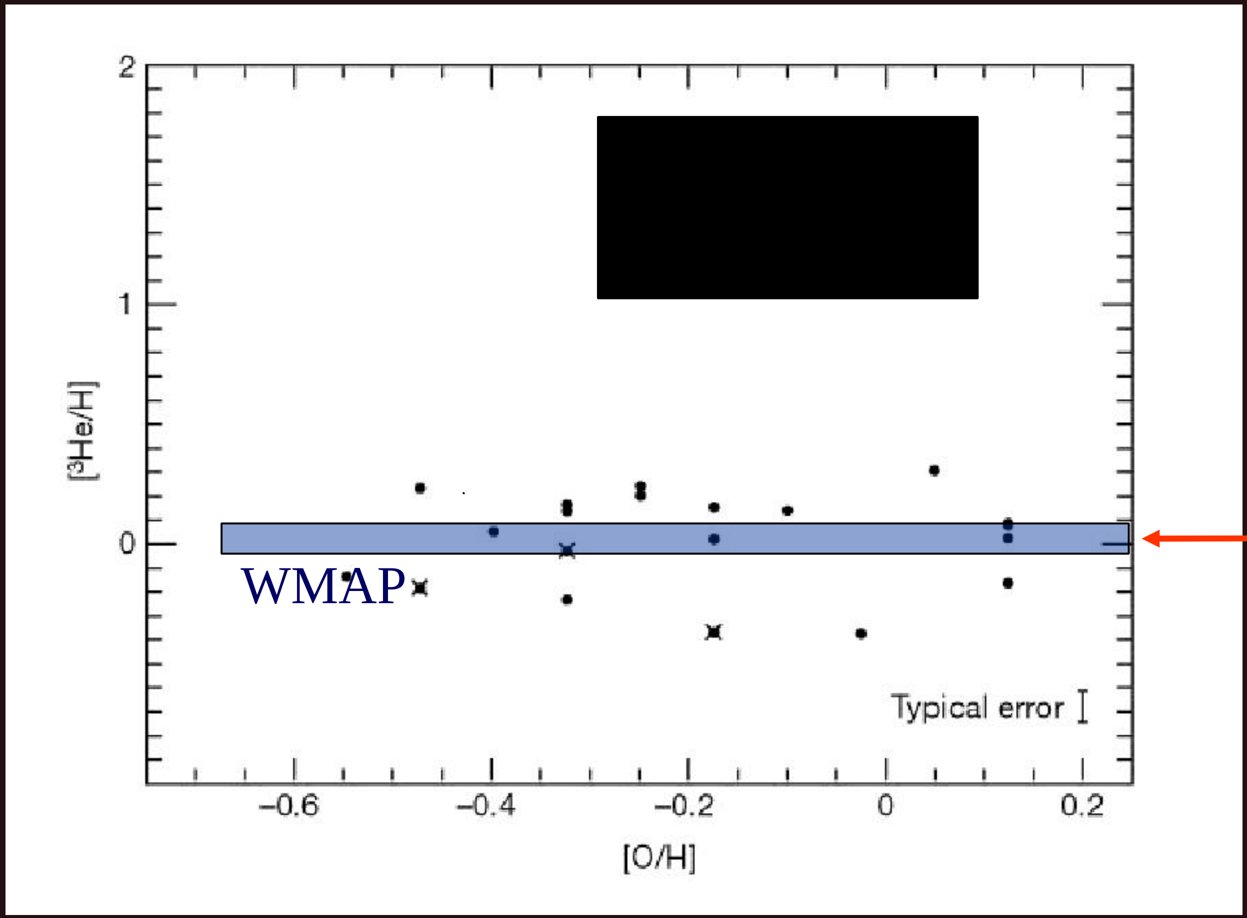
$\eta_{10} = 6.5^{+0.4}_{-0.3}$

$\Omega_B = 0.047 \pm 0.006$

For D highest observed value is a lower limit for cosmological D

For ^{3}He lowest observed ^{3}He/H is an upper limit for cosmological ^{3}He

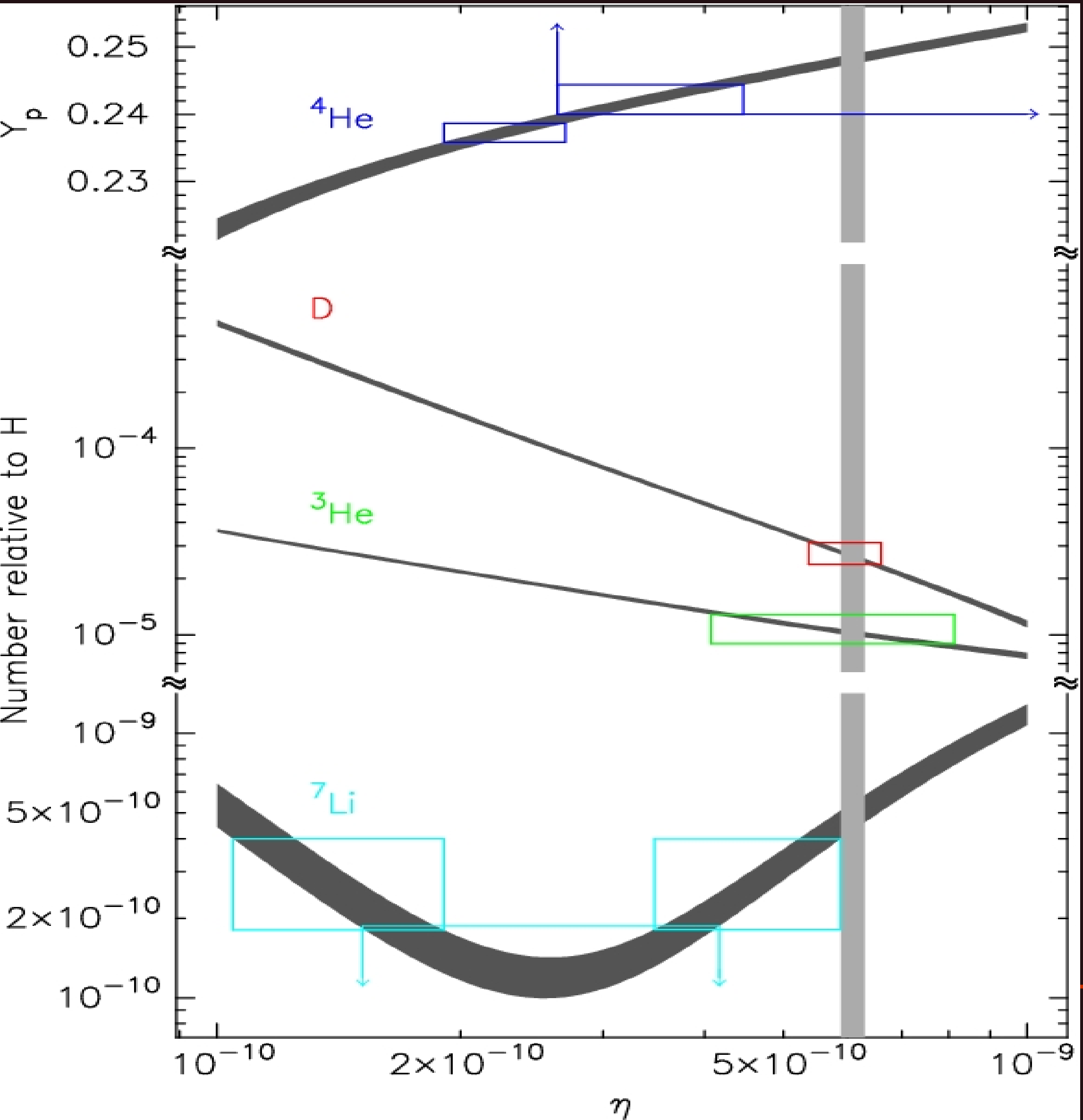
^{3}He Abundance in H II Regions -- *"The ^{3}He Plateau"*



(^{3}He/H)$_p$ = 1.1 x 10^{-5}

Bania, Rood & Balser (2002)

BBNS CONSTRAINTS



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)

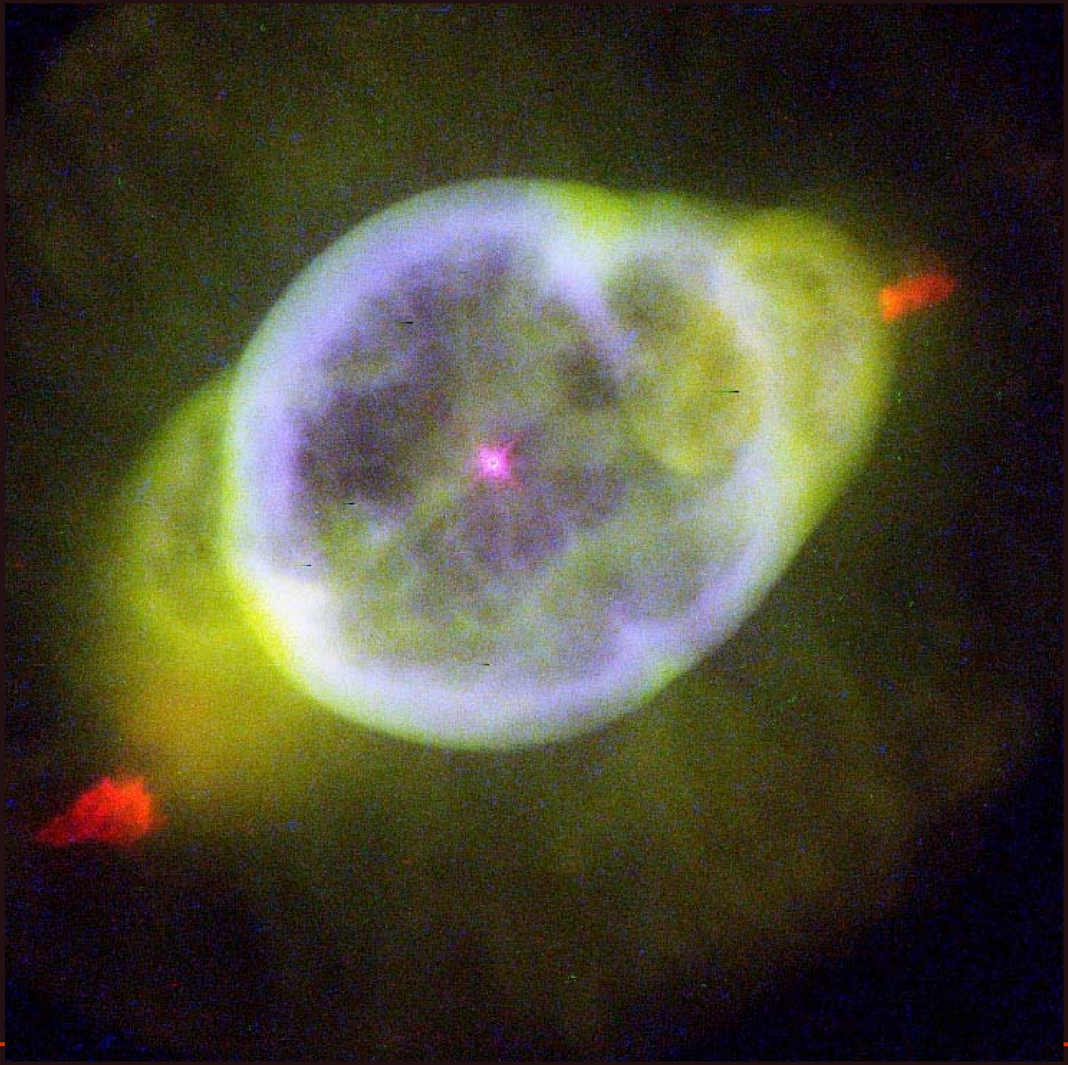
MPIfR 100 m: PNe

Galactic Planetary Nebulae
(1991 – 1995)

NGC 3242 (Eye)
NGC 6543 (Cat's Eye)
NGC 6720 (Ring)
NGC 7009 (Saturn)
NGC 7662 (Blue Snowball)

HPBW = 80 arcsec

NGC 3242: Eye Nebula



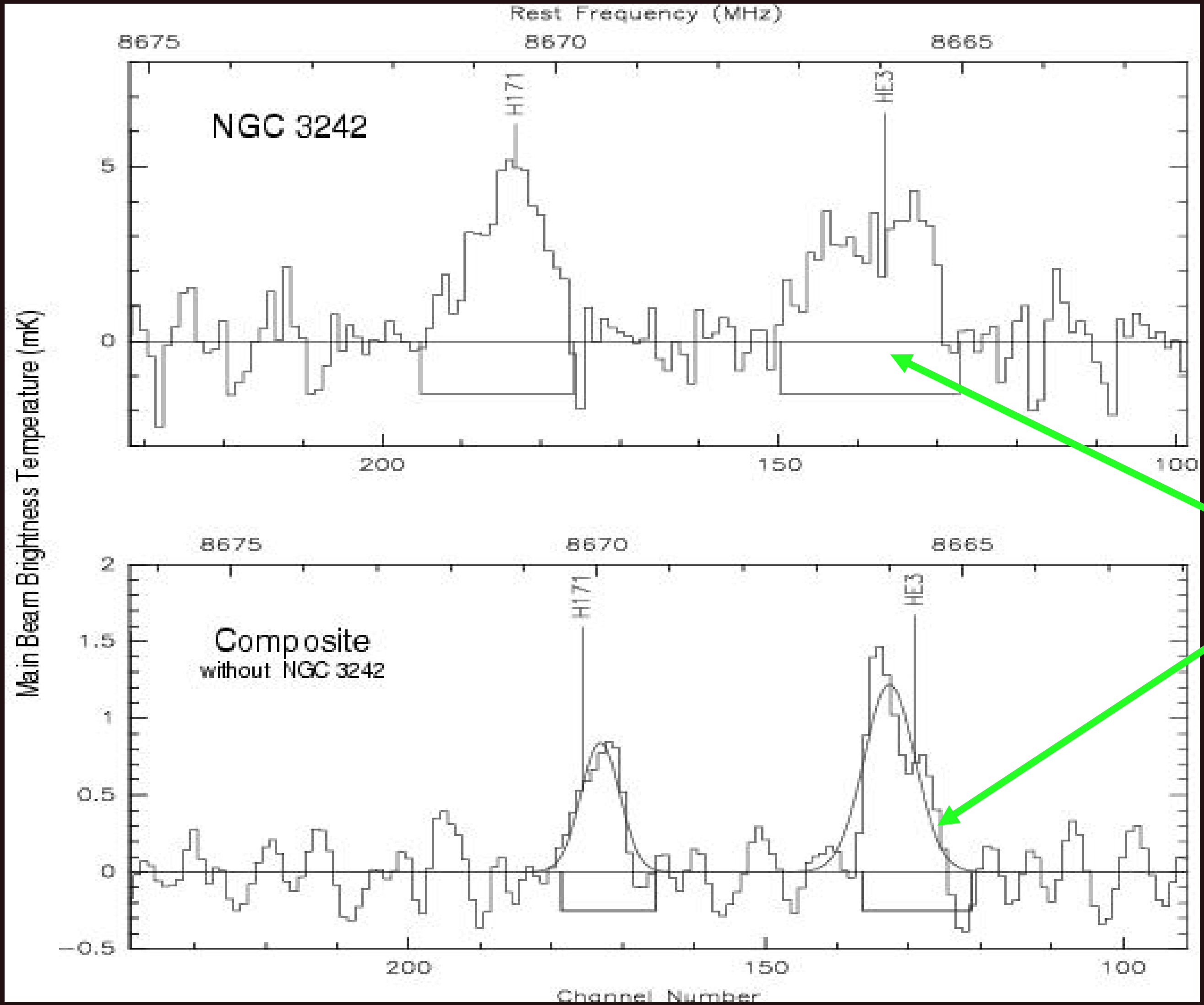
Balick et al.

MPIfR 100 m PNe Survey

Balser, et al. 1997, ApJ 483, 320

106 hr

1987-1997

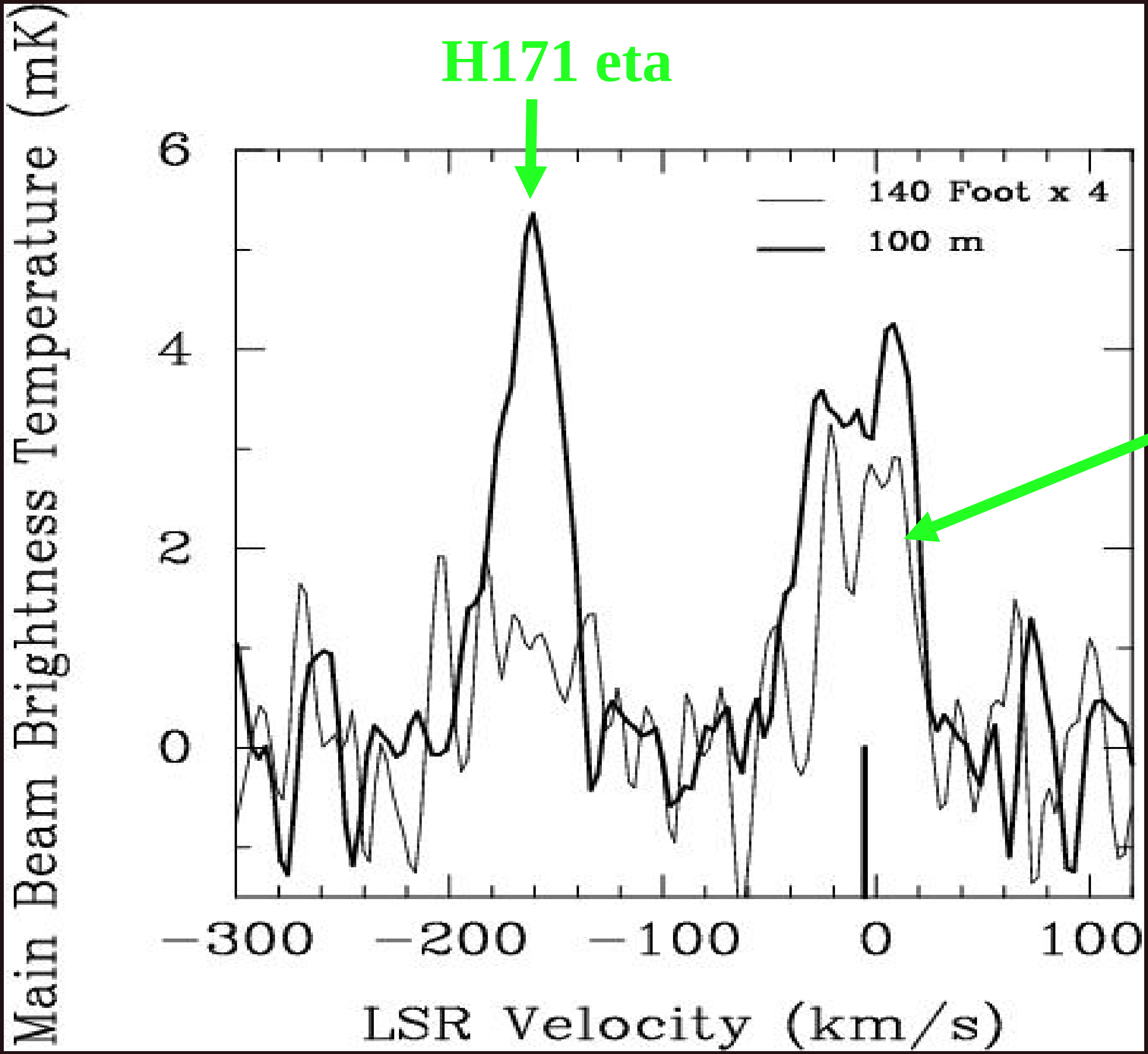


$^3He^+$

443 hr

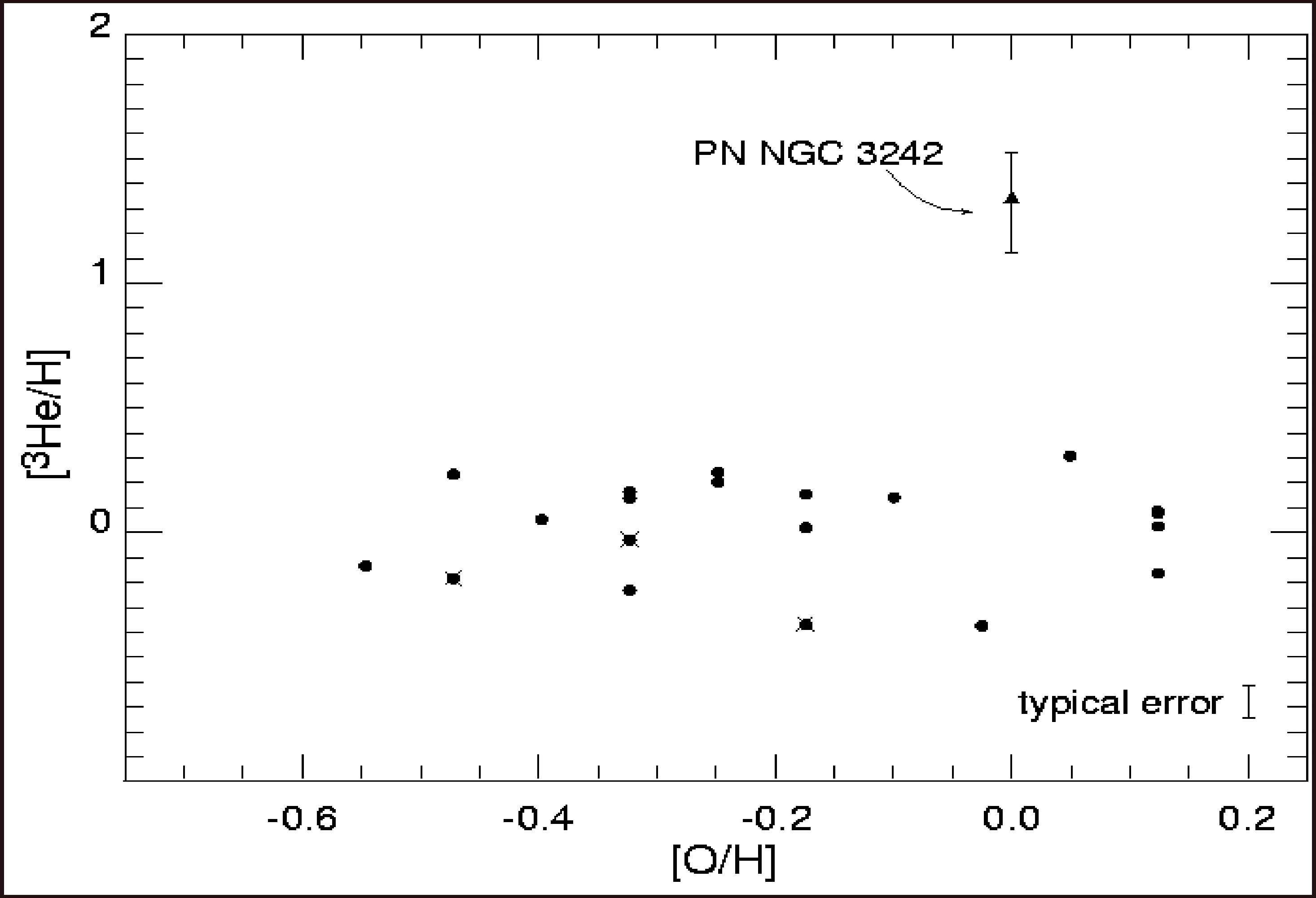
Composite: NGC 6543 + NGC 6720 + NGC 7009 + NGC 7662 + IC 289

NGC 3242 Confirmation Balser, et al. 1999 ApJ 522, L73



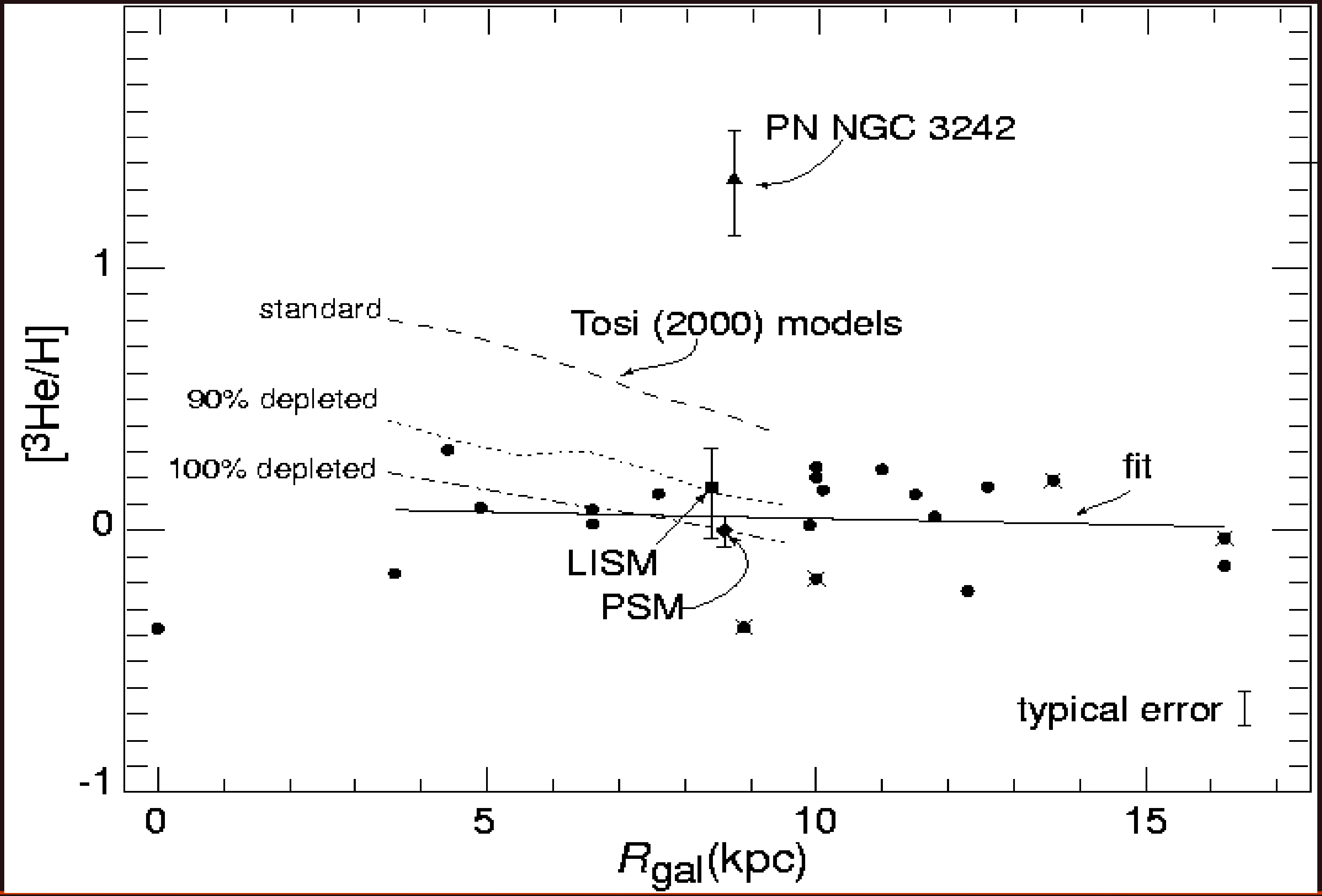
NRAO 140 ft spectrum is a 270 hour integration

Abundance versus [O/H]



Bania, Rood & Balser (2002)

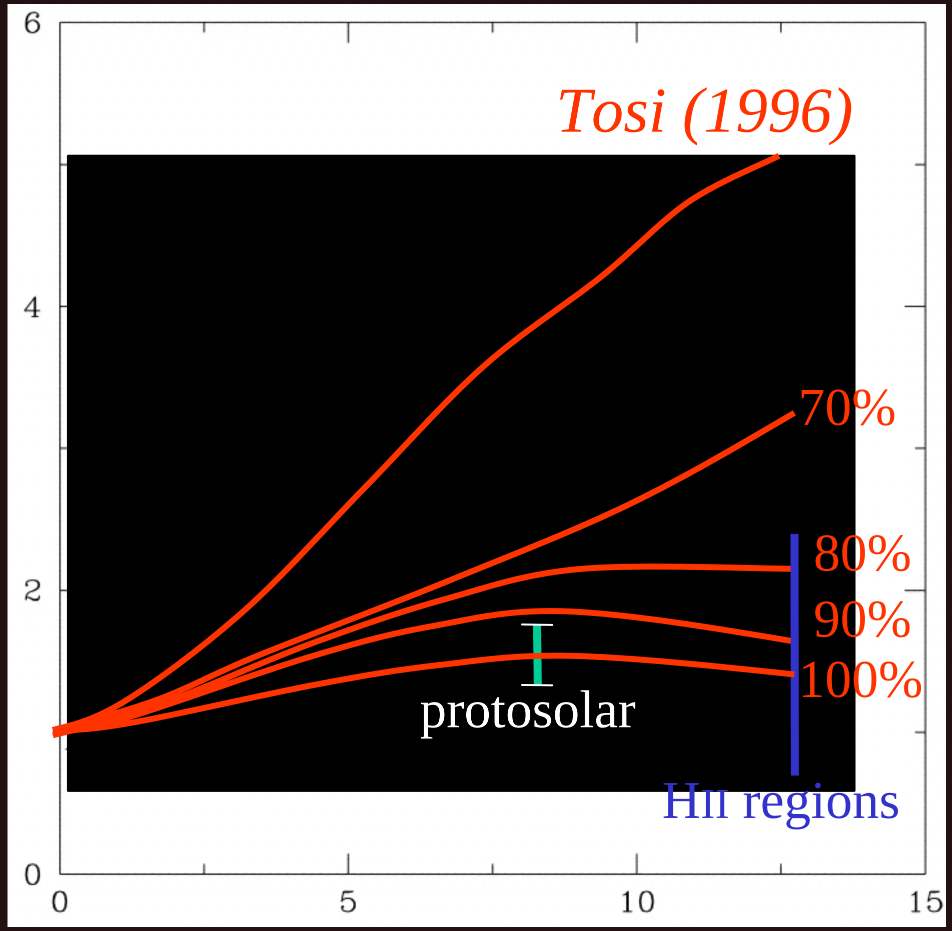
Abundance versus Rgal



Bania, Rood & Balser (2002)

^{3}He evolution with extra-mixing

^{3}He/H x 10^5

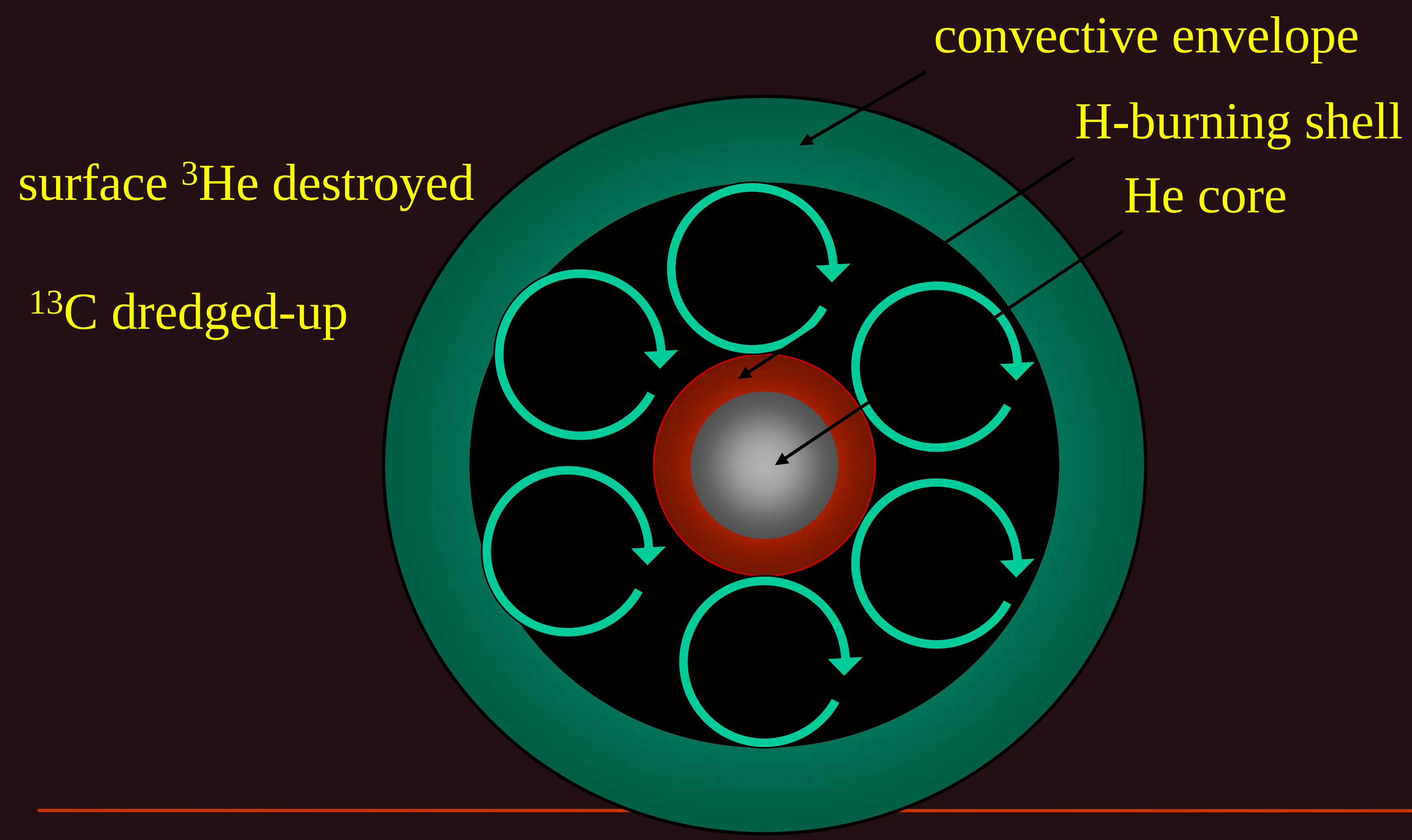


Time (Gyr)

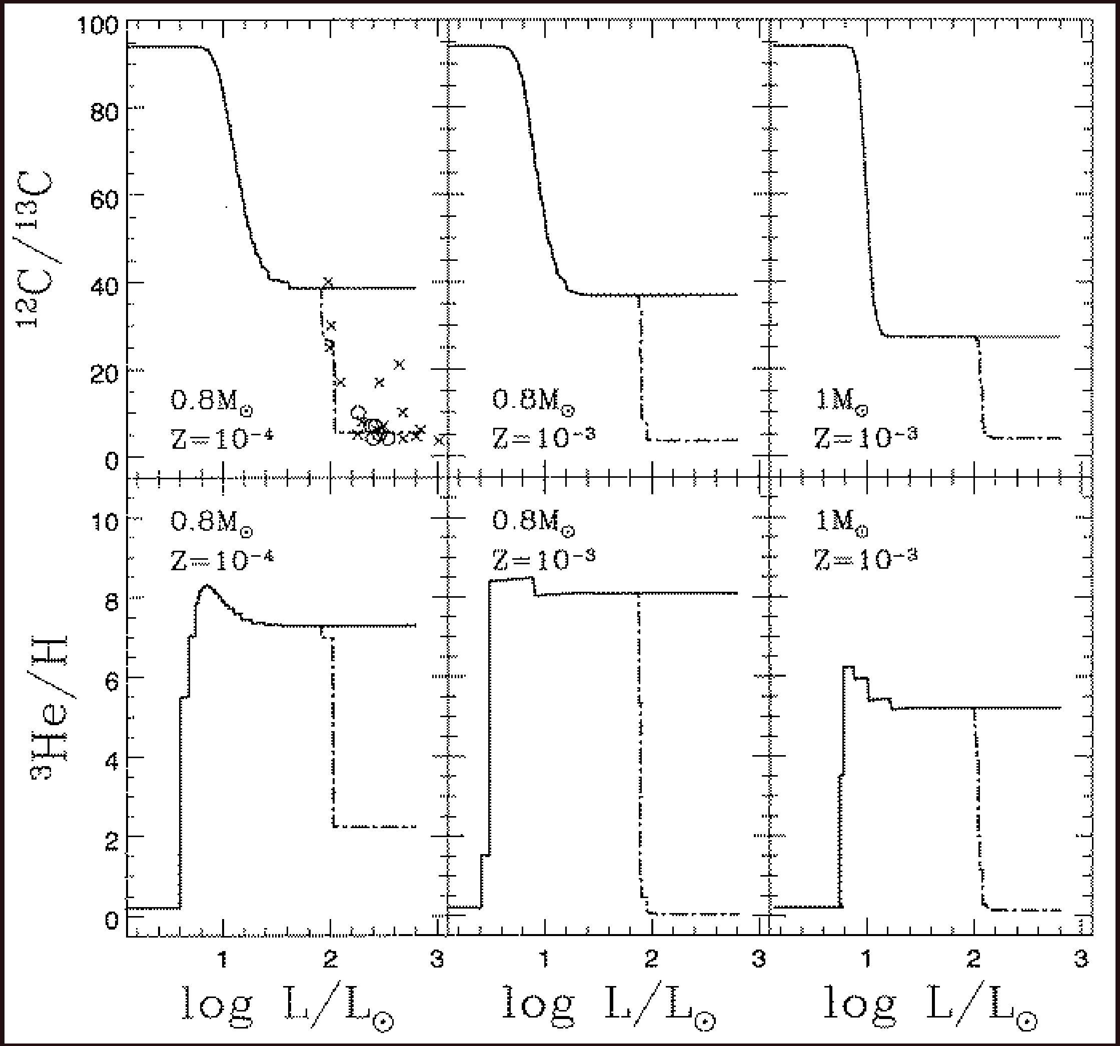
Extra-Mixing Hypothesis

- *Charbonnel 1995* (see also *Hogan 1995*) : an extra-mixing mechanism acting during the RGB and/or AGB phases of stars with mass $M \rightarrow 2\ M_{\odot}$ can reduce the surface ^3He abundance
- Extra-mixing decreases the surface $^{12}C/^{13}C$: the ^3He problem is linked to other isotopic anomalies in RGB and AGB stars

Mixing on the RGB



Extra-mixing Process



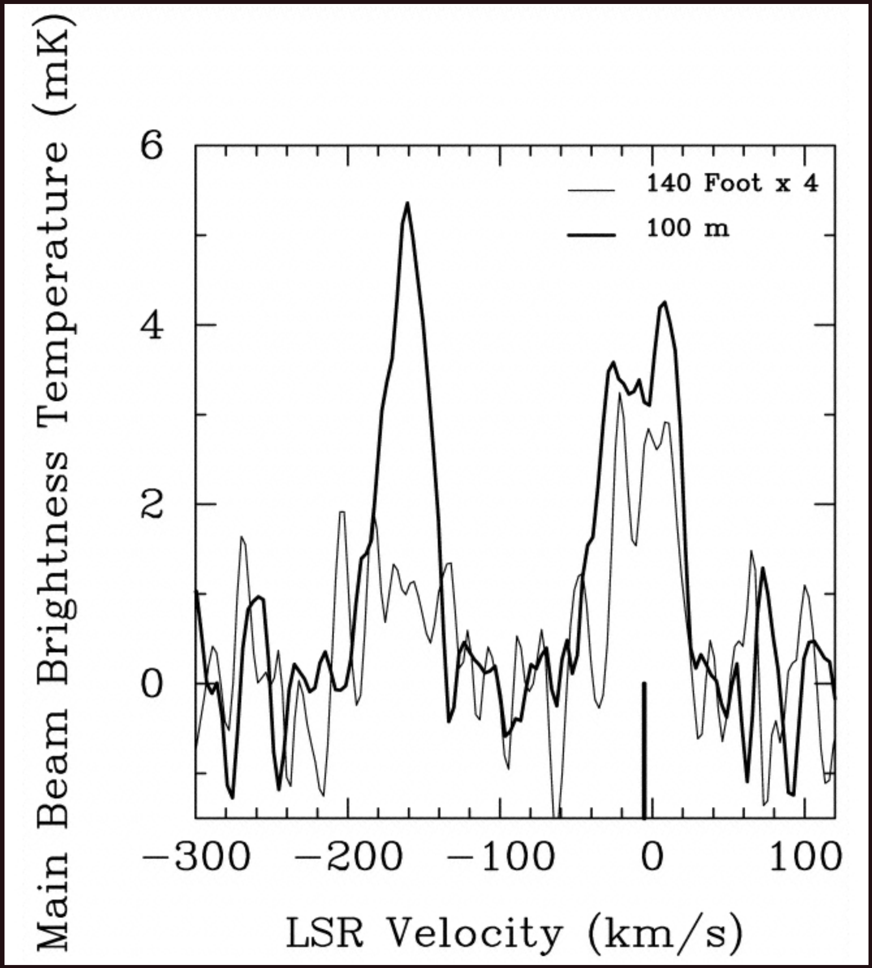
96% of low-mass stars

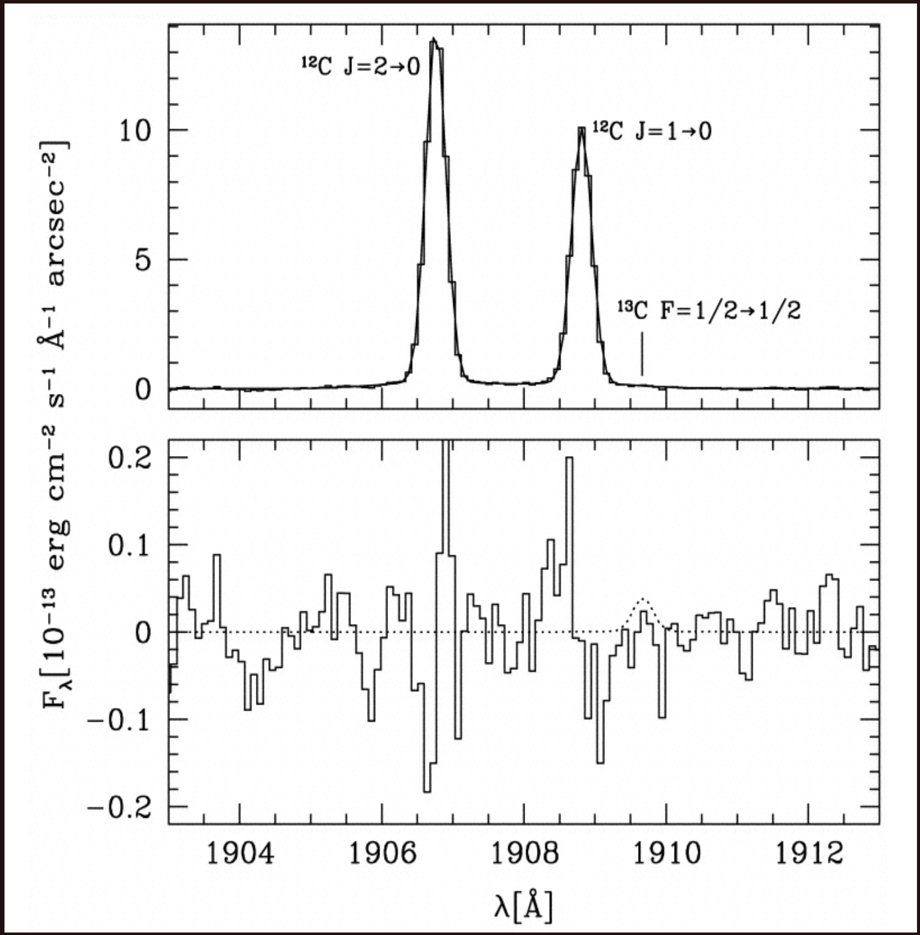
Charbonnel & do Nascimento (1998)

Extra-mixing

Charbonnel (1995)

No Mixing in NGC 3242



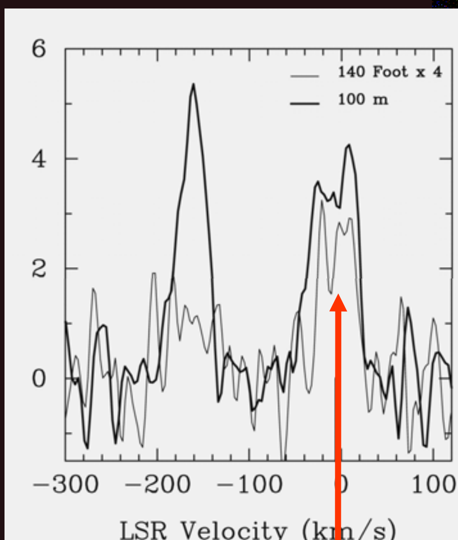


Balser et al. (1999)

Palla et al. (2002)

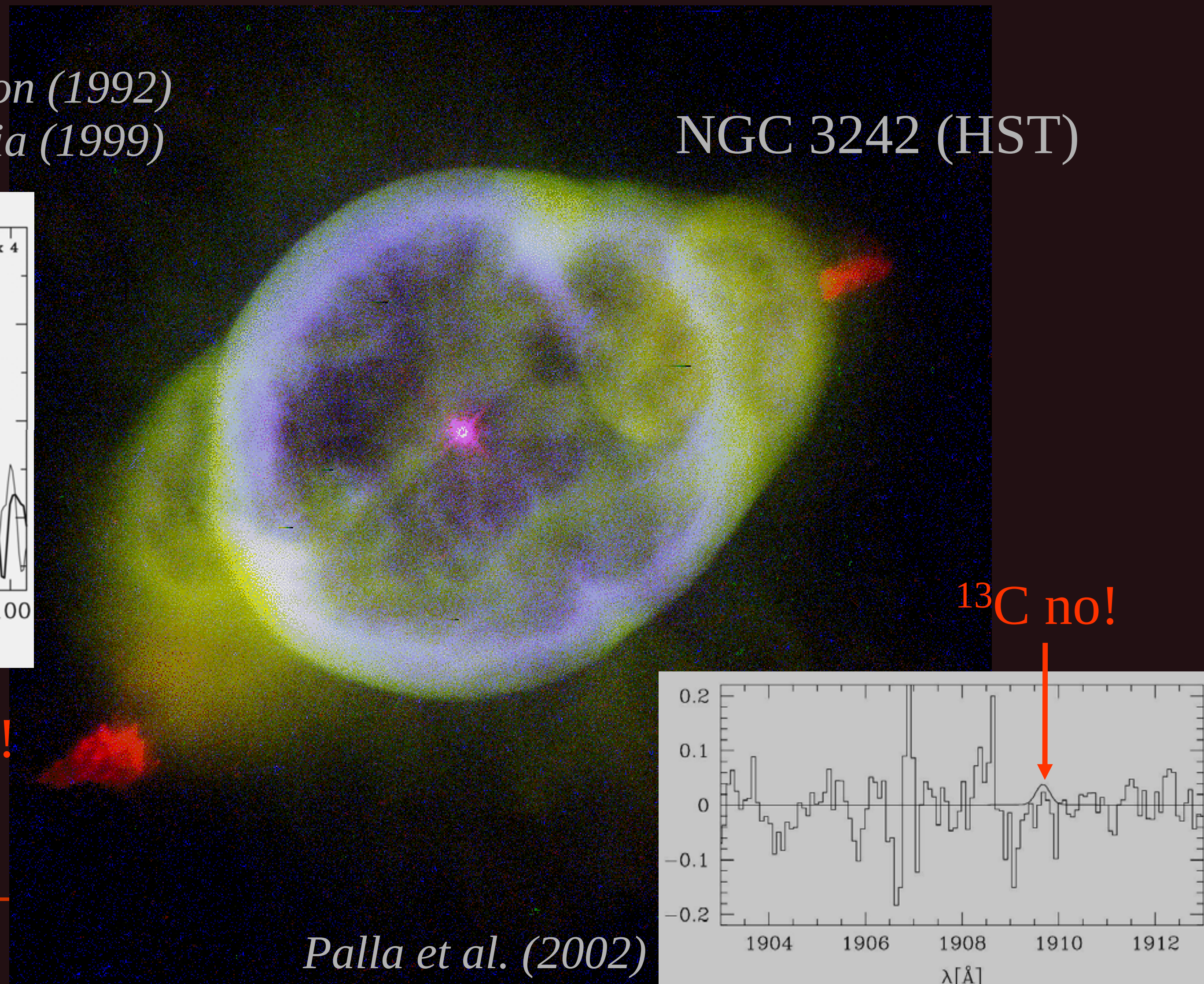
The rescue of the standard model

Rood, Bania & Wilson (1992)
Balser, Rood & Bania (1999)



^{3}He yes!

NGC 3242 (HST)



^{13}C no!

Palla et al. (2002)

- **^{3}He abundance is a good test for cosmology, stellar evolution (standard and non-standard), and Galactic chemical evolution**
- **Solving the *3-He Problem* requires extra-mixing in ~ 90% of stars with**

$M \sim 2\ M_{\odot}$

One is not enough!

Except in cosmology

The PN sample:

PNe progenitor stars with no extra mixing:

$^{4}He / H < 0.125$

[N / O] < -0.3

$^{13}C / ^{12}C$ as low as possible

Oldest possible stellar population has highest 3-He:

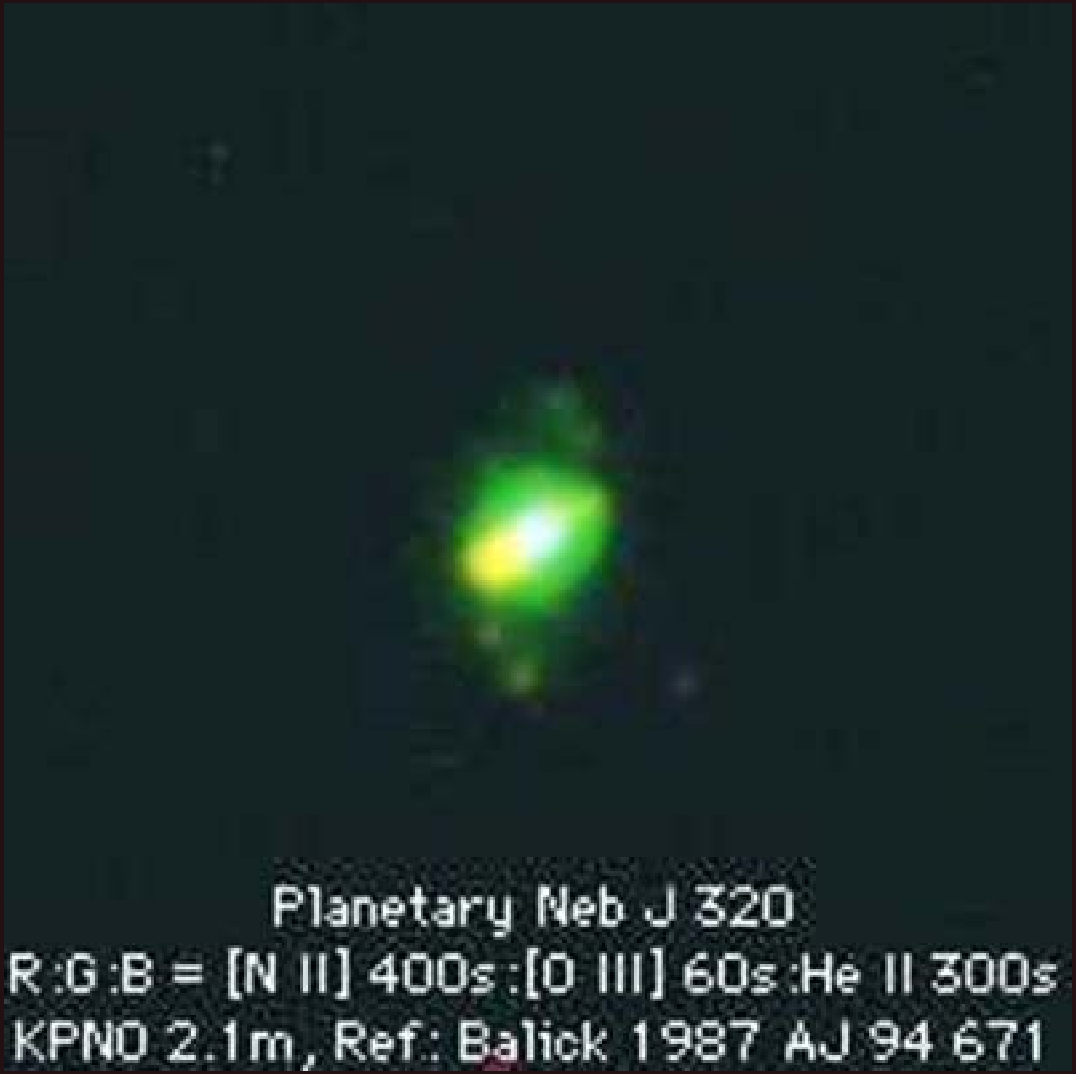
Peimbert Class IIb, III, and IV

Helium is singly ionized

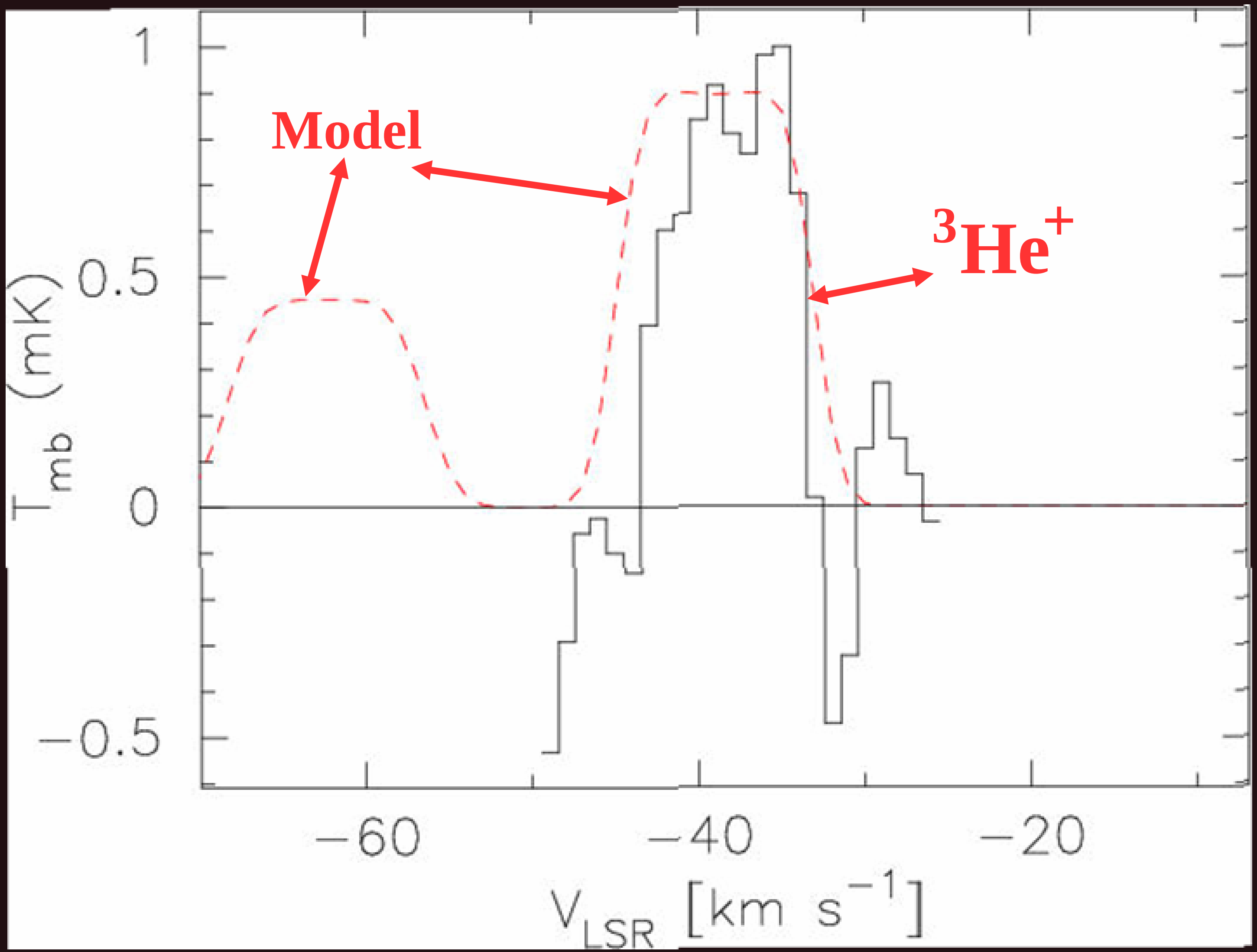
Balser, Goss, Bania, Rood (2005)

Jonckheere 320 – PN G190.3-17.7

J320

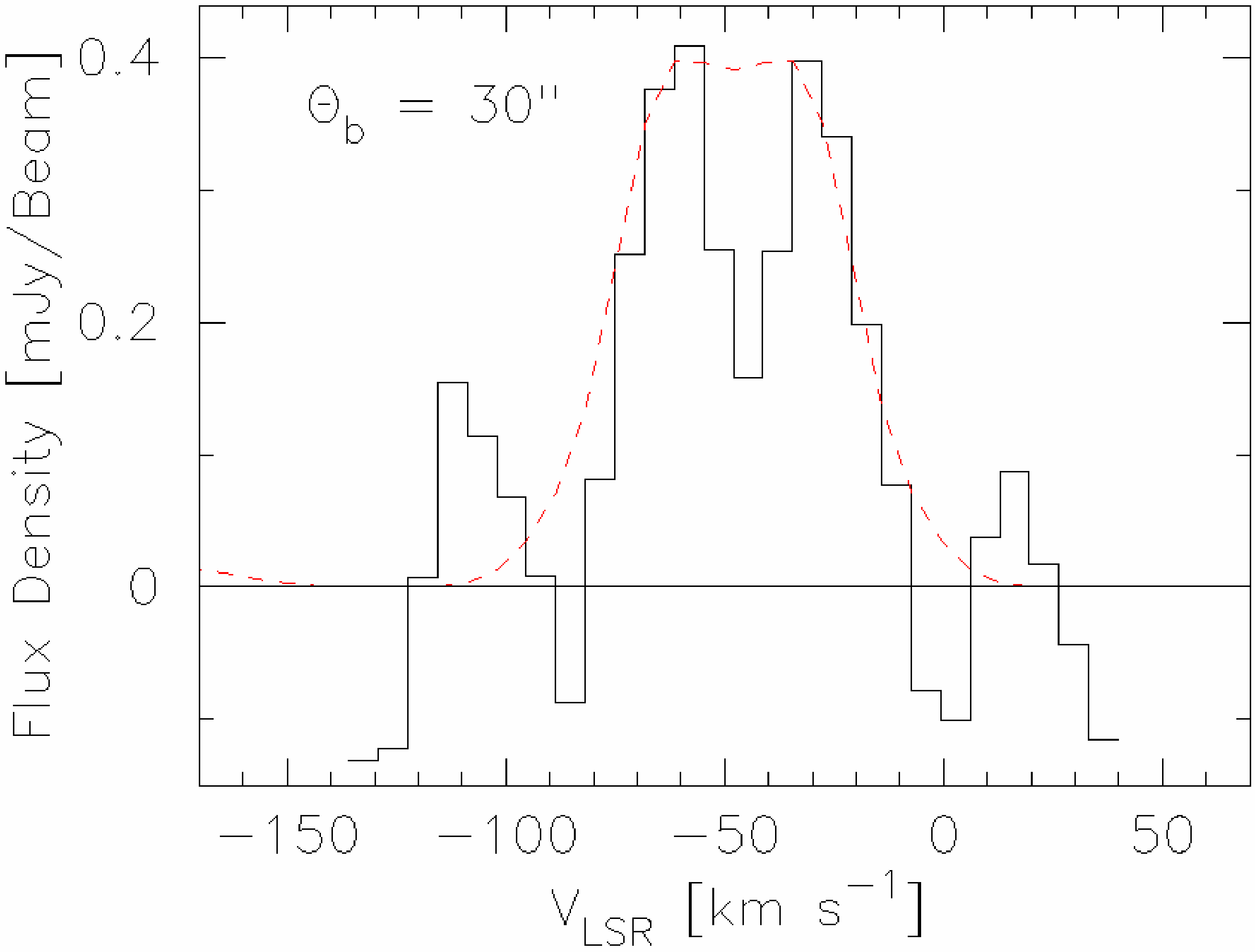


VLA Planetary Nebula J320



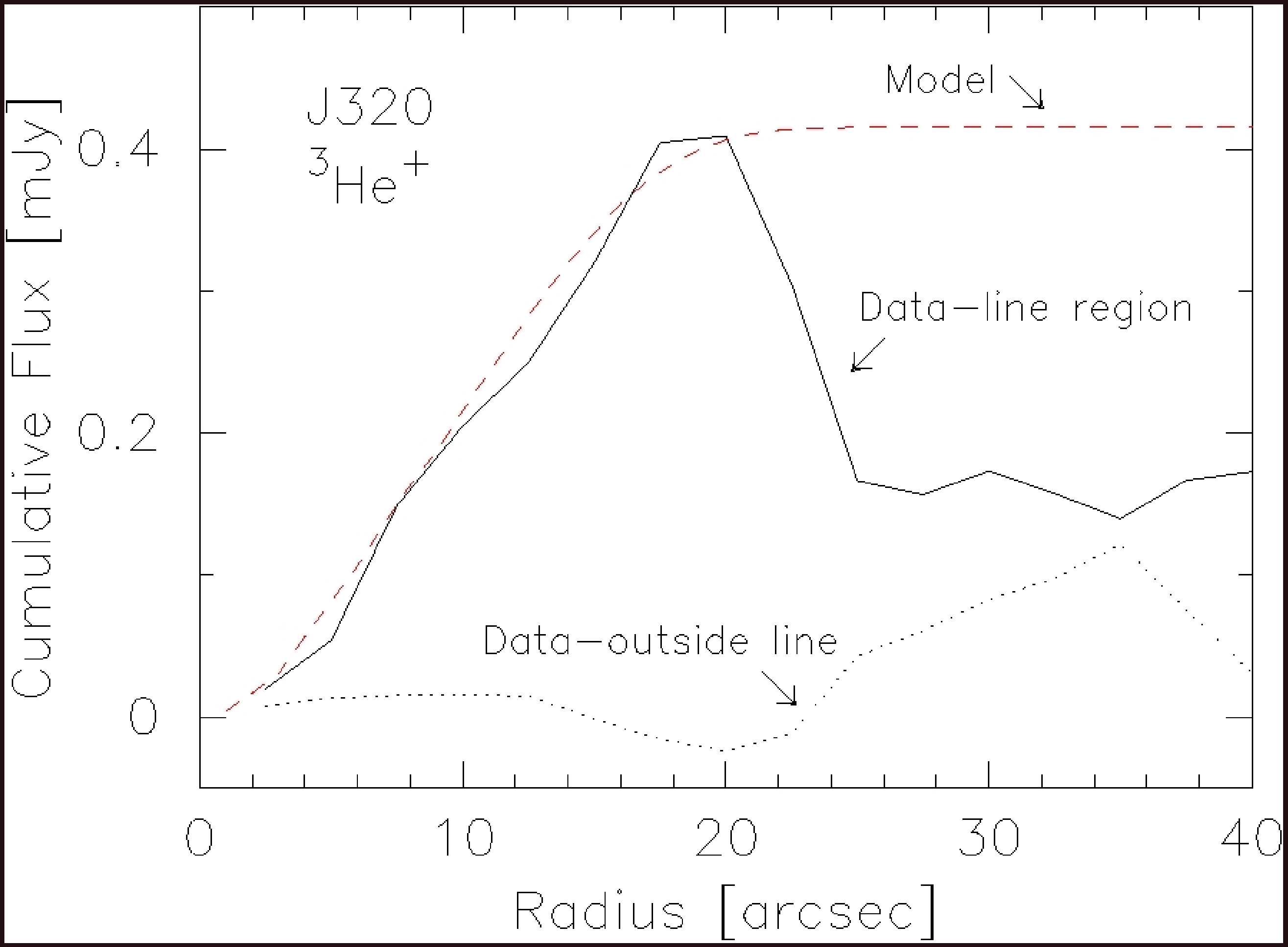
^3He / H abundance = 1.9 x 10 $^{-3}$ by number

J320 $^{3}He^{+}$



Θ_b = 30''
0.4
0.2
0
Flux Density [mJy/Beam]
−150
−100
−50
0
50
V_{LSR} [km s^{-1}]

J320 Halo: 30 arcsec



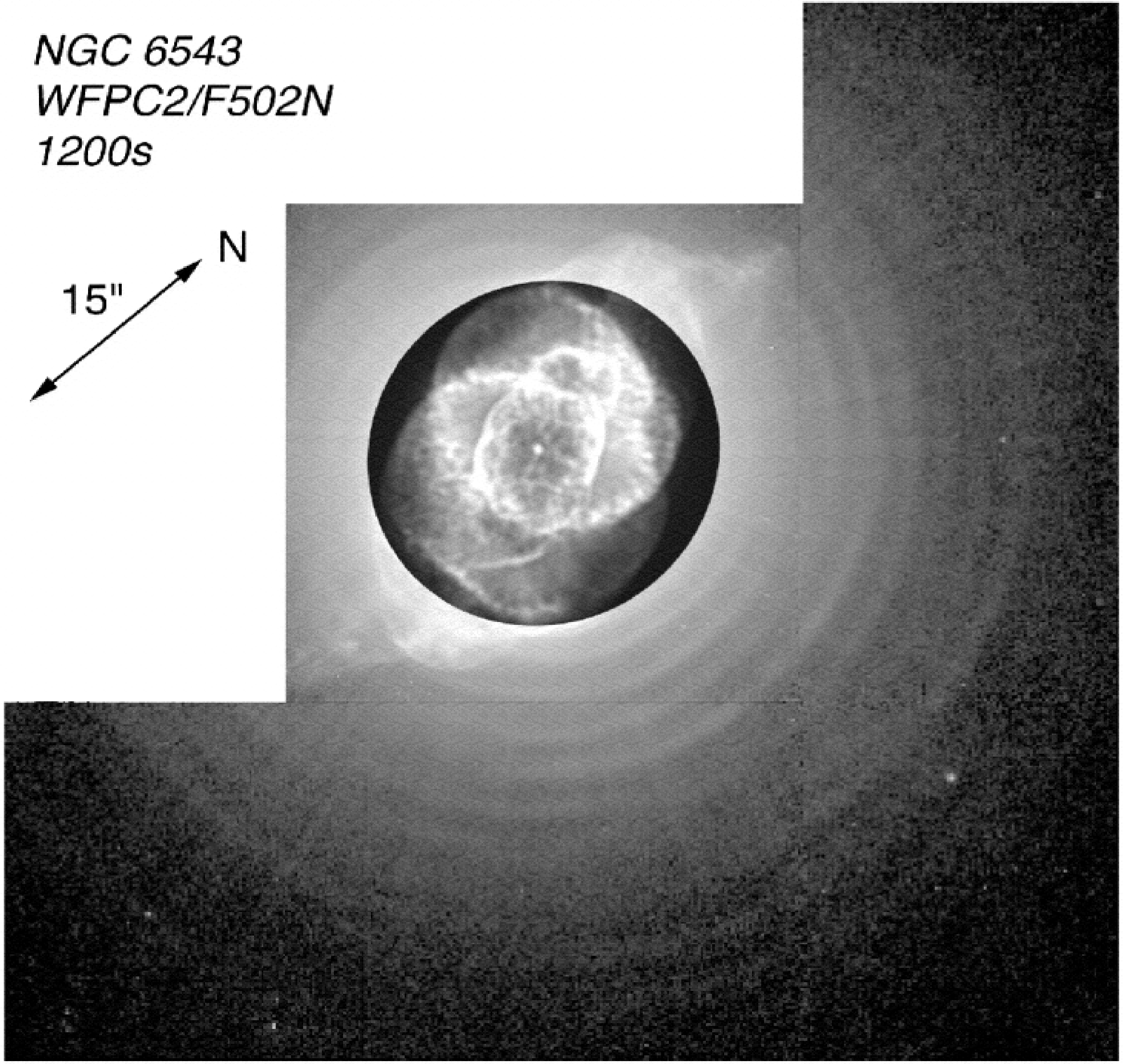
Balser et al. (2006)

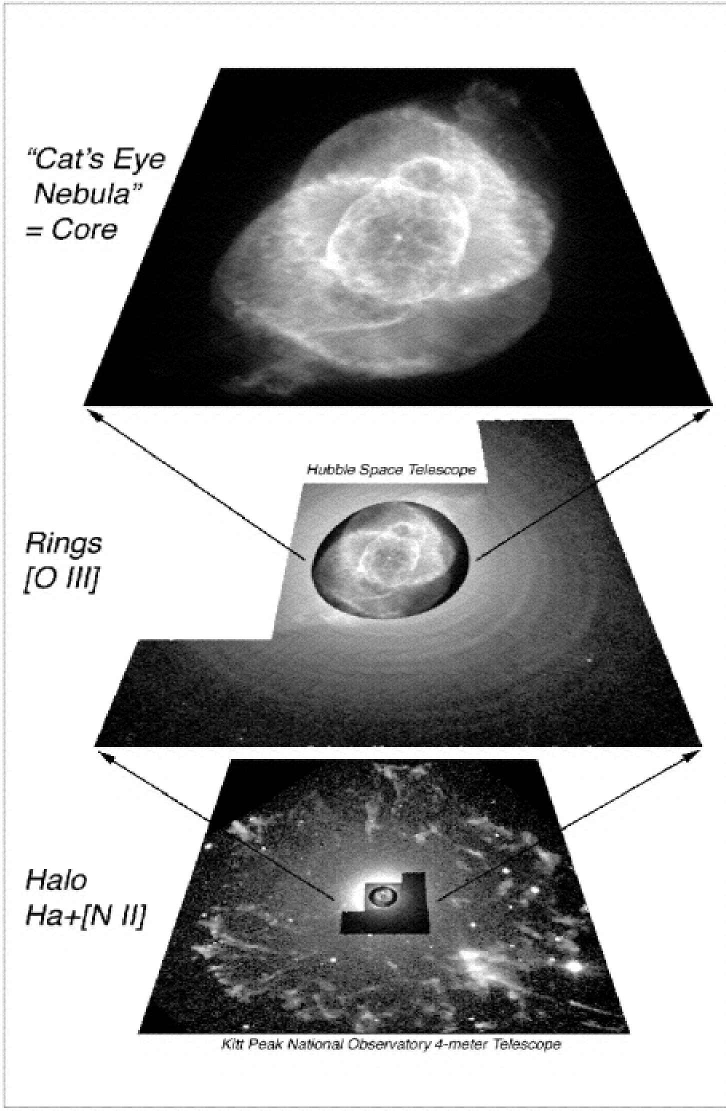
NGC 6543

HST

ACS

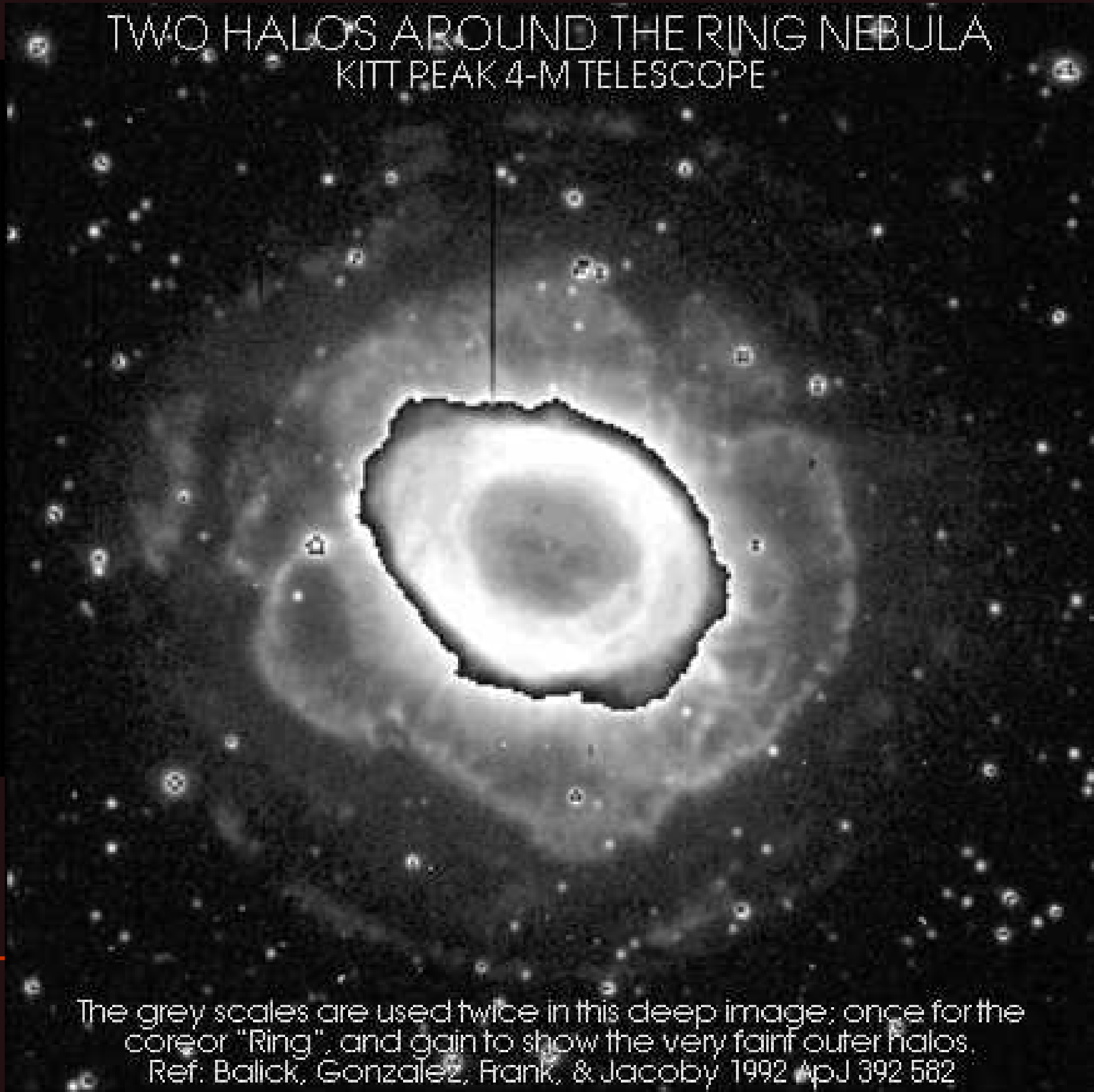
NGC 6543: The Rings Around the Cat's Eye



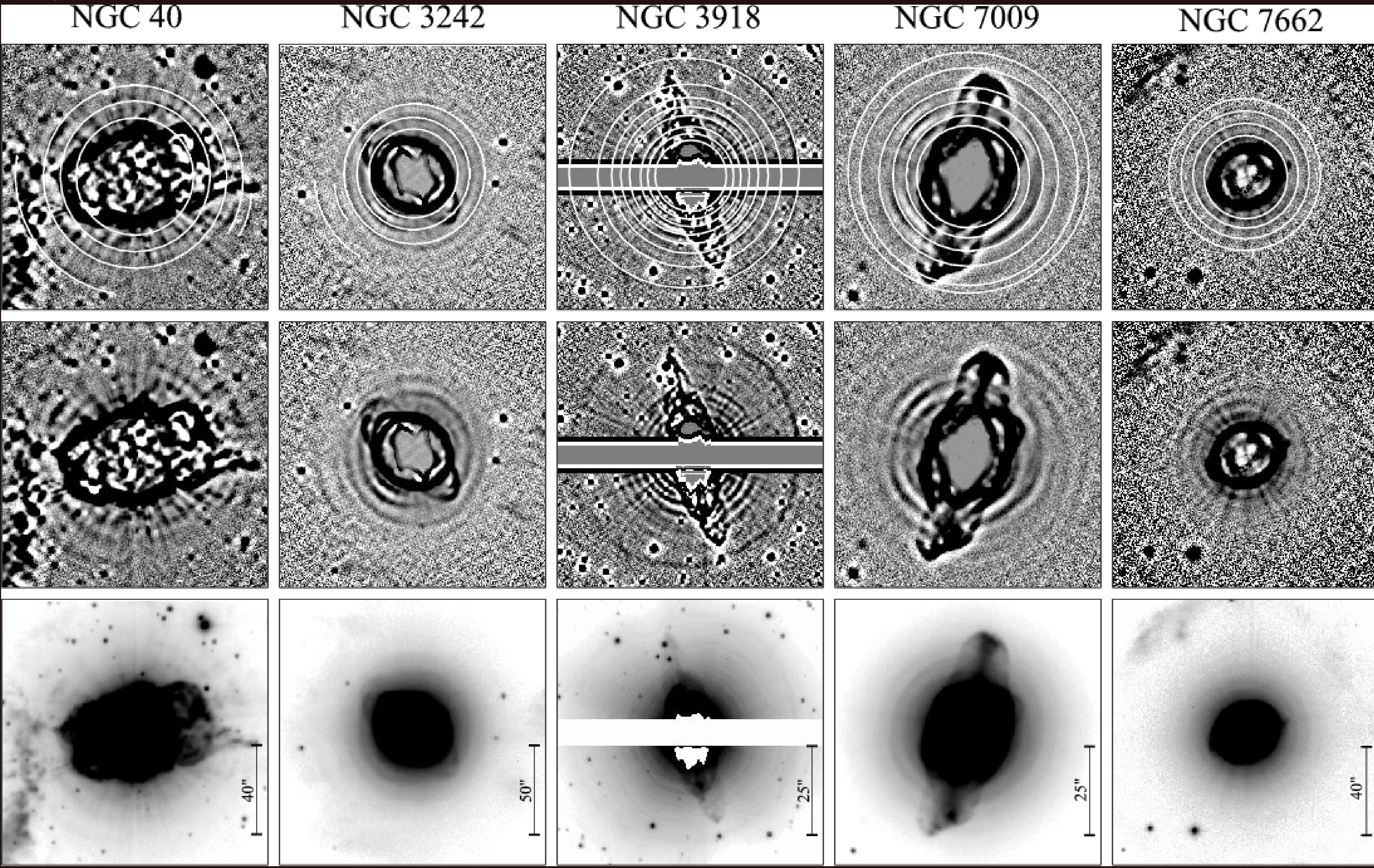


Balick, Wilson & Hajian (2001) AJ, 121, 354

NGC 6720: Rings around the Ring



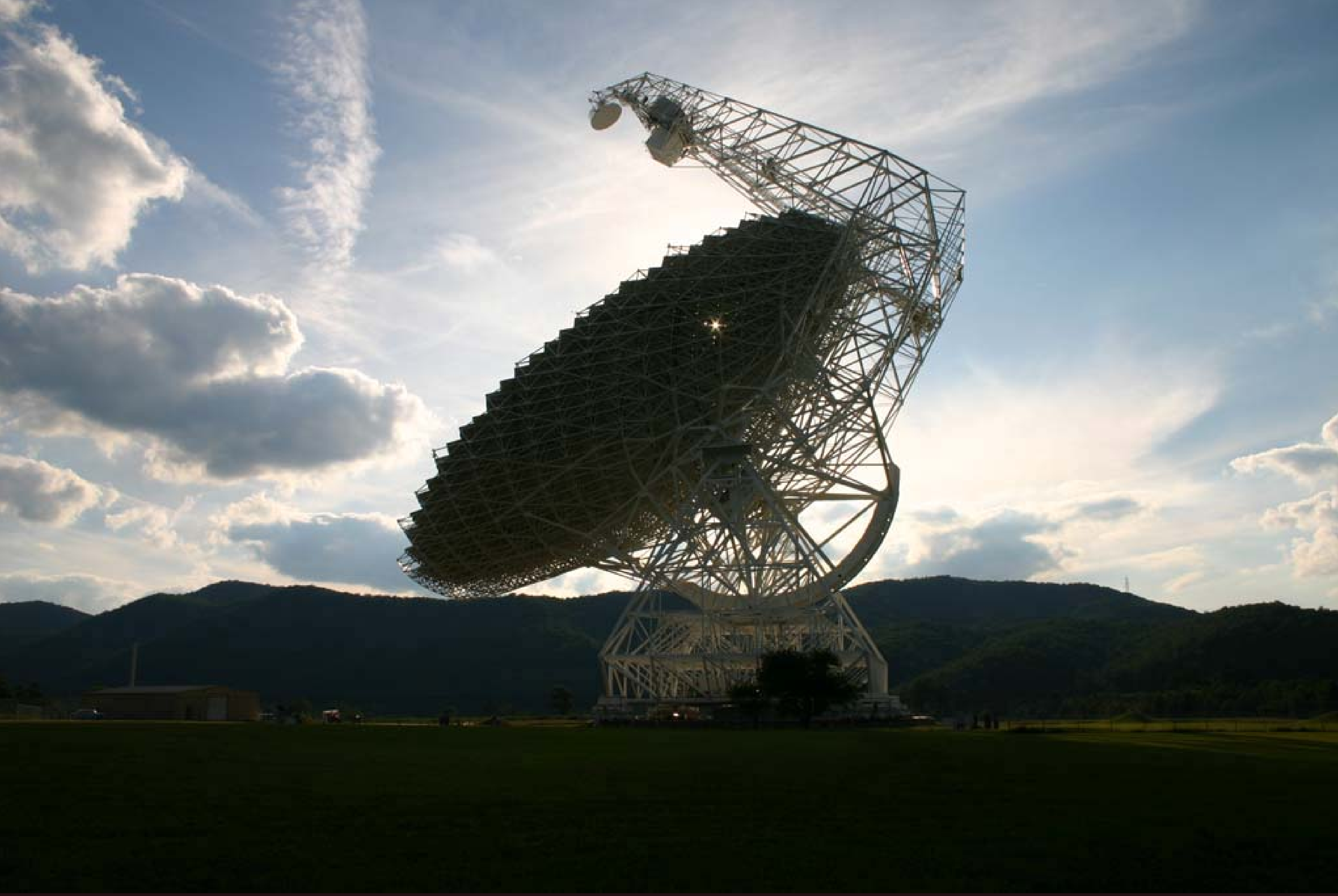
Rings in the Haloes of Planetary Nebulae



Corradi et al. (2004) A&A,417, 637

The Robert C. Byrd

GREEN BANK TELESCOPE



Conventional

Blocked

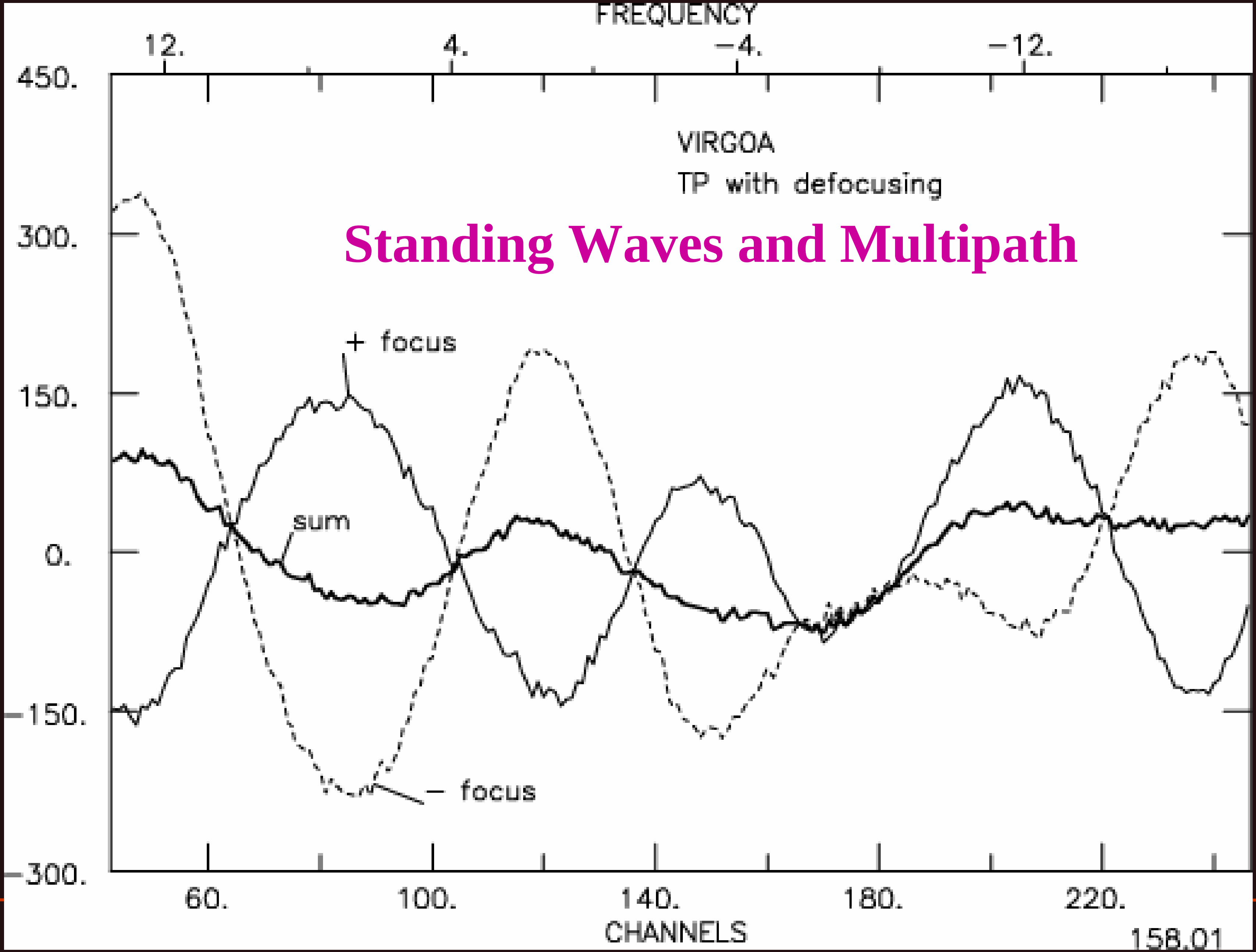
Aperture

Is a very

Bad

Design

Standing Waves and Multipath

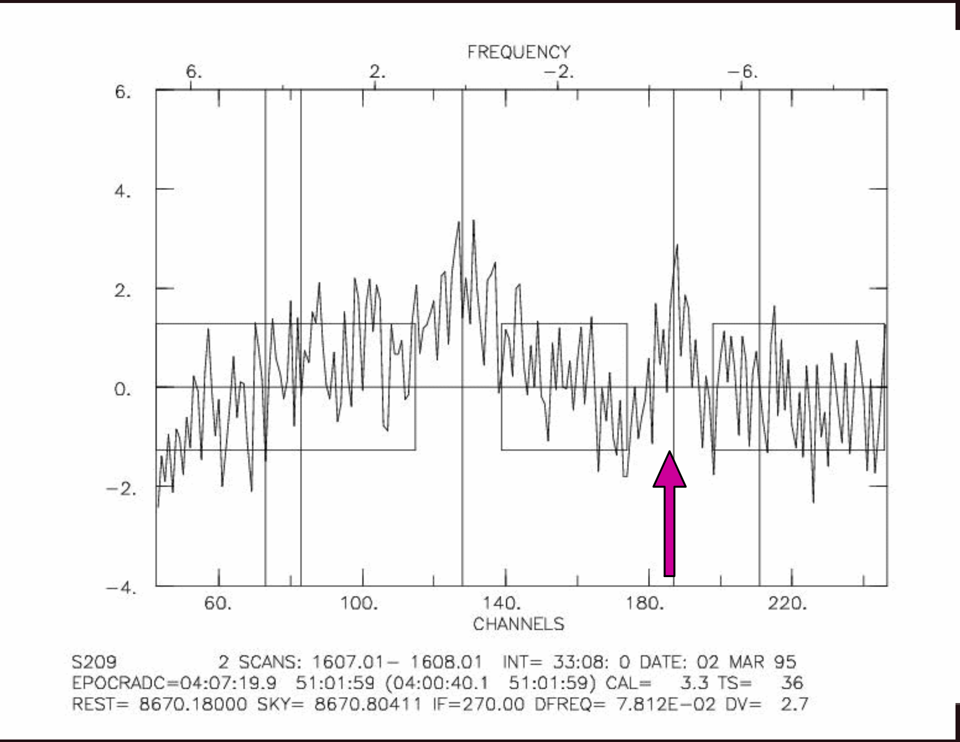


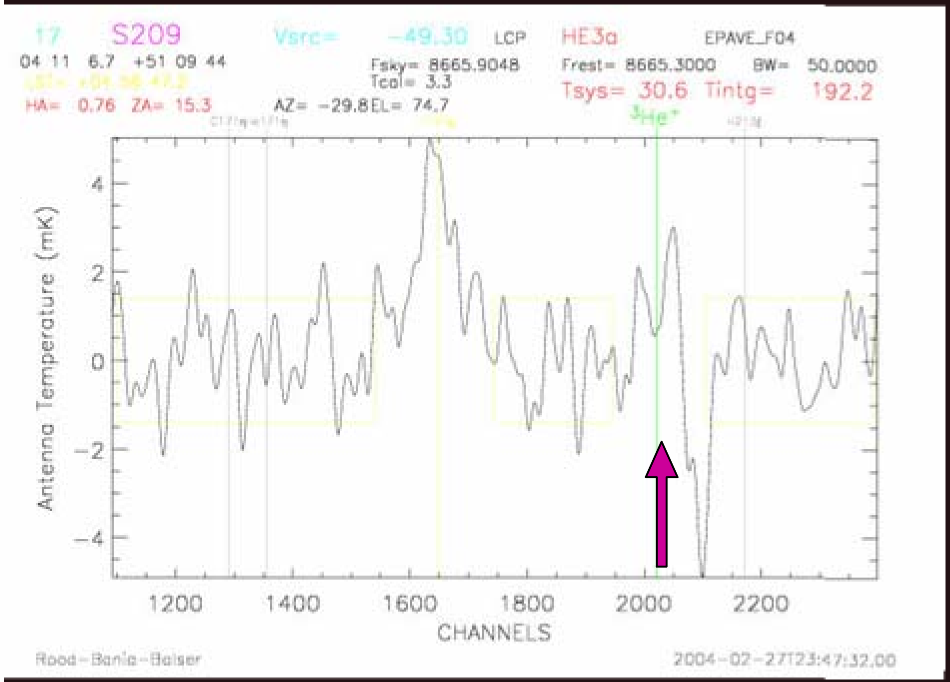
GBT: Clear Aperture Optics

S 209 H II Region

140 ft March 1995

GBT June 2004

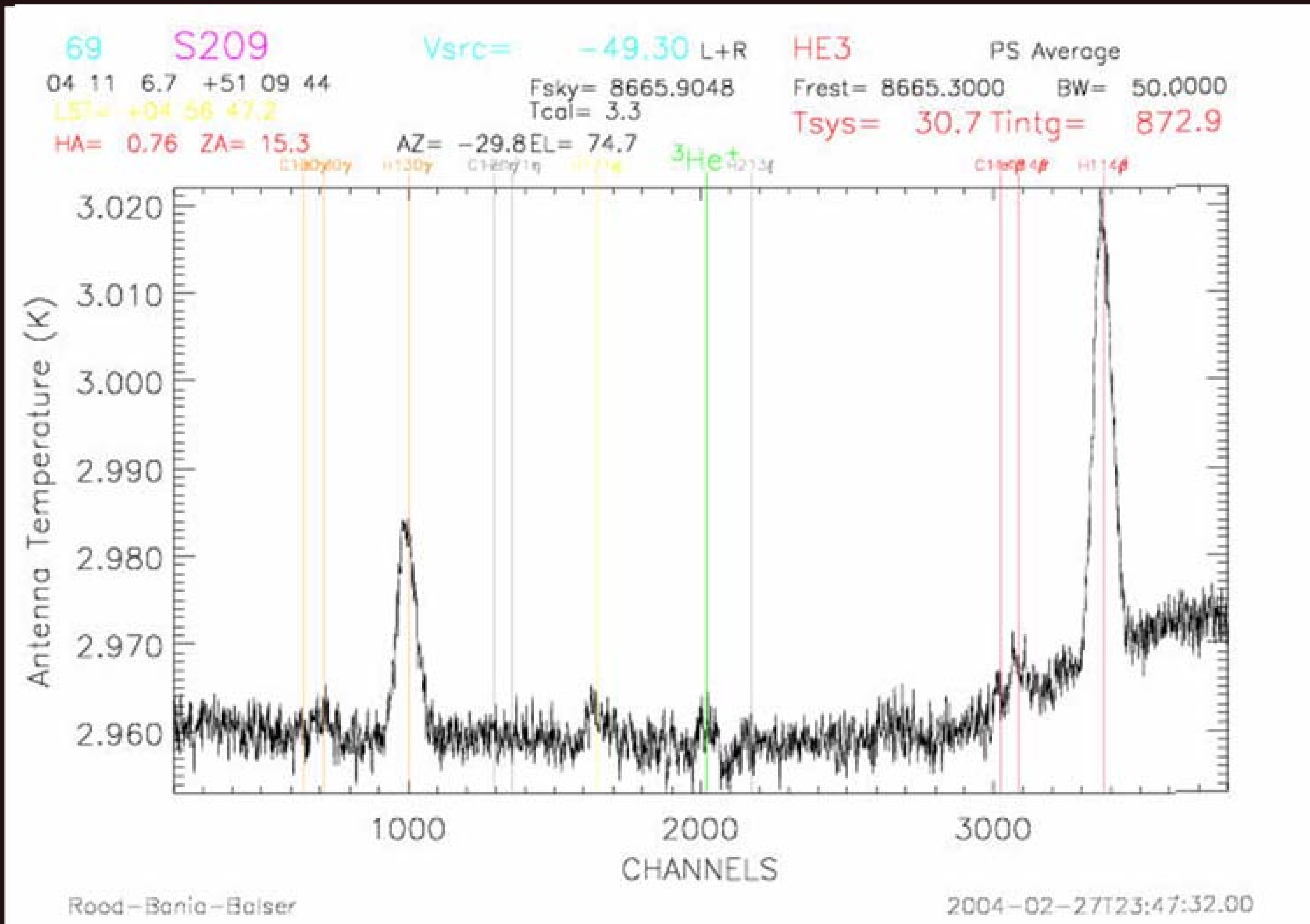




33.1 hr

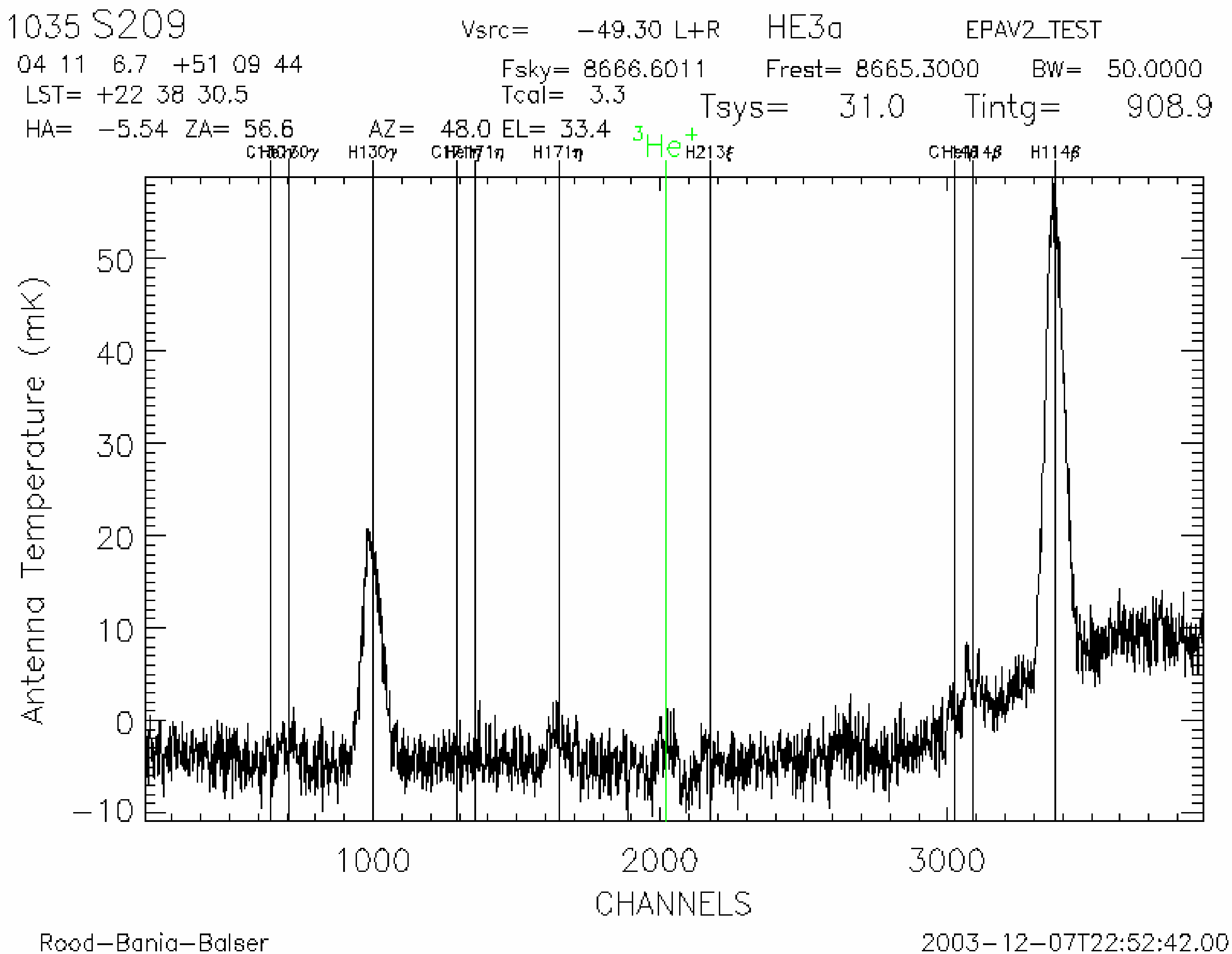
3.2 hr

GBT S 209 H II Region



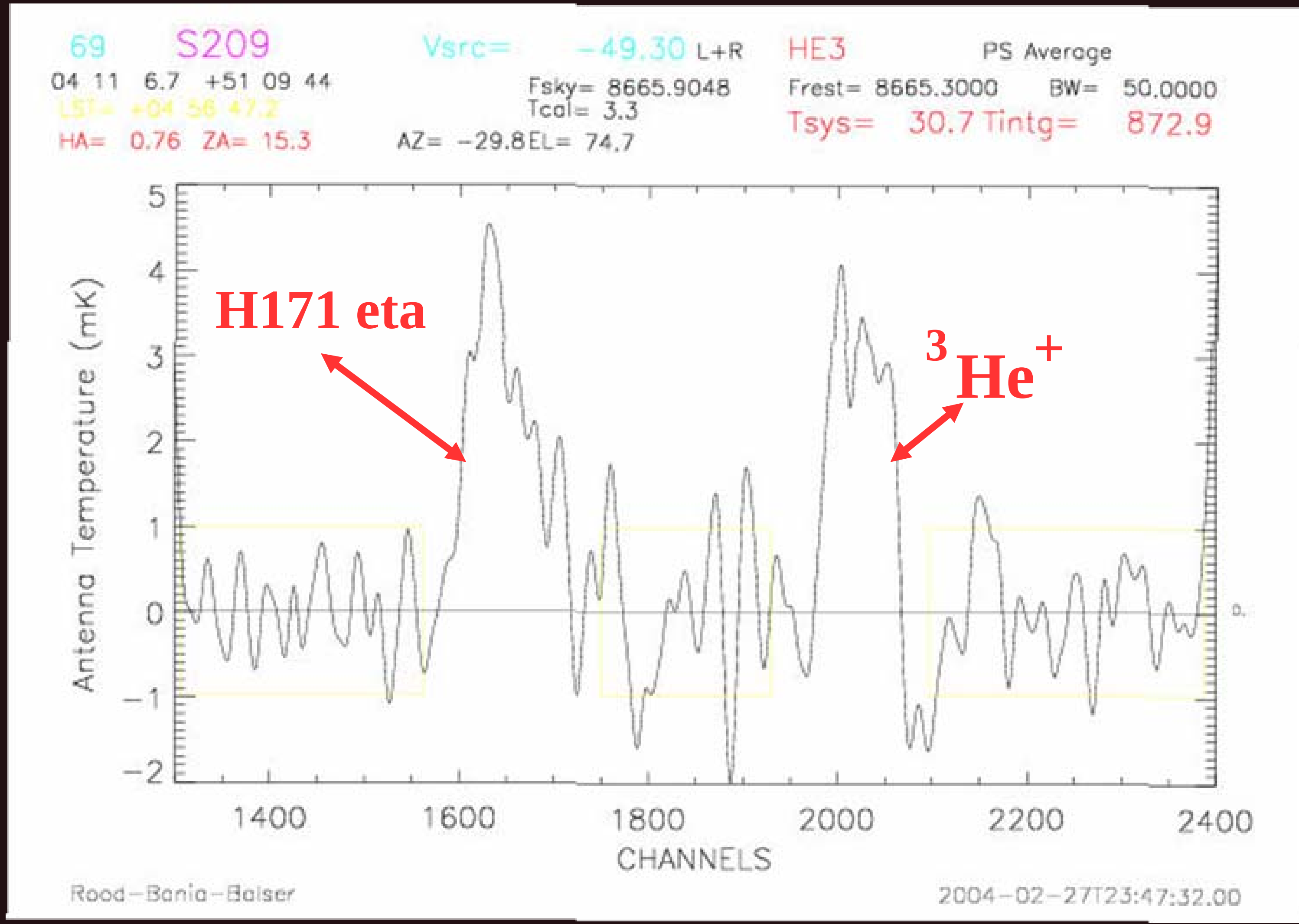
Calibrated Raw Spectrum

14.5 hour integration



DC Level Subtracted **15.1 hr integration**

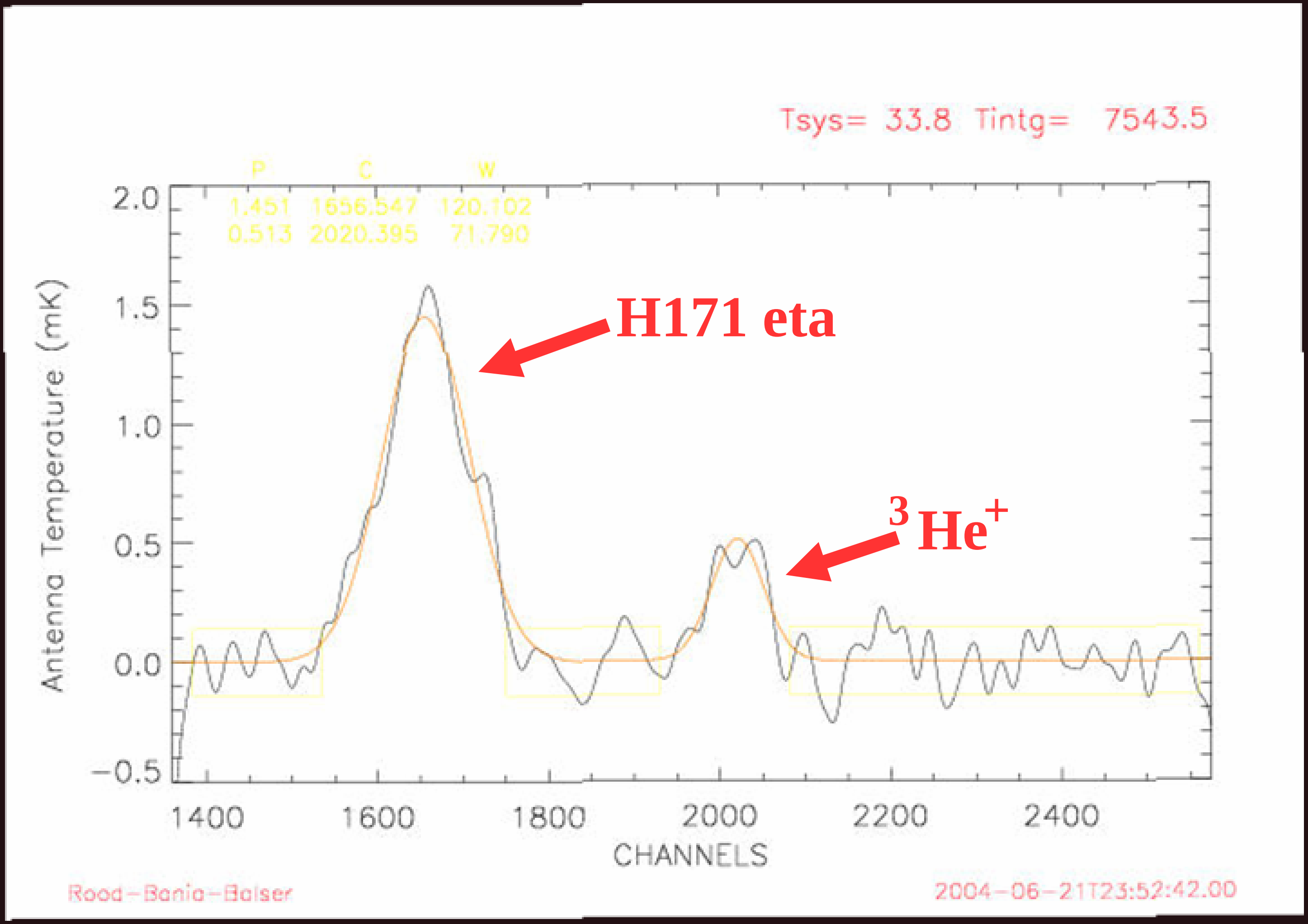
S 209 H II Region



14.5 hour integration **5 km/sec resolution**

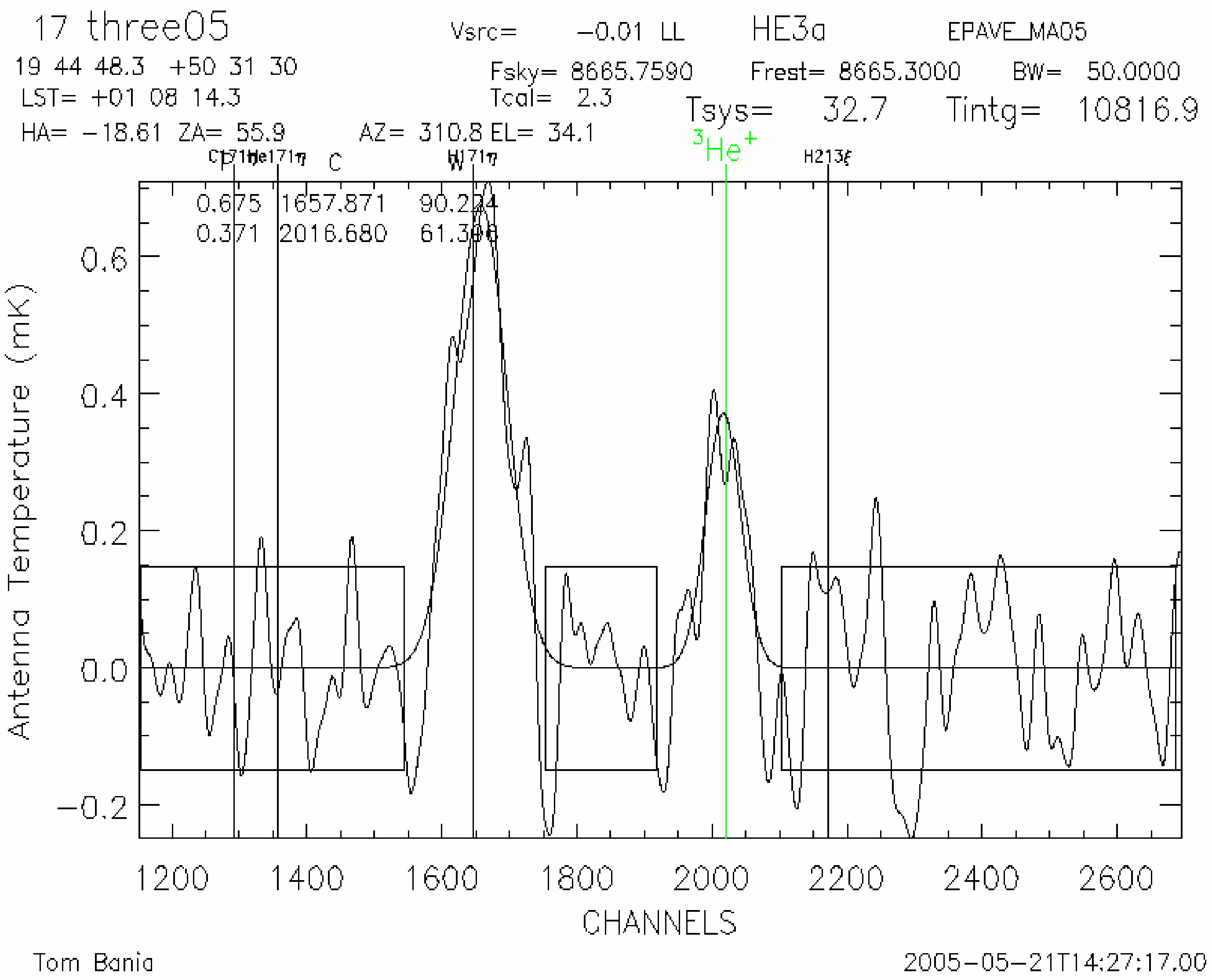
GBT PNe Composite Spectrum

NGC 3242 + NGC 6543 + NGC 6826 + NGC 7009



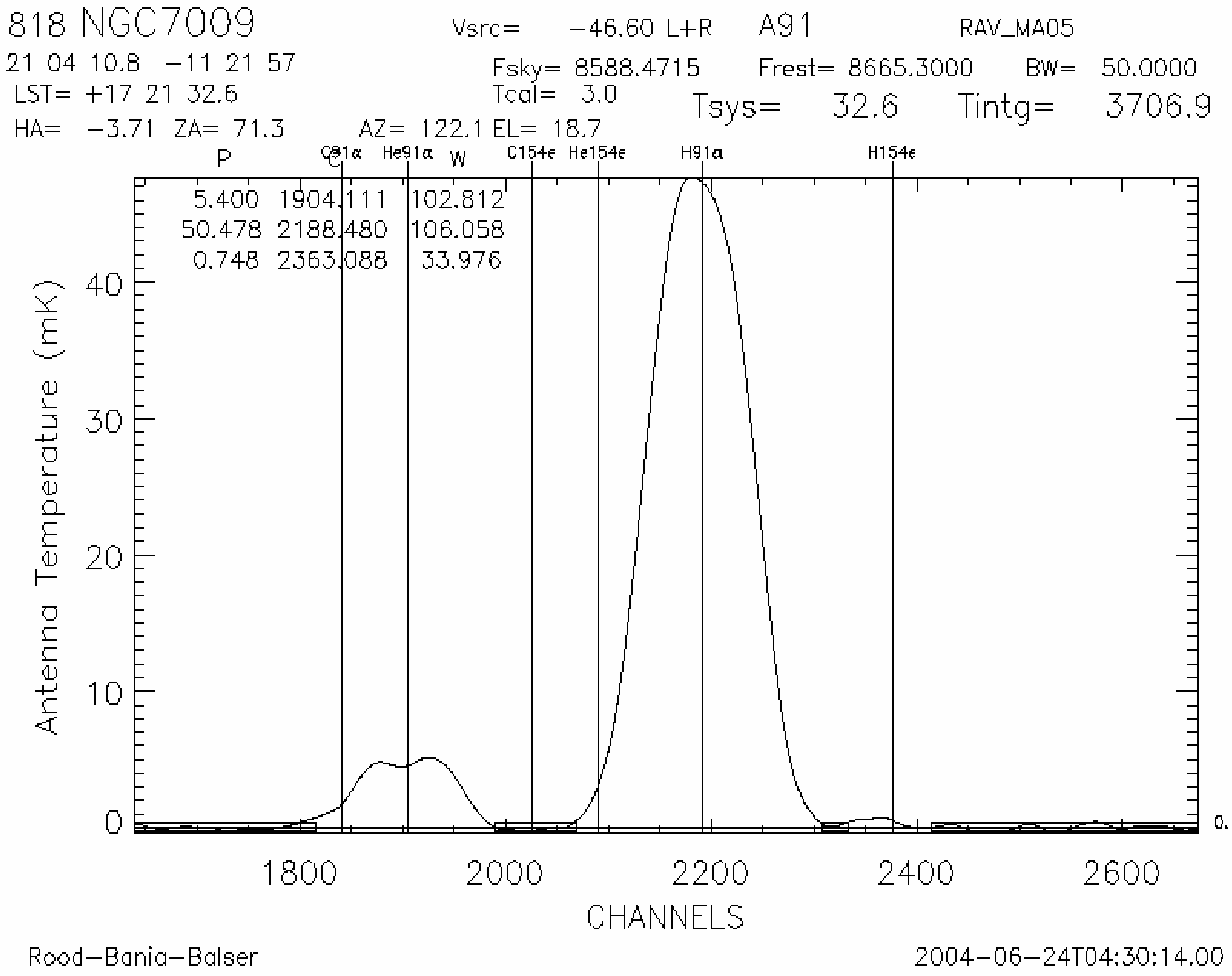
125.7 hour integration

Composite PNe Spectrum 180.3 hr integration

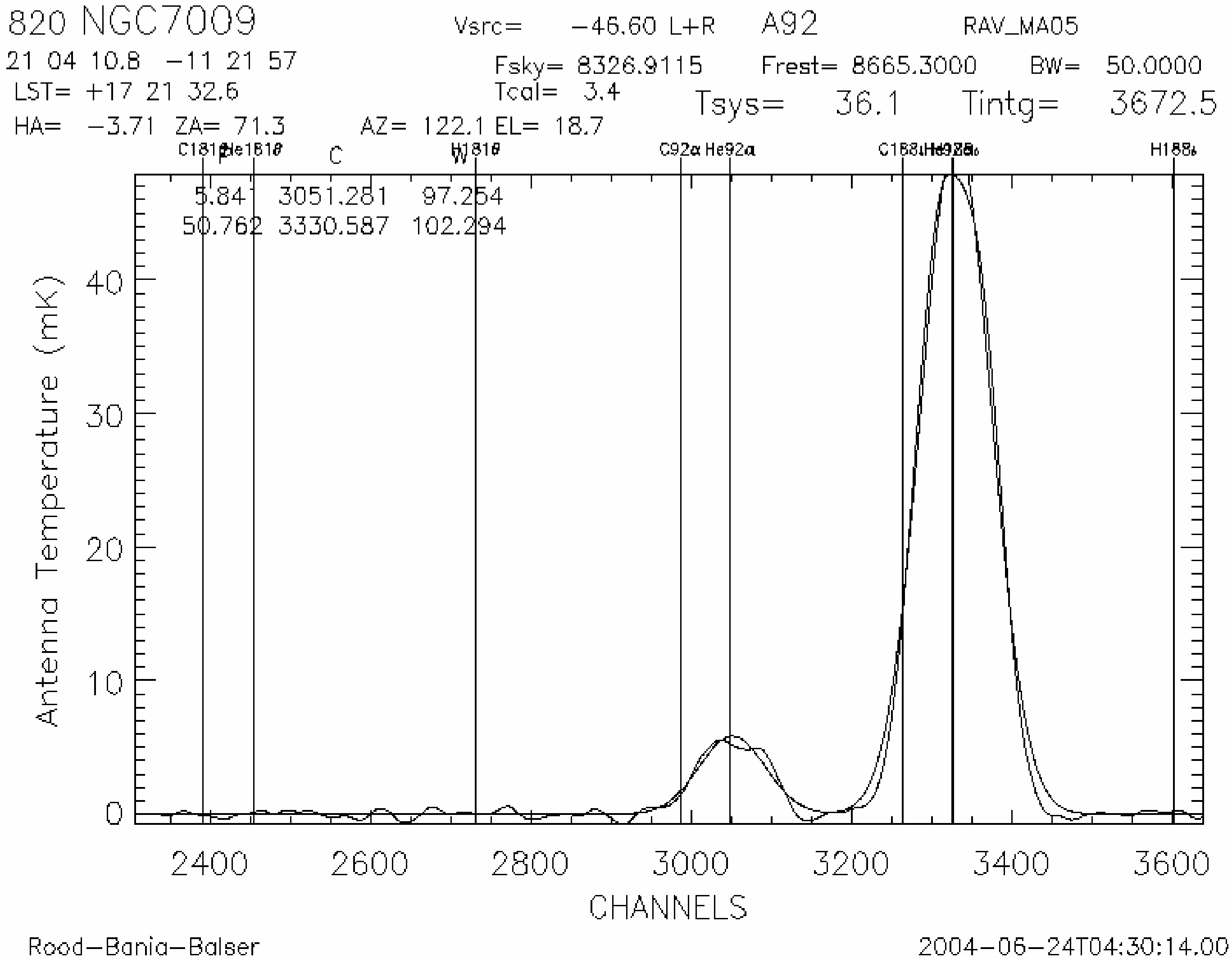


NGC 7009 + NGC 6543 + NGC 6826

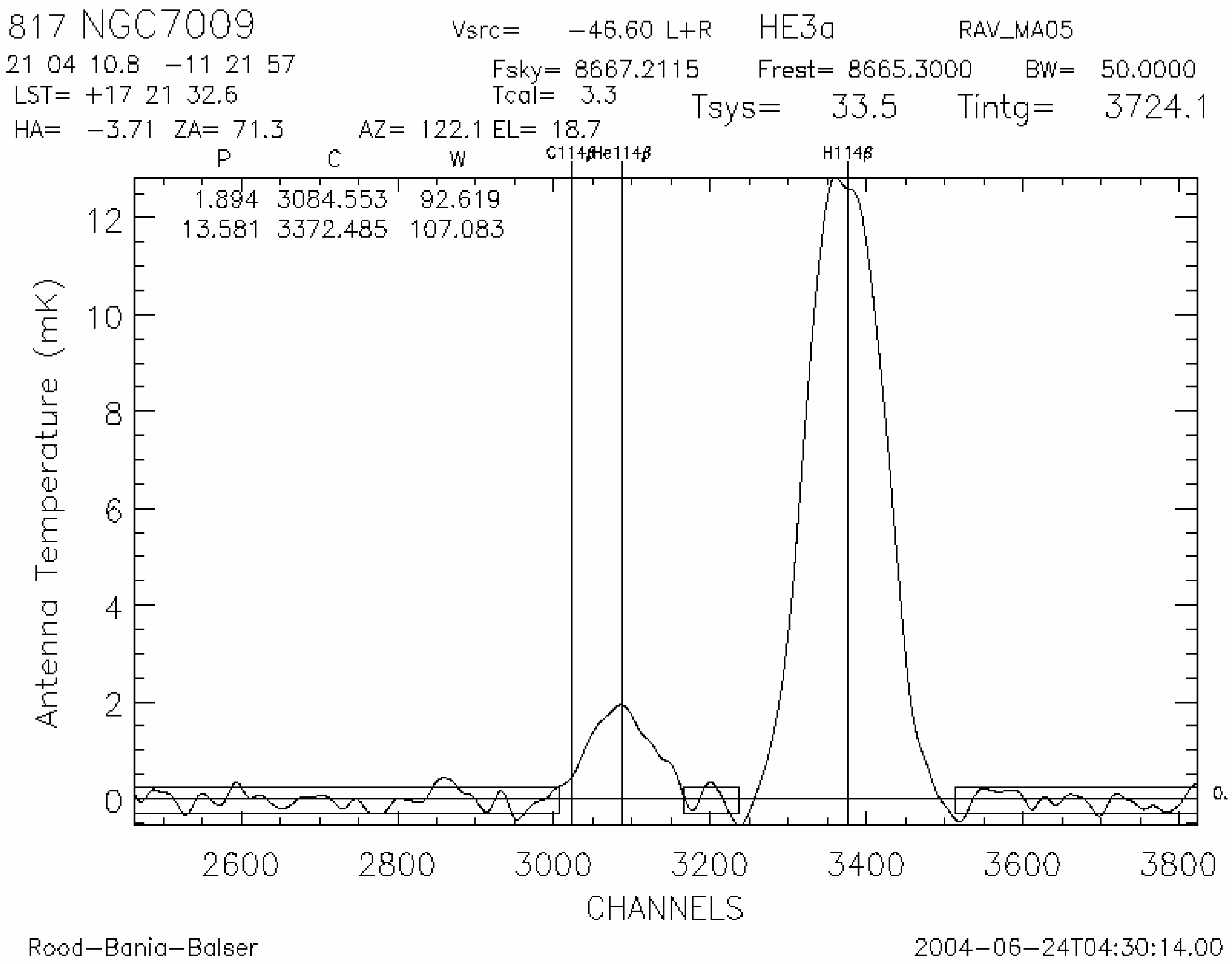
NGC 7009 H 91alpha 61.8 hr



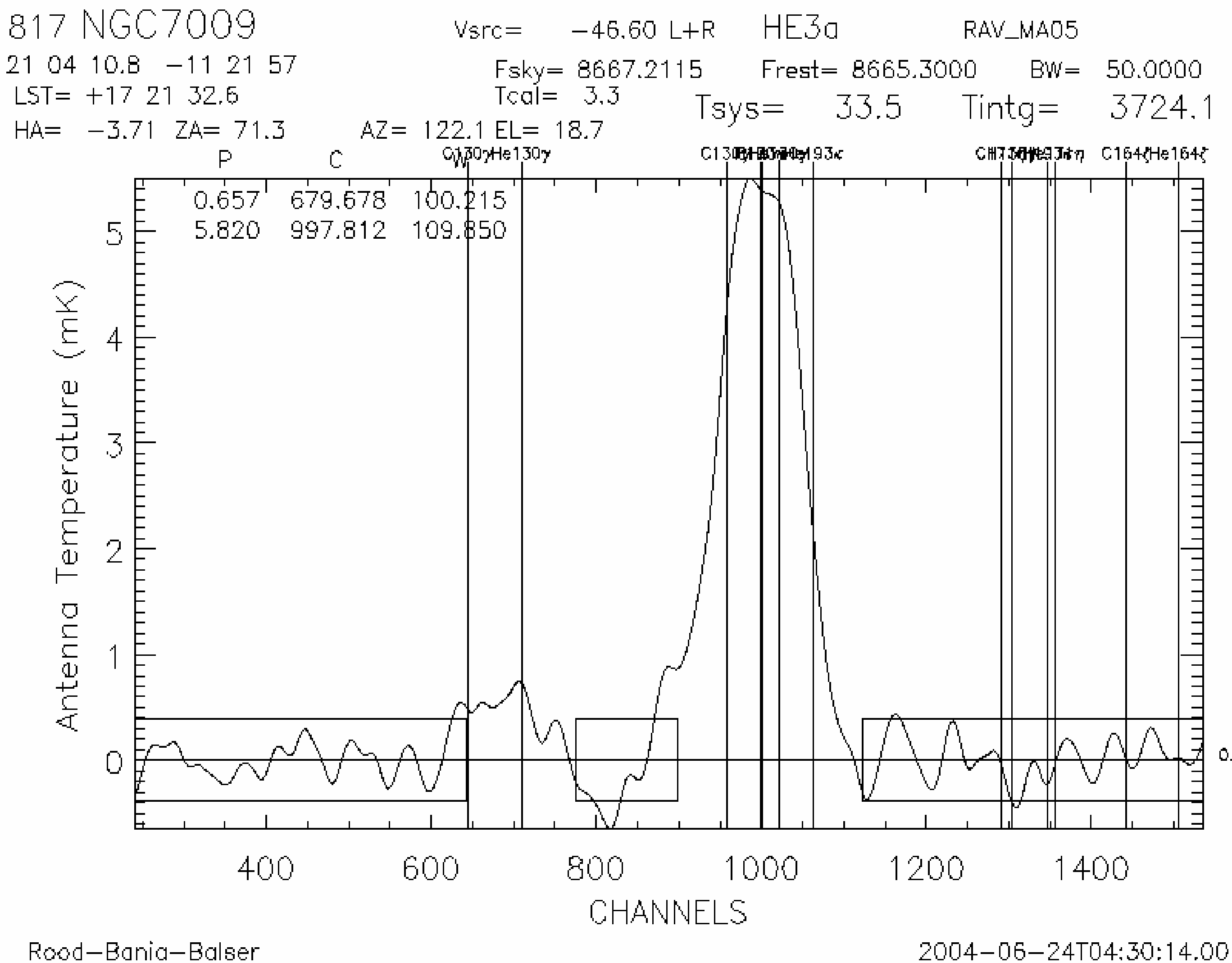
NGC 7009 H 92alpha 61.2 hrs



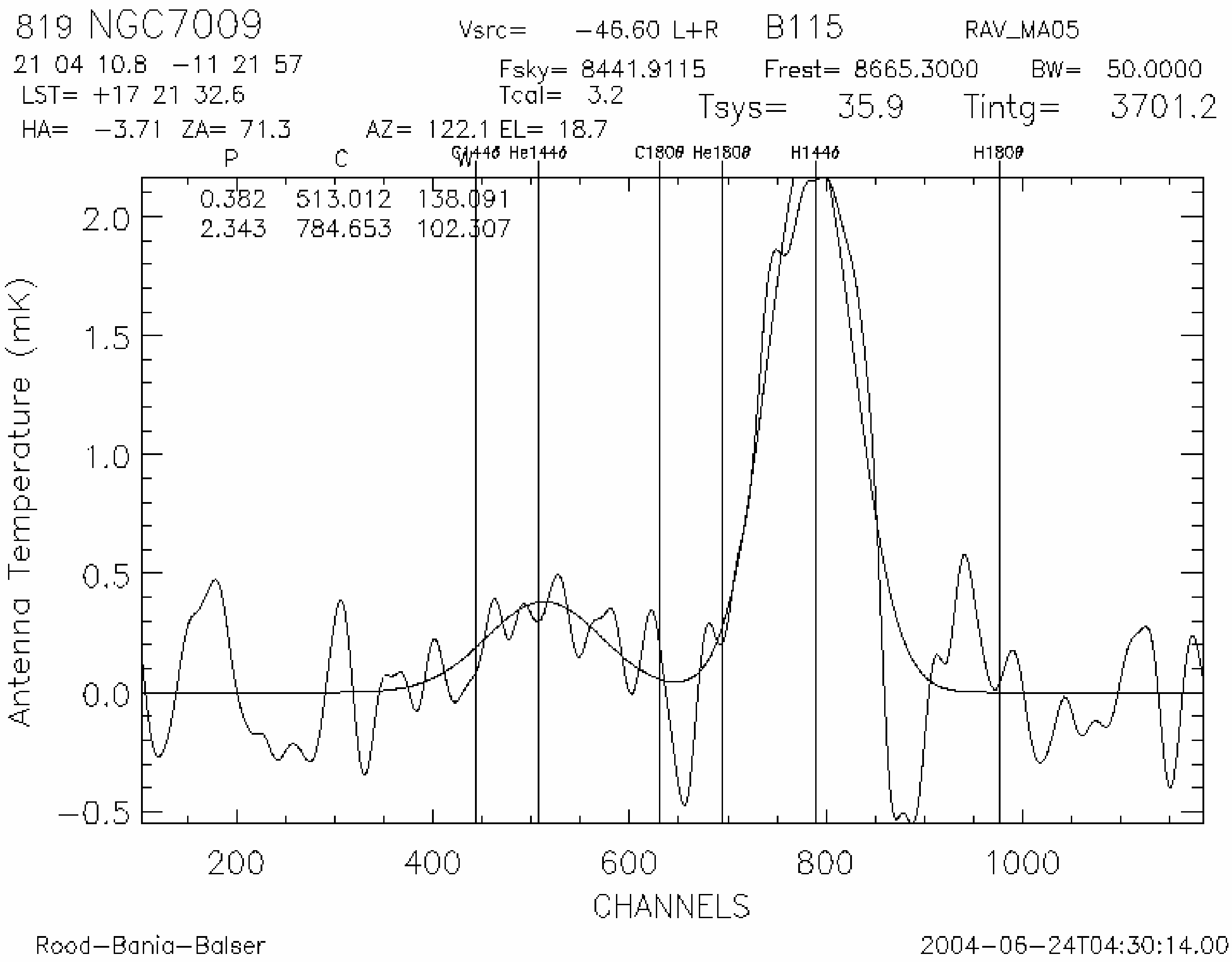
NGC 7009 H 114beta 62.1 hrs



NGC 7009 H130gamma 62.1 hrs

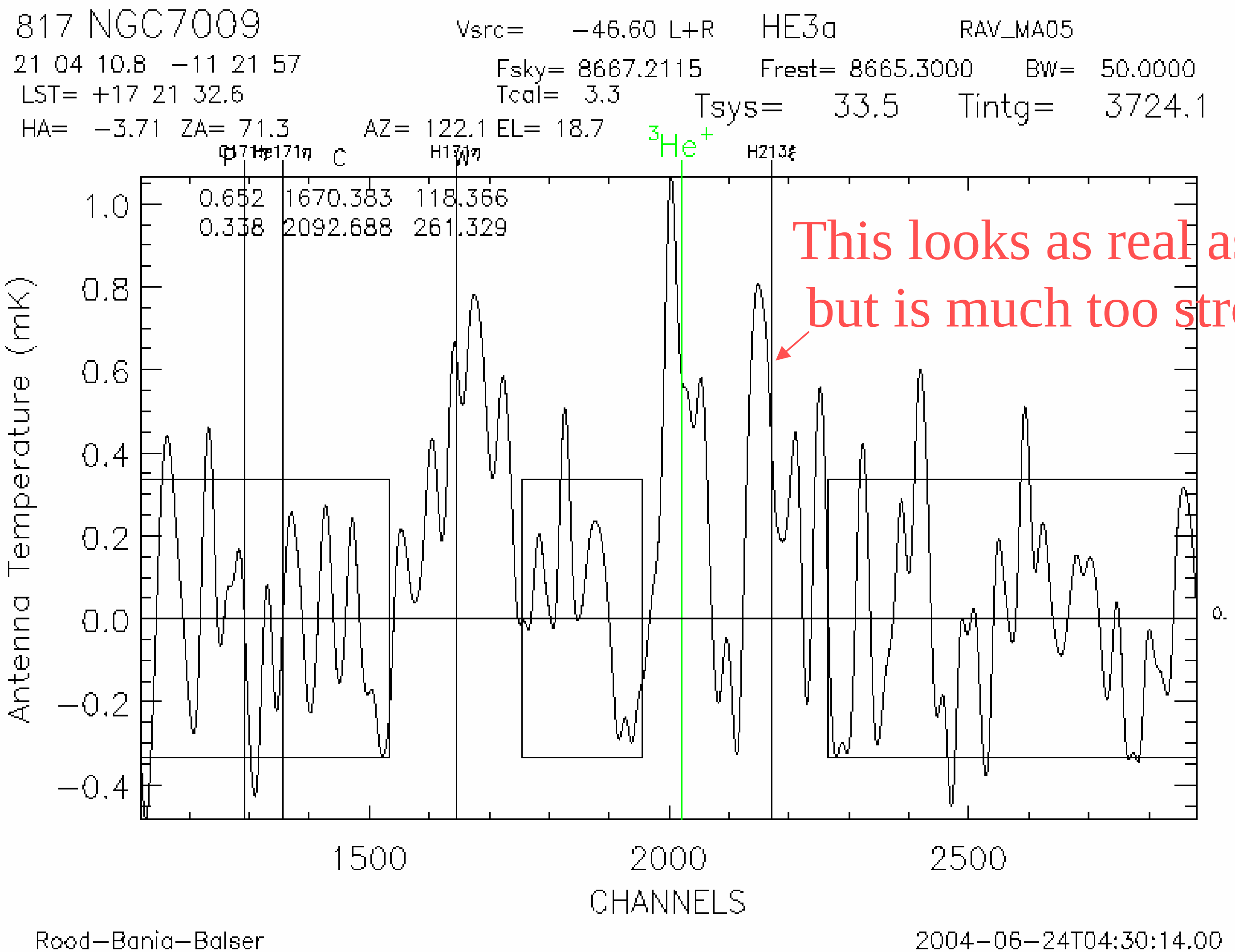


NGC 7009 H 144delta 61.7 hrs



Conclude reliability level for NGC7009 ~ 0.5 mK

NGC 7009 H 171eta 3-He 62.1 hrs



NAIC Arecibo Observatory 305 m

3-Helium Experiment Status

- VLA ^{3}He detection for PN J 320. It has a substantial halo, just as NGC 3242 does.
- Composite GBT PNe spectrum consistent with MPIfR 100 m survey result.
- Probable GBT ^{3}He detection for NGC 7009 A second detection in NGC 6543 is likely.
- First epoch Arecibo observations complete.

3-Helium Experiment Status

- 25% of all planetary nebulae meet our selection criteria. To be consistent with Galactic Chemical Evolution models, only 1/5 of these should show detectible ^{3}He.

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

- LMC/SMC campaign using Parkes planned. (Suprising perhaps, but feasible.)

It had been a very long experiment.

They considered this in silence.

Finally, Bania spoke, very slowly and carefully. For a change.

“I look at it all like this,” he said. “Before I did this damn experiment, I was like everyone else. You know what I mean? I was confused and uncertain about all the little details of life.” “But now,” he brightened up, “while I’m still confused and uncertain it’s on a much higher plane, d’you see, and at least I know I’m bewildered about the really fundamental and important facts of the Universe.”

Rood nodded. “I hadn’t looked at it like that,” he said, “but you’re absolutely right. The 3-He experiment has really pushed back the boundaries of ignorance. There’s so much about the Universe we don’t know.”

The both savoured the strange warm glow of being much more ignorant than ordinary people, who were ignorant of only ordinary things.

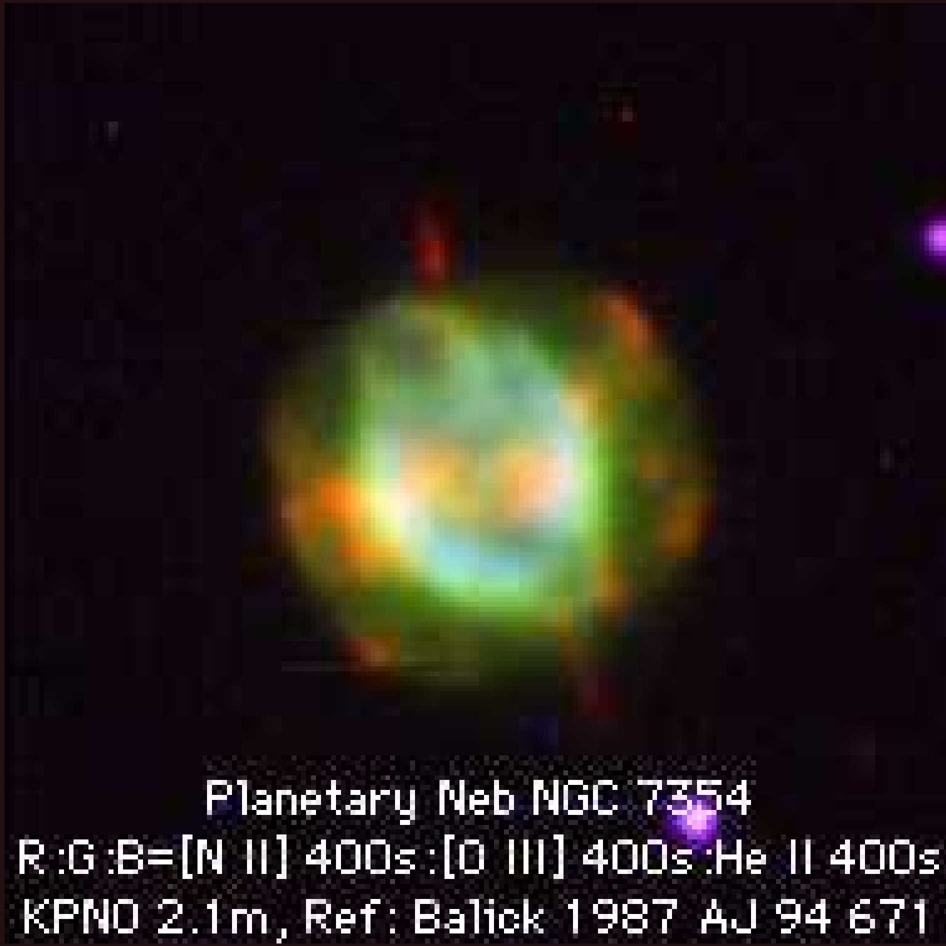
GBT Conclusions

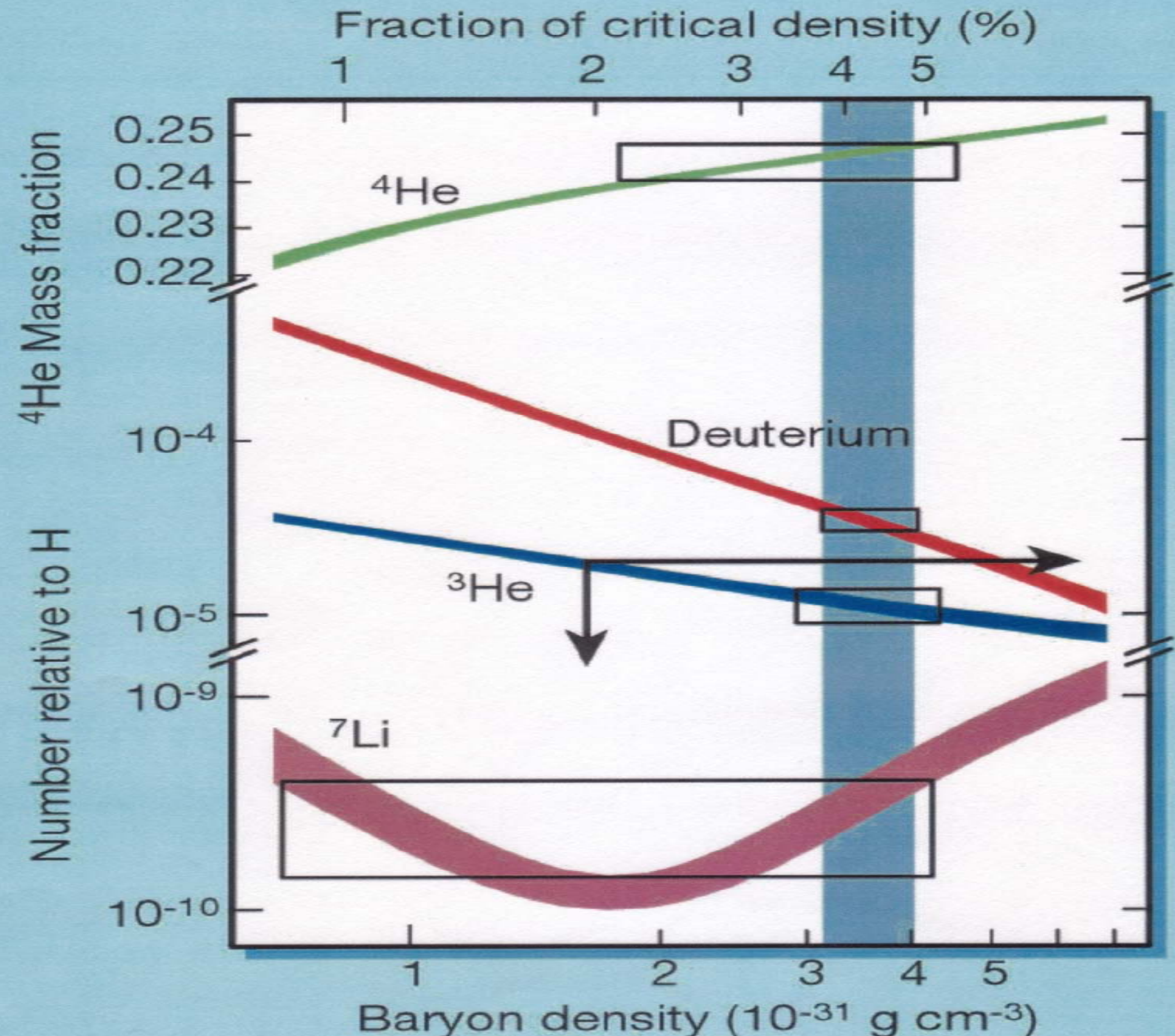
- Standing waves are not a problem
- There is still baseline structure (BS) probably resulting from the broadband feed, the polarizer, and or mismatches in the IF system.
  - BS varies with frequency sometimes almost invisible other times very problematic
  - BS amplitude is proportional to source continuum and moves with sky frequency
- At the mK level there are pseudo-lines
- In some AC bands there are short duration spikes in the ACF at seemingly random times, lags, and amplitudes

Helium-3 Conclusions

- We have found helium-3 in another PN, J320, using the VLA
- We probably have found helium-3 in NGC7009 using the GBT and may have a second detection in NGC6543
- Roughly 25% of PNe meet our selection criteria. To avoid conflict with Monica we should detect 3He in only 1/5
- The scheduling mode and proposal pressure on the GBT may not allow us to solidify these results in the near future.
- The EVLA (10 x more sensitive than the VLA) has great potential

NGC 7009 NGC 7354

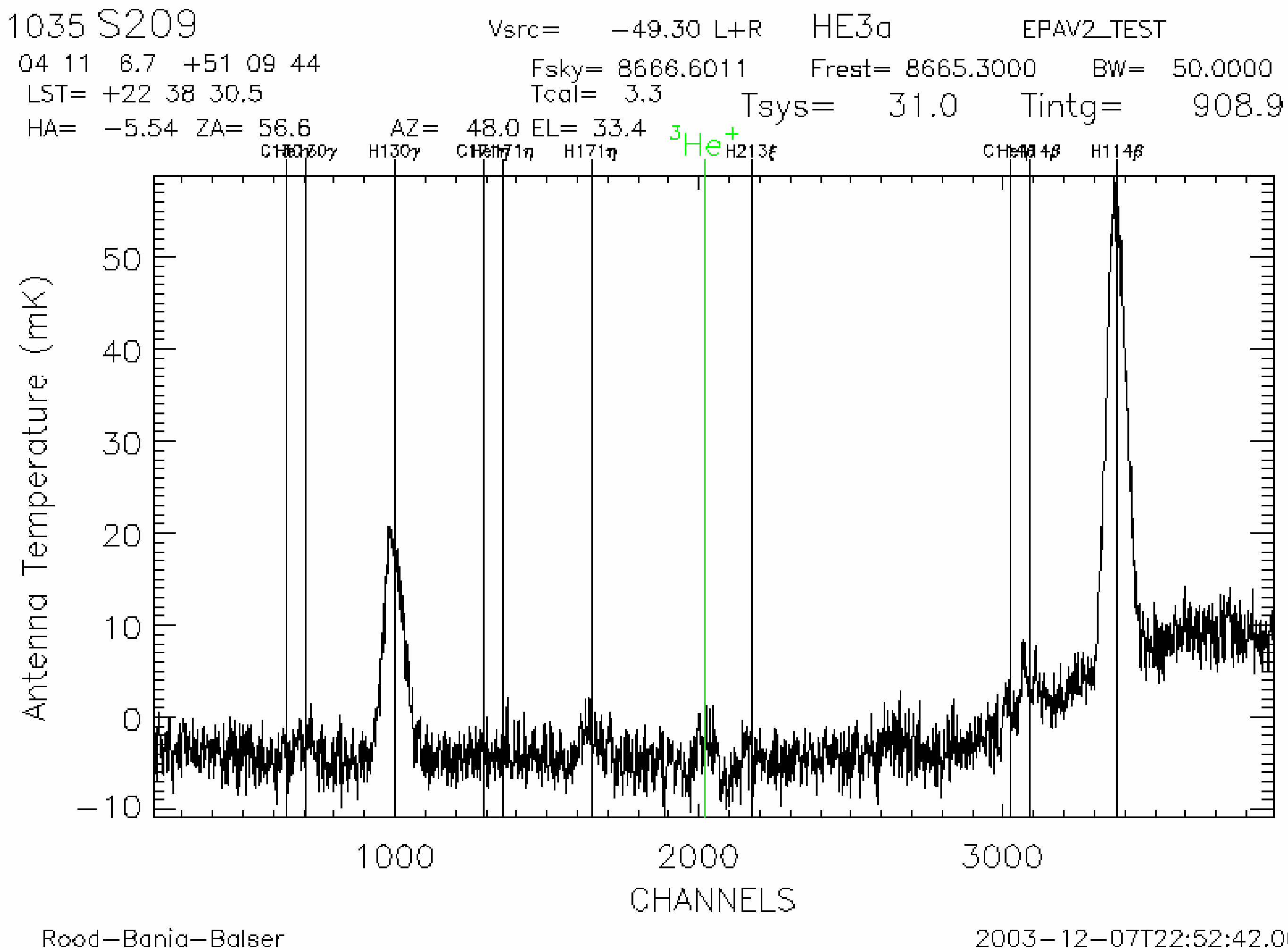




Fraction of critical density (%)
1
2
3
4
5
0.25
0.24
0.23
0.22
^{4}He Mass fraction
^{4}He
Deuterium
^{3}He
10^{-4}
10^{-5}
10^{-9}
10^{-10}
Number relative to H
^{7}Li
1
2
3
4
5
Baryon density (10^{-31} g cm^{-3})

3-Helium Experiment Status

- GBT now fully operational for 3-He
- Two GBT 3-He epochs complete
- Spectral baselines of excellent quality
- Composite PNe spectrum consistent with MPIfR survey results
- VLA 3-He 4-sigma detection' for PN J320 (see Balser et al. poster)
- First epoch NAIC Arecibo Observatory observations complete



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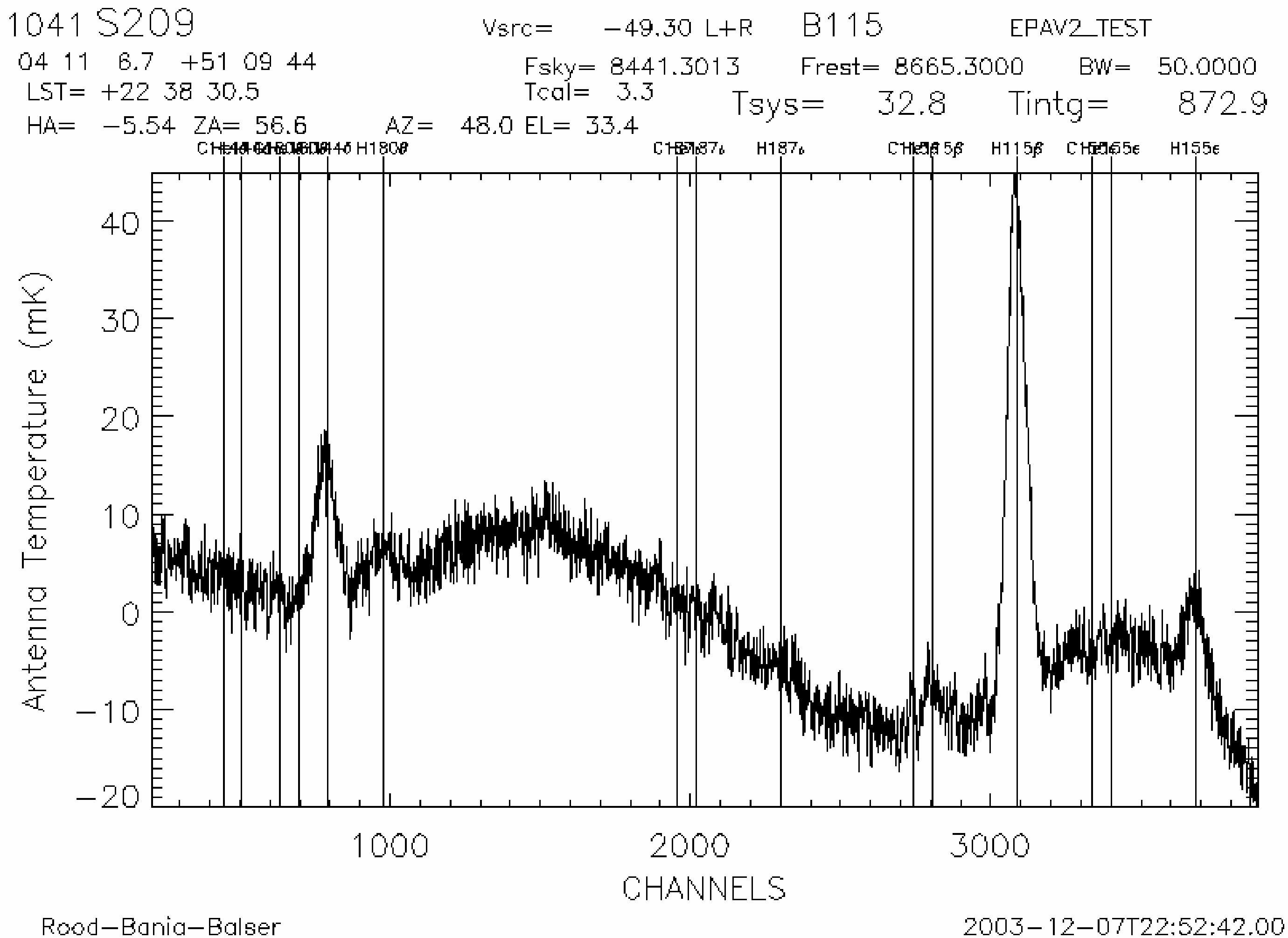
04 11 6.7 +51 09 44
LST= +22 38 30.5
HA= −5.54 ZA= 56.6
AZ= 48.0 EL= 33.4
Vsrc= −49.30 L+R
HE3a
EPAV2_TEST
Fsky= 8666.6011
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 31.0
Tintg= 908.9
H130γ
H171η
H213ξ
H114β
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2003−12−07T22:52:42.00



1041 S209
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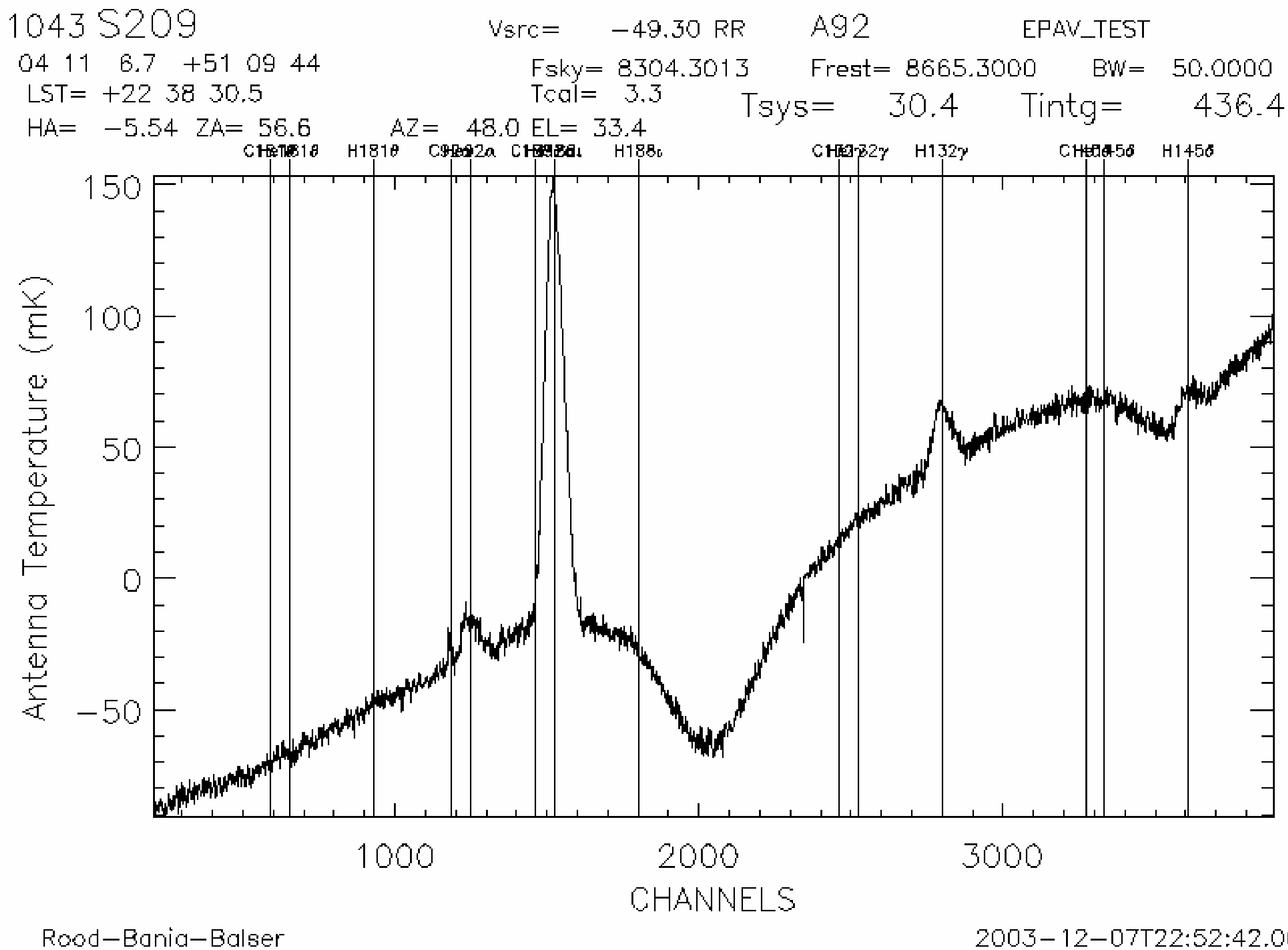
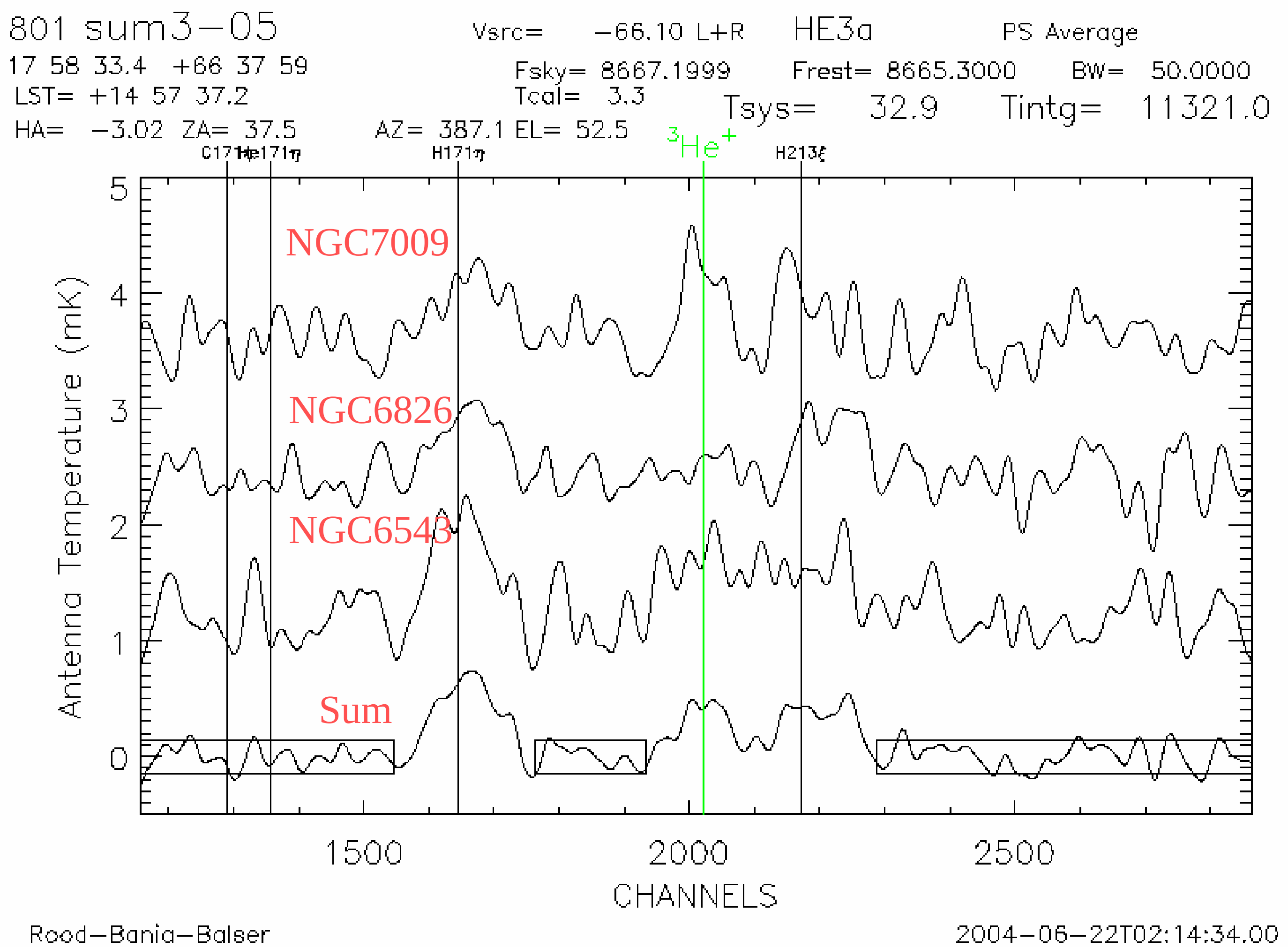
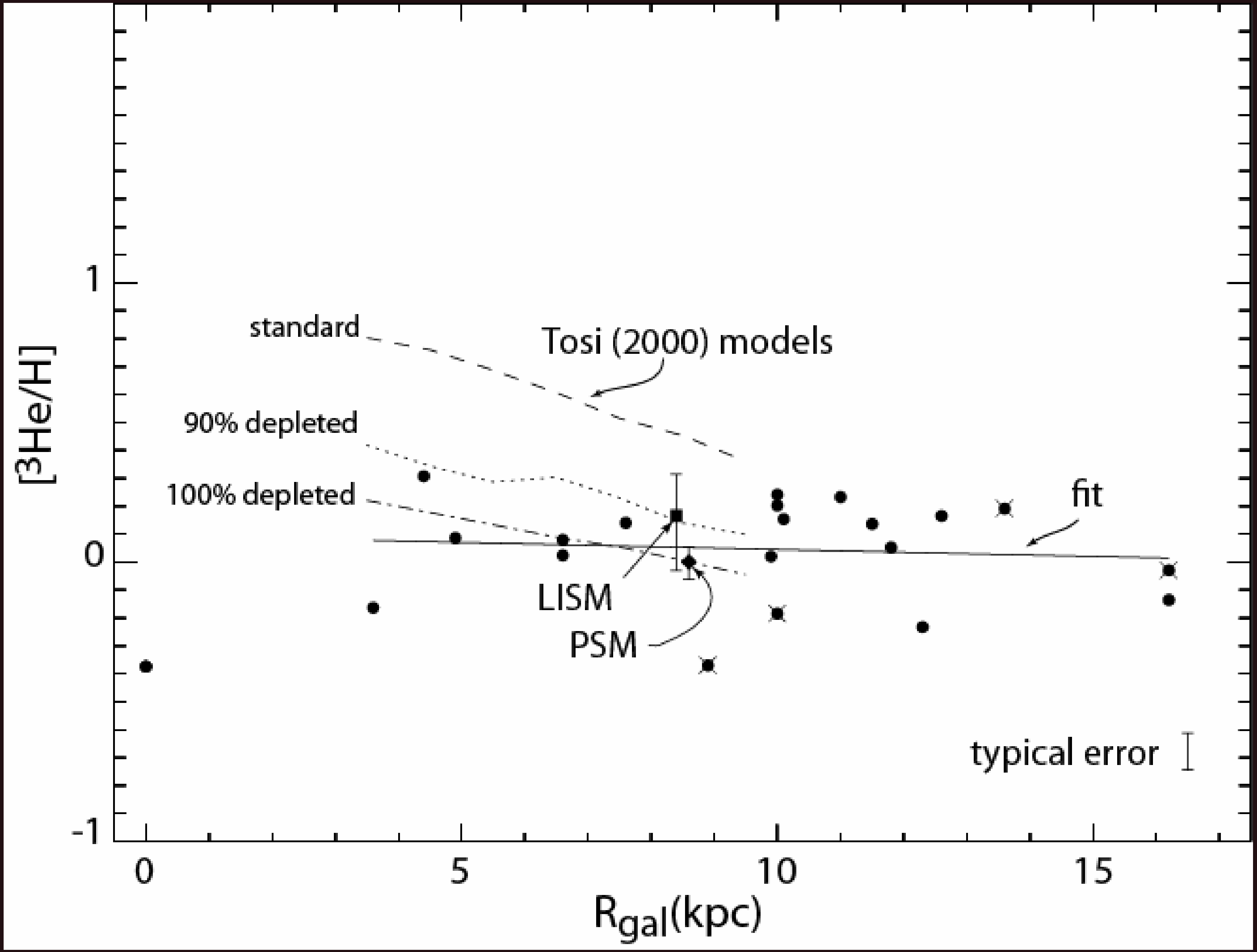
B115
EPAV2_TEST
04 11 6.7 +51 09 44
Fsky= 8441.3013
Frest= 8665.3000
BW= 50.0000
LST= +22 38 30.5
Tcal= 3.3
Tsys= 32.8
Tintg= 872.9
HA= −5.54 ZA= 56.6
AZ= 48.0 EL= 33.4
H180θ
H187ι
H115β
H155ε
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2003−12−07T22:52:42.00

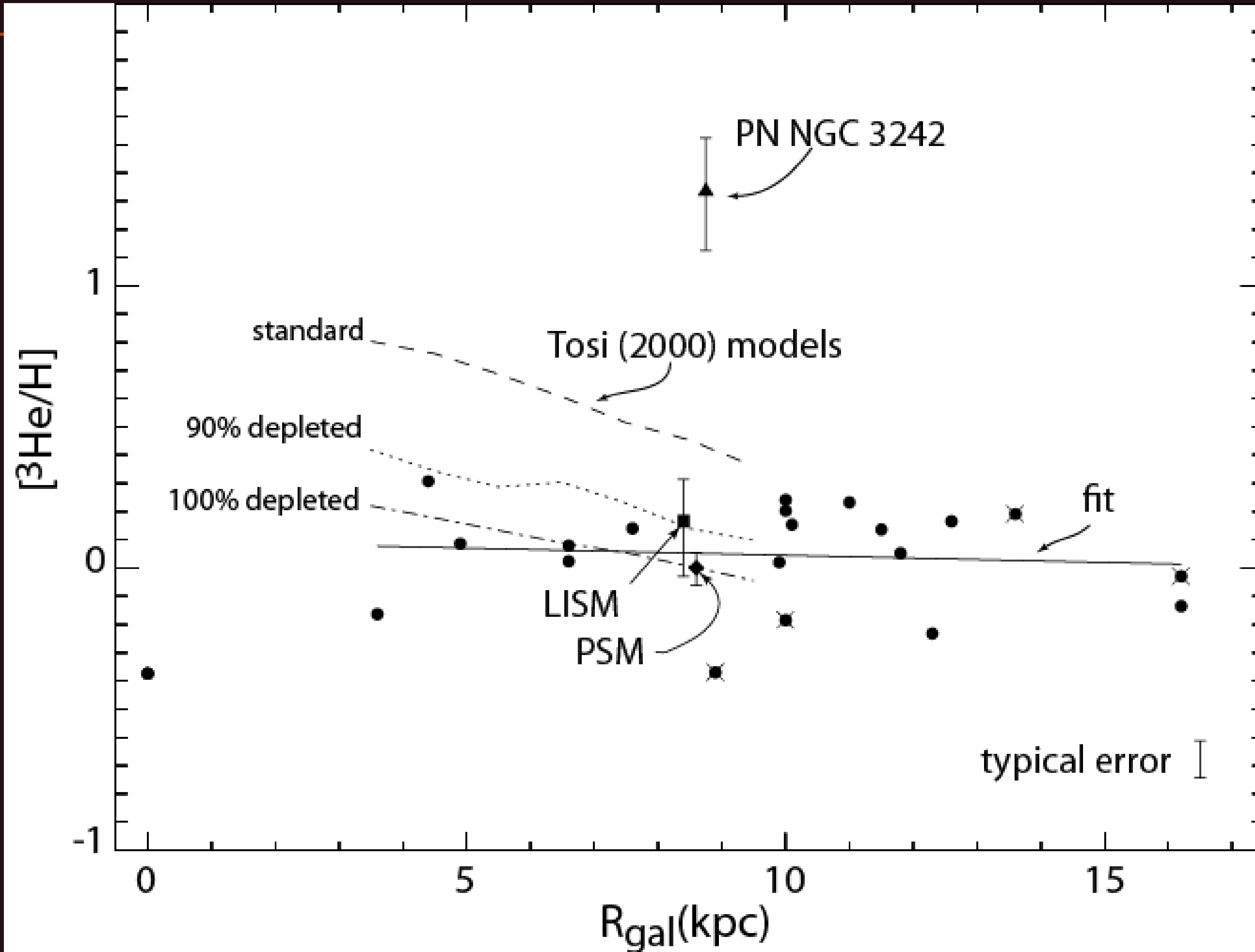


Some days it’s chicken; some days it’s feathers


801 sum3−05
17 58 33.4 +66 37 59
LST= +14 57 37.2
HA= −3.02 ZA= 37.5
Vsrc= −66.10 L+R
HE3a
PS Average
Fsky= 8667.1999
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 32.9
Tintg= 11321.0
AZ= 387.1 EL= 52.5
$^3He^+$
H171η
H213ξ
NGC7009
NGC6826
NGC6543
Sum
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2004−06−22T02:14:34.00

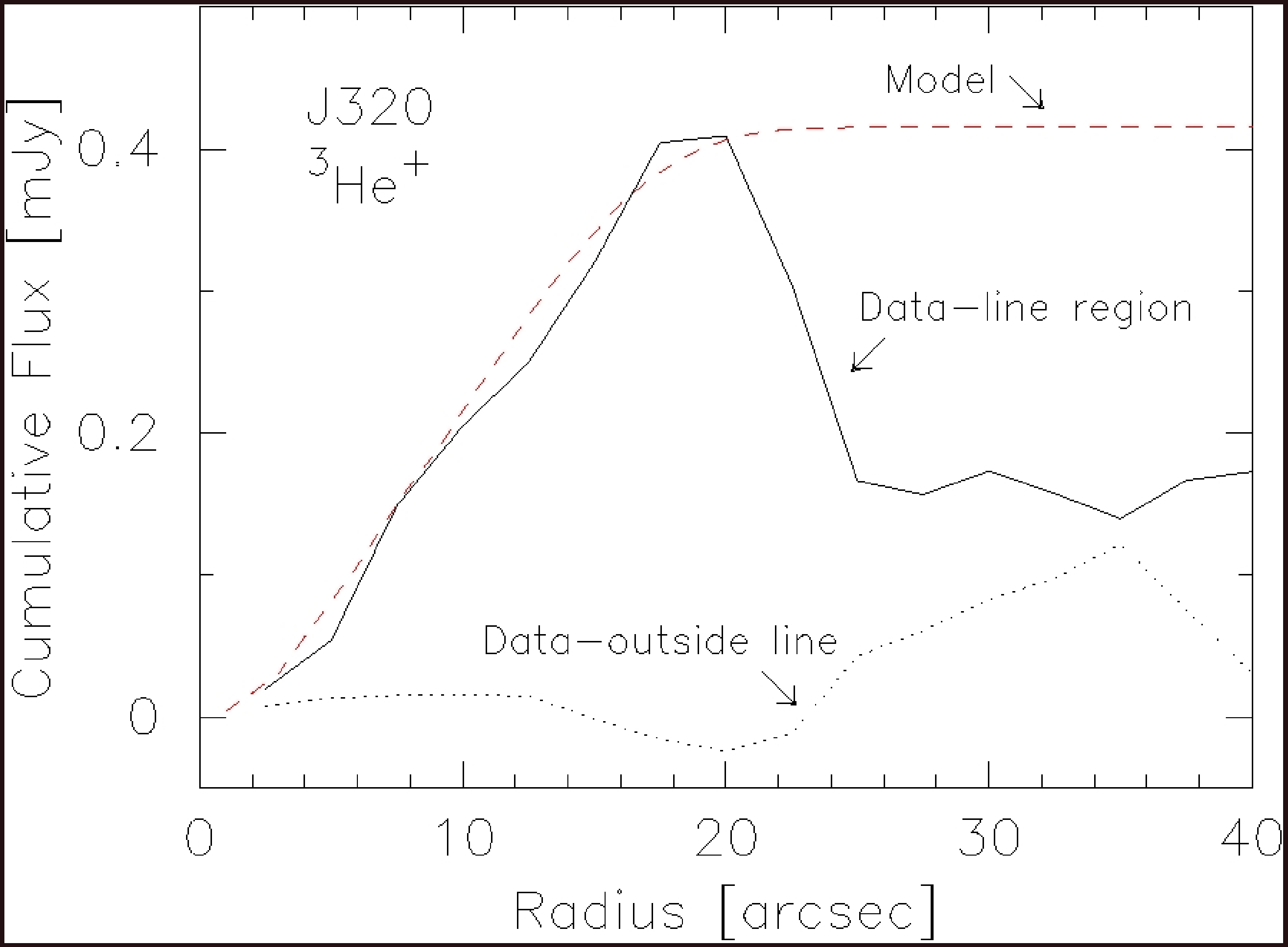


standard
Tosi (2000) models
90% depleted
100% depleted
fit
LISM
PSM
typical error
[3He/H]
1
0
-1
0
5
10
15
Rgal(kpc)

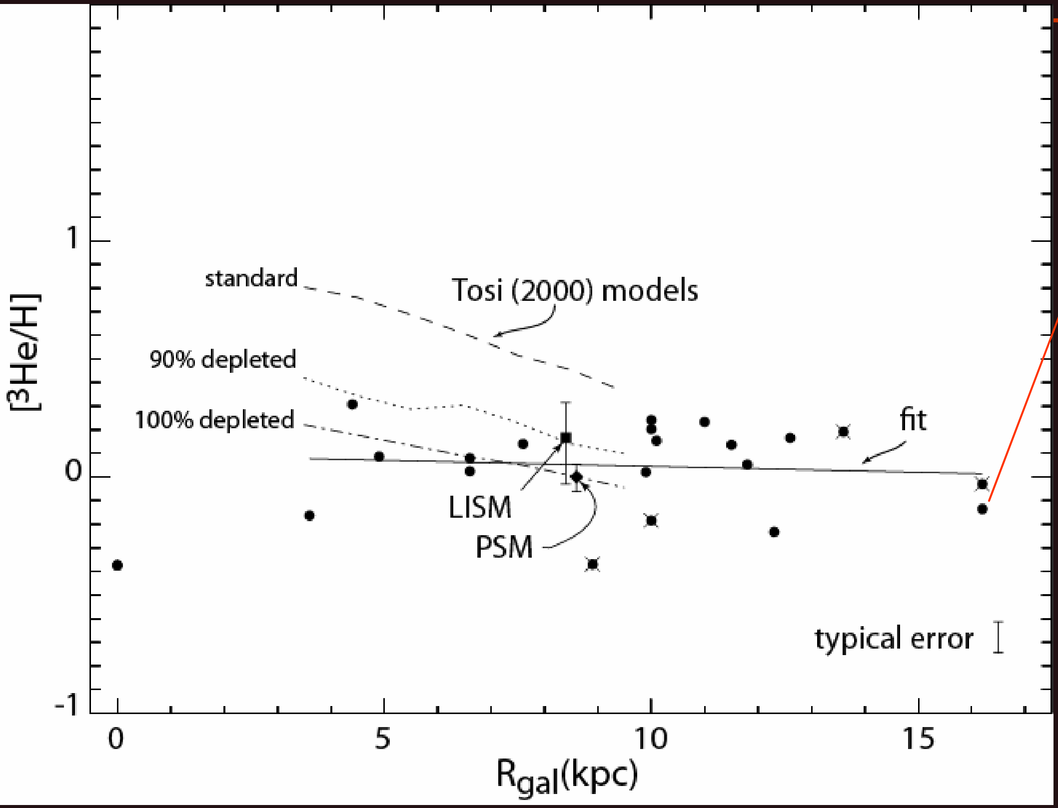


PN NGC 3242
Tosi (2000) models
standard
90% depleted
100% depleted
fit
LISM
PSM
typical error
[3He/H]
1
0
-1
0
5
10
15
Rgal(kpc)

PNe: J320



Balser et al. (2006)



Bania, Rood, & Balser 2002

$\eta_{10} = 5.4^{+2.2}_{-1.2}$

$\Omega_B = 0.04$

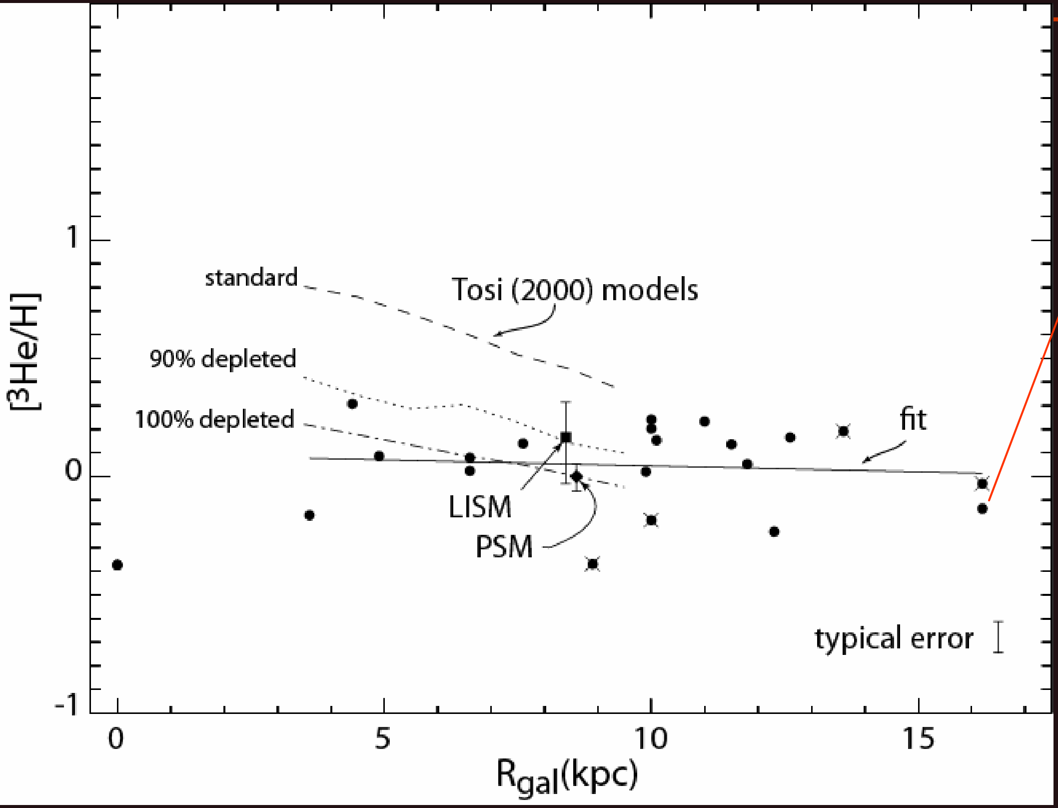
Spergel et al. 2003, WMAP

$\eta_{10} = 6.5^{+0.4}_{-0.3}$

$\Omega_B = 0.047 \pm 0.006$

For D highest observed value is a lower limit for cosmological D

For ^{3}He lowest observed ^{3}He/H is an upper limit for cosmological ^{3}He



Bania, Rood, & Balser 2002

$\eta_{10} = 5.4^{+2.2}_{-1.2}$

$\Omega_B = 0.04$

Spergel et al. 2003, WMAP

$\eta_{10} = 6.5^{+0.4}_{-0.3}$

$\Omega_B = 0.047 \pm 0.006$

For D highest observed value is a lower limit for cosmological D

For ^{3}He lowest observed ^{3}He/H is an upper limit for cosmological ^{3}He

Mixing and the ^{3}He problem

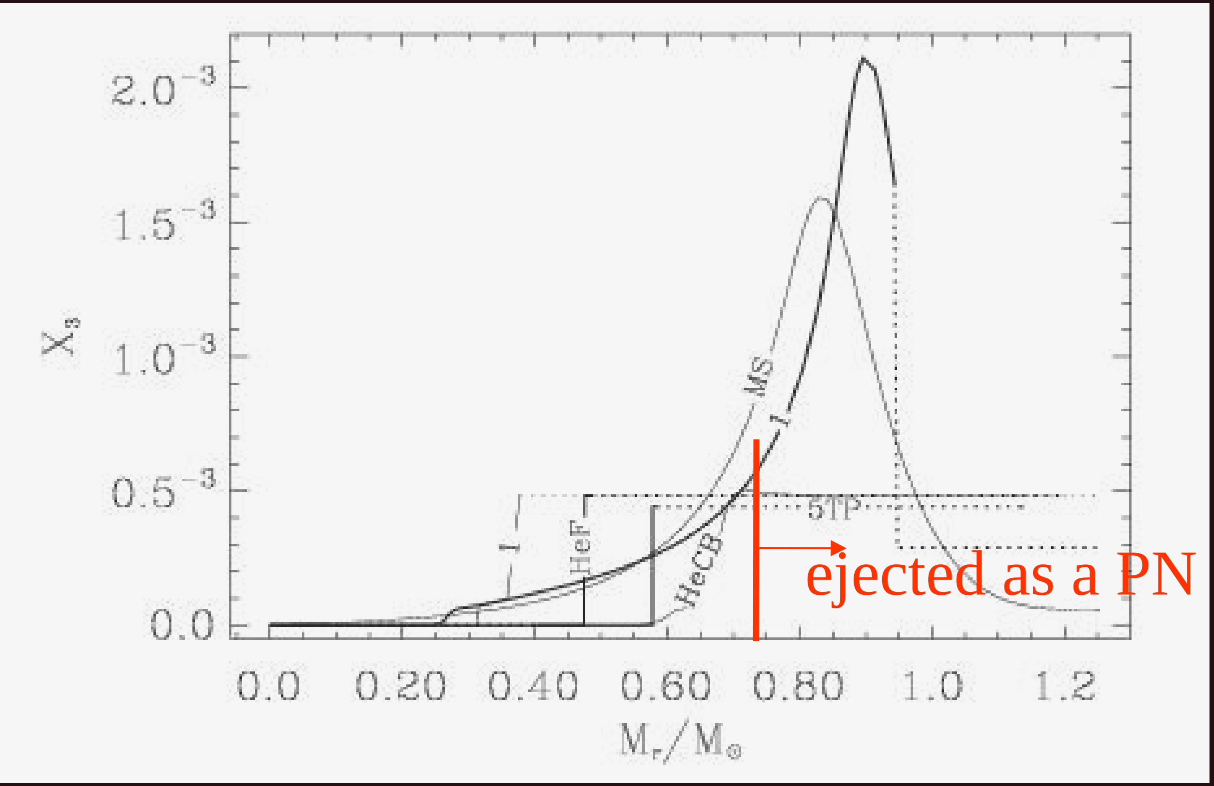
- ***Daniele Galli (INAF-Arcetri)***
- ***Francesco Palla (INAF-Arcetri)***
- ***Monica Tosi (INAF-Bologna)***
- ***Federico Ferrini (Univ. Pisa)***
- ***Letizia Stanghellini (HST)***
- ***Oscar Straniero (INAF-Teramo)***

A long standing problem

Rood, Steigman & Tinsley (1976)

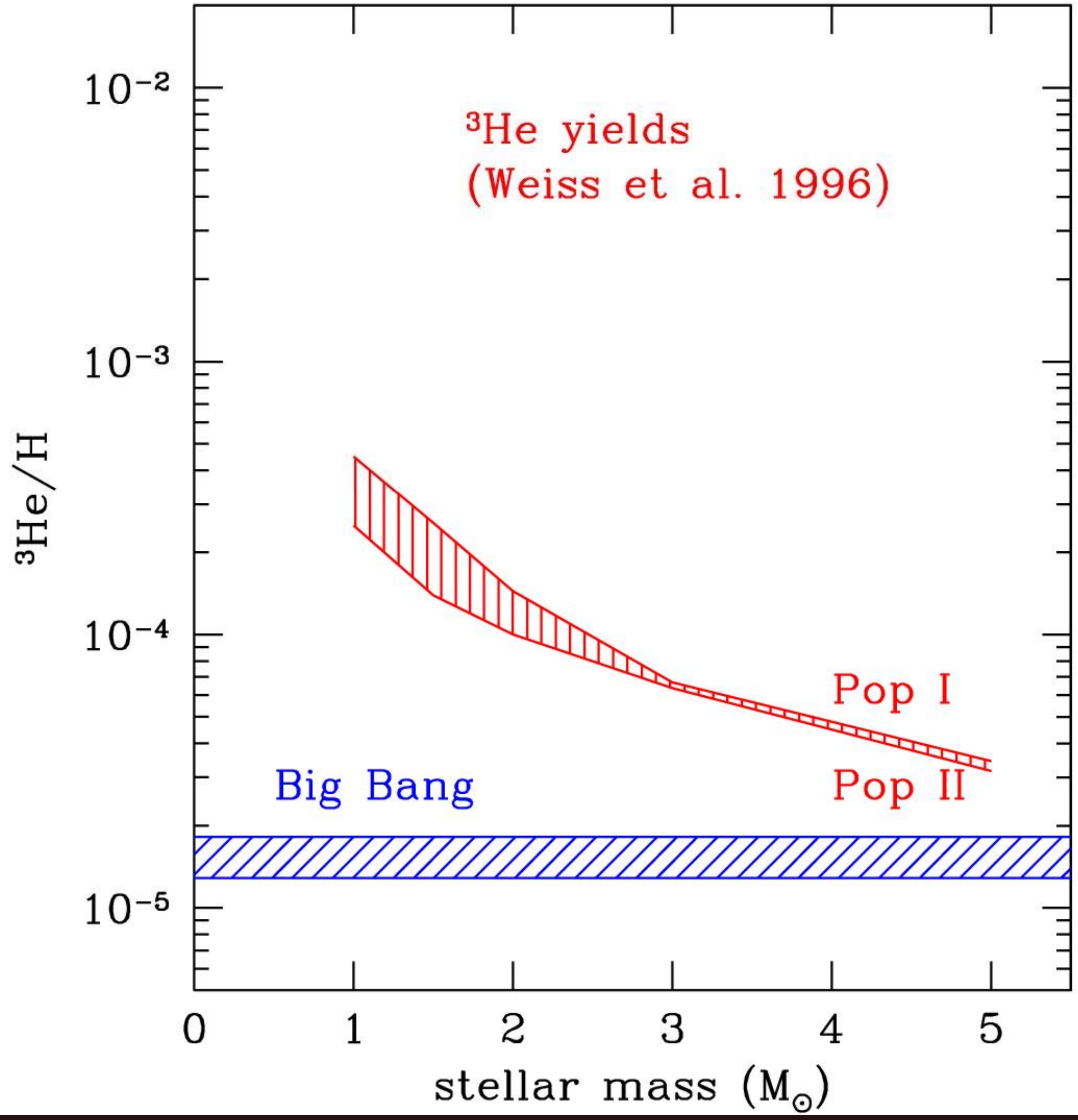
- Low-mass stars produce substantial amounts of ^{3}He, enriching the ISM: X_3♋ ➚ 10^{-3}
- But the measured protosolar value is much lower: $X_{3\odot}$ ➚ 10^{-5} ⇨ *problem!*

^3He profile in a 1.25 $M_\odot$ PopII star



Weiss, Wagenhuber & Denissenkov (1996)

The “standard” ^{3}He yields



Theorists at work…

- Wrong extrapolation of the ^3He-^3He nuclear cross section at low energies?
- Pollution of winds from massive stars in HII regions?
- Continuous infall of primordial gas?

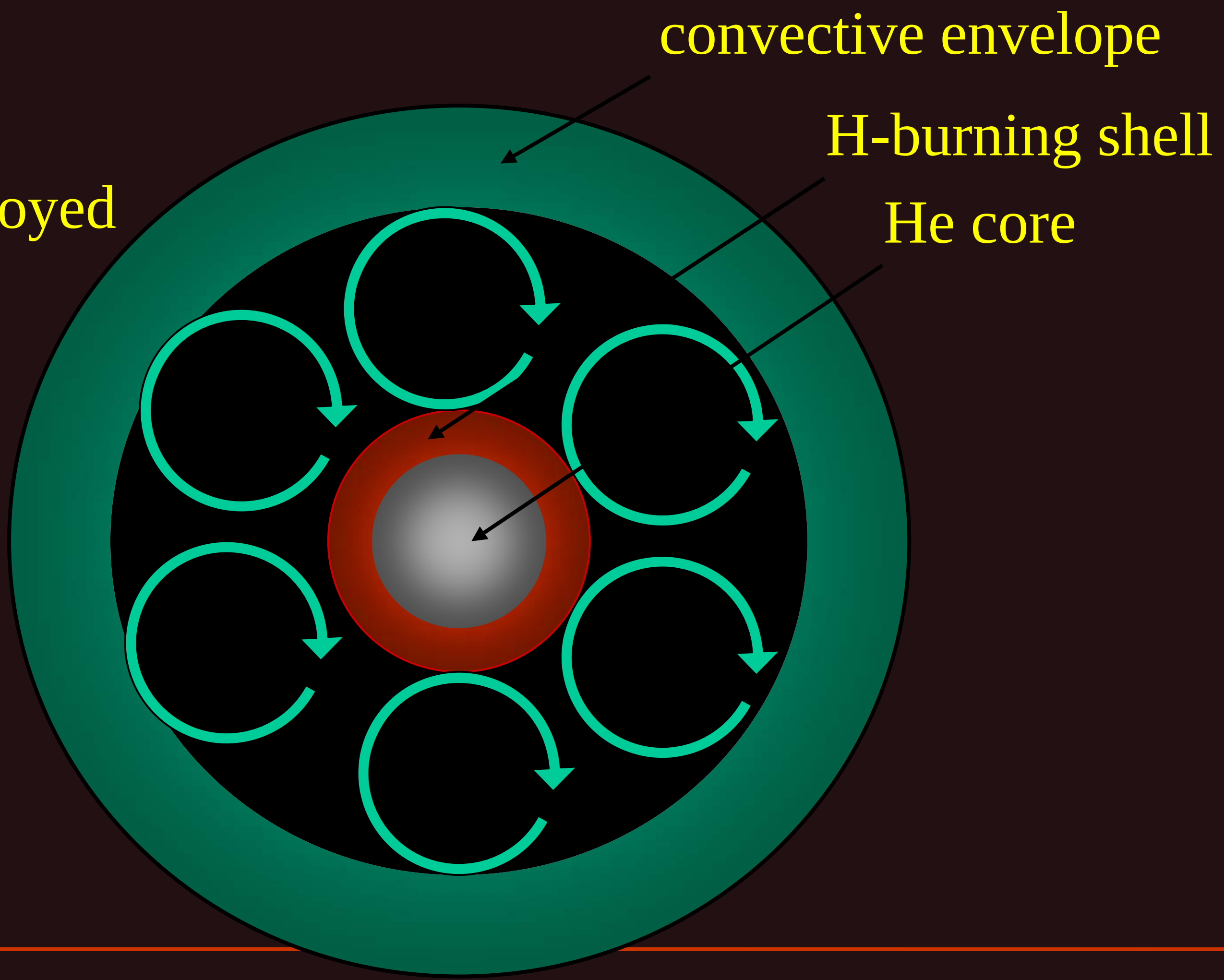
Mixing takes over

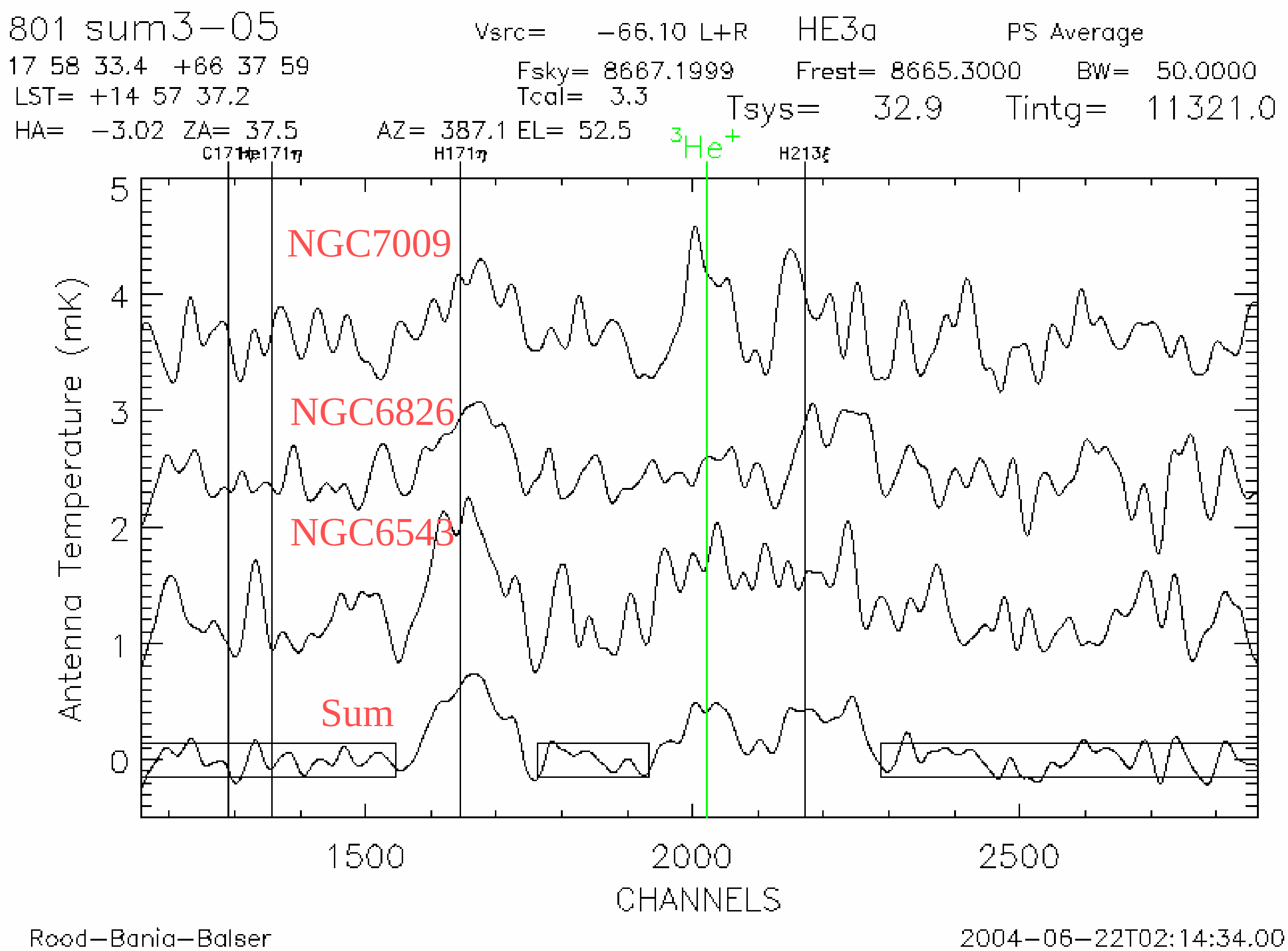
- *Charbonnel 1995* (see also *Hogan 1995*) : an extra-mixing mechanism acting during the RGB and/or AGB phases of stars with mass $M \rightarrow 2\ M_\odot$ can reduce the surface ^3He abundance
- Extra-mixing decreases the surface $^{12}C/^{13}C$: the ^3He problem is linked to other isotopic anomalies in RGB and AGB stars

Mixing on the RGB

surface ^{3}He destroyed

^{13}C dredged-up





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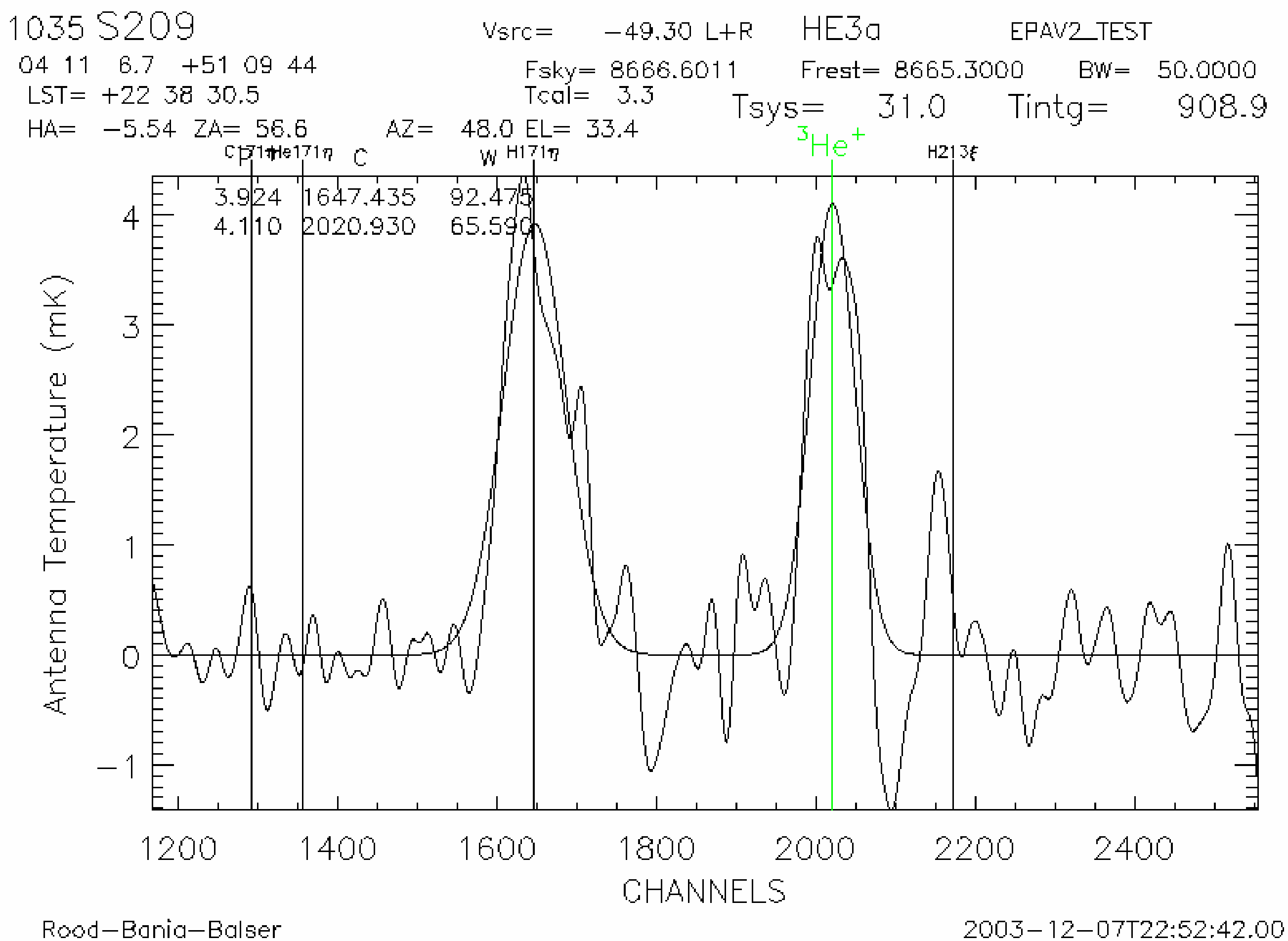
17 58 33.4 +66 37 59
LST= +14 57 37.2
HA= −3.02 ZA= 37.5
AZ= 387.1 EL= 52.5
Vsrc= −66.10 L+R
HE3a
PS Average
Fsky= 8667.1999
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 32.9
Tintg= 11321.0
3He+
H171η
H213ξ
NGC7009
NGC6826
NGC6543
Sum
Antenna Temperature (mK)
5
4
3
2
1
0
1500
2000
2500
CHANNELS
Rood−Bania−Balser
2004−06−22T02:14:34.00



1035 S209
04 11 6.7 +51 09 44
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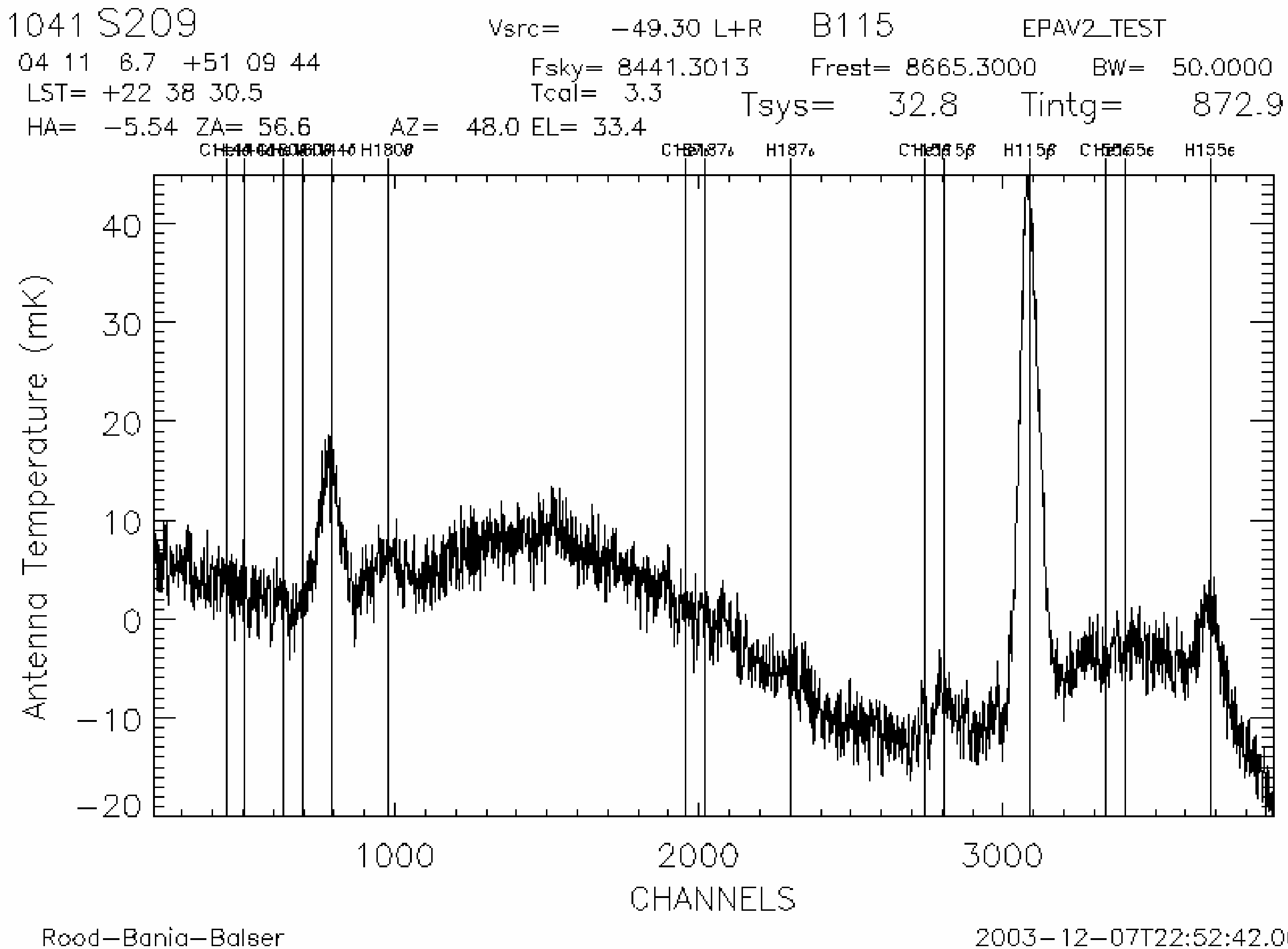
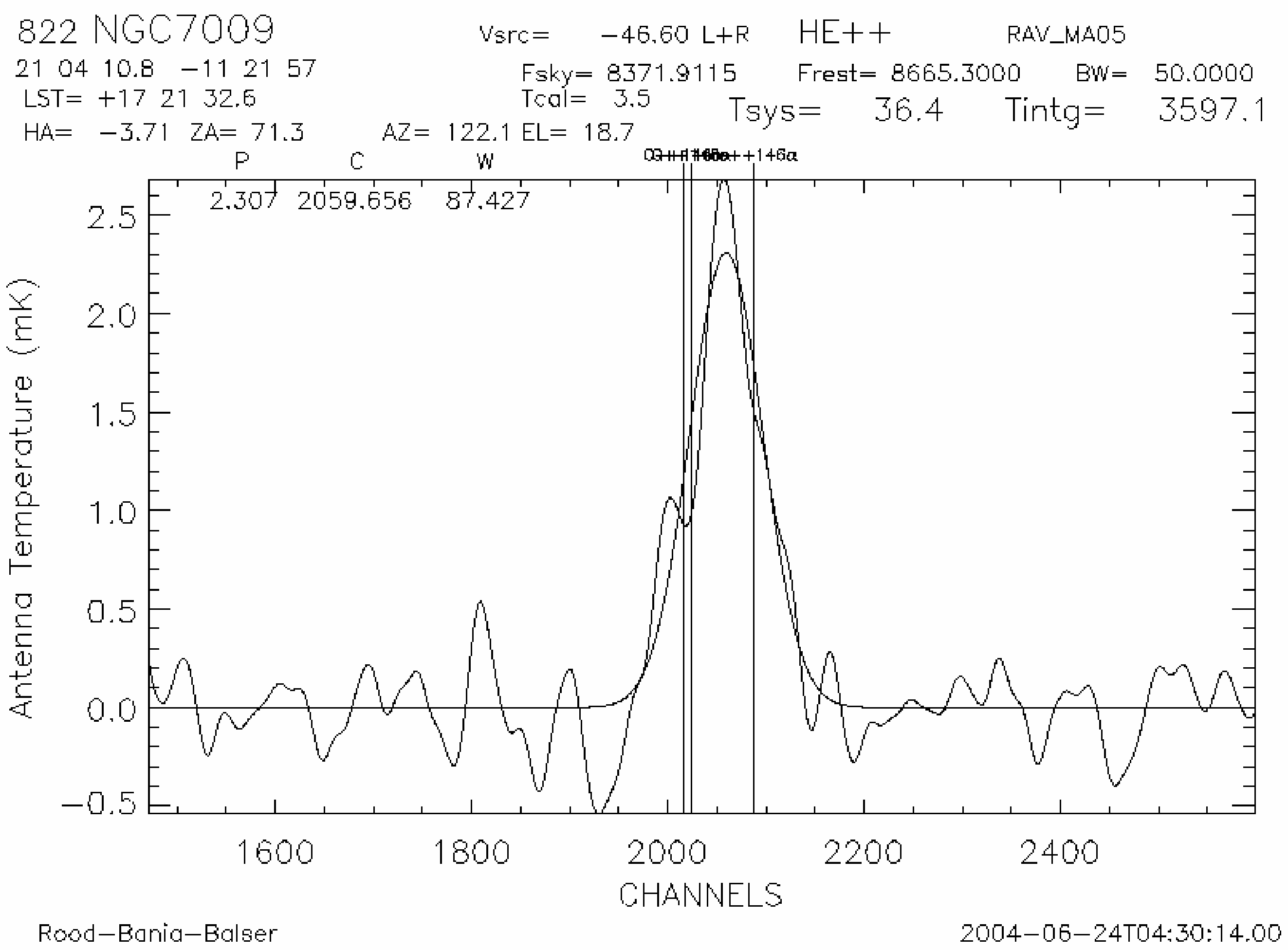
Vsrc= −49.30 L+R
HE3a
EPAV2_TEST
Fsky= 8666.6011
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 31.0
Tintg= 908.9
3.924 1647.435 92.475
4.110 2020.930 65.590
H171η
3He+
H213ξ
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2003−12−07T22:52:42.00

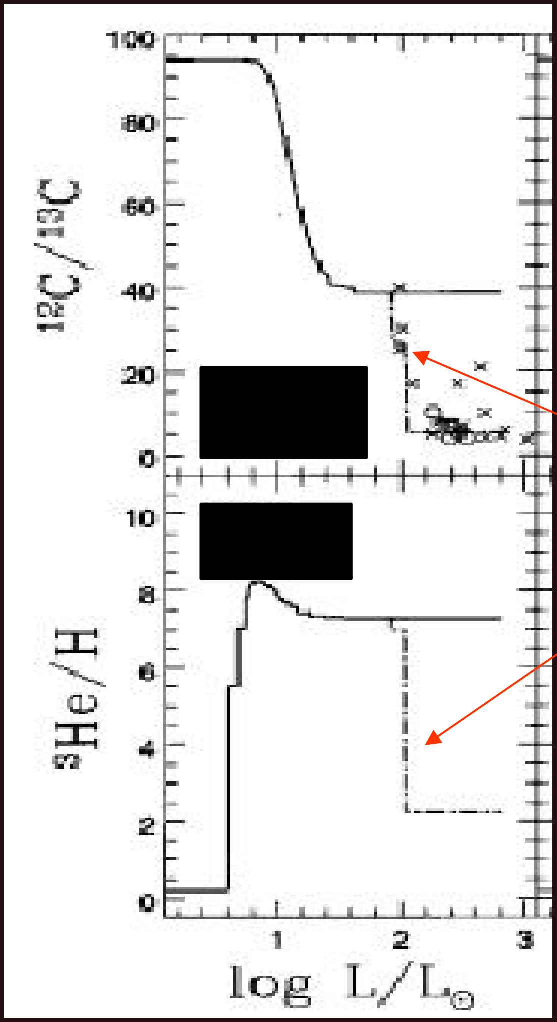


1041 S209
Vsrc= −49.30 L+R
B115
EPAV2_TEST
04 11 6.7 +51 09 44
Fsky= 8441.3013
Frest= 8665.3000
BW= 50.0000
LST= +22 38 30.5
Tcal= 3.3
Tsys= 32.8
Tintg= 872.9
HA= −5.54 ZA= 56.6
AZ= 48.0 EL= 33.4
H180β
H187ι
H115β
H155ε
Antenna Temperature (mK)
40
30
20
10
0
−10
−20
1000
2000
3000
CHANNELS
Rood−Bania−Balser
2003−12−07T22:52:42.00

A bonus: He^{++} or O^{++} RRL (a first?)



Calibrating the mixing on the RGB



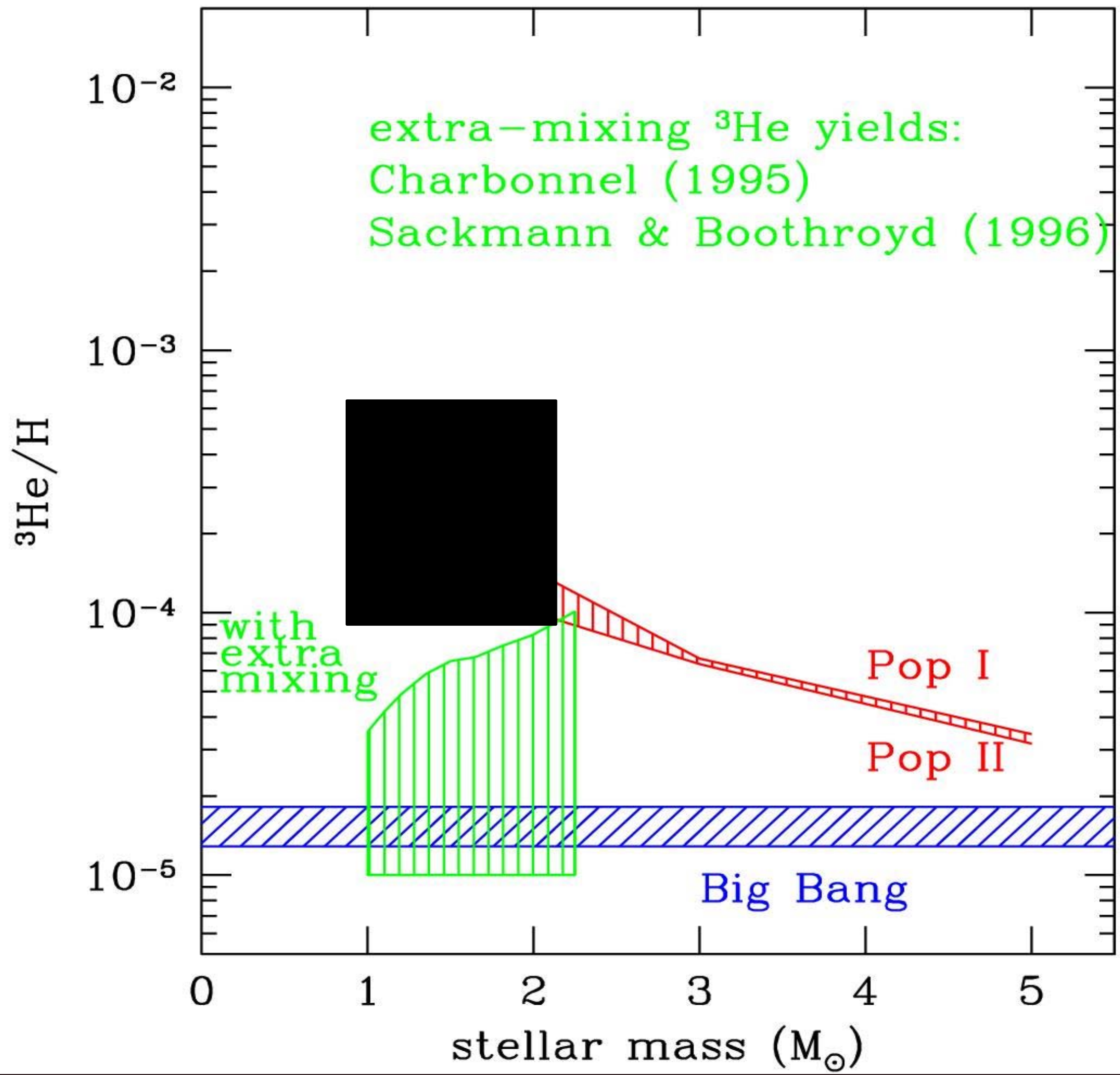
0.8 $M_{\odot}$

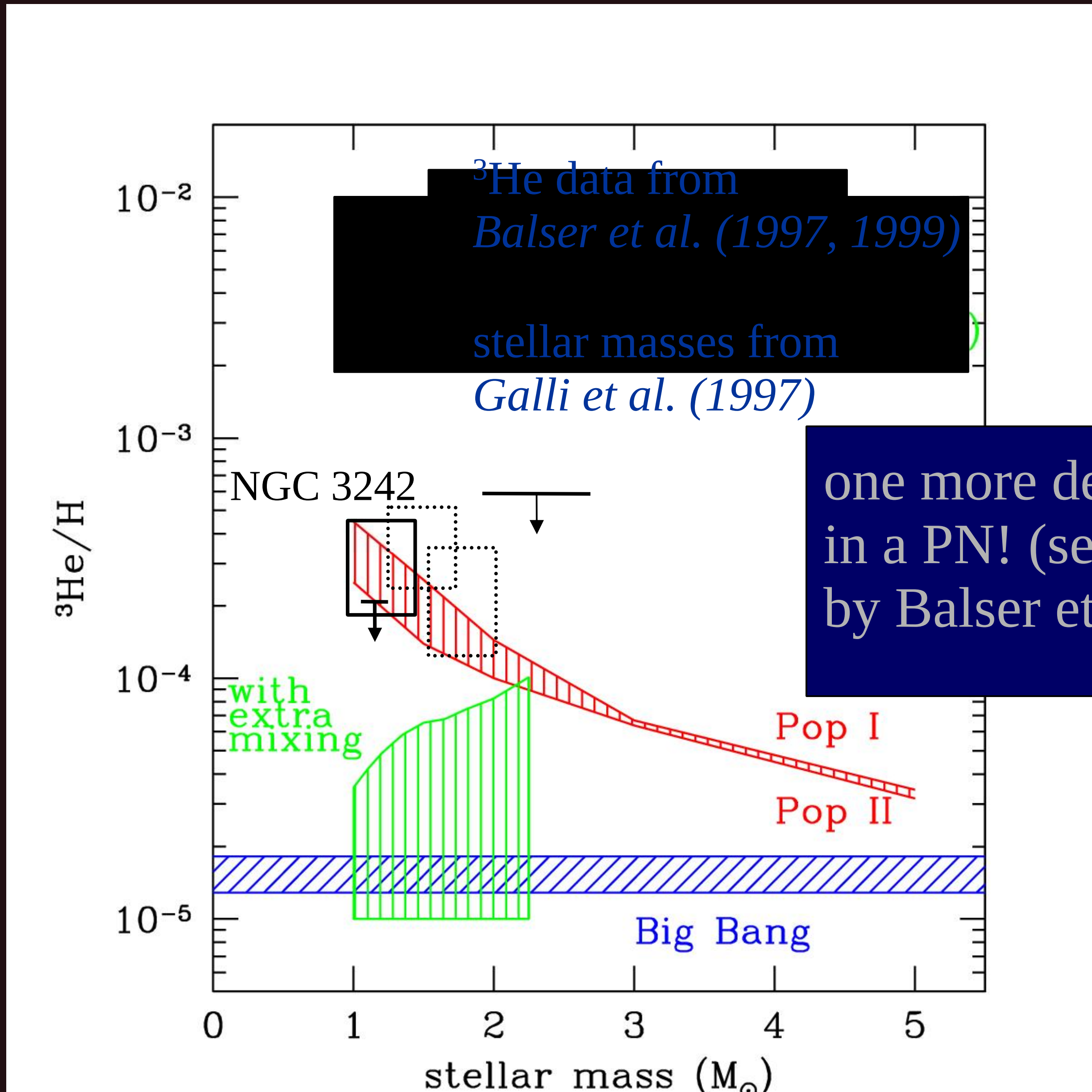
$Z=10^{-4}$

extra-mixing

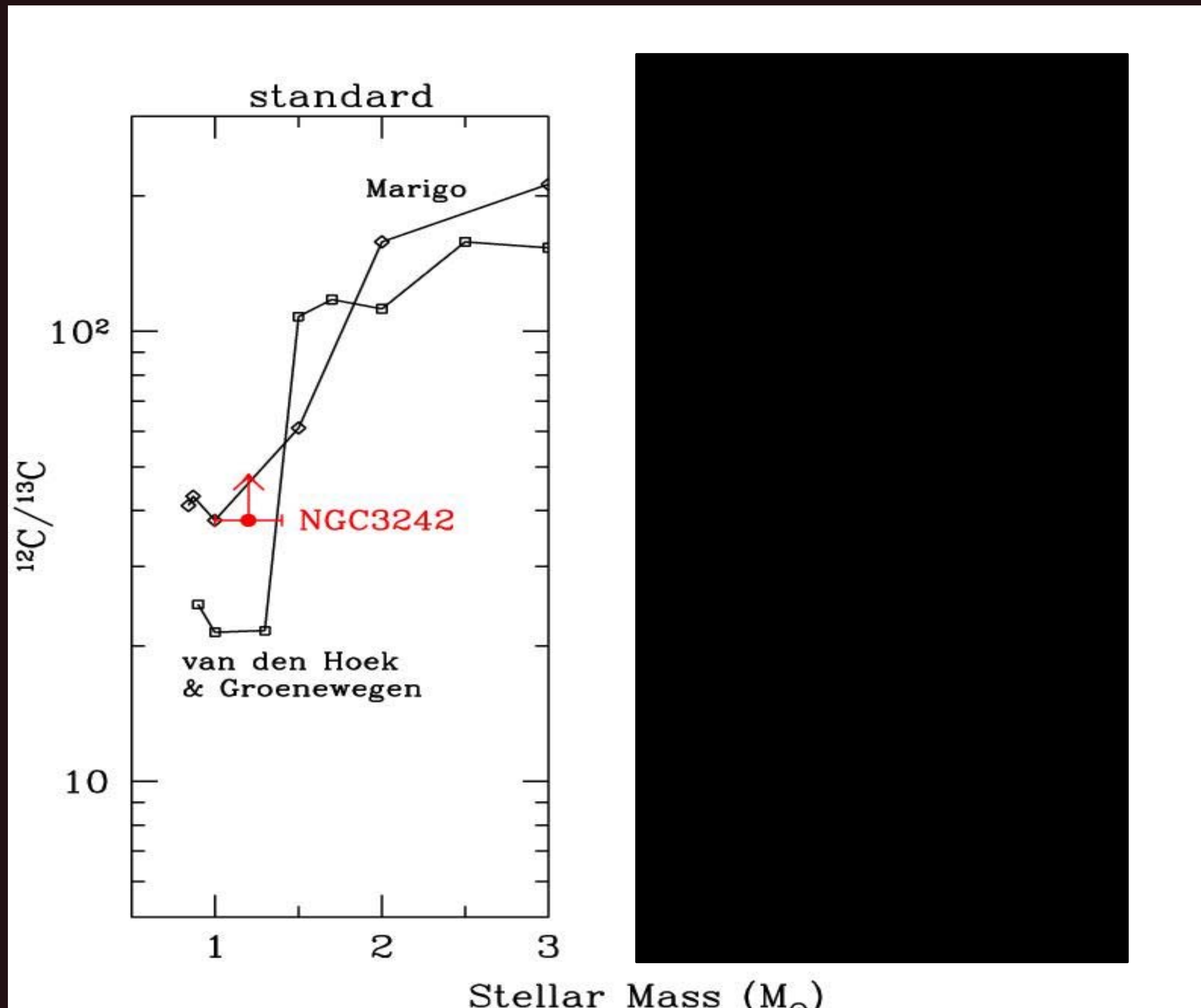
Charbonnel (1995)

The "new" ^{3}He yields

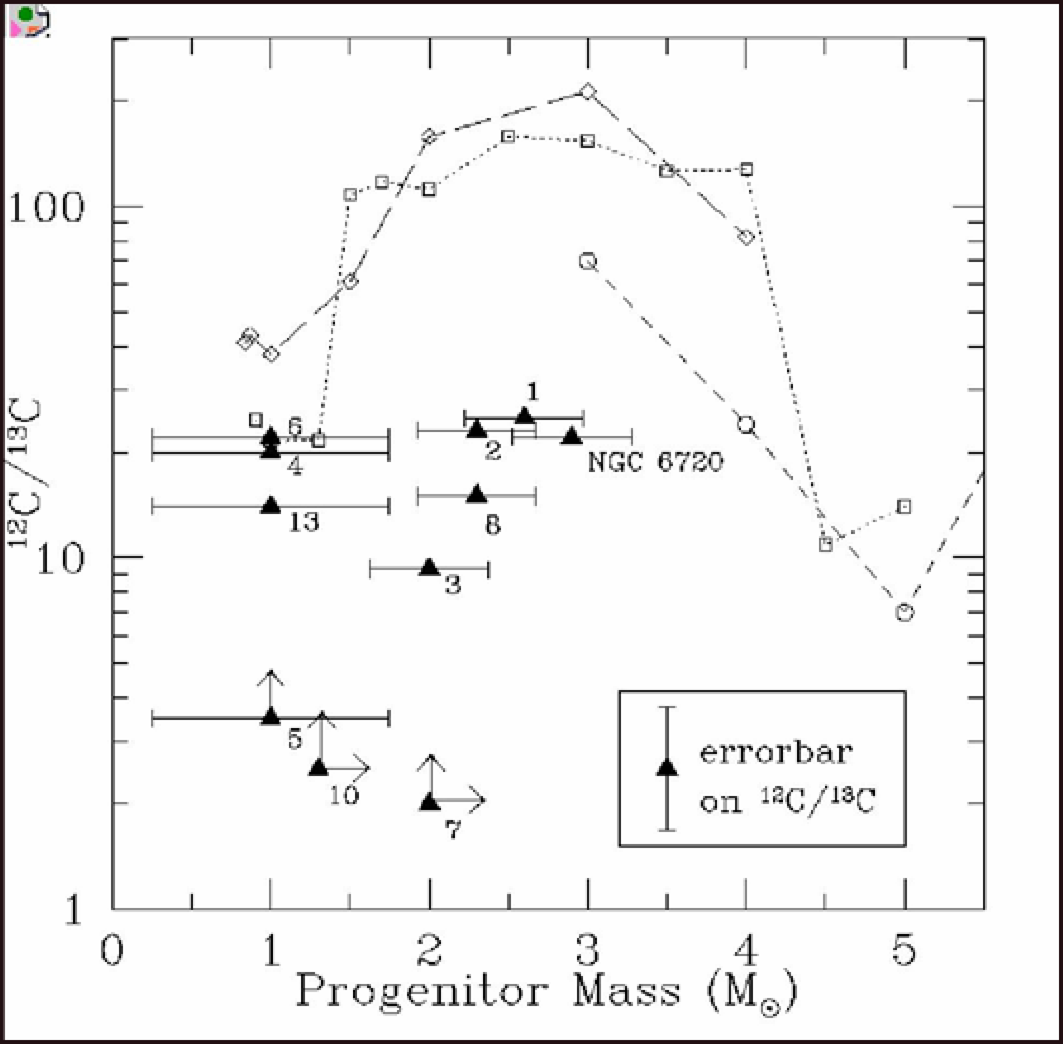




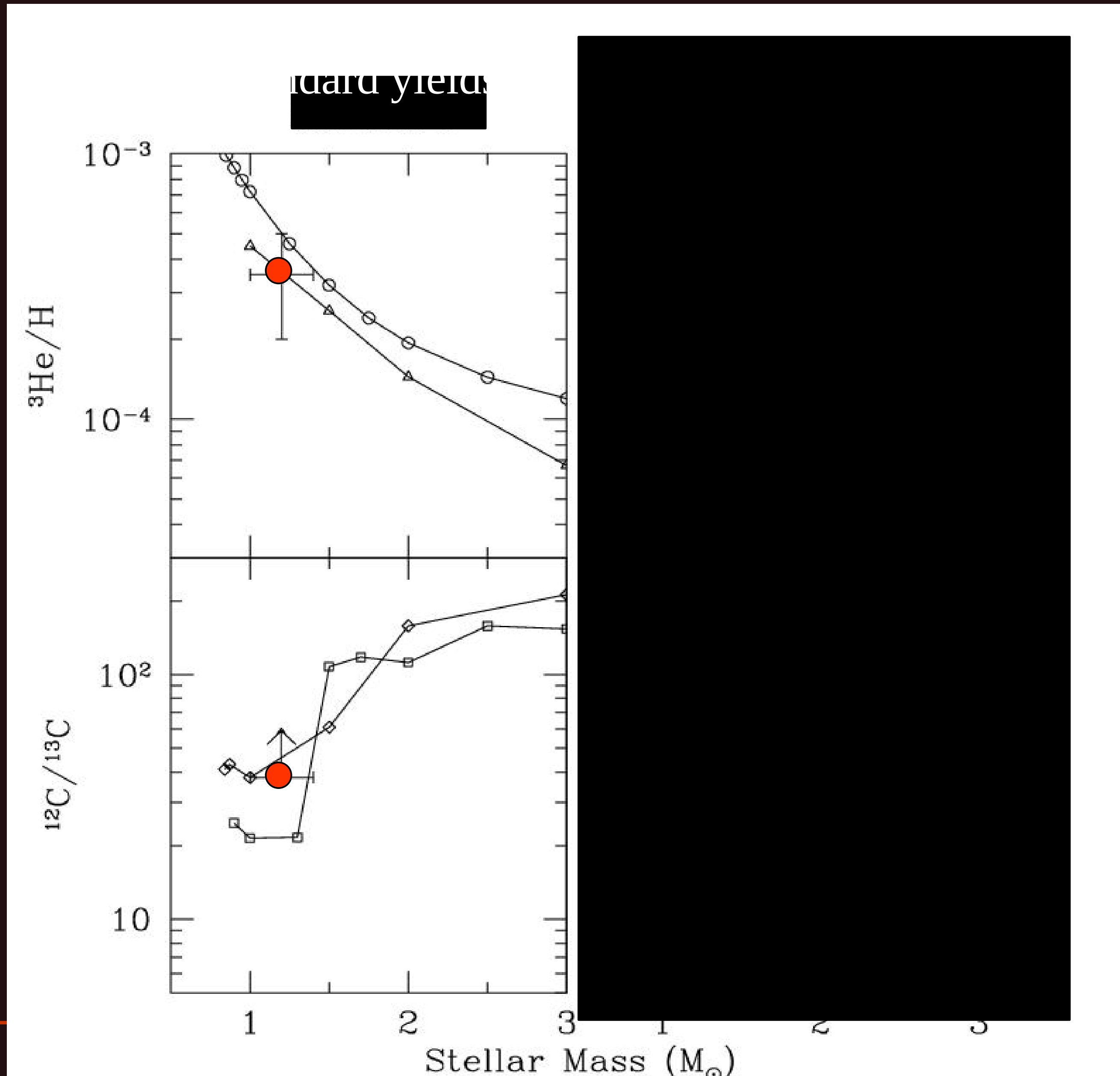
one more detection in a PN! (see poster by Balser et al.)



Palla, Galli, Marconi, Stanghellini & Tosi (2002)

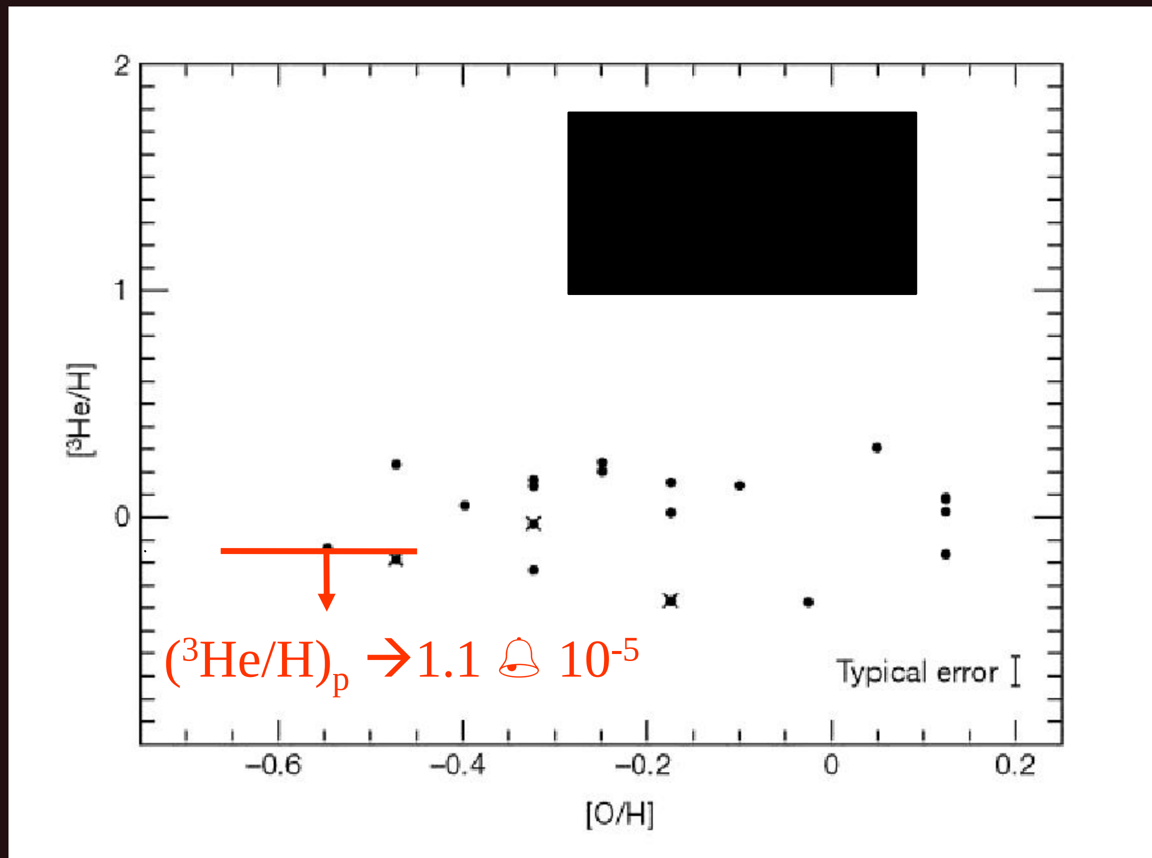


Palla et al. (2000)

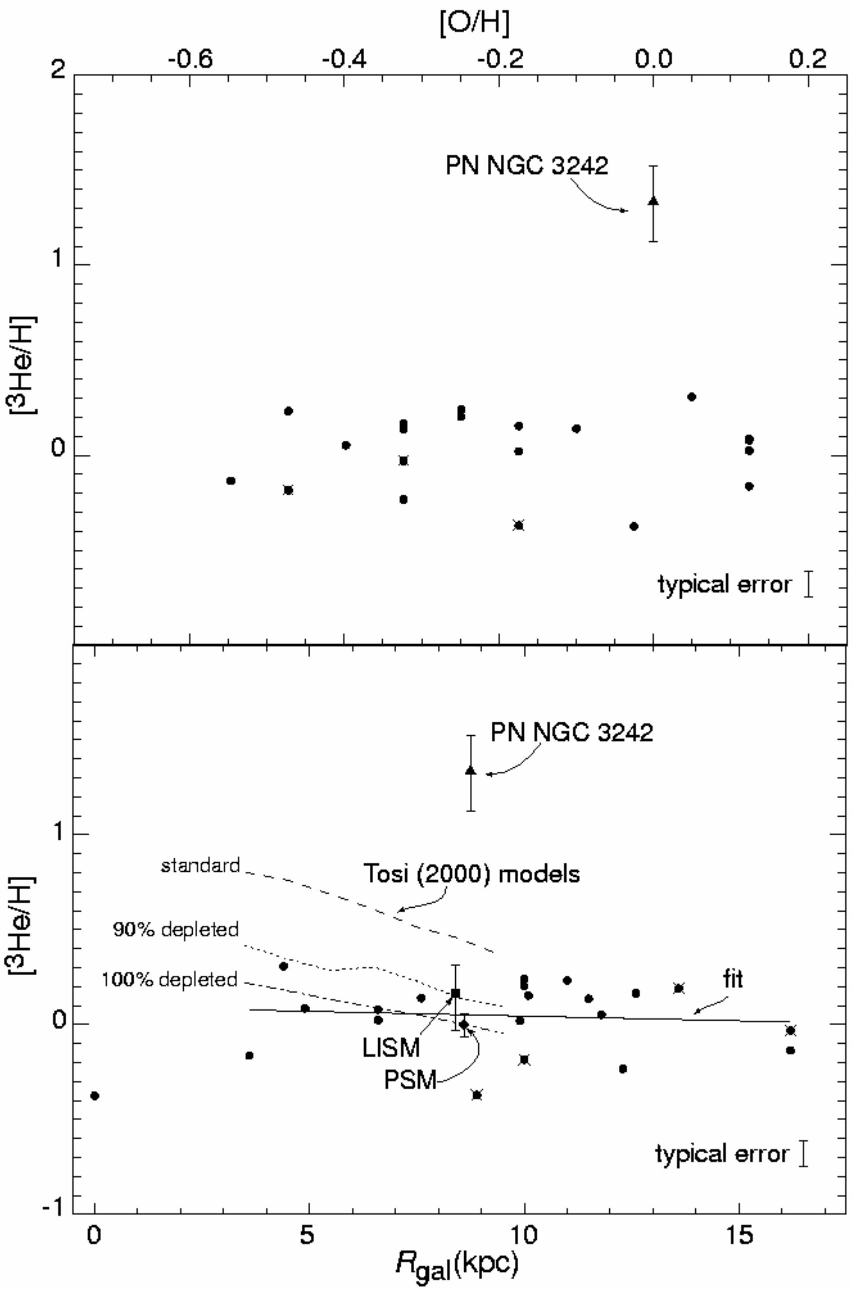


ndard yields
[redacted]
10⁻³
10⁻⁴
³He/H
10²
10
¹²C/¹³C
1
2
3
Stellar Mass (M⊙)

^{3}He abundance in HII regions



Bania, Rood & Balser (2002)



Bania, Rood, & Balser 2002

$\eta_{10} = 5.4^{+2.2}_{-1.2}$

$\Omega_B = 0.04$

Spergel et al. 2003, WMAP

$\eta_{10} = 6.5^{+0.4}_{-0.3}$

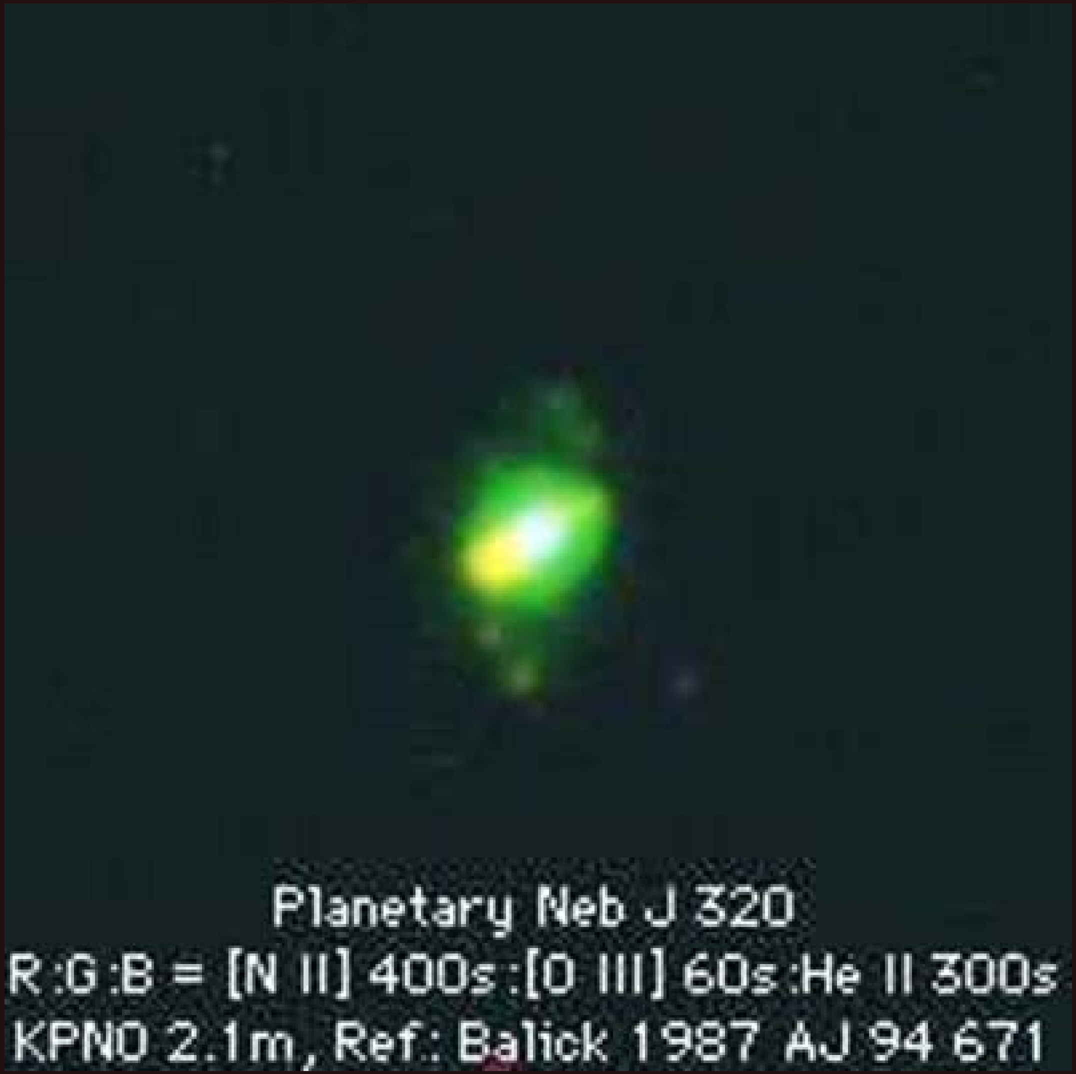
$\Omega_B = 0.047 \pm 0.006$

GBT Conclusions

- There is still baseline structure (BS) probably resulting from the broadband feed, the polarizer, and or mismatches in the IF system.
  - BS varies with frequency sometimes almost invisible other times very problematic
  - BS amplitude is proportional to source continuum and moves with sky frequency
- Standing waves are not a problem
- At the mK level there are pseudo-lines
- In some AC bands there are short duration spikes in the ACF at seemingly random times, lags, and amplitudes

Jonckheere 320 – PN G190.3-17.7

J320

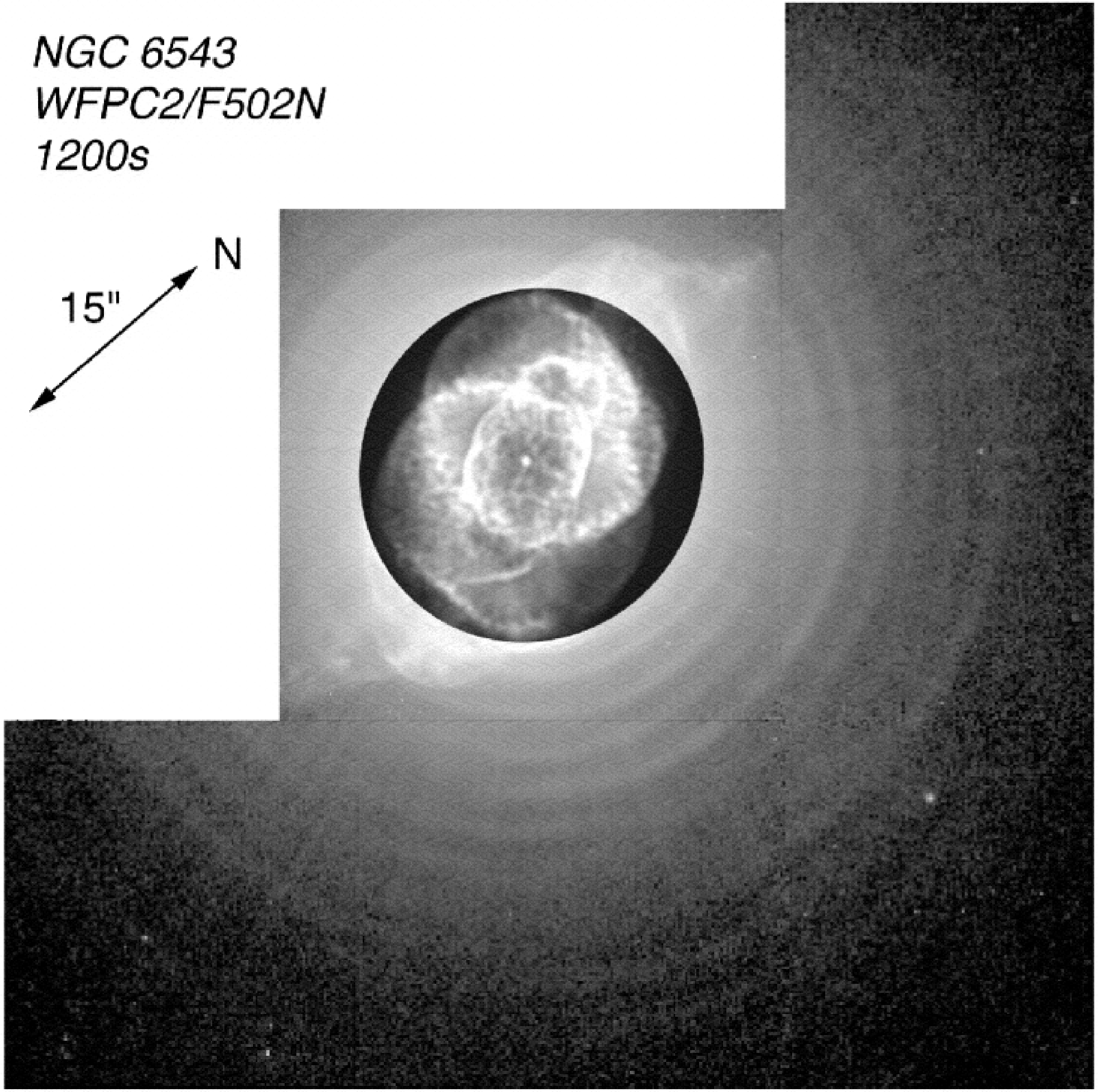


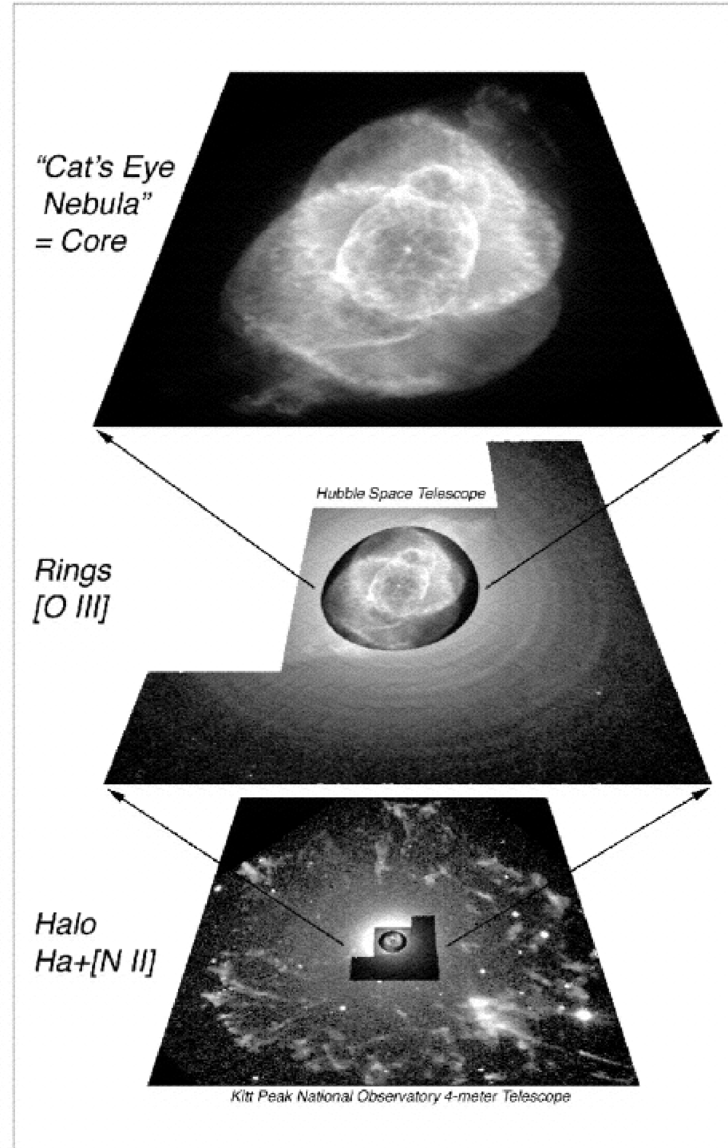
NGC 6543

HST

ACS

NGC 6543: The Rings Around the Cat's Eye





Balick, Wilson & Hajian (2001) AJ, 121, 354