New Deuterium and 3-Helium Abundance Determinations for the Galactic ISM

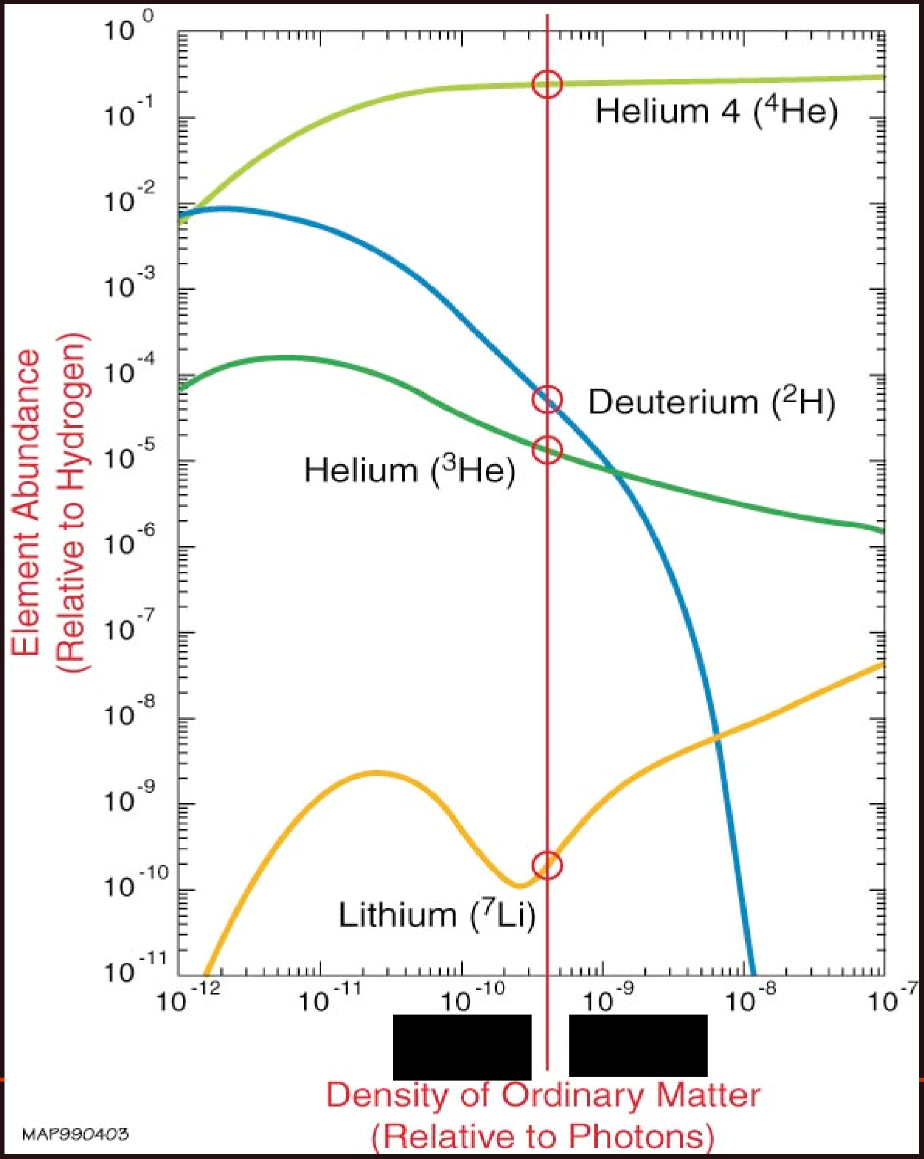
TOM BANIA

Institute for Astrophysical Research

Department of Astronomy

Boston University

Light Elements as Baryometers



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

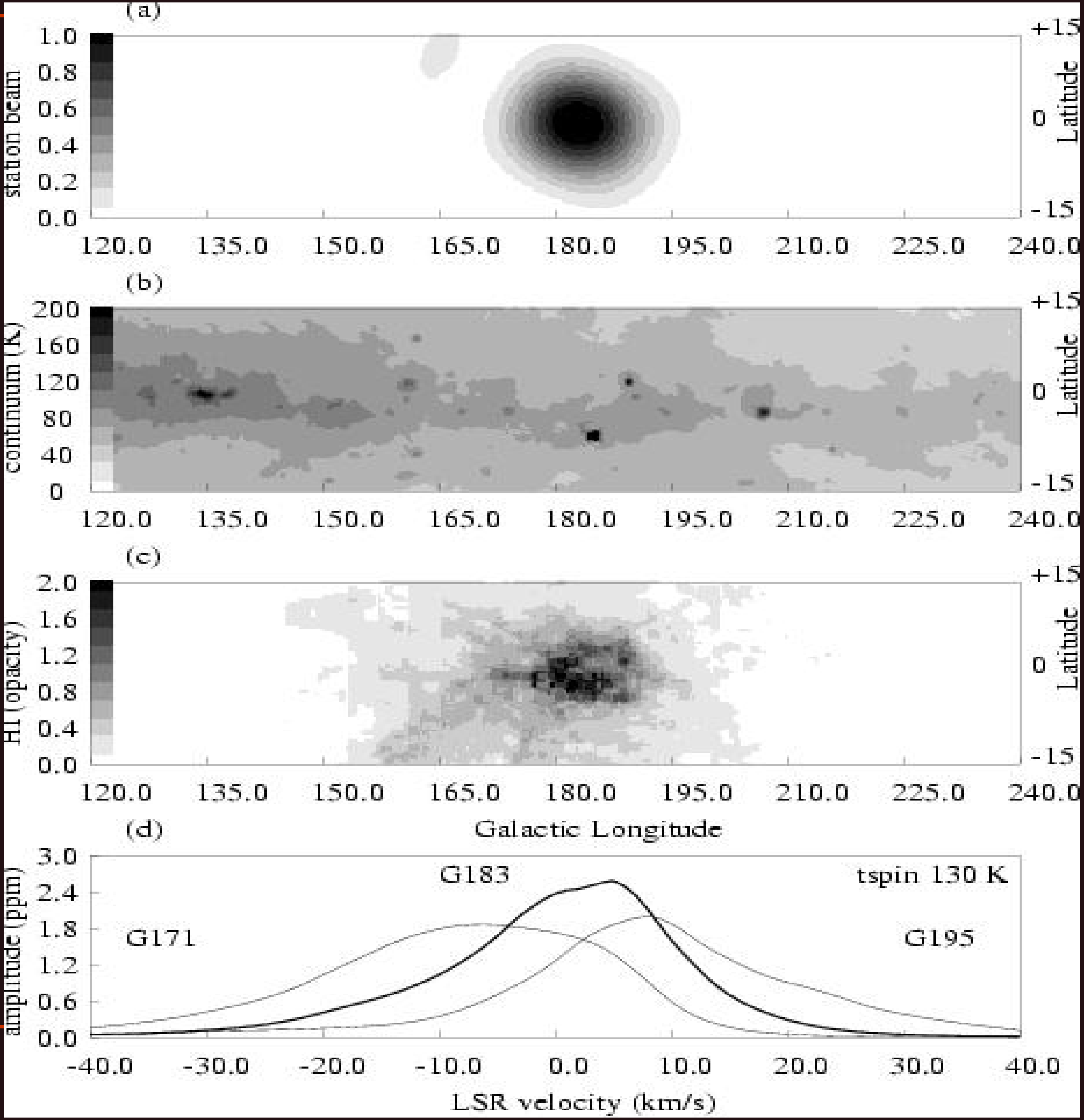
D I

Beam

Continuum

H I

Model D I Spectra

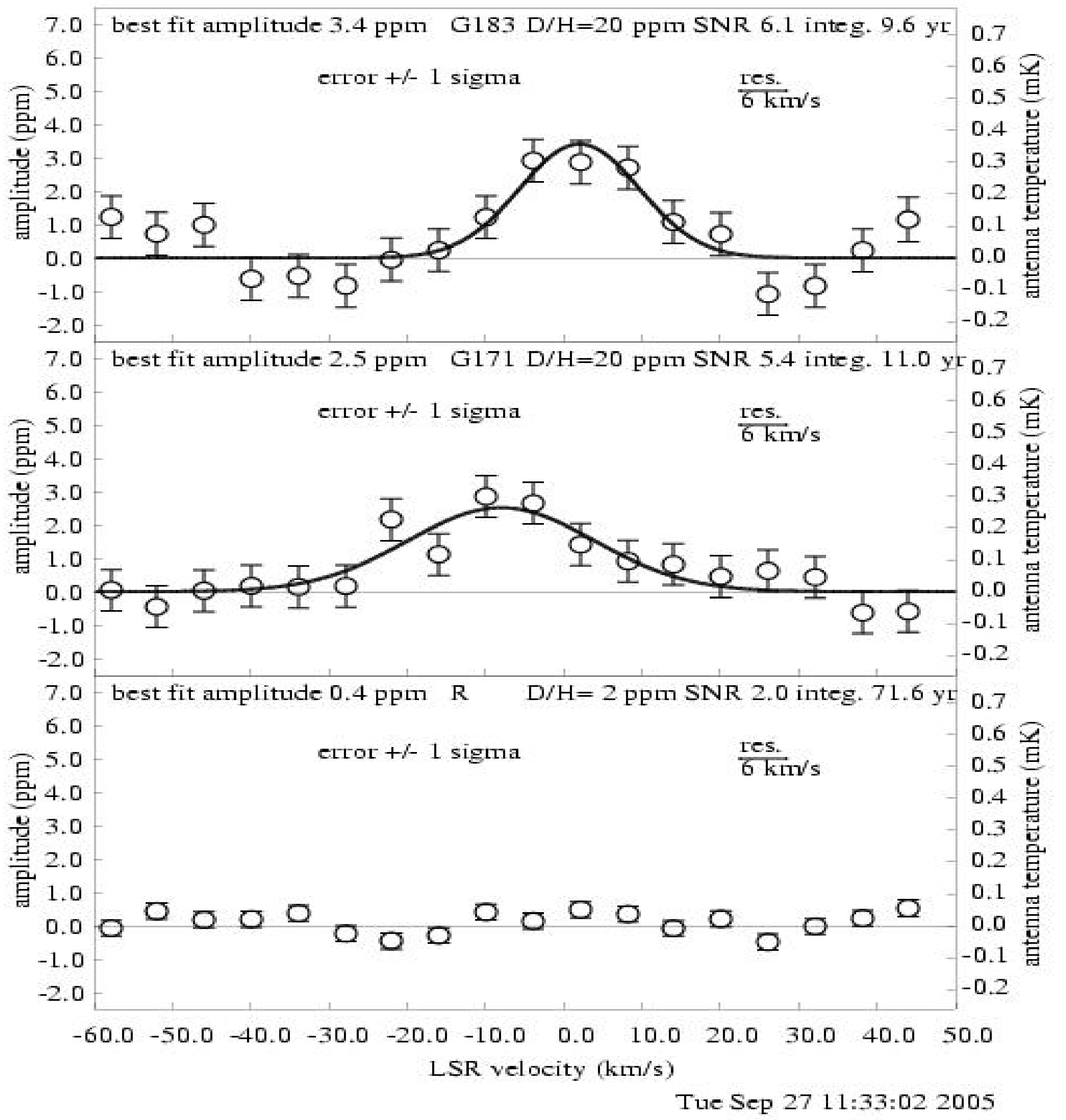


Oct 2005

L = 183°

L = 171°

Blank Fields



GALACTIC ANTICENTER D/H ABUNDANCE

L (deg)	D/H x 10^{+5}	Integration (yr)	
183	2.3 +/- 0.4	6.5	RDCFKB
	2.0 +/- 0.3	9.6	Oct 2005
171	1.5 +/- 0.5	7.2	RDCFKB
	2.0 +/- 0.4	11.0	Oct 2005
195	1.7 +/- 0.8	3.1	RDCFKB

* Spin Temperture Range: 100-150 K

* Continuum Uniformly Distributed Along Line of Sight

* 1 Sigma measurement errors

=> <D/H> = (2.0+/-0.7) x 10^{-5} <=

for Rgal = (10+/-1) kpc

I ♥ ^{3}He

3-Helium in Planetary Nebulae

Tom Bania (BU),

Bob Rood (UVa),

Dana Balser (NRAO),

Miller Goss (NRAO),

Cintia Quireza (ON, Brazil),

Tom Wilson (MPIfR)

Observe 3He using the hyperfine (spin-flip) line of $^3He^+$

Analog of the 21 cm line of H

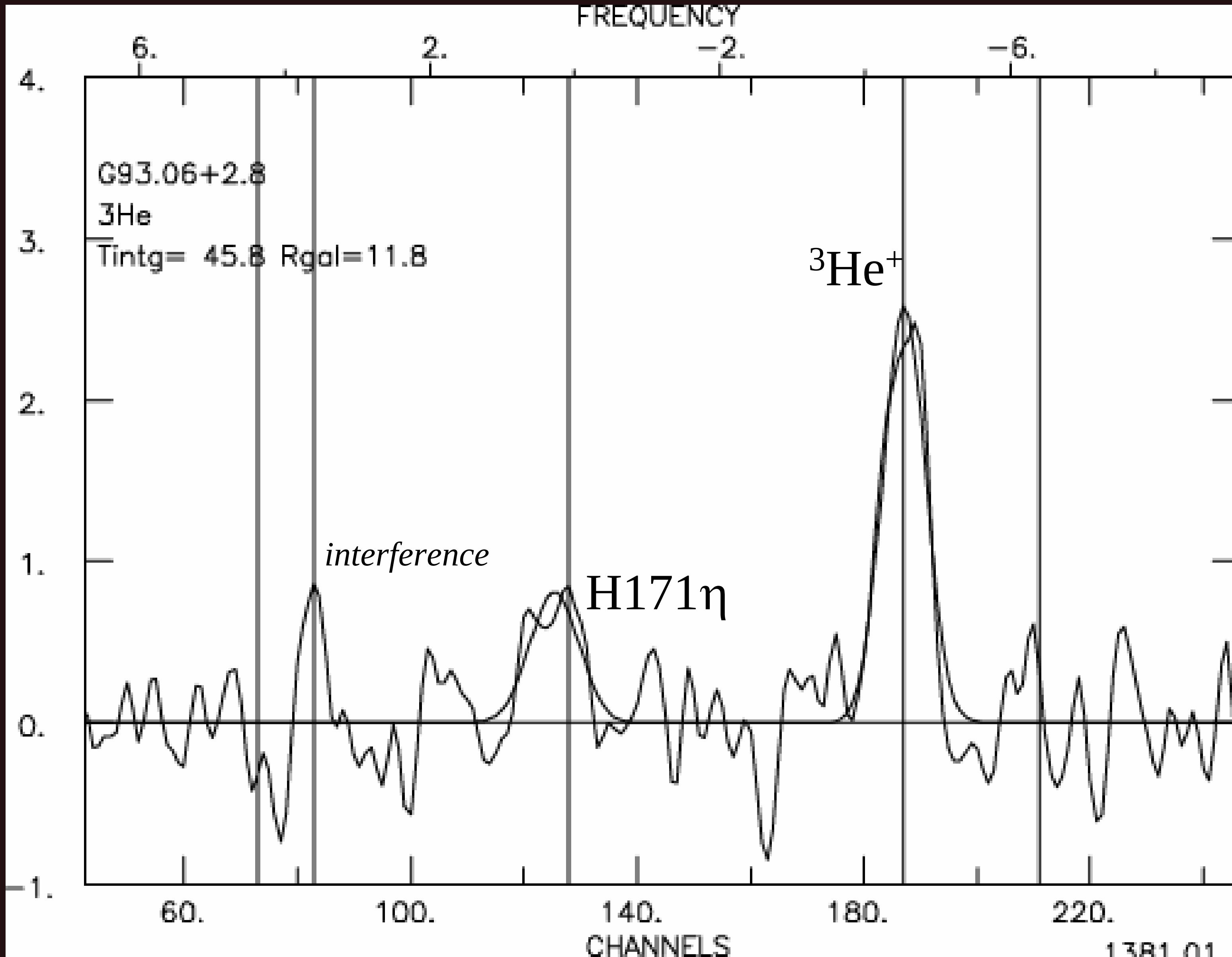
ν = 8665.65 MHz **λ = 3.36 cm**

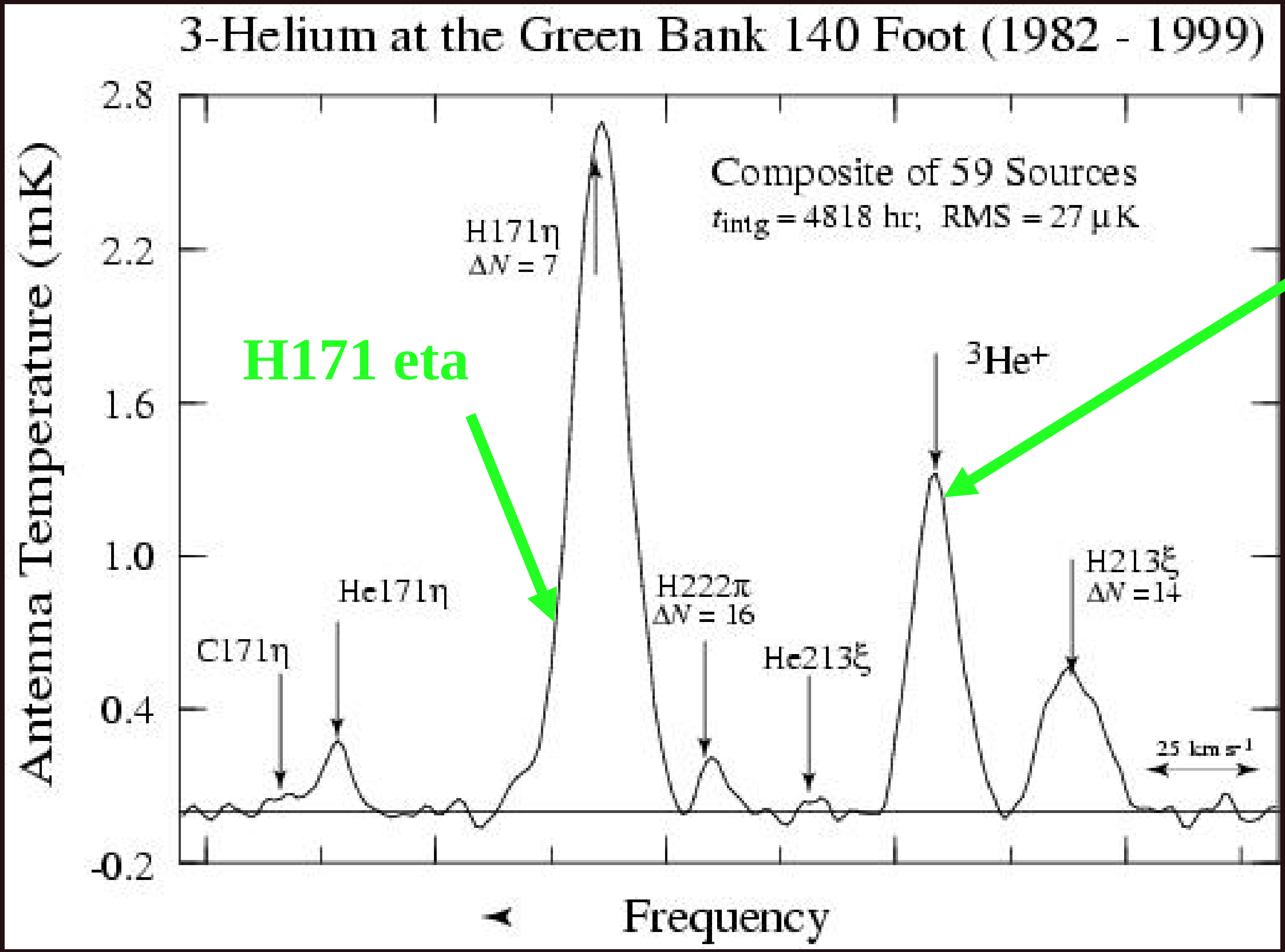
NRAO 140 ft

H II Regions

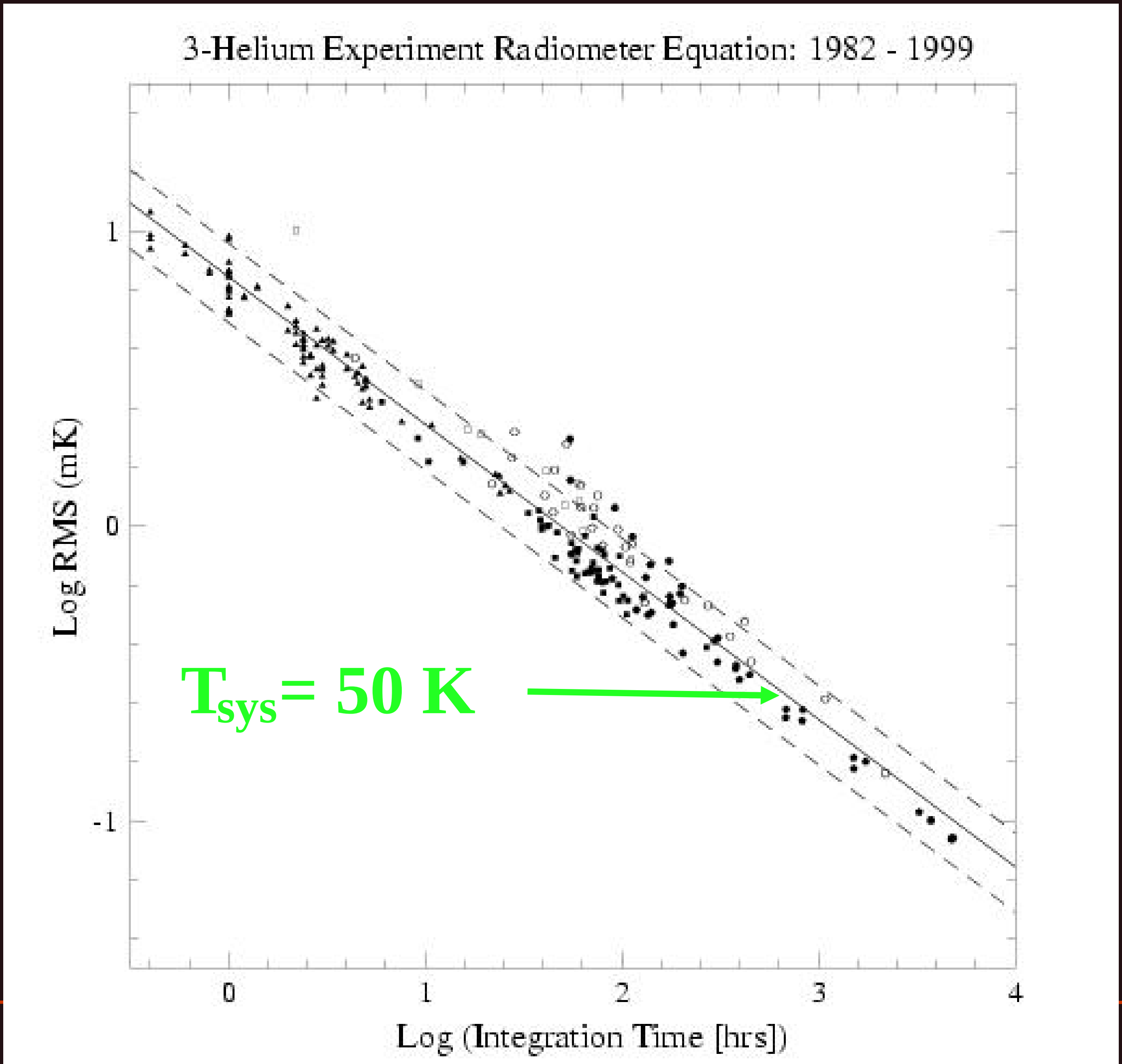
MPIfR 100 m

Planetary Nebulae (PNe)

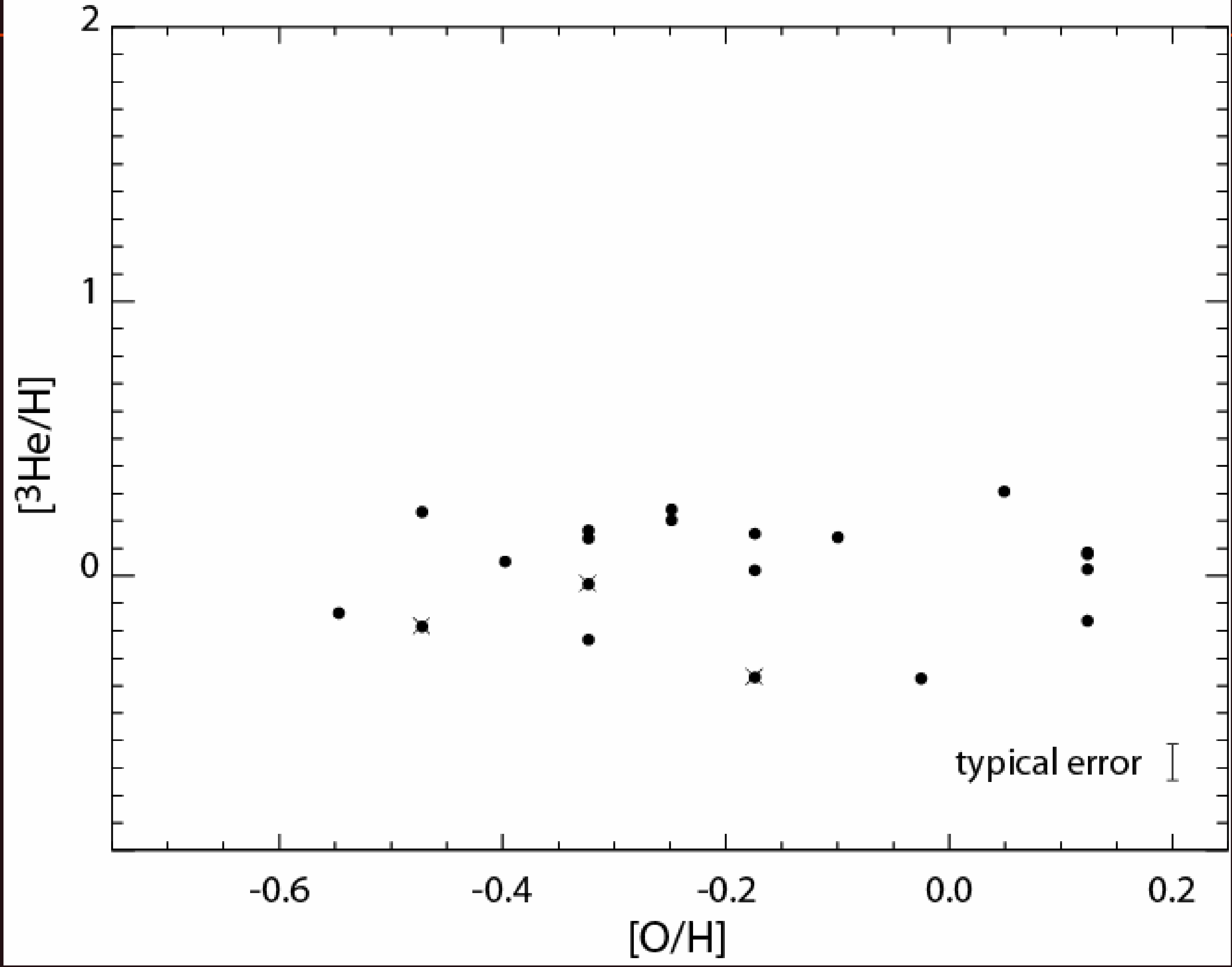

FREQUENCY
6.
2.
−2.
−6.
4.
3.
2.
1.
0.
−1.
G93.06+2.8
3He
Tintg= 45.8 Rgal=11.8
$^3He^+$
interference
H171η
60.
100.
140.
180.
220.
CHANNELS
1381.01



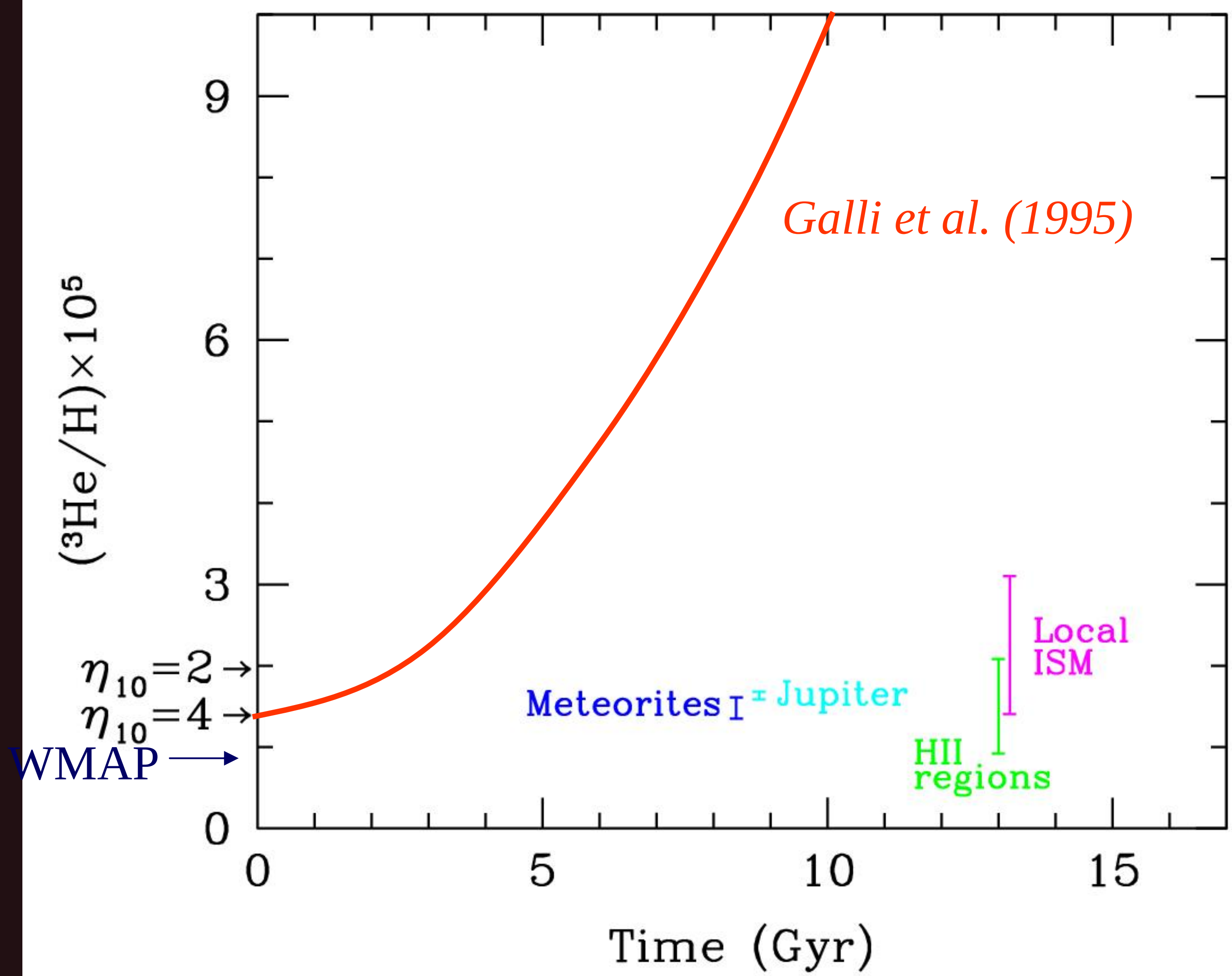
200 Day Integration: 27 microKelvin RMS



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



“Simple” H II Regions



Meteorites: Geiss (1993)

Jupiter: Mahaffy et al. (1998)

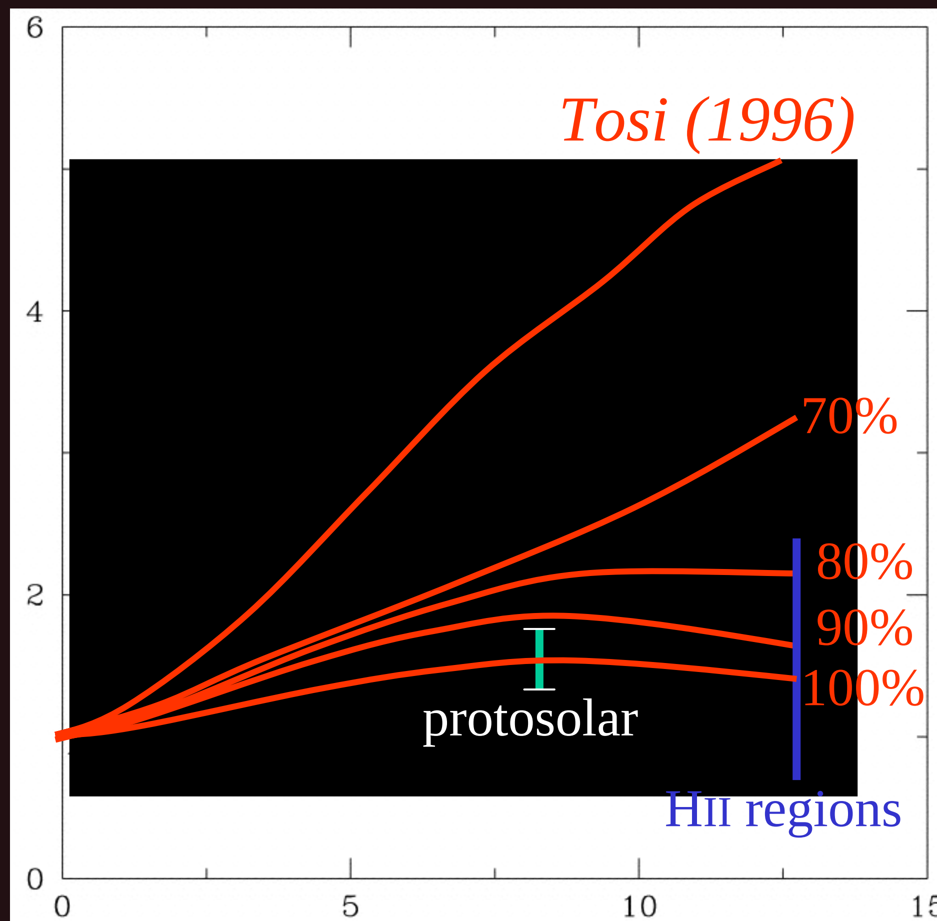
HII regions: Bania, Rood & Balser (2000)

Local ISM: Gloecker & Geiss (1998)

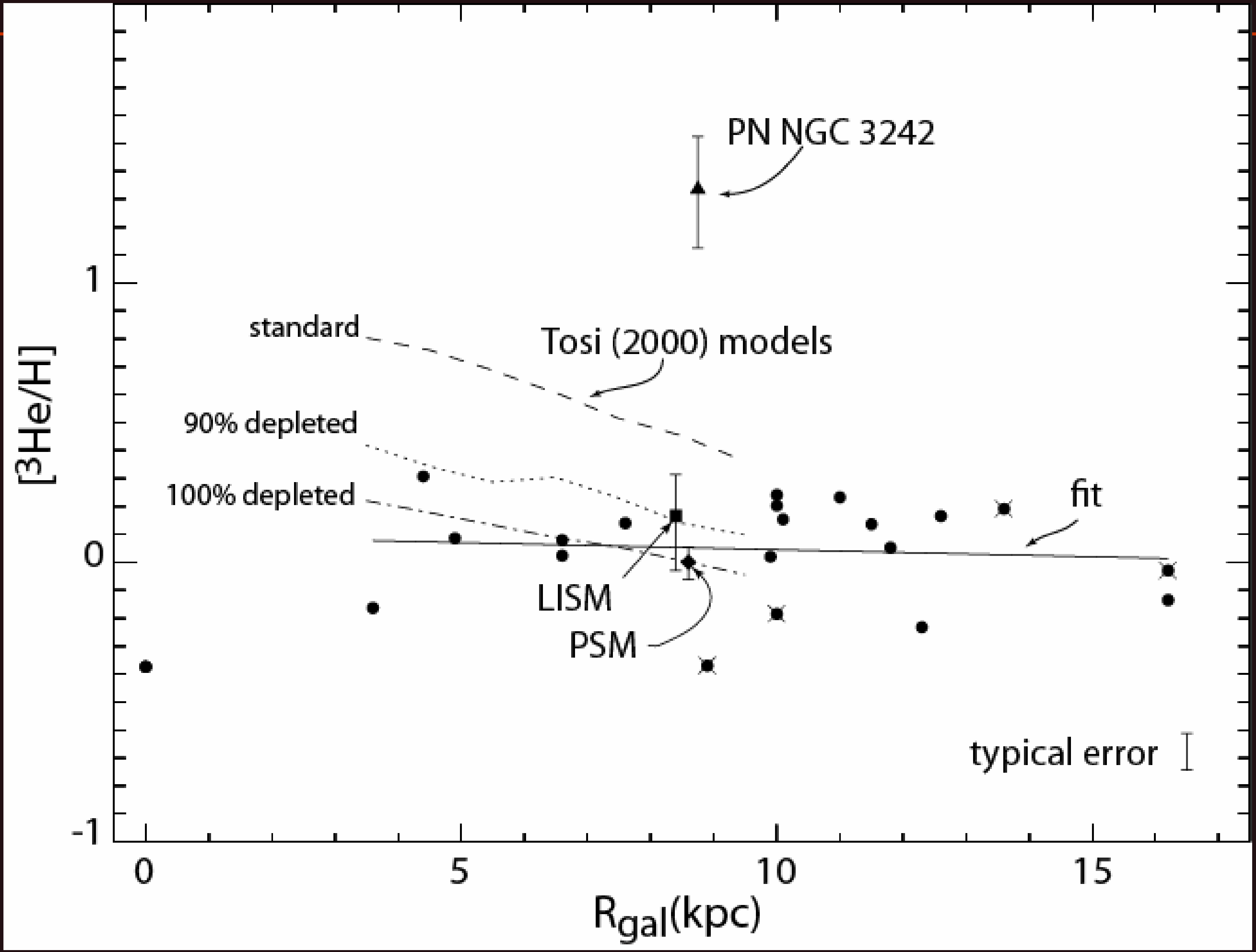
^{3}H

in agreement with *Charbonnel & do Nascimento (1998):*
extra-mixing in 93-96 % of low-mass stars
is needed to explain the $^{12}C/^{13}C$ ratio in RGB stars

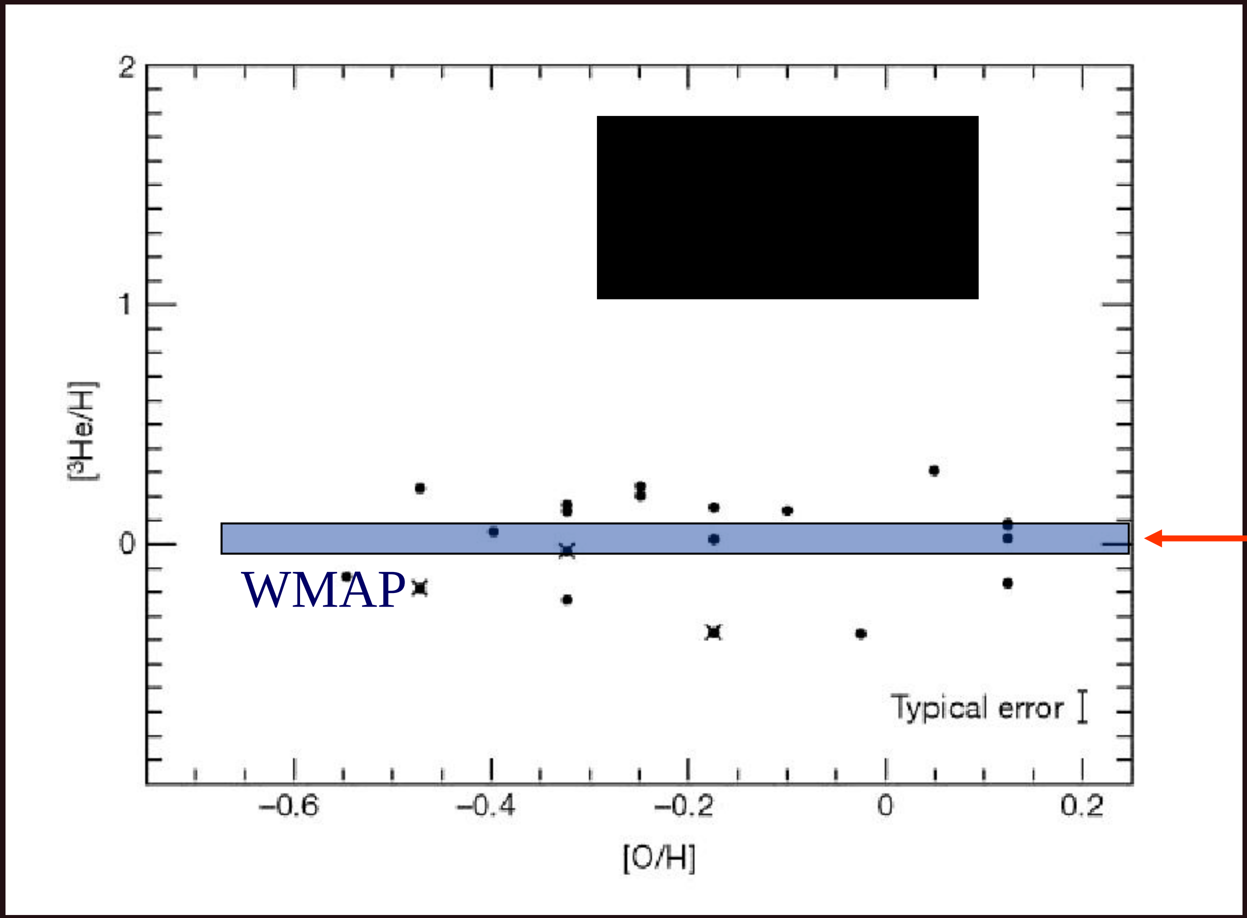
^{3}He/H x 10^5



Time (Gyr)

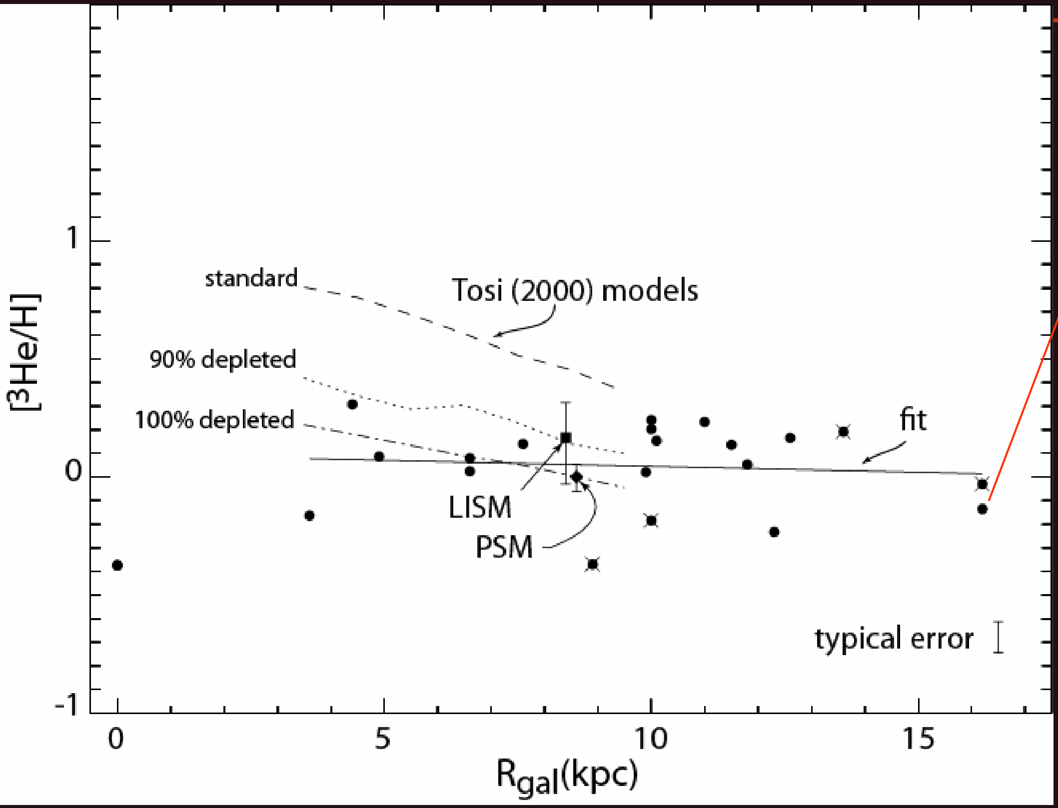

PN NGC 3242
Tosi (2000) models
standard
90% depleted
100% depleted
fit
LISM
PSM
typical error
[3He/H]
Rgal(kpc)
1
0
-1
0
5
10
15

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



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

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

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

$\Omega_B = 0.047 \pm 0.006$

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

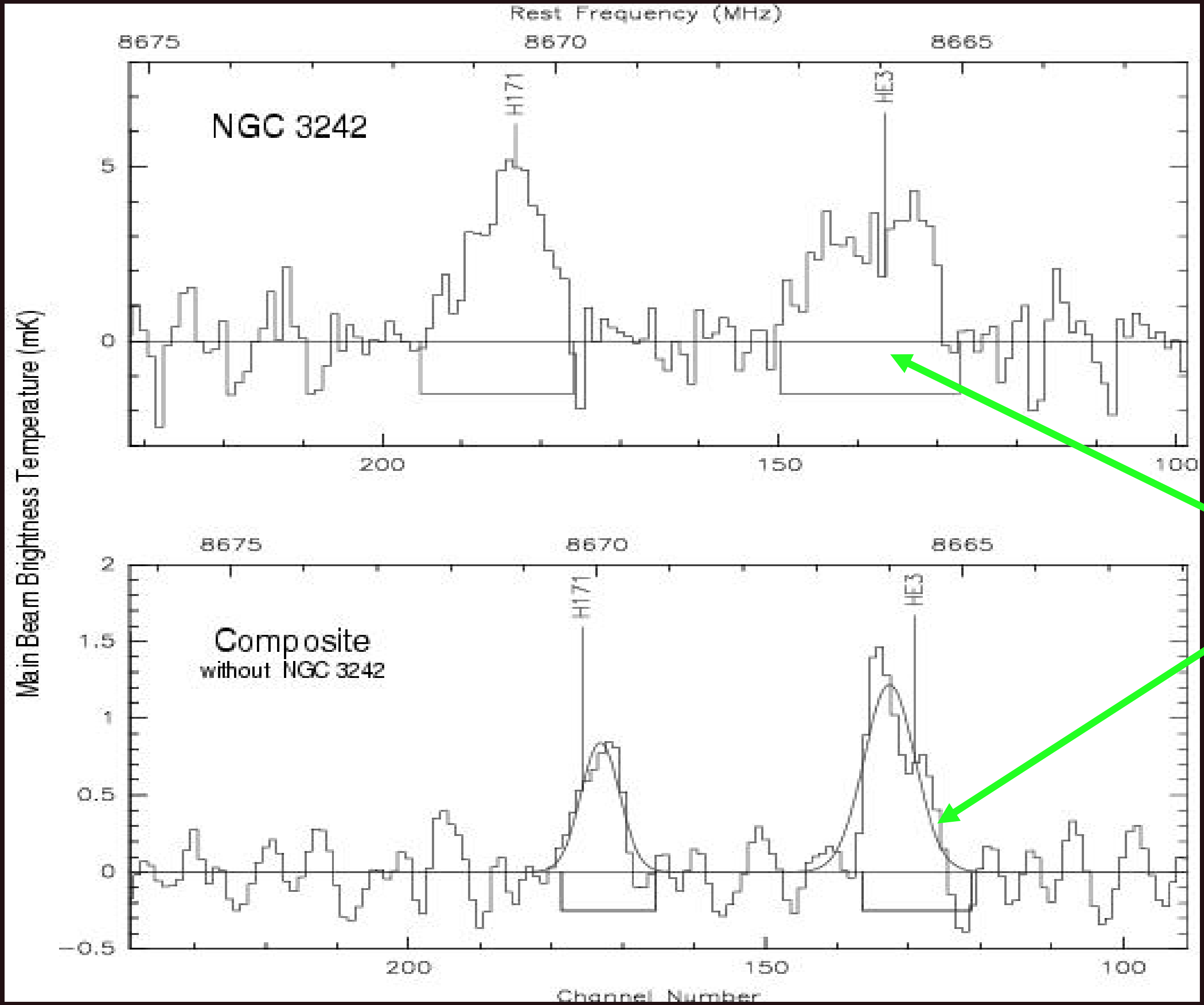
For ^3He lowest observed $^3He/H$ is an upper limit for cosmological ^3He

MPIfR 100 m PNe Survey

Balser, et al. 1997, ApJ 483, 320

106 hr

1987-1997

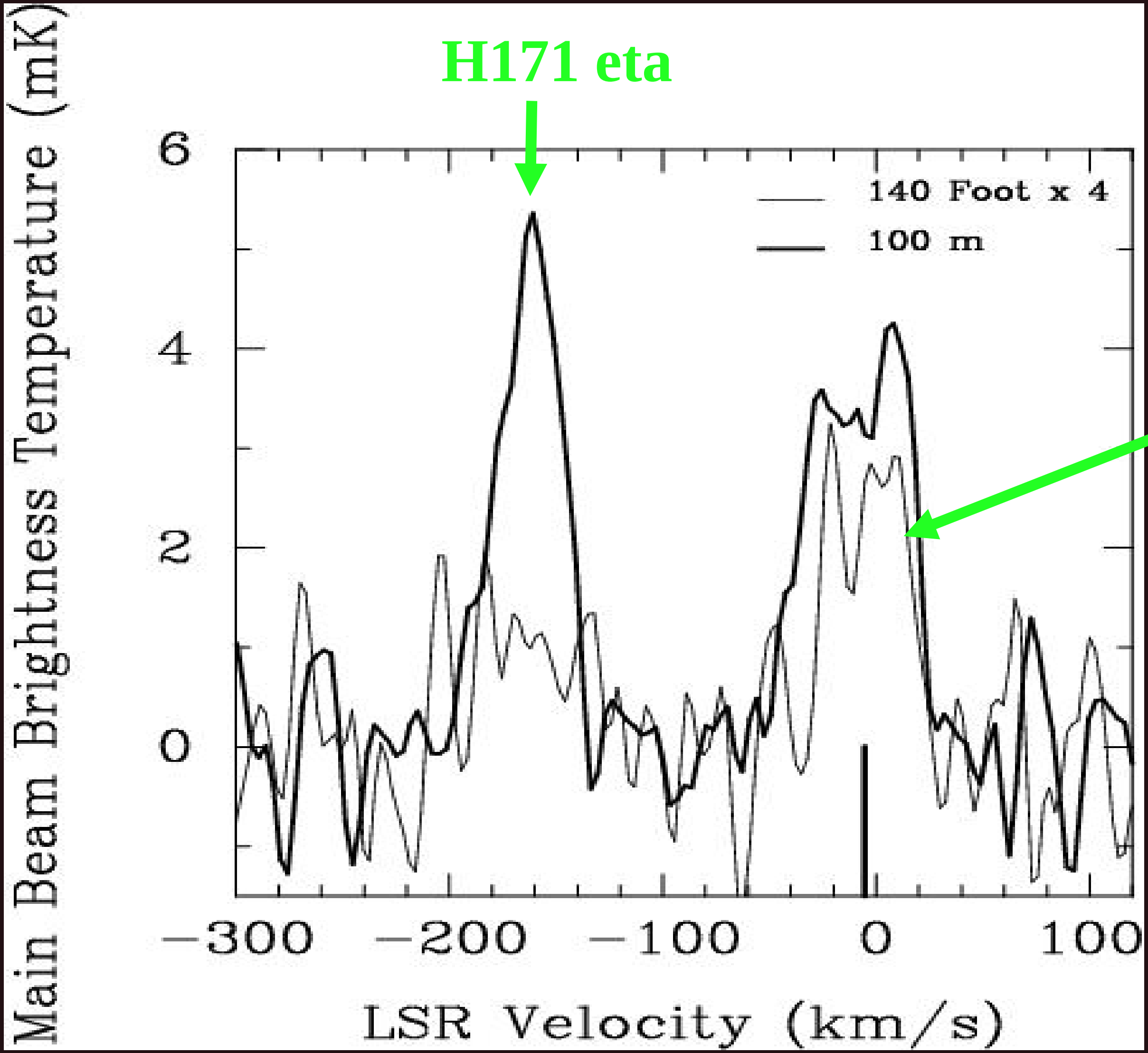


$^3He^+$

443 hr

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

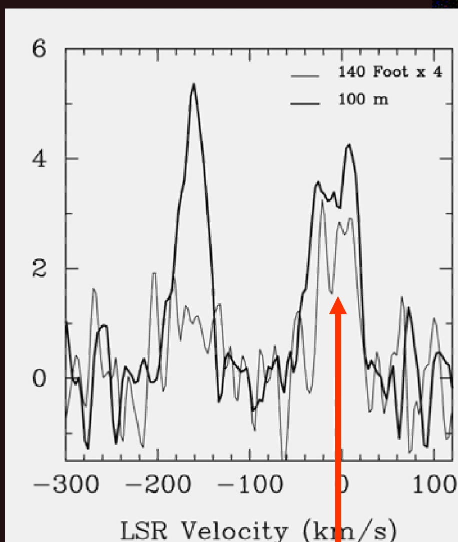
NGC 3242 Confirmation Balser, et al. 1999 ApJ 522, L73



NRAO 140 ft spectrum is a 270 hour integration

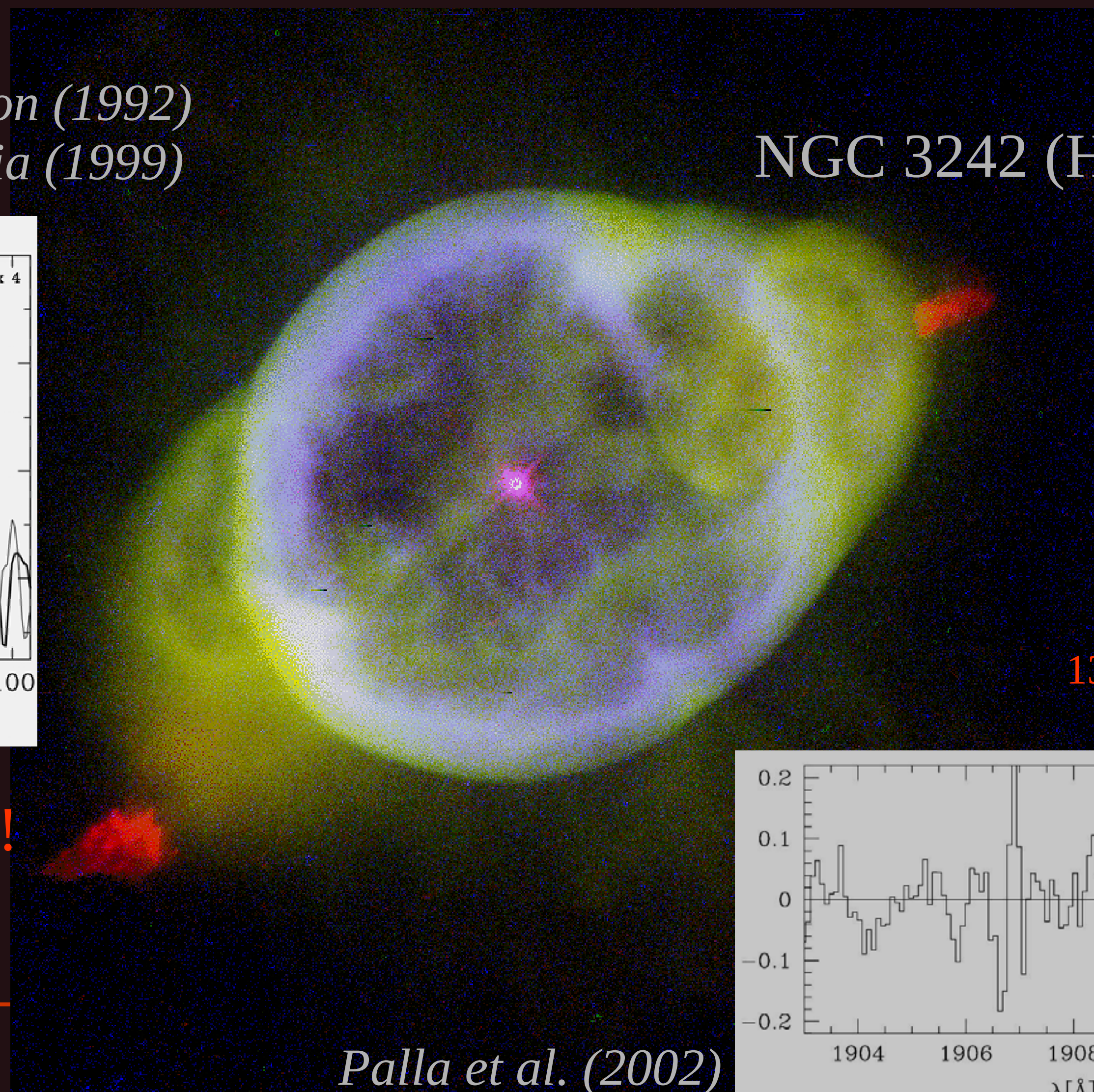
The rescue of the standard model

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



^{3}He yes!

NGC 3242 (HST)



Palla et al. (2002)

^{13}C no!

- ^{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:

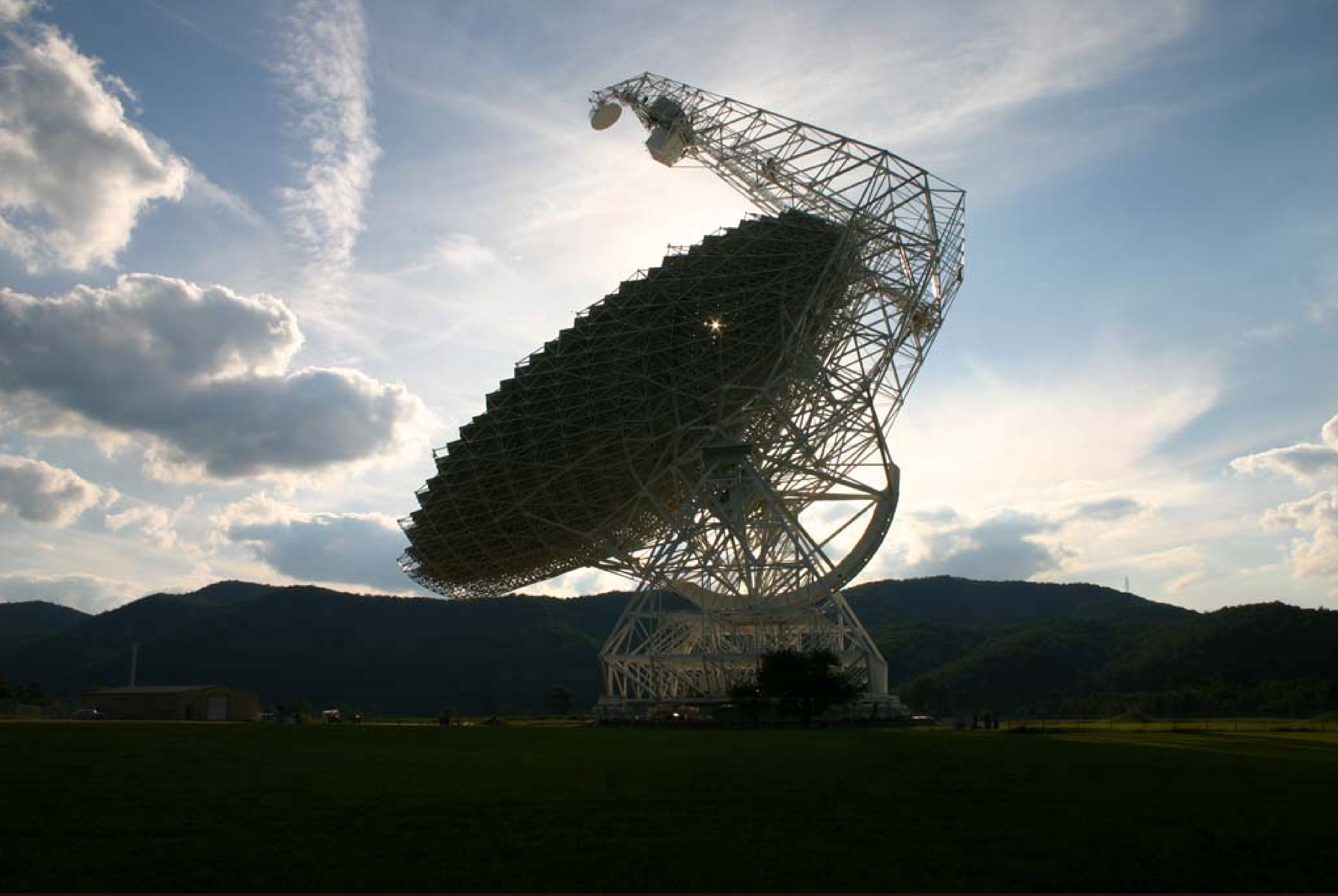
Peimbert Class IIb, III, and IV

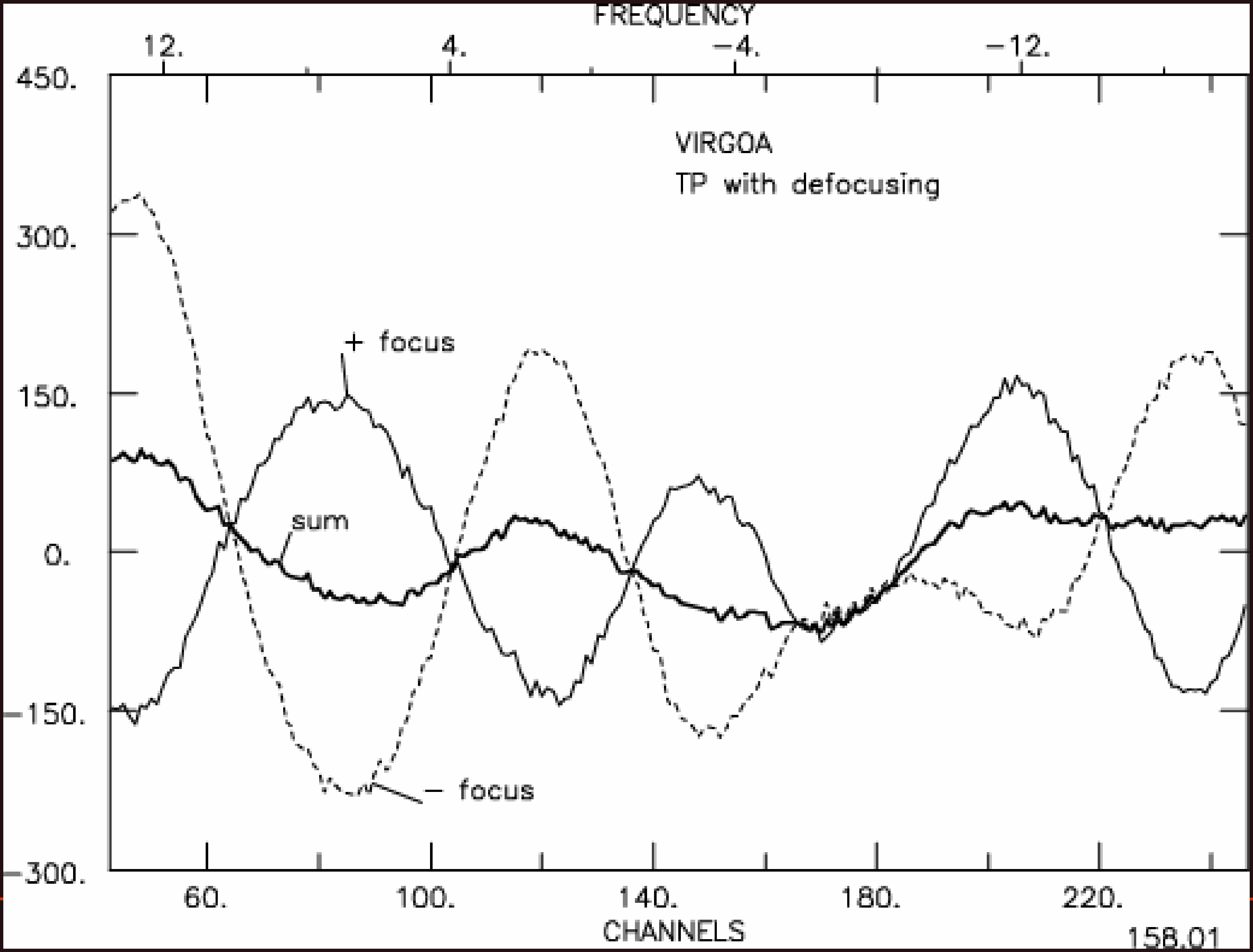
The Robert C. Byrd

GREEN BANK TELESCOPE

GBT: Surface Area is 8,000 m^2

GBT: Mass is 7,300,000 kg



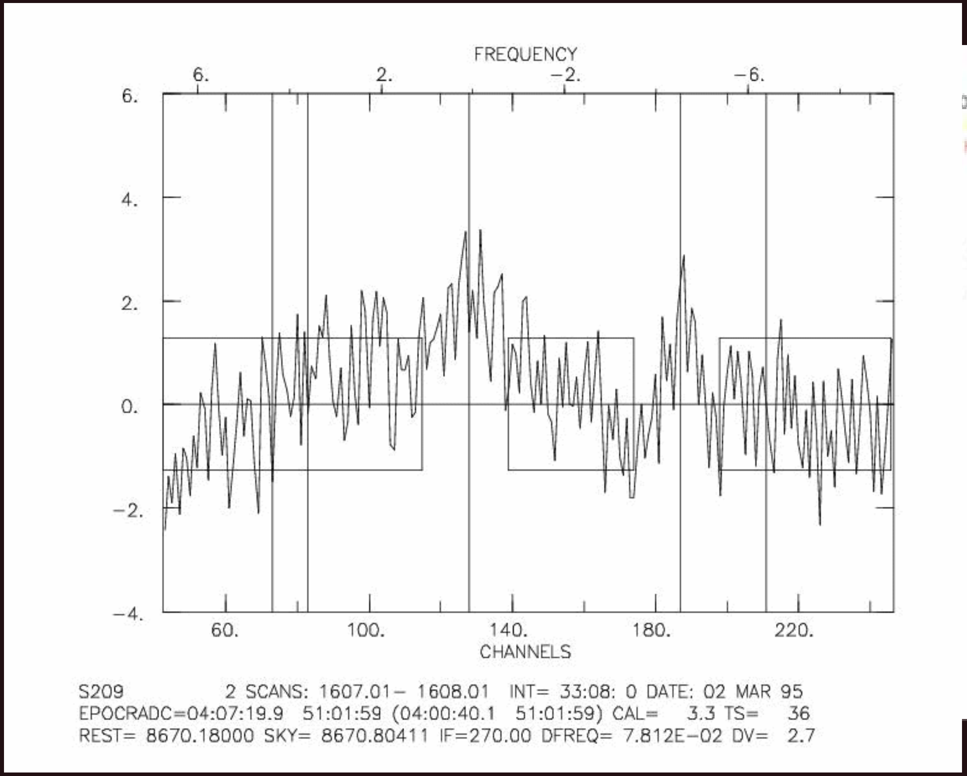


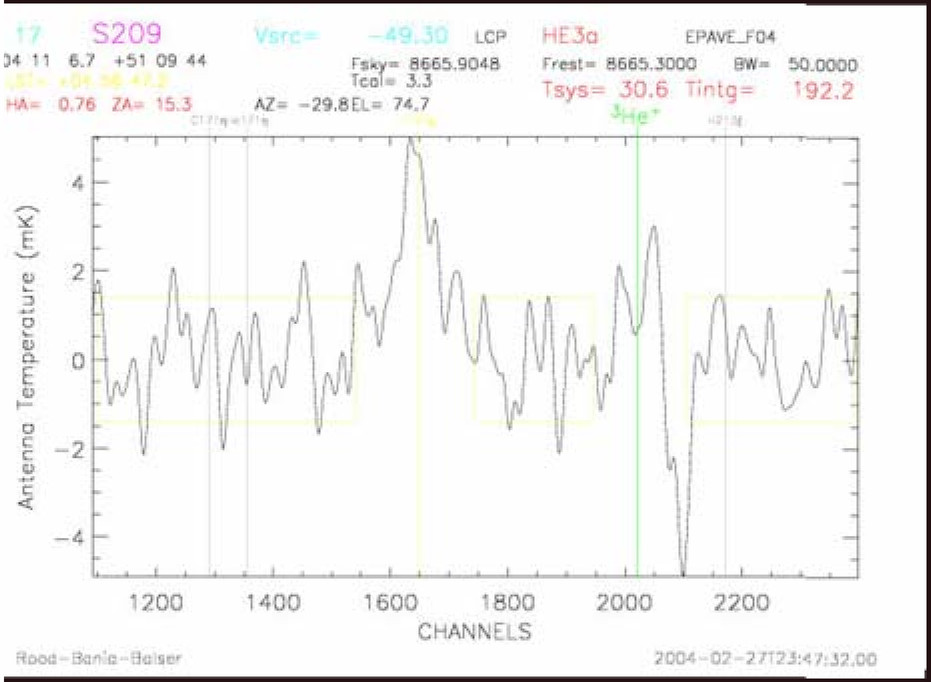
FREQUENCY
12.
4.
−4.
−12.
450.
300.
150.
0.
−150.
−300.
VIRGOA
TP with defocusing
+ focus
sum
− focus
60.
100.
140.
180.
220.
CHANNELS
158.01

GBT: Clear Aperture Optics

S 209 H II Region

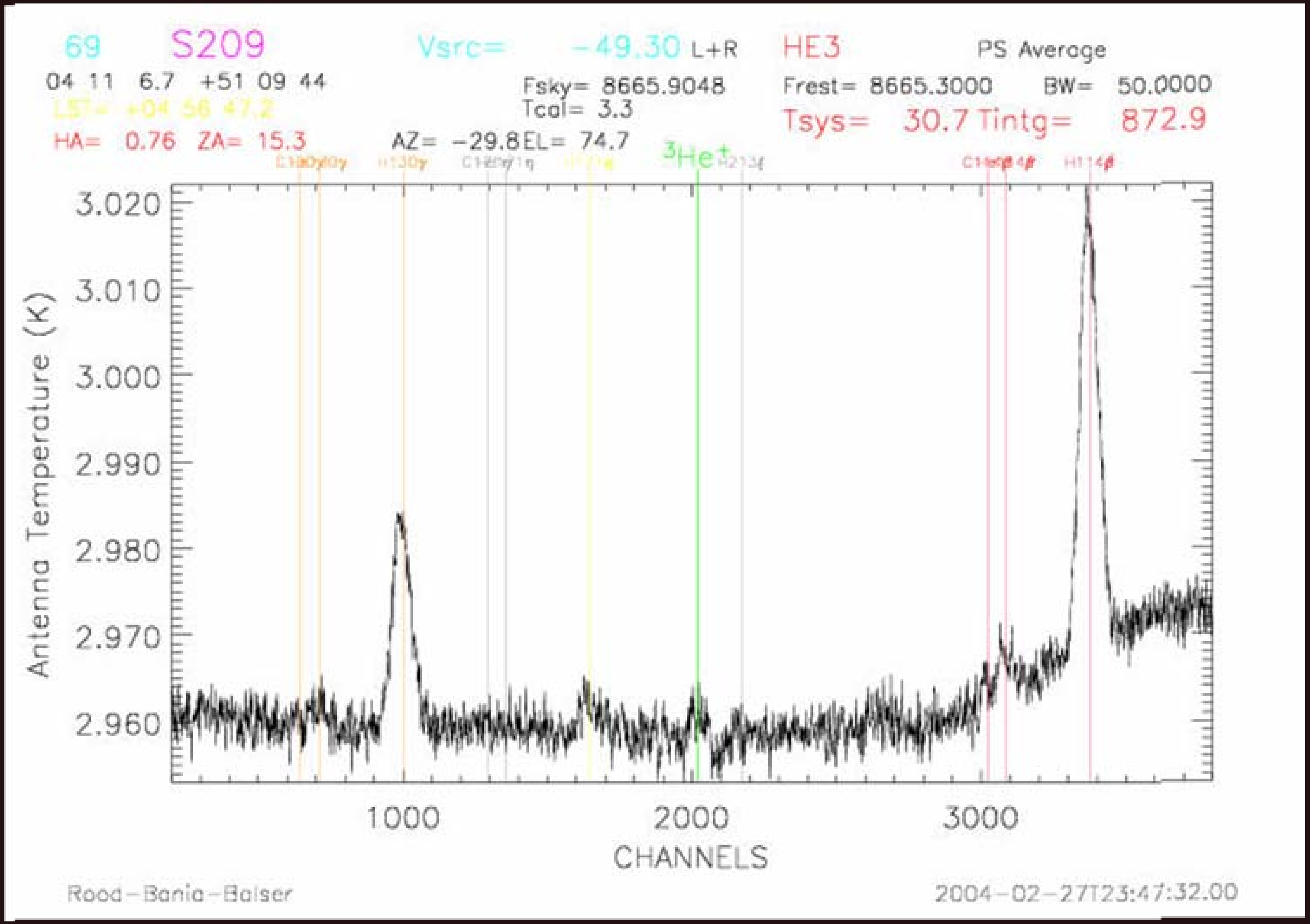
140 ft March 1995 | **GBT June 2004**



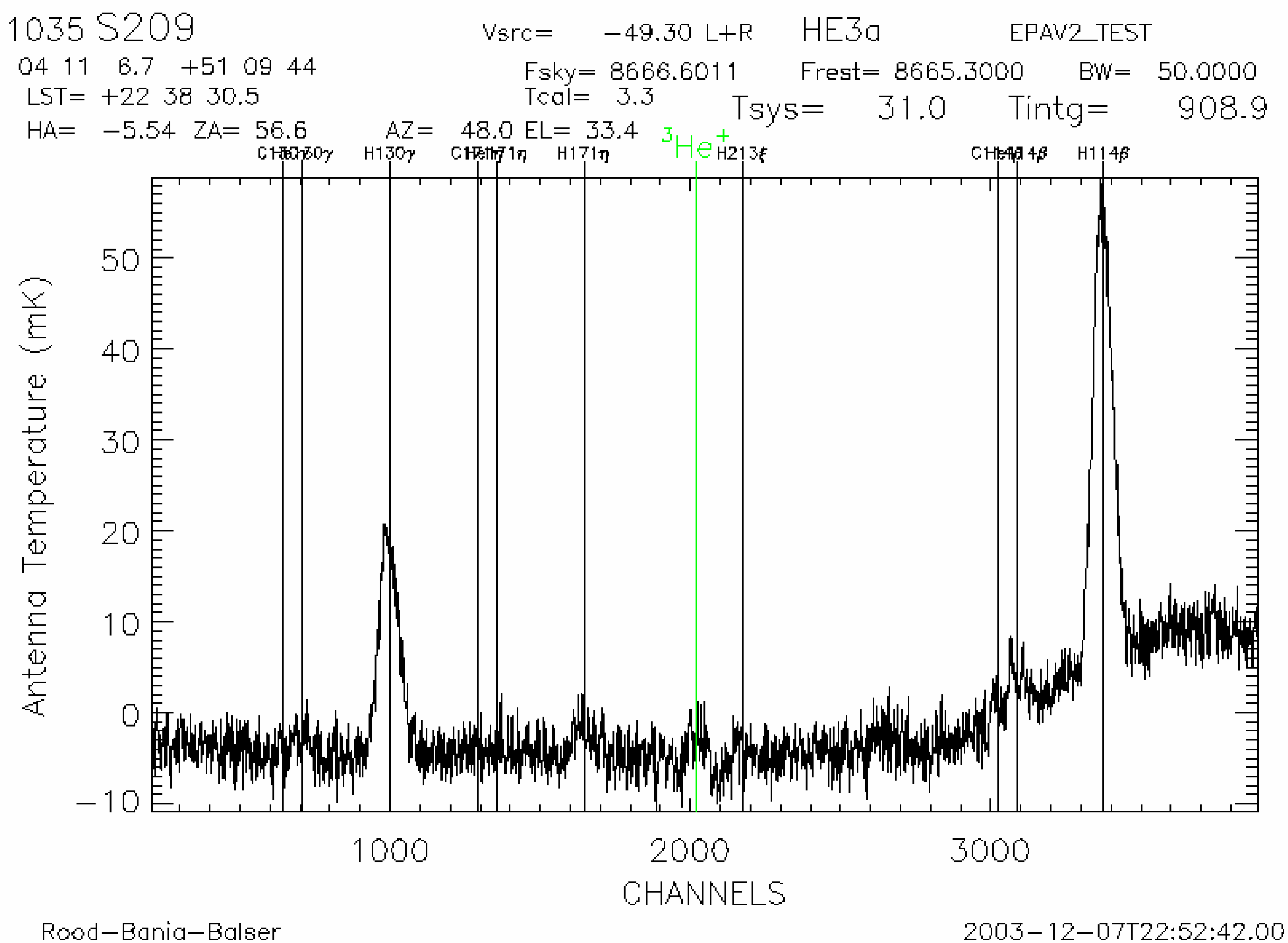


33.1 hr | **3.2 hr**

GBT S 209 H II Region

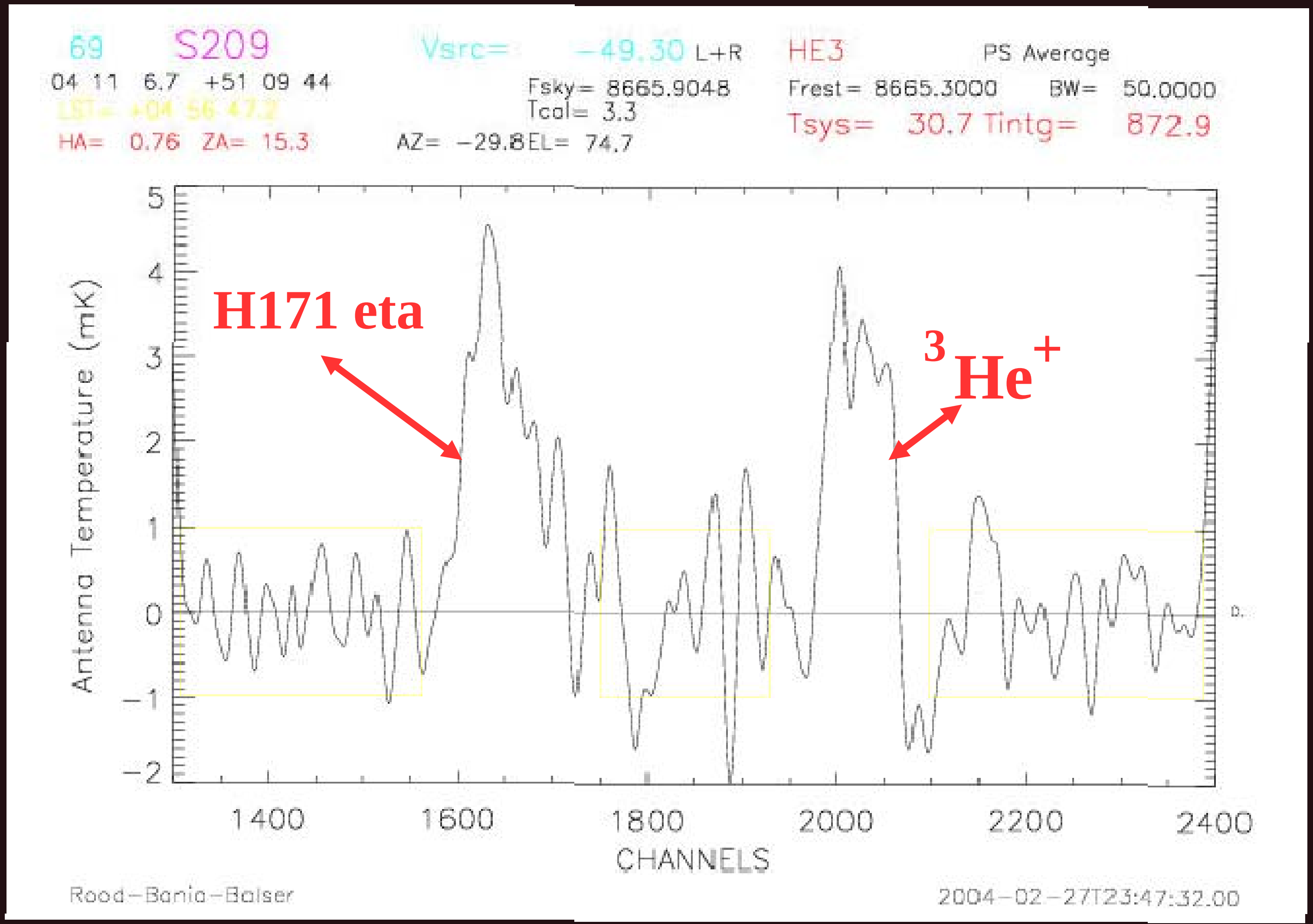


14.5 hour integration



1035 S209
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
³He⁺
H213ξ
H114β
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2003−12−07T22:52:42.00

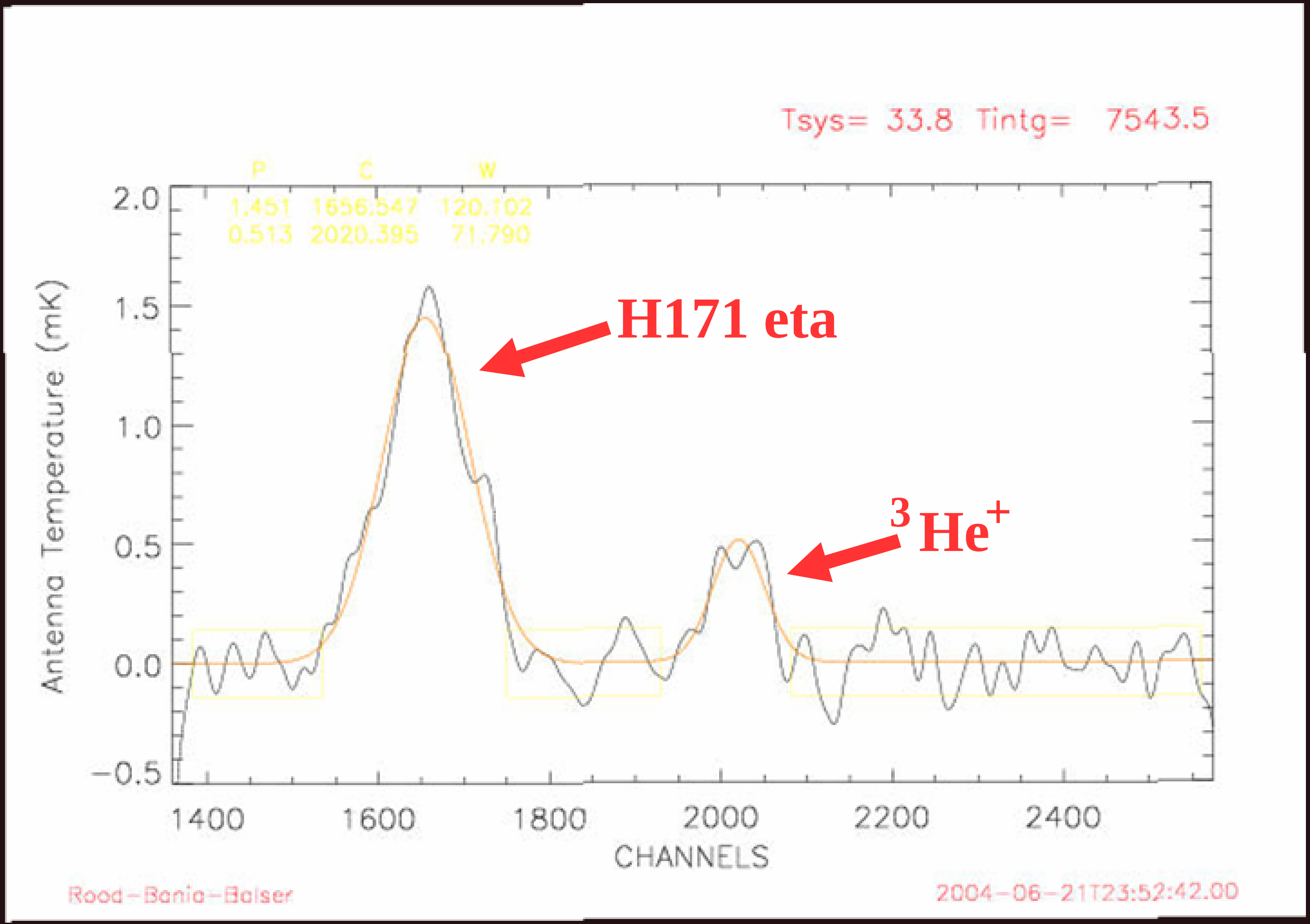
S 209 H II Region



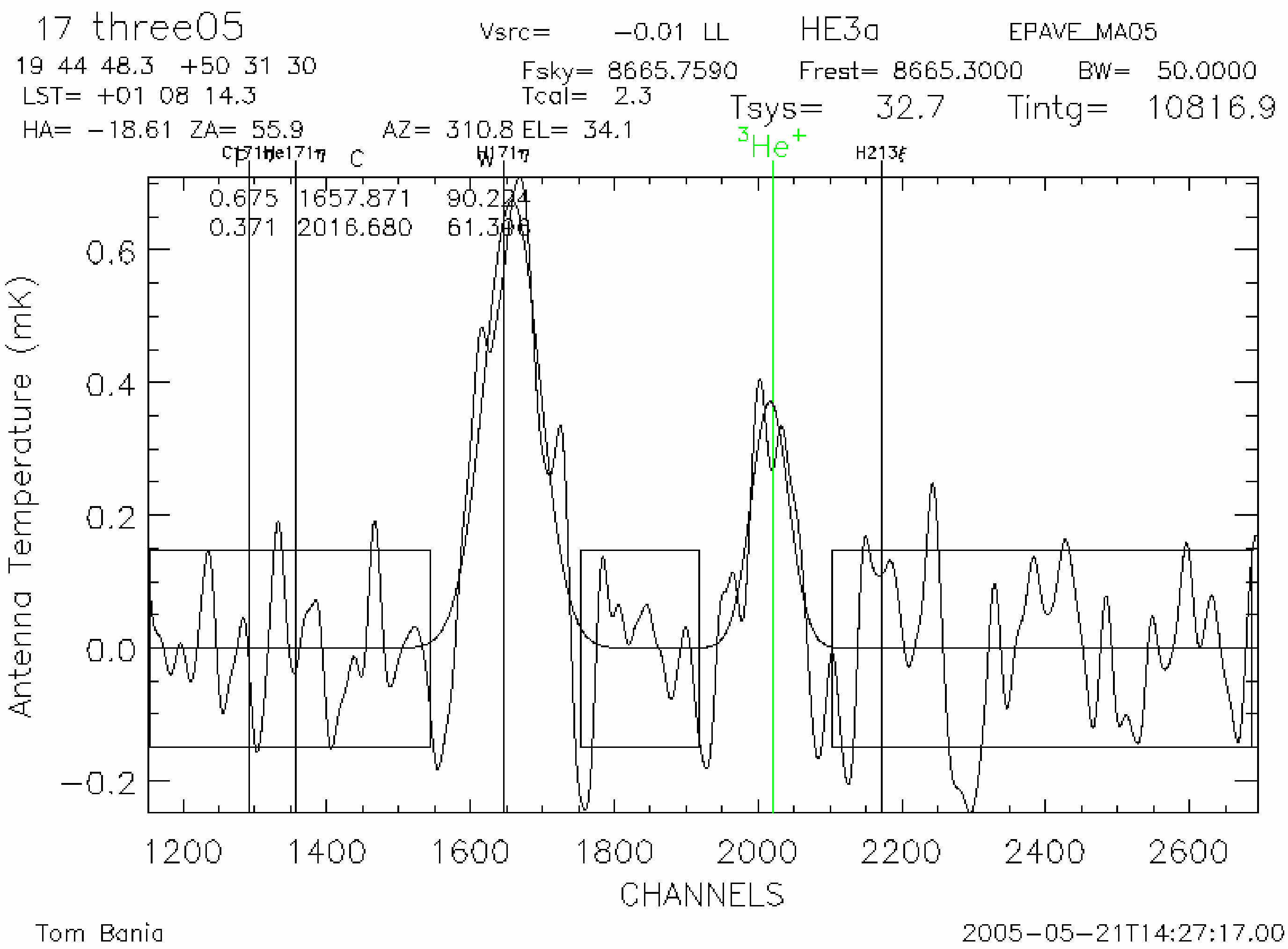
14.5 hour integration **5 km/sec resolution**

GBT PNe Composite Spectrum

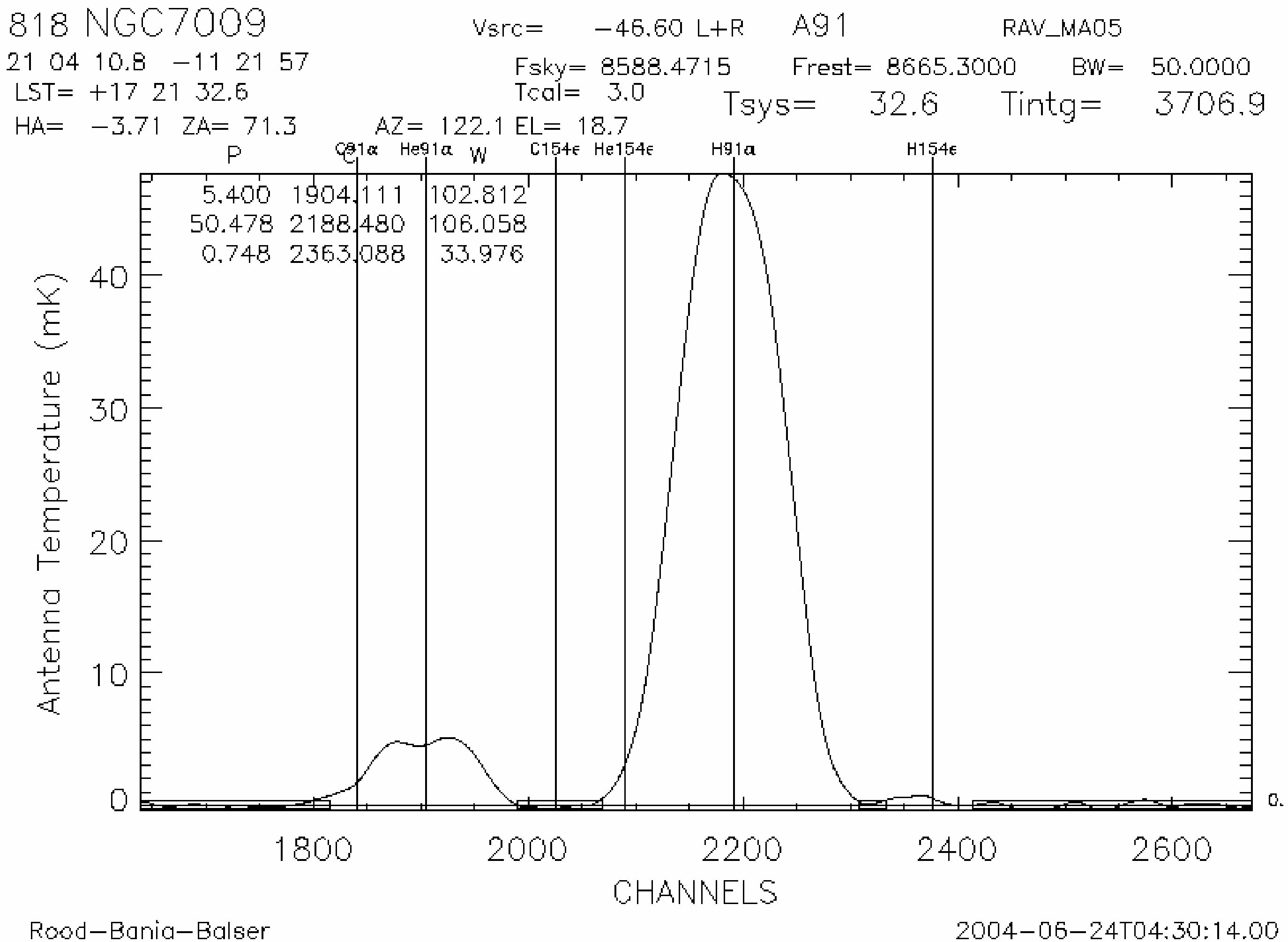
NGC 3242 + NGC 6543 + NGC 6826 + NGC 7009



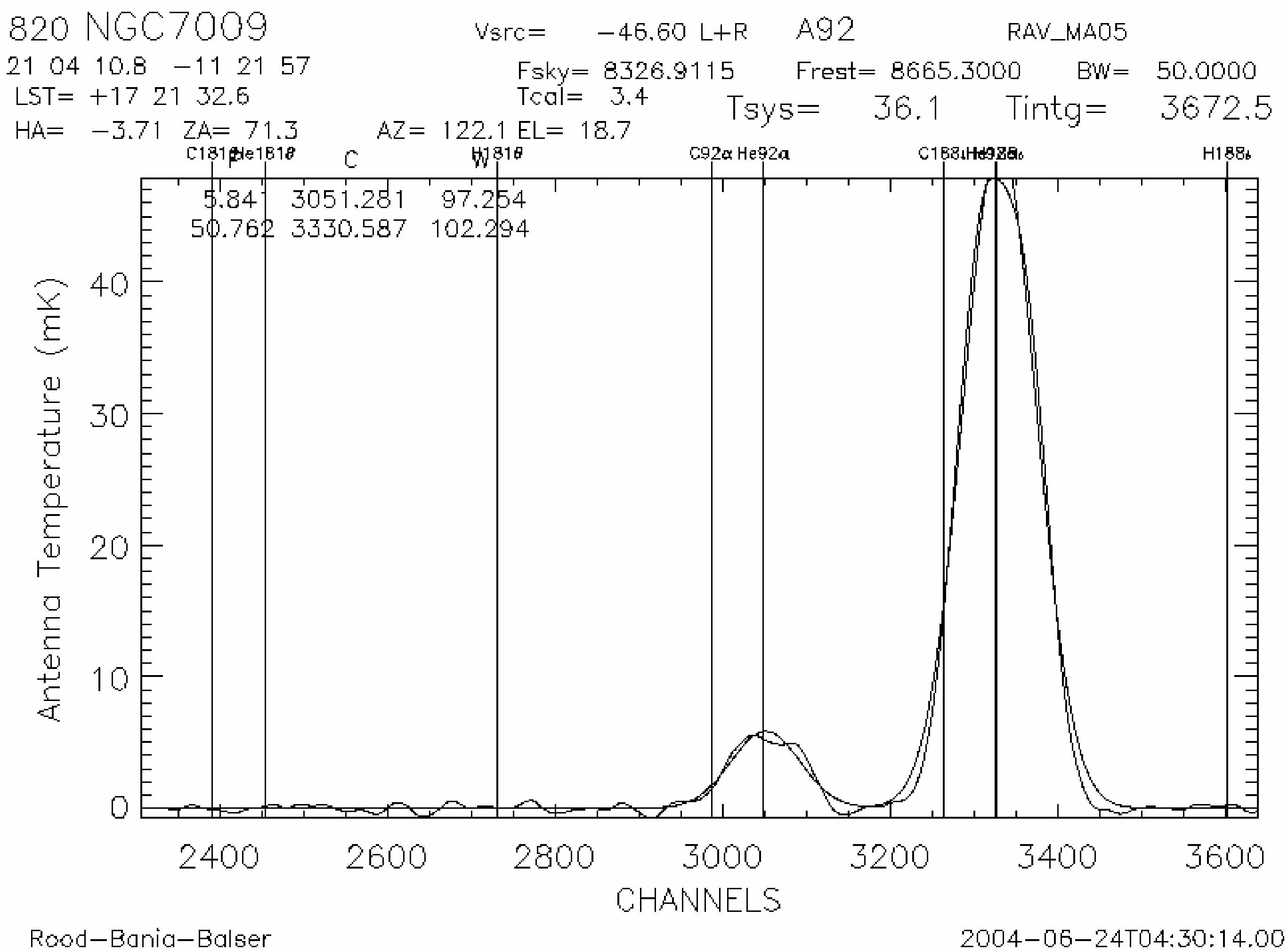
125.7 hour integration



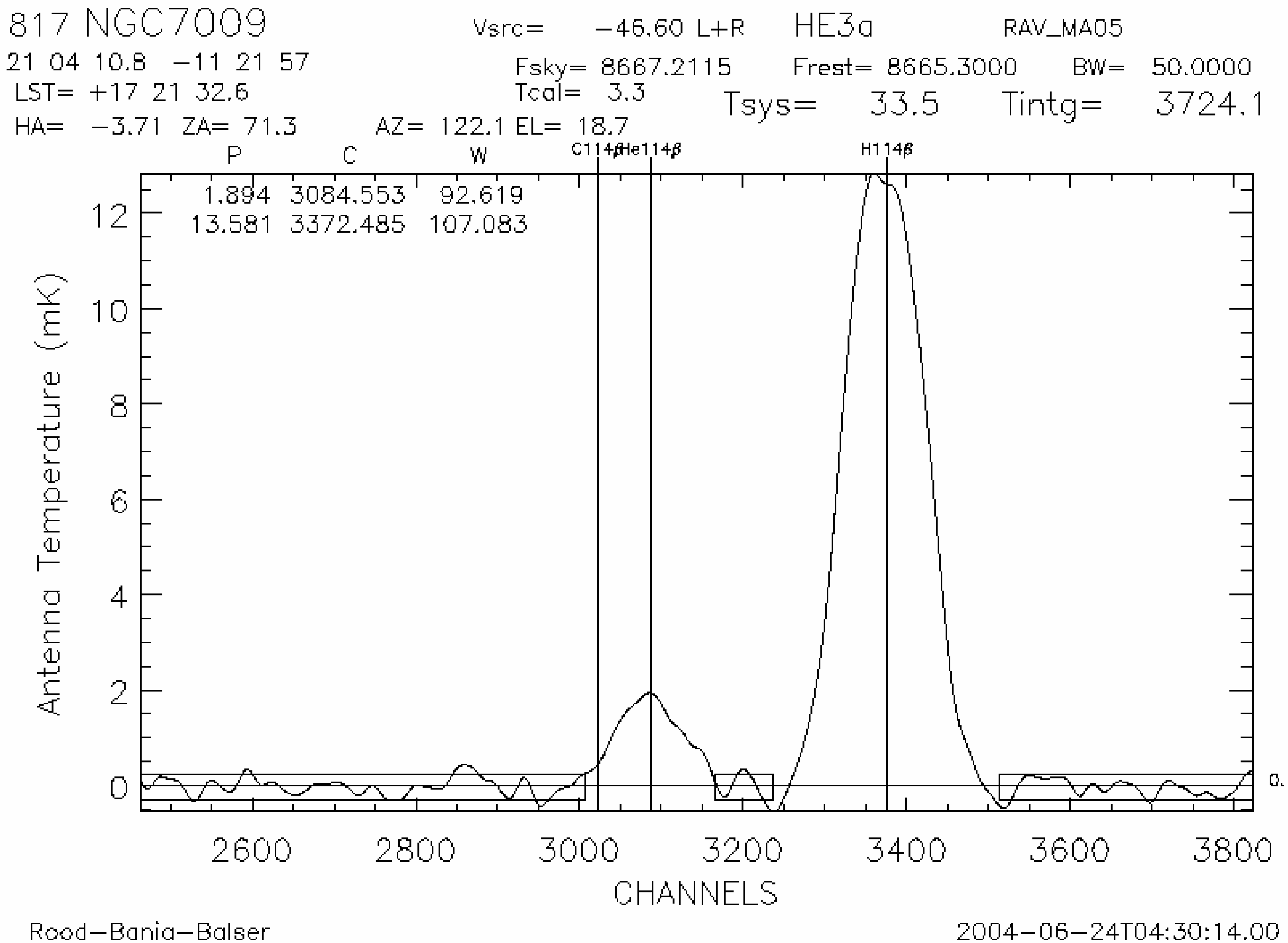
NGC7009 + NGC6543 + NGC6826

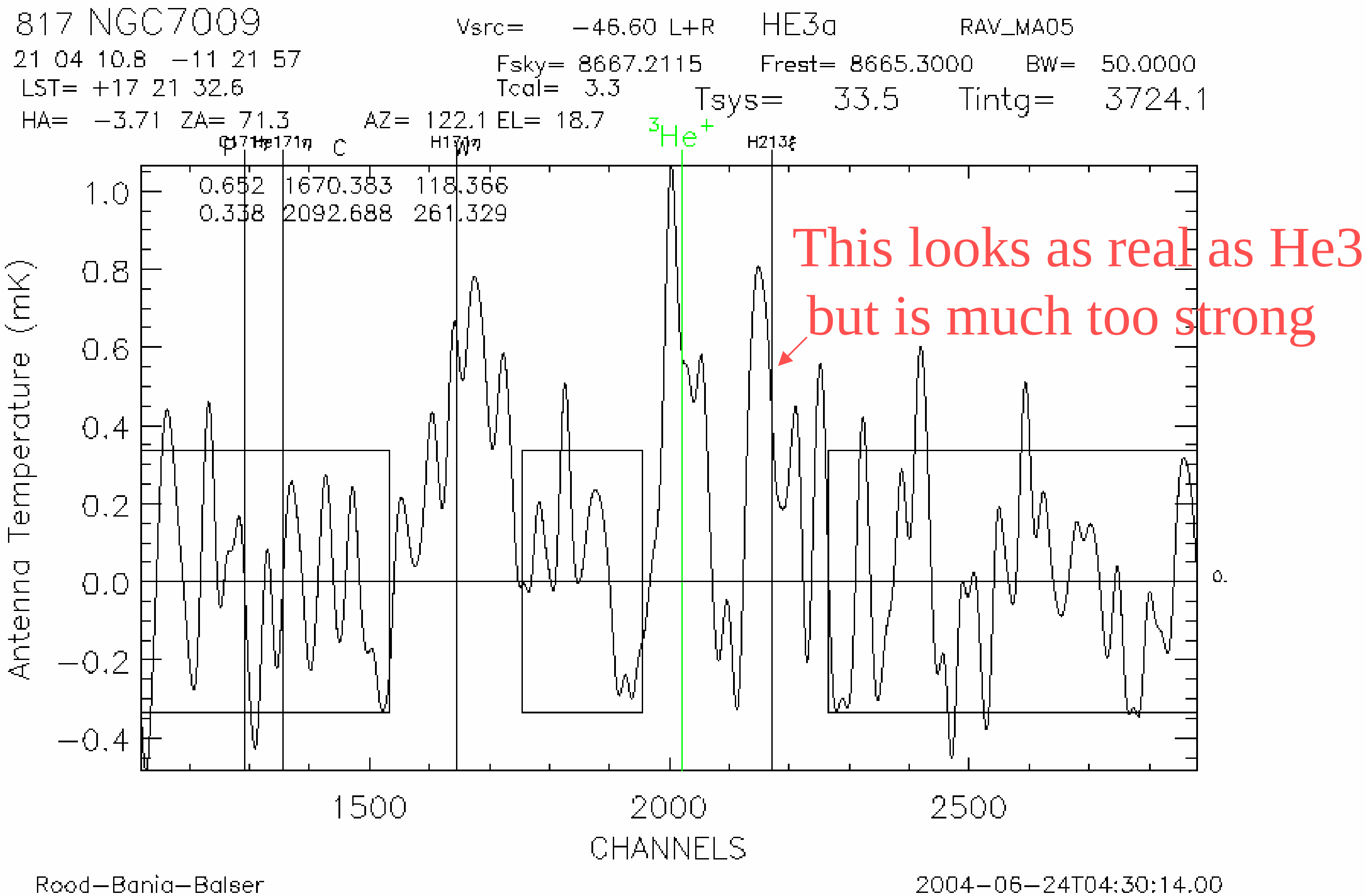


818 NGC7009
21 04 10.8 −11 21 57
LST= +17 21 32.6
HA= −3.71 ZA= 71.3
AZ= 122.1 EL= 18.7
Vsrc= −46.60 L+R
A91
RAV_MA05
Fsky= 8588.4715
Frest= 8665.3000
BW= 50.0000
Tcal= 3.0
Tsys= 32.6
Tintg= 3706.9
P
C
W
C91α
He91α
C154ϵ
He154ϵ
H91α
H154ϵ
5.400 1904.111 102.812
50.478 2188.480 106.058
0.748 2363.088 33.976
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2004−06−24T04:30:14.00



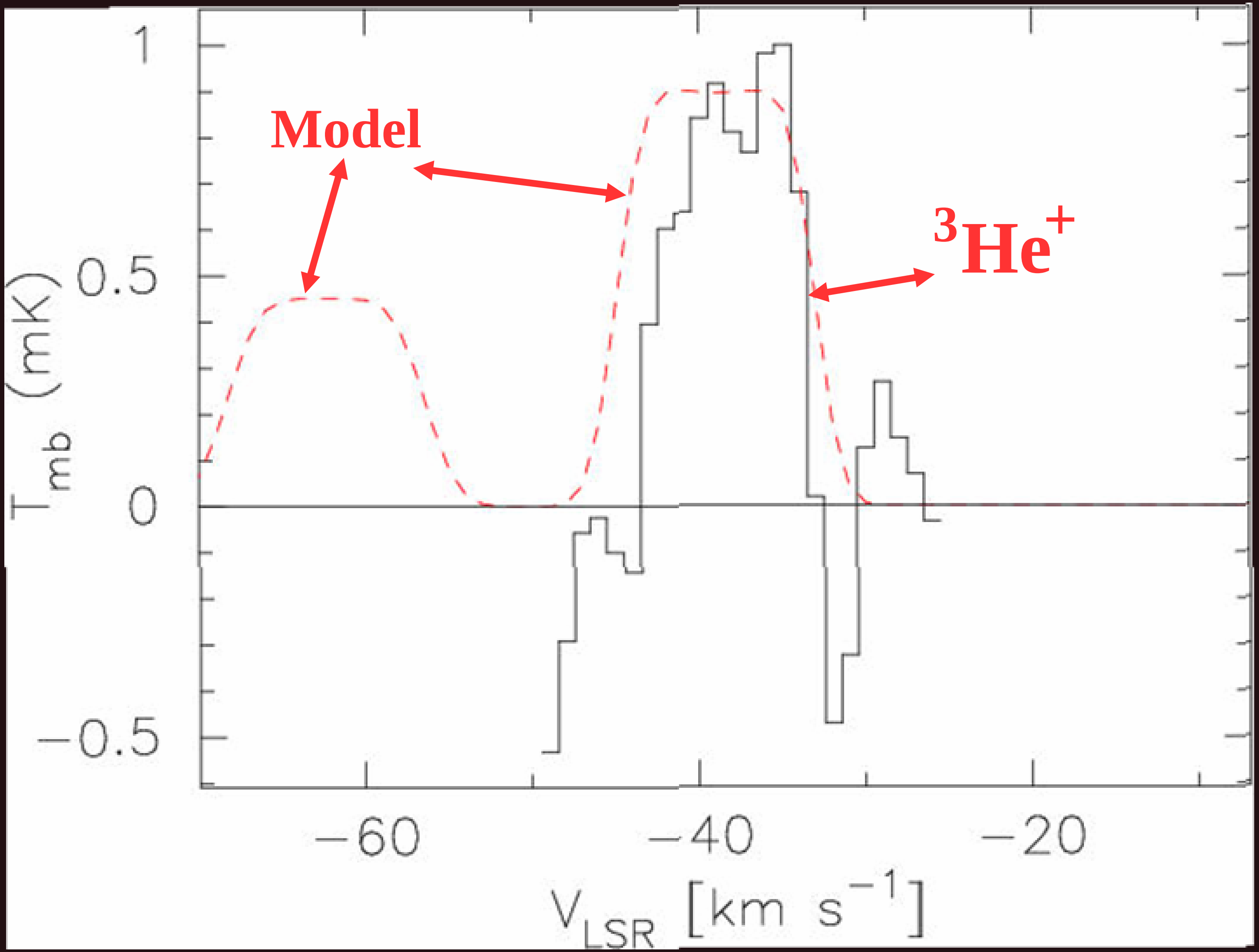
820 NGC7009
21 04 10.8 −11 21 57
LST= +17 21 32.6
HA= −3.71 ZA= 71.3
AZ= 122.1 EL= 18.7
Vsrc= −46.60 L+R
A92
RAV_MA05
Fsky= 8326.9115
Frest= 8665.3000
BW= 50.0000
Tcal= 3.4
Tsys= 36.1
Tintg= 3672.5
5.841 3051.281 97.254
50.762 3330.587 102.294
C92α He92α
H188
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2004−06−24T04:30:14.00


817 NGC7009
21 04 10.8 −11 21 57
LST= +17 21 32.6
HA= −3.71 ZA= 71.3
AZ= 122.1 EL= 18.7
Vsrc= −46.60 L+R
HE3a
RAV_MA05
Fsky= 8667.2115
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 33.5
Tintg= 3724.1
P C W
1.894 3084.553 92.619
13.581 3372.485 107.083
C114β He114β
H114β
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2004−06−24T04:30:14.00


817 NGC7009
21 04 10.8 −11 21 57
LST= +17 21 32.6
HA= −3.71 ZA= 71.3
AZ= 122.1 EL= 18.7
Vsrc= −46.60 L+R
HE3a
RAV_MA05
Fsky= 8667.2115
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 33.5
Tintg= 3724.1
3He+
H213ξ
0.652 1670.383 118.366
0.338 2092.688 261.329
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2004−06−24T04:30:14.00
This looks as real as He3
but is much too strong

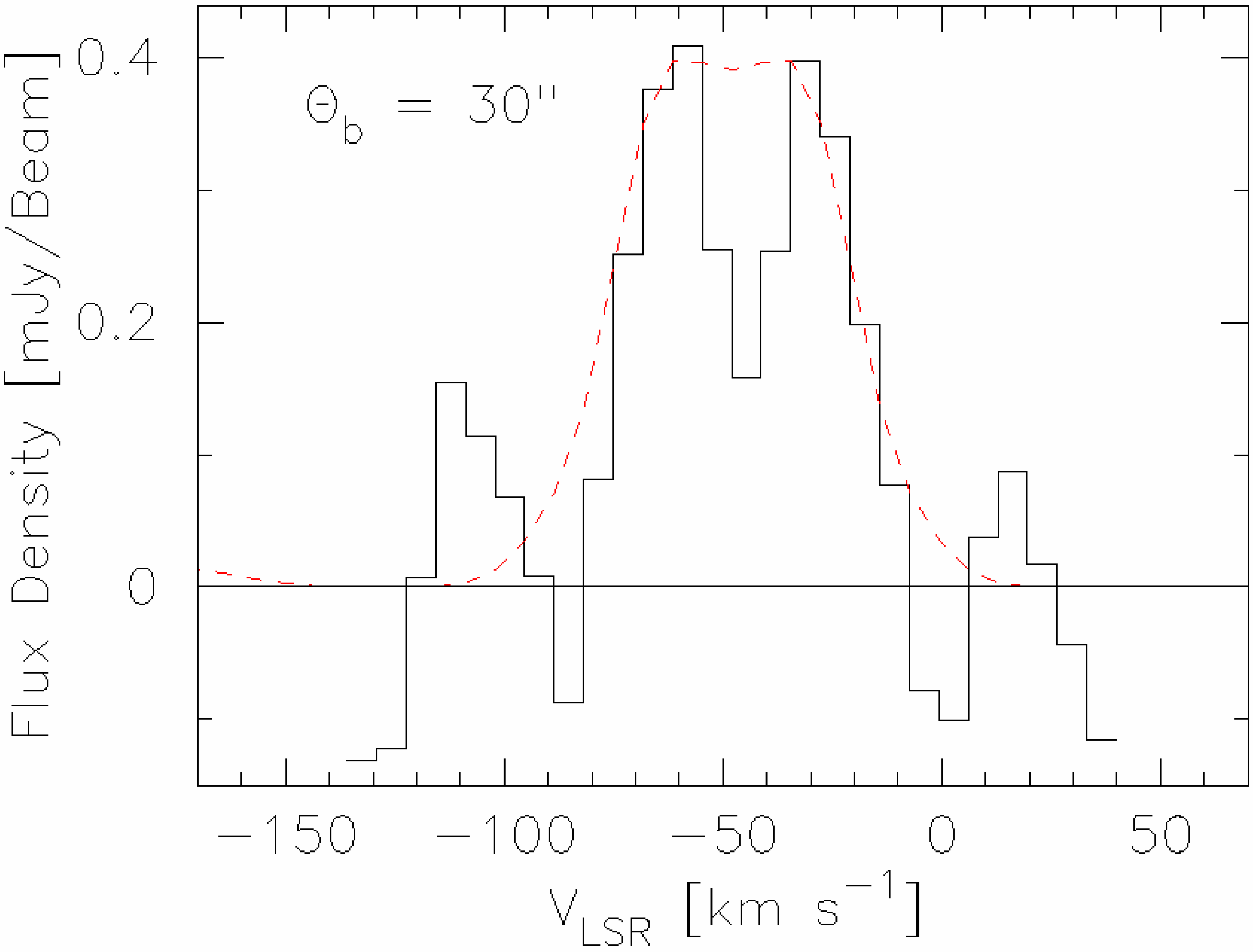
PNe He3 at the VLA: Balser, Goss, Bania, Rood (2005)

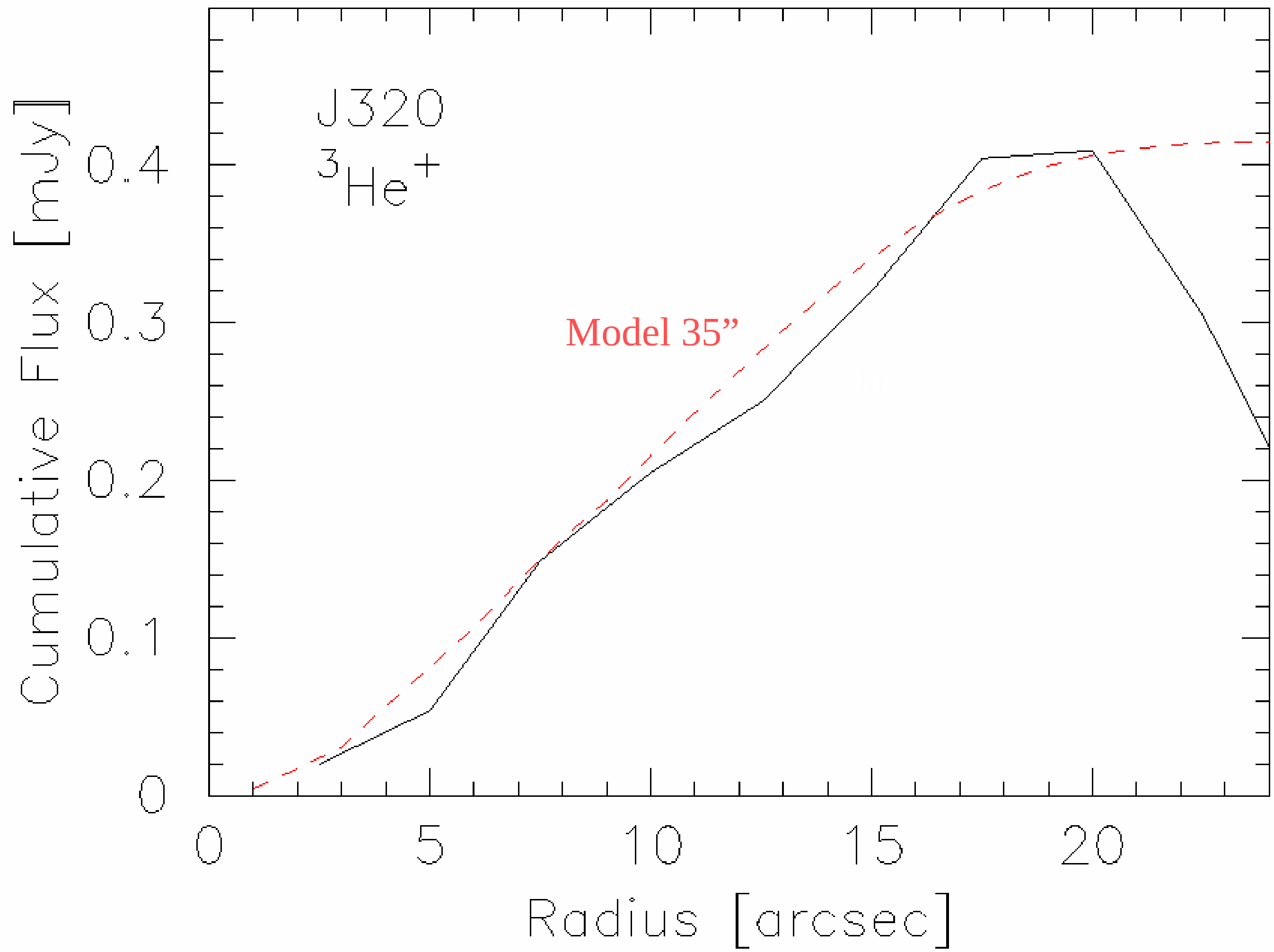
VLA Planetary Nebula J320



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

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





J320
$^3He^+$
Model 35”
Cumulative Flux [mJy]
0
0.1
0.2
0.3
0.4
0
5
10
15
20
Radius [arcsec]

Helium-3 Conclusions

- ~ 25% of PNe meet our selection criteria. To avoid conflict with Monica we should detect ^3He in only 1/5.
- We detect ^3He in the PN J320 with the VLA. The EVLA will be 10 x more sensitive than the VLA.
- We probably have found ^3He in NGC 7009 with the GBT and may have another detection in NGC 6543.
- Proposal pressure on the GBT may not allow us to solidify these results in the near future.

NAIC Arecibo Observatory 305 m

Helium-3 Conclusions

- The scheduling mode and proposal pressure on the GBT may not allow us to solidify these results in the near future.
- 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

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

Mixing and the ^{3}He problem

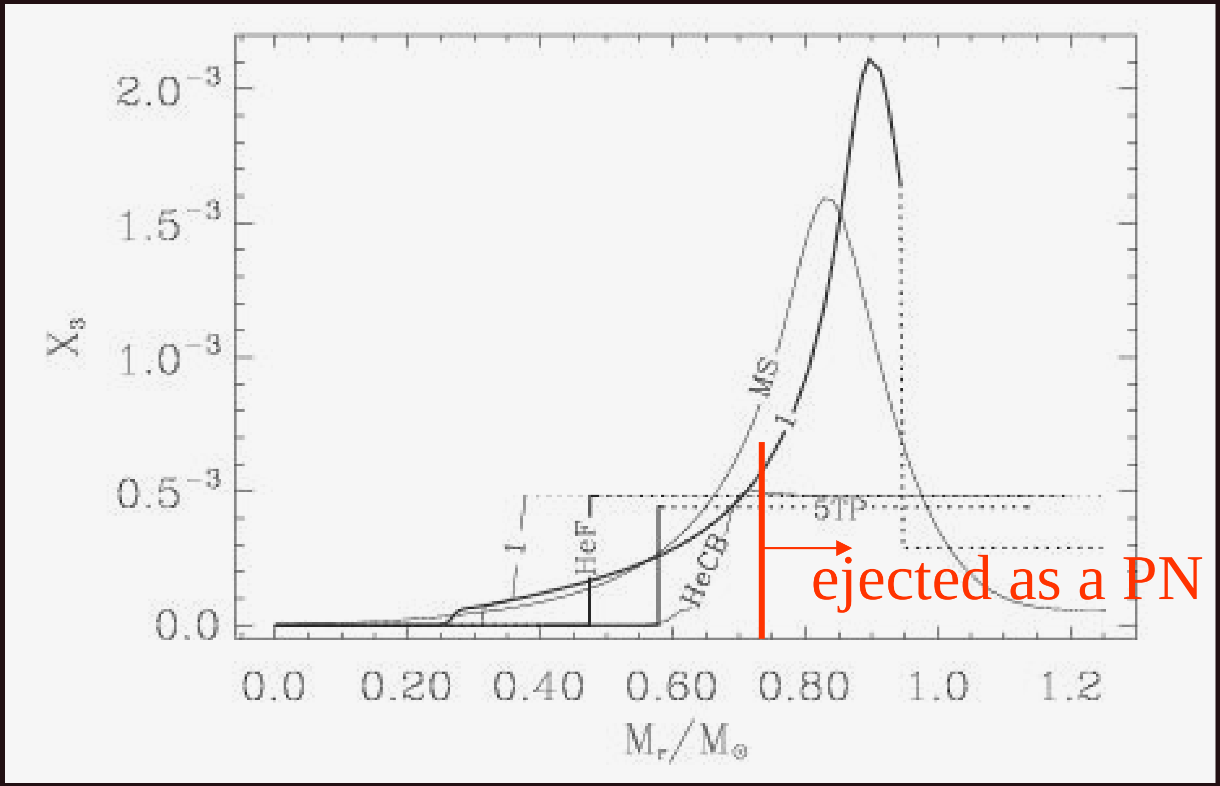
- *Daniele Galli (INAF-Arcetri)*
- *Francesco Palla (INAF-Arcetri)*
- *Monica Tosi (INAF-Bologna)*
- *Federico Ferrini (Univ. Pisa)*
- *Letizia Stanghellini (HST)*
- *Oscar Straniero (INAF-Teramo)*

A long standing problem

Rood, Steigman & Tinsley (1976)

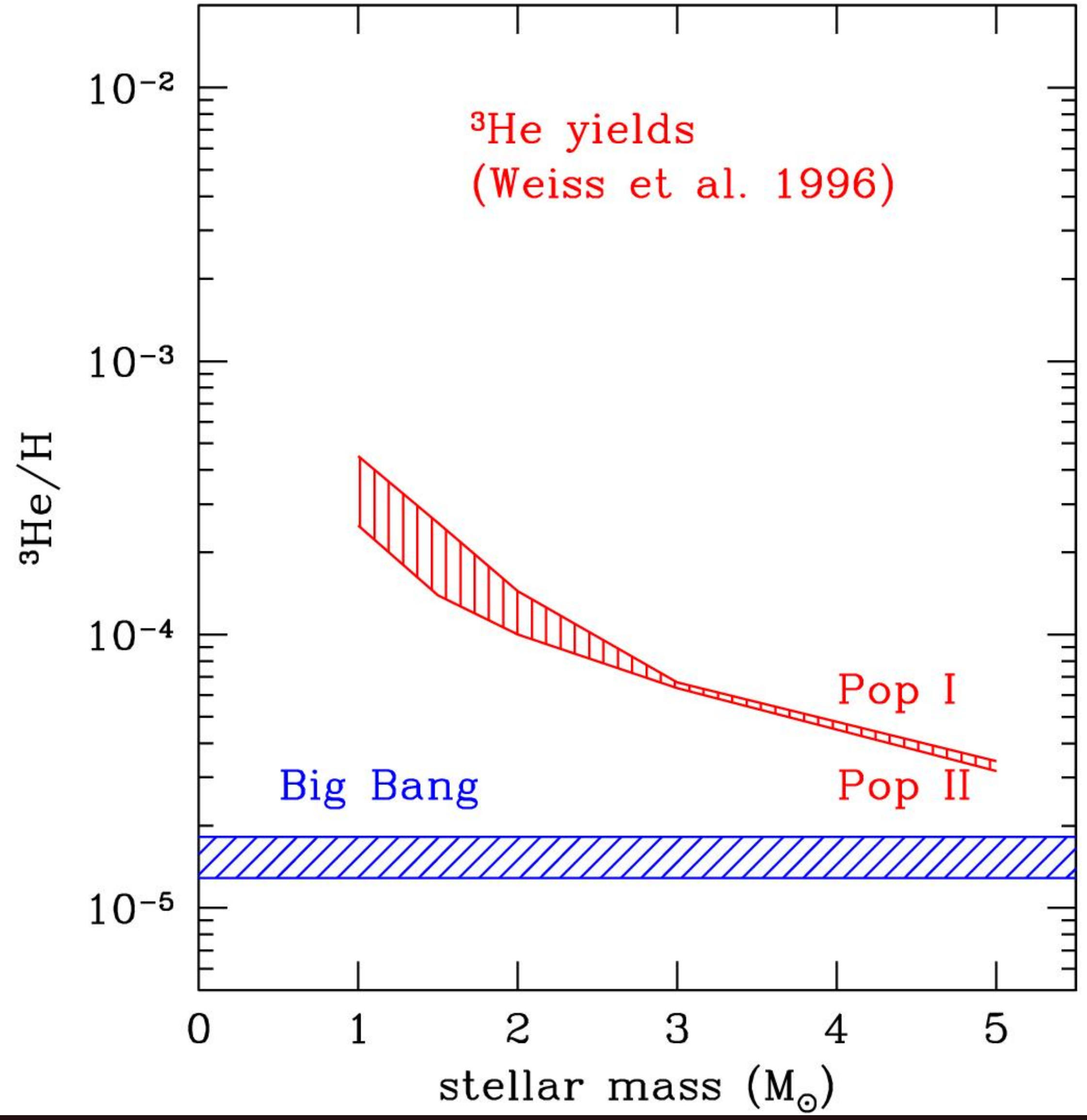
- Low-mass stars produce substantial amounts of ^{3}He, enriching the ISM: X_{3}♋ ↗ 10^{-3}
- But the measured protosolar value is much lower: $X_{3\odot}$ ↗ 10^{-5} ⇨ *problem!*

^{3}He 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?

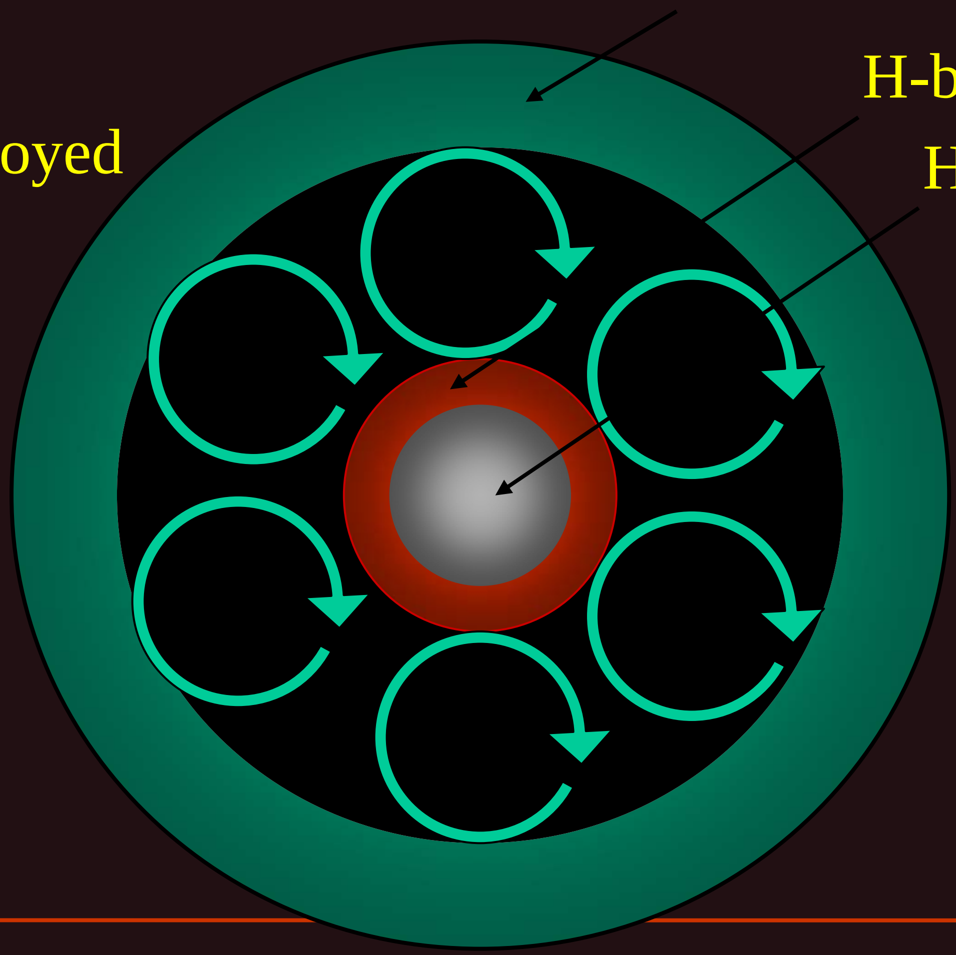
Mixing takes over

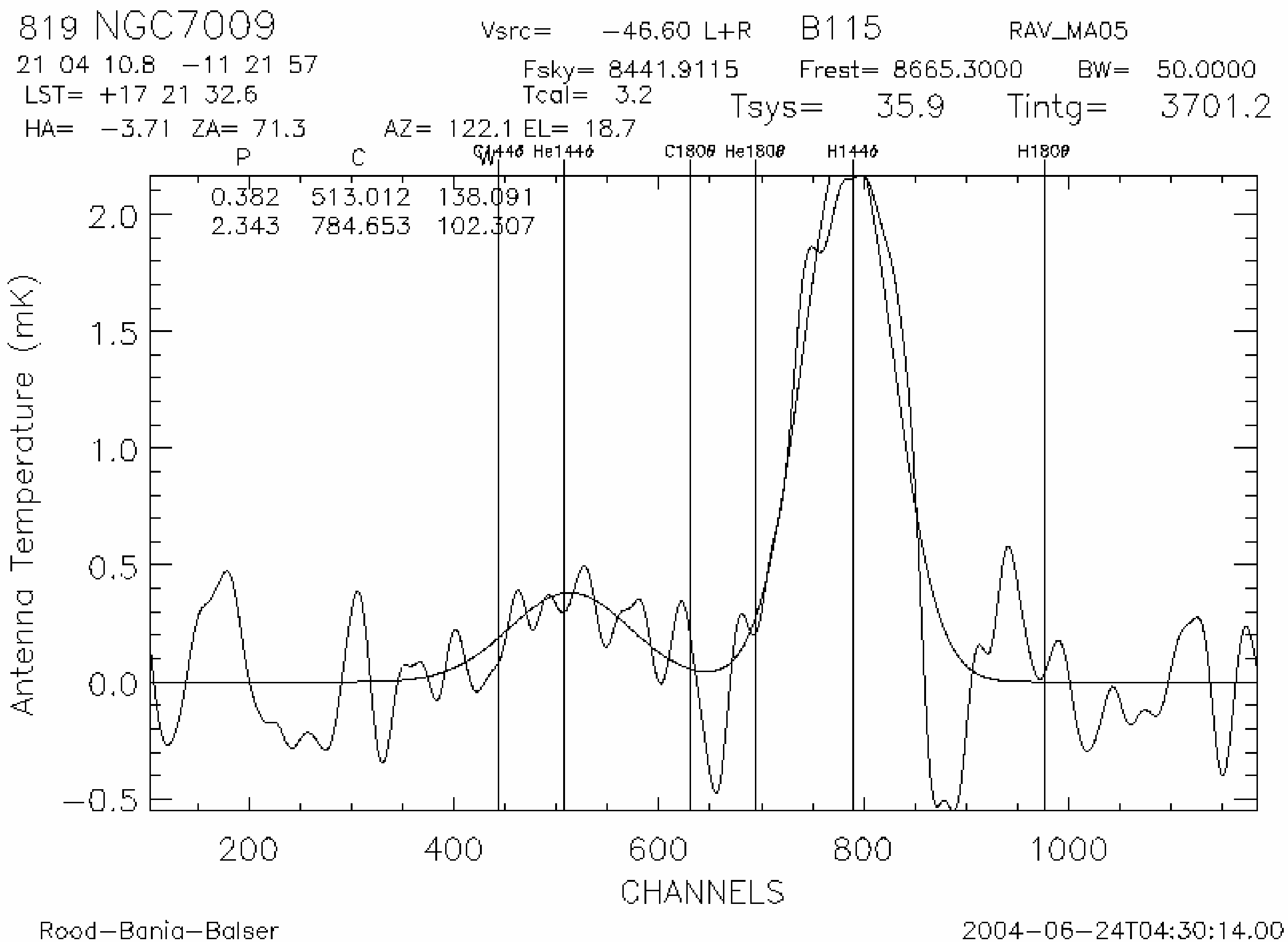
- *Charbonnel 1995* (see also *Hogan 1995*) : an extra-mixing mechanism acting during the RGB and/or AGB phases of stars with mass $M \rightarrow 2\ M_{\odot}$ can reduce the surface ^{3}He abundance
- Extra-mixing decreases the surface $^{12}C/^{13}C$: the ^{3}He problem is linked to other isotopic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

Mixing on the RGB

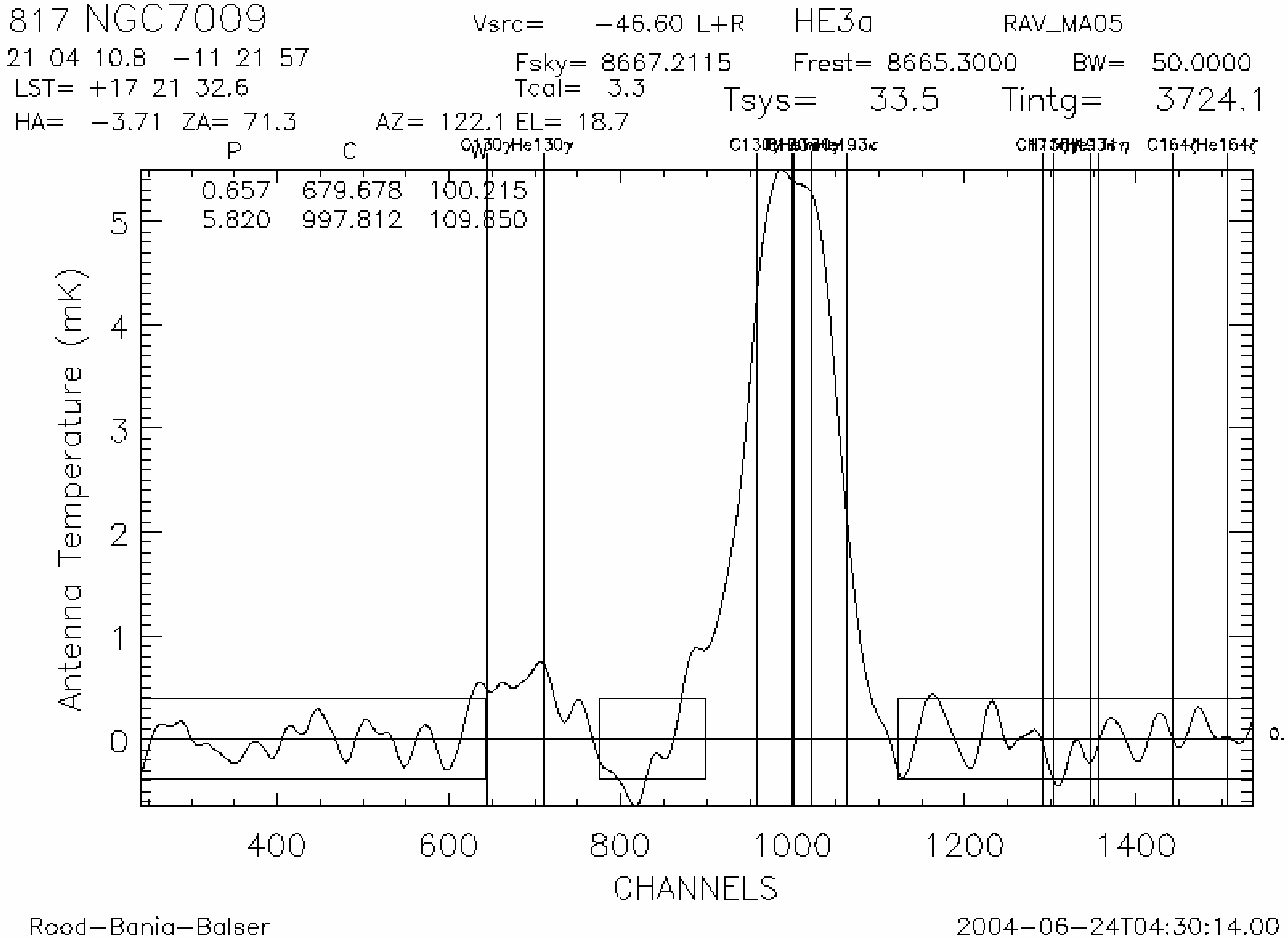
surface ^{3}He destroyed

^{13}C dredged-up





Conclude reliability level for NGC7009 ~ 0.5 mK



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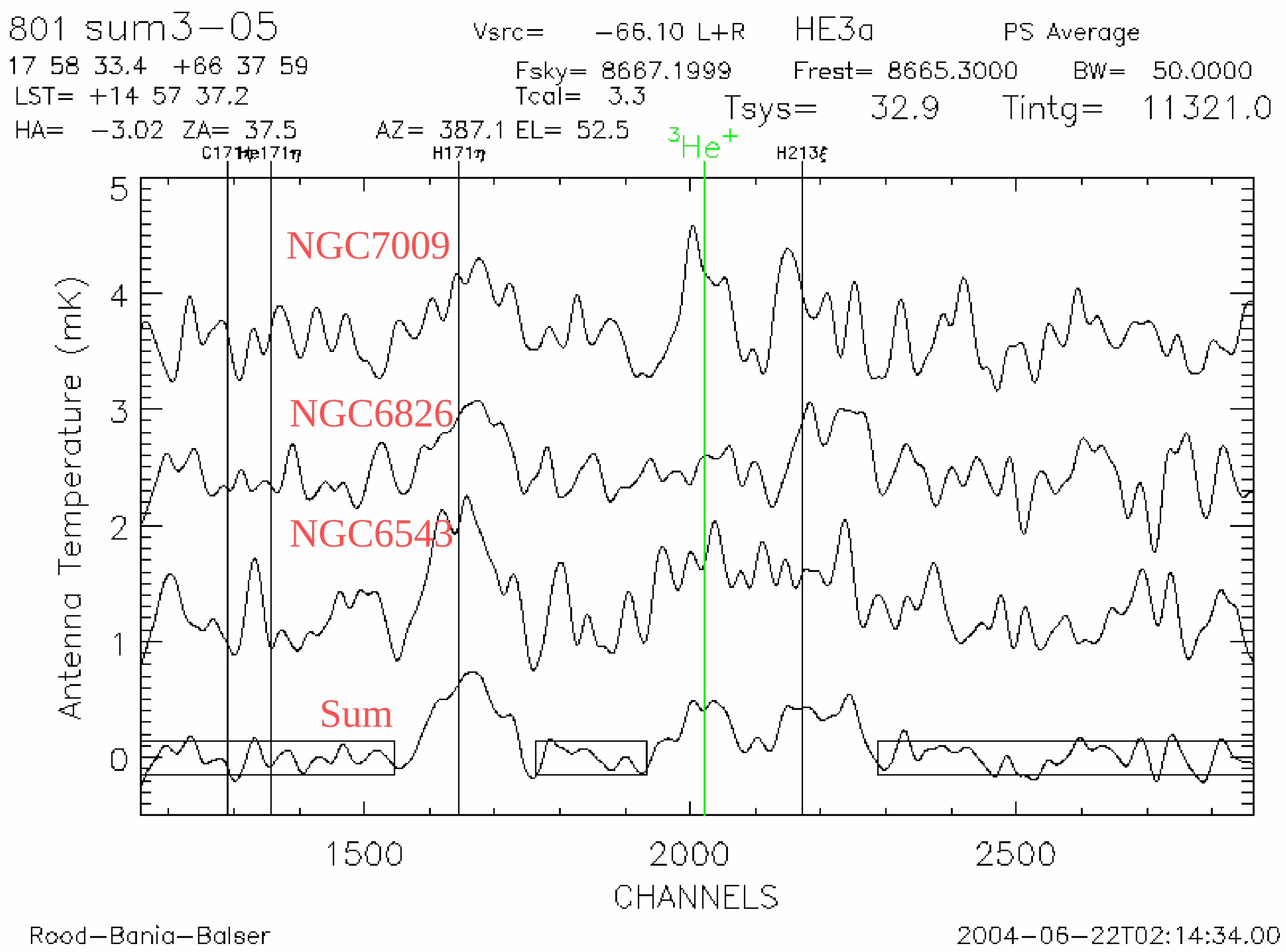
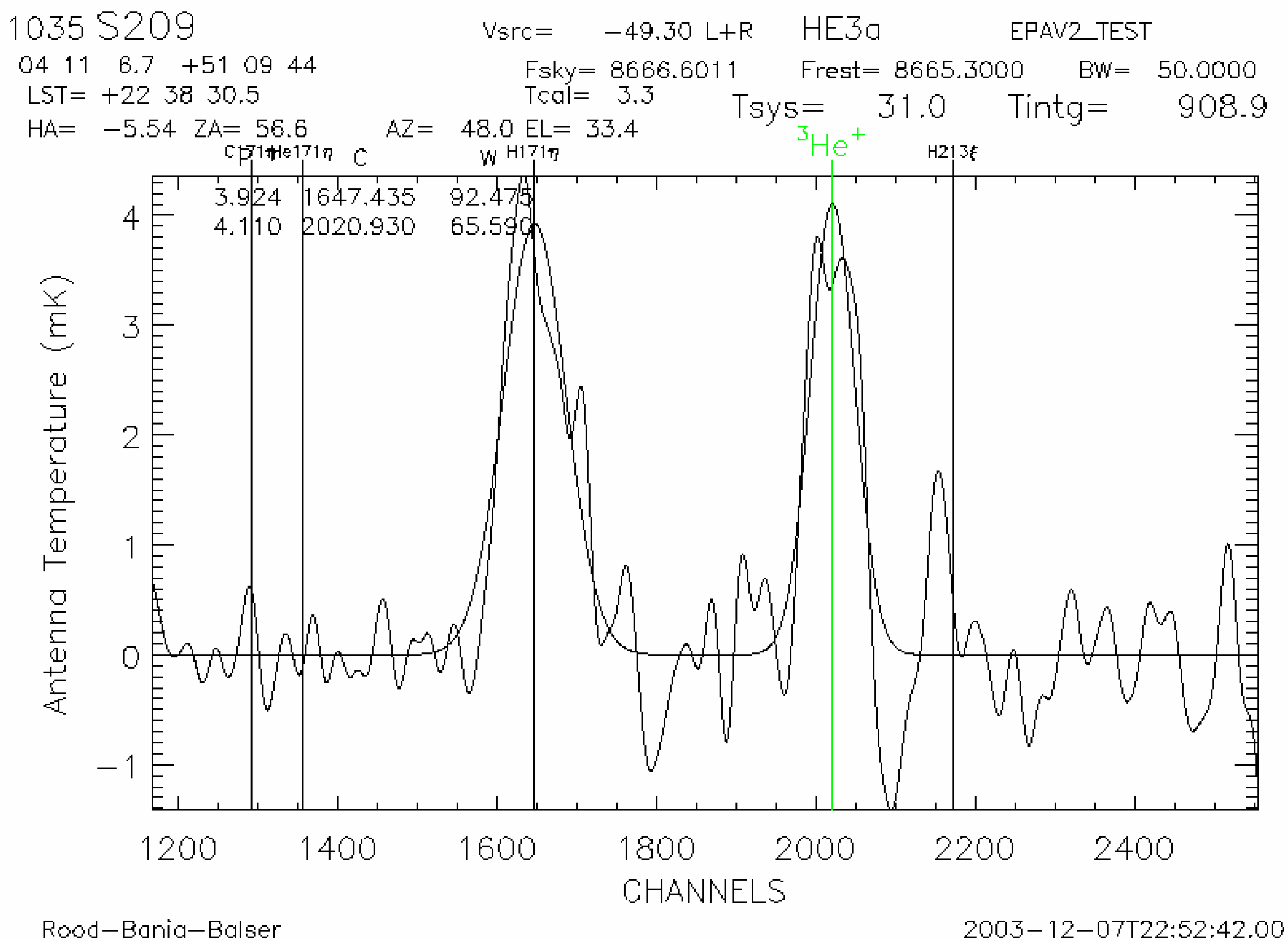
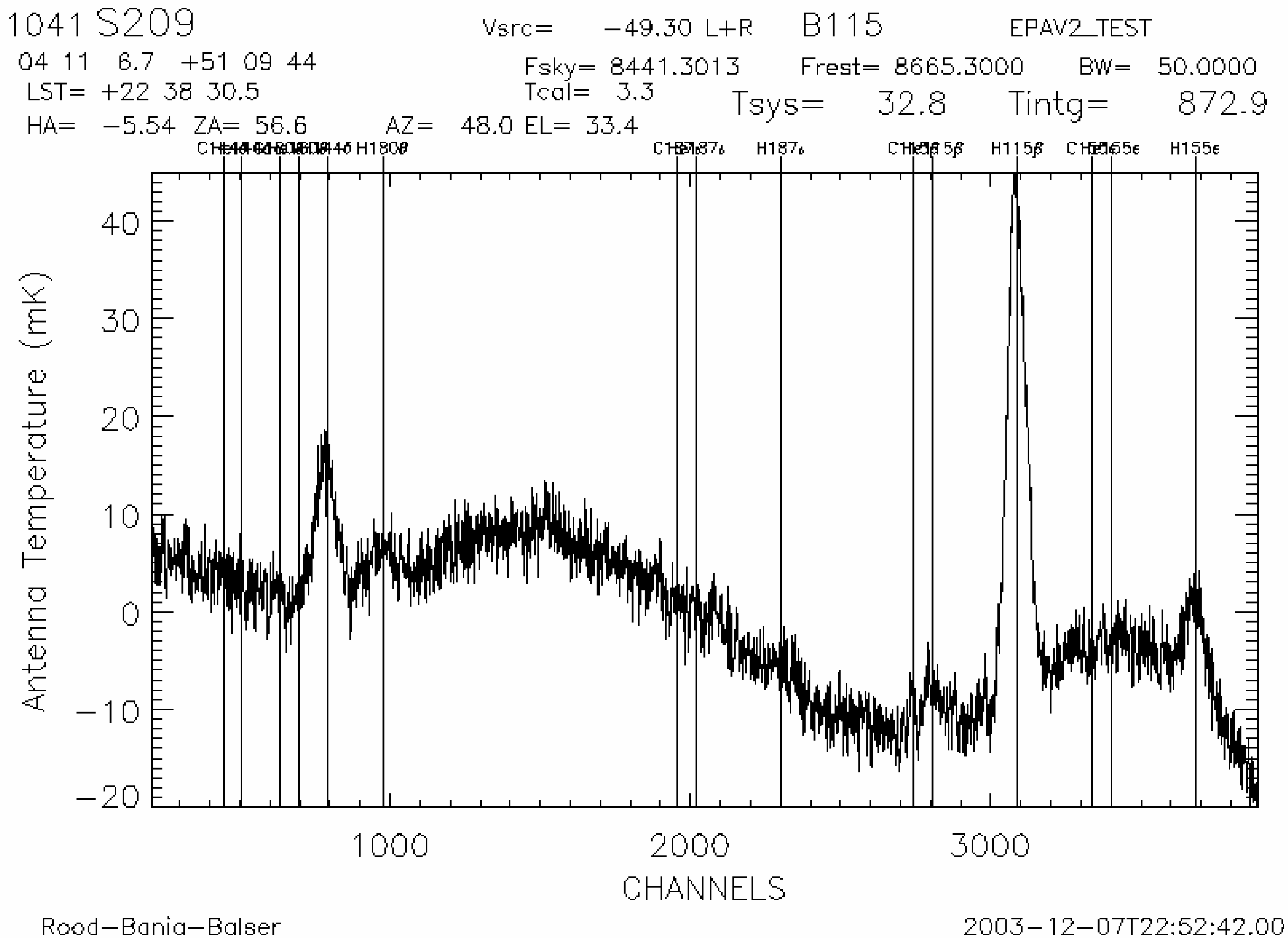
HA= −3.71 ZA= 71.3
AZ= 122.1 EL= 18.7
Vsrc= −46.60 L+R
HE3a
RAV_MA05
Fsky= 8667.2115
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 33.5
Tintg= 3724.1
P C W
0.657 679.678 100.215
5.820 997.812 109.850
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
2004−06−24T04:30:14.00

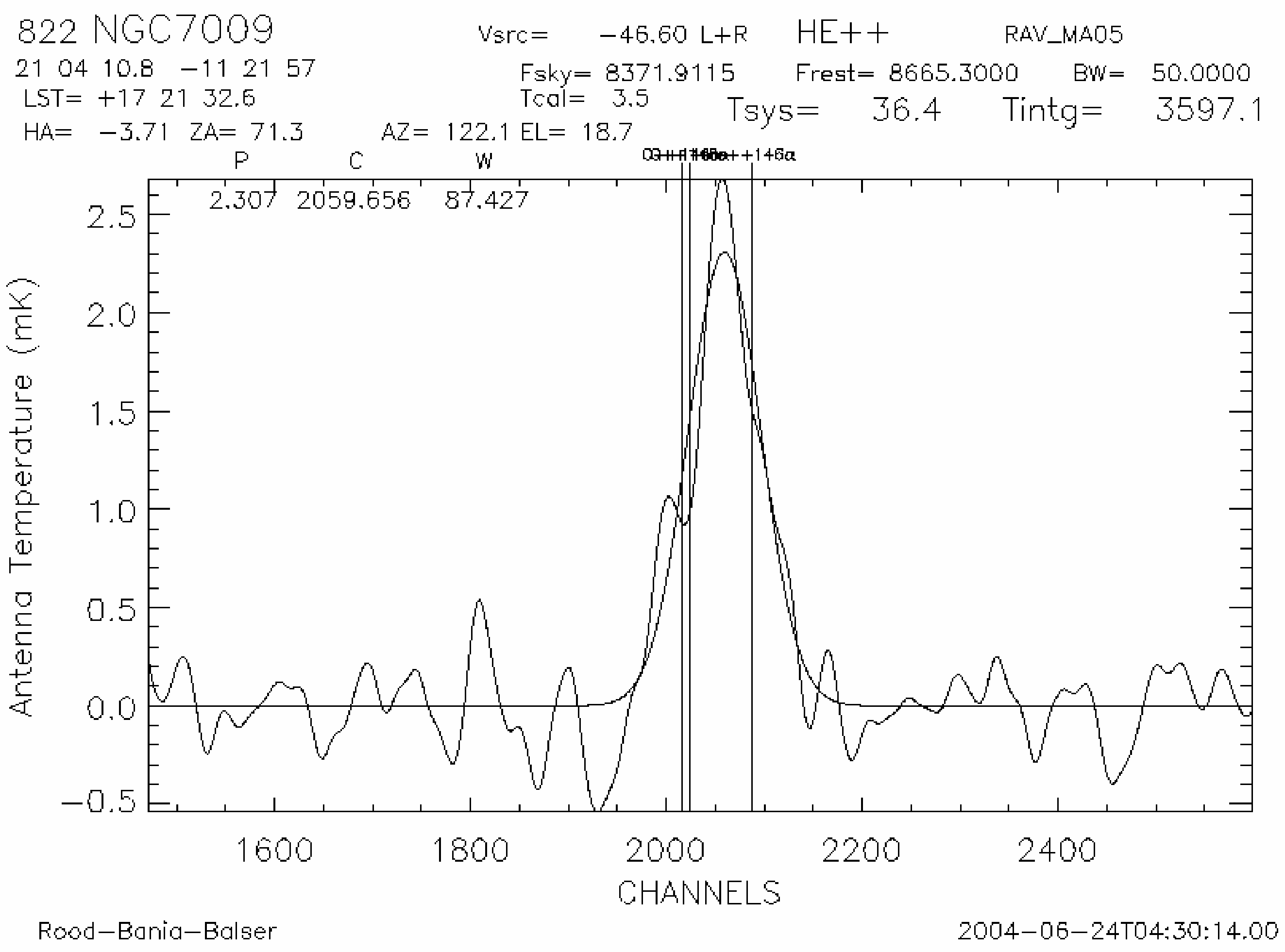


801 sum3-05
17 58 33.4 +66 37 59
LST= +14 57 37.2
HA= -3.02 ZA= 37.5
Vsrc= -66.10 L+R
HE3a
PS Average
Fsky= 8667.1999
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 32.9
Tintg= 11321.0
AZ= 387.1 EL= 52.5
3He+
H213ξ
H171η
NGC7009
NGC6826
NGC6543
Sum
Antenna Temperature (mK)
CHANNELS
1500
2000
2500
Rood-Bania-Balser
2004-06-22T02:14:34.00

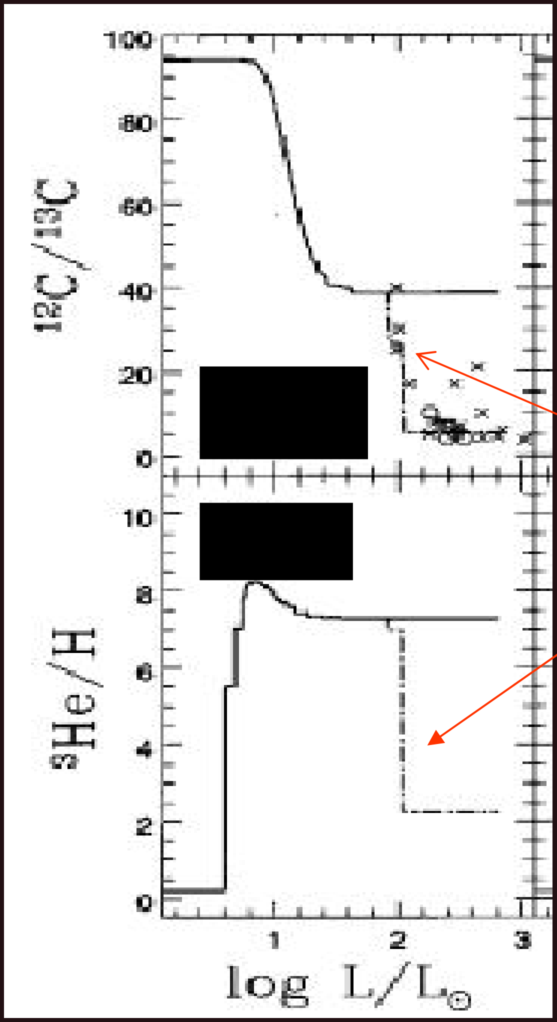

1035 S209
04 11 6.7 +51 09 44
LST= +22 38 30.5
HA= −5.54 ZA= 56.6
AZ= 48.0 EL= 33.4
Vsrc= −49.30 L+R
HE3a
EPAV2_TEST
Fsky= 8666.6011
Frest= 8665.3000
BW= 50.0000
Tcal= 3.3
Tsys= 31.0
Tintg= 908.9
3He+
H171η
H213ξ
3.924 1647.435 92.475
4.110 2020.930 65.590
Antenna Temperature (mK)
CHANNELS
Rood−Bania−Balser
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
40
30
20
10
0
−10
−20
Antenna Temperature (mK)
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



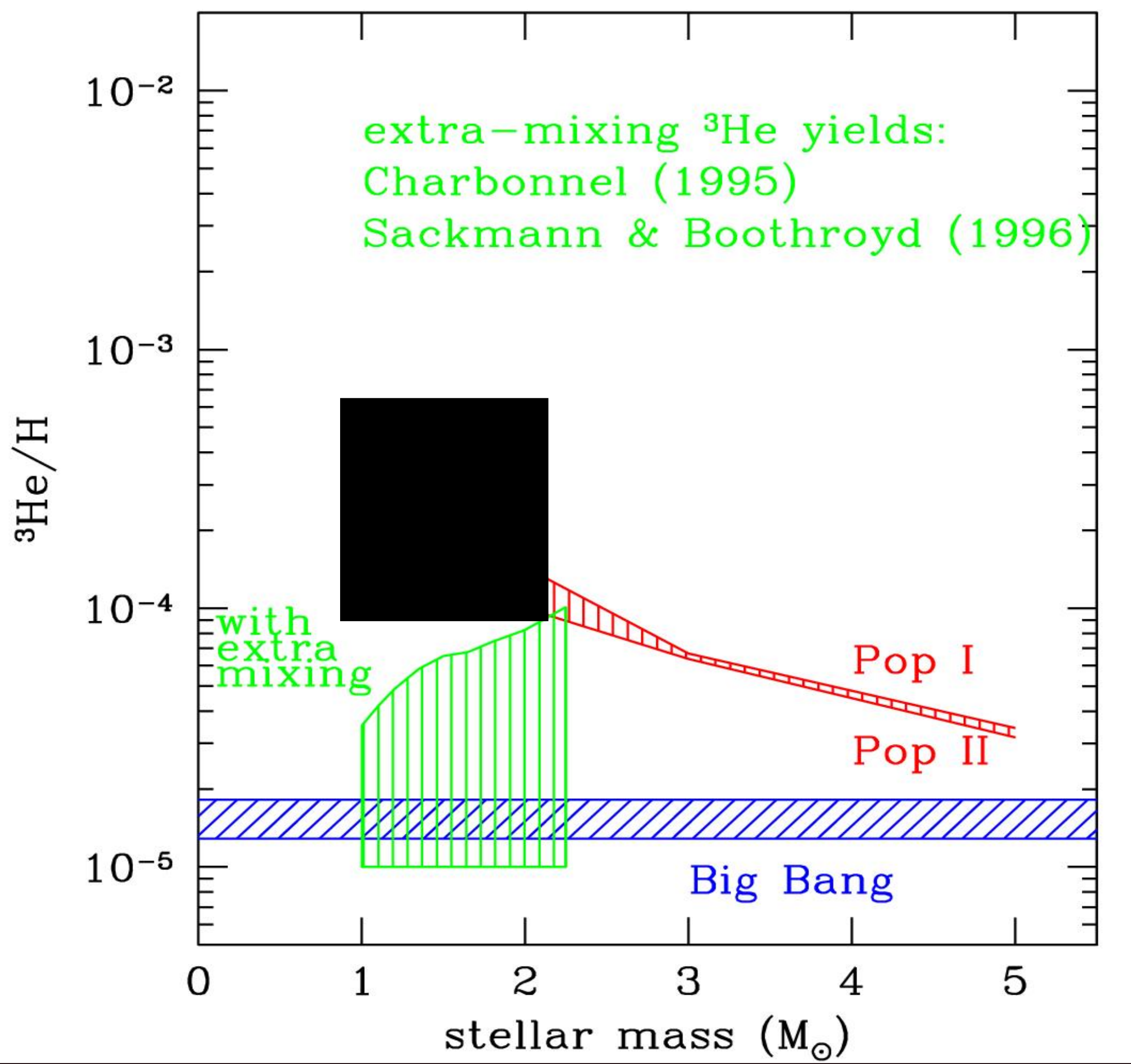
0.8 $M_\odot$

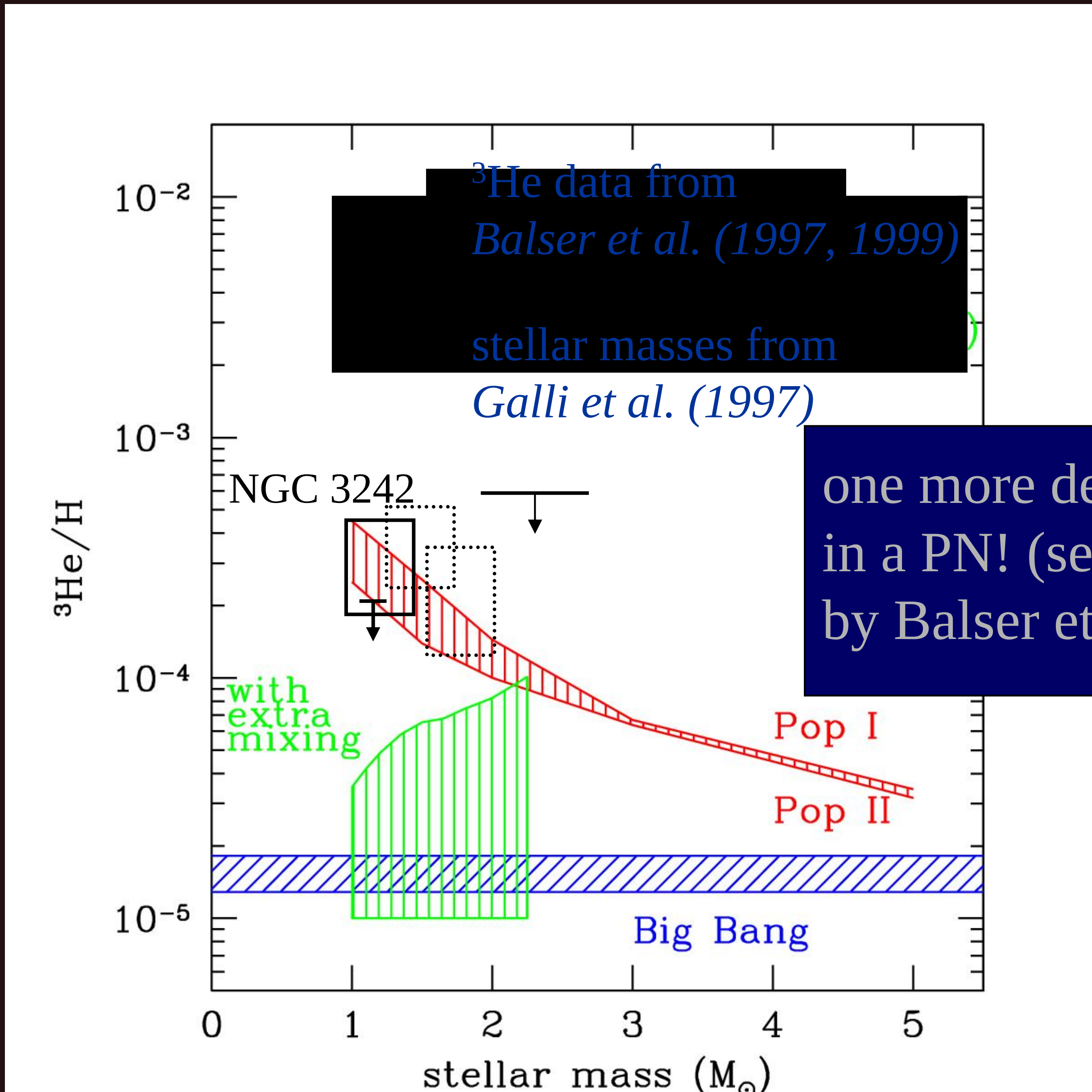
$Z=10^{-4}$

extra-mixing

Charbonnel (1995)

The “new” ^{3}He yields

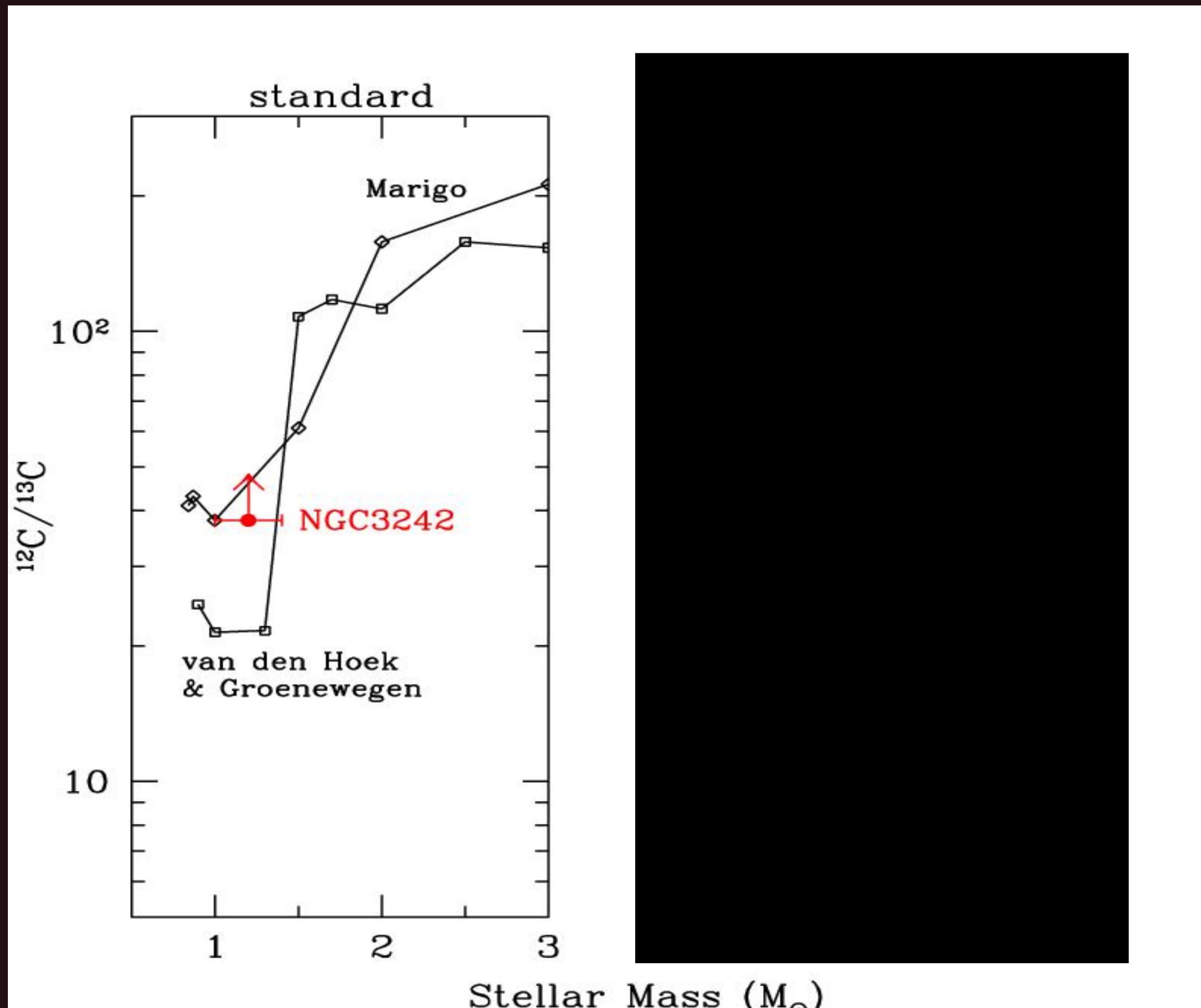




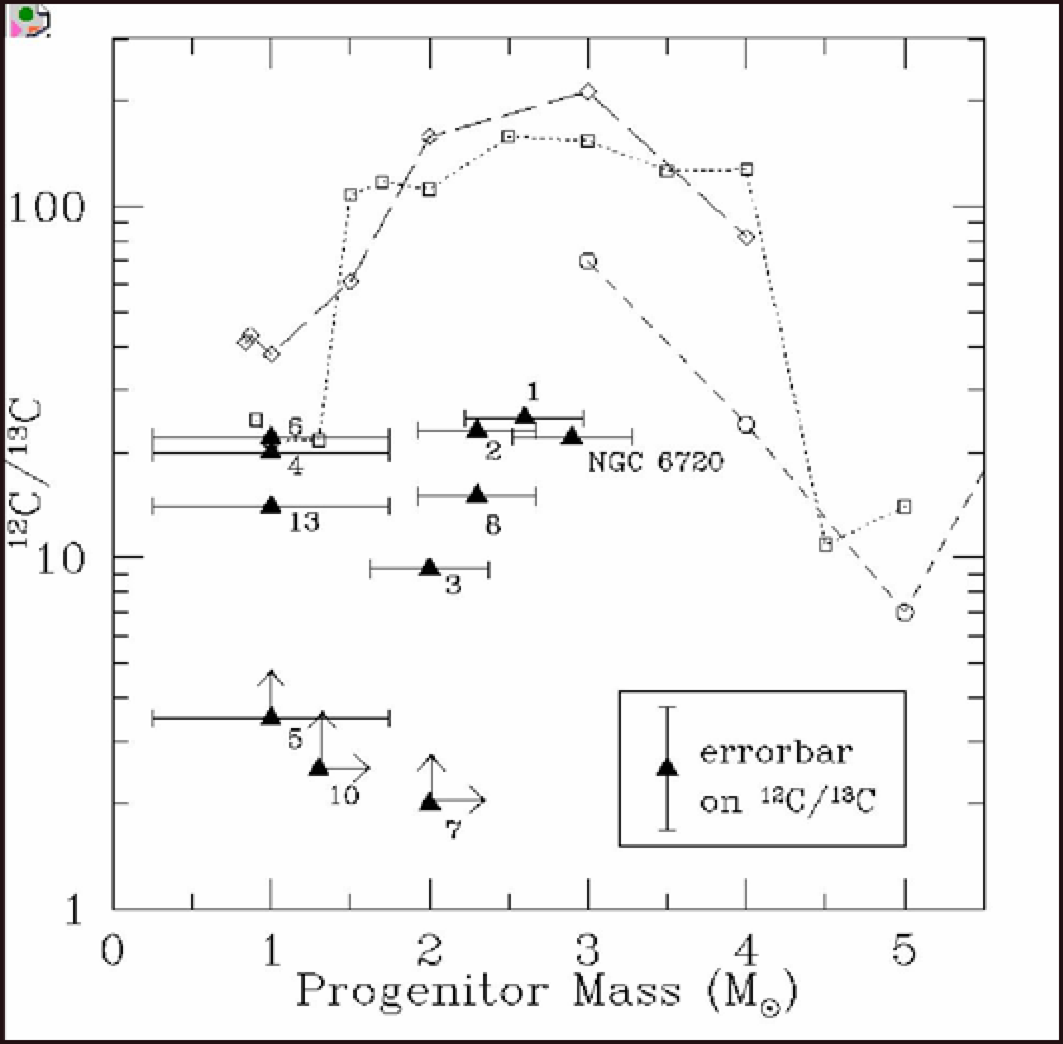
^{3}He data from
Balser et al. (1997, 1999)

stellar masses from
Galli et al. (1997)

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

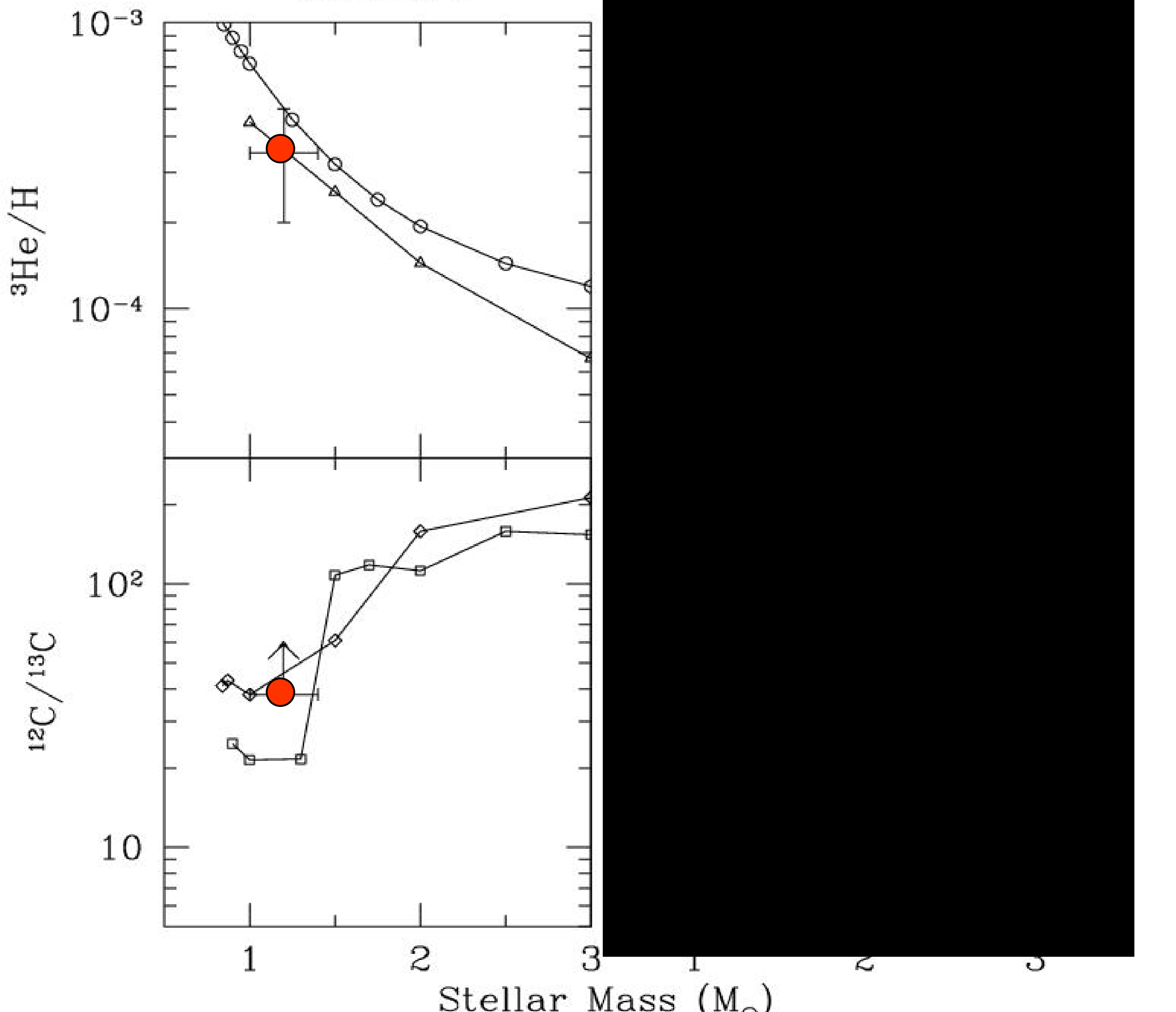


Palla, Galli, Marconi, Stanghellini & Tosi (2002)



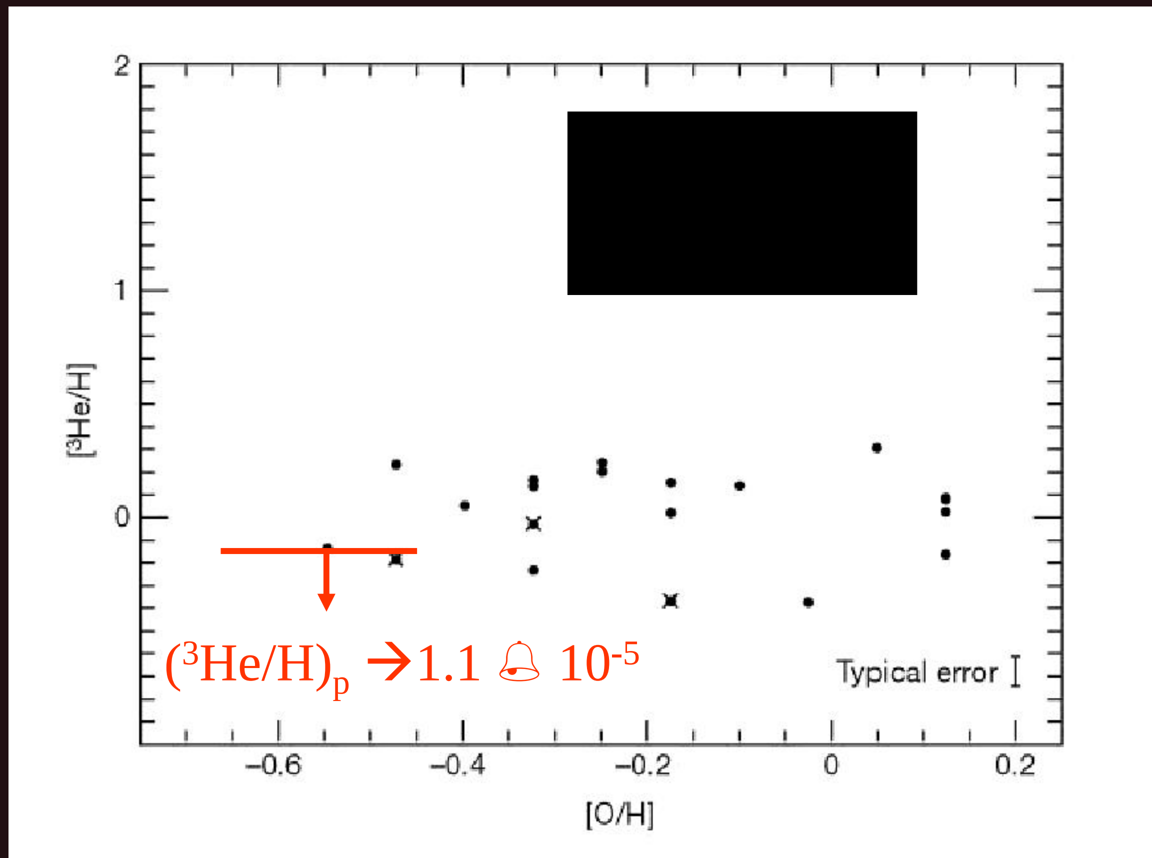
Palla et al. (2000)

ndard yields

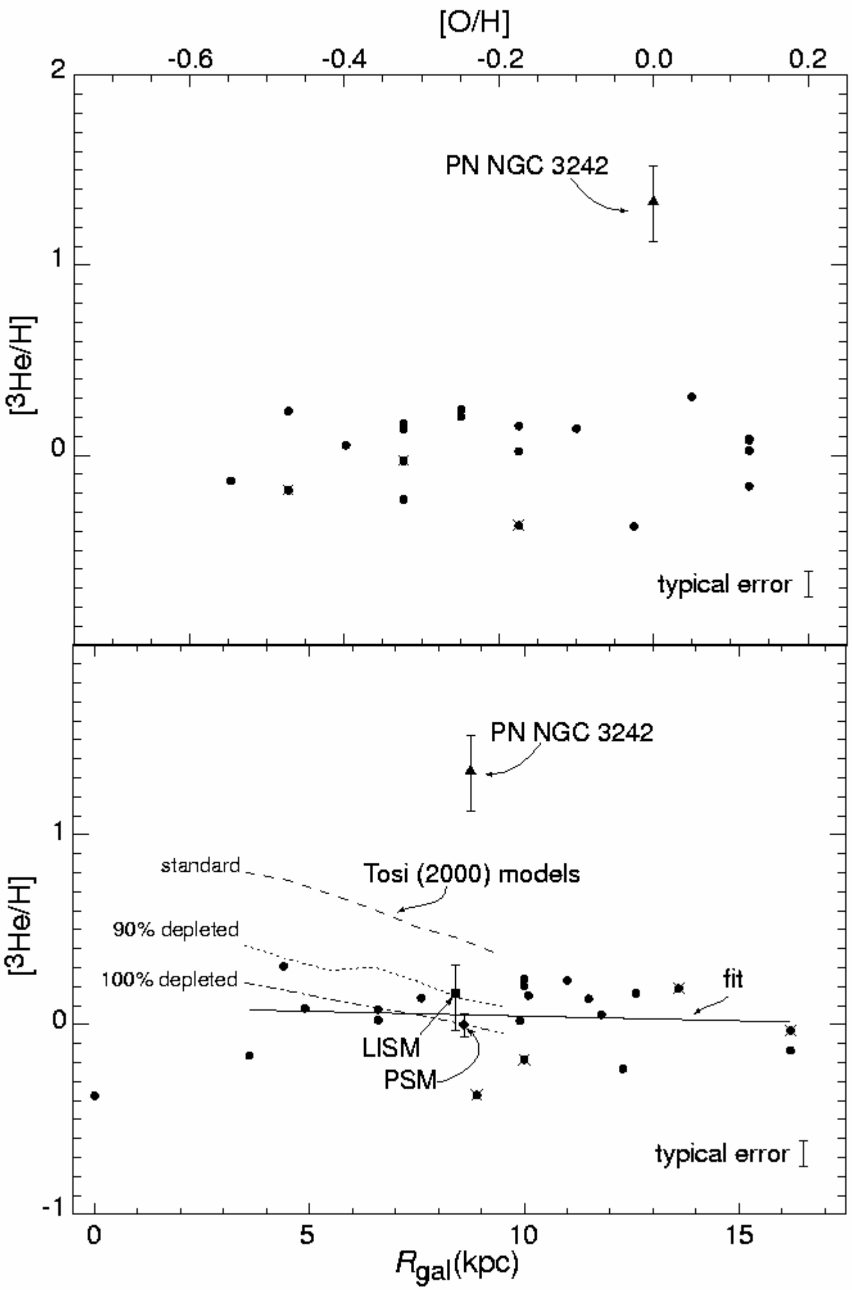


[redacted]

^{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