The Challenge to Understanding ^{26}Al Emission from OB Associations

Richard E. Rothschild, Richard E. Lingenfelter
Center for Astrophysics and Space Sciences
University of California, San Diego

and

James C. Hidgon
W. M. Keck Science Center
Claremont Colleges

``Faulty predictions are interesting, and can even help motivate and fund discoveries. But really, Nature has surprised us by giving us much more ^{26}Al that we had any right to expect. Your discovery is, therefore, typical of all great discoveries in that, rather than confirming our prejudices, it sets us on our ears! Me especially! What one can say when passing out credits, I think, is that Hoyle, B^2FH, and Cameron developed stellar nucleosynthesis, that Clayton developed the theory of testing the former by gamma ray astronomy, that Ramaty and Lingenfelter pointed out ^{26}Al as a possible target of interest, and that Arnett and Woosley calculated its yield from supernovae and nova.''

Donald D. Clayton in a letter to W.A. Mahoney on the
occasion of the HEAO-3 discovery of cosmic ^{26}Al gamma
rays, Feb 4, 1985

In the beginning…

1977-- Arnett and concurrently Ramaty and Lingenfelter predicted that ^{26}Al intensity from the direction of the Galactic center would be comparable to those from ^{56}Ni, ^{44}Ti, and ^{60}Fe, which had been identified by Clayton.

The predicted yield per supernovae along with a supernova rate of 1 per 30 years implied **$<M_{26}> \sim 0.4\ M_o$** from core collapse SNe.

1984-- Mahoney et al. announced the HEAO-3 detection of the ^{26}Al line at 1809 keV with a flux of 5+/-1 x10^{-4} photons cm^{-2} s^{-1} radian.

Since then-- Satellite and balloon instruments have confirmed the result which implies an average steady state mass **$<M_{26}> \sim 1.5—3\ M_o$** from all sources of ^{26}Al.

Conclusion -- ``… core collapse supernovae are not the dominant sources of Galactic ^{26}Al.''

Diehl, Prantzos, and von Ballmoos 2005

Early searches for the source of ^{26}Al in the Galaxy:

Not explosive Ne burning and neutrino interactions in SNII of $M>25\ M_o$ stars without wind losses, since winds greatly affect final masses.

Not type II SNa of $M<25\ M_o$ stars → only 10-15% contribution.

Not older population (novae and AGB stars) since ^{26}Al flux correlated with sources of UV emission, i.e. O stars.

Maybe it is Wolf-Rayet winds carrying dredged-up ^{26}Al

So, what about WR winds?

Initial work assumed wind mass loss rates twice what most optical observations suggested, and increased the yield by x4-6 over homogeneous wind models matched to optical data. Still, yields could only account for ½ of the ^{26}Al.

Consideration of non-homogeneous flow (``clumping'') required lowering of mass loss rates by x4-6.

Since ^{26}Al yield scales as mass loss rate squared, implied yields were down over an order of magnitude.

Considering effect of metallicity in inner Galaxy, gain back a factor of 2.

Stellar rotation effects can regain another factor of 2.

In the end, Wolf-Rayet wind models yield 0.6 – 1.4 M_o of the 1.5 – 3 M_o of the average steady state mass of ^{26}Al in the Galaxy.

Continuing challenges for the WR wind source of ^{26}Al:

The Nearest WR star --- γ^2 Velorum:

Initial Mass = 57+/-15 M_o;

Distance = 258^{+41}_{-31} pc;

$F_{1809} < 1.1 \times 10^{-5}$ photons cm^{-2} s^{-1} (2σ) COMPTEL

$< 2.6 \times 10^{-5}$ photons cm^{-2} s^{-1} (2σ) SPI

Prediction:

$M_{26} = 2.2 \times 10^{-4}$ M_o for 60 M_o initial mass, solar metallicity, 300 km/s wind

(Palacios et al. 2005)

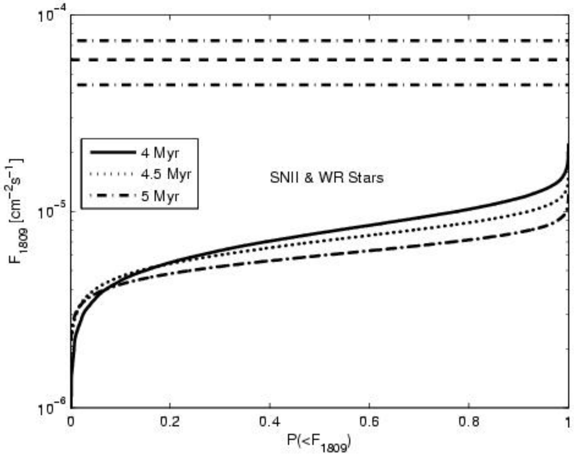
$F_{1809} = (3\text{-}5) \times 10^{-5}$ photons cm^{-2} s^{-1} at 227-299 pc

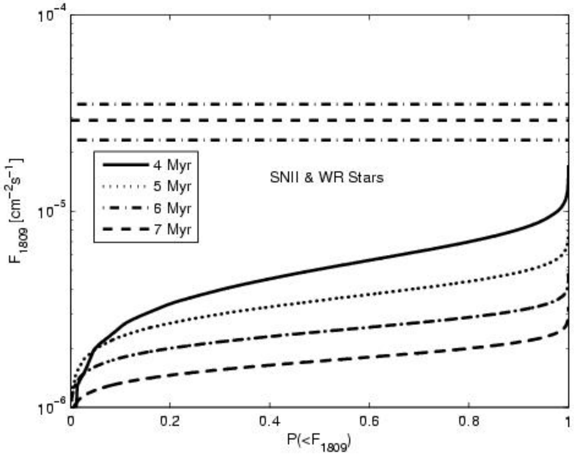
Continuing challenges for the WR wind source of ^{26}Al:

Nearby OB Associations:

Cyg OB2	Vela OB1
F_{1809}=5.8+/-1.5x10^{-5} cm^{-2} s^{-1}	F_{1809}=2.9+/-0.6x10^{-5} cm^{-2} s^{-1}
Distance=1.7+/-0.4 kpc	Distance=1.8+/-0.4 kpc
Age=1-5 Myr	Age=5+/-2 Myr
#stars 15-40 M_o=40	#stars 15-40 M_o=38

Monte Carlo simulation to model ^{26}Al yields from OB Associations





Continuing challenges for the WR wind source of ^{26}Al:

Of the 9 largest, nearby (<2 kpc) OB associations,

Significant ^{26}Al flux has been detected from regions of the sky containing only 3 of them (Vela OB1, Cyg OB2, & Ori OB1a).

Flux not detected from 6 others (Cep OB2, Gem OB1, Mon OB2, Cen OB1, Ara OB1, and Sco OB1).

Wolf-Rayet winds and SNII may not be the dominant source of ^{26}Al in the Galaxy

^{26}Al from close binary SNIb/c events

WR stars in close binaries undergo mass transfer, losing mass to companion.

Nakamura et al. (2001) calculated ^{26}Al yield from SNIb/c of He cores from these stars.

M_{final} = 6 – 8 M_o gives M_{26} = 6.7 to 12 x10^{-2} M_o

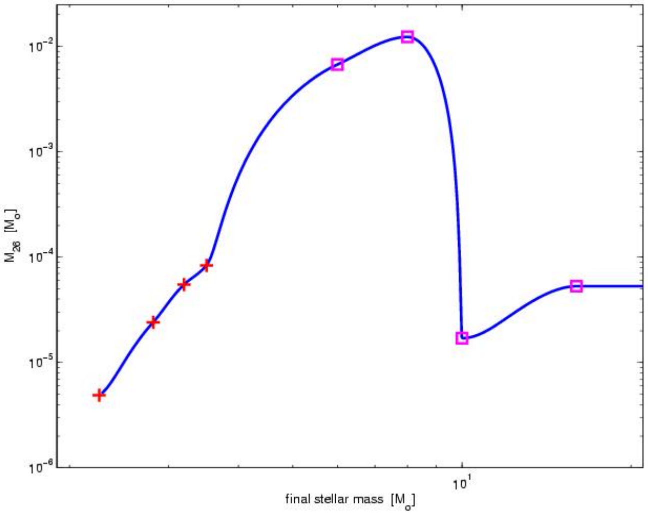
M_{final} = 10 – 16 M_o gives M_{26} = 1.7 to 5.2x10^{-5} M_o

Woosley, Langer & Weaver (1995) calculated ^{26}Al yields for lower final mass SNIb/c

M_{final} 2.3 – 3.5 M_o gives M_{26} = 4.9 to 8.4x10^{-5} M_o

Extrapolated low WLW to Nakamura using a $E^{6.5}$ power law in mass, giving 7.6x10^{-3} M_o at 7 M_o, which agrees with Nakamura et al.

M_{final} ~ 6-8 M_o dominates M_{26} yield



But wait! How does one get final masses in the 6-8 M_o range?

For single stars,

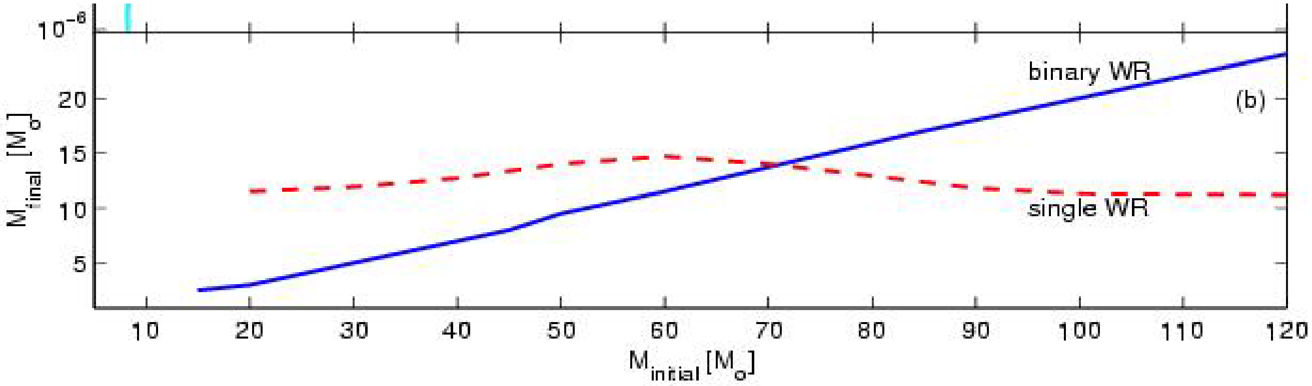
$M_{final} > 8\ M_o$ → neutron stars and black holes via SNII

$M_{final} <$ few M_o → white dwarfs and then SNIa or SNIb/c

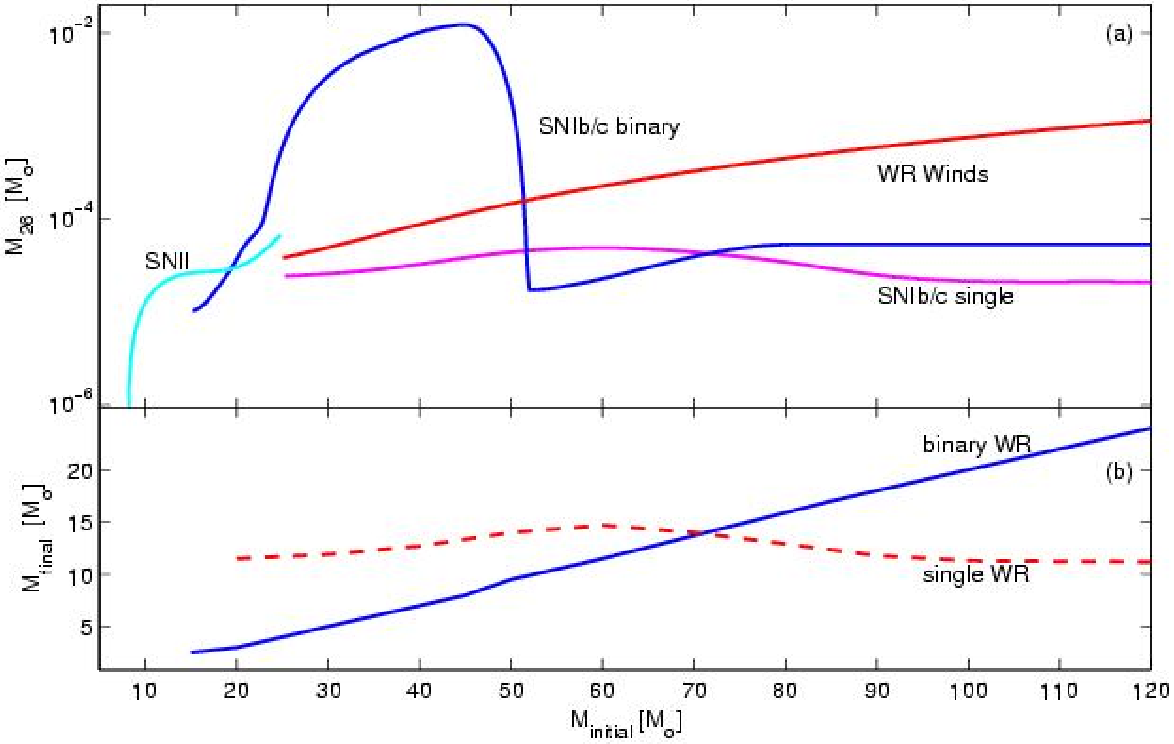
Mass transfer in close binary systems (Van Bever & Vanbeveren 2003):

Systems with 1 day to 10 years orbital periods yield 6-8 M_o final masses

Includes 1/8 of all stars if 40% are in binaries



Combine the various sources of ^{26}Al as a function of initial mass



SNIb/c binary: Woosley/Nakamura combo + Vanbeveren close binary calc.

SNIb/c single: Woosley/Nakamura combo + Maynet & Maeder single WR calc.

WR winds: Maynet & Maeder

SNII: Timmes et al. and Rauscher et al.

The Challenge to Understanding ^{26}Al Emission from OB Associations

The dominant yield is from SNIb/c of 30-50 M_o

This range represents ~8% of all core collapse SN progenitors (>8 M_o)

And since 1/8 of all stars are in close binary systems,

Close binary SNIb/c represent 1% of all Galactic core collapse SN progenitors.

Very stochastic nature for timescales of 10 Myr or less.

Estimated Galactic ^{26}Al Content

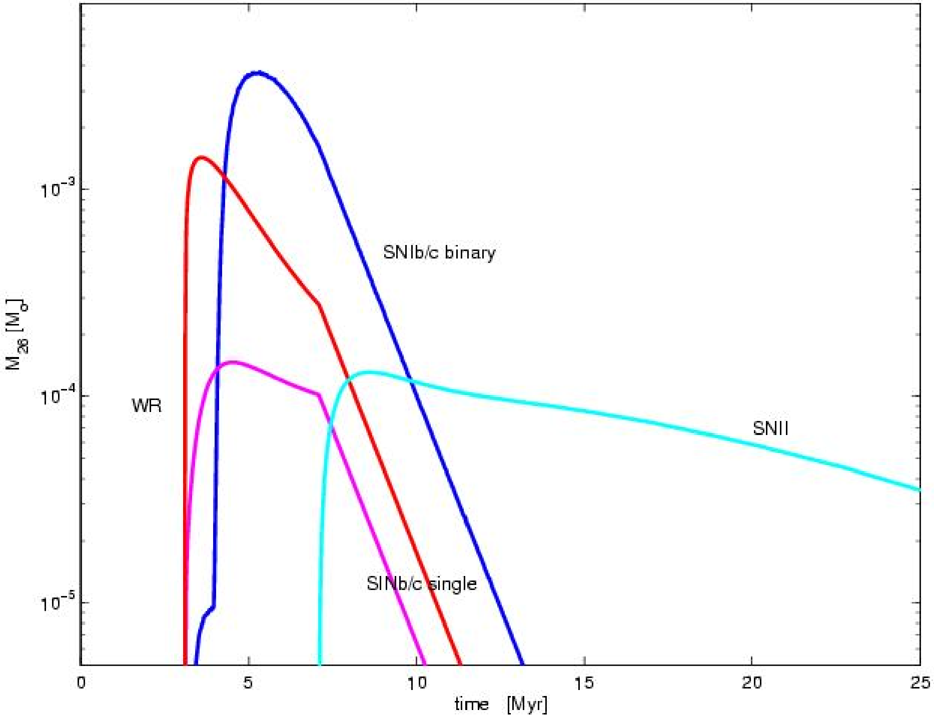
Integrate yields over Salpeter IMF and total core collapse SN rate of 1/40 yr

Close binary SNIb/c:	2.5 M_o
WR winds:	1.4 M_o
SNII:	0.4 M_o
Single SNIb/c:	0.14 M_o
Total	4.4 M_o

A bit higher than the present estimate of 3.1+/-0.9 M_o (Knodlseder 1999)

60% of ^{26}Al attributable to close binary SNIb/c of 30-50 M_o WR stars

Moderate Sized OB Association



Time dependent 1.809 MeV emission from moderate sized OB association

100 core collapse SN (8-120 M_o); calculated stellar ages vs initial mass (Schaller et al (1992)

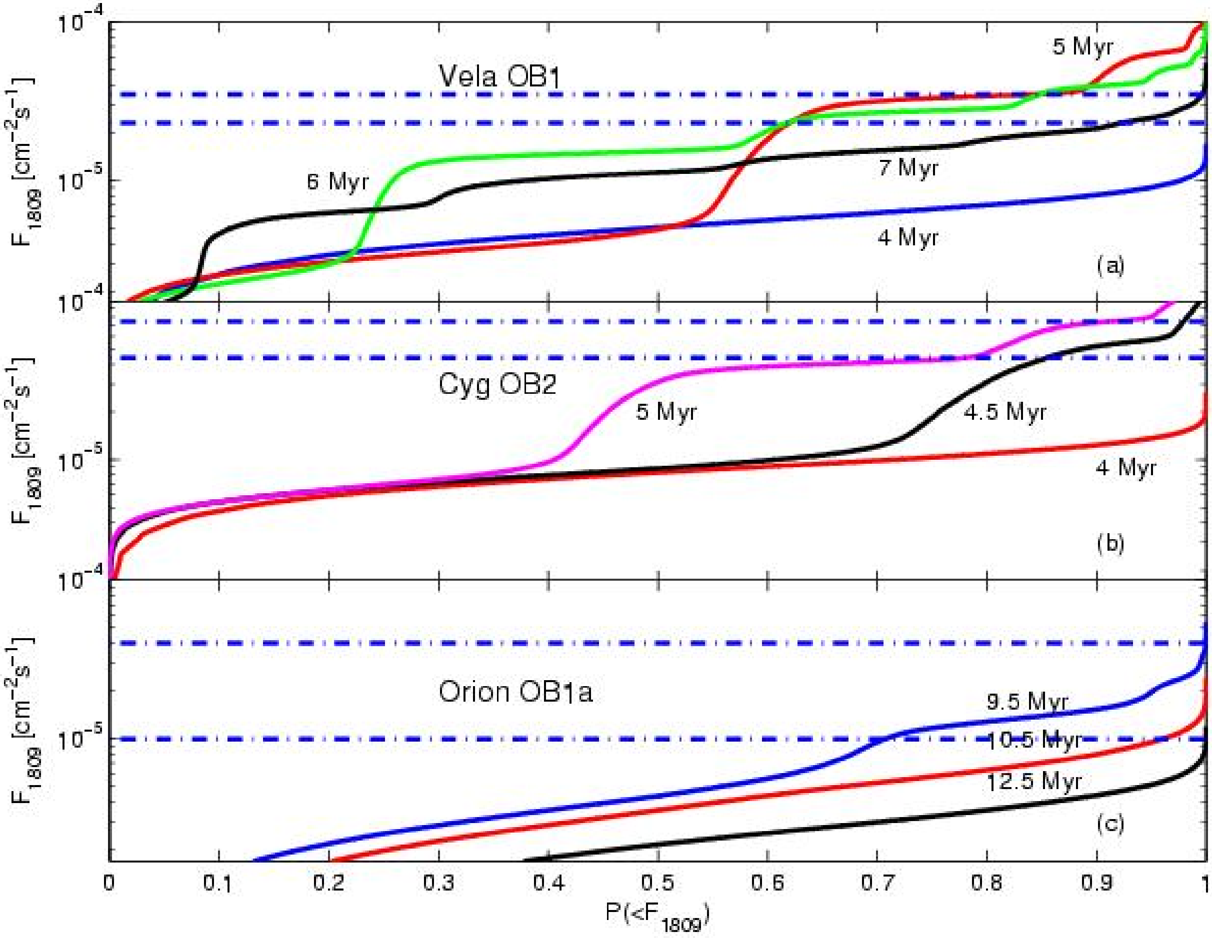
The Challenge to Understanding ^{26}Al Emission from OB Associations

Vela OB1: 5+/-2 Myr; 118-155 SN

38 stars (15-40 M_o)

One or two close binary SNIb/c

~40% chance of observed flux for 5-6 Myr age



Cyg OB2: 1-5 Myr; >120 SN

40 stars (15-40 M_o); 3x more?

One or two close binary SNIb/c

~20% chance of observed flux for 5 Myr age

Orion OB1a: 11.4+/-1.9 Myr;

25 SN; mostly SNII contribution

~30% chance of observed flux for 9.5-10 Myr age

The Challenge for Understanding ^{26}Al Emission from OB Associations

Note the stochastic nature of the dominant ^{26}Al emission

One or two close binary SNIb/c provides the flux in addition to WR winds and SNII, depending upon age, to match observations.

Only 1/3 of the 9 largest nearest OB associations have been detected at 1.809 MeV where the flux from a single close binary SNIb/c could be detected.

Conclusions:

1. The flux from OB associations is under-predicted in many cases for the largest nearby associations, while the flux from WR winds is over-predicted for individual stars.

   NEED DETAILED OBSERVATIONS OF OTHER 6 OB ASSOCIATIONS

2. The yield from He core collapse SNIb/c appears to be a very steeply rising function of final stellar mass from 2-8 M_o with maximum yields 6-8 M_o.

   NEED DETAILED CALCULATIONS IN THIS RANGE

3. 30-50 M_o initial mass WR stars reach 6-8 M_o final mass through close binary mass transfer, and dominate the ^{26}Al yields for associations of age 5-10 Myr.

   NEED INDEPENDENT CALCULATIONS

Until then:

1. The addition of close binary WR SNIb/c as contributors to the average steady state Galactic ^{26}Al mass can explain total contribution observed.
2. The detection/non-detection of the largest, closest OB associations at 1.809 MeV can be explained by the **STOCHASTIC NATURE** of the dominant close binary SNIb/c sources.

Those that object to the close binary SNIb/c idea might consider

1. Providing the stochastic nature through increased WR wind yields at high (shorter lived) mass end.
2. Note, γ^2 Velorum at ~60 M_o is over-predicted, so increased wind yields need to be for higher mass WR stars.