Nucleocosmochronology and the r Process

Brad Meyer

Clemson University

The basic program

- We know the solar system's initial abundance of $^{238}U/^{232}Th$:
  - $N(^{238}U/^{232}Th) = 0.431$
- We compute the production ratio $P(^{238}U)/P(^{232}Th)$ in the r-process
- We determine the age of the Galaxy by computing the age of the elements from these data

Single-Event Age

$$\frac{N(^{238}U)}{N(^{232}Th)} = \frac{P(^{238}U)}{P(^{232}Th)} \frac{e^{-\lambda_{238}T}}{e^{-\lambda_{232}T}}$$

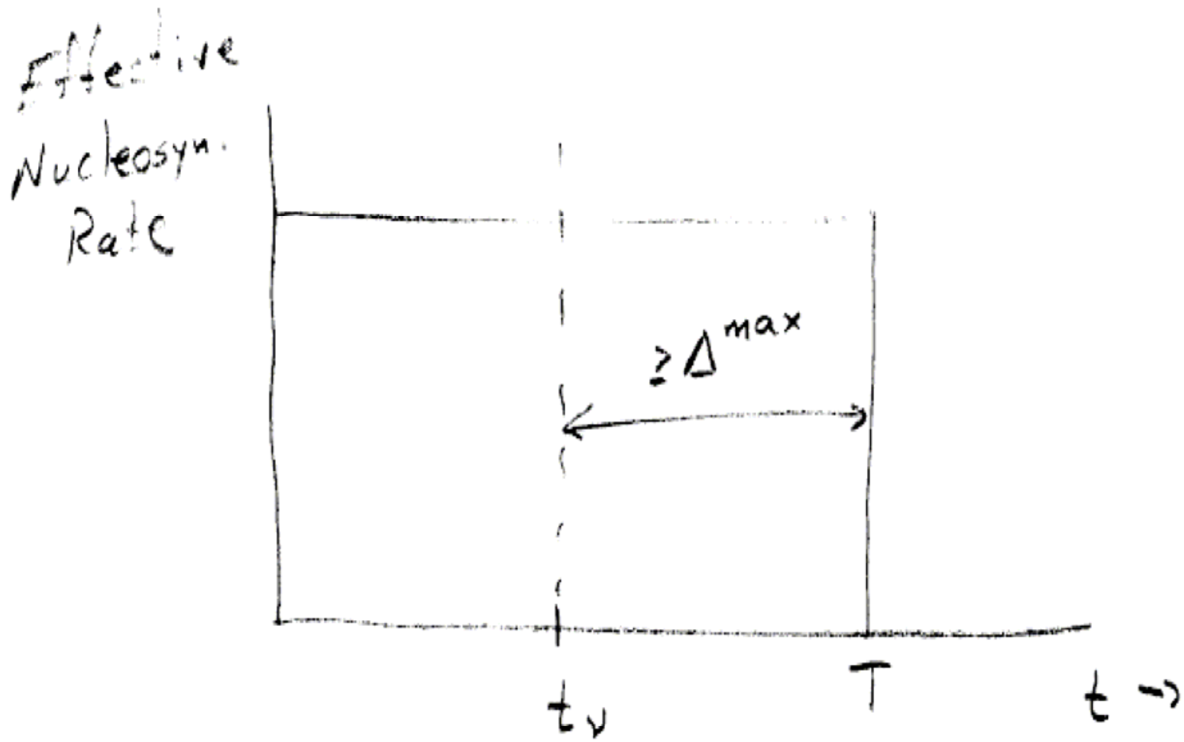
thus

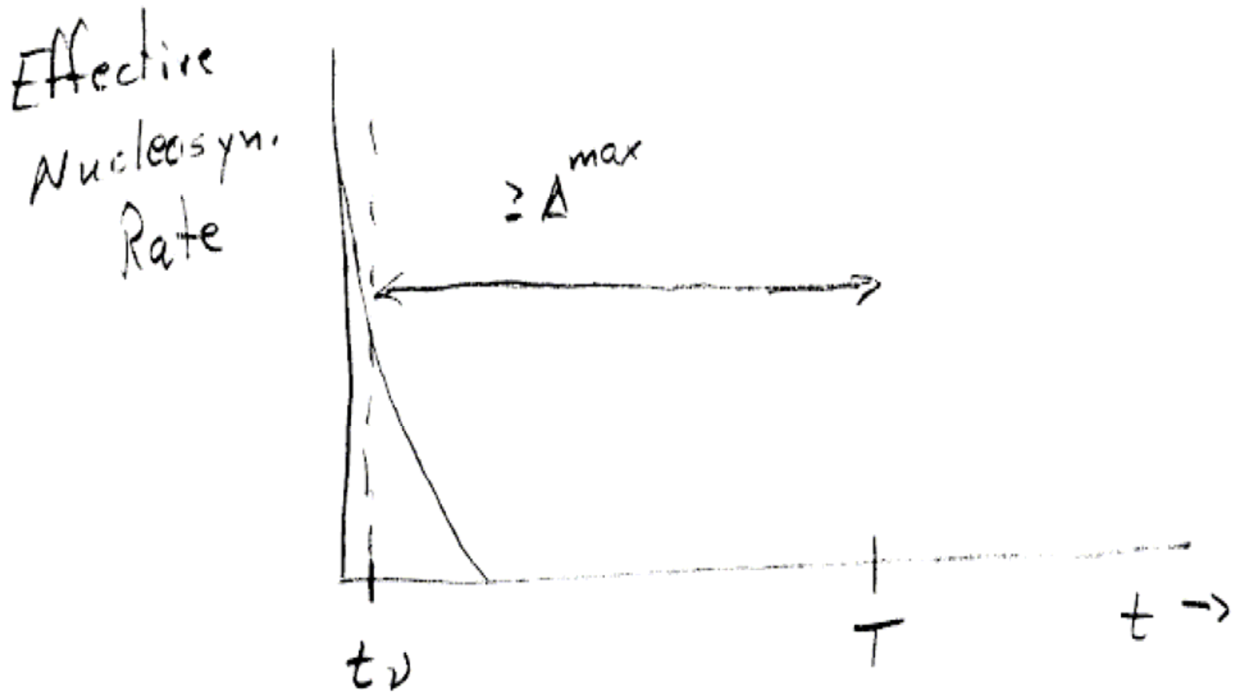
$$\Delta^{\max} = \frac{1}{\lambda_{238} - \lambda_{232}} \ln\left(\frac{P(^{238}U)/P(^{232}Th)}{N(^{238}U)/N(^{232}Th)} \right)$$

Chemical Evolution

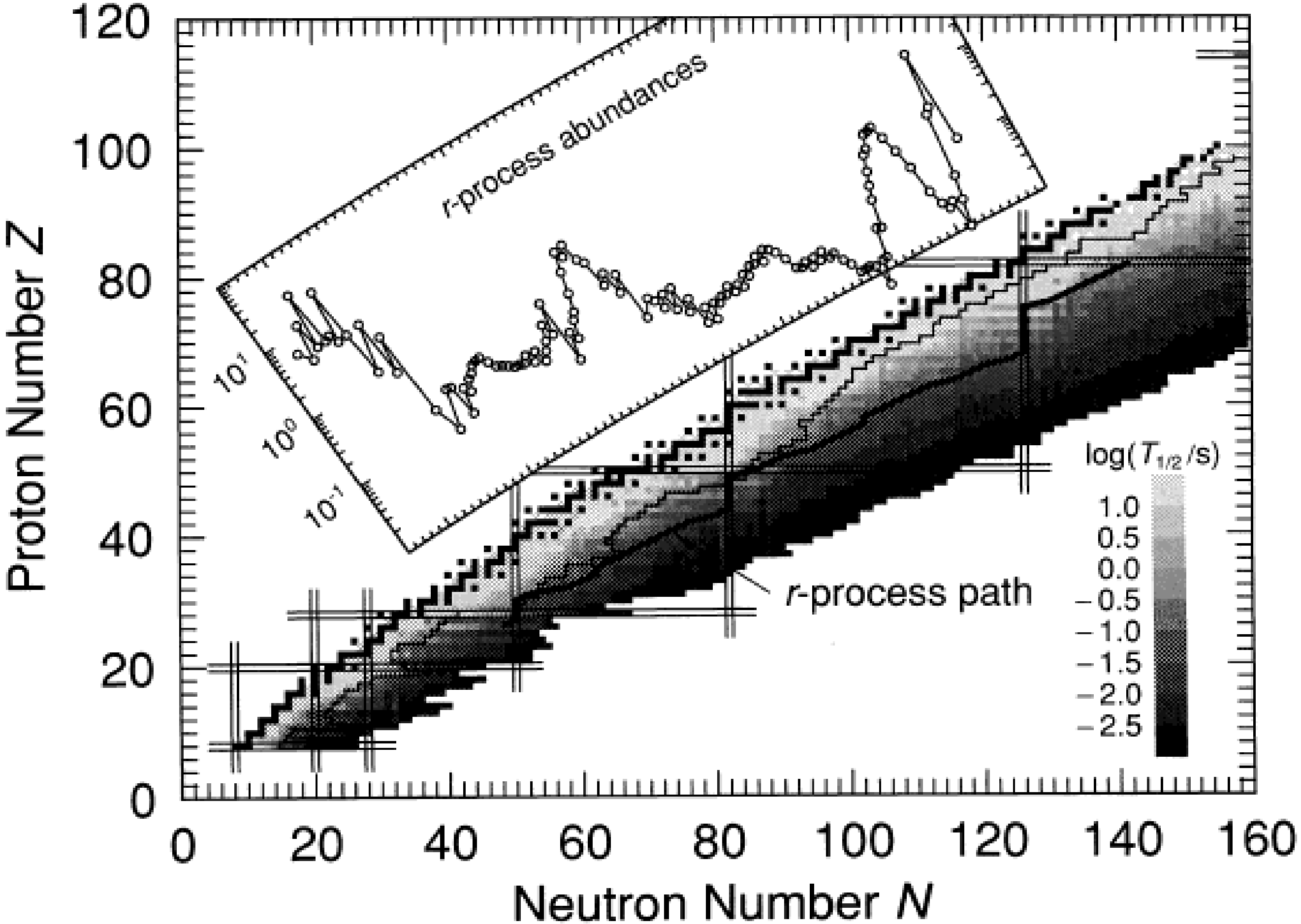
$$T - t_\nu \geq \Delta^{\max}$$

Schramm and Wasserburg (1970)
Meyer and Schramm (1986)


Effective
Nucleosyn.
Rate
≥ Δ^max
t_ν
T
t →



$$T \simeq \Delta^{max}$$



r-process abundances
r-process path
log($T_{1/2}$/s)
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
10^1
10^0
10^{-1}
Proton Number Z
Neutron Number N
0
20
40
60
80
100
120
140
160

Production Ratio

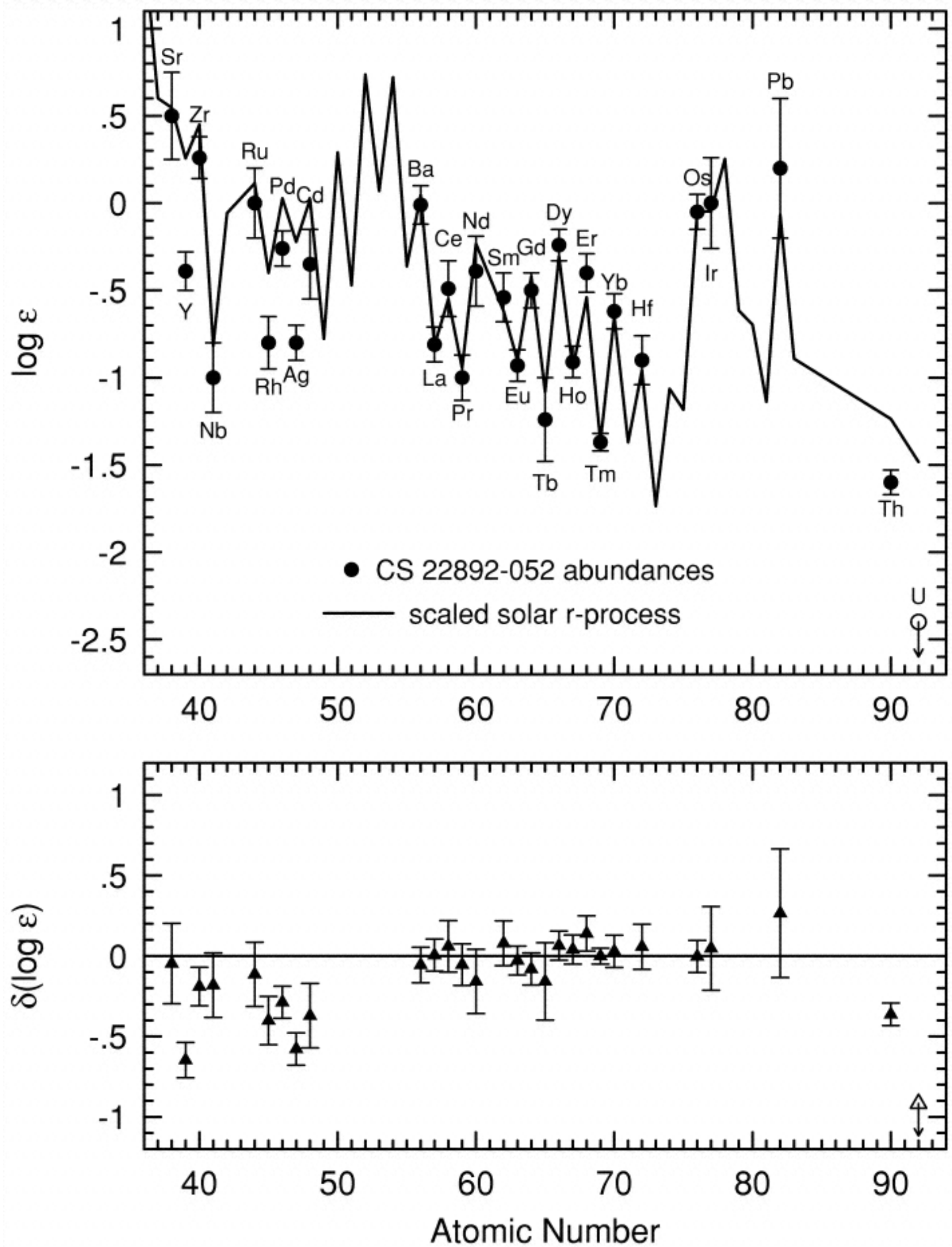
- Computed from models
- Simplest: equal production of progenitors
  - ^{238}U: ^{238}U (100%), ^{242}Pu (100%), ^{246}Cm(99.97%), and ^{250}Cm (18%) = 3.2
  - ^{232}Th: ^{232}Th (100%), ^{236}U (100%), ^{240}Pu (99.97%), ^{244}Pu (99.88%), ^{248}Cm (91.61%), ^{252}Cf (96.91%) = 5.8 progenitor
  - P = 3.2/5.8 = 0.55 => T = 2.3 Gyr => T_G>6.9 Gyr
- R-Process models give P in the range 0.4 – 0.7.

Difficulties with Nucleocosmochronology

- Production ratio
  - Mechanism of the r-process itself
  - Uncertain nuclear physics
- Chemical evolution model
  - Factors of two uncertainties

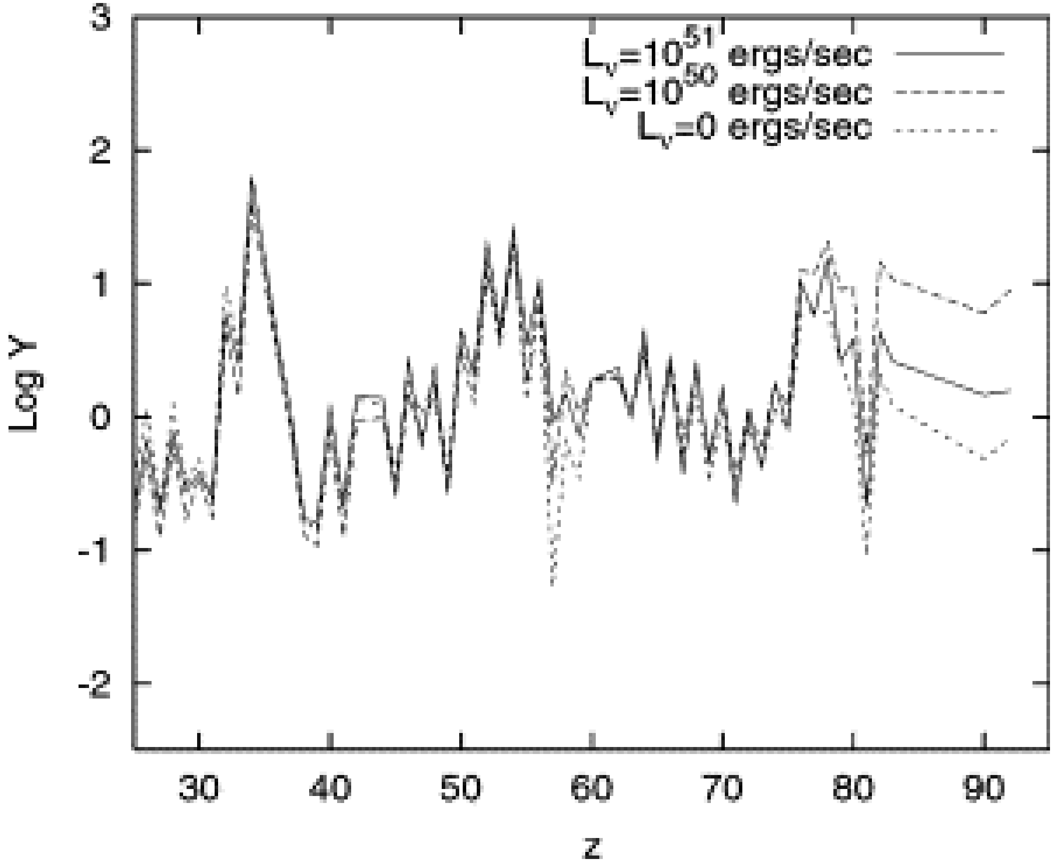
$$\Rightarrow T_{Galaxy} = 10 - 20 \text{ Gyr}$$

Sneden et al. (2000)



Th/Eu=15.2 Gyr (+4.5-3.7)

Meyer and Truran (2000)

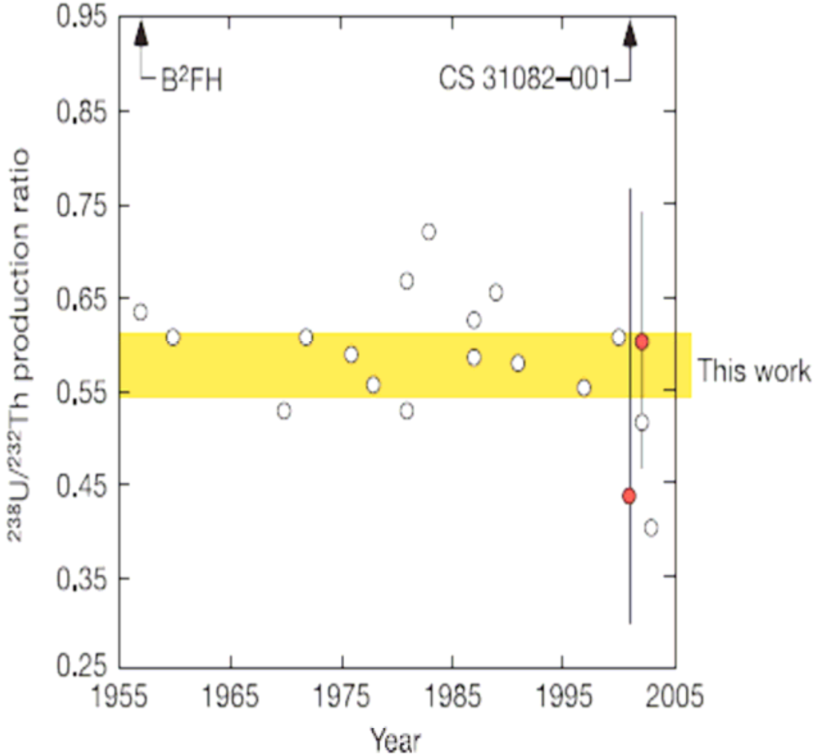


Otsuki, Mathews, and Kajino (2003)

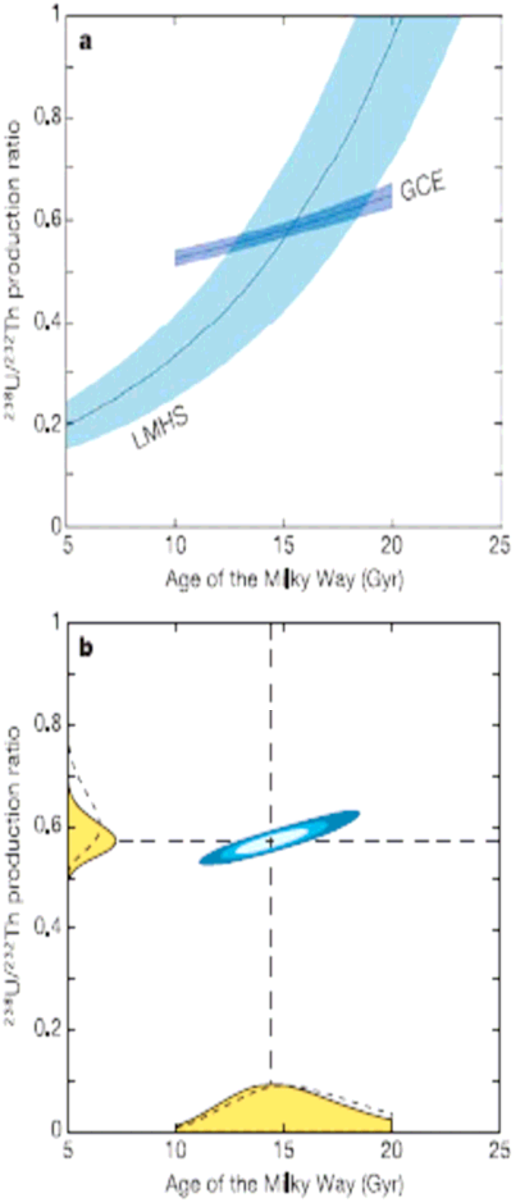
What about U/Th?

- Neighboring isotopes
- Some recent determinations:
  - Goriely and Arnould (2001) give 0.435+0.329-0.137
  - Schatz et al. (2002) give 0.603+-0.139

Dauphas (2005)



Dauphas (2005)



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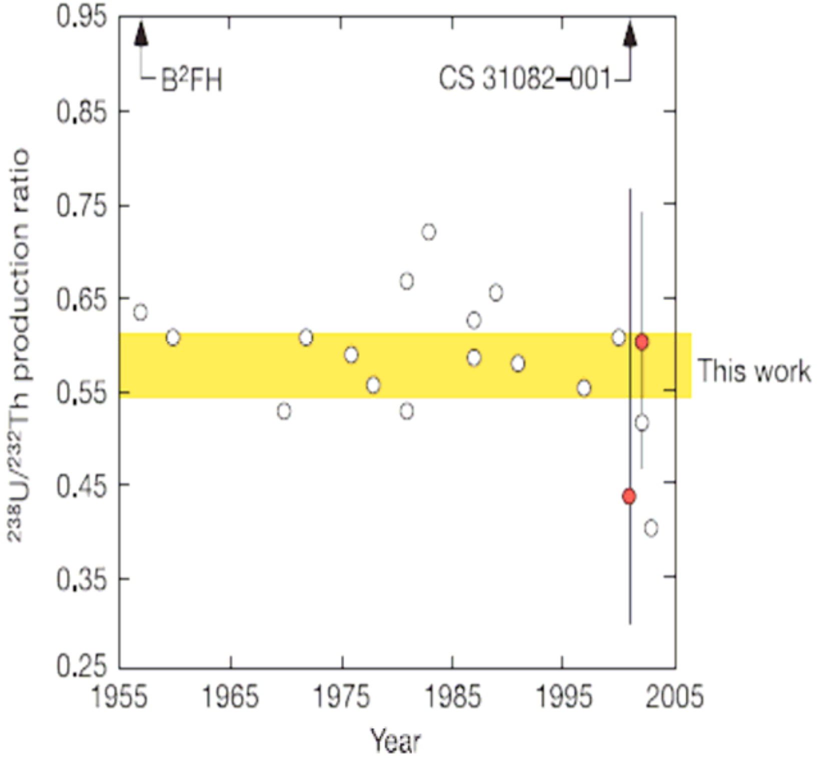

P = 0.571+0.037-0.031

=>T_{Gal}=14.5+2.8-2.2 Gyr

Conclusions

- From metal-poor stars and chemical evolution, it is becoming possible to constrain the U/Th production ratio
- This will constrain r-process models and/or the nuclear physics input

Radioactivity with Astronomies