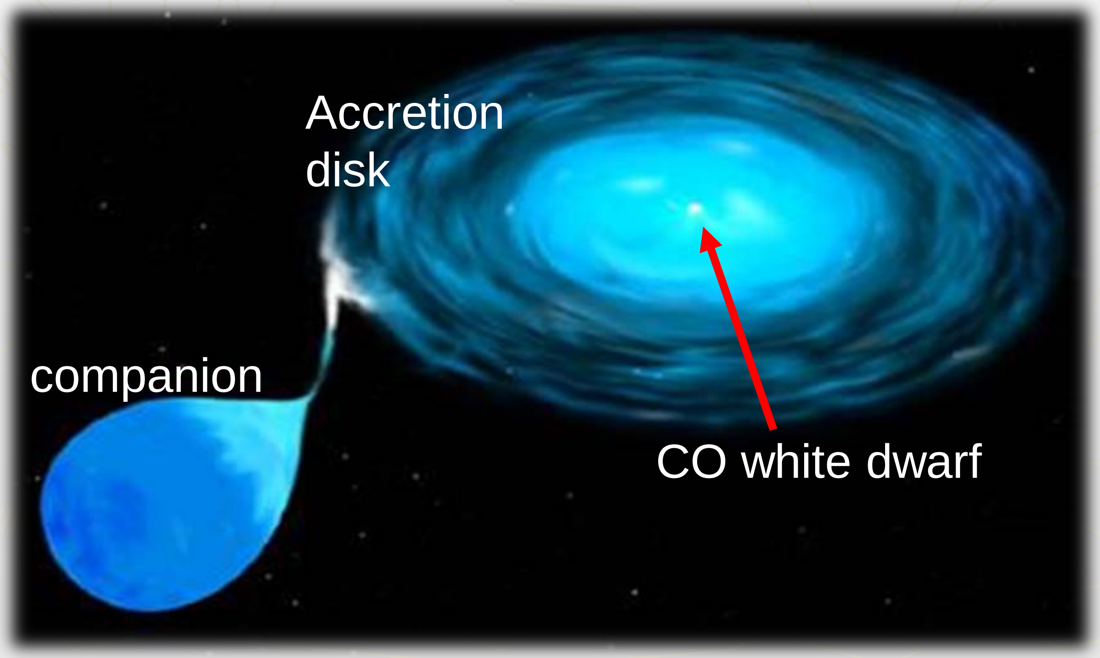
Workshop on Thermonuclear Reaction Rates for Astrophysics Applications, Athens

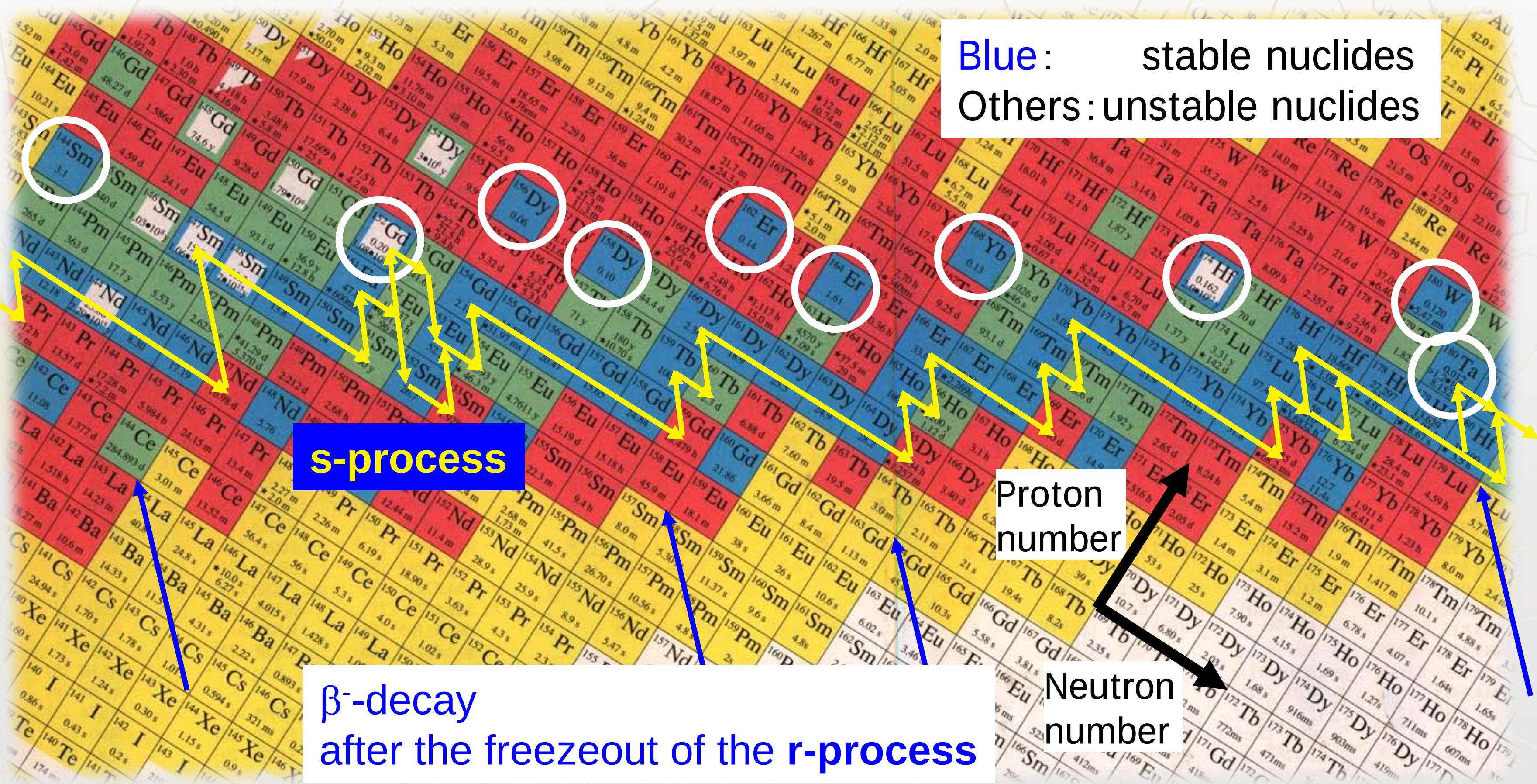
p-Process Nucleosynthesis in Type Ia Supernova



Nobuyuki Iwamoto

p-Nuclei

- Stable, proton-rich, rare isotopes of elements
- 1-0.1% (with increasing Z) of the bulk elemental abundances
- 35 p-nuclei (atomic number Z≧34)
- Difficult to produce p-nuclei by neutron capture reactions (bypassed by s- and r-processes.)
- Only identified in the solar system



History of p-Process Studies

- H-rich envelope in SN explosions
  - Audouze & Truran (1975) – proton captures
- Hydrostatic oxygen burning layer
  - Arnould (1976)
- Core collapse SN (O/Ne layer – Explosive O burning layer)
  - Woosley & Howard (1978) - analytic explosion model
  - Rayet et al. (1990) - analytic explosion model
  - Prantzos et al. (1990) - Shigeyama (1988) explosion model
  - Rayet et al. (1995) - Hashimoto (1993) explosion model
- Type Ia SN
  - Howard et al. (1991); Howard & Meyer (1992); Travaglio et al. (2011, 2D hydro. simulation) - Chandrasekhar-mass C/O WDs with enhanced seeds by s-process
  - Goriely et al. (2001) - He accreting sub-Chandrasekhar-mass WDs
- Neutrino-driven winds, etc.
  - Wanajo et al. (2011)

Drawbacks in Probable Sites

► **O / Ne layer of core-collapse SNe**

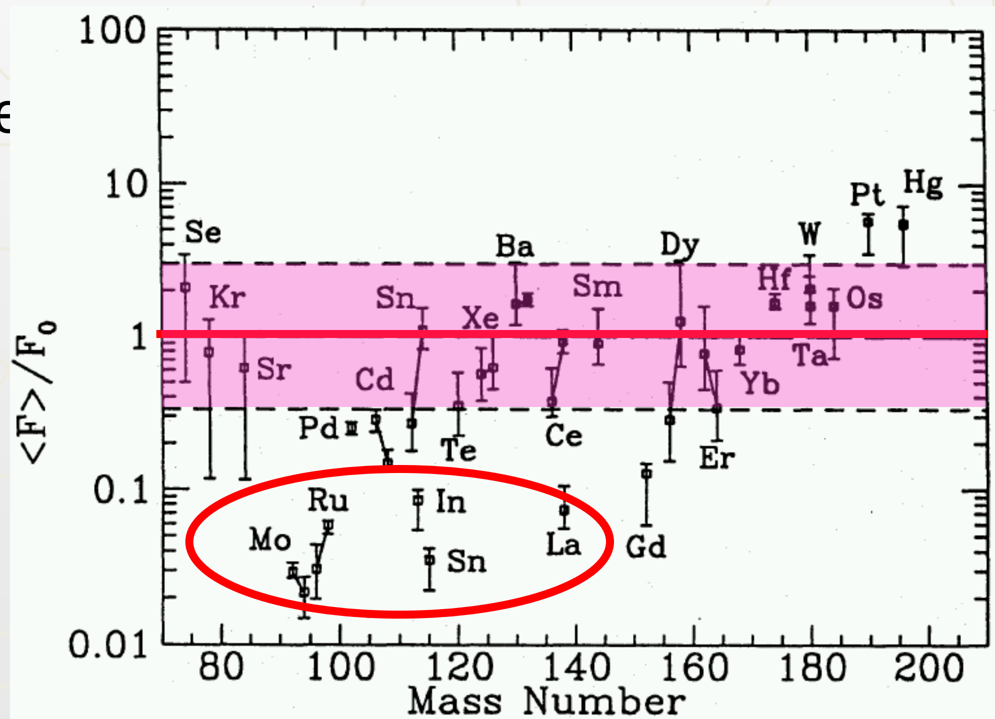
① Underproduction of some p-nuclei of e.g. ^{92,94}Mo, ^{96,98}Ru, ^{113}In, ^{115}Sn and ^{138}La

② Ejected yield of p-nuclei relative to those of oxygen is ¼.

- Oxygen: main product of CCSN → same level of enhancements are needed

► **Type Ia SNe**

① Seed abundance ... ain than in SNe II. → no ... an accreting WD.



(Rayet et al. 1995)

Traditional Values for p-Process Results

Mean overproduction factor

$$< F_i > = \frac{1}{M_{PPL}} \int_{PPL} \frac{X_i}{X_{i,\odot}} dM_r$$

X_i ……… mass fraction at each mass shell
$X_i/X_{i,\odot}$ … overproduction factor for each nucleus
M_{PPL} …… total mass of the p-process layer (PPL)

$<F_i>$: degree of enhancements in PPL

overproduction factor averaged over 35 p-nuclei

$$F_0 = \sum_i < F_i > / 35$$

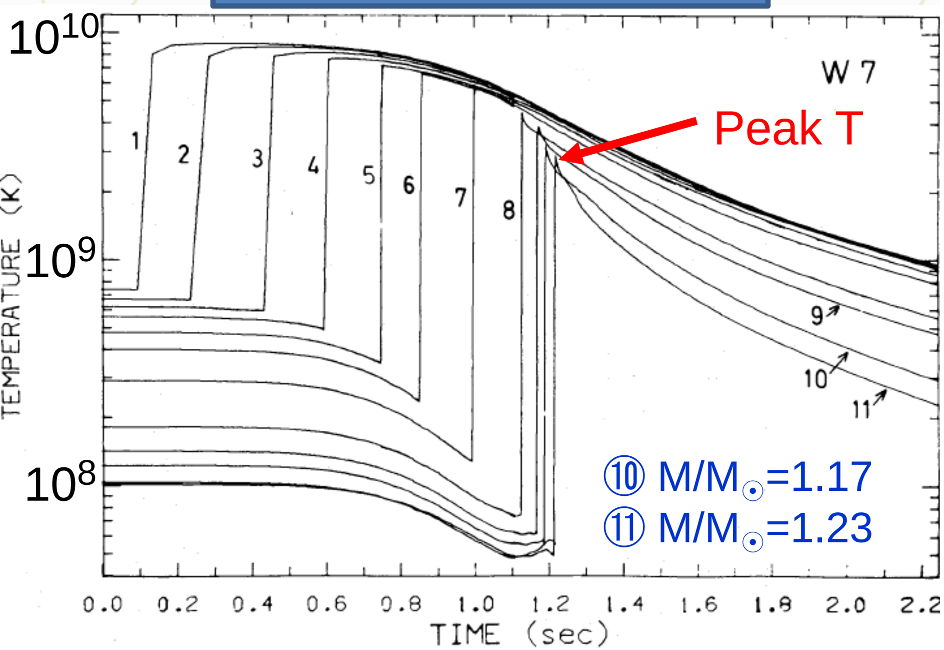
F_0 : averaged enhancement of p-nuclei in PPL

All of the p-nuclei ➔ $<F_i>/F_0=1$.
➡ The distribution is the same as solar.

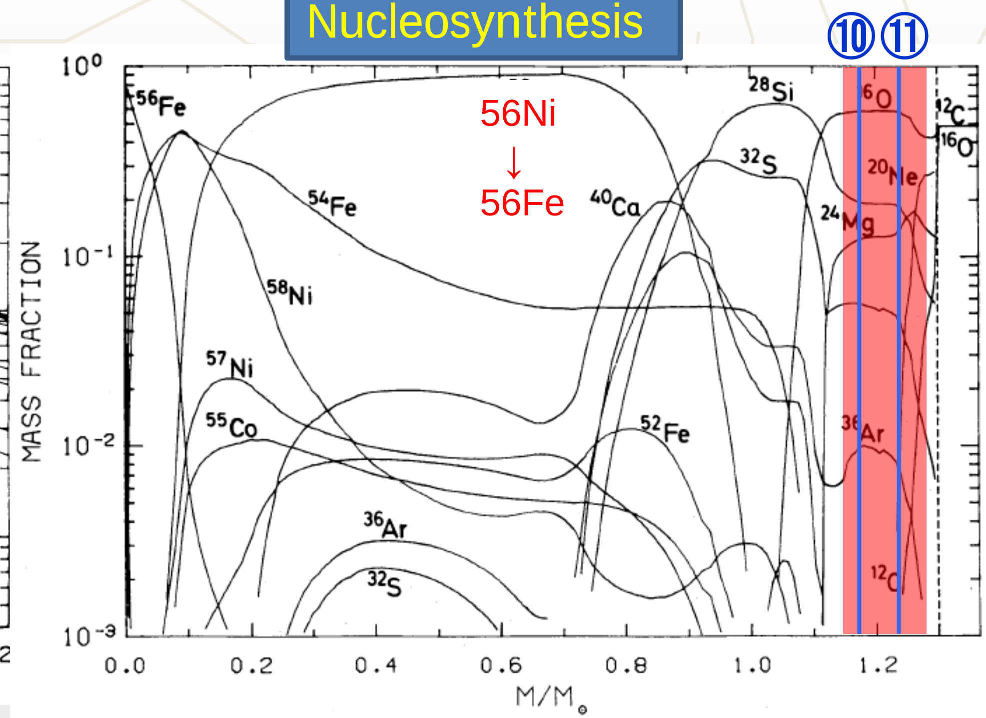
p-Process in W7 Model

Carbon Deflagration Model for Type Ia Supernova (W7; Nomoto et al. 1984)

T variation at each layer



Nucleosynthesis



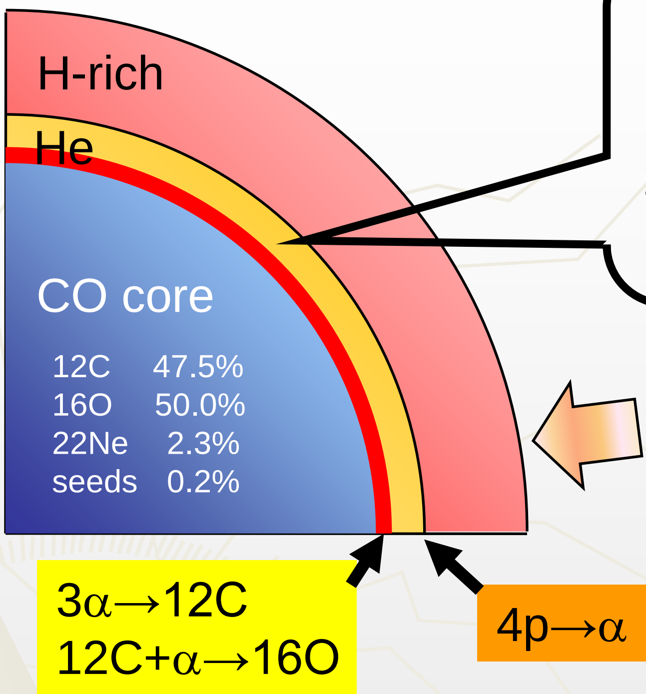
- ► p-process layer (3.6~1.8GK) is very close to the surface of WD
- ► Peak density (1~3x10^{7}g/cc) higher than SNII by ~100

$$\dot{Y}_i = \sum_j N^i_j \lambda_j Y_j + \sum_{j,k} N^i_{j,k} \rho N_A \langle j,k \rangle Y_j Y_k + \sum_{j,k,l} N^i_{j,k,l} \rho^2 N_A^2 \langle j,k,l \rangle Y_j Y_k Y_l.$$

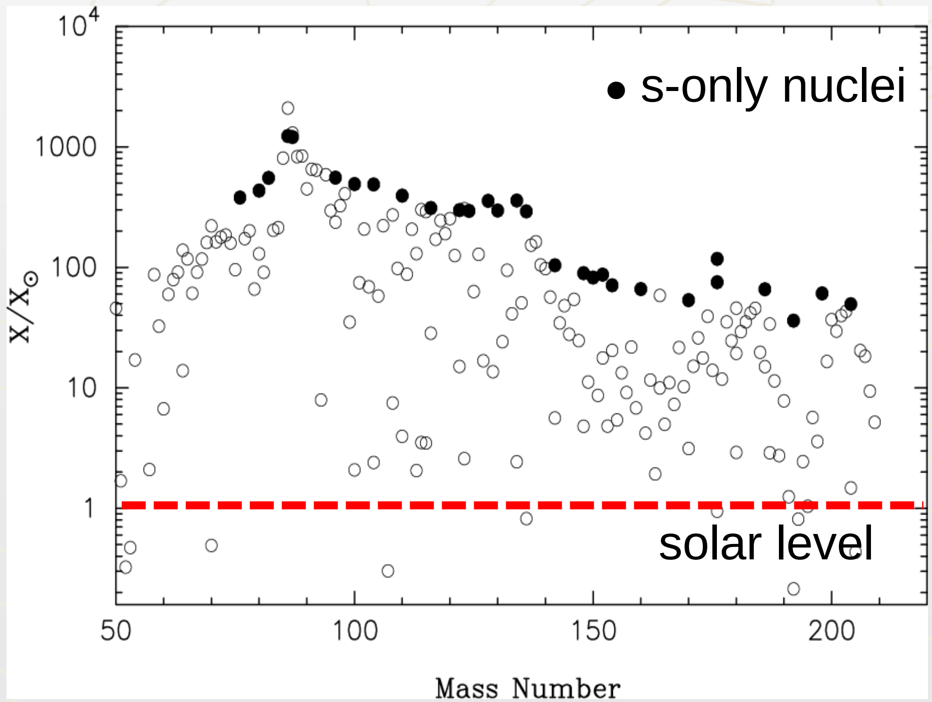
Abundance Distribution of Seeds

assumption

1. Occurrence of s-process as in the He shell of an AGB star.
2. Production of seed nuclei at the same level as in an AGB star.

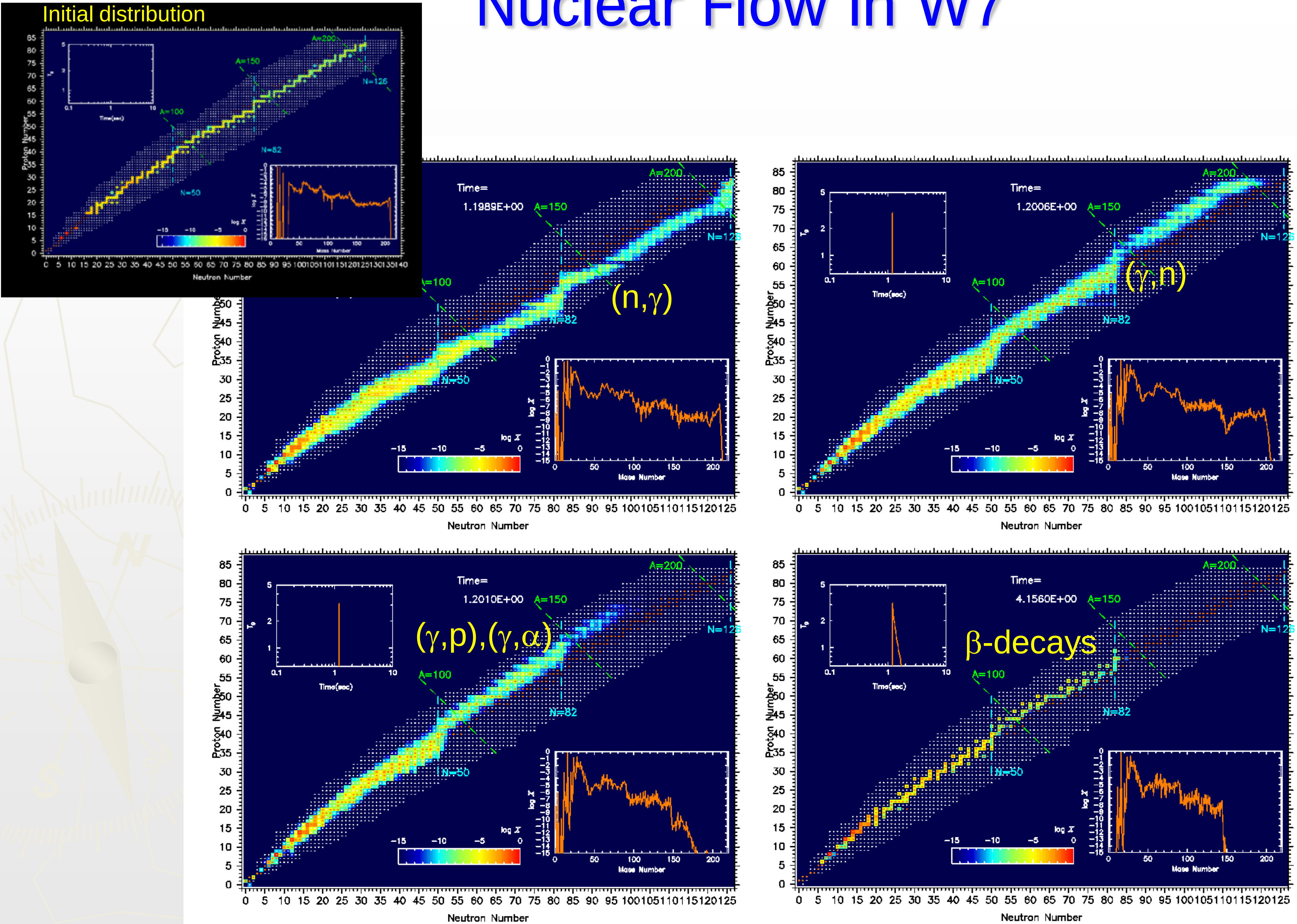


Supply of H-rich gas from the companion

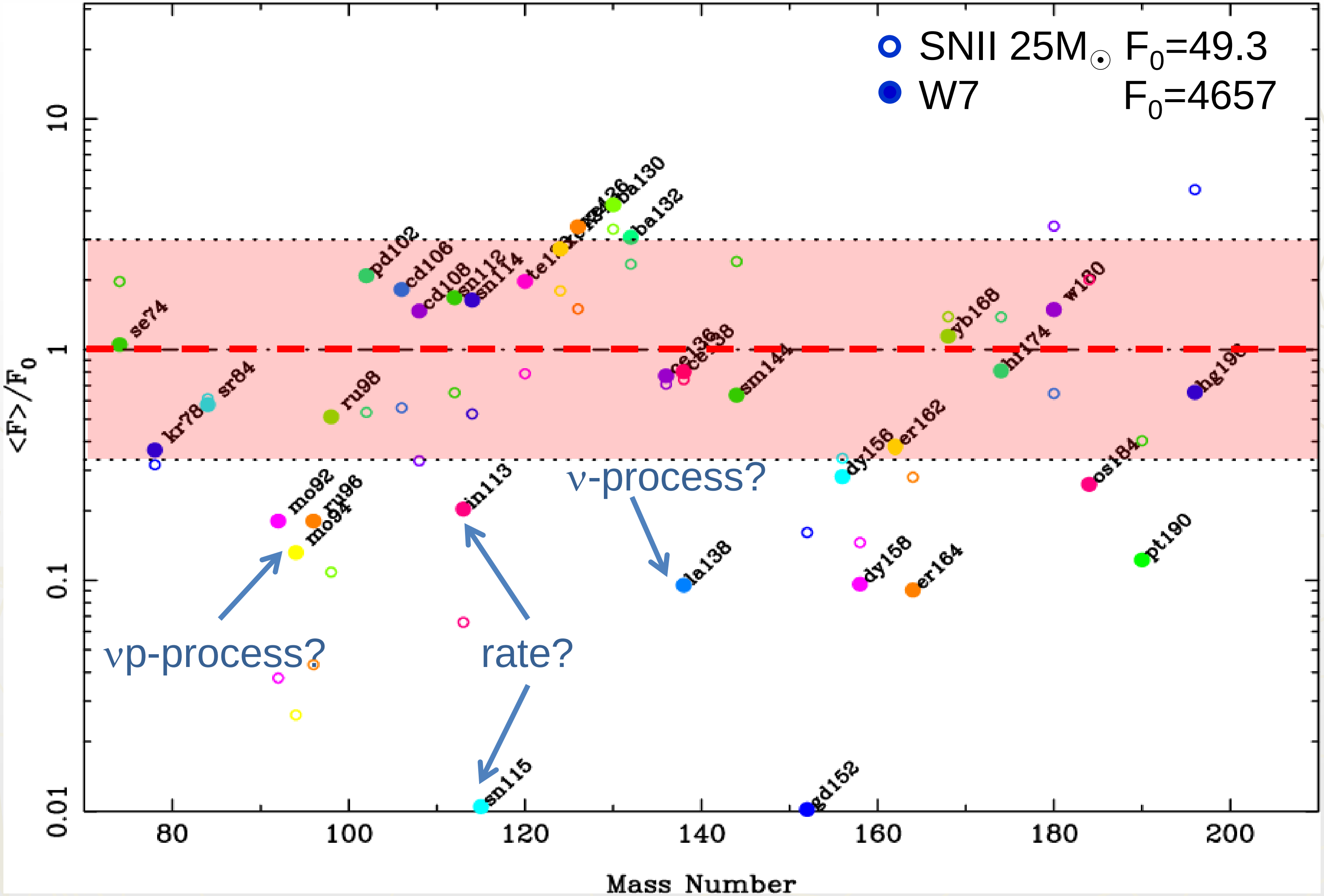


Seed distribution:
calculated by a classical s-process model with τ_0=0.15mb^{-1}.

Nuclear Flow in W7

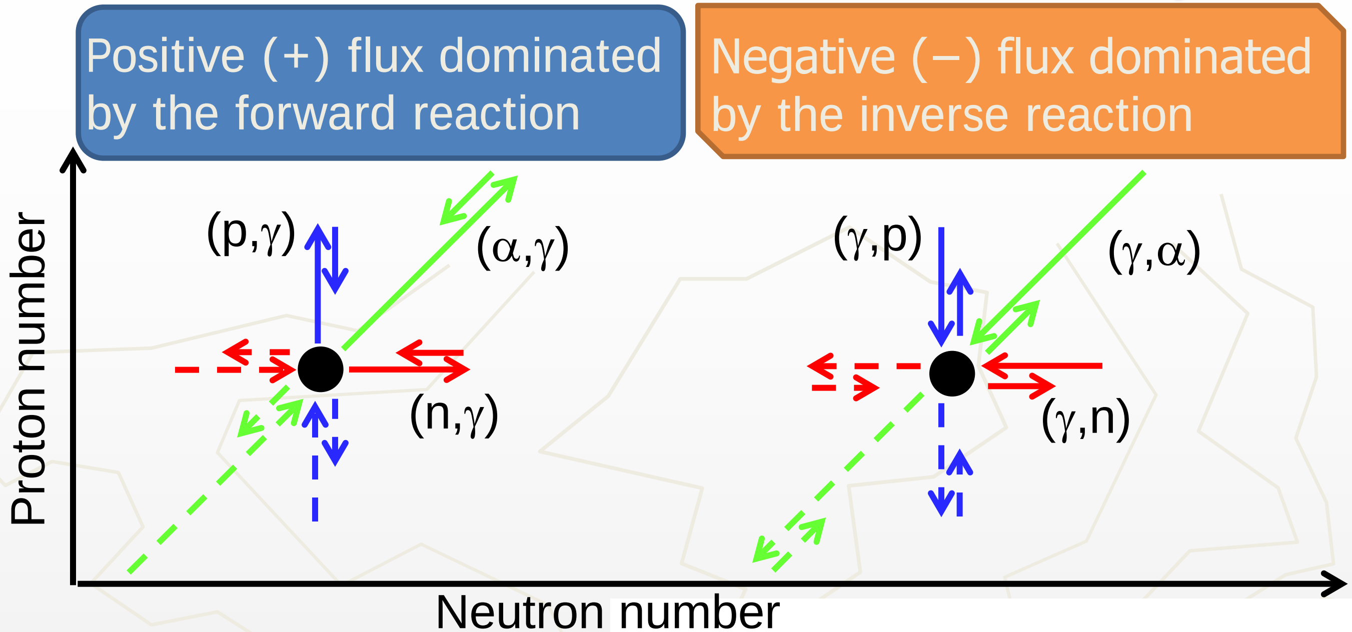


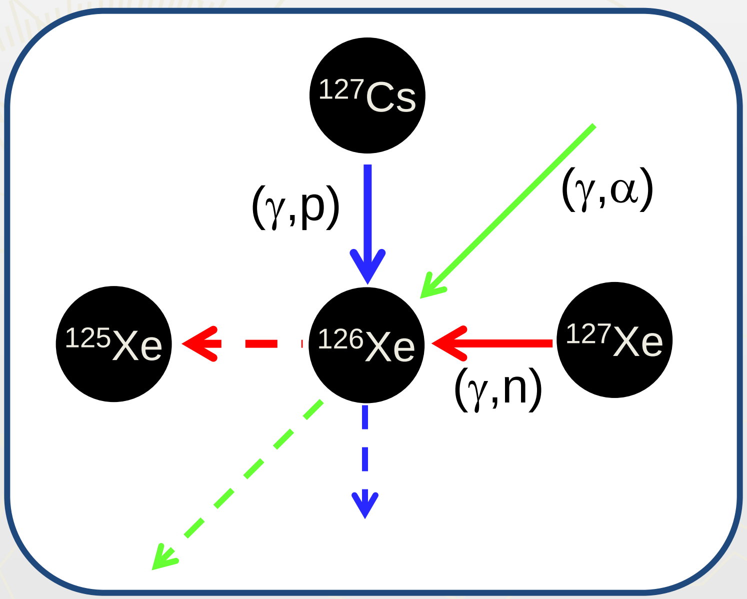
Result of p-process in W7

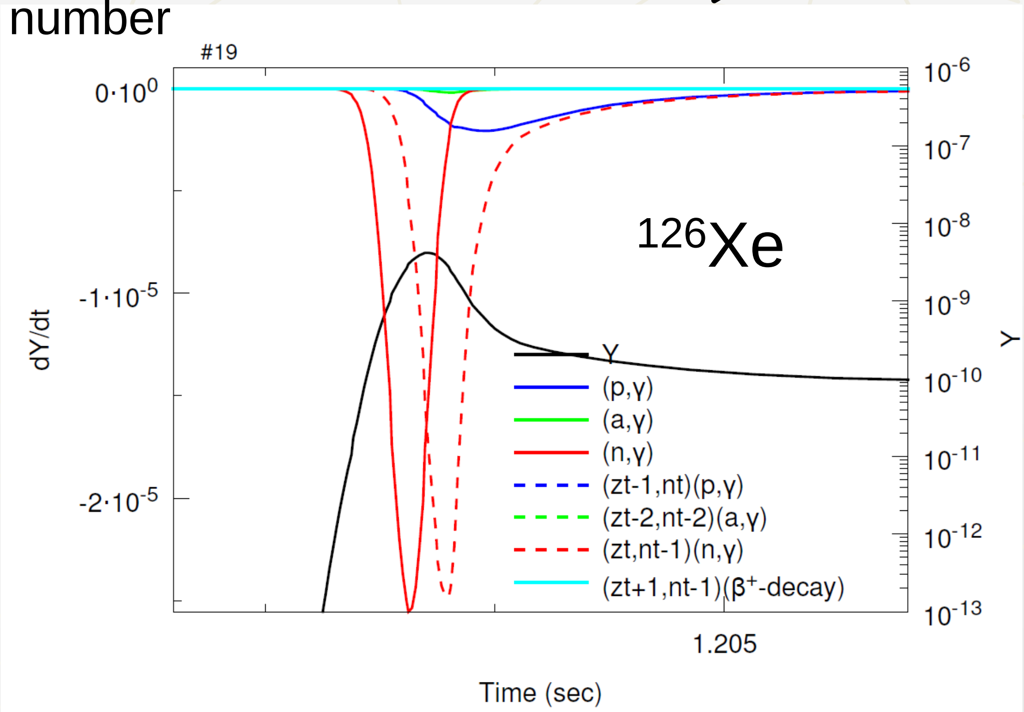


① Some underproductions are left with this set of assumptions!
→ other sites for the production needed

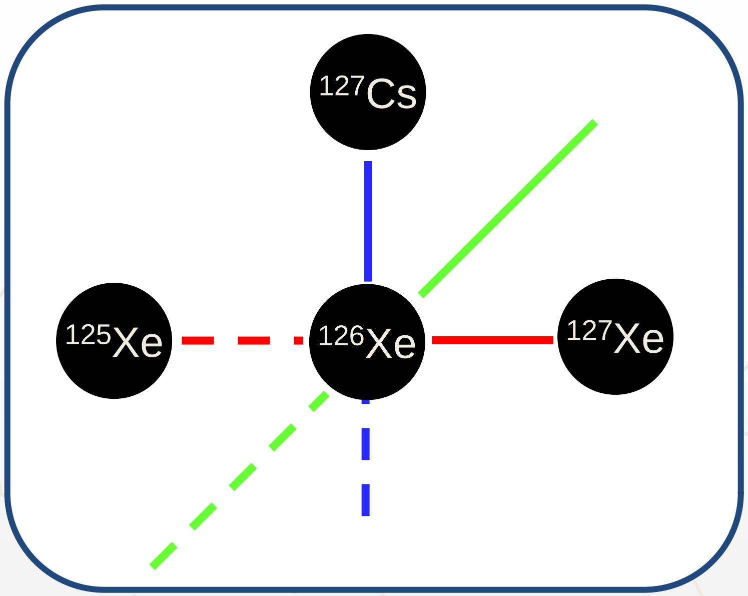
Nuclear Flow and Production of p-nuclei

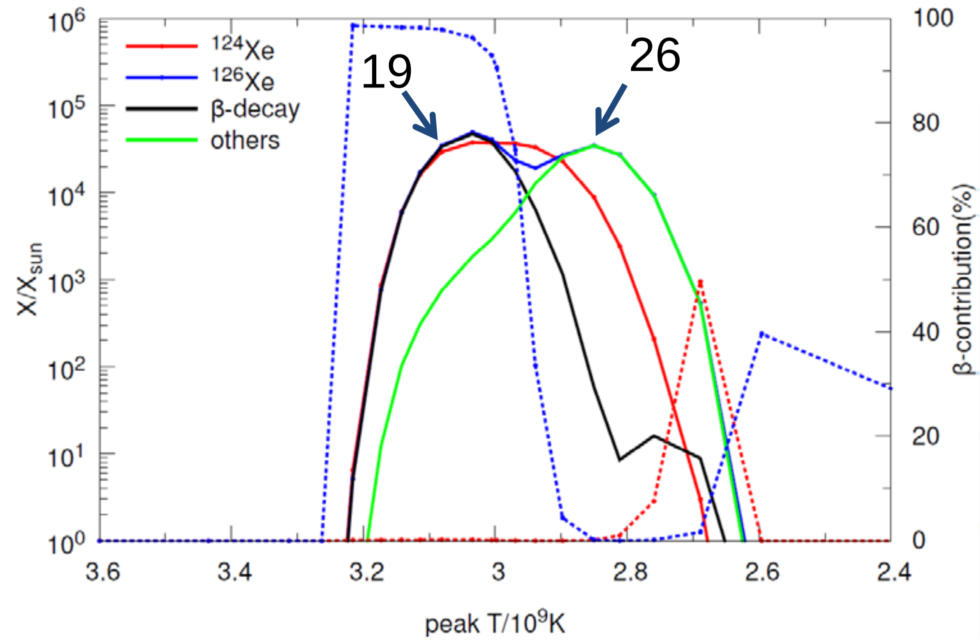


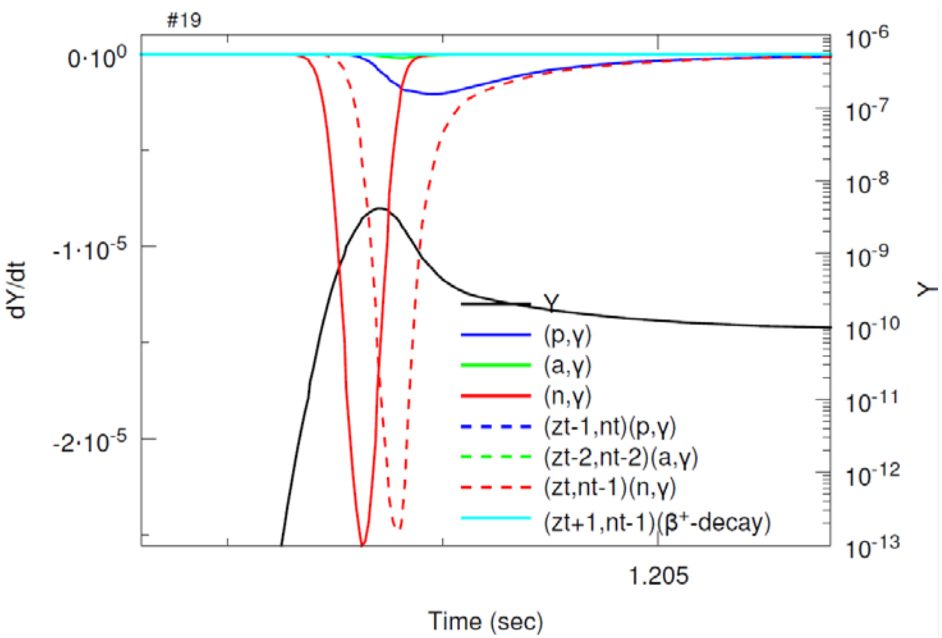


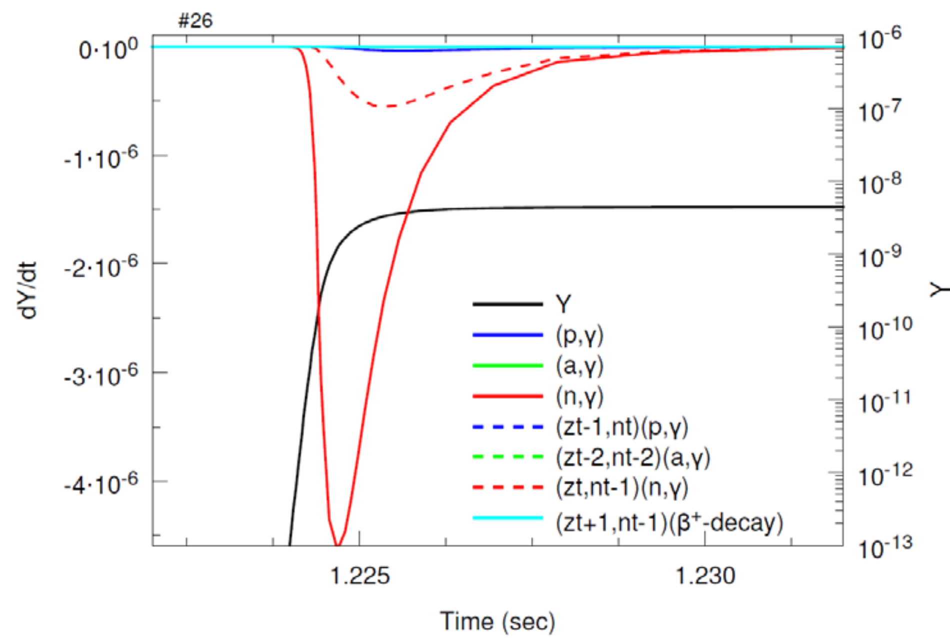


Nuclear Flow and Production of ^{126}Xe

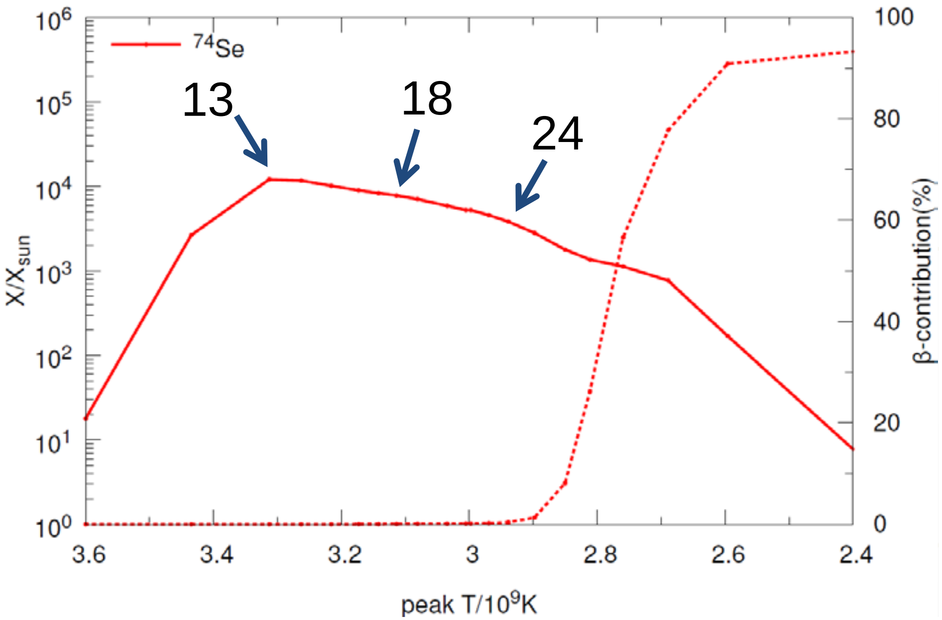


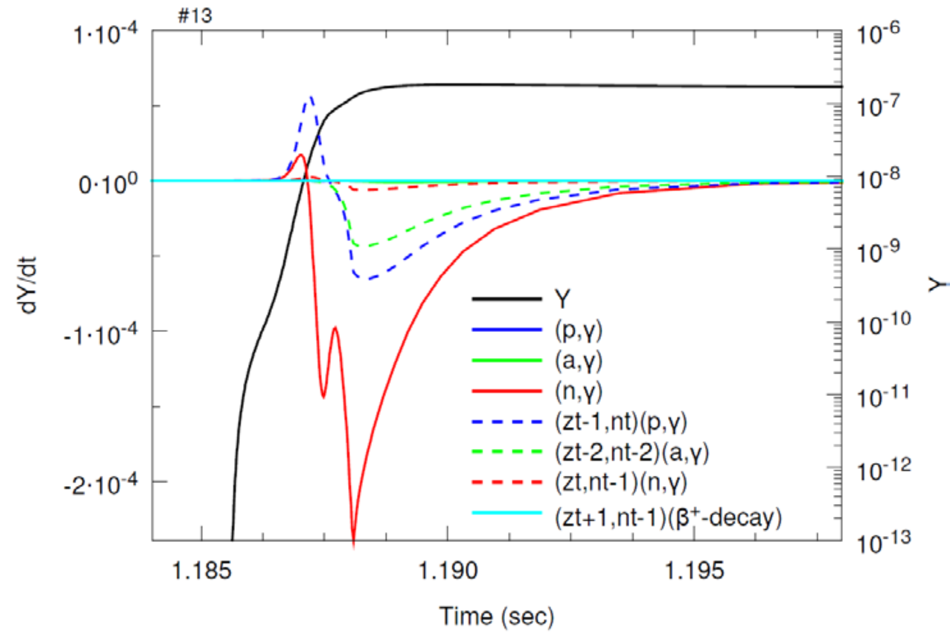


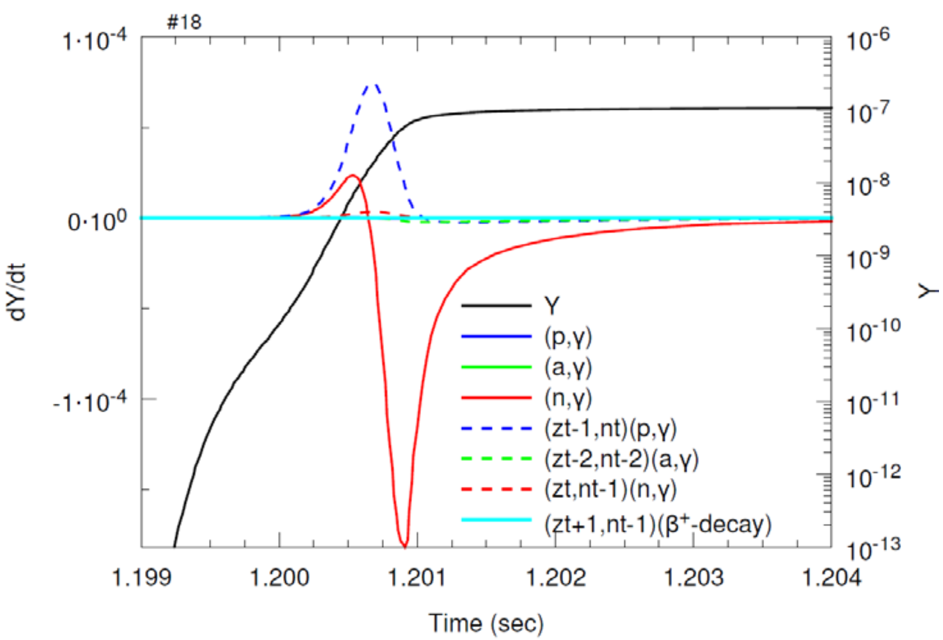


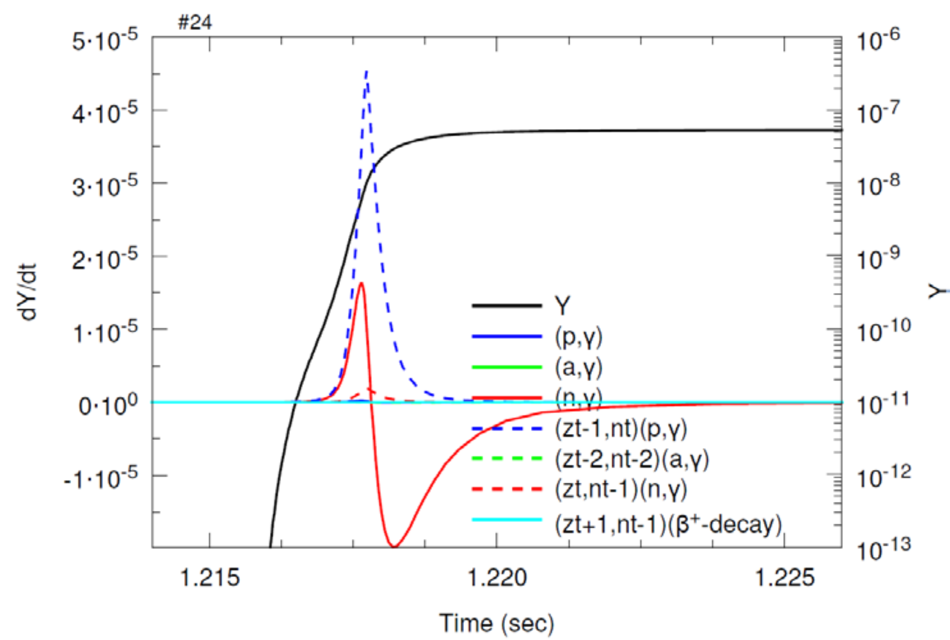


Nuclear Flow and Production of ^{74}Se

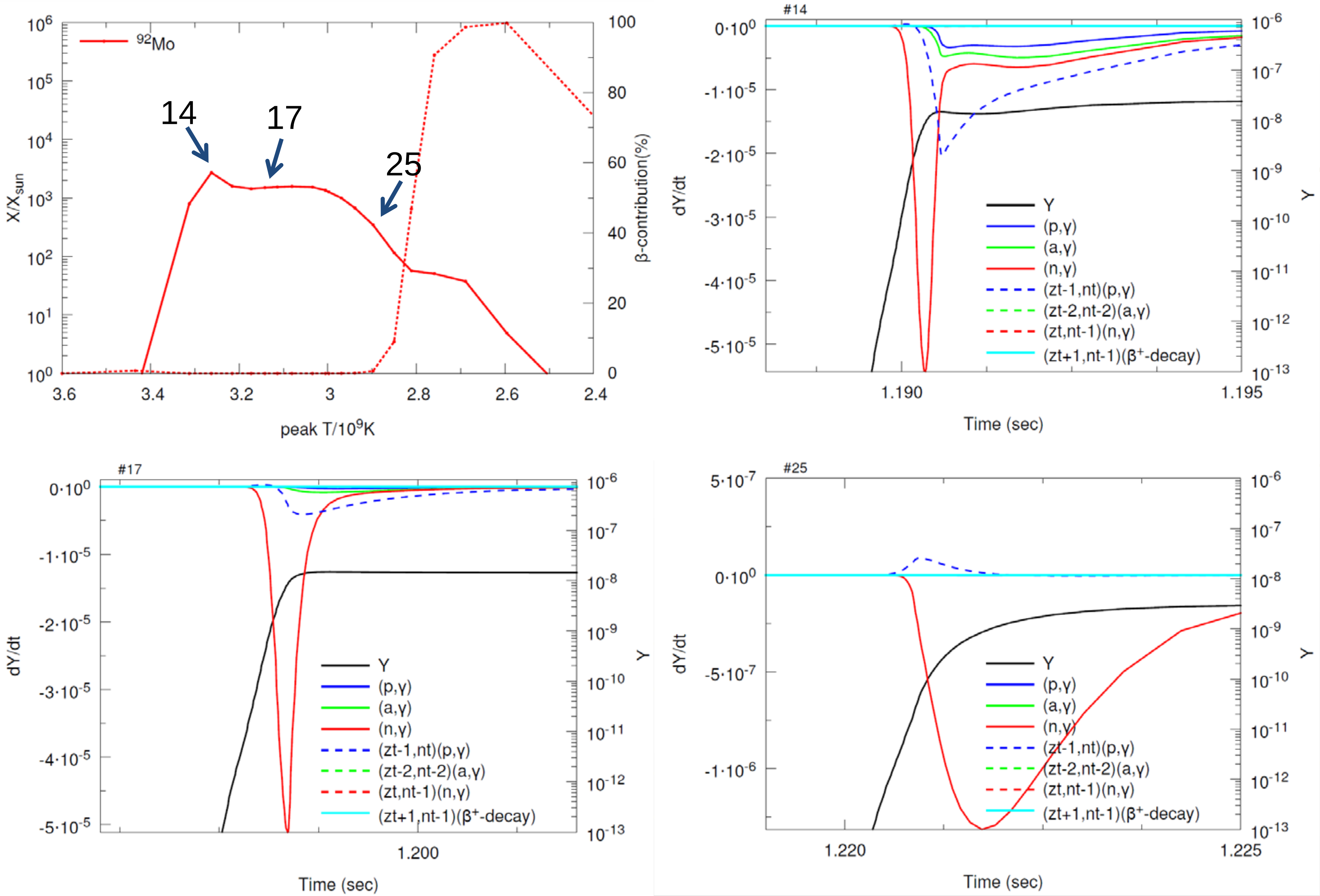




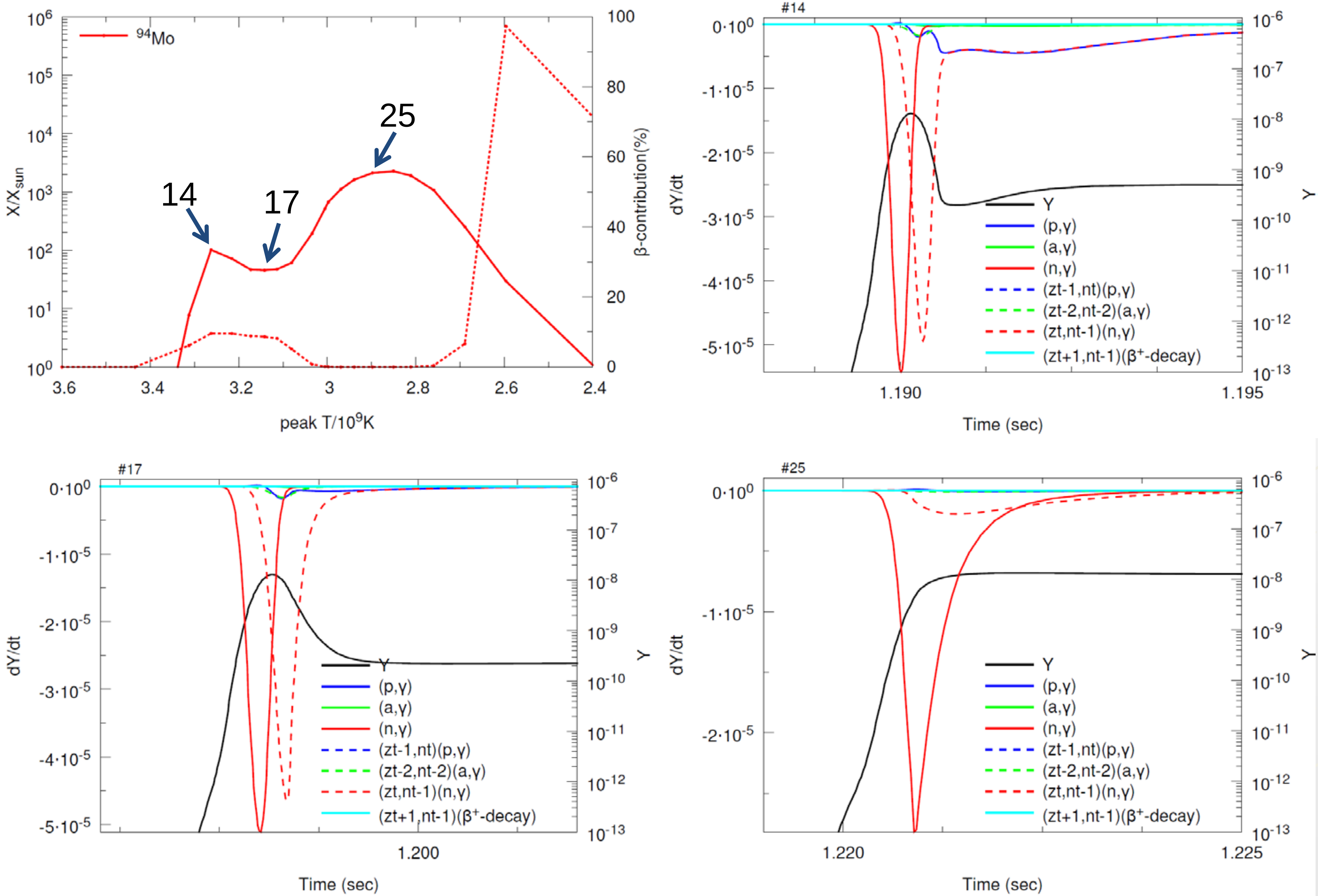




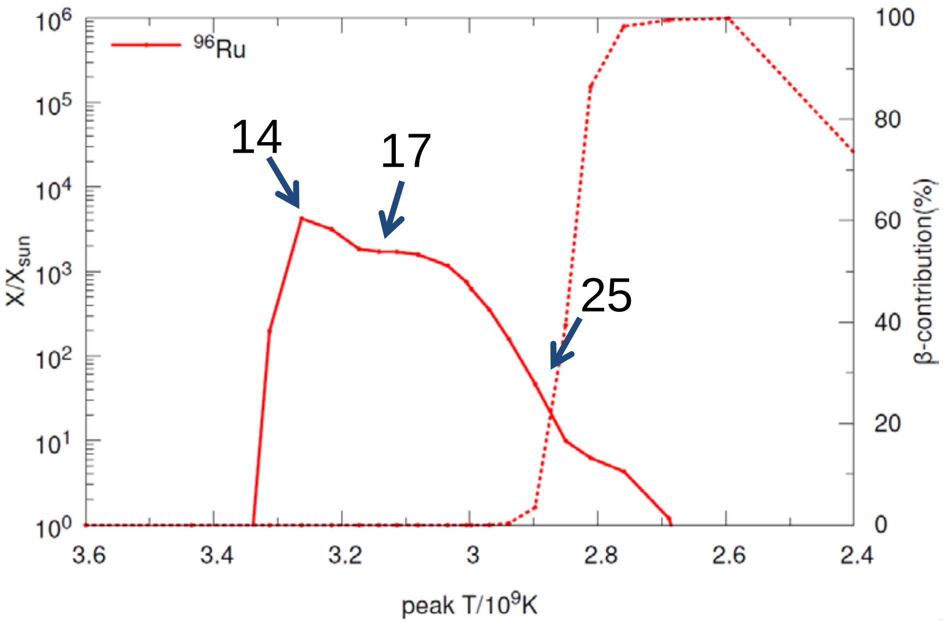
Nuclear Flow and Production of ^{92}Mo

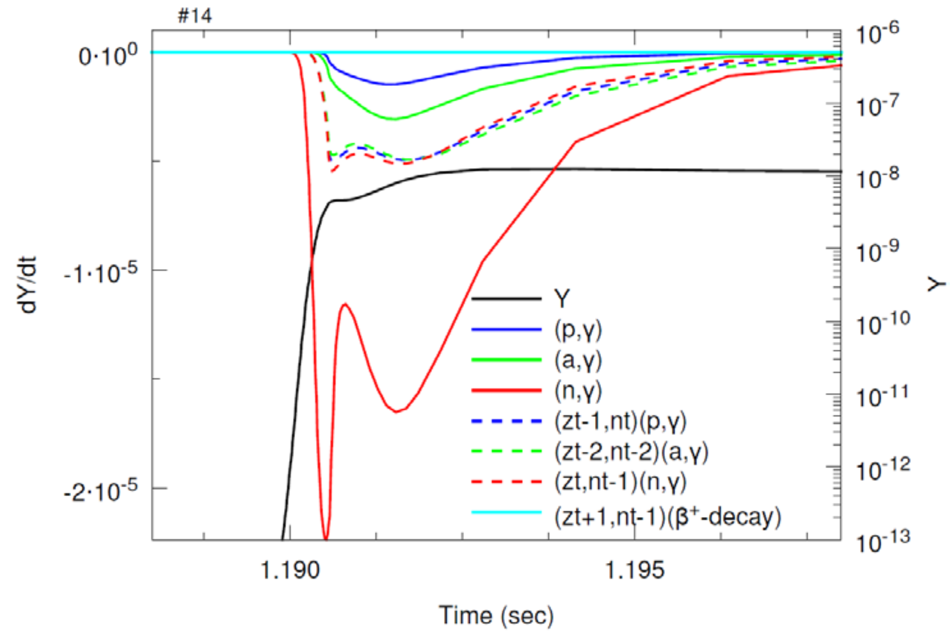


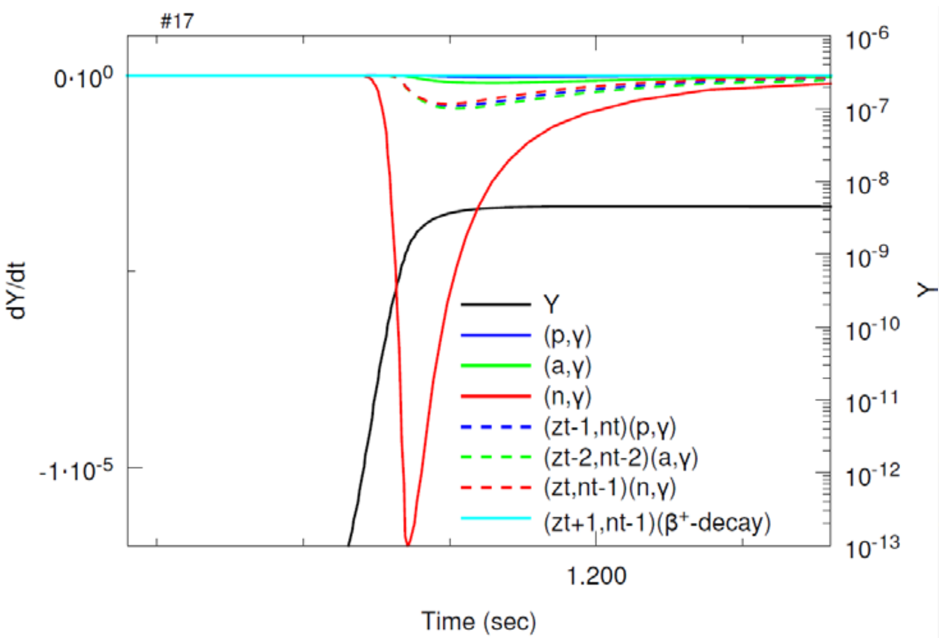
Nuclear Flow and Production of ^{94}Mo

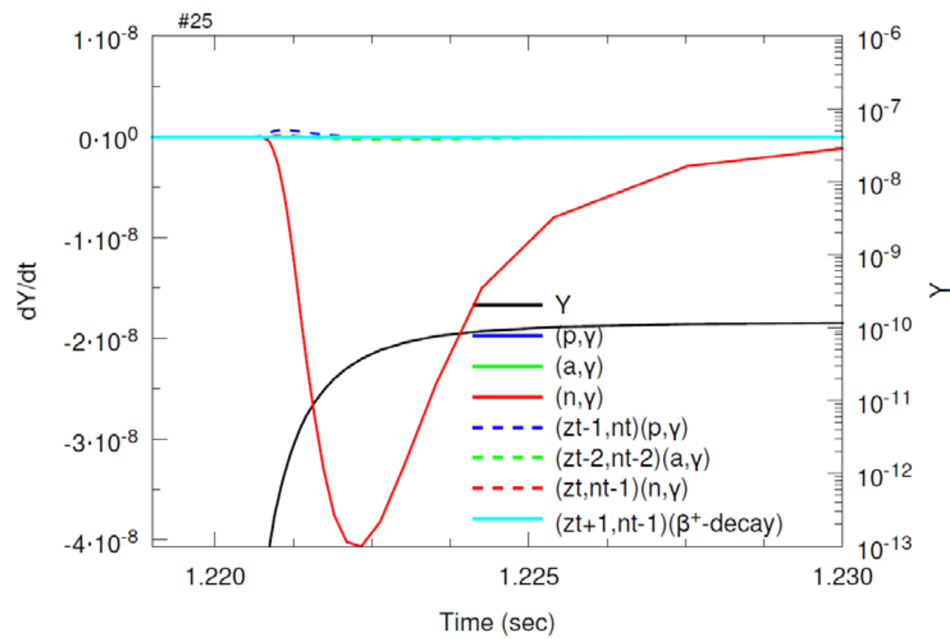


Nuclear Flow and Production of ^{96}Ru

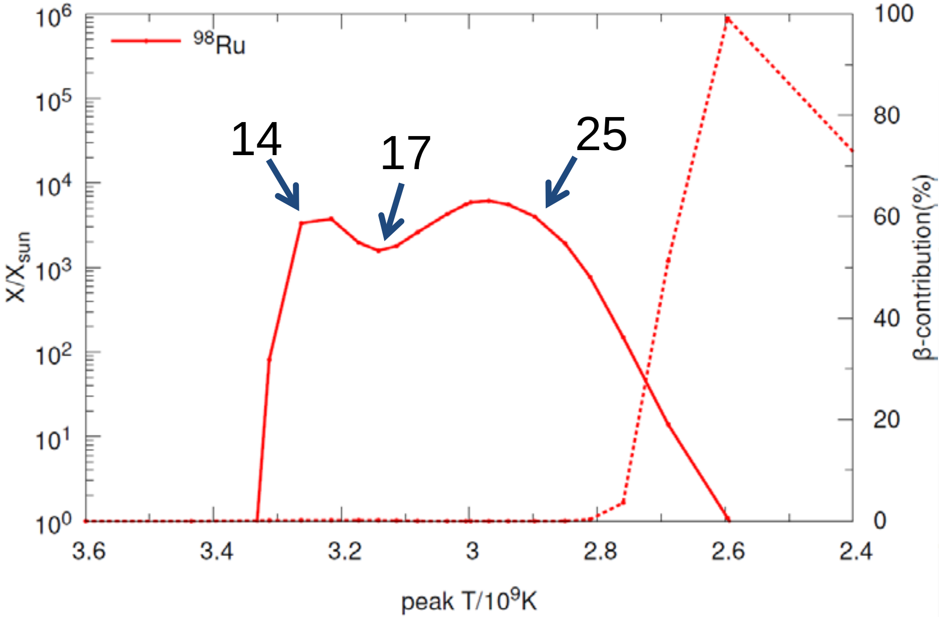


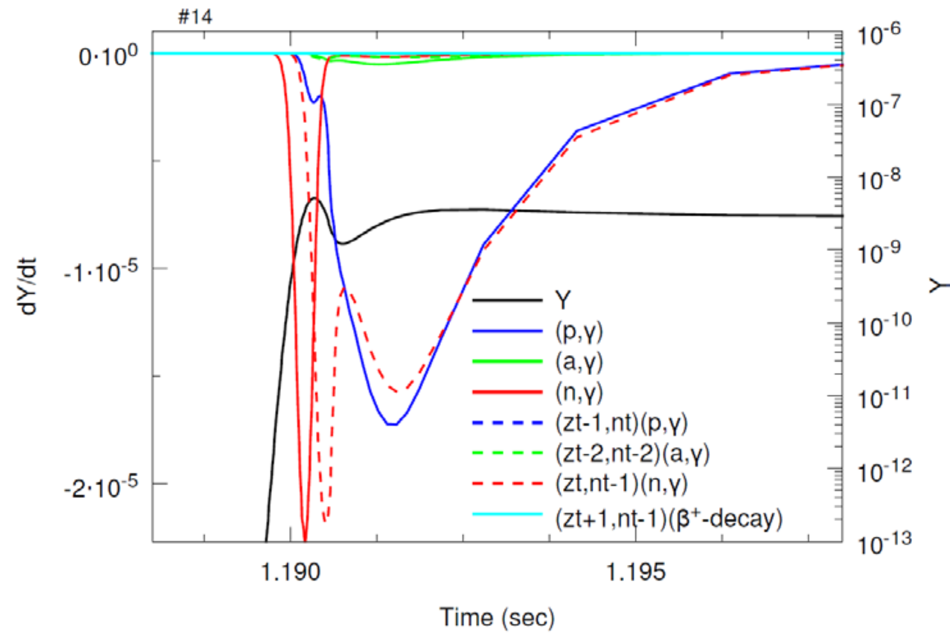


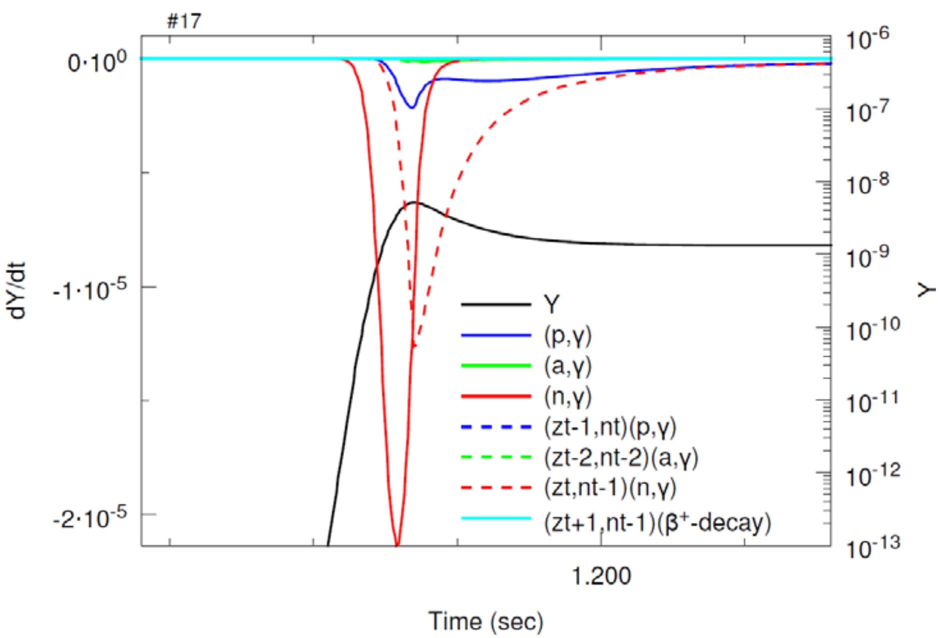


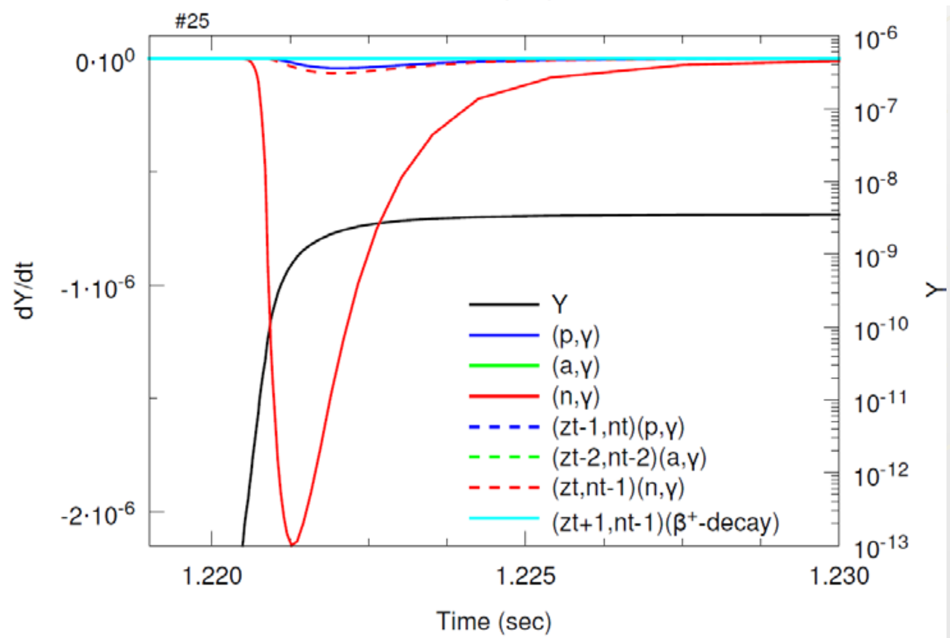


Nuclear Flow and Production of ^{98}Ru

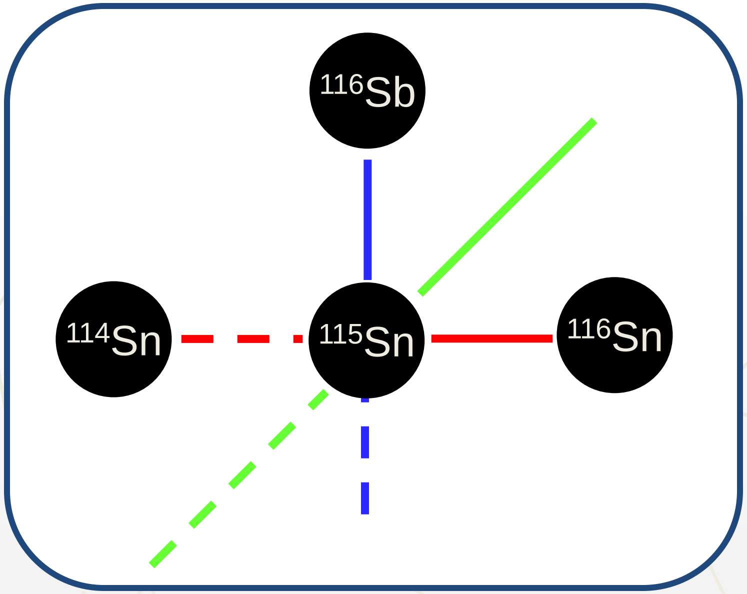


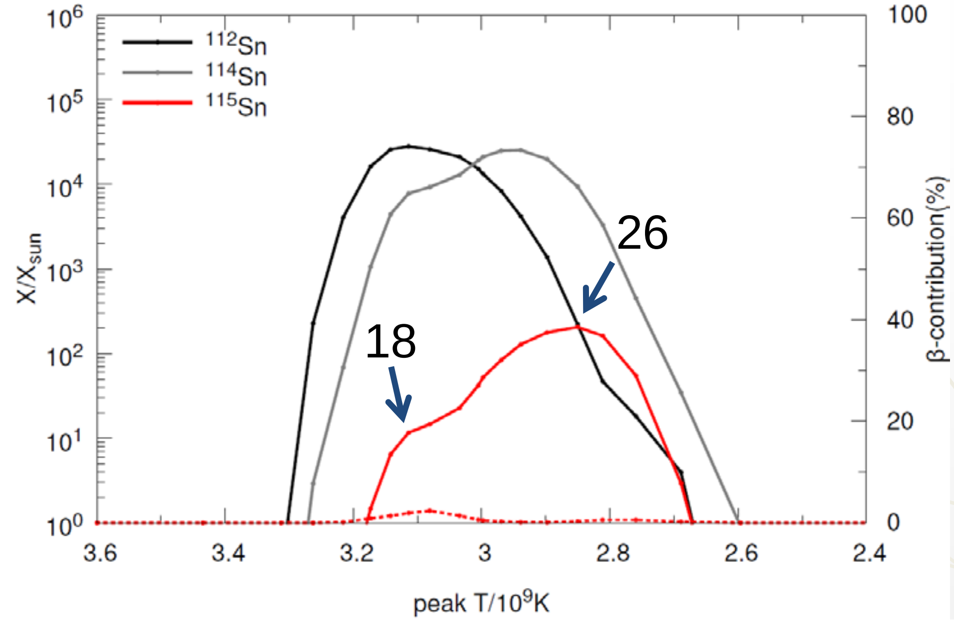


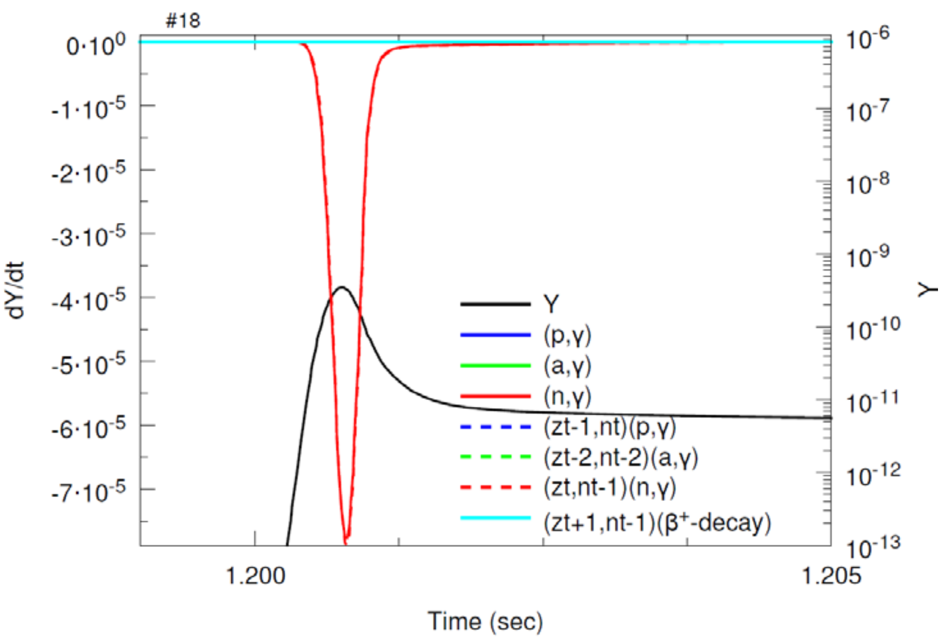


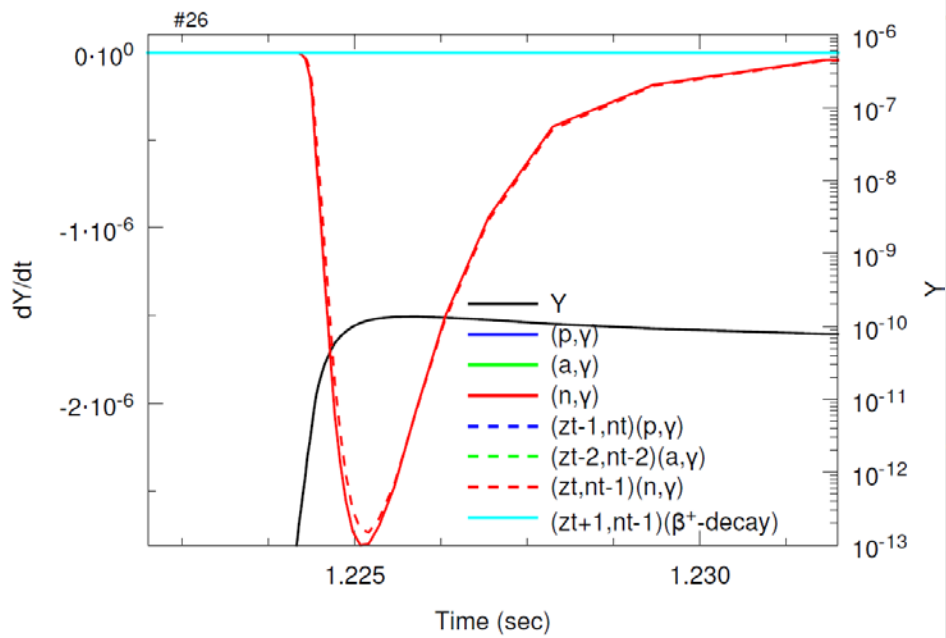


Nuclear Flow and Production of ^{115}Sn

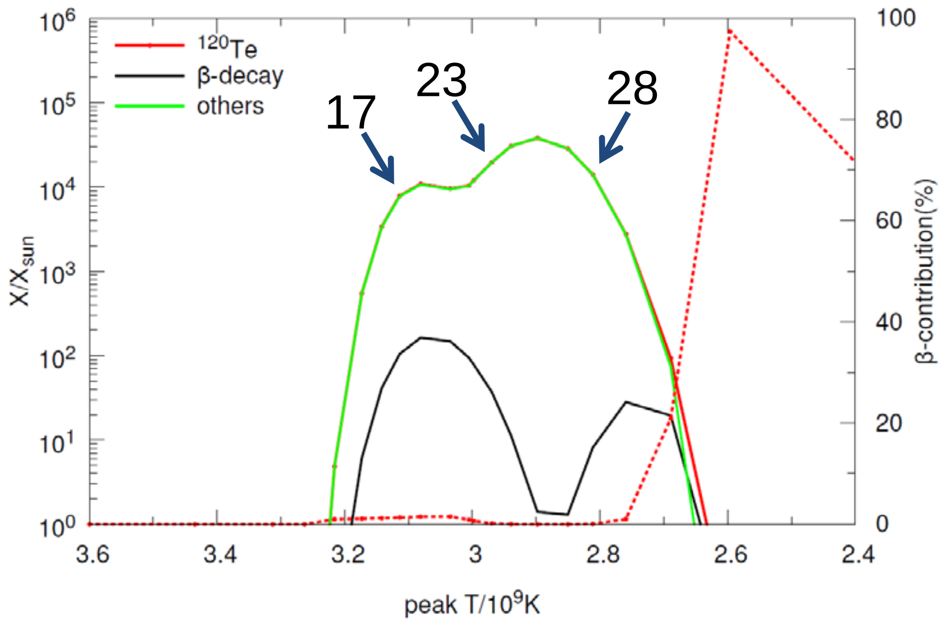


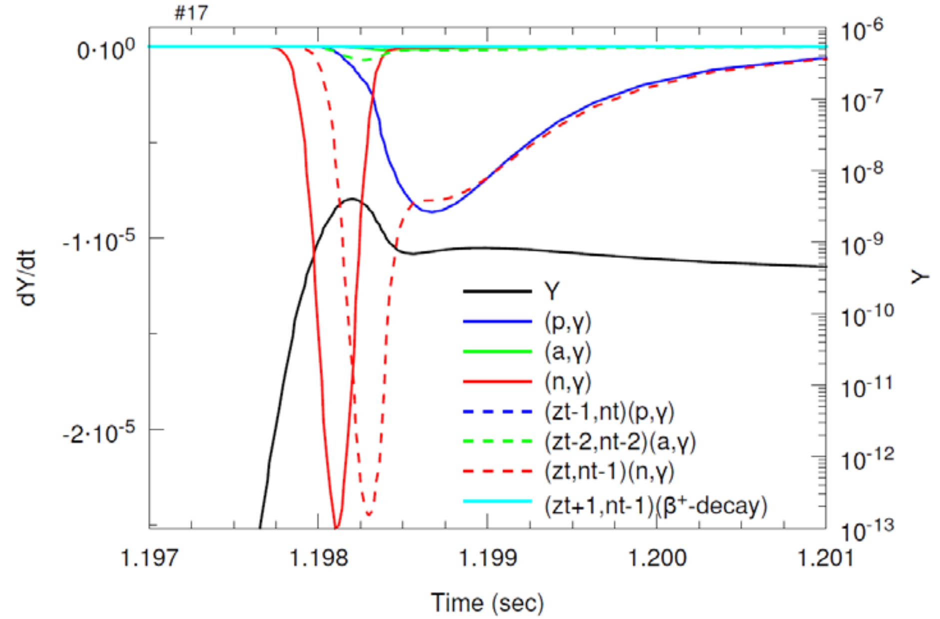


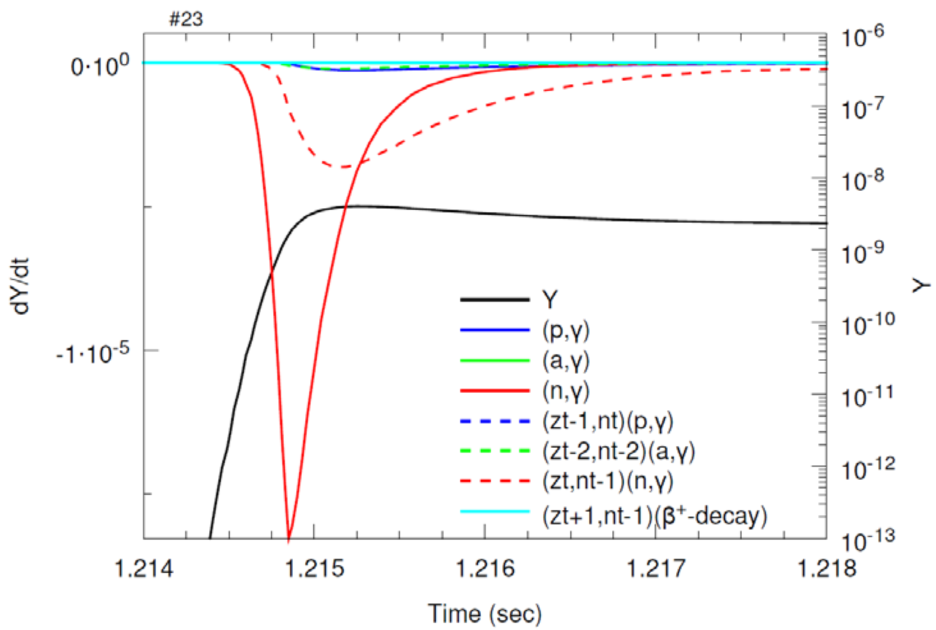


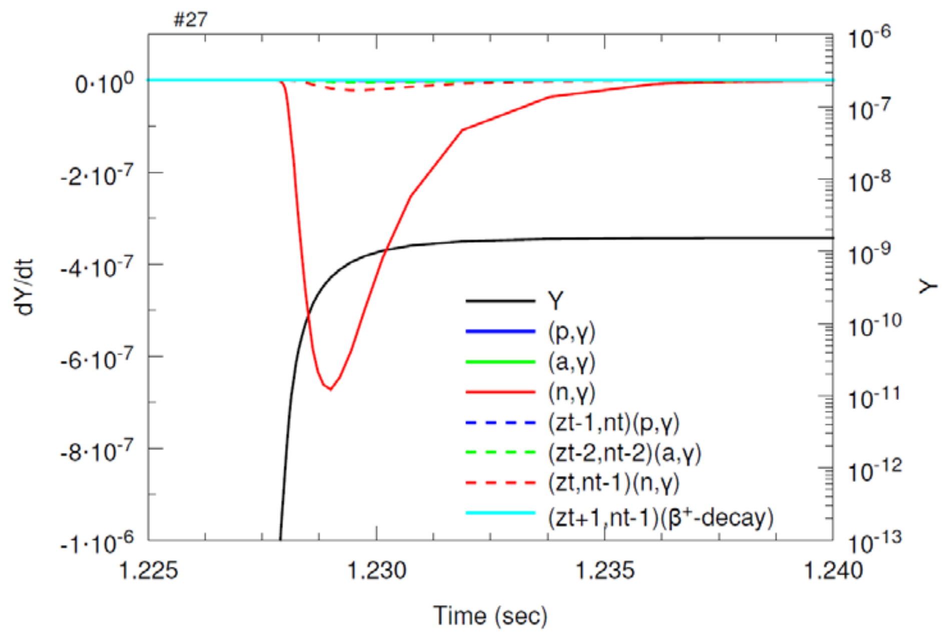


Nuclear Flow and Production of ^{120}Te

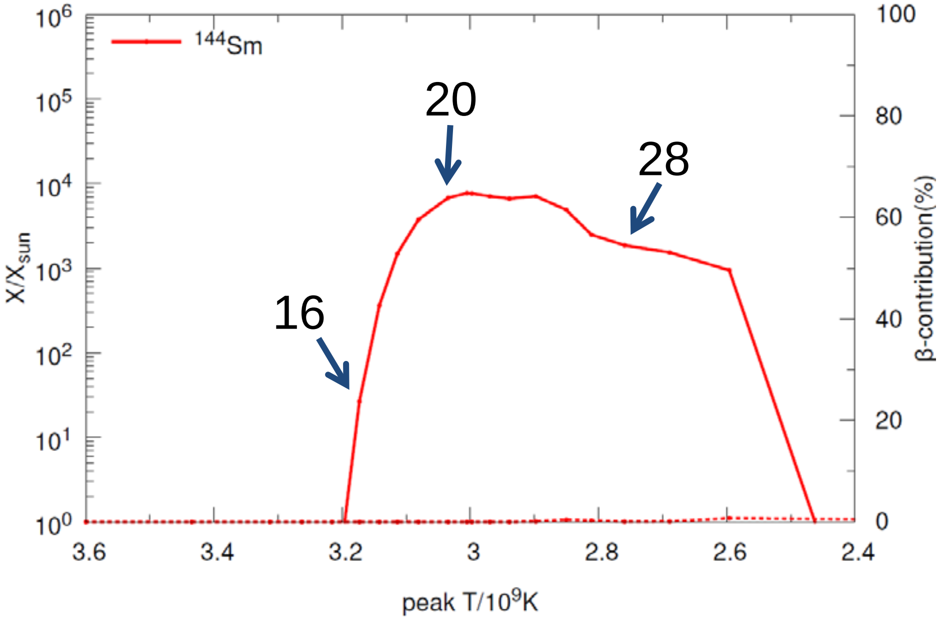


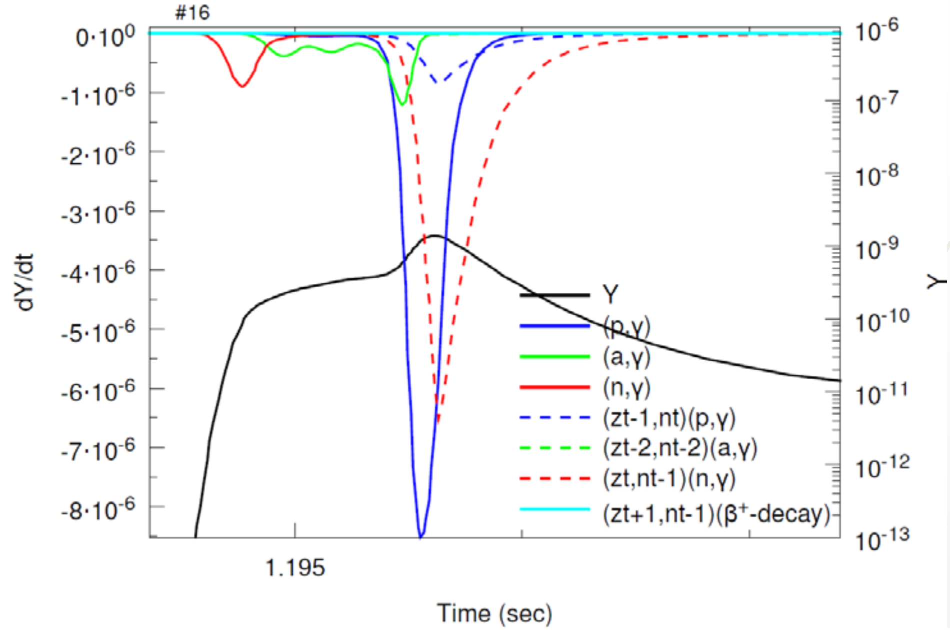


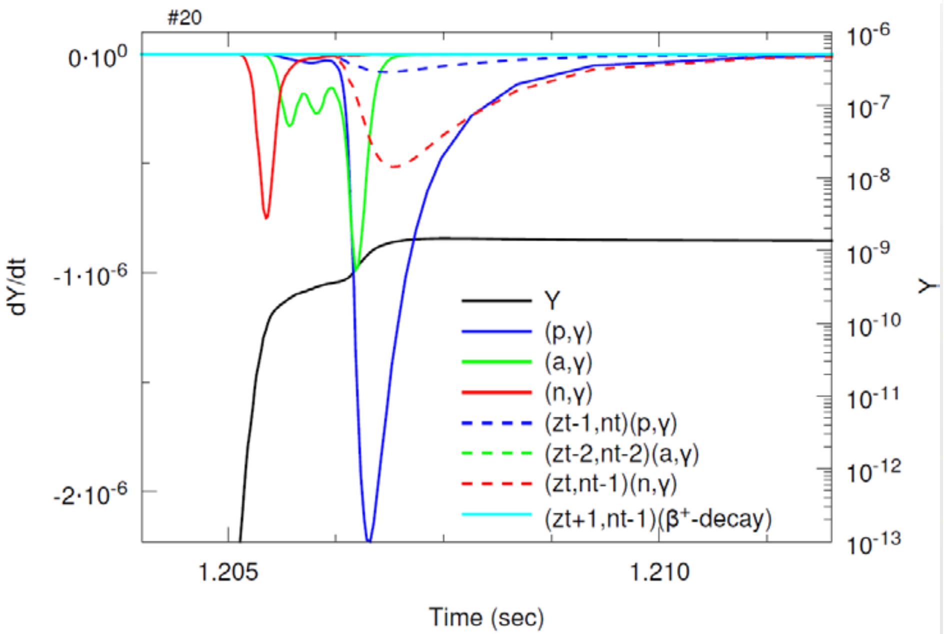


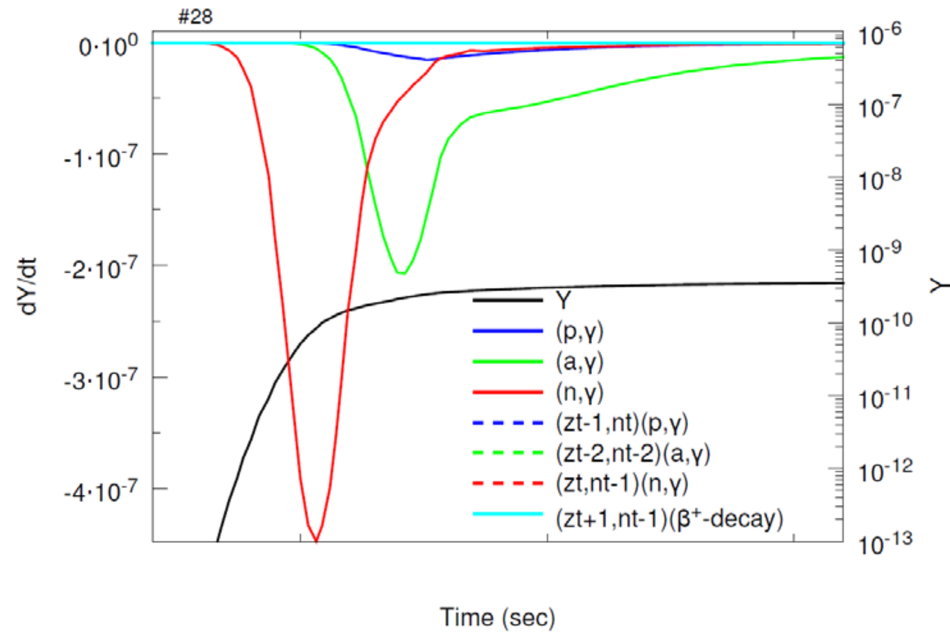


Nuclear Flow and Production of ^{144}Sm

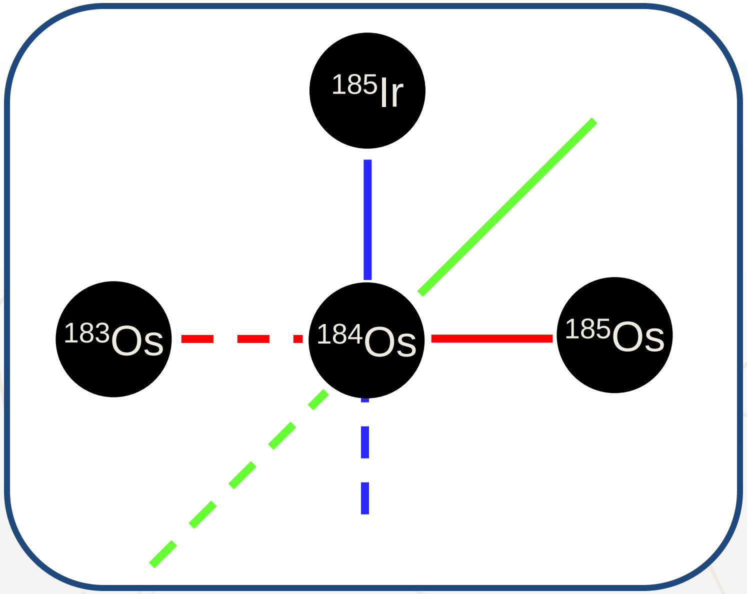


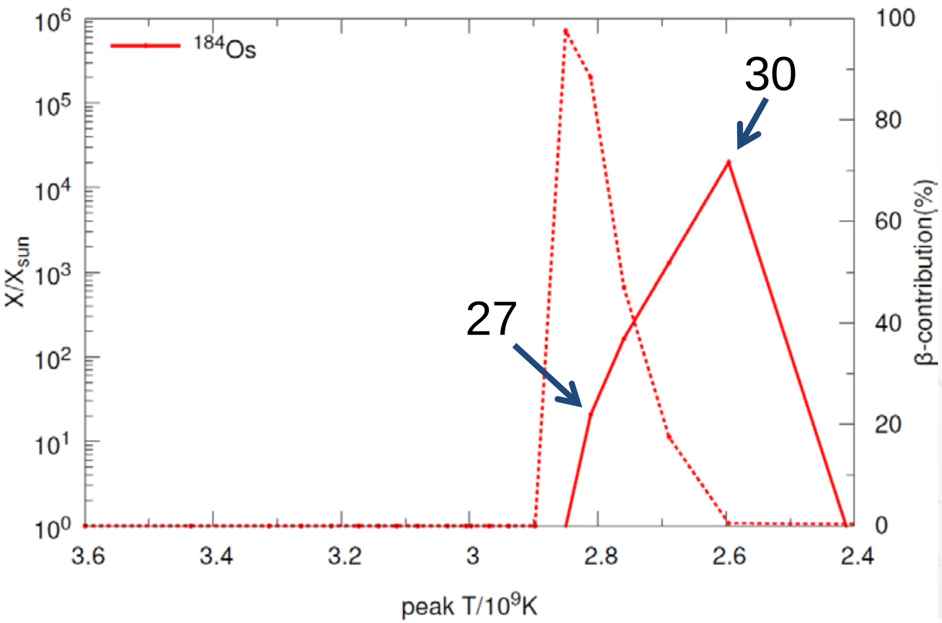


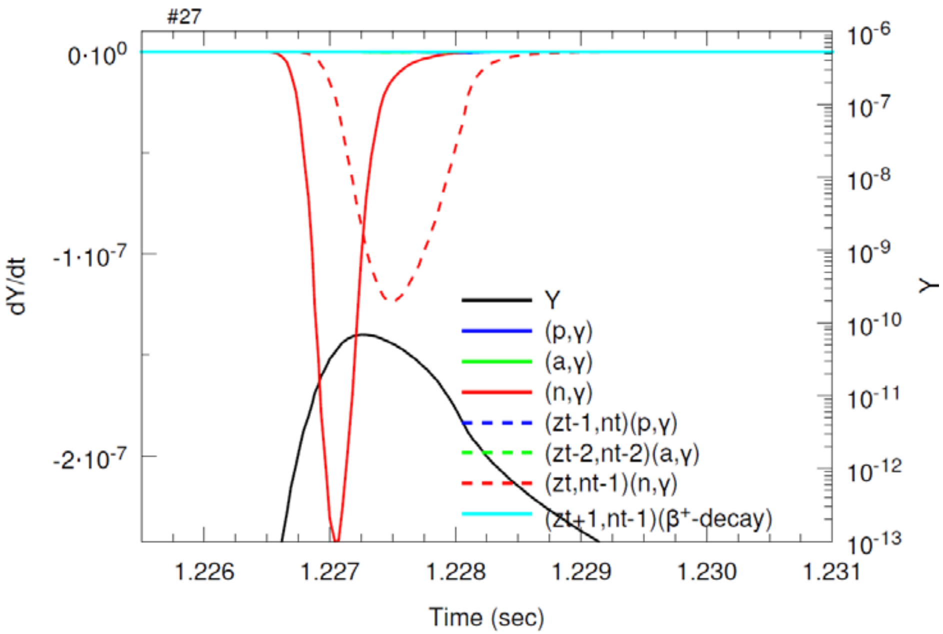


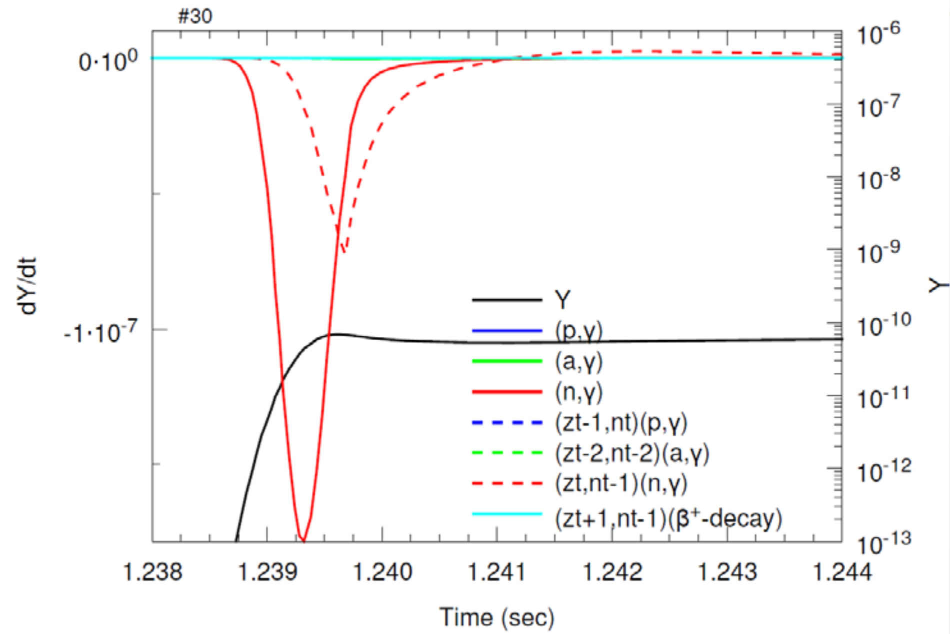


Nuclear Flow and Production of ^{184}Os

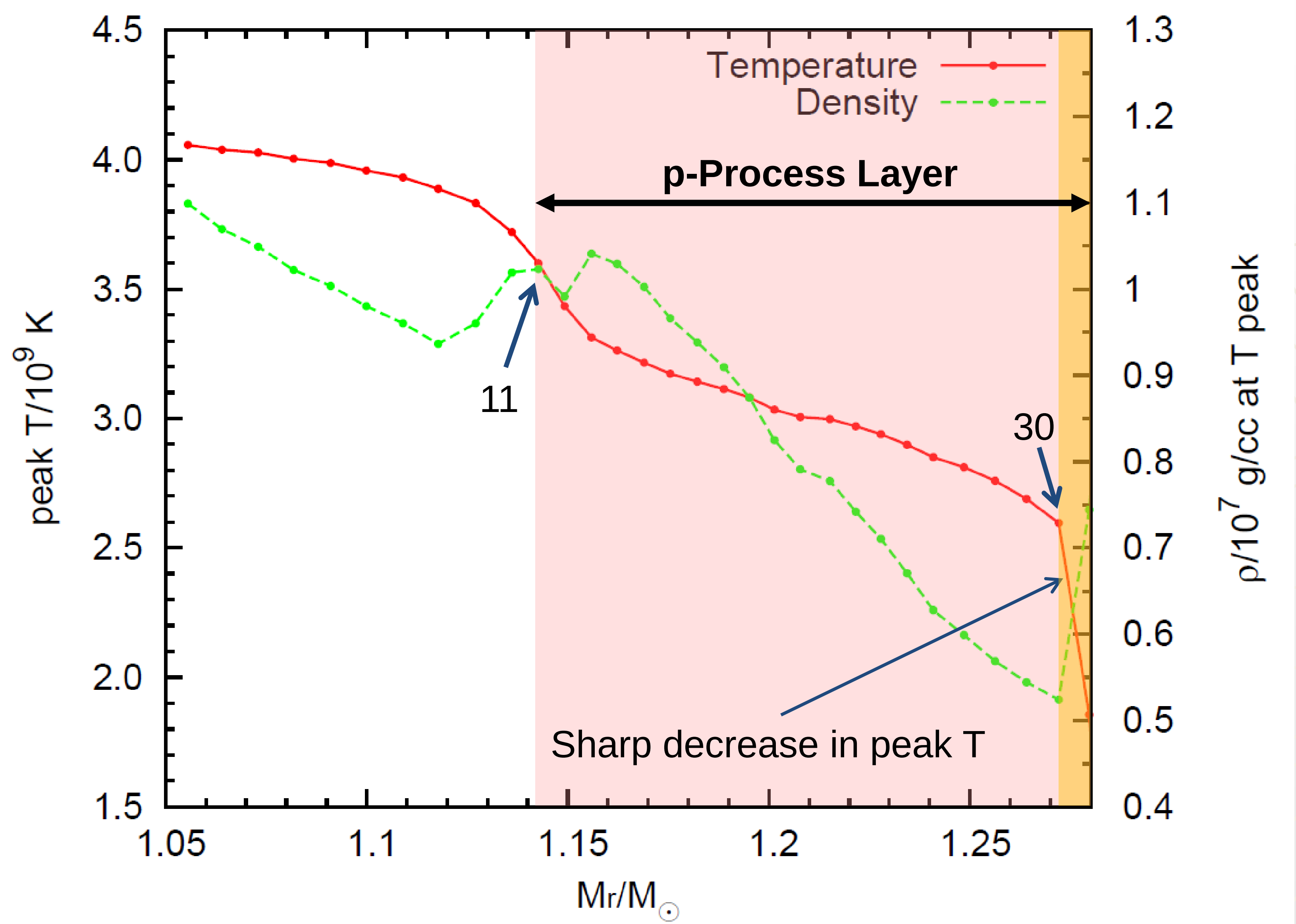




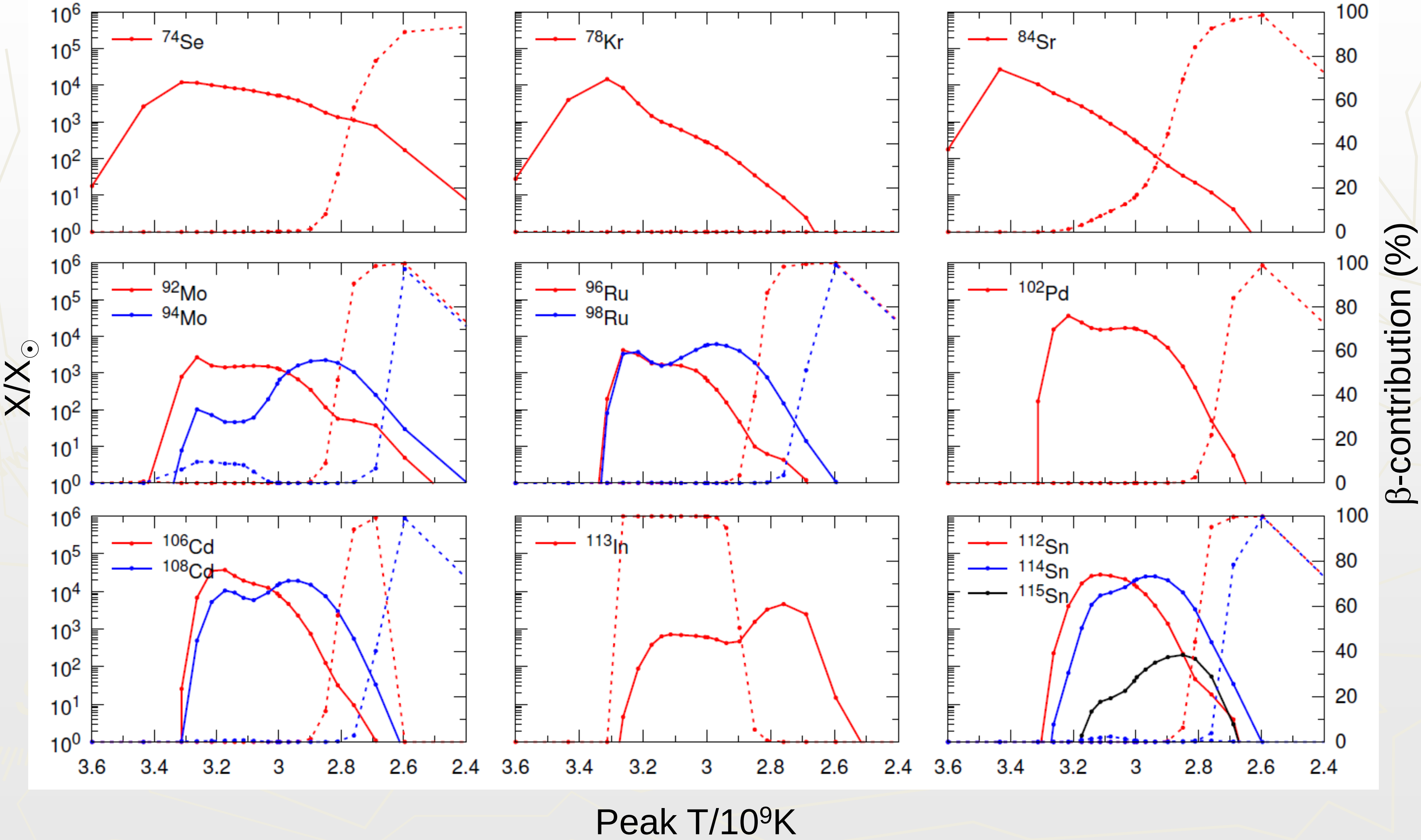




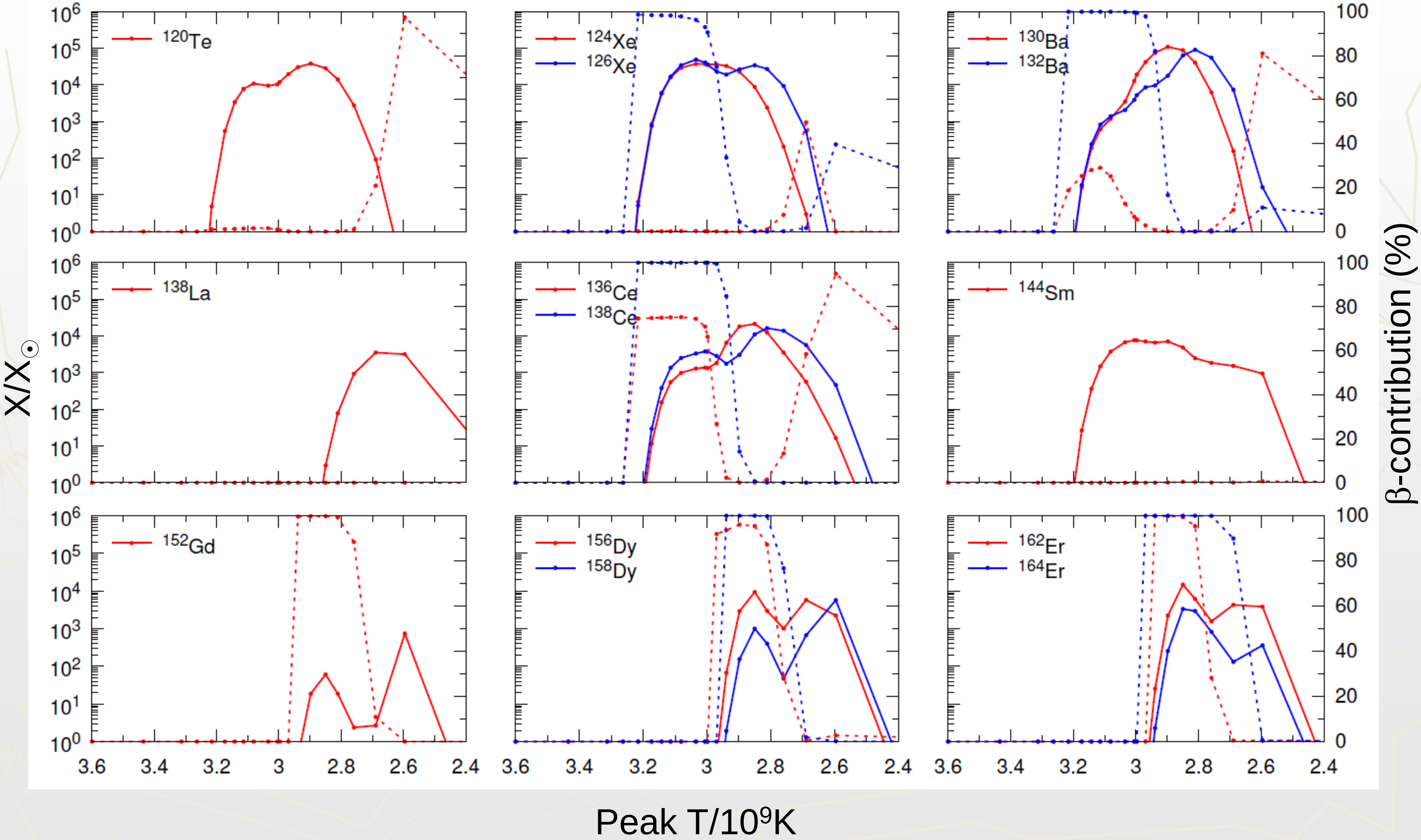
Peak Temperatures of Trajectories



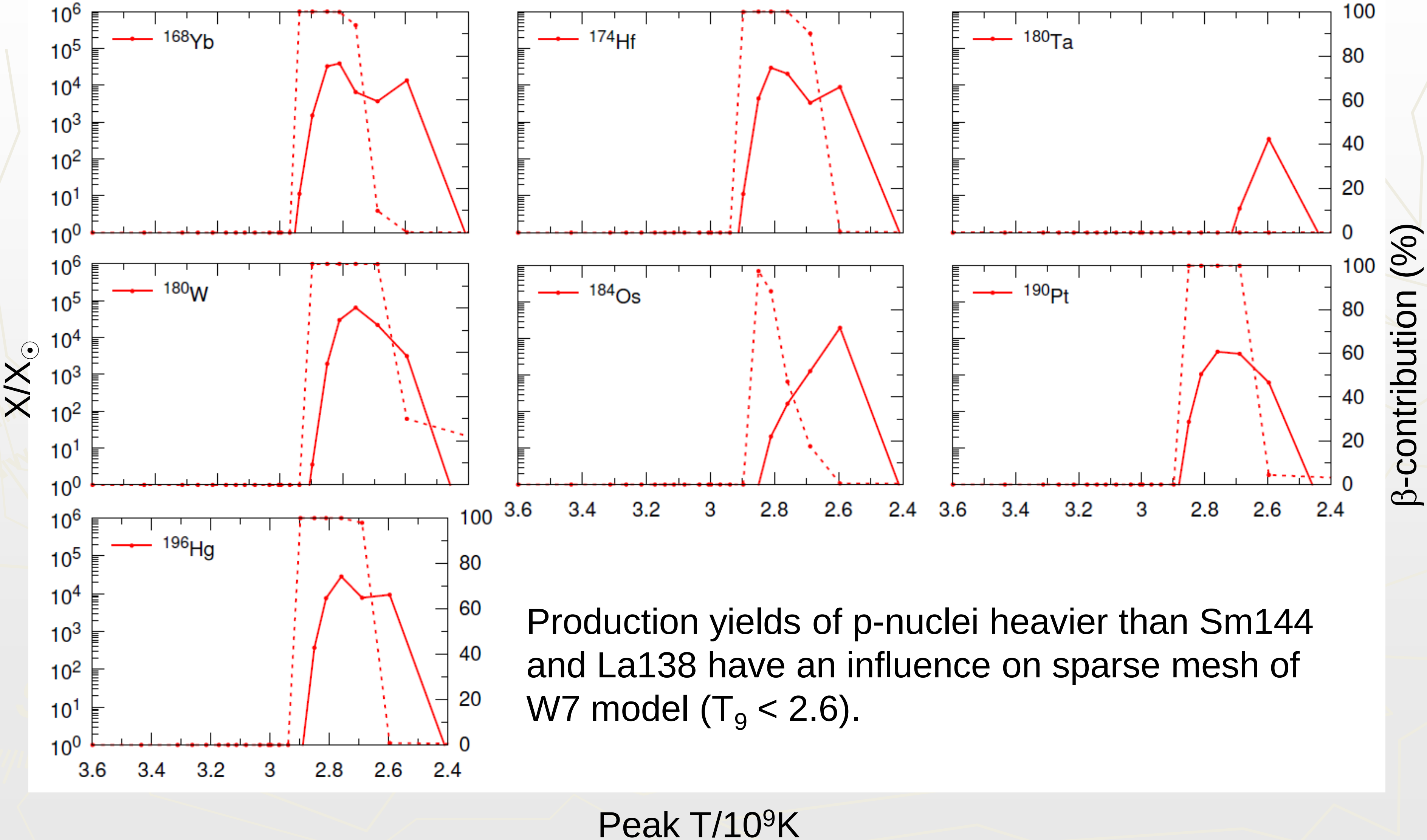
Summary of p-process ①



Summary of p-process ②



Summary of p-process ③



Production yields of p-nuclei heavier than Sm144 and La138 have an influence on sparse mesh of W7 model ($T_9 < 2.6$).

Summary

- Rates of neutron capture reaction and the inverse on most of p-nuclei are important to determine the final abundances.

Previous Experimental Efforts on n-capture (from EXFOR & KaDoNiS)

2000s	Se74, Kr78, Sr84, Ru96, Pd102, Te120, Ba130, Ba132, Dy156, Er164, Yb168, Hf174, W180, Os184, Pt190, Hg196, Ta180
1990s	Cd106, Cd108, Sn114, Sn115, Xe124, Xe126, Ce136, Ce138, Sm144, Gd152, Er162
1980s or earlier	Mo92, Mo94, In113, Sn112
No exp.	Ru98, La138, Dy158

- Much efforts are devoted to measure the neutron capture rates on p-nuclei.