Radioactive Gamma-Ray Emission from Neutron Star Mergers

报告人：陈梦华（广西大学）

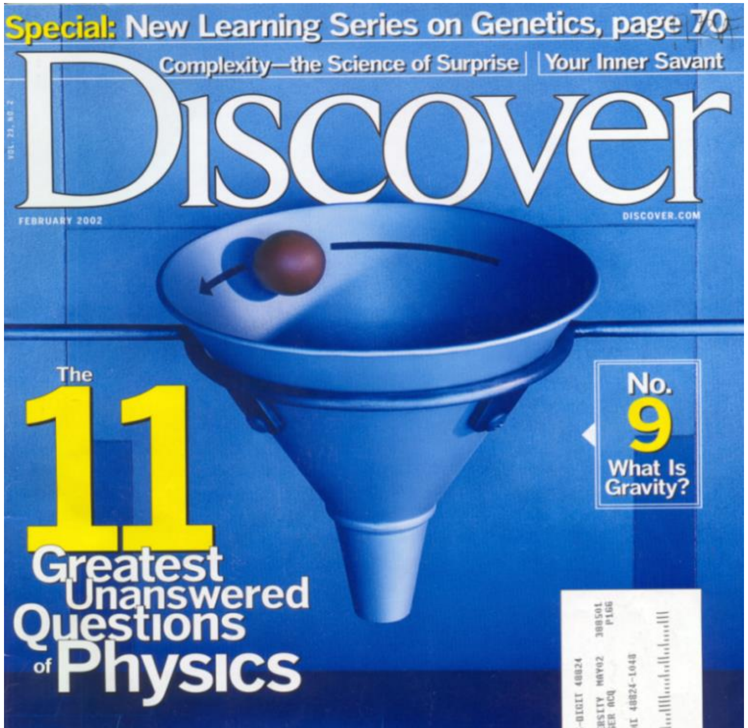
合作者：梁恩维、李立新、林达斌

2020/10/31

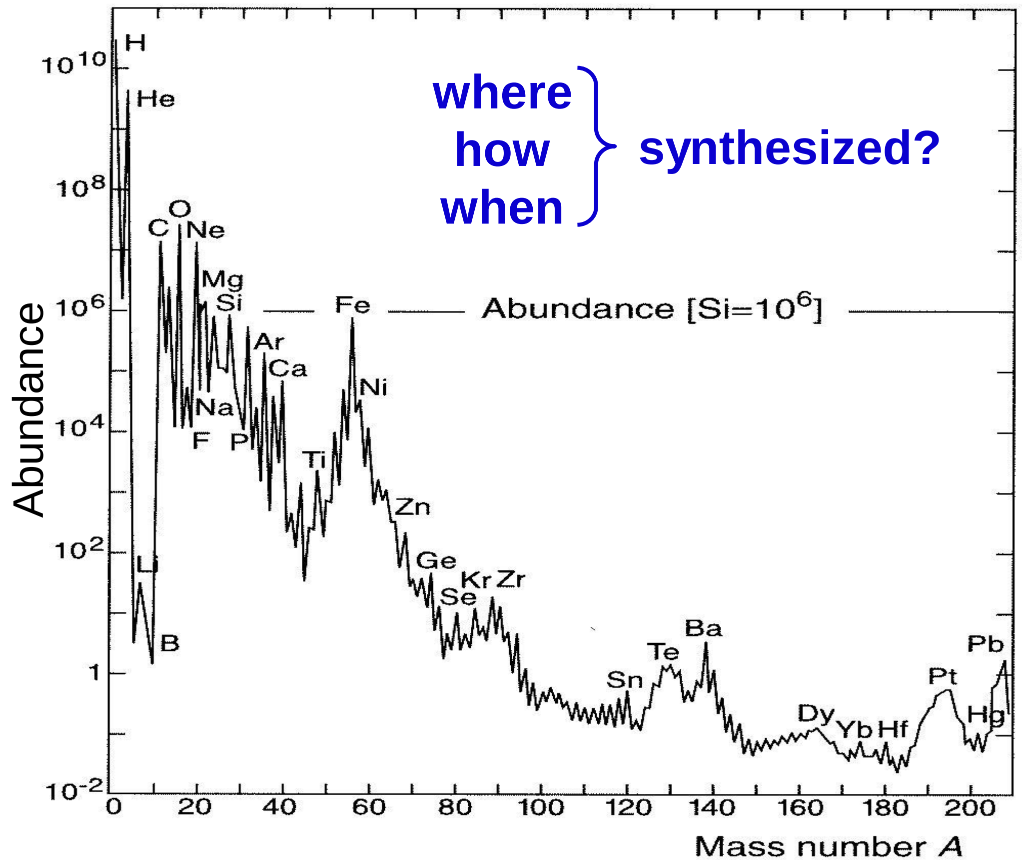
Outline

- Origin of the heavy elements
- r-process nucleosynthesis
- Radioactive gamma-ray emission
- Summary

Origin of the heavy elements



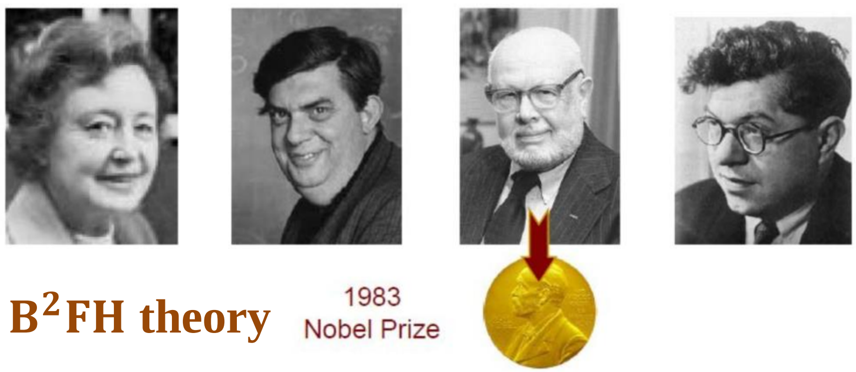
- How were the heavy elements from iron to uranium made?



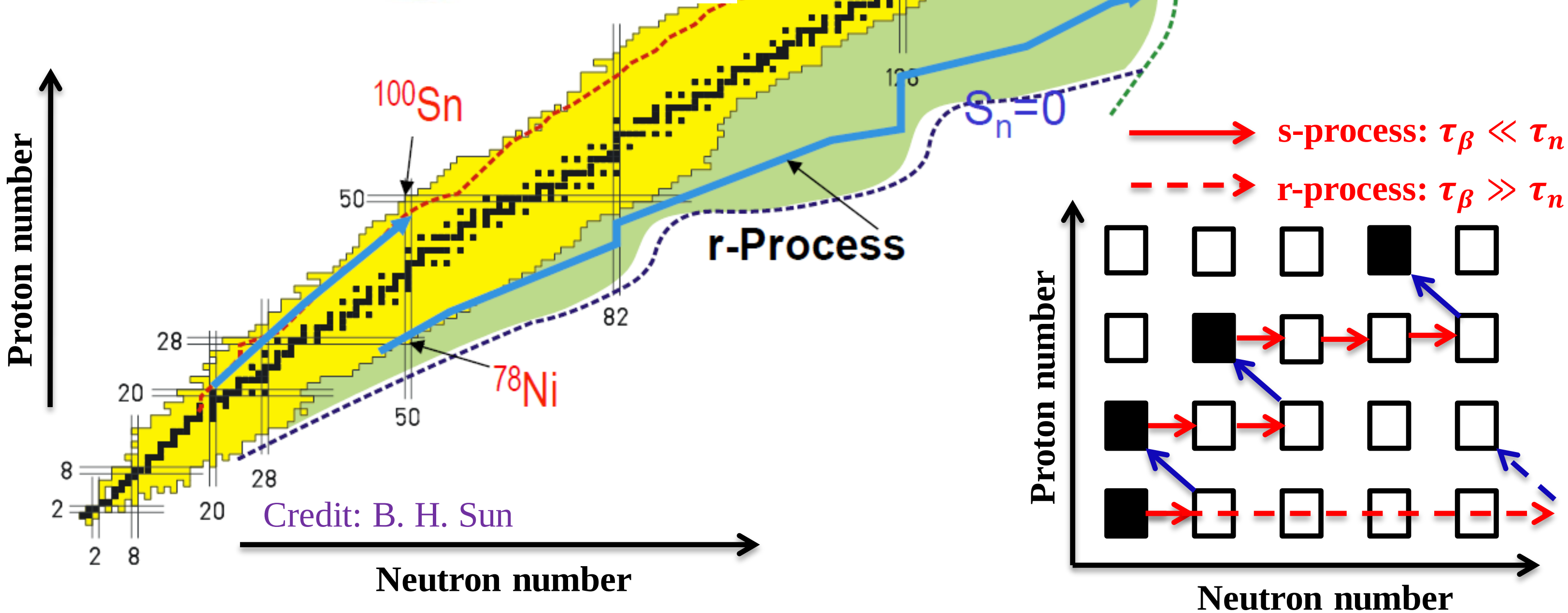
- **Primordial nucleosynthesis: H, He, Li;**
- **Stellar nucleosynthesis: C, N, O,…, Fe;**
- **Explosive nucleosynthesis: Fe→U?**

☼ *R. A. Alpher et al. PR, **162**(1948); E. M. Burbidge et al. RMP, **29**(1957).*

r-process nucleosynthesis



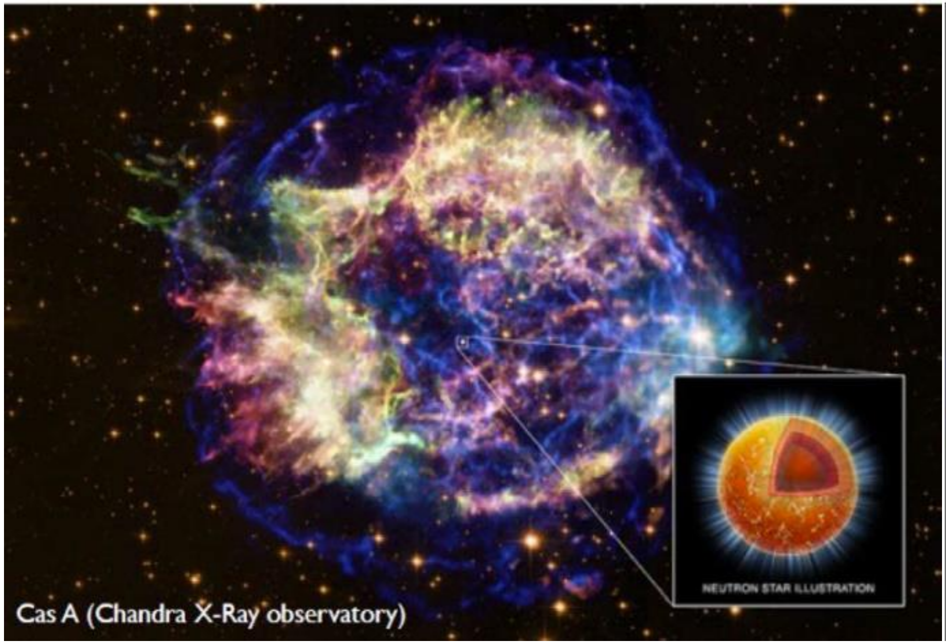
B^{2}FH theory 1983 Nobel Prize



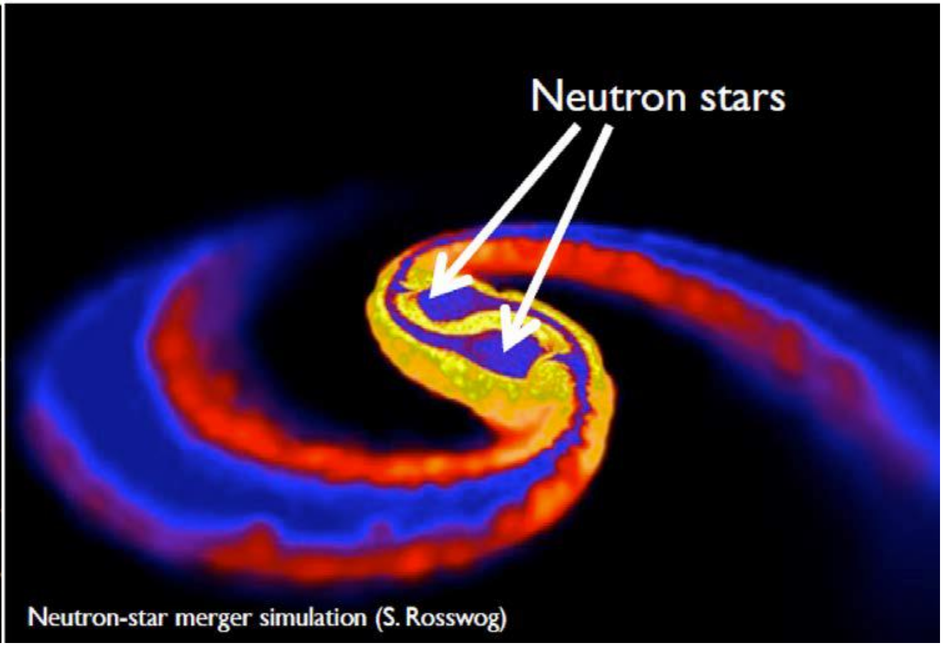
➢ **r-process ➡ produces about half of the heavy elements.**

☼ *E. M. Burbidge et al. Rev. Mod. Phys.* ***29****(1957).*

r-process sites



Cas A (Chandra X-Ray observatory)

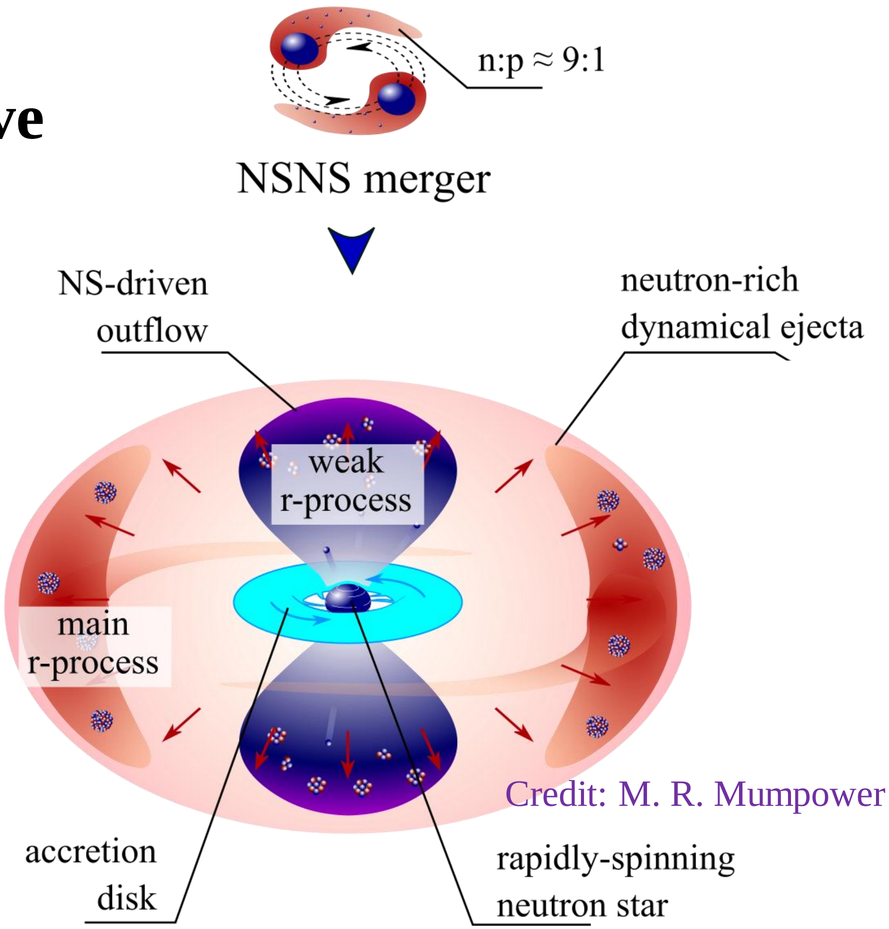


Neutron-star merger simulation (S. Rosswog)

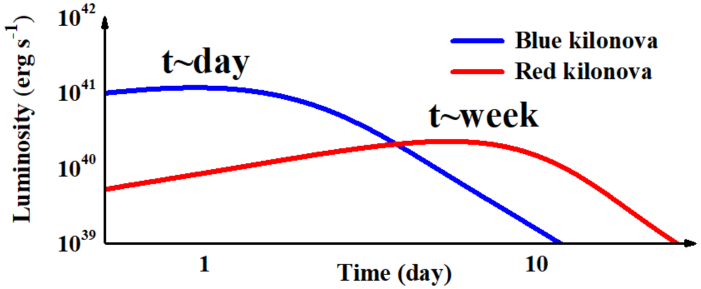
- **(1) Core-Collapse Supernovae**
  - ☼ *B. Meyer, et al. ApJ, **399**(1992); S. E. Woosley, et al. ApJ, **433**(1994) .*
- **(2) Binary Neutron Star Mergers**
  - ☼ *J. M. Lattimer, et al. ApJ, **192**(1974); E. Symbalisty, et al. ApJ, **22**(1982).*

Observational signature: kilonova

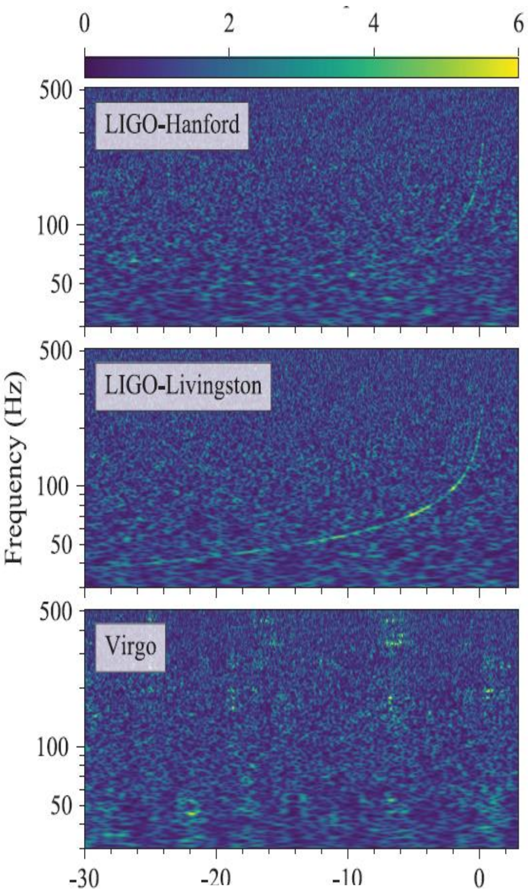
- **Kilonova: powered by radioactive decay of r-process elements.**
  - *L. X. Li, et al. ApJL,* ***507****(1998);*
  - *B. D. Metzger, et al. MNRAS,* ***406****(2010);*
  - *B. D. Metzger, et al. LRR,* ***20****(2017).*
- **Blue kilonova: lanthanide-free; low-opacity; t~day.**
  - *B. D. Metzger, et al. MNRAS,* ***406****(2010);*
  - *L. F. Roberts, et al. ApJL,* ***736****(2011);*
  - *B. D. Metzger, et al. MNRAS,* ***441****(2014).*
- **Red kilonova: lanthanide-rich; high-opacity; t~week.**
  - *D. Kasen, et al. ApJ,* ***774****(2013);*
  - *M. Tanaka, et al. ApJ,* ***775****(2013);*
  - *J. Barnes, et al. ApJ,* ***775****(2013).*



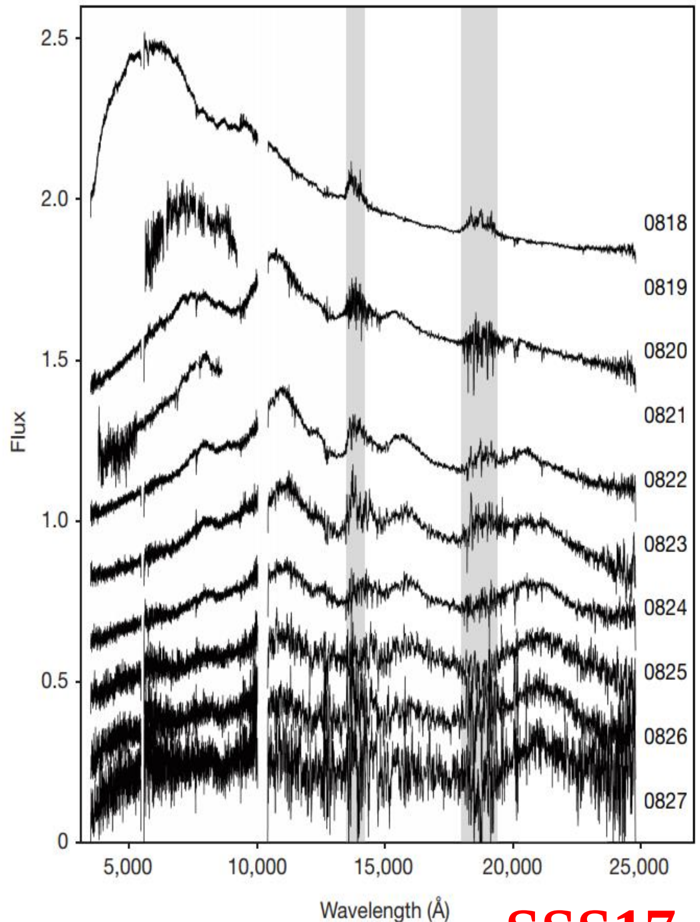
Credit: M. R. Mumpower

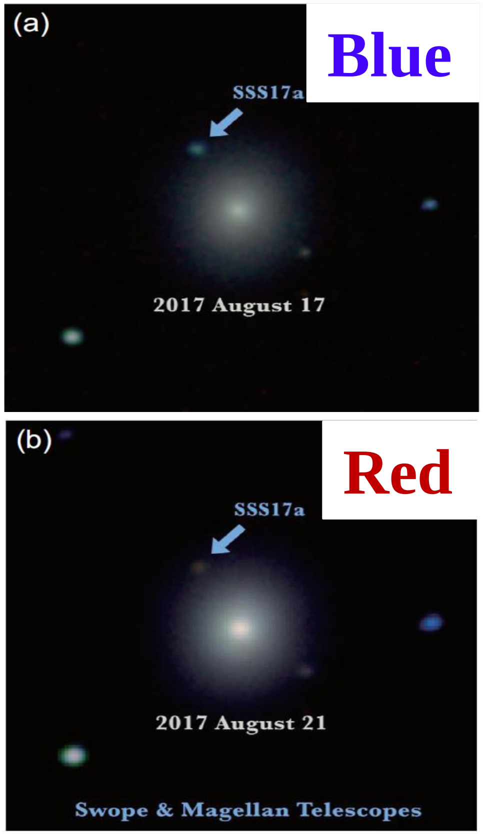


GW170817 & AT2017gfo



GW170817



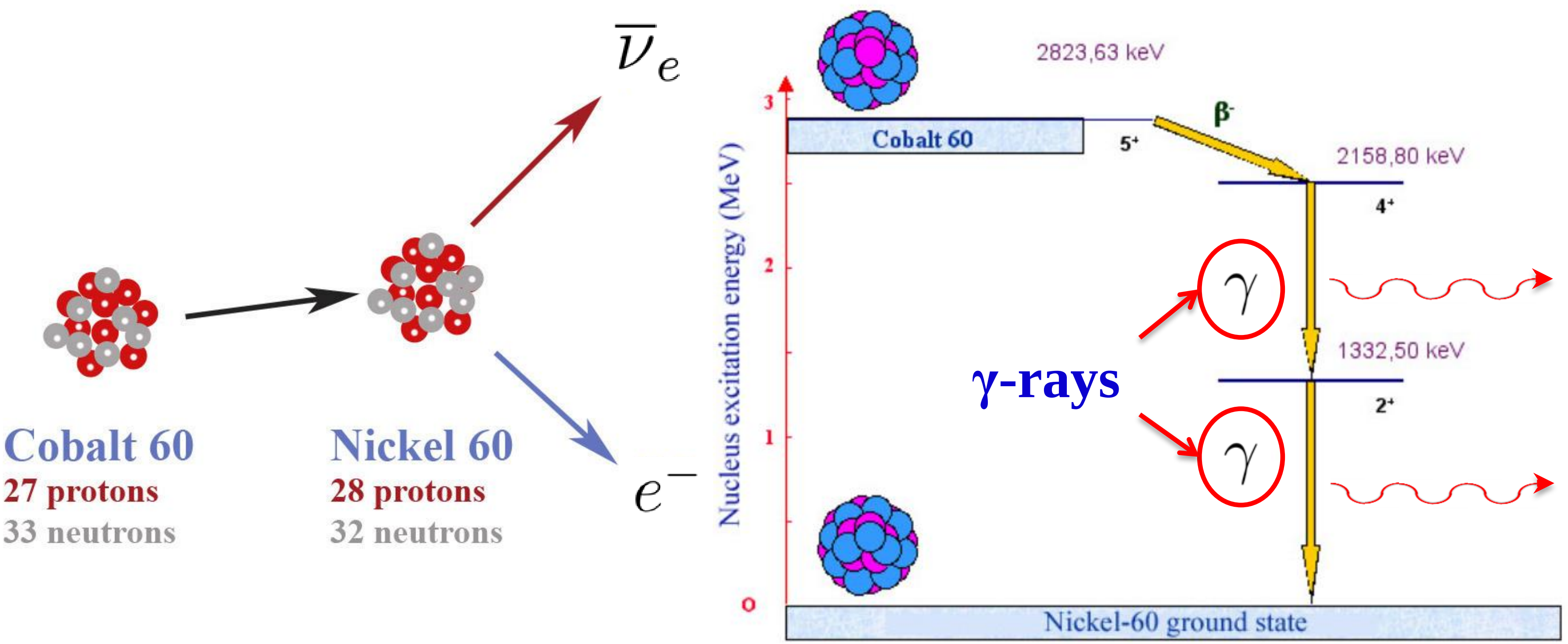


SSS17a/AT2017gfo

- **It is difficult to obtaining detailed nuclide compositions of the merger ejecta.**

☼ *B. P. Abbott el al. PRL,* ***119****(2017);*
☼ *E. Pian, et al. Nature,* ***551****(2017); M. R. Drout et al. Science,* ***358****(2017).*

Radioactive γ-rays: a potential probe

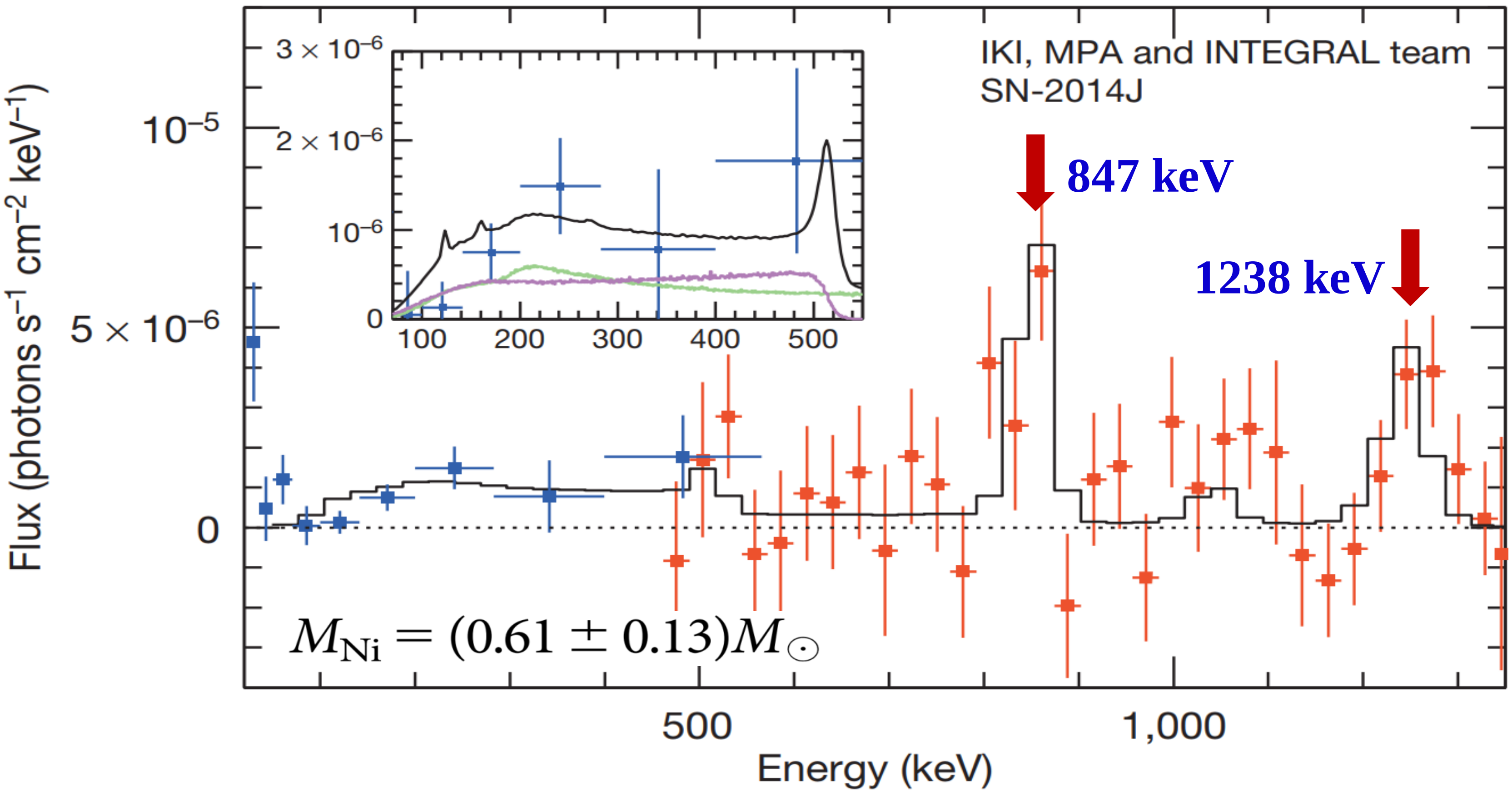


β-decay: $${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + e^{-} + \gamma + \overline{\nu}_e$$

- **MeV gamma-ray is an important message from r-process nucleosynthesis.**

Radioactive γ-rays in SN 2014J

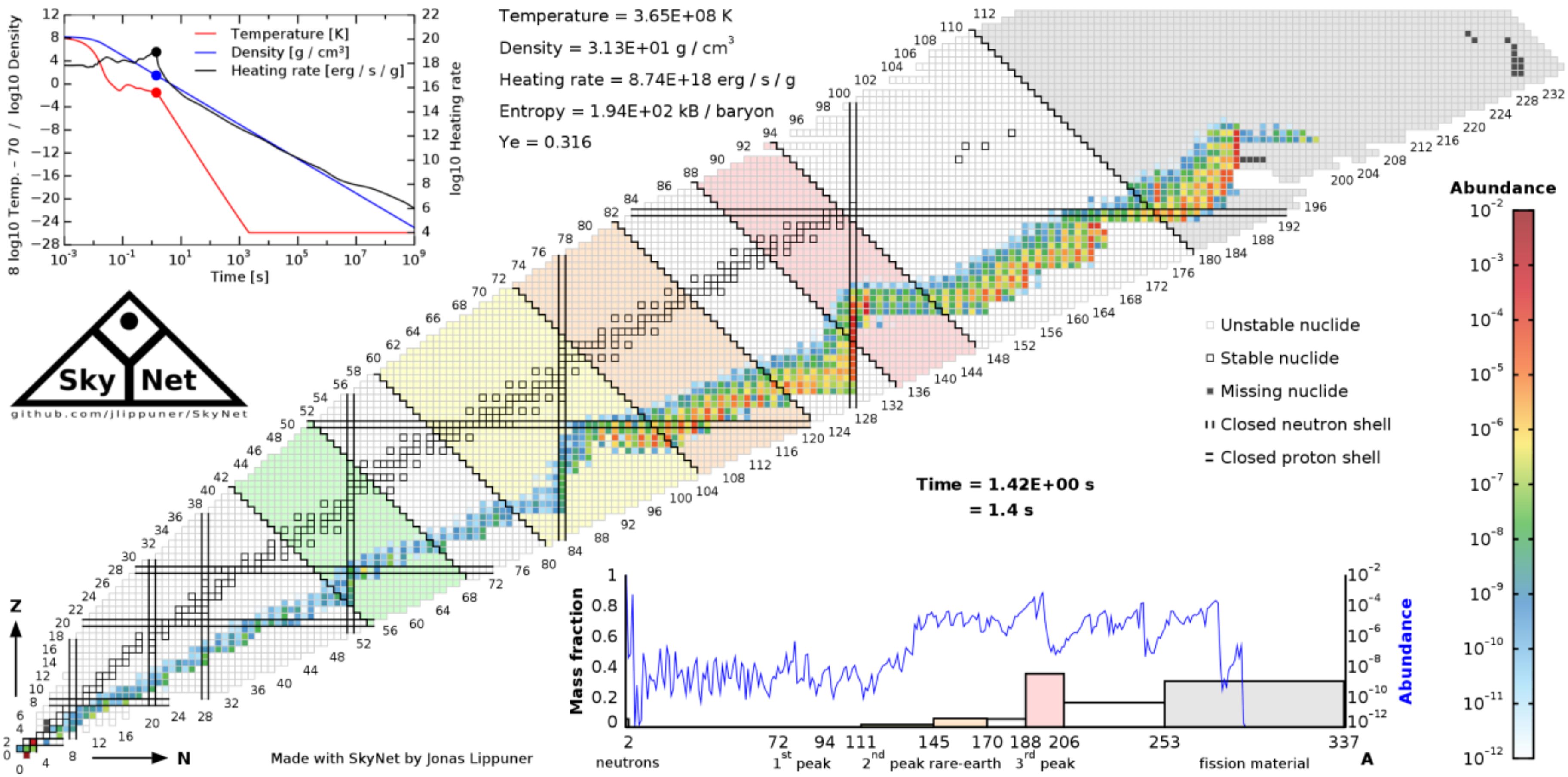
γ-rays from ^{56}Co decay at 847 and 1238 keV.



- **It is successfully derived that about $0.6M_\odot$ radioactive ^{56}Ni were synthesized during the explosion.**

☼ *E. Churazov, et al. Nature, **512**(2014).*

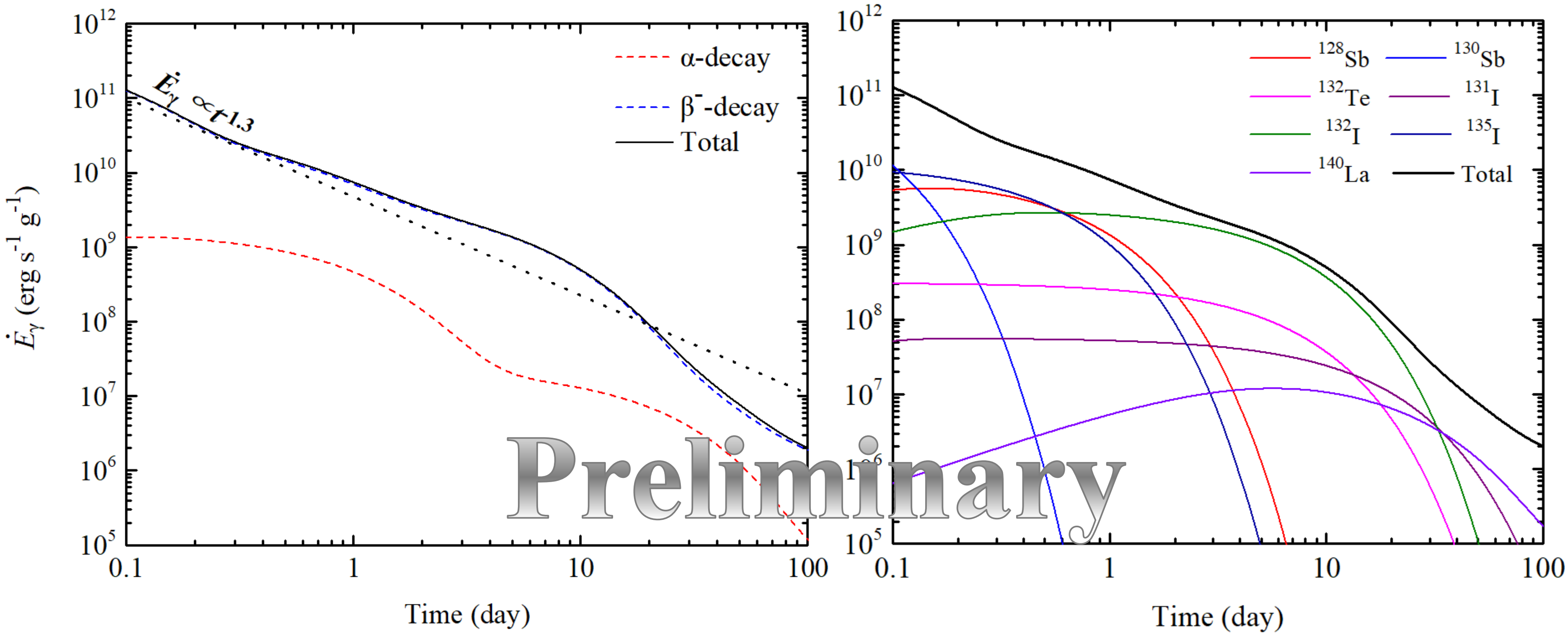
r-process simulations



- ➢ **Input: electron fraction, temperature, entropy**
- ➢ **Output: time-dependent nuclear abundances** $Y_i(t)$

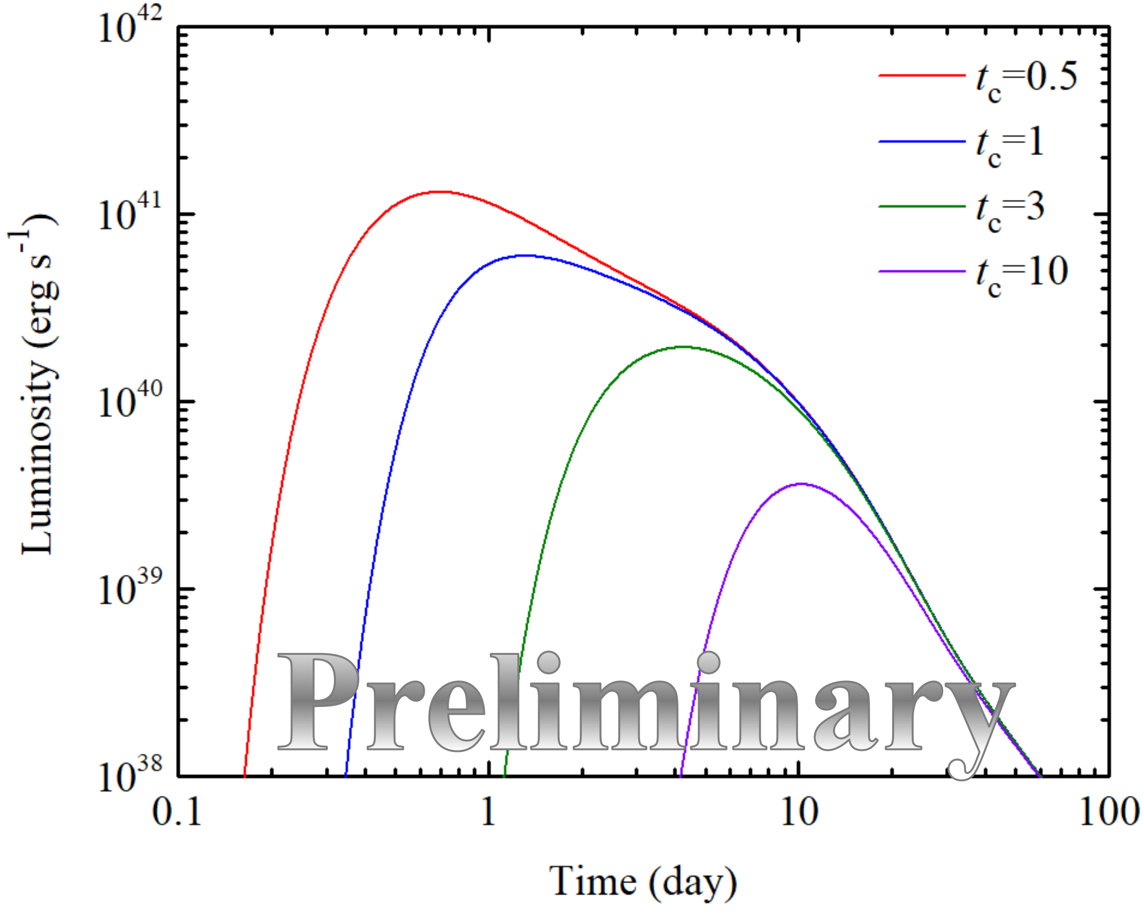
☼ *J. Lippuner, et al. ApJS,* ***233****(2017).*

Gamma-ray energy



- ➢ **The 95% of gamma-ray energy comes from the contribution of the β^--decay;**
- ➢ **Total gamma-ray energy generation rate, $\dot{E}_\gamma \propto t^{-1.3}$;**
- ➢ **The dominant contributors of gamma-ray energy are the nuclides around the second r-process peak (A~130).**

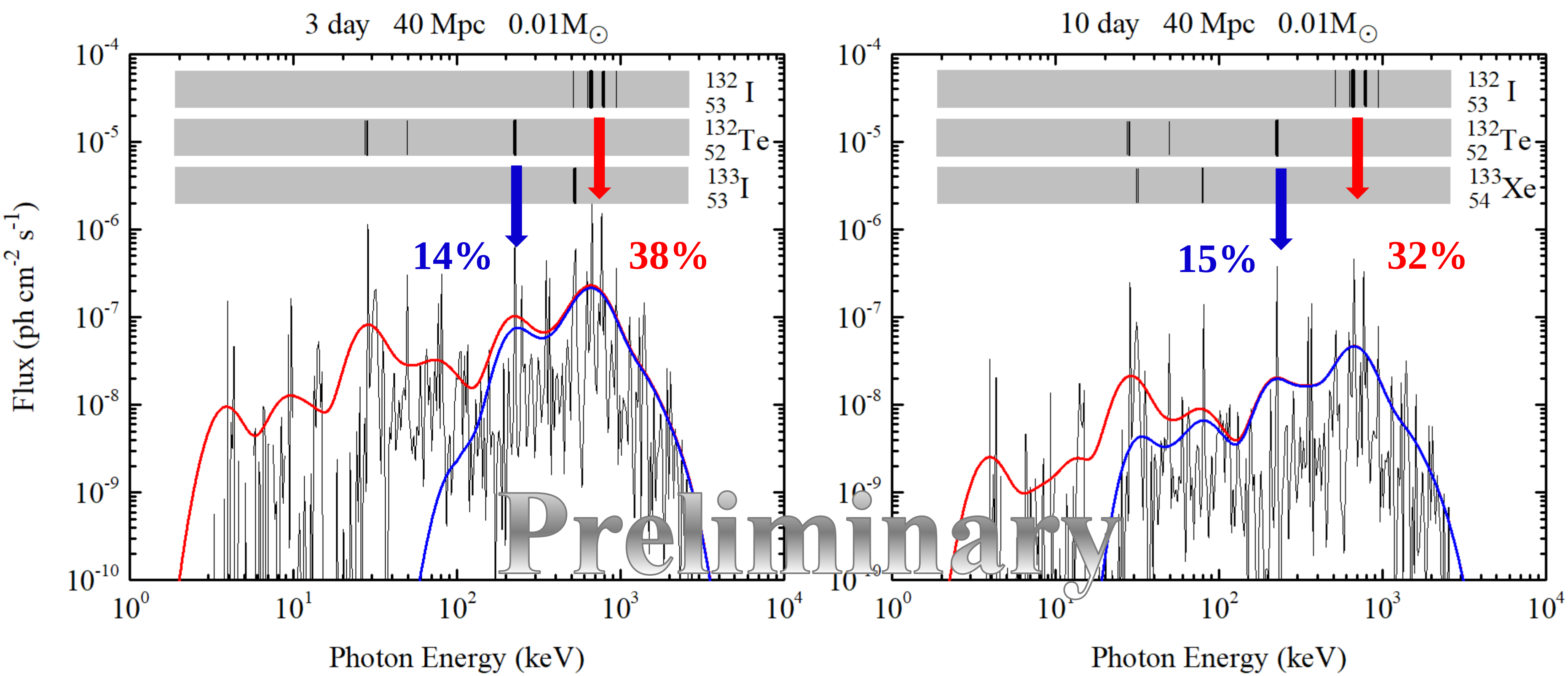
Gamma-ray luminosity



➢ **For t_c=1 day, peak luminosity $\sim 6.0 \times 10^{40}$ erg/s.**

* Note that t_c is the time when the ejecta starts to be transparent to photons.

Gamma-ray spectrum



- For t ≥ 3 days, the observed spectrum has remarkable double peaks around 230 keV and 700 keV.
- The decay chain of ^{132}Te→ ^{132}I→ ^{132}Xe produces several bright gamma-ray lines with energies of 228.16 keV, 667.71 keV, and 772.60 keV.

☼ *M. H. Chen, et al. submitted.*

Summary

- **The 95% of gamma-ray energy comes from the contribution of the β^{-}-decay;**

- **The dominant contributors of gamma-ray energy are the nuclides around the second r-process peak (A~130);**

- **The decay chain of ^{132}Te→ ^{132}I→ ^{132}Xe produces several bright gamma-ray lines with energies of 228.16 keV, 667.71 keV, and 772.60 keV, which would be the most promising decay chain to be detected by future observations.**

Thank you for your attention!