

素核宇宙融合レクチャーシリーズ 第13回

“超新星1987Aから超新星残骸まで”



長瀧天体ビッグバン研究室

理化学研究所
准主任研究員

長瀧 重博

主催：計算基礎科学連携拠点 (JICFuS) HPCI戦略プログラム分野5「物質と宇宙の起源と構造」
共催：理化学研究所 iTHESプロジェクト 2014年11月27日-28日、理研和光キャンパス





Hubble
Heritage



親星は大質量星

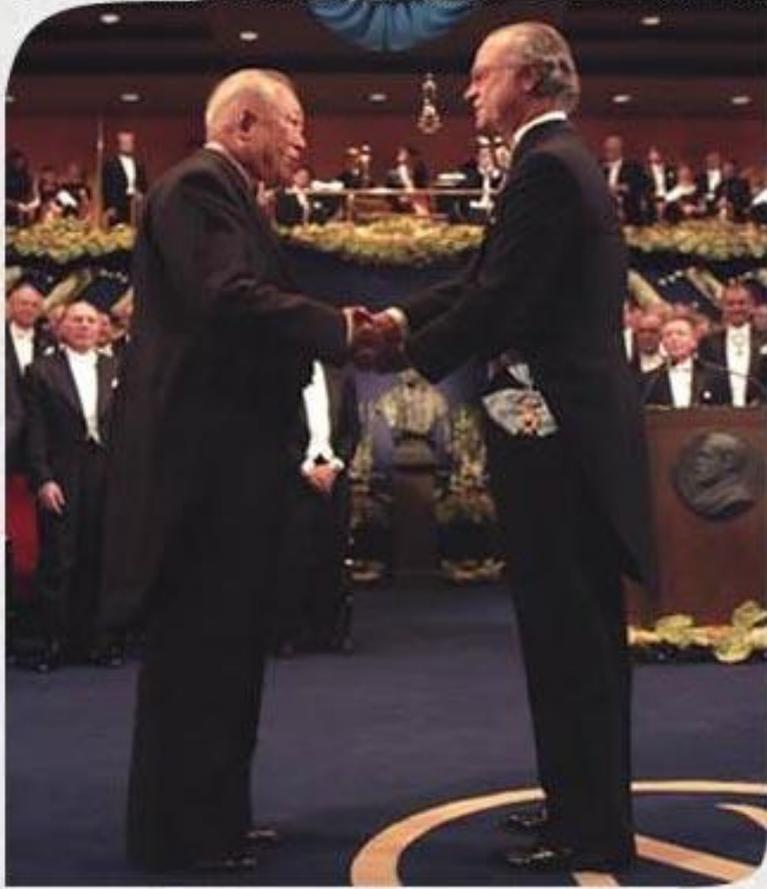
After: SN1987A

Before: Sanduleak -69° 202

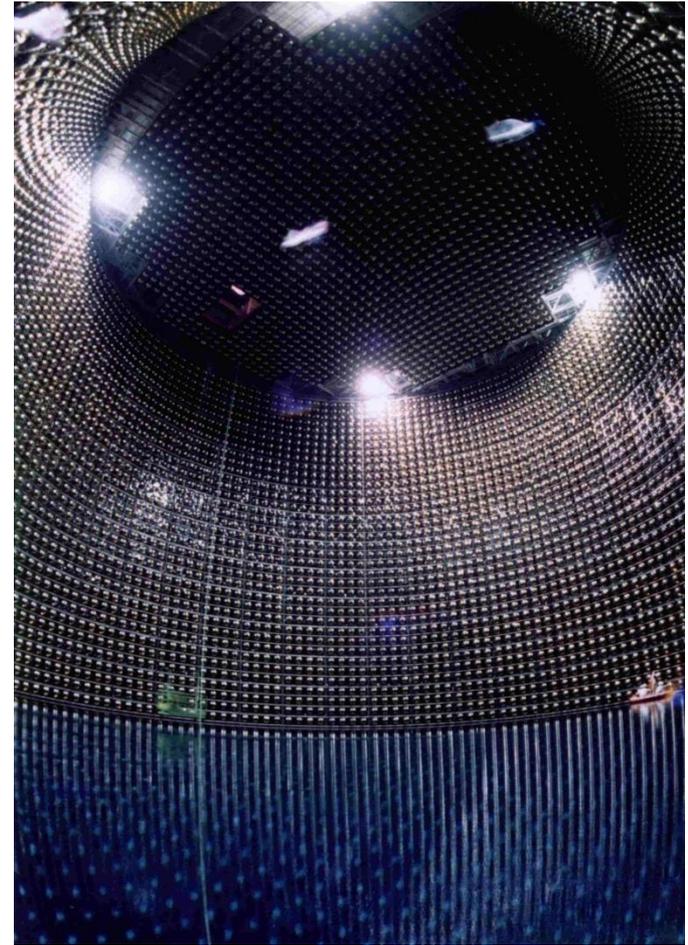


Detection of Neutrinos from SN1987A

▼ ノーベル賞を受ける小柴名誉教授 (2002年12月10日)

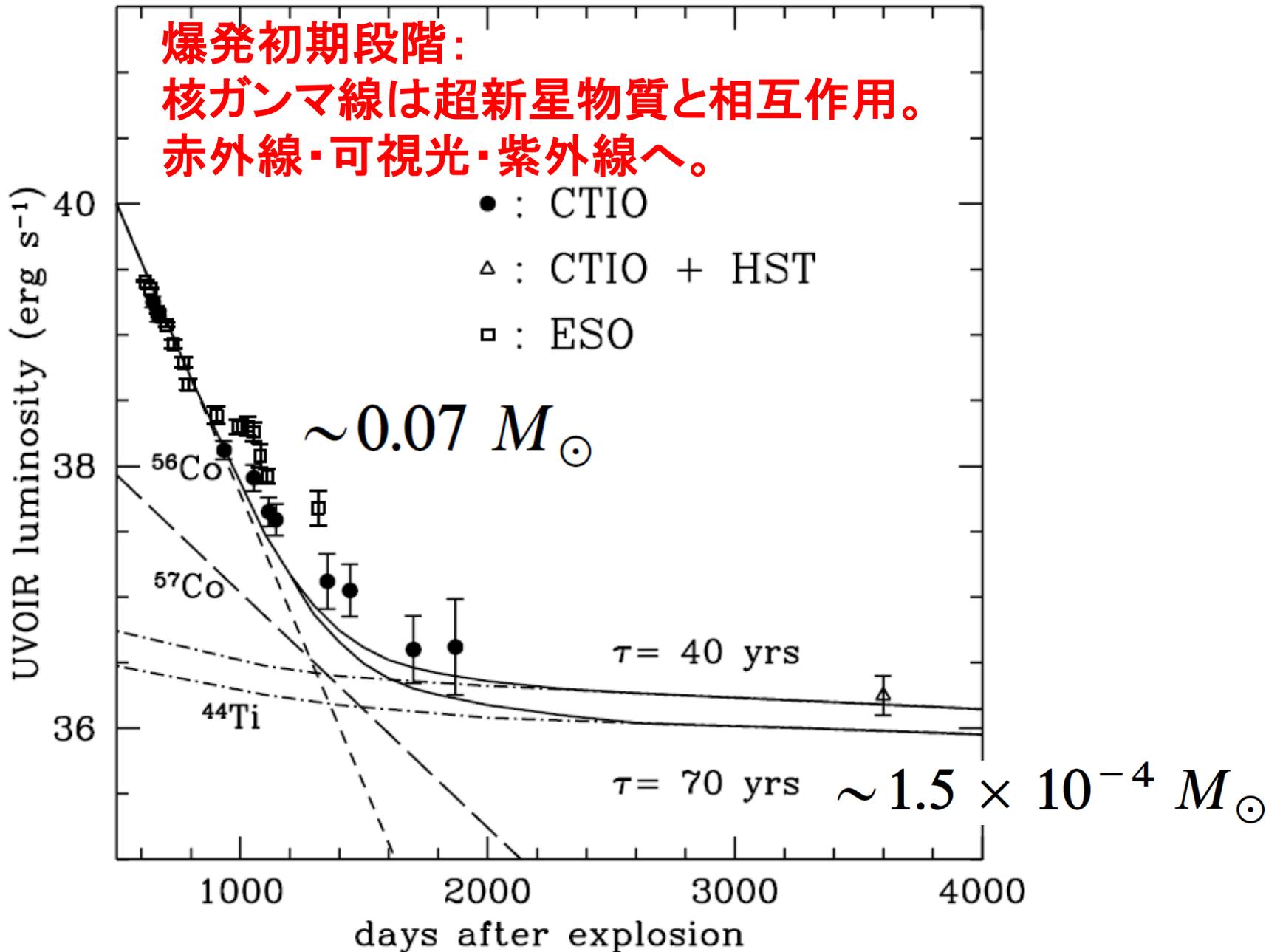


Prof. Koshihira



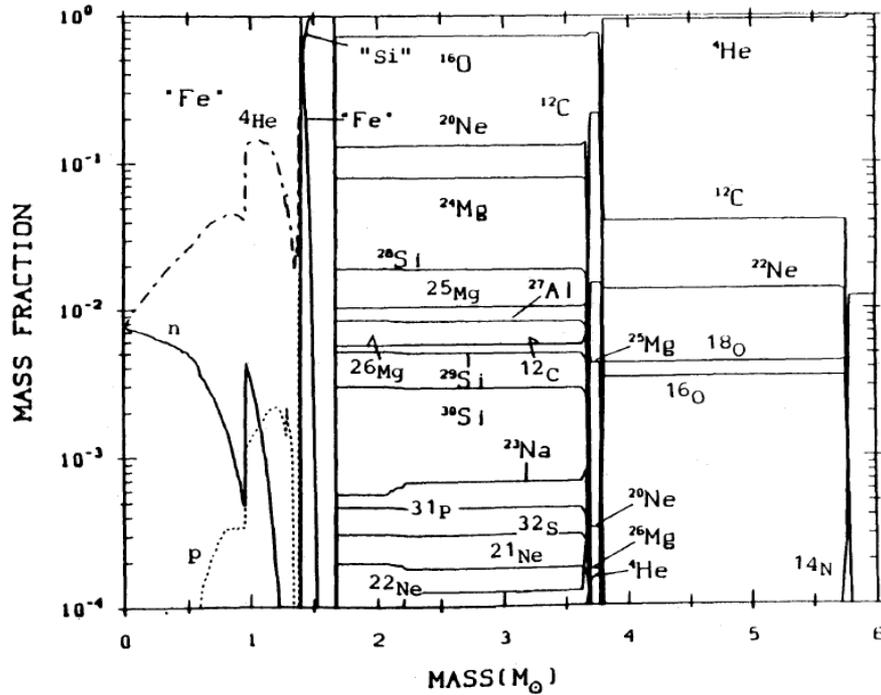
Super-Kamiokande

爆発初期段階：
核ガンマ線は超新星物質と相互作用。
赤外線・可視光・紫外線へ。

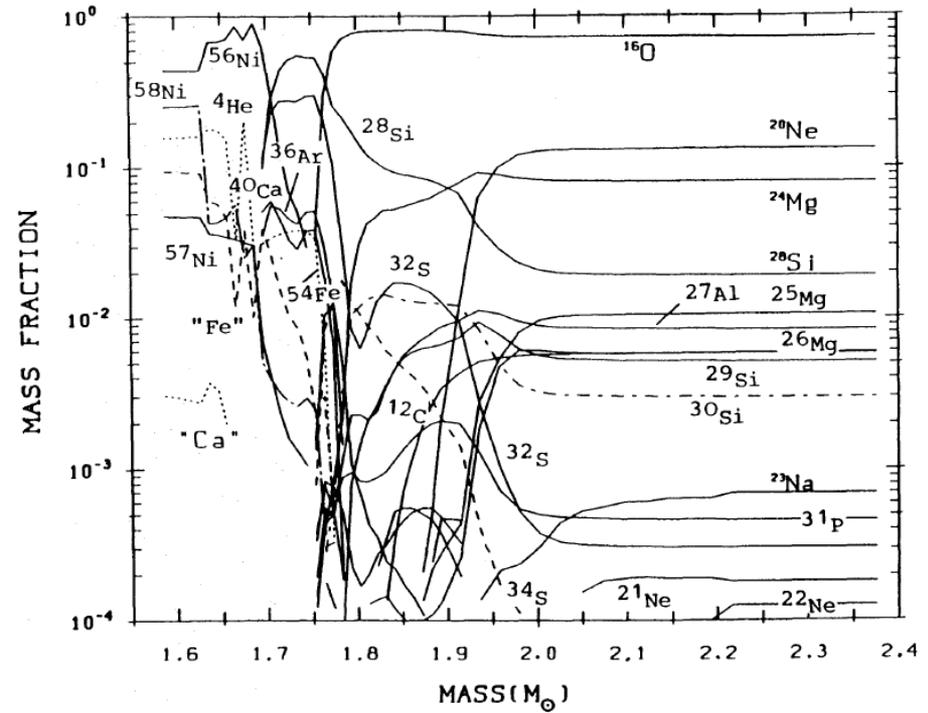


SN1987Aに於ける元素合成

Hashimoto, Nomoto, Shigeyama 1989



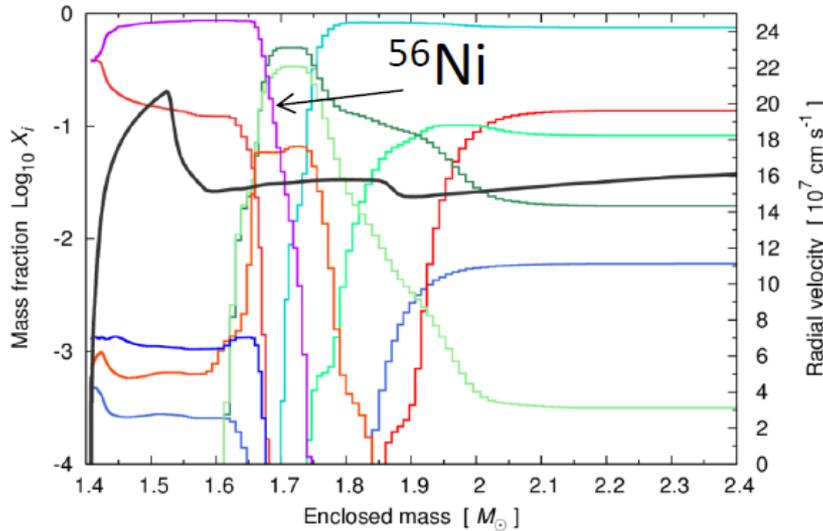
爆発前(親星)



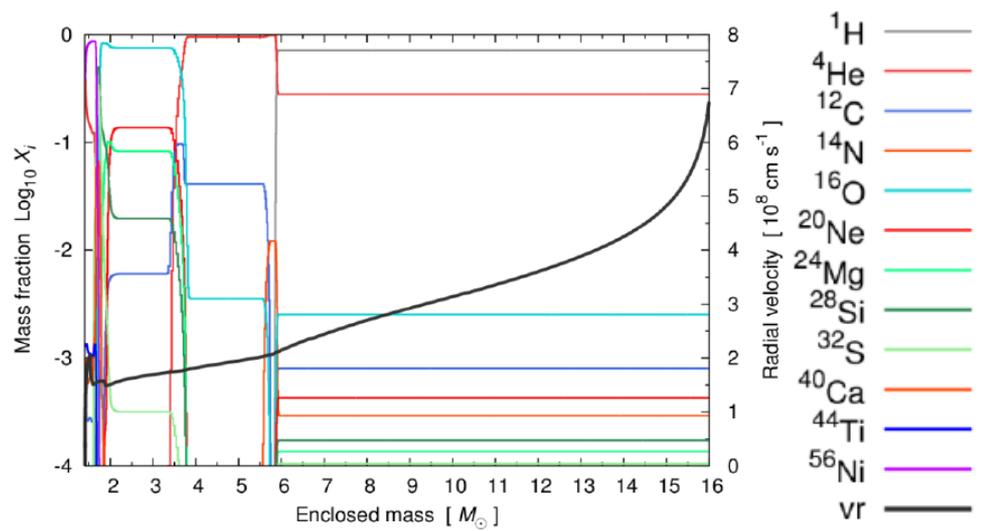
爆発後

球対称爆発の組成・速度分布

$E_{\text{exp}} = 2 \times 10^{51} \text{ erg}$: (自己重力エネルギー込み。最終爆発エネルギー)



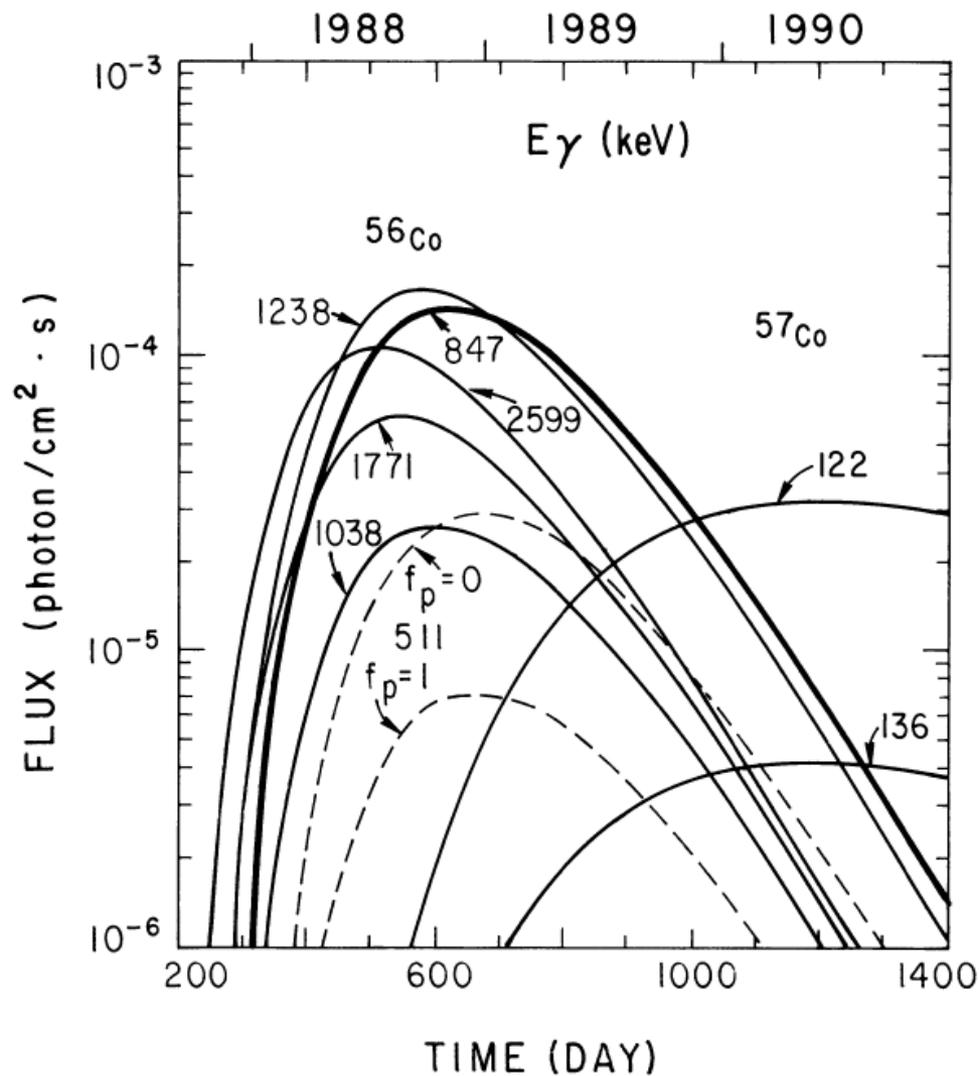
星の内部の拡大図



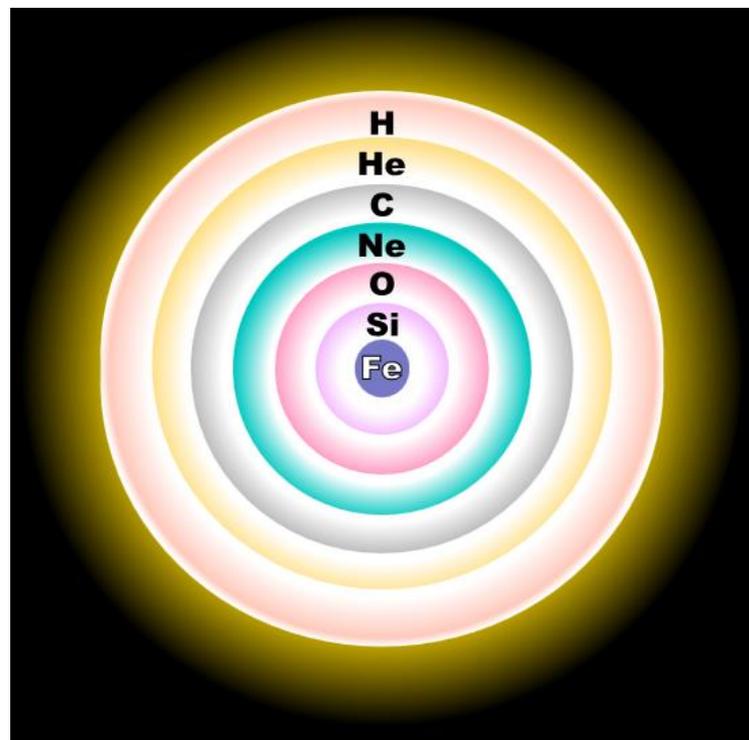
星の全体図

^{56}Ni & ^{44}Ti are trapped inside, with low velocity.

核ガンマ線についてのシンプルかつ 重要な理論予想

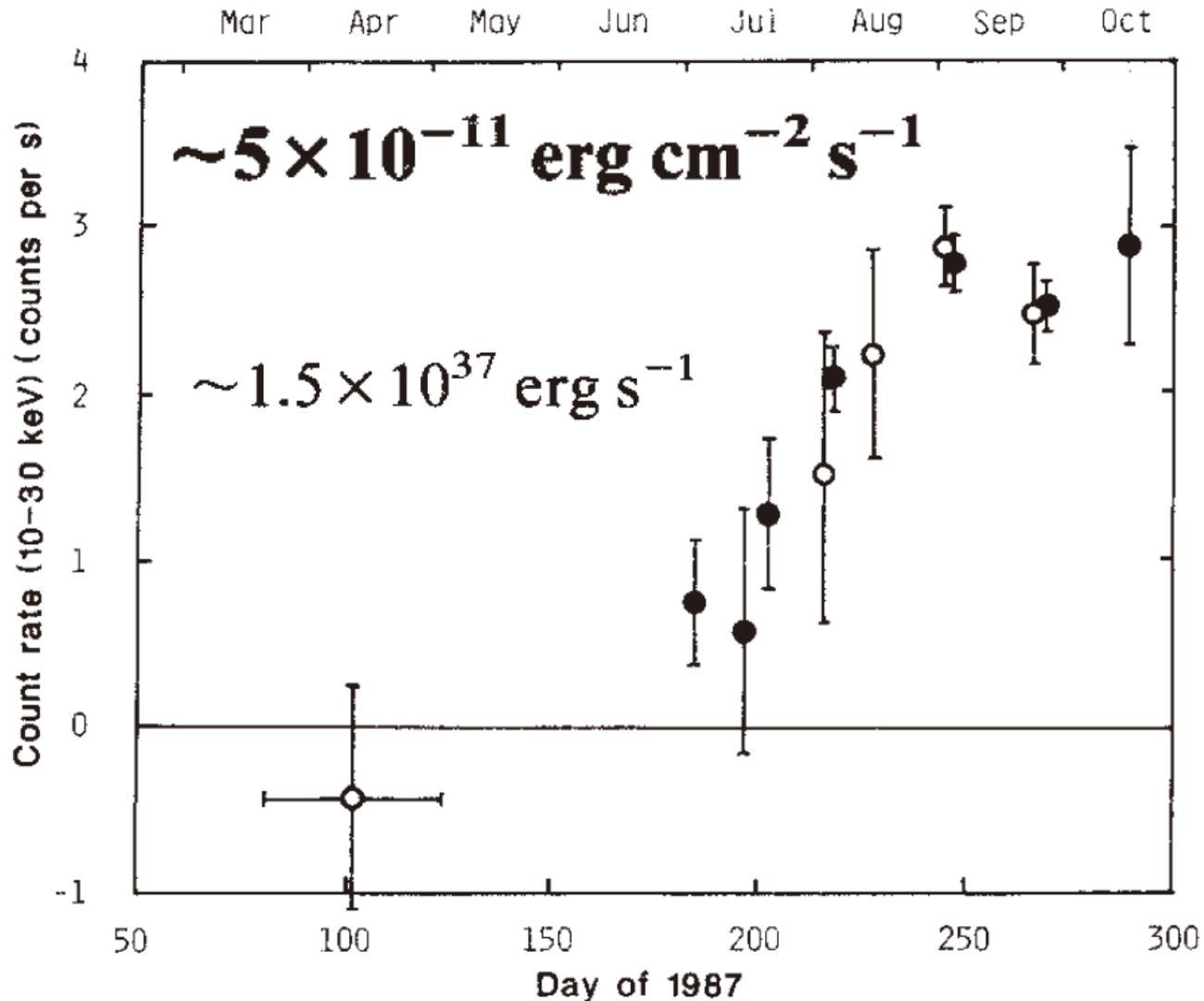


Chan & Lingenfelter 1987 ApJL

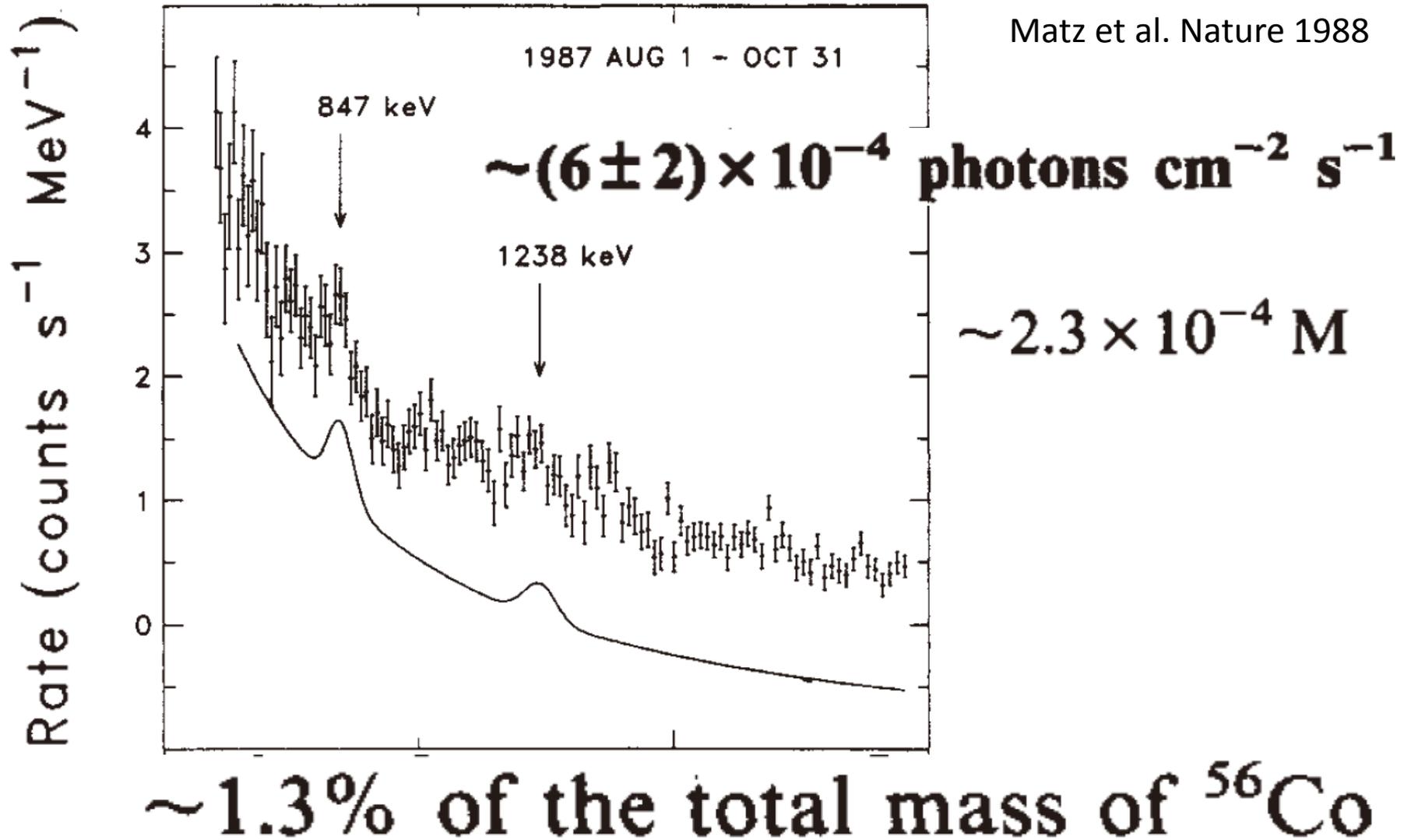


核ガンマ線起源の早期X線検出！

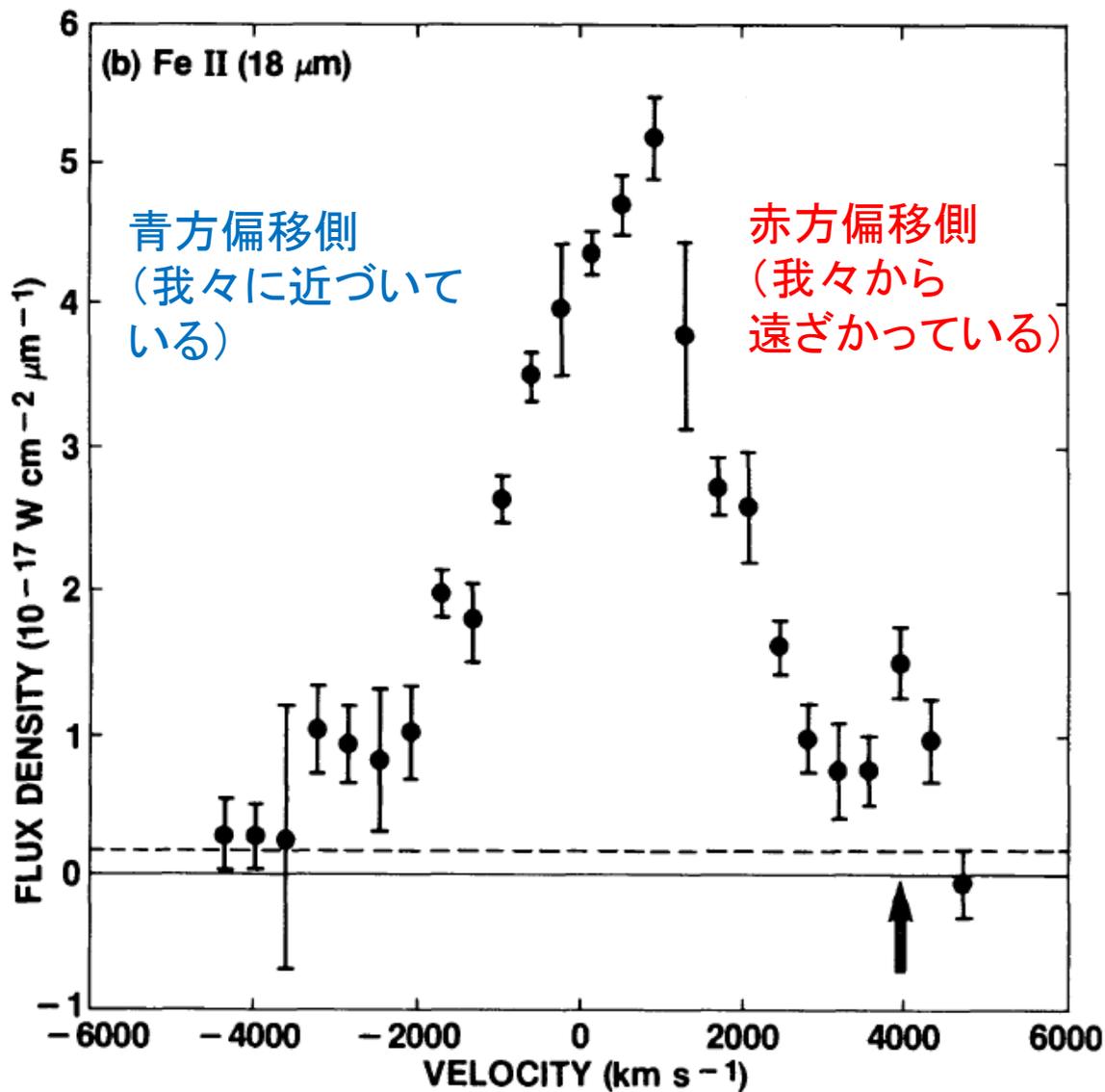
Dotani et al. Nature 1987 by GINGA



核ガンマ線早期検出！



観測された鉄の速度分布(409日後)!



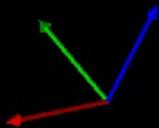
Haas et al.
1990

Asymmetric Explosion & Neutron Star Kick

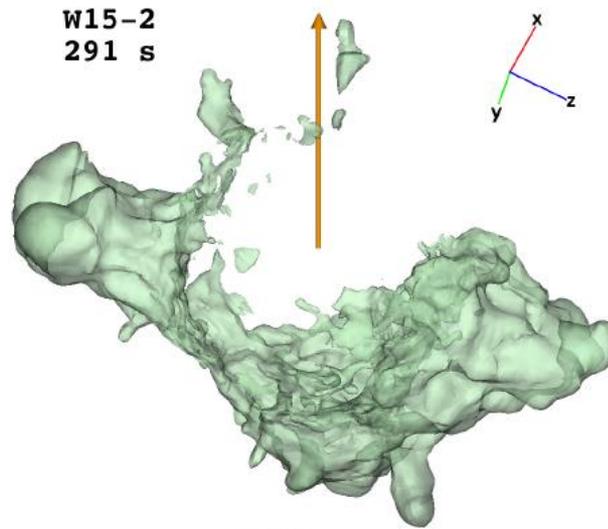
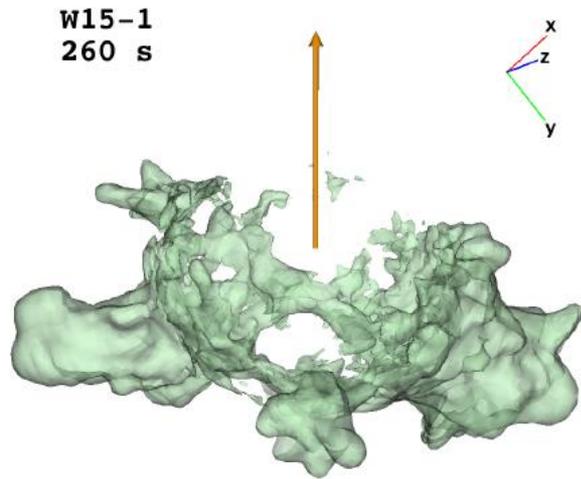


Model W15-6
Time: 15.10 ms
NS displacement: 0.00 km

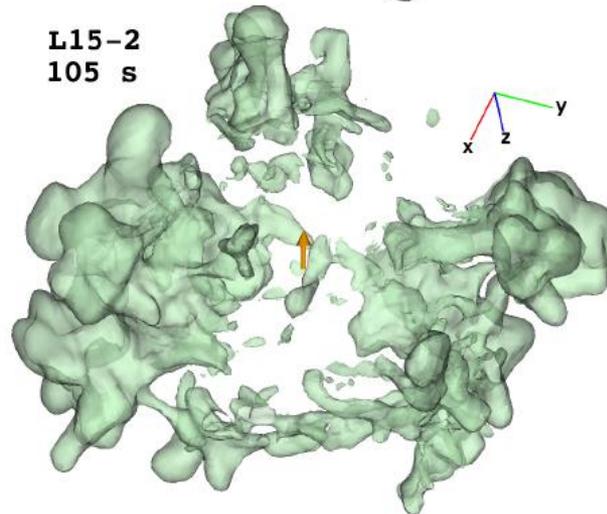
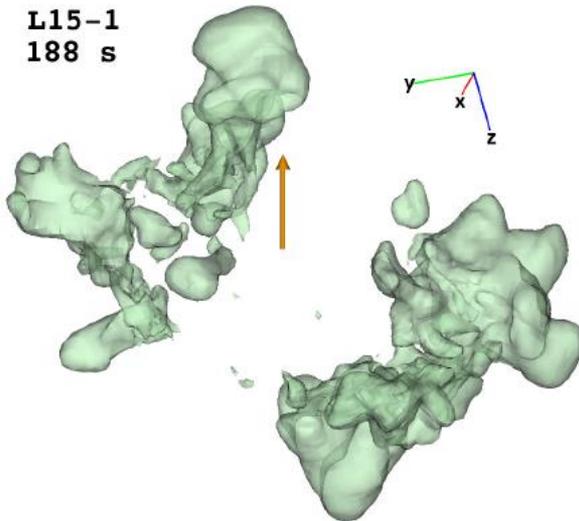
A. Wongwathanarat
(MPA → RIKEN)



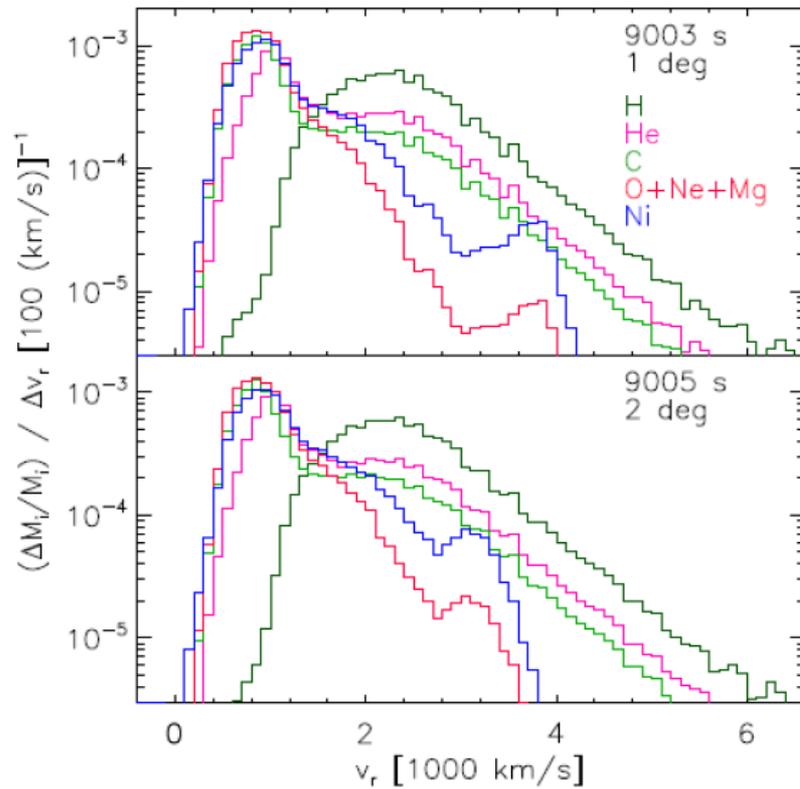
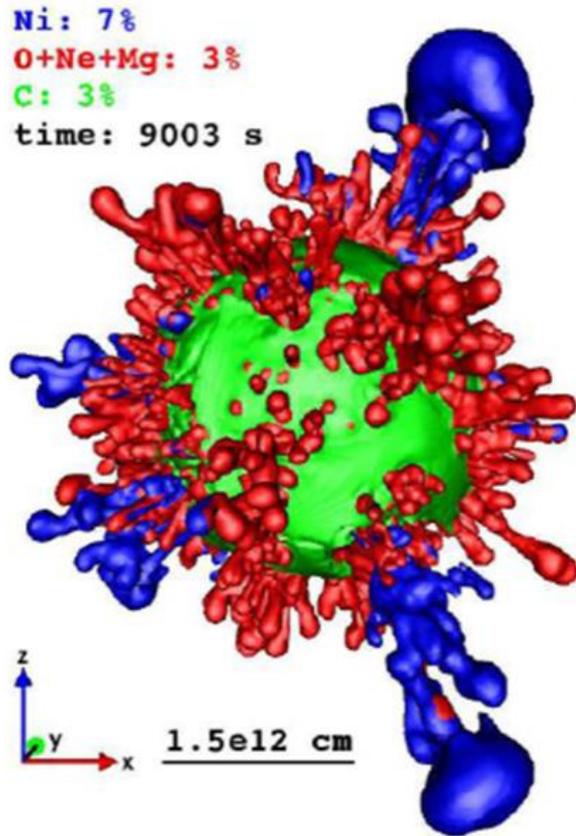
Asymmetric Ejection of ^{56}Ni & Neutron Star Kick



A. Wongwathanarat
(RIKEN)



Successful Reproduction of High Velocity Component of ^{56}Ni



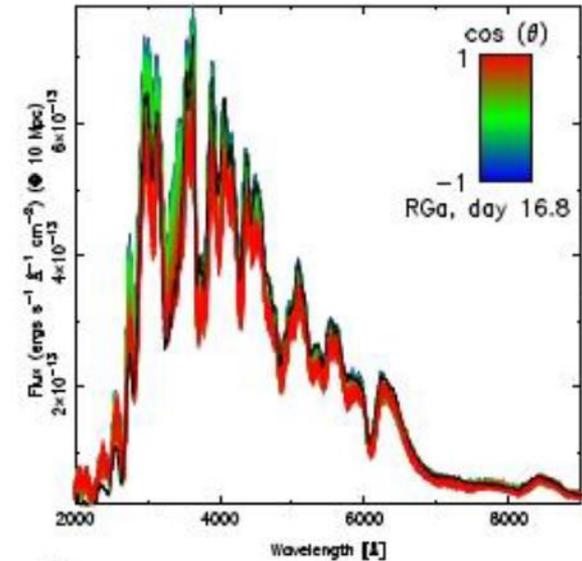
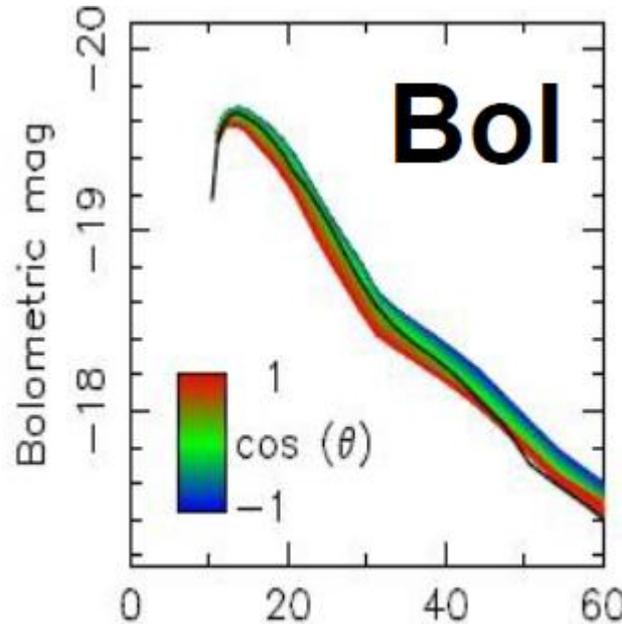
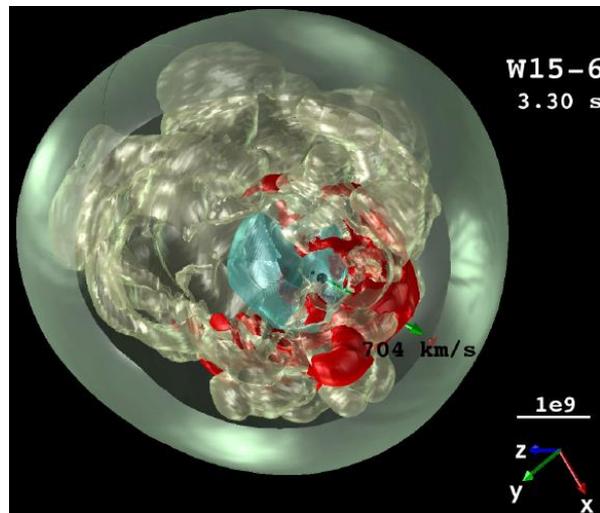
A. Wongwathanarat
(RIKEN)

For Future Works:
Neutrino- driven
wind boundary
condition.

14 species (^4He - ^{56}Ni +X)
alpha-reactions network

Great Collaborations Started (2014-)

- Radiation Transfer, including Gamma-Ray Line Transfer.



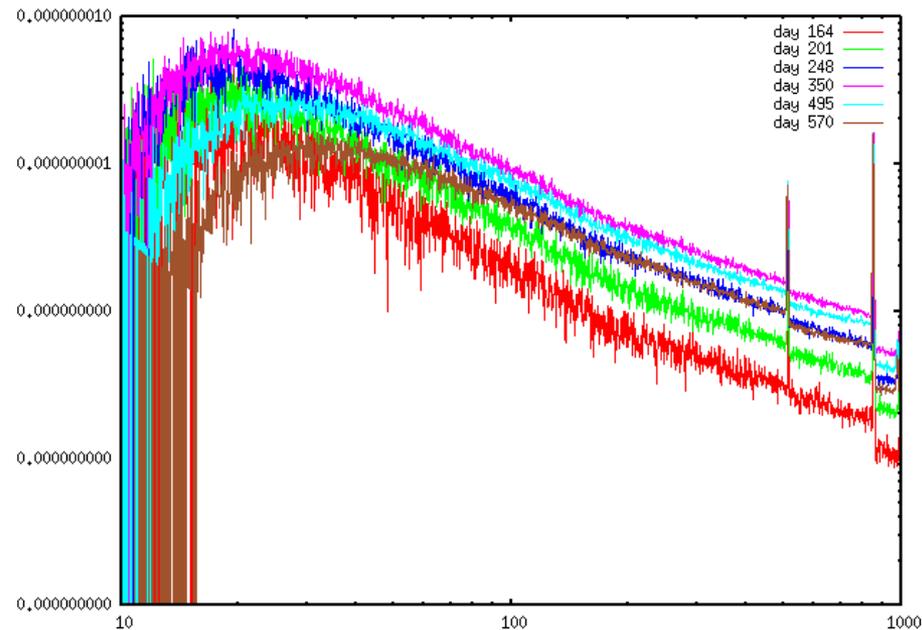
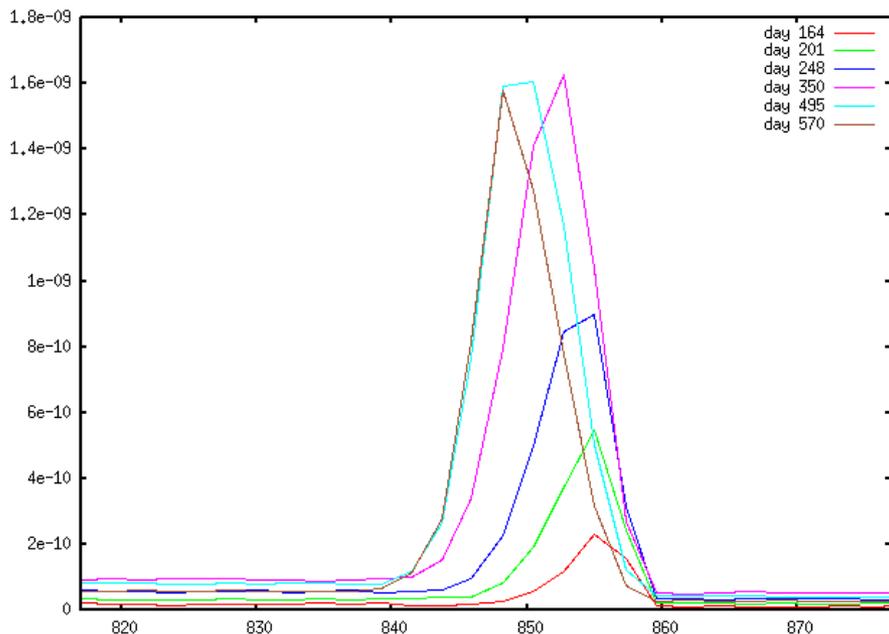
Left:
A. Wongwathanarat
(RIKEN)
Right:
K. Maeda (Kyoto)



最初のテスト計算例

847KeV ラインガンマ線の明るさ

ガンマ線スペクトルの時間進化



820keV

840keV

860keV

10keV

100keV

1MeV

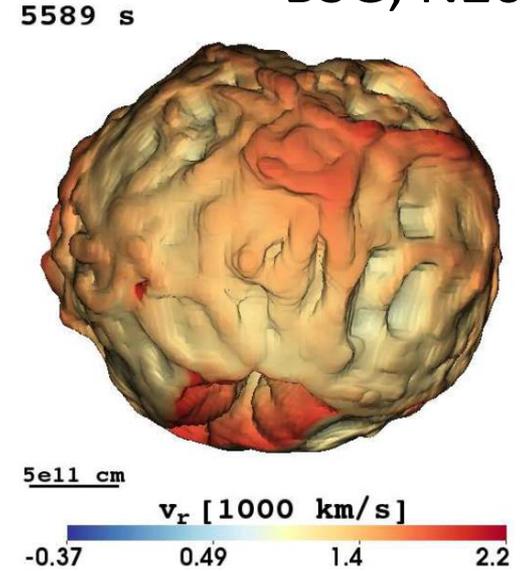
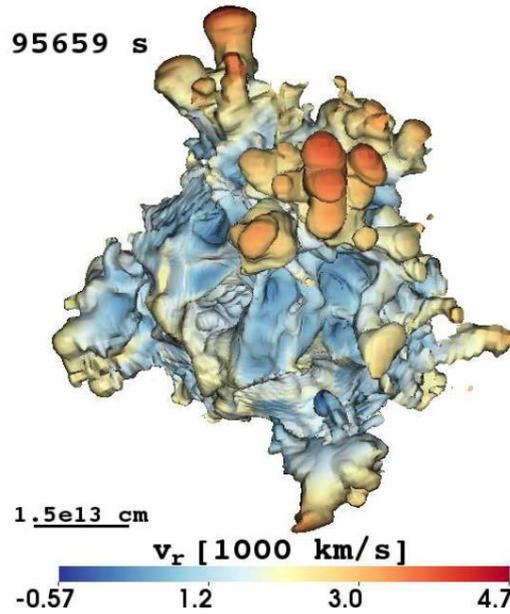
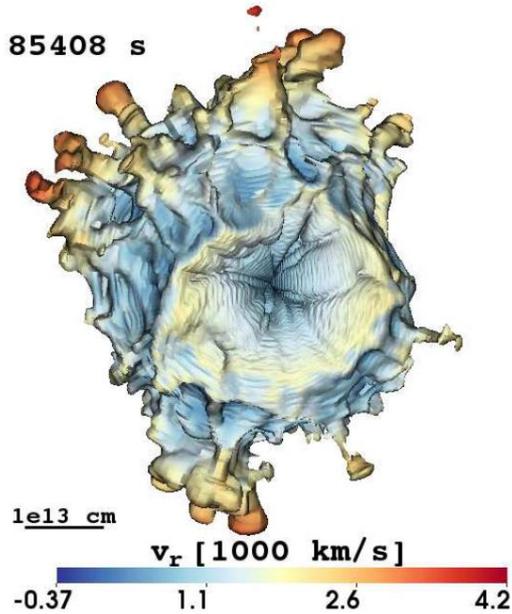


Preliminary



親星依存性がかなりありそうである。

Shigeyama&Nomoto (1990)
BSG, N20

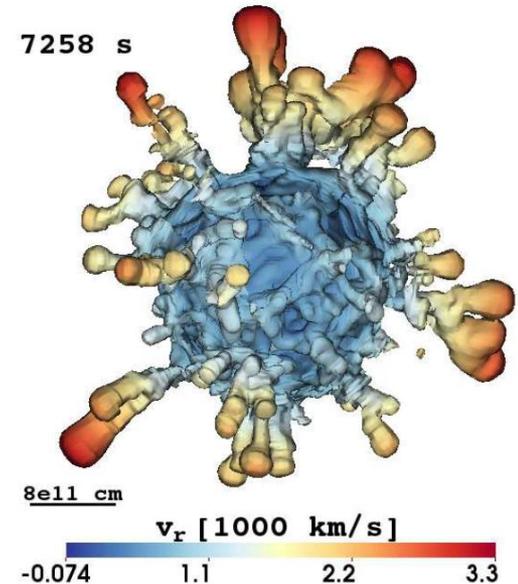


Woosley&Weaver
(1995)
RSG, W15

Limongi+ (2000)
RSG, L15

Nickel-rich ejecta at shock
breakout

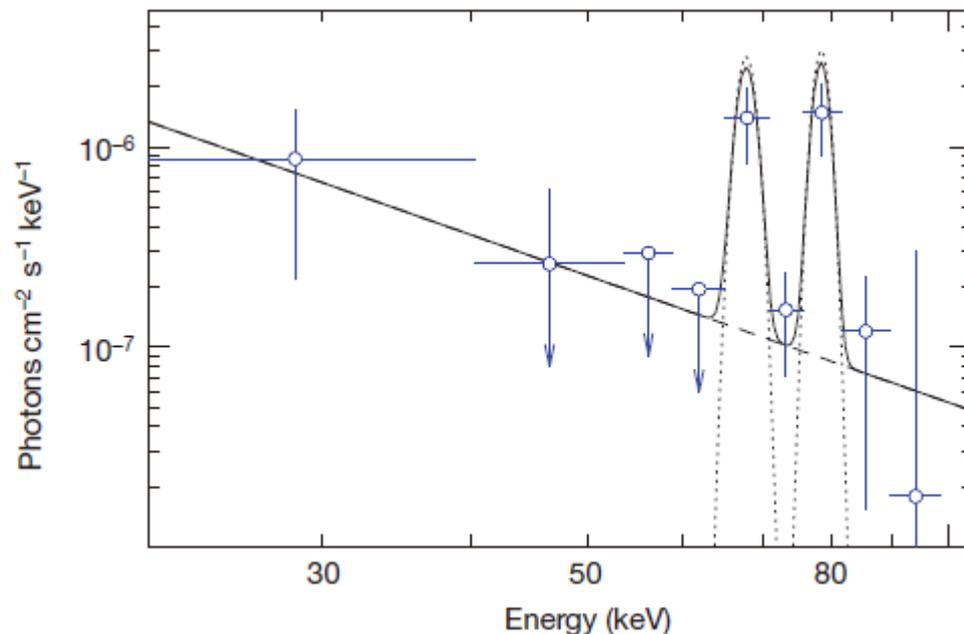
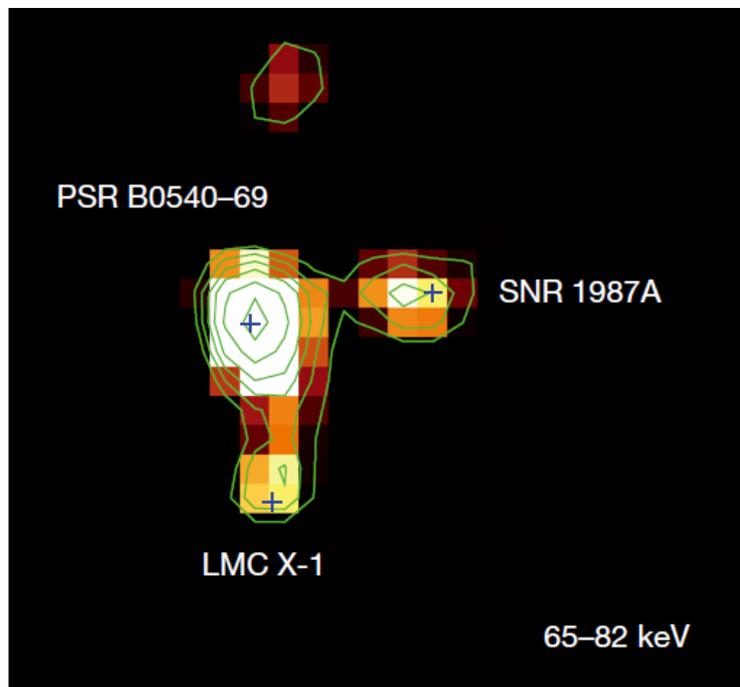
Woosley+ (1988) BSG, B15



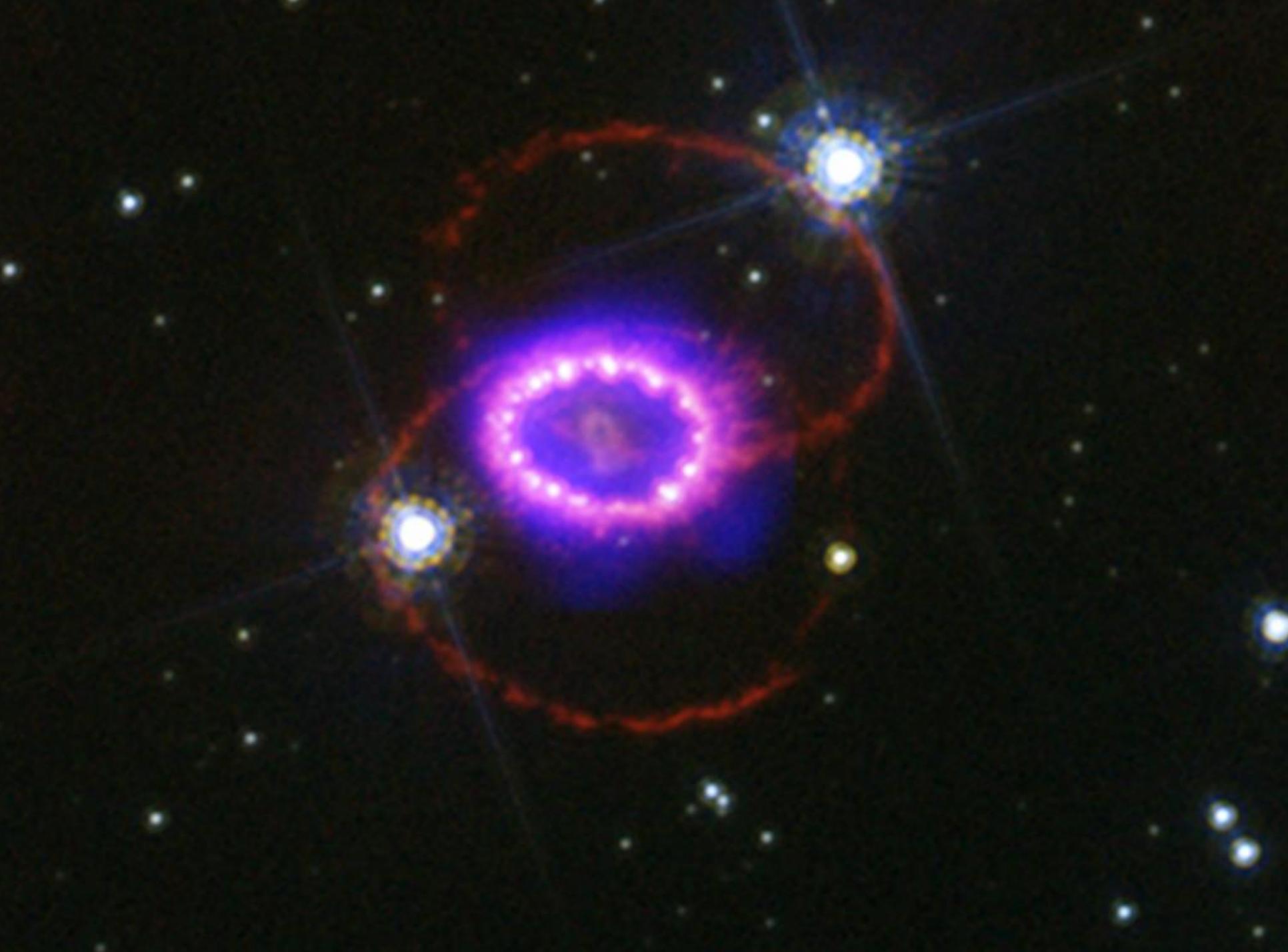
最近の話題:

SN1987Aから多量の ^{44}Ti 核ガンマ検出!

Grebenev et al. Nature 12

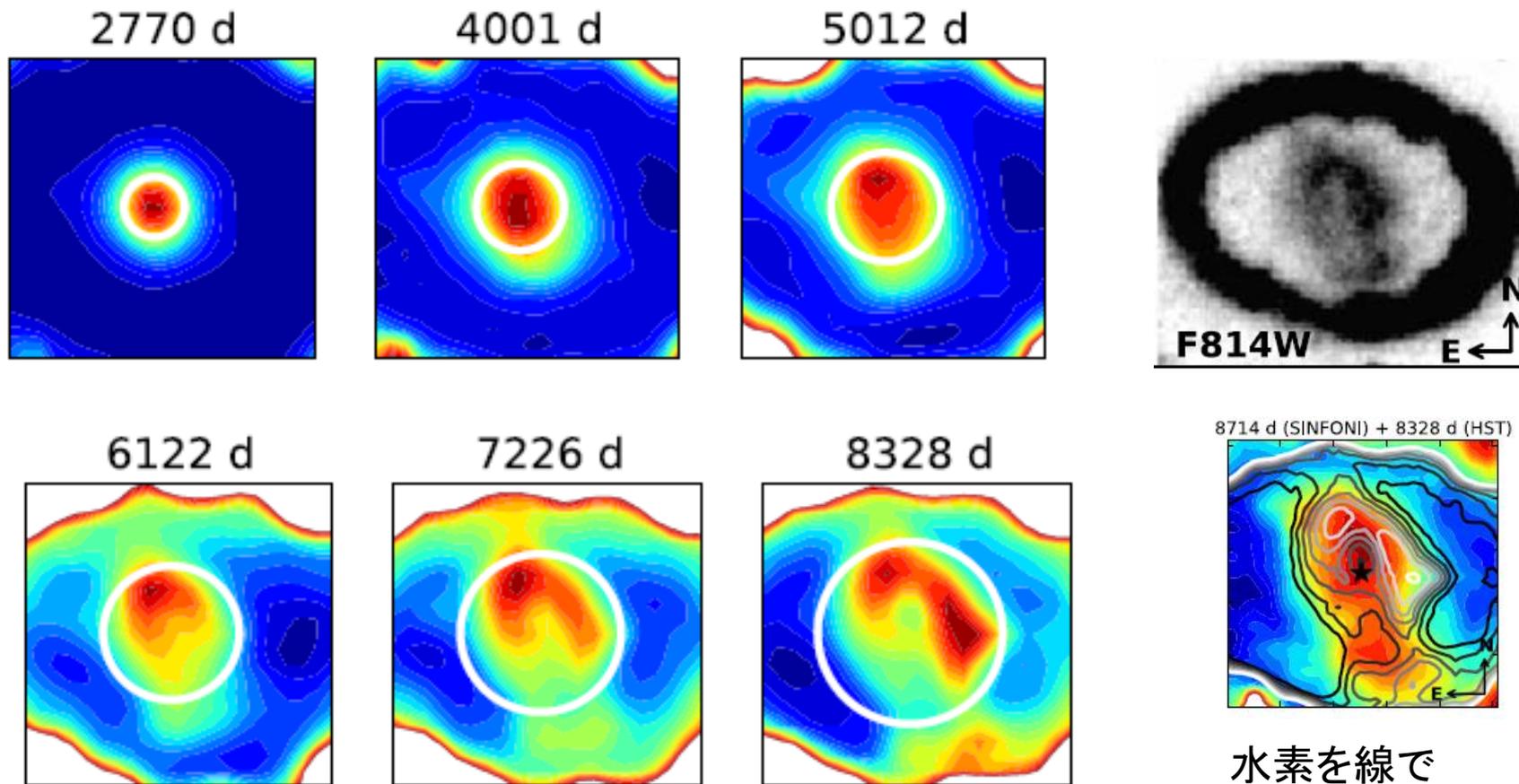


^{44}Ti の推定量 $(3.1 \pm 0.8) \times 10^{-4} M_{\odot}$



1987Aは超新星から超新星残骸へ

Larsson et al. 2013



水素輝線で見たSN1987A。リングはこの外側にある。

水素を線で
Si+Feをカラーで
描いてみた。

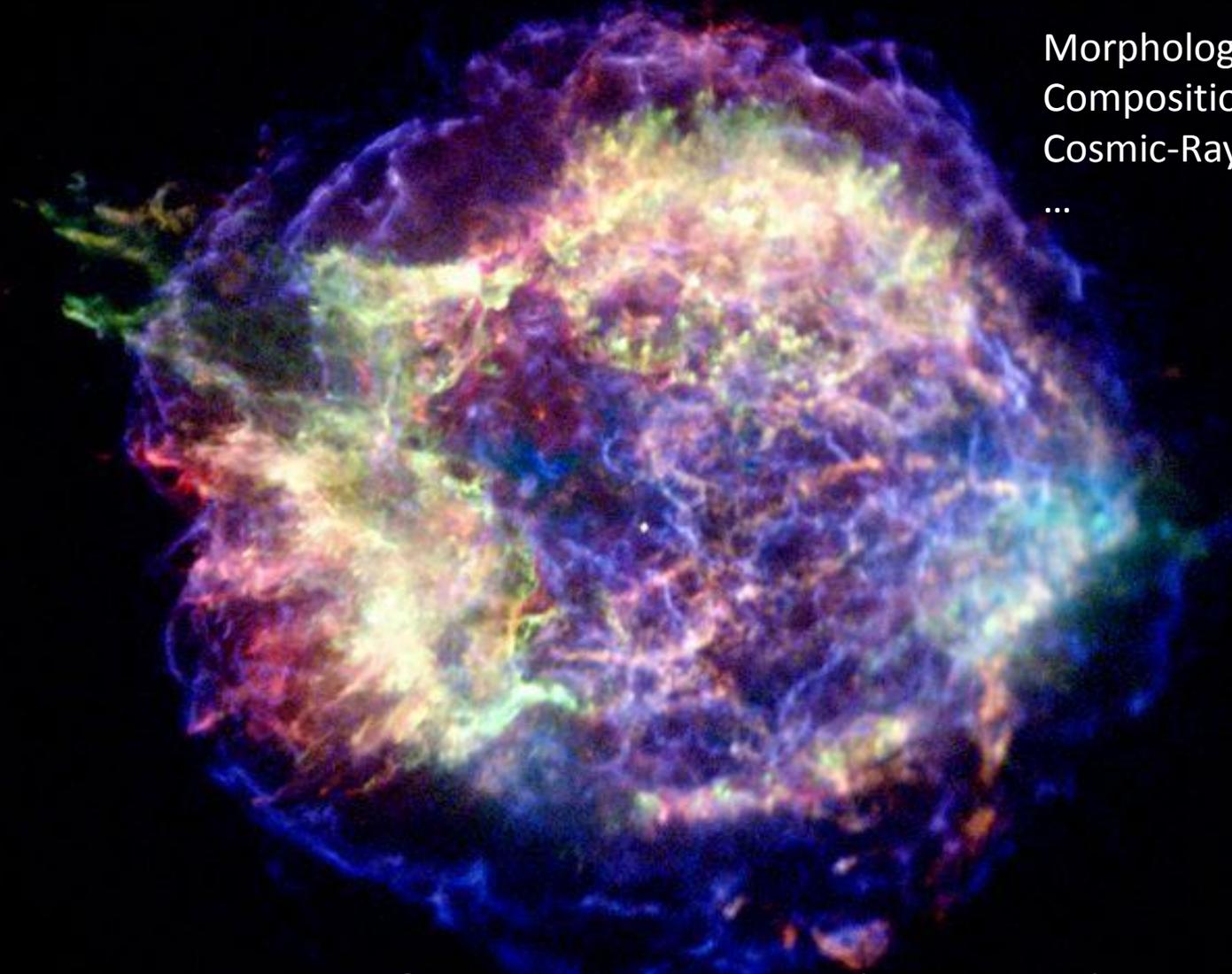
SN1987Aに関する将来計画

- Self-Consistent Simulations (Simulations of Explosion Mechanism & Explosive Nucleosynthesis).
- Explosive Nucleosynthesis (such as ^{44}Ti) with Large Reaction Network Coupled with Multi-Dimensional Hydro Simulations.
- Gamma-Ray Transfer/X-ray Transfer, including Line Transfer.
- Interactions between Supernova Ejecta and the Surrounding Ring.

Very Exciting!

超新星残骸

超新星残骸は物理と謎の宝庫

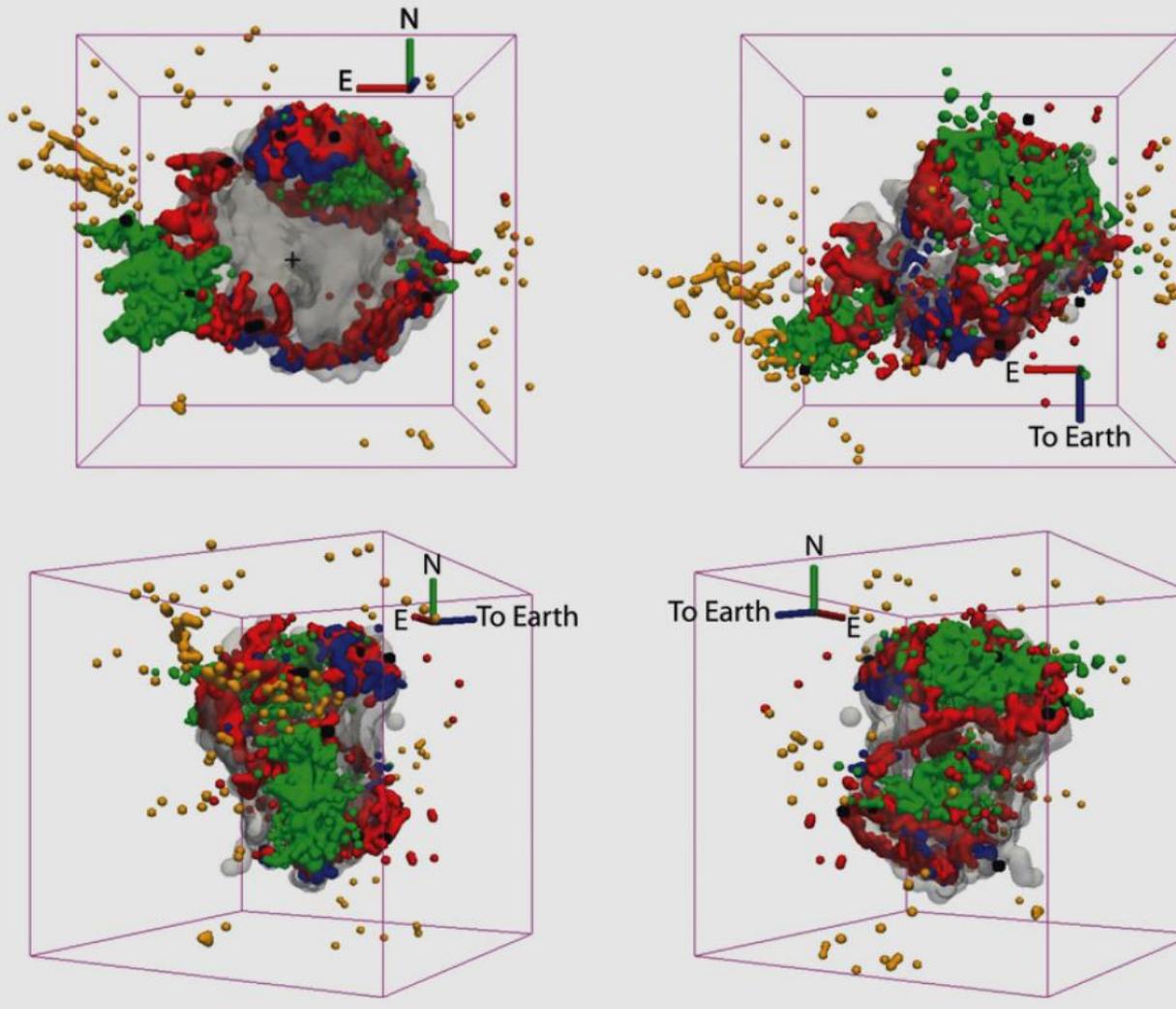


Morphology?
Composition?
Cosmic-Ray Production?
...

X-ray Image of Cassiopeia A by Chandra (~ 350 yrs old).

3D structure of Cas A: Fe is Outside!

Delaney et al. 2010



Green: X-ray Fe-K

Black: X-ray Si XIII

Red: IR [Ar II]

Blue: [Ne II]/[Ar II]

Grey: IR [Si II]

Yellow:
optical outer ejecta

Chandra 's X-rays & Spitzer 's Infrared

44Ti is inside of Iron!!

Cas A

NuSTAR: Ti (68-78 keV)

Chandra: Fe

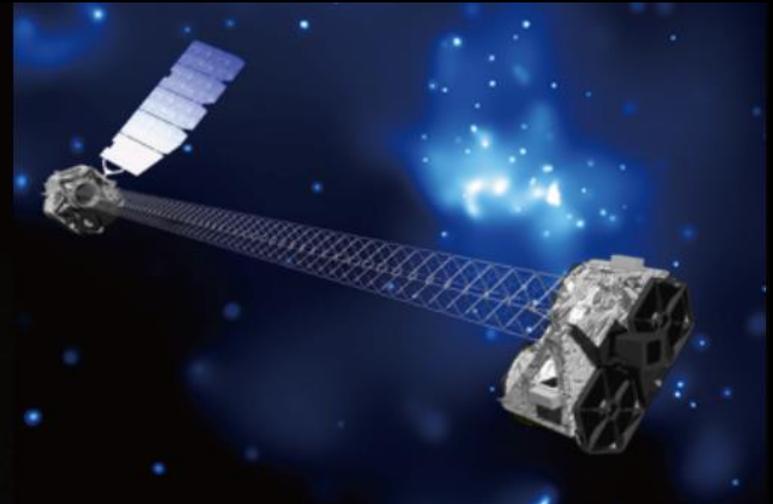
Blue: 44Ti, Green: Si/Mg, Red: Fe.



Hot Iron

Cas A

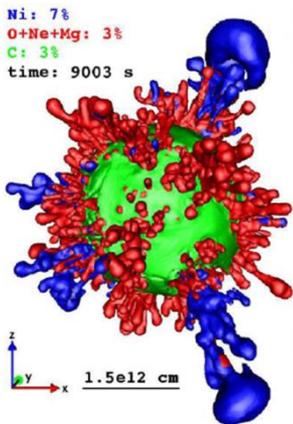
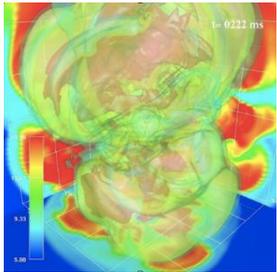
Radioactive Titanium



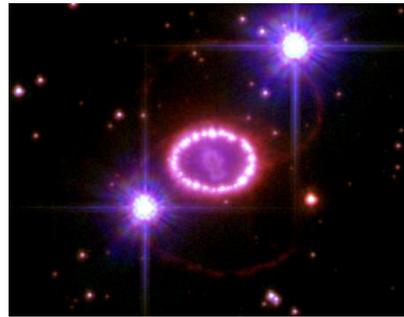
NuSTAR (2012~)
Hard X-ray imager

超新星から超新星残骸まで

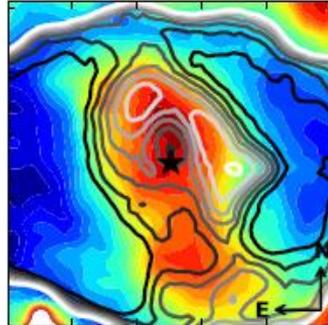
Engine/Nucleosynthesis



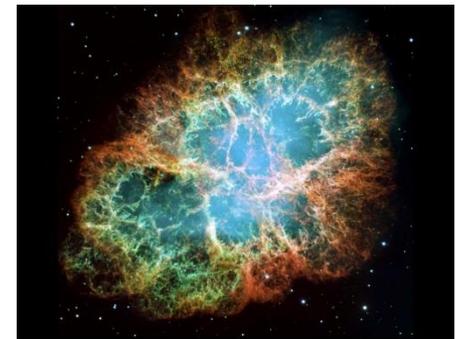
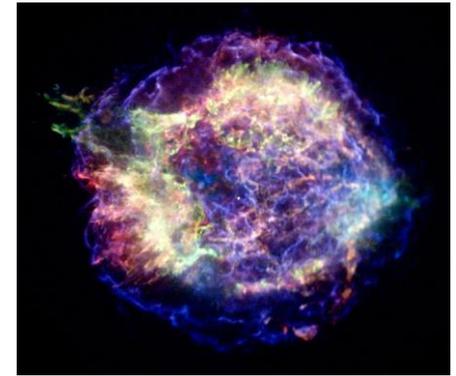
SN1987A



8714 d (SINFONI) + 8328 d (HST)



Remnants



1-10 sec.
< 1000-10000km.

27yrs
 10^{17} cm

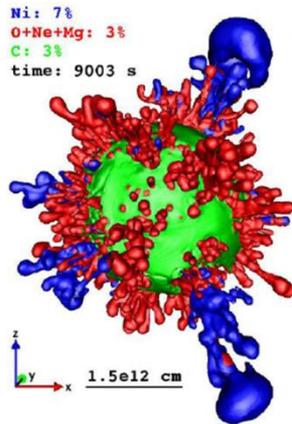
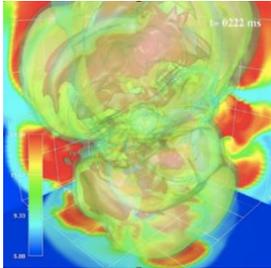
100-10000 yrs
 10^{18} - 10^{19} cm.

Our Big Challenge:

From (Takiwaki & Wongwathanarat) To (Lee, Ono, Warren)



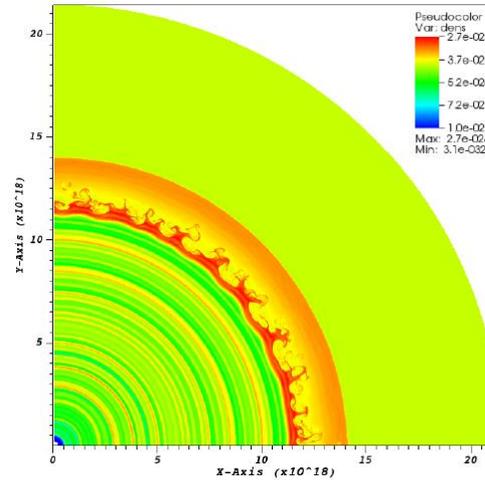
T. Takiwaki
(RIKEN)



A. Wongwathanarat
(RIKEN)



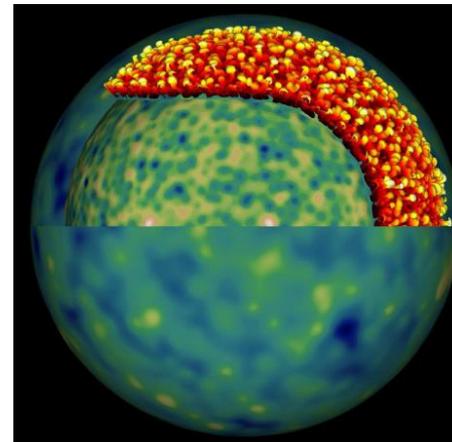
Ono+14, in prep.



How do they
Evolve?

Origin of
Asymmetries?

Legacy of
Supernovae?



Warren & Blondin 13



S.H. Lee
(RIKEN → JAXA)



M. Ono
(RIKEN → Kyushu U.)



D. Warren
(NCSU → RIKEN)

完