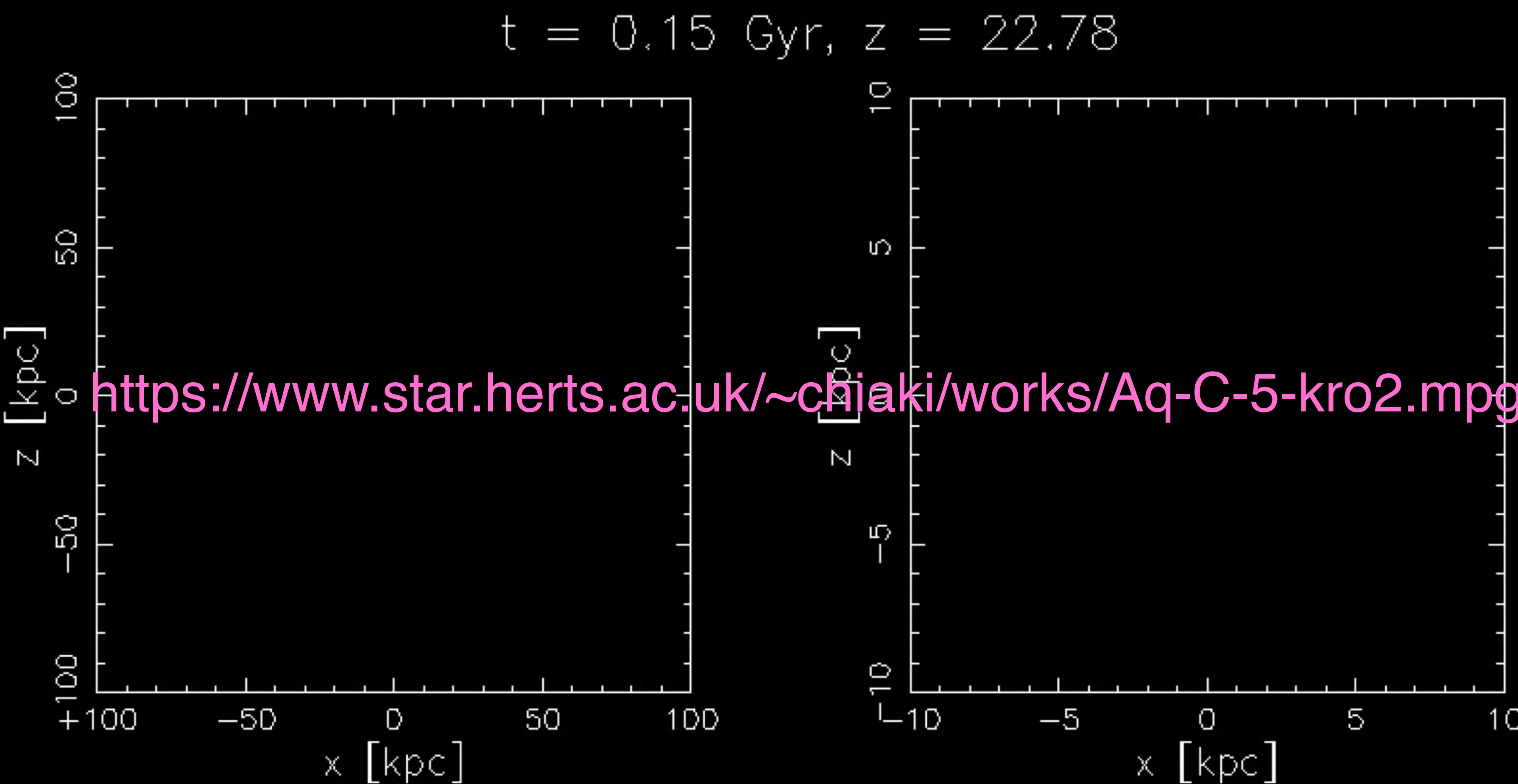
Galactic chemical evolution & the origin of the elements



https://www.star.herts.ac.uk/~chiaki/works/Aq-C-5-kro2.mpg

Chiaki Kobayashi

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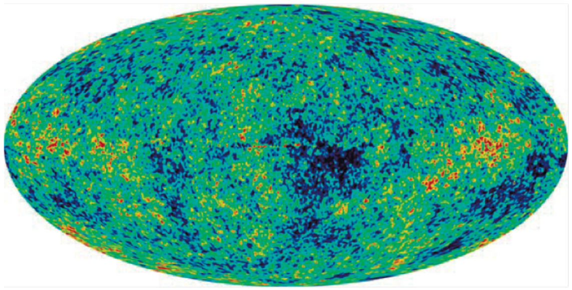
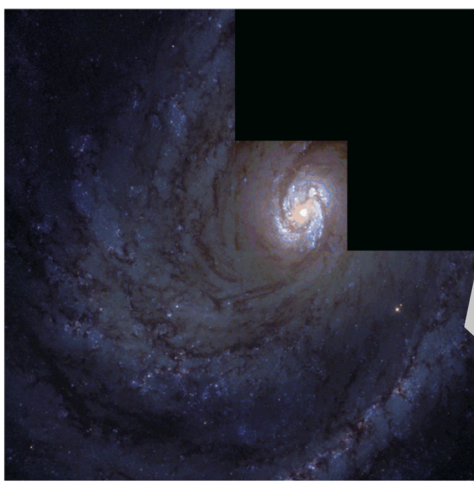
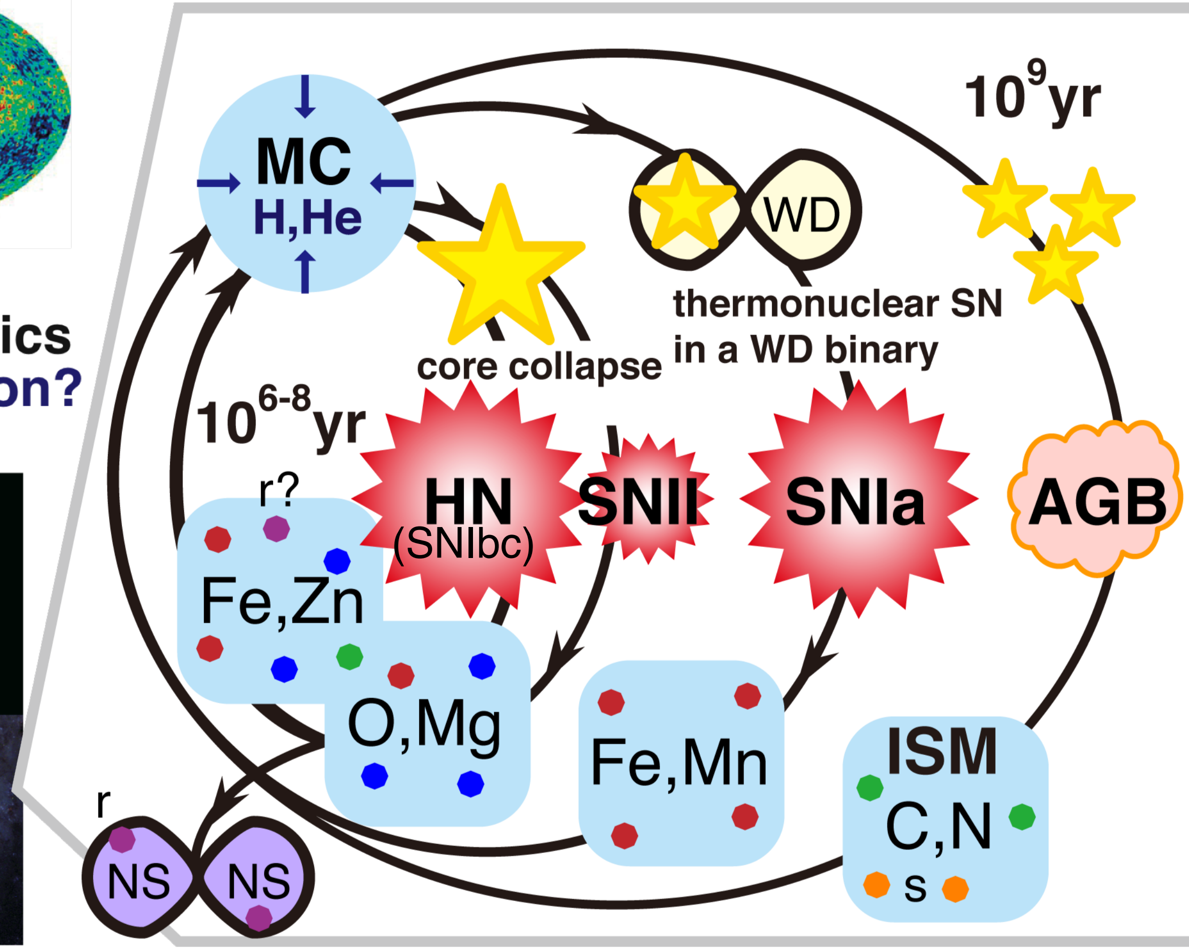
Chemical Enrichment

Nomoto, CK, Tominaga 2013 ARAA



Gravity
Hydrodynamics
Star Formation?
Feedback?





- [Fe/H] and [X/Fe] evolve in a galaxy: fossils that retain the evolution history of the galaxy → **Galactic Archaeology**

※ Metallicity Z = mass fraction of elements heavier than He

Galactic Chemical Evolution

$$\frac{d(Zf_{\mathrm{g}})}{\mathrm{dt}} = E_{\mathrm{SW}} + E_{\mathrm{SNcc}} + E_{\mathrm{SNIa}} - Z\psi + Z_{\mathrm{inflow}}R_{\mathrm{inflow}} - ZR_{\mathrm{outflow}}$$

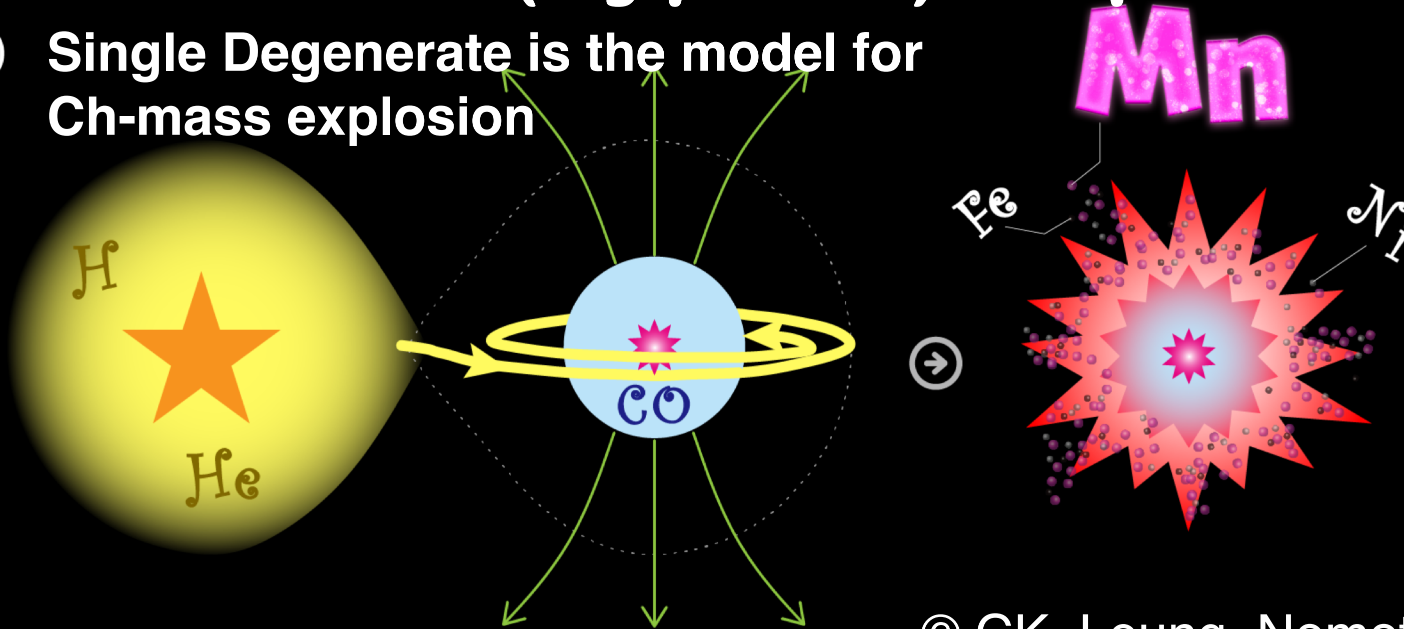
Our new model: CK, Karakas, Lugaro 2020, ApJ, 900, 179

- New solar abundances
- New initial (BBN) abundances
- New SNIa yields (CK, Leung, Nomoto 2020, ApJ, 895, 138)
- With super-AGB stars (~8-10$M_\odot$)
- With failed SNe at >30$M_\odot$, keeping Hypernovae >=20$M_\odot$
- Elements up to U with s and r-processes

Nuclei in the Cosmos XII, *Cairns 2012 &* XIII, *Debrecen 2014*

Thermonuclear (Type Ia) Supernovae

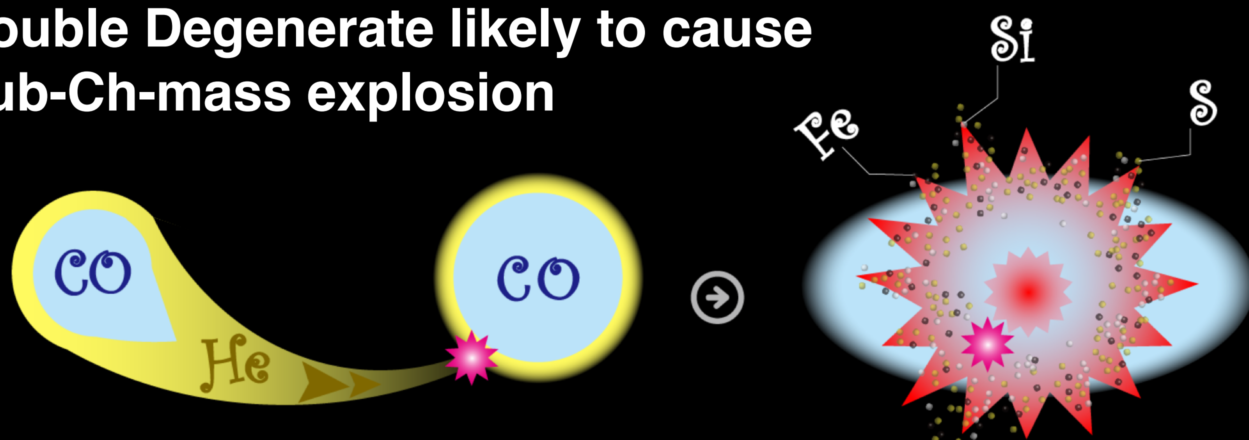
(a) **Single Degenerate is the model for Ch-mass explosion**



>75%
from GCE

© CK, Leung, Nomoto 2020

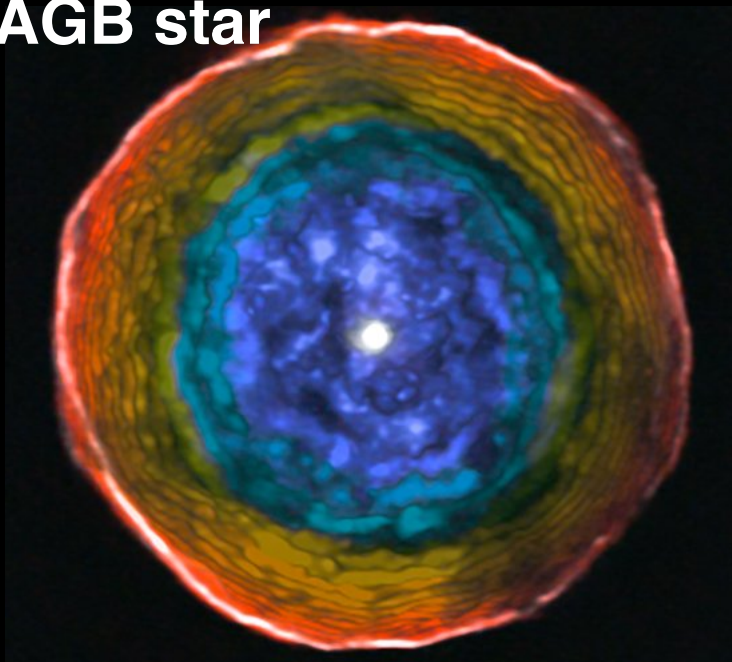
(b) **Double Degenerate likely to cause Sub-Ch-mass explosion**



CK+2020, ApJ, 895, 138; 2D hydrodynamical explosions, nucleosynthesis, & GCE

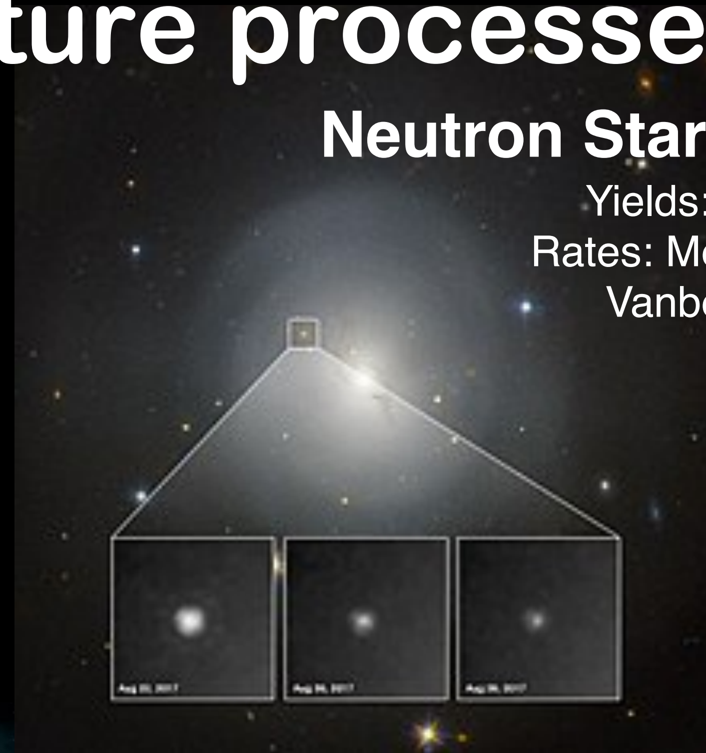
Neutron-capture processes

AGB star



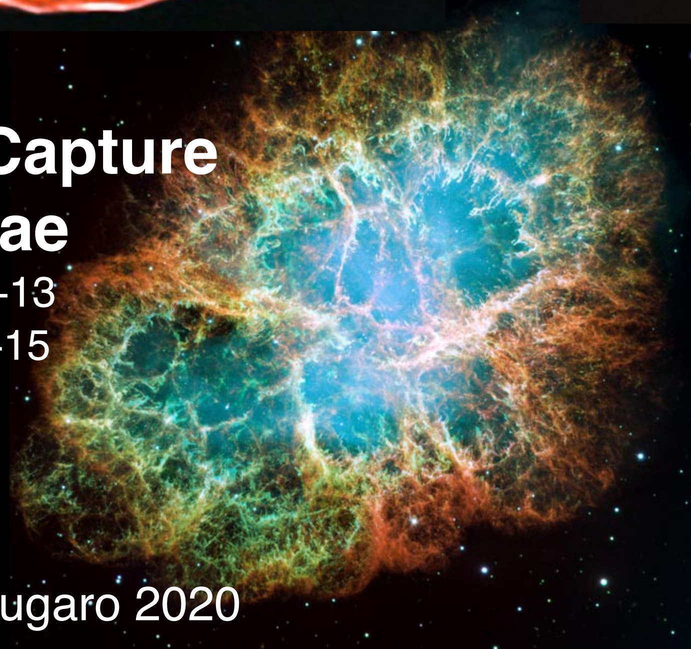
Neutron Star Merger

Yields: Wanajo+14
Rates: Mennekens & Vanbeveren 2014

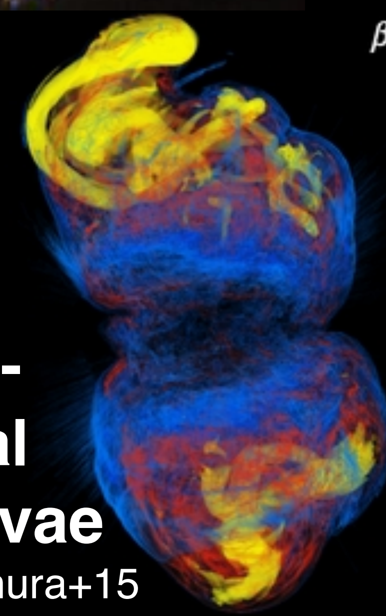


Electron Capture Supernovae

Yields: Wanajo+13
Mass: Doherty+15



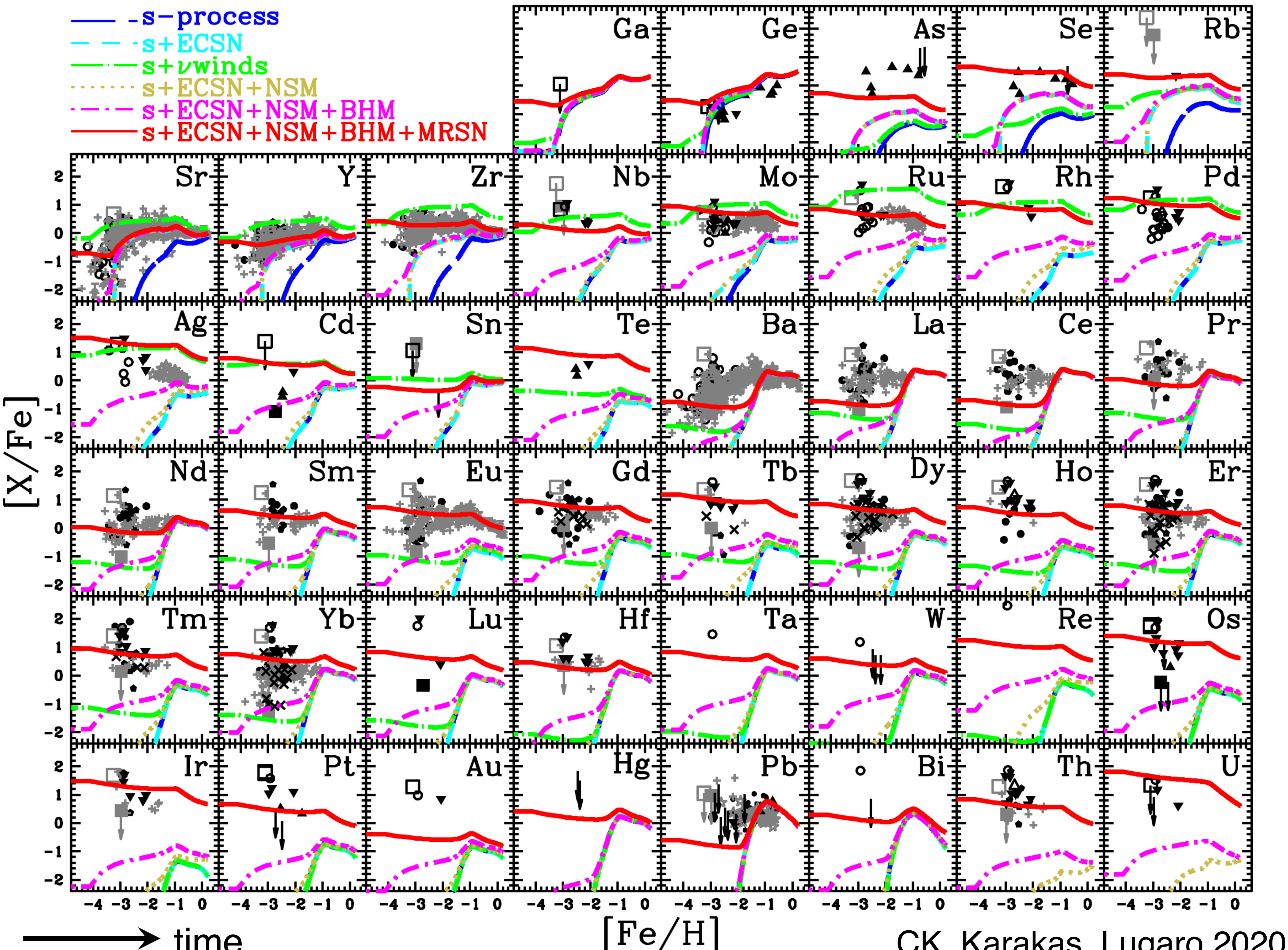
$$\beta = \frac{P_{gas}}{P_{mag}}$$



Magneto-rotational Supernovae

Yields: Nishimura+15

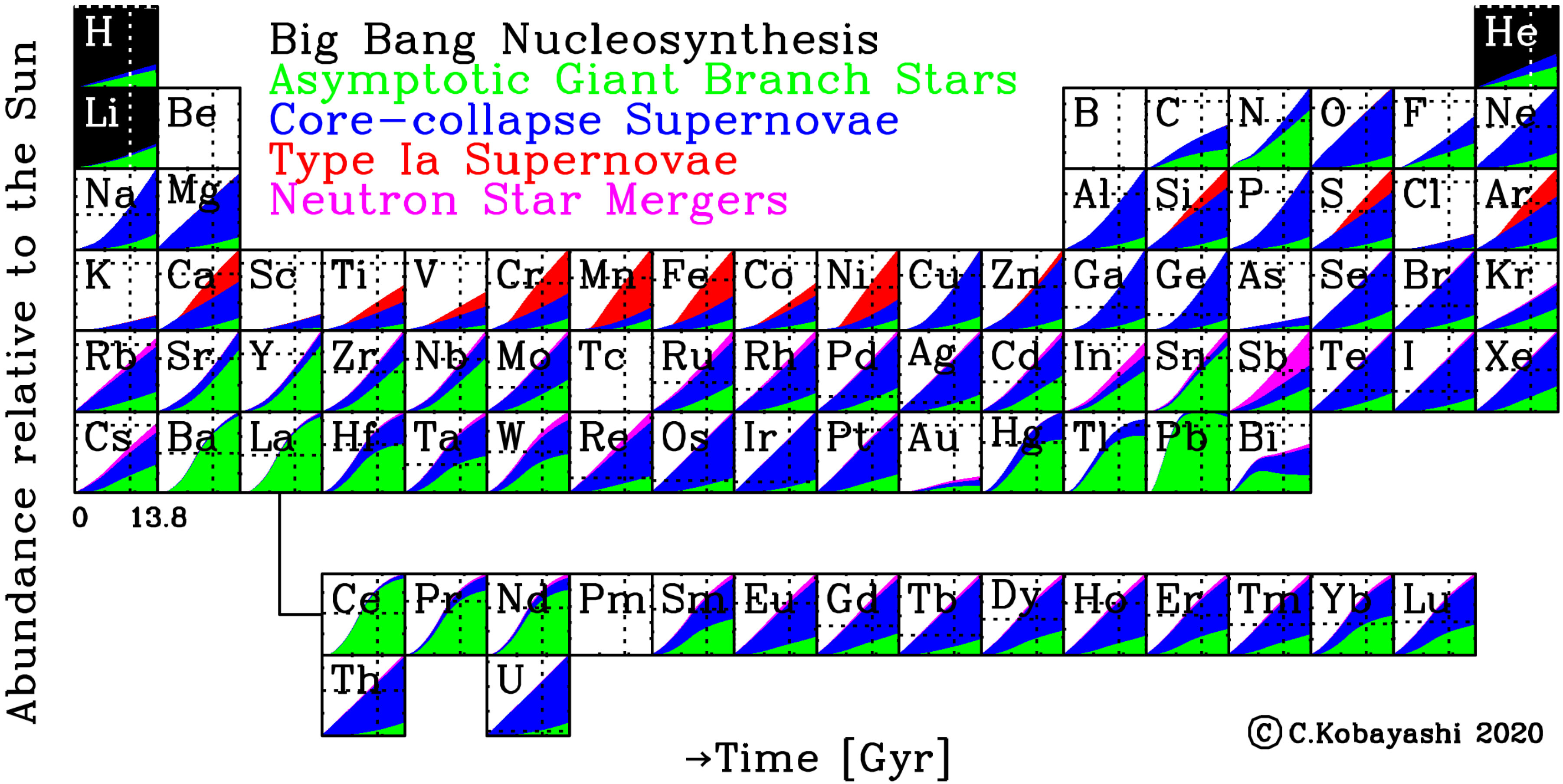
CK, Karakas, Lugaro 2020



s−process
s+ECSN
s+νwinds
s+ECSN+NSM
s+ECSN+NSM+BHM
s+ECSN+NSM+BHM+MRSN
Ga
Ge
As
Se
Rb
Sr
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
Sn
Te
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Pb
Bi
Th
U
[X/Fe]
[Fe/H]
time
CK, Karakas, Lugaro 2020

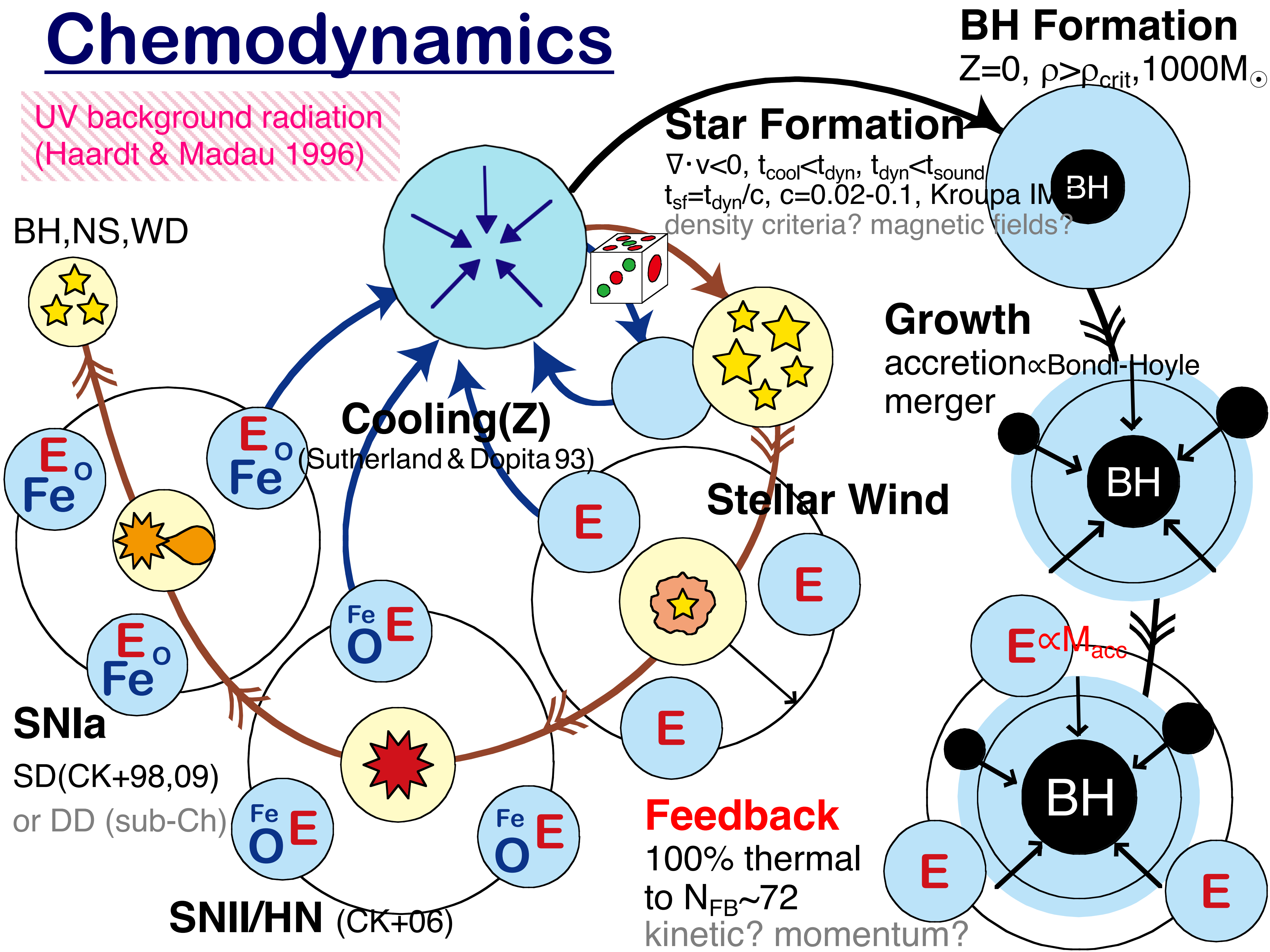
The Origin of Elements

CK, Karakas, Lugaro 2020, ApJ



※Purely theoretical, no empirical equations.

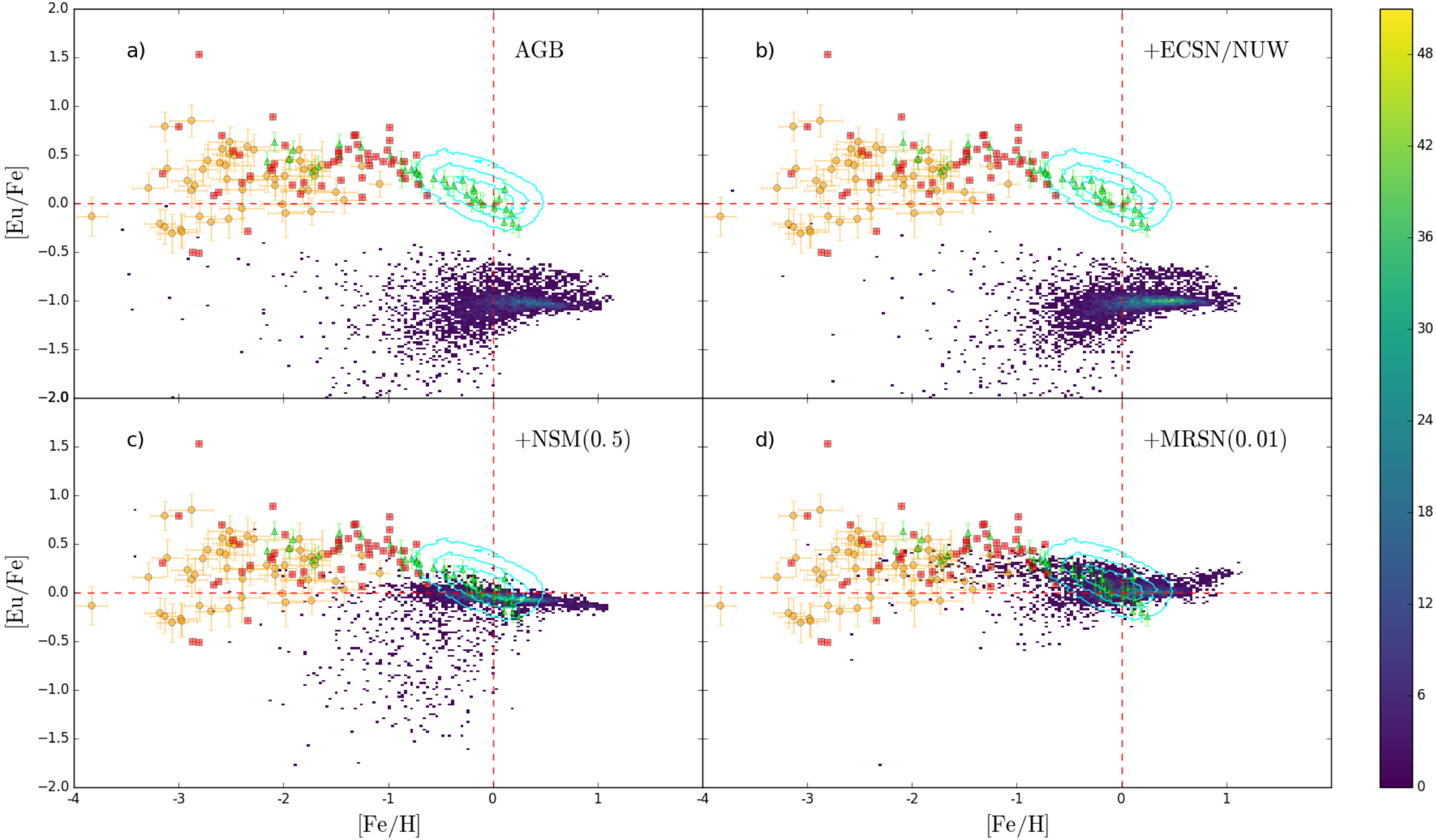
dotted lines: solar values



Chemodynamics
UV background radiation
(Haardt & Madau 1996)
BH,NS,WD
Star Formation
∇·v<0, t_cool<t_dyn, t_dyn<t_sound
t_sf=t_dyn/c, c=0.02-0.1, Kroupa IMF
density criteria? magnetic fields?
BH Formation
Z=0, ρ>ρ_crit, 1000M☉
BH
Growth
accretion∝Bondi-Hoyle
merger
BH
Cooling(Z)
(Sutherland & Dopita 93)
Stellar Wind
E
Fe
O
E∝M_acc
SNIa
SD(CK+98,09)
or DD (sub-Ch)
SNII/HN (CK+06)
Feedback
100% thermal
to N_FB~72
kinetic? momentum?

[Eu/Fe]-[Fe/H]

Chemo-hydrodynamical Simulation
Haynes & CK 2019



Neutron star mergers alone cannot reproduce the observations.

Hansen+17; Roederer+16; NLTE Zhao+16; HERMES-GALAH

Nature | Vol 595 | 8 July 2021 | 223

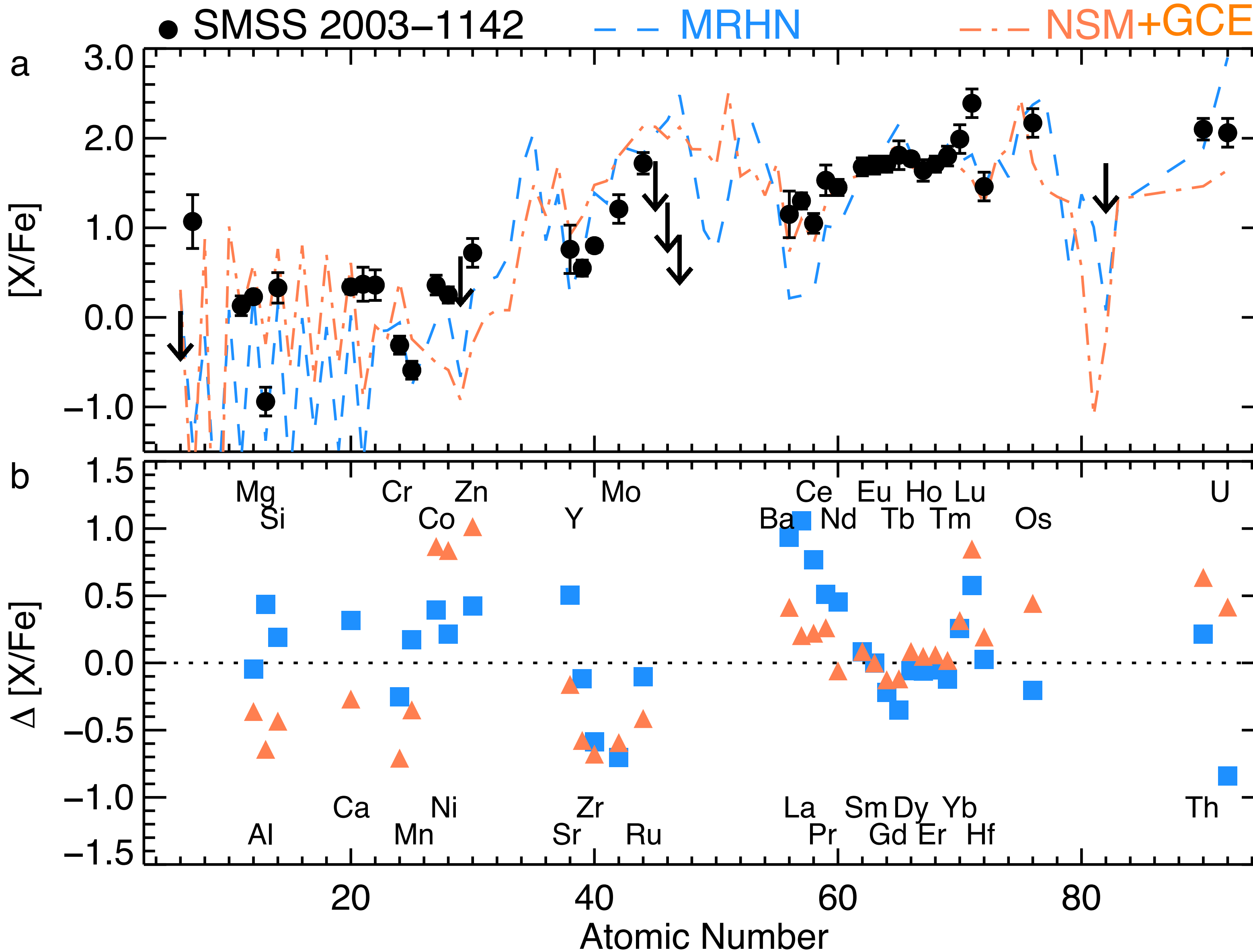
r-Process elements from magnetorotational hypernovae

D. Yong[1,2]✉, C. Kobayashi[2,3], G. S. Da Costa[1,2], M. S. Bessell[1], A. Chiti[4], A. Frebel[4], K. Lind[5], A. D. Mackey[1,2], T. Nordlander[1,2], M. Asplund[6], A. R. Casey[2,7], A. F. Marino[8], S. J. Murphy[1,9] & B. P. Schmidt[1]

- ~26000 SkyMapper photometric candidates
- 2618 EMP candidates with ANU 2.3m spectra (Da Costa+19)
- 479 stars in SkyMapper DR1.1 (Yong+21b)
- SMSS J200322.54-114203.3, [Fe/H]= -3.5, 2.3kpc, Halo orbit

Yong star, [Fe/H]= -3.5

Yong, CK, Da Costa+ 21, Nature



Conclusions

- The origin of elements are well understood, except for Ti (due to the lack of 3D effects of SNe) and Au (due to nuclear physics?) – CK+20
- At low metallicity, a significant fraction (50%) of massive stars (>20$M_\odot$) is likely to explode as HN, and a small fraction (1.5%) as MRHN. – Yong+21
- This is predicted by GCE models (Argast+04, Wehmeyer+15, Cote+19, Molero+21), and is confirmed by chemo-hydro dynamical simulations (Haynes & CK 19; van de Voort+20).
- The required fractions depends on the NSM rate, which depends on binary pop. syn. models, due to limited understanding of binary physics.
- Frequency of r-rich stars as a function of metallicity, from galactic archaeology surveys (e.g., HERMES-GALAH), will help constraining further.