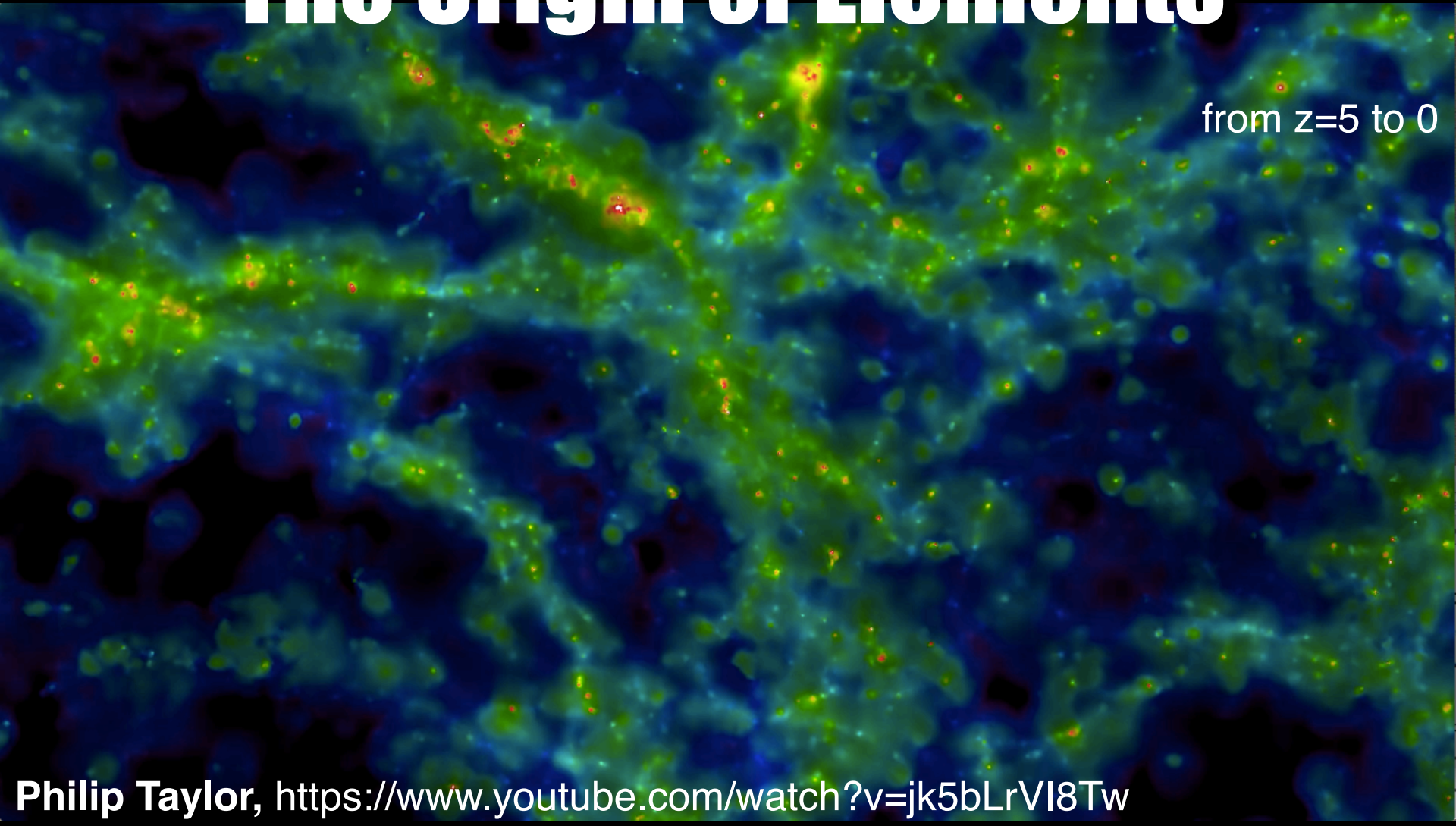
The Origin of Elements

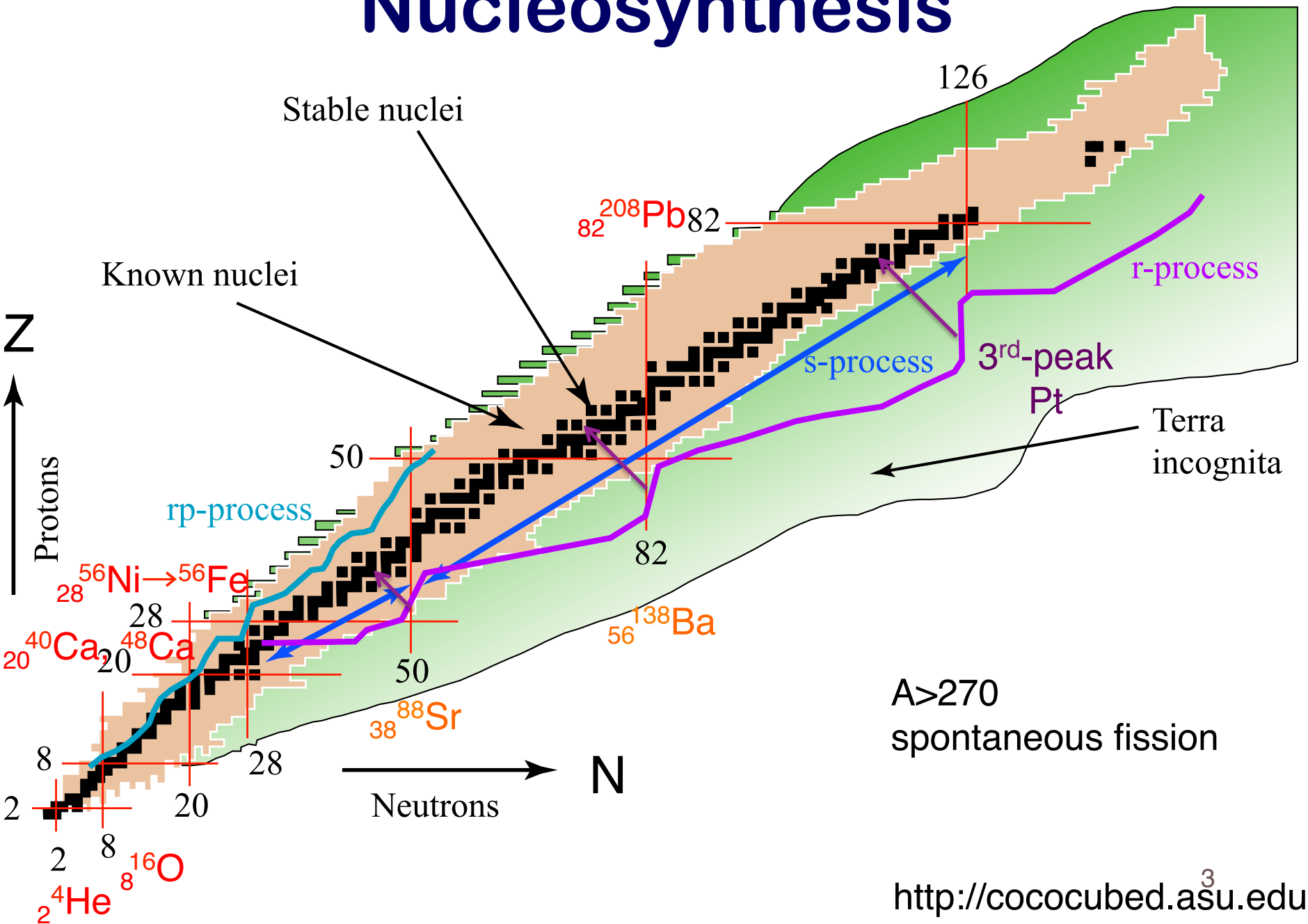


Philip Taylor, https://www.youtube.com/watch?v=jk5bLrVI8Tw

[O/H] = –5 (blue) to -1 (red); > -1 (white)

Chiaki Kobayashi (Univ. of Hertfordshire, UK)

Nucleosynthesis

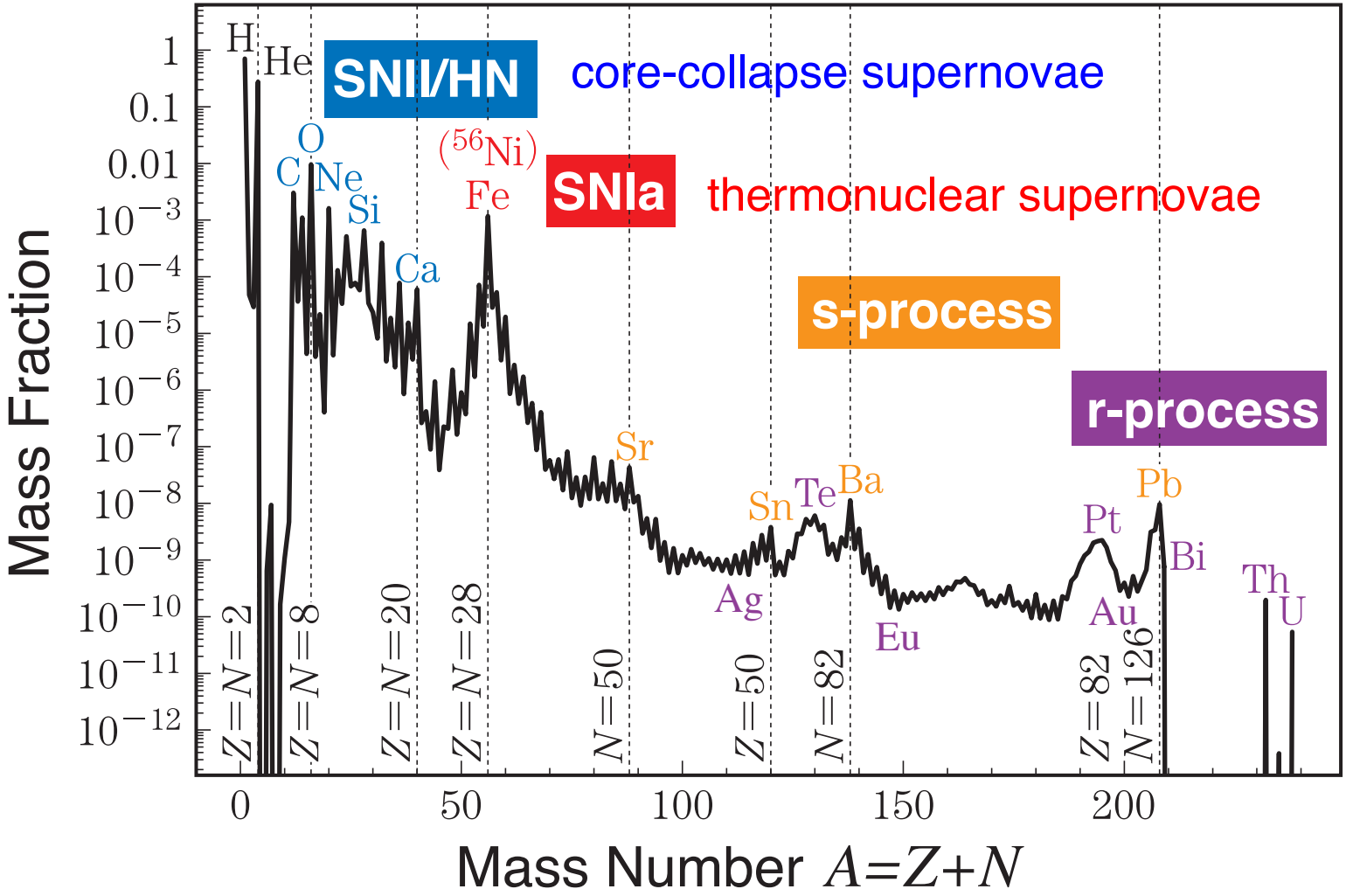


A>270
spontaneous fission

http://cococubed.asu.edu

Origin of Elements in the Sun

Big Bang Nucleosynthesis: 1H, 2H, 4He, 7Li



Galactic Archaeology

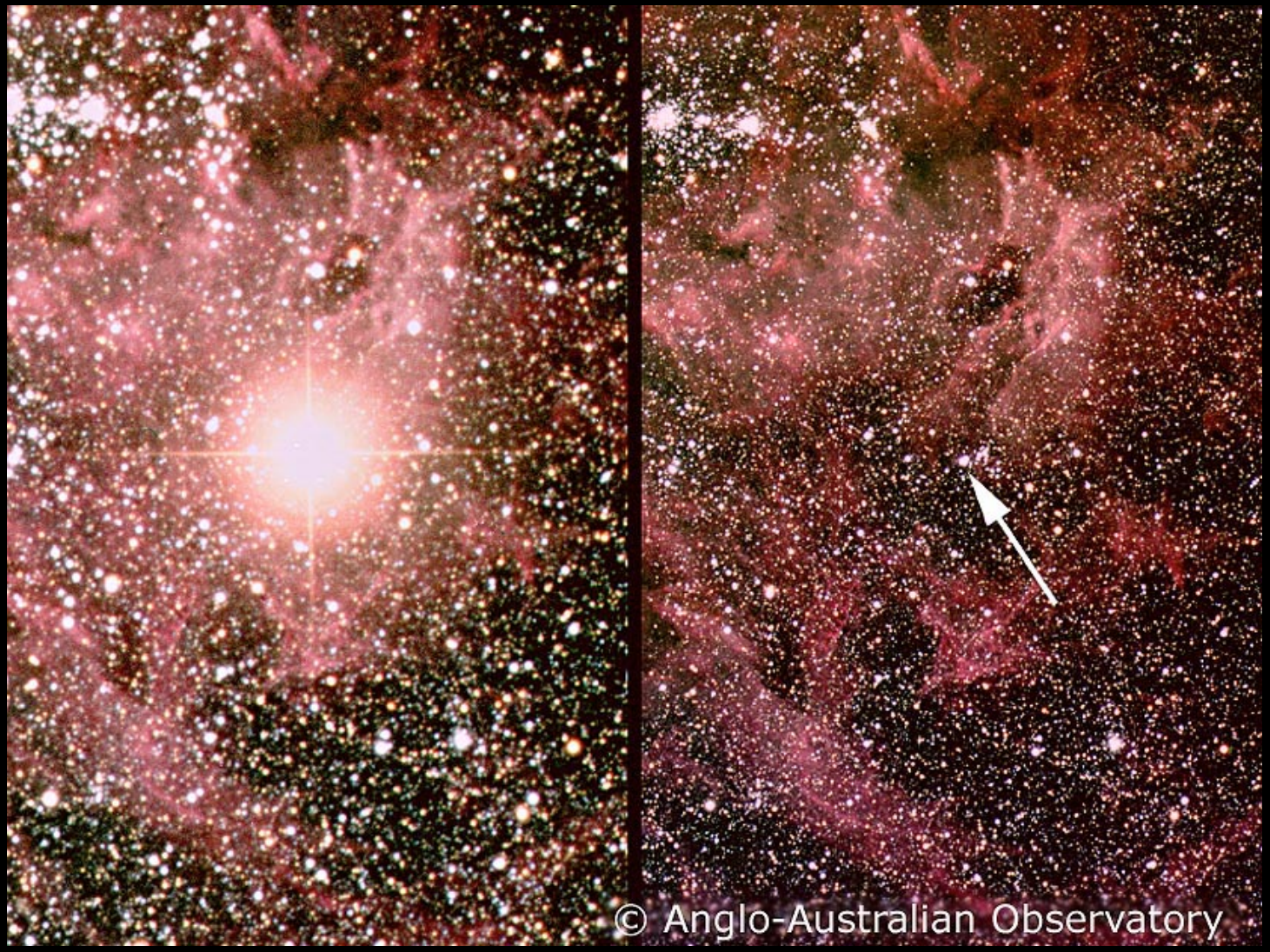
for Milky Way and local dwarf galaxies

- Motions of one billion stars are measured with GAIA.
- Ages from asteroseismology COROT, Kepter, K2, TESS…
- Elemental Abundances (from Li to Eu) of one million stars will be measured with multi-object spectrographs:
  - **SEGUE** (Resolution~1800) on SDSS
  - **RAVE** (R~7500) on 1.2m UKST
  - **HERMES** on AAT (R~28000/50000)
  - **APOGEE** (R~20000, IR) on SDSS
  - **GAIA-ESO with VLT** (R~20000/40000)
  - ~~WFMOS on Subaru~~
  - **WEAVE** on WHT (R~5000/20000)
  - **4MOST** on VISTA (R~5000/18000)
  - **PFS** on Subaru (R~2300-5000)
  - **MSE** (R~2000/6500/20000)
- Chemical and dynamical evolution of the Milky Way Galaxy are being revealed!

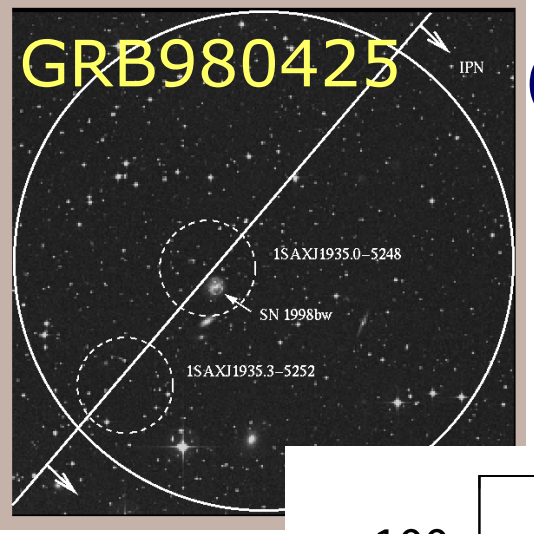
GAIA spacecraft http://sci.esa.int/gaia/

Core-collapse Supernovae

SN1987A in LMC on 2/23/1987; Betelgeuse xx/xx/2020-3020

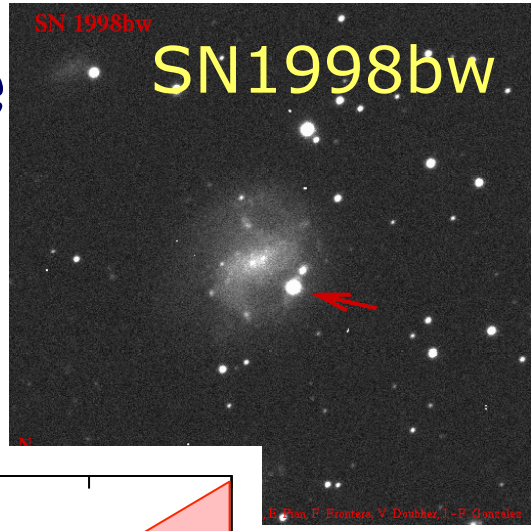


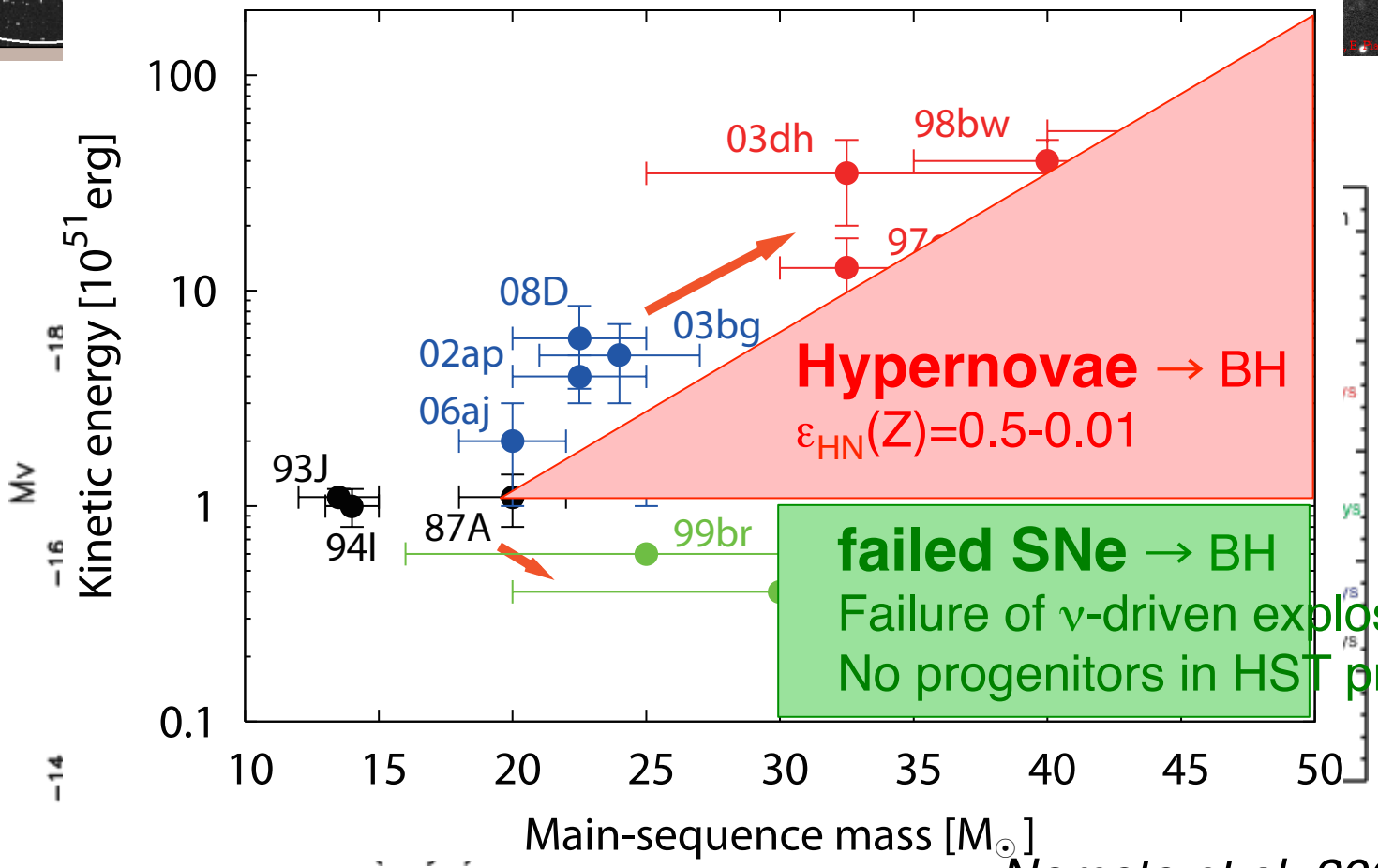
BSG



Core-collapse SNe

- SN light curves & spectra fitting → M, E_{kin}, M(Fe)
- Mixing-fallback model





Nomoto et al. 2002, 2013

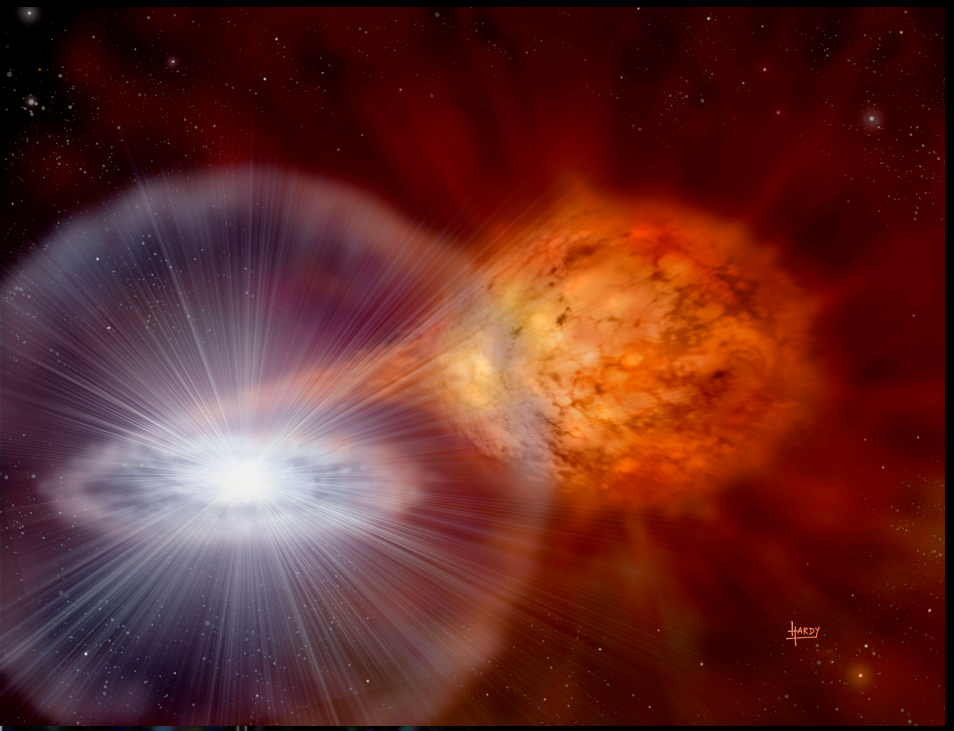
Thermonuclear (Type Ia) Supernovae

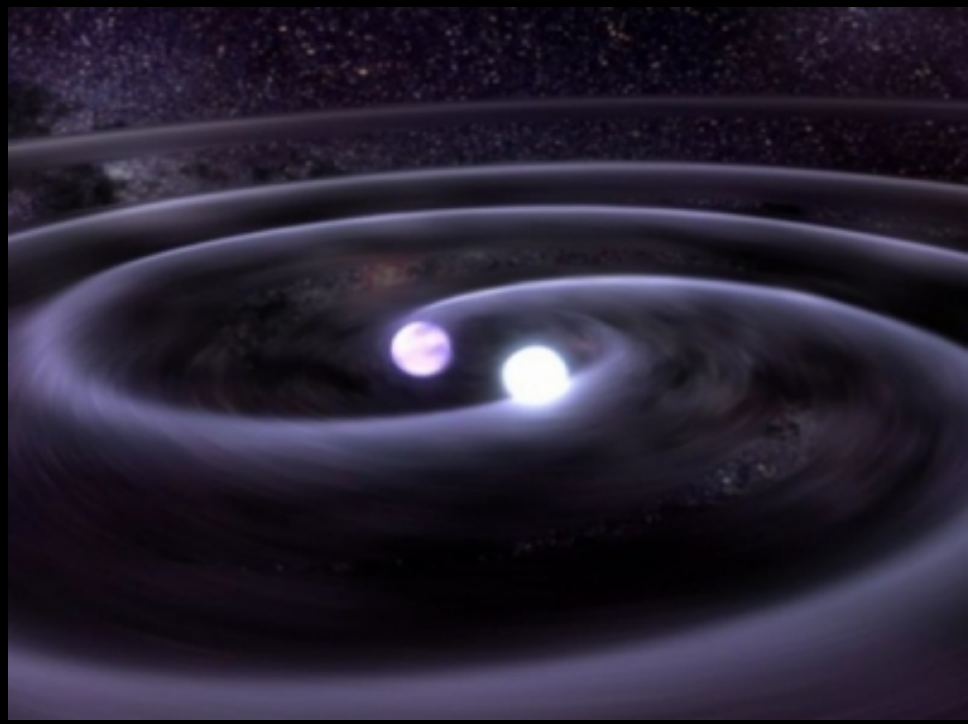
Thermonuclear explosion in a binary with C+O white dwarf

Ch-mass explosion
(deflagration or delayed detonation) possibly in SD

vs

sub-Ch mass explosion
(double detonation) in DD and SD

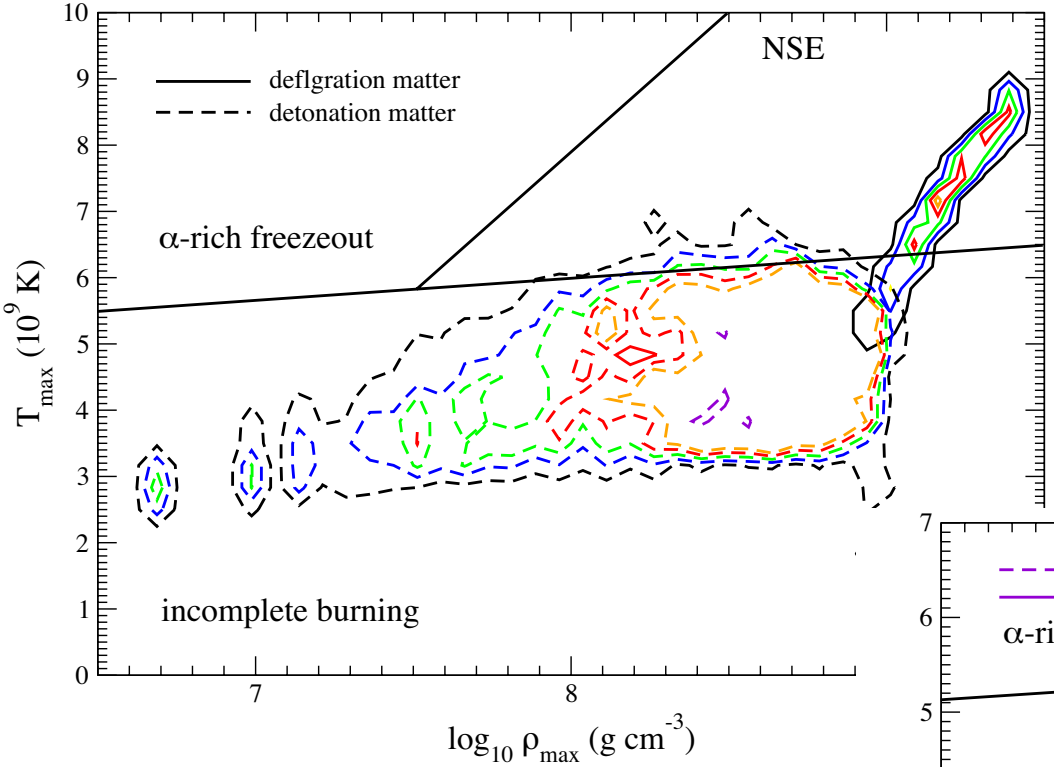




McCully+14

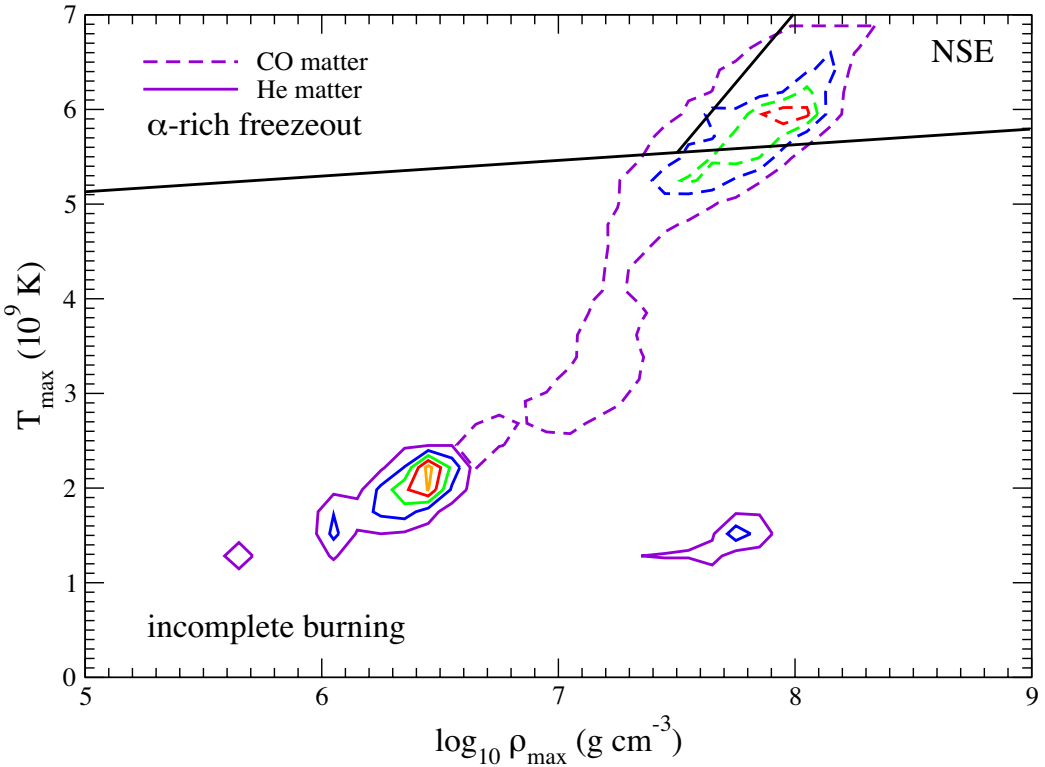
CK, Leung, Nomoto 2019, submitted, ArXiv:1906.09980 (2D nucleosynthesis)

2D Nucleosynthesis: Ch vs sub-Ch



CK, Leung, Nomoto 19

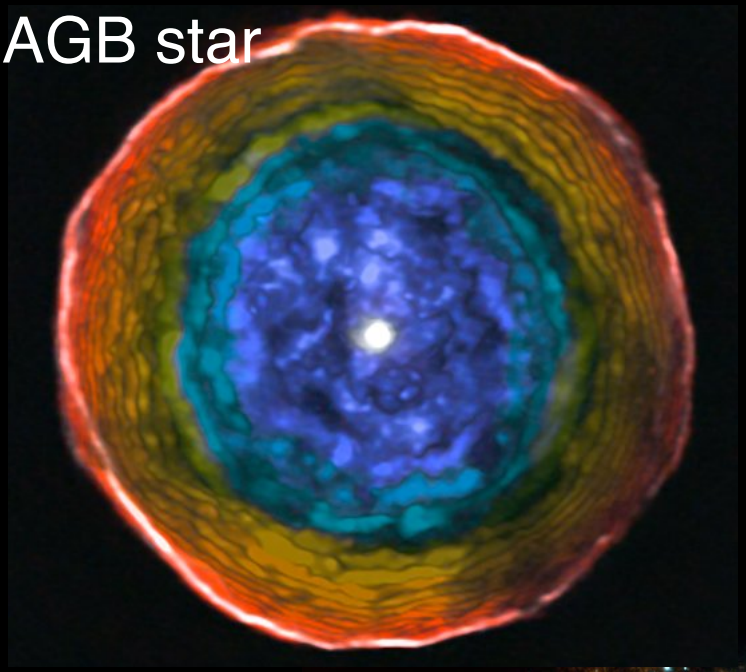
- **Double detonation of sub-Ch WD** (below)
- Ye > 0.499
- [(Si,S,Ar,Ca)/Fe] close to the solar ratios



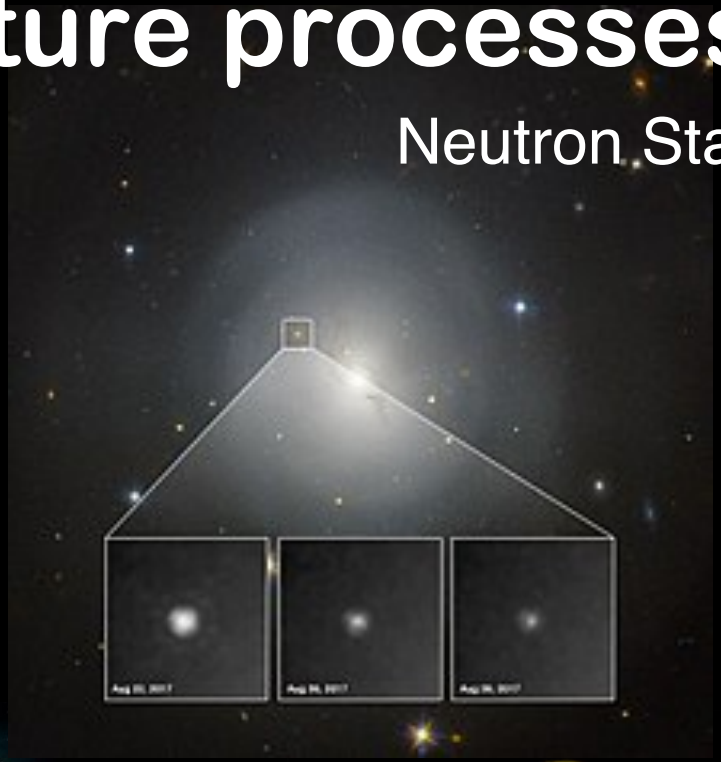
- **Delayed detonation of Ch WD** (above)
- Ye can be as low as 0.46 for deflagration
- ^{54}Fe, Mn, ^{58}Ni enhanced

Neutron-capture processes

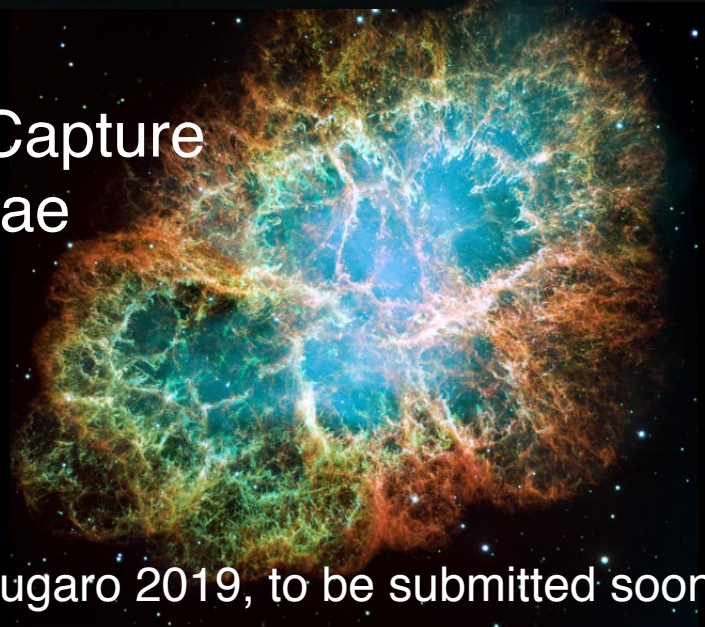
AGB star



Neutron Star Merger

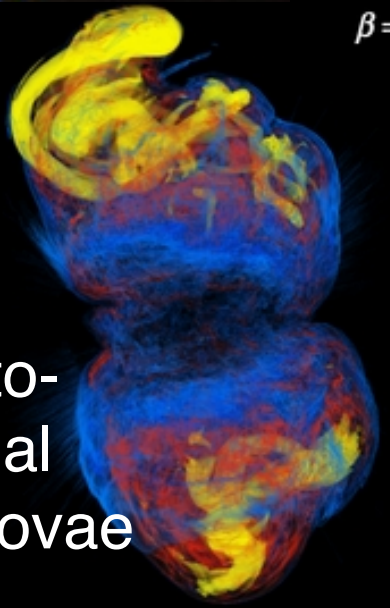


Electron Capture Supernovae



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

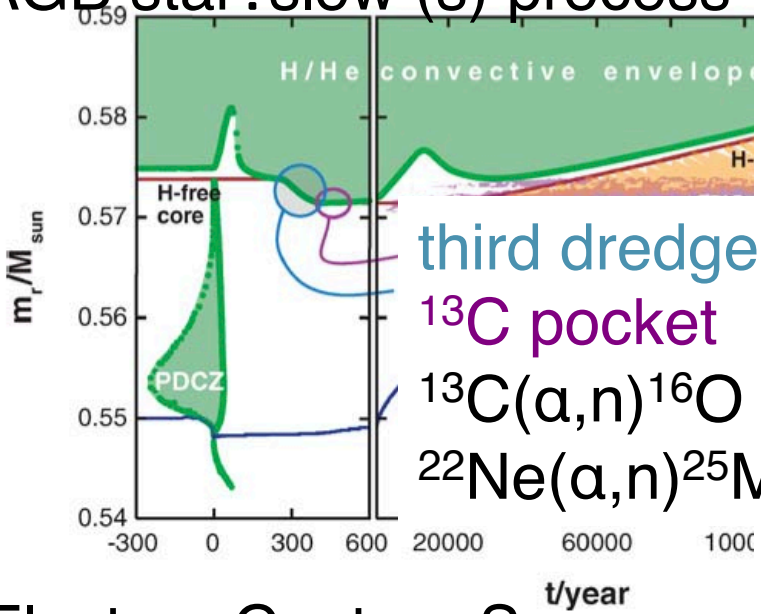
Magneto-rotational Supernovae



CK, Karakas, Lugaro 2019, to be submitted soon

Neutron-capture processes

AGB star : slow (s) process



third dredge-up

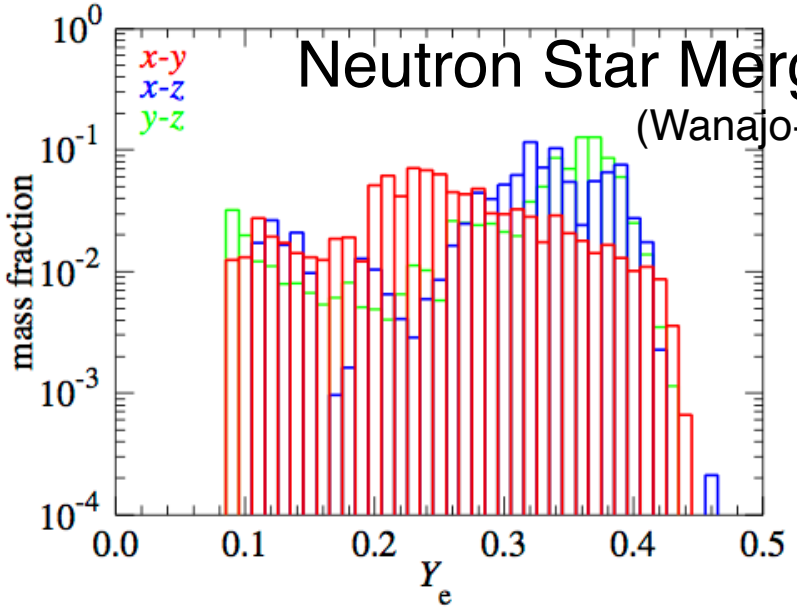
^{13}C pocket

$^{13}C(\alpha,n)^{16}O$

$^{22}Ne(\alpha,n)^{25}Mg$

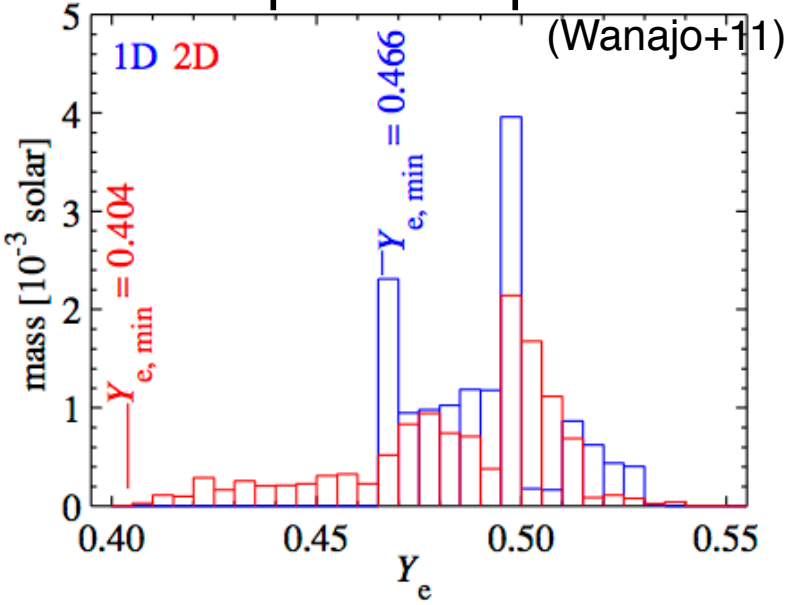
Neutron Star Merger

(Wanajo+14)



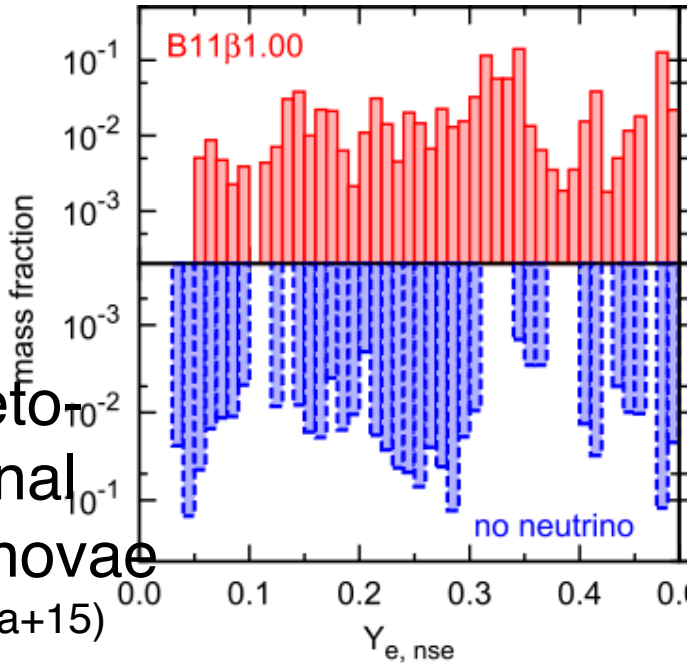
Electron Capture Supernovae

(Wanajo+11)



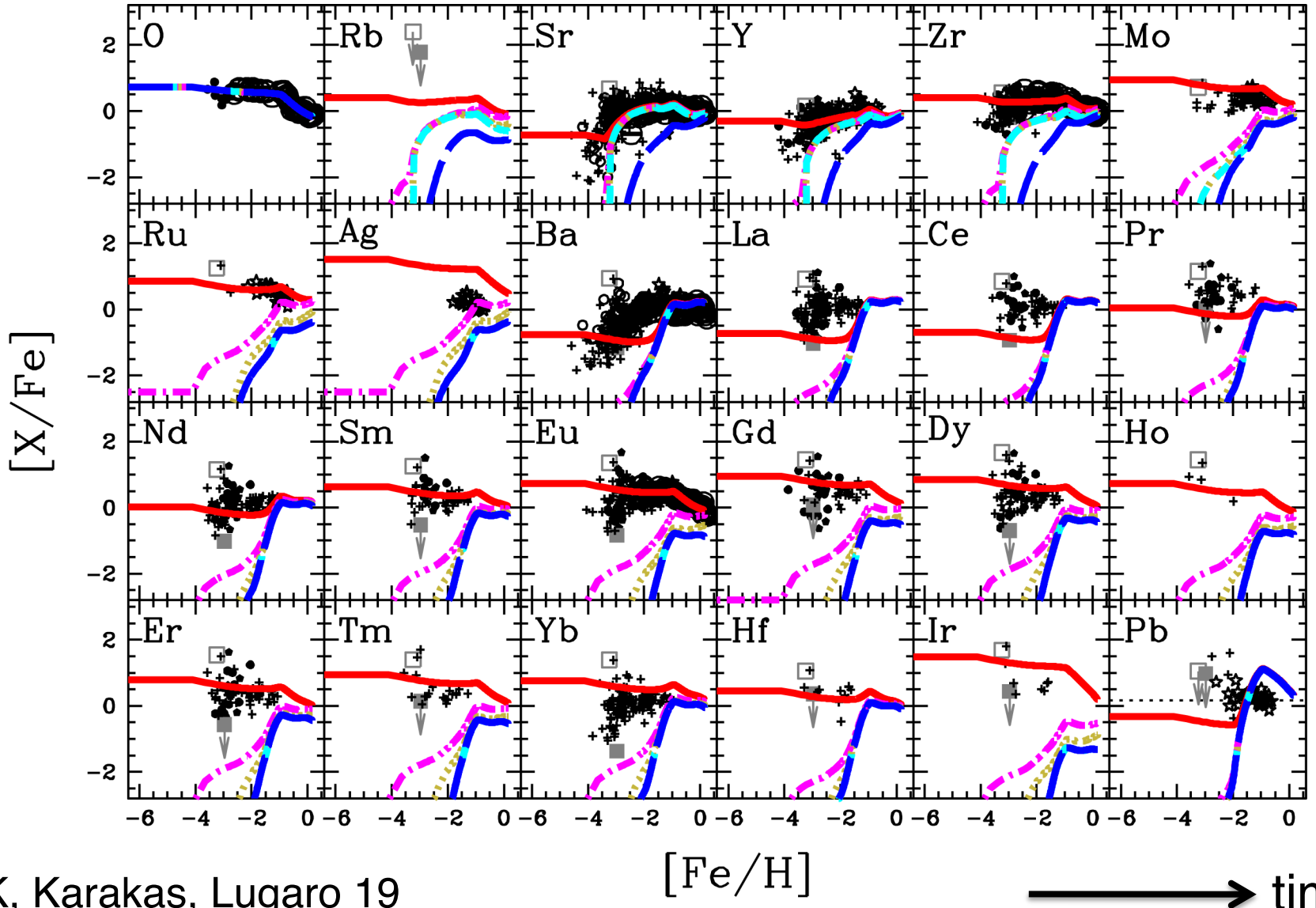
Magneto-rotational Supernovae

(Nishimura+15)



Neutron-capture elements

s-process, ECSN, ν-winds, NS+NS&NS+BHM, MRSN



CK, Karakas, Lugaro 19

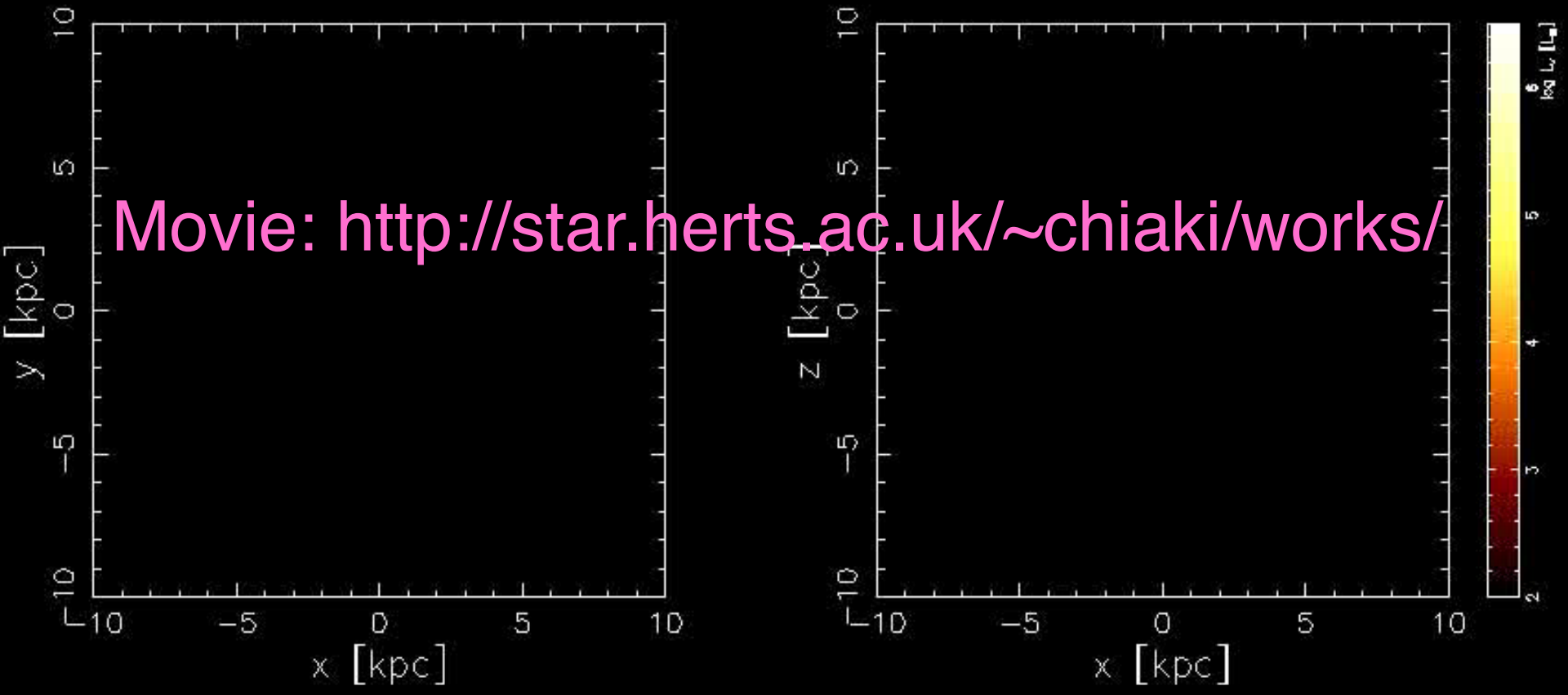
time

Milky Way-type simulations

Initial Condition: λCDM fluctuated sphere with λ~0.1, r~3Mpc,
M_{tot}~10^{12} $M_\odot$, N_{tot}~120.000, M_{gas}~10^6 $M_\odot$, M_{DM}~10^7 $M_\odot$
(CK & Nakasato 2011, ApJ, 729, 16)

Face on

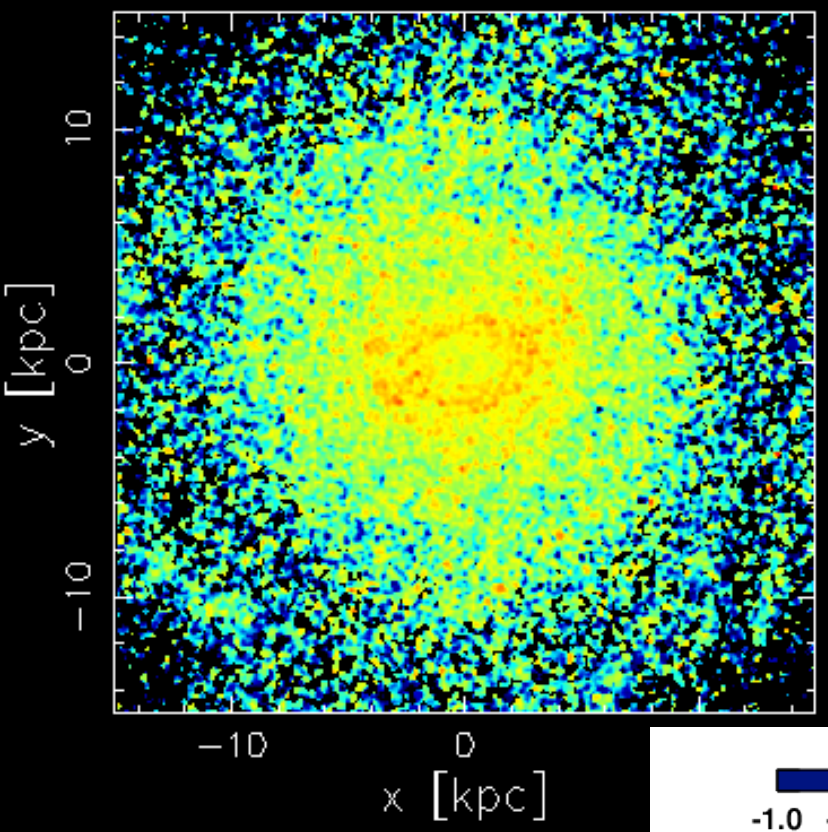
Edge on

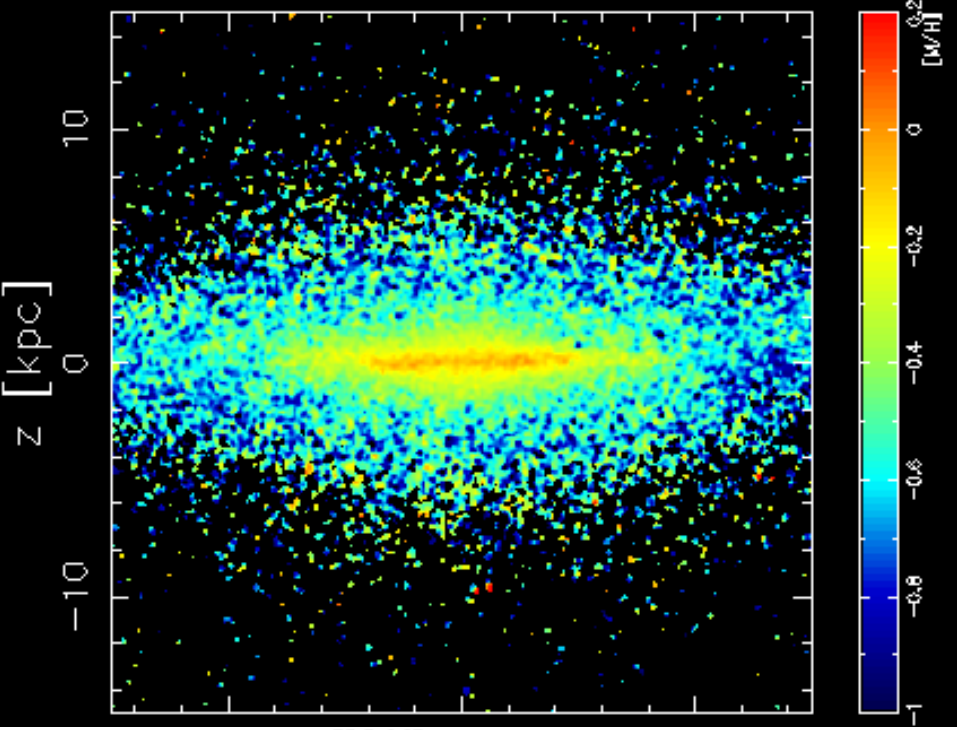


Movie: http://star.herts.ac.uk/~chiaki/works/

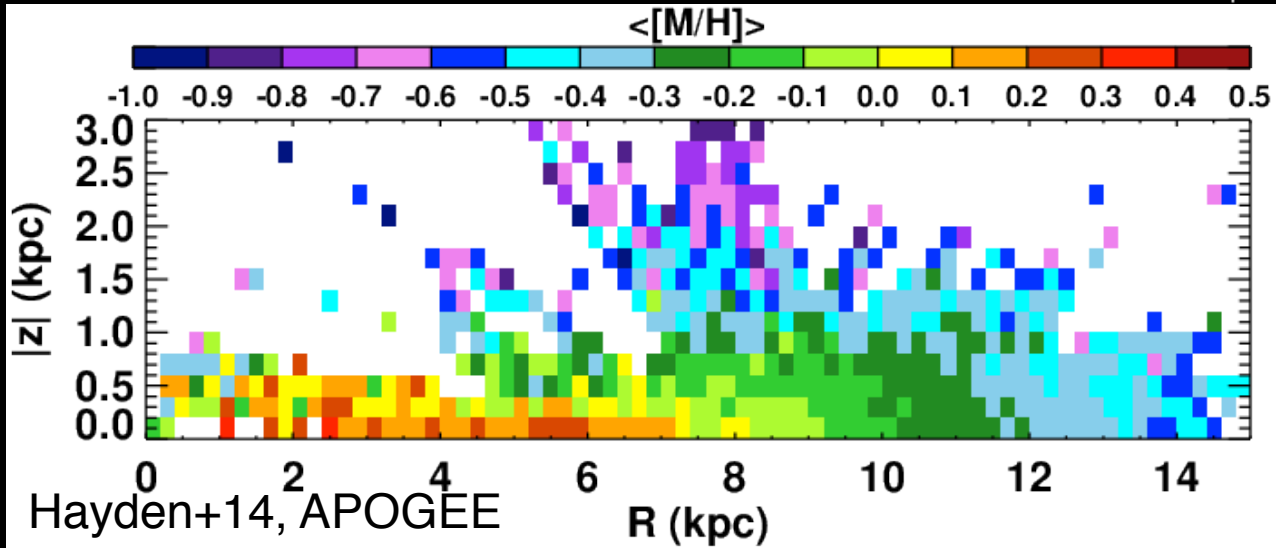
Similar results obtained also with Aquarius Initial Condition (CK 2015).

Metallicity Map



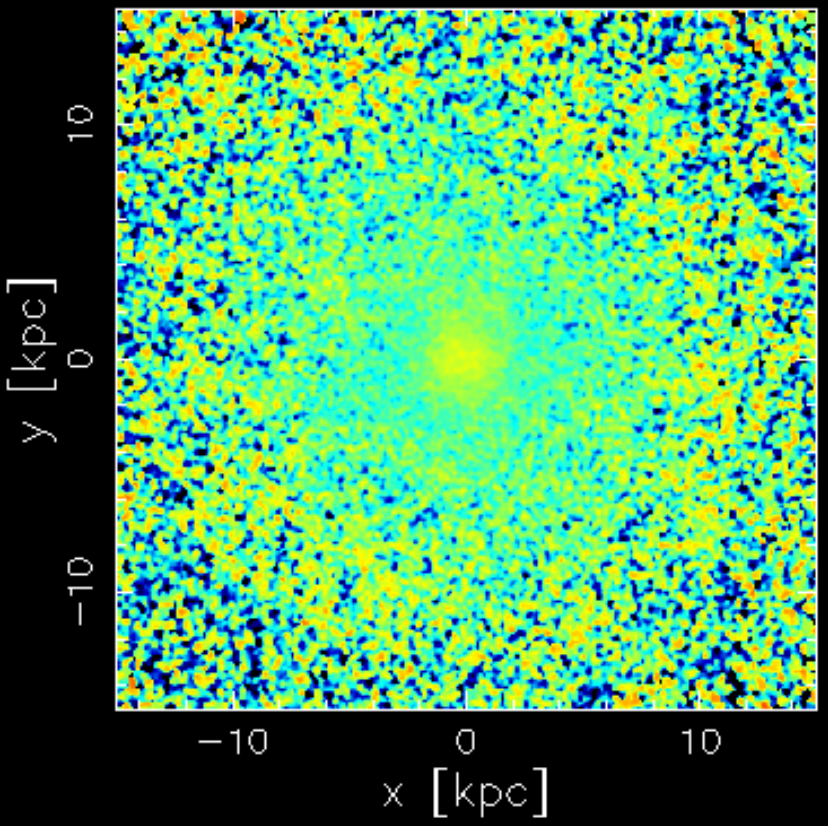


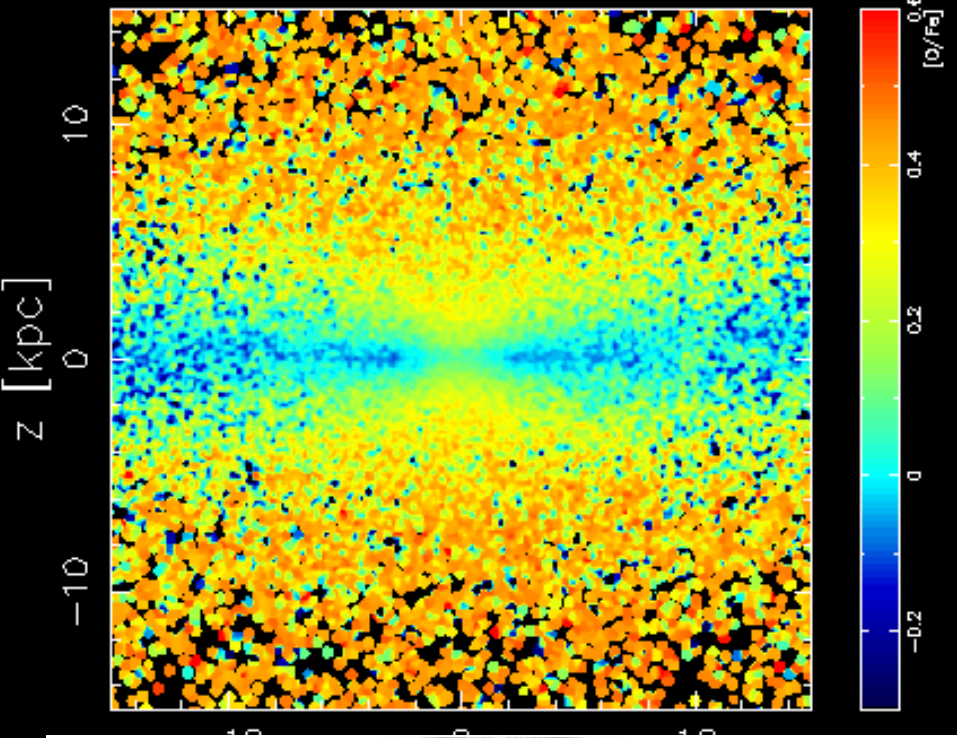
low-mass stellar mass weighted, projected



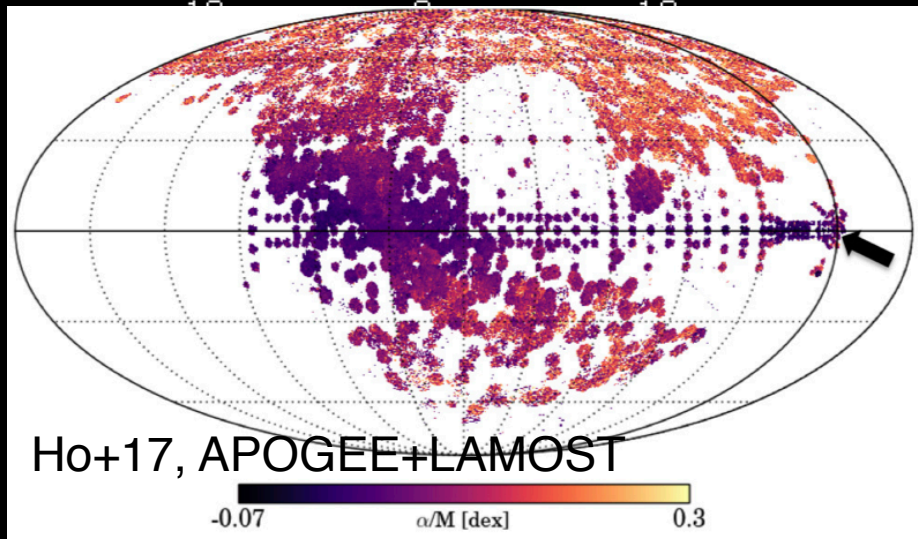
Hayden+14, APOGEE

[O/Fe] Map



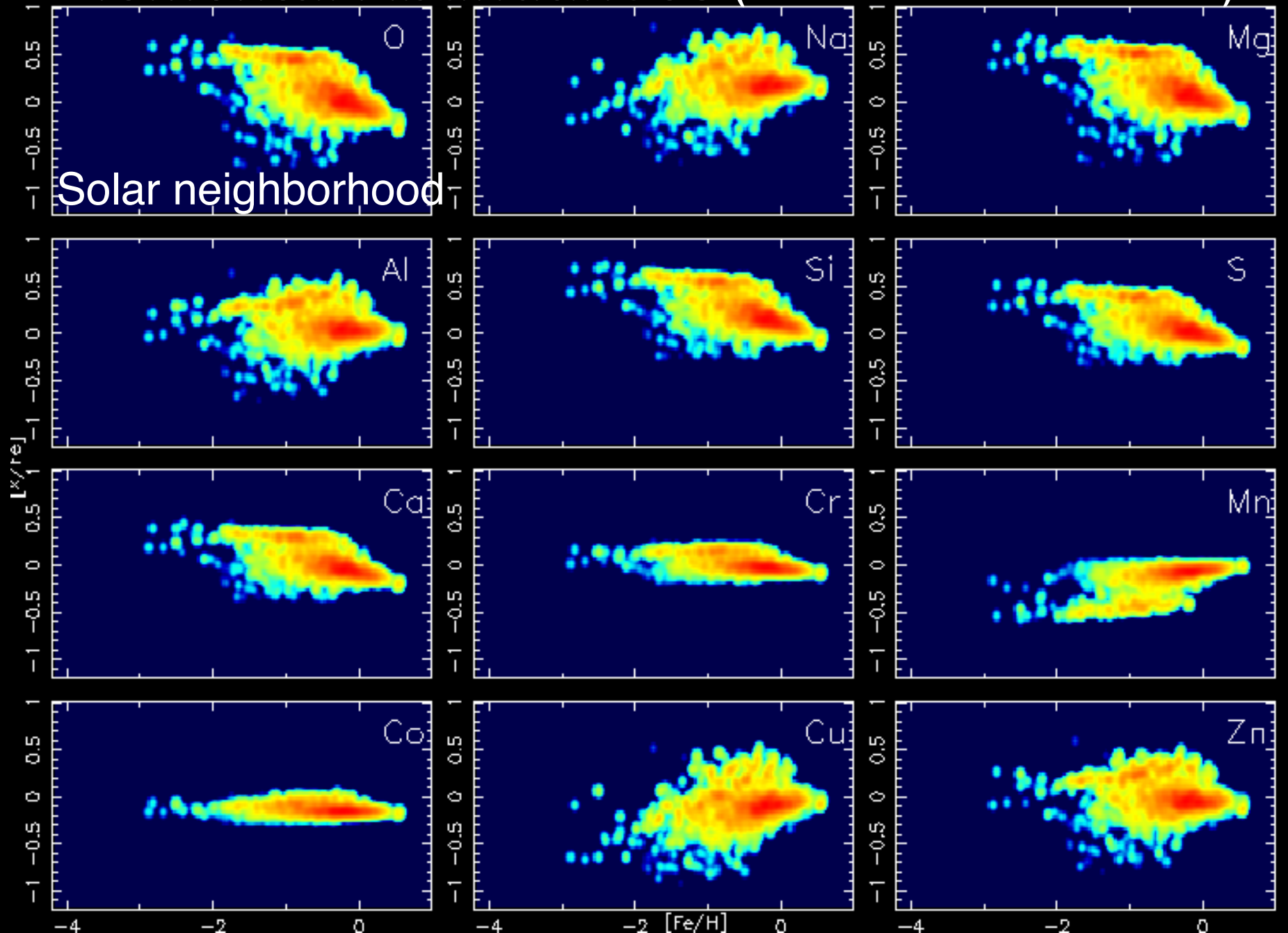


low-mass stellar mass weighted, projected

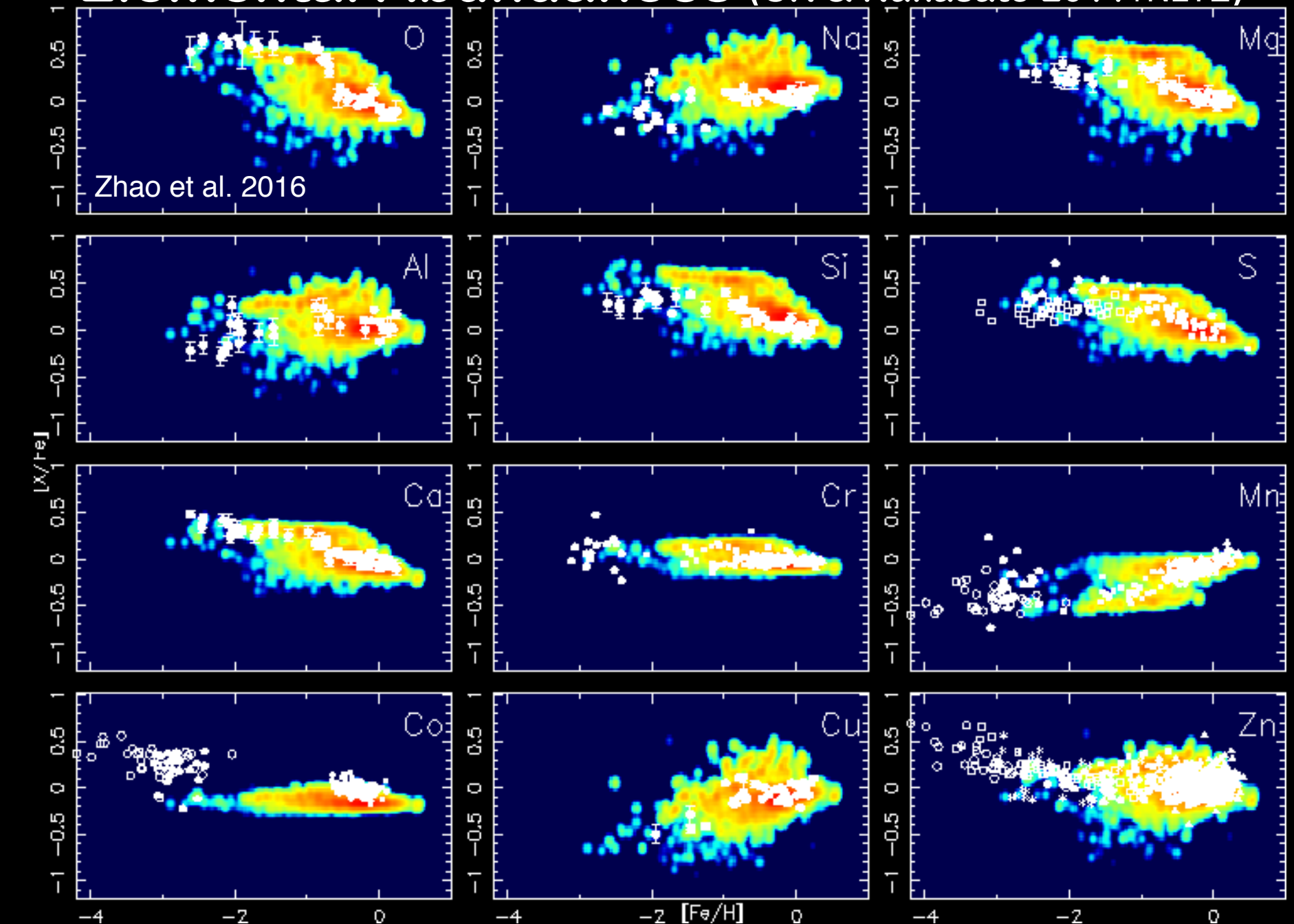


Ho+17, APOGEE+LAMOST

Elemental Abundances (CK & Nakasato 2011+NLTE)

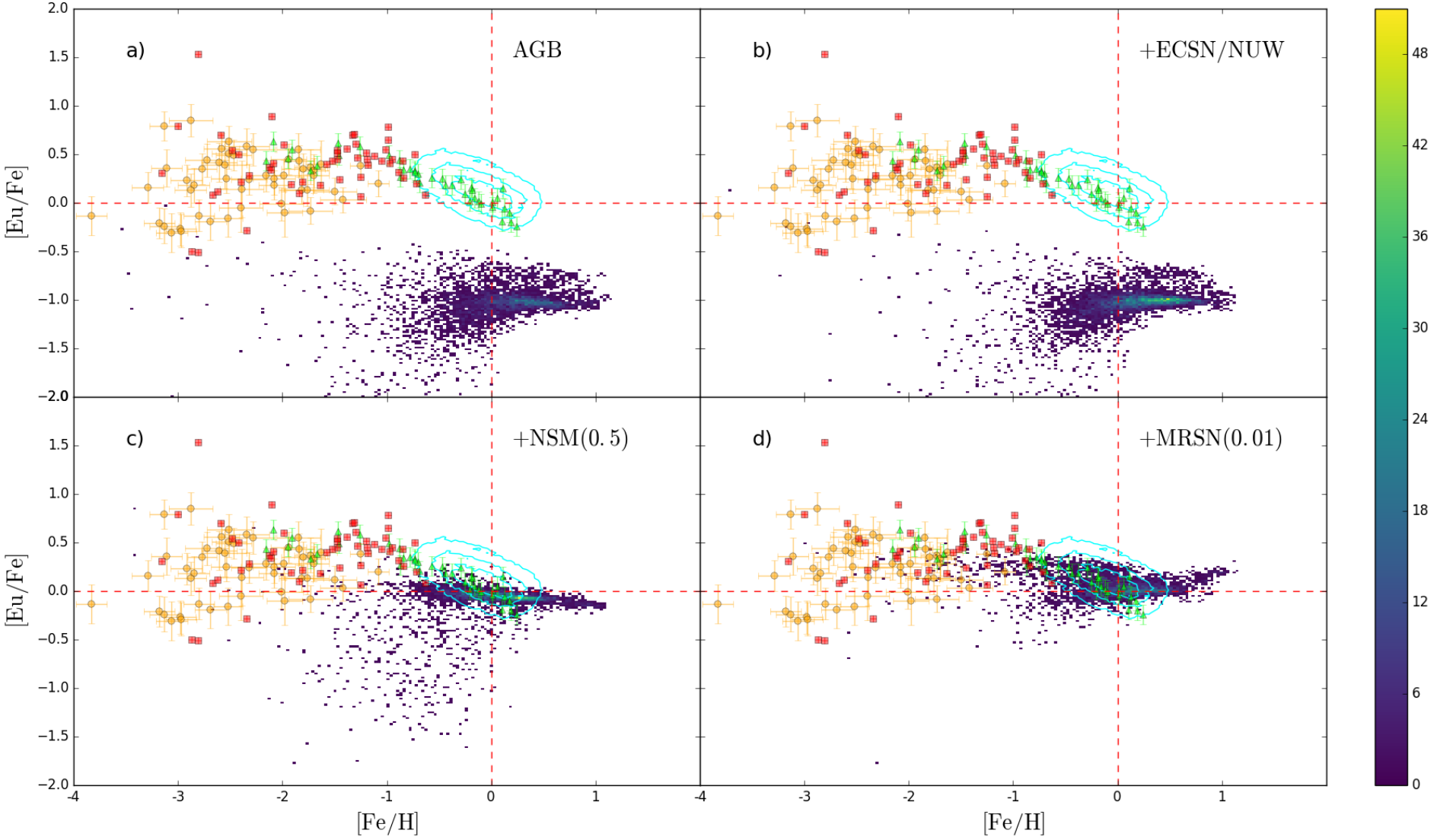


Elemental Abundances (CK & Nakasato 2011+NLTE)



[Eu/Fe]-[Fe/H]

Chemo-hydrodynamical Simulation
Chris Haynes & CK 2019

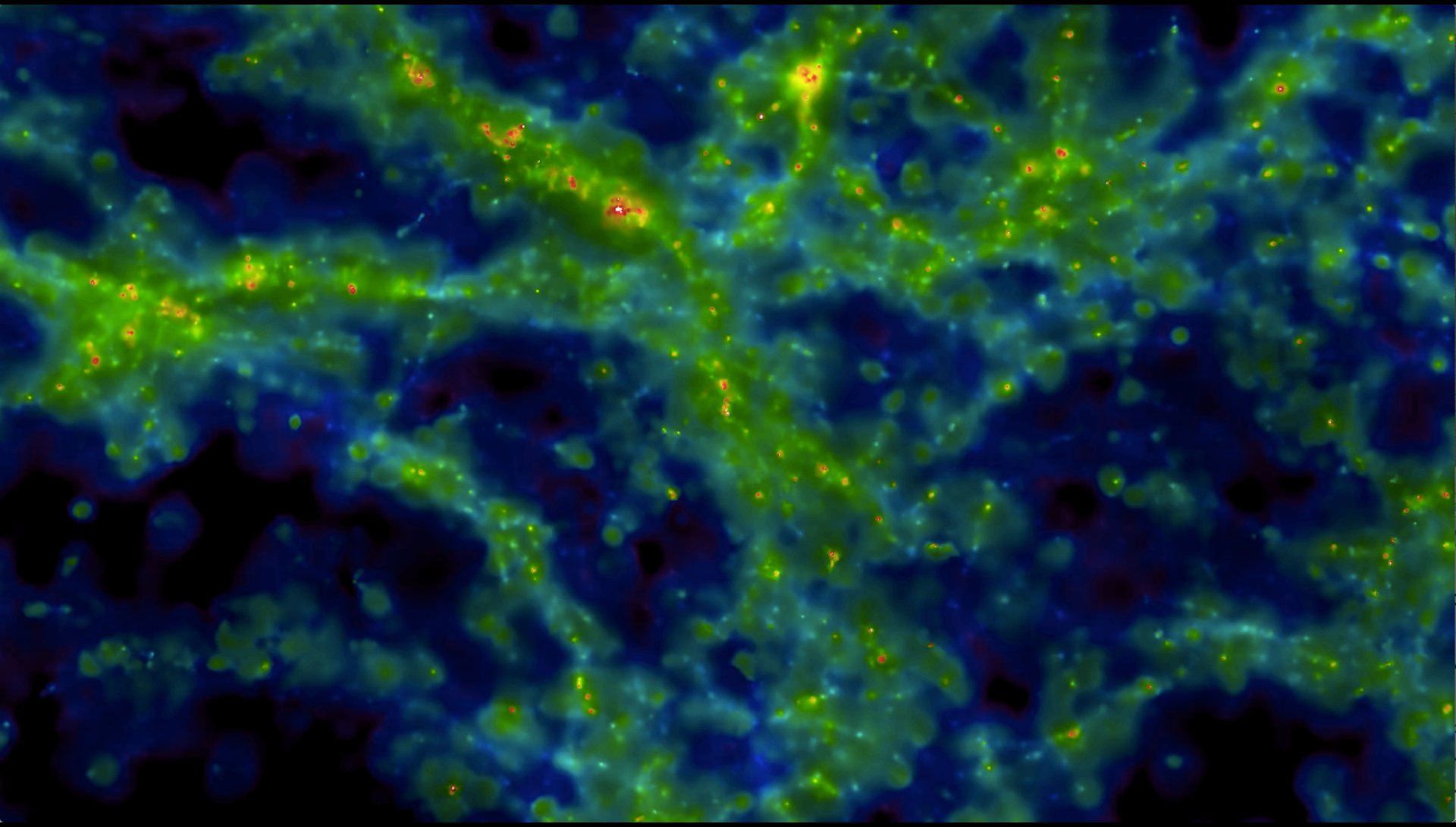


Neutron star mergers alone cannot reproduce the observations.

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

Cosmological Simulations

from z=5 to 0

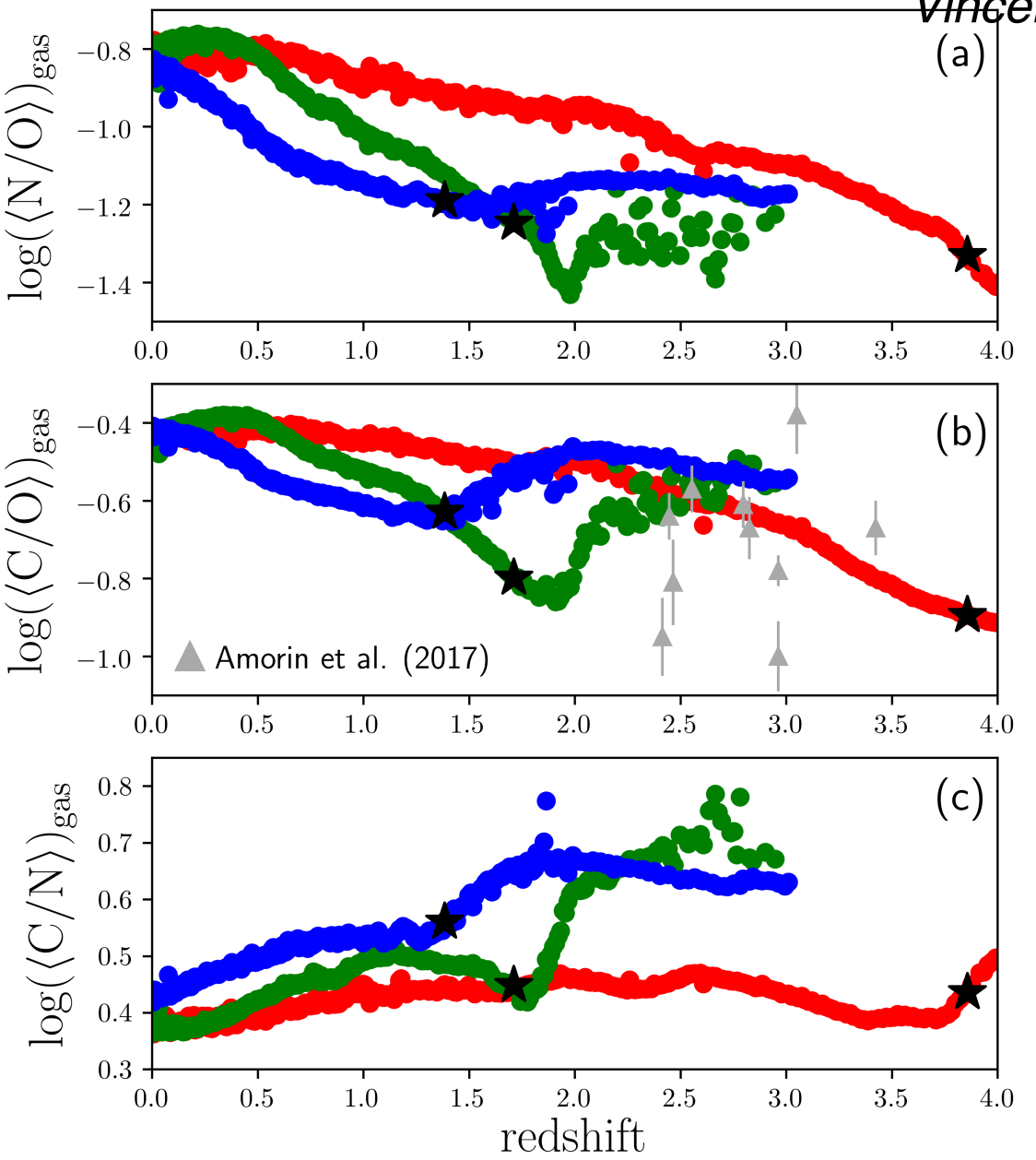


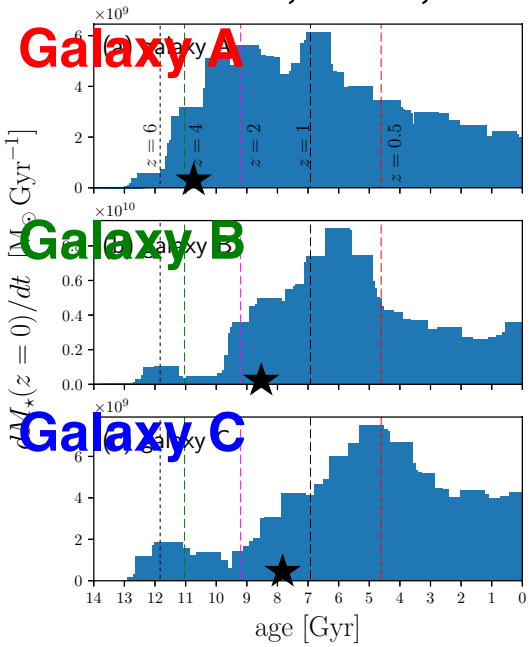
[O/H] = –5 (blue) to -1 (red); > -1 (white)

Philip Taylor, https://www.youtube.com/watch?v=jk5bLrVI8Tw

Redshift evolution of CNO ratios

Vincenzo & CK 2018a, A&A, 610, 16





C: low-mass AGB, <4$M_\odot$

N: massive AGB, >4$M_\odot$

O: core-collapse SNe

Currently, N/O (z<2.5), C/O (z>2), but C/N is possible with JWST!

Extra-galactic Archaeology

- Internal structures, i.e., kinematics and 2D map of gas, stars, chemical abundances, are measured with Integral Field Units (SAURON, CALIFA, MaNGA, SAMI, Hector, MUSE, KMOS…)

- Chemodynamical simulations can predict their redshift evolution for JWST, and explain the physical origins to test the galaxy formation theory.

JWST http://www.jwst.nasa.gov