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Production of carbon and nitrogen in core-collapse supernovae: constrains from presolar grains

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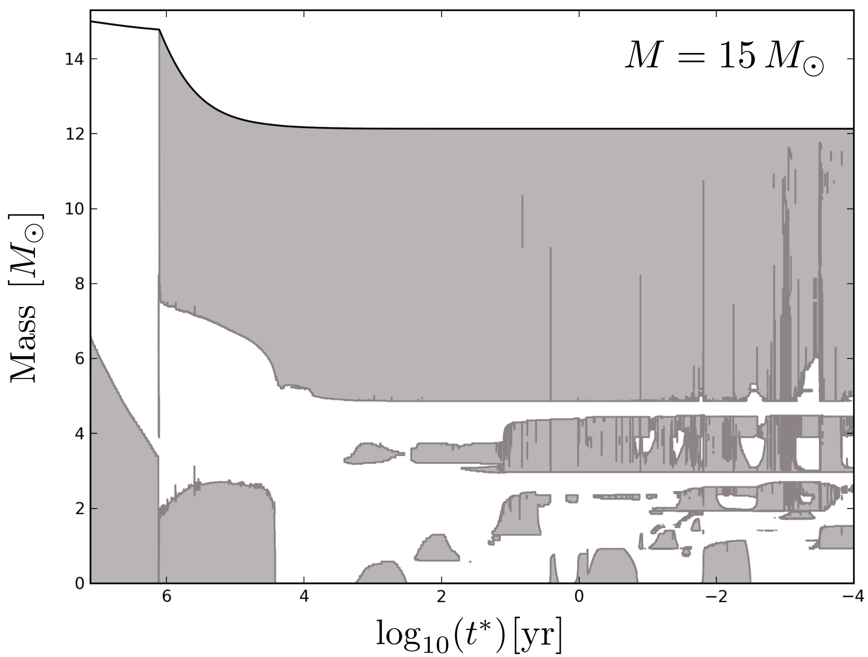
Nuclear burning stages

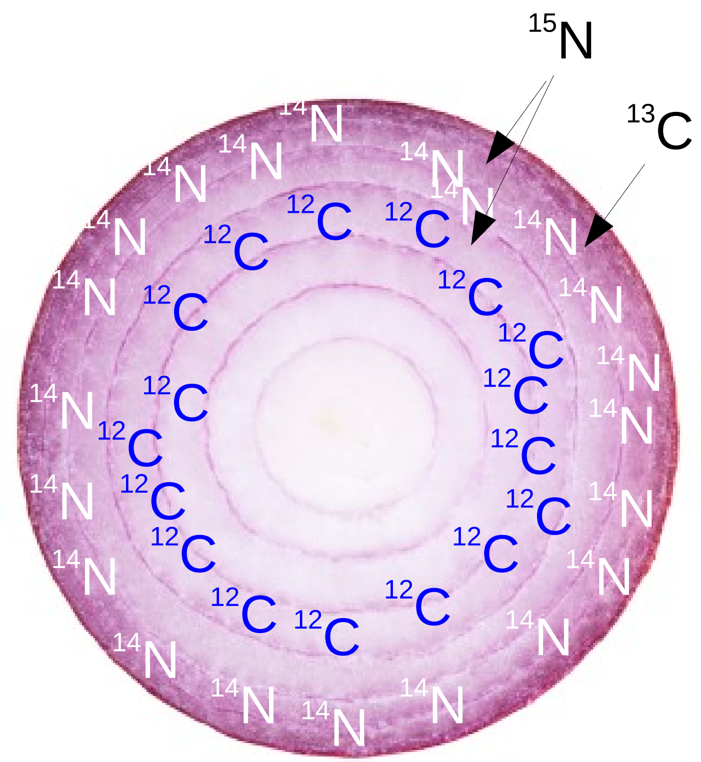
(e.g., 20 solar mass star)

Fuel	Main Product	Secondary Product	T (10^9 K)	Time (yr)	Main Reaction
H	He	^{14}N	0.02	10^7	$4\ H \xrightarrow{CNO} {}^4He$
He	O, C	^{18}O, ^{22}Ne s-process	0.2	10^6	$3\ He^4 \rightarrow {}^{12}C$ $^{12}C(\alpha,\gamma)^{16}O$
C	Ne, Mg	Na	0.8	10^3	$^{12}C + {}^{12}C$
Ne	O, Mg	Al, P	1.5	3	$^{20}Ne(\gamma,\alpha)^{16}O$ $^{20}Ne(\alpha,\gamma)^{24}Mg$
O	Si, S	Cl, Ar, K, Ca	2.0	0.8	$^{16}O + {}^{16}O$
Si, S	Fe	Ti, V, Cr, Mn, Co, Ni	3.5	0.02	$^{28}Si(\gamma,\alpha)\ldots$

From: Alex Heger

Nucleosynthesis in Core Collapse Supernovae

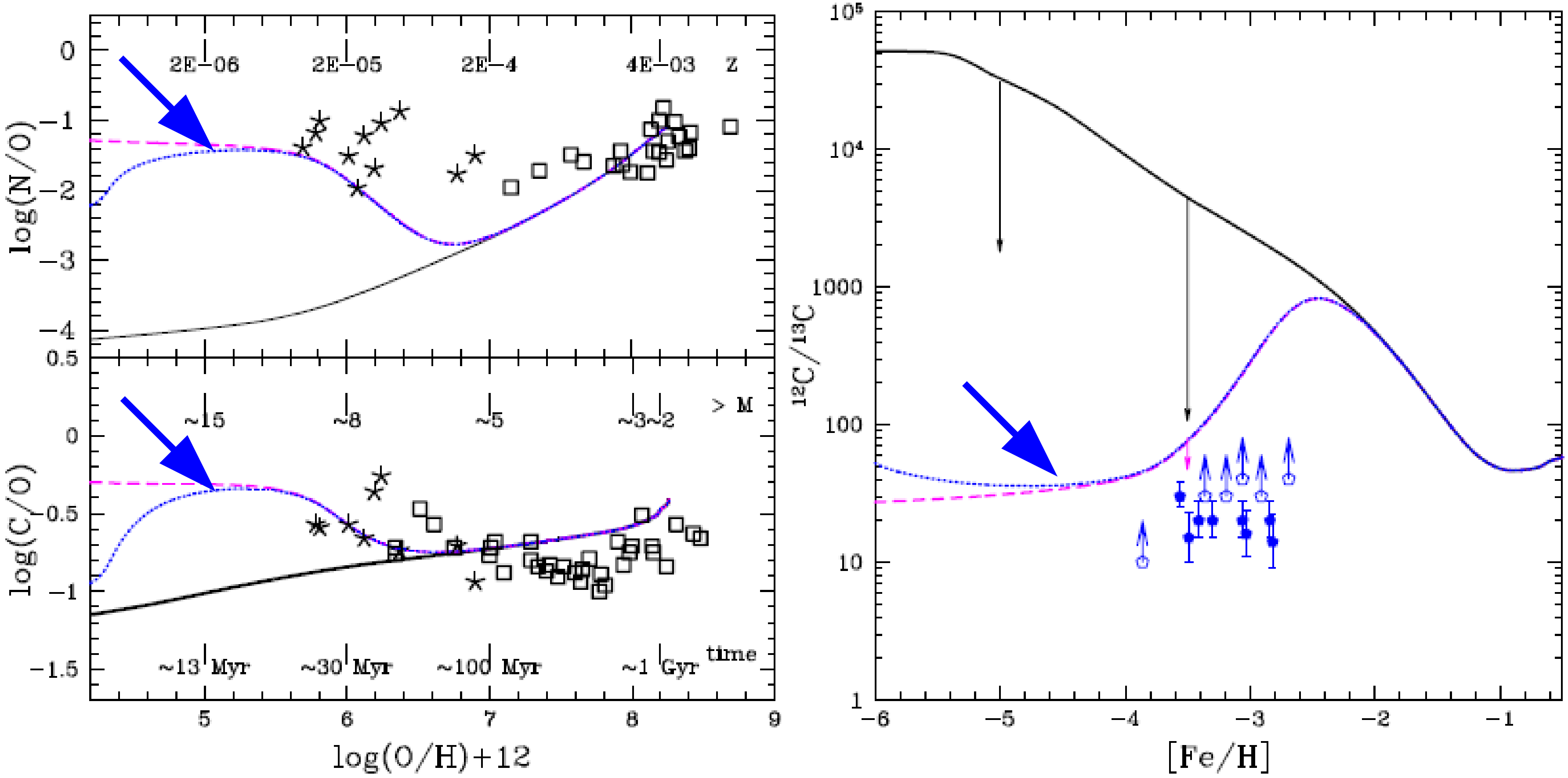




- Element production from the nucleosynthesis in the pre-explosive evolution:
C, O, Na, Mg, s process (Cu, Ga, Ge)

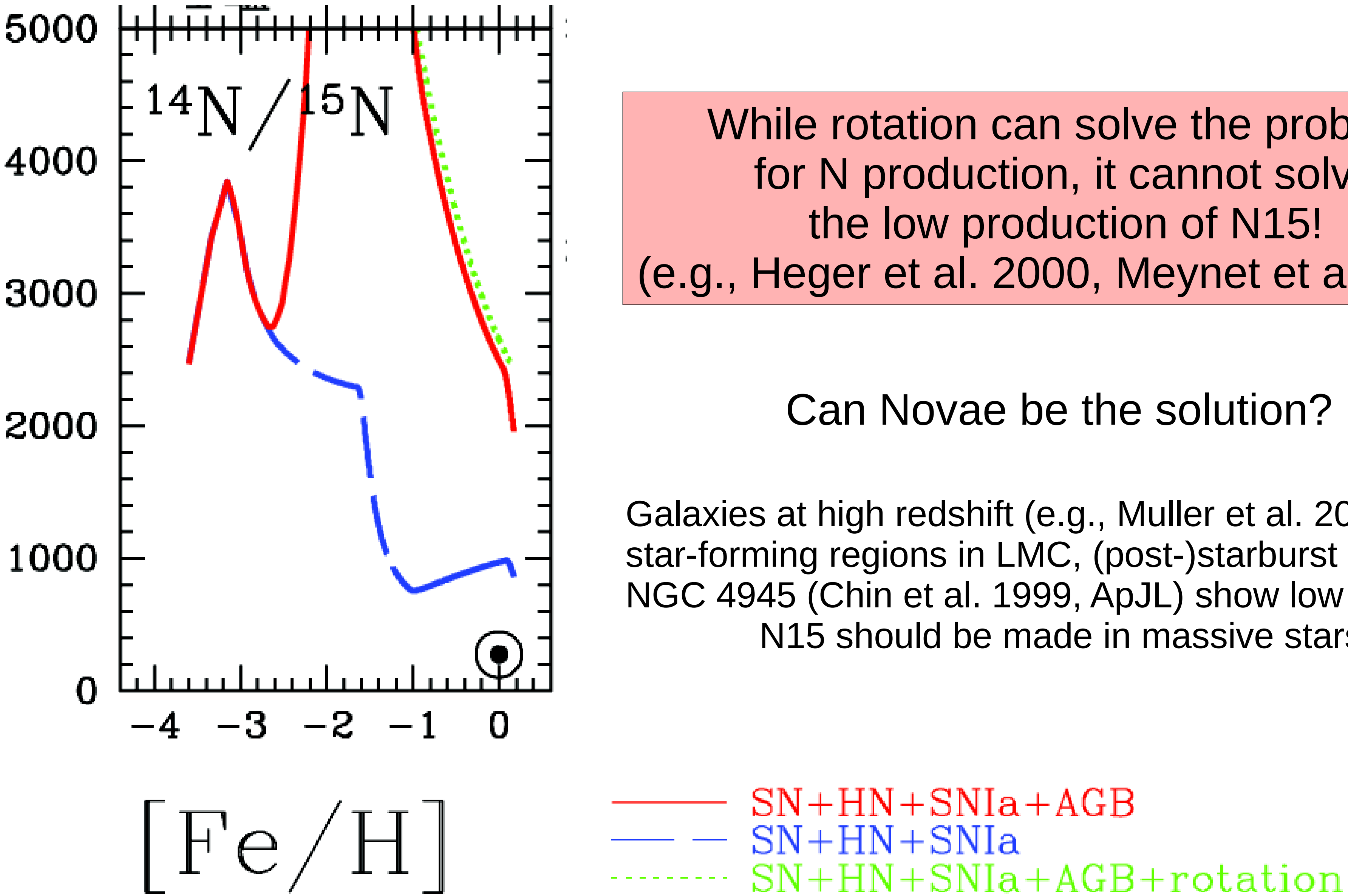
- Element production from the nucleosynthesis in the CCSN:
Si, Ca, S, Ti, **iron group**, p process (γp- and νp-), n process, α process, (r process?)

Carbon is primary, and nitrogen is a secondary product. At low metallicities an extra source of N is needed to explain observations: Rotation?



Chiappini 2013

Kobayashi et al. 2011, MNRAS



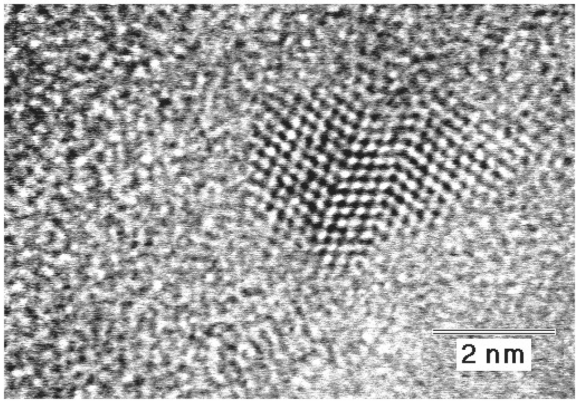
While rotation can solve the problem
for N production, it cannot solve
the low production of N15!
(e.g., Heger et al. 2000, Meynet et al. 2006)

Can Novae be the solution?

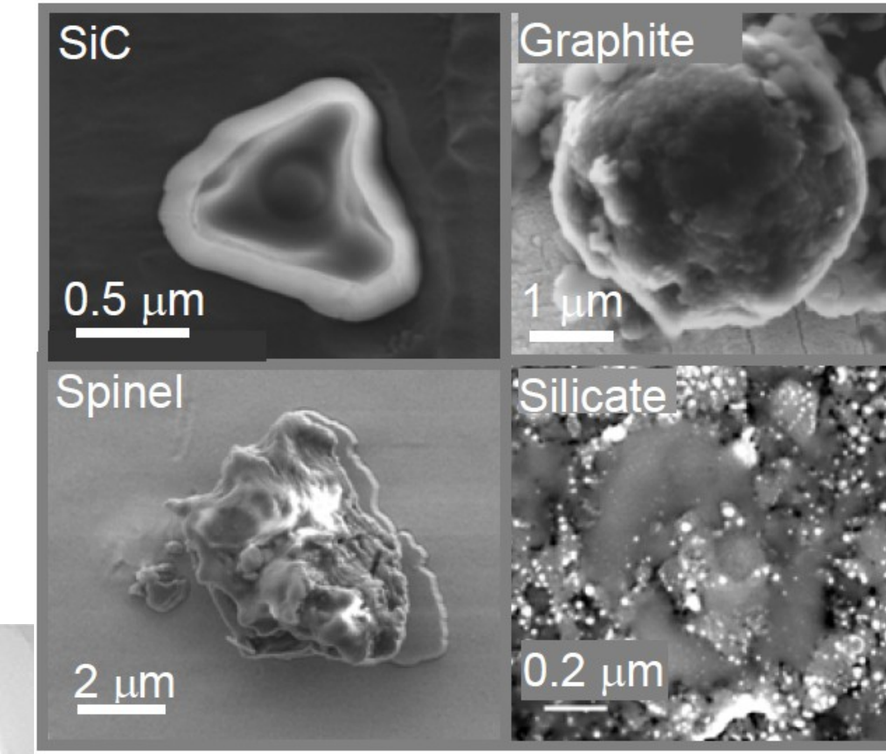
Galaxies at high redshift (e.g., Muller et al. 2006), star-forming regions in LMC, (post-)starburst galaxy NGC 4945 (Chin et al. 1999, ApJL) show low N14/N15.
N15 should be made in massive stars.

Presolar grains zoo

Nano-diamonds

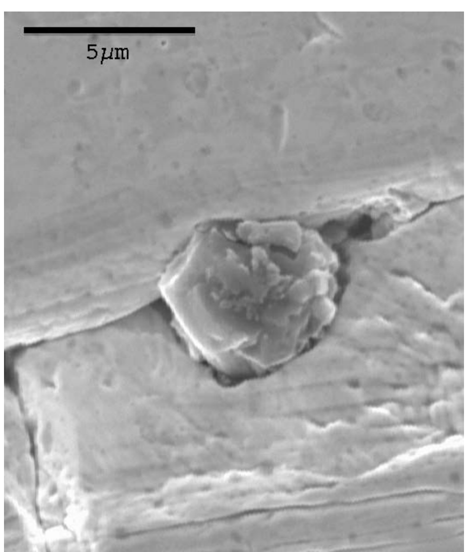


F. Banhart (MPI for Metal Research, Stuttgart)

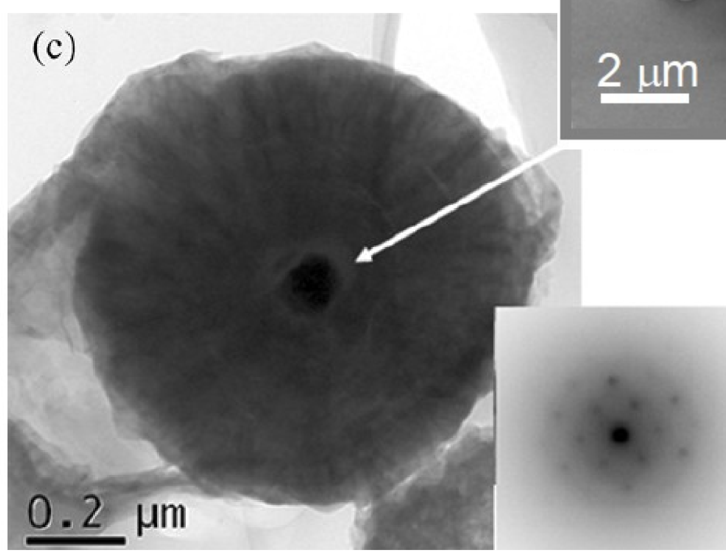


Hoppe 2010 PoS

SiC-X grain



From Reto Trappitsch (Uni of Chicago)

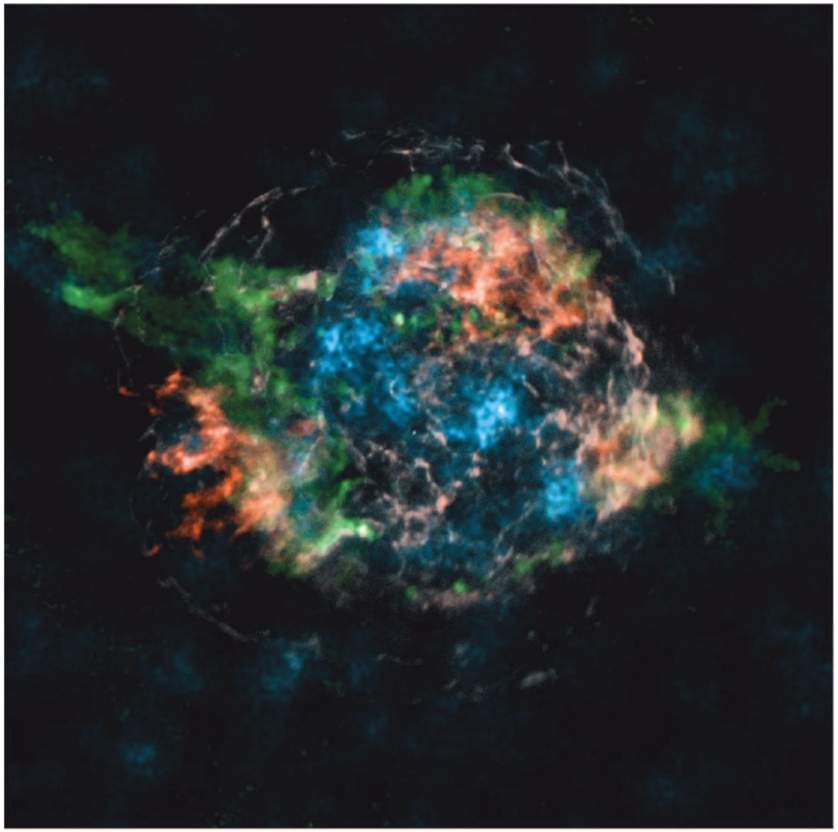


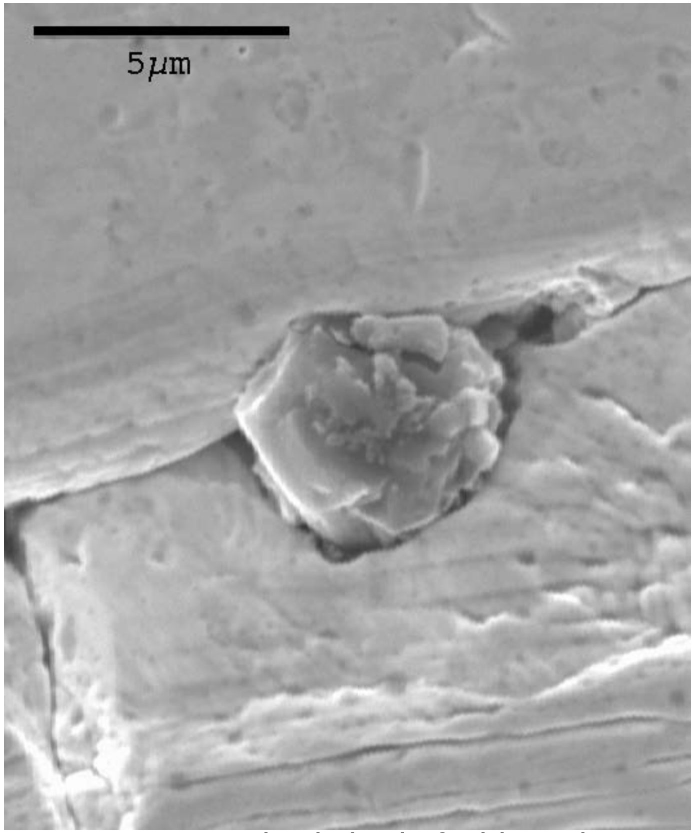
Croat et al. 2010, AJ 139

Graphite (and a SiC in the center)

CCSN remnant

Presolar grain from an old CCSN





From Reto Trappitsch (Uni of Chicago)

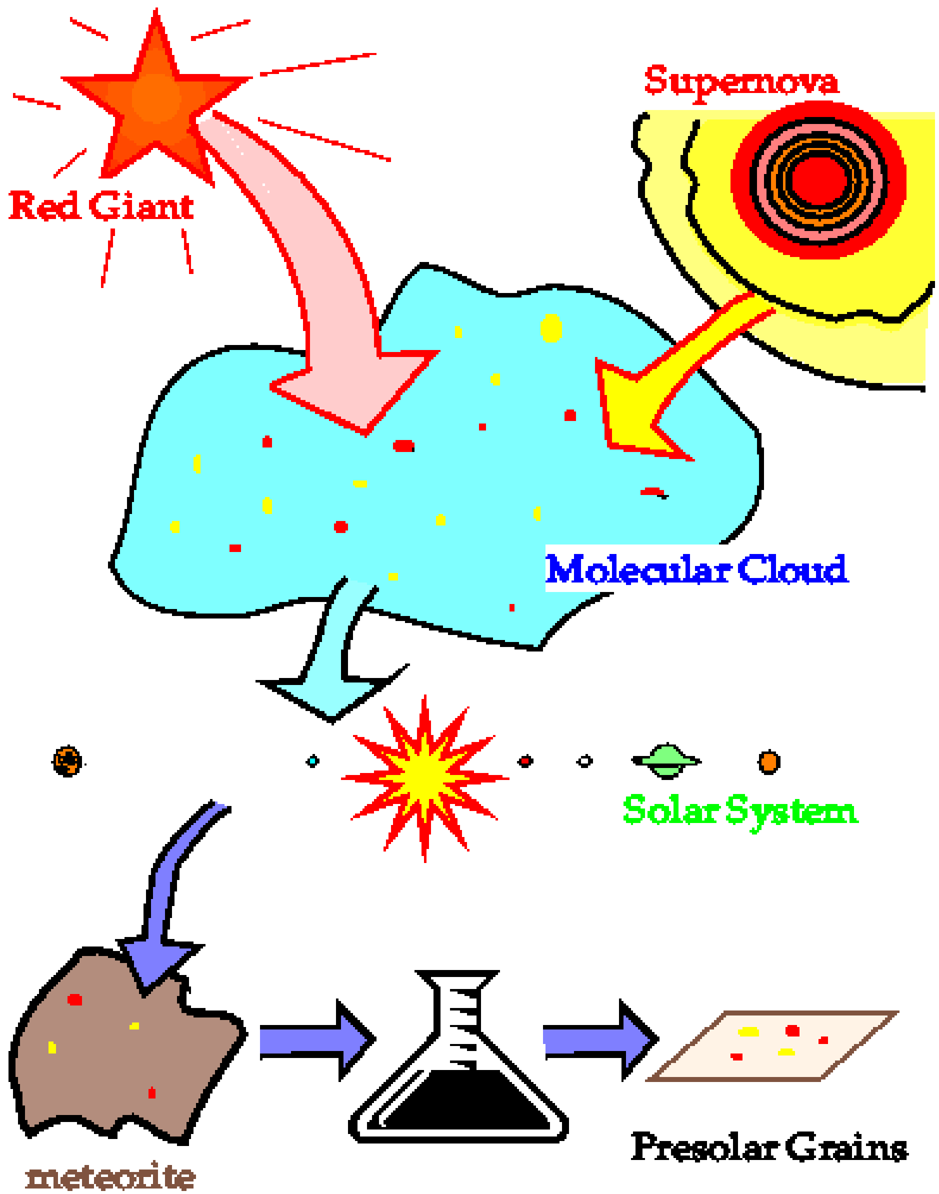
Cas A
11000 ly
~ 300 years ago

unknown
? - (today in a lab)
~ 4.5-5 Gyrs ago

See Grefenstette et al. 2014, Nature (NuSTAR data)

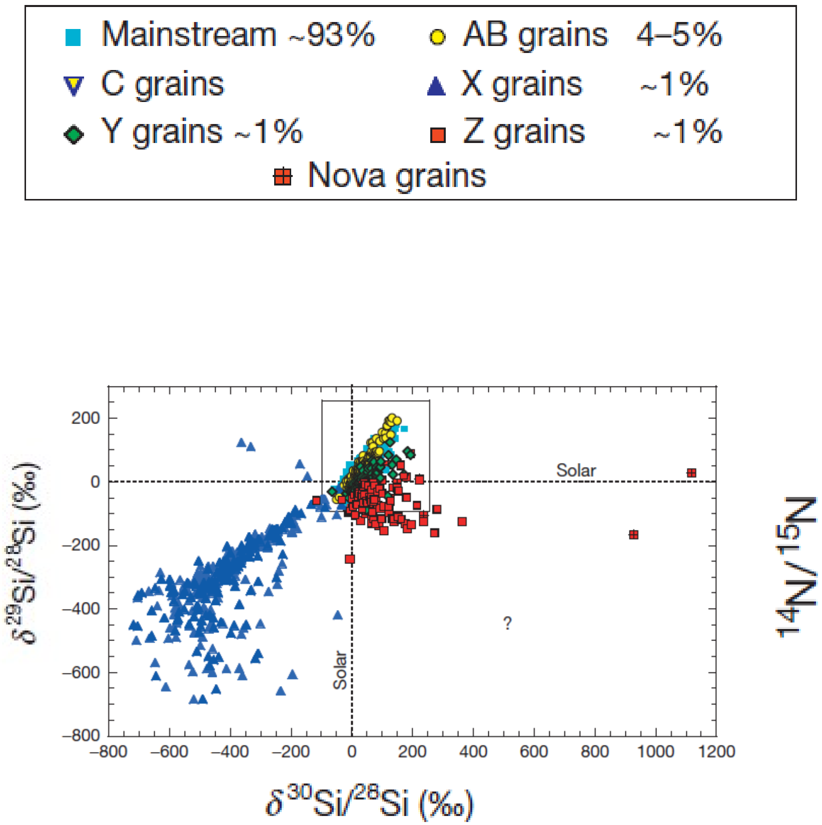
Zinner 2014, Tr. Geochem.

To make the long story short: the presolar grain journey from stars to us



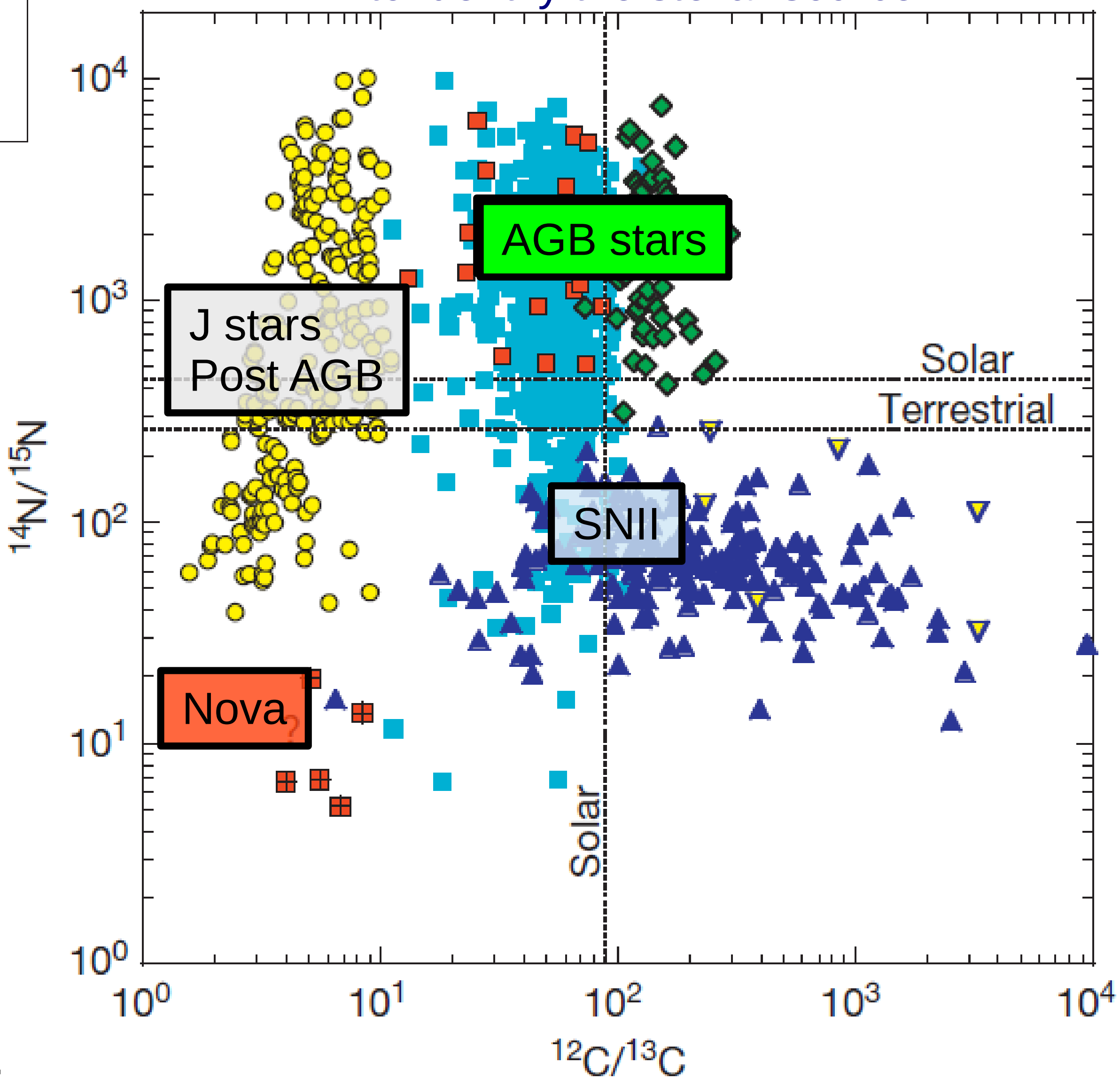
L. Nittler

The analysis to disentangle the origin of different types of presolar grains is based on the comparison between their isotopic composition and stellar models.



δ = (ratio/solar - 1)*1000

C and N isotopic ratios are key diagnostics to identify the stellar source



St. Louis Presolar Grains database:
Hynes & Gyngard 2009 LPIS 40

Zinner 2014, Treat. Geochem 1.4

The Astrophysical Journal, 631:L89–L92, 2005 September 20

ARE PRESOLAR SILICON CARBIDE GRAINS FROM NOVAE ACTUALLY FROM SUPERNOVAE?

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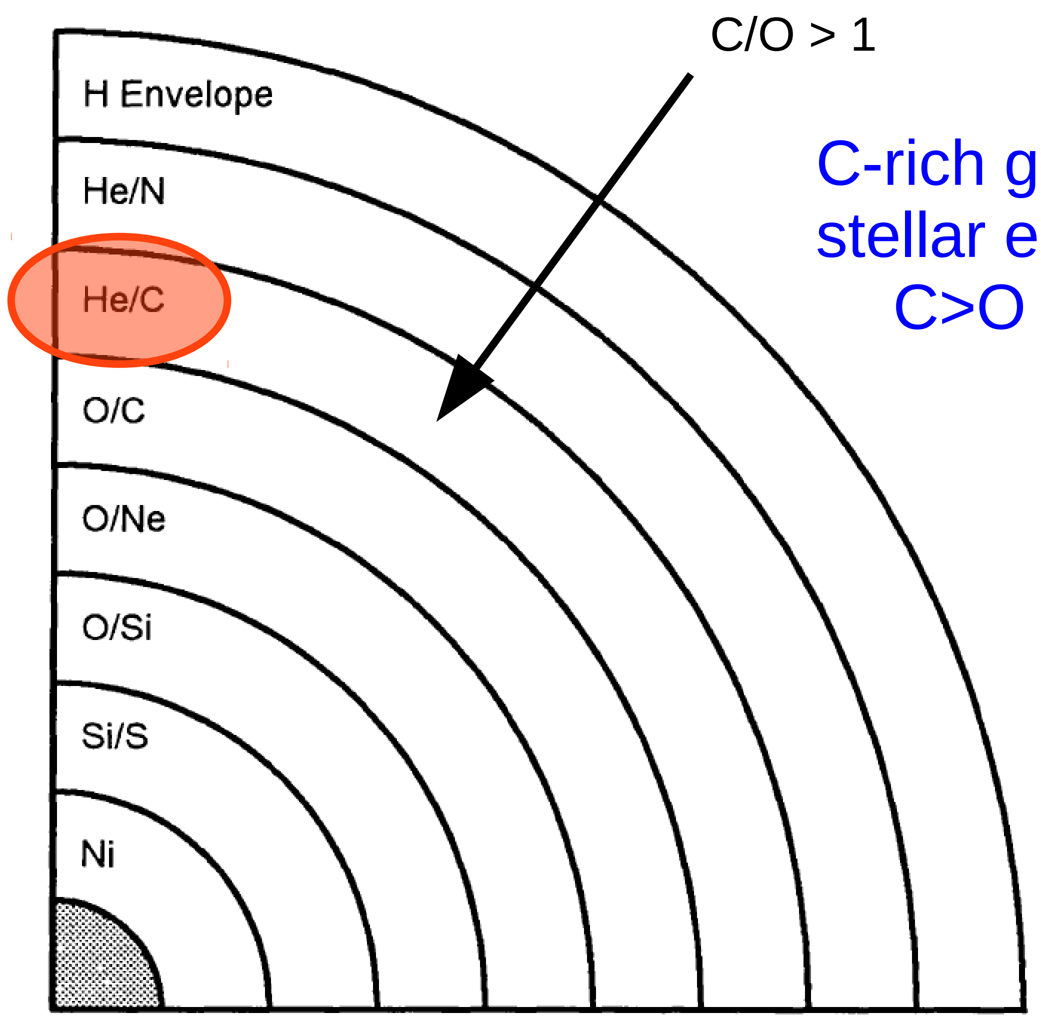
The Nova grain 334-2 with typical CCSN signatures, including ^{44}Ti enrichment.



Meyer et al. 1995, Met 30.

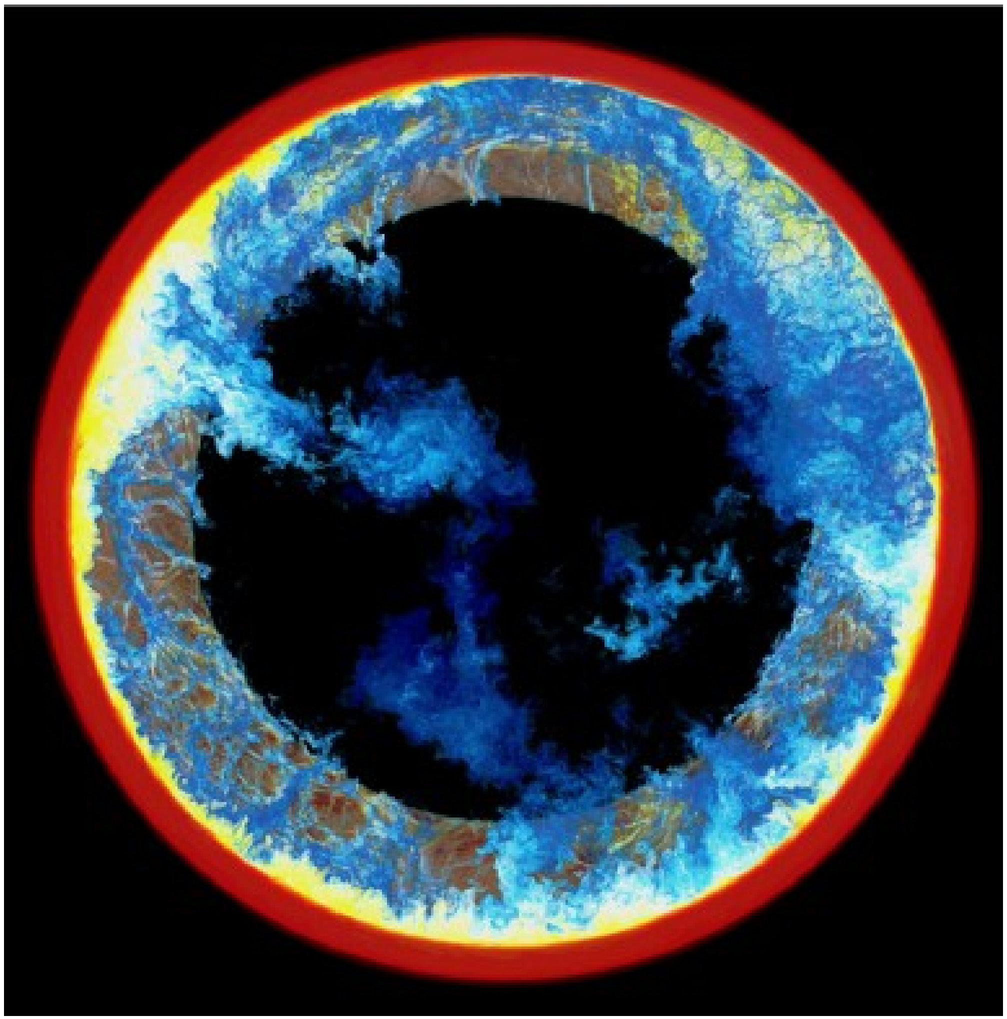
C-rich grains require a stellar environment with C>O to condense.

The Astrophysical Journal Letters, 808:L43 (6pp), 2015 August 1 doi:10.1088/2041-8205/808/2/L43

CARBON-RICH PRESOLAR GRAINS FROM MASSIVE STARS: SUBSOLAR $^{12}C/^{13}C$ AND $^{14}N/^{15}N$ RATIOS AND THE MYSTERY OF ^{15}N

M. Pignatari[1,2,13], E. Zinner[3], P. Hoppe[4], C. J. Jordan[5,14], B. K. Gibson[5,14], R. Trappitsch[6,13], F. Herwig[7,8,13], C. Fryer[9,13], R. Hirschi[10,11,13,14], and F. X. Timmes[8,12,13]

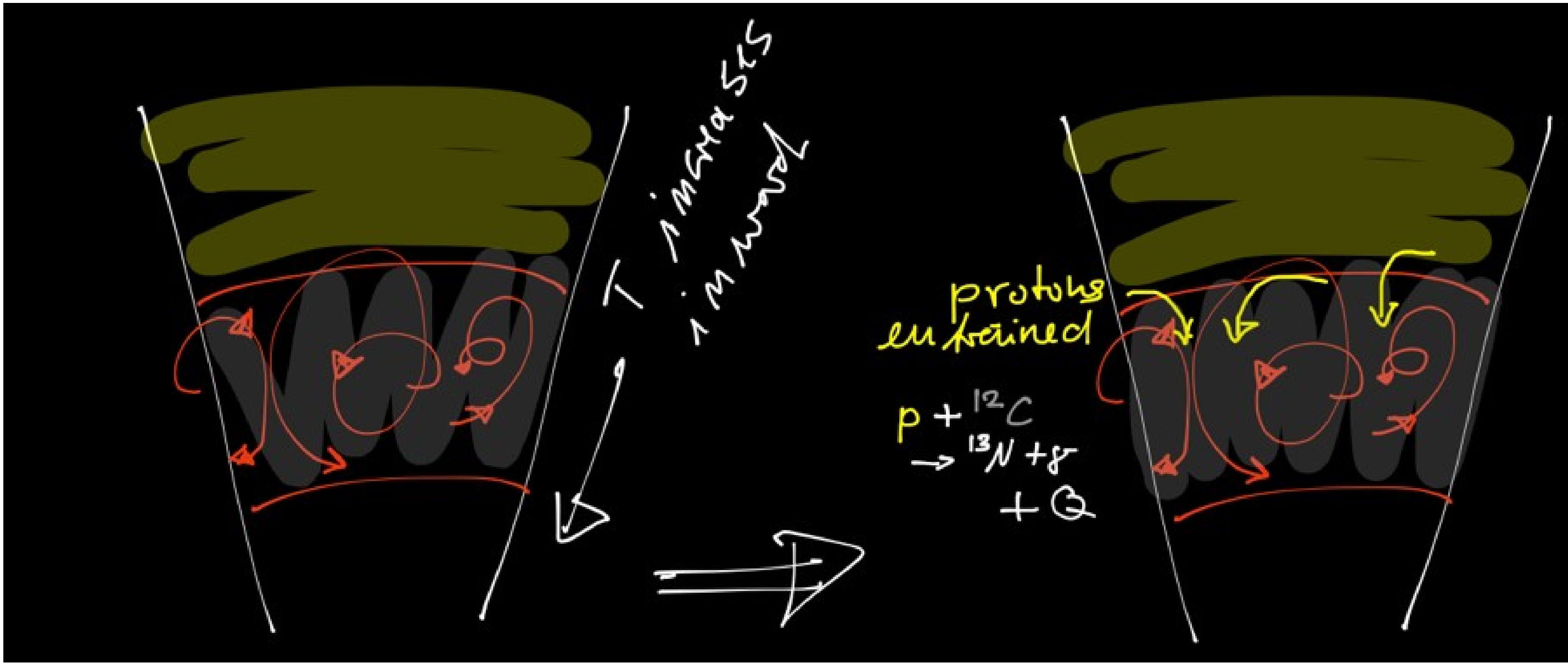
H ingestion in He-burning layers



+ Herwig et al. 2014, ApJL 792
+ Woodward et al. 2015, ApJ 798, 49

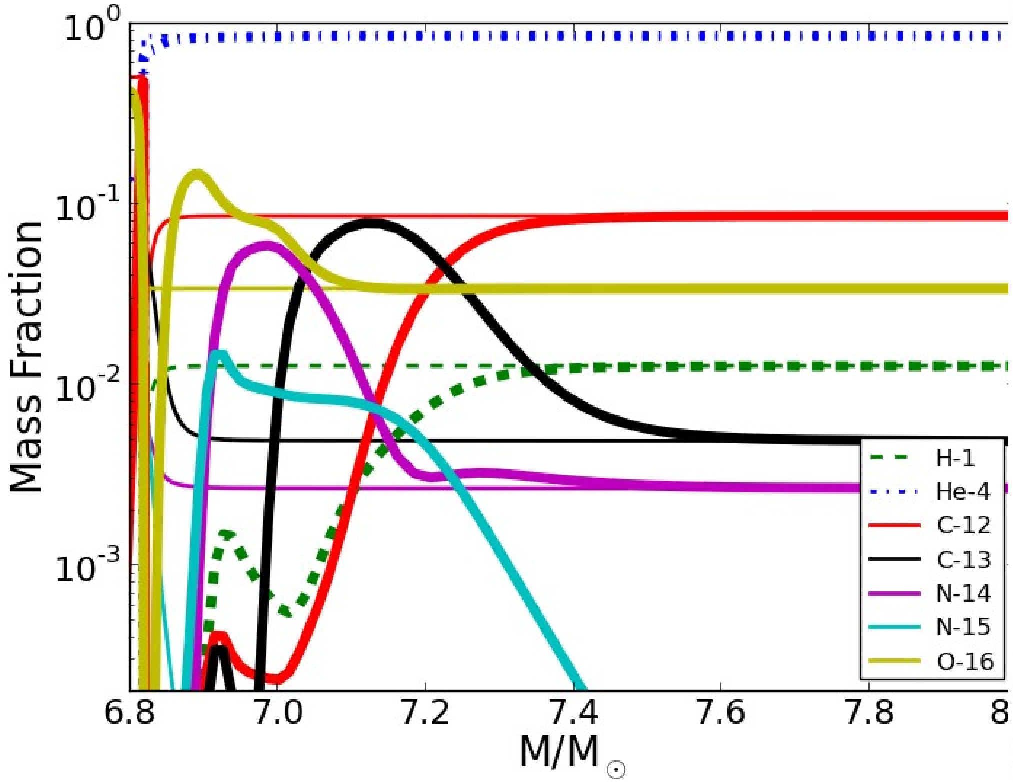
- Multi-dimensional hydrodynamics simulations needed to solve this problem right.
- 1D hydrostatic models have a poor predictive power, but with good nuclear physics important constraints can be derived.

+ For other hydrodynamics simulations of H ingestion (at low metallicity): Mokak et a. 2011 A&A, Stancliffe et al. 2011 ApJ

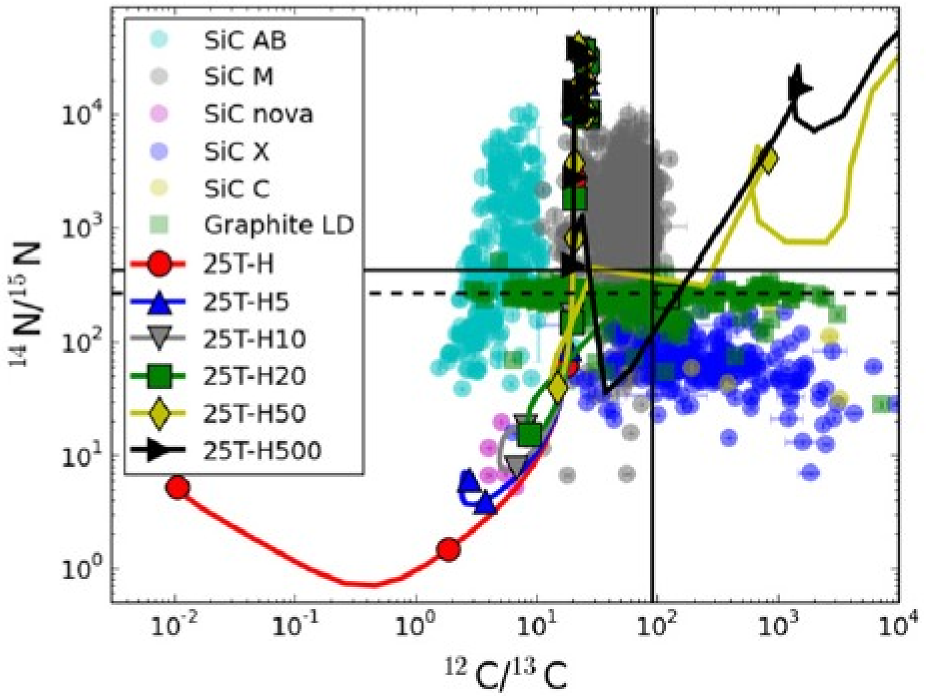


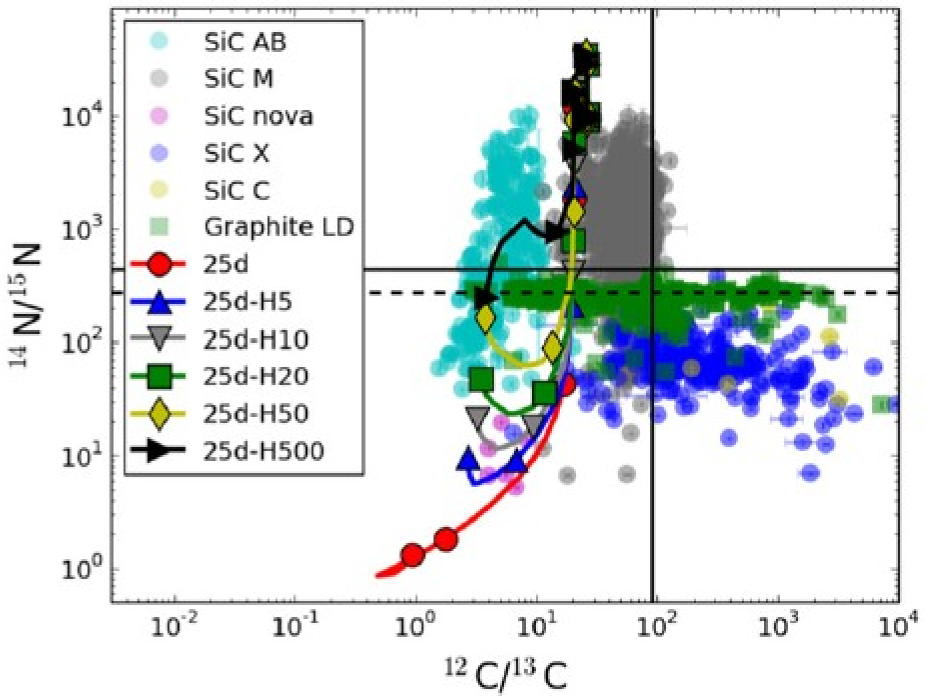
Large production of C13 and N14 during the H ingestion.
Some N15 is made, but according to present models not as much as N14 (ongoing effort to measure N14/N15 ratio in the Sakurai's object using ALMA).

Model 25T
Metallicity = Z=0.02
Explosive He shell nucleosynthesis
With alive H ingested

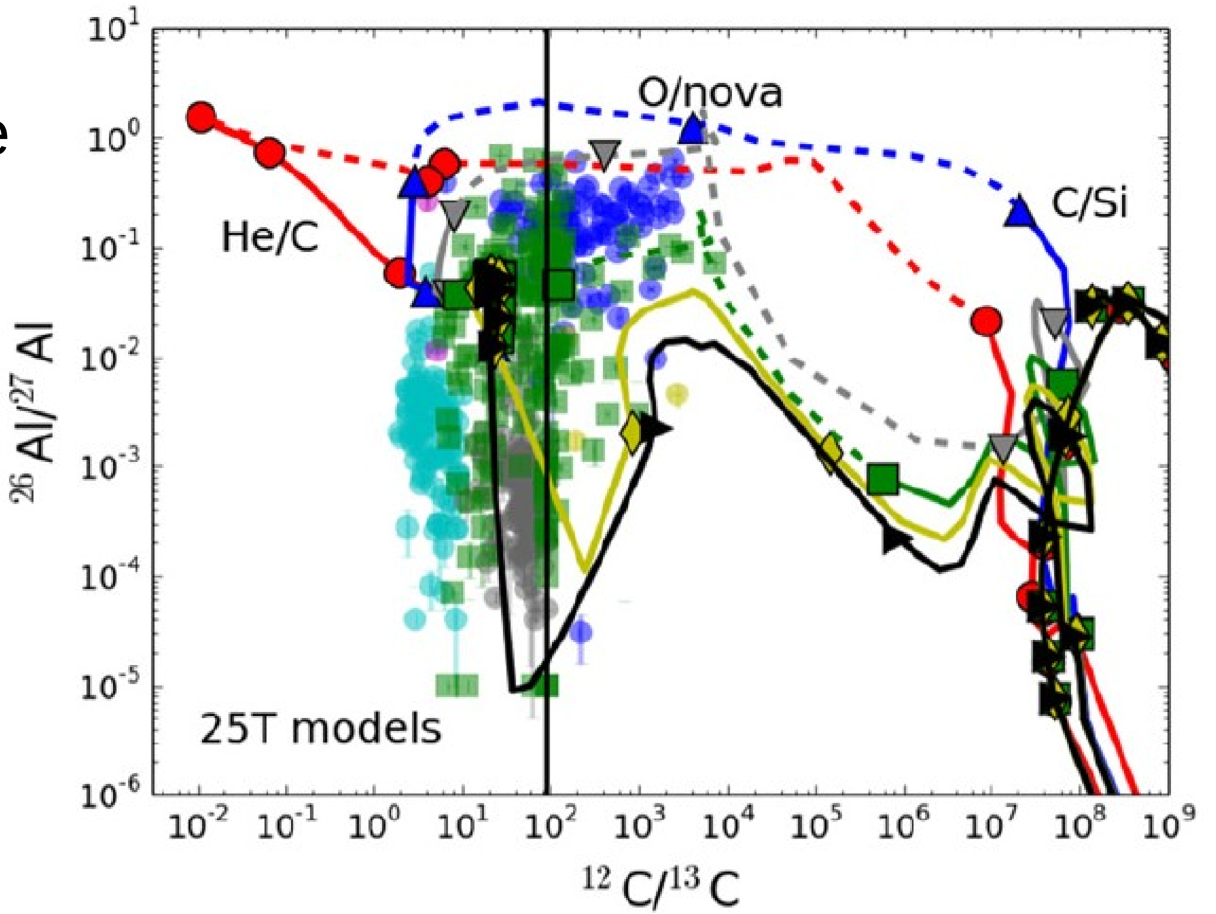


H ingestion gives the conditions to produce large amount of N15 in the He shell during the CCSN explosion.

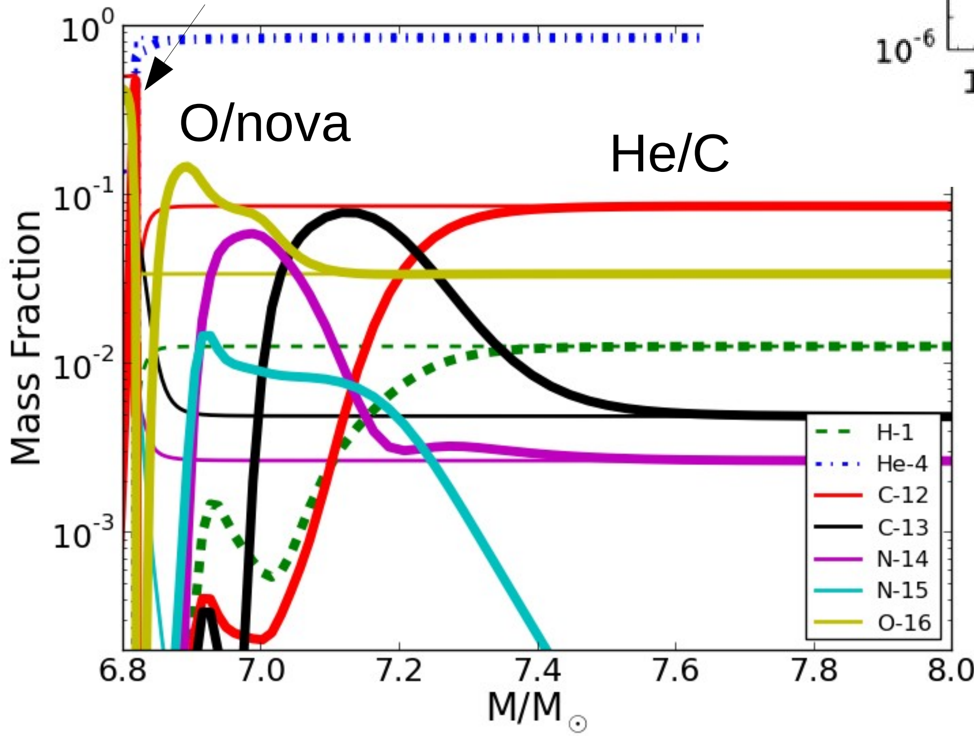




Al26 production compatible with observations

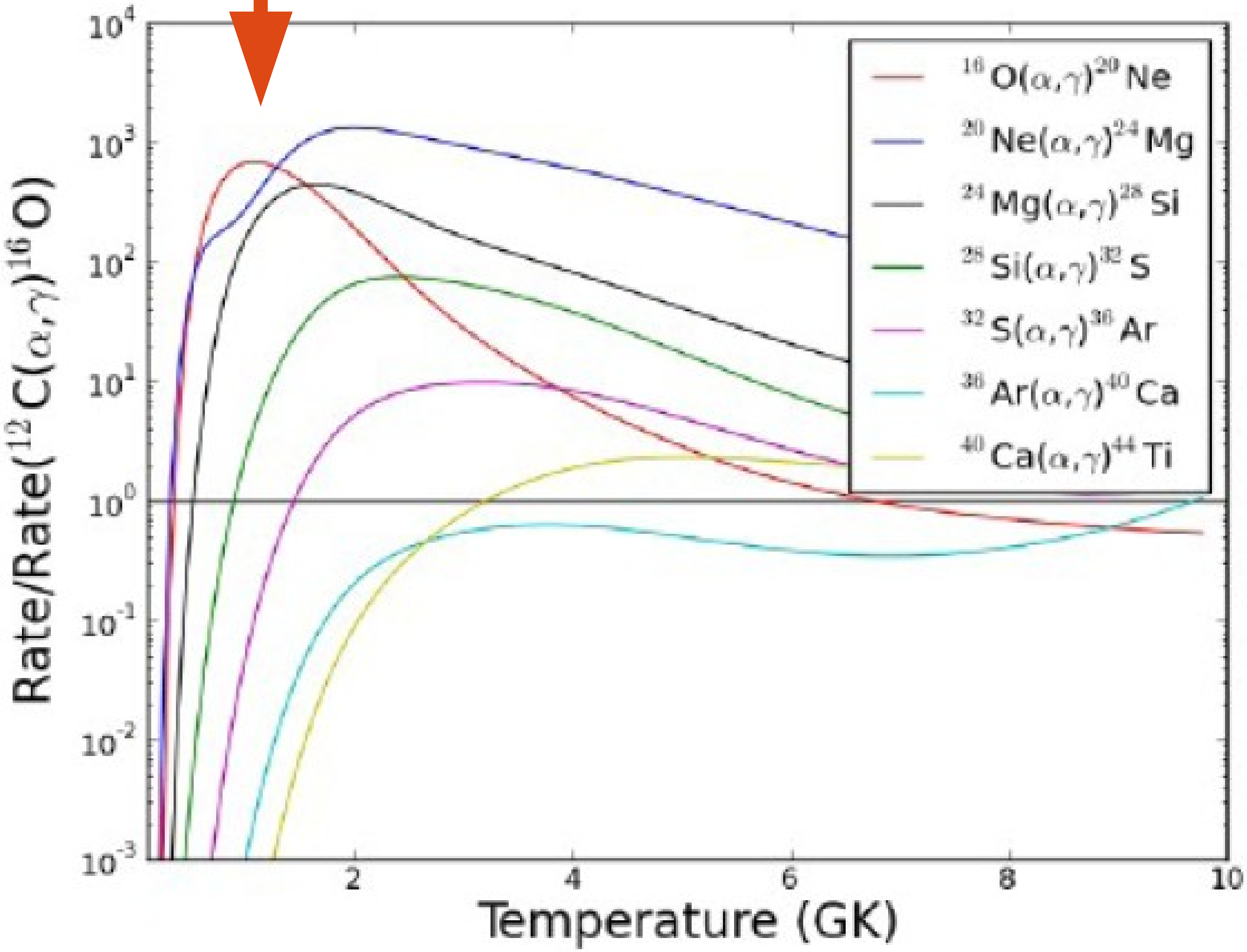


Giving names to different zones of the CCSN ejecta using the final concentrations:



Is this relevant for the GCE of N?

Explosive He-burning conditions in CCSN

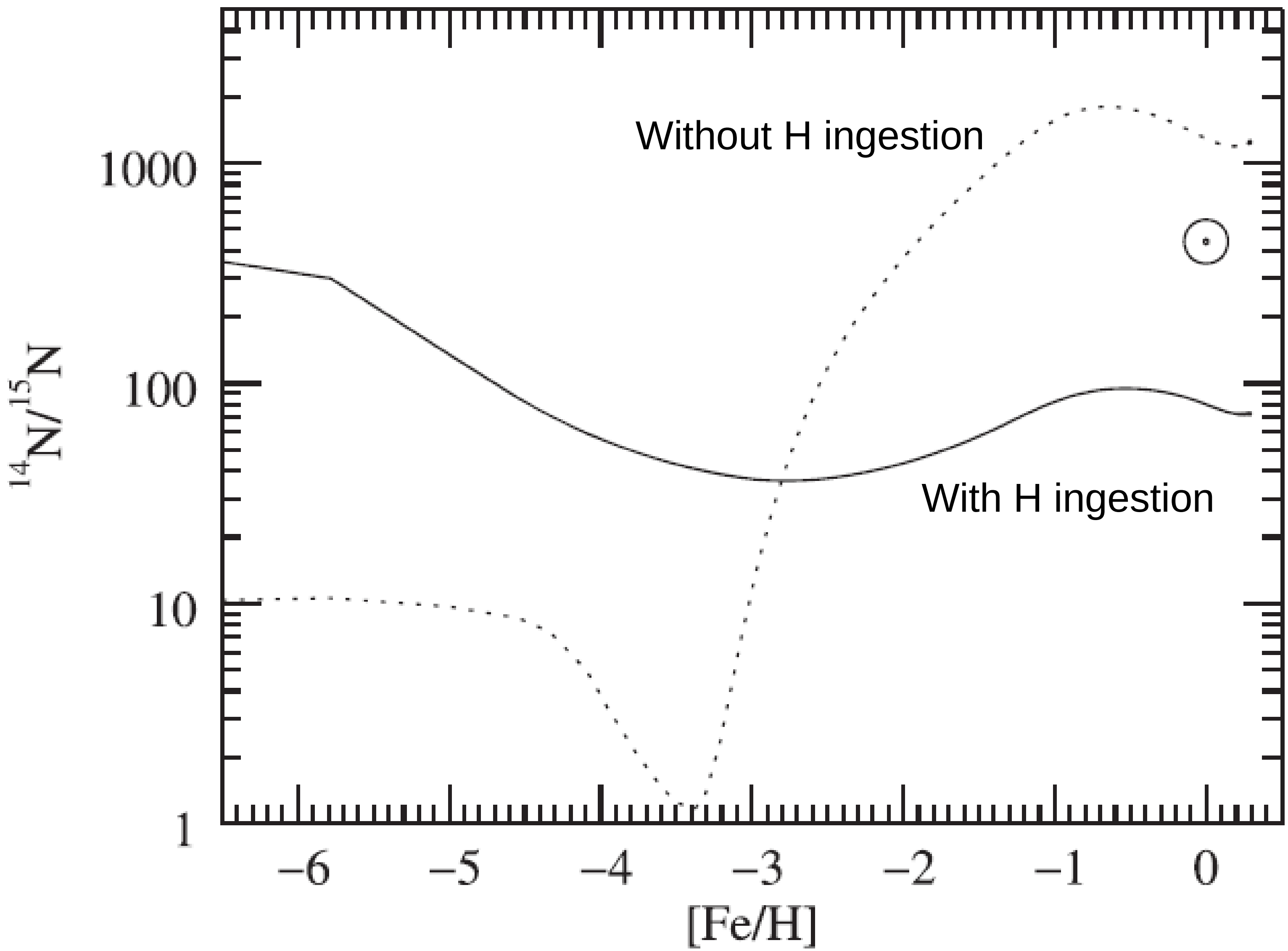


The Astrophysical Journal Letters, 767:L22 (6pp), 2013 April 20 doi:10.1088/2041-8205/767/2/L22

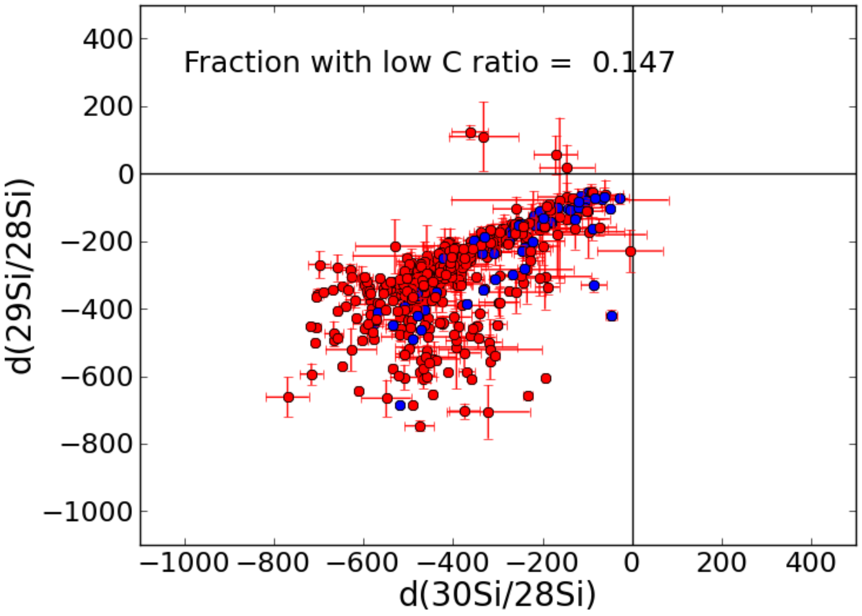
PRODUCTION OF CARBON-RICH PRESOLAR GRAINS FROM MASSIVE STARS

M. Pignatari[1,10], M. Wiescher[2,3], F. X. Timmes[3,4,10], R. J. de Boer[2,3], F.-K. Thielemann[1],
C. Fryer[5,10], A. Heger[6,10], F. Herwig[3,7,10], and R. Hirschi[8,9,10]

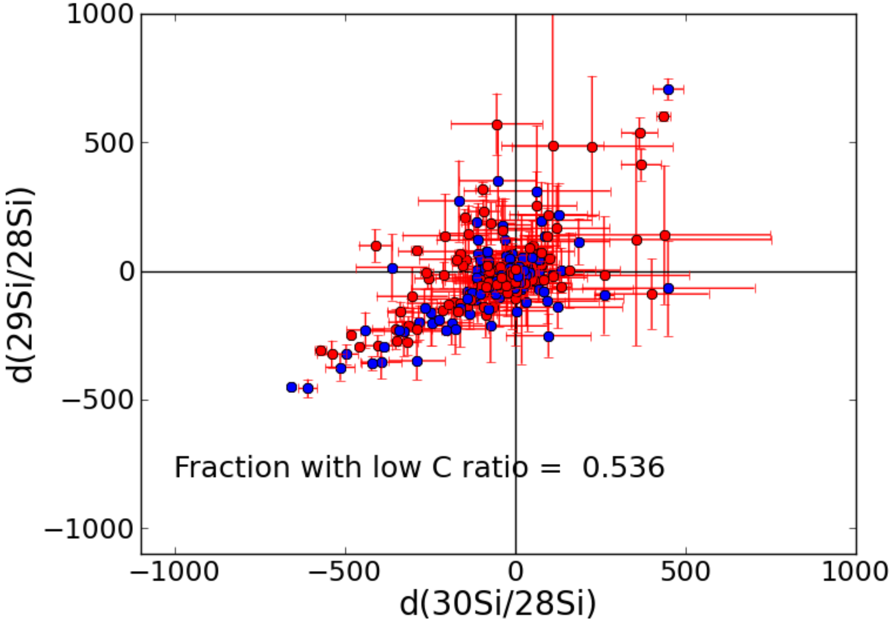
GCE calculations, using N yields from massive stars including H ingestion.



How frequent is the H ingestion/shell merger?

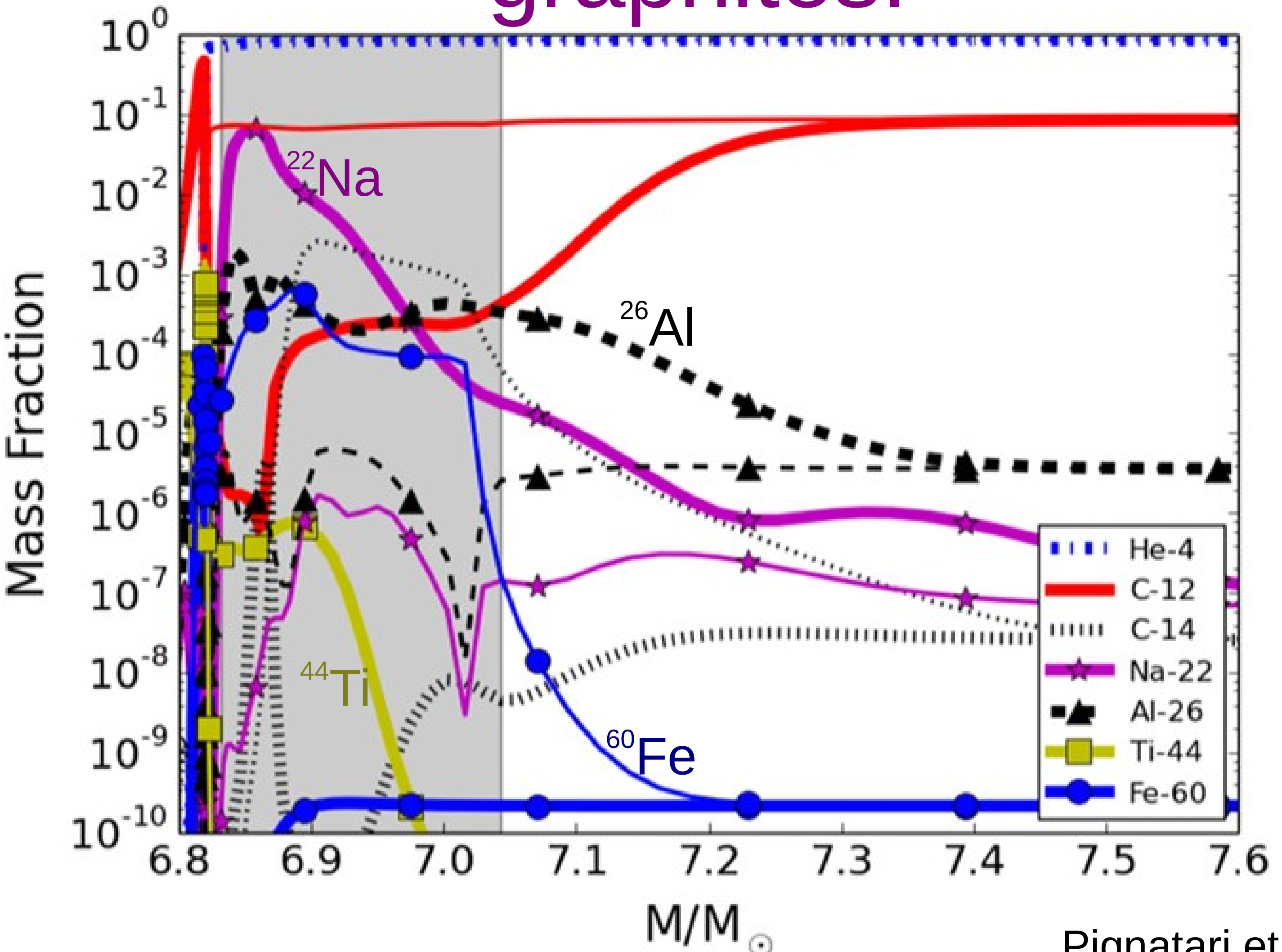


SiC-X grains



LD graphites

Important impact also for the $^{26}Al/^{60}Fe$ story and for the Ne-E(L) in presolar LD graphites.



Pignatari et al. 2015

Summary

- Present 1D stellar models cannot reproduce consistently the GCE of Nitrogen. Why? The N15 made is not enough, and Novae cannot supply the N15 observed at low metallicity and at high redshift. The source must be CCSNe.
- Nuclear physics tells that rotation cannot be the physics mechanism to make N15 in massive stars.
- Presolar grains from supernovae tells that nova-like conditions can be obtained in the He shell material of CCSNe. This naturally provide the condition to explain grains observations for different isotopic ratios. In particular, presolar grains carry the signature of a strong production of N15. GCE likes that to fit the N isotopic ratio.
- The physics event that allow to fit presolar grains observations is H ingestion in He-burning material, before the SN shock is reaching the He shell. It is also required that there is some H still present in the He-rich material to efficiently make N15 (and Na22, Al26, ...!).
- 1D models tell that we are moving in the right direction, but for definitive conclusions the full hydrodynamics simulations are needed.
- Is this all real? Can we understand better the old supernovae that made these grains?

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