# Isotopic structures in meteorite grains of presolar origin: Records of nucleosynthesis processes in stars

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U. Ott

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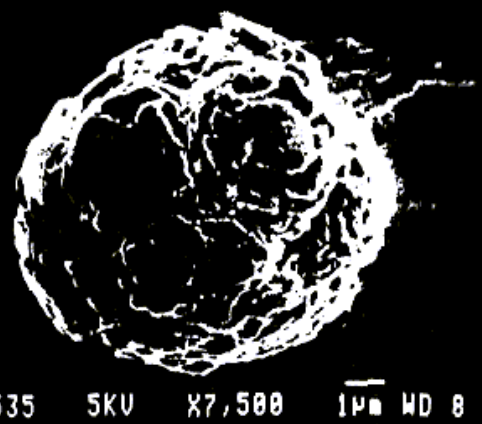
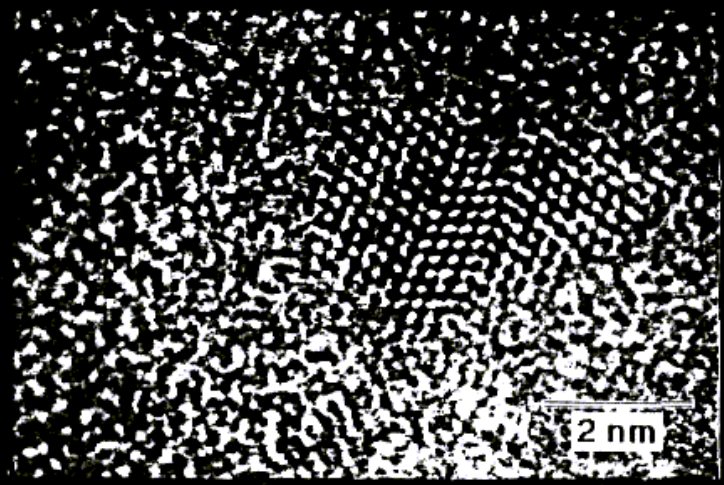
in this talk:

♣concentrate




presolar SiC




presolar diamond

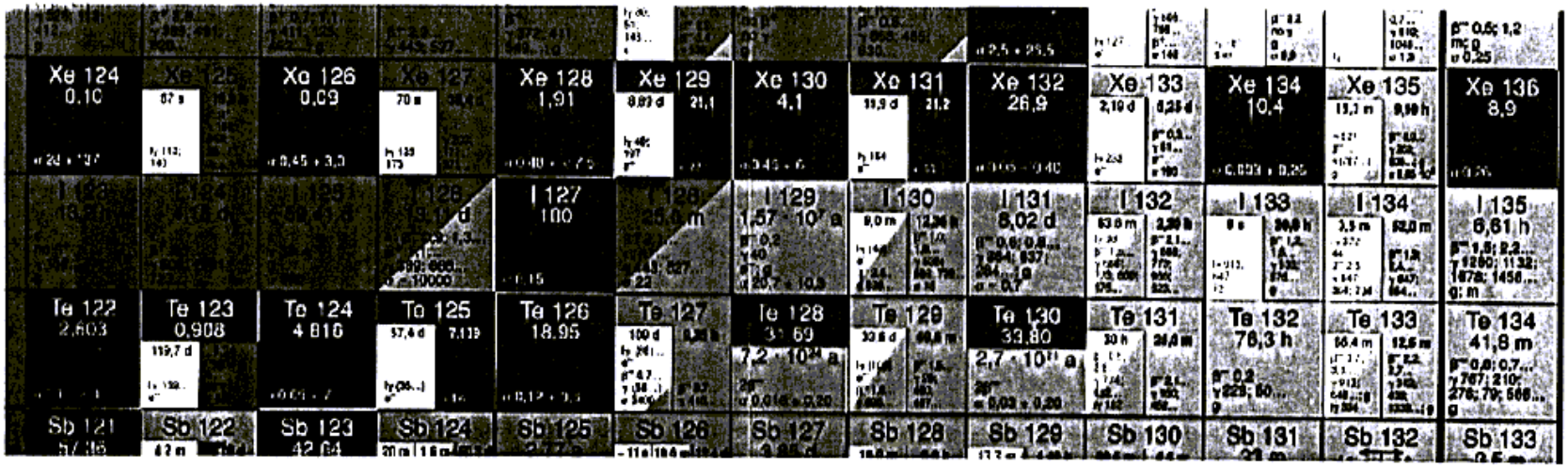
and

♣nucleosynthesis of heavy elements

♣to show some things that have been learned from the studies so far; and will try to say a few words about (our) plans for the future

Reasons for concentrating on the heavy elements:

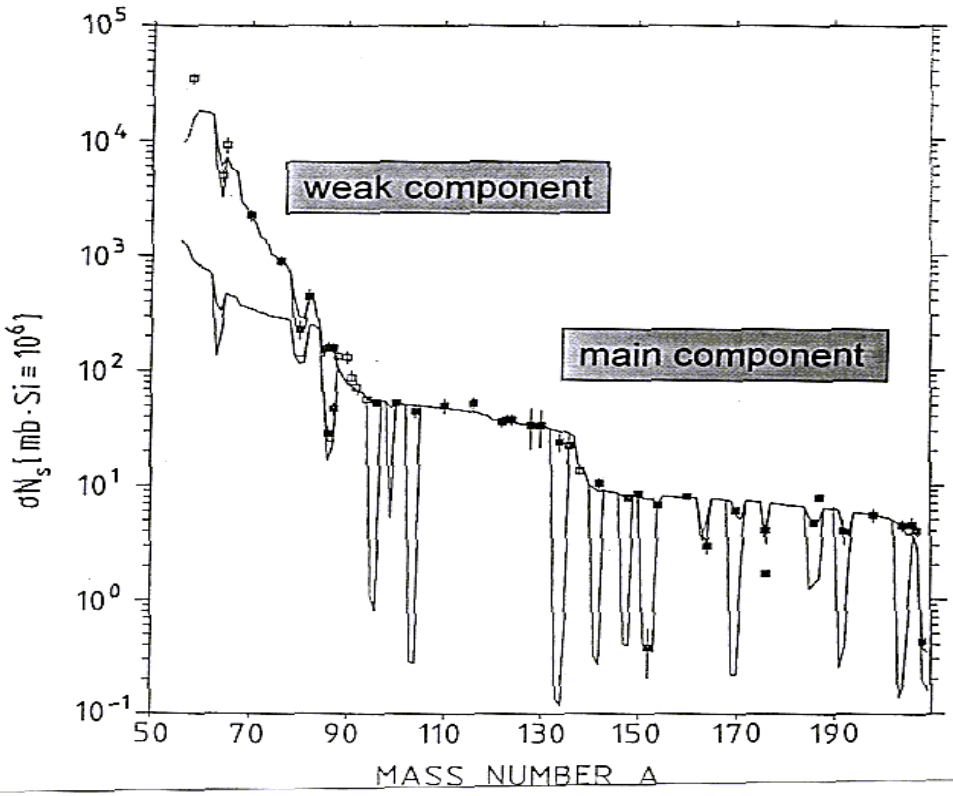
- ♣ from solar abundances
  - → only few – conceptually well defined – processes that made the bulk of these elements: s, r, p – processes




- ♣ hence: more straightforward to deduce about the *conditions* of these processes
- ♣ *however:* situation more complex than originally (naively) thought

## A. The well-understood

- most straightforward case
  = "mainstream SiC grains"
- contain trace elements with signature of s-process
- specifically: of main component thought to be made in the He shell of AGB stars



- last decade or so
  → developments in parallel
  - improvement of nuclear parameters
  - improvement of theoretical understanding of s-process main component
  - and in obtaining presolar grain data helping to refine the understanding

1. <u>The Simple Cases</u>

showed the need to get the cross sections right

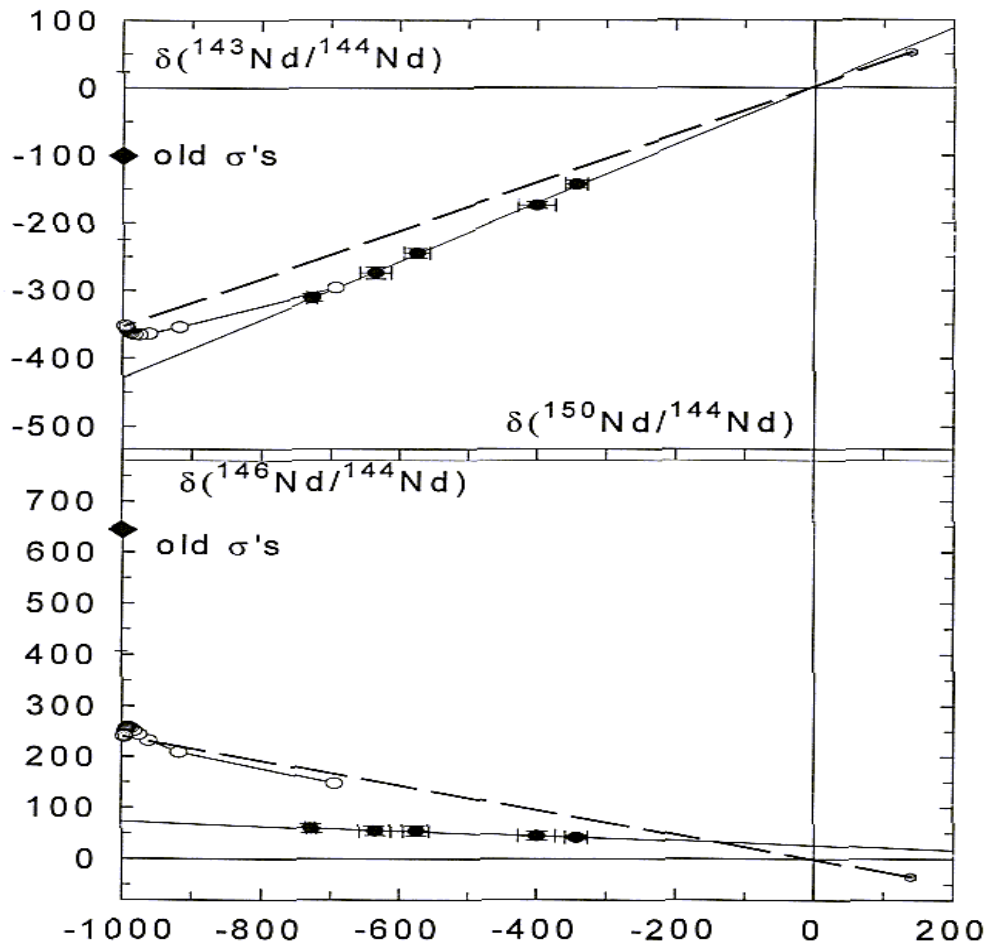
- simple = within validity range of local approximation

$$\sigma N = \text{const.}$$

- not sensitive to details of the process or "classical" vs. "stellar" model
- within classical model (exponential distribution of neutron exposures):

$$\sigma(A) \times N(A) = \sigma(A-1) \times N(A-1) / [1 + \tau_0 \times \sigma(A))^{-1}]$$

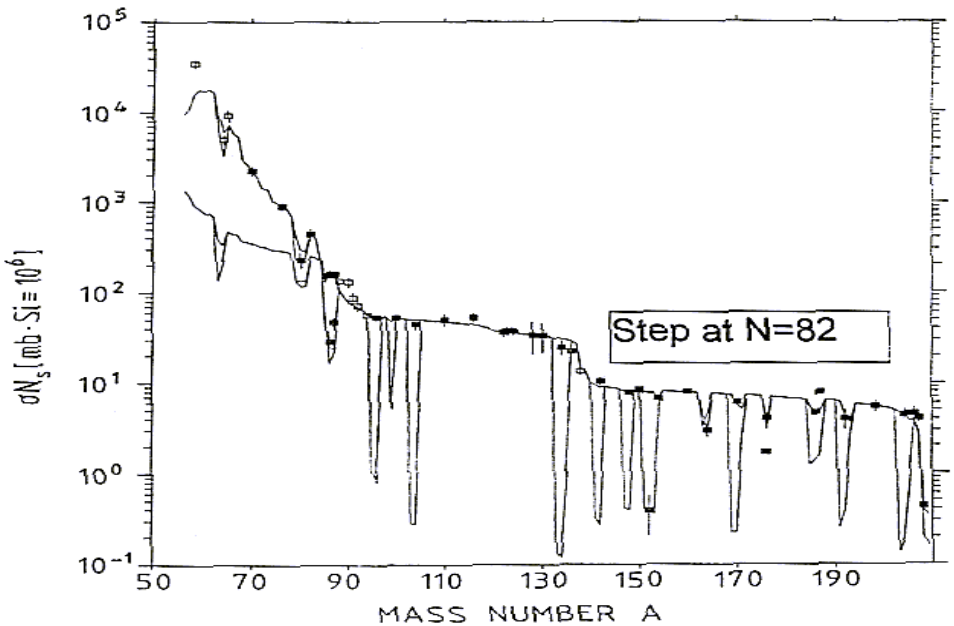
- first results on"simple cases", e.g. Nd:
  → indications for severe (not covered by analytical errors) discrepancies




- by now: much better

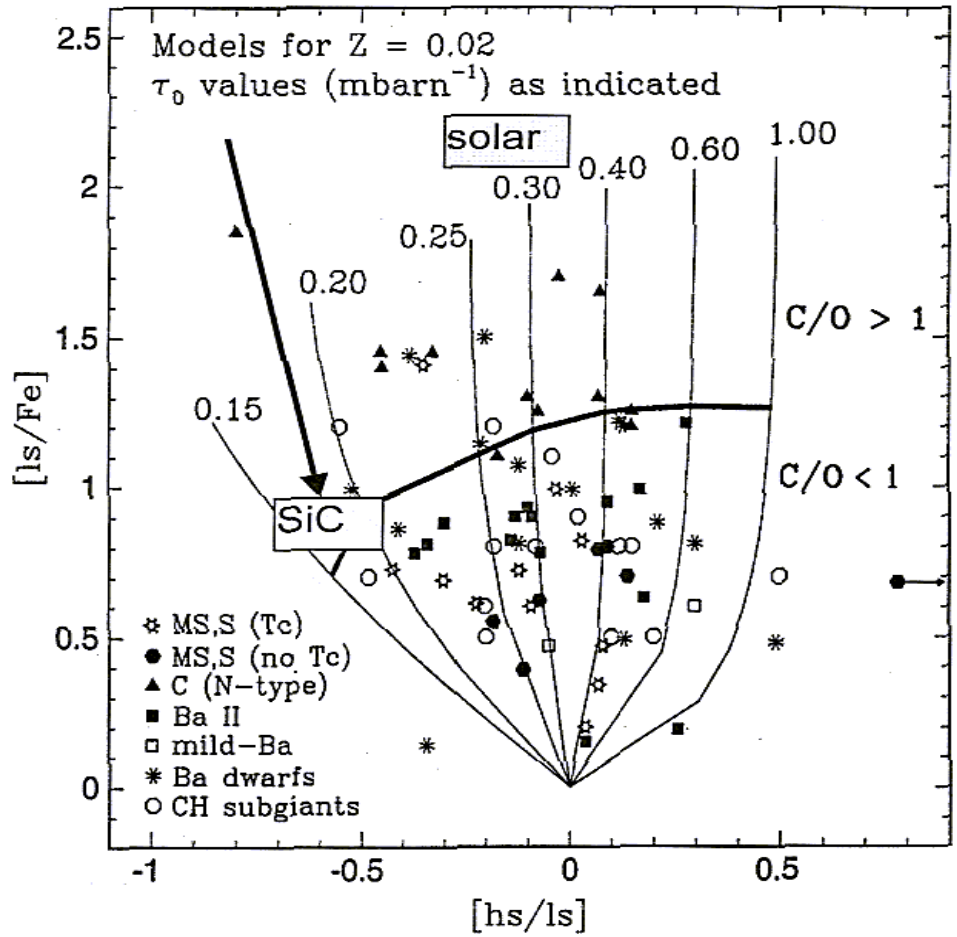
II. an important parameter in the classical description: mean exposure $\tau_0$:

$$\sigma(A) \times N(A) = \sigma(A-1) \times N(A-1) / [1 + \tau_0 \times \sigma(A))^{-1}]$$




- influence shows up as the step in the $\sigma N$ curve, because there is *not* $\tau_0 \times \sigma \gg 1$
- observation: $\tau_0$ (SiC-Ba) $\approx$ 0.15 $mb^{-1}$; rather than $\tau_0$ (s-SSAD) $\approx$ 0.30 mb-1 [30 keV]

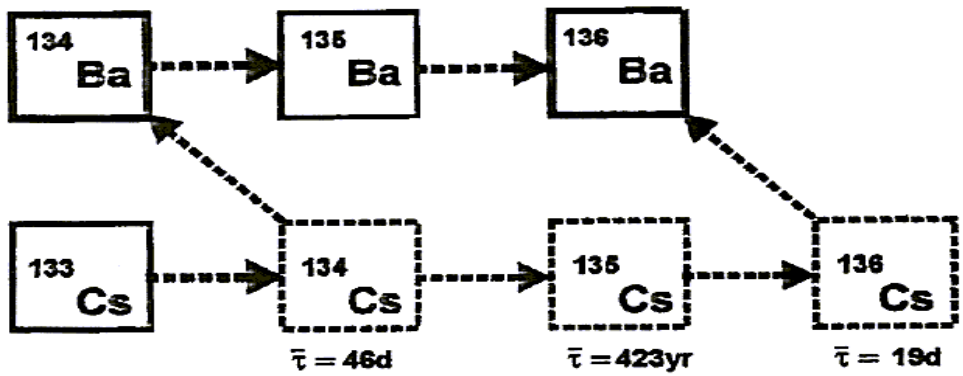
- comparative stellar observations plus models



## III. The more interesting questions: density, neutron density, temperature

- inferred from branchings
  = places with effective competition
  neutron capture ↔ β-decay

e.g. $^{134}$Cs-branching:



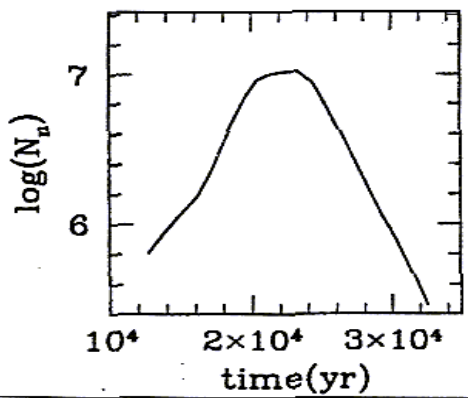

- "effective" conditions for n density from SiC grain measurements:
  $n_n \approx 3 \times 10^8$ cm$^{-3}$ (from $^{147}$Nd branching), similar to SSAD-derived value

- however, lower temperature ($^{79}$Se) and somewhat lower density ($^{163}$Dy) indicated

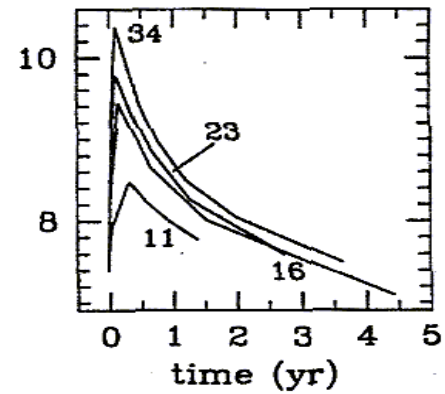
- measurements discussed so far:
  on "bulk samples" of SiC,
- interpretation within "classical model",
  i.e. "effective values" at freezeout

<u>New developments:</u>

stellar model, non-fixed $n_n$, T,...



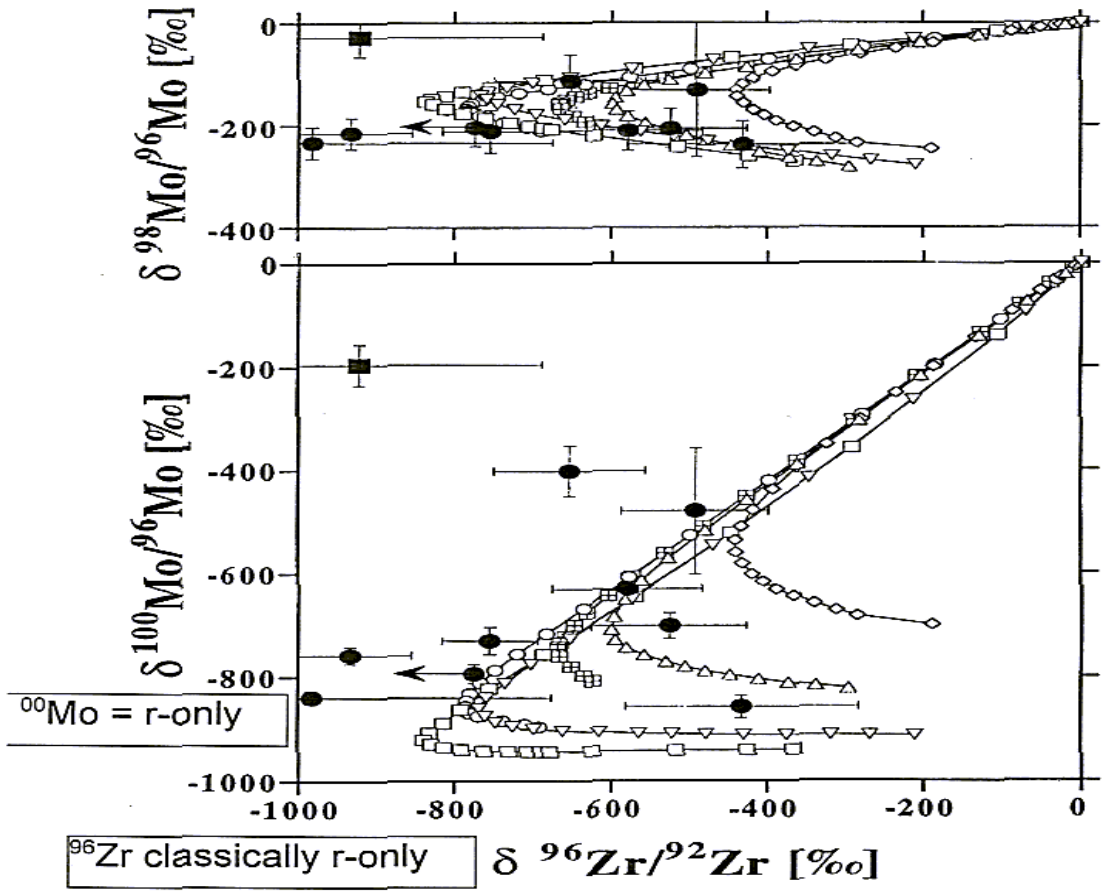

$^{13}$C source interpulse period




$^{22}$Ne source during pulses

- makes sense to measure *<u>individual grains</u>* of SiC that sampled
  - s-process matter from different stars
  - s-process matter at different steps
- technically feasible with development RIMS at Argonne

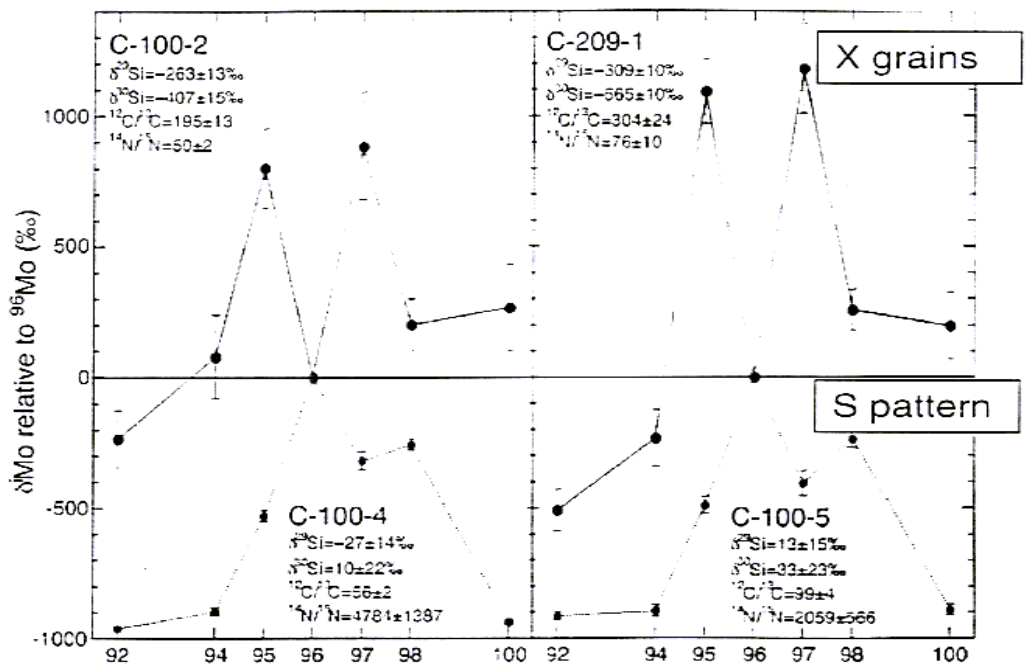
- results (Zr, Mo, Sr, Ba) from individual particle analyses generally within data space occupied by model predictions




- however: $^{96}$Zr should be produced at the high $n_n$ of the $^{22}$Ne source; observed $^{96}$Zr often outside predicted range, lower

## B. The unexpected

- subpopulation of SiC X-grains (~ 1%): very likely of supernova origin (← light elements, e.g. Si, $^{44}$Ti → $^{44}$Ca)
- strange pattern in heavy elements: not s, not r



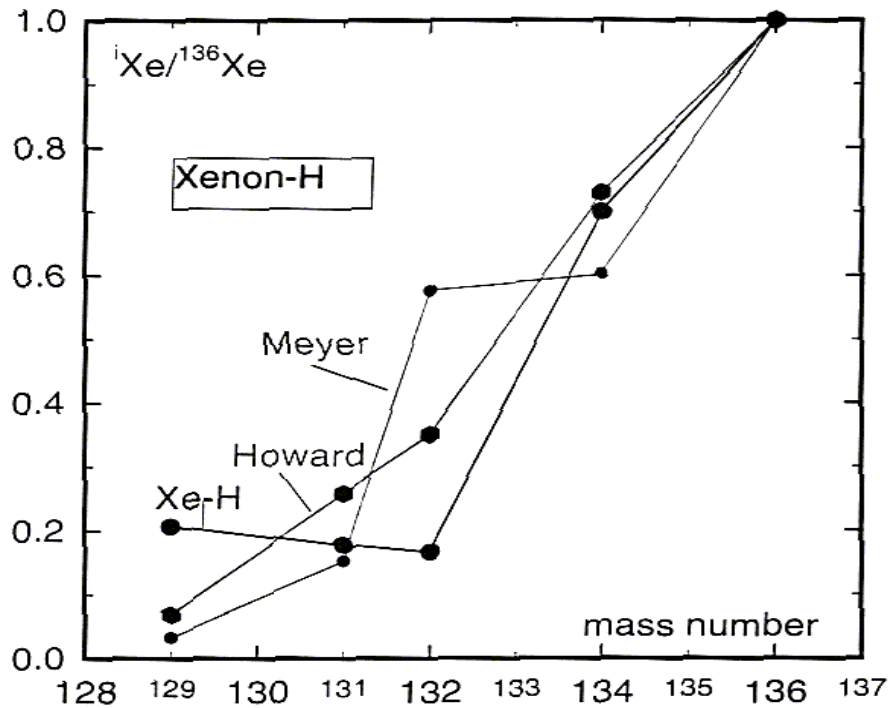

- X grain pattern not "mirror image" of s-pattern; largest overabundance not at r-only $^{100}$Mo, but at $^{95}$Mo and $^{97}$Mo

## Possible solution

- neutron burst model (Clayton, 1989; Howard et al., 1992)
- updated: Meyer (2000)
- predicts – relative to $^{96}$Mo– very large overabundances of $^{95}$Mo, $^{97}$Mo, not so much at $^{100}$Mo
- scenario: a weak s-process in the He shell of a pre-supernova followed by a neutron burst during the explosion
- devised in order to explain Xenon-HI anomaly in presolar diamonds

## C. The puzzle

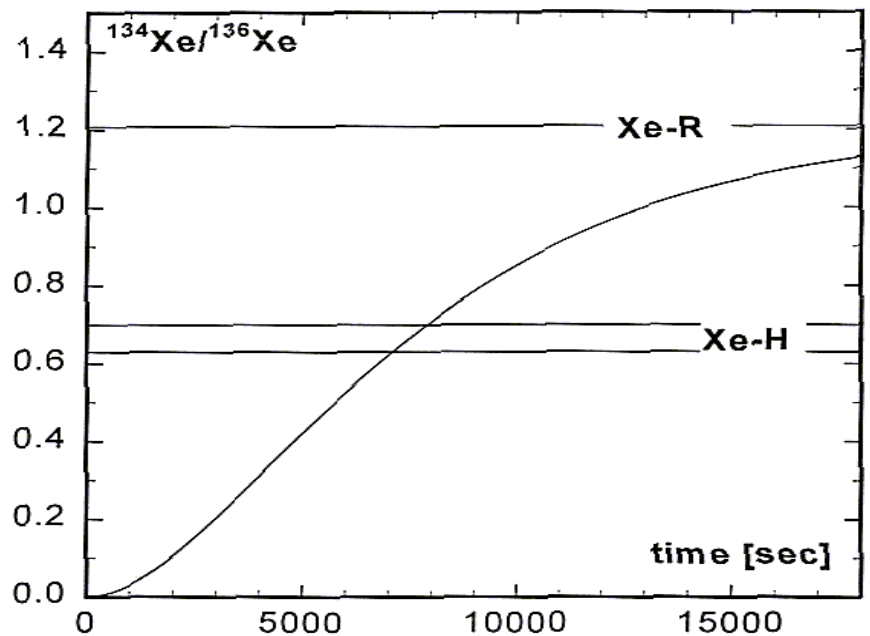
- Xenon-HL in presolar diamonds



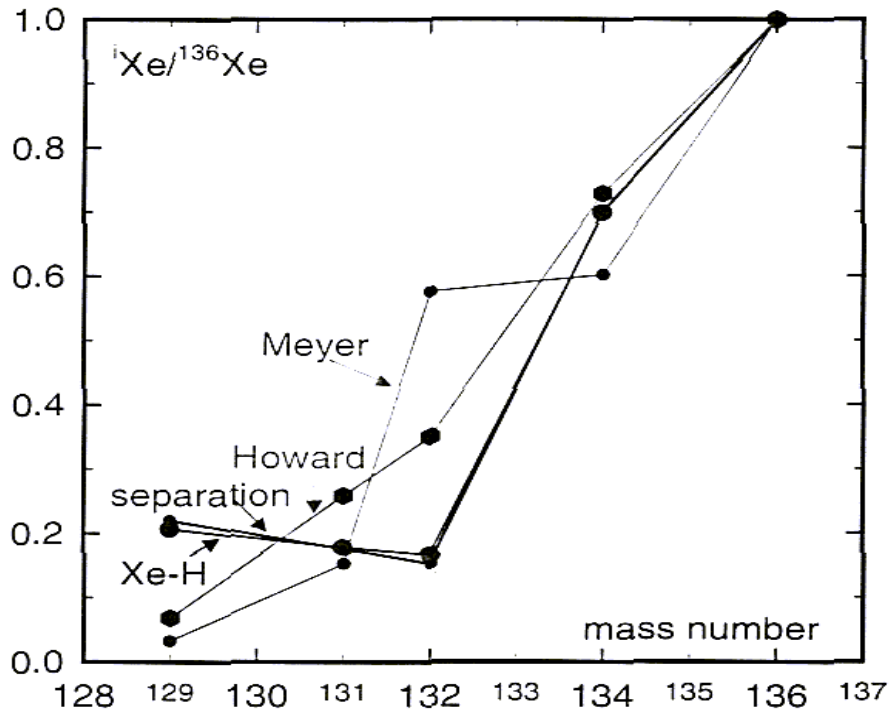

- Neutron burst of Howard et al. does not particularly well, although designed for it; Meyer (2000) predictions better except for problem with $^{132}Xe$

- hence: attempt of an alternative model for Xe-H:
  "standard r-process" followed by rapid separation of stable end products from radioactive precursors

Application to Xe-H



- alternative model:
  - explains Xe-H quantitatively



## The problem lies in the scenario

- Possibilities how to achieve rapid separation (?)

(1) pre-condensation (of the less volatile precursors)
  - requires early grain formation

(2) recoil loss from grains of decay products
  - requires early trapping of trace elements

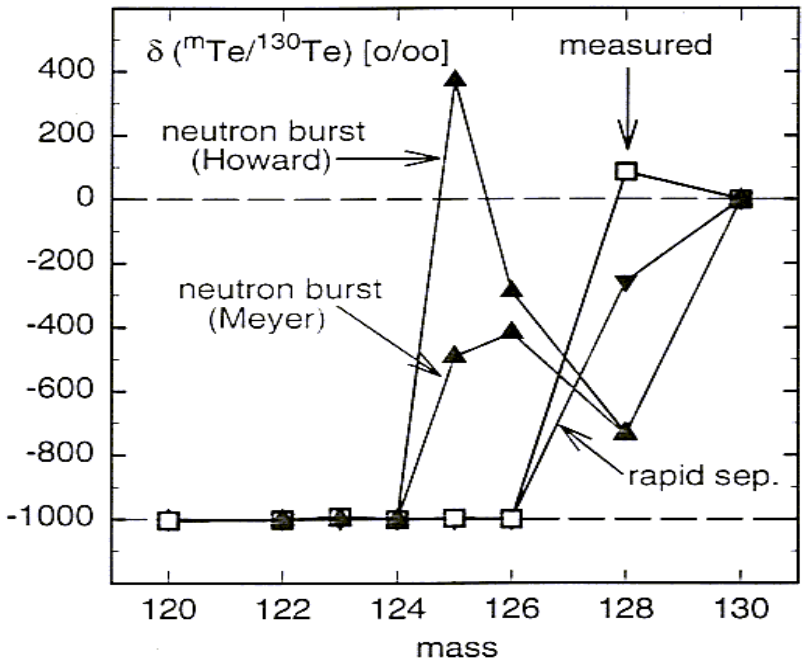
(3) separation in strong magnetic field according to charge / mass

(4) a combination

- <u>however:</u>
  possible in environment of exploding supernova at such an early stage ?

## another element with a telling signature: tellurium

- close to xenon and on top of r-process abundance peak (neutron magic N = 82)



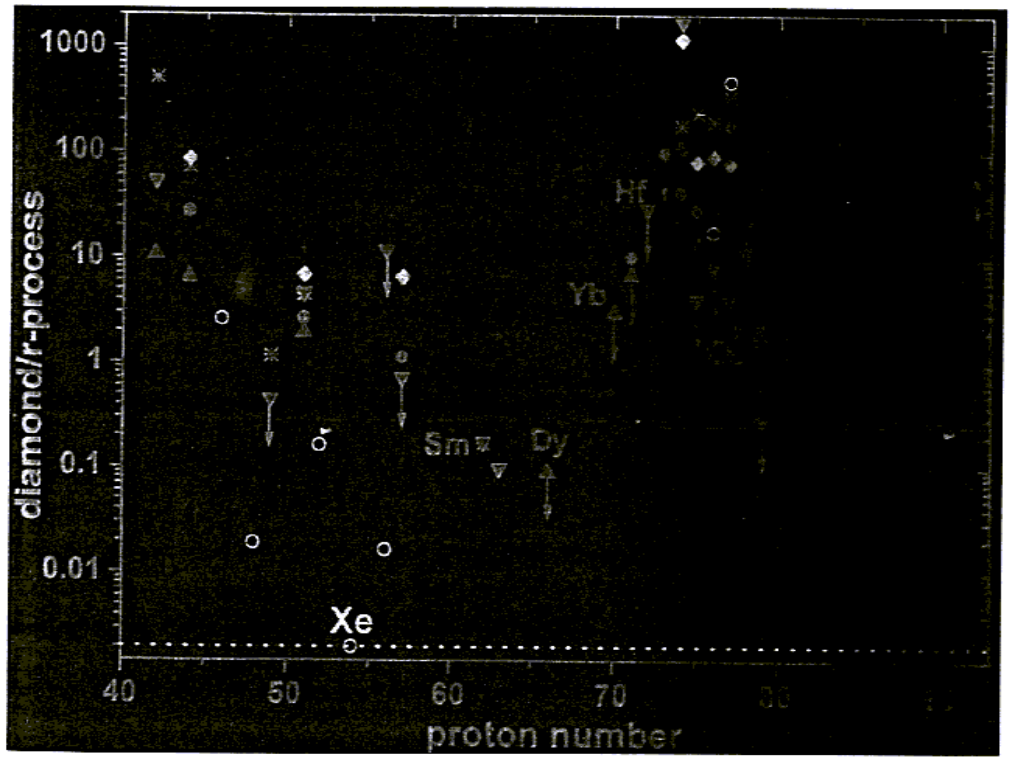

- best agreement with separation model (again)
- but: a problem with $^{128}Te/^{130}Te$
  → non-standard r-process (?)
  (another indication?

## in order to know what is really going on: data needed for more elements

- obvious candidates: those that are likely to be abundant enough, e.g. associated with N=126 r-process peak
- problem with those:
  platinum group elements, occur as metal nuggets in Fremdlinge in Ca-Al-rich inclusions; difficult to remove from diamonds with standard chemistry !

<u>hence:</u> new chemical approaches needed

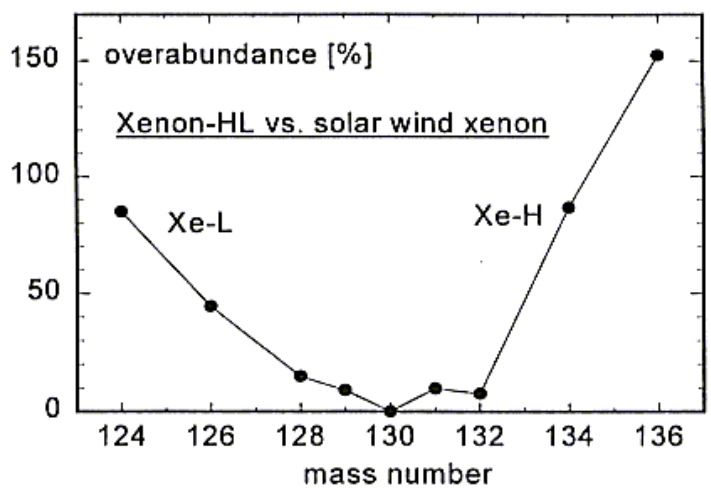
- microwave digestion results in "purer diamonds"
  unfortunately: silicon carbide grains lost
- first results; abundances compared eith r-process and relative to Xe

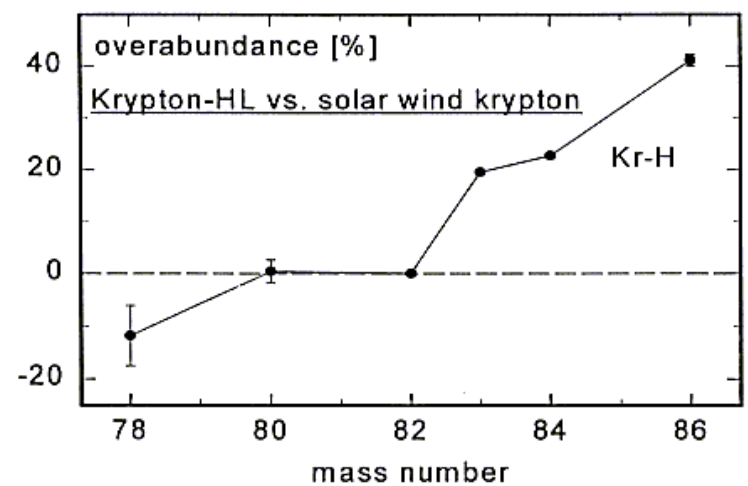



- relative to Xe and r-process abundances: heavy elements relatively enriched; but some maybe not too much (given general abundance increase with Z observed in noble gases) for useful isotopic analysis
- possible candidates at this time:
  PGE's: Os & Pt
  but also Hf, Sm, Dy, Yb may make sense

## The tricky details (sometimes)

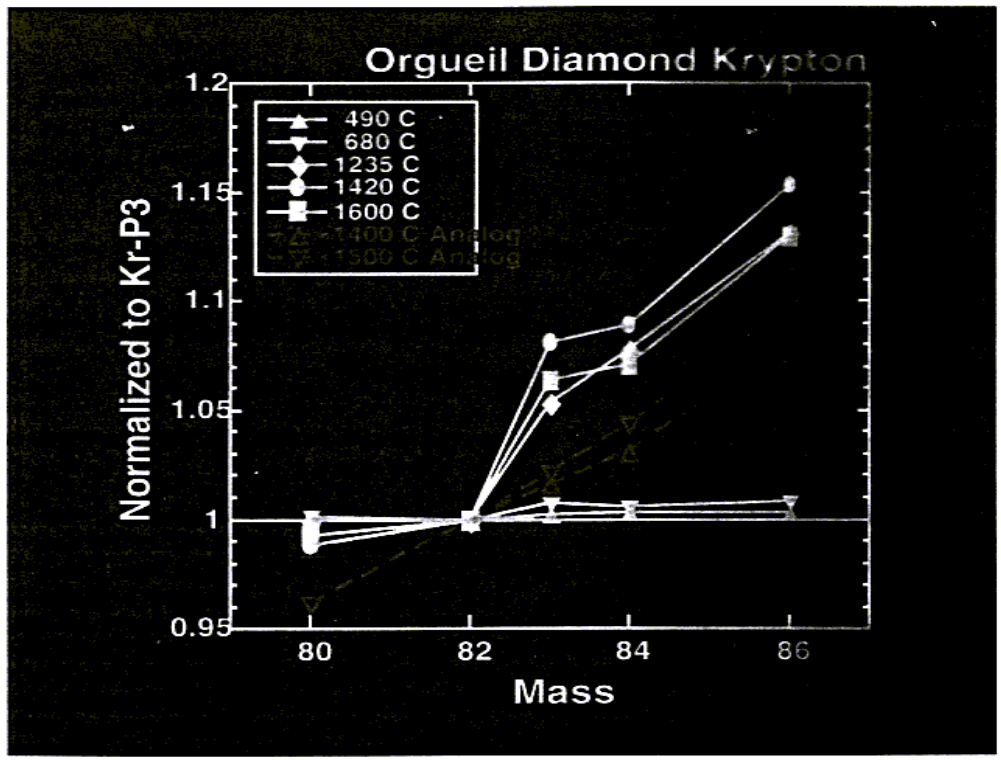
- most of the time straightforward:
  determine unusual isotopic composition → look for nucleosynthesis
- however not always, e.g. for more than two decades a puzzle:
  Xenon-H accompanied by Xenon-L, but in Kr different
  (also problem for how to make Xe-L)



## The implantation process

- new insights (possibly) from understanding of trapping process of noble gases in nanodiamonds
- indication for mass fractionation during ion implantation




- compared to fractionated solar Kr: there *is* Kr-L (but maybe no Ar-H, no Ne-H, ..)

# Summa Summarum (sic!)

✪ isotope abundance anomalies of heavy elements in presolar grains

(1) provide details on s-process nucleosynthesis

(2) indicate need for more processes beyond the "classical (s, r, p)" ones

(3) sometimes show the need to study more than just an isotopic composition