Seeking the origin of CEMP r/s stars

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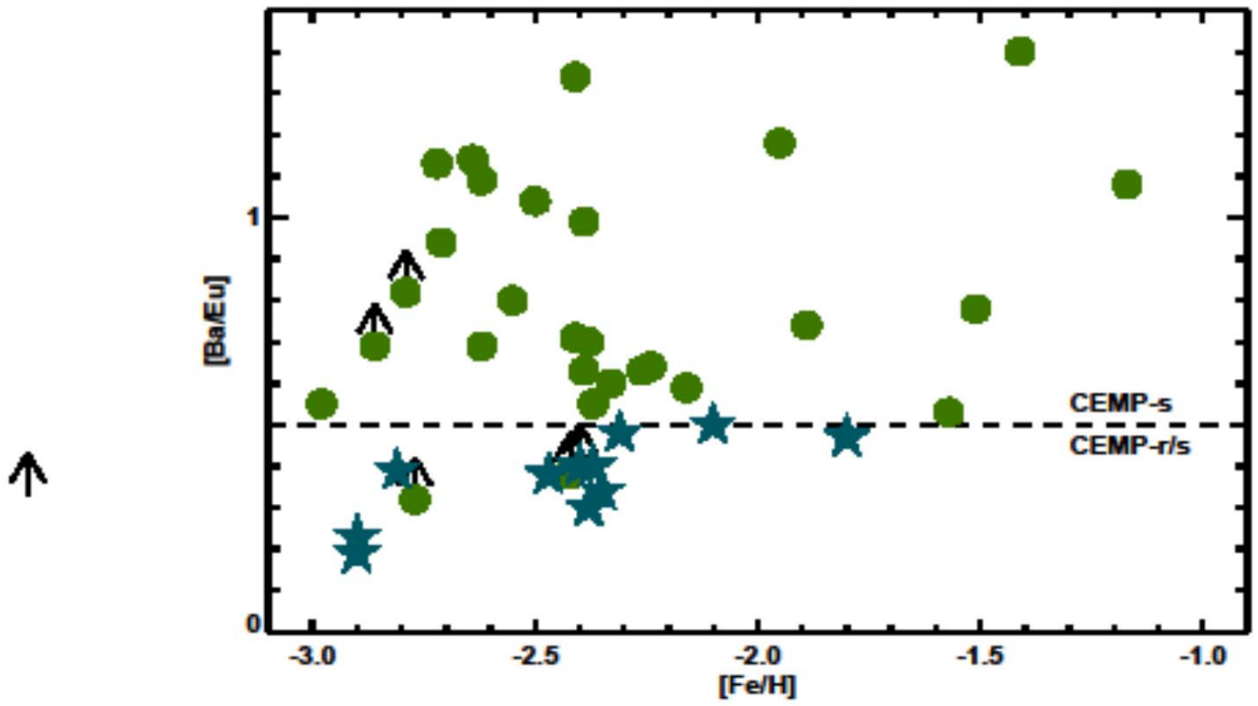
Categories of CEMP stars (definitions):

- CEMP-s stars show s-process enhancement: Barium [Ba/Fe] >1, [Ba/Eu] >0. s-process enrichment. [Eu/Fe] < 1

➔ CEMP–s/r stars show enhancement of Barium [Ba/Fe] >1 and [Ba/Eu] >0, also [Eu/Fe] > 1.

- CEMP-r stars show enrichment in r-process elements [Eu/Fe] >1, [Ba/Eu]<0. Only few stars.
- CEMP-no stars. No particular enhancements in heavy elements.

[Ba/Eu] for CEMP-s (●) and CEMP-r/s(*)



How did CEMP stars become rich in C and neutron capture (s-, r-process) elements?

- Mass transfer via more massive (faster evolving) component?
- RV can reveal binarity.
- Orbital elements can reveal type of binary.
- Orbit (circular or eccentric), Period

Terese T. Hansen et al.:

RV monitoring of 46 stars: 24 CEMP-no (17% binaries)

19 CEMP-s (82% binaries)

3 CEMP-r/s (all binaries, mass transfer from binary?)

r/s sample too small. Necessary to determine orbital parameters.

Binarity in CEMP stars:

- CEMP-s stars. Binaries with circular orbits, P~=1yr.
- CEMP–s/r stars. Not well studied, P=several yrs

➔*yields from i-process fit high-mass super AGB star?*

(Bertolli et al., 2013)

- (C)EMP-r stars. Generally *not* binaries.
- CEMP-no stars. No particular enhancements in heavy elements. Most (83%) are *not* binaries. Why C-enhanced?

Long-term RV monitoring project
to study binary frequency

- CEMP-s with Nordic Optical Telescope (8 yrs)

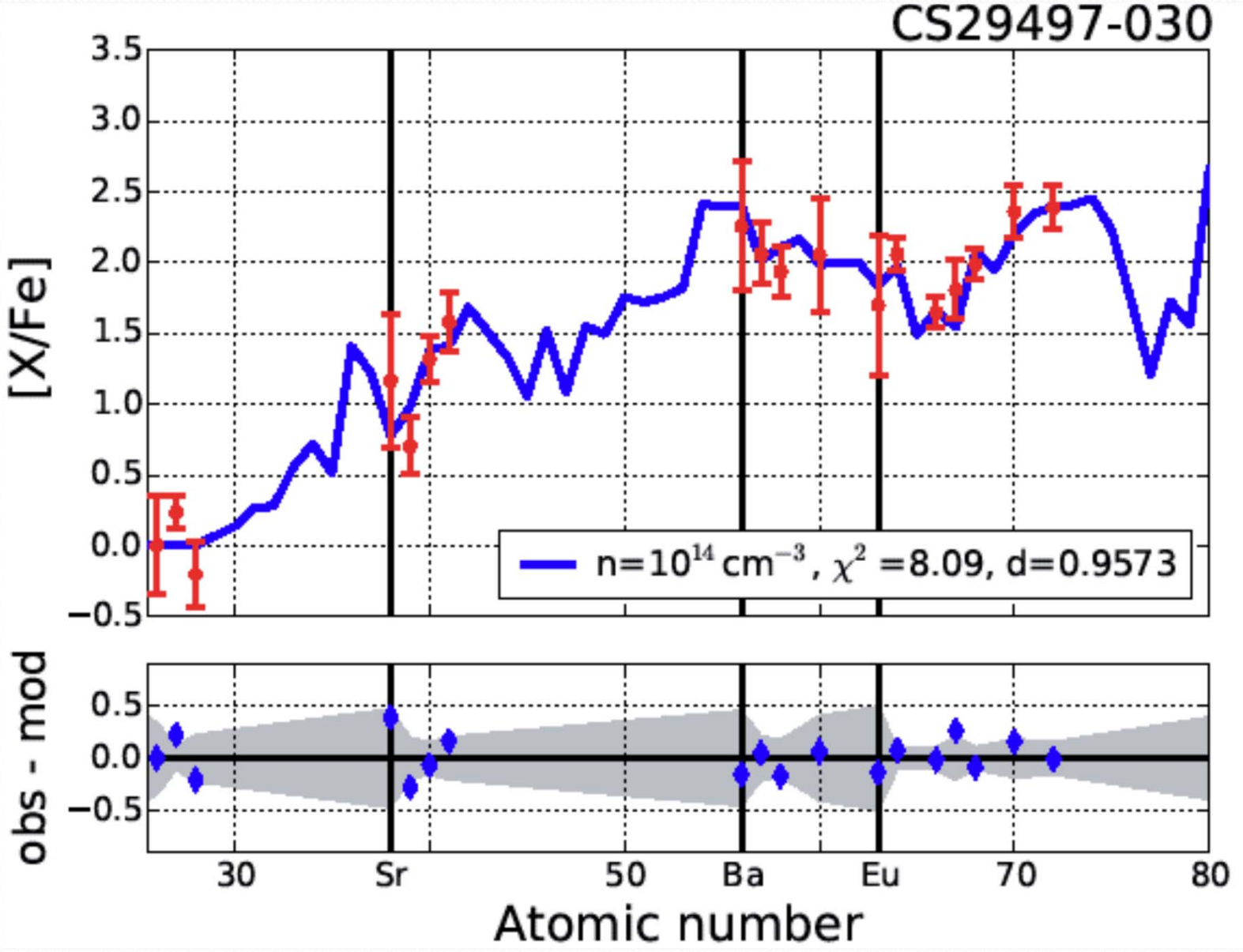
  see Hansen T.T.: A&A 2017
- CEMP-r with Nordic Optical Telescope (8 yrs)

  see Hansen T.T.: A&A 2015
- Now: observe RV for CEMP r/s with 2.7 m at McDonald, Texas.

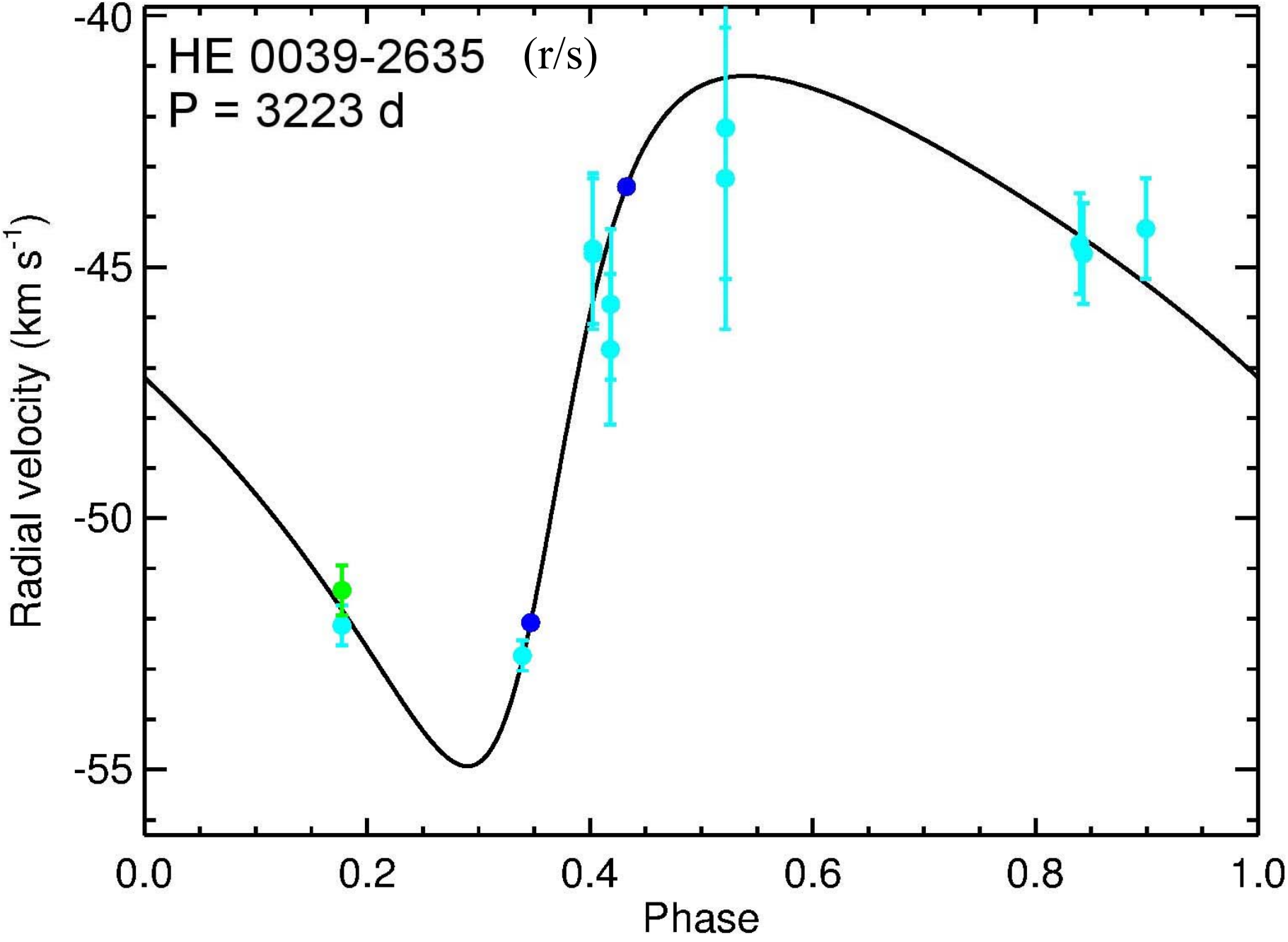
- Neutron capture s- elements require neutron densities 10^{6}-10^{10}cm^{-3}
- r- elements require neutron densities 10^{20} - 10^{15} cm^{-3}
- i (intermediate) process up to 10^{15} cm^{-3} Hampel (2015)

CEMPs_RVconst.eps

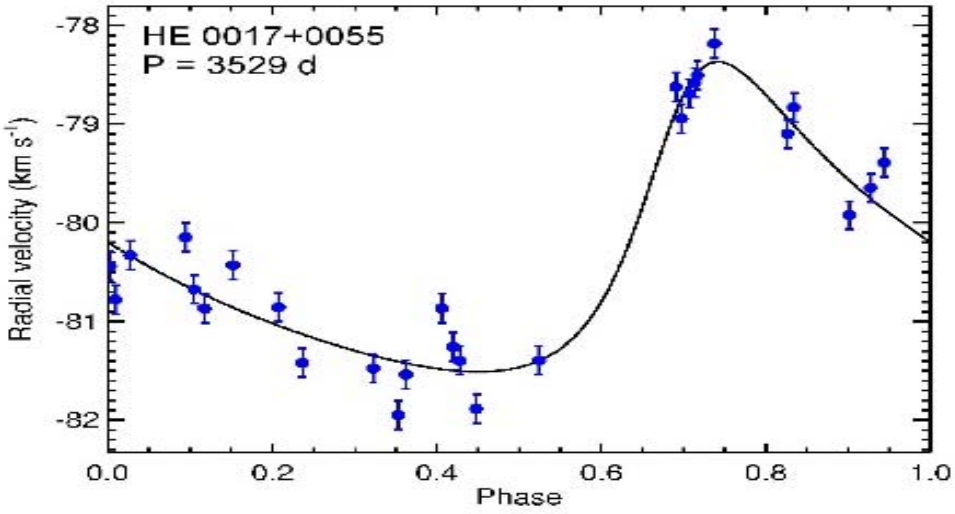
From Hempel — — i-process



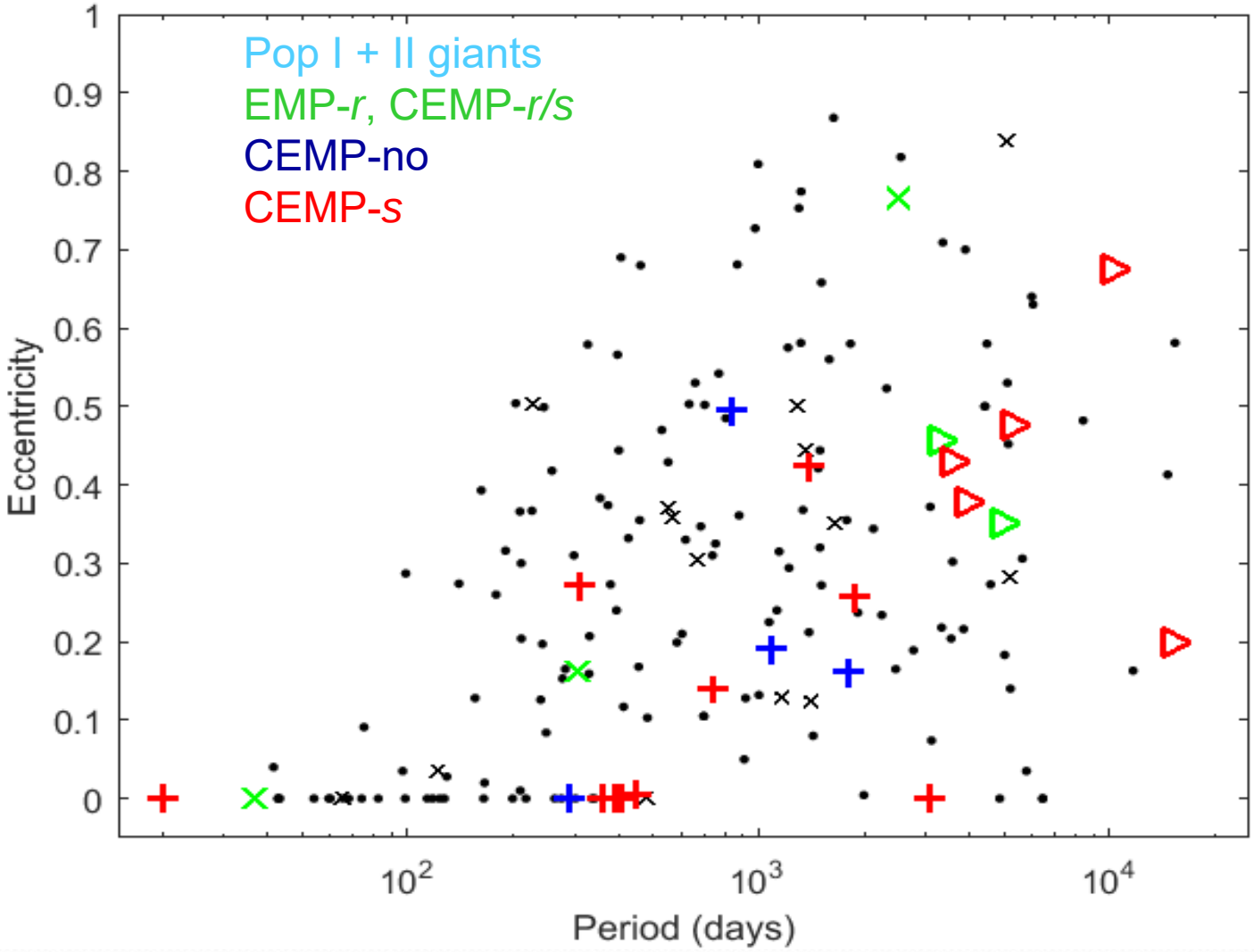
Green: Lucatello 2005, light blue: Barbuy 2005, blue: Hansen 2016



HE0017+0055


HE 0017+0055
P = 3529 d
Radial velocity (km s-1)
-78
-79
-80
-81
-82
0.0
0.2
0.4
0.6
0.8
1.0
Phase

Net Result After ~8 Years:



Previous Results/Conclusions:

- CEMP-no and EMP-*r* stars are basically ***single***
- ~20% of the CEMP-*s* stars are single as well(!)
- Most, but not all CEMP-*s* stars are **binaries**
- Origin of CEMP r/s stars?
- Abundance anomalies are ***intrinsic*** and were imprinted on the parent clouds across interstellar space in ISM at $z \geq 3$(?)
- Some early enrichment processes were complex and *non-local?*
- Alternatives: 'Faint' SNe with fallback & mixing?
- Is there an intermediate process (i) which irequires lower neutron densities than r-process and higher than that for s-process?

Observations of more r/s stars are needed

RV monitoring needed to:

- Verify if single or binary stars
- Determine orbital elements to find out about progenitors (type of binarity)
- Etc.

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