Kinematics and chemical analysis of CH and CEMP stars

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Current issues

- Large uncertainties still remain in estimates of the contribution of Low to IM stars to the chemical enrichment of the Galaxy.

- Pass through AGB phase of evolution:
  Short-lived, obscured by circumstellar envelope due to mass-loss.

  Several factors limit accurate estimates of the contribution of the AGB nucleosynthesis:

  a) sparse data
  b) analysis limited by low resolution, wavelength regions,
  c) poor understanding of the astrophysical processes that govern evolution of these stars
  d) inadequate understanding of model predictions
  e) lack of high resolution abundance data for validation

Tracers of AGB nucleosynthesis

- CEMP-s, CH stars, Barium stars:
  Chemically peculiar stars: Giants and sub-giants
  Exhibit enhancement of C and slow n-capture elements
  Provide observational constraints for models of n-capture nucleosynthesis

- Binary systems with a now invisible white dwarf companion.

- Chemical compositions - tracers of AGB nucleosynthesis.

Approach

- Detection of CEMP-s and CH stars: Low and Medium resolution spectroscoy

  Targets: Field stars, FHLC stars of Hamburg ESO survey,

- Determine surface chemical composition - C, n-capture elements

- Derive observational constraints for theoretical models.

- Complement spectroscopic studies with photometry, polarimetry

Low Resolution Spectroscopy

Subjected 269 stars to LR spectroscopic analysis:
[Observed with HCT and VBT (R ~1300)]

Spectra with strong C_2 bands are classified -

C-N, C-J, C-R and CH

Sp Criterea: strength of CH, CN, and C_2 and Ba absorption line

C-R	12
C-N	23
CH/CEMP	115
HdC	01
With Hα emission feature	04
With no prominent C & CH Bands	38

High Resolution spectroscopy

56 objects : Barkevicius catalog of CH stars

Source of HR spectra:

HDS attached to 8m SUBARU; (R ~ 50000)

ELODIE archive (R ~ 42000),

FEROS spectra (1.52m Tel at ESO, Chile) (R ~ 48000)

Methodology

Stellar parameters: T_eff, log g, and [Fe/H] are determined from LTE analysis using model atmospheres.

Estimation of elemental abundances:

From the measured equivalent widths of lines due to neutral and ionized elements and spectrum synthesis calculations
(i.e., Sc, Sr, Y, Zr, Ba, La, Eu)

Stellar evolution code: Updated version of MOOG (of Sneden 1973)

Atomic line data: Kurucz Atomic line database. (http://cfaku5.cfa.harvard.edu/)

Molecular line data: Masseron et al. (2014), Brook et al. (2013), Sneden et al. (2014), Ram et al. (2014)

Estimated abundances for 28 elements and isotopic ratios $^{12}C/^{13}C$

Elemental Abundances

Light elements: C, N, O, Na, Al

Alpha elements: Mg, Si, Ca, Sc, Ti, V

Iron peak elements: Cr, Mn, Co, Ni, Zn

Light s-process elements: Sr, Y, Zr

Heavy neutron-capture elements: Ba, La, Ce, Pr, Nd, Sm, Eu, Dy

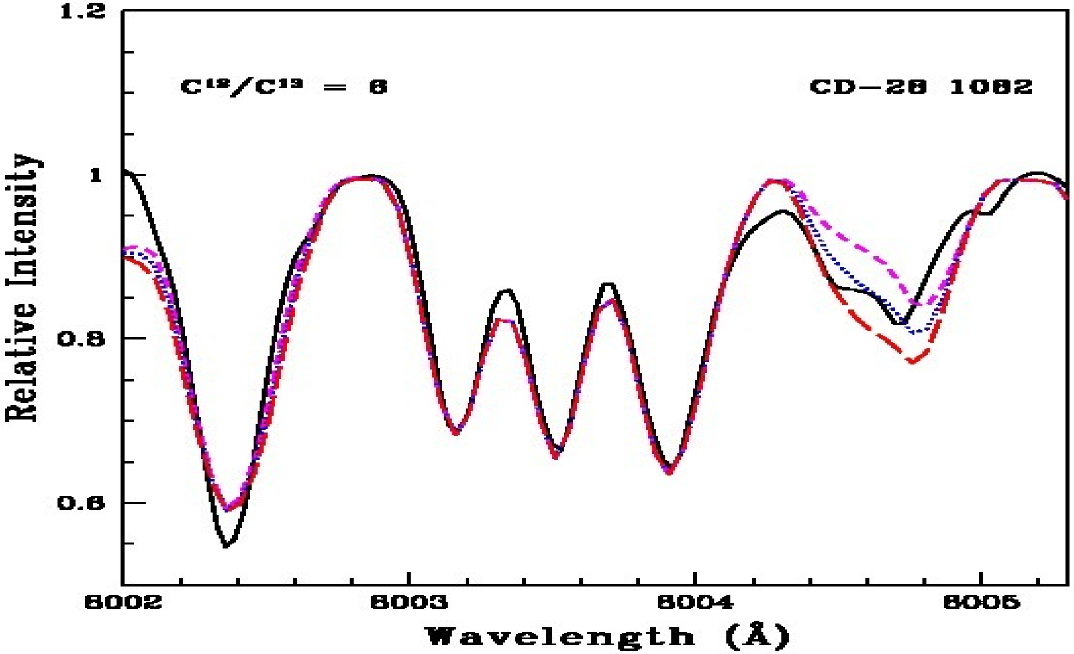
Estimates of stellar masses: Used Parallex method,
Evolutionary tracks of Girardi et al. (2000)

Luminosity estimates: Evolutionary phase (Giants, sub-giants)

For most of the objects [X/Fe] > 1 (X: Sr, Y, Zr, Ba, La, Ce)

Origin: binary companion.

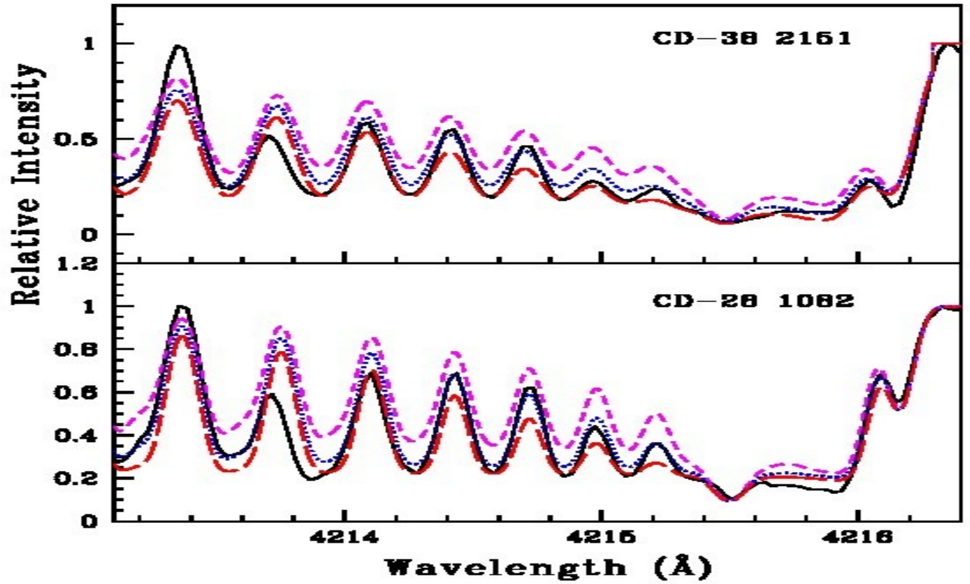
Performed parametric model based analyses to determine the contributions of s- and r-processes to the observed abundances of heavy elements.



Synthesis of CN band at 8005 Å.

Dotted : synthesized

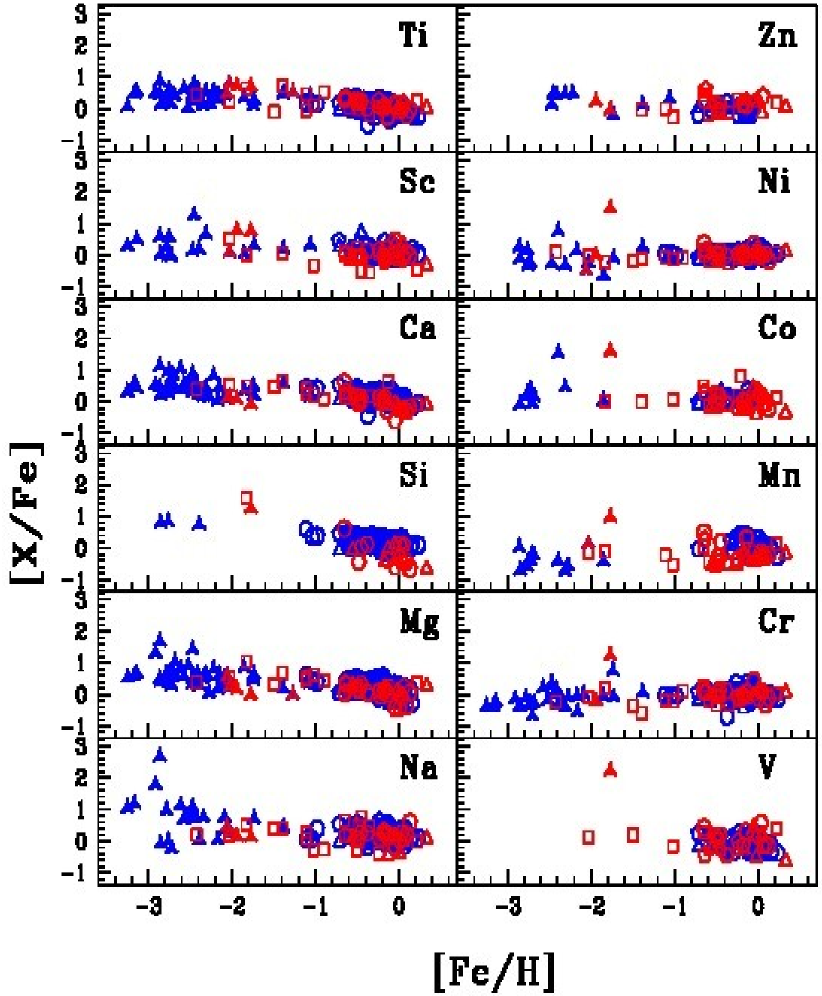
Solid: Observed

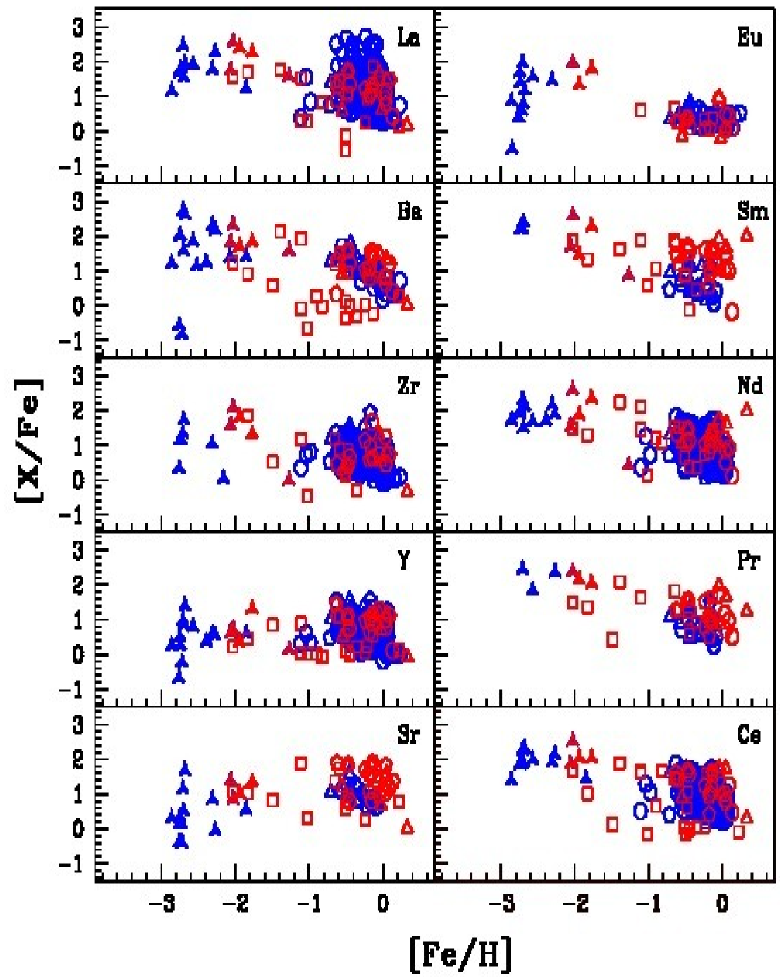


Synthesis of CN band around 4215 Å.

Dotted: synthesized

Solid: Observed





Red: Program stars; Blue: Stars from literature

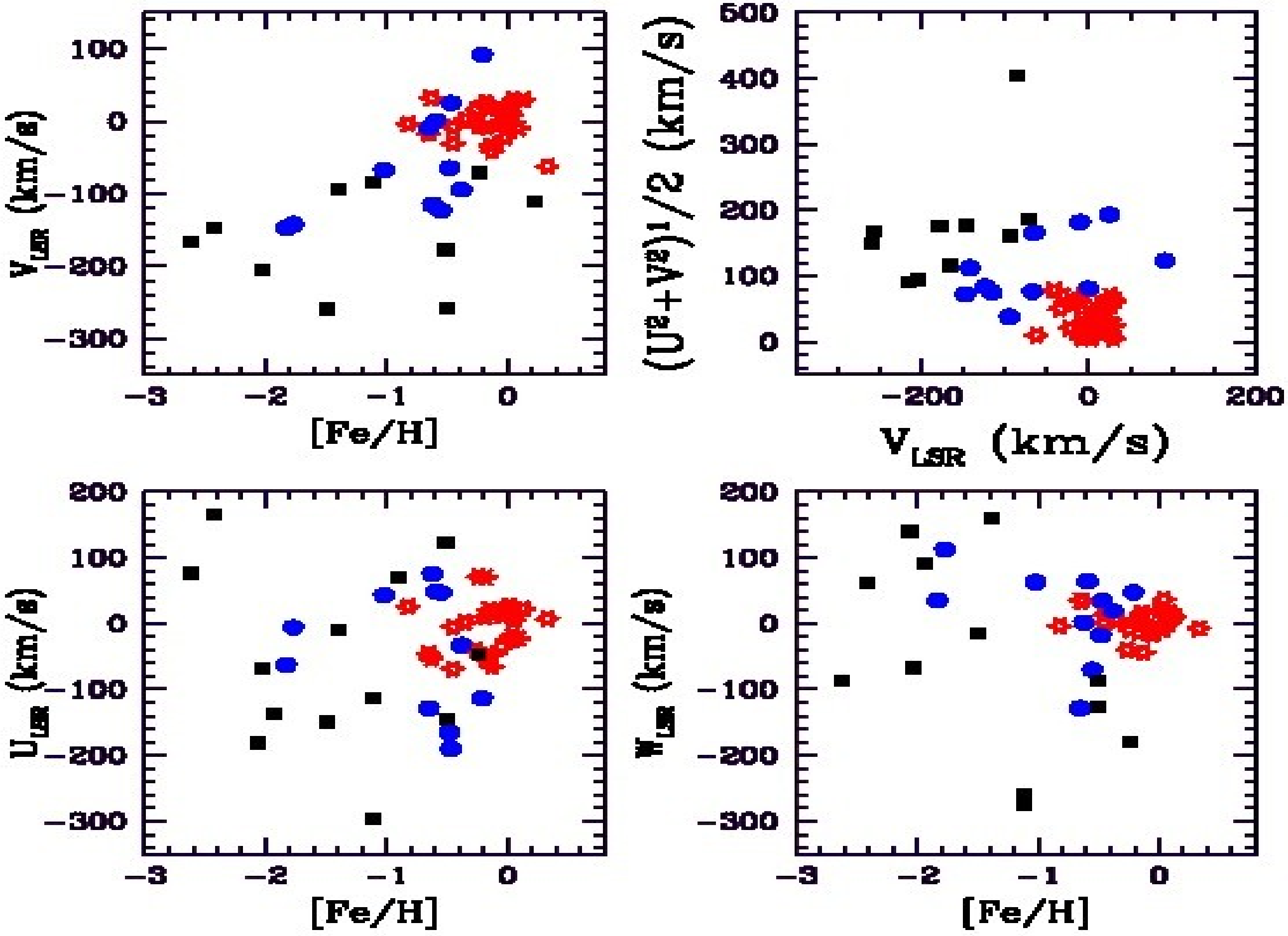
Open circle: Ba giants, Open triangle: Ba dwarf, Open hexagon: Ba subgiants; Starred triangle: CEMP stars; Open Pentagon: CH subgiants; Open square: CH giants

RESULTS

56 objects (Barkevicius): High Resolution spectroscopy

CH giants	03
CH subgiants	10
CEMP-s	04
CEMP-r/s	02
CEMP-r (?)	01
Ba Giants	08
Ba subgiants	07
Ba Dwarfs	02
Unclassified	19

Kinematics



Red: Thin disk, Blue: Thick disk, Black: Halo stars

Kinematics

[Fe/H] = -0.9 : halo-disk boundary

[Fe/H] > -0.9 and V_{LSR} > -120km/s Old disk objects

Thin disk: Vspa < 85 km/s

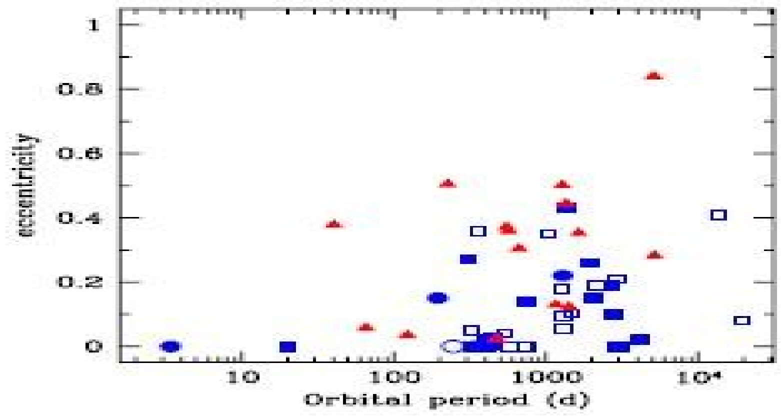
Thick disk: 85 < Vspa < 180 km/s

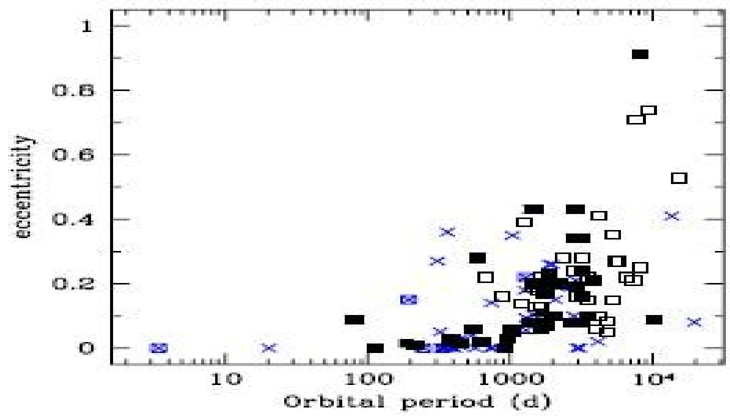
Halo: Vspa > 180 km/s

Component	No. of Stars	Probability
Thin Disk stars	30	0.98 - 0.99
Thick Disk stars	11	0.81 - 0.96
Halo objects	15	0.81 - 1.0

Binarity

Period-eccentricity diagrams (Jorissen et al. 2016)





Filled symbols: CEMP stars ; Open symbol: CH stars; Circle: Dwarf C-stars; Squares: giant C-stars; Red triangles: low-metallicity giants

Crosses: CEMP-s and CH stars; Squared crosses: Dwarf C-stars; Filled squares; strong Ba stars; open squares: mild Ba stars

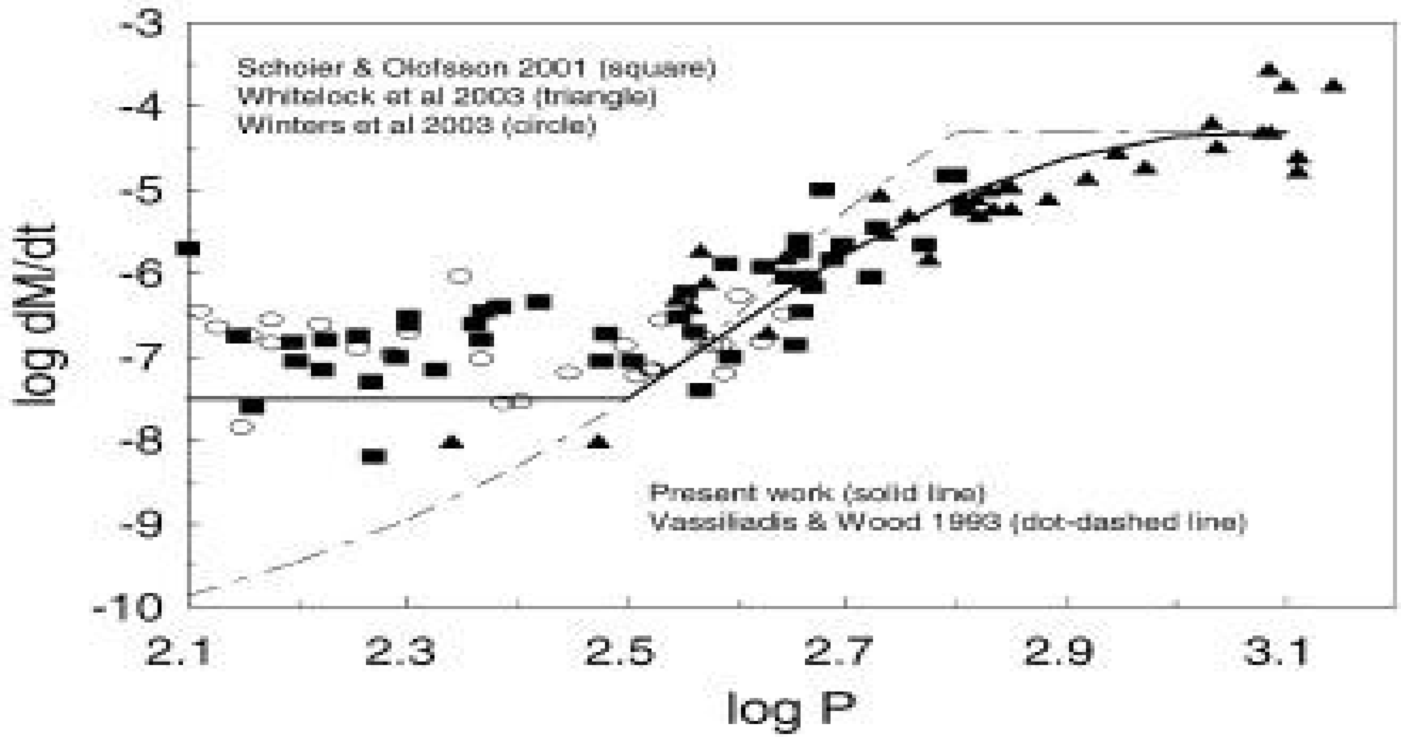
Orbital similarity between CH and CEMP-s stars suggests, they followed the same binary-evolution channel; can be treated as a single group.

Can we use CH/CEMP stars to constrain the physics of low-mass AGB stars?

Stellar Evolutionary Code (Straniero et al.)

- Treatment of convective borders
- Mass-loss formula
- C-rich molecular opacities
- Rotation
- Nuclear network

➢ Mass loss



Comparison of various mass loss rates versus period measurements (Squares: Schoier et al. 2001; Triangles: Whitelock et al. 2003; Circles: Winters et al. 2003); prescriptions used in stellar evolution calculations (Lines: Adopted in Straniero et al. 2006; Dot-dashed Vassiliadis et al. 1993. (Straniero et al. 2006; Fig 5)).

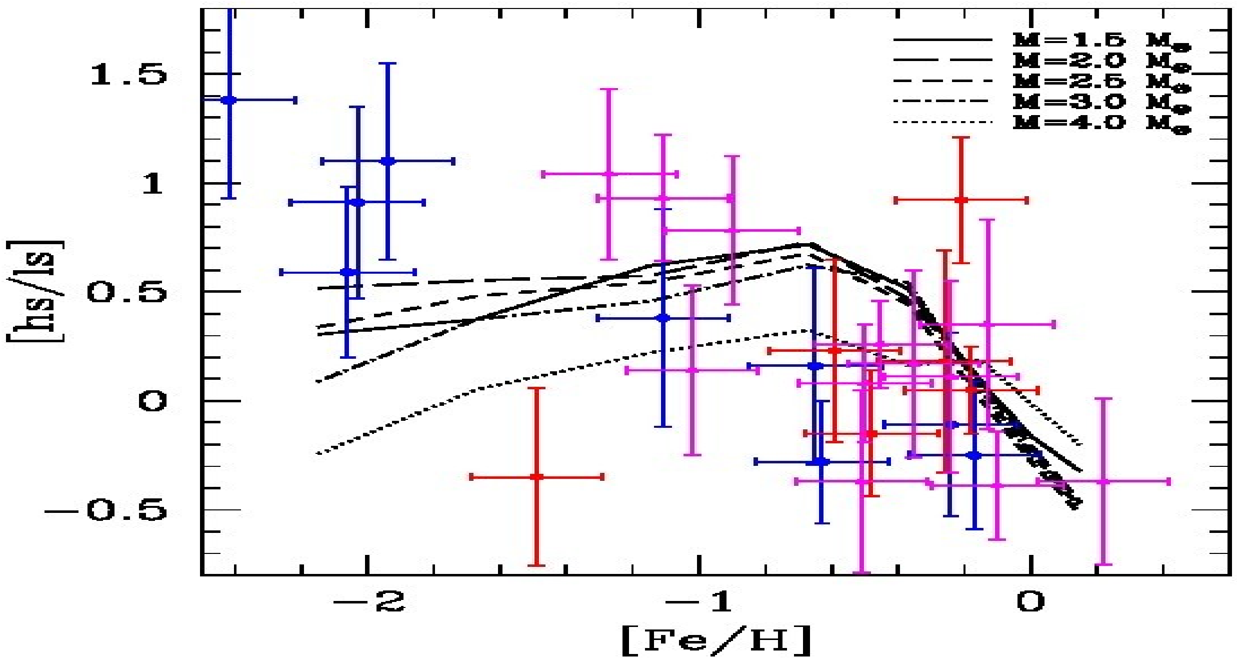
C-rich Molecular opacities

Use of C-rich molecular opacities leads to a larger mass loss rate with respect to a case in which a solar-scaled distribution is used to calculate opacities.

Rotation

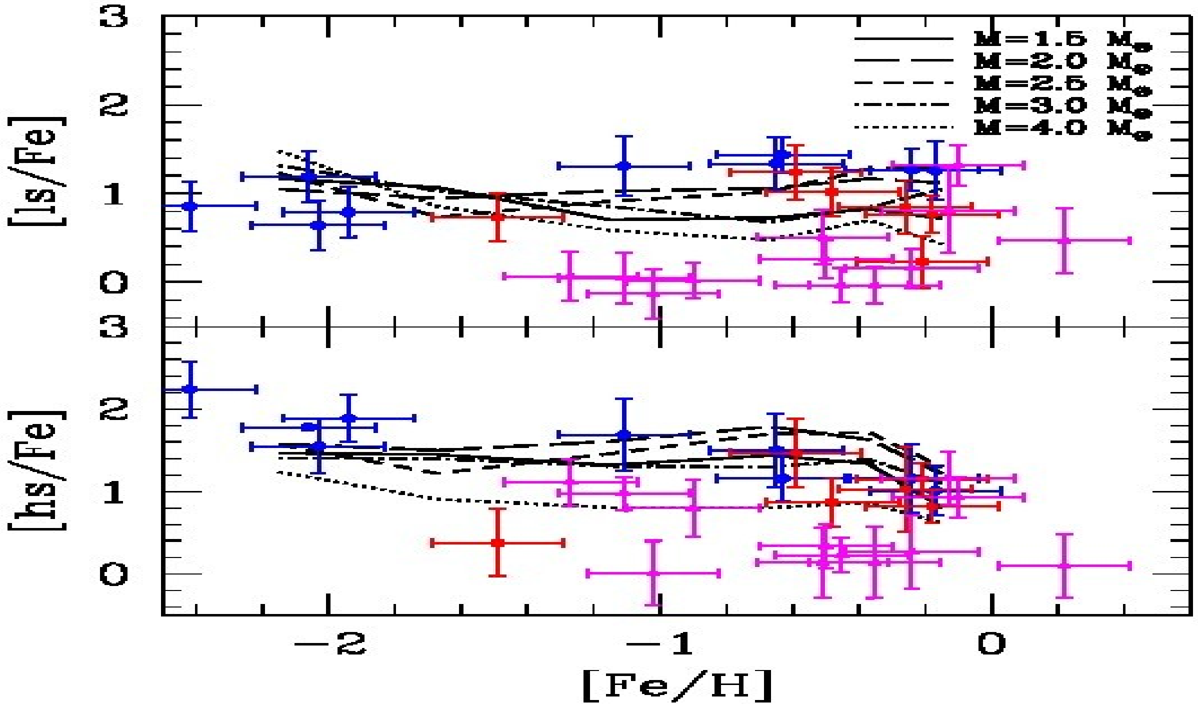
Induced rotation smears off the profiles of the ^{13}C and ^{14}N pockets. As a consequence, the neutron-to-seed ratio decreases and the efficiency of the s-process decreases.

[hs/ls] vs [Fe/H] for different masses



Observed vs Ref models predictions. Blue: known binaries; Red: radial velocity variables; Magenta: no information on binarity

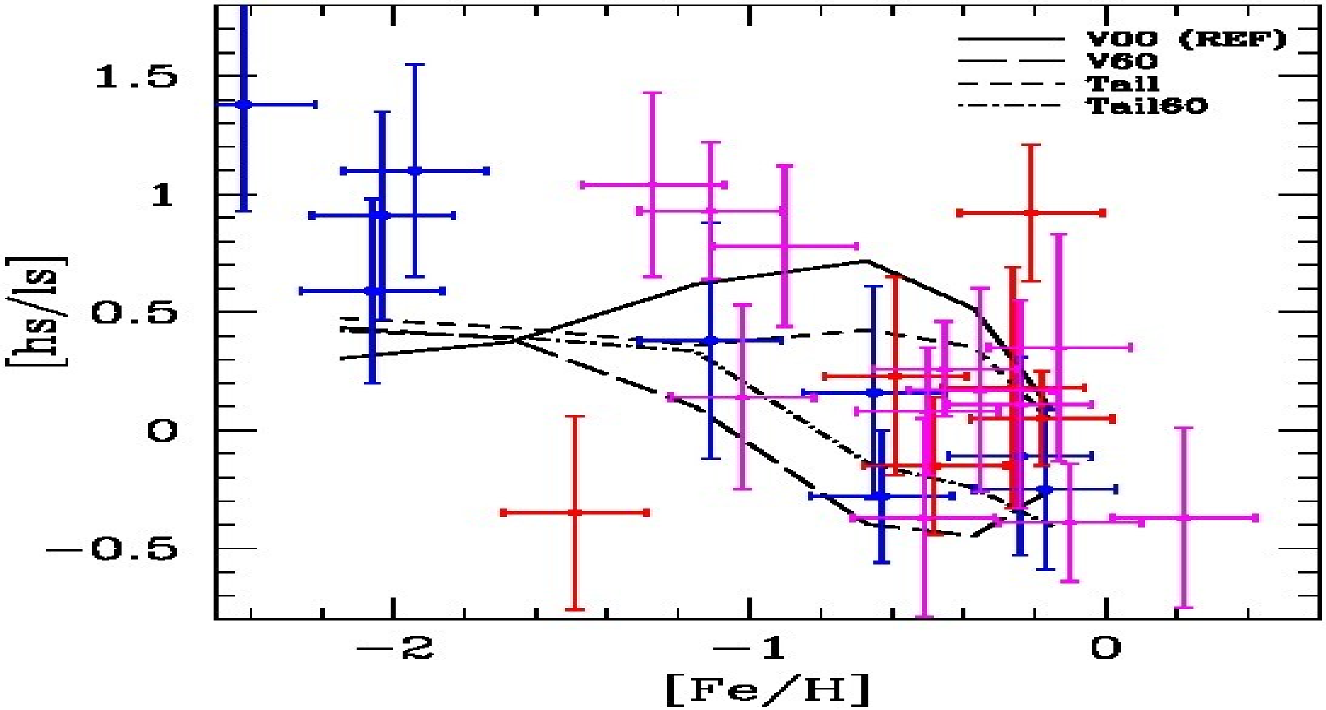
Cristallo, Karinkuzhi, Goswami, Piersanti, Gobrecht, (ApJ, 2016,)



[ls/Fe] and [hs/Fe] ratios as a function of metallicity compared to models. Blue: known binaries; Red: radial velocity variables; Magenta: No information on binarity

Cristallo, Karinkuzhi, Goswami, Piersanti, Gobrecht (ApJ, 2016)

[hs/ls] vs [Fe/H]: For 1.5 $M_{\odot}$ stars with different prescriptions



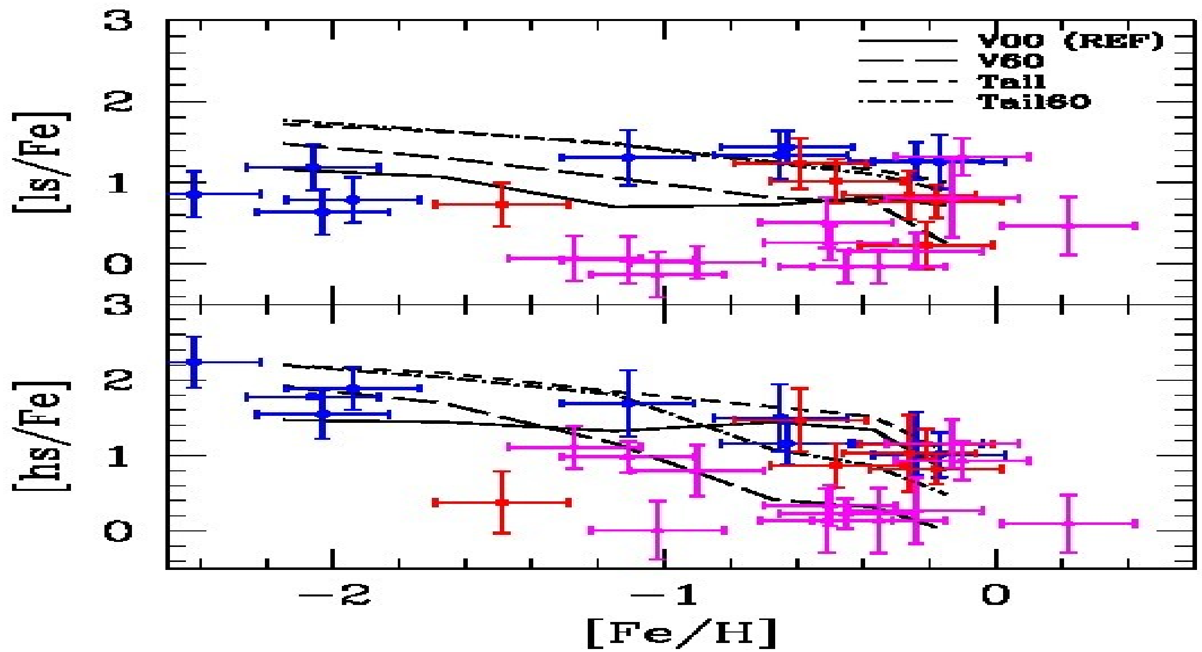
V60: Ref rotating models with initial V_rotaional velocity 60 km/sec

Tail: Non-rotating models with extended ^{13}C pockets,

Tail60: Rotating models V60 with extended ^{13}C pocket

Blue : Group I; Red : Group II; Magenta : Group III.

Cristallo et al. (ApJ, 2016)



[ls/Fe] vs [Fe/H] (upper panel), [hs/Fe] vs [Fe/H] (lower panel). for a set of 1.5 $M_{\odot}$ stars and different prescriptions.

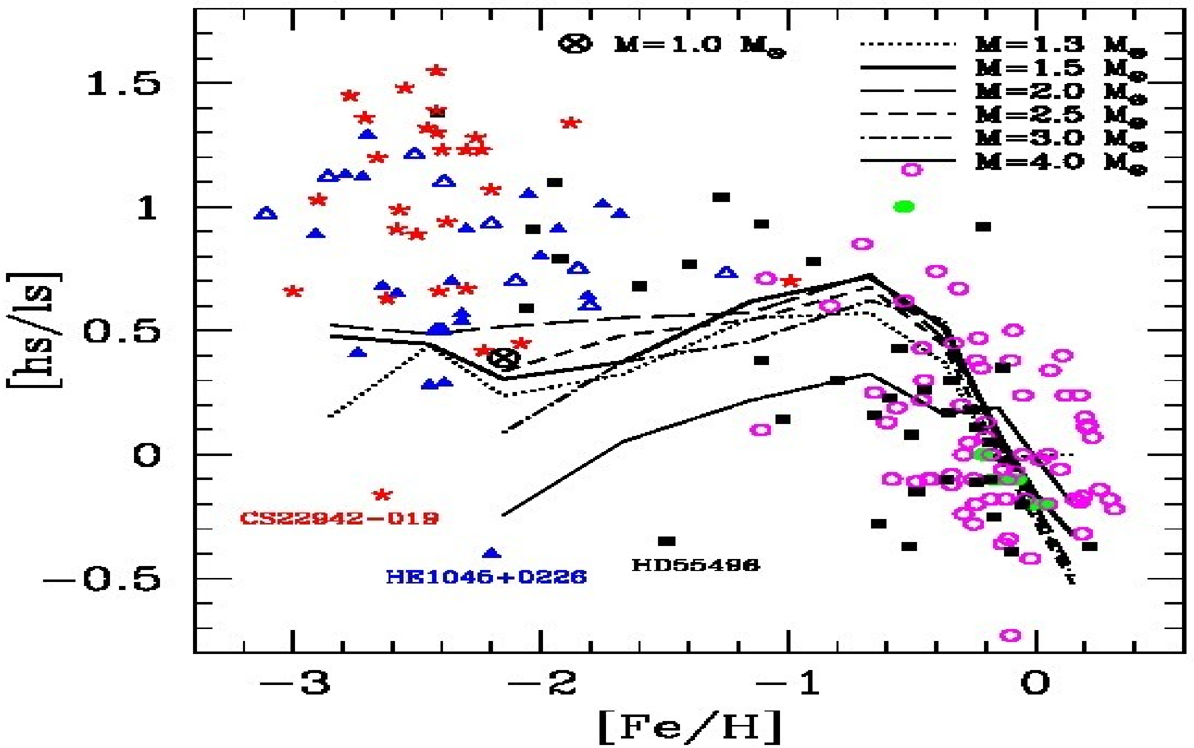
V60: rotating models with initial rotational velocity 60 km/sec,

Tail: non-rotating models with extended ^{13}C pockets,

Tail60: rotating models V60 with extended ^{13}C pocket.

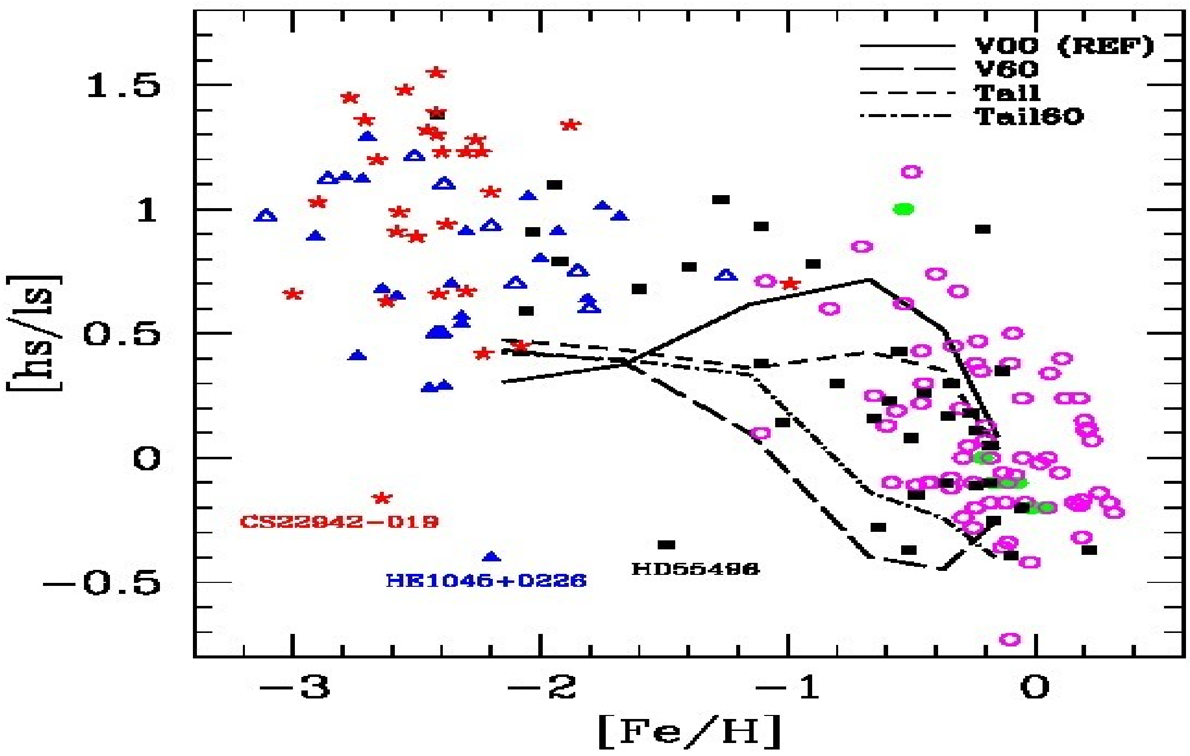
Blue: known binaries; Red: radial velocity variables; Magenta triangles: no information on binarity

[hs/ls] vs [Fe/H] for different masses



Green: extrinsic O-rich; Magenta: Ba stars; Filled dark squares: CH stars; Filled blue triangles: CEMP-s sars; open blue triangles: CEMP without Eu detection; Red asterisks: CEMP-rs stars

Results: [hs/ls] vs [Fe/H] , M = 1.5 M_{Θ}



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Summary

- Created a homogeneous abundance database for CH stars to constrain the nucleosynthesis of low mass AGBs.
- Examined the effects induced on the surface AGB s-process distribution by different prescriptions for convection and rotation.
- Model fits only a part of the observations; s-process observational spread for a fixed metallicity could not be reproduced.
- At [Fe/H] > -1, for CH and Ba stars obtained good fits when rotation and a different treatment of inner border of the convection envelope are simultaneously taken into account.
- Unable to attain [hs/ls] ratios characterizing CEMP stars surfaces
- Observed abundance distribution in CEMP-r/s stars may result from proton mixing episodes leading to a very high n- density (i-process).