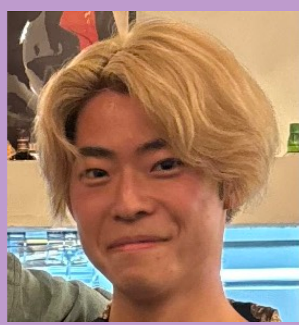
The Origin of Phosphorus-rich Stars

Ryota Hatami (SOKENDAI/NAOJ), Nozomu Tominaga, Koh Takahashi (NAOJ),
Noriyuki Matsunaga (U. Tokyo), Daisuke Taniguchi (TMU), Wako Aoki, Takuji Tsujimoto (NAOJ)



Abstract

Precise measurements of phosphorus abundance in stars contribute not only to understanding chemical evolution of the universe but also to the origin of life because P is one of the most essential elements for earthly life. Available phosphorus absorption lines do not exist in the optical wavelength range, requiring observations in the near infrared (NIR) or ultraviolet, and until recently, such measurements were scarce. In recent years, observations by The Apache Point Observatory Galactic Evolution Experiment (APOGEE) have measured the P abundance of numerous stars using two absorption lines in the H band. Among these, P-rich stars with [P/Fe] > +1.0 have been discovered. Despite having [Fe/H] ~ -1.0, these P-rich stars contain almost equivalent P abundance of Sun. Furthermore, not only P but also elements surrounding P, such as Al, Mg, and Si, as well as s-process elements like Ce, are enhanced. Thus, their high P composition must be reproduced by simulations, including correlations with these elements. Therefore, the aim of this study is to confirm the chemical composition, including P, of the P-rich stars measured by APOGEE using Subaru/IRD. APOGEE only used the H band, but since four more usable P absorption lines exist in the Y band, Subaru/IRD allows for precise measurement using all available six lines in NIR. In the future, we will compare the confirmed abundances of these P-rich stars with results of the simulations of stellar and supernova nucleosynthesis to discuss whether the models can reproduce the observational abundances or not.

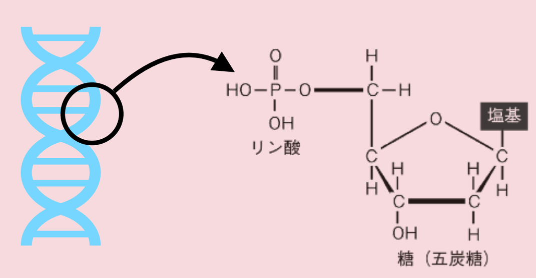
1.Introduction

<Phosphorus in the Universe>

Components of DNA/RNA, ATP, and Phospholipid
→ Essential elements for earthly life

P synthesis site is not fully understood

DNA



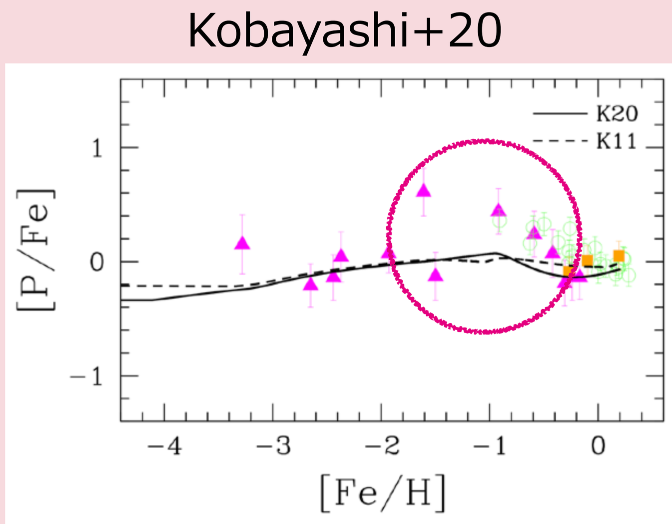
<Phosphorus Synthesis and Evolution>

P synthesis site …?

- Massive Nova (Bekki & Tsujimoto+24)
- Explosive Nucleosynthesis (Nomoto+13)
- C-O shell merger (Ritter+18)
  etc.

Phosphorus abundance and its time evolution can't be reproduced by simulations around [Fe/H] ~ -1

Kobayashi+20

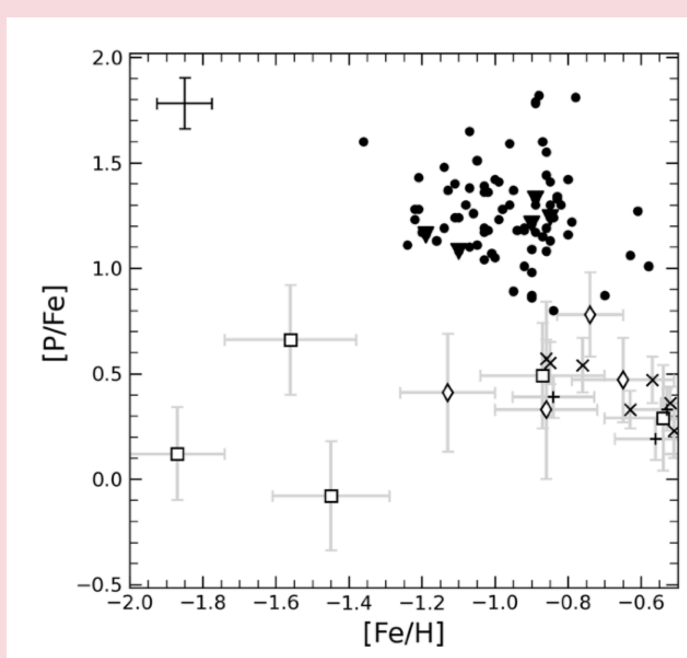


<P-rich Stars>

Even though P-normal stars abundance haven't been reproduced…

Recent observations revealed
P-rich stars w/ [P/Fe]>+1.0
(Masseron+20, Brauner+23)
=> Synthesis of P and other elements around P should be investigated!!

Brauner+23

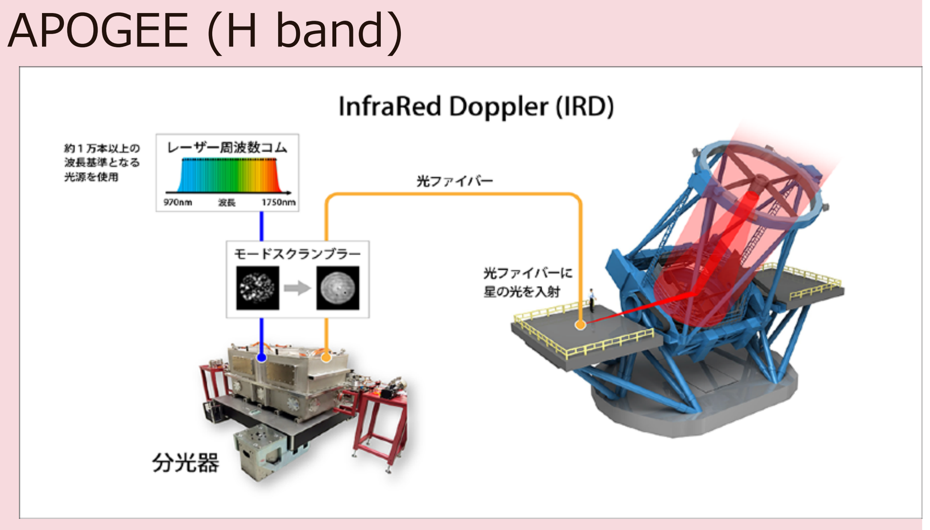


<P Measurement w/ Subaru/IRD>

P absorption lines are available in NIR or UV

- P-rich stars are observed only by APOGEE (H band)
- 2 available lines in H band
- 4 additional lines in Y band

=> Using Subaru/IRD, we can measure P abundance more precisely



<Aims>

Goal 1: **Confirm the P abundance in P-rich stars**

Goal 2: **Reveal/Identify the origin of high-P abundance**

Step 1. Observe P-rich stars and measure the chemical abundances not only P but also other elements (e.g. Mg, Al, Si, K, Sc etc. …)

Step 2. Calculate nucleosynthesis in massive stars and compare with observational abundances (This Poster)

2.Observations

<Observed P-rich Stars>

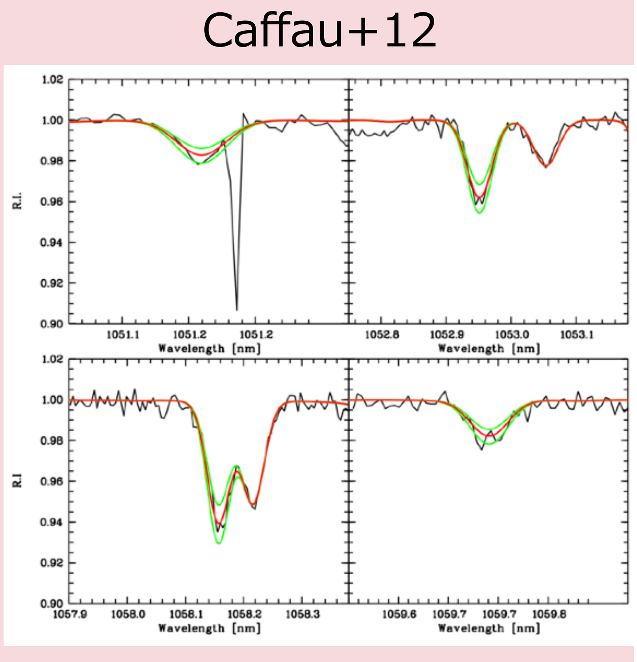
We have already observed 12 P-rich stars w/ Subaru/IRD and analysis is in progress……

<Using Absorption Lines>

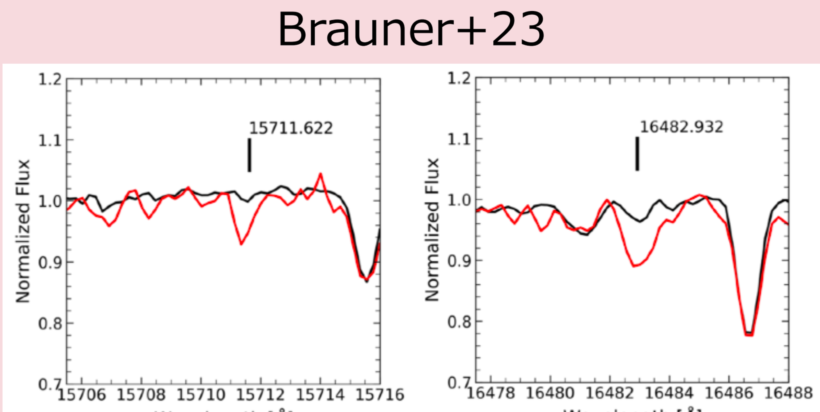
Y band (μm): 1051.2, 1053.0, 1058.2, 1059.7

H band (μm): 1571.1, 1648.3

Caffau+12



Brauner+23



3.P Synthesis in Massive Stars

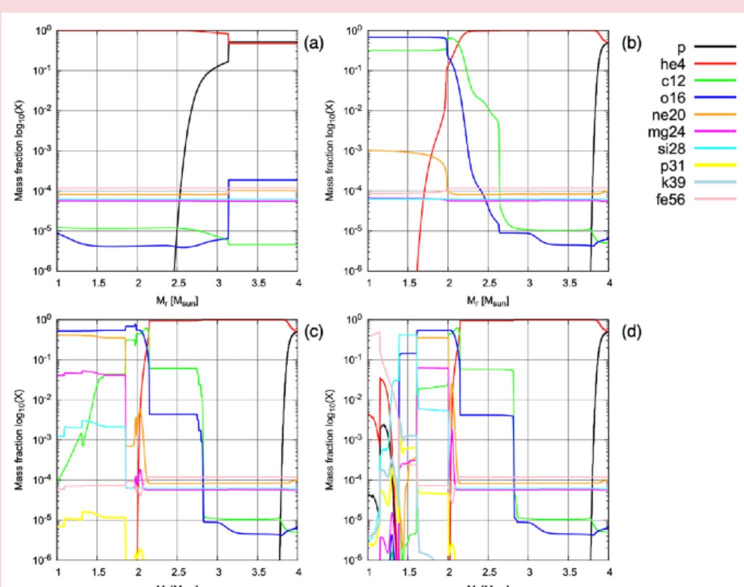
<Stellar Nucleosynthesis>

Calculation Code: HOSHI (Takahashi+18)

Parameters: $M_{\rm ZAMS}$, Z, $\alpha_{\rm MLT}$, $f_{\rm ov}$, $\omega/\omega_{\rm Kep}$

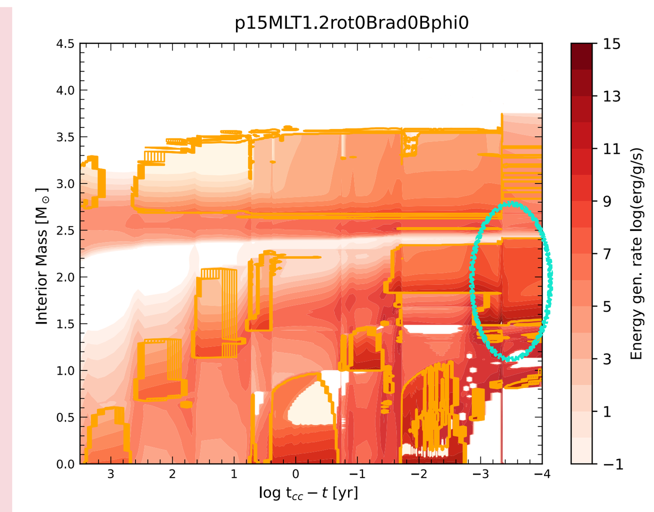
- Mass: $10, 13, 15, 18, 20, 25, 30, 40\ (M_\odot)$
- Metallicity: $0, 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, 1\ (Z_\odot)$
- MLT parameter: $1.2, 1.5, 1.7, 2.0$
- Overshoot: $0.001, 0.005, 0.01, 0.02, 0.05, 0.1$
- Rotation: $0, 0.2, 0.3, 0.5, 0.6$

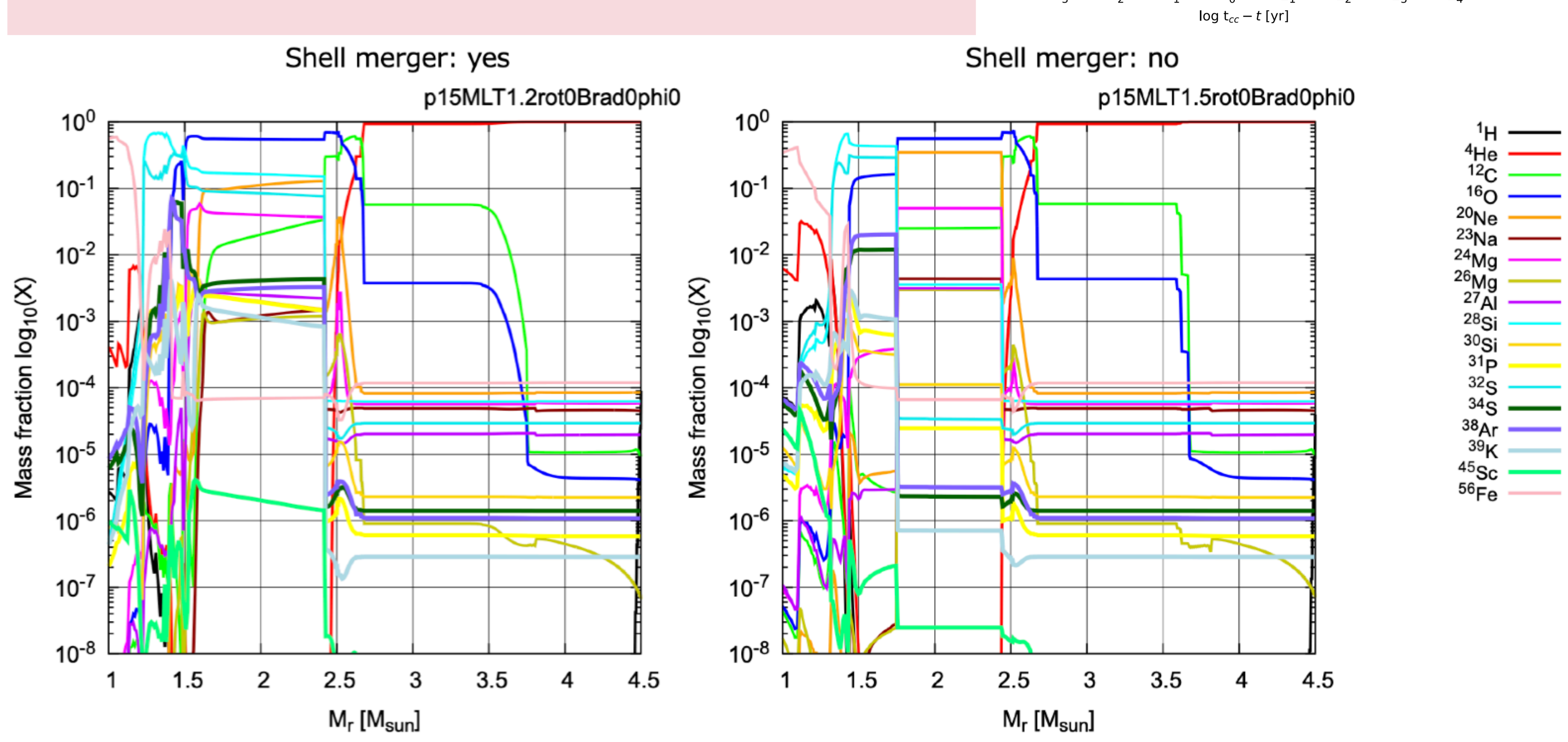
Nuclear Network: 300 species (p~^{79}Br)



<C-O Shell Merger>

A few days~hours before collapse,
O burning shell and **C burning shell** might mix and merge (**C-O shell merger**)
→ Odd-Z elements (P, Cl, K, Sc) are enhanced
In some model, C-O shell merger successfully occur and P is enhanced





Although P is enhanced by C-O shell merger, the abundance is not sufficient to reproduce P-rich star
→ It could be reproduced by combining C-O shell merger with neutrino process in CCSN…?

4.Summary/Future work

<Summary>

- Our goals are
  1. Confirm the P abundance in P-rich star candidates reported as P-rich star by APOGEE observations
  2. Reveal the origin of high-P abundance by calculating stellar and supernova nucleosynthesis
- We observed 12 P-rich star candidates and analysis is in progress
- We calculated more than 500 stellar models, C-O shell merger occurs in some models
- Although there are C-O shell merger occurring model, the P abundance is insufficient to reproduce P-rich star

<Future Work>

- Confirm the elemental abundance of P-rich stars
- Combining supernova nucleosynthesis, investigate whether the abundance could be reproduced or not and identify the origin of P enhancement

Reference

[1] Bekki, K., & Tsujimoto, T., 2024, ApJL [2] Nomoto, K., et al., 2013, Annual Review of Astronomy and Astrophysics, 51, 457 [3] Ritter, C., et al. 2018, MNRAS, 474, L1 [4] Kobayashi, C., et al., 2020, ApJ, 900, 179 [5] Masseron, T., et al. 2020, Nat.Commun., 11, 3759 [6] Brauner, M., et al. 2023, A&A, 673, A123 [7] Caffau, E., el al, 2011, A&A, 532, A98 [8] Takahashi, K., 2018, ApJ, 857, 111