The Ba stars Mystery

Introduction

The barium stars present overabundances in barium on their surface which was accreted a long time ago from the wind of a companion star. However, this scenario cannot explain their high eccentricities and orbital periods that have remained a mystery for decades. We investigate how white-dwarf kicks and/or the presence of a circumbinary disk can solve this problem.

1. The Barium Stars

The Ba stars show barium absorption lines in their spectra yet have not gone through the asymptotic giant branch (AGB) phase, i.e. they cannot have made the barium themselves. The canonical picture of their evolution suggests they accreted their barium from the wind of a companion AGB star which has long since turned into a white dwarf.

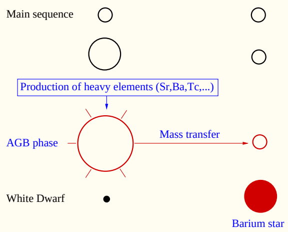
Jorissen 2001: Ba Stars

$[Ba/Fe] \geq 0.5$ for strong Ba

$0.2 \leq [Ba/Fe] < 0.5$ for mild Ba

$C/O < 1$

$\overline{M_{Ba}} = 2.0\,M_{\odot}$ ($M_{WD} = 0.67\,M_{\odot}$)



McClure showed in 1990 that all of Ba stars are in binary systems.

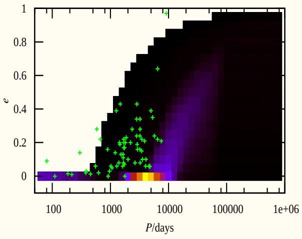
Ba-Star binary fraction: 100%

Ba stars are not rare

$N_{Ba}/N_{G-Kgiants} = 1\%$

2. Stellar Evolution Mystery

Most of the barium stars have periods $500 \lesssim P \lesssim 10^4$ days and eccentricities $0 \leq e \lesssim 0.4$. However, binary population synthesis models predict (colored regions, yellower means more populated) that these systems should have circularized and that the only eccentric barium stars should have $P \geq 3000$ days.



We investigate two mechanisms to explain the large eccentricities of barium stars

- **White-dwarf kicks**
- **Interaction with a circumbinary disk**

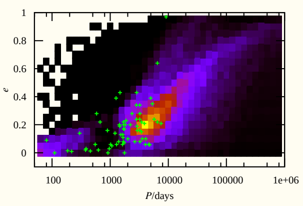
Other classes of stars present a similar evolution than Ba stars and are then used as constraints: **post-AGB**, **dwarf Ba**, **subgiant CH**, **CH**, and **extrinsic S**

Conclusions

- Orbital properties of barium stars are difficult to explain.
- We investigate how they can be predicted by white-dwarf kicks or circumbinary disks:
  - White-dwarf kicks have support from observations but need strong angular momentum loss to match the observations.
  - Circumbinary disks are commonly-observed promising-candidates but their formation and evolution are not yet understood.

3. White-Dwarf Kicks

The idea that White Dwarfs are kicked at their birth with a velocity of a few $km\,s^{-1}$, probably due to asymmetric mass loss during the AGB phase, has support from observations of globular clusters.



Our models of binary population synthesis with natal white-dwarf kicks are able to explain the eccentricities of barium stars, but predict too many long period systems (left).

If we add strong orbital angular momentum loss

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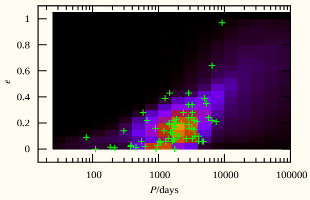
We can shrink Ba stars down to observed periods (right)



Specifically, strong angular momentum loss means:

- $\dot{J}_{orb} = f\,J_{orb}\,\dot{M}_{binary}/M_{binary}$ with $2 \lesssim f \lesssim 4$
- α_{CE} includes **envelope-recombination energy** ($\lambda_{ion} > 0$)

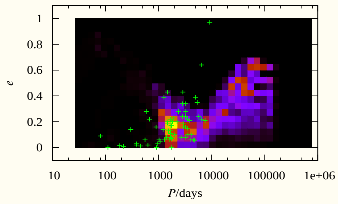
4. Interaction with a Circumbinary Disk

In contrast to white-dwarf kicks that are difficult to confirm by observation, circumbinary disks are very common around post-AGB stars. Their origin and evolution are not yet understood, but observations suggest a mass of $10^{-5} - 10^{-3}\,M_{\odot}$ and a lifetime of $10^4 - 10^8$ years.

Binary-disk resonant interaction:

increases the eccentricity

extracts angular momentum



Prescriptions:

$\dot{M}_d = 0.1\dot{M}_{sys}$

$\tau_d = 3 \times 10^4$ yr

$\lambda_{ion} > 0$

Result:

e is pumped in a few 10^4 yr.

- M_d reaches $\sim 10^{-3}\,M_{\odot}$ as observed.
- The short disk lifetime is consistent with observations.
- The eccentricity is pumped rapidly enough to explain eccentricities of post-AGBs.

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