Previous Research

The two themes in my thesis work are stellar rotation and binary interaction. Using different state-of-the-art stellar evolutionary codes I addressed a variety of topical problems in the field, varying from globular clusters and the existence of multiple populations within them, via the most metal-poor stars in the halo of our galaxy, massive X-ray binaries for which I proposed a new formation scenario.

Before my thesis I worked during a summer internship at Tenerife, Spain where I reduced and analyzed optical data of disk galaxies. I am involved in the VLT-flames consortium of massive stars, which is currently conducting the Tarantula survey of massive stars, which will result in the largest homogeneous sample of massive stars. Furthermore I am co-investigator on a proposal to observe an eclipsing high mass x-ray binary in the galactic center, aiming to determine the mass and nature of the compact object. However, my main expertise is of theoretical and computational nature. Below, I summarize the main papers that are part of my thesis work.

Effects of rotation on massive stars in short-period binaries: a new formation scenario for X-ray binaries containing massive black holes

--- De Mink, Cantiello, Langer et al. A&A, 2009

Rotation has shown to be of large influence on the evolution of massive stars; it is now considered as one of the main parameters determining the fate of star, along side with mass and metallicity. However, recent observations by the VLT-flames consortium of massive stars have challenged the concepts of mixing induced by rotation. In this paper I study these effects on short-period detached binaries, where rapid rotation is induced by the tides. Such systems often show eclipses enabling accurate determination of stellar parameters. Therefore they may provide stringent test for the concept of rotational mixing.

A surprising outcome of this study is that rotational mixing can be very efficient in the most massive, short-period binaries. So efficient that helium produced in the center is mixed throughout the star. In contrast to normal evolutionary scenarios, where the stars expand with the inevitable consequence Roche lobe overflow, these stars stay compact, gradually evolving into massive Helium stars, see Figure 1 for a cartoon. We propose this scenario to solve the mystery of the formation of high-mass X-ray binaries containing a massive stellar-mass black hole such as M33 X-7.

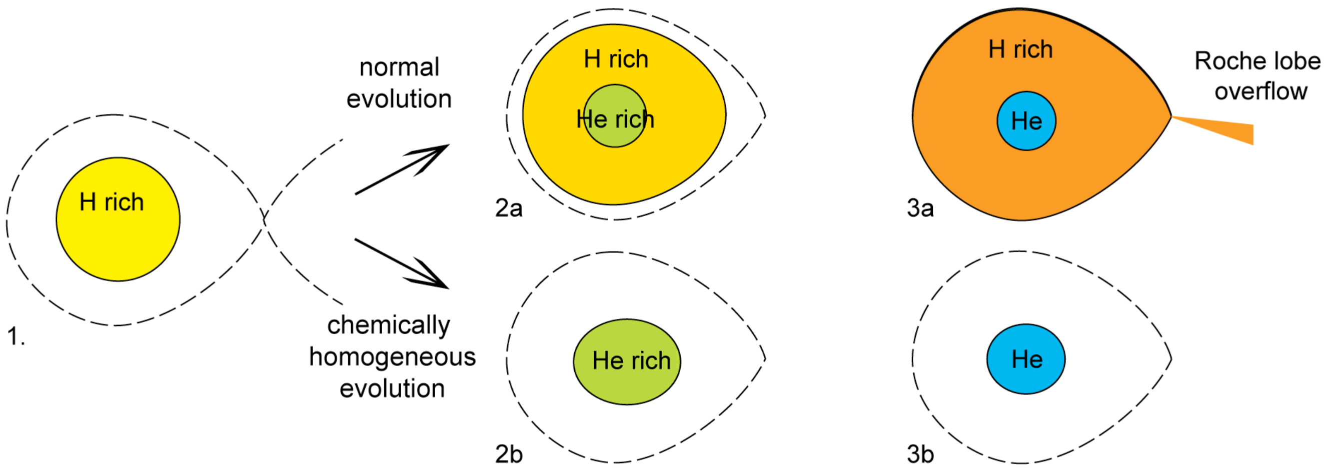

Figure 1: Cartoon representation of the effects of rotational mixing in massive short period binaries. In standard evolutionary models (a), stars form a core-envelope structure. The envelope expands and severe mass loss via Roche lobe overflow is inevitavle in close systems. If we consider the effects of efficient mixing (b) helium is transported throughout the envelope. The stars stays compact and prevents the onset of mass transfer to its companion. This type of evolution naturally leads to the formation of massive, stellar-mass black-holes in close orbits around their companion, such as M33 X-7.

Mass loss from interacting binaries

--- De Mink, Pols & Hilditch A&A, 2007

One of the major uncertainties in binary evolution is the efficiency of mass transfer: how much mass and angular momentum is transferred between the two stars and how much is lost to the surroundings. We computed a grid of over 20.000 detailed binary evolutionary models on a highperformance computing cluster, for different assumptions of the mass transfer efficiency. After a systematic comparison with the well-determined parameters for 50 eclipsing binaries in the Small Magellanic Clouds -- the largest homogeneous available – we found evidence for severe mass loss. Our models show that about 50-75% of the binary systems with orbital periods smaller than 5 days come into contact, depending on the assumed mass transfer efficiency. These systems are likely to merge and they will appear as massive blue stragglers in young star clusters. This model grid will be used as the start for the project I propose to undertake with the CfA fellowship.

The source of abundance anomalies in globular clusters:

--- De Mink, Pols, Langer & Izzard A&A Letters in press

Globular clusters appear to host multiple populations of stars with different ages or different chemical composition within them. It has been proposed that a first stellar generation polluted the cluster, after which a second generation of stars formed out of enriched material. Two sources of pollution have been proposed in the literature, Asymptotic Giant Branch (AGB) stars and Fast Rotating massive stars. Although both sources are promising they have severe problems to match the observed abundance patterns and to provide enough material to form a second generation, which is more numerous than the first generation.

In this letter we argue that severe mass loss from interacting binaries if a common phenomenon, we demonstrate that these ejecta show the same abundance patterns as observed in globular clusters, see Figure 2 for a cartoon. We argue that the amount of ejecta by binaries is likely to be larger than the ejecta of both previously proposed sources combined, see Figure 3.

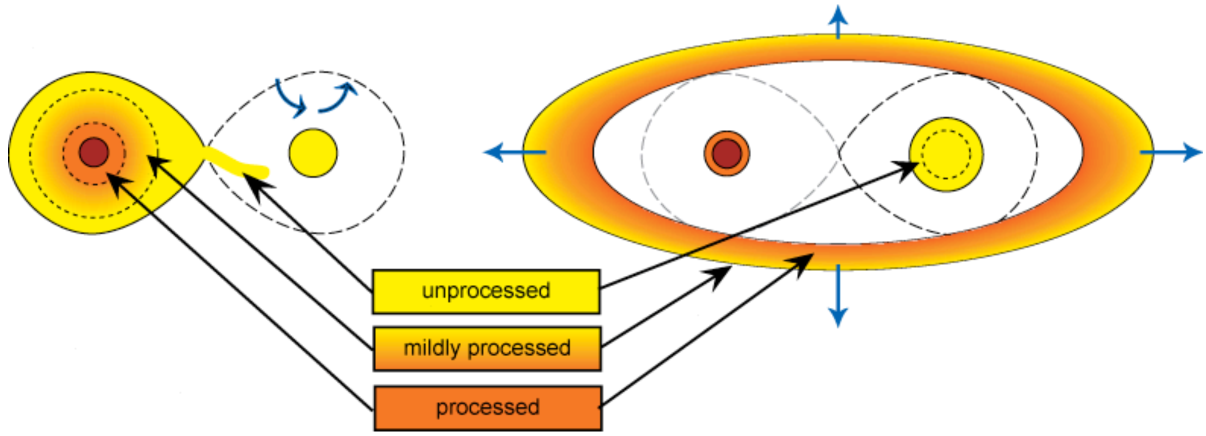

Figure 2: Cartoon representation of interacting binaries as sources of processed material. Initially the companion star accretes all transferred mass, but by the time deeper layers of the donor star are exposed, the accretor has been spun up to break-up speed. From this moment on mass is preferably shedded from the system into a circum-binary disk. The massive interacting binary RY Scuti is thought to recently have gone through this phase. As the ejected material originates from deeper layers of the mass loosing stars it is enriched with H-burning products, such as He, but also N, Na and Al, similar to what is observed in anomalous globular clusters stars.

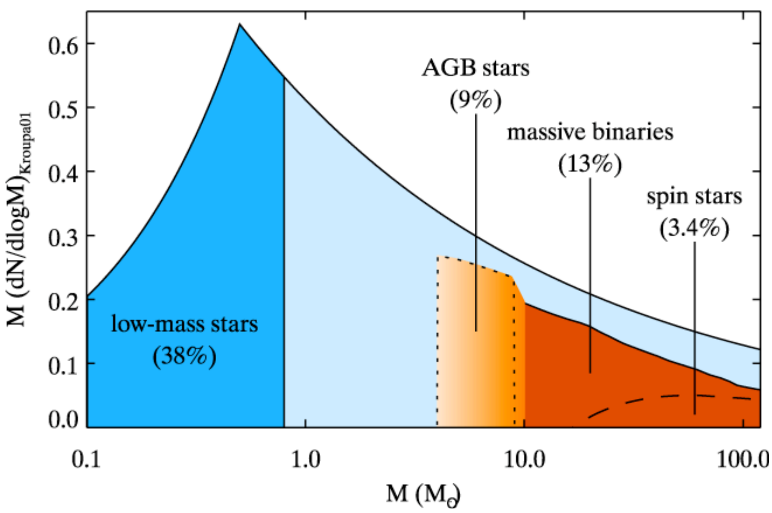

Figure 3: Mass weighted stellar initial mass function. The surface area on the left indicate the mass contained in the first generation of long-lived, low mass stars (38% of the total mass initially contained in stars).

A second generation of long lived low mass stars can be formed out of the ejecta of more massive stars such as the ejecta from AGB stars (below the dotted line) or fast rotating massive stars (below the dashed lines).

We propose interacting binaries as an alternative promising source. The ejecta of massive and intermediate mass systems combined is larger than that of the two previously proposed sources. For details see De Mink et al A&A in press.

Are the apparent multiple populations in intermediate-age clusters real?

--- Bastian & De Mink MNRAS Letters, 2009

After the discovery of multiple populations in massive globular clusters, evidence for the same phenomenon was claimed for intermediate-age clusters. This evidence was based on the distribution of stars in the color-magnitude diagram, in particular the spread observed near the turn-off. In this letter we investigate whether stellar rotation can provide an alternative explanation for this spread.

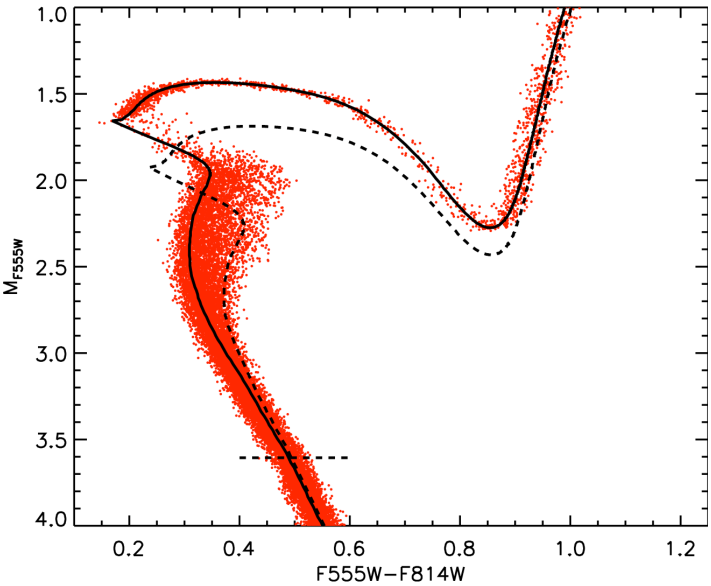

Figure 4: Simulation of the effects of rotation on a color magnitude diagram of a 1.25 Gyr old cluster (isochrone indicated by the full line) using a Monte Carlo method.

The dashed line is a 1.5 Gyr isochrone. The effects of rotation can mimic an age spread in the order of 0.25 Gyr. See Bastian and De Mink 2009 for details.

Interestingly, intermediate-mass stars, the stars near the turn-off of such clusters, are probably the fastest rotators of all stars. Lower mass stars slow down due to the magnetic field generated in their convective envelopes. Higher mass stars spin down due to angular momentum loss in their stellar winds.

In this we estimate the effect of rotation on the magnitude and colors of intermediate-mass stars near the turn-off and we show that rotation results in a spread near the turn-off (see Figure 4), which can mimic an age spread of about 0.25 Gyr, similar to what is observed.

I computed the effects of rotation on the structure of stars due centrifugal and deformation effects. I developed the method and provided the main ideas. Bastian initiated and managed the project. Because of my large contribution to this paper it is part of my Ph.D thesis.

The formation of intermediate mass-black holes through multiple collisions?

--- Glebbeek, Gaburov, De Mink et al A&A 2009

In this paper we follow the evolution of a runaway collision product, a massive stars in the center of a dense star cluster, which repeatedly collides and merges with other stars. We investigate the hypothesis that this scenario leads to the formation of intermediate-mass black holes by taking into account the latest mass loss rate prescriptions. We find that severe mass loss, especially during the Wolf-Rayet phase, prevents the formation of an intermediate mass black hole, even at low metallicity.

An interesting finding in this paper, which links it to my other work, is that the runaway collision product provides ejecta processed by H-burning. These may be partially responsible for the observed abundance anomalies in the most massive globular clusters.

For this paper I updated the stellar evolutionary code with the latest opacity tables. Furthermore I investigated and discussed the peculiar core-halo structure of the merger product. Because my substantial contribution to this paper it is included in my Ph.D thesis.

The most metal-poor stars in the halo and Fluorine:

-- Lugaro, De Mink, Izzard et al. A&A Letters 2008

The old, low-mass stars in the galactic halo are the most metal-poor objects in our galaxy. They provide a window to the past, as they are formed from the ejecta of the very first generations of stars that enriched their surroundings with nuclear burning products. However, it has been proposed that some abundance patterns, in particular enhancement in Carbon, may be due to pollution via mass transfer by a former AGB companion star.

In this letter we discuss the recent discovery of a metal-poor star strongly enriched in Fluorine (Schuler et al. 2007). We show that its surface abundances can be explained with a binary pollution scenario (see Figure 5) and we predict that, according to this scenario, nearly all metal-poor stars that are enriched in Carbon, are also expected to be enriched in Fluorine.

I share first authorship on this paper with Lugaro, who took the initiative for this paper and managed the collaboration with the large number of co-authors. I came up with and developed the method, performed the computations, provided the plots and wrote the main sections. Because the large contribution I made to this paper it is part of my Ph.D thesis.

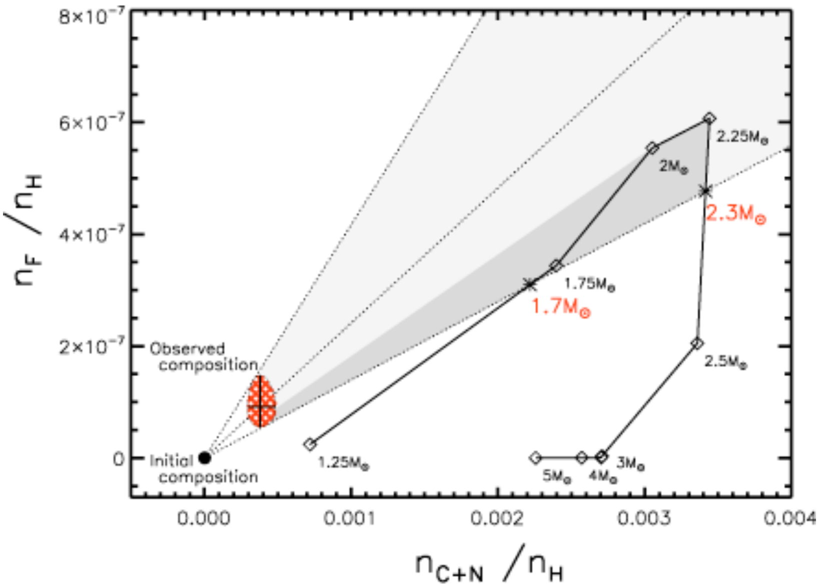

Figure 4: The abundance by number of Fluorine and Carbon plus Nitrogen with 1 sigma error bars as observed for the Fluorine-rich halo star (Schuler et al. 2007, hatched ellipsoid).

If these abundance patterns originate from mass accretion from an AGB companion and subsequent dilution into the envelope of star itself which has a composition indicated as “initial composition”, the composition of the AGB ejecta should lie in the grey area.

The average ejecta computed from AGB models with different masses (diamonds, connected by a line) is over plotted. The ejecta of models with initial masses between 1.7 and 2.3 solar can match the observed abundances after dilution. More information, Lugaro et al (2008).