Magnetic stars, 2004, 268-271

The movie about the magnetism in isolated white dwarfs

Śliwiński M.S.[1], **Krzyczkowska L.I.**[1]

Astronomical Observatory of the Warsaw University, Al. Ujazdowskie 4, 00-478 Warsaw, Poland sliwinsk@astrouw.edu.pl, lunarismaar@wp.pl

Abstract.

We present the movie about magnetism in the isolated white dwarfs. We tried to create a brand new form of presentation of astronomical knowledge. This one was made to show it to the scientists, so we assumed some level of knowledge that was needed to understand the movie. However it still can be a way to arouse interest of non-astronomers (even children) in astronomical research. This could also be the best way to teach young people or help them to understand astronomy and astrophysics that they have to learn at school. Below we report the plot of the movie adding, in some parts, comments that will follow.

Key words: white dwarfs – stars: magnetic fields – education

1 Isolated white dwarfs

White dwarfs are intensively studied end products of stellar evolution. However, investigations of white dwarfs have generally focused on the dominant group of nonmagnetic stars for which realistic model atmospheres can be constructed and fundamental properties, such as their masses or interior chemical composition can be determined. Similar progress in understanding properties of the magnetic white dwarfs has been more difficult to achieve, although significant advances have been made. Following the discovery of a magnetic field of 1500 G in the Ap star (78Vir) by Babcock in 1947, it became apparent that sizeable magnetic fields were present in stars other than our Sun. If the magnetic flux was conserved during stellar evolution, then some white dwarfs should be expected to have magnetic fields of order of $\sim 10^7 - 10^8$ G. The number of known members of this class continually grows. As the basic data for this movie we used the survey by Wickramasinghe and Ferrario (2000) containing 65 isolated magnetic white dwarfs. At that time there were about 150 magnetic white dwarfs known. The observed fraction of magnetic objects is about 5% for isolated white dwarfs (Wickramasinghe & Ferrario 2000). Their magnetic fields reach $\sim 10^4 - 10^9$ G and their space density is 1.5×10^{-4} per cubic parsec. About 80% of the isolated magnetic white dwarfs have almost pure hydrogen atmospheres and show only hydrogen lines in their spectra (this is magnetic DA type). The remaining stars show neutral helium lines (DB type) or molecular bands of carbon and hydrocarbons (DQ). The latter group has helium as the dominant atmospheric constituent, mirroring the situation in the nonmagnetic white dwarfs. The incidence of stars of mixed composition (H & He) appears to be higher among the magnetic stars. The progenitors of the vast majority of the isolated magnetic white dwarfs are likely to be the magnetic Ap and Bp stars. However, there is also a class of massive, rapidly rotating magnetic white dwarfs, for example, PG 1031+254 (3 hr), Feige 7 (3 hr) and the recently discovered high-field star EUVE J0317-855 (725 s). For these stars, the rotation periods appear to be very high, even compared to their nonmagnetic counterparts. Surprisingly that the strong magnetic fields have not been effective in spinning down these stars, although they appeared to have played such a role in most stars of this type. This fact has led to the suggestion that some of these stars could be the result of double-degenerate mergers.

2 Rotational periods

The observational results suggest efficient angular momentum transfer from the core to the envelope and large-scale angular momentum loss during the post-main-sequence evolution. The magnetic white dwarfs should rotate slower than the nonmagnetic stars because the magnetic fields are likely to cause increased braking of the stellar core as it approaches the white dwarf state. Two subclasses could be identified among the rotating magnetic white dwarfs. The first class appears to rotate slowly with no evidence of spectral or polarimetric variability over periods of tens of years, while the other exhibits rapid rotation with periods in the range of tens of minutes to hours or days. Magnetic white dwarfs which are likely progenitors of magnetic Ap and Bp stars, are known as a class of slow rotators (Borra et al. 1982). The fast rotating isolated magnetic white dwarfs may include as a subclass stars which have been spun up during a double degenerate merger or a previous phase of mass transfer from a companion star. There is a strong suggestion of a bimodal period distribution, depending on the kind of progenitor: a single star or a binary. The largest measured rotation period is 17.9 days for KUV18134-14. However, searches for changes in the polarization angle in several other high-field magnetic white dwarfs over periods of tens of years have led to negative results. These stars must have a rotation period of the order of 100 years (West 1989; Schmidt & Norsworthy 1991). Extreme slow rotation may therefore be a characteristic of the large majority of the magnetic white dwarfs. If angular momentum was conserved at the post-main-sequence phase of evolution, the rotational velocities of white dwarfs could reach the break-up value.

3 Mass distribution

There is growing evidence based on trigonometric parallaxes, space motions, and spectroscopic analyses that the isolated magnetic white dwarfs as a class have higher masses than the nonmagnetic stars (Liebert 1988). From the EUVE survey (Vennes 1999), a very large fraction, 25%, of the discovered fifteen ultramassive white dwarfs are magnetic objects. The mass distribution of magnetic white dwarfs also appears to be bimodal with the primary peak at 0.8 solar mass, and the lower secondary peak at 1.2 solar masses. There is a possibility that the magnetic white dwarfs cluster around a mass peak corresponds to single star evolution and the second peak arises from evolution of binary systems. Both peaks could be shifted toward higher masses. The shift toward higher masses could simply indicate that magnetic fields play an important role in post-main-sequence evolution controlling both mass and angular momentum loss, resulting in a different initial-final mass relation for the magnetic stars. There are other results shown in the latest paper by Nalezyty and Madej (2004). They show no evidence for bimodal mass distribution. Moreover, it appears to be rather flat and does not show the secondary maximum at 1.2 solar masses. However, most of the magnetic white dwarf masses are not exactly known. Large error boxes in both cases and differences in mass determination methods could play an important part in generating mutually inconsistent results. Comparing the results obtained by Valyavin and Fabrika (1998), Wickramasinghe and Ferrario (2000) to these of Nalezyty and Madej (2004), we have found, however, some similarities.

4 Field distribution

The field spread of the magnetic white dwarfs is about a factor 100 larger than that of their progenitors, ranging from 10^5 to 10^9 G, peaking at 1.6×10^6 G. Attempts of measuring lower fields have led to negative results in most cases, possibly indicating that the field distribution turns over at about 10^5 G. Most stars have directly measured field strengths from the Zeeman effect in hydrogen, helium, or hydrocarbon lines. These span a field range from 10^5 to 10^9 G. A few stars are classified as strongly magnetic ($>100\,$MG) objects purely on the basis of peculiar absorption-line spectra. For objects with weaker fields, where the spectral resolution does not allow observing Zeeman splitting, high signal-to-noise ratio circular spectropolarimetry of the H-alpha line was used. 5.1% of known isolated white dwarfs are magnetic stars. Searching for some correlation between magnetic field and mass has brought to no results, but the exact masses are known but for very few objects. There appears to be no correlation between magnetic field strength and cooling age either. Among the 65 known magnetic white dwarfs there is an approximately equal number of stars between 5 and 10,000 K, and between 10 and 20,000 K (Wickramasinghe & Ferrario 2000). Their number drops rapidly at higher temperatures. It has been confirmed by the results of the latest survey by Nalezyty and Madej (2004).

5 The origin of the magnetic fields

Magnetic flux conservation of a fossil field could naturally lead to the observed field distribution in white dwarfs as a star in radius by a factor of 100, as it evolves toward the white dwarf sequence. It is therefore tempting to identify the progenitors of the magnetic white dwarfs, resulting from a single star evolution, to be Ap and Bp stars. Moreover, the estimated "birth rate" of magnetic white dwarfs appears to be generally consistent with this hypothesis (Angel et al. 1981). The timescale for the free ohmic decay of the low order field components would typically exceed the cooling time of a white dwarf ($\sim 10^{10}$ years), supporting the fossil origin of the fields (Chanmugham & Gabriel 1972; Fontaine et al. 1973). An interesting method of testing this theory has been proposed by Kanaan et al. (1999). On the assumption of coeval star formation in clusters, clusters young enough for Ap stars not to have evolved off the main sequence should not show evidence of magnetism in white dwarfs. On the other hand, clusters old enough for Ap stars to end the main sequence should include such stars. The first results reported for M44 showed a massive (0.912 $M_\odot$) magnetic white dwarf EG 61 with a field of 2 MG, few normal and one low-mass nonmagnetic white dwarf. From the age of the cluster and the estimated cooling age of the magnetic white dwarfs, the progenitor mass is estimated to be 2–3 solar masses, which is in the mass range where Ap stars are found. Subsequent observations showed, that the most massive white dwarfs in M44 are magnetic, which adds support to the statement, that the magnetic field inhibits mass loss in post-main-sequence evolution and favors the formation of more massive stars. In fact we did not manage to find any paper about the continuation of this experiment.

6 Field structure

The field strength and the complexity of the observed sample are expected to be related to the origin of the magnetic field and its evolution during the cooling sequence. The surface field distributions tend in general to be strongly nondipolar, and in a first approximation can be modeled by dipoles that are offset from the center by $\sim$ 10%–30% of the stellar radius along the dipole axis. Other stars show extreme spectral variations with rotational phase, which cannot be modeled by off-centered dipoles. More exotic field structures with spot-type field enhancements appear to be necessary. It is even more difficult to investigate whether there is any evidence for the evolution of the complexity of the field with age. The surface dipolar component decays by a factor of 2 during 10^9 yr for a 0.6 solar mass white dwarf when matter in the deep interior is in the Coulomb liquid state (Wendell et al. 1987; Muslimov et al. 1995). The higher order components decayed significantly faster, so the presence of a dominant quadrupolar or higher order components in magnetic white dwarfs were difficult to explain by these free ohmic decay models. Even though the Ap and Bp stars do show evidence for complex field structures, the complex field structures seen in the magnetic white dwarfs were unlikely to be fossil remnants of this phase. Because of growing evidence for the existence of complex fields in white dwarfs, an additional ingredient in the field decay models was included — the Hall drift (Muslimov et al. 1995). The Hall drift effectively couples the different poloidal modes in a nonlinear manner, so that the field decay is no longer free ohmic. The white dwarf acquires a strong (10^9 G) toroidal field through differential rotation at the pre-white dwarf phases of evolution in addition to a poloidal component. The inclusion of the Hall effect allows the field to continue its evolution after the core has frozen. Through the nonlinear coupling, the higher order poloidal components may in fact be amplified relative to the dipolar component, and under certain circumstances relative amplification by up to a factor of $\sim$ 2–20 of the quadrupolar component occurs on a timescale of 10^{10} yr. The field decay of the dipolar component and the relative amplification of the quadrupolar mode were strong functions of white dwarf mass. The Hall effect may therefore play a crucial role in explaining the bizarre field structures in magnetic white dwarfs. In spite of constant progress in conducted researches, our knowledge of magnetism in white dwarfs is still incomplete. These stars represent a province where the unknown is awaiting right beyond the horizon...

Acknowledgements. We would like to thank Professor Jerzy Madej for consulting and encouragement. We are also very grateful to Miroslaw Nalezyty for useful information and great amount of paper work. Finally we would like to thank Greg Wade and scientists of SAO for helping us with forcing this movie to work.

References

Angel J.R.P., 1978, Annu. Rev. Astron. Astrophys., **16**, 487
Babcock H.W., 1947, Astrophys. J., **105**, 105

Borra E.F., Landstreet J.D., & Mestel L., 1982, Annu. Rev. Astron. Astrophys., **20**, 191
Blackett P.M.S., 1947, Nature, **159**, 658
Chammugam G., Gabriel A.H., 1972, Astron. Astrophys., **16**, 149
Cumming A., 2002, Mon. Not. R. Astron. Soc., **333**, 589
Heber U., Napiwotzki R. & Reid I.N., 1997, Astron. Astrophys., **323**, 819
Kanaan A., Claver C.F. & Liebert J., 1999, in: ASP Conf. Ser., **169**, 221
Liebert J., 1988, Publ. Astr. Soc. Pacific, **100**, 1302
Muslimov A.G., van Horn H.M. & Wood M.A., 1995, Astrophys. J., **442**, 758
Nalezyty M., Madej J., 2004, Astron. Astrophys., in print
Schmidt G.D. & Norsworthy J.E., 1991, Astrophys. J., **366**, 270
Schmidt G.D. & Smith P.S., 1995, Astrophys. J., **448**, 305
Sion E.M., Fritz M.L., McMullin J.P. & Lallo M.D., 1988, Astron. J., **96**, 251
Valyavin G.G., Fabrika S.N., 1998, Bull. Spec. Astrophys. Obs., **45**, 69
Valyavin G.G., Fabrika S.N., 1998, Bull. Spec. Astrophys. Obs., **45**, 84
Vennes S. 1999, Astrophys. J., **525**, 995
West S.C., 1989, Astrophys. J., **345**, 511
Wendell C.E., van Horn H.M. & Sargent D., 1987, Astrophys. J., **313**, 284
Wickramasinghe D.T., Ferrario L., 2000, Publ. Astr. Soc. Pacific, **112**, 873