Plausibility of the planet-engulfing scenario for V838 Mon from the current knowledge on extrasolar planets

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Abstract.

One of the hypothesis to explain the outburst of V838 Mon is the engulfment of planets. More than 170 extrasolar planets were discovered in the past years. Their properties and the characteristics of their host stars can be used to evaluate the plausibility of this hypothesis. However, the large mass and young age of V838 Mon make the object rather different from the typical targets of current planet searches. Therefore, the expectations of planet engulfing events derived from them are not directly applicable to the case of V838 Mon. Some of the properties of V838 Mon (as the probable large stellar mass and sub-solar metallicity) make somewhat unlikely the presence of planets around it, but the uncertainty on the mass and age of the progenitor and the lack of knowledge of planet formation around massive star do not allow a firm conclusion.

1. Introduction

One of the hypothesis to explain the spectacular outburst of V838 Mon is the engulfment of planets (Retter & Marom 2003; Retter et al. 2006). More than 170 extrasolar planets were discovered in the past years (Butler et al. 2006). Their properties and the characteristics of their host stars may help the evaluation of the plausibility of this hypothesis. This approach is independent and complementary to the physical modeling of planet swallowing by different types of stars, aimed to study whether the unusual evolution of V838 Mon and related objects can be explained by such an event.

We recall here some properties of V838 Mon that can be relevant for a study of the possibility of having planets around it.

• V838 Mon is a massive and young star. The details remain to be established because of the uncertainties on the photometry of the progenitor, on the contribution of the B3V companion to the integrated light of the system, and on reddening and distance. Munari et al. (2005) favour a high mass of $\geq 30 \, M_\odot$ for the progenitor and an age of a few Myr, on the basis of the location of the progenitor blueward of the main sequence (see also R. Hirschi, this conference) while Tylenda et al. (2005) propose two scenarios depending on the adopted photometry of the progenitor and reddening and distance scales: a $9 \, M_\odot$ star $< 20 \, \text{Myr old}$ or a $5 \, M_\odot$ in pre main-sequence phase (age 0.3 Myr). It appears that there are no chance for the star to have been an AGB star in the past.
V838 Mon is a binary star, as it has a B3V companion (Desidera & Munari 2002). This star remained apparently unaffected by the outburst, implying a separation larger than a few AU.

V838 Mon lies at a galactocentric distance of about 15 kpc. At such galactic location a low metallicity for the young galactic population is expected ([Fe/H] about -0.5; Maciel et al. 2005) and indeed suggested by the analysis of Kipper et al. (2004) and Kaminsky & Pavlenko (2005).

2. Properties of giant planets

The on-going searches for extrasolar planets have deeply changed our knowledge of planetary systems, based until a few years ago only on the Solar System. Now we know that giant planets can be found even at very small separations from the parent stars and that planets with period longer than 10 days (the limit of tidal circularization of the orbits) can have eccentricities much larger than those of Solar System planets (Butler et al. 2006). The mass function rises steeply toward lower masses, and there is likely overlap in mass between objects formed in a circumstellar disk (planets) and objects formed via cloud fragmentation (brown dwarfs). Multi-planet systems are rather common, showing a large variety of configurations. Two systems (55 Cnc and GL 876) have two giant planets and one Super-Earth or Neptune-mass planet closely packed within 0.25 AU from the star (Mc Arthur et al. 2004; Rivera et al. 2005) with a further planet in external orbit in the case of 55 Cnc, somewhat resembling the planetary system architecture with three close giant planets postulated by Retter & Marom (2003) for V838 Mon. However, the uniqueness of these cases among more than 3000 stars under high-precision radial velocity monitoring indicates an intrinsic rarity of such a configuration.

3. Properties of the host stars

The most relevant property of planet host is the high metallicity: the frequency of planets is a strong function of the metallicity of the parent star (Fischer & Valenti 2005) As an example, at [Fe/H]=−0.2 the frequency of giant planets is more than 6 times smaller than that at [Fe/H]=+0.2. Statistic concerning metal poor stars is not sufficient to determine if below [Fe/H]=−0.4 the planet frequency continues to decrease or remains nearly constant at lower metal content (Santos et al. 2004). The lowest metallicity planet hosts have [Fe/H]≈−0.6, if one excludes the planet candidate around a pulsar in the globular cluster M4 ([Fe/H]≈−1.2), that may have been formed in different way to planet found around solar-type stars (Sigurdsson et al. 2003).

Planets are found in binary systems with a large range of separations (Eggenberger et al. 2004; Desidera & Barbieri 2006), indicating that planets can exists even in presence of fairly strong dynamical interactions.

The frequency of planets as a function of stellar mass is only poorly constrained from available data. Infact, most of the planet search surveys are focused on solar-type stars (late F and G-K dwarfs). A few surveys are considering M dwarfs, with preliminary indications for a lower frequency of giant planets and
a similar frequency of Neptune-mass planets with respect to solar-type stars (e.g. Bonfils et al. 2005).

4. Planets and disks around intermediate and high mass stars

Search for planets around main-sequence stars more massive than 1.5 solar masses is limited by the shallowness of absorption lines of early type stars. Some planet search programs are focusing on their evolved counterparts, i.e. giants, and a few planets have been discovered around K and G giants (Hatzes et al. 2006 and references therein). The most massive planet host is probably HD 13189 (3.5 $M_\odot$); however the nature of the companion is somewhat uncertain as it has a mass at the boundary between planets and brown dwarfs (Schuler et al. 2005). More in general, the typically fairly large mass of planets orbiting stars more massive than 1.5 solar masses might suggest that planet formation process scales with the primary mass, but further studies are required to exclude the occurrence of selection effects. In any case, the mass range corresponding to the probable mass of the progenitor of V838 Mon remains basically unexplored by current planet search projects.

The metallicity of giant stars with planets is not anomalously high, possibly indicating that the planet-metallicity connection observed for solar-type stars does not apply to intermediate mass stars. This might be explained by intrinsic differences of planet formation processes at larger stellar masses (e.g. if metal-poor disk around massive stars reach adequate dust content to allow giant planet formation while those round solar-type star do not). However, selection effects in the radial velocity surveys of giant stars might be at work (e.g. lower average metallicity of giants included in radial velocity surveys, larger radial velocity jitter and then lower planet detection capabilities for colder giants, color cuts in sample selection) and should be carefully investigated.

Indirect evidence for the occurrence of planet formation around intermediate mass stars can be drawn from the presence of debris disks around a significant fraction of A type stars (Greaves & Wyatt 2003). Some late B type stars also possess debris-disks. This indicates that planet formation proceeded at least until the formation of planetesimals around these stars (mass $\sim 1.6 - 3 \, M_\odot$).

Circumstellar disks around young stellar objects as massive as $\sim 10 - 20 \, M_\odot$ were observed, while observational evidences of the presence of circumstellar disks around stars more massive than $\sim 20 \, M_\odot$ remain elusive (Cesaroni et al. 2006). In most cases, the observed disks around $\geq 10 - 20 \, M_\odot$ stars are likely to be unstable and with short lifetimes (Cesaroni et al. 2006); possible long-lived structures were recently reported around two B[e] hypergiants in the Large Magellanic Cloud (Kastner et al. 2006). Formation of planets through the standard core-accretion process in the circumstellar environment of massive stars might be hampered by photoevaporation of dust grains.

5. Planets engulfing

The period distribution and frequency of extrasolar planets implies that a significant fraction of solar-type stars (about 3-5%) should engulf one or more giant planets during the RGB or AGB phases (see e.g. Livio & Soker 2002).
However, as noted in Sect. 1, the progenitor of V838 Mon was a rather warm star, likely with effective temperature higher than main sequence stars of similar luminosity. The hypothesis of planet engulfing caused by an increase of stellar radius driven by stellar evolution appears then unlikely. Furthermore, the high temperature of the central star represents a severe challenge for the presence of a Jupiter-mass hydrogen-rich planet orbiting close to the star. In fact, the UV flux of V838Mon progenitor was larger by several orders of magnitude than that of a solar-like star, probably resulting in evaporation of gaseous planets at small separation (Lammer et al. 2003).

An additional channel to planet engulfing is represented by the dynamical interactions within a planetary system, that most likely result in the ejection of planets from the system but sometimes cause infall of planets into the central star (Marzari & Wiedenschilling 2002). A phase of dynamical instability of a planetary system most likely arises at young ages, during the formation of the planetary system (e.g. as the result of the runaway gas accretion on the icy cores, if planets form according to the core-accretion scenario). The timescales for the formation of giant planets in the core-accretion model are of a few Myr (Alibert et al. 2005), comparable with the probable age of V838 Mon (Sect. 1). In the case of V838 Mon, the presence of the massive B3V companion and the interactions within the star cluster of which the star is probably a member (Afsar & Bond, this volume) can also be a source of dynamical instability.

A planet engulfing event caused by dynamical instability appears more suited to explain the high-energy outburst of V838 Mon, as the impact velocity of the infalling planets should be larger than in the case of planet engulfing caused by the increase of stellar radius driven by stellar evolution, and the planet could have been formed sufficiently far away to avoid evaporation.

6. Conclusions

The large mass and young age of V838 Mon make the object very different from the typical targets of current planet searches. Therefore, the expectations of planet engulfing events derived from them are not directly applicable to the case of V838 Mon. However, some indication for the evaluation of the planet-engulfing hypothesis to explain V838 outburst can be derived.

- An initial mass larger than $10^{-20} M_\odot$ would be critical for planet formation. Planets can be found around such a massive star likely only if they form in a different way around massive stars with respect to solar type stars (e.g. by disk instability).
- The young age of the system (a few Myr) is similar to the timescales of planet formation around solar-type stars and then is compatible with the presence of planets.
- Dynamical instability of a young planetary system might cause infall of a planet on the central star with large impact velocity. Planet engulfing caused by an increase of stellar radius appears less viable because of the evolutionary status of the progenitor and the probable planet evaporation for a planet in stable orbit close to the star.
• The low metallicity of V838 Mon works against the presence of planets around it, without being conclusive

• The binarity of V838 Mon does not exclude the presence of planets

• In any case the engulfment of three giant planets in two months during the outburst (Retter & Marom 2003) seems to require a very special architecture of the planetary system, which appears very unlikely for mature planetary systems and quite unlikely also for a scenario of dynamical instability during the early phases of a planetary system. If lower mass planets or a single engulfment event might be responsible of the outburst, the plausibility of the scenario would become larger.

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