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Constraints on the formation mechanism of the planetary mass companion of 2MASS 1207334-393254

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ABSTRACT
In this paper we discuss the nature and the possible formation scenarios of the companion of the brown dwarf 2MASS 1207334-393254. We initially discuss the basic physical properties of this object and conclude that, although from its absolute mass ($5M_{\rm Jup}$) it is a planetary object, in terms of its mass ratio q and of its separation a with respect to the primary brown dwarf, it is consistent with the statistical properties of binaries with higher primary mass. We then explore the possible formation mechanism for this object. We show that the standard planet formation mechanism of core accretion is far too slow to form this object within 10 Myr, the observed age of the system. On the other hand, the alternative mechanism of gravitational instability (proposed both in the context of planet and of binary formation) may, in principle, work and form a system with the observed properties.

Key words: stars: individual: 2M1207 – stars: low mass, brown dwarfs – planetary systems: formation.

1 INTRODUCTION

The system 2MASS 1207334-393254 (2M1207) is remarkable. Found in the TW Hydra association (distance ∼70 pc, age ∼10 Myr), the most massive object, 2M1207A, is a brown dwarf with mass $M_\star = 25\,M_{\rm Jup}$ (Gizis 2002), known to be surrounded by a circumstellar disc (Sterzik et al. 2004). The other body, 2M1207B, has a mass in the planetary range ($M_{\rm s} \sim 5\,M_{\rm Jup}$) and lies at a projected distance $R_{\rm s} \approx 55$ au from 2M1207A (Chauvin et al. 2004). This planetary-mass object has been shown to be comoving with 2M1207A (Chauvin et al. 2005). We will refer to its components, 2M1207A and 2M1207B, as primary and secondary respectively. The intriguing feature of the system is the mass of the secondary, although we note that mass estimates for these very low-mass objects are still subject to considerable uncertainties. The very existence of this system raises the question of the possibility of the formation of planets around brown dwarfs.

However, it is worth noting that this system is quite peculiar, if considered as a star-and-planet system. First, the mass ratio between the 'star' and the 'planet' ($q = M_\star/M_{\rm s} = 0.2$) is very high for a planet companion. Secondly, its semimajor axis is quite large (larger than the orbit of Neptune, which is 30 au). On the other hand, this system could easily be considered as a very low-mass binary. Mass ratios of $q \approx 0.2$ (even if they are low in the context of binaries) are not uncommon in binaries with a solar-like primary.

In this paper we discuss whether this system should be considered as a planetary system or rather as a very low-mass binary. In Section 2 we start by discussing the properties of the system in the context of the statistical properties of binaries with a higher mass primary. Then, in Section 3, we consider the constraints that the observed properties of the system place on its formation mechanism. We consider a number of possible scenarios: the core accretion model (which is generally considered for planet formation), the gravitational instability model (considered both for planets and for binary systems) and other possible binary formation processes. We conclude that the core accretion model is not able to account for the formation of the companion of 2M1207, its formation timescale largely exceeding the age of the system. On the other hand, the gravitational instability model and, possibly, other binary formation mechanisms are in principle able to form this system.

2 IS 2M1207 A 'BINARY-LIKE' OR A 'PLANET-LIKE' SYSTEM?

Evidently, the absolute mass of the companion of 2M1207 places it firmly in the planetary regime. Indeed, $5\,M_{\rm Jup}$ planets are commonly detected around solar-mass stars. However, since radial velocity surveys only probe systems with separation $a \lesssim 5$ au (i.e. ≈0.1 times the separation of 2M1207), we do not know whether such massive planets at large separations are common around solar-mass stars.

On the other hand, the *mass ratio* is binary-like. In order to assess this, we compare the properties of 2M1207 with those of binaries with a higher mass primary. In particular, we consider the two samples of Fischer & Marcy (1992), who analyzed the binary properties of M dwarfs (with primary mass in the range 0.1–0.57 $M_\odot$), and

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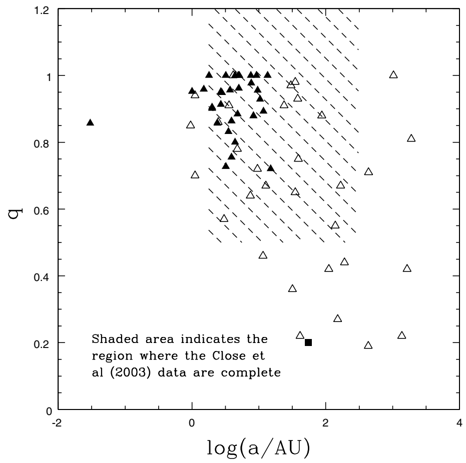

Figure 1. Correlation between the logarithm of the separation a (in au) and the mass ratio for the binaries observed by Fischer & Marcy (1992, open triangles) and Close et al. (2003, filled triangles). The filled square illustrates the properties of the companion in 2M1207.

the sample of Close et al. (2003), who have collected a number of binaries with primary masses in the range 0.05–0.095 $M_{\odot}$.

In Fig. 1 we show the correlation between separation and mass ratio for the two samples of Fischer & Marcy (1992) (open triangles) and of Close et al. (2003) (closed triangles), including only resolved binaries, for which the mass ratio can be reliably determined (see discussion in Mazeh & Goldberg 1992). In the Fischer & Marcy (1992) sample, a slight tendency of having lower q for wider systems can be seen, in agreement with the conclusion of Mazeh & Goldberg (1992) for higher mass primaries. On the other hand, the Close et al. (2003) sample shows a shortage of systems with large separation, even if very few systems with separations larger than 10 au have also been found (Luhman 2004; Phan-Bao et al. 2005).

Where does 2M1207 stand in this context? The mass ratio and separation of 2M1207 is plotted in Fig. 1 with a filled square. With respect to the Close et al. (2003) sample, it appears to be unusual in that it has a larger separation (roughly a factor 3 larger than the widest system in Close et al. 2003). However, it can be seen that the properties of 2M1207 are perfectly consistent with the distribution seen in Fischer & Marcy (1992). 2M1207 could therefore be just a rare wide system for brown dwarf binaries, but with a mass ratio perfectly consistent with the distribution observed for primaries of higher masses. Note that the mass of the companion of 2M1207 is below the completeness level of Close et al. (2003) and could not have been detected by them.

We therefore conclude that, if the companion orbited a star, it would have been classified as a planet according to its absolute mass and as a binary according to its mass ratio q and separation a.

3 POSSIBLE FORMATION MECHANISMS

We now proceed to the discussion of the formation mechanisms for this systems, considering: (i) the core accretion mechanism (Pollack et al. 1996), which is usually considered for planet formation, (ii) a gravitational instability in a massive disc (Boss 2000), which is sometimes invoked both for planets and for binaries and (iii) other binary formation mechanisms.

3.1 Formation via core accretion

In this section we will show that the standard core accretion model, generally assumed to be the most likely formation mechanism for planets around solar-like stars, is not able to account for the formation of the companion of 2M1207 within 10 Myr, the observed age of the system.

We will not provide a detailed core accretion model for the formation of this system. Rather, we will give simple estimates of the relevant time-scales involved and will try to put constraints on the physical properties of the protostellar disc where the planet was born, based on these time-scales.

We start by noting that if the secondary formed out of a protostellar disc, this disc must have been quite massive, with $M_{\rm disc} \gtrsim qM_{\star}$. Such massive discs are uncommon around T Tauri stars, but might have been more common in earlier phases of star formation. In any event, such a massive disc must have been self-gravitating. In the context of gravo-turbulent models of cluster formation, it is difficult to explain the presence of extended discs surrounding such low-mass objects. In fact, in most numerical simulations of star formation (Bate, Bonnell & Bromm 2003), brown dwarfs are ejected from their parental cloud, and only in a few cases they are able to retain a large disc after ejection. On the other hand, there is now evidence for discs on small scales surrounding rather evolved (T Tauri-like) young brown dwarfs (Klein et al. 2003; Sterzik et al. 2004).

The core accretion model assumes that the formation of a giant planet proceeds in two steps. First, planetesimal of mass $m \approx 10^{18}$g accrete on to protoplanetary cores. After an initial rapid increase in the core mass due to accretion, the protostellar disc becomes depleted of solid material and the planetesimal accretion rate on to the core decreases substantially. In this phase, the core mass increases much more slowly with time and as the energy input from planetesimal accretion is turned off, the planetary atmosphere becomes unstable, starting a rapid phase of gas accretion, which occurs on the Kelvin–Helmholtz time-scale, $\tau_{\rm KH}$, given by (Ida & Lin 2004):

$$\tau_{\rm KH} = 10^9 \left(\frac{M_{\rm p}}{M_{\oplus}}\right)^{-3} \left(\frac{\kappa_{\rm d}}{1\,{\rm g}^{-1}\,{\rm cm}^2}\right)\ {\rm yr}, \quad (1)$$

where $M_{\rm p}$ is the mass of the planetary core and $\kappa_{\rm d}$ is the opacity of the gas disc. If we assume that the value of the opacity is the typical interstellar value of 1 cm^2 g^{-1}, in order to be able to accrete the gaseous envelope within 10 Myr (the age of the system), the planetary core in our case must therefore reach a mass of at least 4.6 $M_{\oplus}$ (see also Ida & Lin 2004). Recently, Hubickyj, Bodenheimer & Lissauer (2005) have shown how reducing the opacity can speed up the formation process. This is also clear from equation (1). However, since the dependence of the Kelvin–Helmholtz time-scale on mass is rather steep, even relatively large changes in the opacity only result in minor modifications of the required core mass. For example, if we assume $\kappa_{\rm d} = 0.02\,{\rm cm}^2\,{\rm g}^{-1}$ (the value used by Hubickyj et al. 2005), then the required core mass is only reduced to $\approx$1.26 $M_{\oplus}$.

In order to proceed further, we have to make some simplifying assumptions. In particular, we will initially assume that the planet formed at $R_{\rm s} = 55$ au (the effect of planetary migration is discussed below). We will also assume that the protostellar disc has a gas density profile $\Sigma_{\rm g} \propto R^{-1}$ and that the solid-to-gas ratio is 0.01, so that the surface density of solids is $\Sigma_{\rm d} = 0.01\Sigma_{\rm g}$. The surface density of the disc at $R_{\rm s}$ is:

$$\Sigma_{\rm g}(R_{\rm s}) = \frac{M_{\rm disc}}{2\pi R_{\rm s}^2}\frac{R_{\rm s}}{R_{\rm out}} \lesssim \frac{M_{\rm disc}}{2\pi R_{\rm s}^2}, \quad (2)$$

where $R_{\rm out} \gtrsim R_{\rm s}$ is the disc outer radius. If we take $M_{\rm disc} = 5\,M_{\rm Jup}$ (the minimum mass it should have in order to form the planet) and $R_{\rm s} = 55$ au, we get $\Sigma_{\rm g}(R_{\rm s}) \lesssim 2.33\,{\rm g\,cm}^{-2}$. Consequently, the surface density of solids at $R_{\rm s}$ is $\Sigma_{\rm d} \lesssim 0.023\,{\rm g\,cm}^{-2}$.

Note that, for such a density distribution of solids, there is in principle more than enough solid material in the disc for the core to grow up to $M_{\rm p} \approx 4M_\oplus$. However, the question is what is the time-scale needed for the core to reach this mass? Here, we again follow Ida & Lin (2004), and assume that the core mass as a function of time is given by:

$$M_{\rm p}(t) \approx 8\left(\frac{t}{10^6\,{\rm yr}}\right)^3\left(\frac{\Sigma_{\rm d}}{10\,{\rm g\,cm^{-2}}}\right)^{21/5} \left(\frac{R_{\rm s}}{1\,{\rm au}}\right)^{-9/5}\left(\frac{M_\star}{{\rm M}_\odot}\right)^{1/2}\left(\frac{m}{10^{18}\,{\rm g}}\right)^{-2/5} M_\oplus, \quad (3)$$

where m is the mass of the planetesimals and where we have also assumed that $\Sigma_{\rm d} = 0.01\,\Sigma_{\rm g}$.

Within 10 Myr (and assuming $M_\star = 25\,M_{\rm Jup}$, $m = 10^{18}$ g and $R_{\rm s} = 55$ au), the mass of the core will therefore be:

$$M_{\rm p} \approx 0.9\,M_\oplus\left(\frac{\Sigma_{\rm d}}{10\,{\rm g\,cm^{-2}}}\right)^{21/5}. \quad (4)$$

In order for $M_{\rm p}$ to be at least $4\,M_\oplus$, the surface density of planetesimals must be $\Sigma_{\rm d} \gtrsim 14\,{\rm g\,cm^{-2}}$, much larger than the estimate given above ($\sim$0.02 ${\rm g\,cm^{-2}}$), based on the estimated mass of the disc. If the density of solids were as high as $14\,{\rm g\,cm^{-2}}$, then the total disc mass must have been at least $M_{\rm disc} \approx 3500 M_{\rm Jup}$, which is far too large. Increasing the solid-to-gas ratio to 0.1 would not ease the situation, since it would require a disc mass of 350 $M_{\rm Jup}$, which is still unreasonably large. Note that if we only require the core to grow to $M_{\rm p} \approx 1.26\,M_\oplus$ (the minimum core mass required if we assume $\kappa_{\rm d} = 0.02$ cm^2 g^{-1}), the density of solids should still be as large as $\Sigma_{\rm d} \gtrsim 11\,{\rm g\,cm^{-2}}$, with little improvement. In principle, another possible way to speed up the core accretion is to reduce the mass of the planetesimals. However, the dependence on planetesimals' mass is much shallower than that on surface density (see equation 3), so that even reducing m by 10 orders of magnitude would only reduce the required surface density by a factor of 10.

We now consider the possible effect of planetary migration. When the protoplanet has acquired enough mass to open up a gap in the disc, it will undergo Type II migration, and its orbital evolution will be therefore locked to the viscous evolution of the disc. The outer parts of the disc spread out as a consequence of viscous forces, so, if the protoplanet formed at a sufficiently large radius, it could in principle migrate further out. We therefore proceed by estimating the maximum radius at which the protoplanet could have reached $4\,M_\oplus$ within 10 Myr, based on equation (3), assuming that $\Sigma_{\rm d}(R_{\rm s}) = 0.02$ g cm^{-2}, and considering the radial dependence of $\Sigma \propto R^{-1}$. In this way, we find that the maximum formation radius is $R_{\rm max} \approx 0.6$ au. This radius is well inside the typical radius separating the inward and outward moving portions of the disc (which is typically 10 au, see Ida & Lin 2004), so that even planetary migration would not reconcile the core accretion model with the observed properties of the system.

Finally, note that the above estimates assume that the surface density of solids and of gas in the disc is not dependant on time. In fact, both solids and gas are depleted on a time-scale comparable to the lifetime of the disc. This would increase the core accretion time-scale and would make it even harder (see equation 3) for the planetary core to grow to the required mass at late stages.

We can therefore conclude that the secondary in the system 2M1207 cannot have formed through core accretion, mainly because of its distance from the primary, which leads to a very small surface density of solids (even if the total disc mass is a significant fraction of the primary mass) and to a very large core accretion time-scale. We note that Laughlin, Bodenheimer & Adams (2004) came to similar conclusions regarding the possibility of forming giant planets through core accretion around M dwarfs.

3.2 Formation via gravitational instability

The discussion of the previous section shows that there must be a physical process *different from core accretion* able to form planetary mass companions, at least around brown dwarfs. In the context of planet formation, the natural alternative to the core accretion model is the gravitational instability scenario, where planets form from the fragmentation of a self-gravitating disc (Boss 2000). Here we examine the plausibility and the uncertainties of this model.

As we have already shown in the previous section, the total mass of the disc $M_{\rm disc}$ must have been at least of the order of $qM_\star = 0.2M_\star$. Such a massive disc must have been self-gravitating. In particular, the condition for being subject to gravitational instability at radius R (usually described in terms of Toomre's stability criterion $Q = c_{\rm s}\kappa/\pi G\Sigma_{\rm g} \approx 1$, where $c_{\rm s}$ is the sound speed and $\kappa \approx \Omega$ is the epicyclic frequency) is that the disc mass contained within R satisfies the following relation:

$$\frac{M_{\rm disc}(R)}{M_\star} \gtrsim \frac{H}{R}, \quad (5)$$

where H is the disc thickness. In the following we will assume that $H/R \approx 0.1$, a typical requirement for protostellar discs. What would be the mass of a fragment produced in such an unstable disc? It can be easily shown that the most gravitationally unstable wavelength is $\lambda \approx 2\pi H$ and therefore the typical mass of a fragment would be:

$$M_{\rm frag} \approx \Sigma_{\rm g}\lambda^2 = (2\pi)^2\Sigma_{\rm g}H^2 = 2\pi\left(\frac{H}{R_{\rm s}}\right)^2 M_{\rm disc}(R_{\rm s}) \gtrsim 2\pi\left(\frac{H}{R_{\rm s}}\right)^3 M_\star, \quad (6)$$

where we have used the constraint that the disc mass at $R_{\rm s}$ should be high enough to be gravitationally unstable (equation 5). Putting in the relevant estimates for H/R and $M_\star$, we get $M_{\rm frag} \approx 50\,M_\oplus$. Note that this mass is large enough (cf. equation 1) for the corresponding Kelvin–Helmholtz time-scale to be shorter than the lifetime of the system. Therefore, if sufficiently resupplied, the fragment is able to adjust its internal structure and grow to planetary mass. The mass accretion rate needed to grow to 5 $M_{\rm Jup}$ in 10 Myr is $\dot{M} \approx 5 \times 10^{-10}\,{\rm M_\odot\,yr^{-1}}$. Accretion rates of the order of $10^{-10}\,{\rm M_\odot\,yr^{-1}}$ are usually observed in the disc of brown dwarfs (Mohanty, Jayawardhana & Basri 2005), and, since most of the planet's mass is accreted before the planet is able to open up a substantial gap in the disc, it is able to accrete a sizable fraction of the mass accretion rate through the disc.

The major obstacle in the gravitational instability scenario is that the condition $Q \approx 1$ (or, equivalently, our equation 5) is a necessary but not sufficient condition for fragmentation. The development of a gravitational instability heats up the disc (Lodato & Rice 2004, 2005), making it more stable. Fragmentation occurs only if the cooling time-scale in the disc is sufficiently fast (of the order of $3\,\Omega^{-1}$; Gammie 2001; Rice et al. 2003). In fact, it has been shown (Rice, Lodato & Armitage 2005) that, depending on the assumed adiabatic index in the disc, fragmentation can occur relatively more easily, i.e. for cooling times of the order of $10\,\Omega^{-1}$. The results of Rice et al. (2005) suggest that gravitational instabilities cannot provide an indefinitely large dissipation in the disc, larger than $\alpha \approx 0.06$ (using the standard α description of dissipative processes in discs).

If this dissipation term is not sufficient to balance the cooling of the disc, then fragmentation occurs.

Rafikov (2005) has computed the requirement on the disc structure in order for the cooling to be fast enough to allow fragmentation, under fairly general conditions. He found that fragmentation occurs if the gas disc surface density is larger than a given threshold $\Sigma_{\rm inf}$. If we compute $\Sigma_{\rm inf}$ from equation (7) in Rafikov (2005), and scale it down to our system, we find that $\Sigma_{\rm inf} \approx 10\,{\rm g\,cm^{-2}}$ only slightly larger than our simple estimate for the disc density $\Sigma_{\rm g} \approx 2.3\,{\rm g\,cm^{-2}}$. However, in his estimate of $\Sigma_{\rm inf}$, Rafikov (2005) assumed that the cooling time threshold for fragmentation was $3\,\Omega^{-1}$, while, as discussed above, Rice et al. (2005) have shown that, depending on the adiabatic index, it can be larger and up to $10\,\Omega^{-1}$. In this case, equation (7) of Rafikov (2005) would result in the smaller value of $\Sigma_{\rm inf} \approx 6\,{\rm g\,cm^{-2}}$. We therefore conclude that disc fragmentation is not unlikely for this particular system.

3.3 Other binary formation mechanisms

Binary stars have traditionally been thought to form via any of three different mechanisms: capture, fission and fragmentation. Capture supposes that the two components form independently and that, following a close dissipative encounter, become bound. The probability for this is remarkably low and thus this formation mechanism is highly unlikely (Tohline 2002). Fission assumes that a fast rotating contracting protostar can reach the break-up limit and split into two close components (Durisen & Tohline 1985). There is no evidence that this can actually happen in reality, although a final proof has not been given yet (Tohline & Durisen 2001). However, we can discard this possibility, as 2M1207 is a relatively wide system, while this mechanism would naturally produce close systems. Finally, binaries can form through disc (Bonnell 1994) or core fragmentation (Boss & Bodenheimer 1979; Bonnell et al. 1991). Disc fragmentation has already been addressed in the previous section. Core fragmentation involves some kind of $m = 2$ perturbation in a collapsing cloud, which is later amplified by gravity until the onset of Jeans instability which results in two individual, albeit bound, pressure-supported objects. Gravitational fragmentation in *isolated cores* can produce a large variety of binary systems, depending on the size and mass of the core, and the amount of angular momentum it contains (Bate 2000; Fisher 2004). The problem with this scenario, from a theoretical point of view, is that simulations of star formation with realistic initial conditions (e.g. random initial 'turbulent' velocities; Bate et al. 2003; Mac Low & Klessen 2004) do not produce cores that are as well defined as in models of isolated star formation. Cores are seen as active entities, that grow in mass, that are typically elongated because they are part of larger filamentary structures, and that move in converging trajectories, driven by the underlying velocity field and the gravitational attraction of high density regions.

Typically, star formation calculations (Bate et al. 2003; Delgado-Donate, Clarke & Bate 2004a; Delgado-Donate et al. 2004b; Goodwin, Whitworth & Ward-Thompson 2004) under-produce binary stars with low component masses. Extremely low masses, such as those of the 2M1207 components, are only found among objects that are promptly ejected from their parent cloud, and thus cannot accrete much beyond the opacity limit for fragmentation mass. The objects that are not ejected invariably grow to stellar masses. However, ejection implies a bias against binarity. The binding energy of 2M1207 is so low that it could have hardly survived as a bound system after a close dynamical interaction with, by necessity, a more massive binary. In this unlikely event, we would expect the system to be eccentric. On the other hand, the primary could have been ejected and the secondary formed in the circumprimary disc, which survived the ejection process. This would bring us back to the gravitational instability in a disc scenario (Section 3.2).

Current star formation calculations also under-produce binary stars with mass ratios as low as that of 2M1207. As Clarke & Delgado-Donate (in preparation) have shown, all processes that occur in a turbulent star-forming cloud – efficient fragmentation, intersecting flows, accretion of high angular momentum material from circumbinary disc – favour the formation of bound pairs with similar masses from the start and, even for a binary with initial low q, favour the evolution of the mass ratio towards unity. However, these models cannot follow yet the long term evolution of discs. Thus, in the context of dynamical star formation models (Bate et al. 2003; Delgado-Donate et al. 2004a,b; Goodwin et al. 2004), the formation of systems such as 2M1207 is challenging, but not impossible, provided that such systems turn out to be rare.

4 CONCLUSIONS

In this paper we have discussed the nature and possible formation mechanisms of 2M1207B, the $5\,M_{\rm Jup}$ companion of 2M1207A, a $25\,M_{\rm Jup}$ brown dwarf. Even if the absolute mass of 2M1207B places it clearly in the planetary range, we have discussed how, in terms of separation and mass ratio, it is perfectly consistent as being the secondary of a very low-mass binary system.

We have considered the formation mechanism of such a system, and found that the standard planet formation scenario of core accretion can be ruled out, since the time-scale to form the planetary core is many orders of magnitude larger than the observed age of the system. On the other hand, we have shown that the alternative planet/binary formation mechanism via gravitational instability leading to disc fragmentation is a viable possibility in this particular case. In order for this mechanism to work, however, the proto-brown dwarf must have been surrounded by a massive disc in its early days, a rare (but possible) event in the context of dynamical theories of star formation.

The very existence of 2M1207B poses therefore interesting constraints on star formation theories. In fact, unless 2M1207 is a rare system, that is, the result of an ejection of a brown dwarf with a large, massive disc, its existence poses a challenge to the most dynamical view of star formation. This system, if found not to be an exception, seems to be saying that star formation can proceed sometimes more 'quietly' (i.e. with fewer dynamical interactions) than seen in current numerical simulations. In this sense, it is not surprising that 2M1207 has been found in the TW Hydrae association, a moving group which was never massive enough to form a cluster, and hence is not expected to have ever possessed a high enough stellar density for widespread strong dynamical interactions to be commonplace. Thus, the challenge from an observational point of view is to try to constrain not only the occurrence of systems like 2M1207 but also their relative frequency among different star-forming environments. These observations would provide interesting constraints on theories of star formation.

More generally, we have shown how the gravitational fragmentation of a protostellar disc might be possible, at least under peculiar circumstances (such as those that might have led to the formation of 2M1207). The main obstacles that work against this model for giant planet formation around solar-mass stars (long cooling times, high fragment mass) are not a concern in this case. In fact, Rafikov (2005) has already shown that the cooling time problem is not a serious concern at large distances (∼100 au) from the central star, such as the observed distance of 2M1207B from the primary. Concerning the fragment mass, we have shown (equation 6) that $M_{\rm frag} \approx 2\pi (H/R)^3 M_\star$. Whereas for a solar-mass star the fragment mass is well in excess of Jupiter, for a brown dwarf primary the fragment mass is much lower ($\sim$50 $M_\oplus$) and could lead to the formation of an object of planetary mass.

Finally, we note that the mechanism that we favour for the formation of 2M1207B (i.e. gravitational instability of a disc) is one that has been invoked in the context of both binary formation and planet formation. Whether 2M1207B should be classified as a 'binary companion' or a 'planet' is therefore a semantic issue of secondary interest.

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