Planetary Systems Around Close Binary Stars: the Very Dusty, Sun-like, Spectroscopic Binary BD+20 307

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ABSTRACT

Field star BD+20 307 is the dustiest known main sequence star, based on the fraction of its bolometric luminosity, 4%, emitted at infrared wavelengths. Data from all three Spitzer instruments indicate that the dust particles are confined to a narrow range of (warm) temperatures and enable a great improvement in modeling the dust composition beyond what was possible from ground-based spectra. Probably the dust around this close binary star has nothing at all to do with planet formation and everything to do with some major catastrophic collision that took place recently near 1 AU in a mature planetary system.

1. Background

Many main sequence stars are orbited by dusty debris disks, of which the star Vega is the prototypical example. Most debris disks can be envisioned as more massive counterparts of the Sun's Kuiper Belt. (see Figure: Kuiper Belt vs asteroid belt)

Two notable exceptions are BD+20 307 and HD 23514 which have massive amounts of warm dust analogous to the asteroid belt. (see Figure: Two unusually dusty sun-like stars)

A spectral energy distribution (SED) of BD+20 307 that combines IRAS and ground-based photometry and broad-band spectroscopy is shown in the next Figure. This SED was published by Song et al (2005 Nature 436, 363). Note the gigantically strong silicate feature at 10 microns wavelength.

The next Figure shows the SED for Pleiad HD 23514 and its large excess emission in the mid-IR. Quantitatively, the excess infrared luminosity is characterized by the ratio L(IR)/L(star), where L(IR) and L(star) represent the excess IR emission and the bolometric luminosity of a star, respectively.

The following table gives L(IR)/L(star), also called "tau" for short, for seven stars of age 100 Myr or greater and known to have associated warm dust. Note the large tau of BD+20 307 and HD 23514 relative to the other stars. These two taus are so large that the dust disks or rings around BD+20 307 and HD 23514 cannot be thin and flat as per

Saturn's rings (see Figure of Saturn). Rather these disks must be either warped or puffed up in the vertical direction.

Compared to the more typical Vega-like star which has cool rather than warm dust, the tau values of BD+20 307 and HD 23514 are very large indeed, as may be seen from the next figure that shows tau vs stellar age. On this graph HD 23514 would plot at tau = 0.02 and 100 Myr and BD+20 307 at tau = 0.04 and at 1000 Myr or older (see Section 3). When looking at such a graph, it is important to realize that the plotted points are only the tip of the iceberg – 80% or so of nearby main sequence would plot below the points shown.

The next figure shows the region of the 10 micron silicate feature at the two stars – BD+20 307 is the dashed line and HD 23514 is the solid line with data points. While the peak wavelength of the BD+20 307 feature is quite standard, the relatively short wavelength of the HD 23514 feature is very unusual. Comparable peak wavelengths are seen in only a few T Tauri star IRS spectra, for example those presented in papers by Elise Furlan and Dan Watson and their colleagues. Based on Bill Forrest's presentation at this conference and his private commentary, amorphous silica could be a plausible carrier of the HD 23514 feature. IRS spectra, that will soon be obtained, should confirm or deny this suggestion.

2. New Spitzer results for BD+20 307

The next Figure displays the SED of BD+20 307 with new data from all three Spitzer instruments included (Weinberger, Becklin, Song & Zuckerman, in preparation). The purple data points from IRAC show that there is no evidence for hot dust at BD+20 307. The purple MIPS data points indicate that there is no evidence for cold dust at BD+20 307. Thus, the data are consistent with a model whereby all of the dust is warm and confined to a narrow range of semimajor orbital axes at about the distance of Venus from the Sun.

The following Figure focuses in on the region of the silicate emission feature. This plot is still a work in progress (the Weinberger et al. paper in preparation). A moderately good fit can be obtained with model grains of size of order 1 to 10 microns.

A similar study of the Spitzer IRS spectrum of HD 23514 is currently in progress (Song et al. 2009).

3. Discussion

Dust particles, especially warm ones near a star, cannot remain long in orbit. So, the following Figure asks how is it possible to understand the presence of so much warm dust near BD+20 307 and HD 23514. One possibility, as noted in the subsequent Figure, is that the two stars are undergoing episodes similar to an era of heavy bombardment in the inner solar system, an era that is believed to have occurred about 600 Myr following the formation of the Sun. For reasons that I won't go into now, the "heavy bombardment" model is quite unlikely to account for the dust at these two stars. More likely, as remarked on the next Figure, the origin of the dust is due to a collision between two rocky planets or, in the case of HD 23514, perhaps planetary embryos.

While we know the approximate age of HD 23514 (because it is a member of the ~100 Myr old Pleiades star cluster), the age of BD+20 307 has not been easy to deduce. In their initial Nature paper, Song et al. used conventional techniques to derive an age of about 300 Myr (see next Figure). But then, in 2007, we all received a big surprise when Alycia Weinberger (next Figure) discovered that BD+20 307 is composed of not one, but two sun-like stars, orbiting each other with a period of about 3.5 days (Weinberger 2008 ApJ 679, L41). Subsequently, as shown on the next Figure, Frank Fekel and Michael Williamson obtained, at Fairborn Observatory, a more complete velocity curve for the two stars. In 2004 when the Song et al echelle spectrum was obtained, by a low probability chance (<10%), the two stars had approximately the same radial velocity.

As noted in the following three Figures, because the rotation period will be locked to the orbital period, it is not possible to use activity indicators to learn about the age of BD+20 307 and other types of age indicators must suffice. Our revised age estimate indicates that BD+20 307 is an old star, probably at least 1 Gyr old and perhaps as old as the Sun. Details may be found in a paper by Zuckerman et al (ApJ 688, 1345, 2008). An artist's conception of the collision that might have produced the observed dust is shown in the following Figure (artwork by Lynette Cook). Because of the old age of BD+20 307 and its planets, it is possible that one or both of the colliding planets might have had time to evolve continents and oceans and, perhaps, even life.

One cannot help but wonder if such a cosmic catastrophe might, some day, occur in our own solar system. Various researchers, perhaps beginning with J. Laskar in France, have attempted to calculate the long-term stability of the Sun's planets. The conclusion seems to be that the orbit of Mercury might be unstable on a time scale short enough that Mercury could leave its present orbit and suffer a variety of fates, including collision with another planet, in the coming few gigayears.

In a 2006 paper, Tokovinin et al found that, for a close binary system with orbital period of 3.4 days, the probability is ~70% that a third star will also be present. So, as noted in the following Figure, we wondered if there might be a third, as yet unseen, star present in the BD+20 307 system. Two ways to search for such a tertiary component are via adaptive optics (AO) imaging and long term radial velocity monitoring of the systemic velocity of the two already known stars.

The Figure that displays detection limit vs angular separation was obtained in the near-IR at the Keck telescope using AO imaging. The limits are meaningful beginning at about 0.2 arc sec (20 AU) where all tertiary main sequence stars more massive than about mid-M type star can be excluded. At increasing angular separations, first L-type and then even early T-type brown dwarfs can be ruled out as possible tertiary companions.

The subsequent two Figures present our preliminary radial velocity results for the center of mass motions of the known binary pair based on a set of assumptions about the mass and semimajor axis of a putative tertiary companion. Because we have velocity data extending over only 1/2 year, a substantial range of parameter space in mass and semimajor axis remains unconstrained for a possible tertiary. We plan to continue to monitor the radial velocity of BD+20 307 over the coming years to either reveal or rule out the existence of a third star in the system.

The final Figure presents an important conclusion of our study. Because the precision radial velocity technique is not sensitive to planets in close binary systems, virtually nothing is known about the presence of planets in orbit around such stars. BD+20 307 thus represents the first known example of planets of any mass in orbit around close binary stars. And it also represents perhaps the first indication of the existence of rocky planets in orbit around sun-like stars.