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Exocomets and their link to astrobiology

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Abstract. The presence of circumstellar gas liberated by the evaporation of exocomets on their grazing approach to nearby A-type stars is now well established (Welsh & Montgomery 2015, 2018). More than 20 young (<300 Myr), fast rotating A-type stars with associated debris disks have been shown to harbor significant numbers of comet-like bodies that can produce nightly (and in some cases hourly) changes in the circumstellar CaII K-line absorption profile, the prime example being that of the many transient red-shifted Falling Evaporating Body (FEB) absorption events recorded towards Beta Pictoris (Lagrange-Henri et al 1992). The orbital instabilities in the debris disk are most probably due to the gravitational presence of a large body such as an exoplanet. Thus, detecting the presence of exocomet absorption activity in other solar systems might indicate the presence of life forms, since exocomets are a possible carrier of organics and ices that may be collisionally deposited on any exoplanets in these systems.

1. Introduction

Exocomets are kilometer-sized planetesimal-like bodies that originate in the gaseous and dusty debris disks surrounding young ($T <$ 100 Myr) main sequence stars. They represent the remnants of the building blocks of planetary bodies and thus their chemical composition may give us insights into the early stages of planetary formation. However, debris disks surrounding A-type main sequence stars should dissipate on timescales $\ll$1 million years and thus these disks must be continually replenished with (non-primary) secondary gas and dust through the collisions between the remnant planetesimal bodies.

The discovery of exocometary bodies was initiated through the realization that the young A-type star, beta Pictoris, was accompanied by an infrared emitting dust/gas disk as detected by the IRAS satellite. Subsequent ground-based spectroscopic observations of the surrounding circumstellar gas in the beta Pictoris disk revealed appreciable variability of the CaII-K absorption line at 3933 Å (Ferlet et al. 1987; Lagrange-Henri et al. 1992). The deep circumstellar absorption line was located at the (stable) radial velocity of the star, but the profile was accompanied by far weaker absorption components at red-shifted velocities that varied as a function of time (hours to days), and that they moved towards negative absorption velocities. A time-series of the characteristics of the CaII-K circumstellar line (with varying red-shifted components) is shown in Figure 1.

Since the debris disks surrounding young stars are supposed to be gas-free (due to their destruction by stellar radiation) a source of secondary disk gas was required. This gas source was forwarded as being due to the collisions between km-sized bodies (which we now call "exocomets"), and the absorption behavior observed towards beta Pic was explained through the "Falling Evaporating Bodies" model of Beust et al. (1990) under the assumption that the red-shifted absorption components were

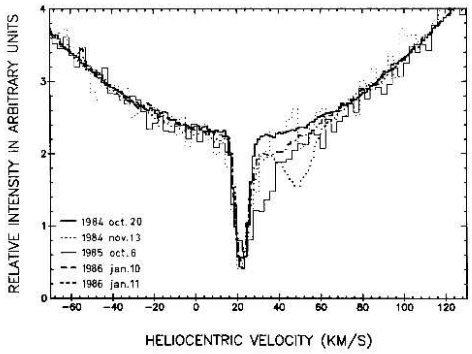

Fig. 1. Time variable observations of the circumstellar CaII-K line towards beta Pictoris (from Ferlet et al. 1987).

due to the evaporation of gas from star-grazing exocomets as they fell towards the central star. In order to possess star grazing orbits the exocomet bodies required a mechanism to bring them out of their Keplerian orbits in the debris disk, and this most probably was provided by gravitational peturbations due to the presence of at least one exoplanet in the beta Pic system (Beust et al. 1990). This was eventually proved to be the case with the discovery of the beta Pictoris-b exoplanet some 20 years later (Lagrange et al. 2010).

2. Detection and observations of exocometary gas

In 2010 we started an observing campaign to search for exocomet absorption activity around other A-type stars that have similar physical properties to beta Pictoris. This meant sampling the (CaII-K) absorption characteristics towards young ($T < 100$ Myr), fast rotating stars with known IR emitting circumstellar dusty gas disks. Such observations entailed observing the CaII-K line absorption profile at high spectral resolving power ($R \sim 65,000$) on at least 3 occasions typically each separated by at least 24 hours. The absorption profiles were extracted and compared in order to identify any statistically significant changes in the central circumstellar profile and to detect the presence of any weak and transient red-shifted absorption events whose velocity may change as a function of time.

Over the past 8 years we have discovered at least an additional 18 A-type stellar systems with time-variable absorption behavior presumably due to the evaporation of gas from star grazing exocomets (Montgomery & Welsh 2012; Welsh & Montgomery 2018). In Figure 2 we show the circumstellar CaII-K line profiles observed on 4 successive nights towards the the A0V-type star HD 21620 that has an estimated age of ~5 Myr. The arrows point towards the weak absorption components (presumably due to moving evaporating exocomet gas). Note how the component located at V$\sim$ +65 km/s on 11-04-2012 moves towards V$\sim$ -30 km/s on the next night, and is also accompanied by a new exocometary evaporation at V$\sim$ +80 km/s. All these components disappear in the subsequent two nights data.

Circumstellar absorption due to the evaporation of exocomet gas has also been detected through observations of the FeI line at 3860 Å (Welsh & Montgomery 2016) and the CaII triplet at 8542 Å. However, it is in the UV and sub-mm wavelength range that the most recent progress has been made in the field of exocometary research. These results have importance for any astro-biological evolutionary effects since it is widely believed that water and pre-biotic organics were delivered to the young Earth through collisions with solar system comets. Hence, if the presence of exocomets is linked to the presence of exoplanets around a young star, then we have a possible delivery system for potential life giving molecules throughout the galaxy. For example, high resolution spectral observations of beta Pictoris using the STIS UV spectrograph on the HST have shown that the circumstellar gas has a large overabundance of C and O relative to their values, whereas N has a solar abundance value (Roberge et al. 2000). The element abundance pattern for the beta Pictoris gas is presently best explained through photodesorption from ice grains rich in C and O, or by collisional vaporization of C and O rich dust in the disk.

The large overabundance of C relative to metals produces a "braking force effect" that

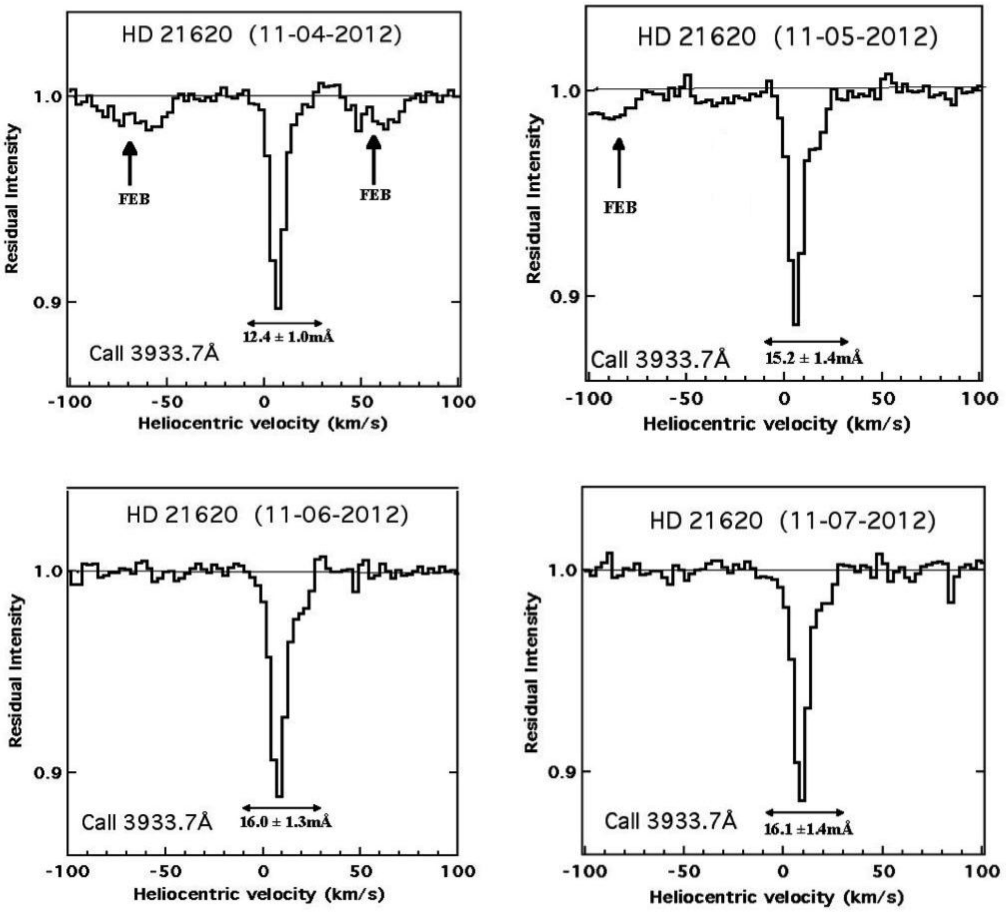

Fig. 2. Four nights spectral observations of the circumstellar CaII-K line towards HD 21620 that show the presence of evaporating exocomet gas (see arrows on plots).

keeps evaporating exocomet gas within the disk as opposed to being blown away by the stellar radiation (Fernández et al. 2006). In addition UV spectral observations of the circumstellar disk gas around 49 Ceti have found that the C/Fe abundance ratio is far greater then the solar value suggesting it harbors a volatile rich gas disk similar to that of beta Pictoris (Roberge et al. 2014). Hot (evaporated) gas was detected falling towards 49 Ceti through the time-variable absorption profiles of the CIV 1550 Å and CII 1335 Å lines (Miles et al. 2016).

Recent UV observations of the circumstellar gas surrounding HD 172555 by Grady et al. (2018) have shown that it has a high volatile content compared with most solar system asteroids, and that time-variable absorption was detected over a one week period in the profiles of the SiIV 1394 Å and CII 1335 Å line profiles.

The cold molecular gas in the debris disks around beta Pictoris and 49 Ceti has been observed with the ALMA sub-mm array and shown that the CI and CO emission line profiles are very similar suggesting that C co-

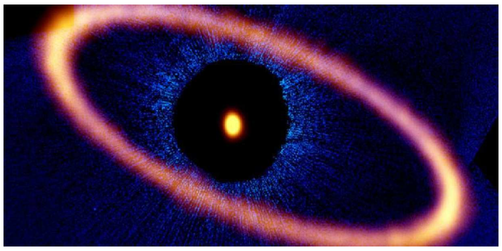

Fig. 3. ALMA 1.33mm image of the debris disk surrounding the star Fomalhaut (from MacGregor et al. 2017).

exists with CO and is likely formed by the photo-dissociation of CO within the disks (Higuchi et al. 2017). At 1.3mm ALMA has also imaged the Fomalhaut circumstellar disk which shows continuum emission from cold dust that is associated with the collisional erosion of comet-like bodies that form a debris disk. The image of this system shown in Figure 3 is consistent with what the final stages of the formation of a 450 Myr old planetary system (MacGregor et al. 2017).

3. Future trends in exocometary-astrobiological research

To date all the stellar systems with associated exocomet absorption activity have been detected towards A-type stars with ages <500 Myr. Many of these systems may prove (through future high resolution imaging) to harbor exoplanets (like beta Pictoris). However, even if a link can be shown to exists between the impacts of exocomets and the delivery of potentially life-forming organics to these exoplanets, the relatively short life-time of the A-type stars would seem to preclude the possibility of the existence and presence of advanced life forms.

However, our recent discovery of exocomet absorption activity towards the 1.4 Gyr old F2V star eta Crv (Welsh & Montgomery 2019) gives us some hope that we will be able to extend our detection of similar systems to older stars of a later spectral type. Eta Crv is surrounded by at least two dust belts and

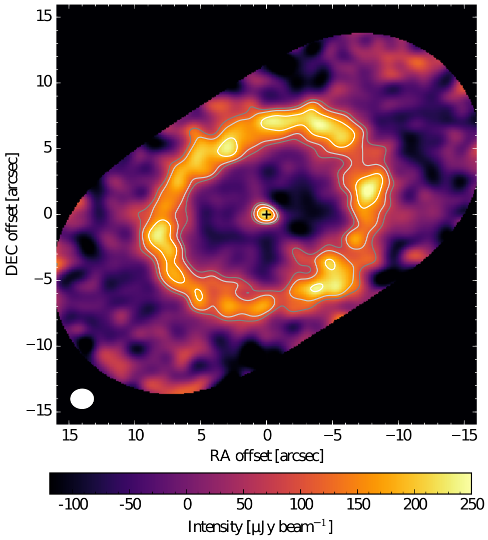

Fig. 4. Figure 4: ALMA image of dusty gas rings around the star 1.4 Gyr-old star eta Crv. (from Marino et al. 2017).

is presently thought to harbor multiple exoplanets . In Figure 4 we show the ALMA 0.8mm image of eta Crv that clearly shows the presence of large amounts of dust surrounding the central star. This is quite peculiar since we would expect that collisions between dust and gas producing planetesimals should have ceased around a star of such great age by now.

Presently only 23 exocomet systems have been discovered, all through observing time-variability of the CaII-K line absorption line. With the advent of the launch of the TESS satellite, it may be possible to detect the transit of exocomets across the stellar disks of stars with a wide range of ages and spectral types. For example, a distinctive "shark-fin" like transit absorption profile has been found for the beta Pictoris system (Zieba et al. 2019), and thus an archival search for this type of flux dip with respect to time (~6 hours for the beta Pictoris transit) should prove very useful in the identification of new systems.

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