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Summary of the workshop "Gaia and the unseen: the brown dwarf question"

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Abstract. In this summary, I review two topics frequently discussed during the workshop. First, many attendees wanted to know how many brown dwarfs Gaia would observe. Many of the talks and posters presented information relevant to this question, and I have tried to encapsulate those results in a short table along with an explanation about how the numbers were derived. Second, group discussions often revolved around plans for analysis of Gaia data and supporting follow-up observations. Some of this follow-up will involve a significant allotment of time at other facilities, so large, coherent collaborations may stand the best chance of success in securing these resources. I present a summary of those results in part to encourage the brown dwarf community to begin forming these teams now.

Key words. stars: low-mass, brown dwarfs – (stars:) subdwarfs – stars: fundamental parameters – (Galaxy:) solar neighborhood – catalogs

1. Introduction

The workshop opened with welcomed good news – that Gaia was working as planned and having only minor technical issues. It seems rather fitting, in fact, that this news came to us in Torino, because the spacecraft now orbits around the Sun-Earth L_2 Lagrangian point (Lagrange 1772) named in honor of Torino native and mathematician extraordinaire Joseph Louis Lagrange. Rather than providing a synopsis of the workshop talks, this paper addresses two general questions that were frequently heard during coffee breaks, panel discussions, and brainstorming sessions.

2. How many brown dwarfs will Gaia observe?

This workshop was entitled "Gaia and the Unseen: The Brown Dwarf Question." As the workshop proceeded, it became obvious that the first brown dwarf question that many attendees wanted to have answered was "How many brown dwarfs will Gaia observe?"

The question is, surprisingly, not a straightforward one to answer, as Gaia will observe some brown dwarfs directly and others indirectly. Table 1 addresses the answer and is an expanded version of a similar summary presented by Ricky Smart during the waning hours of the workshop. In the following paragraphs, an explanation of each row in the table is given.

Ricky Smart, in his contribution to the workshop proceedings, uses the compendium at DwarfArchives.org to estimate the number of L and T dwarfs that Gaia will directly image. For a limit of G=20 mag, the number is ~500, or ~2000 if the limit is extended to G=21 mag.

Table 1. The Number of Brown Dwarfs with Supporting Gaia Observations

Type of object	Number	Refer to conference paper by
Directly imaged L and T dwarfs	~a thousand	Smart
Directly imaged young brown dwarfs in the nearest star clusters	~several hundred	Sarro
Brown dwarfs indirectly detected via microlensing events	~a few	Evans
Brown dwarf companions indirectly detected via astrometric wobbles	~thousands	Sozzetti
Brown dwarf companions indirectly detected via transits	~tens to hundreds	Dzigan
Brown dwarf companions detected elsewhere but for which Gaia will provide vital data for the primaries	~thousands	Burningham

During the workshop, Luis Sarro presented a table listing the latest spectral type that Gaia could observe in some of the nearest star clusters and star formation regions. In the Hyades and the Pleiades, those limits are roughly L0 and M7, respectively. The dividing line between stars and brown dwarfs is thought to lie >M8 (Bouvier et al. 2008) and at ~M6.5 (Stauffer et al. 1998) in the Hyades and Pleiades, respectively, so Gaia may not be able to probe significantly into the substellar regime for either. For younger clusters, the situation is more optimistic. In the Taurus Molecular Cloud and the ρ Ophiuchi star formation region, for example, spectral types down to M9 and L0, respectively, can be detected. These limits are well below the spectral type of ~M6 that marks the lowest mass stars at these ages (Luhman 2006). In fact, the Gaia limits may be able to probe down to the deuterium-burning limit in these regions (see Figure 10 of Briceño et al. 2002). Given that there are a number of other relatively nearby, young clusters in the solar vicinity, we roughly estimate that several hundred young brown dwarfs of late-M spectral type can be directly detected by Gaia.

Neil Wyn Evans' presentation pointed out that we would need samples of high proper motion brown dwarfs ($\mu > 0\farcs3\ yr^{-1}$) reaching a few hundred (see also Paczynski 1995) before there would be a sufficient population from which to find a few viable brown dwarf candidates for astrometric microlensing. Astrometric follow-up of color-selected objects (e.g., Marocco et al. 2013; Beichman et al. 2014) and new proper motion surveys at infrared wavelengths (e.g., Luhman 2014; Kirkpatrick et al. 2014) are quickly producing the numbers of high-motion brown dwarfs needed to make this a possibility. Even if this method only results in a handful of brown dwarf microlensers with measured masses, it is the only way in which the masses of single brown dwarfs can be directly measured.

Alessandro Sozzetti's talk discussed that there are currently only ~60 brown dwarfs known in the brown dwarf desert around higher mass main sequence stars (see Ma & Ge 2014; Sahlmann et al. 2011; Sozzetti & Desidera 2010). Gaia's detection limits will allow sensitivity to brown dwarf companions around approximately a million stars, resulting in the astrometric detection of thousands of brown dwarfs in close orbits around these objects.

Yifat Dzigan showed that carefully crafted follow-up observations of photometric transients detected by Gaia can result in the discovery of thousands of transiting exoplanets. (See also Dzigan & Zucker 2013.). If we assume that the brown dwarf yield will be roughly one hundredth to one tenth that of exoplanets, then tens to hundreds of transiting brown dwarfs will result. Similar estimates for the number of transiting brown dwarfs are found by (Sozzetti et al. 2014).

Ben Burningham's talk demonstrated that new surveys being conducted over the next several years could result in catalogs of brown dwarfs reaching one million objects. Most of these will, of course, be undetectable by Gaia but some small fraction will be widely separated companions to higher mass stars that Gaia will detect directly. Gaia-measured distances and kinematics for the host suns can be applied directly to these brown dwarf companions. Gizis et al. (2001) find that in a volume-limited sample of L and T dwarfs, 5±3% of objects discovered in the field are later revealed to be wide-separation, common proper motion companions to higher mass stars. The million brown dwarfs expected by Burningham could then potentially translate into tens of thousands of companions whose primaries Gaia will characterize. However, at larger distances many brown dwarf companions, even with large physical separations from their primaries, will begin to be lost in the glare of the host star and will be missing from the million object sample. Thus, we conservatively estimate that "only" thousands of companions will remain with Gaia-characterized hosts.

3. How can the brown dwarf community best reap the rewards of Gaia?

On the first morning of the workshop, the attendees were divided into several groups of roughly ten people each and asked to pose unanswered questions in brown dwarf astrophysics that they believed Gaia data would help address, to discuss the ground-based (or other) observations already underway to help support the analysis, and to identify other observations (if any) needed to answer the question definitively. Each group was asked to come up with around five burning topics. After those topics were fully discussed and transcribed onto paper, the attendees were mixed and divided into several new groups. Each new group was then asked to give feedback on the topics put forth by one of the previous groups and to prioritize those topics for further consideration.

These five tasks received the most discussion:

(1) Assigning membership of known young brown dwarfs to nearby moving groups, finding new brown dwarf members of these groups, or identifying new groups themselves;
(2) determining the local initial mass function (or, observationally, the space density per spectral type bin) of L dwarfs using Gaia's much improved statistics;
(3) identifying new benchmarks systems in which the physical parameters of the host star can be applied to its brown dwarf companion in an effort to constrain models for the brown dwarf itself;
(4) identifying astrometric binaries that will determine how arid the brown dwarf desert is as a function of separation, brown dwarf mass, and primary mass; and
(5) recognizing brown dwarf binaries to use both as probes of formation mechanisms and as direct measurements of radii for those that transit.

Also frequently discussed were these endeavors:

(1) Searching for subdwarf brown dwarfs to explore star formation efficiency and to test theoretical spectra at low metallicities;
(2) studying optical variability as a probe of clouds and atmospheric dynamics;
(3) using microlensing events of known brown dwarfs to measure their masses directly; and
(4) obtaining accurate luminosities for hundreds of brown dwarfs both to test models and to measure directly the scatter in luminosity at each spectral subtype.

Several other topics, suggested by only one group, are certainly worthy of additional consideration as hot topics:

(1) Using new Gaia discoveries in the Solar Neighborhood to search for colder T or Y dwarf companions via deep infrared imaging;

(2) leveraging Gaia data to verify or eliminate brown dwarf candidates proposed in nearby clusters and star forming regions;
(3) studying the star to brown dwarf ratio as a function of age, metallicity, and environment; and
(4) searching for possible young "runaway" brown dwarfs to test whether ejection mechanisms play a major role during formation.

The most frequently discussed follow-up observations were these:

(1) medium- to high-resolution spectroscopy for radial velocity measurements, Hα and lithium studies, and model fitting,
(2) low-resolution spectra for classification of new discoveries and for measurements of the bolometric luminosity,
(3) photometry in standard bandpasses to ease comparison to other published results,
(4) photometric monitoring to provide more variability information, and
(5) deep imaging to search for colder companions. Also discussed were the need for the latest state-of-the-art evolutionary and atmospheric models.

Some of the topics addressed will require large allotments of telescope time to accomplish. By discussing ideas early, the hope is that large teams will begin to form now. If the brown dwarf community can be well organized and unified in its requests, the hope is that such large requests will be easier for allocation committees to grant.

4. Conclusions

Gaia holds great promise for advances in brown dwarf research. With careful planning and organization, our community should be able to leverage significant resources to aid in analysis and interpretation of results. We eagerly anticipate the first data releases.

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