Research Networking Programmes

Science Meeting – Scientific Report

***Proposal Title*:** **Gaia and the Unseen: The Brown Dwarf Question**

Application Reference N°: 5055

Summary
The conference was hosted by the University of Torino in the Aula Magna of the Rettorato. It was attended by over 80 participants from all over the world. The format adopted was to have interactive activities in the mornings and more traditional presentations in the afternoons. The morning sessions included brainstorming in small groups, round table discussions and online Virtual Observatory problem solving. The afternoon sessions always began with an overview of a particular area presented by an experienced researcher followed by talks from both experienced and new researchers.

Proceedings from the presentations will be published in volume 85 number 4 of the Memorie della Societa' Astronomica Italiana which will be distributed to all members of the Societa' Astronomica Italiana and major Italian and International astronomical institutes.

The areas addressed ranged from theory, models and simulations to ground based followup observations of Gaia science alerts. The audience had a very broad range of expertise and there was a significant amount of exchange of information from the DPAC scientists knowlegable about the limitations and possibilities of Gaia to the experts on brown dwarf and exo-planets science and vica versa.

The after conference activities comprise the inclusion of the presentations online at the meeting webpage (gaiabds.oato.inaf.it), the preparation of the proceedings and the birth of a working group to observe and collect medium to high resolution spectra for the 500+ L dwarfs that Gaia will observe directly. This is being coordinated via links on the meeting webpage.

1) Description of the scientific content of and discussions at the event

Day 1: Started with a summary of the status of Gaia provided by Jos De Bruijne which discussed the launch, throughput evolution, straylight, periodic basic-angle variations and the Gaia's faint-end limit (G=20 or G=21). Luis M. Sarro described the DPAC brown dwarf pipeline preparations and Alessandro Sozzetti the binary system procedures for star+BDs, BD+BDs and Bds + planets.

For the rest of the first morning we carried out a brainstorming session where all the participants were split into 6 groups of 10-12 people per group arranged in a way to have mixed experience and background participants in each group. Each group was chaired by a member of the Science Organising Committee and co-chaired by a member of the Local Organising Committee. The outcome of this sessions was a number of questions on brown dwarfs that Gaia can address:

> Density of field BD in the Milky Way
> Brown subdwarfs, old populations classified from kinematics
> Photometric variability of UCD and BDs
> BD in systems: mass and radius of BD from transiting systems orbital parameters distribution link between massive exo-planets and low-mass stars
> Benchmark systems with Fe/H, age known from the primary Solving the problem of age-mass degeneracy
> Luminosity Function of BD within a specified space volume (radius depending on spectral type)
> BD in kinematic structures (moving groups, etc..)
> Ratio of stars/BD among field stars to investigate Galactic disc origin
> Radii of single BDs to test evolutionary models
> Binary fraction of star/BD, BD/planets, BD/BD
> Determination of BD luminosities through distance measurement.
> Completing the L dwarf census in the solar neighborhood; determination of the galactic field mass function
> Determine binary orbits using space motion from perspective proper motion.
> Identifying ultra cool moving group members through kinematics.
> Metallicity constraints on BDs from the primary in binaries.
> Identifying new brown dwarfs in moving groups (or previously known brown dwarfs whose membership can now be established)
> Identifying new subdwarf brown dwarfs in order to measure brown dwarf formation efficiency at low metallicities
> Identifying previously unrecognized moving groups and the brown dwarf members associated with them
> Measuring the intrinsic scatter in luminosity per spectra bin and determining its underlying cause.
> Identifying "exemplar" brown dwarfs that will have masses, radii, and ages all measured by Gaia; these will serve as bellwethers to test/refine model predictions.
> Determine with more accuracy the membership of high-mass brown dwarfs in nearby clusters
> Test the frequency and magnitude of variability at optical wavelengths for late-M, L, and T dwarfs to gain more clues about their atmospheric physics.
> How does the distribution of brown dwarf separations vary with stellar parameters when found as astrometric companions.

> How dry is the brown dwarf desert
> What is the best strategy for measuring the BD mass from astrometric lensing.
> What is the full extent of the indirect (piggy back) science we can do with Gaia.
>What will Gaia do for defining brown dwarfs in various galactic populations (e.g. Halo, thick disk, thin, young groups).

In the afternoon we concentrated on hot subjects in brown dwarf science with an overview by Davy Kirkpatrick with a summary of outstanding issues (Is Temperature the parameter most influencing spectral type? How do we probe specifics regarding clouds?, What's happening at the L/T transition?) and topics that may be to come (Very nearby objects that were missed before? Rare BDs not previously recognized? New moving groups having only low-mass members?). There was a presentation on brown dwarf formation mechanisms showing that BDs may have different spatial distributions to stars in some nearby star-forming regions, dynamical evolution can lead to differences, different initial conditions for star formation give very different spatial distributions in clusters/associations, and strong dynamical evolution is shown by mass segregation and high local surface densities around massive stars. Finally there were two talks on transits of brown dwarfs showing that transiting hot Jupiters will be particularly valuable, a directed follow-up strategy will help Gaia yield thousands of transiting planets.

The morning of day 2 was dedicated to a discussion session on brown dwarf modeling with talks from Christiane Helling Derek Homeier, Elena Manjavacas and Esther Buenzli. Models should consistently describe physical and chemical processes in atmospheres for a given minimum set of global parameters, e.g. effective temperature, flux, surface gravity and element abundances. The physical principles that must be applied are energy conservation, hydrostatic equilibrium and chemical equilibrium. In particular cloud formation for brown dwarfs is a complicating factor with a play of opacity sources, element sinks, cloud particle sizes, material composition, number of particles. Gaia providing a large number of consistent examples will provide the boundary constraints for this field.

The afternoon started with two talks on the possibilities offered by Gaia both in terms of the standard sample (-1% astrometry +10m/s velocities on 1000's of ultra cool dwarfs) by John Bochanski and the more exotic micro-lensing of brown dwarfs by Wyn Evans. In particular Gaia will discover 1000s of wide binary systems revolutionizing the study of benchmark systems and with just a few micro-lensing objects more than double the number of brown dwarfs with measured masses.

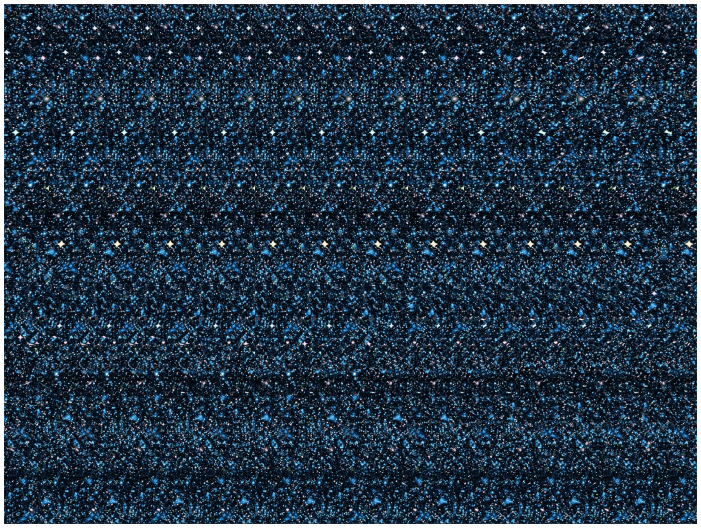
The last part of the afternoon was devoted to a discussion session on brown dwarfs and moving groups. These are important for a number of reasons: they confirm the shape of the initial mass function, they are direct exo-planet imaging, understanding the formation mechanisms and stellar evolution, understanding the complex relation between luminosity-mass-age. Over 30 moving groups are thought to exist:eps Cha 6 Myr • eta Cha (Tiny cluster) 6 Myr • TW Hya 3 - 15 Myr • beta Pic 10 - 20 Myr • Chameleon - Near 10 - 20 Myr • Octans – Near 10 - 20,200 Myr • Octans 20 Myr • Tucana - Horologium 20 - 50 Myr • Columba 20 - 50 Myr • Carina 20 - 50 Myr • Argus 30 - 50 Myr • Carina - Vela 40 - 50 Myr • Carina - Near 40 - 50 Myr • IC 2391 Supercluster various • B4 50 Myr • AB Dor 50 or 120 Myr • Pleiades (Cluster) 120 Myr • Hercules - Lyra 250 Myr • Castor 200 - 400 Myr • Coma Berenices (Cluster) 400 Myr • Ursa Major

500 Myr • Hyades (Cluster) 650 Myr. Gaia will confirm and discover new ones and these will be tied into the upcoming IR surveys to find brown dwarf members.

Day 3 started with an introduction to TOPCAT and the Virtual Observatory by the author Mark Taylor. Afterwards together with Simon Murphy's they went through with some hands on examples of the procedures needed for brown dwarf research.
In parallel there was a discussion on the Age determination for Brown Dwarfs with talks by Jackie Faherty, Sarah Casewell, ZengHua Zhang and Sarah Jane Schmidt. The Techniques for Age Dating Brown Dwarfs are Surface Gravity Indications, Li Absorption Studies, Population Kinematics, Benchmarks, Chromospheric activity, companionship to Age-Calibrated Stars. Gaia will add to all these areas but in particular to the companionship to Age-Calibrated Stars.

In the afternoon we discussed ground based activities that will be enhanced by Gaia results. A introduction by Ben Burningham that showed that in the not to distant future we will discover over a million brown dwarfs, Céline Reylé discussed the luminosity and mass function of field brown dwarfs compared to the cluster function. Jose A. Caballero and Juan Carlos Beamin gave overviews of the activity on brown dwarf research in Spain and Chile, all in relation to the expectations of Gaia

There were a number of posters presented on proper motion catalogs, planned spectroscopic programs to support Gaia results, ground based parallax programs, methods for identifying M dwarfs with ultra cool companions, Kepler results, UKIDSS and looking for brown dwarfs in clusters. These are all included and linked in the web page of the meeting. One both Monday and Tuesday afternoon there was 15 minutes set aside for people to make short presentations on their posters. On the last day the poster by Federico Marocco titled "A spectroscopic census of Brown Dwarfs observed by Gaia - completing the 3D picture." was awarded a prize of a trip to the European Space Center from SpaceLand for astronaut-training.

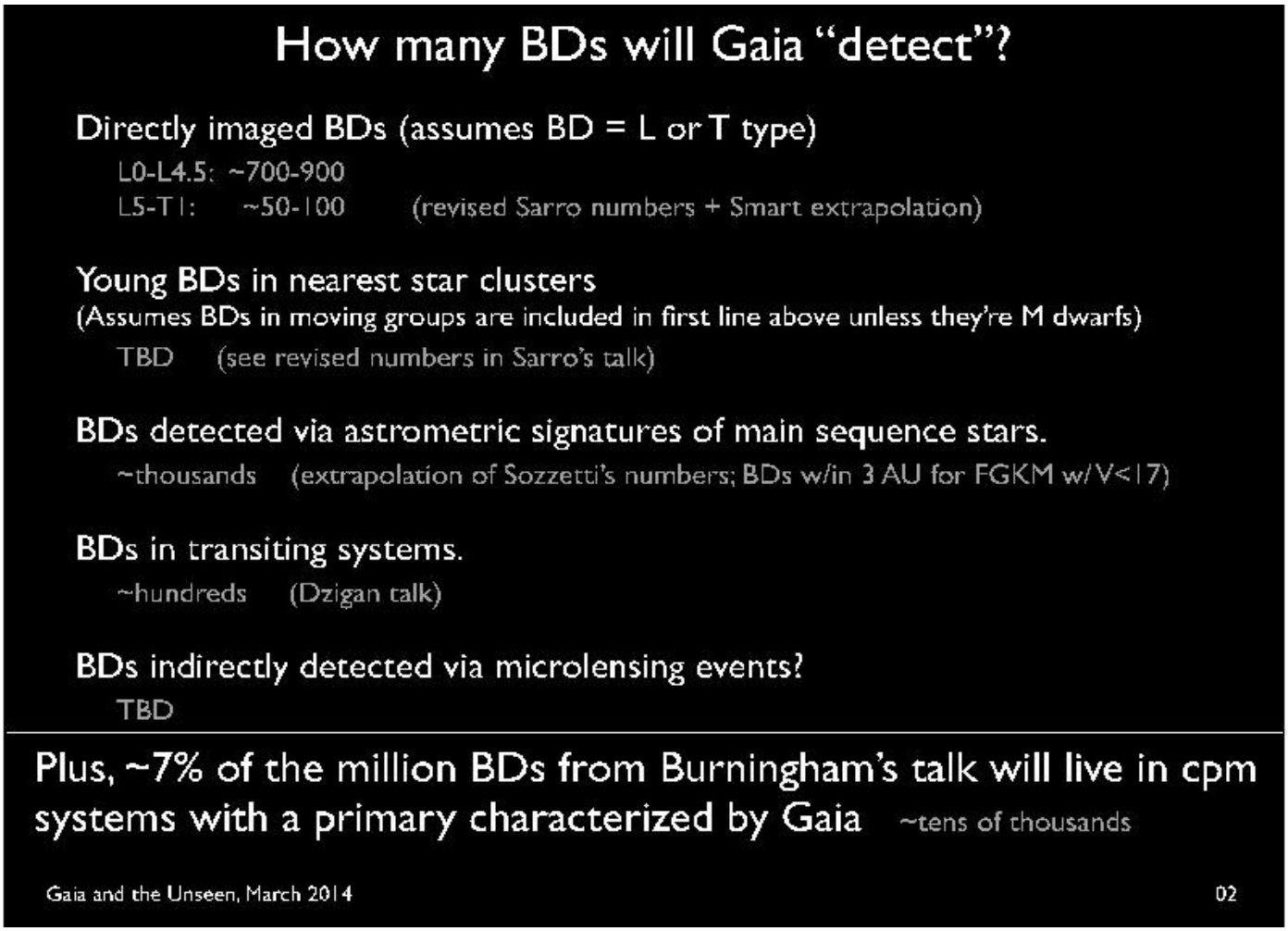


The conference image was a custom Hidden Image Stereogram created by eyeTricks 3D Stereograms - www.eyetricks-3d-stereograms.com. These are the images that popularized Stereograms in the mid 1990's. Objects or text are only visible when viewed with parallel vision. A large version is available at http://gaiabds.oato.inaf.it/images/PlanetsandStarsIIWeb.jpg

2) Assessment of the results and impact of the event on the future directions of the field (up to two pages)

The meeting instigated the beginning of a number activites that involved all participants :
The preparation of the proceedings that will indicate the possibilities and status of brown dwarf research with Gaia right now. These proceedings will be published by the Memorie della Societa' Astronomica Italiana.
The beginning of a working group on the collection and observation of medium and high resolution spectroscopy for the 500 or so brown dwarfs that will be directly observed by Gaia. These are being followed on the main page of the meeting.

Preparation for the Gaia brown dwarf exploitation summerised in the below image:



From the meeting a number of collaborations have begun to address the various expectations of Gaia summerized by this overhaed. In particular there have been important new collaborations between the Gaia scientisits and brown dwarf experts. This will be beneficial for Gaia and it's exploitation.

Annexes 4a: Programme of the meeting

Programme Monday 24th March

09:00-09:10 -- Intro, welcome, logistics.
09:10-09:50 -- Status of Gaia - Jos De Bruijne
09:50-10:20 -- Gaia's Data Processing and Analysis Consortium BD preparation - Luis M. Sarro
10:20-10:50 -- Star + Brown Dwarf & Brown Dwarf + Planet processing - Alessandro Sozzetti
10:50-12:30 -- Brainstorming GAIA + BDs over coffee - Ricky Smart + SOC/LOC
12:30 Lunch
14:00-14:40 -- Outstanding Brown Dwarf questions - Davy Kirkpatrick
14:40-15:05 -- Probing brown dwarf formation mechanisms with Gaia - Richard Parker
15:05-15:30 -- Follow-up of transiting BD companions identified with GAIA - Francois Bouchy
15:30 Coffee
16:00-16-25 -- Finding Hot Jupiters: Gaia photometry and a Directed follow-up strategy - Yifat Dzigan
16:25-16:50 -- Astrometric planet search around southern ultracool dwarfs - Johannes Sahlmann
16:50-17:15 -- Brown dwarf binaries with GAIA - Viki Joergens
17:15-17:40 -- Brown dwarfs at low radio frequencies - Nadia Kudryavtseva
17:40-17:50 – Posters

Tuesday 25th

09:00-12:00 -- BD Models (includes coffee)
- How GAIA will improve model atmospheres for Brown Dwarfs - Facilitator France Allard
- Models across the substellar boundary - Derek Homeier
- Formation/settling of dust constraints in young M / L dwarf atmospheres - Elena Manjavacas
- Cloud structure of brown dwarfs from spectral variability observations - Esther Buenzli
- Expect the unexpected: non-equilibrium processes in BD atmospheres - Christiane Helling
- Round Table

12:00 Lunch
13:30-14:10 -- 1% astrometry +10m/s velocities on 1000's of UCDs, what can we learn- John Bochanski
14:10-14:50 -- Gaia and micro-lensing of Brown Dwarfs - Wyn Evans
14:50-17:50 -- BDs and Moving Groups (includes coffee)
- Identifying and confirming moving groups members - Facilitator Eric Mamjek
- Kinematics and Luminosities of brown dwarfs with the BDNYC group - Adric Riedel
- A Pre-Gaia search for low-mass members of the Octans association - Simon Murphy
- Complementing Gaia from the ground - Herve Bouy
- Searching for young objects in the Solar neighborhood - Lison Malo
- Round Table

Wednesday 26th

09:00-10:00: Exploring Gaia data with TOPCAT and the Virtual Observatory Facilitator Mark Taylor
- This session will continue with hands-on worked examples in the white room after coffee

10:00-10:30: Coffee
10:30-12:30 BD Ages
- Age determination for Brown Dwarfs - Jackie Faherty
- Gaia and white dwarf + brown dwarf binaries - Sarah Casewell
- Halo brown dwarf and Gaia potential - ZengHua Zhang
- Examining the Age Activity Relationship of Ultracool Dwarfs with GAIA - Sarah Jane Schmidt
- Round Table

12:30 Lunch
14:00-14:40 -- Who wants a millions brown dwarfs, and why? - Ben Burningham
14:40-15:05 -- The luminosity and mass function of field brown dwarfs - Céline Reylé
15:05-15:30 -- Gaia and brown dwarfs from Spain - Jose A. Caballero
15:30-15:55 -- Brown dwarfs with the VVV survey - Juan Carlos Beamin
15:55-16:10 -- SpaceLand - key lecture by - Eng. Doct. Carlo Viberti + poster prize

Annex 4b: Full list of speakers and participants

Name	Surname	Nationality	Gender	Speaker/Pa	Name	Surname	Nationality	Gender	Speaker/Pa
Adric	Riedel	USA	M	S	Jos	de Bruijne	European	M	S
Aldo	Stefano Bonomo	italian	M	P	Jose	A. Caballero	Spanish	M	S
Alessandro	Spagna	Italian	M	P	Juan Carlos	TERRAZAS VAF	Bolivian	M	P
Alessandro	Valvano	Italian	M	P	Juan Carlos	Beamin	Chilean	M	S
Alessandro	Sozzetti	italian	M	S	Jucira	Penna	Brasil	F	P
Alexandre	Humberto Andrei	Brasil	M	S	Kevin	Cao	Chinese	M	P
Alice	Zurlo	Italian	F	P	lebreton	victor	French	M	P
Amelia	Bayo	Spanish	F	P	Leigh	Smith	British	M	S
Anna	Curir	Italian	F	P	Lison	Malo	French	F	S
Attilio	Ferrari	Italy	M	P	Luciano	Nicastro	Italian	M	P
Beate	Stelzer	German	F	P	Luis	M. Sarro	Spanish	M	S
Beatrice	Bucciarelli	Italian	F	P	Mariateresa	Crosta	Italian	F	P
Ben	Burningham	Canada	M	S	Marica	Sarasso	Italian	F	P
Carlo	Viberti	Italian	M	S	Mario	Damasso	Italian	M	P
Céline	Reylé	french	F	S	Mario	Gai	Italian	M	P
Charles	Beichman	USA	M	S	Mario	Lattanzi	Italian	M	P
Christiane	Helling	German	F	S	Mark	Taylor	British	M	S
Christine	Ducourant	French	F	P	Neil	Cook	British	M	S
Claudio	Maccone	Italian	M	P	Neil	Wyn Evans	Welsh	M	S
David	Barrado	Spanish	M	P	Paola	Re Fiorentin	Italian	F	P
Derek	Homeier	German	M	S	Paolo	Giacobbe	Italian	M	P
Elena	Manjavacas	German	F	S	Piero	Bianucci	Italian	M	P
Eric	Mamajek	USA	M	S	Ramachrisna	TEIXEIRA	Brazilian	M	P
Estelle	Moraux	French	F	S	Richard	Parker	UK	M	C
Esther	Buenzli	Switzerland	F	S	Richard	Smart	UK	M	S
Federico	Marocco	Italian	M	S	Roberto	Morbidelli	Italian	M	P
France	Allard	French	F	P	Roberto	Silvotti	italian	M	P
francesco	palla	Italian	M	P	Ronald	Drimmel	USA	M	P
Francisco	Maia	French	M	P	Sarah	Casewell	British	F	S
Francisco	J. Galindo Guil	Spanish	M	P	Sarah	Jane Schmidt	USA	F	S
Francois	Bouchy	Spanish	M	S	Simon	Murphy	Germany	M	S
Herve	BOUY	Spanish	M	S	Tullia	Carriero	Italian	F	P
Hugh	Jones	British	M	P	Viki	Joergens	German	F	S
J. Davy	Kirkpatrick	USA	M	S	Yifat	Dzigan	Israeli	F	S
Jacqueline	Faherty	USA	F	S	Youfen	Wang	Chinese	F	P
Javier	Olivares	Mexican	M	P	ZengHua	Zhang	Chinese	M	P
Johannes	Sahlmann	Germany	M	S	Zhaoxiang	Qi	Chinese	M	P
John	Bochanski	US	M	S	Zheng-Hong	TANG	Chinese	M	P