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Review

A Review on Substellar Objects below the Deuterium Burning Mass Limit: Planets, Brown Dwarfs or What?

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Abstract: "Free-floating, non-deuterium-burning, substellar objects" are isolated bodies of a few Jupiter masses found in very young open clusters and associations, nearby young moving groups, and in the immediate vicinity of the Sun. They are neither brown dwarfs nor planets. In this paper, their nomenclature, history of discovery, sites of detection, formation mechanisms, and future directions of research are reviewed. Most free-floating, non-deuterium-burning, substellar objects share the same formation mechanism as low-mass stars and brown dwarfs, but there are still a few caveats, such as the value of the opacity mass limit, the minimum mass at which an isolated body can form via turbulent fragmentation from a cloud. The least massive free-floating substellar objects found to date have masses of about 0.004 M_{sol}, but current and future surveys should aim at breaking this record. For that, we may need LSST, *Euclid* and *WFIRST*.

Keywords: planetary systems; stars: brown dwarfs; stars: low mass; galaxy: solar neighborhood; galaxy: open clusters and associations

1. Introduction

I can't answer why (I'm not a gangstar)
But I can tell you how (I'm not a flam star)
We were born upside-down (I'm a star's star)
Born the wrong way 'round (I'm not a white star)
I'm a blackstar, I'm not a gangstar
I'm a blackstar, I'm a blackstar
I'm not a pornstar, I'm not a wandering star
I'm a blackstar, I'm a blackstar
Blackstar, ★ (2016), David Bowie

The tenth star of George van Biesbroeck's catalogue of high, common, proper motion companions, vB 10, was from the end of the Second World War to the early 1980s, and had an entry on the least massive star known [1–3]. At only 6 pc (actually 5.91 pc with recent *Gaia* DR2 data [4]) and with an M8.0 V spectral type [5,6], the mass of vB 10 was estimated at about 0.08 M_{sol}, at the theoretical limit for sustaining nuclear fusion of ordinary hydrogen (^{1}H). The red dwarf had not only a very low mass, but it was also very cold (T_{eff} ~ 2600 K) and very small (R ~ 0.11 R_{sol}) and, therefore, had a very low luminosity (L ~ 0.0004 L_{sol}). Although later its mass was revised to above 0.09 M_{sol} [7] and LHS 2924, first [8], and many other red dwarfs, afterwards, took its place as "the least massive star in the solar neighborhood", the existence of vB 10 challenged both observational and theoretical astrophysicists for four decades.

Is there a mass limit for the least luminous stars? Is there a bridge between the least massive stars and the most massive planets? Are there planets larger than Jupiter? What are the physics inside such bodies? In the early 1960s, these questions fluttered in the heads of several theoretical astrophysicists [9]. In a pioneering work published in 1963, Shiv S. Kumar constructed a grid of completely convective models of "stars" of masses from 0.09 M_{sol} to 0.04 M_{sol} and showed that there is a lower limit to the mass of the stellar main sequence. In his words:

"The stars with mass less than this limit become completely degenerate stars or 'black' dwarfs as a consequence of gravitational contraction, and, therefore, they never go through the normal stellar evolution" [10].

To this, Chushiro Hayashi and Takenori Nakano added in the same year that,

"The stars less massive than 0.08 M_{sol} are found to contract toward the configurations [sic] of high electron-degeneracy without hydrogen burning" [11].

That is, Kumar, Hayashi and Nakano predicted that there could be substellar objects beyond the bottom of the stellar main sequence but, if they existed, they would be degenerate, completely convective, not able to burn hydrogen in their interiors, and would cool down and get faint for ever. To avoid the confusion with actual "black dwarfs", i.e., theoretical extremely old white dwarfs that will cool sufficiently that their radiation in the visible and near-infrared will hardly be detected [12,13], in 1975 Jill Tarter coined the name "brown dwarfs" for such substellar objects [14].

The publication of less and less massive stars and some controvertible brown dwarf candidates populated astronomy journals in the late 1980s and early 1990s: PC 0025+0047 and DY Psc (BRI 0021-0214), dwarfs with spectral spectral type "M9 or later" [15,16]; GD 165 B, recognized as an L dwarf companion to a white dwarf over a decade after its discovery [17,18]; HD 114762 b, a radial-velocity companion to an F9 V star with a minimum mass of only 0.011 M_{sol} [19]; vB 8 B and ZZ Psc B, fake brown dwarfs based on poor quality data [20,21]; LP 944-20, a very late field M dwarf discovered in 1975 that could be very young and, thus, have a substellar mass [22,23]; [24] Oph 2321.1-1715, 2408.6-2229 and 2412.9-2447, three reddened, embedded sources in the core of ρ Ophiuchi and whose nature is still debated [24,25], and many more.

In 1994, "there was a palpable sense of frustration at the failure of many efforts to confirm a single brown dwarf" [26]. However, in the following year, the same miraculous year when the first exoplanet was found in orbit to a main sequence star, 51 Peg b [27], the first two uncontrovertible brown dwarfs appeared on stage: Teide 1, a free-floating high-mass brown dwarf that passed the lithium test in the young Pleiades cluster [28,29] (published just before PPl 15 AB, a pair of true brown dwarfs also in the Pleiades [30]), and GJ 229 B, a T-type wide companion to the nearby star HD 42581 (also known as GJ 229) [31,32].

Since then, we have found hundreds, if not thousands, of substellar objects: from accreting and disk-bearing brown dwarfs in the young σ Orionis open cluster [33–35], through Luhman 16 AB, a brown dwarf binary at the L-T transition and the third-closest-known system to the Sun after α Centauri and Barnard's star [36], to the numerous ultracool dwarfs in the field with parallaxes measured by the ESA *Gaia* mission [37]. Almost a quarter-century after the discovery and correct identification of the first brown dwarfs, we have compared our theoretical models [38–44] with our observations [45–55], defined three new spectral subtypes for classifying them, L, T and Y [56–60], and found that some substellar objects can have effective temperatures as cool as 225–260 K (e.g., WISE 085510.83-071442.5 [61]); a temperature colder than a Siberian winter night!

By definition, brown dwarfs do not burn the common isotope of hydrogen (^{1}H) through the proton-proton chain reaction. However, it is widely accepted that all of them burn deuterium (^{2}H) and, only the most massive ones, lithium (especially the most abundant isotope, ^{7}Li). As we will see below there are, however, some alternative brown dwarf definitions based on their formation mechanism (i.e., similar to that of planets in circumstellar discs) rather than in their internal physics.

Similarly to main-sequence stars, the lower the mass of the brown dwarf, the lower its central temperature. The minimum temperature for hydrogen burning is about 3 10^6 K, which translates at solar metallicity into a theoretical substellar boundary mass of 0.072 M_{sol}. It is the hydrogen burning mass limit or, in other words, the bottom of the main sequence. Lithium nuclei are destroyed by collisions with protons at slightly lower central temperatures of about 2 10^6 K. According to the Lyon theoretical models [40], a 0.06 M_{sol}-mass object of solar metallicity and age destroys all its lithium, but a 0.05 M_{sol}-mass one preserves 92% of the original lithium content (this is the basis of the lithium test for assessing the substellar nature of an object: after a certain time, if its spectrum displays the Li I λ6707.8 Å resonant doublet line—and there has not been lithium dragging or other exotic process–then the object is indeed a brown dwarf [62,63]).

The minimum temperature for deuterium burning is much lower, of only 0.5 10^6 K (while the proton-proton chain is driven by the weak nuclear force, the primary reaction of the deuterium thermonuclear fusion, $D(p+,\gamma)^3He$, is driven by the electromagnetic force [64,65]). A brown dwarf of 0.013 M_{sol} and solar metallicity can reach, and only for a brief duration at the early stages of evolution, such an internal temperature. Any substellar object below that mass, the deuterium burning mass limit, will not be able to sustain any nuclear fusion reaction in their interior (Figure 1).

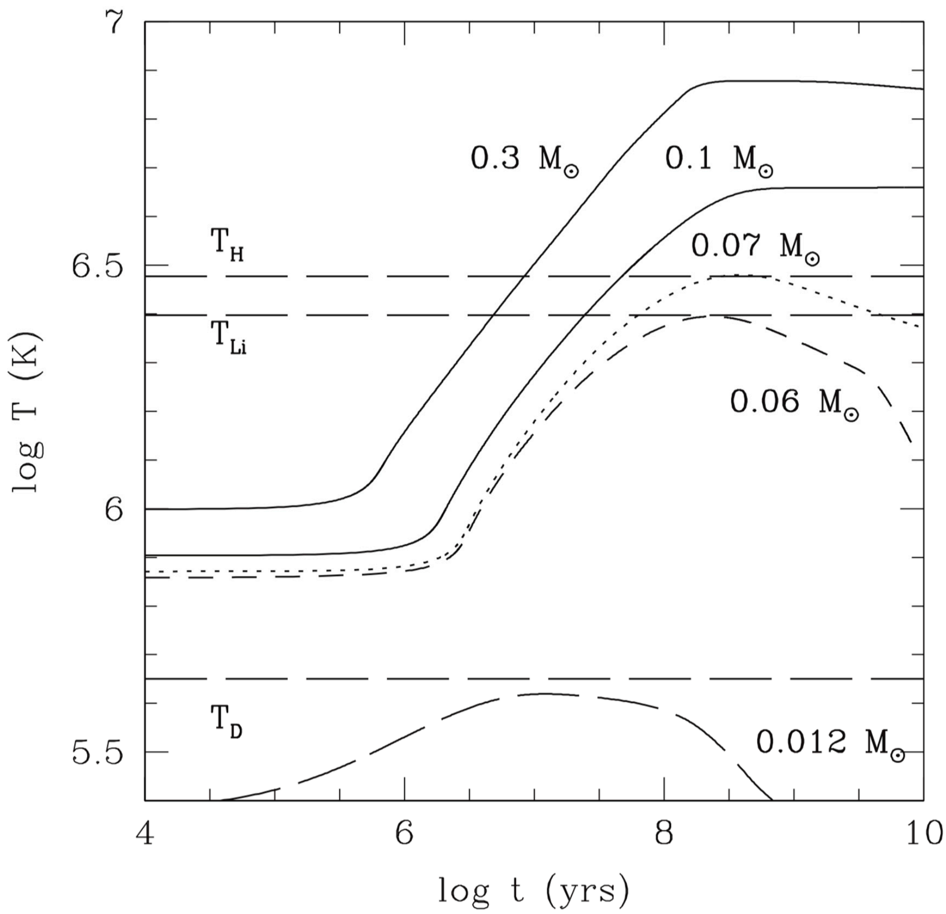

Figure 1. Central temperature of stars, brown dwarfs and "planetary-mass objects" as a function of age for 0.3, 0.1, 0.07, 0.06 and 0.012 M_{sol}, from top to bottom. Dashed horizontal lines mark the burning temperatures for ^1H hydrogen, ^7Li lithium and ^2H deuterium. "Planetary-mass objects" never reach a central temperature for deuterium fusion. Reproduced with permission from [66].

In parallel to the brown dwarf discoveries of the last two decades and a half, the exoplanet hunters have competed against themselves in the search for the radial-velocity planet with the lowest minimum mass, the transiting planet with the smallest radius, the planet with the most suitable atmosphere for characterization, the planet with the most similar conditions to the Earth, the closest planetary system, the planetary system with most planets [67–78]. In a 21st century version of the Olympic motto *Citius*, *altius*, *fortius*, exoplanet hunters pursuit not only "more", but "the most". And in this pursuit they also find "superjupiters": exoplanets with masses several times greater than that of Jupiter. These superjupiters are found around stars in close orbits (with periods of a few days), mostly with spectroscopy and the radial velocity method, and in wide orbits (with periods of decades and centuries), mostly with direct imaging and adaptive optics. Examples of such superjupiters are, on one side, 70 Vir b and τ Boo Ab, with minimum masses of about 0.005–0.007 M_{sol} [79,80], and, on the other side, the four planetary companions of HD 218396 (also known as HR 8799), with masses between 0.004 M_{sol} and 0.010 M_{sol} [81,82]. (Actually, exoplanet hunters use Jupiter masses, M_{Jup}, or even Earth masses, M_{Terra}, instead of solar masses: 1 M_{sol} = 1047.6 M_{Jup}; 1 M_{Jup} = 317.8 M_{Terra}).

Now we can interrogate ourselves again: Is there a mass limit for the least luminous *brown dwarfs*? Is it the deuterium burning mass limit? Is there a bridge between the least massive *brown dwarfs* and the most massive planets? How do we call free-floating substellar objects that do not fuse deuterium and have masses similar to those of superjupiters? Are they planets or brown dwarfs? Where and how do we find them? How do they form? How do they evolve? How is the physics inside such bodies? Here I try to answer these questions and review the most important ideas on free-floating, non-deuterium-burning, substellar objects detected with direct imaging (see [83] in this volume for a review on free-floating, non-deuterium-burning, substellar objects detected with microlensing).

2. Nomenclature

Finding an appropriate, short name for our "free-floating, non-deuterium-burning, substellar objects" is a dilemma. Here there are some of the names used for designating them:

- Cluster planet
- Directly-imaged gas-giant planet
- Free-floating planet
- Free-floating planetary-mass brown dwarf
- Interstellar planet
- Isolated extrasolar giant planet
- Isolated planetary-mass object
- Nomad planet
- Orphan planet
- Plamo (contraction of "planetary-mass object")
- Planemo (idem)
- Planetar (originally coined for designating brown dwarfs)
- Rogue planet
- Starless planet
- Sub-brown dwarf
- Sunless planet
- Superjupiter
- Wandering planet

In 2003, the Working Group on Extrasolar Planets (WGESP) of the International Astronomical Union presented a position statement on the definition of a planet, which is complementary to the definition voted in Prague in 2006 of a solar system planet (the one in which Pluto became a dwarf planet). WGESP agreed on the following [84]:

1. Objects with true masses below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses [0.013 M_{sol}] for objects of solar metallicity) that orbit stars or stellar remnants are "planets" (no matter how they formed). The minimum mass/size

required for an extrasolar object to be considered a planet should be the same as that used in our Solar System.

2. Substellar objects with true masses above the limiting mass for thermonuclear fusion of deuterium are "brown dwarfs", no matter how they formed nor where they are located.
3. Free-floating objects in young star clusters with masses below the limiting mass for thermonuclear fusion of deuterium are not "planets", but are "sub-brown dwarfs" (or whatever name is most appropriate).

This position statement is illustrated by the flowchart in Figure 2. As emphasized by WGESP, this was a working definition and "*a compromise between definitions based purely on the deuterium-burning mass or on the formation mechanism*". WGESP also "*expected this definition to evolve as our knowledge improves*" [84]. This definition does not include free-floating, non-deuterium-burning, substellar objects around a brown dwarf (Section 3.2). The first WGESP name proposal for substellar objects that are neither brown dwarfs or planets was "sub-brown dwarf". However, this term may lead to confusion with "brown subdwarfs", i.e., low-metallicity ultracool dwarfs of mid-L spectral type or later that extrapolate the luminosity class VI at the bottom of and slightly below the main sequence [85–90]. All other names enumerated at the beginning of this section carry the chain "plane-" (e.g., rogue planet, isolated planetary-mass object, planemo or "brown" (e.g., free-floating planetary-mass brown dwarf)). Given the difficulty in reading "free-floating, non-deuterium-burning, substellar object" or its corresponding acronym (FFNDBSO), that this review is part of a special issue on "Detection and characterization of extrasolar planets", and for emphasizing that such bodies are not physically bound to any star or stellar remnant, hereafter I will use the term "isolated planetary-mass object" or, better, the acronym iPMO for designating them.

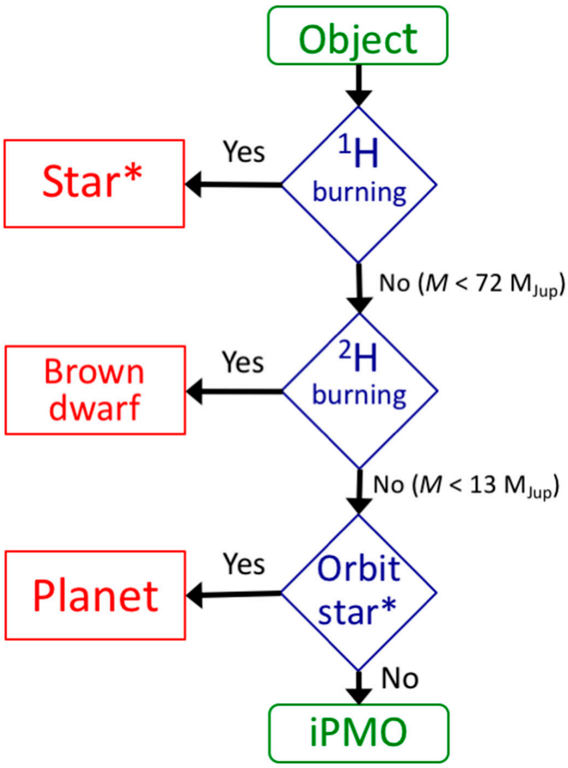

Figure 2. Flowchart of the Working Group on Extrasolar Planets position statement on the definition of a planet (1 M_{sol} = 1047.6 M_{Jup}). The acronym iPMO stands for "isolated planetary-mass object", but it can be replaced by "sub-brown dwarf (or whatever name is most appropriate)". The asterisks of stars indicate that some of them also burn helium and more massive isotopes, and that planets orbit stars, white dwarfs, neutron stars or black holes. Image courtesy of the author.

The planet/brown dwarf/iPMO classification used here and by WGESP is in contradiction with the physical criteria for including a candidate in exoplanet catalogues. For example, The Extrasolar Planets Encyclopaedia [91] tabulates to date 3820 exoplanet candidates in 2854 planetary systems. The encyclopaedia's former upper mass limits were 0.013 M_{sol}, based on the deuterium burning limit, and 0.030 M_{sol}, based on some formation scenarios (Section 5). However, the current limit is 0.060 Msol + 1σ because, as pointed out by [92], "the mass-density-radius distribution shows a clear difference between giant planets and stars at 60 M_{Jup} [0.060 M_{sol}]." As a result, the encyclopaedia currently lists many brown dwarfs according to the WGESP definition (either single, as Teide 1 [28], or companions, as GJ 229 B [31]), as well as a few nearby iPMO candidates, which may also lead to confusion to newcomers (Figure 3).

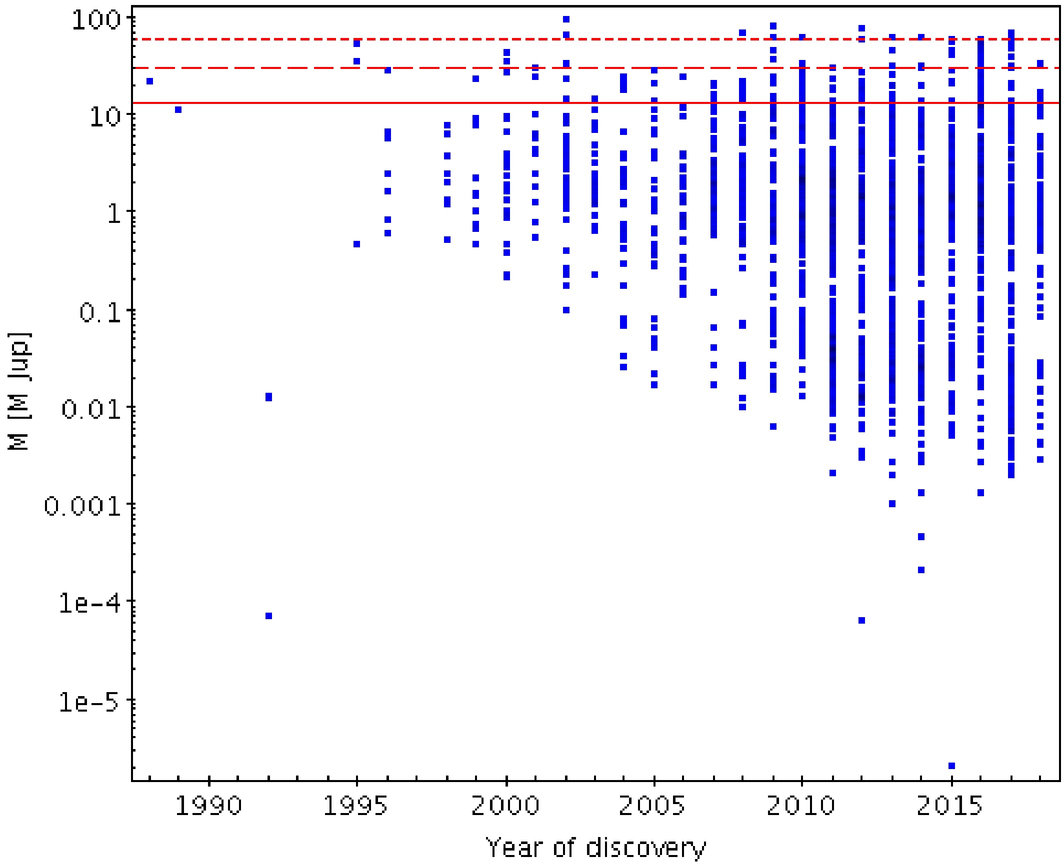

Figure 3. Mass or minimum mass of objects catalogued in The Extrasolar Planets Encyclopaedia as a function of year of discovery until August 2018 [91]. The horizontal lines mark the different Encyclopaedia upper mass limits at 0.060 M_{sol} (dotted), 0.030 M_{sol} (dashed) and 0.013 M_{sol} (solid), from top to bottom. Objects above the solid line (±1σ) are brown dwarfs or stars according to the WGESP definition of planet. Below the solid line there are also a few iPMO candidates. Image courtesy of the author.

3. History of Discovery

The discovery of the first brown dwarfs was a natural consequence of the development of astronomical instrumentation and techniques and the use of larger telescopes with respect to previous searches of low-mass stars. Likewise, the discovery of the first iPMOs originated from new deep searches for faint brown dwarfs, especially in young open clusters. The deeper the survey, the less massive the cluster members. The main aim of these searches was to determine the shape and end of the initial mass function [93–96] at very low masses, down to below the hydrogen burning limit.

The first iPMOs were published in 2000 in the Orion Nebula Cluster (ONC) by Lucas & Roche [97] and the σ Orionis open cluster by Zapatero Osorio et al. [98], in this order. The UK team did not present any spectroscopic data of their targets until one year later [99], while the Spanish one did it already. Since at least spectral type determination is necessary at these very low masses for identifying possible contaminants, both European teams [97,98] are now widely recognized by their quasi-simultaneous discoveries. One year before, another Japanese team had also found a few embedded targets in the clouds of Chamaeleon [100], but the high extinction prevented astronomers from confirming their nature for years [101], while [102] reached the deuterium burning mass limit in IC 348, but could not go deeper.

The targets found and the techniques and facilities used by both UK and Spanish teams were quite similar. ONC and σ Orionis are more or less at the same heliocentric distance (d ~400 pc) [103–108] and galactic latitude, have solar metallicity [109,110], are located in the same direction towards the antapex in the Ori OB1 association, and project the same angular size on the sky of about 1 deg. ONC in the Orion Sword is slightly younger (t ~1 Ma) than σ Orionis in the Orion Belt (t ~3 Ma) [34,111–114]. As a result, the extinction is larger in ONC than in σ Orionis: while one could see all Milky Way stars in the line of sight of the Orion Belt with an ultradeep survey [115], there is only contamination by foreground sources towards the Orion Sword. The age and extinction effects compensate each other, and the substellar boundary in ONC and σ Orionis roughly lies at the same magnitude $I = 17-18$ mag [35].

The two teams used wide-field cameras at 2–4 m telescopes and the reddest optical bands suitable at that moment (*RIZ*). They minimized the number of pointings by surveying the central parts of both clusters, but avoiding the bright Trapezium and Trapezium-like stars at the very centers, which saturate the detectors and generate wide bleeding and smearing lines and optical ghosts (see example of a representative deep survey in Figure 4). After bias and flat-field corrections, they performed the corresponding photometric analysis on the CCD images (generally, aperture photometry first, and point spread function photometry, next), discarded non-stellar sources, plotted color-magnitude diagrams, extrapolated the cluster sequence with the help of theoretical isochrones and bona fide cluster members of higher mass, and applied a certain selection criterion in the diagram(s). After compiling a list of brown dwarf and iPMO candidates, the most promising ones were subject of follow-up near-infrared imaging and spectroscopy at larger telescopes. Given the faintness of iPMOs (and extinction in the case of ONC), with red optical magnitudes of $I = 22-25$ mag, spectroscopy could be performed only at 4 m to 10 m-class telescopes, and with low spectral resolution.

Before 2006, very few iPMOs had published spectroscopy because of its faintness. The targets listed in Table 1 consumed hours and hours of research: preparing telescope time proposals, being awarded by time allocation committees, observing in imaging mode in the optical for several consecutive nights (Orion is a winter constellation in the Northern hemisphere, so the fraction of time lost due to bad weather is high), reducing and analyzing the data, selecting iPMO candidates, back to proposals and committees after one semester, back to telescope for near-infrared imaging and spectroscopy, back to reduction and analysis. While today this process can be routine, in the late 1990s and early 2000s the available hardware (hard disks of more than 8 GB were rare) and software (Python 3.0 was released in 2008) made the process to be slow and poorly automated.

Not all iPMO candidates listed in Table 1 are actually free-floating, non-deuterium-burning, substellar objects (with masses in parenthesis; actual masses of Cha 110913-773444, S Ori 69 and S Ori 70 are higher than tabulated, but subject to a large uncertainty—Section 4.1). Most of them were found in σ Orionis (they were baptized with the misleading name "S Ori"), but a few of them were also found in ONC, Chamaeleon and as a common proper-motion companion of a young brown dwarf in the TW Hydrae association (Section 3.4). With the extensive use of larger telescopes and deeper surveys, the number of iPMOs with spectroscopy has increased, although not dramatically. However, as we will see below, there is a recently new site for discovering iPMOs, very different from young open clusters and nearby associations, and that has started to bear fruits: just in our immediate vicinity!

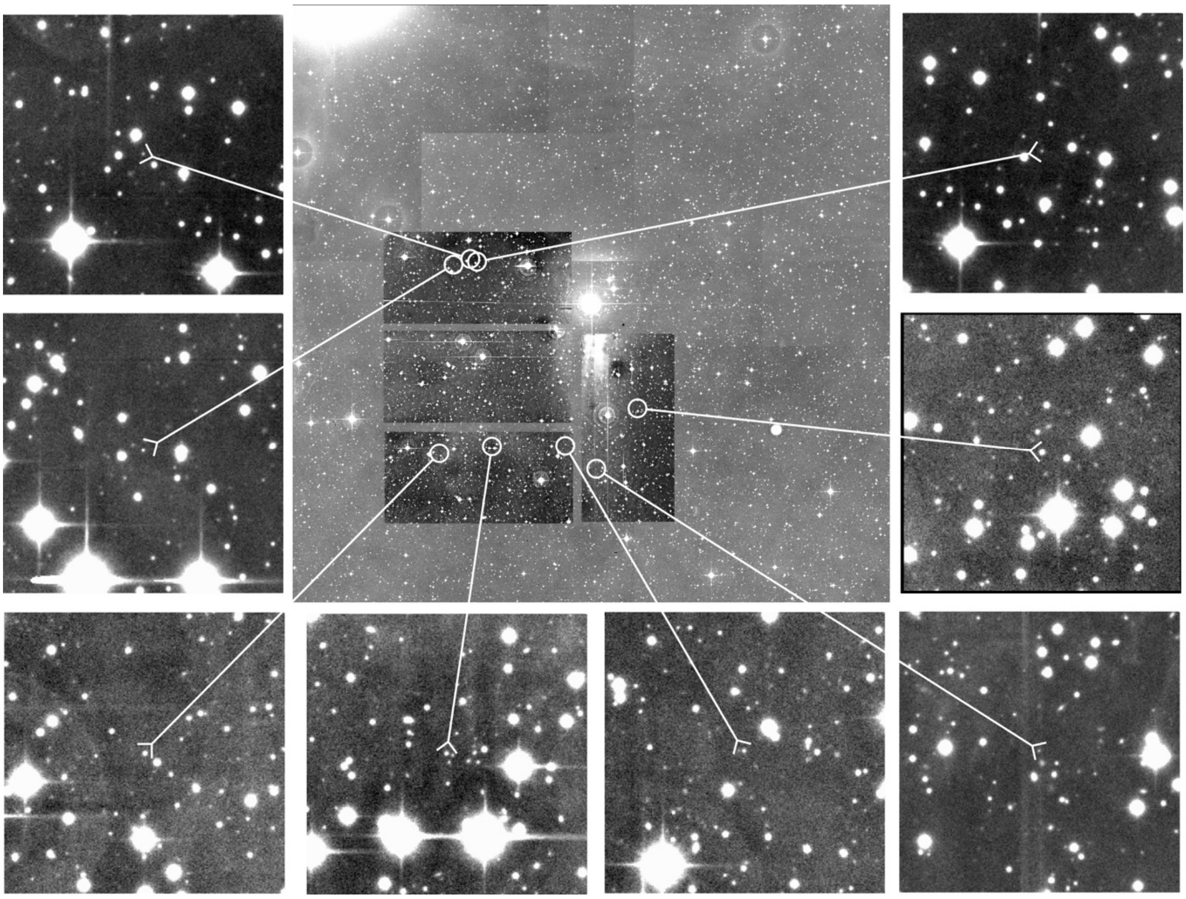

Figure 4. Mosaics of *I*-band images of σ Orionis taken with the Wide Field Camera on the 2.5 Isaac Newton Telescope showing the location of some iPMO candidates in [35]. The size of each small inset picture is 2 × 2 arcmin^2; the size of each Wide Field Camera frame is about 11 × 22 arcmin^2; the size of the background image from Digitized Sky Survey II Infrared is 1 × 1 deg^2. Image courtesy of the author.

Table 1. iPMO candidates with published spectroscopy before 2006 [1].

Name	M [M_{Jup}]	References
S Ori 53	$14^{+6}{}_{-7}$	[35,98]
S Ori 55	$12^{+4}{}_{-4}$	[98,116]
61-401	12	[99]
S Ori 56	10:	[98]
S Ori 58	10:	[98]
S Ori 60	$8^{+7}{}_{-3}$	[35,98]
Cha 110913-773444	(8)	[117]
23-115	8	[99]
S Ori 62	$7^{+7}{}_{-3}$	[35,98]
S Ori 65	6	[98]
S Ori 67	6	[98]
S Ori 68	5	[98]
S Ori 69	(5)	[98]
2M1207-29b	$5^{+2}{}_{-2}$	[118,119]
S Ori 70	$(3^{+5}{}_{-1})$	[120,121]

[1] Based on a Table by [122] (see summary in English in [123]) after deleting star companions GQ Lub b and AB Pic b. Masses have been revised with new data.

4. iPMOs Here and There

4.1. iPMOs in Young Open Clusters

Surveys for iPMOs in open clusters offer advantages over those in the field. All bona fide cluster members, under several assumptions, share a common heliocentric distance, mean proper motion, age and composition, not counting that they are located in a limited region of the sky [124–126]. Of course now one can investigate the three-dimensional structure of the Hyades [127,128], look for outlier Pleiads with abnormal proper motions [129,130], quantify an age spread in NGC 2264 [131,132] or refine the age determination of IC 2391 with the lithium depletion boundary method [133,134], but after the second data release of *Gaia* [4] the major contributors to uncertainty of iPMO masses are theoretical models at very young ages [135] and, in the case of high-extinction star-forming regions, the quality of spectroscopic data from which effective temperatures and, therefore, luminosities are derived.

Besides, as well as giant exoplanets, brown dwarfs and low-mass stars, iPMOs in young open clusters and star-forming regions are overluminous with respect to substellar objects of the same mass, but much older, in the field (as a reference, the Sun is 4.6 Ga old). In a sense, they are in a pseudo-Hayashi track that never reaches the zero-age main sequence. As shown in Figure 5, iPMOs younger than about 10 Ma have bolometric luminosities equal or greater than those of the lowest mass stars older than the Hyades (650 Ma [136]).

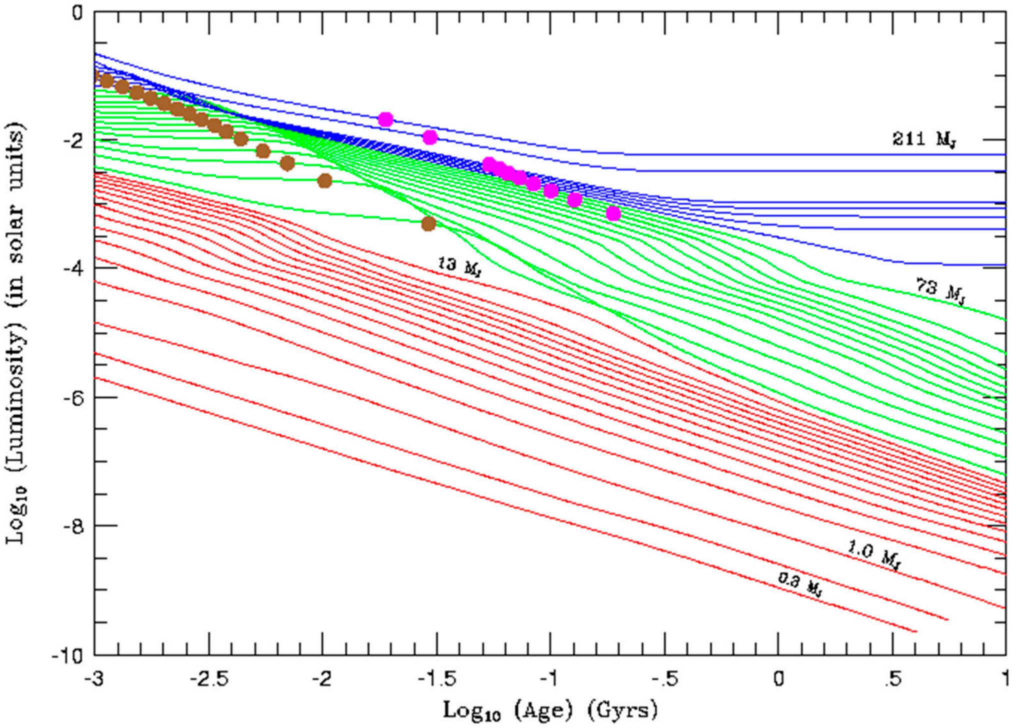

Figure 5. Cooling curves for M dwarfs (blue), brown dwarfs (green), and "extrasolar giant planets" (red) according to the evolutionary models of [84]. Magenta and brown circles indicate the times when deuterium fusion ends and grain formation begins, respectively. "Planetary-mass objects" of a few megayears can have luminosities greater than low-mass stars of a few gigayears. Heritage scientific graphic downloaded from Adam Burrows' home page [137].

The younger, the brighter. Moreover, the younger, the easier recognizing a bona fide cluster member. Since iPMOs share characteristics with other cluster stars and brown dwarfs, there is a number of youth features that make them different from field interlopers. Spectroscopically, young iPMOs display weaker alkali neutral resonance lines (K I, Rb I, Cs I; but Li I deserves a separate discussion: Section 1), stronger titanium and vanadium oxide and weaker hydride absorption bands, and more peaked *H*-band pseudocontinuum than field objects of the same effective temperature [138,139], and references therein]. Besides, their spectra can also show Hα , which may be strong and/or broad, and other emission lines typical in accreting T Tauri stars and brown dwarfs [140,141]. The spectral energy distributions of several young iPMOs show mid- (or even near-) infrared excess, which is a signpost of a circumsubstellar disc, from which there can be accretion (Section 4). Juvenile iPMOS (t = 30–200 Ma) do not have infrared flux discs, but may also have a flux redistribution between *J* (1.2 mum) and *WISE W2* (4.6 µm) passbands, while keeping a constant bolometric luminosity [142–145]. Usually iPMOs in young clusters have L spectral types (T_{eff} < 2200 K), but the least massive and/or in juvenile clusters (i.e., the Pleiades) have T spectral types (T_{eff} < 1300 K). However, a T dwarf in the Hyades is still a brown dwarf (e.g., the two early T-dwarf Hyads discovered by [146] have masses of about 0.05 M_{sol}). Non-deuterium-burning substellar objects in the Hyades might have a Y spectral type.

There have been claims of iPMO detections in a number of young open clusters with a wide range of heliocentric distances, ages and extinctions:

- Chamaeleon cloud complex [100,147–149]
- Collinder 69 open [150,151]
- IC 348 and NGC 1333 in Perseus [152–157]
- Lupus 3 [158]
- Orion Nebula Cluster [98,99,159–164]
- Pleiades [165–170]
- ρ Ophiuchi cloud complex [171–177]
- Serpens Core [178]
- σ Orionis open cluster [34,35,98,120,145,179–187]
- Taurus-Auriga [188,189]
- Upper Scorpius [138,139,190–193]

Béjar and Martín [194] compiled 82 spectroscopically-confirmed iPMOs in open clusters and star-forming regions. Of them, 30 belonged to σ Orionis, 20 to the Orion Nebula Cluster, 21 to Upper Scorpius, seven to ρ Ophiuchi, and four to Chamaeleon, Lupus, Taurus and the Pleiades. There are a few differences between the compilation in [194] and Table 1 in this review, such as Cha J110913-773344, S Ori 69 and, especially, S Ori 70 now being considered as interlopers [34,187,195–198]. Besides, since the compilation by [194] there have been a few new discoveries.

Below, I briefly review four works that present the very latest results in four representative regions: Taurus-Auriga, σ Orionis, Upper Scorpius and the Pleiades. Each of them have their own pros and cons for iPMO searches: Taurus-Auriga is very young and relatively nearby (t ~1 Ma, d ~140 pc) and has a substantial proper motion, but also has high, variable extinction of up to 20 mag and occupies an extended region in the sky [199–201]; Upper Scorpius and Taurus have very similar heliocentric distances, projected size and mean total proper motions, but the former has a much lower extinction, which is counterweighted by an older age of about 10 Ma [202–204]; except for the thin nebulae around Merope, Alcyone, and Electra-Celaeno-Taygeta, the Pleiades cluster is virtually free of extinction and slightly closer than Taurus and Upper Scorpius, but is also much older, of about 120 Ma, which makes their iPMOs intrinsically fainter [205–207]; σ Orionis is located much further than the other three regions (d = 386 pc [105]), but has an age intermediate between Taurus and Upper Scorpius (t = 3 Ma [34,208]), is much more compact than them and, because of the intense radiation emitted by the eponymous central Trapezium-like system (which erodes the famous Horsehead Nebula [209]), the extinction towards the cluster is very low [210].

Most of the other listed star-forming regions (Chamaeleon, Perseus, Lupus, Orion Nebula Cluster, Ophiuchus, Serpens) have also high extinction and their iPMO candidates need a proper de-reddening. Only the Collinder 69 open cluster, in the Hunter Head, has a low extinction, probably due to the supernova explosion that originated the 12-deg ring around Meissa (λ Orionis) but, with t = 5–10 Ma, it is slightly older than σ Orionis [211–213].

4.1.1. Taurus-Auriga

There are planets in Taurus: two of them have been imaged at wide physical separation of FW Tau AB and 2M0441+2301 B [214,215] (see also FU Tau B, a 0.015 M_{sol} brown dwarf at the deuterium-burning mass limit and companion of FU Tau A, a brown dwarf about three times more massive [216]). There are non-deuterium-burning substellar objects with similar masses as well, M ~0.008–0.010 M_{sol}, but free-floating in filaments in the intracluster medium together with stars and brown dwarfs (Figure 6).

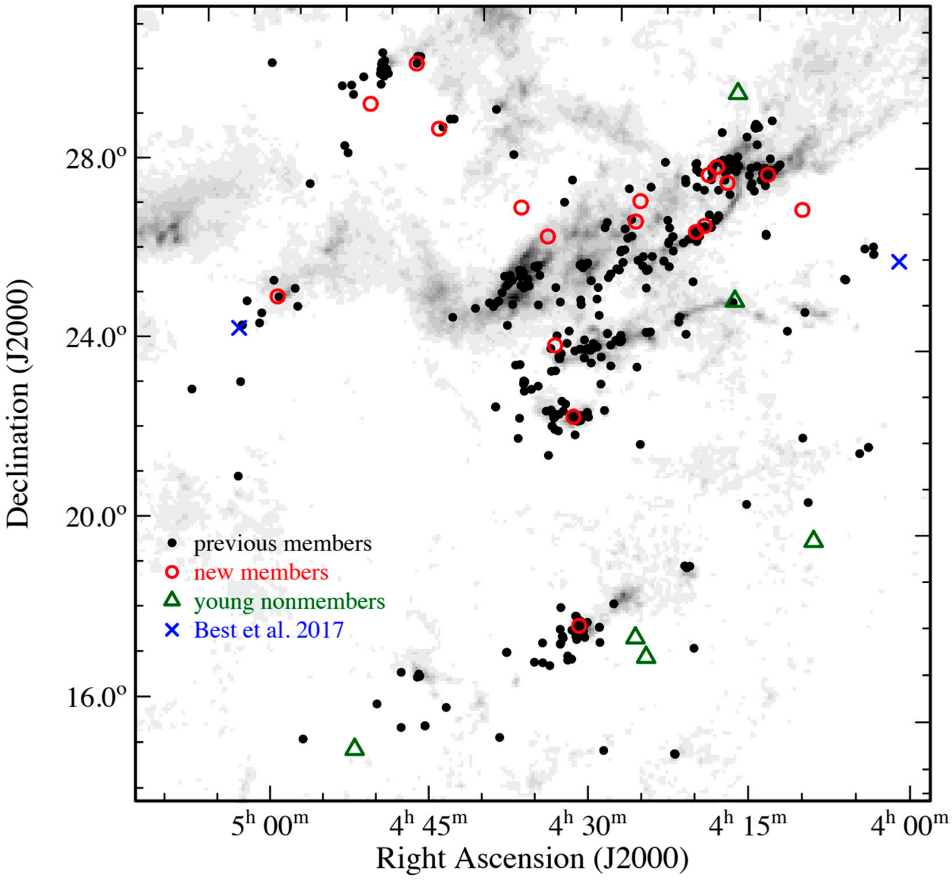

Figure 6. Spatial distribution of known members in Taurus. Black filled circles: members known before 2017; red open circles: new members from [189]; blue crosses: new members from [217]; green open triangles: young objects that do not appear to be members; grey scale: extinction map of [218]. Reproduced with permission from [189].

The latest and perhaps most comprehensive search for iPMOs in Taurus was done by Esplin and Luhman [189]. They used astrophotometric data from SDSS [219], IRAC/*Spitzer* [220], 2MASS [221], UKIDSS [222], Pan-STARRS1 [223], *WISE* [224] and *Gaia* DR1 [225]. First, they updated the list of Taurus members of [226] with the new candidates proposed by [217] and [227]. Next, they identified the best candidates with color-magnitude diagrams and proper motions, and obtained near-infrared spectroscopy of the most promising iPMOs candidates with SpeX/IRTF. After spectral classification (M9-L2), their sample included the four faintest known Taurus members and eight of the ten faintest ones in extinction-corrected *Ks* band. Their least luminous targets should have masses as low as 0.004–0.005 M_{sol} according to evolutionary models, and at least two of them have red mid-infrared colors relative of photospheres of young diskless objects of the same spectral type, which they ascribed to flux excesses from circum(sub)stellar disks (in the same work, [189] also obtained spectra of low-mass brown dwarfs and iPMOS in IC 348 and NGC 1333 clusters in Perseus).

4.1.2. σ Orionis

The σ Orionis open cluster in Ori OB1b is the region *par excellence* for iPMO searches: it is very young, extinction-free, relatively close, and compact (the spatial distribution of bona fide members follow a stepped power-law radial profile up to 20 arcmin from the cluster center [228]—in this core there is no second radial-velocity population as described by [229], but there is overlapping with other younger stellar populations near the Horsehead Nebula and Alnitak/Flame Nebula at more than 30 arcmin [230]).

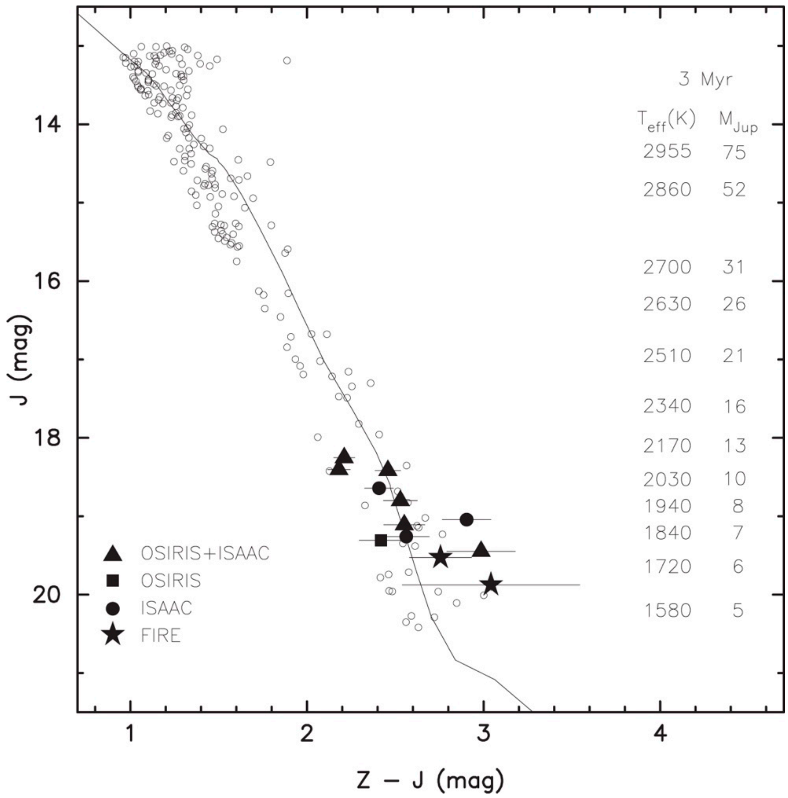

Figure 7. Optical/near-infrared color–magnitude diagram of σ Orionis low-mass star, brown dwarf, and iPMO candidates from [186] (open circles) and [145] (filled symbols, with new spectroscopic follow-up; see legend). Solid line: 3 Ma isochrone [40]. Columns: theoretical effective temperatures and masses (in M_{Jup}) for this isochrone. Reproduced with permission from [145].

The work of Zapatero Osorio et al. [145] was the culmination of a two-decade effort in the search for the mass limit to formation via the opacity-limited fragmentation in σ Orionis. Already ten years earlier, [35] had found that such limit must lie below 0.006 M_{sol}, but at that time, very few iPMOs had spectroscopy, and even less had clear signposts of youth. To fill this gap, [145] compiled the largest collection of high-quality spectra of the least massive objects in the cluster. In particular, they obtained low-resolution spectroscopy in the red optical and near-infrared of 12 iPMOs with magnitudes J = 18.2–19.9 mag. With Osiris/GTC, ISAAC/VLT and FIRE/Magellan, they derived spectral types L0-4.5 and M9-L2.5 in the optical and near infrared, respectively, which correspond to effective temperatures of 2350–1800 K (for low surface gravities log g ~4.0). The targets' spectra revealed signposts of youth (Section 3.1), thus "corroborating their cluster membership and planetary masses" (0.006–0.013 M_{sol}). Including six previously known σ Orionis L dwarfs in the spectrophotometric cluster sequence (Figure 7), two of which have disks [179,180,196], their observations completed spectroscopically, and the σ Orionis mass function presented by [186] down to the limit of their study at 0.006 M_{sol}—there are likely less massive objects that are cluster members. Their concluding remarks, if true, will have an impact on future iPMO searches in the field (Section 6): [145] expected as many 0.006–0.0013 M_{sol} iPMOs as 0.075–0.15 M_{sol} late M and early L stars in the solar neighborhood.

4.1.3. Upper Scorpius

There are also planets in Upper Scorpius. Some of them are wide companions to stars and found in direct imaging, such as 1RXS J160929.1-210524 b [231,232] (GSC 06214-00210 B is likely a brown dwarf companion [233,234], such as HD 143567 B [235]), while others are close companions to stars and found with *Kepler* and the transit method [236,237]. Of them, K2-33 b, a super-Neptune transiting an M3 Upper Scorpius low-mass star, is a cornerstone for understanding the formation and evolution of planets [238–240].

Based on a previous photometric survey for objects in the planetary-mass domain, Lodieu et al. [139] presented the most exhaustive characterization of iPMOs in Upper Scorpius. The basis of their work was a very deep 13.5 deg^2 *ZYJ* VIRCAM/VISTA survey complemented with *ZYJHK* UKIDSS Galactic Cluster Survey data sets and *z*-band IMACS/Magellan imaging [193]. In their new work, [139] used very deep *i*-band Osiris/GTC imaging and optical and near-infrared spectroscopy with Osiris/GTC and X-shooter/VLT (Figure 8), together with *WISE* mid-infrared photometry (and EMIR/GTC near-infrared spectroscopy of one target). Thanks to the corresponding analysis of the photometric and spectroscopic properties of young L-type Upper Scorpius members, they defined the first sequence of iPMOs in the association. Since their survey was limited by the *Y*-band depth, their *J*-band images might contain "some yet-to-be-found T-type dwarfs" with masses below 0.005 M_{sol}.

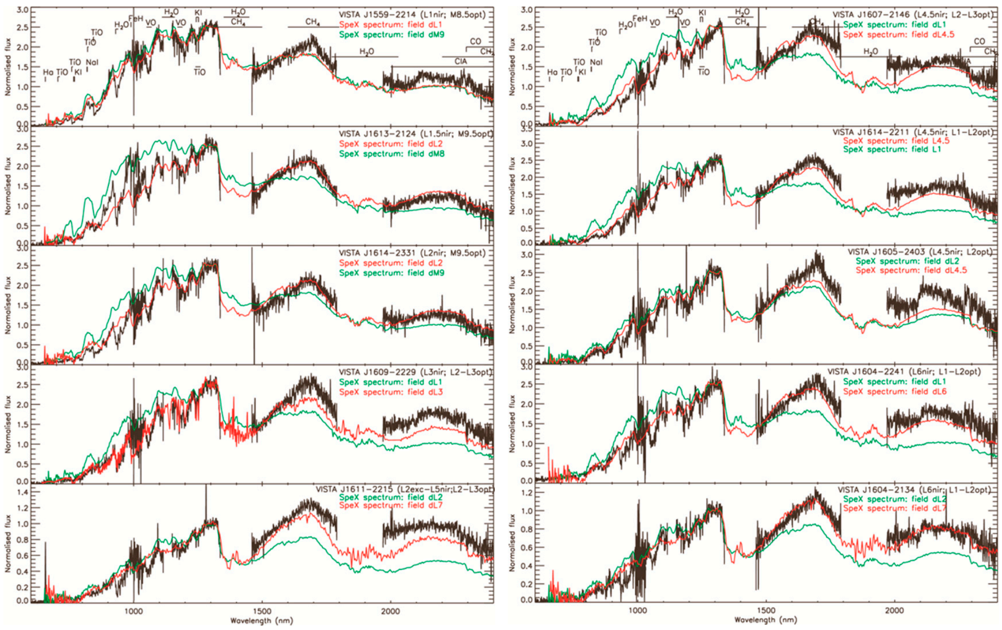

Figure 8. Normalized Osiris/GTC and X-shooter/VLT (smoothed) spectra of nine Upper Scorpius objects at the deuterium burning mass limit, compared to SpeX spectra of late M and early L field dwarfs. The overall spectral energy distribution matches best the infrared classification. Reproduced with permission from [139].

4.1.4. Pleiades

The Pleiades (Messier 45, Seven Sisters, Siete Cabritillas, Siebengestirn, Sette Palommielle, daughters of Pleione, Manilius' narrow cloudy train of female stars, Bayer's Signatricia lumina et septistellium vestis insistoris, Hesperides, Al Thurayya/Al Najm, Subaru/Mutsuraboshi, Baba/Nasedha, Matariki, Krittika, Kimah, Cajupal, Sar en, Ulgher, Πλειαδεσ, 昴, ^{MUL}MUL) was the first open cluster known to host substellar objects (Teide 1, PPl 15 AB [28,30]). However, it took almost a decade to find the first objects with masses below the deuterium-burning limit [165,241–243], including the ambiguous detection of T-dwarf candidates [244]. In a survey that covered only about 3% of the total area of the cluster, [168] discovered for the first time a population of 19 Pleiades iPMO candidates with proper motions consistent with cluster membership.

Using input data from [168], in their new work, Zapatero Osorio et al. [170] imaged six Pleiades iPMO candidates in *z* band with Osiris/GTC: Calar 21, 22, 23, 24, 25 and 26. With the same instrument, they also imaged Calar 24 in *i* band, and took low-resolution (R ~270) optical spectroscopy of Calar 21 and 22. Because of its extended full width at half maximum with respect to point-like sources, Calar 23 is a background galaxy. Besides, the proper motion of Calar 26, the faintest source in *J* band, is compatible with that of the cluster at the 2.5 σ level, so only Calar 21, 22, 24 and 25 remain as astro-photometric Pleiad candidates. Of them, Calar 21 and 22, with approximate spectral types L6-7, extrapolate the spectro-photometric cluster sequence down to the deuterium-burning mass limit (Figure 9). The other two candidates, Calar 24 and 25, may have masses as low as 0.011–0.012 M_{sol}. The [170] findings demonstrated that not all iPMOs have completely escaped the Pleiades, in spite of their very low mass and cluster dynamical relaxation [168,245]. Besides, the four Calar iPMOs are excellent targets for the deuterium test, which was proposed already by [33] to discriminate between brown dwarfs and "free-floating, non-deuterium-burning, substellar objects".

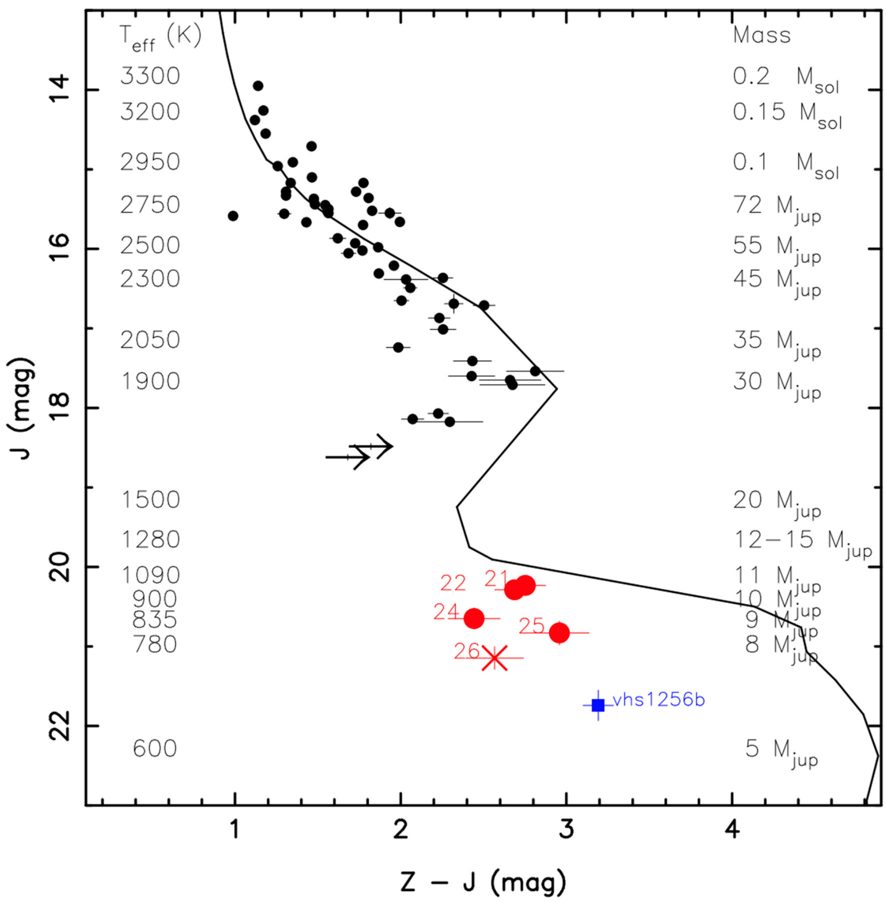

Figure 9. Optical/near-infrared color–magnitude diagram of Pleiades low-mass star, brown dwarf, and planetary-mass candidates from [166,168] (black dots) and [170] (red filled circles; see legend). Red asterisk: likely non-member Calar 26. Black arrows: color from Z-band upper limits. Solid line: 120 Ma isochrone [40]. Columns: theoretical effective temperatures and masses (in M_{Jup}) for this isochrone. Blue square: VHS J1256-911257 b [246] shifted to the Pleiades distance. Compare with Figure 7. Reproduced with permission from [170].

4.2. (i)PMOs Around Brown Dwarfs

The 2003 WGESP definition of star, brown dwarf, planet and iPMO (Section 2) did not include the possibility of "non-deuterium-burning substellar objects" in orbit to brown dwarfs. A few such possible "planetary-mass companions to brown dwarfs" have been proposed (not the use of "B" instead of "b" in the name):

- TWA 27B (widely known as 2M1207-39b or 2M1207b) [118,119,247–252]. It is the ~0.005 M_{sol}-mass common proper motion companion to the young brown dwarf TWA 27A in the ~10 Ma-old TW Hydrae association. They are separated by about 40 au and, because of the low mass of the primary, the system mass ratio is as low as 0.1–0.2, with a moderately high uncertainty that comes from the determination of the actual masses of both TWA 27 A and B. Furthermore, for explaining an apparent underluminosity of the secondary, it may have a surrounding disk, as well as the system primary, which has an impact on the derived mass [253–258].
- S Ori 68 [259]. Previously classified as an ~0.005 M_{sol}-mass iPMO in σ Orionis [98,179], it lies at a projected physical separation of ~1700 au to the X-ray-flaring brown dwarf SE 70 [260,261]. In spite of being much more separated than TWA 27AB, [259] showed that the probability of chance alignment between the two cluster bodies was extremely low. Because of the system faintness (J_A = 15.27 mag, J_B = 20.2 mag), it misses a common proper motion confirmation. The corresponding system mass ratio is 0.2.
- L Ori 167 B [262]. It is a slightly older S Ori 68+SE 70 analog in the Collinder 69 (λ Orionis) open cluster. Although L Ori 167 AB is poorly characterized, the two pairs share similar properties (location in Orion, projected physical separation of ~2000 au, secondary mass of ~0.008 M_{sol}). In the case of L Ori 167, the system mass ratio could be as high as 0.5.
- UScoCTIO 108 B [263]. It is another wide (s ~670 au) companion to a young brown dwarf, in this case a high-mass one in Upper Scorpius. However, UScoCTIO 108 B could be as massive as 0.014 M_{sol}, which would disqualify it as a planetary-mass object. The system mass ratio is about 0.2.
- 2MASS J0441489+2301513 B (also known as 2M0441+23Bb) [214,264,265]. With a mass of 0.010 M_{sol}, it is the lowest-mass member of a young, hierarchical, quadruple system in Taurus containing a low-mass star, two brown dwarfs and the planetary-mass object. The primary 2M0441+23Ba at only 15 au is an M8.5V low-mass brown dwarf, and the pair is located at 1800 au to the more massive pair 2MASS J04414565+2301580 AB (2M0441+23AaAb). The Bb/Ba mass ratio is 0.5 [214].

All five planetary-mass companion candidates above have early to mid L spectral types [119,179,214], except for UScoCTIO 108 B, which is an M9.5V [263]. Besides, L Ori 167 B has not been spectroscopically investigated yet, but its effective temperature estimated from photometry is 1750 K [262], well within the L domain. With ages younger than 10 Ma approximately, the five systems are also very young. 2MASS J16222521-2405139 B, also known as Oph 11 B [266–268], is not listed above because it is a low-mass brown dwarf companion to another higher mass brown dwarf, perhaps in Upper Scorpius [269].

Even if they are gravitationally bound today, wide "brown dwarf+(i)PMO" systems in star-forming regions such as S Ori 68+SE 70, L Ori 167 AB or UScoCTIO 108 AB may not survive the interactions with other more massive cluster members and be disrupted in relatively short time scales (see [270] and references therein). Furthermore, regardless TWA 27AB (2M1207-39b) and 2M0441+23Bb will eventually survive disruption by the Galactic gravitational potential, too, the mass ratio of the five systems, M_B/M_A ~0.1–0.5, is very high. Indeed, they look like a "petite version" of a brown dwarf (or stellar) binary formed through cloud fragmentation [271] instead of a typical radial-velocity or transiting stellar system.

For complementing the 2003 definition, at the time of writing these lines, WGESP has proposed several definition amendments to be voted during the 30th General Assembly of the International Astronomical Union (21–30 August 2018, Vienna, Austria). One of them is applying the term "planets" only to objects that have a mass ratio to the central object below the limiting ratio for stability of the triangular Lagrangian L4 and L5 points, i.e., $M_B/M_A < 2/(25 + \sqrt{261})$ ~0.02. This mass ratio draws a boundary between two widely-separated groupings: stellar binaries and planets orbiting stars. With this new definition amendment, the objects listed above must not be considered planets, and become instead "brown dwarf-companion, non-deuterium-burning, substellar objects". Therefore, no planet around a brown dwarf has been detected yet (mid-L-type brown dwarfs have a shrinking habitable zone for those to-be-detected planets; T-type brown dwarfs are so faint that their theoretical habitable zone is inside the Roche radius [123,272,273]).

4.3. iPMOs in Our Vicinity

Either they are companions to stars (or brown dwarfs) or are "really isolated", non-deuterium-burning substellar objects do exist in very young star-forming regions and open clusters. Gigayears later, when clusters are evaporated within the Galactic disk and iPMOs have cooled down to effective temperatures typical of Y dwarfs (T_{eff} < 500 K [60,274–283]), they should be "just out there". Actually, TWA 27AB in TW Hydrae is located at merely about 55 pc. For that reason, it was not a great surprise when the first iPMOs in the solar neighborhood were reported as members in young kinematic associations [284,285]. More iPMOs arrived afterwards, especially in the 10 Ma-old TW Hydrae and 20 Ma-old β Pictoris associations [286–294] and the slightly older AB Doradus and Carina-Near moving groups [295,296]. See [144] for a compilation of young ultracool (spectral type > M7 V) member candidates in moving groups. Besides, CFBDSIR J2149-0403 was presented as an isolated planetary-mass object in AB Doradus [297], but to date it is not known whether it is a high-metallicity low-mass brown dwarf or a young iPMO not associated to any moving group [298].

Finally, *WISE*, with its astro-photometric capability in the mid infrared, also discovered a population of not-so-young iPMOs at very close heliocentric distances. These objects have very cool effective temperatures and the CH_4 absorption at 3.4 μm is so deep that they had escaped all earlier near-infrared all-sky surveys. They are so faint that they had not been able to characterize them spectroscopically in the near infrared until recently [299,300]. The most extreme cases are perhaps L 97-3 B (WD 0806-661B) [301–304] and, especially, WISE J085510.83-071442.5 [61,305–308], which is the fourth closest stellar or substellar system and the coolest Y dwarf found to date (it has water ice clouds on the upper cloud layers; see [309] for a discussion on atmospheric habitable zones in Y dwarfs). At d = 2.41+0.08 pc [306] and the age of the Sun, WISE J085510.83-071442.5 would be a 0.005-M_{sol} iPMO [300]. Several gigayears ago, it was a young iPMO at the L/T transition, like those found now in Taurus, Upper Scorpius or, especially, σ Orionis [145].

To sum up, free-floating, substellar objects of a few Jupiter masses are indeed "just out there".

4.4. iPMOs Everywhere

As a summary, Table 2 lists the names and ages of the regions where we find and characterise iPMOs spectroscopoically, their number and the most relevant references (see the previous sections for all references). The actual number of iPMOs depends on the authors' mass estimation, which is affected by uncertainties in photometry, spectral synthesis, age determination, extinction correction, and theoretical isochrones.

Table 2. Approximate number of iPMO candidates with spectroscopic follow-up per region [1].

Region	*t* [Ma]	# iPMOs	References	Remark
Taurus-Auriga	~1	~10	[188,189]	High extinction
σ Orionis	~3	~30	[98,145]	Well investigated
Upper Scorpius	~10	~20	[139,193]	Future: Y-band imaging
Pleiades	~120	2	[166,170]	Very small surveyed area
Other very young open clusters	~1	~30	[98,100,149,151,160,174]	High extinction, heterogeneity
Around brown dwarfs [2]	~1–10	5	[118,259,262–264]	Probably "brown dwarf binaries"
Vicinity (young)	~5–20	~20	[284,286,295]	In young moving groups
Vicinity (old)	~1000	2	[301,304]	Very cool and nearby

[1] See also in [194]. [2] PMOs around brown dwarfs overlap with iPMOs in young open clusters.

5. Formation

It was Shiv S. Kumar himself who proposed in 1963 for the first time, based on theoretical assumptions, that brown dwarfs (and objects below the deuterium burning mass limit) share the same formation mechanism [9,310]. He was also the first one to conclude that "*the mass of a gaseous fragment, formed by the star formation process, is much smaller than the minimum hydrogen burning mass*" [9,311]. This mass is what we call now opacity-mass limit, and has been settled at about 0.005 or slightly below M_{sol} [42,312–317]. [318] reviewed from a theoretical perspective the five non-mutually-exclusive mechanisms for forming brown dwarfs, which are (1) turbulent fragmentation of molecular clouds, producing very-low-mass prestellar cores by shock compression; (2) collapse and fragmentation of more massive prestellar cores; (3) disk fragmentation; (4) premature ejection of protostellar embryos from their natal cores; and (5) photoerosion of pre-existing cores overrun by H II regions. Ref. [319] complemented the [318] review on brown dwarf formation from an observational perspective. These mechanisms can in principle be extrapolated to iPMOs, together with the standard paradigm for the formation of giant planets in the Solar System plus subsequent ejection through very efficient dynamical interactions [320–322]. This standard planet-formation paradigm was reviewed by [323] and has six stages: (a) infall of dust grains onto the disk, evaporation and condensation; (b) formation and growth of solid particles from millimeter to kilometer sizes; (c) runaway coagulation of planetesimals into prototerrestrial planets; (d) concurrent accretion by gap formation in the disk; (e) termination of accretion by gap formation in the disk; and (f) clearing of the disk material.

By 2006, observational astronomers still looked for planet-like-formed iPMOs, which may have different internal structure (inner rocky core), composition (higher metallicity) and kinematics and position (ejected from birth system at high velocity). However, in that year Caballero concluded in his PhD thesis that "*very low-mass stars, brown dwarfs and iPMOs share the same formation mechanism [via turbulent fragmentation]*" (see [35,123]). While the other mechanisms must not be ruled out completely and "*their relative importance probably depends on environment*" [318], the standard mechanism of low-mass star formation can be extrapolated in general to brown dwarfs and iPMOs because of the following reasons:

- Continuity in the mass function. Even if it is described by a power law [95] or a log-normal function [96], the mass function (or the mass spectrum) in the low-mass stellar domain extrapolates smoothly to the substellar domain down to about 0.004–0.006 M_{sol} or less [35,139,149,186,189]. This limit of about 0.005 M_{sol} is entirely based on the sensitivity limits of the surveys. Actually, there is no indication that the mass function ends at about 0.005 M_{sol} (see Section 6).
- Continuity in the frequency of discs. Isolated PMOs have discs, from which they accrete [116,198]. In particular, [182] measured for the first time the frequency of inner discs of objects between 0.007 and 0.014 M_{sol}. The observed rate in σ Orionis, greater or equal than 50%, was consistent with the rates measured for cluster brown dwarfs and low-mass stars, but suggested that "*there is a trend for the inner rate to increase with decreasing mass, which may be due to a mass-dependent timescale for the dissipation of the interior discs*" [182].

- Isolated PMOs, brown dwarfs and low-mass stars have the same spatial distribution (cf. [35,139,149,186,189]) (but high-mass stars tend to be more concentrated towards the center of radially-symmetric clusters [228,324]). The lack of iPMOs in the very center of the σ Orionis cluster, near the Trapezium-like system, could be real or just an observational bias [325,326].
- Proplyds, globulettes, proto-brown dwarfs and "Class 0 iPMOs" with substellar masses derived from radio and millimetric observations share the same properties as proto-stellar cores in extremely young star-forming regions [327–335].

The star-like formation of iPMOs via turbulent fragmentation is now widely accepted as the most important, although not unique, scenario for explaining the formation of free-floating, non-deuterium-burning, substellar objects. However, regardless how they form, the fate of an iPMO is always the same: cool and cool forever.

6. Future

Apart from cooling until Universe heat death, the mid- and long-term future of "free-floating, non-deuterium-burning, substellar objects" or iPMOs is summarized in three words: LSST, *Euclid*, *WFIRST*. The Large Synoptic Survey Telescope [336], ESA *Euclid* mission [337] and NASA *Wide Field Infrared Survey Telescope* [338], with their large apertures and étendues in the optical and, especially, near infrared, will expand the sample of iPMOs with parallax determination in the solar vicinity, with proper-motion determination in open clusters and associations, and with accurate spectral energy distributions at all distances.

In the meantime, very deep surveys such as BASS-Ultracool [289], which aims at detecting T-type, planetary-mass members of young moving groups in the solar neighborhood, or SONYC [149], which provides a census of Substellar Objects in Nearby Young Clusters down to about 0.005 M_{sol}, will try to reach the opacity mass limit. Other key issues that will become very common in iPMO searches and analyses, and that need further development, will be narrow-band photometry [170,339], for which 8–10 m-class telescopes would work in survey mode, and improved theoretical models at very low temperatures and young ages [135]. Beyond 2021, we will also use the *James Webb Space Telescope* [340–343] and the next generation of 30–40 m-class ground telescopes, such as the European Extremely Large Telescope E-ELT [344], for the spectroscopic follow-up in the near and mid infrared of the faintest iPMOs.

A concluding science-fiction remark: because of their closeness, the coolest iPMOs may be eventually useful for mankind. What about mining their atmospheres in the far future? The atmosphere will be unbreathable, winds will be hurricane-force, surface gravity will be 100 times greater than on Earth (which implies difficulty for spaceflight [345,346]), but temperature will be comfortable and our descendants may be able to extract valuable ores demanded in the Solar System. Views from the iPMO terminator will be magnificent!

7. Postlude

There are examples of musical astronomy and astronomical music [347–352]. As an unexpected end of review, I will show two examples of music and iPMOs. One is the videoclip of *El ordenador simula el nacimiento de las estrellas* (*Computer simulates birth of stars*), a song in Antonio Arias' album *Multiverso* that displays a reappraisal of the M. Bate's hydrodynamical modelling of the collapse and fragmentation of a cold, isothermal cloud, resulting in more than 1250 stars, brown dwarfs and iPMOs [352–354].

The other example was "composed" by F. M. Walter in May 2002 in Hawai'i. Inspired by the discussion during the International Astronomical Union Symposium 211 *Brown Dwarfs* [355] that resulted in the WGESP definition in Section 2 [356], Fred prepared the lyrics below, to be accompanied of Woody Guthrie's *Talking Blues* (a talking blues is a strict-rhythm, free-melody, near-speech form of American folk/country music). Fred entitled the new song *The Brown Dwarf Talking Blues* but, as you will read (or sing) below, he could instead have entitled it *The Free-Floating Non-Deuterium-Burning Substellar Object Talking Blues*.

Soaking up the rays at Waikoloa,
Two years before two thousand four,
Pondering problems with nomenclature
Of heavenly orbs of tiny stature.
Brown Dwarfs... Magenta Midgets...

After dinner I attended a session,
hoping to learn a useful lesson.
The big kahunas, and the Boss-man too
delivered the opinion of the IAU.
Gas Giants... Sub-brown dwarfs...

Things that fuse in the night are stars,
And orbiting them are planets like Mars.
Can't see those cause of their low mass,
So we argue about great balls of gas.
Free Floaters... Superplanets...

Observations show they're free in space,
Theory says they must have come from some place.
So what do you call that Jovian ball
Floating in space and not in thrall?
Substellar mass objects... Plamos...

Nature or nurture was the question to some,
Others just cared for the mass, by gum!
Political correctness carried the day:
Tally up the names in the papers, they say.
Mass-challenged stars... russet runts...

If you ask me it doesn't make much sense
To hotly debate our ignorance.
Seems to me planets are really obscene...
When you see it you'll know it, if you get what I mean.
Damn Degenerates...

I echo the lyrics of Fred's talking blues with my last digression. When the time comes with improved knowledge on iPMOs, the hot debate on their nomenclature will be back. As a preparation for that moment, I present a new old point of view: Latin. In the classical "language of international communication, scholarship and science until well in the 18th century", brown dwarf is *pumilio fusca*. However, brown dwarfs are not actual dwarfs because they never reach the main sequence; this fact takes on relevance especially at very young ages, when coeval stars above the hydrogen burning mass limit and very low surface gravities belong to spectroscopic classes different from V. Since we should avoid the terms *stella*, *astrum* and *aster* (astro-, star) for brown dwarf, we could use instead other Latin term for designating heavenly bodies in general: *sidus* (sideral). In Table 3, I compiled the color terms for "brown" in Botanical Latin; *fuscus* is greyish brown. If we use instead *rufus*, red brown and keep the root of *sidus* without its proper declension (third, neuter), we get a funny word for brown dwarf: *siderufo*. If we use the prefix *hypo-* from Ancient Greek instead of *sub-* from Latin for indicating that they are "under brown dwarfs", and put everything together, my naming proposal for "free-floating, non-deuterium-burning, substellar object" (iPMO) gets *hyposiderufo*.

Table 3. Color terms for "brown" in botanical Latin [357].

Botanical Latin	Meaning
badius	chestnut brown
boeticus	Spanish brown
brunneus	pure dull brown
cacainus	chocolate brown
chocolatinus	chocolate brown
cinnamomeus	cinnamon
coffeatus	coffee-bean brown
cupreus	brownish red
ferrugineus	rusty brown
fuligineus	sooty brown
fuliginosus	sooty brown
fuscus	greyish brown
glandaceous	yellowish red brown
haematiticus	brown red
hepaticus	liver brown
ligneus	wood brown
luridus	cloudy brown
nicotanus	tobacco leaf brown
phaeo-	greyish brown
porphyreus	reddish brown
rubiginosus	brown red
rufescens	red brown
rufus	red brown
sanguineus	dull red, brownish black
spadiceus	bright brown
theobromius	chocolate brown
umbrinus	umber brown
ustalus	charred wood brown
vaccinus	cow brown
xerampelinus	dull red with brown

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Conflicts of Interest: The author declares no conflict of interest.

Note to the Reader: I use SI symbol "a" (annus) for year.

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