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# Ordinary stars matter!

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After decades of almost fruitless searches, 1995 heralded a new era for astronomy with the simultaneous discoveries of 51 Peg b (Mayor & Queloz 1995), the first exoplanet orbiting a solar-type star, and of Gliese 229B (Oppenheimer et al. 1995), the first unambiguous brown dwarf to be detected directly. This occurred at a time when the scientific community was expecting these discoveries (e.g. Stevenson 1991; Burrows et al. 1995) while having a lingering feeling that both planets and brown dwarfs were rare, maybe extremely rare (e.g. Walker 1995). When 1995 struck, it demonstrated that these objects –although not extremely frequent- could be found relatively easily with modern instruments when one knew where and how to look for them: in the case of (giant) planets, in orbit and possibly extremely close to solar-type stars; for brown dwarfs, in young clusters, when they were still bright enough to be detectable (e.g. Rebolo et al. 1995). In parallel, observations of star-forming regions had progressed so much that one could image young stars with circumstellar disks, soon to be assigned the adjective "protoplanetary" because planets were expected to form there (e.g. O'Dell & Wen 1994). At last, astronomers had managed in one fell swoop to link stars, brown dwarfs, planets, and disks.

The study of these three new astronomical objects required, however, stellar evolution models capable of precisely translating observations (colors, effective temperatures, gravities) into masses and ages. Accurate masses were critical for the distinction between stars and brown dwarfs, the study of young objects (disks, clusters, young brown dwarfs, forming stars) required precise age and mass determinations, and the characterization of planets also called for an accurate knowledge of the evolution of the parent star. The work by Baraffe et al. (1998) combined physical ingredients necessary for a precise calculation of the evolution of low-mass stars and provided tables that were easy to use and apply to observations. In 2001, the tables were extended in mass down to brown dwarfs of 0.02 $M_{\rm Sun}$ and up to stars of 1.4 $M_{\rm Sun}$.

The underlying theory developed by the authors involved state-of-the art micro-physics, which is still in use in current evolutionary models. This included: (i) an equation of state appropriate to describing the complex thermodynamical properties of H and He matter under the temperature and pressure conditions relevant to these objects; (ii) developing non-gray atmosphere models including improved treatment of molecular opacities, characteristic of the cool surface temperatures of these objects; (iii) the coupling between inner thermal profile and atmospheric profile, thereby providing fully consistent evolutionary models.

The synthetic spectra derived from the atmosphere models also allowed Baraffe et al. to compute fully consistent colors and magnitudes, enabling a direct comparison with observations in color–magnitude diagrams. This new generation of models thus marked a decisive improvement over older models. Indeed, previously, uncertain empirical temperature scales, spectral-type effective-temperature ($T_{\rm eff}$) relations, and empirical bolometric corrections were used to transform observed colors and magnitudes in $T_{\rm eff}$ and luminosity $L$ for comparison with theoretical models. The previous generations of models showed significant discrepancies with observations of low mass stars.

The models by Baraffe et al. were successful in reproducing many observational constraints for low mass stars and brown dwarfs, such as color-magnitude diagrams of globular clusters (see e.g. Pulone et al. 1998) and of relatively young clusters such as the Pleiades and the Hyades (Martin et al. 2000; Bouvier et al. 2008), mass-magnitude relations (Delfosse et al. 2000), mass-radius relations (Ségransan et al. 2003), and tests provided by multiple systems (e.g. White et al. 1999). They then were extensively used to identify young objects in star-forming regions and to infer initial mass functions of stars and brown dwarfs (Luhman 1999; Caballero et al. 2007), crucial information for understanding star formation. Finally, they are also used to precisely characterize the parent stars of transiting exoplanets, hence to better constrain the mass and radius of the planets themselves (e.g. Gillon et al. 2007).

Uncertainties in the modeling remain, however: as already noted by Baraffe et al. (1998), for effective temperatures below 3700 K, predicted $V - I$ colors are too blue by 0.5 mag for a given magnitude. Also, measurements of close-in eclipsing binaries have led to radii measurements that are 5–15% greater than theoretical predictions (Torres & Ribas 2002; Morales et al. 2009), as opposed to main field stars for which the comparison is very good (e.g. Ségransan et al. 2003). This is probably caused by magnetic activity (e.g. Chabrier et al. 2007), yet it highlights that the evolution of stars is not defined solely by their mass and metallicity, so that other parameters ultimately come into play. With better measurements of star sizes by interferometry, of distances from parallax measurements, of densities using

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photometric information from transiting planets and with new constraints on their structure from asteroseismology, future studies will require even more elaborate models of the evolution of these otherwise very ordinary stars.

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