# Biases in Population Statistics Introduced by YSO Magnetic Fields

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Joseph Turner (1843)
Heidelberg in Sunset

**Abstract**: Timescales for star and planet formation derive from comparisons of the observed positions of young stellar clusters in the HR diagram with theoretical isochrones. While there are many reasons to expect an intrinsic scatter in the HR diagram (initial conditions, accretion histories, duration of star formation, etc.), for the youngest clusters, the act of determining effective temperatures and luminosities is fraught with uncertainty. Using MoogStokes, a polarized radiative transfer spectral synthesis code, to account for the effects of magnetic fields on the emergent spectra, I show that strong magnetic fields (of the strengths measured in young stellar objects) can significantly alter the appearance of the spectrum. Neglecting the effects of these strong magnetic fields when determining properties of the young object (spectral type and luminosity) will artificially shift the the location of the object in the HR diagram, biasing any statistics derived from populations of young objects. By accounting for the effects of the magnetic field, it is possible to a) properly place objects on the HR diagram, and b) measure magnetic field strengths in young objects.

Stars in the youngest clusters are often embedded deep within their natal clouds. The extreme extinction towards these stars makes optical spectroscopy impossible for the most embedded objects. The suite of available and planned sensitive infrared spectrographs (SPEX, TripleSpec, XSHOOTER, IGRINS, etc.) has made infrared spectroscopic investigations of these young objects feasible. However, strong kilo-Gauss magnetic fields seem to be a ubiquitous feature of young stellar objects (Johns-Krull 2008). These strong magnetic fields can affect spectral features often used in characterizing young objects. For example, the strength of the Na feature (Figure 2) at 2.2 microns is often used in determining infrared spectral types for K and M type YSOs, as well as characterizing excess continuum emission (due to a circumstellar disk). The equivalent width (EW) of this feature increases with decreasing effective temperature, but also depends on the surface gravity and the photospheric magnetic field strength (Figure 3). Imperfect knowledge (or outright neglect) of the surface gravity and magnetic field strength results in a systematic uncertainty of the derived effective temperature of ~+/-200K. This systematic uncertainty translates into large uncertainties in isochronal ages (+/- 1 Myr) and YSO mass (+/- ~0.5 Msun) when compared to theoretical isochrones (Figures 4 and 5, Baraffe et al. 1998)..

MoogStokes is an extension of the MOOG spectral synthesis code, and is an artisanal polarized radiative transfer code. Painstakingly handcrafted in vintage FORTRAN 77, MoogStokes allows users to synthesize spectra from stars with strong magnetic fields and agrees well with the predictions of INVERS10, a well tested PRT code (see figure below). The MoogStokes code is available from http://www.mpia.de/~deen ,from the following QR code, or at http://arxiv.org/abs/1306.6625

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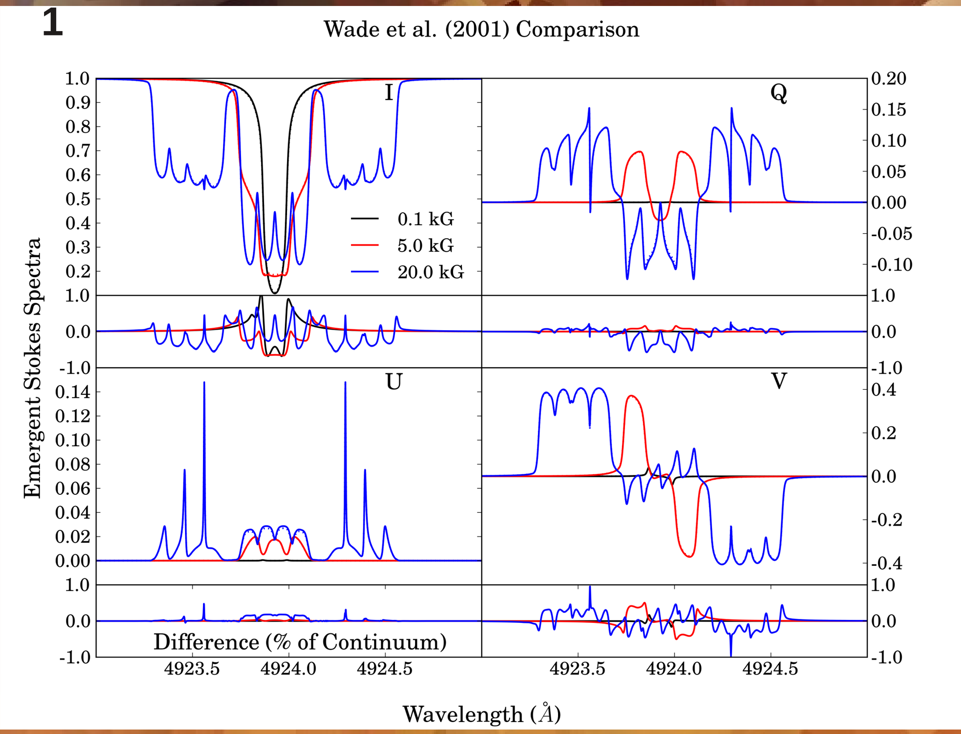


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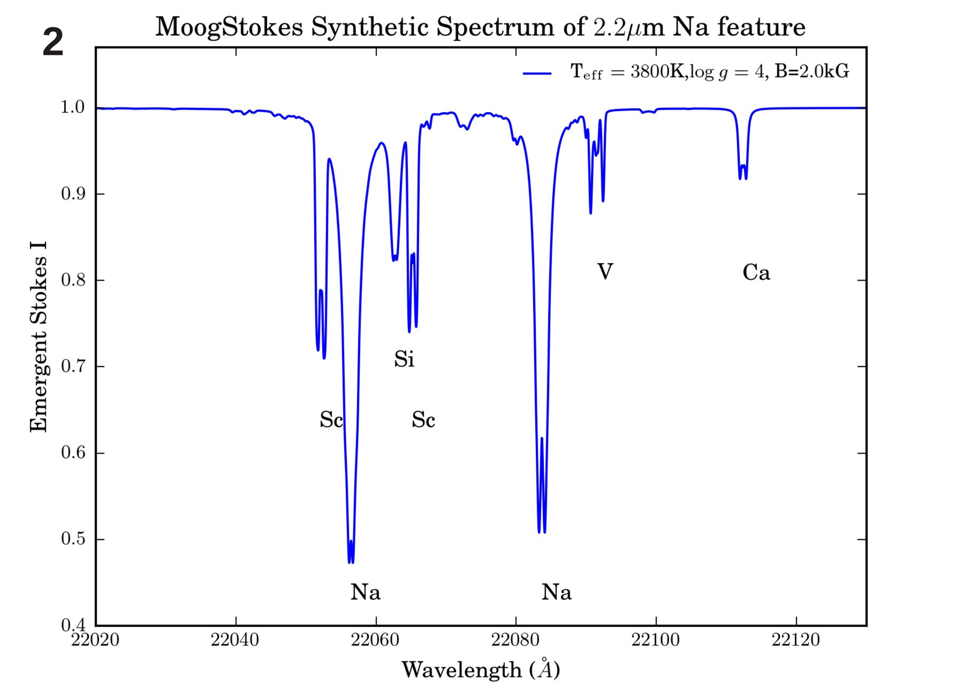


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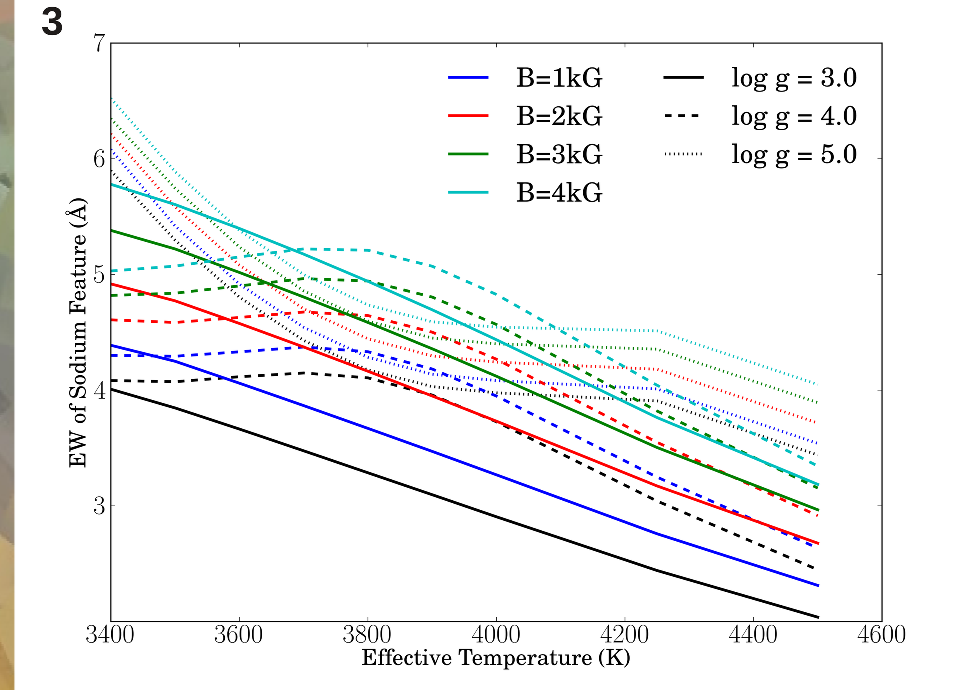


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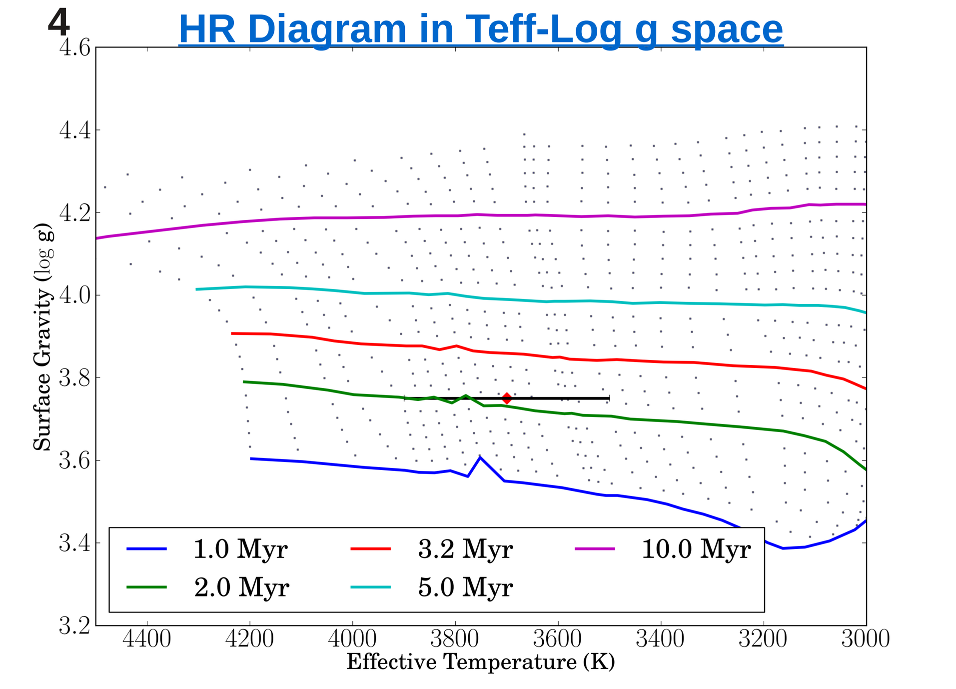


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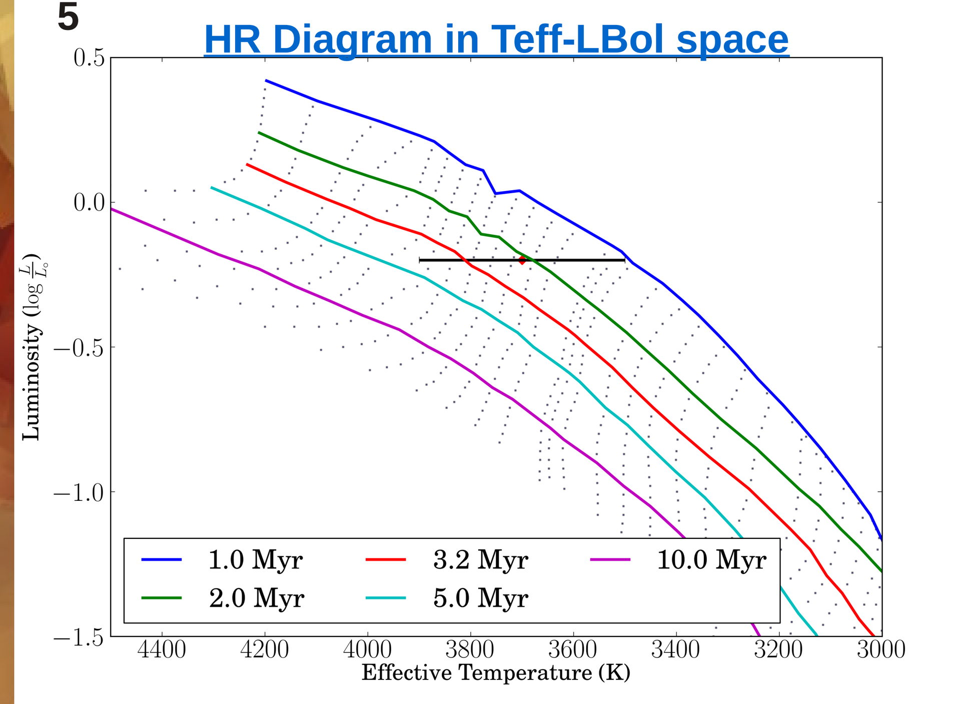


Theoretical Isochrones from Baraffe et al. 1998

Synthetic Spectra computed with MoogStoke allow better characterization of young stellar photospheres, permitting the astronomer to search a 3D grid of synthetic spectra (Teff, log g, and mean magnetic field strength) to find the best-fitting set of parameters. This in turn will improve the locations of objects on the HR Diagram. At right, I show a K-band region of synthetic spectra smoothed to the resolving powers of TripleSpec (R=3500, Figure 6), XSHOOTER (R=9100, Figure 7), and IGRINS (R=40,000, Figure 8). The bottom of each panel shows the emergent Stokes I at the detector, while the top part shows the differential sensitivities of each point in the spectrum to changes in Teff, log g, and B.

**TripleSpec – Resolving Power = 3,500**

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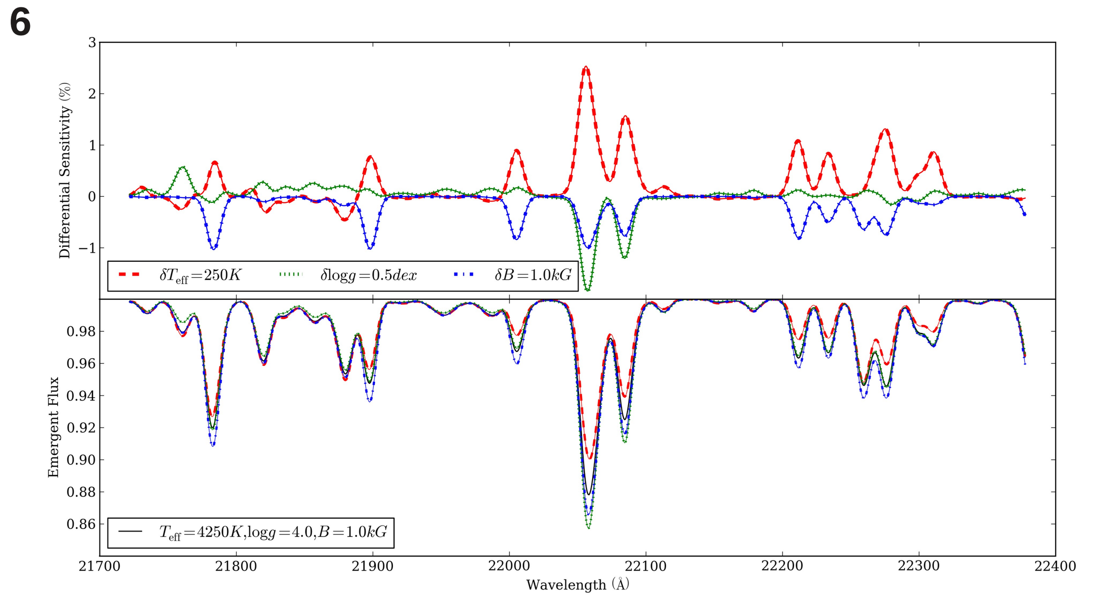


**XSHOOTER – Resolving Power = 9,100**

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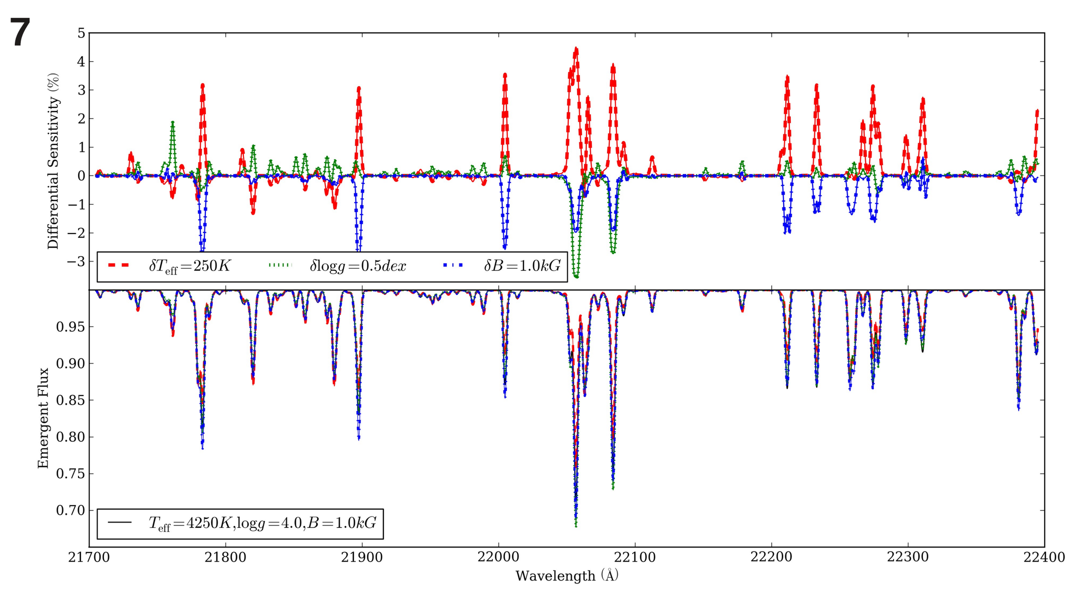


**IGRINS – Resolving Power = 40,000**

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