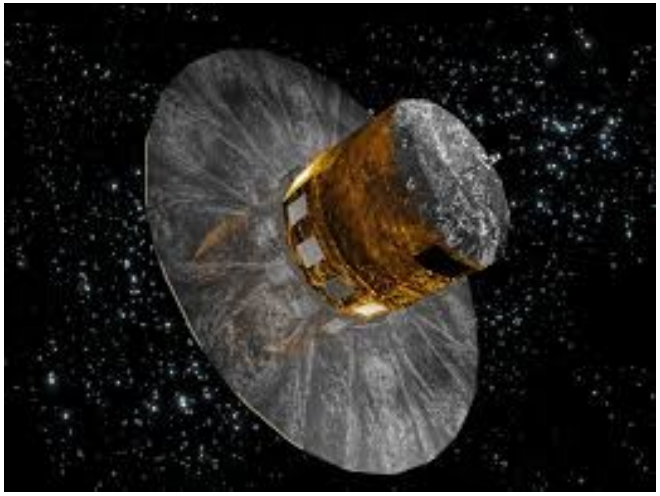
Ages of Brown Dwarfs Session



10:00-10:30 Ages of Brown Dwarfs Overview **Jackie Faherty**

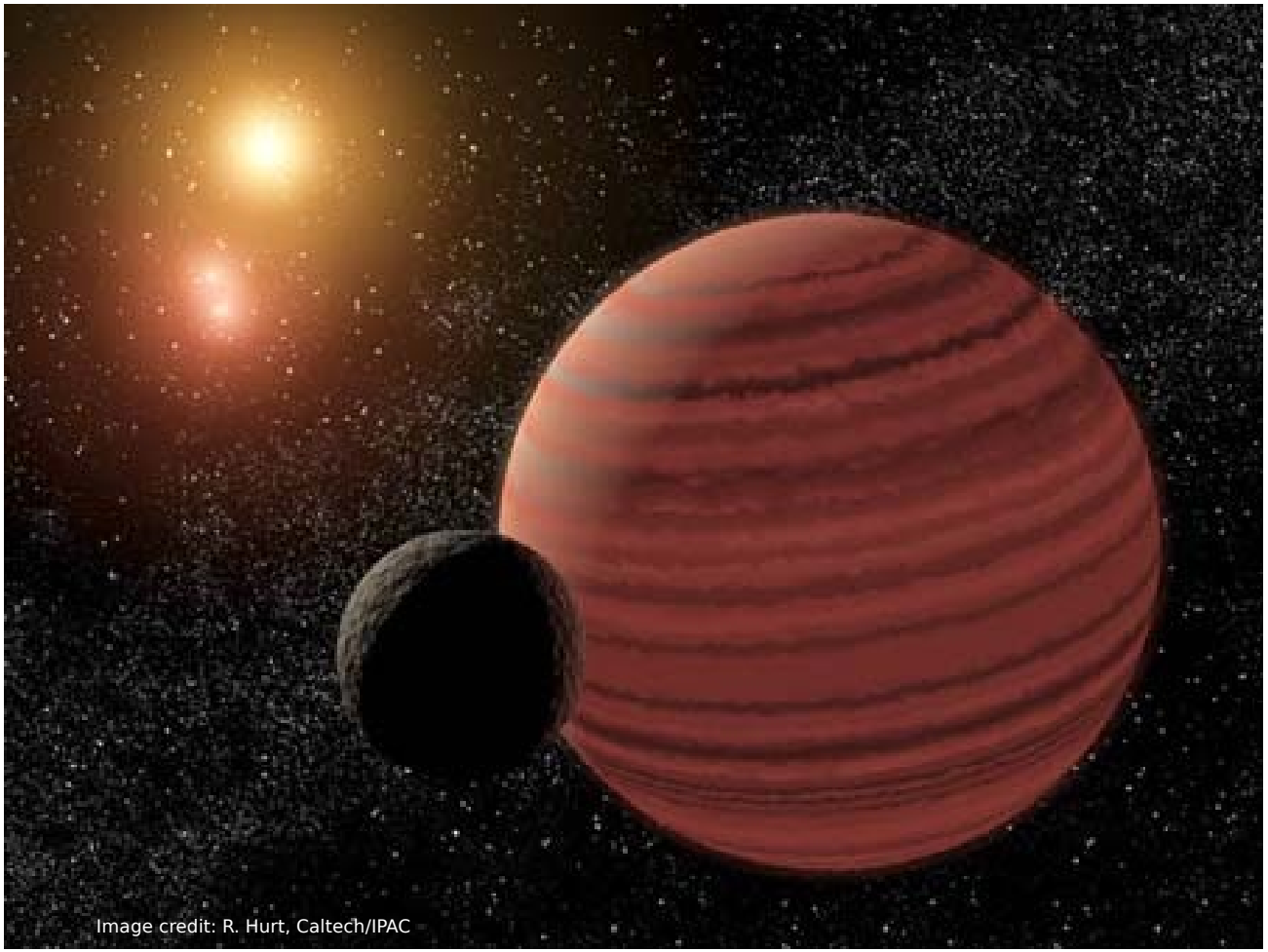
10:30 – 10:50 COFFEE

10:50-11:15 Gaia and white dwarf+ brown dwarf binaries **Sarah Casewell**

11:15-11:40 Halo brown dwarf and Gaia potential **Zenghua Zhang**

11:40- 12:05 Examining the Age Activity Relationship of Ultracool dwarfs with Gaia **Sarah Schmidt**

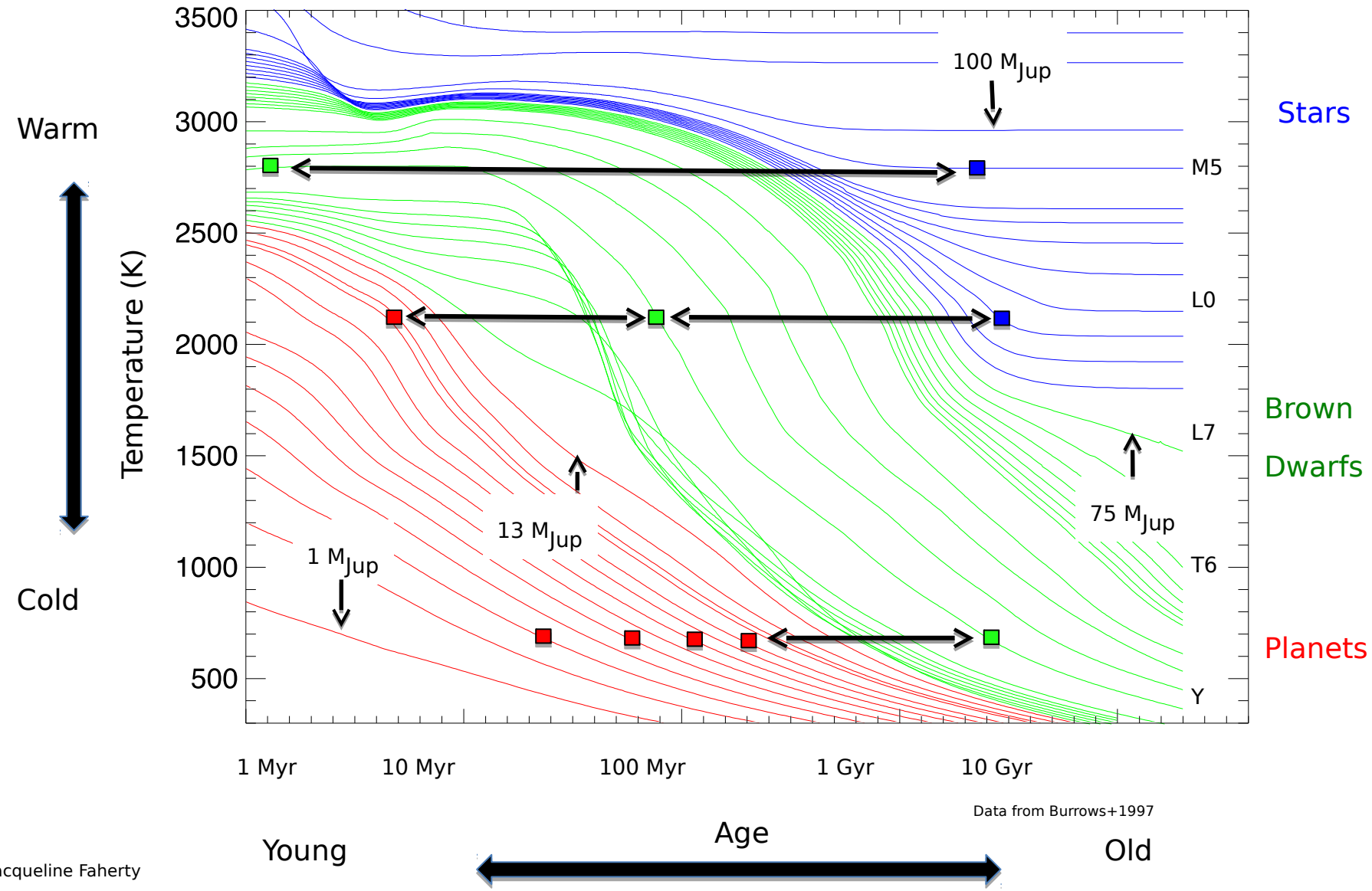
Ages of Brown Dwarfs



Jacqueline K. Faherty

Hubble Fellow at Carnegie Institution of Washington (DTM)

Ages Are Required to Measure Mass



Jacqueline Faherty

Ages of Brown Dwarfs Session

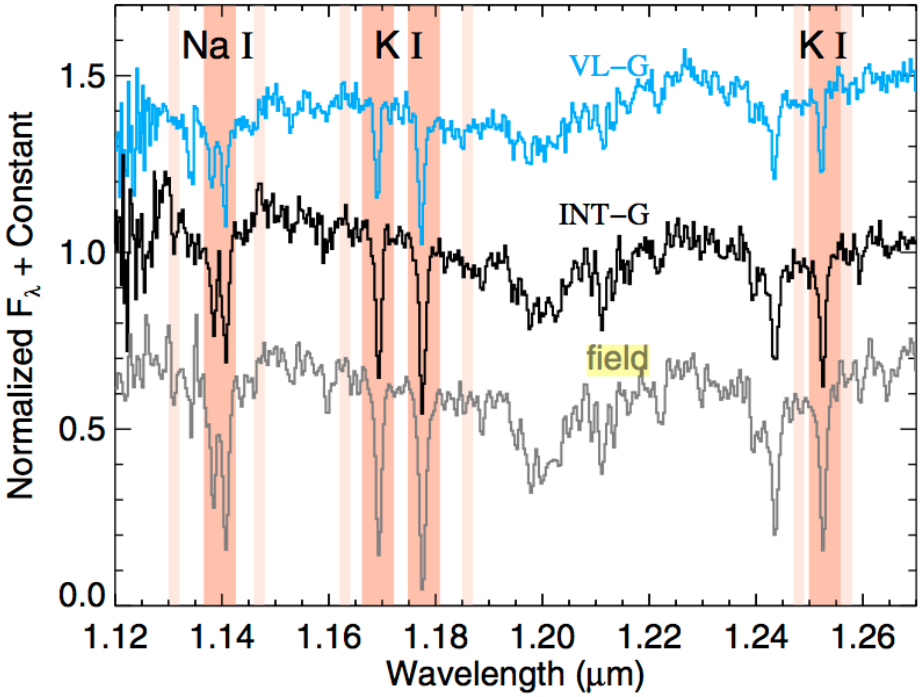
Techniques for Age Dating Brown Dwarfs

- Surface Gravity Indications
- Li Absorption Studies
- Population Kinematics
- Benchmarks (“Mass standards”)
- Chromospheric activity (Sarah Schmidt will handle this)
- COMPANIONSHIP to Age-Calibrated Stars

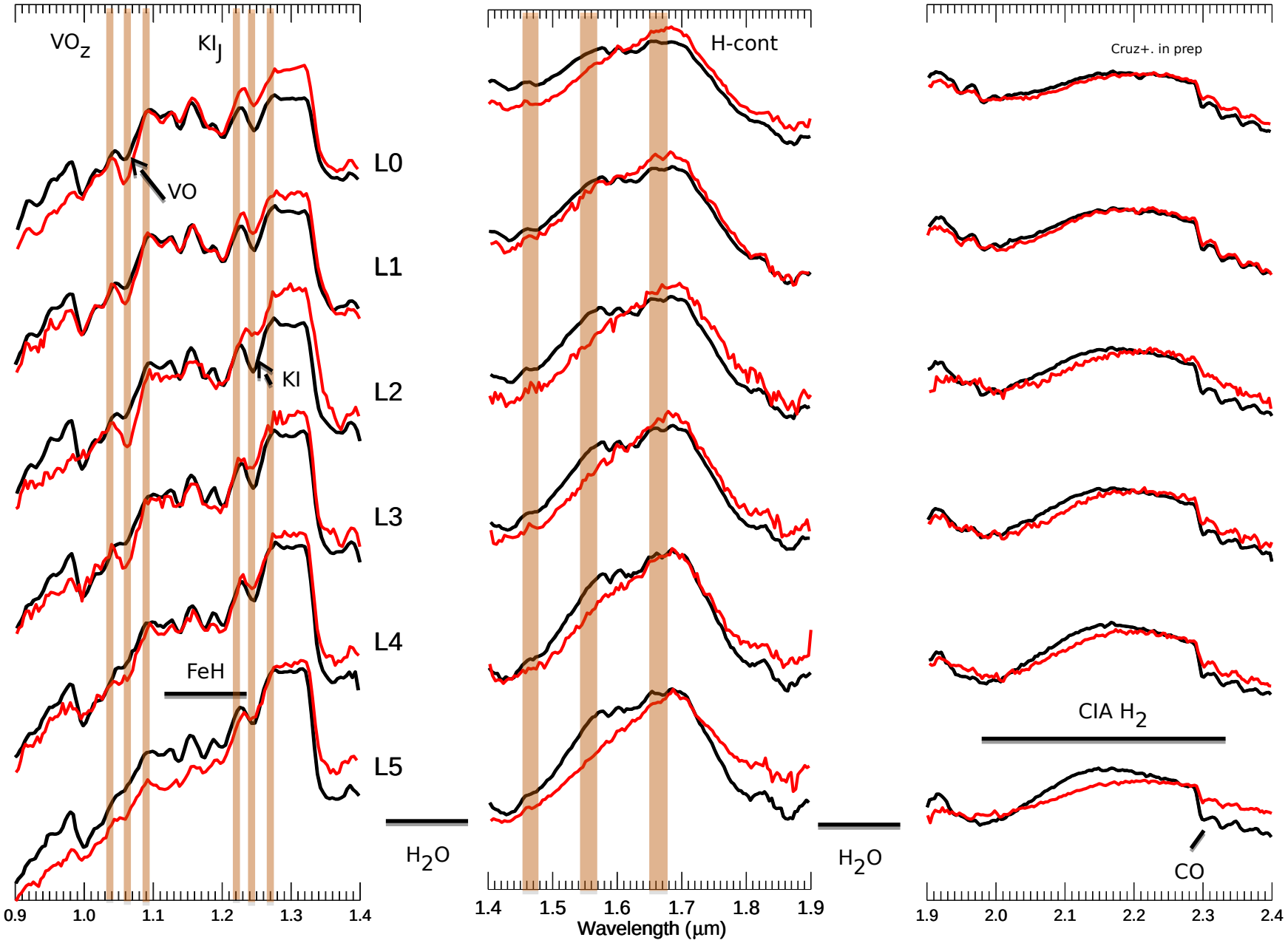
For reference see Burgasser et al. 2008

Ages of Stars contribution on Brown Dwarfs

Surface Gravity Indications



The Near-Infrared Young L Dwarf Sequence

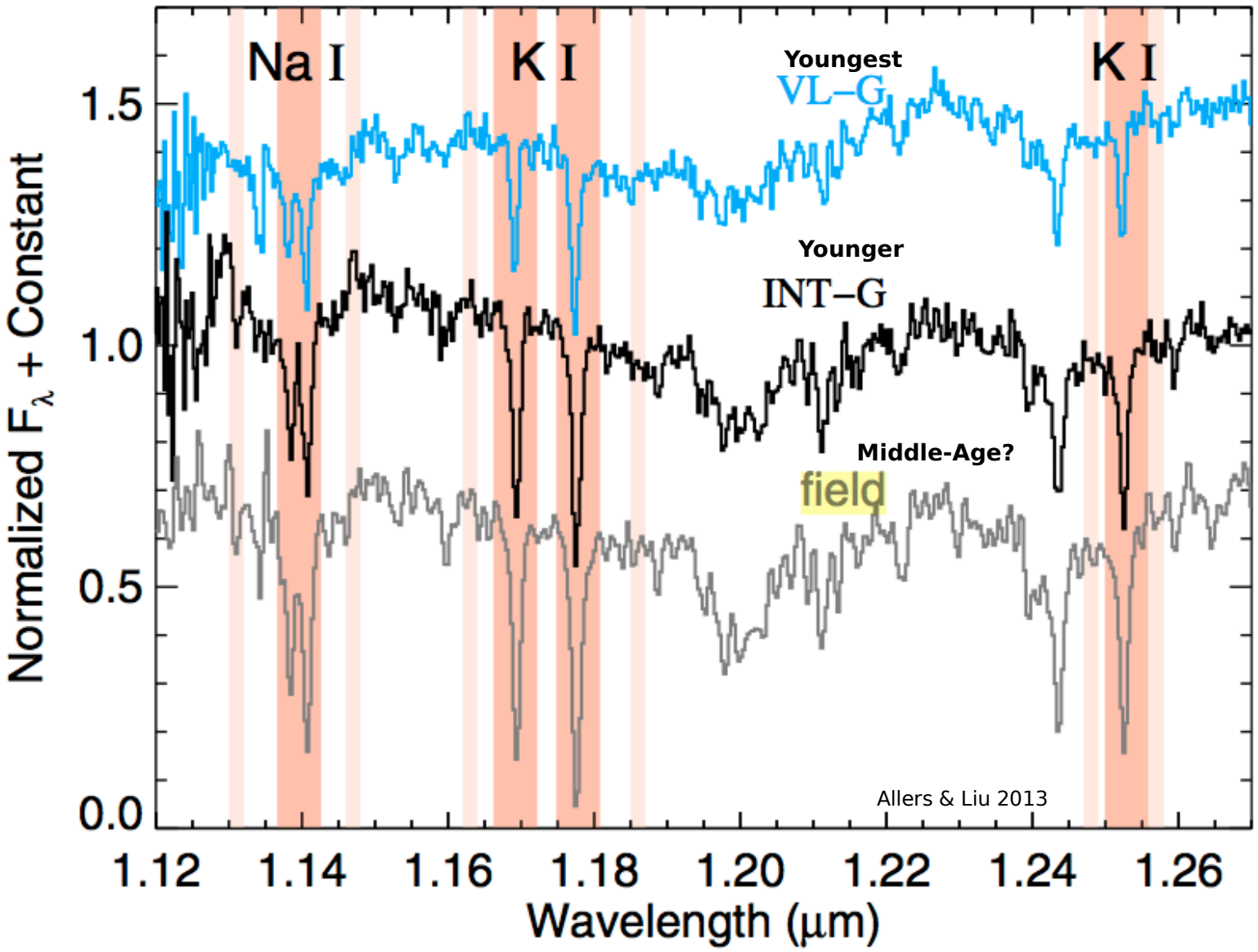


See also Lucas+2001, Gorlova+2003, Luhman+2004, McGovern+2004, Allers+2007, Rice+2010, 2011

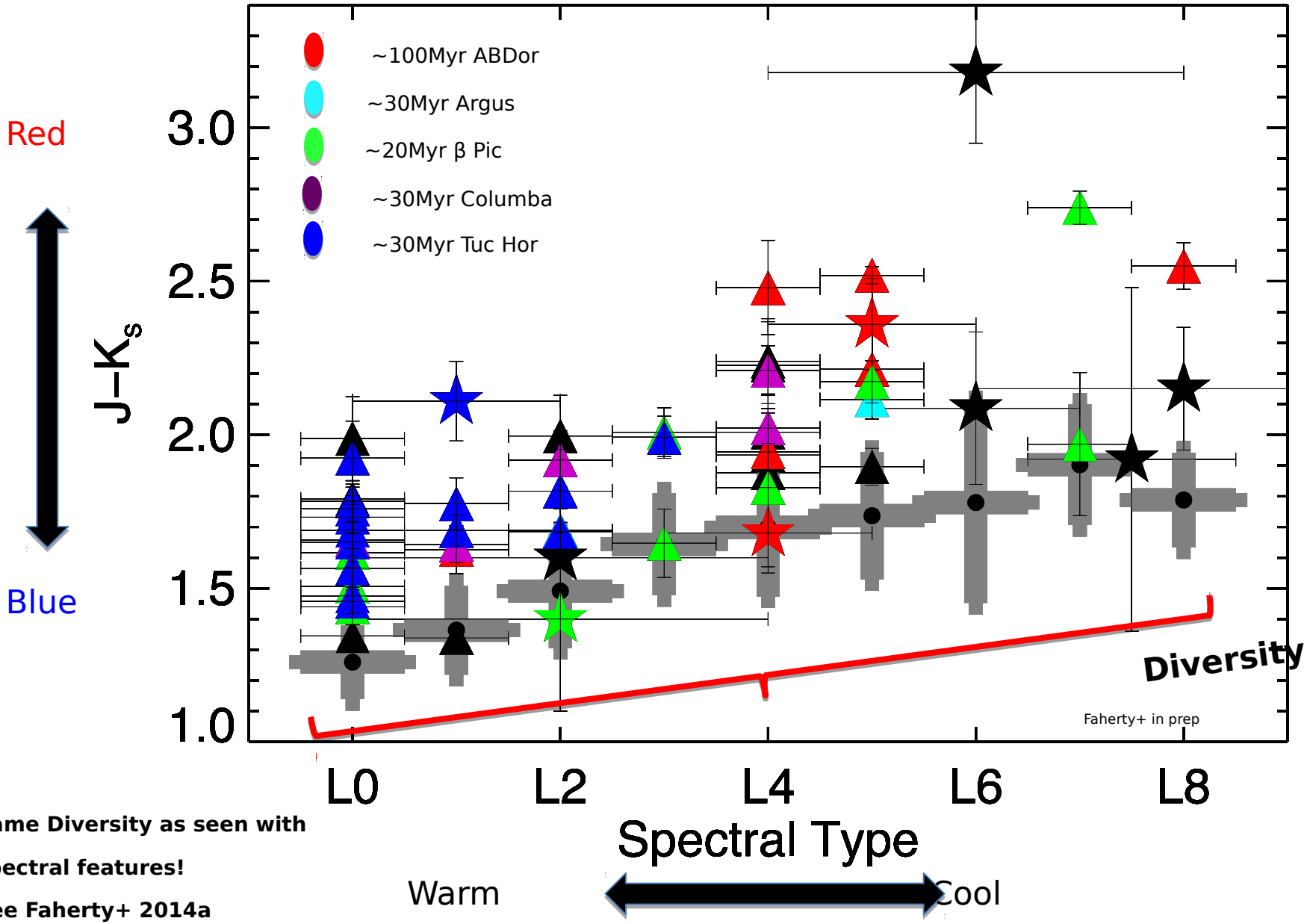
Young Brown Dwarfs Have Weakened Alkali Lines

The Gravity Classes do not Obviously Coincide with Age

Faherty+2014a, Allers & Liu 2013, Gagne+2014



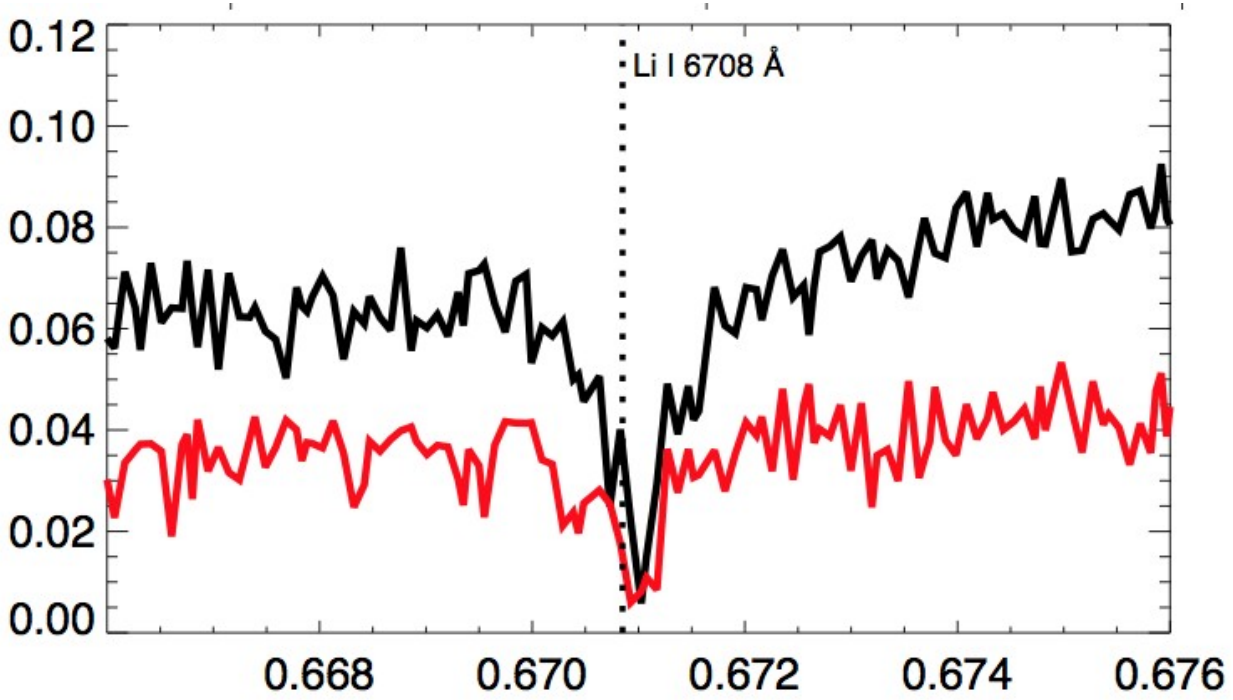
Near-Infrared Color Sequence for L Dwarfs



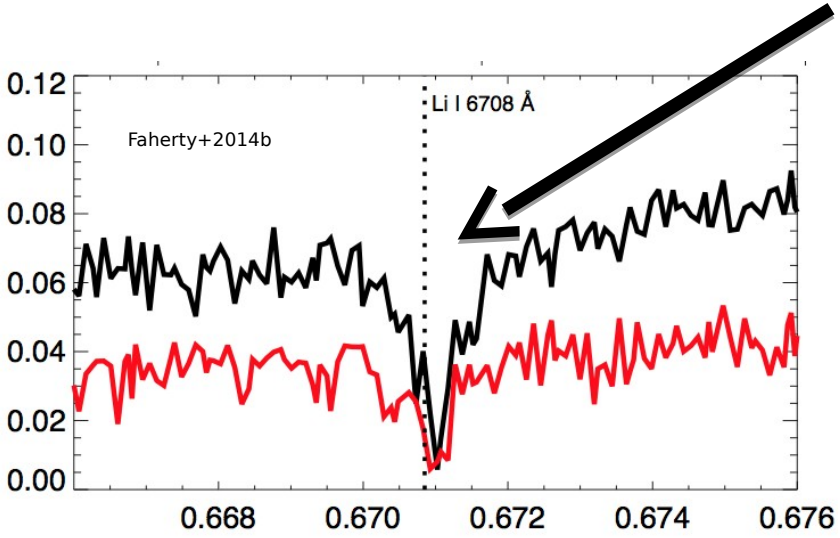
Same Diversity as seen with spectral features!

See Faherty+ 2014a

Li Absorption Studies



Li Absorption is a Mass/Age Indicator



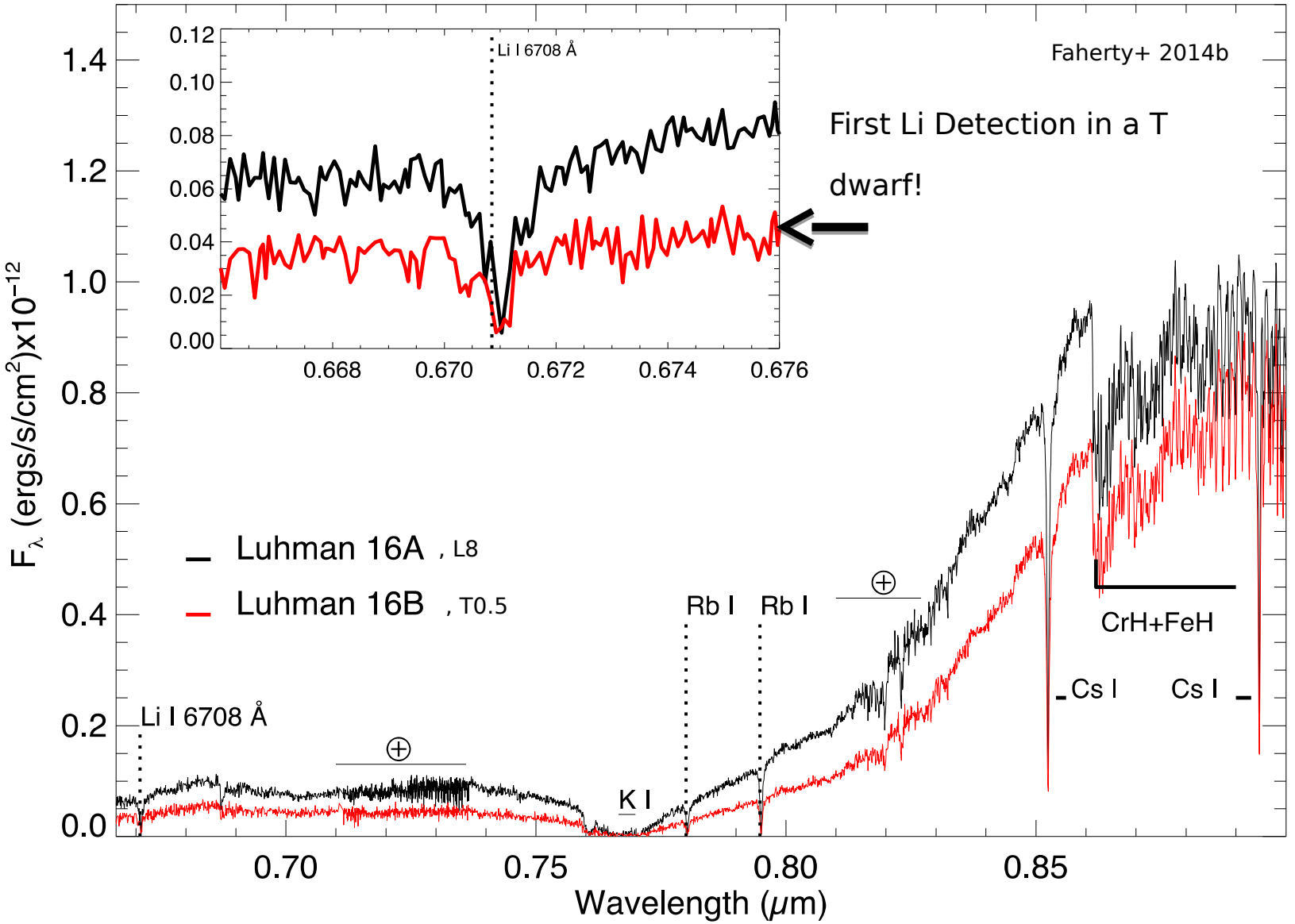
1st Order Effect: Li is a Mass indication

- #1: Li is fused at a lower temperature than Hydrogen
- #2: The lower temperature can be converted to a mass indication. M<~65 M_{jup} (Rebolo+1992, Basri 1998)
- #3 Mass limits can be converted to age upper limits (remember beginning slides!)

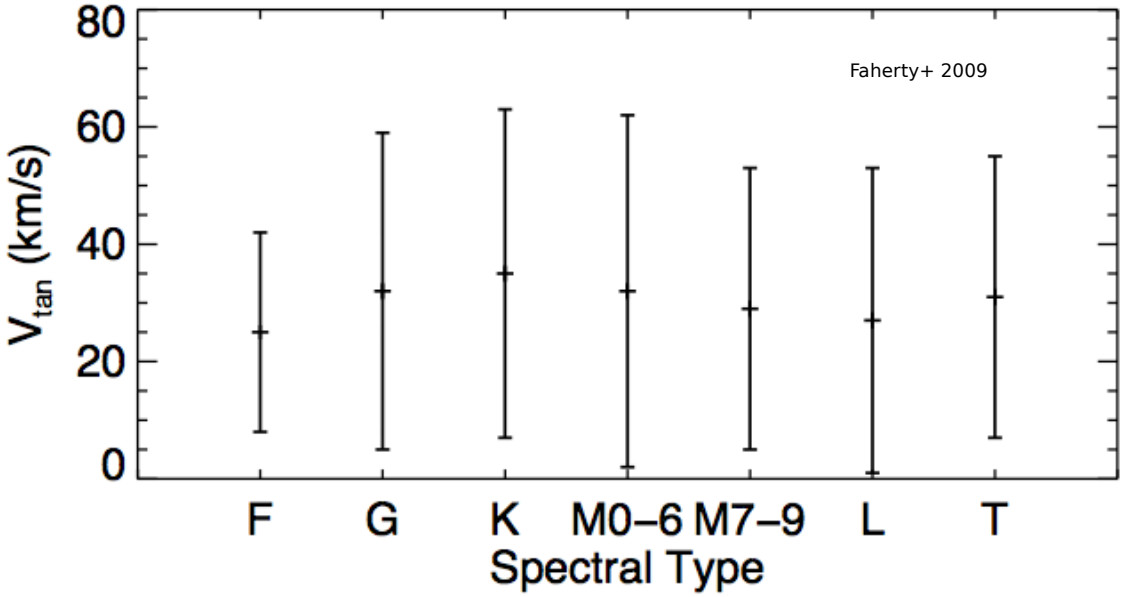
2nd Order Effect: Li EW comparison of similar Teff sources “could” indicate age.

- Li line is gravity sensitive so it will be weaker/undetectable in young sources (Kirkpatrick et al. 2008, Cruz et al. 2009)

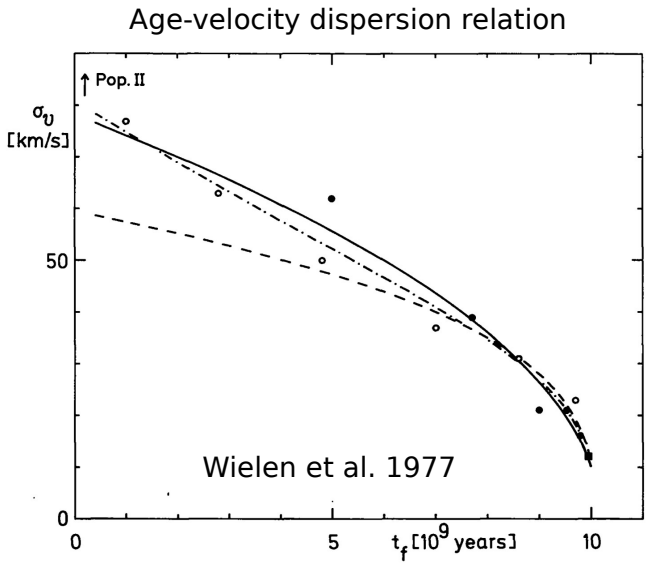
Li Absorption is a Mass Hence Age Indicator



Kinematic Age of the Population



Population Kinematics Indicate Ages

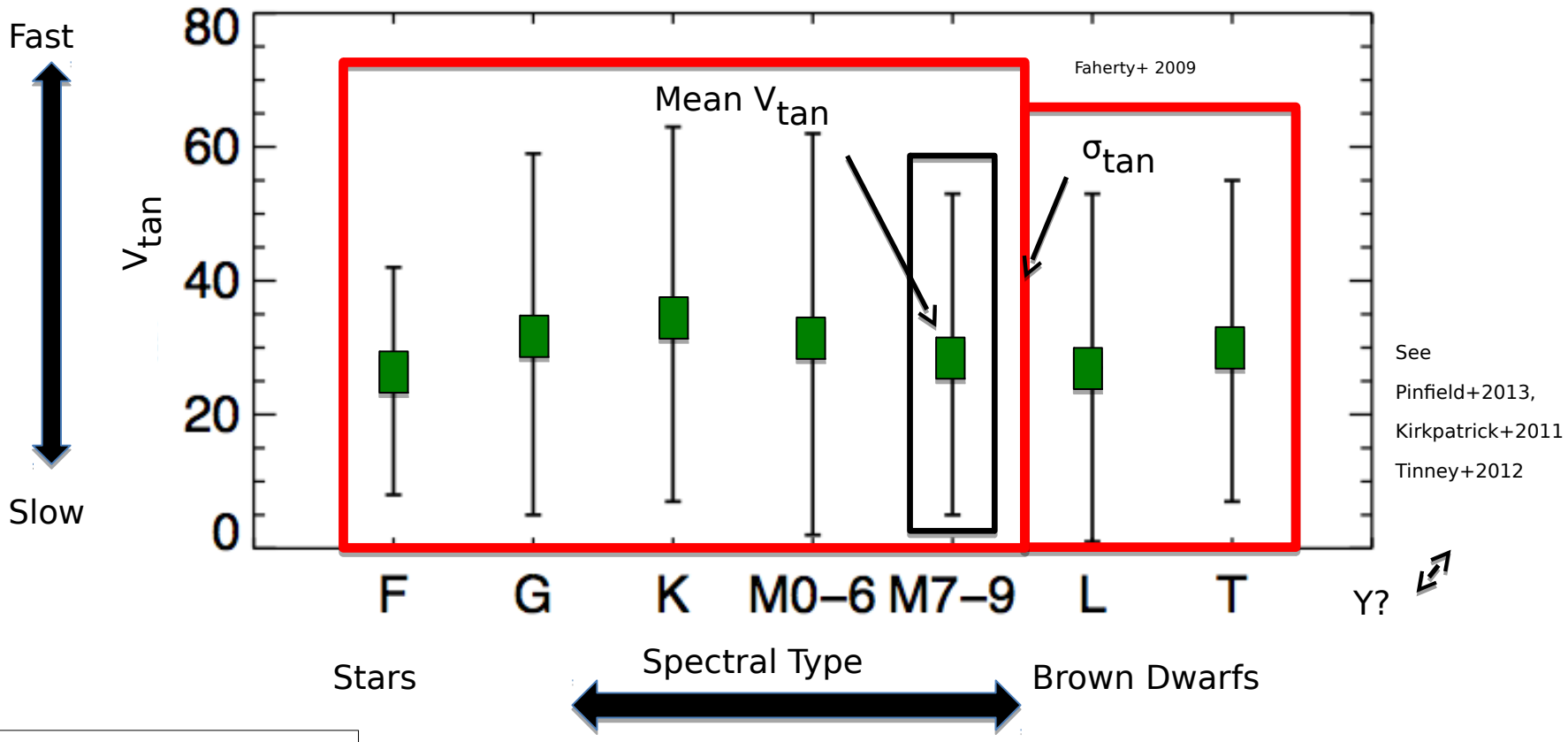


$$t = [(\frac{\sigma(t)}{\sigma_0})^{\frac{1}{\alpha}} - 1] \times \tau$$

(t is age reported in Gyr) w/ α, τ, σ_0 from Wielen 1977

Also: Wielen+ 1992; Dehnen & Binney 1998; Fuchs+ 2001, Hänninen & Flynn (2002)

The Kinematic Age of Brown Dwarfs

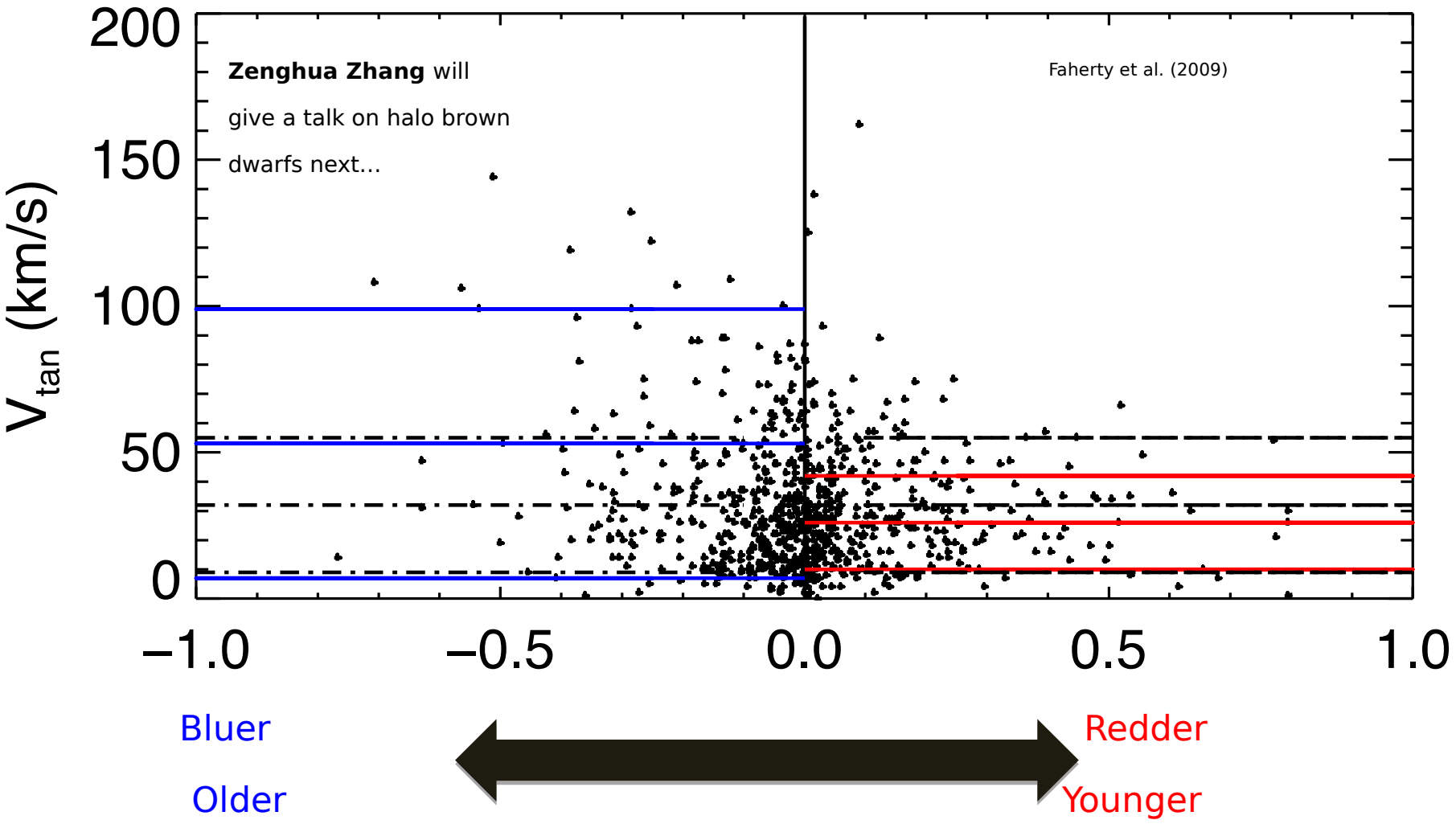


See Also: Gizis+ 2000; Zapatero Osorio+ 2007; Dahn+ 2002, Schmidt+ 2007; Reiners & Basri 2009; Seifahrt+ 2010, Kirkpatrick+ 2010

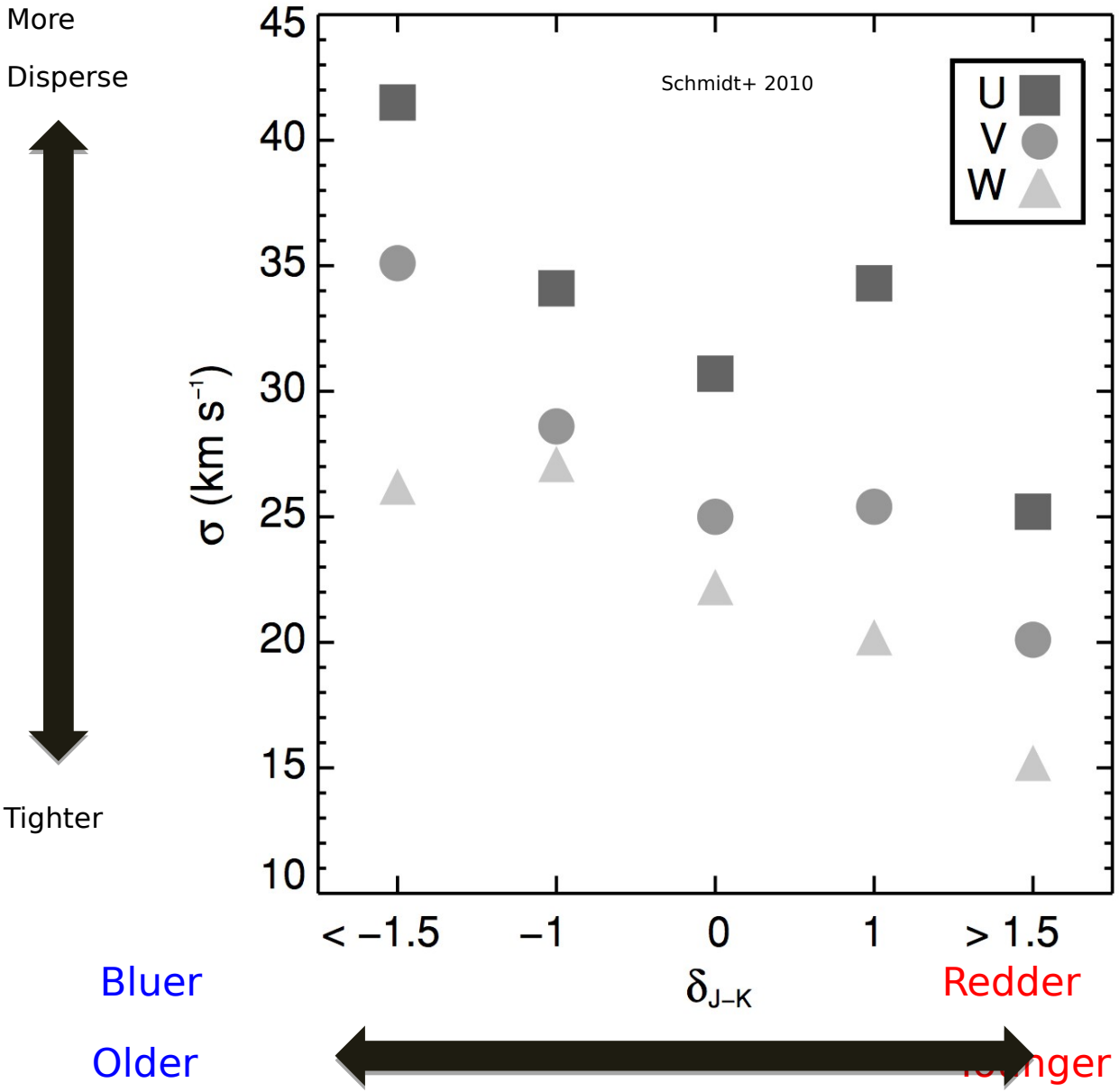
Brown Dwarfs are kinematically consistent with the population of nearby main Sequence stars.

Population Kinematics Indicate Ages

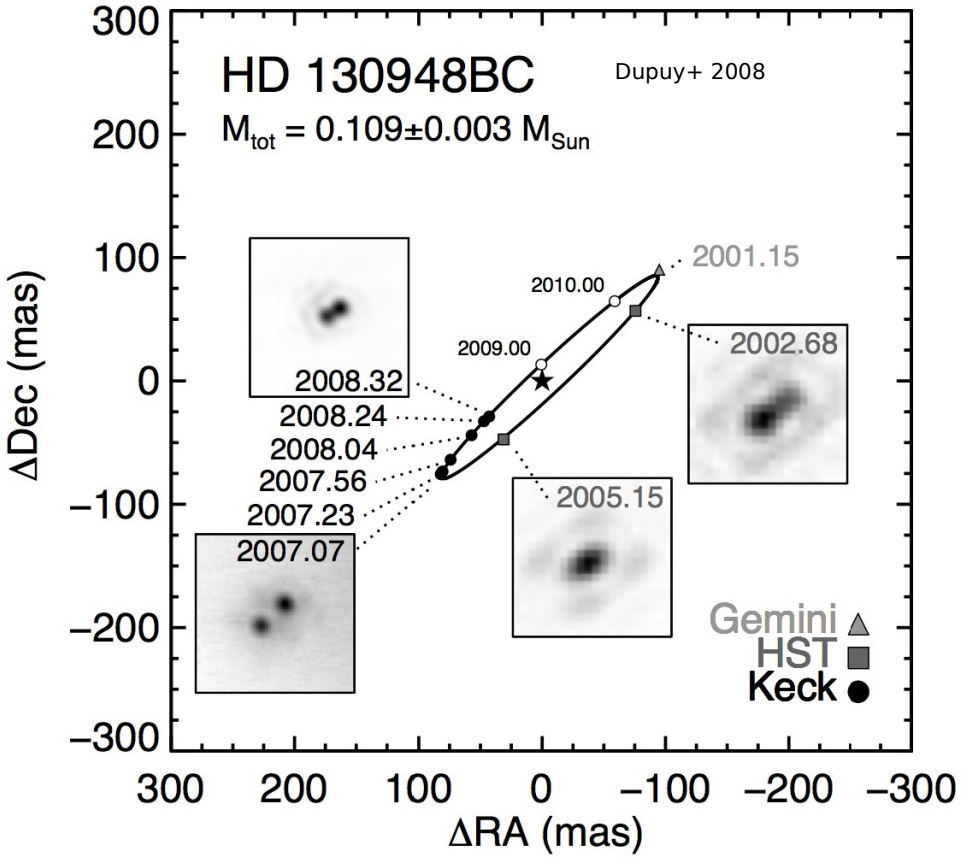
Blue objects are Older. Red Objects are Younger.



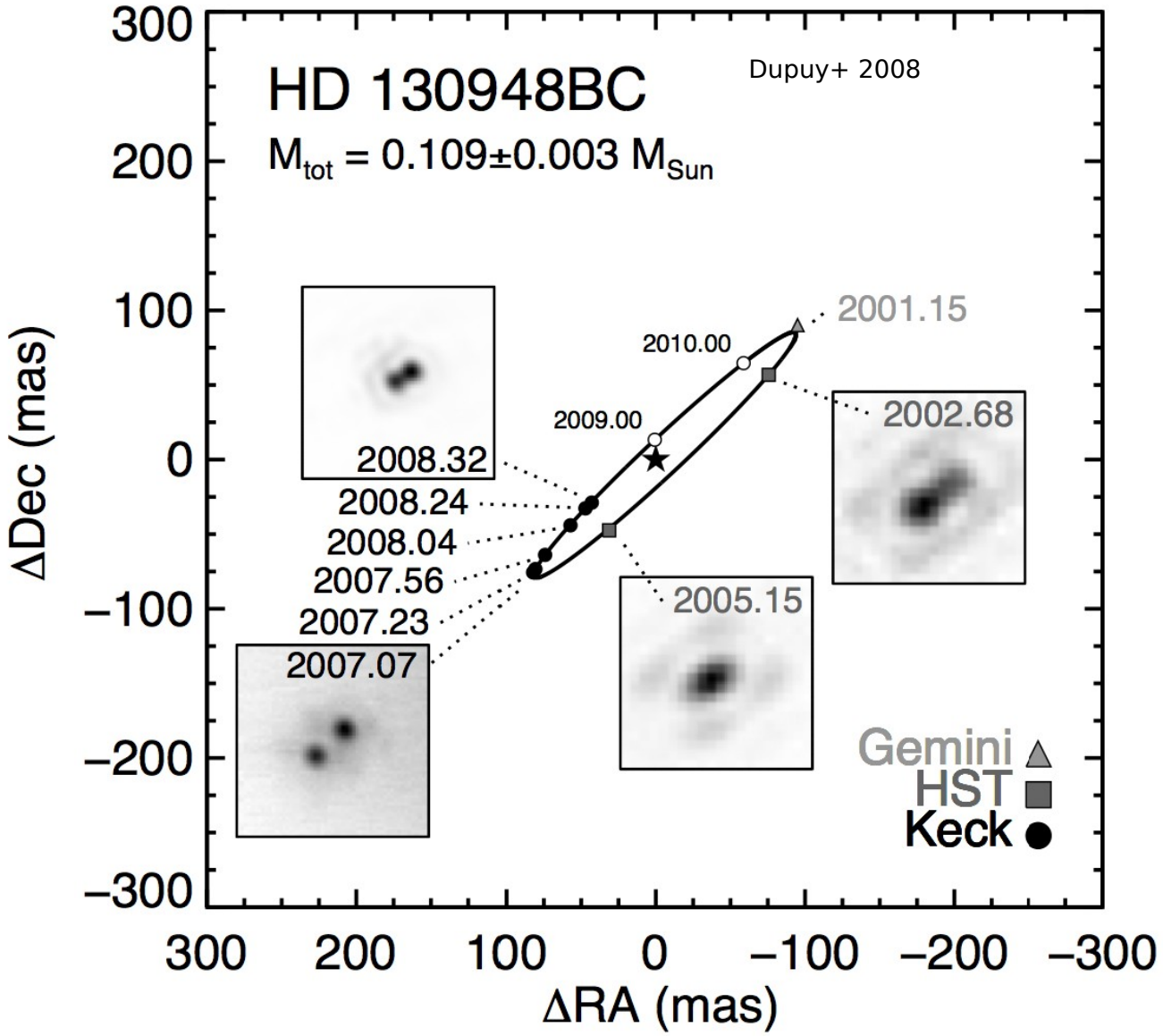
Blue BDs are Older. Red BDs are Younger.



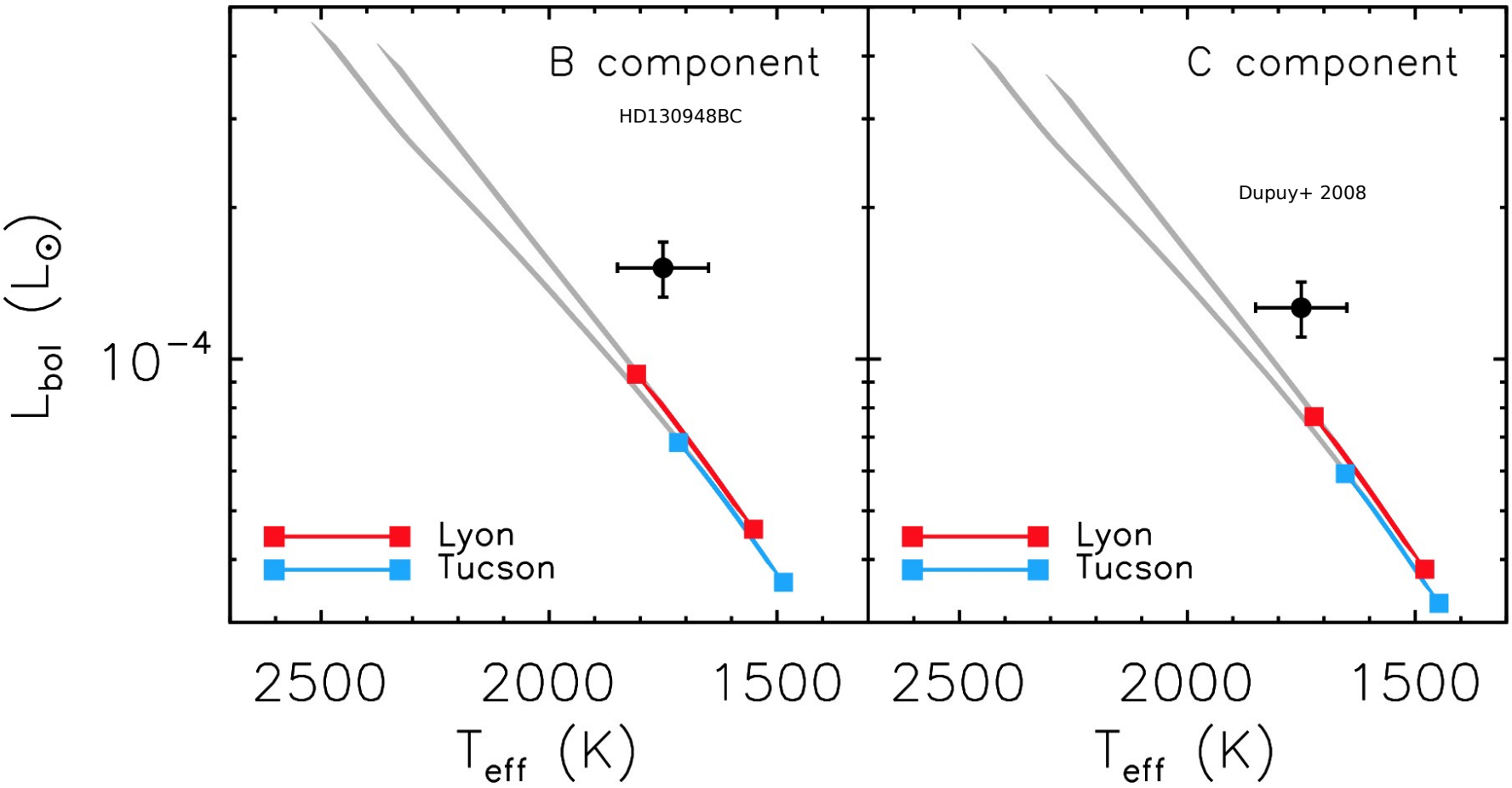
Mass Standards



Mass Standards are Benchmarks for Age



Mass Standards are Benchmarks for Age

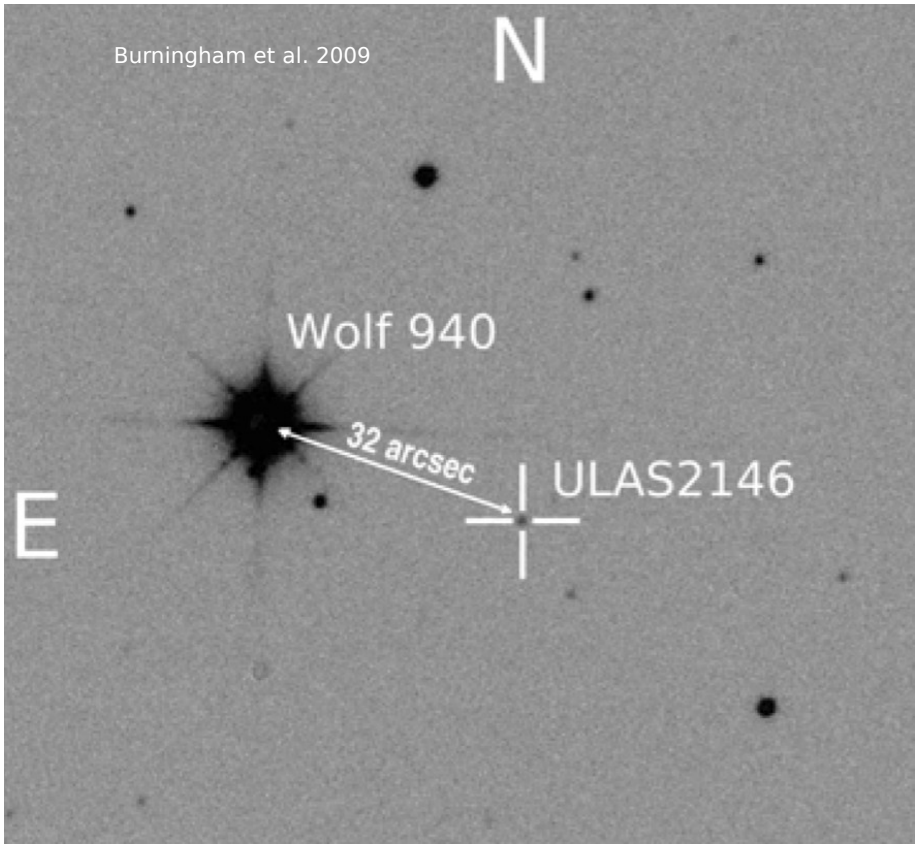


Dupuy+2008 found that substellar evolutionary models may underpredict the luminosity of BDs by as much as a factor of ≈2–3×.

See also: Stassun+2006, Dupuy+2009b,2009c, 2010, Konopacky+2010, Liu & Leggett 2005

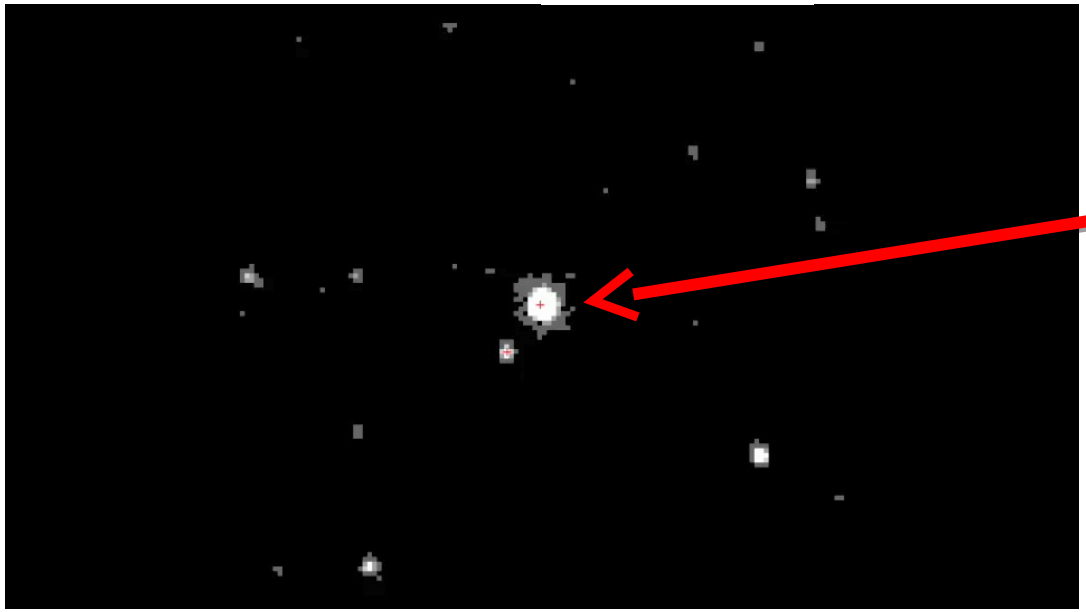
Companions:

The Anchors



Companionship to Age-Calibrated Stars

...Or Piggyback Science

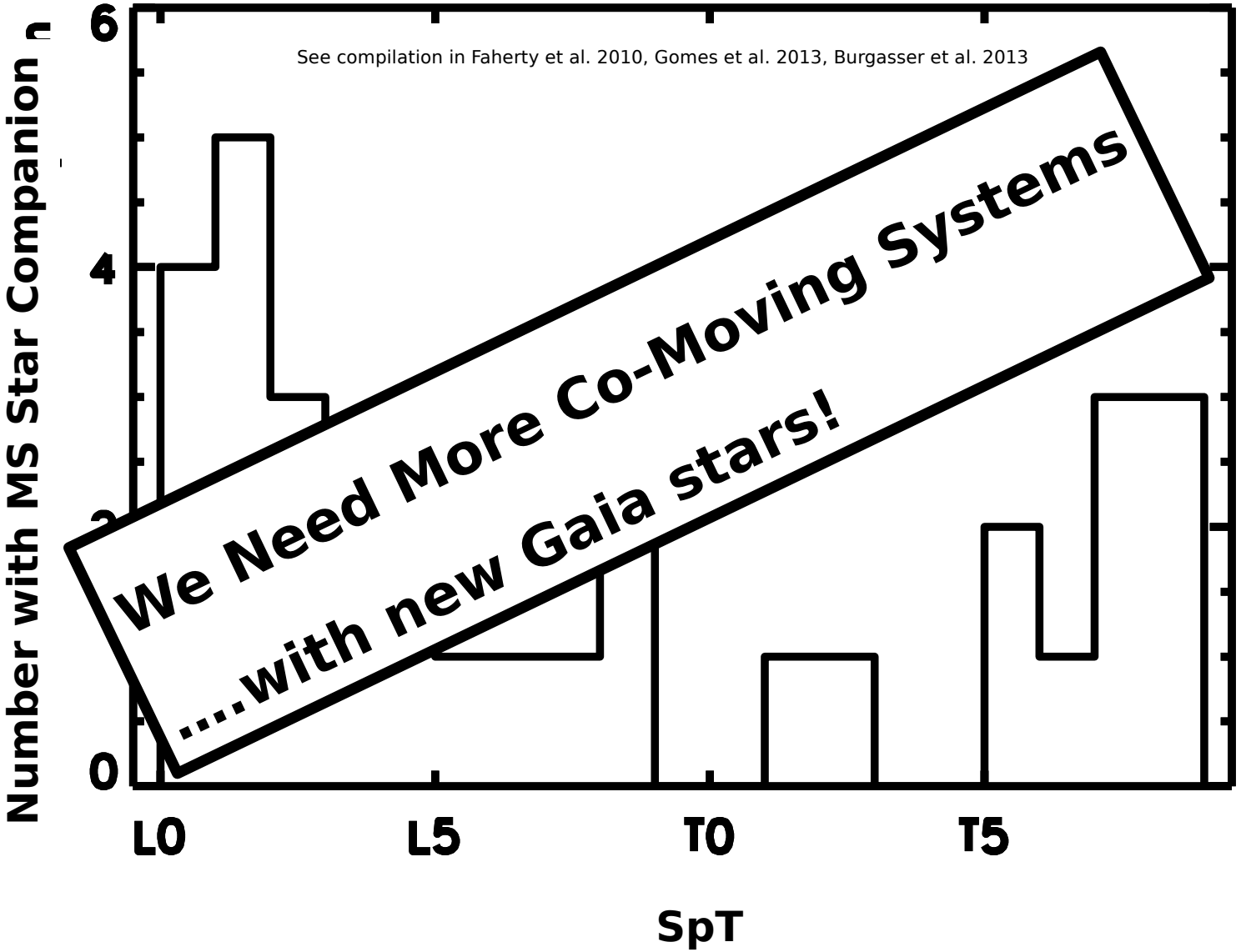


Age-Dating Main Sequence Stars

- X-Ray Activity
- Gyrochronology
- Asteroseismology
- Chromospheric Activity
- Lithium Abundances
- Theoretical Isochrones
- Kinematics
- Metallicity Measurements
- Cluster or SFR Associations

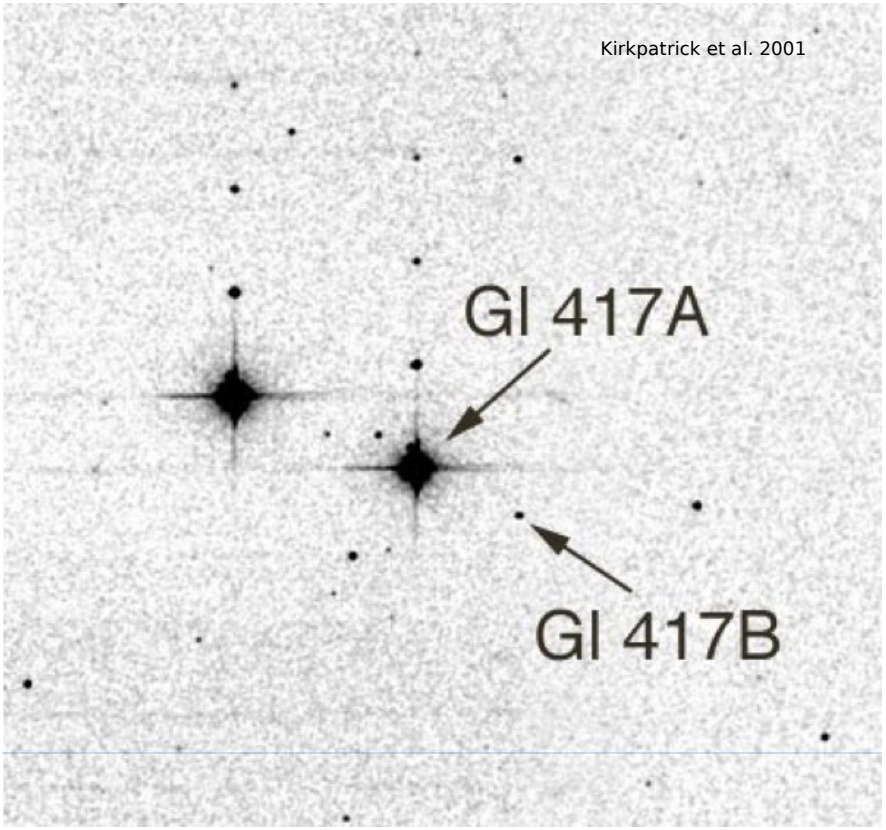
For Details see: Soderblom+ chapter for PPVI, “Ages of Stars” Proceedings (Mamajek+2009), Hillenbrand+2009, Covey+2009, Mamajek & Hillenbrand 2008

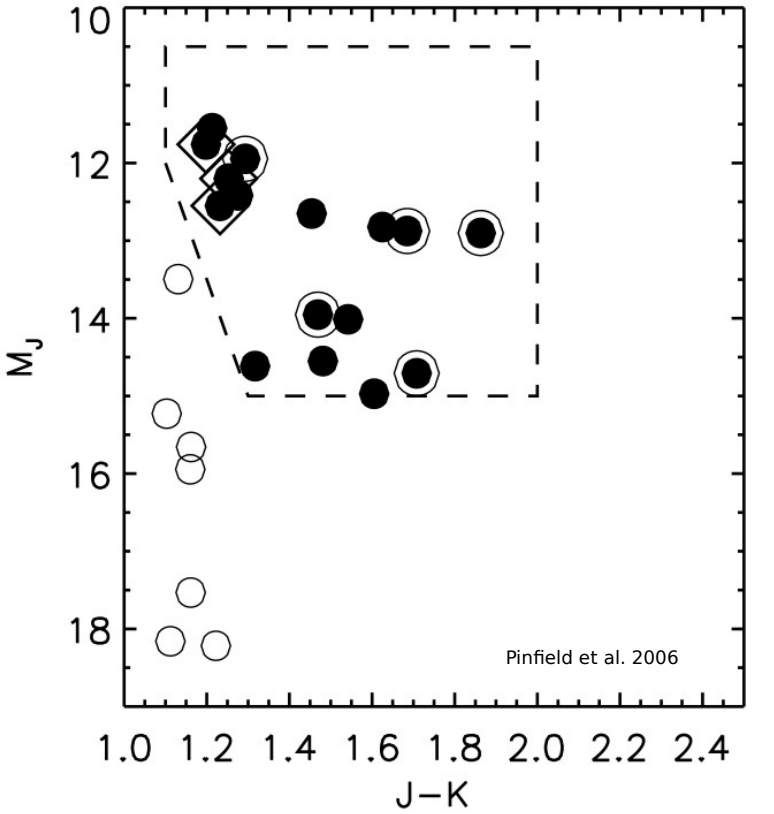
The Benchmarks



Wide (> 100au) Companion Frequency of BDs to Stars: >~5-8% (Gomes+2013, Burningham+2013)

Individual Star Companions found because



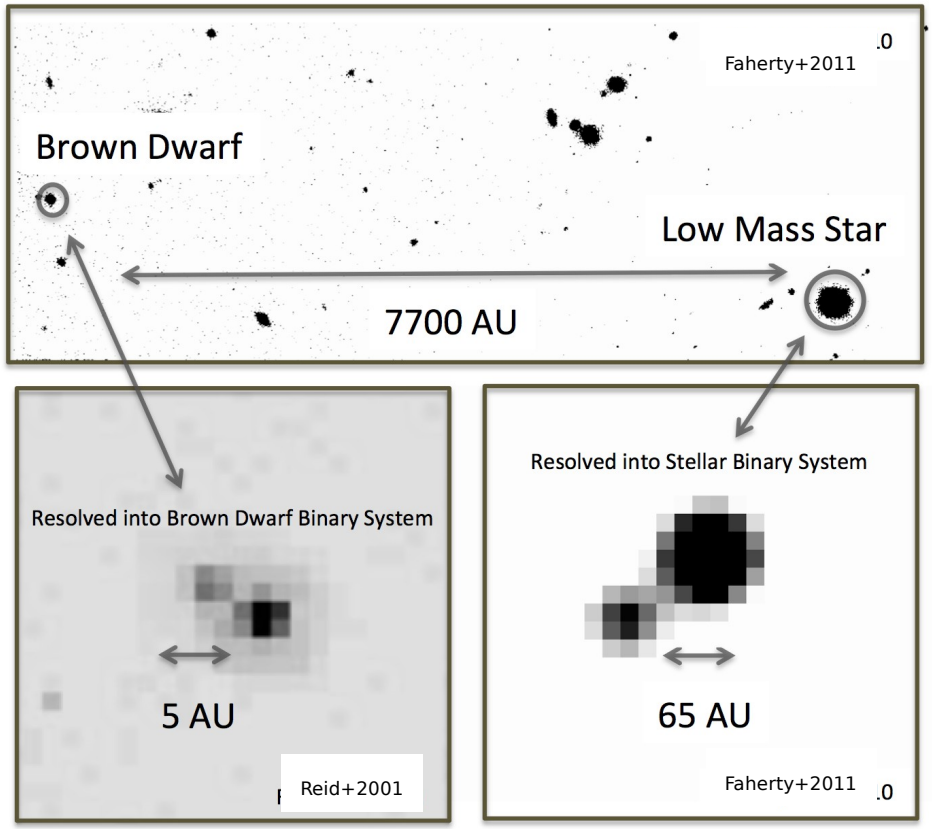


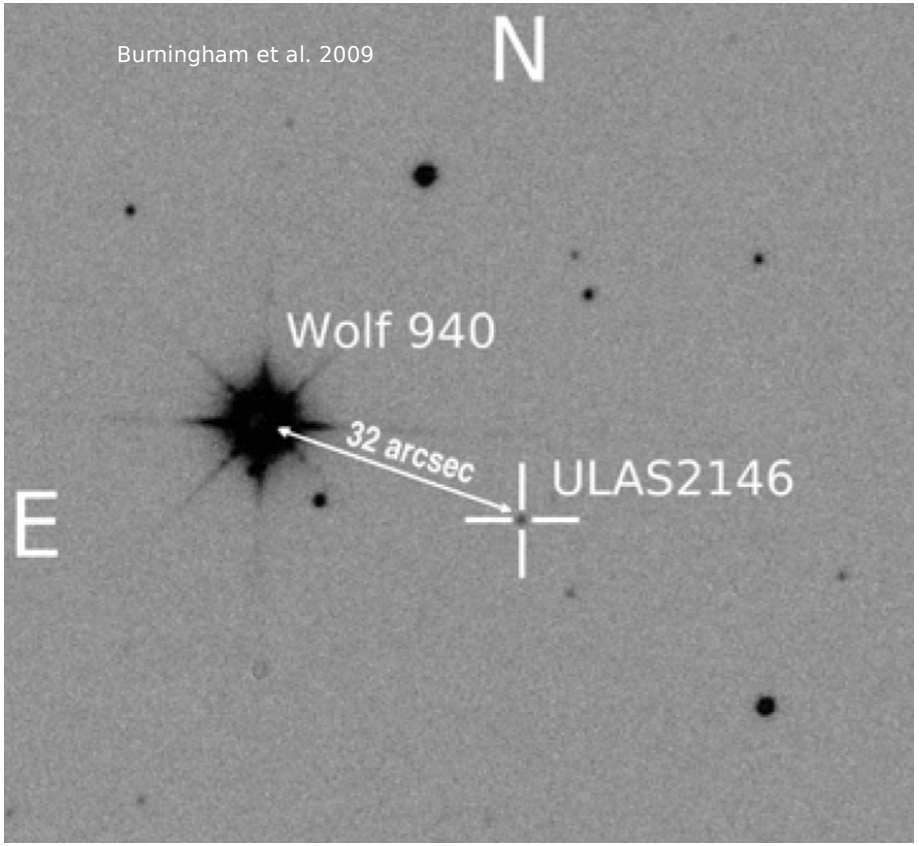
Brown Dwarfs were at a close angular separation to a nearby star

Candidates had the right color and magnitude for co-moving with a nearby star

See also Wilson+2001, Allen+2005

Individual Star Companions found because



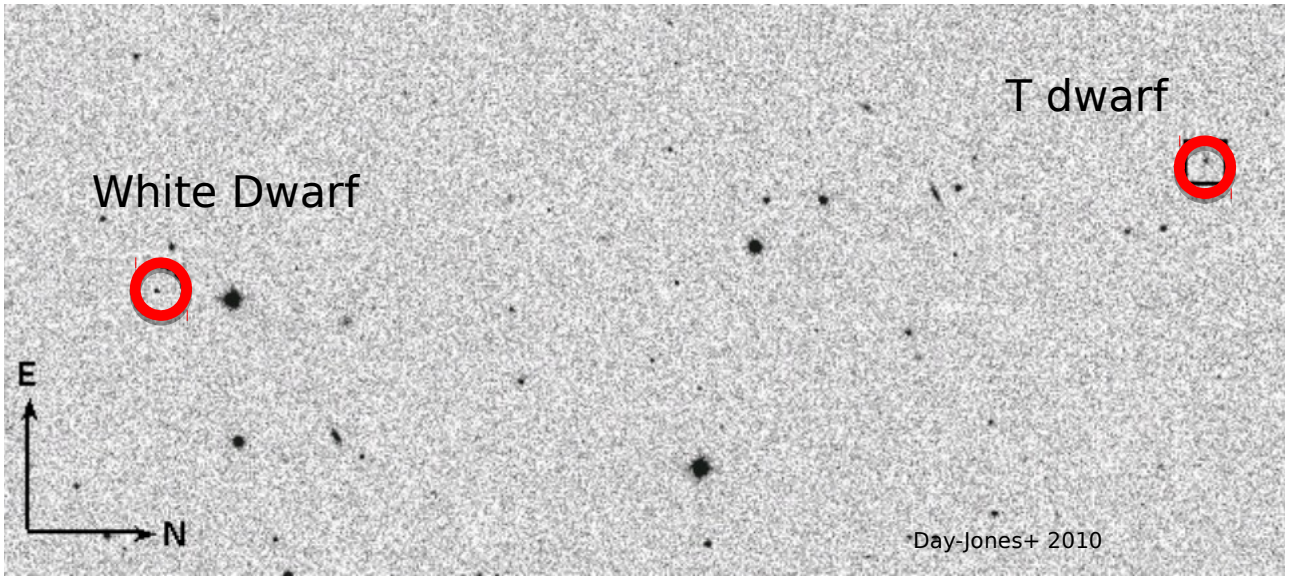


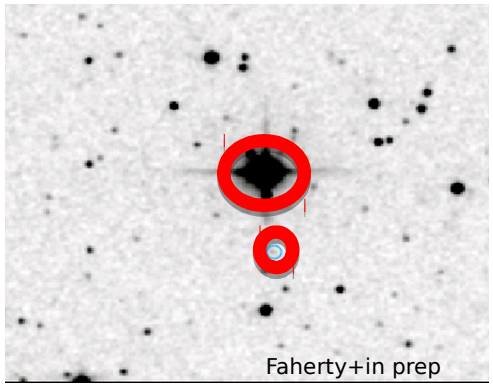
Brown Dwarfs were Co-moving with Widely Separated Stars

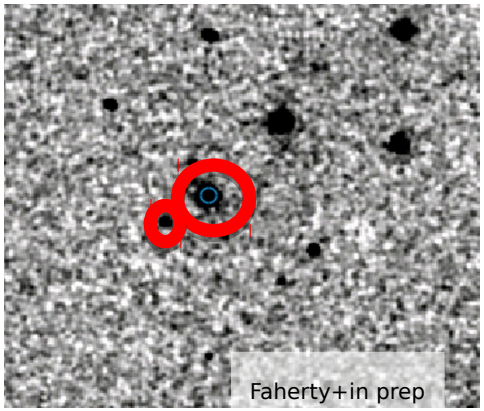
See Also: Faherty+2010, Burningham+2013, Caballero+2007ab, Artigau+2009, Siefahrt+2005ab, Radigan+2009, Muzic+2012, Deacon+2012

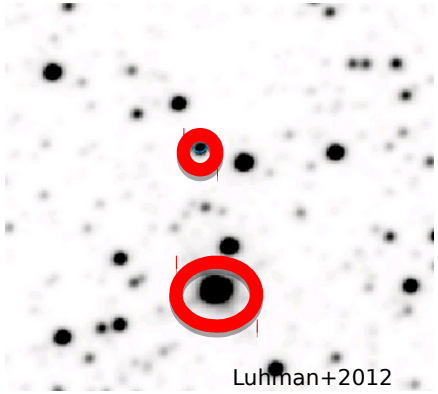
Individual Star Companions found because

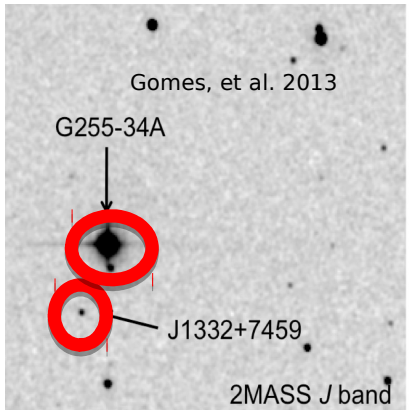
Sara Casewell will give a talk on the White Dwarf-Brown Dwarf connection next...







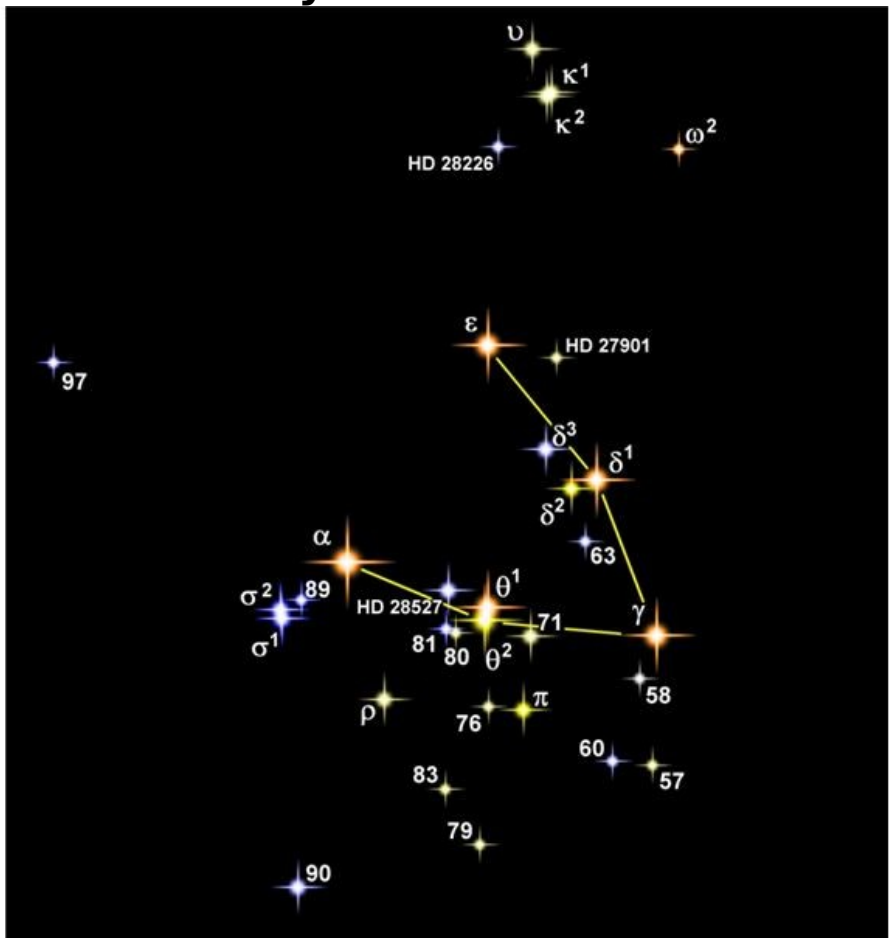




Second epoch imaging around a known age-calibrated source yielded matching colors and proper motions

Association with Star Forming Regions

Hyades



Rho Ophiucus

Age: ~600 Myr

Gaia Limit: L0

Mass Limit: ~40 M_{Jup}

See NEW Sarro plot on workshop website

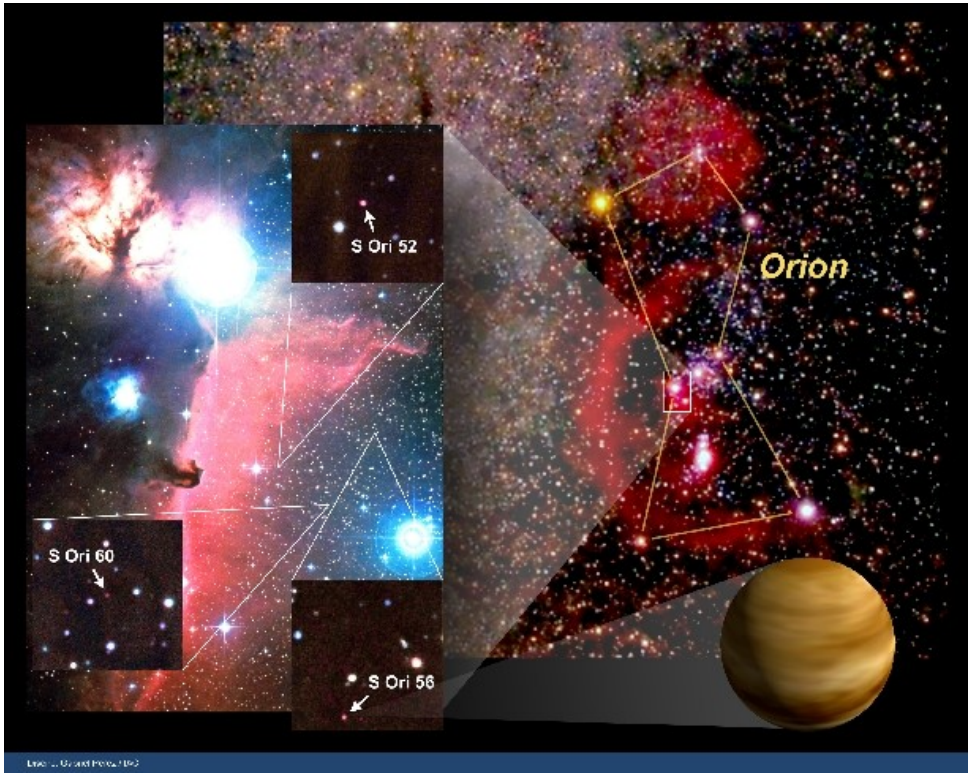
Age: ~1 Myr

Gaia Limit: L0

Mass Limit: ~10 M_{Jup}

Association with Star Forming Regions

σ Orion



Pleiades

Age: ~3-5 Myr

Gaia Limit: M7

Mass Limit: ~40 M_{Jup}

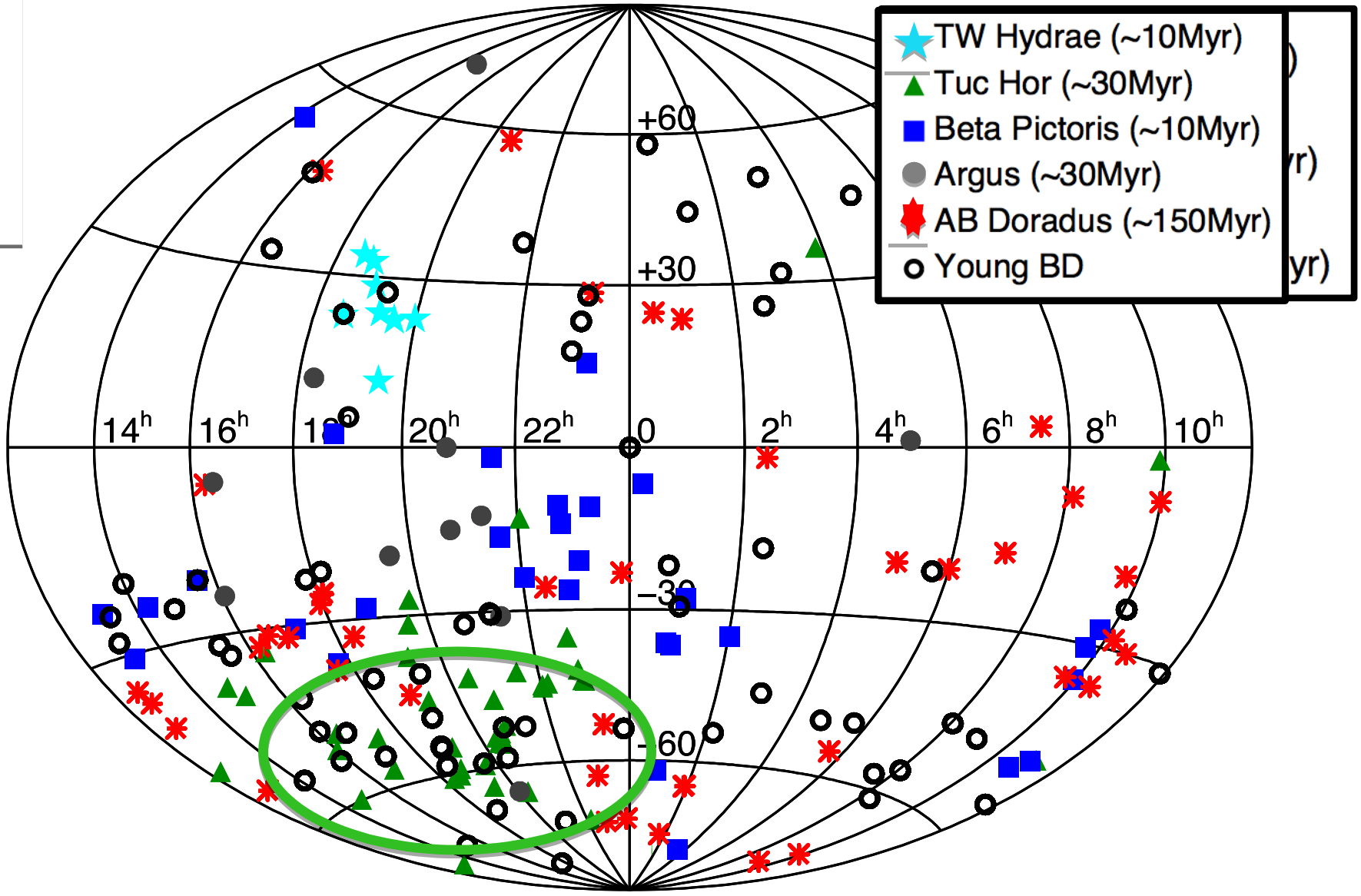
See NEW Sarro plot on workshop website

Age: ~125 Myr

Gaia Limit: M7

Mass Limit: ~60 M_{Jup}

Age Calibrated Groups are Optimal Targets



See: Malo+2012, Gagne+2014, Faherty+2013,2014a, Liu+2013, Cruz+2009, Kirkpatrick+2006, 2008, Gizis+2012, Rice+2010

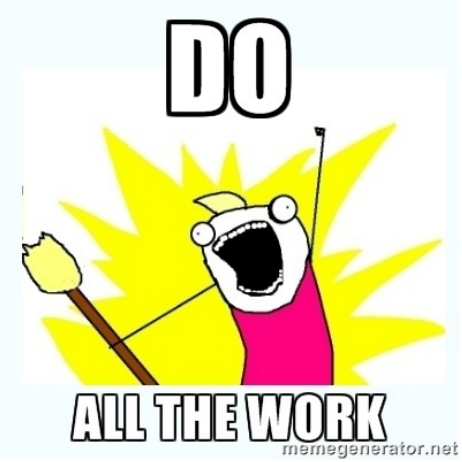
Conclusions

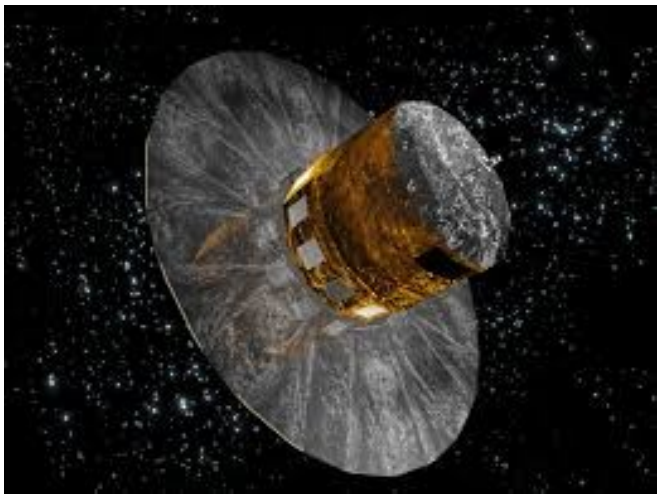
- Determining Brown Dwarf Ages is Extremely Important as it breaks the Age-Mass degeneracy

- There are several age dating methods for brown dwarfs that we would love to calibrate with well studied main sequence stars.

Gaia may be the key to future brown dwarf benchmark systems.

Gaia...





Questions?

Ages Session:

10:50-11:15 Gaia and white dwarf+ brown dwarf binaries Sara Casewell

11:15-11:40 Halo brown dwarf and Gaia potential Zenghua Zhang

11:40- 12:05 Examining the Age Activity Relationship of Ultracool dwarfs with Gaia