SIM Stellar Astrophysics: Mandatory Testing for Stellar Models

A. Boden – Caltech

25 Sept 2008

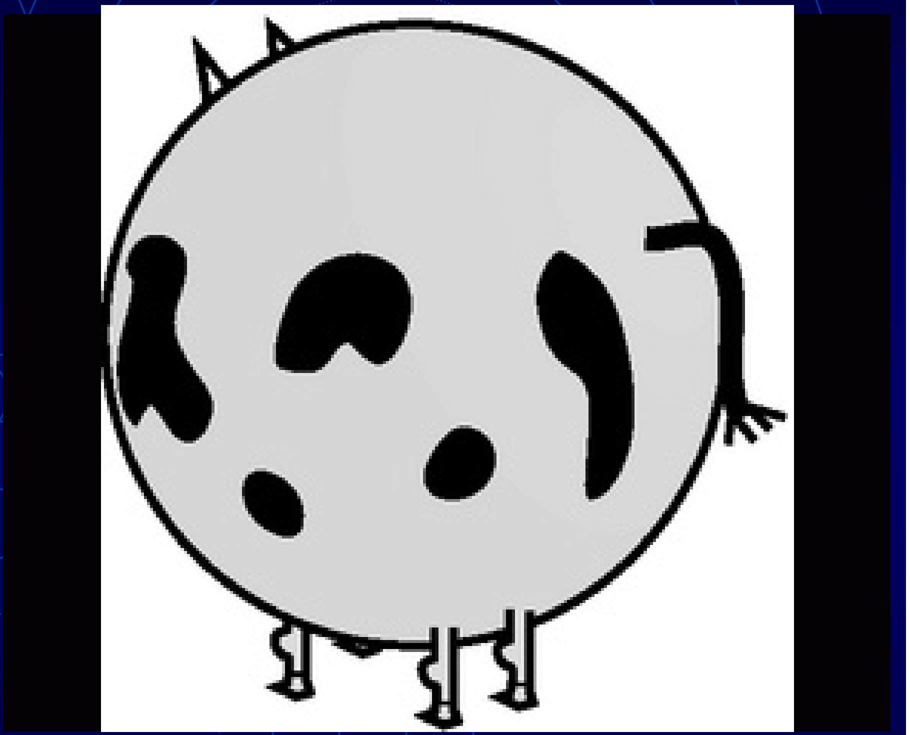
Testing Stellar Evolutionary Models

- Stellar Models underpin *a lot* of we do in astronomy, e.g.:
  - Stellar Initial Mass Function and star formation history
  - Estimating the mass and radius of (e.g. transiting) exoplanets
  - Estimating Milky Way's age (e.g. from Globular Clusters)
  - Estimating star formation rate in the early universe

- Consequently, we *should* be motivated to *test* the stellar models we use…

Stellar Empirical Properties

- Testing stellar models requires *reliable* determination of stellar empirical properties
  - Mass
  - Luminosity
  - Radius
  - Elemental Abundance (or *Abundances*…)
  - Rotation
  - Surface Gravity (combination of *M* and *R*)
  - Effective Temperature (combination of *L* and *R*)



Dynamical Mass Determinations

- Stars convert gravitational potential energy into luminosity → mass is "the most fundamental of all stellar properties"
- (Model-free) mass is generally only accessible through dynamical interactions, and (typically) through binary associations in particular – very traditional
- Essentially all stellar dynamical masses result from measuring the "physical" orbits of binary systems

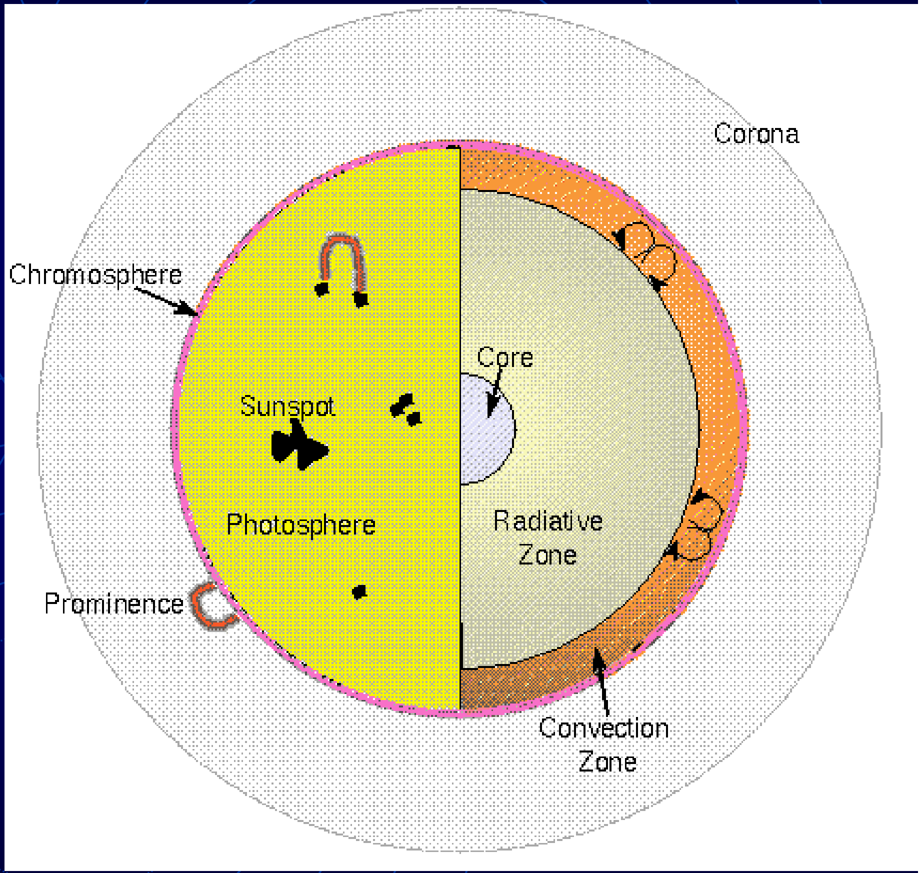
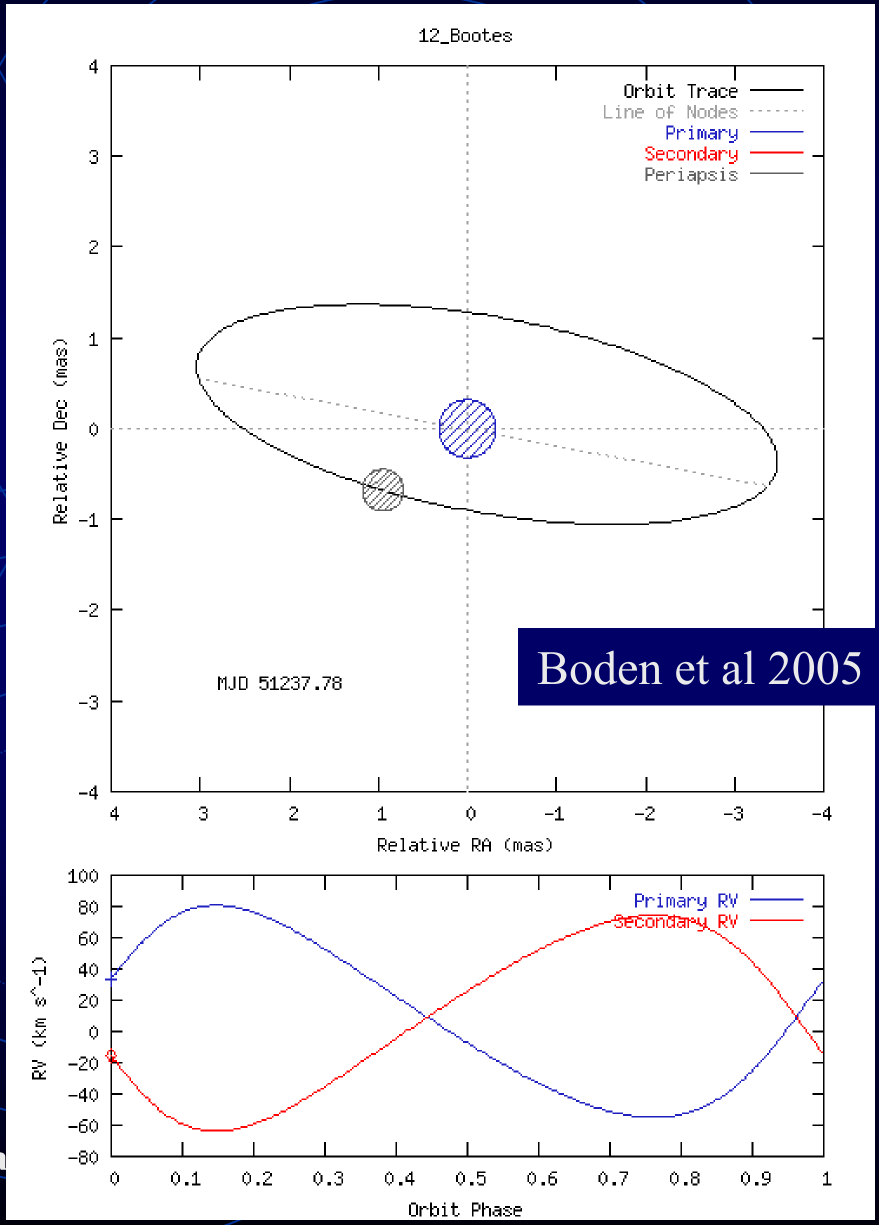


Image Credit:
www.astronomynotes.com

“The Deal” with Binary Star Studies

- In most cases, observational objective is to determine “*physical orbit*” (physical dimensions, orientation), this provides component masses
- **Eclipsing** systems provide that with spectroscopy (“*spectroscopic orbit*”) & photometry (inclination), and additionally provide radii
- **Non-eclipsing** systems require integrating the “*visual orbit*” to determine system orientation – astrometry (or proxy observable, e.g. interferometric visibilities)
- Ratio of physical and angular scales (e.g. semi-major axis) yields *direct* system distance (and *luminosities!*)



Boden et al 2005

What Binary *Information* is Interesting?

- Component properties
  - Mass (*M*), Radius (*R*), Luminosity (*L*) (the "big" three)
  - Elemental Abundance(s!)

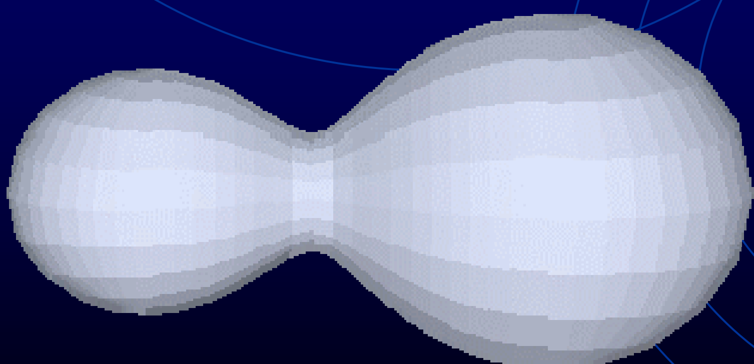
    critical to place M, R, L in proper context
  - Rotation

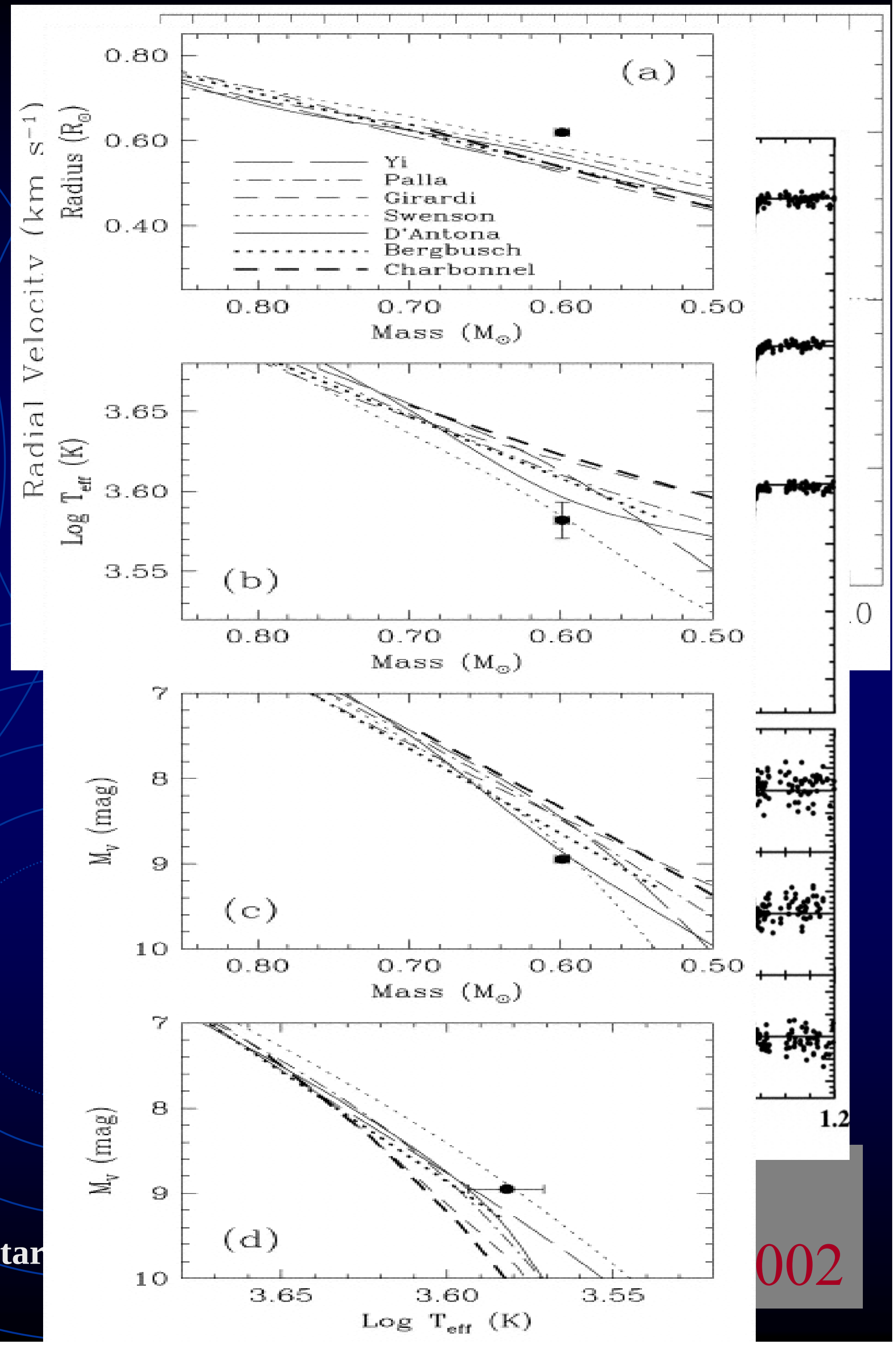
    as indirect tracer of tidal interaction & internal convective structure
- Distance ("orbital parallax")

  for direct & indirect luminosity calibration
- Multiplicity statistics
- Orbit parameter statistics – *remnants of the formation process*
- Age – *using binary systems as chronometers*

Eclipsing Binary Systems: The Gold Standard

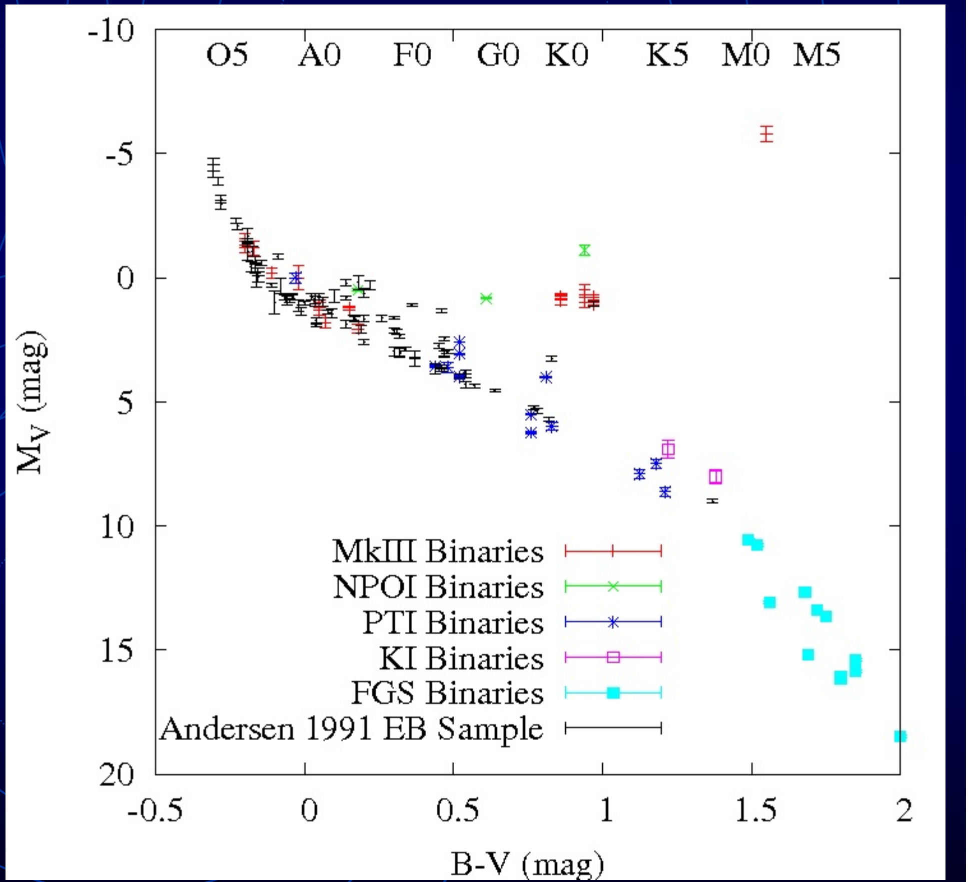
- Eclipsing Binaries are the ‘Gold Standard”:
  - Eclipses define inclination
  - Optimal orientation for mass determinations
  - Directly probe radii
  - Ratio of T_{eff}
- e.g. Recent work by Torres, Ribas, Stassun





"Interferometric" Binary Systems: Inclinations Beyond Eclipsing

- Because of limited eclipsing systems we are motivated to consider non-eclipsing systems
- "Interferometric" systems making biggest impact in areas not covered by EBs
  - Mass
  - Evolutionary state
  - Abundance

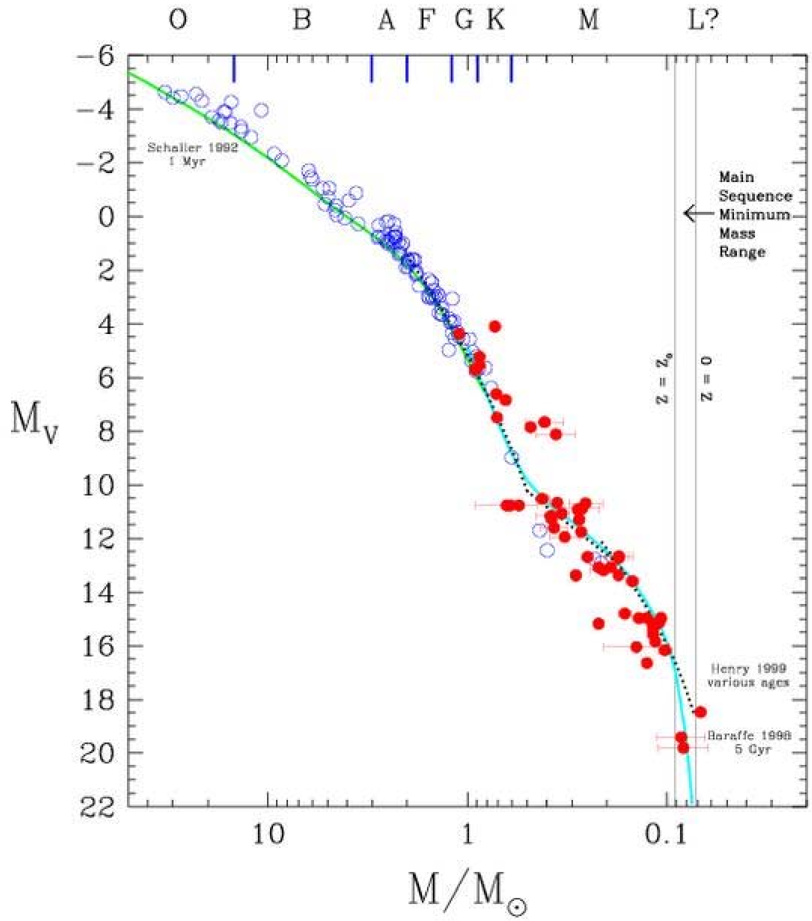


SIM Stars Projects

- MASSIF – Mass-Luminosity calibrations across H-R diagram – Henry et al
- PopII Stars – Charboyer et al
- Cluster Distances – Worthy et al
- Young Stars – Beichman et al
- X-ray binaries – Quirrenbach et al
- White Dwarfs – Kulkarni et al

MASSIF – Henry PI

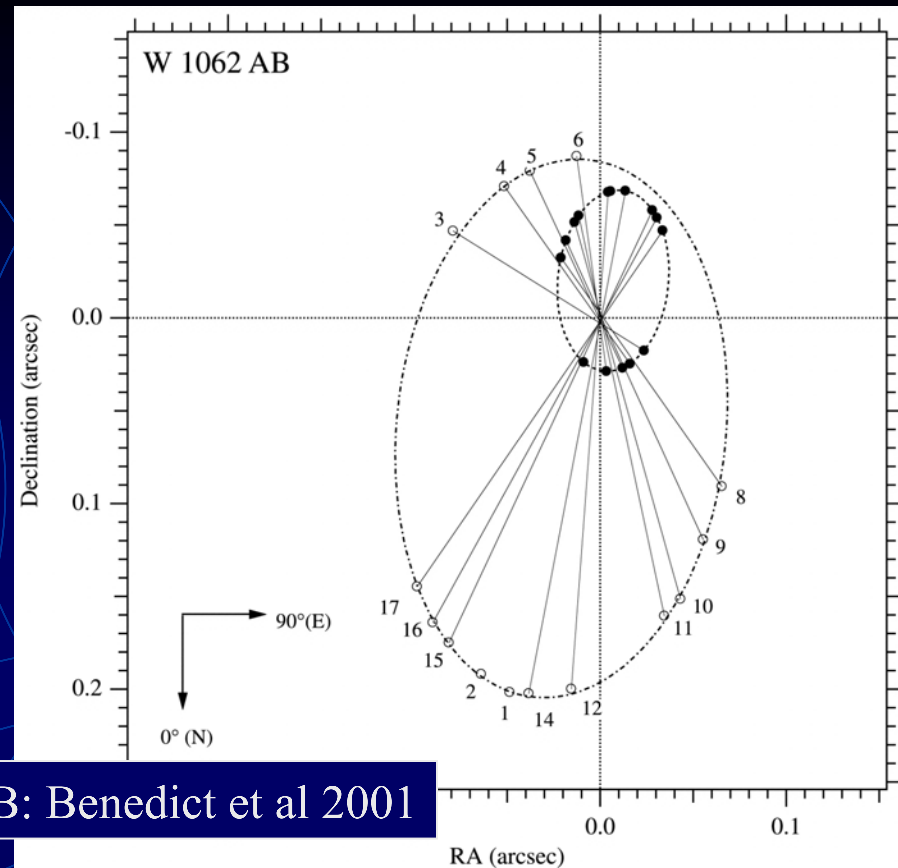
- M.O. Mass-Luminosity Calibrations with Binaries
- Two Components to Program
  - Clusters – 1% masses
    - Ten (10) targets per cluster spanning factor of 10 in mass
    - Orion, IC 2391, Pleiades, M7, Hyades, M67
  - Special Samples – 1 % masses
    - Ten targets in each sample defining ends of main sequence
    - Spanning factor of 10 in abundance



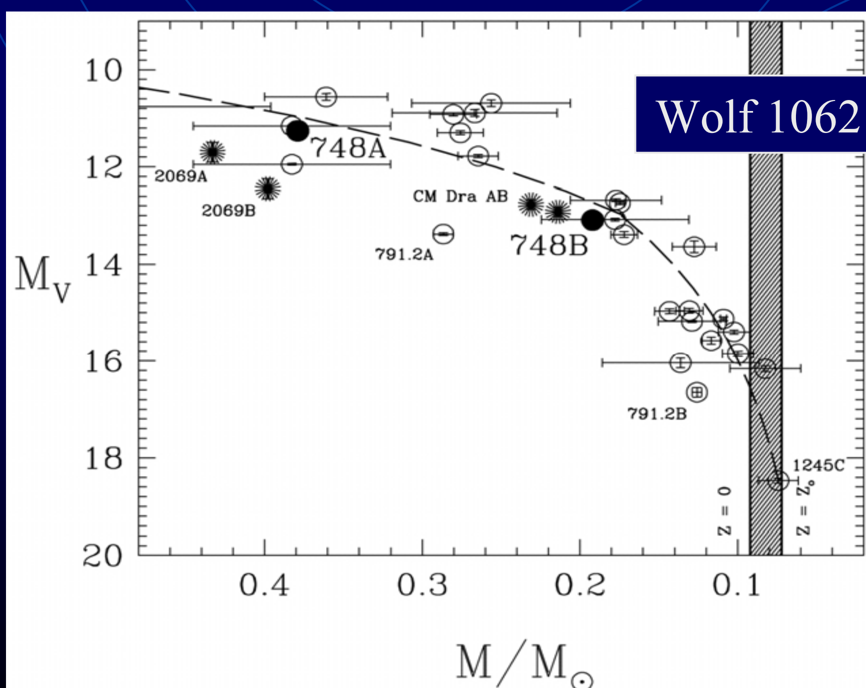
Mass/Magnitude Diagram
Henry & Torres in Prep

Low-Mass Stars

- Stellar census dominated by M-dwarfs, yet few high-precision mass & luminosity determinations exist
- System are difficult primarily because they are faint & elemental abundances hard to measure



Wolf 1062 AB: Benedict et al 2001



- Sensitivity of HST FGS (& eventually SIM) make low-mass systems (nearly) unique purview of FGS
- With HST SM4 near, prospects are good for additional work here pre-SIM

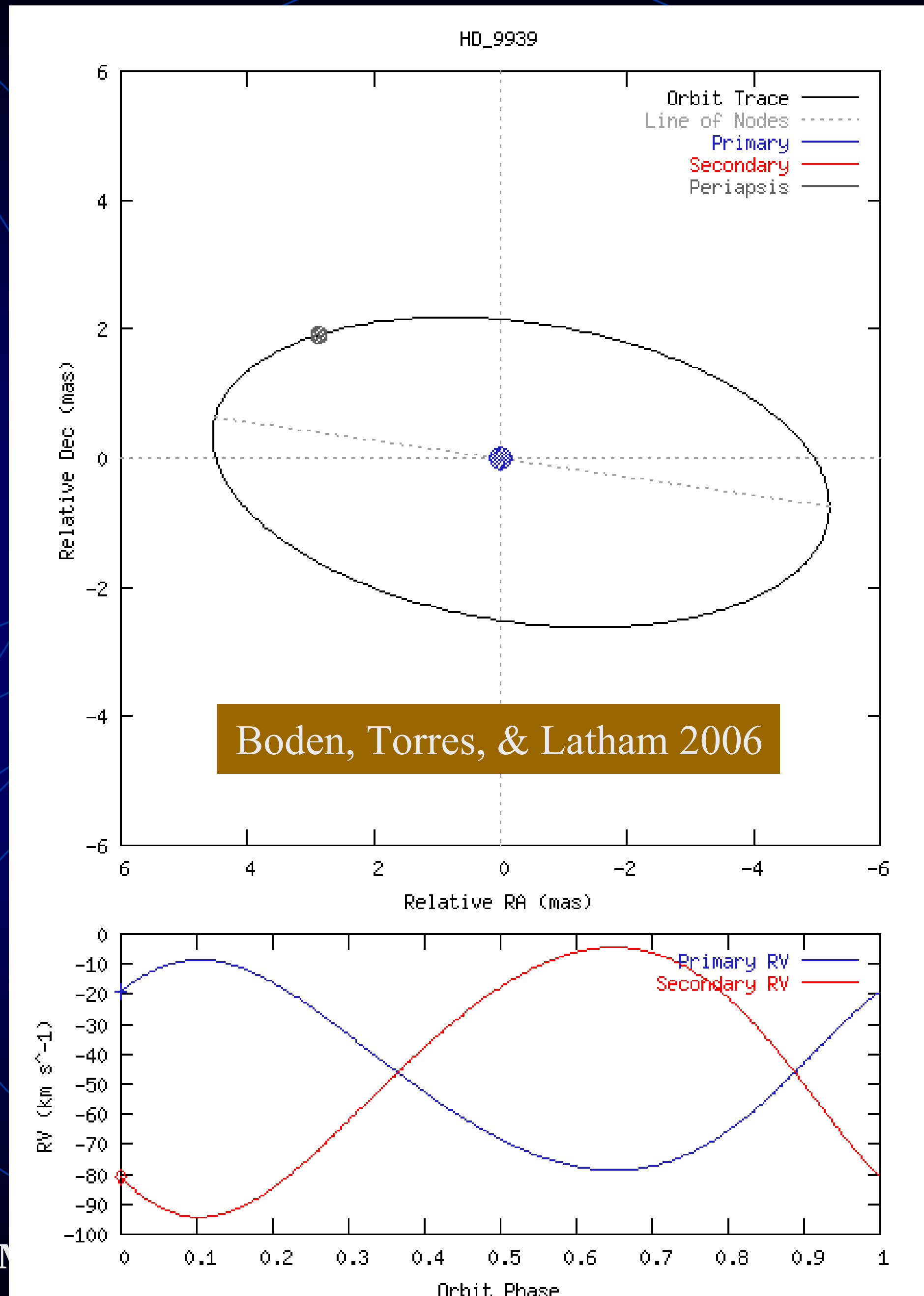
PopII Distances – Charboyer

- Charboyer program will measure accurate parallaxes to a number of PopII stars:
  - Isolated halo stars
  - Globular cluster stars (giants & RR Lyr)
- Goals of this project:
  - Better constrain PopII models
  - Determine (more) reliable ages for GCs (& constrain Galaxy formation scenarios)

47 Tuc (from Gilliand & HST WFPC2)

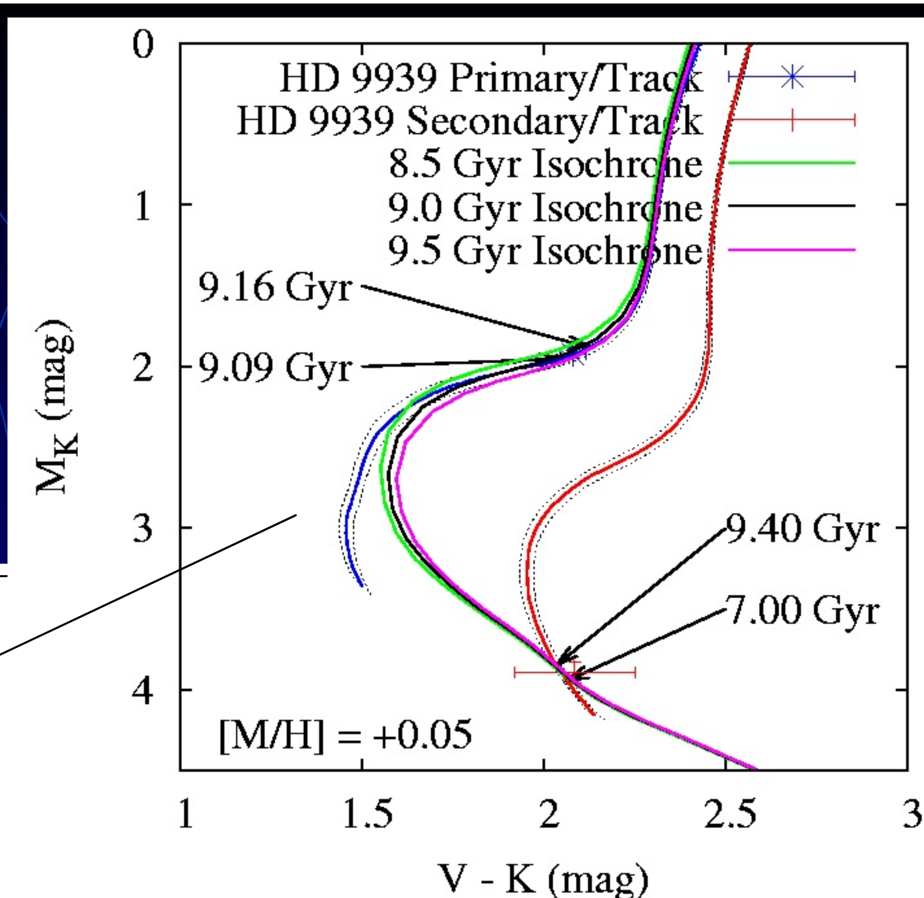
HD 9939

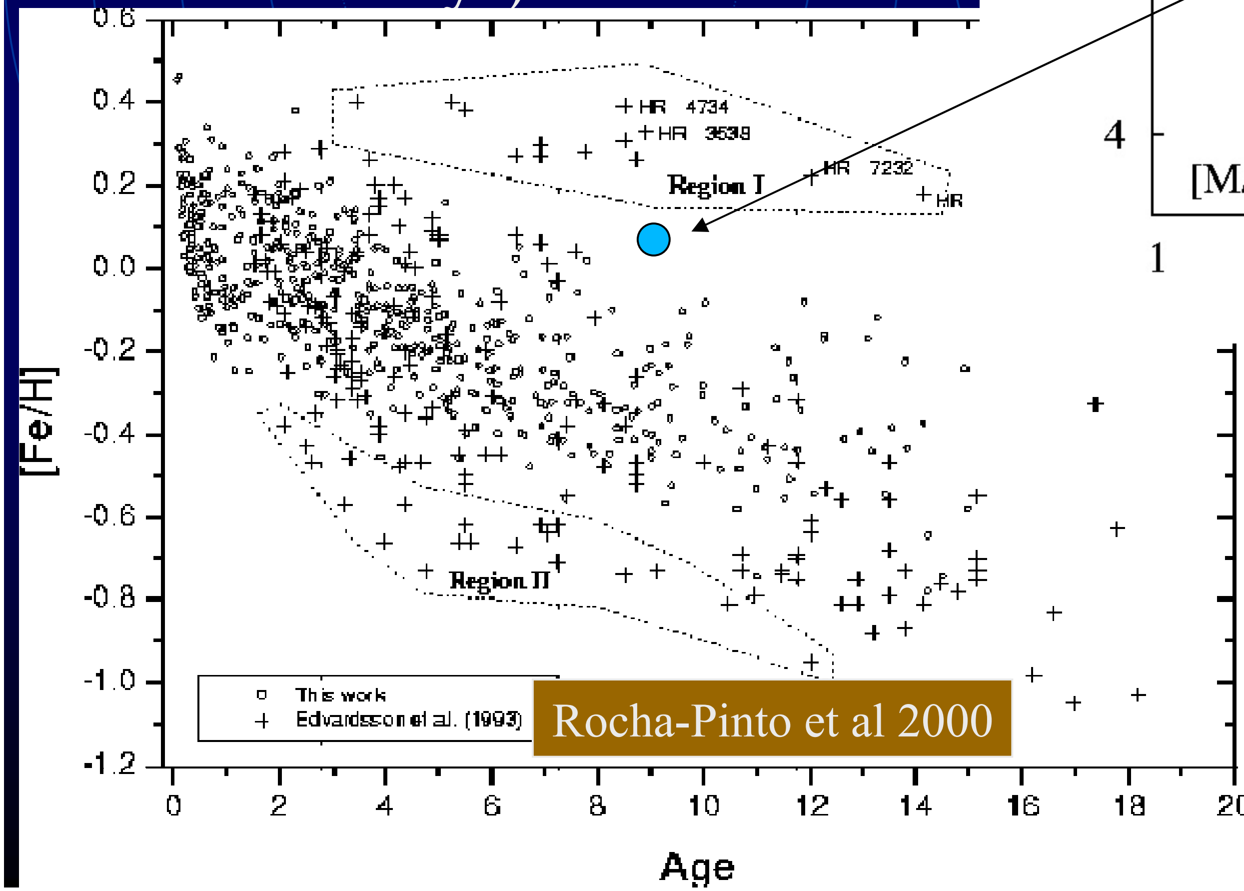
- In 2000 we (Willie Torres, Dave Latham, and myself) began a program to test models of metal-poor stars
- HD 195987 (Torres et al 2002) was the first such test of a non-solar metallicity system – *some model issues relating to elemental (α-process) composition*
- HD 9939 was the next system in the program…kinematically selected from Carney & Latham sample (90 km/s WRT LSR)



HD 9939 Age

- Primary dead in H-gap → system age extraordinarily well determined (9.1 +/- 0.25 Gyr)



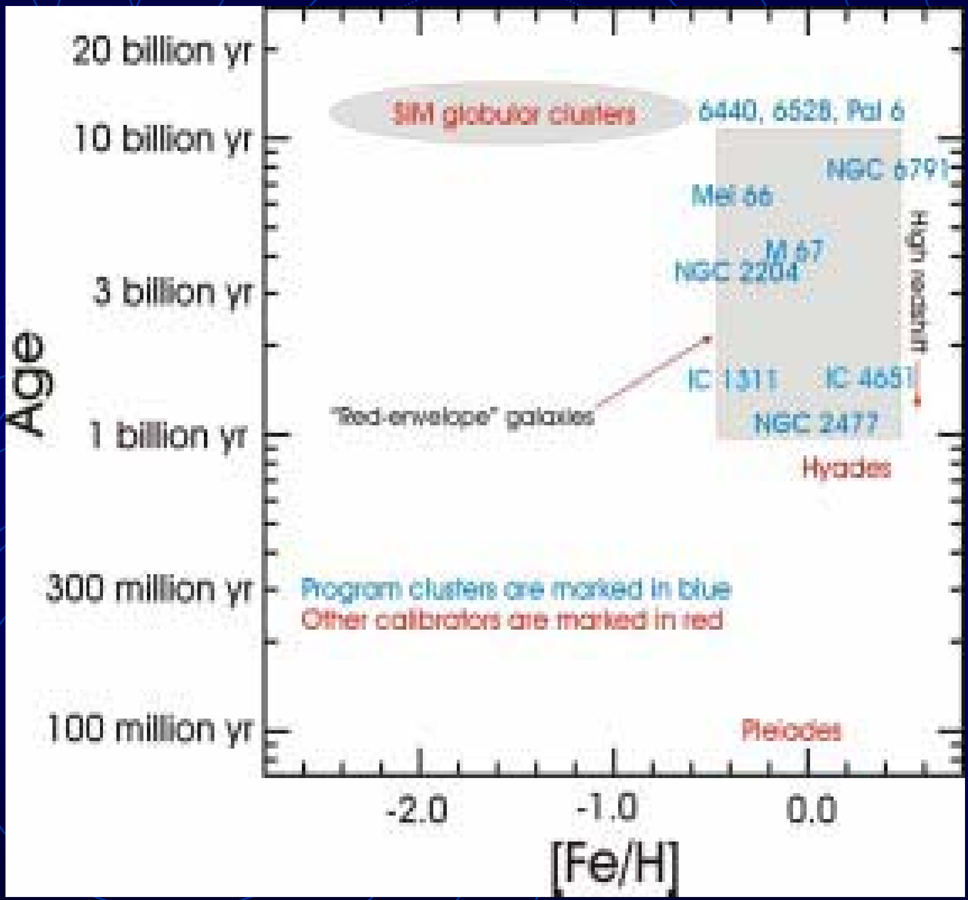


Rocha-Pinto et al 2000

- Best-fit abundance [M/H] = +0.05 +/- 0.05; old(er) & metal-rich!!!

"Open and Globular" Cluster Distance Project – Worthy

- Objective: "Open and Globular" Cluster Parallax Measurements (& Radiometric CMD)
- Cluster set includes several with "interesting" elemental abundance patterns & key linkages to local group clusters

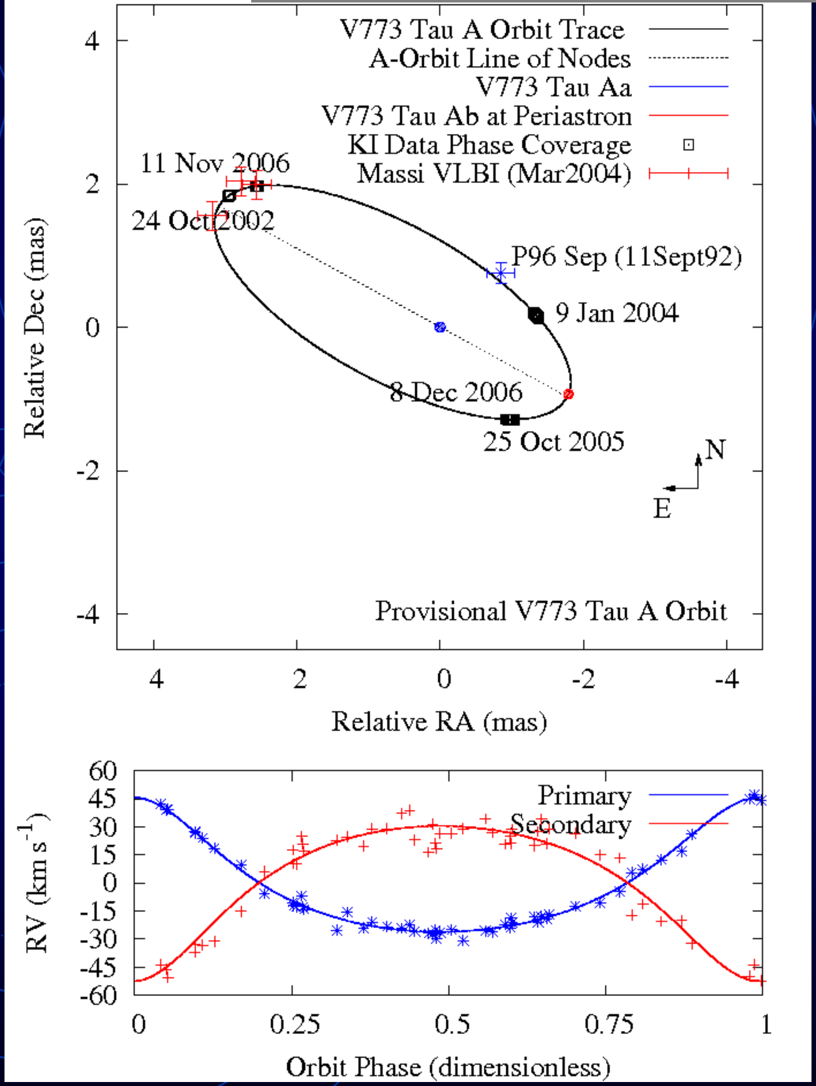


Young Stars – Beichman

Beichman/Young Stars program aims to:

- Detect gas-giant planets in late T-Tauri-phase stars (5-10 Myr)
- Measure PMS binary physical orbit (& resulting mass/luminosity constraints)

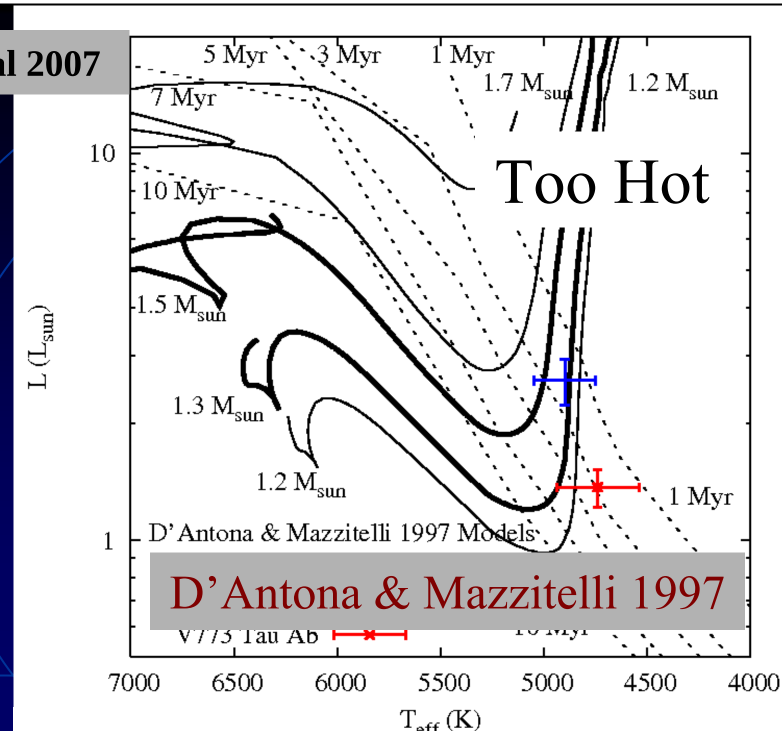
V773 Tau A – Boden et al 2007

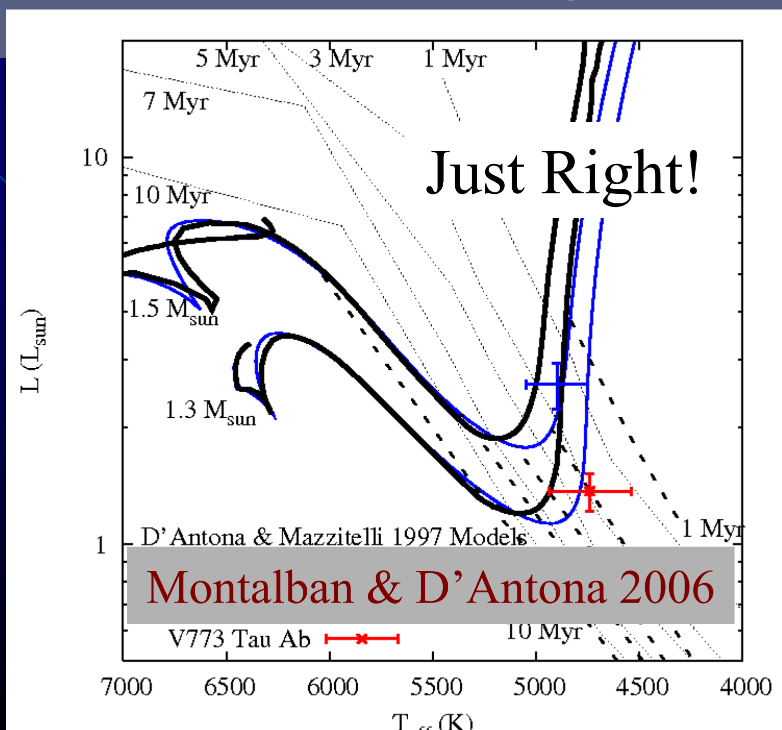


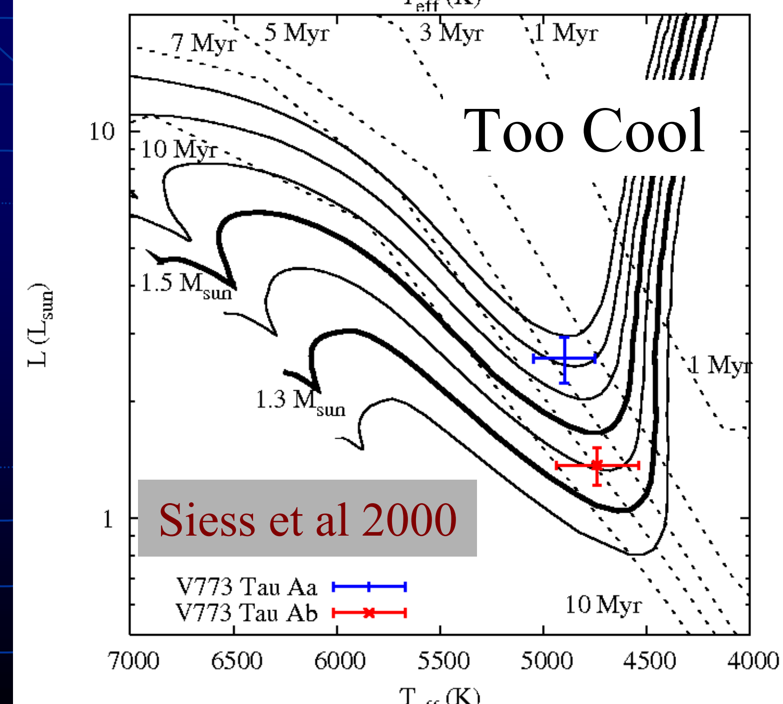
V773 Tau A PMS Model Comparisons

Boden et al 2007

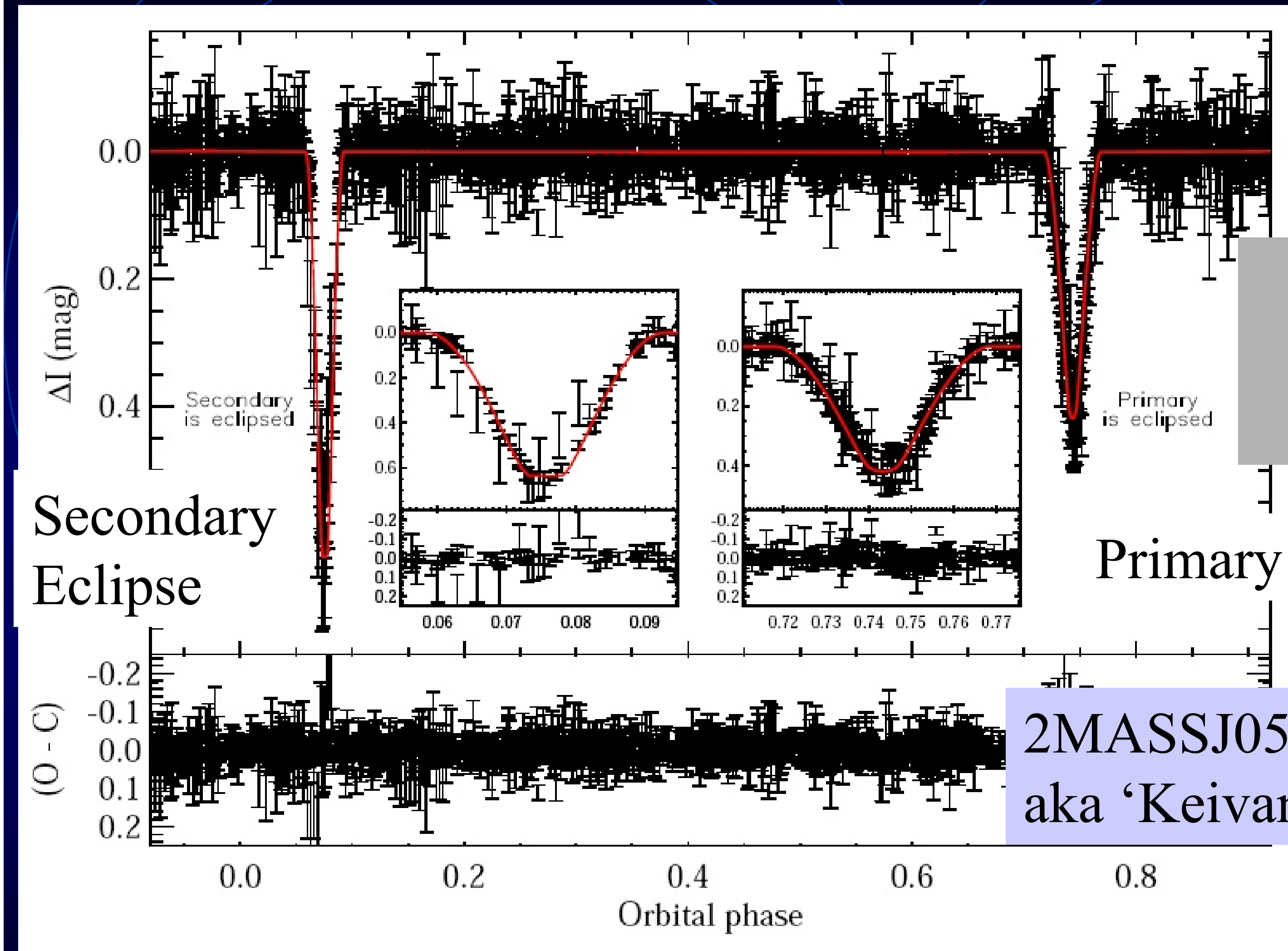
- ~3+/- 1 Myr System Age (intermediate Taurus population Palla & Stahler 2002)
- D'Antona & Mazzitelli 1997 models **too hot**…
- Siess et al 2000 models **too cool**… (see Montalban et al 2004)
- Montalban & D'Antona 2006 models (added 2D convection) **just right**…







PMS Eclipsing Binaries



Stassun et al 2006

Stassun et al 2007

Reiners et al 2008

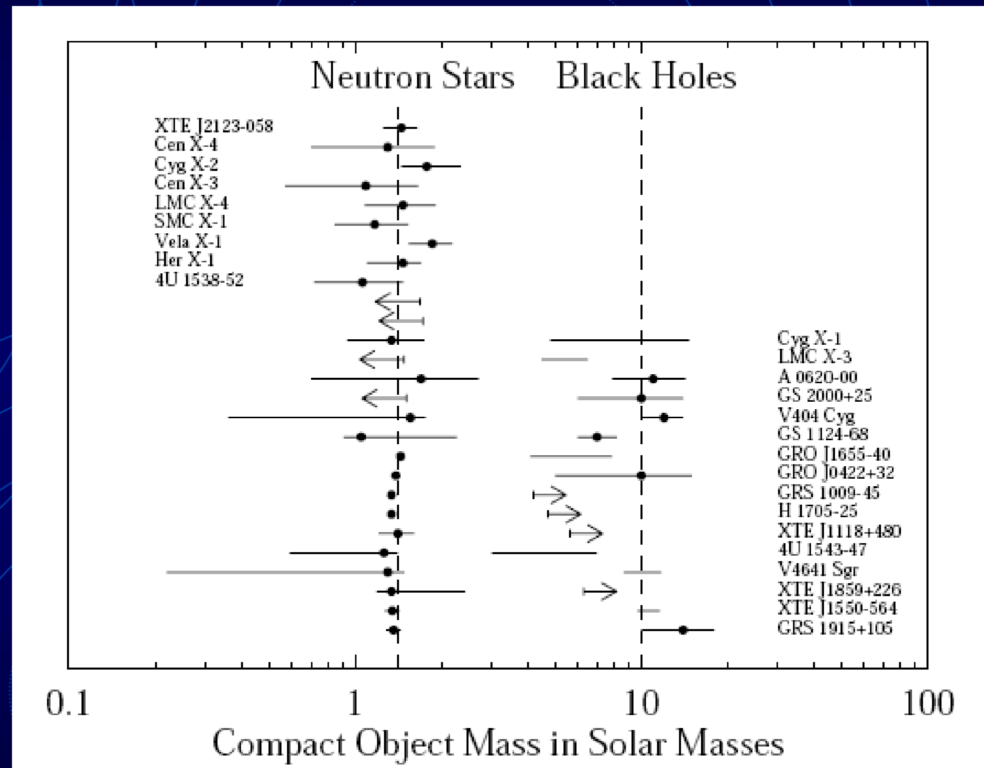
2MASSJ05352184-0546085
aka 'Keivan's weird system'

- Only a handful of known EBs in the PMS sector (particularly at low mass…)
- Significant survey projects looking to find more (e.g. MONITOR)
- PMS properties significantly effected by "initial conditions"…

Stellar End States: X-ray Binaries – Quirrenbach WD, NS, BH – Kulkarni

Two smaller projects on stellar end states:

- X-ray binaries – Quirrenbach: focus on dynamical masses for EoS constraints
- End-state collection – Kulkarni:
  - planetary companions to WD
  - BH & NS kinematics to constrain SN event dynamics



Summary

- In addition to its planet-finding mission, SIM will contribute greatly to our knowledge of stellar astrophysics
  - Dynamical Mass-Luminosity calibrations across the H-R diagram, with excursions in age and abundance
  - Dynamical masses for dark components in X-ray binaries to constrain their Equation of State
  - Luminosity calibrations for a broad sample of clusters

  - ***Contributions from viewers like you*** – roughly half of the selected studies in this program are focused on stars