SIM Stellar Astrophysics: Mandatory Testing for Stellar Models

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Testing Stellar Evolutionary Models

• Stellar Models underpin *a lot* of what 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
“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!)
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 $T_{\text{eff}}$

- 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)
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 ($\alpha$-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)

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 PMS Model Comparisons

- ~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 just right…
PMS Eclipsing Binaries

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”...

Stassun et al 2006
Stassun et al 2007
Reiners et al 2008

2MASSJ05352184-0546085 aka ‘Keivan’s weird system’
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