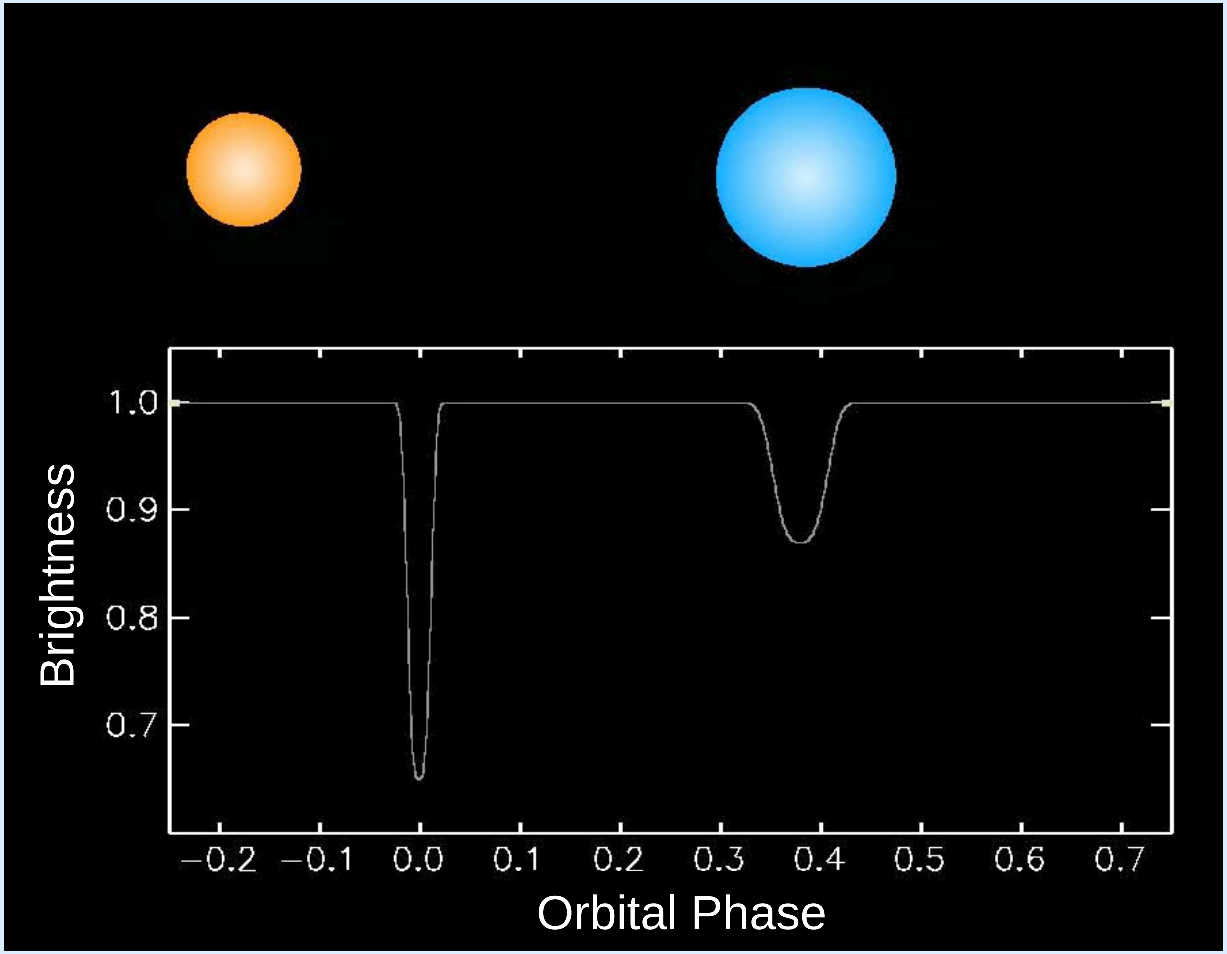
How I Learned to Stop Worrying and Love Eclipsing Binaries



Maxwell Moe (University of Arizona)

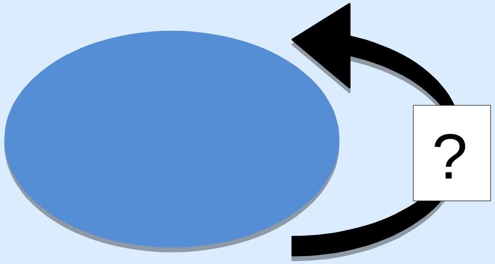
Einstein Symposium – Oct. 28, 2015

Main Collaborator: Rosanne Di Stefano (CfA)

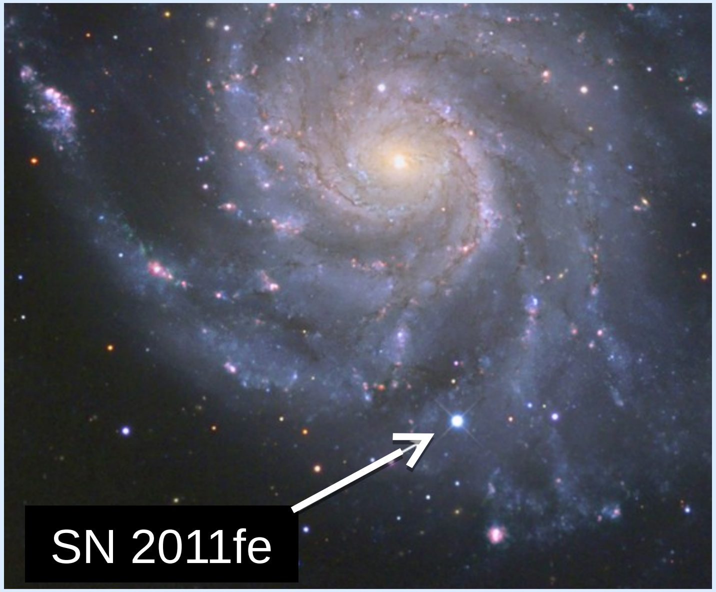
Malachi Regulus Moe

Regulus (α Leonis - the heart of the lion):

- Rapidly rotating B-type MS star;
  $v_{rot} \sin i = 350$ km s^{-1}
- Single-lined spectroscopic binary (SB1)
- Companion either K-dwarf or white dwarf



Half of B-type (3 - 16 $M_{\odot}$) and O-type (>16 $M_{\odot}$) MS stars will interact with a binary companion, and can evolve to produce:



Type Ia Supernovae

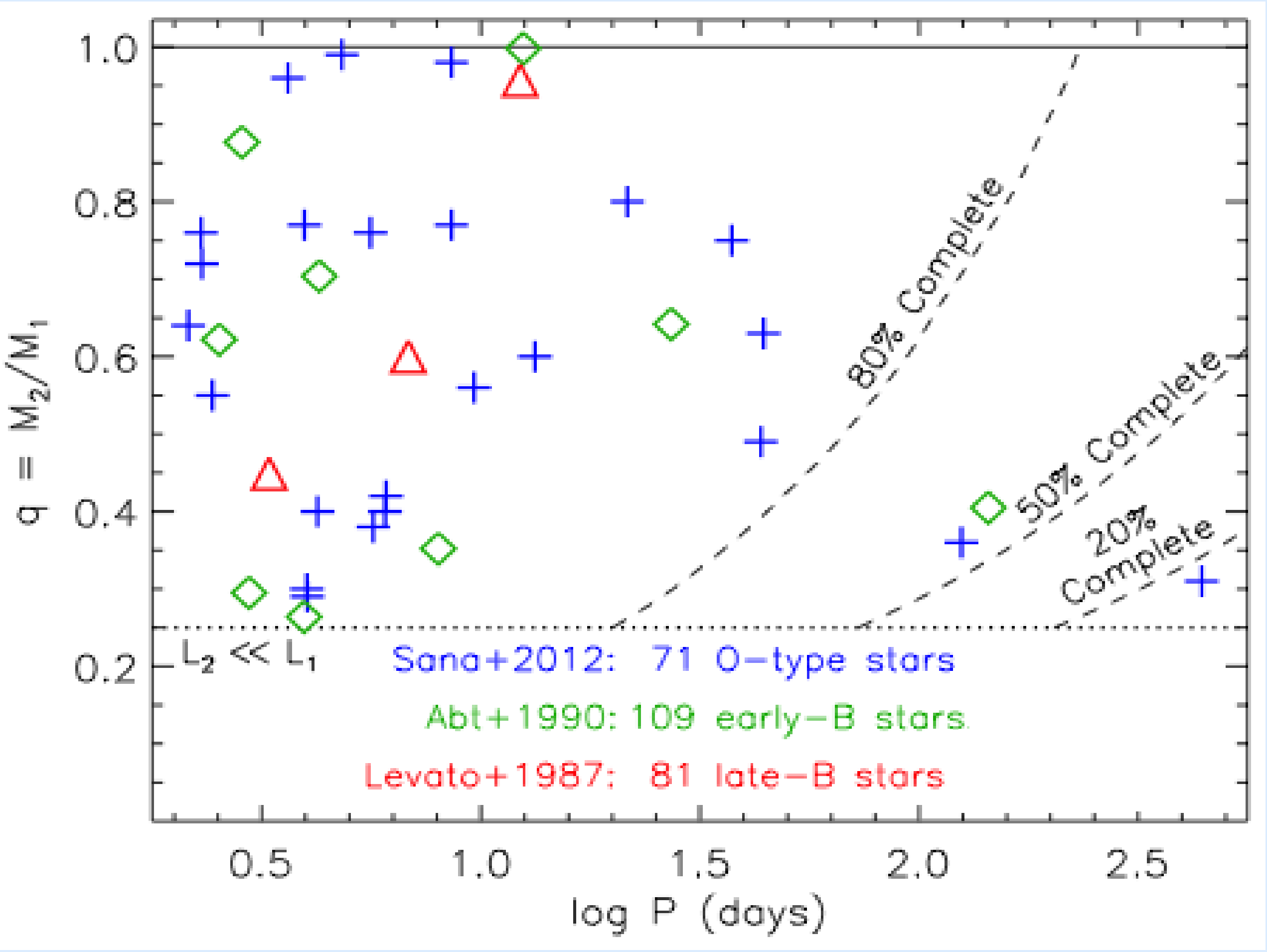
X-ray Binaries

Millisecond Pulsars

Neutron Star Mergers
& Gravitational Waves

Gamma-ray Bursts

Census of Close Companions to Early-type Stars (as of 2012)



Spectroscopic Binaries

Milky Way: $Z \approx Z_{\odot}$

SB2s: $q = M_2/M_1 > 0.25$

SB1s: may contain compact remnants (e.g., Regulus)

Incomplete at intermediate periods

How can we probe lower Z, smaller q, and longer P?

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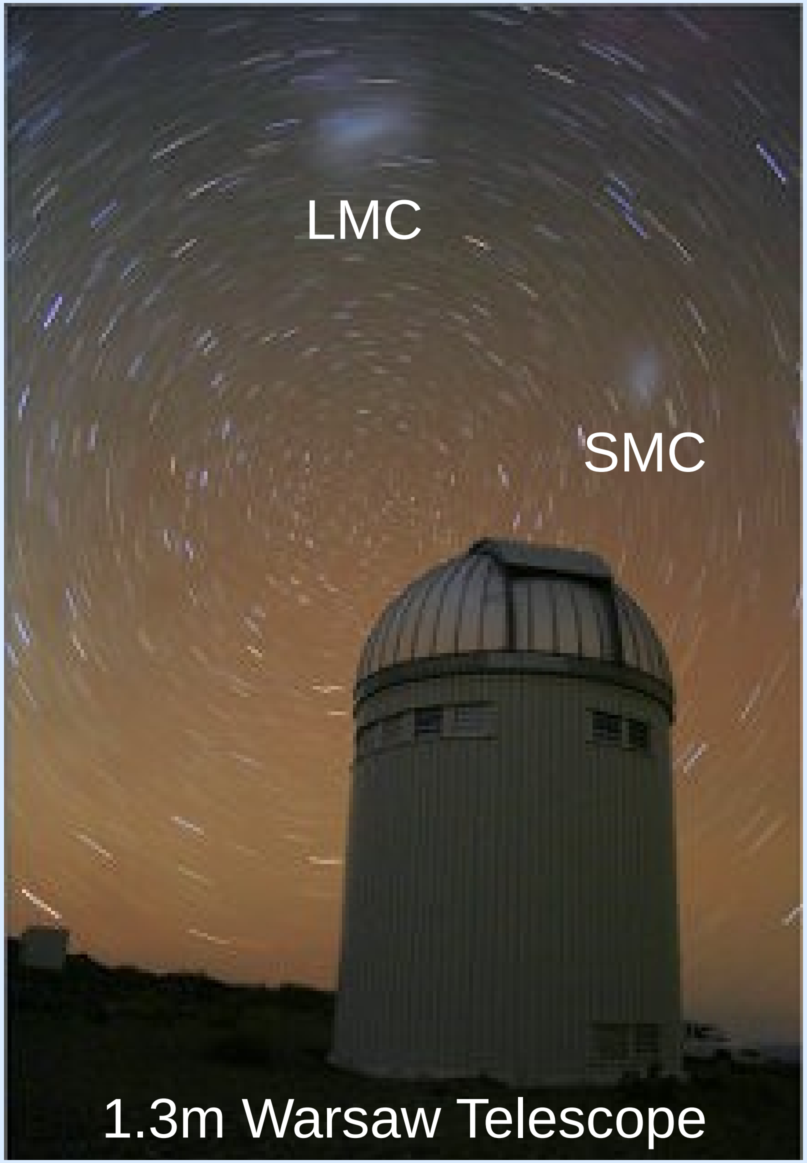


Optical Gravitational Lensing Experiment (OGLE)

50+ million stars

7+ years of observations

500+ photometric measurements

30,000+ EBs in Magellanic Clouds
(Graczyk et al. 2011)

3,000+ EBs with B-type MS primaries
(I = 16 - 18 mag)

Advantages of OGLE samples of EBs in MCs

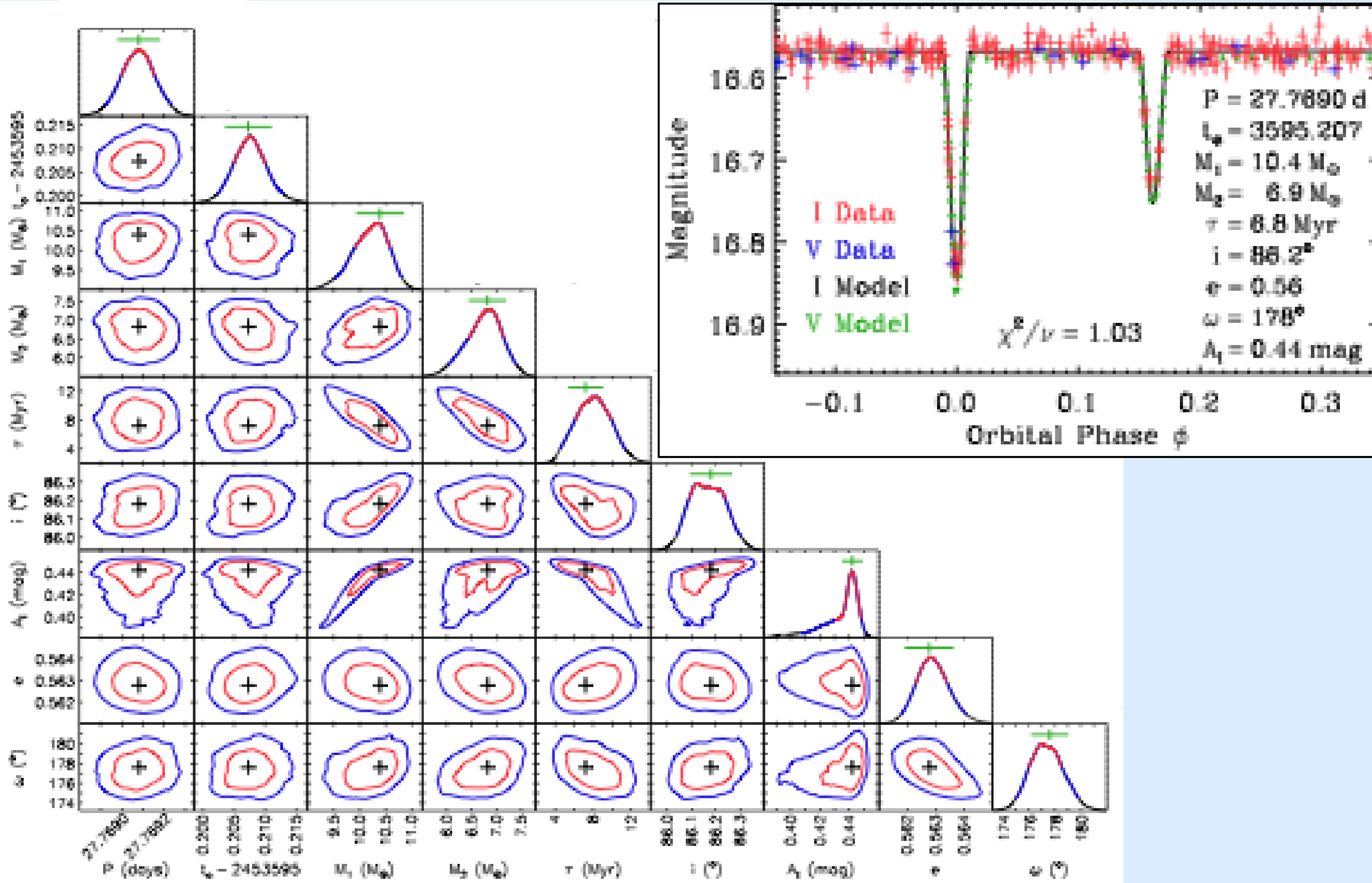
Lower metallicities in LMC (log $Z/Z_{\odot}$ = –0.4) and SMC (log $Z/Z_{\odot}$ = –0.7) → Massive binary properties have **no dependence on Z** (Moe + Di Stefano 2013)

Sensitive to shallow eclipses ΔI = 0.1 mag → Can detect EBs with **extreme mass ratios** (M+D 2014)

Thousands of early-type EBs → Large samples with **intermediate orbital periods** (M+D 2015a)

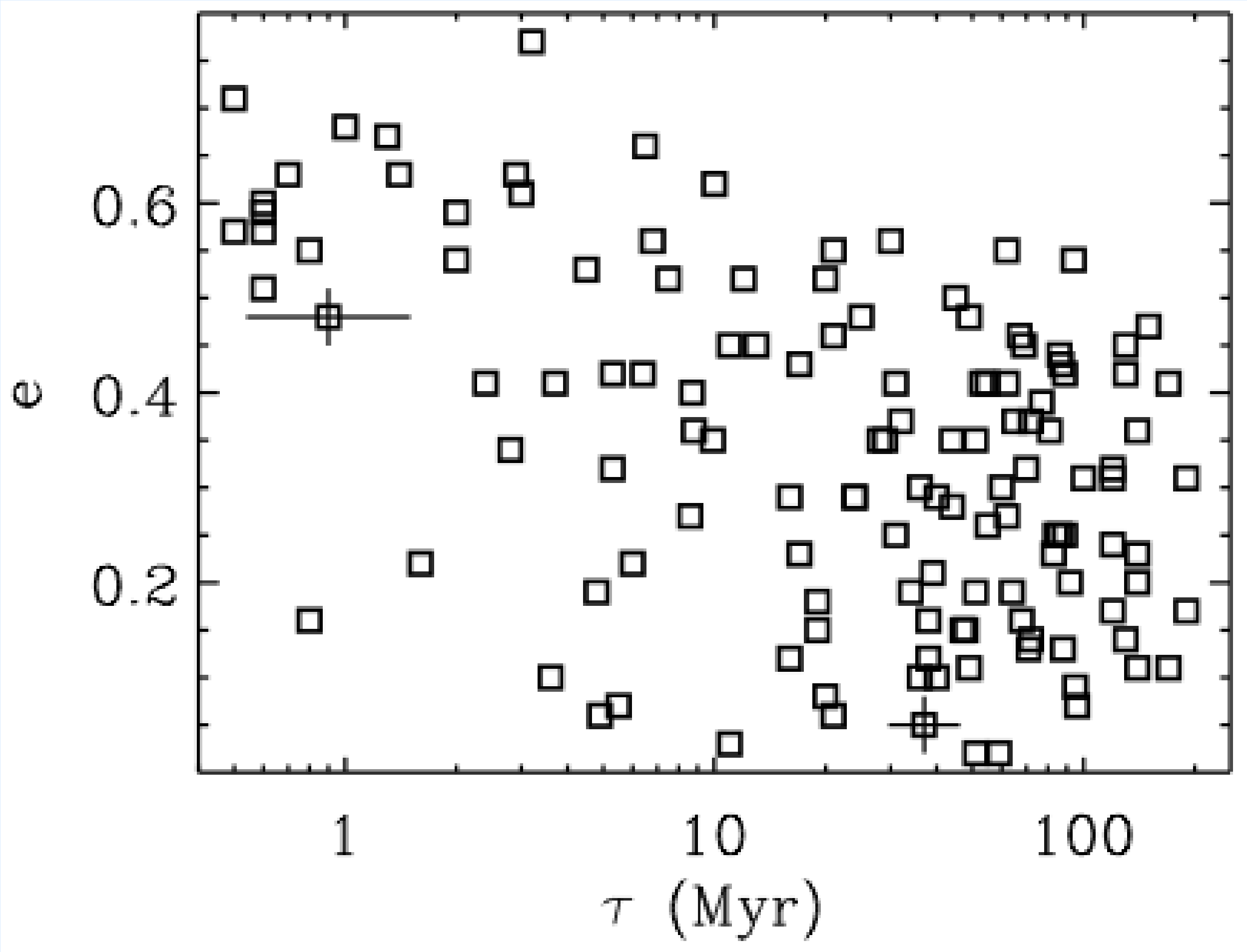
Known distance & dust reddening law; calibrated stellar evolutionary tracks → **Measure properties (M_1, q, τ, e) of detached (unevolved) EBs solely from photometric light curves** (M+D 2015a)

Advantages of OGLE samples of EBs in MCs



Measure EB ages τ and component masses M_1 & M_2 to 30% and 15% accuracy, respectively (Moe & Di Stefano 2014, 2015a)

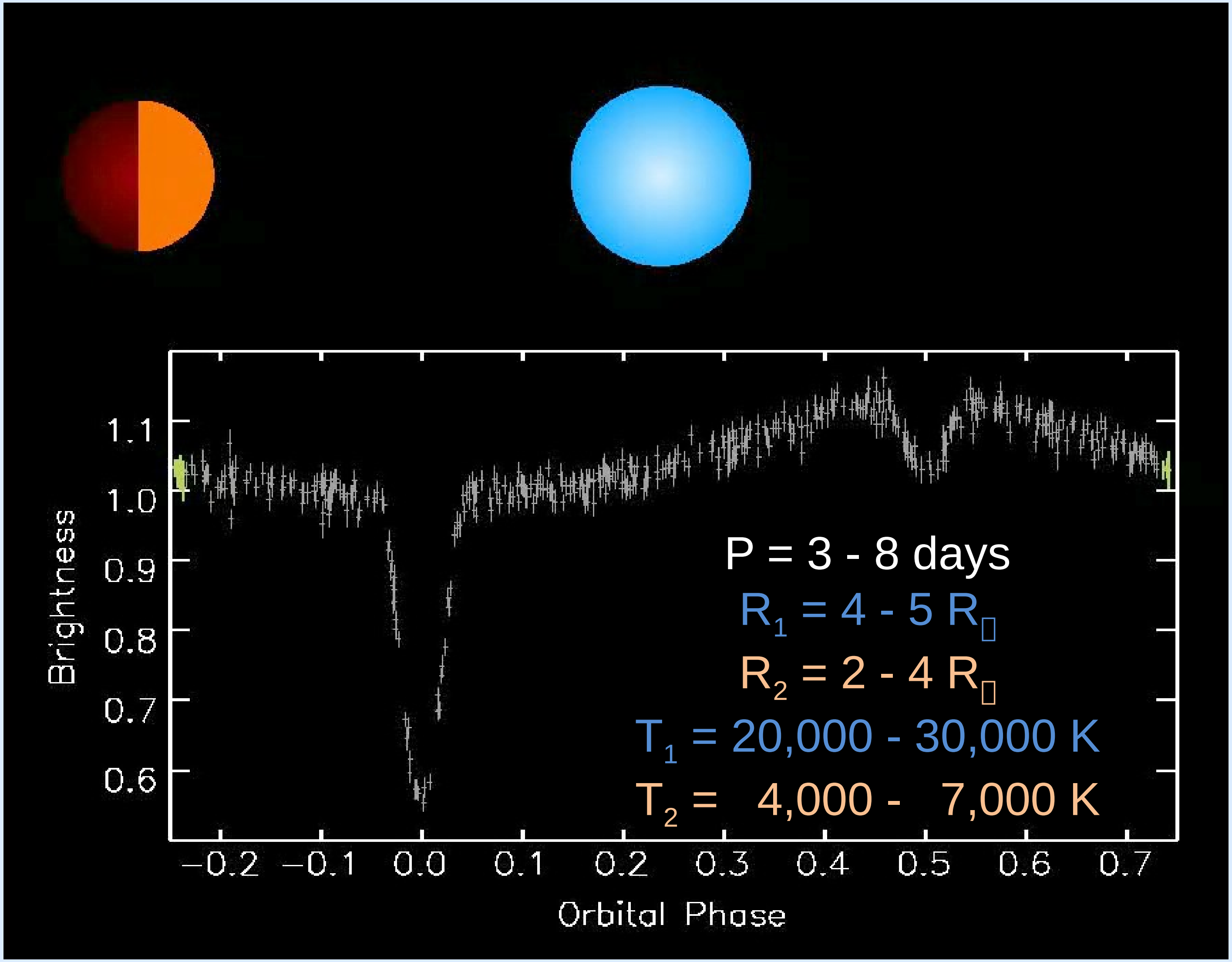
Detached EBs with B-type MS primaries & P = 20 - 50 days (M+D 2015a)



Early-type binaries with intermediate orbital periods born with **large eccentricities**, indicating they **formed via dynamical interactions**.

Age-eccentricity trend provides constraint for **tidal damping constant** in massive MS stars with hot radiative envelopes.

A New Class of Nascent EBs with Extreme Mass Ratios (M+D 2014)



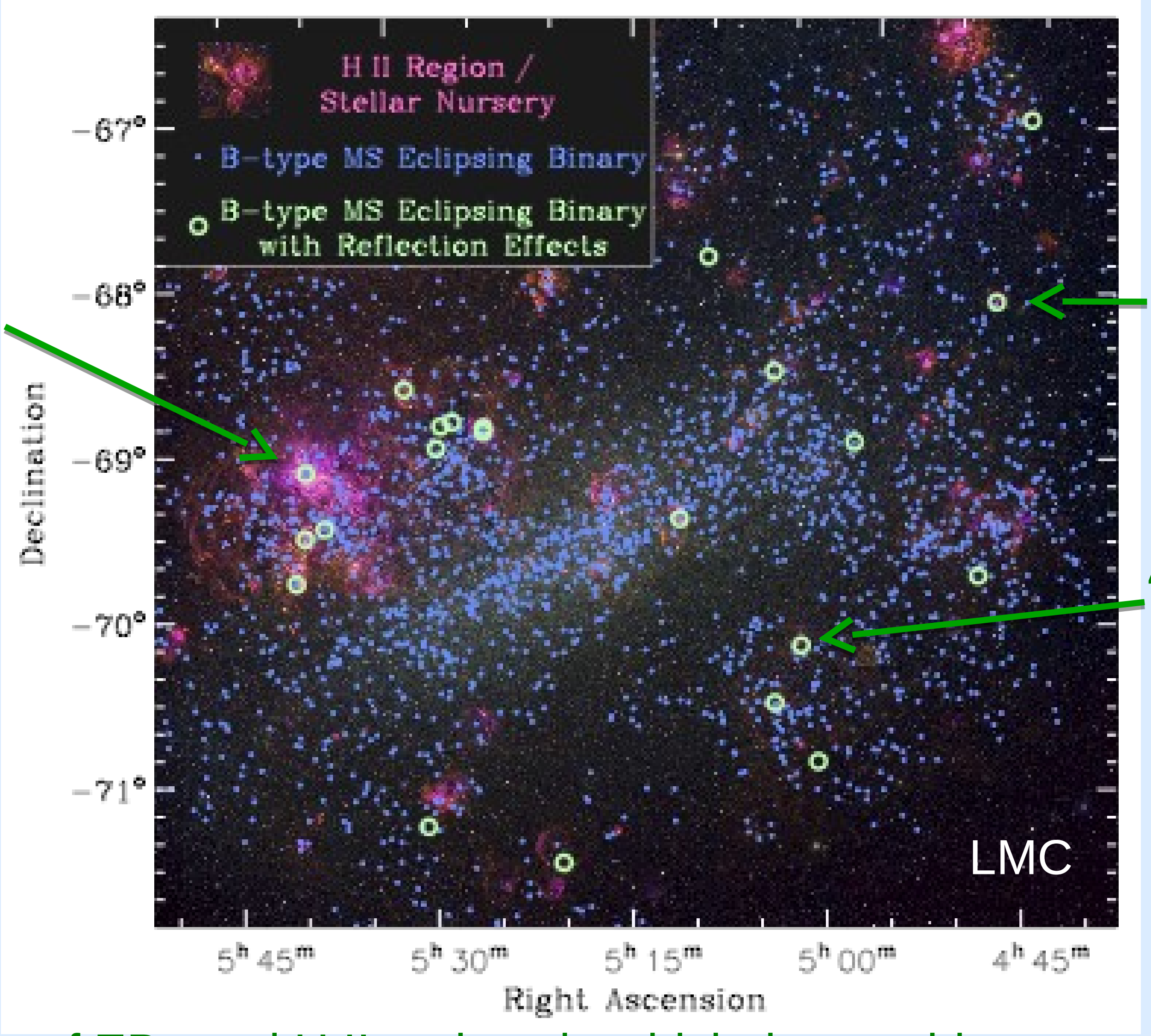
Identified 22 **pre-MS + MS EBs with reflection effects** in LMC:

M_1 = 7-16 $M_\odot$, M_2 = 0.8-2.4 $M_\odot$ (q = 0.07 - 0.36), and τ = 0.6-8 Myr.

A New Class of Nascent EBs with Extreme Mass Ratios (M+D 2014)

Predominantly in **LMC H II regions**

ΔI_1 = 2.8 mag, ΔI_{refl} = 0.12, & τ = 0.6 Myr in bright Tarantula Nebula

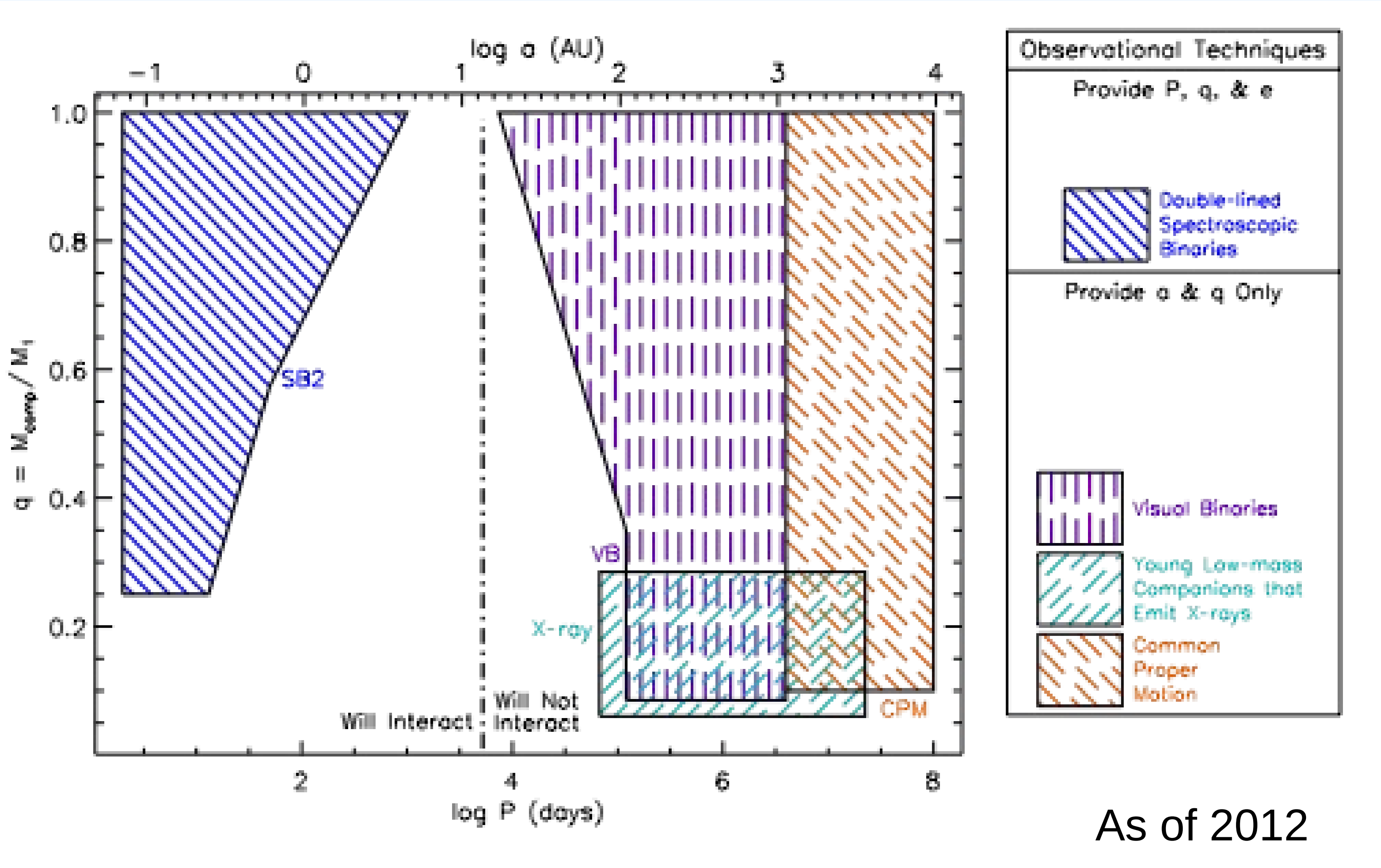


τ = 0.9 Myr in compact H II region

ΔI_1 = 0.2 mag, ΔI_{refl} = 0.02, & τ = 13 Myr in large diffuse H II region

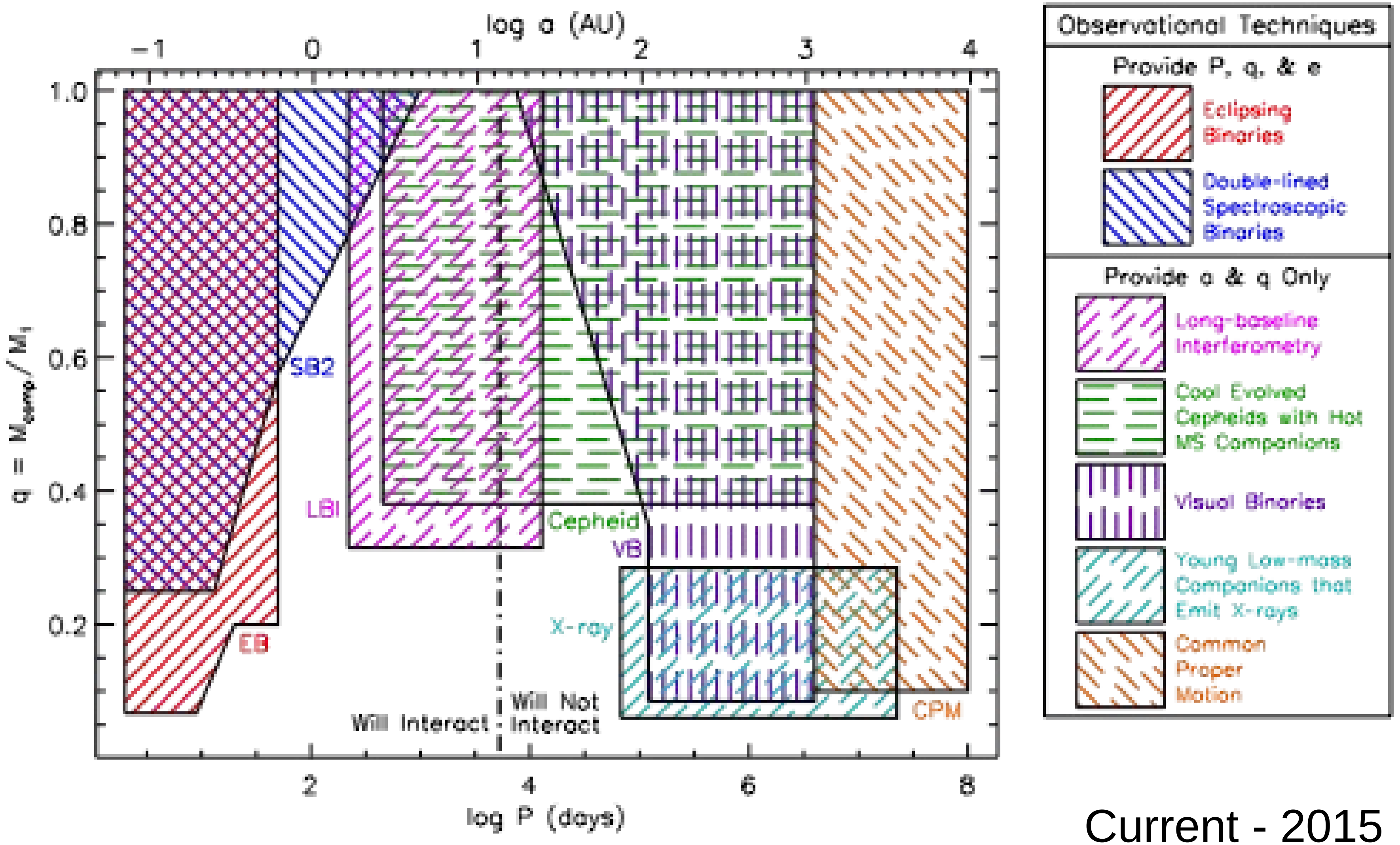
Properties of EBs and H II regions in which they reside are correlated; provides **kinematics of H II regions – can be used to measure feedback**

Mind your Ps and Qs: $f(P, q) \neq f(P) \times f(q)$ (Moe & Di Stefano 2015b)



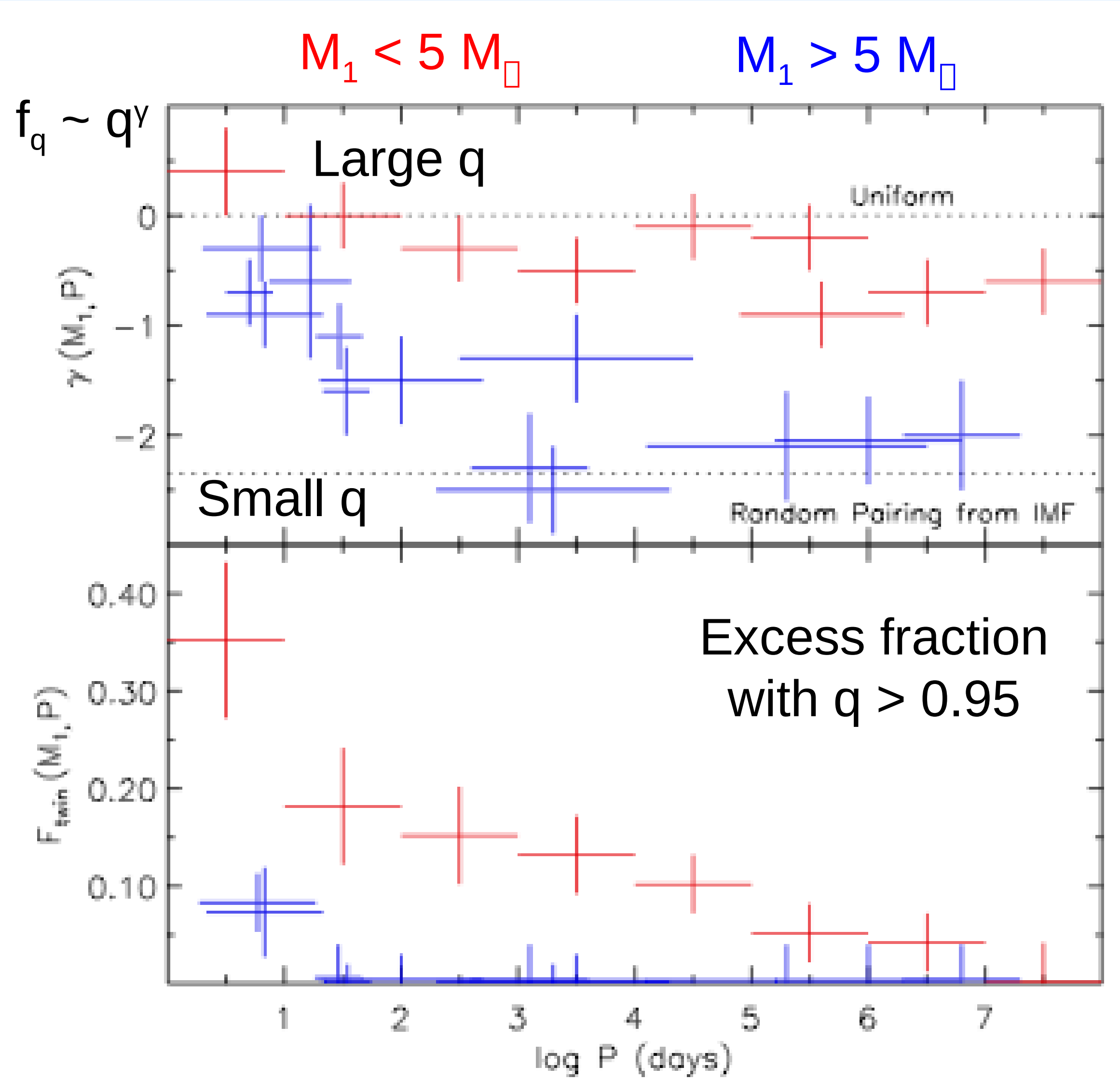
As of 2012

Mind your Ps and Qs: f(P, q) ≠ f(P) × f(q) (Moe & Di Stefano 2015b)



Current - 2015

Mind your Ps and Qs: f(P, q) ≠ f(P) × f(q) (Moe & Di Stefano 2015b)



Massive Binaries

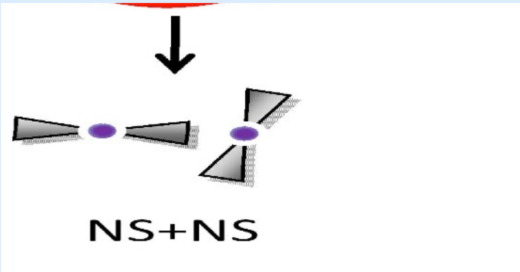
Closer binaries: correlated component masses – **coevolved** via competitive accretion in primordial disk

Wider binaries: consistent with random pairings drawn from IMF – components formed **relatively independently**

Solar-type binaries: same trend but still have correlated component masses at wide separations due to long-lived primordial disks

Formation of Galactic LMXBs and MSPs (Moe+ in prep)

$M_1 > 10\ M_\odot$ $M_2 < 1.5\ M_\odot$



LMXBs and MSPs evolve from ZAMS binaries with extreme mass ratios and intermediate orbital periods (Kalogera & Webbink 1998)

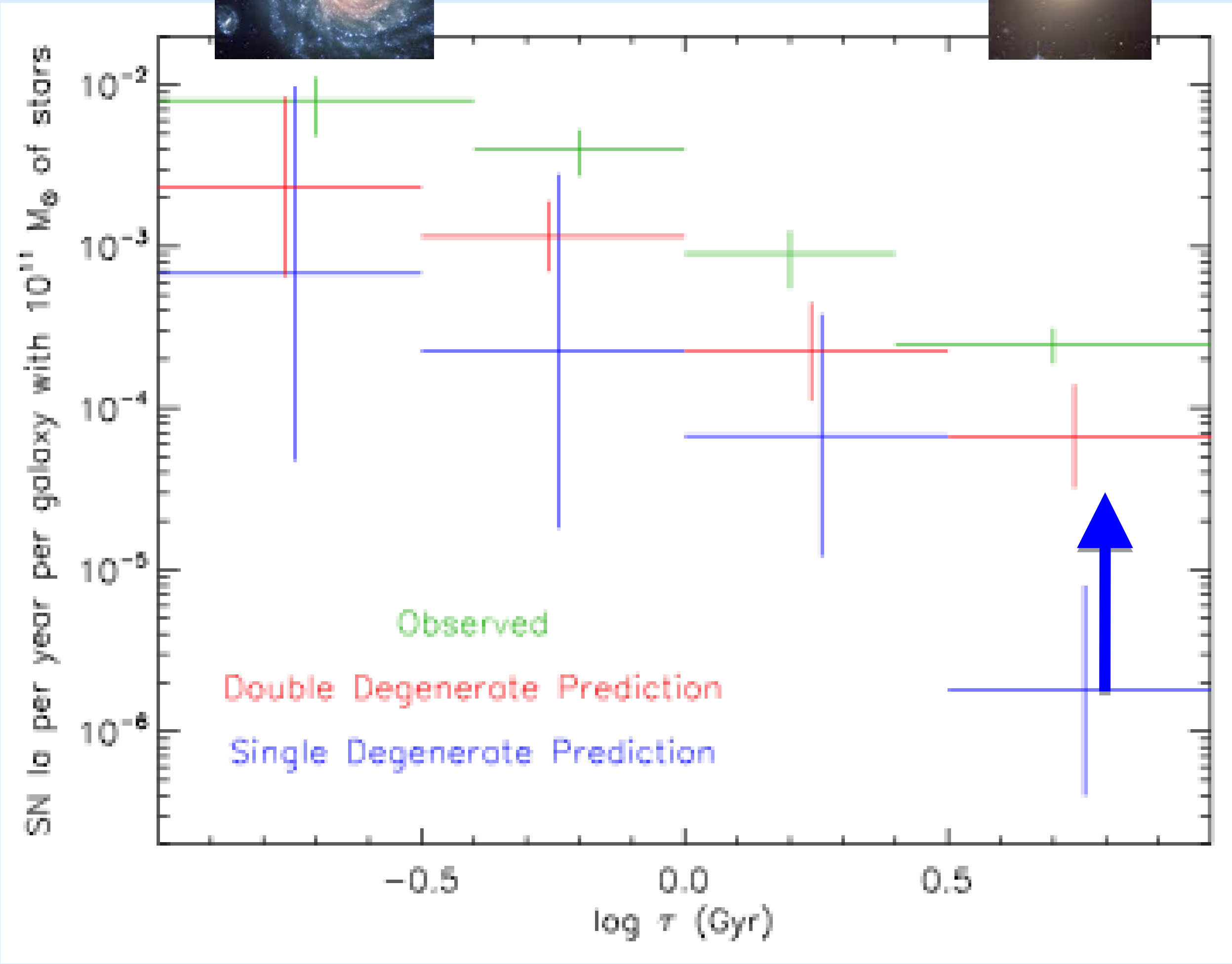
Predicted rates from binary population synthesis underestimate rates inferred from observations by
1 - 2 orders of magnitude
(Kiel & Hurley 2006)

Previous solution: invoke (unrealistic) prescriptions for binary evolution,
e.g., $\alpha_{CE} \sim 1$, $v_{SNkick} < v_{orb}$ etc.

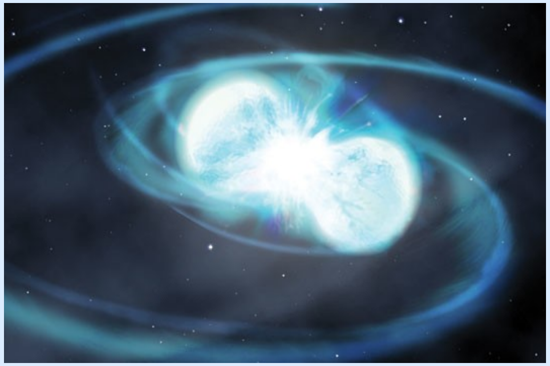
Proposed solution: we measure
~30 times more progenitors
with $q \sim 0.1$ and $\log P$ (days) = 2 - 3

Progenitors of Type Ia Supernovae (Moe+ in prep)

SN Ia Delay Time Distribution (adapted from Nelemans et al. 2012)



Double Degenerate



Single Degenerate

Late-time single-degenerate SN Ia derive from symbiotics that evolved from **MS binaries with extreme q and intermediate P**

Summary/Conclusions

~⅓ of SB1s contain compact remnant companions (Regulus)

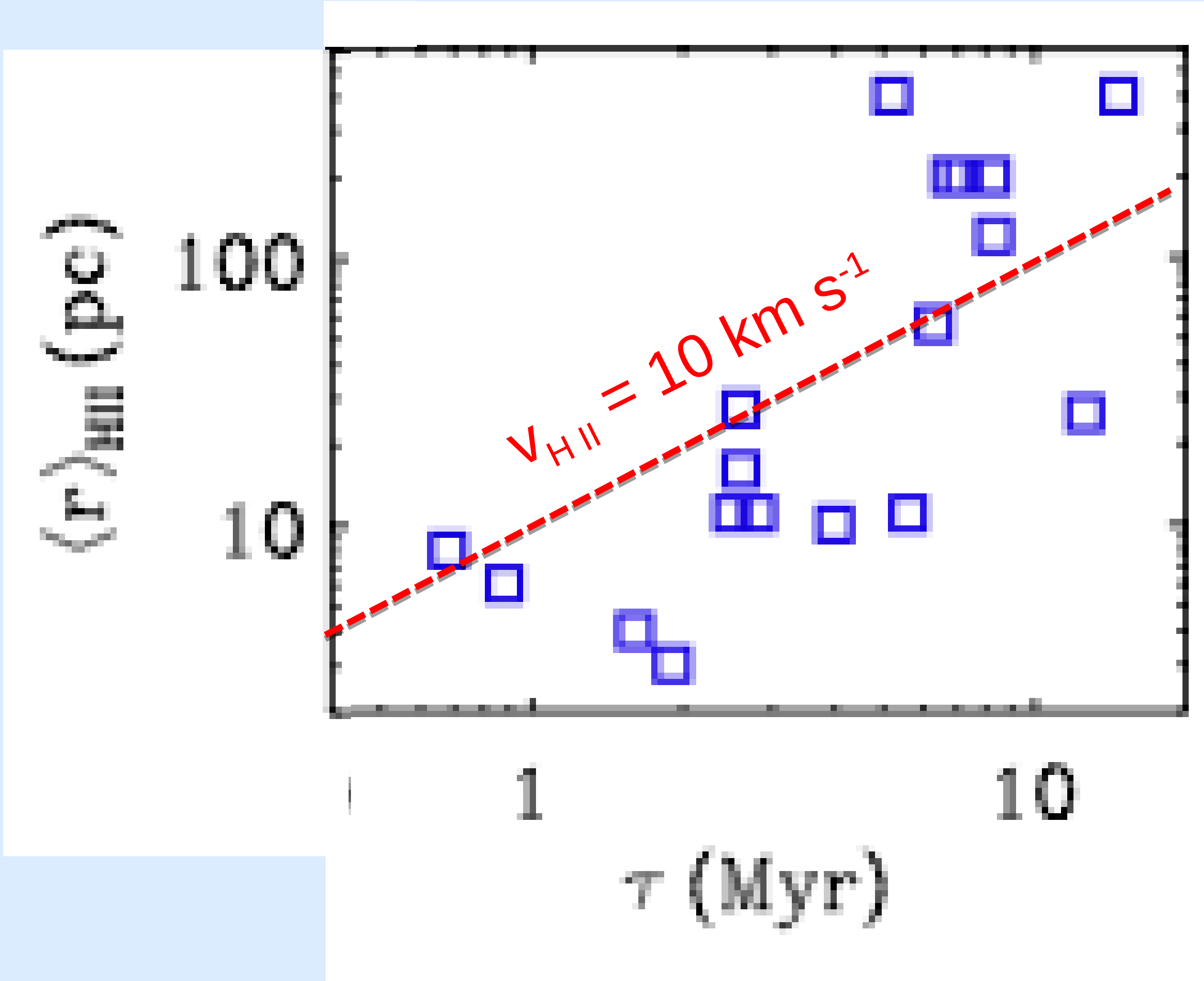
OGLE EBs in MCs probe low Z, extreme q, and intermediate P

Discovered new class of reflecting pre-MS + MS EBs

EBs as age indicators: - kinematics of H II regions (feedback)
- evolution of eccentricity (tides)

Mind your Ps and Qs:
at intermediate P: - small q (formed independently)
- large e (dynamical formation)

Progenitors of LMXBs, MSPs, and symbiotic SNe Ia:
~20 - 30 times more than previously predicted



$\langle r \rangle_{\rm HII}$ (pc)
100
10
1
10
τ (Myr)
$v_{H\,II}$ = 10 km s^{-1}