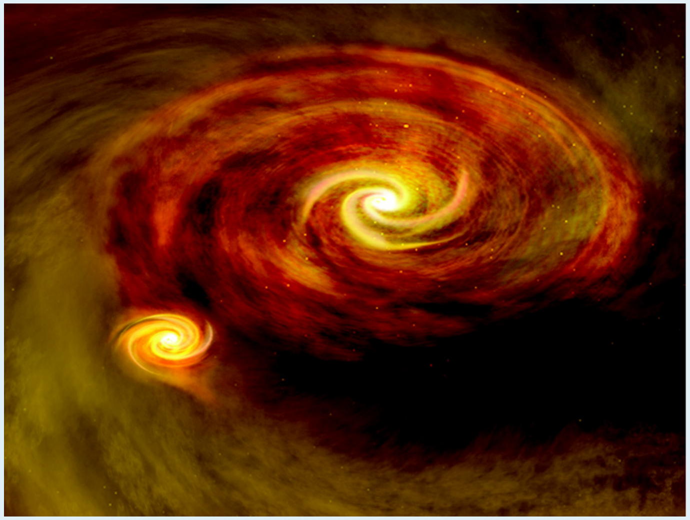
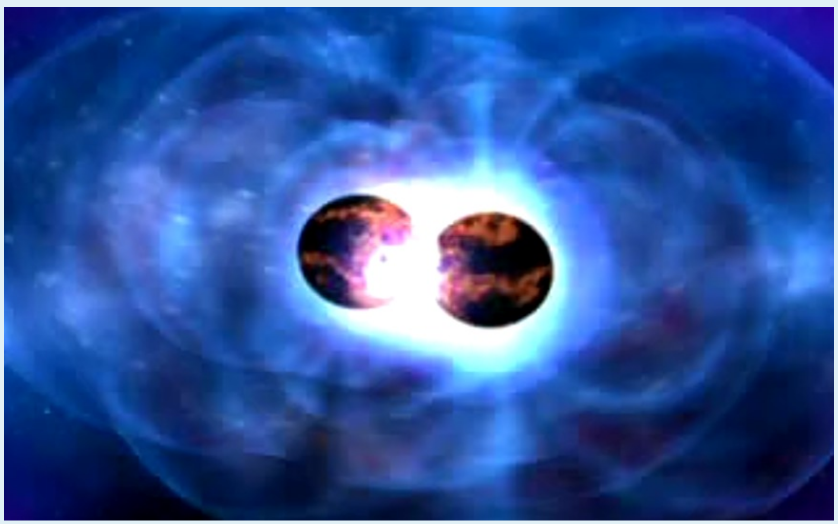
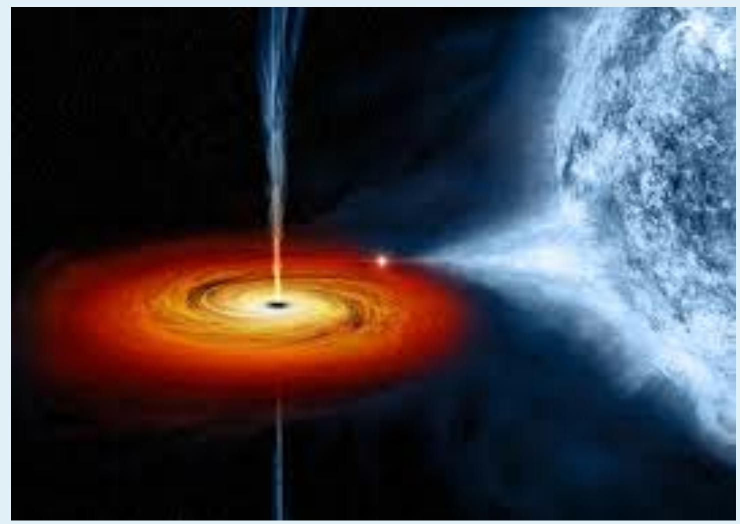
The Formation and Evolution of Binary Stars

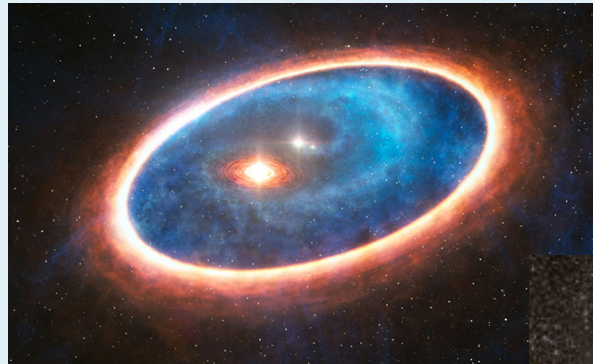


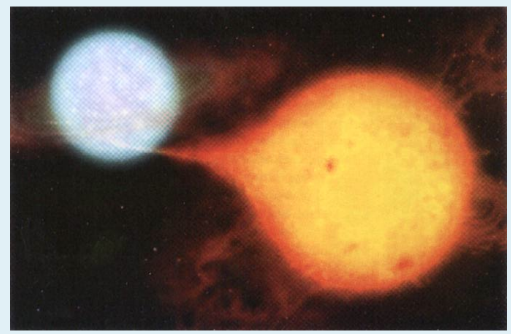
Max Moe (University of Arizona)

Einstein Fellows Symposium – October 18, 2016

Outline



1) Binary Star Statistics (8 min.)
   - A) Diagnostics for Binary Star Formation
   - B) Initial Conditions for Binary Star Evolution



2) Undergraduate Research (3 min.)
   - A) Tidal Evolution in Massive Binaries
   - B) Mass Transfer in Algol Binaries

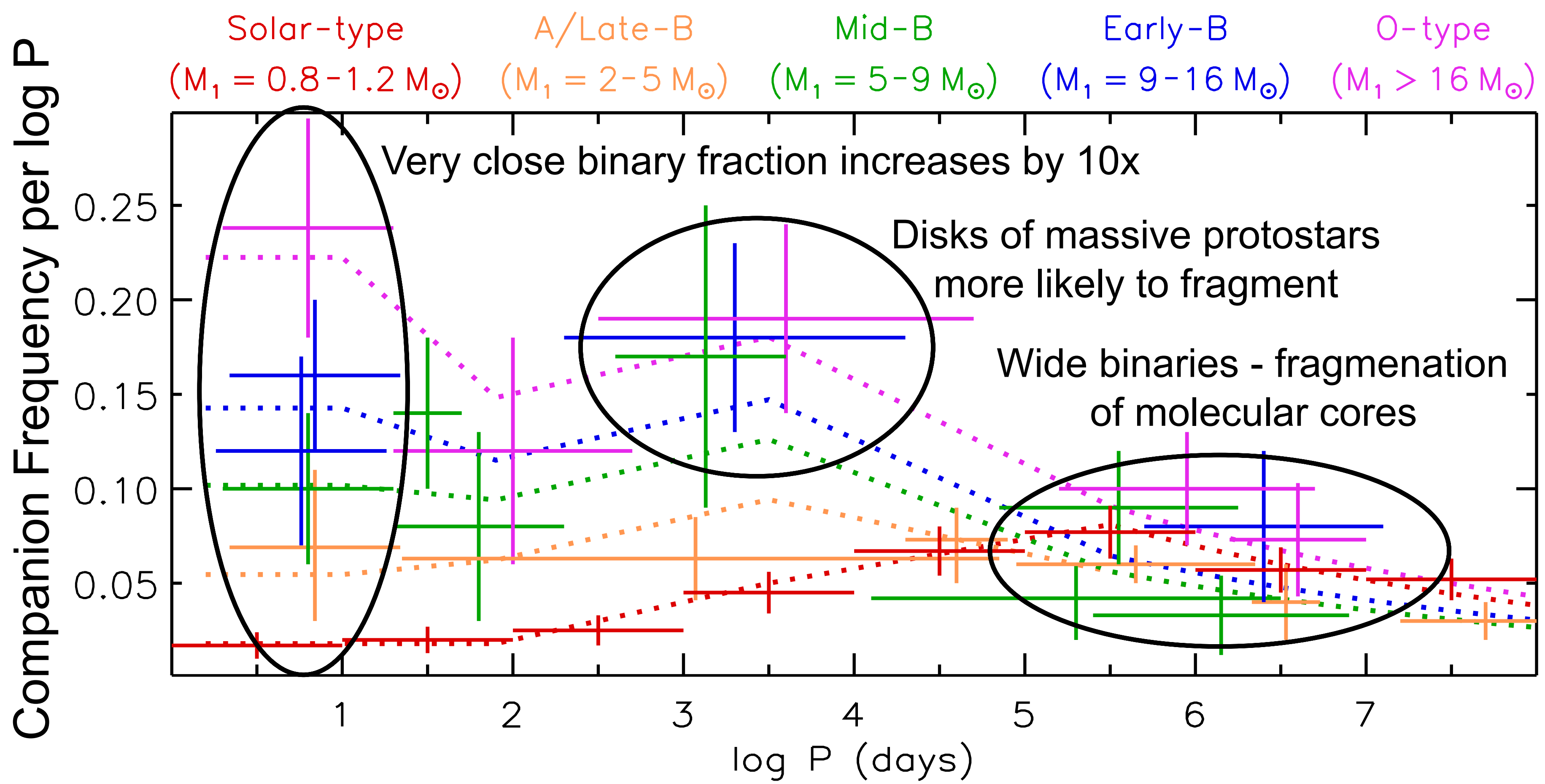
3) VARSTAGA – Variability Survey of M33 (4 min.)
   - A) Helium Stars (SN Ib/c; reionization)
   - B) Distance to ~1.5% Precision
   - C) FU Orionis Outbursts

Mind your Ps and Qs:

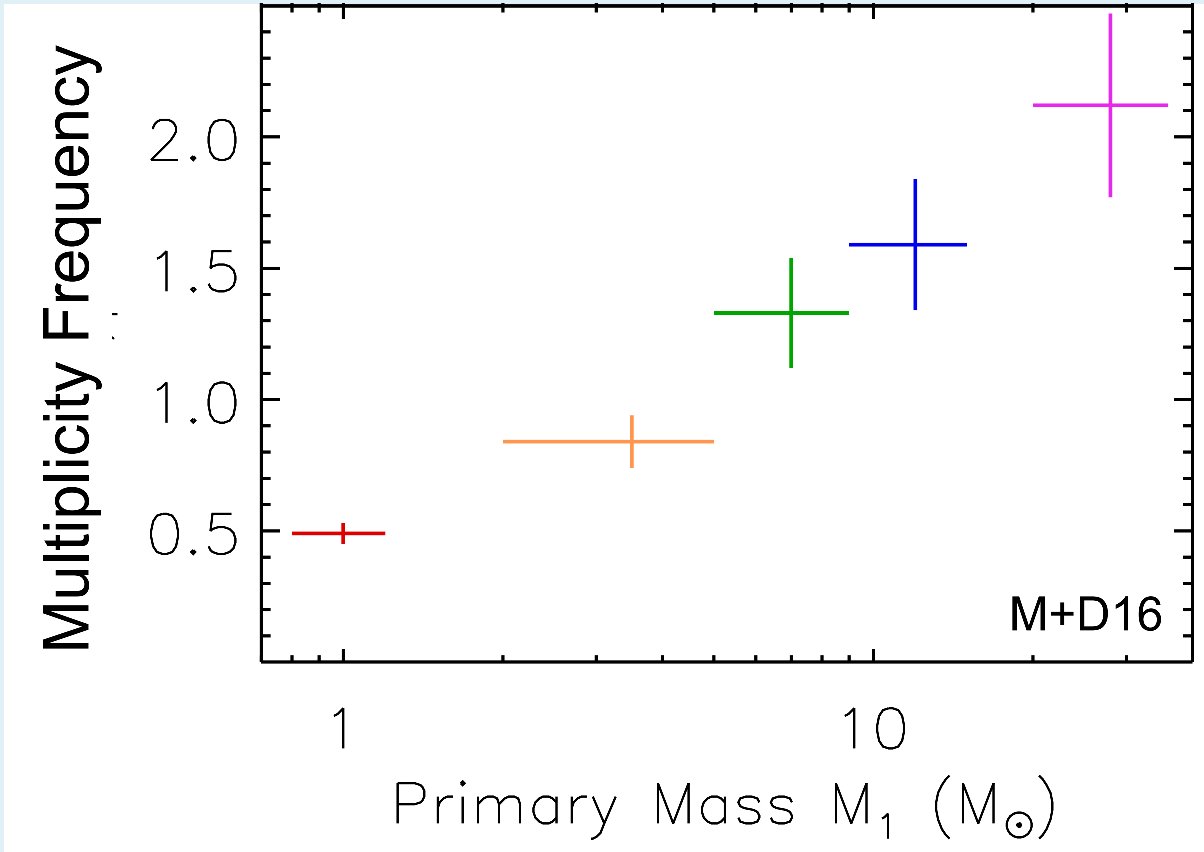
the Interrelation between Binary Orbital Periods P and Mass Ratios Q

(Moe & Di Stefano 2016; M+D16; arXiv-1606.05347)

$$f(M_1, P, q, e) \neq f(M_1) \times f(P) \times f(q) \times f(e)$$



3 out of 2 stars are in binaries !?!

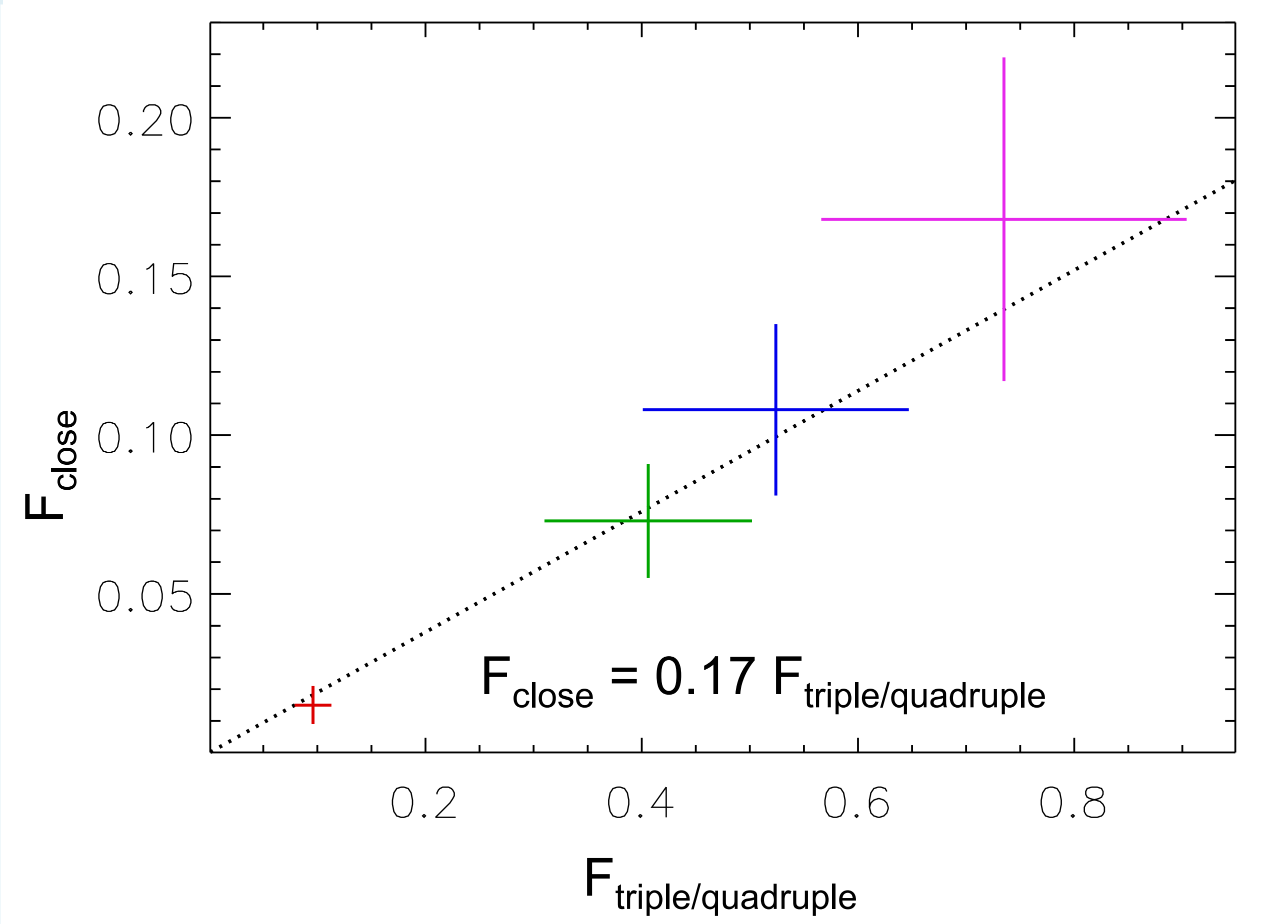


Solar-type primaries: Multiplicity Frequency = 0.48 ± 0.04;
~60% single; ~30% binary; ~10% triple/quadruple

O-type primaries: Multiplicity Frequency = 2.1 ± 0.3;
<10% single; ~20% binary; ~75% triple/quadruple

Close binary fraction (P = 2 - 6 days) vs. triple/quadruple fraction (M+D16)

Solar-type primaries:
(80-90)% of
close binaries
have outer tertiaries
(Tokovinin+2006)

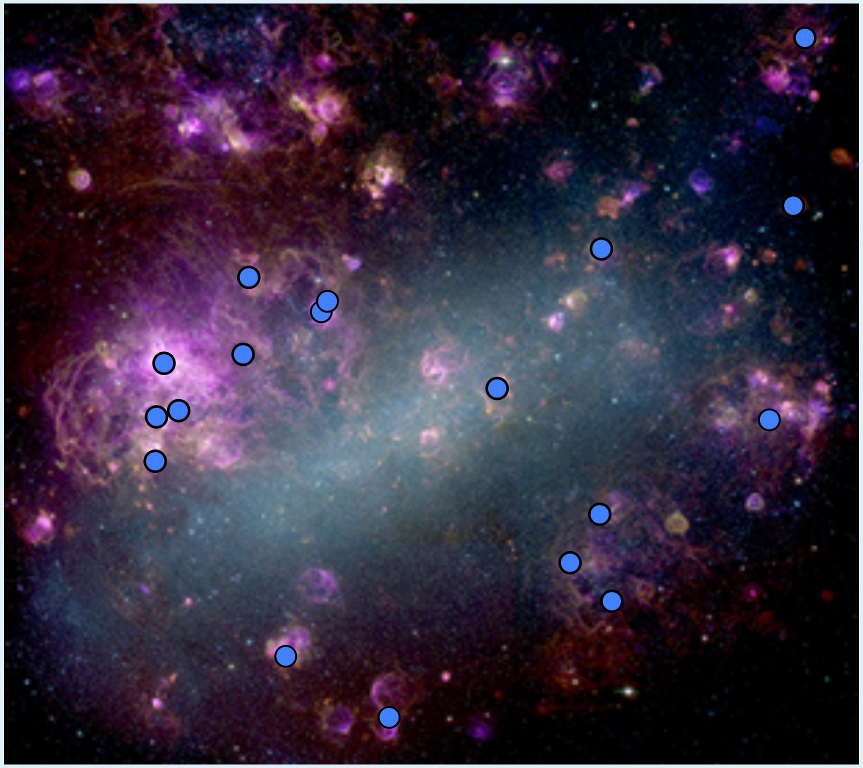


1. Nearly directly proportional

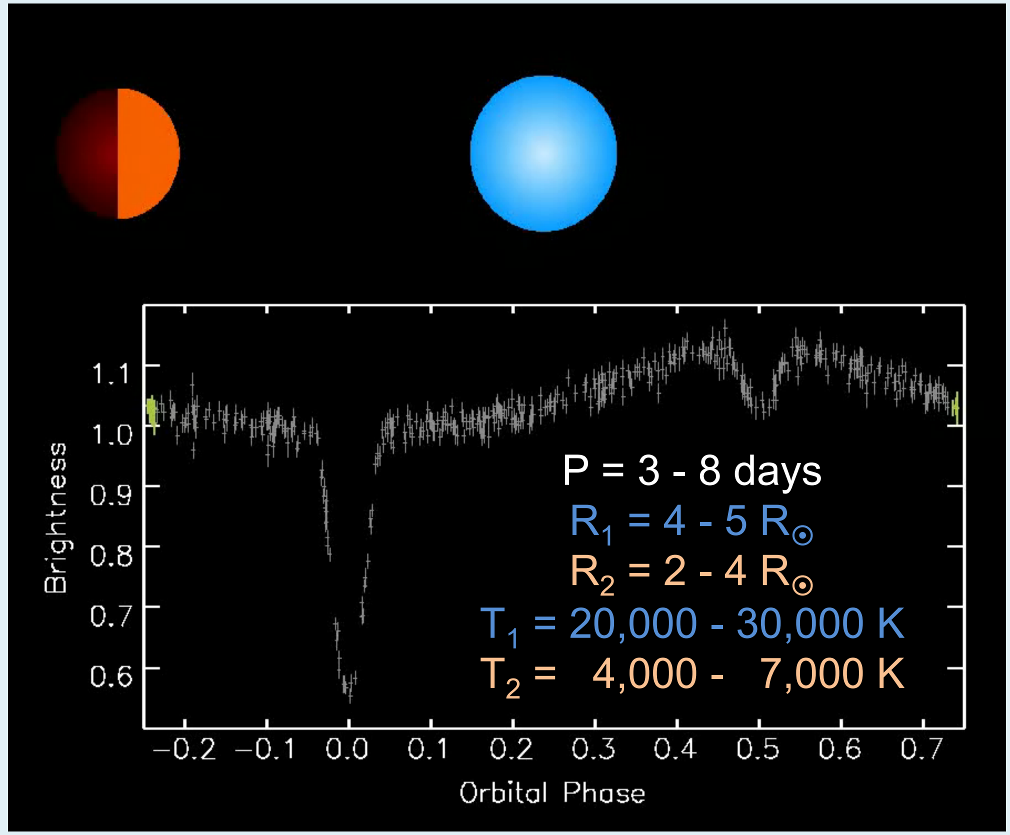
2. One in six triples have P_{inner} = 2 - 6 days

3. Independent of primary mass;
larger companion frequency at intermediate P + dynamics in triples
= larger close binary fraction

A New Class of Nascent Eclipsing Binaries (M+D15b)



Narrow-band color image of Large Magellanic Cloud

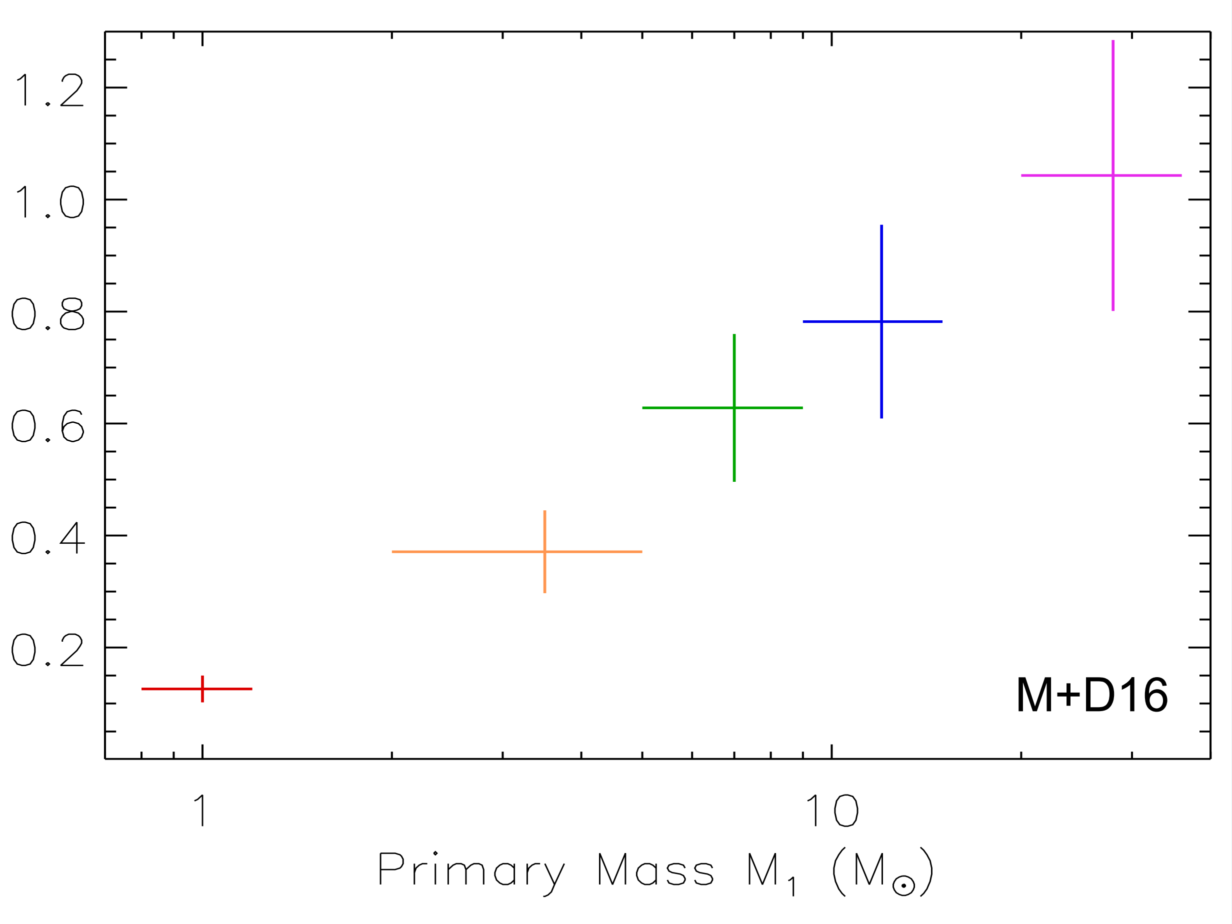


Discovered 18 MS + pre-MS EBs exhibiting **reflection effects**:
M_1 = 7 - 16 $M_\odot$, M_2 = 0.8 - 2.4 $M_\odot$, and τ = 1 - 8 Myr.

Observing run with high-resolution MIKE spectrograph on Magellan / Clay 6.5m in 2 days!

Binary Star Evolution via Roche-lobe Overflow (RLOF)

Frequency of companions with log P (days) < 3.7 (a < 10 AU)



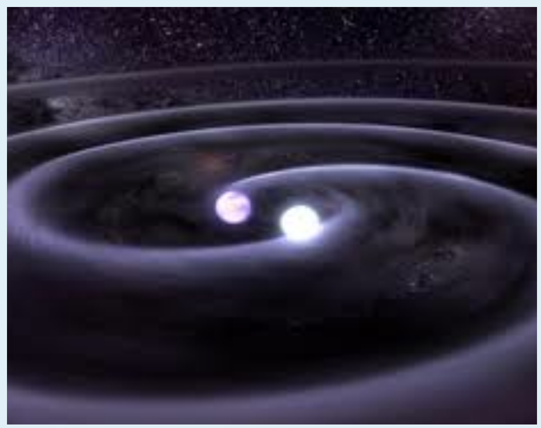
- Only 13% of solar-type primaries will interact via RLOF
- Essentially all O-type primaries will experience RLOF
- (5-20)% of O-type primaries are in compact triples with a_{outer} < 10 AU

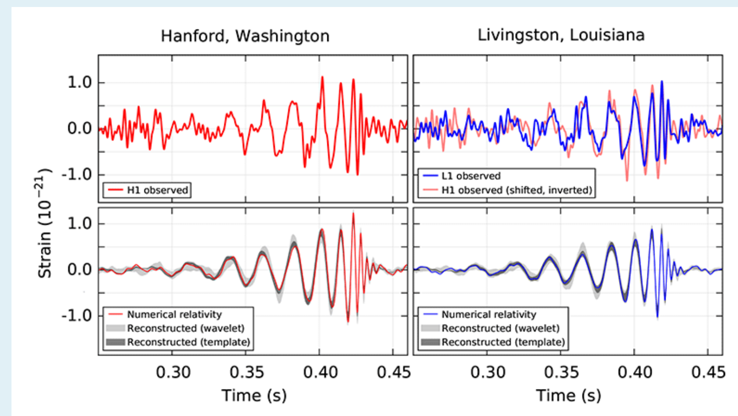
Initial Conditions for Population Synthesis of Binary Star Evolution

$$f(M_1, P, q, e) \neq f(M_1) \times f(P) \times f(q) \times f(e)$$

Density in certain pockets of this parameter space are up to **50 times** different than that assumed using canonical initial conditions!

Important implications for predicted rates and properties of:

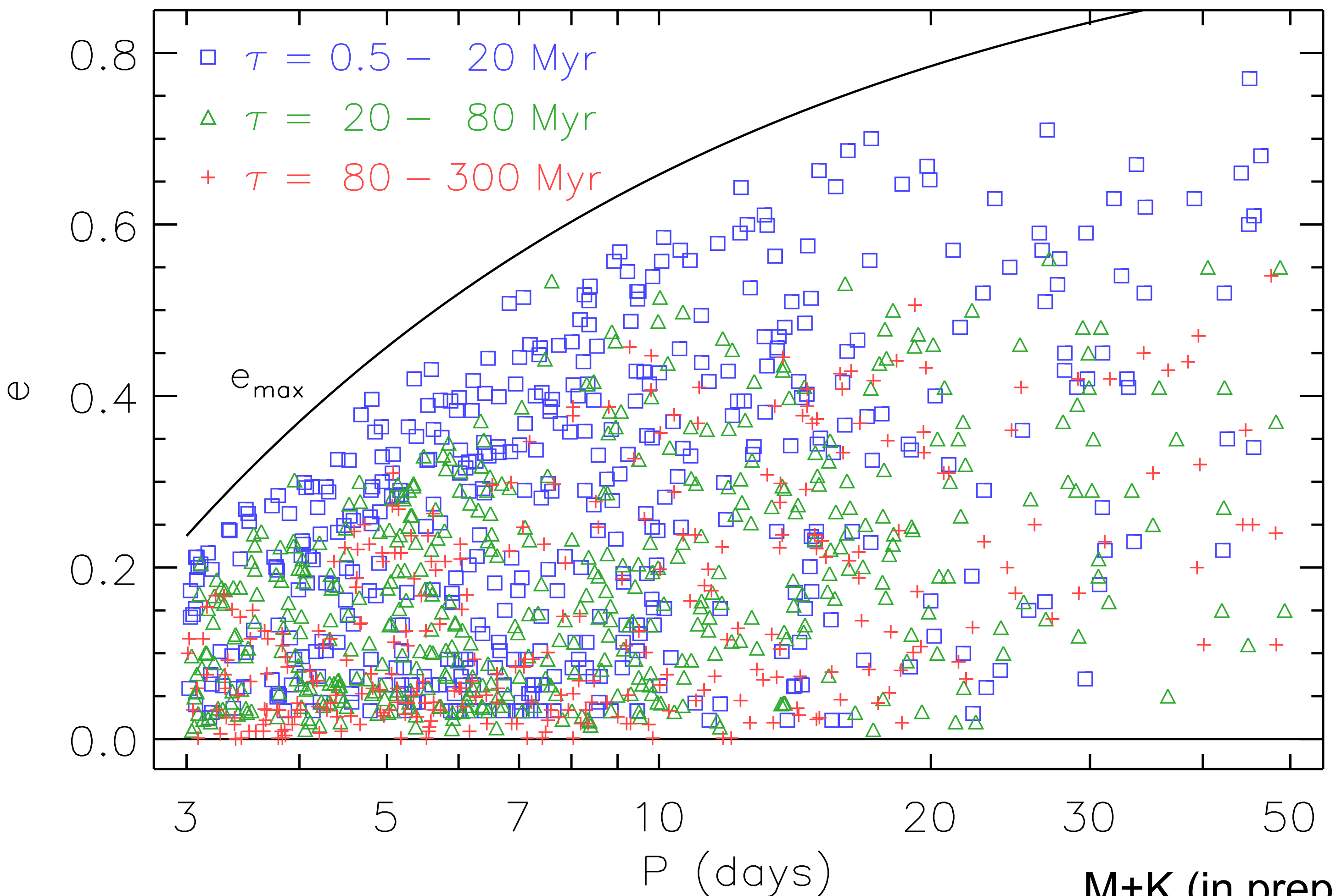




Type Ia supernovae:
single degenerate & double degenerate
(Moe et al., in prep.)

Compact object mergers & sources of gravitational waves detectable by advanced LIGO
(Klencki, Belczynski, Moe et al., in prep.)

Research with Summer 2016 Undergraduate Intern



M+K (in prep.)

Aaron Kilgallon

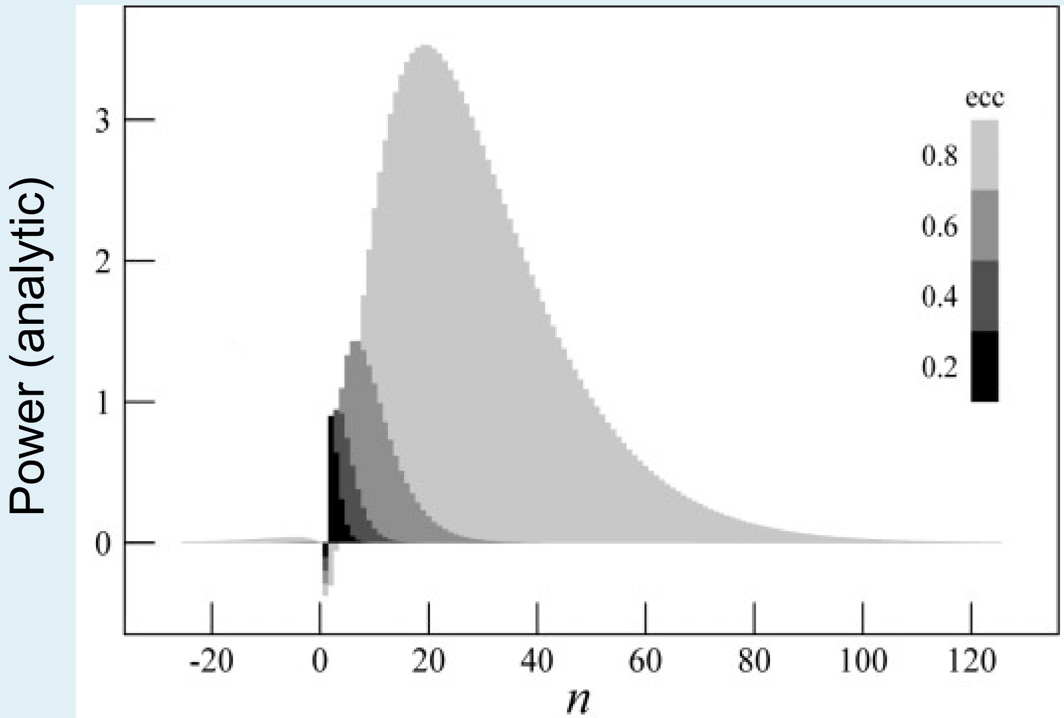
- Measured parameters of 2,100 early-type MS (M_1 = 3 - 20 $M_\odot$) detached EBs in LMC
- Massive close binaries are born with e = (0.5 - 0.9) e_{max}; dynamical formation process
- For P = 20 days, timescale to tidally evolve from e = 0.7 to e = 0.4 is ~10^4 times faster than that predicted from linear theory of dynamical tides (K+M, in prep.)

Tidal Evolution in Massive Binaries (K+M, in prep.)

Aaron Kilgallon

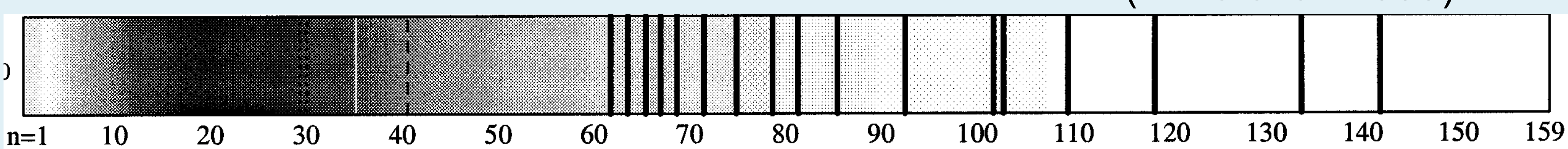
Most binary population synthesis studies assume tidal energy in massive binaries is dissipated solely through the n = 2 mode of dynamical oscillations

At large e > 0.5, however, higher-order modes dominate and can lead to resonance locking

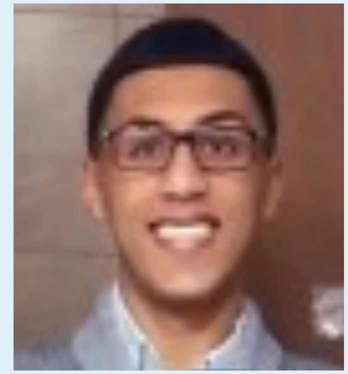


Incorporating the observed EB sample and a MCMC method, Aaron fitted a general formula $\dot{e}(M_1, P, q, e, \tau)$ to describe dynamical tides in massive binaries (K+M, in prep.)

Numerical power spectrum for e = 0.8 (Witte et al. 1999)



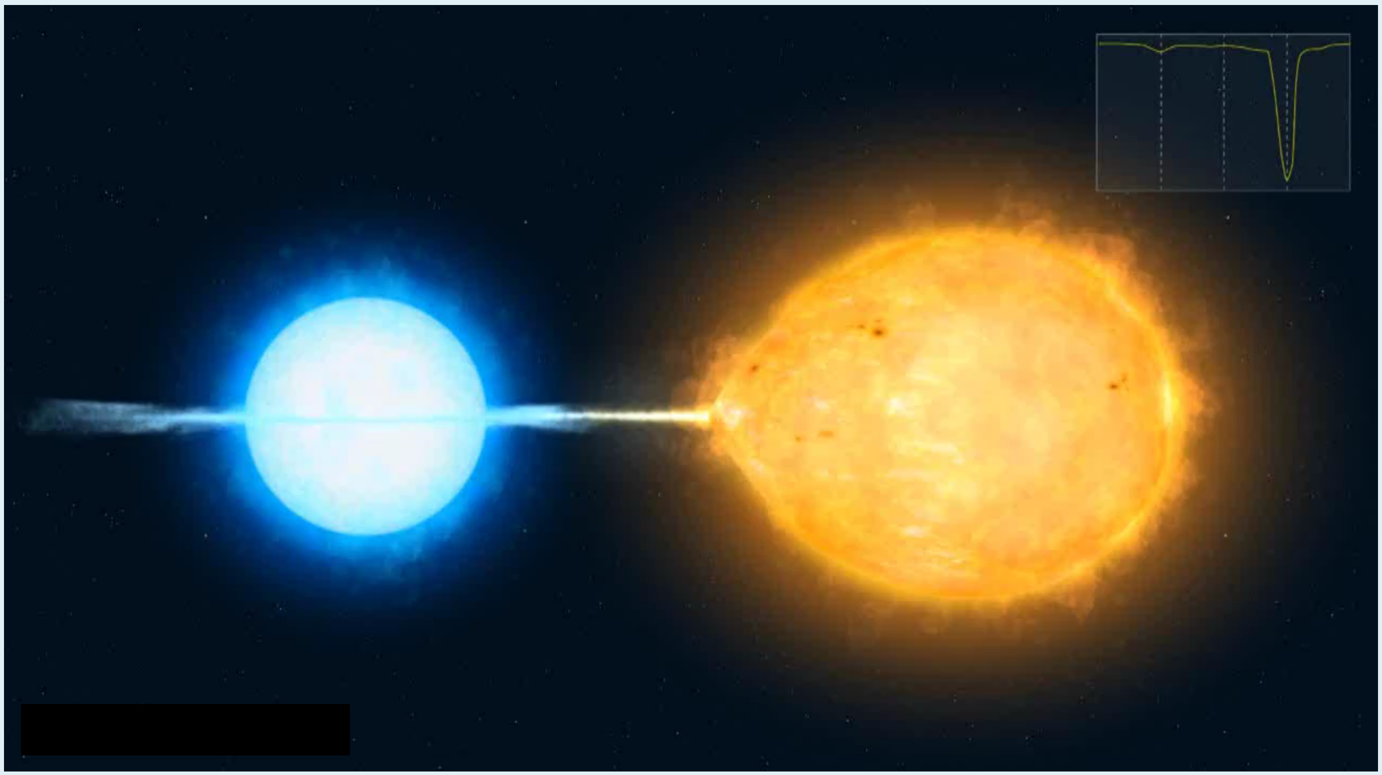
Research with 2016-17 Academic Year Undergraduate Intern



Qasim Mahmood

By fitting detailed models to the observed light curves,
Qasim is measuring the physical properties of ~400 Algol EBs in LMC

Algols: slowly mass-transferring binaries
that have already inverted their mass ratios $M_{accretor} > M_{donor}$



[redacted]

With large sample, we can empirically measure $q_{critical}$ and $\beta = \Delta M_{accretor}/\Delta M_{donor}$

VARSTAGA: VARiability Survey of the TriAngulum GAlaxy (recently proposed)

90Prime Imager on Bok Telescope
- 1.2° x 1.2° FOV
- Get M33 w/ one pointing

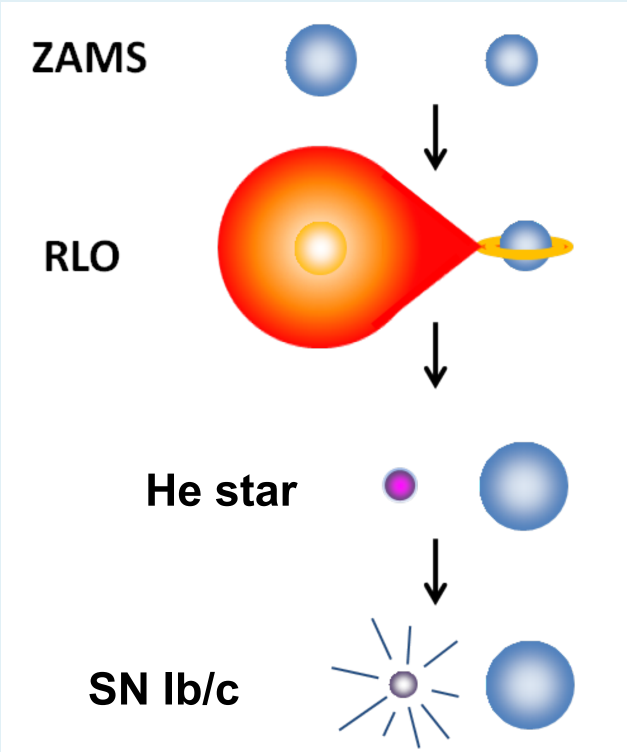
Cadence
- 200 - 250 epochs
- 3 semesters (17A,17B,18A)
- Hourly, daily, & weekly intervals

Bands
- 85% in g
- 9% in i
- 3% each in u & r
- Possibly J & K with UKIRT

Exposures for “1 epoch”
- 10 dithered 6-minute exposures
- Longer in ancillary bands
- σ = 0.02 mag at g = 22 mag
- 5σ depth of g = 25 mag

Estimated Yields (1.0” - 2.0” seeing)
- ~2 million resolved stars
- ~60,000 variables

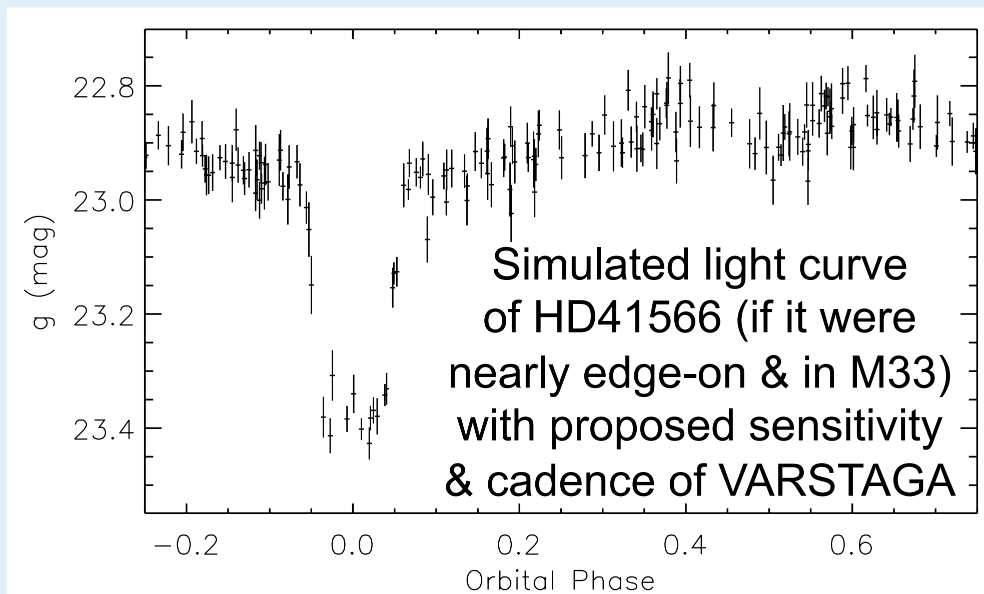
Primary Goal #1: B-type MS + Helium Star Eclipsing Binaries



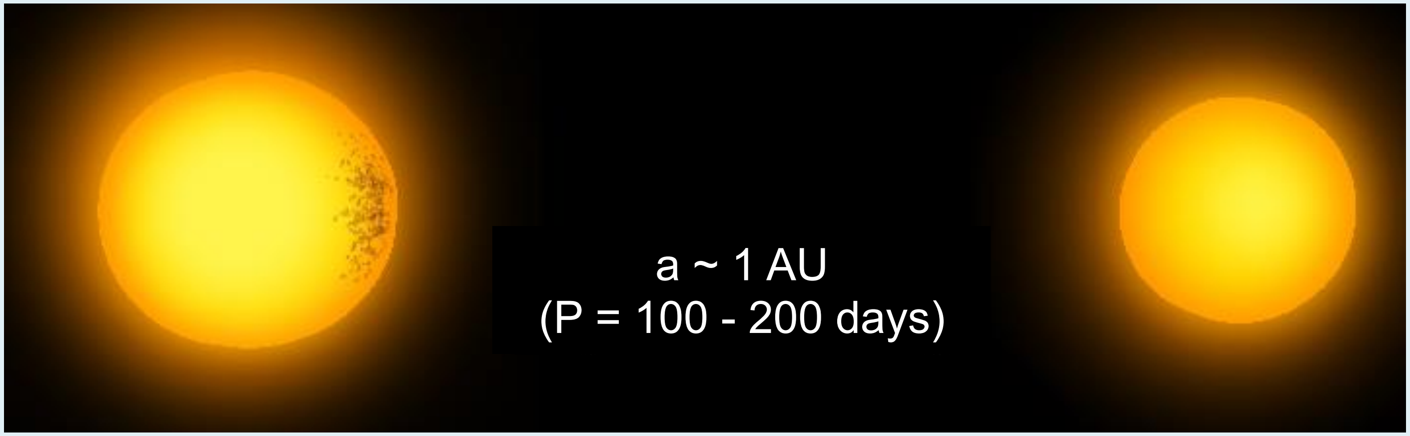
- Putative progenitors of Type Ib/c supernovae
- Hot He stars (T_{eff} ~ 50,000 - 120,000 K) produce hard UV photons and may be a major contributor to the epoch of reioniziation

- Only 1 probable candidate in Milky Way: HD41566 (Groh et al. 2008):
  - P = 1.6 days
  - Nearly face-on orbit
  - M_{He} = 4 $M_{\odot}$; T_{He} = 60,000 K; R_{He} = 0.9 $R_{\odot}$
  - M_B = 5 $M_{\odot}$; T_B = 16,000 K; R_B = 3.5 $R_{\odot}$

Will identify 10 - 100 B-type MS + He Star EBs in M33 with VARSTAGA



Primary Goal #2: Detached EBs with two G-type giant/supergiant components



Bolometric corrections & limb darkening coefficients
of G-type stars known to <1% precision.

By combining photometric light curves and spectroscopic radial velocity measurements of 8 yellow giant + giant detached EBs in the LMC, Pietrzynski et al. (2012) measured a geometrical distance to the LMC accurate to ~1.5%.

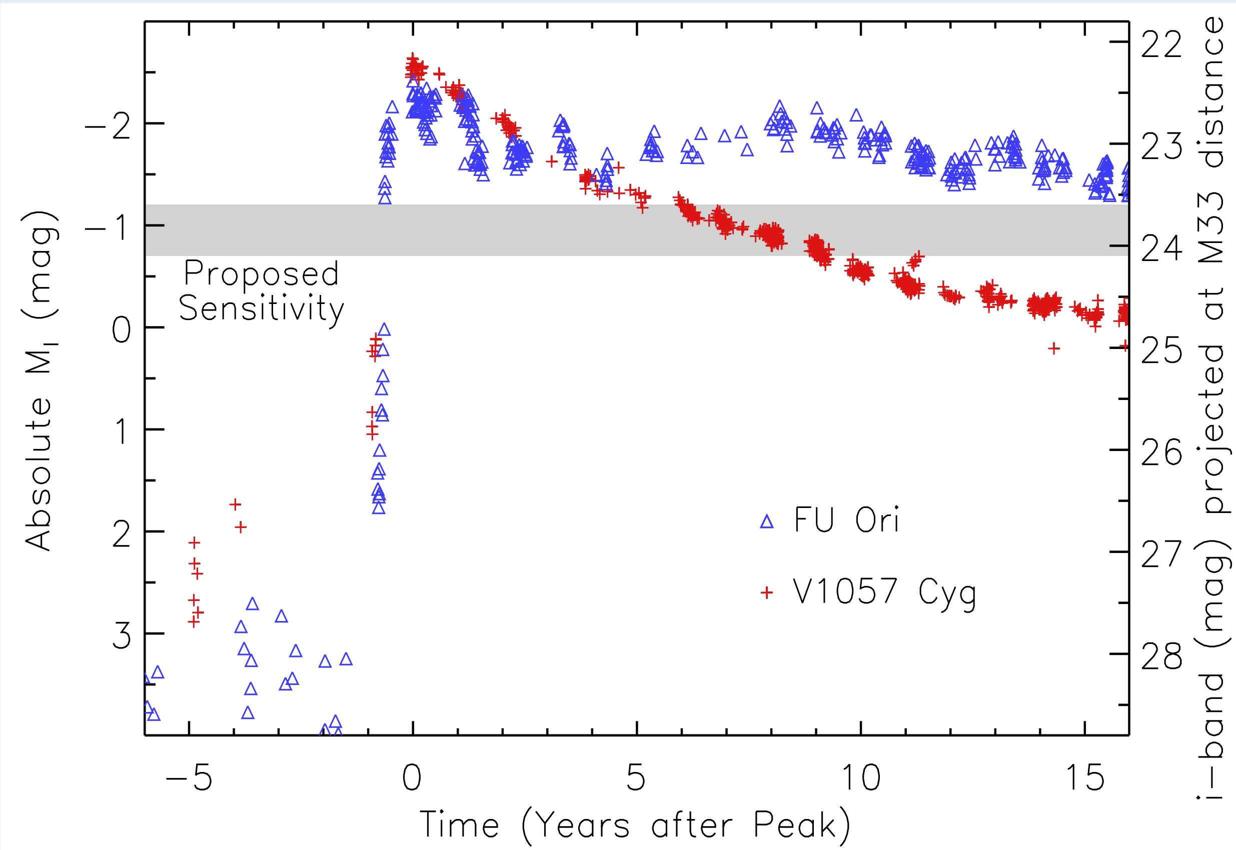
VARSTAGA will find 10 - 20 such EBs with V < 21 mag in M33 suitable for follow-up spectroscopic distance measurements.

VARSTAGA will also more fully characterize ~3,000 Cepheids in M33 with ugriJK monitoring, allowing a measurement of H_o to < 2% precision.

Primary Goal #3: FU Orionis Outburts

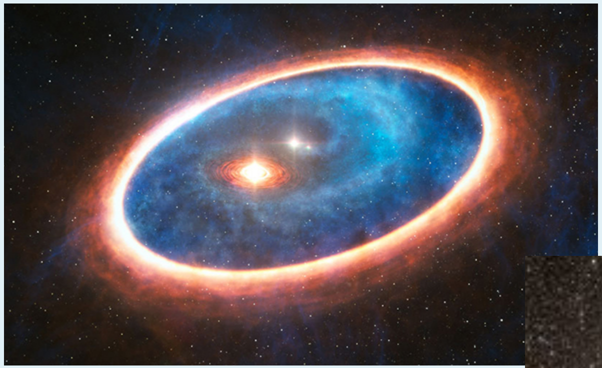
FU Ori Systems: young T Tauri stars (τ < 2 Myr)
brighten by 4 - 6 mag in 6 - 12 months
take decades, possibly centuries, to return to quiescence

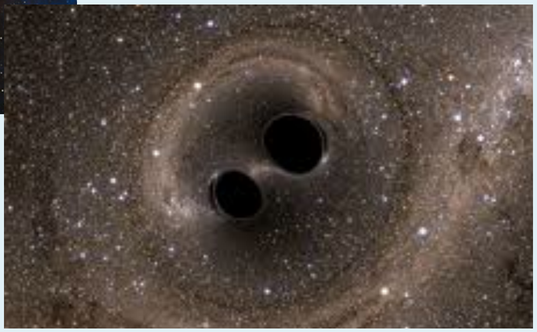
Outbursts thought to be due to disk instabilities, BUT mechanism debated:
- recurrent thermal disk instabilities (Hartmann & Kenyon 1996)
- companion dynamically triggers disk instability (Reipurth & Apsin 2004)



VARSTAGA will
detect 10 – 20 outbursts
(single star paradigm)
or 1 – 2 outbursts
(binary star paradigm)

Conclusions





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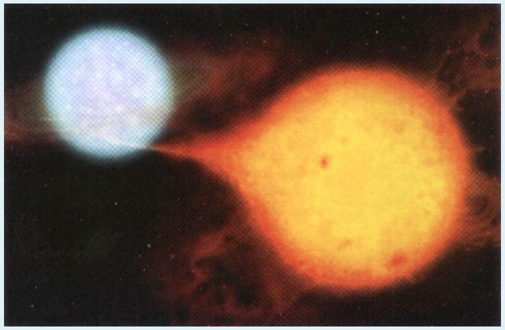

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