BINARIES IN MASSIVE STAR FORMATION

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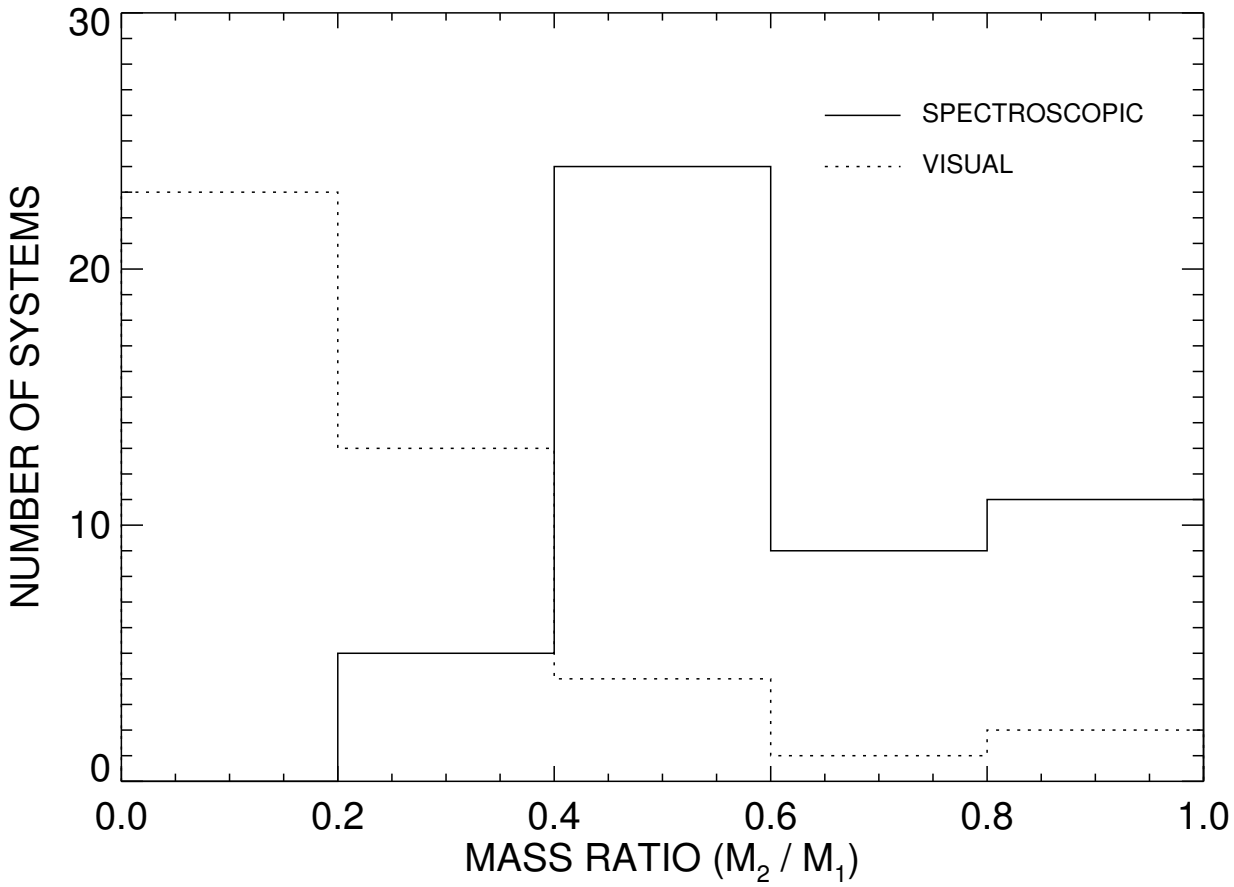
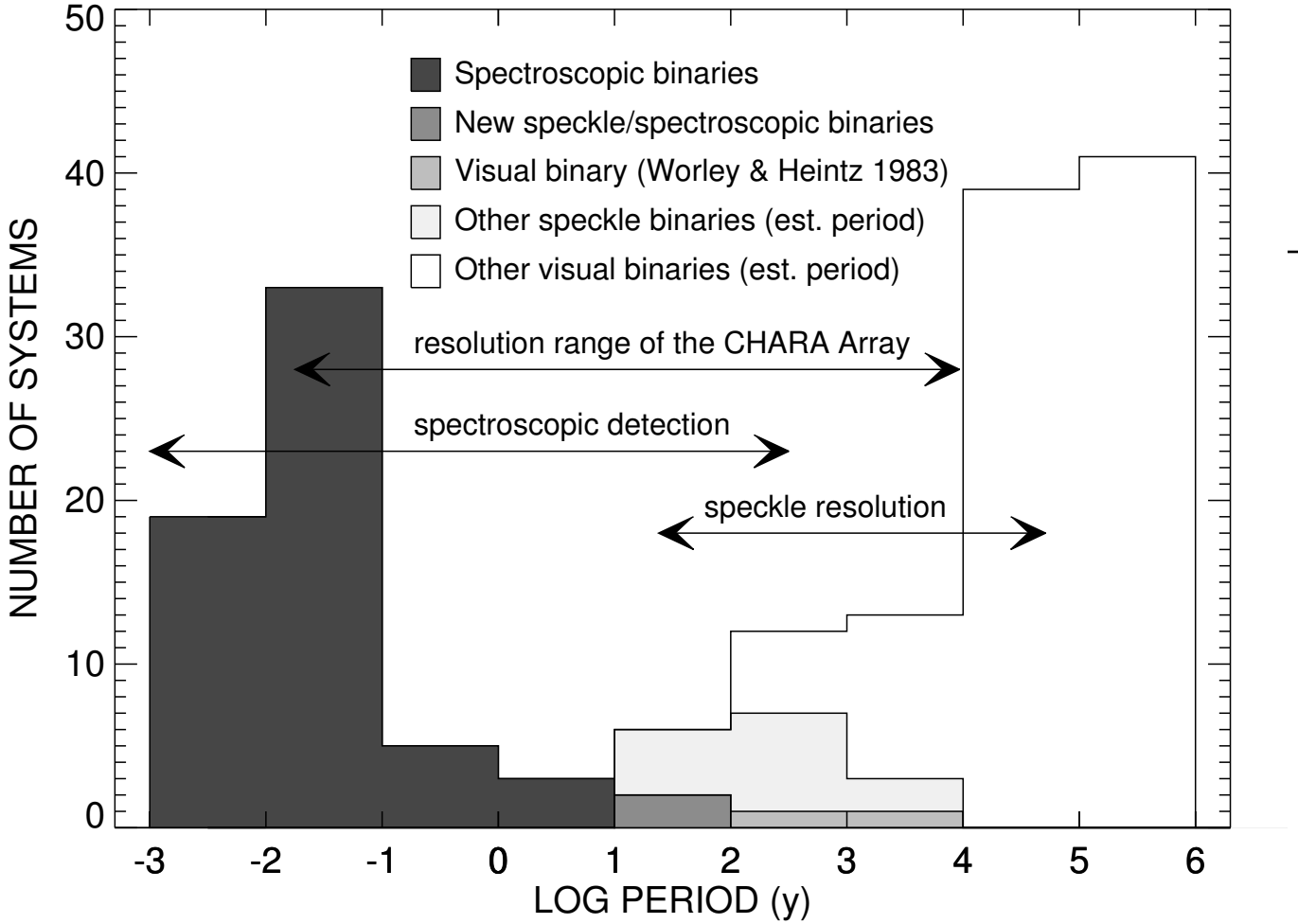
- Introduction: O-type stars
- Detecting binaries
- Implications for massive star formation

Introduction:
Binaries among massive O-type stars

- Speckle survey of Galactic O-stars:
  sep.> 30 mas, Δm< 3 (Mason et al. 1998)
- Included published results on
  spectroscopic/visual binaries
- Binaries are common:
  >59% have companions among
  O-stars in clusters and associations
  (fewer in field and runaway stars)
- More binaries than among lower mass stars
  (Orion - Preibisch et al. 1999)



- Companion masses:
  similar to IMF sampling for wide binaries;
  more comparable masses in close binaries



- Period gap due to observational bias
- If distribution is flat in log *P*, then <u>most O-stars have companions</u>

Detecting binaries

- Eclipsing binaries
- Spectroscopic binaries
- Spectro-astrometry
- Long baseline interferometry
- Space interferometry
- Speckle interferometry
- Adaptive optics imaging
- Accounting for observational bias

Detecting binaries: Orbital flux variations

- Due to eclipses and tidal distortion
- Find mainly close binaries where the stellar radii are not too much smaller than the Roche radii
- Hilditch et al. (2005) survey of 50 eclipsing binaries of OB stars in SMC (from OGLE)
- Survey by Massey et al. now underway to find eclipsing binaries among ten dense star clusters (Galaxy, LMC, SMC)
- Found 107 young, O-star binaries; tenfold number increase (Gies 2003)

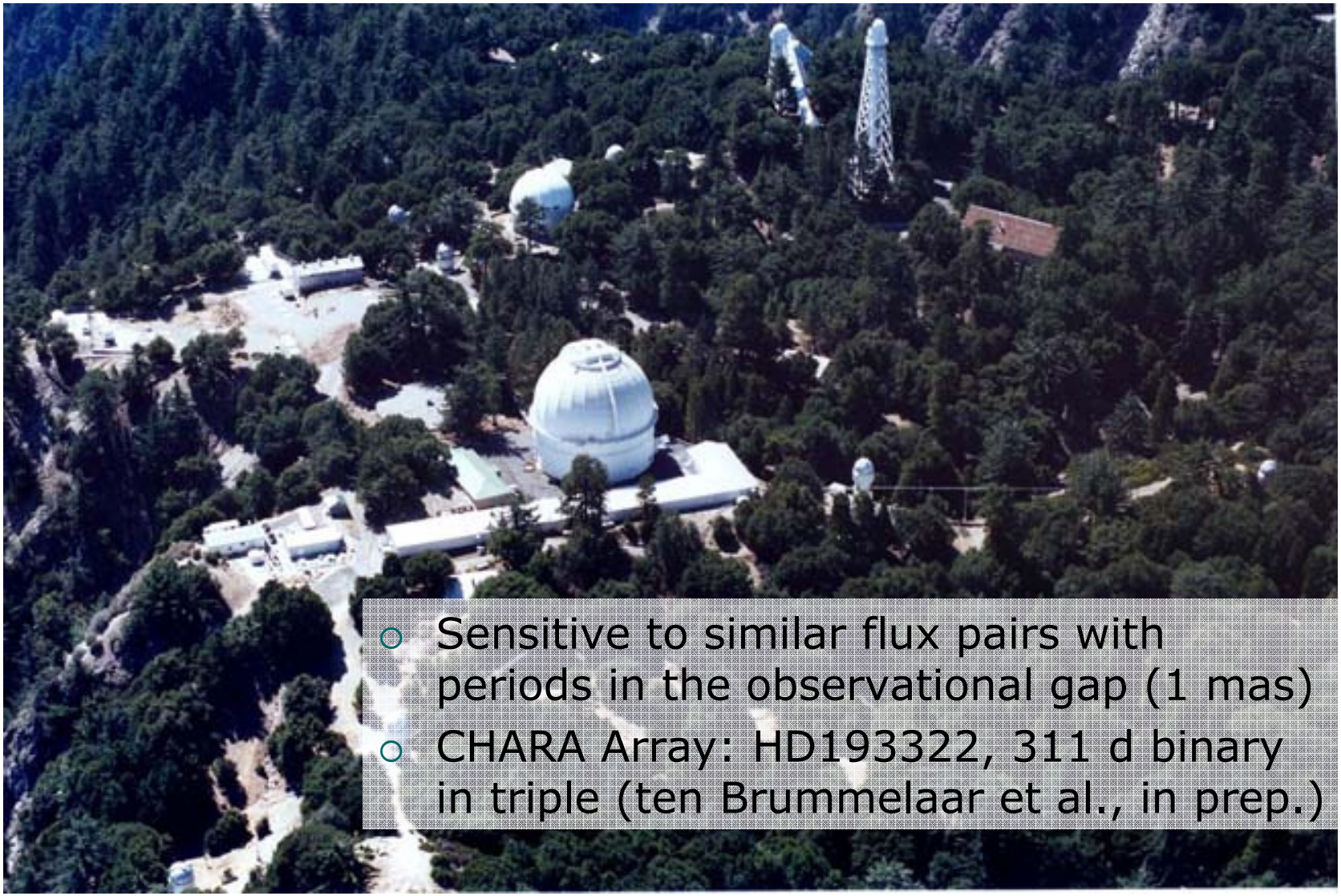
Detecting binaries: Radial velocity variations

- Measurements difficult because of stellar rotation, pulsation, emission
- Need many observations and long term programs
- Favors close, massive binaries with orbital planes close to line of sight
- Cas OB6: 50±19% spectroscopic binary (Hillwig et al. 2006)
- NGC 6231: 63±20% spectroscopic binary (Sana et al. 2007)

Detecting binaries: Spectroastrometry

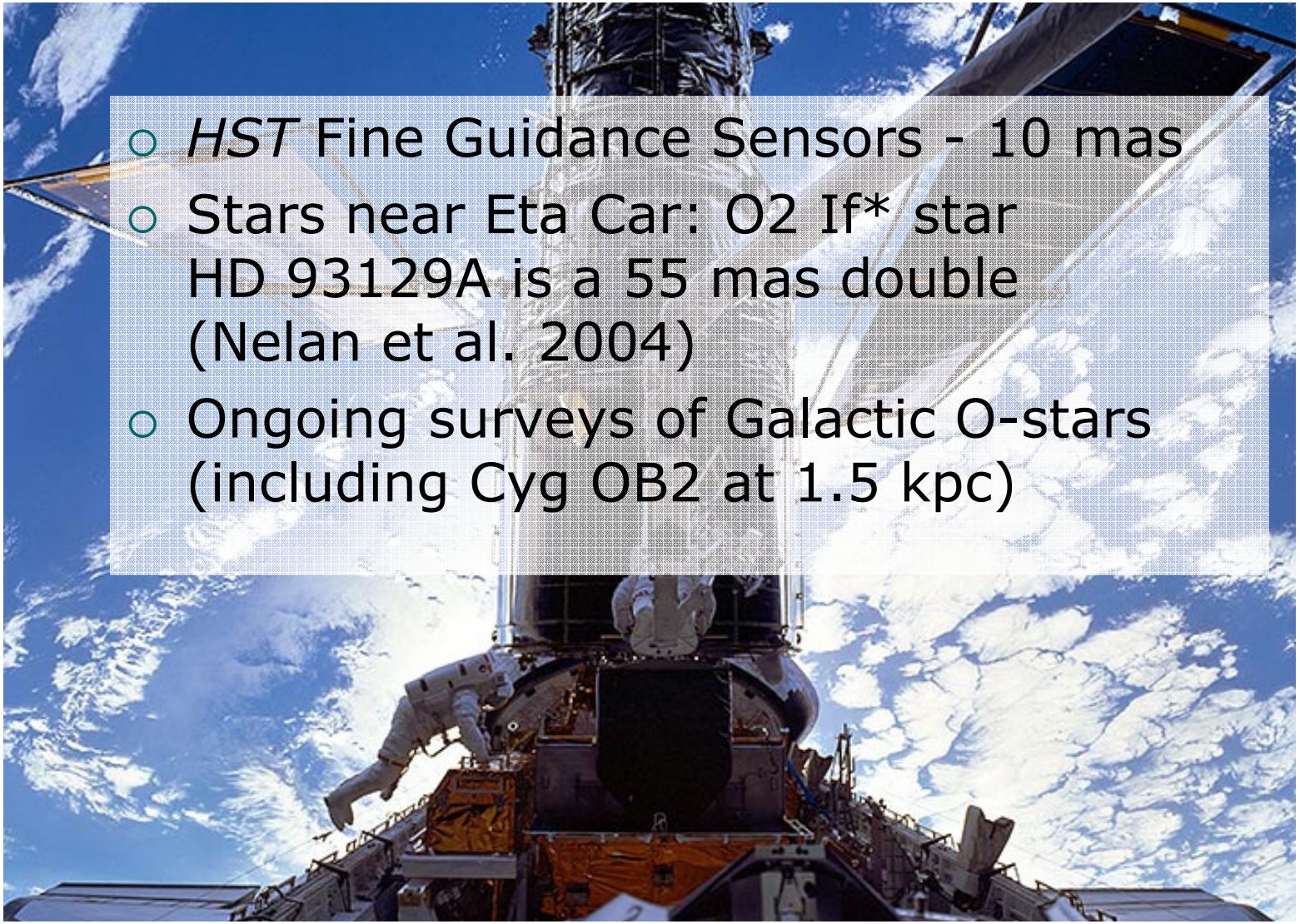
- Search for small variations in spatial profile of spectra to find sub-PSF separated binaries (~mas)
- Sensitive to binaries with differing spectral features
- Intermediate mass Herbig Ae/Be stars: 70% binary frequency (Oudmaijer et al. 2006)

Detecting binaries: Long baseline interferometry



- Sensitive to similar flux pairs with periods in the observational gap (1 mas)
- CHARA Array: HD193322, 311 d binary in triple (ten Brummelaar et al., in prep.)

Detecting binaries: Space interferometry



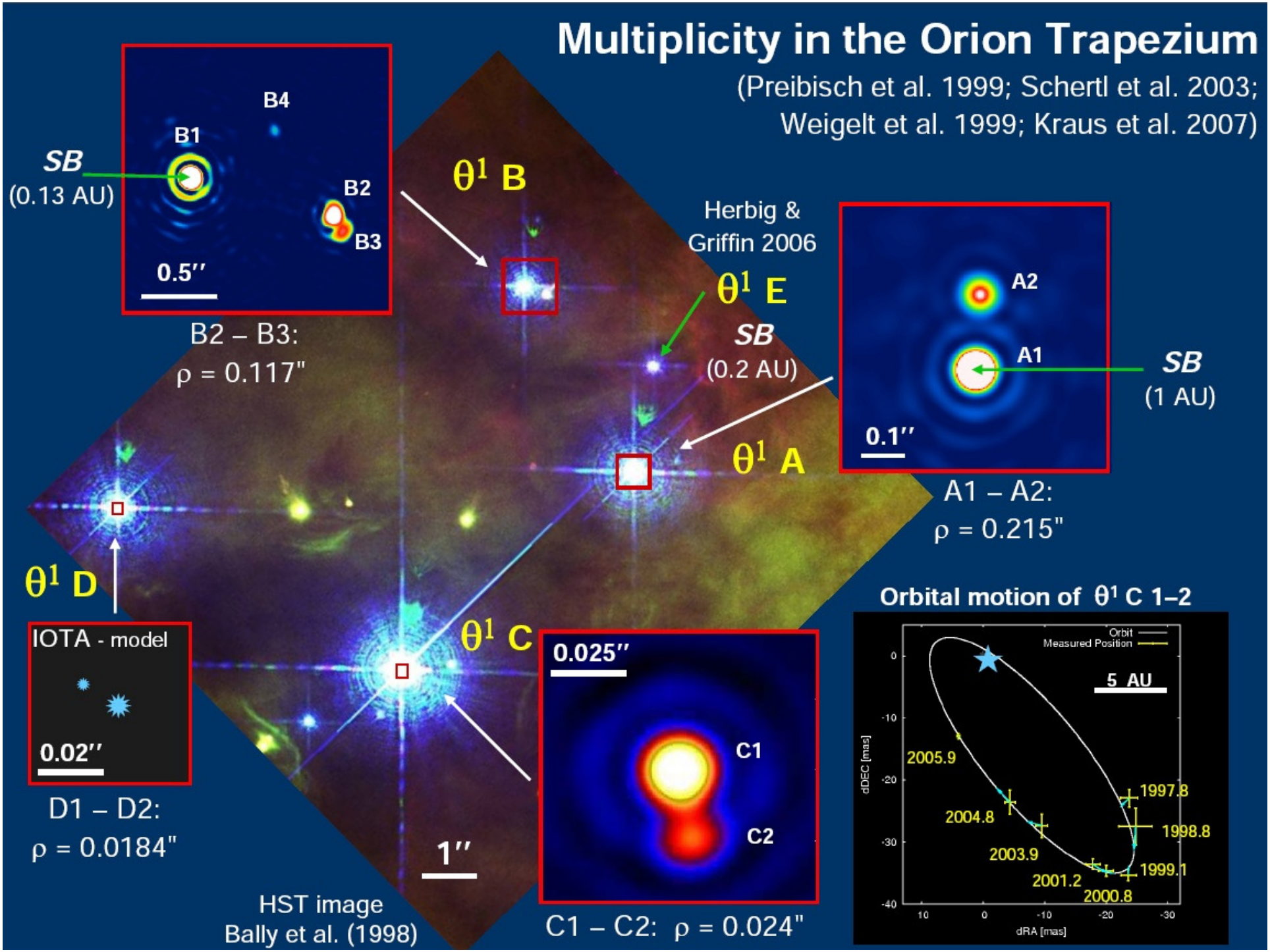
- *HST* Fine Guidance Sensors - 10 mas
- Stars near Eta Car: O2 If* star HD 93129A is a 55 mas double (Nelan et al. 2004)
- Ongoing surveys of Galactic O-stars (including Cyg OB2 at 1.5 kpc)

Detecting binaries: Speckle interferometry

- Long period, similar flux pairs (30 mas)
- New survey (10 years later) by Mason et al. finds 23% visual binary frequency (14 new binaries)
- Studies of Orion (nearest massive star complex) show high incidence of binaries and multiples among the high mass stars (Schertl et al. 2003; Kraus et al. 2007) compared to the low mass stars (Köhler et al. 2006)

Multiplicity in the Orion Trapezium

(Preibisch et al. 1999; Schertl et al. 2003;
Weigelt et al. 1999; Kraus et al. 2007)



Detecting binaries: Direct and adaptive optics imaging

- Select long period and potentially faint companions (best nearby)
- Difficult to distinguish physical companions from field stars at faint limit ($\Delta m > 8$)
- NGC6611 survey (Duchêne et al. 2001): >18% binary frequency with more than half with low mass companions ($q=M_2/M_1<0.2$)

Detecting binaries: Direct and adaptive optics imaging

- B-star survey (70): 23±6% binary (*I*-band; Roberts et al. 2007)
- O-star survey (116): 29±5% binary (for delta $I<8$; Turner et al., in prep.)
- Cyg OB2 survey (8): 50±25% binary (Gemini North, NIRI/ALTAIR, *JHK*; Baines et al., in prep.)


Cyg OB2-22 (*K*-band)
B: O6 V((n)) A: O3 If*
1 arcsec

Detecting binaries: Combining results with biases

- All these methods select only certain kinds of binaries, so the total binary frequency remains unknown
- Kouwenhoven et al. (2007) developed Monte Carlo simulations of how observational programs of RV and AO measurements sample the binary population in Sco OB2 (intermediate mass sample at 130 pc distance)

Detecting binaries: Kouwenhoven et al. (2007) – Sco OB2

- Binary fraction is about 100% among A, B stars
- Semimajor axis distribution $\sim a^{-1}$ (or $\sim P^{-1}$, flat in log P increments)
- Mass ratio distribution $\sim (M_2/M_1)^{-0.4}$
- "… *multiplicity is a fundamental parameter in the star forming process*."

Implications for massive star formation

- Disk fragmentation & wide binaries
- Accretion onto a wide binary
- Disk-assisted capture
- Dynamical processes

Implications for massive star formation: General comments

- Binaries contain most of angular momentum from natal cloud
- Star formation processes lead to similar mass stars in close pairs
- Low mass stars do form in same vicinity as high mass ones
- Processes summarized in review by Zinnecker & Yorke (2007)

Implications for massive star formation: Disk fragmentation and wide binaries

- Kratter & Matzner (2006): massive star accretion disks more subject to fragmentation as mass increases
- Fragmentation results in low mass companion(s) in wide orbits
- Fragmentation starves accretion; may ultimately limit stars to <110 solar masses

Implications for massive star formation: Accretion onto a wide binary

- Bonnell & Bate (2005) show that accretion onto a wide binary causes the separation to decrease ($R_{bin} \sim M_{bin}^{-2}$)
- Simulations result in near equal mass pairs (as observed for close binaries)
- Krumholz & Thompson (2007) argue that protostars expand during deuterium shell burning; binaries will come into contact → mass transfer to equal masses in circular orbits

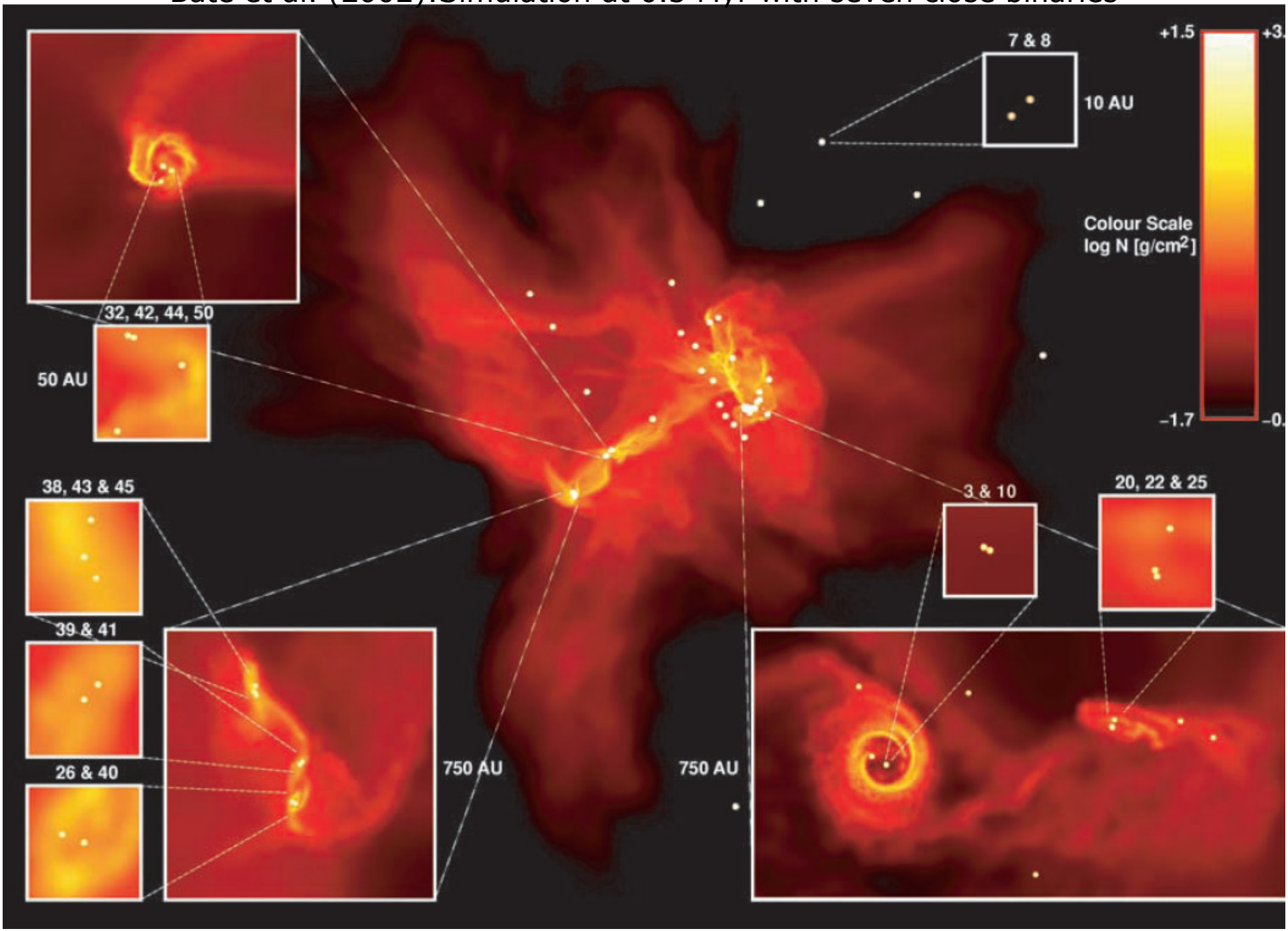
Implications for massive star formation: Disk-assisted capture

- Large accretion disk radius of protostar increases stellar interaction cross section
- Moeckel & Bally (2007) use *n*-body and SPH simulations of star-disk encounters
- Captures produce 30% binary frequency at 0.5 Myr for Orion-like parameters

Implications for massive star formation: Dynamical processes

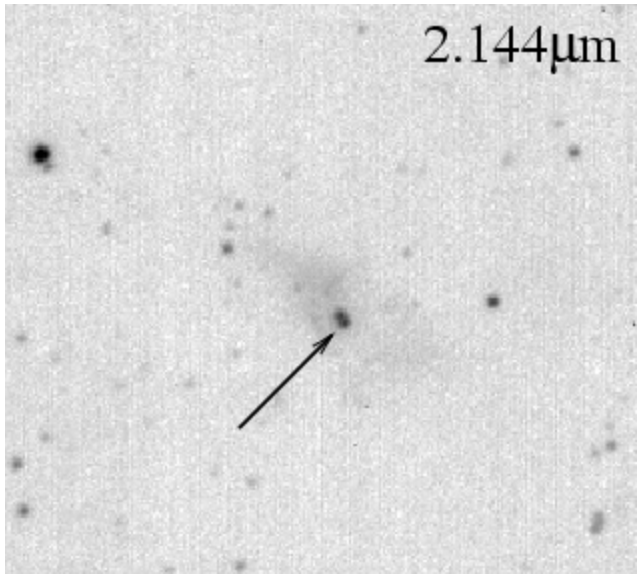
- Bate et al. (2002): 3D SPH models of collapse of gas-rich protoclusters
- Binary formation via 3-body capture
- Exchange reactions eject lower mass object to create massive pairs
- Subsequent interactions cause binary to "harden" (shrink), and energy is imparted to lower mass stars
- Usual result: massive binary with lower mass wide companion (often observed)

Bate et al. (2002):Simulation at 0.3 Myr with seven close binaries



Conclusions:
Binaries should be present near birth

- Near IR radial velocity studies of very young, embedded stars also indicate >20% spectroscopic binary (Apai et al. 2007)
- Resolution of central binary in ultracompact H II regions (G76.188+0.098; Comerón et al. 2006)



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