

# Southern Massive Stars at High Angular Resolution

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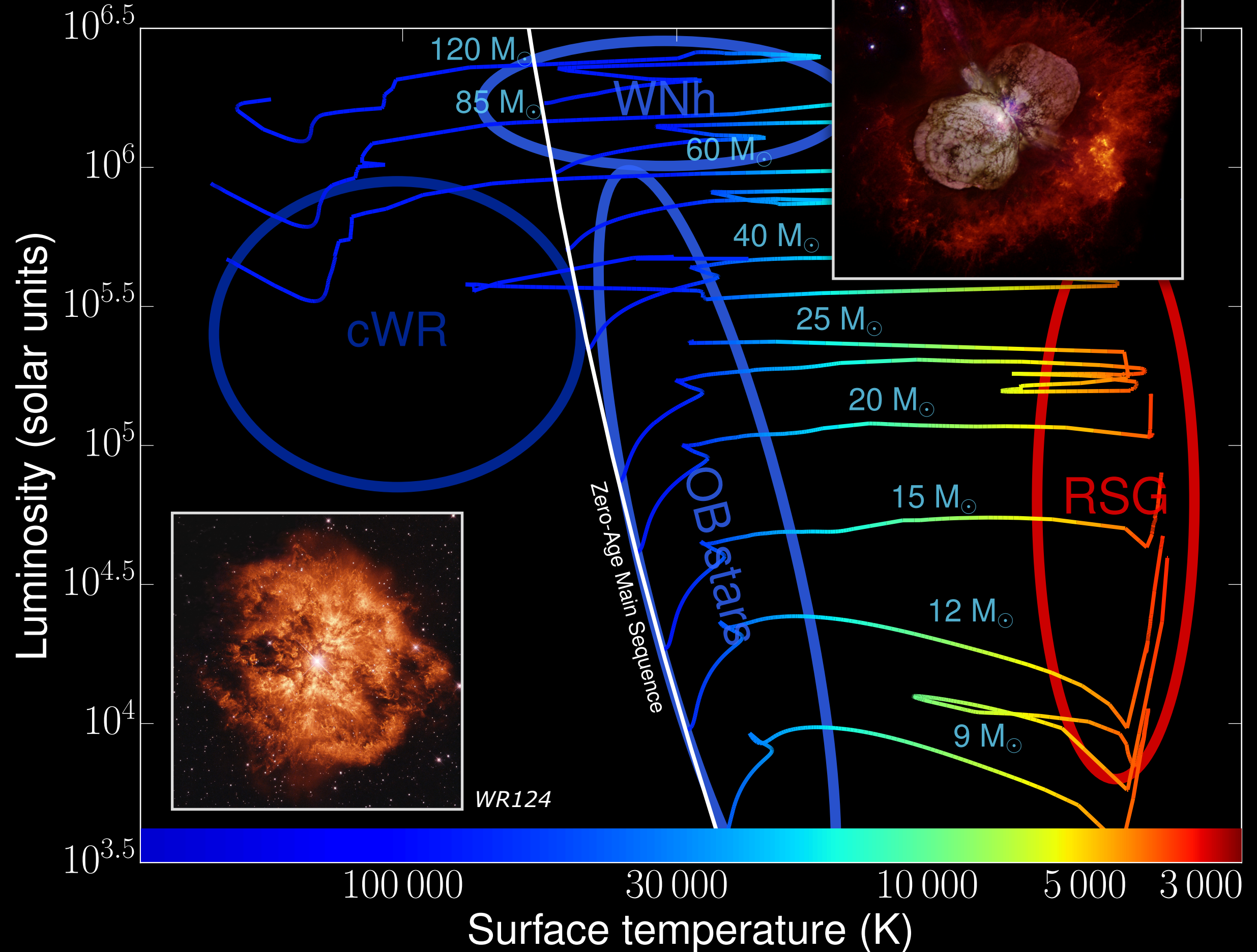
# Introduction - Massive Stars

- Rare and short-lived, but key players in the Universe
  - Strong impact on their surroundings
    - Dominant sources of momentum (stellar winds and SNe)
    - Strong ionising radiation
    - May halt or start star formation
    - Chemical enrichment: main producers of alpha-elements (C, O, etc.)
    - Re-ionization of the Universe
  - Evolution affected by:
    - Mass-loss
    - Rotation
    - Binary interactions
- } Metallicity



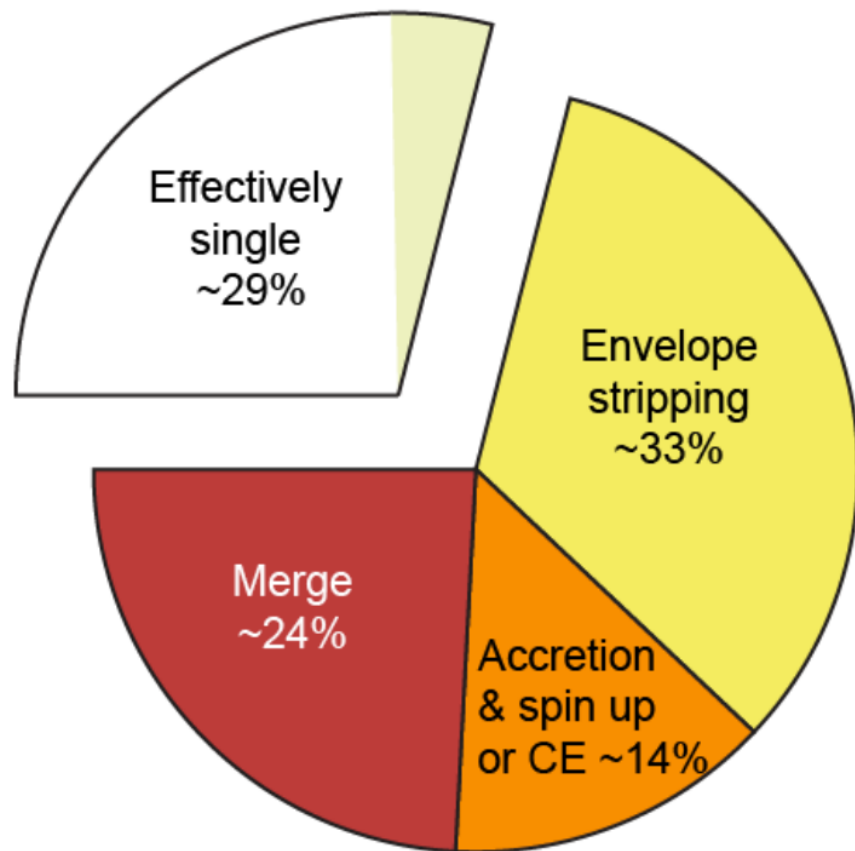


# Massive star evolution

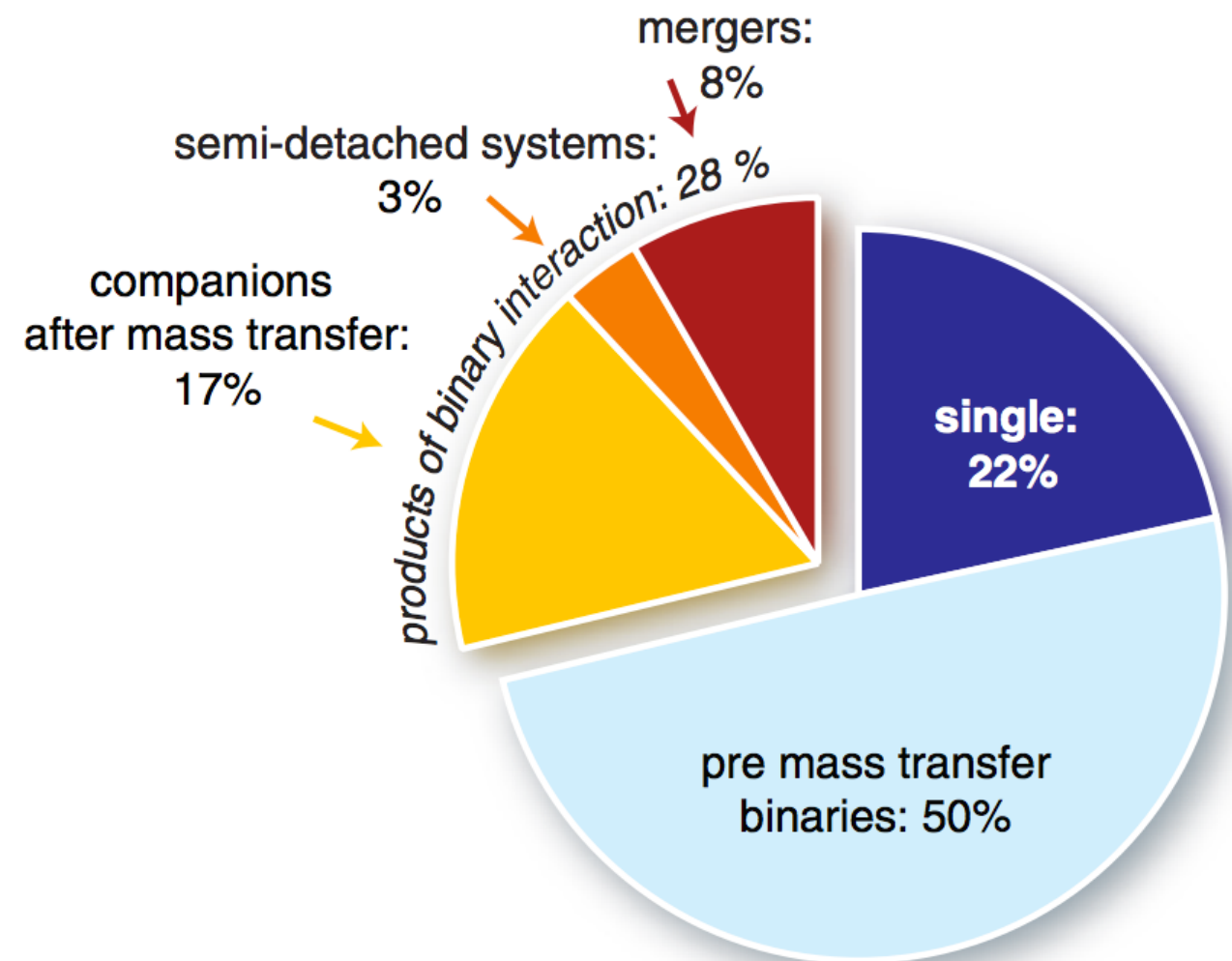


# Binaries

- Interactions dominate massive star evolution: 71% of all stars born as O-type will interact during their lifetime (*Sana+ 2012*)



*Sana+ 2012*

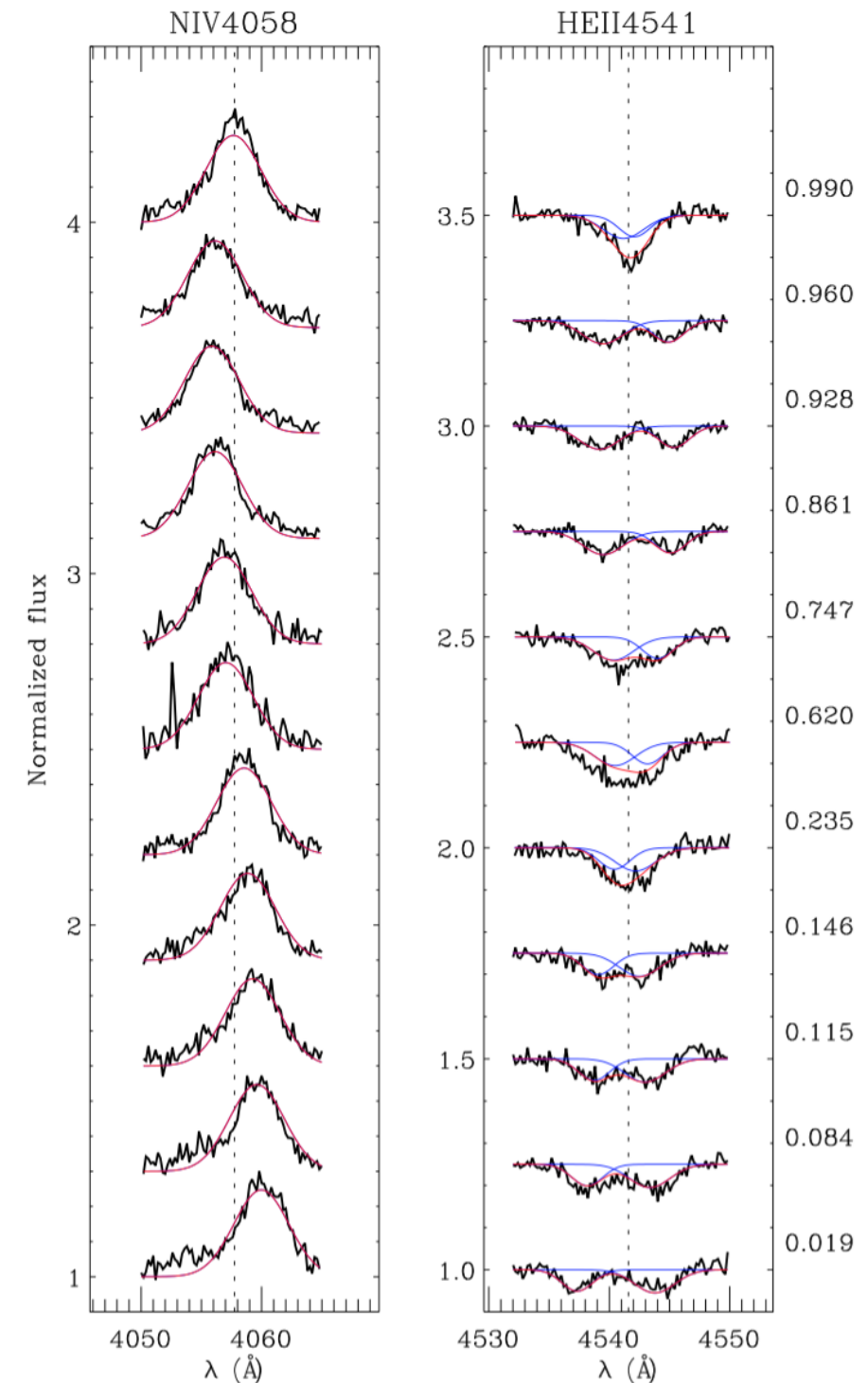


*de Mink+ 2014*



# Detecting Binaries

- Spectroscopy
  - SB1s: One star visible
  - SB2s: Two stars visible
  - Short-period systems, periods up to  $\sim 10$  years
- Direct imaging
  - Very long-period systems
  - Only nearby stars
- Need to fill the gap for intermediate periods



*WR21a; Trammer+ 2016a*



# Interferometry

- Optical interferometry can fill the gap between spectroscopy and direct imaging for nearby stars (separations 1-300 mas)
  - Only done for a handful of systems
- Smash: 'Southern MAssive Stars at High angular resolution'
  - PI: Sana (Sana+ 2014)
  - All southern O-type stars brighter than 7.5 in H-band (2 kpc for dwarfs, 4 kpc for supergiants)

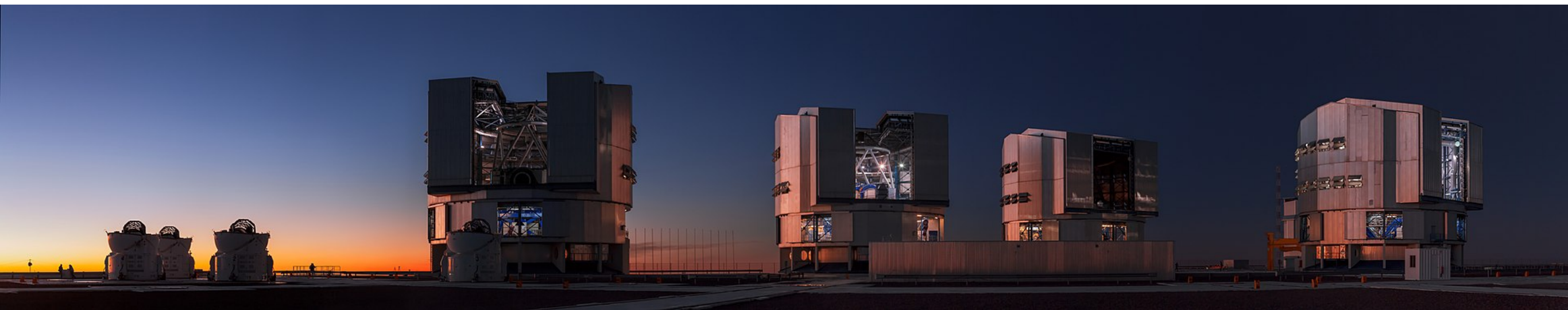


# Smash

- VLT(i) Large Program + various separate smaller programs: 23 + 10 nights
- PIONIER
  - Visitor instrument using VLTi (ATs)
  - <1-45 mas
  - 117 stars
- NACO/SAM
  - UT4 + AO
  - 30-250 mas
  - 162 stars
- NACO/FOV
  - AO corrected image
  - < 8"

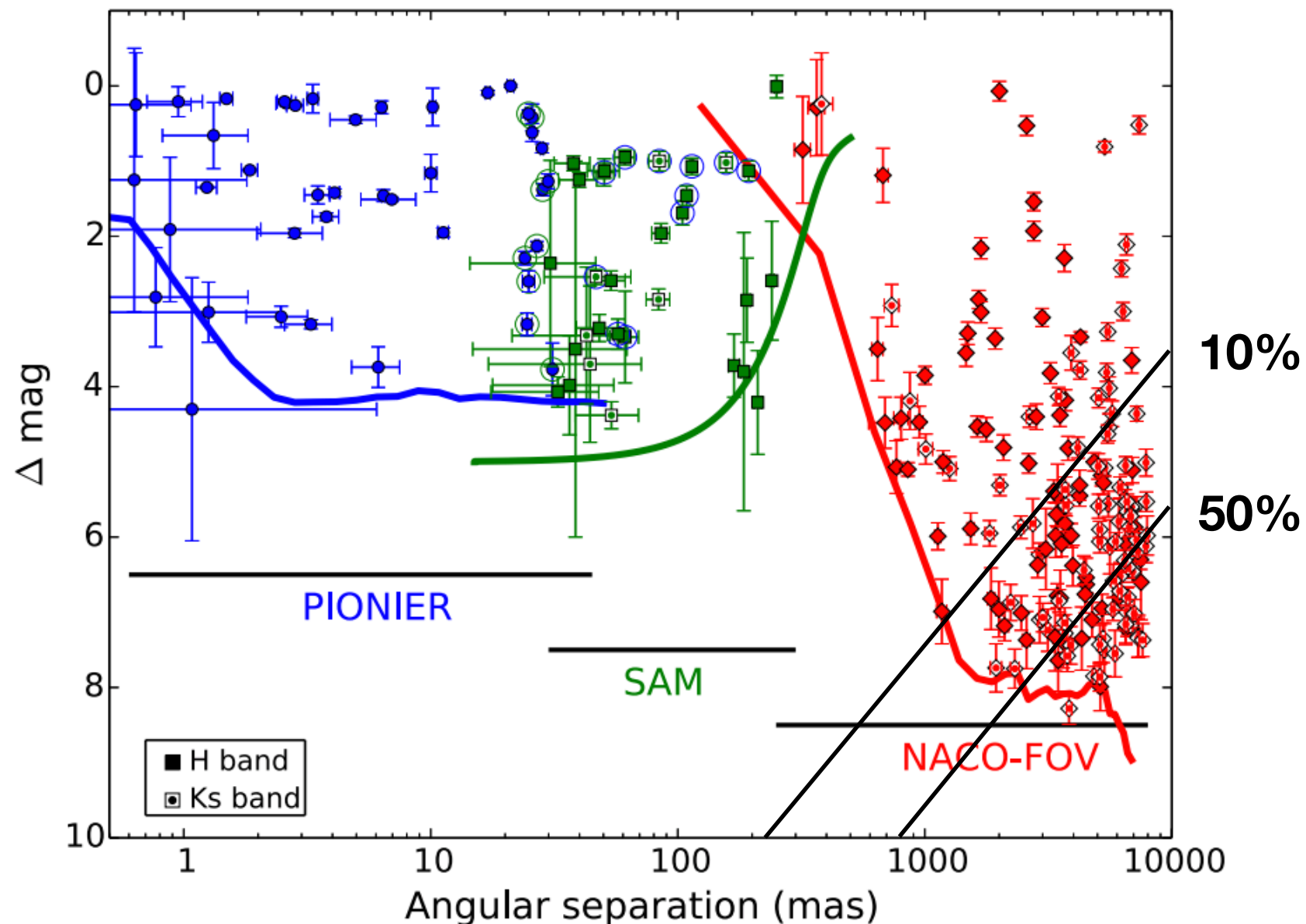
96 stars observed with both instruments
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Instrument	Epoch	Nbr. of Nights
NACO/SAM	2011 Mar	3
NACO/SAM	2012 Feb	3
NACO/SAM	2012 Jun	3
NACO/SAM	2013 Jan	2
NACO/SAM	2013 Jul	0.8
VLTi/PIONIER	2012 Jun	5
VLTi/PIONIER	2012 Aug	2.5
VLTi/PIONIER	2012 Sep	2.5
VLTi/PIONIER	2012 Nov	2.5
VLTi/PIONIER	2013 Jan	6
VLTi/PIONIER	2013 Mar	2





# Results

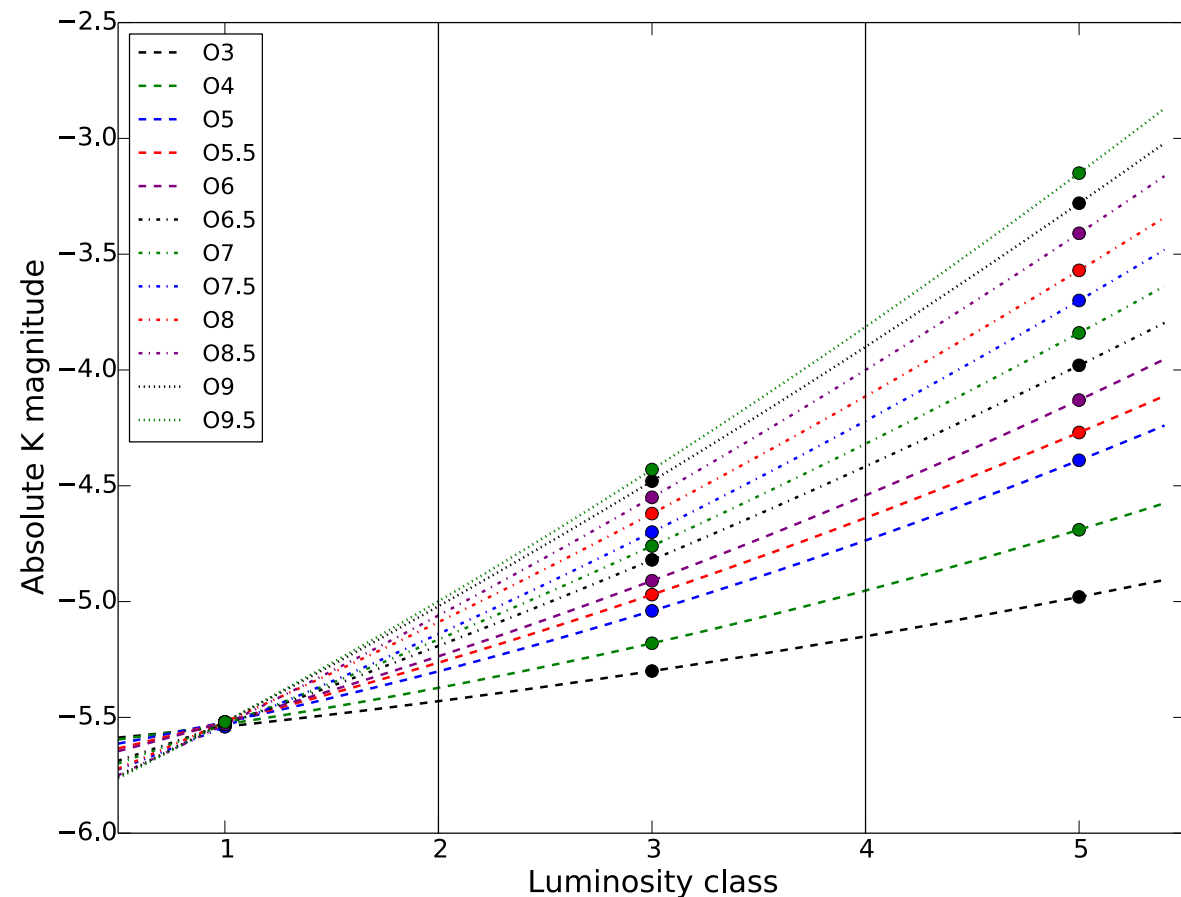


- Multiplicity fraction 1-200 mas: 53%
- Within 8", including SBs: 91%
- For LC V (dwarfs) 100% within 30 mas
  - Average number of companions: 2.3
- Multiplicity fraction of runaway stars: 0%

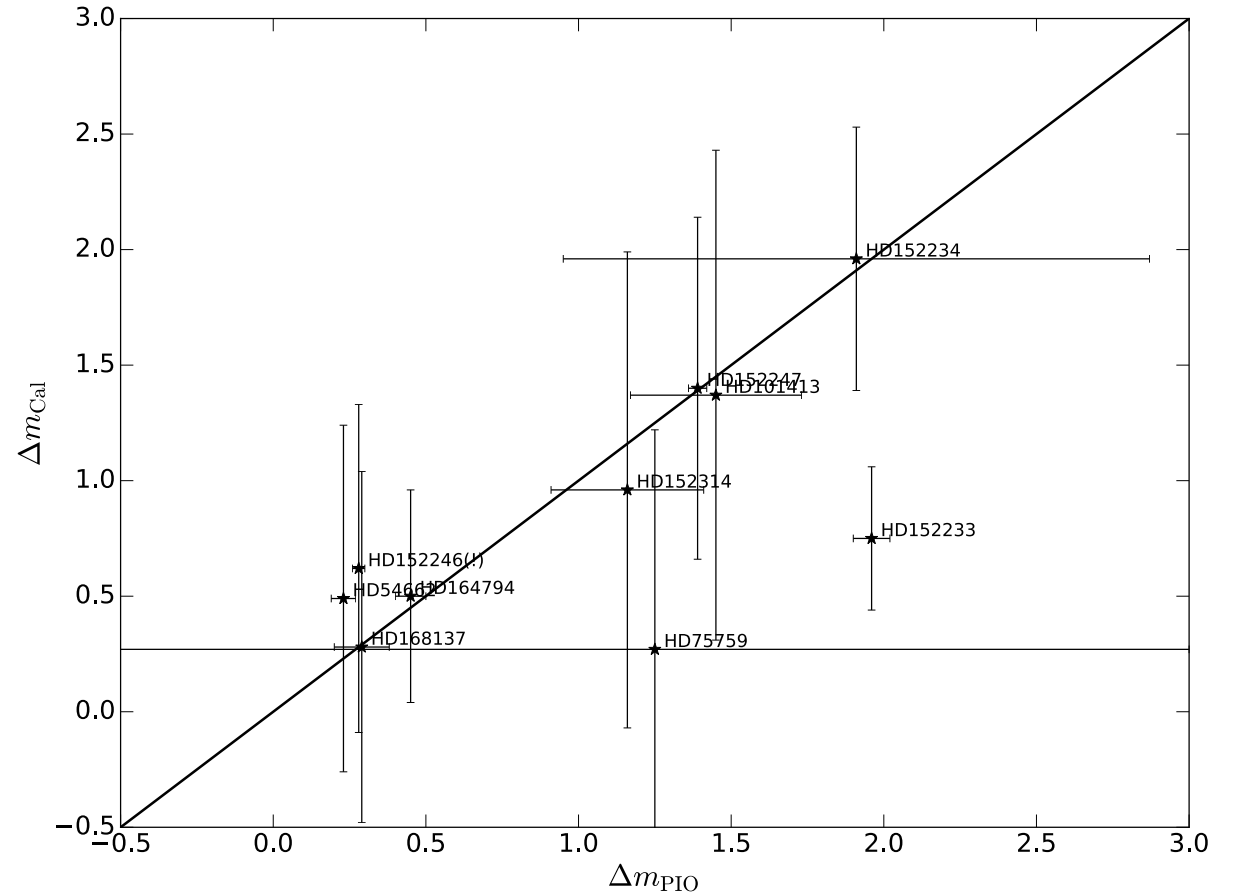


# Angular separation (mas) -> physical separation (AU)

- Need distance
  - Gaia DR2 unsuitable (brightness/crowding)
- Absolute K-band magnitude calibration based on spectral type and luminosity class using Martins+ 2006
- Test: SB2s with known SpTs resolved by Pioneer



Tramper+ in prep.





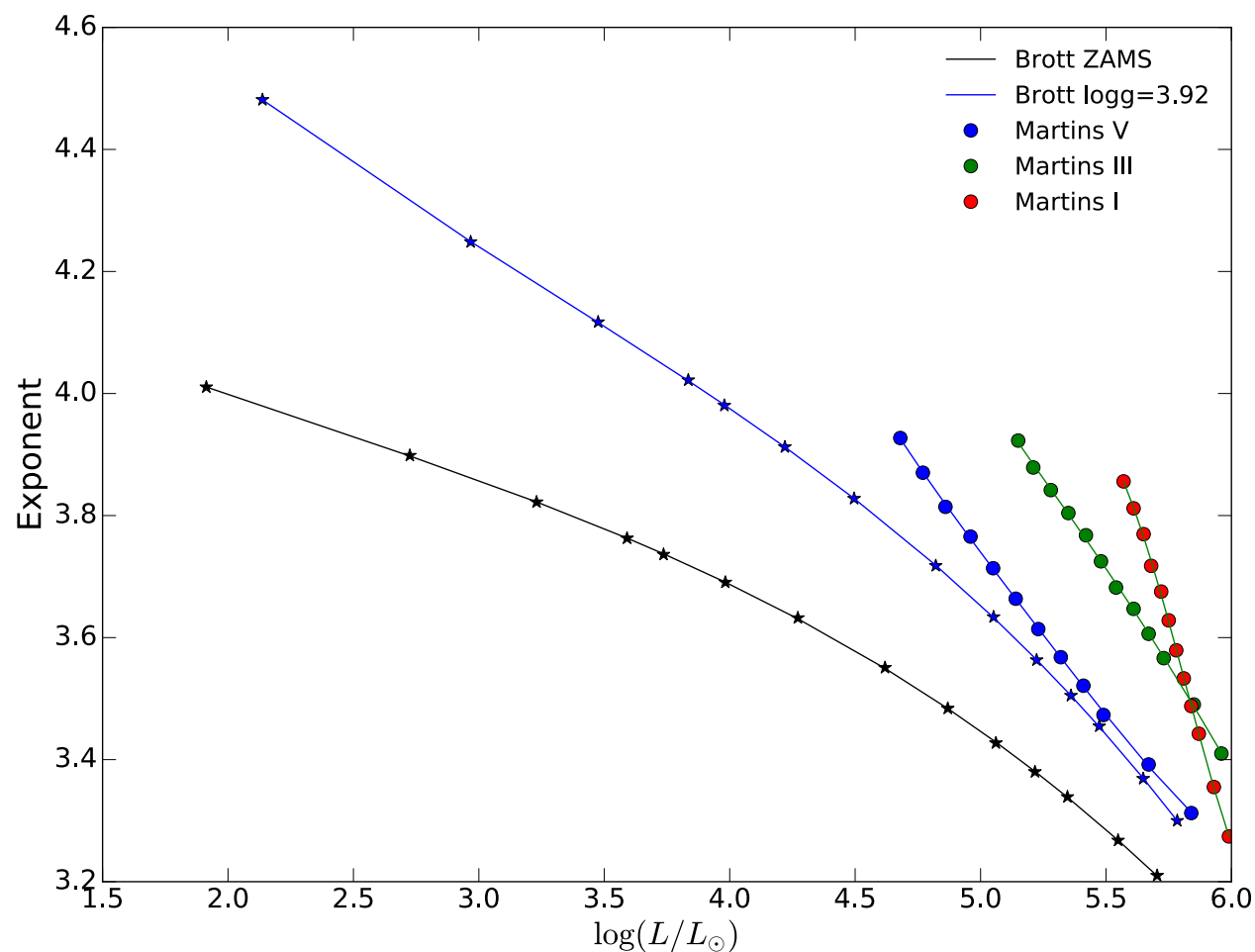
# Magnitude contrast -> mass ratios

- Primaries:

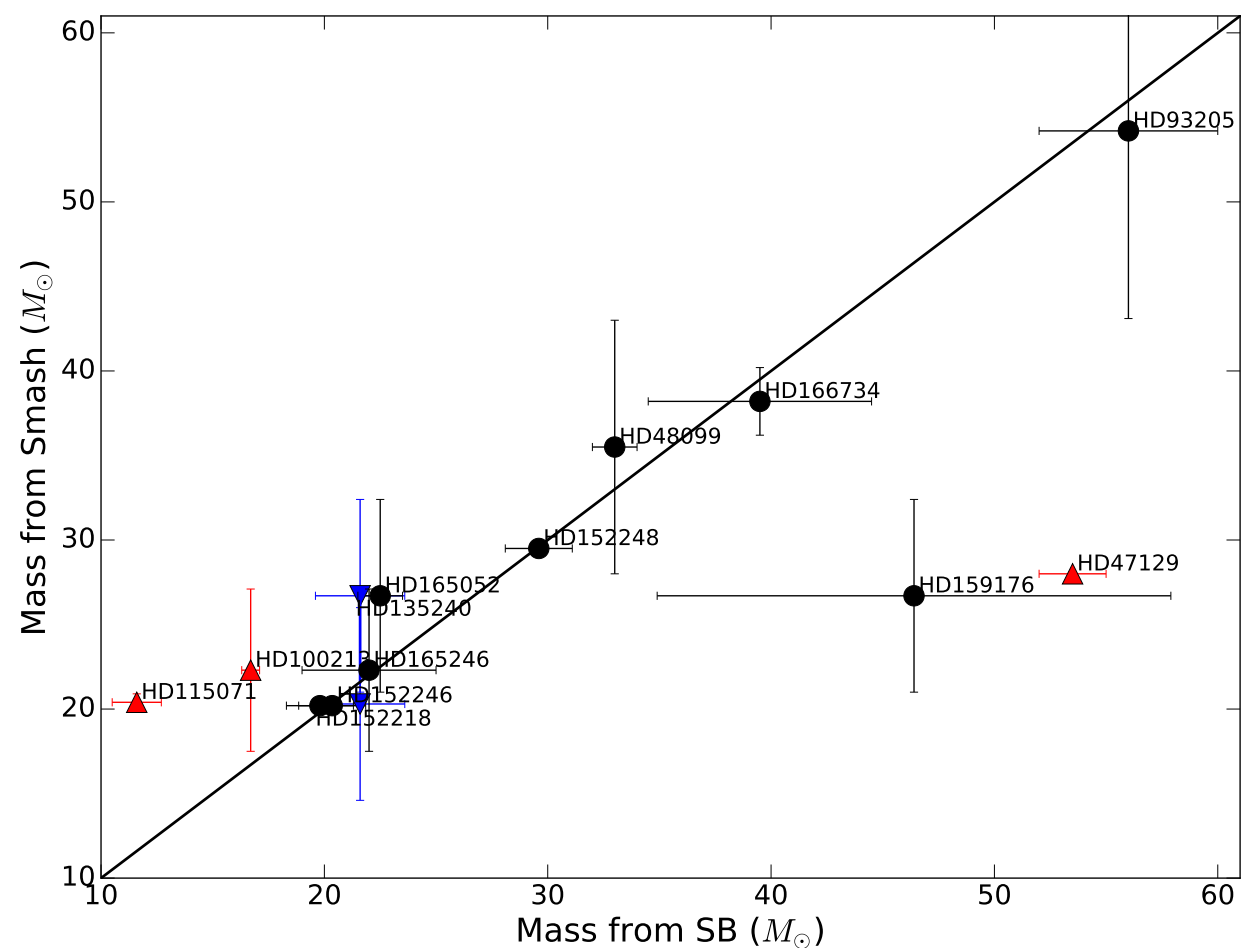
- Derive bolometric correction as function of SpT and LC based on Martins+ 2006 and Brott+ 2011

- Use mass-luminosity relations based on Martins+ 2005 ( $L = M^x$ )

- Test: stars with known dynamical masses



*Tramper+ in prep.*





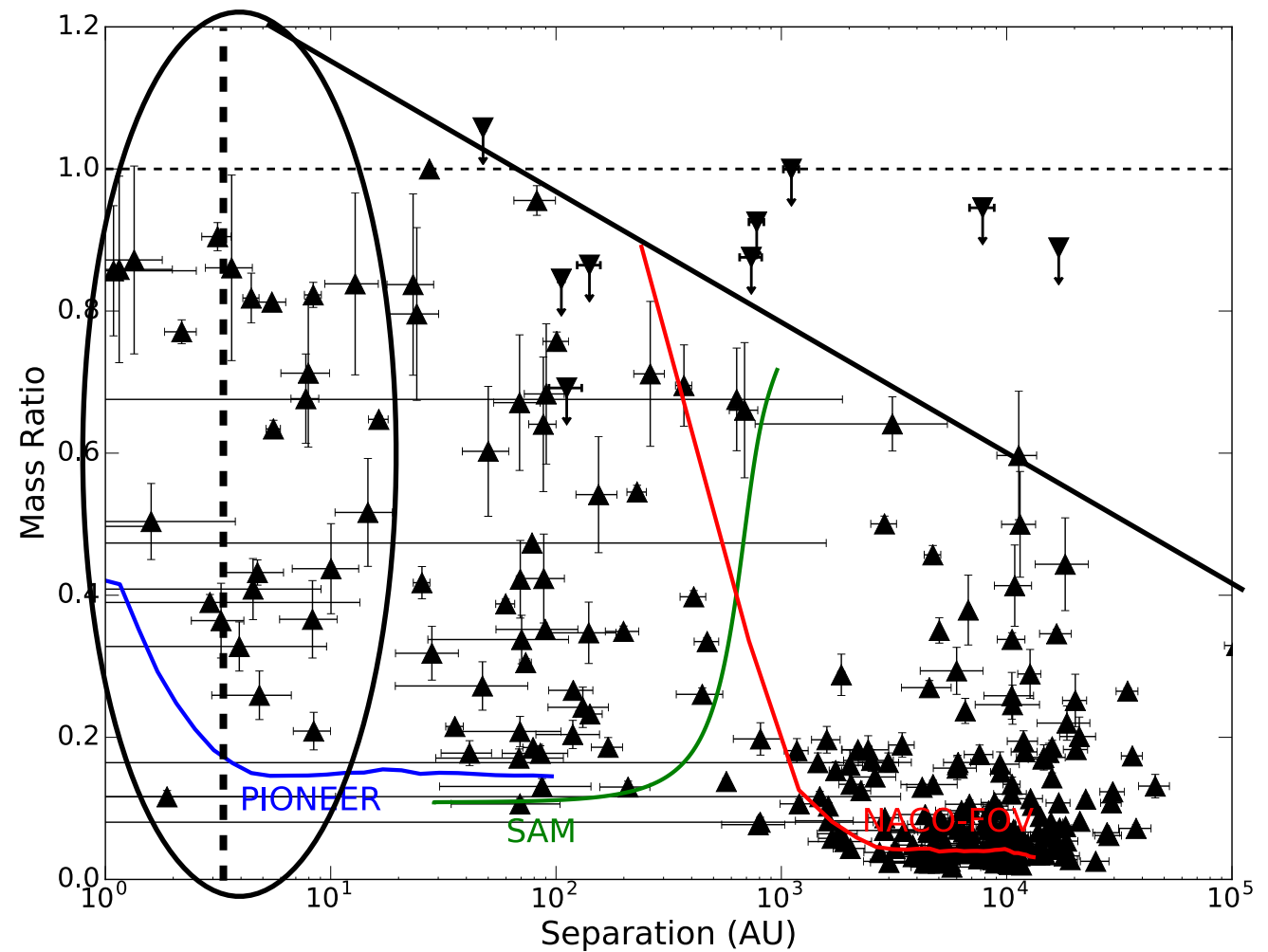
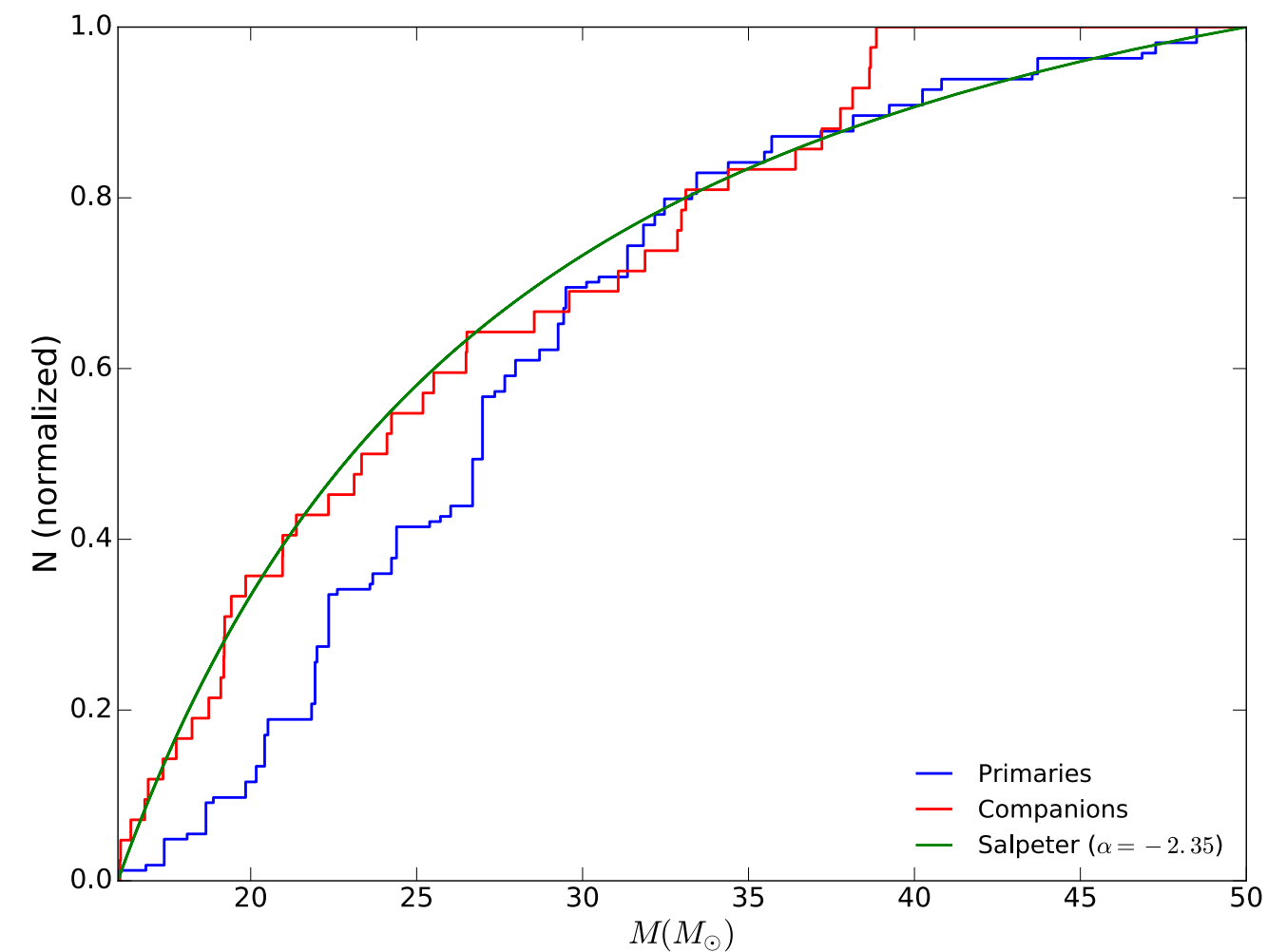
# Magnitude contrast -> mass ratios

- Companions:
  - Spectral types unknown
  - Most should be dwarfs -> use calibrations based on H-band magnitude for dwarfs
  - Only switch to other luminosity classes when dwarfs give mass ratios  $> 1$



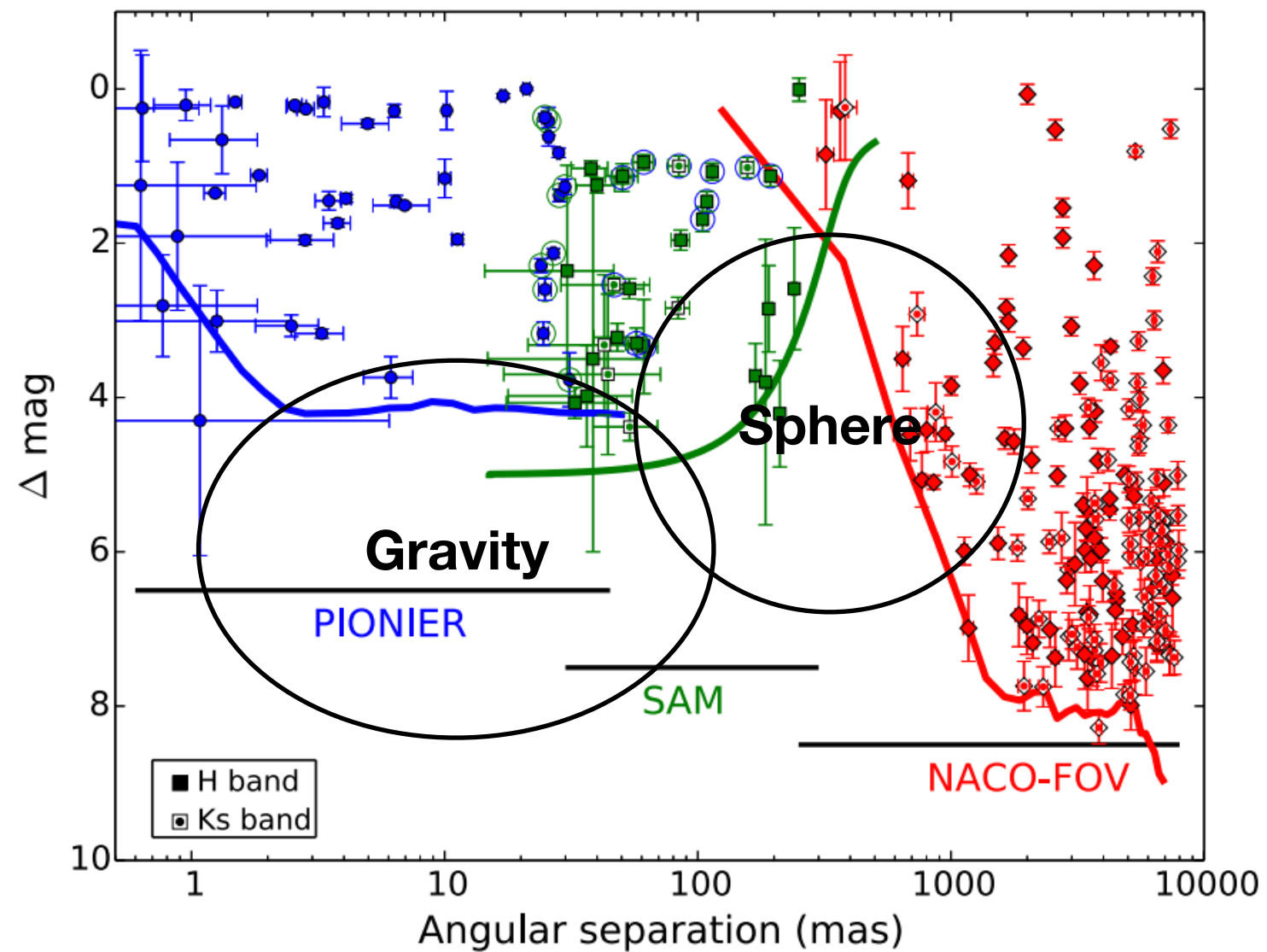
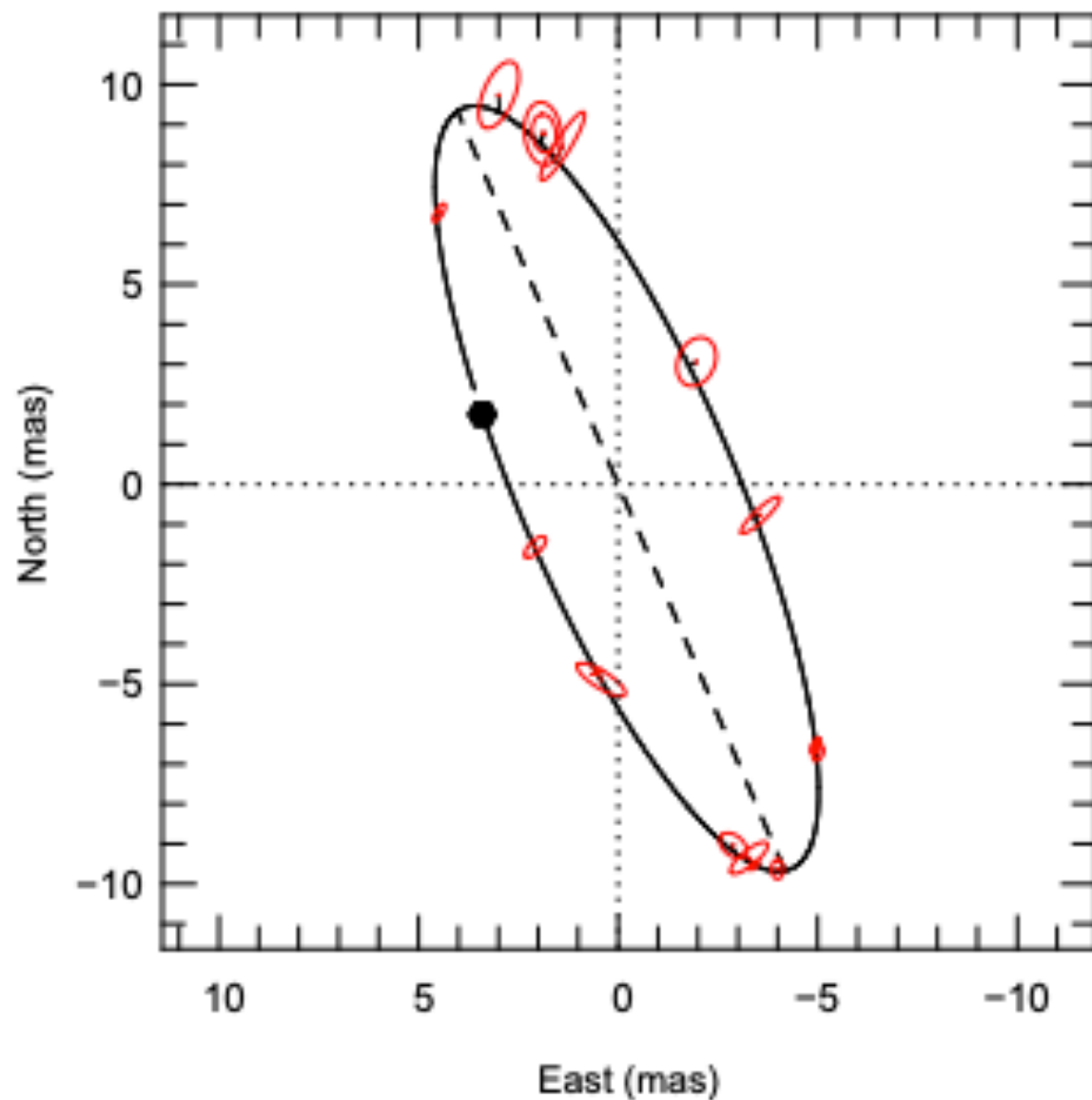
# Results

- Companions compatible with Salpeter mass function
- No massive companions at large separations



# Ongoing and future observations

- Ongoing monitoring, orbit determination (Le Bouquin+ 2018)
- Gravity and Sphere





# Take-home message

Most, if not all, massive stars are formed in multiple systems and will interact during their lifetime