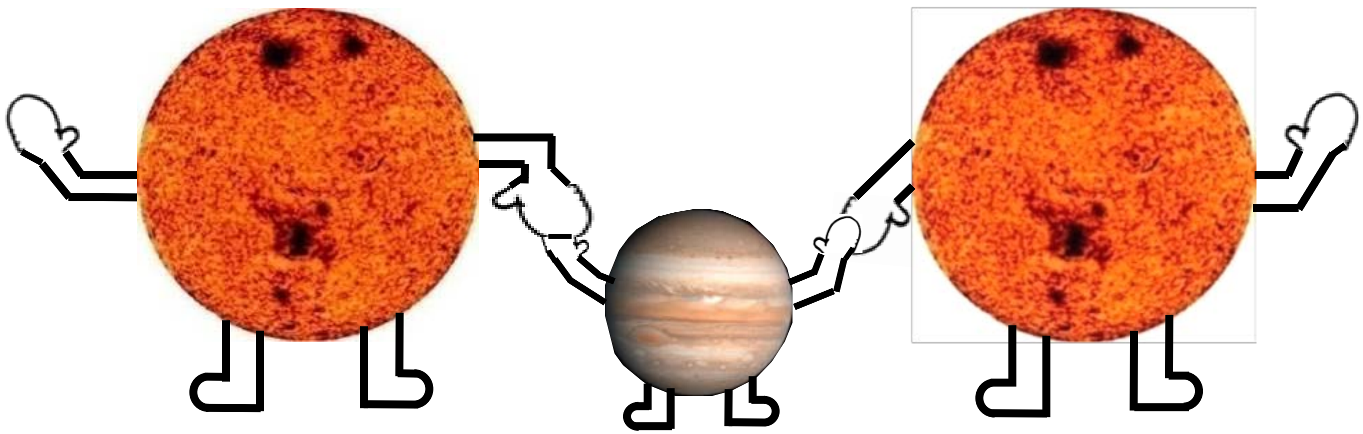
A Survey of Stellar Families

Multiplicity of Solar-type Stars



Deepak Raghavan

GSU/CHARA

November 18, 2009

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The CHARA Team

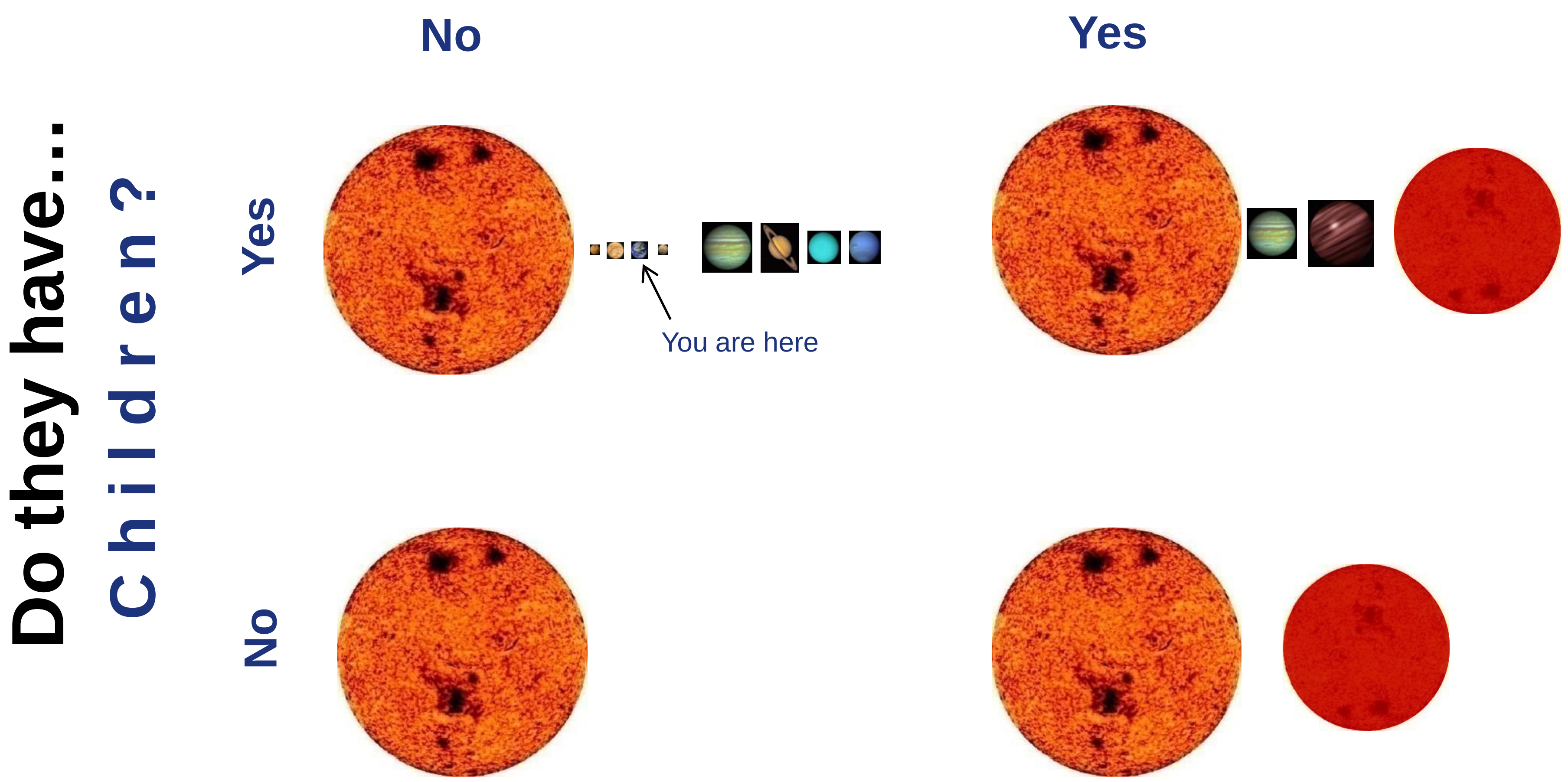
Presentation Outline

- Motivation for this effort
- The sample of nearby solar-type stars
- Survey methods & observing techniques
- Current Results

Understanding Stellar Families

Do Sun-like stars have…

Companions?



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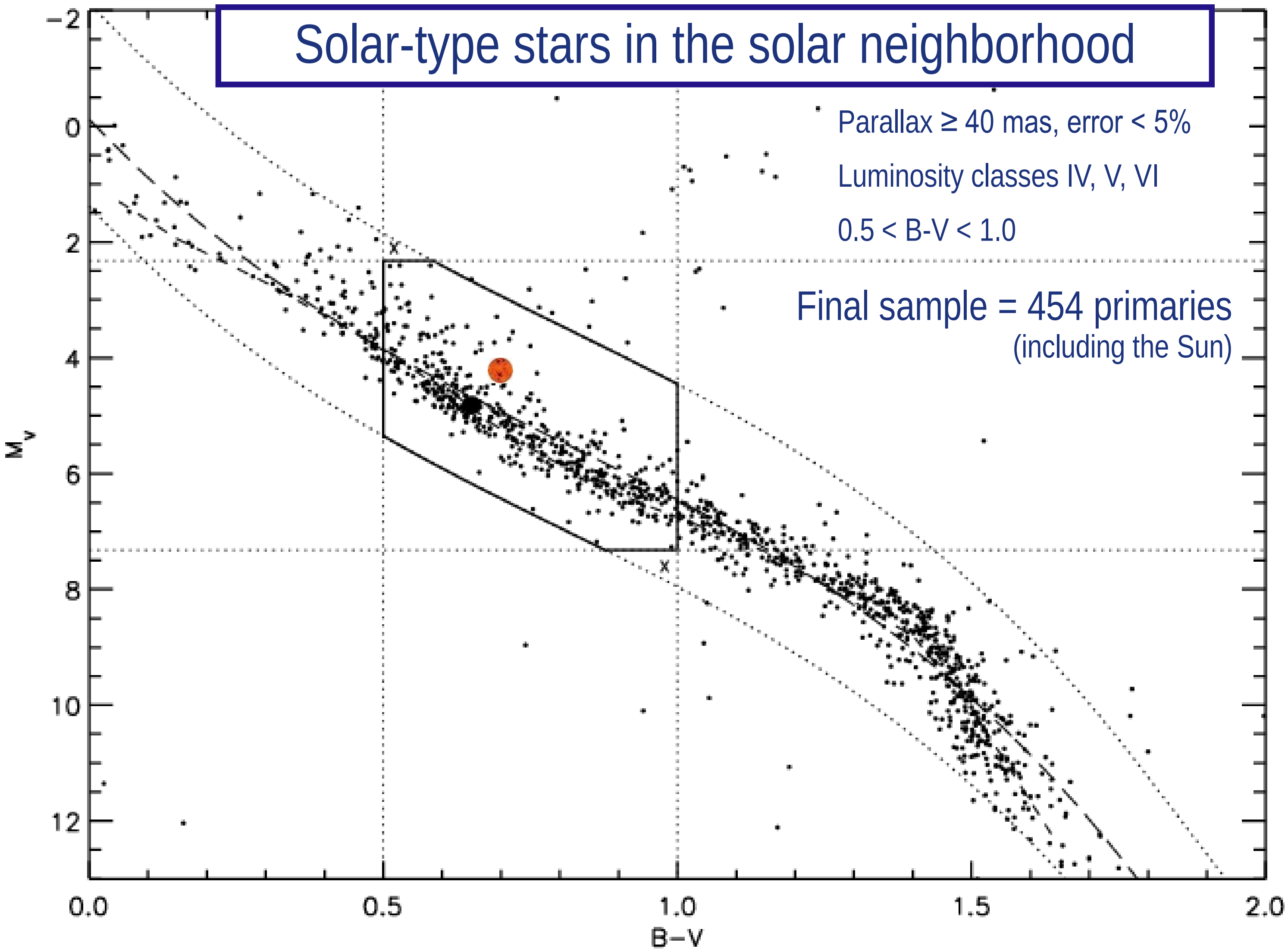
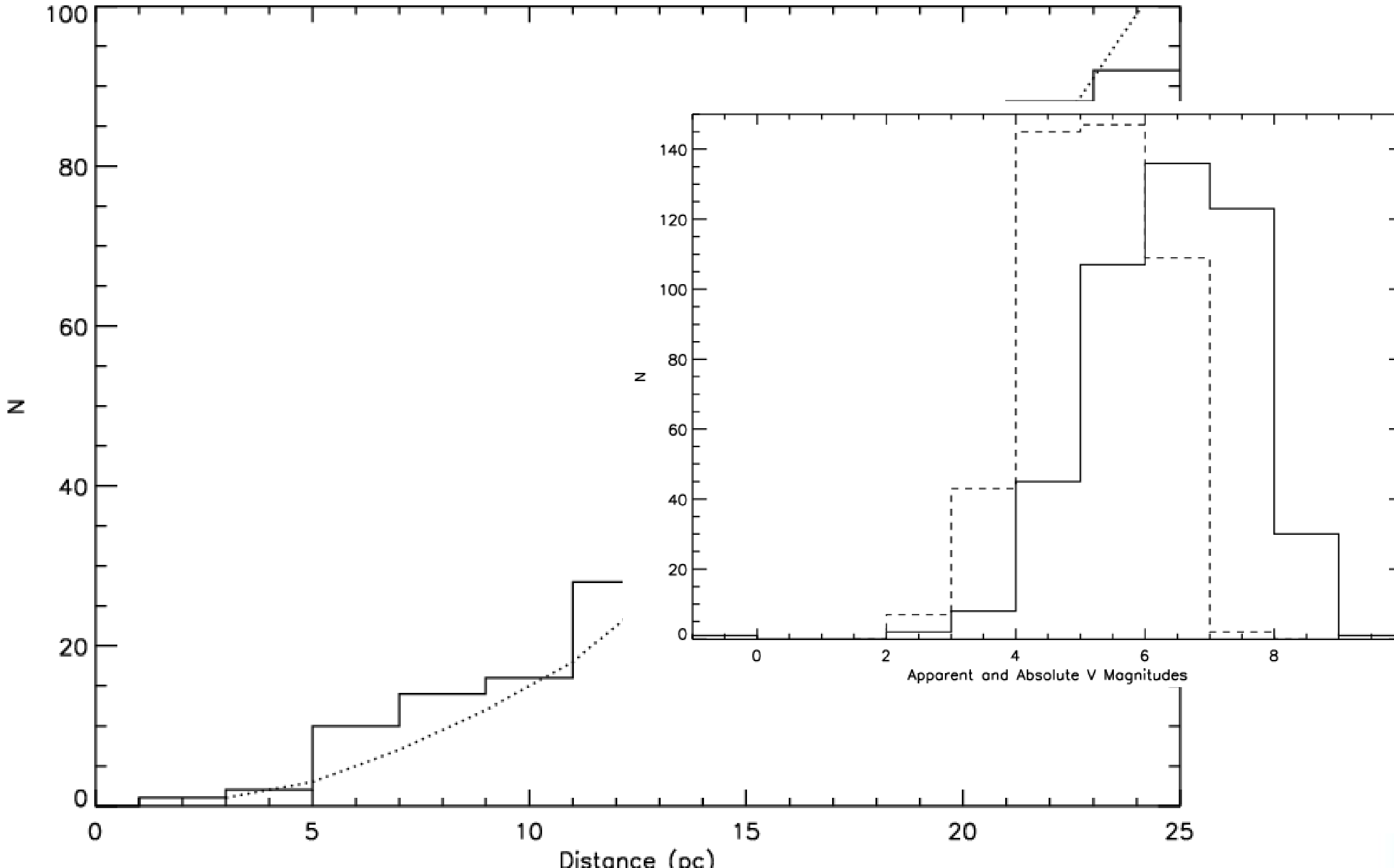
Defining the Sample



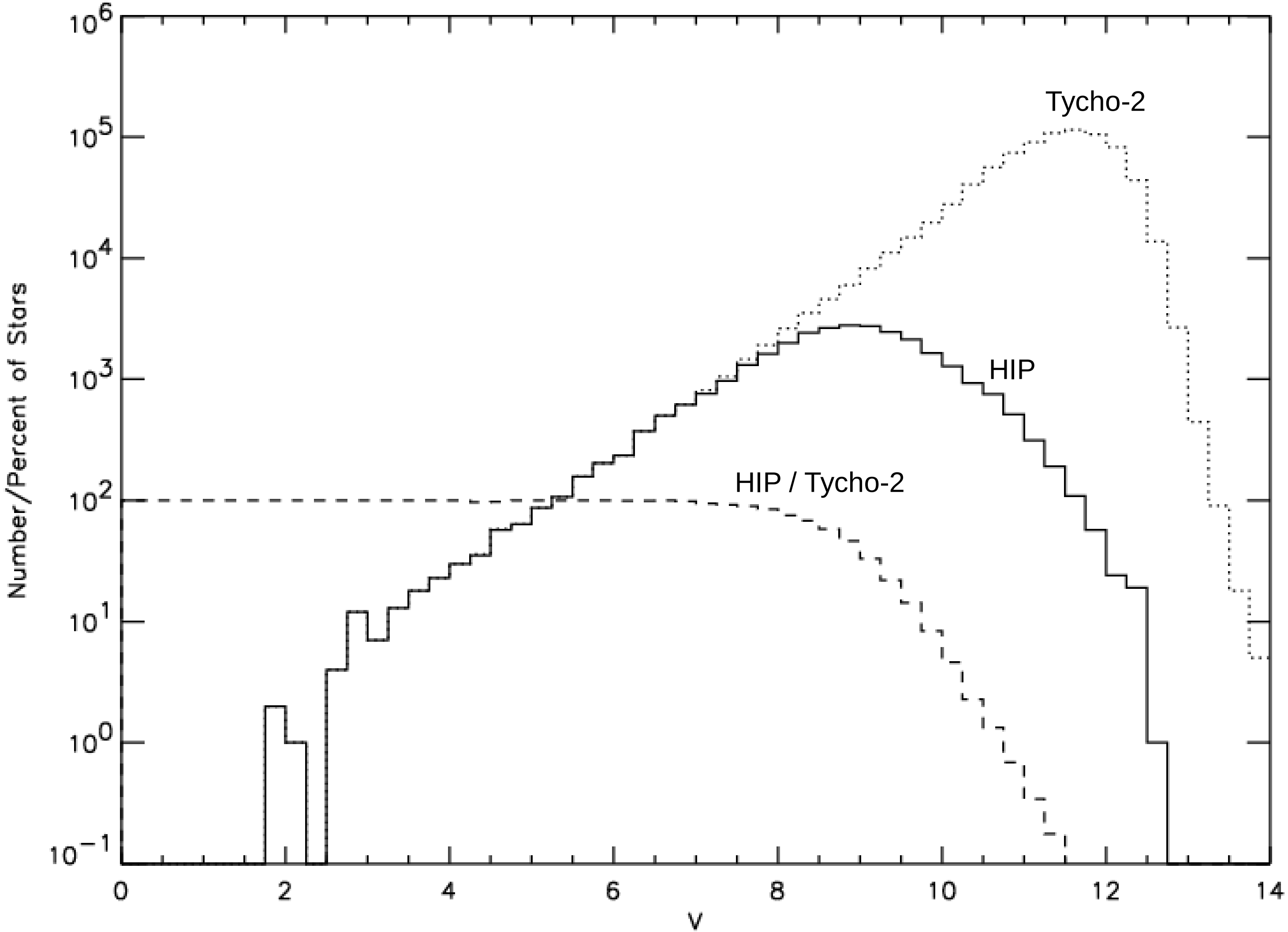
AAQ: Allen's Astrophysical Quantities (2000)

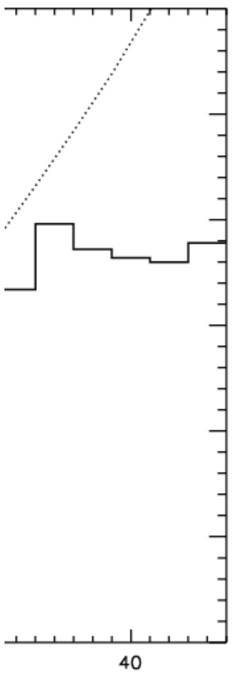
Data from the Hipparcos Catalog

Sample Distribution



Sample Completeness





Tycho-2 completeness: V < 11 (Hog et al. 2000)

Hipparcos completeness: V_{lim} < 7.9 + 1.1 sin |b| SpT < G5

V_{lim} < 7.3 + 1.1 sin |b| SpT > G5 (Turon et al. 1992)

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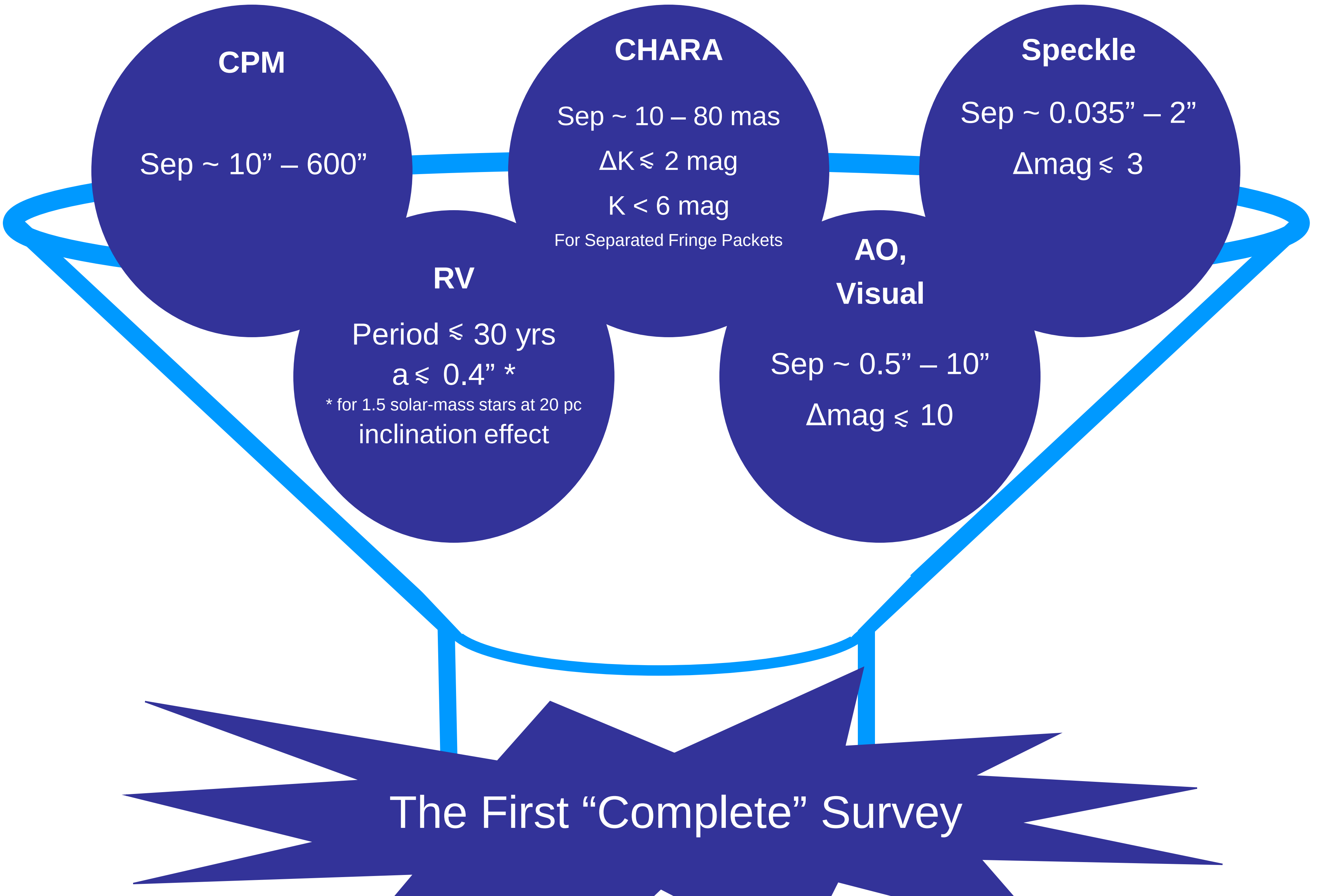
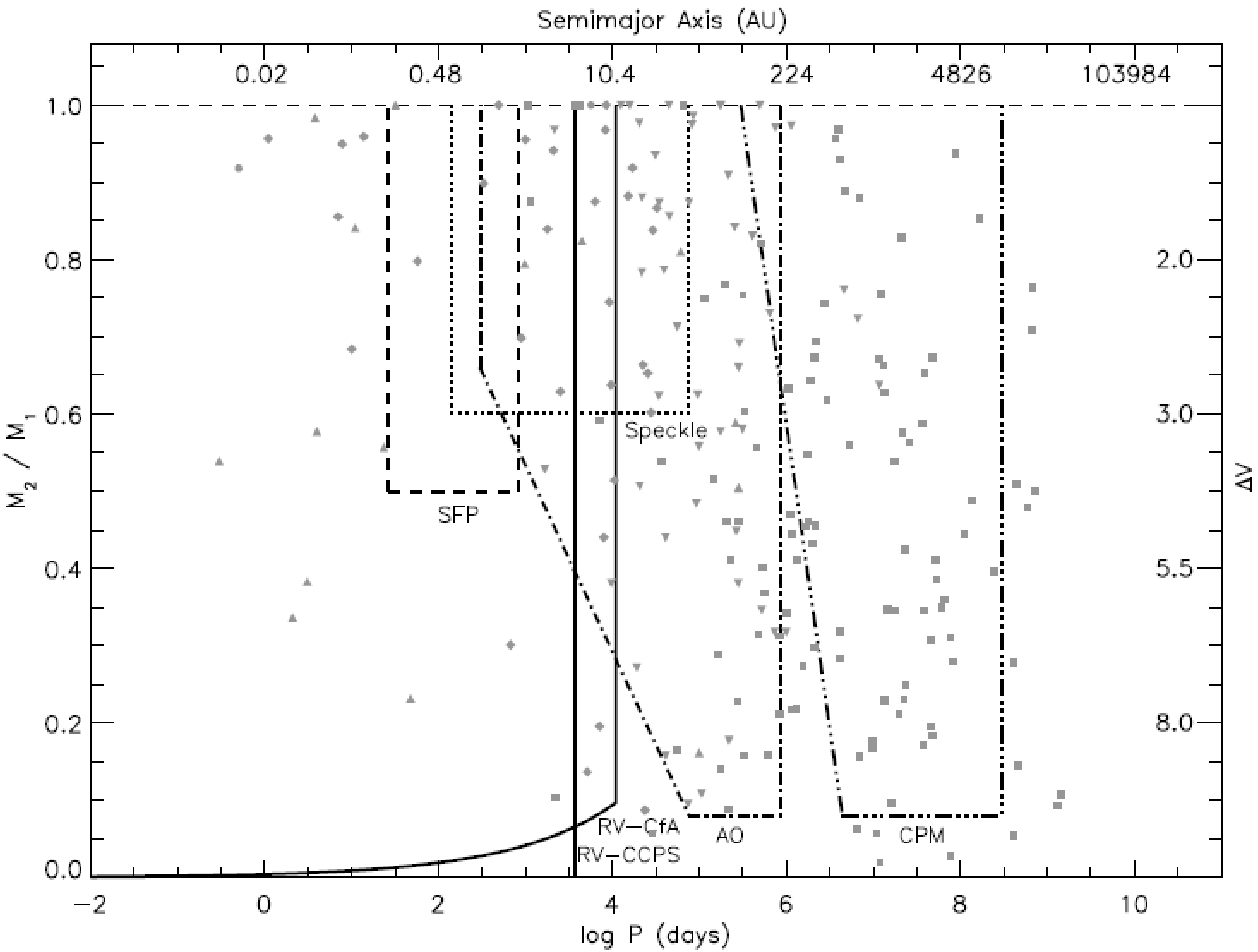
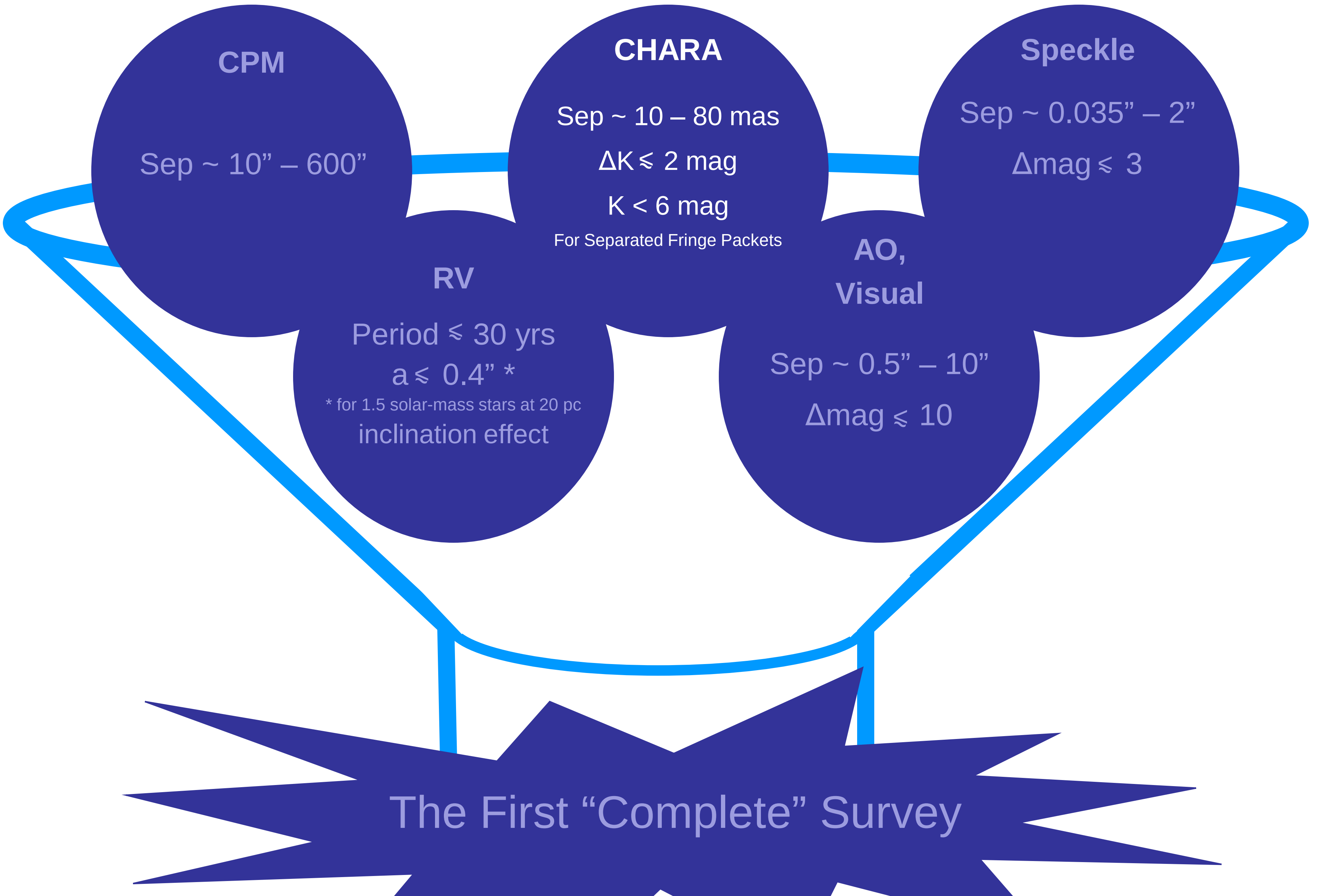
A Comprehensive Effort



Detection Limits of the Survey



CHARA Astrometry

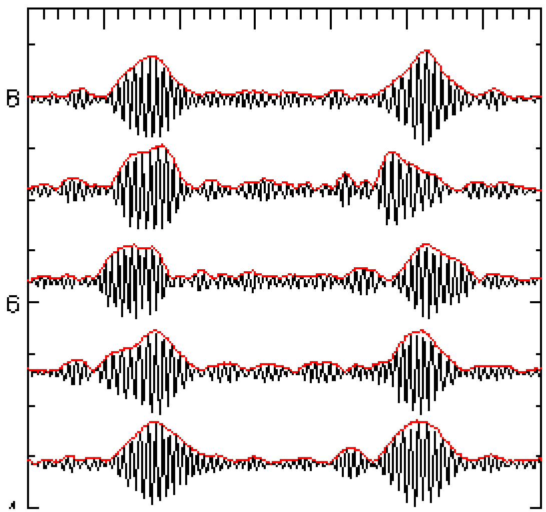


Modeling SFP Fringes

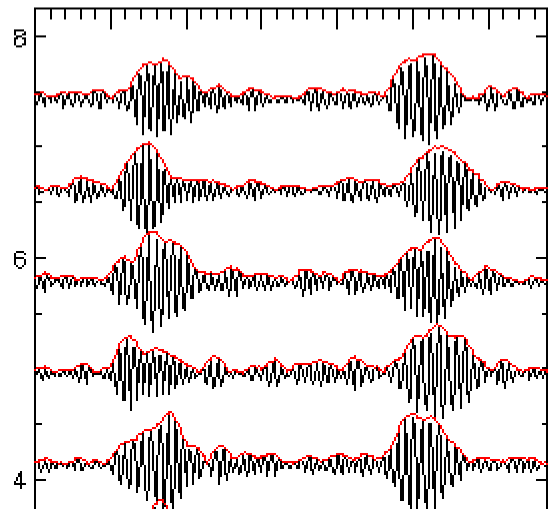
- All stars assumed to be 20 pc away
- fakecc parameters
  - b: 331 m (S1-E1 baseline)
  - f: If R0 >= 6 cm –f 750/150, else –f 500/100
  - n: photon count for primary $N_{ph} = 2.37 \times 10^{(9- M)/2.5}$
  - p: R0=10 cm (velocity assumed 10 m/s)
  - r: 145 microns (dither mirror scan range)
  - S: V,sep,beta
    - Separation in microns = Baseline * sep-arcsec * unit-conv
    - Beta = Sec-flux / Prim-flux
    - V = secondary visibility (B, diameter, wavelength)
  - V: primary's visibility

Varying Flux: R0=10 cm, Sep=50 mas

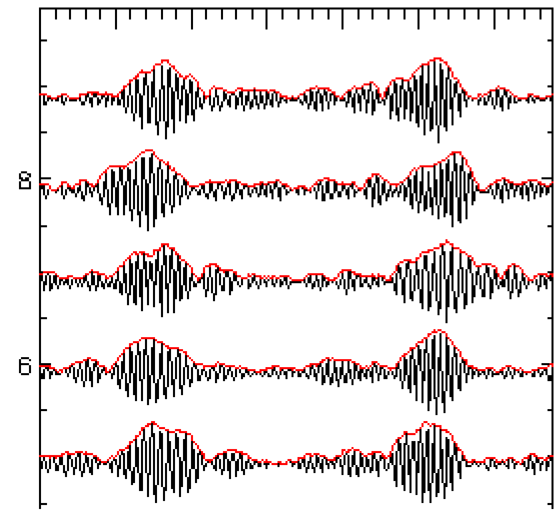
G0 pair, K=4.7



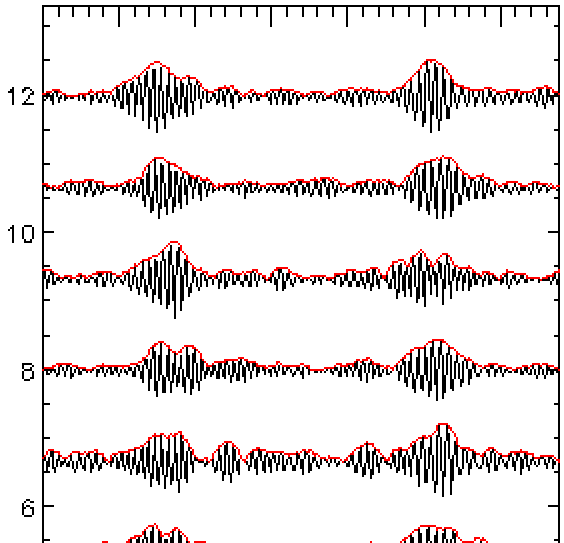
G5 pair, K=5.0



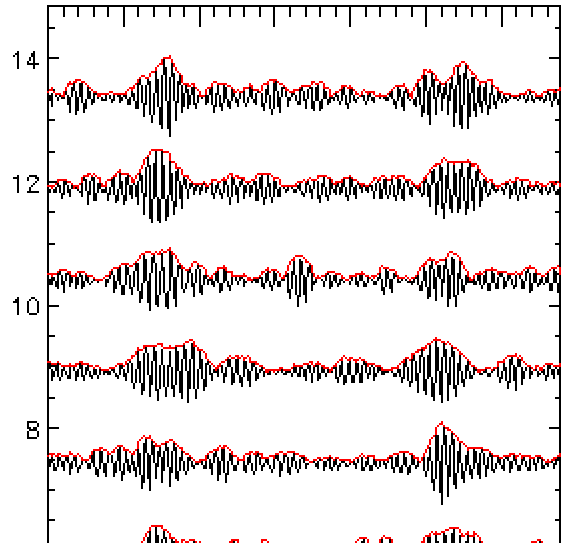
K0 pair, K=5.6



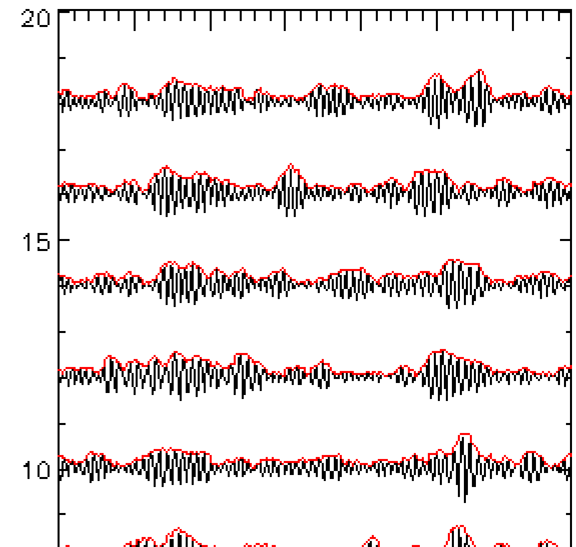
K5 pair, K=6.1



M0 pair, K=6.7

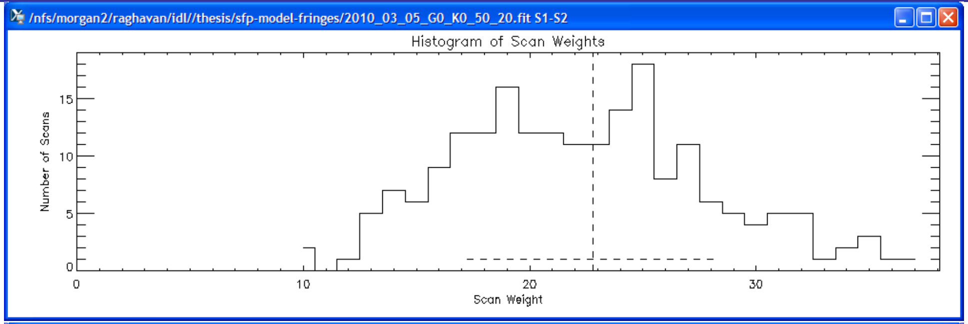


M2 pair, K=7.3

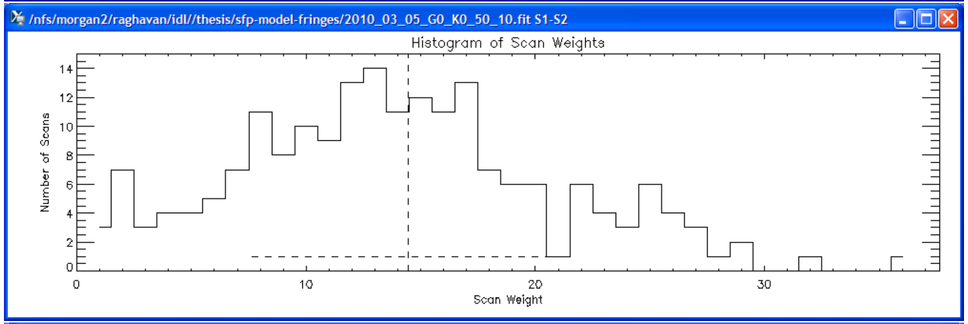


Varying Seeing: G0+K0, Sep=50 mas

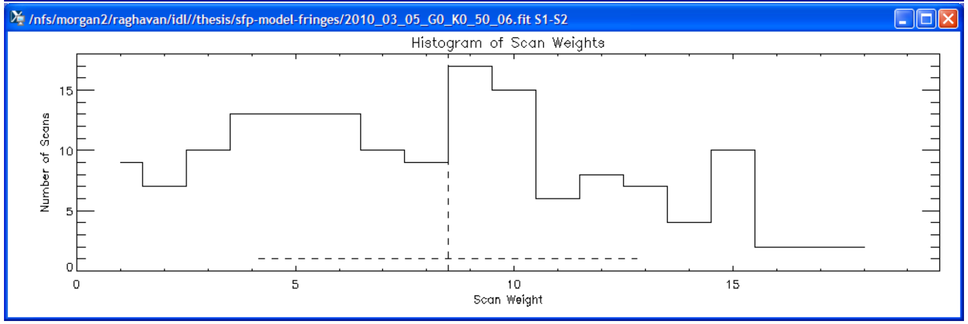
R0=20



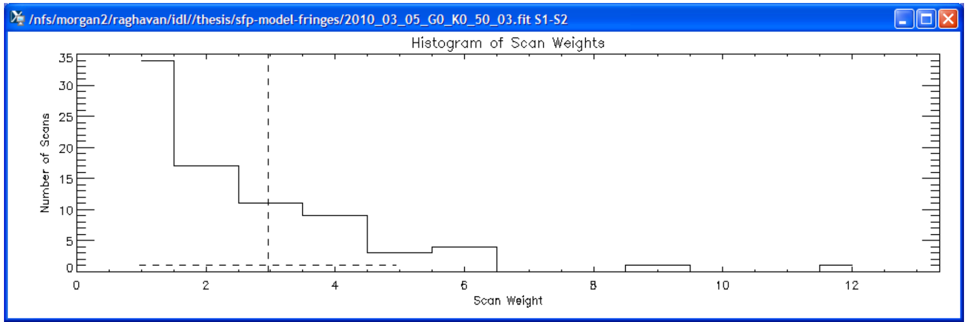
R0=10



R0=6

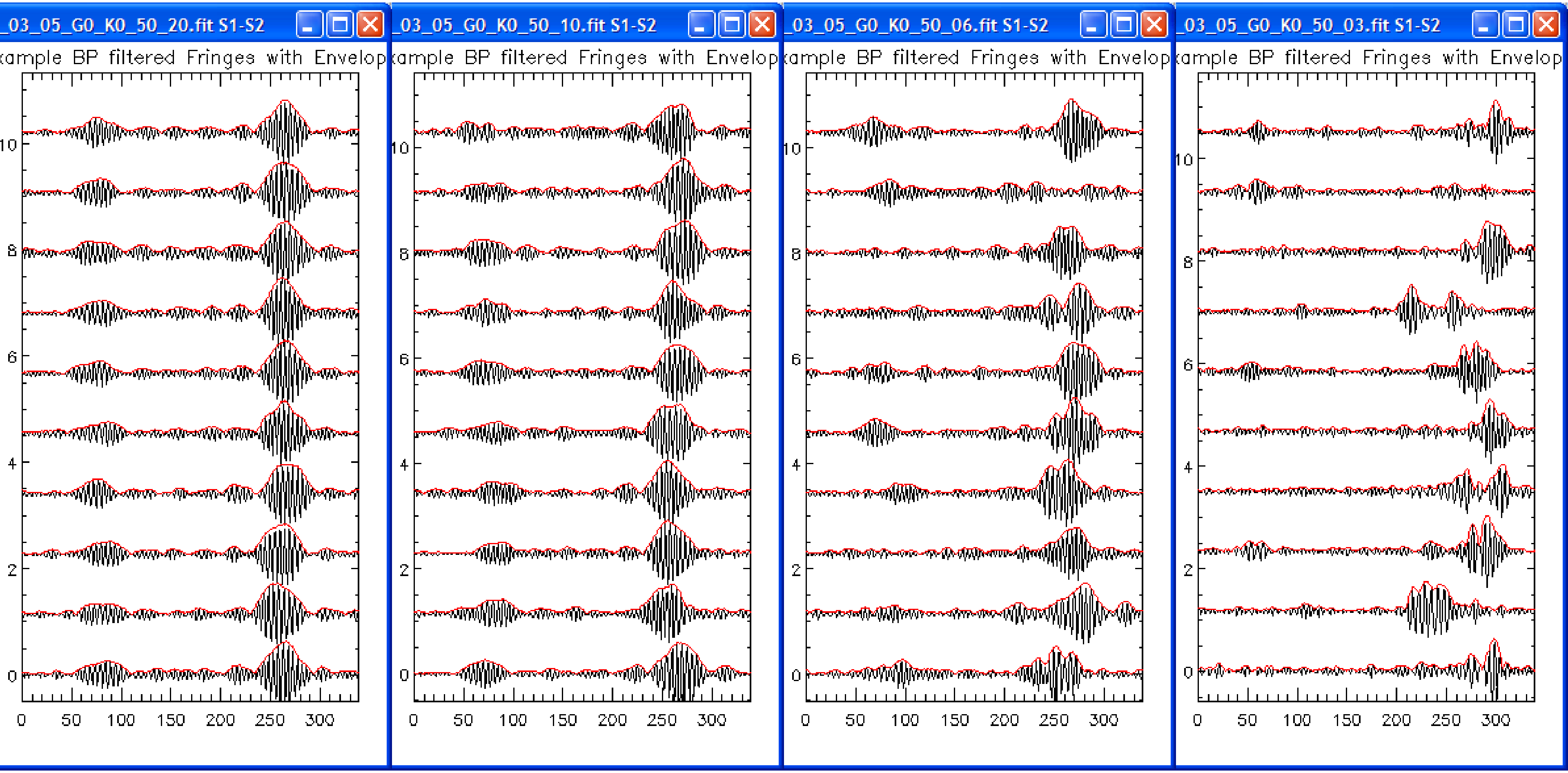


R0=3



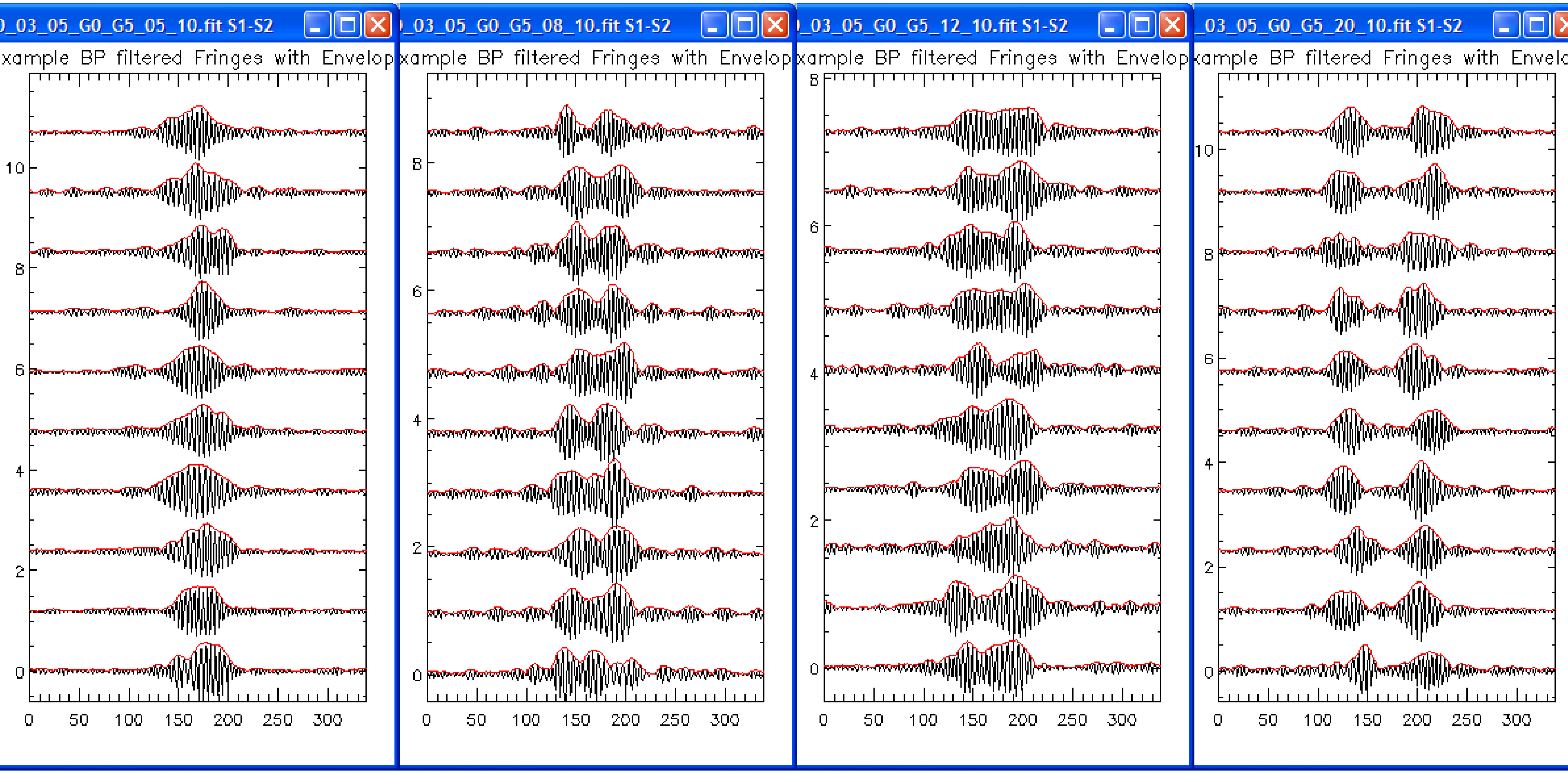
Varying Seeing: G0+K0, Sep=50 mas

R0=20 R0=10 R0=6 R0=3



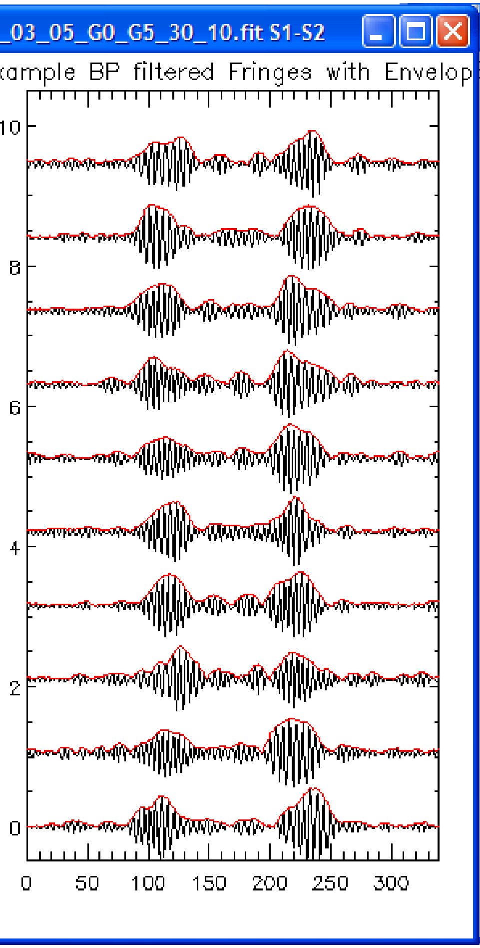
Varying Separation: G0+G5, R0=10

Sep = 5 mas　　Sep = 8 mas　　Sep = 12 mas　　Sep = 20 mas

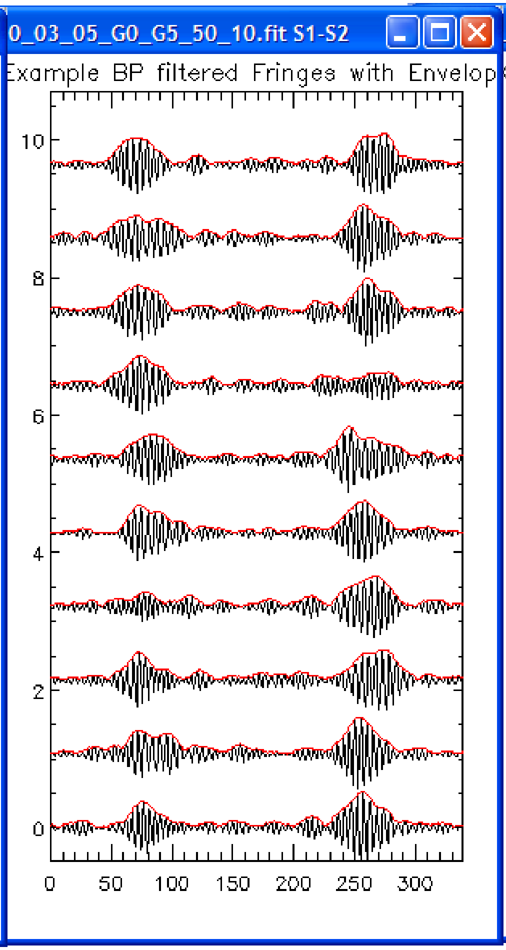


Varying Separation: G0+G5, R0=10

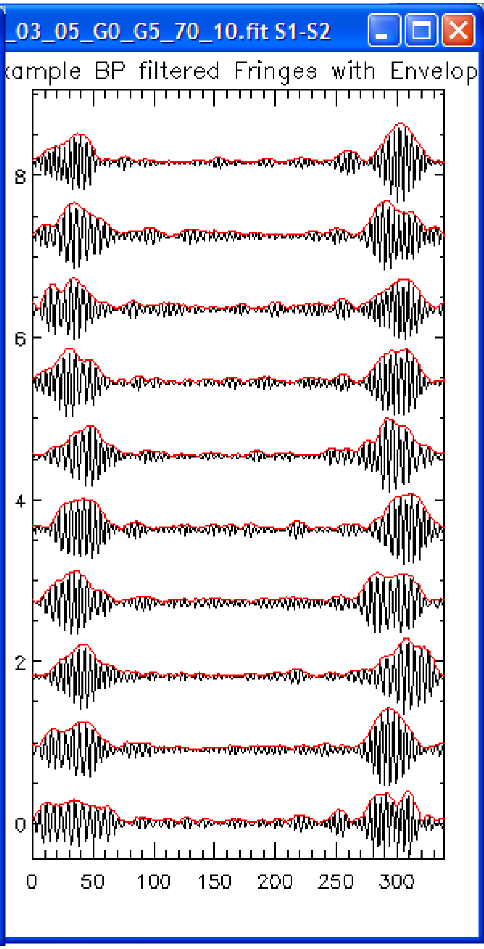
Sep = 30 mas



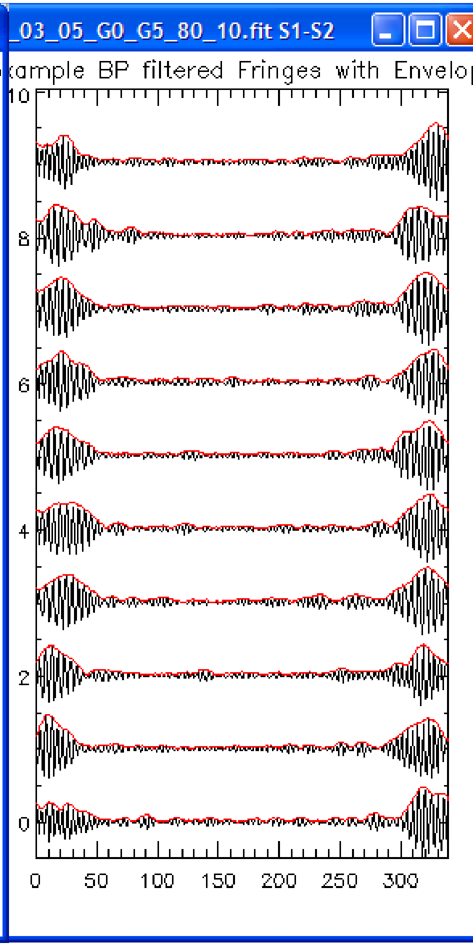
Sep = 50 mas



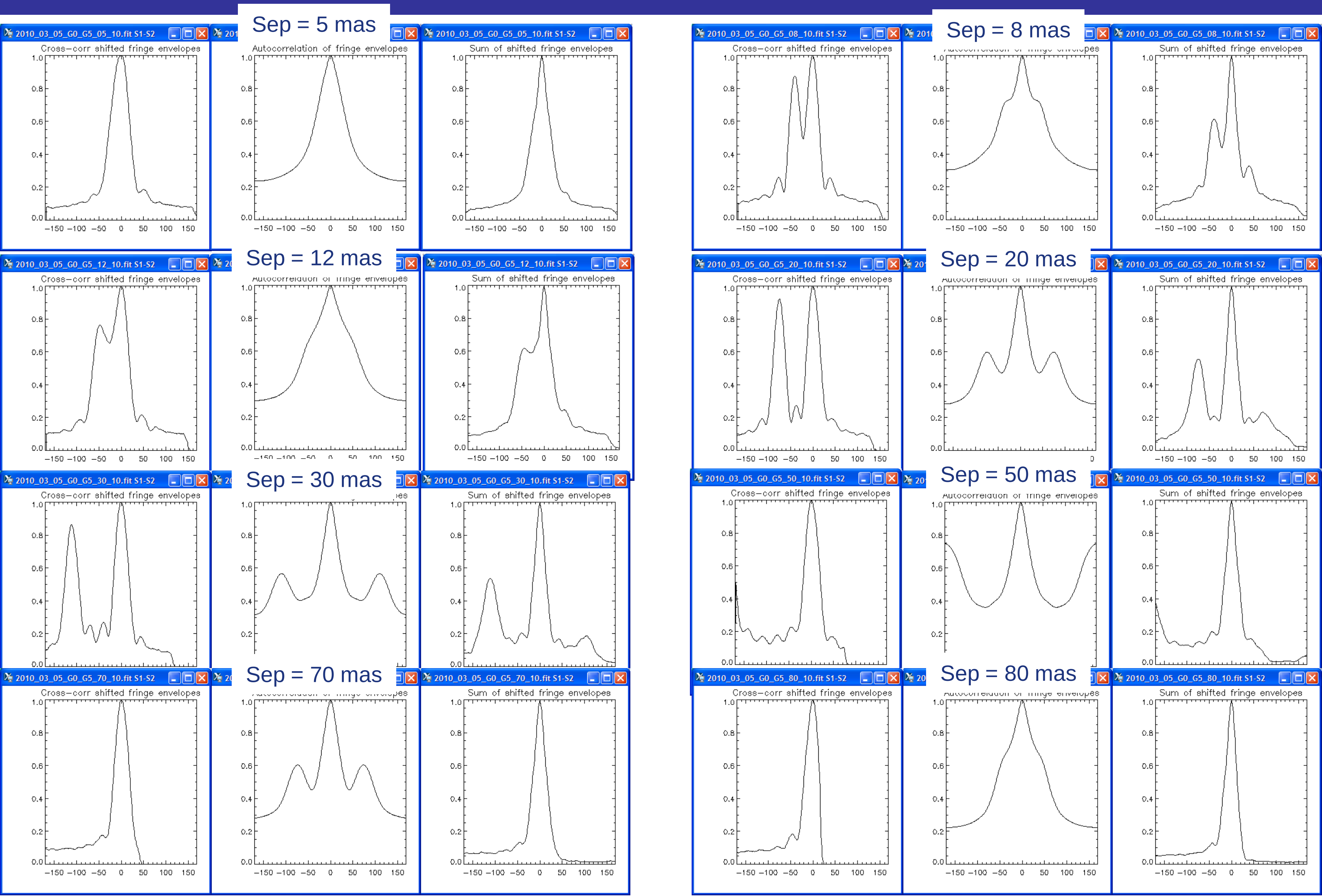
Sep = 70 mas



Sep = 80 mas

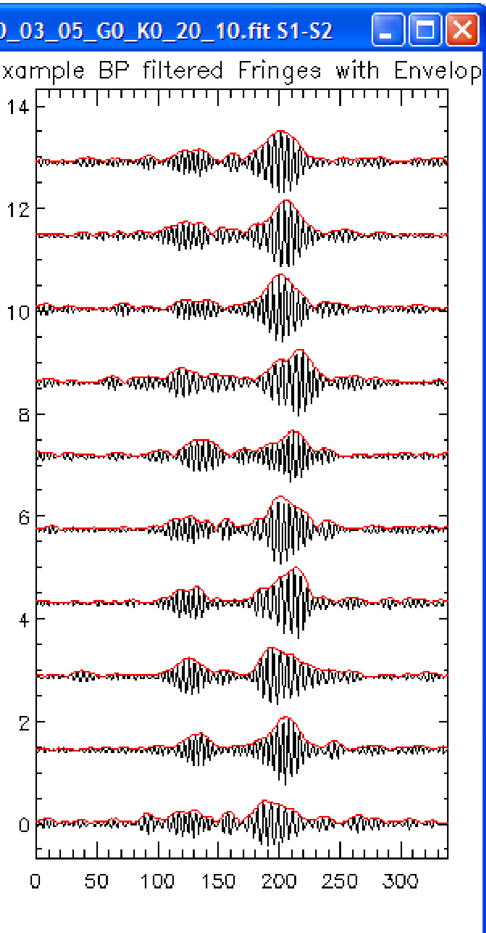


Varying Separation: G0+G5, R0=10

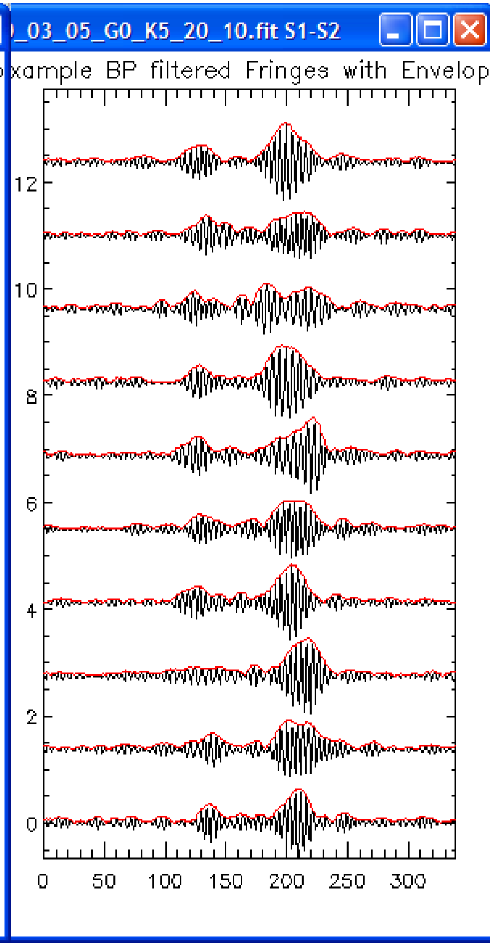


Varying Contrast: G0, R0=10, Sep=20 mas

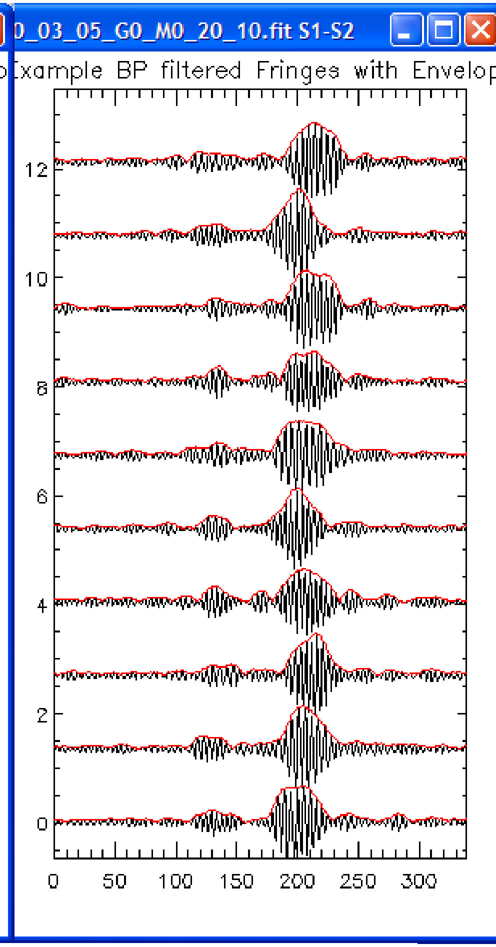
Comp K0, dK=0.9



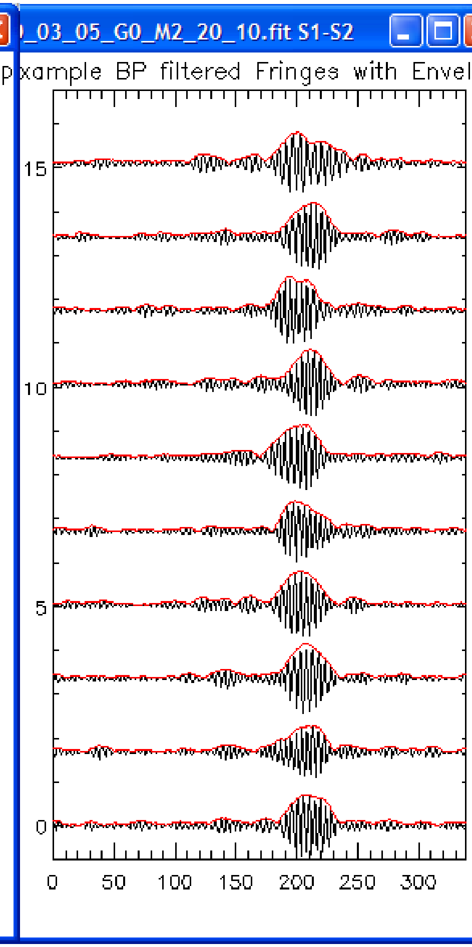
Comp K5, dK=1.4



Comp M0, dK=2.0

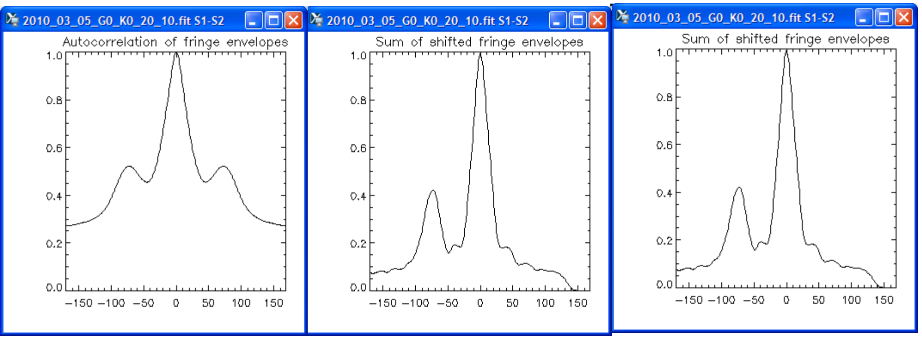


Comp M2, dK=2.6

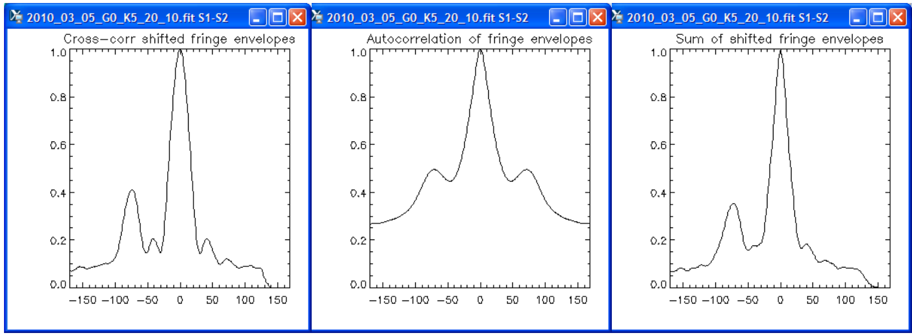


Varying Contrast: G0, R0=10, Sep=20 mas

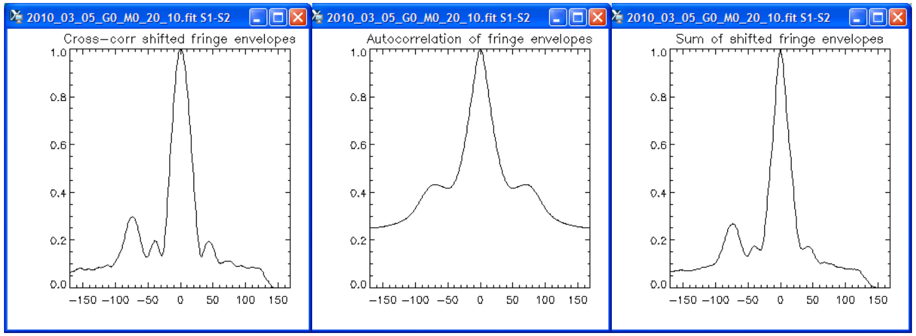
Comp K0, dK=0.9



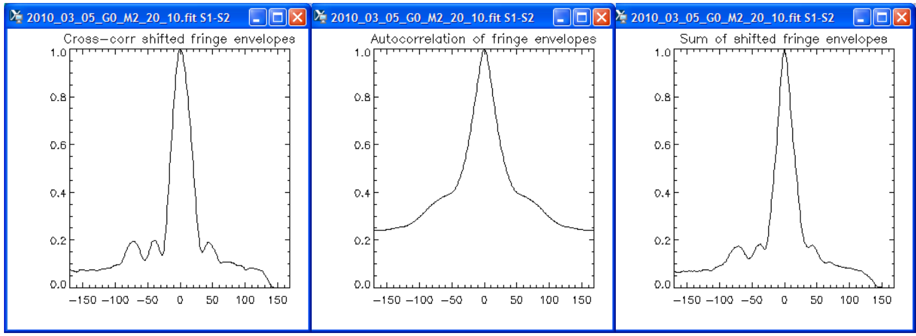
Comp K5, dK=1.4



Comp M0, dK=2.0

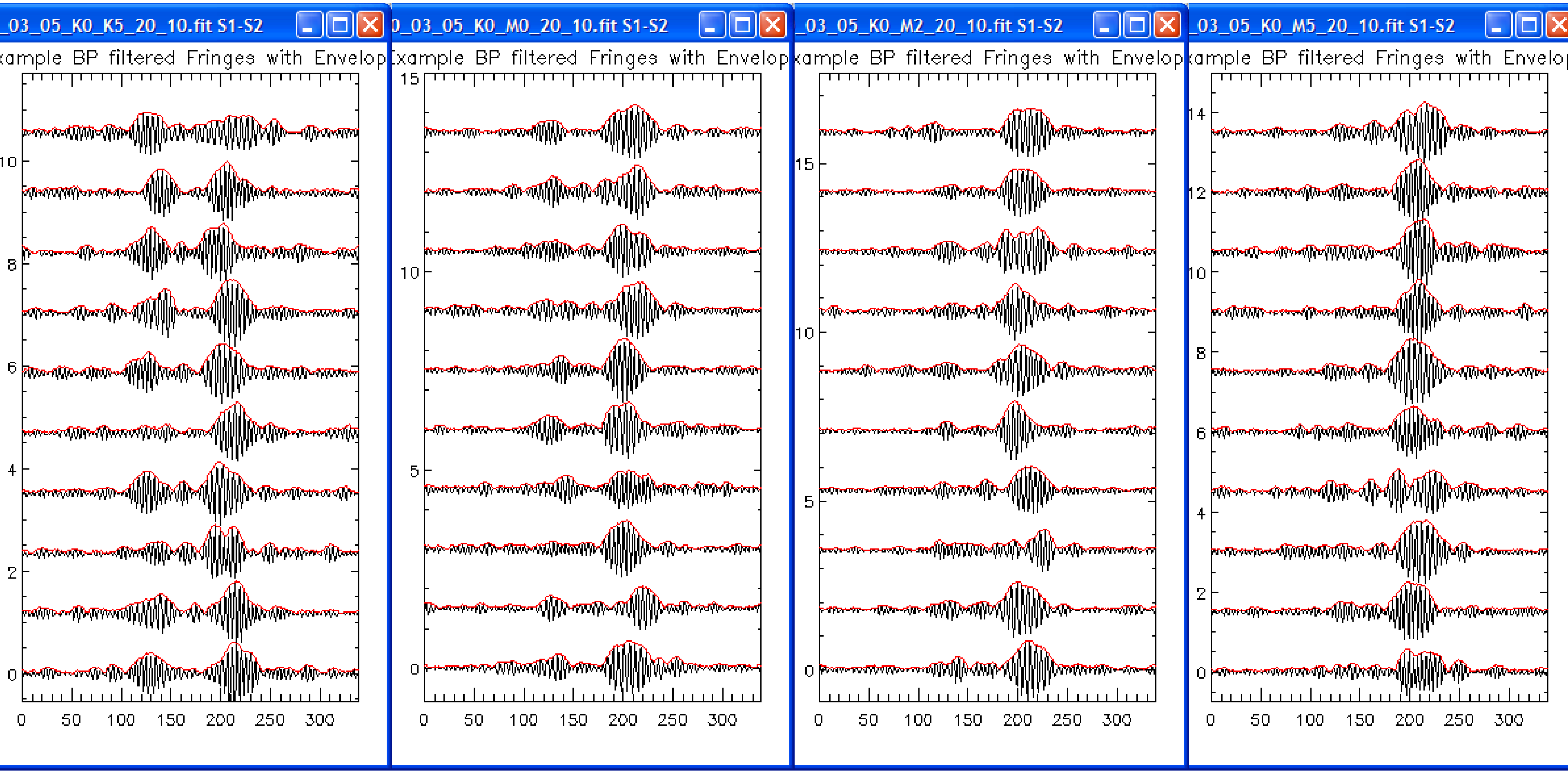


Comp M2, dK=2.6



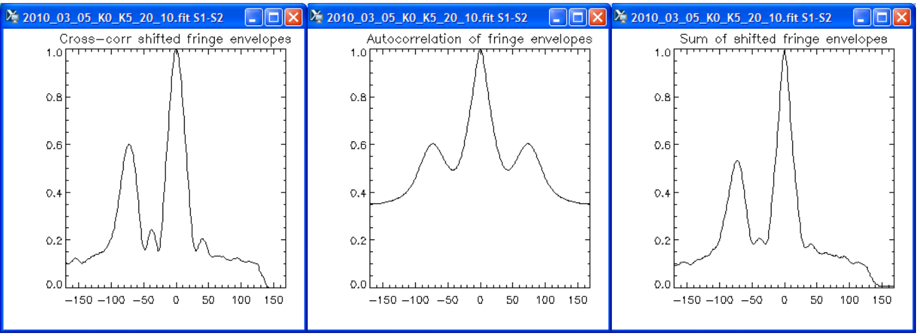
Varying Contrast: K0, R0=10, Sep=20 mas

Comp K5, dK=0.5 | Comp M0, dK=1.1 | Comp M2, dK=1.7 | Comp M5, dK=2.9

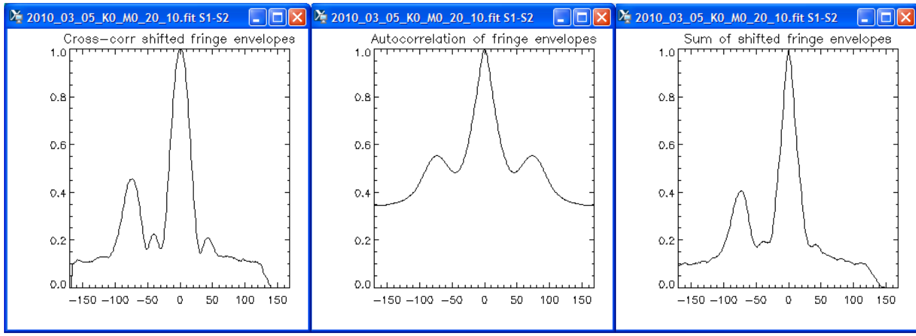


Varying Contrast: K0, R0=10, Sep=20 mas

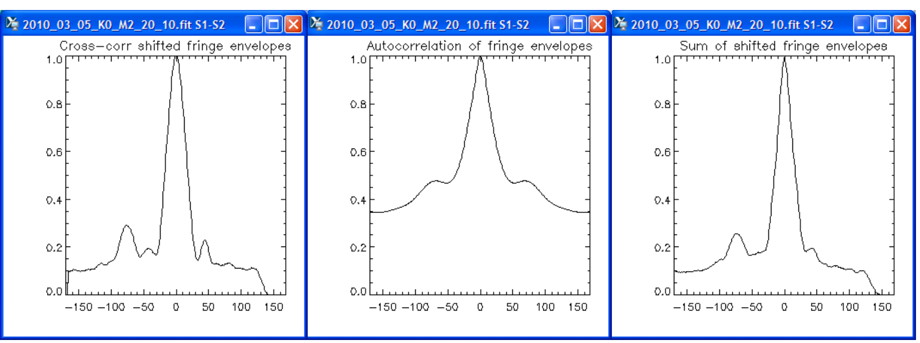
Comp K5, dK=0.5



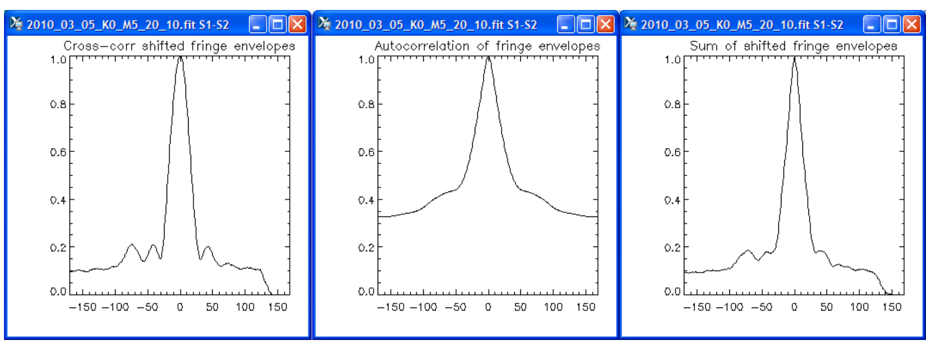
Comp M0, dK=1.1



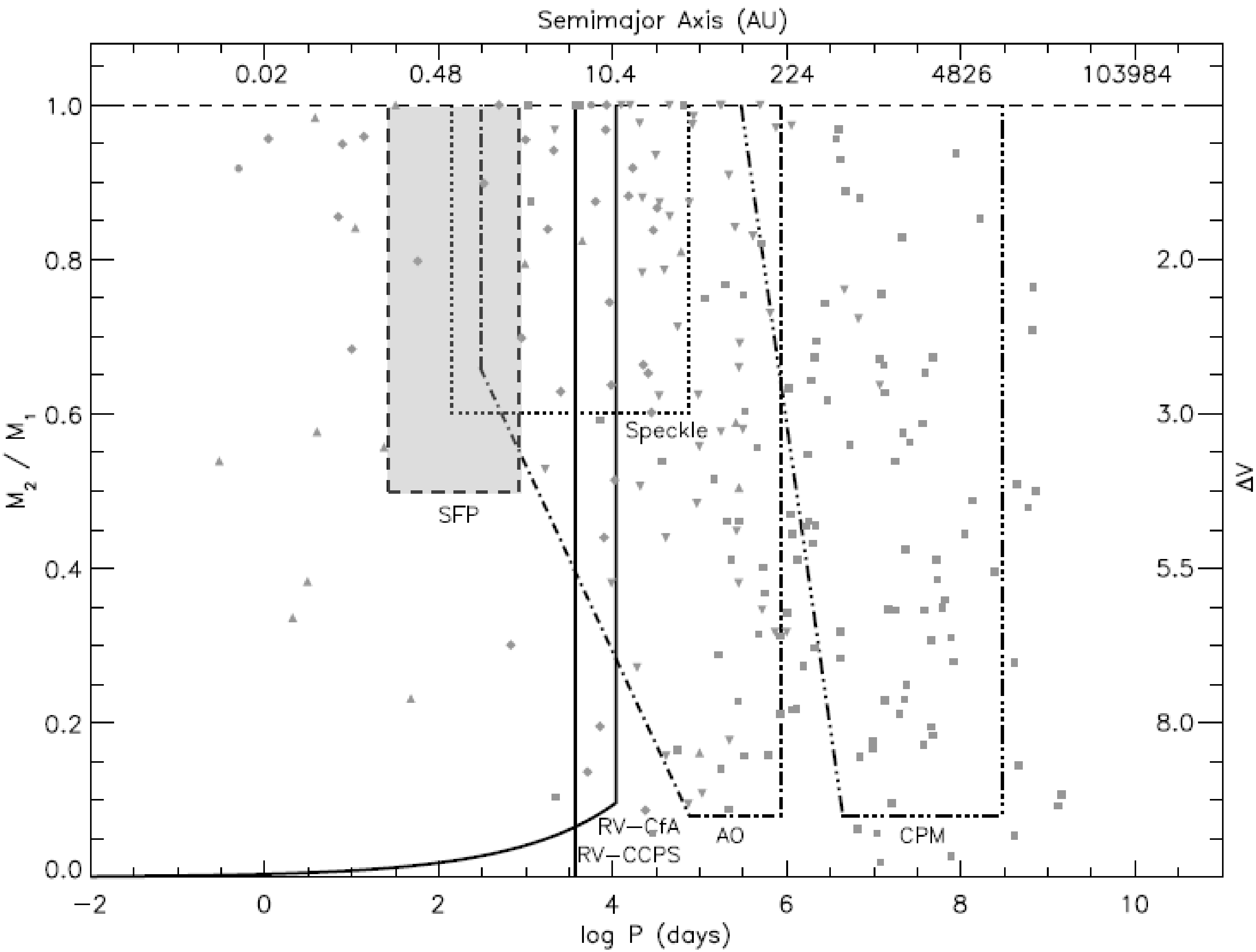
Comp M2, dK=1.7



Comp M5, dK=2.9



SFP Null Result



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- Motivation for this effort
- The sample of nearby solar-type stars
- Survey methods & observing techniques
- Current Results
  - Multiplicity statistics
  - Orbital elements & physical parameters

Multiplicity Results

	Percentage of stars					
	★	★★	★★★	★★★★	★★★★★	★★★★★★
DM91 observed (N = 164)	57	38	4	1		
DM91 including P(χ^2) < 0.01	51	40	7	2		
DM91 incompl alysis (q > 0.1)	43					
DM91 single stars (M_2 < 10 M_J)	33					
This work, observed (N = 454)	57±3	33±2	8±1	2±1	0.4	
This work, including candidates	55±3	34±2	9±2	2±1	0.2	0.2
This work, incompl analysis (q > 0.01)	54±3	35±2	9±2	2±1		
Among Planetary Systems						
Raghavan et al. 2006 (N = 131)	77	21	2			
This work, observed (N = 34)	68	29	3			
This work, planet-host frequency	8±2	7±2	3±3			

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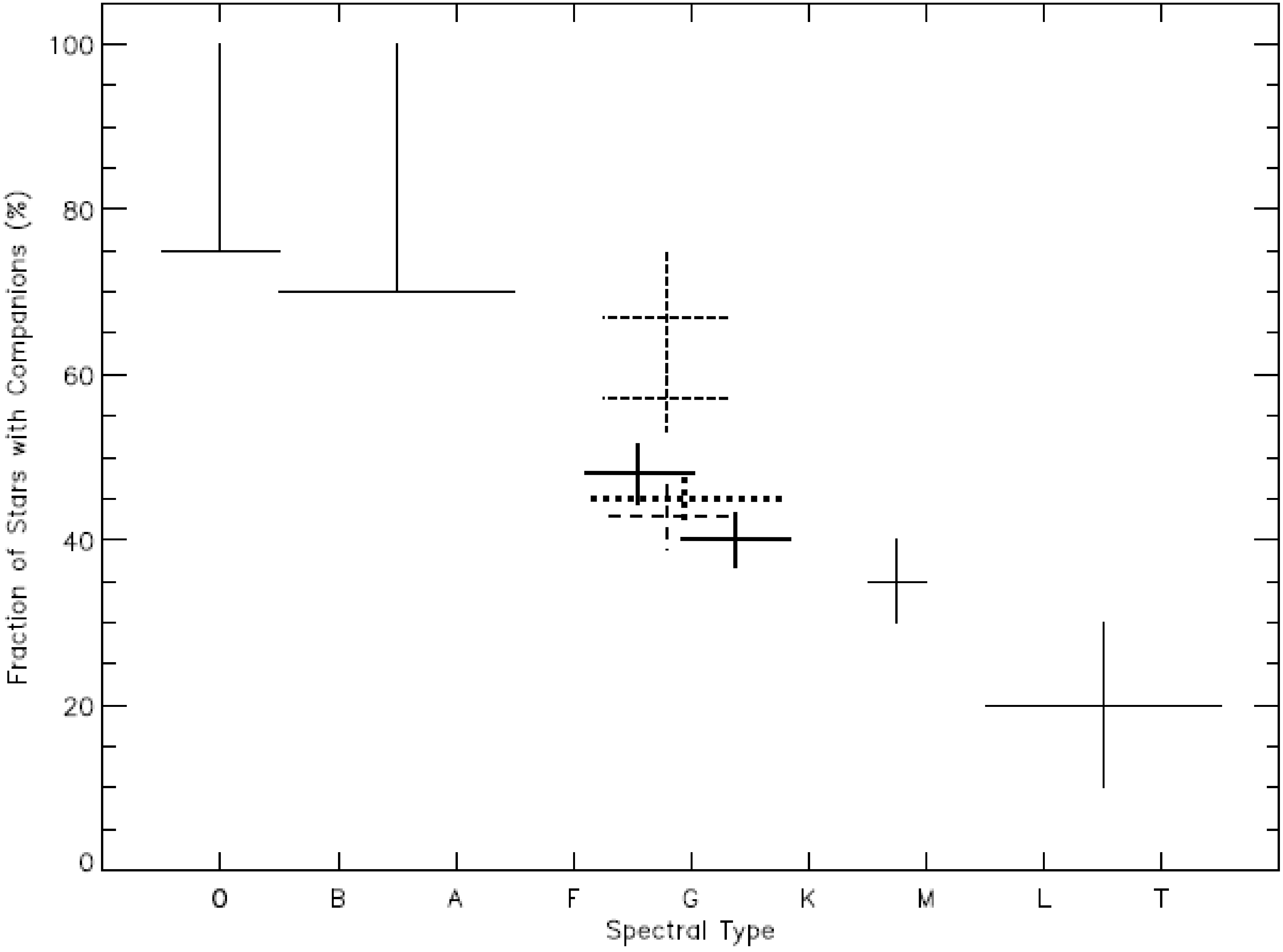
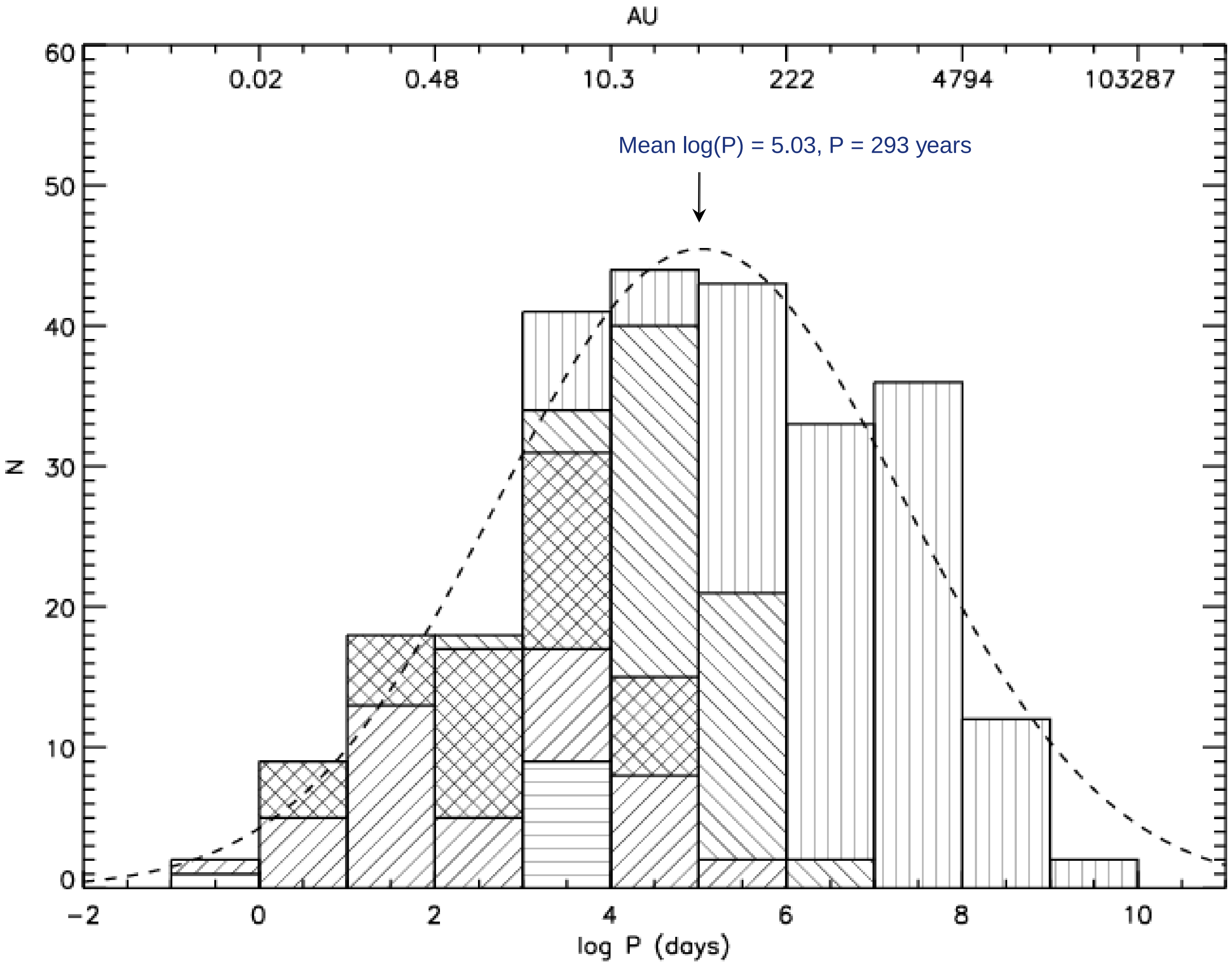
Multiplicity by Spectral Type

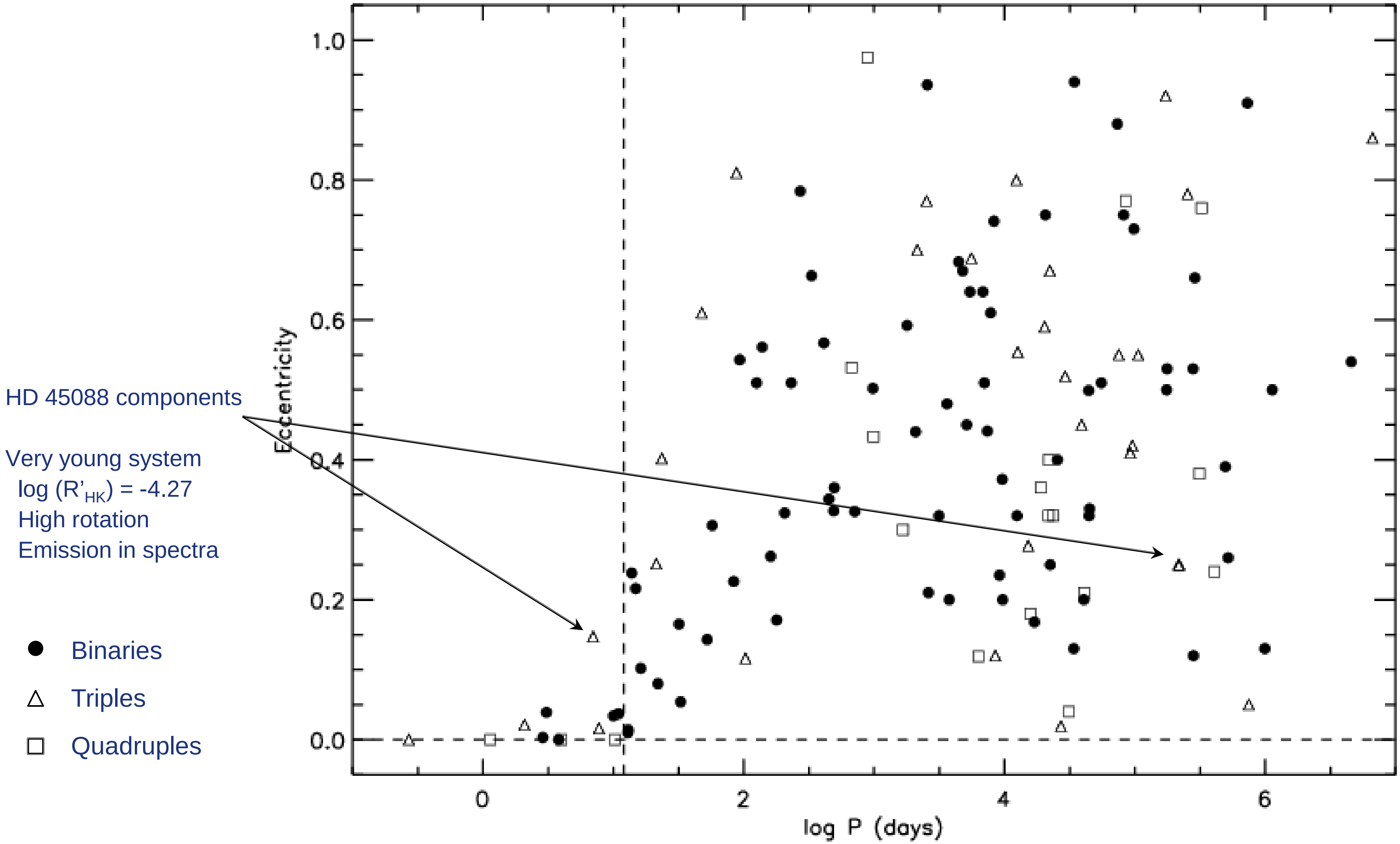


Period Distribution



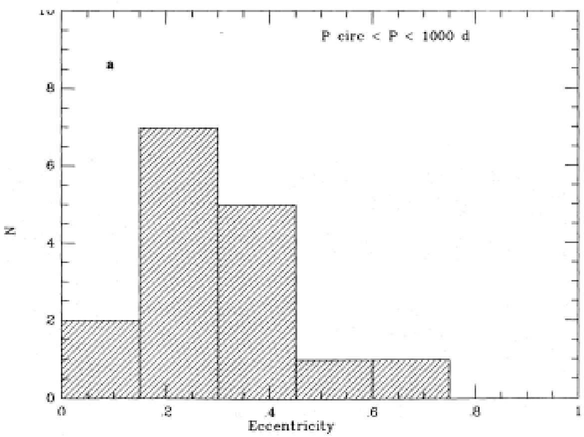
- Significant overlap of techniques in all but the longest period bins (SB, VB gap closed)
- 66% of pairs have separations greater than 10 AU, leaving room for planets

Period-Eccentricity Relationship

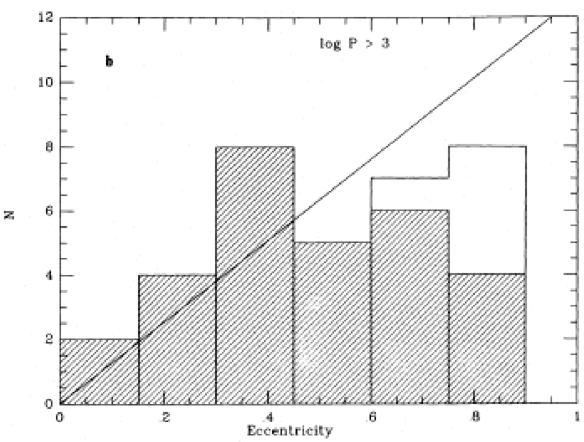


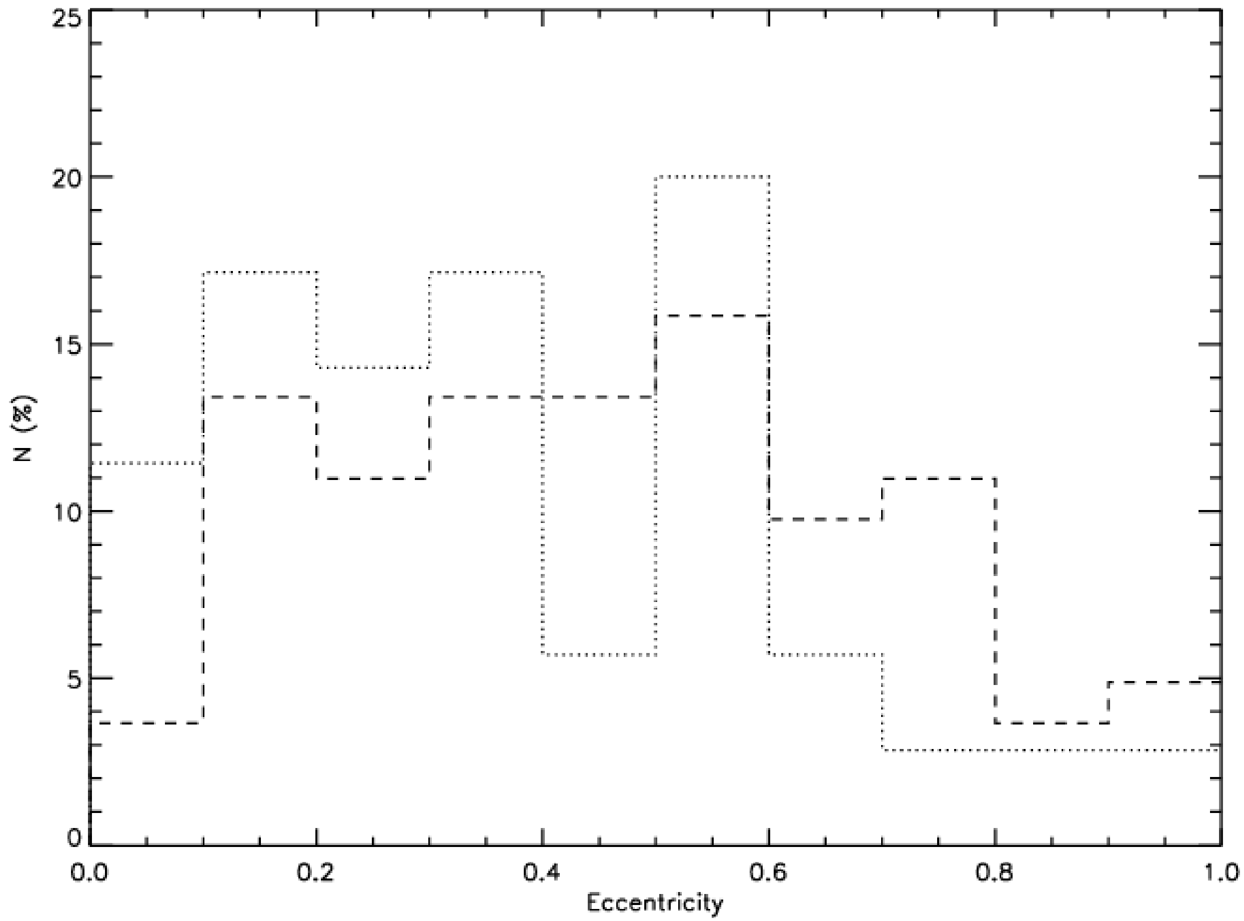
- Consistent with DM91, components of triples seen to have higher eccentricity
- Period < 12 days circularized

Eccentricity Distribution



DM91 results



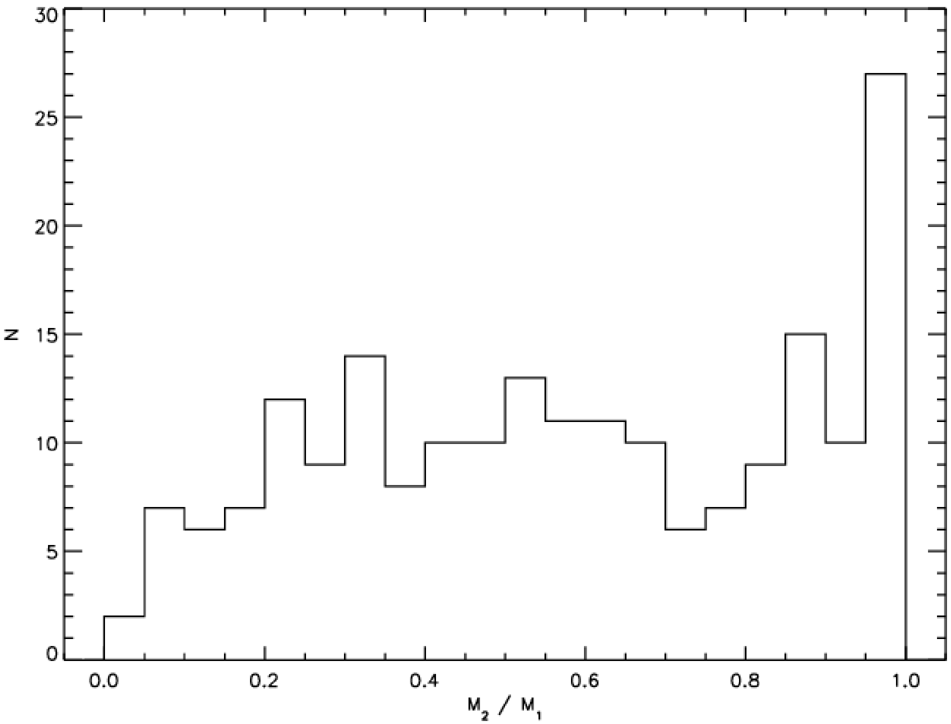


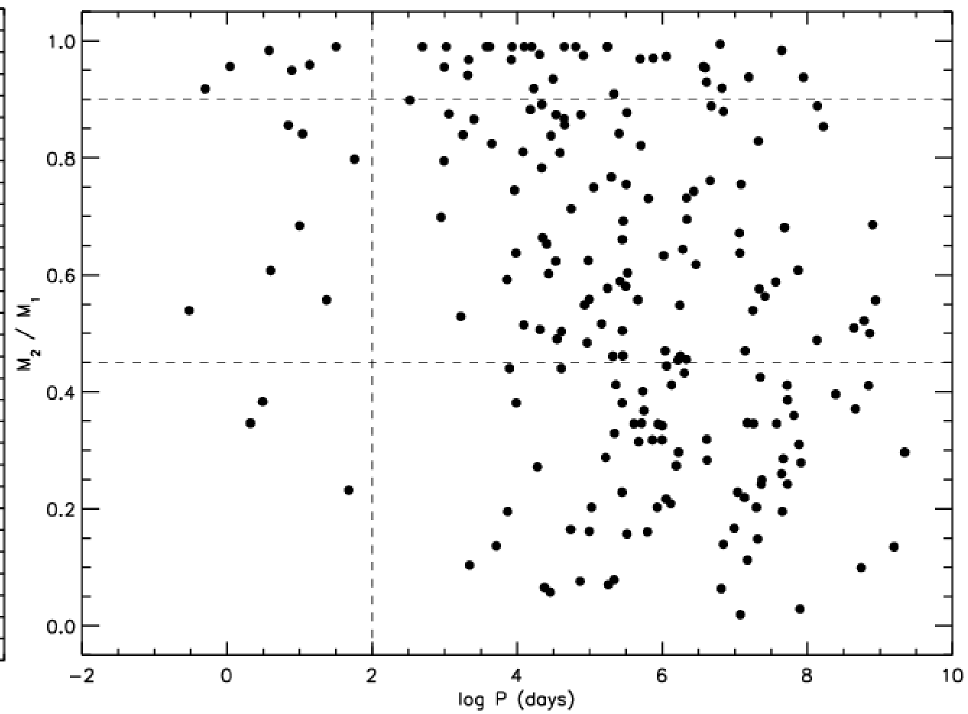
In contrast to DM91, no relationship is seen between period and eccentricity distribution

P < 1000 days (35 systems)

P > 1000 days (82 systems)

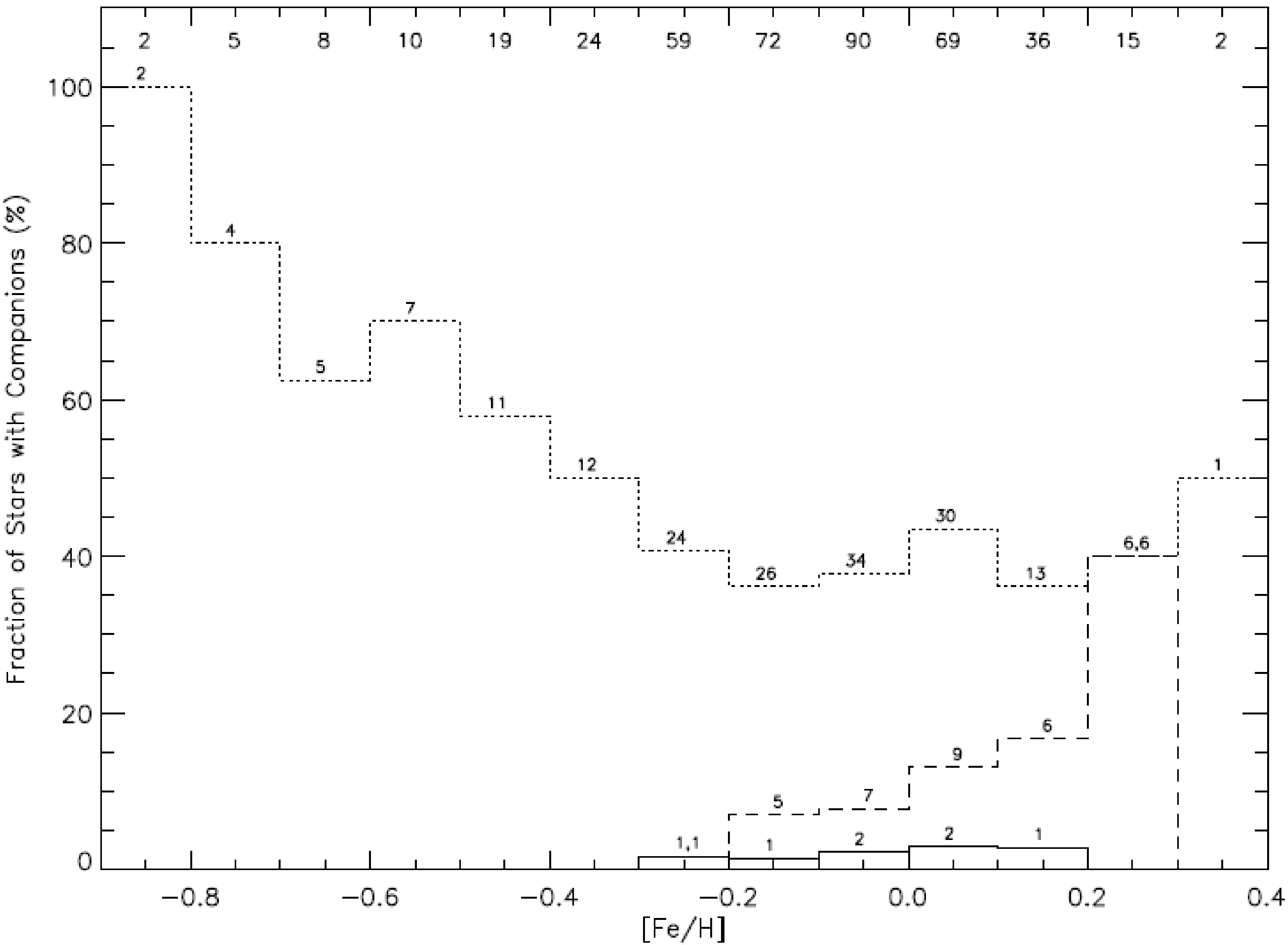
Mass-Ratio Distribution





- Another departure from DM91
  - Twins are definitely preferred (consistent with Abt & Levy 1976)
- Correlation between mass-ratio and period
  - Percentage of systems with P < 100 days
    - 4% for mass-ratio < 0.45; 8% for 0.45 < mass-ratio < 0.9; 16% for mass-ratios > 0.9
- Twins are not confined to short-period systems

Effect of Metallicity on Multiplicity



Conclusions

- Large sample of solar-type stars, comprehensive survey
- SFP survey identified no new companions
  - **Gap between spectroscopic and visual companions bridged**
- **CPM search revealed four new companions**
- **Robust RV coverage**
  - 4 new companions in CfA data, 2 in CCPS data
- **Majority (55% ± 3%) of solar-type stars are single**
- More massive and younger stars are more likely to have companions
- Period distribution is Gaussian with a mean of about 300 years
- Eccentricity distribution is largely flat beyond circularization regime
- **Twins are preferred, suggesting multiple formation mechanisms**
- **Planets are equally likely to form around single, binary, and multiple stars**
  - Most stellar companions are wide, implying larger real-estate for planets