

# NEARBY RED DWARFS & THEIR DANCE PARTNERS: THE MULTIPLICITY OF OUR LOW-MASS NEIGHBORS

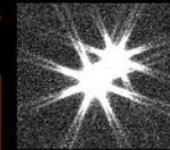
JEN WINTERS

3 July 2017



HARVARD-SMITHSONIAN  
CENTER FOR ASTROPHYSICS

The  
MEarth  
Project



RECONS  
Research Consortium on Nearby Stars

# MOTIVATION

- **What fraction of M dwarf systems are multiples?**
- **Where are the companions to M dwarfs found?**
- **How much mass is in multiple systems, & what is the distribution of that mass?**
- **How do M dwarf systems evolve over time?**
- **Are star systems primarily singles or multiples?**

# M DWARF PROPERTIES

- **MASSES:**  $0.075 - 0.64 M_{\odot}$
- **RADII:**  $0.1 - 0.6 R_{\odot}$
- **LUMINOSITIES:**  $0.02\% - 6\% L_{\odot}$
- **TEMPERATURES:**  $2400 - 3900 \text{ K}$
- **COLORS:**  $3.7 \leq (V-K) \leq 9.5$
- $8.8 < M_V < 20.0$

Tarter+ 2007  
Benedict+ 2016  
RECONS

# PREVIOUS NEARBY M DWARF MULTIPLICITY SURVEYS

Reference	# of Targets	Technique	Notes
Skrutskie+ (1989)	55	Infrared Imaging	Mult. Fr. not given
Henry & McCarthy (1990)	27	Infrared Speckle	BD search
Henry (1991)	74	Infrared Speckle	Amazing!!!
Fishcher & Marcy (1992)	28-62	Various	Varied Sample
Tokovinin (1992)	200	Radial Velocity	K's&M's; BD search
Simons+ (1996)	63	Infrared Imaging	BD search
Delfosse+ (1999)	127	Radial Velocity	Mult. Fr. not given
Endl+ (2006)	90	Radial Velocity	Jovian search
Law+ (2006)	32	Lucky Imaging	M5 – M8
Law+ (2008)	77	Lucky Imaging	Later M's
Bergfors+ (2010)	124	Lucky Imaging	Young M0 – M6
Law+ (2010)	36	Adaptive Optics	Wide binary search
Dieterich+ (2012)	126	HST-NICMOS	BD search

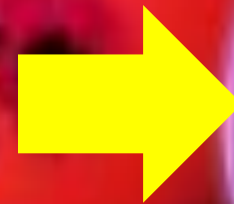
**ANSWER:**

**7 – 42 %**

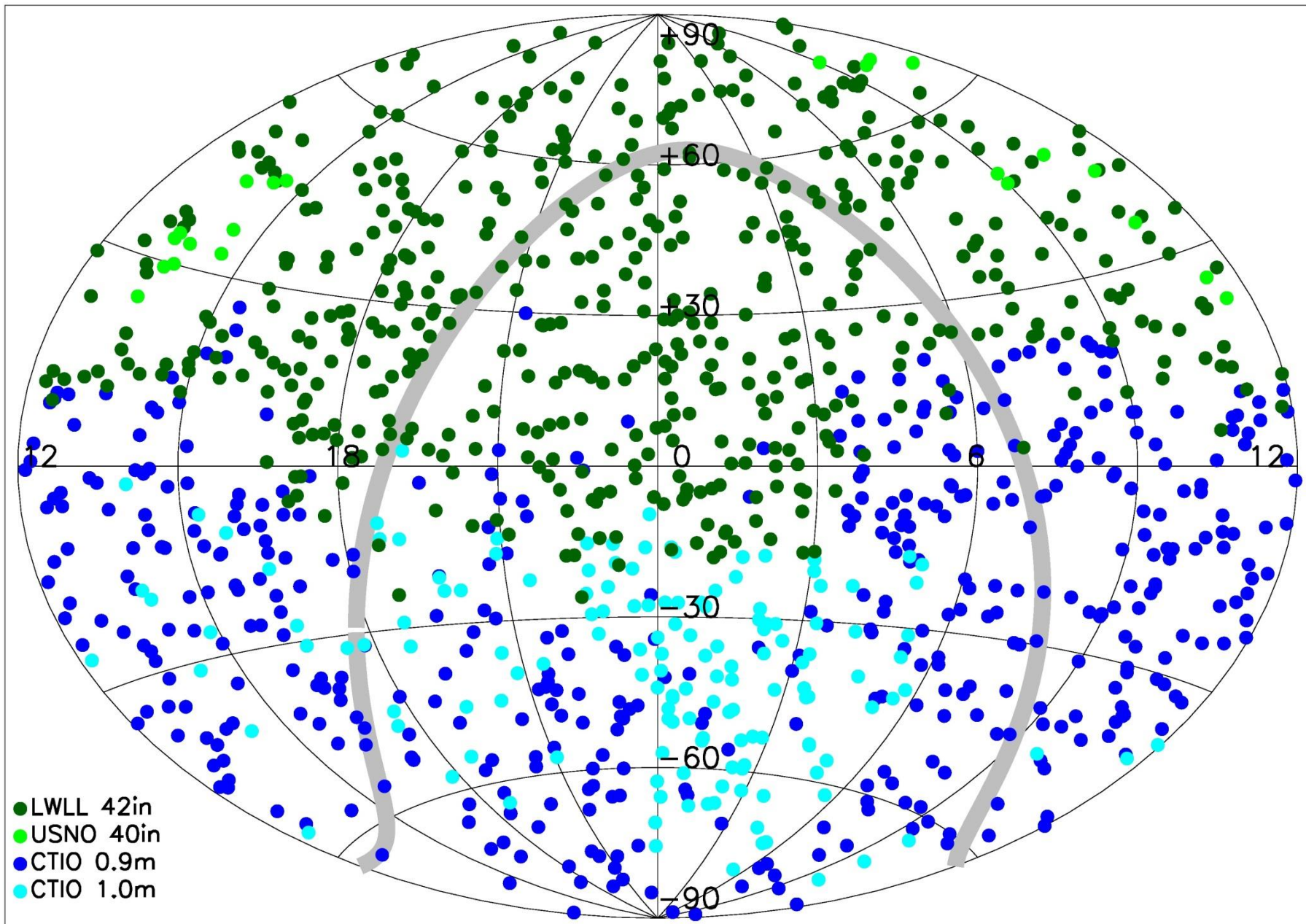
**MY GOAL:  
LOOK AT > 1000  
M DWARFS FOR  
COMPANIONS**

# DEFINING THE SAMPLE

- ALL-SKY
- NO PROPER MOTION LIMITS
- COLORS:  $3.7 \leq (V-K) \leq 9.5$
- $8.8 \leq M_V \leq 20.0$
- $\pi \geq 40 \text{ mas}, \sigma_\pi \leq 10 \text{ mas}$
- NO WHITE DWARFS
- NO BROWN DWARFS



**1121**  
**Systems**

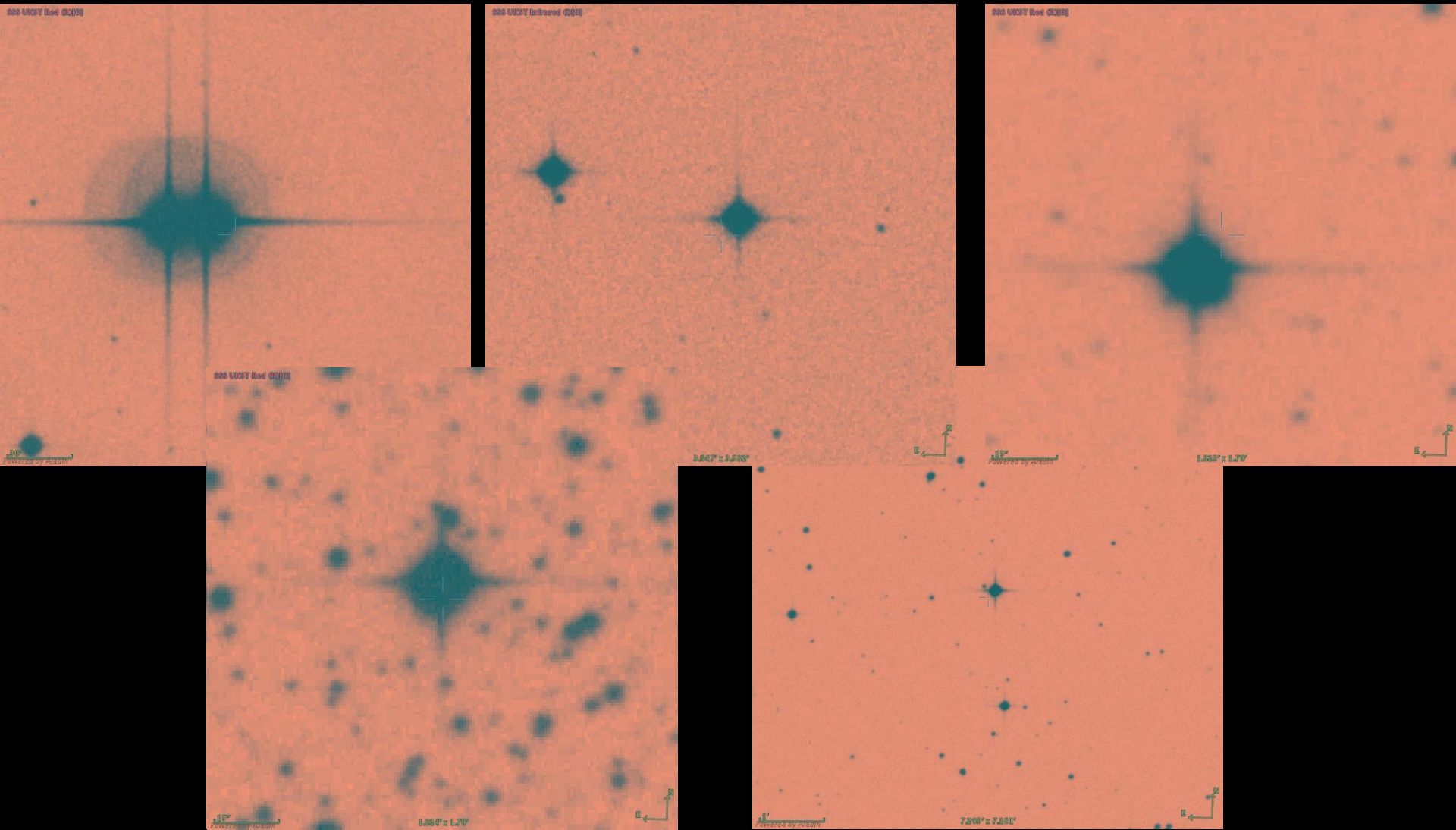




# SEARCH REGIONS

- *Literature Search*
- **Wide Separations: 5 – 300''**  
**(50 – 7500 AU)**

# WIDE COMPANIONS



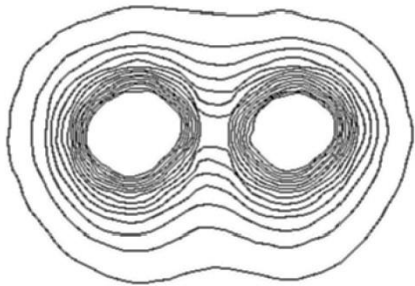
# SEARCH REGIONS

- *Literature Search*
- **Wide Separations: 5 – 300''**  
(50 – 7500 AU)
- **Close Separations: 2 – 5''**  
(20 – 125 AU)

# CLOSE COMPANIONS

Lowell Obs. +  
Cerro Tololo Obs.  
Separations:  
2 - 5" (20 - 125 AU)

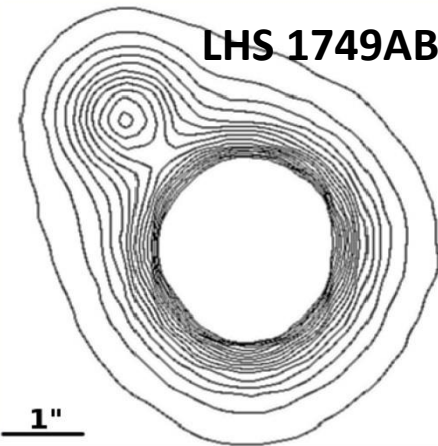
LHS 225AB



$\Delta I = 0.1$   
 $\rho = 2.5''$

$\Delta I = 1.0$   
 $\rho = 1.6''$

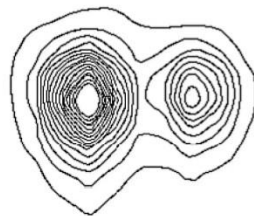
LHS 1749AB



$\Delta V = 3.0$   
 $\rho = 2.9''$

$\Delta I = 0$   
 $\rho = 1.1''$

SCR 0644-4223AB



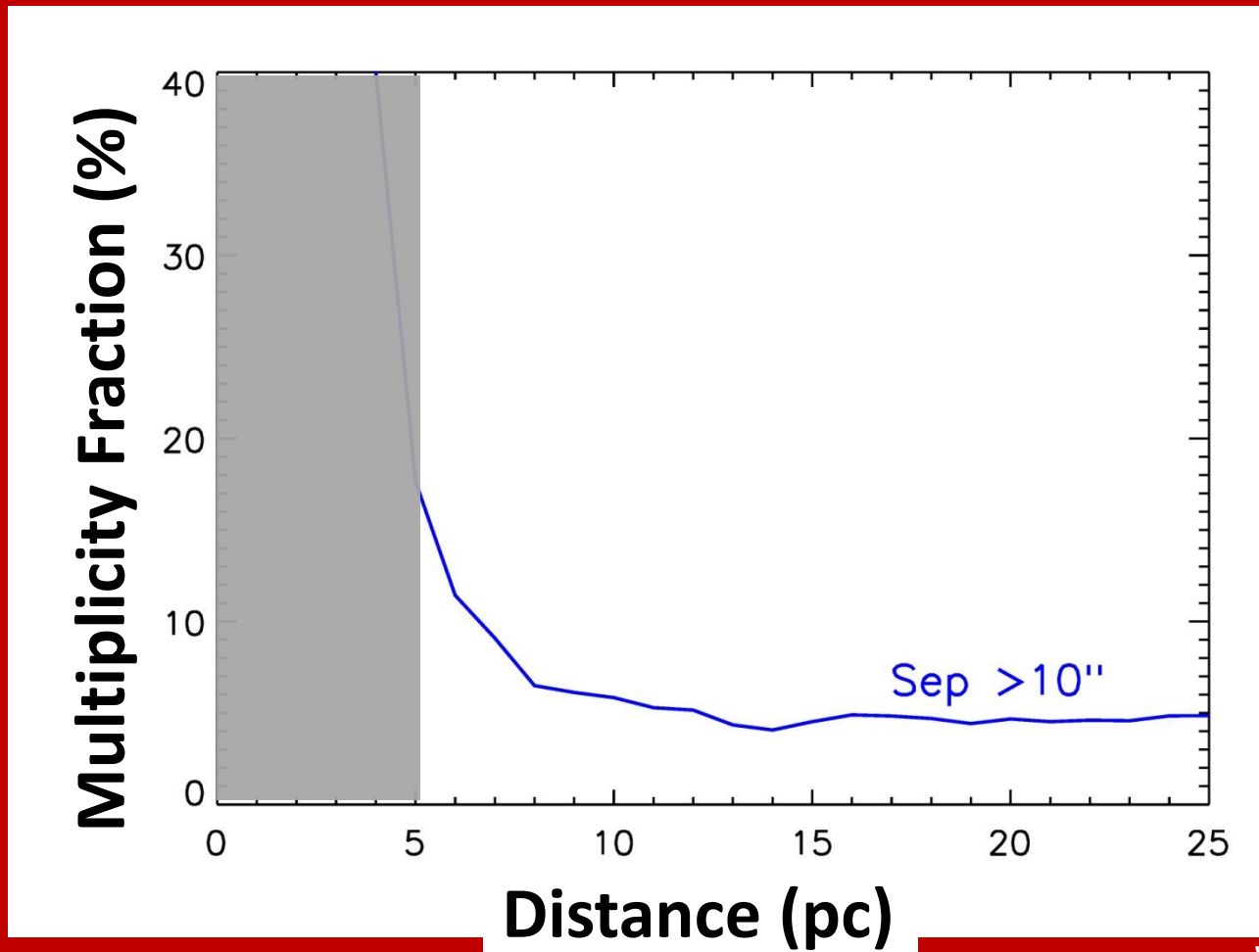
SCR 1856-4704AB



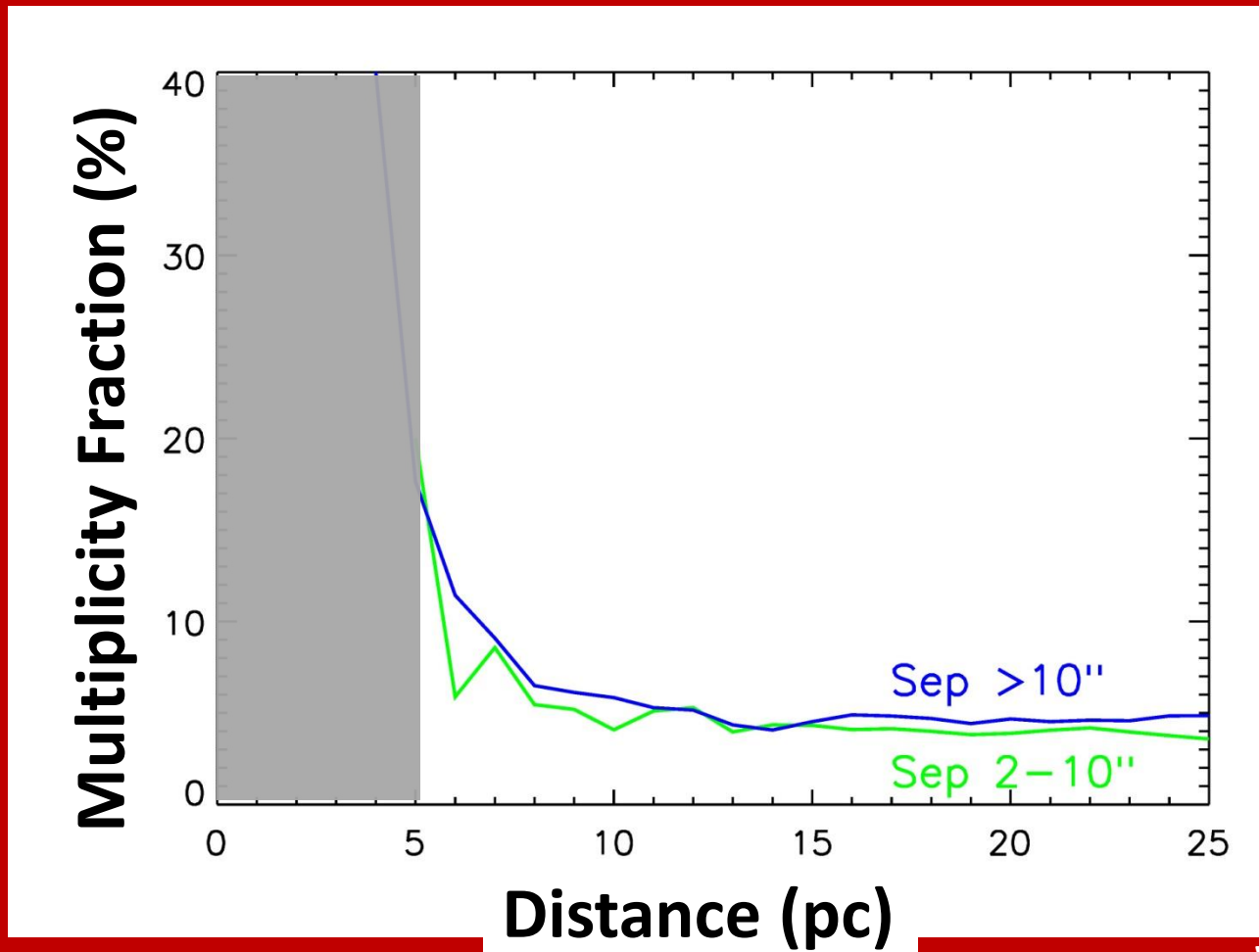
# SEARCH REGIONS

- *Literature Search*
- **Wide Separations: 5 – 300''**  
(50 – 7500 AU)
- **Close Separations: 2 – 5''**  
(20 – 125 AU)
- **Even Closer Separations: < 2''**  
(< 50 AU)

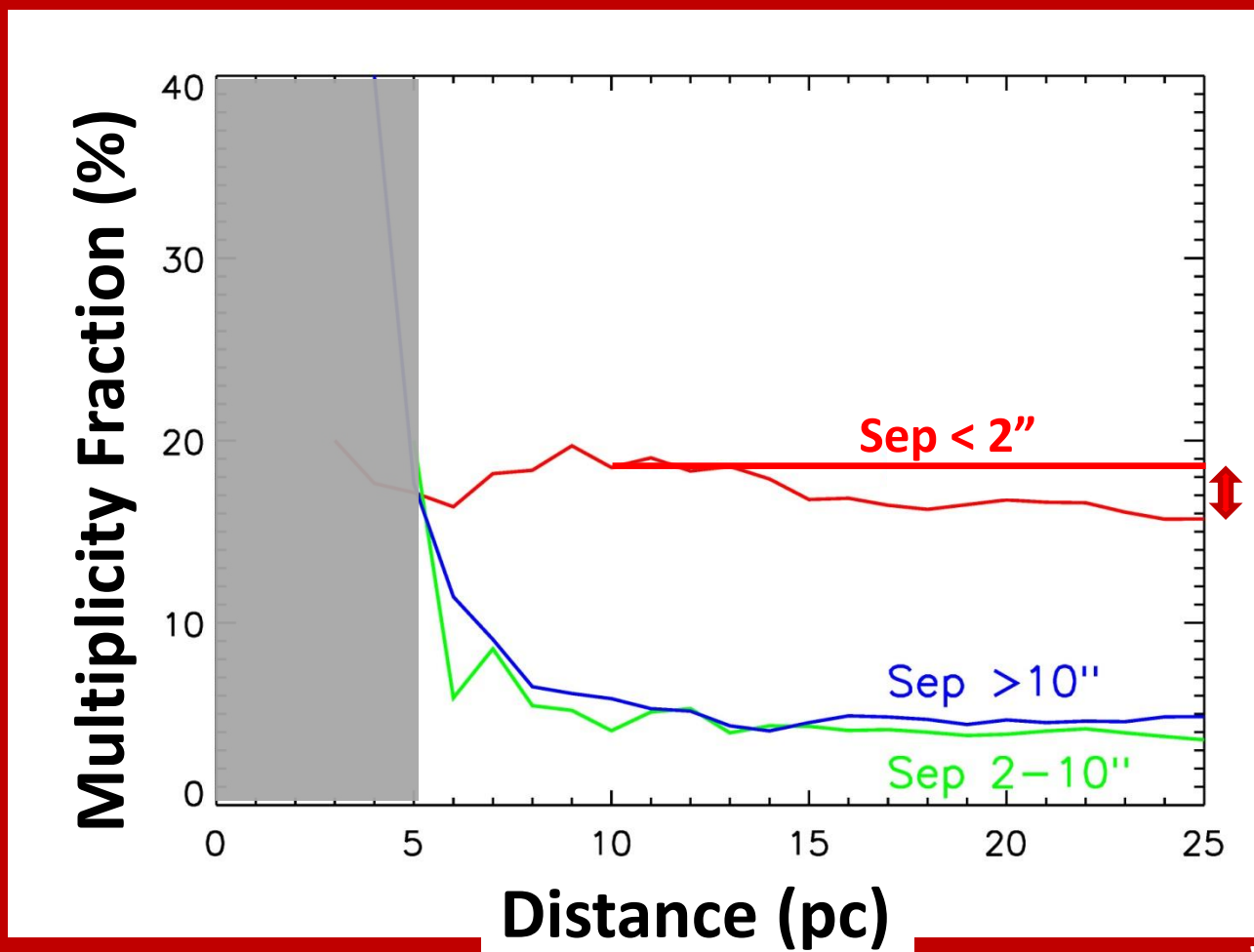
# CORRECTING THE MULTIPLICITY FRACTION



# CORRECTING THE MULTIPLICITY FRACTION

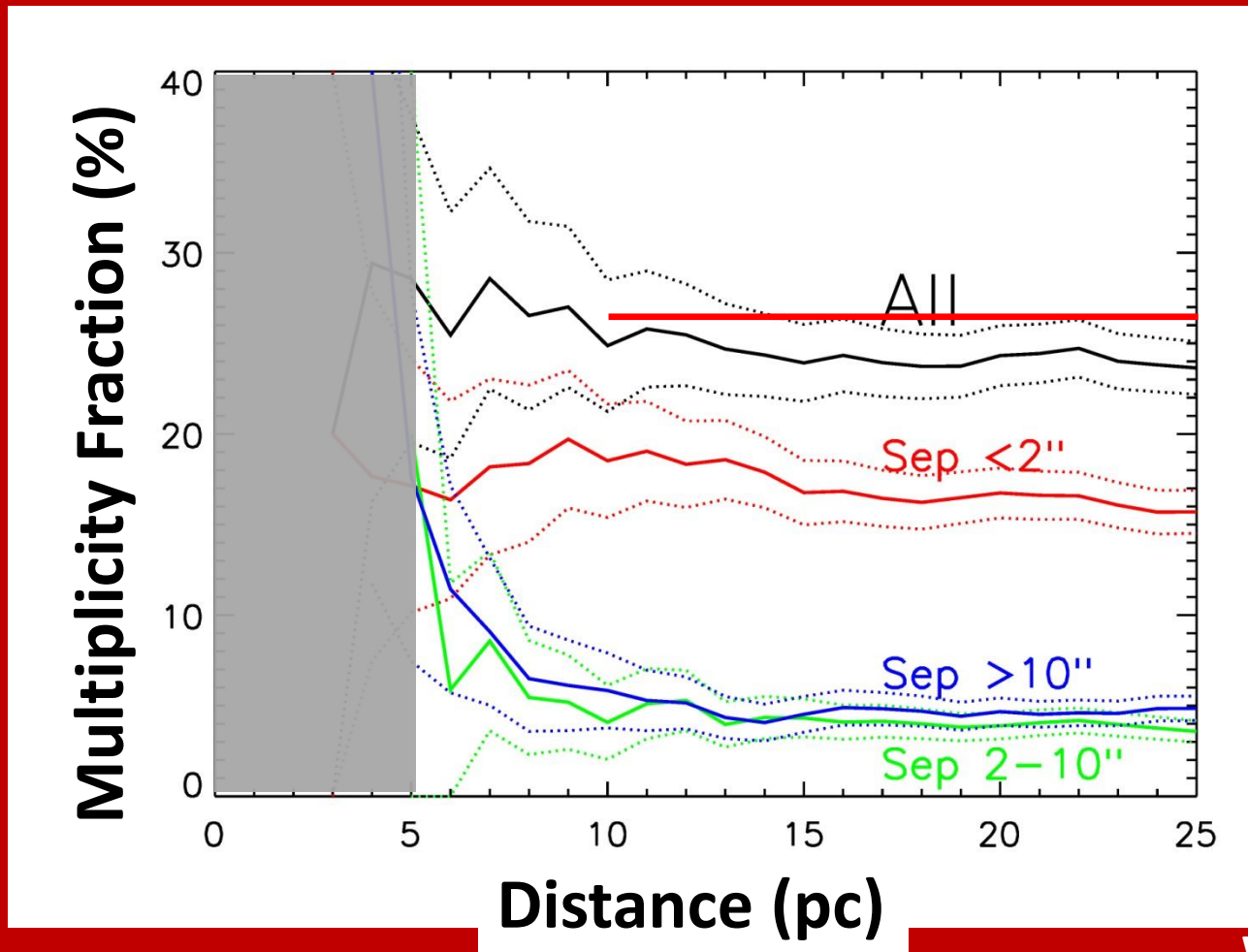


# CORRECTING THE MULTIPLICITY FRACTION





# CORRECTING THE MULTIPLICITY FRACTION



# M DWARF MULTIPLICITY

**26%  $\pm$  1.3%**

# M DWARF MULTIPLICITY

**26%  $\pm$  1.3%**



**Singles**

**856**

**( 77%**

# M DWARF MULTIPLICITY

**26%  $\pm$  1.3%**

**Singles:Binaries**

**856 :223**

**( 77% :20%**



# M DWARF MULTIPLICITY

**26%  $\pm$  1.3%**

**Singles:Binaries:Triples**

**856 :223 :39**

**( 77% :20% :3%**



Winters, in prep

# M DWARF MULTIPLICITY

**26%  $\pm$  1.3%**

**Singles:Binaries:Triples:Quads**

**856 :223 :39 :1**

**( 77% :20% :3% :0.1%**



Winters, in prep

# M DWARF MULTIPLICITY

**26%  $\pm$  1.3%**

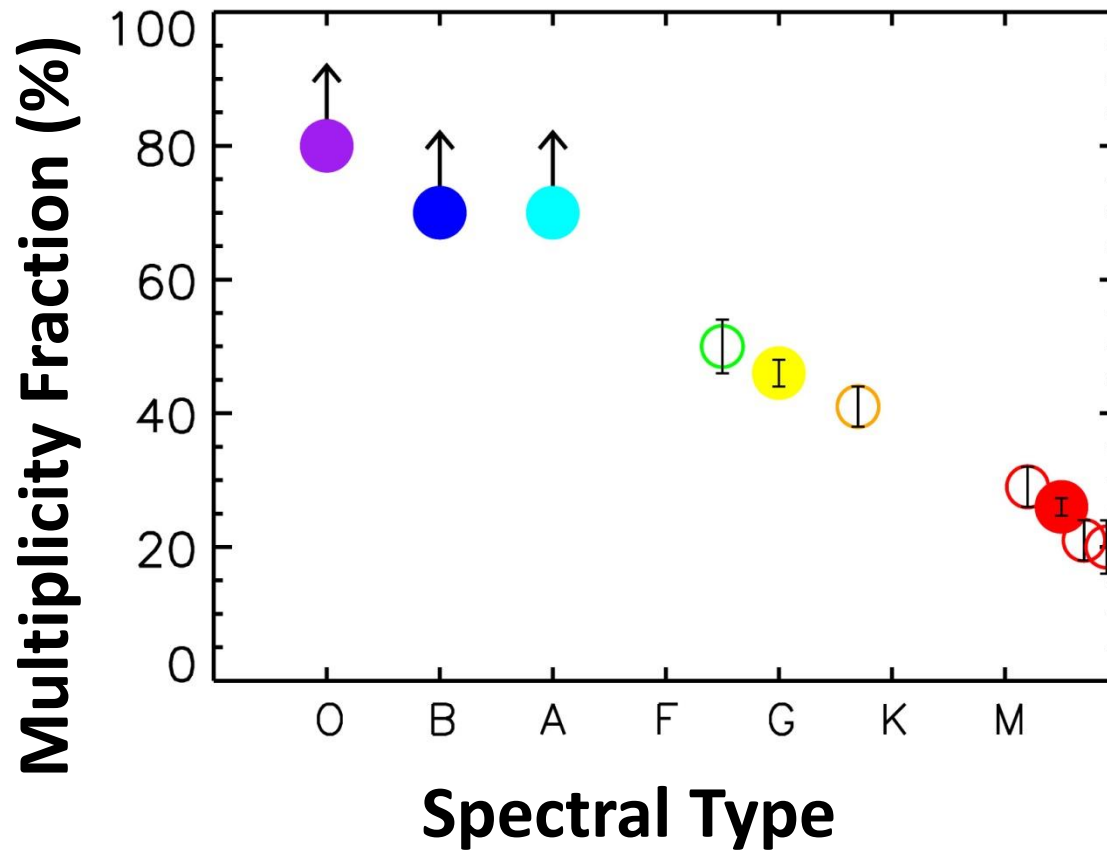
**Singles:Binaries:Triples:Quads:Quins**

**856 :223 :39 :1 :2**  
**( 77% :20% :3% :0.1% :0.2%)**



Winters, in prep

# MULTIPLICITY IN CONTEXT



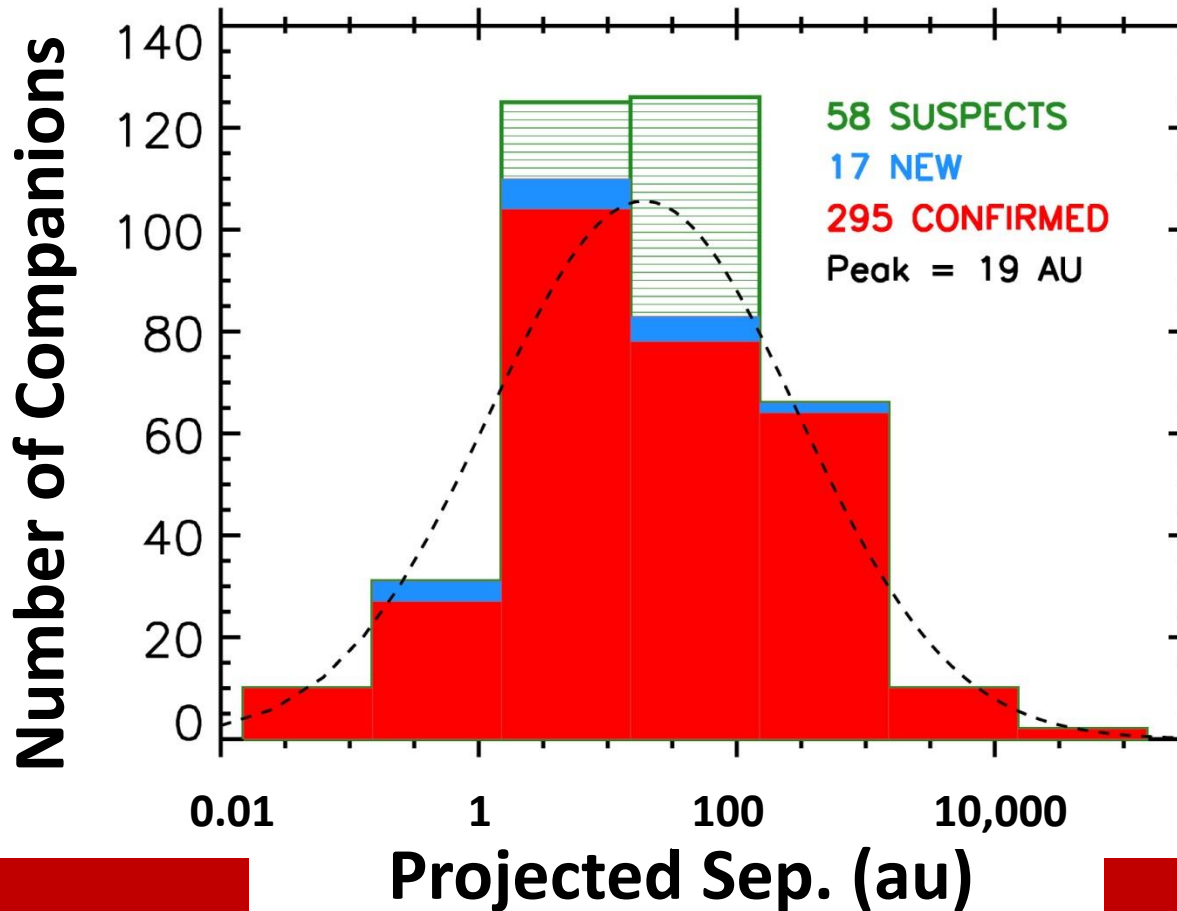


# ARE MOST SYSTEMS SINGLE OR MULTIPLE?

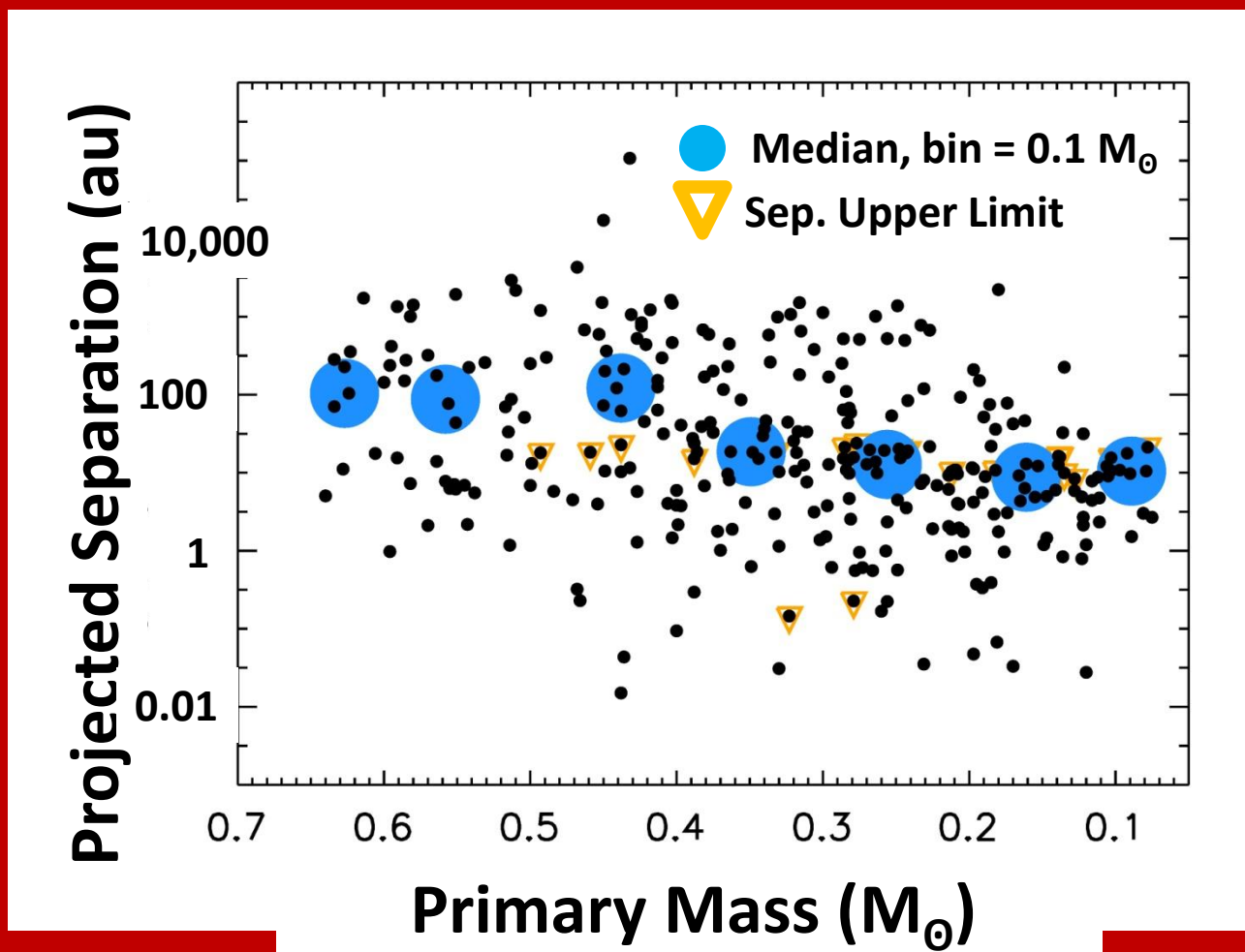
SPECTRAL TYPE	% OF ALL SYSTEMS	MULTIPLICITY FREQUENCY	REFERENCE
O	<0.003	>80	Mason+ 2009
B	0.1	70	Raghavan+ 2010
A			
F			
G			
K	10.2	40?	
M	75	26	This work

**Mult. Fr. ~30%  
FOR ALL SYSTEMS**

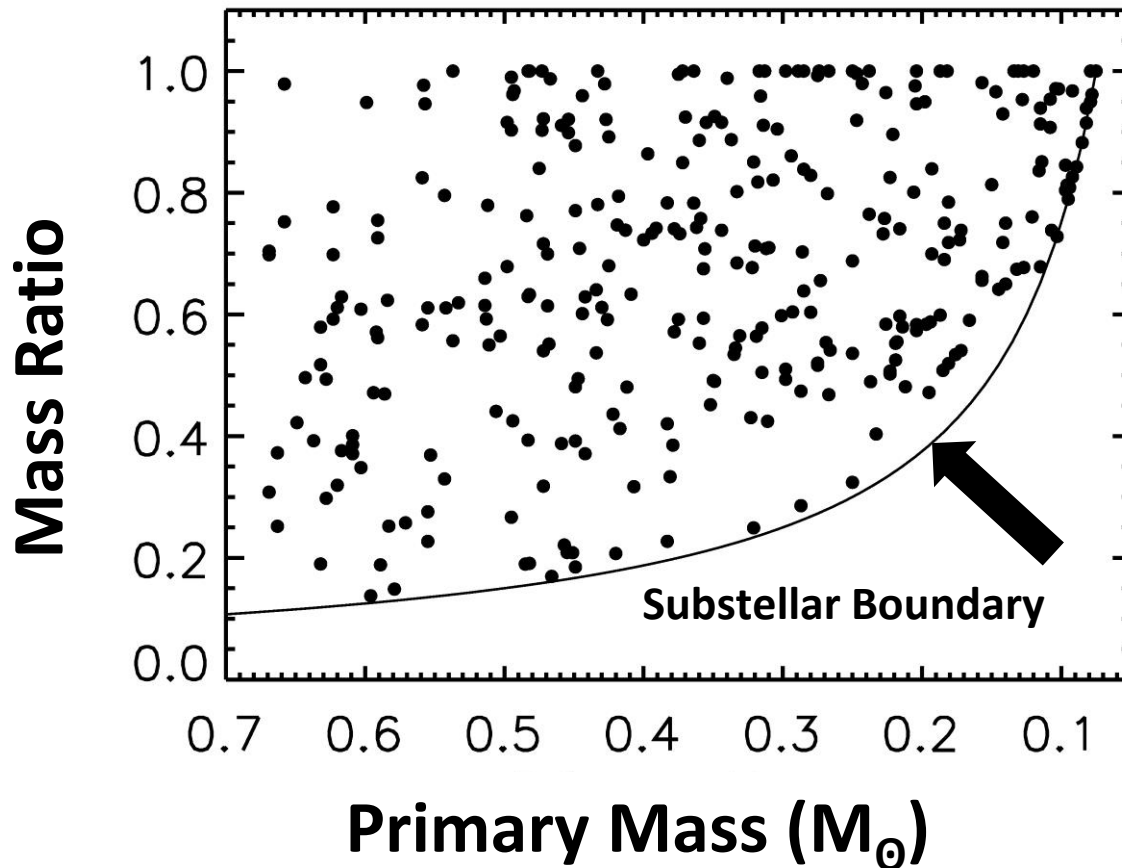
# COMPANIONS TO M DWARFS ARE FOUND AT SOLAR SYSTEM SCALES



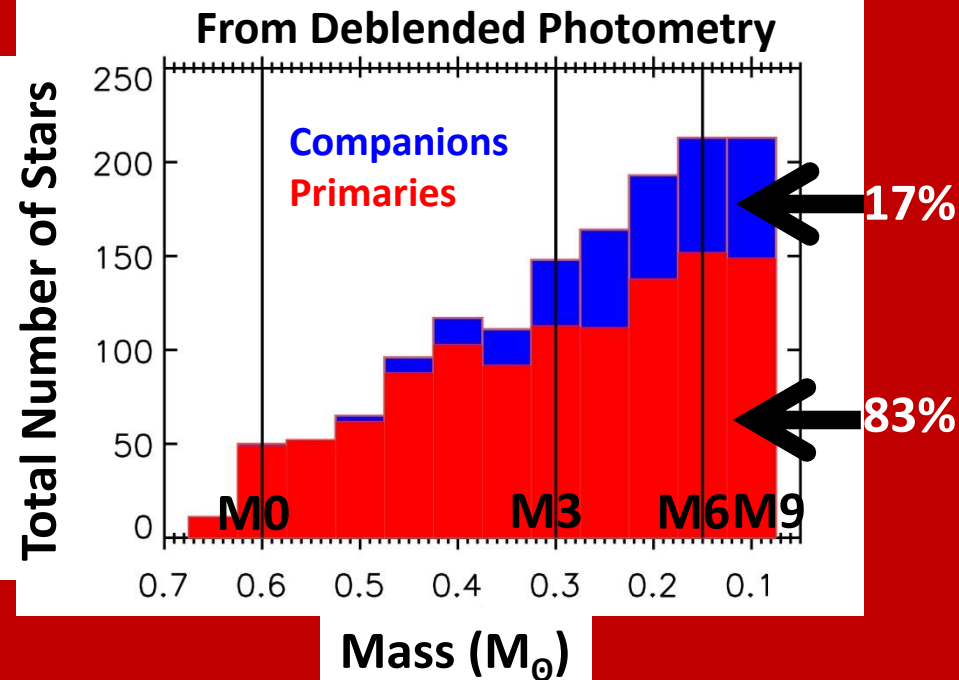
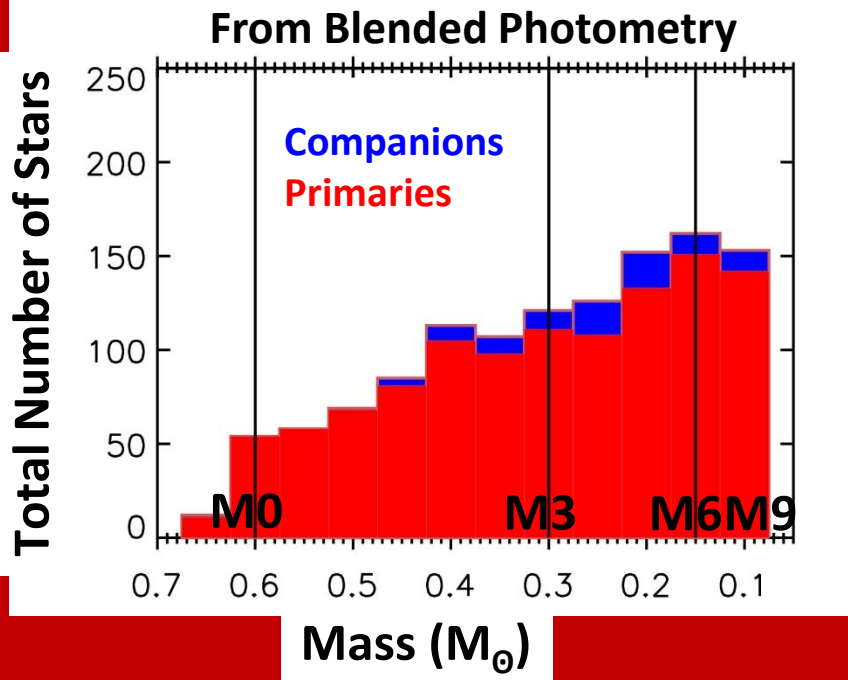
# IS COMPANION SEPARATION A FUNCTION OF PRIMARY MASS?



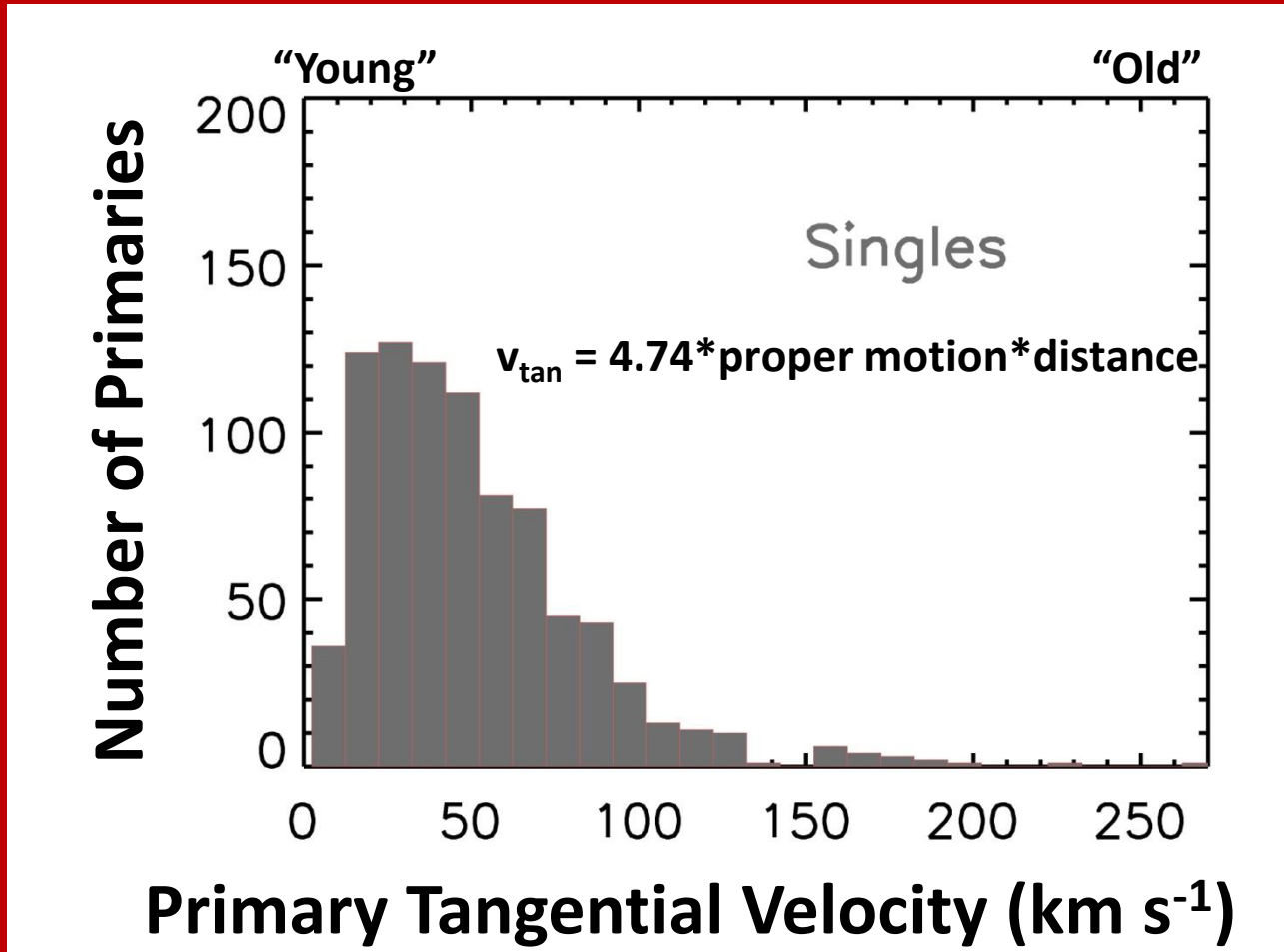
# NO PREFERRED MASS RATIO



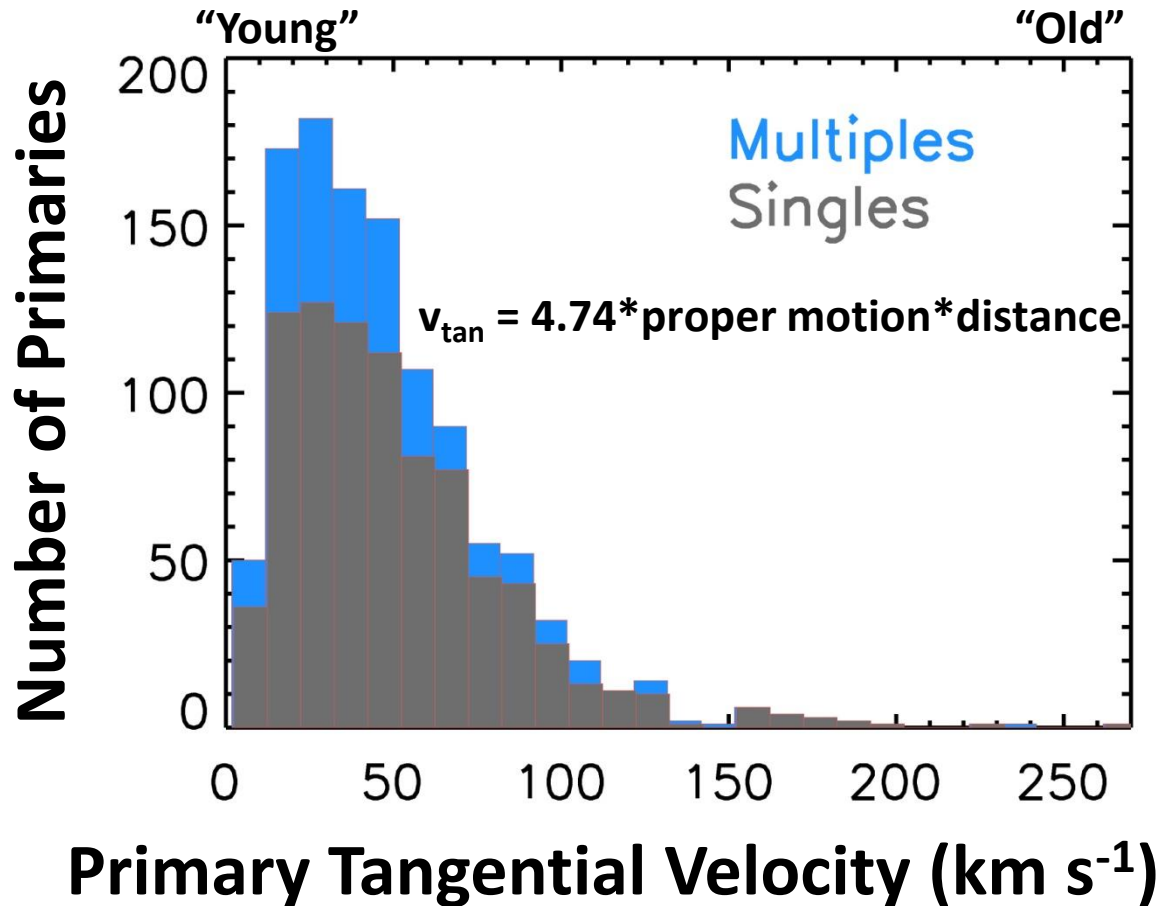
# MASS FUNCTION



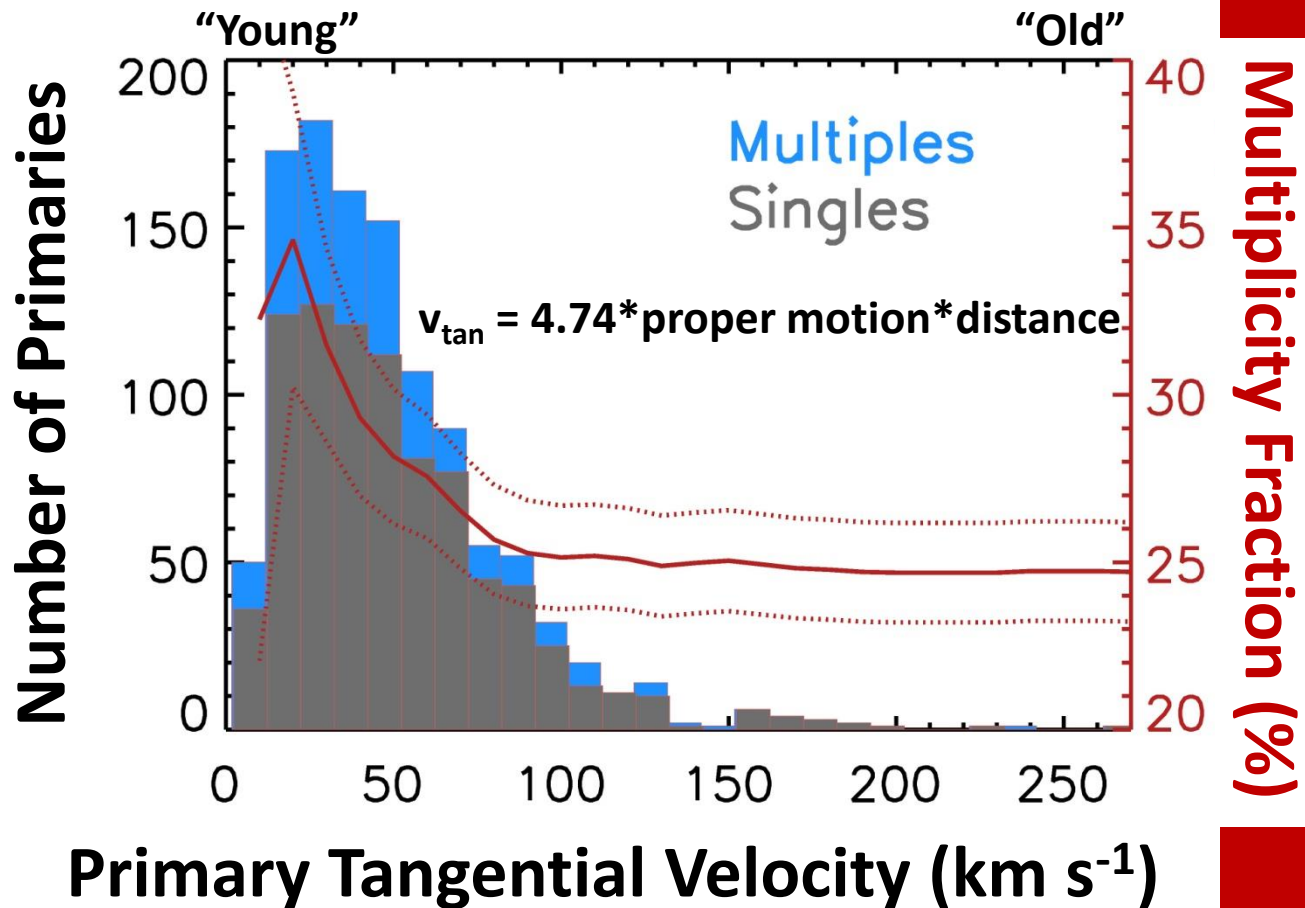
# M DWARF MULTIPLICITY AS A FUNCTION OF AGE



# M DWARF MULTIPLICITY AS A FUNCTION OF AGE

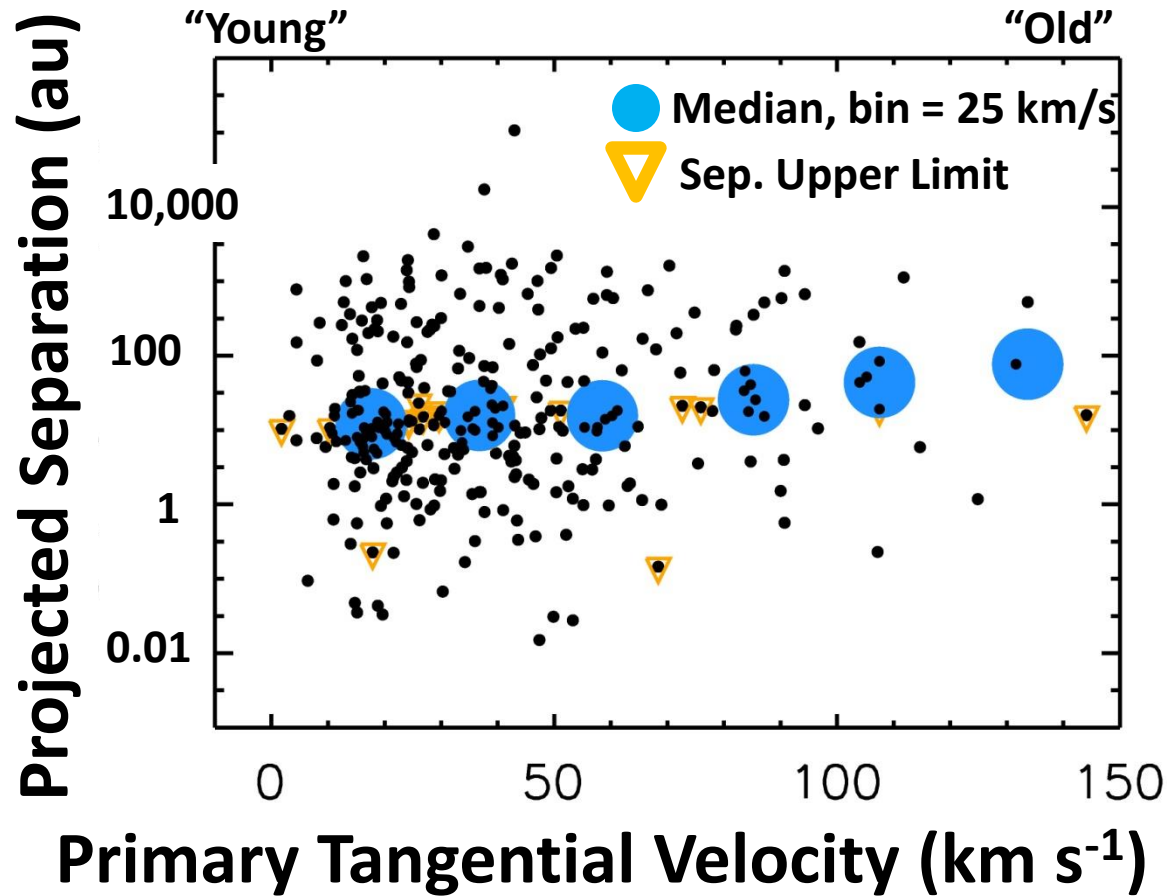


# M DWARF MULTIPLICITY AS A FUNCTION OF AGE





# IS COMPANION SEPARATION A FUNCTION OF AGE?



# RESULTS

- **26%** of M dwarf systems are multiples.
- Companions to M dwarfs are found at **separations on Solar System scales: 1-100 au.**
- Mass function for all M dwarfs **increases** to the end of the main sequence.
- M dwarf multiplicity & age *may* be related.
- *At least* **17% of M dwarf mass** is found in companions.
- Most stellar systems are **single.**

# BIG PICTURE

- The Universe makes LOTS of little stars.
- Most are alone.
- Are they born that way, or do they become separated?

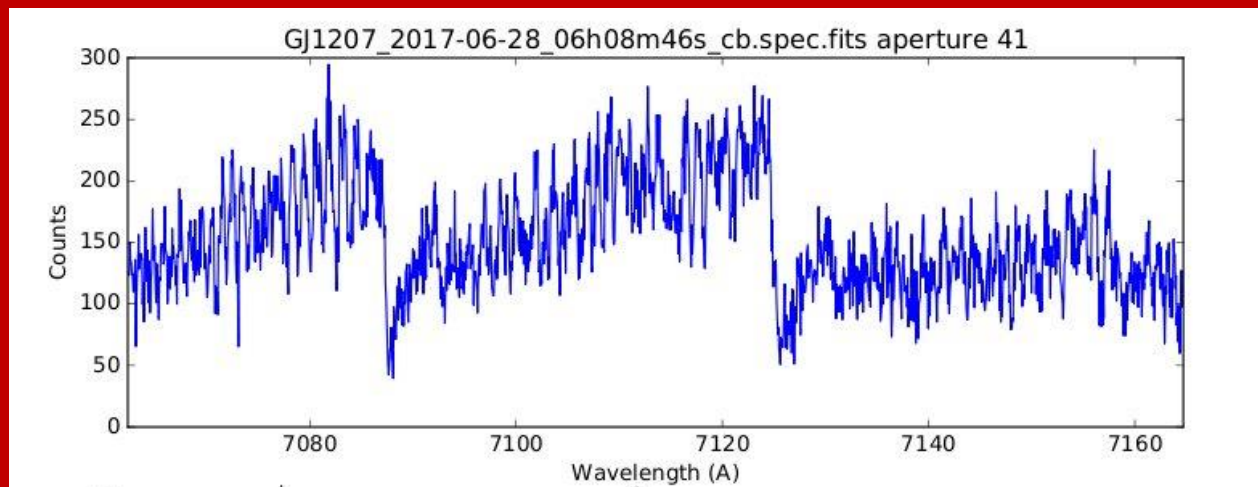


Image credit:

<http://www.geeksofdoom.com/2014/04/26/geek-gear-the-hitchhikers-guide-to-the-galaxy-constellation-42-marvin-on-life>

# FUTURE

- **NEW** high-resolution spectroscopic project targeting the **mid-M dwarfs ( $0.1 - 0.3 M_{\odot}$ )** within **15 pc**
  - **TRES** ( $R \approx 44,000$ ) on FLWO 1.5m on Mt. Hopkins in AZ
  - **CHIRON** ( $R \approx 80,000$ ) on CTIO 1.5m in Chile
  - ID **SBs**, measure **RVs**, ***vsinis***, **H $\alpha$**  equivalent widths



# RESULTS

- **26%** of M dwarf systems are multiples.
- Companions to M dwarfs are found at **separations on Solar System scales: 1-100 au.**
- Mass function for all M dwarfs **increases** to the end of the main sequence.
- M dwarf multiplicity & age *may* be related.
- *At least* **17% of M dwarf mass** is found in companions.
- Most stellar systems are **single.**

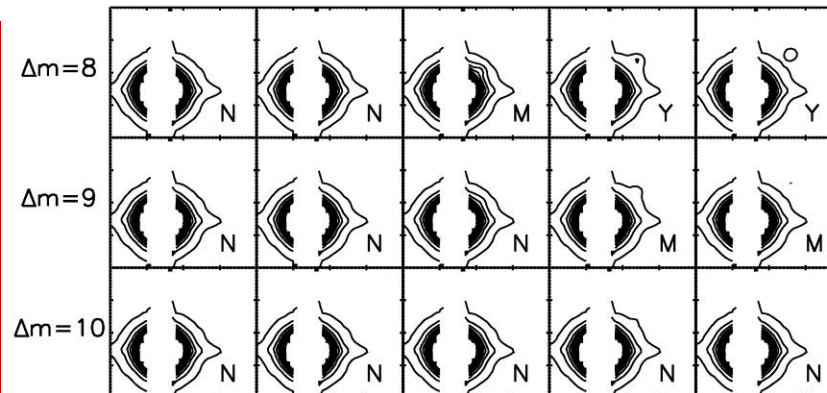
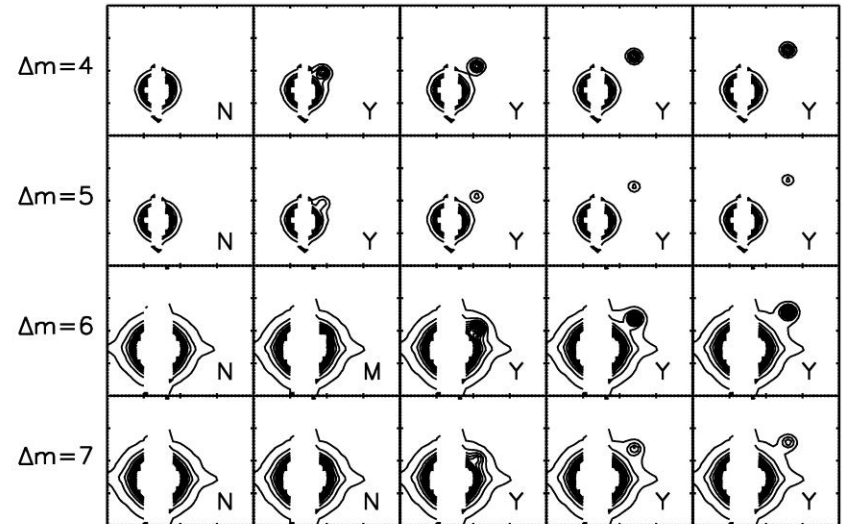
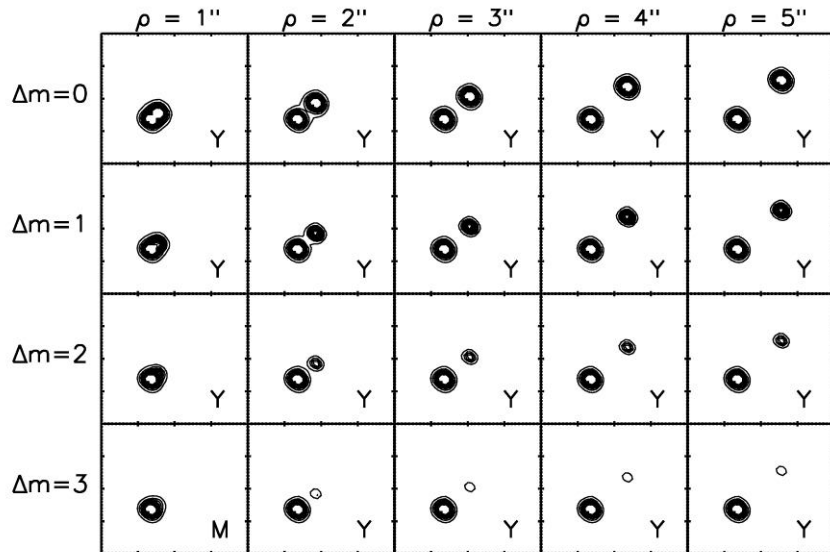
# REFERENCES

- Bergfors, C., Brandner, W., Janson, M., et al. 2010, AAP, 520, A54
- Delfosse, X., Forveille, T., Beuzit, J.-L., et al. 1999, AAP, 344, 897
- Delfosse, X., Forveille, T., Ségransan, D., et al. 2000, AAP, 364, 217
- Duchêne, G., & Kraus, A. 2013, ARAA, 51, 269
- Endl, M., Cochran, W.D., Kürster, M., et al. 2006, ApJ, 649, 436
- Fischer, D.A., & Marcy, G.W. 1992, ApJ, 396, 178
- Hambly, N.C., Henry, T.J., Subasavage, J.P., Brown, M.A., Jao, W.-C. 2004, AJ, 128, 437
- Henry, T.J. 1991, Ph.D.Thesis,
- Henry, T.J., Subasavage, J.P., Brown, M.A., et al. 2004, AJ, 128, 2460
- Jao, W.-C., Henry, T.J., Subasavage, J.P., et al. 2003, AJ, 125, 332
- Jao, W.-C., Mason, B.D., Hartkopf, W.I., Henry, T.J., & Ramos, S.N. 2009, AJ, 137, 3800
- Law, N.M., Dhital, S., Kraus, A., Stassun, K.G., & West, A.A. 2010, ApJ, 720, 1727
- Law, N.M., Hodgkin, S.T., & Mackay, C.D. 2006, MNRAS, 368, 1917
- Law, N.M., Hodgkin, S.T., & Mackay, C.D. 2008, MNRAS, 384, 150
- Mason, B.D., Hartkopf, W.I., Gies, D.R., Henry, T.J., & Helsel, J.W. 2009, AJ, 137, 3358
- Raghavan, D., McAlister, H.A., Henry, T.J., et al. 2010, ApJS, 190, 1
- Reid, I.N., & Gizis, J.E. 1997, AJ, 114, 1992
- Riedel, A.R., Finch, C.T., Henry, T.J., et al. 2014, AJ, 147, 85
- Simons, D.A., Henry, T.J., & Kirkpatrick, J.D. 1996, AJ, 112, 2238
- Skrutskie, M.F., Forrest, W.J., & Shure, M. 1989, AJ, 98, 1409
- Tarter, J.C., Backus, P.R., Mancinelli, R.L., et al. 2007, Astrobiology, 7, 30
- Tokovinin, A.A., 1992, AAP, 256, 121
- van Altena, W.F., Lee, J.T., & Hoffleit, E.D. 1995, New Haven, CT: Yale University Observatory, c1995, 4th ed., completely revised and enlarged,
- van Leeuwen, F. 2007, Astrophysics and Space Science Library, 350
- Winters, J.G., Henry, T.J., Jao, W.-C., et al. 2011, AJ, 141, 21

# BIASES & SELECTION EFFECTS

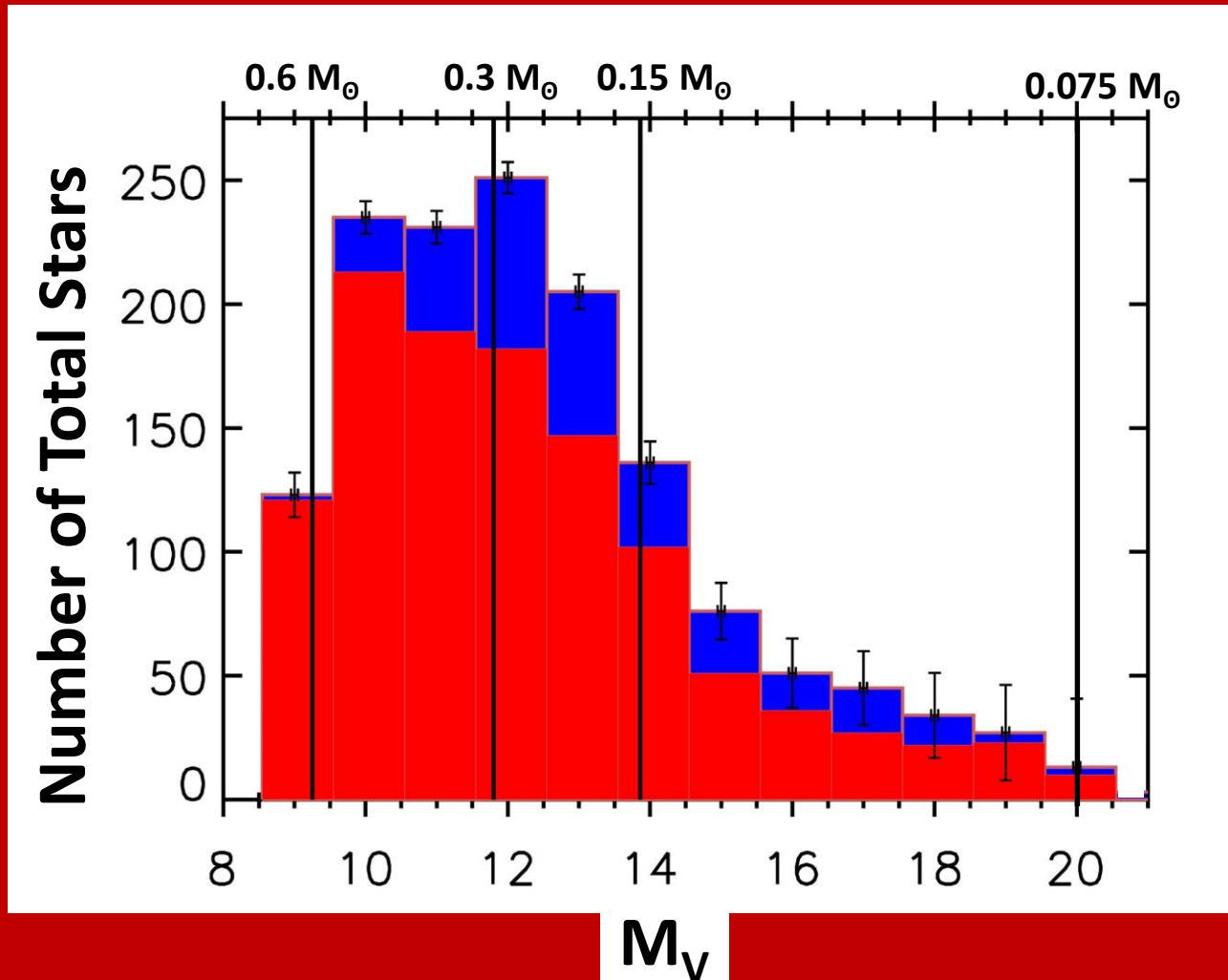
- **Close Companions (corrected)**
- **Malmquist Bias ( $\uparrow$  MR)**
- **Parallax Error Limits ( $\downarrow$  MR)**
- **Faint Companions ( $\downarrow$  MR)**
- **Missing Faint Primaries ( $\uparrow$  MR)**

# DETECTION LIMITS

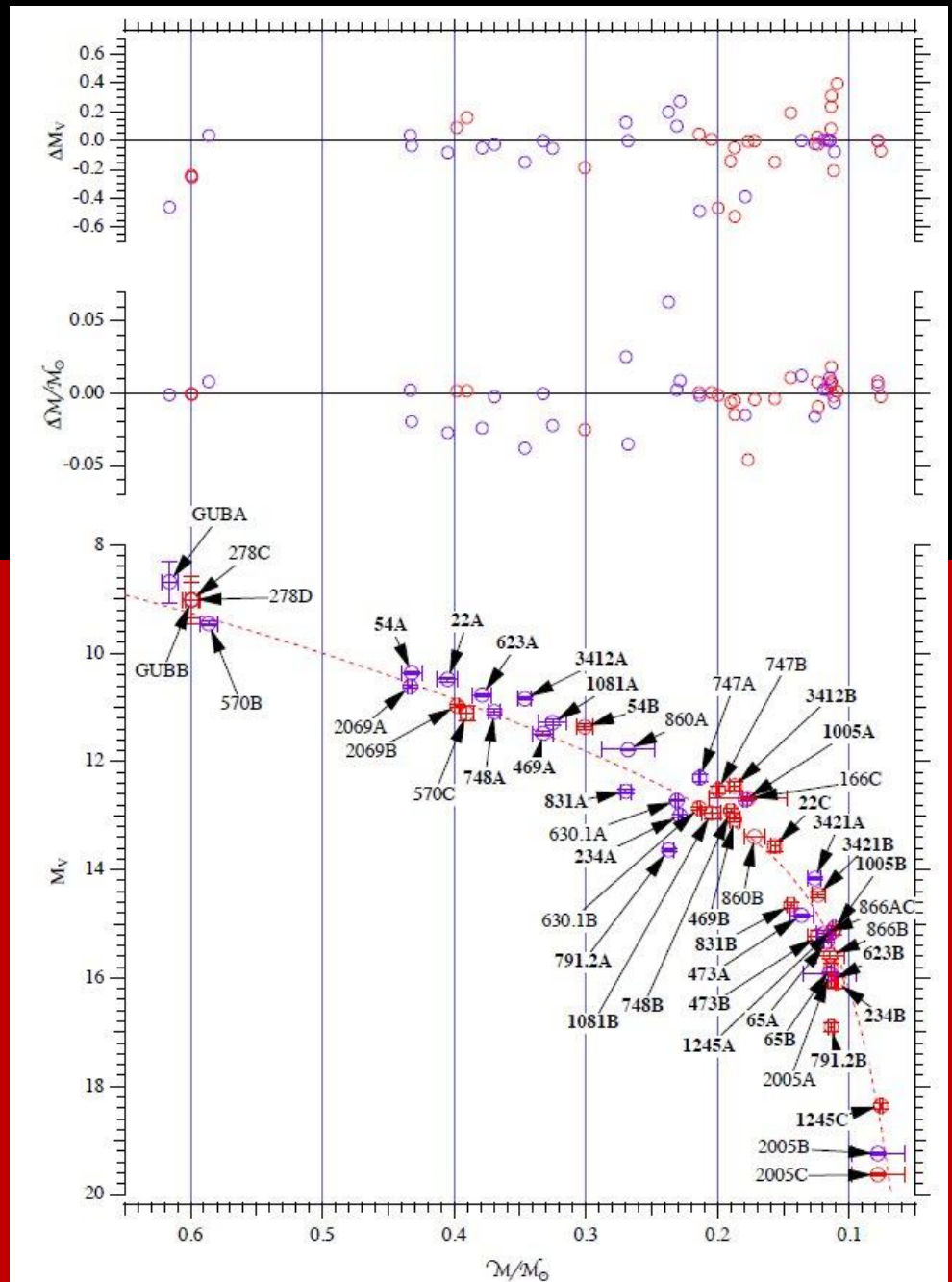




# LUMINOSITY FUNCTION – Primaries + Companions



# MASS – LUMINOSITY RELATION

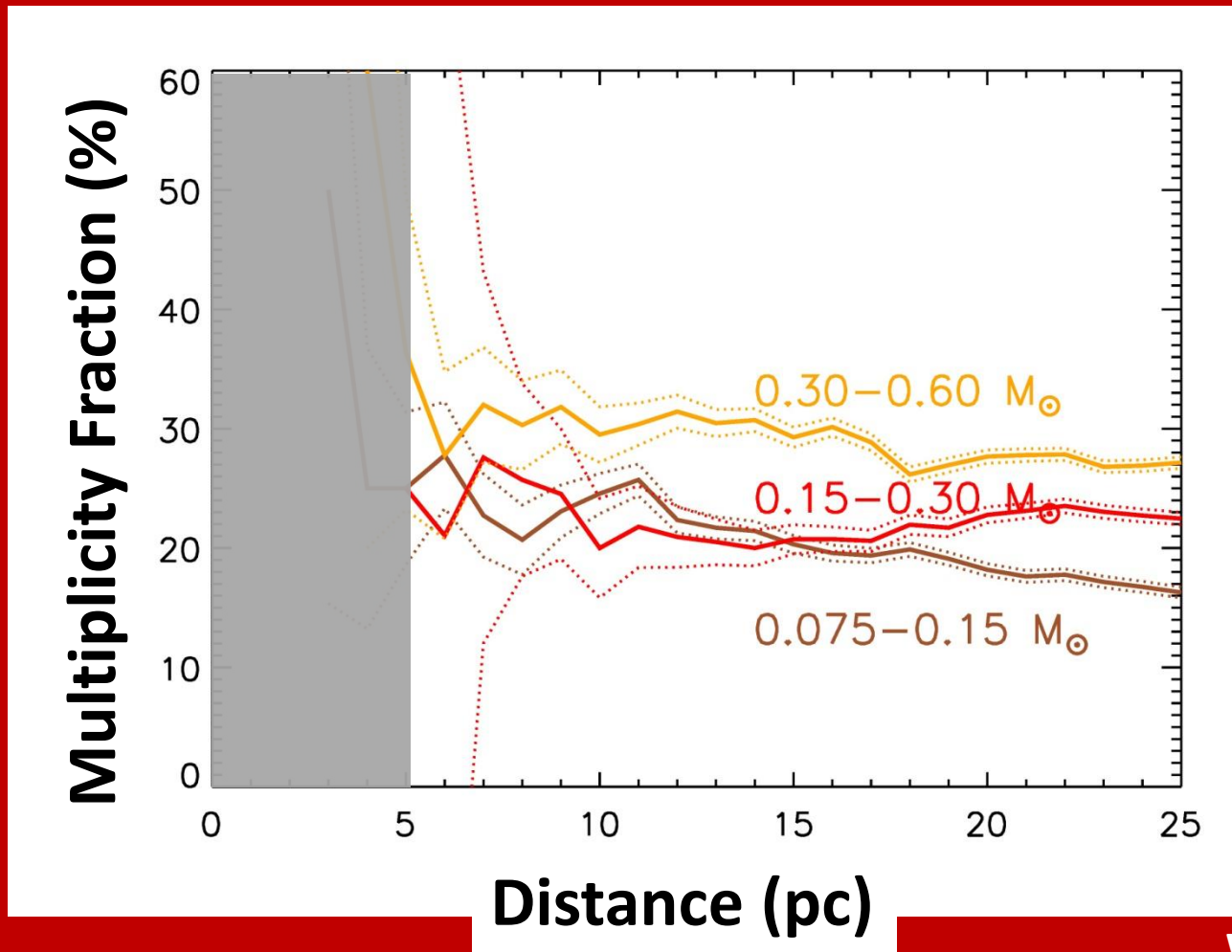


from Benedict+ 2016

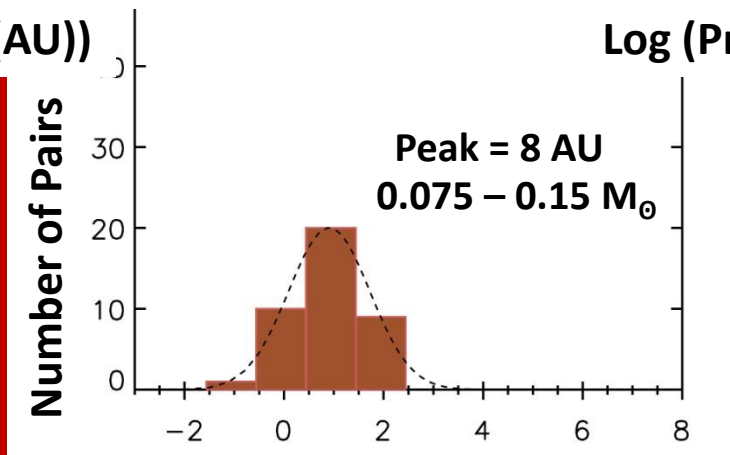
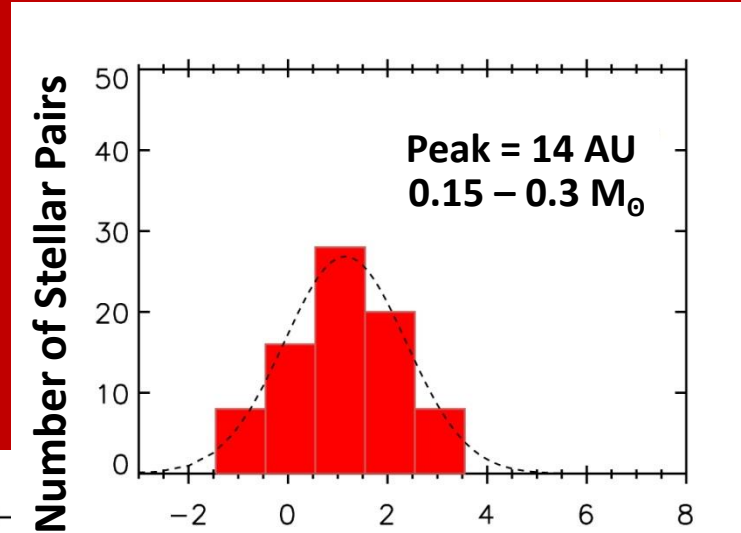
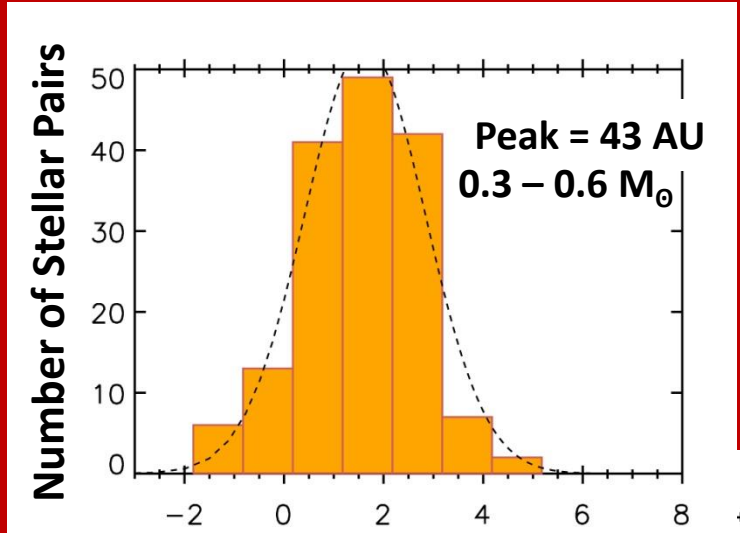
# PARALLAX SOURCES

SAMPLE ORIGIN	NORTH	SOUTH	Notes
YPC + HIP	472	269	Within 25.0 pc from Compendia
RECONS - Published	26	247	Already in Literature
RECONS - Unpublished	5	27	This Work + Coming Soon
From Literature (1995 – 2012)	55	20	Additions from Others
<b>TOTAL</b>	<b>558</b>	<b>563</b>	<b>1121</b>

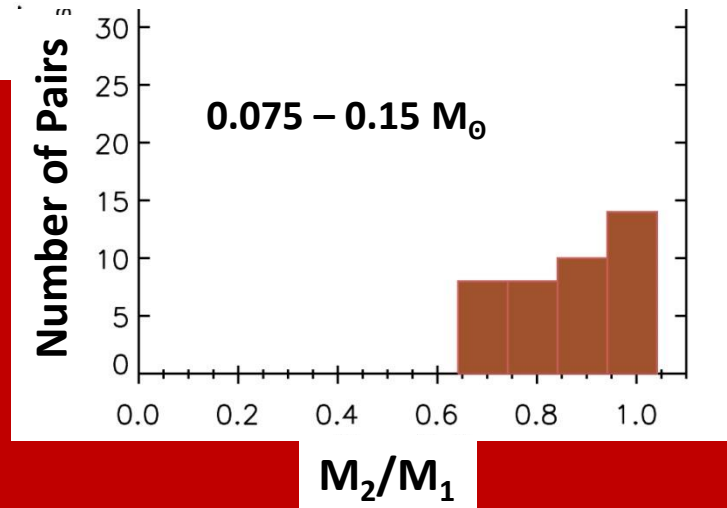
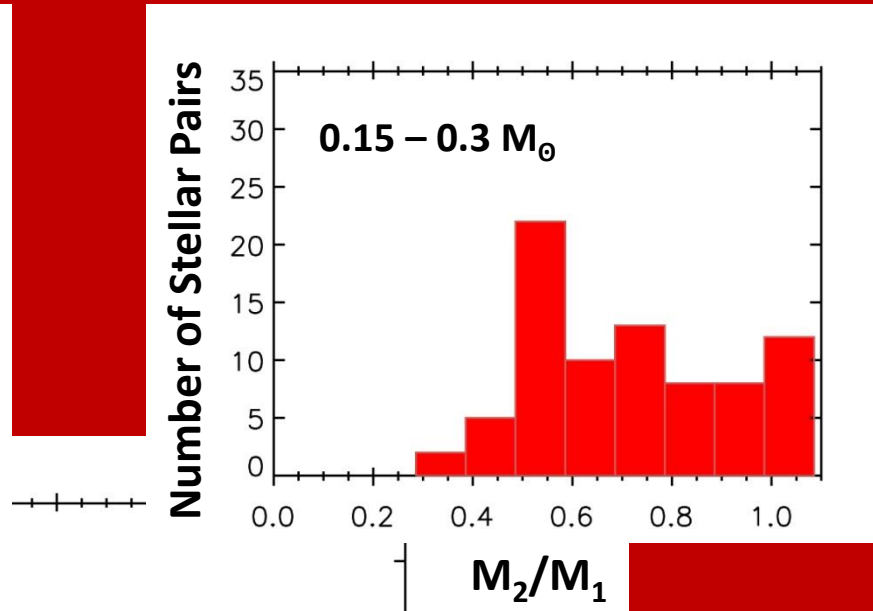
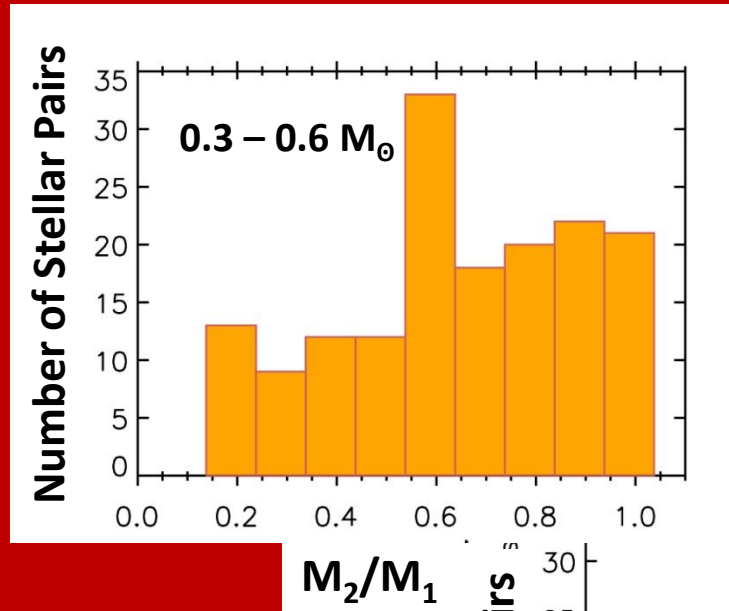
# M DWARF MULTIPLICITY AS A FUNCTION OF MASS



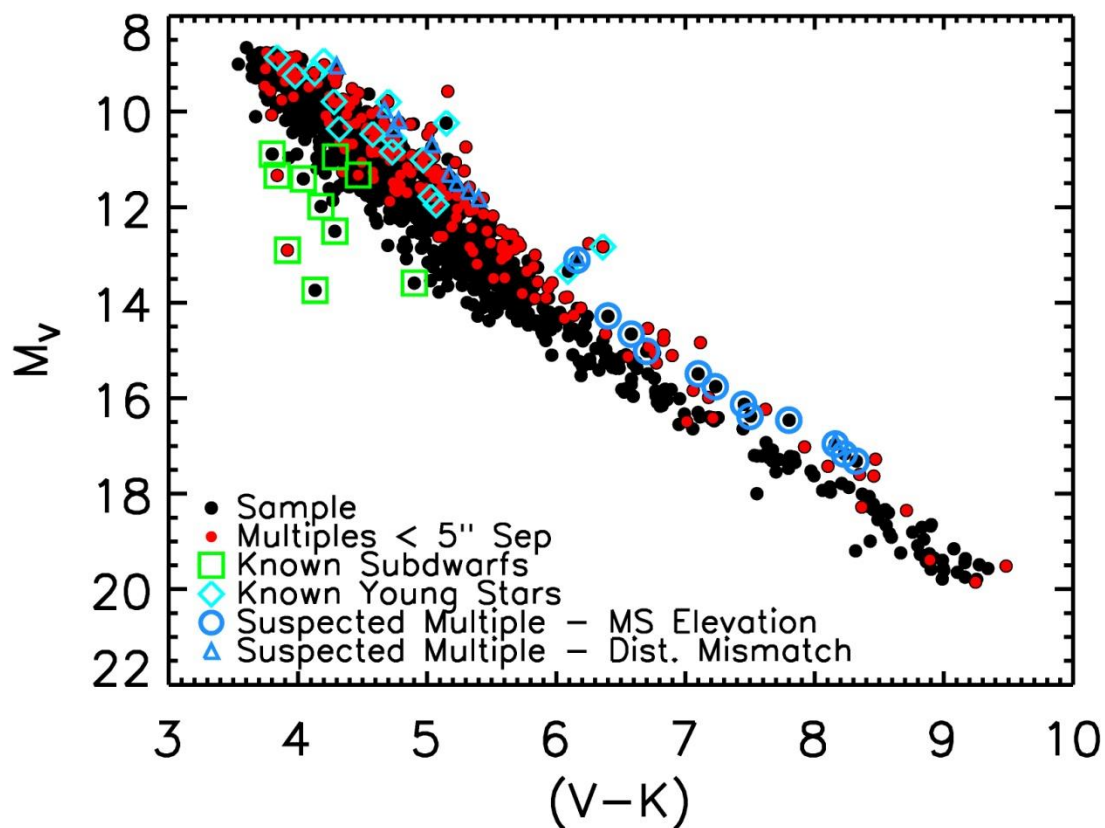
# SEPARATION BY MASS SUBSET



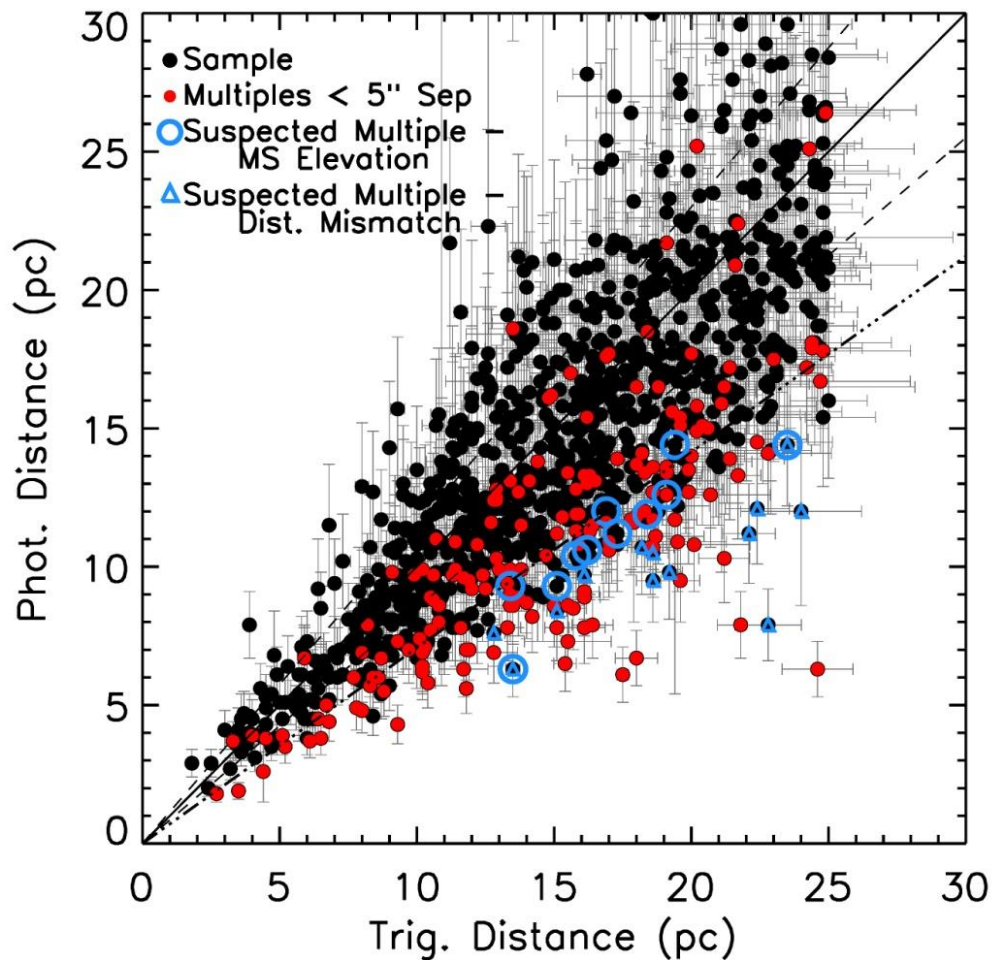
# MASS RATIO BY MASS SUBSET



# H-R DIAGRAM ELEVATION



# DISTANCE MISMATCH





# HOW IS THE MASS IN MULTIPLES DISTRIBUTED?

