A Visual Double Star Campaign

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Maui International Double Star Conference
February, 2013

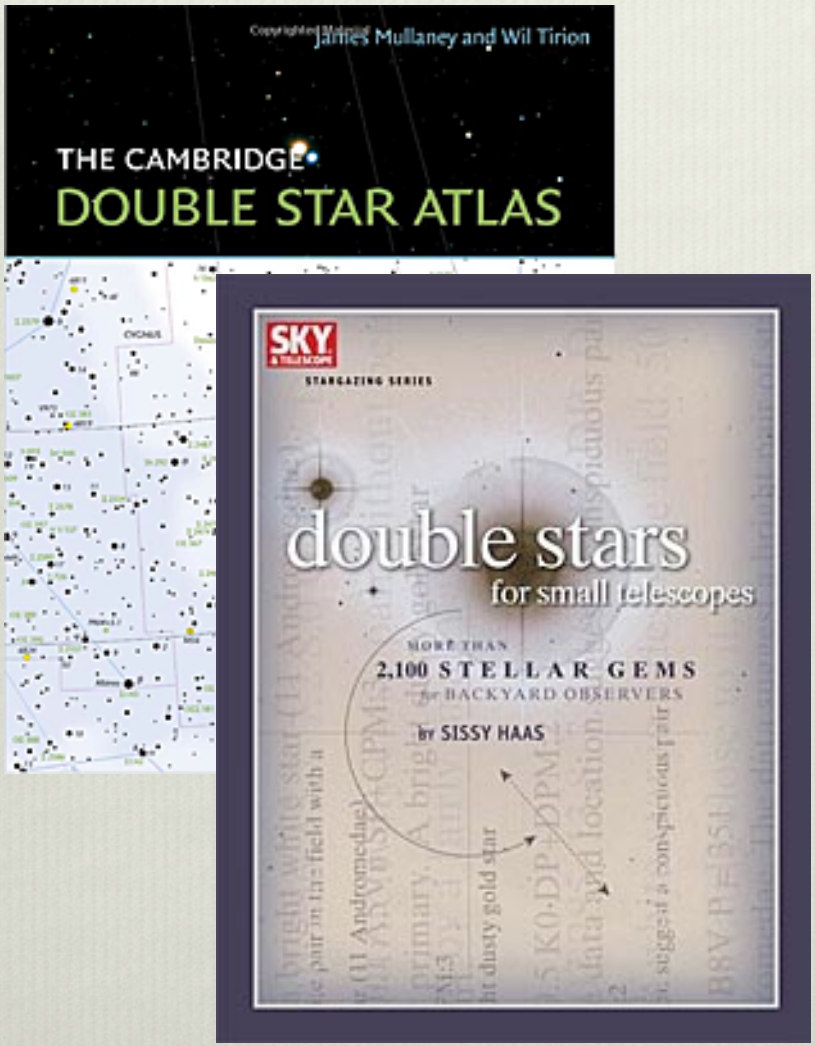
http://www.handprint.com/ASTRO/PREZ/DSCampaign.pptx

Why a "Campaign"?

Campaign: Series of observations based on an established list or sample

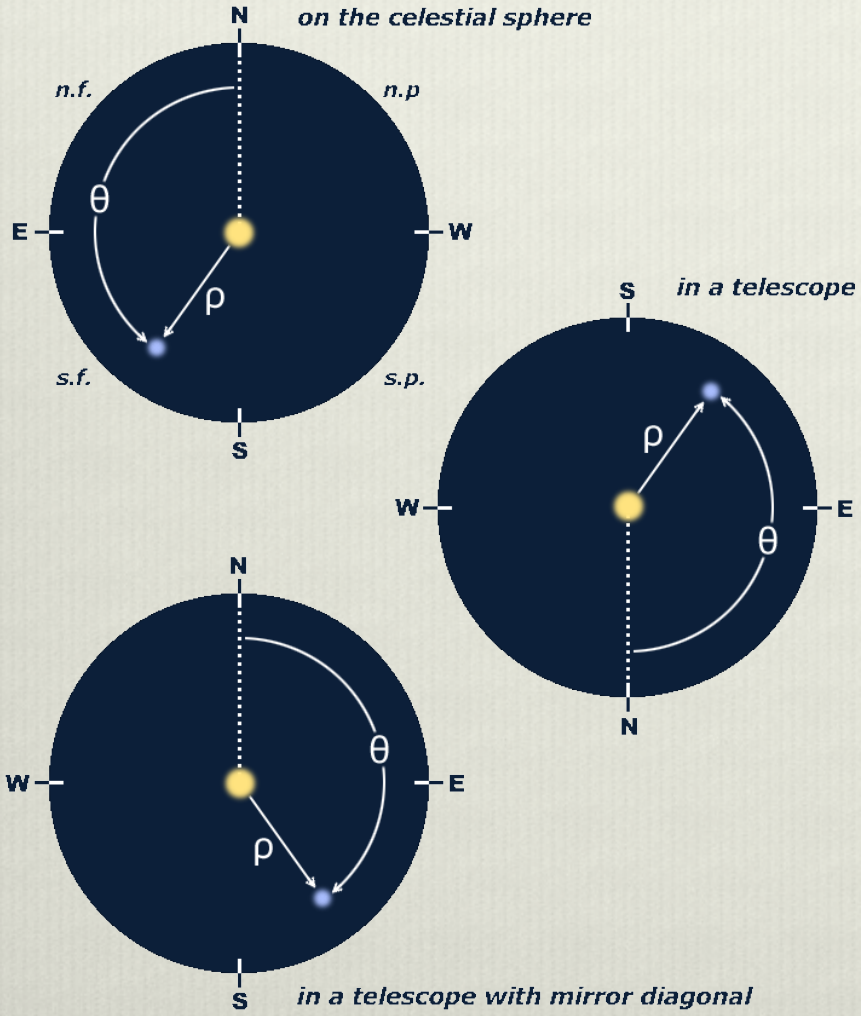
- A personal achievement and recreation in intensive visual astronomy
  - Already popular with deep sky astronomers (Messier marathon, Herschel, Caldwell lists)
- Observational knowledge of the double star population
  - A field experience akin to a surveyor, geologist, biologist, anthropologist, archaeologist
- Huge number and variety of targets, from *very easy* to *very difficult*
  - *Messier, Caldwell lists: 109 objects*
  - *NGC+IC: ~13,200 deep sky objects*
  - *WDS (edited): ~101,100 double star systems*
- The pleasure of personal "discoveries"
- An appreciation of 19th century observational achievements
- Educational incentive to explore astronomical research … or just meditate on the Galaxy

Which Observing List?



- There is no "standard" double star list, but many are available — RASC, Norton, Saguaro, Couteau, Webb …
  - All lists show a "bright star" selection bias: most lists overlap substantially in showcase pairs within reach of small apertures
  - Shortest lists are ~200 stars, the longest contain several thousand
- My choice: I combined the lists in *Cambridge Double Star Atlas* (Mullaney & Tirion) and *Double Stars for Small Telescopes* (Haas)
  - Eclectic selections from many catalogs, already edited, but only 2170 unique systems (at 38°N) due to bright star bias
- Grrr! CDSA omits position angle and uses nonstandard catalog synonyms

Essential Catalog Data



- *WDS ID and Catalog Synonym*
  - Bayer/Flamsteed is useful
- *Celestial Coordinates (Epoch 2000)*
- *Position angle* (PA, θ) is measured in counterclockwise degrees from the line to celestial north
- *Separation* (Sep., ρ) is angular width in arcseconds (= 1/3600º … the visual width of 1mm at 200 meters)
- *Visual magnitudes* (m_1, m_2 and Δm) … these vary significantly in quality
- I trained myself to *visually estimate separation* (using a standard eyepiece) *and position angle* (from star drift or declination slews) in an inverted (rotated) or reflected telescope image

Classic Measurement Catalogs

Many 19th and early 20th century catalogs comprise a few hundred to a few thousand systems within amateur equipment limits. These make excellent double star observing lists.

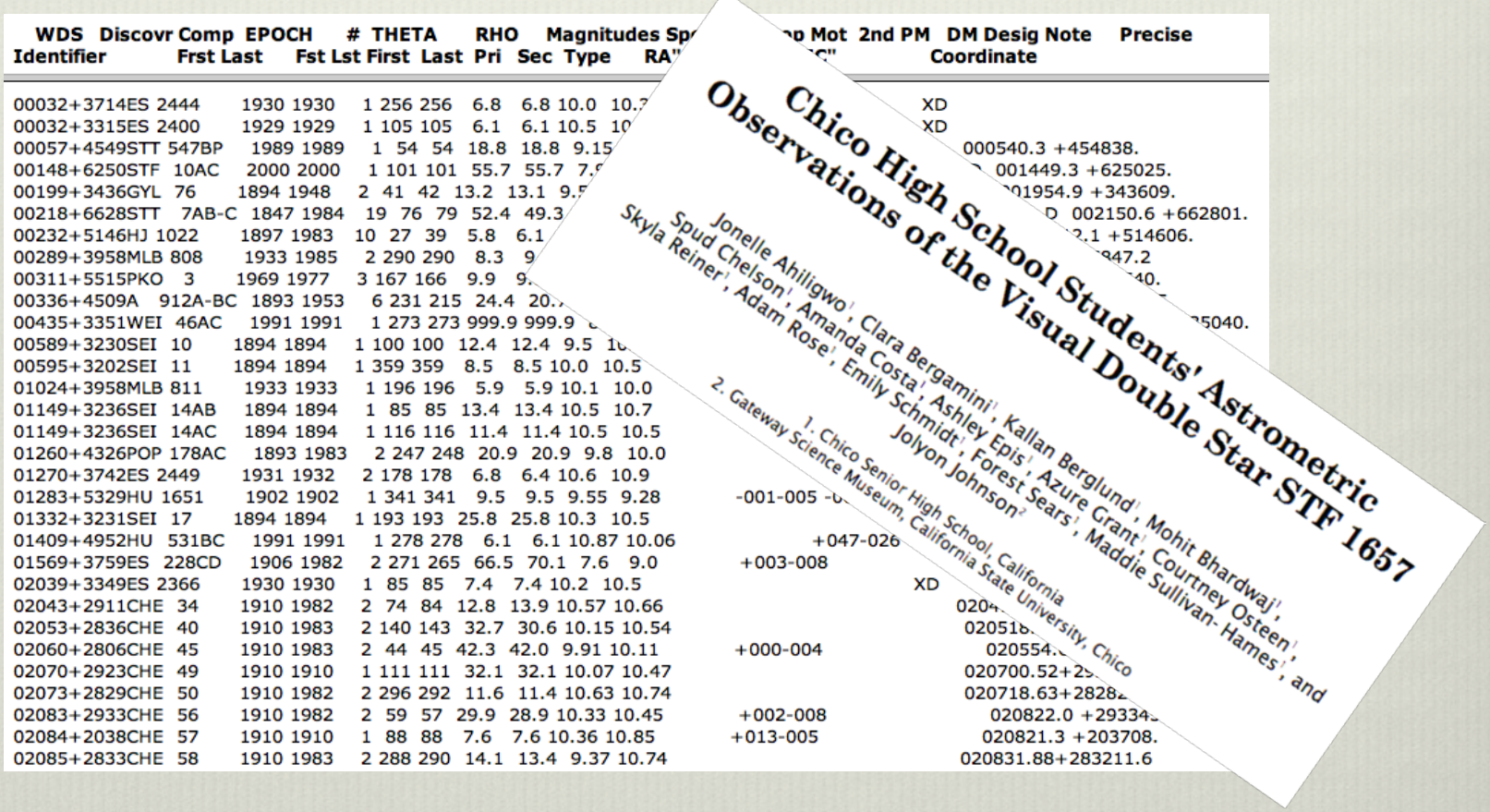
Observer	*Active*	*Systems in WDS*	*WDS Catalog Code [Obsolete Catalog Symbol]*
Willam Herschel	c.1790-1815	139 *[805]*[1]	H + *class number*
John Herschel James South	c.1820-1840 c.1820	4720 168	HJ [h] S, SHJ [Sh]
Friedrich Wilhelm Struve	c.1830-1850	2627[2]	STF, STFA, STFB [Σ]
Otto Wilhelm Struve	c.1840-1860	609	STT, STTA [OΣ]
Sherburne Burnham	c.1870-1900	1445	BU, BUP [β]
Rev. T.E. Espin	c.1900-1920	2545	ES
Robert Jonckheere	c.1910-1915	2834	J
Robert Grant Aitken W.J. Hussey	c.1900-1930	3019 1570	A [ADS]

[1] *Actual number of discoveries. See "Herschel Double Star Catalogs Restored."*

[2] *Systems attributed to F.W. Struve in WDS with a first measurement epoch earlier than 1865.*

Neglected Doubles

The US Naval Observatory publishes lists of "neglected doubles" that have been observed only once or twice since their discovery — 23% of pairs in WDS have been measured only once, some not since the 19th century. Students can contribute!



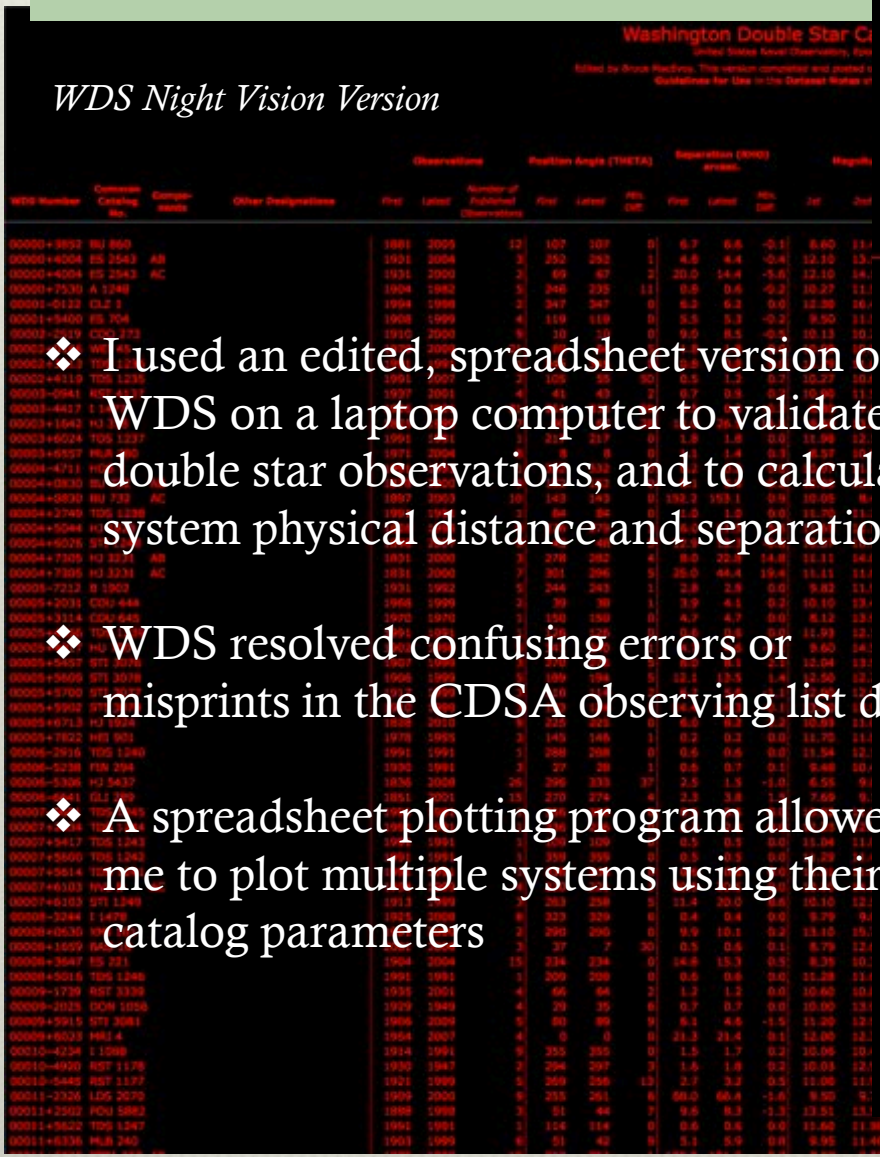
WDS Identifier	Discovr	Comp	EPOCH Frst	EPOCH Last	# Fst	# Lst	THETA First	THETA Last	RHO Pri	RHO Sec	Magnitudes Type	Magnitudes	Sp	p Mot	2nd PM	DM	Desig	Note	Precise Coordinate
00032+3714ES	2444		1930	1930	1	256	256	6.8	6.8	10.0	10.7					XD			
00032+3315ES	2400		1929	1929	1	105	105	6.1	6.1	10.5	10					XD			
00057+4549STT	547	BP	1989	1989	1	54	54	18.8	18.8	9.15									000540.3 +454838.
00148+6250STF	10	AC	2000	2000	1	101	101	55.7	55.7	7.6									001449.3 +625025.
00199+3436GYL	76		1894	1948	2	41	42	13.2	13.1	9.5									001954.9 +343609.
00218+6628STT	7	AB-C	1847	1984	19	76	79	52.4	49.3							D			002150.6 +662801.
00232+5146HJ	1022		1897	1983	10	27	39	5.8	6.1										2.1 +514606.
00289+3958MLB	808		1933	1985	2	290	290	8.3	9										847.2
00311+5515PKO	3		1969	1977	3	167	166	9.9	9.										40.
00336+4509A	912	A-BC	1893	1953	6	231	215	24.4	20.										
00435+3351WEI	46	AC	1991	1991	1	273	273	999.9	999.9										5040.
00589+3230SEI	10		1894	1894	1	100	100	12.4	12.4	9.5	10								
00595+3202SEI	11		1894	1894	1	359	359	8.5	8.5	10.0	10.5								
01024+3958MLB	811		1933	1933	1	196	196	5.9	5.9	10.1	10.0								
01149+3236SEI	14	AB	1894	1894	1	85	85	13.4	13.4	10.5	10.7								
01149+3236SEI	14	AC	1894	1894	1	116	116	11.4	11.4	10.5	10.5								
01260+4326POP	178	AC	1893	1983	2	247	248	20.9	20.9	9.8	10.0								
01270+3742ES	2449		1931	1932	2	178	178	6.8	6.4	10.6	10.9								
01283+5329HU	1651		1902	1902	1	341	341	9.5	9.5	9.55	9.28			-001-005	-0				
01332+3231SEI	17		1894	1894	1	193	193	25.8	25.8	10.3	10.5								
01409+4952HU	531	BC	1991	1991	1	278	278	6.1	6.1	10.87	10.06			+047-026					
01569+3759ES	228	CD	1906	1982	2	271	265	66.5	70.1	7.6	9.0			+003-008					
02039+3349ES	2366		1930	1930	1	85	85	7.4	7.4	10.2	10.5					XD			
02043+2911CHE	34		1910	1982	2	74	84	12.8	13.9	10.57	10.66								020
02053+2836CHE	40		1910	1983	2	140	143	32.7	30.6	10.15	10.54								02051
02060+2806CHE	45		1910	1983	2	44	45	42.3	42.0	9.91	10.11			+000-004					020554.
02070+2923CHE	49		1910	1910	1	111	111	32.1	32.1	10.07	10.47								020700.52+29
02073+2829CHE	50		1910	1982	2	296	292	11.6	11.4	10.63	10.74								020718.63+2828
02083+2933CHE	56		1910	1982	2	59	57	29.9	28.9	10.33	10.45			+002-008					020822.0 +29334
02084+2038CHE	57		1910	1910	1	88	88	7.6	7.6	10.36	10.85			+013-005					020821.3 +203708.
02085+2833CHE	58		1910	1983	2	288	290	14.1	13.4	9.37	10.74								020831.88+283211.6

Chico High School Students' Astrometric Observations of the Visual Double Star STF 1657

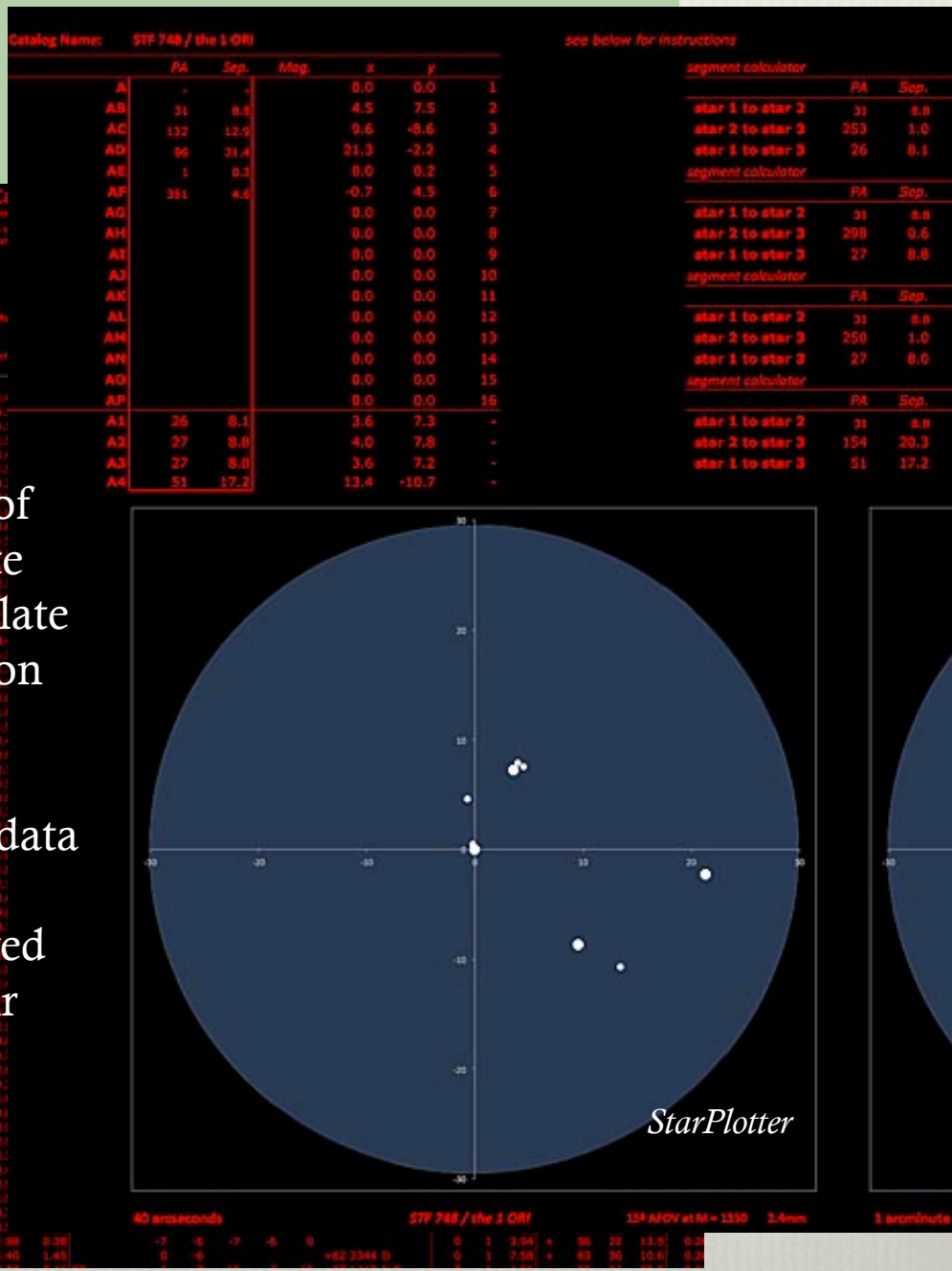
Jonelle Ahiligwo[1], Clara Bergamini[1], Kallan Berglund[1], Mohit Bhardwaj[1], Spud Chelson[1], Amanda Costa[1], Ashley Epis[1], Azure Grant[1], Courtney Osteen[1], Skyla Reiner[1], Adam Rose[1], Emily Schmidt[1], Forest Sears[1], Maddie Sullivan-Hames[1], and Jolyon Johnson[2]

1. Chico Senior High School, California
2. Gateway Science Museum, California State University, Chico

Spreadsheet Tools



- I used an edited, spreadsheet version of WDS on a laptop computer to validate double star observations, and to calculate system physical distance and separation
- WDS resolved confusing errors or misprints in the CDSA observing list data
- A spreadsheet plotting program allowed me to plot multiple systems using their catalog parameters



What Is a "Good" List?

At least four factors affect the proportional representation of catalogued DS attributes

	naked eye primary ($m \leq 6.5$)	*binary system*	*matched binary ($\Delta m \leq 0.5$)*	*$q < 0.5$ binary ($\Delta m > 3.0$)*	*wide binary ($\rho > 45$")*	*multiple system*
Total WDS (edited) $\rho \geq 0.1$", $m_1 \leq 15.0$ *(91,201 systems, 100%)*	0.03	0.91	0.32	0.12	0.07	0.09
Struve (STF, STFA, STFB) $\rho \geq 0.4$", $m_1 \leq \sim 11.0$ *(2627 systems, 2.9%)*	0.12	0.65	0.20	0.04	<0.01	0.35
300mm aperture $\rho \geq 0.5$", $m_1 \leq 11.5$ *(58,321 systems, 63.9%)*	0.04	0.89	0.28	0.16	0.03	0.11
150mm aperture $\rho \geq 0.9$", $m_1 \leq 10.4$ *(29,578 systems, 32.4%)*	0.07	0.83	0.12	0.27	0.05	0.17
Naked eye primary $m_1 \leq 6.5$ *(2028 systems, 2.2%)*	1.00	0.57	0.01	0.45	0.14	0.43

visual search salience

physical distance vs. angular scale ———

physical distance vs. limit mag. ———

limit magnitude "ceiling" ———

Choosing a Telescope

- I returned to astronomy after teenage experience with a Cave 10" reflector in the 1960's … mostly ignorant of innovations since then
- I opted for moderate aperture (D) reflector to increase both *resolution* (as 1/D) and *light grasp* (as D^2)
  - Aperture dictated choice of a reflector over a refractor, the traditional DS instrument
  - I was unaware of the issues in larger aperture reflectors with cool down, atmospheric turbulence and mirror currents
- The modern $f/2$ to $f/4$ primary, Cassegrain reflector provides ample D and long f, with viewing comfort and portability
- My instruments: 12" $f/10$ Meade LX200 (SCT) and 10" $f/20$ Royce Dall Kirkham
- I chose the SCT as an all purpose scope, then went for longer focal length specifically for double star observing
- Modern telescope *optics* are of very good quality … but a reliable *mount* — with accurate GOTO computer and celestial coordinate input — is *essential!*

Choosing Eyepieces

- Magnification (M) is anchored on the longest eyepiece focal length (f_e) that displays dark rings around the Airy disk:
  - Standard: f_e = ~1.0 to 1.5N, M = ~1.0-0.67D_{mm}
- Ignore the lunar/planetary magnification rule — *"use only what the seeing allows"* — as high power improves detection of close doubles and makes faint stars visible
  - Magnifier: f_e = ~0.5N, M = ~2D_{mm}
- Large scale (multiple) double stars and complex star fields reward a wide TFOV:
  - Wide: f_e = ~2.5N, M = ~0.40D_{mm}
- *Swap eyepieces often* to examine double star field, dimensions, and close companions
- Also important: "*eye comfort*", *parfocal equivalence, suppression of scattered light*

Wide f_e= ~2.5N

- *A large field of view, with loss of detail*
- *Often with 2" barrels (and adapter swaps)*

Standard f_e= ~1.5N

- *Dark rings around the Airy disk are visible*
- *Used for routine visual comparisons*
- *Needs eye comfort for frequent use*

Magnifier f_e = ~0.5N

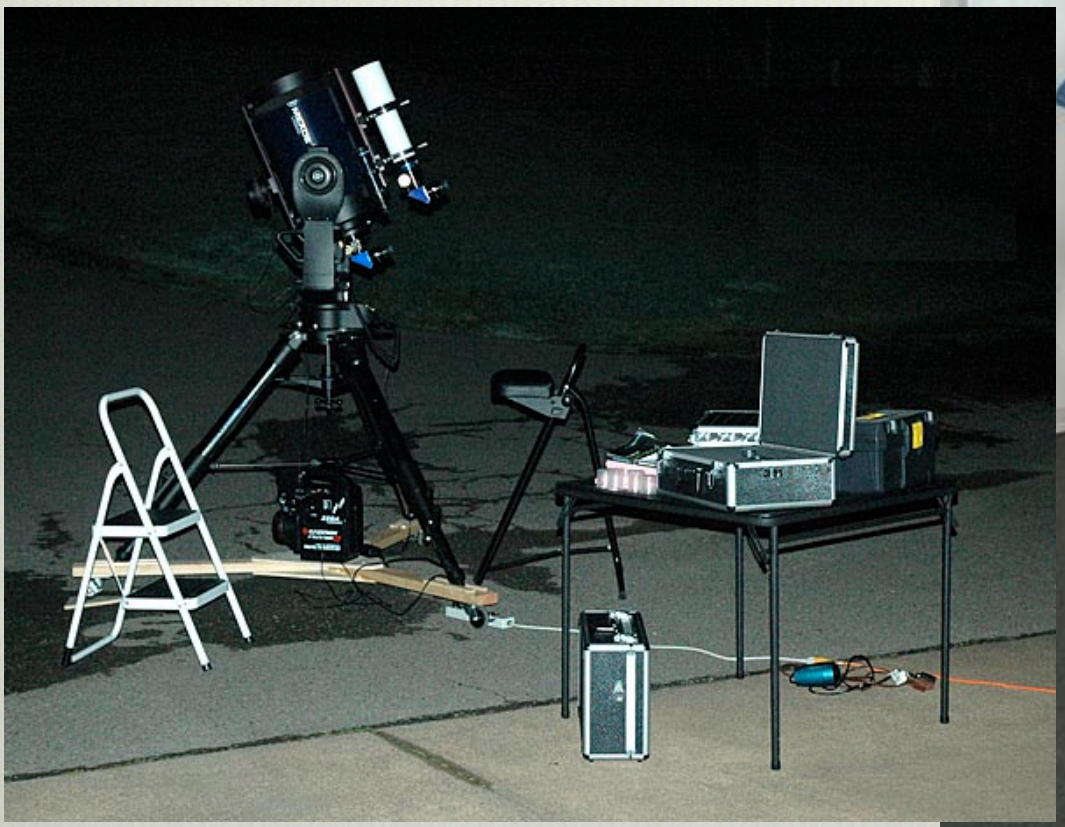
- *Airy disk visible at an ample angular scale*
- *Used to resolve pairs near resolution limit*
- *Suppression of stray light is critical*

Convenient Set Up

- Influenced by personal preferences, and making do with what you have available.
- My priorities:
  - Minimize equipment set up time — if possible, to no more than 15 minutes
  - Allow ample time for cool down — especially over large differences in daytime (storage) and nighttime (viewing) temperatures
- Atmospheric turbulence and local thermal currents (e.g., from a driveway or house) were more significant problems than light pollution
- Electrical power with 12V adapter —except in the field, batteries are a nuisance
- Comfortable document/laptop surface — with red light and document dew shelter
  - A standing height document surface worked best for me … a chair just got in the way
- Minimize tiring activities and cold stress during observation …
  - a sturdy observing chair and compliant, reliable stepladder
  - convenient eyepiece rack, comfortable observing position
  - warm clothes, a thermos of hot beverage …

Dolly & Pier

I began with a telescope dolly and equipment stored in the garage, everything carried out and set up each night … and finished with an observatory shelter and two fixed pier mounts



Black Oak Observatory

My roll off roof observatory was completed in 2011, with equipment storage, book shelf and two standing height work stations

Observing Routine

- *Daytime Research:* I used WDS and online research to answer questions about systems observed in the previous night … *not* about systems I would observe that night!
- *Weather:* reliable astronomical forecasts at *Clear Dark Skies* (http://cleardarksky.com/)
- *Set up:* 1 to 2 hours before start of observing
- *Observing:* good seeing came about 1 hour after dark, and turned worse by midnight

For each system:

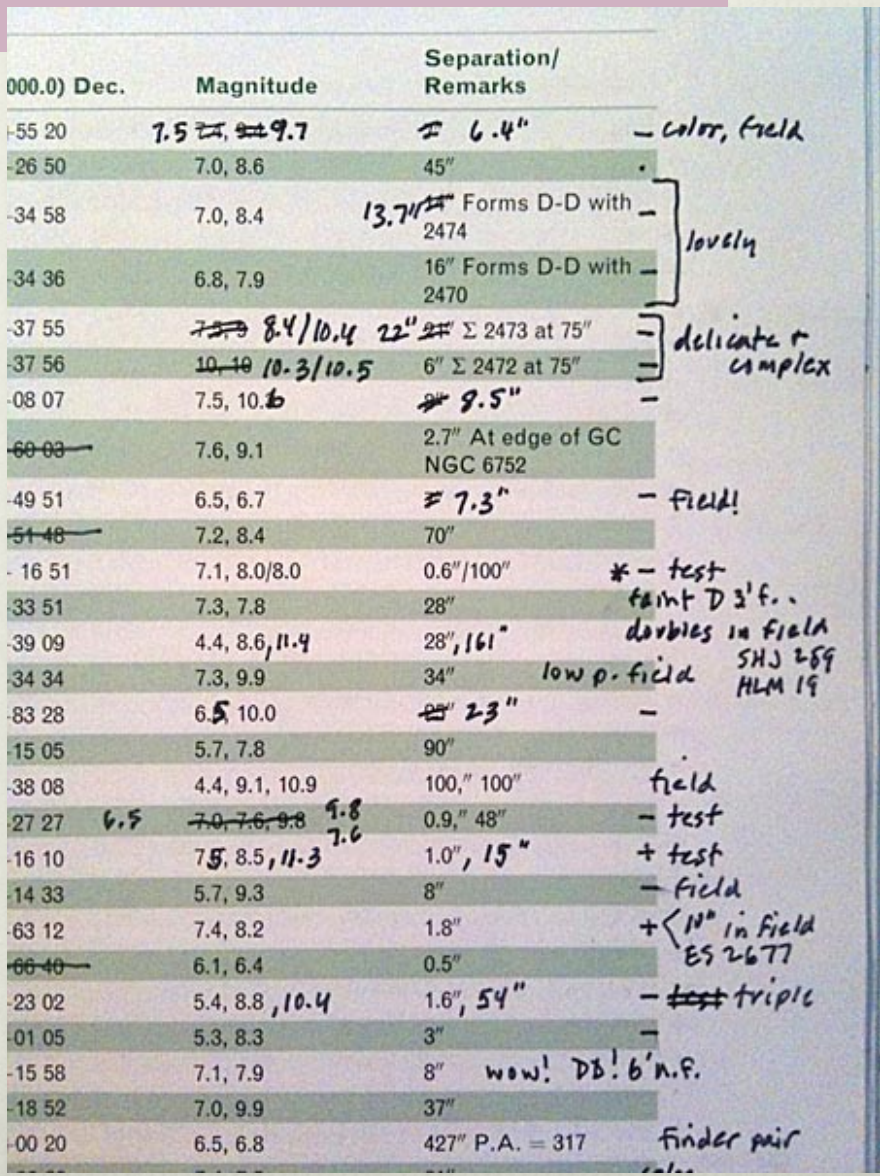
- Slewed to catalog celestial coordinates; identified and centered with "standard" eyepiece
- Briefly noted observations, especially nearby field objects and any apparent discrepancies in magnitude, PA or separation
- Checked multiple systems in WDS and visualized complex or faint systems in StarPlotter

To minimize time and motion:

- Worked within one constellation at a time, in right ascension order (west to east)
- Due to a quirk in the LX200 handset, I worked first above and then below the celestial equator, to avoid changing the declination sign

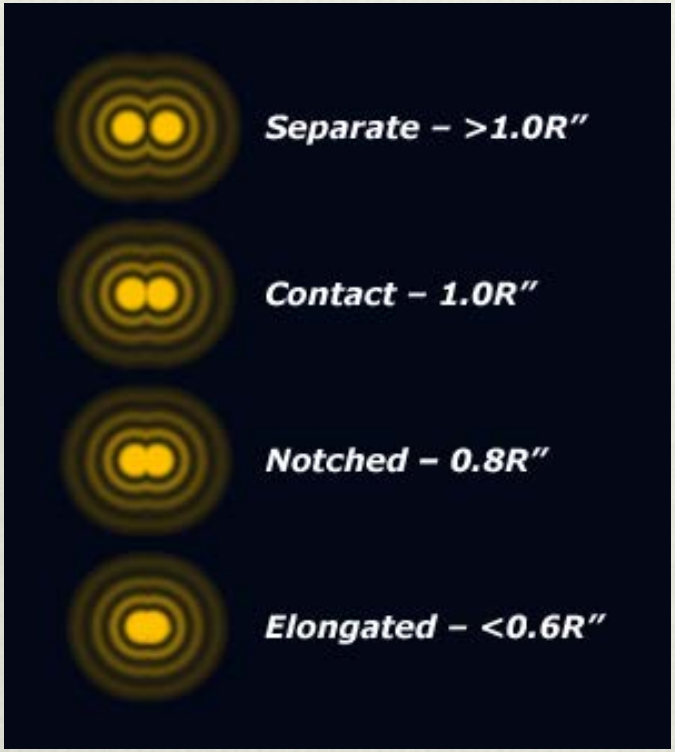
Record Keeping

- Photocopy or format the list to provide ample room for observations and comments
  - List components on separate lines, with catalog letter IDs (AB, AC, etc.)
  - I just wrote on the list in CDSA (shown at right)
- Notes are invaluable, but should be brief.
  - Date, start/end time; changes in seeing and dispersion (radius of nimbus around bright star)
  - Color (the simpler the better) … Herschel basically used *red*, *blue* and *white.*
  - Keywords for esthetic quality
  - Contents of visual field — nearby doubles, clusters, nebulae, with directional indication:
    - *n.f. = north following, s.p. = south preceding, etc.*
  - Number of resolution attempts …
    - *I used vertical hash marks ~~///~~ for each attempt and a crossbar when detected or resolved*
- Diagram interesting multiple systems!



000.0) Dec.	Magnitude	Separation/ Remarks	
-55 20	7.5 ~~7.7~~, ~~8.8~~ 9.7	~~3~~ 6.4"	– color, field
-26 50	7.0, 8.6	45"	.
-34 58	7.0, 8.4	13.7" ~~13.7~~ Forms D-D with 2474	– lovely
-34 36	6.8, 7.9	16" Forms D-D with 2470	– lovely
-37 55	~~7.8~~ 8.4/10.4	22" ~~23~~ Σ 2473 at 75"	– delicate + complex
-37 56	~~10.10~~ 10.3/10.5	6" Σ 2472 at 75"	– delicate + complex
-08 07	7.5, 10.~~6~~	~~9~~ 9.5"	–
~~60 03~~	7.6, 9.1	2.7" At edge of GC NGC 6752	
-49 51	6.5, 6.7	~ 7.3"	– field!
~~51 48~~	7.2, 8.4	70"	
- 16 51	7.1, 8.0/8.0	0.6"/100"	* – test
-33 51	7.3, 7.8	28"	faint D 3' f..
-39 09	4.4, 8.6, 11.4	28", 161°	doubles in field SHJ 289 HLM 19
-34 34	7.3, 9.9	34" low p. field	
-83 28	6.~~5~~, 10.0	~~25~~ 23"	–
-15 05	5.7, 7.8	90"	
-38 08	4.4, 9.1, 10.9	100," 100"	field
-27 27	6.5 ~~7.0, 7.6, 9.8~~ 9.8 7.6	0.9," 48"	– test
-16 10	7~~5~~, 8.5, 11.3	1.0", 15"	+ test
-14 33	5.7, 9.3	8"	– field
-63 12	7.4, 8.2	1.8"	+ < 10' in field ES 2677
~~66 40~~	6.1, 6.4	0.5"	
-23 02	5.4, 8.8, 10.4	1.6", 54"	– ~~test~~ triple
-01 05	5.3, 8.3	3"	–
-15 58	7.1, 7.9	8" wow! DD! 6' n.f.	
-18 52	7.0, 9.9	37"	
-00 20	6.5, 6.8	427" P.A. = 317	finder pair

Detection Criteria



Most visual astronomers report that a double star is recognizable on first inspection; in fact, the gap between a "separate" matched binary is often just detectable at magnifications near the foveal resolution limit (M =~0.5D_{mm}).

- Visual astronomers use standard criteria and labels to report the appearance of a *close, matched* binary system:
  - *Separate* – a dark gap is clearly visible between two Airy disks (the stars are "resolved")
  - *Contact* – the two disks appear to be touching or barely separated *(Rayleigh Criterion, 140/D_{mm})*
  - *Notched* – the star appears as a clearly elongated bar with distinct notches *(Dawes Criterion, 116/D_{mm})*
  - *Elongated* – the star appears prolate or "rodlike" without notches *(below Sparrow Criterion, 109/D_{mm})*
- *To confirm detection/resolution:* visually estimate the star position angle (θ), then check this in WDS: a match within ±20º of PA confirms you have identified the pair (90% probability)
- Try out any notetaking system on a small group of stars … then *don't change it* as you start the observing campaign

Keeping Momentum

Inevitably … fatigue and frustration become an issue, especially after the halfway point of the "marathon"

- My campaign of 2170 double stars took about one year to complete
- I kept a routine and comfortable pace year round (weather permitting)
- I got the most out of nights of good viewing
  - I aimed to complete 20 to 30 systems each night, on a good night
- I divided an evening's observing into "subcampaigns"
  - I explored one constellation at a time, using whole list pages (~5-8 systems) as incremental goals
- When tired, I stopped to explore the night sky, just to *enjoy the view!*

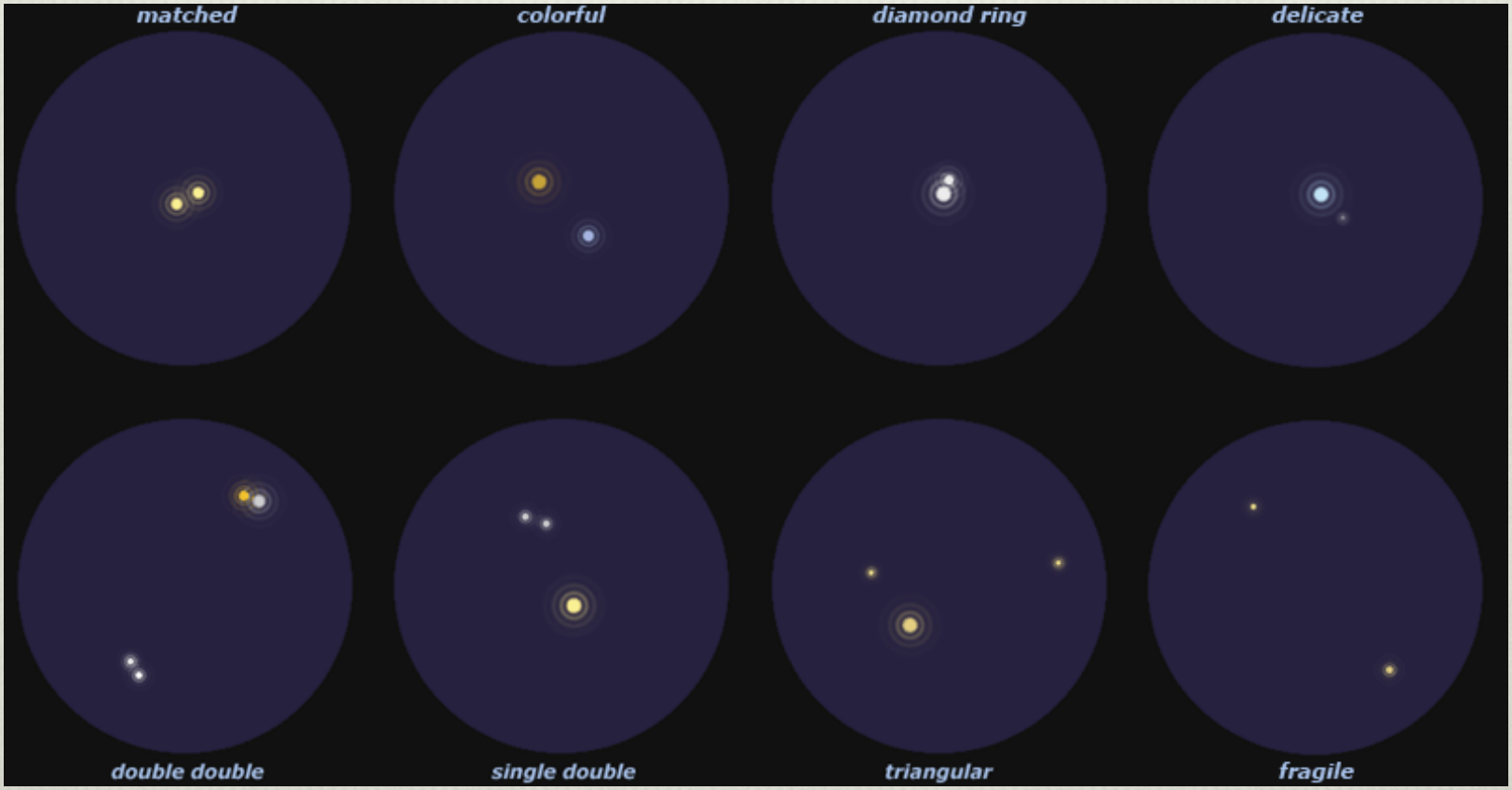
Learning Benefits

I learned more than I anticipated from the observing campaign, such as …

- Development of general equipment (manual) skills and visual observing skills
- Specific visual skills necessary to observe faint, close double stars
- The need for an observing list, and the difficulties of constructing one
  - The emphasis is on visual rather than physical attributes of double stars
  - No reference I found combined an observing program with an understanding of double star origins and evolution, and their role in the history of astronomy
- Use of catalog spectral/luminosity type and angular separation to estimate system physical distance $D_{pc} = 10^{1+((m-M)/5)}$ and orbital radius $a_{AU} = D * 10^{\log(\rho)+0.13}$
- Appreciation of diversity beyond "showcase pairs" and "challenge binaries"
- Analytical observing habits — *looking for* instead of *looking at*
- Self study into binary formation, evolution and population characteristics
  - What is a typical double star?
  - What is the range of binary dimensions and distances?

Fossils of Star Formation

I learned to enjoy the wide variety of double star configurations as "fossil" evidence of their complex origins and dynamical evolution. My novice interest in striking configurations, "challenge doubles" and vivid colors developed into an appreciation of origins, scale, evolution and multiplicity.

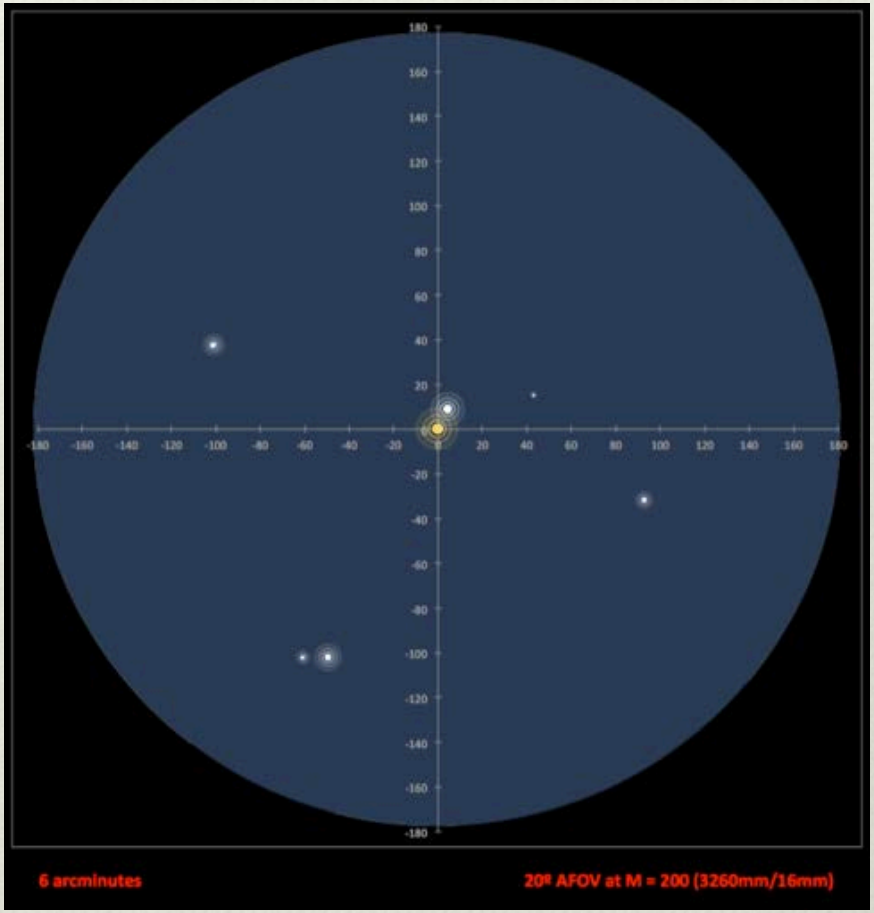


Looking *for* — the "Binary Bias"

- I discovered that many doubles catalogued as binaries in the CDSA list were in fact multiple systems. I called this list inaccuracy a *binary bias*.
- However this catalog bias seems to affect observer expectations. One astronomer's observing notes:

  Despite its faintness, Cancer was surprisingly full of fine doubles. Iota was a splendid yellow and blue pair at low power, doing a very passable impersonation of Albireo. Less striking, but similar in color, was 57 Cancri, whilst STF 1245 was yellowish and white. …

  … in fact, the STF 1245 system comprises at least *seven* stars.
- Analytical looking developed from the pleasure of discovering these systems.



STF 1245 (Cancer)

A Typical Visual Binary

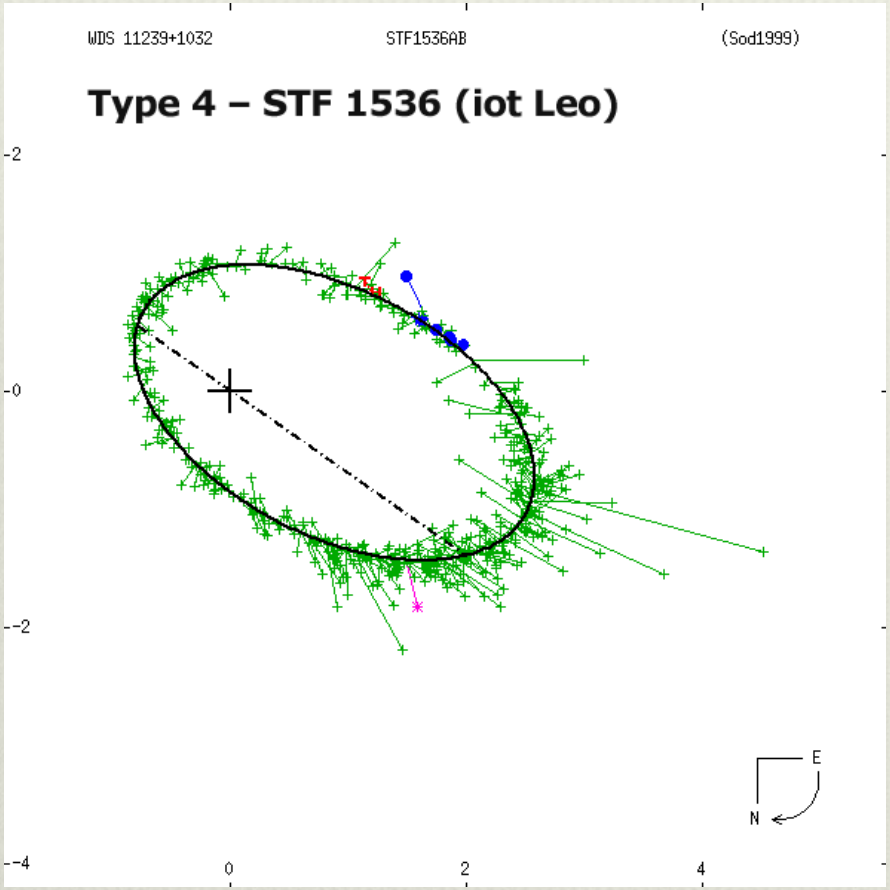


image from 6th Orbital Catalog

period = 186 years; orbit radius = 41 AU
estimated M = 1.85$M_{\odot}$; estimated q = 0.54
semimajor axis = 1.91"; eccentricity = 0.53
STF 1536 C: mag. 11.1, separation 332"

- Distance 24 parsecs — main sequence Type F0 and later visual binaries at v.mag. ≤ 10 are within ~300 parsecs
- Likely formed together — orbit is smaller than the typical radius of protostellar disks (~100 AU)
- High orbital eccentricities (e > 0.5) indicate dynamic interactions with other stars in natal star cluster
- Multiple systems form dynamical hierarchies, at distance ratios of ~1000:1 and periods of ~20,000:1

Range of Binary Dimensions

log(P) days	*Period days / years*	*Orbit SM axis a* $R_\odot$ / AU*	*Distance a = 2" (parsecs)*	*Percent of 6th Orbital*	*Type Label*
0	*1* / 0.003	*5.3* / 0.025	*2500 AU*	0.006	*interacting*
1	*10* / 0.027	*25* / 0.11	*10,000 AU*	0.014	*circularized*
2	*100* / 0.274	*114* / 0.53	0.25	12.7	*short (Venus R = 0.72 AU)*
3	*1000* / 2.74	2.46	1	19.7	*(asteroids R = 2.8 AU)*
4	27.4	11.4	5	43.7	*median (Saturn R = 9.6 AU)*
5	274	53	25	20.4	*(Kuiper Belt R = 50 AU)*
6	2740	245	100	0.012	*long*
7	27,400	1,140	500	0.002	*soft (wide)*
8	274,000	5,270	2500	.	*fragile (very wide)*
9	2,740,000	24,400	10000	.	*(empirical limit at ~30,000AU?)*

**Assumes a binary system of two solar masses: $M_1 + M_2 = 2M_\odot$ and $a^3_{AU} = 2P^2_{yr}$; values of period and radius rounded for simplicity. For constant orbital period, orbital distance increases as system total mass increases.*

Double Star References

- Brian Mason & Bill Hartkopf, *Washington Double Star Catalog* (WDS, ~116,000 records, *~101,000 systems*, updated frequently; all data and dataset notes are available online at http://ad.usno.navy.mil/wds/wdstext.html)
  - WDS ID, historical IDs, epoch, position angle (θ), separation (ρ), magnitudes, etc.
  - An edited spreadsheet version in "night vision" red on black type with distance calculator is available at http://www.handprint.com/ASTRO/XLSX/WDS.xlsx
- James Mullaney & Wil Tirion, *Cambridge Double Star Atlas* (2010, *2300 systems*)
  - The star charts and preface are excellent; observing list is full of ID and parameter misprints
- Sissy Haas, *Double Stars for Small Telescopes* (2008, *2100 systems*)
  - Informative, reliable and even inspirational; excellent observing list
- Ian Cooper & George Kepple, *The Night Sky Observer's Guide* (2008, *2100 systems*)
  - Compiled by skilled amateurs, with selected double stars by constellation (in 3 volumes)
- Ian Ridpath, *Norton's Star Atlas* (2010, *285 systems*, with table of orbital elements)
  - A trustworthy and up to date general reference ... 8 small scale (double page) star charts
- Bob Argyle (ed.), *Observing and Measuring Visual Double Stars, 2nd ed.* (2012)
  - An indispensable reference for double star observation and measurement

Additional References

- Eric Chaisson & Steve McMillan, *Astronomy Today, 7th Edition* (2011)
  - One of many introductory textbooks on astronomy and cosmology — get at least one!
- SAO/NASA Astrophysics Data System ... http://www.adsabs.harvard.edu
- *RASC Observer's Handbook* (annual, *~210 systems*)
- *Webb Deep Sky Society Double Star Section* … http://www.webbdeepsky.com/
- Paul Couteau, *Observing Visual Double Stars* (1978, *744 systems*)
  - Informative, technical but reader friendly; includes observing checklist of close binaries
  - Indispensible general reference; includes two observing checklists
- Wulff Heintz, *Double Stars* (1978)
  - Comprehensive, detailed and concise; although expensive, academic and somewhat dated
- Many planetarium software programs available, but for double stars the best are:
  - AstroPlanner (iLanga)
  - Redshift 7 (United Soft Media)
  - TheSkyX Pro (Software Bisque)
  - Voyager (Carina Software)

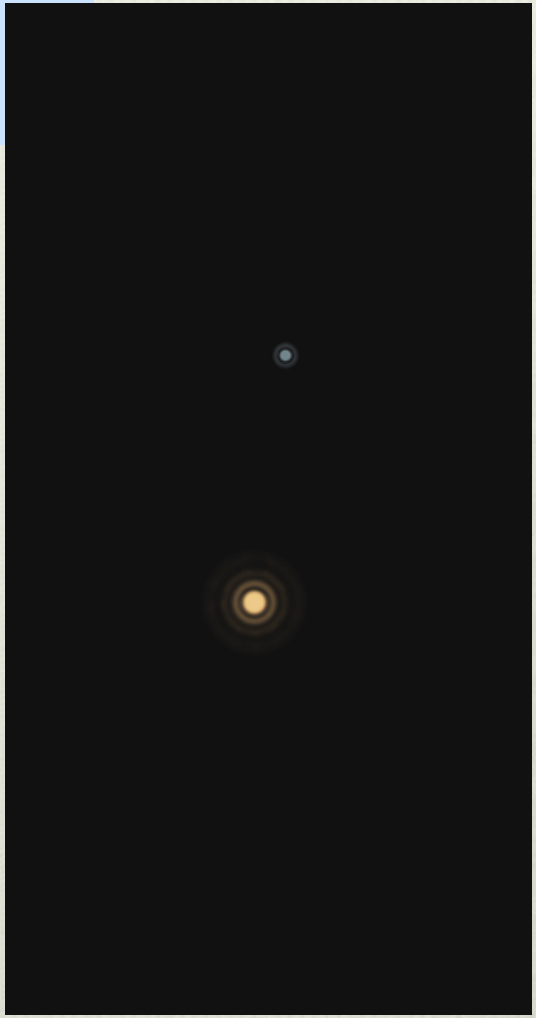
Clear Dark Skies!

"Binary formation is the primary branch of the star formation process."

—Mathieu (1994)

"Binaries are the basic building blocks of the Milky Way as galaxies are the building blocks of the universe. In the absence of binaries many astrophysical phenomena would not exist and the Galaxy would look completely different over the entire spectral range."

—Portegies Zwart, Yungelson & Nelemans (2000)



drawing of S 404 AB (gamma Andromedae)