DASCH to full production scanning, Data Releases, and Early Science

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Prague *Astroplate* Conference (via Skype)

March 21, 2014

Opening the
Digital Access to a Sky Century @ Harvard
(DASCH)

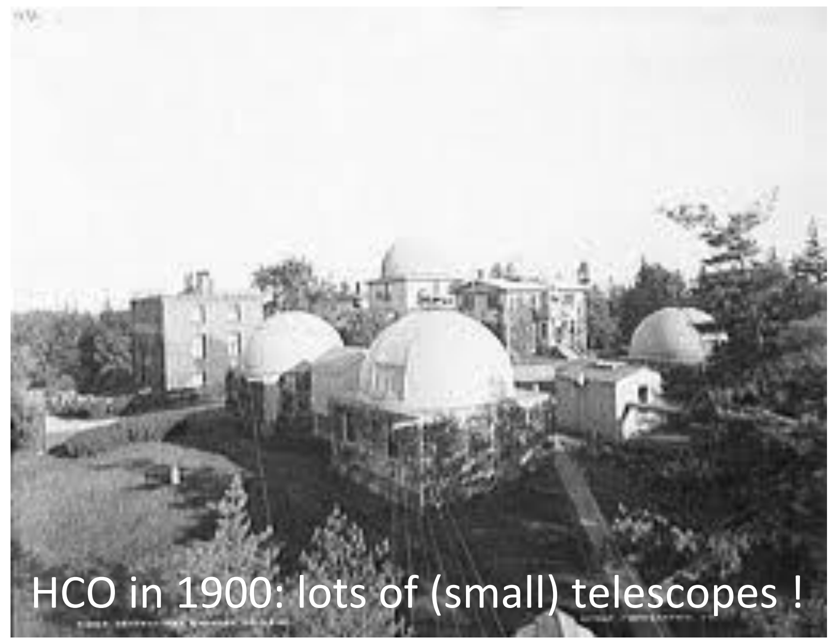
- The Harvard College Observatory (HCO) has the world's largest collection of glass plate images of the full sky:
  - ~500,000 glass plate images covering the *full* sky (each typically 10^o x 10^o), which is 3X larger than second largest collection
  - **~100y time duration** (1885 – 1992!); ~1-2 *thousand* images for any given object **full sky** (typical intervals ~1 wk – 2 mos; ~1500 images)
  - Depth typically B ~13-14, but ~30% to B ~15 and ~15%(?) to B ~17-18
  - Full sky coverage (both northern/southern), any region covered (typically) ~1-3X per month

Opening the

Digital Access to a Sky Century @ Harvard (***DASCH)***

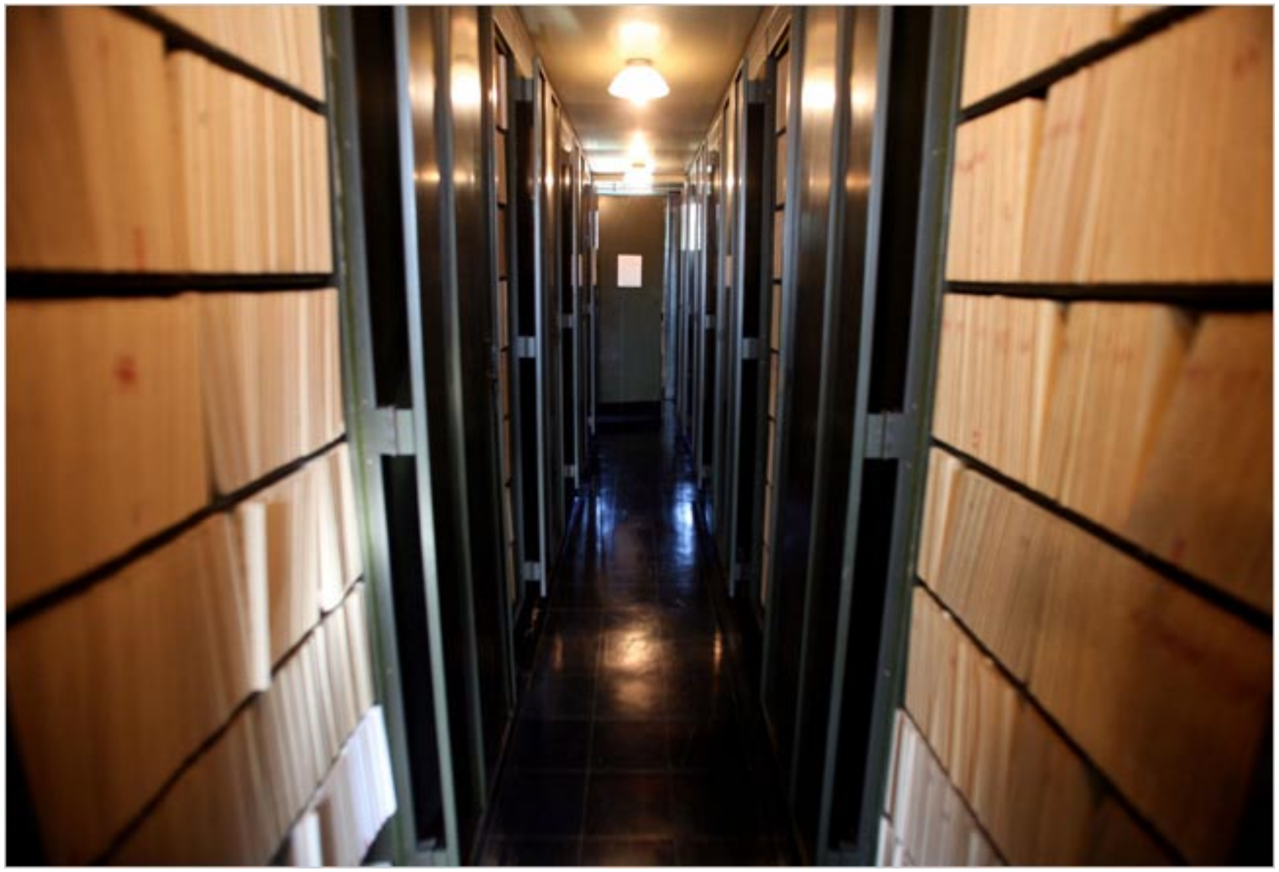
To enable Time Domain Astrophysics on ***unexplored timescales***

- HCO has the world's largest collection of glass plate images of the full sky, recorded from Cambridge, Harvard MA, & Harvard telescopes in Peru, S. Africa and New Zealand:
  - ~500,000 glass plate images of the sky (each typically 10^o x 10^o), or 3X larger than second largest collection
  - ~100y time duration (1885 – 1992); ~1-3 *thousand* images for any given object (typical intervals ~1 week – 2 months)
  - Full sky coverage (both northern/southern), any region covered (typically) ~1-3X per month

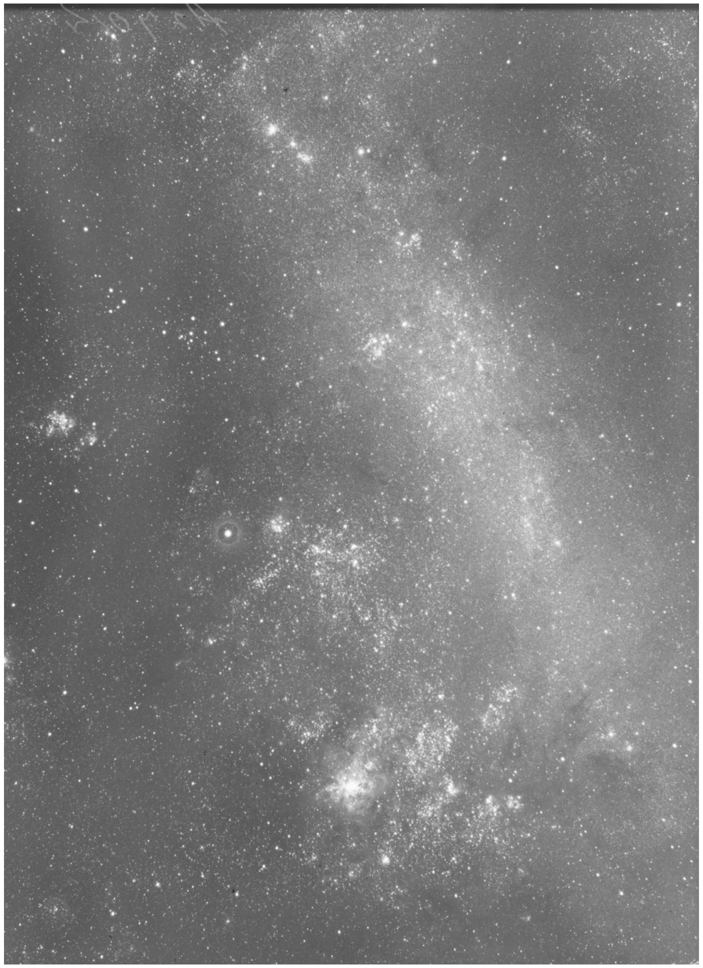


What do ~500,000 plates look like?

Cabinet after cabinet packed with **~200 tons of glass plates** (each is 20 x 25cm) in envelopes filling 3 floors of "Building D" at HCO, built with internal steel framework by **Shapley** in 1932 just to house the plates:



What does a "typical" (well, beautiful…) plate look like?



Large Magellanic Cloud. Plate **a*27014***, Oct. 27, 1949
Cepheid variables were discovered by Henrietta Leavitt to first define their Period-Luminosity relation (image from 24in Harvard telescope in Bloemfontaine, S. Africa)

1910 passage of Halley's comet. Plate ***b41215 (!) -*** a 30min exposure taken with Harvard 8in telescope in Arequipa, Peru

Why undertake *DASCH* now ?

- Time Domain Astrophysics (TDA) is a major field; has never been possible or surveyed on ~100y timescales

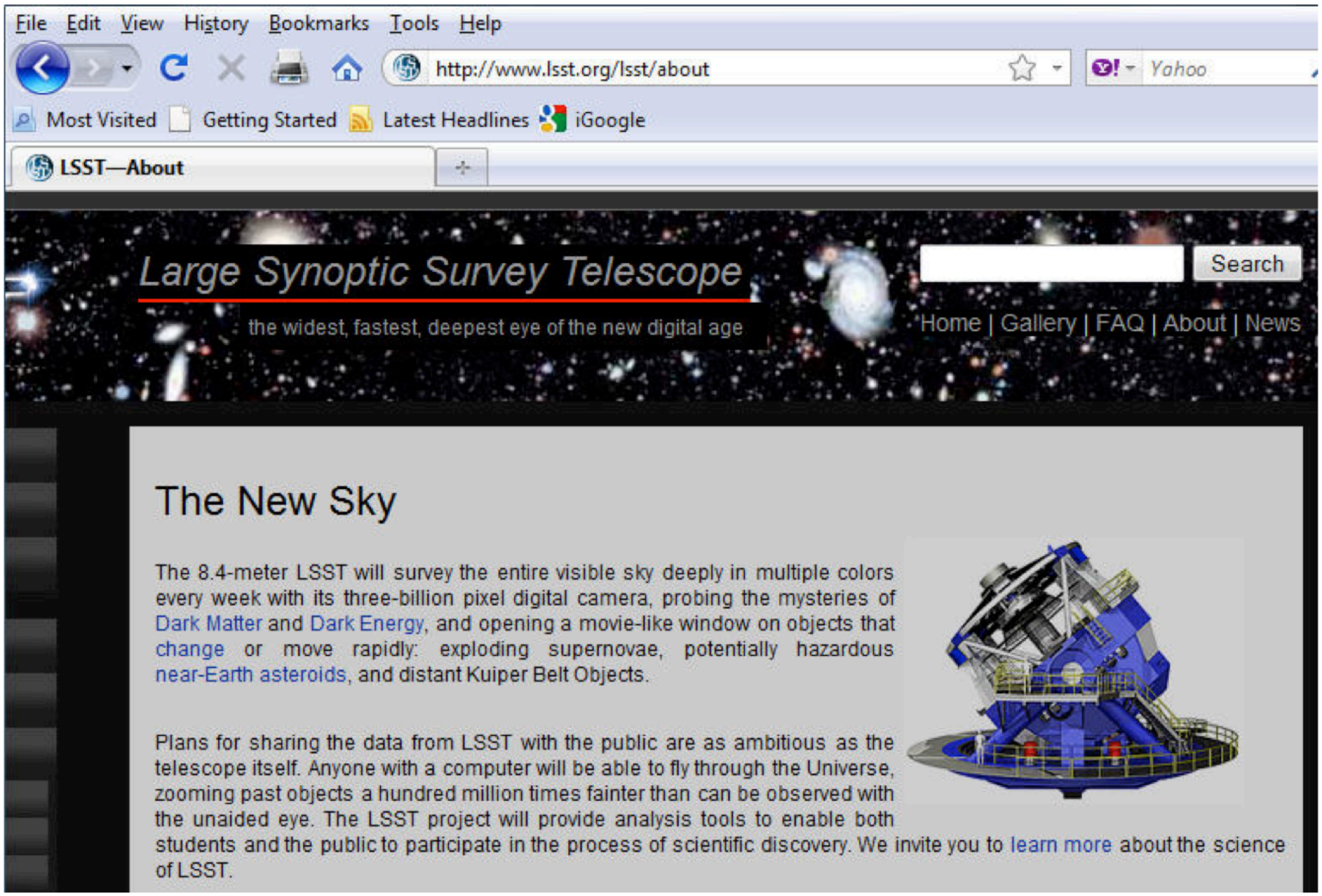
- Complements PanSTARRS (and PTF, etc.) now and LSST later by providing TDA of *long timescales* **and *low duty-cycle* transients and inherently *rare events***

- All-sky photometric catalogs (GSC2.3.2 and now APASS) provide *>10^4 calibration stars on each plate* for photometry-astrometry

- Processing, serving and backup storage of ~1 Pb of ~500,000 digitized images and full database, with “instant” (~10sec) lightcurves on any object now posible at relatively low cost

DASCH complements PTF, CRTS, PanSTARRS now and the *highest priority US telescope,* **LSST** (in 6 years…)

By providing the only past century record of luminous outbursts of a wide range of variables ~5mag fainter that will be discovered with LSST…

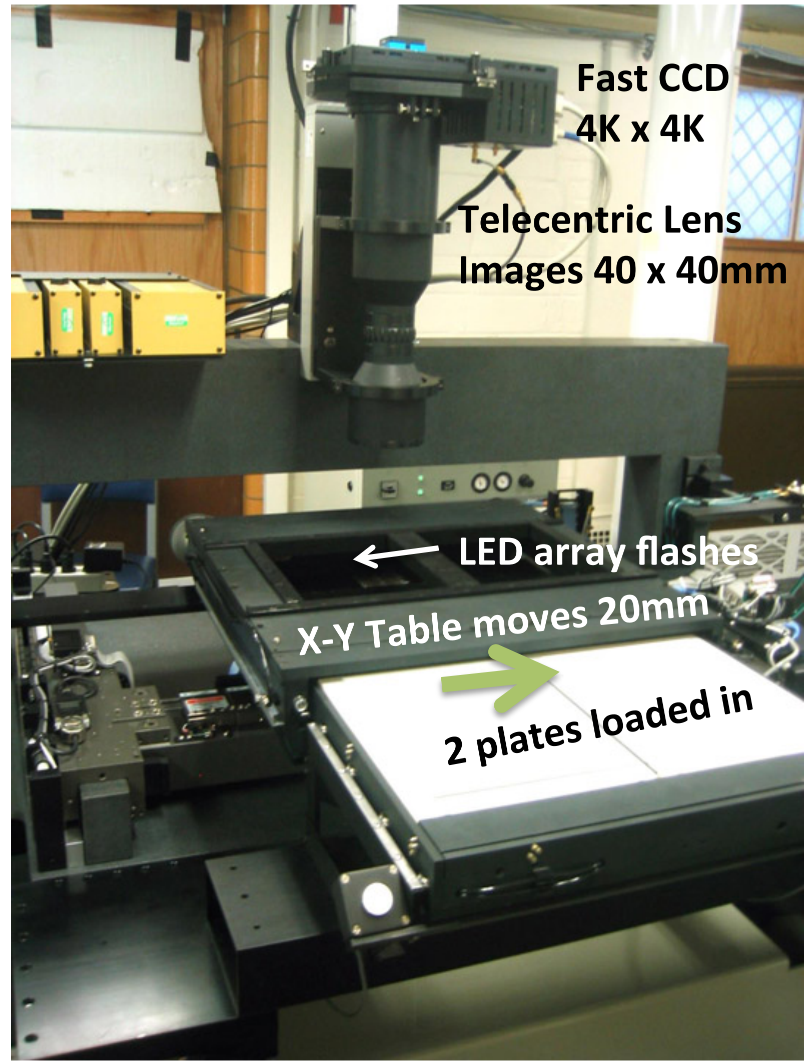


So we designed, built, the world's fastest (and most precise…) *Scanner* **and** *Analysis Pipeline*

- Scan 2 plates (8 x 10in) or 1 plate (14 x 17in) in ~90sec with fast CCD and precise (0.1µm) steps of 60 exposures/ 8x10plate (see website **and videos** at http://dasch.rc.fas.harvard.edu/

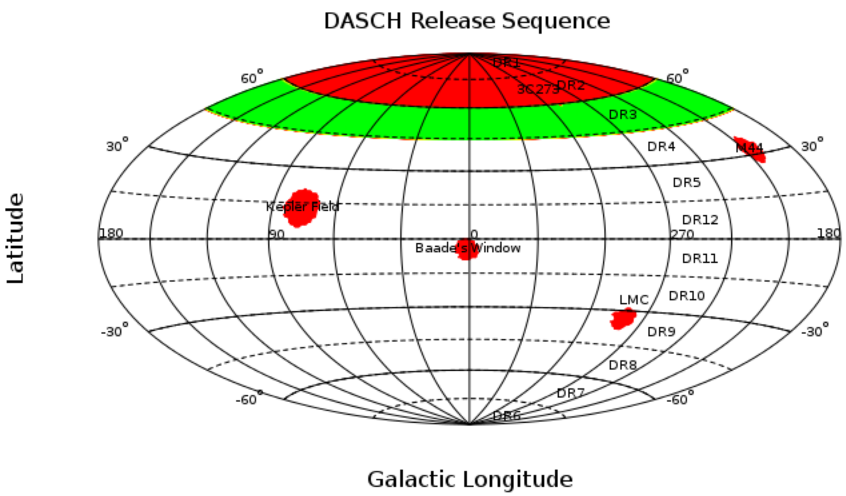
- 11micron pixels over full plate!

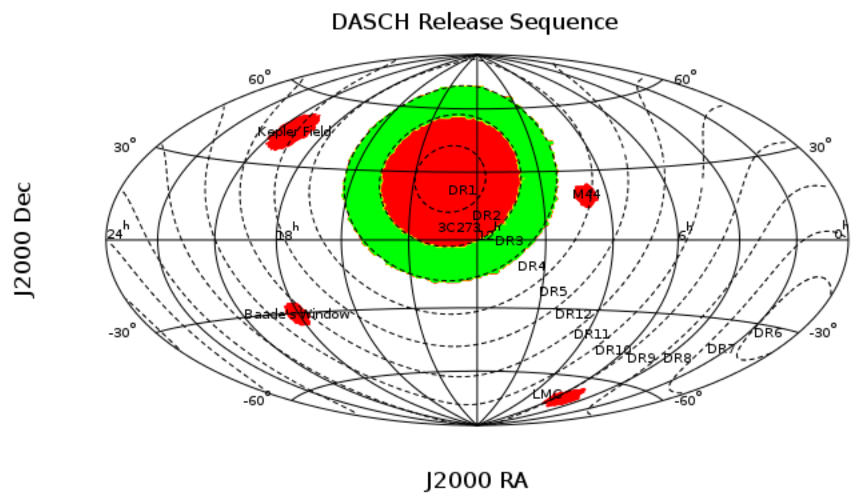
- ~1Gb mosaiced image formed (from 60 image tiles) and analyzed for ~1" positions and ~0.1mag brightness (mag) of *every* object in overnight processing: Pipeline (on *Odyssey*) populates MySQL database for LCs and off-line analysis tools



59,500 out of ~500,000 plates scanned so far

- 5 fields (marked) scanned in hardware/software development phase (5y)
- ***Production scanning*** (from NGP; 15^{o} increments in b per DR) **with 2 Data Releases DR1** (May 2013) & **DR2** (Oct. 2013) helped by summer students
- Limited staff (now increasing) but **DR3** will be released in April 2014
- Full production rate (400 plates/day) will finally be possible with PCM and increased staff by May 2014; DR4 – DR12 by Aug. 2017





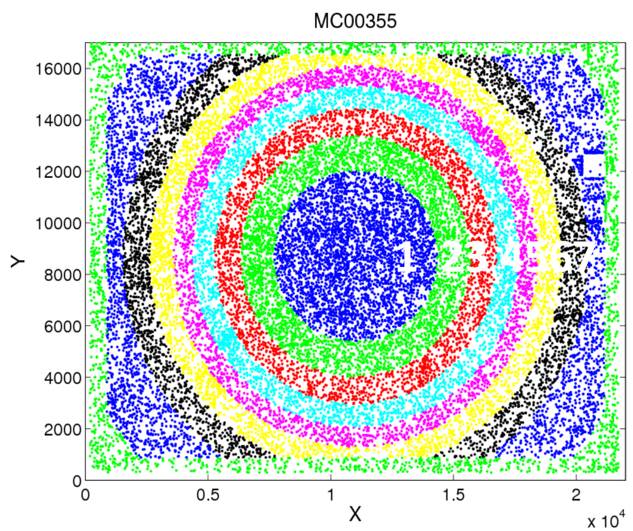
*How to **calibrate** 100y old plates from many telescopes?*

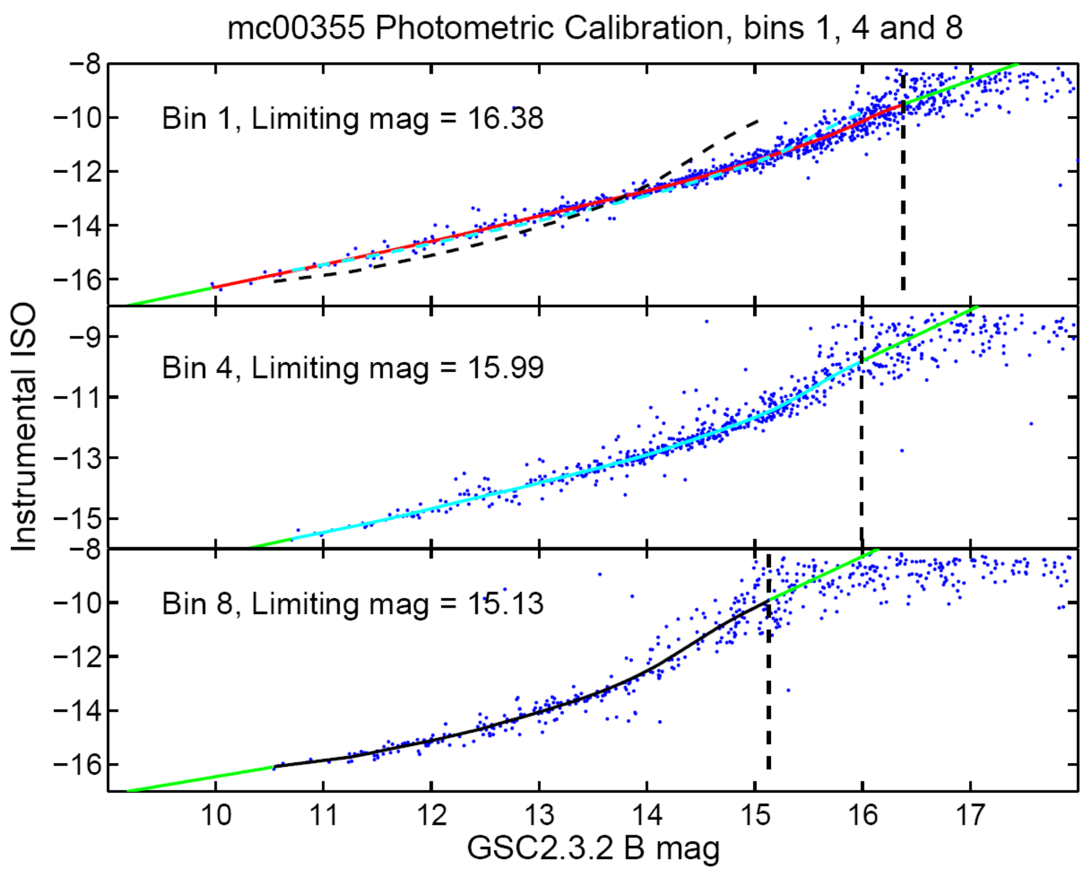
Photometric calibration globally in *annular* bins

There are systematic differences on the plates depend on radial distance from the optical axis, due to vignetting and radially dependent PSF variations. Therefore we derive photometry in 9 equal-area annular bins. Calibrate initially against HST GSC2.3.2 catalog (B) (with 0.22mag uncertainties)

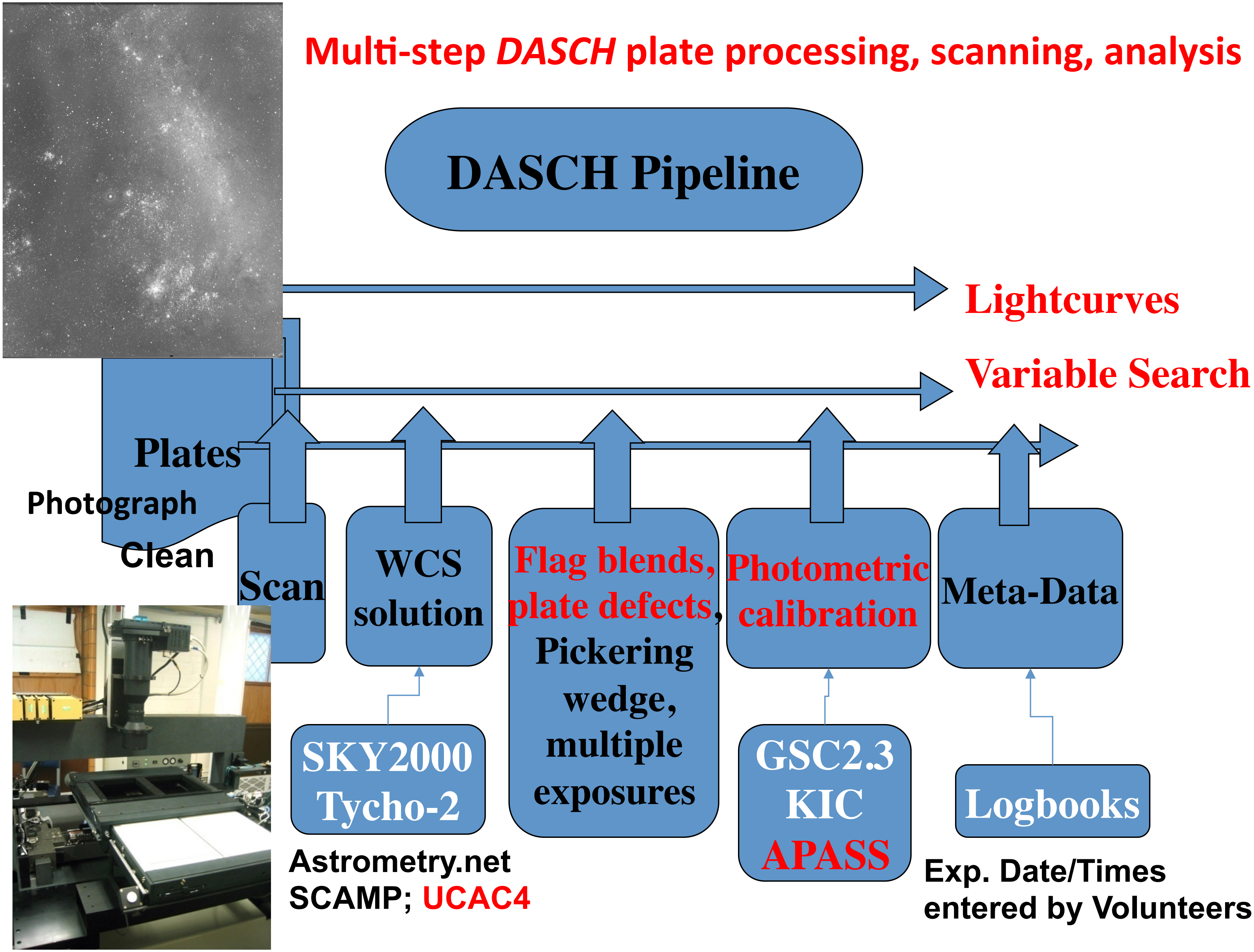
Now use APASS (B,V, g, r, I; 0.03mag)

Do spatially dependent calibration in 9 annuli over full plate ; then in *local bins* to correct airmass, clouds etc.

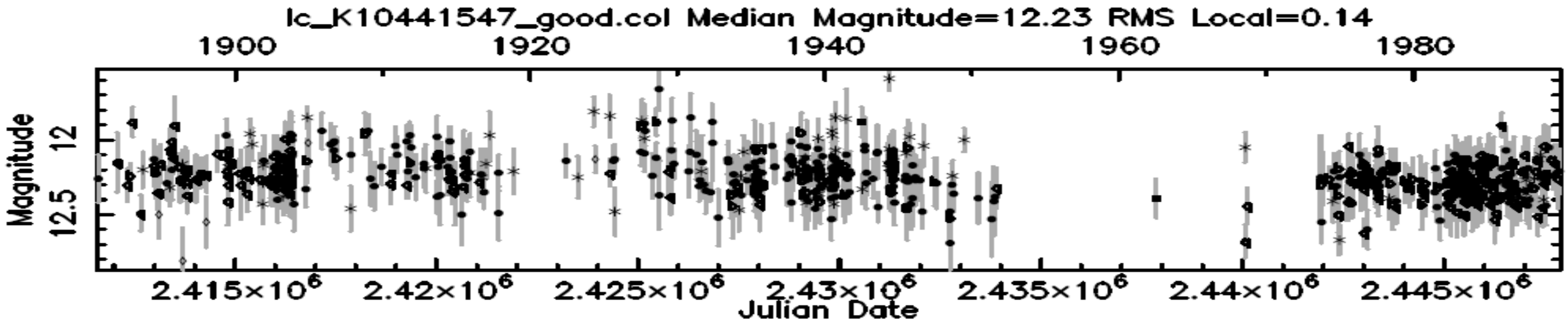




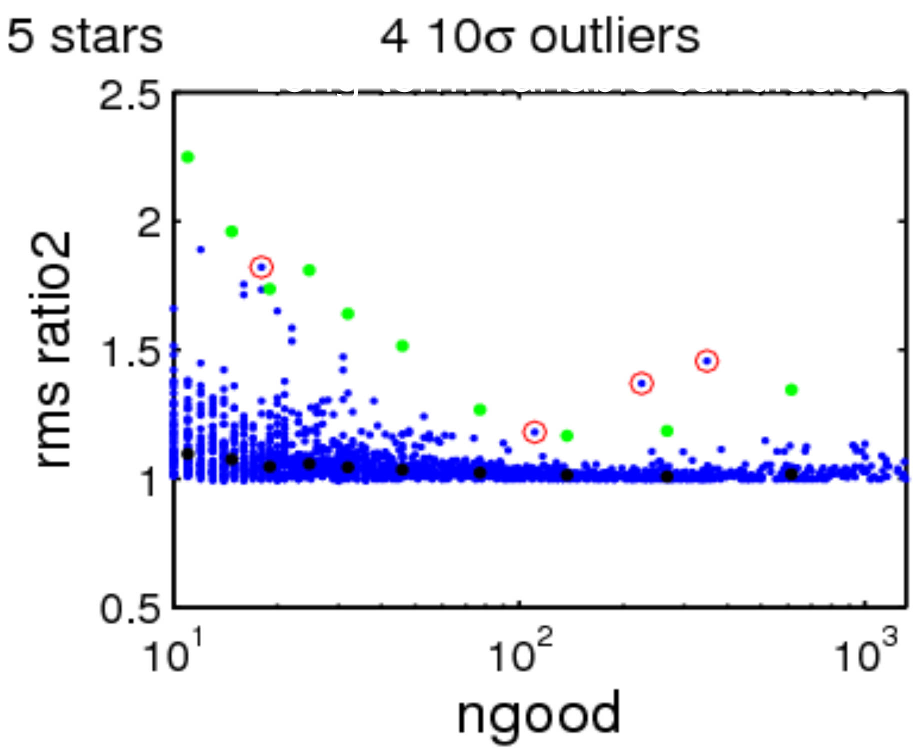
Multi-step *DASCH* plate processing, scanning, analysis

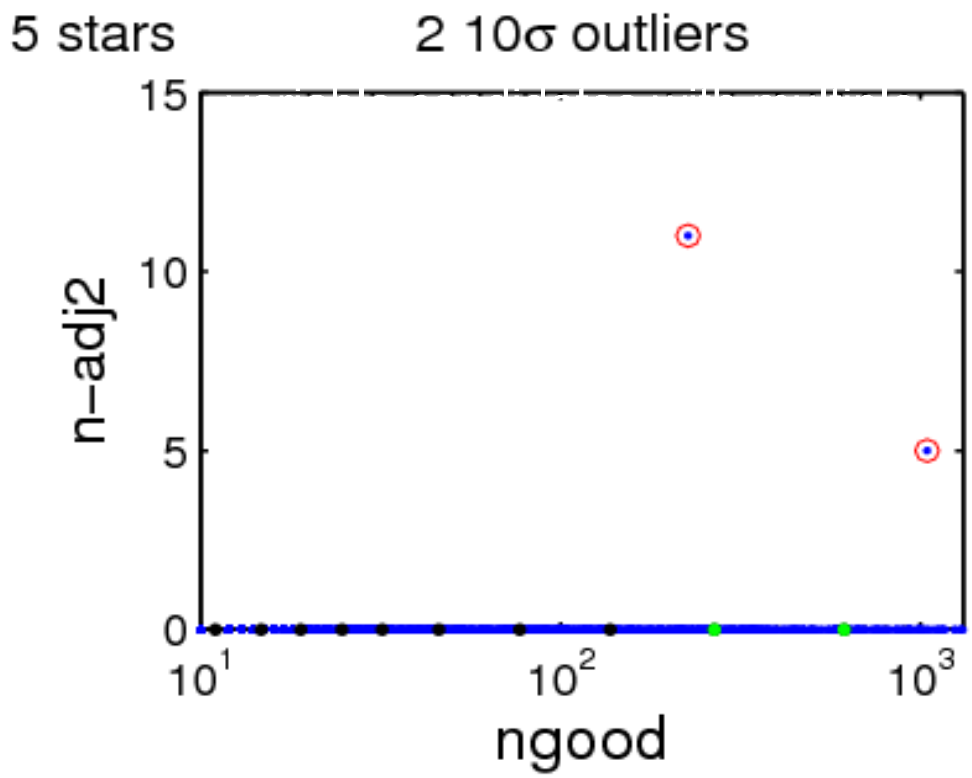


Then create Lightcurves of *every star.* Most are constant:



And search all LCs for *variable stars (or objects) as "Outliers"*:





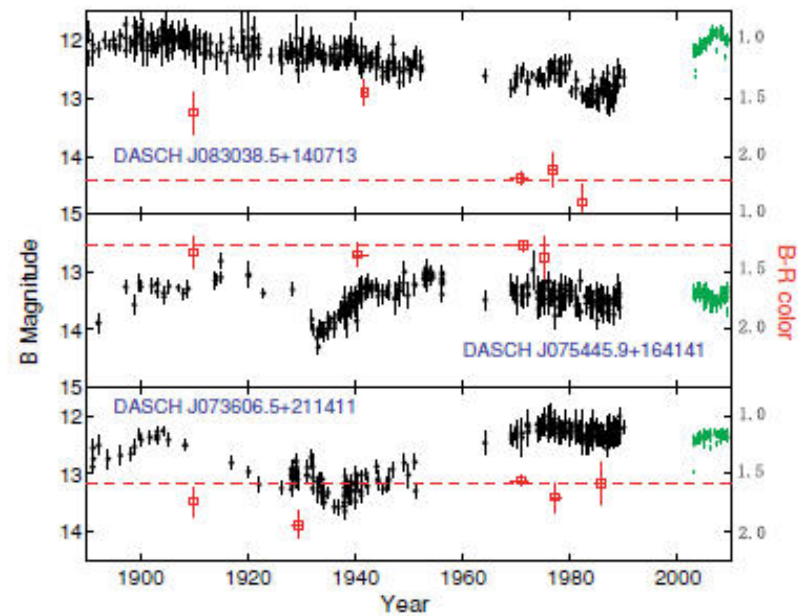
Some DASCH discoveries: 100y changes in cool giants

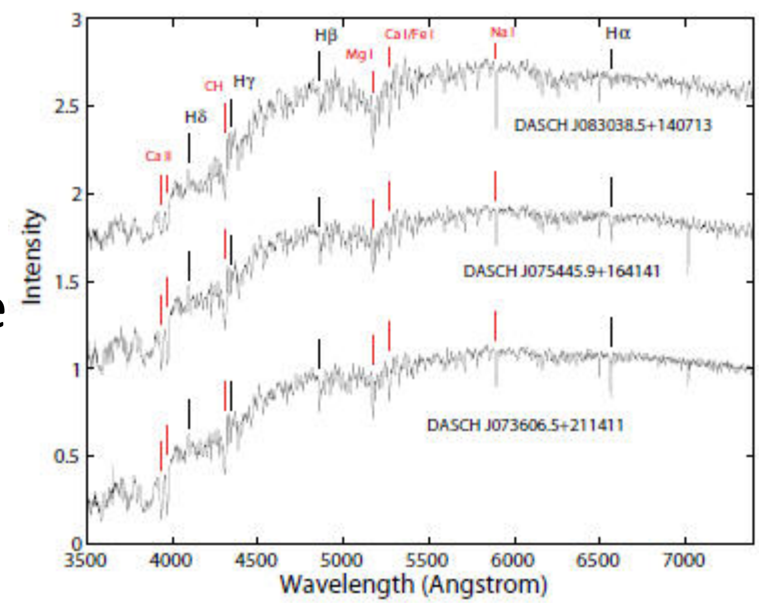
- 3 K3 giants (RGB, *not AGB)* out of ~10^4 stars measured in M44 field *showed ~20% variations over ~10-50years!*

- Never seen before and *not accounted for by stellar models!*

- Followup optical spectra showed all 3 stars have ~identical temps.
  Tang, Grindlay et al (2010)

- More discovered in *Kepler field*: some due to *huge* star spots (in active RSCVn binaries); others from **dust ejection** ? Tang, Grindlay et al (2013)





DASCH Discovery of Dust Accretion:

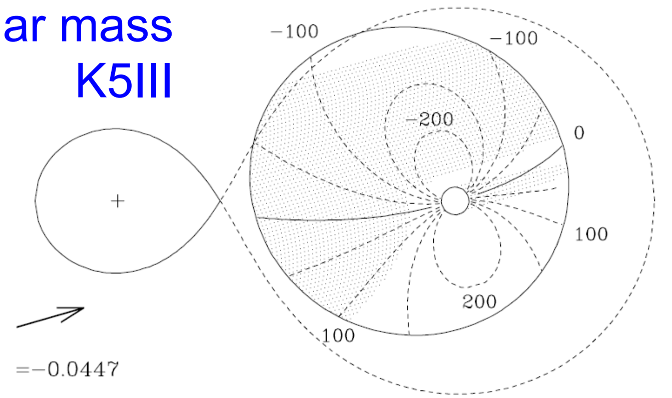
KU Cyg: *dimming* by increased mass transfer of DUST in an eclipsing binary

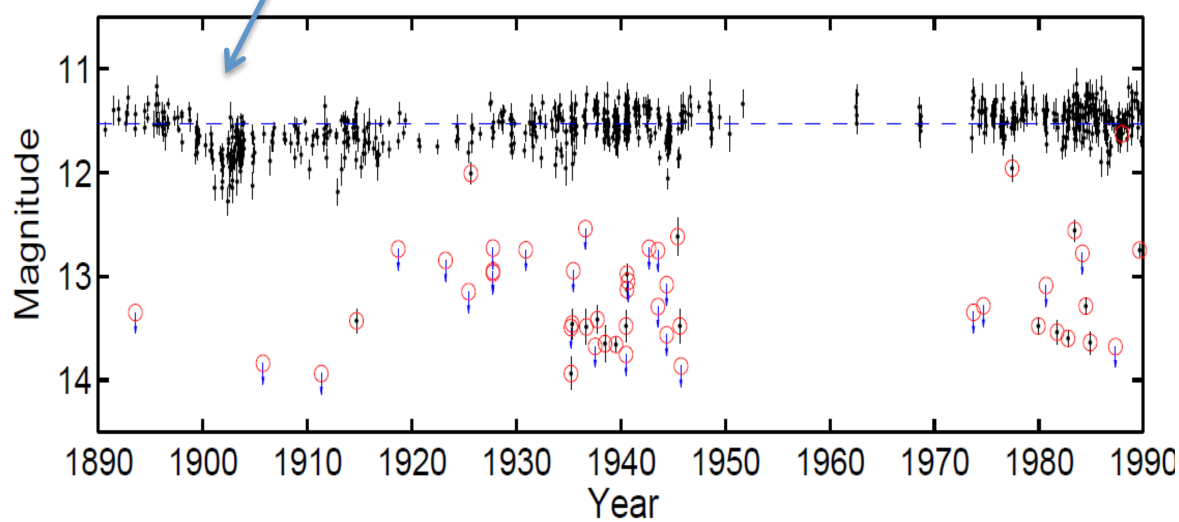
(Tang, Grindlay et al 2011, ApJ)

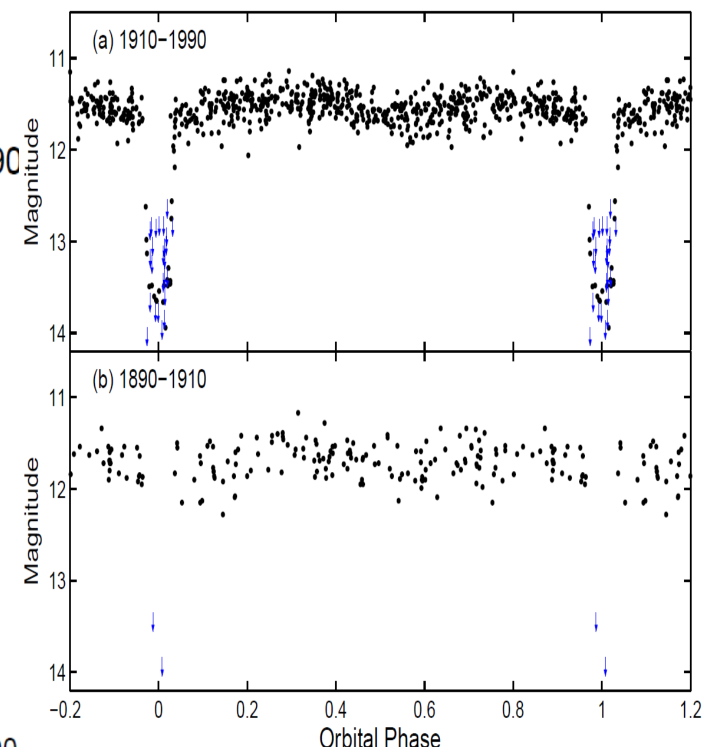
Inclination~86 deg

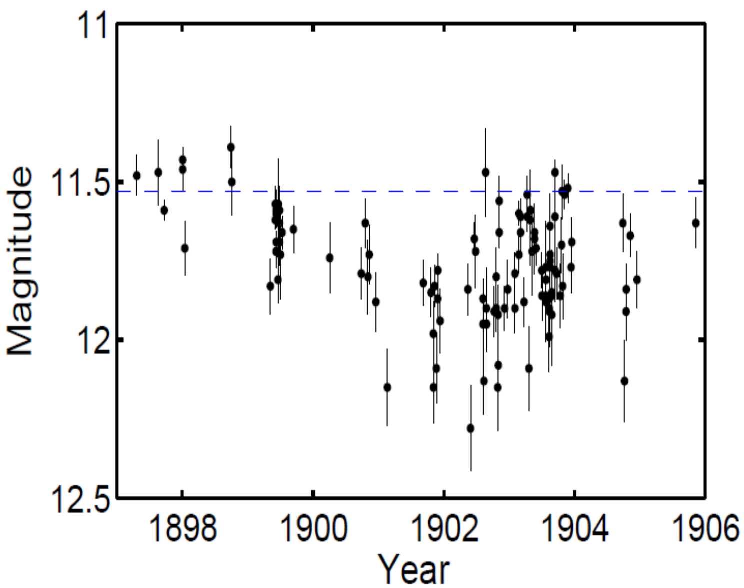
3.5 solar mass
F MS + disk

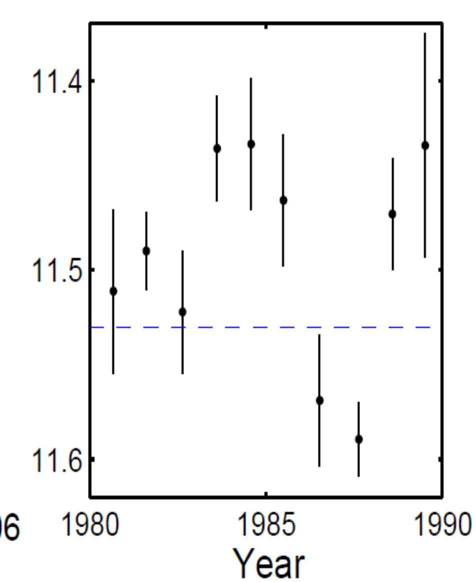
0.5 solar mass
K5III











DASCH

Discovery of a new *Symbiotic Nova* (only 9 known so far)

Nuclear burning on a White Dwarf binary comp. to a giant star… ***without mass ejection***!

=>New clues to **Origin of SNIa's**

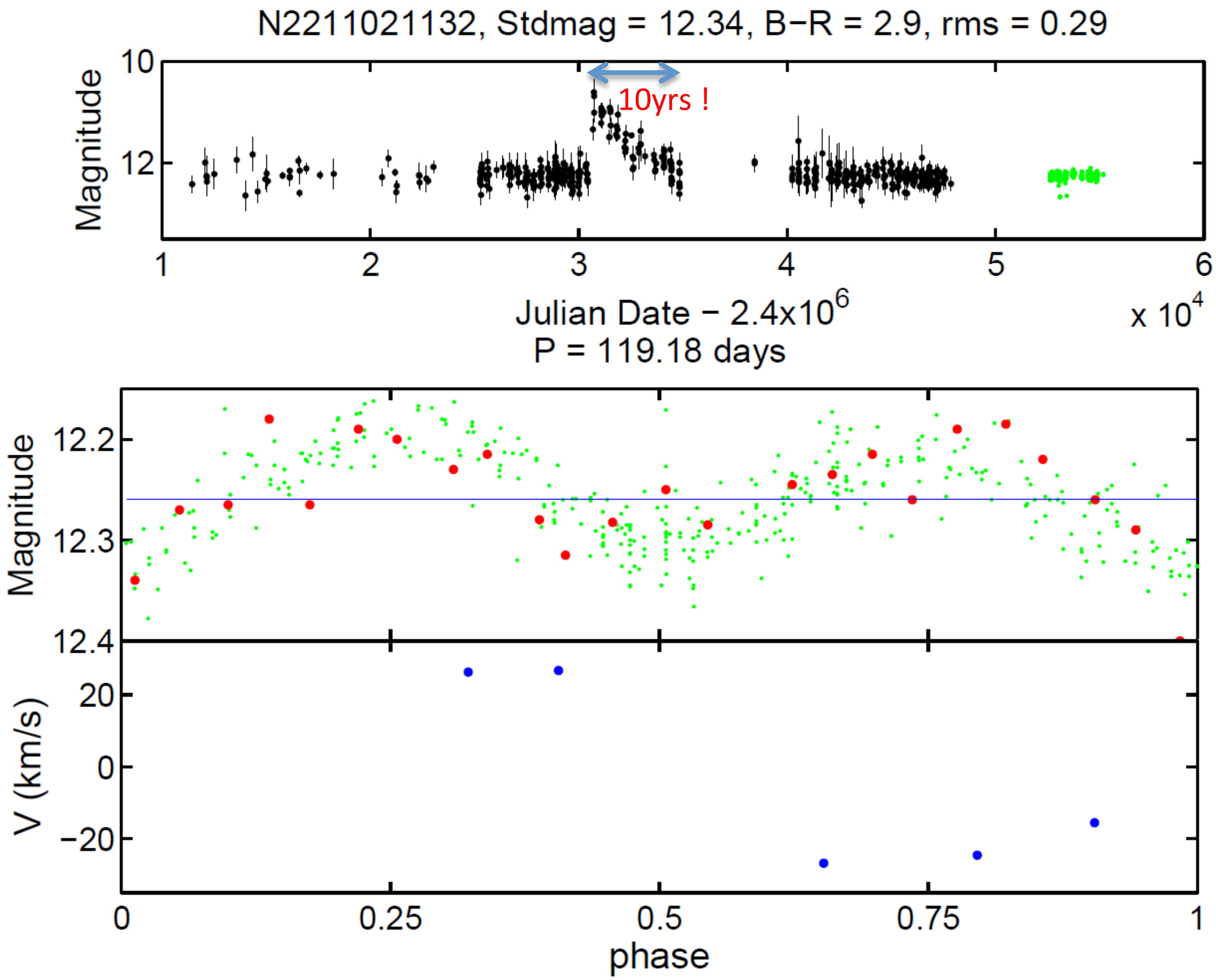


Figure 1: Our new symbiotic nova candidate N2211021132. The upper panel shows its 100 yr DASCH lightcurve (black) and recent ASAS lightcurve (green). The middle panel shows its folded lightcurve with period 119.18 days; green dots are ASAS data, and red dots are binned DASCH data. The lower panel shows its velocities vs phase; the 5 velocity measurements are from TRES.

Tang, Grindlay et al 2012, ApJ

Stellar Mass black holes (sBHs) in Low Mass X-ray Binaries

BH-LMXBs

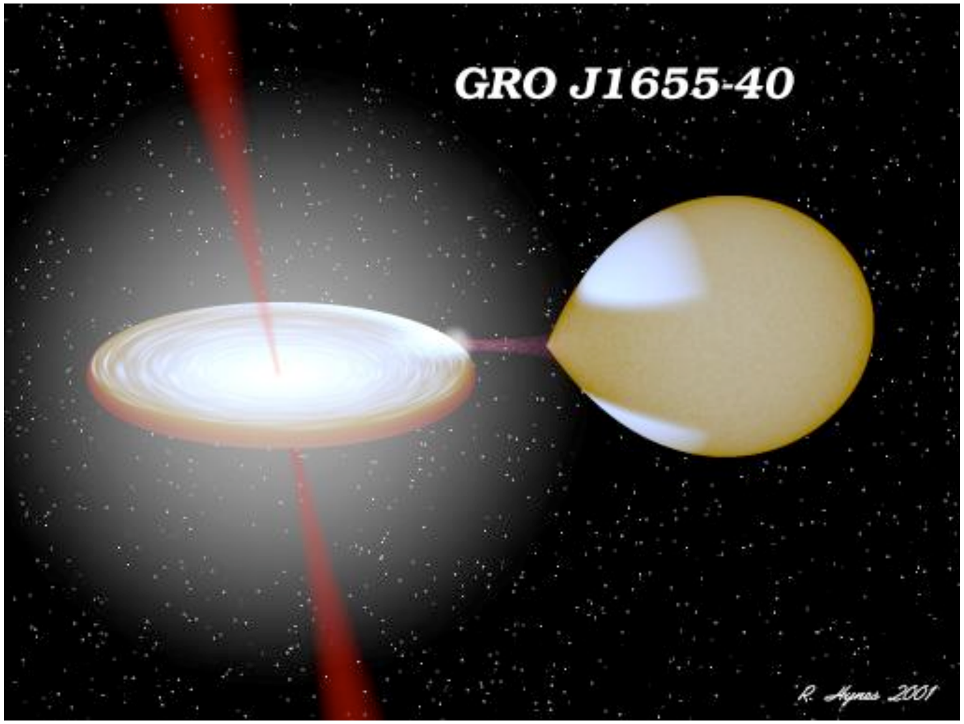
(one of the original motivations for undertaking *DASCH* !)

- More than 20 sBHs in BH-LMXBs inthe Galaxy now confirmed *dynamically*

- Only 1 sBH (Cyg X-1,) is *persistent* and with High Mass companion. Two others (Cyg X-3 & SS433) are likely BH-HMXBs and persistent

- All others are BH-LMXBs with K, M main seq. companions (B star in 1 case; **or** (in 4 cases) F or G of K *sub-giant* companions

- **ALL BH-LMXBs are RLOF accretors and ALL are *transient sources***



"True" scale depiction of sBH GROJ1655-40 with its FIV sub-giant comp. in a P = 62h orbit showing disk, hot spot and relativistic jets (courtesy R. Hynes)

Some (overlooked…) sBH "statistics"

- In addition to the dynamically confirmed ≥20 sBHs in LMXBs (BH-LMXBs), there are *≥40 strong candidates based on their spectral and temporal properties* (see Ozel et al 2010 for 32 of these).

- Neutron stars accreting in NS-LMXBs are uniquely identified by X-ray bursts (~60 sources) or pulsations (~15 sources; AMSPs) or luminous persistent "Z sources" (~10) so that for LMXBs, the *observed* fraction with accreting sBHs is $f_{BH/NS} \sim (20+30)/(60+15+10) \sim 0.7$

- **Puzzle #1: *Why should the BH/NS fraction in LMXBs*** *detected with 16y complete coverage from RXTE and now Swift/BAT (9y) and MAXI (3y)* ***exceed that expected from IMF of their BH vs. NS progenitors:***

$$f_{LMXB(BH/NS)} \sim \mathbf{0.7} >> f_{IMF(BH/NS)} \sim (20^{-1.4}-(40 \text{ to } 100\mathbf{?})^{-1.4})/(8^{-1.4}-20^{-1.4}) \sim \mathbf{0.2 - 0.3}$$

where we assume Salpeter or Kroupa IMF with index 1.4 and NS vs. BH formation mass cuts as shown ?? (**Note uncertain upper mass cut limit for sBHs** !)

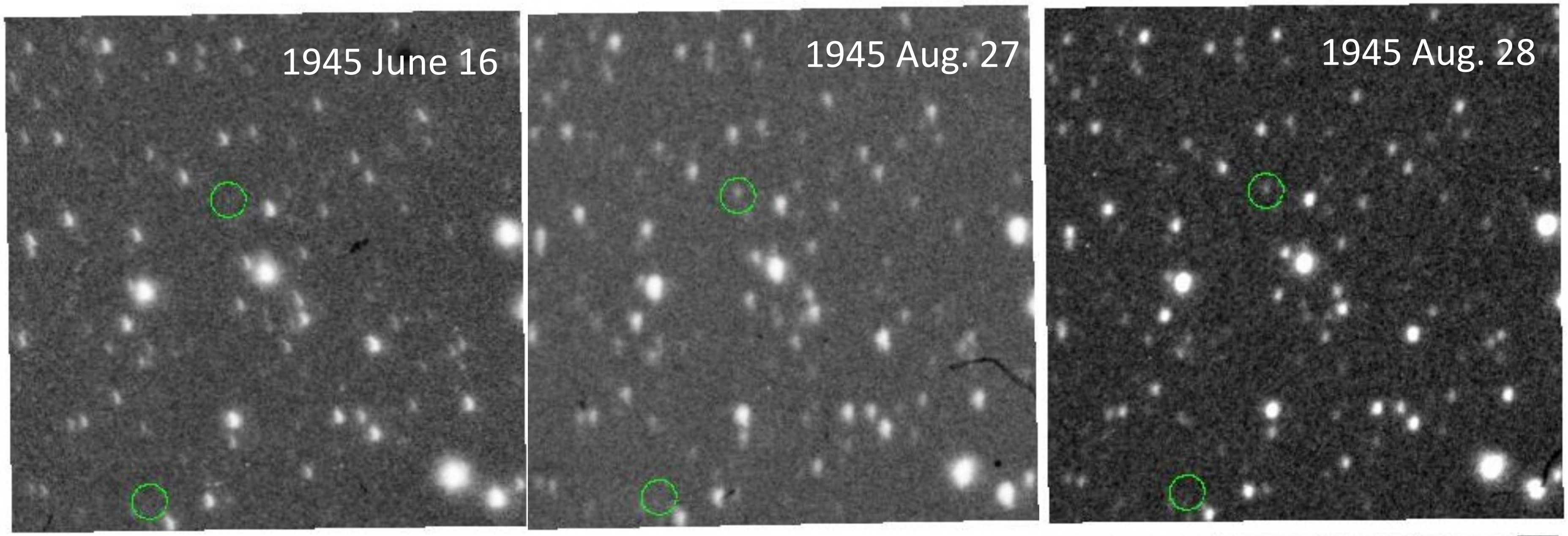
So best Population constraints for sBHs: measure *duty cycles&rec. times* of BH vs. NS-LMXB outbursts

- Design new surveys for Optical and/or X-ray *Transients* since >95% of all *accreting* sBHs (in LMXBs OR HMXBs) are transient! **So need Time Domain Astronomy (TDA survey(s) to estimate source totals from observed totals corrected for Duty Cycle (=fraction f "source on" time): $N_{tot} \sim N_{obs}/f$**

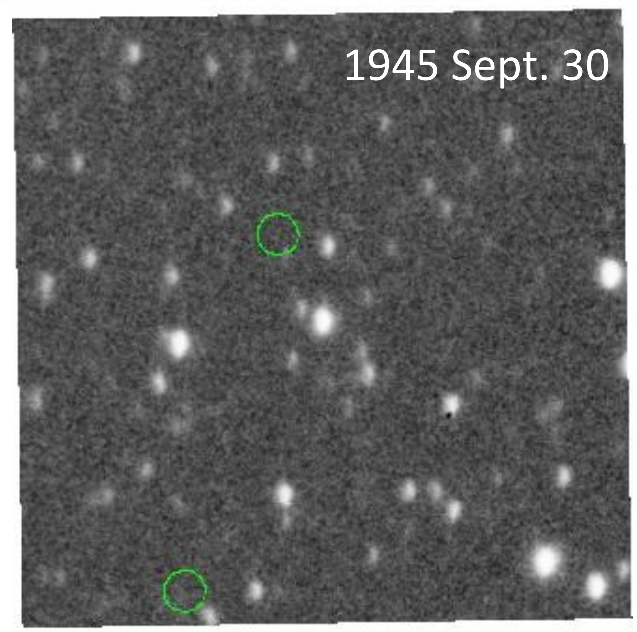
- Most BH-LMXBs are "off" at any given time; duty cycles are low; "on" times ≤1mo every ~50 years (highly uncertain) vs. NS-LMXB transients have shorter (<5y) recurrence times so that BH systems NOT favored in short duration surveys

- ALSO Need *long-duration* optical surveys (**DASCH**) as well as future *high-cadence*, wide-field optical (LSST) and more sensitive/higher resolution **X-ray** (**MIRAX-HXI?**) surveys

1st DASCH BH-LMXB search was for J1655-40: *1945 outburst*!



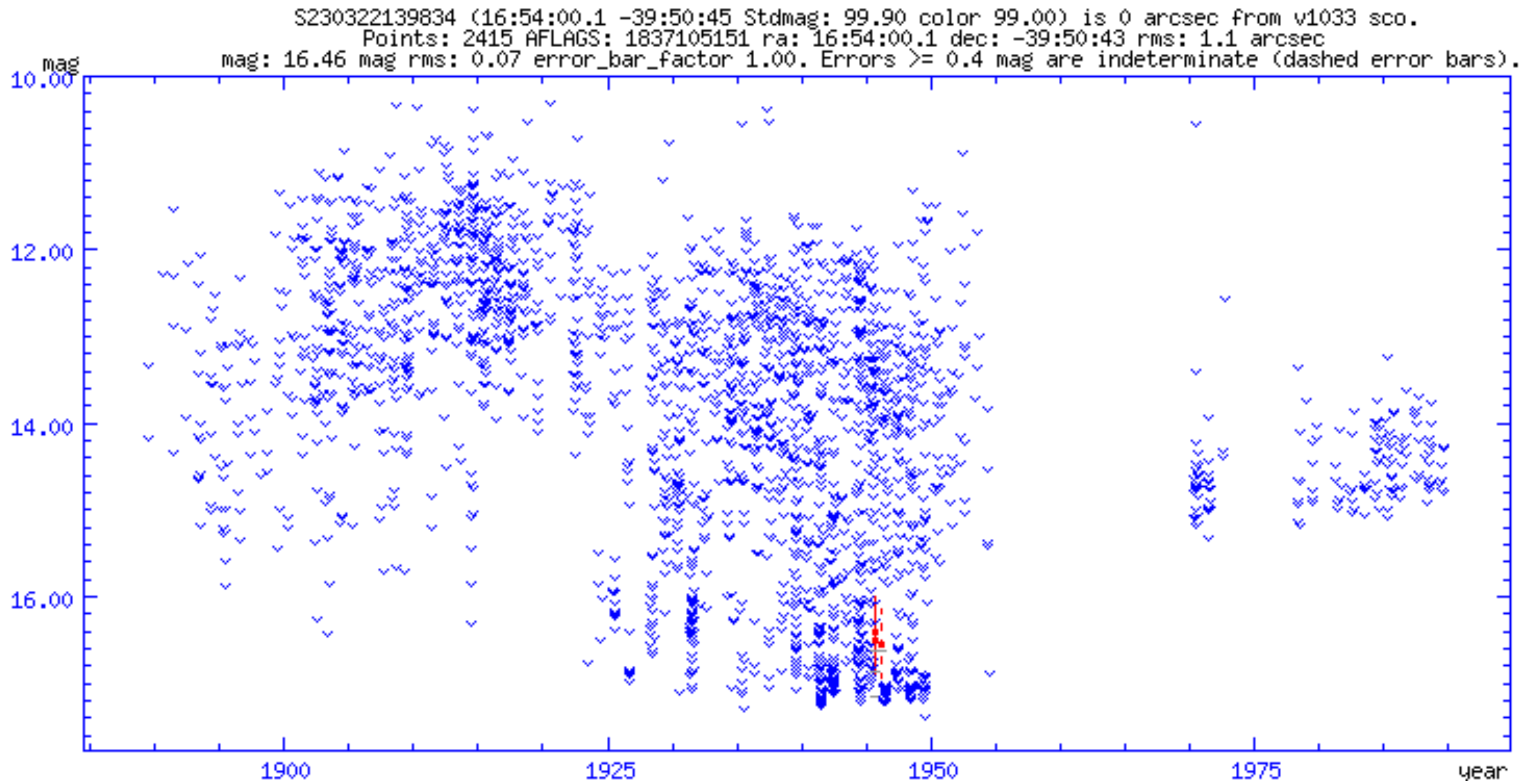
10’ x 10’ images from digitized Harvard plates (~B band)



- *This is only the 3rd BH-qLMXB recurrence time (after A0620 & V404 Cyg); again, ~50y*

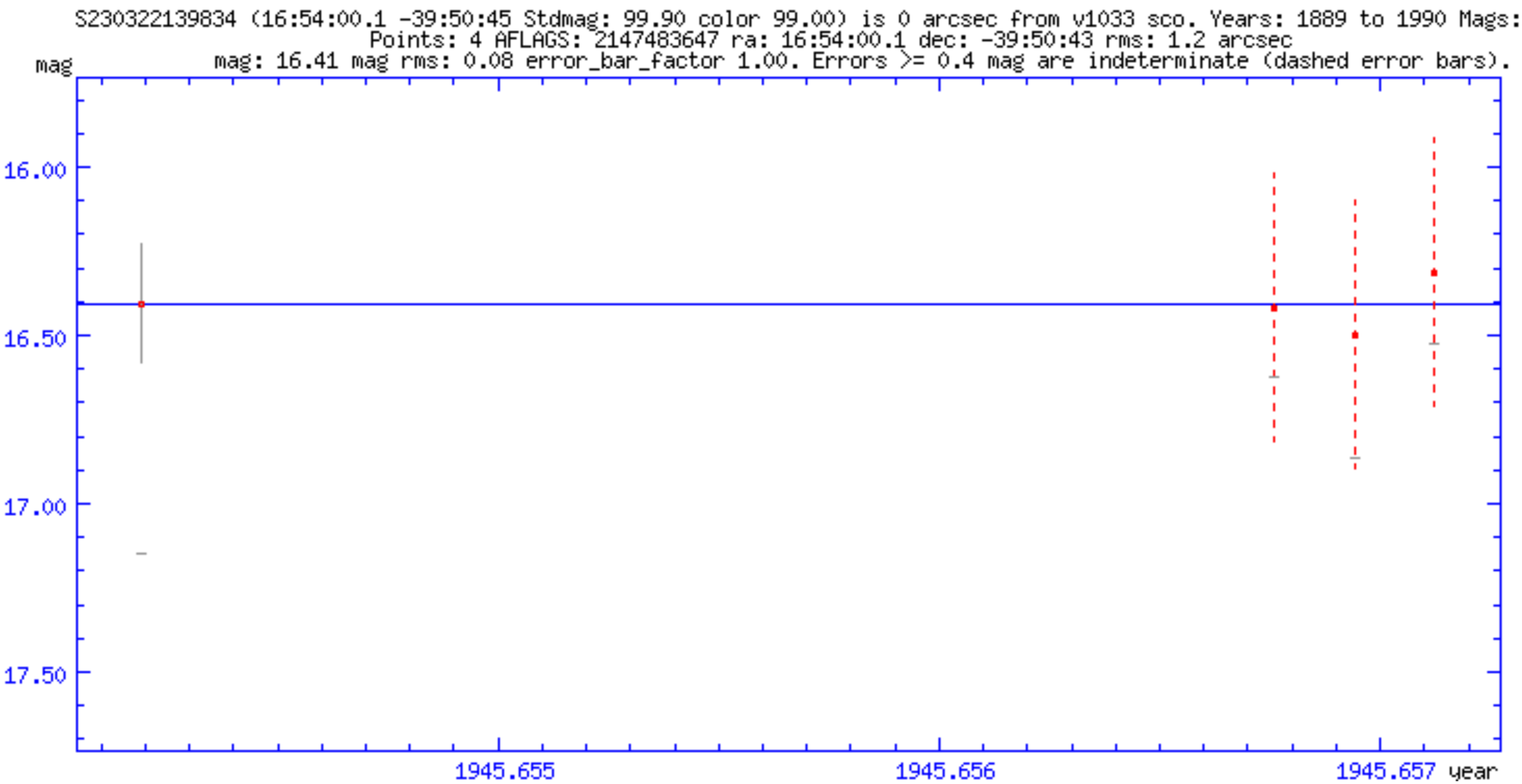
- Still partial DASCH coverage; more to come!

DASCH upper limits (V's) & detections of GROJ1655-40



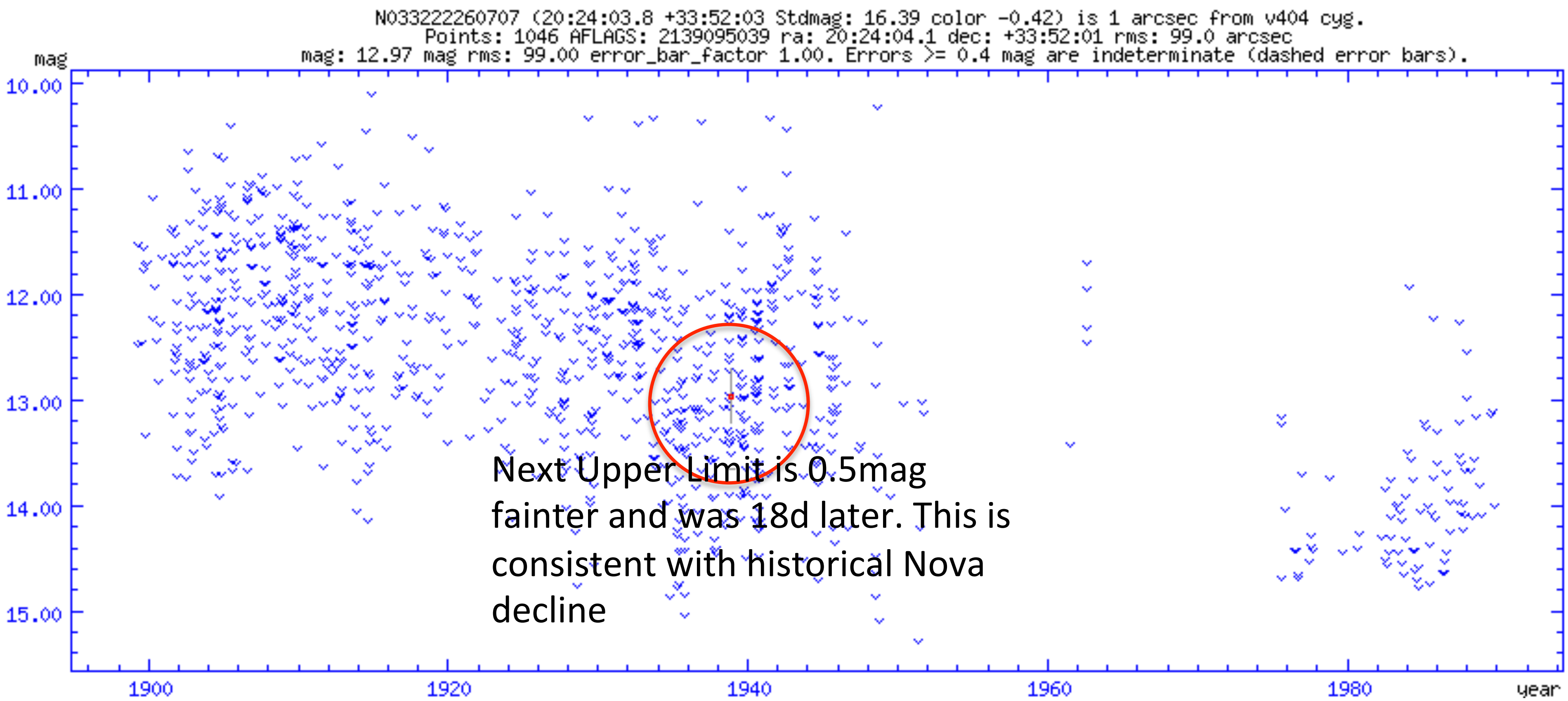
DASCH lightcurve for GROJ1655-40 (thus far)

outburst, 1945.65 (limited coverage)

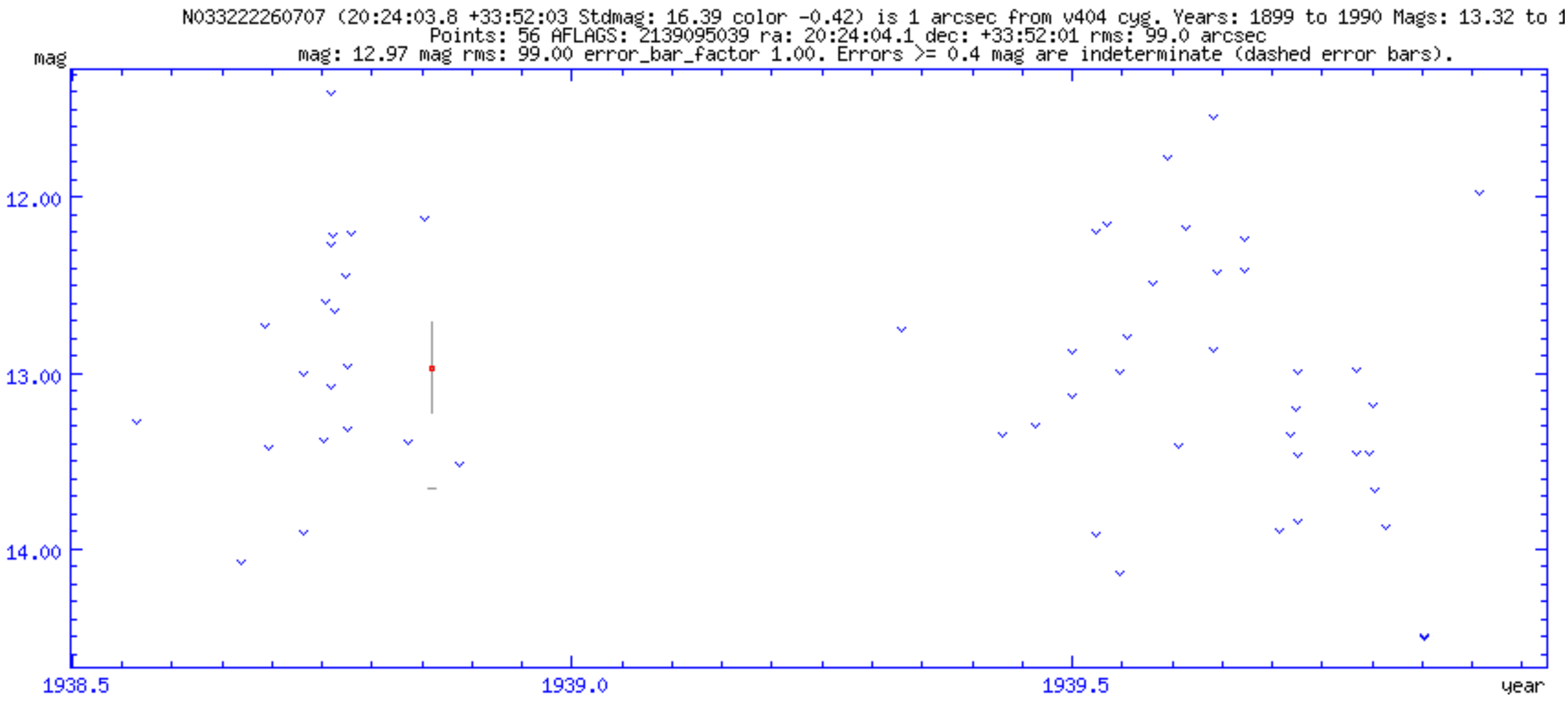


DASCH recovers V404 Cyg 1938.8 outburst (only)

No outbursts 1899-1938; scanning incomplete after but outbursts UNlikely



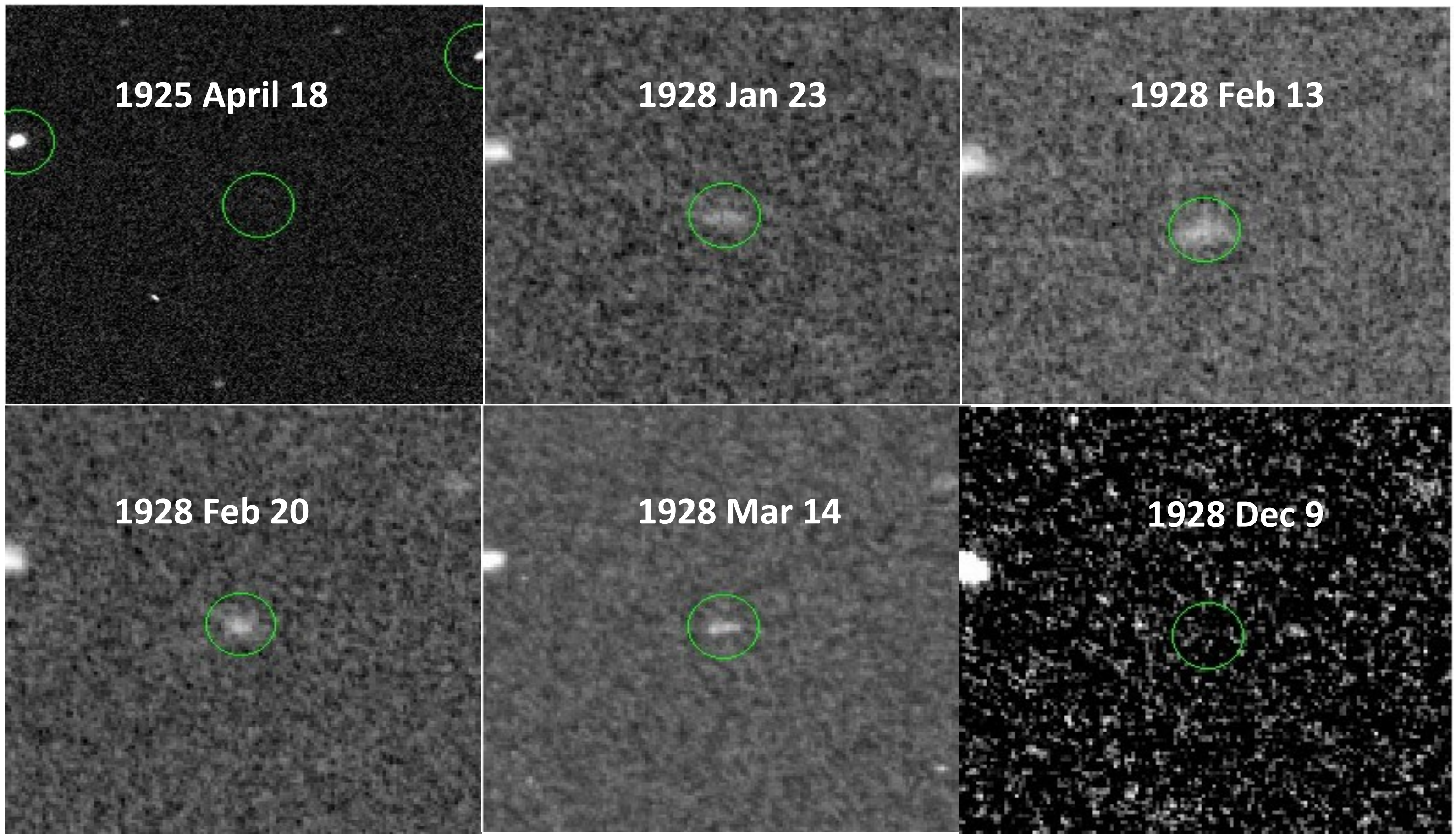
V404 Cyg (Nova Cyg 1938) recovered by DASCH (partial data, still...)



And with start *of Production Scanning* (NGP, down…),

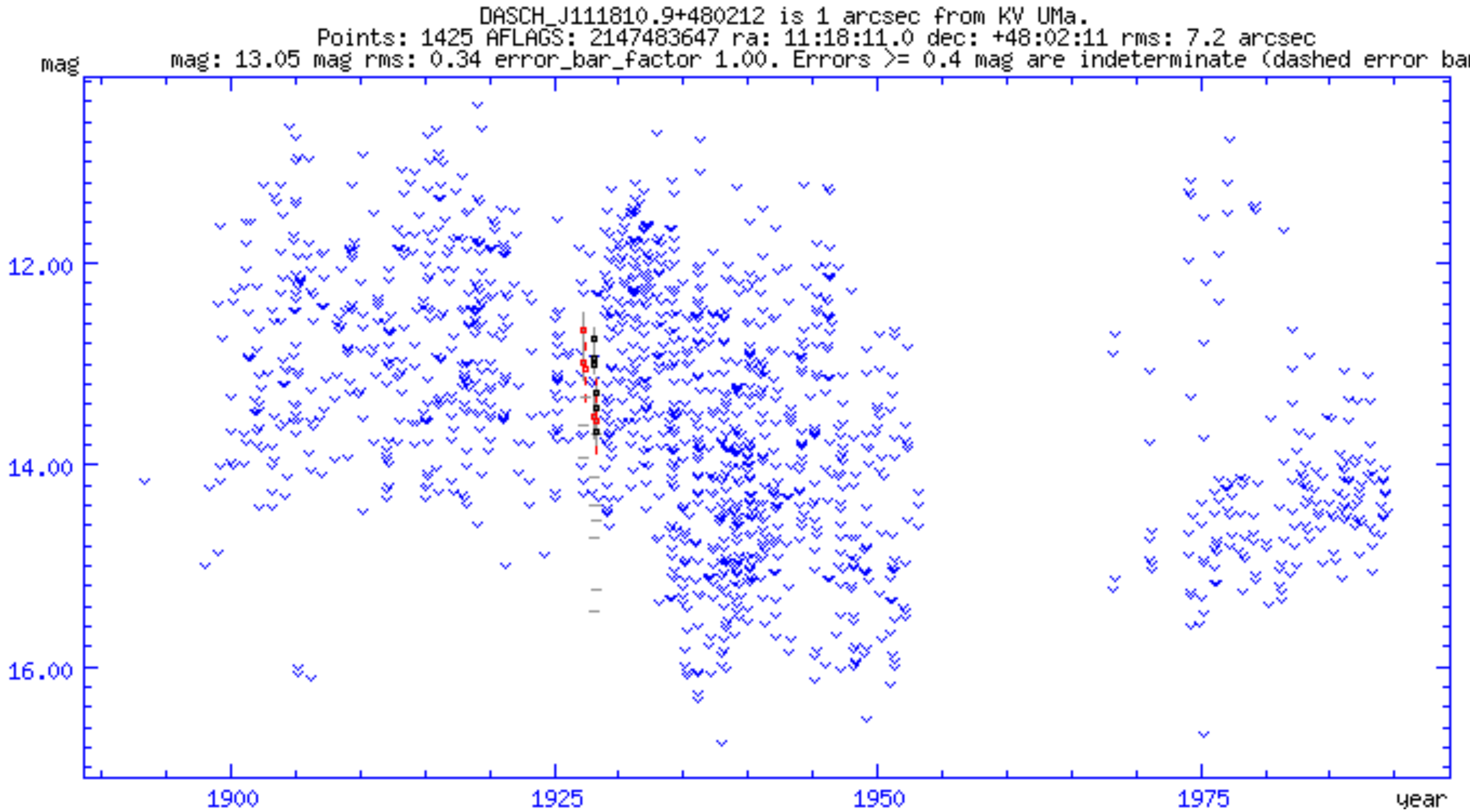
Discovery of a historical outburst from XTE J1118+480

(Halo BH-LMXB, discovered with ~40mCrab X-ray outburst, but ~6mag optical(!) in 2000)

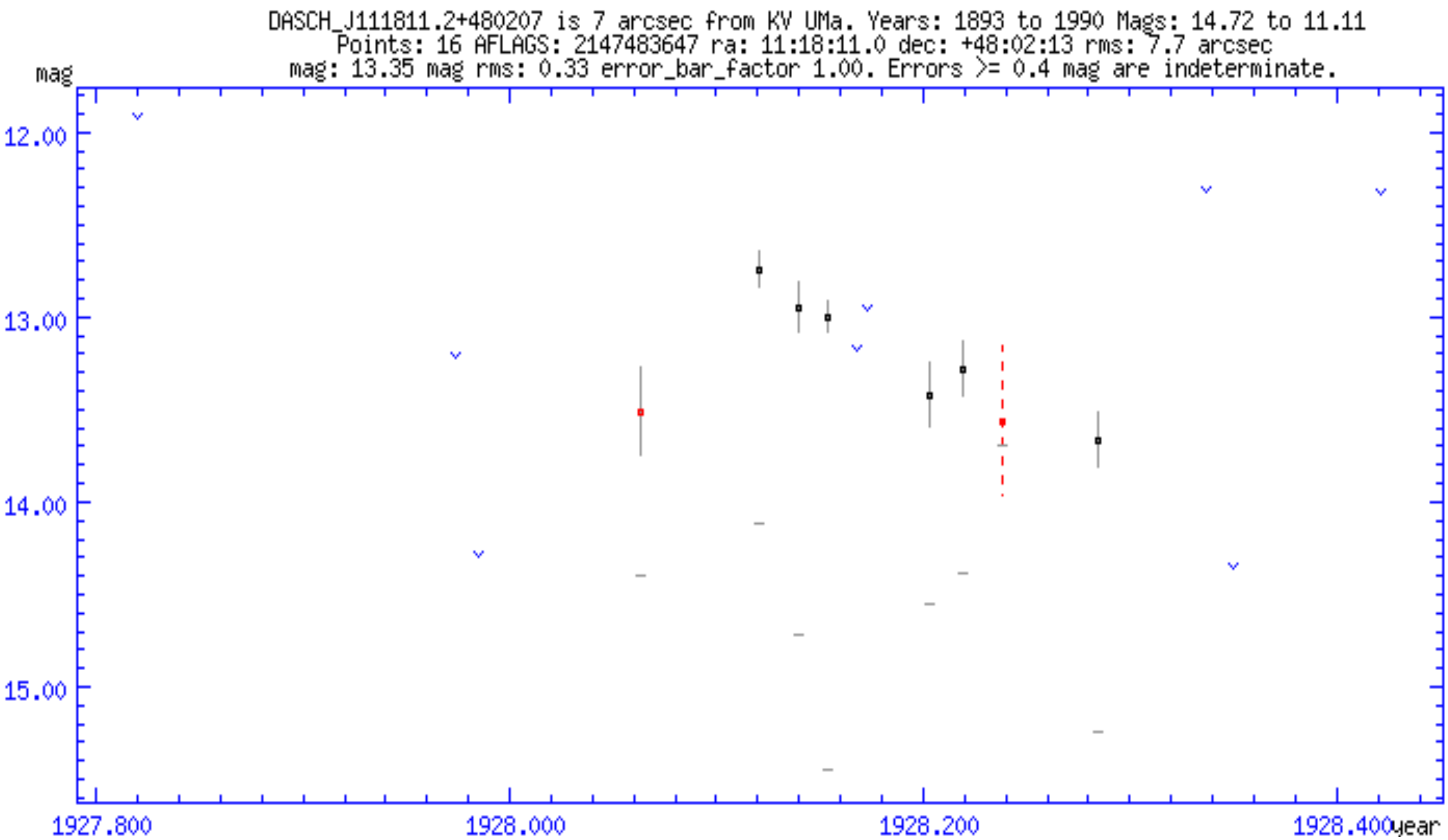


~3month 1928 outburst (B ~13; from quiescent B ~18) in 1928 resembles 2000 outburst!
(Grindlay + 2013)

DASCH coverage of BH-LMXB XTEJ1118+480

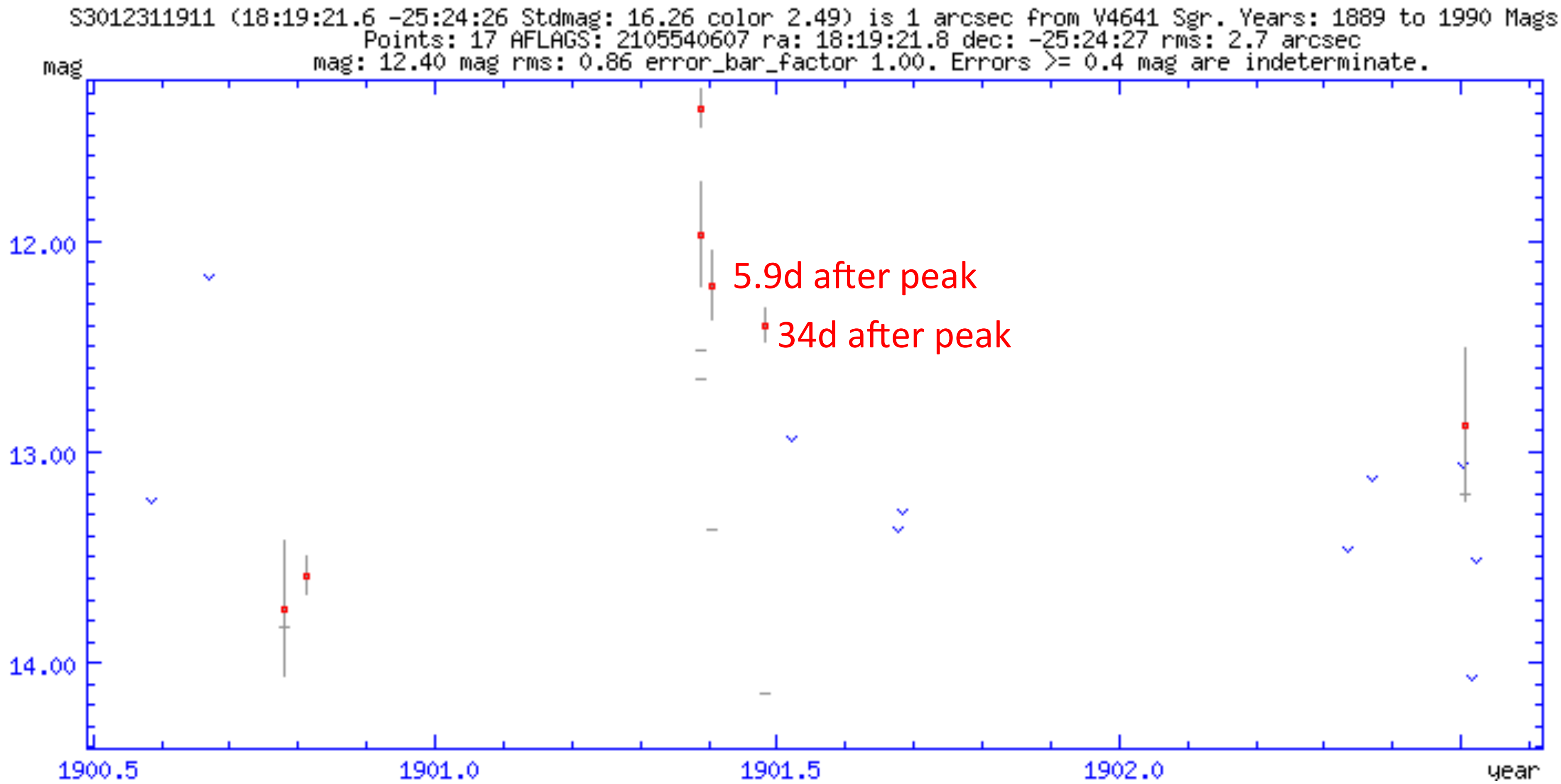


DASCH lightcurve for XTE J1118+48: a BH-LMXB in the Halo of our Galaxy: an ***≥80day outburst in 1928***

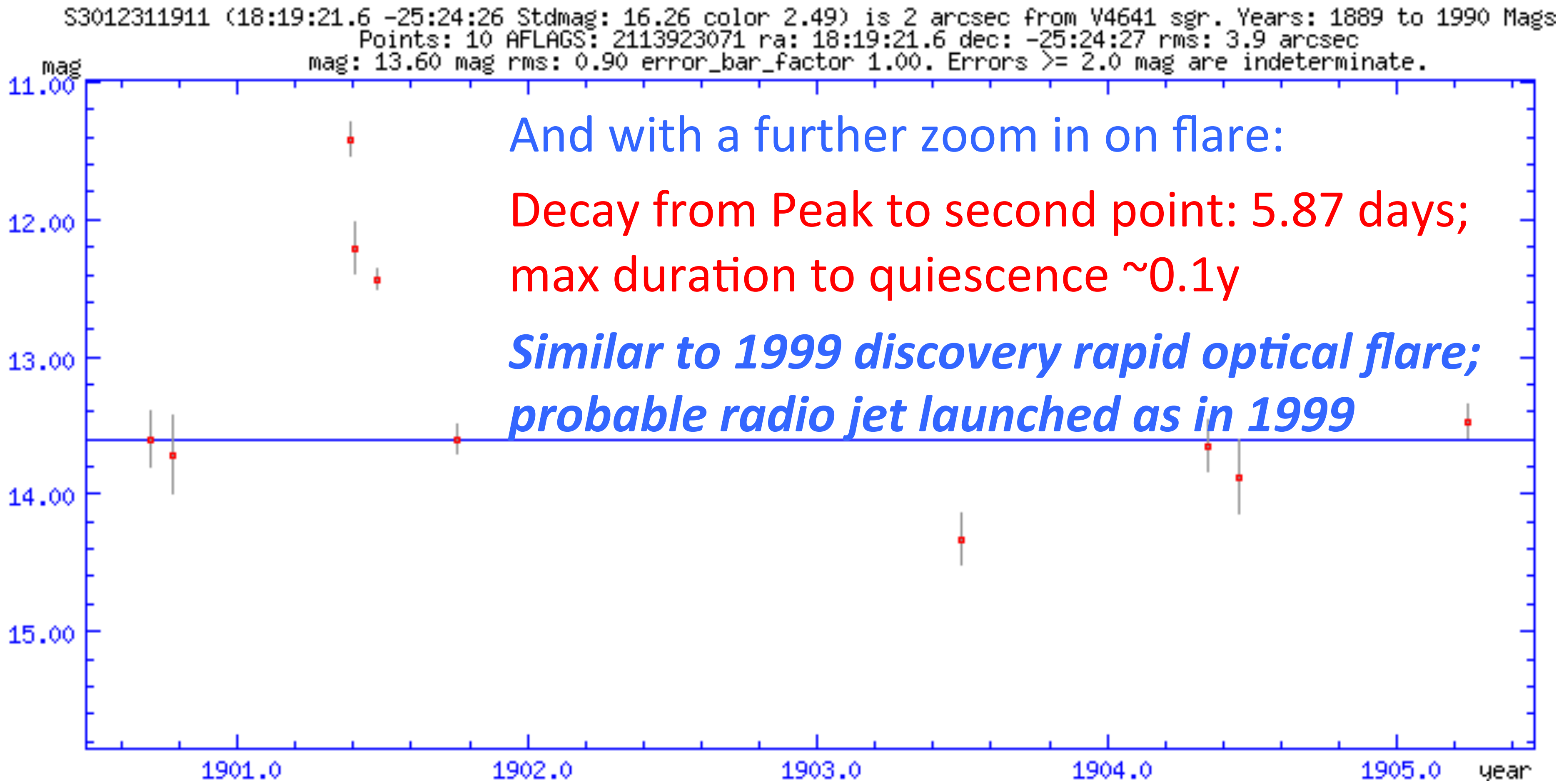


And perhaps most interesting thus far, V4641 Sgr

had a ***single LARGE/Short outburst in 1901***



V4641 Sgr 1901 Flare timescale ~6d

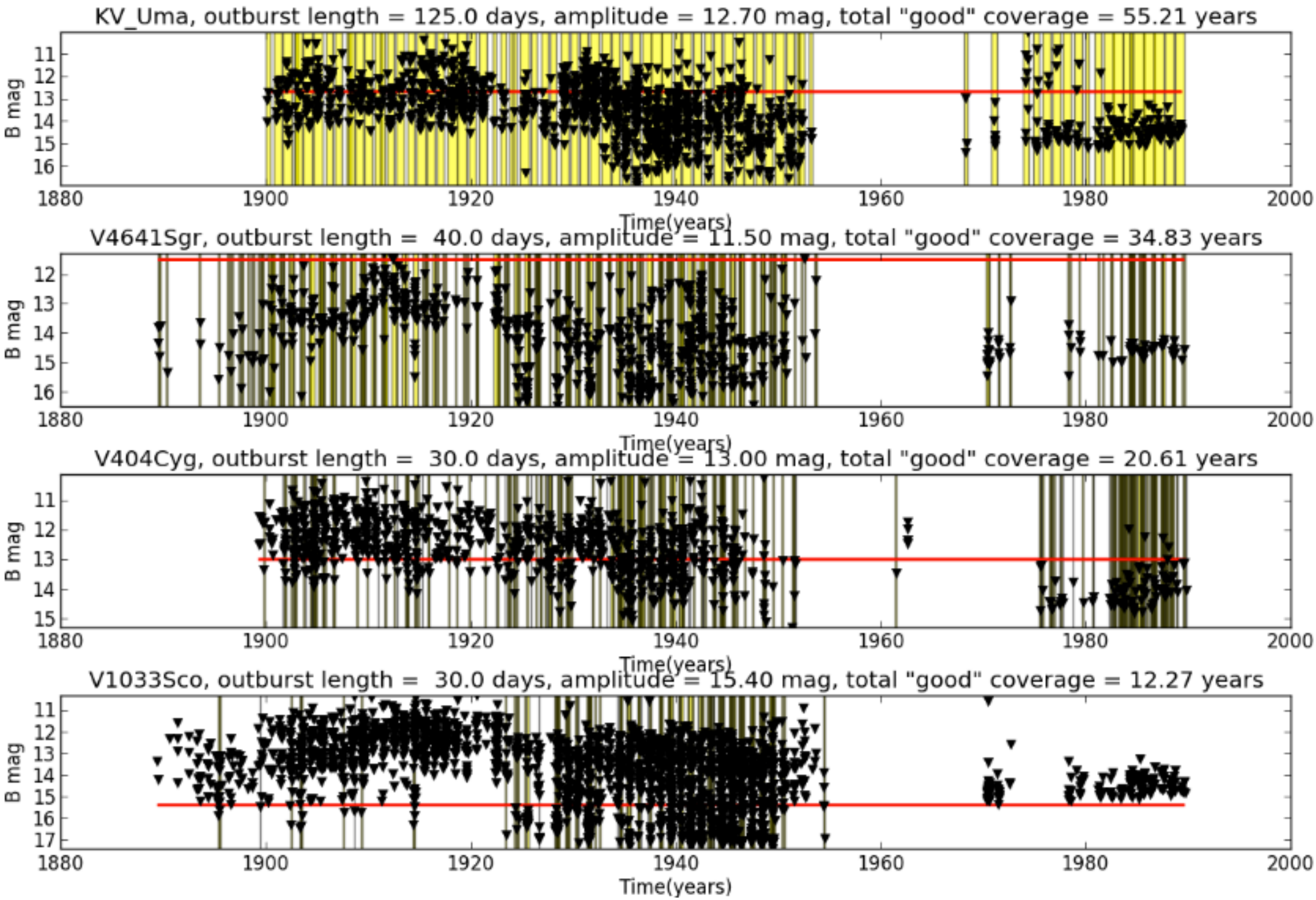


And with a further zoom in on flare:

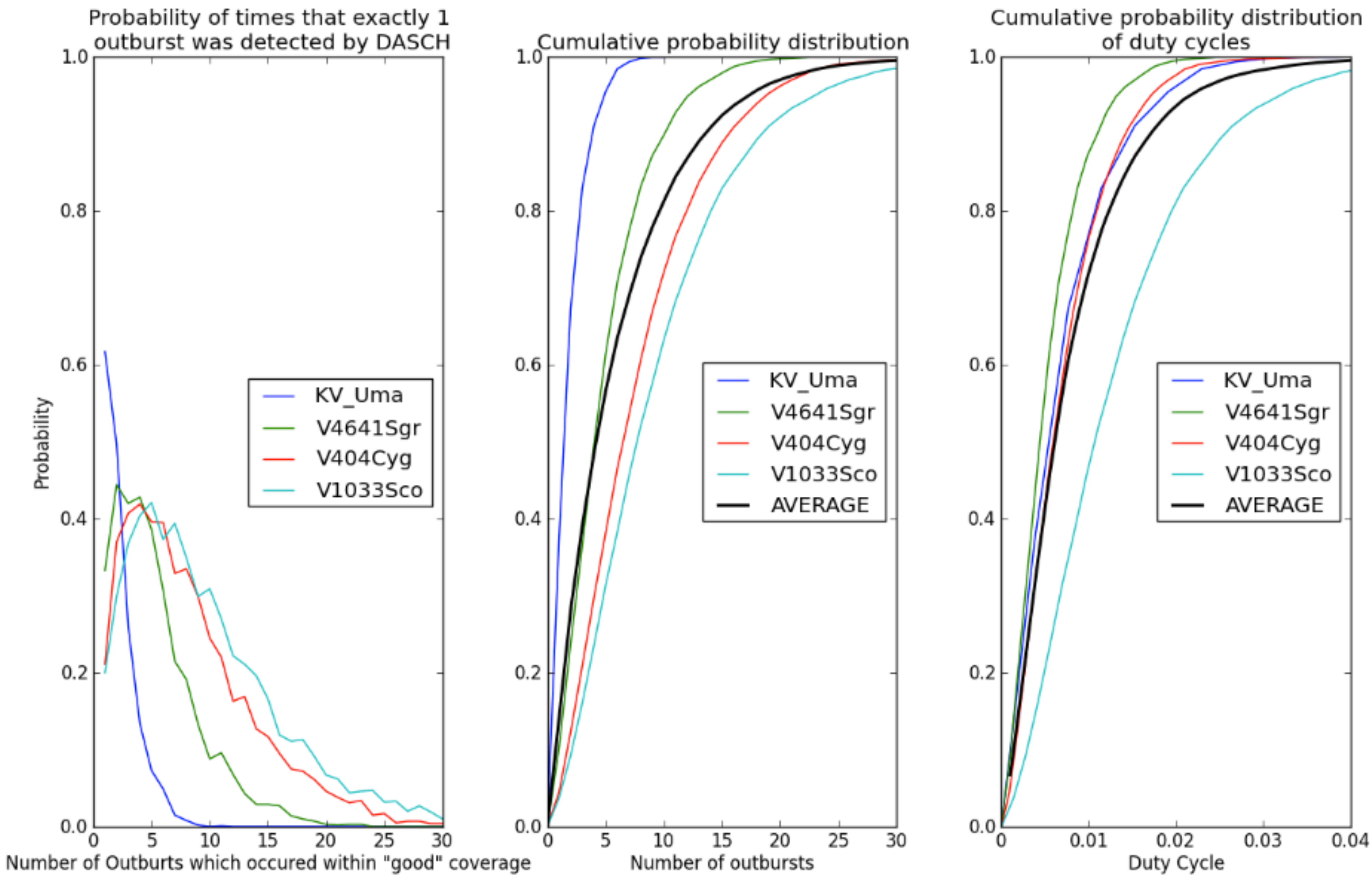
Decay from Peak to second point: 5.87 days; max duration to quiescence ~0.1y

Similar to 1999 discovery rapid optical flare; probable radio jet launched as in 1999

All 4 BH-LMXB DASCH historical outburst lightcurve *coverage* at sensitivities to detect "modern" outburst B mag with their "modern" outburst Durations



Monte Carlo simulation for Outburst numbers possible in actual coverage and resulting *Duty Cycles*



Duty Cycles of DASCH BH-LMXB outbursts 1890-1990

BH-LMXB	Outburst Yr	Duration = Td (days)	Coverage Tc (yrs)	Duty cycle (90% conf. upper limit) Td/Tc
GROJ1655-40	1945	30	12.3	0.025
V404 Cyg	1938	30	20.6	0.015
XTEJ1118+48	1928	125	55.2	0.015
V4641 Sgr	1901	40	34.8	0.01
"Average"		54	0.5	**0.015**

Tentative conclusions from available DASCH (& ASM) BH-LMXB sample

- Average Duty Cycle or fractional time detected f ~ 0.015 (DASCH value)
- Consistent with RXTE/ASM value (16y) for same 4 sources: f ~0.043 (since J1655 had bright outburst in 2004). **All 14 BH-LMXBs (not including semi-persistent GRS1915+105 & GX339-4) have f = 0.019 (consistent w/ DASCH)**
- Total BH-LMXB population (all transients) 1/f ~53 X larger or ~2200??
- Additional 5-10 have bright enough outbursts (B <16) for DASCH detections

vs. *Transient* NS-LMXBs

- Most in Bulge (many obscured) so not yet scanned by DASCH

- Use sample of 16 NS-LMXBs from sample of Jonker & Nielemans (2004) with optical coverage *(for eventual coverage with DASCH)* and derive Duty Cycle from RXTE/ASM X-ray coverage (16y)

NS-LMXB X-ray (ASM) outburst Duty Cycle = 0.070

- So ratio of Duty Cycles ~ 0.070/0.015 ~4.7 for NS vs. BH LMXB transients**. *So we miss ~4.7X more BH than NS LMXBs !***

And so Population of BH-LMXBs > NS-LMXBs (?!)

LMXB type	No. Persistent Np	No. Transient Nt	DutyCycle f	Total Sources Np + Nt/f
NS-LMXBs	30	50	0.07	~750
BH-LMXBs	1	30	0.015	~2000
BH/NS LMXB ratio				~2.7
BH/NS IMF ratio				~0.3

Implied BH/NS LMXB *<u>formation enhancement</u>* *vs. IMF ~ 2.7/0.3 = 9 !*

NOTE: total source numbers and derived quantities based on *currently observed totals of accretion-powered LMXBs, including AMXPs (accretion-powered MSPs). But NOT their descendents, rotation-powered MSPs*

This is "fair" since BH-LMXBs will also become "dormant" (non-accreting)

BH-LMXBs from *Exchange Collisions* in Disk/Bulge ?

- The "Standard Model" that LMXBs (NS or BH) evolve from a single primordial binary by *Common Envelope Evolution* may work for accreting WDs and NSs (moderate mass ratios) but must be enhanced, GREATLY, for BH-LMXBs

- NS kick velocities (from their SN) are surely larger than for BHs, but for both, *most are ejected as single objects if in primodial binaries*

- *BHs at lower space velocity and larger mass* will more easily undergo **exchange collisions** with low-mass ms-ms stellar binaries (~0.5-1 $M_{\odot}$) *in the field. Exchange (vs. ejection or merger) cross sections (Davies 95) are favorable (Grindlay+2014)*

- *BH-LMXBs should then be favored in high stellar density regions. The Galactic Center Region (GCR) should contain a large population of* ***QUIESCENT BH-LMXBs, as can be tested by NuSTAR for hard power law emission from faint Chandra sources***

Conclusions and Prospects

- TDA is a major part of Astronomy; DASCH (and other!) archival surveys play a unique role complementing/extending LSST
- DASCH has now fully developed the plate processing, photometry, & astrometry Pipeline and *fast (~10sec) serving of data to public*
- *Compelling Science*, e.g: 1) New types of variability discovered from most common stars, K-giants: long baselines needed for rare events
- and 2) Comparison of BH/NS-LMXB ratios with IMF***: factor of ~9 (!) excess rate of formation of BHs vs. NSs into LMXBs.*** A new LMXB formation model seems required ***Exchange* collisions in Bulge**?!