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# Is sCMOS the next Imaging Revolution ?


Maria Mitchell Observatory
Bailyhill Observatory
Sierra Remote Observatory
AAVSO
Gary Walker



Credits to Arne Henden, Geoff Stone, Lew Cook & Tolga Astro


**ESV2019: Belgium: Sept 14-15**

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- Sputnik Kid
- Saw Saturn in 1957 in Neighbors 3 inch reflector
- Took my first astrophoto in 1960
- Fully Equipped was a clock drive—wish
- Won Stellafane Engr & Crafsmanship 1986
- Bought my first CCD camera in 1989
- Imaged for 2 years, then Photometry
- >85,000 CCD measurements in AAVSO AID
- Experienced Film to CCD, is it going sCMOS?

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- Lost Automated Dome, AT16RC, EM500, Princeton Instruments Pixis 512B E2V Back IL CCD Camera
- Substantial Smoke & Water Damage
- Gas Meter Exploded—Carbon Black
- Needed to use Foam (C-Cl 4 based?)
- Entire House was damaged
- 100 % Replacement Coverage

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| | CCD | sCMOS |
|---|---|---|
| Dynamic Range (db) | 76 | 95 |
| Array Size (pixels) | 2Kx2K | 2Kx2K |
| Pixel Size (microns) | 11 | 11 |
| Read Noise, e | 10 to 15 | 1.5 |

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- Phone Call about sCMOS
- 1.5 e- read noise, 95 db Dynamic Range
- But sCMOS has Higher Dark Current
- Would Stacking overcome the Dark Current?

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$$SNR = \sqrt{Nstar}$$

$$SNR = Nstar / \sqrt{Nstar}$$

$$\frac{Nstar}{\sqrt{[\ Nstar + npix(\ Nsky + Ndark + Nread*Nread + H.O.T.\ )]}}$$

(Steve Howell, George Jacoby, Jim Janesick…)

$$Noise = \sqrt{(\ Nsky + Ndark + Nread*Nread + Systematics\ )}$$

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- Developed a Theory that the low read noise of the sCMOS chips will enable a stacking advantage for fixed cadence observations to overcome dark current for exposures of less than about 3 minutes.

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| | | | | | | | 25000e- |
|---|---|---|---|---|---|---|---|
| | Exposure | Stacks | Nsky/sub | Ndk/sub | Nread^2 | SUM | SNR |
| Single sCMOS | 180.0 | 1 | 360.0 | 72.0 | 2.25 | 434 | 43 |

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| | Exposure | Stacks | Nsky/sub | Ndk/sub | Nread^2 | SUM | 25000e- SNR |
|---|---|---|---|---|---|---|---|
| Single sCMOS | 180.0 | 1 | 360.0 | 72.0 | 2.25 | 434 | 43 |
| Stack on The Fly sCMOS | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | | 6 | 147.0 | 29.4 | 6 | 182 | 60 |

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| | Exposure | Stacks | Nsky/sub | Ndk/sub | Nread^2 | SUM | 25000e- SNR |
|---|---|---|---|---|---|---|---|
| Single sCMOS | 180.0 | 1 | 360.0 | 72.0 | 2.25 | 434 | 43 |
| Stack on The Fly sCMOS | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
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| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | | 6 | 147.0 | 29.4 | 6 | 182 | 60 |
| 15 e- Read CCD | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | | 6 | 147.0 | 0.5 | 551 | 699 | 35 |

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| | Exposure | Stacks | Nsky/sub | Ndk/sub | Nread^2 | SUM | 25000e- SNR |
|---|---|---|---|---|---|---|---|
| Single sCMOS | 180.0 | 1 | 360.0 | 72.0 | 2.25 | 434 | 43 |
| Stack on The Fly sCMOS | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | 30.0 | 1 | 60.0 | 12.0 | 2.25 | | |
| | | 6 | 147.0 | 29.4 | 6 | 182 | 60 |
| 15 e- Read CCD | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | 30.0 | | 60.0 | 0.2 | 225 | | |
| | | 6 | 147.0 | 0.5 | 551 | 699 | 35 |
| Single CCD | 180.0 | 1 | 360.0 | 9.0 | 225 | 594 | 38 |

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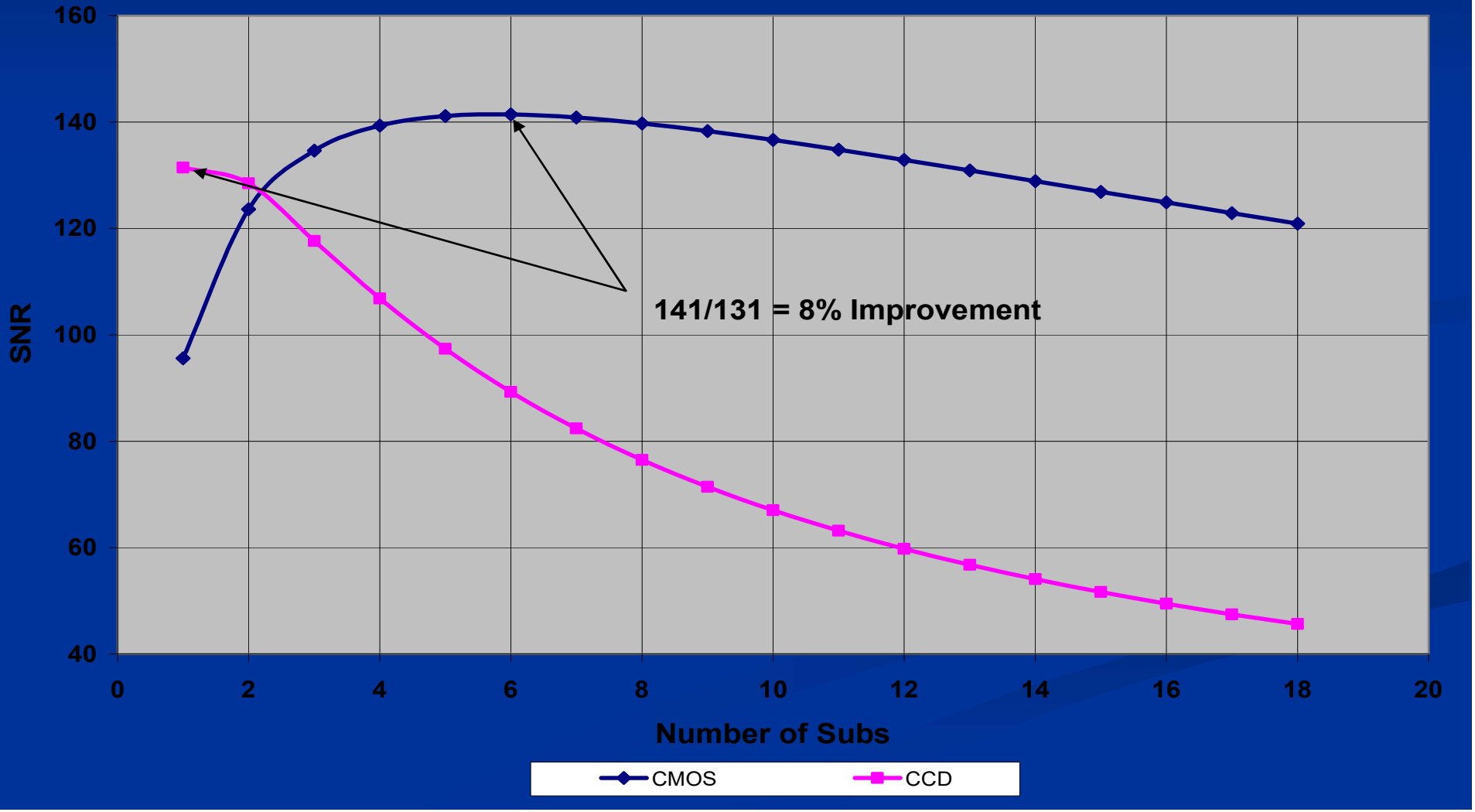
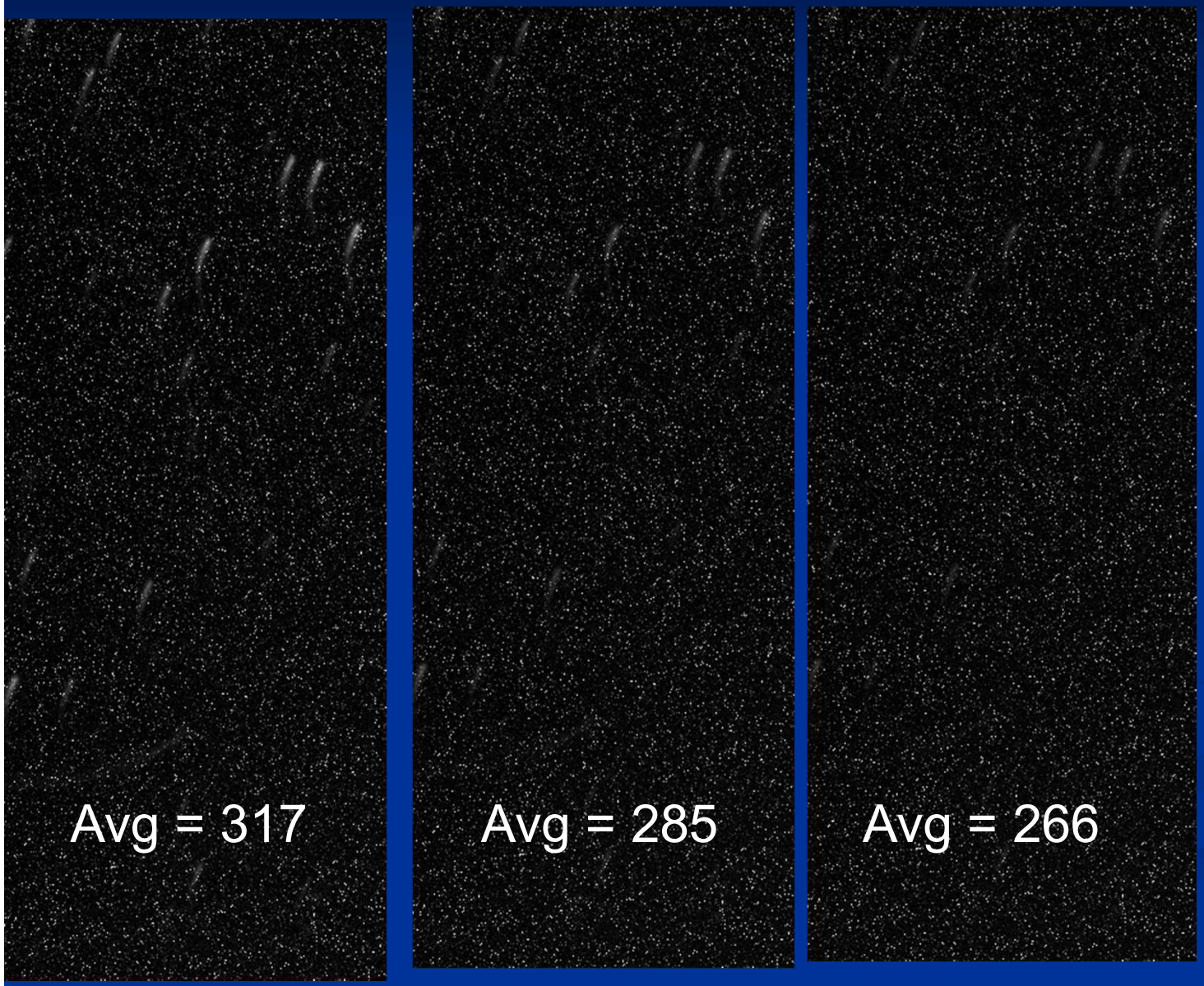
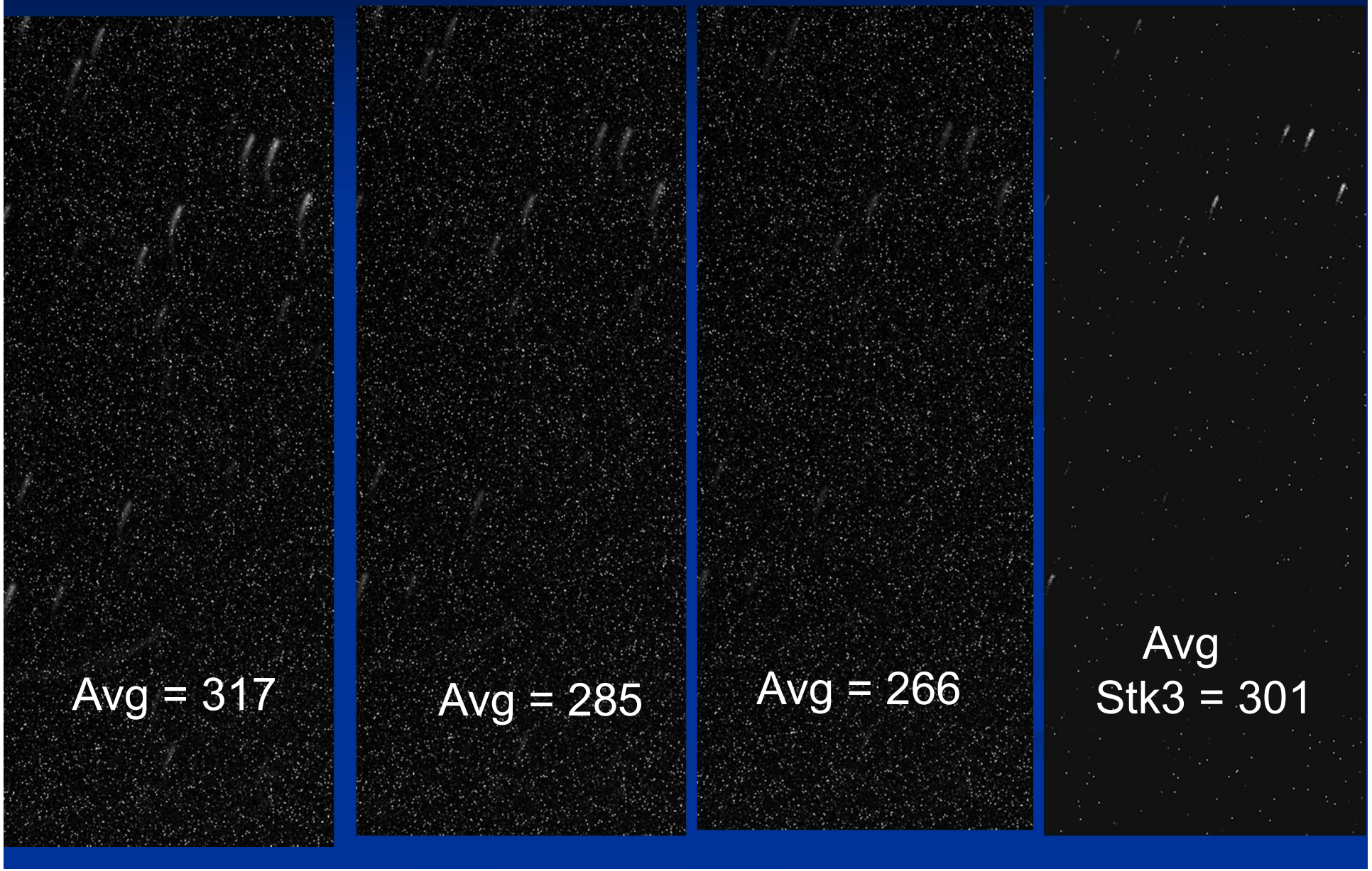
## Comparison Star = 25,000, CMOS vs CCD



# Stacking of Darks



# Stacking of Darks



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- Made a test Plan
- There was a window of one night until midnight of clear weather at my NH observatory
- Wife accompanied me for safety reasons
- Took images thru my AT16RC (0.7 arc sec/px)

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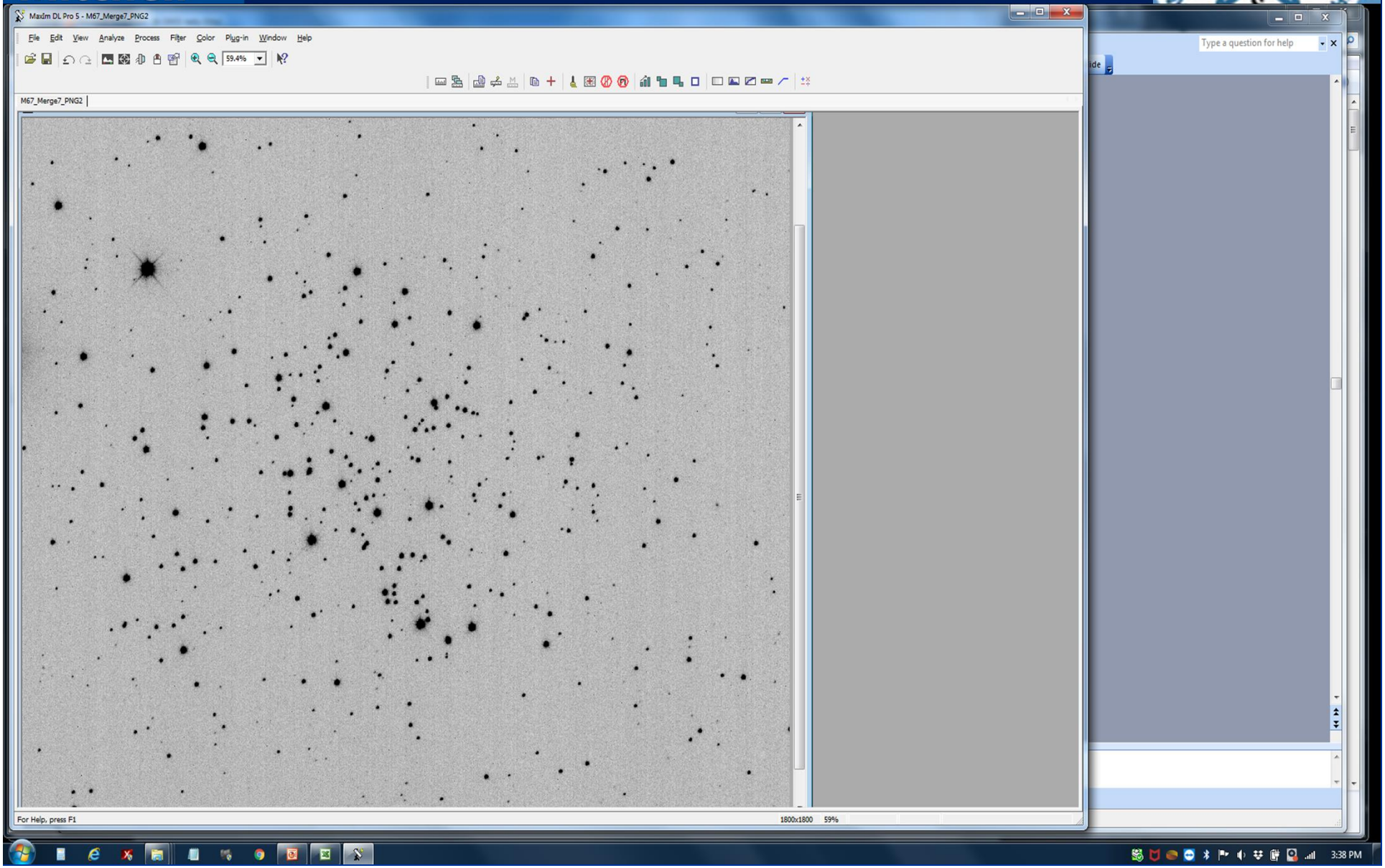

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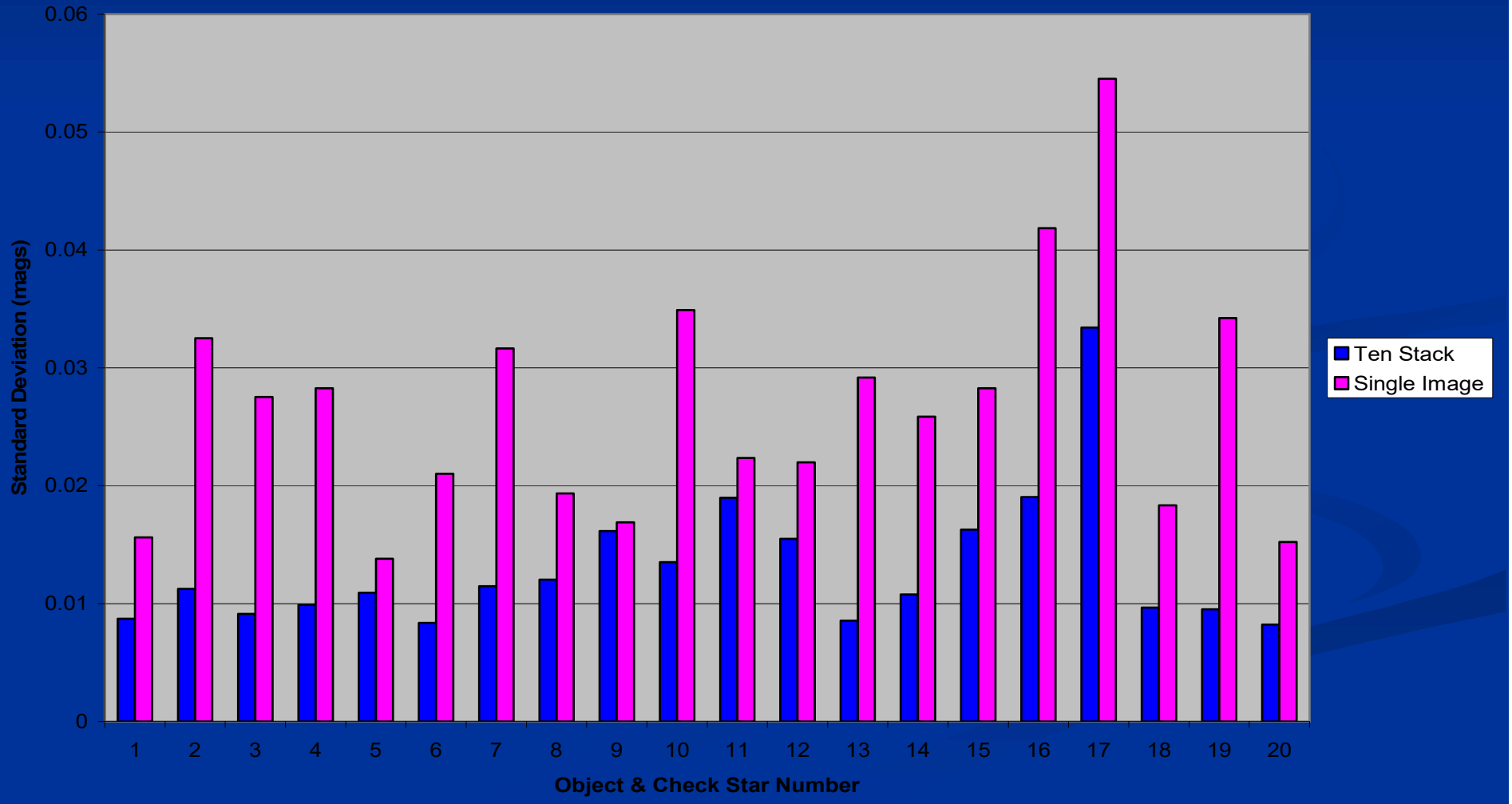
## Comparison of Systematics--Ten Stack vs Single Stack



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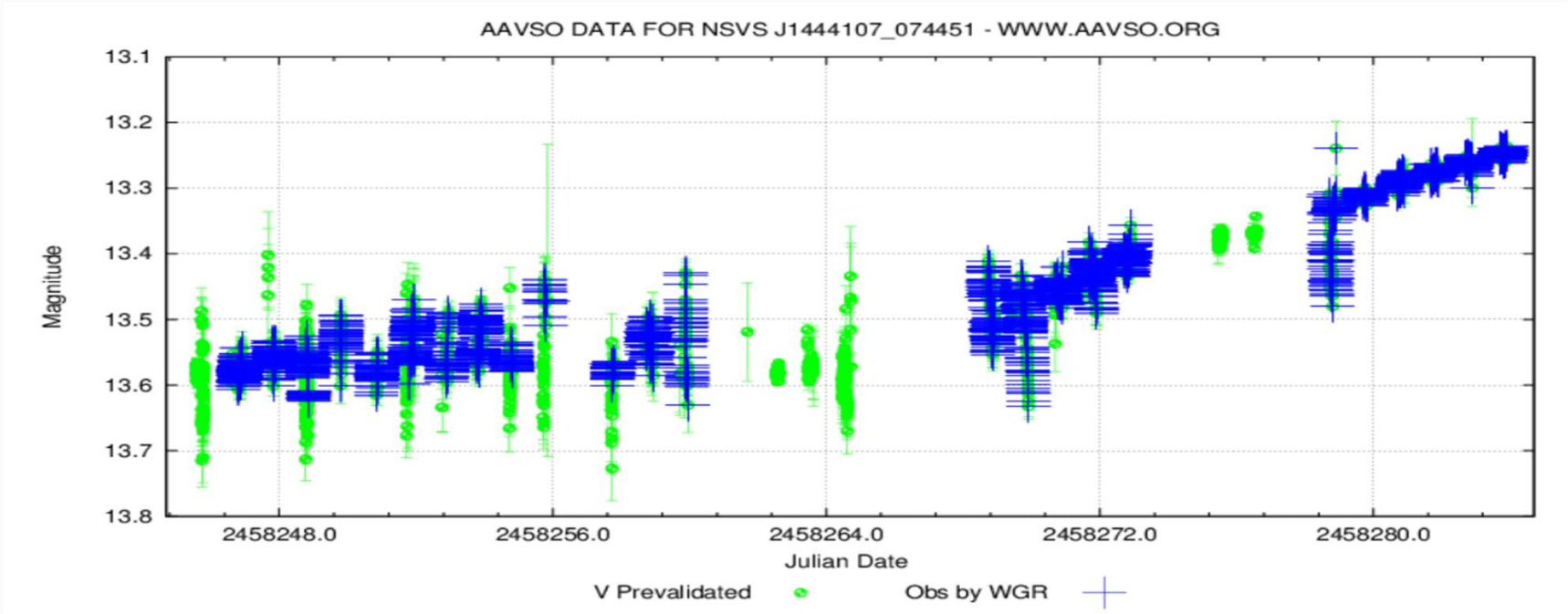
ot?auid=000-BMQ-651&starname=NSVS%20J1444107_074451&lastdays=40&start=&stop=2458284.6972454744&obscode=wgr&obscode_symbol=2&obstotals=yes&calendar=JD&forcetics

Outlook, Office, Skype, Bing, Br...

X3 Map Tesla DCU TD Gog AT16RC CC BH ACK TMO61 SRO Tel SSA Hyline Faz FITS GogF BMW blog VPhot VStar James Tolga QSI

## *Light Curve Generator (LCG)*

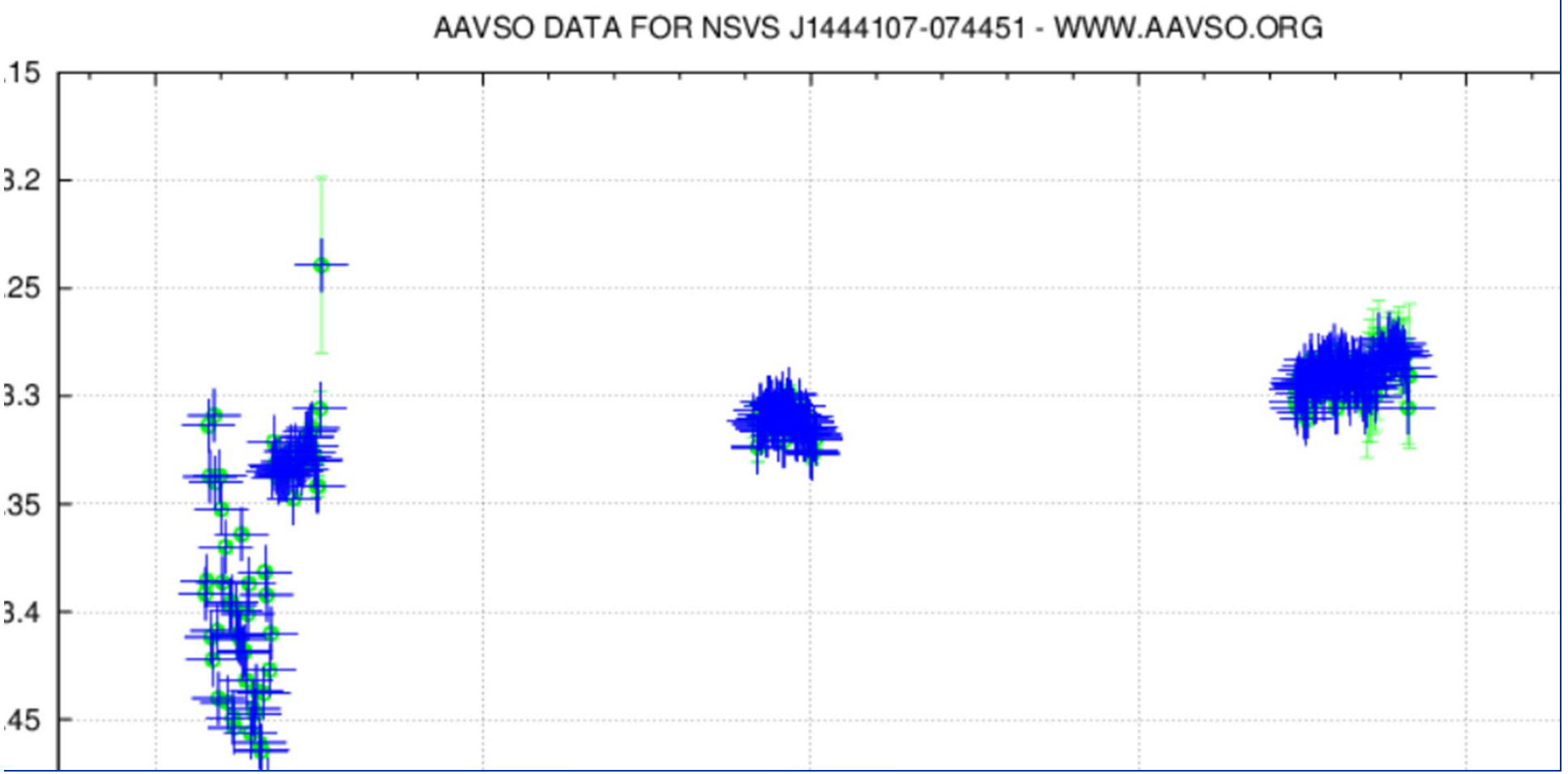
- Plot another light curve
- Search observations for NSVS J1444107_074451
- Create star chart for NSVS J1444107_074451
- Search VSX for NSVS J1444107_074451



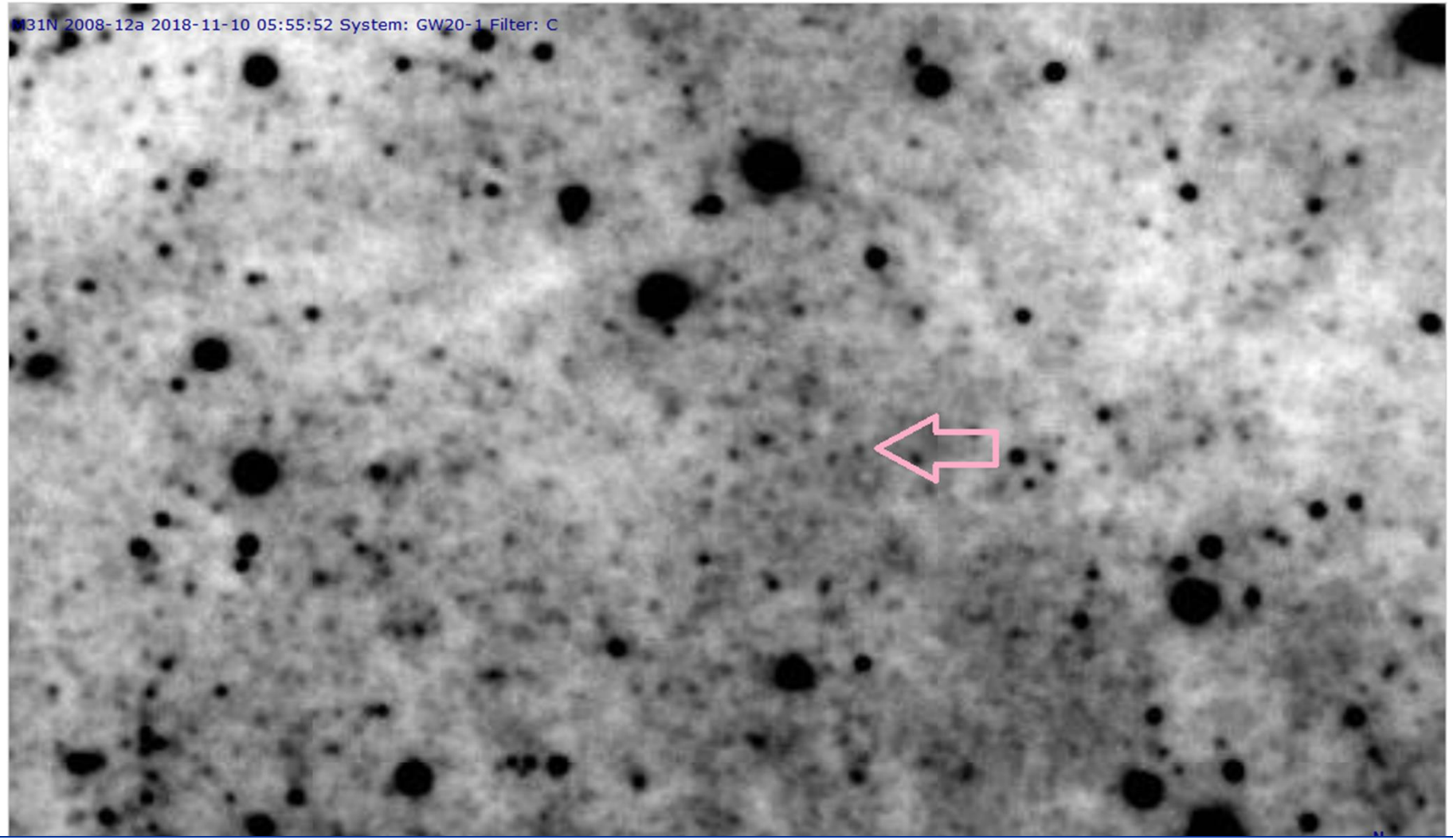

1_Default Design

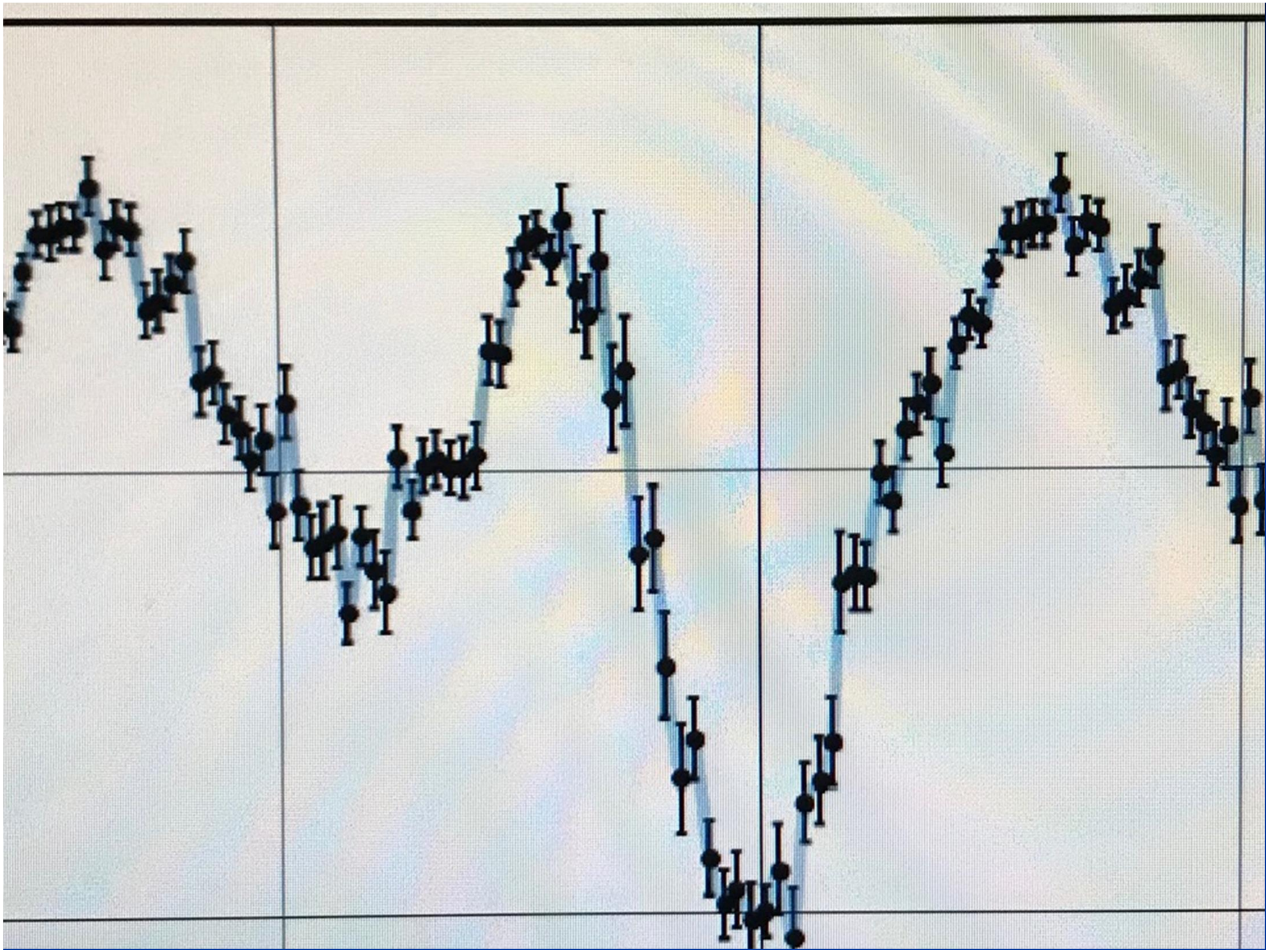
# urve Generator (LCG)

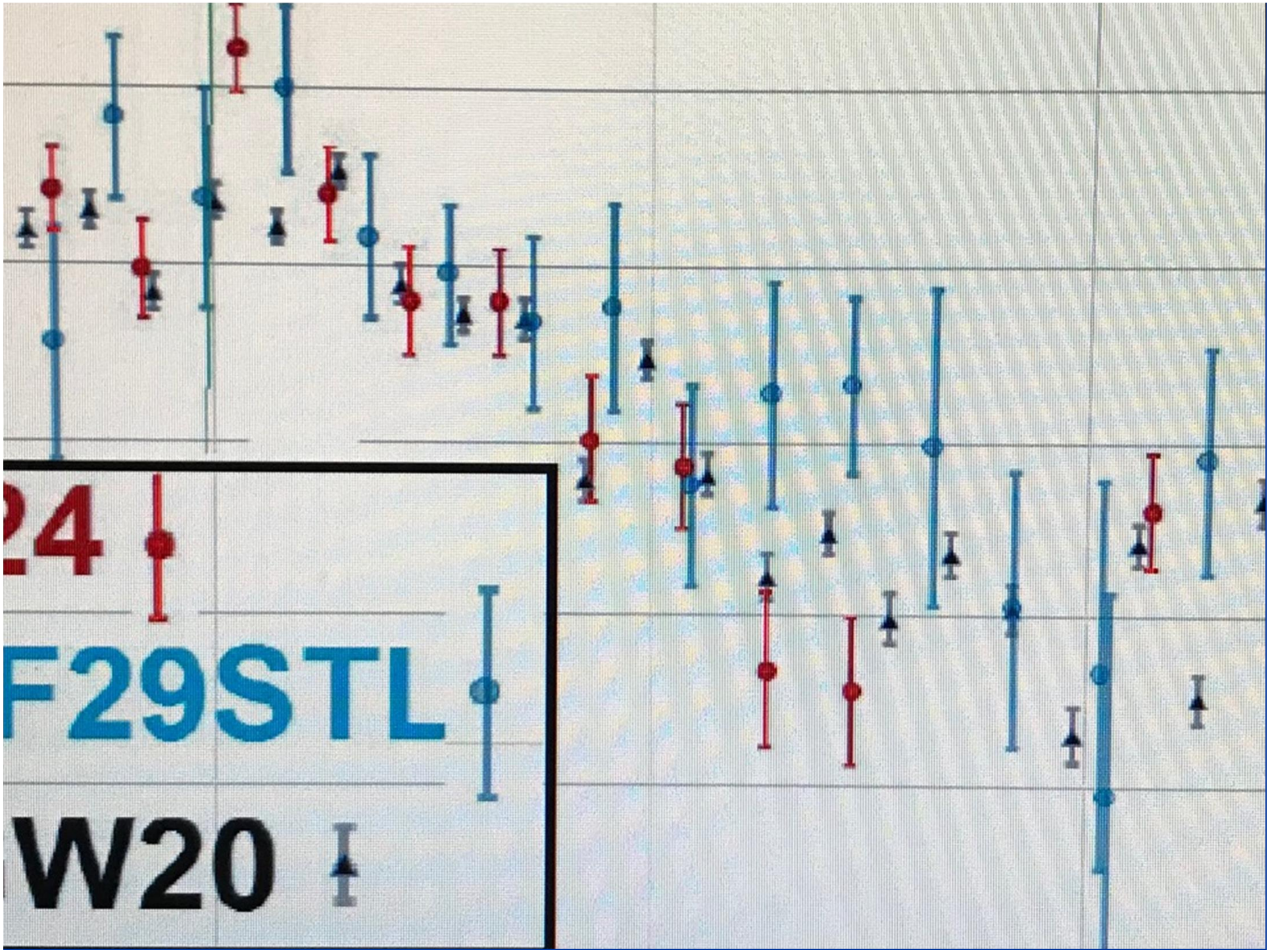
another light curve ■ Search observations for NSVS J1444107-074451
reate star chart for NSVS J1444107-074451 ■ Search VSX for NSVS J1444107-



1 Hour Stack on GW20 Planewave CDK Telescope with L500 PW Mount and an FLI Kepler 400 sCMOS Camera Shows the early Erruption of M31N 2008-12a, a recurrent Nova in the Andromenda M31.  Vphot gives 21.06 +/- 0.15 mag.






24
F29STL
W20

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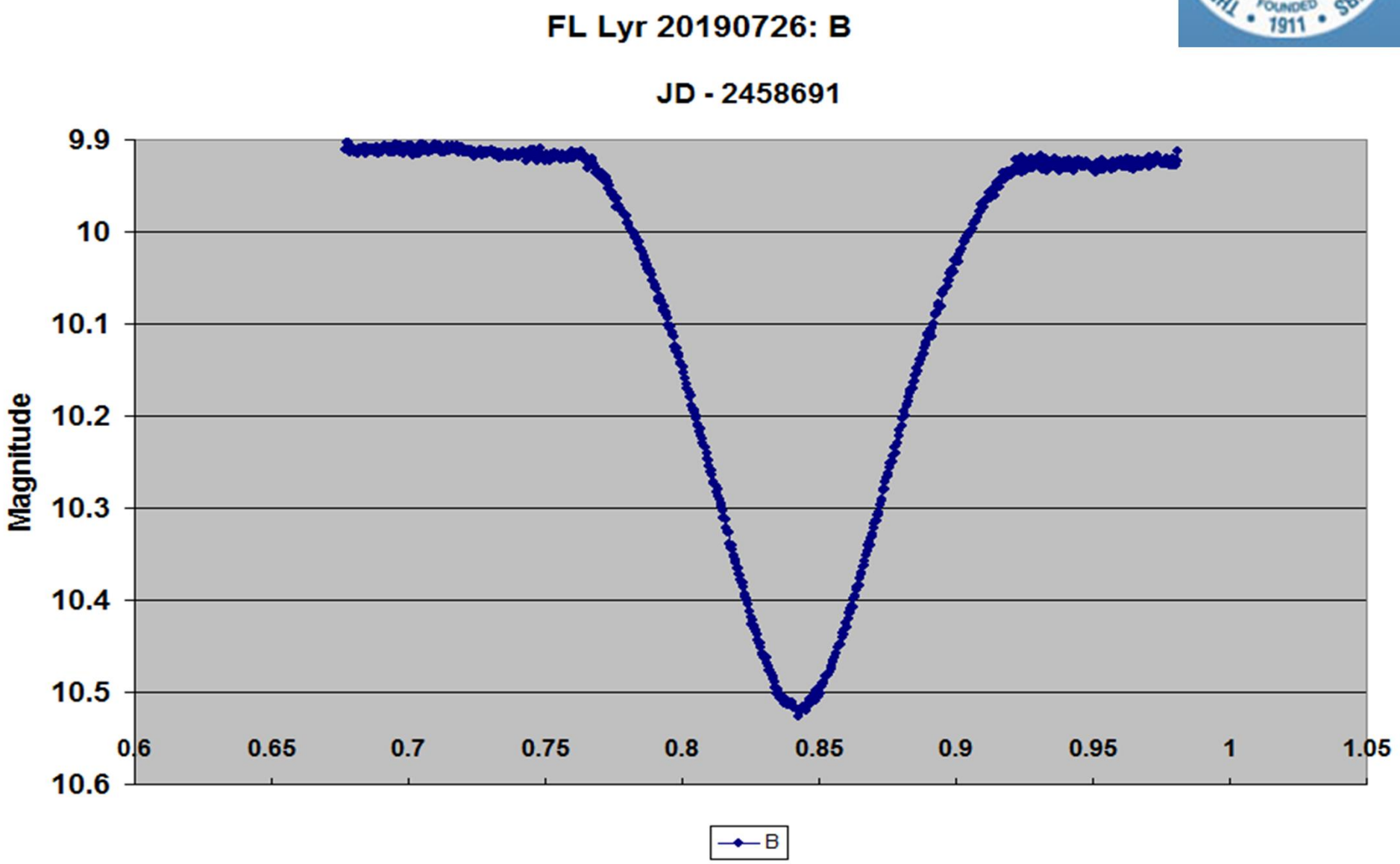

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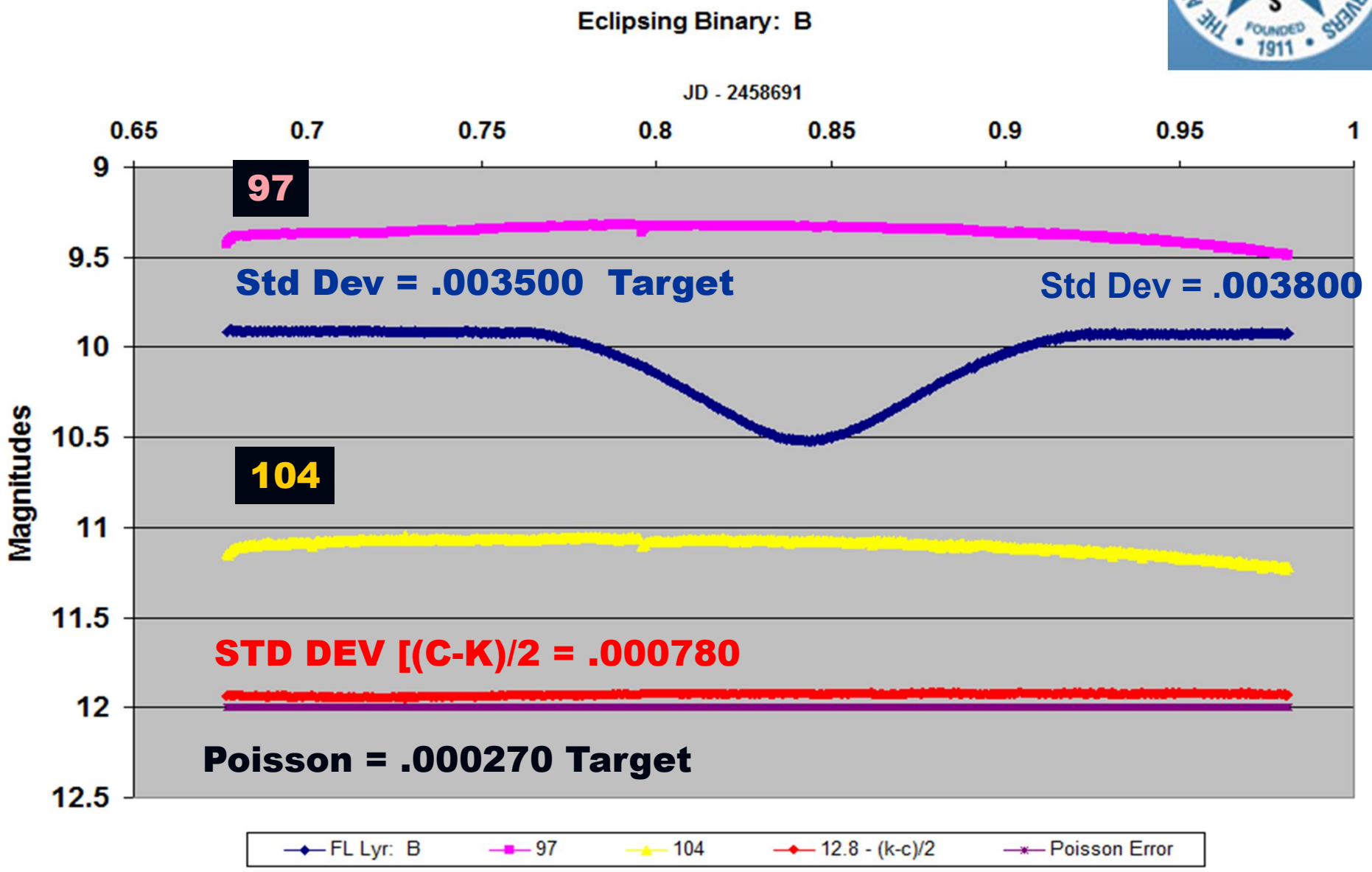

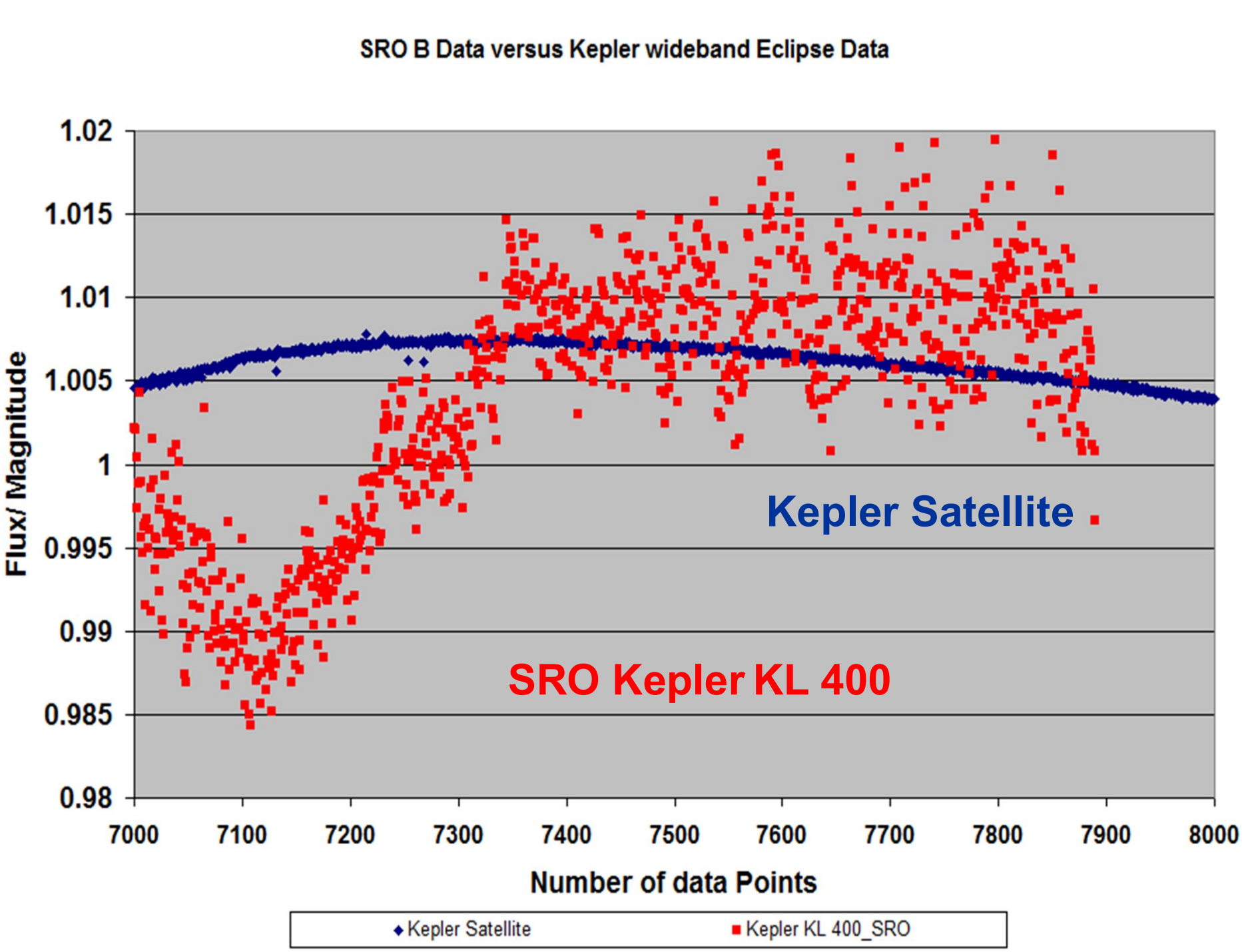
SRO B Data versus Kepler wideband Eclipse Data
Flux/ Magnitude
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
7000
7100
7200
7300
7400
7500
7600
7700
7800
7900
8000
Number of data Points
Kepler Satellite
SRO Kepler KL 400
Kepler Satellite
Kepler KL 400_SRO

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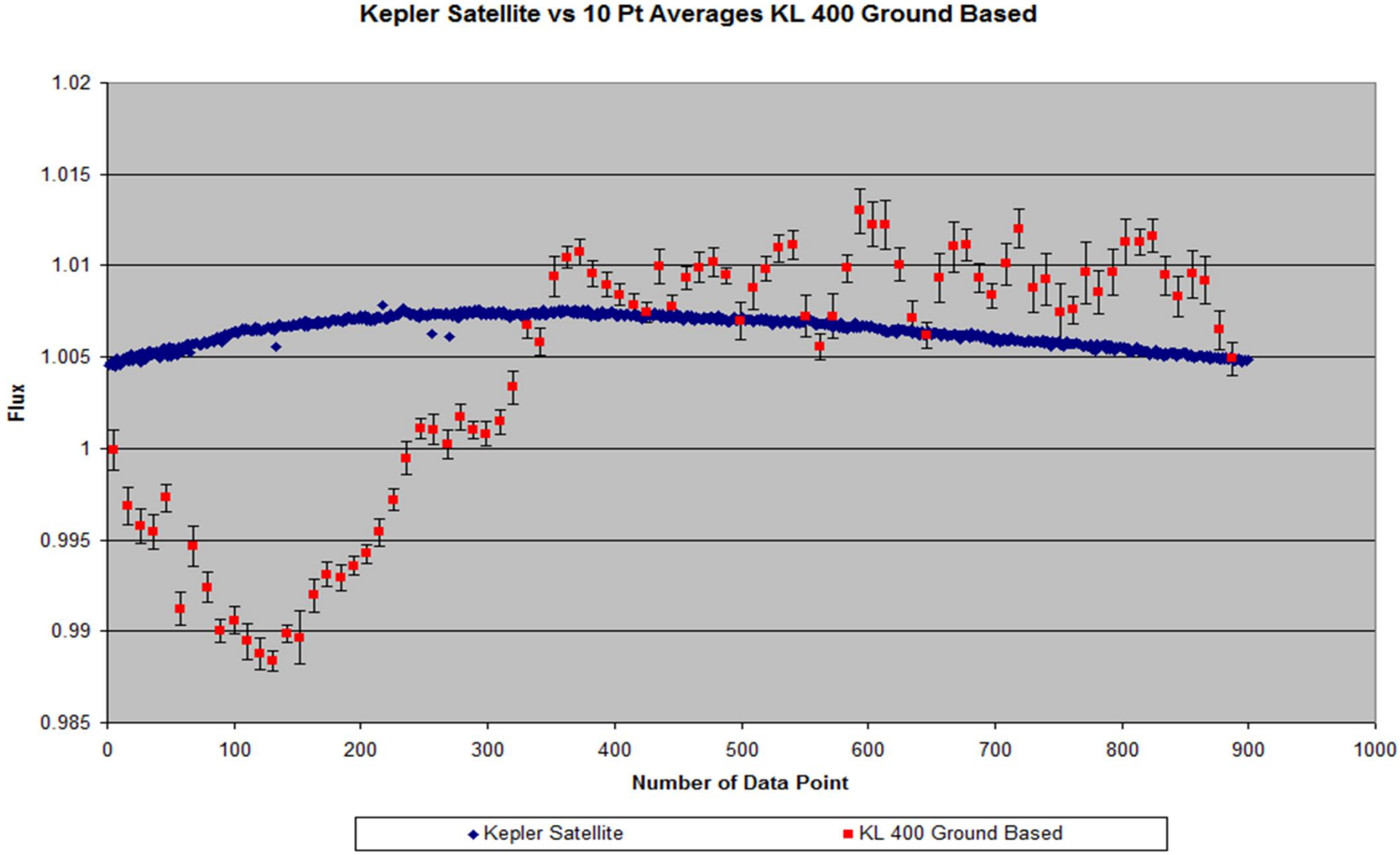

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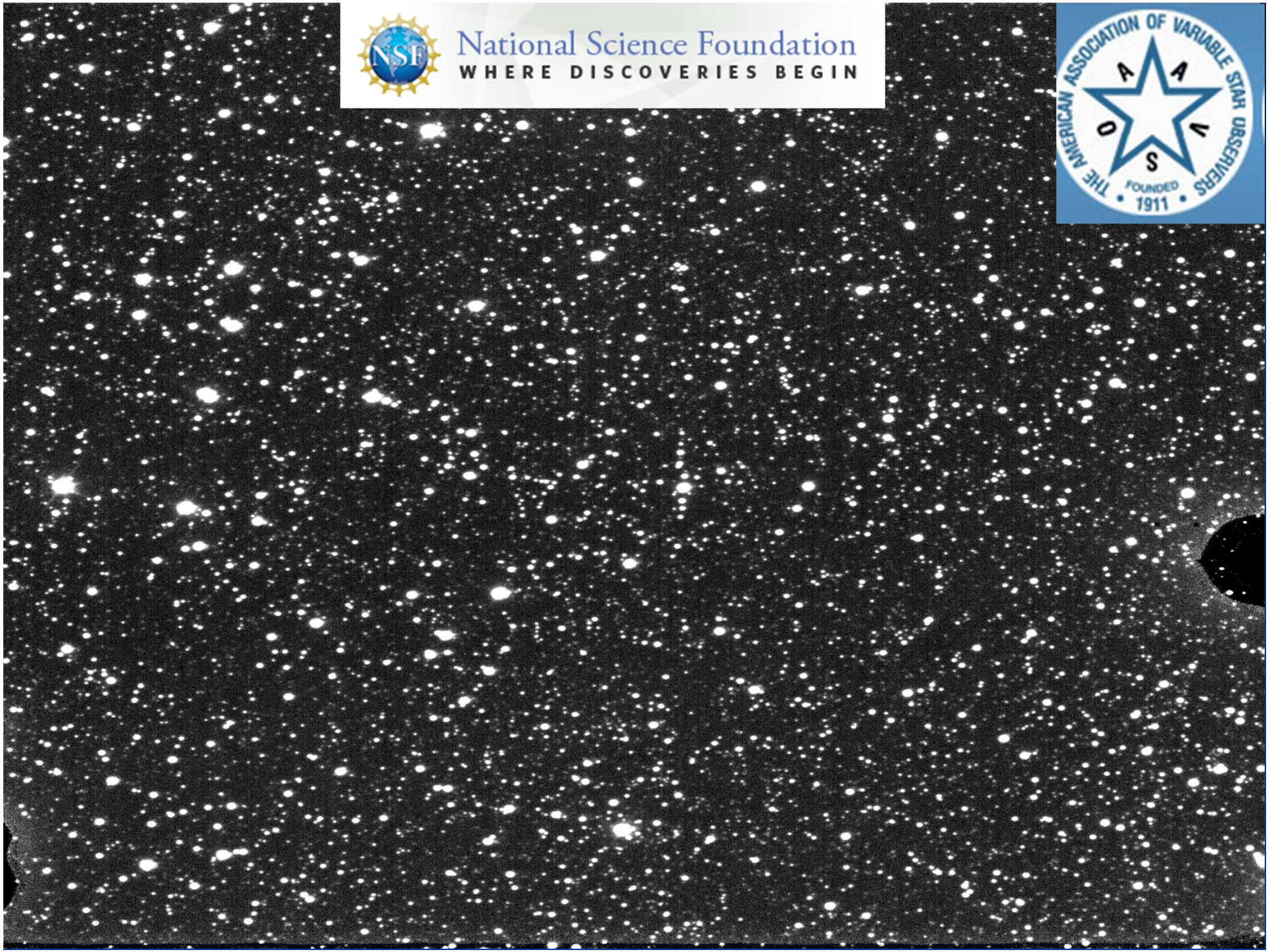
- Its mostly good, but How about?
- …  Amplifier Glow


Raw 240 second Image; Stretched 2:1; No Processing


Amplifier Glow completely Flat Fielded Out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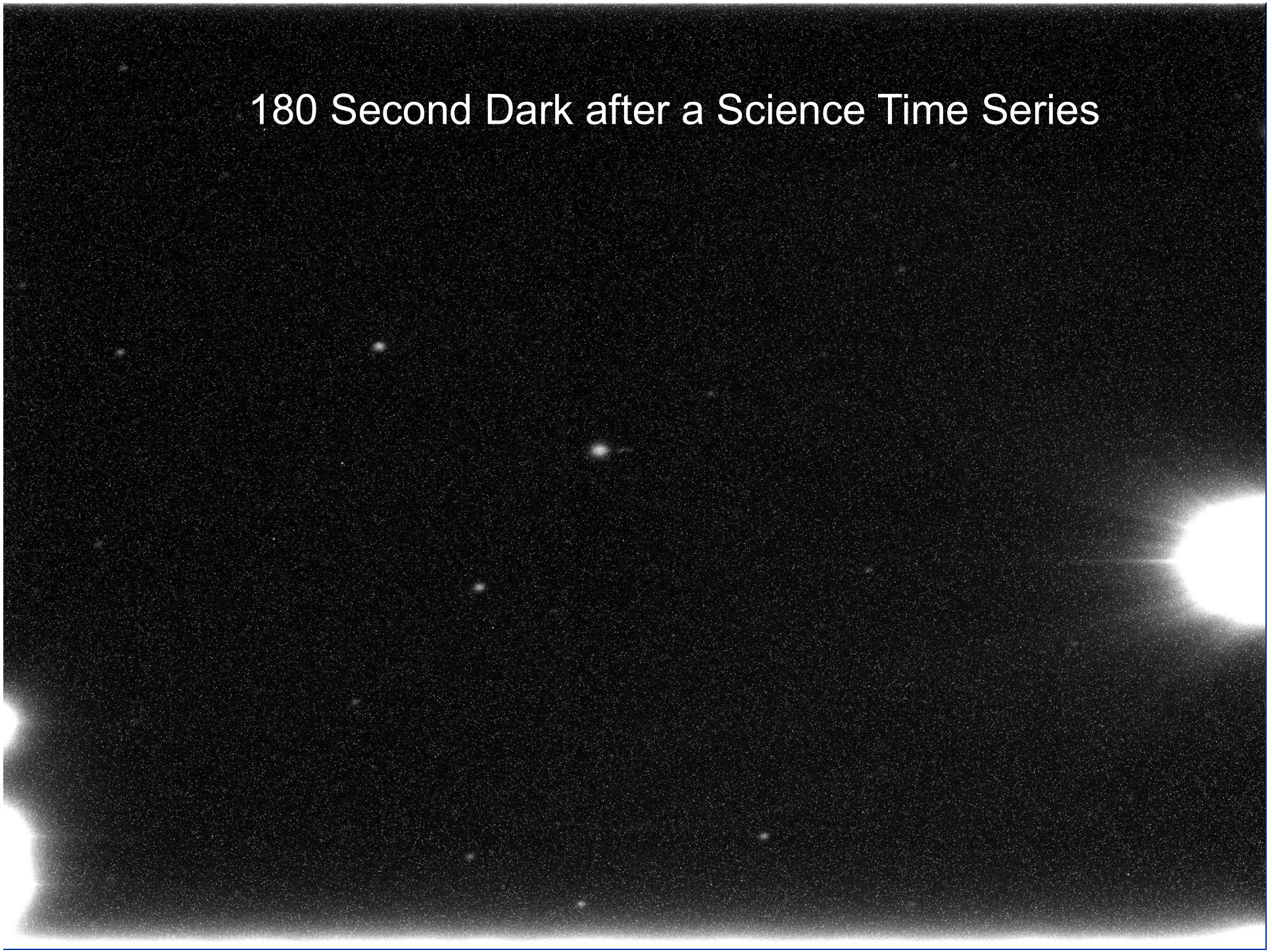
- Second Issue
- RBI—Residual Bulk Image

- You can see it
- For PT it's a Common Mode effect
- Target and the Comparison Star


180 Second Dark after a Science Time Series

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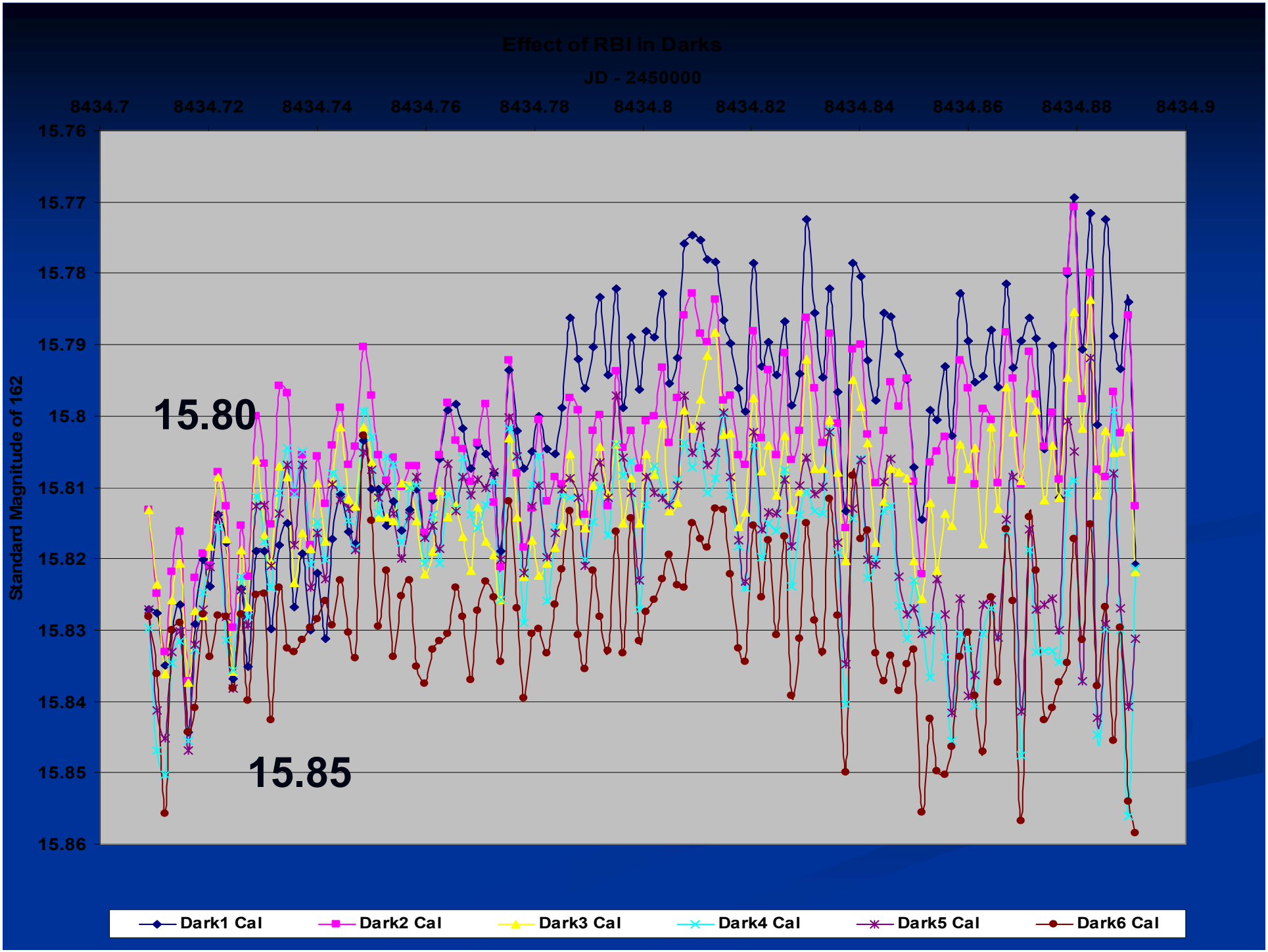
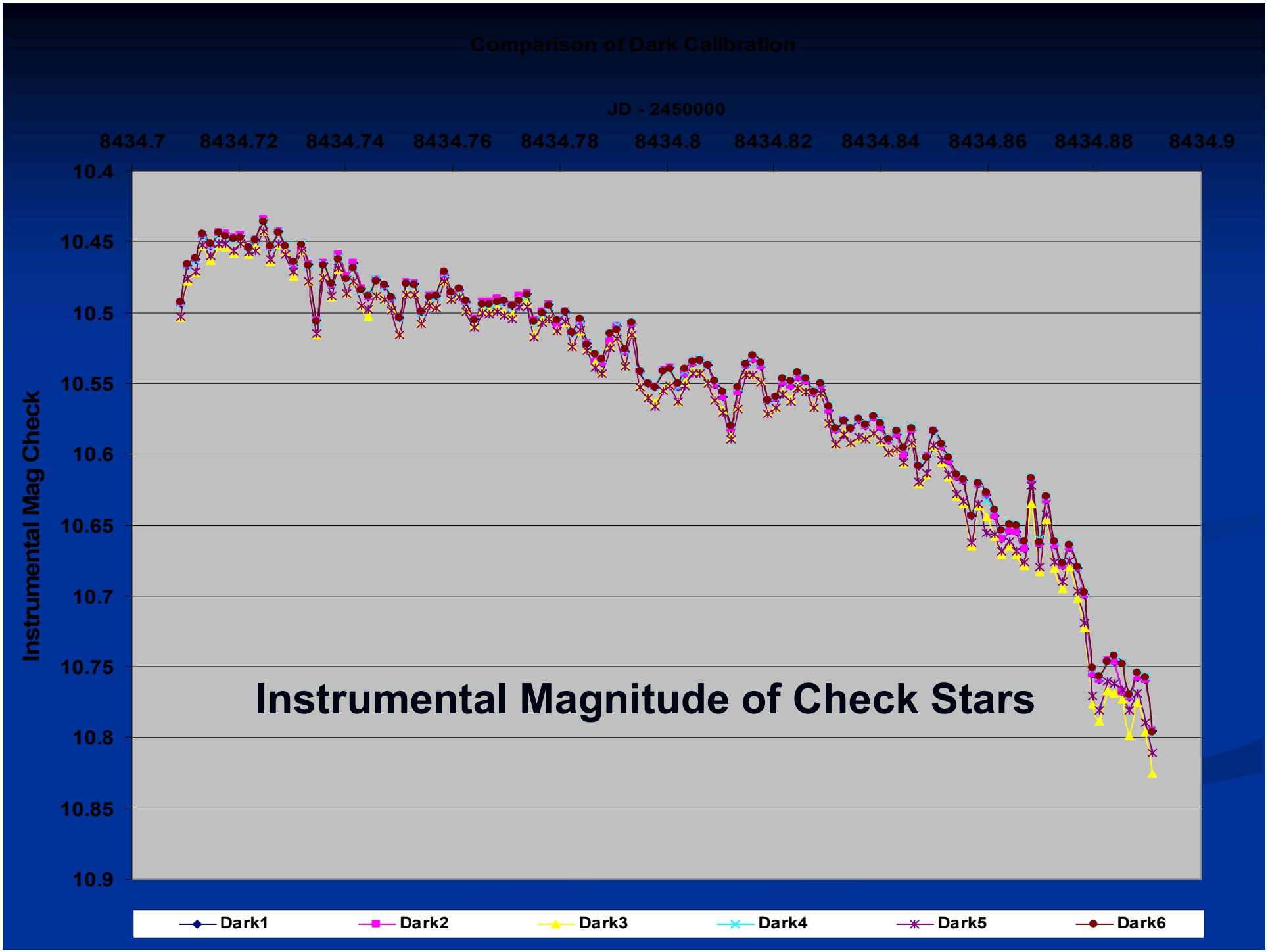
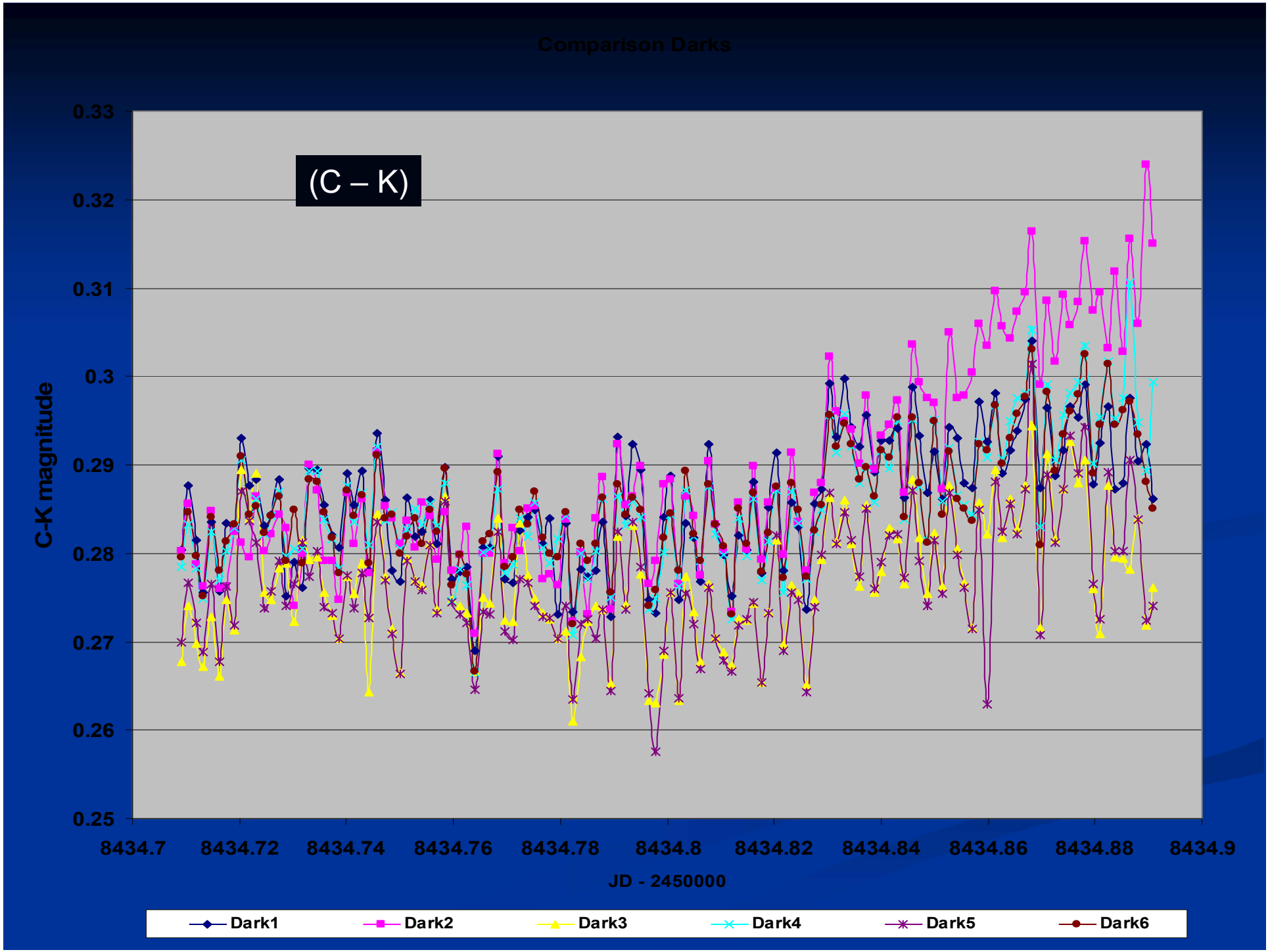
## RBI = Residual Bulk Image Experiment

- Dark1 = 3 Darks before Science
- Science = 130 Images, 120 Secs, 4.5 hours
- Dark2 = 3 Darks right after Science
- Dark3 = 10 Darks 0-1 hour later
- Dark4 = 10 Darks 1-2 hours later
- Dark5 = 10 Darks 2-3 hours later
- Dark6 = 10 Darks 3-4 hours later

- How Badly does it affect the Photometry?


Effect of RBI in Darks
JD - 2450000
8434.7
8434.72
8434.74
8434.76
8434.78
8434.8
8434.82
8434.84
8434.86
8434.88
8434.9
15.76
15.77
15.78
15.79
15.8
15.81
15.82
15.83
15.84
15.85
15.86
Standard Magnitude of 162
15.80
15.85
Dark1 Cal
Dark2 Cal
Dark3 Cal
Dark4 Cal
Dark5 Cal
Dark6 Cal


Comparison of Dark Calibration
JD - 2450000
8434.7
8434.72
8434.74
8434.76
8434.78
8434.8
8434.82
8434.84
8434.86
8434.88
8434.9
Instrumental Mag Check
10.4
10.45
10.5
10.55
10.6
10.65
10.7
10.75
10.8
10.85
10.9
Instrumental Magnitude of Check Stars
Dark1
Dark2
Dark3
Dark4
Dark5
Dark6


Comparison Darks
(C – K)
C-K magnitude
0.33
0.32
0.31
0.3
0.29
0.28
0.27
0.26
0.25
8434.7
8434.72
8434.74
8434.76
8434.78
8434.8
8434.82
8434.84
8434.86
8434.88
8434.9
JD - 2450000
Dark1
Dark2
Dark3
Dark4
Dark5
Dark6

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- Complements Geoff Stone, Larry Van Vleet
  - Sierra Remote Observatory

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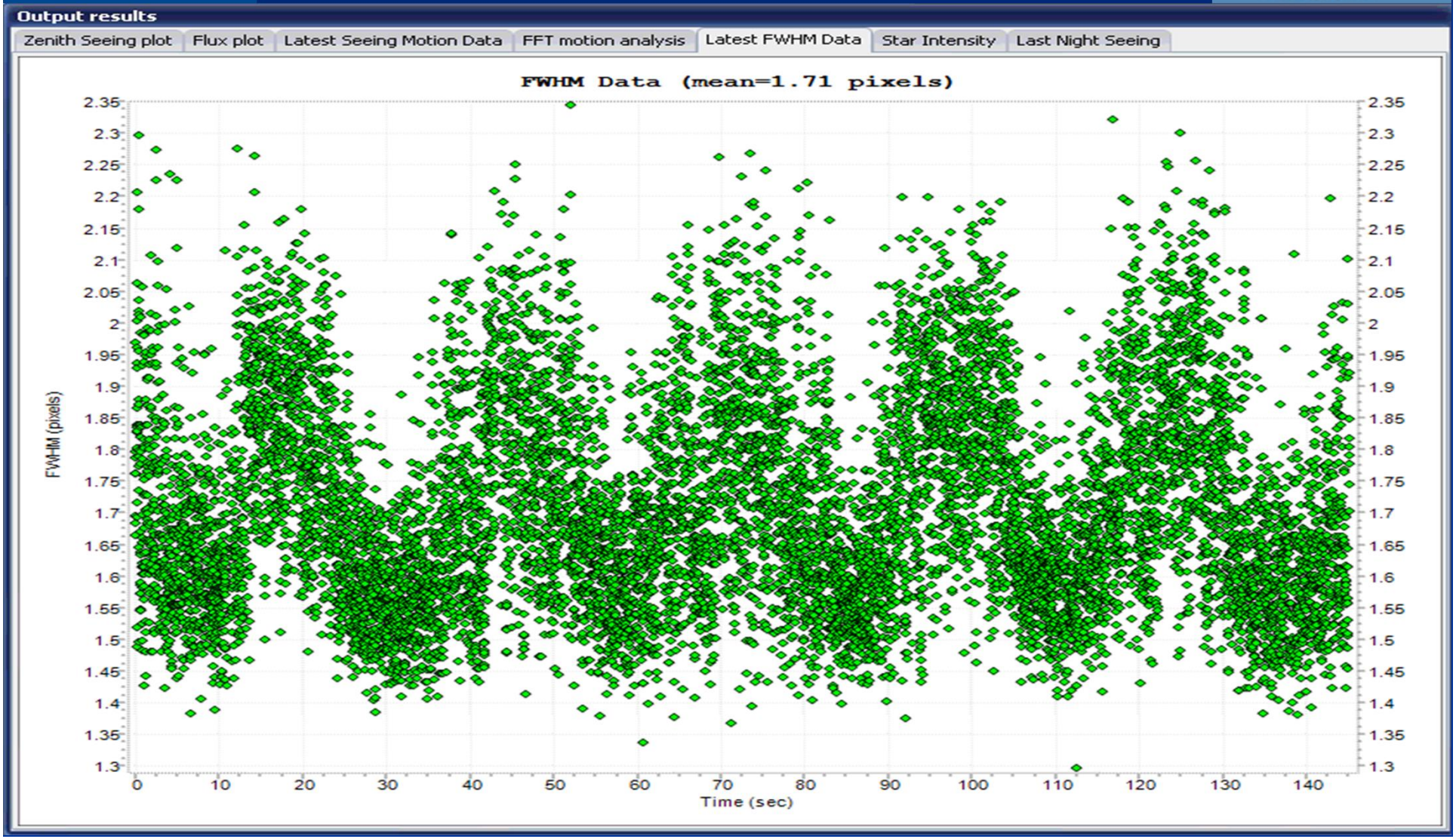

# Cardinal sCMOS Rules So Far

Must Manage your Darks

Darks Must be same Exposure as Science Frames

Cannot Scale from a Master Dark

Darks Right before Science

May Mitigate RBI if it effects your Science

Will discover new artifacts with the 1-2 e read noise

Get Quantitative with your thinking

The sCMOS Train is a Coming

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# Take Aways

- sCMOS has higher dark current
- But, incredibly lower read noise
- Stacking mitigates the effect of high dark current
- Systematics in light curves are lower with sCMOS
- Two 12 bit adc's, merged to 16 bits works
- Amplifier readout glow is Manageable for PT
- Seeing is dynamic and varies on a time scale of Minutes or an angle scale of arc minutes
- Expect future gains in sCMOS
- Maxim, ASCOM, FLI, ACP: "Auto stacking on the Fly" feature Is In BETA

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- **Questions and Answers?**