Predictions for A Next-Generation Rapid-Optical-IR-Response GRB Mission

2nd Moscow GRB Conference 2013 October

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UCB SSL

Collaborators: George Smoot & Students of the EUL

Background

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- Previously -
  - Presented details of a Next-Generation GRB Mission (NGRG) that would image GRBs in the Optical **~ 1 s after trigger.**
  - Scaled-down BAT for rough positions + Beam-steering system points optical/IR Camera within ~1 s

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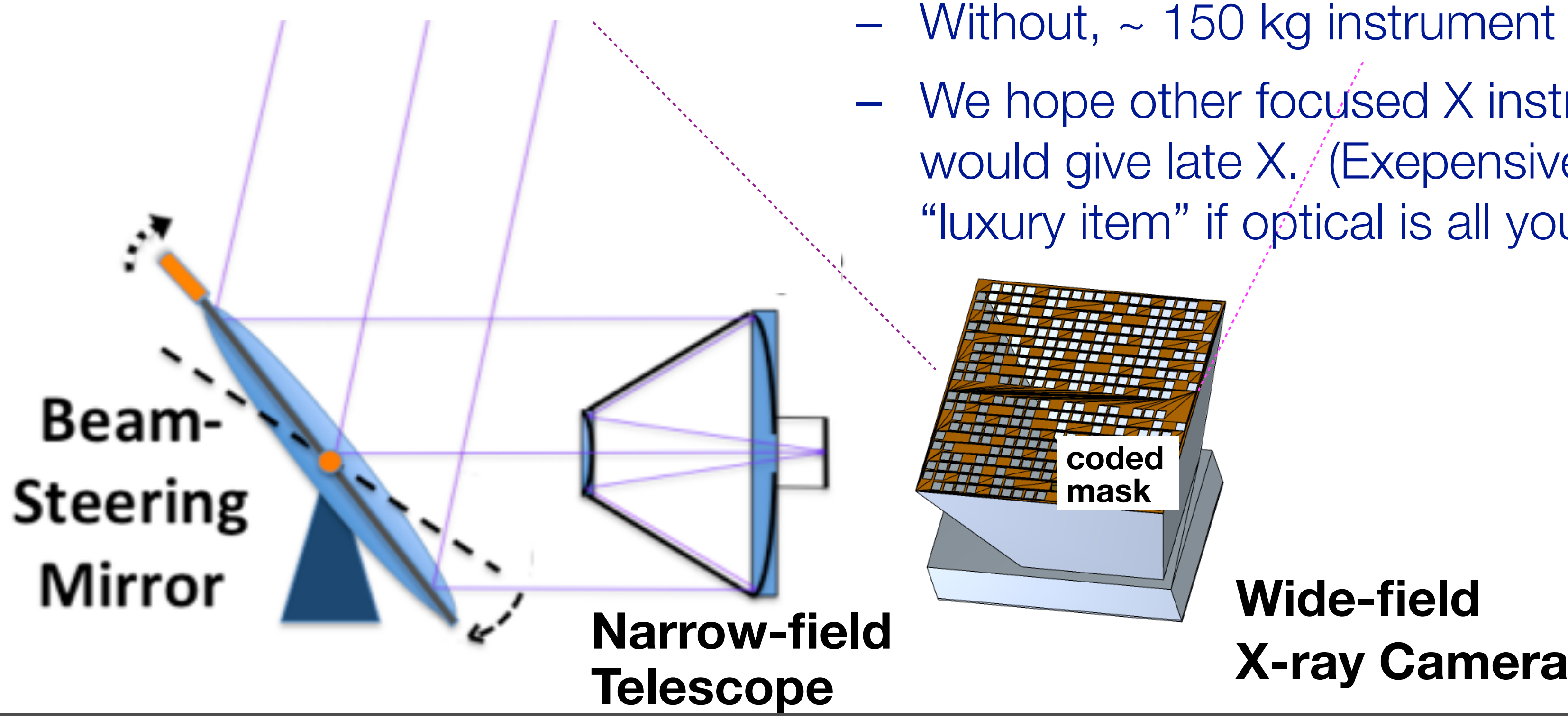
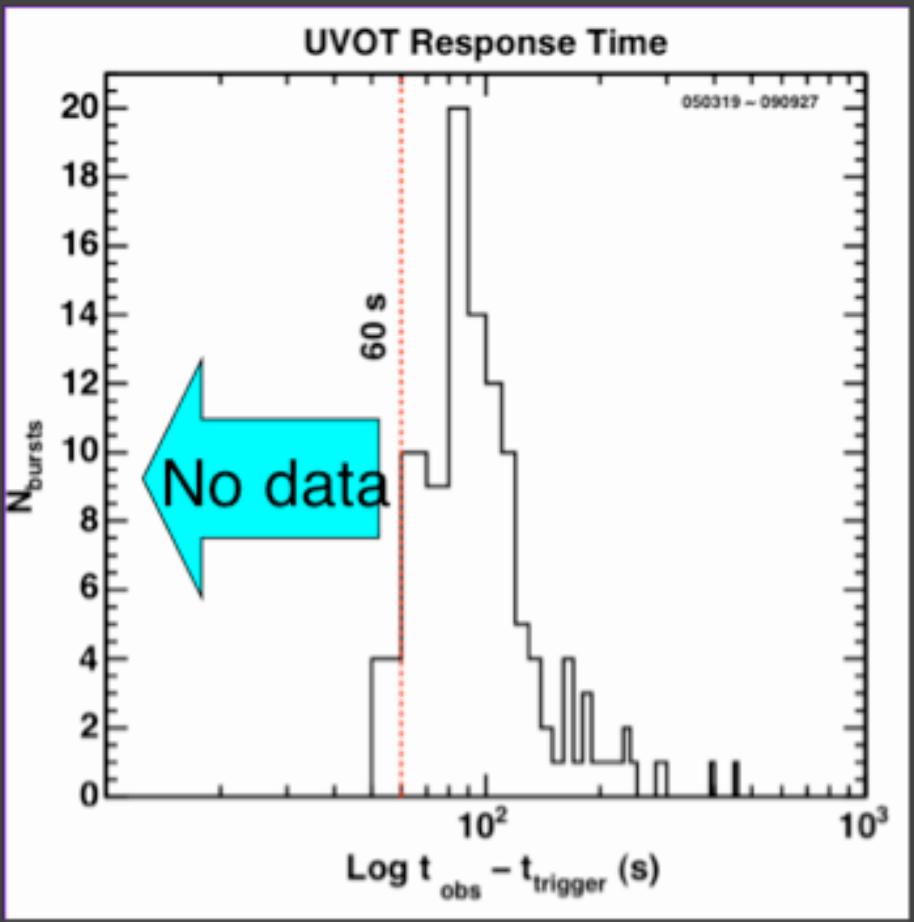
NGRG Concept

- “Mini-Swift” designed to have same FOV X, opt
- Coded mask X-ray camera localizes GRB...
  - (“optimal” instrument sense - see Burrows+)
- Big Difference: Beam-steering mirror points optical telescope - *Much* faster than *Swift*: ~ 1 s to target.
- What about XRT?
  - Without, ~ 150 kg instrument possible.
  - We hope other focused X instrument TOOs would give late X. (Exepensive, complex “luxury item” if optical is all you want.)



1. RAPID OPTICAL RESPONSE TO DATE

We are Starved for Early Optical Data



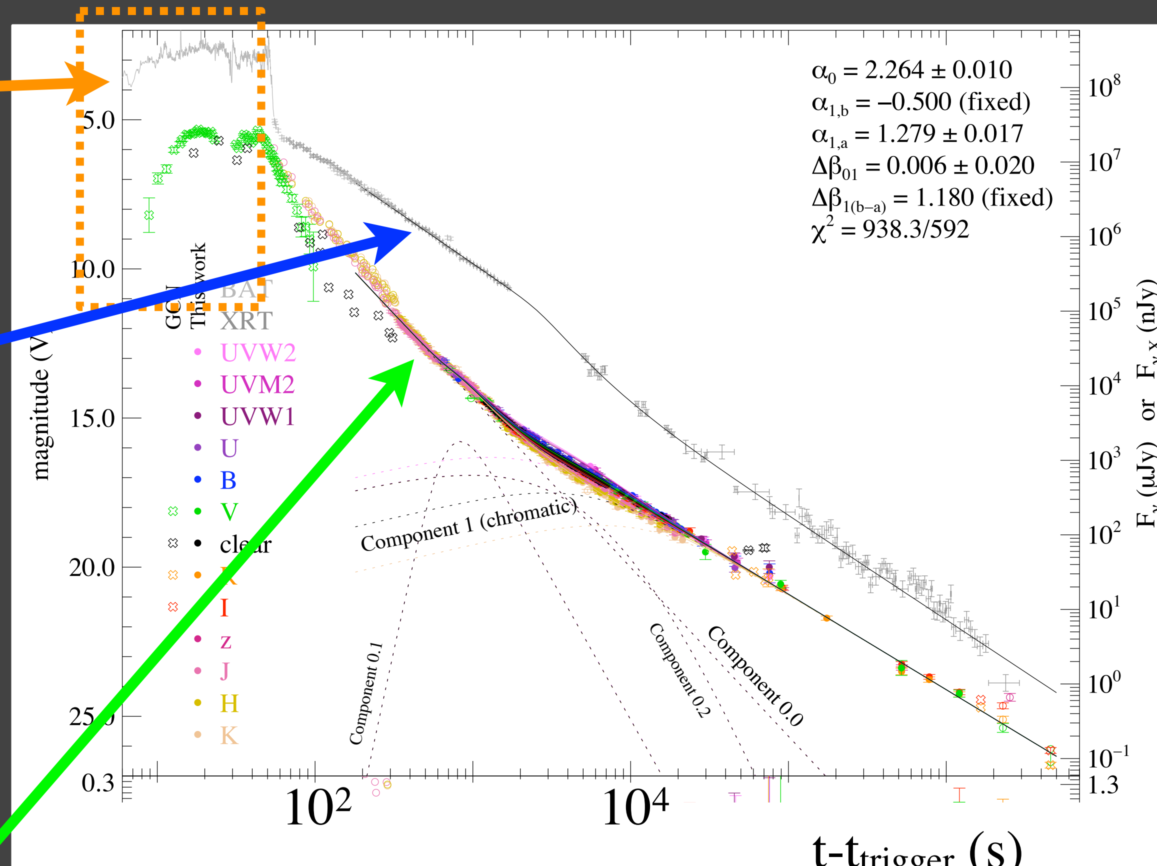
- **Swift dominates optical GRB early measurements... but Optical Response Speed Limited: Few data t< 60 s**
- ROTSE, etc. important, but small number of t_{rise} < 60 s.

Friday, October 11, 13

Early Emission

"Naked-Eye Burst", Best-Studied, brightest ever burst

- Prompt X-γ,
  - phot index ~2.0 (low-E), Jagged in time
- X Afterglow
  - breaks, phot index ~ 1.7
- UVOpt:
  - prompt seen (RARE!!!), with structure
  - Afterglow -----------



Racusin et al.

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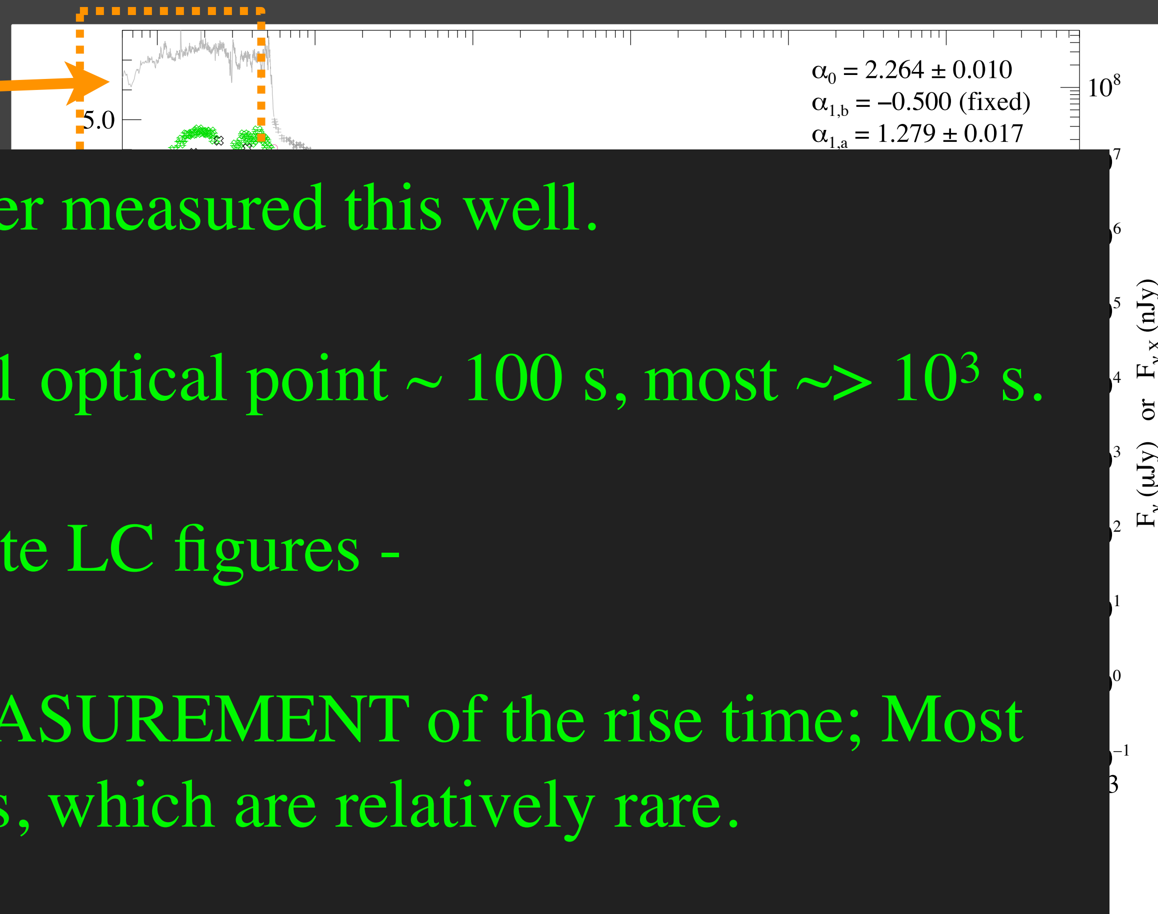


- Prompt X-γ

- But this is the **ONLY** GRB ever measured this well.

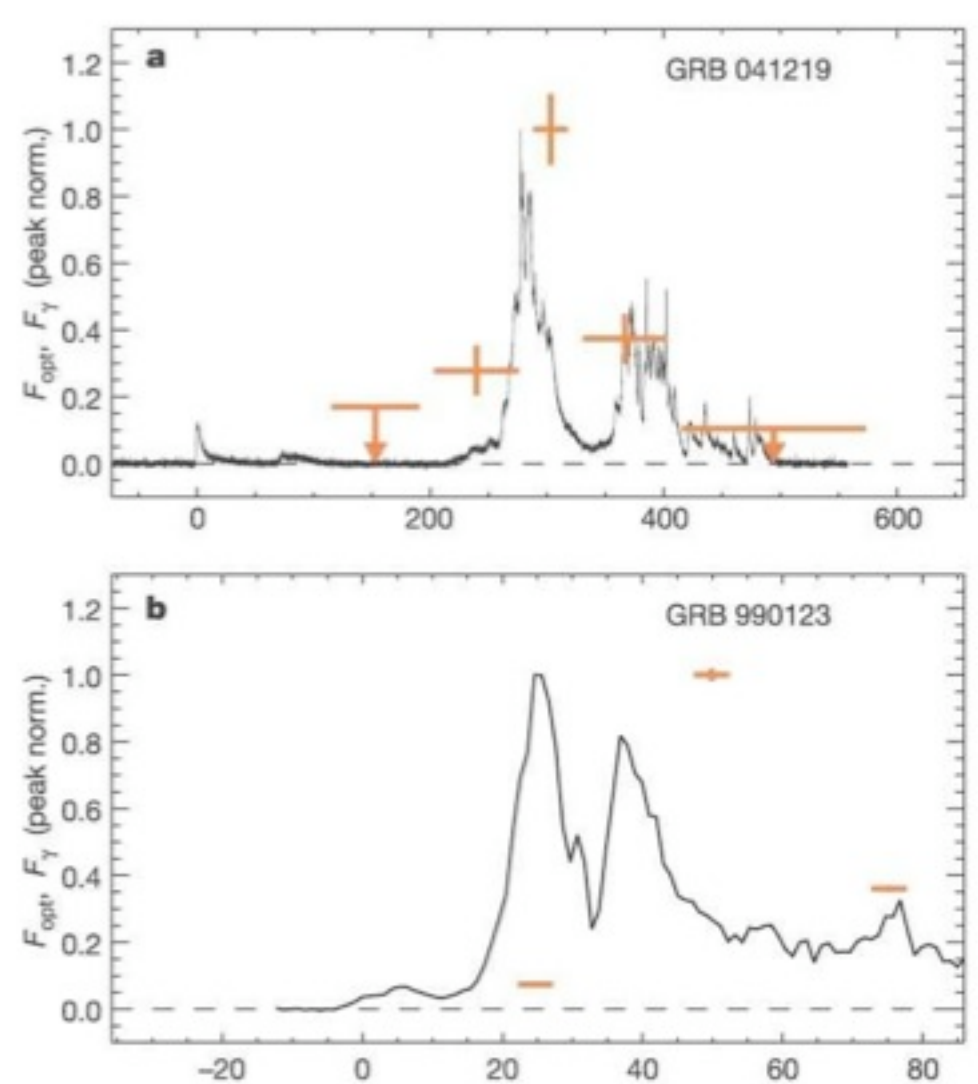
Typical GRB much more faint, 1 optical point ~ 100 s, most ~> 10^3 s.

- Look Carefully at the composite LC figures -

The vast majority have NO MEASUREMENT of the rise time; Most rise times are for very slow rises, which are relatively rare.

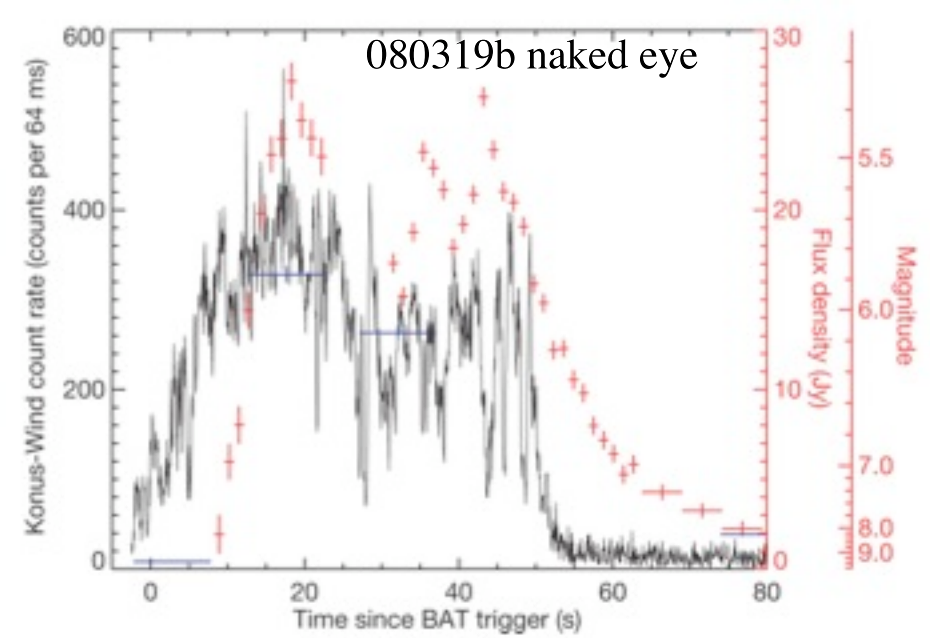
Are Opt, γ early emission correlated?

- Both examples, and counter-examples
  - Data poor unless ultra-bright
  - ...but useful to associate emission processes, to understand jet



Vestrand et al. 2005

- 041219 - Probably.
- 990123- No.
- 080319b- Mostly
  - (best data)



080319b naked eye Racusin et al. 2008

- B. Grossan. 2MG

A "UVOT Early Response Sample"

- ***Goal: Uniform, Earliest, UVOT LC points***
- GRBs 060502 - 081007
  - UVOT responded uniformly: 100 s exposure, W (open) filter
  - W exposures begin t~ 70-150 s
- Require <t_{mid}> < 170 s
- Defines "Early Emission & Response" Sub-sample:

  no image triggers, ground analysis, etc.

NGRB	224	NGRB_rly	209
RGRB(yr^{-1})	92	RGRB_rly (yr^{-1})	86
Robs_uvot_rly (yr^{-1})	38	Rdet_uvot_rly (yr^{-1})	18

SWIFT+ GROUND TO DATE

- UVOT - t~60+ s
  W<19.2 mag/10s
  ~18 detections / yr.

- ROTSEIII dominates t ~20+s
  R < 16.9 mag/10 s
  Detections[1]:~ 3 / yr. in GCN (probably not all reported)

- Master-Net fast & wide....
  but < ~15.2 mag
  many UL

(1) GCN notices 2011 - 2012

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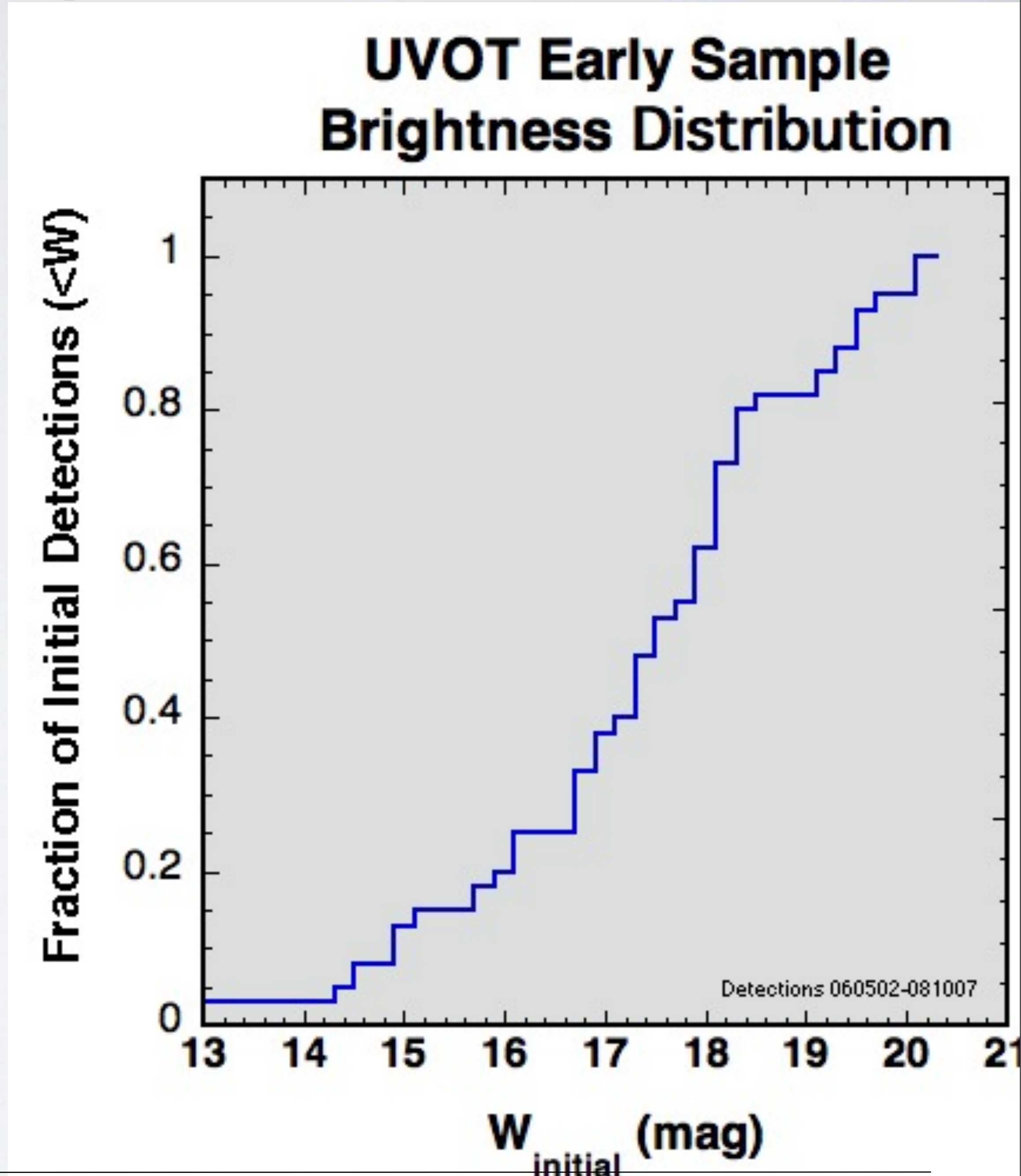

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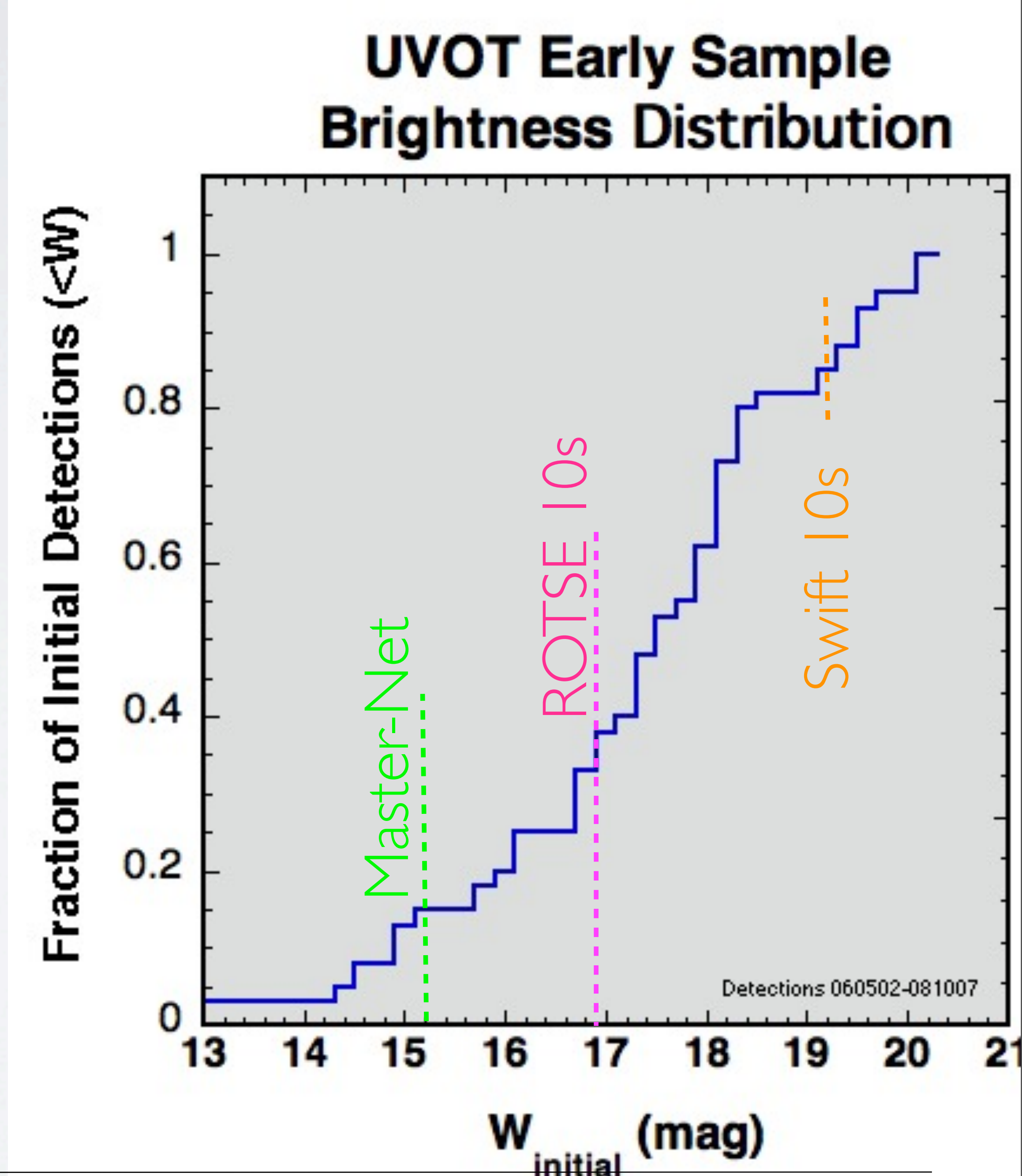

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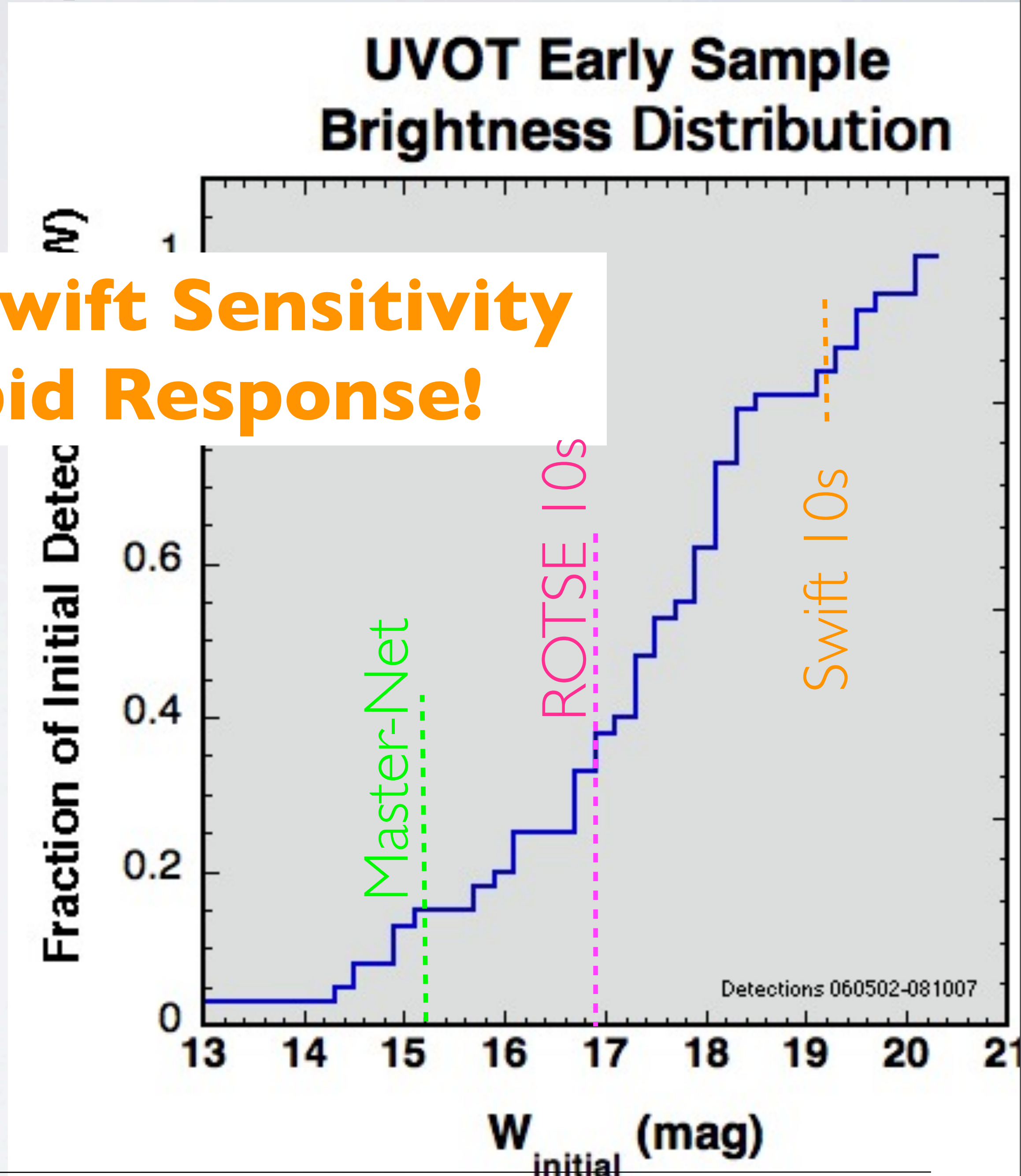
• Need Swift Sensitivity w/Rapid Response!



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II. RAPID RESPONSE SCIENCE

Emission physics

adapted from page et al.

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- With small fraction of first 60 s observed, how can we say anything statistical about e.g. "*no* bright early peak"?
- Shock Breakout Test for LLGRB - *E. Nakar Tue Talk*

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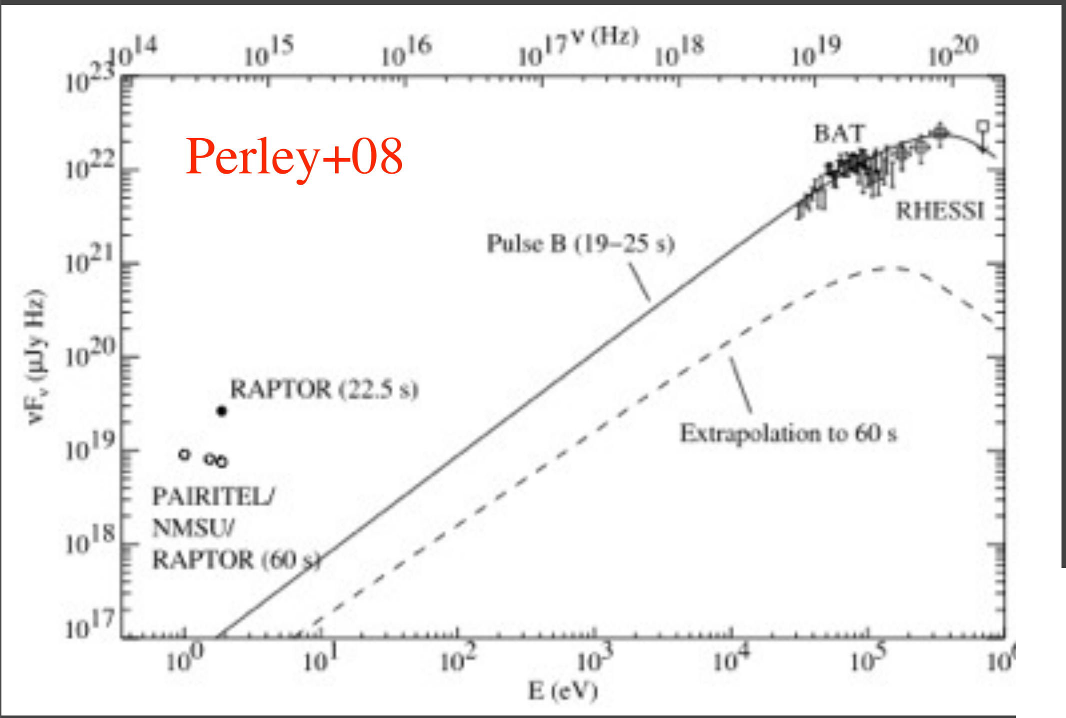
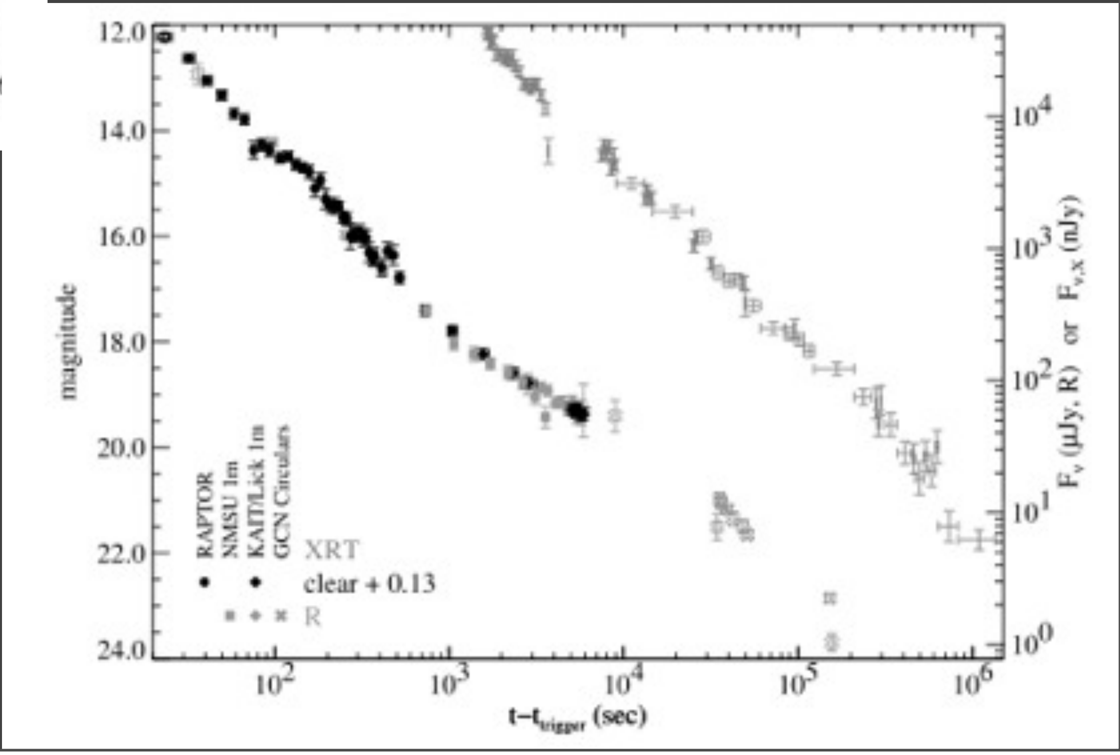
External shock-061112



- Early opt too bright for extrapolation of X, gamma

Perley+08



Thanks to Alex Kann for pointing these out!

"Multi-Messenger" Science

- Physics in correlation and delay for
  - Short GRB: gravitational wave vs. optical-gamma light [1]
    - GRB optical emission for source ID, GW vs. photon arrive time for models.
  - SN-GRB: neutrinos vs. optical-to-gamma prompt light
  - GRB UHECR: Air shower detector signals vs. optical prompt light
    - test models, identify sources
  - physics of explosion, jet processes
    - time between gamma and optical peak agree with models?
      - e.g. same time scale for all components constrains radiation mechanism, different time scales& correlations, suggestions different mechanisms
  - GR alternative models- UHE photons vs. Low E delay - (can do experiment to $z \geq 8$, large $\Delta\nu$) constrains alternative models.

... though most of these come with caveats on complex jet structure.

[1] e.g. Nishizawa, Taruya & Saito, cosmology with Space GW detectors also needs red shift; perhaps get many from prompt observations of SHGRB.

Dust Evaporation

- Many GRB in dusty star forming regions
- GRB have enough energy to vaporize dust of typical star forming cloud - ≤ 60 s time scale
  - Models: Salvaterra+09, Perna+03; >60 s too late: Oates+09, Perley+10
- Time-dependent extinction measurement would
  - confirm calculations of dust density, evaporation
  - locate a given GRB within star-forming local cloud, not behind dust lane
- Need time-dependent spectral slope starting earlier than most previous measurements

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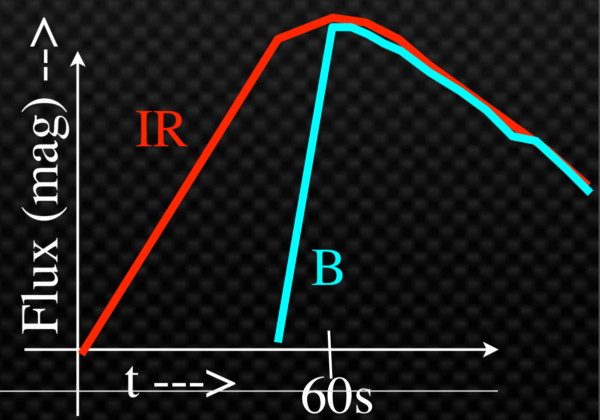
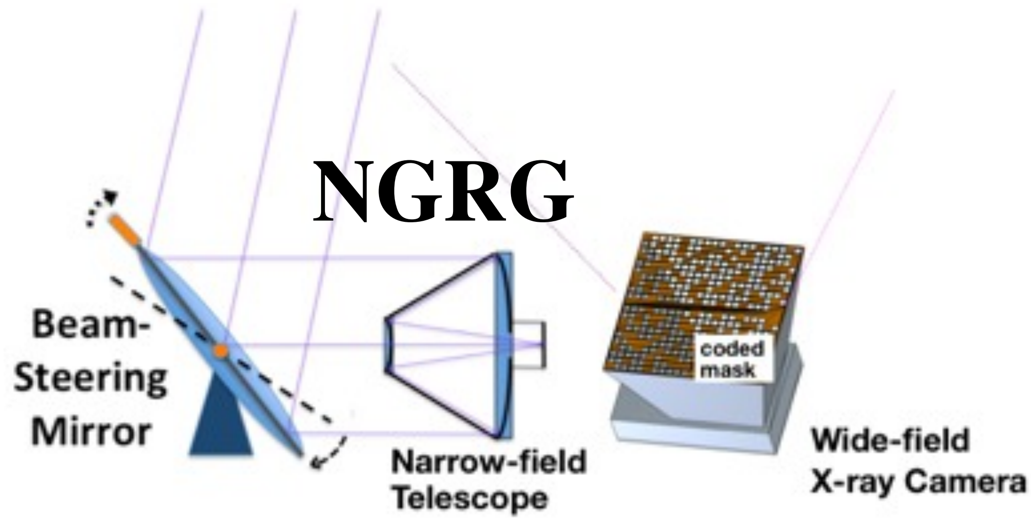


III. Rapid Response Science with *Less* Instrument

- attractive idea in age of limited support

A Rapid-Optical Response Replacement for *Swift*



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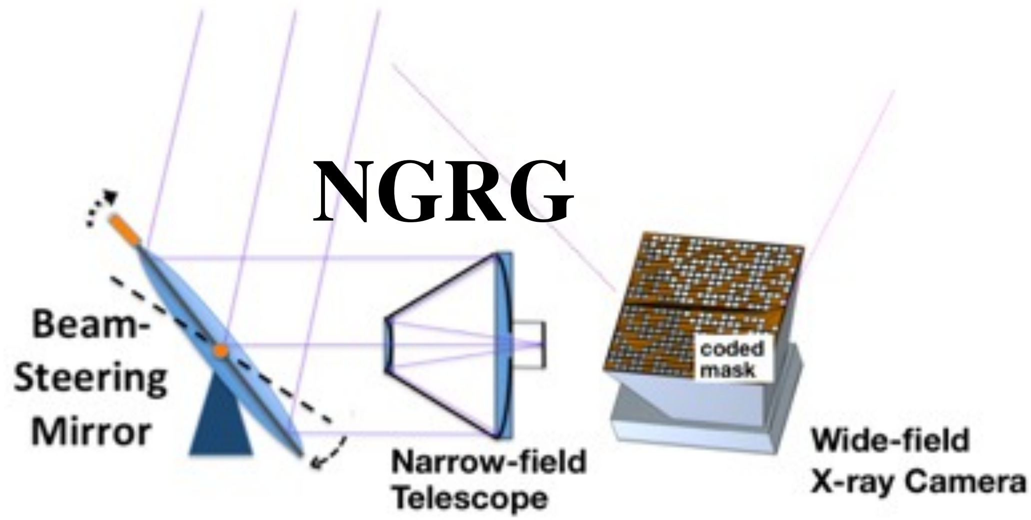

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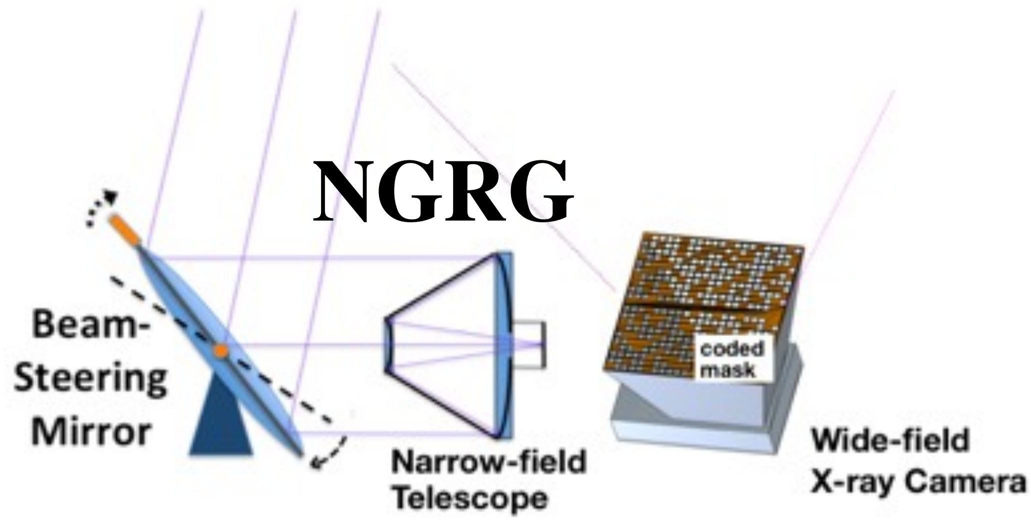

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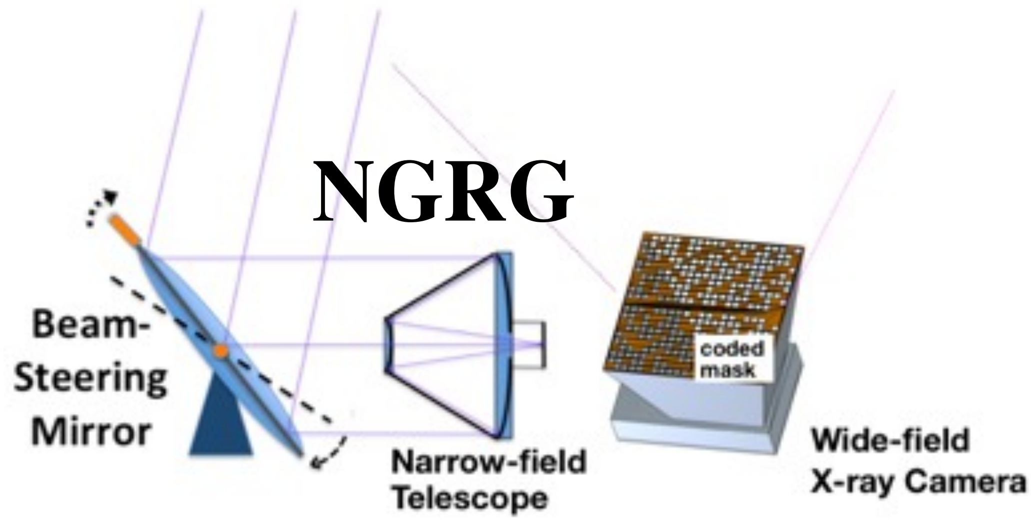

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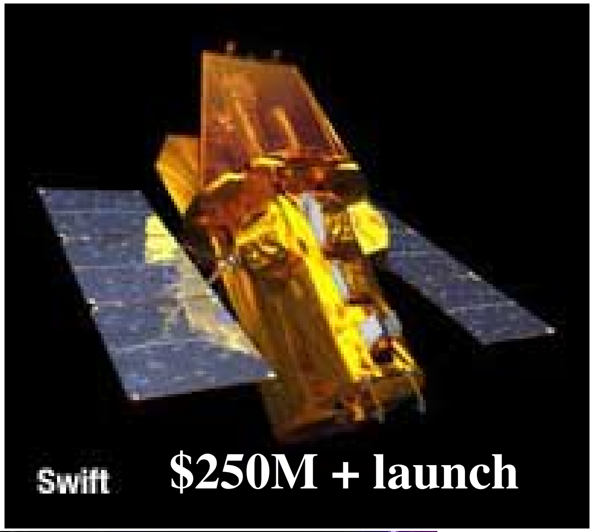

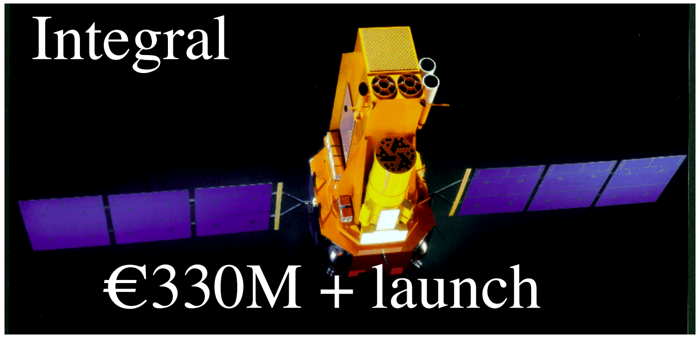

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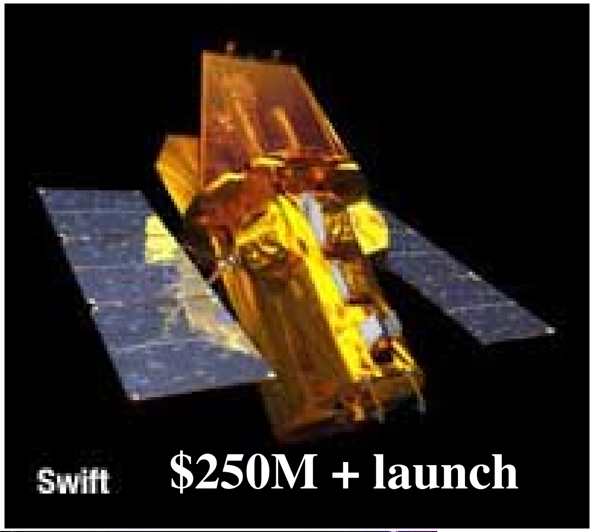

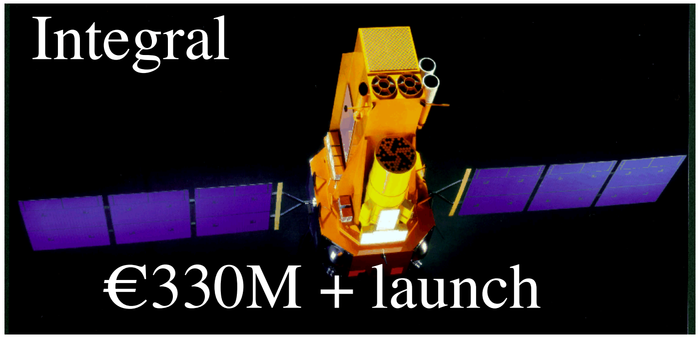

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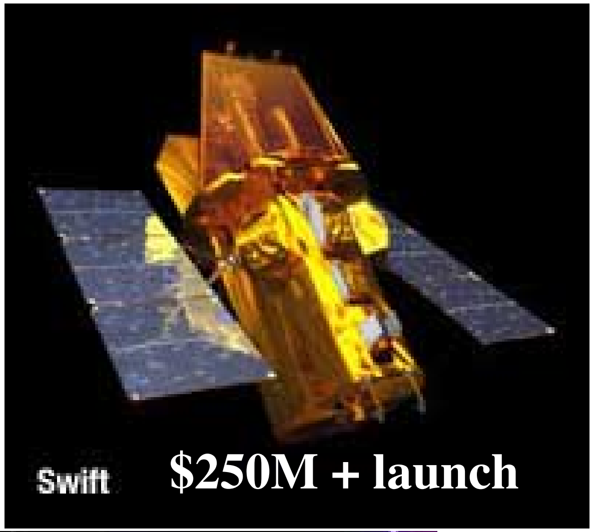
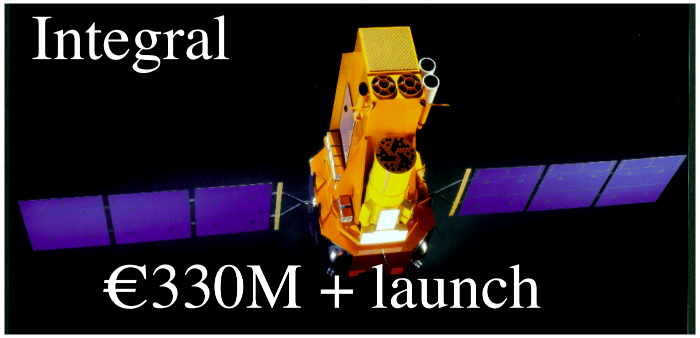
  - private???





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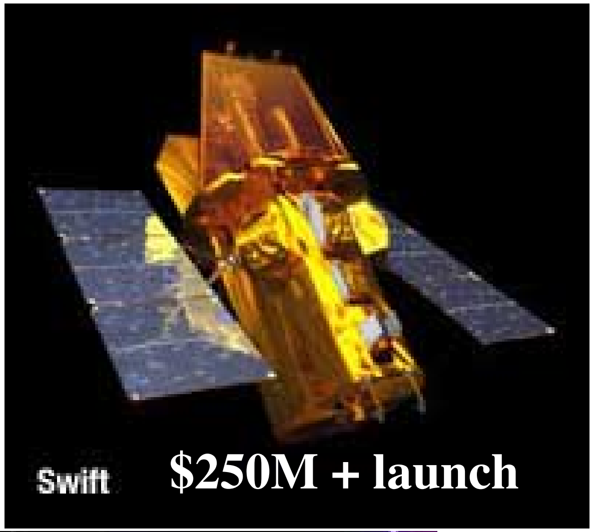
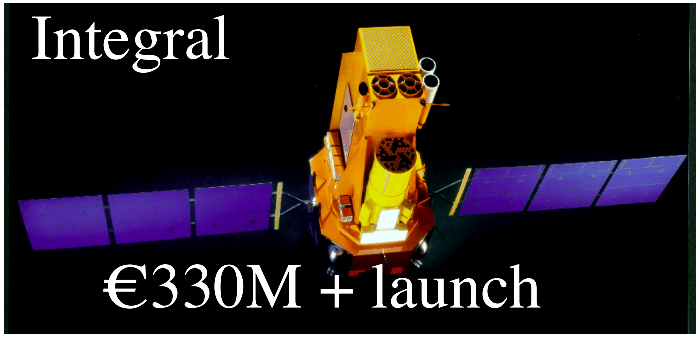
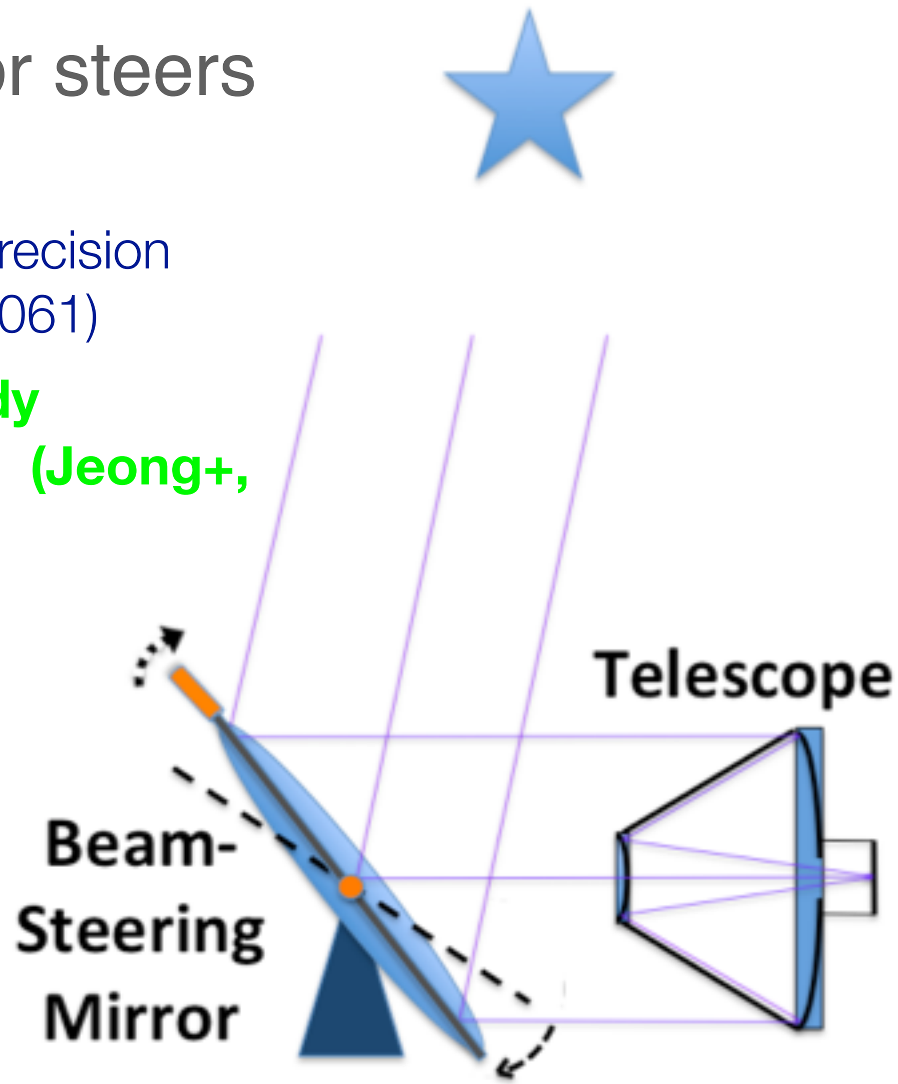
- ..But these **do not point**,
  => sensitive exposures impossible
  => Arc sec pointing stabilized space-craft *very* expensive (few per decade).



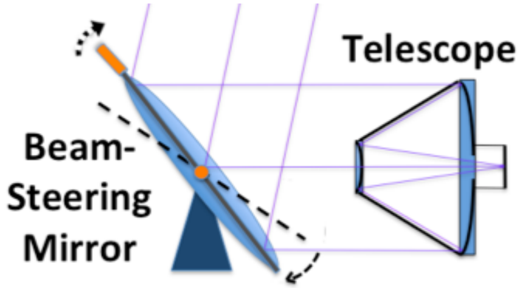


Solution Part I.
Beam-Steering for Rapid Response

- Simple motor-driven flat mirror steers beam rapidly
  - Many industrial motors have ~ 0.05" precision encoders & control (e.g. Kollmorgen D061)
  - **UFFO-pathfinder instrument already demonstrates ~ 60 deg. travel / 1s (Jeong+, optics express 2013)**
  - **=> Driving the mirror fast enough possible.**



Solution Part II: Beam-Steering for Image Stabilization



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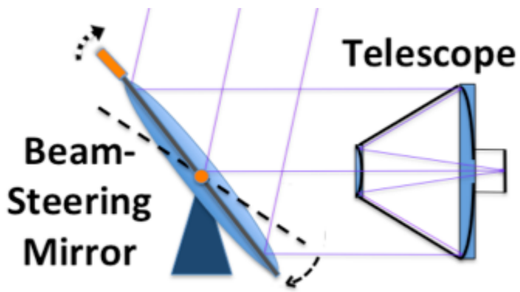

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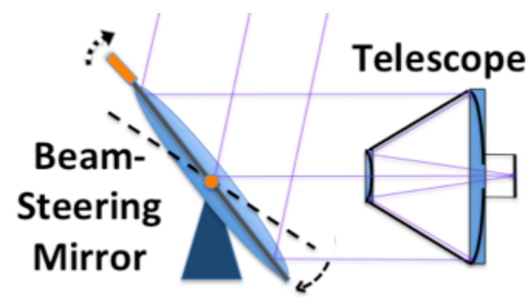

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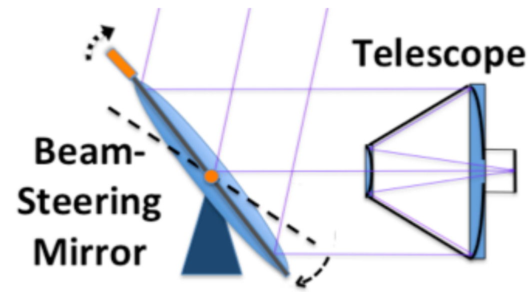

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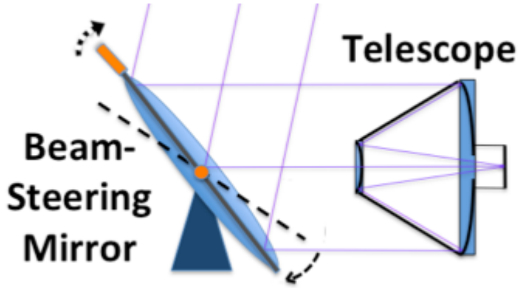

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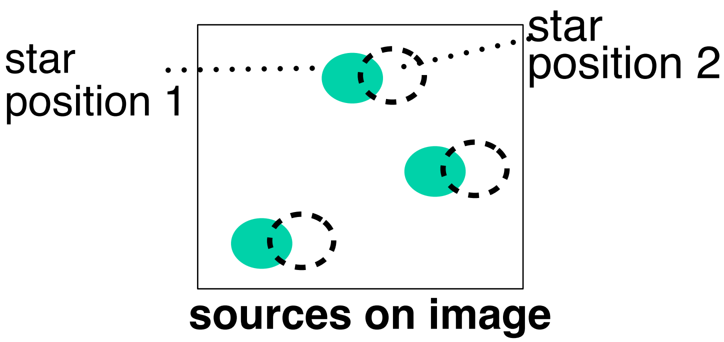

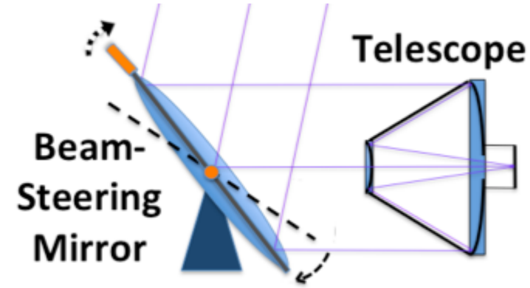

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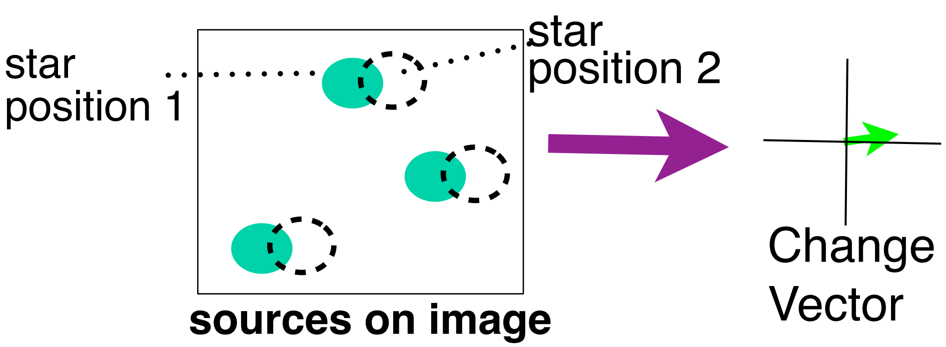

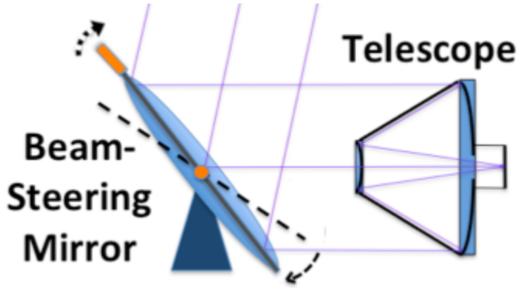

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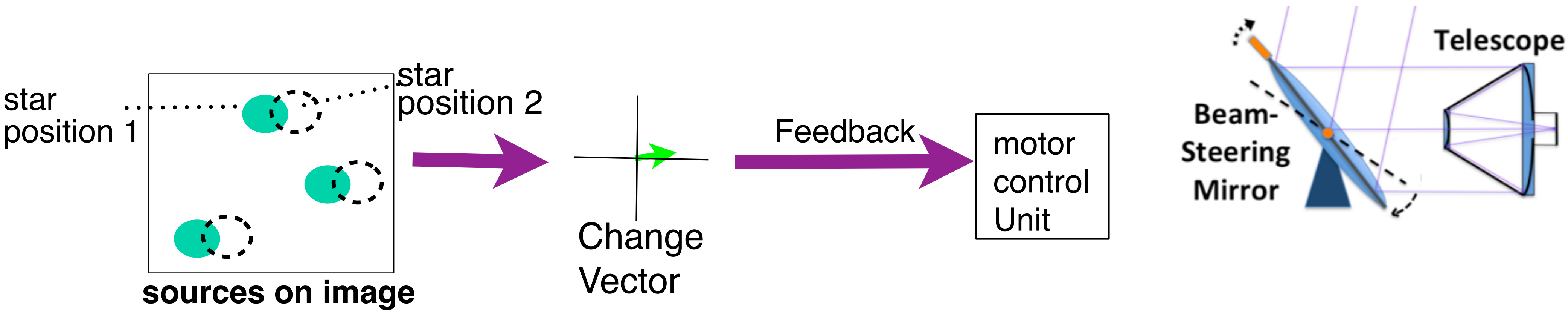

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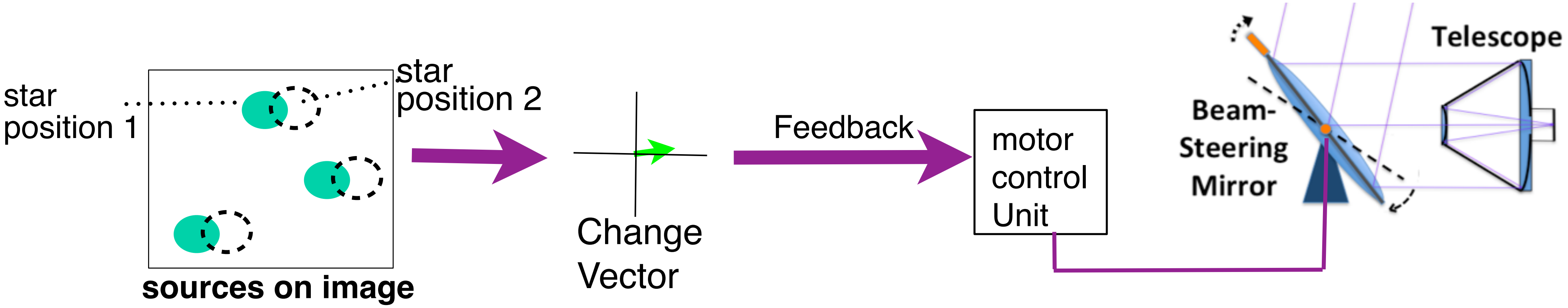

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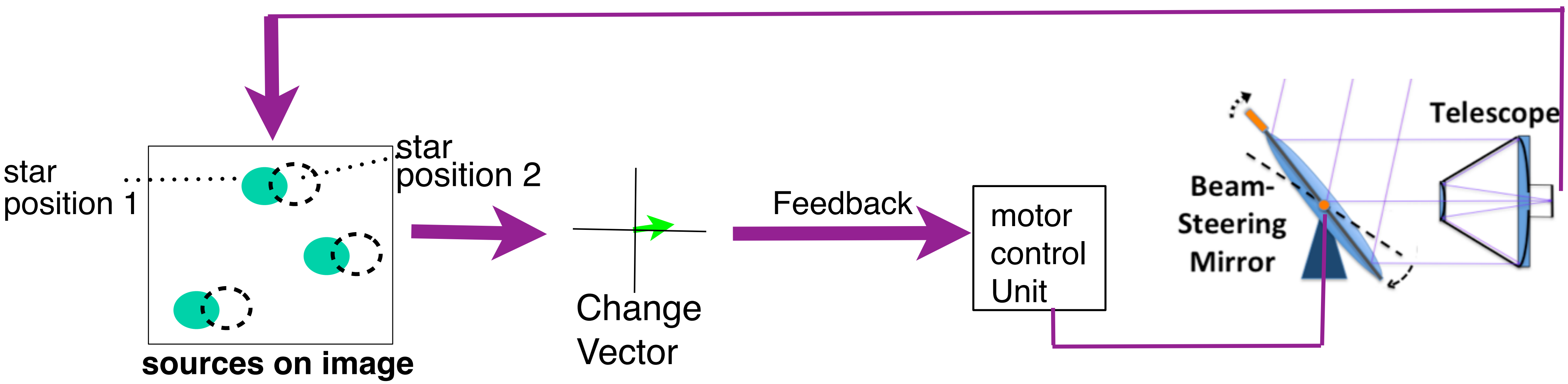
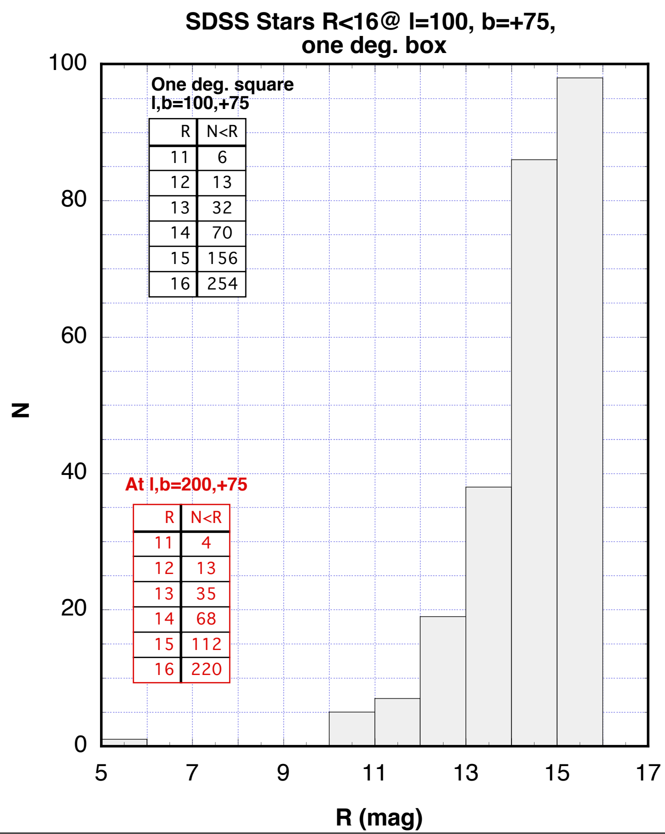


Control w/Feedback via Field Star Positions



(*) sensitivity calculation assumes zodi dominates

Control w/Feedback via Field Star Positions

- Star centroids: SNR> 8 gives σ < 0.1 pix (0.2”)
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  - σ=0.13” / 20 ms
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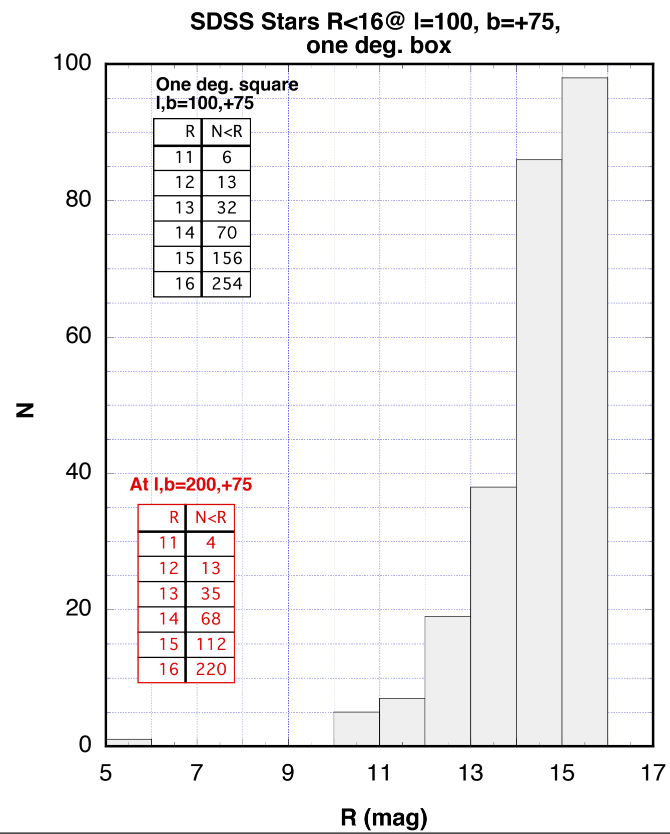

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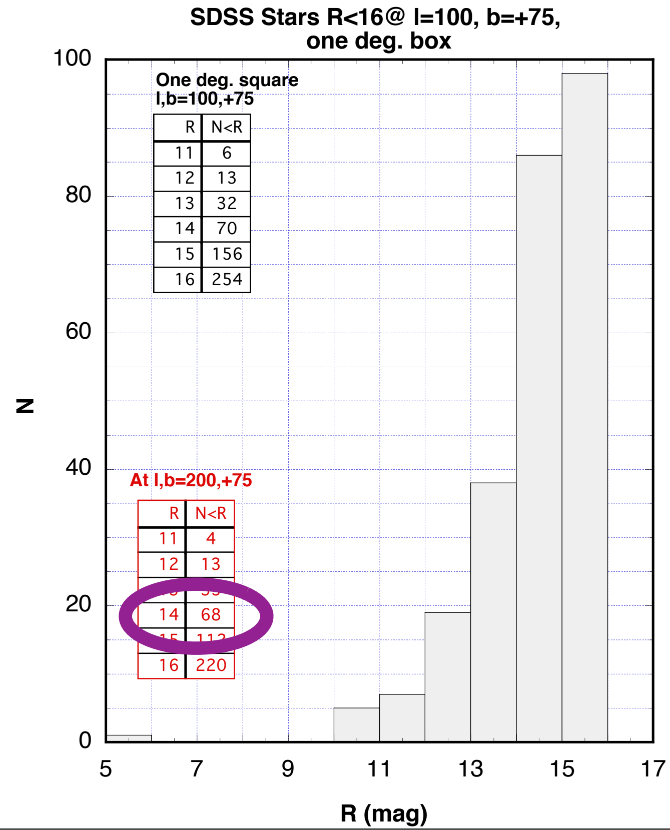

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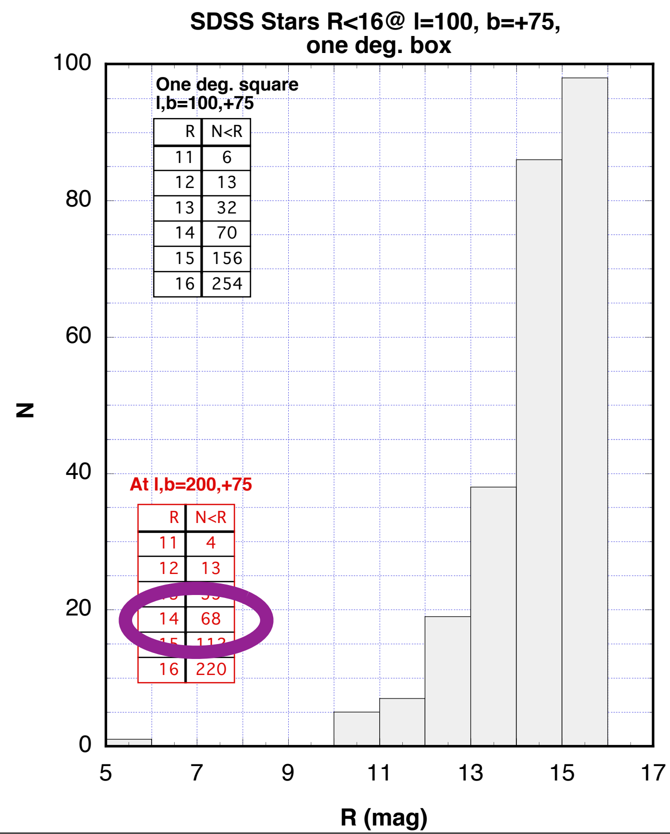
- **=> No Problem for wide range of frame rates, apertures**



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IV. Conservative & Accurate Rate Predictions for Small Instruments

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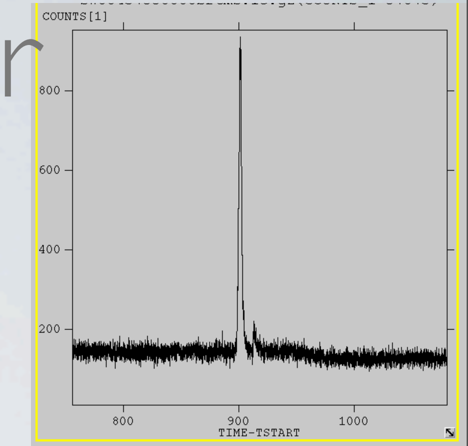
(because useful = large N)

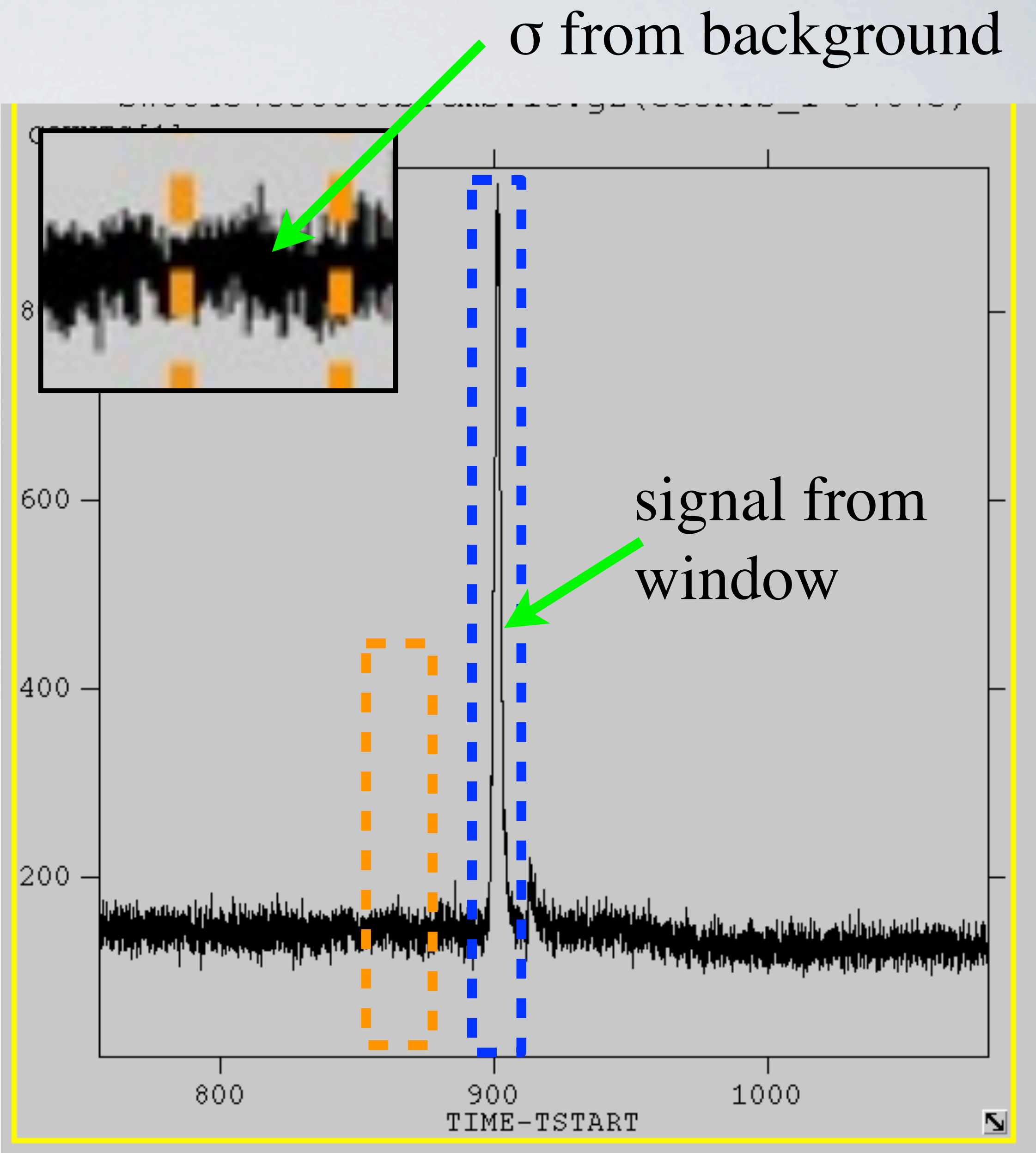
Use **Data**, Not Assumptions, for Realistic Predictions



- Detection dependent on actual light curves & background
  - because trigger by peak **SNR**, not e.g., fluence
- For scaled down BAT, should be able to make perfect detection predictions for any scale smaller than 1:1 -- because **SNR** ~ $A^{1/2}$
  - Run trigger algorithm on actual BAT history
  - Scale SNR for reduced collecting area
    - Results much more accurate than assumed spectra & light curves
- Predictions depend on Swift operations history (point restrictions, transmission scheduling, etc.)
  --- But then. rates are realistic for a **real** mission!

BAT 64 ms data

- Signal from trigger time window
- Noise from background window
- Simple algorithms PLUS temporal "model" of background (geomag maps, monitors, etc.)



Triggering & Detection

- BAT location algorithm must be **triggered**
  - Rate Trigger - fluctuation > N sigma
  - Image Trigger - good for long, faint bursts only
- Used Simplest Rate Trigger:
  - Used 64 ms data channels 1-3 summed, (15-100 kev), the highest S/N combination
  - Used time windows of 0.25, 0.5, 1, 2, 4, 8 s
  - Used **trailing** average background t–19.2 to t–6.4 s
- Determine Max SNR in all windows
- After trigger, detection for all SNR>5 sources
  - Simulations by Paul Connell
  - location quality ~ 1/SNR

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- Used Simplest Rate Trigger:
  - Used 64 ms data channels 1-3 summed, (15-100 kev), the highest S/N combination
  - **NOT sophisticated, but yielded very good results, high detection rate**
    - ***image trigger may boost rates few %, may be problem on small instrument***
- Determine Max SNR in all windows
- After trigger, detection for all SNR>5 sources
  - Simulations by Paul Connell
  - location quality ~ 1/SNR

V. OPTICAL/IR RATE PREDICTION

- Accurate rate predictions for any instrument less sensitive than Swift
  - ...or very robust *lower* limits for more sensitive instruments
- Can use actual X/ray and Optical 2-variable rate predictions

UVOT *and BAT* Early Response Sample"

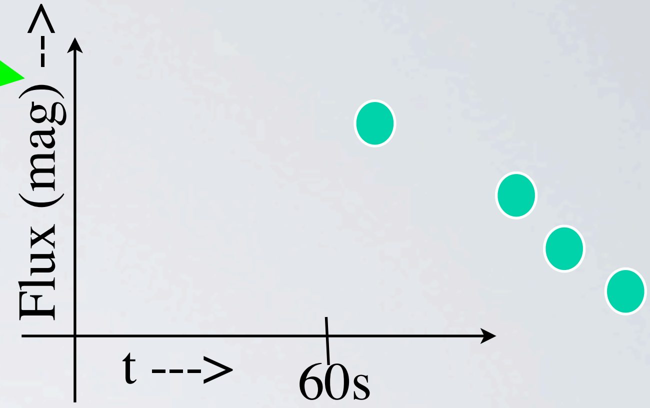
- GRBs 060502 - 081007
  - UVOT responded uniformly: 100 s exposure, W (open) filter
  - W exposures begin t~ 70-150 s
- Require $<t_{mid}>$ < 170 s
- Defines "Early Emission & Response" Sub-sample:

  no image triggers, ground analysis, etc.

NGRB	224	NGRB_rly	209
RGRB(yr^{-1})	92	RGRB_rly (yr^{-1})	86
Robs_uvot_rly (yr^{-1})	38	Rdet_uvot_rly (yr^{-1})	18

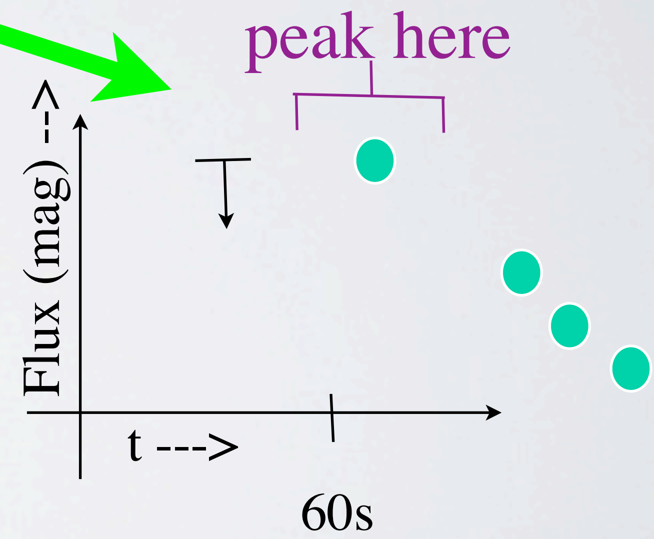
Optical Detection

- Most current data have no peak



- With sensitivity ≥ UVOT early, can determine a peak

- Early detection declared if 10 s sensitivity sufficient to detect UVOT early measurement.



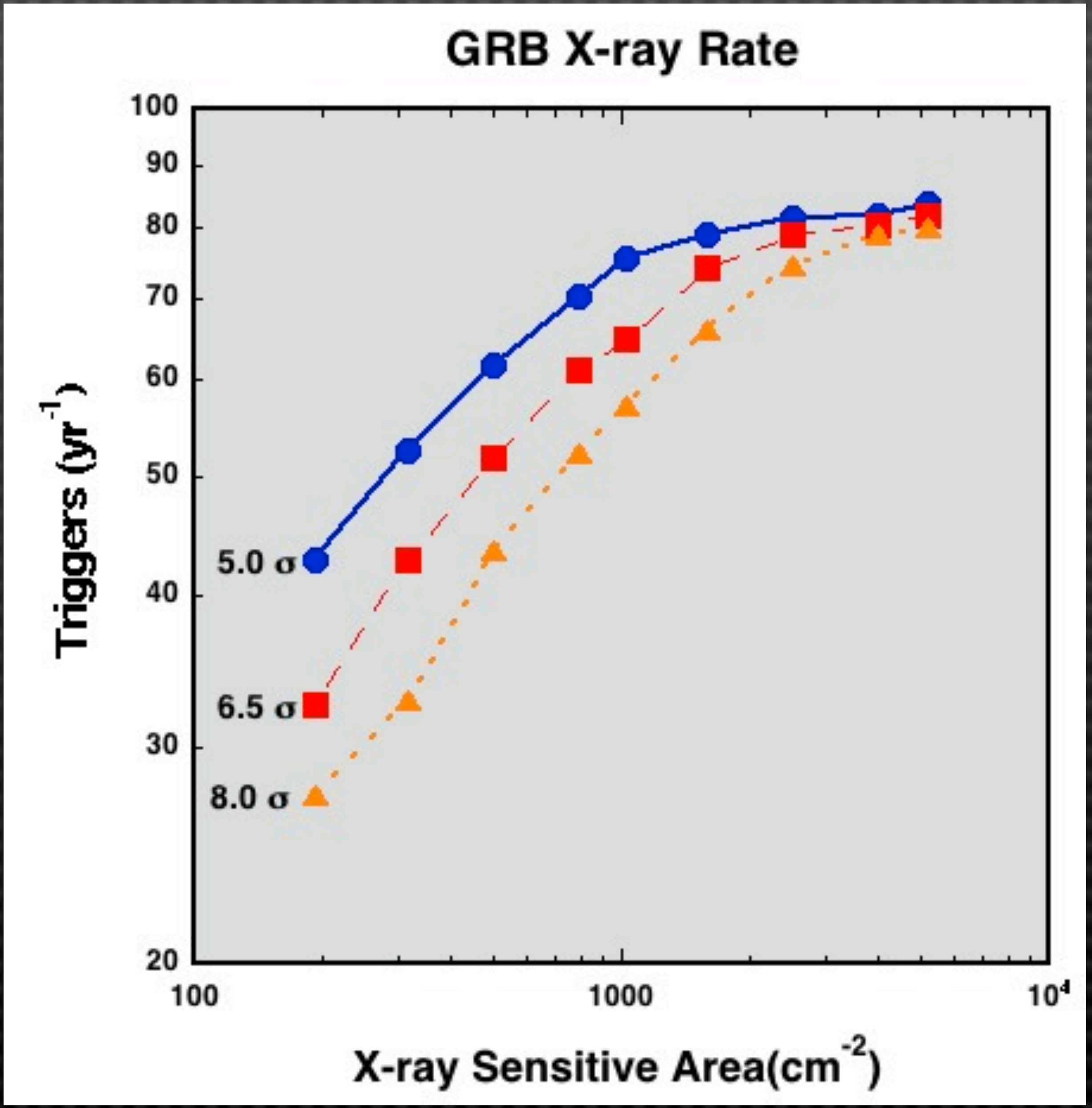
- Note: Optical rates based on 10 s exposure time (but higher time resolution possible).

VI. Rate Prediction Results

X-ray Rates vs. Collecting Area

- Little sensitivity for A > 1000 cm^2
  - X-ray camera 5X smaller than Swift still has good rate!

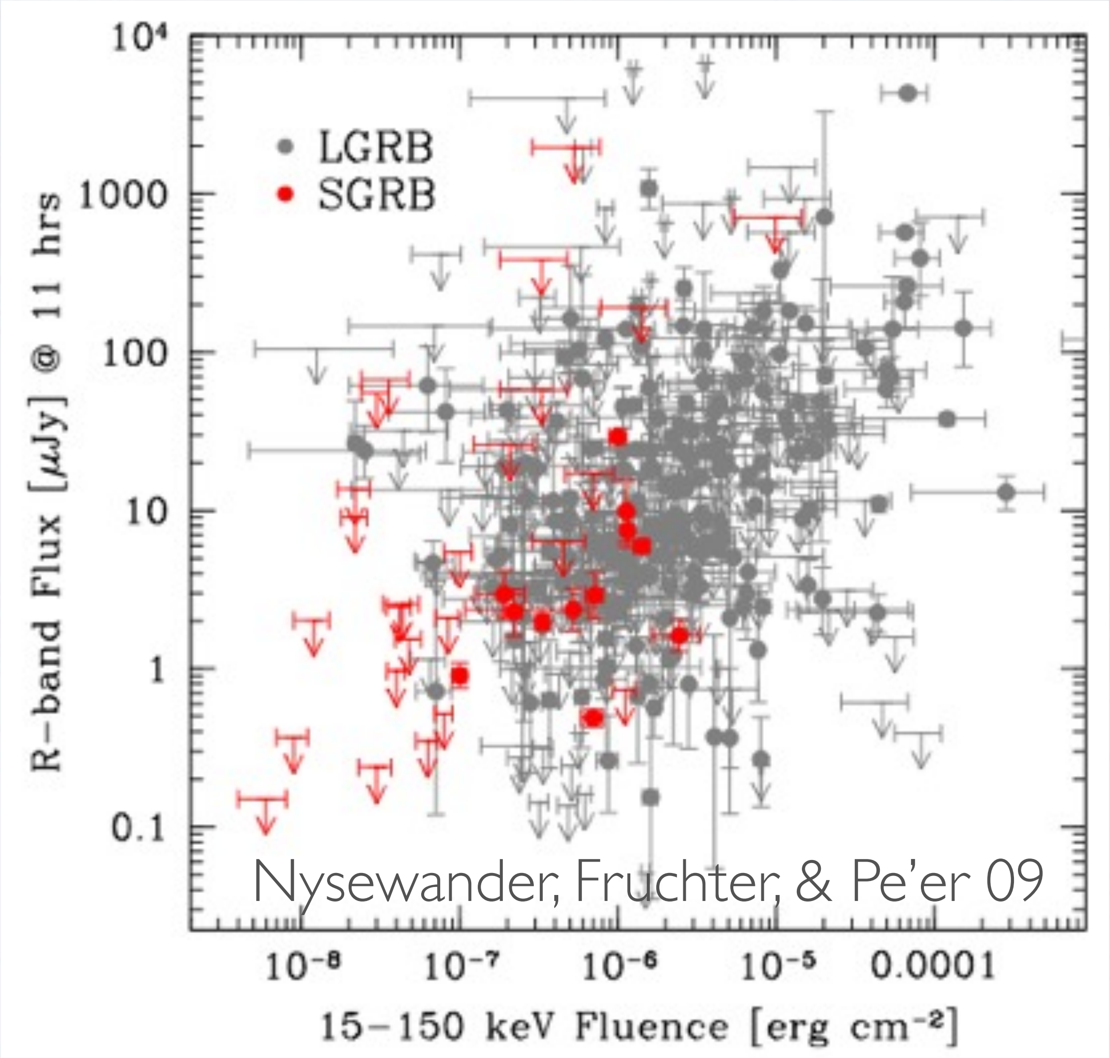
- Conservative Values - real-time simple rate triggers only



EARLY OPTICAL BRIGHTER FOR BRIGHT GRBS?

- There is a correlation of X_fluence & Optical *afterglow* brightness

--**w/significant spread**



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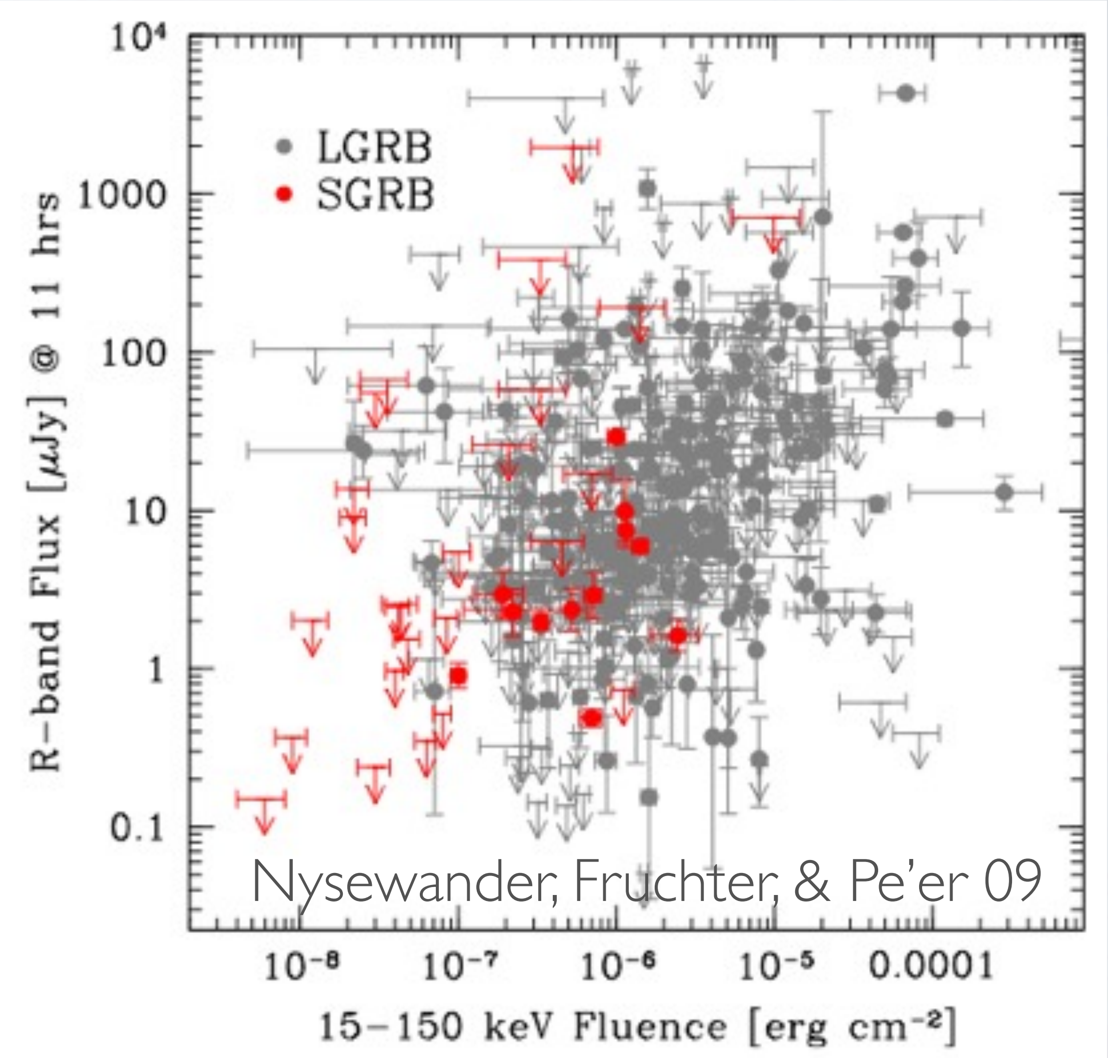
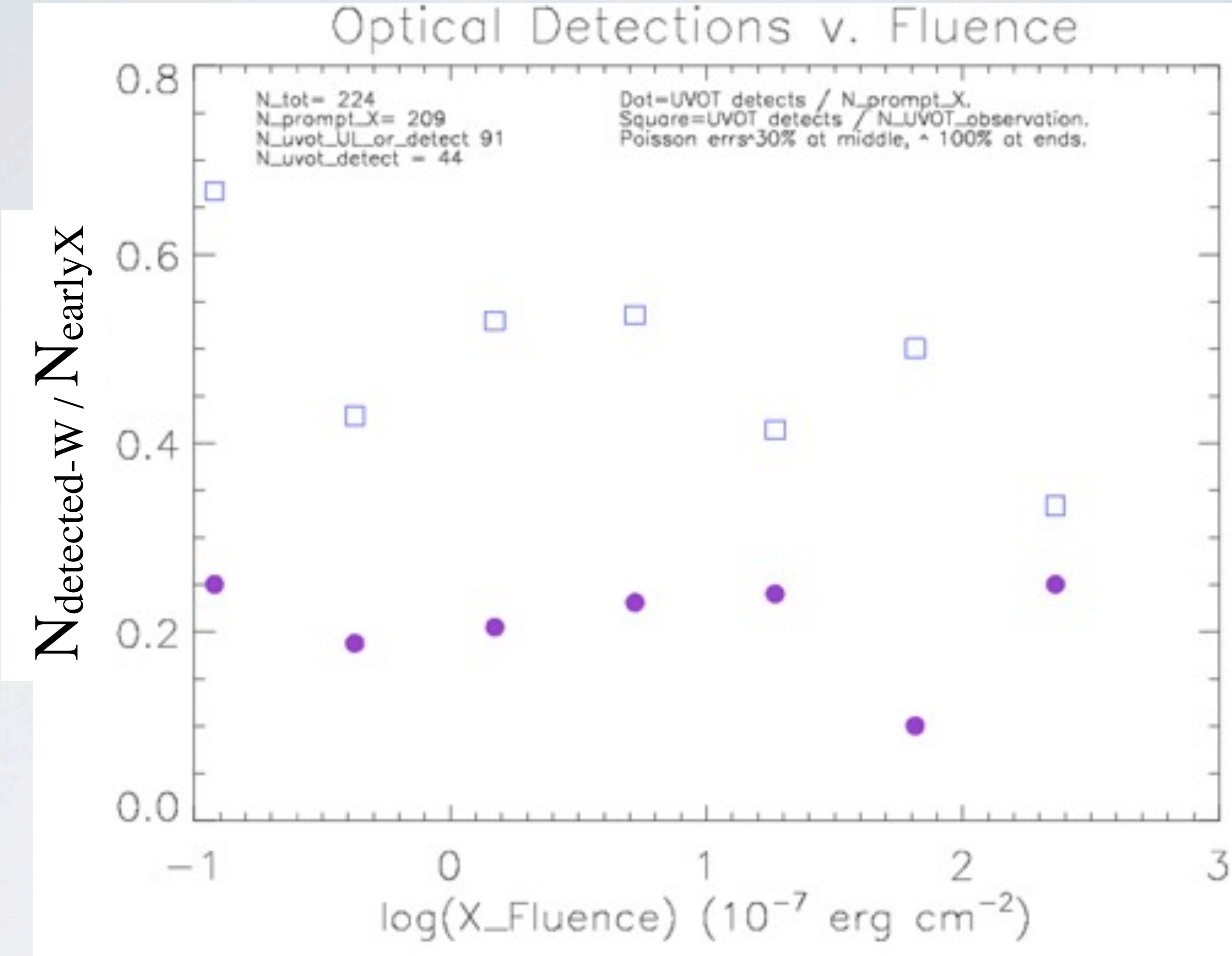
- **..... True for Swift Early?**



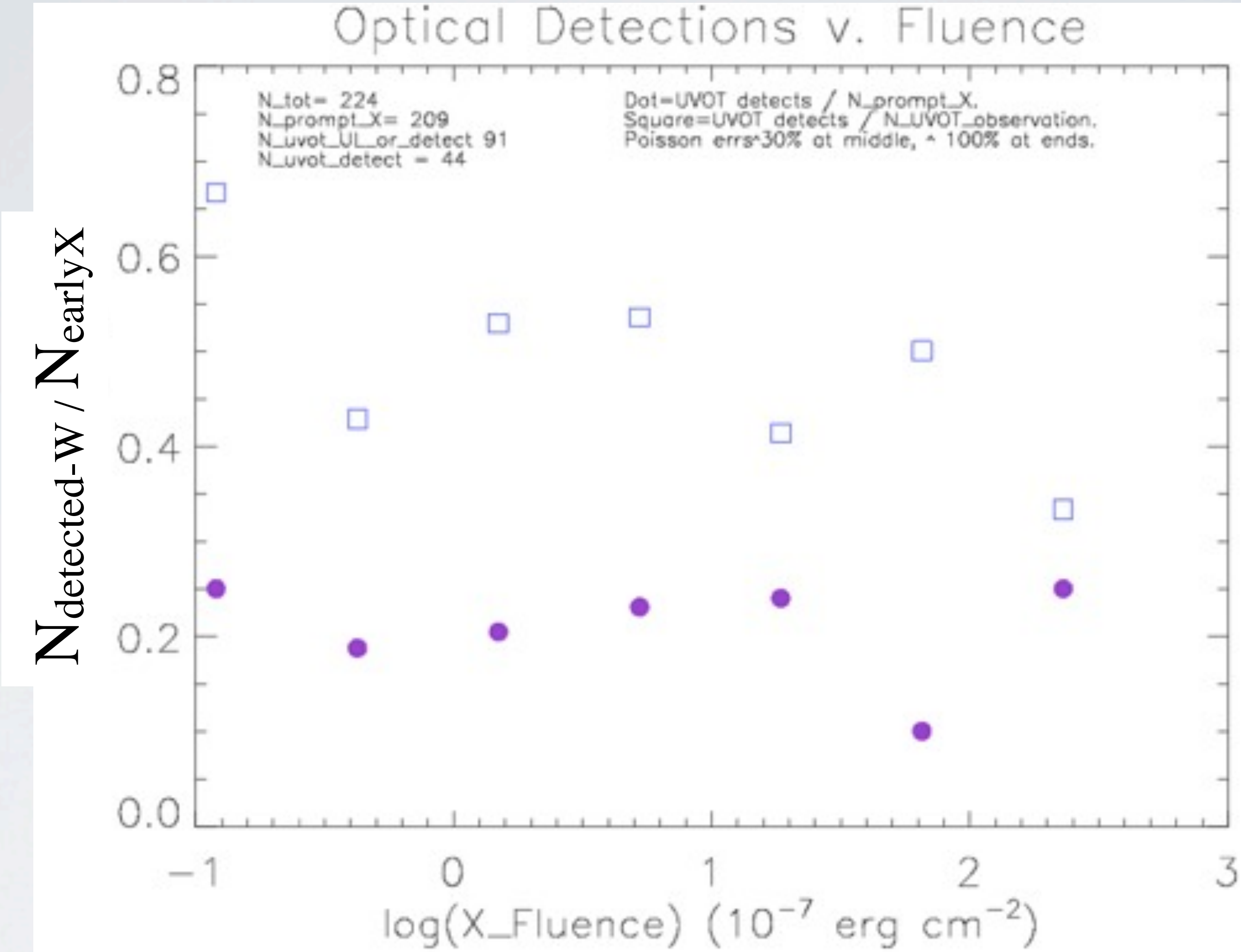
Nysewander, Fruchter, & Pe'er 09

Swift Early Opt *Detection*-Xray Correlation



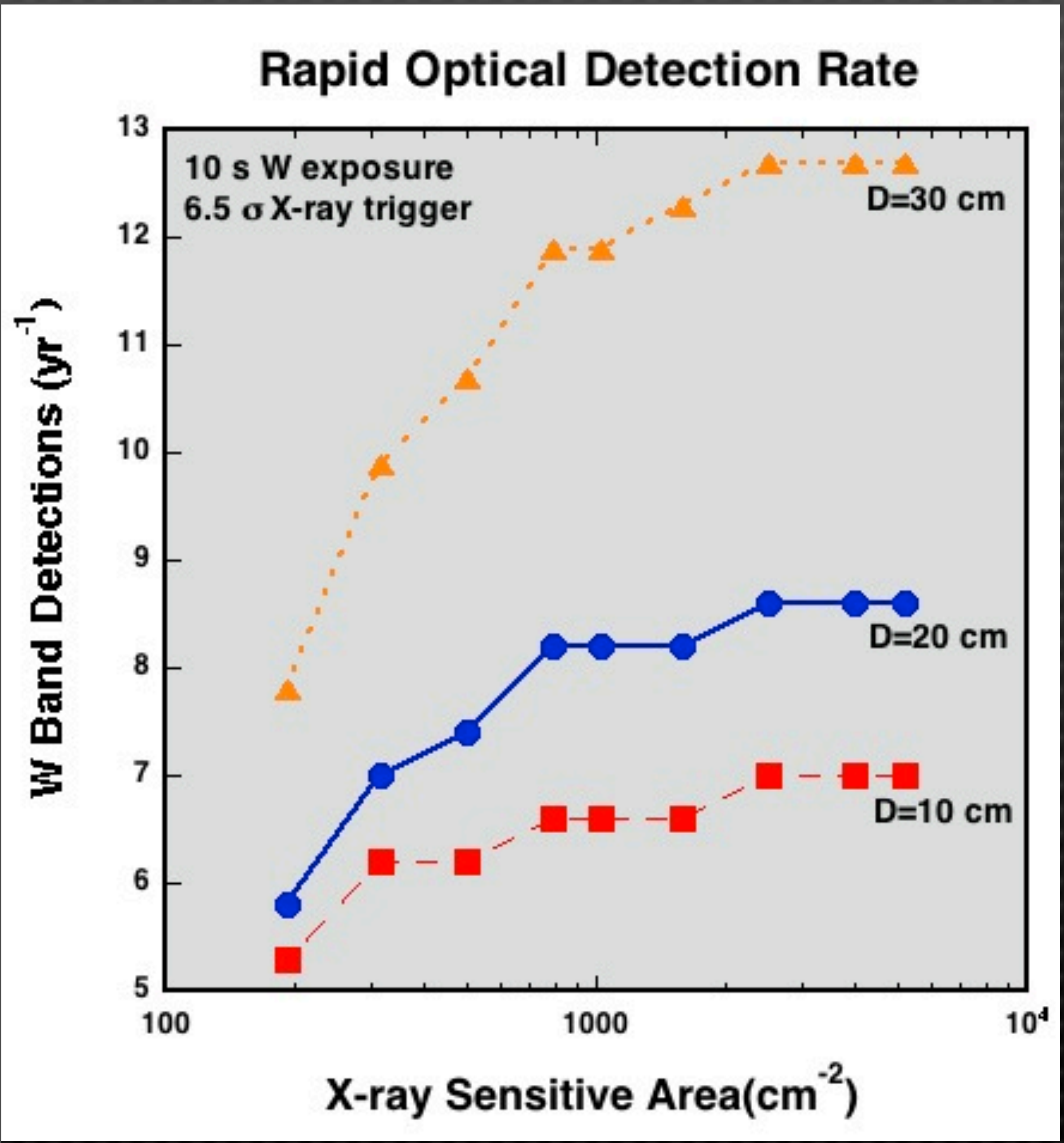
- Detection rate *weakly* dependent on on fluence.
  - Error bars show marginal effect (1 sig = 30% center bin; 100% ends).
    - spread in correlation dominates correlation

Swift Early Opt *Detection*-Xray Correlation



- Seems like there is great variation in early optical
- --- Why?

Early Optical Rates vs. Area



- Sensitive to Diameter ! (Much less then X rates)
- Threshold ~ 800 cm^2 (1/6 the area of Swift!!!)
- Based on *average* fluxes - **conservative!**
- **Includes operational constraints!**

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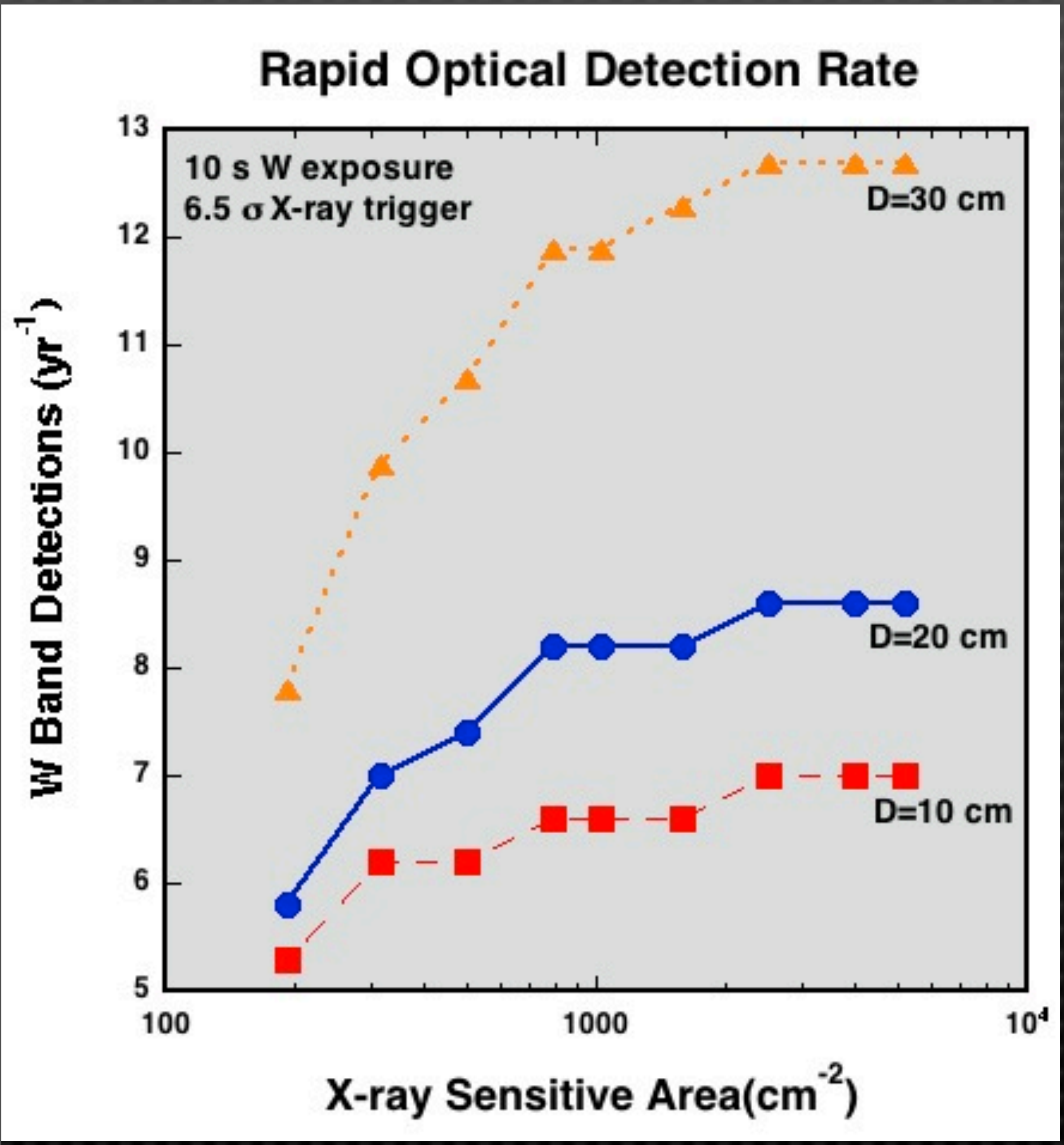

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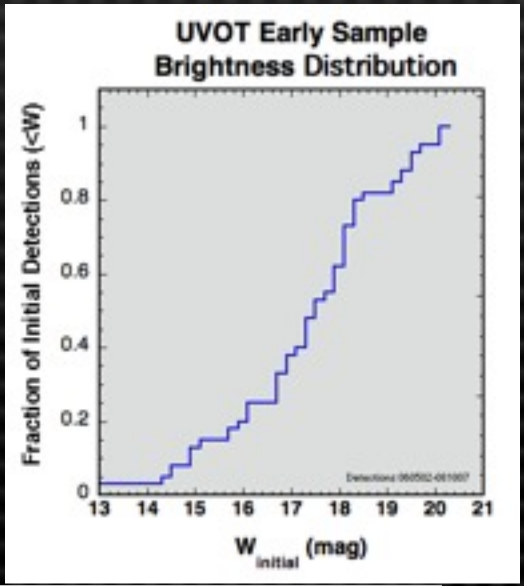

BUT
WE CAN DO BETTER!

Better Optical Detectors

- We went from 18/yr to 13/yr because we went down to 10 s exposures ... any way to recover?

- YES! Swift has TERRIBLE Q.E.

- Use an EMCCD for 4X as many photons!
  - 1.1 mag more sensitive
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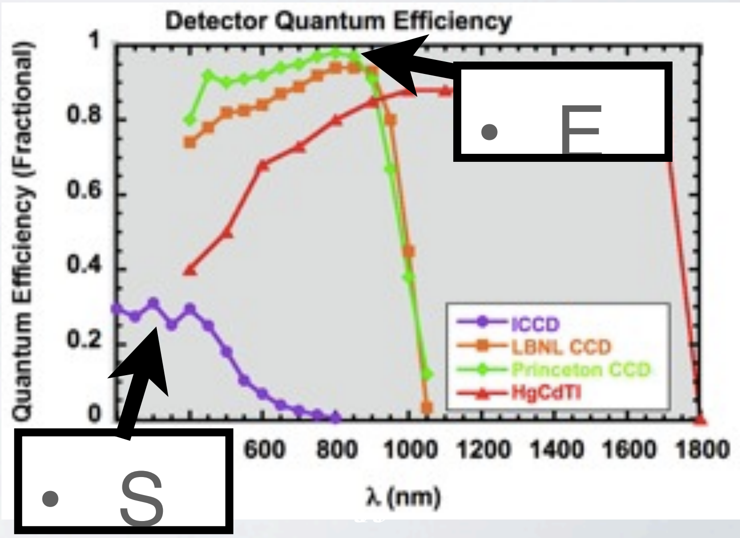

Friday, October 11, 13

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NIR & Extinguished GRB

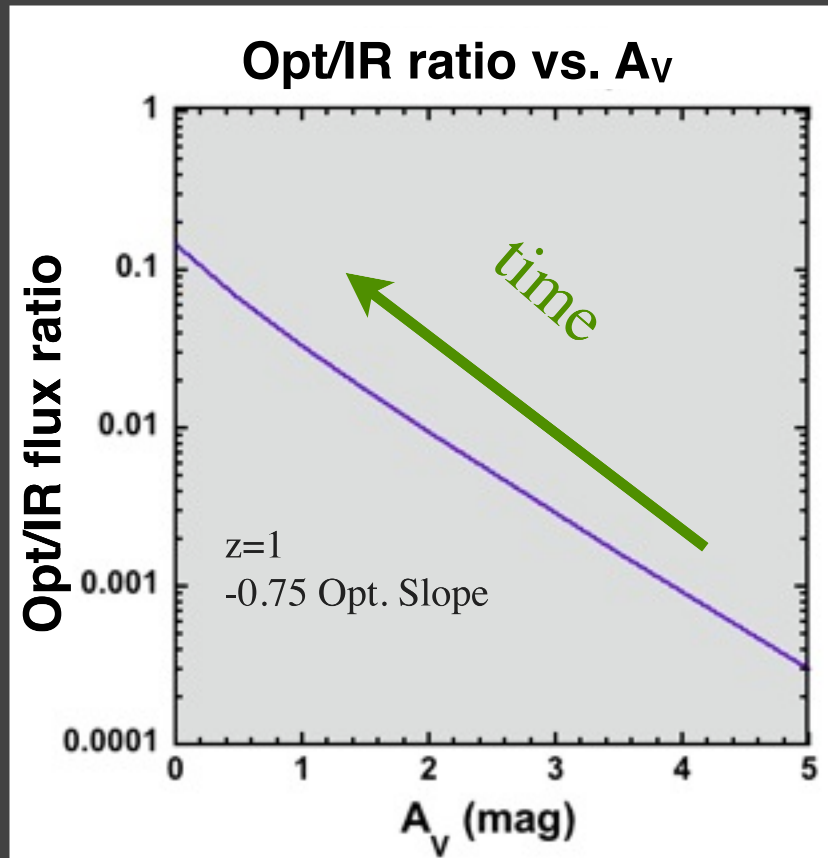
- NIR broad-band camera is 2.8 mag **more sensitive** than UVOT in W for –0.75 spectrum [(1)]
  - 0.9 - 1.8 μm band; zodical background; H2RG sensor[(2)]
  - ALL UVOT sources detected ***with an additional 5 mag A_V.***
- Perley+09: Many GRB extinguished!
  - 29 Swift GRBs, 15 detected by UVOT,
  - **8 MORE detected in NIR**
  - **=> 8/15 boost in rate with NIR!**
- **> 25 NIR Detections/yr.**
  - **1024 cm^2 X-ray detector, 6.5 σ**

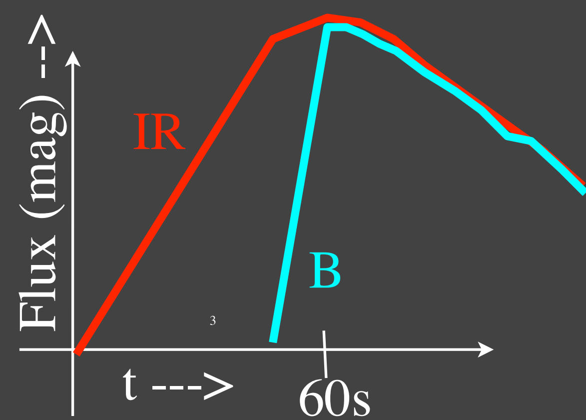
1. Rykoff, et al., 2009
2. Q.E. from Beletic 08

Rapid Color Information

Dynamic Dust *via* Dynamic Color Measurement

- **Sub-60 s: allows dynamic dust vaporization measurement**





Models: Salvaterra+09, Perna+03; >60 s too late: Oates+09, Perley+10

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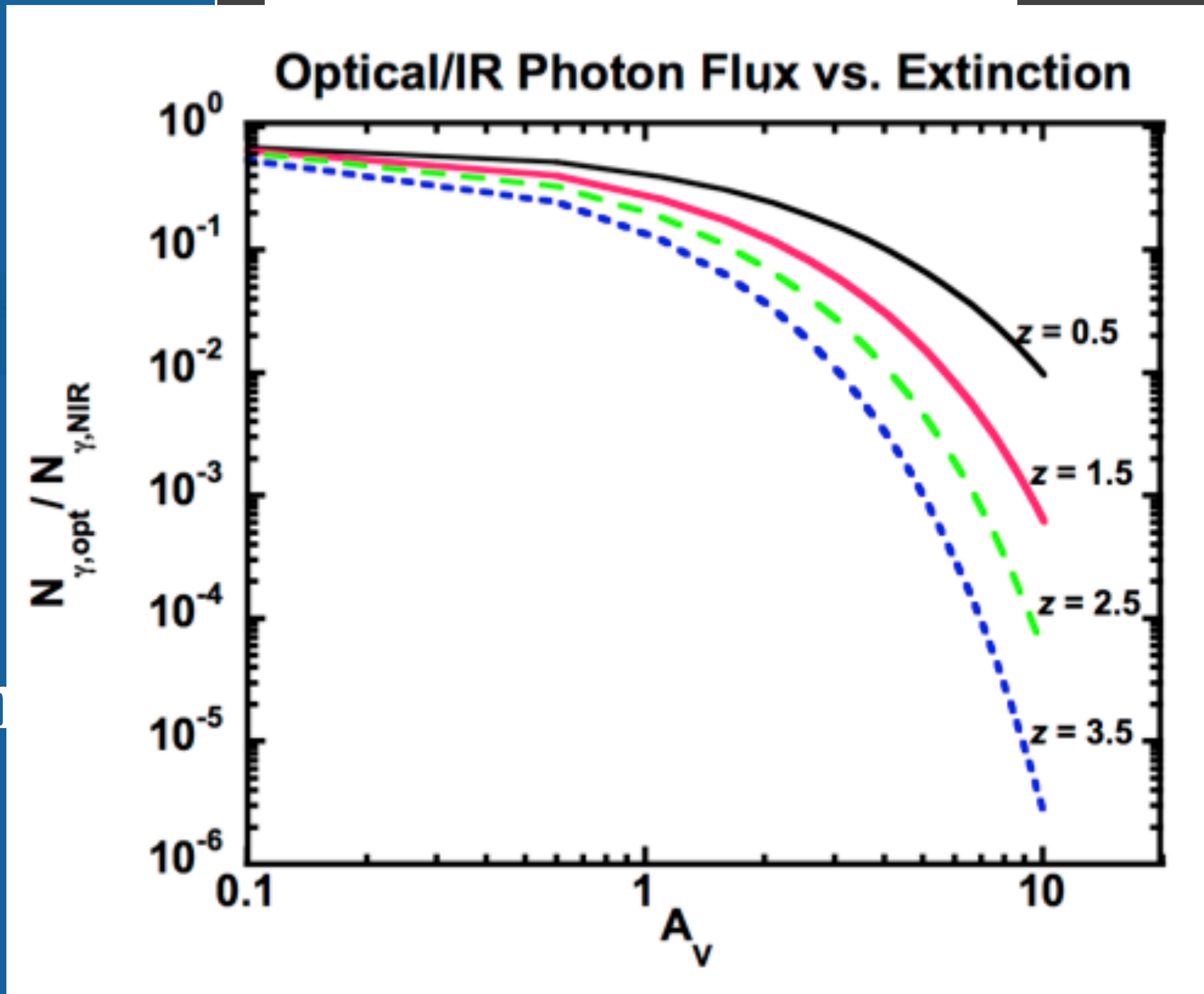

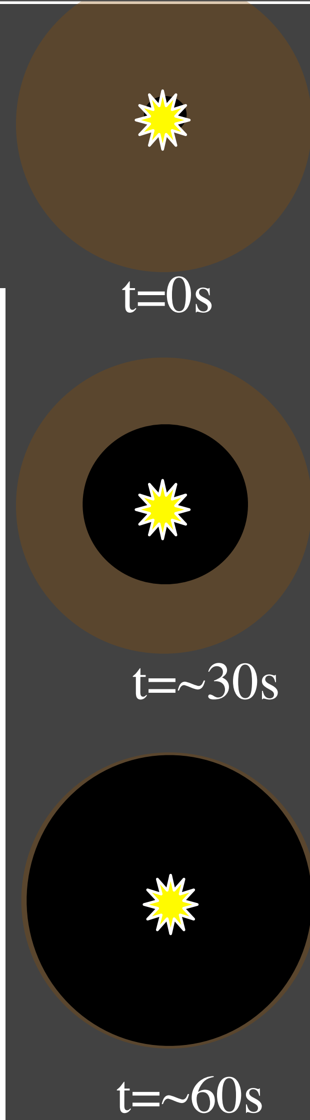

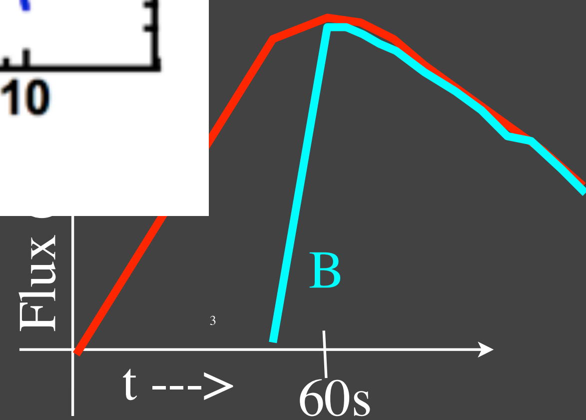

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BUT
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Improving on BAT

- BAT uses CZT
  - Low-Energy Threshold **15 keV**
- SVOM team using CdT cooled to -20 C
  - Low-Energy Threshold **4 keV** !!! (1)
  - **Factor of 5.8 in photons!!!**
- (Don't know instrumental background at LE, but DXRB is less steep, so significant improvement must result.)
  - But not included in rate predictions here due to background uncertainty.

(1) 2012, Philippe Laurent, CEA, private comm.

Other Instruments

- If you are not exactly Swift-like, you must adjust for background, duty cycle, etc. etc.
- ISS - high background regions passage=> duty cycle for typical X-ray camera is ~ 50% (private comm., Motoko Serino, 2012).
- UFFO-pathfinder - 89° orbit
  - Swift decay time for activation after high background region ~ 1000 s (Greiner+09). After four belt passages, only 1000 s remains. I find duty cycle ~ 20% of Swift
    - 191 cm^2 X-ray camera, FOV .84 * BAT => 4.3 GRB yr^{-1}, SNRtrig =6.5
    - 10 cm optical aperture => ~ 1 optical detection yr^{-1}

Future

- Lots of instrument work - e.g. simulations of feedback control, optimum frame rate...
  - should include more detailed information on S/C motion
- Estimate LE background to see improvement for LE response
- Find uniform samples for shorter UVOT exposures
  - should be able to re-reduce UVOT to 10 s, 1 s time resolution (but I have not checked on that yet.)

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    =>NEW RAPID-RESPONSE SCIENCE (w/ "old" Swift population)
  - **NIR - information on extinction, dynamic dust evaporation**

Thank You!

If you are going to VKO for ~ 9: 30 AM flight, please contact me.

-Bruce