Gamma-Ray Bursts & Rapid Follow-up Instruments

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Outline

1. Gamma-Ray Bursts (GRBs)

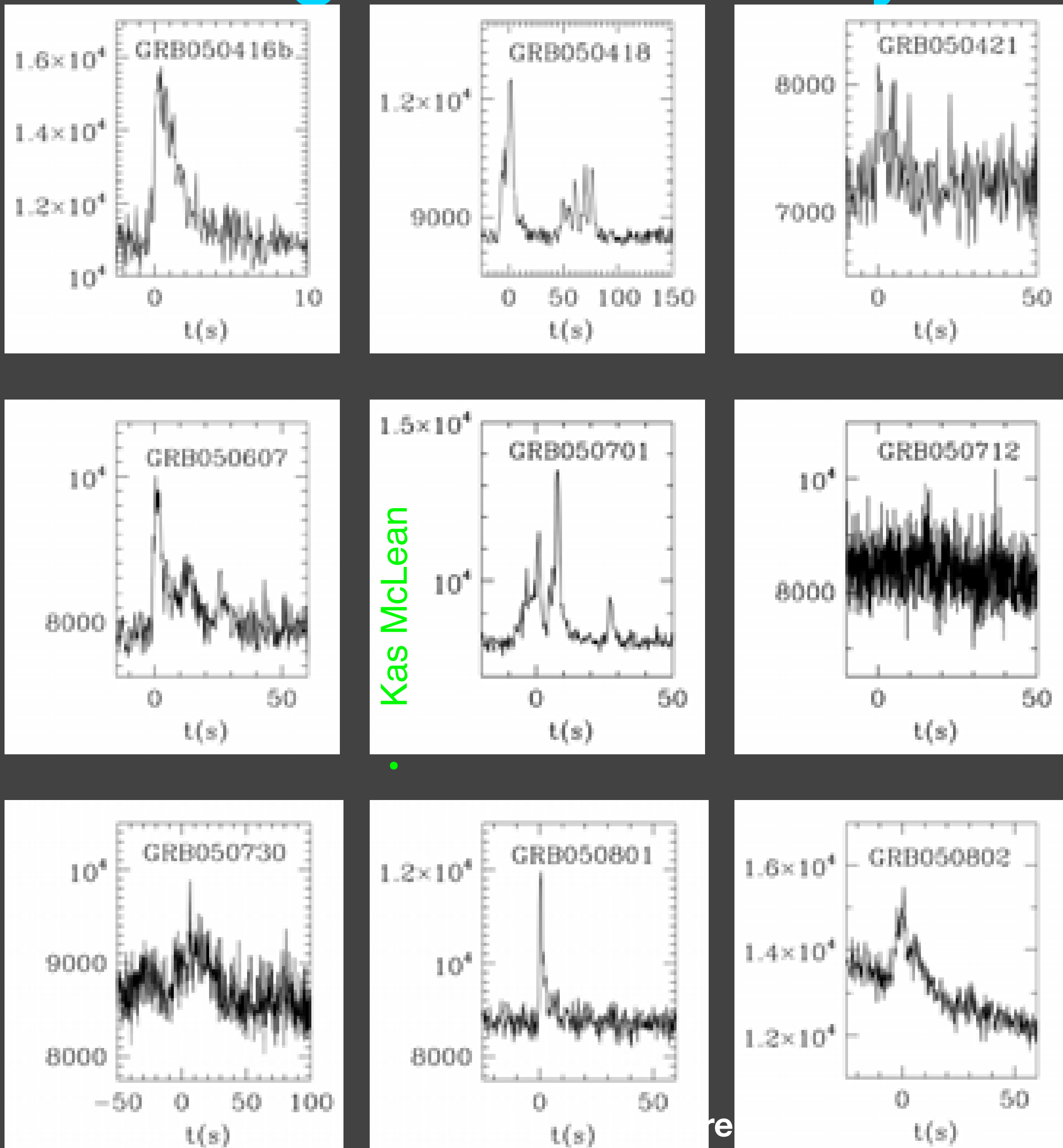
2. GRB in the universe (time-history of the universe).

3. GRBs-Interesting Physics

4. Limits of Current Measurements: Response Speed

5.Get There Faster - The UFFO example of real research.

Long Gamma-Ray Bursts(GRBs)



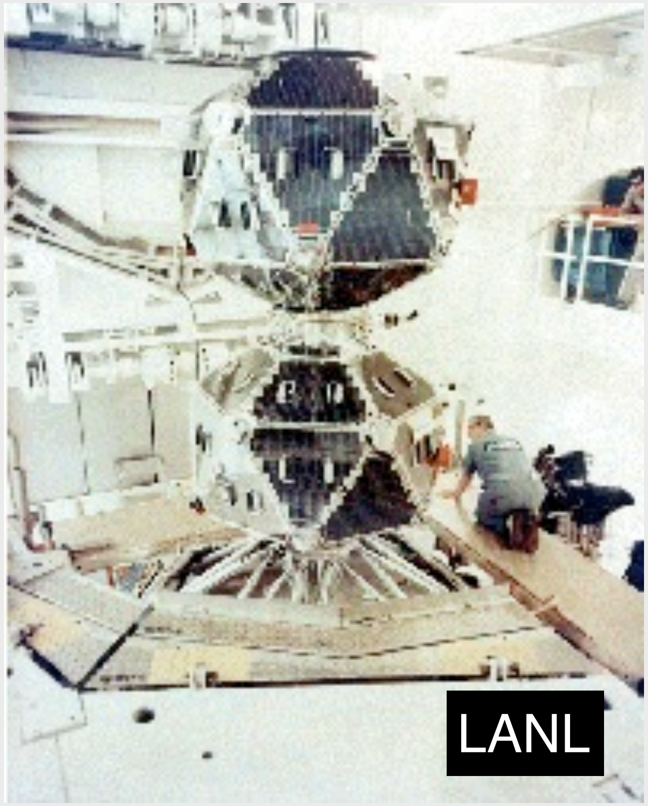
- 15-200 keV Swift BAT light curves (LCs)
- LCs by Kas McLean

re

all sources-

Discovery of GRBs

- Discovered in late 60’s by cold war nuclear weapon monitoring sat Vela
- From up or down?
  - required much timing analysis to rule out sun and earth.
- In 1973, this discovery was announced in Ap.J. letters by Klebesadel, Strong, and Olsen. Their paper discusses 16 cosmic gamma-ray bursts observed by Vela 5a,b and Vela 6a,b between July 1969, and July 1972.



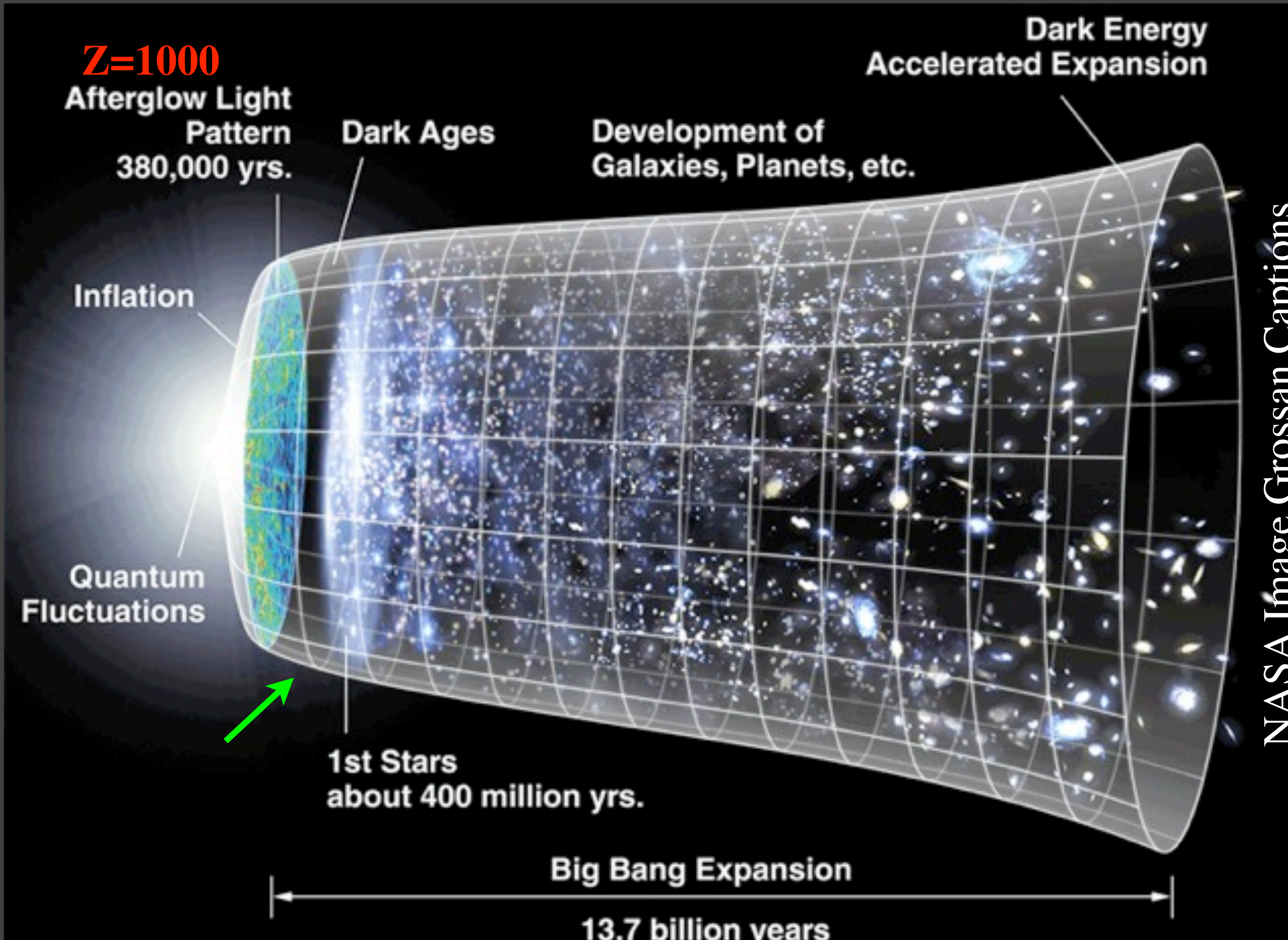
Gamma-Ray Bursts In 1 Slide

- Most energetic events in the universe
  - measured to z = 8.2 (GRB090423)
    - Can be seen to z~12 with large detectors
- Gamma-Ray Bursts (GRB) last msec – hr.
- Measured up to GeV
- Afterglow can be detected weeks after burst, has power law decay light curve in all bands
- Long Type GRB associated with massive star collapse SNe

Observing the Universe

- The universe is expanding: the farther away something is, the faster it moves away from us.
- Light from things moving away from us is observed with a shift in wavelength, $\lambda_{observed}=(1+z)\ \lambda_{emitted}$
- Astronomers use *z* as all of:
  - **wavelength shift**
  - **distance (because of universe expansion)**
  - **cosmic time (because light takes a longer time to reach us from greater distances)**

Brief History of the Universe



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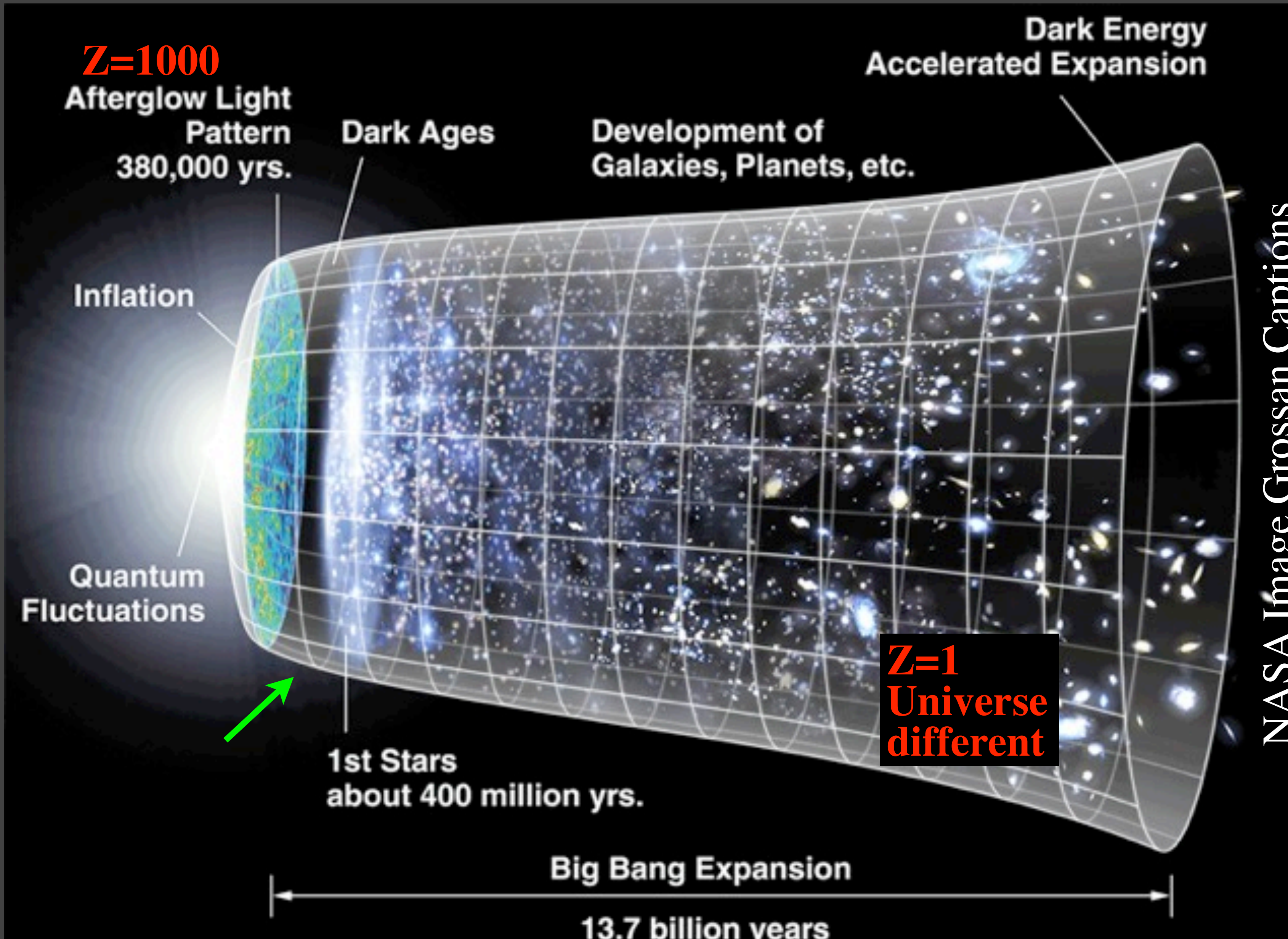

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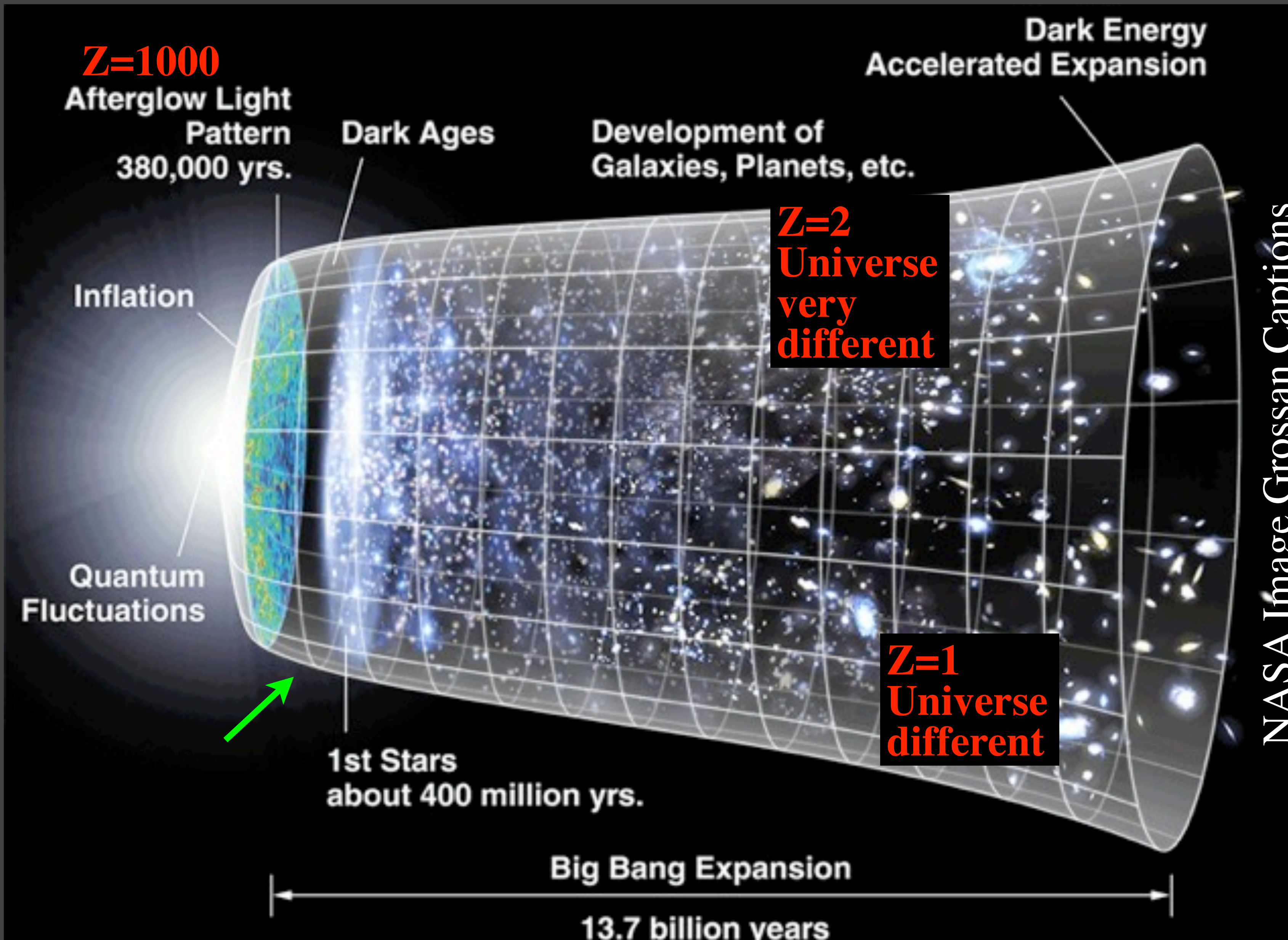

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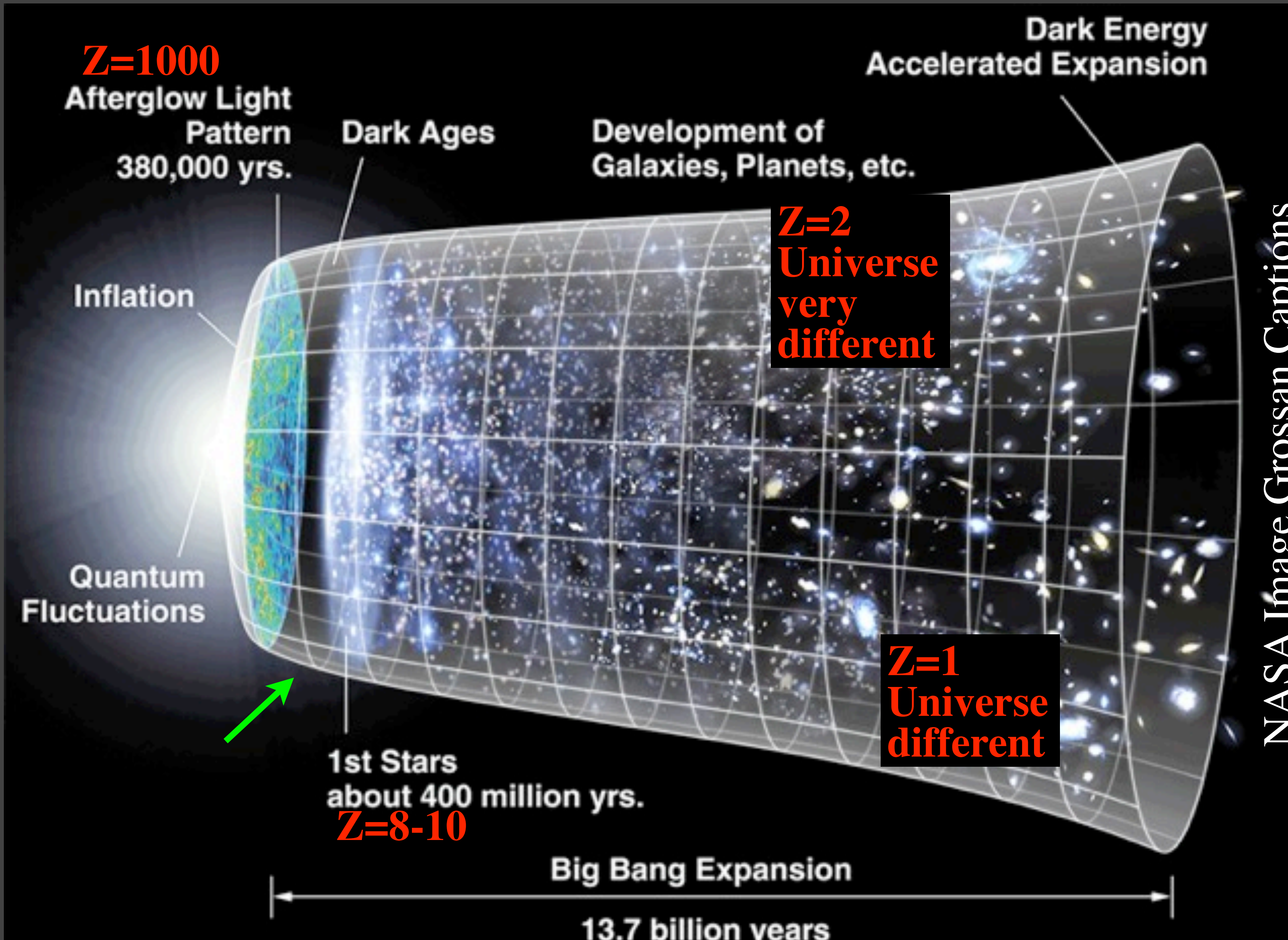

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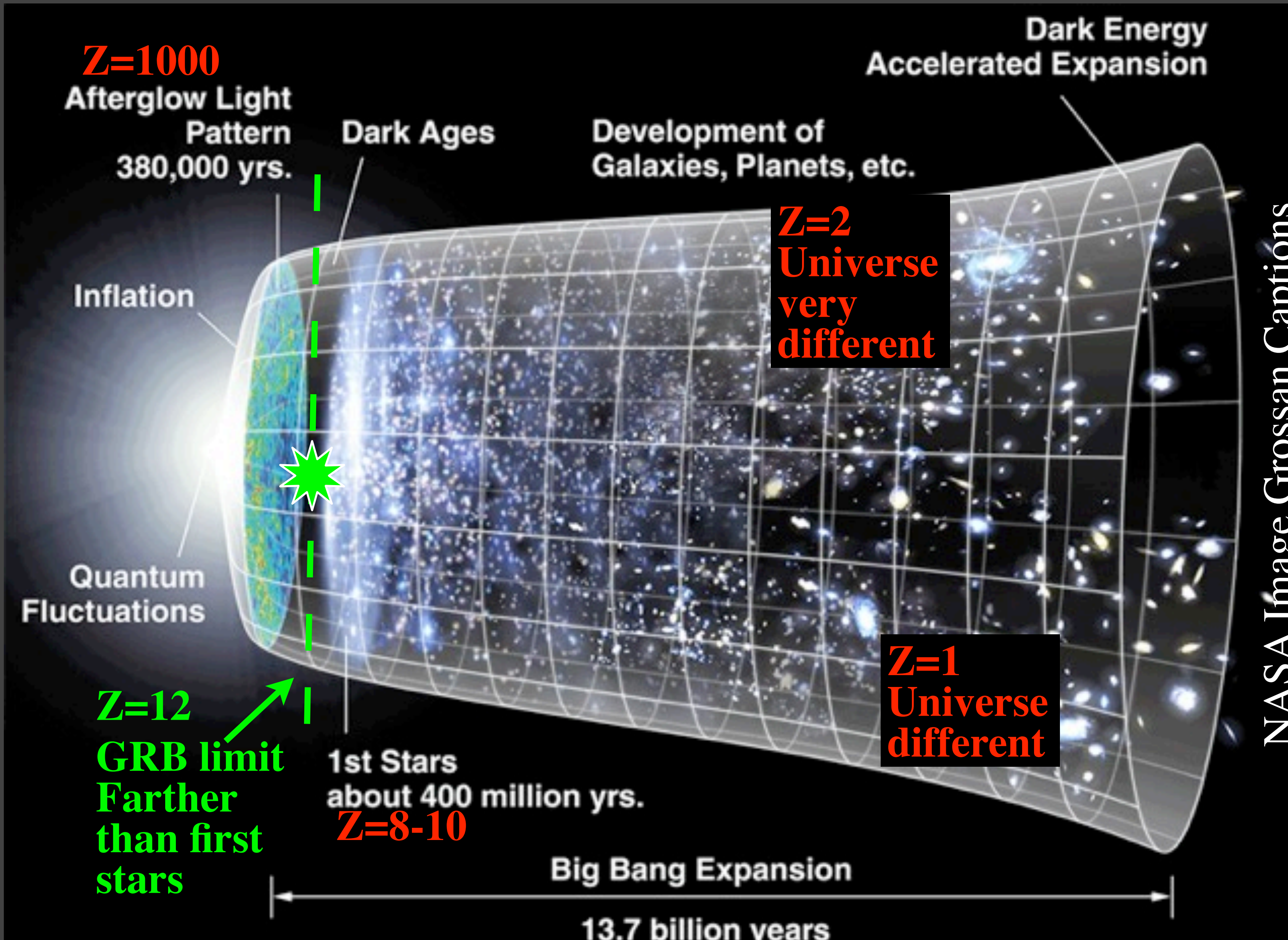
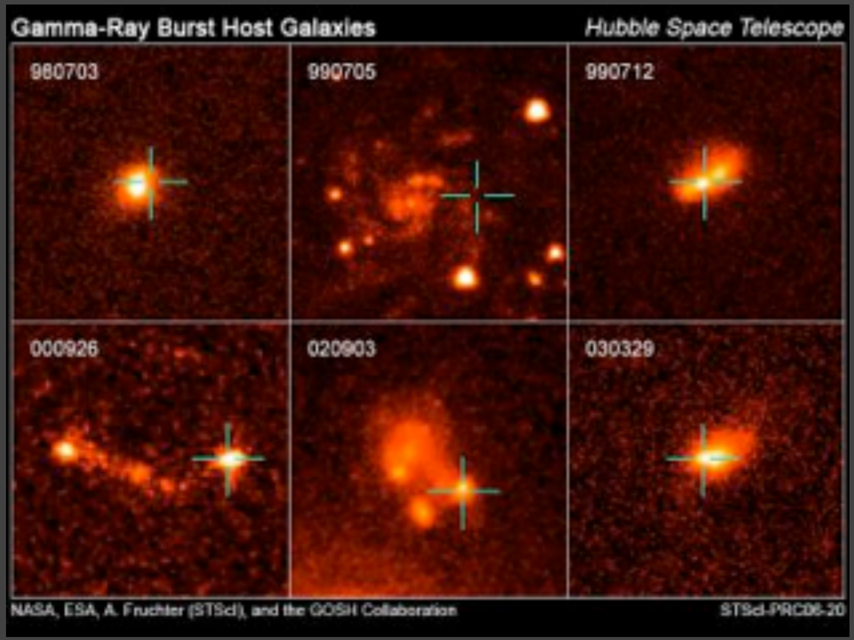


Long GRB

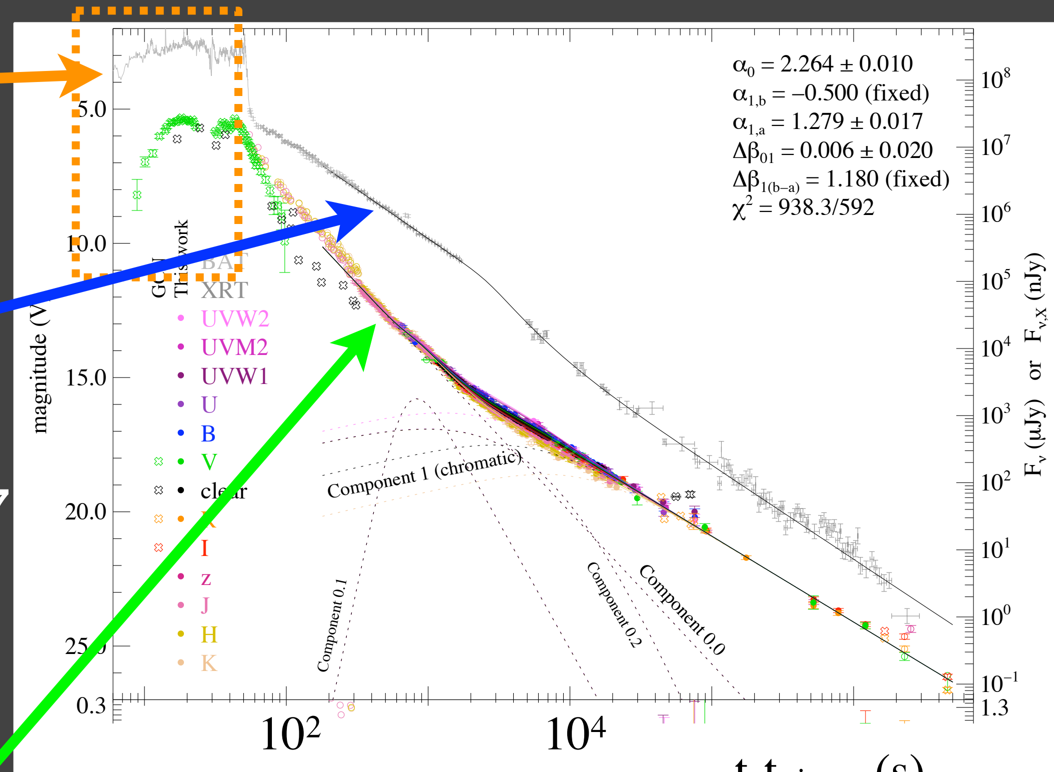
- Most Common GRB
- Associated with Star-forming regions, SNe
- Typical z ~ 2



GRB 080319B

"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 -----------



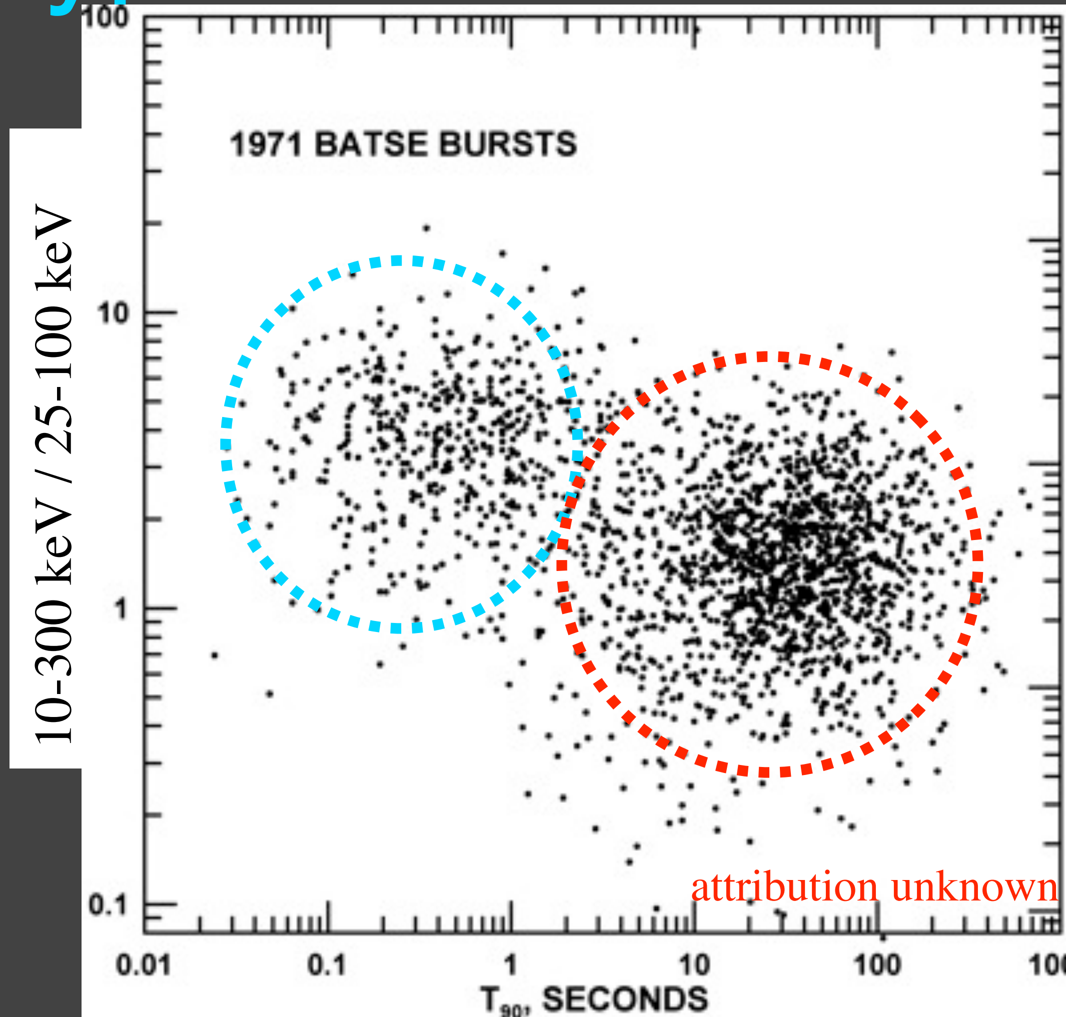
Racusin et al.

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

- B. Grossan. Use requires attribution of all sources-

2 Main Types of GRB

- GRB=Gamma-Ray Burst
- LGRB=Long, softer
  $t_{90\gamma}$ >2 s, Typical ~ 20 s
- SGRB = Short GRB
  $t_{90\gamma}$ < 2 s, Typical ~ 0.4 s
    - "harder" X-γ spectra,
    - much fainter all optical
    - faint X-γ afterglow
- (OTHER classifications exist)



"we show that the fundamental defining characteristic of the short-burst class is that the initial spike exhibits negligible spectral evolution at energies above ~25 keV. "- Norris & Bonnell 2005

$t_{90\gamma}$ = GRB duration = interval of 90% fluence in γ light curve.

Hard = flatter spectrum = crude ratio of high, low energy channels.

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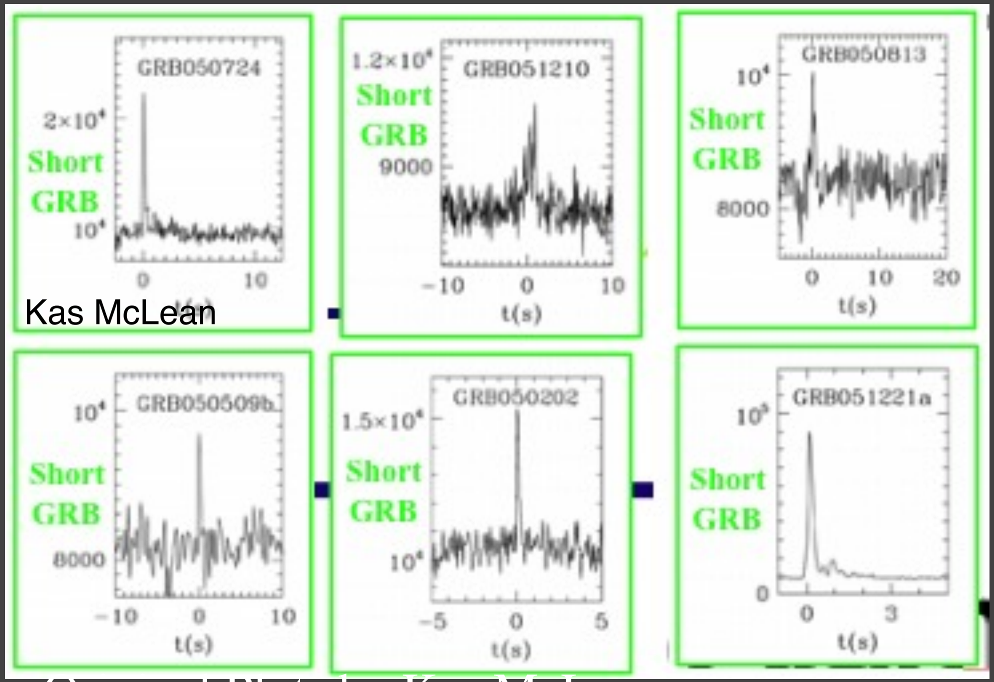
Short GRB

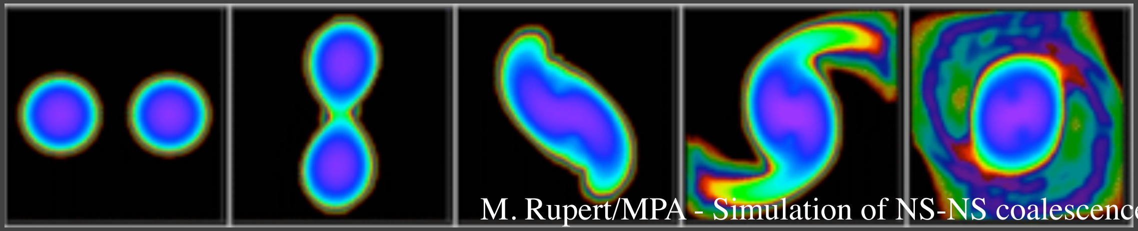
- SGRB = Short GRB
  $t_{90\gamma} <$ 2 s, Typical ~ 0.4 s
  - "harder" X-γ spectra,
  - much fainter all optical
  - faint X-γ afterglow



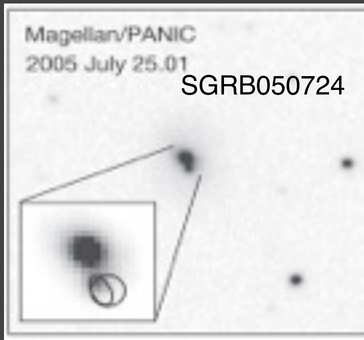
Original Plots by Kas McLean

SHGRB Origin Unknown

- SHGRB now associated with coalescence models


M. Rupert/MPA - Simulation of NS-NS coalescence

  - *consistency*
    - *SHGRB faint compared to LGRB, lower energy.*
    - *Usually not in star forming regions, far from galaxy, so could be evolved system - like dead neutron start (NS) or black holes (BHs)*

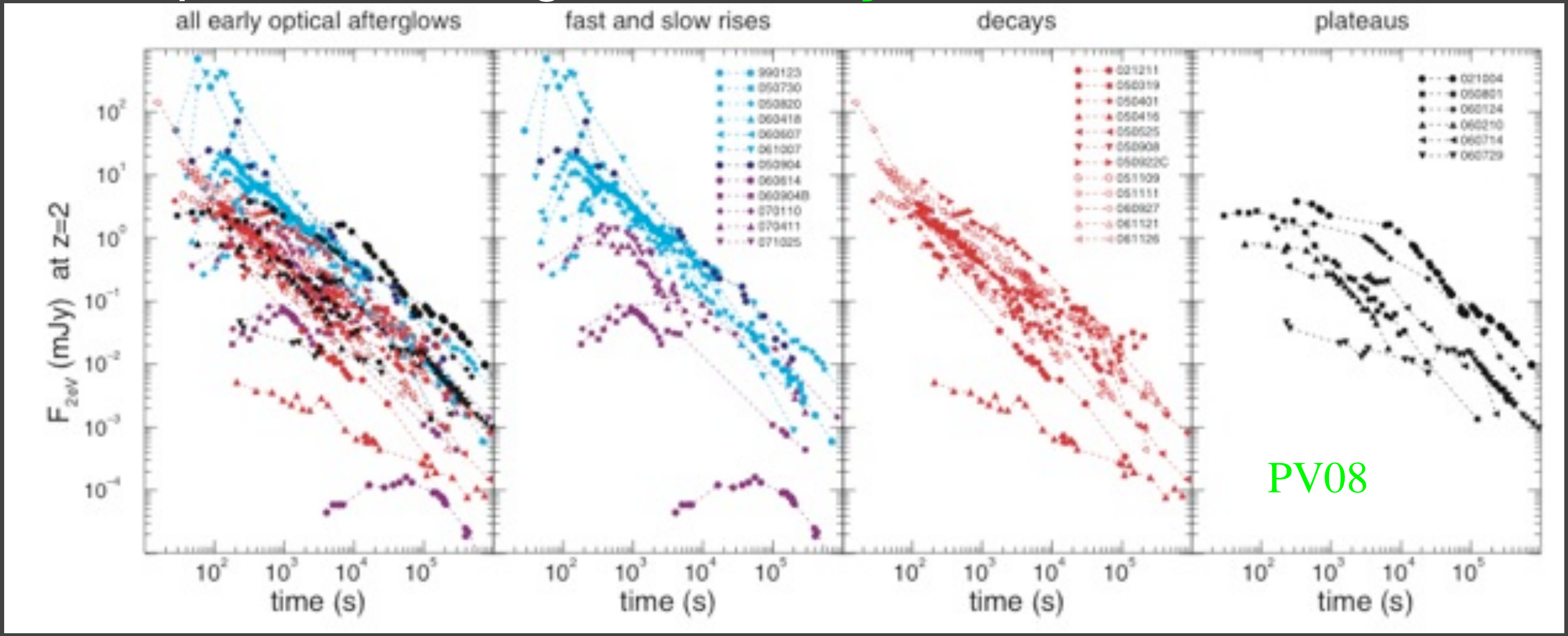


  - *No actual proof; outstanding mystery*
  - Compact object coalescence would mean Gravitational Waves (GW), likely detectable by next-generation GW detectors if close enough.

Early GRB *Optical* Light Curves Are Interesting

Early GRB Light Curves

- SWIFT showed complexity in optical light curves.
- Panaitescu & Vestrand '08 - important to classify / separate GRB light curves **by rise time**.



- Rise-phase behavior likely rich & complex (like variations in late-time light curves).

Analogy to Supernovae

- We couldn't do the physics until we had the taxonomy
  - Progress was held back while core-collapse SNe were "put on the same Hubble diagrams" as SNIa, i.e. confused studies until separated.
- We couldn't do the taxonomy until we had the data
  - stretch and other corrections would not be possible without catching the SN near and before peak
    - PV08 work says you should separate GRB by rise time, but little data

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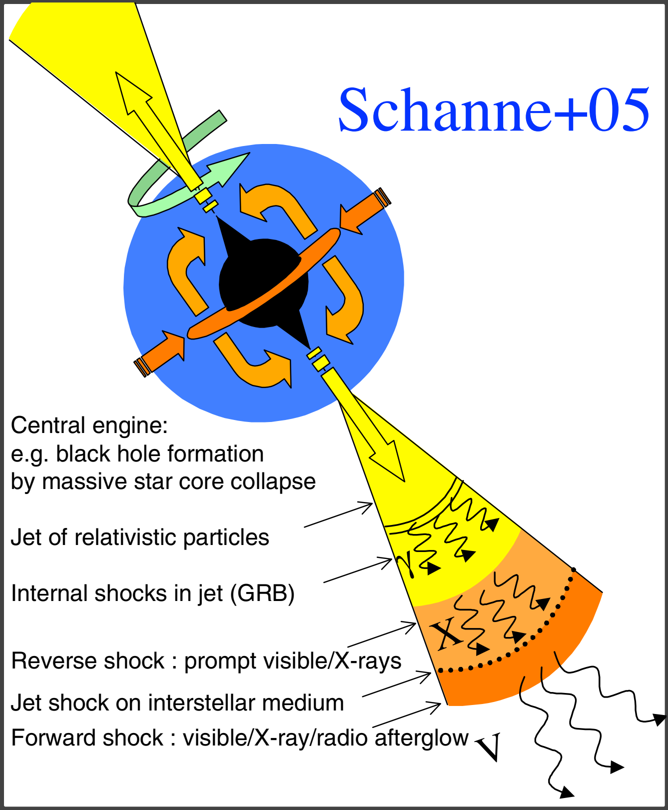
  - **GRB have few measurements in optical before peak.**

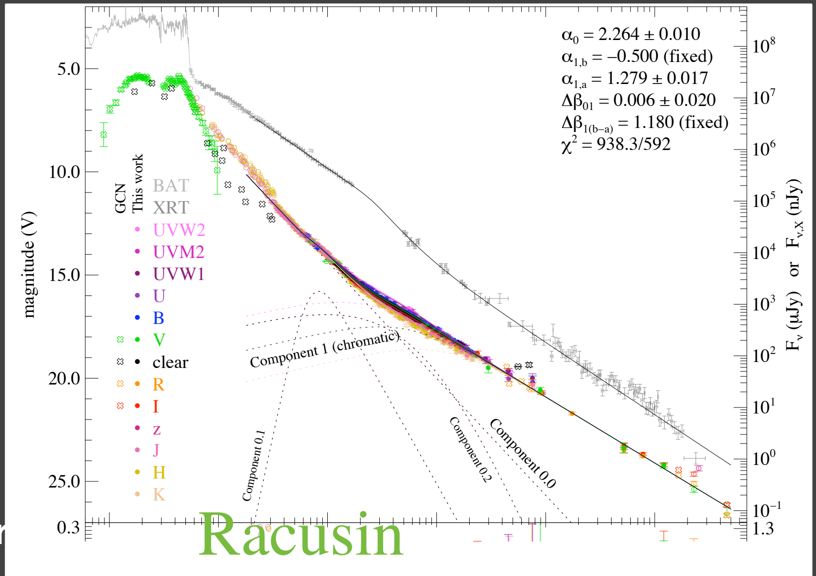
II. Interesting GRB Physics

- Jet Physics
- Cosmic Rays
- Gravitational Waves
- Cosmology
- GR

GRB Jets.

- Prompt X-γ: internal shock
- Afterglow optical: reverse shock; X-ray: Forward shock (interaction with ISM)





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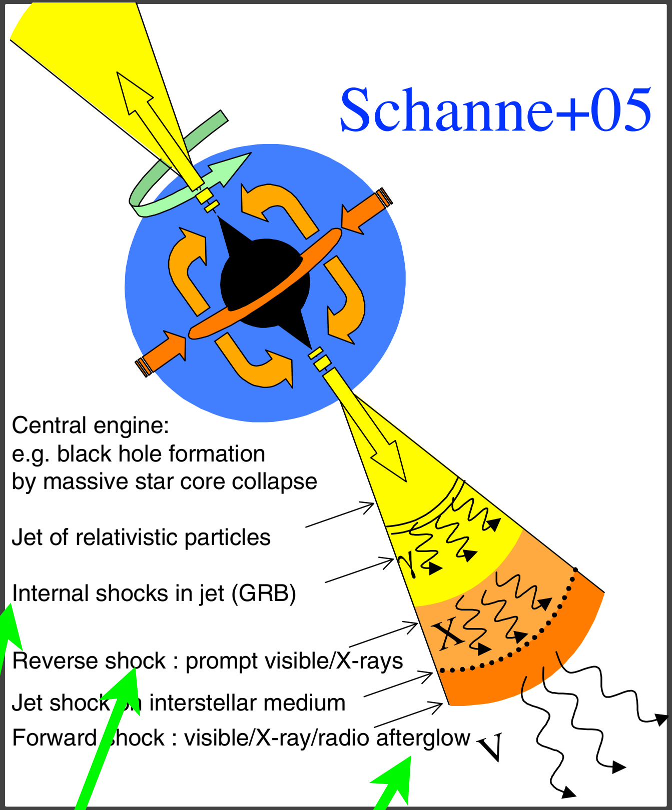

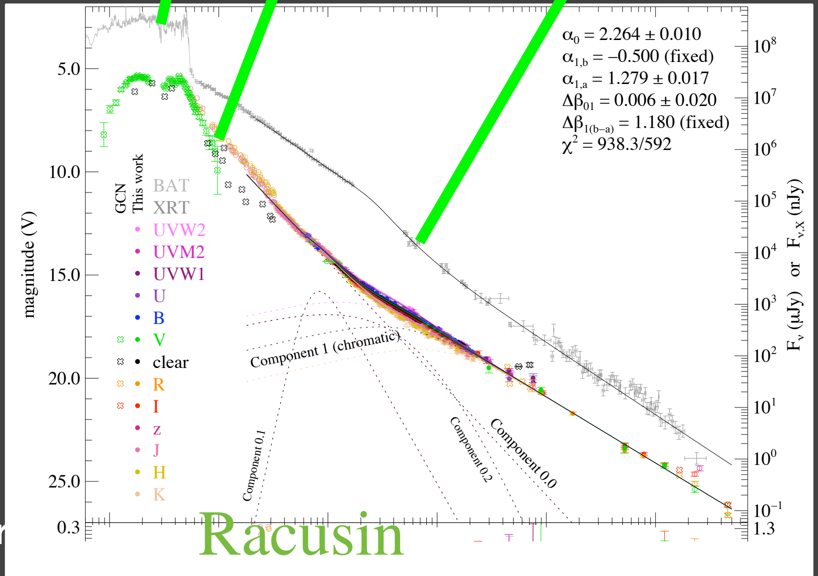

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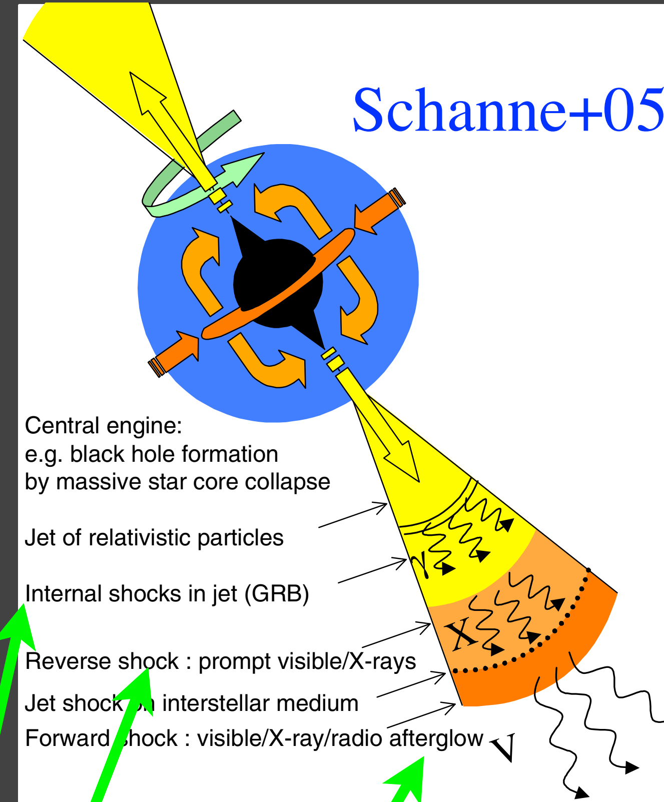
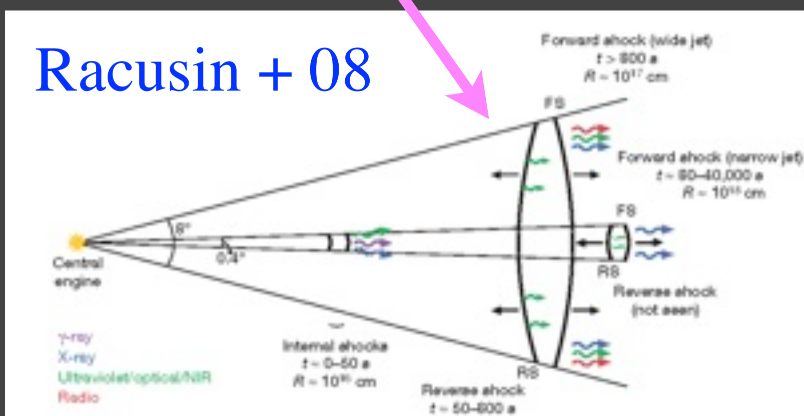
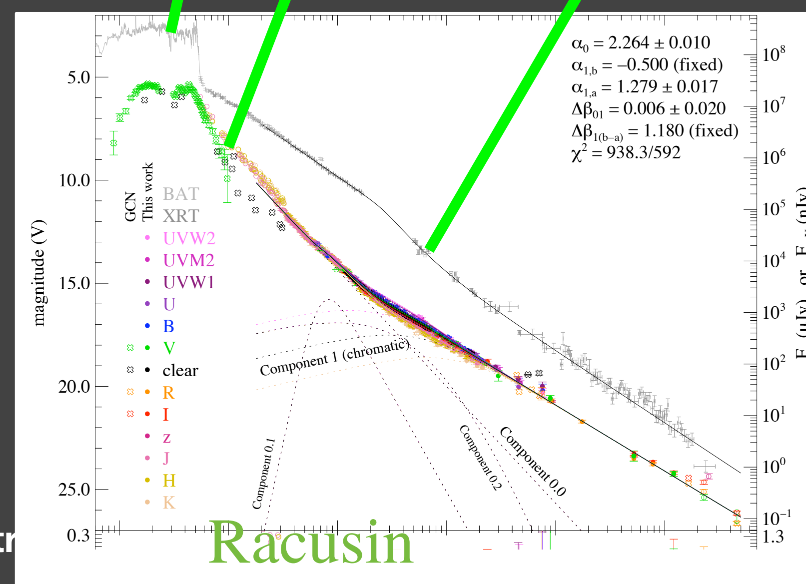
- Some GRB: Multi-component jets?







- B. Grossan. Use requires attr

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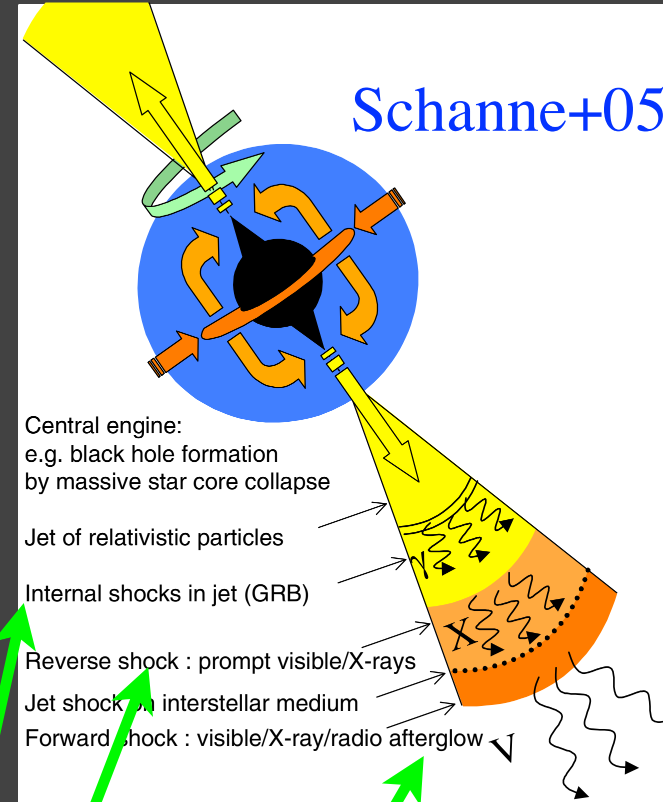
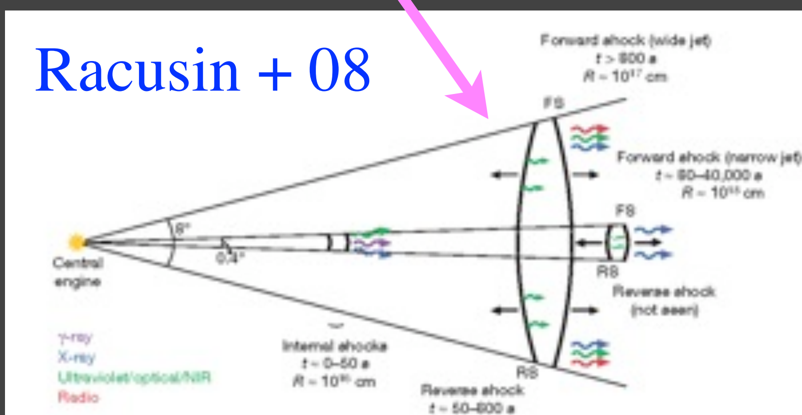
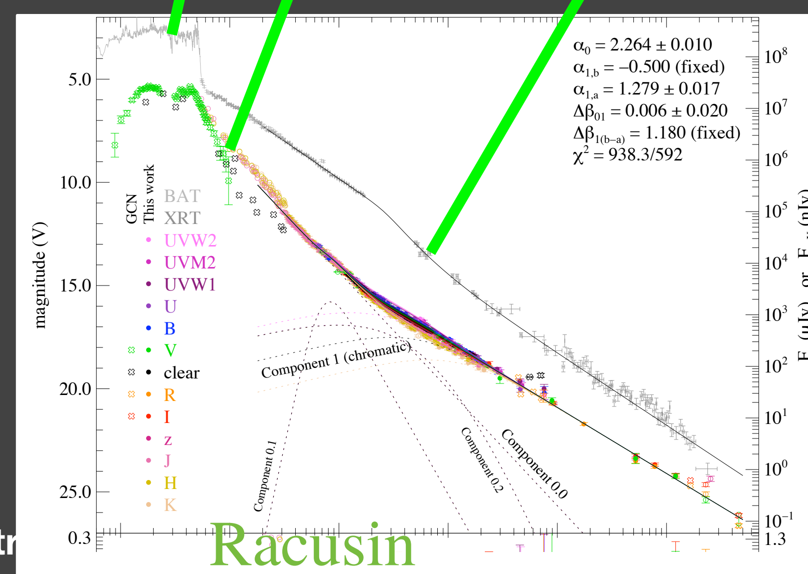


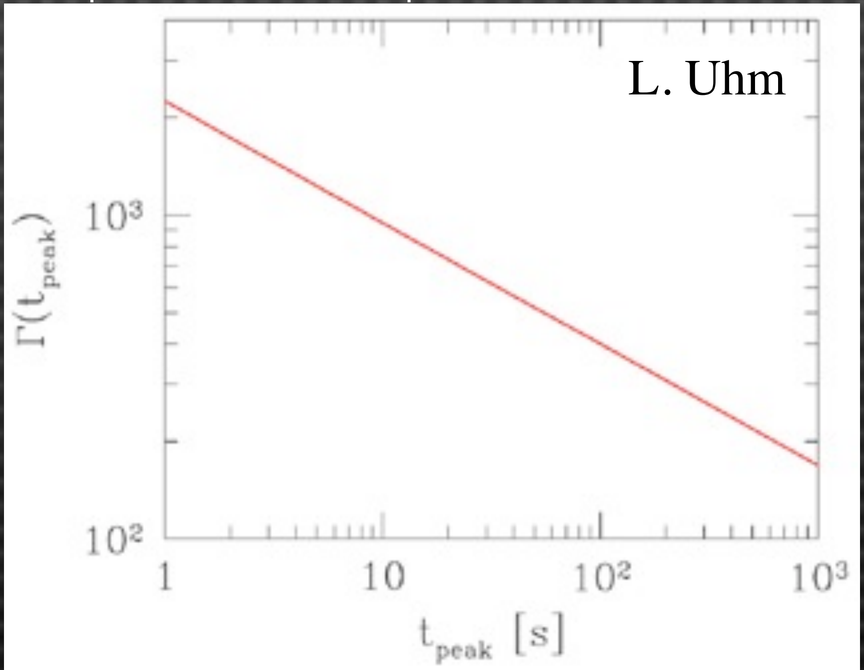


- **What about early optical?**



Rapid-Response Measurements

- Measure Bulk Lorentz Factor of Optical Emission
  - given by time of the early UV-optical emission peak
    - from Molinari et al. 2007
    - Sari & Piran 1999



  - Some dependence on external density; assumes external shock
  - Bulk Lorentz Factors measured by Fermi may be too high
- Note need rapid response to measure the bulk Lorentz Factors > few hundred

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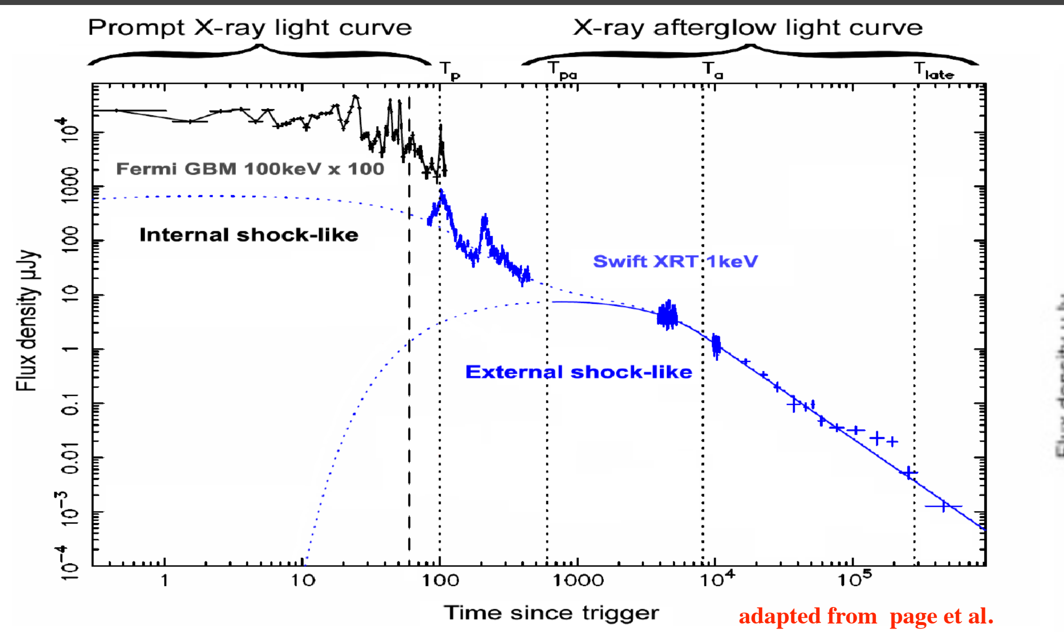
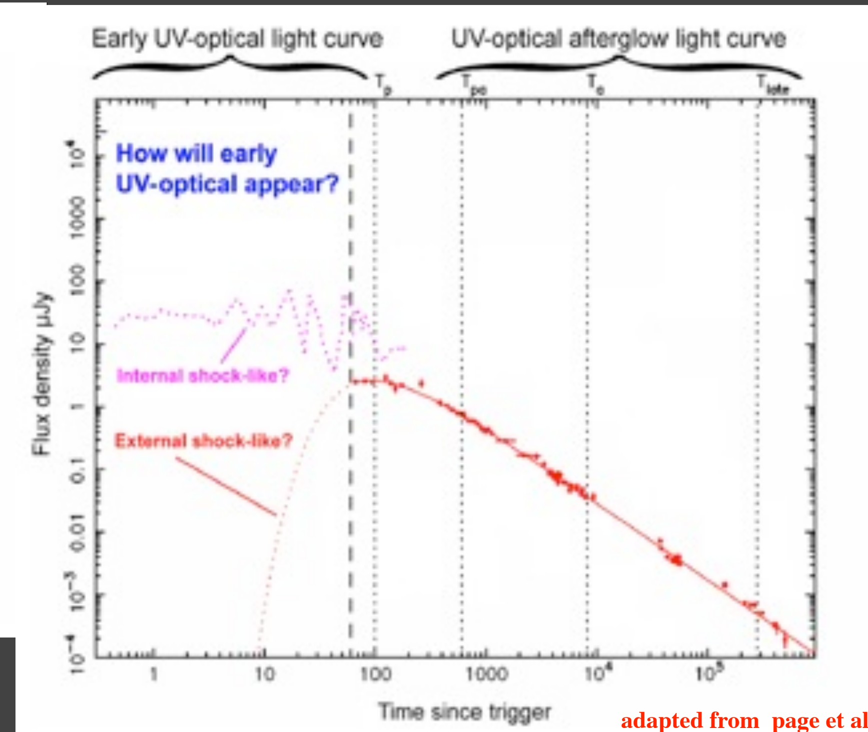
Internal vs. External Shock

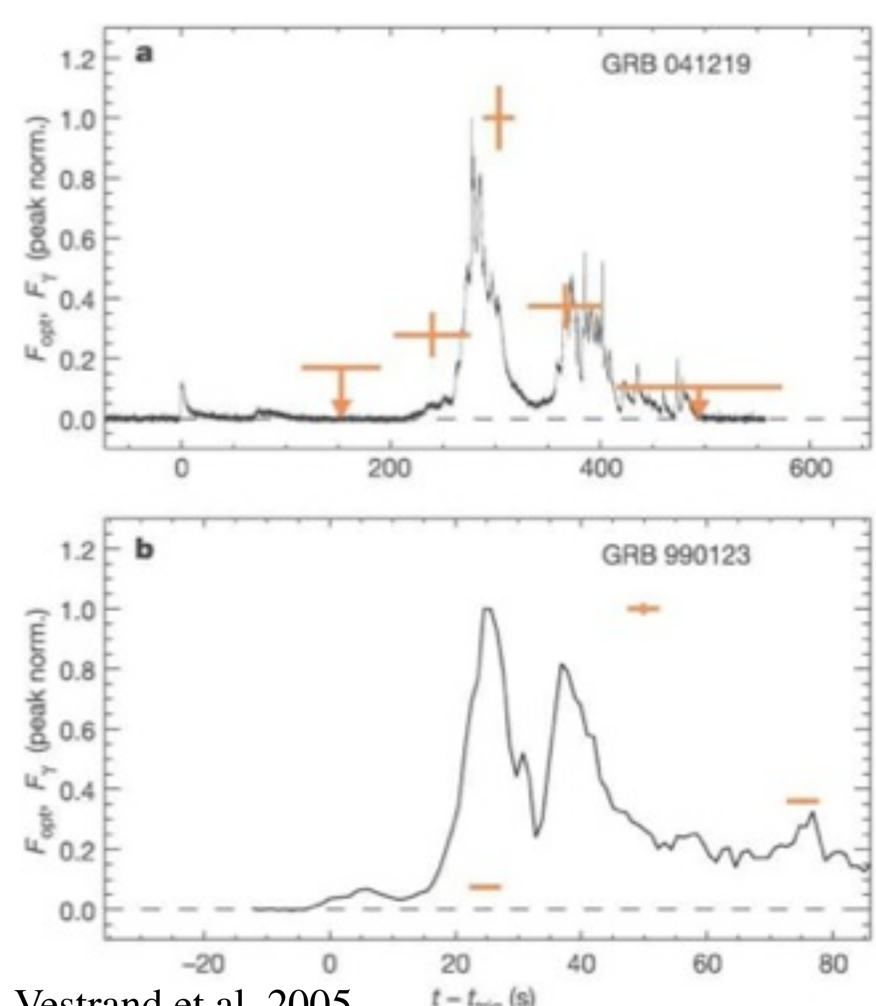




- X-ray burst light curve shows internal shock behavior.
- How will optical appear during burst?
  -Need rapid response, high time resolution.

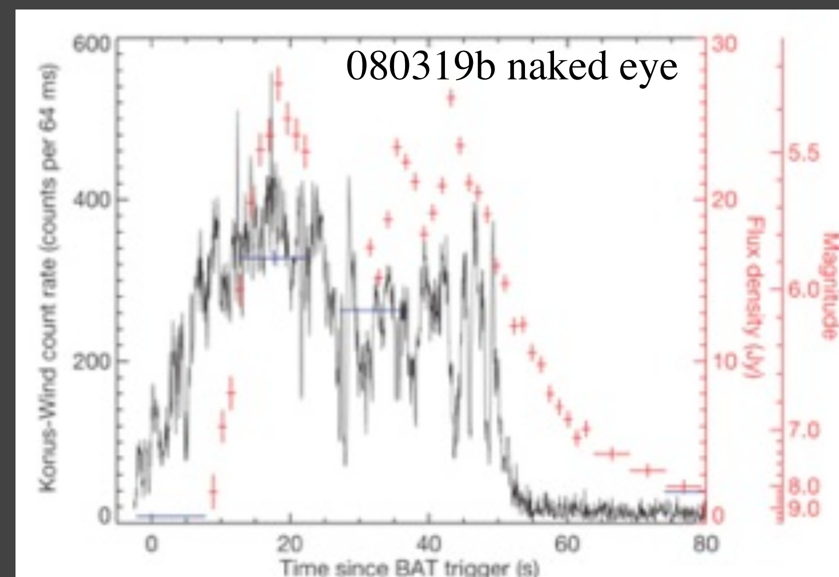
Are Opt, γ early emission correlated?

- 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

"Multi-Messenger" Measurements

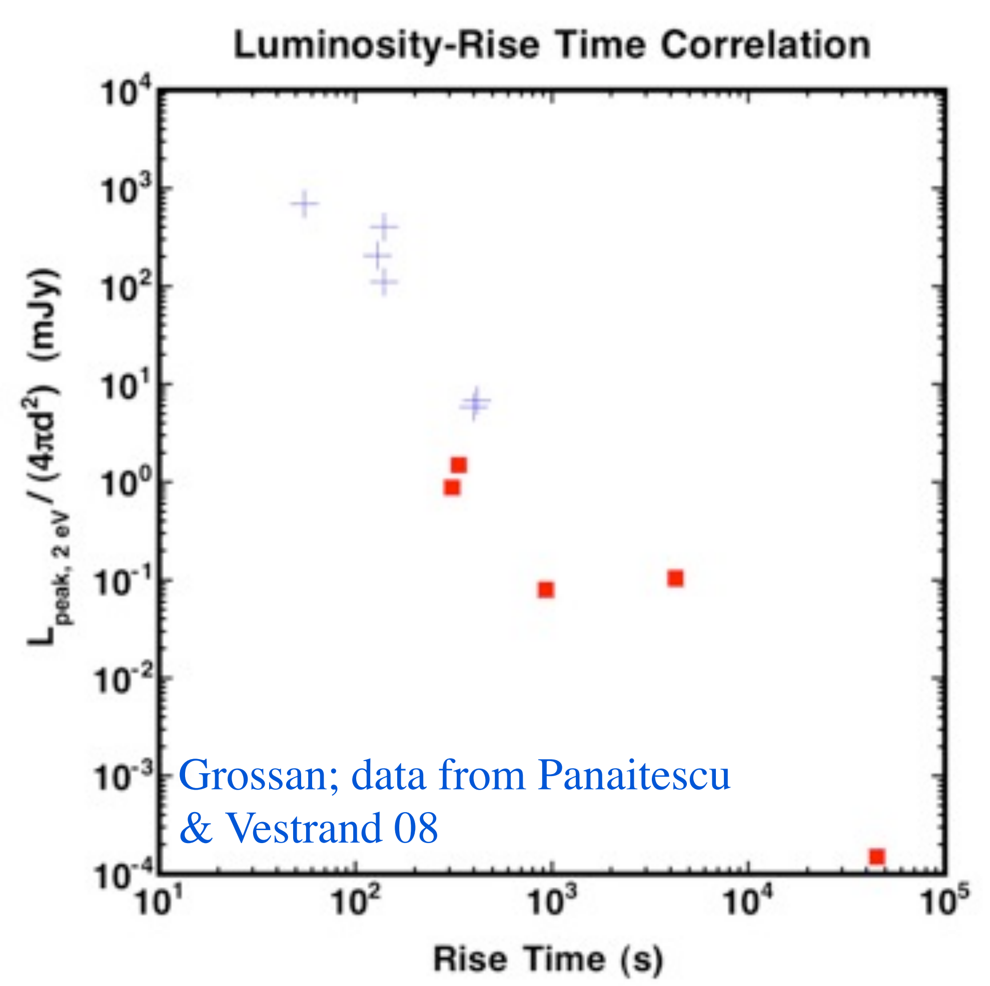
- Physics in correlation and delay for
  - Short GRB: gravitational wave vs. optical-gamma light [1]
    - GRB optical emission for source ID, GW vs. photon arrive time for models.
  - SN-GRB: neutrinos vs. optical-to-gamma prompt light
  - GRB UHECR: Air shower detector signals vs. optical prompt light
    - 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.

GRB Luminosity Calibration? Cosmological tool?

- PV08: calibrate L_{peak} with rise time:



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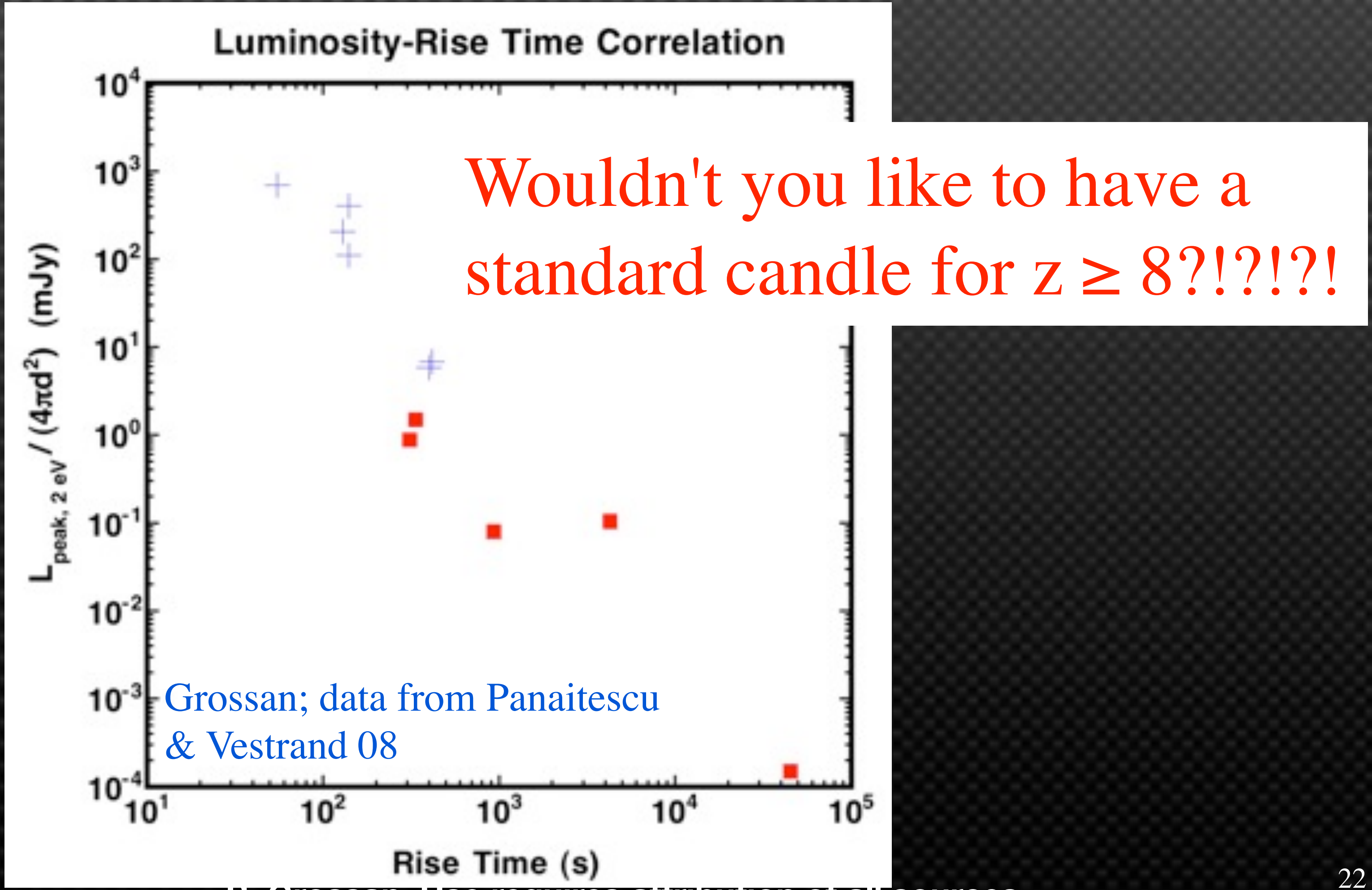
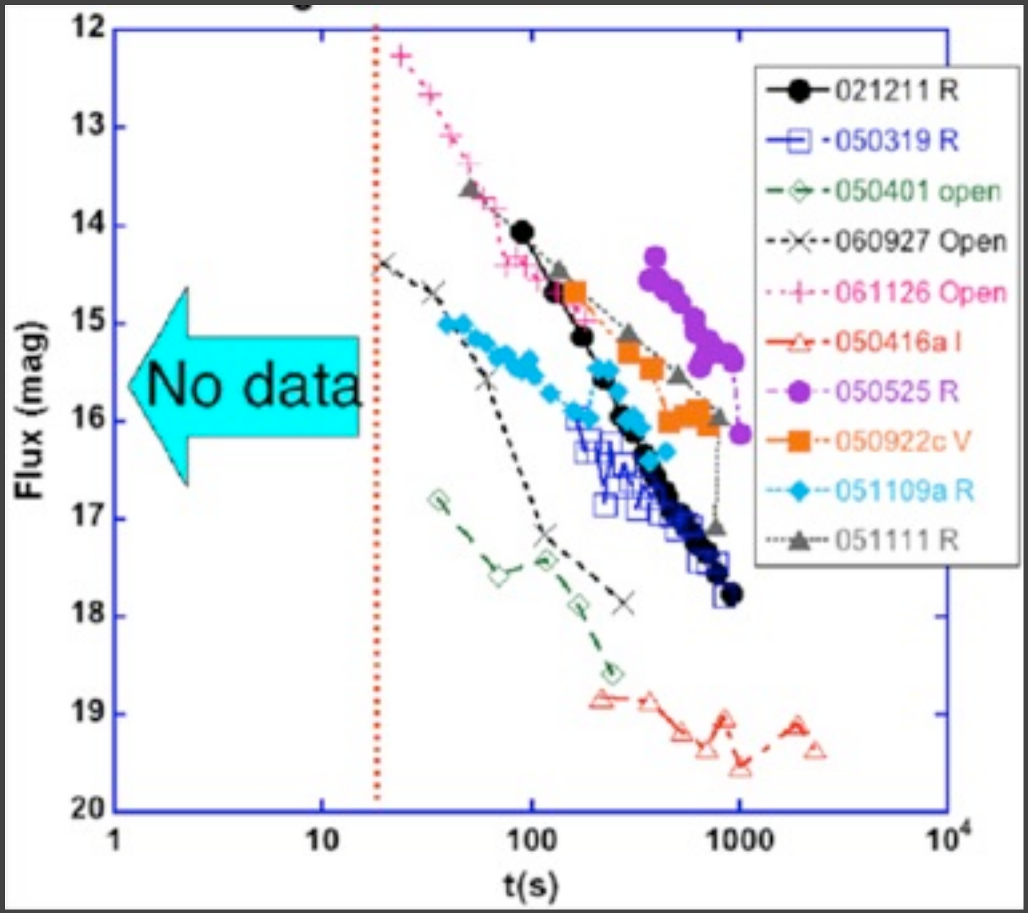


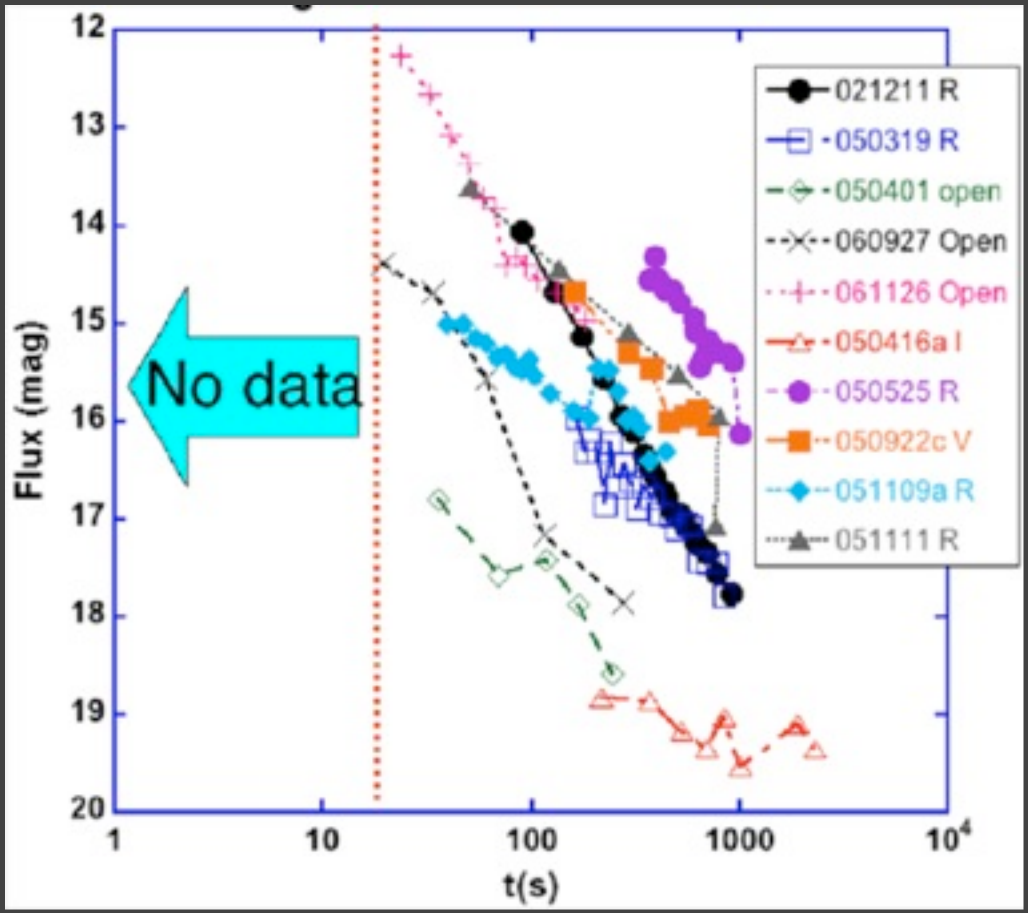
What about the *rest* of the data?



- 17 of 28 GRB NOT included in PV08 Analysis for lack of early data

What about the *rest* of the data?

- **Majority** of sample data not plotted... **because lack of early data...**



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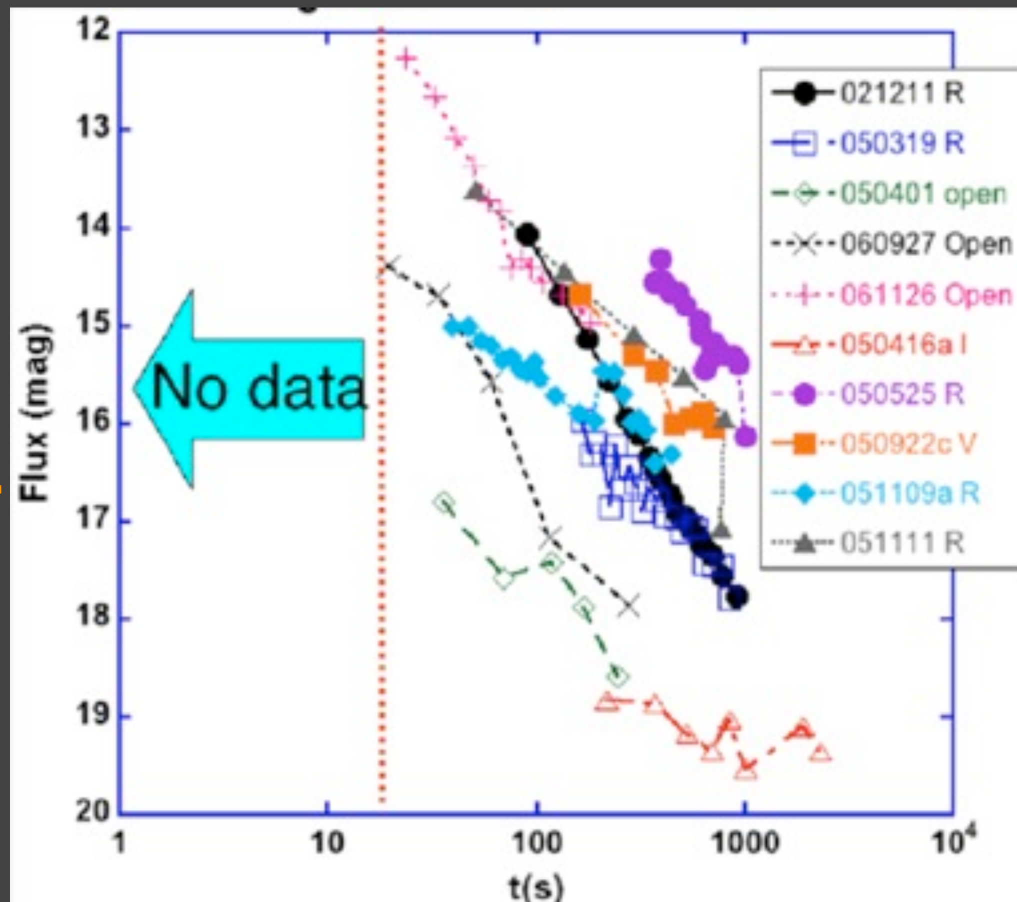

- **MOST t_{rise} unknown.**
- **Need more data at earlier time!**

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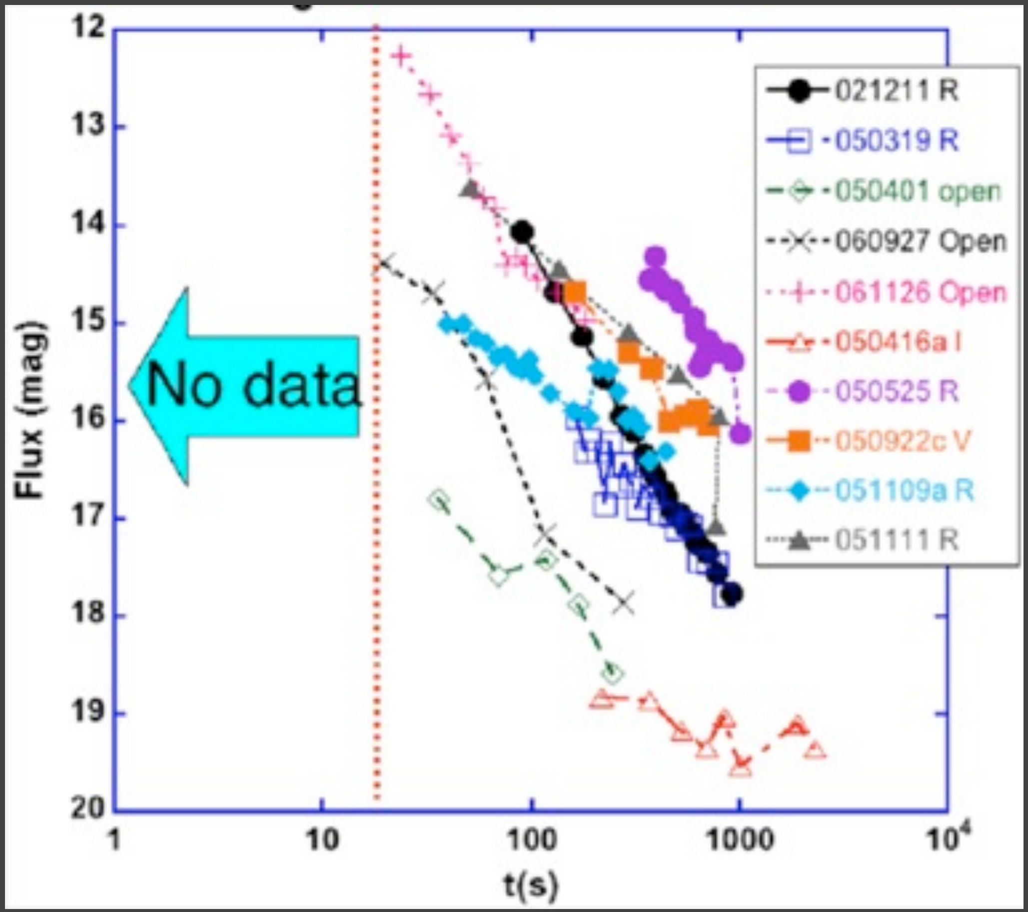

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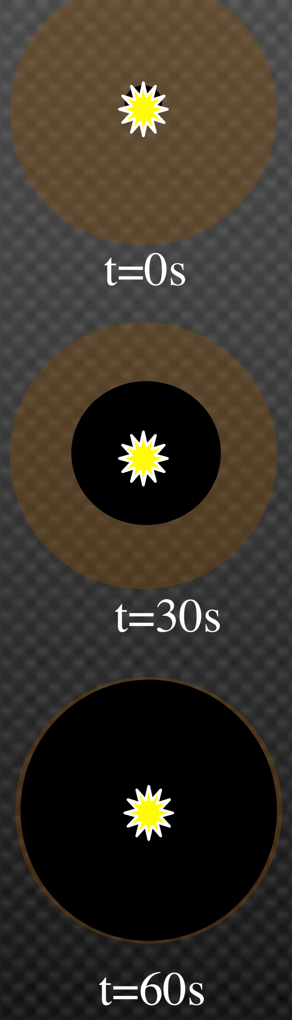
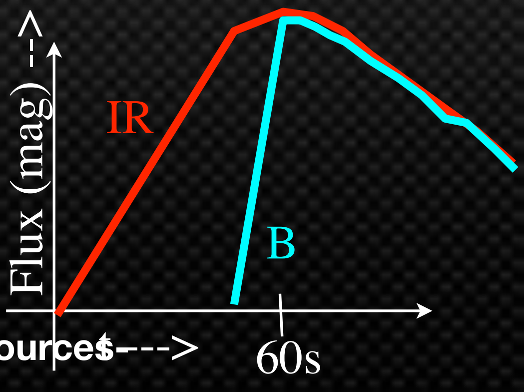
- **NEED FASTER RESPONSE TO EVALUATE!**

Dust Evaporation

- (Sorry, astrophysics/astronomy...)
- Many GRB associated with dusty star forming regions
- GRB should have enough energy to vaporize dust throughout typical star forming cloud
  - Typical cloud size ~ 10's of light sec
- 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





- B. Grossan. Use requires attribution of all sources

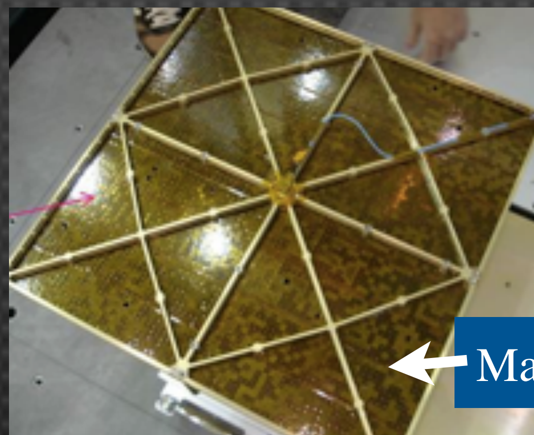
III. (Quick) GRB Detection and Location

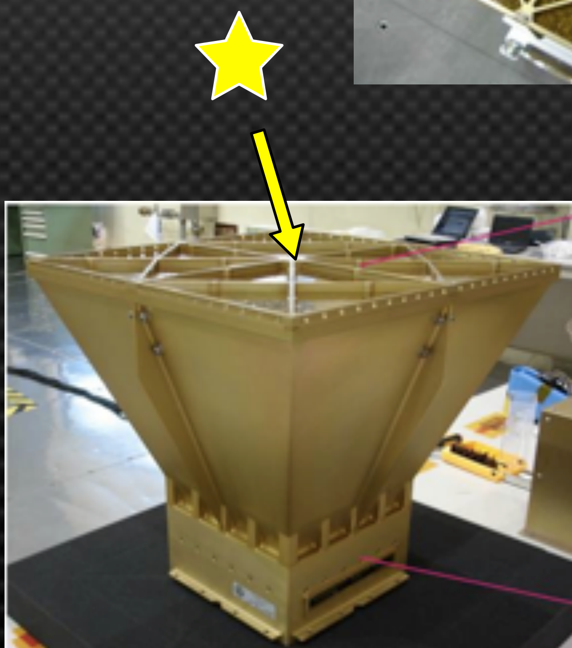
Coded-Mask Imaging

- How does the BAT locate the bursts?

X-rays: Shadow Imaging (No Lenses)

- Coded Mask Aperture
  - random open/closed tile pattern casts shadows on 2-d detector array;
  - shadow is ***unique*** for any position of source





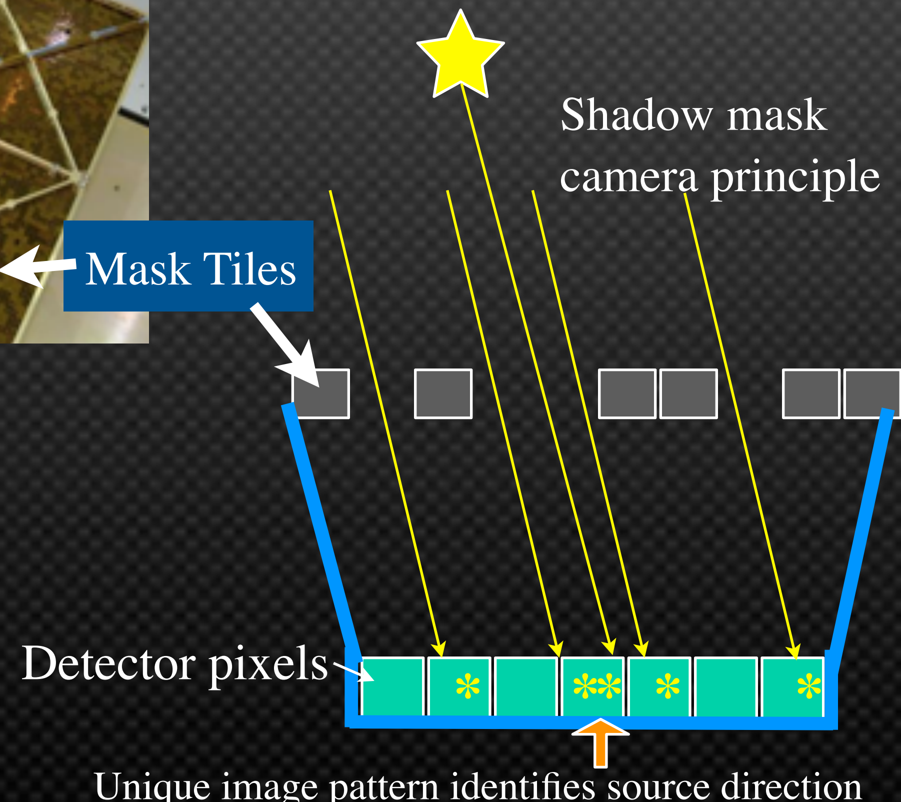


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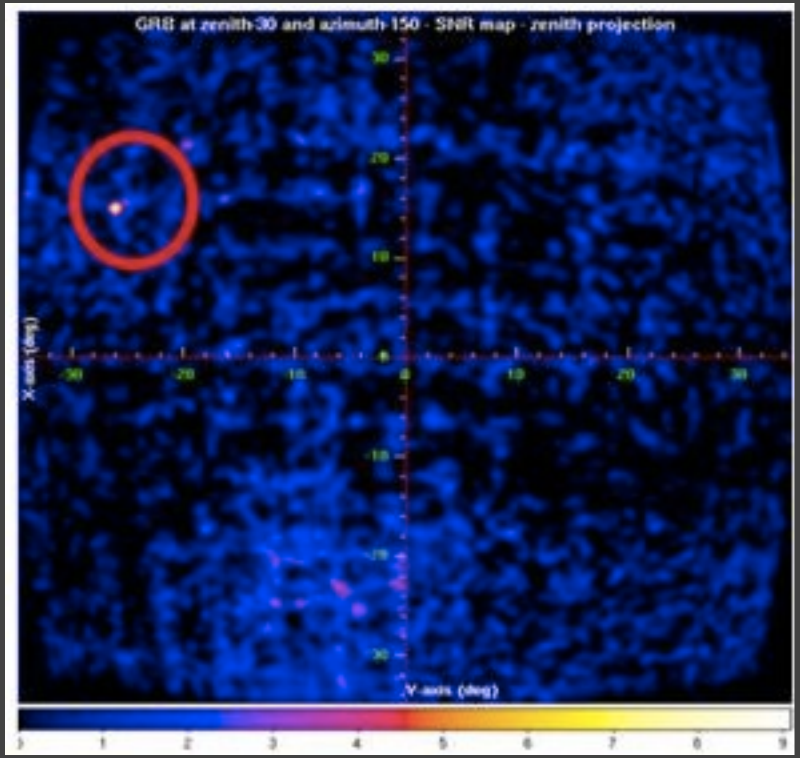
Image reduction via cross-correlation

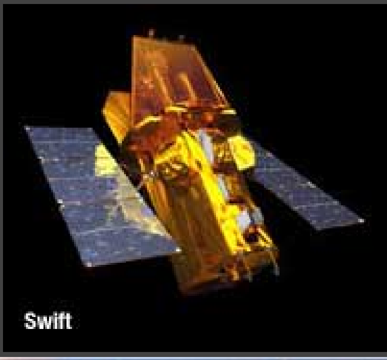
- cross-correlation allows us to invert problem to obtain source distribution on sky.
  - Note location precision improves with Signal/Noise of detection

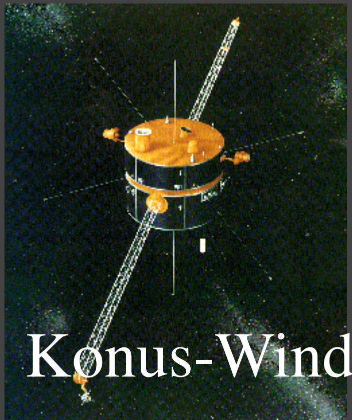


III. Limits of Current Measurements

Current Gamma-ray Sats

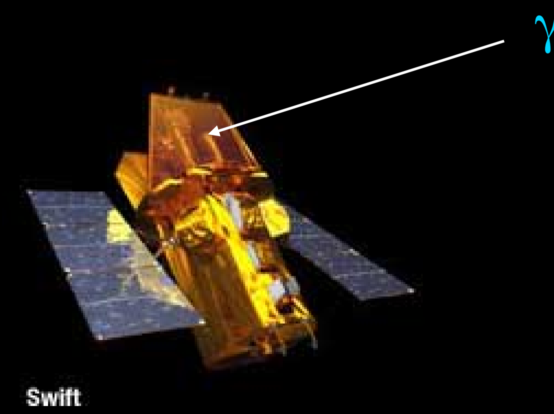
- Various Gamma-X telescopes (SWIFT, Fermi, Integral, Konus-Wind, Suzaku, etc.)
  - Coordinates sent over internet
  - GRB studies dominated by SWIFT,
    X-ray camera to localizes to ~ 10 arc minutes
  - (Note Fermi has ~ degree positions, little value for optical observations.)



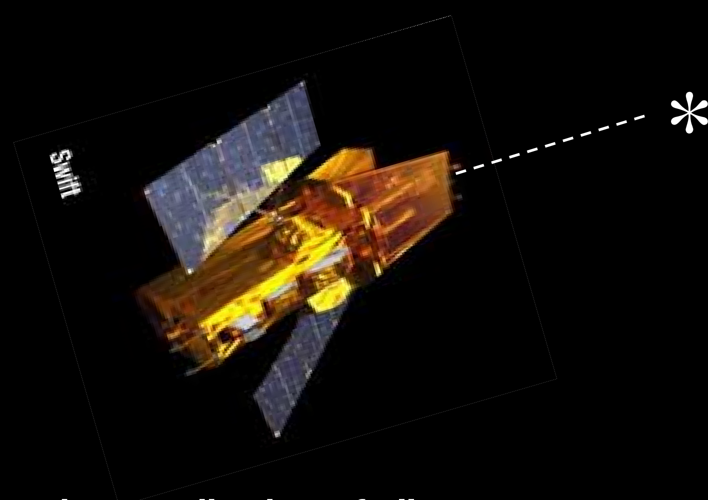


Great Inovation: X-Trigger + Optical Follow-Up

1. X-Ray Coded Mask Camera
   trigger/ID & locate GRB

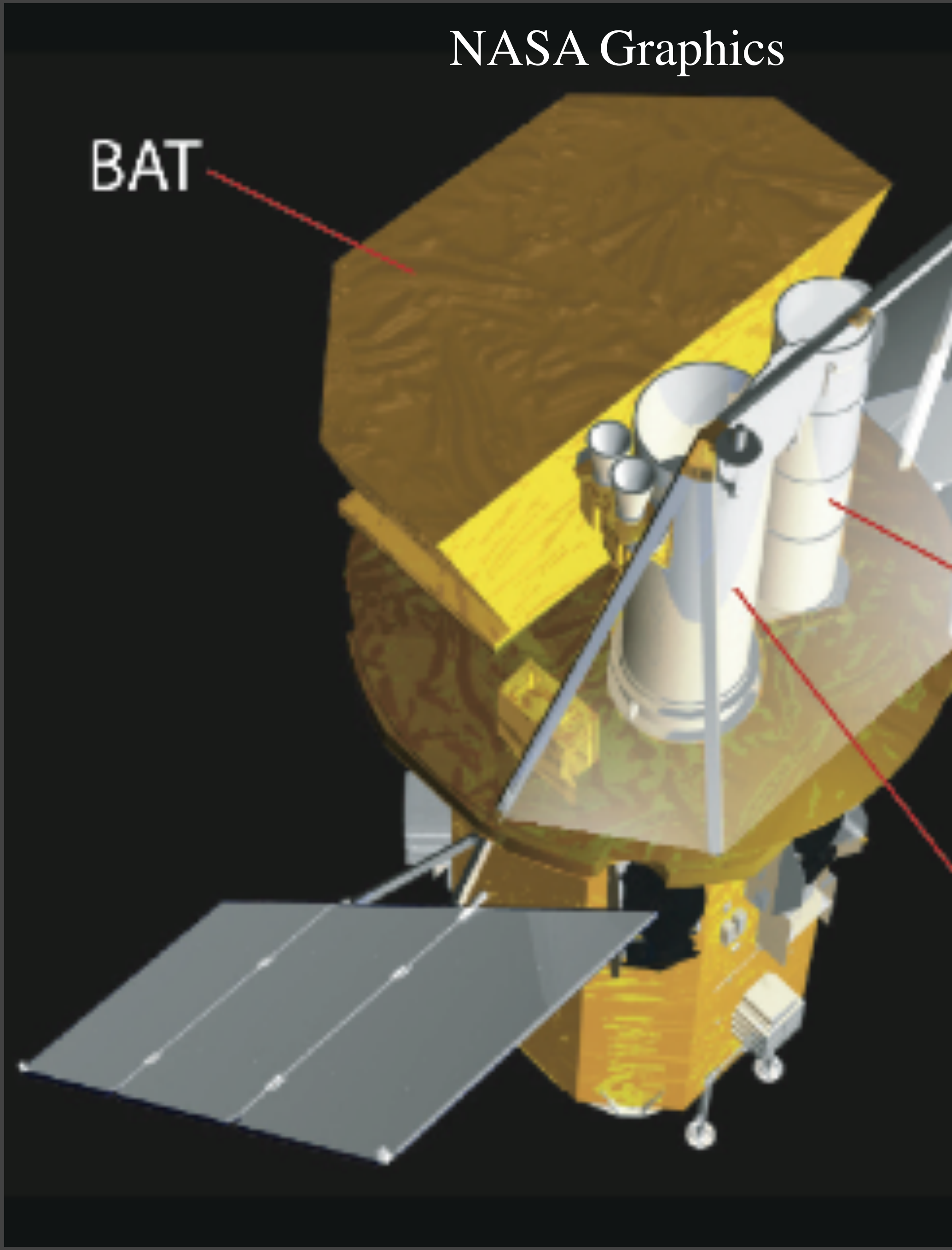


2. UV-Opt (UVO)
   acquire X position *by steering telescope* to detect faint object



SWIFT

(Dominates Prompt Follow-up)



FOV = Field Of View

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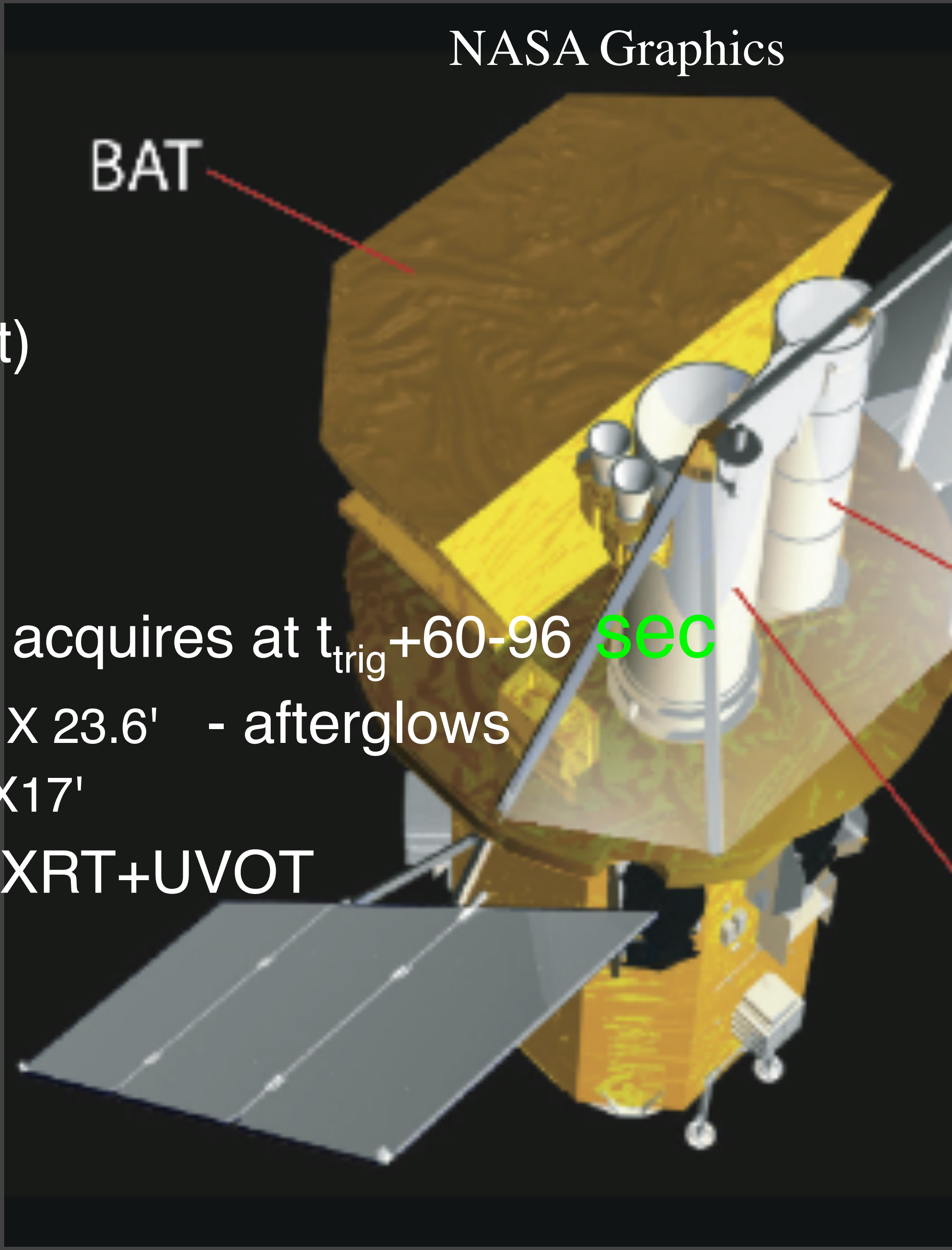
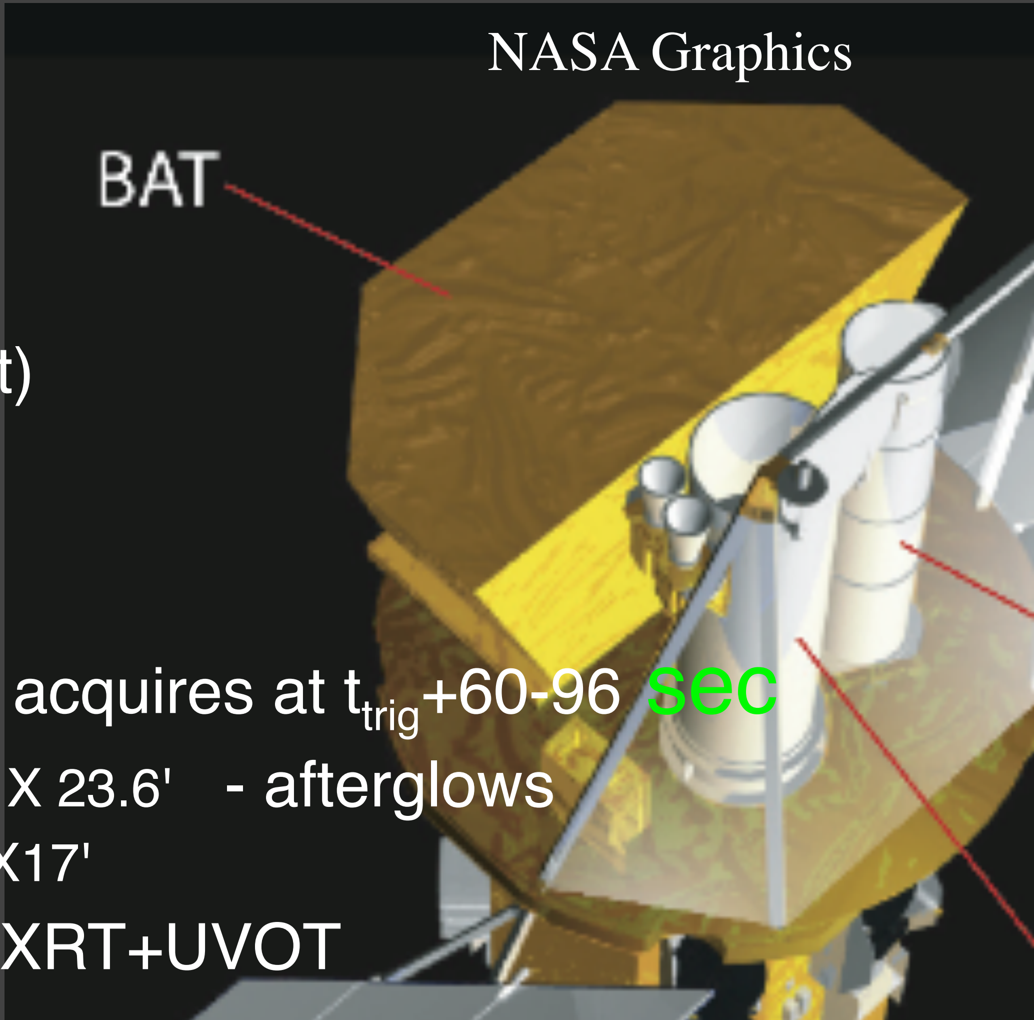


- BAT (15-300keV instrument) gives rough position
  ≥10 sec to localize
  - FOV=1.4 Sr
- Narrow FOV -XRT, UVOT - acquires at t_{trig}+60-96 sec
  - XRT (X-ray Tel.) FOV = 23.6' X 23.6' - afterglows
  - UVOT is 30 cm tel. FOV=17'X17'
- ~ 78 GRBs/yr observed by XRT+UVOT
- ~10% SGRB

FOV = Field Of View

SWIFT

(Dominates Prompt Follow-up)

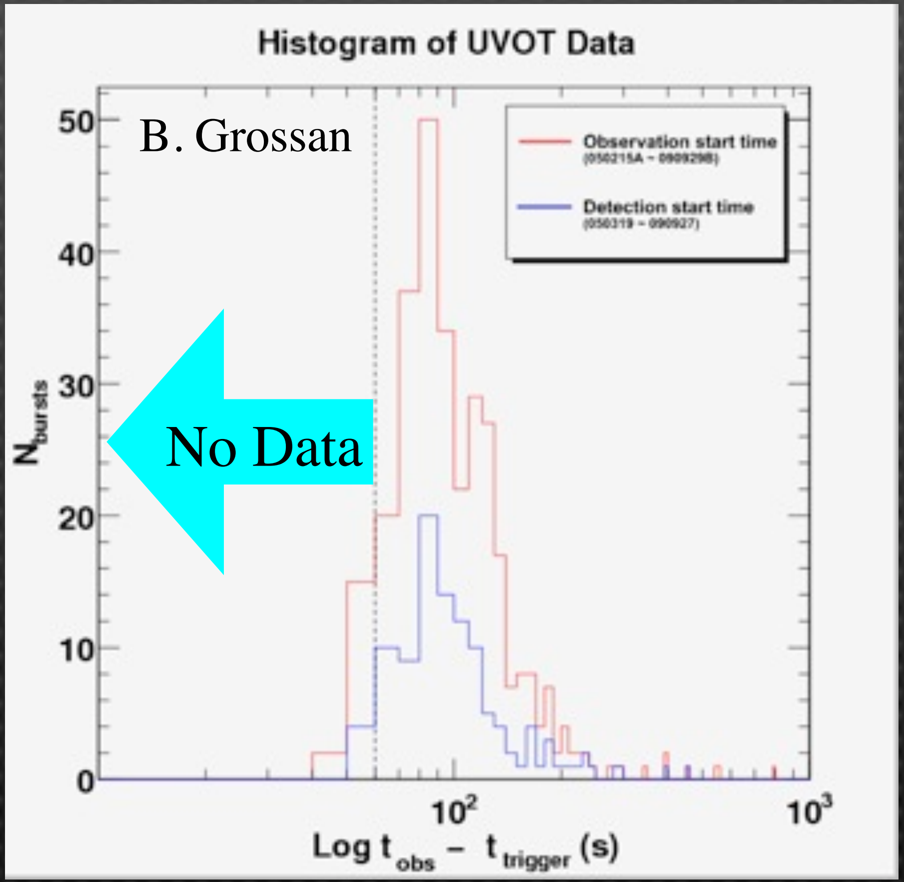


- BAT (15-300keV instrument) gives rough position
  ≥10 sec to localize
  - FOV=1.4 Sr
- Narrow FOV -XRT, UVOT - acquires at t_{trig}+60-96 sec
  - XRT (X-ray Tel.) FOV = 23.6' X 23.6'   - afterglows
  - UVOT is 30 cm tel. FOV=17'X17'
- ~ 78 GRBs/yr observed by XRT+UVOT
- ~10% SGRB

FOV = Field Of View

SWIFT response speed limited

- Few detections t< 60 s
- Response speed limited by time to rotate, point spacecraft
  - After 5 years, SWIFT has few data < 60 s



How will we ever get a large sample of rise times, shapes?

Current UV-Optical Experiments

- SWIFT UVOT (2005+) optical ~ t_{trig}+96 s
- ROTSE-III (ground optical) responds ~ t_{trig}+25 s
  - small! - Limiting mag ~18 in 100 s

- GROND response in ~ few minutes (2.2 m aperture, La Silla) in 7 filters!
- Others - e.g. super-lots- rarely catch bursts, but have potential

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Future Prospects

- Small number of Rapid Ground *Detections* in past, *same expected in future (~ 10 in 6 yrs)*
  - Super-wide monitors TORTORA, PI of SKY< 10-12 mag, RARE!
  - Weather, limited sky insurmountable problems
  - Rapid response = small aperture = poor sensitivity
- Ground observations dependent on Swift, now very old.
- Large area surveys (e.g. PAN-STARRS, FIGGS) FAR too slow cadence - few times/night
- Swift can't beat 60s; no faster space missions approved

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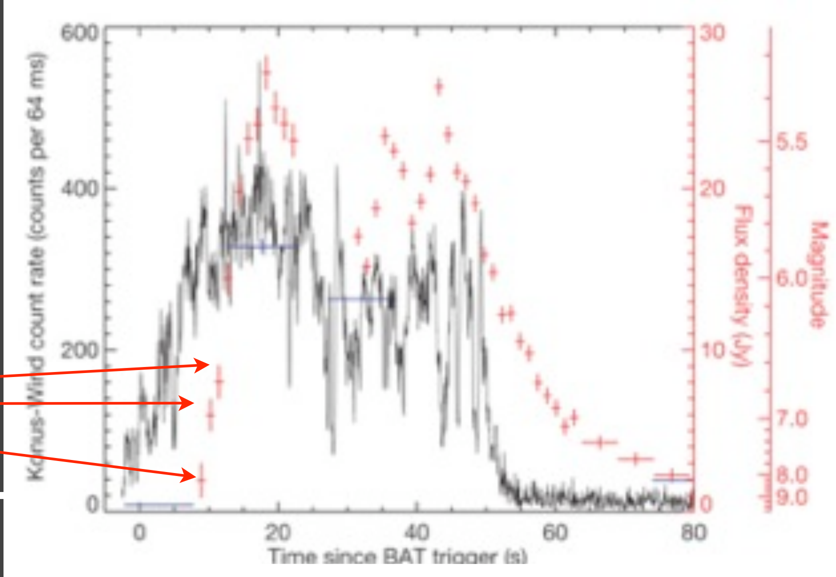
How will we ever get a large sample of rise times, shapes?

GRB080319B - "Naked Eye" or **"Lucky"** Burst?

- Very improbable confluence of events:
  - Brightest burst ever...
  - ...within 10 deg. of 080319a,
  - *... and* 30 minutes!
    - virtually every instrument in (human) universe already on target!



080319b naked eye Racusin et al. 2008

- This time resolution due to wide-field instruments-such detections **rare.**

- We may ***never again*** be so lucky. Need more frequent, more sensitive, earlier response.

IV. How to Get There Faster

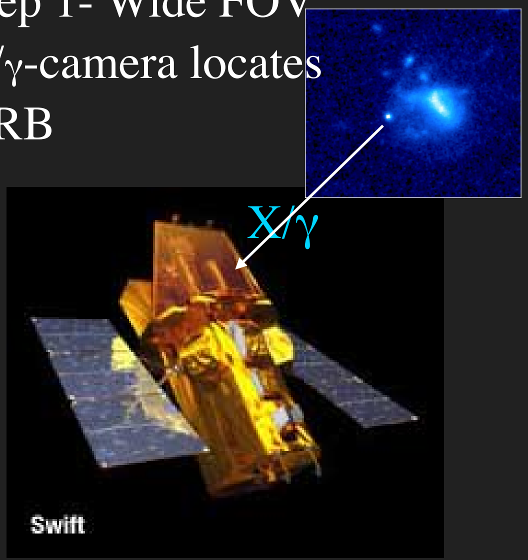
The UFFO Example

- The Ultra-Fast Flash Observatory is a project we work on here at IEU, Grossan contributed to the development of the idea (white paper)
- We offer this as an example of research in progress
  - it's a crazy idea. In 10 years, will it be forgotten, or put in text books?
  - We don't know, but this is how research goes! Get a bold idea, do your best to make it happen and sucessful with high probability
- Since this is unproven, feel free to ask questions for justification and proof of the ideas!

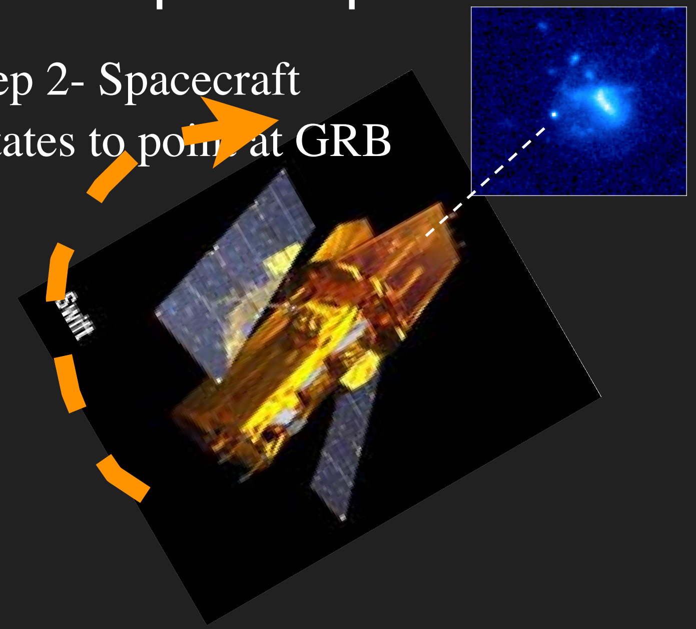
Faster-Steer the Beam

- SWIFT rotates entire spacecraft to point opt instrument

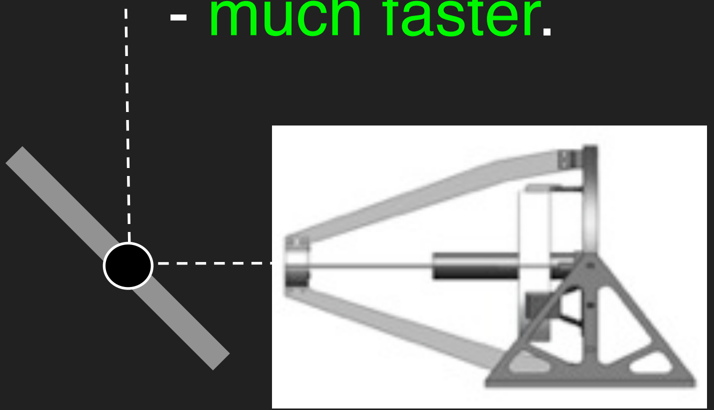
Step 1- Wide FOV X/γ-camera locates GRB

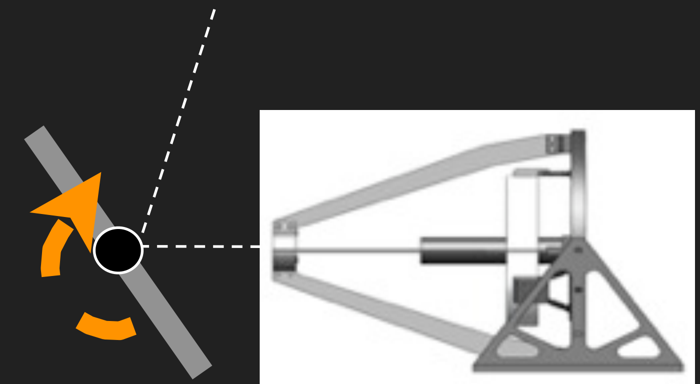


Step 2- Spacecraft rotates to point at GRB



- We use mirrors to steer the *beam*, not the spacecraft - much faster.





UFFO
The Ultra-Fast Flash Observatory Program

The UFFO Program is a Collaboration between scientists of Berkeley, Institute for the Early Universe (IEU), and the RCMST (Research Center for MEMS Space Telescope) at Ewha Womans University, Seoul, Korea and **MSU SINP** and many others....

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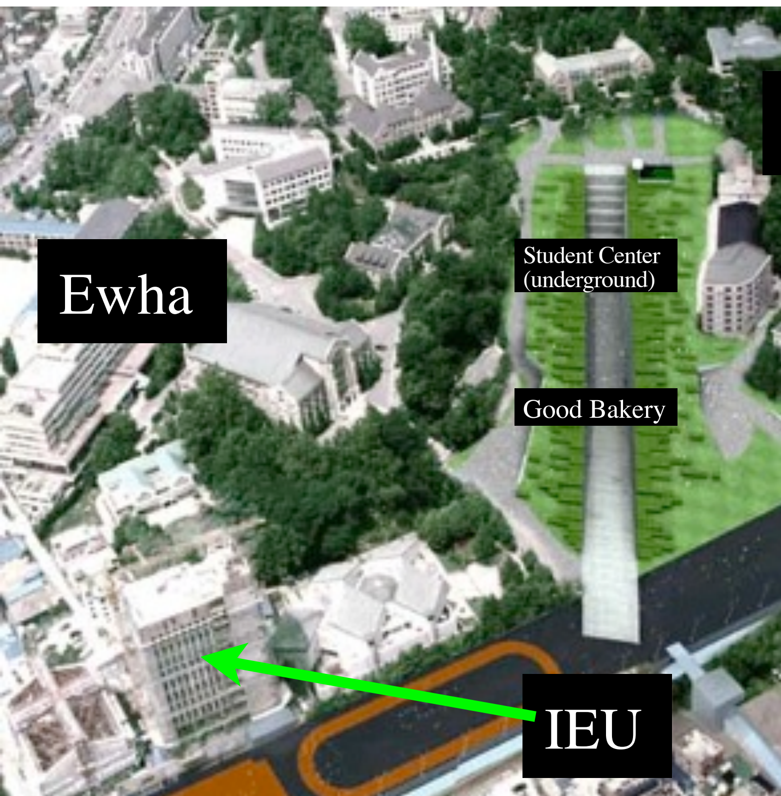

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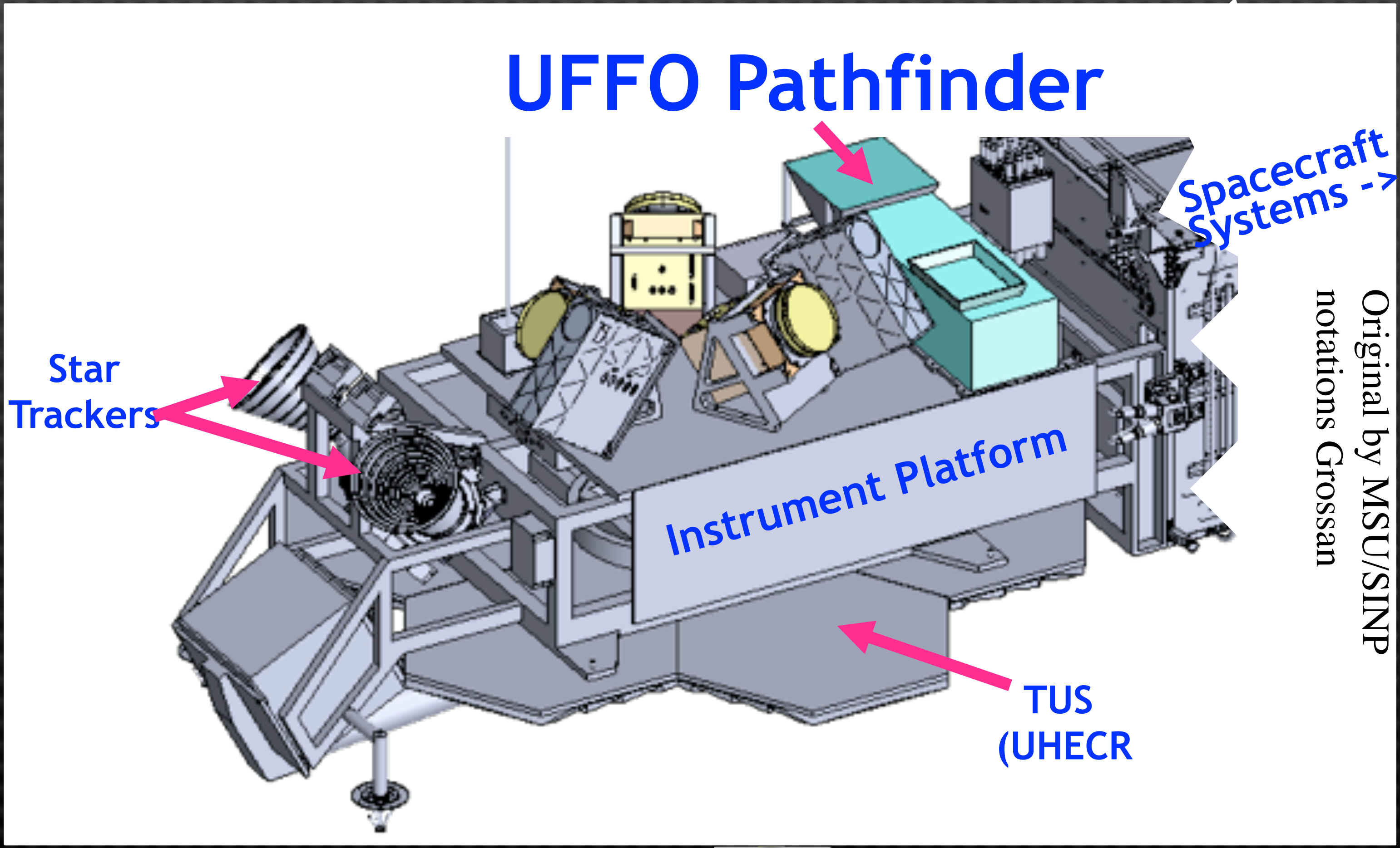
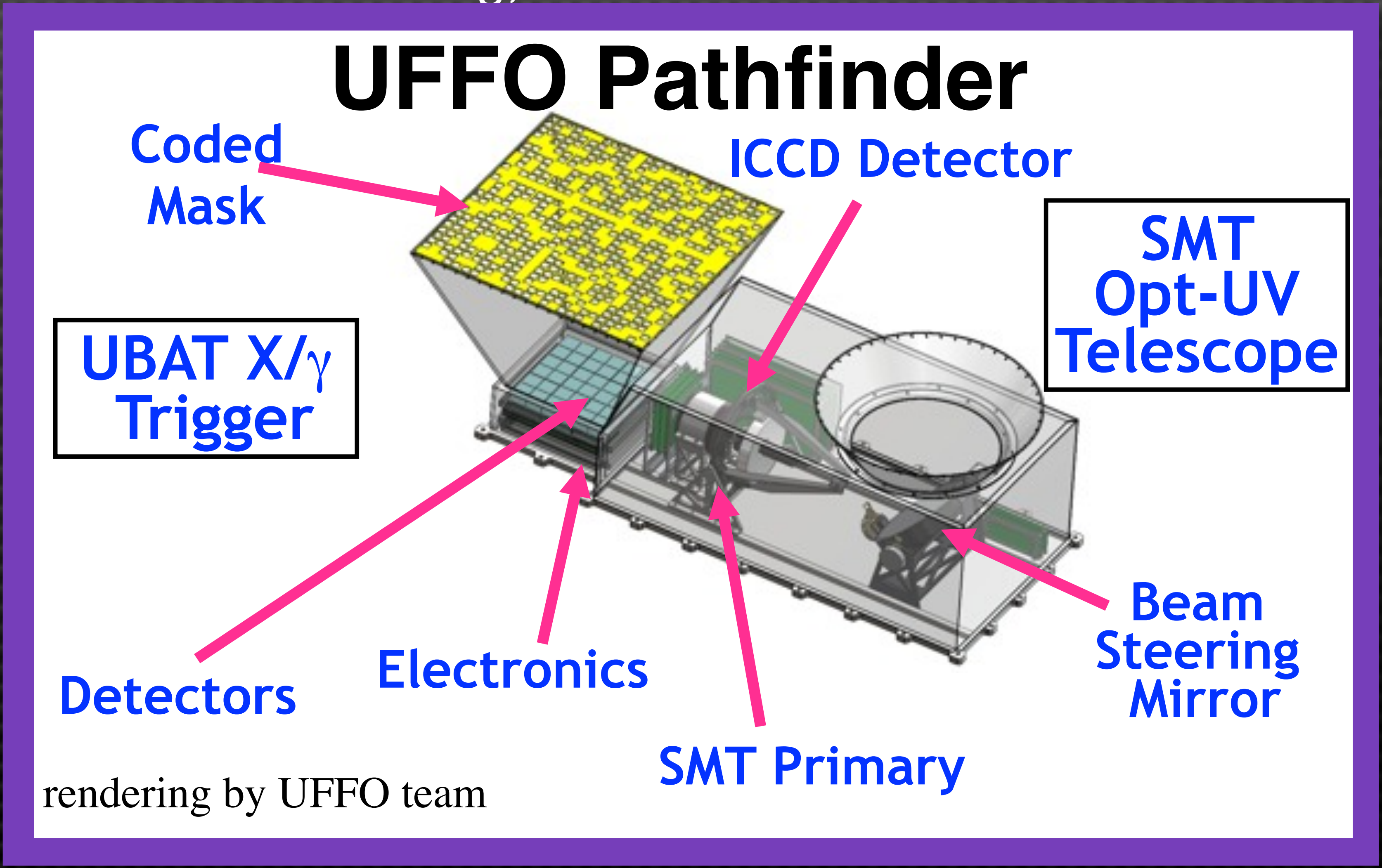
UFFO -pathfinder mission

- We were *given* 20 kg on the Russian Lomonosov spacecraft in UNIVERSITAT program-Launch in Nov!

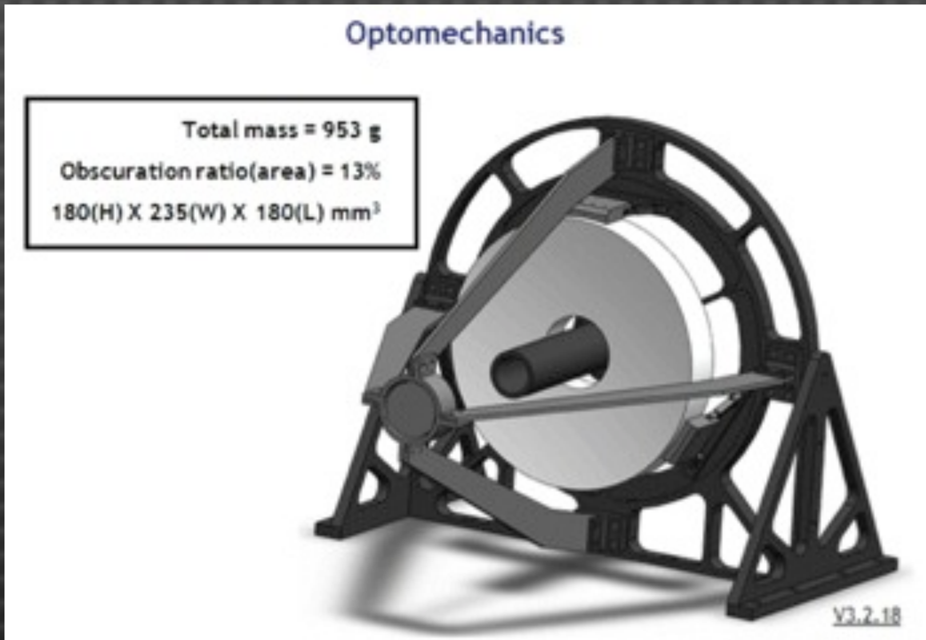


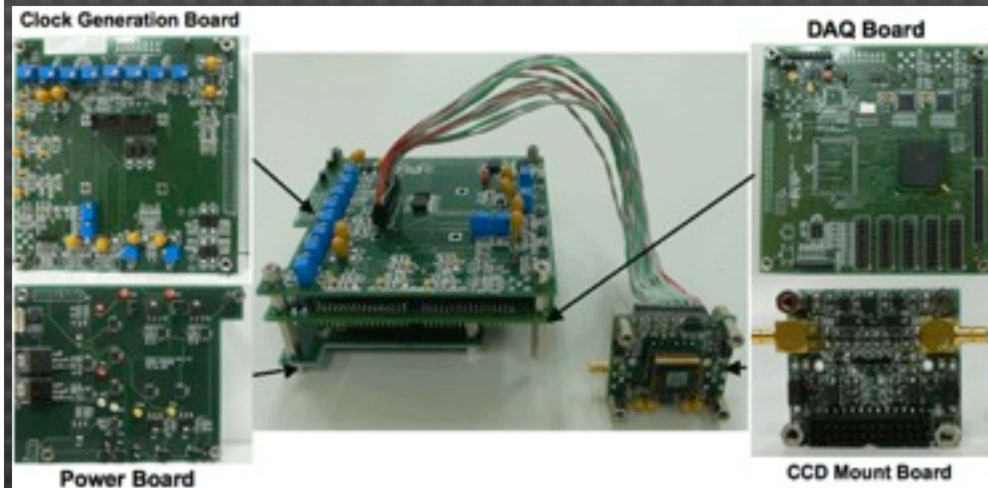
UFFO pathfinder design

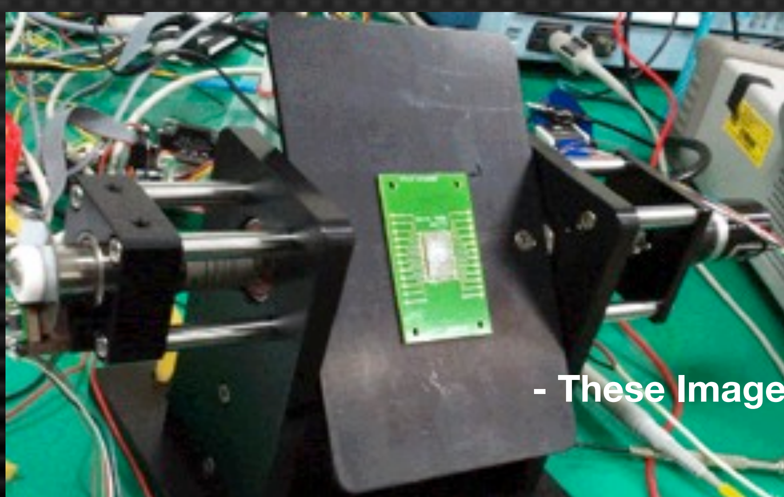
- MODEST! - 20 kg, 10 W



Random Pathfinder Components



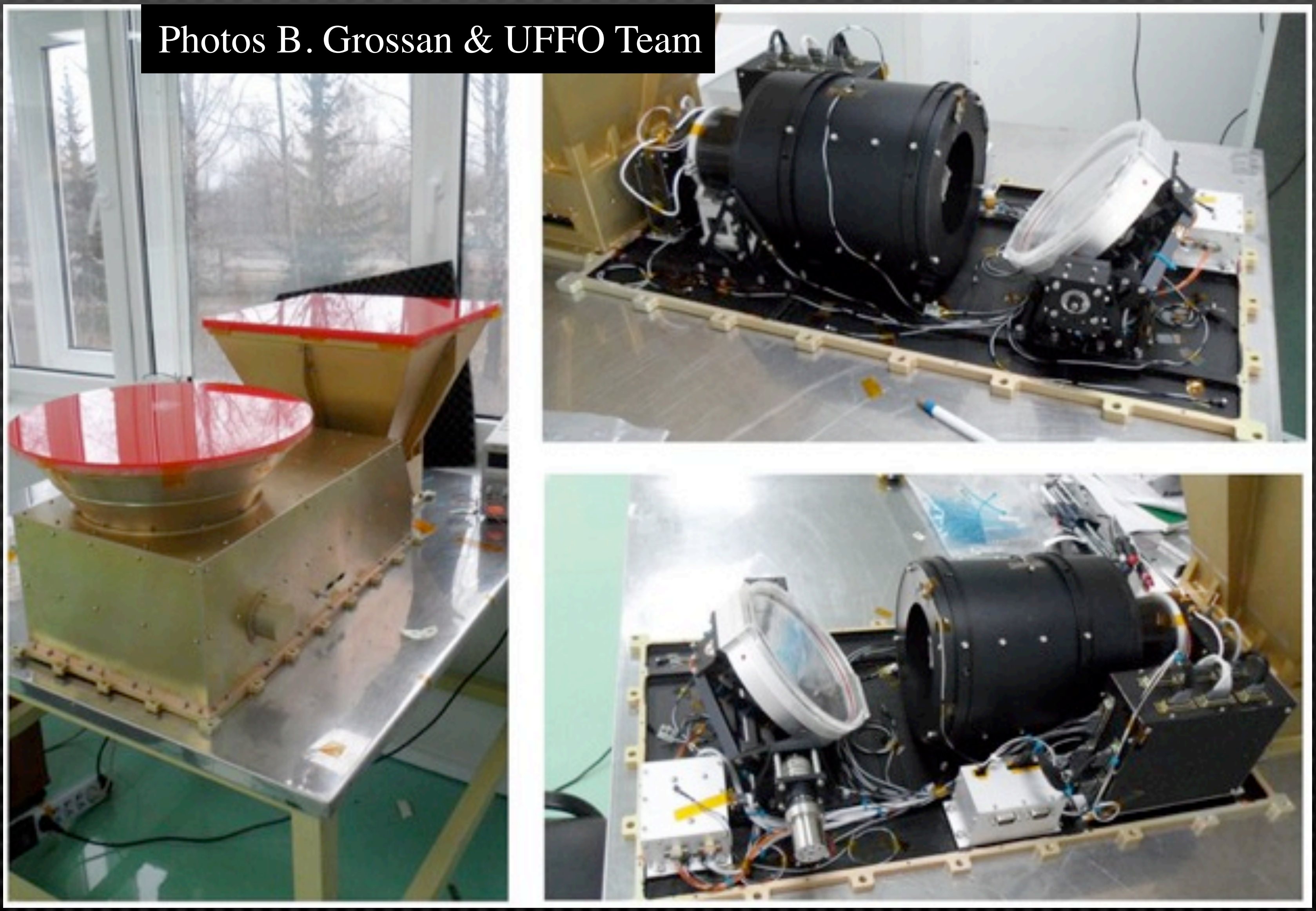




- These Images by UFFO Tam; use requires permission & attribution-

More UFFO Pics

- UFFO at Istra



Photos B. Grossan & UFFO Team

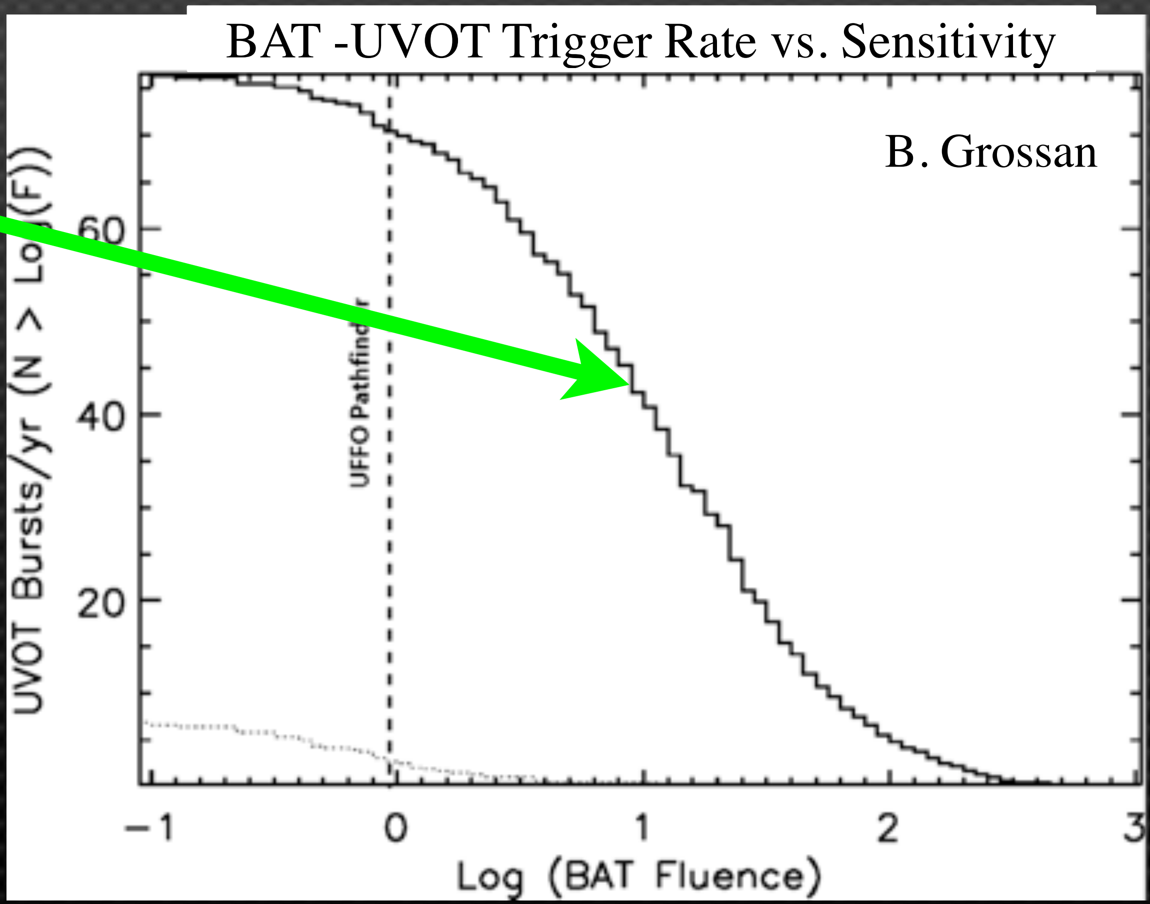
More Details about UFFO later

- Main instruments covered in separate talks tomorrow and later

Science in 20 kg?

- UFFO-pathfinder is only ~ 20 kg. Tiny!
- Active X-ray area only 191 cm²
  - DO NOT NEED lots of X-ray sensitivity to catch GRB!

- Even factors of 100 in sensitivity loses <50% of GRB!
- Due to unique "Log N-LogS" curve of GRB. (see Butler+ 08)
- Caveat: Detection based on trigger, background, etc., but bursts are "spikey", so generally easy detection.



BAT Fluence 15-150 keV, 10^{-7} erg cm^{-2}

Conservative numbers: not BAT bursts, but actual BAT+UVOT triggers.

UFFO-Pathfinder Numbers

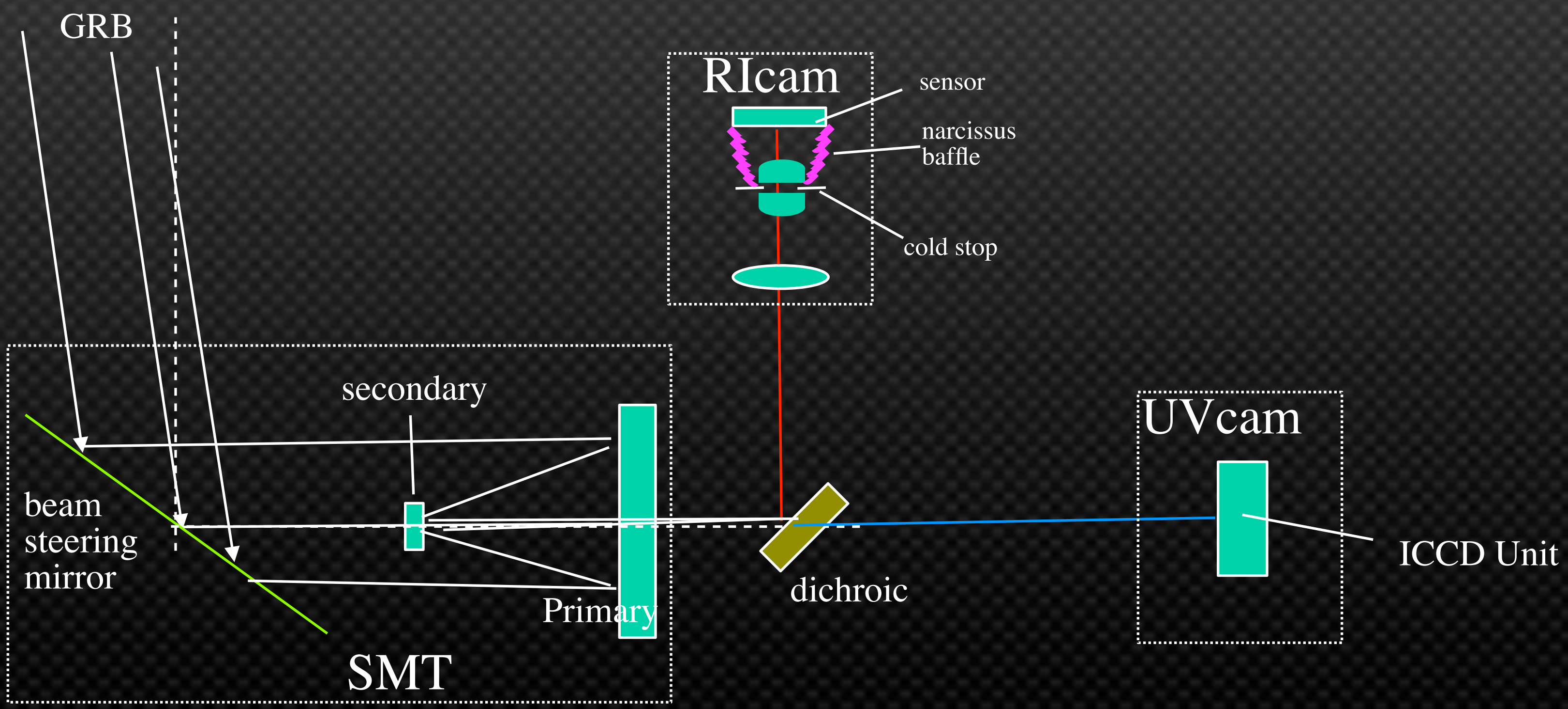
- X-ray Sensitivity - factor of 0.75 dex to S-BAT
- Optical Sensitivity - factor of 3 to UVOT
  V≤17.5 mag (10s), ≤18.7 mag (100s)
- Triggers per year - 44
- Optical Detections/yr - 5.7 (10 s), 10 (100s)
  - assumes simple fraction based on peak V flux

What if we made UFFO bigger?

- Here are some of my proposals for a bigger UFFO...

Optical/IR **Instruments**

- Dichroic splits beam to TWO cameras:
- U-Vcam - just like ICCD in UFFO-Pathfinder
- R-Icam - HgCdTe array



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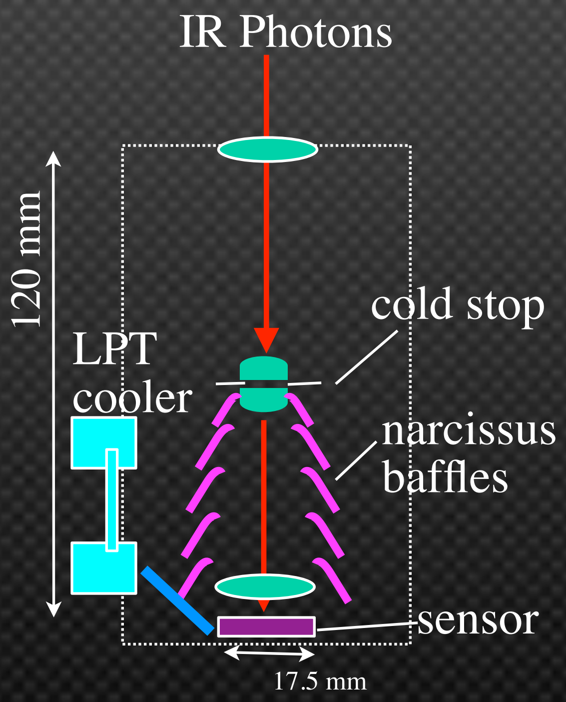
R-Icam - HgCdTe

- HgCdTe Sensor HnRG w/1.7 μm cutoff
  - lower I_{dark} than 2.5 μm cutoff
  - less sensitive to thermal background
- Optics Design
  - Brian Sutin, originally from Lick
  - cold stop, narcissus baffles help reduce background
- Big, Wide Band 0.6 -1.7 μm
  - GRB are wide band - gets more photons
  - Get Spectral slope from ratio of two cameras
    - always simultaneous
  - more reliable, less expensive than filters- which are problematic for rapid variability



Wide Band • Low Space Background • Steep Object in IR

This is a winning combination!

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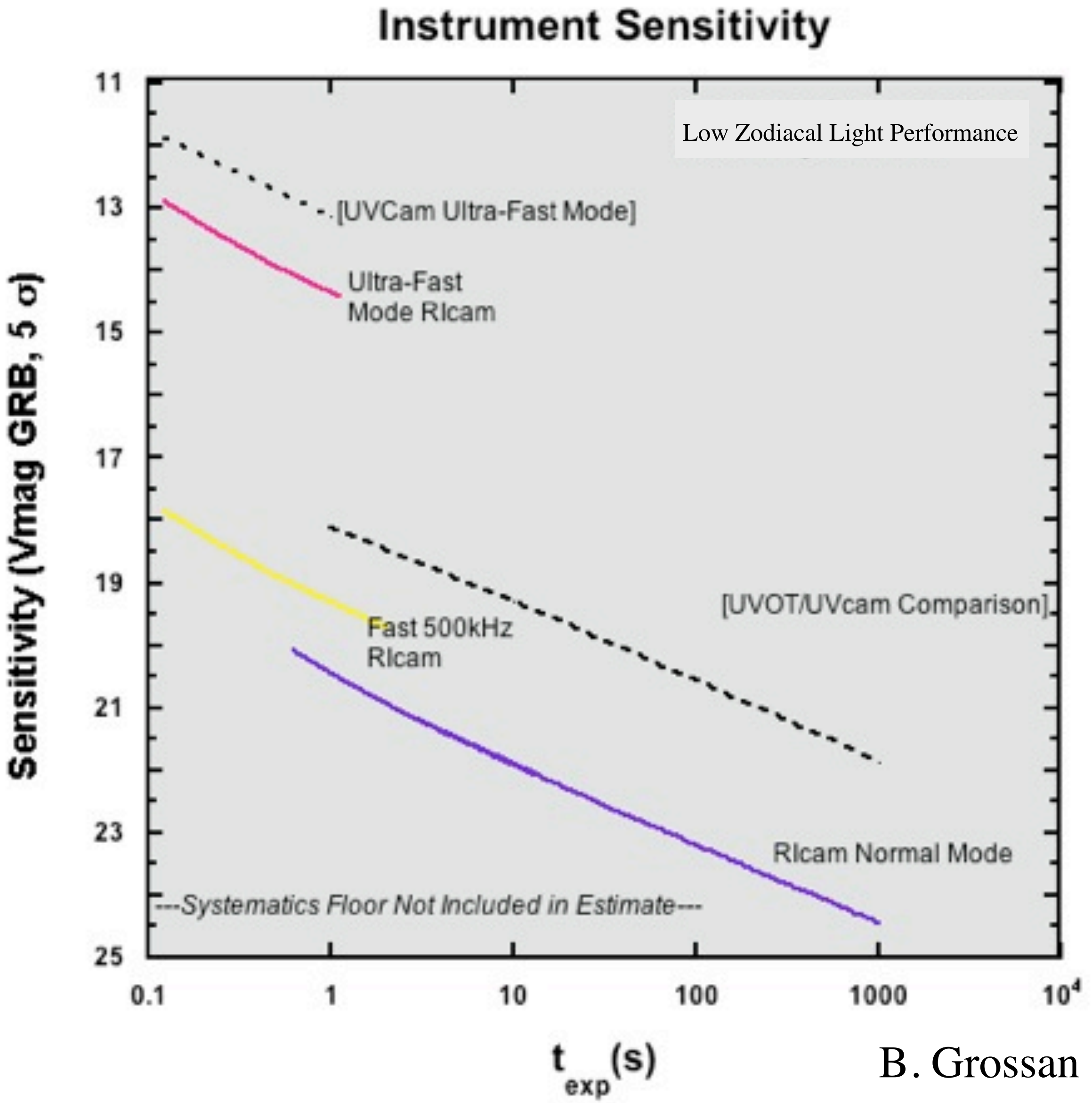
RIcam Sensitivity

- Equivalent V-mag shown, GRB opt slope= -0.75 assumed (for compare to UVOT)
- Optimistic Zodi, will be worse by ~ mag in other parts of sky
- Systematics not included
- About two mag more sensitive than SWIFT UVOT
- Compare to NICMOS 1.4μm: within 1.9 mag (on-line exposure calculator)good performance because: (1)wide band, (2) low-bgnd, (3)steep spec. target



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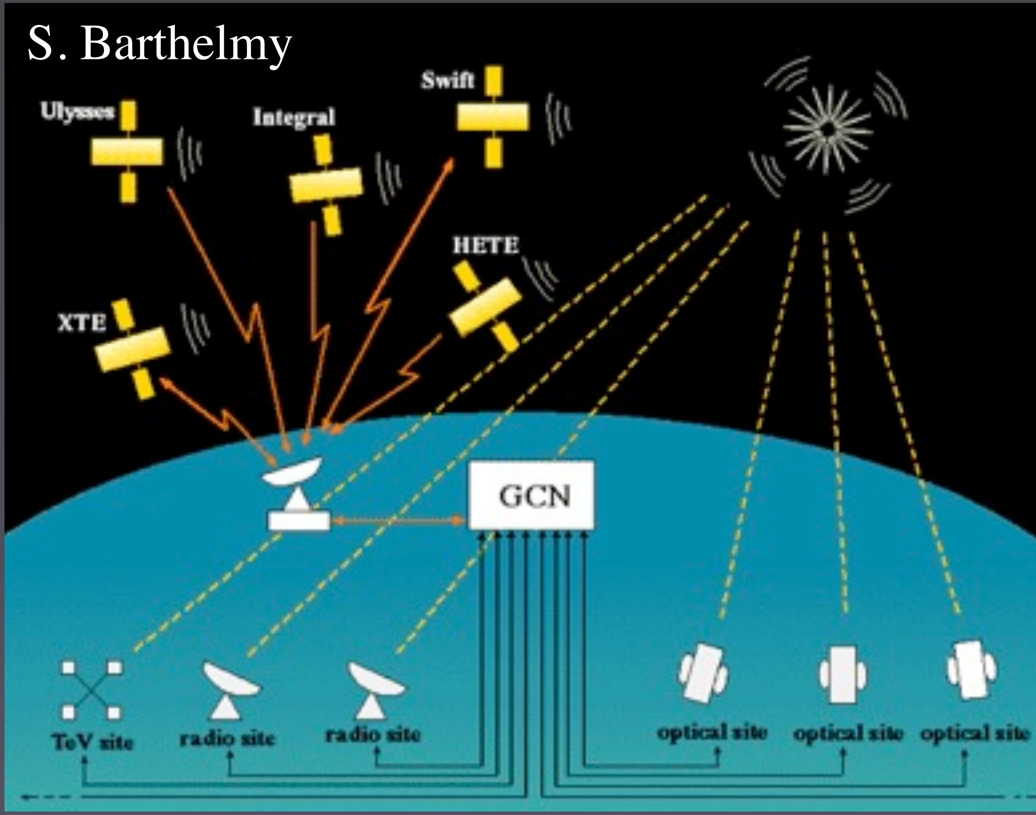
IRCam Good for Dusty GRB

- Perley+09 Study:
- ~ 1/3 GRB extinguished by $A_V = 1$ to 5 mag.
  - > 1 micron extinction is < 0.4 to 2 mag, most still detectable
  - Boosts rate by 30%!
- Detects IR emission early, UVCam detects optical later, for good measurement of dust evaporation.
- UVCam + RICam give evolution of optical-IR slope

Followup

- Will broadcast on GCN via Globalstar SMS
  - What about gamma/X followup?
    - Fermi has lots of sky coverage for much better "prompt" coverage to higher-E
    - pointed X-ray observations
      - SWIFT & Suzaku, Integral, and future instruments can follow up
  - spectroscopy especially welcome.



Thanks to N. Vedenkin for Globalstar SMS, Barthelmy for figure

UFFO-100 Predictions:X

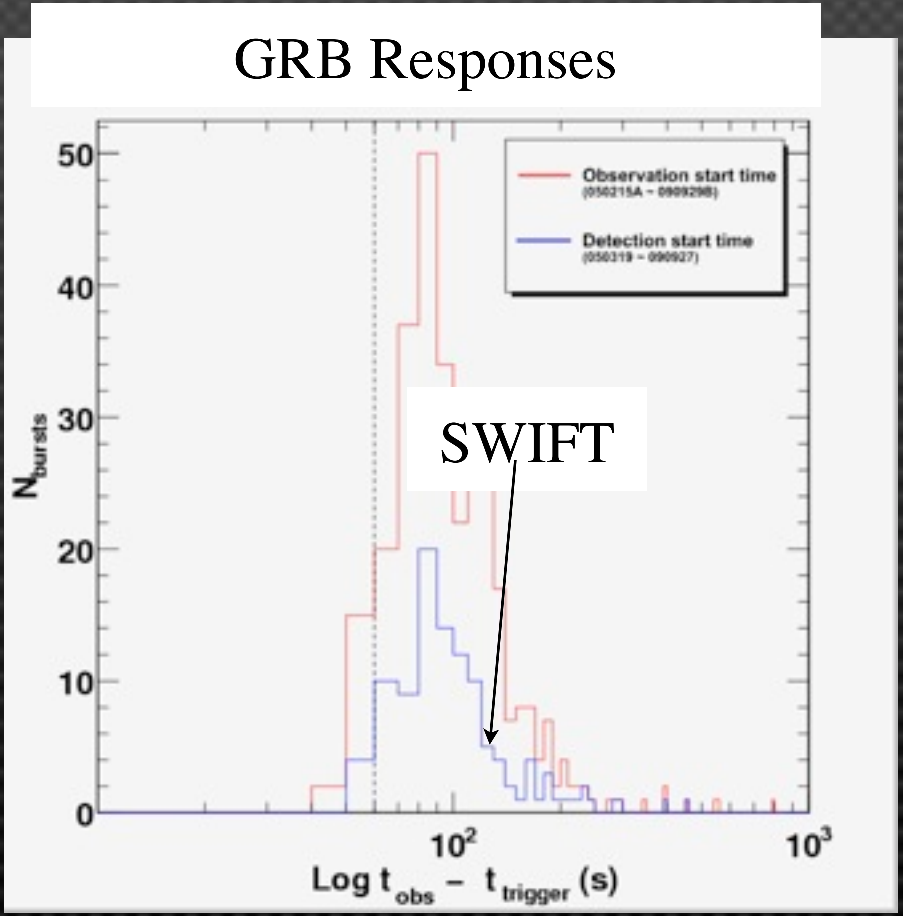
	SWIFT BAT	UFFO XTL
Area (cm^2)	5200	1024
Triggers/yr	77	64
SHGRB/yr	6.9	~ 5 (uncertain)

- Approximate: Scales SWIFT, Uses fluence histo, assumes duty cycle

	UVOT[1]	**UVcam**	**RIcam[1]**
sensitvity (Vmag,5σ) 1/10/100 s	18.1/19.3/20.5	<--- ~ same	14.3 ultra/ 19.3 fast t=1s Normal:.../ 21.9/ 23.2
N_{detect} / yr	27	15-22 10s (> 15 for early peaks, because we are faster!)	≥ 29 (including extinguished) more via sensitivity? All 5 SHGRB?

- Approximate: assume fixed fraction detectable, 1.3X for RIcam due to extinguished bursts
- (1)UVOT Sens. from GCNs; RICam & UVOT both at low zodiacal light

Wouldn't you like to see this?*



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- Response time function of mode/sensitivity + true t_{peak}

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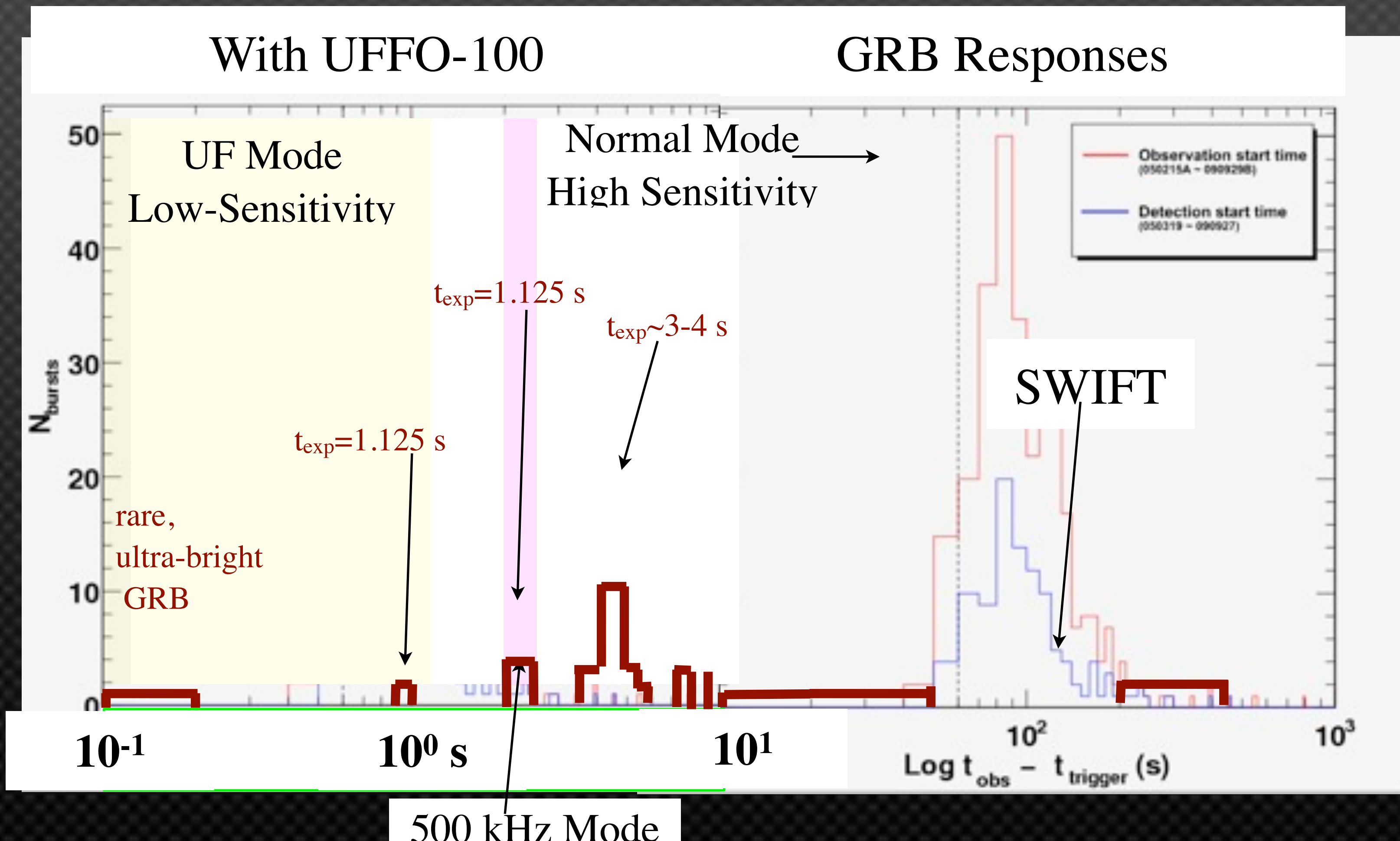

(* Please note this plot is grossly unprofessional conjecture.)

- Response time function of mode/sensitivity + true t_{peak}

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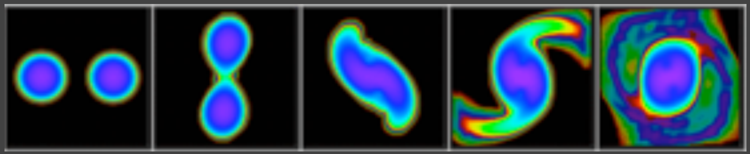
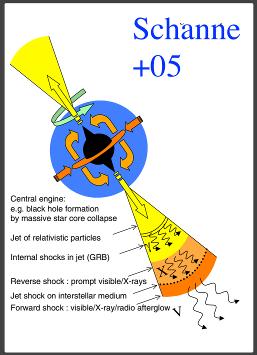
UFFO Summary

- UFFO-Pathfinder D=10 cm Nov. 2013 on Lomonosov
- UFFO-100 D=30 cm proposed for 2015
  - NUCLEON 2015... Elsewhere if not ... we have ideas!
  - Significant sample of GRB rise phase light curves
  - some 0.1-1 s measurements
  - Bulk Lorentz factors, rise times, X-opt correlations, possible multi-messenger measurements
- All projects open to follow-up & other contributions

Prompt GRB Science Summary

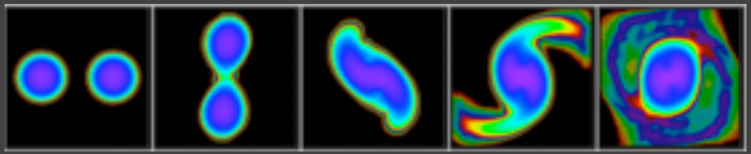


M. Rupert/MPA



Prompt GRB Science Summary

- Origin of Short Bursts?
  - **EXCITING accomplishment!**
  - Prompt may add key missing info, e.g. size scales



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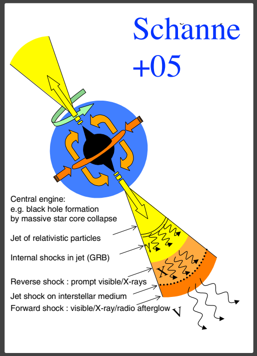

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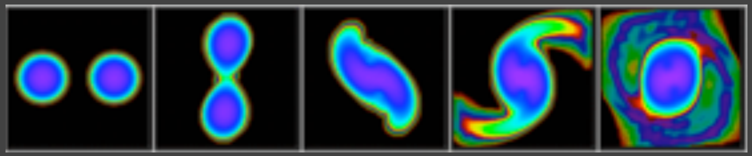

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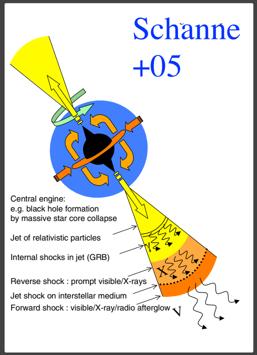
- Gravitational Wave Signal
  - Prompt response increases chance of ID of GW source



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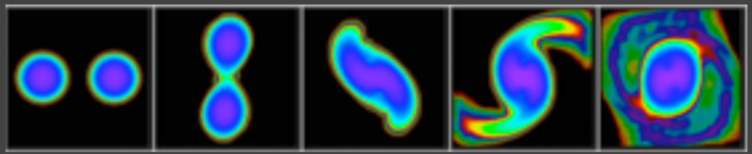

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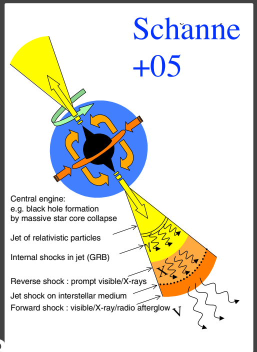

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  - Measure optical BLF, Refine models to include prompt optical emission, perhaps separate classes

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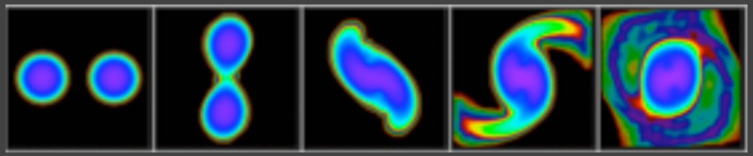

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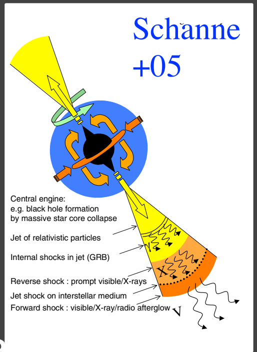

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  - Measure optical BLF, Refine models to include prompt optical emission, perhaps separate classes
- Cosmology-Can GRB be "calibrated" standard candle?
  - Revolutionary tool...Hubble diagrams to z>8, etc.
  - More Cosmology: finding early galaxies, finding earliest stars, GR tests ...

The End

-Thank You-