Early Light from Gamma Ray Bursts

Prof. George F. Smoot

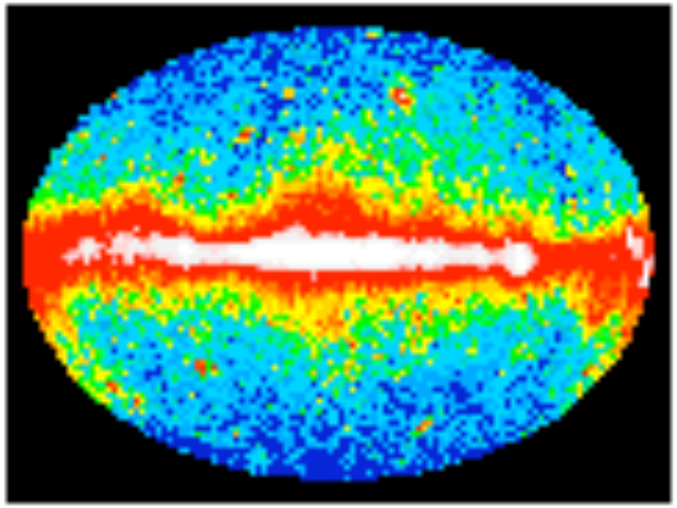
For UFFO-Pathfinder Collaboration:

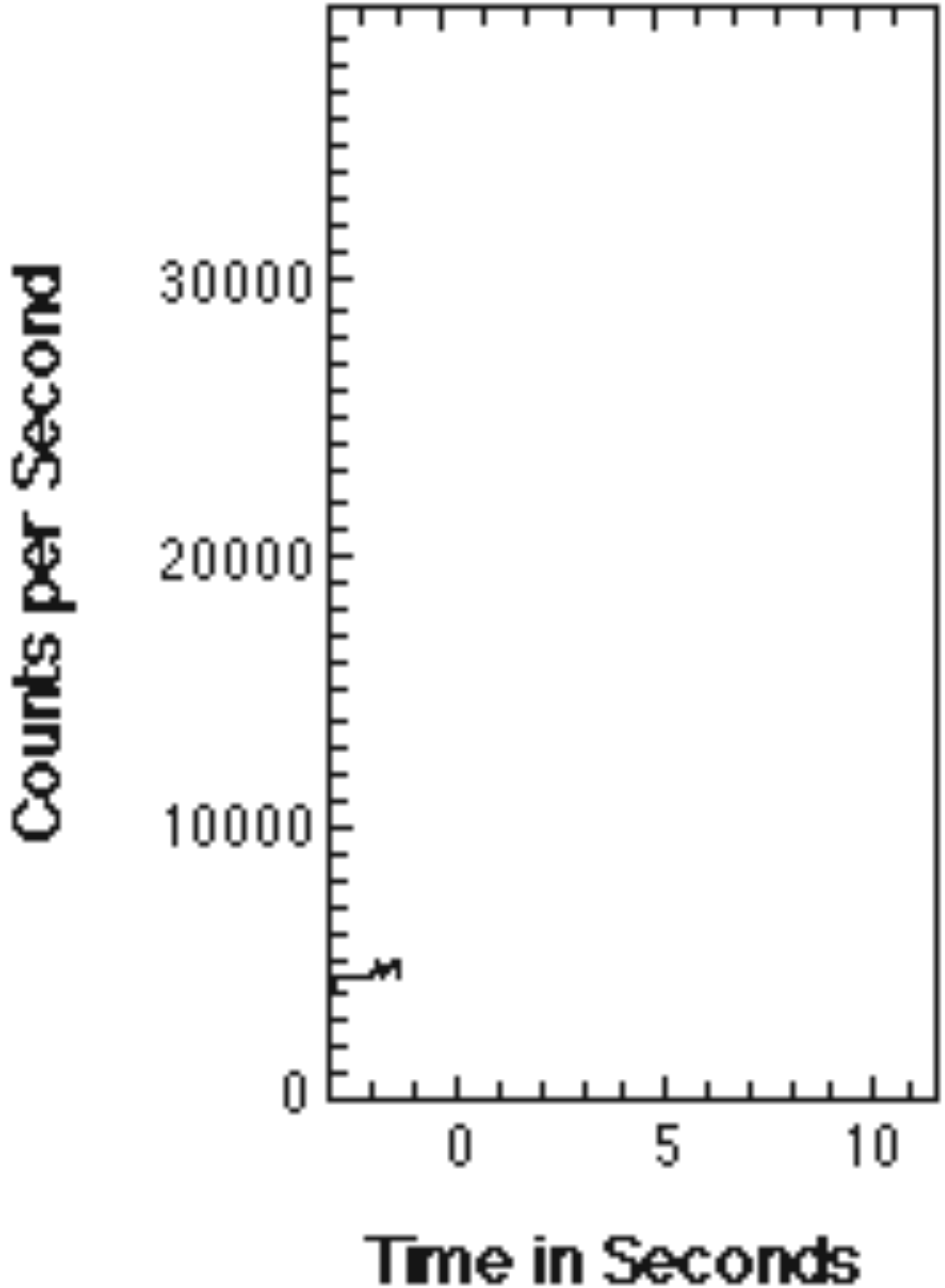
Ewha Womans University, Seoul, Korea
Yonsei University, Seoul, Korea
Korea Institute of Industrial Technology, Ansan, Korea
Korea Advanced Institute of Science and Technology, Daejeon, Korea
University of Paris-Sud 11, France
Universite Paris Diderot, France
National Space Institute, Denmark
Instituto de Astrofisica de Andalucia, Consejo Superior de Investigaciones Cientificas, Spain
University of Valencia, Spain
University of California, Berkeley, USA
National Taiwan University, Taipei, Taiwan
National United University, Miao-Li, Taiwan
Moscow State University, Moscow, Russia

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 (rest energy of a proton)
- Afterglow can be detected weeks after burst, has power law decay light curve in all bands for some long type GRBs
- Long Type GRB associated with massive star collapse SuperNovae

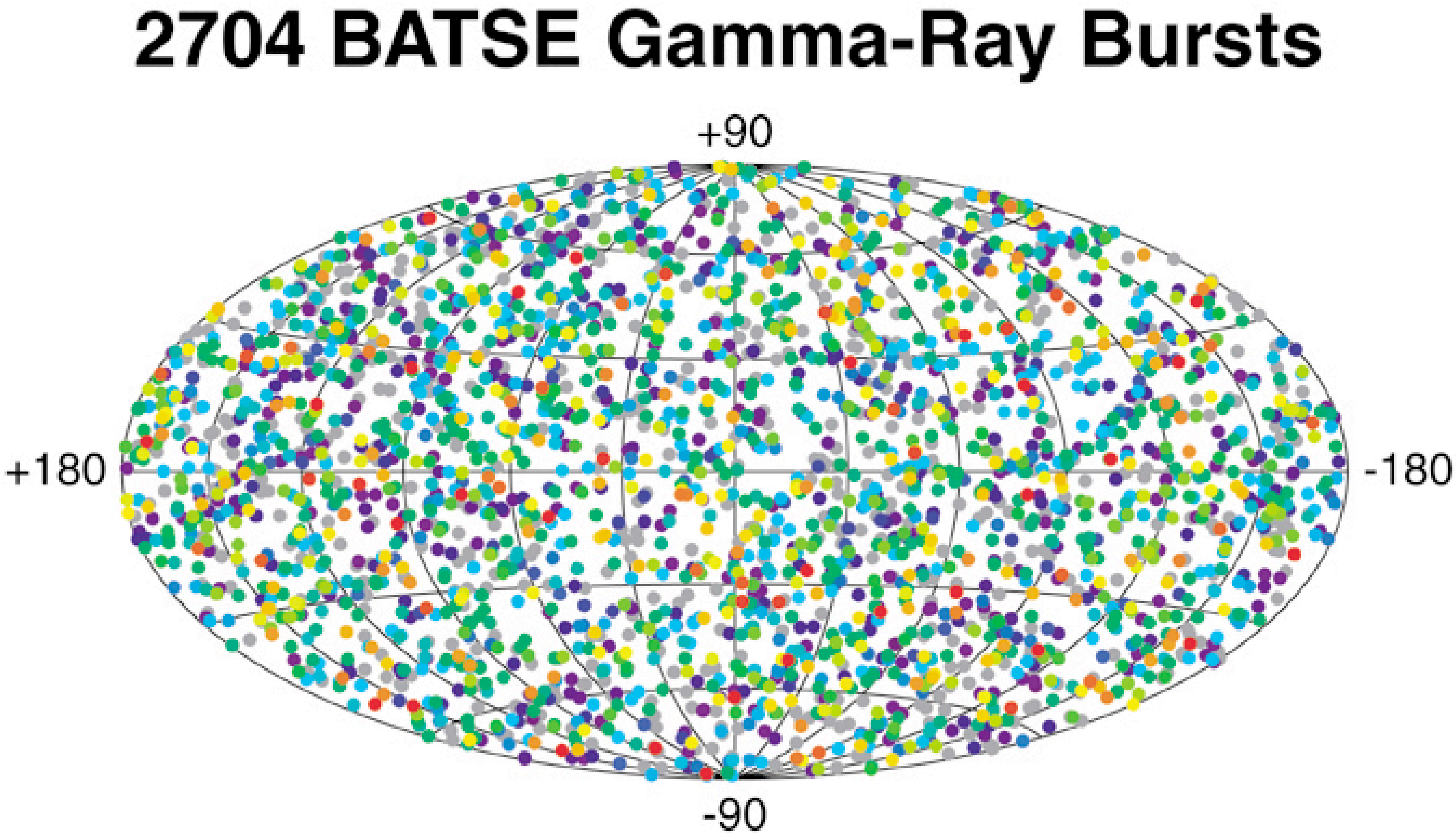




Counts per Second
30000
20000
10000
0
0
5
10
Time in Seconds

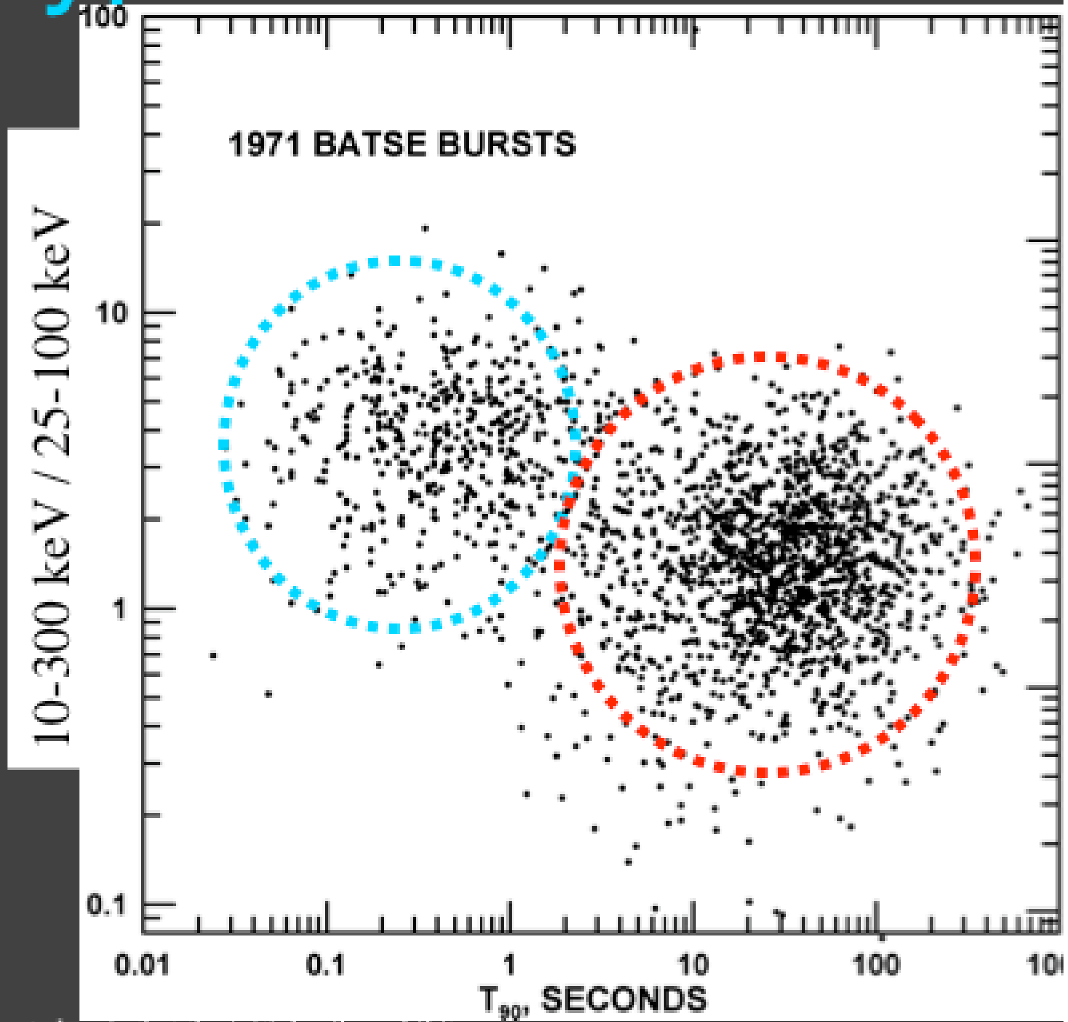
500 GRBs Observed by Swift

GRBs Uniform on Sky => Extragalactic



2 Main Types of GRB

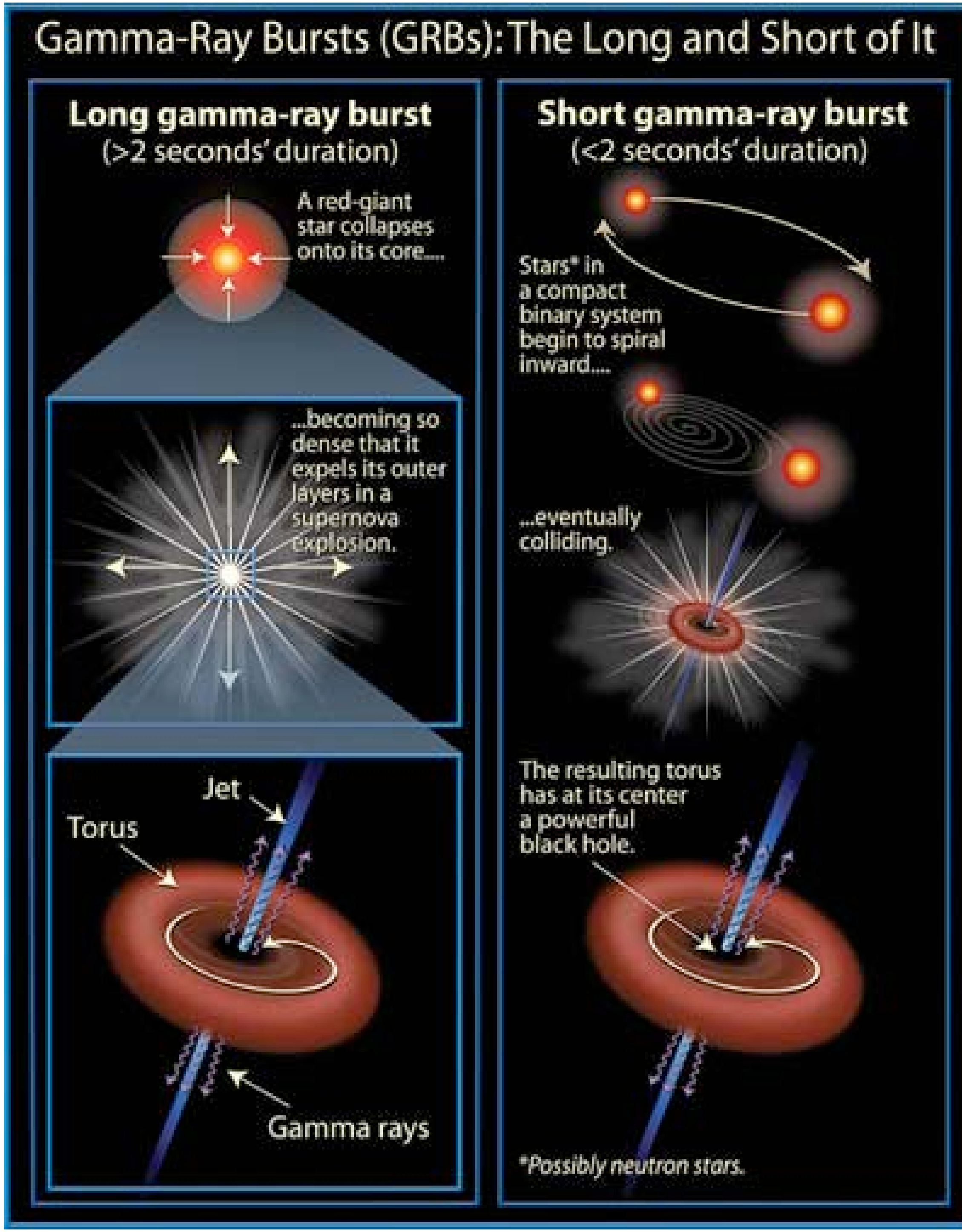
- GRB=Gamma-Ray Burst
- LGRB=Long, softer
  $t_{90\gamma}$ >2 s, Typical ~ 20 s
- SGRB = Short GRB
  $t_{90\gamma}$ < 2 s, Typical ~ 0.4 s
  - "harder" X-γ spectra,
  - much fainter all optical
  - faint X-γ afterglow
- (OTHER classifications exist)

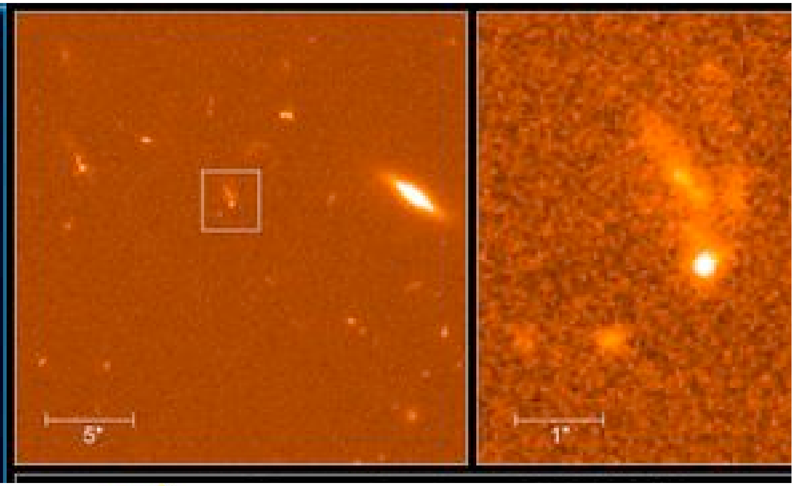


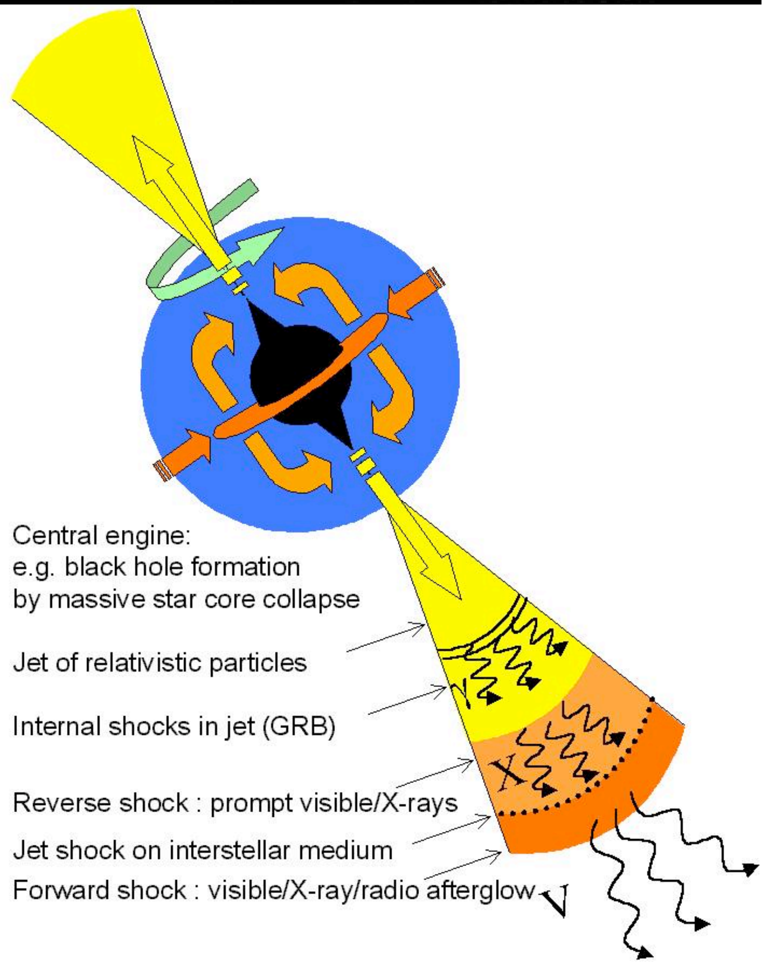
-we show that the fundamental defining characteristic of the short-burst class is that the initial spike exhibits negligible spectral evolution at energies above ~25 keV. "- Norris & Bonnell 2005

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

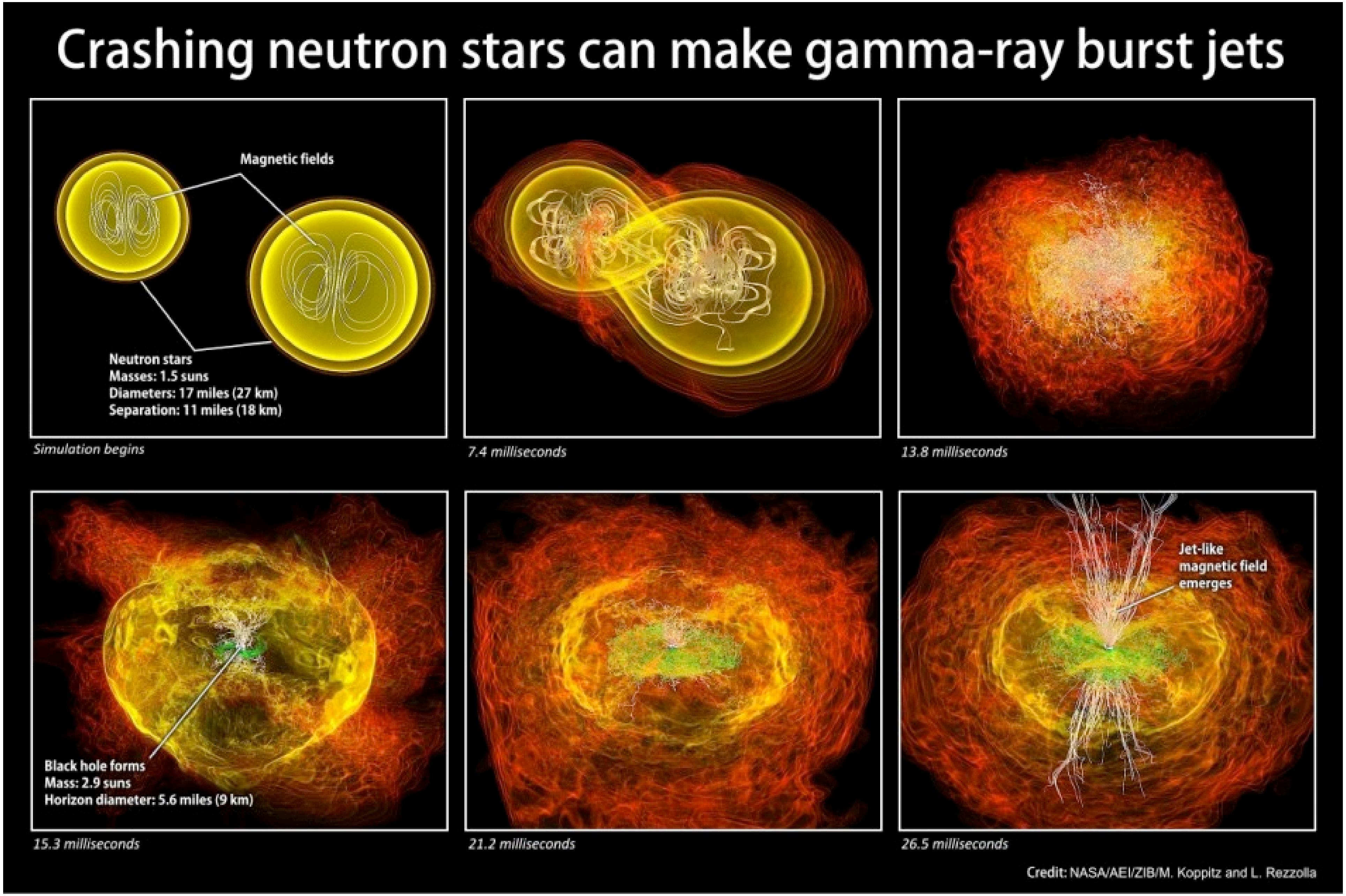
Hard = flatter spectrum = crude ratio of high, low energy channels.


Gamma-Ray Bursts (GRBs): The Long and Short of It
Long gamma-ray burst
(>2 seconds' duration)
A red-giant star collapses onto its core....
...becoming so dense that it expels its outer layers in a supernova explosion.
Jet
Torus
Gamma rays
Short gamma-ray burst
(<2 seconds' duration)
Stars* in a compact binary system begin to spiral inward....
...eventually colliding.
The resulting torus has at its center a powerful black hole.
*Possibly neutron stars.

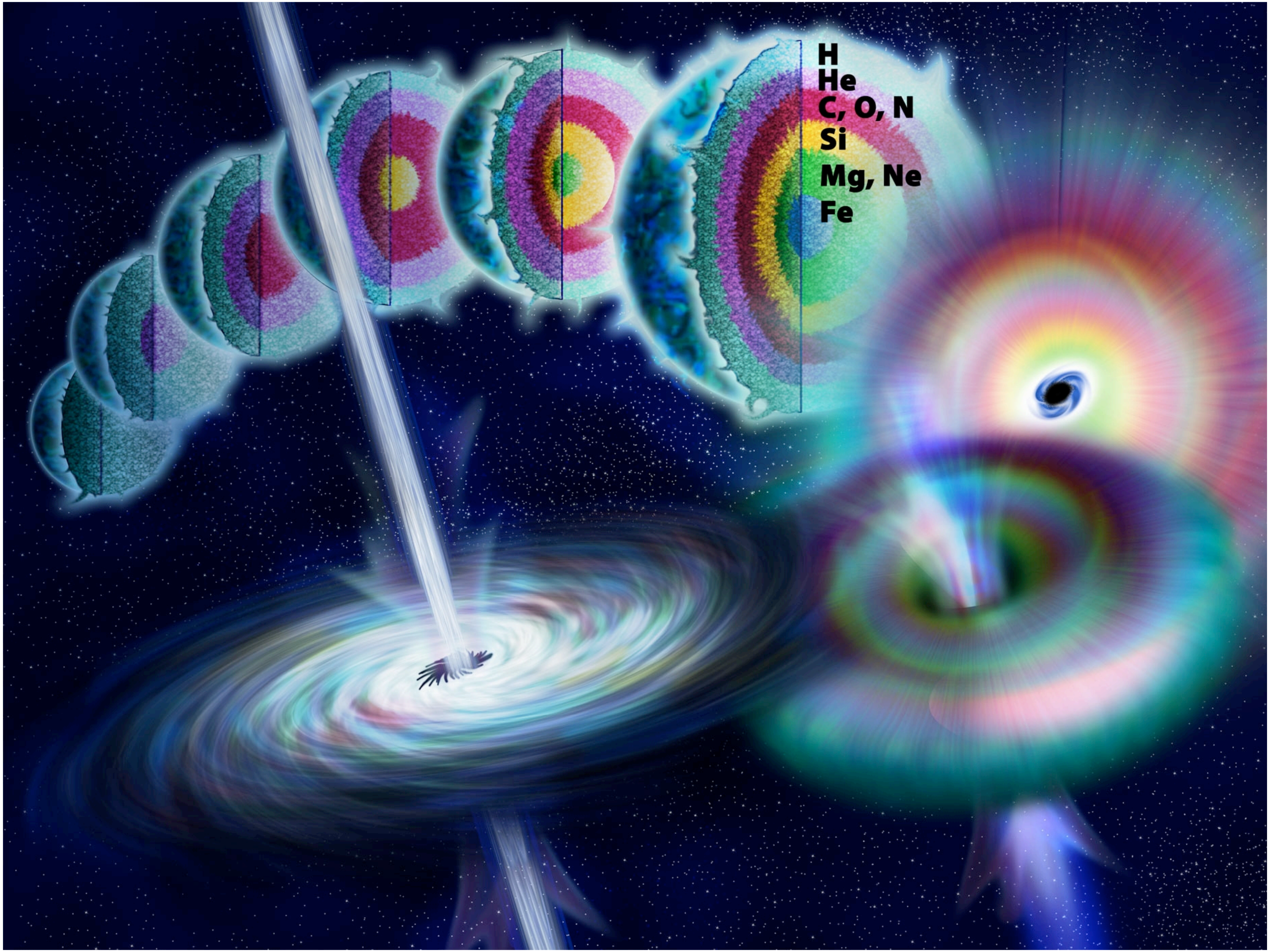


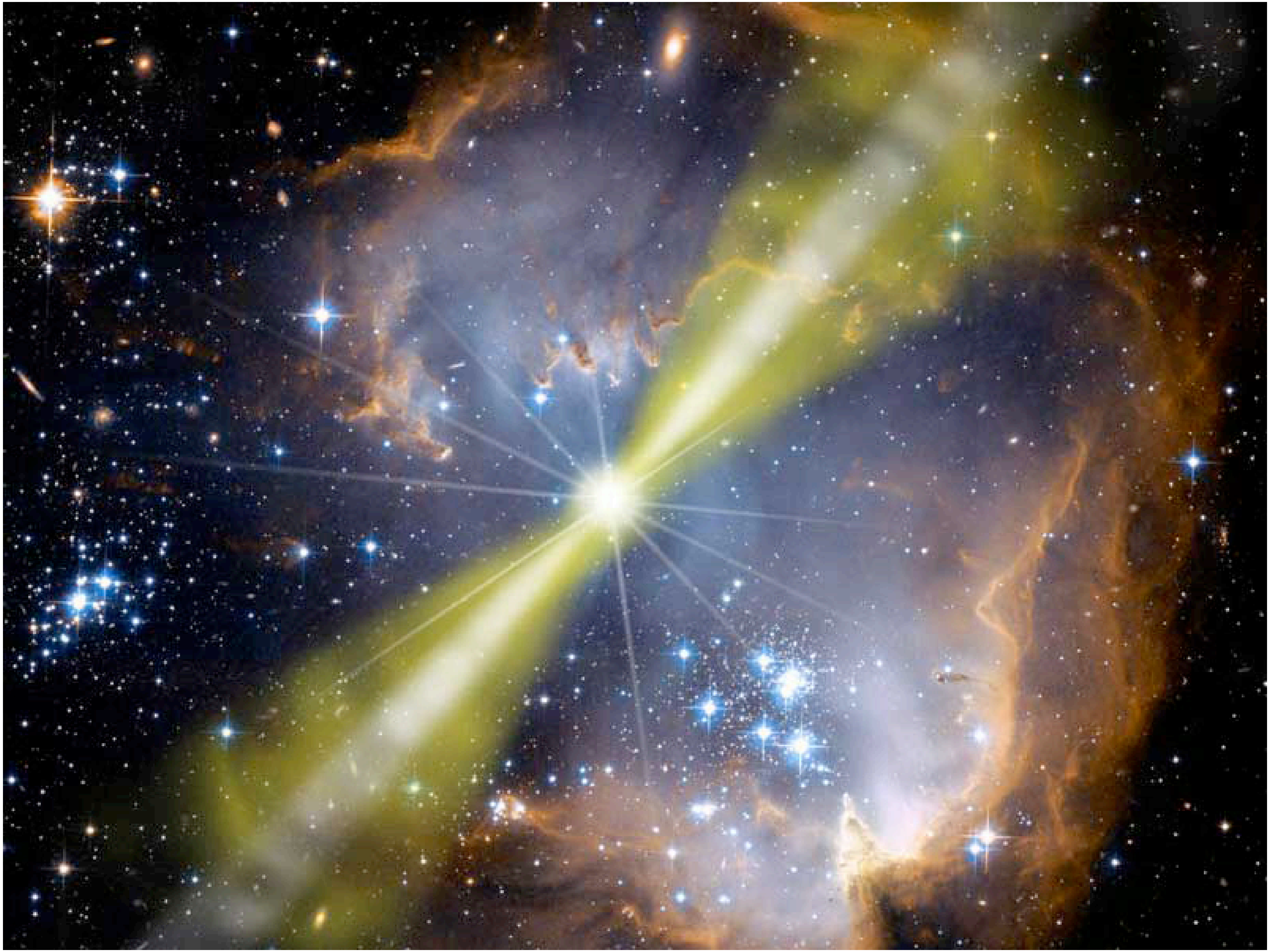

Central engine:
e.g. black hole formation
by massive star core collapse
Jet of relativistic particles
Internal shocks in jet (GRB)
Reverse shock : prompt visible/X-rays
Jet shock on interstellar medium
Forward shock : visible/X-ray/radio afterglow

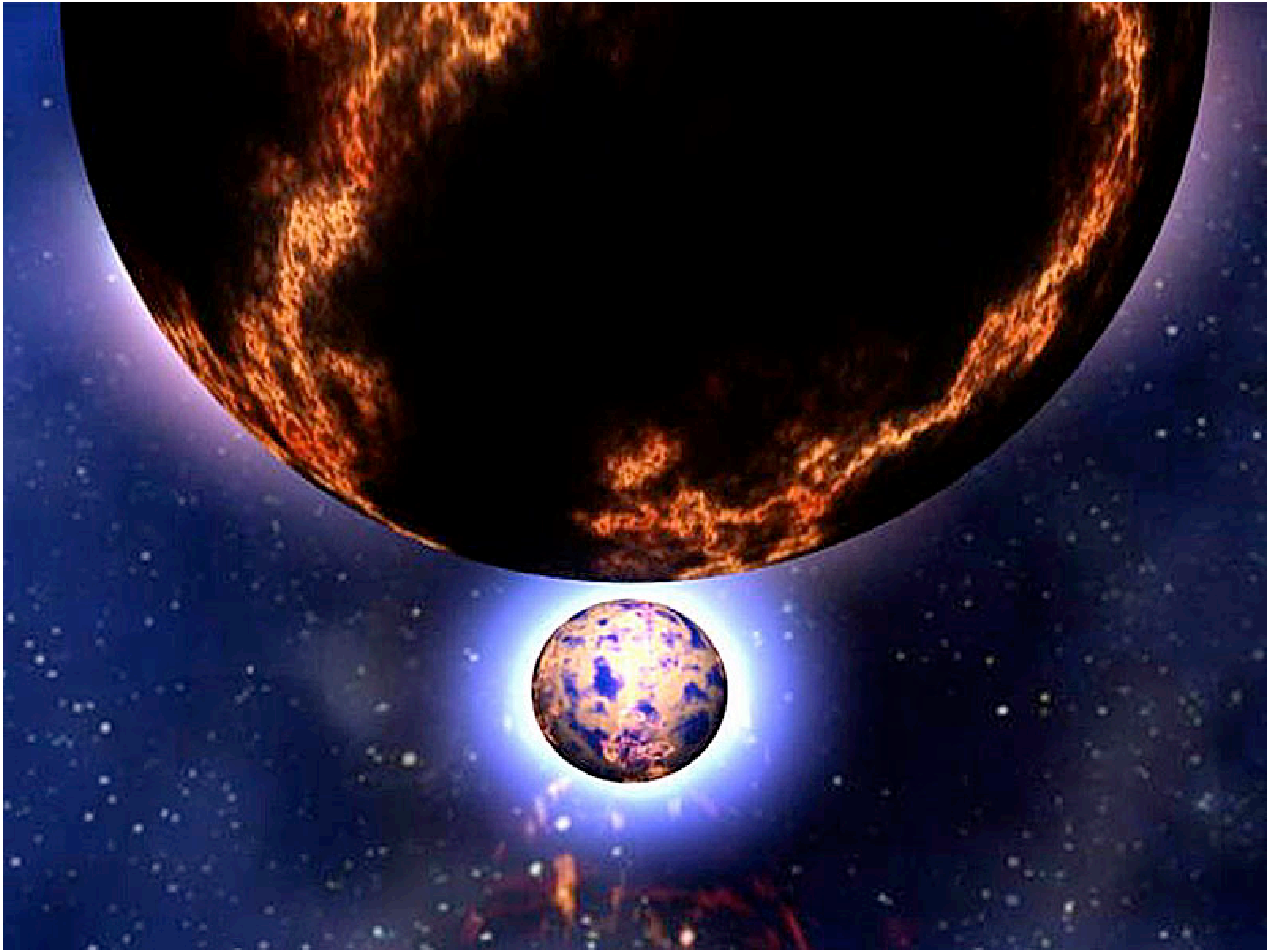
Inspiraling & Merging Neutron Star Model

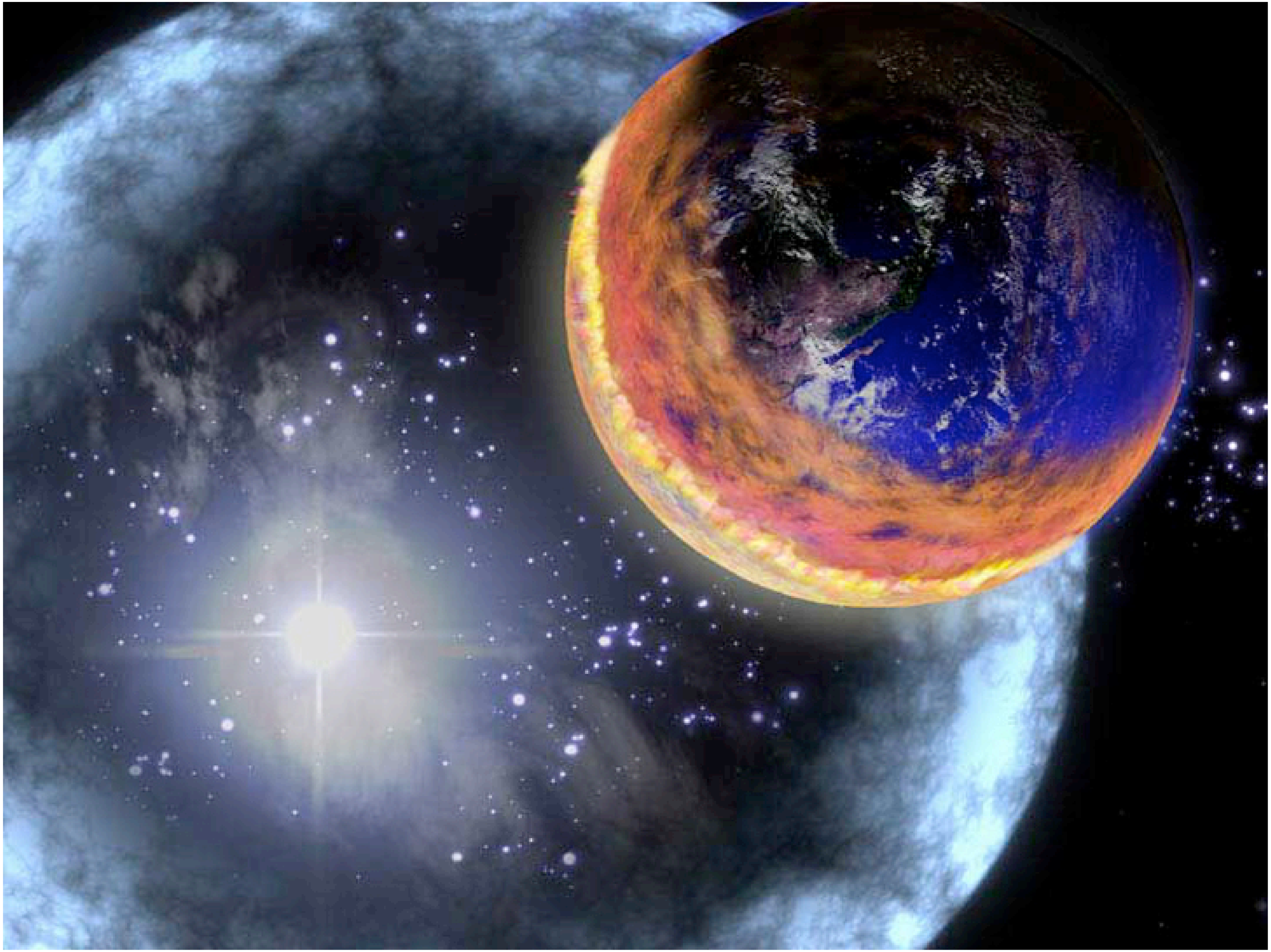


Neutron Star Inspiral Model Video

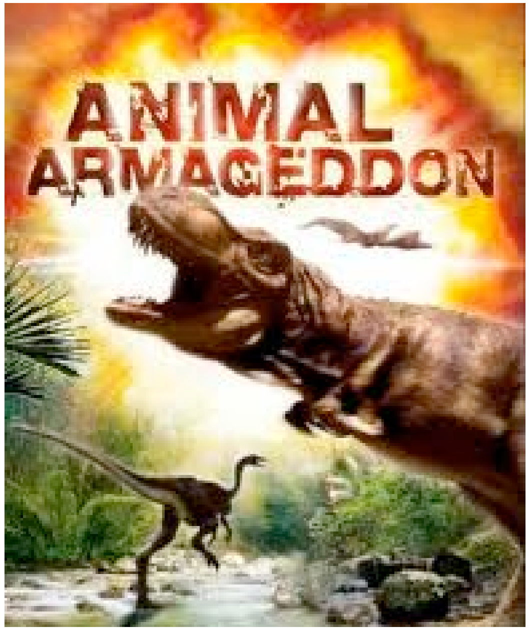

H
He
C, O, N
Si
Mg, Ne
Fe





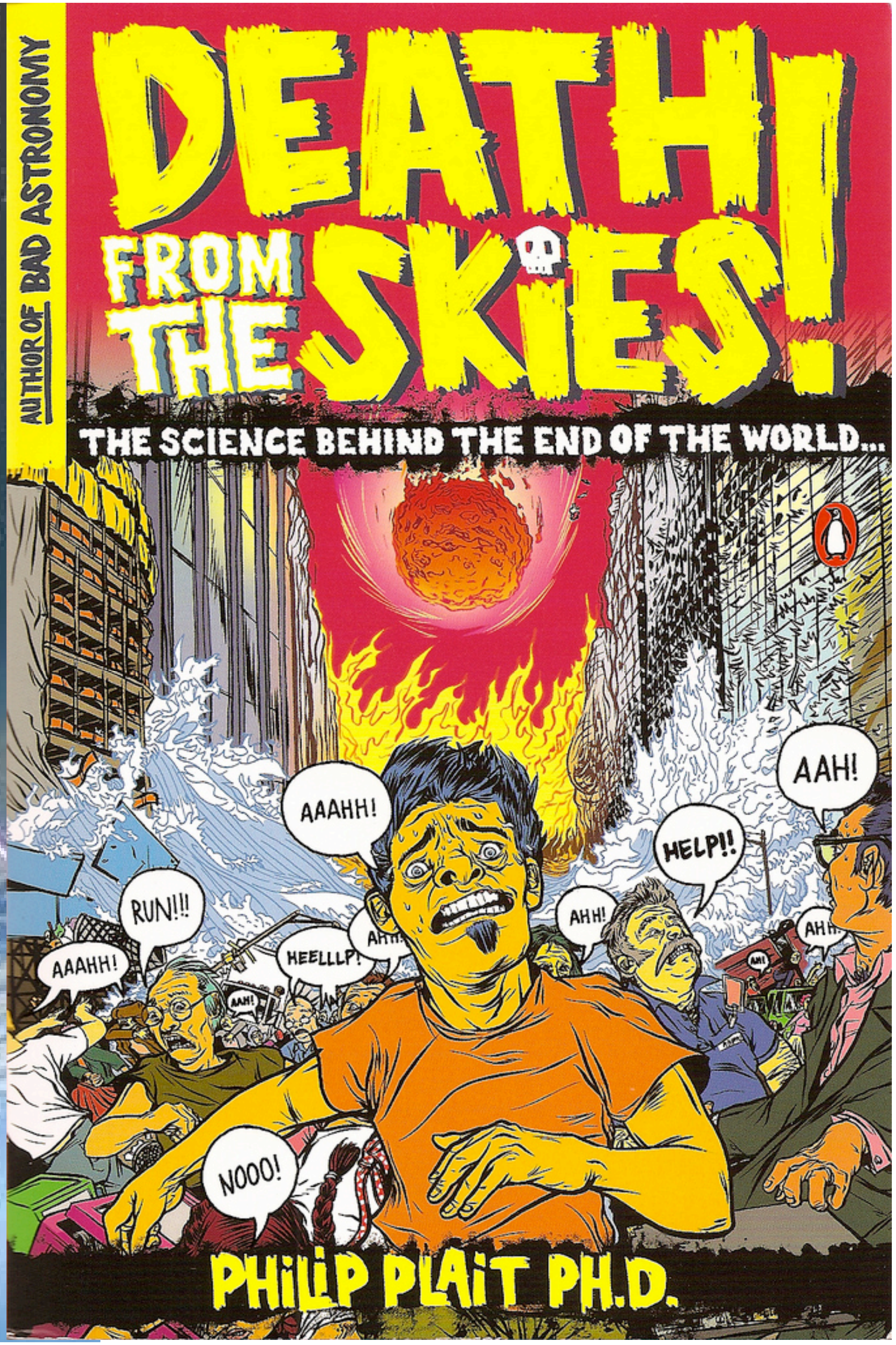


Extinctions or Sterilization of Earth



- Using cutting edge research, the latest scientific theories and incredible CGI to bring prehistoric animals back to life,
- Animal Armageddon an eight-part mini-series
  - transports viewers
    disasters ever to ro
  - From a cosmic gam
    atmosphere, trigger
  - to an asteroid the s
    the Yucatan, killing
    natural events caus
  - oughout the 600
    stence, some 99.
    ever lived is no
  - mal Armageddon
    inction of these a
    datory sea mons
    tiloid, to vicious
    giant mammals li
  - mal Armageddon
    ath had on these
    owed.

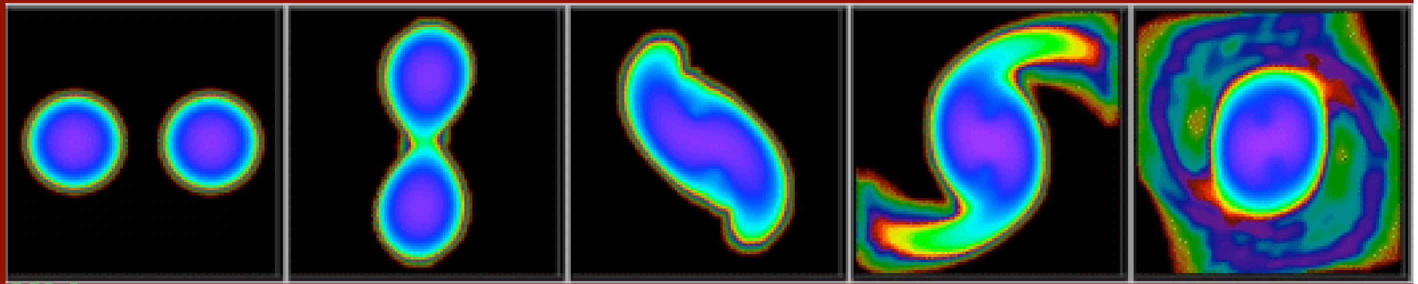
It seems that gamma-rays from space may have been responsible for the massed extinction of the Ordovician period (488 to 443 million years ago) where about 70% of sea life died out.
Creepy stuff.



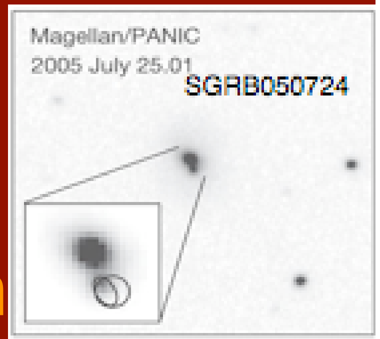
AUTHOR OF BAD ASTRONOMY
DEATH FROM THE SKIES!
THE SCIENCE BEHIND THE END OF THE WORLD...
AAH!
AAAHH!
HELP!!
RUN!!!
AHH!
AAAHH!
HEELLLP!
NOOO!
PHILIP PLAIT PH.D.

SHGRB Origin Unknown

SHGRB now associated with coalescence models



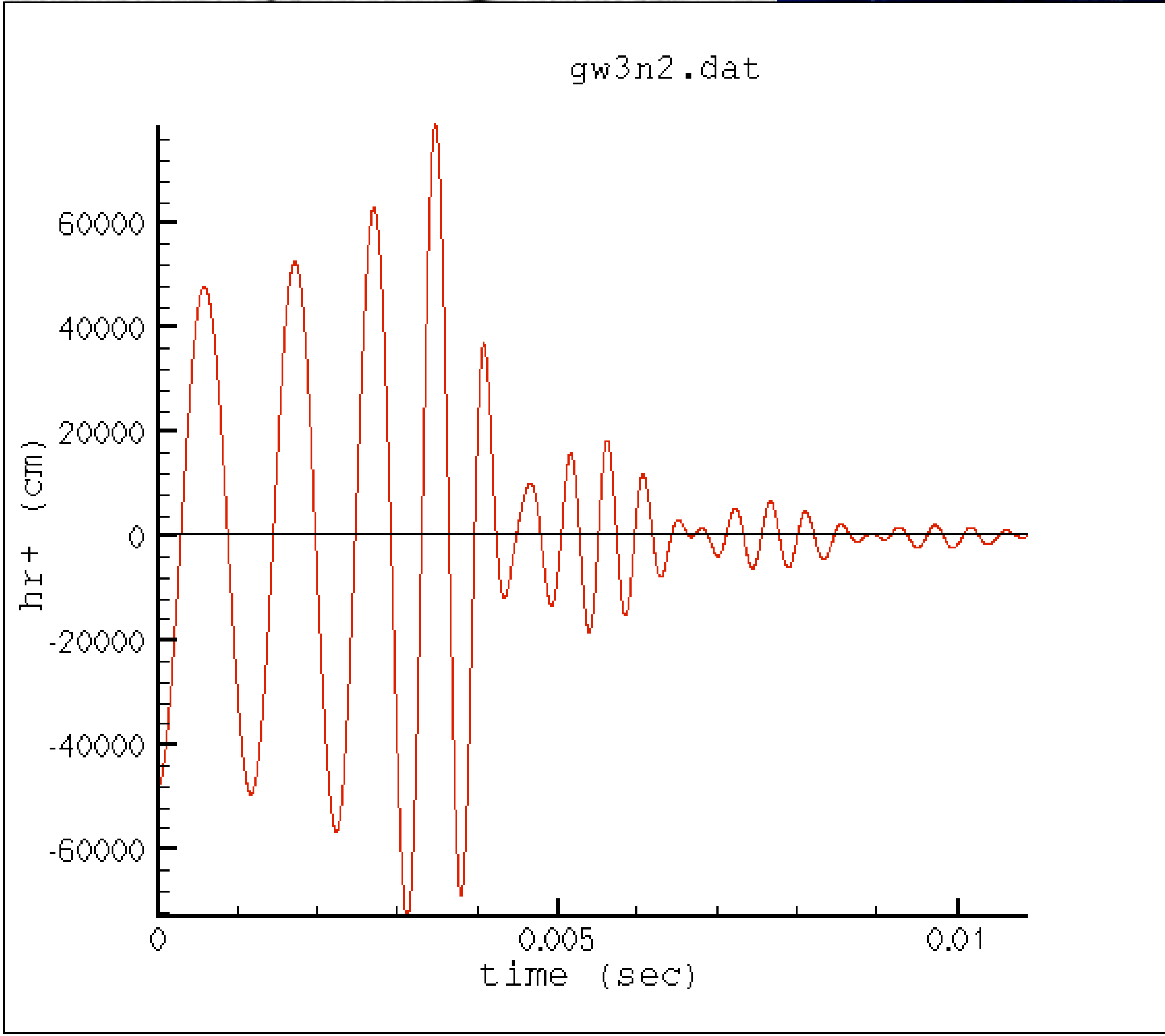
- *Consistency*
  - *SHGRB faintcompared to LGRB, lower energy.*
  - *Usually not in star forming regions, far from galaxy, so could be evolved system - like dead neutron start (NS) or black holes (BHs)*
  - *No actual proof;*
- *Outstanding Mystery*

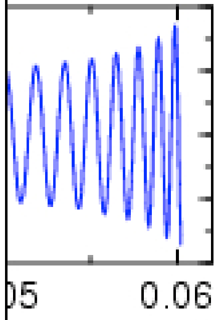


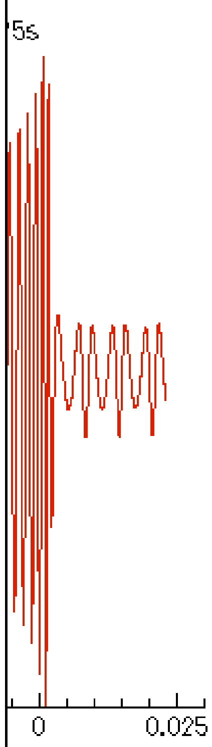
- Compact object coalescence would mean Gravitational Waves (GW), likely detectable by next-generation GW detectors if close enough.

ry Inspiral

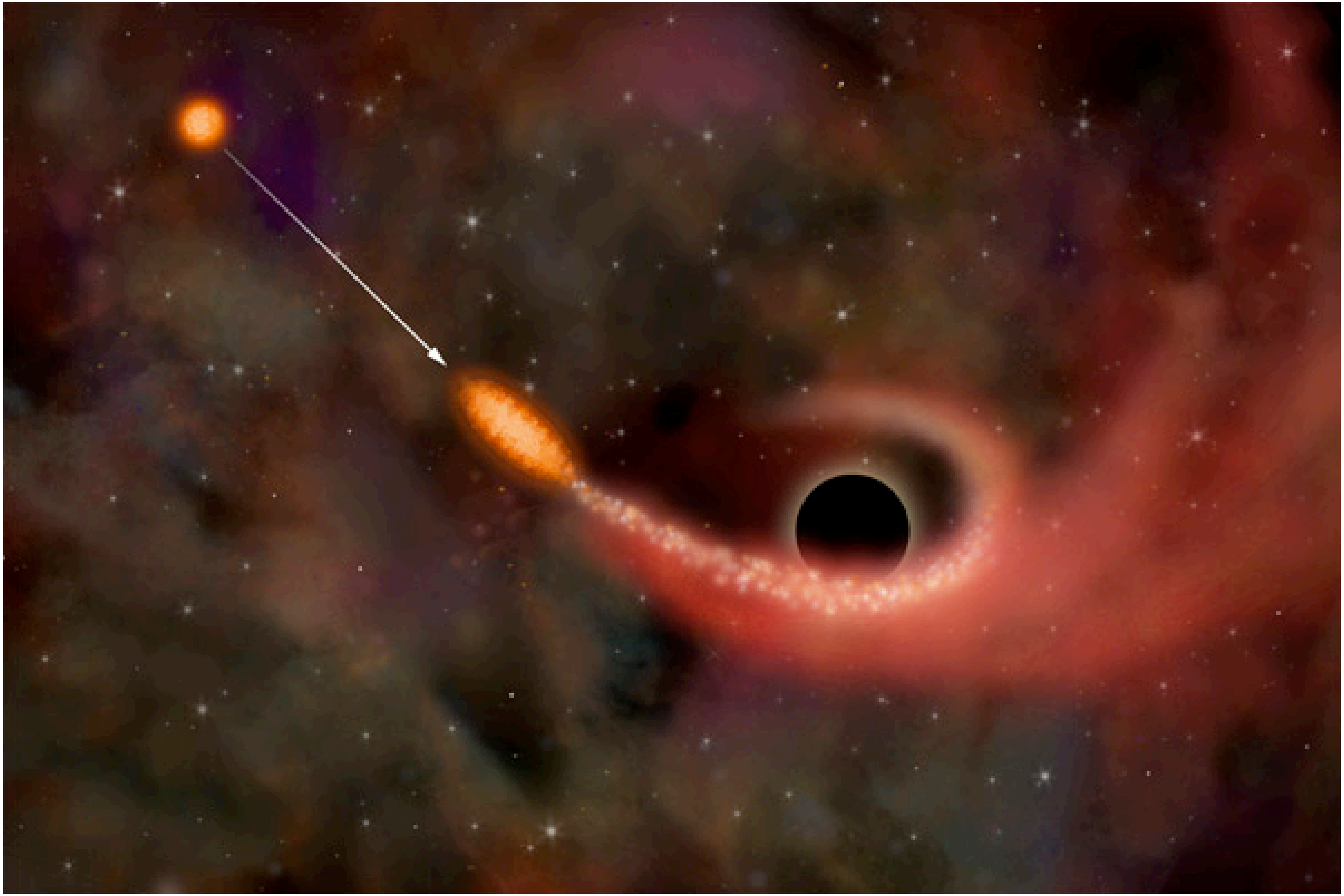
cence: f=635Hz



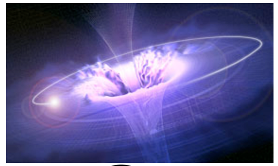




Black Hole disrupts and swallows star



Very Short GRBs ? Black Hole Evaporation Bombs?



- **“Does Very Short Gamma Ray Bursts originate from Primordial Black Holes?”** by D.B. Cline & S. Otwinoski arXiv:1105.5363
- Primordial Black Holes with mass of about 5 x 10^{14} gm evaporate now in a final state explosion. (Power goes as $1/m^4$ and lifetime as $1/m^3$ and see plot to right)

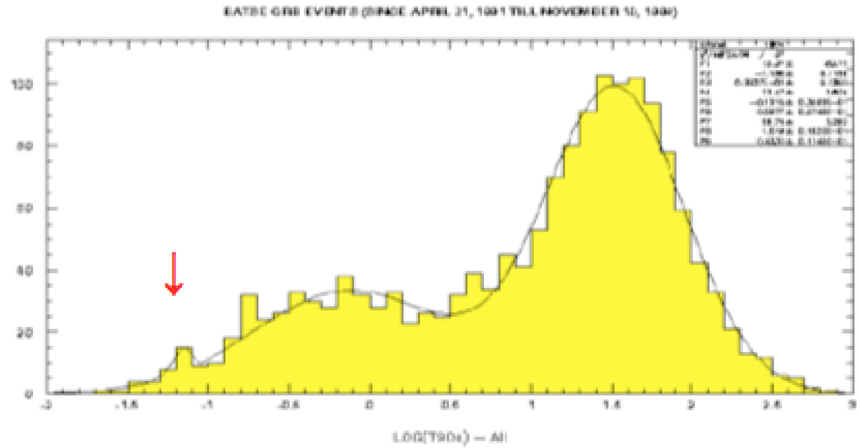


Fig.1. The time distribution T_{90} for all GRB from BATSE detector [1].

7. Time profile of rising part of BATSE VSGRBs is in agreement with evaporation PBH.

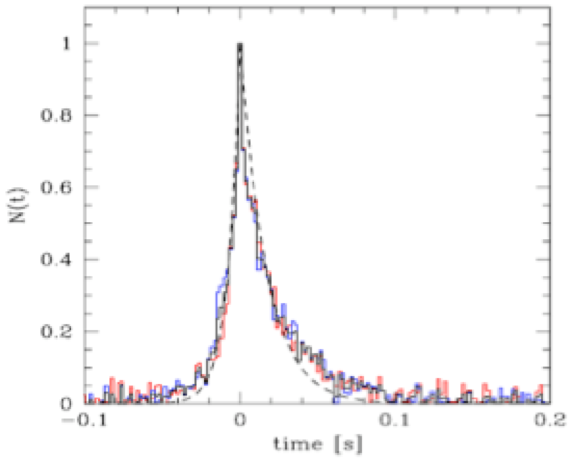
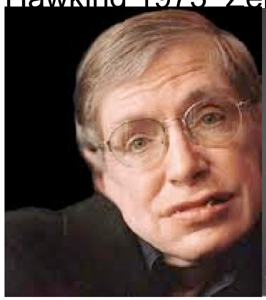
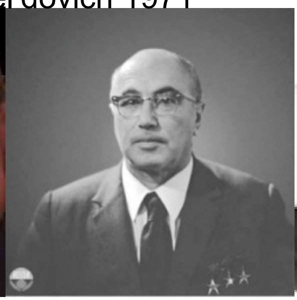


Fig.10. Composite burst profiles for all VSGRB (black line), for bursts from Galactic Anticenter region (red line) and for bursts from outside that region (blue line). The analytical fit (dashed line) is given by Eq.1. Better fit for the decay part is provided by Ryde & Svensson function (Eq. 2) [10].

Hawking 1973, Zel’dovich 1971

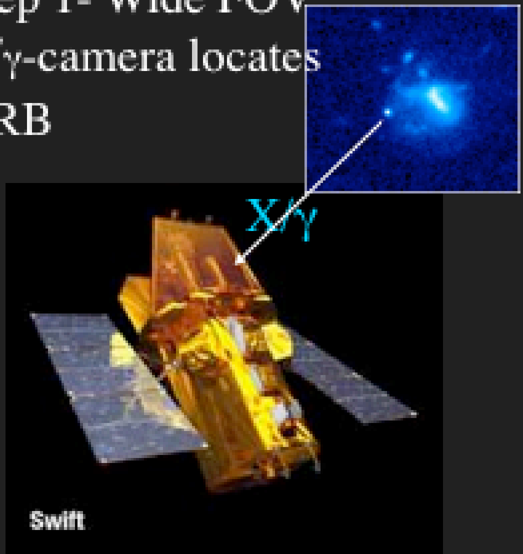




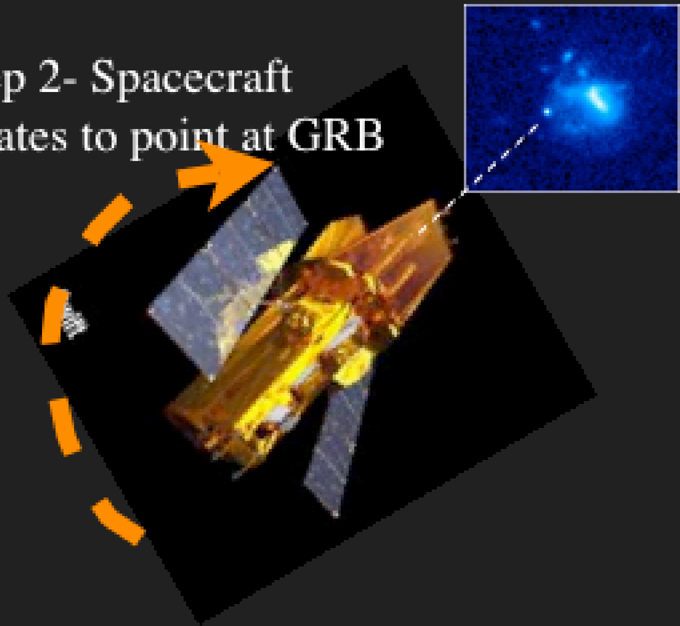
Faster-Steer the Beam

- SWIFT rotates entire spacecraft to point opt instrument

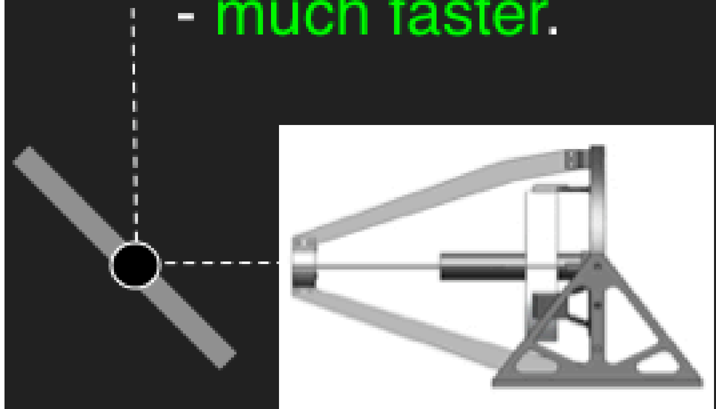
Step 1- Wide FOV X/γ-camera locates GRB

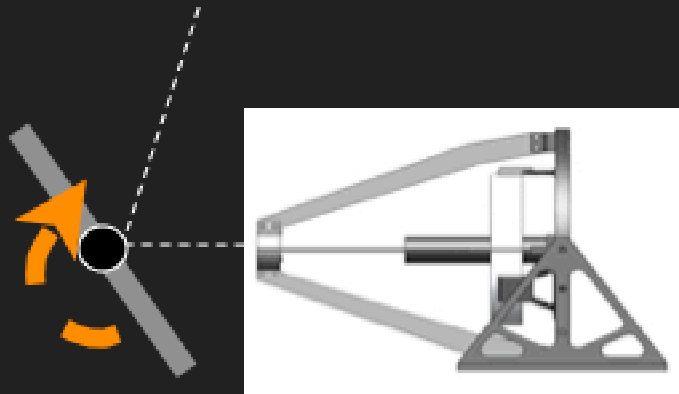


Step 2- Spacecraft rotates to point at GRB



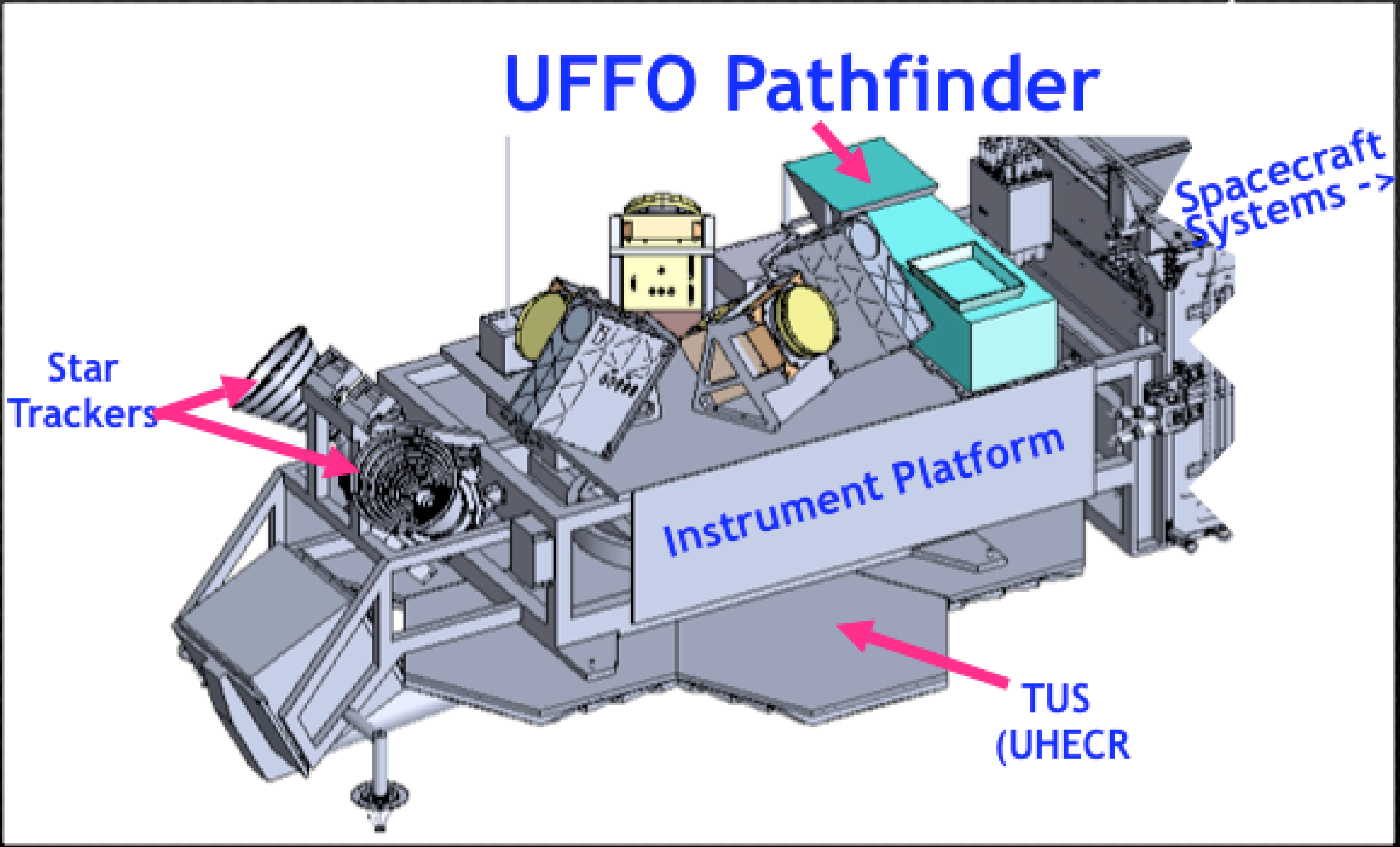
- We use mirrors to steer the *beam*, not the spacecraft - much faster.





UFFO -pathfinder mission

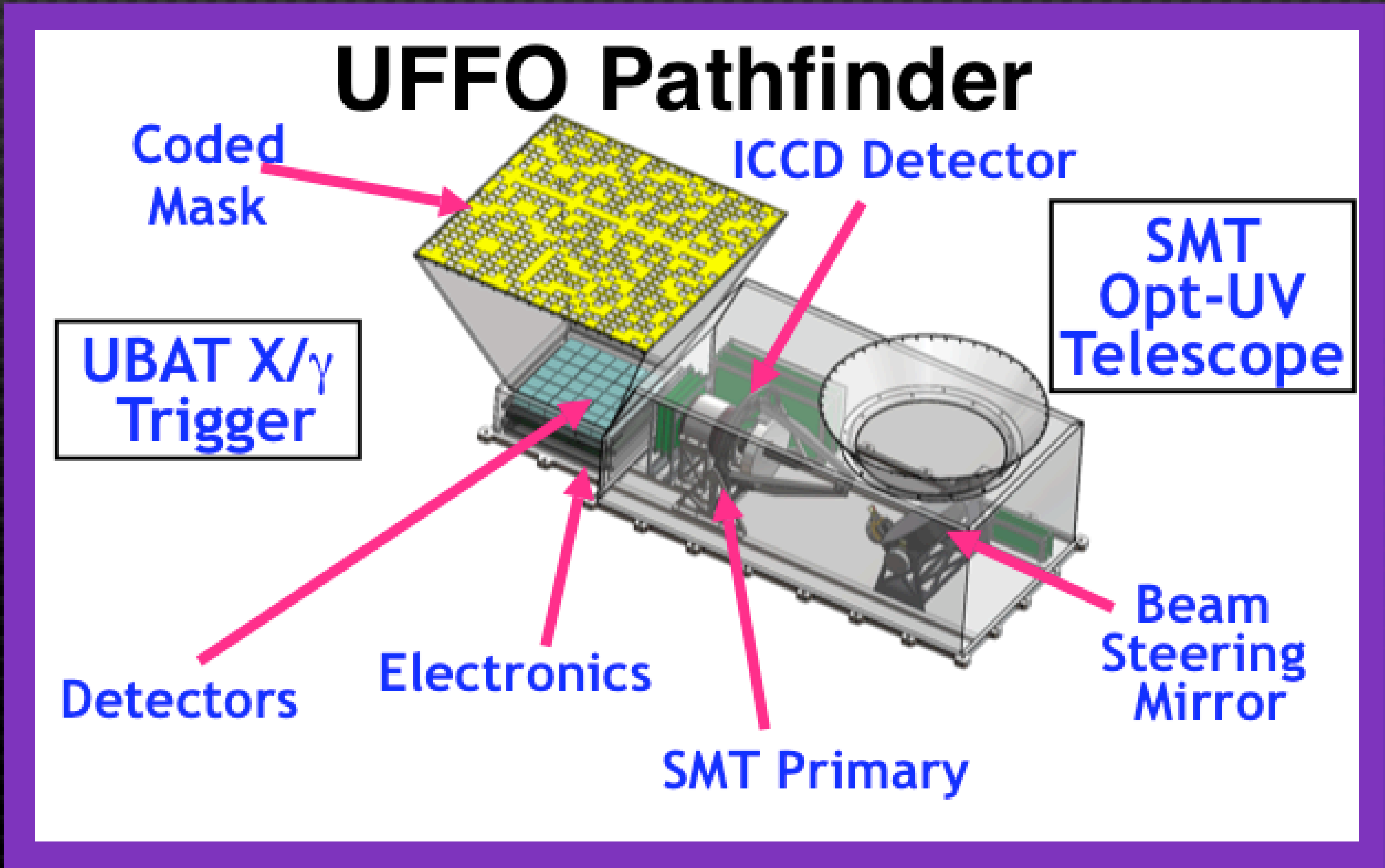
- We were *given* 20 kg on the Russian Lomonosov spacecraft in UNIVERSITAT program-Launch in Nov!

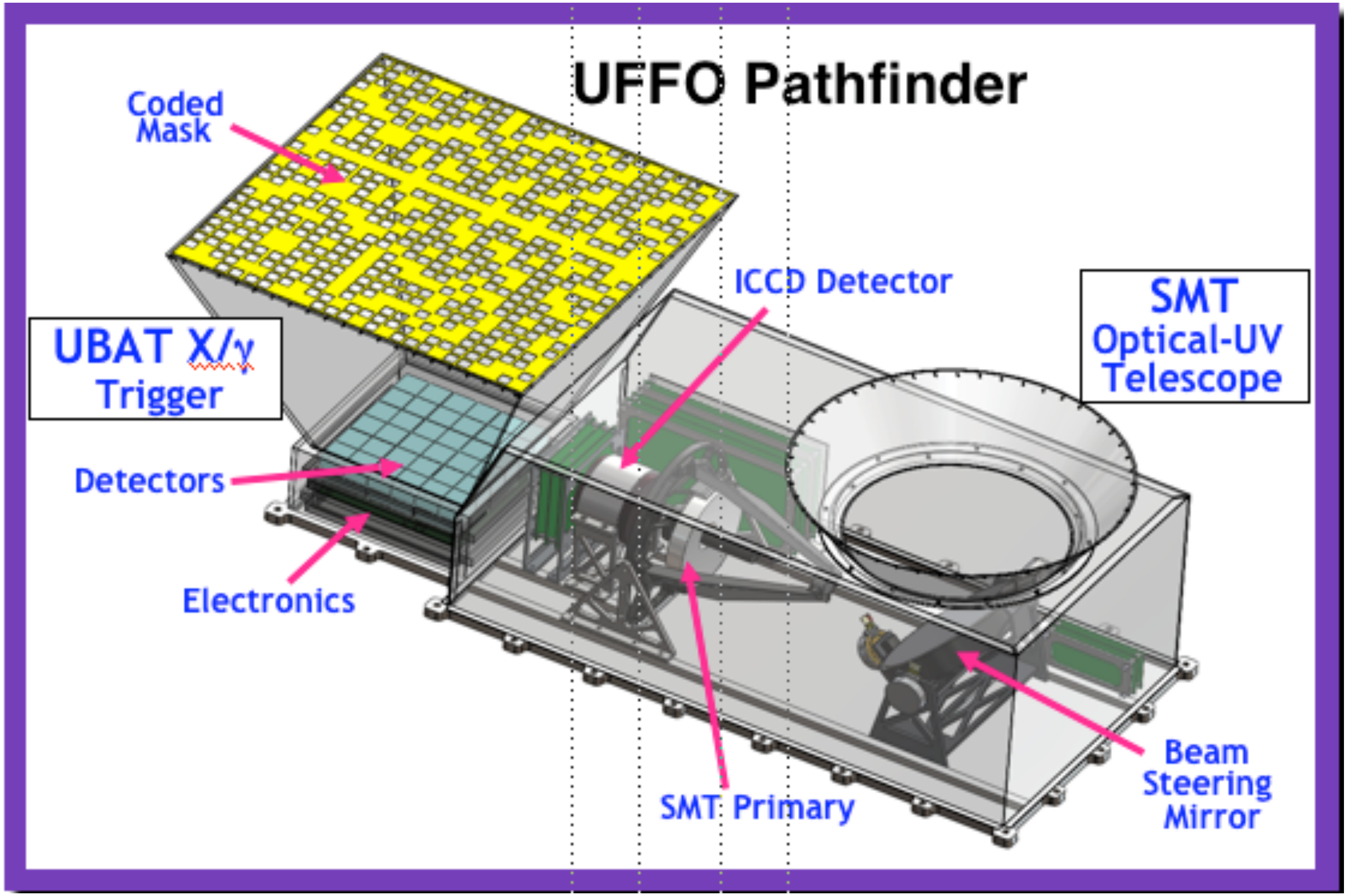


Il Park is P.I. UFFO-Pathfinder

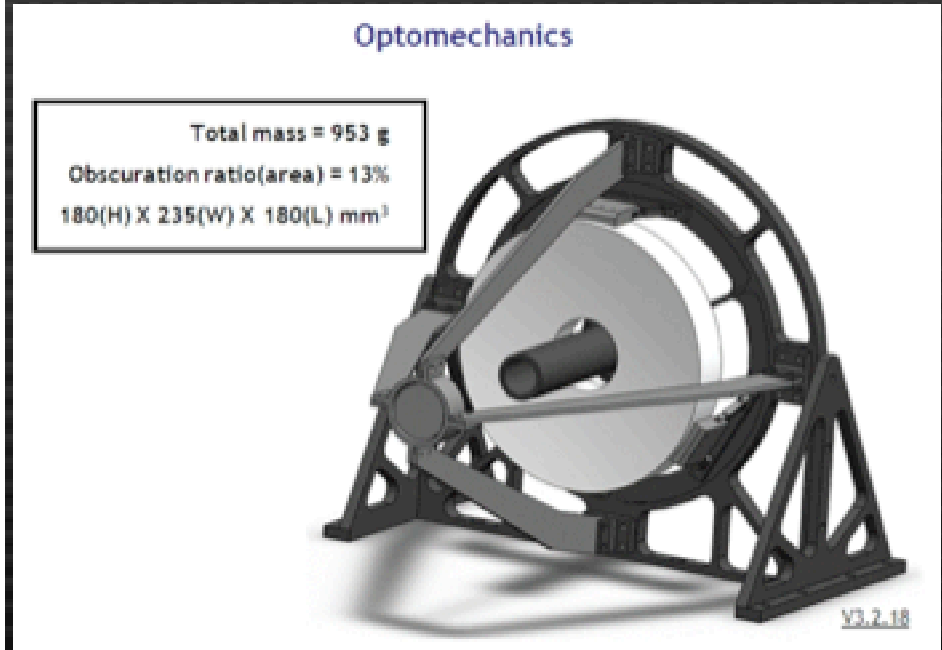
UFFO pathfinder design

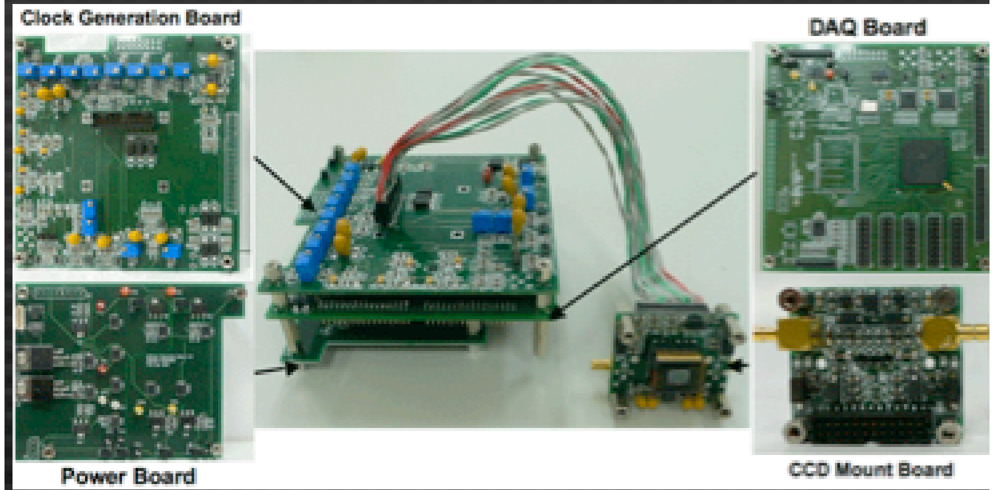
- MODEST! - 20 kg, 10 W

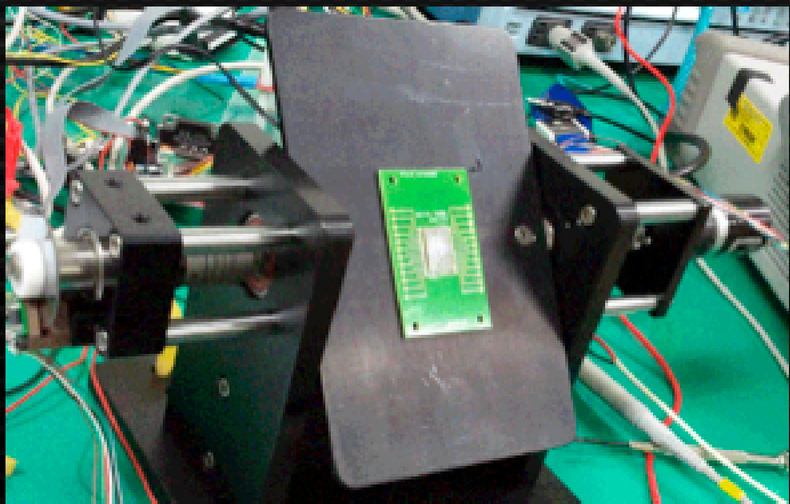


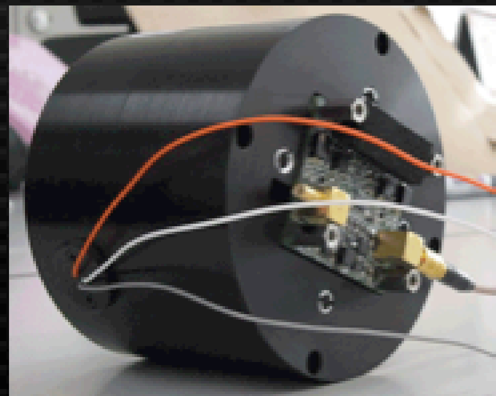

UFFO Pathfinder
Coded
Mask
UBAT X/γ
Trigger
Detectors
Electronics
ICCD Detector
SMT
Optical-UV
Telescope
SMT Primary
Beam
Steering
Mirror

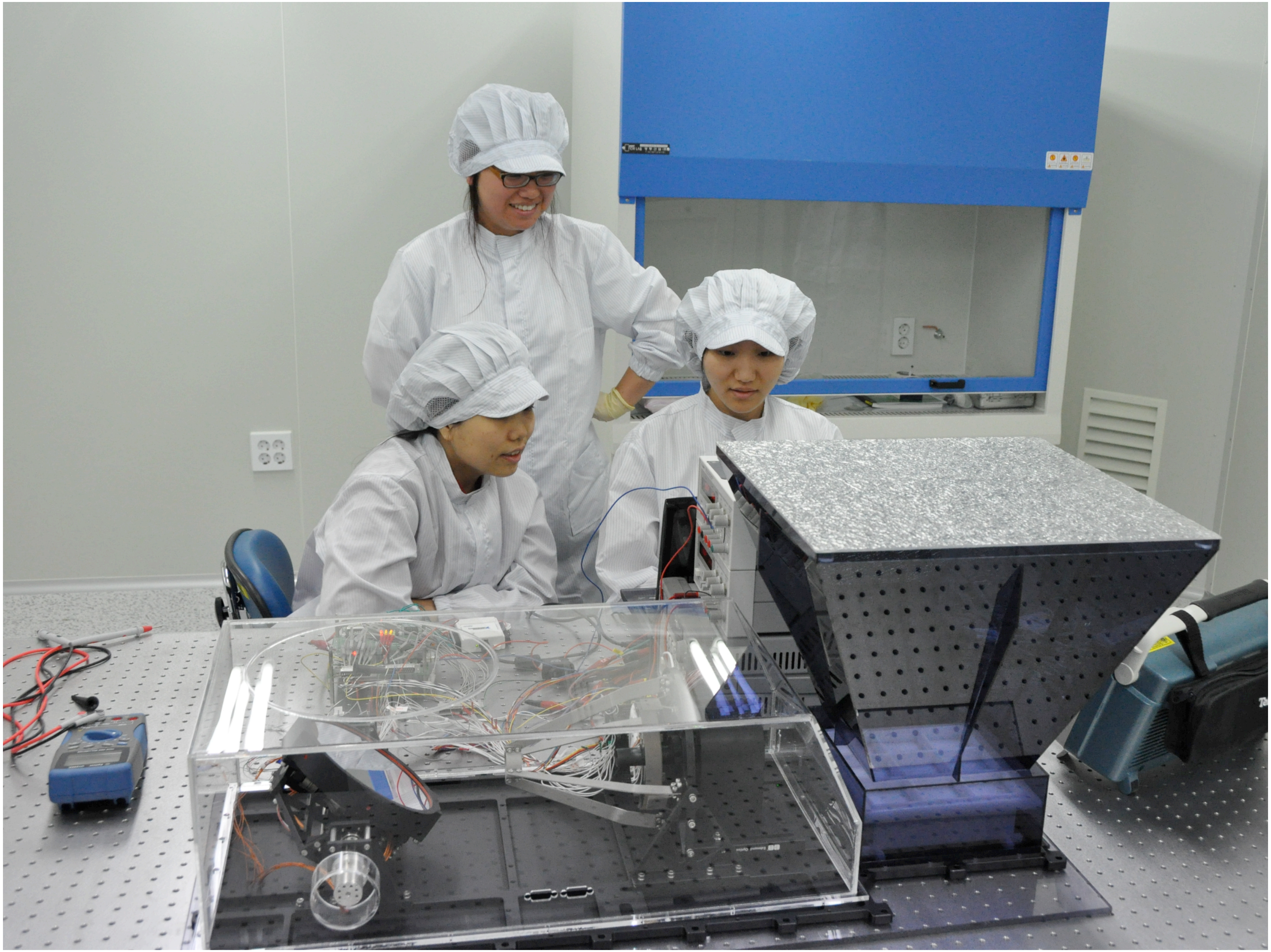
Random Pathfinder Components



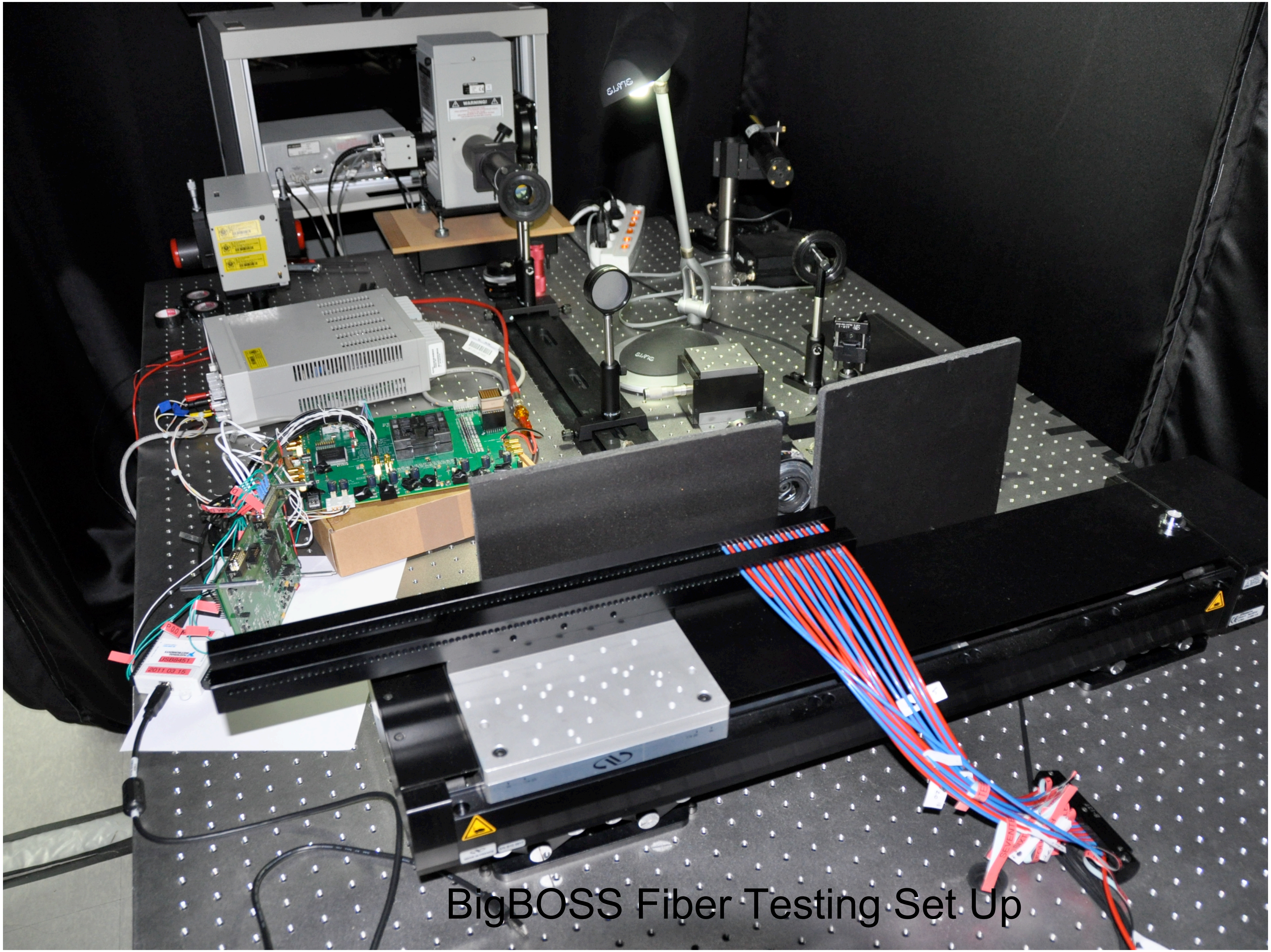




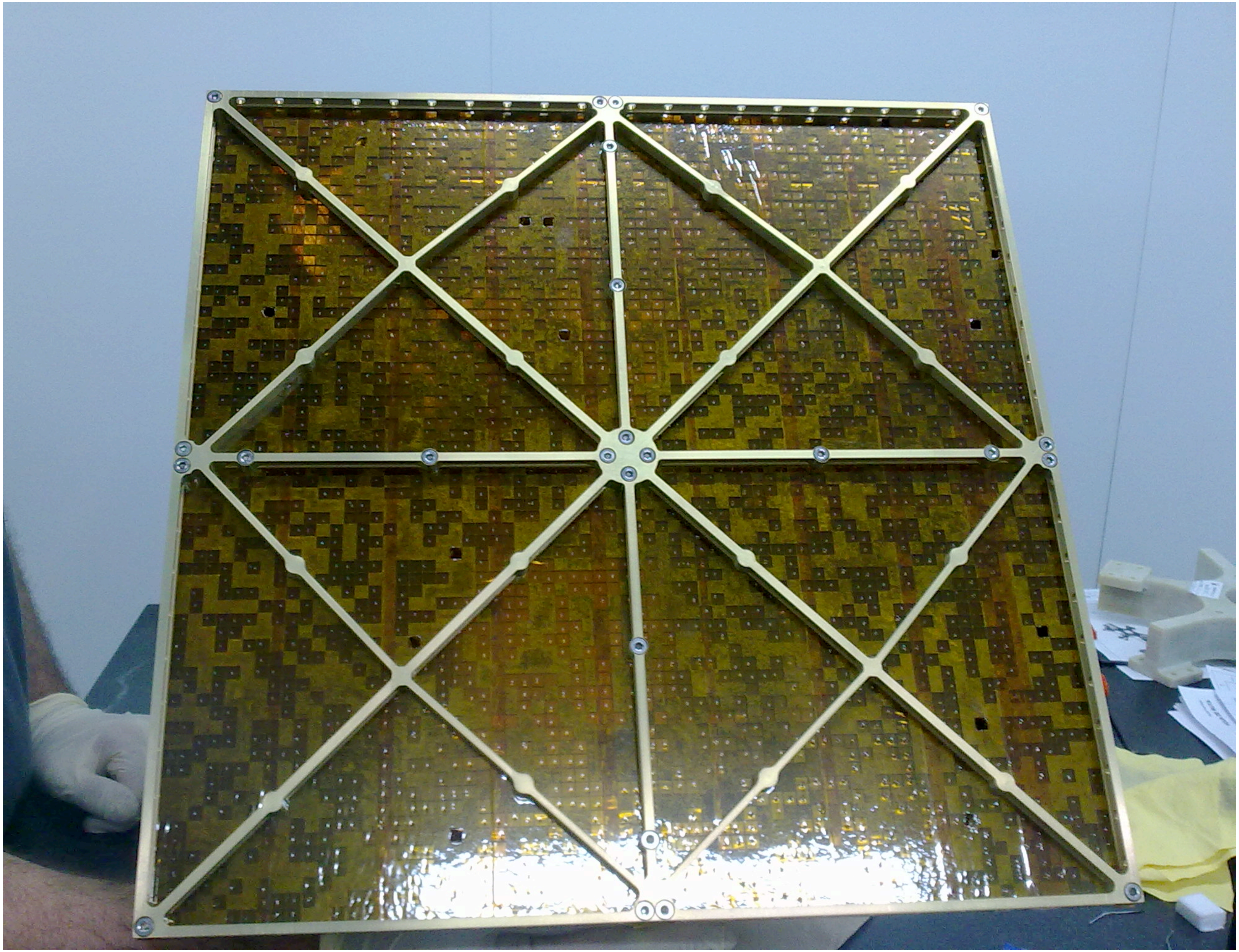




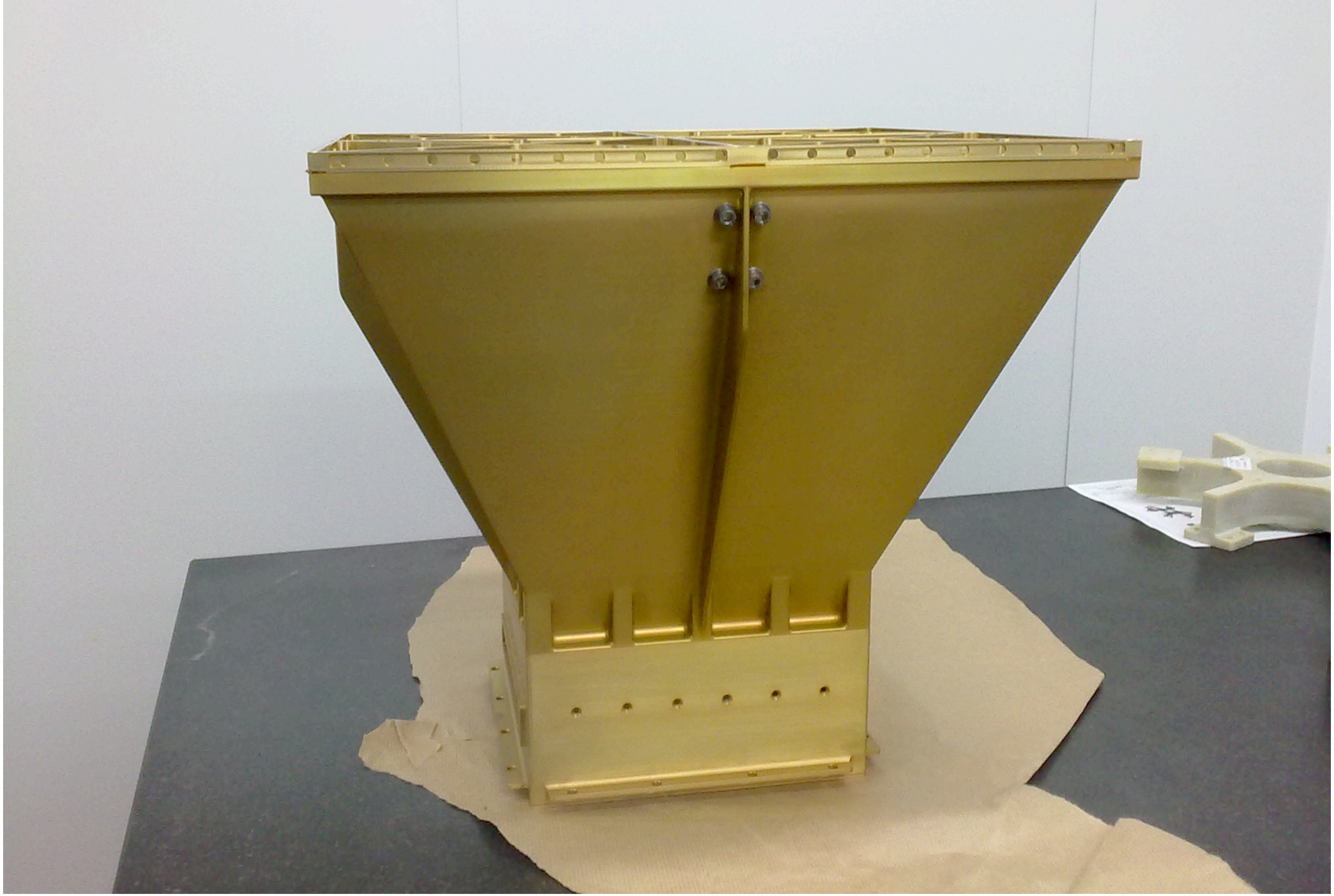

Ultra Fast Flash Observatory
UFFO
ABCDEF
GHJKLM
NOPQRS
TUVXYZ
RCMST
WOW!

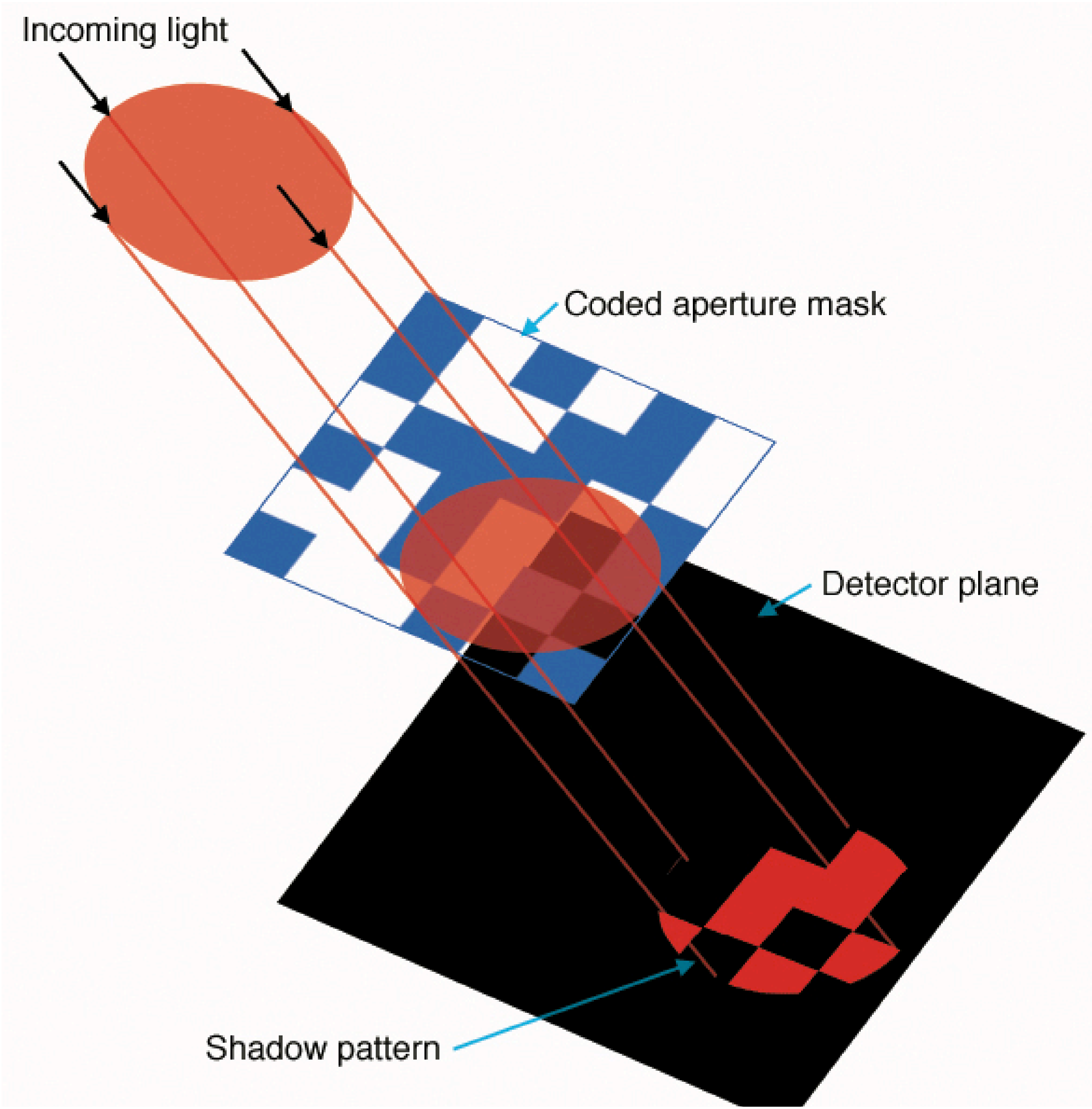


BigBOSS Fiber Testing Set Up

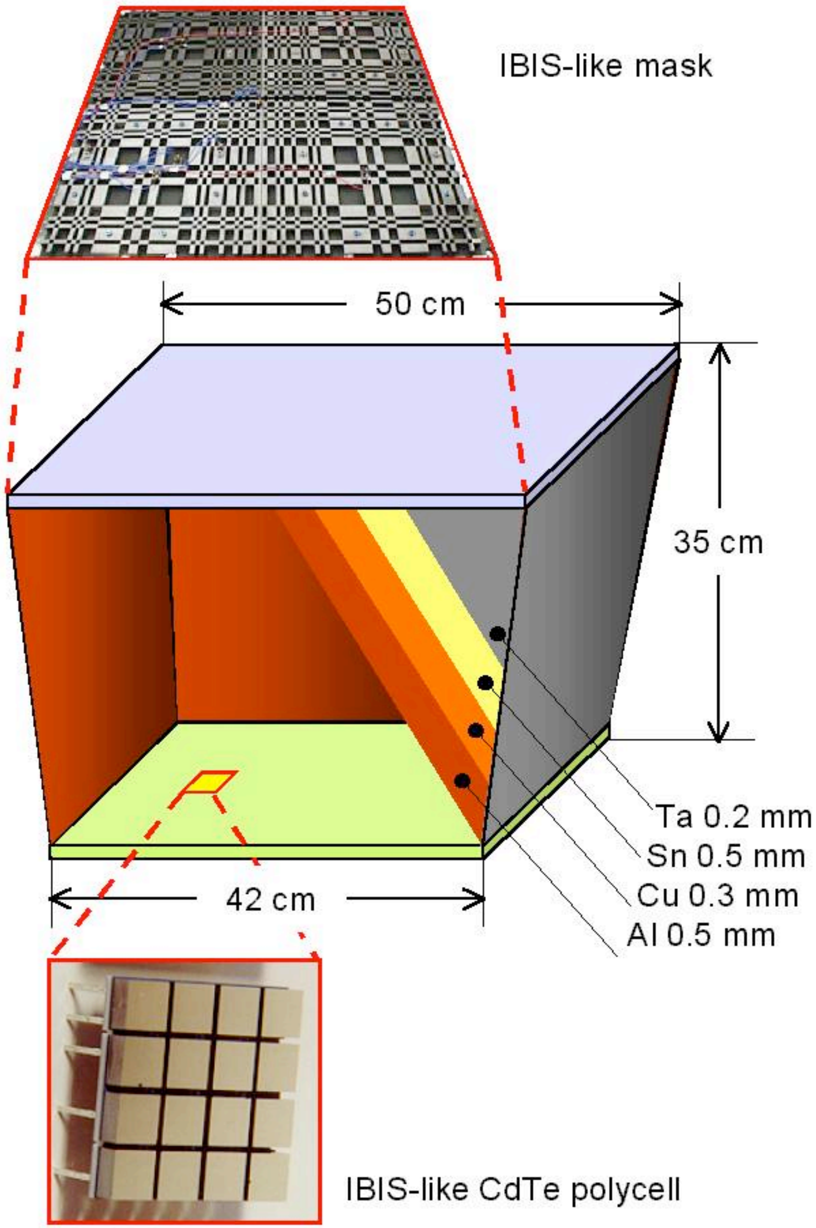


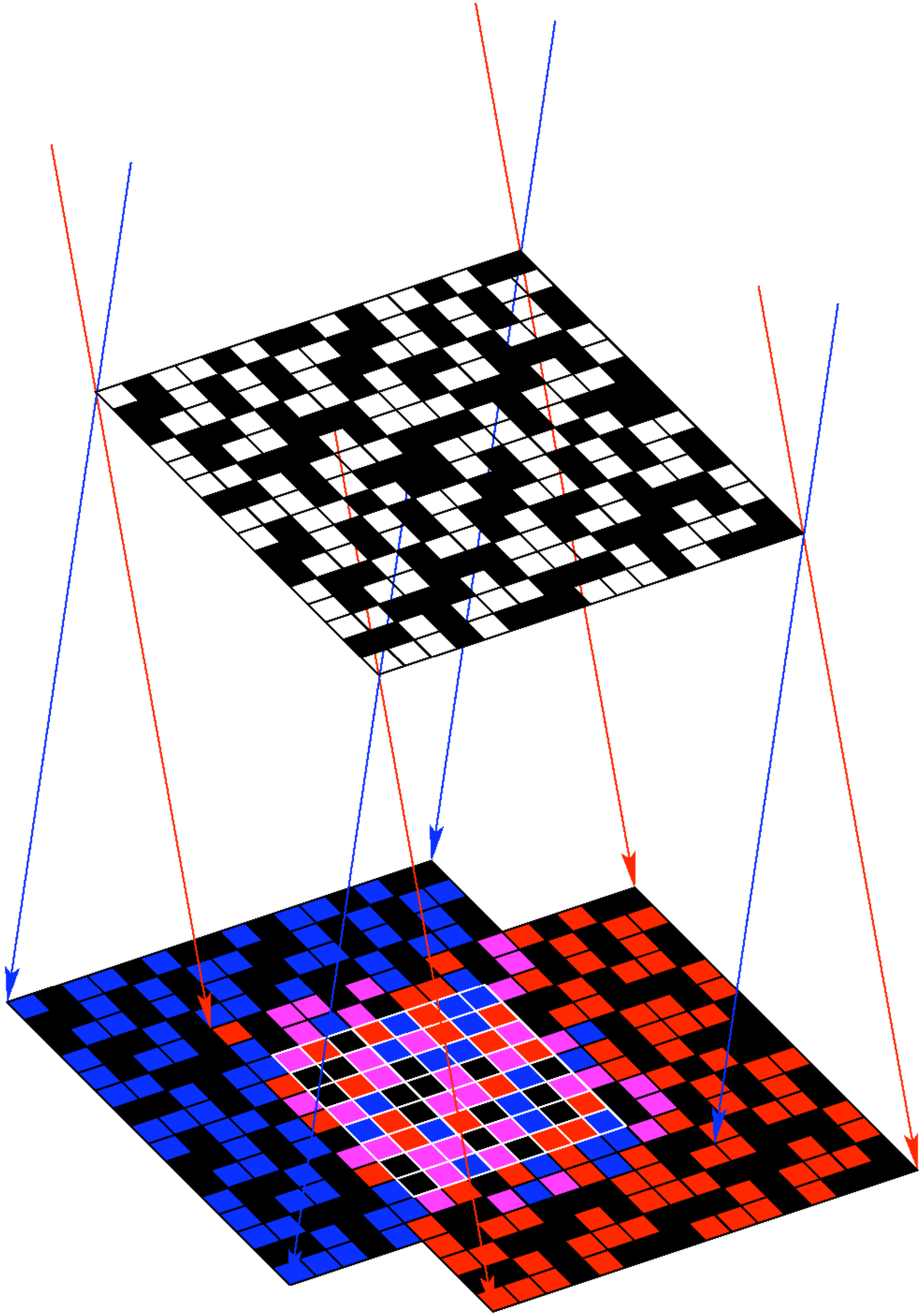
UBAT - Structure - Coded Mask and detector focal plane

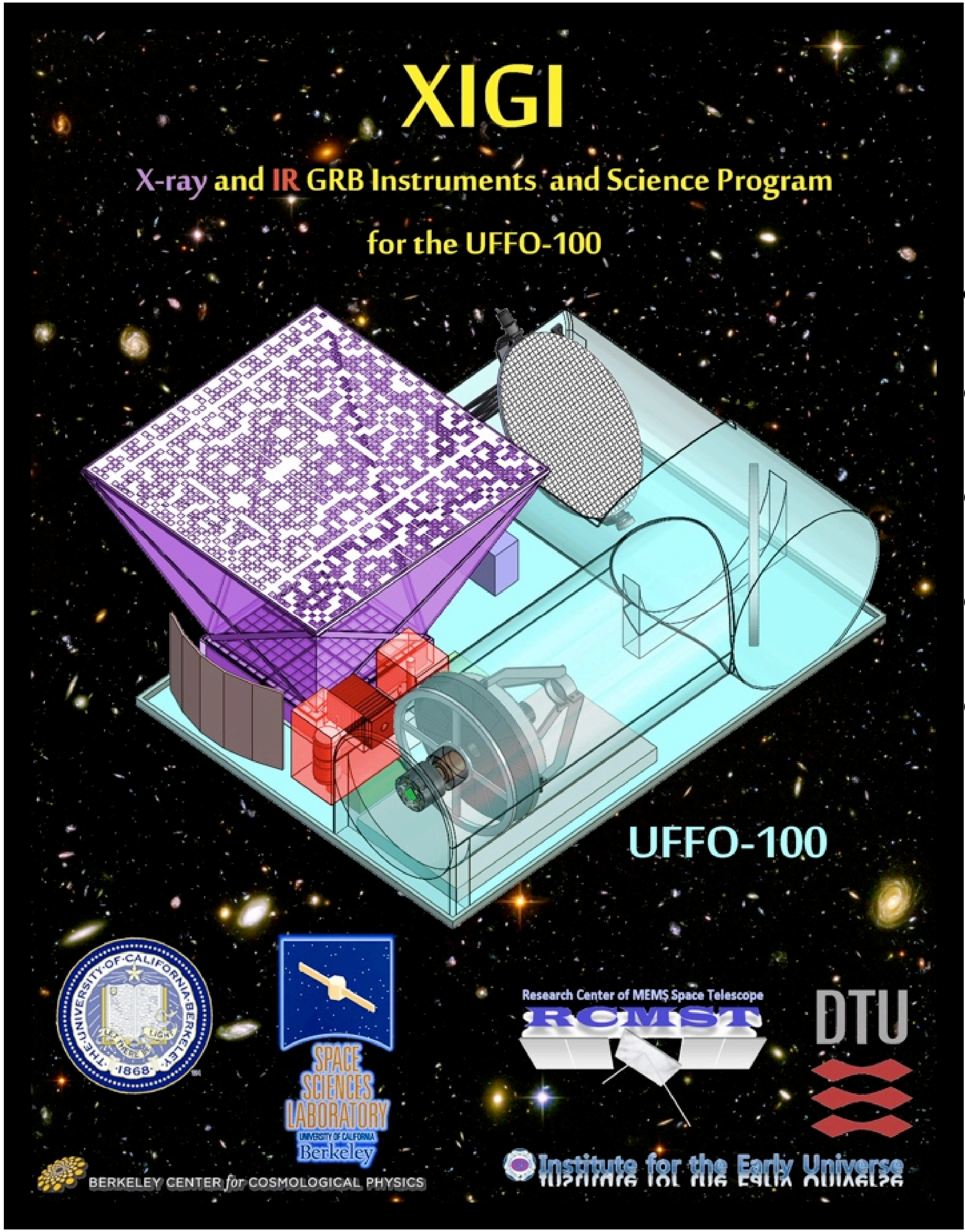




Burst Alert Telescope


IBIS-like mask
50 cm
35 cm
Ta 0.2 mm
Sn 0.5 mm
Cu 0.3 mm
Al 0.5 mm
42 cm
IBIS-like CdTe polycell





UFFO-100

- Dr. Bruce Grossan PI
- 120 kg design cpt.
- X-Ray Coded Mask
- 30-cm optical teles
- Science Goals
  - Lorentz factor
  - Calibration
  - Internal vs External shocks
  - Multimessenger

The UFFO (Ultra Fast Flash Observatory) Pathfinder: Science and Mission

P. CHEN[1], S. AHMAD[2], K. AHN[3], P. BARRILLON[2], S. BLIN-BONDIL[2], S. BRANDT[4], C. BUDTZ-JORGENSEN[4], A.J. CASTROTIRADO[5], H.S. CHOI[6], Y.J. CHOI[7], P. CONNELL[8], S. DAGORET-CAMPAGNE[2], C. DE LA TAILLE[2], C. EYLES[8], B. GROSSAN[9], I.HERMANN[7], M.-H. A. HUANG[10], S. JEONG[11], A. JUNG[11], J.E. KIM[11], S.H. KIM[3], Y.W. KIM[11], J. LEE[11], H. LIM[11], E.V.LINDER[9,11], T.-C. LIU[1], NIELS LUND[4], K.W. MIN[7], G.W. NA[11], J.W. NAM[11], K. NAM[11], M.I. PANAYUK[12], I.H. PARK[11], V. REGLERO[8], J.M. RODRIGO[8], G.F. SMOOT[9,11] , Y.D. SUH[7], S. SVELITOV[12], N. VEDENKEN[12], M.-Z WANG[1], I. YASHIN[12], M.H.ZHAO[11] [THE UFFO COLLABORATION]

Abstract: Hundreds of gamma-ray burst (GRB) optical light curves have been measured since the discovery of optical afterglows. However, even after nearly 7 years of operation of the **Swift** Observatory, only a handful of measurements have been made soon (within a minute) after the gamma ray signal. This lack of early observations fails to address burst physics at short time scales associated with prompt emissions and progenitors. Because of this lack of sub-minute data, the characteristics of the rise phase of optical light curve of short-hard type GRB and rapid-rising GRB, which may account for ~30% of all GRB, remain practically unknown. We have developed methods for reaching sub-minute and sub-second timescales in a small spacecraft observatory. Rather than slewing the entire spacecraft to aim the optical instrument at the GRB position, we use rapidly moving mirror to redirect our optical beam. As a first step, we employ motorized slewing mirror telescope (SMT), which can point to the event within 1s, in the UFFO Pathfinder GRB Telescope onboard the **Lomonosov** satellite to be launched in Nov. 2011. UFFO's sub-minute measurements of the optical emission of dozens of GRB each year will result in a more rigorous test of current internal shock models, probe the extremes of bulk Lorentz factors, provide the first early and detailed measurements of fast-rise GRB optical light curves, and help verify the prospect of GRB as a new standard candle. We will describe the science and the mission of the current UFFO Pathfinder project, and our plan of a full-scale UFFO-100 as the next step.

Future

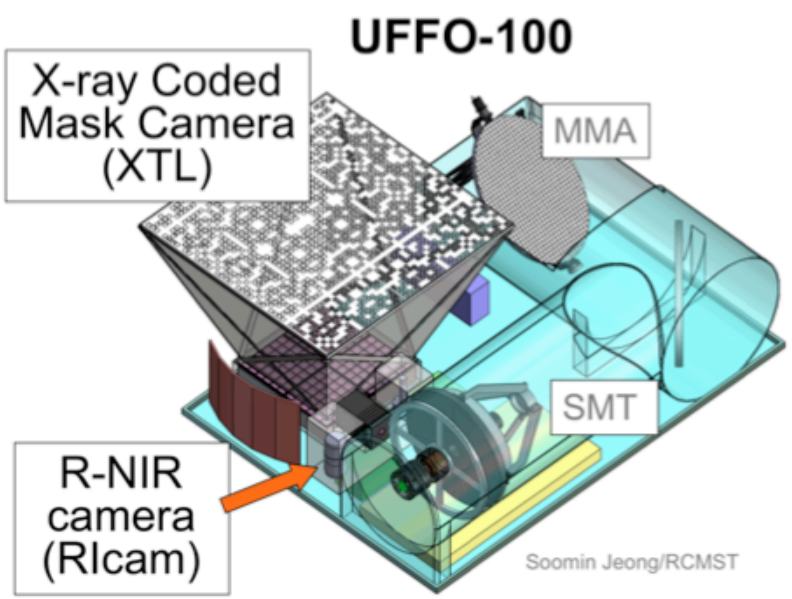
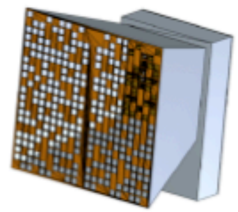


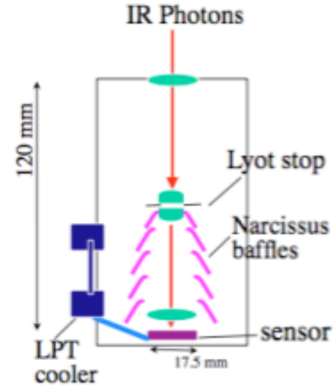
Fig. 1 A rendering of the UFFO-100 with proposed instruments indicated at left (optional compact configuration shown).

XTL



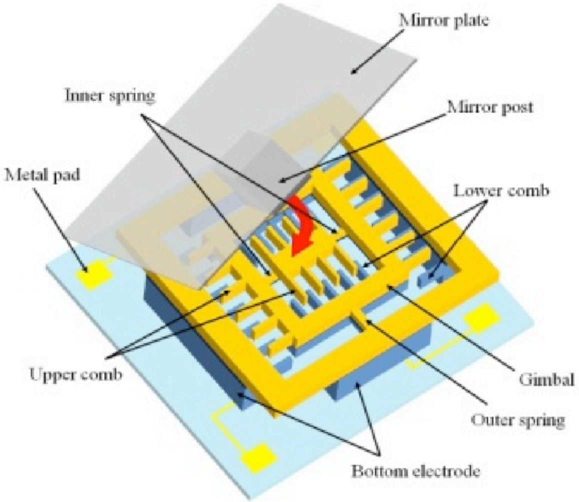
XTL Characteristics	
Detector	CZT crystal
Active Area	1024 cm^2
Band	15-200 keV
Optics	coded mask aperture
Source Location	r < 8.5',(90% prob., 8 σ)
FOV	HCFOV=1.4 Sr
Mask-Detector Sep	400 mm
Mask Width	575 mm
Mask Element Size	5.5mm
Npix	16,384
Data/GRB	<5 MB

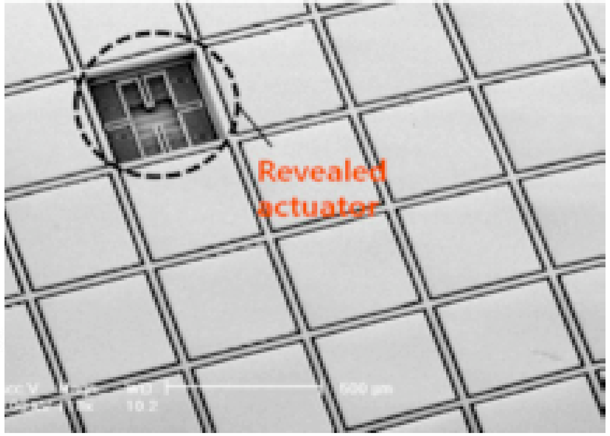
RICam

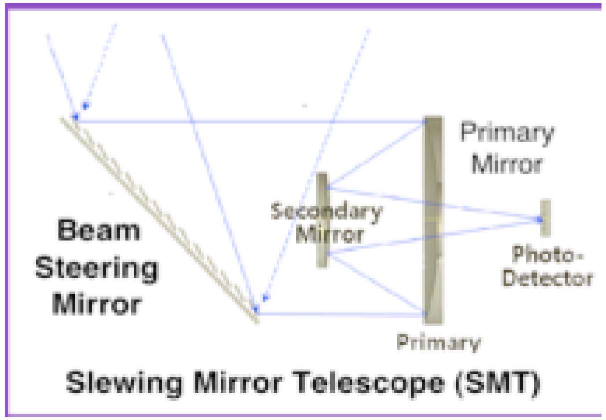


RICam Characteristics	
Band	0.57 – 1.7 μm
Thermal Design	Lyot Stop, Narcissus baffles, 1 cooled lens, Linear Pulse Tube Cooler
Detector	H2RG HgCdTe array
Cooling	Linear Pulse Tube Cooler
FOV	17.1'
Npix	2048 X 2048
Operations modes (noise for 2 reads)	500kHz read (23e-), 100 kHz read (15 e-).
Data/GRB	640 MB

MEMS Technology

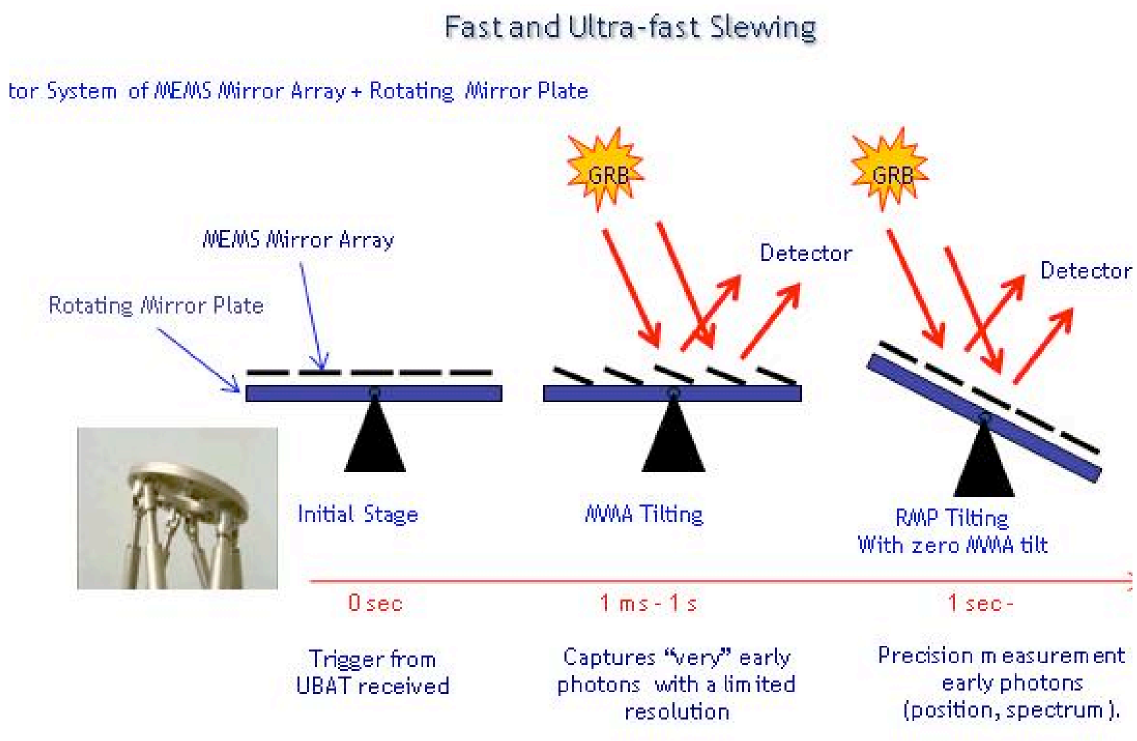






- MEMS technology mirror arrays @ Ewha RMST Lab
  - FAST from +30 deg. to -30 deg. in ~ ms, including settling, negligible power, moment of Inertia
- Speed Costs:
  - limiting factor is uniformity of manufacture
  - ~ 2 arc minute PSF
  - correction possible? NO- any individual control greatly increases # lines on chip
  - "grating effect" and diffraction limit also give problems so slew large mirror plate in 1 second

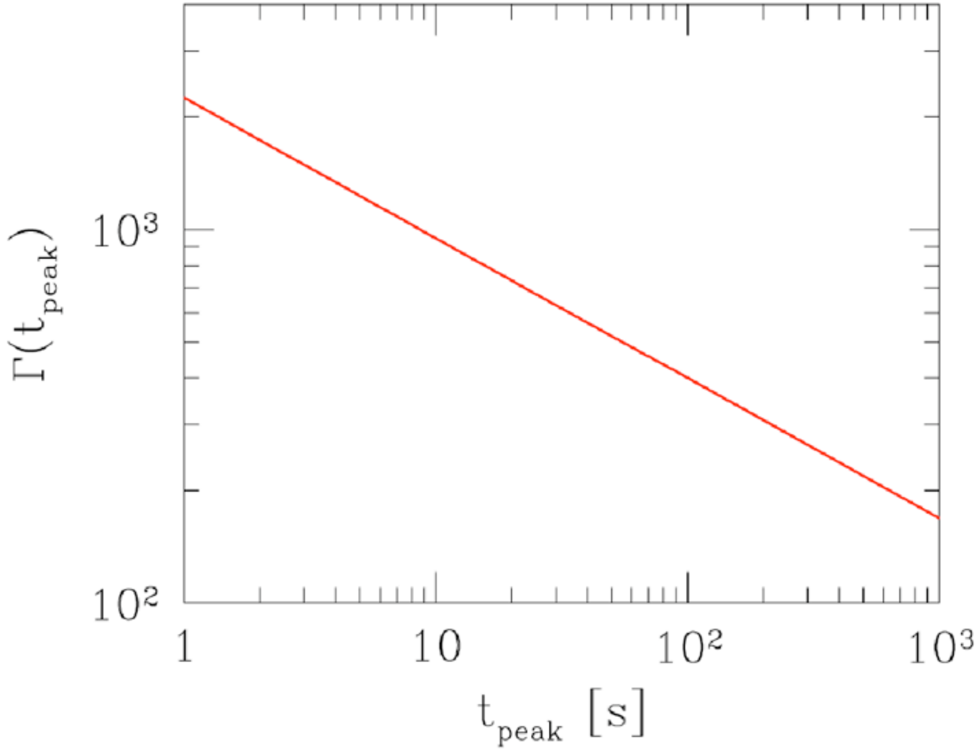
Hybrid MEMS/Gimbal Concept



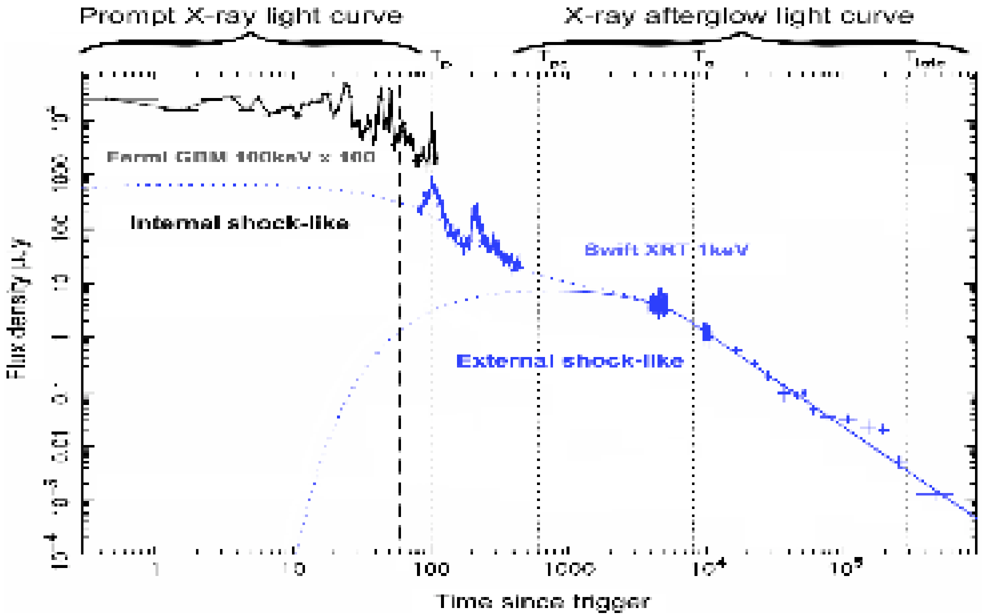
- Ultra-fast Mode:
  - MEMS array responds in ~ 10^{-3} s
  - PSF ~ up to 2 arcmin
    means reduced sensitivity!
    - **OK for brightest bursts.**
- Fast-Reponse Mode:
  - MEMS array off.
  - PSF now < 1 arcsec
  - Gimbals respond < 1 s over 90^{o}–field.

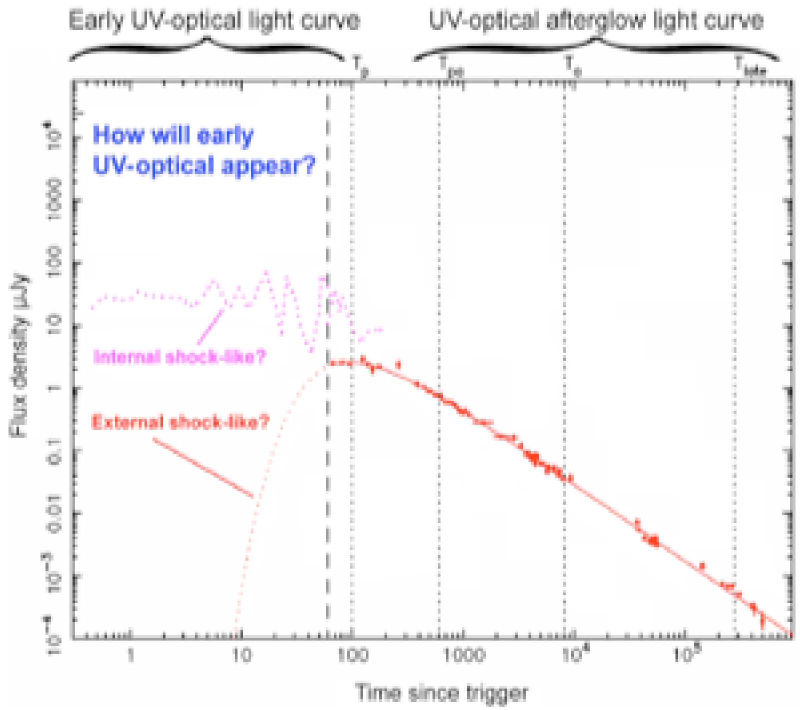
Rapid-Response Measurements needed to measure Lorentz factor

- Measure Bulk Lorentz Factor of Optical Emission
- given by time of the early UV-optical emission peak
  (from Molinari et al. 2007,
  Sari & Piran1999)
- 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**



Internal vs. External Shock

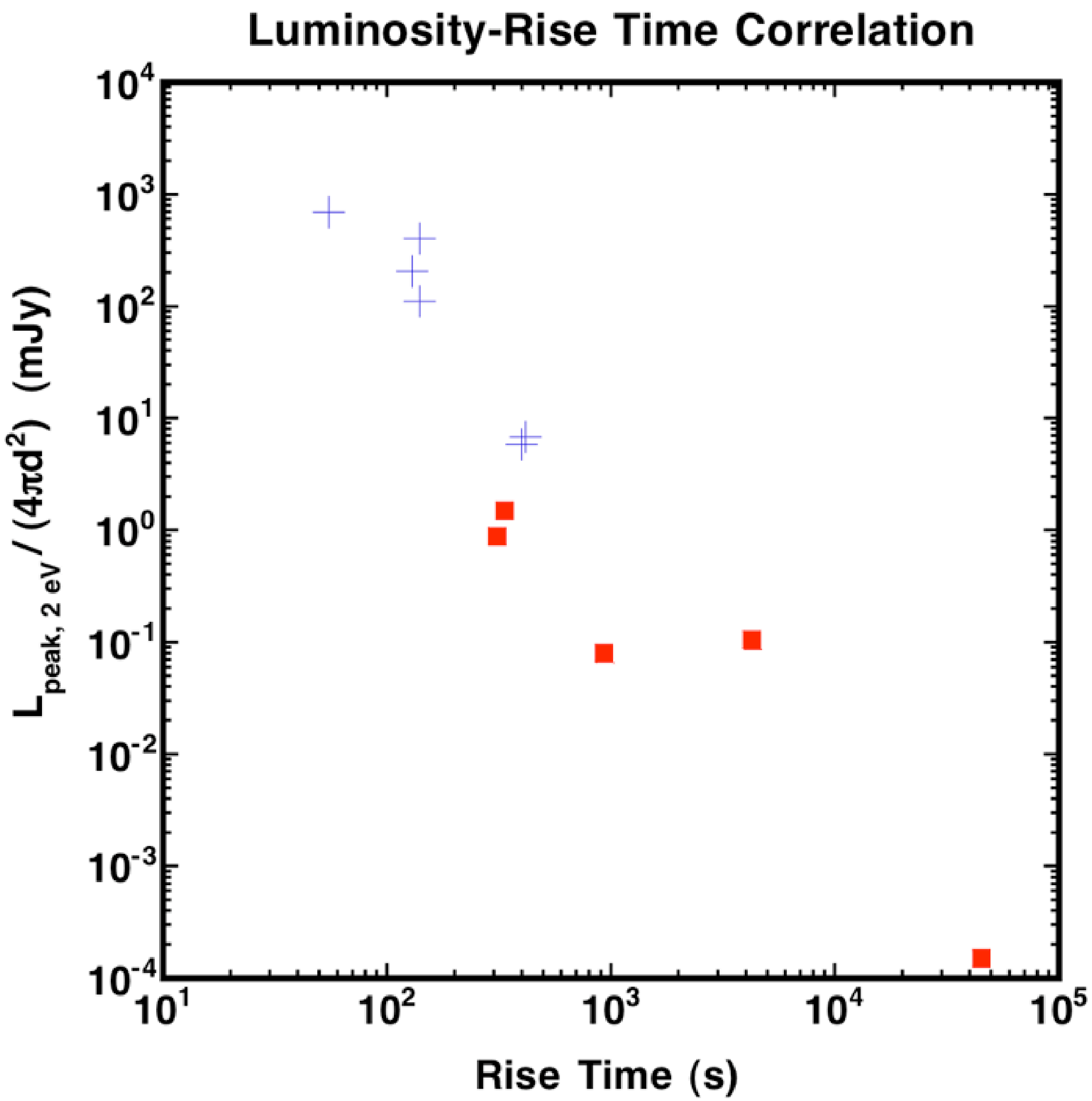




shock behavior.

- How will optical appear during burst? Need rapid response, high time resolution.

GRB Luminosity Calibration? Cosmological tool?



Wouldn't you like to have a standard candle for $z \geq 8$?!?!?! Maybe to $z = 12$!

calibrate L_{peak} with rise time

"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 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.

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