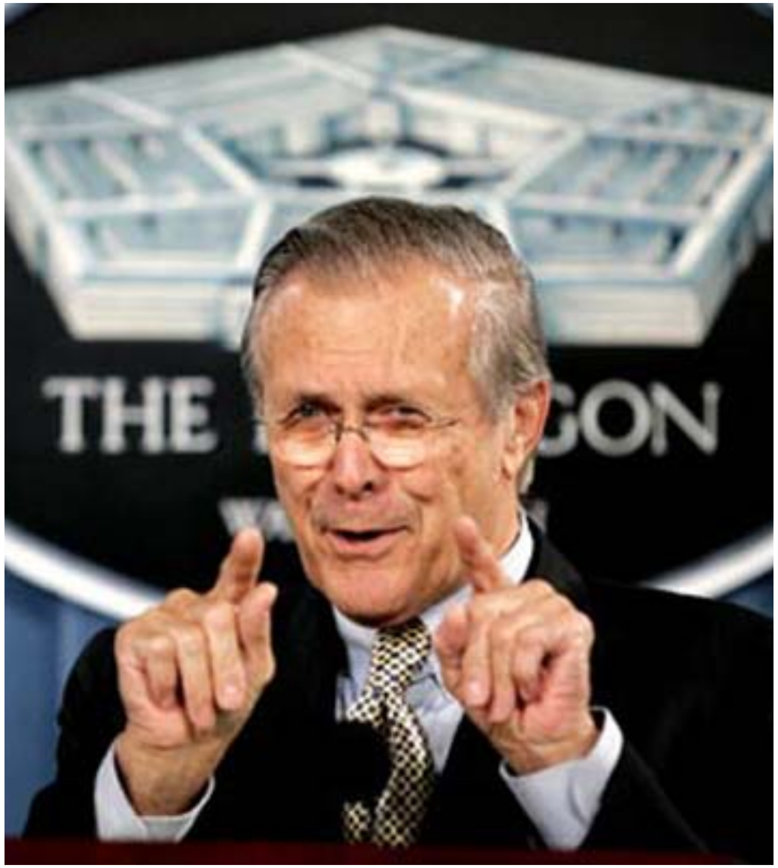
宇宙X線 の50年（２）

突発現象とその追跡を中心に

河合誠之
(東工大/理研MAXIチーム)

Unknown unknowns



"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. **But there are also unknown unknowns - the ones we don't know we don't know**"

— Donald Rumsfeld

"I must admit that my main motivation for pressing forward was a deep seated faith in ***the boundless resourcefulness of nature, which so often leaves the most daring imagination of man far behind****."*

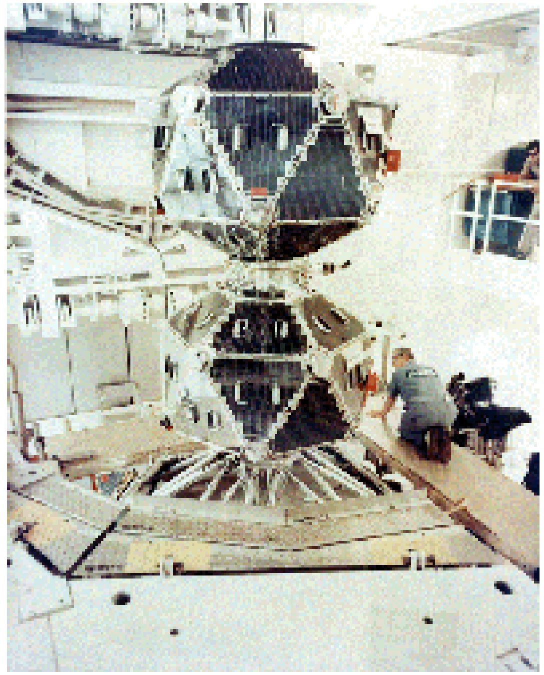
-Bruno Rossi

Photograph courtesy of the MIT Museum

宇宙は人間の想像力を超えている

ガンマ線バーストの発見

- 核実験監視衛星によって、宇宙からのガンマ線爆発を初検出: 1967年?
- ロスアラモス研究所のグループ（クレベサデル他）



THE ASTROPHYSICAL JOURNAL, 182:L85–L88, 1973 June 1

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

Vela衛星によるガンマ線バーストの観測

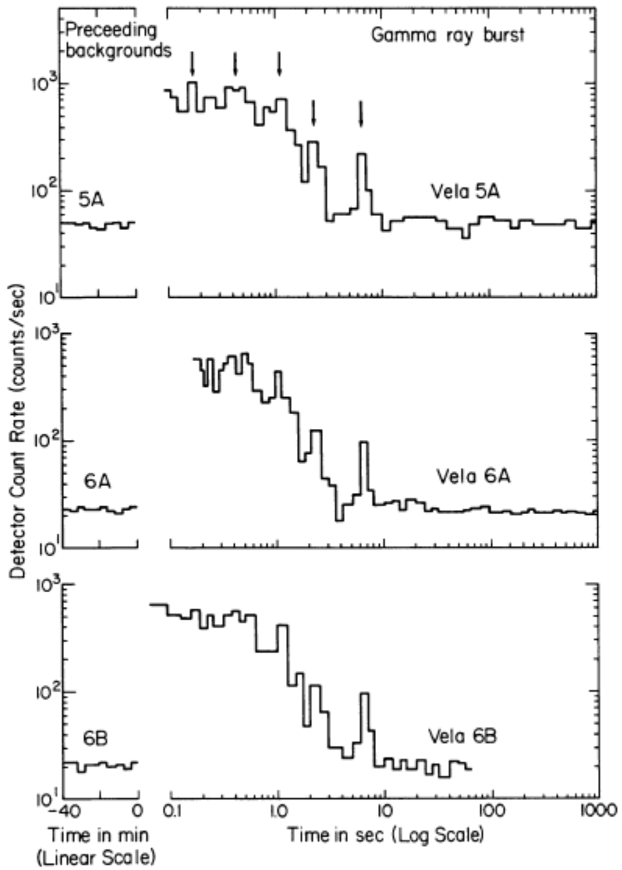
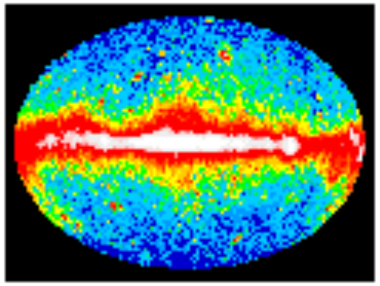
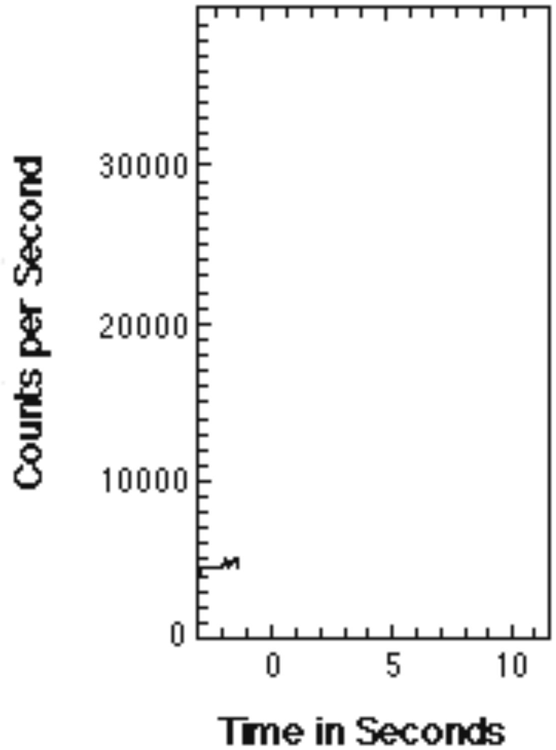


FIG. 1.—Count rate as a function of time for the gamma-ray burst of 1970 August 22 as recorded at three Vela spacecraft. Arrows indicate some of the common structure. Background count rates immediately preceding the burst are also shown. *Vela 5A* count rates have been reduced by 100 counts per second (a major fraction of the background) to emphasize structure.



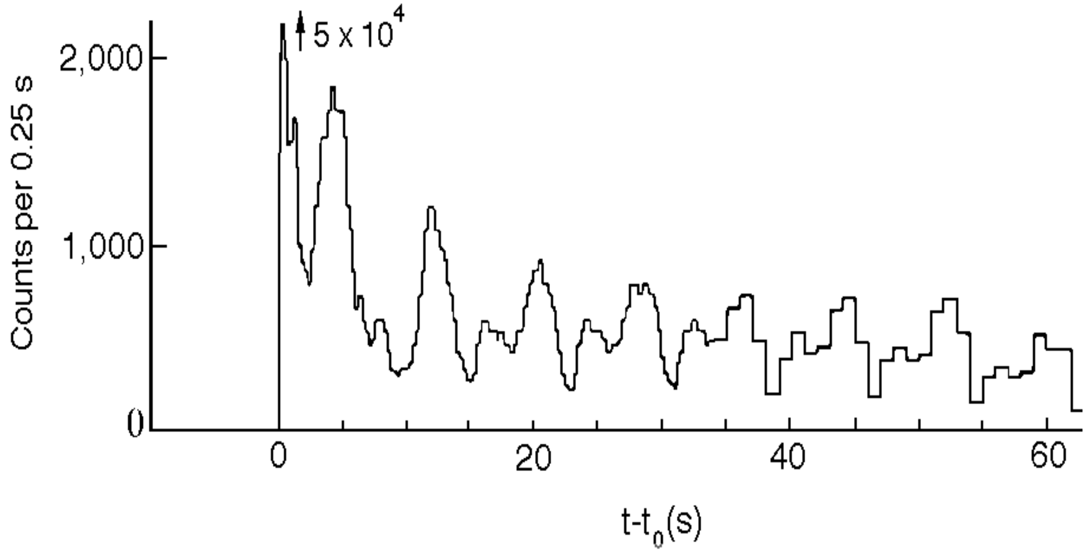


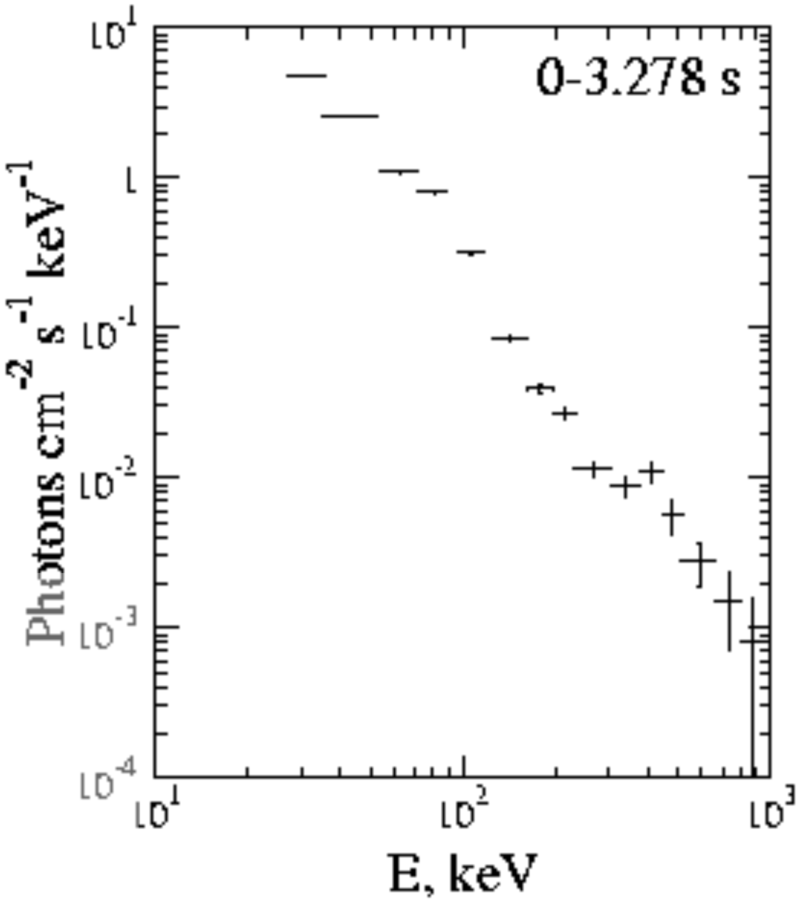
偶然の発見ではない

ガンマ線バーストは発見後30年間謎だった

- 既知の天体に関連づけられない
  - 地上から観測できない
  - 短時間（秒〜分）、一回きり、予測不可能
  - γ 線で方向を正確に決めるのは困難

GRB790305



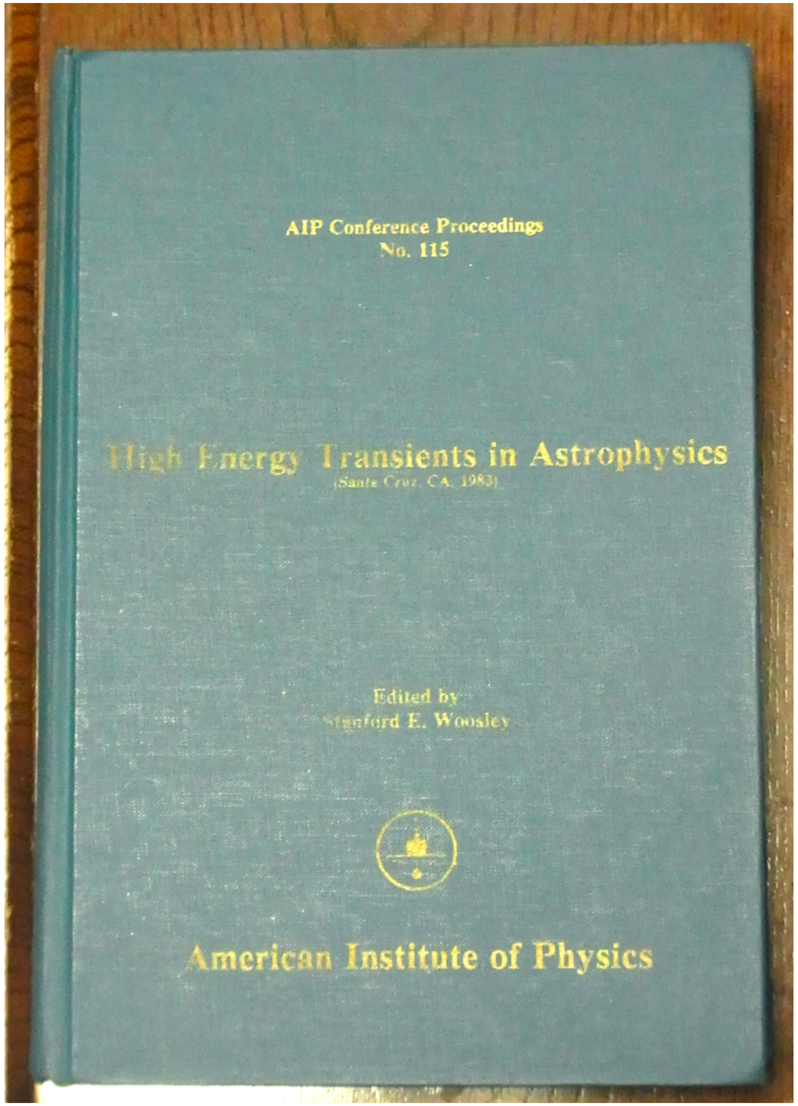


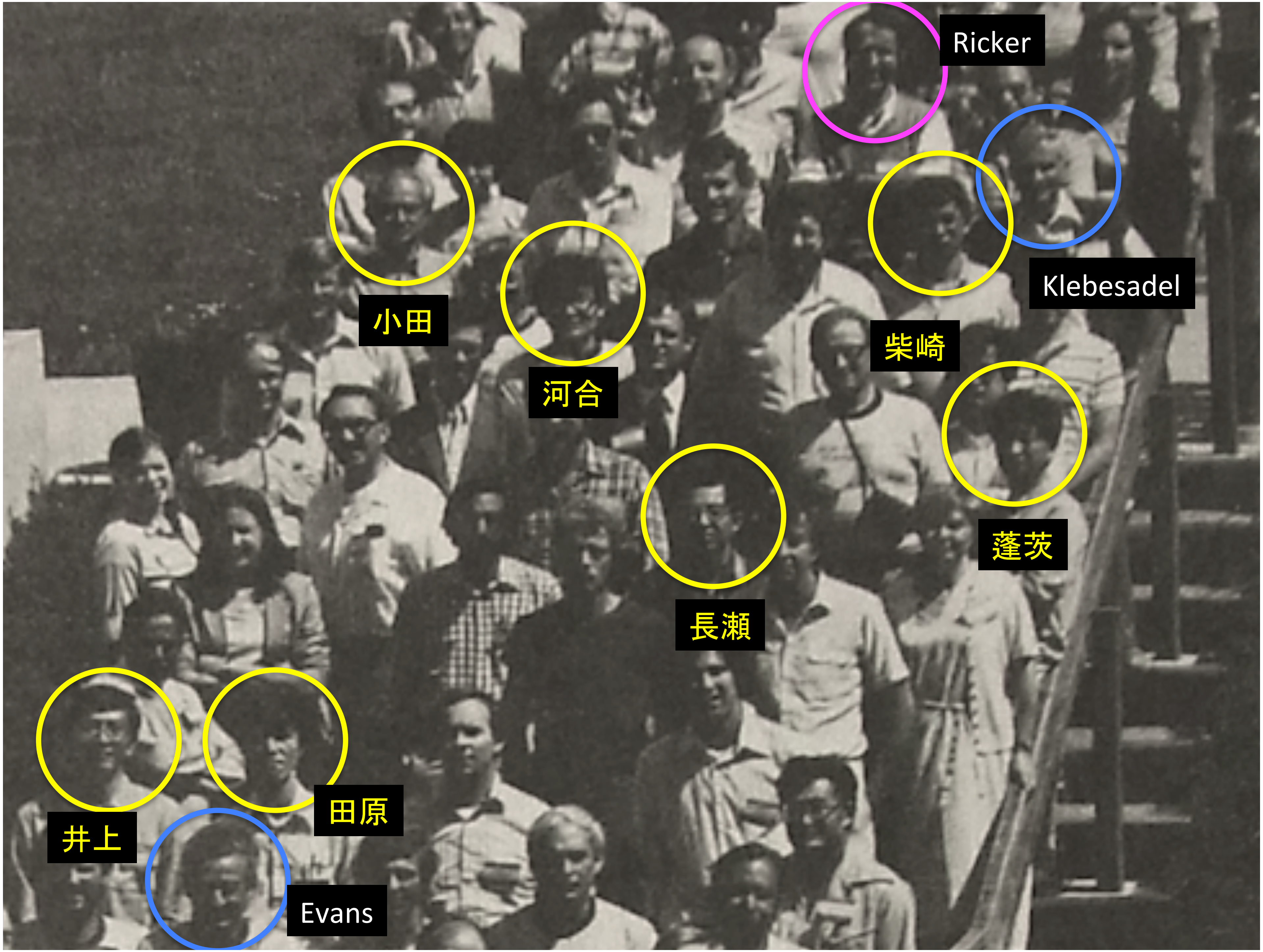
- 当初は “GRB” に分類
- 類似スペクトル（~MeV)
- 8-s pulsation
- 大マゼラン星雲の超新星残骸の中

γ線バーストは中性子星上の現象！？

　その後、繰り返し発生するバースト → 今は “マグネター”

"High Energy Transients in Astrophysics"
Santa Cruz 1983




Ricker
Klebesadel
小田
河合
柴崎
蓬茨
長瀬
井上
田原
Evans

THE HIGH ENERGY TRANSIENT EXPLORER (HETE)

During the meeting, a number of workshops were held to discuss the need for and properties of a possible space mission of the Explorer class dedicated to the study of high-energy transients. Capabilities of other current and planned missions, both U.S. and foreign, were reviewed along with the scientific need for such studies. It was the consensus of the participants in these workshops, (confirmed by all those participating in the meeting at large), that a "High Energy Transient Explorer" was both feasible and desirable and that a document should be prepared defining the scientific need for the mission. This document would then be submitted to NASA and its advisory committees for response.

The High Energy Transient Explorer (HETE)

- For the observer, high energy transients are a special challenge to develop new types of instrumentation and new observational strategies. In the case of γ-ray bursts, a signal appears from a totally unpredictable direction in the sky, lasts a few seconds, and is gone. Yet we desire precise location, time resolved spectroscopy, and flux measurements over an energy range reaching from optical to hard γ-rays (a factor of $\sim 10^6$ in energy).

γ線バースト最初の高精度位置決定

Nature Vol. 272 23 March 1978 337

letters to nature

Nishimura et al. 1978

γ-Ray burst observed at balloon altitude

SINCE the γ-ray burst was discovered in 1973, approximately 50 events have been observed using artificial satellites[1,2]. In addition, several bursts of smaller size have been found using balloon-borne detectors[3–6] with large sensitive areas. No burst has yet been located on the celestial sphere, with an adequate precision to associate it with an astronomical object. To determine the precise position of a γ-ray burst which had not been predicted to occur, the detector must have a wide field of view and the capability of precise location of the source. A rotating cross-modulation-collimator (RCMC) proposed[7] as a device to fulfill these apparently conflicting requirements was used in the series of balloon observations reported here. A small γ-ray burst was found during ~ 150 h of observations and its celestial position was determined with a precision of ~ 0.3°.

Two modulation collimators were installed in the balloon gondola so that the fields of view of the collimators were pointed towards the zenith, and the directions of the collimator transmission bands projected on the celestial sphere were perpendicular to each other. Scintillation counters of NaI(T1) of 5″ in diameter were installed underneath the two collimators. An additional monitor detector, which consisted of a

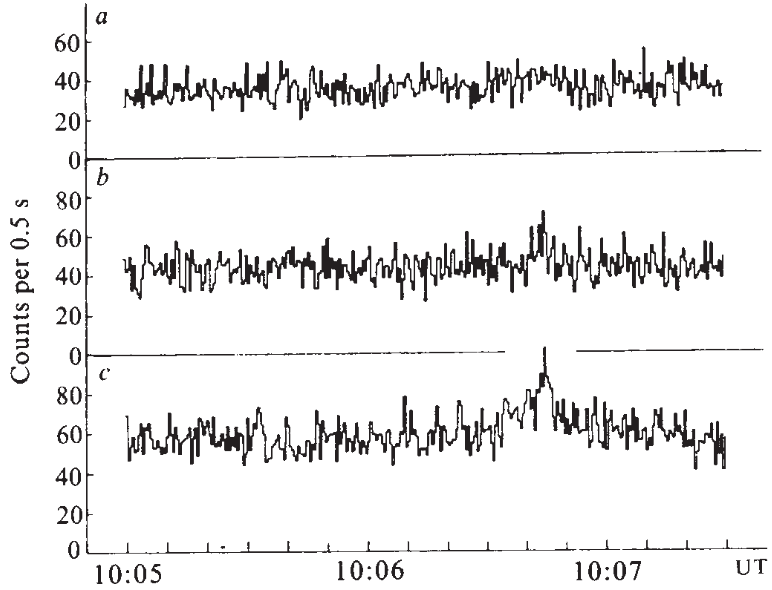


Fig. 2 Time profile of the count-rate 23 September 1975: *a*, and *b*, observed by the detector with the different modulation collimator as shown in Fig. 1; *c*, observed by the detector without the collimator.

γ線バーストのX線観測の先駆け

OBSERVATION OF A COSMIC GAMMA-RAY BURST ON HAKUCHO

M. Katoh, T. Murakami, J. Nishimura, T. Yamagami,
M. Fujii and M. Itoh
Institute of Space and Astronautical Science, Komaba, Tokyo, Japan

ABSTRACT

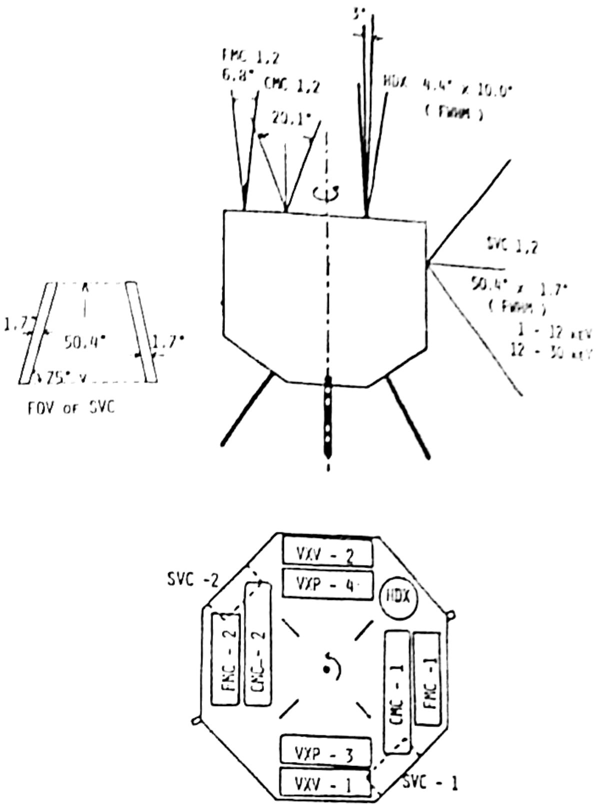


Fig. 1. Detectors on Hakucho Satellite

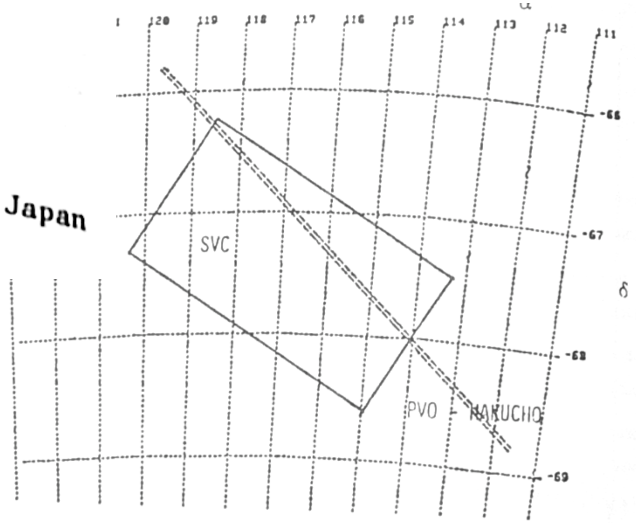


Fig. 4. Location of the burst source

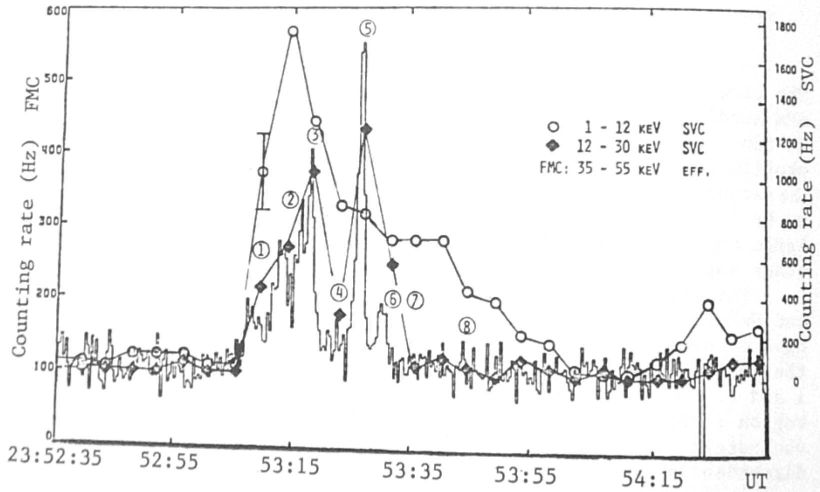
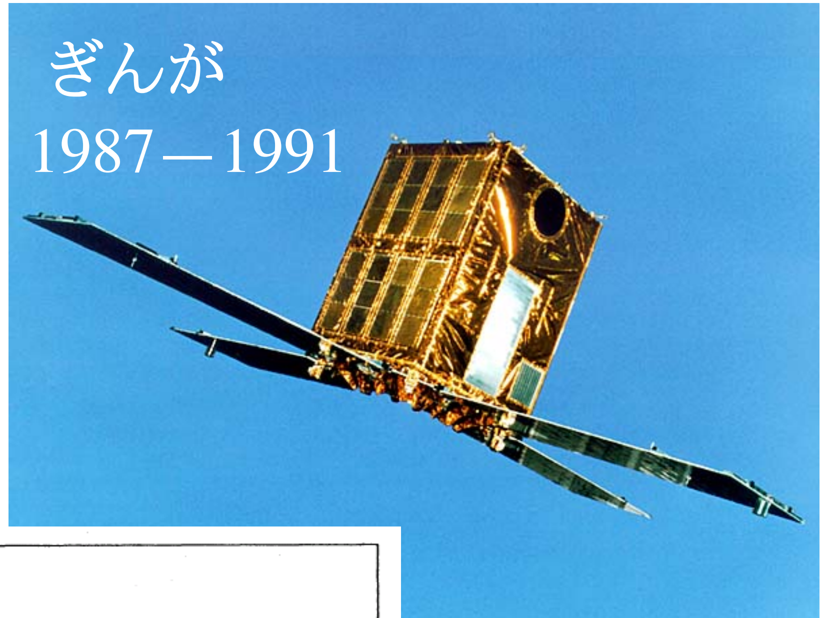


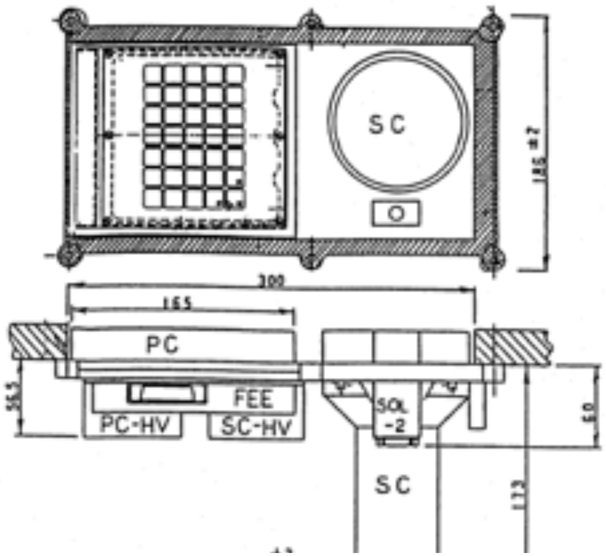
Fig. 5. Time profile of the counts in each counter

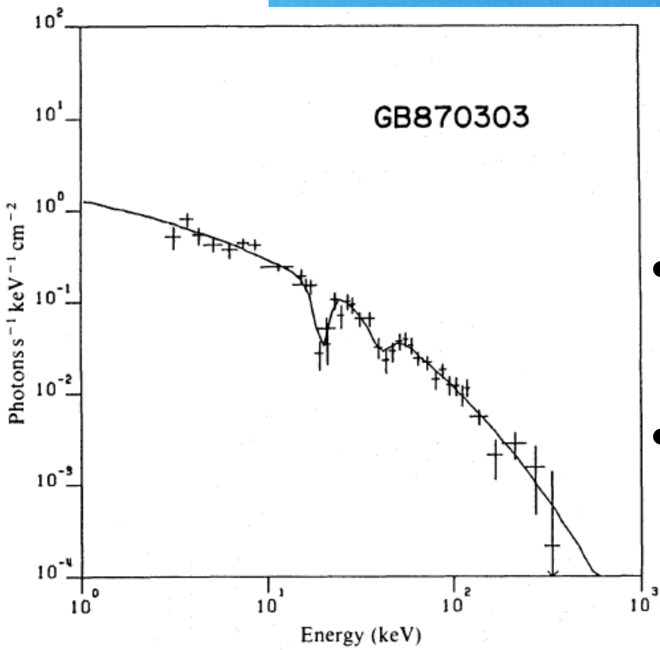
Kato et al. 1983

「ぎんが」ガンマ線バースト検出器

- 小田-Evans (LANL) 会談で搭載決定
- “Every space mission should carry GBD”
- “Negative Mass”
- X線+γ線広帯域







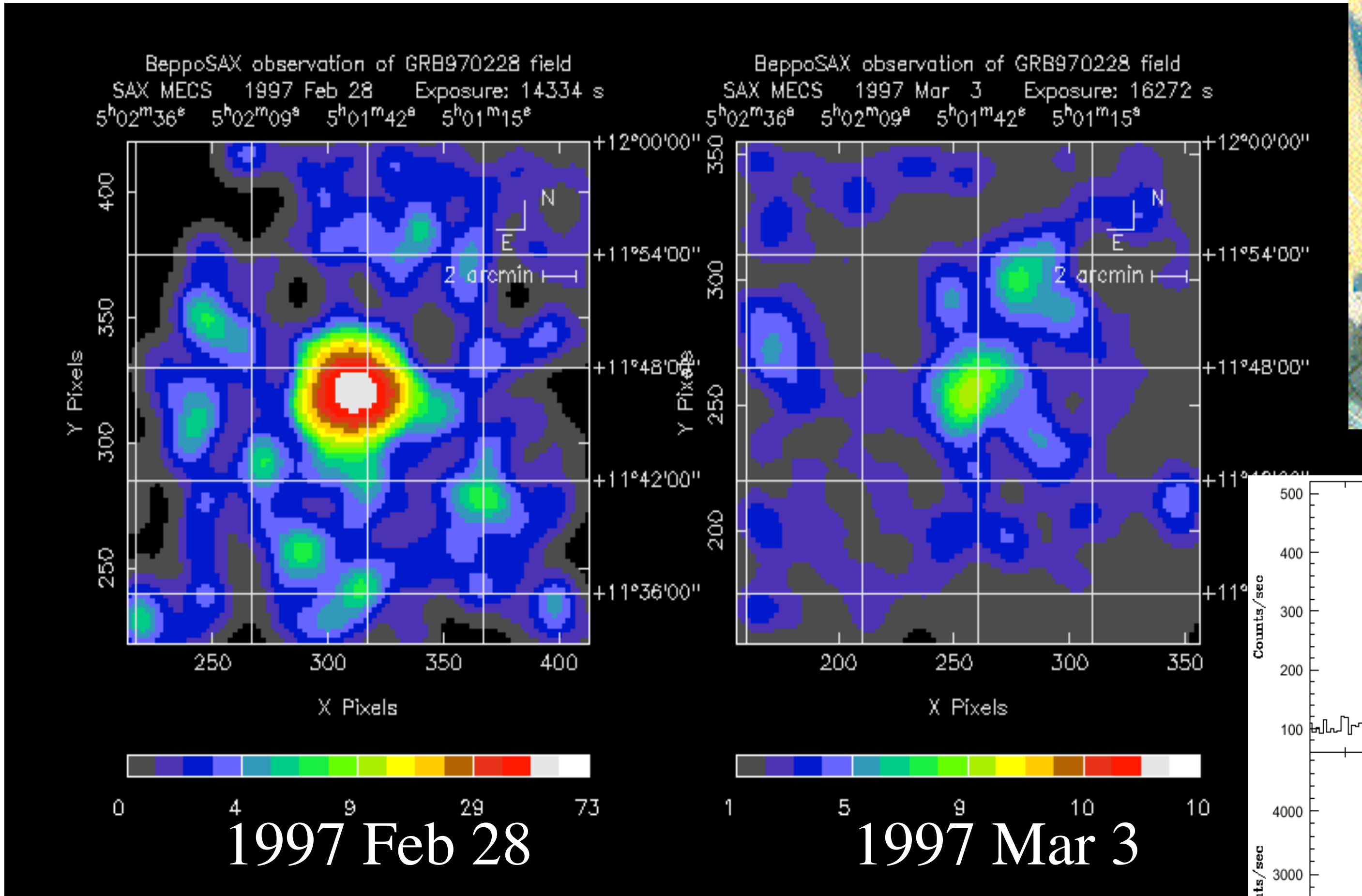
- サイクロトロン吸収構造
- 中性子星磁場の証拠!?

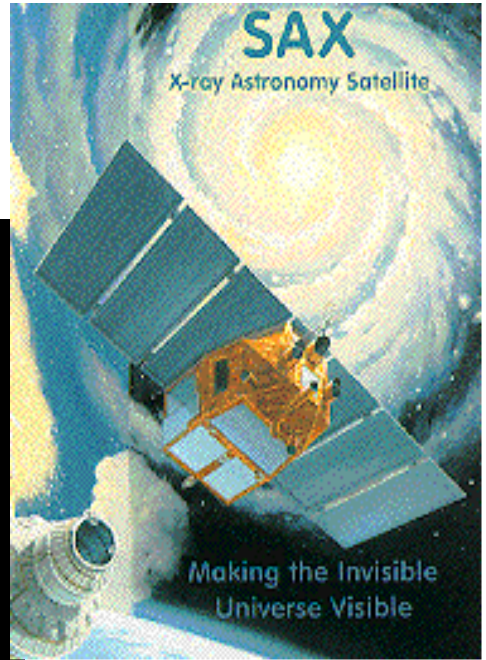
HETE (High Energy Transient Explorer)
高エネルギー変動天体探査機

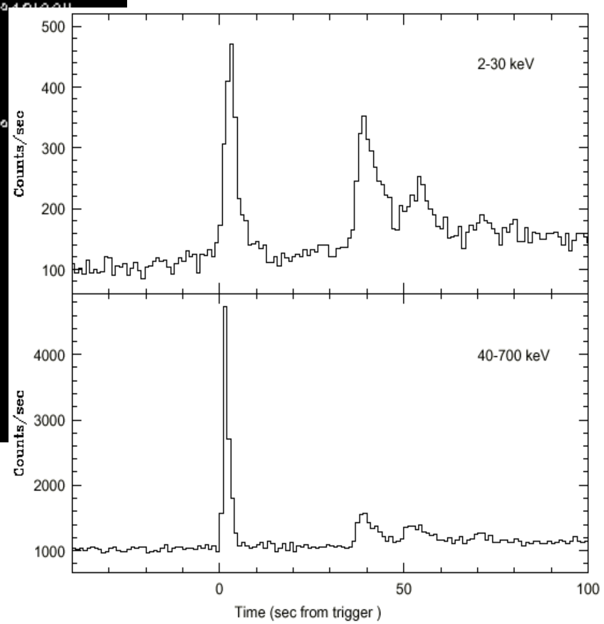
- 1983 Santa Cruz: mission concept (Wooseley et al.)
- 1986 Houston AAS (G. Ricker + E. Fenimore)
- 1988? Unsolicited proposal to NASA
- 1990 start
  - 日・米・仏の国際共同プロジェクト
  - G.Ricker (MIT), 松岡（理研）、J-L. Atteia (CESR)
  - “Cheaper, Faster, Better”
- 1996/11/14 HETE 打上失敗
- 1997/3/5 BeppoSAXによる GRB 970228 のX線残光、理研で発表
- 1997 “HETE-2” 再挑戦開始
- 2000年10月9日に HETE-2 打上げ成功
  - 特徴：ガンマ線バーストの正確な位置* を発生直後(数十秒以内)に全世界に速報する。
  - HETEの位置情報は、無条件・無償で誰にでも提供

* 〜10分角（年間20個）
〜10秒角（年間10個）

ベッポサックス衛星による
X線残光の発見 (GRB970228)







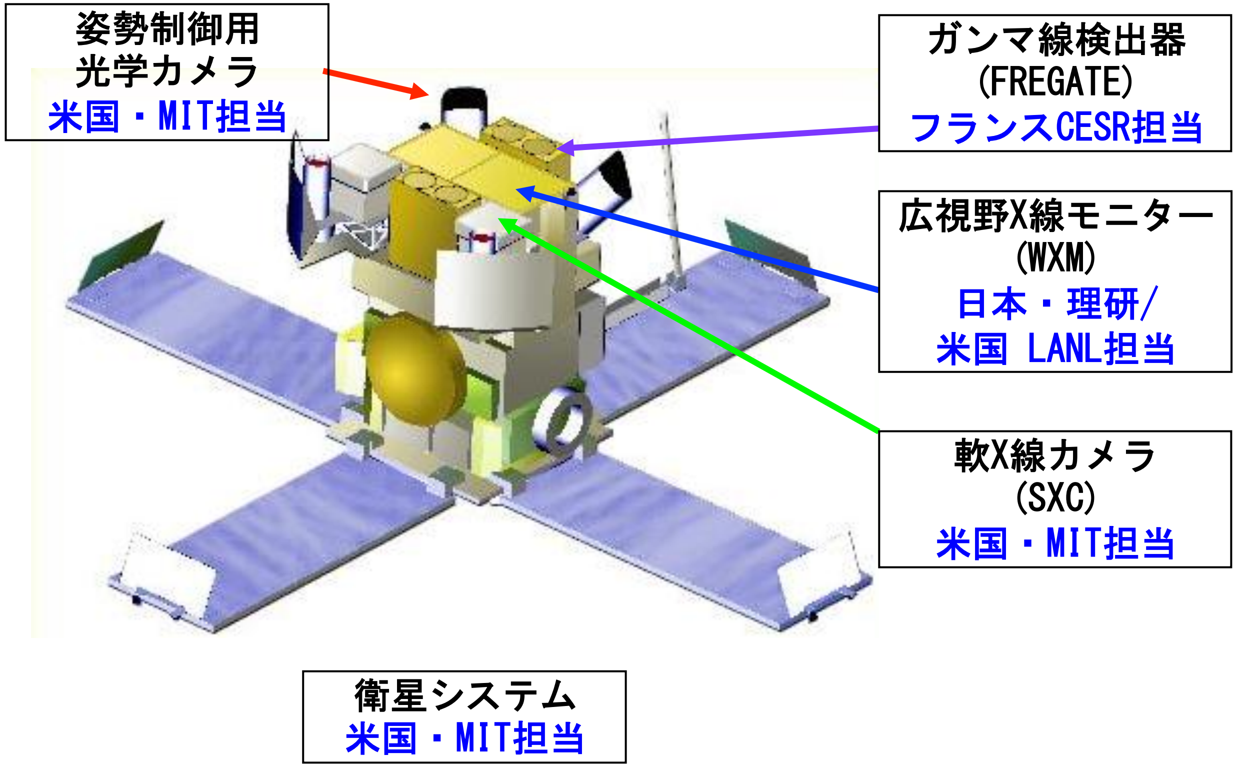
8時間後　　　　**3日後**

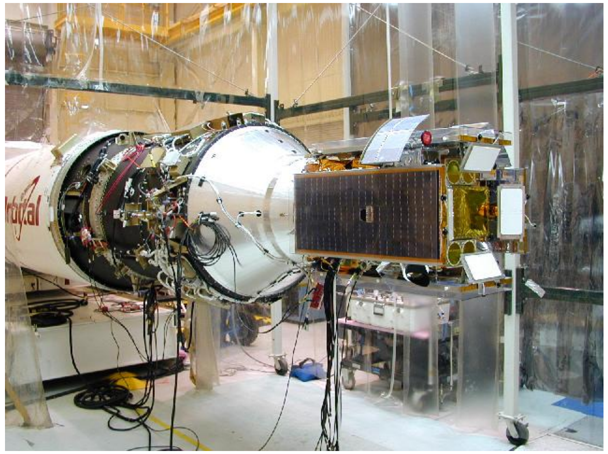
衛星のマネージャーは理研出身者（L. Piro）

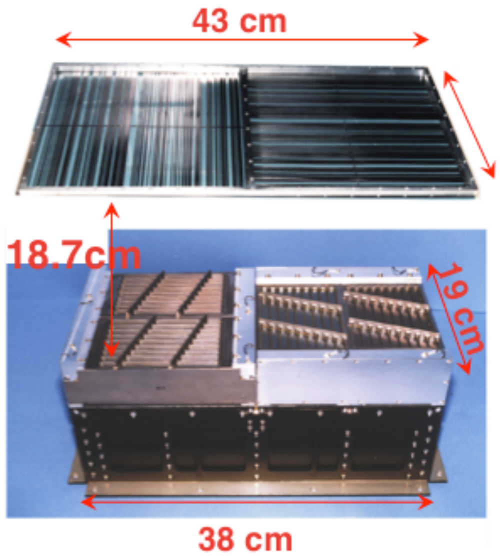
残光の発見による突破口

- X線残光→正確な位置→光学観測
- 赤方偏移測定と母銀河の発見
  →宇宙論的距離
- 莫大なエネルギー
  - GRB源の可能性のある天体は少ない
    - 大質量星の重力崩壊
    - 中性子星連星の衝突・合体
    - 中性子星強磁場(10^{15} G)の突然の消滅
    - ミリ秒パルサーの突然のブレーキ
- 高赤方偏移
  - GRBで太古の宇宙を読み解く可能性

HETE-2 日米仏の国際協力による製作



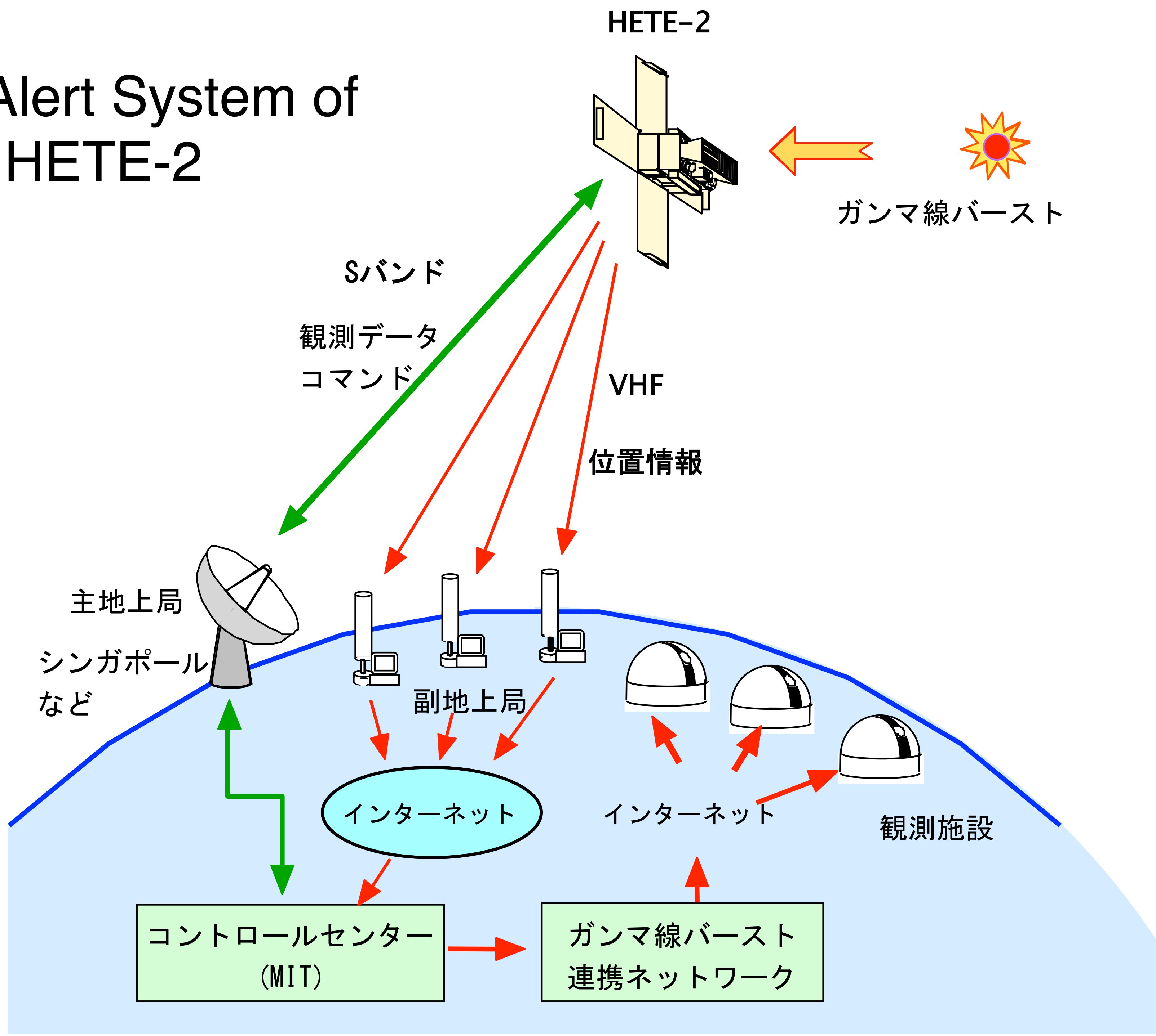




重さ　124 kg
高さ　89 cm
横幅　66 cm
軌道　高度 625 km 、赤道軌道
寿命　2年～
姿勢　反太陽方向を常に向く

通信　送信　S-band (2.272 GHz) 250 kbps
VHF (137.96 MHz) 300 bps
受信　S-band (2.092 GHz) 31 kbps

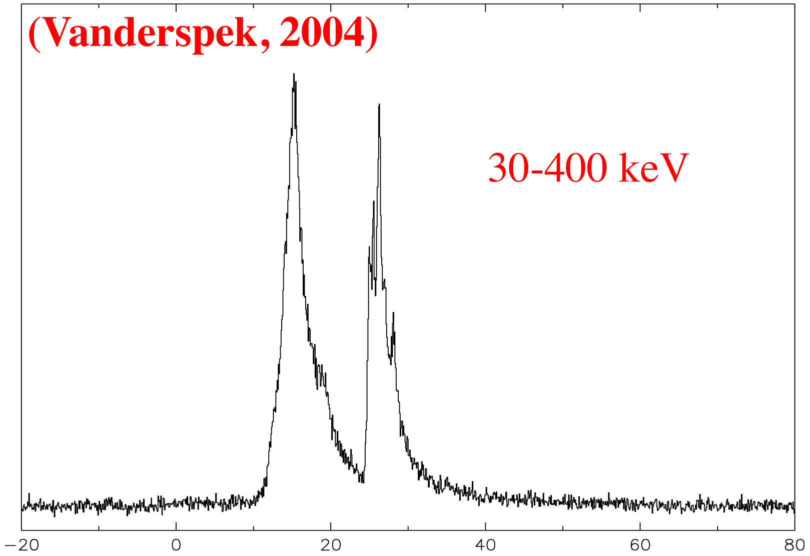
GRB Alert System of HETE-2

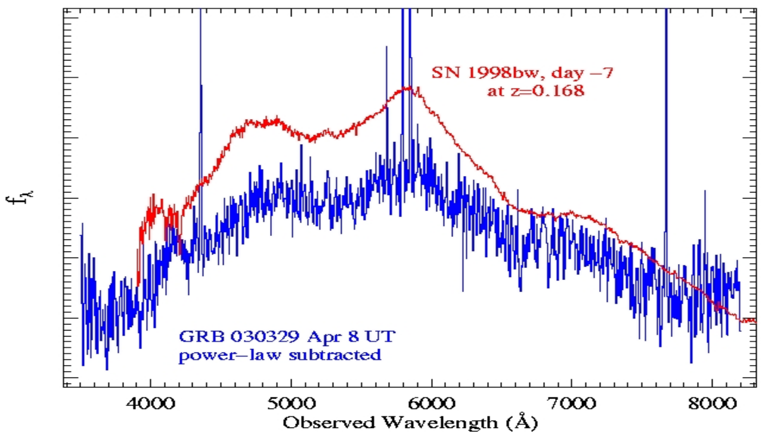


11/27/12

HETEの代表的成果

(2) GRB-SN connection





Stanek et al. (2003; also Fynbo et al. 2003)

GRB 030329

典型的なGRB (本体・残光)
z=0.1675

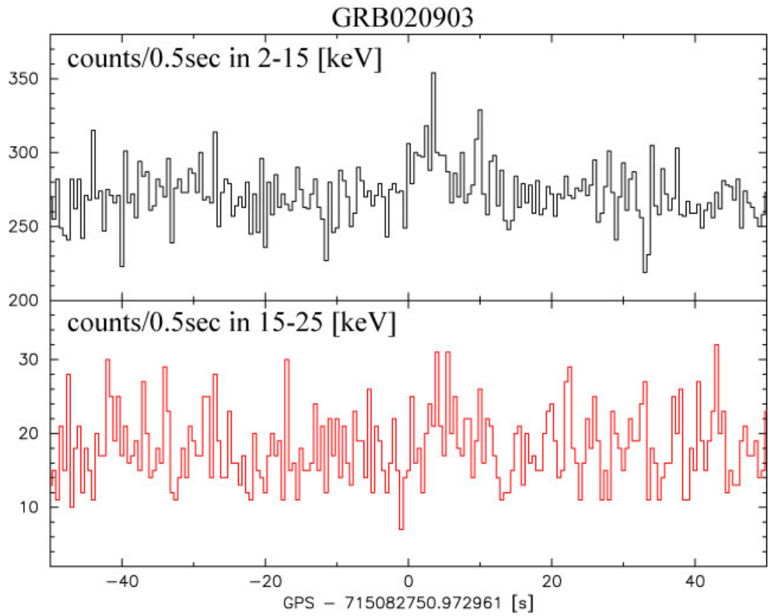
Type Ic 超新星の発見

⇒ SN2003dh

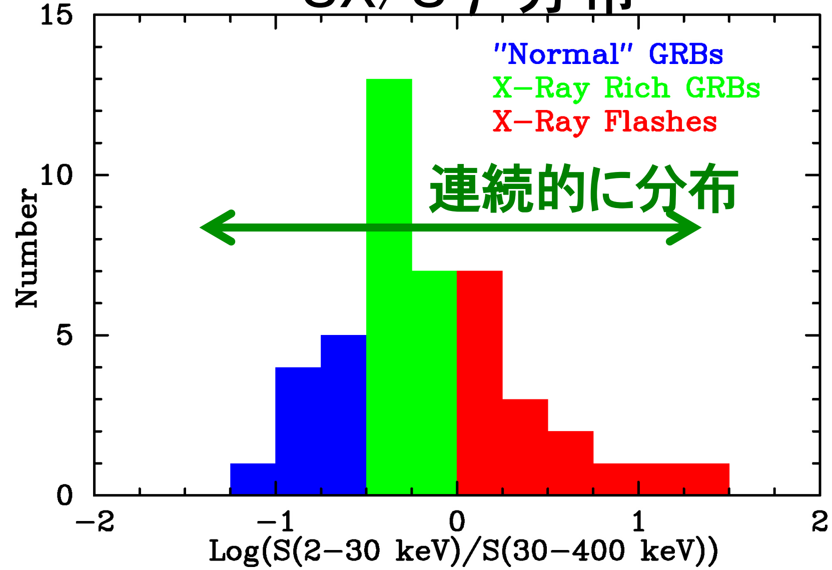
GRB-SN connections

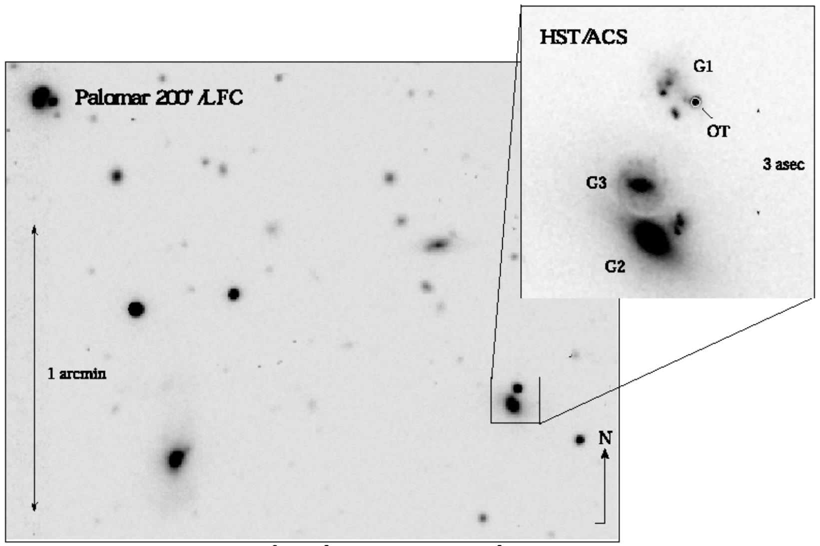
GRB 980425/1998bw
GRB 030329/2003dh 確立
GRB 031203/2003lw
GRB 060218/2006aj

(3) X-Ray Flashes

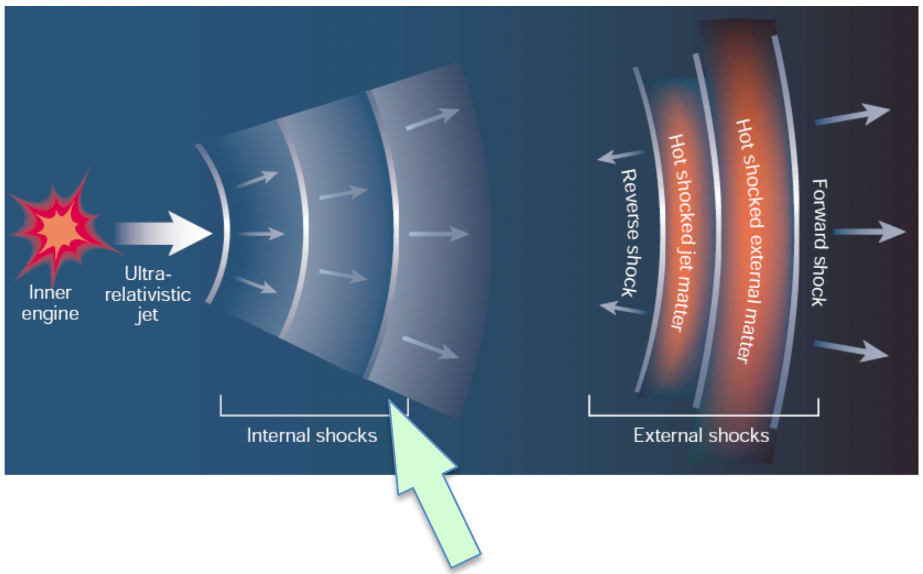


SXγ分布



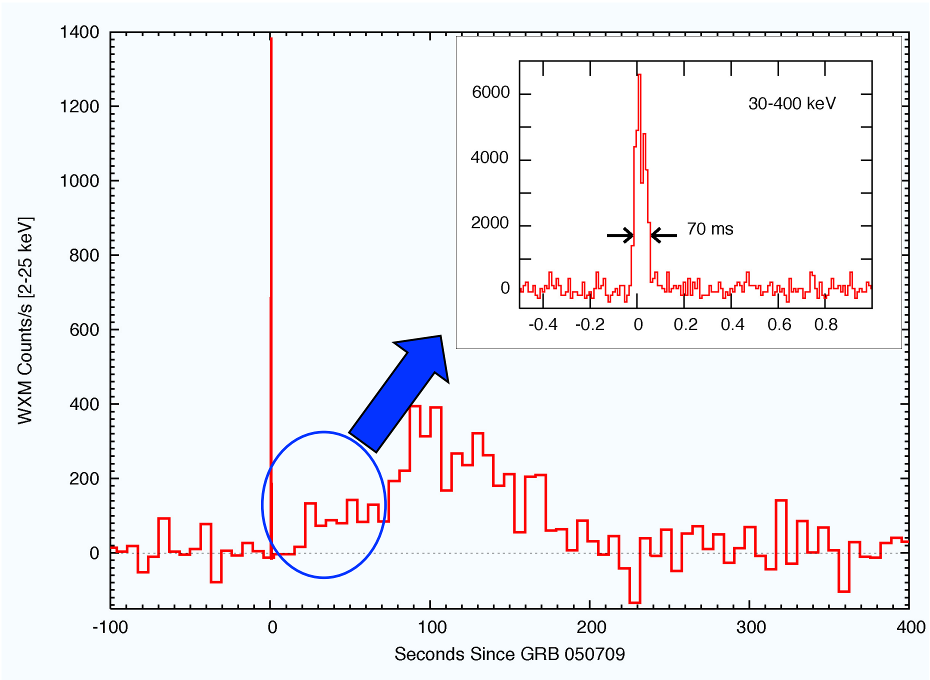


Soderberg et al 2003

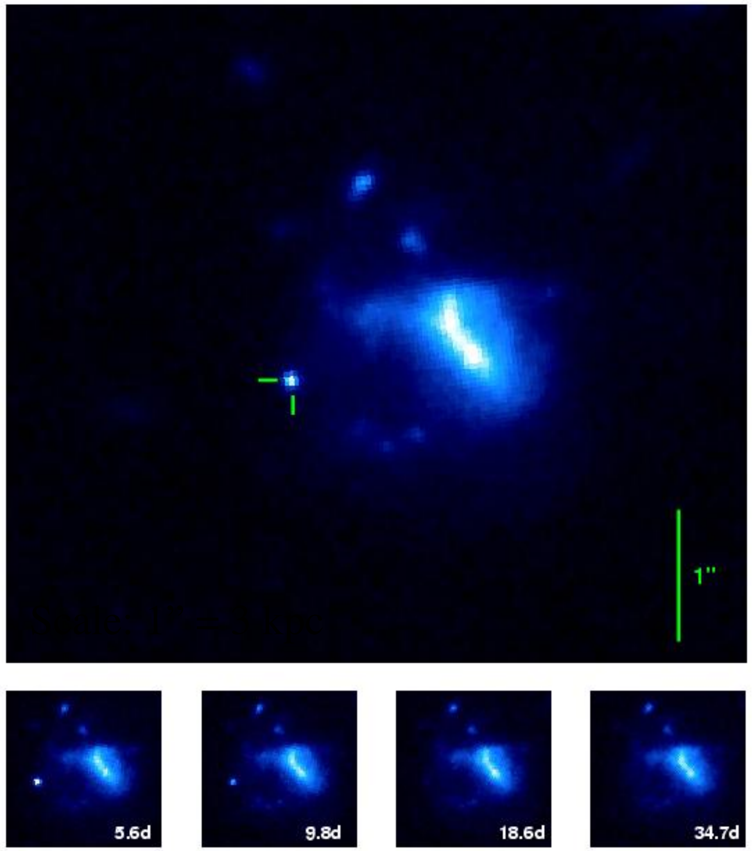


(4) Short GRB

GRB 050709



HST Images at 4 Epochs



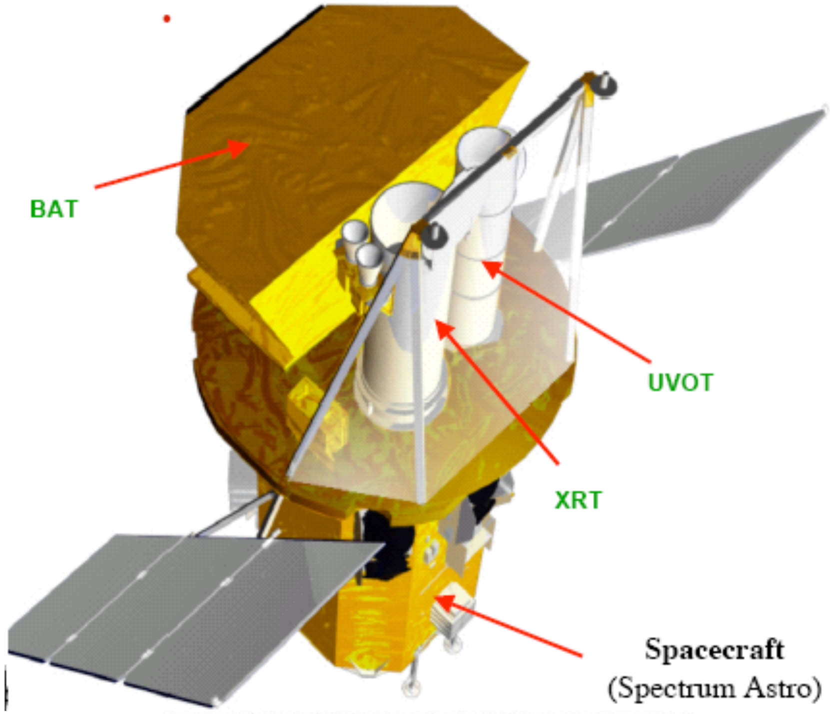
Fox et al., Nature (6 October 2005)

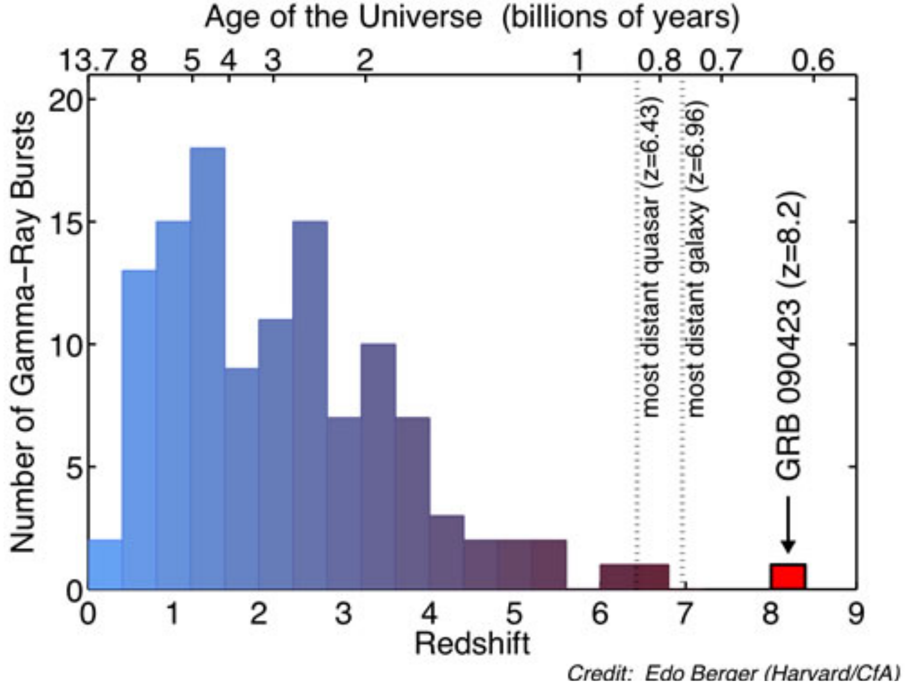
Redshift z=0.160

Swift

- 2004/10～
- ～100 GRB/year
  - 位置精度：数分角（～数秒）
    →数秒角（数分）
- 自身で追跡観測
  - XRT　0.4 –10 keV
  - UVOT --- 赤外はなし

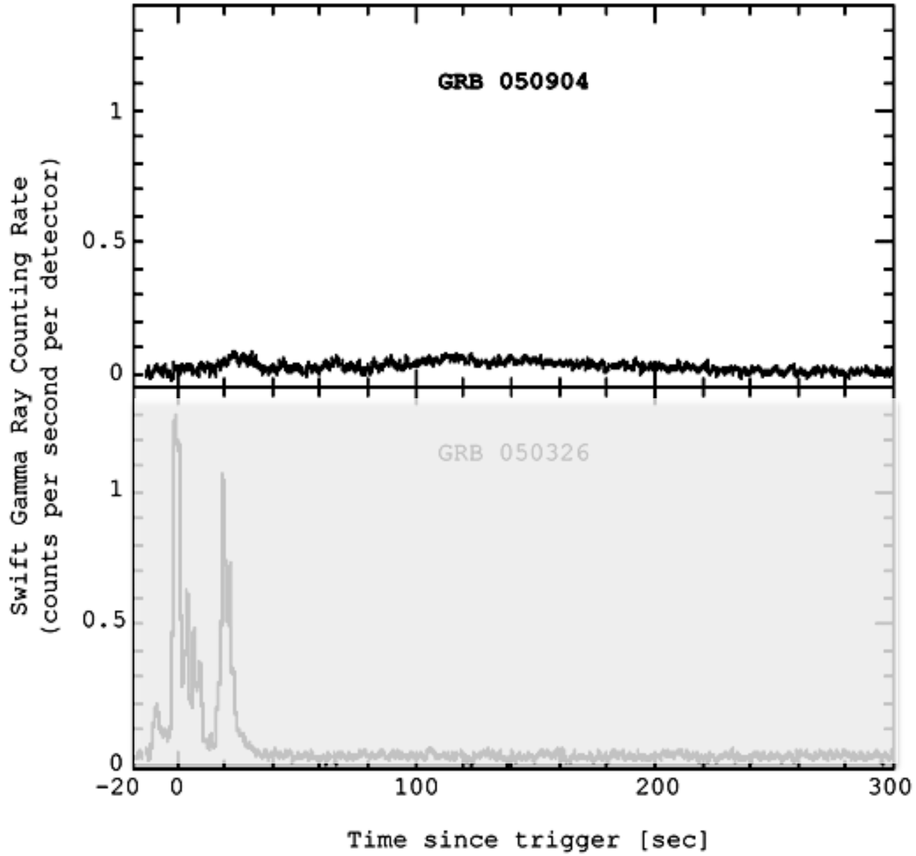
理研出身者（坂本）が
BATチーム中心メンバーの一人



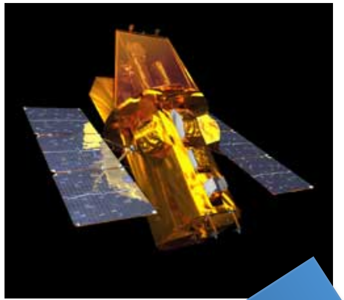


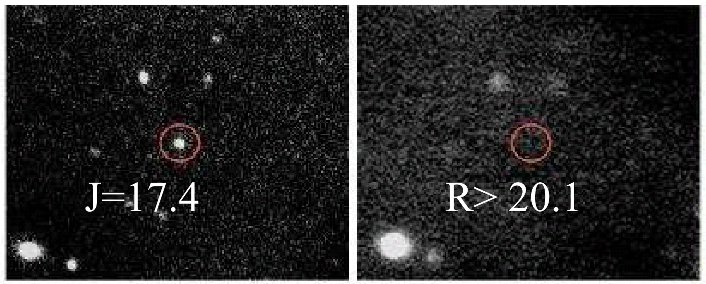
GRB 050904

Cusumano et al. 2006



Long GRB (duration T90 = 225 s) detected by ***Swift*** on 4 September 2005, 01:51:44 UT,

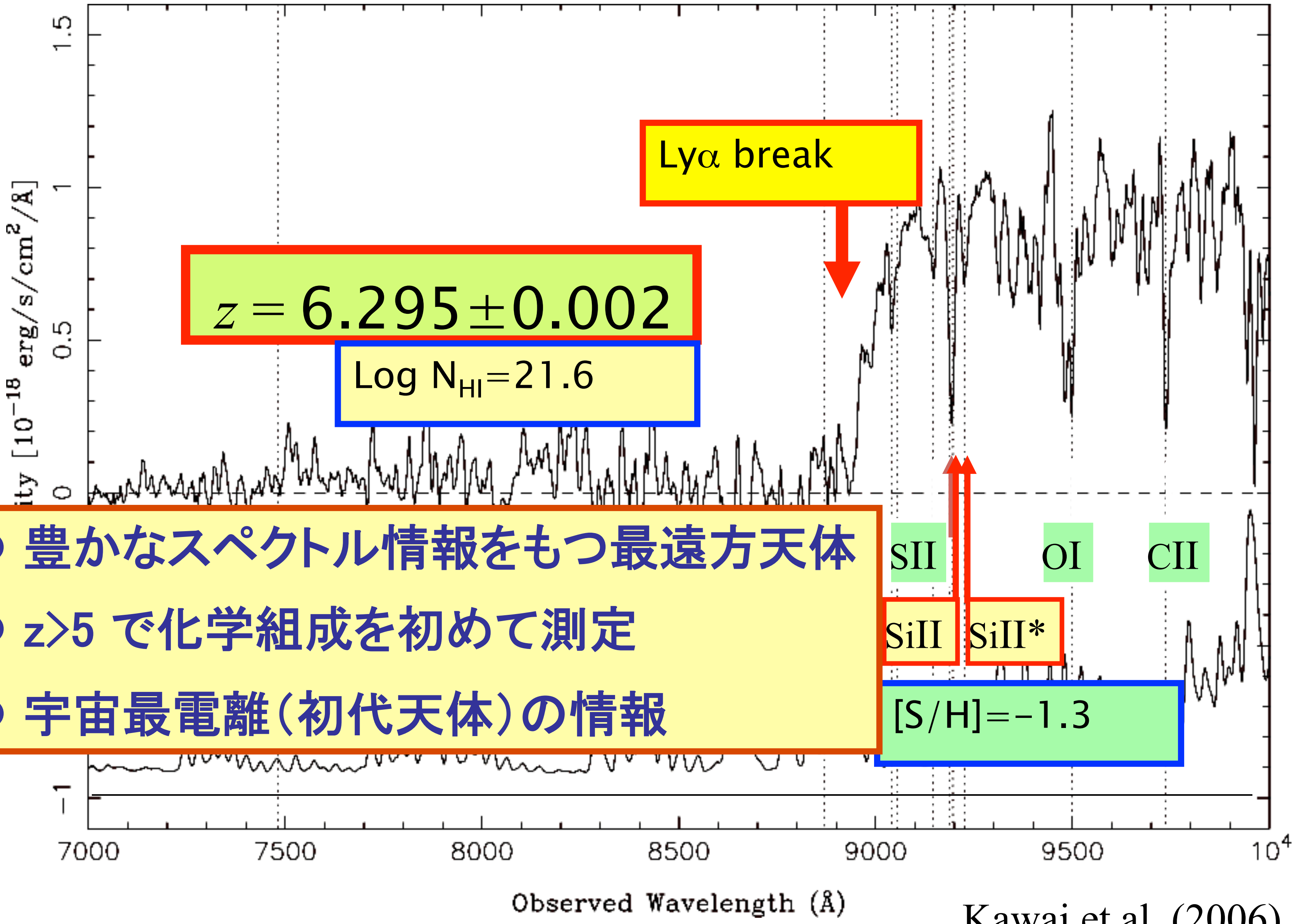




Bright in infrared, but dark in the optical band

Haislip et al. 2006

GRB 050904 at t=3.4 d



- 豊かなスペクトル情報をもつ最遠方天体
- z>5 で化学組成を初めて測定
- 宇宙最電離（初代天体）の情報

Subaru FOCAS 4.0 hrs, $\lambda/\Delta\lambda \approx 1000$

Kawai et al. (2006)
Totani et al. (2006)

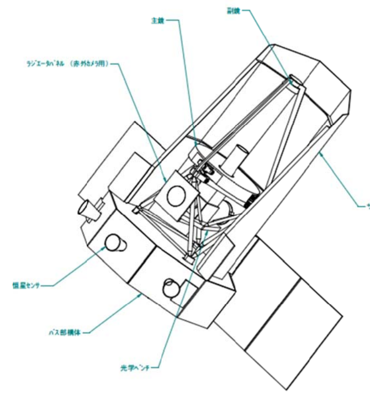
GRB観測の決定的要因

- 正確かつ迅速な位置決定
- 多波長、特に可視・近赤外の追観測
  - 速報＋観測開始の仕組み
    - GCN : インターネット上のGRB連絡網
    - HETE VHF: 衛星→地上への速報
    - Swift: 望遠鏡を発見衛星自体が搭載

- 将来
  - Swiftのような多波長衛星は難しい ☹
  - 発見➔追観測　衛星への司令がいつでも
    - ORBCOMM等、衛星電話メッセージの活用など

破局的突発現象：今後の発見空間

- 宇宙最初の星
  - GRB検出→赤外線撮像、分光
    - 赤外線望遠鏡衛星との連携



WISH
赤外

- 短いGRB
  - 中性子星連星合体 → 重力波との共同観測
- 新現象
  - 潮汐破壊現象
  - Ultrafast X-ray Nova
  - 超新星(+近傍GRB) Shock breakout

  →軟X線に discovery space