Gamma-Ray Bursts and Cosmology

Attila Mészáros

Astronomical Institute, Charles University, Prague

Praha TAU listopad 2015 - leden 2016

Čtyři temata (pět?)

- Dějepis (historie) pro "gamma-ray burst" (GRB) - česky?
- Přehled pozorovacích dat
- Modely
- Vlastní "snažení": 2 nebo 3 podskupiny u GRB a kosmologie
- Skupina v Ondřejově ???? (René Hudec a spol.)

The key members of the team

- **Zsolt Bagoly**, Eötvös Univ., Budapest, Hungary
- **Lajos Balázs**, Konkoly Observatory, Budapest, Hungary
- **István Horváth**, Zrínyi Univ., Budapest, Hungary
- **Attila Mészáros**, Charles Univ., Prague, Czech Republic
- **Peter Mészáros**, Penn State Univ., State College, USA
- **Jakub Řípa**, Taiwan University, Taipei, Tajvan
- **Péter Veres**, Huntsville, NASA, USA

Figure: The magnificent seven!

Some other collaborators - occasionally captured

- **David Huja**, Charles Univ., Prague, Czech Rep.
- **Sylvio Klose**, Tautenburg Observatory, Germany
- **Stefan Larsson**, Stockholm Univ., Sweden
- **Il H. Park**, Sungkyunkwan Univ., Seoul, Korea
- **Felix Ryde**, Stockholm Univ., Sweden
- **Dóra Szécsi**, Eötvös Univ., Budapest, Hungary
- **Jiří Štoček**, Charles Univ., Prague, Czech Rep.
- **Roland Vavrek**, Konkoly Observatory, Budapest, Hungary

A survey of the gamma-ray burst (GRB) topic

Discovery: 1967-1973 - Vela military satellites
Since 1973 - many other X-ray satellites
(Pioneer-Venus, Compton, BeppoSAX,...)
Total number of all discovered GRBs: cca 8000
Typical energy range od photons: $20\,keV - 1\,MeV$
Durations: $0.1\,s - 1000\,s$
Peak fluxes: $0.2 - 50\,photons/(cm^2 s)$
Fluences: $10^{-8} - 10^{-4}\,erg/cm^2$
The cosmological origin is doubtless (since 1997)
Redshifts (z): $0.0085 - 8.2$
There are different types of GRBs (since eighties)

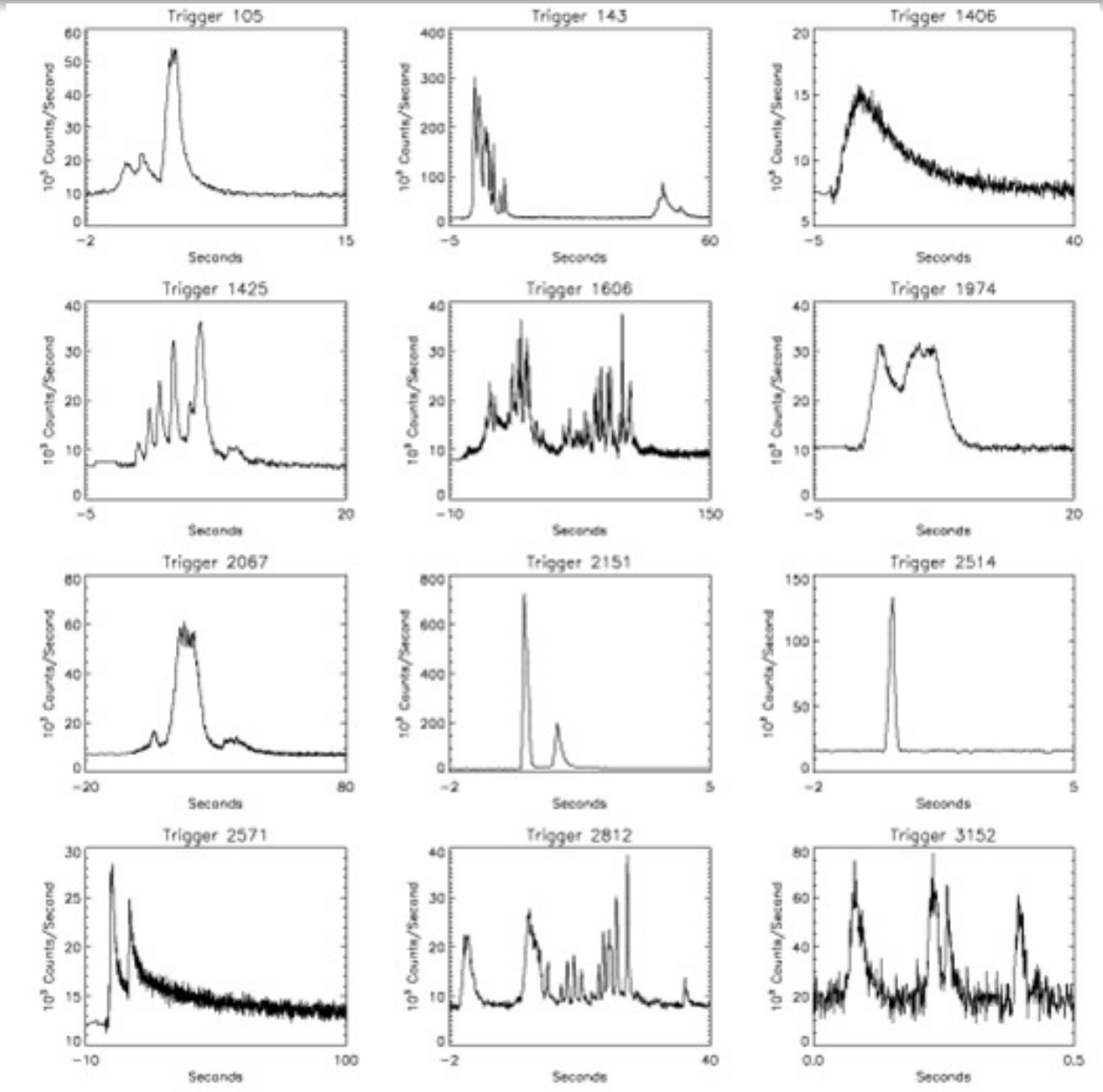

Figure: Typical light curves

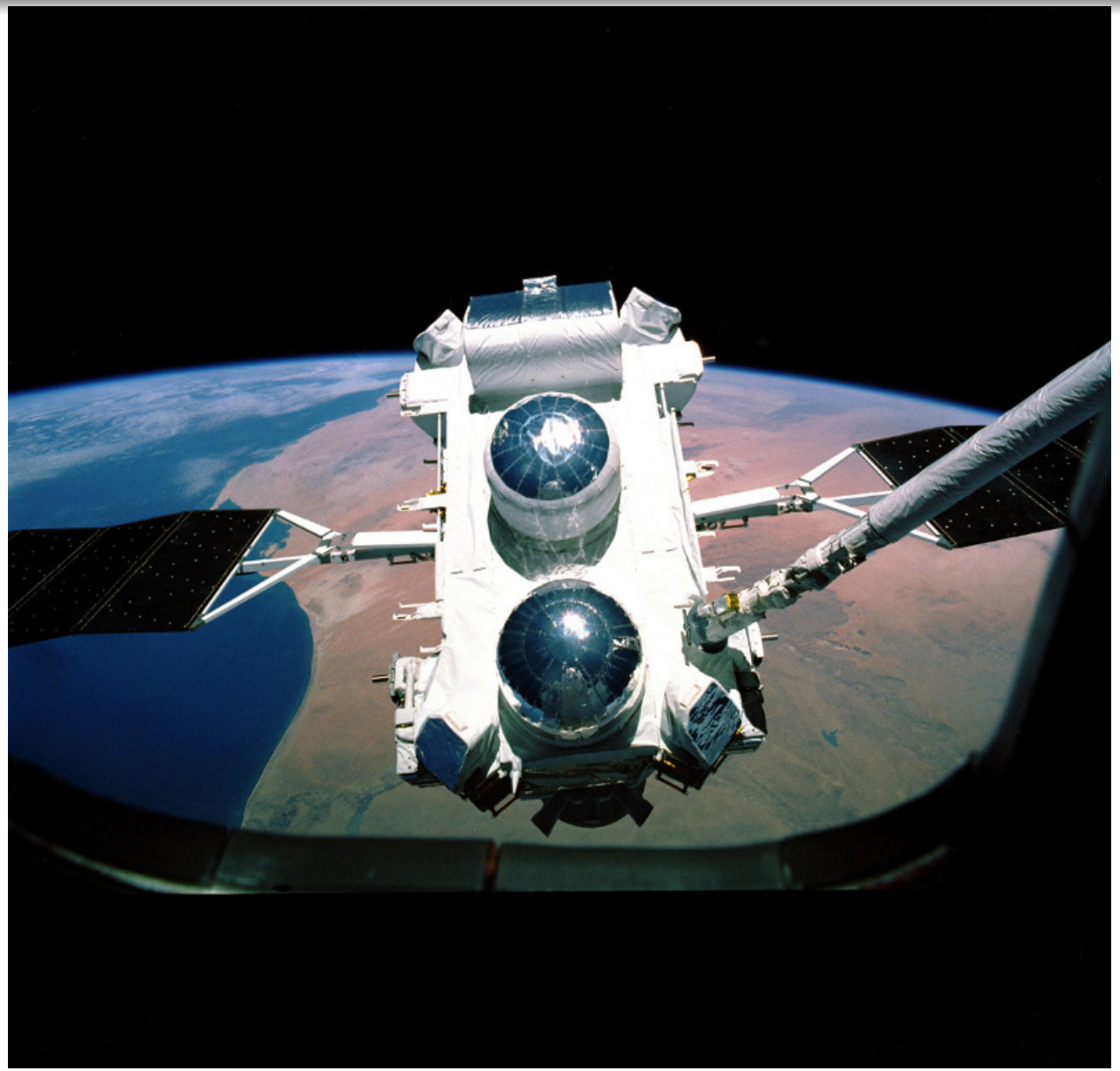

Figure: BATSE on Compton 1990-2000 - data publicly available

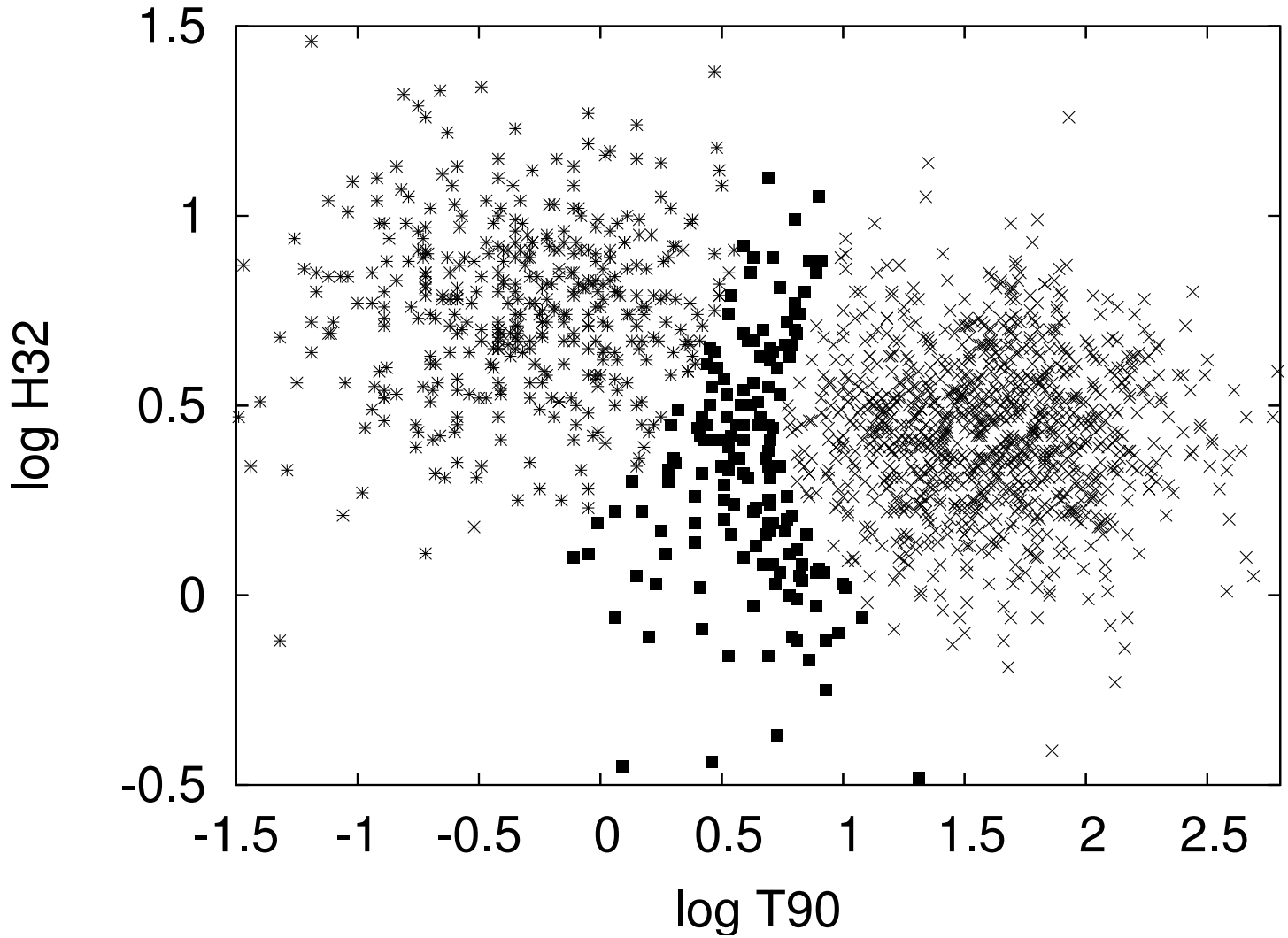

Figure: Two subgroups of the BATSE's GRBs separated with respect to the duration and hardness. T90 is in seconds.

2 subgroups of GRBs - an observational proof

Since eighties = two different types od GRBs (short and long ones) - **astrophysically different phenomena**

Separation with respect to durations and "hardnesses"

Hardness: (fluence at a higher energy channel)/(fluence at a softer energy channel)

Separation at different satellite databases

2704 BATSE Gamma-Ray Bursts

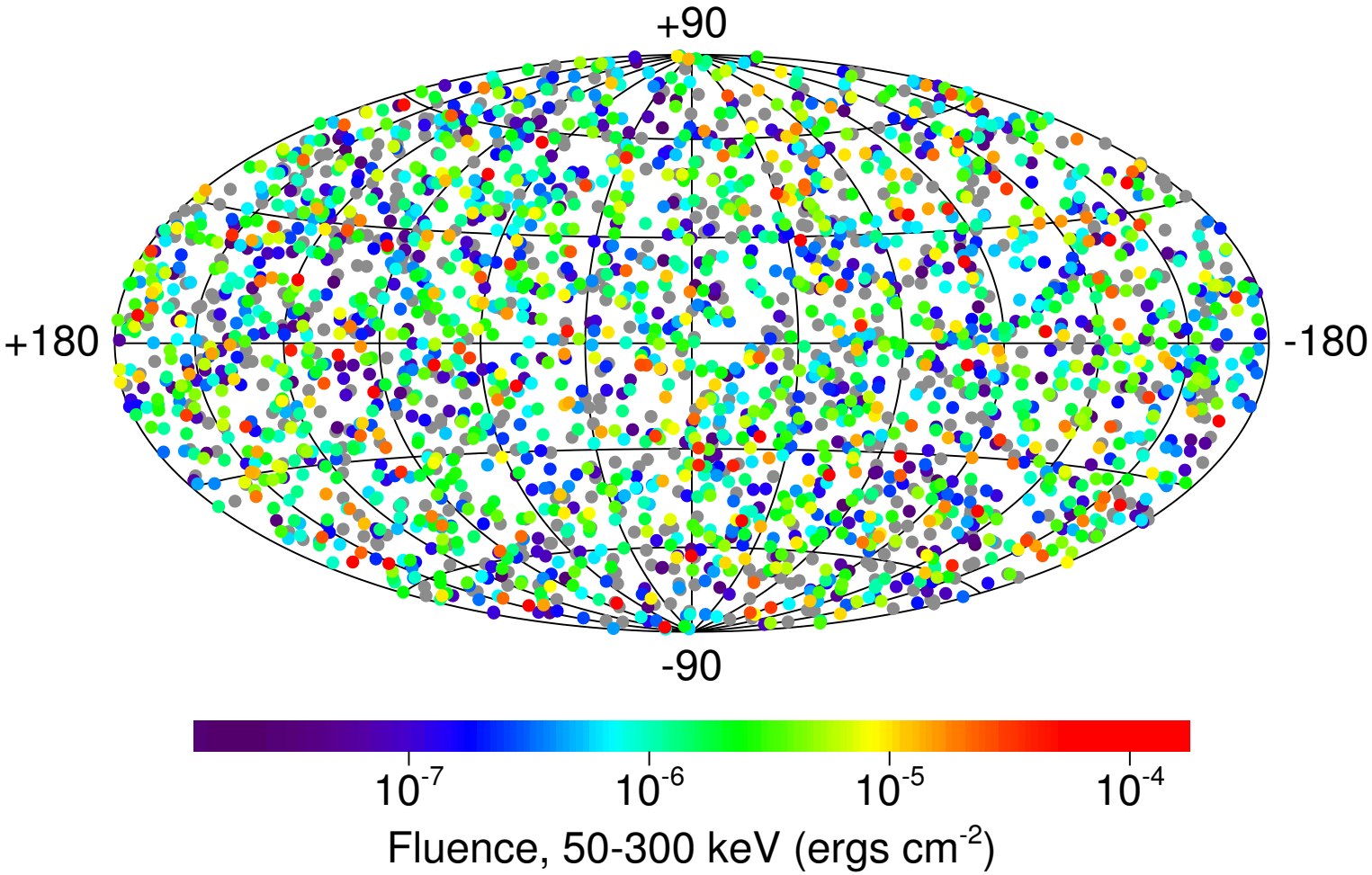

Figure: Sky distribution of the BATSE's GRBs

AŽ SEM JSME SE DOSTALI DNE 11.11.2015

1997 - The Year of BeppoSAX!

The first directly measuered redshift for 970228

$z = 0,695$ 1997 February - 2000 June
BeppoSAX & BATSE simultaneously - 9 BATSE GRBs have direct redshifts

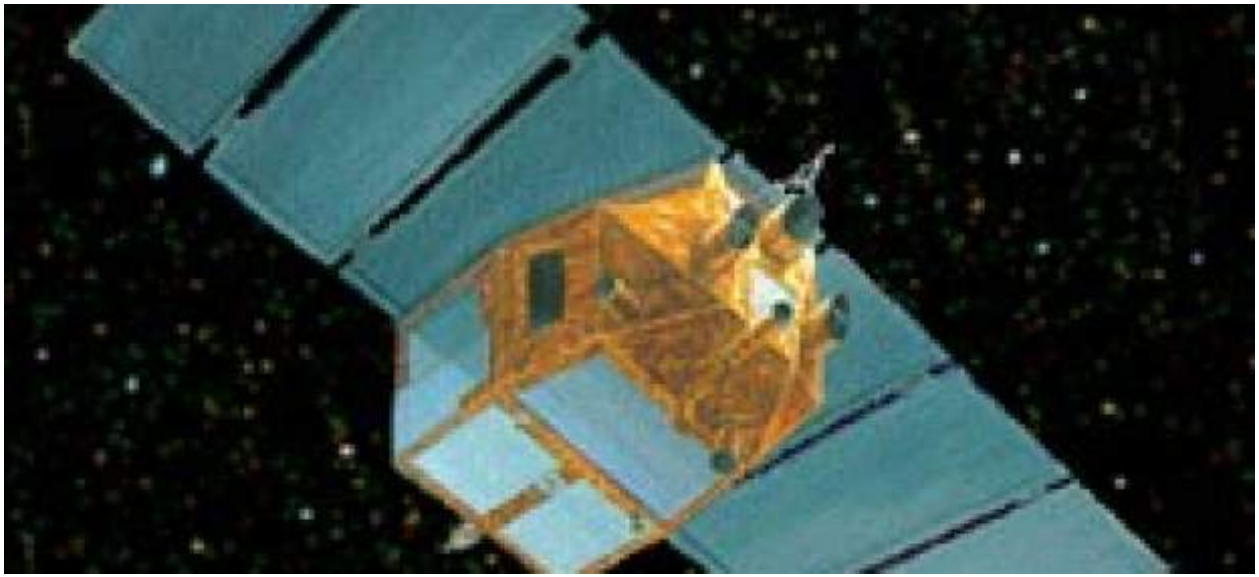

Figure: BeppoSAX

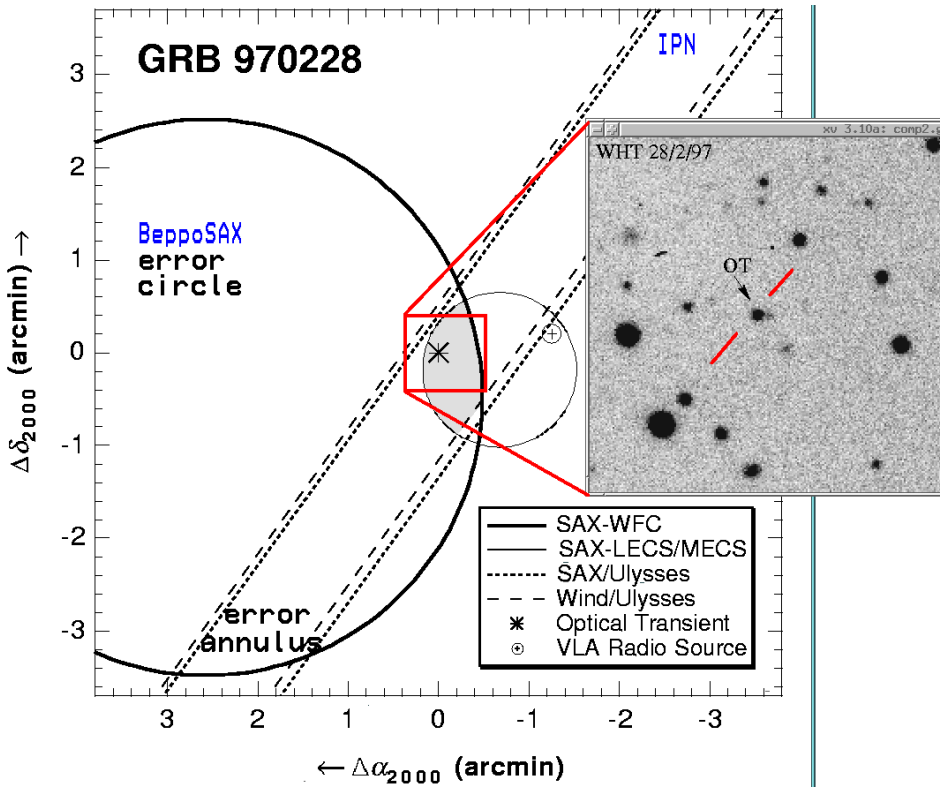

Figure: Discovery of the optical afterglow - error circle

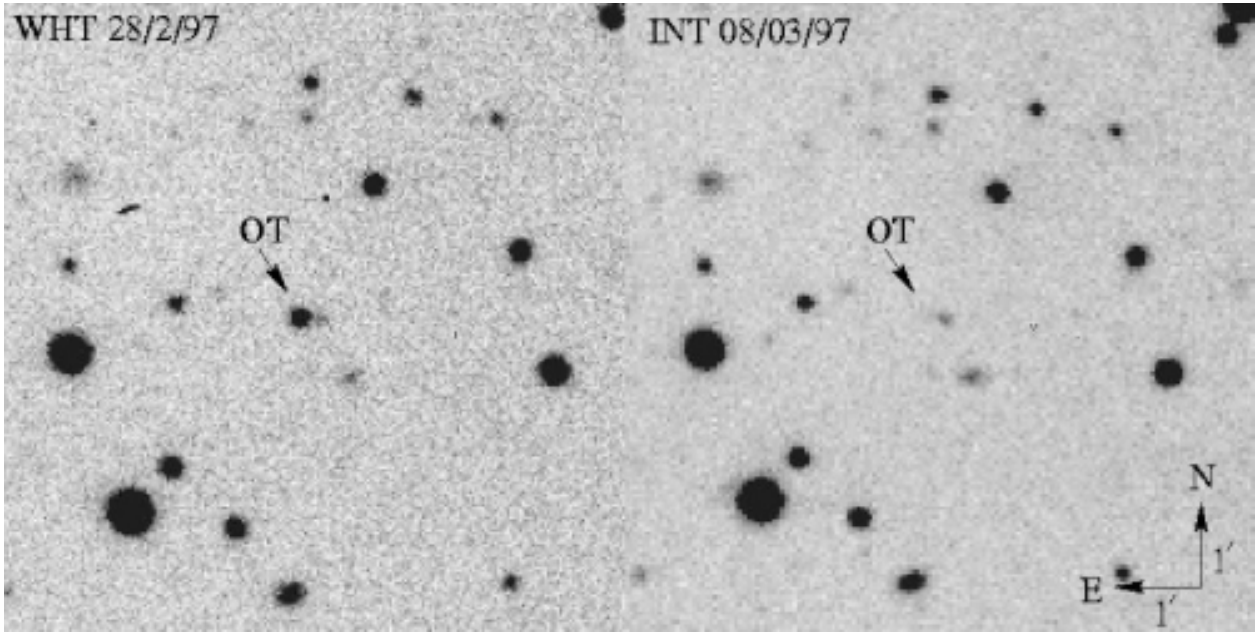

Figure: Discovery of the optical afterglow

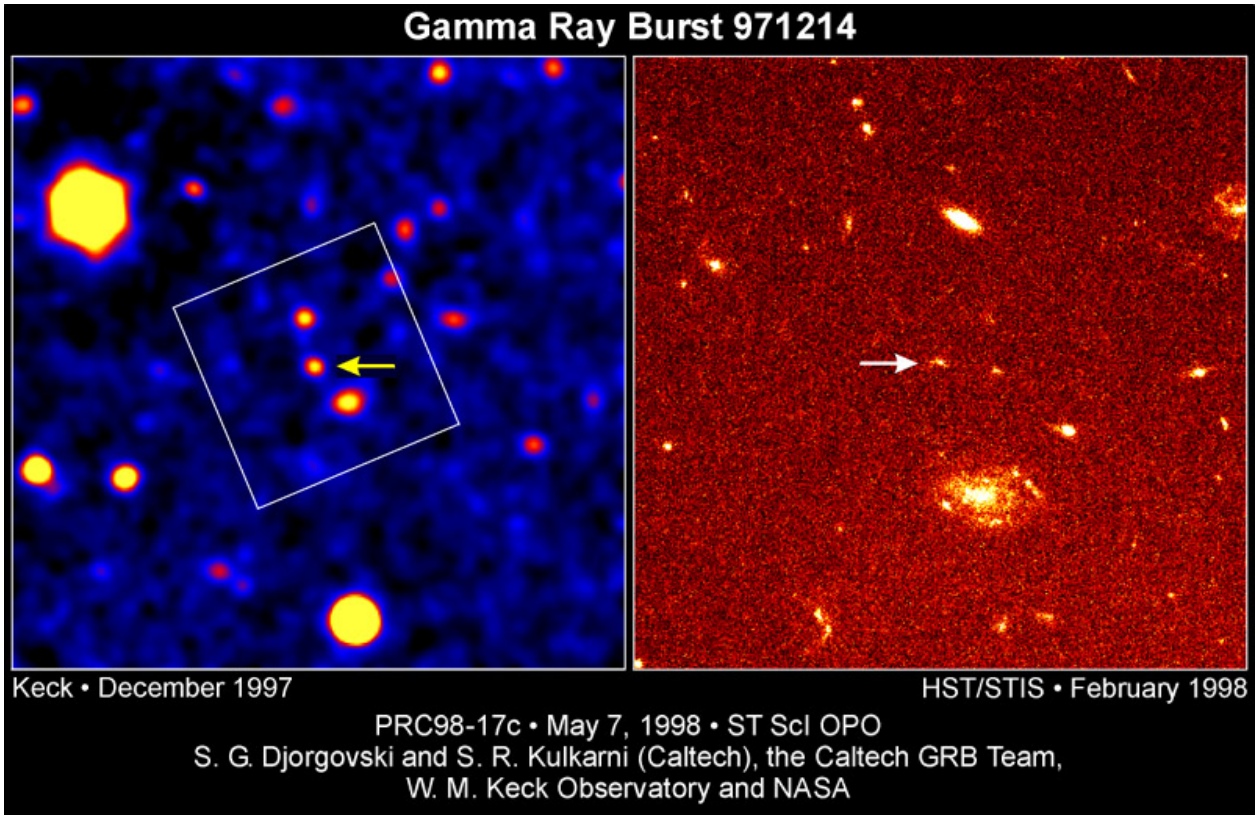

Figure: Dosvit-ilustrace

TROCHU O MODELECH

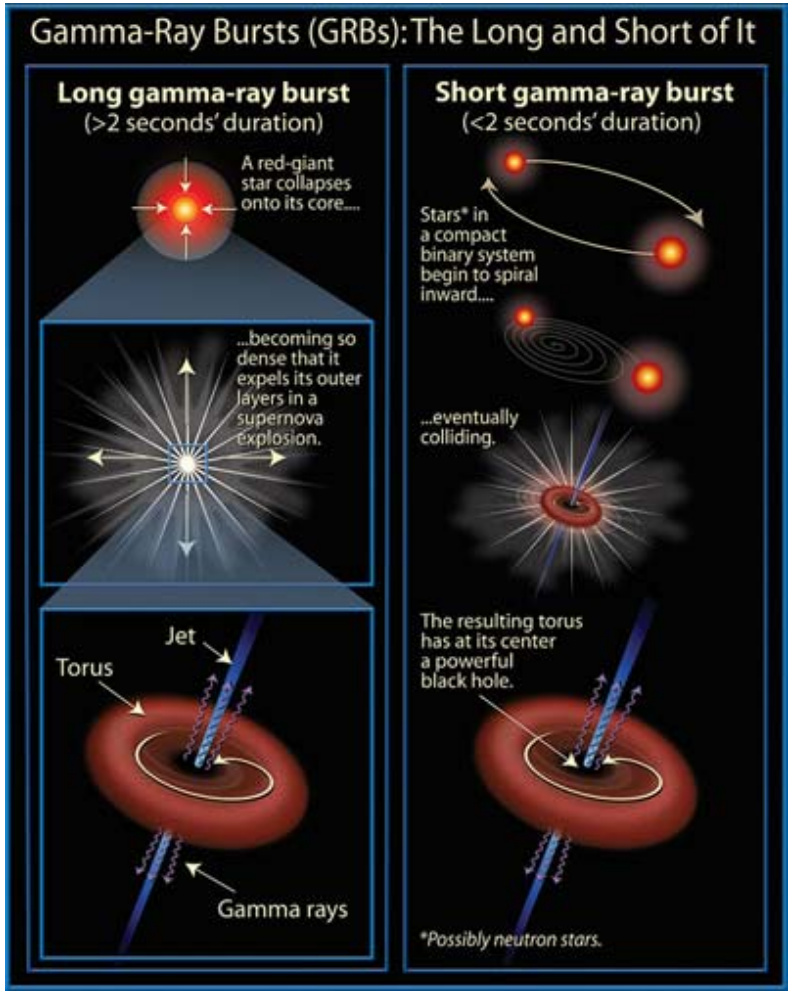

Figure: Dva druhy GRB - modely

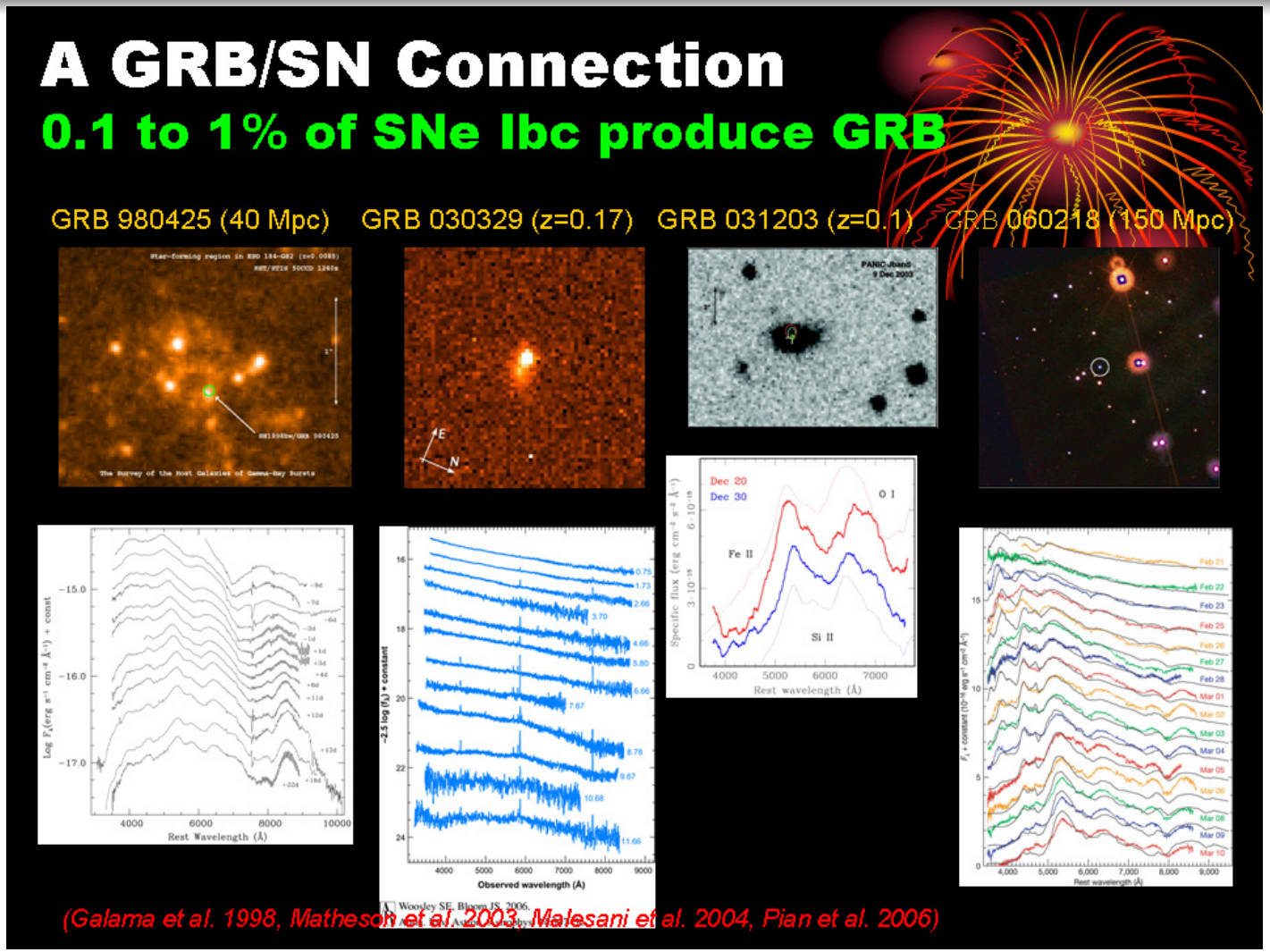

Figure: Long GRB - SN connection

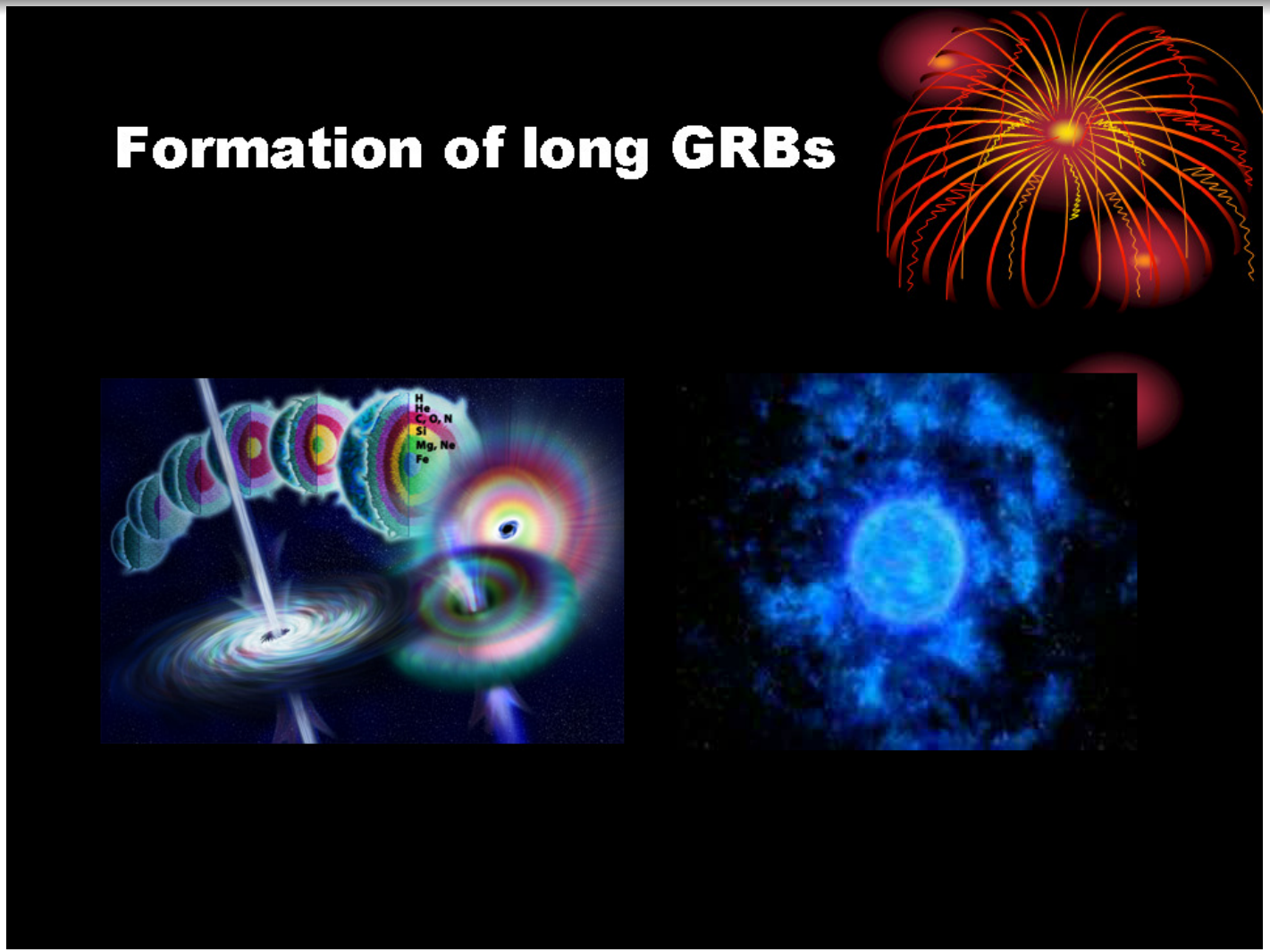

Figure: Long GRB - SN connection - illustration of the SN explosion.

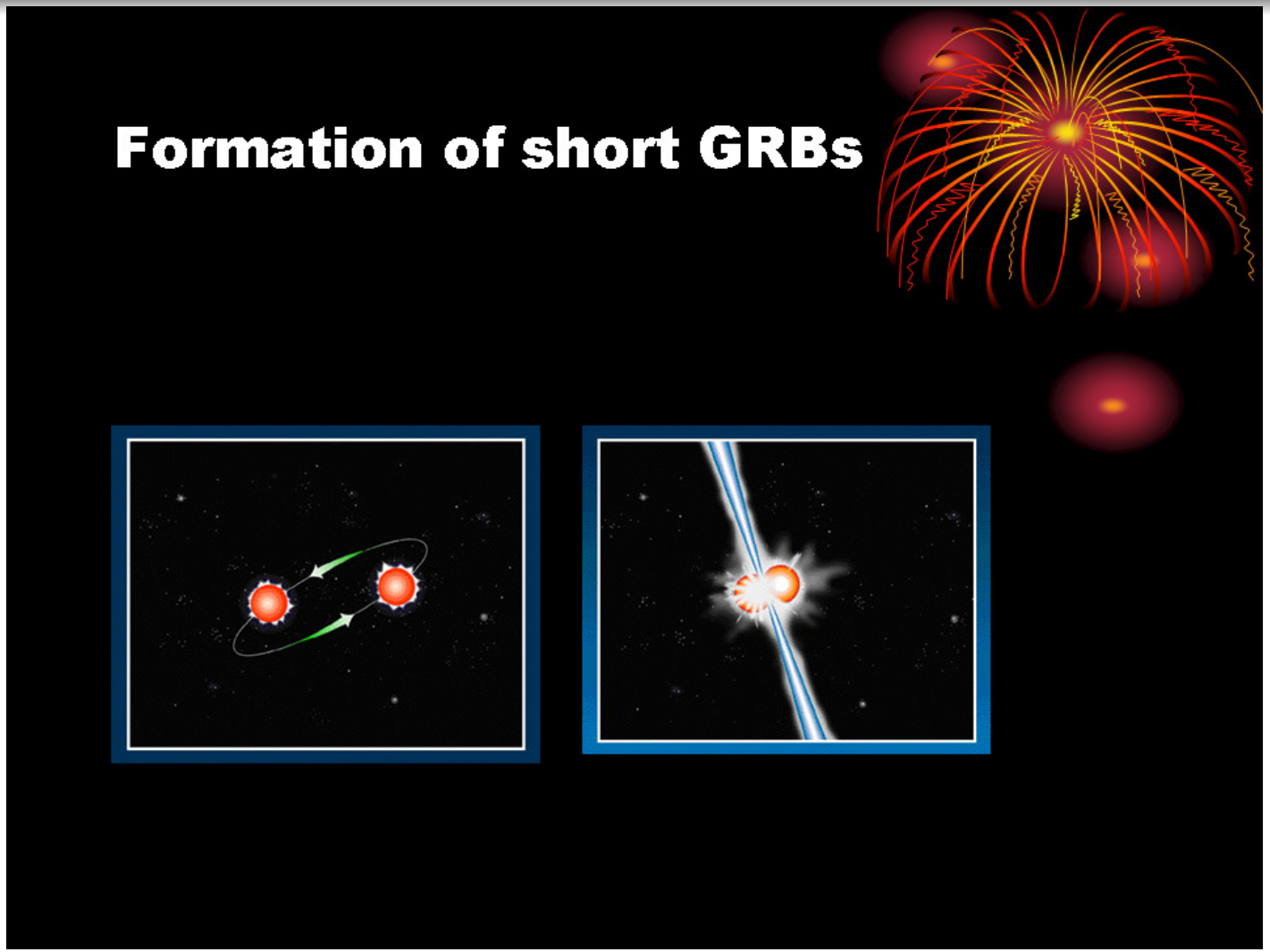

Figure: Formation of the short GRB - illustration of the merging.

AŽ SEM JSME SE DOSTALI DNE 18.11.2015

PŘEHLED VLASTNÍ SNAHY ("SEDM STATEČNÝCH A SPOL."):

1. Radiální rozdělení GRB - jak pro krátké tak pro dlouhé = rozdělení v rudých posuvech
2. Třetí podskupina?
3. Příčné rozdělení na obloze $\longrightarrow$ plasnost kosmologického principu

Three important satellites - their data used by us:

BATSE instruments on the Compton Gamma-Ray Observatory (1991 - 2000)
BATSE = Burst And Transient Source Experiment
RHESSI (2002 -)
RHESSI = Ramaty High Energy Solar Spectroscopic Imager
Swift (2004 -) - the name of a fast flying bird

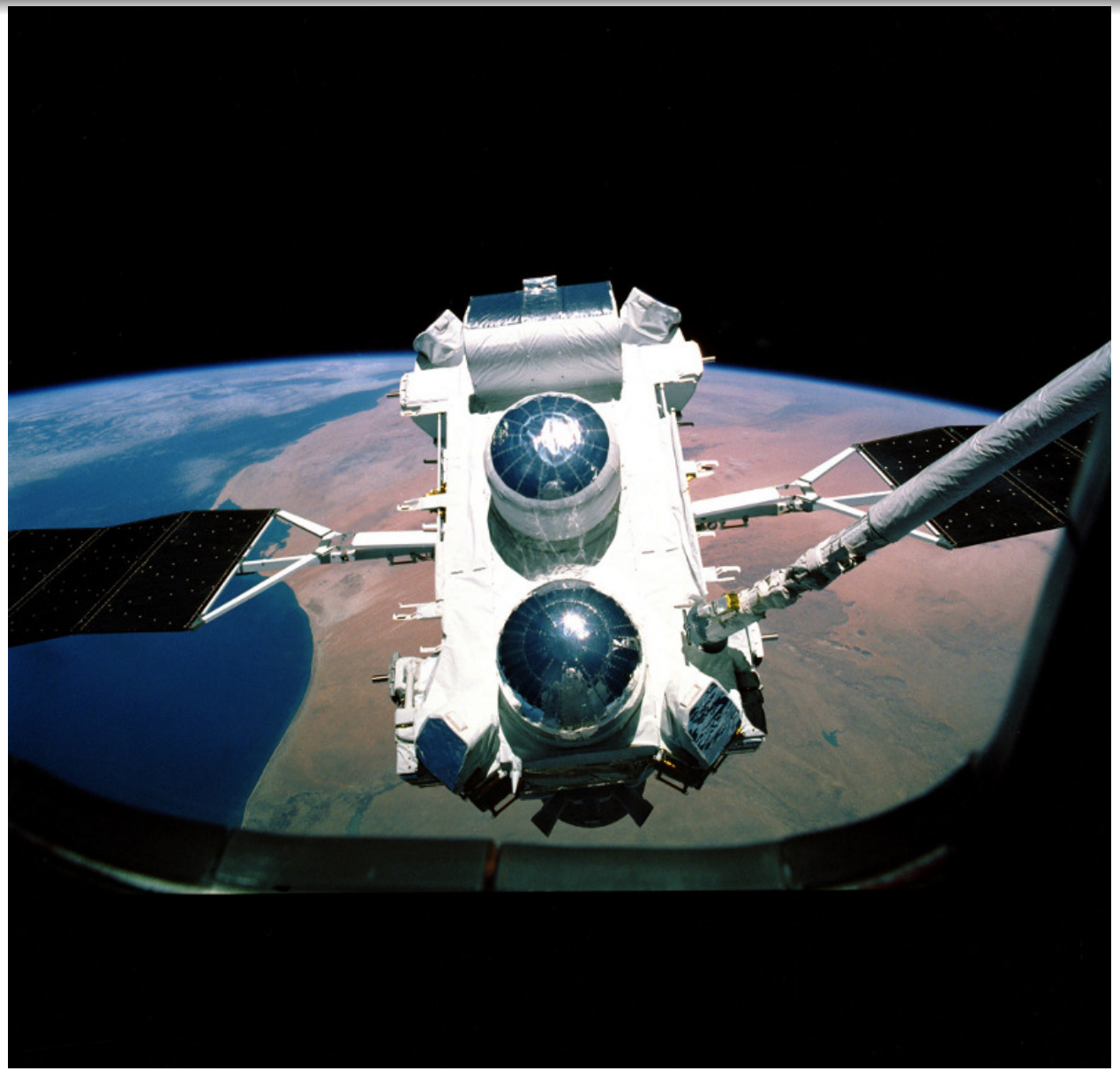

Figure: BATSE on Compton 1990-2000 - data publicly available

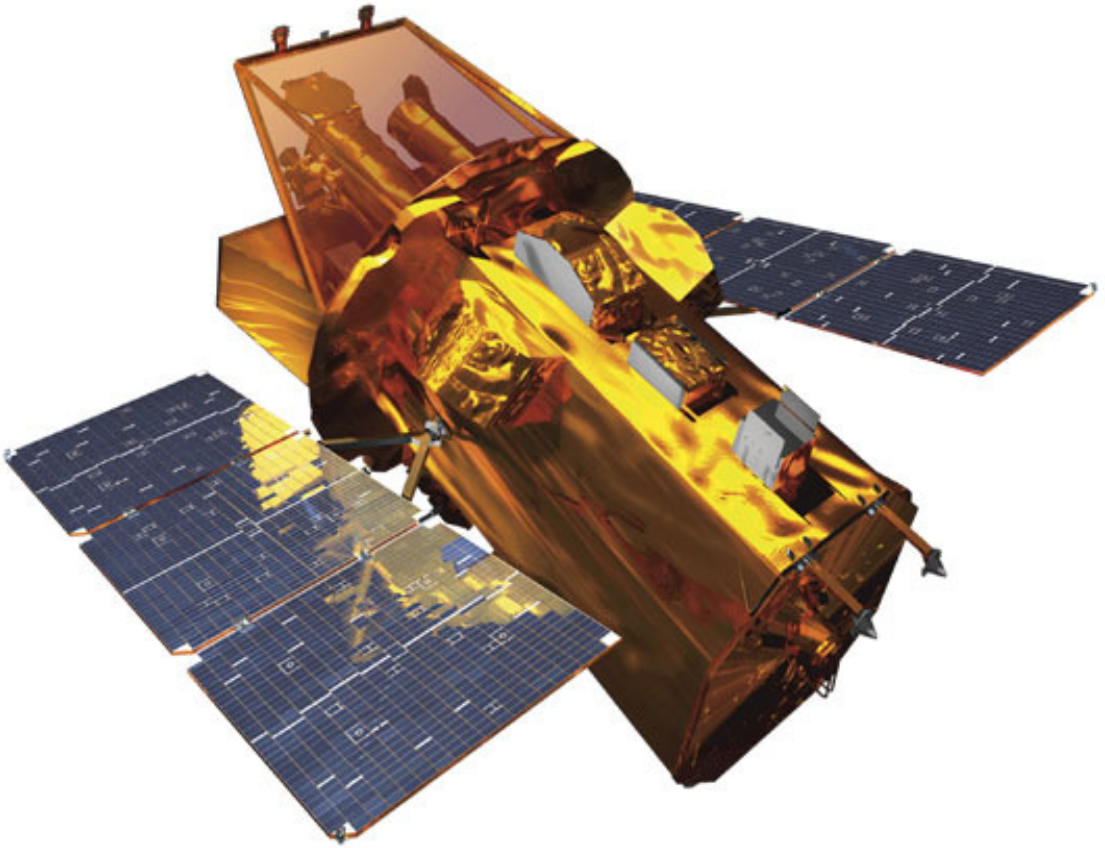

Figure: The Swift satellite - data publicly available

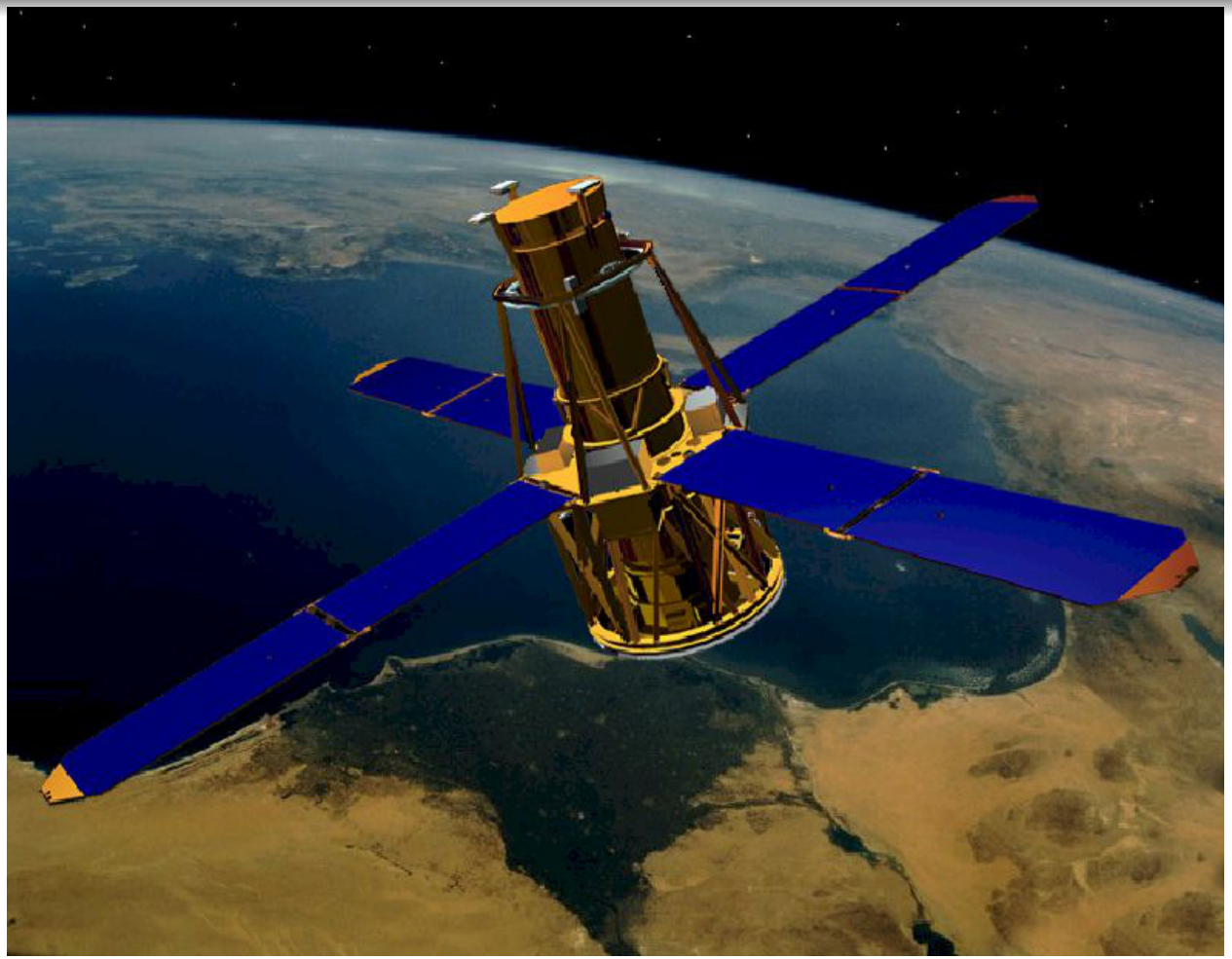

Figure: The RHESSI satellite - data analysis done mainly by J. Řípa

VÝSLEDEK VLASTNÍ SNAHY:
1. Radiální rozdělení GRB - jak pro krátké tak pro dlouhé = rozdělení v rudých posuvech (v z-tech)
1994-96 - GRB nejen, že jsou v kosmologických vzálenostech, ale jsou **vůbec nejvzdálenějšími** objekty ve Vesmíru: $\longrightarrow$ jsou až do $z = 20$ - tři ApJ články dvou Mészárosů.

VÝSLEDEK VLASTNÍ SNAHY:

2. Třetí podskupina: Detaily následují

3 subgroups of GRBs? Some observational evidences

Since 1998 = also a third intermediate subgroup; Horváth 1998; Mukherjee et al. 1998 - simultaneous ApJ papers

Separation again with respect to durations and "hardnesses"

Separation again at different satellite databases

Many statistical articles of the team in this topic since 1998

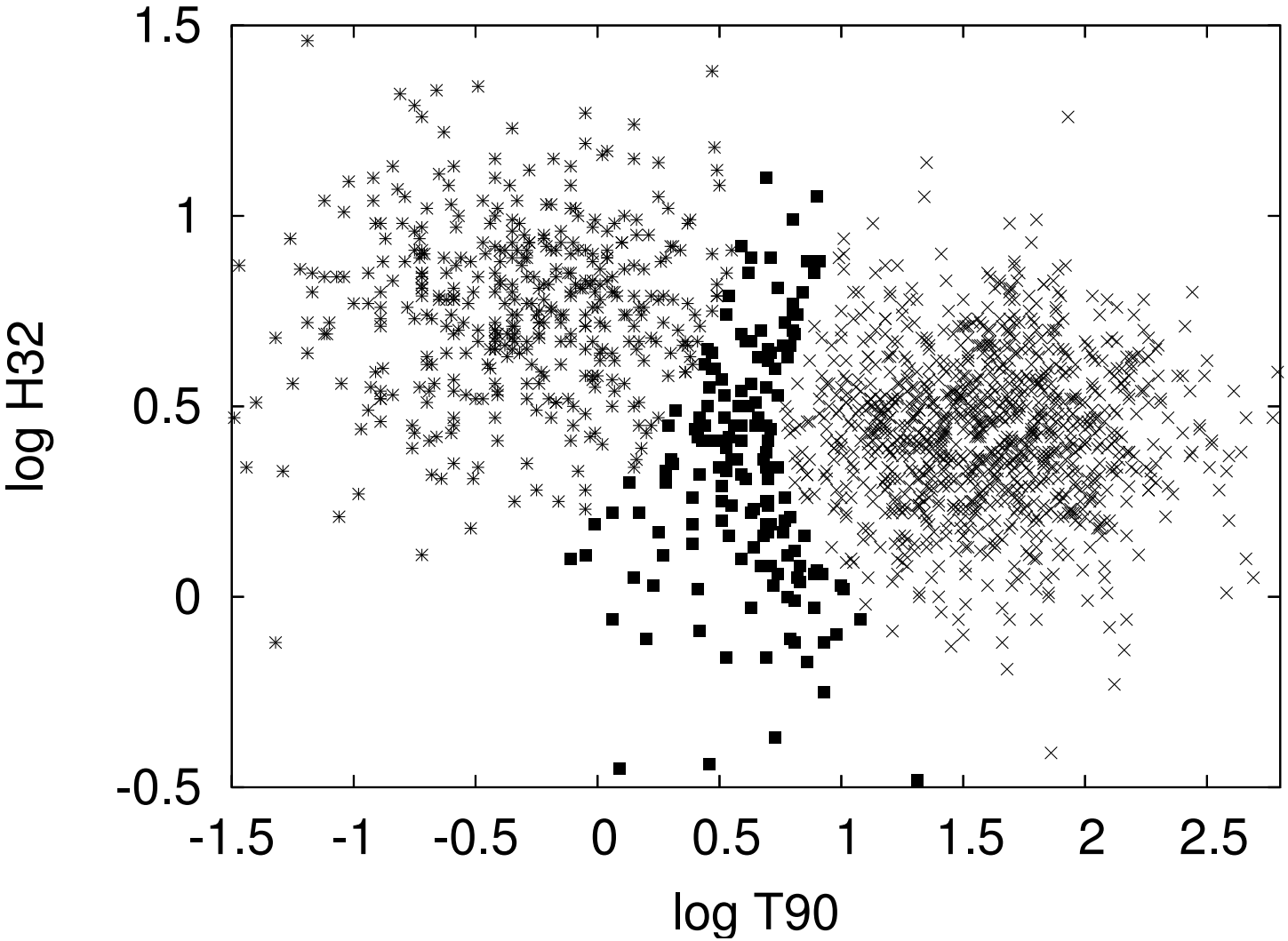

Figure: Three (?) subgroups of the BATSE's GRBs separated with respect to the duration and hardness. T90 is in seconds.

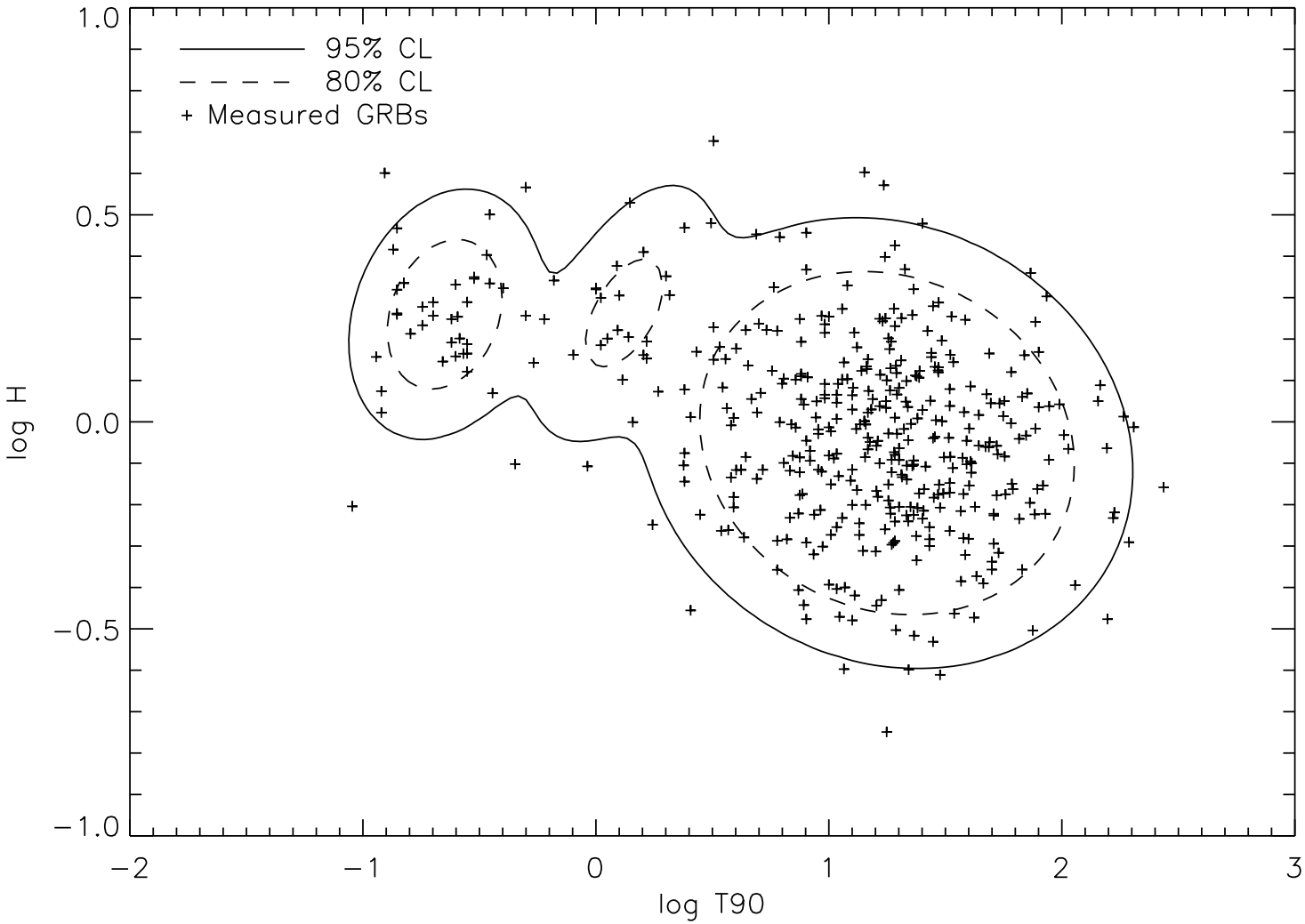

Figure: The three subgroups of the RHESSI's GRBs. T90 is in seconds.

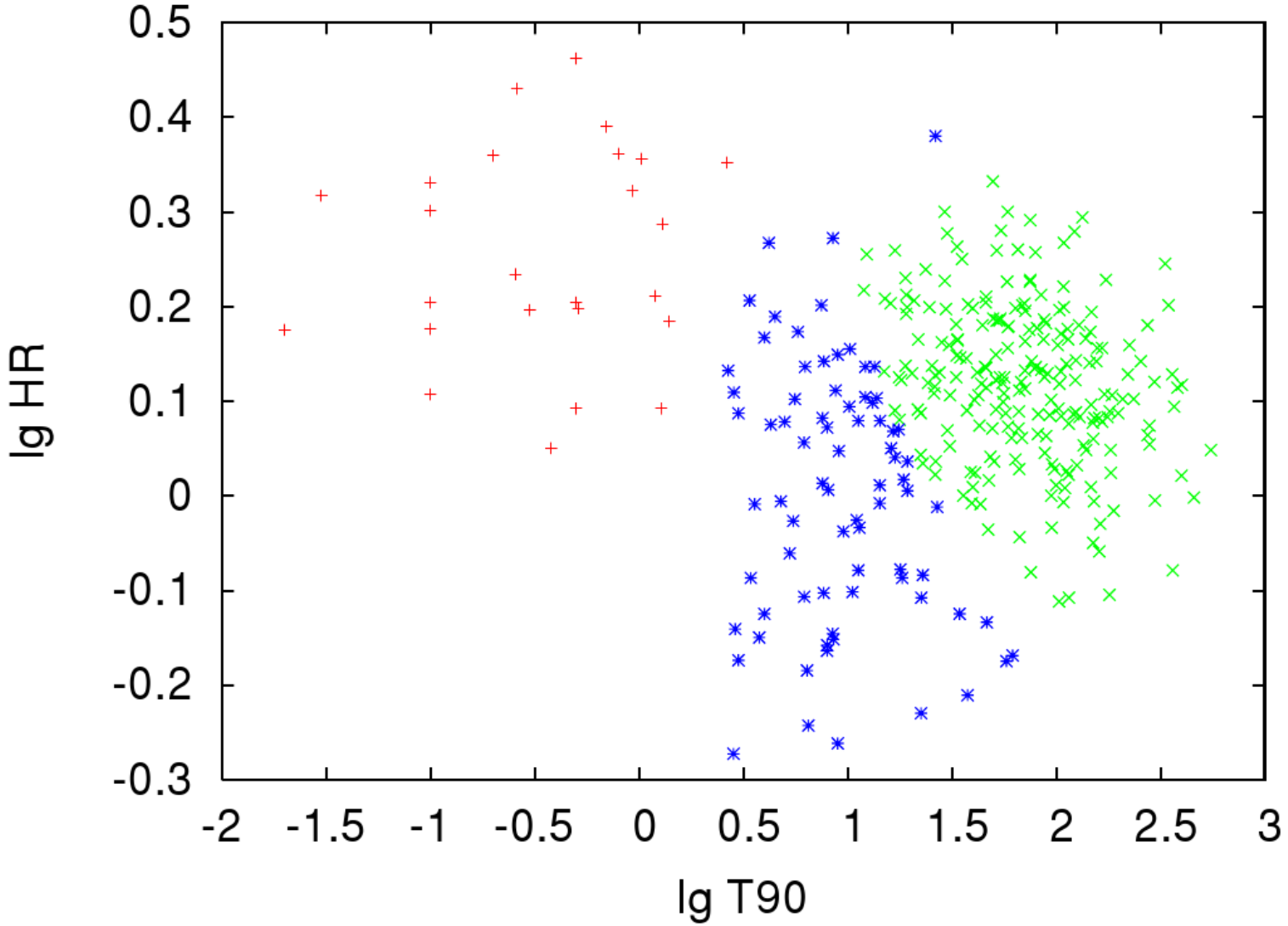

Figure: The similar three subgroups of the Swift's GRBs. T90 is in seconds.

Intermediate subgroup: **It exists, but...!**

From the observational point of view:
Statistical tests **confirm** its existence!
But, carefully: This can still be a consequence of some selection effects, biases, etc...
The intermediate subgroup **need not be** an astrophysically different GRB class

Simply: **Carefully with the physical meaning!**

Astrophysics of the third subgroup - year 2015

Intermediate GRBs: Physical meaning - a key step

Veres P., Bagoly Z., Horváth I., Mészáros A., Balázs L.G. ApJ, 725, 1955 (2010)

Intermediate subgroup in the **Swift** database =

X-Ray Flashes (XRFs)

$\longrightarrow$ X-Ray Flashes (XRFs) = in essence long bursts
Conclusion for Swift: Intermediate bursts **are not** astrophysically different phenomena; $\longrightarrow$ they are in essence long GRBs.

Intermediate GRBs - year 2011-15

Intermediate GRBs - Physical meaning for RHESSI data:

Is it the same as for Swift? No, it is not!

Řípa J., Mészáros A., Veres P., Park I.H., ApJ, 2012, 756, 44

Řípa J., Mészáros A. in preparation

Intermediate subgroup in the RHESSI database $\neq$ X-Ray Flashes (XRFs)!

Intermediate subgroup in the RHESSI database is similar to short bursts!

No relation to the long bursts!!!

Intermediate GRBs - year 2011-15

Intermediate GRBs - Physical meaning for BATSE:
Is it the same as for Swift? Or as for RHESSI?
Řípa J., Mészáros A. in preparation
Intermediate subgroup in the BATSE database = X-Ray Flashes (XRFs) cannot hold for the whole intermediate subgroup. The indentity can be fulfilled only partly.

VÝSLEDEK VLASTNÍ SNAHY:

3. Příčné rozdělení na obloze $\longrightarrow$ plasnost kosmologického principu:

Detaily následují

2704 BATSE Gamma-Ray Bursts

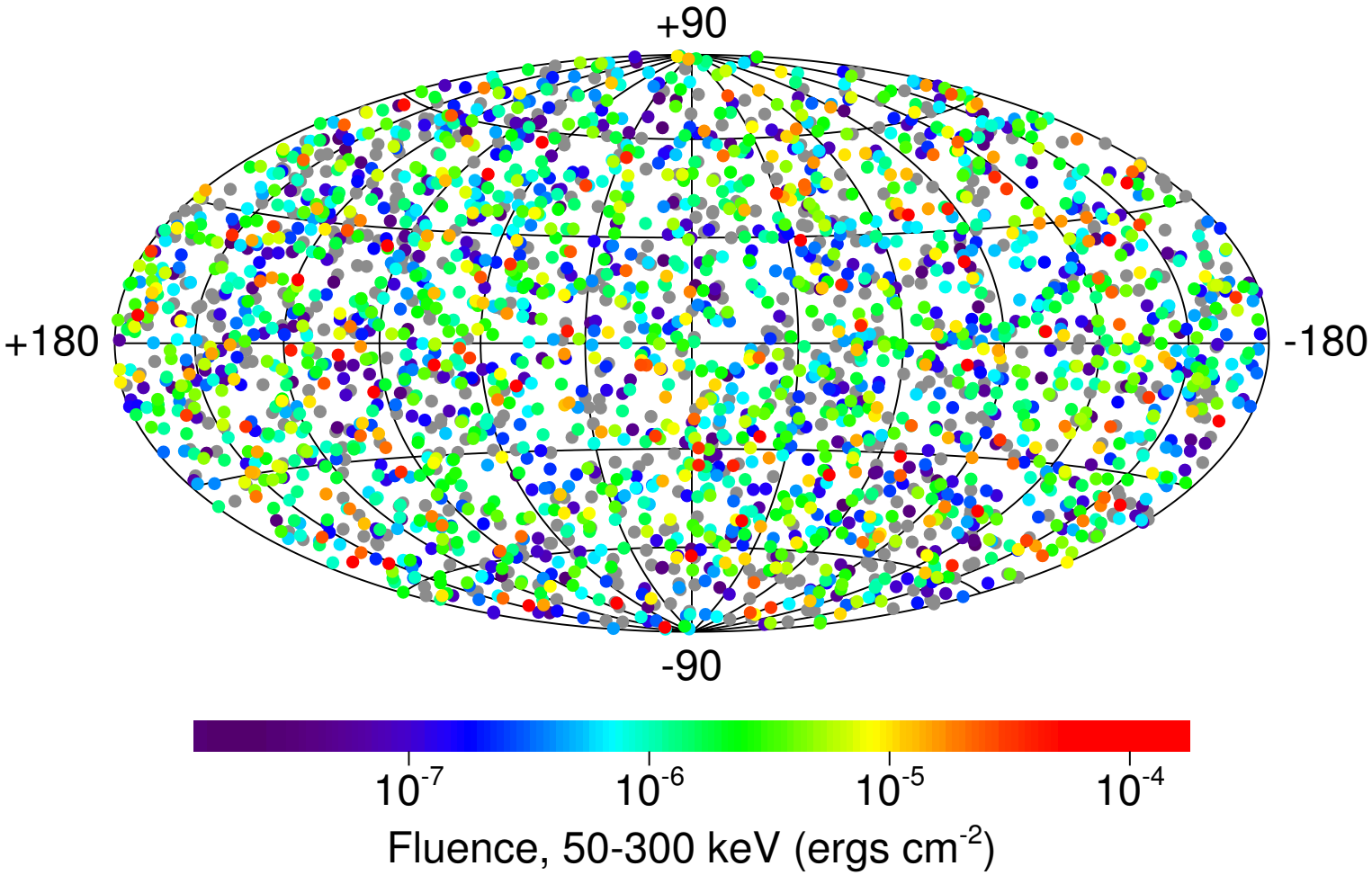

Figure: Sky distribution of the BATSE's GRBs: No isotropy!
Balázs, Mészáros A., Horváth, AA, 339, 1, 1998

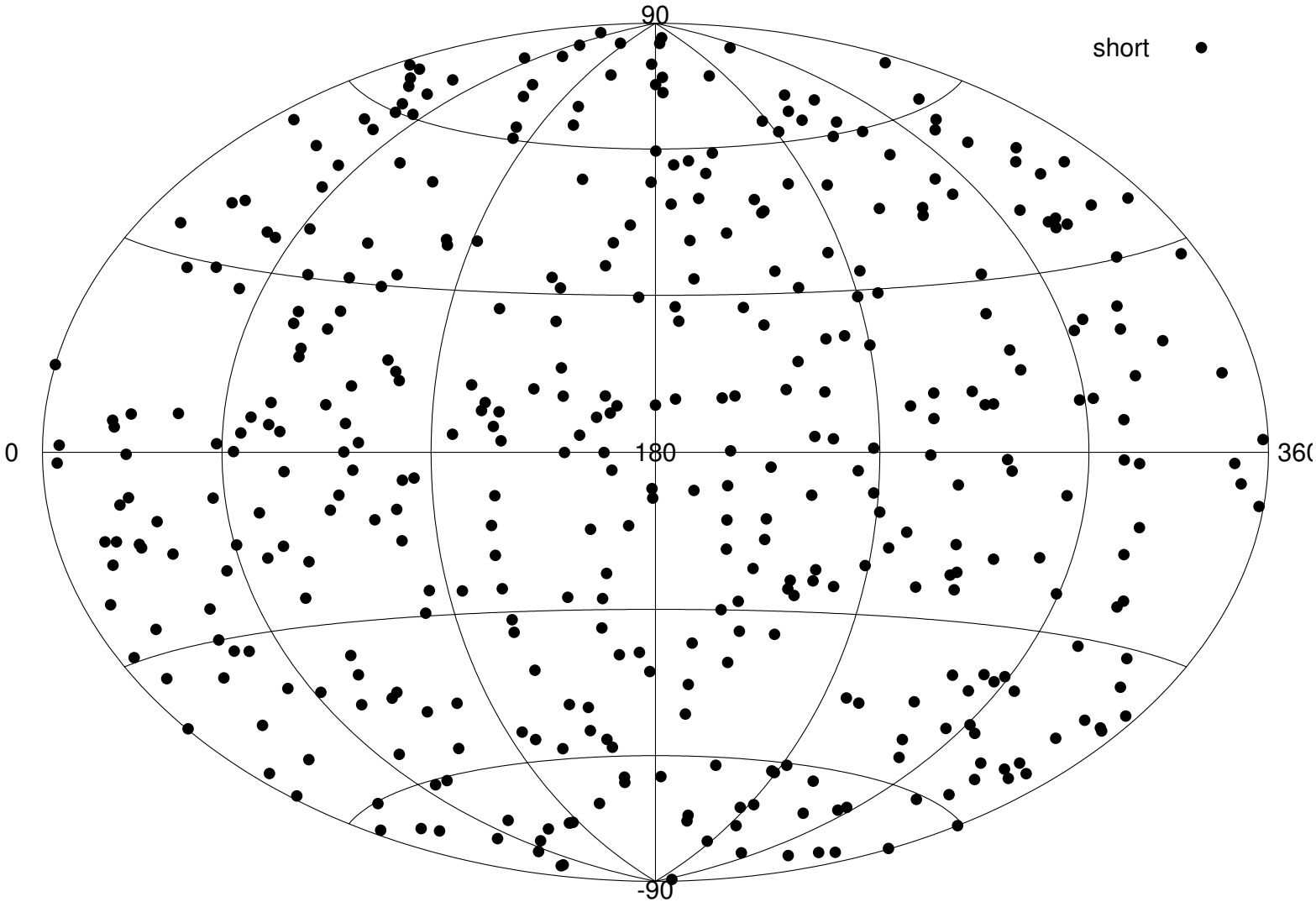

Figure: Celestial distribution of the short BATSE's GRBs. Short GRBs **are not distributed isotropically** (Vavrek et al. 2008).

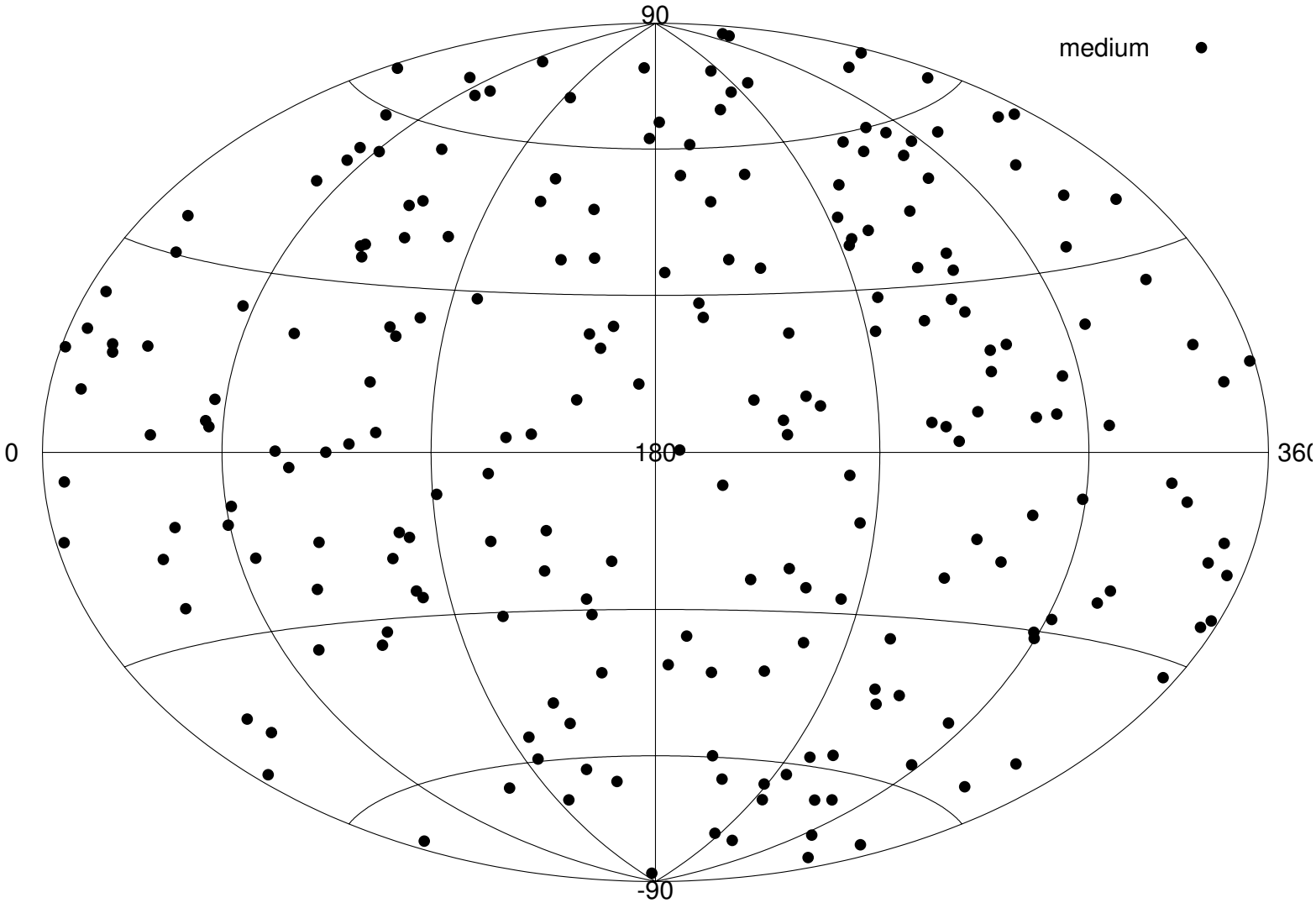

Figure: Celestial distribution of the intermediate BATSE's GRBs. **No isotropy!** (Mészáros A. et al. 2000).

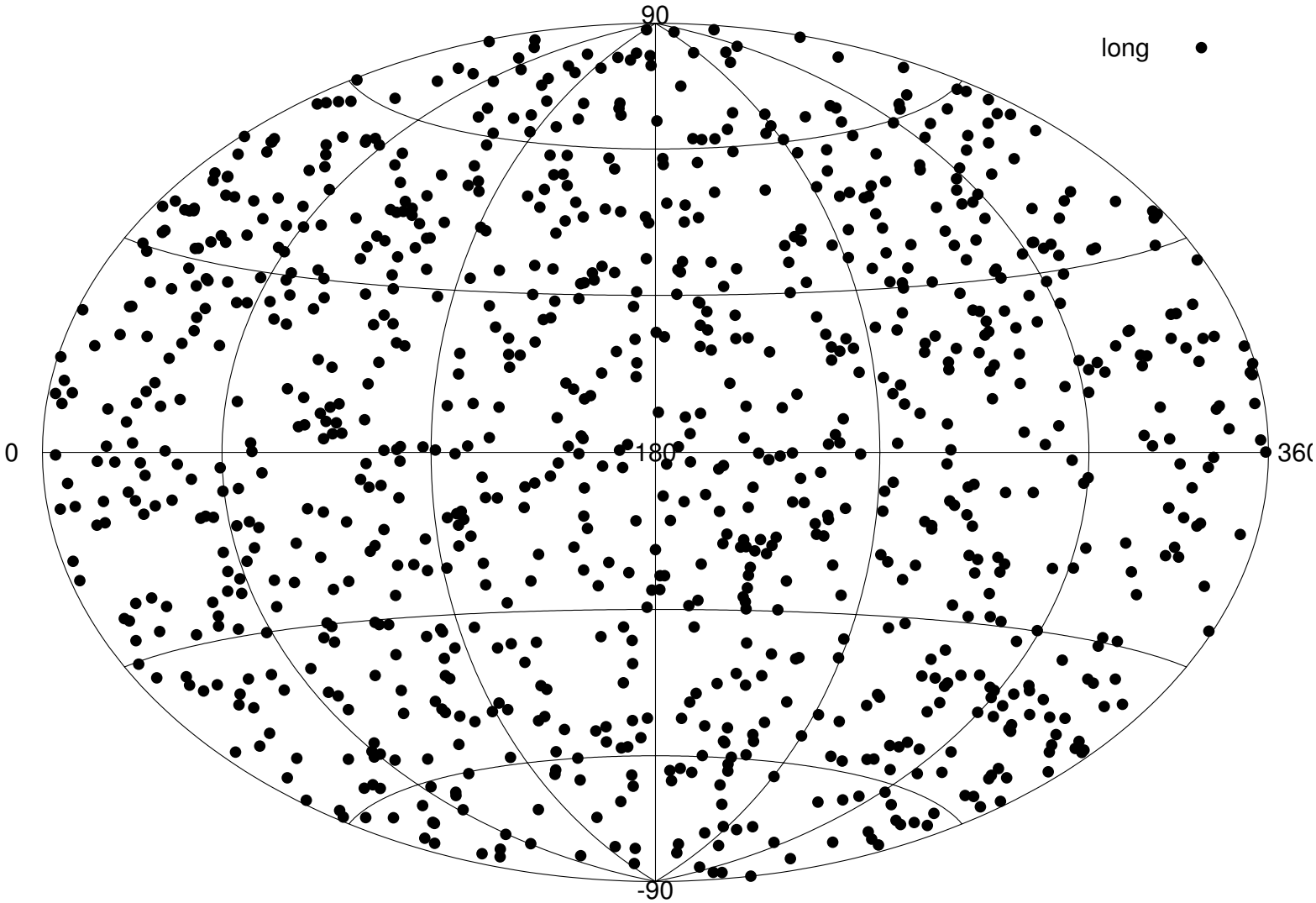

Figure: Celestial distribution of the long BATSE's GRBs; no clear result (Mészáros A. & Štoček 2003; Vavrek et al. 2008).

Impact of these discoveries on the cosmology:
1. Short GRBs are different phenomena and are distributed anistropically: in redshifts - where they dominantly are - the cosmological principle need not be fulfilled.
2. If the intermediate GRBs are in average at the same - or even at higher redshifts - this confirms point No.1.
3. **Generally: The cosmological principle is in serious doubt! First claimed this in: Mészáros A. et al.: Baltic Astronomy, 16, 293, 2009; Mészáros A. et al.: AIP Conf.Proc., Vol. 1133, 483, 2009**

Cosmological principle

= the Universe is spatially homogeneous and isotropic in average on large enough scales

= there exists a maximal structure ("the large enough scale") smaller than the size of Universe.

Two cardinal questions:

- 1. Where are the BATSE's short and intermediate GRBs dominantly?
- 2. What is the biggest observed structure in the Universe?

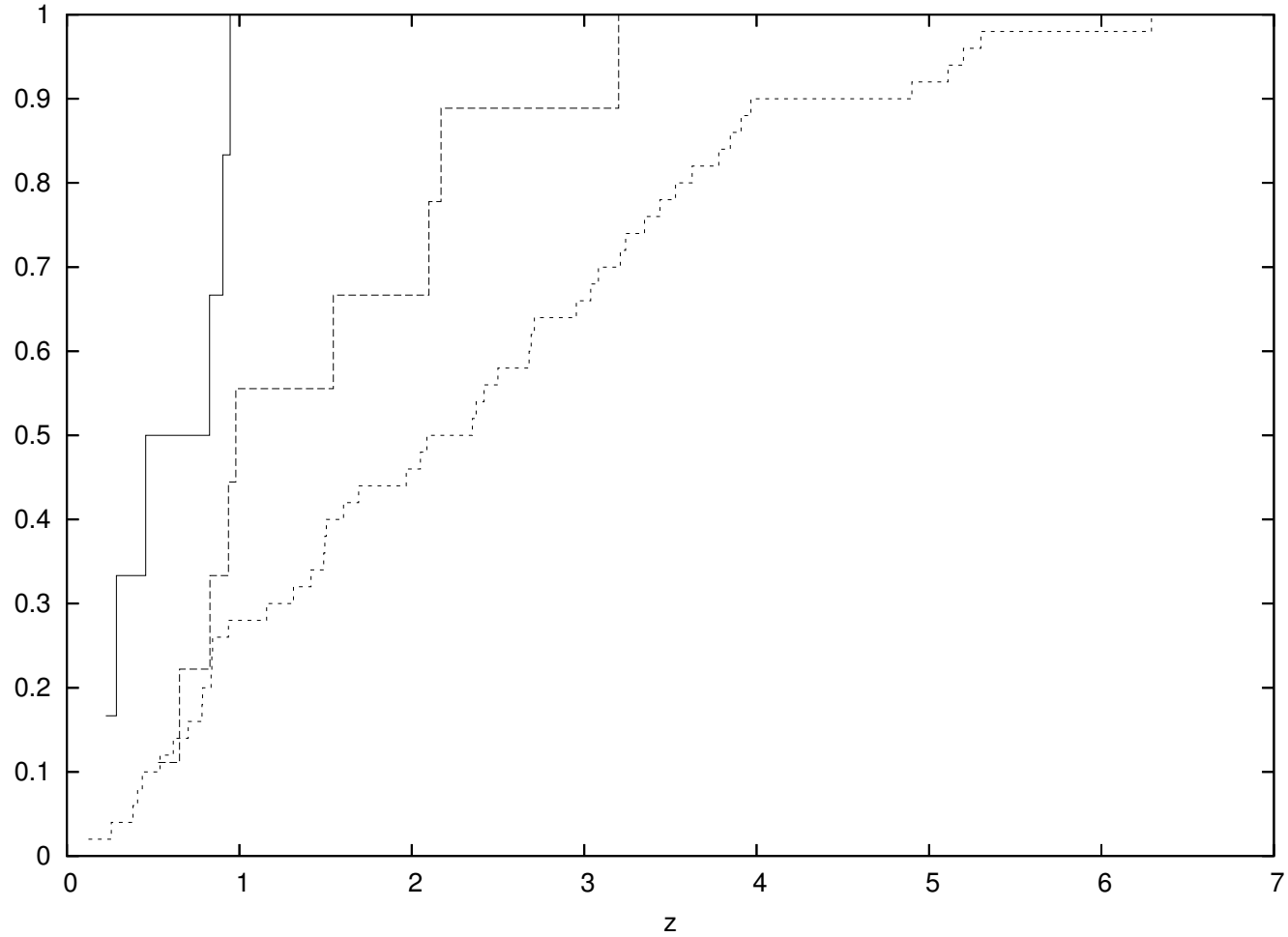

Figure: Known redshifts of the Swift's GRBs. The intermediate GRBs are even at higher redshifts than the short ones. But these are Swift's data - not the BATSE's data: $\longrightarrow$ some care is needed.

Answer to Question 1.: The short and intermediate BATSE's GRBs should be till $z \sim (1-2)$; the long ones till $z \sim (10-20)$. Some care is still needed - because the redshifts are indirect values.

Answer to Question No.2.:

- A. Up to $z \simeq 0.1$ bold inhomogeneities - many observational proofs.
- B. Also for $1.0 > z > 0.1$ inhomogeneities should exist - not only in the GRB topic: Birch, Nature, 1982, 298, 451; Kashlinsky et al. ApJ, 2008, 686, L49.
- C. Recently a huge structure of size of Gpc was found around $z \simeq 2$; Horváth et al., AA, 561, L12, 2014.

Summary

- There are at least two different GRB subgroups
- The short/hard and long/soft GRBs are different objects
- Intermediate GRBs: the team claims permanently that their existence is real - at least statistically
- Swift's intermediate GRBs = long bursts; $\rightarrow$ they are not astrophysically different objects
- RHESSI's intermediate GRBs = no relation to the long bursts; they remember the short ones
- BATSE's intermediate GRBs = no clear result yet
- Intermediate and short BATSE's GRBs: distributed anisotropically on the sky $\rightarrow$ **impact on the cosmology!**
- The celestial distribution of the long BATSE's GRBs: probably also anisotropic (not proven yet obviously)
- **The high redshifts and the anisotropies cause huge structures in the Universe: $\rightarrow$ does the cosmological principle still hold?**

Summing up the open questions:

The physics of the short subgroup is a fully open problem!
The question of the intermediate subgroup is a fully open problem!
The impact on the cosmology is a fully open problem!
Challenge to the observers: To detect an orphan afterglow!

Danke für die Aufmerksamkeit! Spasibo za vnimanije! Köszönöm a figyelmet! Děkuji za pozornost! Thanks for attention!