Story of a discovery 25 years later: GRB afterglow with BeppoSAX

GRBs history and GRBM role

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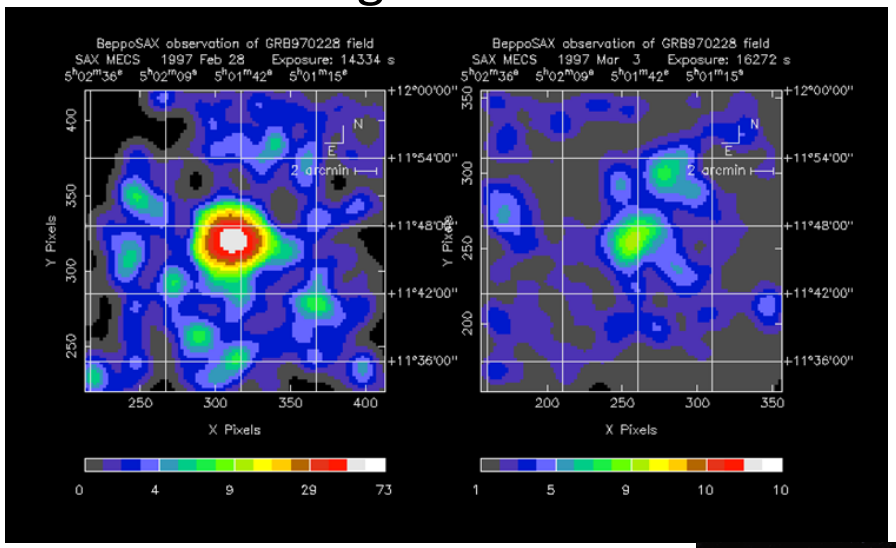
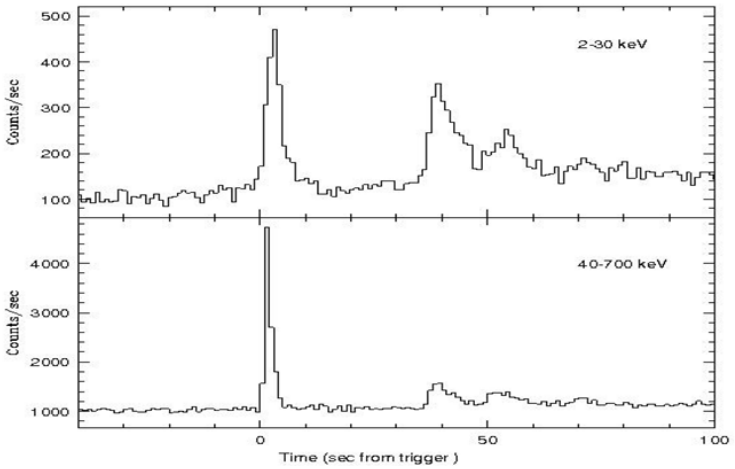
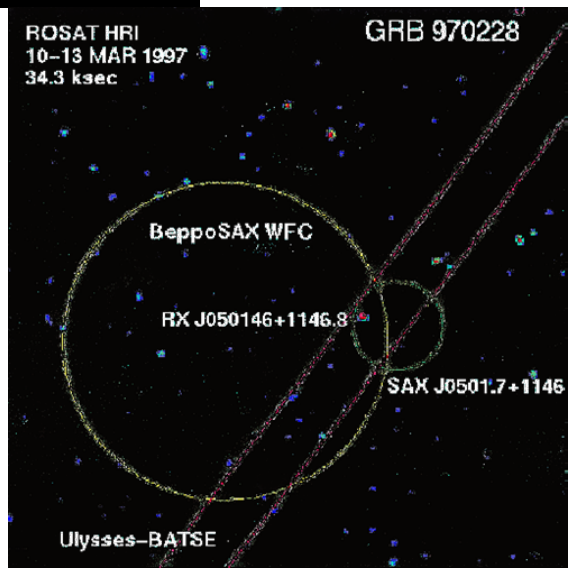
V congresso nazionale sui GRB
Trieste 11-15 Agosto 2022

25 years ago, on 28 February 1997, in less than 1 yr from the BeppoSAX launch, the about 30 yr mystery about GRB sites was unveiled: GRBs are huge explosive events in galaxies at cosmological distances.





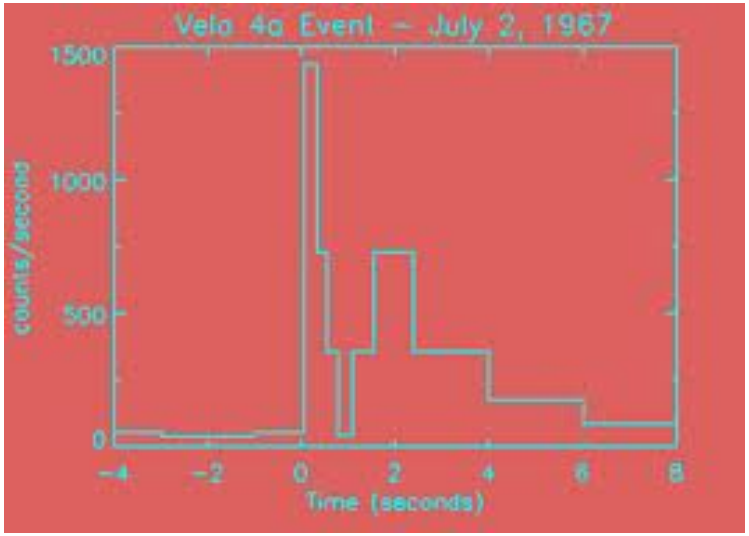
Why so long time for this discovery?



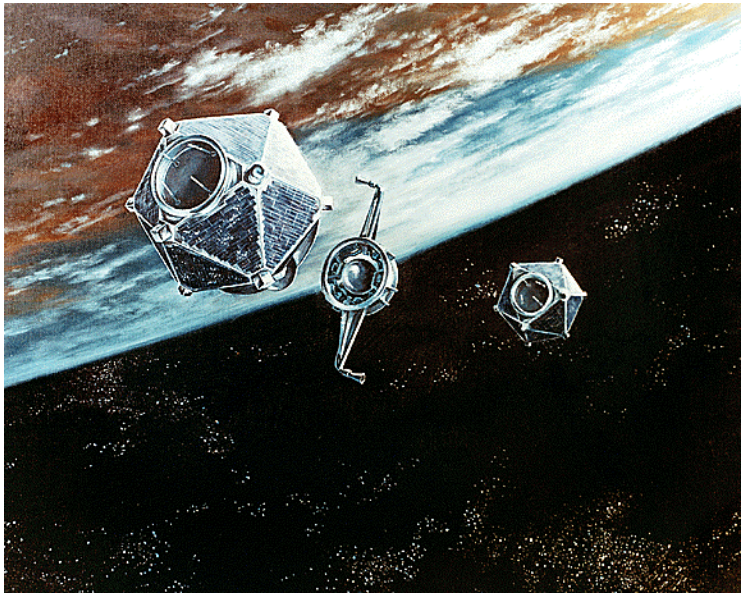
Why BeppoSAX?

GRB discovery

- Discovered at the end the 60's with the American Vela spy satellites, devoted to monitor compliance with the 1963 "Partial Test Ban Treaty" by the Soviet Union, and by other nuclear-capable states.
- First published paper by R. Klebesadel, I. Strong & R. Olson in 1973.

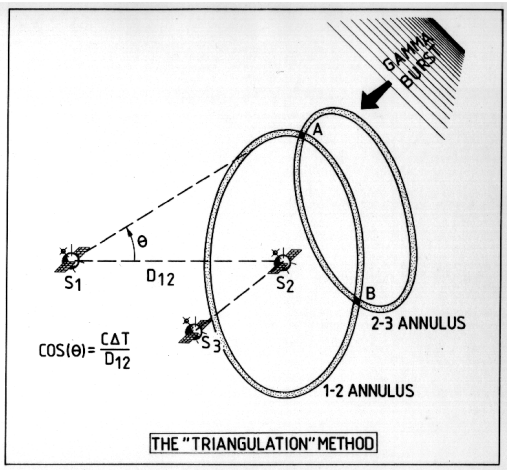


Vela satellites



Major issues about GRBs

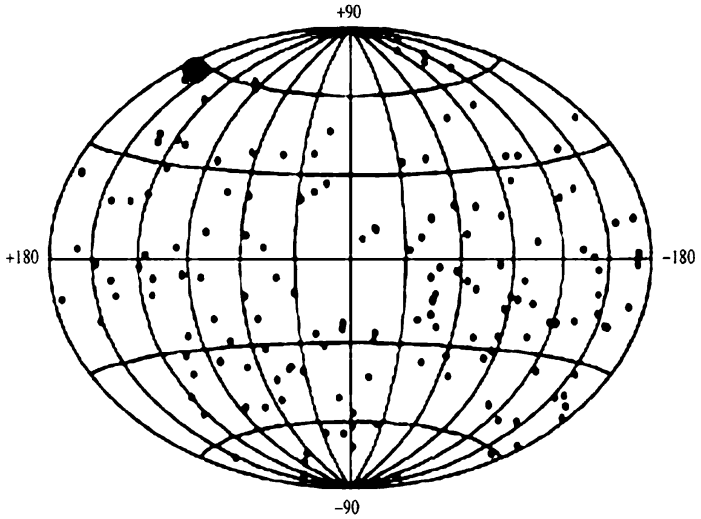
- **Which are their progenitors? Normal stars? Compact stars (WD, NS, BH)? Comets? Insterstellar medium?**
- **Which are their sites (Local, Galactic, Extragalactic); which was the power involved?**
- **More theories than GRBs!**
- **How to observationally solve these issues?**
- **Find counterparts. For that:**
- **Accurate localization of the event:**
  - **a tough task in the gamma-ray band;**
  - **To search GRB counterparts at lower energies.**



Main results in the early '80s

- **Many satellite missions (mostly French-Russian), but small progress:**
  - **Very rough localizations. The most accurate with IPN after a long time (even months) from events.**
  - **No evidence of counterparts.**

- **Best results obtained with the Konus experiment (aboard Venera 11 and 12 (Sept. 1978), Venera 13 and 14 (Oct.1981)):**
  - **Earliest evidence of isotropic distribution (Mazets et al. 1981; Mazets and Golenetskii 1988).**
  - **Earliest evidence of time-resolved correlation between luminosity and peak energy.**



Mazets and Golenetskii 1988

GRB issues vs. other issues in the early 80's

- In spite of its importance, given the meagre results, little interest in the Astrophysical Community to GRBs.
- Most of the interest was given to the compact objects, Galactic and extragalactic: X-ray pulsars, Binary Black Holes, AGNs.

- This situation conditioned the science goals of the missions proposed in the 80's .

SAX story 1/4

- **1979**: **Italian government establishes the "National Space Plan" (PSN) in order to**:
  - **strenghten Italian industry;**
  - **compete with European partners for development and management of large space programmes.**

- PSN management is committed to CNR, through a **Scientific Board and an Advisory Board**.

- Among the earliest PSN decisions
  - **Development of a scientific satellite.**

SAX story 2/4

- **1981: Call for proposals of an Italian satellite**

- **Selection criteria:**
  - **Space mission of primary importance for space science;**
  - **Involvement of Italian scientific Community and its potentialities;**
  - **Involvement of the Italian industry for its advancement e promotion;**
  - **International participation.**

SAX story 3/4

- A mission, OOXA (Orbiting Observatory for X-ray Astronomy), devoted to stellar spectroscopy at soft X-ray energies (<2 keV), based on an improved configuration of the "Einstein" satellite (P.I. Pippo Vaiana, OAPa). To be developed by American CFA and American companies already involved in the Einstein satellite (e.g., Perkin-Elmer for mirrors).
- A mission, SAX (Satellite Astronomia X), devoted to celestial X-ray source observations in a broad band (2-300 keV), submitted by a Consortium of CNR Institutes and GIFCO groups plus 2 international partners (SRON, SSD/ESA). To be developed by Italian CNR Institutes and Italian Industries (Aeritalia, Laben, Telespazio).

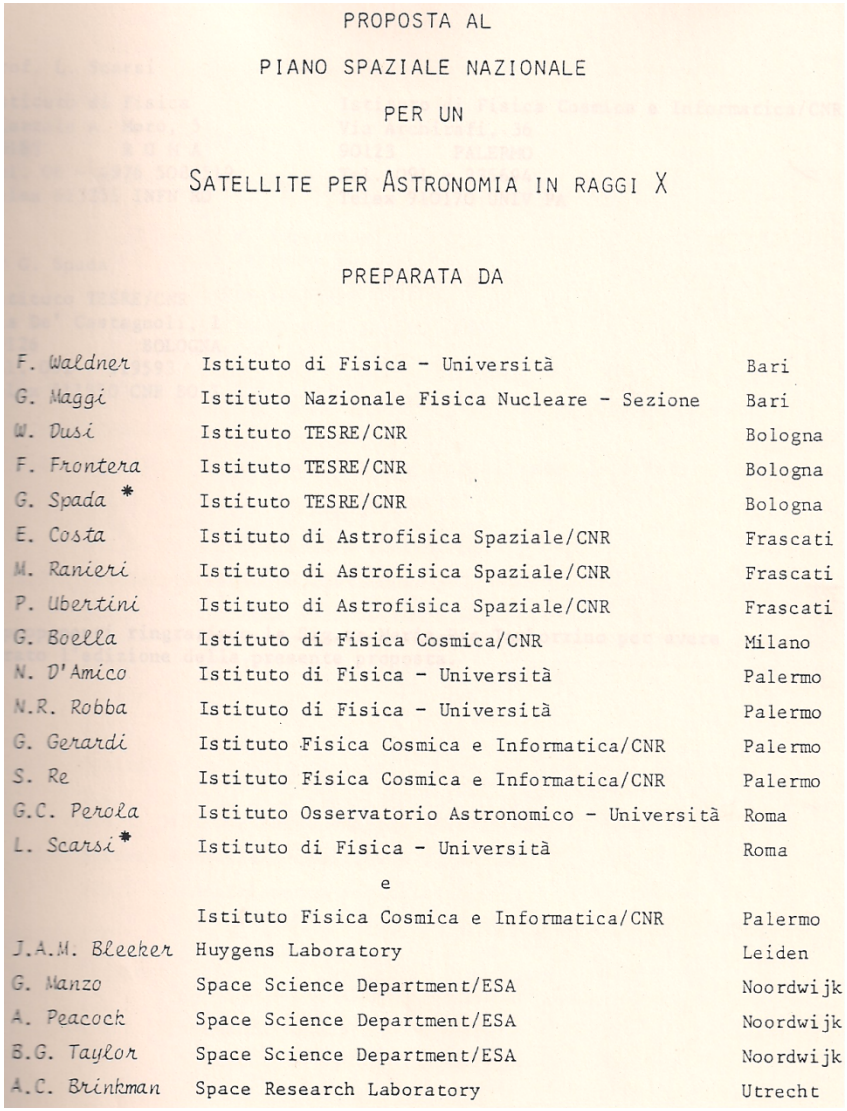
SAX story 4/4

- Proposals were submitted in 1981.
- Selection in 1982
- Advisory Panel for proposal selection: E. Amaldi, G. Occhialini, B. Rossi, G. Setti, L. Woltjer.

- **Selected proposal: SAX**

BeppoSAX proposal (1981)

- **Mainly CNR Institutes**
- **Main science goals:**
  - **Study of celestial X-ray sources in a broad band 2-300 keV;**
  - **2-30 keV sky monitoring of the Galactic plane.**
- **GRBs were not included among the main science objectives.**



PROPOSTA AL

PIANO SPAZIALE NAZIONALE

PER UN

SATELLITE PER ASTRONOMIA IN RAGGI X

PREPARATA DA

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M. Ranieri	Istituto di Astrofisica Spaziale/CNR	Frascati
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G. Manzo	Space Science Department/ESA	Noordwijk
A. Peacock	Space Science Department/ESA	Noordwijk
B.G. Taylor	Space Science Department/ESA	Noordwijk
A.C. Brinkman	Space Research Laboratory	Utrecht

Earliest SAX instruments proposed

- 2 narrow field telescopes:
  - A gas scintillator proportional counter (GSPC) (2-35 keV) surmounted by a coded mask.
    PI G. Manzo, IFCAI CNR, Palermo
  - High energy collimated (1.4° fwhm) instrument (PDS, 15-200 keV).
    PI F. Frontera, ITESRE, CNR, Bologna

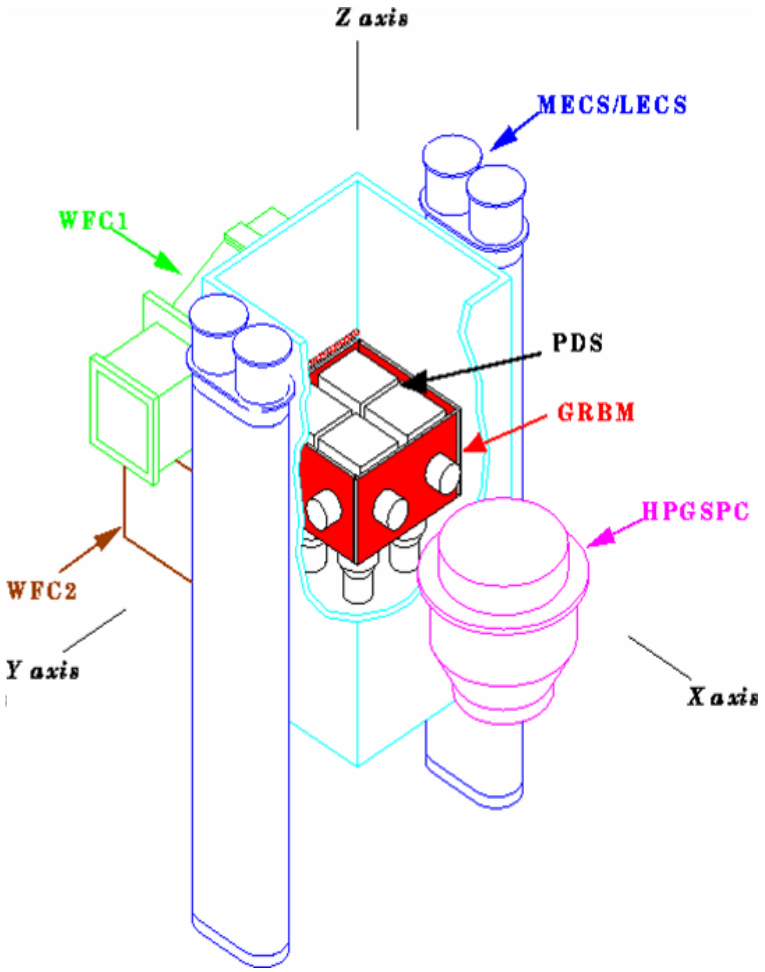
- 2 Wide Field Cameras (WFM, 2-28 keV, 20°x20°) with imaging capabilities, based on proportional counters surmounted by coded masks.
  Angular resolution: 3 – 4 armin.
  PI R. Jager (SRON, Utrecht)

1984-85: P/L upgrades implemented during the industrial phase A study (Aeritalia)

- **Thanks to 0.1-10 keV X-ray mirror development (using replication technology) at CNR-IFCTR Milan by Oberto Citterio, GSPC is replaced by 4 focusing telescopes:**
  - **1 LECS (0.1-10 keV),**
  - **3 MECS (2-10 keV).**
- **A HP-GSPC (6-60 keV) with collimator.**

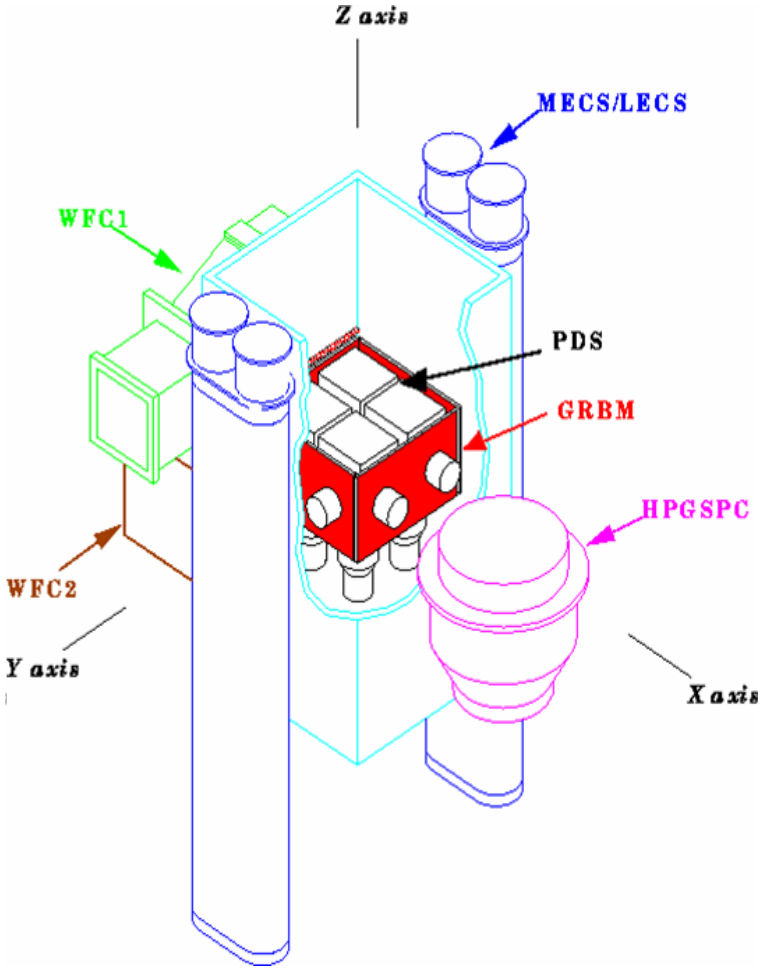
The proposed GRBM

- During the phase A (1984) FF proposes (Internal report ITESRE no. 99) to exploit the PDS Anti-Coincidence shield as GRBM.
  - 4 independent units of CsI(Na), 1136 cm^2/unit, FOV >2π.
- Main requirements:
  - Three short integration times (2, 32, 256 ms) for trigger decision;
  - Variable trigger threshold;
  - Absolute trigger time
  - 1 s PHA spectra of each unit
  - In case of GRB trigger, 0.5 ms (for 10 s) and 10 ms (for 100 s) count bins



Main motivation of GRBM proposal

- **2 Units were coaligned with WFCs (FOV: 40°x40° FWZR) !!!**
- **Expected 2-3 GRBs/yr simultaneously detected with WFCs and localized with arcmin accuracy.**
- **International echo (Hurley 1986)**



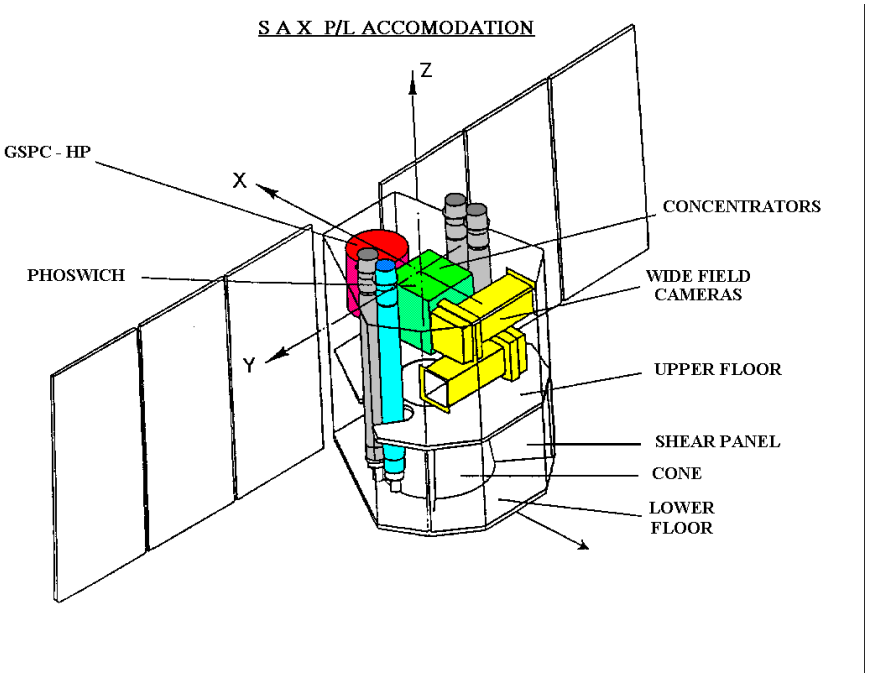
Crisis in the SAX project and restart

- 1986: Phase B study suspended as a consequence of the Challenger shuttle disaster:
  - NASA interrupted commercial satellite launches from Shuttle, while SAX was designed to be launched by the Italian IRIS launcher from Shuttle.
- 1988: New phase B for a launch with an Atlas-Centaur rocket from Cape Canaveral.
- 1989: Restart of the project up to the launch (Phase to Completion).
- 1990: a less expensive configuration of the GRBM proposal is approved by SSC and ASI.

Final SAX configuration

- **Narrow Field Instruments:**
  - 4 focusing telescopes (1 LECS 0.2-10 keV + 3 MECS 2-10 keV), PI G. Boella (CNR-IFCTR, Mi)
  - HPGSPC (4-60 keV), PI G. Manzo (CNR-IFCAI, Pa)
  - PDS (15-200 keV), PI F. Frontera (UNIFE, CNR-ITESRE, Bo).
- **WFCs (2-28 keV, PI R. Jager):**
  - 2 Coded Mask- Imaging Spectrometers

  (FOV 20°x20° fwhm, Angular resolution 3'-4').ù
- **GRBM (40-700 keV). PI F. Frontera.**

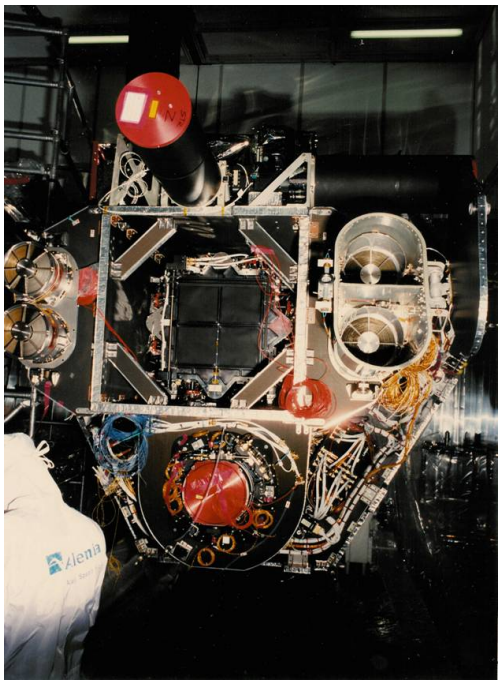


GRBM development: configuration

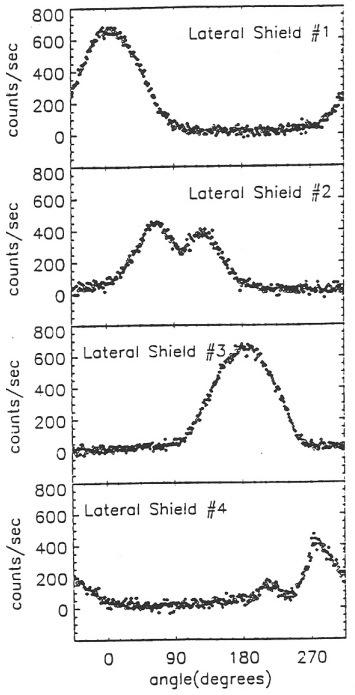
- **After its approval (1990), developed GRBM instrument:**
  - **CsI(Na) scintillators confirmed (Costa +1987)**
  - **Energy band: 20/40 – 200/700 keV**
  - **A trigger system with a single SIT: $\geq$2 units to identify GRB events**
  - **4 electronic chains for getting continuously 128 s spectra and 1 s ratemeters from each GRBM unit;**
  - **Gain monitoring exploiting the albedo 511keV e+/e- annihilation line;**
  - **In case of a trigger: high time resolution ratemeters (down to 0.5 ms).**

GRBM development: Tests and calibrations

- **Test of GRBM prototype with the SATURNE proton accelerator (Saclay).**
- **Flight model developed by Laben.**
- **Two sets of calibrations:**
  - **in Laben (Milan) of the single instrument**
  - **at ESTEC after the PDS integration in the satellite.**



SAX P/L



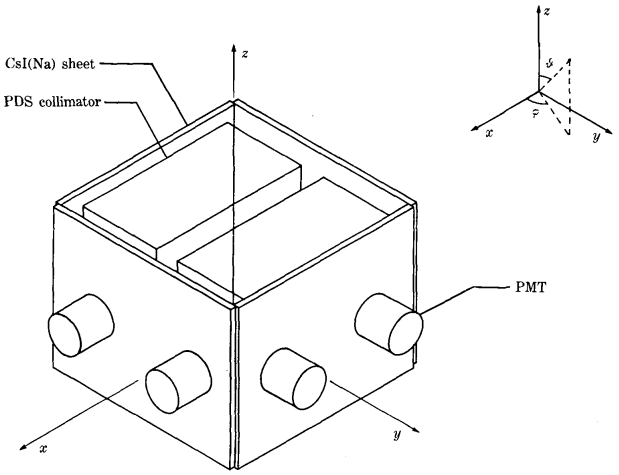
WFC1

WFC2

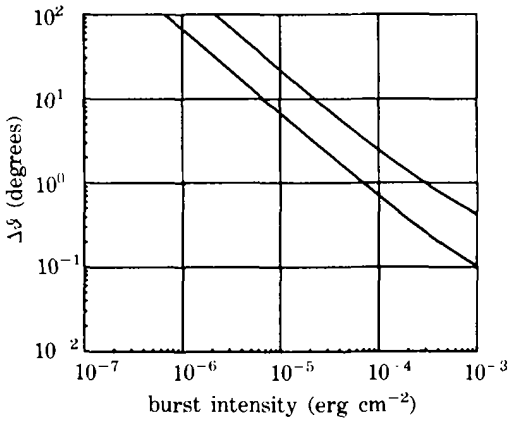
From ESTEC calibration campaign

GRBM development: MC codes

- **GRB direction determination capability (Pamini+1990).**
- **Preliminary response function by MNCP (Rapisarda +1997).**
- **Test of the response MNCP function using GRBM calibrations (Amati+1997).**
- **Refined response function (Calura, Montanari+2000)**

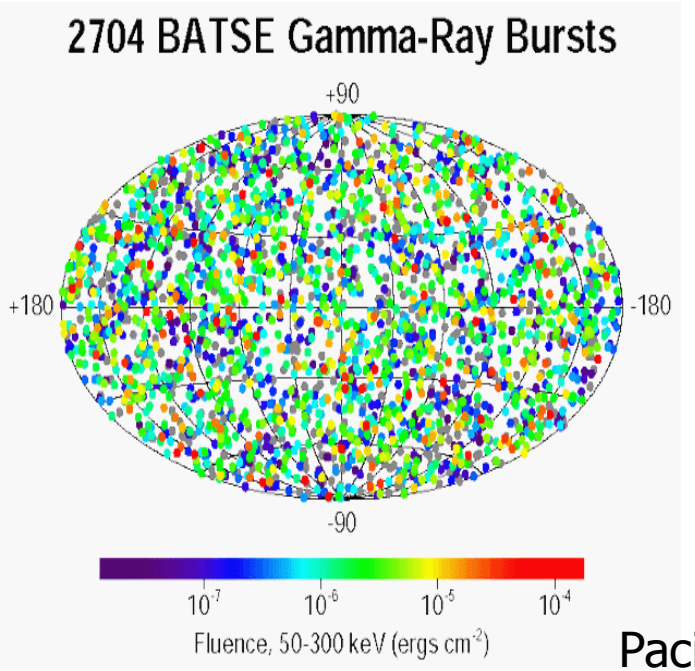


From Pamini+1990

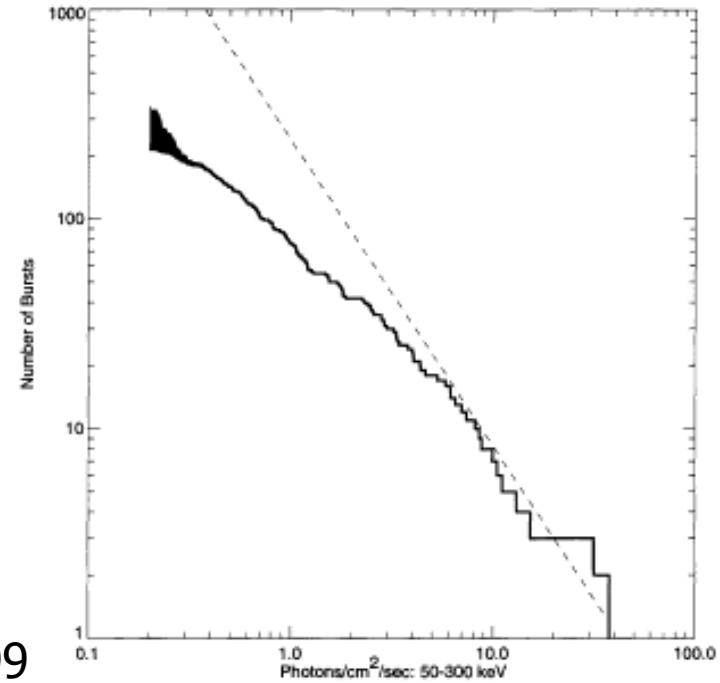


1995: higher interest to GRBs thanks to the BATSE results

- **Confirmed isotropic distribution of GRBs directions (localization uncertainty ranging from 2° to 30°)**
- **Discovered paucity of weak events with respect to what expected in an euclidean space**
- **A cosmological origin of GRBs?**



Paciesas+1999



"The SAX Spirit": title of the session devoted to SAX at the 1995 SPIE meeting

The SAX spirit

F. Frontera[1,2] and L. Scarsi[3,4]

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[4]Istituto di Fisica Cosmica e Informatica, CNR, Via M. Stabile, 172, 90139 Palermo, Italy

It is an exciting opportunity that offered by this SPIE conference to devote a session to the presentation of the final calibration test results of the SAX payload.
SAX has eventually achieved its final phase for a launch next year. The launch date is planned from March 21 to April 20, 1996, with nominal launch date on April 10, 1996.
The hystory of SAX (Italian acronym for 'Satellite per Astronomia in raggi X') is rather complex and it was marked, in some occasions, by events which dramatically influenced its course of life.
The first proposal for the SAX mission was submitted to the Italian National Space Plan (PSN) in 1981, in response to an Announcement of Opportunity for a mission in the framework of the Science Programme of PSN. The AO guidelines specified that the mission proposals should be not only of primary importance for modern science, but also involve as far as possible the Italian scientific community and its potentiality in research, and be coherent with the programme of development planned for the national space industry; international partecipation to the mission was considered of primary importance.
SAX initially competed with another proposal for an X-ray astronomy mission devoted to observations below a few keV. In spite of the scientific interest among the Italian astrophysical community at that epoch, this mission was conceived as a follow-on of a program and technology implemented abroad. The philosophy beyond SAX was instead of exploiting at its best the potentiality of the space science Italian community grown up essentially around balloon experiments and participation to European space projects of ESRO/ESA and, in part, of NASA. The choice for SAX of a wide energy band with particular attention to high energy X-rays (up to 300 keV) finds an explanation on this choice, together with the multi-detector approach typical of a multi-institutes consortium. The collaboration with the Dutch groups and the Space Science Department of ESA naturally followed.
The mission was conceived with a low, circular equatorial orbit to minimize the level of particle induced background and its modulation. Tha launch system envisaged was Shuttle based, coupled with an experimental Italian development Payload Assistance Module (IRIS); the adopted TTC station was that of San Marco at Malindi (Kenya).
After an assessment phase carried out by Aeritalia during 1982 SAX, following also the advice of an Advisory Panel made by E. Amaldi, G. Occhialini, B. Rossi and A. Woltjer, was finally selected by PSN for inclusion in the Italian Science Programme.
An extended Phase A study was then performed by Aeritalia and Laben during 1984 and 1985. It was during this phase that the concentrators spectrometers LEC/S (0.1– 10 keV) and MEC/S (1-10 keV) instruments were included in the payload. In the original proposal the operative energy band of SAX was from 2 to 300 keV and the band above 2 keV was covered by a high pressure gas scintillator proportional chamber (HP-GSPC) with coded mask. The HP-GSPC continue to be included in the payload, without mask, given the high energy resolution of the instrument of key importance for the study of cyclotron lines in X-ray pulsars. The inclusion of X-ray mirrors in the SAX payload had a relevant impact on the SAX performance and marked the beginning of the replication technology by electroforming of the X-ray mirrors.

The Phase B was due to start in 1986, but a deep crisis developed in January 1986 because of the 'Challenger disaster'. The SAX program was stopped and put in a moratorium for more than one year. Given the decision by NASA to abandon 'commercial flights' with the STS, SAX needed to be reoriented to an expendable vehicle and the program was finally approved at mid 1987 for an Atlas–Centaur launch. A new phase B restarted in 1988, with the present 'Phase to Completion' beginning in 1989. We are now finally approaching to the 'zero' count down with less than 9 months to go.
In spite of the long incubation time period, SAX preserves its initial scientific interest. Its main feature of covering an energy band from 0.1 to 300 keV, that could seem, at the beginning, the result of a political compromise among the participating scientific groups, as the time elapsed, represents today the major interest for SAX, which is yet is the only mission with such a broad operative energy range. The long incubation period, in some ways similar to that of the American XTE satellite, gave rise to scientifically injustified critics and attacks. Instead it was just the huge potentiality of SAX the hidden spring of the people involved in SAX that permitted to overcome the numerous difficulties and fits of depression that a very long period of incubation unavoidably produces. We call that the 'SAX spirit'.
The SAX team is proud to present today a mission that it is acquiring an increasing interest from the world astrophysical community.

The 1995 debate at the Baird Auditorium of the Smithsonian museum of Natural History in Washinghton

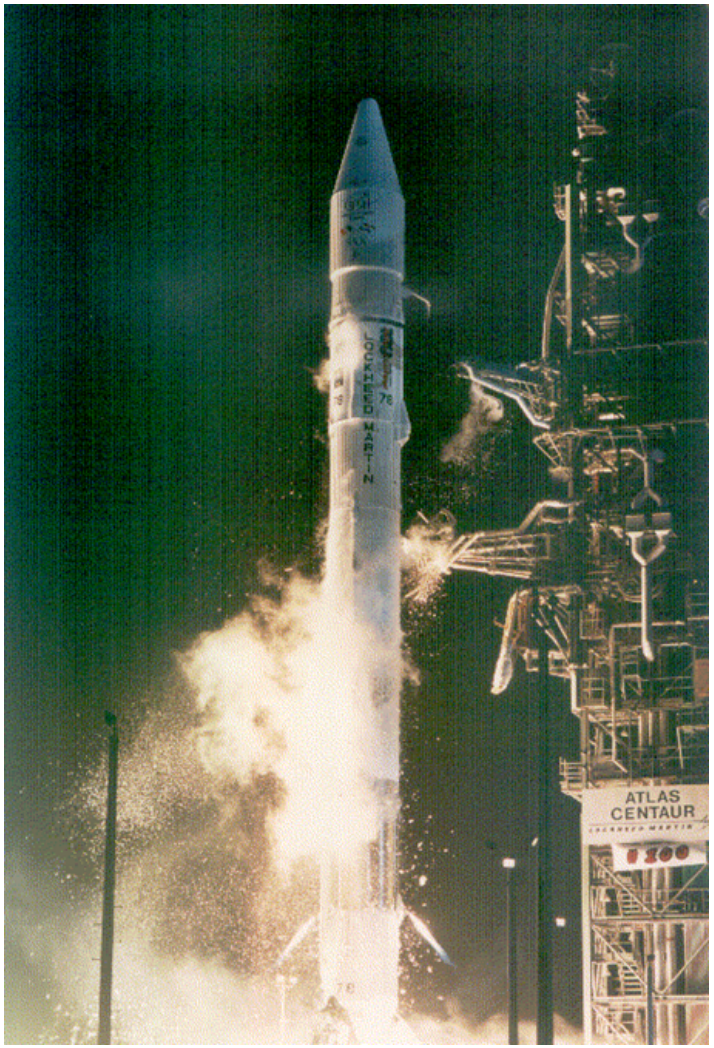
- **Bodhan Paczynski**: "At this time, the cosmological distance is strongly favored over the Galactic one, **but it is not proven**. ….At this time we have no clue as to their nature, even though well over a hundred suggestions were published in the scientific journals."
- **Don Lamb**: "We do not know the distance scale to GRBs. First I describe the recent discovery that many NS have high enough velocities to escape from the Milky Way. These high-velocity NS form a distant, previously unknown Galactic 'corona'. This corona is isotropic when viewed from the Earth, and consequently, the population of NS in it can easily explain the angular and brightness distribution of the BATSE bursts."

Conclusion of the Washinghton debate by Martin Rees (1995)

"I'm enough an optimist to believe that it will only be a few years before we know where (and perhaps even what) the gamma-ray bursts are."

SAX launch and its phases

- **30 April 1996**: launch from Cape Canaveral with Atlas-Centaure rocket
- **16 May 1996**: SAX renamed **BeppoSAX**, in memory of Beppo Occhialini
- **May-June 1996**: commissioning phase (Alenia);
- **July-September 1996**: Science Verification phase (SVP);
- **Since October 1996**: Operational phase.
- **On 23 Feb 1996,** proposal by K. Hurley to include GRBM in the IPN.



AO for WFC data in SOT 1/2

- **AO Issued during the SAX Commissioning phase**.
- **The PDS/GRBM team** submitted a proposal to get WFC data in the case of GRBs identified with the GRBM.
- **With the contribution by G. Pizzichini, the proposal was prepared by FF, who decided to entrust the PI-ship of the proposal to E. Costa** (EC was PI deputy and the vicinity of his group to the BeppoSAX Control Center was very important).
- **John Heise**, leader of the WFC team, **joined our proposal.**

Letter to G. Pizzichini for her complaints 21March1997

---------- Forwarded message ----------
Date: Fri, 21 Mar 1997 13:32:30 +0100 (NFT)
From: Enrico Costa <costa@saturn.ias.fra.cnr.it>
To: Graziella Pizzichini <graziella@botes1.tesre.bo.cnr.it>
Cc: SAX/PDS Hardware Team -- Maria Nerina Cinti
<cinti@alpha1.ias.fra.cnr.it>,
Daniele Dal Fiume <daniele@tesre.bo.cnr.it>,
Marco Feroci <feroci@alpha1.ias.fra.cnr.it>,
Filippo Frontera <frontera@ferrara.infn.it>,
Luciano Nicastro <nicastro@botes2.tesre.bo.cnr.it>,
Mauro Orlandini <orlandini@botes1.tesre.bo.cnr.it>,
Massimo Rapisarda <rapisarda@frascati.enea.it>,
Guido Zavattini <zavattini@vaxfe.fe.infn.it>
Subject: answer to Graziella complaints

Graziella,
It is time to answer to your continuous complaints, even if we have scientific work to do in these days. You maintain that the PDS group stole your idea of asking the WFC data when a burst was triggered by our GRBM. This is false. The importance of the simultaneous presence of WFC and GRBM was one of the most convincing arguments for the approval of our GRBM experiment onboard SAX. Moreover, given the SAX instrumentation, this scientific objective was so obvious, that it was written in the scientific objectives in the "SAX Observers' Handbook" (pages 141-2), dated July, 7, 1995.
The reality is that after the SAX launch we invited you to join our group to contribute to our research programs (for example in our meeting of 13/9/96 you expressed interest to analyze SVP data concerning the observation of LMC field, even if your major interest was in the GRBs). Before the deadline to present proposals for WFC secondary data (June 15 1996) we had a group meeting (6-7 June 1996) during which we discussed all together the possible proposals to submit and their content. These proposals
concerned both X-ray sources and GRBs. As far as the GRBs were concerned you informed us, without giving details, about other proposals (in which you were involved as Co-I) to be presented by J. van Paradijs on the subject. As a result of a general discussion, in which you stressed some aspects and other people stressed other aspects, as it is the rule in a scientific group, we decided our scientific justifications for X-ray sources and GRBs. Concerning the GRBs, the proposal to get the WFC data in the case of a GRB triggered by GRBM was justified to perform different types of studies, some of which suggested by you and others suggested by other people.
Taking into account that different proposals were to be prepared (LMXRBs, X-ray pulsars, GRBs, etc.), and that many members of the PDS group were deeply engaged with the commissioning activities (the PDS and its lateral shields had been switched on few days before) you volunteered to write down a draft of our proposal on GRBs. Once the draft was written, you and one of us (Filippo) discussed the draft for a few hours before arriving to an almost final text.
Concerning the PI-ship, it was natural that people who worked for many years (first proposal in 1981) in the SAX/PDS experiment (GRBM is a part of PDS) were the natural candidates to be PI of this proposal; among them, the PI of SAX/PDS experiment (F. Frontera) and his deputies (D. Dal Fiume and E. Costa). Filippo proposed as PI Enrico Costa taking into account that the PDS group in Frascati had been mainly involved in the lateral
shield activity and logistic reasons (the SAX SOC is in Rome and the Frascati group can immediately react in the case of GRBM triggers, as demonstrated by the recent results obtained).
You did not disagree with this proposal and the draft was e-mail sent by you
to Enrico (Subject: vanno bene autori e loro ordine? van Paradijs non lo trovo), as well as to other CoI's in various countries. The proposal was accepted (surprisingly before the selection you declared your support to the competing proposal ! !) and for the triggers belonging both to SAX and BATSE we were selected for the exploitation of WFC data. The main reason for this selection is of course the fact that we have a GRBM aboard the same satellite of WFCs and not so evidently due to the fact that our proposal was better scientifically motivated than that of Van Paradijs.
We remind that only PDS group is entitled to exploit the GRBM data.
But just after the deadline you began with your complaints. that grew with time, in spite of your involvement in the burst detection of July 20, 1996 (GRB960720) (see IAUC 6467 and the paper submitted to Nature) not as a Co-I of the above proposal but as member of GRBM group. Indeed these publications do not include in the authorship other CoI's of the GRBM/WFC proposal who are not part of the SAX Team.. It can be worth noticing that this GRB detection was the result of a huge amount of work done by the GRBM hardware team, in reducing, analysing and screening GRBM data, performed instead of taking summer vacations. Alike the further fast detection and reaction on GRB970111 and GRB970228 is the result of an huge but accurate work of preparation to analyse the data flow, the software structure, propose the needed changes, assess procedures and write documents to obtain the needed approvals by the Mission.. All these works have been supported by PDS/GRBM, SOC/SDC and SRON people, and you haughtily denied the value to these kind of activities (e-mail to Enrico Costa).
Notwithstanding, your contribution was never refused to acknowledge. When the first GRBM-WFCs event actually belonging to the proposal was observed (GRB970111), you were invited to a meeting in Rome (22/1/1997) devoted to organize the data analysis and interpretation of the results. No GRBM data was refused to you and you were solicited as the other members of the group to take initiatives for follow up observations in other bands.
Now it is a fact that our group thanks to a well performing instrument, to hard work and to a good capability of co-ordination with other scientists is significantly contributing to the progress of Gamma Ray Burst Astrophysics. It is also a fact that you instead of participating and contributing, on a scientific ground , to these activity with your experience, which has never been questioned by us, only contribute with continuous complaints, inform whoever you meet about a story that, while including some fragments of
reality, is substantially false because is based on an underestimation by orders of magnitude of the role of the PDS/GRBM group in this research.
With these basis we do not see how we can collaborate and we solicit you to define your role within the GRBM/WFC program in terms that are compatible with the work of 15 other persons.
Regards

Enrico Filippo

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AO for WFC data in SOT 2/2

- **A similar proposal was submitted by the BATSE team (PI C. Kouveliotou) to get WFC data for GRBs identified with BATSE.**
- **Both proposals were approved.**
- **At the 2nd INTEGRAL workshop** held in Saint Malo (France) from 16 to 20 Sept 1996, FF proposed to **Gerald Fishman and Chrissa Kouveliotou** to merge the proposals.
  - **The answer was positive by GF but negative by CK. No merging done.**
- **On 20 Feb. 1997, CK, after the earliest GRBM-WFC results, changes her position.**
- **Our answer was negative, but which were the results that changed the CK position? EC will clarify this point.**

Main members of SAX PDS/GRBM group

- **From ITESRE Bologna:**
  - Filippo **Frontera**, Daniele **Dal Fiume**, Mauro **Orlandini**, Luciano **Nicastro**, Eliana **Palazzi**, Lorenzo **Amati**, Elena **Pian**
- **From UNIFE Ferrara**
  - Cristiano **Guidorzi**, Guido **Zavattini**, Enrico **Montanari**, Francesca **Rossi**, Francesco **Calura**, Daniela **Carturan,** Massimo **Pamini**
- **From IAS Roma:**
  - Enrico **Costa**, Marco **Feroci**, Massimo **Rapisarda**, Lorenzo **Amati (PhD thesis**), Marina **Cinti**

End