## GOALS OF THE WORKSHOP

The objective of this workshop is to consider the next generation of instrumentation to be required within the domain of nuclear astrophysics. A small, but growing community has been pursuing various techniques for the focusing of hard X-rays and gamma-rays with the aim of achieving a factor of up to 100 improvement in sensitivity over present technologies.

Balloon flight tests of both multilayer mirrors and a Laue lens have been performed and ideas abound. At present, implementation scenarios for space missions are being studied at ESA, CNES, and elsewhere. The workshop will provide a first opportunity for this new community to meet, exchange technological know-how, discuss scientific objectives and synergies, and consolidate implementation approaches within National and European Space Science programs.

This workshop is organized with the help of

cnes esa ALCATEL SPACE EADS ASTRIUM

## WORKSHOP ORGANIZERS

### Advisory Committee

Nikolai Abrosimov, IKZ Berlin
Ken Andersen, ILL Grenoble
Giovanni Bignami, CESR Toulouse
Filippo Frontera, Universita'di Ferrara
Fiona Harrison, Caltech, Pasadena
Mark Leising, Clemson University
Bob Lin, SSL Berkeley
Niels Lund, DSRI Copenhagen
Anthony Peacock, ESA, Noordwijk
Bob Smither, Argonne Natl. Laboratory, Chicago
Pietro Ubertini, IASF Roma
Peter von Ballmoos, CESR, Toulouse (Chair)

### Organization

Angela Bazzano, IASF Roma
Hubert Halloin, MPE Garching
Gerry Skinner, CESR Toulouse
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# GENERAL INFORMATION

## Presentations

All speakers are encouraged to make their talks generally accessible to a multi-disciplinary audience, which will include both theorists and experimentalists from a variety of domains : astrophysics, X- and gamma-ray reflection and diffraction, crystallography, photon detection, nuclear, medicine, spacecraft systems and orbitography ...
Each talk includes 5 minutes discussion. A video projector for electronic presentations and an overhead projector you will be available for your presentation. Posters will be displayed throughout the workshop.

## Registration

The registration desk will be open at the conference site on Sunday 11th September form 17 h- 19 h and on Monday from 8h30 - 9h30. In order to avoid congestion on Monday morning, we encourage you to register on Sunday.

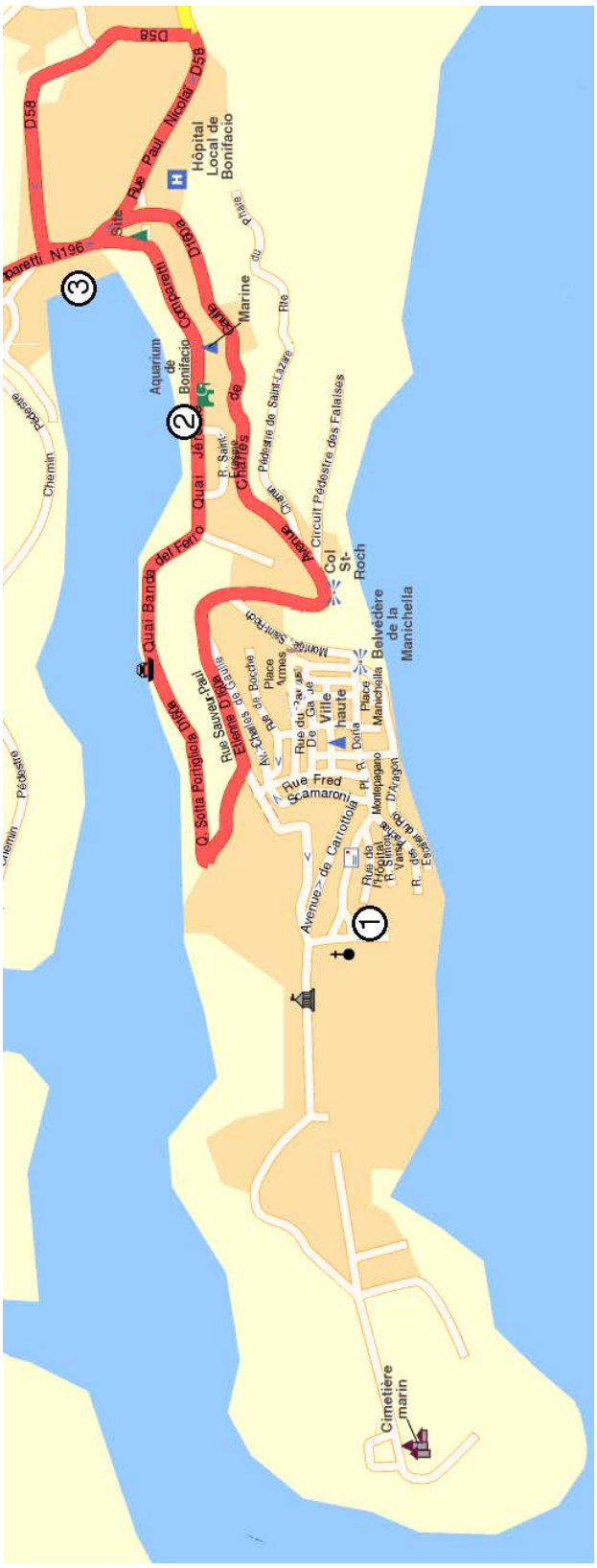
The conference fee for all participants is 200 Euros. The participation in the social event and dinner of Tuesday evening for accompanying persons is 100 Euros. Both Euros and credit cards (VISA, Master) are accepted, however personal checks or currency other than Euros cannot be accepted.

## Internet Connection

Workshop participants have the possibility to connect to the internet at the Cyber Café Boniboom, situated on the Quai Comparetti (no. ② on the map). The Cyber Café is open every day from 7:00 AM to 01:00 AM. You can either connect your own laptop using the Café's WIFI system or with an ethernet cable. If there is availability, you may use one of the seven PC's of the Cyber Café. Please bring your workshop badge to identify yourself.

**Map of Bonifacio**

① Espace St. Jacques ② Cyber Café ③ capitainerie (embarcation for social event)




## PROCEEDINGS

All workshop papers will be published in a special issue of the journal "Experimental Astronomy". In addition, every participant will receive a hardcover volume of the proceedings entitled "Focusing Telescopes in Nuclear Astrophysics" (Springer).

Contributions should normally be four to eight pages of "Experimental Astronomy" format; they will undergo refereeing and have to conform to the rules of "Experimental Astronomy". The deadline for proceedings contributions is November 15, 2005. We do not require camera-ready materials. All papers will be typeset by Springer and proofs will be mailed to authors for correction.

Contributors will be asked to submit their papers through Springer's online submission and review system Editorial Manager : www.editorialmanager.com/expa. Details on the preparation of the proceedings will be made available on the workshop www site : www.cesr.fr/~g-wave05.

**Deadline for Proceedings Contributions : 15 November 2005**

Publication of the Proceedings : 15 March 2006

## PROGRAM OF MONDAY 12 SEPTEMBER

Morning chairperson : Mark LEISING

| | | |
|---|---|---|
| 9h00 | registration | |
| 9h30 | Peter VON BALLMOOS<br>CESR Toulouse | Introduction and Welcome |
| 9h40 | Jürgen KNÖDLSEDER<br>CESR Toulouse | Prospects in Space-Based Gamma-Ray Astronomy |
| 10h10 | Sergey SAZONOV<br>MPI Garching | Annihilation of Positrons in the Galaxy |
| 10h40 | Richard GRIFFITHS<br>Carnegie Mellon University | AGN at High Energy and the Prospects<br>for 511 keV Annihilation Lines |
| 11h10 | coffee break | |
| 11h40 | Pierre BASTIE<br>LSP, St Martin d'Hères | The Basic Principles of Crystal Diffraction |
| 12h10 | Hubert HALLOIN<br>MPE Garching | Laue diffraction lenses for astrophysics :<br>physics basis and simulations |
| 12h40 | Giovanni PARESCHI<br>INAF, Osservatorio Astronomico di Brera | Hard X-ray optics based on Bragg reflection<br>from mosaic crystals: a review |
| 13h00 | end of session | |

Afternoon chairperson : Fiona HARRISON

| | | |
|---|---|---|
| 17h00 | Brian RAMSEY<br>Marshall Space Flight Center, Huntsville | Replicated Nickel Optics for the Hard-X-Ray Region |
| 17h30 | Carsten JENSEN<br>Danish Natl. Space Center, Copenhagen | Small d-spacing WC/SIC multilayers for future hard x-ray telescope designs |
| 17h50 | Ernst-Jan BUIS<br>Cosine Science and Computing, Leiden | On and Off-Axis Response of Grazing Gamma-Ry Optics |
| 18h10 | Mel ULMER<br>Northwestern University, Evanston | Progress Toward Light Weight High Angular Resolution<br>Multilayer Coated Optics |
| 18h30 | coffee break | |
| 19h00 | P. GIOMMI & S.COLAFRANCESCO<br>ASI / INAF, Roma | Non-thermal Cosmic Backgrounds from Blazars.<br>Cosmological impact of gamma-ray observations of point-like and diffuse extragalactic sources |
| 19h30 | Andrea COMASTRI<br>INAF-Osservat.Astronomico di Bologna | The sources of the hard X-ray / gamma-ray backgrounds |
| 20h00 | end of session | |

## PROGRAM OF TUESDAY 13 SEPTEMBER

Morning chairperson : Pietro UBERTINI

| | | |
|---|---|---|
| 9h00 | Didier BARRET<br>CESR Toulouse | Focusing on X-ray Binaries and Microquasars |
| 9h30 | Mark LEISING<br>Clemson University | Focusing on Supernovae |
| 10h00 | Margarida HERNANZ<br>IEEC Barcelona | Nucleosynthesis in nova explosions: prospects for their observation with focusing telescopes |
| 10h30 | David SMITH<br>Santa Cruz Institute for Particle Physics | Puzzles and Potential for Gamma-ray Line Observations of Solar Flare Ion Acceleration |
| 11h00 | coffee break | |
| 11h30 | Nikolai ABROSIMOV,<br>Institut für Kristallzüchtung, Berlin | Mosaic and Gradient Single Crystals<br>for Gamma ray Laue Lenses |
| 12h00 | Bob SMITHER<br>Argonnel Natl. Laboratories, Chicago | High Diffraction Efficiency, Broadband Diffraction Crystals |
| 12h30 | end of session | |

Afternoon chairperson : Gerry SKINNER

| | | |
|---|---|---|
| 14h00 | Pietro UBERTINI<br>IASF Roma | The INTEGRAL - HESS connection: a new class of cosmic high energy accelerators from keV to TeV |
| 14h30 | Jean-François OLIVE<br>CESR Toulouse | Focusing on Pulsars |
| 15h00 | coffee break | |
| 15h30 | Niels LUND<br>Danish Natl. Space Center, Copenhagen | Imaging with Laue Optics |
| 16h00 | Alessandro PISA<br>INFN, Dipartimento di Fisica, Ferrara | Optical properties of Laue lenses for hard X-rays (>60 keV) |
| 16h20 | Pierre COURTOIS<br>Institut Laue-Langevin, Grenoble | Copper Mosaic Crystals for Laue Lenses |
| 16h40 | Dante ROA<br>University of California, Irvine | Development of a new photon diffraction imaging system for nuclear diagnostic medicine |
| 17h00 | end of session | |
| 17h30 | departure for the Conference Dinner<br>("capitainerie" ③ at the port of Bonifacio) | |

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Chairperson : Niels LUND

| | | |
|---|---|---|
| 9h00 | Fiona HARRISON<br>Caltech, Pasadena | The Nuclear Spectroscopic Telescope Array (NuSTAR) |
| 9h30 | Giovanni PARESCHI<br>INAF, Osservatorio Astronomico di Brera | The SIMBOL-X hard X-ray mission |
| 9h50 | Fillipo FRONTERA<br>INFN, Dipartimento di Fisica, Ferrara | HAXTEL: a Laue lens telescope for a deep exploration of the hard X-ray (>60 keV) sky |
| 10h10 | Peter VON BALLMOOS<br>CESR Toulouse | CLAIRE : First Light of a Crystal Diffraction Lens |
| 10h30 | Nicolas BARRIERE<br>CESR Toulouse | MAX, a Laue diffraction lens for nuclear astrophysics |
| 10h50 | Nicola RANDO<br>Science Payload & Adv. Concepts Office | The Gamma Ray Lens –<br>An ESA Technology Reference Study |
| 11h20 | coffee break | |
| 11h50 | Jacques BORDE<br>ASTRIUM, Toulouse | Small-sat Platforms and Formation Flying :<br>an opportunity for the gamma ray telescope MAX |
| 12h10 | Emmanuel HINGLAIS<br>CNES, Toulouse | Distributed space segment architectures for high energy astrophysics : Similarities and specificities |
| 12h30 | Rodolphe CLEDASSOU<br>CNES, Toulouse | The Formation Flying mission SIMBOL-X |
| 12h50 | Paul DUCHON<br>CNES, Toulouse | The Formation Flying mission MAX |
| 13h10 | Michel SGHEDONI / Bertrand HUET<br>Alcatel Alenia Space, Cannes | Recent Advances and Low cost concept for the Gamma-Ray Lens Project MAX |
| 13h30 | end of session | |

## PROGRAM OF THURSDAY 15 SEPTEMBER

Morning chairperson : Fillipo FRONTERA

| | | |
|---|---|---|
| 9h00 | Tadayuki TAKAHASHI<br>ISAS, Kanagawa | High Sensitivity Si/CdTe Compton Telescope |
| 9h30 | Ezio CAROLI<br>INAF-Osservat.Astronomico di Bologna | Polarimetric performance of CdTe pixel detector for Laue foccusing telescope Laue hard x ray focussing telescope |
| 9h50 | Mauro QUADRINI<br>INAF-IASF Sez OCCHIALINI MILANO | Solid state CZT detectors for<br>Gamma Ray Telescope Application |
| 10h10 | Ernst-Jan BUIS<br>Cosine Science and Computing, Leiden | New scintillators for focal plane detectors in<br>gamma-ray missions |
| 10h30 | coffee break | |
| 10h50 | Gerry SKINNER<br>CESR Toulouse | Fresnel Lenses - why not ? |
| 11h20 | John KRIZMANIC<br>USRA/NASA/GSFC, Greenbelt | X-ray Imaging Performance of a Phase Fresnel Lens |
| 11h50 | Giovanni PARESCHI<br>INAF, Osservatorio Astronomico di Brera | Calibration of hard X-ray (15-50 keV) optics<br>at the MPE test facility PANTER |
| 12h10 | Gianluca LOFFREDO<br>INFN, Dipartimento di Fisica, Ferrara | The Ferrara hard X-ray facility for testing/calibrating hard X-ray focusing telescopes |
| 12h30 | end of session | |

Afternoon chairperson : Brian RAMSEY

| | | |
|---|---|---|
| 14h30 | Cornelia WUNDERER<br>Space Sciences Lab., UC Berkeley | Performance of the Nuclear Compton Telescope |
| 14h50 | Georg WEIDENSPOINTNER<br>CESR Toulouse | Monte Carlo Study of Detector Concepts for the MAX Laue Lens Gamma-Ray Telescope |
| 15h10 | Cornelia WUNDERER<br>Space Sciences Lab., UC Berkeley | Performance of a dedicated Ge Strip Compton Telescope<br>as Gamma-Lens Focal Plane Instrumentation |
| 15h30 | Laurent KOECHLIN<br>OMP Toulouse | Multiwavelength Focusing with the Sun<br>as Gravitational Lens |
| 15h50 | Giovanni BIGNAMI<br>CESR Toulouse | Gamma-rays and Cosmic Vision |
| 16h20 | Peter VON BALLMOOS<br>CESR Toulouse | Conclusion |
| 16h30 | end of workshop | |

## POSTER PRESENTATIONS

| | |
|---|---|
| Jack TUELLER<br>GSFC Greenbelt | In-Focus |
| Robert ANDRITSCHKE et al.<br>MPE Garching | The MEGA detector as focal plane instrument |
| André LAURENS and Jean EVRARD<br>CNES Toulouse | Balloon Gondolas for high Energy Focusing Telescopes |

# 1. Scientific requirements and prospects

Scientific requirements and prospects
Monday, September 12, 9h40

## Prospects in Space-Based Gamma-Ray Astronomy

Jürgen Knödlseder
CESR, 9, avenue du Colonel-Roche, 31028 Toulouse, France

At the uppermost part of the electromagnetic spectrum, observations of the gamma-ray sky reveal the most powerful sources and the most violent events in the Universe. While at lower wavebands the observed emission is generally dominated by thermal processes, the gamma-ray sky provides us with a view on the non-thermal Universe, where particles are accelerated by still poorly understood mechanisms to extremely relativistic energies, and nuclear interactions, reactions, and decays are organising the basic elements of which our world is made of. Cosmic accelerators and cosmic explosions are the major science themes that are addressed in this waveband.
With the unequaled INTEGRAL observatory, ESA has provided a unique tool to the astronomical community that has made Europe the world leader in the field of gamma-ray astronomy. INTEGRAL provides an unprecedented survey of the soft gamma-ray sky, revealing hundreds of sources of different kinds, new classes of objects, extraordinary views of antimatter annihilation in our Galaxy, and fingerprints of recent nucleosynthesis processes.
While INTEGRAL provides the longly awaited global overview over the soft gamma-ray sky, there is a growing need to perform deeper, more focused investigations of gamma-ray sources, comparable to the step that has been taken in X-rays by going from the ROSAT survey satellite to the more focused XMM-Newton observatory. Technological advances in the past years in the domain of gamma-ray focusing using Laue diffraction techniques have paved the way towards a future European gamma-ray mission, that will outreach past missions by large factors in sensitivity and angular resolution. Such a future Gamma-Ray Imager will allow to study particle acceleration processes and explosion physics in unprecedented depth, providing essential clues on the intimate nature of the most violent and most energetic processes in the Universe.

Scientific requirements and prospects
Monday, September 12, 10h10

## Annihilation of Positrons in the Galaxy

Sazonov Sergey
Max-Planck Institute for Astrophysics, Garching, Germany

The Galactic Center is a site of copious production of positrons, whose origin is not clear - the hypotheses range from stellar nucleosynthesis to annihilating dark matter. INTEGRAL has made the most precise measurements of the GC annihilation spectrum, sheding some light on the properties of the ISM where positrons are annihilating. The measured width of the 511 keV line is 2.37+/-0.25 keV, while the strength of the ortho-positronium continuum suggests that most positrons (94+/-6 per cent) form positronium before annihilation. These spectral parameters can be explained by a warm (7000-40000 K) gas with degree of ionization larger than a few per cent. One of the widespread ISM phases - warm (8000 K) and weakly ionized - satisfies these criteria. The observed spectrum can also be explained by annihilation in a multiphase ISM. We discuss how future telescopes with higher angular resolution and lower background could improve our understanding of the GC 511 keV emission.

Scientific requirements and prospects
Monday, September 12, 10h40

## AGN at High Energy and the Prospects for 511 keV annihilation lines

Richard E. Griffiths
Univ. Carnegie Mellon, Physics Dept., 5000 Forbes Avenue, 15213-3890 Pittsburg PA

The properties of known Active Galactic Nuclei are reviewed from the point of view of their high energy X-ray and gamma-ray spectra. The requirements on focussing telescopes in this energy range are then derived. Special emphasis is given to the possibility that AGN are also sources of 511 keV annihilation radiation. Nearby AGN such as M87 in Virgo, NGC 1275 and Cen A are excellent candidates for the detection of this emission.

Scientific requirements and prospects
Monday, September 12, 19h00

## Non-thermal cosmic backgrounds from Blazars

## Cosmological impact of gamma-ray observations of point-like and diffuse extragalactic sources: the cases of Blazars and clusters of galaxies

Paolo Giommi and Sergio Colafrancesco

ASI, Science Data Center, Frascati, Italy
INAF - Osservatorio Astronomico di Roma, Via Frascati, 33 I-00040 Monteporzio (Roma) ITALY

Gamma-ray observations can provide unique information on some crucial astrophysical and cosmological aspects of extragalactic sources. I will review the impact of gamma-ray observations of two specific classes of cosmologically relevant structures:
1) Blazars, which are the main extragalactic contaminants of the CMB temperature and polarization anisotropy spectrum (a fundamental tool to probe the physics of the early universe);
2) Galaxy clusters, which are the largest bound structures in the universe, and thus the largest containers of cosmic material (Dark Matter, baryons, cosmic rays), whose study might yield unique information of the cosmological parameters, on the nature of Dark Matter and on the origin of cosmic rays in the universe.

Scientific requirements and prospects
Monday, September 12, 19h40

## The sources of the hard X-ray / gamma-ray backgrounds

Andrea Comastri
INAF, Osservatorio di Astronomico, Via Frascati 33, Monteporzio, 00040, Roma, Italy

The fraction of the hard X-ray background (XRB) resolved into discrete sources strongly depends from the considered energy range While around a few keV deep Chandra and XMM surveys have essentially resolved the entire XRB flux above 7-8 keV no more than 50\% of the flux is due to resolved sources. At energies greater than 10 keV, where the bulk of the CXB energy density is produced, the resolved fraction is negligible, being strongly limited by the lack of imaging X--ray observations. Within the framework of AGN synthesis models the shape of the CXB spectrum and intensity in the 10--100 keV range is modeled assuming an important contribution from heavily obscured Compton thick ($N_H > 1.5 \times 10^{24}$ cm$^{-2}$) sources around 20--30 keV. Moreover a high energy cut--off ($E_{cut}$) usually parameterized as an exponential roll--over with an e--folding energy of the order of a few hundreds of keV has to be present in the high energy spectrum of all the sources in order not to overproduce the observed flux above 100 keV. The lack of a detailed knowledge of the absorption distribution at the highest column densities and of the distribution of exponential cut-off leaves a relatively wide portion of the parameter space unexplored. It can be shown that depending on the adopted high energy cut-off and the poorly known redshift evolution of the most heavily obscured sources the shape of the residual (not yet directly resolved) CXB spectrum is strongly dependent from the value assumed for the above mentioned parameters. An additional source of uncertainties comes from the contribution to the hard (around 100 keV) background from radio loud blazars which are known to provide a significant contribution to the gamma-ray background. I will discuss how high energy (above a few tens of keV) observations will improve our present understanding of the physical mechanisms associated to the AGN primary emission mechanism and the cosmological evolution of the most obscured sources.

Scientific requirements and prospects
Tuesday, September 13, 9h00

## Focusing on X-ray binaries and microquasars

Didier Barret
CESR, 9, avenue du Colonel Roche, 31028 Toulouse cedex4, France

Gamma-rays above a few hundreds of keV carry unique informations on the thermal and non-thermal emission mechanisms at work around compact stars. In this talk, I will discuss the prospects of observing X-ray binaries, including microquasars, with a high- sensitivity focussing gamma-ray instrument. In particular I will emphasize the complementarity of gammay-ray observations with those performed in the classical X-ray band.

Scientific requirements and prospects
Tuesday, September 13, 9h30

## Focusing on Supernovae

Mark Leising
Clemson Univ., Dept. Of Physics & Astronomy, SC 29634-0978, Clemson, USA

We discuss the contributions to our understanding of supernova physics that a high-sensitivity focusing gamma-ray instrument can uniquely provide. For a number of objectives we outline the instrument parameters, especially sensitivity and energy resolution, required. We discuss the number of supernovae that can plausibly be expected to be studied in detail with such an instrument considering realistic observing constraints and the likely efficiency of supernova discoveries in the future.

Scientific requirements and prospects
Tuesday, September 13, 10h00

## Nucleosynthesis in nova explosions: prospects for their observation with focusing telescopes

Margarida Hernanz
IEEC CSIC, Inst. d'Estudis Espacials de Catalunya, Campus UAB, Facultat de Ciencies, Torre C-5 Parell 2a Planta, 08193, Bellaterra, Barcelona, Espagne

Nova explosions are caused by the explosive burning of hydrogen in the envelope of accreting white dwarfs. During the thermonuclear runaway many radioactive isotopes are synthesized, which emit gamma-rays when they decay. The gamma-ray signatures of a nova explosion still remain undetected, because even the best instruments like SPI onboard INTEGRAL are not sensitive enough for the dim and broad lines emitted by novae at their typical distances. A very different situation is expected with a focusing telescope, like MAX. Prospects for detectability with a future gamma-ray lens telescope will be presented, with a special emphasis on the important information that gamma-rays would provide about the explosion mechanism and the underlying white dwarf star.

Scientific requirements and prospects
Tuesday, September 13, 10h30

## Puzzles and Potential for Gamma-ray Line Observations of Solar Flare Ion Acceleration

David Smith
Santa Cruz Institute for Particle Physics

The acceleration and interaction of high-energy electrons in solar flares can be studied via the copious bremsstrahlung x-rays they produce and their synchrotron emission in the radio and microwave. To study flare-accelerated ions at the Sun, we use gamma-ray lines from positron annihilation, nuclear de-excitation, and neutron capture. Recent data from RHESSI have shown that the positron-annihilation line is often surprisingly broad, offering a unique probe into the temperature, density and ionization state of the flaring atmosphere. The Doppler profiles of the de-excitation lines provide information on the direction and angular distribution of the accelerated ions. But these observations have only been made on the very brightest flares due to sensitivity limitations. In addition to reviewing the state of our knowledge and what we'd like to observe next, I will give sensitivity requirements and discuss the required field of view and pointing issues. I will close by touching briefly on the need for hard x-ray imaging instrumentation to study electron acceleration in microflares and nanoflares.

Scientific requirements and prospects
Tuesday, September 13, 14h00

## The INTEGRAL – HESS connection: a new class of cosmic high energy accelerators from keV to TeV

Pietro Ubertini
Istituto di Astrofisica Spaziale, INAF, Roma, Italy

The recent completion and operation of the High Energy Stereoscopic System (Aharonian et al., 2005), an array of ground based imaging Cherenkov telescopes, have provided a survey with unprecedented sensitivity of the inner part of the Galaxy and revealed a new population very high energy gamma-rays sources emitting at E>100 GeV. At least two of them were reported to have no known radio or X-ray counterpart and hypothesised to be representative of a new class of dark nucleonic cosmic sources. In fact, very high energy gamma-rays with energies E > 10 exp 11 eV are the best proof of non-thermal processes in the universe and provide a direct in-site view of matter-radiation interaction at energies by far greater than producible ground accelerators. At lower energy INTEGRAL has regularly observed the entire galactic plane during the first 1000 day in orbit providing a survey in the 20-100 keV range resulted in a soft gamma-ray sky populated with more than 200 sources, most of them being galactic binaries, either BHC or NS (Bird et al., 2005).
Very recently, the INTEGRAL new source IGR J18135-1751 has been identified as the soft gamma-ray counterpart of HESS1813-178 (Ubertini et al., 2005) and AXJ1838.0-0655 as the X/gamma-ray counterpart of HESS J1837-069 (Malizia et al., 2005).
Detection of non thermal radio, X and gamma-ray emission from these TeV sources is very important to discriminate between various emitting scenarios and, in turn, to fully understand their nature.
The implications of these new findings in the high energy Galactic population will be addressed.

Scientific requirements and prospects
Tuesday, September 13, 14h30

## Focusing on pulsars

Jean-François Olive
CESR, 9, avenue du Colonel Roche, 31028 Toulouse cedex4, France

Energetic and young pulsars accelerate electrons and positrons to very high energies in their magnetosphere. The location of the accelerating regions is still being debated. The particle outflows can interact with the surrounding medium to produce synchrotron nebulae. Our understanding of the pulsars and their nebulae has increased dramatically in the past few years, with the high resolution imaging X-ray telescopes. These observations have revealed the complex and time-varying structures of the centermost regions with rings, jets and hot spots. In this talk, the advantage to observe such systems with a sensitive focusing gamma-ray telescope will be presented. In particular, I will discuss the instrument parameters in terms of energy and angular resolution that will allow us to infer very important informations on the particle winds and the pulsating neutron stars themselves.

Scientific requirements and prospects
Thursday, September 15, 15h50

## Gamma-rays and Cosmic Vision

Giovanni Bignami
CESR, 9 avenue du Colonel Roche, BP 4346, 31028 Toulouse cedex 4, France

## 2. Gamma-Ray Optics

Gamma-Ray Optics
Monday, September 12, 11h40

## The basic principles of diffraction by crystals

Pierre Bastie
Laboratoire de spectrométrie Physique and Institut Laue Langevin, Grenoble, France

Focusing of high energy X rays can be performed using crystal diffraction. However the choice of crystals is a delicate problem when a given angular resolution is required and a good efficiency is sought. In this talk, we shall give, in a qualitative way, some keys for driving the choice of the crystals.
First, the physical mechanism of the diffraction by the atoms will be recalled. Then the case of a periodic arrangment of atoms will be considered leading to the concepts of "the perfect crystal "and "the ideally imperfect crystal" allowing to define the extinction length and to introduce the two limiting cases : the dynamical and the kinematical theories for diffracted intensity calculations. In a next step, the mosaic crystal model will be presented and the old but useful notion of primary and secondary extinctions given. From these qualitative explanations, some possible ways to design efficient crystals to build an x-ray lens will be suggested though the most difficult stage will remain their elaboration.

Gamma-Ray Optics
Monday, September 12, 12h10

## Laue diffraction lenses for astrophysics : physics basis and simulations

Hubert Halloin
MPI for extraterrestrische Physik, Postfach 1312, 85741, Garching, Allemagne

The laws of X-ray diffraction in crystals have been written almost 100 years ago and are widely used in crystallography. Nevertheless, their application in atrophysics is much more recent, the requirements and constraints being specific to this field.

In this workshop, we will present the basics of X-ray diffraction in crystals and their application to Laue lenses in gamma-ray astrophysics. We will also underline the implications and specific constraints in gamma-rays. Finally, these theoretical predictions are compared with experimental data, through the use of Monte-Carlo simulations and the results of the CLAIRE project.

Gamma-Ray Optics
Monday, September 12, 12h40

## Hard X-ray optics based on Bragg reflection from mosaic crystals: a review

Giovanni Pareschi[(1)], Filippo Frontera[(2)]
[(1)]INAF, Osservatorio di Astronomico, Brera, Via E. Bianchi 46, 23807, Merate, Italy
[(2)]Dipartimento di Fisica - Universit di Ferrara and INAF/IASF-Bologna, Italy

The use of Bragg reflection optics for the hard X-ray (10 - 150 keV) astronomy is very attractive due to the wide energy band and reflection angles allowed by natural mosaic crystals. The concept already found many applications in fields different from astronomy (e.g. medical radiology and fluorescence analysis in synchrotron radiation experiments). Also the design and development of hard X-ray astronomical telescopes based on mosaic crystals was carried out by several groups, the most recent study being done at the University of Ferrara, Italy. In this paper we will review the work that has been done so far and the status of this technological approach, with a critical discussion about the design, fabrication methods, materials for the implementation of Bragg focusing systems. The perspectives of the use of Bragg telescopes in reflection configuration in future astronomical programs, and the comparison with other kinds of high energy focusing optics like multilayer coated Wolter I mirrors and Laue diffracting lens will be also be treated.

Gamma-Ray Optics
Monday, September 12, 17h00

## Replicated Nickel Optics for the Hard-X-Ray Region

Brian Ramsey
NASA, Marshall Space Flight Center, 320 Sparkman Drive, Alabama, 35805, Huntsville, USA

Replicated nickel optics has been used extensively in x-ray astronomy, most notable for the XMM/Newton mission. The combination of relative ease of fabrication and the inherent stability of full shell optics, make them an attractive approach for medium-resolution, high-throughput applications. MSFC has been developing these optics for use in the hard-x-ray region. Efforts at improving the resolution of these, particularly the very-thin shells required to meet the weight budget of future missions, will be described together with the prospects for significant improvements down to the 5-arcsec level.

Gamma-Ray Optics
Monday, September 12, 17h30

## Small d-spacing WC/SIC multilayers for future hard x-ray telescope designs

Carsten P. Jensen, Kruse Kristin Madsen, F. E. Christensen
DNSC, Danish National Space Center, Juliane Maries Vej 30, DK-2100, Copenhagen, Denmark

Multilayer coatings for reflecting X-rays up to 80 keV have been studied for several years, and in May 2005 the HEFT balloon mission successfully flew 3 focusing optics using W/Si multilayers. The NASA SMEX mission NuSTAR, planned for flight in 2009, will also employ focusing mulitlayer optics of a similar design. The upper energy limit for these optics is partly constrained by how thin the bilayer thicknesses can be made without detrimental effects to the interface roughness. With new material combinations like W/SiC, WC/SiC, and Pt/SiC the interface roughness can be reduced in some cases down to 0.2 nm enabling bilayer thicknesses down to 1.0 nm to reflect effectively. The production of thinner period coatings thus enables the possibility for focusing optic designs with reasonable throughput up to several hundred keV. This will enable the investigation of the nuclear continuum and cutoff in AGN and Seyfert galaxies, as well as the Compton backscatter radiation at 170 keV emitted from accreting massive galactic objects, and the 56-Ni 158 keV line in supernova type 1a.

Gamma-Ray Optics
Monday, September 12, 17h50

## On and off Axis response of a multilayer coated gamma-ray imager

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If sensitive enough, future mission for nuclear astrophysics will be a great help in the understanding of supernovae explosions. In contrast to coded-mask instruments, both crystal diffraction lenses and grazing angle mirrors offer a possibility to construct a sensitive instrument to detect soft gamma-ray lines in supernovae. The most dominant gamma-ray line due to 56Ni decay in type-Ia supernovae has an energy of 158 keV. This line provides a natural objective for future missions with multilayer coated optics. An other line of interest is the positron-electron line at 511 keV, but might be out of reach for multilayers. We have studied various configurations of gamma-ray optics and determined the on and off axis response for optics in the 30-511 keV energy range. Moreover, we discuss the bandwidth of the oprtics.

Gamma-Ray Optics
Monday, September 12, 18h10

## Progress Toward Light Weight High Angular Resolution Multilayer Coated Optics

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We have been working on 3 separate projects that together will give us the ability to make 1 arc second, light weight Wolter I optics that work above 40 keV. The three separate tasks are: (a) coating of the inside of Wolter I mirrors, (b) actuator designs for improving figure quality; (c) plasma spraying of metal-coated micro-balloons. We will give a progress report on our work on all three areas

Gamma-Ray Optics
Tuesday, September 13, 11h30

## Mosaic and gradient single crystals for gamma ray Laue lenses

Nikolaï V. Abrosimov
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One of the possible solutions on the way to gamma ray detection is a crystal diffraction lens telescope. In this case one can increase the collection area of gamma rays without to increase the detection area. There are some approaches to realize such telescope including Laue lens as diffracting unit. But the question is: what crystals could be used to build the lens?
Possible material candidates for the diffracting lens are bulk crystals of SiGe solid solutions both in form of mosaic crystals and gradient crystals. For example, two CLAIRE experiments were made using diffracting lens telescope consisted of 556 GeSi mosaic crystals (diffracting elements, 1x1 cm2) mounted in concentric rings. Recently SiGe gradient crystals were tested by R. Smither (Advanced Photon Source, Argonne National Laboratory) and the results will be presented on this conference.
This paper will describe the growth techniques used for the growth of SiGe single crystals and will give the comparison of some crystal parameters that are important for the gamma-ray lens application.

Gamma WAVE

FOCUSING TELESCOPES IN NUCLEAR ASTROPHYSICS

September 12 - 15, 2005
Espace St. Jacques, Bonifacio, Corsica

Gamma-Ray Optics
Tuesday, September 13, 12h00

# High Diffraction Efficiency, Broadband, Diffraction Crystals for Use in Crystal Diffraction Lenses

Robert E. Smither, ANL, Advanced Photon Source, 9700 South Cass Ave., IL 60439, Argonne, USA

One of the major goals of the MAX program is to be able to detect and measure the relative intensity of the gamma rays that are produced by the nuclear reactions that take place in a super nova explosion. The main problem in this endeavor is the very weak nature of the flux from these nuclear reactions. If the super nova were to occur in our own galaxy one could observe these gamma rays with our present satellite detectors, but this occurs only once in 100 years and therefore is not frequent enough to justify a satellite program. One must be able to detect gamma rays from super nova that occur in other galaxies. The flux from these sources is expected to be a few times 10-7 gamma rays per cm2 per sec. Thus a 100% efficient detector with an area of one square meter area will only detect a few gammas every 1000 sec. The expected background in this large detector will obscure the gamma ray signal. The advantage of using a crystal diffraction lens telescope is that one can separate the size of the collection area from the size of the detector. Thus one can expand the size of the lens without increasing the size of the detector. The detector can then be sized to fit the energy of the gamma ray being detected and then left unchanged as the size of the lens is increased. The crystals used to build the lens need to have both high diffraction efficiency and a relatively broad energy bandwidth and a relatively broad acceptance angle for the incident gamma rays. These last two requirements are actually the same requirement. With mosaic crystals there is a trade off between bandwidth and diffraction efficiency that limits the product of these two parameters. Thus one can have either high efficiency or large bandwidth, but not both. A recent breakthrough in our understanding of crystal diffraction for high energy gamma rays has made it possible to develop crystals that have both high diffraction efficiency and a relatively broad energy bandwidth. These crystals have near perfect crystal structure, except that the crystalline planes are slightly curved. This new type of crystal can be produced in 3 different ways. First, they can be grown as a two component crystal where the relative concentration of the two components is varied as the crystal is grown, second, they can be produced by applying a thermal gradient to a near perfect crystal and third, they can be produced by bending a near perfect crystal. A series of experiments have been performed using crystal made with all 3 approaches, using high energy x-ray beams from the Advanced Photon Source, a large synchrotron facility located at the Argonne National Laboratory, and with gamma rays from radioactive sources. One of the advantages of using the synchrotron beams to test these crystals is that as sources they look very much like the flux coming from a distant super nova source. The radiation is collimated to a few arc sec and has a narrow but finite energy bandwidth. The thermal gradient approach has demonstrated that one can have crystals with 90 percent diffraction efficiency and an angular bandwidth of 50 arc sec. At 100 keV this corresponds to an energy bandwidth of 1,27 keV and at 500 keV, a bandwidth of 6.33 keV, when using the [111] crystalline planes of silicon. These energy widths correspond to Doppler shifts of 3800 km per sec. This paper will compare the 3 approaches as applied to the construction of a crystal diffraction lens. There is a potential of increasing both the diffraction efficiency and the bandwidth by a factor of 5 as compared to what can be done with mosaic crystals.

Gamma-Ray Optics
Tuesday, September 13, 15h30

## Imaging with Laue lenses

Niels Lund
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Laue lenses designed to have a wide energy coverage possesses limited imaging capabilities. These can be used on-line to assure a good centering of the target object during an observation and also offers the possibility to construct spatial maps of the emission from supernova remnants.

Gamma-Ray Optics
Tuesday, September 13, 16h00

## Optical properties of Laue lenses for hard X-rays (>60 keV)

Alessandro Pisa
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We report on preliminary results obtained with a Monte Carlo (MC) code developed to study the optical properties of Laue lenses for astrophysical observations. The MC code is written in the Python programming language and relays on open source libraries.Among the physical quantities which can be investigated with the MC code, we paid our attention mainly to the estimation of the effective area, sensitivity, field of view (FOV) and point spread function (PSF) of the lens for observation of sources on-axis and off-axis.

Gamma-Ray Optics
Tuesday, September 13, 16h20

## Copper Mosaic Crystals for Laue Lens

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A gamma Laue lens for astrophysical applications based on mosaic copper single crystals requires crystals of high quality, with a homogeneous intrinsic mosaic distribution of less than 30 seconds of arc at high diffracted energy (> 500 keV). Copper crystals being used in transmission geometry, the thickness of the crystals, which depends on the energy, needs to be optimized in order to obtain the maximum integrated intensity. The aim of this study is to show the feasibility of such a gamma Laue lens, which is a real challenge with regard to the growth and preparation of the copper crystals. The X-ray diffraction properties of copper single crystals produced at I.L.L. were studied for x-ray energies ranging from 120 keV to 400 keV. It is shown that it is possible to grow large single crystals of copper with a uniform and very narrow intrinsic mosaic between 45 seconds and 5 minutes of arc. Several monocrystalline plates having different thickness and mosaic were then prepared from the as-grown crystals in order to measure their diffraction efficiency (peak and integrated intensity) as a function of energy. As expected, the value of the peak reflectivity (at constant x-ray energy) depends strongly on the thickness of the copper crystal and the integrated reflectivity depends strongly on the mosaic distribution. Extinction effects are also observed when measuring the width of the peak reflectivity as a function of the x-ray energy.
Some technical aspects on the preparation of copper single crystal plates are also discussed.

Gamma WAVE
FOCUSING TELESCOPES IN NUCLEAR ASTROPHYSICS
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Gamma-Ray Optics
Tuesday, September 13, 16h40

# Development of a new photon diffraction imaging system for nuclear diagnostic medicine

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The objective of this project is to develop and construct an innovative imaging system for nuclear medicine and molecular imaging that, by using photon diffraction, can be capable of generating 1-2 mm spatial resolution images in two or three dimensions. The proposed imaging system would be capable of detecting radiopharmaceuticals that emit 100-200 keV gamma rays which are typically used in diagnostic imaging in nuclear medicine and in molecular imaging. However, the system is expected to be optimized for the 140.6 keV gamma ray from a Tc-99m source which is frequently used in nuclear medicine. This new system will focus the incoming gamma rays in a manner analogous to a magnifying glass focusing sunlight into a small focal point on a detector's sensitive area. Focusing gamma rays through photon diffraction has already been demonstrated with the construction of a diffraction lens telescope for astrophysics and a scaled-down lens for medical imaging, both developed at Argonne National Laboratory (ANL). In addition, spatial resolutions of 3 mm have been achieved with a prototype medical lens. The proposed imaging system would be comprised of an array of photon diffraction lenses tuned to diffract a specific gamma ray energy (within 100 - 200 keV) emitted by a common source. The properties of photon diffraction make it possible to diffract only one specific gamma ray energy at a time, which significantly reduces scattering background. The system should be sufficiently sensitive to detecting small concentrations of radioactivity that can reveal potential tumor sites at their initial stages of development. Moreover, the system's sensitivity would eliminate the need for re-injecting a patient with more radiopharmaceutical if this patient underwent a prior nuclear imaging scan. Detection of a tumor site at its inception could allow for an earlier initiation of treatment which can increase the chances of patients' survival.

KEYWORDS: medical imaging, photon diffraction, radiopharmaceuticals, nuclear medicine.

Gamma-Ray Optics
Wednesday, September 14, 9h00

## The Nuclear Spectroscopic Telescope Array (NuSTAR)

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NuSTAR will be the first satellite-borne focusing telescope to image the hard X-ray (8 - 80 keV). NuSTAR's unprecedented combination of sensitivity, angular and spectral resolution allow itto carry out a number of high priority scientific investigations, including: 1) taking a census ofblack holes on all scales, achieved through deep, wide-field surveys of extragalactic fields andthe Galactic center, 2) mapping recently-synthesized material in young supernova remnants toconstrain nucleosynthesis and explosion models, and 3) studying the spectra and time-variabilityin the most extreme AGN. In this talk I will provide an overview of the science goals, instrumentarchitecture, and results from the flight of the HEFT balloon instrument, a prototype forthe NuSTAR mission.

Gamma-Ray Optics
Wednesday, September 14, 9h30

## The SIMBOL-X hard X-ray mission

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SIMBOL-X is a hard X-ray mission, operating in the 0.5 - 70 keV (extendable up to 80 keV and beyond) range, which is proposed by a consortium of European laboratories in response to the 2004 call for ideas of CNES for a scientific mission to be flown on a formation flying demonstrator. A large participation from the Italian Space Agency (ASI) is currently envisaged and under discussion. Relying on two spacecrafts in a formation flying configuration, SIMBOL-X makes uses of a 30 m focal length X-ray mirror to focus for the first time X-rays with energy above 10 keV, resulting in at least a two orders of magnitude improvement in angular resolution and sensitivity in the hard X-ray range with respect to non focusing techniques. The SIMBOL-X revolutionary instrumental capabilities will allow to elucidate outstanding questions in high energy astrophysics, related in particular to the physics of accretion onto compact objects, to the acceleration of particles to the highest energies and to resolving the sources giving rise to the Cosmic X-ray Background in the region where its spectrum peaks (30 keV). In the case, under study, that multilayer coated optics are implemented (instead of the single layer Pt mirrors of the baseline design), with the operational range extended up to 80 keV, also the investigation of 44Ti nuclear decaying lines from supernova remnant will be enabled. It must be noted that Simbol-X will also represent the necessary pathfinder experiment for other high energy missions that will make use of the formation flight architecture as e.g. XEUS and, perhaps , Constellation-X. The mission is currently in final assessment study in CNES, anda cmpetitive phase A study is expected to start, to be carried out in close collaboration with ASI, in autumn 2005, leading to a flight decision at the end of 2006. The mission science objectives, design, instrumentation (in particular for what related to the focusing optics) and status will be presented.

Gamma-Ray Optics
Wednesday, September 14, 9h50

## HAXTEL: a Laue lens project for a deep exploration of the hard (>60 keV) X-ray sky

Filippo Frontera
Univ. Di Ferrara, Dipartimento di Fisica, Via Saragat, 1, 44100, Ferrara, Italy

I will give an overview of the status of the HAXTEL project. In particular I will discuss its sceintific objectives of the project, the main features and criteria used for the Laues lenses we are developing, their development status, and the sensitivity expectations from multi-lens configurations in the 60 to 600 keV bandpass.

Gamma-Ray Optics
Wednesday, September 14, 10h10

# CLAIRE : First Light for a Gamma-Ray Lens

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The objective of the R&D project CLAIRE was to prove the principle of a Laue lens for nuclear astrophysics. After tests with a ground-based prototype, and measuring diffraction efficiencies of individual Ge crystals on a synchrotron light source, the next logical step towards a space borne crystal lens telescope was to demonstrate the principle for astrophysical observations.On June 14 2001, the gamma-ray lens telescope CLAIRE was flown on a stratospheric balloon by the French Space Agency CNES; the astrophysical target was a "standard candle", the Crab nebula. The lens was composed of Ge-Si mosaic crystals, focusing gamma-ray photons from its 511 cm2 area onto a small solid state detector, with only ~ 18 cm3 equivalent volume for background noise. CLAIRE's first light consisted of ~33 diffracted 170 keV photons from the Crab. The performance of the gamma-ray lens during the balloon flight has been confirmed by ground data obtained on a 205 m optical bench, set up on a small airfield near Figueras in northern Catalonia.

Gamma-Ray Optics
Wednesday, September 14, 10h30

## MAX, a Laue diffraction lens for nuclear astrophysics

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The next generation of instrumentation for the domain of nuclear astrophysics will have to achieve a factor of 10-100 improvement in sensitivity over present technologies. With the focusing gamma-raytelescope MAX we take up this challenge : combining unprecedented sensitivity with high spectral and angular resolution, and the capability of measuring the polarization of the incident photons.MAX consists of a Laue diffraction lens containing more than 7800 germanium and copper crystal tiles disposed on 24 concentric rings. It simultaneously focuses in two energy pass bands, each one centered on main scientific objectives of the mission: the 800 - 900 keV band is dedicated to the study of nuclear gamma ray lines from type Ia supernovae (e.g. 56Co decay line at 847 keV) while the 450 - 530 keV band concentrates on electron-positron annihilation (511 keV emission) from the Galactic Center. MAX will make use of satellite formation flight to achieve a 86 m focal length, with the lens being carried by one satellite and the detector by the other. MAX has already successfully undergone a pre-phase A study with the French Space Agency CNES.After a summary of the principal scientific objectives of MAX, the characteristics of the instrument are reviewed, and sensitivity estimates for various crystal and detector options are compared. Finally, the status of the MAX R&D is presented, in particular the techniques for crystal mounting and orientation, and the development of new diffracting materials such as composites crystals.

Gamma-Ray Optics
Wednesday, September 14, 10h50

## Gamma Ray Lens – An ESA Technology Reference Study

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The Science Payload and Advanced Concepts Office (SCI-A) of the ESA Science Directorate conducts a number of Technology Reference Studies (TRS) on hypothetical scientific missions that are not part of the approved Science programme. Such TRS activities allow identifying at an early stage technology development needs as well as exploring future mission scenarios.
As part of this effort, the Gamma Ray Lens (GRL) mission, a future generation gamma-ray observatory, has been the subject of a preliminary internal investigation.
The present paper provides an overview of the science goals assumed for this study, the selection of the reference mission profile, together with a preliminary description of the spacecraft design. The reference payload is also described, as well as the list of technology development activities derived from the study.

Gamma-Ray Optics
Thursday, September 15, 10h50

## Fresnel lenses - why not?

Gerry Skinner
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Fresnel lenses offer the possibility of concentrating the flux of X-rays or gamma-rays flux falling on a geometric area of many square metres onto a focal point which need only be a millimetre or so in diameter (and can even be very much smaller). They can do so with an efficiency that can approach 100%, and yet they are easily fabricated and have no special alignment requirements. Fresnel lenses can offer diffraction-limited angular resolution, even in a doamin where that limit corresponds to less than a micro second of arc.
Given all these attributes, it is natural to ask why Fresnel gamma ray lenses are not already being used, or at least why there is not yet any mission that plans to use the technology. Possible reasons (apart from the obvious one that nobody thought of doing so) are the narrow bandwidth of simple Fresnel lenses, their very long focal length, and the problems of target finding. It will be argued that none of these is a 'show stopper' and that this technique should be seriously considered for nuclear astrophysics.

Gamma-Ray Optics
Thursday, September 15, 11h20

## X-ray Imaging Performance of a Phase Fresnel Lens

John Krizmanic
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Diffractive/refractive optics, such as Phase Fresnel Lenses (PFL's), offer the potential to achieve exquisite imaging performance in the x-ray and gamma-ray photon regimes. In principle, the angular resolution obtained with these devices can be diffraction limited. Furthermore, improvements in signal sensitivity can be achieved as virtually the entire flux incident on a lens can be concentrated onto a small detector area. In order to experimentally verfiy the imaging performance, we have fabricated PFL's in silicon using gray-scale lithography to produce the required Fresnel profile. These devices are to be evaluated in the recently constructed 600-meter x-ray interferometry testbed at NASA/GSFC. Results on the imaging performance measurements of these silicon PFL's will be presented.

Gamma-Ray Optics
Thursday, September 15, 15h30

## Multiwavelength Focusing with the Sun as Gravitational Lens

Laurent Koechlin
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We present investigations on using the space curvatures caused by the gravitational field of the sun as a means of focussing electromagnetic radiation.
The gravitation lens formed by the sun is by no means stigmatic, but it is achromatic. Its optical characteristics present a "caustic" line starting at 1200 astronomical units (UA) from the sun. A satellite or formation flying fleet moving away from the sun along or in the vicinity of this line would benefit from the microlensing effect. This would provide a powerful means of focussing radiation that cannot be focussed easily otherwise. The amplification factor could reach 10^9. The point spread function (PSF) of the sun as a lens is studied, taking into account the gravitational field deformations caused by the non symmetry of the mass distribution within and close to the sun, and by solar system bodies.
Once launched, missions of this type would be dedicated to a single field. Some possible targets are considered, such as Sagitarus A.

Gamma-Ray Optics
poster session

## InFOCuS hard X-ray imaging telescope

J. Tueller, H. A. Krimm, T. Okajima, S. D. Barthlemy, S. M. Owens, P. J. Serlemitsos, Y. Soong, K.-W. Chan, (NASA/GSFC), Y. Ogasaka, R. Shibata, K. Tamura, A. Furuzawa, H. Kunieda, K. Yamashita (Nagoya University)

InFOCuS is a new generation balloon-borne hard X-ray telescope with focusing optics and spectroscopy. We had a successful 22.5 hour flight from Fort Sumner, NM on September 16-17, 2004. In this paper, we present the performance of the hard X-ray telescope, which consists of a depth-graded platinum-carbon multilayer mirror (called a supermirror) and a CdZnTe detector. Supermirrors are coated on thin aluminum substrates 150 um as reflectors. The mirror is similar to the Astro-E/E2 XRT grazing incidence optics, but with a longer focal length of 8 m. It has an effective area of 49 $cm^2$ at 30 keV, an angular resolution of 2.6 arcmin (HPD), and a field of view of 10 arcmin. The CdZnTe detector is a pixellated solid-state device capable of imaging spectroscopy. The CdZnTe detector is configured with a 12x12 segmented array of detector pixels. The pixels are 2 mm square, and are placed on 2.1 mm centers. An averaged energy resolution is 4.4 keV at 60 keV and its standard deviation is 0.36 keV over 128 pixels. The detector is surrounded by a 3-cm thick CsI anti coincidence shield to reduce background from particles and photons not incident along the mirror focal direction. Owing to the active shield, 97.3% of the background was rejected as vetoed events. The observed background rate is $2.9 \times 10^{-4}$ cts/sec/$cm^2$/keV (20-50 keV). We achieved sensitivity as great as $5 \times 10^{-6}$ cts/sec/$cm^2$/keV with 8-hour observations (in 20-50 keV and three sigma detection) in this flight. We present detailed performance based on the ground calibration, background and sensitivity we achieved.

## 3. Focal plane instrumentation

Focal plane instrumentation
Thursday, September 15, 9h00

## High Sensitivity Si/CdTe Compton Camera for a gamma-ray lens

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In the soft gamma-ray band up to 1 MeV, a narrow field-of-view Compton gamma-ray telescope utilizing several tens of layers of thin Si or CdTe detector will provide precise spectra with much higher sensitivity than present instruments. Based on our recent achievements of high resolution Si strip detectors and CdTe pixel detectors, we have succeeded to demonstrate Si/CdTe Compton camera. In addition to the imaging and spectroscopic observation, we have succeeded to measure polarization by using phi distribution of scattered photon. Here we will present the concepts of a narrow-FOV Compton telescope based on the results from our prototype. A proposal of a focal plane detector for a gamma-ray lens will also be presented.

Focal plane instrumentation
Thursday, September 15, 9h30

# Polarisation measurements with CdTe pixel array detector for Laue hard X-ray focusing telescopes

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Polarimetry is an area of high energy astrophysics which is still relatively unexplored, even though it is recognized that this type of measurement could drastically increase our knowledge of the physics and geometry of high energy sources. For this reason, in the context of the design of a Gamma-Ray Imager based on new hard-X and soft gamma ray focusing optics for the next ESA Cosmic Vision call for proposals (Cosmic Vision 2015-2025), it is important that this capability should be implemented in the principal on-board instrumentation. For the particular case of the wide bandpass Laue optics we propose a focal plane based on a thick pixelated CdTe matrix detector operating with high efficiency between 60-600 keV. The high segmentation of this type of detector (0.5-1 mm pixel size) and the good energy resolution (a few keV at 500 keV) will allow high sensitivity polarisation measurements (a few % for a 10 mCrab source in 105s) to be performed. We have evaluated the modulation Q factors and minimum detectable polarisation through the use of Monte Carlo simulations (based on the GEANT 4 toolkit) for on-axis sources with power low emission spectra using the analytical response parameters of the Laue lens. An evaluation of possible background reduction using Compton kinematics will also be presented.

Focal plane instrumentation
Thursday, September 15, 9h50

## Solid state CZT detectors for Gamma Ray Telescope Application

Egidio Quadrini
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The success of the IBIS Imager detector arrays on board the ESA Gamma-ray mission INTEGRAL has encouraged the high energy community to continue a robust R&D program. This activity is a mandatory work to be ready for the next Announcement of Opportunity to propose a new generation Space-born Gamma Ray focusing instrument. Such an instrument, in view of the high energy focusing feature and large sensitive area will be naturally designed with room temperature CZT/CdTe detectors. The Scientific Requirement foresee an energy range in the ~5-600 keV span, good sensitivity (1mCrab in a day observation), energy resolution of ~ 1% at 100keV and unprecedented spatial (arcmin to arcsec) and timing resolution.
CZT detectors have good linearity versus temperature or bias, can be arranged in compact matrix and operate well at room temperature. The desired performances can be achieved trough a great care in the crystal production and with the help of an enhanced readout system. This is based on a flash ADC coupled to a signal form elaboration unit. The use of powerful FPGA devices will allow to get round the amplitude uncertainty due to the photon interaction deep, to remove unwanted signals (adronic tracks, random coincidences) and to permit multiple events reconstructions and signal polarisation analysis. Finally, due to the possibility to select the pixel dimension in a wide range, e.g. from <0.1 mm up to > 1 cm, this detector has the flexibility to be profitably used in large area arrays, up to several squared meter, as well as in the focal plane of high energy optics.

Focal plane instrumentation
Thursday, September 15, 10h10

## New scintillators for focal plane detectors in gamma-ray missions

Ernst-Jan Buis
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Recent developments of cerium doped Lanthanum halide scintillators like LaBr3:Ce show a remarkable performance in gamma-ray spectroscopy. When high energy resolution in combination with stopping power is required they provide excellent gamma-ray detector candidates for the use in space missions. Moreover, irradiation tests have shown that such detectors, in contrast to commonly used spectrometers like germanium, are radiation tolerant. In this paper we show results on recent proton irradiation test at KVI in Groningen (NL) and discuss the damage and activation effects after irradiation. We have studied the possible applications of LaBr in nuclear astrophysics missions. We therefore have simulated the expected signal on the focal plane and convolved it with the measured instrument response. Finally we discuss a possible design for such a focal plane detector.

Focal plane instrumentation
Thursday, September 15, 14h30

## Performance of the Nuclear Compton Telescope

Cornelia Wunderer and Steve Boggs
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NCT is a balloon-borne Compton telescope designed to study source of nuclear line emission and compact object polarization in the soft gamma-ray band (0.2-10 MeV). The heart of NCT is an array of 3-D positioning germanium detectors, which maintain the high spectral resolution of non-imaging germanium detectors. NCT underwent a prototype flight on June 1, 2005. We will discuss the goals of this flight, and preliminary results from the ground calibrations and flight.

Focal plane instrumentation
Thursday, September 15, 14h50

## Monte Carlo Study of Detector Concepts for the MAX Laue Lens Gamma-Ray Telescope

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MAX is a proposed gamma-ray telescope consisting of a Laue lens that focuses incident photons onto a distant detector. The lens and the detector are carried by two separate satellites flying in formation. Significant effort is being devoted to studying different types of crystals that may be suitable for focusing gamma rays in two energy bands centered on two lines which constitute the prime astrophysical interest of the MAX mission: the 511 keV positron annihilation line, and the 847 keV line from the decay of 56Co copiously produced in Type Ia supernovae. However, to optimize the performance of MAX, it is also necessary to optimize the detector used to collect the source photons concentrated by the lens. We address this need by applying proven Monte Carlo and event reconstruction packages to predict the performance of MAX for three different Ge detector concepts: a standard co-axial detector, a segemented Ge detector, and a Compton camera consisting of a stack of strip detectors. Each of these exhibits distinct advantages and disadvantages regarding fundamental performance characteristics such as detection efficiency or background rejection, which ultimately determine achievable sensitivities.

Focal plane instrumentation
Thursday, September 15, 15h10

## Simulated Performance of dedicated Ge Strip Compton Telescopes as gamma-Lens Focal Plane Instrumentation

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With focusing of gamma-rays in the nuclear-line energy regime starting to establish itself as a feasible and very promising approach for high- sensitivity gamma-ray (line) studies of individual sources, optimizing the focal plane instrumentation for gamma-ray lens telescopes is a prime concern. Germanium detectors offer the best energy resolution available at ~2 keV FWHM and thus constitute the detector of choice for a spectroscopy mission in the MeV energy range. Using a Compton detector focal plane has three advantages over monolithic detectors: additional knowledge about (Compton) events enhances background rejection capabilities, the inherently finely pixellated detector naturally allows the selection of events according to the focal spot size and position, and Compton detectors are inherently sensitive to gamma-ray polarization. We will use the extensive simulation and analysis package used for the ACT Vision mission study to explore achievable sensitivities for different Ge Compton focal plane configurations as a first step towards determining an optimum configuration.

Focal plane instrumentation
poster session

## The MEGA detector as focal plane instrument

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We describe the development and calibration of a prototype for a new telescope in Medium Energy Gamma-ray Astronomy (MEGA).
As a successor to COMPTEL and EGRET (at low energies), MEGA aims to improve the sensitivity for astronomical sources by at least an order of magnitude over the energy range 0.4-50 MeV. MEGA could thus fill the severe sensitivity gap between scheduled or operating hard-X-ray and high-energy gamma-ray missions and act as a pathfinder mission for future Advanced Compton Telescopes or Imaging
Instruments with smaller fields of view. MEGA records and images gamma-rays by completely tracking Compton and Pair creation events in a stack of double sided Si-strip track detectors surrounded by a pixelated CsI calorimeter. The experimental highlights of this concept are a wide field of view with uniform sensitivity and potentially a controlled and reduced instrumental background.
High priorities among the scientific goals for a MEGA type mission are measurements of polarization below 5 MeV (targets: GRBs, pulsars, blazars), spectral features (bends, absorption lines) in the MeV-10s of MeV band, and compilation of a much deeper survey and continuous monitoring of often highly variable sources in this energy range.

# 4. Ground facilities and Flight systems for focusing telescopes

Gamma WAVE
FOCUSING TELESCOPES IN NUCLEAR ASTROPHYSICS
September 12 - 15, 2005
Espace St. Jacques, Bonifacio, Corsica

Ground facilities and Flight systems for focusing telescopes
Wednesday, September 14, 11h50

# Small-sat Platforms and Formation Flying : an opportunity for the gamma ray telescope MAX

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This paper presents the results of a study performed by EADS Astrium in support to the Centre d'Etude Spatiale des Rayonnements (CESR, Toulouse, France) for the preliminary definition of the MAX space segment, based on a small-sat platform in the 200 kg range.
MAX is a new concept of gamma ray telescope with as prime objective the study of type Ia supernovae by measuring intensities, shifts and shapes of their nuclear gamma-ray lines. When finally understood and calibrated, these profoundly radioactive events will be crucial in measuring the size, shape, and age of the Universe.
The concept of MAX is radically different from the traditional gamma ray telescopes: gamma rays are focussed from the large collecting area of a crystal diffraction lens on a very small detector volume. Thus, the implementation of the MAX space mission consists in flying a lens-detector duo satellites in an active Formation Flying geometry. The lens satellite is kept inertial and pointing to the gamma ray source with an accuracy of 15 arcsec, while the detector satellite is controlled in position and attitude with respect to the lens at a constant distance of 86 m, within an accuracy of 1 cm in lateral and 10 cm in longitudinal.
This paper discusses the various complex technical challenges of the MAX mission: GNC (Guidance Navigation Control) algorithms for the deployment, initialisation and control of the lens-detector geometry, accurate pointing of the lens to the gamma ray sources, definition and accommodation of the optical metrology, mechanical and thermal accommodation of the 8200-crystal lens, fine attitude/position actuators sizing, FDIR (Failure Detection Isolation and Recovery) and collision avoidance algorithms.
This paper depicts a baseline mission derived from these analyses and provides a preliminary definition of the space segment, with an emphasis on the command / control architecture of the formation, including the distributed on-board data management, the formation-to-ground interface and the inter-satellites communication. The paper then describes the GNC, metrology and propulsion systems required to fulfill the requirements of the MAX mission with margins.
Beyond its scientific interest for nuclear astrophysics, MAX is a good opportunity for demonstrating Formation Flying concepts and technologies in space.

Ground facilities and Flight systems for focusing telescopes
Wednesday, September 14, 12h10

# Distributed space segment architectures for high energy astrophysic: Similarities and specificities

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Pilot studies have been carried out in CNES for X and Gamma energy band missions. These missions are based on distributed space segment architecture utilizing formation flying technics. Some similarities are identified which could be re used for other missions of the same type. On the other hand, these kinds of missions allow to embark new type of instruments as large specific lens or mirror for instance. Their stability is a challenge which is specific to each mission.

Ground facilities and Flight systems for focusing telescopes
Wednesday, September 14, 12h30

## SIMBOL-X a hard-X ray Formation Flying

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SIMBOL-X is a part of a more general CNES (PASO*) study entitled "Formation Flying for Astrophysics" (AMPS : ASPICS, MAX, PEGASE & SIMBOL-X) . The main objective is to demonstrate the feasibility of this new hard-X ray formation flying mission . Description of the space segment corresponding to this scientific mission.

Ground facilities and Flight systems for focusing telescopes
Wednesday, September 14, 12h50

## MAX Formation Flying for nuclear astrophysics

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MAX is a part of a more general CNES study entitled "Formation Flying for Astrophysics" (AMPS : ASPICS, MAX, PEGASE & SIMBOL-X). The main objective is to demonstrate the feasibility of this Nuclear Astrophysics mission with an important innovation ("Laue Lens" + FF). Description of the space segment corresponding to this scientific mission.

Gamma WAVE
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Ground facilities and Flight systems for focusing telescopes
Wednesday, September 14, 13h10

# Recent Advances and Low cost concept for the Gamma-Ray Lens Project MAX

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A first outline of the MAX project (gamma-ray lens for nuclear astrophysics) has been elaborated by Alcatel Alenia Space in the frame of Formation Flying missions for the French national programs of CNES . This preliminary concept had demonstrated that such ambitious configurations enabling low signal/noise ratio as well as high angular and energy resolution were feasible and offered promising perspectives for future instrumentation.
Recent developments and achievements in Formation Flying mission components have brought confirmation that the expected performances would be achieved with reasonable developments .Following a brief overview of the MAX concept from Alcatel Alenia Space, this paper will describe the major recent steps that give confidence in the MAX project feasibility and will highlight the key areas, at satellite and instrument levels, that would deserve short term efforts to secure the MAX programme .

Gamma WAVE
FOCUSING TELESCOPES IN NUCLEAR ASTROPHYSICS
September 12 - 15, 2005
Espace St. Jacques, Bonifacio, Corsica

Ground facilities and Flight systems for focusing telescopes
Thursday, September 15, 11h50

# Calibration of hard X-ray (15 50 keV) optics at the MPE test facility PANTER

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The Max-Planck-Institut fr extraterrestrische Physik (MPE) in Garching, Germany, operates the large X-ray beam line facility PANTER for testing astronomical systems. At PANTER a number of telescopes like EXOSAT, ROSAT, SAX, JETX, ABRIXAS, XMM and SWIFT operating in the soft energy range (0.02 15 keV) have been successfully calibrated. In the present paper we report on an important upgrade recently implemented that enables the calibration of hard X-ray optics (from 15 up to 50 keV). Currently hard X-ray optics based on single and multilayer coating are being developed for several future X-ray missions. The hard X-ray calibrations at PANTER are carried out by a high energy source based on an electron gun and several anodes, able to cover the energy range from 4.5 up to 50 keV. It provides fluxes up to 104 counts/sec/cm2 at the instrument chamber with a stability better than 1 %. As detector a pn-CCD camera operating between 0.2 and 50 keV and a collecting area of 36 cm2 is used. Taking into account the high energy resolution of the CCD (145 eV at 6 keV), a very easy way to operate the facility in hard X-ray is in energy-dispersive mode (i.e. with a broad-band beam). A double crystal monochromator is also available providing energies up to 20 keV.
In this paper we present a number of results obtained by using PANTER for hard X-ray calibrations, performed on prototype multilayer optics developed by the INAF-Osservatorio Astronomico di Brera (OAB), Milano, Italy, in collaboration with the Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA, USA. The extension to energies even larger than 50 keV, and the discussion of the problematic and possible solutions for the calibration of very long focal length optics (like e.g. for the Simbol-X mission) will be also discussed.

Ground facilities and Flight systems for focusing telescopes
Thursday, September 15, 12h10

## A hard X-ray facility for testing/calibrating hard X-ray focusing telescopes

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We will report on the equipment and performance of the X-ray facility of the University of Ferrara. Initially developed to test the PDS (Phoswich Detection System) instrument aboard the BeppoSAX satellite and to perform reflectivity measurements of mosaic crystal samples of HOPG (Highly Oriented Pyrolytic Graphite), with time the facility has been improved and its applications extended. Now these applications include test and calibration of hard X-ray (10 keV) detectors, reflectivity measurements of hard X-ray mirrors, reflectivity tests of crystals and X-ray transparency measurements. The facility is being further improved in order to determine the optical axis mosaic crystals in Laue configuration within a project devoted to develop a hard X--ray focusing optics.

## CLAIRE gondola and successors

Jean Evrard and André Laurens
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On June 14th 2001, the Crab Nebula would be in conjunction with the Sun. This astronomical configuration has been made profitable to achieve the demonstration flight, on a balloon borne gondola, of the first gamma-ray lens for astronomy.

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