

INTEGRAL et les pulsars

Christian Gouiffès

En collaboration avec Philippe Laurent
et avec le concours de François Lebrun et Michael Forot

(Service d'Astrophysique CEA-Saclay)

**Simultaneous γ -ray/radio observations of
giant radio pulses from the Crab Pulsar**

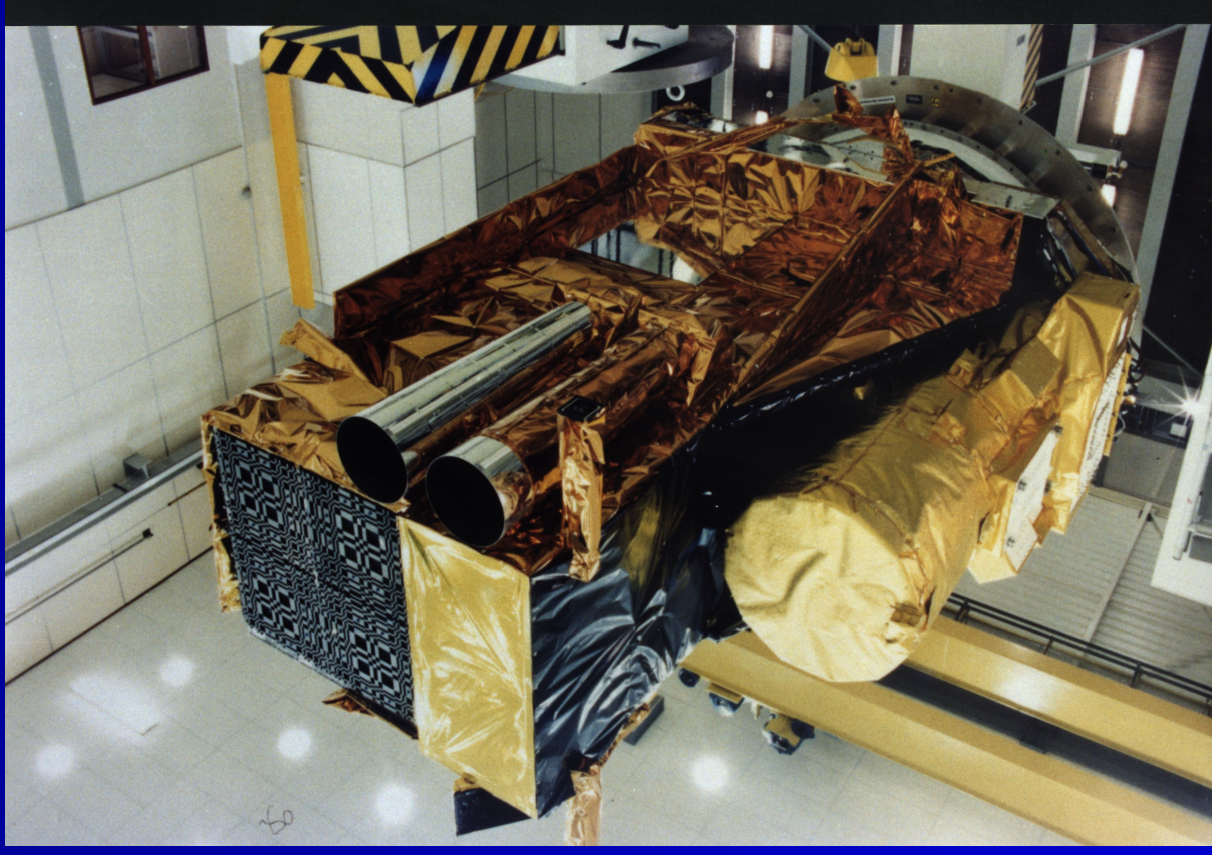
Aaron Golden

(National University of Ireland, Galway)

Atelier " pulsars, théories et observations " , 16 et 17 janvier 2006, IAP, Paris

La mission INTEGRAL

- Mission moyenne de l'ESA
- Collaboration ESA-RKA-NASA
 - ESA: satellite (copie XMM-Newton)
 - RKA: lancement (fusée PROTON)
 - NASA: station écoute (Goldstone)
- Instruments:
 - IBIS: Italie-France
 - SPI: France-Allemagne
 - JEM-X: Danemark
 - OMC: Espagne
- Mis en orbite en Octobre 2002 depuis Baïkonour
- Mission type observatoire (temps ouvert: 75%)
- Appels d'offre annuels
- Logiciels de traitement et données distribuées par l'ISDC (INTEGRAL Science data Centre)
- Mission prévue pour 3-5 ans, extension jusqu'en 2008 acceptée (décision novembre 2005), nouvelle revue en 2007 (avis favorable jusqu'en 2010-2012?)



L'observatoire INTEGRAL

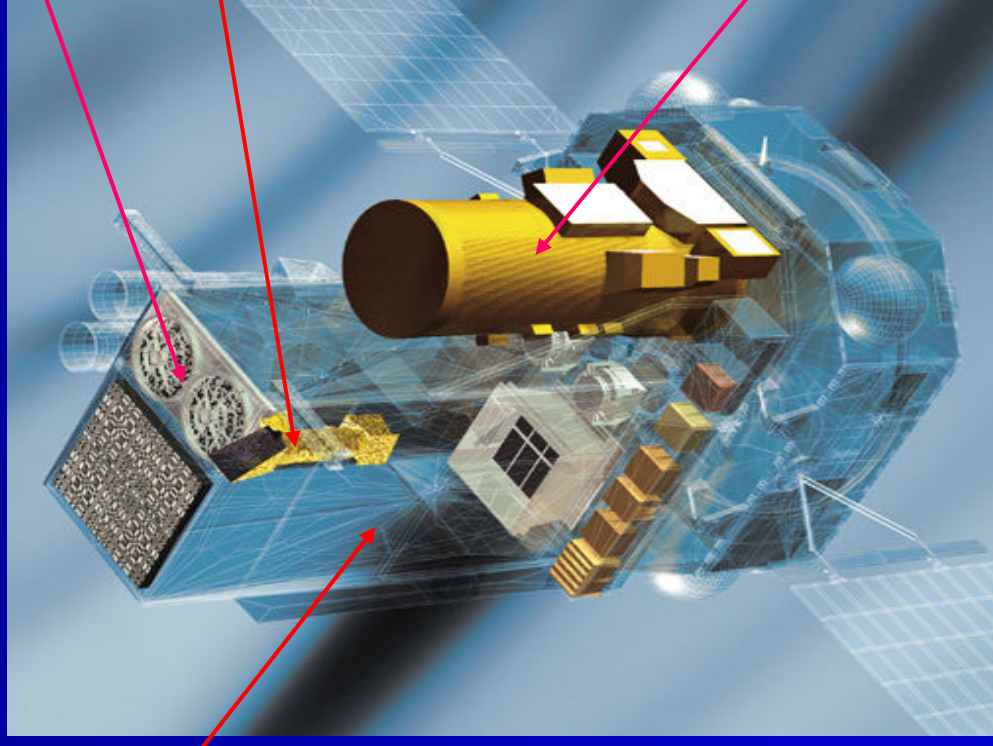
L'imageur IBIS

(15 keV - 10 MeV)

2 plans de détections

ISGRI : 15 keV – 1 MeV

PICsIT: 170 keV - 10 MeV



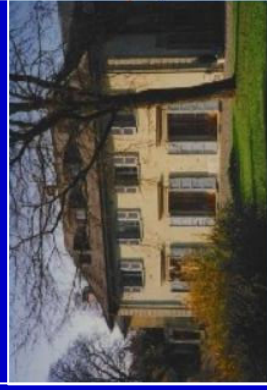
2 détecteurs JEM-X

Caméra optique

Le spectromètre SPI (20 keV – 8 MeV)

- $\Delta E/E$ (FWHM): ~ 2 keV
- Sensibilité: 3 milliCrabe
- Champ: 24° (diamètre)
- Résolution: 2.6°

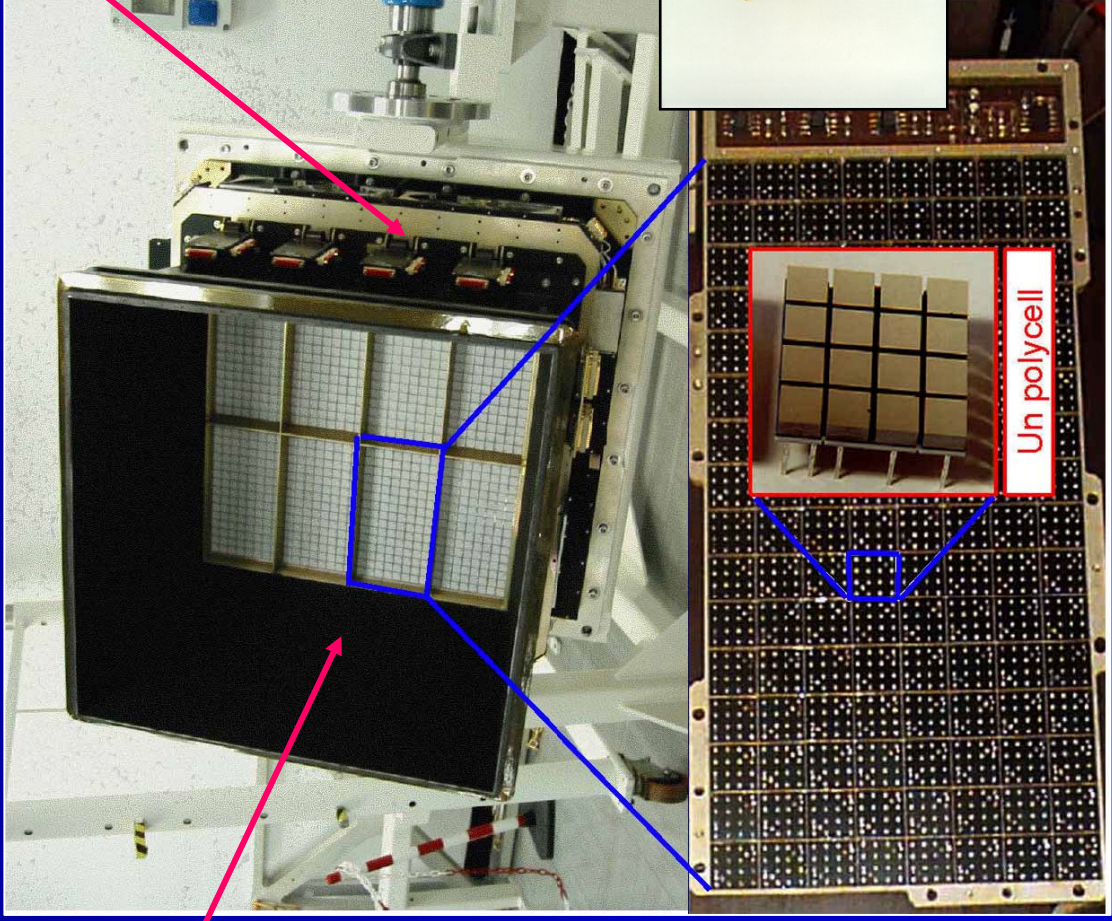
+ ISDC



L'imageur IBIS

PICsIT:

- Caméra CsI
- 170 keV-10 MeV



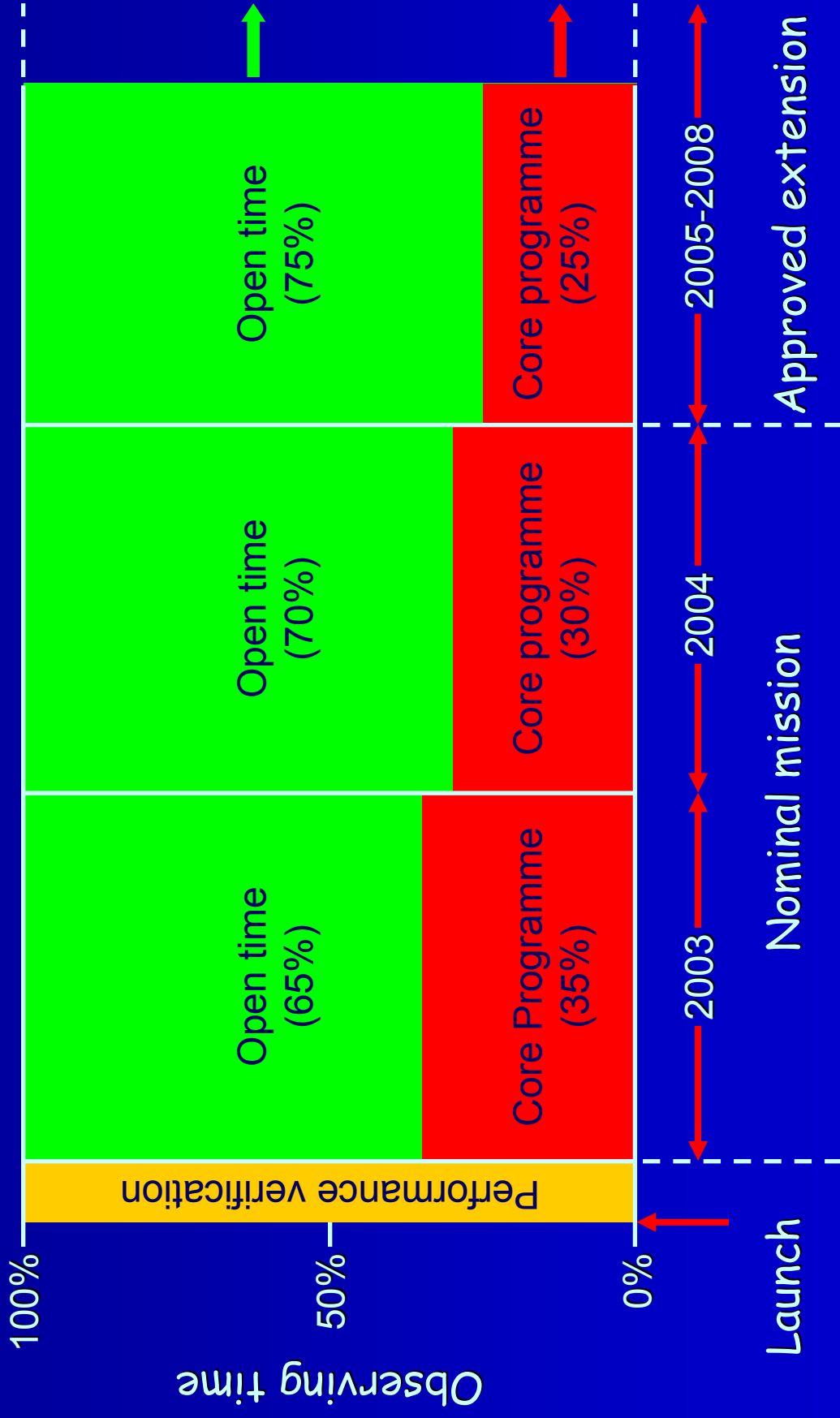
La caméra ISGRI:

- CdTe (16384 pixels)
- 15 keV – 1 MeV
- Champ de vue : $19^\circ \times 19^\circ$
- Résolution : 12'
- précision de localisation 1'
- $\Delta E/E$ (FWHM) : $\sim 5-10\%$
- Sensibilité : 1 milliCrabe

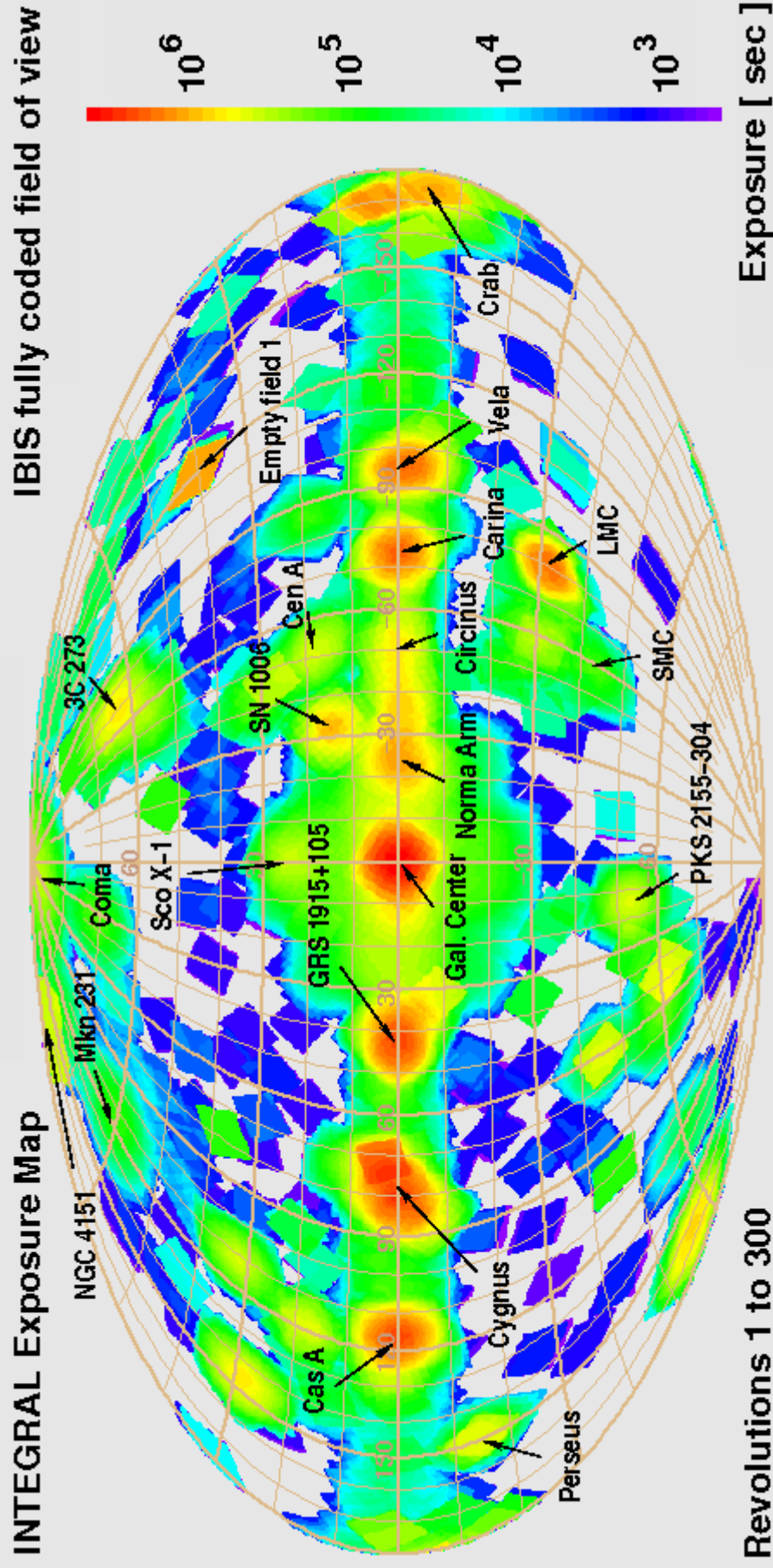
ISGRI (INTEGRAL Soft Gamma-Ray Imager)

- Spectro-imageur à base de semiconducteurs non refroidis
- 1^{ère} mondiale
- Détecteur: Tellure de cadmium (CdTe) 4 x 4 x 2 mm
- 16384 voies indépendantes de mesure spectrométrique
- Mesure de la hauteur et du temps de montée de l'impulsion (→ correction des pertes de charge)
- Fond interne très faible
- Réglage automatique des seuils de chaque pixel avant chaque observation
- Surveillance continue du bruit des détecteurs
- Défauts d'uniformité <1% (garanti par la géométrie des détecteurs)
- 6 ans de développement

Milestones of the observing programme

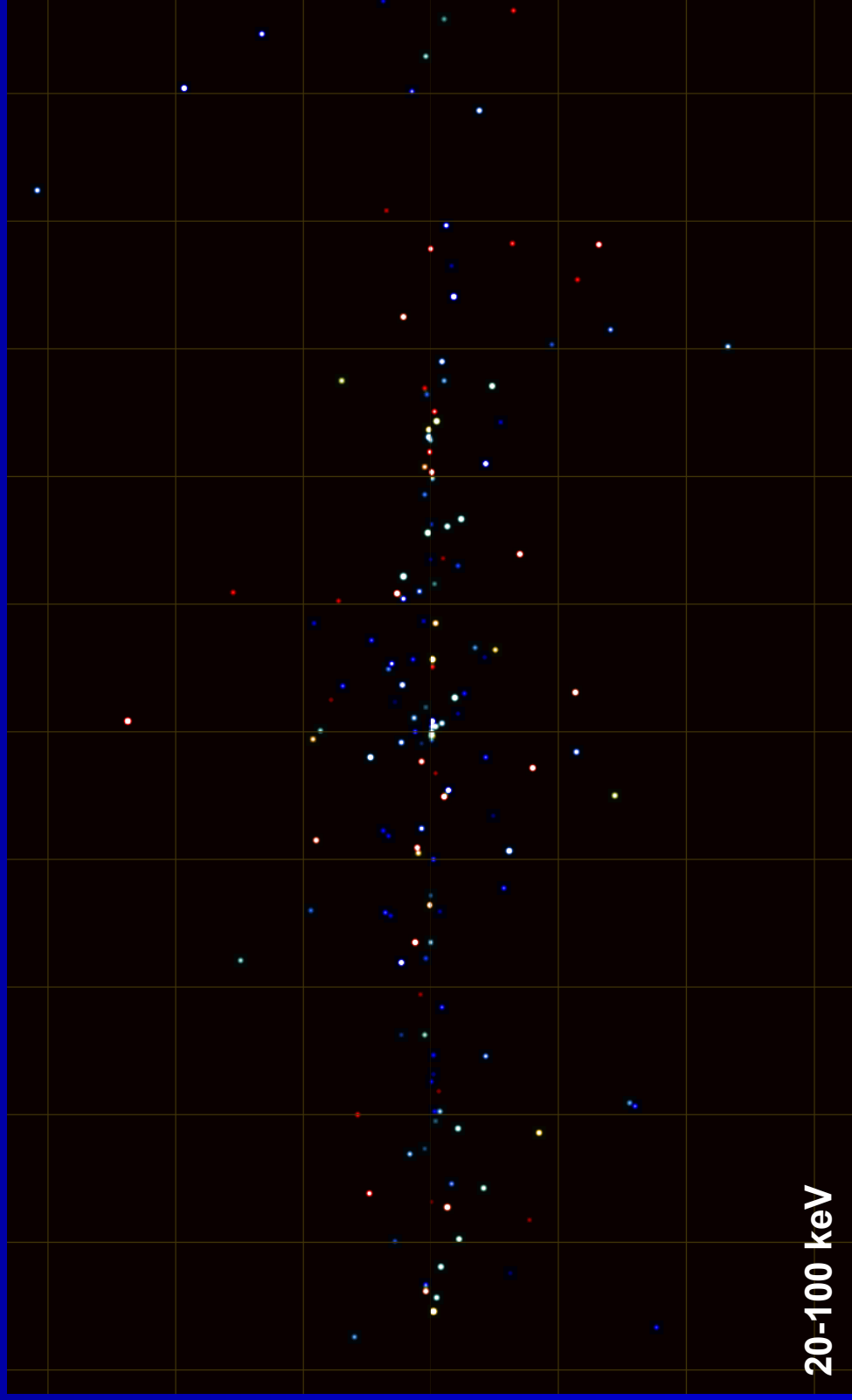


Carte d'exposition du télescope IBIS jusqu'à la révolution 300 (mars 2005)



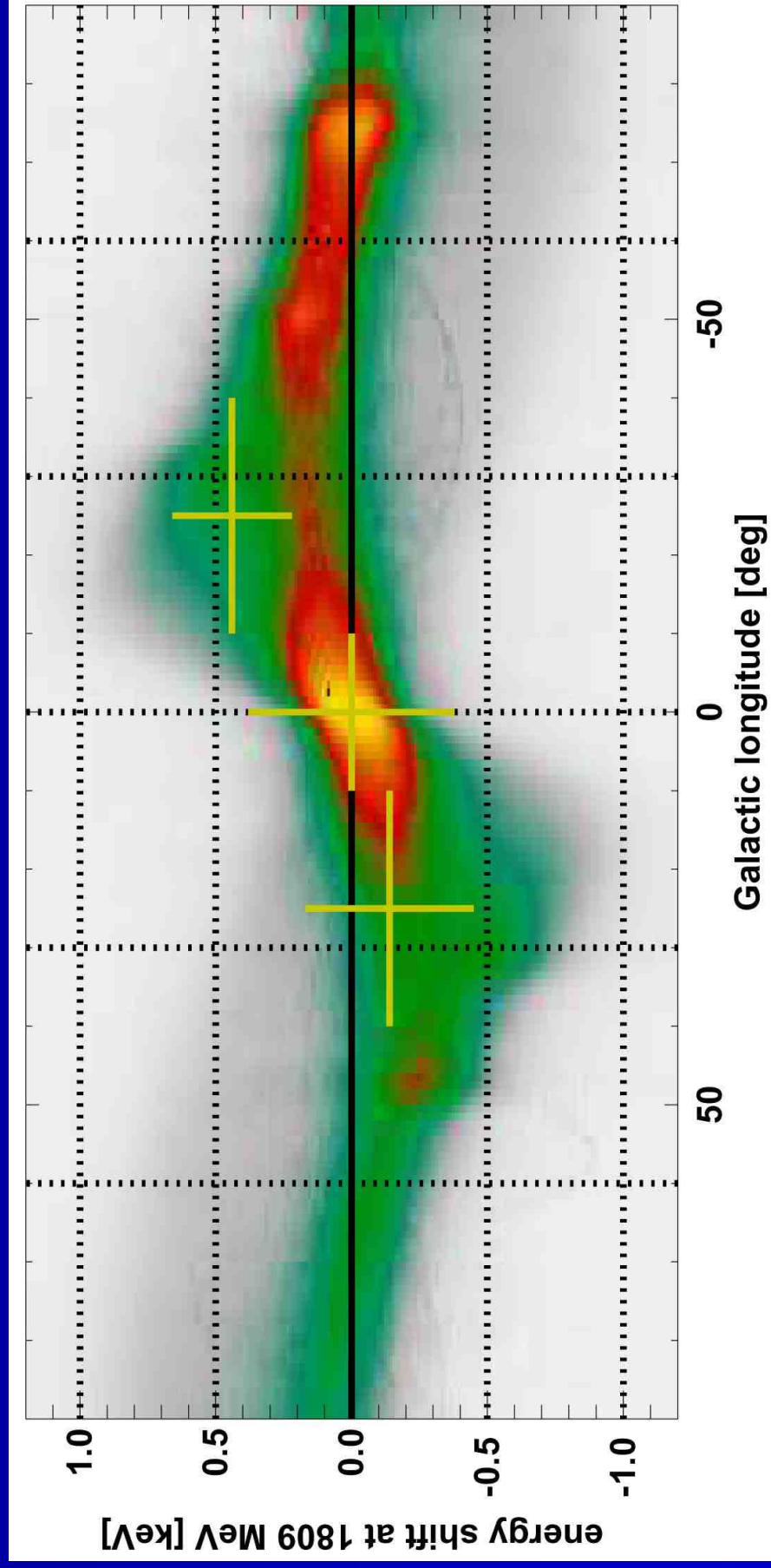
Les régions centrales de la Voie lactée vue par IBIS/ISGRI

- résolution du fond diffus gamma à basse énergie: > 90% de l'émission est due à des sources ponctuelles (Lebrun et al, 2004)
- catalogue de sources: découverte de nouvelles populations de sources (Bird et al, 2005)



Carte de l' ^{26}Al dans les régions centrales de la Galaxie vue par SPI

- Confirmation de la production de ^{26}Al dans les étoiles massives et les supernovae
 - estimation du taux de supernovae dans la Galaxie
- (Diel et al, 2006)



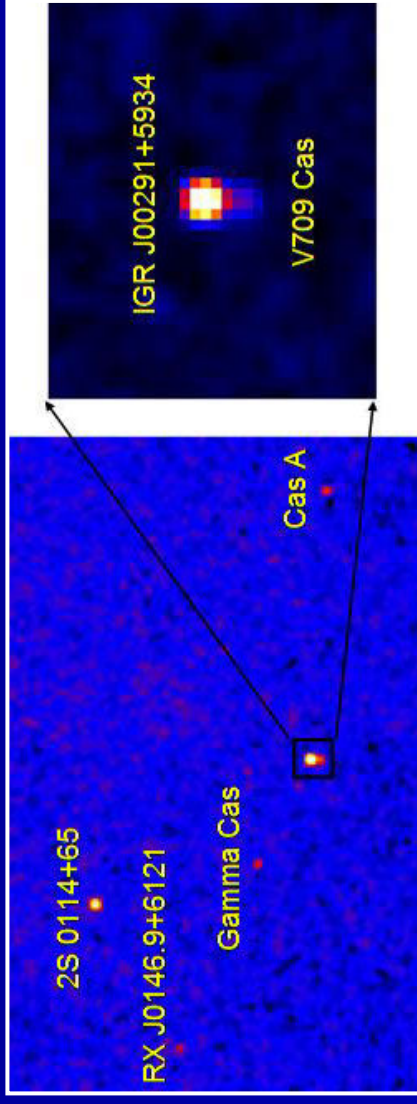
Analyse temporelle avec INTEGRAL

- résolution temporelle de ~ 100 microsecondes pour chaque instrument
- non spécifiée par des contraintes électroniques et/ou de télémétrie (pas de pression de la communauté scientifique pour obtenir une meilleure résolution temporelle)
- enseignement pour les futures missions → voir présentation de Philippe Laurent (projet Simbol-X)

IGR J00291+5934 : un cas d'école pour INTEGRAL

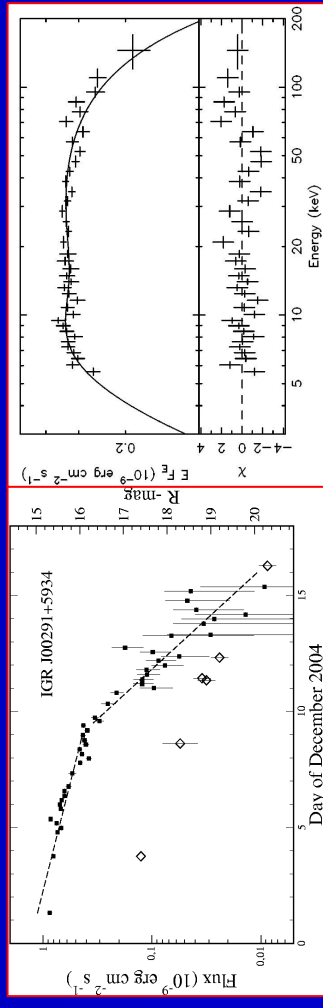
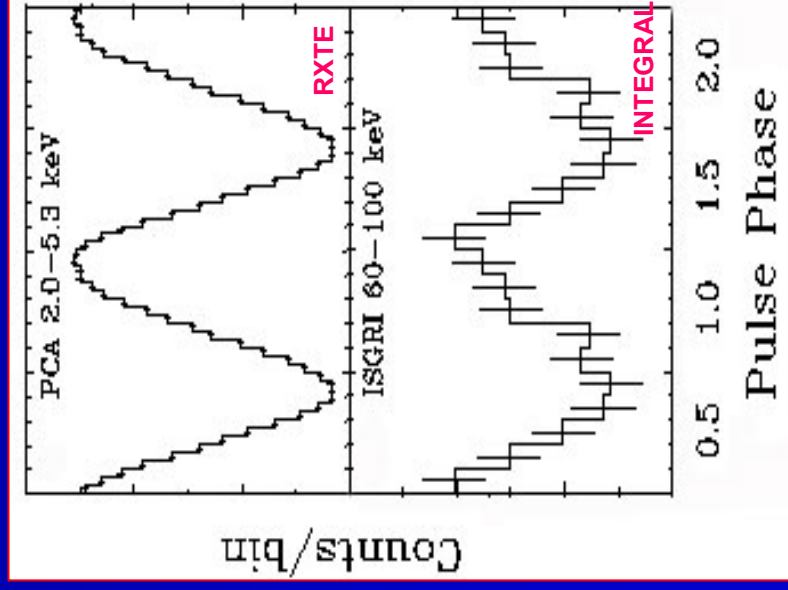
$P_{rot} = 1,6 \text{ msec}$, $P_{orb} = 2,5 \text{ h}$

Grand champ de vue
+ résolution angulaire



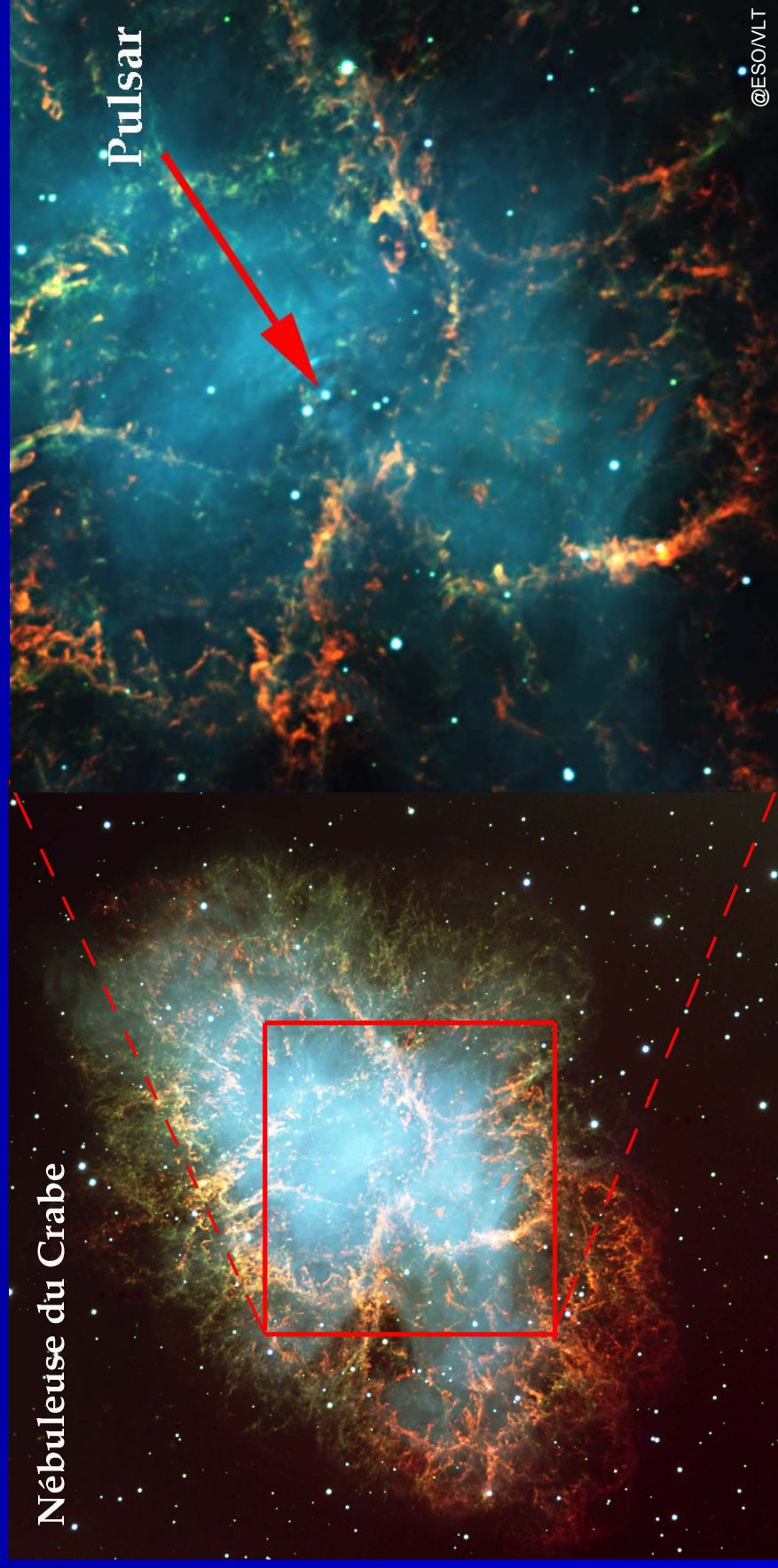
Résolution temporelle

Spectroscopie



La nébuleuse et le pulsar du Crabe

La source de référence pour l'analyse temporelle



Exposition 1965-2005 40 ans d'Astrophysique Spatiale au CEA

2005

1995

1989

2002

1999

1990

1975

1979

1972

1965

Du lundi 16 janvier
au jeudi 2 février 2006
à EL3 (Bâtiment 607 G)

Ouverture :
12 h 00 à 14 h 00

Des visites guidées par
des chercheurs du SAp
sont organisées :

Jeu*di* 19 et 26 Janvier
et Jeu*di* 2 février
de 13 h 00 à 14 h 00
Mardi 24 et 31 Janvier
de 12 h 00 à 13 h 00

Projection quotidienne du documentaire
(«L'astrophysicien, le ciel et la Cordillère»
(45 minutes)
tourné au Chili pendant la campagne
d'observation de Juin 2004,
réalisé par
Jean-Louis Berdot.

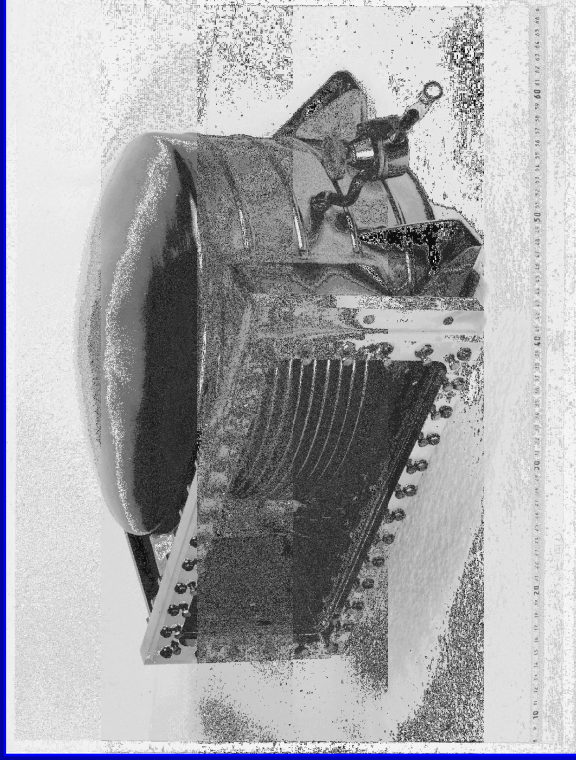


Manifestation organisée par le service d'astrophysique de Daphnia et l'unité Communication et affaires publiques Centre CEA de Saclay

Un peu d'histoire !

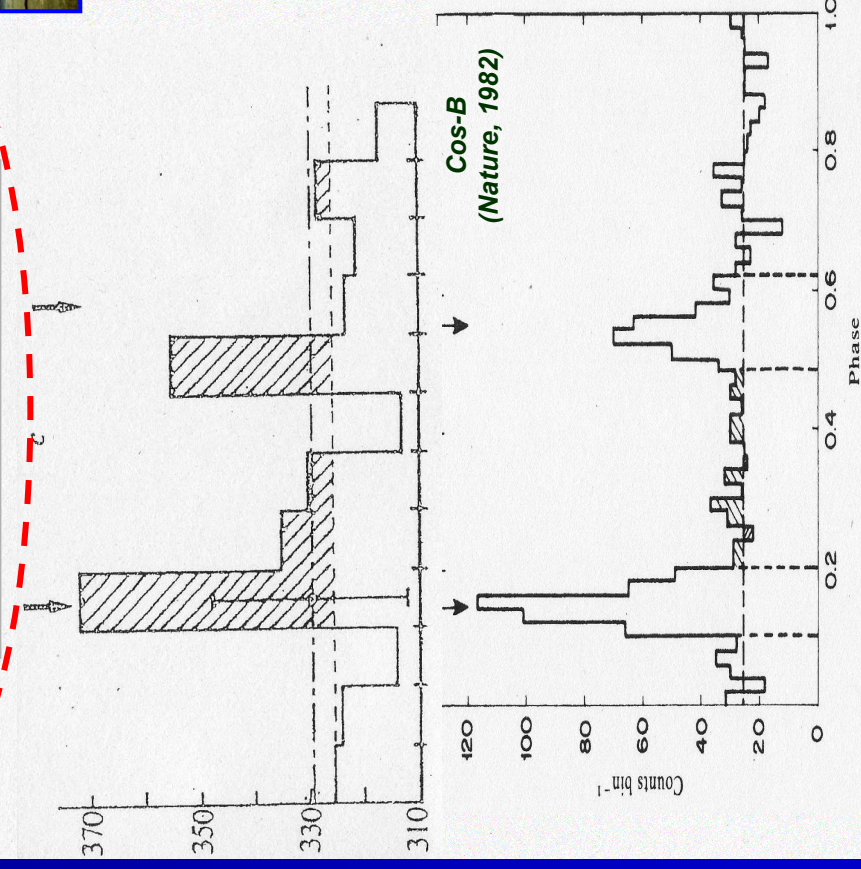
Observation de NP 0532 $E_\gamma > 20$ MeV

La chambre à étincelles

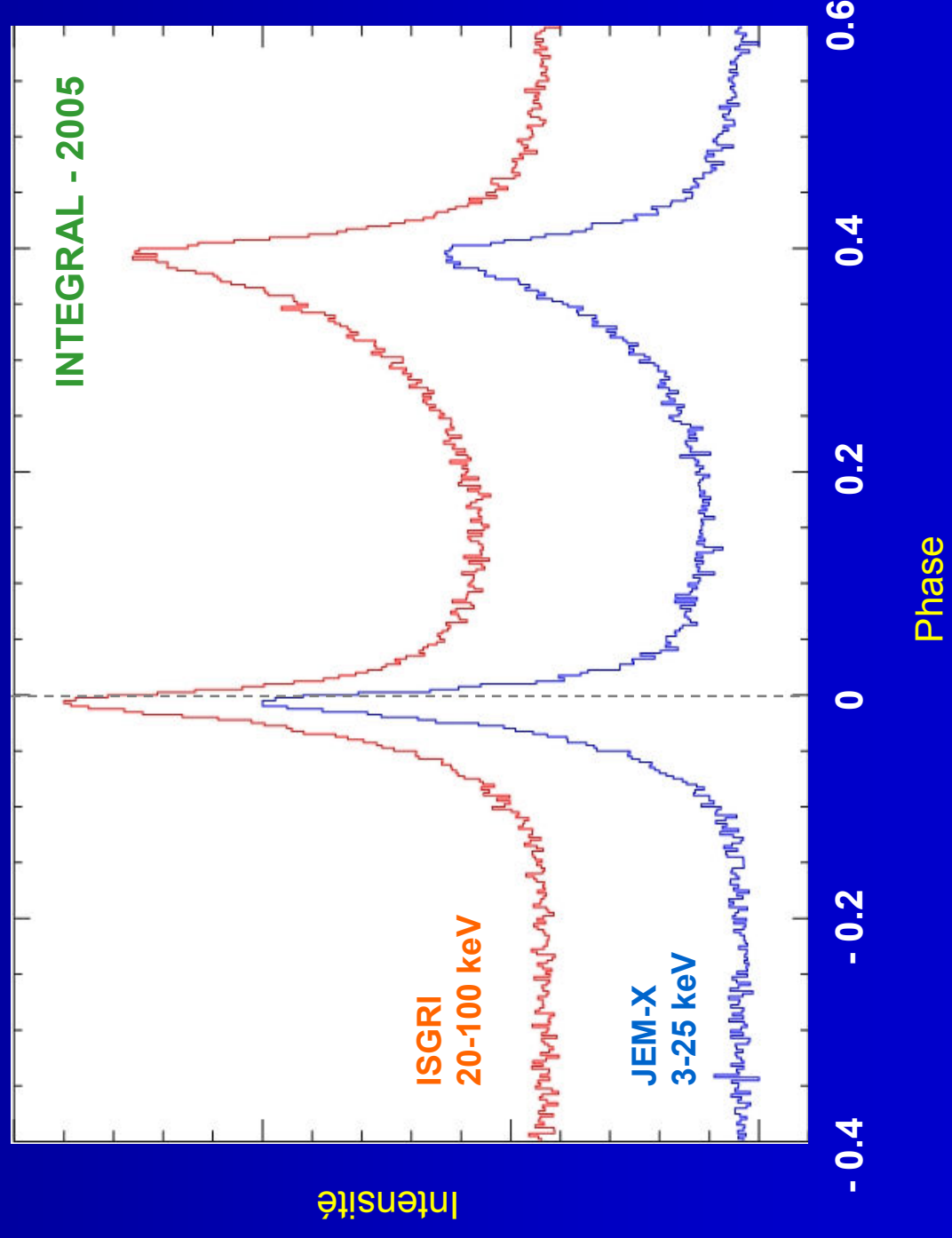


La signature d'un photon gamma

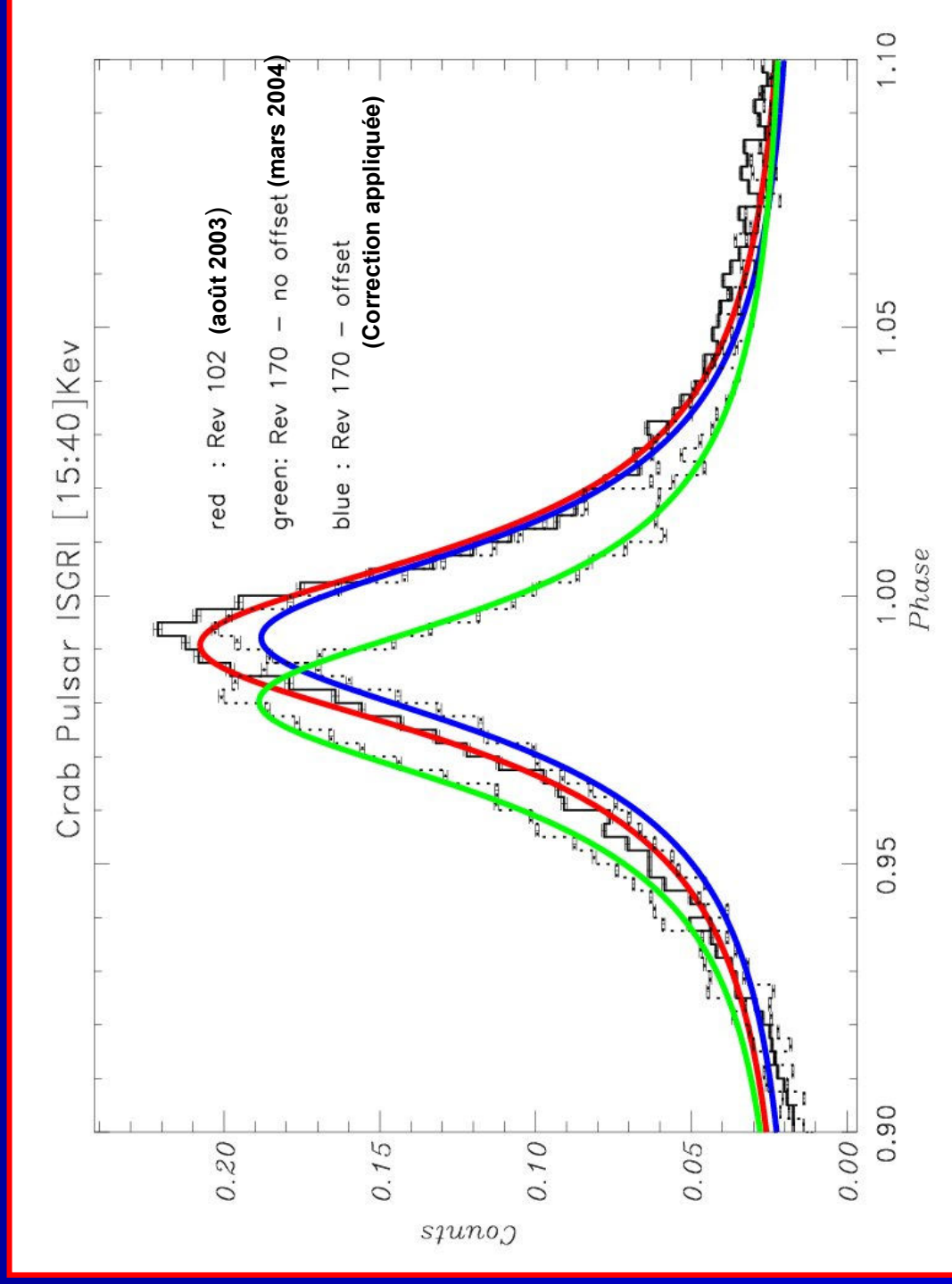
1973, Nature, 242, 117
Gamma-ray Emission above 20 MeV
from the Crab Nebula and NP 0532



La courbe de lumière du Crabe



Une petite recommandation : Vérifier le marquage en temps de l'instrument avant de développer une nouvelle théorie sur l'émission des pulsars !

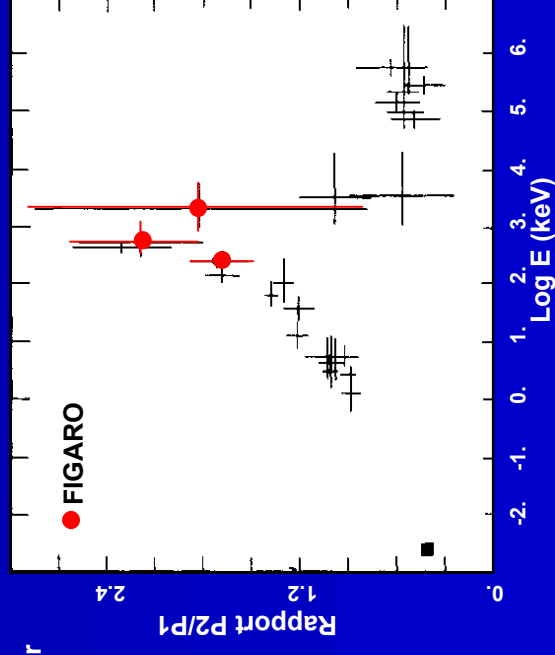
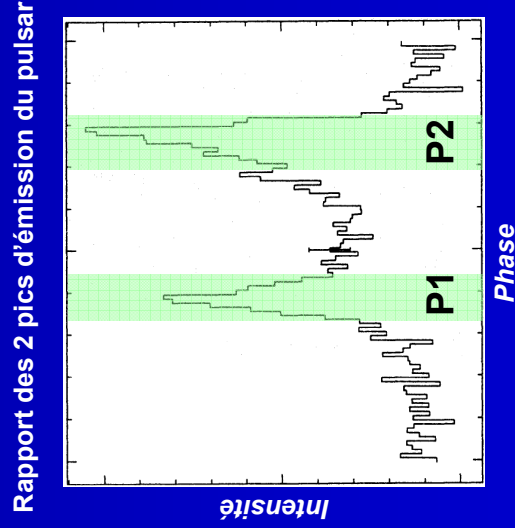
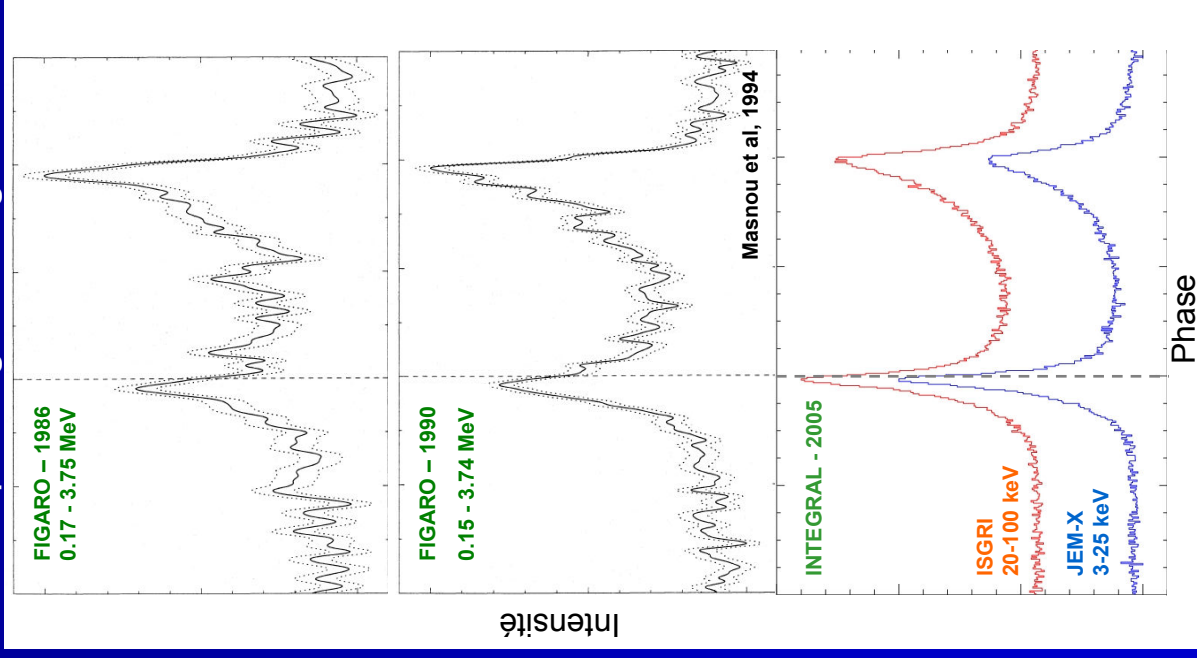


Erreur lors d'une mise à jour d'un logiciel : ligne de code malencontreusement commentée!

F.I.G.A.R.O. (French and Italian Gamma-Ray Observatory)

Déphasage radio-gamma

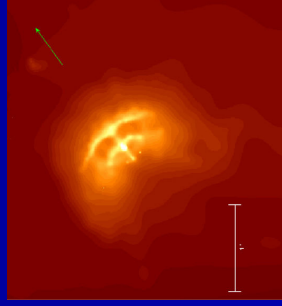
Bernard Agrinier, Forum Sap, 2 décembre 2005



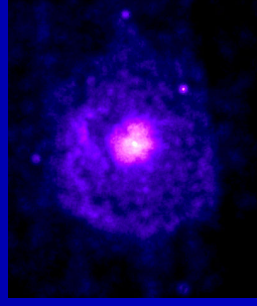
IBIS Compton mode
(200-500 keV)



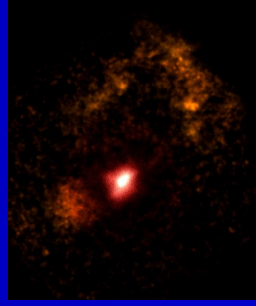
Travaux en cours



Recherche de PSR 0833-45



Recherche du pulsar PSR J1833-1034 dans
SNR G21.5-0.9, période = 61.8 msec



Recherche PSR0540-69 dans le Grand
Nuage de Magellan, P=50msec

Sur vos tablettes : prochain appel d'offre

- Release of AO-4: **13 March 2006**
- Due date for Proposals: **21 April 2006**

(informations sur <http://integral.esac.esa.int/>)

Simultaneous γ -ray/radio observations of giant radio pulses from the Crab Pulsar

Aaron Golden, Andy Shearer, Padraig O'Connor

(National University of Ireland, Galway)



avec le concours de Christian Gouiffès et Philippe Laurent

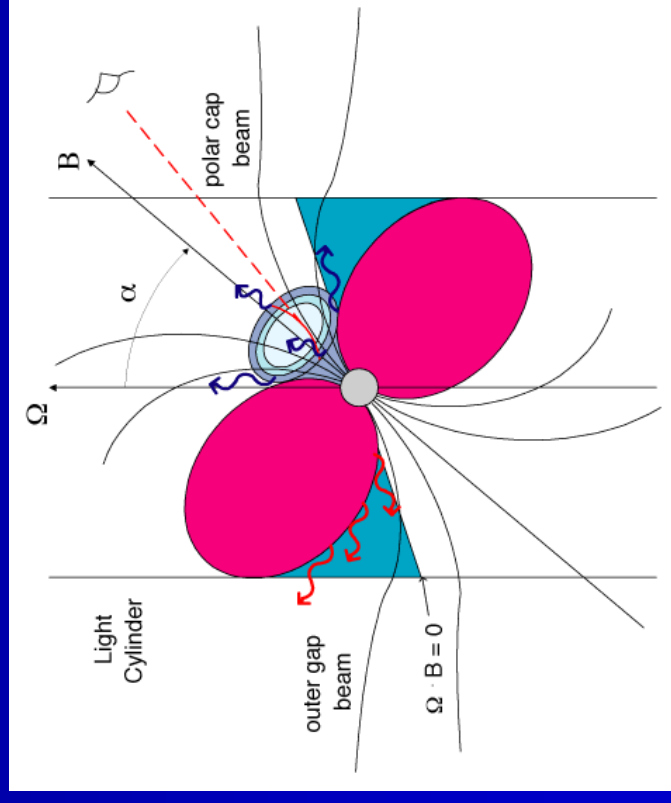
Atelier " pulsars, theories and observations " , 16 et 17 janvier 2006, IAP, Paris

Multiwavelength Observations of the Magnetosphere

Traditional observations of pulsars made at 'mono' wavelengths

Traditional understanding of magnetospheric emission

- radio emission occurs 'close' to polar cap
- HE emission occurs 'elsewhere' (i.e. outer gap)
- *not clear* there is an obvious connection between the two...



Multiwavelength Observations of the Magnetosphere

Problems with models

- Polar cap - explains fluxes, not light curves
- Outer gap - explains light curves, not fluxes...

We need temporally resolved, multiwavelength (polarimetric?) observations to complement full scale magnetosphere models...

BUT the missing link - how do we make the connection between radio & HE emission??

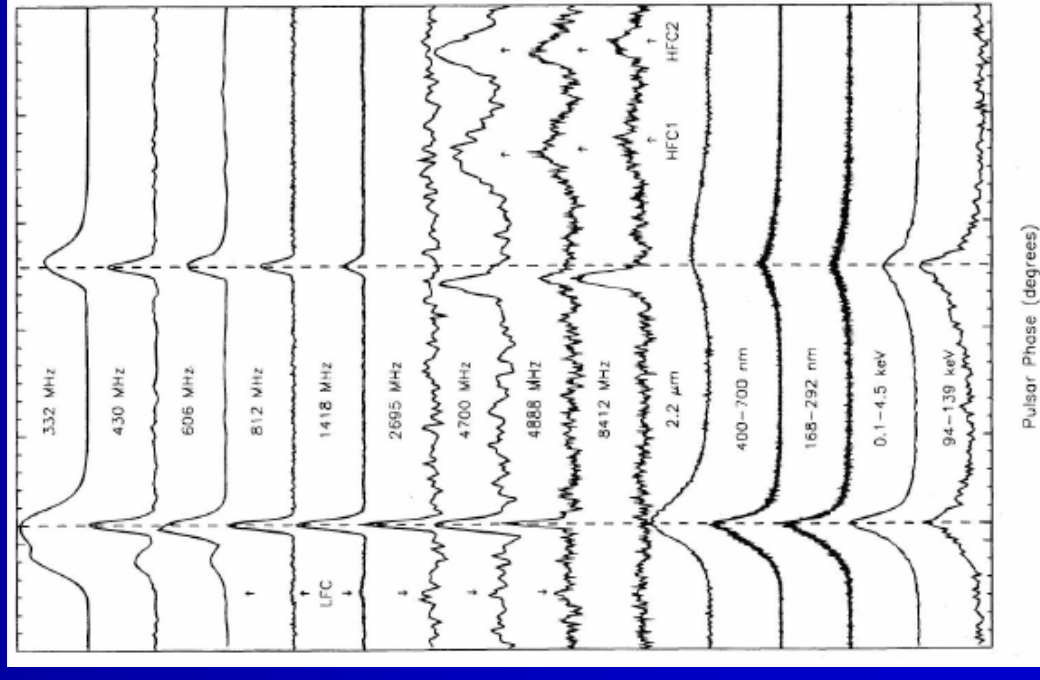
Multiwavelength Observations of the Crab Pulsar

Crab pulsar provides 'gold standard' magnetosphere

Radio emission is 'coincident' with HE emission, 'radio precursor' → pole, double-peaks → magnetosphere.

Bright HE source at magnetosphere dominated bands, IR, optical, hard X-ray, γ -ray, UHE γ -ray.

Also, radio emission unusual - Crab emits 'giant radio pulses' ...



Giant Radio Pulses - A new window on the magnetosphere...

Stochastic bursts of radio emission $10^1 - 10^3$ greater
than mean flux

Duration $\sim \mu\text{secs}$
- localised emission region

Usually associated with **specific** regions of phase
- localised emission regions

Associated with a 'mixed bag' of pulsars - 'new' and 'old'

Giant Radio Pulses - Census

Name	P (s)	\dot{P}	Age (yr)	B_{lc} (G)	$B_{surface}$ (G)
PSR B1937+21	0.0015578	1.051e-19	2.35e+08	1.02e+06	4.09e+08
PSR B0531+21	0.0330847	4.227e-13	1.24e+03	9.80e+05	3.78e+12
PSR B1821-24	0.0030543	1.618e-18	2.99e+07	7.40e+05	2.25e+09
PSR B1957+20	0.0016074	1.685e-20	1.51e+09	3.76e+05	1.67e+08
PSR B0540-69	0.0503540	4.790e-13	1.67e+03	3.65e+05	4.97e+12
PSR J0218+42	0.0023230	7.738e-20	4.76e+08	3.21e+05	4.29e+08
PSR B0950+08	0.2530651	2.297e-16	1.75e+07	1.41e+02	2.44e+11
PSR B0031-07	0.9429509	4.082e-16	3.66e+07	7.02e+00	6.28e+11
PSR B1112+50	1.6564397	2.492e-15	1.05e+07	4.24e+00	2.06e+12

msec

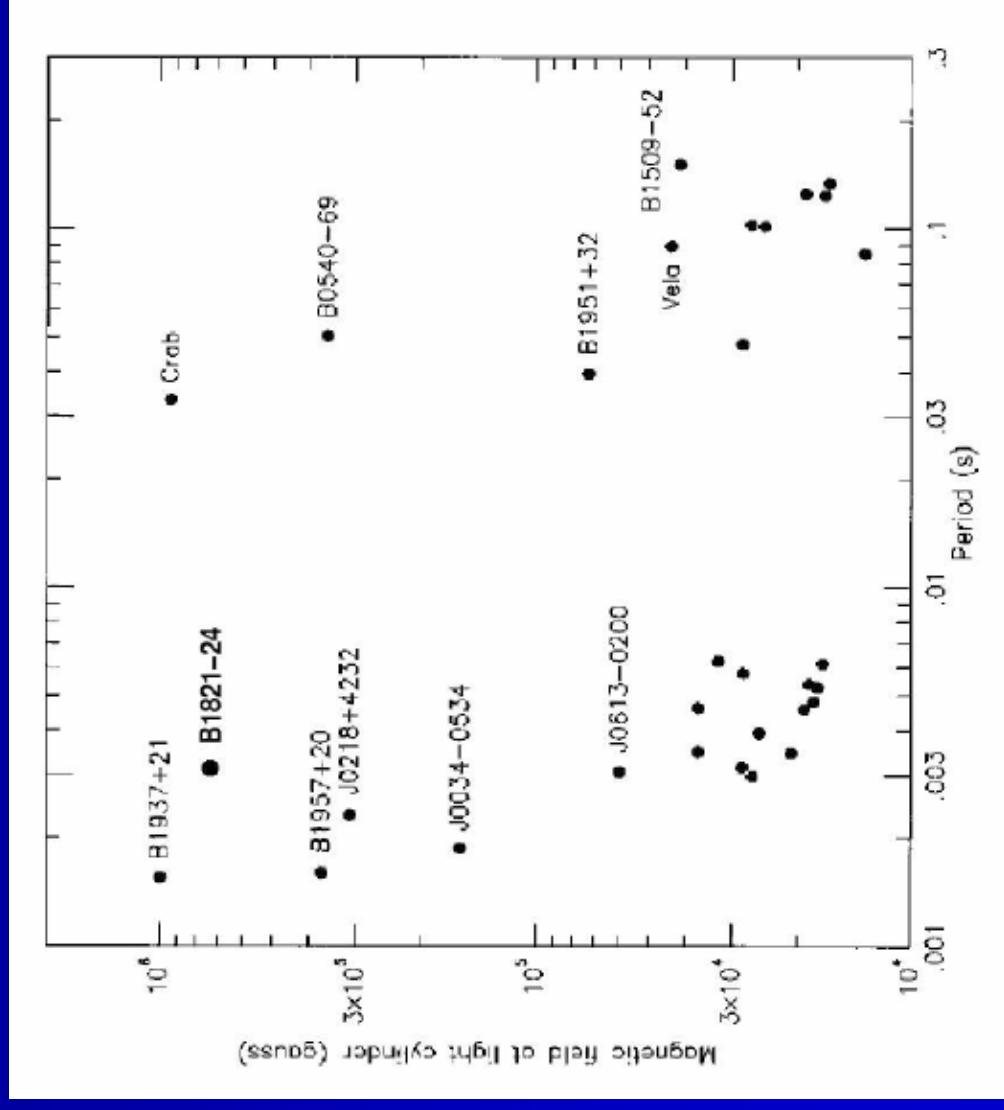
'Crab'

'old'

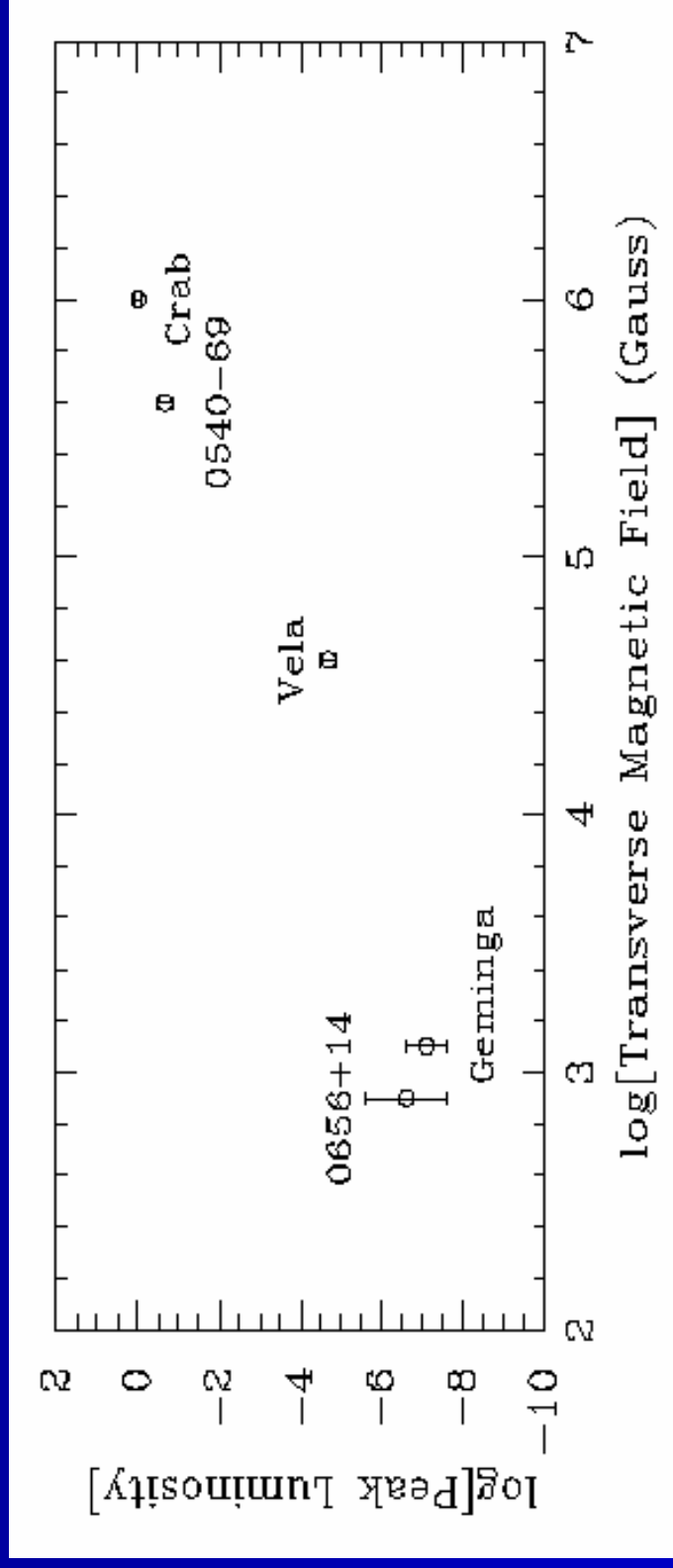
Giant Radio Pulses - Trends...

Cognard the first to notice the scaling with the magnetic field at the light cylinder...

This is familiar...



Light Cylinder B_{field} & Optical Emission...



Optical peak vs B_{ly}

Possible to show correlation in optical luminosity with magnetic field strength at the light cylinder... interesting phenomenology...

Giant Radio Pulses & the Crab

- Crab GRPs...
 - Three features...
 - Power law tail
 - Roll-over
 - Sharp cut-off
 - At 2 distinct phases
 - Main pulse and inter pulse
 - Structure seen down to a few nsec..!

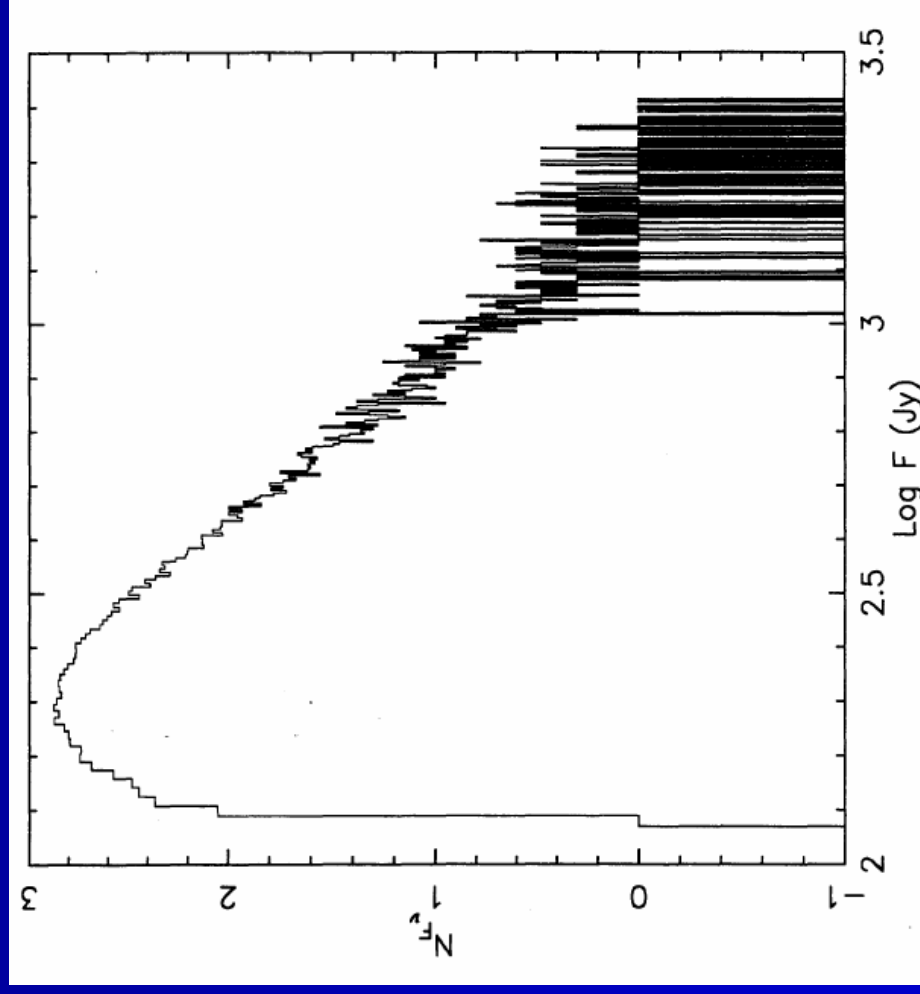


FIG. 4.—Distribution of giant-pulse flux densities is displayed in a log-log plot. The average flux density of 2 Jy is off the scale of the plot. Each bin contains the total number of pulses observed within the corresponding 5 Jy flux-density range.

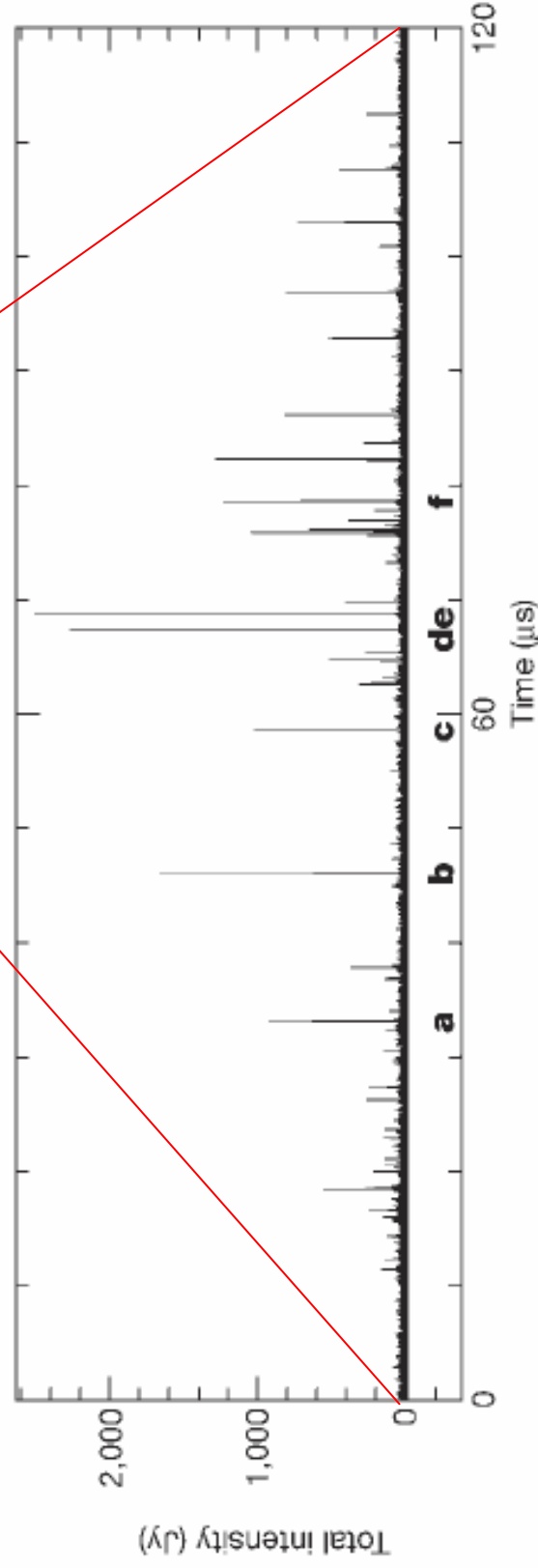
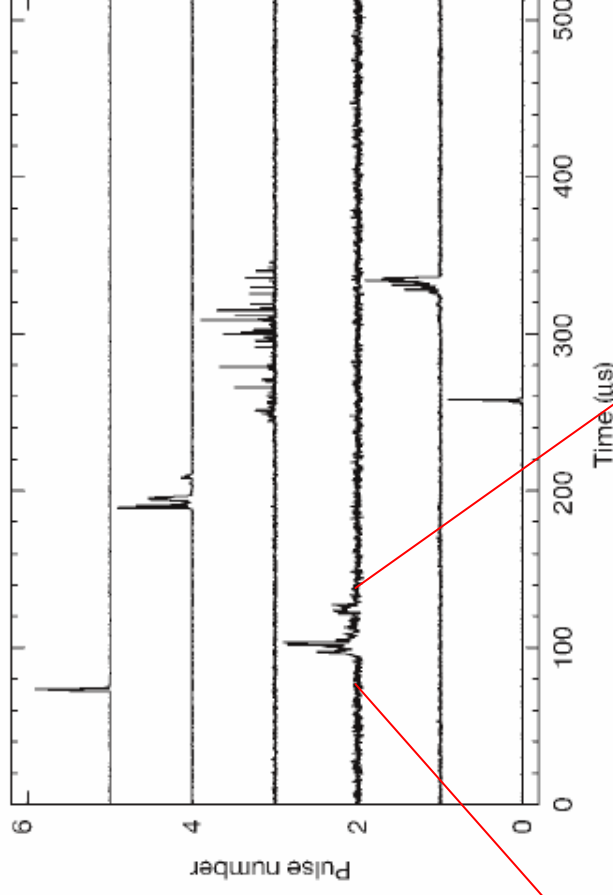
.....
Nanosecond radio bursts from strong plasma turbulence in the Crab pulsar

T. H. Hankins*, J. S. Kern†, J. C. Weatherall* & J. A. Eilek*

*Physics Department, New Mexico Tech, and † National Radio Astronomy Observatory, Socorro, New Mexico 87801, USA

.....
The Crab pulsar was discovered¹ by the occasional exceptionally bright radio pulses it emits, subsequently dubbed 'giant'

**Structure at 3 nsec level
(resolving 1m at 2 kpc)!!**



Giant Radio Pulses & HE Emission

Questions:

Can we show a correlation in GRP emission and HE emission?

Are the profound variations in radio associated with detectable changes at HE bands?

Can we link coherent radio emission with the presumed source of HE emission, pair-production?

Simultaneous γ -ray/radio observations - CGRO/GBT (1995)

THE ASTROPHYSICAL JOURNAL, 453:433-445, 1995 November 1
© 1995. The American Astronomical Society. All rights reserved. Printed in U.S.A.

GIANT PULSES FROM THE CRAB PULSAR: A JOINT RADIO AND GAMMA-RAY STUDY

S. C. LUNDGREN,^{1,2,3,4} J. M. CORDES,^{3,4} M. ULMER,⁵ S. M. MATZ,⁵
S. LOMATCH,⁵ R. S. FOSTER,¹ AND T. HANKINS^{6,7}

Received 1994 May 5; accepted 1995 May 8

ABSTRACT

The Crab Nebula pulsar emits bursts of radio emission as strong as 2000 times the average pulse amplitude. Using joint radio and gamma-ray observations of these giant radio pulses, we characterized intensity variations measured absolutely during with 70 ms resolution, and determined the spin-down model and interstellar

- 3,600 coincident pulses
- γ flux < 2.5 mean flux @ GRP events
- Unlikely via Inverse Compton Scattering
- Explicable as ~ 1% particle flux increase & turbulence?

Giant Radio Pulses & HE Emission

Problem:

Getting GRPs not a problem...

Getting sufficient HE photons a problem!

Go to the best window to get highest S/N data (and avoid over-subscribed facilities)...

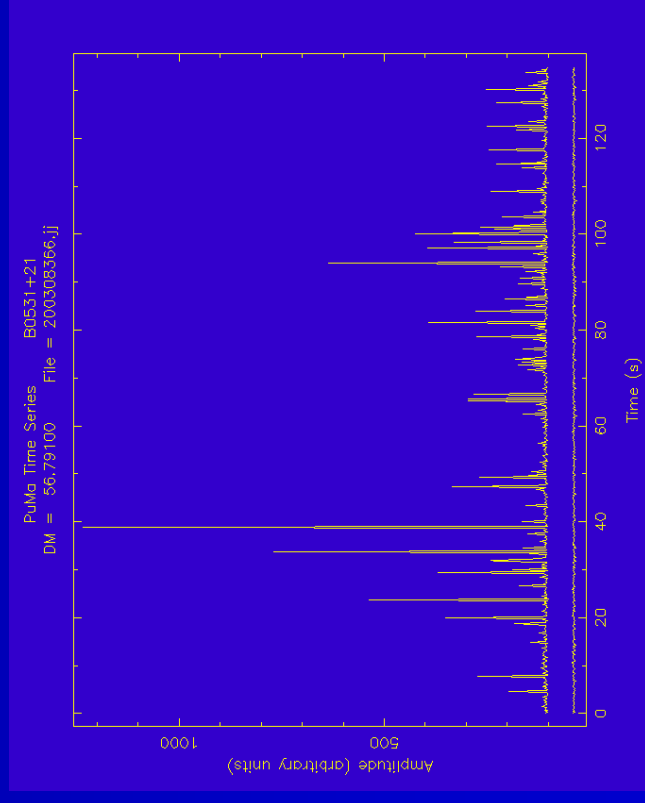
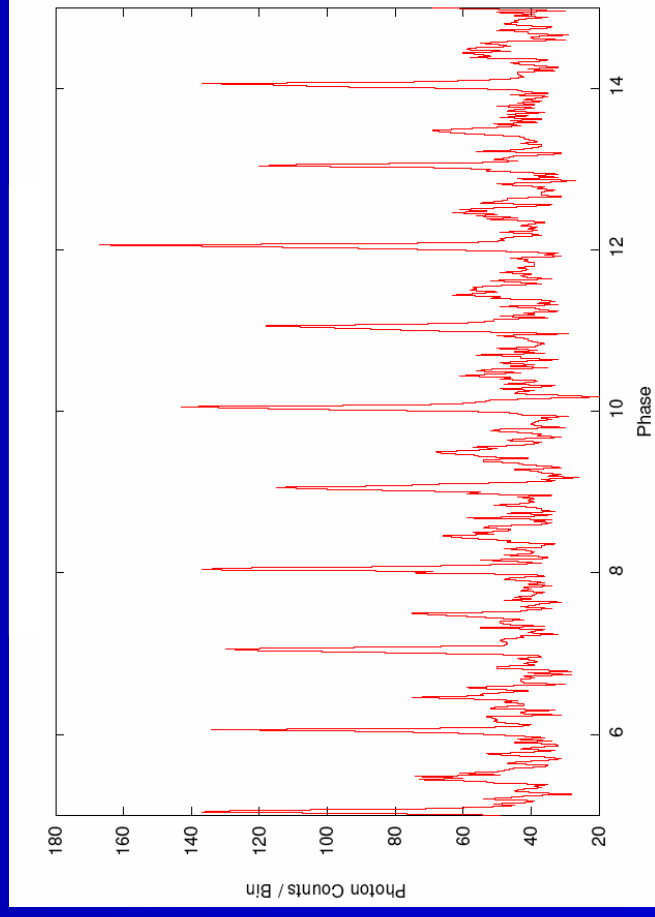
→ high speed optical photometry

Simultaneous optical/radio observations - APD/PuMa

WHT (La Palma)



Westerbork (NL)



Enhanced Optical Emission During Crab Giant Radio Pulses

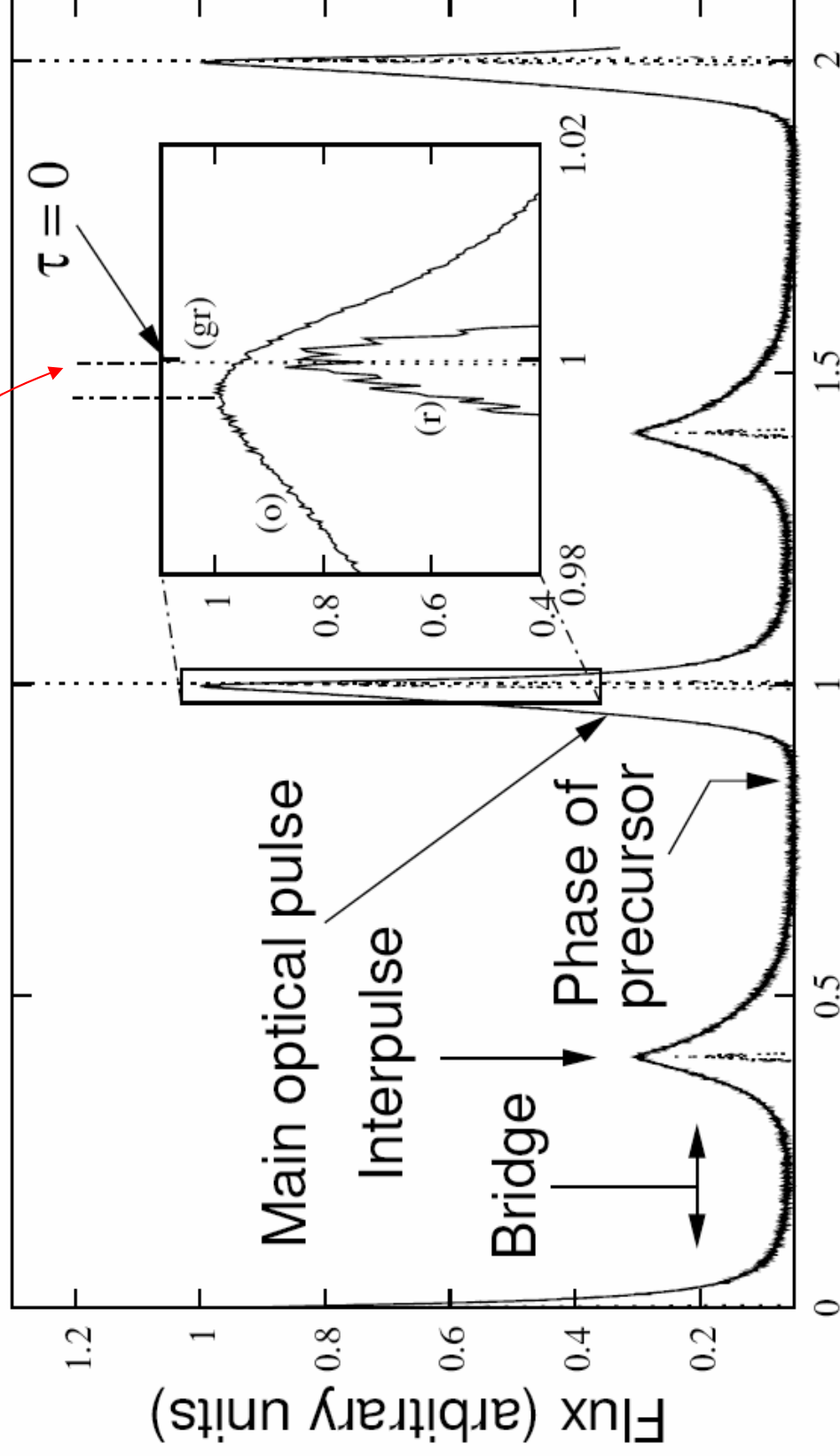
A. Shearer,^{1*} B. Stappers,^{2,3} P. O'Connor,¹ A. Golden,¹
R. Strom,^{2,3} M. Redfern,¹ O. Ryan¹

We detected a correlation between optical and giant radio pulse emission from the Crab pulsar. Optical pulses coincident with the giant radio pulses were on average 3% brighter than those coincident with normal radio pulses. Combined with the lack of any other pulse profile changes, this result indicates that both the giant radio pulses and the increased optical emission are linked to an increase in the electron-positron plasma density.

Despite more than 30 years of observation, regions, the pulse profile is constant at the 1% the emission mechanism of pulsars is still a level (7, 8).

Optical time resolution 5 μ s, radio time resolution 6.4 μ s

90 μ sec



Phase (0, 1 = radio phase)

Data Analysis Caveats

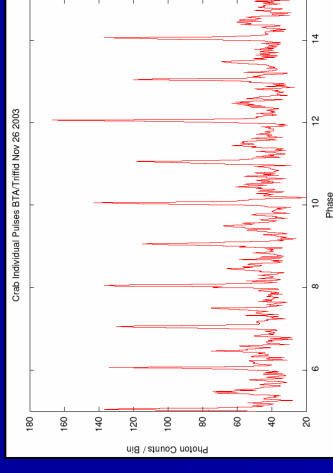
Sky transparency ($\tau_c \sim 30$ secs)

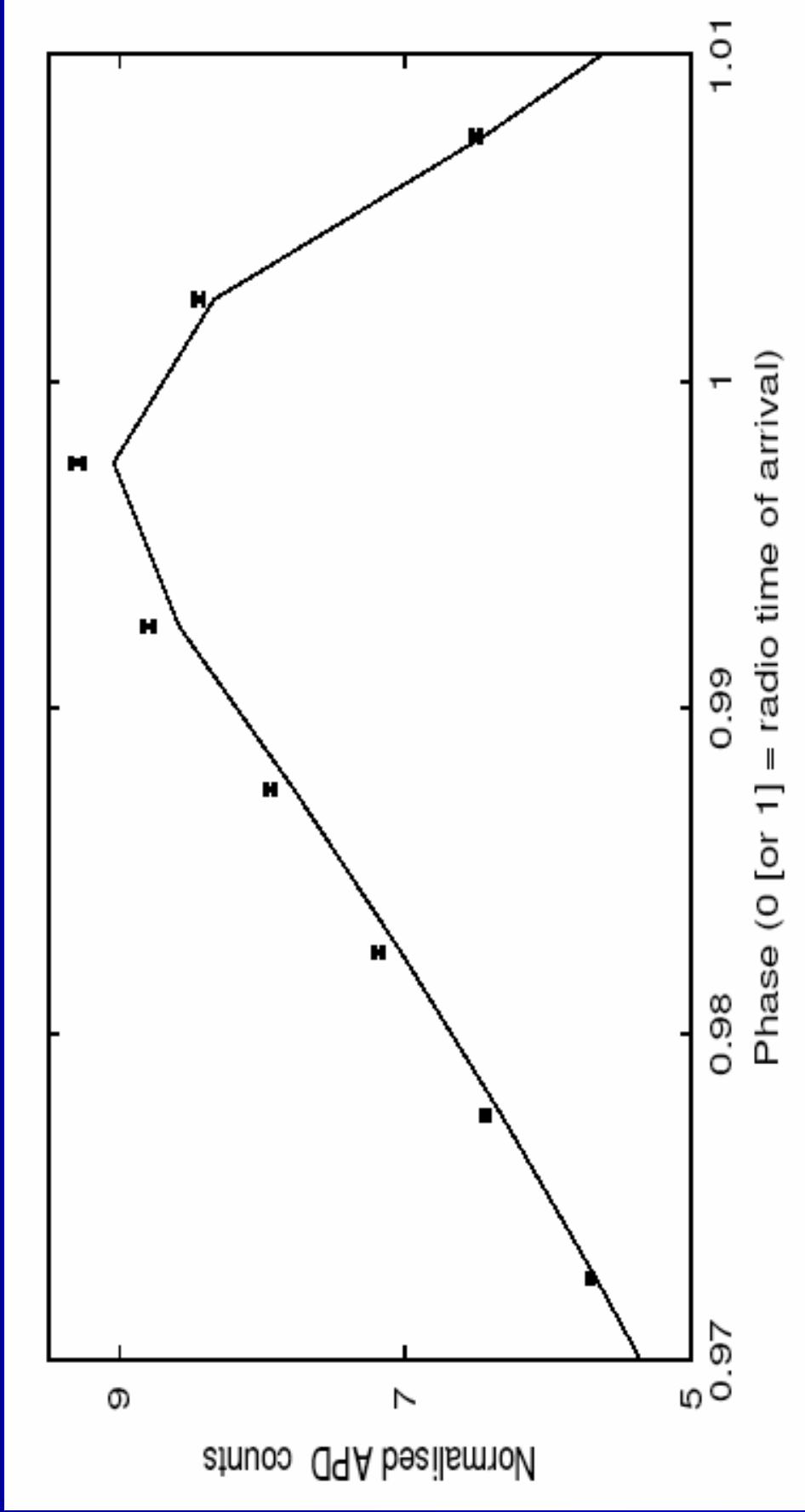
Optical photons 20 periods \pm GRP TOA used,

- placed in 200 bins per period
- 10,034 data sets of 41 periods each

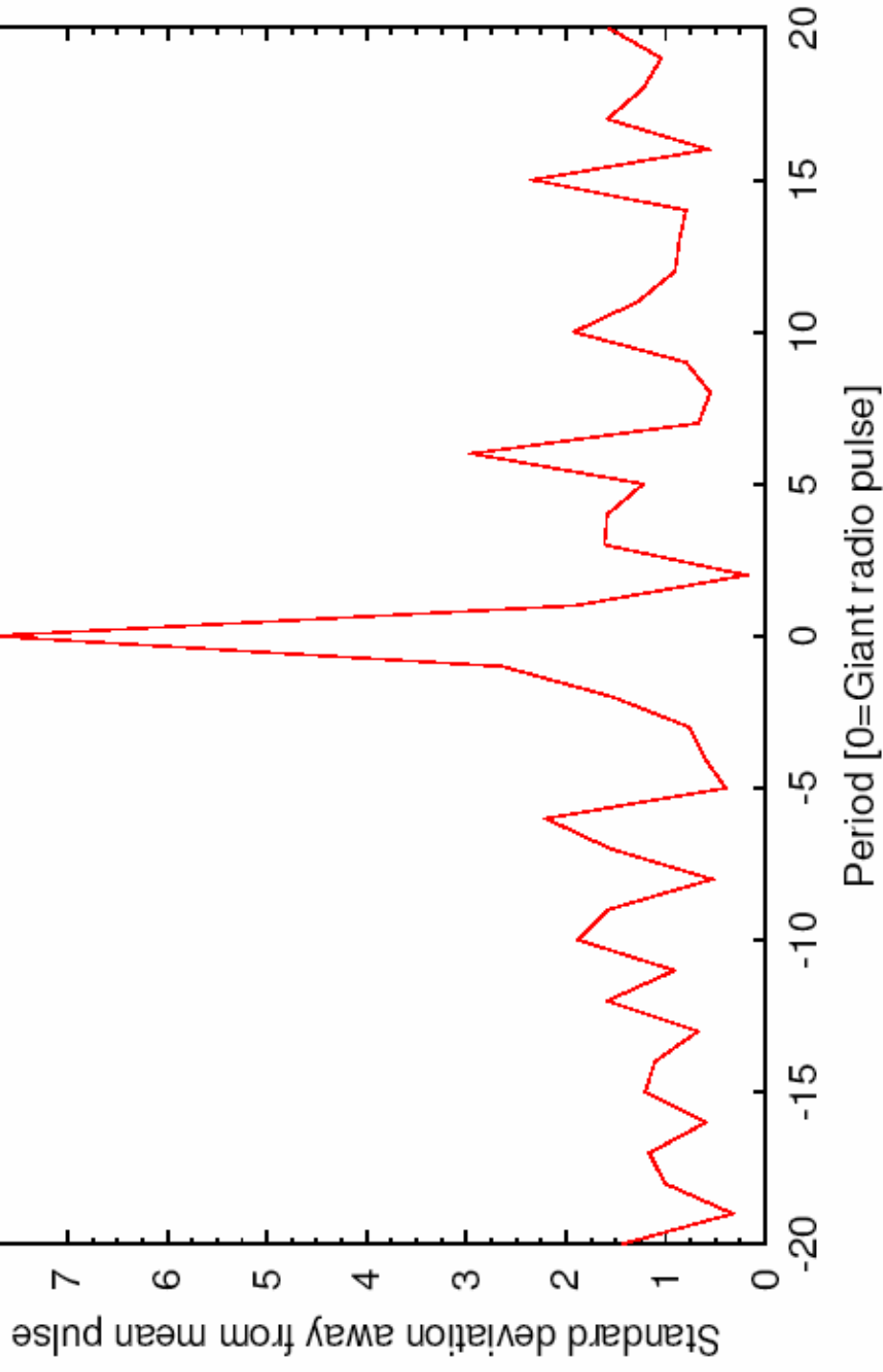
Folding all *non-GRP* phase photons \rightarrow average pulse profile

Folding at *GRP* phase photons \rightarrow optical ‘GRP’ pulse profile





Giant optical pulses are on average 3% brighter than normal optical pulses



Optical pulses coincident with GRPs are 7.8σ brighter than the mean profile.

Giant Radio Pulses & Optical Emission

- **Optical link**
 - 3% enhancement in optical emission
 - ~ 30% of GRP energy - expect ~ 1% from ICS
 - not Inverse Compton Scattering
 - Density increase $\text{Flux}_{\text{opt}} \propto N$ (incoherent)
 - Phase alignment (plus high energy alignment?)
 - outer magnetosphere

Plasma turbulence?

- local density enhancements < 10 μsec duration, could explain observations...

Can we rule out variation in pair production?

Not immediately - need γ -ray data...

Simultaneous γ -ray/radio observations with INTEGRAL?

Observations in optical \rightarrow flux increase at high energies associated with giant radio pulse

Expectation is that similar flux increase associated with X-ray and γ -ray emission from the same regions in magnetosphere

Using ISGRI (15-20 keV), estimate 100~200 ksecs data required to reach 3%

Crab observed bi-annually by INTEGRAL as calibrator - idea was to coordinate simultaneous radio observations...

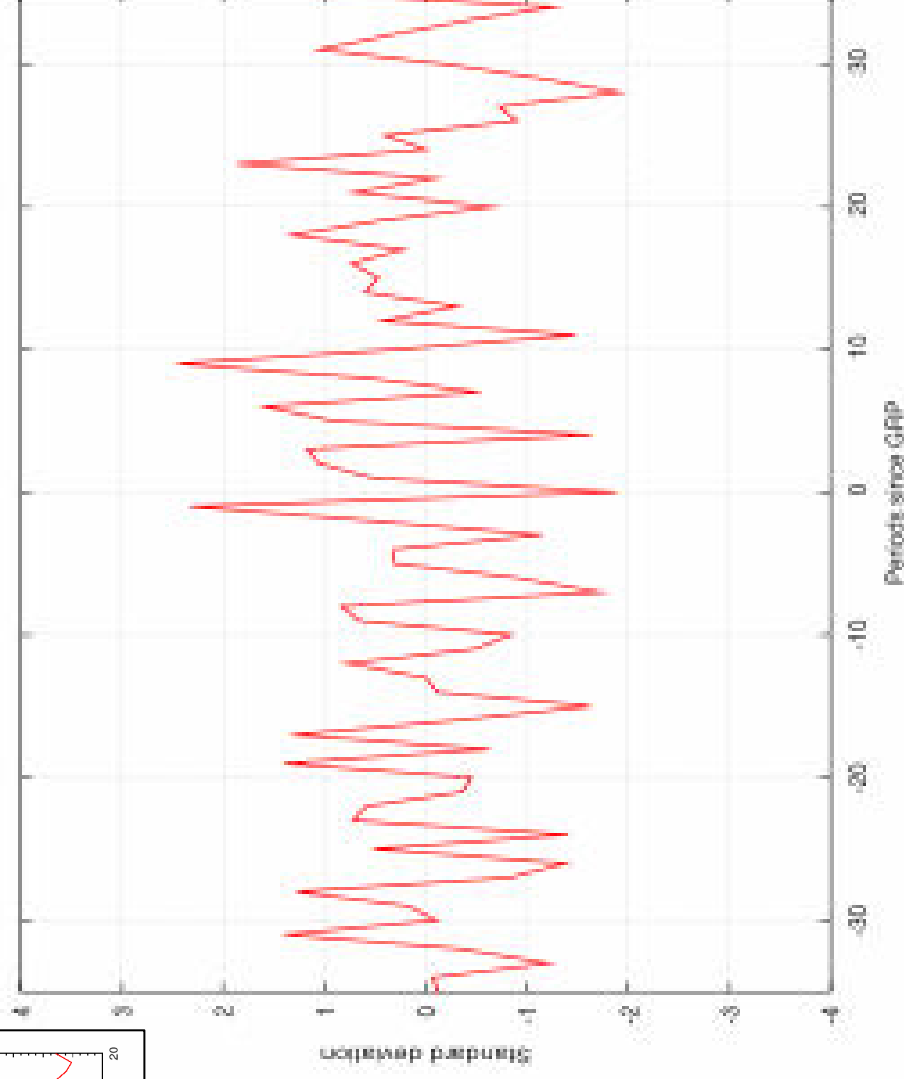
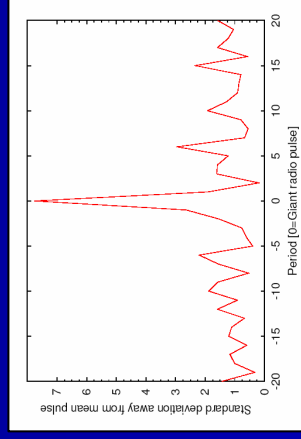
Calibration run ~ 50 ksec of temporal data suitable for analysis

First run with PuMa at Westerbork in March 2004.

Table 5.2: Summary of gamma and radio observations

	Start time (UTC)		Duration (s)
Date	Gamma	Radio	Gamma Radio
6 March 2004	14:31:11	15:48:30	~54560 ~24590

Simultaneous γ -ray/radio calibration run - results



Simultaneous γ -ray/radio calibration run

- conclusions

Preliminary analysis of the data $\sim 2\sigma$ deviation of γ -ray GRP from mean pulse - promising...

Estimations from optical observations \rightarrow need for ~ 200 ksec simultaneous data from Crab

Detection in optical argues strongly for γ -ray/radio correlation.

Future joint γ -ray/radio observations with INTEGRAL

Other calibration runs to be analysed...

We plan a request for 200 ksec AO time + simultaneous radio...

Need to maximise radio coverage with following
radio telescopes

- Lovell (UK)
- Effelsberg (GER)
- Westerbork (NL)
- Parkes (Australia)
- GBT/Arecibo (USA)

.....Nancay (France)?