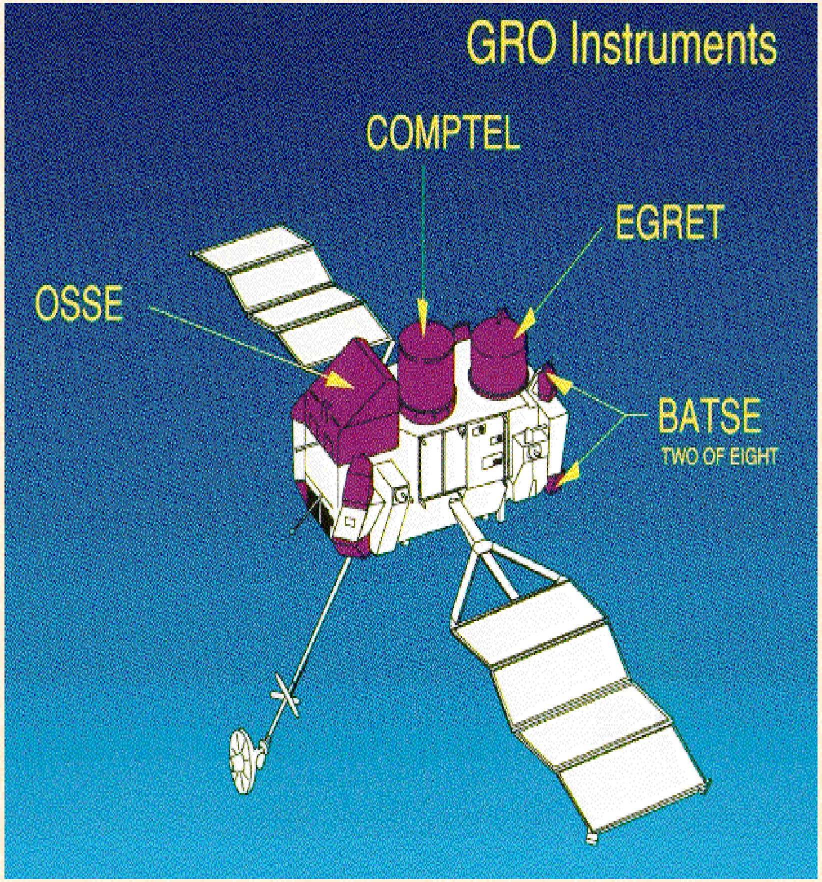
Introduction
to
EGRET Data Analysis

The Compton – Gamma Ray Observatory



BATSE - The Burst and Transient Source Experiment : energy range 25 keV-2 MeV

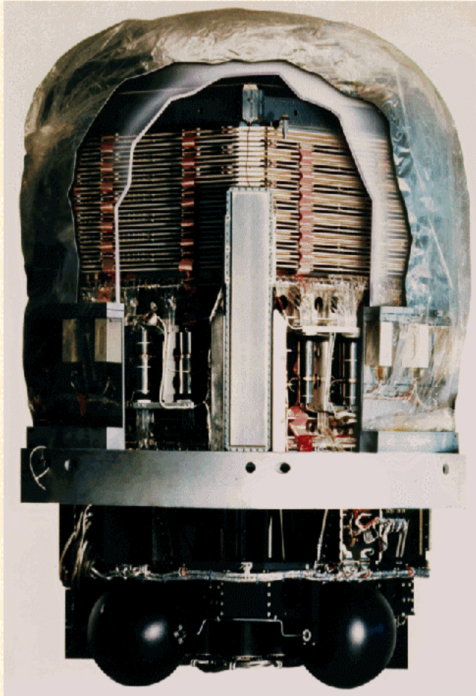
OSSE -The Oriented Scintillation Spectrometer Experiment in the 0.05-10 MeV energy range,

COMPTEL -The imaging Compton in the 1-30 MeV enery range

EGRET - The instrument in the energy range 20 MeV to 30 GeV.

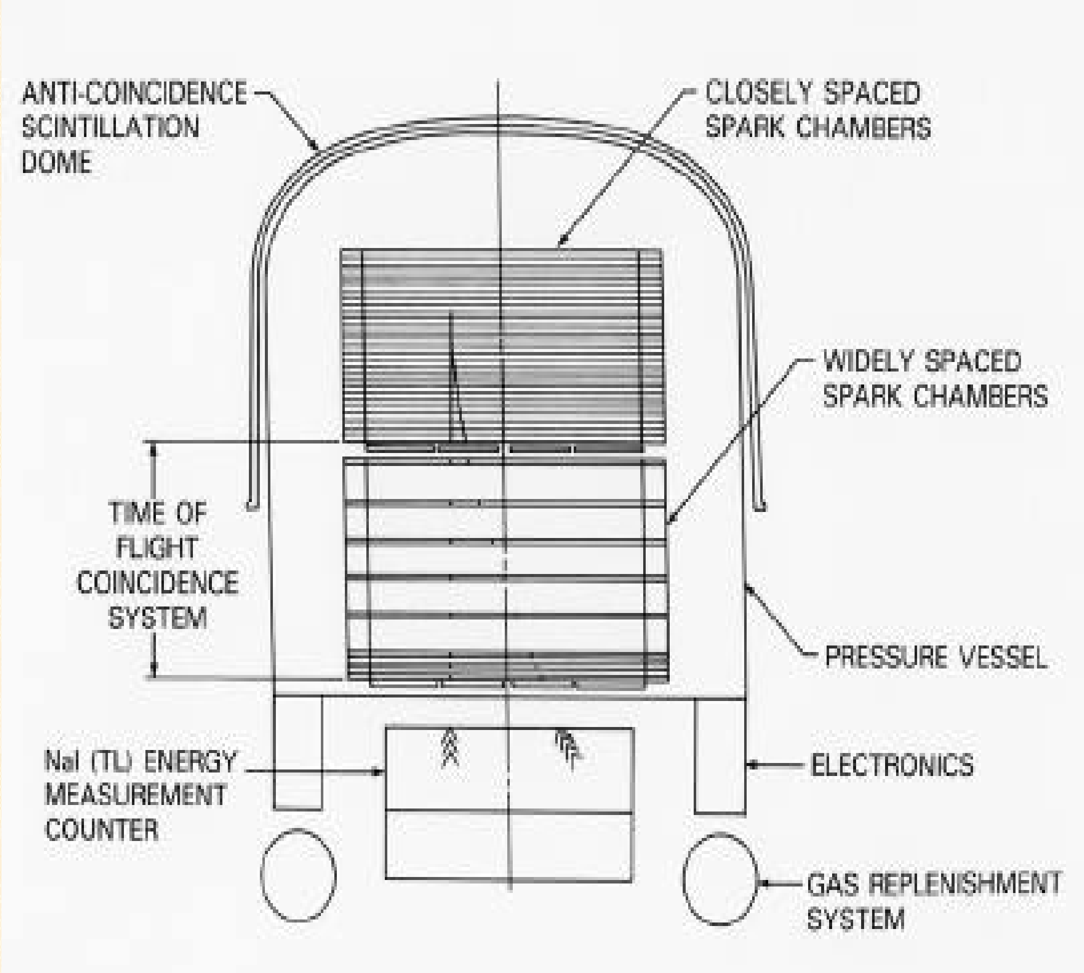
EGRET
(Energetic Gamma-Ray Experiment Telescope)

A:April 1991
Ω:June 2000



Orbit radius: about 450 km
Orbital Period: about 93 min
Inclination: 28°.5

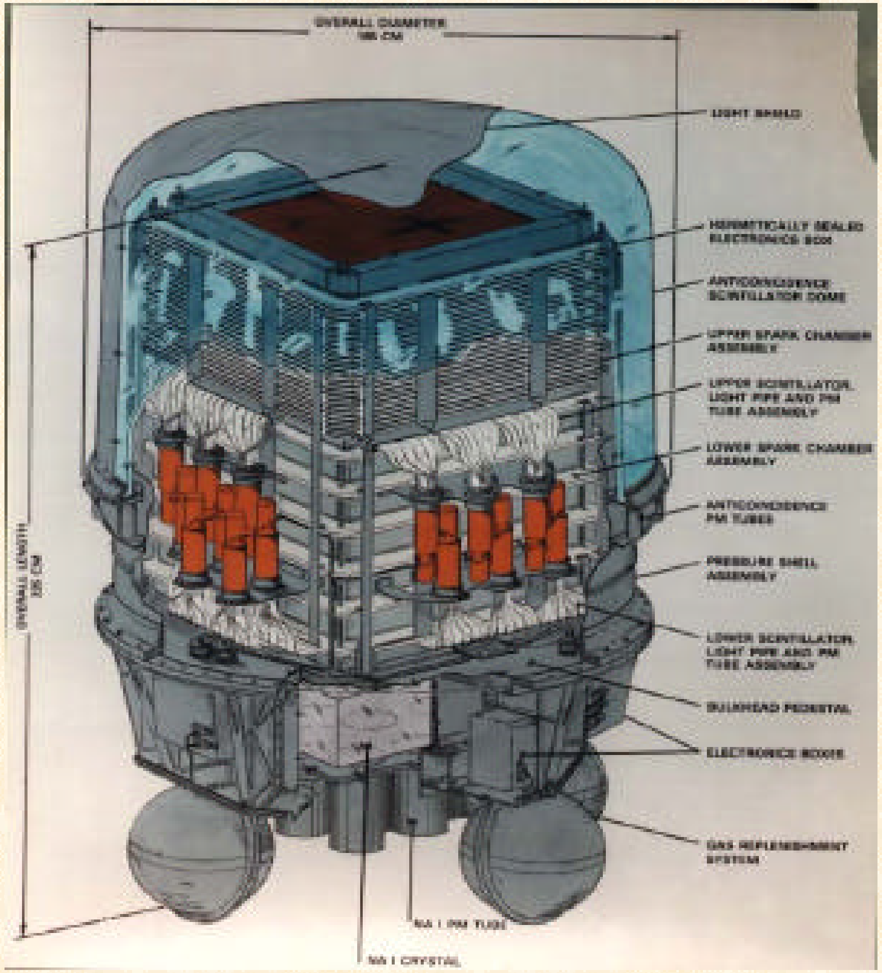
EGRET – General layout



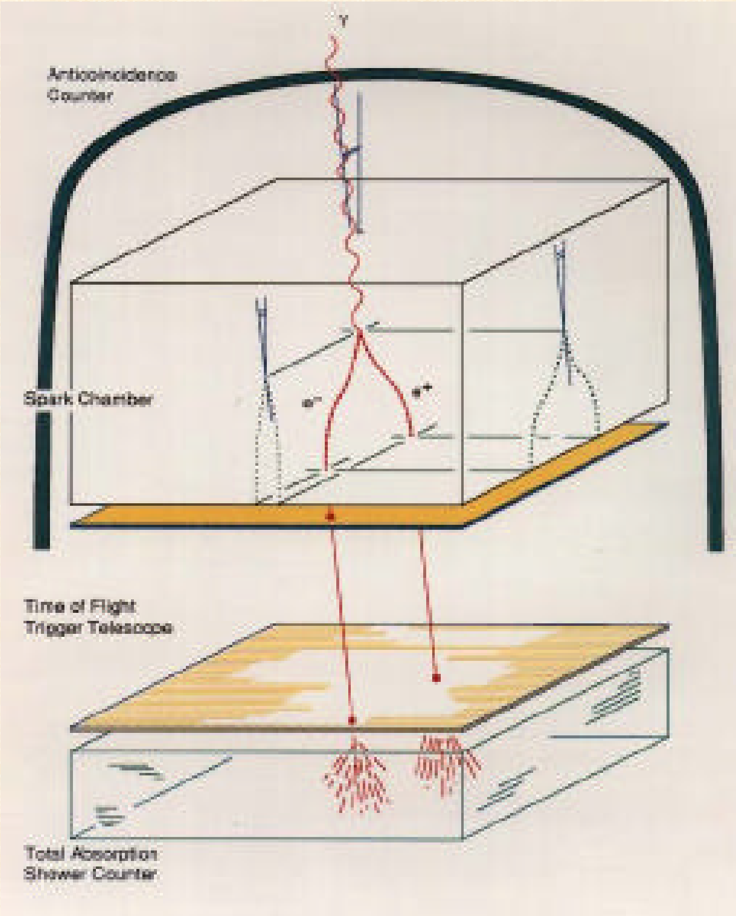
EGRET is multilevel spark chamber triggered by a scintillator coincidence system, with a large NaI(Tl) crystal spectrometer to measure the energy.

EGRET - Main Characteristics

- ***Field-of-View***: approx 20 degrees half-width at half maximum
- ***Time Resolution***: absolute accuracy 0.1 msec
- ***Energy range***: 20 MeV - 30 GeV
- ***Energy Resolution***: around 20% over central energies
- ***Effective Area***: peaks at 1500 cm^2 from 200-1000 MeV
- ***Source Localization***: approx. 10 arcmin for strong sources



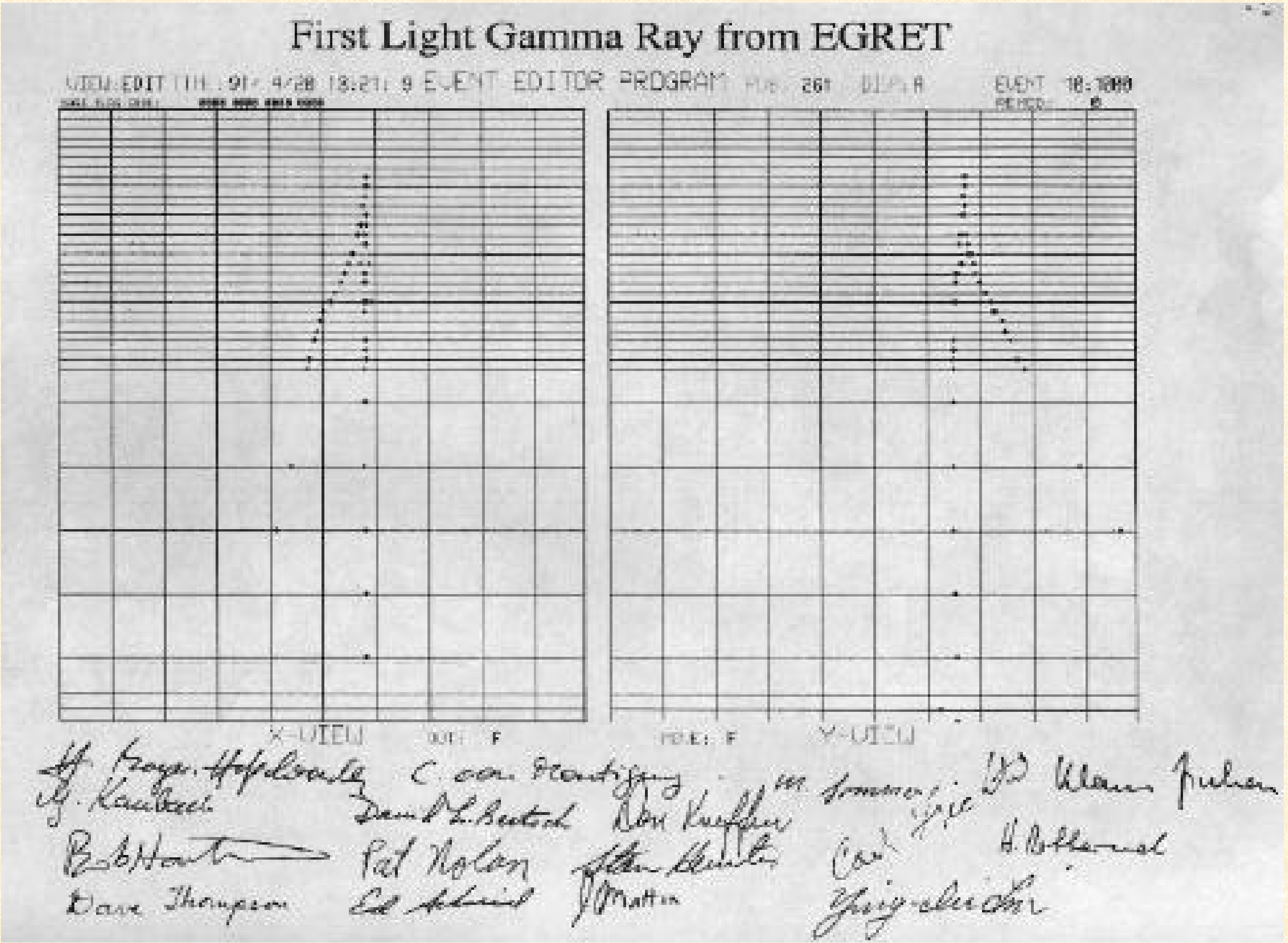
EGRET – Principle of gamma ray detection



EGRET: Principle of Detection of High Energy Gamma Rays

A γ_ray which enters the top of the EGRET instrument will pass undetected through the large anticoincidence scintillator surrounding the spark chamber and has a probability 33% of converting into an electron_positron pair in one of the thin tantalum (Ta) sheets interleaved between the 28 closely spaced spark chambers in the upper portion of the instrument.
Below the conversion stack are two 4 x 4 arrays of plastic scintillation detector tiles spaced 60 cm apart which register the passage of charged particles. If the time_of_flight delay indicates a downward moving particle which passed through a valid combination of upper and lower scintillator tiles, and the anticoincidence system has not been triggered by a charged particle, the track information is recorded digitally. In this manner, a three dimensional picture of the path of the electron_positron pair is measured.
The energy deposition in the NaI(Tl) Total absorption Shower Counter (TASC) located
directly below the lower array of plastic scintillators is used to estimate the photon energy.

EGRET – First Light, 1991/04/20



EGRET – Significant Events

TABLE 1

Significant Instrument Events

Date (mm/dd/yy)	Event
04/15/91	Began instrument activation and testing
05/16/91	Began science operations Cycle 1
07/15/91	Adjusted the TASC tube gains
12/03/91	Replaced spark chamber gas (fill no. 1)
04/01/92	*CGRO* tape recorders failed; start extended real-time coverage
11/17/92	Started viewing Cycle 2
12/04/92	Replaced spark chamber gas (fill no. 2)
01/29/93	Adjusted the TASC tube gains
06/15/93–06/17/93	Orbit reboosted
08/17/93	Started viewing Cycle 3
11/19/93–11/23/93	Orbit reboosted
12/15/93–2/17/94	Orbit reboosted
02/09/94	Replaced spark chamber gas (fill no. 3)
10/04/94	Started viewing Cycle 4
03/11/94	Gas circulation pump failed
10/28/94	Coincidence tube C43 failed
11/02/94	Replaced spark chamber gas (fill no. 4)
10/03/95	Started viewing Cycle 5
	Began narrow angle mode as the primary configuration
	Implemented autotrigger to wide angle for BATSE burst
04/19/95	Adjusted the TASC tube gains
09/07/95	Replaced spark chamber gas (fill no. 5). Last complete fill
10/15/96	Started viewing Cycle 6
03/24/97–04/01/97	Orbit reboosted
05/28/97–06/14/97	Orbit reboosted
08/06/97	Circulation pump 2 failed
10/03/97	Coincidence tube B24 rate reduced
11/04/97	Spark chamber B (interleaved stack B) failed
11/11/97	Started viewing Cycle 7
07/07/98	Coincidence tube B44 rate reduced

(Esposito et al. 1999)

EGRET – Instrument and Observations (1)

The CGRO mission has been divided into Cycles which focus on different mission Objectives (e.g. Cycle 1 lasted from 1991 April through 1992 November).

A typical EGRET observation (Viewing periods = time intervals with spacecraft pointing fixed) lasts from one to three weeks. During this time, the pointing axis of the instrument is stable to within 0° 5.

TABLE 2

SOURCE LOCATION ACCURACY FOR IDENTIFIED SOURCES NEAR THE GALACTIC PLANE

Source	Offset (deg)	Nearest Error Contour (%)
Solar flare	0.39	68%
Crab pulsar	0.06	95%
Geminga pulsar	0.08	>99%
Vela pulsar	0.08	>99%
PSR B1055−52......	0.17	95%
PSR B1706−44......	0.20	>99%

EGRET TIMELINE SUMMARY

Viewing Period	Start Date (mm/dd/yy)	Start Time (hh:mm)	End Date (mm/dd/yy)	End Time (hh:mm)	Instrument Mode*	Z-Axis R.A. (deg)	Z-Axis Decl. (deg)	Target Region
0002......	04/22/91	21:09	04/28/91	15:12	W,T	86.76	22.09	Crab pulsar
0003......	04/28/91	16:02	05/01/91	16:37	W,T	89.80	15.25	Crab pulsar
0004......	05/01/91	17:19	05/04/91	16:16	W,T	89.77	15.24	Crab pulsar
0005......	05/04/91	16:50	05/07/91	15:53	W,T	83.52	22.02	Crab pulsar
0006......	05/07/91	16:32	05/10/91	19:40	W,T	162.44	57.26	Gal 150+53
0007......	05/10/91	20:15	05/16/91	16:39	W,T	135.19	−45.11	Vela pulsar
0010......	05/16/91	17:19	05/30/91	18:51	W,T	88.07	17.14	Crab pulsar
0020......	05/30/91	20:01	06/08/91	00:08	W,T	301.39	36.58	Cyg X-1
0021......	06/08/91	01:24	06/15/91	18:44	W,T	87.83	12.47	Sun
0030......	06/15/91	19:38	06/28/91	19:30	W,T	191.54	2.62	SN 1991T
0040......	06/28/91	20:14	07/12/91	17:56	W,T	179.84	41.52	NGC 4151
0050......	07/12/91	18:48	07/26/91	19:25	W,T	270.39	−30.96	Gal center
0060......	07/26/91	20:25	08/08/91	15:36	W,T	91.28	−67.96	SN 1987A

Search and Analysis of Gamma-ray Events (SAGE)

For every event in the EGRET telemetry, the spark chamber tracks are analyzed by SAGE in a nine step process:

•First, the event must have generated a given minimum number of sparks in both orthogonal views.

•Second, three sparks must be found within a specified distance of each other, and must define a reasonable path.

•In the third step, triplets which start in the top conversion plate or trace back to the instrument walls are rejected. In addition, at least one triplet must form before the upper scintillator array.

•In the fourth step, all possible tracks from the remaining triplets are constructed, with duplicate tracks eliminated.

•The fifth step selects the electron and positron tracks from the candidates calculated in step four.

•Step six checks to see if there is better choice of vertex between the two paths.

•In the seventh step, the two sets of tracks in the two orthogonal views are correlated.

•The eighth step determines event descriptors such as the number of spurious sparks and the curvature of the track.

•In the ninth step, the events are stored.

Data Analisys (1) -Instrument Calibration

There are three areas where it is important to know the instrument performance:

the point_spread function, or the distribution of the measured fl_ray incident angles as a function of the true incident angle;

the sensitive (or effective) area, or the physical area for collecting fl_rays multiplied by the efficiency, as a function of position on the sky at any given time;

the energy dispersion, or the distribution of measured energy as a function of the true energy.

Data Analisys (2) -Instrument Calibration

Point_Spread Density

It is important to be able to quantify the ability of a gamma_ray telescope to correctly reconstruct the true incident direction of a fl_ray. To precisely define this, we will distinguish between the ``point_spread density'' and the ``point_spread function.'' The point_spread density, or PSD, refers to the probability density distribution of incident gamma_ray directions measured by the instrument from a point source. This distribution may in general be a function the true position of the point source (the inclination and azimuth relative to the centerline of the telescope) and the energy of gamma_ray:

$$PSD = PSD(\theta, \phi, \theta_0, \phi_0, E_o)$$

Data Analisys (3) -Instrument Calibration

The point_spread function is the differential probability

$$dP = PSD(\theta,\phi,\theta_0,\phi_0,E_o)\sin\theta d d\phi$$

Sensitive Area

The sensitive area (or effective area) is the projected area of the detector multiplied by its efficiency. It too is a function of incident gamma_ray parameters:

$$SAR(E_0;\theta,\phi,m)$$

Data Analisys (4) -Instrument Calibration

Energy Dispersion

The energy dispersion function gives the distribution of measured energy for a given true energy. The measured energy varies from the true energy because of noise in the photomultipliers, fluctuations in the shower leakage from the calorimeter,etc

$$EDP(E_0 E;\theta,\phi,m)$$

Data Analisys (5) -Instrument Calibration

Point Spread Function - PSF(θ)

From the calibration data it is seen that the point_spread function is roughly azimuthally symmetric then:

$$PSF(\theta) = \frac{2\pi}{N} \int_{E=E_{\min}}^{E_{\max}} \int_{E=0}^{\infty} E'^{-\alpha} PSF(\theta, E') EDP(E, E') dE' dE$$

The point_spread function PSF(θ) is the integral of the true_energy dependent point_spread function, weighted by the spectrum, integrated over the measured energy band from E min to E max , and integrated over all true energies, weighted by the energy dispersion function. This reflects the fact that there is some probability that a gamma_ray of any given true energy will have a measured energy between E min and E max .

A reasonable approximation to the point_spread width assumes a relatively simple functional form. The half_angle which defines a cone containing ¸ 68% of the gamma_rays from a point on the sky may be taken as

$$\theta_{68} = 5^{0}.85(E/100MeV)^{-0.534}$$

Data Analisys (6) -Instrument Calibration

Much of the EGRET calibration was performed in 1986 at the Stanford Linear Accelerator Center (SLAC).
Calibration runs were performed for:

- ten discrete energies (15, 20, 35, 60, 100, 200, 500, 1000, 3000, and 10,000 MeV)
- with the beam incident at each of five inclination angles : 0 ° , 10° , 20° , 30°, and 40 °
- and three azimuth angles: 0° , 22°. 5, and 45° .

The data was stored in three sets of calibration files which form the basis for all analysis of EGRET data.

Data Analisys (7)

Counts – Exposure - Intensity

If a detector has exposure E_T to a source with photon flux F(ph/cm^{2}sec) , then the number of counts N which will be measured is

$$N = FE_T$$

where

$$F(\Delta E) = \int_{\Delta E} I(E)dE$$

ΔE is the energy range being considered and I(E) is the differential flux as a function of energy (ph/cm^{2}secMeV).The differential number of counts that will be detected by EGRET from a source of intensity I(E) is

$$dN = I(E)A(E)dEdt$$

where A(E) is the energy_dependent effective area of the instrument, and dt is the differential unit of time.

Data Analisys (8)

Taking into account the energy dispersion of the instrument, the correct expression for the number of counts that will be measured is

$$N(\Delta E;\theta,\phi,m) = T(\theta,\phi,m)\int_{\Delta E} dE' \int_0^{\infty} dE\, I(E)\, SAR(E;\theta,\phi,m)\, EDP(E,E';\theta,\phi,m)$$

$T(\theta,\phi,m)$ = is the amount of instrument livetime spent observing a source at (θ,ϕ)

$EDP(E,E';\theta,\phi,m)$ = Prob. of true energy E will be measured with an energy E'

solving for exposure:

$$E_T(\Delta E;\theta,\phi) = \sum_m T(\theta,\phi,m)\overline{SAR}(E;\theta,\phi,m)$$

$$\overline{SAR}(E;\theta,\phi,m) = \frac{N(\Delta E;\theta,\phi,m)}{\int_{\Delta E} dE\, I(E)}$$ = average effective area of EGRET

$I(E) = I_o E^{\alpha}\, ph\, cm^{-2} s^{-1} MeV^{-1}$ =source photon spectrum $\alpha \approx -2.0$

Data Analisys (9)– Diffuse Emission Model

The Galaxy is a strong source of high-energy gamma rays arising primarily from the interaction of cosmic rays with the interstellar matter and, to a lesser extent, interstellar
photons. This emission is strongest within +/-60¡ in Galactic longitude and +/-10° in Galactic latitude, where most of the interstellar gas is present. It falls off rapidly at higher latitudes.
The primary processes that produce the observed
Galactic diffuse gamma rays are:

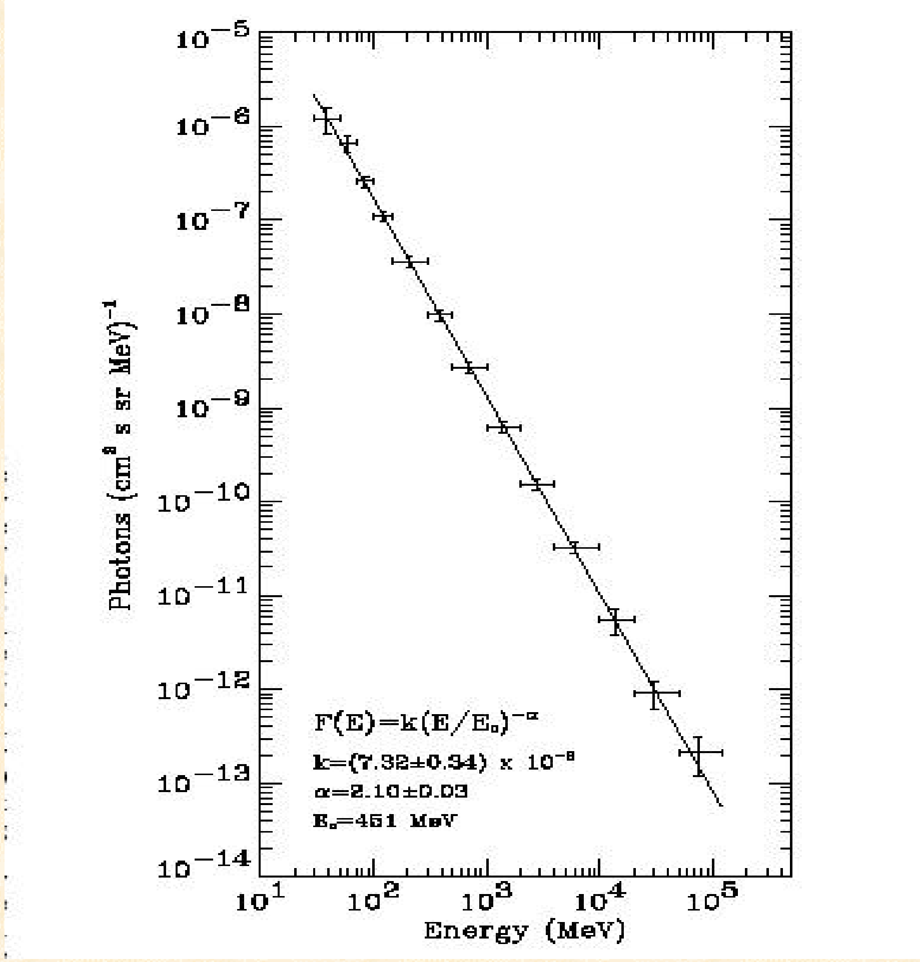
• cosmic-ray nucleons interacting with nucleons in the interstellar gas

• Bremsstrahlung by cosmic-ray electron;

• Inverse Compton interaction of cosmic-ray electrons with ambient low-energy interstellar photons (Bertsch et 1993; Hunter et al.1997).

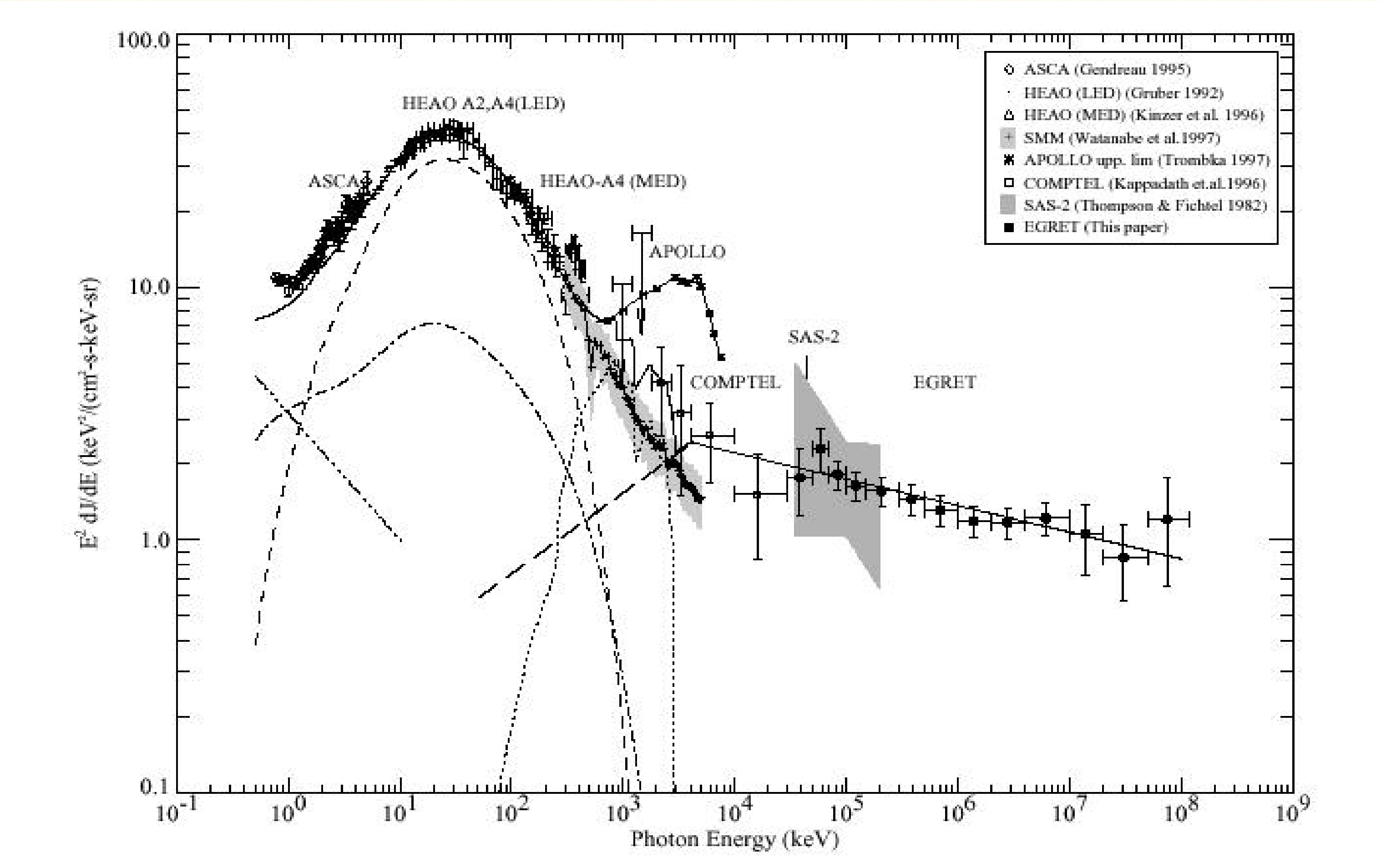
$$I_{tot}(l,b,E) = A + BI_{gal}(l,b,E)$$

Data Analisys(10) – Extragalactic Contribution



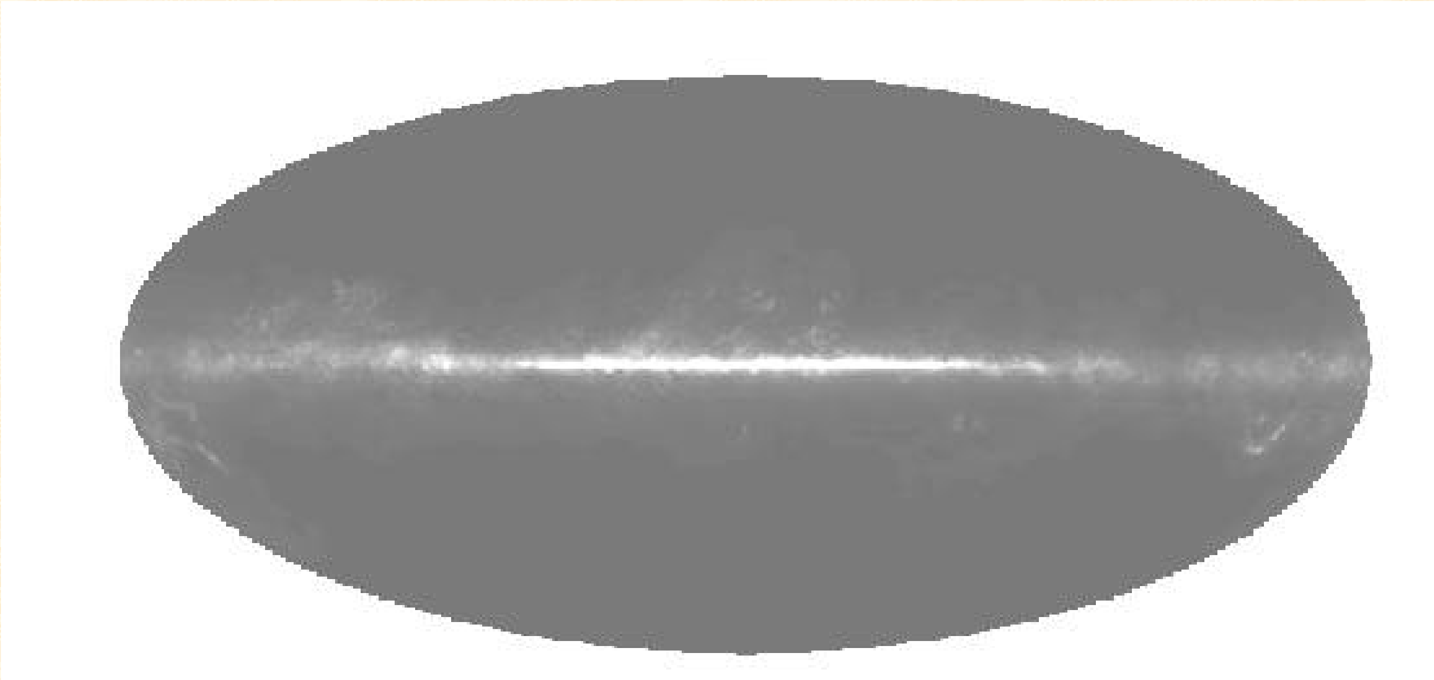
SREEKUMAR ET AL. 1997

Data Analisys (11)– Extragalactic Contribution



SREEKUMAR ET AL. 1997

Data Analisys(12) – Galactic Diffuse Emission



Assumed Galactic contribution convovede with EGRET PSF

Standard Data Files (1)

The events that are determined to be gamma_rays are stored in a Primary Database file corre_ sponding to that observation. These files contain all of the measured and derived quantities for each event. Since these files are too large to be manipulated easily, pertinent information such as photon energy, time of arrival, and direction of incidence are stored in Summary Database (SMDB) files.

The files contained in the public folder (ftp://cossc.gsfc.nasa.gov/pub/data/egret/) are:

High-Level Data Available:

qvp_vp####f.fits	Time-ordered list of all photons detected during the viewing period.
counts_vp####_g00#.fits	Maps of photon counts
exposr_vp####_g00#.fits	Maps of instrumental exposure
intens_vp####_g00#.fits	Maps of gamma-ray intensity
exphst_v01p####.fits	Exposure history file.

Standard Data Files (2)

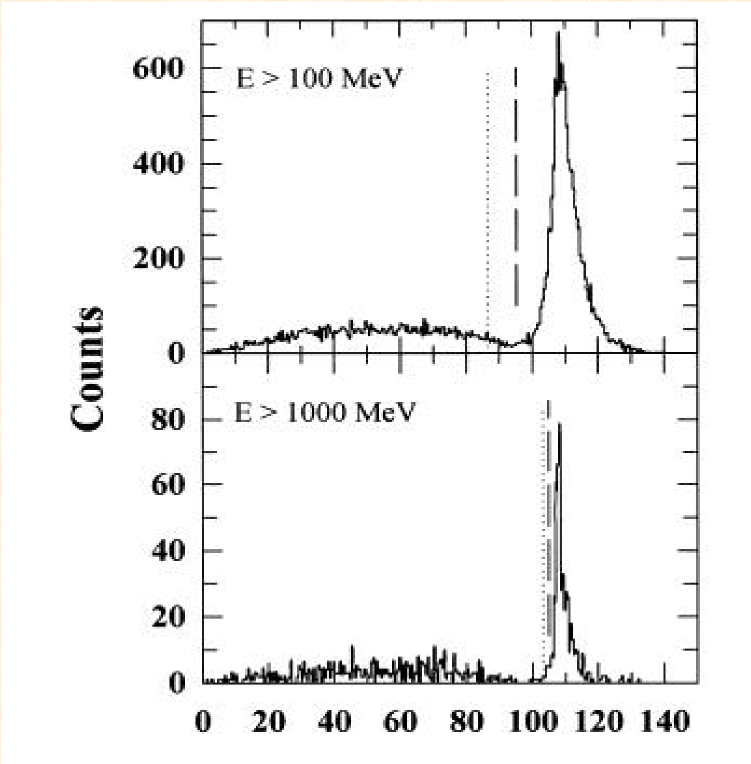
Each CGRO viewing period is summarized by 4 sets of maps, representing different energy binnings covering the entire field-of-view in rectangular coordinates. A single map set contains an exposure, counts, and intensity map.

Every map contains standard values for earth zenith angle cutoffs to avoid albedo events and are binned in 0.5x0.5 degree bins. The standard naming convention for counts maps is counts.vpnnnn.gmmm where nnnn represents the viewing period number, and mmm represents the map version.
The standard map versions use numbers 001-004 while customized maps are allocated higher numbers by EGRET software. Thus the original maps for the viewing period are always identifiable.

The four standard energy binnings are:

- **.g001 ->** $30<E<50$, $50<E<70$, $70<E<100$, $100<E<150$, $150<E<300$, $300<E<500$, $500<E<1000$, $1000<E<2000$, $2000<E<4000$, $4000<E<10000$
- **.g002 ->** $30<E<100$ MeV, $E > 100$ MeV
- **.g003 ->** $100<E<300$ MeV, $E > 300$ MeV
- **.g004 ->** $300<E<1000$ MeV, $E > 1000$ MeV

Earth Albedo



(Esposito et al. 1999)

A potential source of contamination is from Earth's albedo gamma rays. These gamma rays arise from cosmic-ray
interactions in the Earth's upper atmosphere and are indistinguishable from cosmic gamma rays in the spark chamber. EGRET triggering is disabled during the Earth occultation part of the orbit. EGRET carries two 4 x4 arrays of scintillator, tiles that allow a set of 96 possible subtelescope combinations. As the Earth enters the fieeld of view of any of the direction modes, triggering is disabled for that mode, and thus events with an arrival direction de‹ned by that direc-tion mode are not accepted. However, the albedo gamma-ray flux is quite large and peaks toward the horizon.

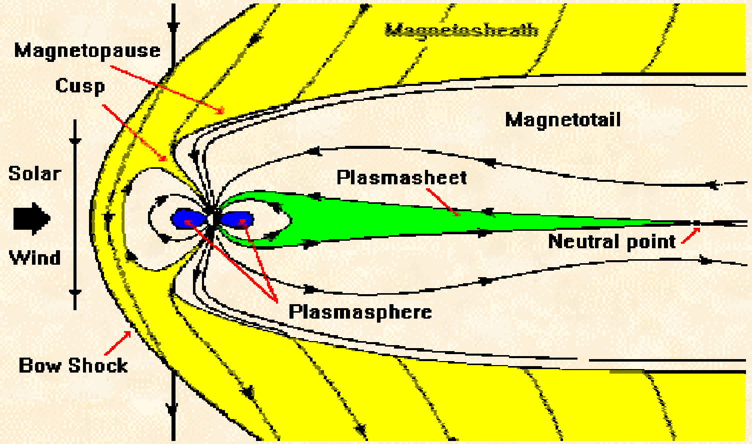
Each mode has a corresponding set of calibration files which are used to calculate instrument response for that particular mode.

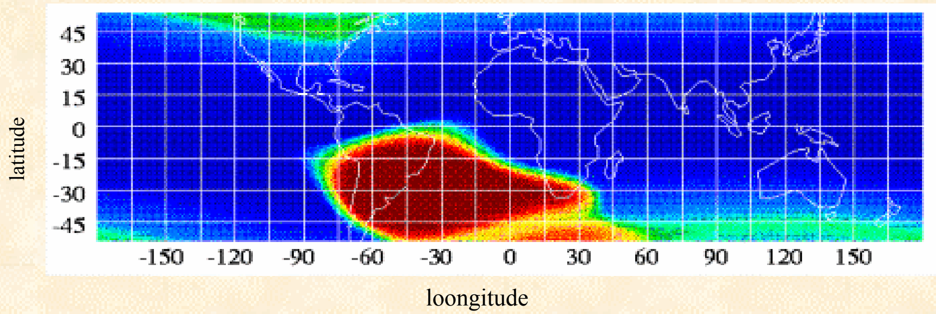
For each observation, an Exposure History file is created to keep track of the times when the EGRET instrument changes mode and how much livetime is spent in that mode.

South Atlantic Anomaly

Earth is surrounded by a close-to-spherical magnetic field, the magnetosphere. According to what we know today, it is being generated by dynamo action in theEarth's interior where conducting liquid metals are kept in motion by the forces of convection (heat exchange), coriolis, and gravitation, and just as the charged windings in the coil of a dynamo generate a magnetic field when moved, these masses create the Earth's magnetic field.

A a certain location over the South Atlantic Ocean, off the coast of Brazil, the shielding effect of the magnetosphere is not quite spherical but shows a "pothole", a dip, which scientists explain as a result of the eccentric displacement of the center of the magnetic field from the geographical center of the Earth (by about 400 Km) as well as the displacement between the magnetic and geographic poles of Earth. For orbits tilted (inclined) between 35 and 60 degrees against Earth's equator and having altitudes of a few hundred miles, this oddity, called the South Atlantic Anomaly (SAA) becomes important, because spacecraft in those orbits periodically pass through that zone of reduced natural shielding and thus spend a few minutes during each passage exposed to higher particle flux than outside it.





South Atlantic Anomaly Detector (SAAD) aboard the ROSAT spacecraft.
It consists of 10 cm_ of Germanium and served as a particle background monitor.

Standard Data Files (3)

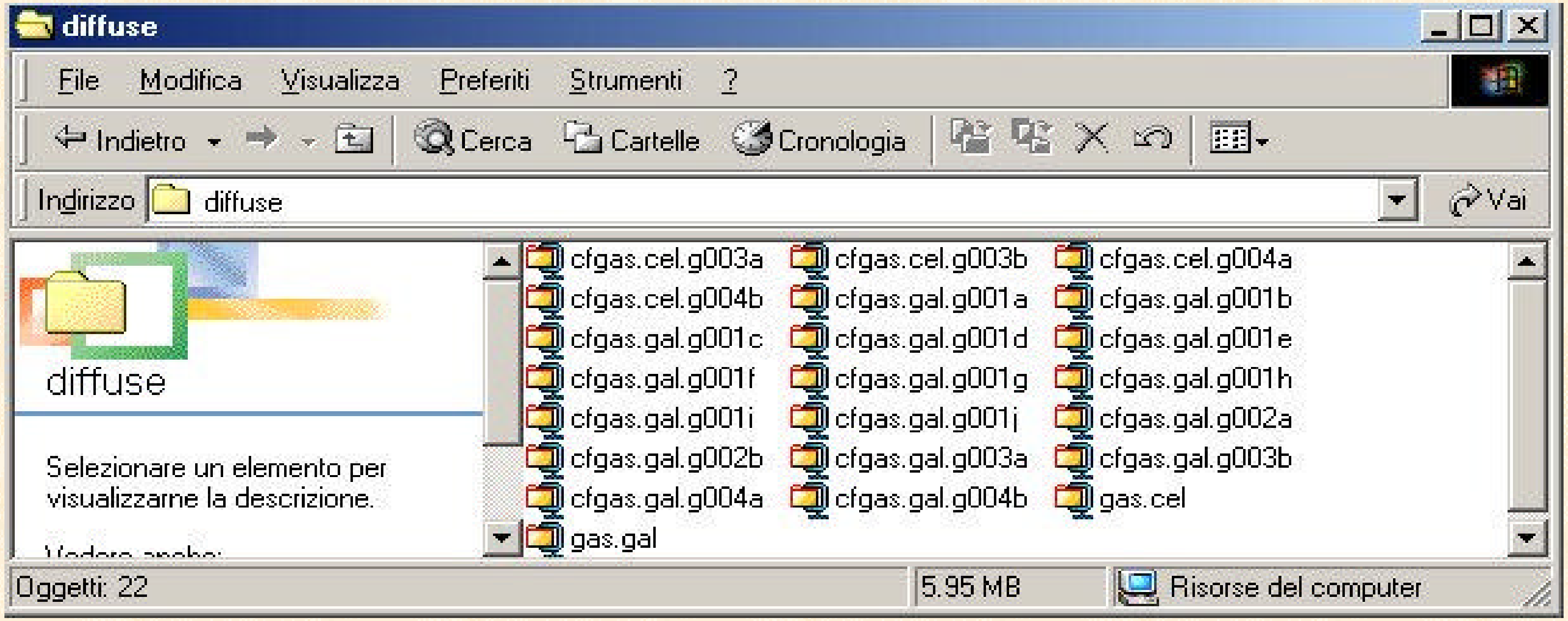
Calibration Files

EGRET calibration files (more properly calibration tables, since the files are the actual photon events).
The three types of tables describe the EGRET :

- **point spread (PSD)**
- **energy deposition (EDP)**
- **and sensitive area (SAR)**

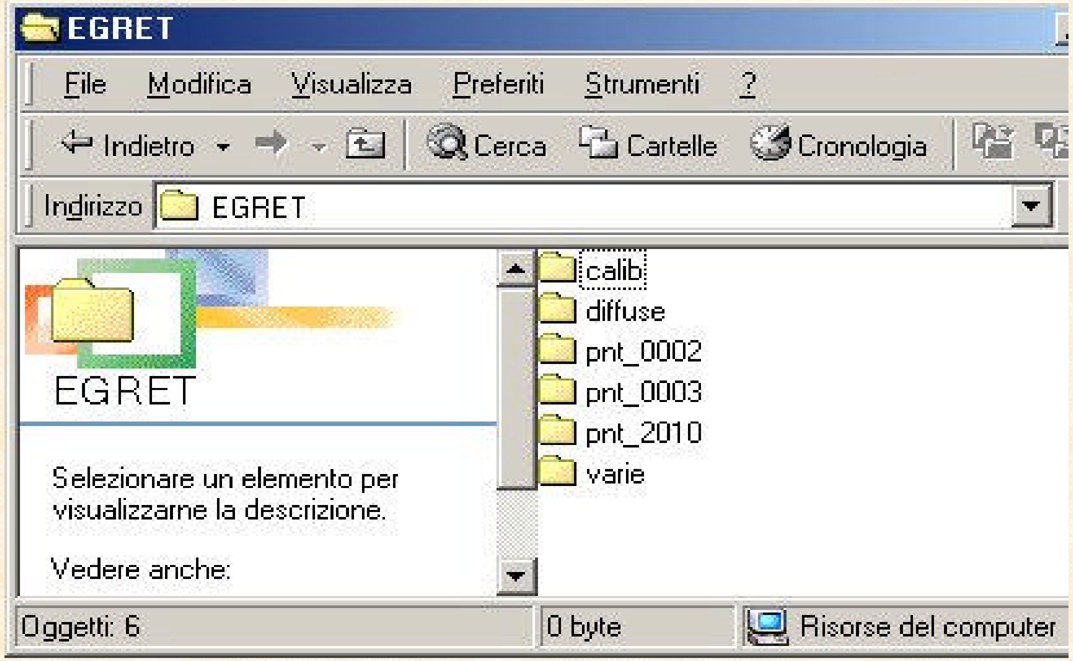
The naming convention for each file is
AAAfilnn where AAA is one of SAR/EDP/PSD and nn is a two digit number which denotes the major mode of EGRET.

Standard Data Files (4)



Diffuse emission model files

Standard Data Files (5)



Structure of the data directory

Standard Analysis Software -Utility programs

•**POINTEXPOSE** - C, FORTRAN, XView, X11 - Calculates the sensitive area and
•livetimes as a function of time for any point in the sky, useful for variability analyses.
•**PTEXPO** - C, FORTRAN, XView, X11 - Calculates the exposure for a given time range for any point in the sky.
•**QUICKLOOK** - FORTRAN, FITSIO, PGPLOT, and X11 - Views and selects individual photon events.
•**SKYMAP** - IDL - Views and manipulates EGRET FITS maps
•**SKYUTIL** - C, XView, X11 - Performs various useful tasks associated with point sources and candidate sources.
•**TRANSMAP** - C, FORTRAN, XView, X11 - Reprojects maps between spherical coordinate systems.
•**XPOSE** - C, FORTRAN, XView, X11 - Calculates the exposure as a function of time for any point in the sky, useful for variability analyses.

Standard Analysis Software - Point Source

ADDMAP - FORTRAN, XView, X11 (an FTOOL version also exists; see below)
• - Combines counts, exposure, and intensity maps for different viewing periods.
•**INTMAP** - FORTRAN, XView, X11 - Creates exposure and intensity maps using counts maps written by MAPGEN
•**LIKE** - FORTRAN, PGPLOT, and X11 –Performs maximum likelihood searches for point sources in EGRET data using counts and exposure maps and EGRET calibration files.
•**MAPGEN** - FORTRAN, X11 - Allows the user to create a custom counts map, e.g. for point source analysis with non-standard energy, spatial, or time binnings.
•**SHOW** - FORTRAN, FITSIO, PGPLOT, and X11 - Simple map analysis.
•**SPECTRAL** - FORTRAN - Makes spectral fits for point sources, taking into account EGRET's response using forward folding.

Standard Analysis Software:Timing Analysis

•**KBURST** - FORTRAN, IDL - Analyzes EGRET photons data for transient sources (up to time scales of orbits) in a given region.

•**PULSAR** - C, XView, X11 - The basic pulsar analysis program. Will look for a pulsed signal from known pulsars using the JPL ephemeris data and the Princeton pulsar catalog.

•**TBURST** - FORTRAN, XView, X11 - Analyzes EGRET TASC data for transient sources.

•**SEARCH** - C, FORTRAN - Period searches for gamma-ray sources.

FITS (1)

FITS was first developed in the late 1970's as a standard data interchange format between various astronomical observatories. Since then FITS has become the standard data format supported by most astronomical data analysis software packages.

A FITS file consists of one or more Header + Data Units (HDUs), where the first HDU is called the \`Primary HDU', or \`Primary Array'. The primary array contains an N-dimensional array of pixels, such as a 1-D spectrum, a 2-D image, or a 3-D data cube. Five different primary datatypes are supported: Unsigned 8-bit bytes, 16 and 32-bit signed integers, and 32 and 64-bit floating point reals. FITS also has a convention for storing 16 and 32-bit unsigned integers (see the later section entitled \`Unsigned Integers' for more details). The primary HDU may also consist of only a header with a null array containing no data pixels.

Any number of additional HDUs may follow the primary array; these additional HDUs are called FITS \`extensions'. There are currently 3 types of extensions defined by the FITS standard:
•Image Extension - a N-dimensional array of pixels, like in a primary array
•ASCII Table Extension - rows and columns of data in ASCII character format
•Binary Table Extension - rows and columns of data in binary representation
In each case the HDU consists of an ASCII Header Unit followed by an optional Data Unit.

FITS (2)

Header or Data unit must be an exact multiple of 2880 8-bit bytes long. Any unused space is padded with fill characters (ASCII blanks or zeros).

Each Header Unit consists of any number of 80-character keyword records or `card images' which have the general form:

KEYNAME = value / comment string

NULLKEY = / comment: This keyword has no value

The keyword names may be up to 8 characters long and can only contain uppercase letters, the digits 0-9, the hyphen, and the underscore character. The keyword name is (usually) followed by an equals sign and a space character (=) in columns 9 - 10 of the record, followed by the value of the keyword which may be either an integer, a floating point number, a character string (enclosed in single quotes), or a boolean value (the letter T or F). A keyword may also have a null or undefined value if there is no specified value string, as in the second example, above The last keyword in the header is always the `END' keyword which has no value or comment fields..

Each Header Unit begins with a series of required keywords which depend on the type of HDU. These required keywords specify the size and format of the following Data Unit. The header may contain other optional keywords to describe other aspects of the data, such as the units or scaling values. Other COMMENT or HISTORY keywords are also frequently added to further document the data file.

The optional Data Unit immediately follows the last 2880-byte block in the Header Unit. Some HDUs do not have a Data Unit and only consist of the Header Unit.

If there is more than one HDU in the FITS file, then the Header Unit of the next HDU immediately follows the last 2880-byte block of the previous Data Unit (or Header Unit if there is no Data Unit).

FITS (3)

The main required keywords in FITS primary arrays or image extensions are:

BITPIX - defines the datatype of the array: 8, 16, 32, -32, -64 for unsigned 8-bit byte, 16-bit integer, 32-bit integer, 32-bit IEEE floating point, and 64-bit IEEE double precision floating point, respectively. NAXIS - the number of dimensions in the array, usually 0, 1, 2, 3, or 4.
NAXISn - (n ranges from 1 to NAXIS) defines the size of each dimension.

FITS tables start with the keyword

XTENSION = `TABLE' (for ASCII tables)
or
XTENSION = `BINTABLE' (for binary tables) and have the following main keywords:
TFIELDS - number of fields or columns in the table
NAXIS2 - number of rows in the table
TTYPEn - for each column (n ranges from 1 to TFIELDS) gives the name of the column
TFORMn - the datatype of the column
TUNITn - the physical units of the column (optional)

More Information at: http://www.cv.nrao.edu/fits/

EGRET Data- Fits Header

qvp0002s_h1

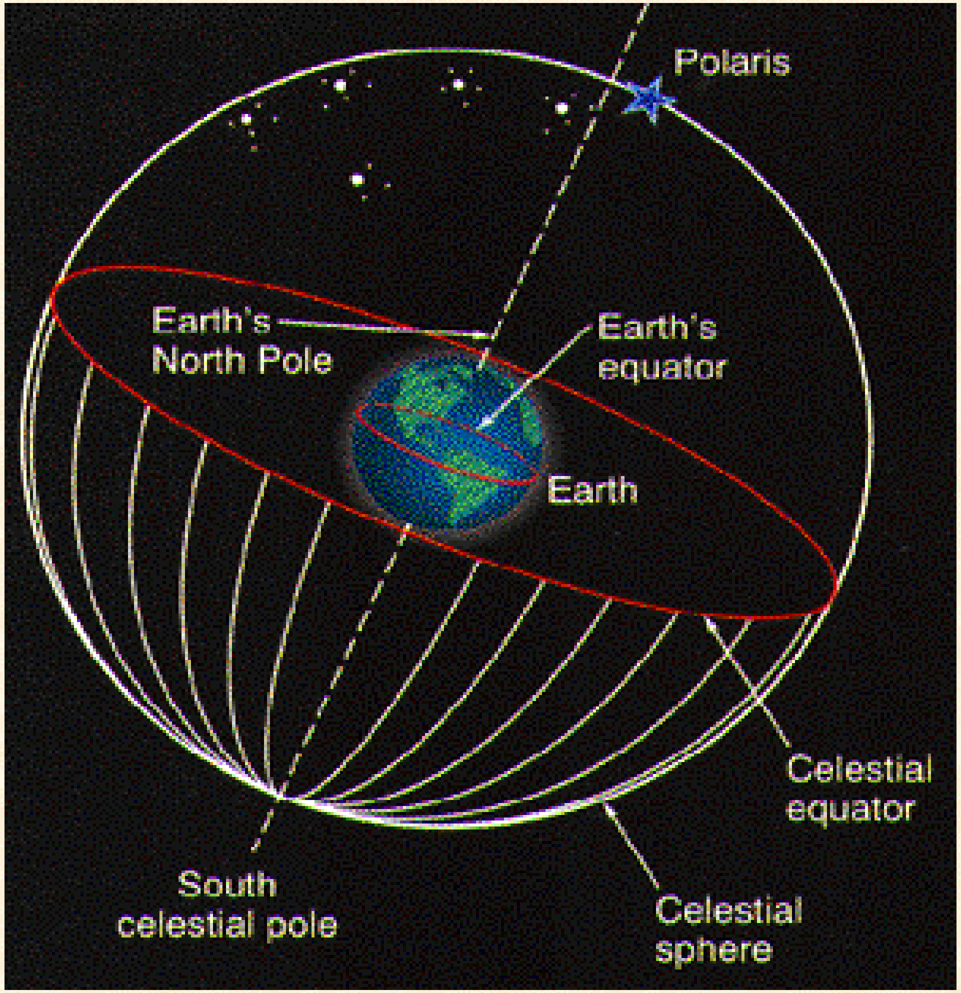
counts_vp0002_g001_h0

exposr_vp0002_g001_h0

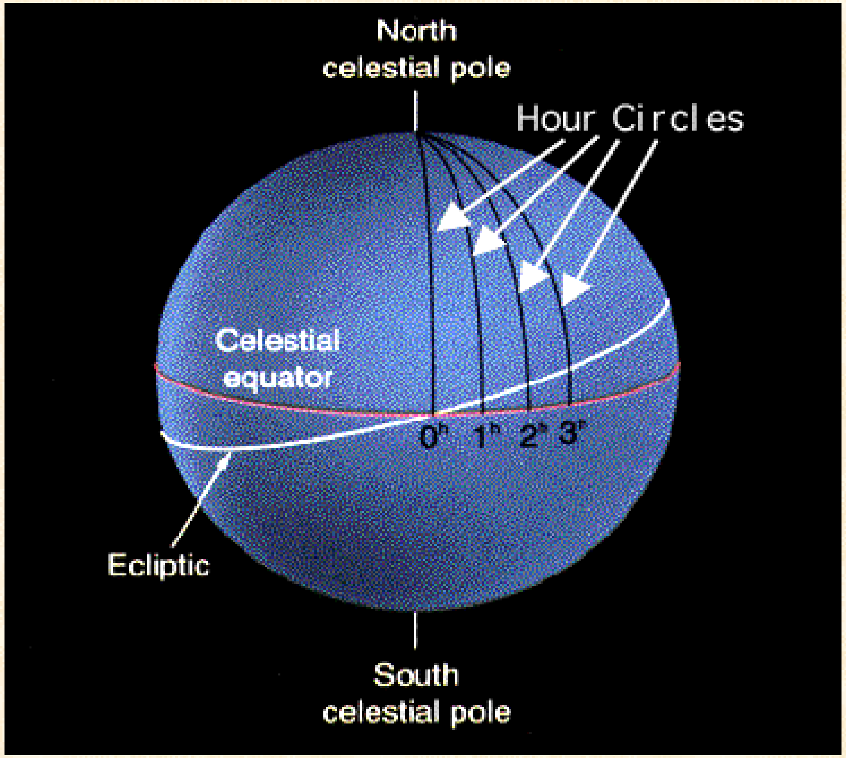
Geocentric coordinate systems

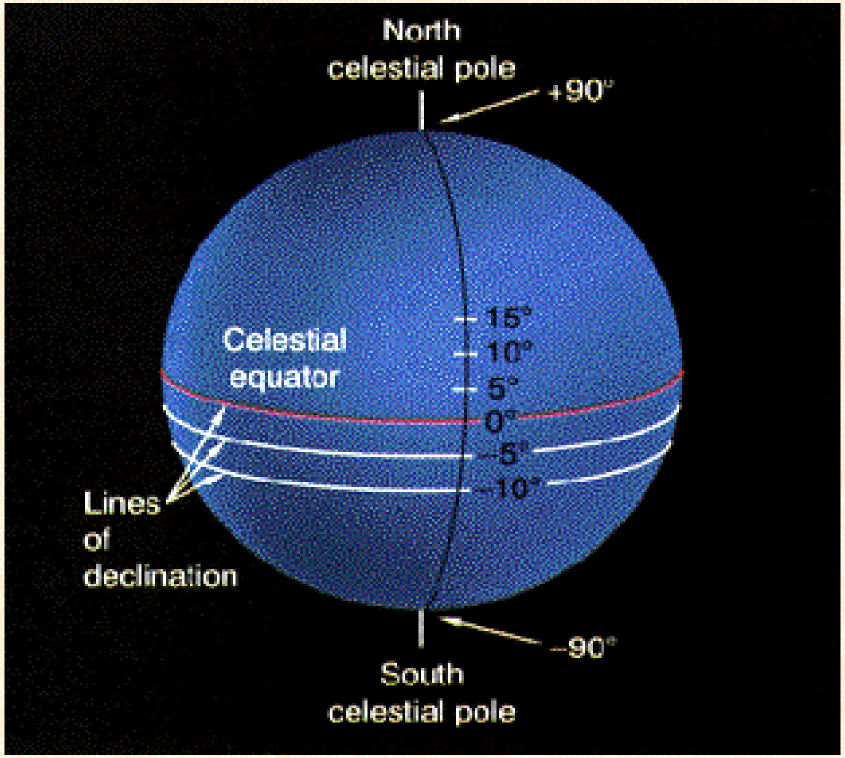
•Geocentric equatorial inertial	GEI	X=First point of Aries Z=Geographic North Pole
•Geographic	GEO	X=Intersection of Greenwich meridian and geographic equator Z=Geographic North Pole
•Geocentric solar ecliptic	GSE	X=Earth-Sun line Z=Ecliptic North Pole
•Geocentric solar magnetosph.	GSM	X=Earth-Sun line Z=Projection of dipole axis on GSE YZ plane
•Solar magnetic	SM	Y=Perpendicular to plane containing Earth-Sun line and dipole axis.Positive sense is opposite to Earth's orbital motion Z=Dipole axis
•Geomagnetic	MAG	Y=Intersection between geographic equator and the geographic meridian 90 degrees east of the meridian containing the dipole axis Z=Dipole axis

The Celestial Sphere



The Equatorial Coordinate System

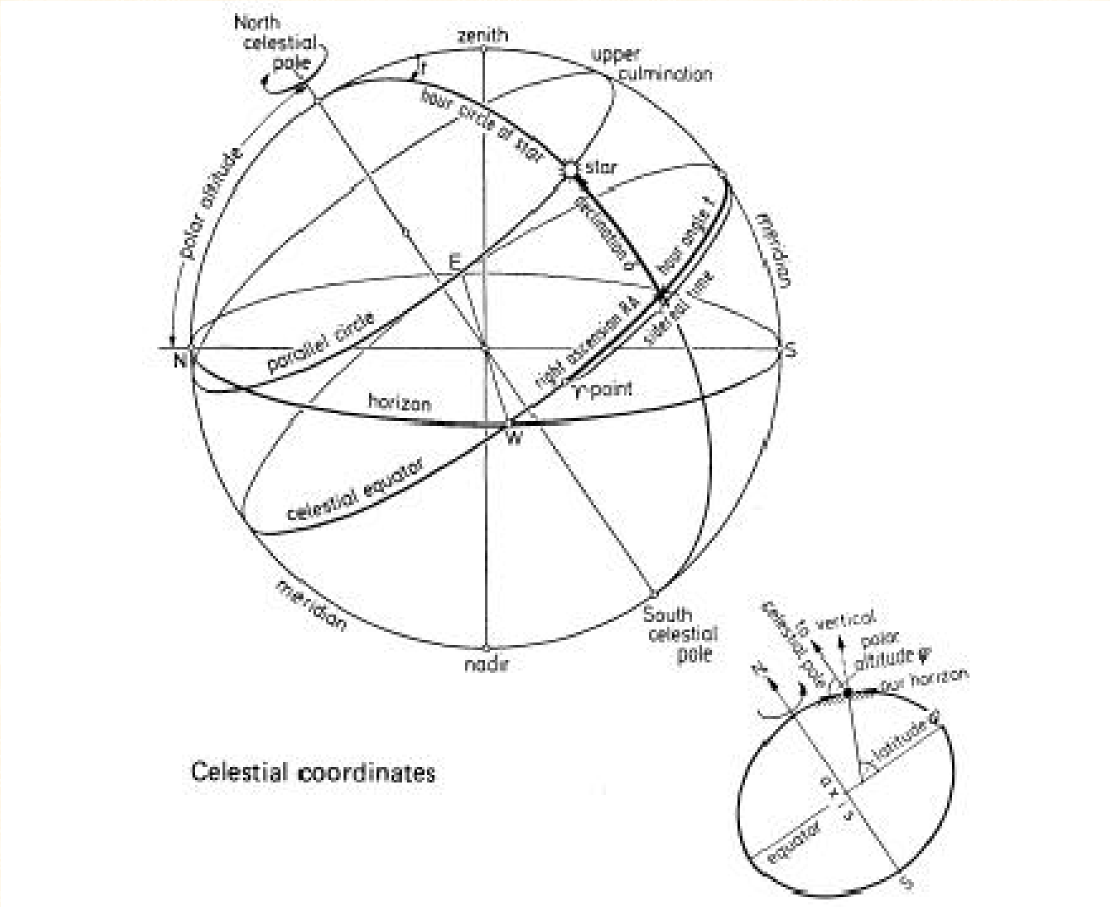




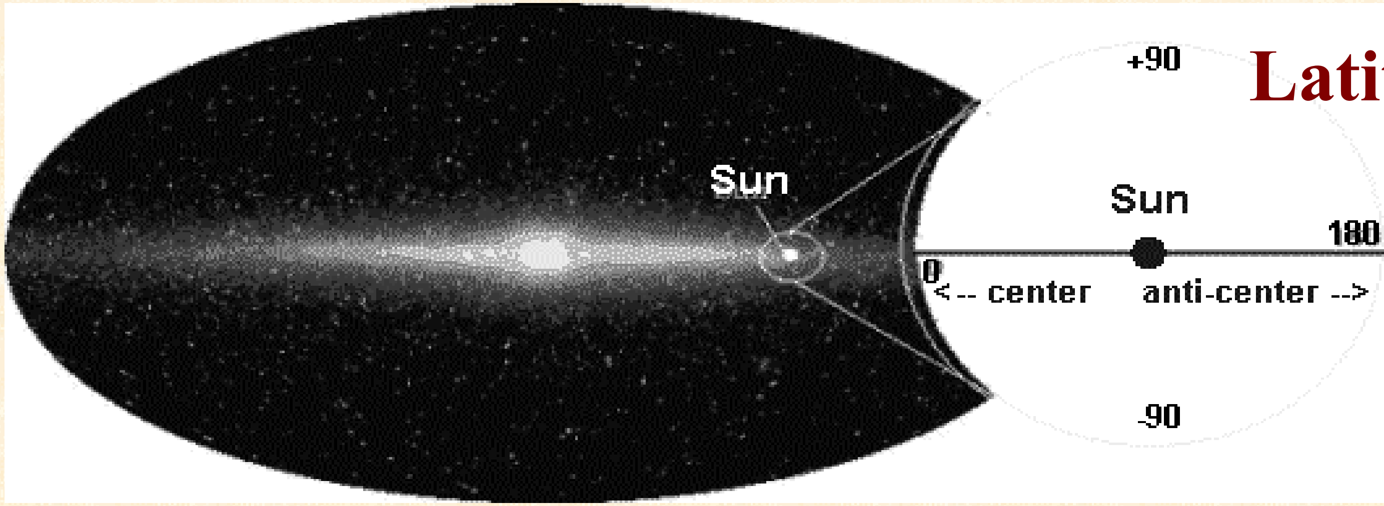
Astronomical coordinates (Equinox)

Most of the time, the direction of the Earth's rotation around its own axis, and the direction of its orbit around the Sun, vary from one another. As the Earth tilts backward and forward in its orbit, though, these two angles coincide from time to time. This event is known as an Equinox, and happens twice a year, in March (the Vernal Equinox) and again in September (the Autumnal Equinox).

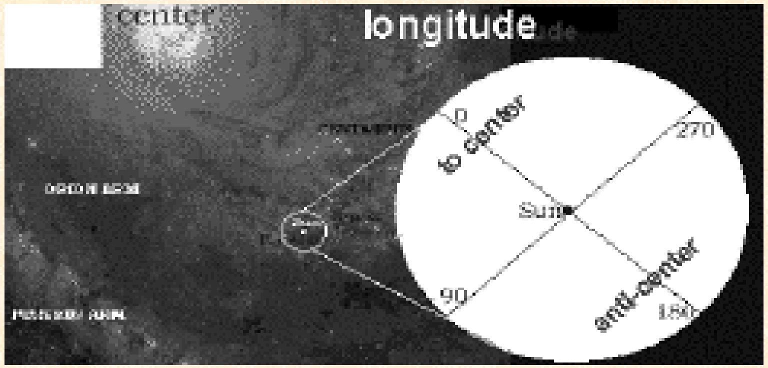
Celestial Coordinate



Galactic Coordinate

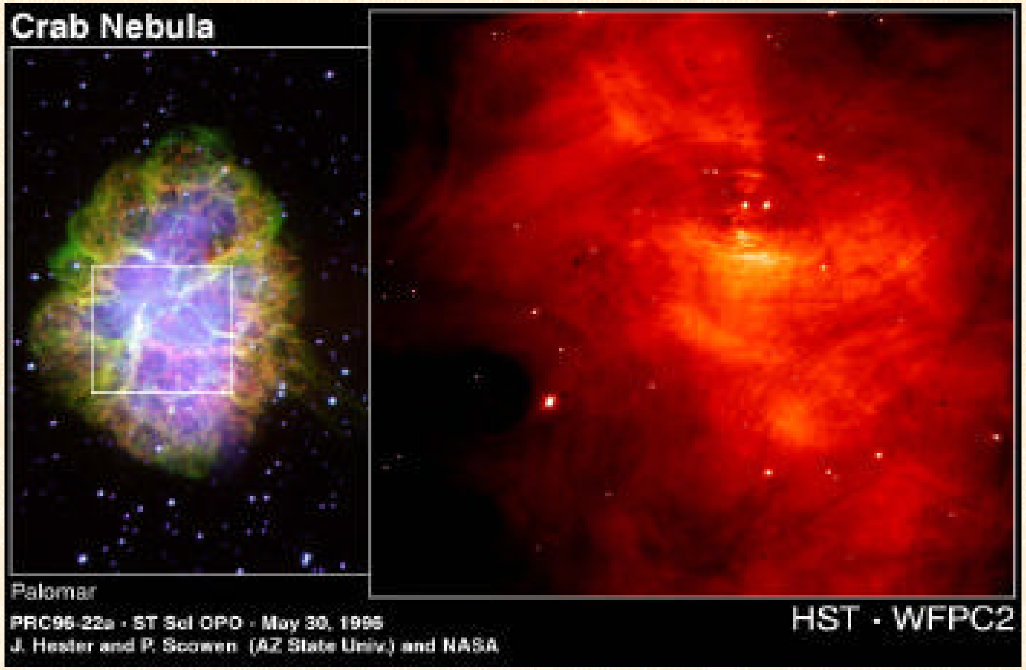


Latitude: l



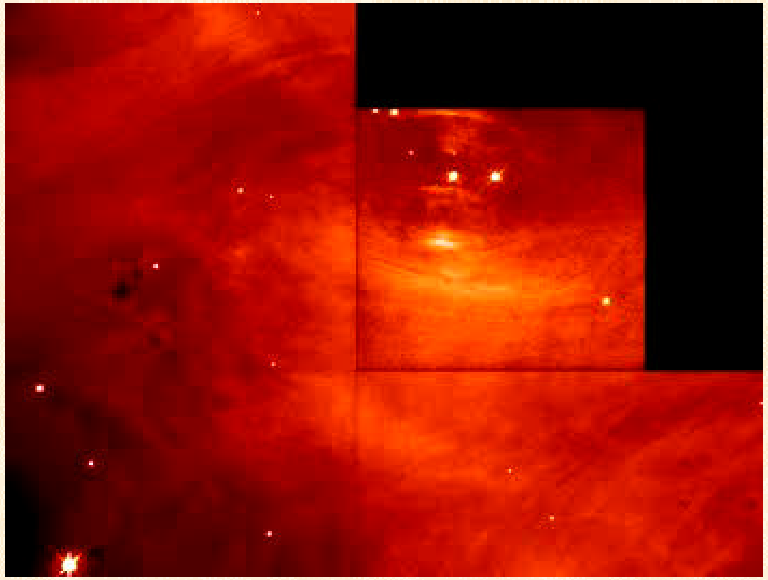
Longitude:b

Example (1) – The Crab Nebula



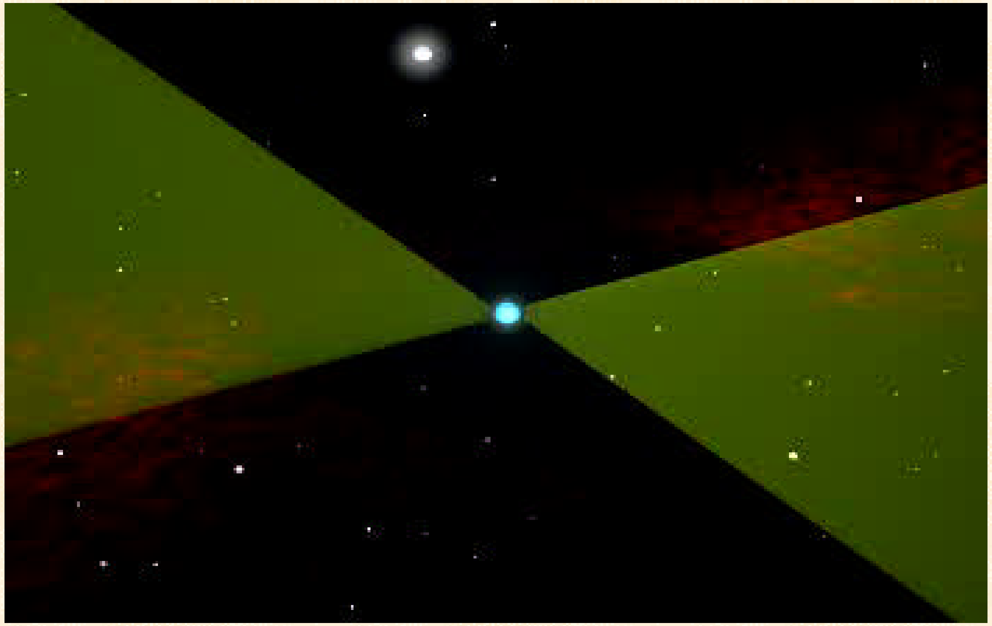
Object Category: Supernova Remnant and Pulsar
Coordinates: (J2000)
Right Ascension 05h34m32s
Declination 22d00m52sec
Constellation: (Tau)
Object Description: The Crab Nebula is the remnant of a supernova explosion that was seen on Earth in 1054 AD. It is 6000 light years from Earth. At the center of the bright nebula is a rapidly spinning neutron star, or pulsar that emits pulses of radiation 30 times a second.

Example (2) – The Crab Nebula



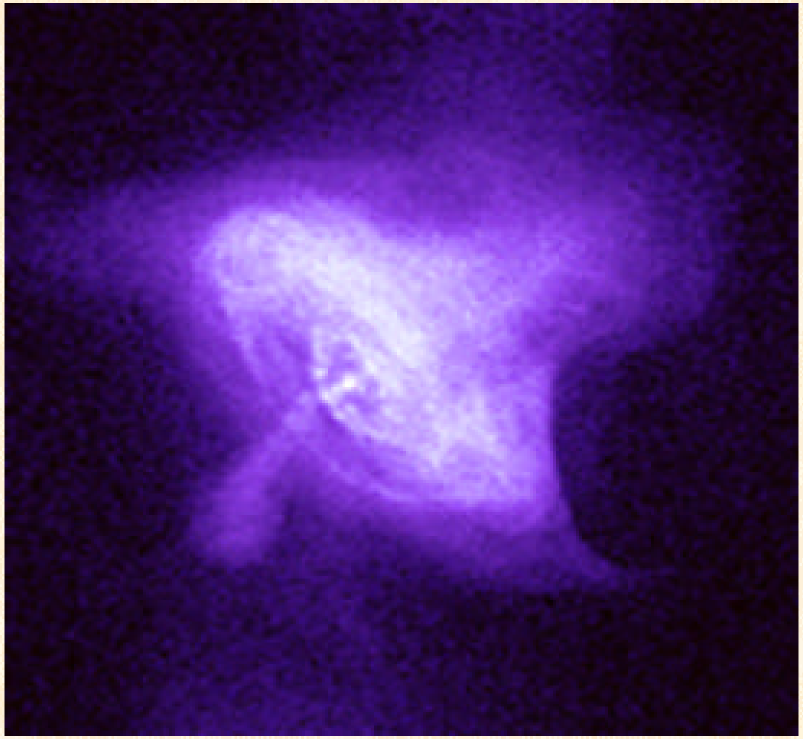
The movie is constructed from eight WFPC2 images and contains four sequences: 1) The full WFPC2 field, 2) a closer view of the pulsar, 3) closer still detailing the "sprite" which appears towards the top, and 4) extreme closeup of the pulsar and the inner knot just above it.

Example (3) – The Crab Nebula



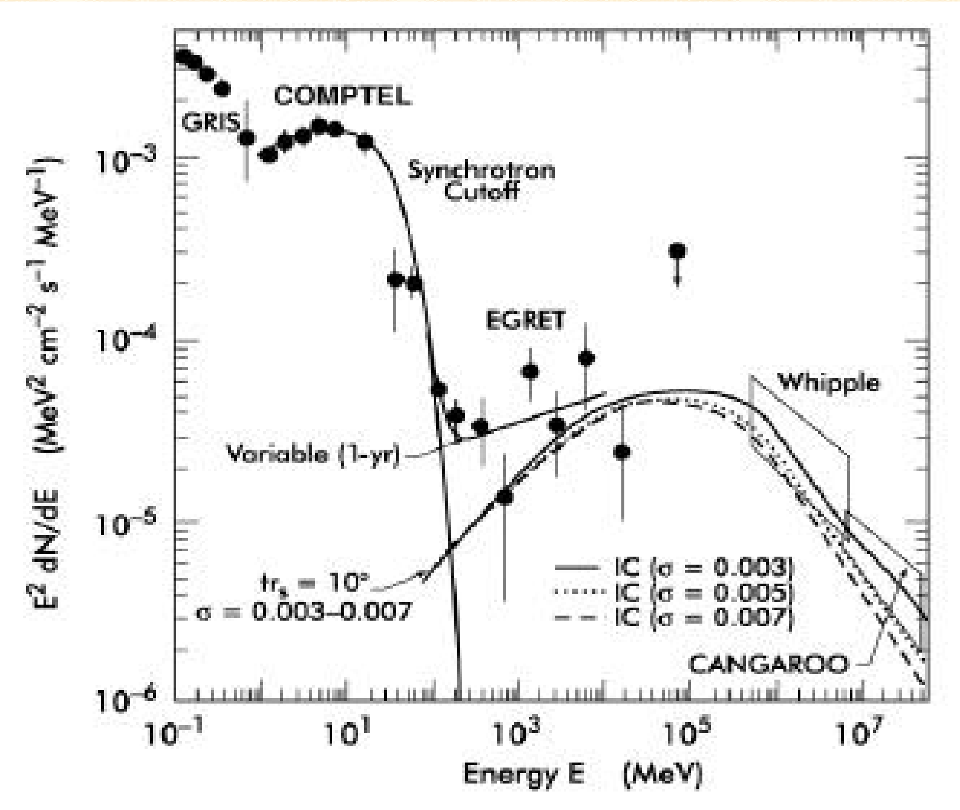
The sequence depicts the environment immediately around the central, rotating pulsar. The twin beams demonstrate the rotation of the neutron star which is surrounded by the equitorial wind (shaded red). As the observer pulls away from the pulsar, first the "inner knot" appears from the upper left, then followed by the "sprite", and finally, the jets which appear on opposing sides of the pulsar

Example (4) – The Crab Nebula

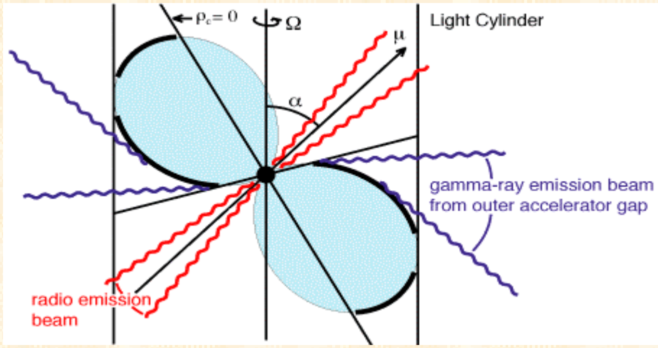


The CRAB in X-ray: CHANDRA observation

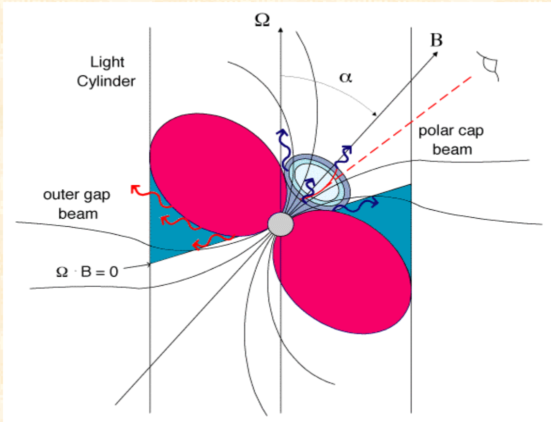
Example (5) – The Crab Nebula



CRAB SED



Outer Gap Model



Polar Gap Model

IDL

Start IDL