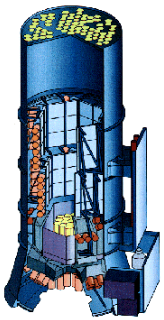
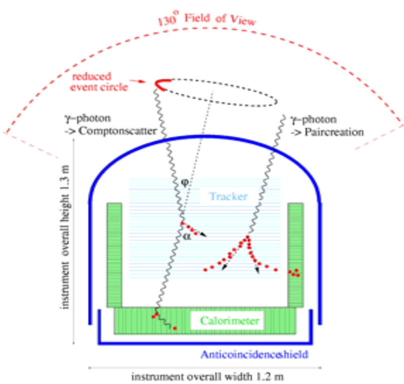
Telescope Principles in HE Astronomy



- **Coded Mask & Detector Array**
  (Multiple Pointings with Shadowing Mask and Position-Sensitive X-ray Detectors)

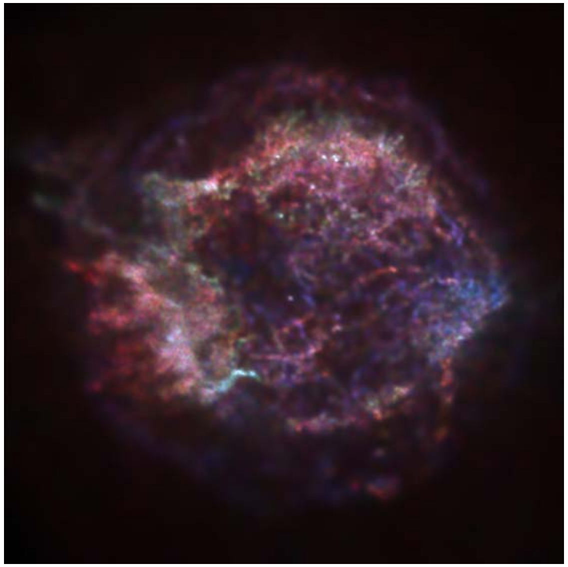


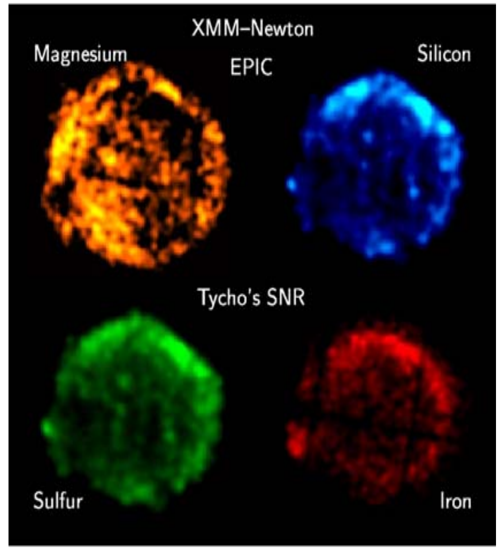
- **Compton Telescopes**
  (Coincidence-Setup of Position-Sensitive Gamma-Ray Detectors)

- **Detector Arrays**
  (Coincidence-Setup of Pixelized Light Detectors)

Data:= Teleskope Trigger Events (multi-parameter vector), NOT an Image

Data Type Examples





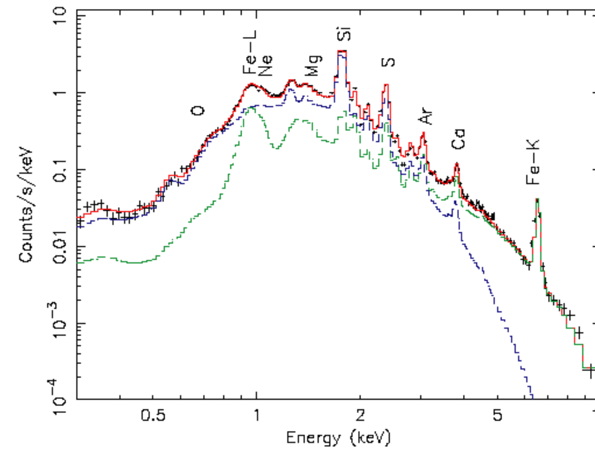
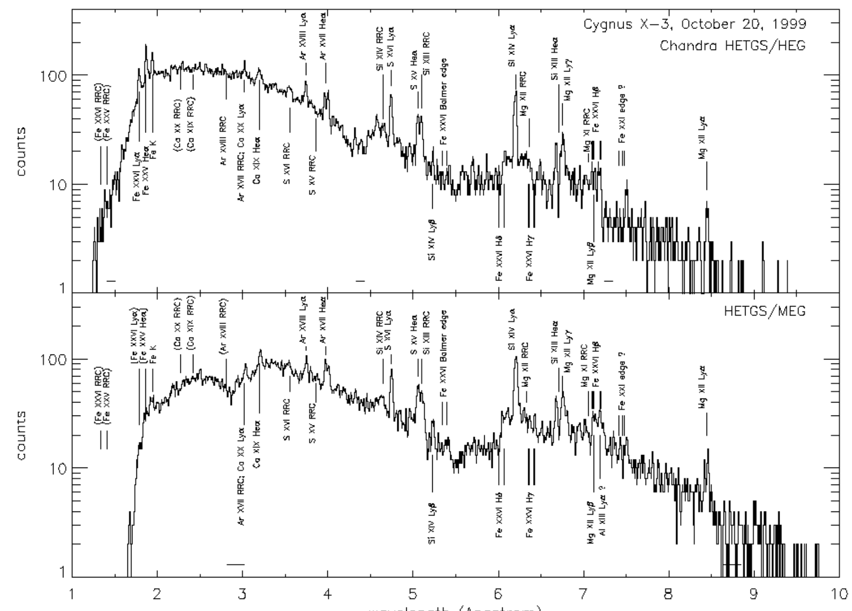
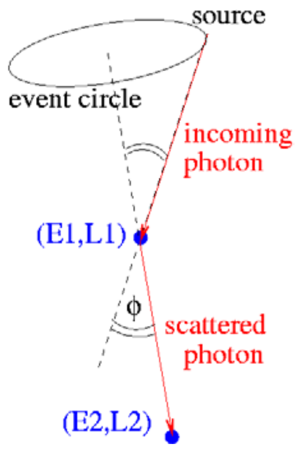


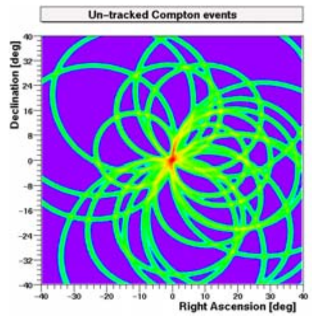
Fig. 2. An example of a spectral fit within a single 20″ × 20″ pixel – cool component in blue, hot component in green and full model in red.

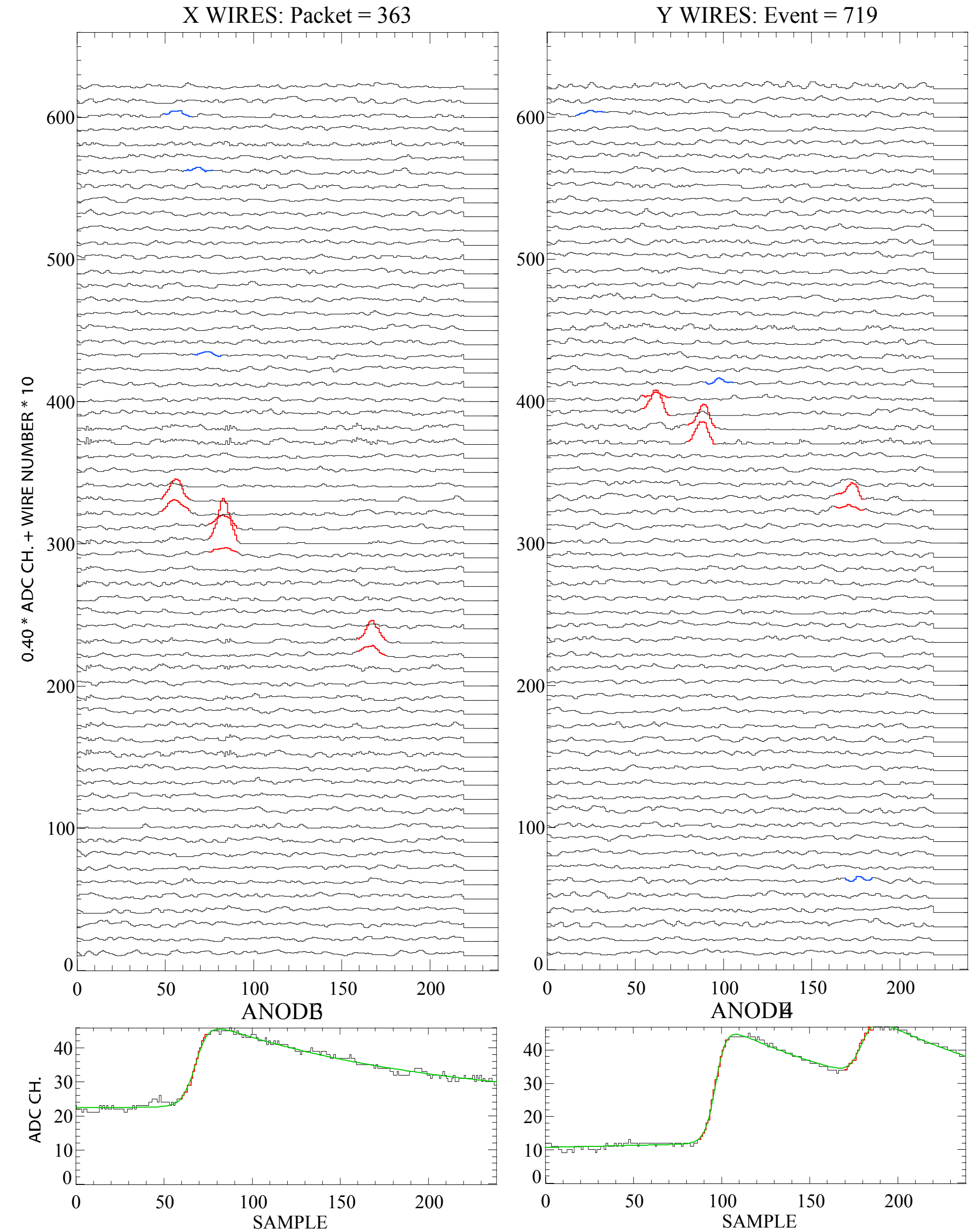
- X-ray Telescopes
  - ☆ Images
  - ☆ Spectra



Data Type Examples







- **Compton Telescopes:**
  - ☆ Time Series of Detector Triggers
    - ☞ Position
    - ☞ Energy
    - ☞ Particle Track

Rules for Making Scientific Statements

- Certainty: If A is certainly true given B, $P(A|B) = 1$
- Falsity: If A is certainly false given B, $P(A|B) = 0$
- Other rules exist for more complicated types of information; for example, invariance arguments, maximum (information) entropy, limit theorems (CLT; tying probabilities to frequencies), bold (or desperate!) presumption. . .

Statistics of a Measurement

☆ We Are Counting Instrument's Triggers

- ☞ Multi-Parameter Event Messages
- ☞ Poisson Statistics

$$P_{n_i} = \frac{{m_i}^{n_i}}{n_i\,!} e^{-m_i}$$

- ☞ Poisson-Likelihood Function for Statistical Tests:

$$L_\alpha = \prod_{\substack{dataspace \\ cells-i}} \frac{{m_i}^{n_i}}{n_i\,!} e^{-m_i}$$

- ☞ Use As Statistical Criterion:

$$\lambda \equiv -2\ln(L_\alpha) = \sum_{dataspacecells} m_i - n_i \cdot \ln(m_i) + \ln(n_i!)$$

(is distributed like $\chi 2$ for n degrees of freedom, n=no of free parameters in fit)

The Data Analysis Problem

- **Facts**
  - ☆ Measurement Obtained Data Instances
  - ☆ Experiment Has (Distorting) Characteristics

$$D = \int_{T_{obs}} S \bullet R dt$$

- **Goals**
  - ☆ Learn from Measurement
  - ☆ Put Lesson into Astrophysical Context

$$S = R^{-1} \bullet D$$

$$p(H \mid D, S)$$

- **Issues**
  - ☆ How to Avoid Bias
  - ☆ How to Account for Imperfections of Measurement, Experiment, Astrophysical Theories

Roland Diehl

The Instrumental Response

- **Instruments Distort the Measurement**
    - ☞Need to Determine Instrumental Response Function
    - ☞Need to Include Instrument Response in Analysis
- **Instrument Response Determination Methods**
    - ☆ Calibration Measurements
        - ☞Known Sources, Controlled Experiment
    - ☆ Simulations
        - ☞Simulated Sources and Environment
        - ☞Simulated Instrument
        - ☞Physical Processes Encoded in Software

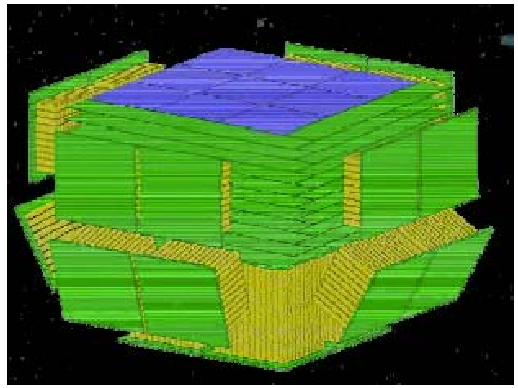
The Role of Simulations in Telescope Design

Prototypes, Balloons, etc.

MEGA Prototype

+

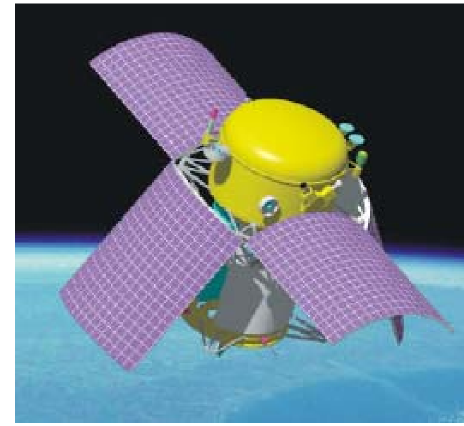
Simulations, Models, etc.



MEGA Prototype Simulation Model

=

Scientific Mission



MEGA Flight Concept

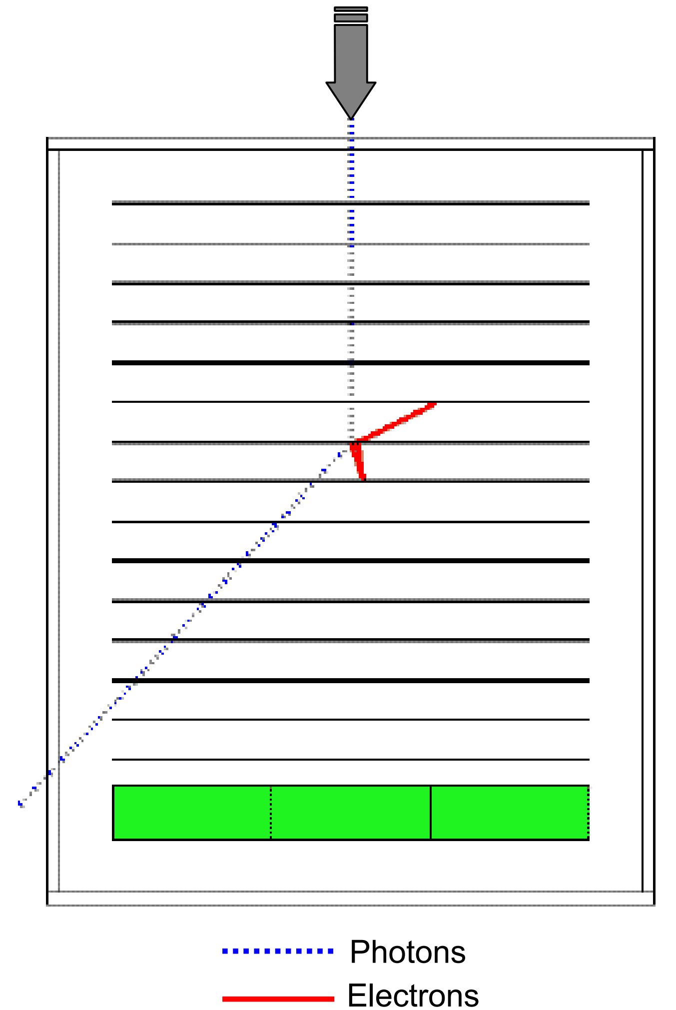
- ✚ Realistic component performance
- ✖ Expensive and time consuming
- ✖ Inflexible configuration
- ✖ Unrealistic environment

- ✚ Inexpensive and comparatively rapid
- ✚ Flexible configuration
- ✚ Flexible environment
- ✖ Must *model* the component performance

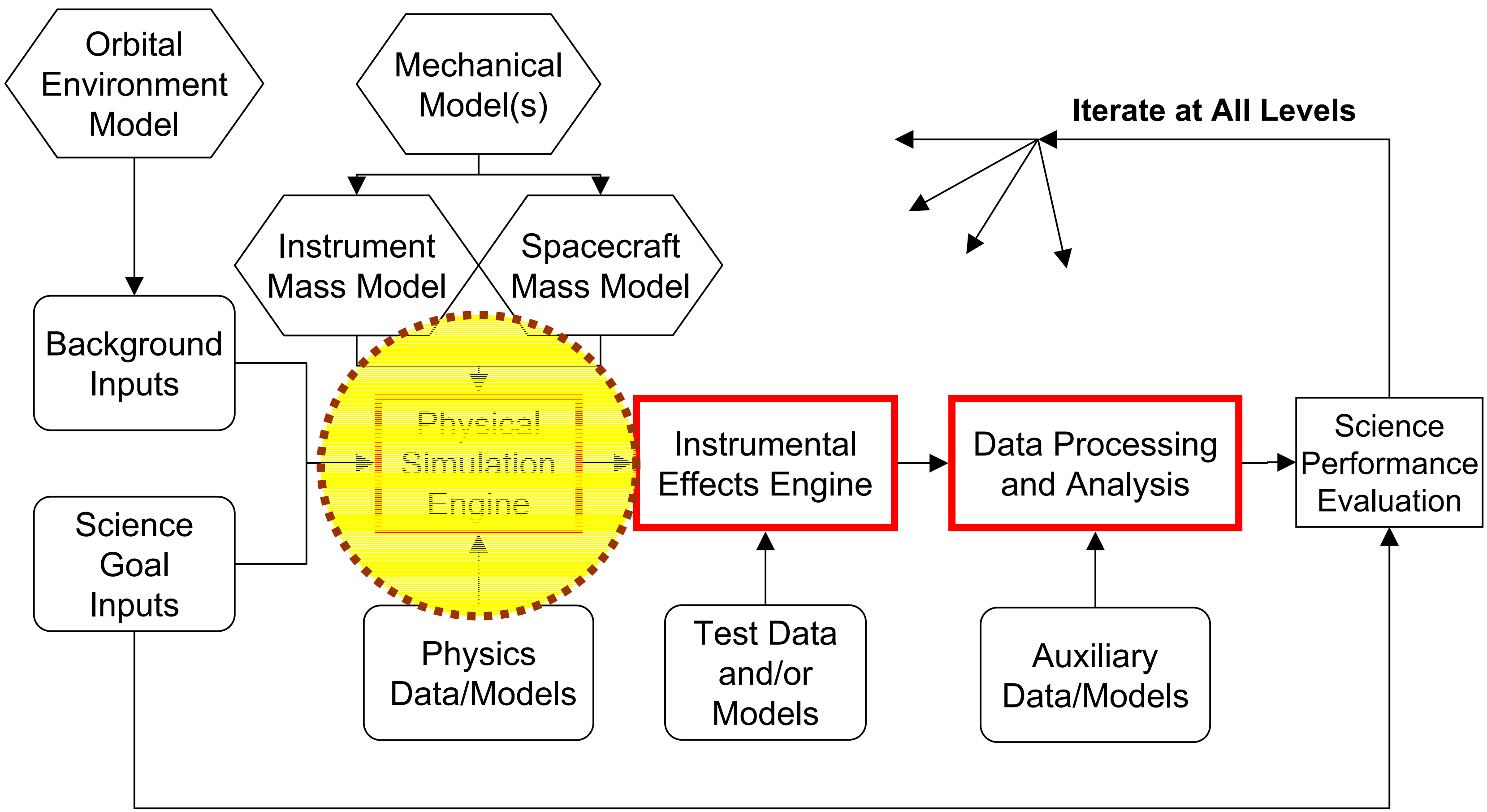
- Successful flight experiment, where:
  - ☆ Realistic estimates of performance help "sell" the mission
  - ☆ Instrument design is optimized for scientific mission and environment

Simulating Compton Telescopes

- Analytical modeling of Compton imager physical response is impractical due to complexities of geometry, scattering, and secondary production
- The most viable approach is *Monte Carlo radiation transport* simulation — probabilistic tracking individual "test particles"
- Other simulations important to instrument design: mechanical, thermal, electronics, etc.



Instrument Simulation Framework



Credible Simulation Requires Credible Inputs at All Levels

Monte Carlo Radiation Transport Packages

- Requirements for (e.g. Compton Telescope) simulations:
  - ☆ Detailed electromagnetic physics for direct telescope response (~1 keV – …100 MeV)
  - ☆ Competent hadronic cascade physics for simulation of prompt cosmic-ray–induced background
  - ☆ Isotope excitation and radioactive decay for simulations of delayed activation-induced background
  - ☆ Convenient and flexible handling of complex geometry and materials for rapid design studies
  - ☆ Modern, modular architecture that allows customization

- The particle and nuclear physics communities have developed several "general-purpose" Monte Carlo transport packages, including:
  - ☆ EGS
  - ☆ FLUKA
  - ☆ HETC/MORSE/MICAP
  - ☆ CALOR
  - ☆ MCNP/MCNPX
  - ☆ GEANT/GEANT4

An Example: Capabilities of GEANT4

GEANT := GEometry And Tracking

- Complex 3D geometry, materials, MC transport, and visualization in <u>one package</u>
- Developed & maintained by CERN + large collaboration
- Modern, object-oriented (C^{++}) “toolkit” architecture
- Comprehensive (nearly) suite of EM <u>and</u> hadronic physics
- Straightforward installation and use on many platforms
  - ☆ Wintel, Sun, HP, Linux, Darwin

geant4.web.cern.ch

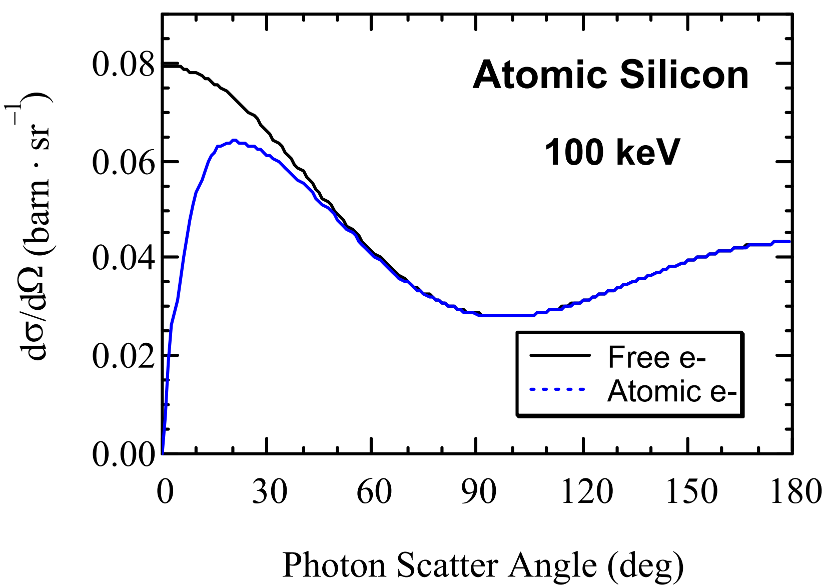
- ESA Space Specific Modules
- General Source Particle Module
  - ☆ Tookit for input spatial/spectral sampling
- Radioactive Decay Module
  - ☆ Provides the capability to model activation-induced background in orbit
  - ☆ Uses detailed Evaluated Nuclear Structure Data Files
- Low-energy EM physics
  - ☆ Uses detailed cross sections from LLNL Evaluated Photon/Electron/Atomic Data Libraries
  - ☆ Applicable above ~250 eV
  - ☆ Ties X-ray and Gamma-ray applications
  - ★ Important omission: electron binding effects in Compton

www.space.qinetiq.com

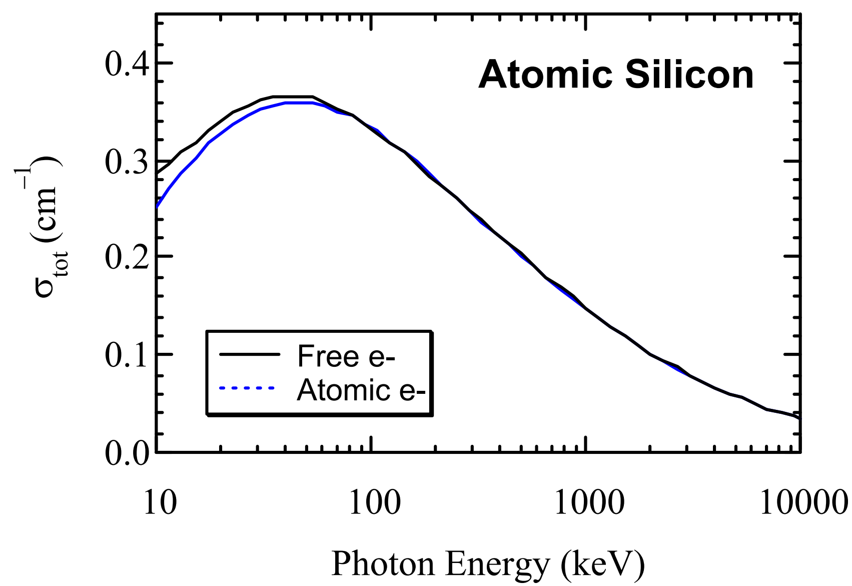
Detailed Physics Example: Effects of Atomic Electron Binding

$$\left(\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega \mathrm{d}k}\right)_i = \frac{r_o^2}{4}\left(\frac{k_f k}{k_o^2}\right)\left(\frac{k_f}{k_o}+\frac{k_o}{k_f}-\sin^2\varphi\right)\frac{\mathrm{d}p_z}{\mathrm{d}k}J_i(p_z)$$

- Suppresses forward scattering, particularly at low energies



- Suppresses total scattering probability at low energies

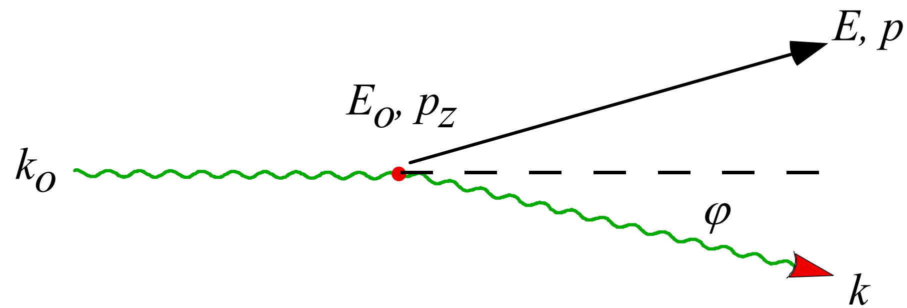


- *GEANT4 Low-energy Compton process includes these effects*

Doppler Broadening Physics & Effects

For free electron: $p_z = 0\,;\, E_o = m_o c^2$

$$k_{\text{free}} = k_o - \frac{k_o k}{m_o c^2}(1-\cos\varphi)$$

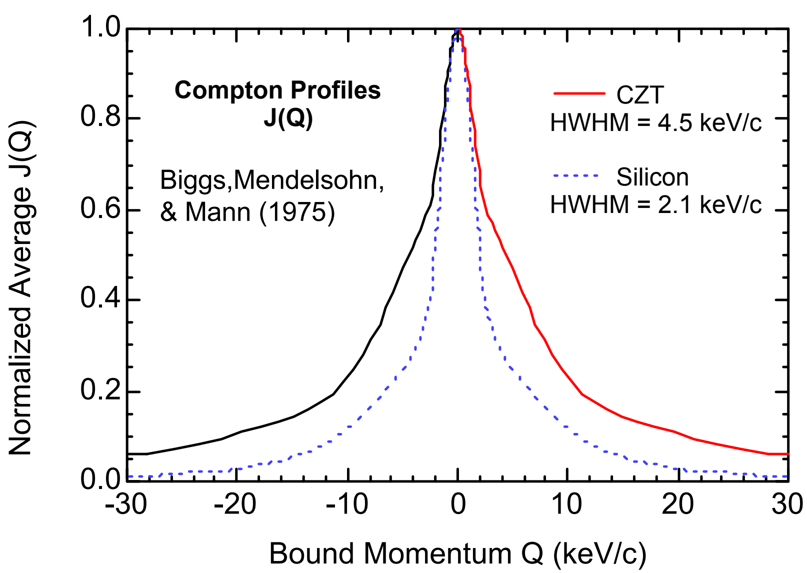


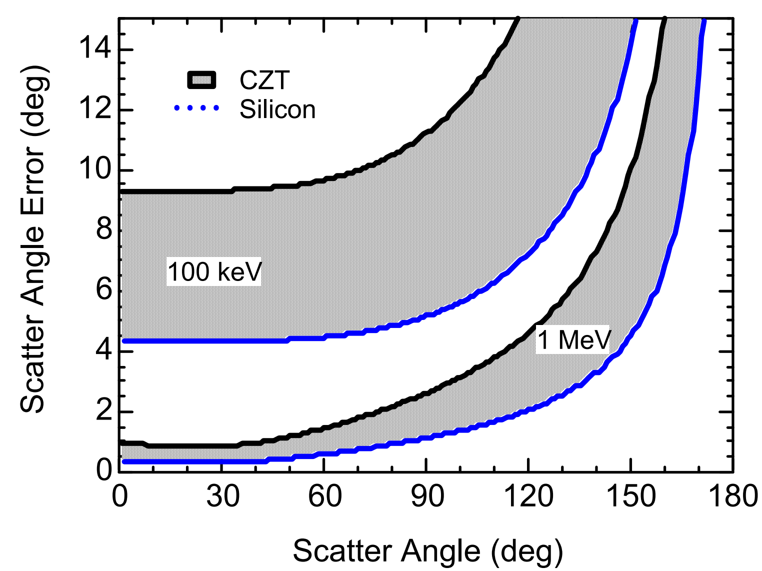
For bound atomic electron:

$$k = k_o - \frac{k_o k}{E_o}(1-\cos\varphi) - p_z\left|\mathbf{k_o} - \mathbf{k}\right|$$

Doppler broadening error:

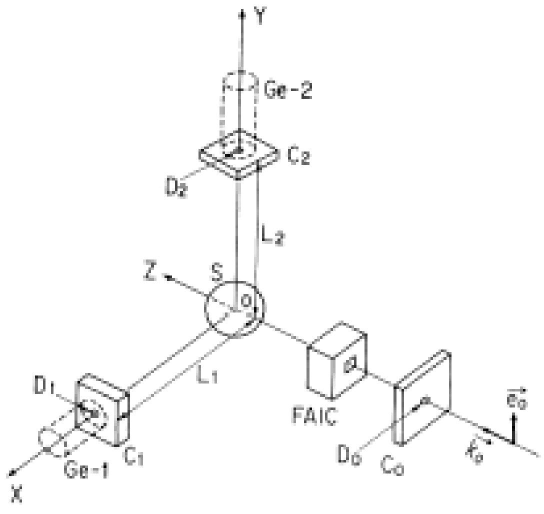
$$\Rightarrow \quad \Delta k = k - k_{\text{free}}; \quad \Delta\varphi = \varphi - \varphi_{\text{free}}$$



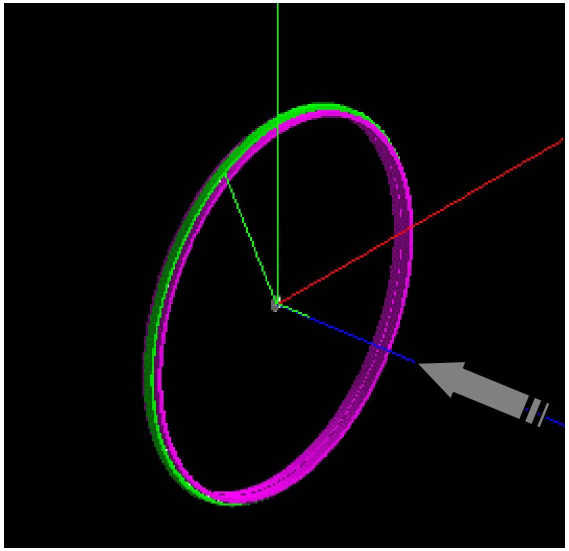


Example: Verification of G4LECS

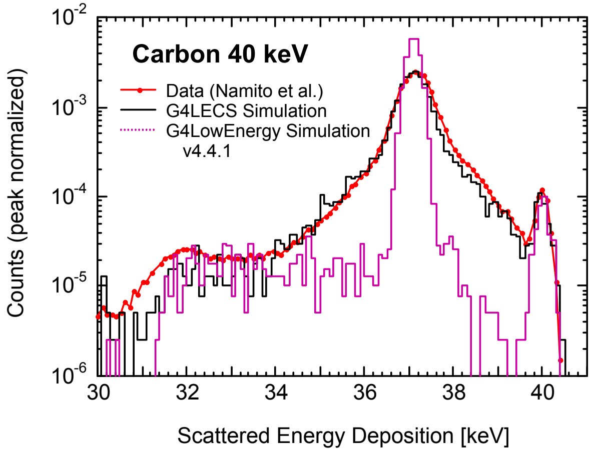
- **G4LECS compared to synchrotron beam experiment**
  - Namito, Ban, Hirayama, et al. (1994, 1995)



Experiment
(Polarized Beam)



Simulation
(Unpolarized Beam)



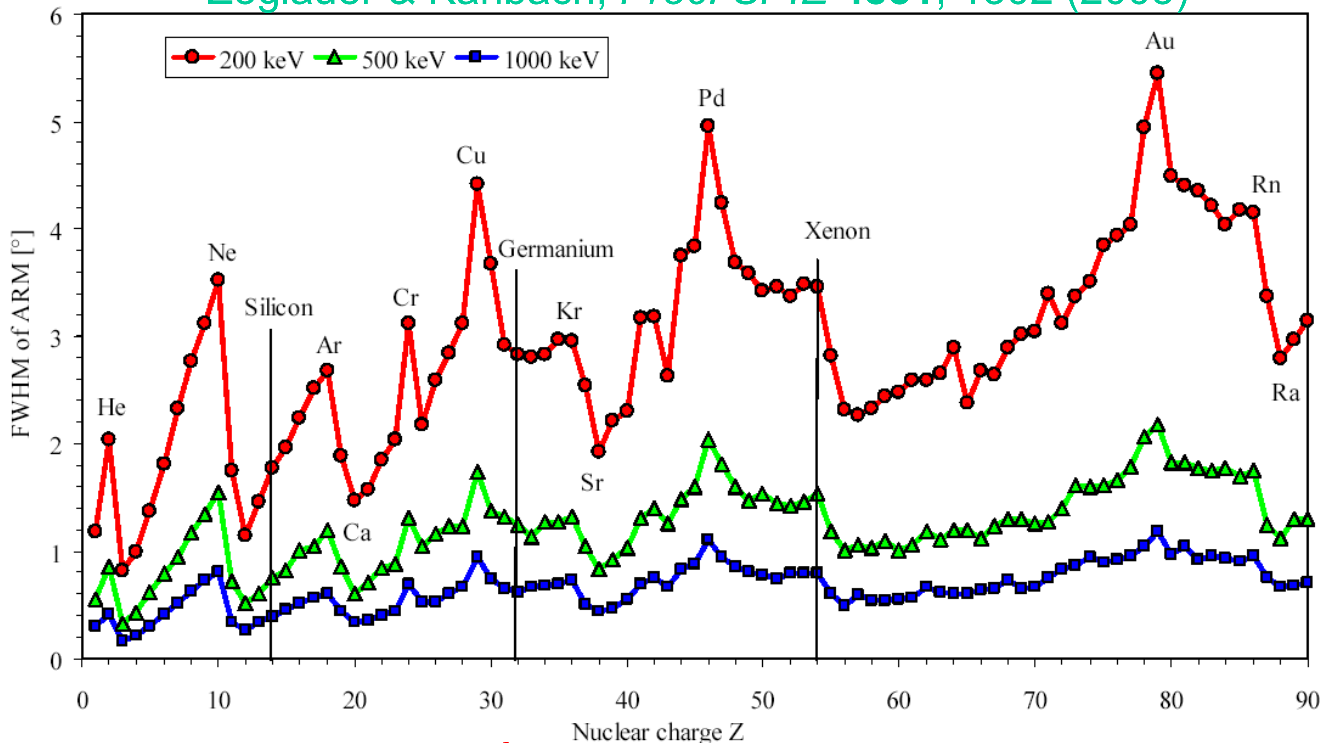
Test Results:

- Good agreement in Compton and Rayleigh peaks (and Ge-K escape)
- Some differences in multi-Compton continuum probably due to approximated geometry

MC Simulations with GEANT: Application to Compton Telescope Design

Doppler Limit Angular Resolution

Zoglauer & Kanbach, *Proc. SPIE* **4851**, 1302 (2003)



Material	Si	Ge	CdTe	Xe	Ne213	CsI	NaI
FWHM at 200 keV [°]	1.80	2.85	3.50	3.30	1.75	2.95	3.00
FWHM at 500 keV [°]	0.80	1.25	1.55	1.45	0.75	1.25	1.40
FWHM at 1000 keV [°]	0.40	0.65	0.85	0.80	0.40	0.75	0.85

Generating an Image (or Spectrum) from a Measurement

- **Problem: Find Best Image as Constrained by Apparatus and Statistical Uncertainty of Data**
  - ☞Do Not Fit Noise
  - ☞Do Not Over-Resolve Image (Spectrum)

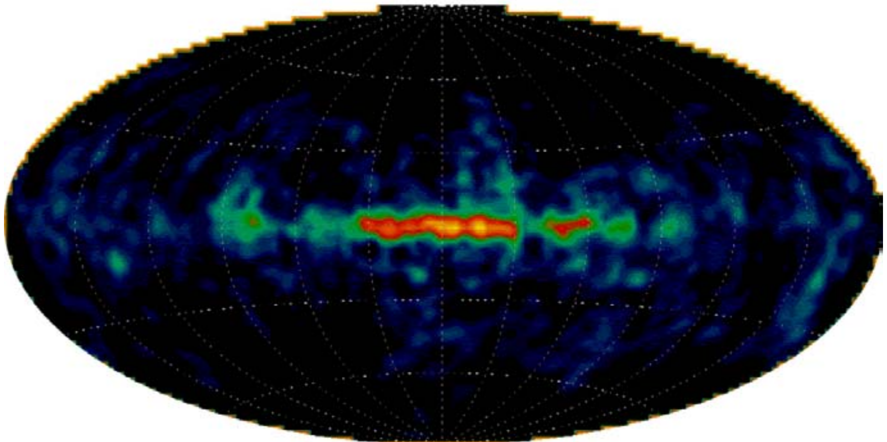
$$D = \int_{T_{obs}} S \bullet R dt$$

- **Ideal: Inversion of Response Matrix**
  - ☞SVD Analysis

$$S = R^{-1} \bullet D$$

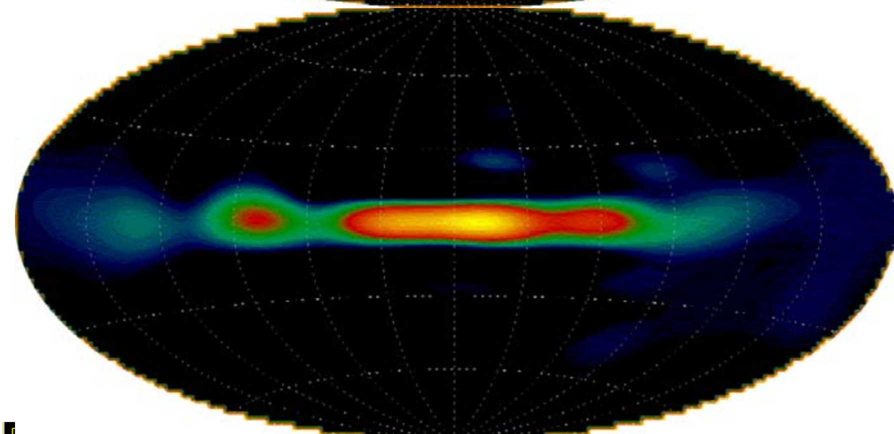
- **Real Case: Singularities in Response Matrix**
  - ☞Iterative Methods:
    - Predict Data from Trial Image
    - Compute Difference to Real Data
    - Compute Gradients of Difference wrt Image Parameters
    - Improve Trial Image
    - Iterate Until Stopping Criterion
  - ☞(Additional) Criteria
    - Measurement Statistics (Poisson, Gauss; Bootstrapping)
    - Goodness-of-Fit (χ^2, Likelihood)
    - Image Entropy (Smoothness)
    - Image Scale Filters (Wavelet Amplitudes)

COMPTEL 1.8 MeV Maps: Different Imaging Methods



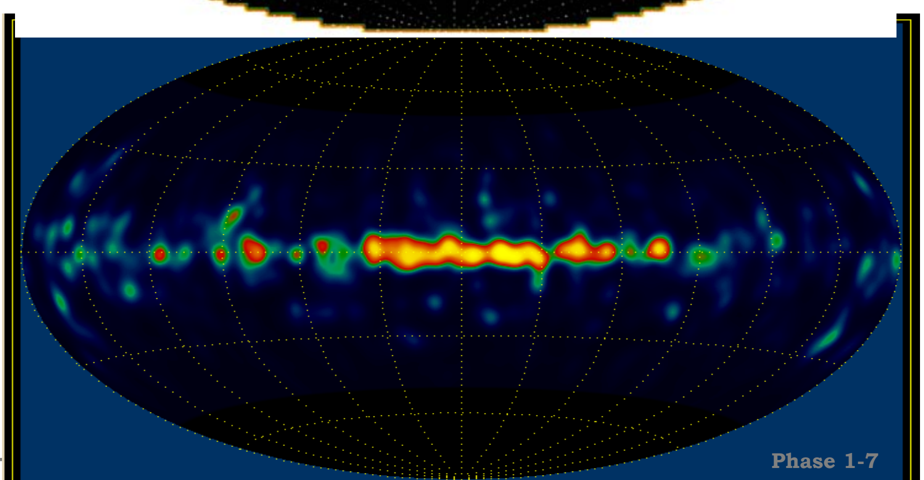
Maximum-Entropy Imaging Deconvolution ("ME"):

Global-Entropy-Damped and Misfit-Gradient-Driven Iterations Towards Maximum-Likelihood Fit.
Background Model from Adjacent Energies



Multi-Resolution Expectation Maximization Imaging Deconvolution ("MREM"):

Misfit-Gradient Driven and Scale-Hierarchically Noise-Damped Iterations (RL) Towards Maximum-Likelihood Fit.
Background Model from Adjacent Energies



Multi-Energy-Band Likelihood Fit of Iteratively-Improved Source Model and Background Docomposition:

Models for Celestial Continuum Emission Simultaneously Fit in Several E Bands with Empirical Bgd Model per E Band,
Likelihood Imaging of Residual Line Flux

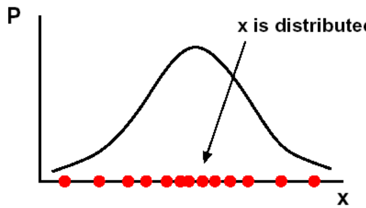
Statistical Data Analysis: Principles

Frequentist: Probability describes "randomness"

Venn, Boole, Fisher, Neymann, Pearson. . .

x is a *random variable* if it takes different values throughout an infinite (imaginary?) ensemble of "identical" sytems/experiments.

$p(x)$ describes how x is distributed throughout the ensemble.



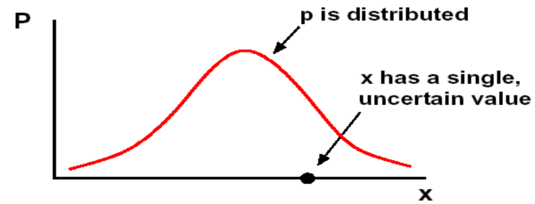
Probability $\equiv$ frequency (pdf $\equiv$ histogram).

Bayesian: Probability describes uncertainty

Bernoulli, Laplace, Bayes, Gauss. . .

$p(x)$ describes how probability (plausibility) is distributed among the possible choices for x in the case at hand.

Analog: a mass density, $\rho(x)$



Relationships between probability and frequency were demonstrated mathematically (large number theorems, Bayes's theorem).

- ☹ Measurements May Be In Error
- ☹ Hypotheses May Be Wrong
- ☞ Use Knowledge About Instrument
- ☞ Make Assumptions Explicit

The Bayesian Recipe

Assess hypotheses by calculating their probabilities $p(H_i|\ldots)$ conditional on known and/or presumed information using the rules of probability theory.

Probability Theory Axioms ("grammar"):

'OR' (sum rule) $$P(H_1 + H_2|I) = P(H_1|I) + P(H_2|I) - P(H_1, H_2|I)$$

'AND' (product rule) $$P(H_1, D|I) = P(H_1|I)\,P(D|H_1, I) = P(D|I)\,P(H_1|D, I)$$

Important Theorems

Normalization:

For *exclusive, exhaustive* H_i

$$\sum_i P(H_i|\cdots) = 1$$

Bayes's Theorem:

$$P(H_i|D, I) = P(H_i|I)\frac{P(D|H_i, I)}{P(D|I)}$$

posterior $\propto$ prior $\times$ likelihood

ref: Tom Loredo

Estimating Parameters
(of an Astrophysical Model)

1. Formulate Model with "parameters-of-interest"
2. Determine "best-fit" Parameter Values
3. Assess Uncertainties

Parameter estimation:

$$p(\theta|D, M) = \frac{p(\theta|M)\mathcal{L}(\theta)}{\int d\theta\, p(\theta|M)\mathcal{L}(\theta)}$$

$I =$ Model M with parameters θ ($+$ any add'l info)

$H_i =$ statements about θ; e.g. "$\theta \in [2.5, 3.5]$," or "$\theta > 0$"

Probability for any such statement can be found using a *probability density function* (pdf) for θ:

$$\begin{aligned} P(\theta \in [\theta, \theta + d\theta]|\cdots) &= f(\theta)d\theta \\ &= p(\theta|\cdots)d\theta \end{aligned}$$

Summaries of posterior:

- "Best fit" values: mode, posterior mean
- Uncertainties: Credible regions (e.g., HPD regions)
- Marginal distributions:
  - Interesting parameters ψ, nuisance parameters ϕ
  - Marginal dist'n for ψ:

$$p(\psi|D, M) = \int d\phi\, p(\psi, \phi|D, M)$$

Generalizes "propagation of errors"

$$\mathcal{L}(M_i) = p(D|M_i) = \int d\theta_i\, p(\theta_i|M_i)p(D|\theta_i, M_i)$$

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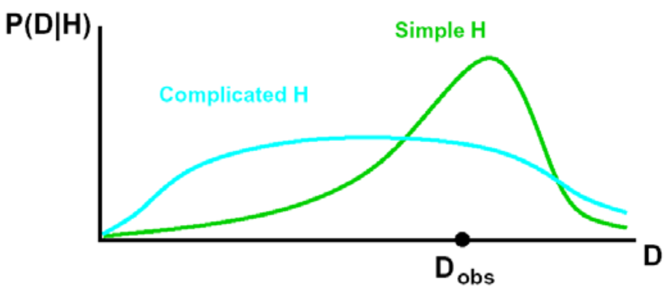
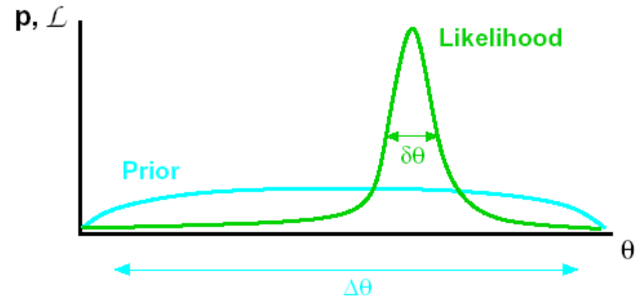
Many (Model) Parameters in Data Analysis

Predictive probabilities can favor simpler models:

$$p(D|M_i) = \int d\theta_i \; p(\theta_i|M) \; \mathcal{L}(\theta_i)$$



The Occam Factor:



$$\begin{aligned} p(D|M_i) &= \int d\theta_i \; p(\theta_i|M) \; \mathcal{L}(\theta_i) \approx p(\hat{\theta}_i|M)\mathcal{L}(\hat{\theta}_i)\delta\theta_i \\ &\approx \mathcal{L}(\hat{\theta}_i)\frac{\delta\theta_i}{\Delta\theta_i} \\ &= \text{Maximum Likelihood} \times \text{Occam Factor} \end{aligned}$$

Select a Model with Least Complexity

(Occam's Principle; "Occam's Razor")

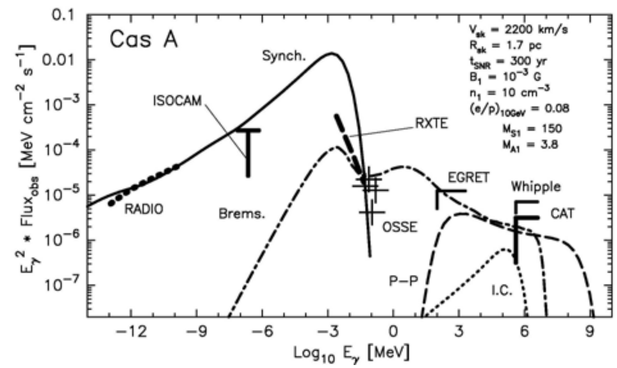
Models with more parameters often make the data more probable— *for the best fit.*

Occam factor penalizes models for "wasted" volume of parameter space.

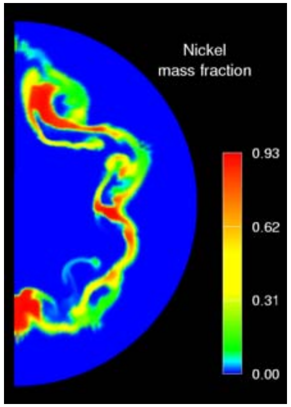
ref: Tom Loredo

Complex Astrophysical Problems

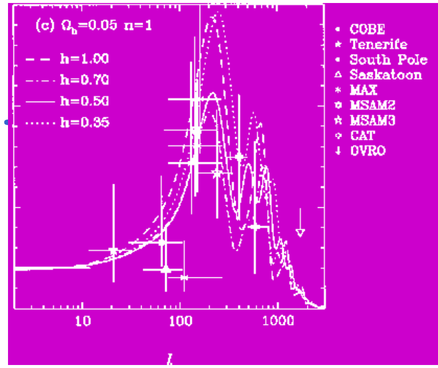
- **Modelling Source Spectra**
  - ☆ Photo-Ionization Codes
  - ☆ MC Photon Transport in SN/SNR
  - ☆ Bremsstrahlung, IC, …
  - ☆ …



- **Modelling Source Dynamics**
  - ☆ Multi-D Explosion Treatments (SN,N,…)
  - ☆ Magneto-Hydrodynamical Codes
  - ☆ …



- **Modelling Complex Objects**
  - ☆ SNR Expansion into ISM, GRB Afterglows, …
  - ☆ Galaxy Rotation: GMC's, Hα Emission Models, …
  - ☆ Galaxy Cluster Gas Evolution
  - ☆ Structure Formation in Early Universe
  - ☆ …



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Hypothesis Testing: Spectral Models in XSPEC

- Spectral Model Fitting

absori	Ionized absorber.
ascac	ASCA PSF mixing model.
apec	APEC thermal plasma model.
atable	Additive table model.
bbody	Blackbody spectrum.
bbodyrad	Blackbody spectrum with norm proportional to surface area.
bexrav	E-folded broken power-law reflected from neutral matter
bexriv	E-folded broken power-law reflected from ionized matter
bknpower	Broken powerlaw.
bmc	Comptonization by relativistically moving matter.
bremss	Thermal bremsstrahlung.
c6mekl	6th-order Chebyshev polynomial DEM using mekal.
c6pmekl	Exponential of 6th-order Chebyshev polyn. DEM using mekal.
c6pvmkl	Variable abundance version of c6pmekl
c6vmekl	Variable abundance version of c6mekl
cabs	Compton scattering (non-relativistic)
cemekl	Multi-temperature mekal.
cevmkl	Multi-temperature vmeka.
cflow	Cooling flow model.
compbb	Comptonized blackbody spectrum after Nishimura et al. 1986
compls	Comptonization spectrum after Lamb and Sanford 1979
compst	Comptonization spectrum after Sunyaev and Titarchuk 1980
comptt	Comptonization spectrum after Titarchuk 1994
constant	Energy-independent multiplicative factor.
cutoffpl	Powerlaw with high energy exponential rolloff.
cyclabs	Cyclotron absorption line.
disk	Disk model.
diskbb	Multiple blackbody disk model.
diskline	Line emission from relativistic accretion disk.
diskm	Disk model with gas pressure viscosity.
disko	Modified blackbody disk model.
diskpn	Accretion disk around a black hole.
dust	Dust scattering out of the beam.
edge	Absorption edge.
equil	Equilibrium ionization collisional plasma model from Borkowski.
etable	Table model for exponential of -1 times the input.
expabs	Low-energy exponential rolloff.
expfac	Exponential factor.
gaussian	Simple gaussian line profile.
gnei	Generalized single ionization NEI plasma model.
grad	GR accretion disk around a black hole.
grbm	Gamma-ray burst model.
gsmooth	Gaussian smoothing with an energy dependent sigma.
highecut	High energy cutoff.
hrefl	Simple reflection model good up to 15 keV.
laor	Line from accretion disk around a black hole.
lorentz	Lorentzian line profile.
lsmooth	Lorentzian smoothing with an energy dependent sigma.
meka	Mewe-Gronenschild-Kaastra thermal plasma (1992).

mekal	Mewe-Kaastra-Liedahl thermal plasma (1995).
mkcflow	Cooling flow model based on mekal.
mtable	Multiplicative table model.
nei	Simple nonequilibrium ionization plasma model.
notch	Notch line absorption.
npshock	Plane-parallel shock with ion and electron temperatures.
nteea	Pair plasma model.
pcfabs	Partial covering fraction absorption.
pegpwrlw	Powerlaw with pegged normalization.
pexrav	Exponentially cut-off power-law reflected from neutral matter.
pexriv	Exponentially cut-off power-law reflected from ionized matter.
phabs	Photo-electric absorption
pileup	CCD pile-up model
plabs	Absorption model with power-law dependence on energy.
plcabs	Cut-off powerlaw observed through dense, cold matter.
posm	Positronium continuum.
powerlaw	Simple photon power law.
projct	3-D to 2-D projection mixing model.
pshock	Constant temperature, plane-parallel shock plasma model.
raymond	Raymond-Smith thermal plasma.
redden	IR/optical/UV extinction from Cardelli et al. -1989
redge	Recombination edge.
reflect	Convolution model for reflection from neutral matter
refsch	E-folded power-law reflected from an ionized relativistic disk.
rgsxsrc	Convolution model for extended sources with the XMM RGS.
sedov	Sedov model with electron and ion temperatures.
smedge	Smoothed absorption edge.
spline	Spline multiplicative factor.
srcut	Synchrotron radiation from cut-off electron distribution.
Synchrotron	radiation from escape-limited electron distribution.
SSS	ice Einstein Observatory SSS ice absorption.
step	Step function convolved with gaussian.
tbabs	Absorption due to the ISM including molecules and grains.
tbgrain	ISM absorption with variable molecule and grain fractions.
tbvarabs	ISM absorption with variable abundances and grain depletion.
uvred	UV reddening.
vapec	APEC thermal plasma model with variable abundances.
varabs	Photoelectric absorption with variable abundances.
vbremss	Thermal bremsstrahlung spectrum with variable H/He.
vequil	As equil but with variable abundances.
vgnei	As gnei but with variable abundances.
vmcflow	Cooling flow model based on vmekal.
vmeka	M-G-K thermal plasma with variable abundances.
vmekal	M-K-L thermal plasma with variable abundances.
vnei	As nei but with variable abundances.
vnpshock	As npshock but with variable abundances.
vphabs	Photoelectric absorption with variable abundances.
vpshock	As pshock but with variable abundances.
vraymond	Raymond-Smith thermal plasma with variable abundances.
vsedov	As sedov but with variable abundances.
wabs	Photoelectric absorption (Morrison & McCammon).
wndabs	Photoelectric absorption with low energy window.
xion	The reflected spectrum from a photo-ionized accretion disk.
zbbody	Redshifted blackbody.
zbremss	Redshifted thermal bremsstrahlung.
zedge	Redshifted absorption edge.
zgauss	Redshifted gaussian.
zhighect	Redshifted high energy cut-off.

Tools for Data Analysis

- **Analysis Environments**
  - ☆ ROOT — by CERN, for HE Physics
  - ☆ PAW — predecessor of ROOT
  - ☆ IDL — by RSI.com, with AstroLib

- **Libraries**
  - ☆ NAG — Numerical Algorithm Group, UK
  - ☆ "Numerical Recipes" Routines
  - ☆ CERNLIB — Analysis tools for ROOT, PAW
  - ☆ FTOOLS — by HEASARC/NASA, with many High-Level Tools (XSPEC, etc)

Literature for Data Analysis Methods

- Bevington, P. R., *Data Reduction and Error Analysis for the Physical Sciences*. (McGraw-Hill) , 1969
- Eadie, W.T., Drijard, D., James, F.E., Roos, M., and Sadoulet, B.: *Statistical Methods in Experimental Physics* (New York: North-Holland) , 1971
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- Wheaton, W. A., et al., ApJ 438, 322, 1995

Scientific Research: Accessing Literature and External Databases

- Classical Approach
  - ☆ Institute Library
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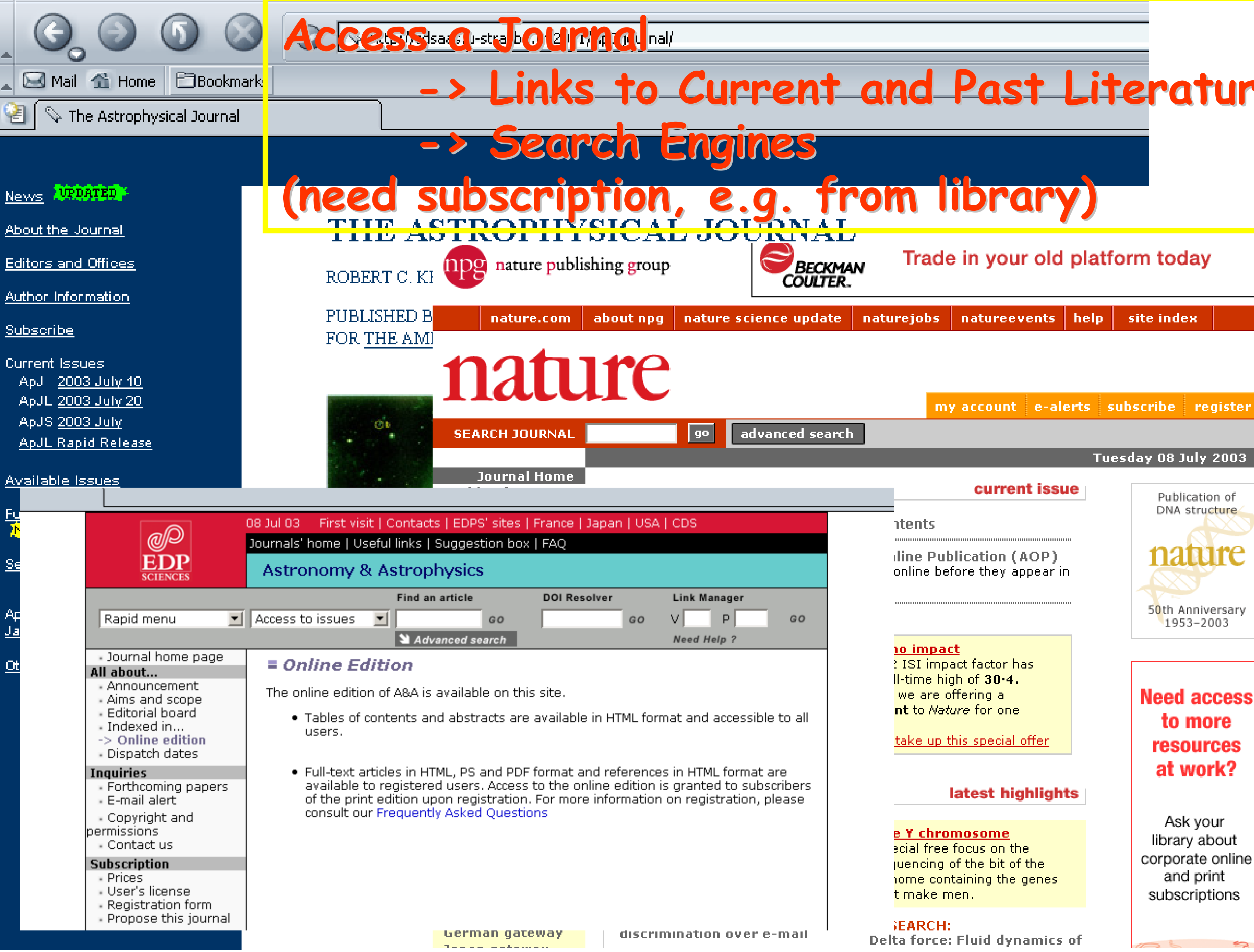

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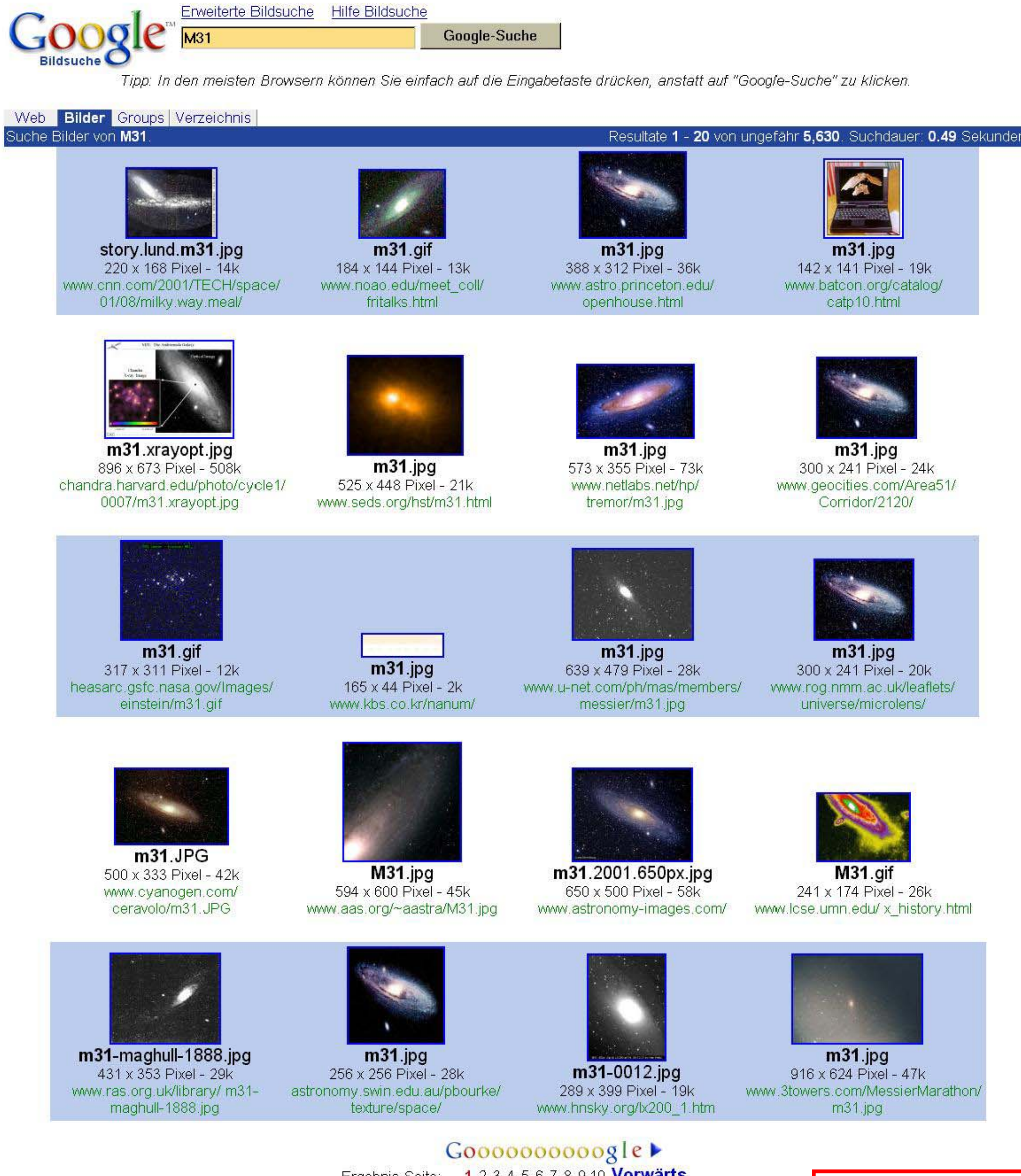

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International Astronomy Meetings List

This list of astronomy meetings is compiled by Liz Bryson of the Canada-France-Hawaii Telescope Corporation and is archived by the Canadian Astronomy Data Centre (CADC) of the National Research Council of Canada's Herzberg Institute of Astrophysics.

Included with each entry of the Meetings List are links to the meeting web page, contact e-mail addresses, and abstracts provided by NASA's Astrophysics Data System (ADS) if, and when they are available.

To add a meeting to the Meetings List select the appropriate link to the left, fill out the displayed form and submit it. After Liz assures herself that your meeting warrants addition to her list she will add it to the database as soon as possible.

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  By default these metacharacters perform regular expression searches. The most useful is ?, which indicates an optional character. For example, colou?r matches both color and colour.
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Title: PSR B1849+00 probes the tiny-scale molecular gas?
Authors: S. Stanimirovic (1), J.M. Weisberg (2), J.M. Dickey (3), A. de la Fuente, K. Devine, A. Hedden (2), S.B. Anderson (4) ((1) UC Berkeley, (2) Carleton College, (3) University of Minnesota, (4) Caltech)
Comments: To be published in the proceedings of "Magnetic fields and star formation: theory versus observations", held in Madrid, April 21-25 2003. Uses Kluwer style file

astro-ph/0307002 [abs, ps, pdf, other] :

Title: The tiny-scale atomic structure: gas cloudlets or scintillation phenomenon ?
Authors: S. Stanimirovic (1), J.M. Weisberg, A. Hedden, K. Devine, T. Greent (2), S.B. Anderson (3) ((1) UC Berkeley, (2) Carleton College, (3) Caltech)
Comments: To appear in the proceedings of "Magnetic fields and star formation: theory versus observations", held in Madrid, April 21-25 2003. Uses Kluwer latex style file

astro-ph/0307003 [abs, ps, pdf, other] :

Title: Skeleton as a probe of the cosmic web: the 2D case
Authors: Dimitri Novikov, Stephane Colombi, Olivier Dore
Comments: 15 pages, 11 figures, submitted to MNRAS

astro-ph/0307004 [abs, ps, pdf, other] :

Title: The Multiphase Intergalactic Medium towards PKS 2155-304
Authors: Michael Shull, Jason Tumlinson, Mark Giroux
Comments: 10 pages, 1 color figure, submitted to ApJL

astro-ph/0307005 [abs, ps, pdf, other] :

Title: The energy scale of inflation: is the hunt for the primordial B-mode a waste of time?
Authors: William H. Kinney (ISCAP/Columbia Univ.)
Comments: To be published in the proceedings of "The Cosmic Microwave Background and its Polarization", New Astronomy Reviews, (eds. S. Hanany and K.A. Olive). 10 pp., 7 figures

astro-ph/0307006 [abs, ps, pdf, other] :

Title: Asymmetric neutrino emission due to neutrino-nucleon scatterings in supernova magnetic fields
Authors: Shin'ichiro Ando
Comments: 19 pages, 1 figure. Accepted by Physical Review D

astro-ph/0307007 [abs, ps, pdf, other] :

Title: A survey of Probable Open Cluster Remnants in the Galactic Disk
Authors: Sandro Villanova (Padova), Giovanni Carraro (Padova), Raul de la Fuente Marcos (Madrid)
Comments: 3 pages, 6 eps figures, proceeding of the Boston Conference "Milky Way Surveys"

astro-ph/0307008 [abs, ps, pdf, other] :

Title: A new approach to gravitational clustering: a path-integral formalism and large-N expansions
Authors: P. Valageas
Comments: 36 pages, submitted to A&A

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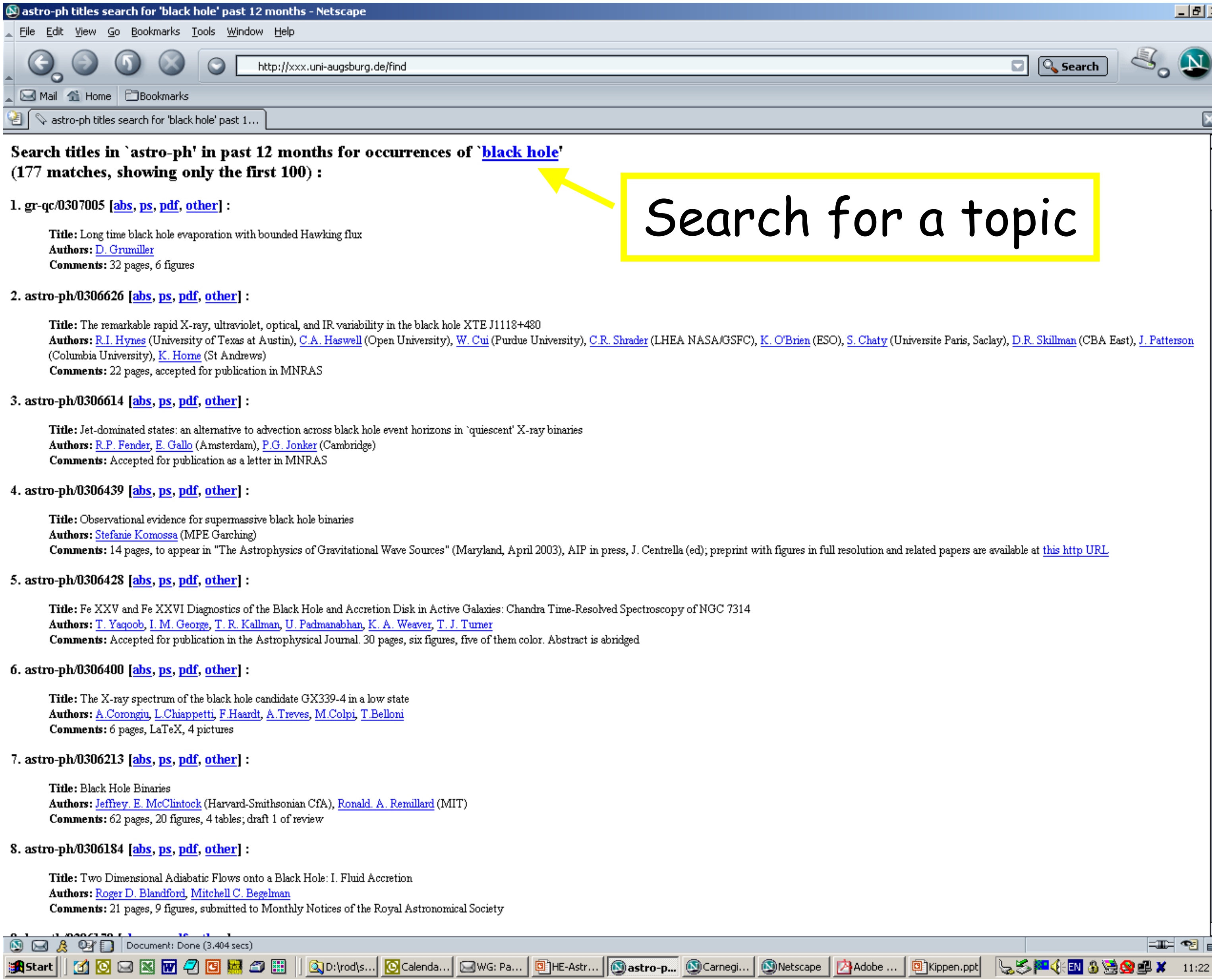
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Authors: D. Grumiller
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Title: The remarkable rapid X-ray, ultraviolet, optical, and IR variability in the black hole XTE J1118+480
Authors: R.I. Hynes (University of Texas at Austin), C.A. Haswell (Open University), W. Cui (Purdue University), C.R. Shrader (LHEA NASA/GSFC), K. O'Brien (ESO), S. Chaty (Universite Paris, Saclay), D.R. Skillman (CBA East), J. Patterson (Columbia University), K. Horne (St Andrews)
Comments: 22 pages, accepted for publication in MNRAS
3. astro-ph/0306614 [abs, ps, pdf, other] :
Title: Jet-dominated states: an alternative to advection across black hole event horizons in `quiescent' X-ray binaries
Authors: R.P. Fender, E. Gallo (Amsterdam), P.G. Jonker (Cambridge)
Comments: Accepted for publication as a letter in MNRAS
4. astro-ph/0306439 [abs, ps, pdf, other] :
Title: Observational evidence for supermassive black hole binaries
Authors: Stefanie Komossa (MPE Garching)
Comments: 14 pages, to appear in "The Astrophysics of Gravitational Wave Sources" (Maryland, April 2003), AIP in press, J. Centrella (ed); preprint with figures in full resolution and related papers are available at this http URL
5. astro-ph/0306428 [abs, ps, pdf, other] :
Title: Fe XXV and Fe XXVI Diagnostics of the Black Hole and Accretion Disk in Active Galaxies: Chandra Time-Resolved Spectroscopy of NGC 7314
Authors: T. Yaqoob, I. M. George, T. R. Kallman, U. Padmanabhan, K. A. Weaver, T. J. Turner
Comments: Accepted for publication in the Astrophysical Journal. 30 pages, six figures, five of them color. Abstract is abridged
6. astro-ph/0306400 [abs, ps, pdf, other] :
Title: The X-ray spectrum of the black hole candidate GX339-4 in a low state
Authors: A.Corongiu, L.Chiappetti, F.Haardt, A.Treves, M.Colpi, T.Belloni
Comments: 6 pages, LaTeX, 4 pictures
7. astro-ph/0306213 [abs, ps, pdf, other] :
Title: Black Hole Binaries
Authors: Jeffrey. E. McClintock (Harvard-Smithsonian CfA), Ronald. A. Remillard (MIT)
Comments: 62 pages, 20 figures, 4 tables; draft 1 of review
8. astro-ph/0306184 [abs, ps, pdf, other] :
Title: Two Dimensional Adiabatic Flows onto a Black Hole: I. Fluid Accretion
Authors: Roger D. Blandford, Mitchell C. Begelman
Comments: 21 pages, 9 figures, submitted to Monthly Notices of the Royal Astronomical Society
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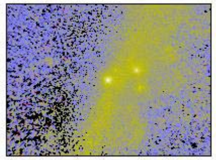

SkyView

The Internet's Virtual Telescope

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***SkyView* is a Virtual Observatory on the Net generating images of any part of the sky at wavelengths in all regimes from Radio to Gamma-Ray.**

March 14, 2002: **The Second Generation Digitized Sky Survey (DSS2)** is now available in *SkyView*. This optical survey provides high-resolution all-sky images in two colors. More information can be found in our Survey Document.

March 20, 2002: The alternate *SkyView* server (skys.gsfc.nasa.gov) will be unavailable for a short period of time over the next couple of days as we update hardware and software. This down time will affect web and batch access. We apologize for any inconvenience.

Start creating images by selecting a *SkyView* interface.

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(*e.g.* "Eta Carinae", "10 45 3.6, -59 41 4.2", or "161.265, -59.685")

Survey[s]:

Gamma-ray:
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- EGRET >100 MeV
- EGRET <100 MeV
- COMPTEL

Xray:
- HEAO 1 A-2
- RASS-Cnt Broad
- RASS-Cnt Hard
- RASS-Cnt Soft
- HRI
- PSPC 2.0 Deg-Inten
- PSPC 1.0 Deg-Inten

EUV:
- ROSAT WFC F1
- ROSAT WFC F2
- EUVE 83 A
- EUVE 171 A
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- UV Total
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Optical:
- Digitized Sky Survey
- DSS2 Red
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Survey	Units	Start	End	Number of Bins	Description
EGRET	Channels				1-10 Channels in 1 Channel Bins
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UV SolSys	Wavelength				915 to 3100 Angstroms in 5 Angstrom Bins
UV Stellar	Wavelength				915 to 3100 Angstroms in 5 Angstrom Bins
UV Galactic	Wavelength				915 to 3100 Angstroms in 5 Angstrom Bins
UV Total	Wavelength				915 to 3100 Angstroms in 5 Angstrom Bins
COBE DIRBE	Bands				1-10 Bands in 1 Band Bins

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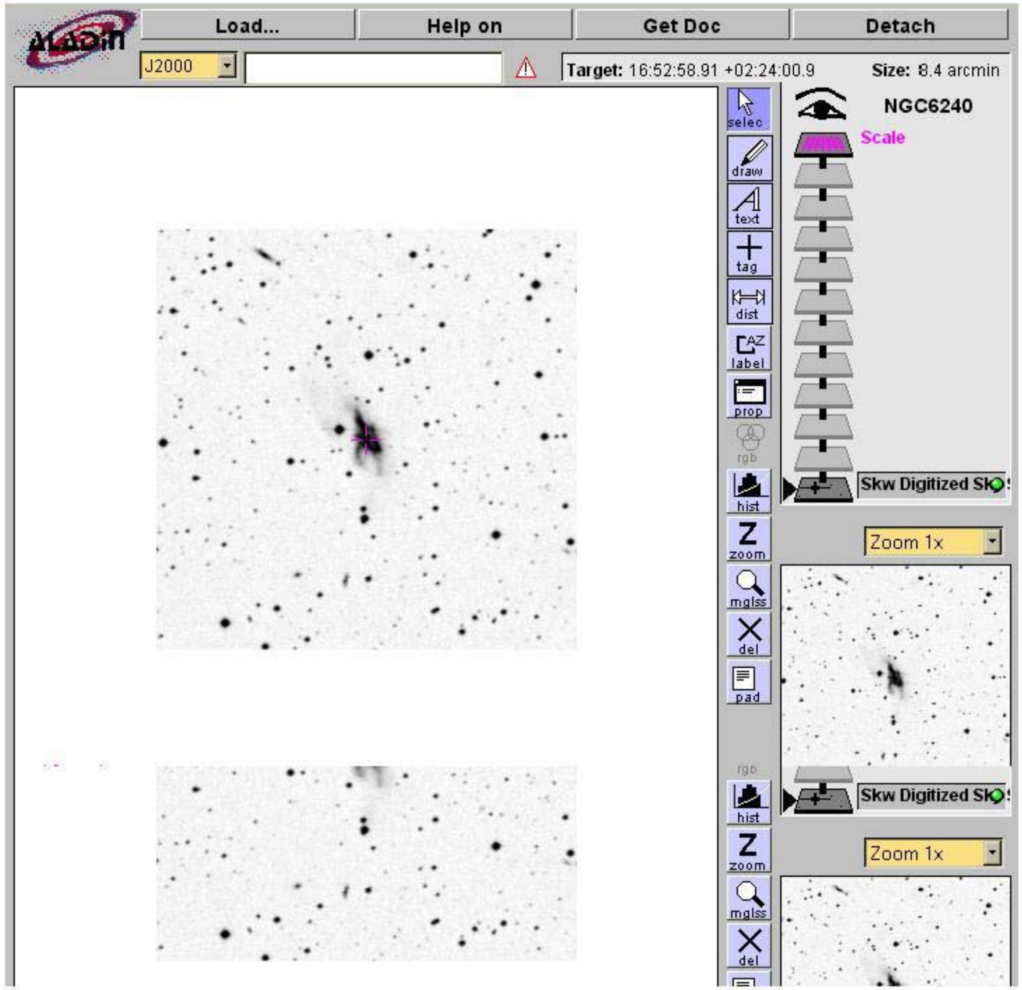

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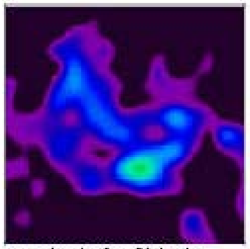
Multiwavelength Milky Way Maps

http://nvo.gsfc.nasa.gov/mw/mmw_images.html



zoomed region from Molecular Hydrogen map

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Education

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This "Education" portion of the Multiwavelength Milky Way Project is intended primarily for use by educators, students, and the general public.

Presented here are maps of the Milky Way galaxy at ten wavelength regions. The maps show the central part of our Milky Way galaxy in a band that extends 10° north and 10° south of the Galactic plane. Below the maps is a finder chart.

Clicking on the map name, to the left of each map, will link you to a brief description of the Milky Way at that wavelength. Or you read the descriptions by scrolling down the page past the maps.

To zoom in on a feature, click on the image you are interested in. A new screen will appear in your browser showing the zoomed-in region along with some information. From that screen you can then pan left or right, or zoom in even further. From the new screen, you can also access that same region of sky in the other wavelength bands.

The maps are low-resolution versions of those used in the poster.

Related resource links can be found at the Multiwavelength Milky Way Education page. Also accessed from the Education page is information about how to read the maps and what we see in the maps. For more technical information, references, and online data access links, please visit the Science Users page.

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Radio (0.4 GHz)

Atomic Hydrogen

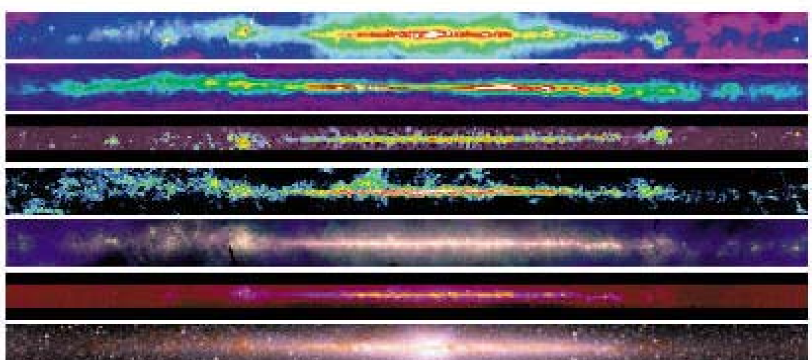
Radio (2.7 GHz)

Molecular Hydrogen

Infrared

Mid Infrared

Near Infrared



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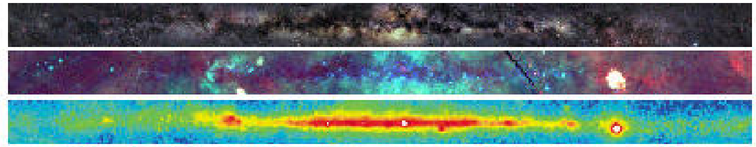
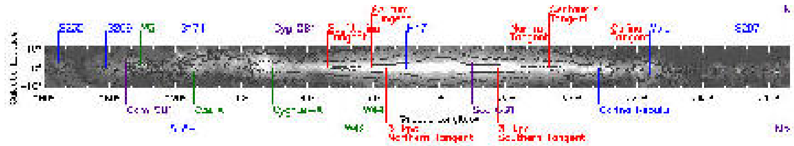
X-Ray

Gamma Ray



Finder



To the Multiwavelength Milky Way Education page

The Images

Each image represents a 360° false color view of the Milky Way within 10° of the galactic plane. The images are in Galactic coordinates with the direction of the Galactic center in the center of each. For scale, the vertical dimension of each image is forty times the angular diameter of the full moon on the sky; the areas shown represent *about one-sixth of the entire sky*.

The images are derived from several space and ground-based surveys, many of which are available through the Astrophysics Data Facility and the Astronomical Data Center of the Space Science Data Operations Office at NASA Goddard Space Flight Center.

The image in the finder chart is derived from the *IRAS* 100 micron map with *COBE* DIRBE 3.5 micron contours overlaid.

The interactive images above were created by Dr. Seth Digel, and Mr. Jay Friedlander (SSDOO Visualization Lab Task Leader).

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Map Descriptions

Radio Continuum (408 MHz)

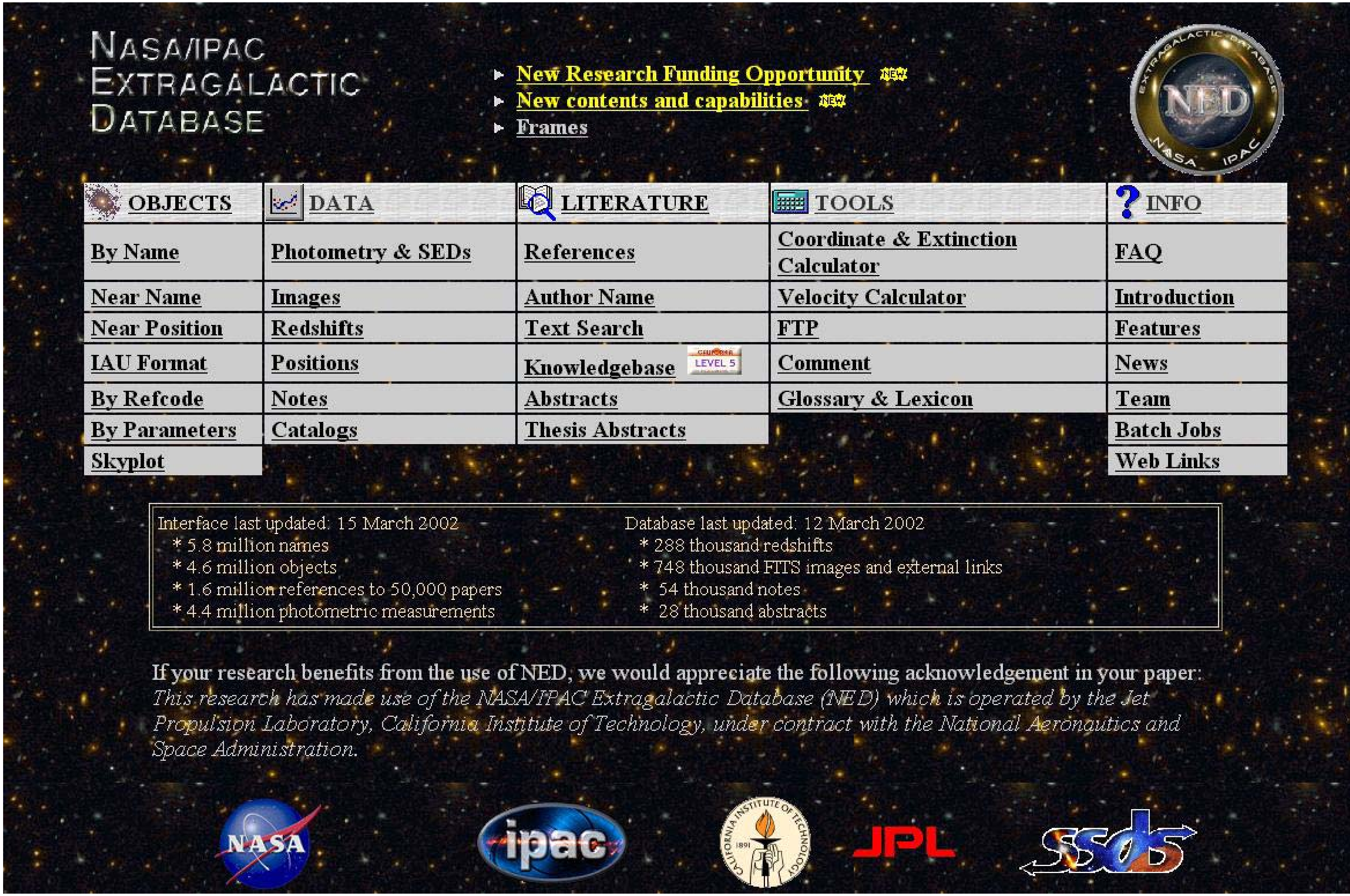
Intensity of radio continuum emission from high-energy charged particles in the Milky Way,from surveys with ground-based radio telescopes (Jodrell Bank Mark 1 and Mark 1A, Bonn 100-meter, and Parkes 64-meter). At this frequency, most of the emission is from electrons moving through the interstellar magnetic field at nearly the speed of light. Shock waves from supernova explosions accelerate electrons to such high speeds, producing especially intense radiation near these sources. Emission from the supernova remnant Cas A near 110° longitude is so intense that the diffraction pattern of the support legs for the radio receiver on the telescope is visible as a cross shape.

Frequency: 408 MHz
Angular resolution: 51 arcminutes

Back to maps

Atomic Hydrogen

Column density of atomic hydrogen,derived on the assumption of optically thin emission, from radio surveys of the 21-cm transition of hydrogen. The 21 cm emission traces the "cold and warm" interstellar medium, which on a large scale is organized into diffuse clouds of gas and dust that have sizes of up to hundreds of light-years. Most of the image is based on the Leiden-Dwingeloo Survey of Galactic Neutral Hydrogen using the Dwingeloo 25-m radio telescope; the data were corrected for sidelobe contamination in collaboration with the University of Bonn.



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INES Archive of IUE ultraviolet spectra

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Projects to which CDS contributes
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AstroWeb (CDS - UK - STScI - NRAO)
StarPages
AstroGLU resource discovery tool
CFHT* Web pages

Information about CDS

General description
CDS Tutorial
The CDS and NASA ADS resources
The staff
Phone directory
What's new ? (Electronic Newsletter)
Observatoire de Strasbourg

The ROSAT X-Ray All-Sky Survey

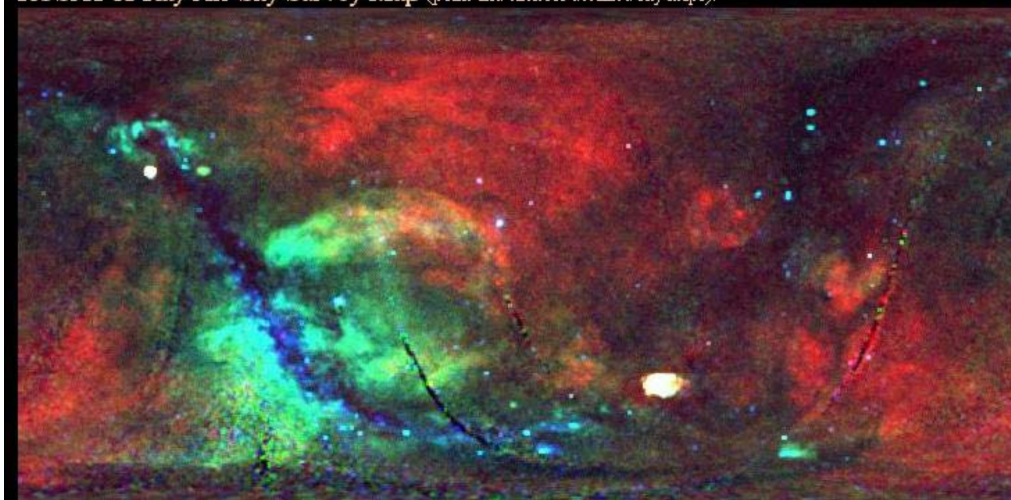
2001-Aug-09: Release of the Completed ROSAT Source Catalogs of Pointed Observations
2000-May-23: RASS Faint Source Catalogue Released!

Help ... Non-Expert Users ... Updates ... ||| ... xray@mpe

Requested product: X-ray color image (active FOV) from PSPC all-sky survey (s)

Coordinates lon. = 9h55m23s , lat. = 69d01m11s , equatorial crd, equ. 2000

ROSAT X-Ray All-Sky Survey Map (point and click for detailled sky maps):



Data	Tools	Projects
Zone-wise Field Lists	RASS Field Conversion	Bright Source Catalogue
Complete Field List	ROSAT Sequence Browser	Faint Source Catalogue
Anonymous ftp	ROSAT Source Browser	Soft X-ray Diffuse
All-Sky Maps	ROSAT Data Browser	Background
		ROSAT All-Sky Survey Links

http://www.xray.mpe.mpg.de/cgi-bin/rosat/rosat-survey

ROSAT Sequence Browser

Home ... Format ... Help ... Archive ... ||| ... rosat@mpe ... rosat@jer ... argus@gsfc

Submit task | default values

Select from: screened ROSAT observations in customary format

☐ **Sort output by** ROR in ascending order.

Selection Criteria:

☑ **Sky field(s):** equatorial coordinates, equinox 2000

◉ single ○ multiple

lon. = 12h35m22s lat. = -45d18m36s radius = 10 deg

from local file: Durchsuchen...

☐ **Time:** begin date from 960801 to 960930

☐ **Substring** MPE (case is ignored)

☐ **Misc.:** ROR = 180150

ignore ROR = 180150

Feedback to info@xray.mpe.mpg.de

Page author: Jakob Englhauser / 1996-Jul-30 ... 2000-Jun-30

Created by seq-browser on 2002-Mar-20

http://www.xray.mpe.mpg.de/cgi-bin/rosat/seq-browser

HEASARC Archive Interfaces

choose one...

HEASARC Resources/Education

choose one...

HEASARC Tools & Software

choose one...

HEASARC

High Energy Astrophysics Science Archive Research Center

HEASARC | OBSERVATORIES | DATA ARCHIVE | SOFTWARE | UTILITIES | HELPDESK/FAQ | EDUCATION & OUTREACH

Bibliography
Coord Converter
Date Converter
Energy Converter
nH
RPS
TOPbase
Viewing
WebPIMMS
WebSpec
X-ray Background
xTime

SITE SEARCH

enter text

Web-based Tools

The links to the left are for various Web-based tools that assist scientists in their proposal efforts. The HEASARC provides these tools as a service to the scientific community.

Tool Descriptions

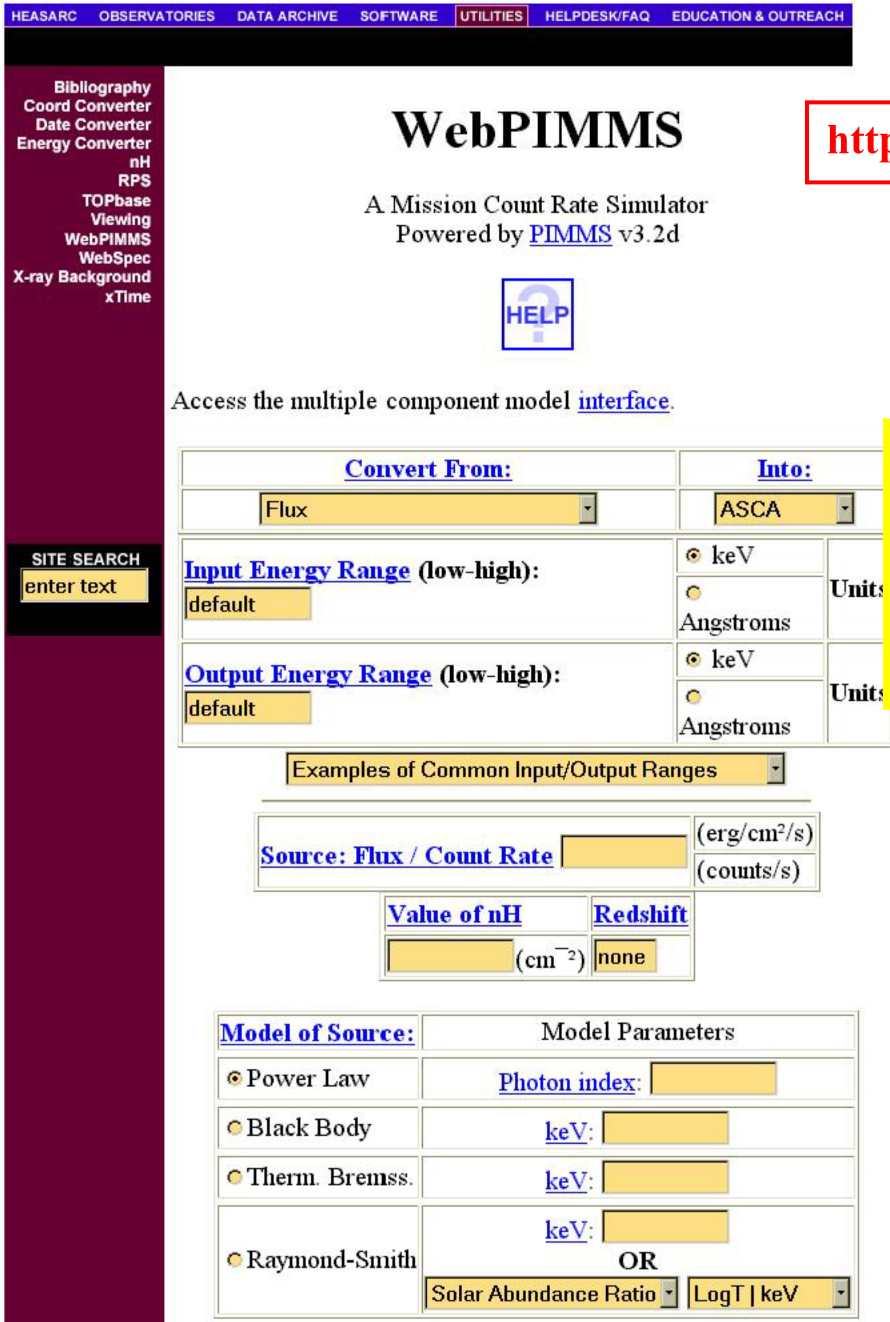
- Bibliography - Query NED, SIMBAD, and ADS for bibliographic references
- Coordinate Converter - CoCo: Object location and coordinate converter
- Date Converter - Convert between Julian date formats and more recognizable date formats
- Energy Converter - Energy/frequency/wavelength converter
- nH - Determine galactic absorption by coordinates
- RPS - Remote Proposal System
- TOPbase - An on-line database of atomic data (energy levels, f-values and photoionisation cross sections) compiled by the Opacity Project
- Viewing - Determine possible viewing times for missions and objects
- WebPIMMS - Determine source flux or count rates
- WebSpec - Simulate spectral data for missions/instruments
- X-Ray Background - Calculate

Latest News

- **New version of Viewing tool improved for XMM-Newton!** (31 Aug)

More News

http://heasarc.gsfc.nasa.gov/Tools/



http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html

Writing an Observing Proposal: -> Access an Observation Simulator

Data Search / Missions / Contacts / STScI / MAST

Site Search

MAST Multimission Archive at Space Telescope

- About MAST
- Cross-Mission Search Tools
- MAST Scrapbook
- What's New
- FAQ
- Science Products
- Software
- FITS
- Related Sites
  - ADS
  - HEASARC
  - IRSA
  - NED
  - NSSDC
- Acknowledgments

The Multimission Archive at STScI supports a variety of astronomical data archives, with the primary focus on scientifically related data sets in the optical, ultraviolet, and near-infrared parts of the spectrum. MAST provides search tools and retrieval support for the following missions:

Missions

HST ASTRO ORFEUS Copernicus
FUSE HUT BEFS ROSAT
IUE UIT IMAPS
EUVE WUPPE TUES

Catalogs & Surveys

SDSS
GSC
DSS
VLA-FIRST

Cross-correlation Target Search and/or Mission Search

Enter Target name (or Coordinates):

Resolver: ◉ SIMBAD ○ NED

and/or Data Type(s):

	X-Ray	Extreme UV	Far UV	Near UV	Optical	Near IR	Radio
Images	☐	☐	☐	☐	☐	☐	☐
Spectra	☐	☐	☐	☐	☐	☐	
Other			☐	☐	☐	☐	

Search Reset Help

Top of Page
Copyright Notice

printer-friendly page
http://archive.stsci.edu/index.html

archive@stsci.edu
Modified: Jan 12, 2002 17:06

http://archive.stsci.edu/

SEARCH | NEWS | HELP | FAQ

ST-ECF

Science Archive Facility

The ESO/ST-ECF Science Archive is a joint collaboration of the European Southern Observatory (ESO) and the Space Telescope - European Coordinating Facility (ST-ECF).
ESO observational data can be requested after the proprietary period by the astronomical community of the ESO member states and Chile. Please read the official 'ESO Data Access Policy' statement for more information. The entire HST archive is available world-wide. To request data you have to register as an ESO/ST-ECF Archive user. Please acknowledge the use of archive data in your publications.

On-Line Services

Archive User Profile
Off-line User Registration
go

ESO Databases
VLT Science Archive
go

Hubble Space Telescope Data
HST Science Archive
go

Catalogs & DSS
Digitized Sky Survey
go

Tools & Development
ESO's Data Interface
go

Related External Services
The Vizier catalogs, CDS
go

ESO & HST Image Galleries
ESO Photo Gallery
go

News and updates

- **UVES query screen is now available.**
- **ESO PI service mode data distribution to take place primarily on DVD starting with Period 68.** A description of the compatibility of our disks with common DVD readers is available.
- **Query forms to access the VLT Science Archive:**
  - A new WFPC2 association scheme is in place. We are still working issues related to the background to the edges of the products.
  - A General form, specially suitable when searching across wavelength range.
  - A FORS1 and a FORS2 forms, giving access to optical images and spectra.
  - An ISAAC form, giving access to the stacks of frames observed in the infrared.

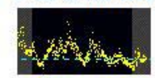
  These new query functions feature FITS headers viewers, DIMM seeing viewers, together with automatic selection of suitable calibrations for FORS1, FORS2, ISAAC and UVES data

- Dedicated Page with the Public Datasets now including **VINCI** commissioning data.
- Stand-alone FITS tools in ANSI-C available. Among the tools, `hierarch28` can convert `HIERARCH ESO` header keywords to IRAF keywords.
- Having trouble using the Science Archive Facility? Pay a visit to our FAQ section (frequently asked questions).
- The Archive Brochure, advertising our services, available in PDF format (1.1MB).

Public Datasets

Digitized Sky

Paranal Meteo



Hubble European Space Agency Information Centre

ASTROVIRTEL

AVO

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http://arch-http.hq.eso.org/

Astronomical Data Center

Access to Astronomy Data and Catalogs

- Astronomy Data (Catalogs & Journal Tables)
- How To...
- News
- About Us
- Site Map
- Search
- FAQ
- Feedback
- Links

The **ADC** has been an important resource for astronomy data, catalogs, and journal tables since 1977. We have thousands of published data sets available.

If your research benefits from the use of ADC's services, please acknowledge the ADC in your publication to ensure continuation of our services. See our recommended acknowledgement for suggested wording.

It is with profound sadness that we announce the untimely death of our dear friend and colleague, Dr. Thomas J. Sodroski, who worked at the ADC from 1998 until January 2002. Please visit our **"Tribute to Tom Sodroski" web site.**

Help Desk: help@adc.gsfc.nasa.gov
Curators: James Gass & Gail Schneider
NASA Official: Dr. Cynthia Y. Cheung
Revised: Friday, 01-Mar-2002 16:10:07 EST

Please see the NASA/GSFC Website Security and Privacy Statement.

FEATURES

Find data by topic with Quick Reference Pages

Sort, subset data with ***ADC Data Viewer***

Plot table data with CatsEye

A graphical interface to astronomical databases **IMPReSS**

ADC's XML Resources
<Xml>

Data Mining & the Virtual Observatory

VizieR data service

Search with AMASE

ADC for Amateur Astronomers

ADC for Students & Educators

http://adc.gsfc.nasa.gov/

Data Search / Missions / Contacts / STScI / MAST

Sloan Digital Sky Survey Archive

SDSS Archive / Catalog / Images / Spectra / Software / SkyServer / Credits / Help

SDSS

Getting Started

Early Data Release

User's Guide

Contributed Data

Credits

What's New

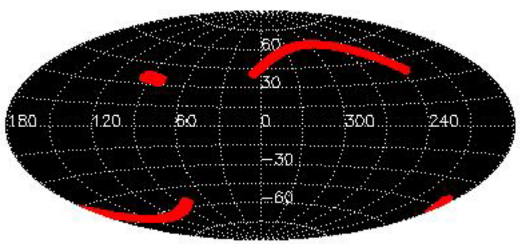
SDSS Links

Welcome to the Sloan Digital Sky Survey Archive!

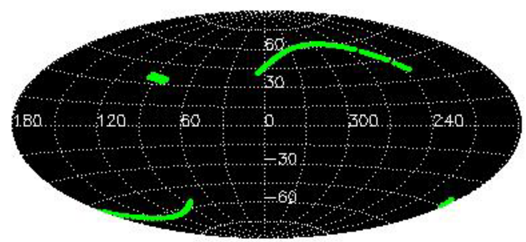
The **Sloan Digital Sky Survey** (SDSS) is using a dedicated 2.5 m telescope and a large format CCD camera to obtain images of over 10,000 square degrees of high Galactic latitude sky in five broad bands (u', g', r', i' and z', centered at 3540, 4770, 6230, 7630, and 9130 Å, respectively). Medium resolution spectra will be obtained for approximately 10^6 galaxies and 100,000 quasars. The early data release (EDR), on June 2001, includes searchable catalogs of images and spectra, images for display and scientific purpose in both 2-D FITS and JPEG formats, and spectra in both 1-D FITS and GIF formats. The EDR covers about 460 square degrees of sky. The next data releases will occur every 18 months or so.

Want to hear more? Sign up for one or both of our users' groups for the latest updates. All regular SDSS users must sign up for the Users' Group, or risk missing critical software and documentation updates.

Check the status of the SDSS archive server.



Aitoff projection in Galactic coordinates of SDSS Early Data Release Imaging Sky Coverage



Aitoff projection in Galactic coordinates of SDSS Early Data Release Spectral Sky Co verage

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Navigations hints:
The upper left SDSS logo takes you to the Public SDSS site
The upper right MAST logo takes you to the main MAST page
The top most banner links you to MAST related topics
The lower top banner links you to SDSS specific links and data products

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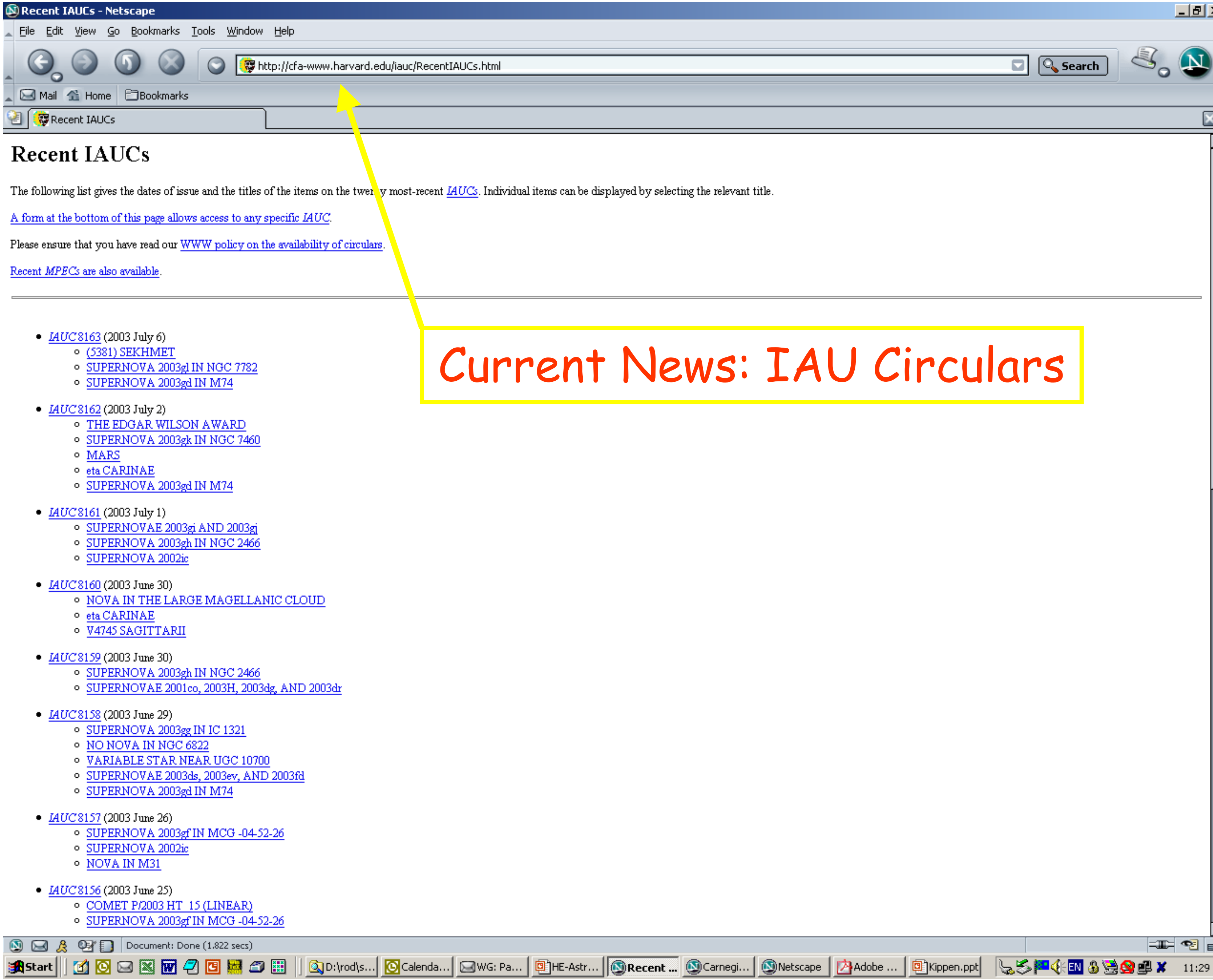
http://archive.stsci.edu/sdss

Current News: IAU Circulars


Recent IAUCs - Netscape

http://cfa-www.harvard.edu/iauc/RecentIAUCs.html

Recent IAUCs

The following list gives the dates of issue and the titles of the items on the twenty most-recent *IAUCs*. Individual items can be displayed by selecting the relevant title.

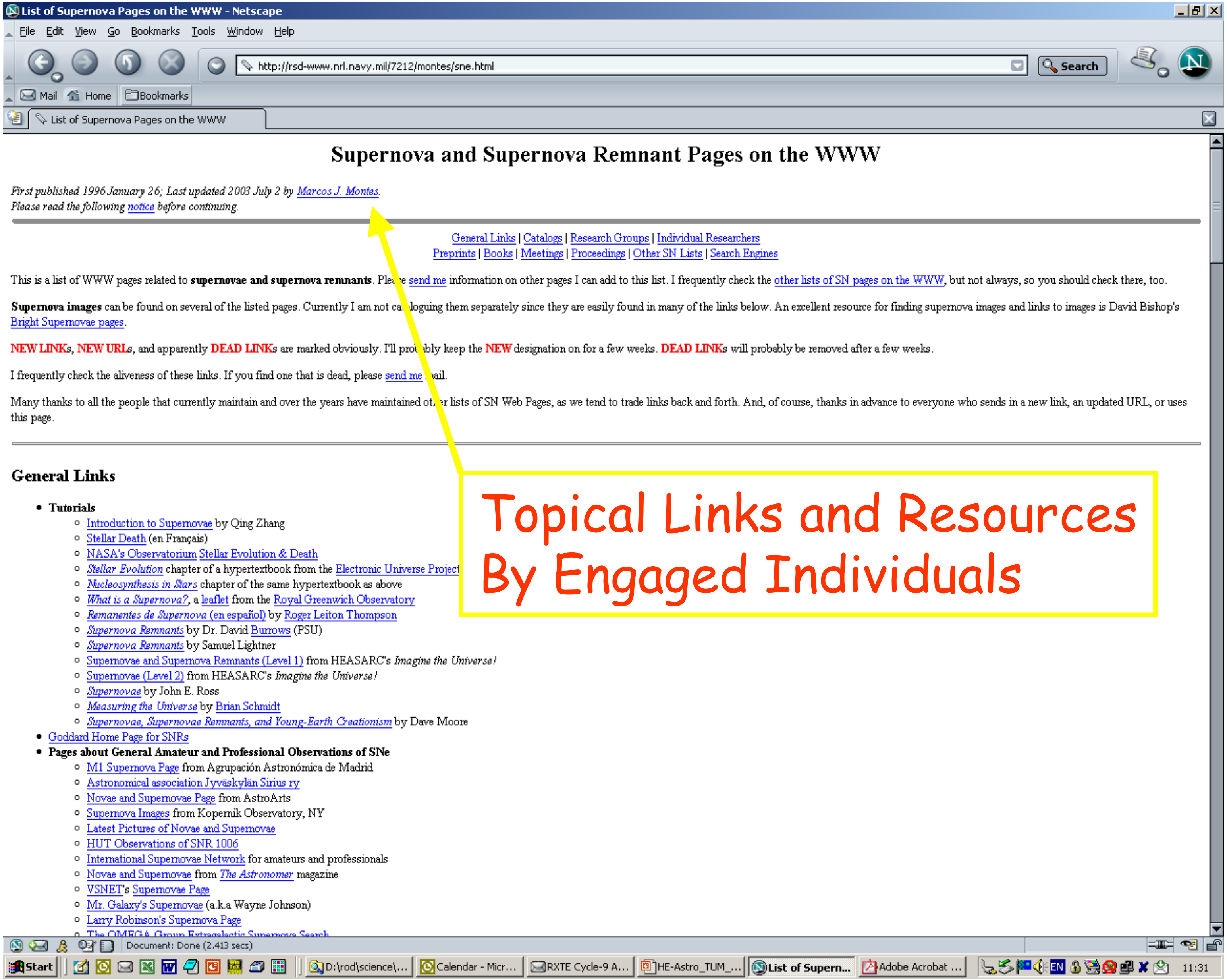
A form at the bottom of this page allows access to any specific *IAUC*.

Please ensure that you have read our WWW policy on the availability of circulars.

Recent *MPECs* are also available.

- *IAUC* 8163 (2003 July 6)
  - (5381) SEKHMET
  - SUPERNOVA 2003gl IN NGC 7782
  - SUPERNOVA 2003gd IN M74
- *IAUC* 8162 (2003 July 2)
  - THE EDGAR WILSON AWARD
  - SUPERNOVA 2003gk IN NGC 7460
  - MARS
  - eta CARINAE
  - SUPERNOVA 2003gd IN M74
- *IAUC* 8161 (2003 July 1)
  - SUPERNOVAE 2003gi AND 2003gj
  - SUPERNOVA 2003gh IN NGC 2466
  - SUPERNOVA 2002ic
- *IAUC* 8160 (2003 June 30)
  - NOVA IN THE LARGE MAGELLANIC CLOUD
  - eta CARINAE
  - V4745 SAGITTARII
- *IAUC* 8159 (2003 June 30)
  - SUPERNOVA 2003gh IN NGC 2466
  - SUPERNOVAE 2001co, 2003H, 2003dg, AND 2003dr
- *IAUC* 8158 (2003 June 29)
  - SUPERNOVA 2003gg IN IC 1321
  - NO NOVA IN NGC 6822
  - VARIABLE STAR NEAR UGC 10700
  - SUPERNOVAE 2003ds, 2003ev, AND 2003fd
  - SUPERNOVA 2003gd IN M74
- *IAUC* 8157 (2003 June 26)
  - SUPERNOVA 2003gf IN MCG -04-52-26
  - SUPERNOVA 2002ic
  - NOVA IN M31
- *IAUC* 8156 (2003 June 25)
  - COMET P/2003 HT_15 (LINEAR)
  - SUPERNOVA 2003gf IN MCG -04-52-26

Document: Done (1.822 secs)



List of Supernova Pages on the WWW - Netscape

File Edit View Go Bookmarks Tools Window Help

http://rsd-www.nrl.navy.mil/7212/montes/sne.html

Supernova and Supernova Remnant Pages on the WWW

First published 1996 January 26; Last updated 2003 July 2 by Marcos J. Montes.
Please read the following notice before continuing.

General Links | Catalogs | Research Groups | Individual Researchers
Preprints | Books | Meetings | Proceedings | Other SN Lists | Search Engines

This is a list of WWW pages related to **supernovae and supernova remnants**. Ple[...]e send me information on other pages I can add to this list. I frequently check the other lists of SN pages on the WWW, but not always, so you should check there, too.

Supernova images can be found on several of the listed pages. Currently I am not ca[...]loguing them separately since they are easily found in many of the links below. An excellent resource for finding supernova images and links to images is David Bishop's Bright Supernovae pages.

NEW LINKs, **NEW URL**s, and apparently **DEAD LINK**s are marked obviously. I'll pro[...]bly keep the **NEW** designation on for a few weeks. **DEAD LINK**s will probably be removed after a few weeks.

I frequently check the aliveness of these links. If you find one that is dead, please send me [...]ail.

Many thanks to all the people that currently maintain and over the years have maintained ot[...]r lists of SN Web Pages, as we tend to trade links back and forth. And, of course, thanks in advance to everyone who sends in a new link, an updated URL, or uses this page.

General Links

- **Tutorials**
  - Introduction to Supernovae by Qing Zhang
  - Stellar Death (en Français)
  - NASA's Observatorium Stellar Evolution & Death
  - *Stellar Evolution* chapter of a hypertextbook from the Electronic Universe Project
  - *Nucleosynthesis in Stars* chapter of the same hypertextbook as above
  - *What is a Supernova?*, a leaflet from the Royal Greenwich Observatory
  - *Remanentes de Supernova (en español)* by Roger Leiton Thompson
  - *Supernova Remnants* by Dr. David Burrows (PSU)
  - *Supernova Remnants* by Samuel Lightner
  - Supernovae and Supernova Remnants (Level 1) from HEASARC's *Imagine the Universe!*
  - Supernovae (Level 2) from HEASARC's *Imagine the Universe!*
  - *Supernovae* by John E. Ross
  - *Measuring the Universe* by Brian Schmidt
  - *Supernovae, Supernovae Remnants, and Young-Earth Creationism* by Dave Moore
- Goddard Home Page for SNRs
- **Pages about General Amateur and Professional Observations of SNe**
  - M1 Supernova Page from Agrupación Astronómica de Madrid
  - Astronomical association Jyväskylän Sirius ry
  - Novae and Supernovae Page from AstroArts
  - Supernova Images from Kopernik Observatory, NY
  - Latest Pictures of Novae and Supernovae
  - HUT Observations of SNR 1006
  - International Supernovae Network for amateurs and professionals
  - Novae and Supernovae from *The Astronomer* magazine
  - VSNET's Supernovae Page
  - Mr. Galaxy's Supernovae (a.k.a Wayne Johnson)
  - Larry Robinson's Supernova Page
  - The OMEGA Group Extragalactic Supernova Search

Document: Done (2.413 secs)

Topical Links and Resources
By Engaged Individuals

Daily Astro-Topic Advertisements