X-RAY SPECTROSCOPY: PART I - DATA BASICS

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-WITH HELP OVER THE YEARS FROM-

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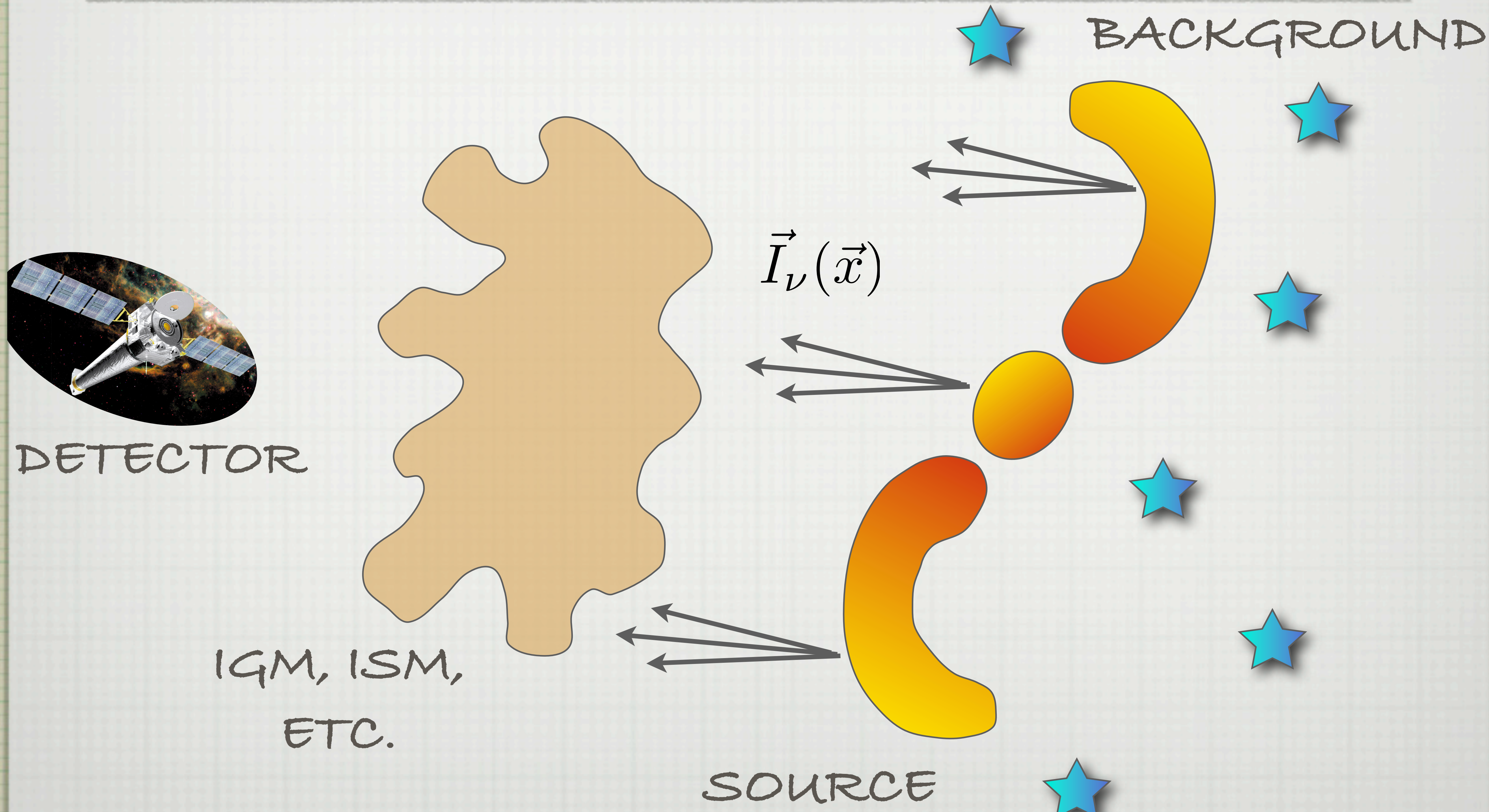
OUTLINE (PART 1):

- THE COMPONENTS OF AN X-RAY SPECTRAL FIT:
  - DATA, SPECTRUM, RMF, ARF, BACKGROUND
  - LOADING & VISUALIZING THE DATA
  - DEFINING A MODEL
    - ISIS EXAMPLES SPRINKLED THROUGHOUT

WHAT YOU WANT TO UNCOVER: ASTROPHYSICAL SPECTRA



INTENSITY AS A FUNCTION OF POSITION & DIRECTION

- BUT, LIMITATIONS ABOUND...
- LACK OF SPATIAL RESOLUTION - SPATIAL RESOLUTION:
  - CHANDRA -> XMM -> SUZAKU -> RXTE
- FOREGROUND ABSORPTION, BACKGROUND EMISSION
- LACK OF ENERGY RESOLUTION - ENERGY RESOLUTION:
  - CHANDRA (HETG) -> XMM (RGS) -> SUZAKU -> RXTE
- LIMITED COLLECTING AREA -> COUNTS, NOT FLUX!

X-RAY SPECTROSCOPY IS ABOUT *COUNTS PER CHANNEL*

- $\vec{I}_\nu(\vec{x})$ IS: ENERGY/SEC/HZ/AREA/STERADIAN
- X-RAY TELESCOPES MEASURE: COUNTS/(INTEGRATED TIME BIN)/"CHANNEL" - TEMPORAL RESOLUTION:
  - RXTE -> XMM -> CHANDRA -> SUZAKU
- COUNTS ARE NOT PHOTONS!
  - POISSON STATISTICS ARE COMMONLY USED
- CHANNELS ARE NOT ENERGY!

WE CONVERT FROM FLUX* TO DETECTOR COUNTS§

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E)\, S_i(E)\, dE\, dT + B(h)$$

DETECTED COUNTS

RESPONSE MATRIX

EFFECTIVE AREA

SOURCE SPECTRA

BACKGROUND COUNTS

CAN "OVERLAP"

(SEE J. DAVIS, 2001, APJ, 548, P. 1010)

*NOT JUST FROM THE SOURCE

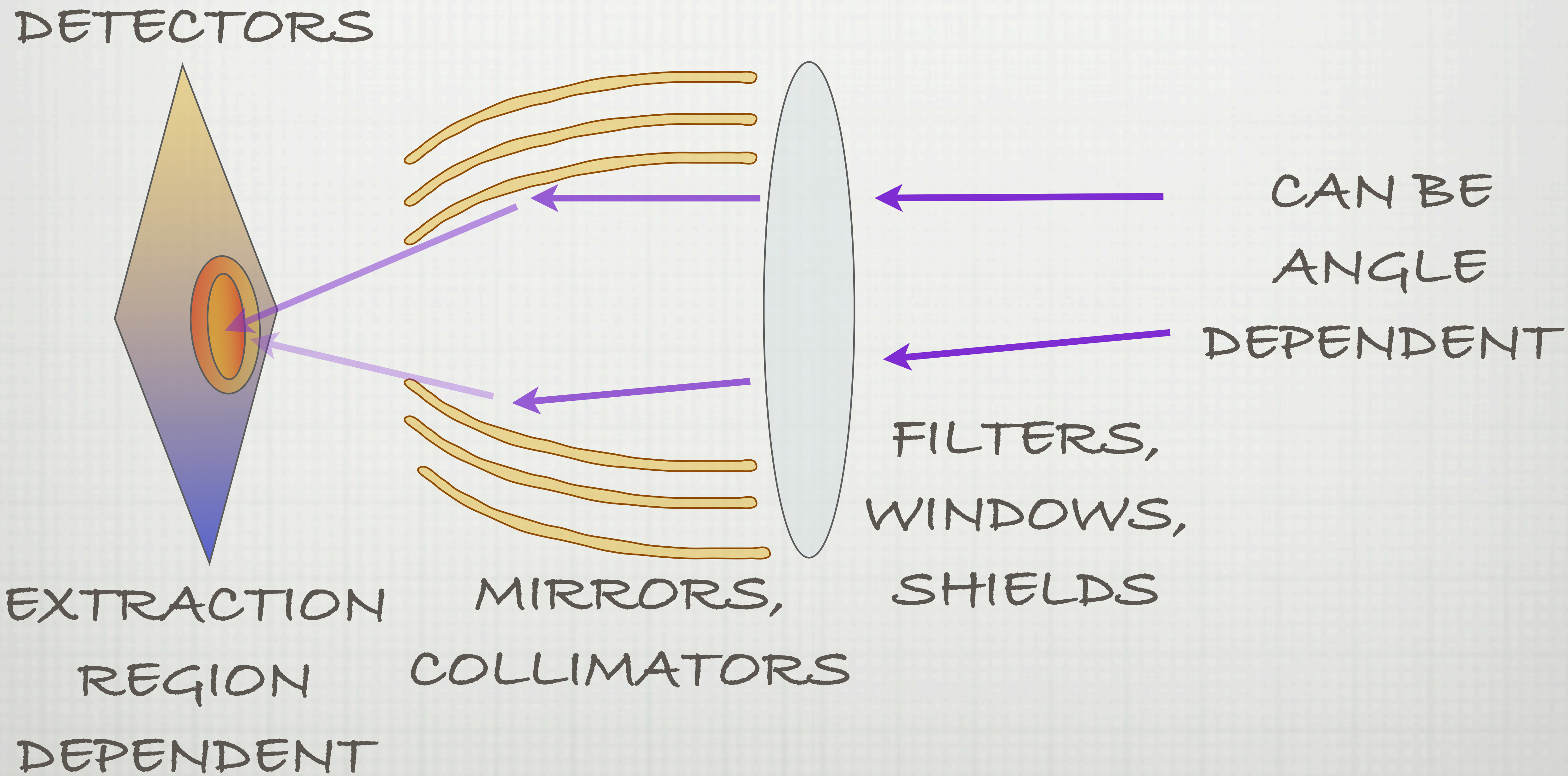
§ALSO NOT JUST FROM THE SOURCE

WHAT ARE THESE PIECES?

- $S(E)$: SPECTRAL ENERGY DISTRIBUTION, UNITS = PHOTONS/SEC/AREA/ENERGY
- $A(E)$: EFFECTIVE AREA/ANCILLARY RESPONSE FUNCTION/ARF, UNITS = AREA/PHOTON
- $R(h, E)$: RESPONSE FUNCTION/RMF, UNITLESS & SOMETIMES NORMALIZED - $\sum_h \int_0^E R(h, E)\ \delta(E - E_0)\ dE\ =\ 1$
- dE, dT : PHOTON ENERGY, INTEGRATION TIME
- $C(h), B(h)$: SOURCE & BACKGROUND COUNTS (EVENTS)
- h : PULSE HEIGHT ANALYSIS (PHA) OR PULSE INVARIANT (PI) CHANNEL. DISCRETE!!!

EFFECTIVE AREA (ARF):

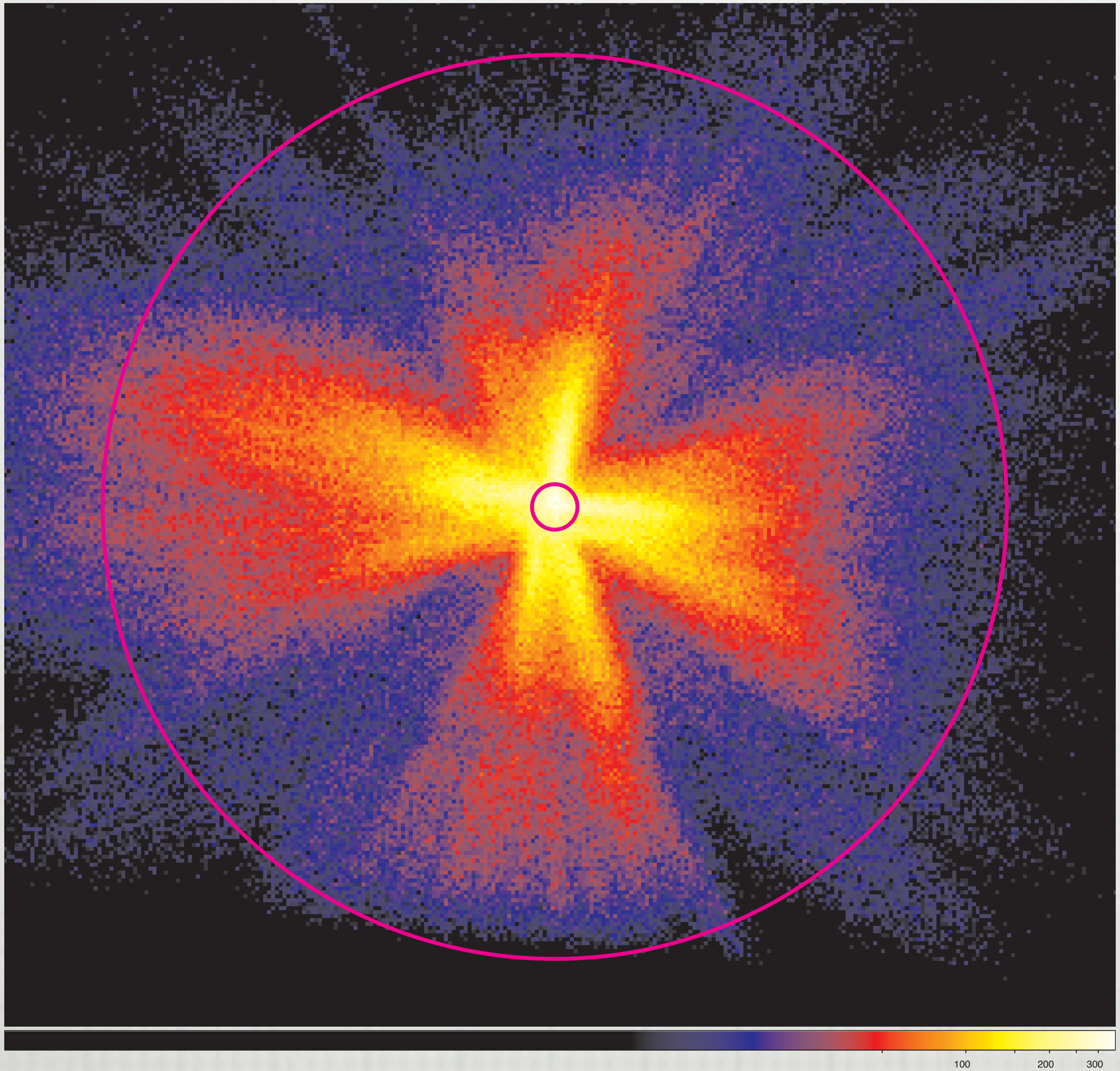
ARF CAN HAVE MANY COMPONENTS



EFFECTIVE AREA (ARF):

- ARF- COMBINATIONS OF TELESCOPE COLLECTING AREA, DETECTOR EFFICIENCIES, FILTER THROUGHPUTS, ETC.
- "STRUCTURE" OFTEN RELATED TO PHYSICS OF THE MIRRORS/COLLIMATORS, DETECTORS, FILTERS, ETC.
- TYPICALLY HIGHEST "ON-AXIS", LOWEST "OFF-AXIS". "OFF-AXIS" CAN BE UP TO $\sim 1^{o}$ (RXTE).
  - UNRESOLVED/OFF-AXIS SOURCES = BACKGROUND
- DEPENDS UPON "EXTRACTION REGION". GET THE WHOLE POINT SPREAD FUNCTION (PSF)? EXTRACT ONLY OUTER RADII (E.G., SUZAKU)? DETECTOR MOVING? ETC.

EFFECTIVE AREA (ARF):



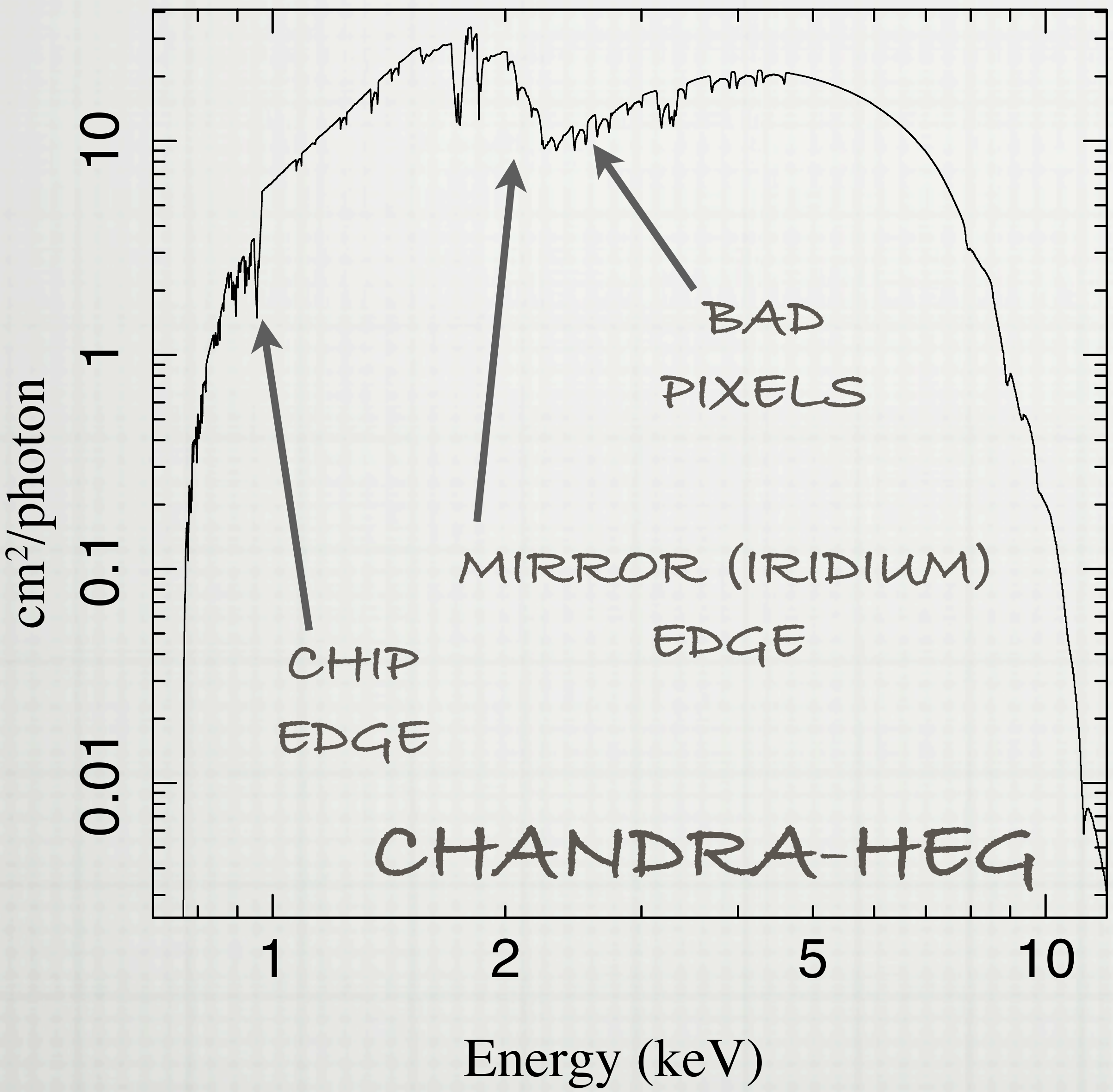
- PSF OUTSIDE BIG CIRCLE WAS EXCLUDED
- PSF INSIDE SMALL CIRCLE WAS EXCLUDED (PILE UP)
- SUZAKU CREATES ARFS VIA MONTE CARLO SIMULATIONS (SPACECRAFT SPECIFIC TOOL!)

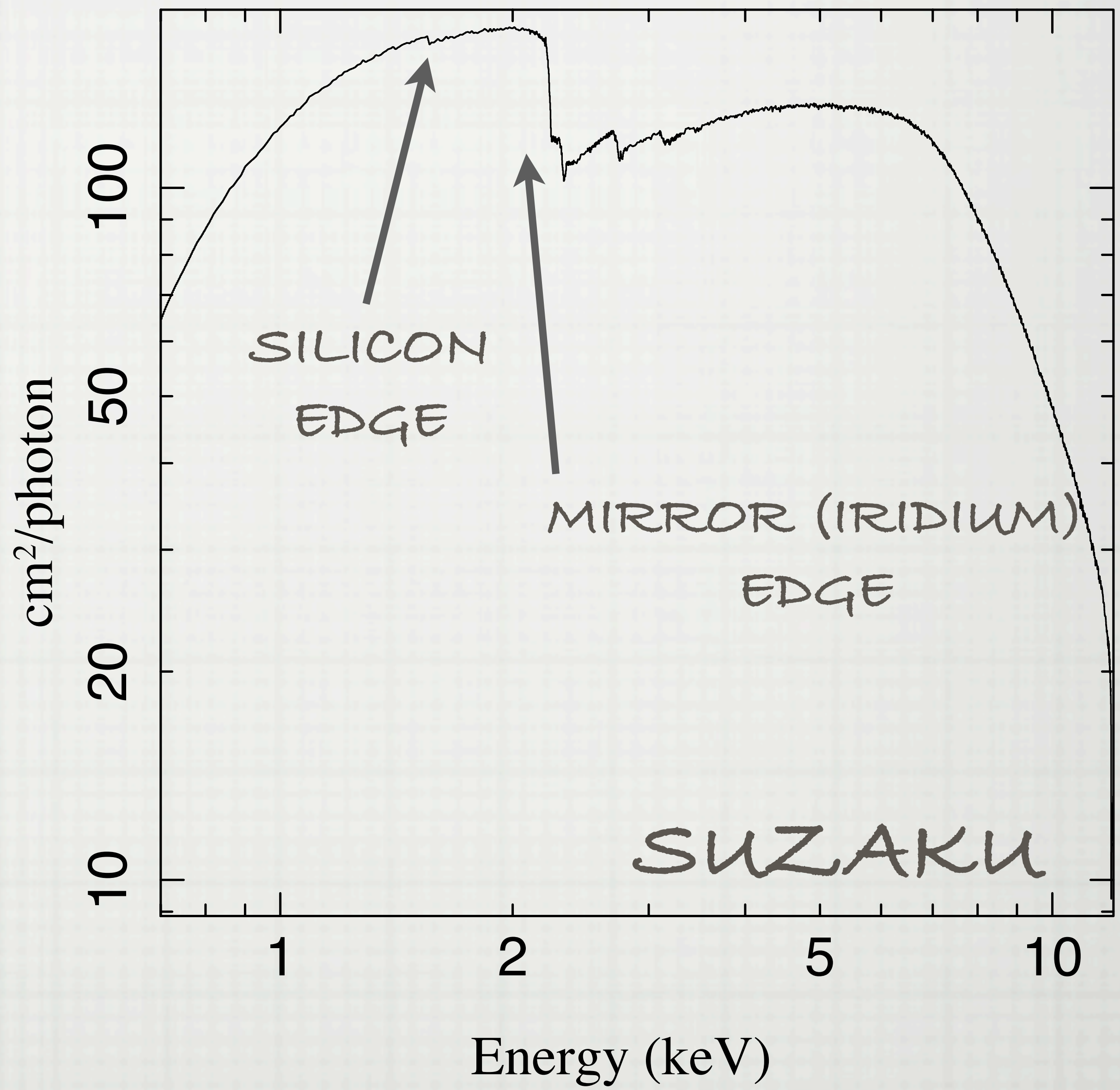
EFFECTIVE AREA (ARF):

- ARF CREATED BY SATELLITE-SPECIFIC SOFTWARE!
- CAN BE VISUALIZED (SEE EXERCISE):

```
isis> arf = load_arf("/path/to/arf/file.arf");
isis> plot_bin_integral;
isis> % Area vs. wavelength (Angstrom):
isis> hplot(arf.bin_lo,arf.bin_hi,arf.value);
isis> % Area vs. energy (keV):
isis> hplot(_A(arf.bin_hi),_A(arf.bin_lo),reverse(arf.value));
```

EFFECTIVE AREA (ARF):





SOME OF THESE FEATURES ARE "FIXED", OTHERS CAN VARY FROM OBSERVATION TO OBSERVATION

RESPONSE FUNCTION (RMF):

- PHOTON HAS MADE IT PAST FILTERS, MIRRORS, DETECTORS, HOW IS IT ACTUALLY REGISTERED?
  - "PULSE HEIGHT" - CHARGE CLOUD, CURRENT, ETC.
  - ENERGY/FLUX -> AMPLITUDE/PEAKS OR COUNTS
  - INPUT ENERGY-> OUTPUT CHANNEL IS ONE -> MANY
  - RMF ENCODES INFORMATION ABOUT DETECTOR RESOLUTION, AND OTHER PHYSICAL EFFECTS
    - RESOLUTION CAN FOLLOW ITS OWN "POISSON STATISTICS", AND OFTEN GOES AS $E^{1/2}$
    - GRATINGS ARE SPATIAL, FOLLOW $\Delta \Lambda$ ~CONSTANT

RESPONSE FUNCTION (RMF):

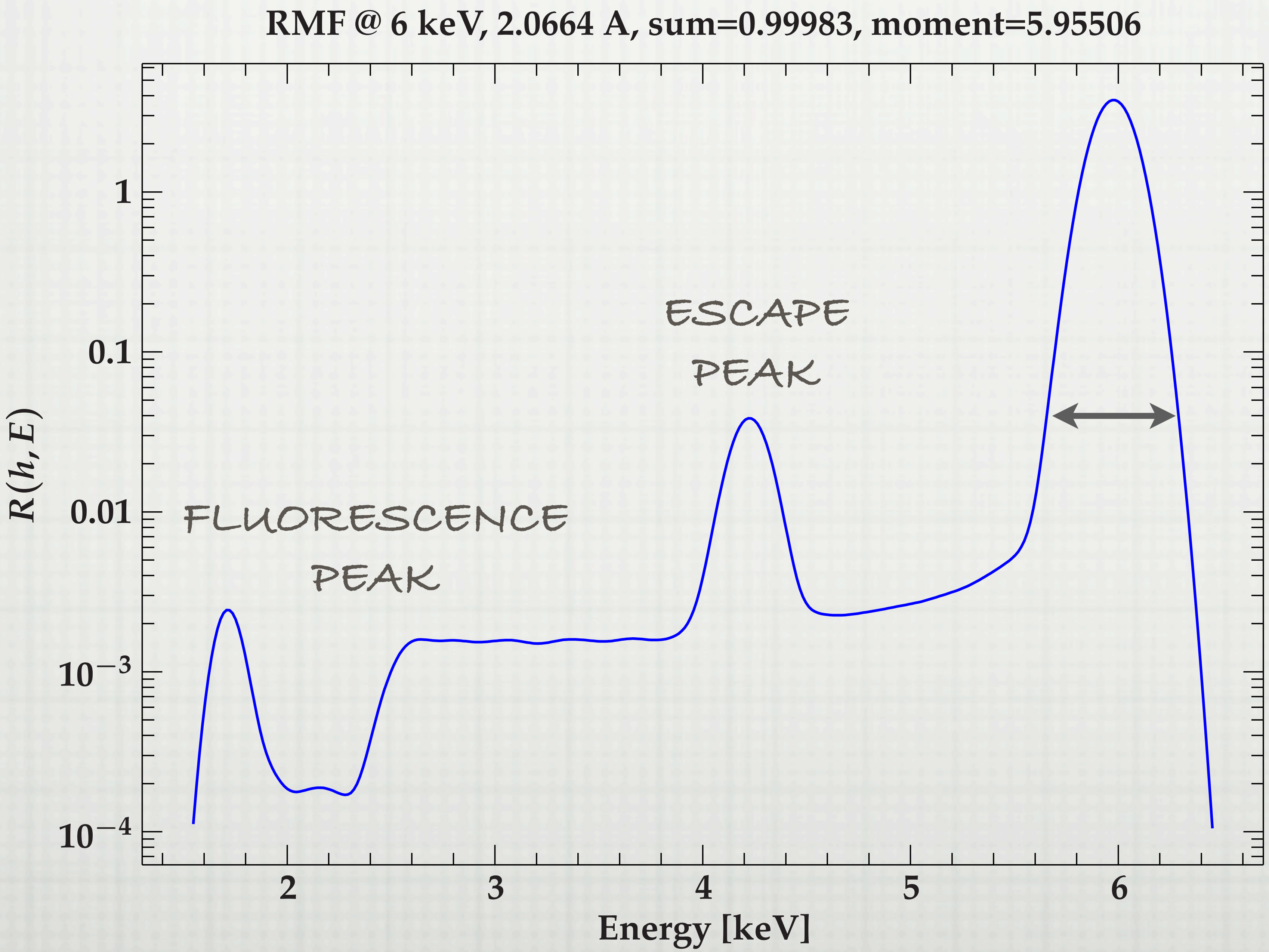
- RMF CREATED BY SATELLITE-SPECIFIC SOFTWARE!
- CAN BE VISUALIZED (SEE EXERCISE):

```
isis> load_rmf("/path/to/rmf/file.rmf");
isis> assign_rmf (1,1);
isis> fit_fun("delta(1)");
isis> set_par (1,1);
isis> set_par (2,_A(6.0));       % 6 keV
isis> eval_counts;
isis> plot_unit(“a”); ylog; plot_model(1);   % Angstrom
isis> plot_unit(“keV”); plot_model(1);       % keV
```

- THIS IS JUST FOLDING A DELTA-FUNCTION THROUGH THE COUNTS EQUATION, YIELDING $C(h) = RMF(h,E_0)$

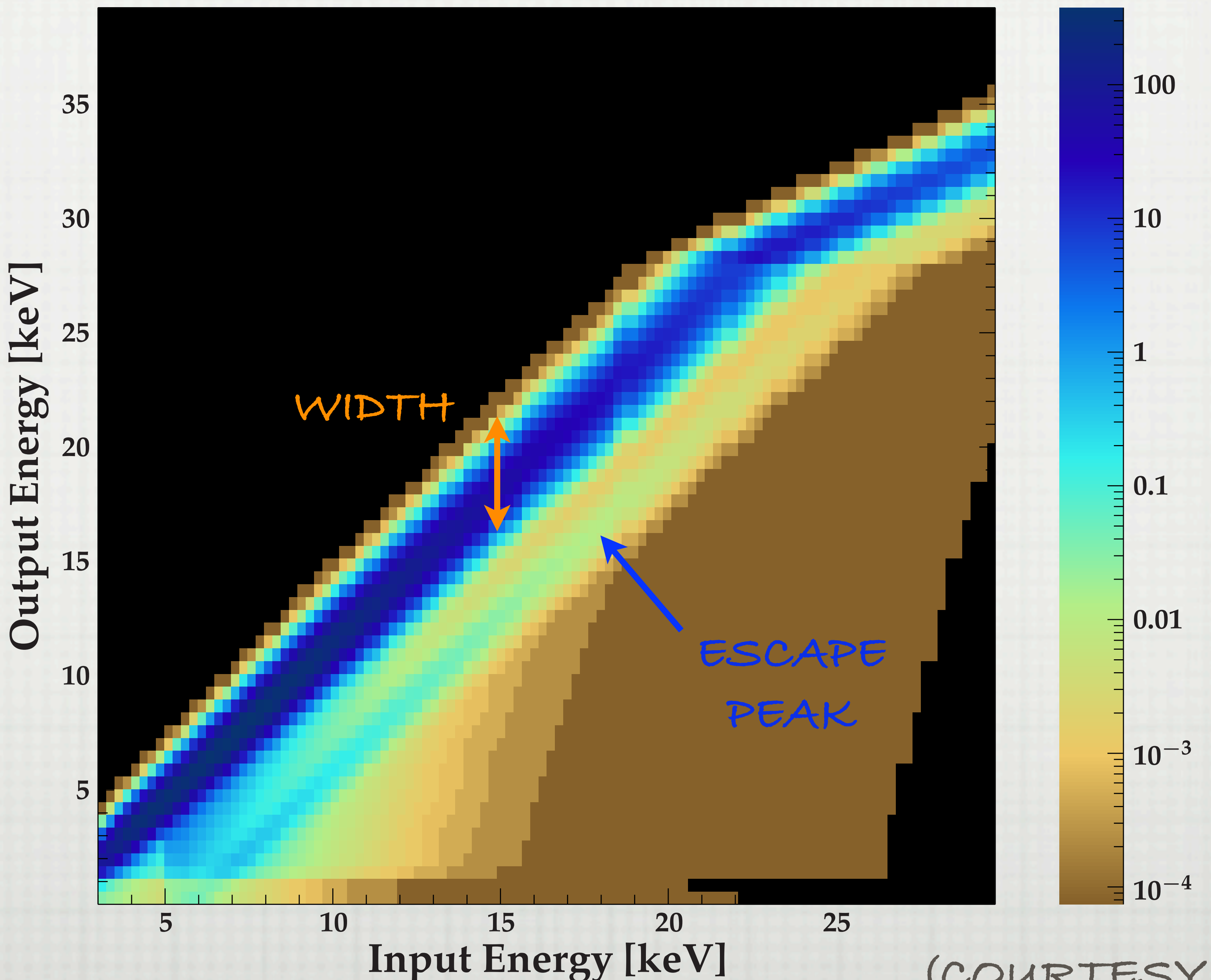
RESPONSE FUNCTION (RMF):

CHANDRA-ACIS RESPONSE



RESPONSE FUNCTION (RMF):

RXTE - PCA RESPONSE



(COURTESY J. DAVIS)

RESPONSE FUNCTION (RMF):

- FLUORESCENCE PEAKS ARE CAUSED BY THE SAME PROCESSES AS IN ASTROPHYSICAL SOURCES
- PHOTON WITH ENERGY > DETECTOR MATERIAL EDGE ENERGY (XENON GAS, SILICON WAFER) KNOCKS OUT INNER SHELL ELECTRON
- L -> K TRANSITION YIELDS FLUORESCENCE PHOTON, WHICH MIGHT BE DETECTED
- LOW ENERGY TRANSITIONS YIELD ESCAPE PHOTON(S) WHICH MIGHT BE DETECTED

$$E_{\text{escape}} = E_{\text{incident}} - E_{\text{fluorescence}}$$

RESPONSE FUNCTION (RMF):

CYG X-1 VIEWED WITH CHANDRA-HETG

SHORT
WAVELENGTH

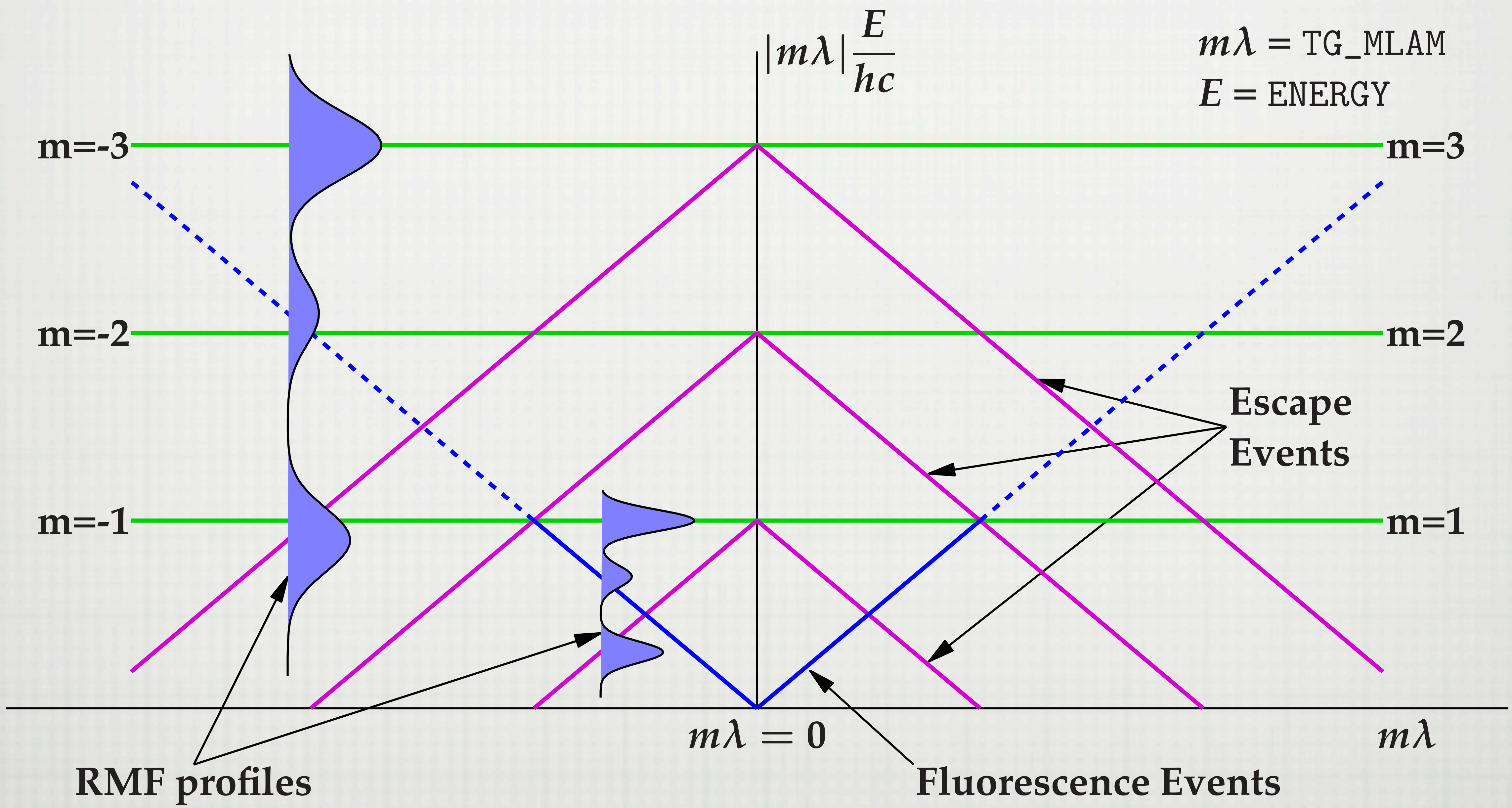
LONG
WAVELENGTH

SHORT
WAVELENGTH

LONG
WAVELENGTH

CAN COMPARE “CCD ENERGY”
WITH “GRATINGS ENERGY”

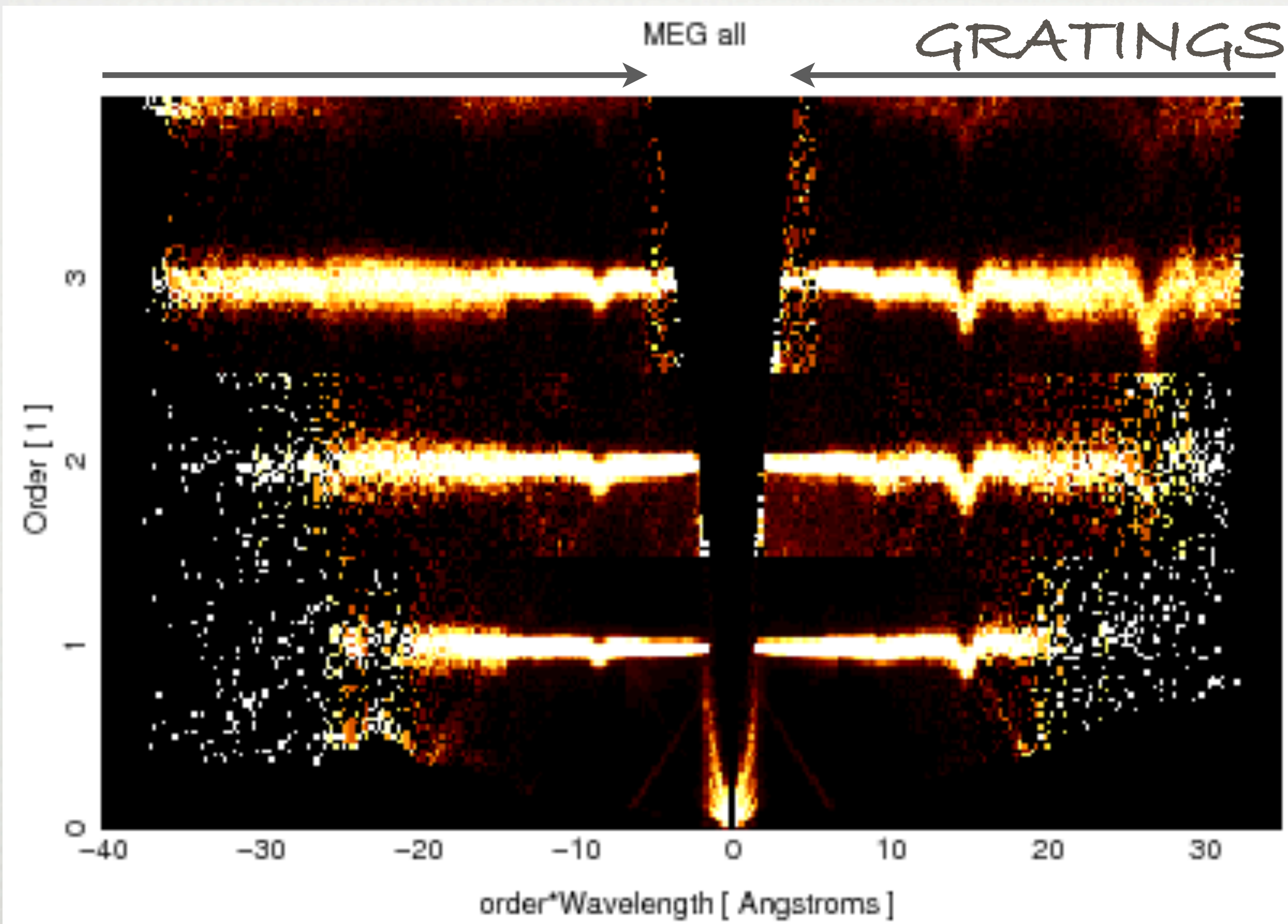
RESPONSE FUNCTION (RMF):



(COURTESY J. DAVIS)

RESPONSE FUNCTION (RMF):

CYG X-1: FROM HTTP://TGCAT.MIT.EDU



GRATINGS ENERGY

CHANNEL

CCD ENERGY

RESPONSE FUNCTION (RMF):

- LABELING CHANNELS WITH AN ENERGY IS A CONVENIENCE!
- ENERGY IS CONTINUOUS, PHA BINS ARE DISCRETE.
- THE MAPPING OF "PHA" VALUES TO ENERGY IS THE GAIN.
- THIS MAPPING CAN VARY FROM POSITION TO POSITION ON THE DETECTOR. IN PRINCIPLE, THIS IS NOT A PROBLEM SINCE THE ARF & RMF SHOULD ENCODE THE MAPPINGS.
- SOMETIMES ITS CONVENIENT TO HAVE THE SAME ENERGIES CORRESPOND TO THE SAME "PHA" VALUES
  - "PHA" -> "PI" = "PULSE INVARIANT"

RESPONSE FUNCTION (RMF):

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E)\ S_i(E)\ dE\ dT + B(h)$$

ADD A MULTIPLICATIVE GAIN CORRECTION HERE

- GAIN MAPPING (PHA $\longleftrightarrow$ ENERGY) IS NOT ALWAYS CORRECT. CAN ADD A CORRECTION IN THE FIT PROCESS.
  - IF FIT DISAGREES WITH "KNOWN" LINE ENERGY
- SOMETIMES FOR CONVENIENCE, RMF & ARF ARE COMBINED IN A SINGLE RESPONSE ("RESP") FILE.
  - BUT NOT ALWAYS, ESPECIALLY WHEN SOME PARTS CHANGE WITH TIME, WHILE OTHERS DO NOT

BACKGROUND

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E) \boxed{S_i(E)}\, dE\, dT + \boxed{B(h)}$$

- UNRESOLVED SOURCES CAN BE BACKGROUND. "X-RAY BACKGROUND", GALACTIC RIDGE EMISSION, ETC.
- "RESOLVED", BUT DIFFUSE EMISSION CAN BE BACKGROUND. DUST, HOT GAS, ETC.
- IN PRINCIPLE, THESE COULD (SHOULD) BE ADDED TO S(E)
- BACKGROUND CAN BE INSTRUMENTAL (DETECTOR NOISE), NON X-RAY (COSMIC RAYS), PARTICLE BACKGROUND, ETC. THESE TYPES OF BACKGROUNDS ARE ADDED TO B(h).

BACKGROUND

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E) \boxed{S_i(E)} \, dE \, dT + \boxed{B(h)}$$

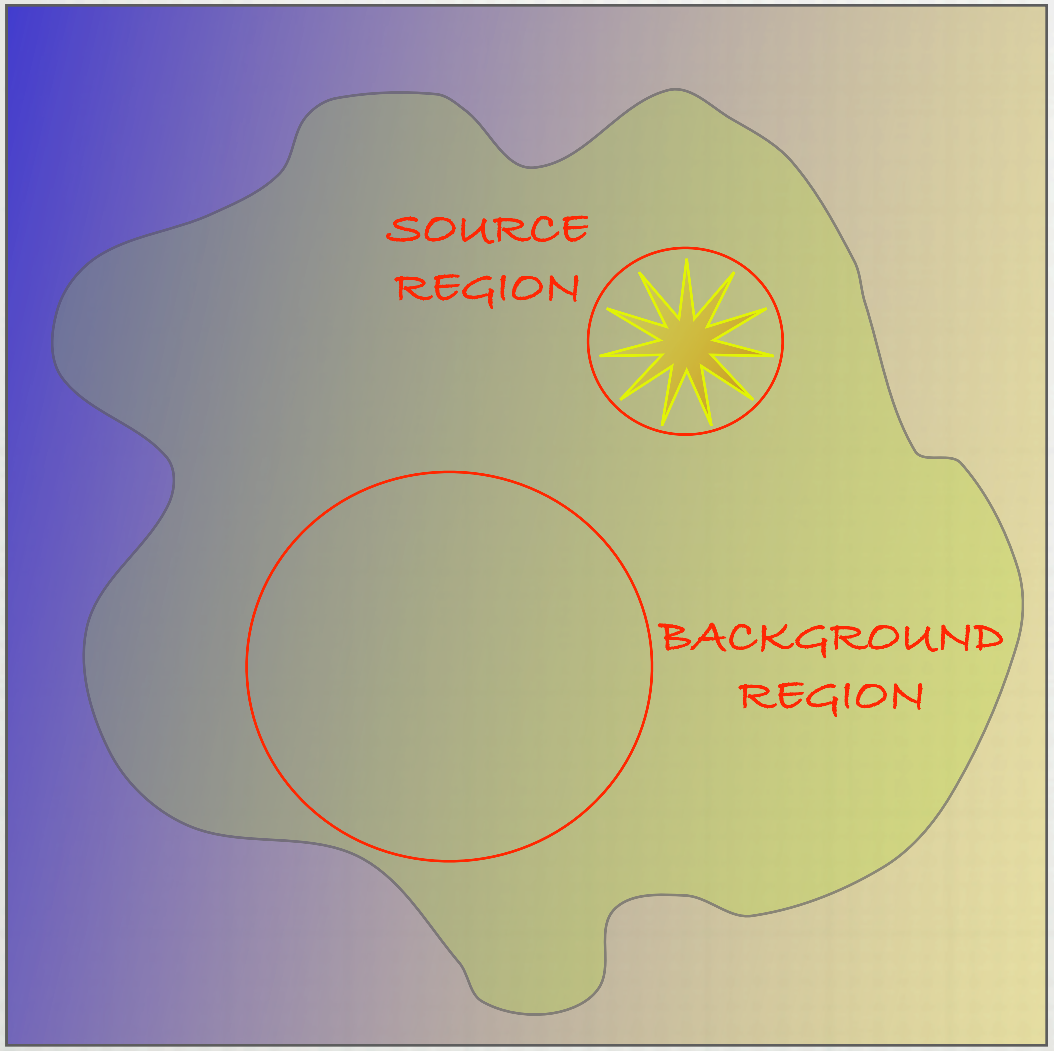
- BACKGROUND MIGHT BE MODELED OR MEASURED
  - MODELED: ADDED TO THE S(E) -OR- B(h) TERMS. I.E., MAY, OR MAY NOT, BE "FOLDED THROUGH" RESPONSE
    - IF MODELED WITH FIT PARAMETERS, (USUALLY) NO CHANGES TO THE STATISTICS.
  - MEASURED: USUALLY ADDED TO THE B(h) TERM. NO "FOLDING THROUGH" THE RESPONSE.
    - (USUALLY) CHANGES THE STATISTICS DEFINITION.

BACKGROUND

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E) \; S_i(E) \; dE \; dT \; + \boxed{B(h)}$$

- ISIS NEVER "SUBTRACTS" THE BACKGROUND. IT IS ADDED TO "MODEL" TERMS, AND COMPARED TO *TOTAL COUNTS*.
  - THE ONLY QUESTION IS, DO YOU REDEFINE THE COMPARISON STATISTICS?
  - DEFAULT STATISTICS (CHI^2 BASED UPON DATA COUNTS) DOES CHANGE WITH BACKGROUND.
  - THIS DEFAULT BEHAVIOR CAN BE ALTERED.

BACKGROUND



SOURCE BACKGROUND = MEASURED BACKGROUND * (SOURCE AREA) * (SOURCE TIME)/ [(BACKGROUND AREA) * (BACKGROUND TIME)]

$$B_s(h) = B_m(h) \times \frac{A_s(h)\ T_s(h)}{A_m(h)\ T_m(h)}$$

THIS INFORMATION IS USUALLY STORED IN THE SPECTRUM DATA FILES & BACKGROUND DATA FILES VIA THE "EXPOSURE" AND "BACKSCALE" KEYWORDS. (USUALLY NO h DEPENDENCE OF A & T).

DEFAULTS INCORPORATE "BACKGROUND MODEL" UNCERTAINTY IN THE COMPARISON STATISTIC:

$$\Delta C(h) = \sqrt{C(h) + \left(\frac{A_s(h)\ T_s(h)}{A_m(h)\ T_m(h)}\right)^2 B_m(h)}$$
$$= \sqrt{C(h) + \left(\frac{A_s(h)\ T_s(h)}{A_m(h)\ T_m(h)}\right) B_s(h)}$$

-OR- FROM NON-SIMULTANEOUS MEASUREMENTS, "BLANK SKY" OBSERVATIONS, DETECTOR MODELS, ETC.

BACKGROUND

- BACKGROUNDS OFTEN CREATED BY SATELLITE-SPECIFIC SOFTWARE!
- CAN BE ACCESSED AND VISUALIZED (SEE EXERCISE):

```
isis> % Load the data, including background if in header
isis> d = load_data("/path/to/obs/data.pha");
isis> ch = get_data_counts(d);     % Data & bin edges
isis> bs = get_back(d);            % “Scaled” background
isis> ts = get_data_exposure(d);   % Ts(h)
isis> as = get_data_backscale(d);  % As(h)
isis> tm = get_back_exposure(d);   % Tm(h)
isis> am = get_back_backscale(d);  % Am(h)
isis> plot_bin_integral;
isis> hplot(_A(ch.bin_lo),_A(ch.bin_hi),
            reverse(ch.value));            % keV plot
isis> ohplot(_A(ch.bin_lo),_A(ch.bin_hi),
            reverse(bs));                  % keV plot
```

SOURCE MODEL

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E) \boxed{S_i(E)} \, dE \, dT + B(h)$$

- SAVED FOR LAST, SINCE IN SOME WAYS THIS IS THE LEAST IMPORTANT THING YOU NEED TO WORRY ABOUT, BUT WHAT MOST PEOPLE ONLY WANT TO THINK ABOUT...
- MODELS ARE COMPUTED ON A DISCRETE GRID, *FINER* THAN THE h-GRID. (SOMETIMES RIDICULOUSLY SO.)
- OUTPUTS OF THESE MODELS ARE: COUNTS/SEC/CM^2/*BIN*
- THE CONTENT OF THESE MODELS IS ASTROPHYSICS... I.E., THE SUBJECT OF THE NEXT 3-5 YEARS OF YOUR LIFE

SOURCE MODEL:

- ISIS DEFAULTS TO WAVELENGTH GRID, WITH LO & HI BINS EXPLICITLY SPECIFIED. (IT HAS WRAPPERS TO INTERFACE WITH EXISTING XSPEC MODELS.) MODELS ARE COUNTS INTEGRATED OVER THE BIN WIDTHS!
- ISIS _A() FUNCTION CONVERTS ANGSTROMS <-> KEV
- KEEP THIS IN MIND WHEN ADDING NEW FUNCTIONS!

```
isis> define qpo_fit(lo,hi,par){
   variable l,rms,qpo,q,f,al,ah;

   % Go from Angstrom to keV (which we pretend is Fourier Hz),
   al = _A(lo); ah = _A(hi);

   rms = par[0]; q = par[1]; f = par[2]; % RMS, Q-value, Frequency

   qpo = rms/(0.5 - atan(-2.*q)/PI);
   qpo = qpo^2/(al-ah)/PI*( atan(2.*q*(al-f)/f) - atan(2.*q*(ah-f)/f) );
   return = reverse(qpo);
}
isis> add_slang_function("qpo",["norm [rms]","Q [f/FWHM]","f [Hz]"]);
```

THE PIECES WE NEED:

- FITS (FLEXIBLE IMAGE TRANSPORT SYSTEM) - BINARY FORMAT TO STORE ASTROPHYSICAL DATA

  http://heasarc.gsfc.nasa.gov/docs/heasarc/fits.html

- FILES READ WITH FTOOLS/CFITSIO (HEASOFT), DMTOOLS (CIAO), OTHERS. INCORPORATED INTO ANALYSIS SYSTEMS.

- PHA (SPECTRAL FILES) HAVE TYPE 1 & TYPE 2.

- TYPE 1 - SINGLE SPECTRUM PER FILE. "HEADER" (WHAT GRPPHA ALTERS) CAN CONTAIN INFORMATION ON ASSOCIATED RESPONSES AND BACKGROUND.

- TYPE 2 - MULTIPLE SPECTRA PER FILE (E.G., MULTIPLE GRATING ORDERS), NO STANDARD STORAGE OF NAMES OF ASSOCIATED RESPONSES AND BACKGROUNDS.

THE PIECES WE NEED:

- SATELLITE SPECIFIC PIECES: PHA, RMF, ARF, BKG = FITS FILES. CAN BE ASSOCIATED VIA FTOOL FUNCTION "GRPPHA".

```
UNIX%> GRPPHA HXTA.PHA
 ** GRPPHA 3.0.1
 ...... USING PHA_GP   VER 1.1.1
PLEASE ENTER OUTPUT FILENAME[] !HXTA.PHA

  -------------------------
  MANDATORY KEYWORDS/VALUES
  -------------------------
  --------------------------------------------------------------------
  --------------------------------------------------------------------
  EXTNAME    - SPECTRUM        NAME OF THIS BINTABLE
  TELESCOP   - XTE             MISSION/SATELLITE NAME
  INSTRUME   - HEXTE           INSTRUMENT/DETECTOR
  FILTER     - NONE            INSTRUMENT FILTER IN USE
  EXPOSURE   - 7086.5          INTEGRATION TIME (IN SECS) OF PHA DATA
  AREASCAL   - 1.0000          AREA SCALING FACTOR
  BACKSCAL   - 1.0000          BACKGROUND SCALING FACTOR
  BACKFILE   - HXTABACK.PHA    ASSOCIATED BACKGROUND FILE
  CORRSCAL   - 0.0000          CORRELATION SCALING FACTOR
  CORRFILE   - NONE            ASSOCIATED CORRELATION FILE
  RESPFILE   - HEXTE-A_SRC.RMF
  ANCRFILE   - HEXTE-A_SRC.ARF
  POISSERR   - FALSE           WHETHER POISSONIAN ERRORS APPLY
  CHANTYPE   - PHA             WHETHER CHANNELS HAVE BEEN CORRECTED
  TLMIN1     - 0               FIRST LEGAL DETECTOR CHANNEL
  DETCHANS   - 256             NO. OF LEGAL DETECTOR CHANNELS
  NCHAN      - 256             NO. OF DETECTOR CHANNELS IN DATASET
  PHAVERSN   - 1.2.0           OGIP FITS VERSION NUMBER
  STAT_ERR   - TRUE            STATISTICAL ERROR
  SYS_ERR    - FALSE           FRACTIONAL SYSTEMATIC ERROR
  QUALITY    - TRUE            QUALITY FLAG
  GROUPING   - FALSE           GROUPING FLAG
  --------------------------------------------------------------------
  --------------------------------------------------------------------
```

- GRPPHA CAN ALSO BE USED TO:
  - BIN DATA
  - SET SYSTEMATIC ERROR BARS
  - SET CORRFILE (ADDITIONAL BACKGROUND)
- WE WILL DO ALL OF THESE DURING ISIS ANALYSIS.

X-RAY SPECTROSCOPY ANALYSIS PACKAGES

- ☑ PACKAGES ARE DESIGNED TO READ & PLOT THE DATA.
- ☑ HANDLE THE "META-DATA", I.E., PROPER ASSOCIATION OF EXPOSURES, RESPONSES, & BACKGROUNDS.
- ☑ KEEP TRACK OF "GROUPING" & NOTICED/IGNORED BINS.
- ☑ MINIMIZE THE FIT STATISTIC(S), AND REPORT THE VALUES OF "BEST-FIT" PARAMETERS AND STATISTICS.
- ☑ CALCULATE PARAMETER ERROR BARS, FLUXES, ETC.
- ☑ SAVE AND PLOT RESULTS.

✓ TODAY ✓ MONDAY & TUESDAY

COMMON ANALYSIS PACKAGES:

- THERE ARE MANY ANALYSIS PACKAGES OUT THERE, RANGING FROM CUSTOM IDL CODES TO WELL-ESTABLISHED, LONG USED PROGRAMS (XSPEC)

- XSPEC IS THE MOST COMMONLY USED, WITH A WIDE RANGE OF INTRINSIC & USER CONTRIBUTED ("LOCAL") MODELS: http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec

- A VARIETY OF OTHER ANALYSIS PACKAGES ARE USED:

  - ISIS: http://space.mit.edu/CXC/ISIS/

  - SHERPA: http://cxc.harvard.edu/sherpa/

  - SPEX: http://www.sron.nl/divisions/hea/spex/

COMPARISON OF SOME ANALYSIS PACKAGE FEATURES:

	XSPEC MODELS	XSPEC LOCAL MODELS	SCRIPTED MODELS	USER SCRIPTS	DATA PRODUCT ACCESS	OTHER FIT KERNEL	USER FIT KERNEL	USER OPTIM. METHS.	USER FIT STATS
ISIS	Nearly All	Yes	S-lang	S-lang	Yes	Gain Pileup	Yes	Yes	Yes
Sherpa	Most	With Effort	Python	Python	Yes	No	Yes	Yes	Yes
XSPEC	All	Yes	Limited-mdefine	TCL	Very Limited	Gain	No	No	No
SPEX	Few	No	No	No	No	No	No	No	No

	NON-X-RAY DATA	ATOMIC DATA ACCESS	MULTI-CORE ERRORS	MULTI-CORE FITS	MULTI-SYSTEM ERRORS	MULTI-SYSTEM MODELS
ISIS	Yes	Yes	Yes	Yes	Yes	Yes
Sherpa	Yes	No	Yes	No	No	No
XSPEC	With Fake RMF, ARF	No	No	No	No	No
SPEX	No	Yes	No	No	No	No

INTERACTIVE SPECTRAL ANALYSIS SYSTEM (ISIS)

- SCRIBTABLE & WIDE SELECTION OF USEFUL MODULES:
  - GNU SCIENTIFIC LIBARY (GSL),
  - STATISTICS & HISTOGRAMS
  - HDF5 (BINARY DATA FORMAT - USED IN ASTRO/ HYDRO SIMULATIONS)
  - XPA (INTERFACE TO DS9 ASTRO IMAGER)
  - GTK (GUIS) & VOLVIEW (3D VISUALIZATION)
  - PARALLEL VIRTUAL MACHINE
    - EXTENSIVE HISTORY OF INCORPORATING PARALLELIZATION METHODS

USING ISIS TO ANALYZE SIMPLE X-RAY SPECTRA

- IN WHAT FOLLOWS, I WILL BE ASSUMING WE'VE LOADED UP THE ISIS UTILITY FUNCTIONS PROVIDED AT: http://space.mit.edu/home/mnowak/isis_vs_xspec/download.html
- ISIS COMMANDS UNIQUE TO THESE SCRIPTS WILL BE HIGHLIGHTED IN RED
- NOTE THAT ISIS ALLOWS YOU TO CHANGE THE NAMES OF ANY COMMANDS. DON'T LIKE A NAME? CHANGE IT!

```
isis> alias("fit_fun", "model");
```

STARTING UP ISIS:

- ISIS CAN MAKE USE OF VARIOUS ENVIRONMENT VARIABLES UPON START UP. USEFUL TO PLACE IN, E.G., A ~/.CSHRC FILE.

```
# If GNU readline has been set, saves input history.  VERY USEFUL!!!
setenv ISIS_HISTORY_FILE /home/mnowak/.isis_history

# Places to search for S-lang scripts
setenv SLANG_LOAD_PATH /home/mnowak/slang_scripts
setenv ISIS_LOAD_PATH /home/mnowak/slang_scripts

# Places to search for modules.  Modules are compiled binaries with
# S-lang interfaces, e.g., GSL or histogram modules
setenv SLANG_MODULE_PATH /home/mnowak/slang_modules
setenv ISIS_MODULE_PATH /home/mnowak/slang_modules

# The editor we will use when editing model parameter files
# You might prefer to use vi instead.
setenv EDITOR /usr/bin/emacs
```

STARTING UP ISIS:

- UPON START UP, ISIS LOADS THE CONTENTS OF ~/.isisrc - FILE CONTAINING S-LANG COMMANDS & FUNCTIONS

```
           Isis_Append_Semicolon=1; % No ';' required interactively
DEFAULT -> Isis_List_Filenames=1;   % Be verbose with list functions
           Isis_Use_PHA_Grouping=1; % Use the grppha applied grouping
           Fit_Verbose=0;           % Only final statistics printed
DEFAULT -> Isis_Verbose=0;          % Not too verbose on ISIS messages
           Minimum_Stat_Err=1.e-30; % =0 forces Poisson errors; we choose
                                    % a value for when we fit radio/IR data
DEFAULT -> Rmf_OGIP_Compliance=2;   % Lower number to read poorly written
                                    % RMFs/ARFs (INTEGRAL requires even more)

           putenv("PGPLOT_BACKGROUND=white"); % invert default for nicer
           putenv("PGPLOT_FOREGROUND=black"); % look - black on white

           % Define places to search for useful code.
           static variable path="/home/mnowak/";
           add_to_isis_load_path(path+"isis_code");
           add_to_isis_module_path(path+"isis_code");

           % You can load-up useful bits of code automatically ...
           ()=evalfile(path+"isis_code/isis_utility_functions_prerelease_1.5.sl");
           ()=evalfile(path+"isis_code/isis_utility_functions.sl");
```

OBTAINING HELP IN ISIS:

- THE who; COMMAND WILL GIVE YOU A LIST OF VARIABLES THAT YOU HAVE DEFINED *ON THE COMMAND LINE*
- .apropos COMMAND WILL GIVE YOU A LIST OF GLOBALLY DEFINED FUNCTIONS (INCLUDING FROM SCRIPTS!) THAT CONTAIN A GIVEN SUBSTRING
- .help COMMAND WILL GIVE YOU A HELP FILE FOR MOST ISIS INTRINSIC FUNCTIONS

```
isis> a = [0:10]; b = "pizza";
isis> who;
a: Integer_Type[11]
b: pizza
isis> .apropos rmf
Found 12 matches in namespace Global:
all_rmfs                    assign_rmf                  delete_rmf
find_rmf_peaks              get_rmf_arf_grid            get_rmf_data_grid
get_rmf_info                list_rmf                    load_rmf
rebin_rmf                   set_rmf_info                unassign_rmf
isis> .help load_arf
load_arf

 SYNOPSIS
    Load an effective area (ARF) file
...
```

BRIEF WORDS ABOUT S-LANG:

- S-LANG IS A SCRIPTING LANGUAGE WITH STRONG NUMERICAL ABILITIES. SEE: WWW.S-LANG.ORG.
- ALL S-LANG FUNCTIONS WORK IN ISIS, *ALL* ISIS COMMANDS CAN BE USED IN ISIS/S-LANG SCRIPTS.

```
isis> a=[0:10]; b = sin(2*PI*a/10)+1;   % Vector math
isis> variable y = struct{time, rate}; % Some ISIS commands return structures
isis> y.time=[0:100:0.1];              % Note we are using % for comments
isis> y.rate=y.time^2;                 % Scripts require ; and 'variable' -
isis>    % latter not required in ISIS, former can be turned off
isis> ()=load_data("pca.pha");         % Note that ()= captures and discards
isis>    % the return value, otherwise placed on and then "popped off" the 'stack'
isis> (a,b,c) = some_funct(b);         % Lets say this returns 1,2,3 ...
isis> print(b);
 2
isis> (,,) = some_funct(b);            % Discard the return values
isis> some_funct(b);                   % 1, then 2, then 3 placed on the 'stack'
 3
 2
 1
isis> % Top of the "stack", 3, pops off first, then 2, then 1 ...
```

LOADING & PLOTTING DATA:

- ISIS WILL ASSIGN NUMERIC IDENTIFIERS TO DATA SETS, RMFS, & ARFS.
- NOTE THAT FOR A GIVEN DATA SET, THESE 3 NUMBERS ARE *NOT* NECESSARILY THE SAME!
- LOAD_RMF("RMF.FITS"); LOAD_ARF("ARF.FITS"); WILL LOAD JUST THE RMF/ARF - USED WITH TYPE 2 PHA FILES.

```
isis> ()=evalfile("/path/.isisrc"); % Auto-loaded if /path=HOME
isis>
isis> pca = load_data("pca_cygx1_I.pha");
RMF includes the effective area
Warning: negative EBOUNDS value E_MIN=-0.161702, set to zero
Warning: 1 hi/lo grid values needed tweaking
isis> print(pca);
1
```

LOADING & PLOTTING DATA:

- FOR RXTE-PCA SPECTRA, RMF & ARF ARE COMBINED. DATA=1, RMF=1, ARF HAS NO NUMBER.
- THE NEXT RMF WE LOAD WOULD BE ASSIGNED #2, THE NEXT ARF WE LOAD WOULD BE ASSIGNED #1

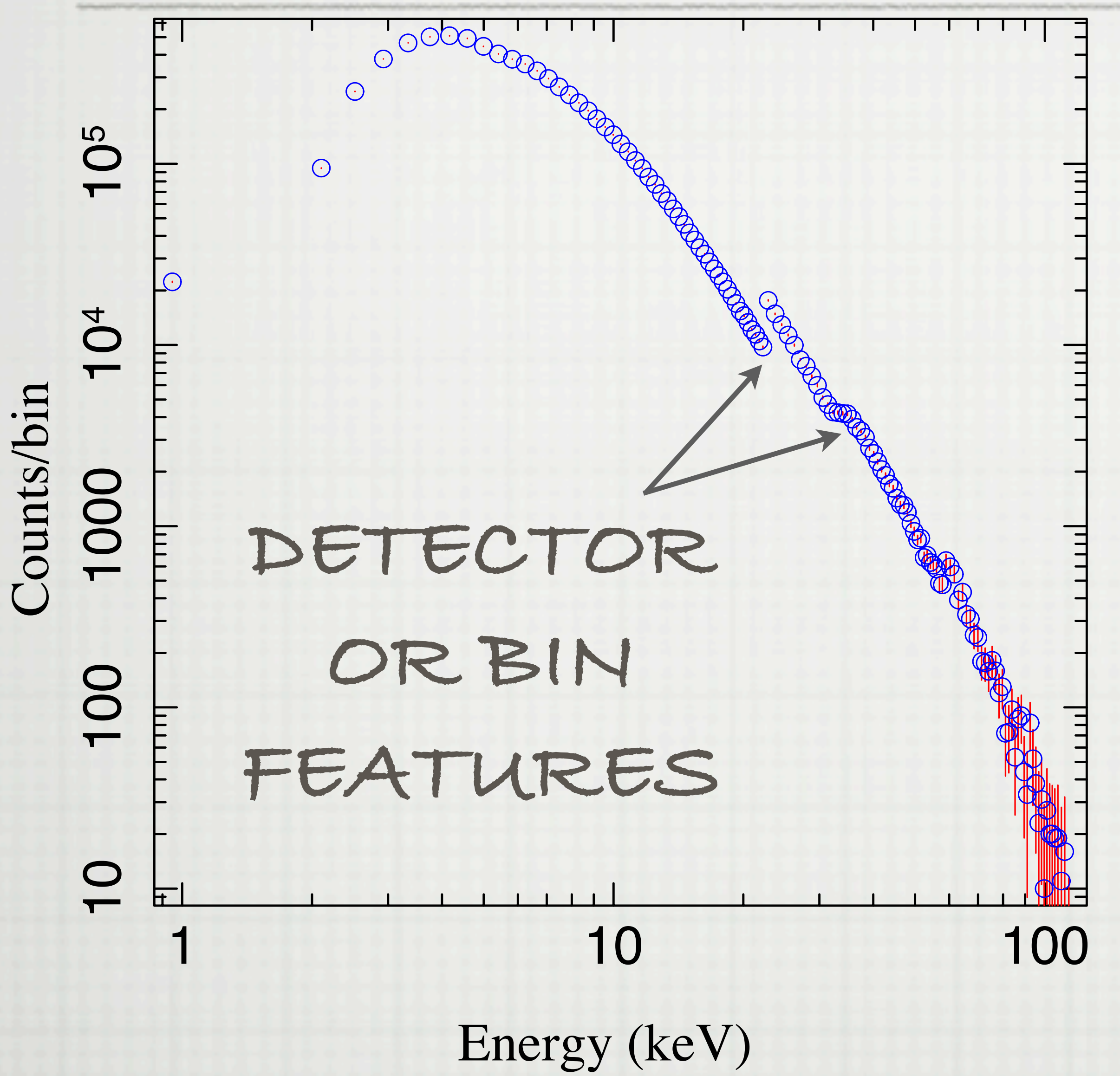
```
isis> list_data;
Current Spectrum List:
 id    instrument   m prt src    use/nbins   A   R     totcts   exp(ksec)
target
  1          PCA   0  0   0     129/  129   -   1  7.8833e+06      9.200
file:  pca_cygx1_I.pha
back:  pcaback_cygx1_I.pha
isis>
isis> list_rmf;
Current RMF List:
 id grating detector    m type   file
  1             PCU2    0 file:  pcaresp_cygx1_I.rmf
isis>
isis> list_arf;
isis>
```

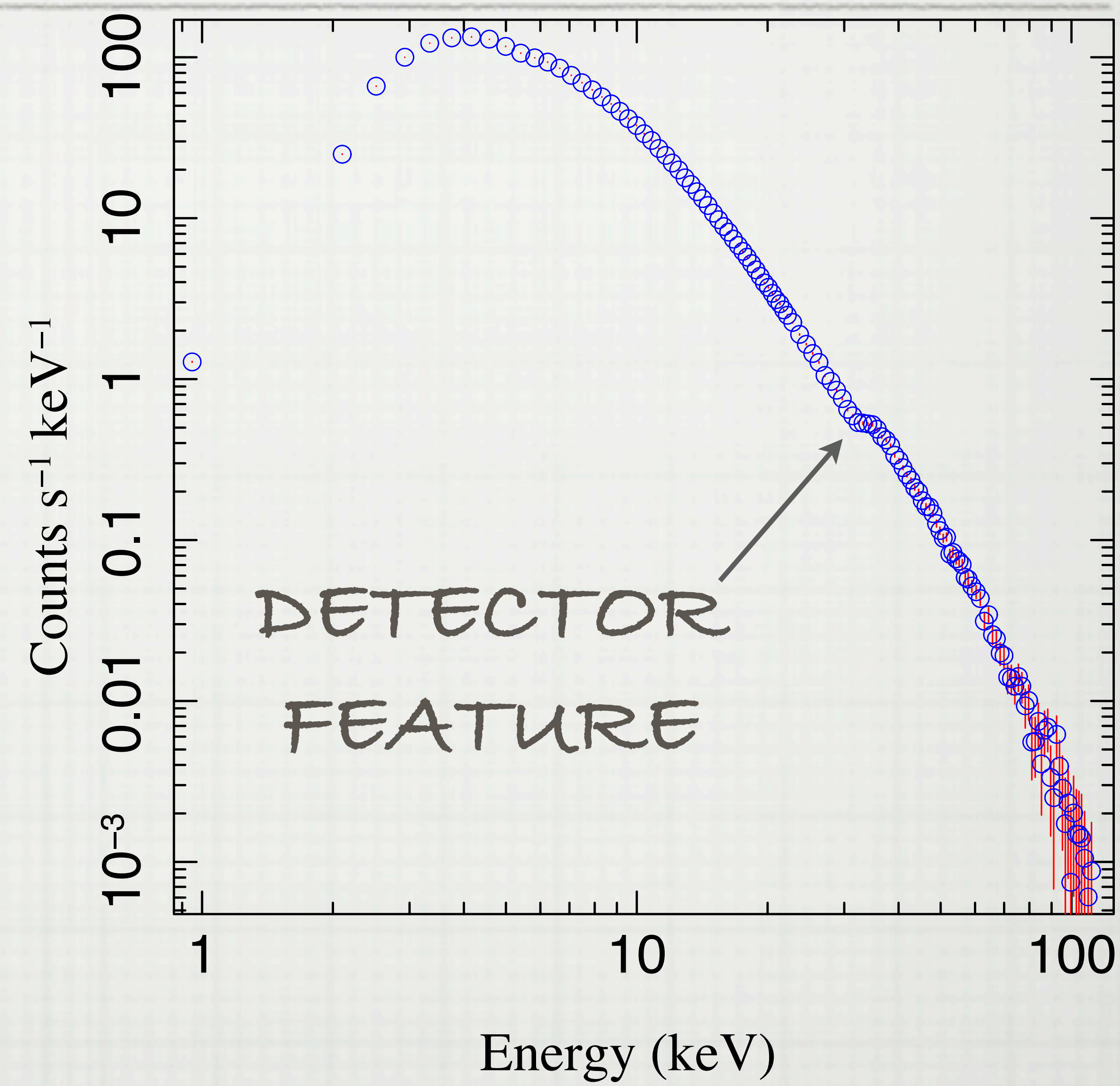
LOADING & PLOTTING DATA:

- INTRINSIC ISIS PLOTS ALWAYS LEAVE BACKGROUND IN, AND AREN'T GREAT FOR MULTIPLE DATASETS.
- THE CUSTOM ROUTINES (.isisrc_plots) ADD FUNCTIONALITY

```
isis> plot_unit("kev");
isis> plot_bin_integral; plot_data_counts(pca);
isis> xlog; ylog; plot_bin_integral; plot_data_counts(pca);
isis> plot_bin_density; plot_data_counts(pca);
isis>
isis> fancy_plot_Unit("kev");
isis>
isis> plot_counts(pca;dsym=4,dcol=4);
isis> plot_data(pca;dsym=4,dcol=4);
isis>
isis> plot_counts(pca;dsym=4,dcol=4,bkg=1);
isis> plot_data(pca;dsym=4,dcol=4,bkg=1);
```

HOW SHOULD I PLOT DATA?

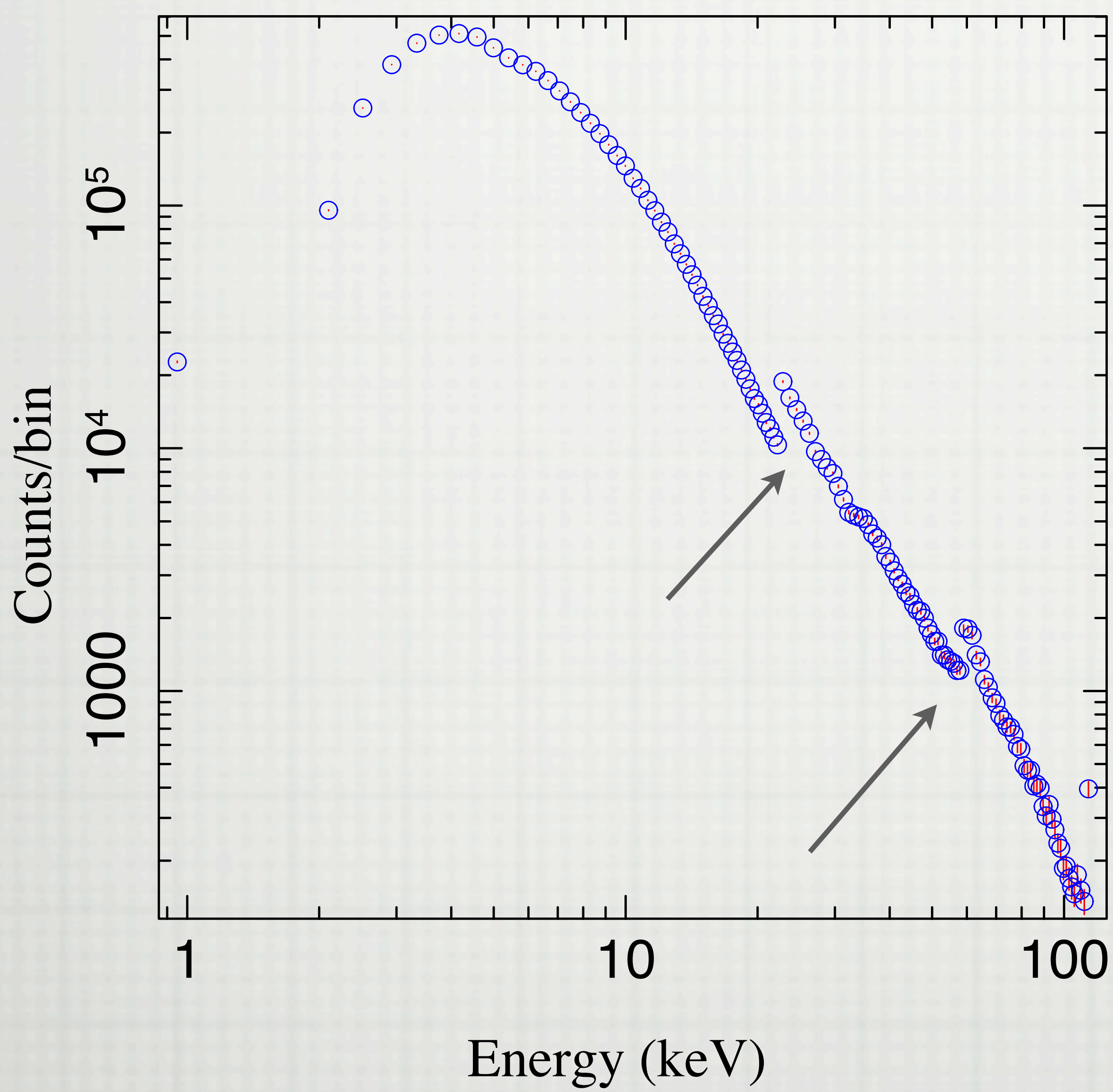


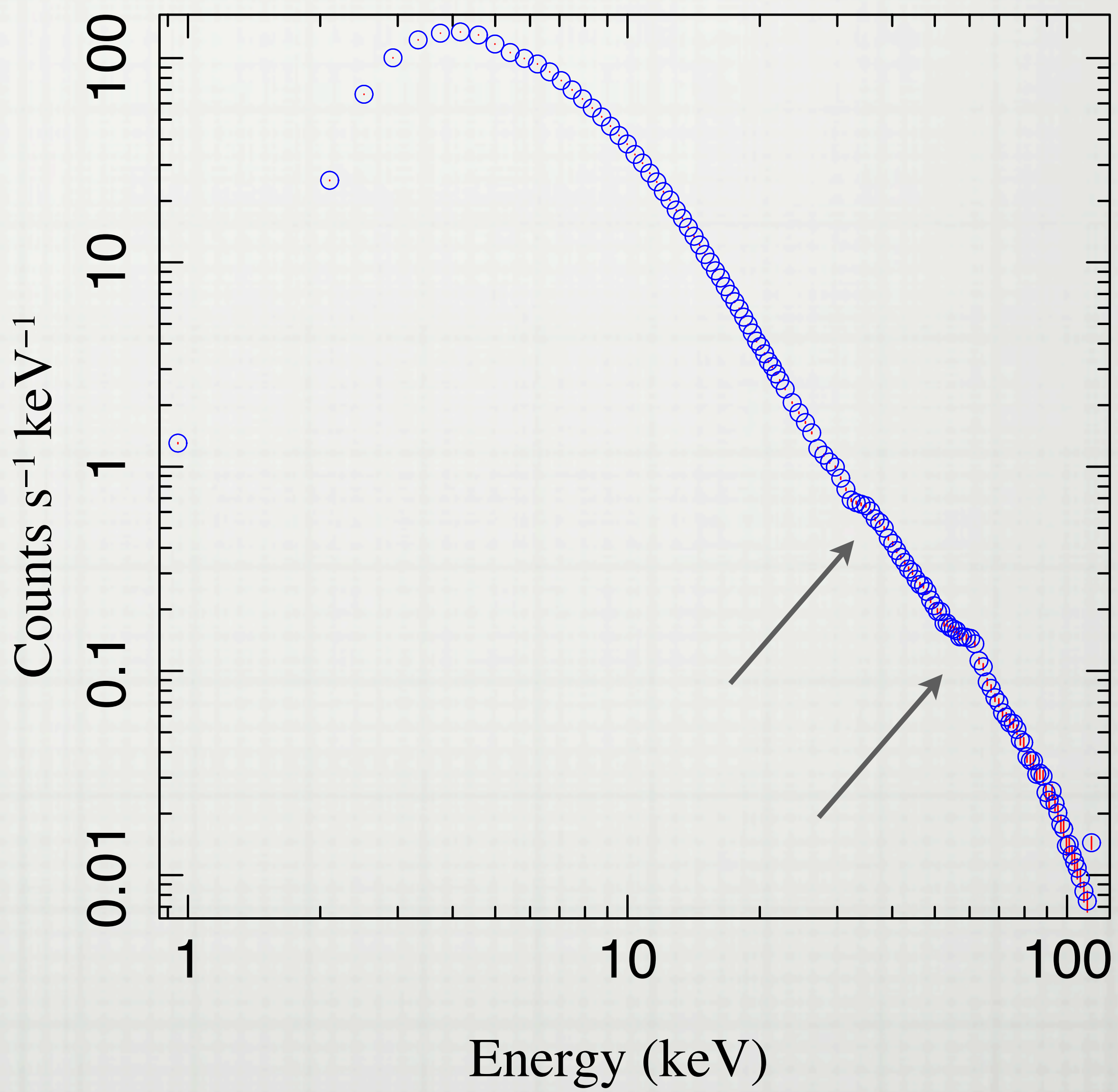


USEFUL *BEFORE* BINNING, *OR* WITH UNIFORM BINS

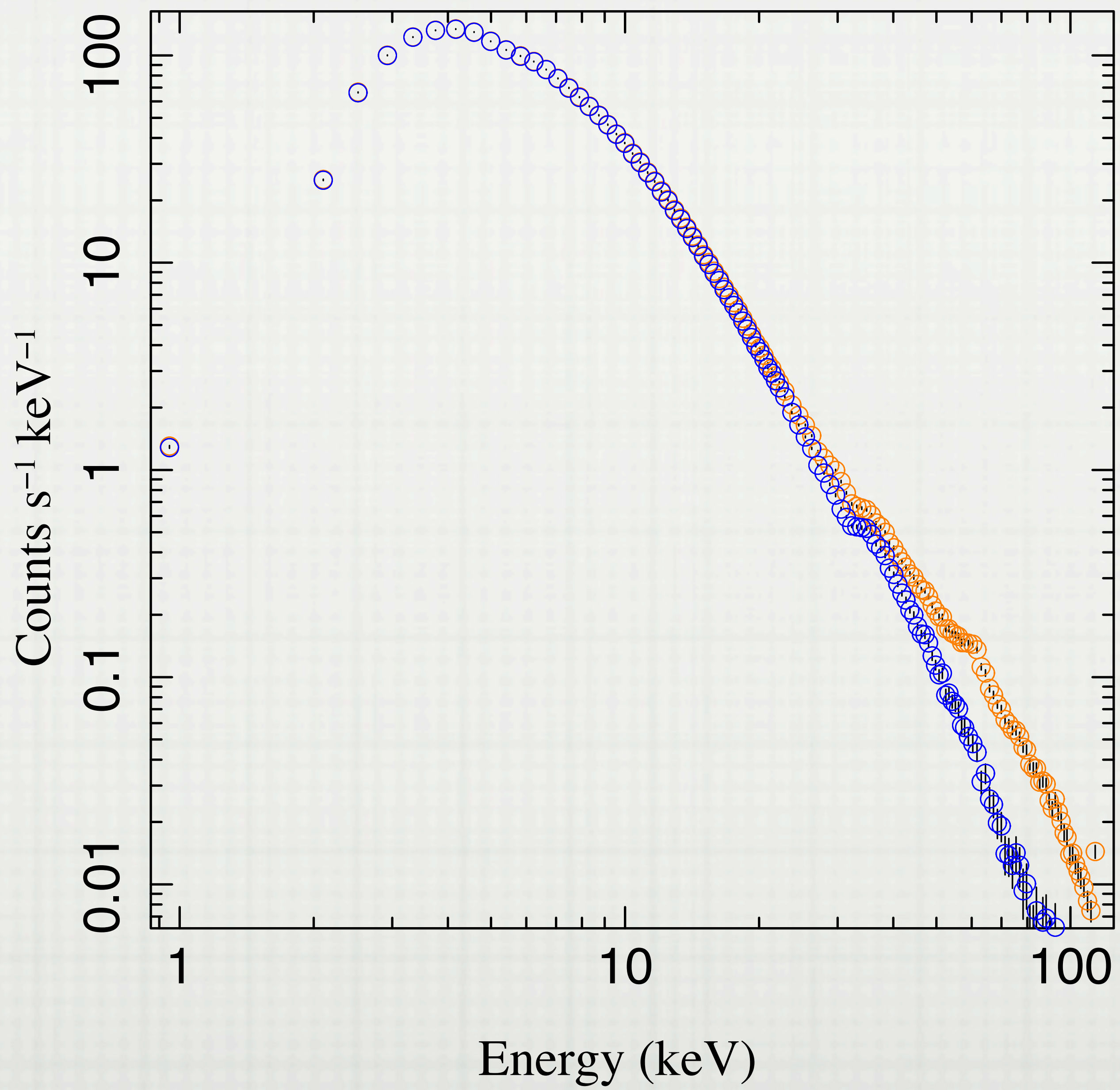
USEFUL AFTER BINNING

PLOTTING WITH BACKGROUND IS USEFUL TO SEE ITS FEATURES



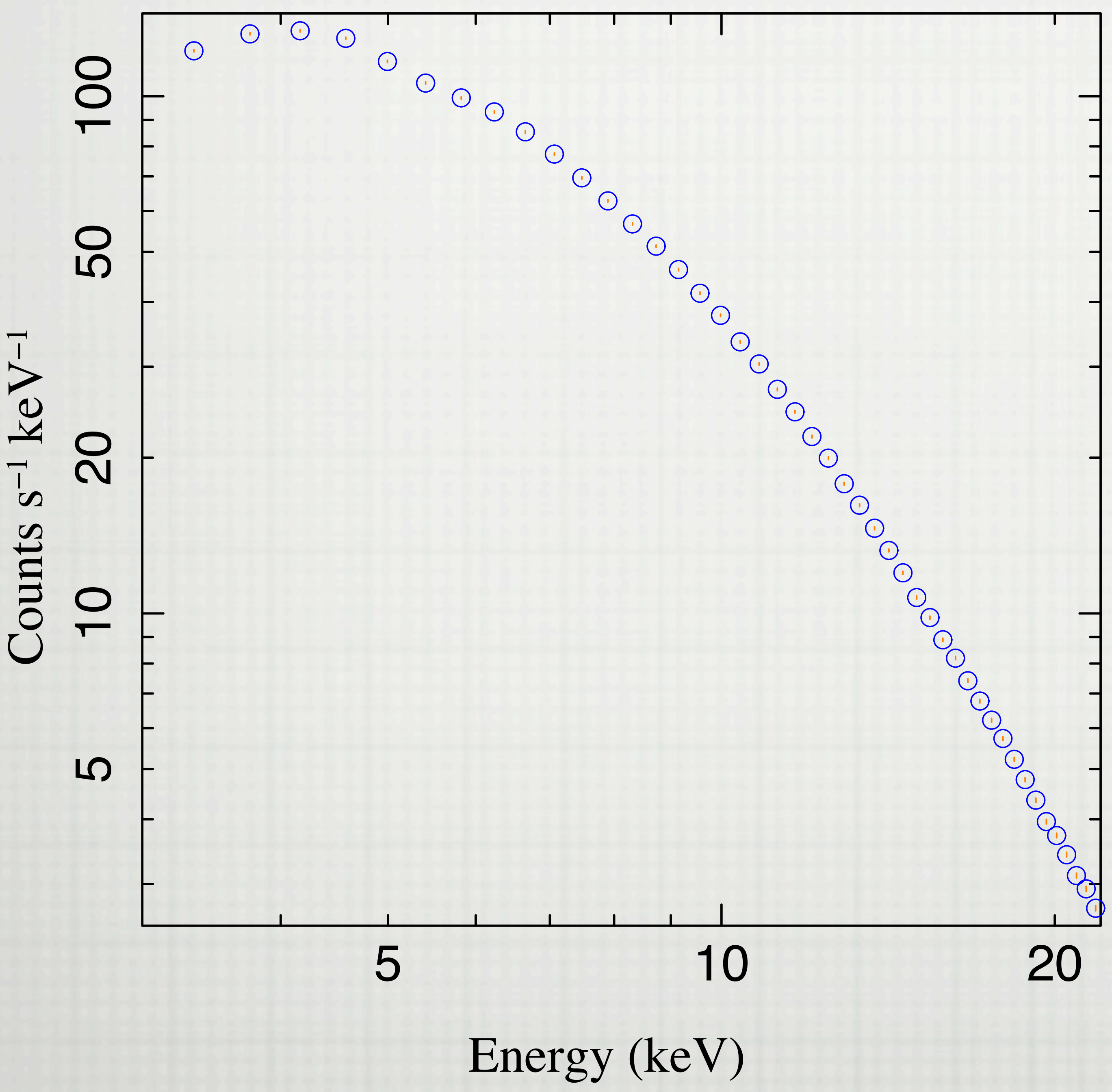


PUTTING BOTH TOGETHER:




```
isis> plot_data({pca,pca};dsym={4,4},
                          dcol={8,4},bkg={1,0});
```

GROUPING & LIMITING DATA:



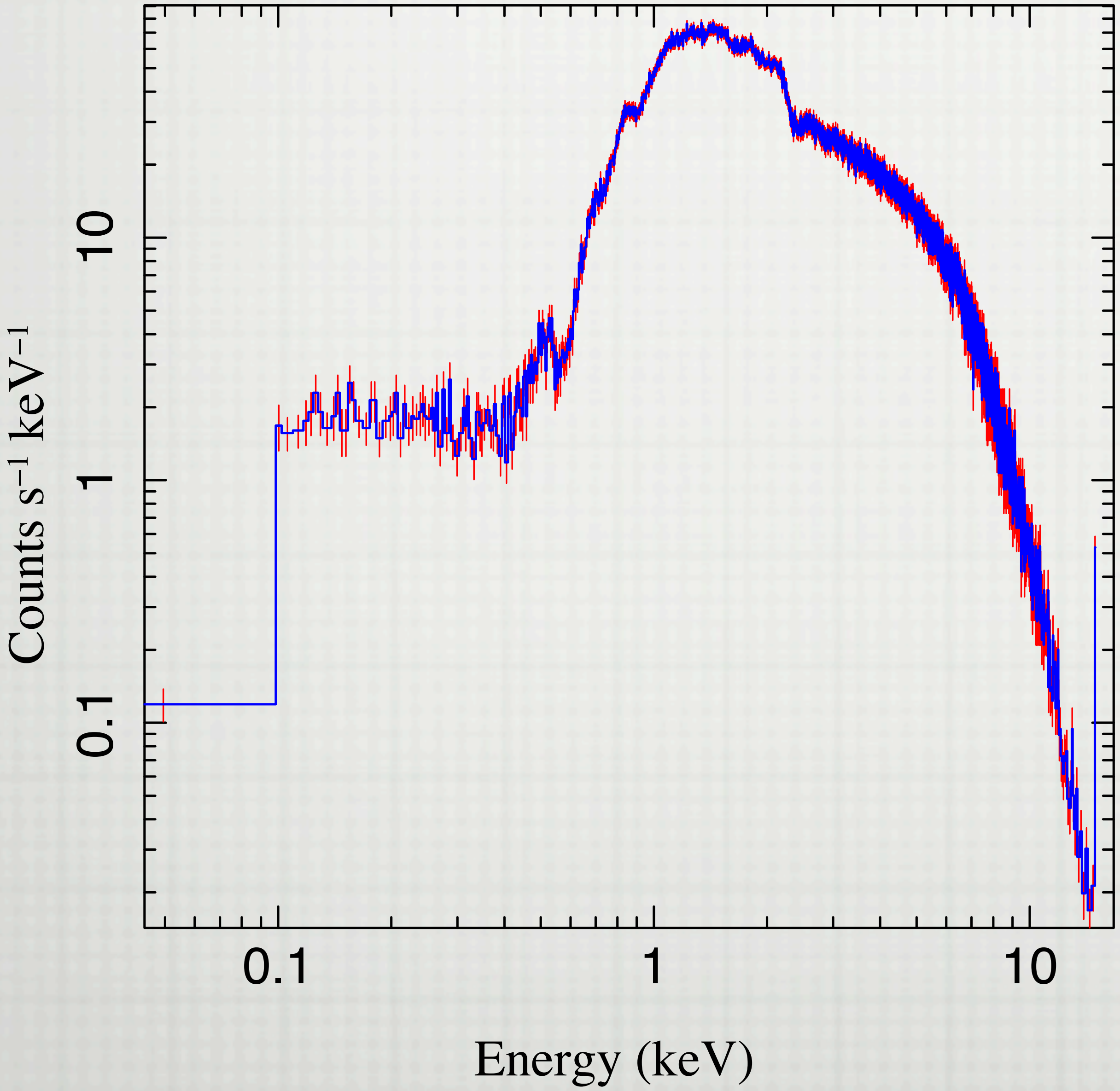
- WHERE TO IGNORE THE DATA IS A MATTER OF KNOWLEDGE OF THE SPACECRAFT, AND EXPERIENCE WITH ITS DATA.
- PCA RESPONSES NOT SO GOOD < 3 keV, BACKGROUND STARTS BECOMING IMPORTANT ABOVE ~20 keV.
- THESE DECISIONS CAN CHANGE OVER TIME, AS CALIBRATIONS IMPROVE.

GROUPING & NOTICING

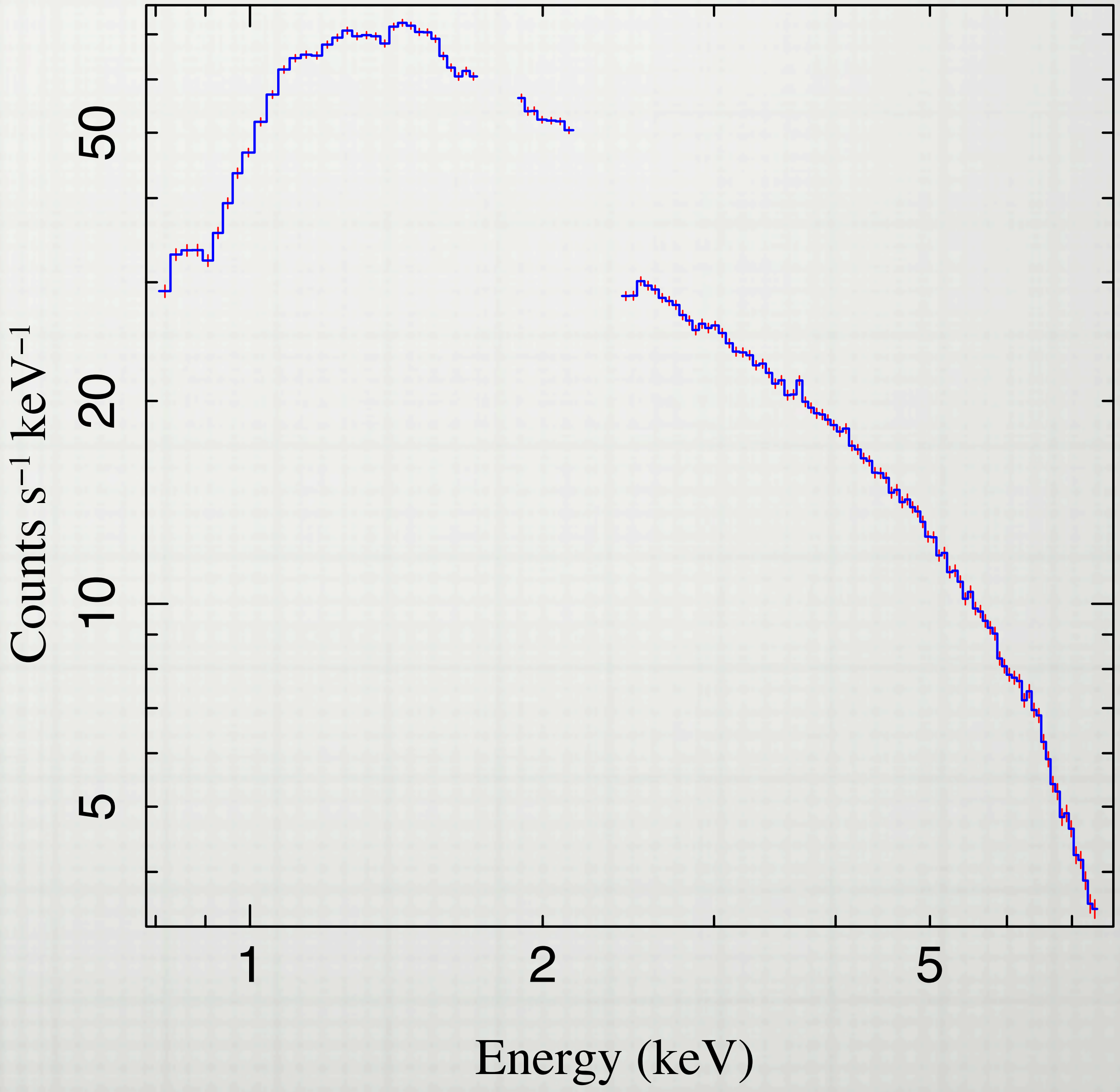
- GROUPING TRADITIONALLY USED TO ACHIEVE SUFFICIENT SIGNAL-TO-NOISE TO USE ~GAUSSIAN STATISTICS WITH ERROR ~ $(\text{COUNTS})^{1/2}$.
  - OFTEN: MINIMUM COUNTS/BIN, UNIFORM CHANNELS/BIN
- IGNORE BINS WITH LOW S/N AND/OR POOR CALIBRATION
- GRPPHA (HEASOFT) OR DMGROUP (CIAO) ALLOW YOU TO CHOOSE MINIMUM COUNTS/BIN, OR SPECIFIED NO. OF CHANNELS/BIN OVER GIVEN RANGES.
- I PREFER TO MAKE THESE CHOICES DURING ANALYSIS, WITH A MORE FLEXIBLE SET OF CRITERIA.

GROUPING & NOTICING

SUZAKU CYG X-1-
NO GROUPING



SUZAKU CYG X-1-
S/N>8 & HWHM RES.



GROUPING & NOTICING

- THERE ARE TWO MAIN FUNCTIONS TO USE IN ISIS:

```
isis> group(pca;min_sn=5,min_chan=1,bounds=3,unit="kev");
isis> notice_values(pca,3,20;unit="kev");
```

- GROUP CAN GET FANCY FOR DATA ON THE SAME GRID:

```
isis> group([1,2];min_sn={5,8},min_chan={1,4},
                   bounds={3,15},unit="kev",sn_data=1);
isis> notice_values([1,2],3,5,8,20;unit="kev");
```

- EXCLUDE/INCLUDE DATA WITHOUT CHANGING BINS"

```
isis> exclude(1);  % ignore dataset #1
isis> include(1);  % bring it back with its previous bins
```