# Intro to Timing Analysis

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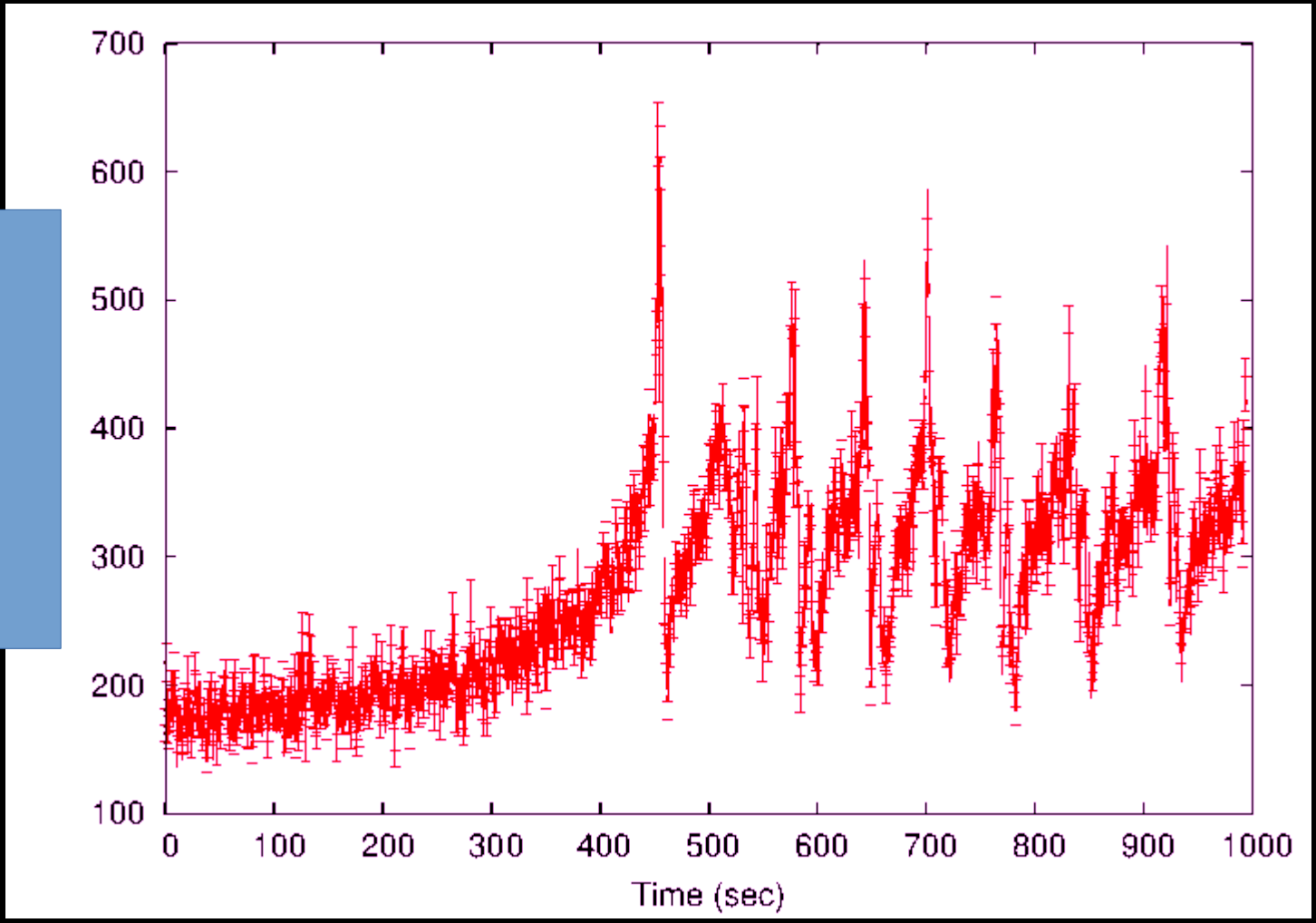
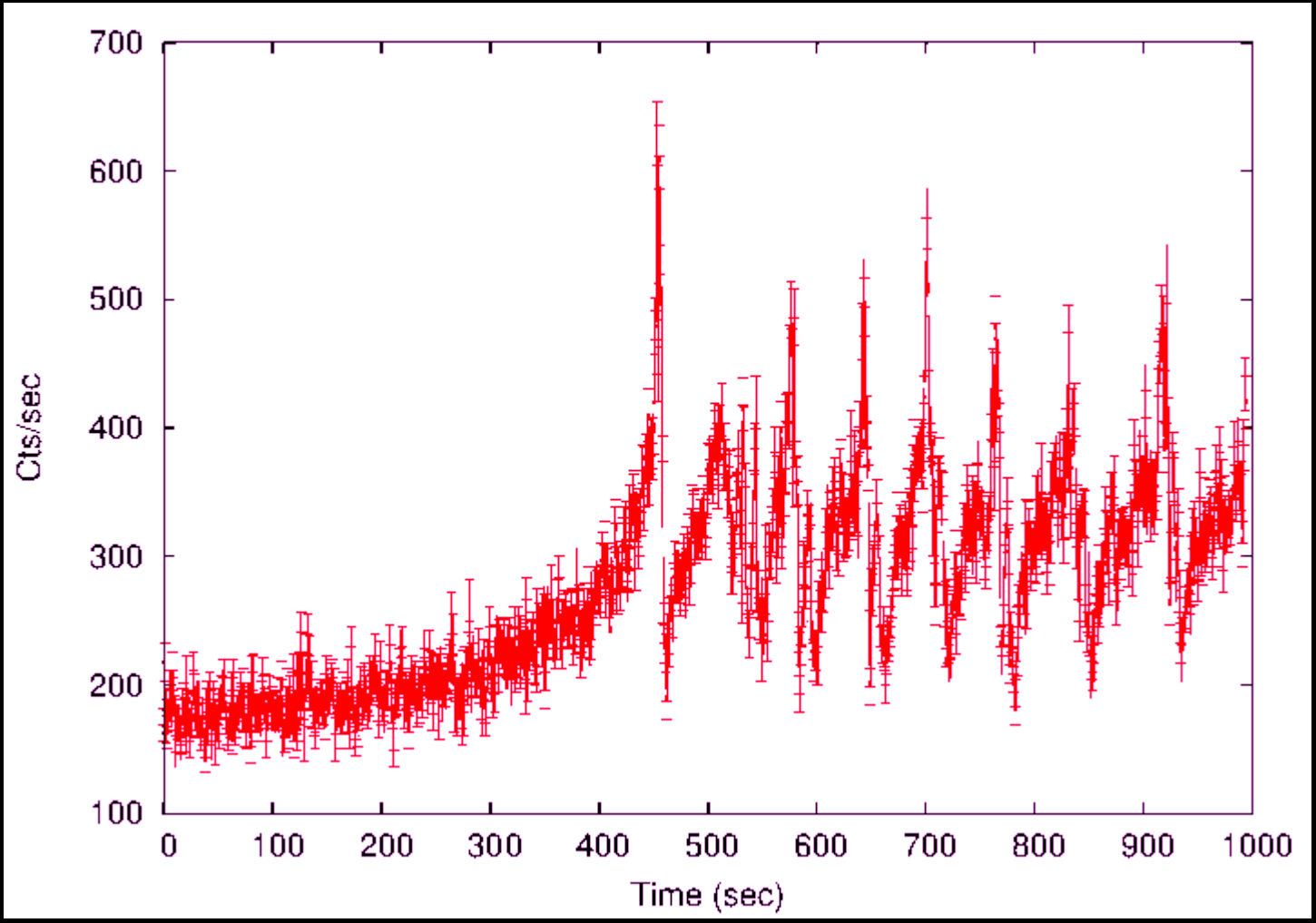
University of Southampton

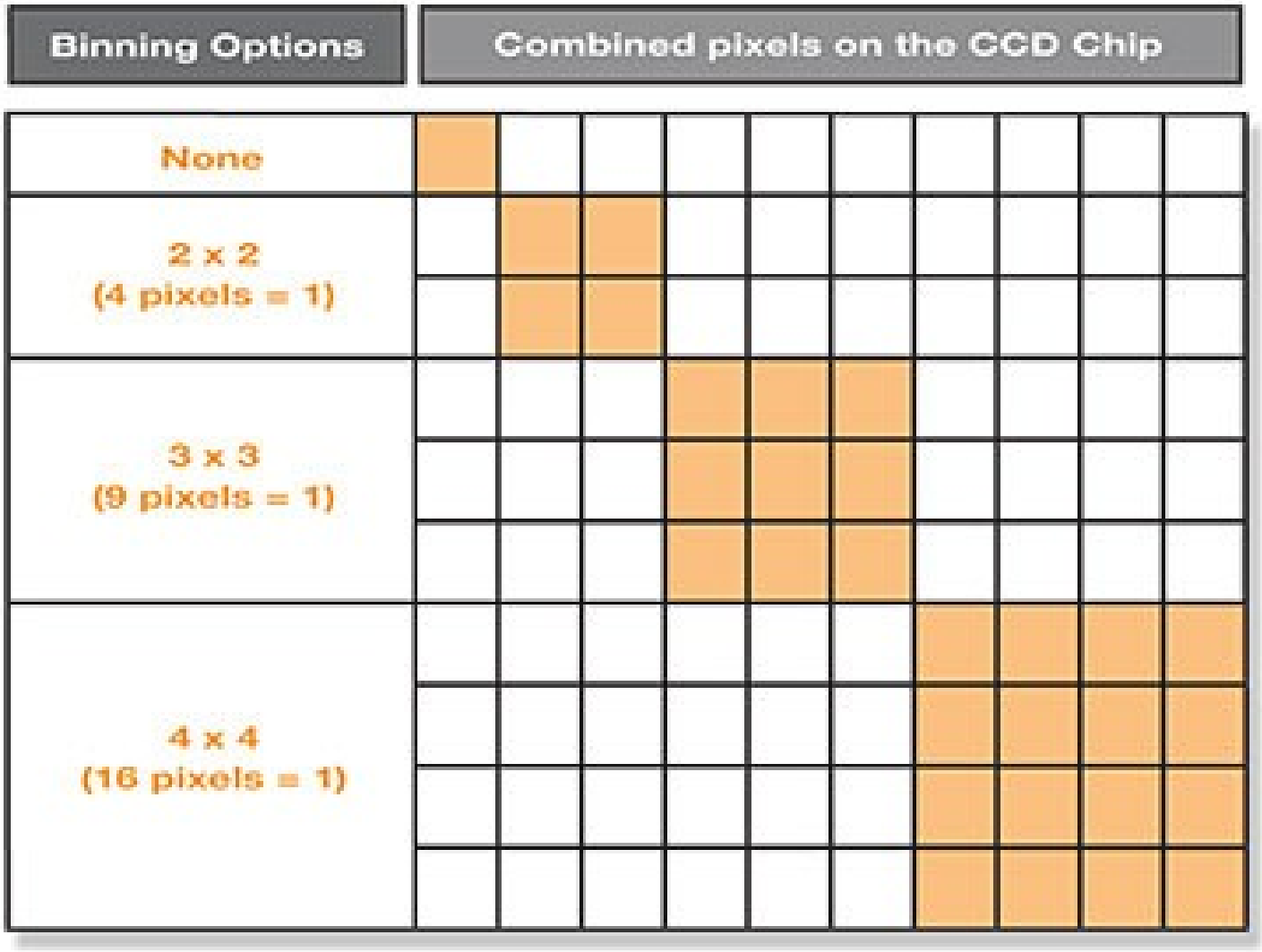
In astronomy, a light curve is a graph of light intensity of a celestial object or region, as a function of time.



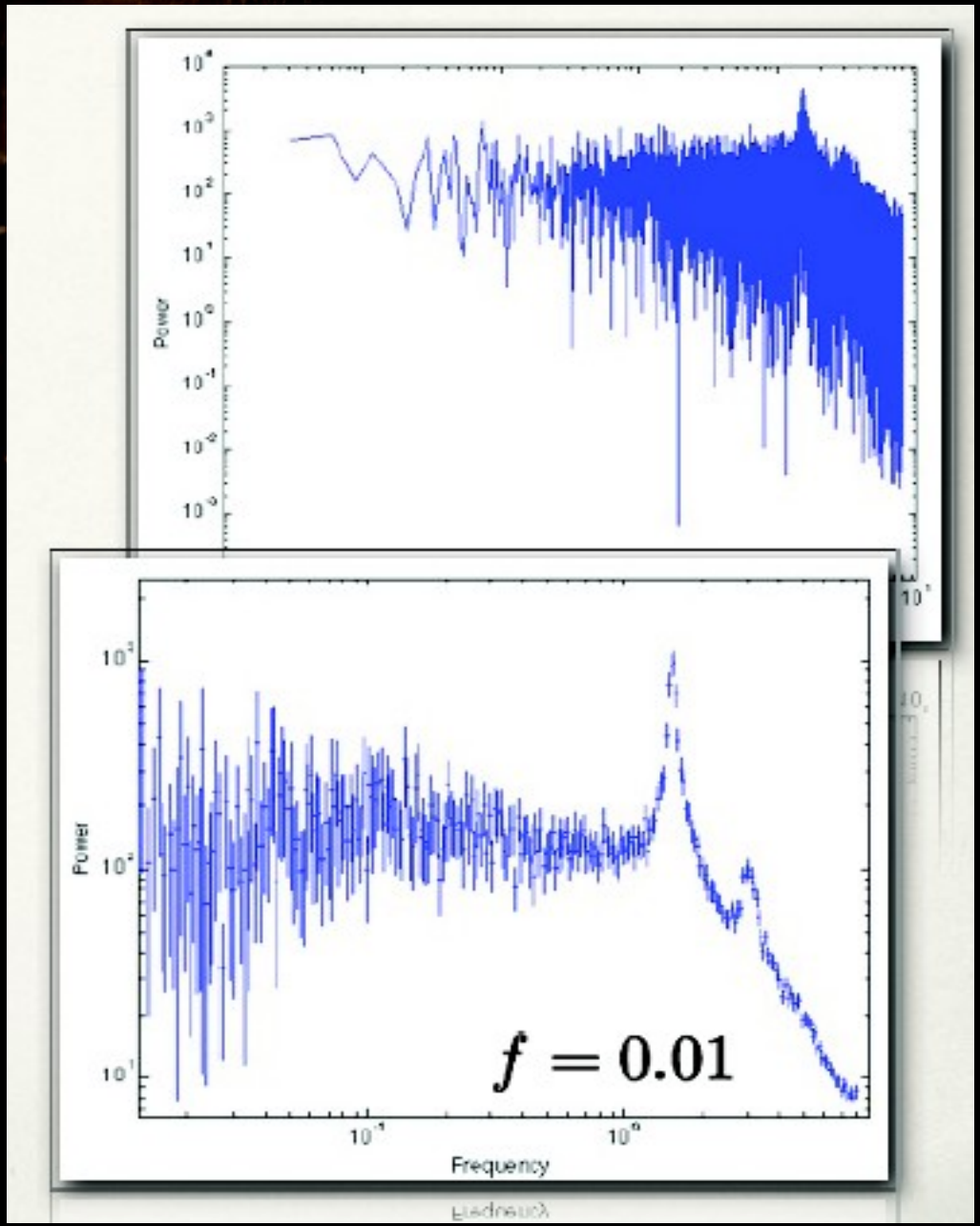
In astronomy, a light curve is a graph of light intensity of a celestial object or region, as a function of time.



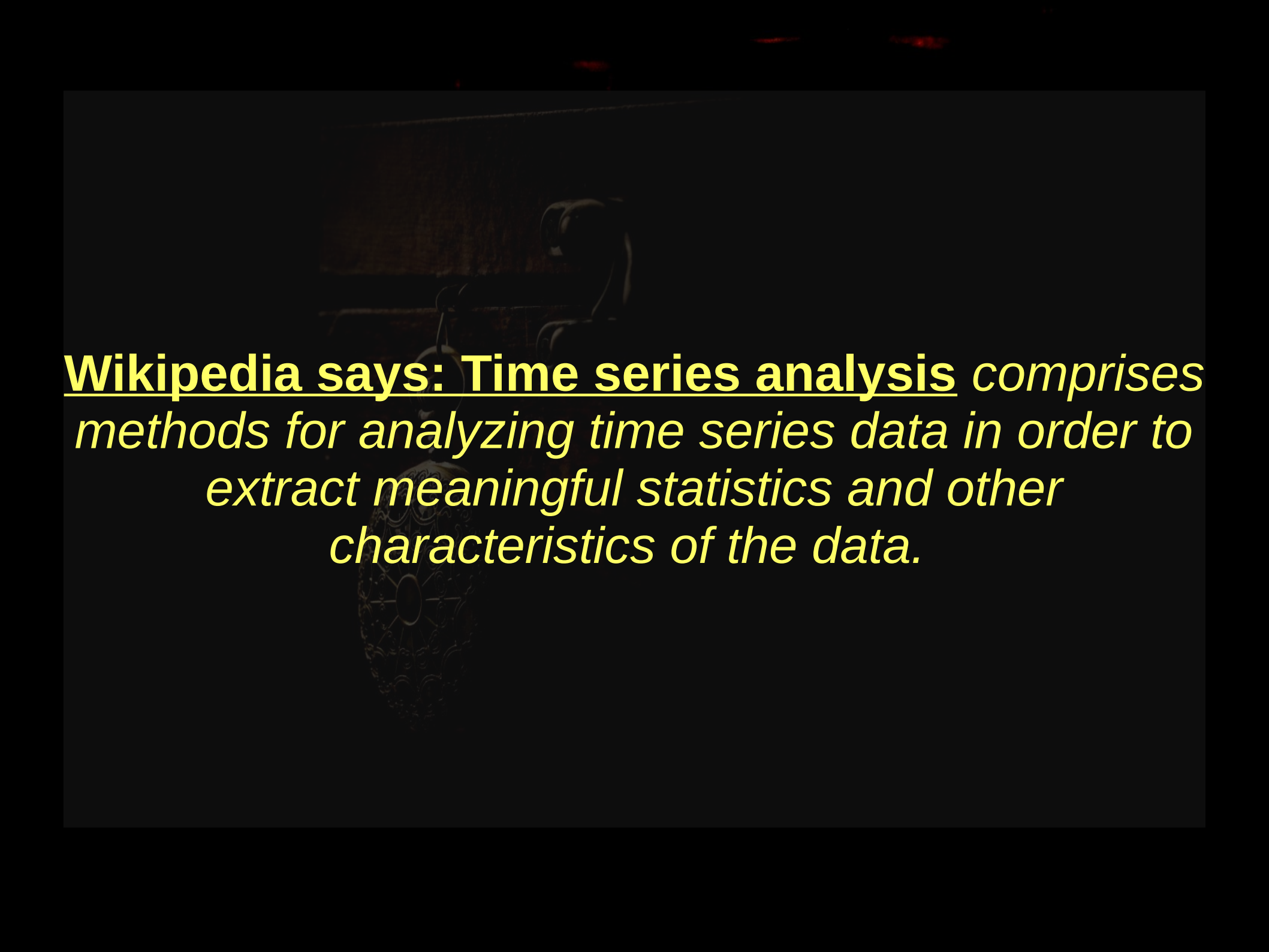
# DATA Binning



# DATA Binning




.... Time Series .... ?
Price trends of the Samsung Galaxy S on idealo
% of original pricing on idealo
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
Release
1 month
2 months
3 months
4 months
5 months
6 months
12 months
18 months
24 months
Months after release
Galaxy S2
Galaxy S3
Galaxy S4
Galaxy S5 (Prediction)
idealo

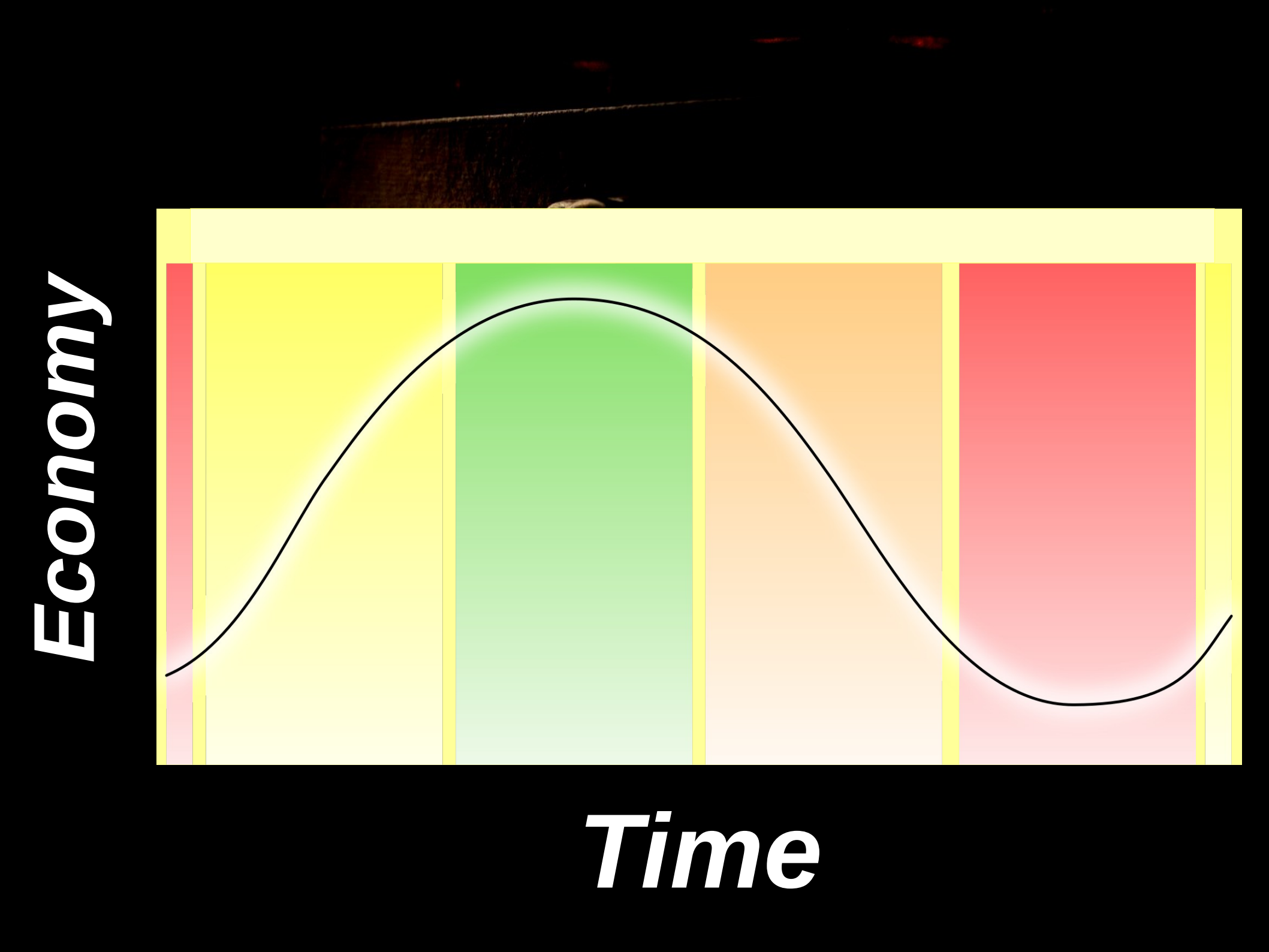

**Wikipedia says: Time series analysis** *comprises methods for analyzing time series data in order to extract meaningful statistics and other characteristics of the data.*

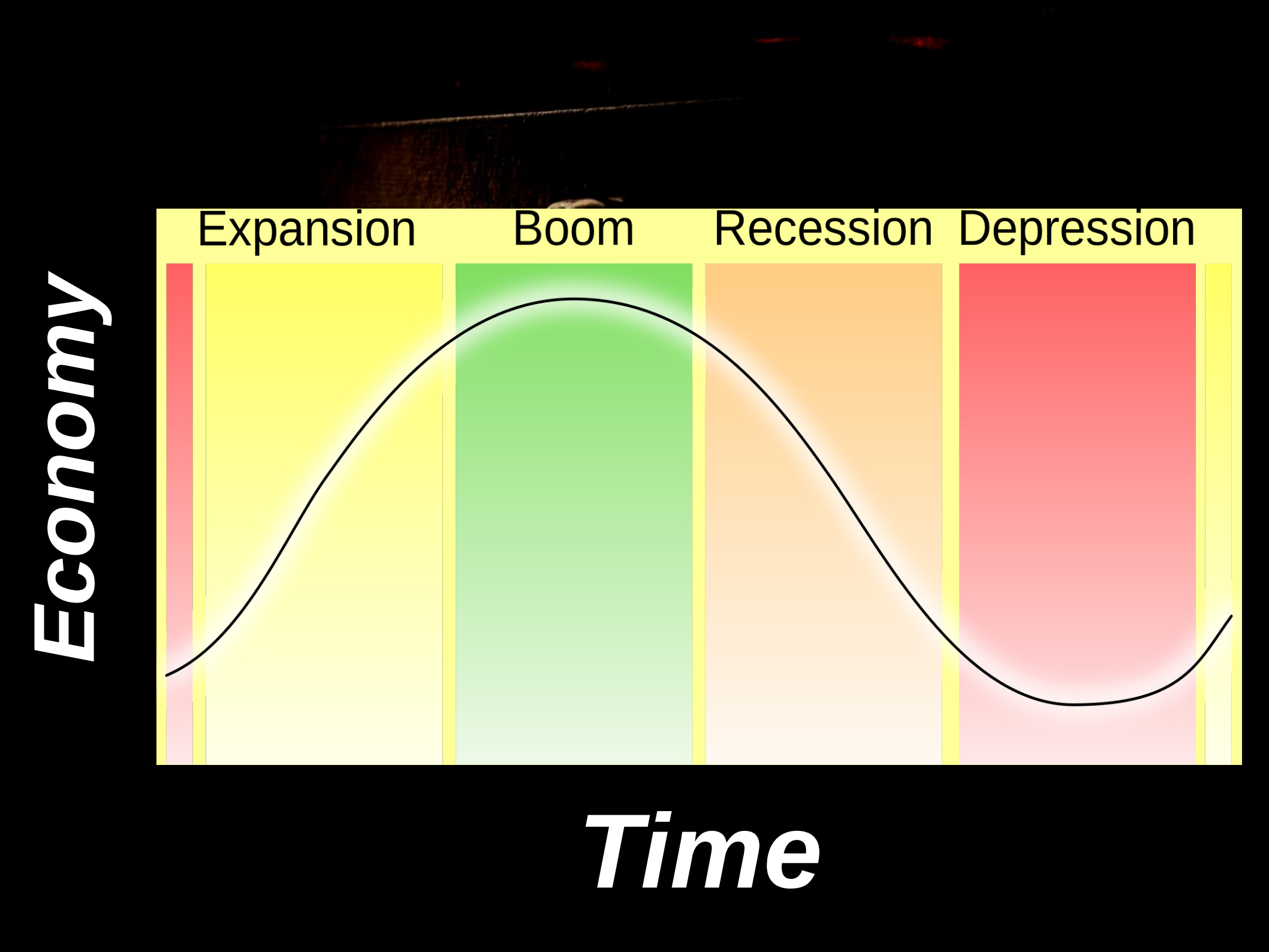
**A time series** *is a sequence of data points, measured typically at successive points in time spaced at uniform time intervals.*

*So here we <u>will not</u> discuss all the time series techniques ... there is a lot out there!*

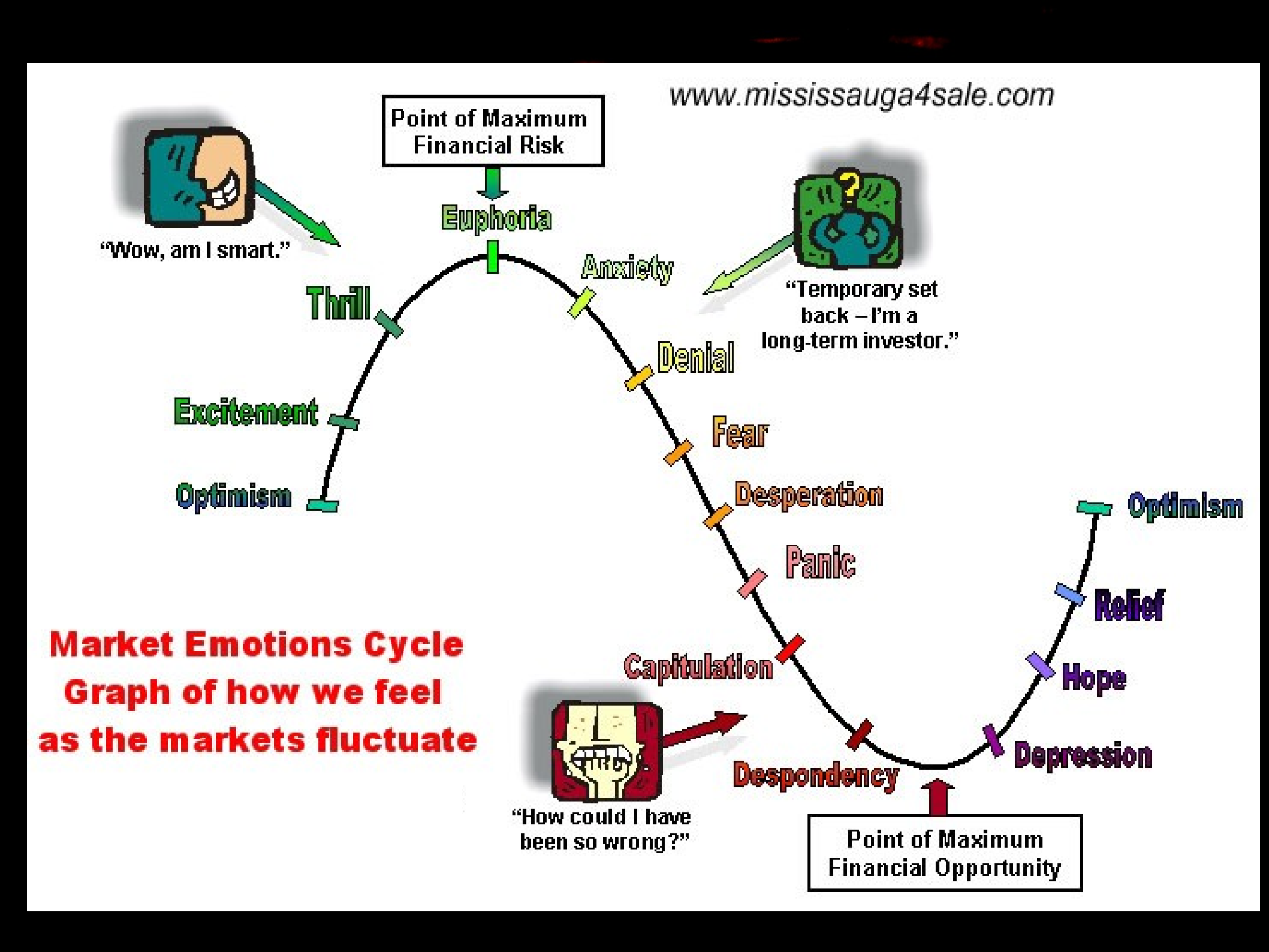
*We aim at understanding what exist, and why you should care.....*


**A time series** *is a sequence of data points, measured typically at successive points in time spaced at uniform time intervals.*

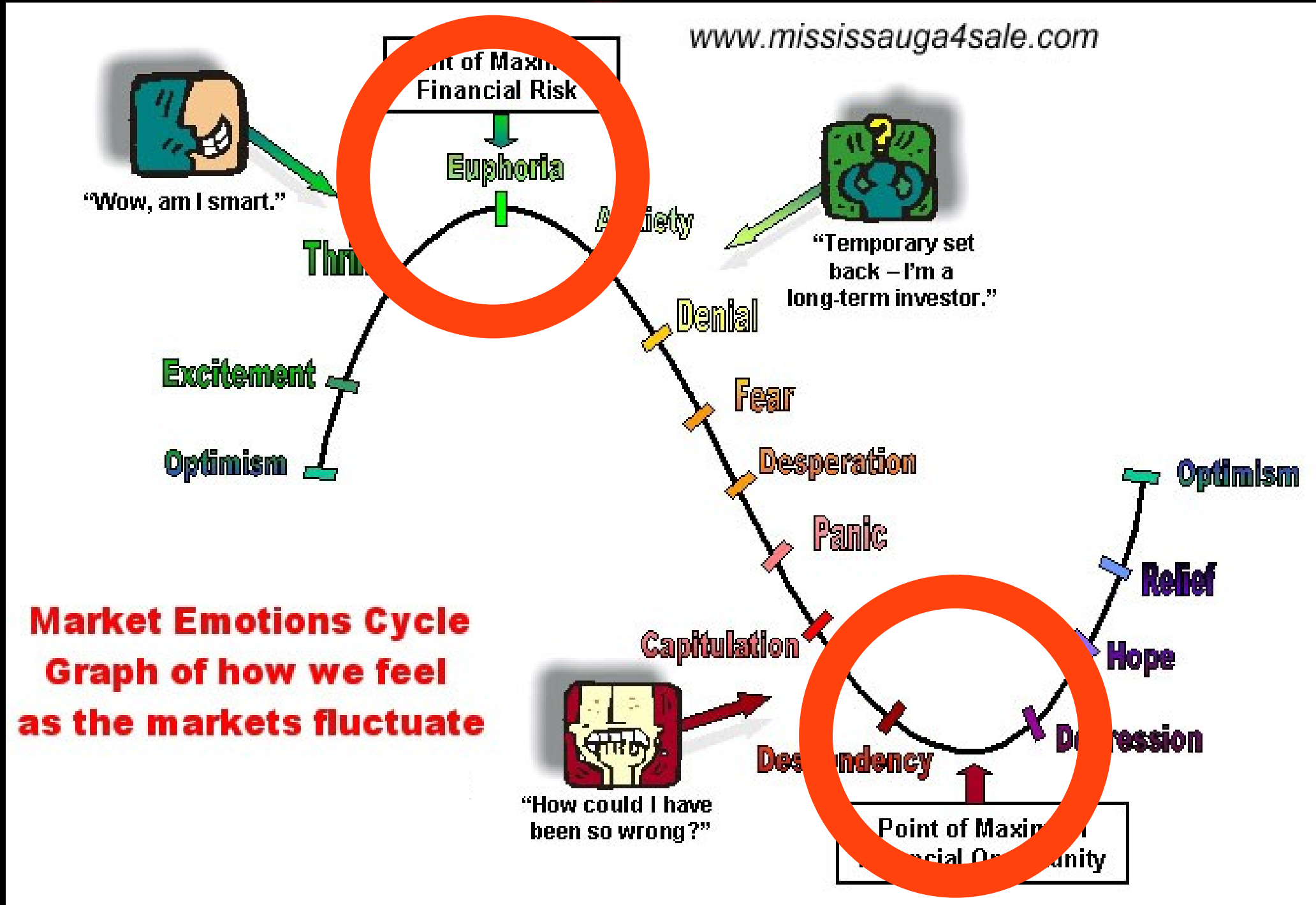

Economy
Time


Expansion
Boom
Recession
Depression
Economy
Time

www.mississauga4sale.com




**Market Emotions Cycle**
**Graph of how we feel as the markets fluctuate**




**Market Emotions Cycle**
**Graph of how we feel**
**as the markets fluctuate**

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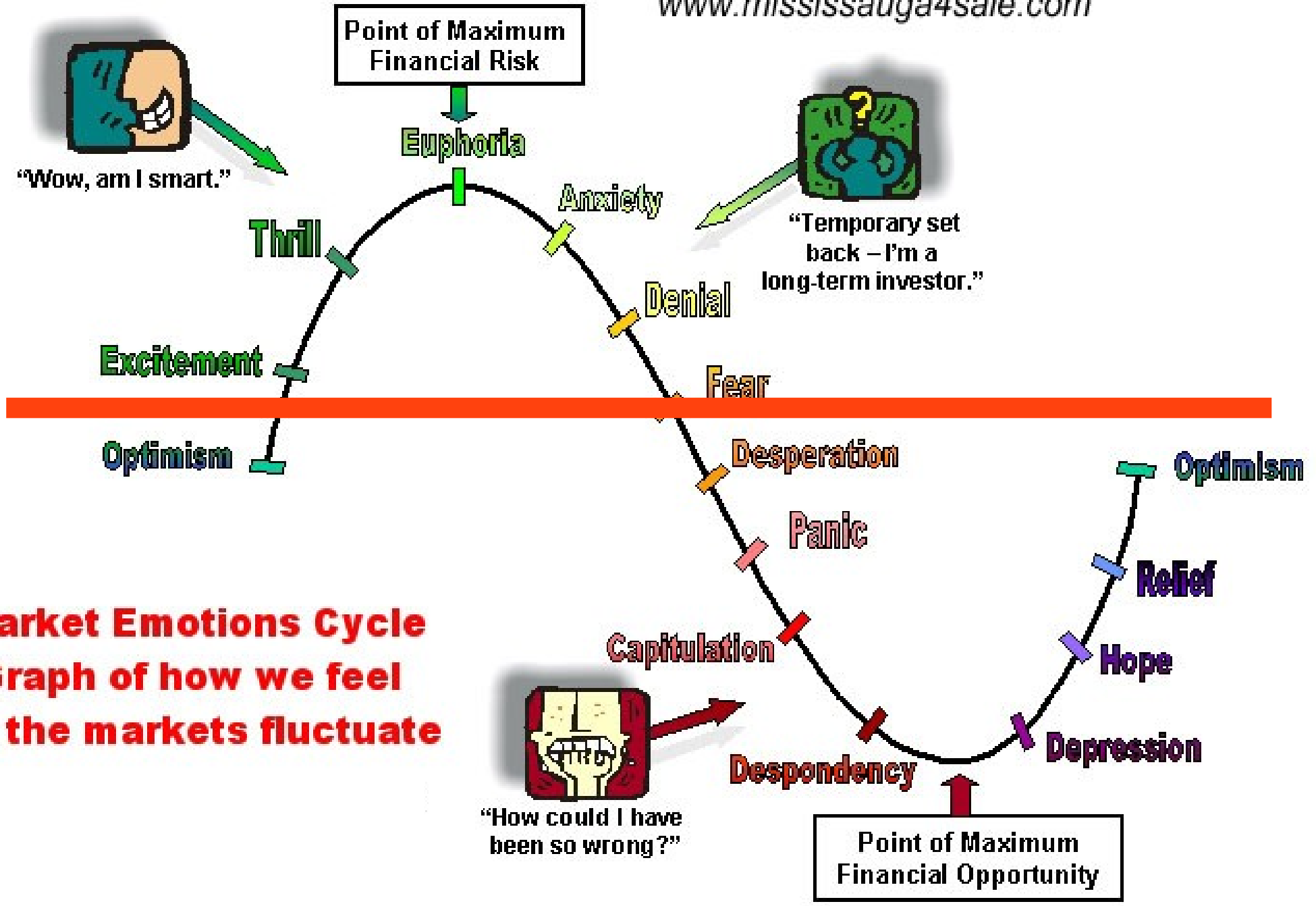


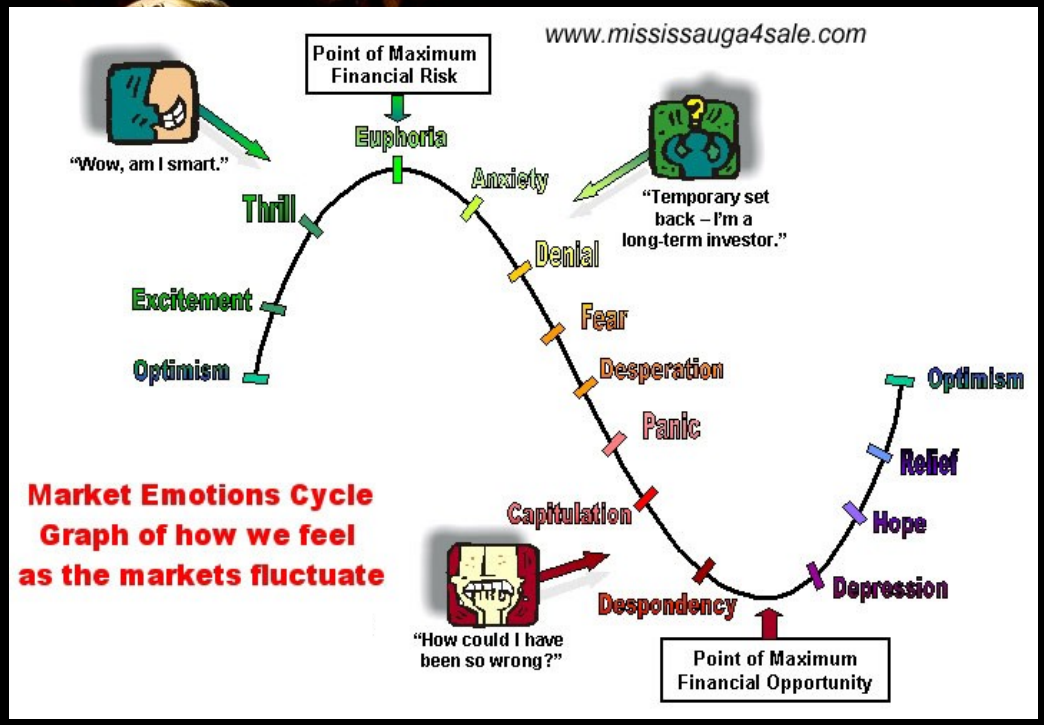

**Market Emotions Cycle**
**Graph of how we feel as the markets fluctuate**

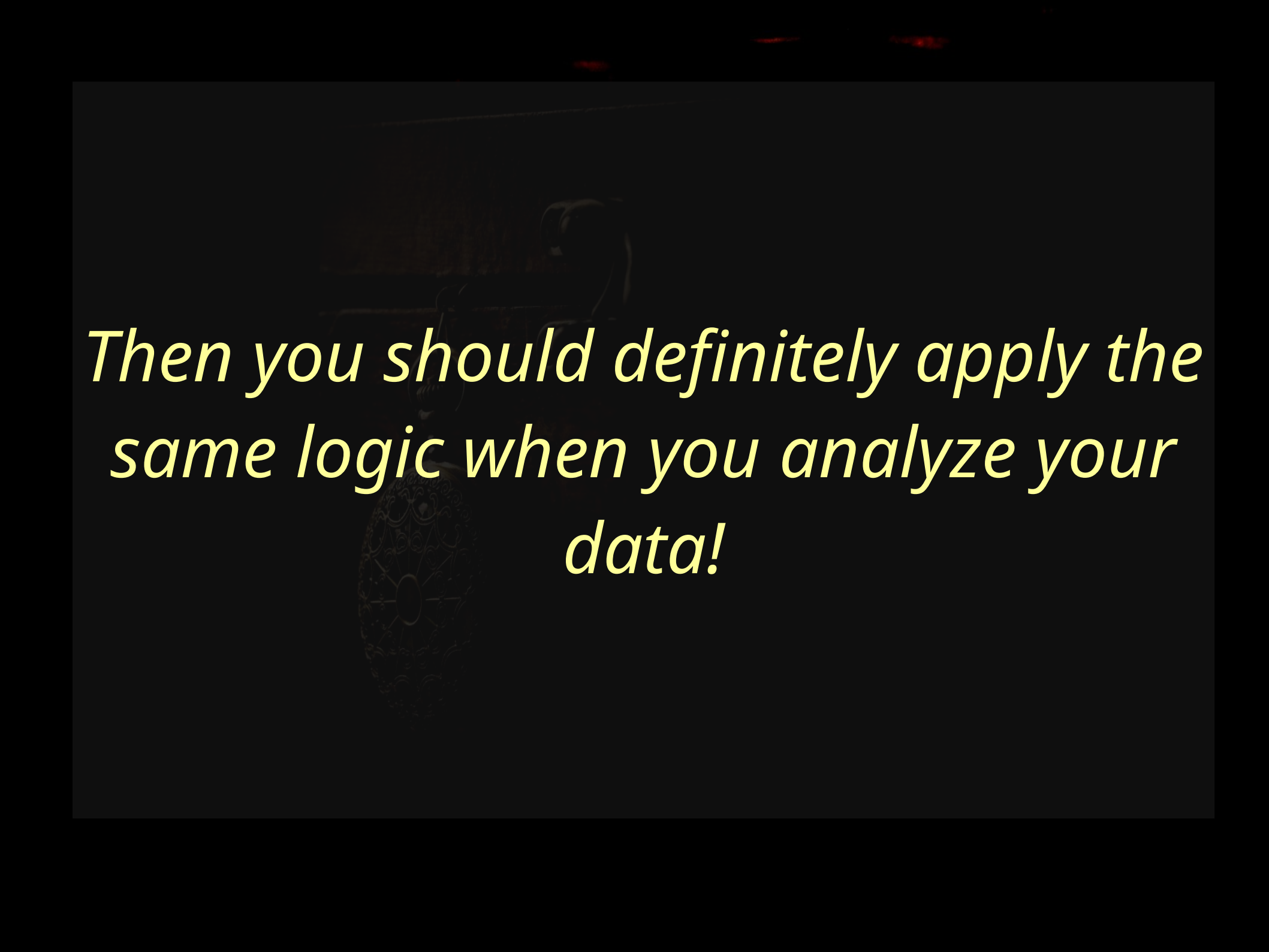
If it is obvious that you would not consider that

*A period of Fear == one of Excitment*

nor

*One of Euphoria == one of Depression*




*Then you should definitely apply the same logic when you analyze your data!*


GTI
Good Time Interval

# GTI

## Good Time Interval

| | |
|---|---|
| 263742929.0000000 | 263743009.0000000 |
| 263743026.0000000 | 263745778.0000000 |
| 263748625.0000000 | 263751841.0000000 |

# GTI

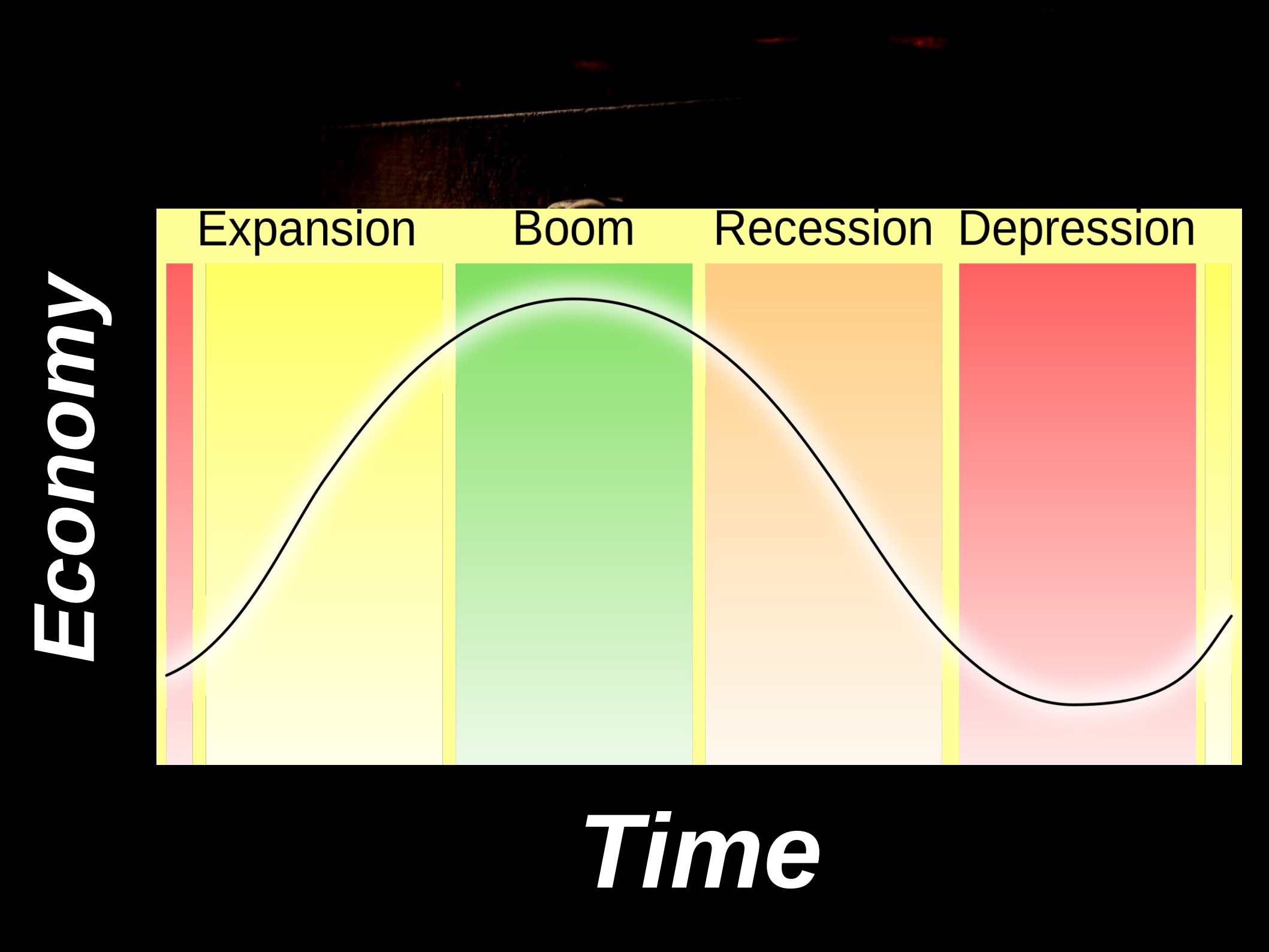
## Good Time Interval

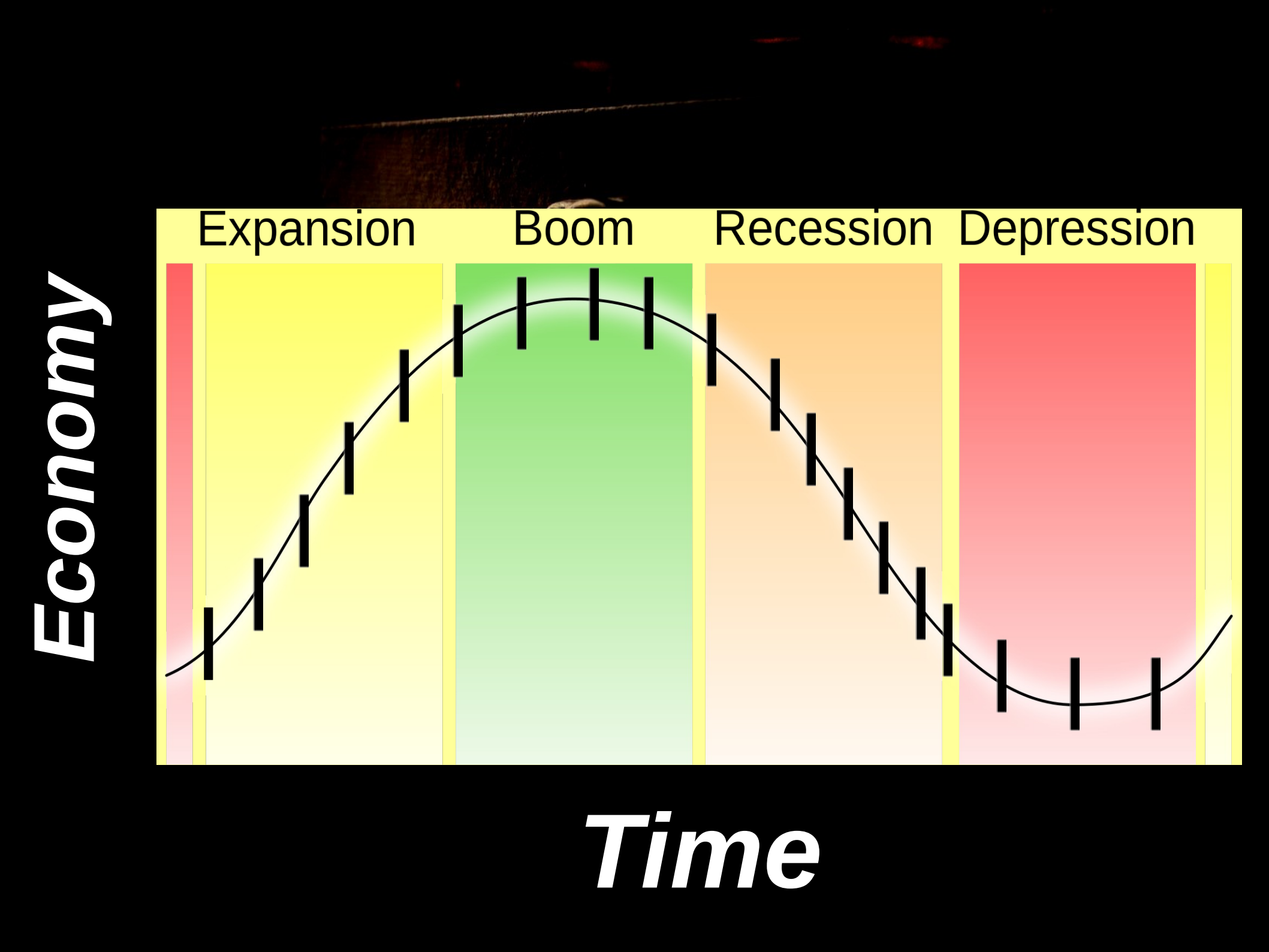
| | | | | |
|---|---|---|---|---|
| 263742929.0000000 | 263743009.0000000 | - offset = | 0 | 80 |
| 263743026.0000000 | 263745778.0000000 | | 97 | 2849 |
| 263748625.0000000 | 263751841.0000000 | | 5696 | 8912 |

# GTI

*Good Time Interval*

There is no standard tool that
you can use for every problem!!


Expansion
Boom
Recession
Depression
Economy
Time


Expansion
Boom
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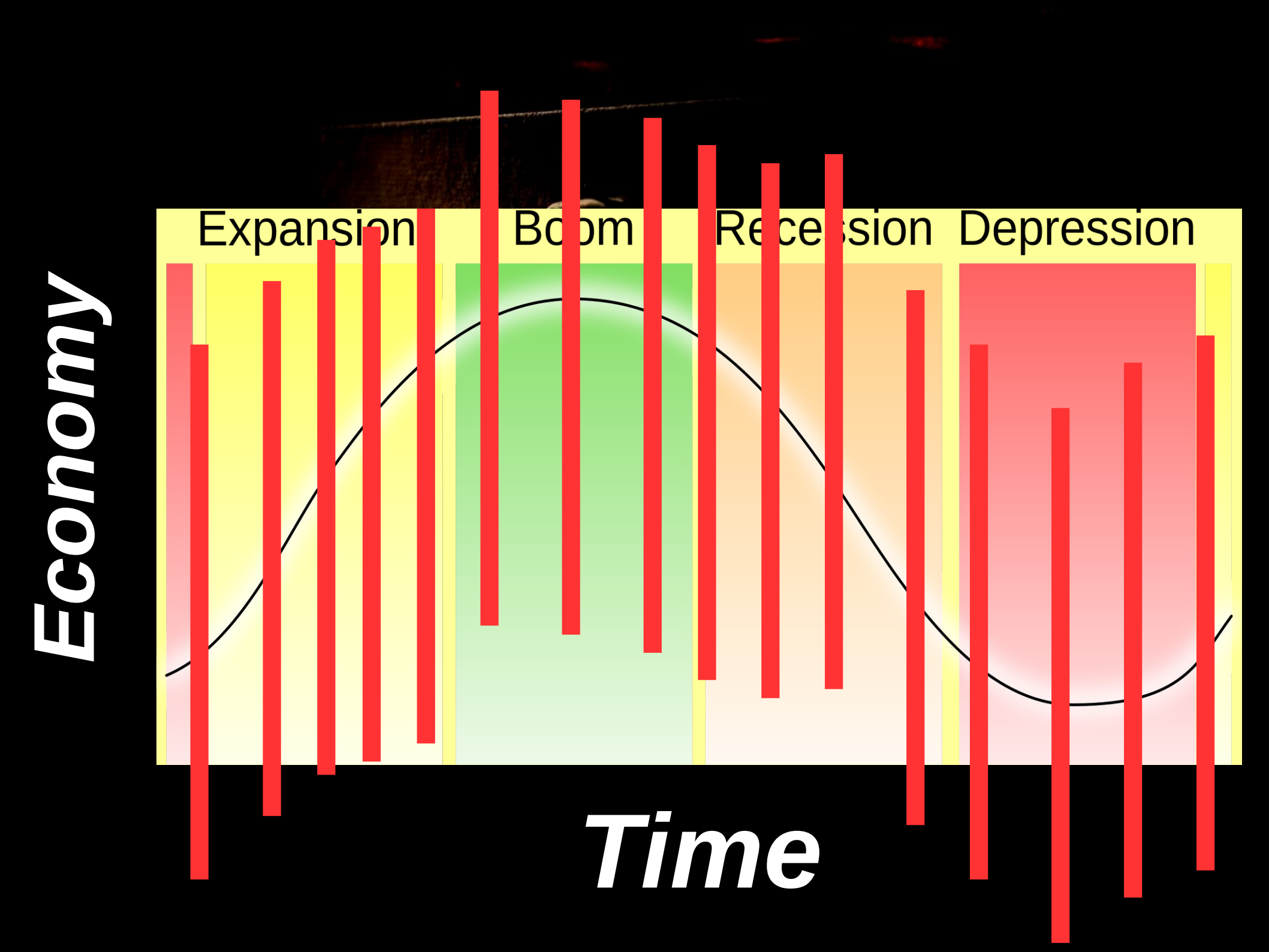
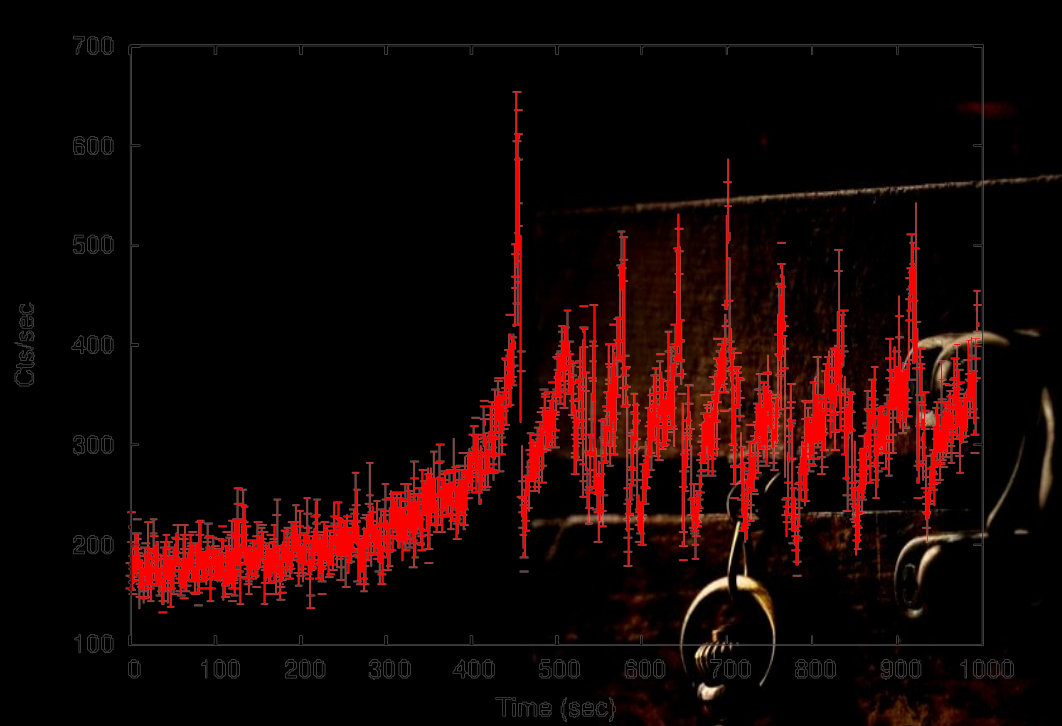
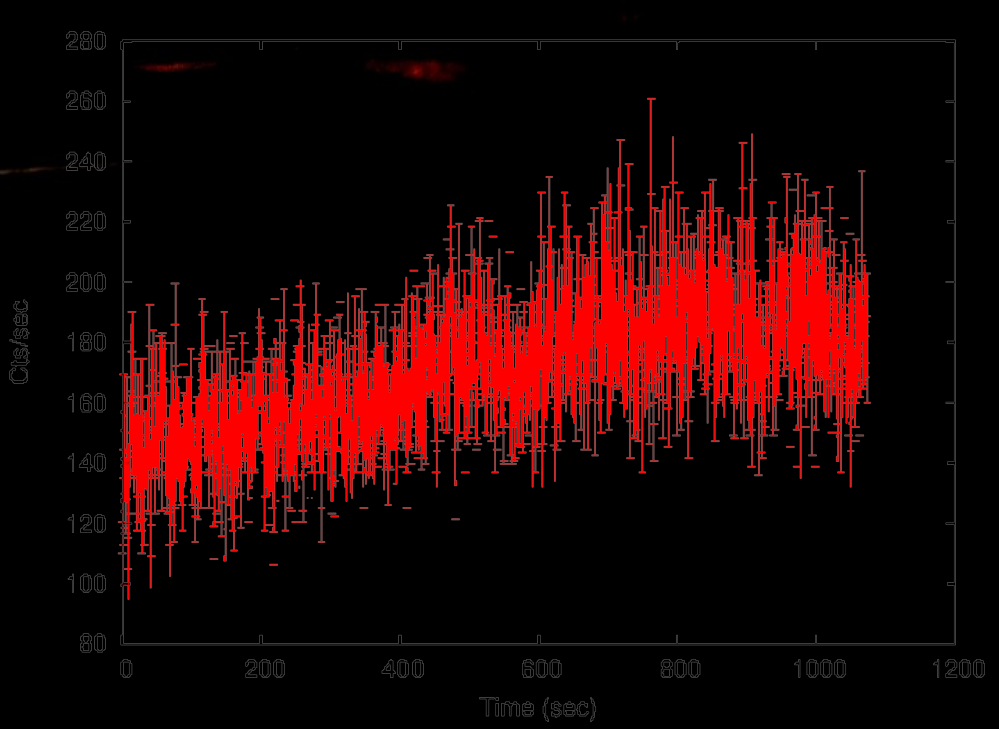
Time


Expansion
Boom
Recession
Depression
Economy
Time


Cts/sec
Time (sec)
100
200
300
400
500
600
700
0
100
200
300
400
500
600
700
800
900
1000


Cts/sec
Time (sec)
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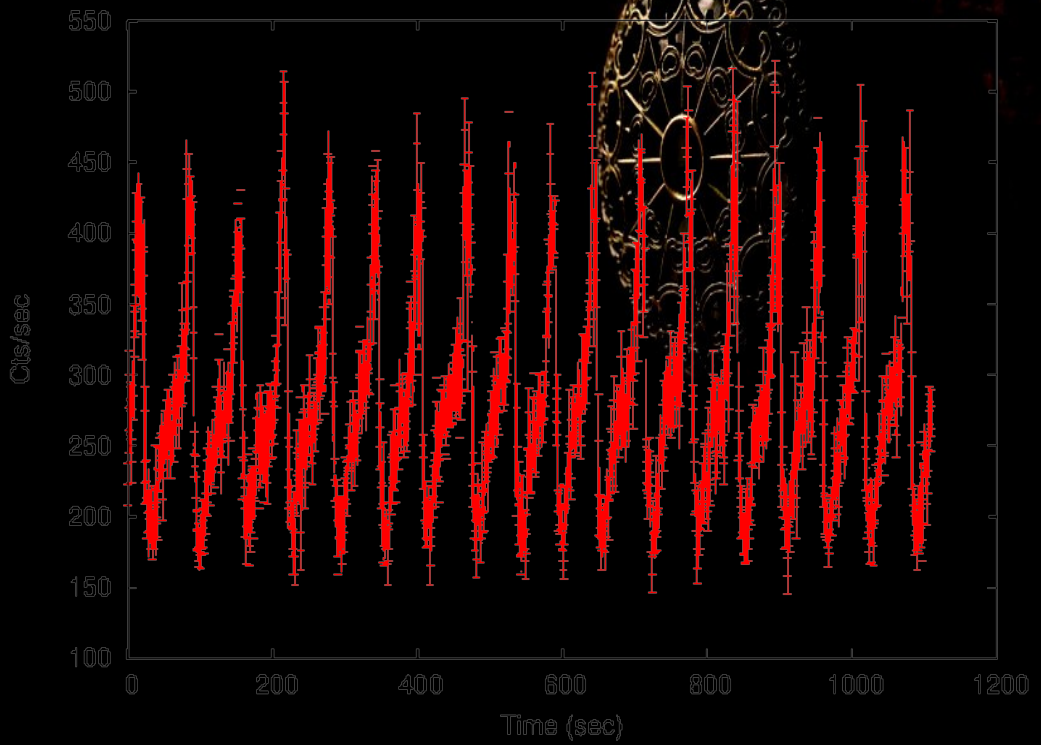
100
120
140
160
180
200
220
240
260
280
0
200
400
600
800
1000
1200


Cts/sec
Time (sec)
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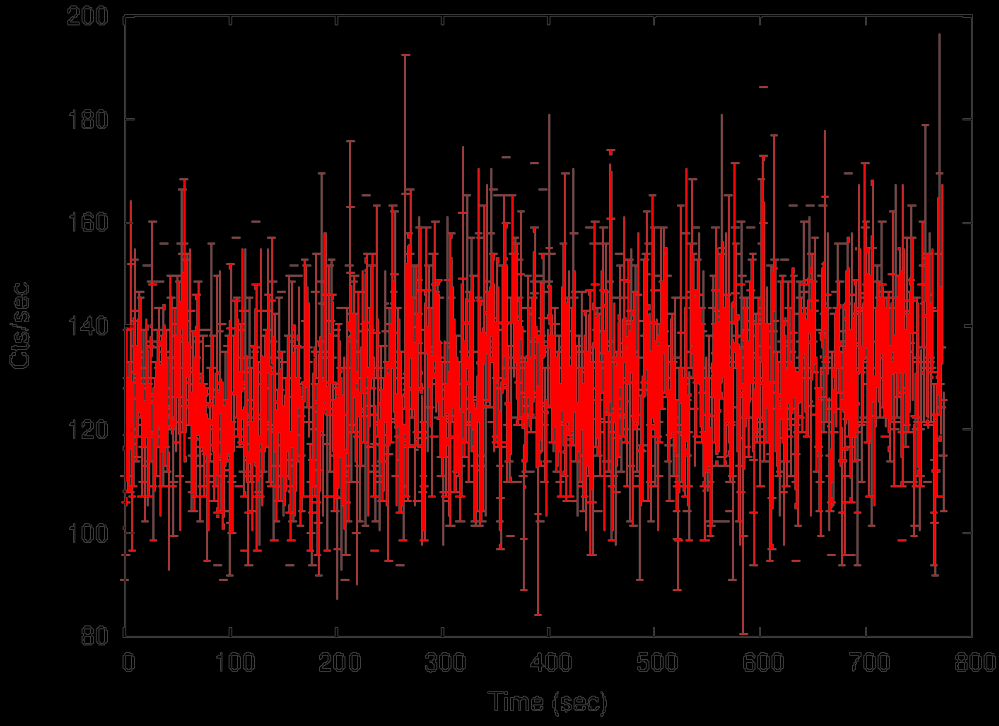
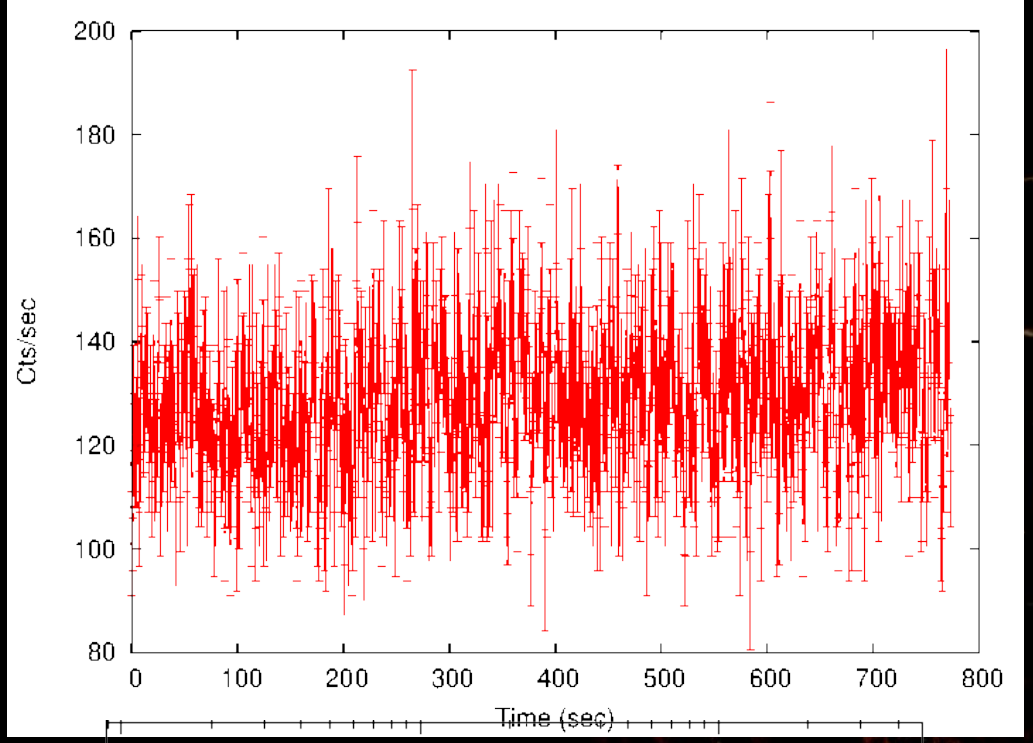
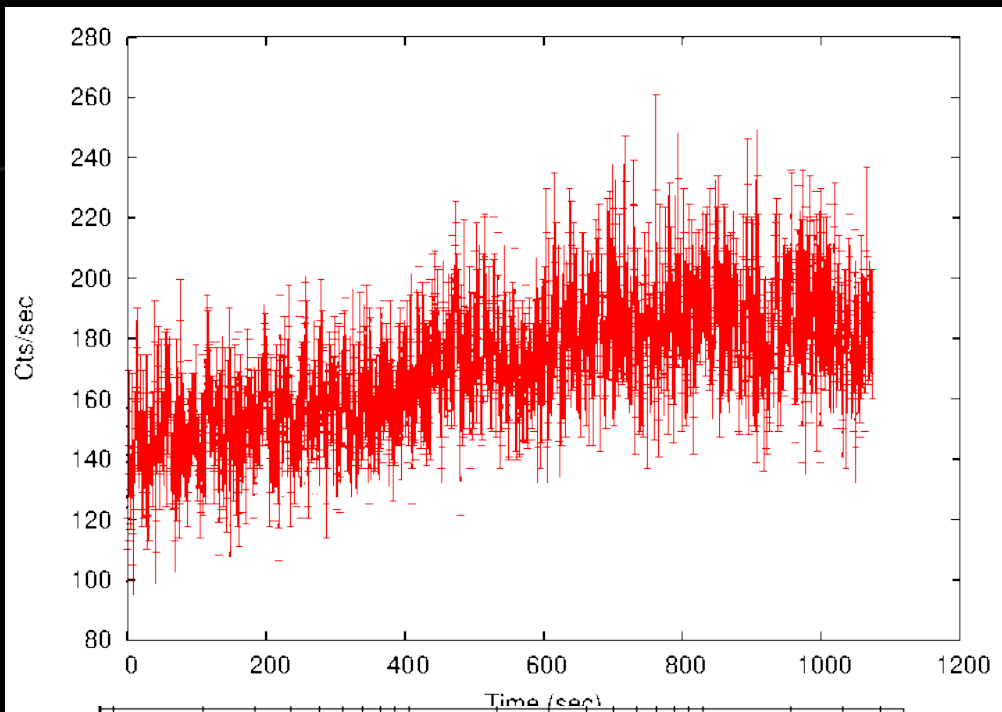
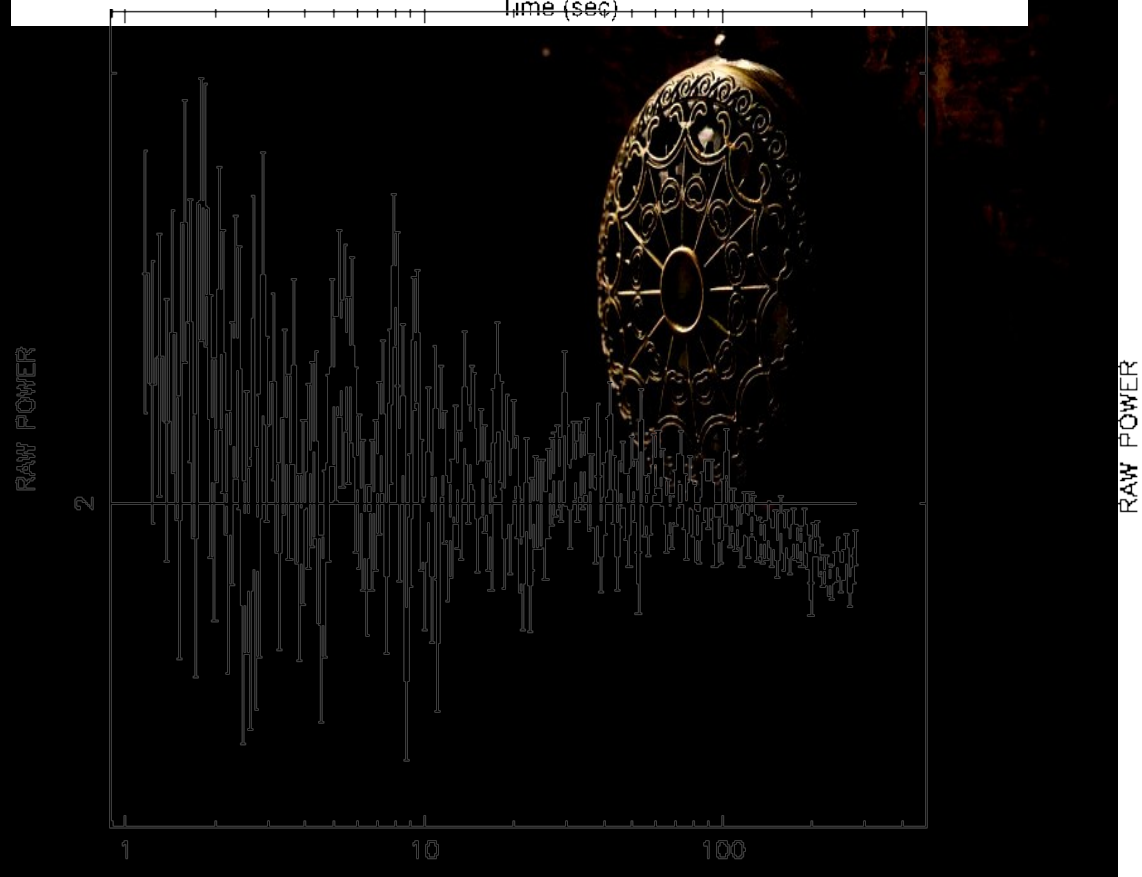
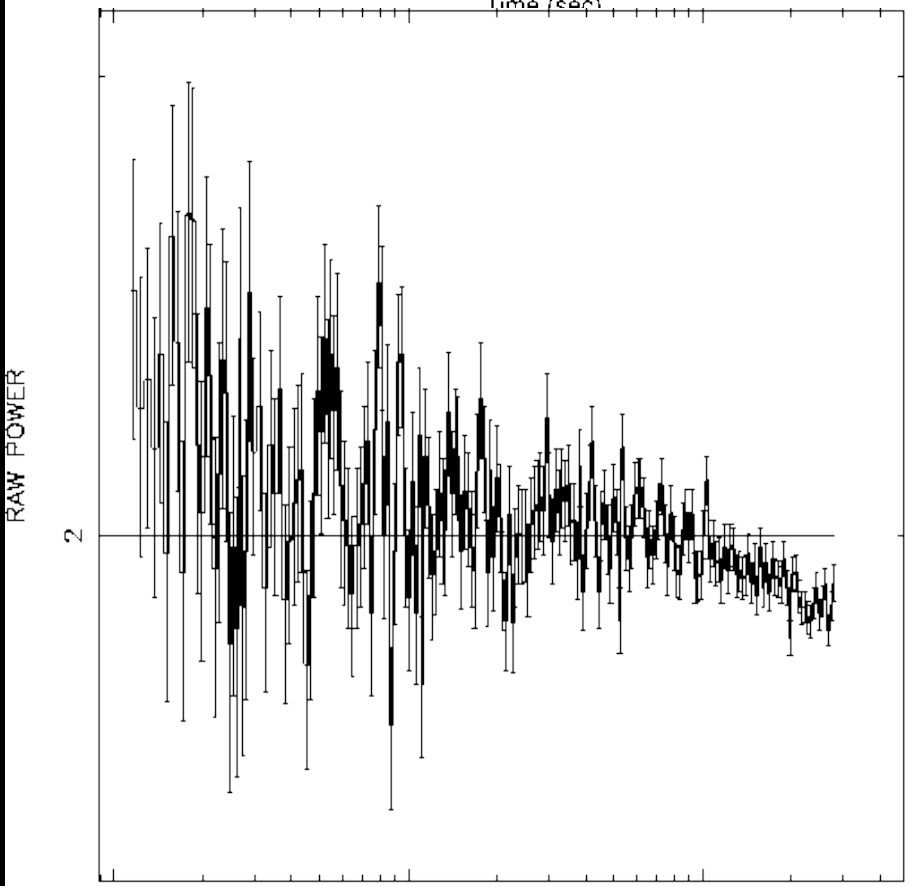
150
200
250
300
350
400
450
500
550
0
200
400
600
800
1000
1200

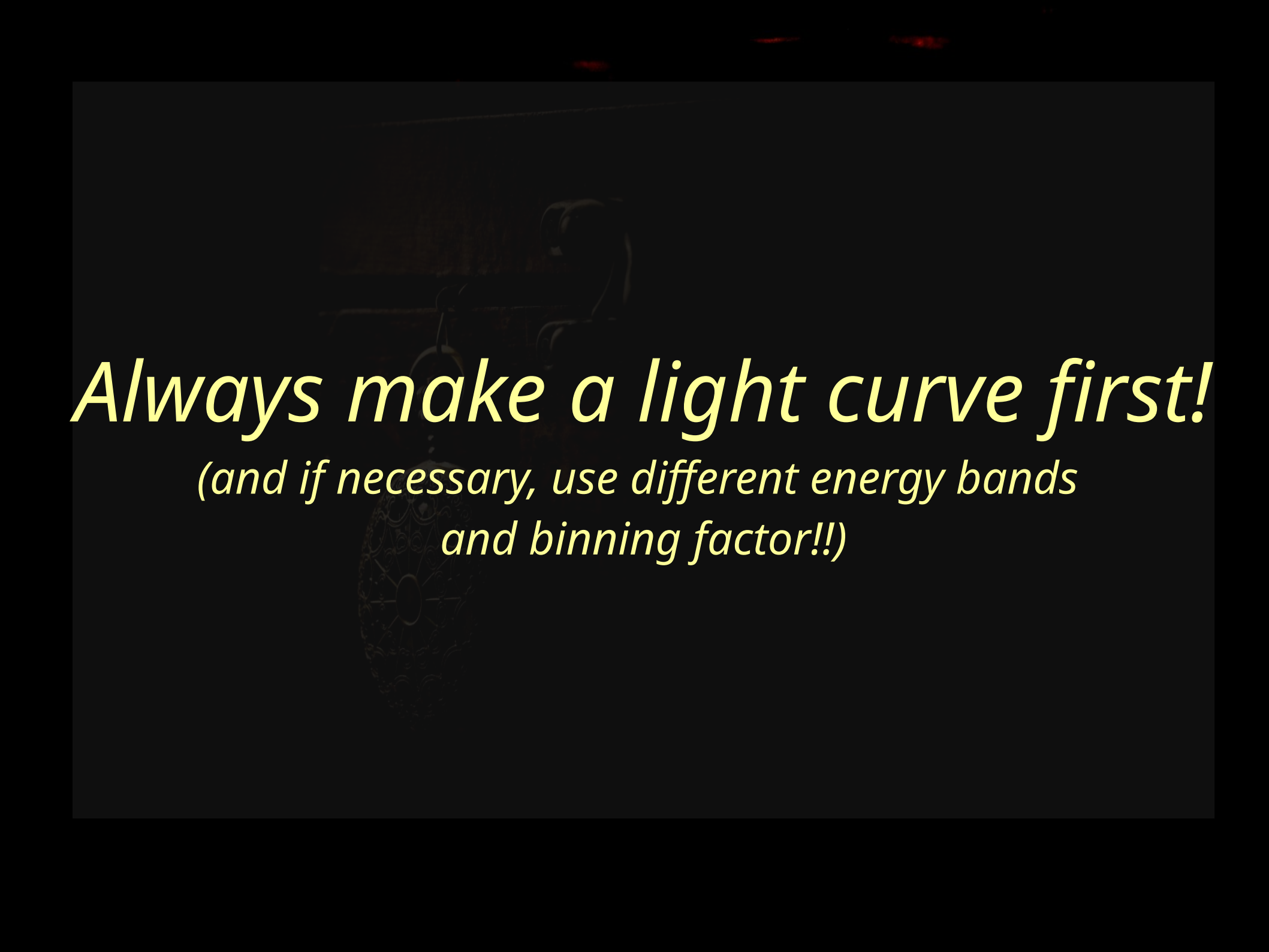

Cts/sec
Time (sec)
80
100
120
140
160
180
200
0
100
200
300
400
500
600
700
800


Cts/sec
Time (sec)
200
180
160
140
120
100
80
0
100
200
300
400
500
600
700
800


Cts/sec
Time (sec)
280
260
240
220
200
180
160
140
120
100
80
0
200
400
600
800
1000
1200

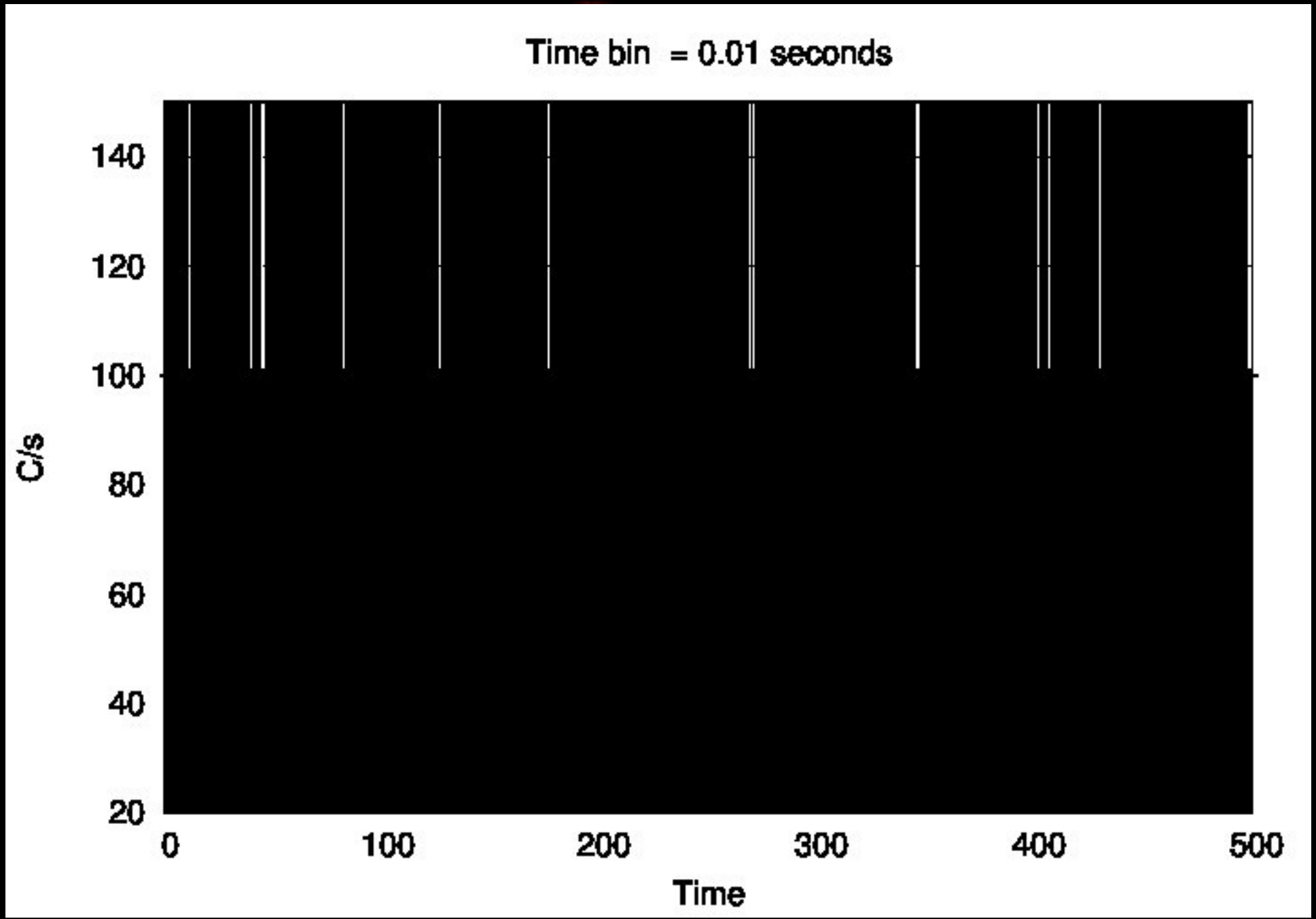

RAW POWER
2
1
10
100

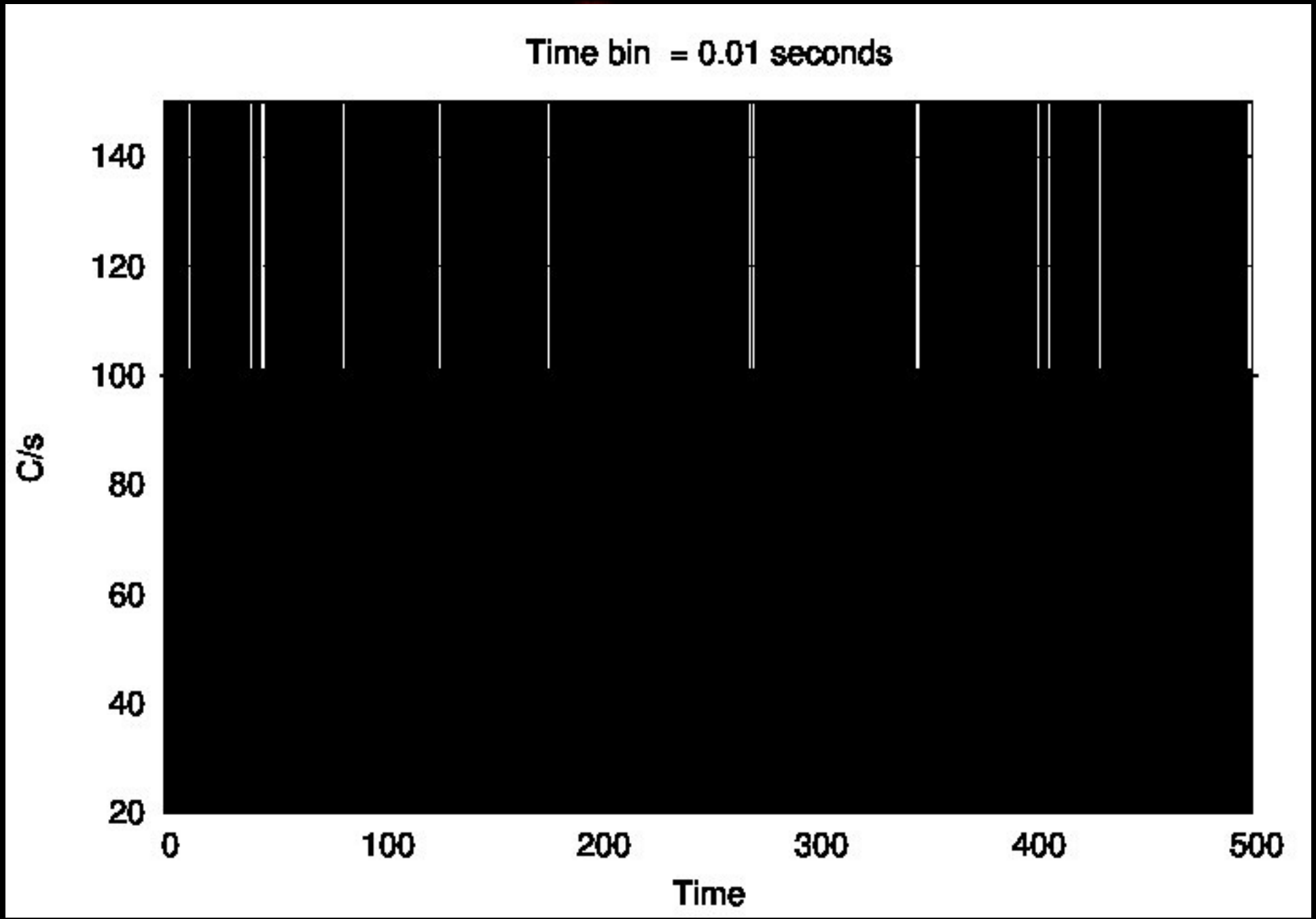

RAW POWER
2


*Always make a light curve first!*
*(and if necessary, use different energy bands*
*and binning factor!!)*

*Time Binning!*

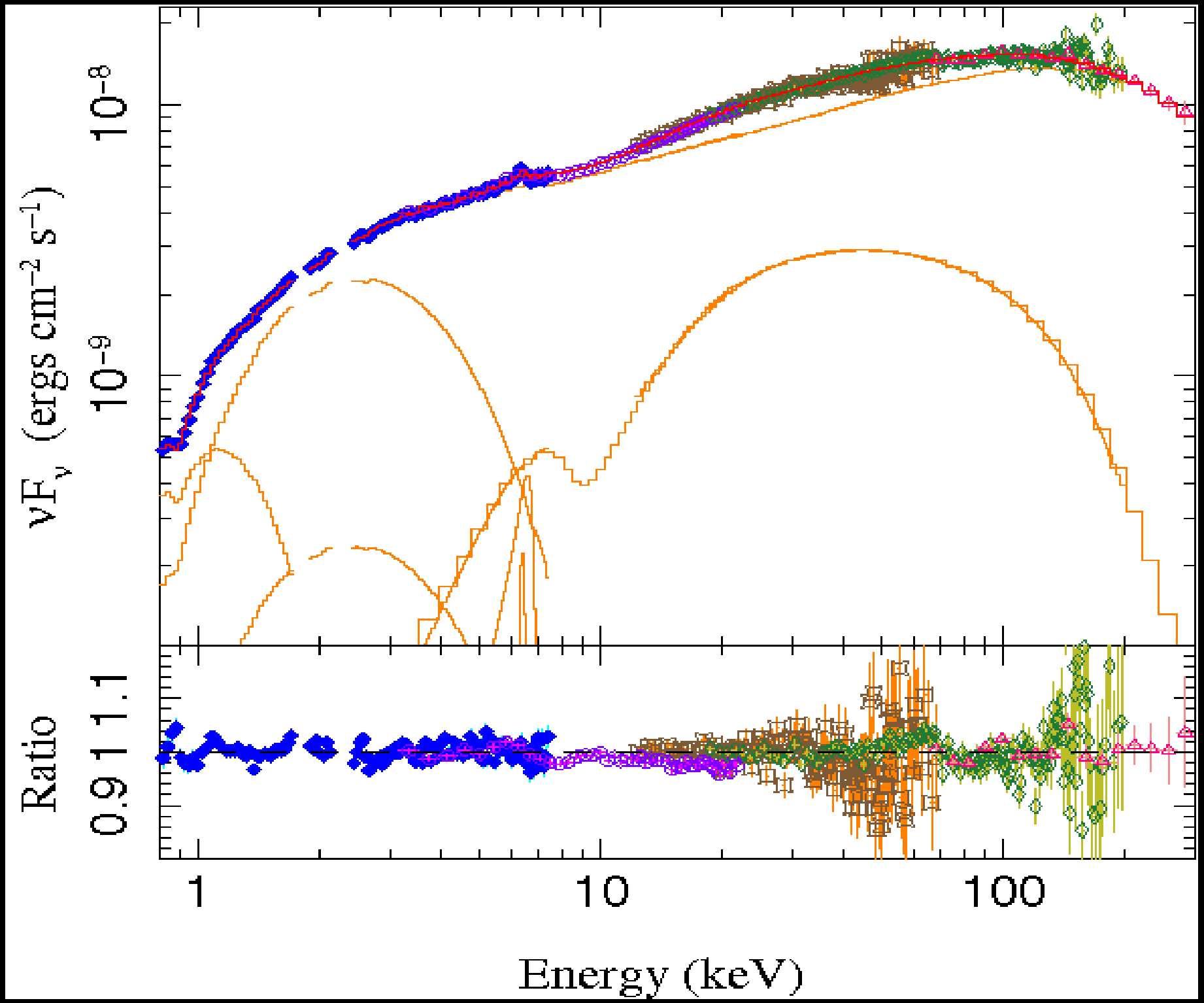
*How do things change?*

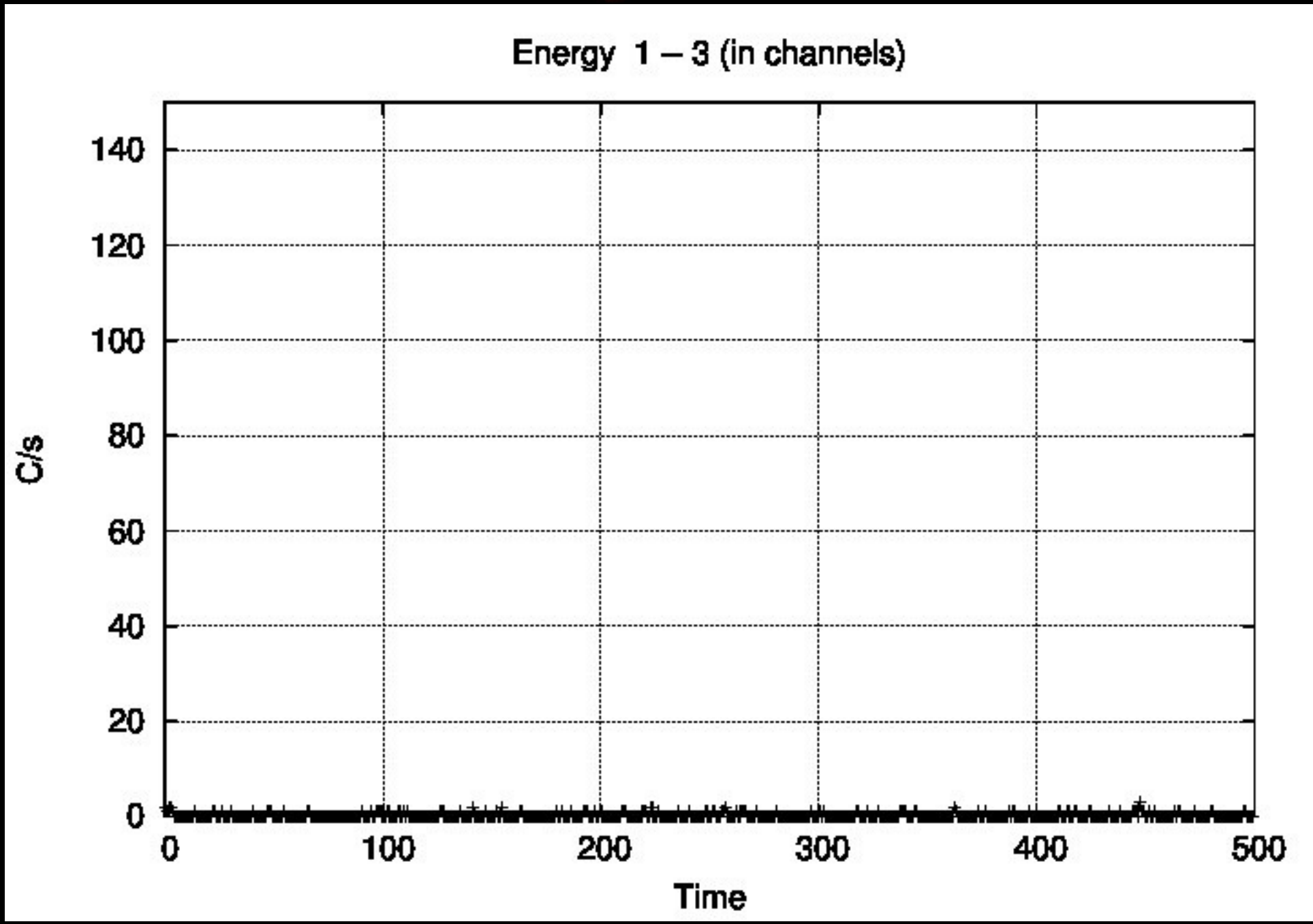

Time bin = 0.01 seconds
140
120
100
80
60
40
20
C/s
0
100
200
300
400
500
Time

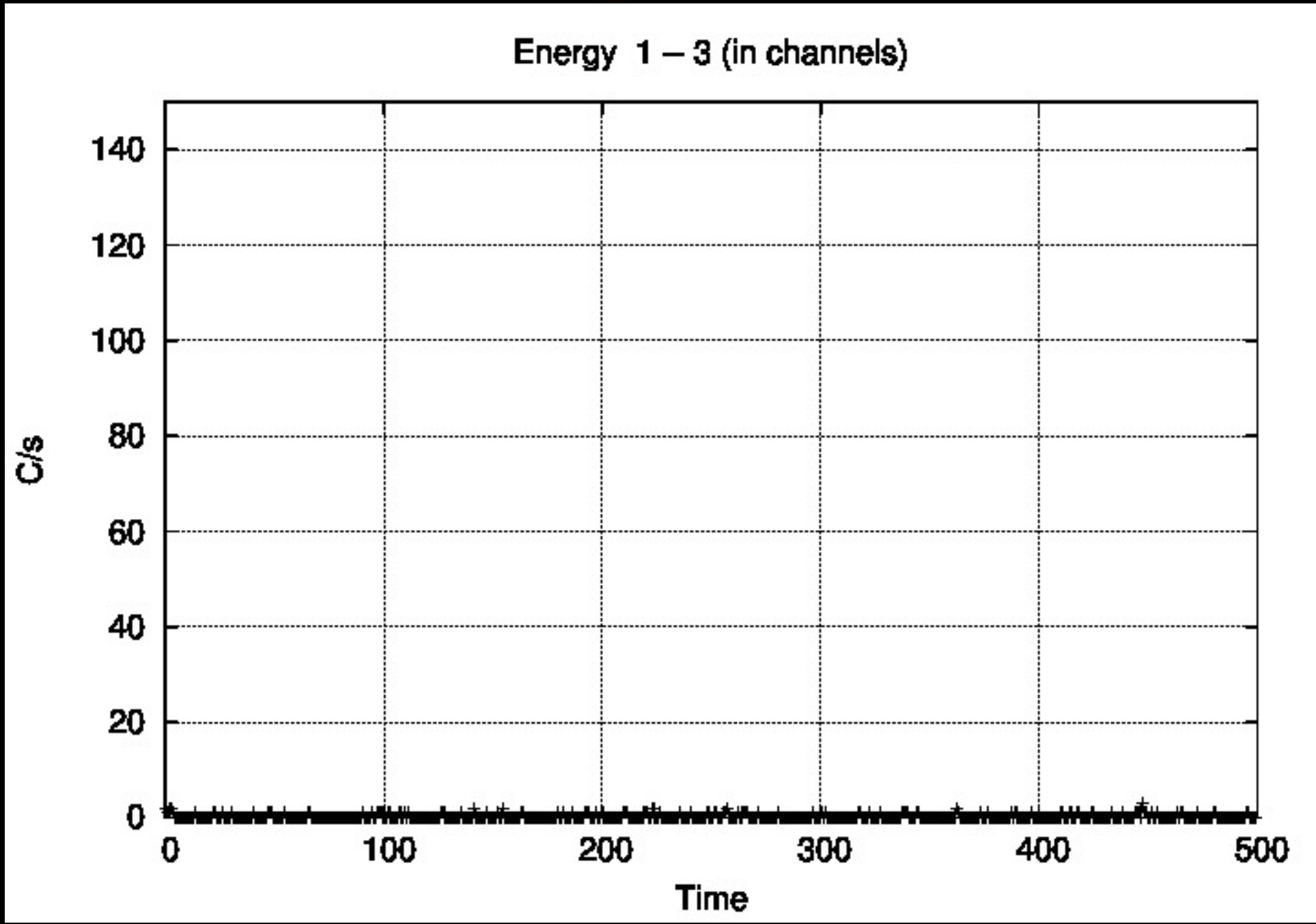

Time bin = 0.01 seconds
140
120
100
80
60
40
20
C/s
0
100
200
300
400
500
Time

*Energy selection...*

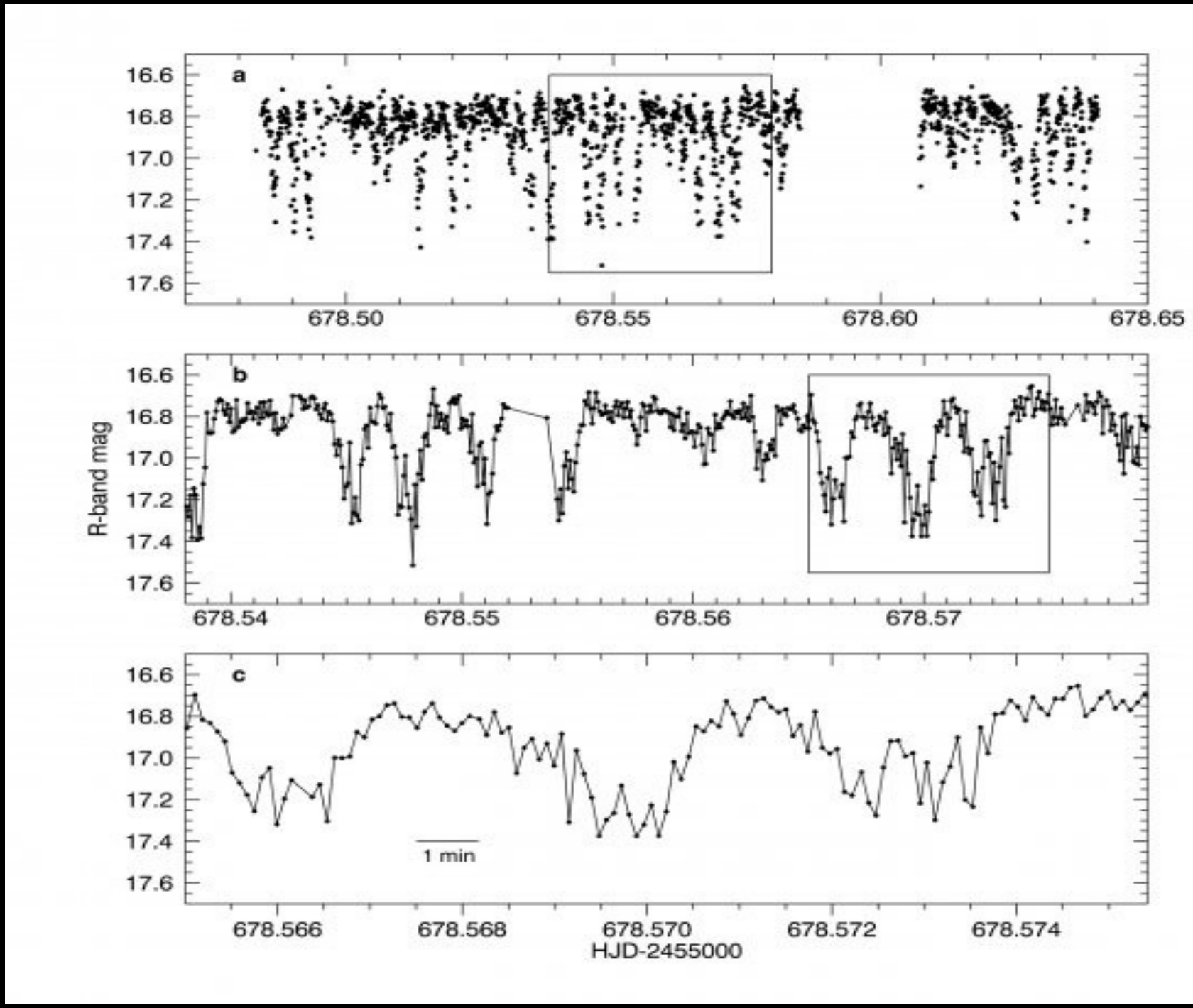
*changes my light curve?*

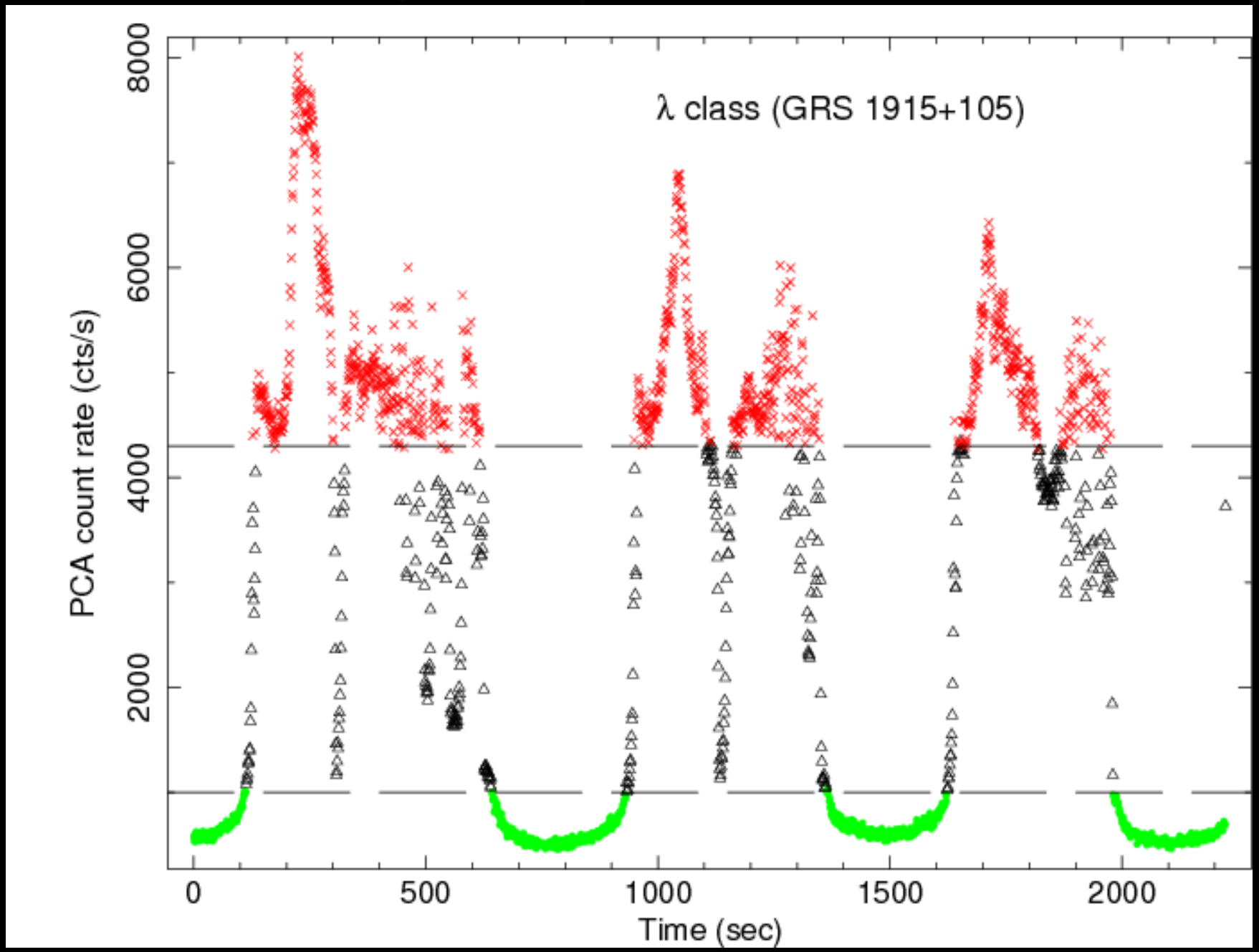

$10^{-8}$
$10^{-9}$
$\nu F_\nu$ (ergs cm$^{-2}$ s$^{-1}$)
Ratio
0.9
1
1.1
1
10
100
Energy (keV)


Energy 1 – 3 (in channels)
C/s
140
120
100
80
60
40
20
0
0
100
200
300
400
500
Time

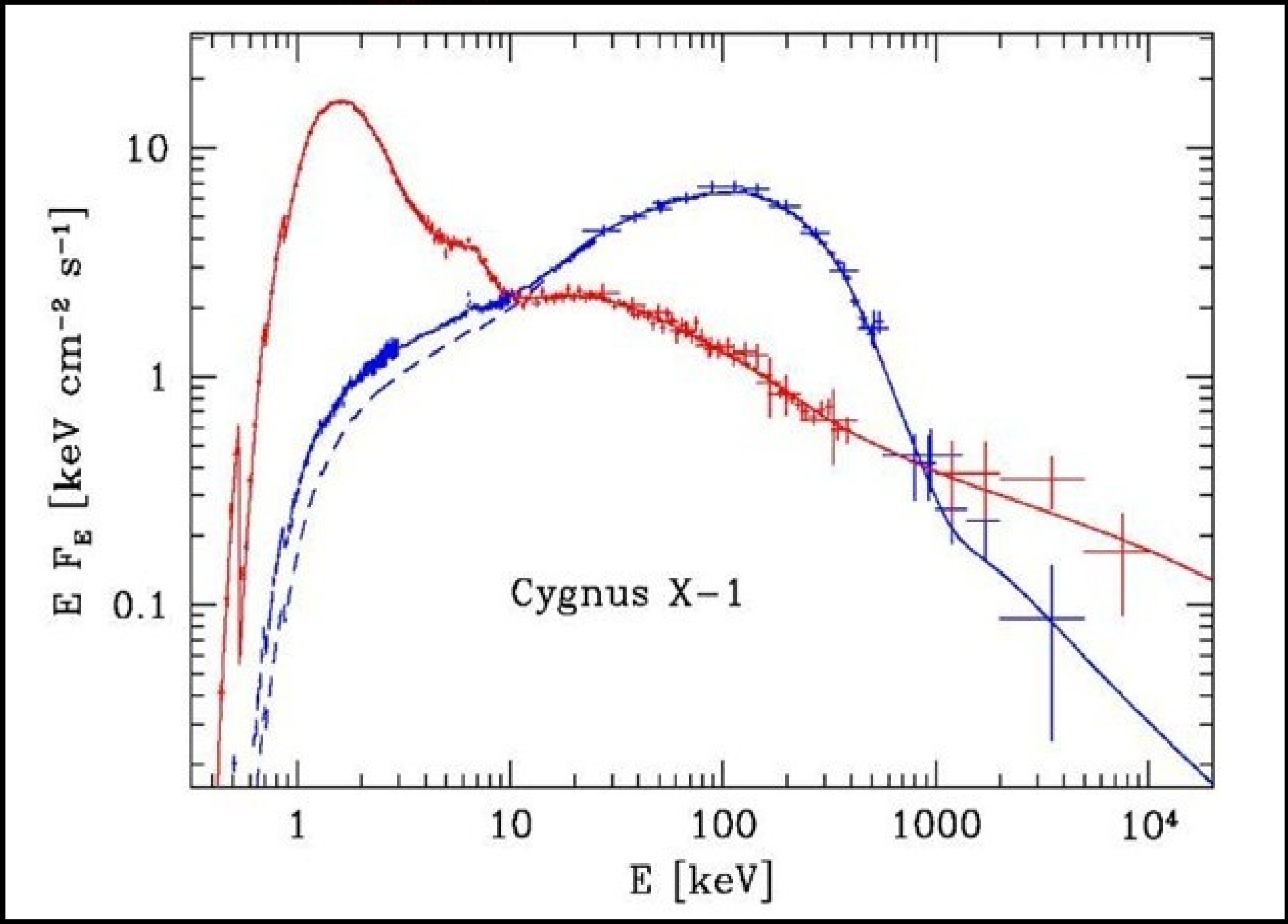

Energy 1 – 3 (in channels)
C/s
140
120
100
80
60
40
20
0
0
100
200
300
400
500
Time

Coming back to the talk....

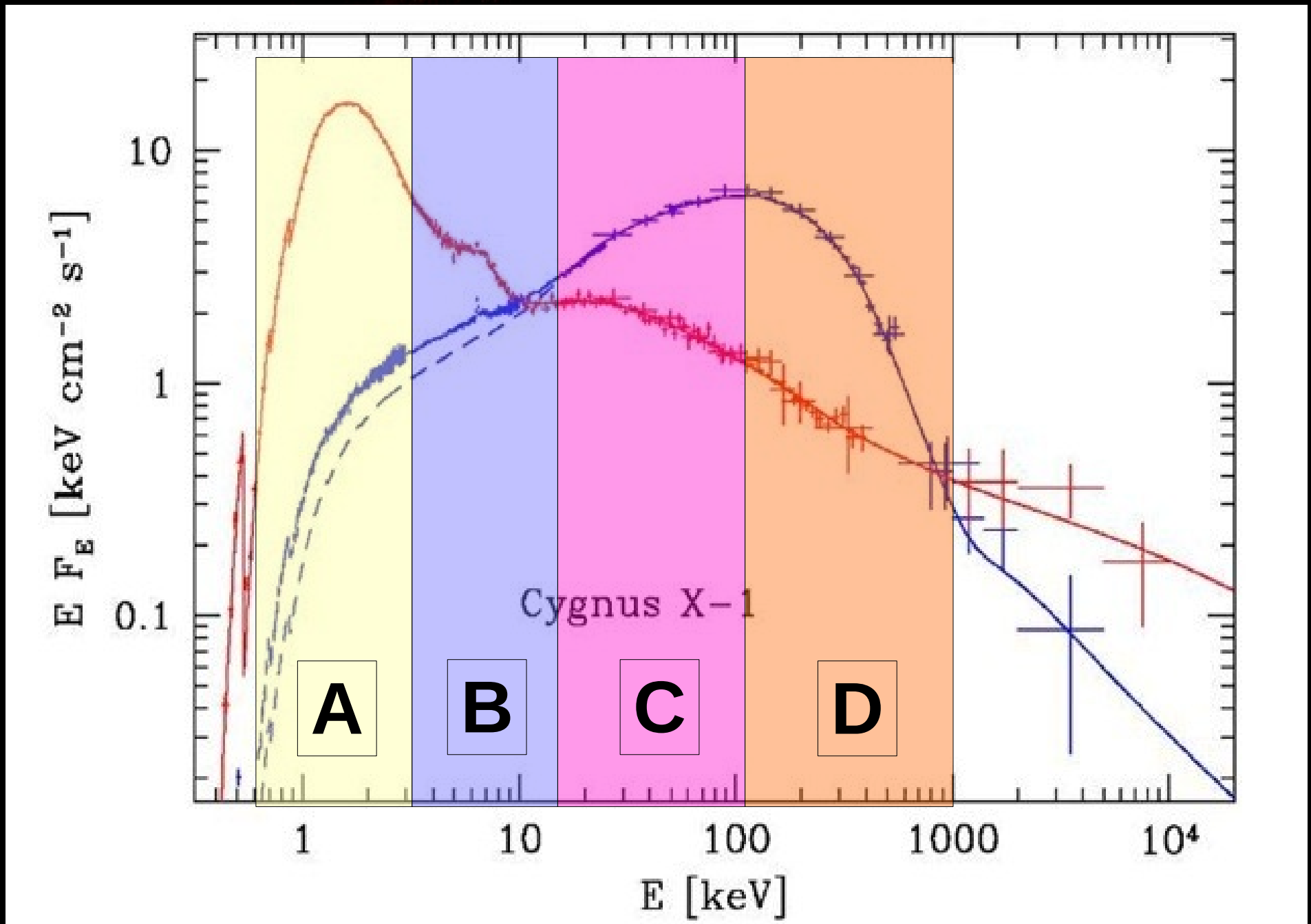

a
b
c
16.6
16.8
17.0
17.2
17.4
17.6
R-band mag
678.50
678.55
678.60
678.65
678.54
678.55
678.56
678.57
678.566
678.568
678.570
678.572
678.574
HJD-2455000
1 min


λ class (GRS 1915+105)
PCA count rate (cts/s)
8000
6000
4000
2000
0
500
1000
1500
2000
Time (sec)

# X-ray colors -> helping tracing variability

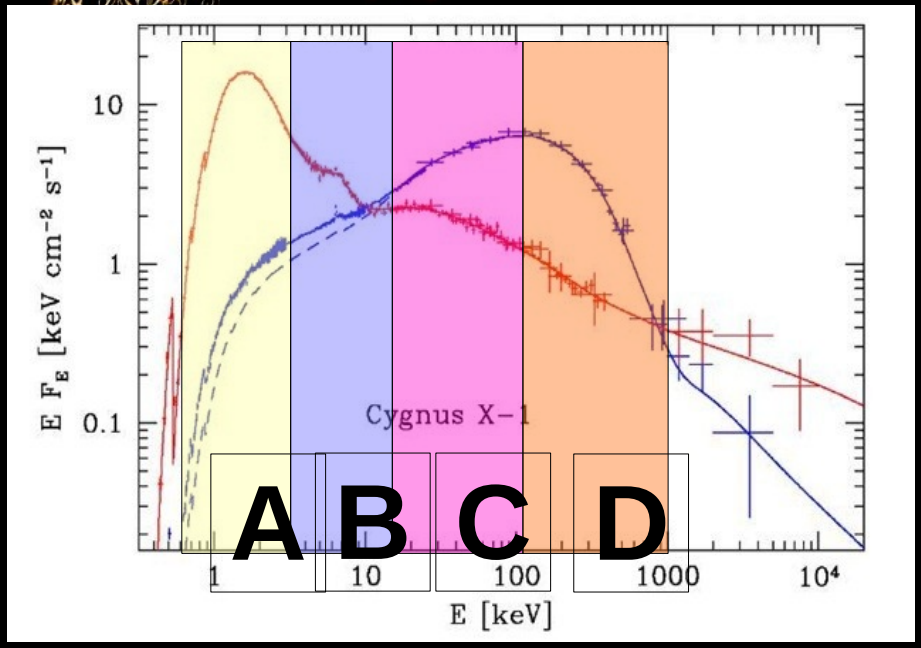


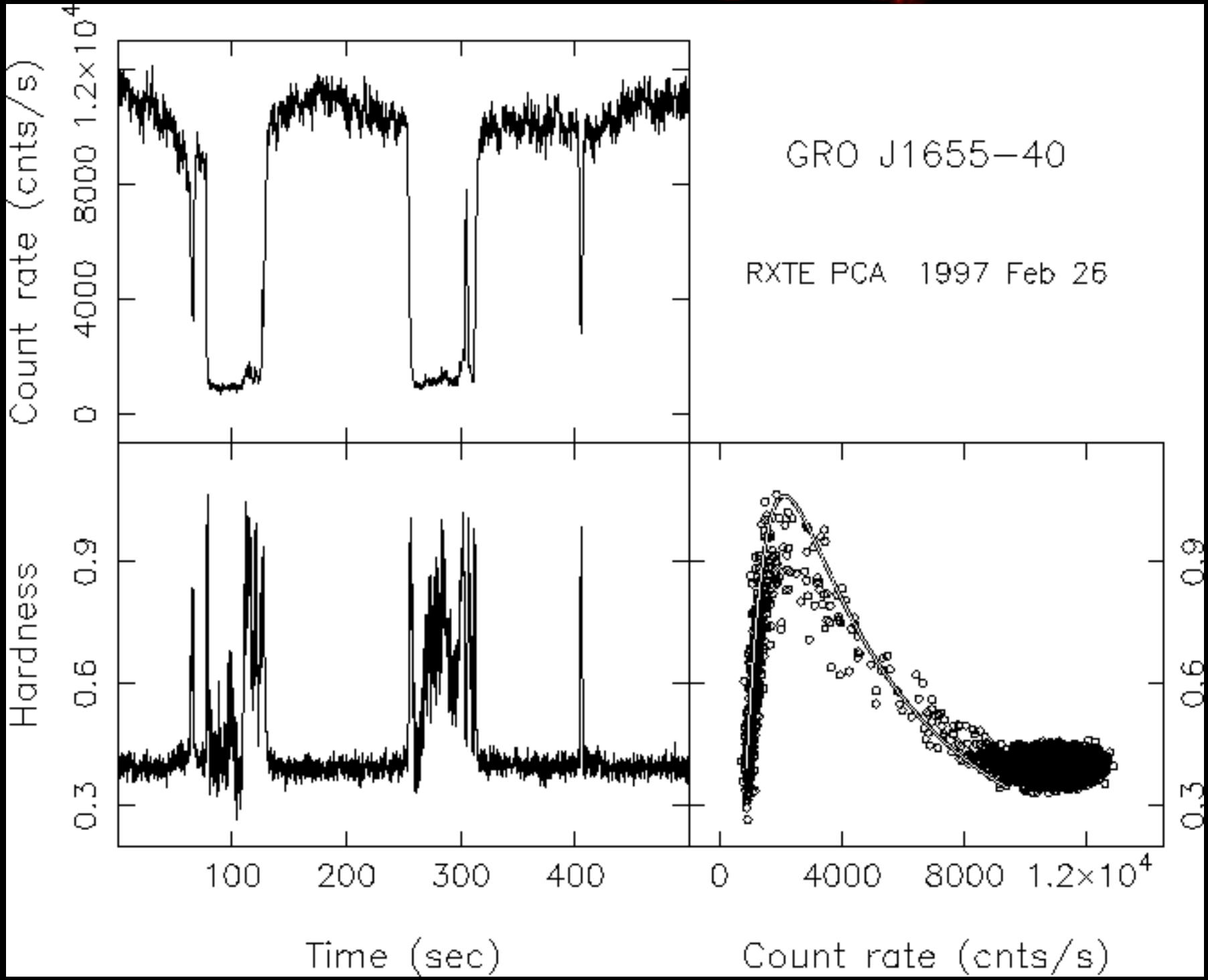
# X-ray colors -> helping tracing variability

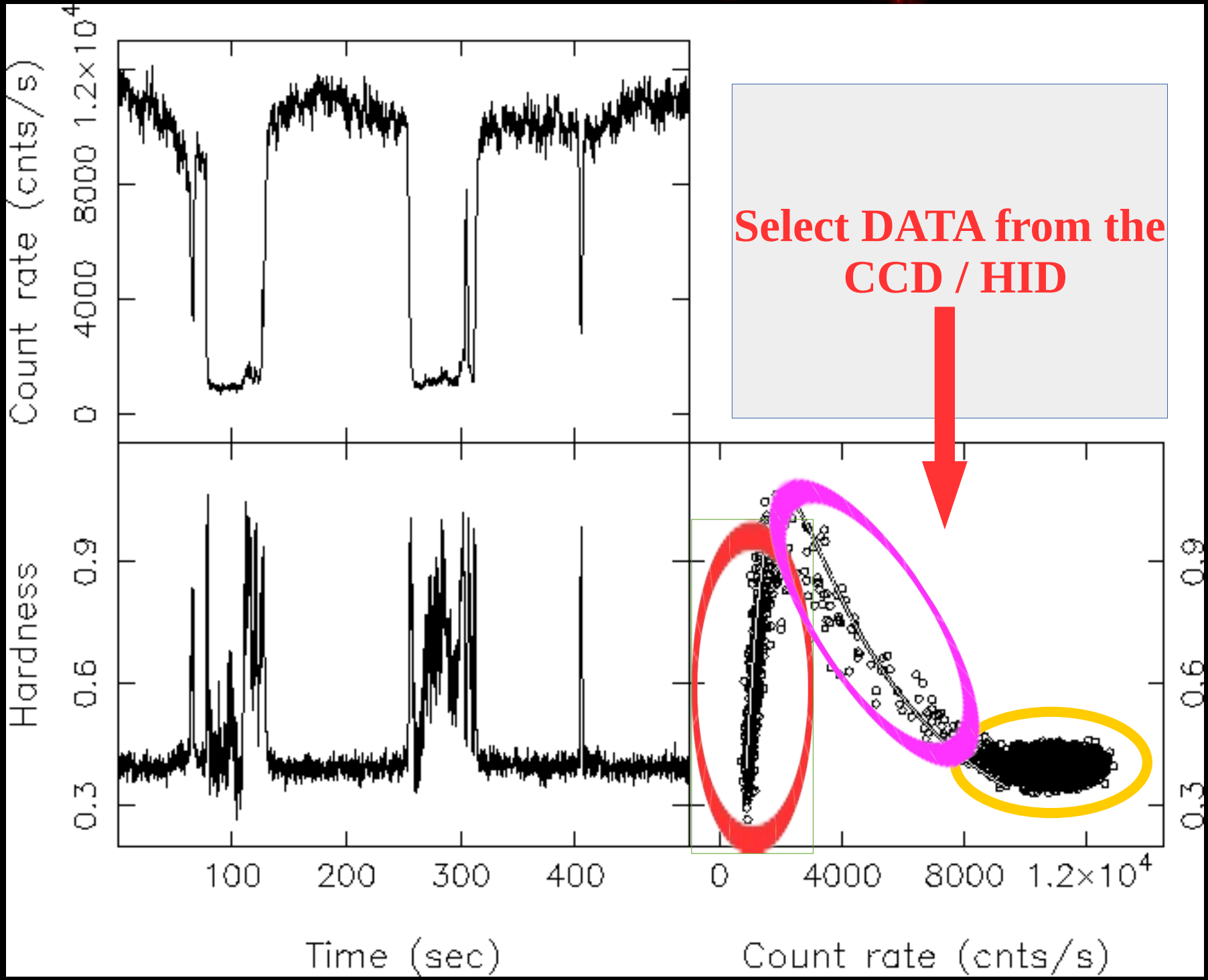


# X-ray colors -> helping tracing variability

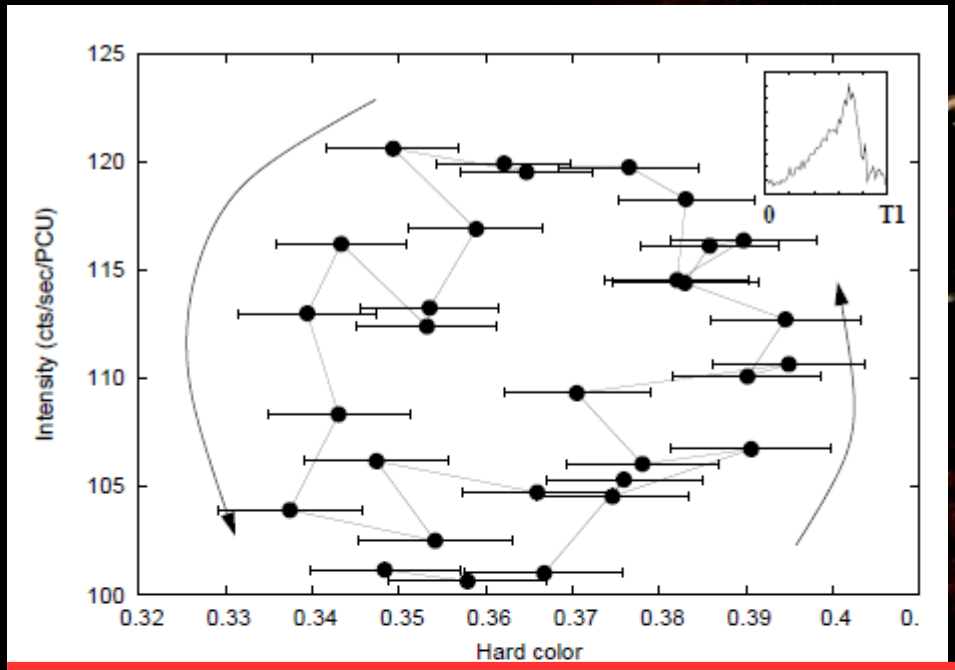
- Color 1 = B/A
- Color 2 = D/C
- Intensity = A+B+C+D

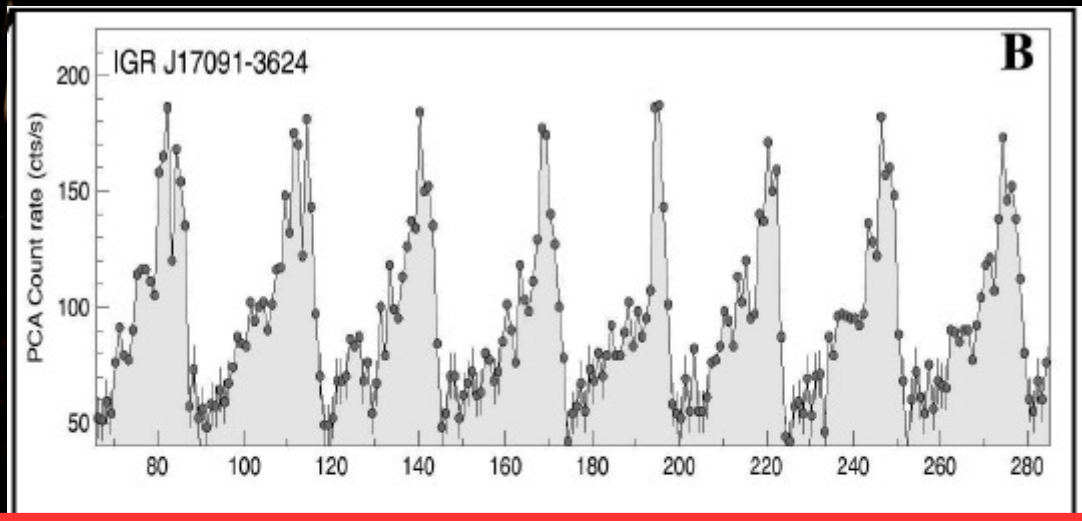


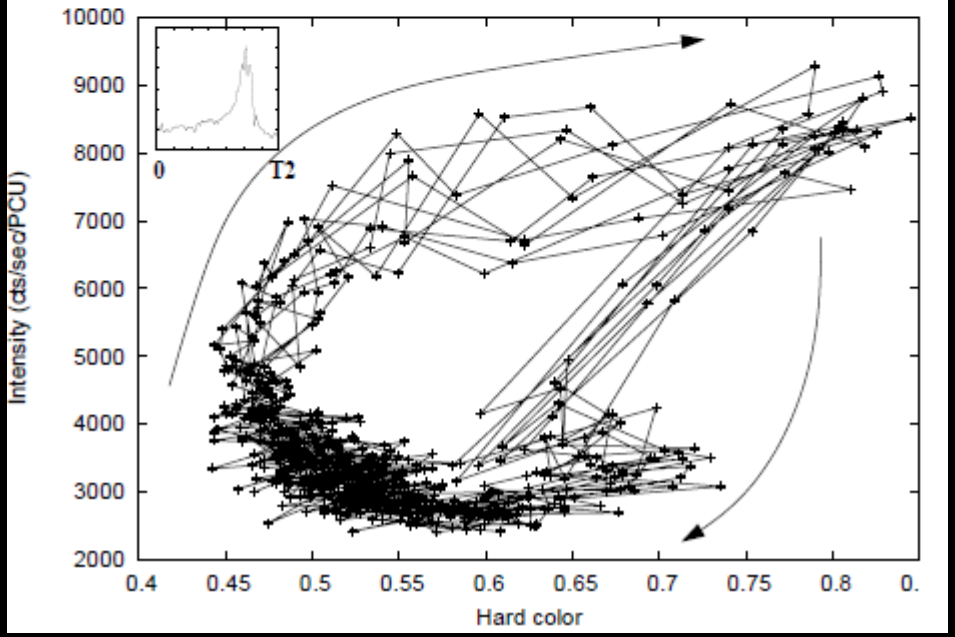

GRO J1655−40
RXTE PCA 1997 Feb 26
Count rate (cnts/s)
0
4000
8000
1.2×10^4
Hardness
0.3
0.6
0.9
100
200
300
400
Time (sec)
Count rate (cnts/s)

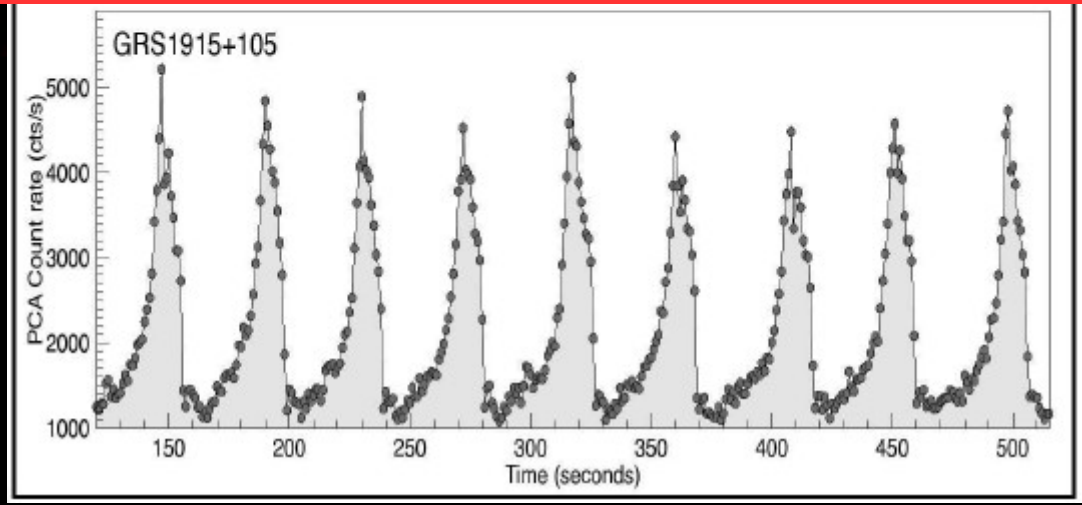

Count rate (cnts/s)
0
4000
8000
1.2×10^4
Hardness
0.3
0.6
0.9
100
200
300
400
Time (sec)
Count rate (cnts/s)
Select DATA from the CCD / HID

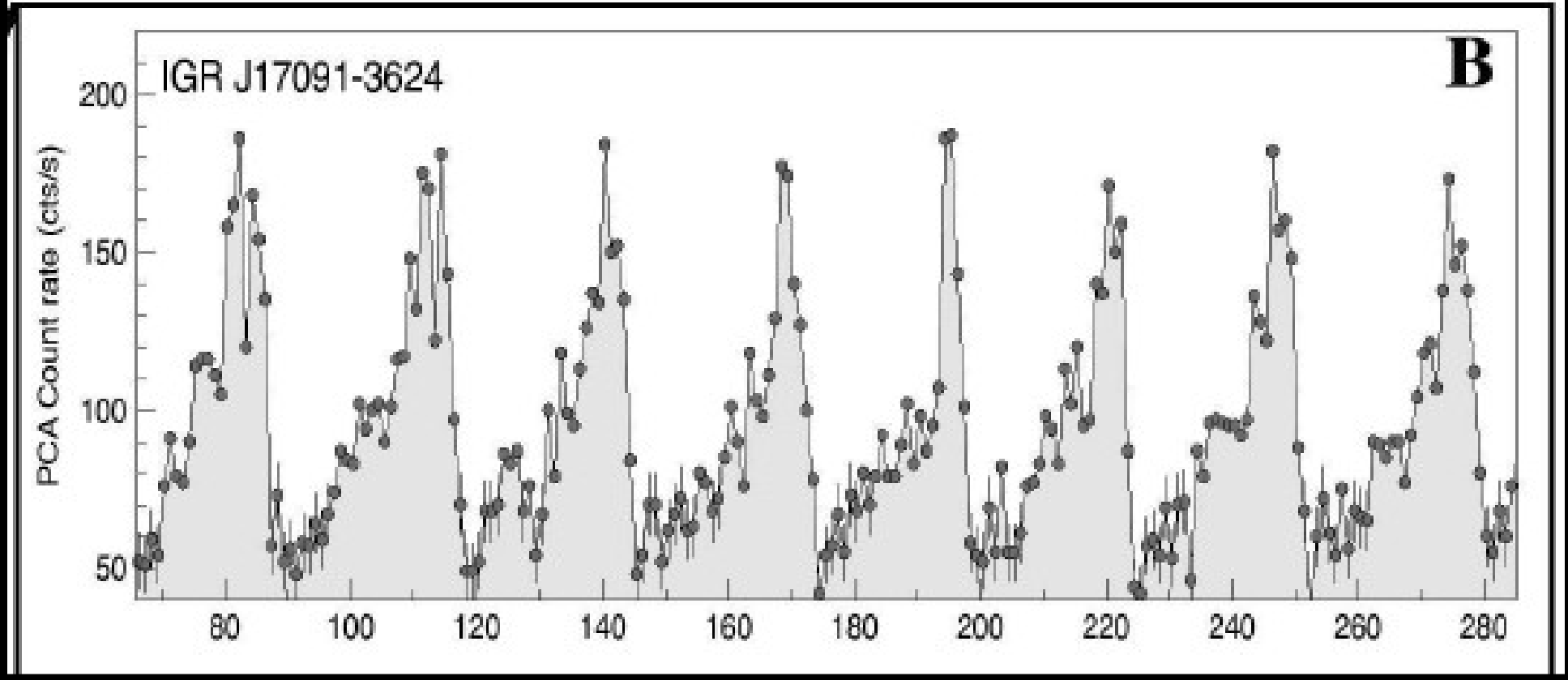
# Folding (or similar techniques)!

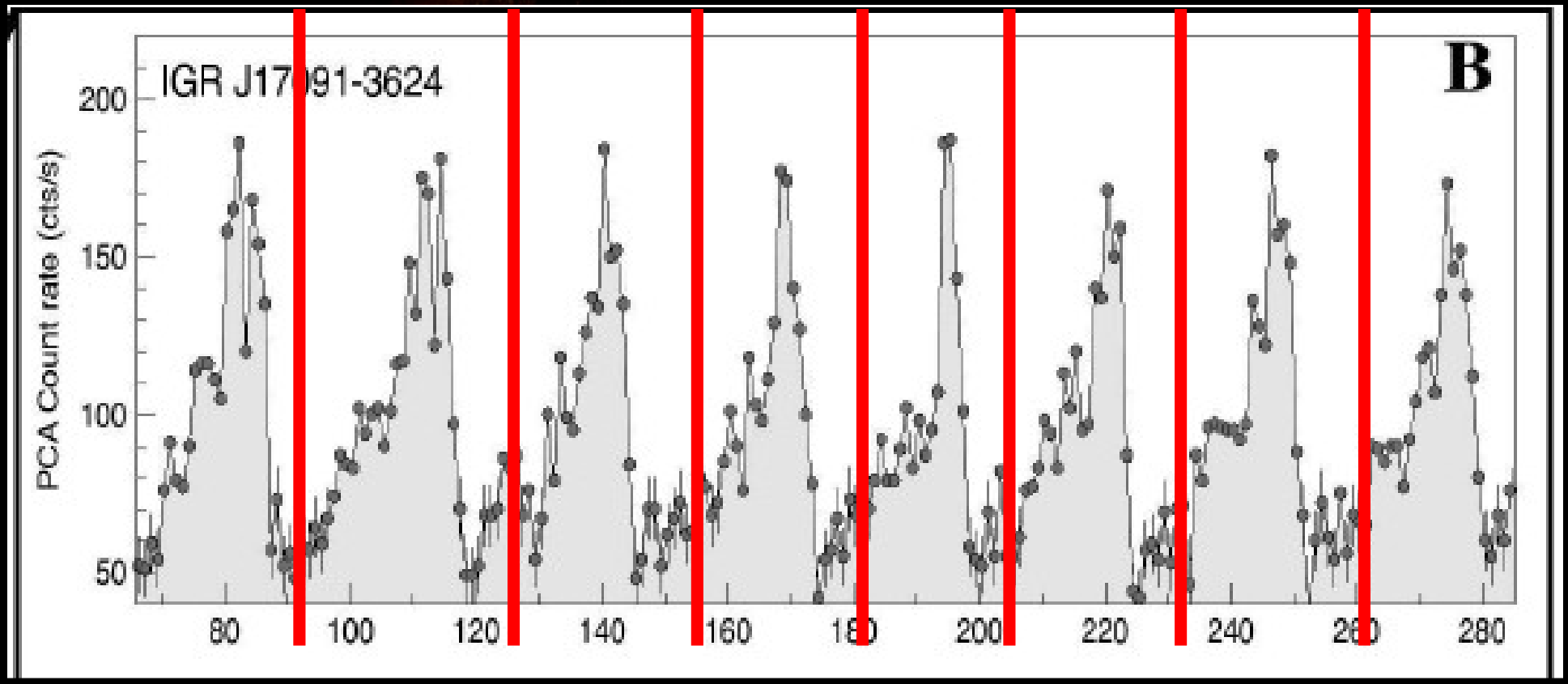


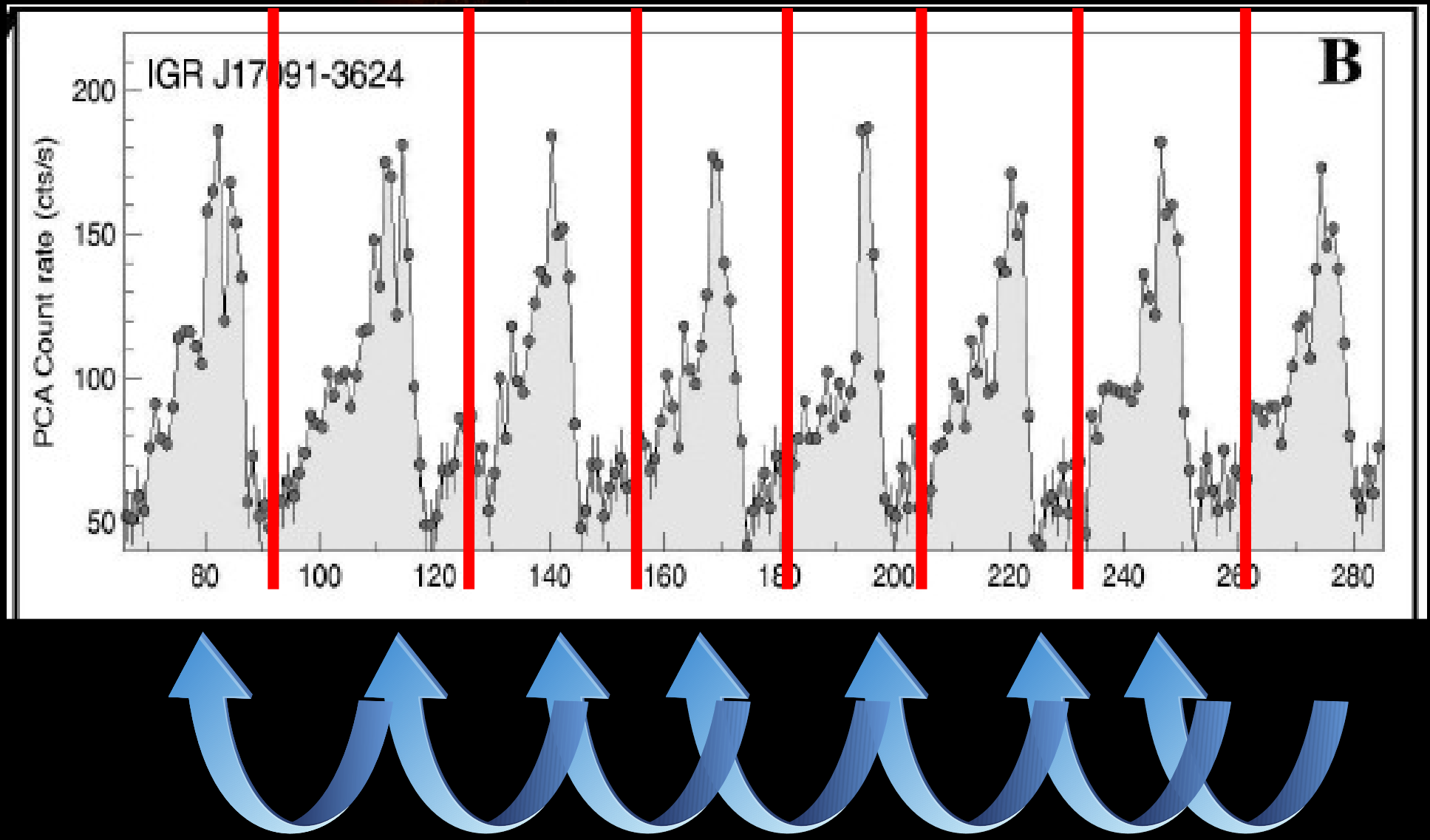



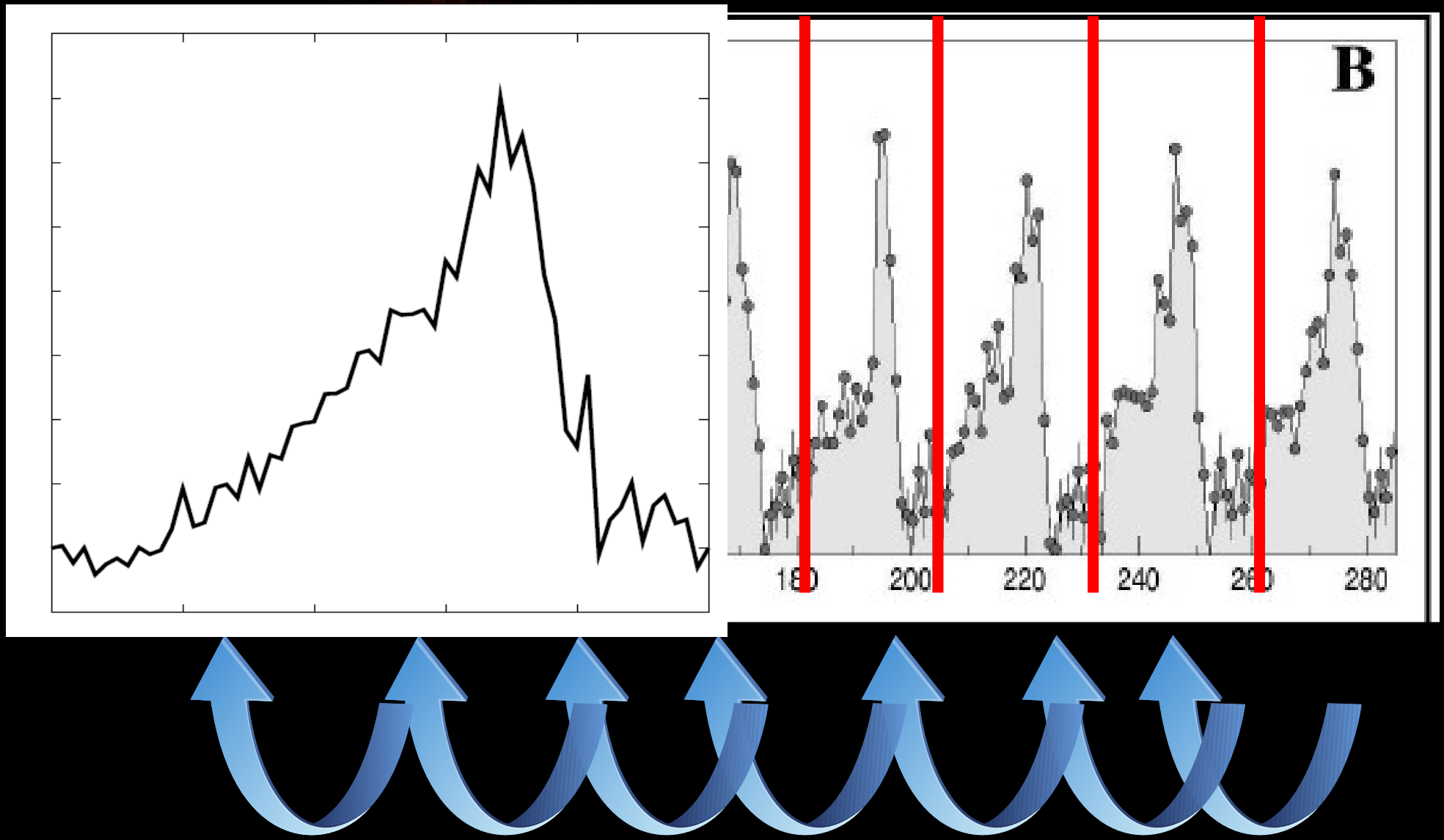



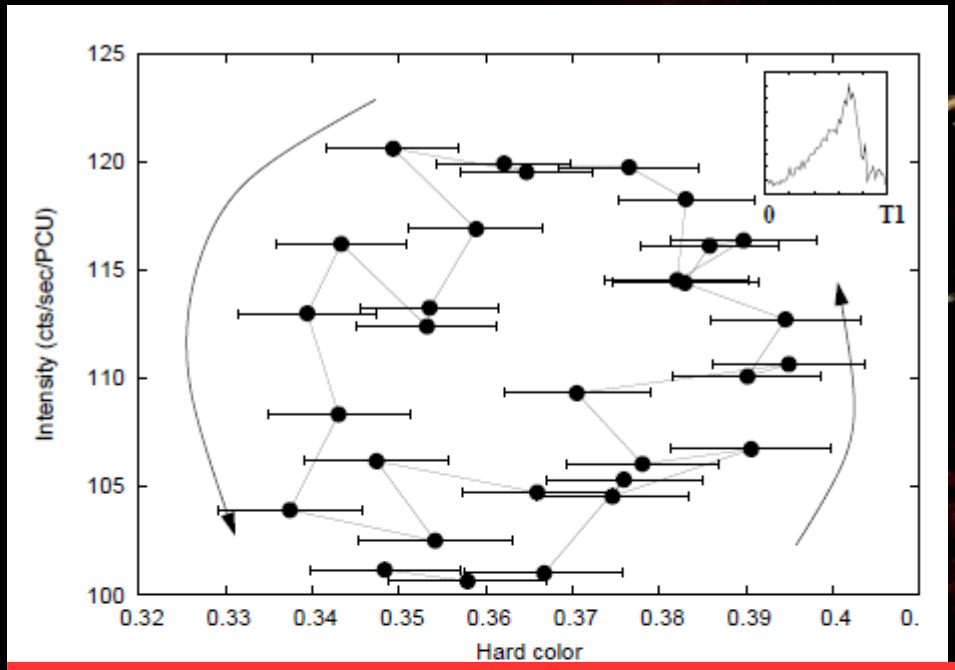

IGR J17091-3624
B
PCA Count rate (cts/s)
200
150
100
50
80
100
120
140
160
180
200
220
240
260
280

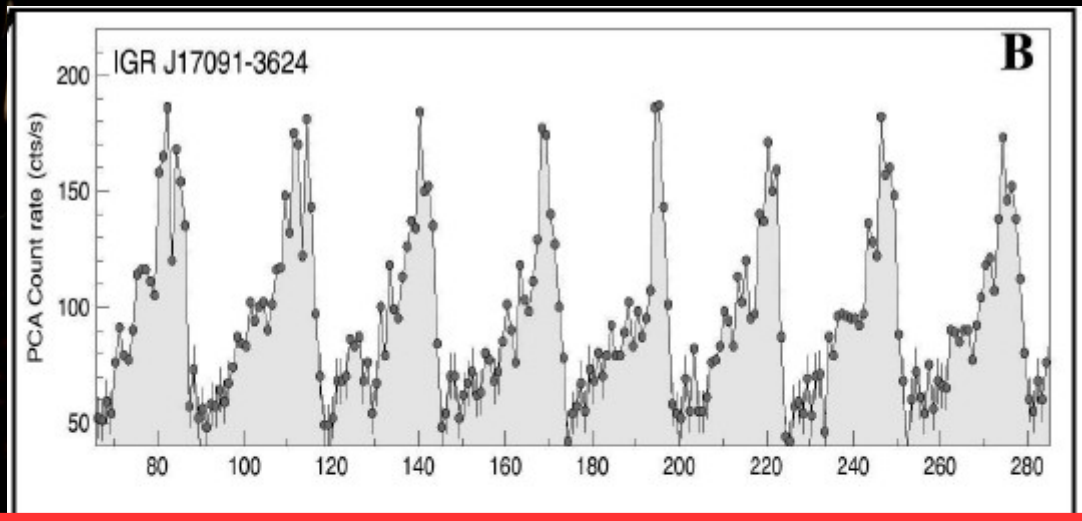

IGR J17091-3624
B
PCA Count rate (cts/s)
200
150
100
50
80
100
120
140
160
180
200
220
240
260
280

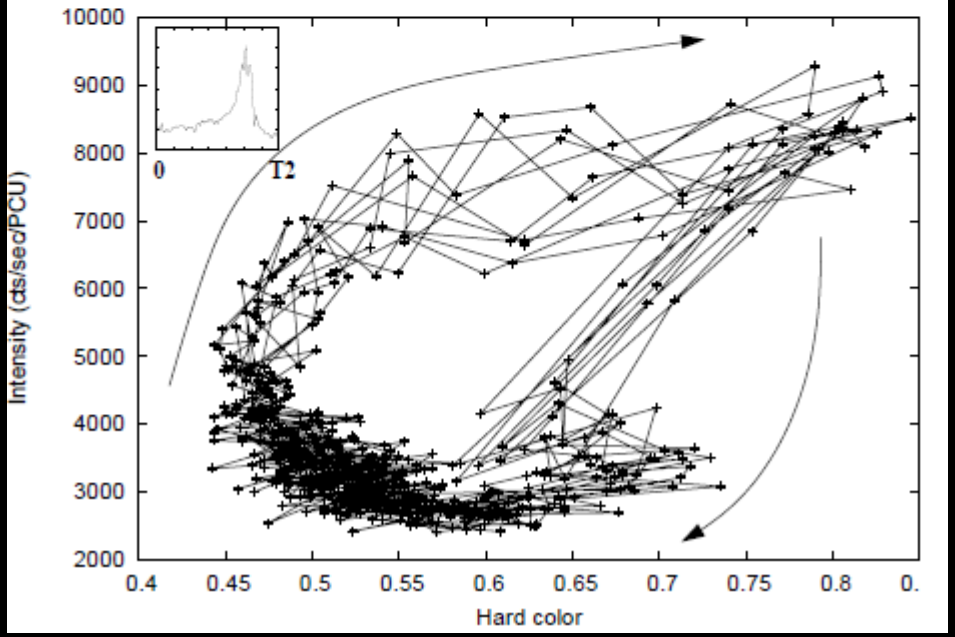

IGR J17091-3624
B
PCA Count rate (cts/s)
200
150
100
50
80
100
120
140
160
180
200
220
240
260
280

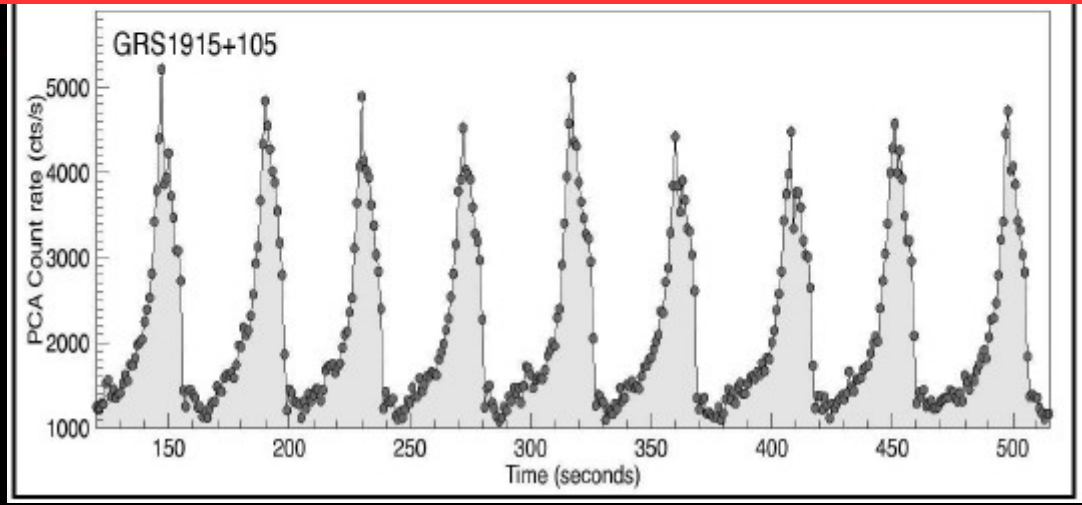

B
200
220
240
280

# Folding (or similar techniques)!



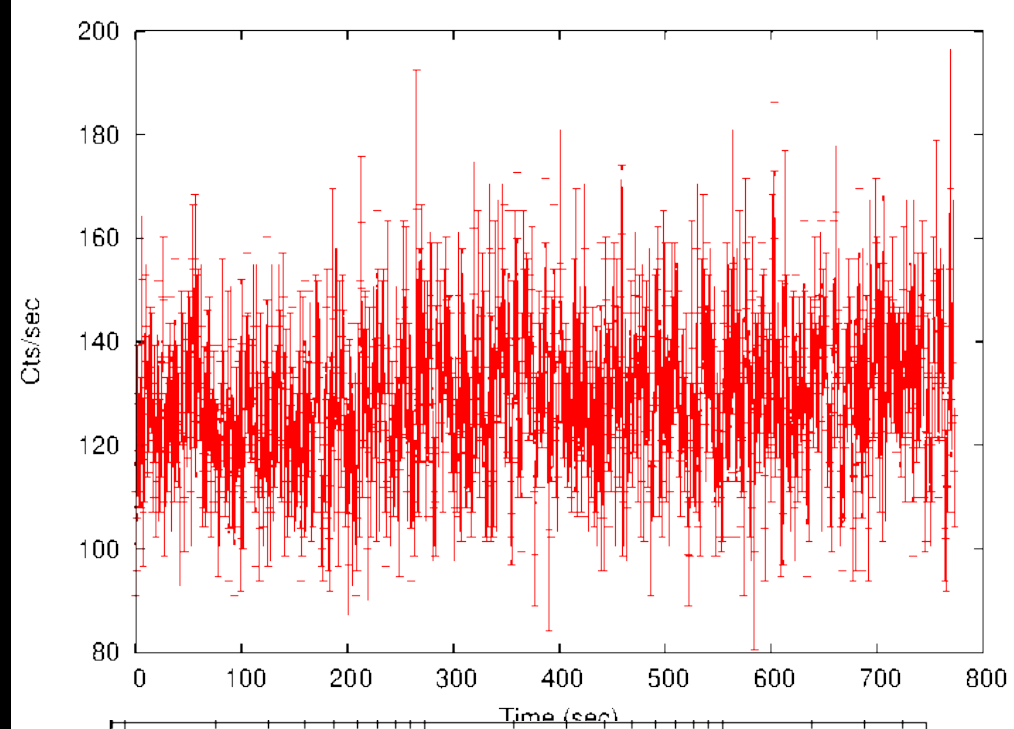
In many cases, we just can't do the selections by eye, or by using spectral colors....

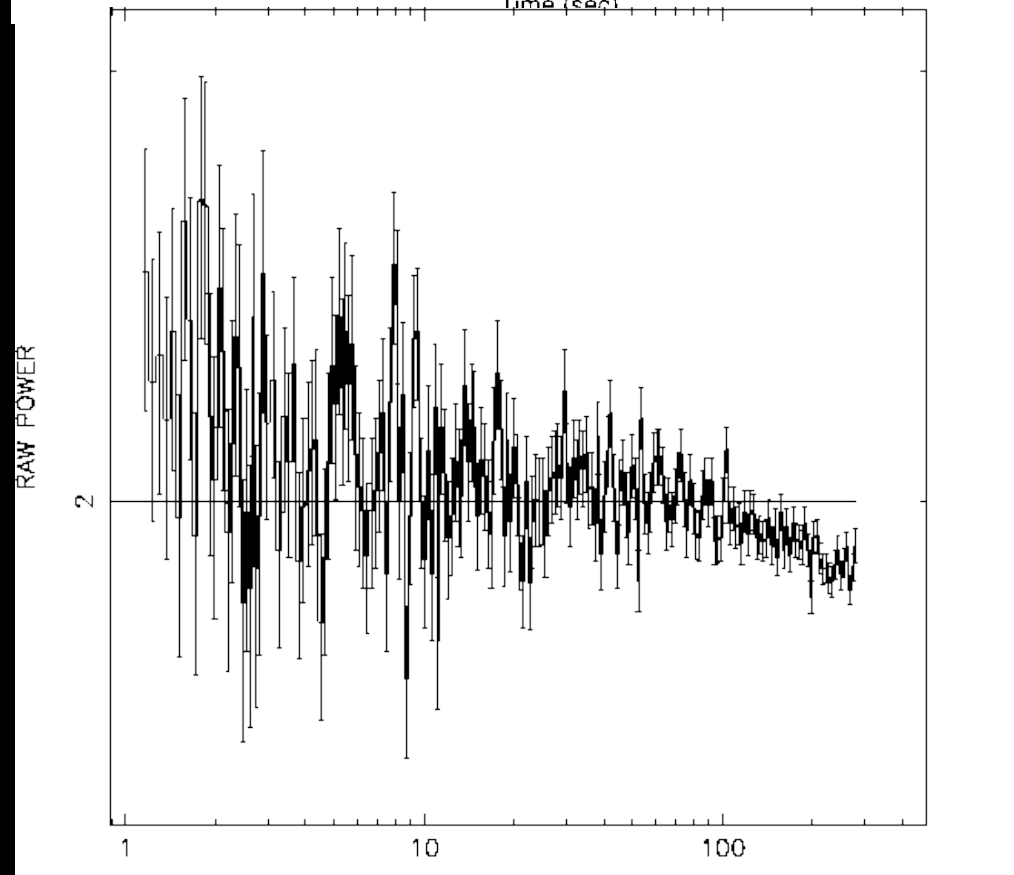
There can be much more variability than that you can see with the naked eye....

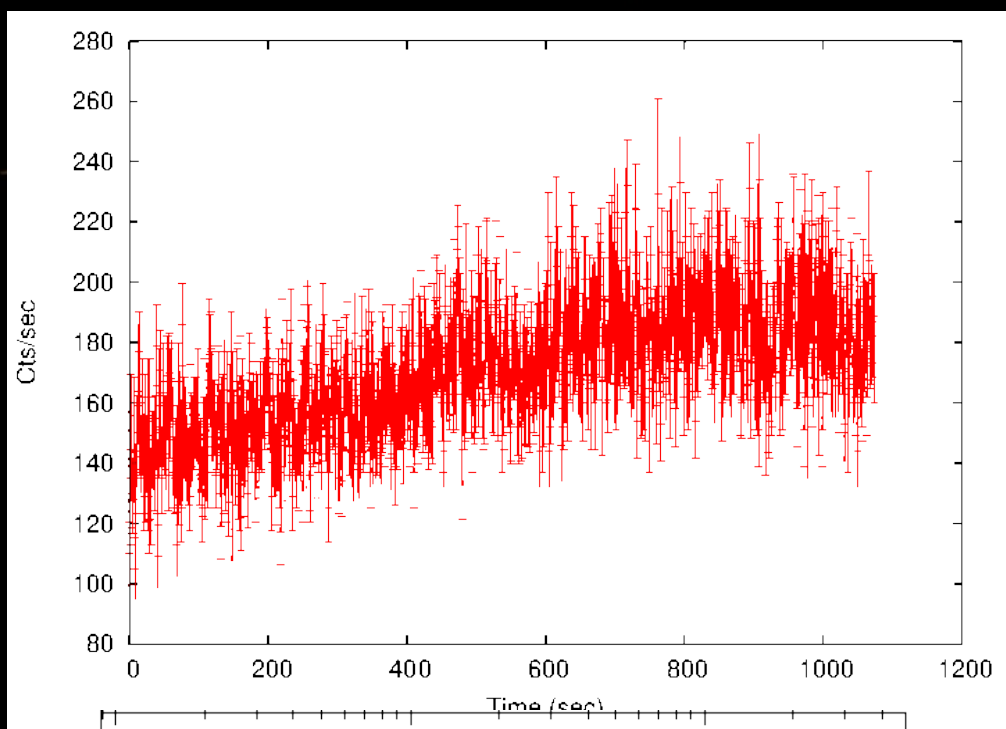
In many cases, we just can't do the selections by eye, or by using spectral colors....

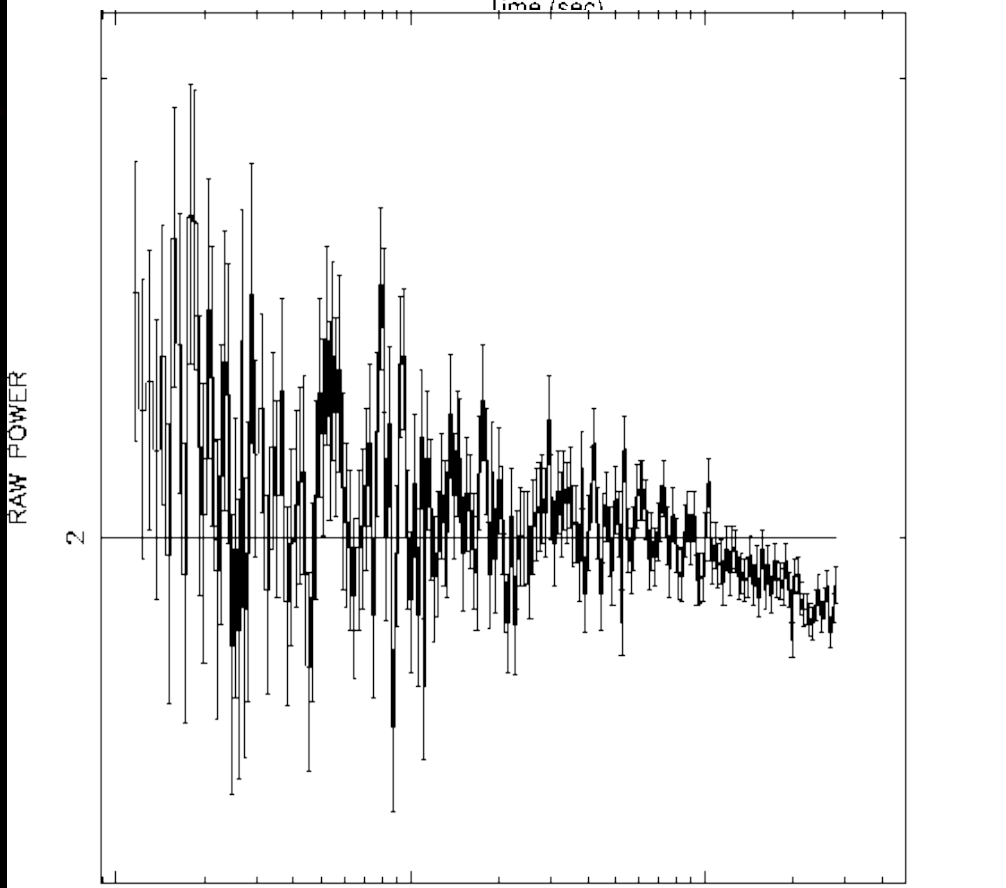
There can be much more variability than that you can see with the naked eye....

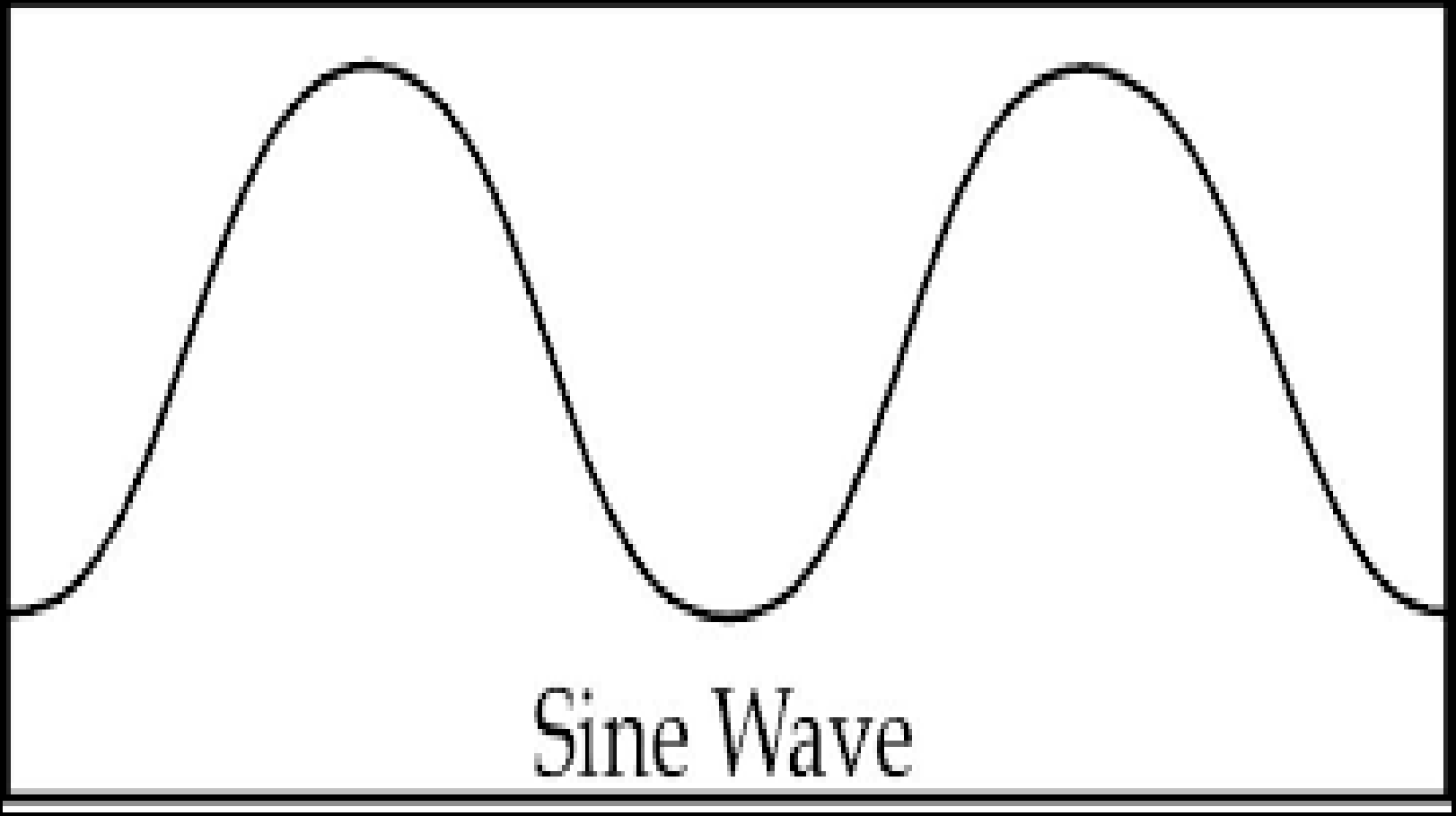
*Statistics some times kill us, but Sir Fourier comes to our help!*

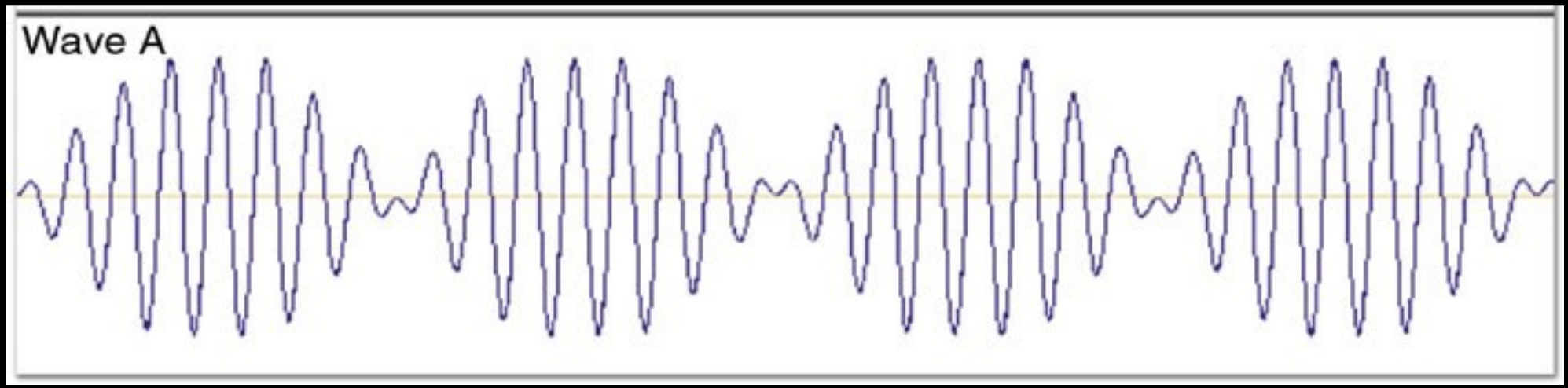

Cts/sec
Time (sec)

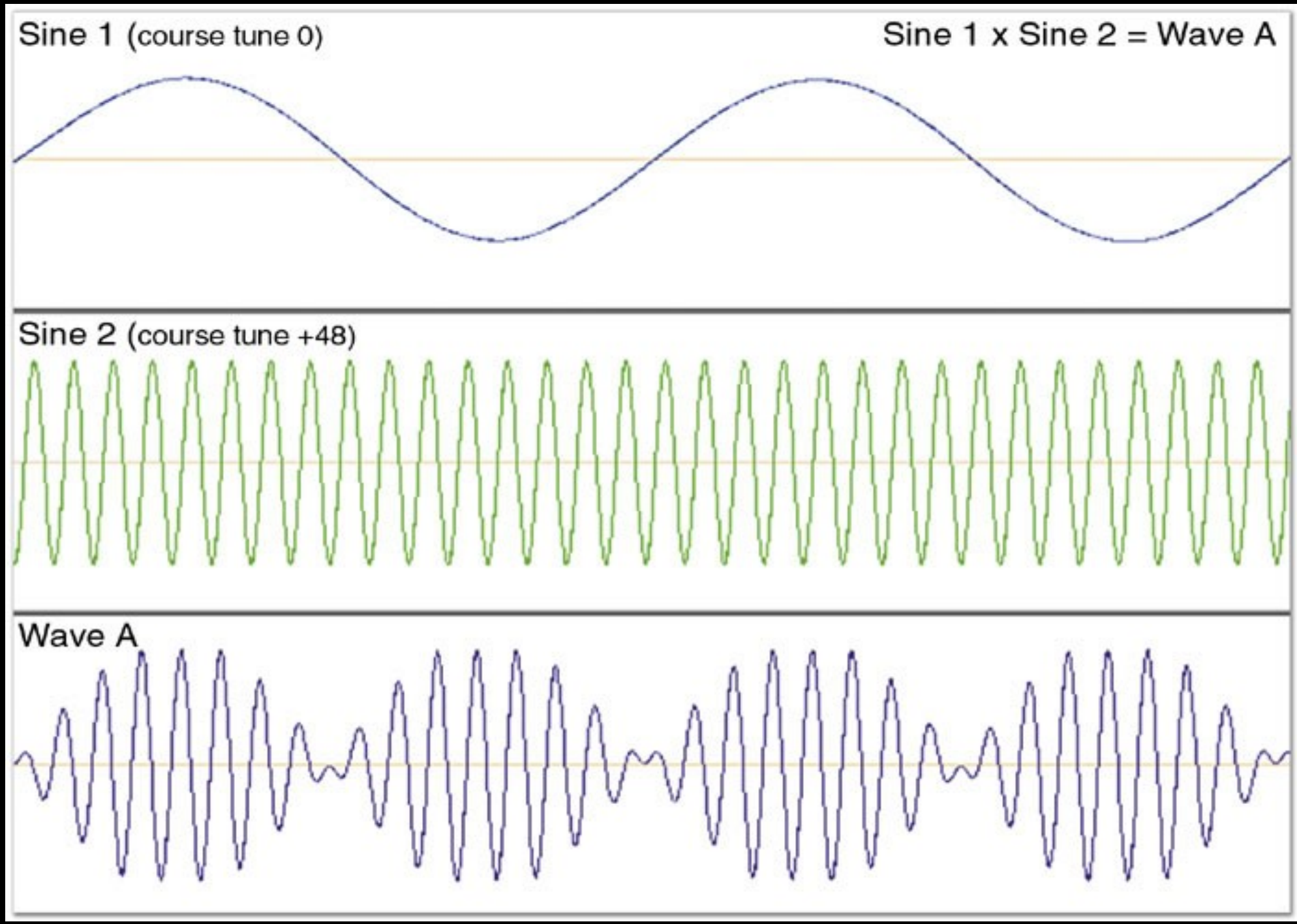

RAW POWER
2


Cts/sec
Time (sec)


RAW POWER
2


Sine Wave


Wave A


Sine 1 (course tune 0)
Sine 1 x Sine 2 = Wave A
Sine 2 (course tune +48)
Wave A

# The Fourier Transform .com

$$\mathcal{F}\{g(t)\} = G(f) = \int_{-\infty}^{\infty} g(t)e^{-i2\pi ft}\,dt$$

$$\mathcal{F}^{-1}\{G(f)\} = g(t) = \int_{-\infty}^{\infty} G(f)e^{i2\pi ft}\,df$$

http://www.thefouriertransform.com/

# Any function can be written as a sum of complex exponentials

$$f(t_j) = \frac{1}{N} \sum_{k=1}^{N} a_k \exp\left(2\pi i j k / N\right)$$

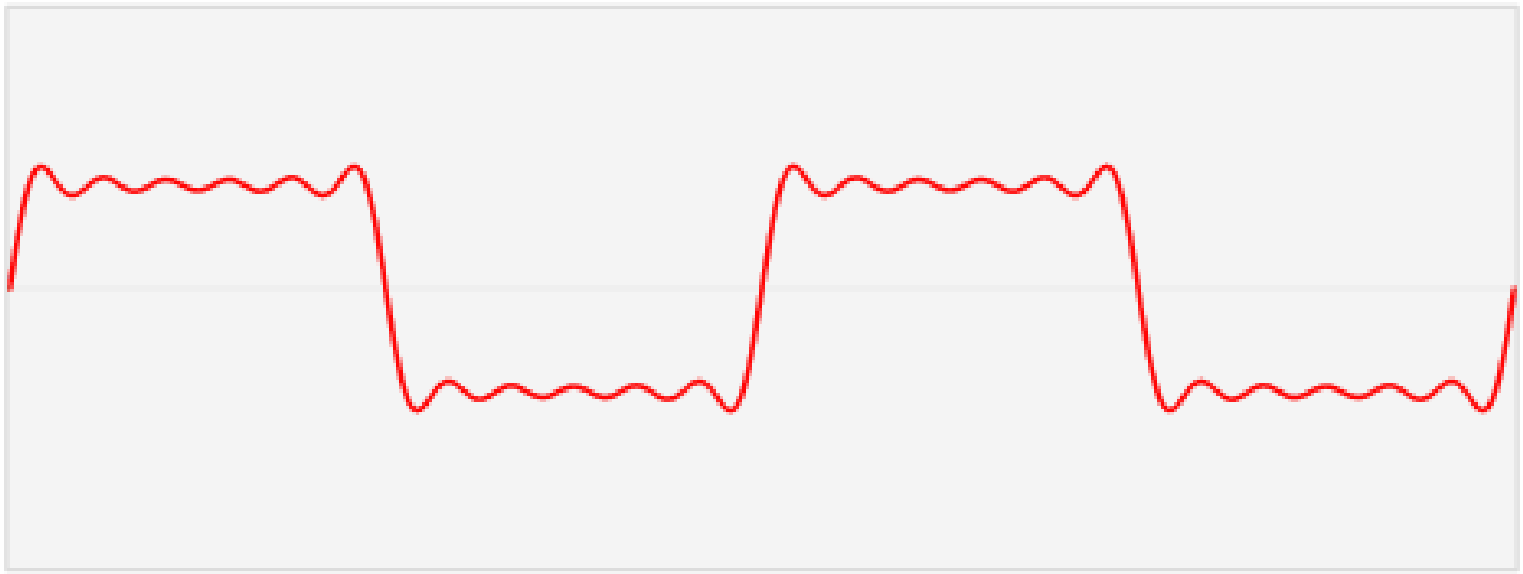
FFT

Fourier coefficients
(or amplitudes)

Once we know the Fourier coefficients, we have divided the time series into its *different frequency components*, and have entered the frequency “domain.”

https://www.youtube.com/watch?v=SpzNQOOBeRg

http://commons.wikimedia.org/wiki/File:Fourier_transform_time_and_frequency_domains.gif



Any function can be written as a sum of complex exponentials

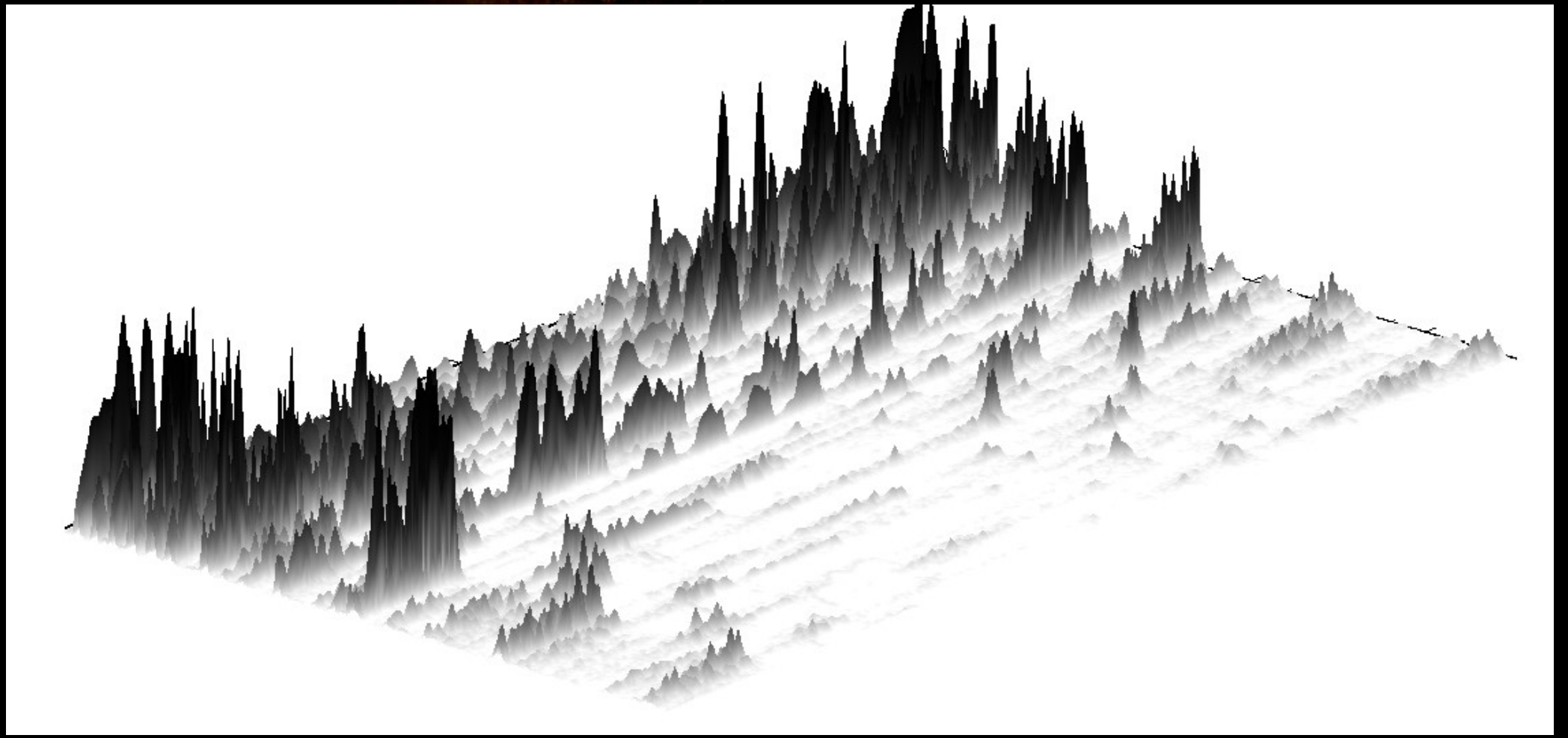
$$f(t_j) = \frac{1}{N} \sum_{k=1}^{N} a_k \exp\left(2\pi i j k / N\right)$$

Fourier coefficients (or amplitudes)

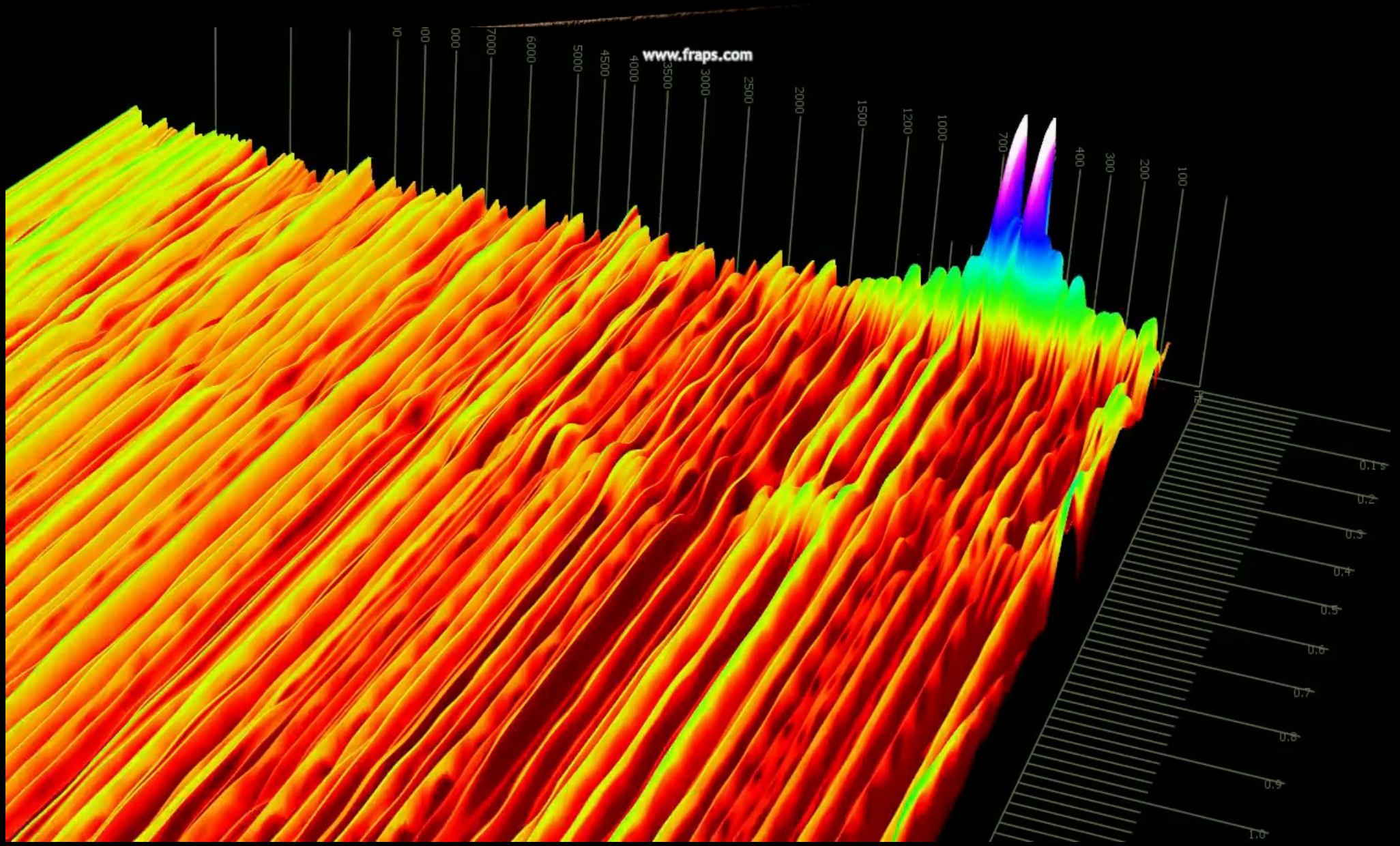
Fourier Powers

$$|a_k|^2$$

***The set of all Fourier powers is the Power Spectrum***



https://www.youtube.com/watch?v=vvr9AMWEU-c



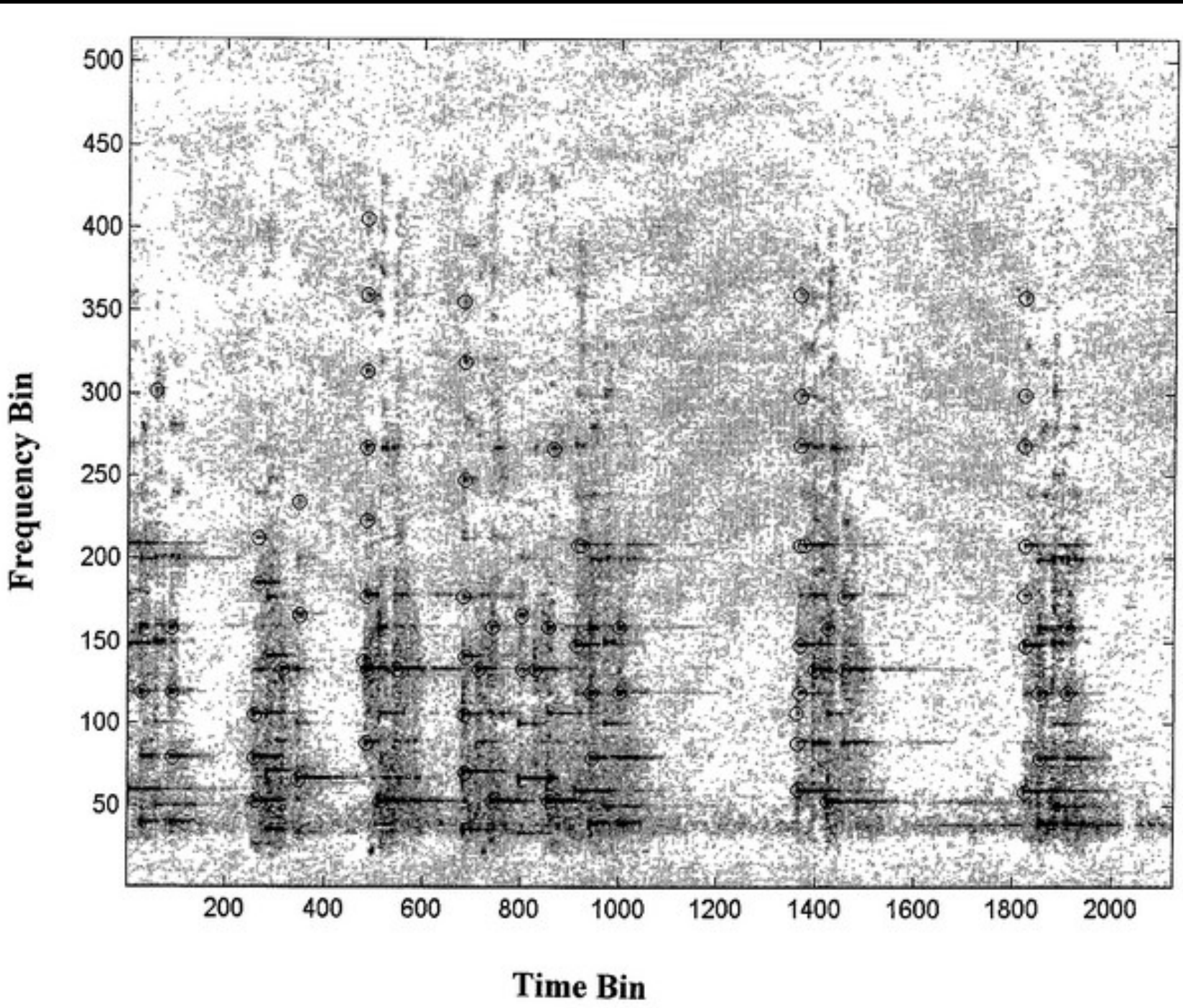

# System and methods for recognizing sound and music signals in high noise and distortion

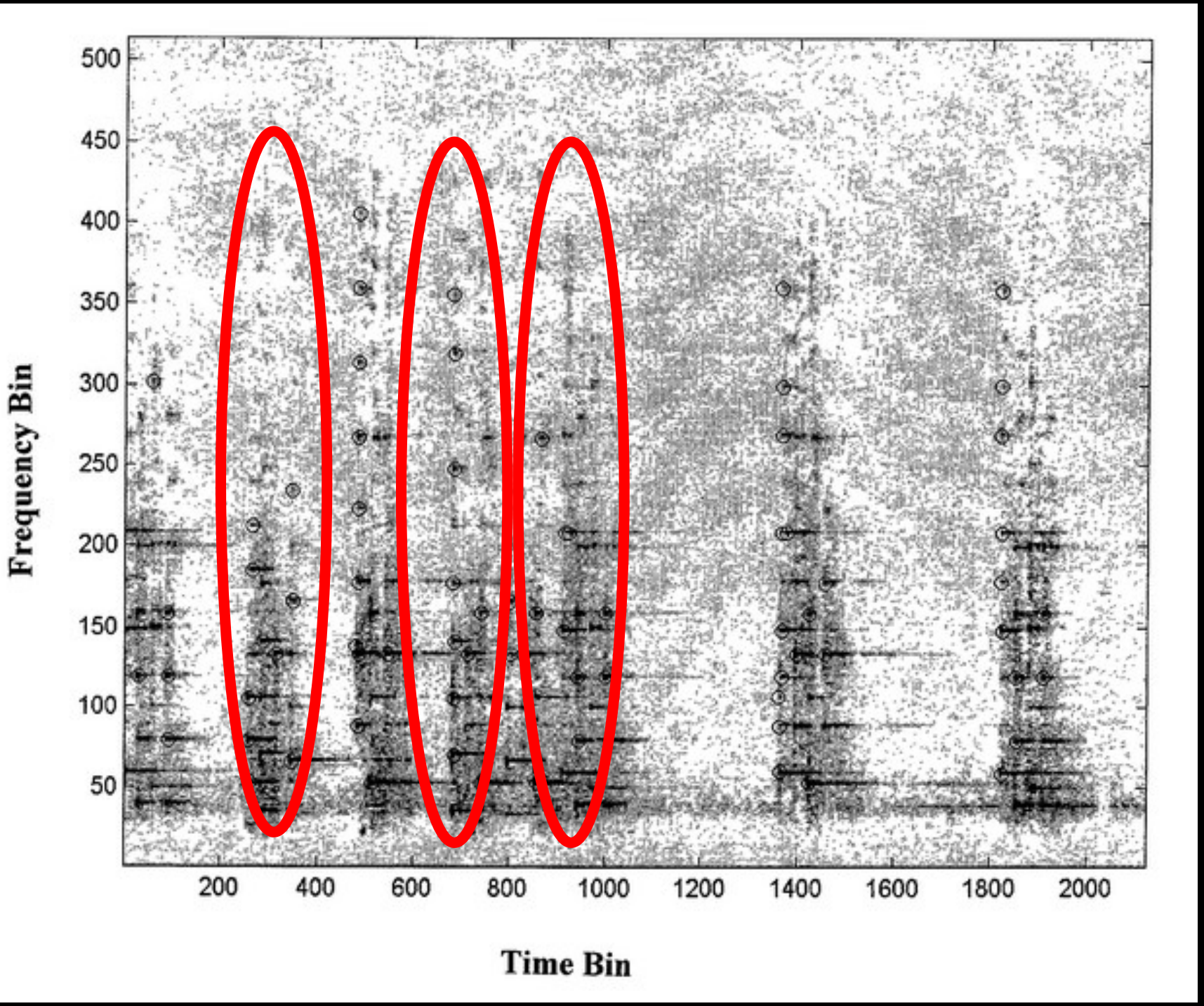
US 6990453 B2

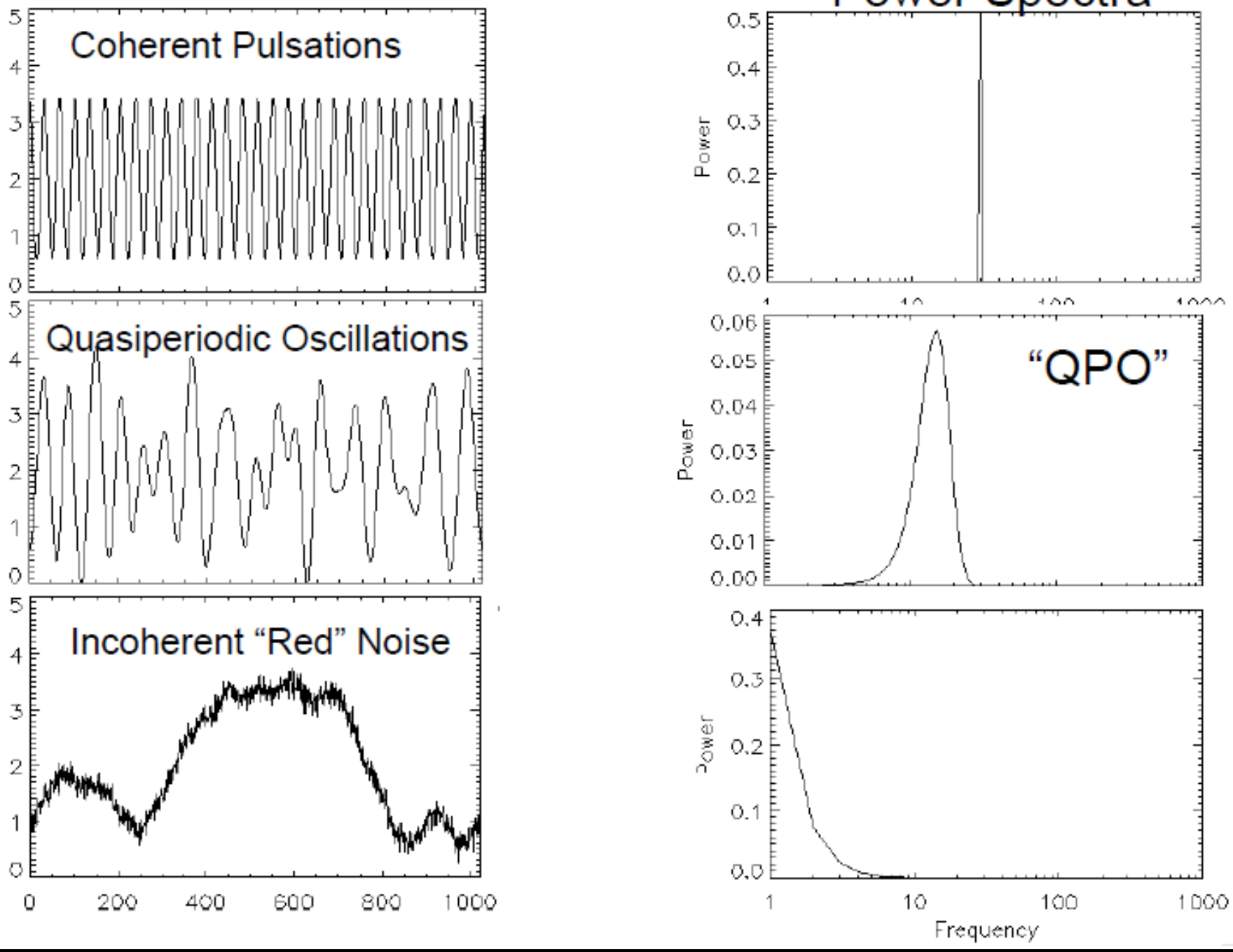
## ABSTRACT

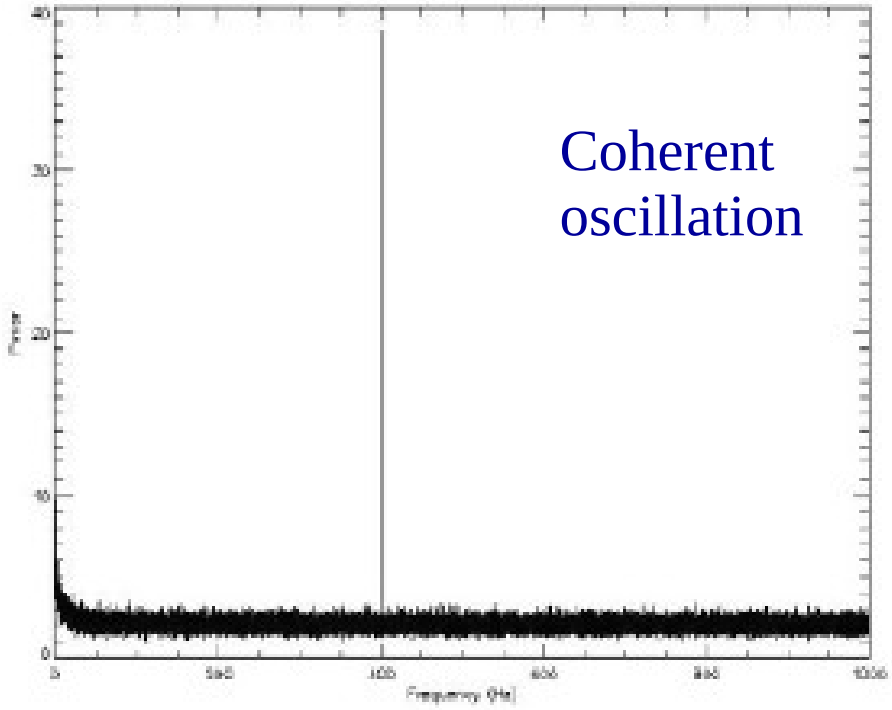
A method for recognizing an audio sample locates an audio file that most closely matches the audio sample from a database indexing a large set of original recordings. Each indexed audio file is represented in the database index by a set


| | |
|---|---|
| **Publication number** | US6990453 B2 |
| **Publication type** | Grant |
| **Application number** | US 09/839,476 |
| **Publication date** | Jan 24, 2006 |
| **Filing date** | Apr 20, 2001 |
| **Priority date** ⓘ | Jul 31, 2000 |
| **Fee status** ⓘ | Paid |
| **Also published as** | CN1592906A, 18 More » |
| **Inventors** | Avery Li-Chun Wang, Julius O. Smith, III |

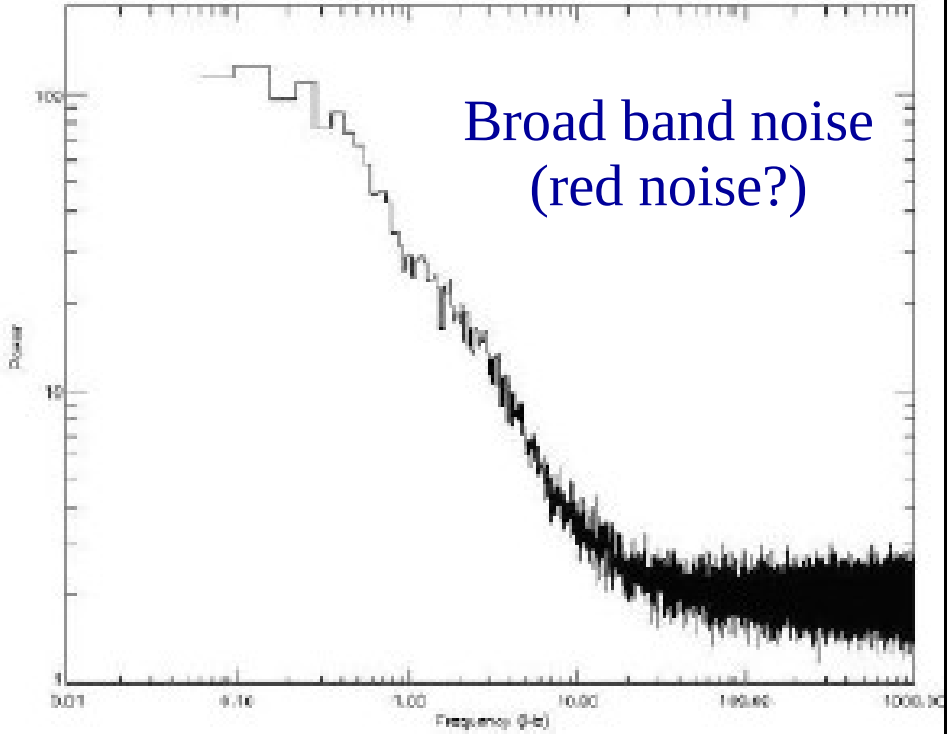

Frequency Bin
500
450
400
350
300
250
200
150
100
50
200
400
600
800
1000
1200
1400
1600
1800
2000
Time Bin


Frequency Bin
500
450
400
350
300
250
200
150
100
50
200
400
600
800
1000
1200
1400
1600
1800
2000
Time Bin

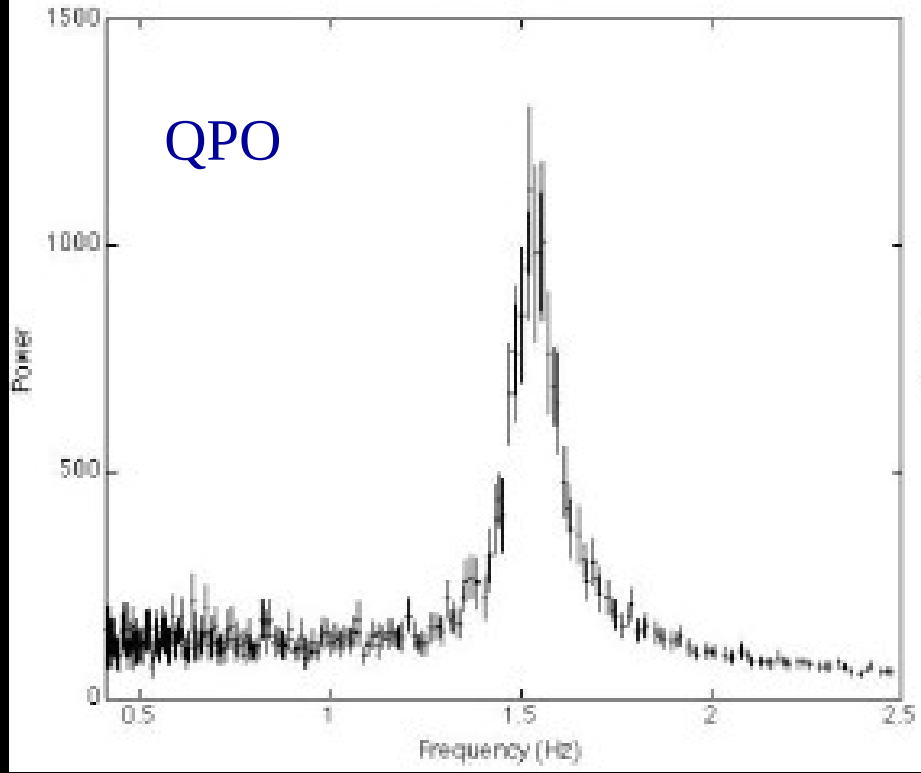

Coherent Pulsations
Quasiperiodic Oscillations
Incoherent "Red" Noise
Power Spectra
"QPO"
Power
Frequency
0
200
400
600
800
1000
1
10
100
1000



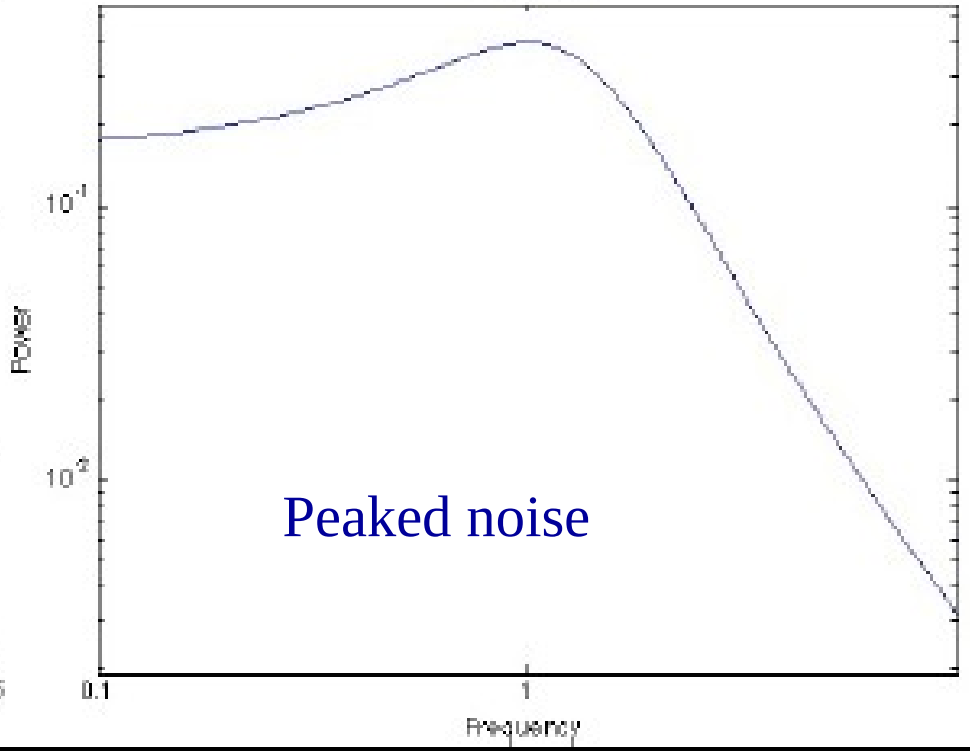
Coherent oscillation



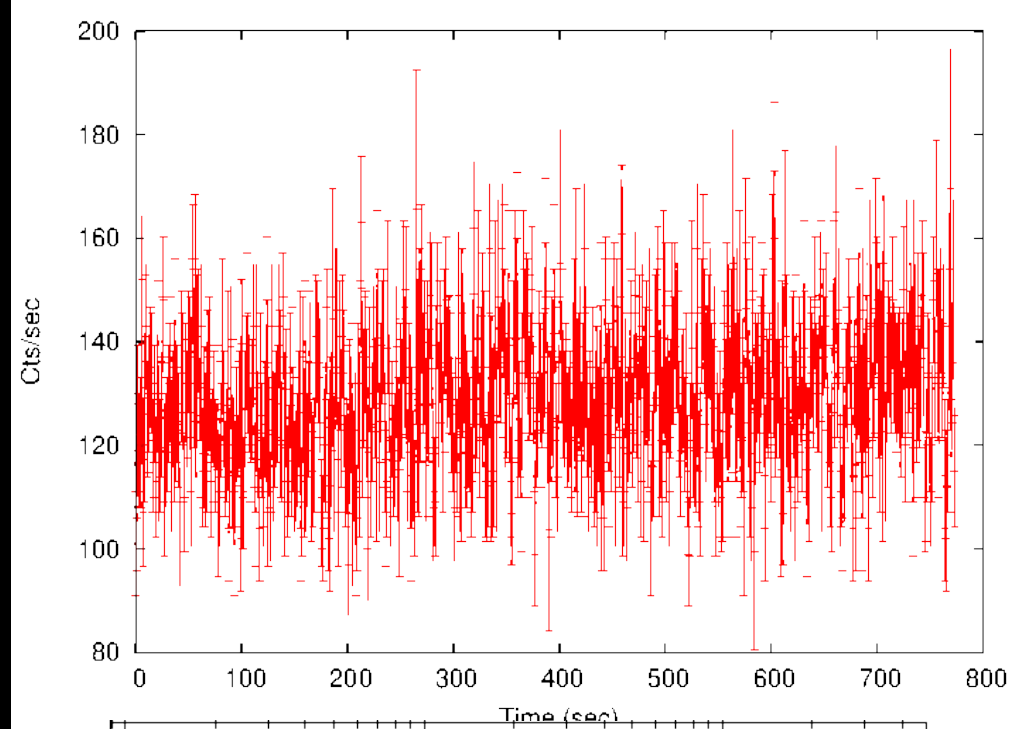
Broad band noise (red noise?)

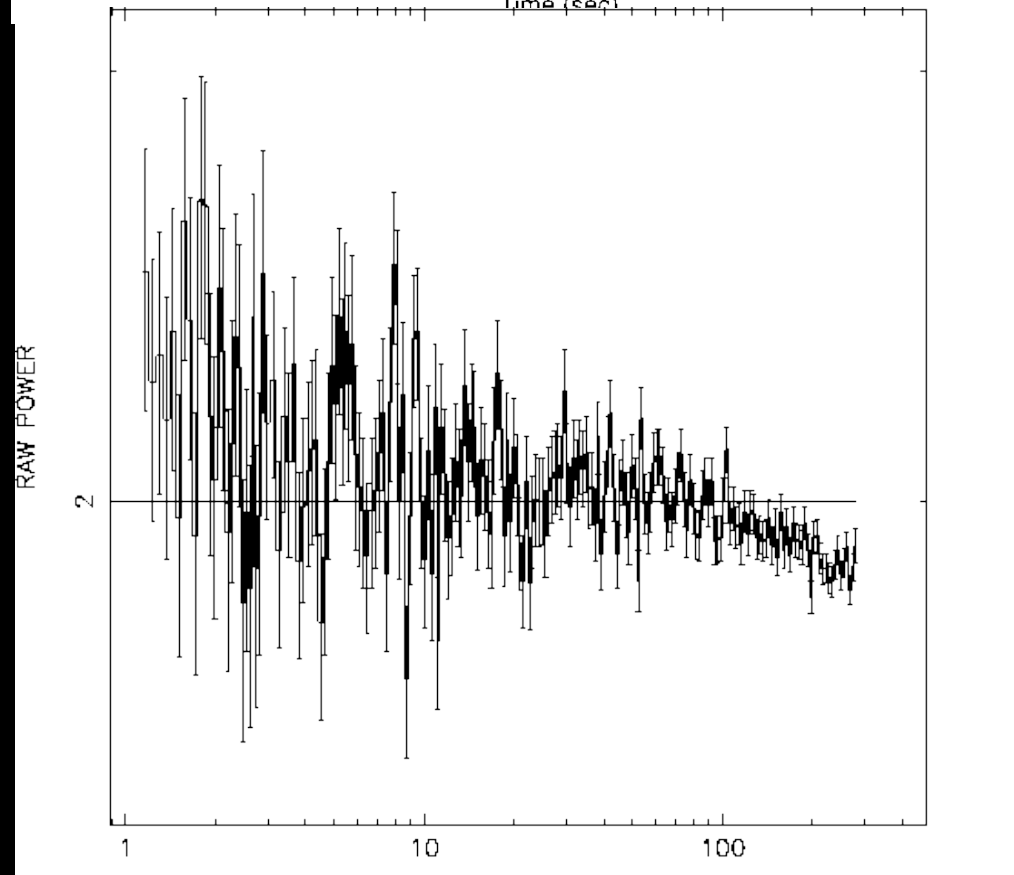


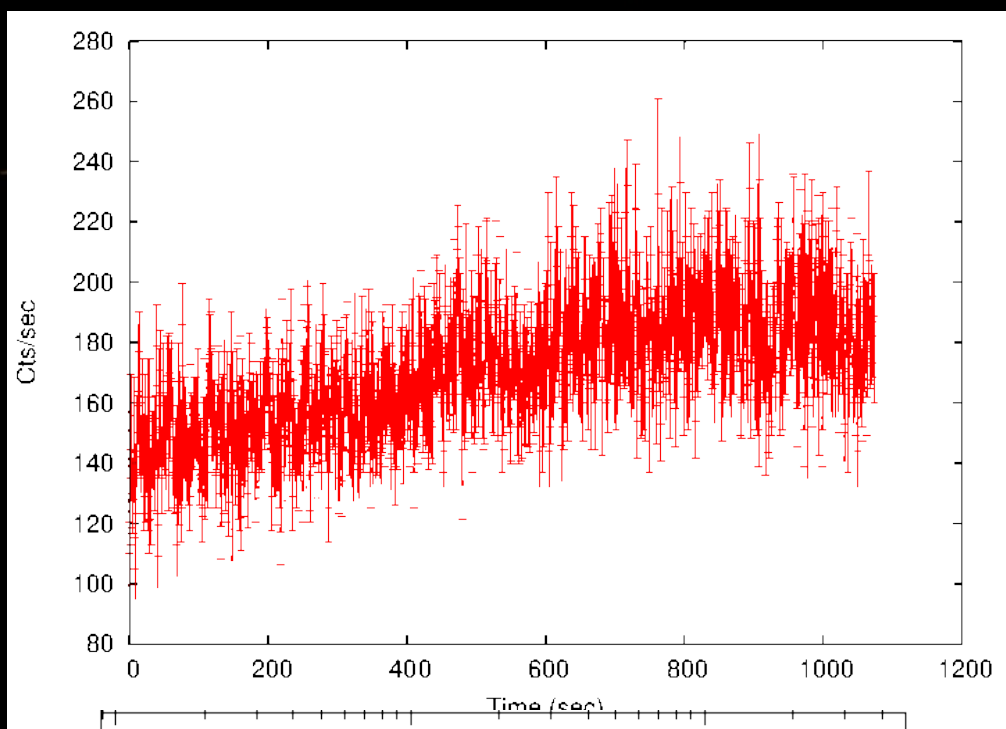

QPO

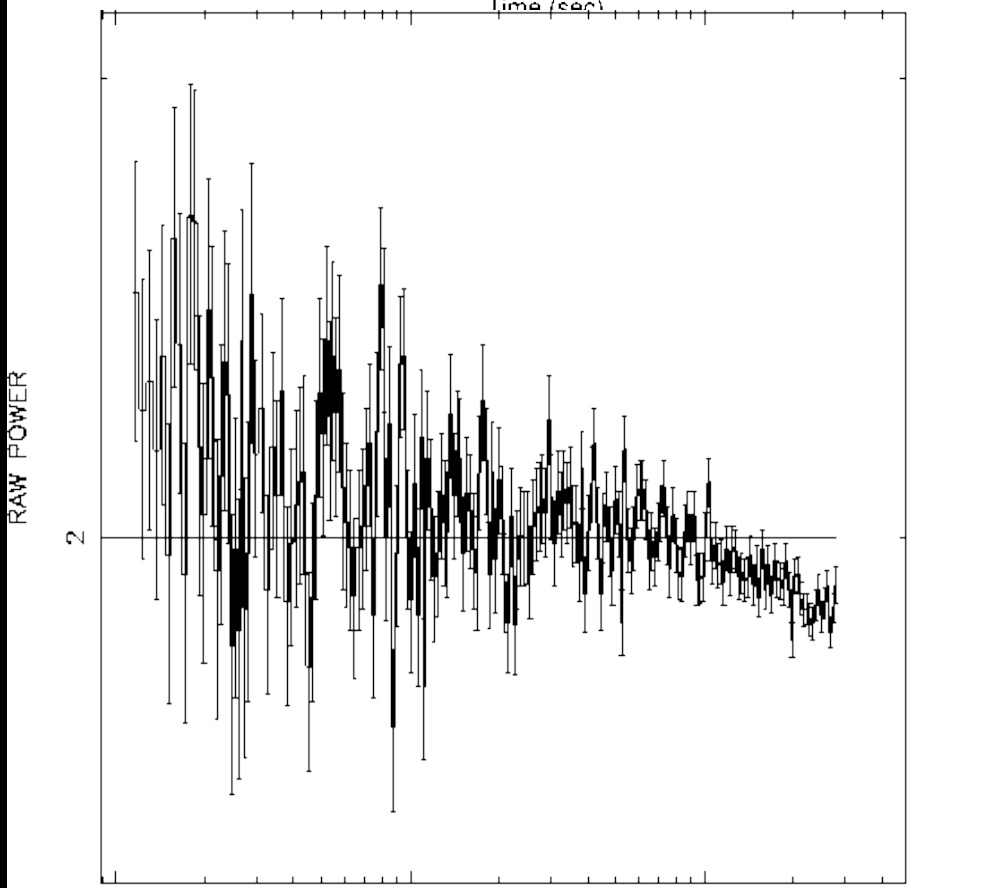


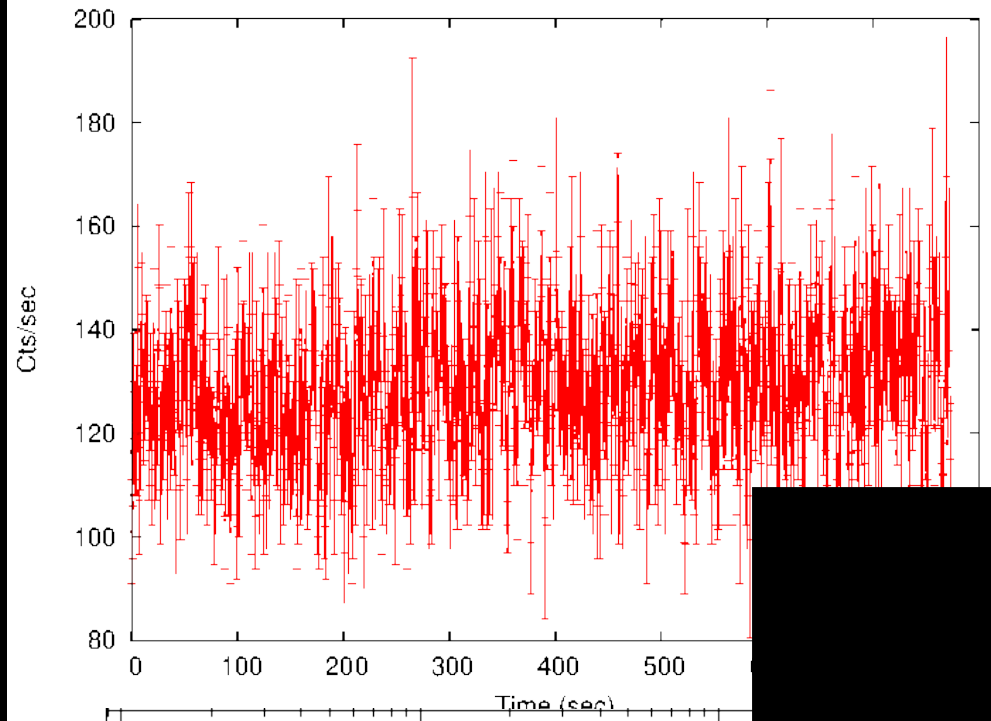

Peaked noise

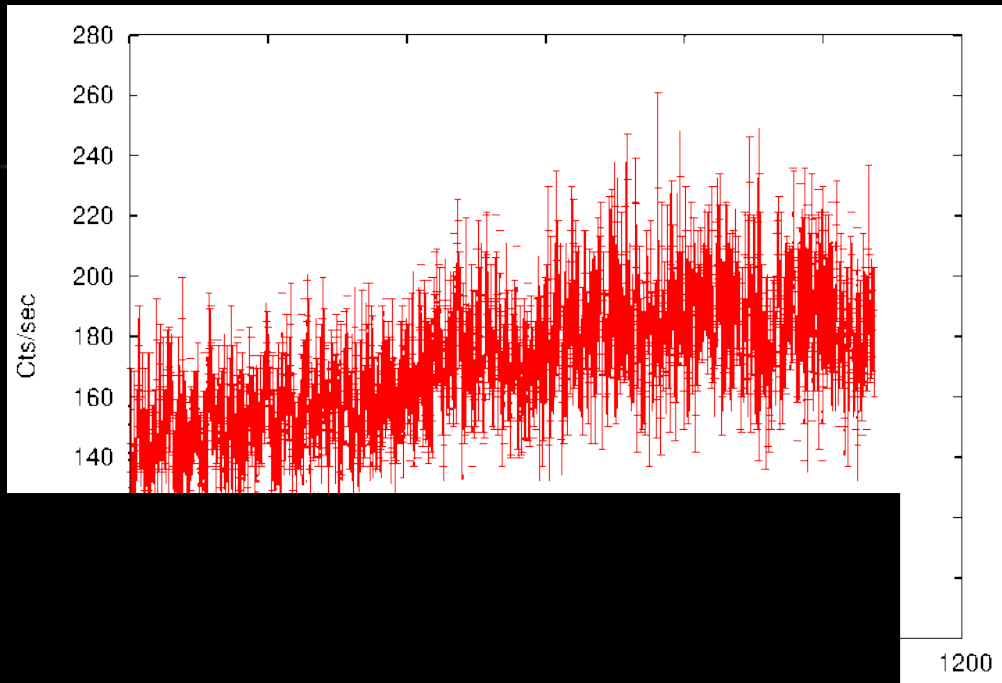

Cts/sec
Time (sec)


RAW POWER
2

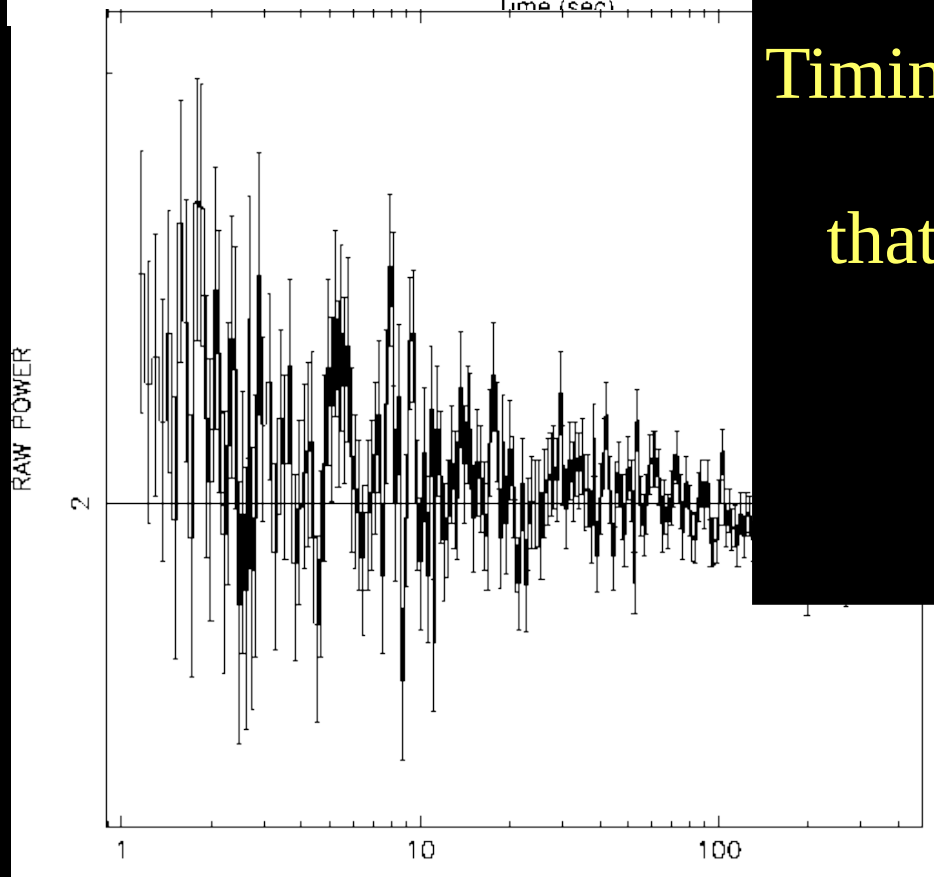

Cts/sec
Time (sec)


RAW POWER
2




Timing analysis may seem like “magic,” since it can reveal features that are not apparent to the eye in the raw data

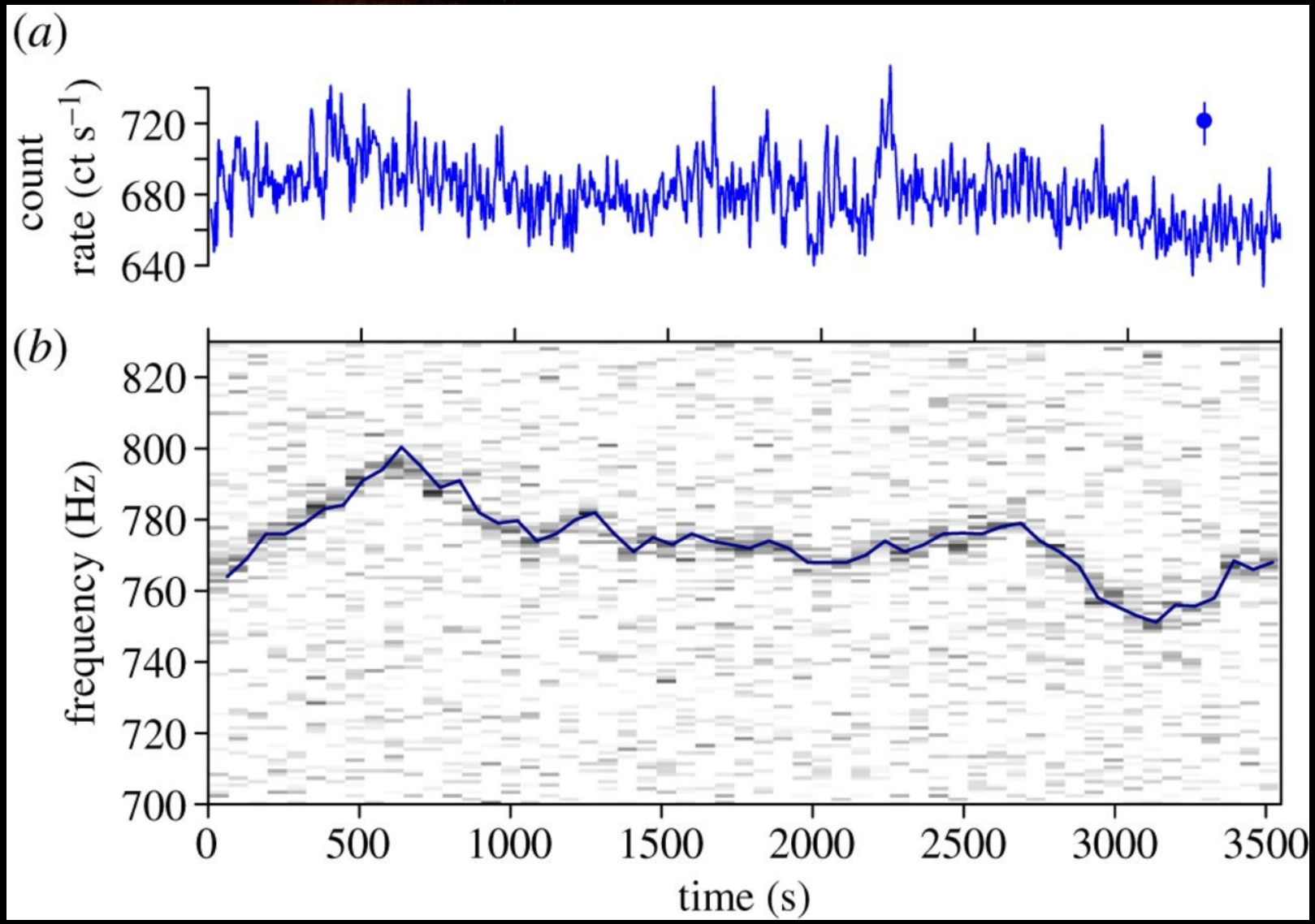


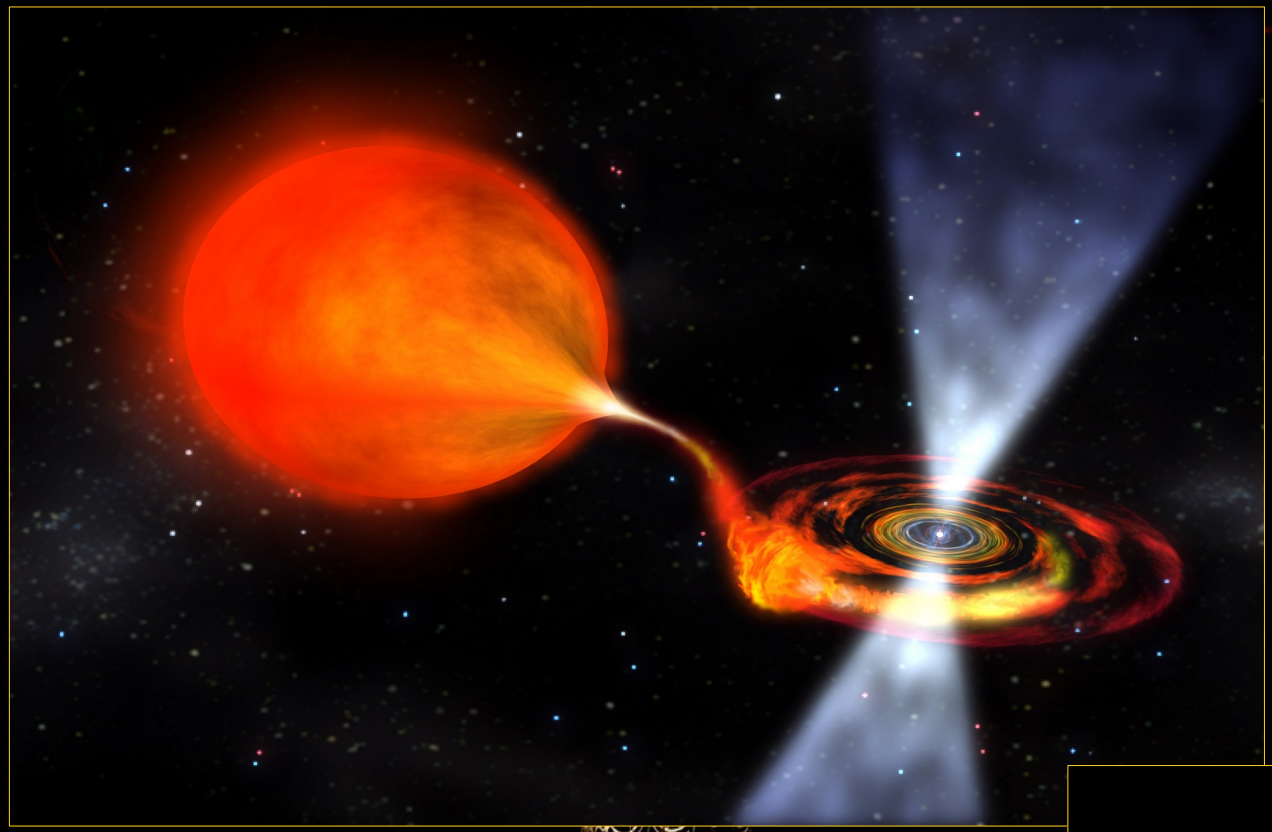
# Number of Trials to First Success

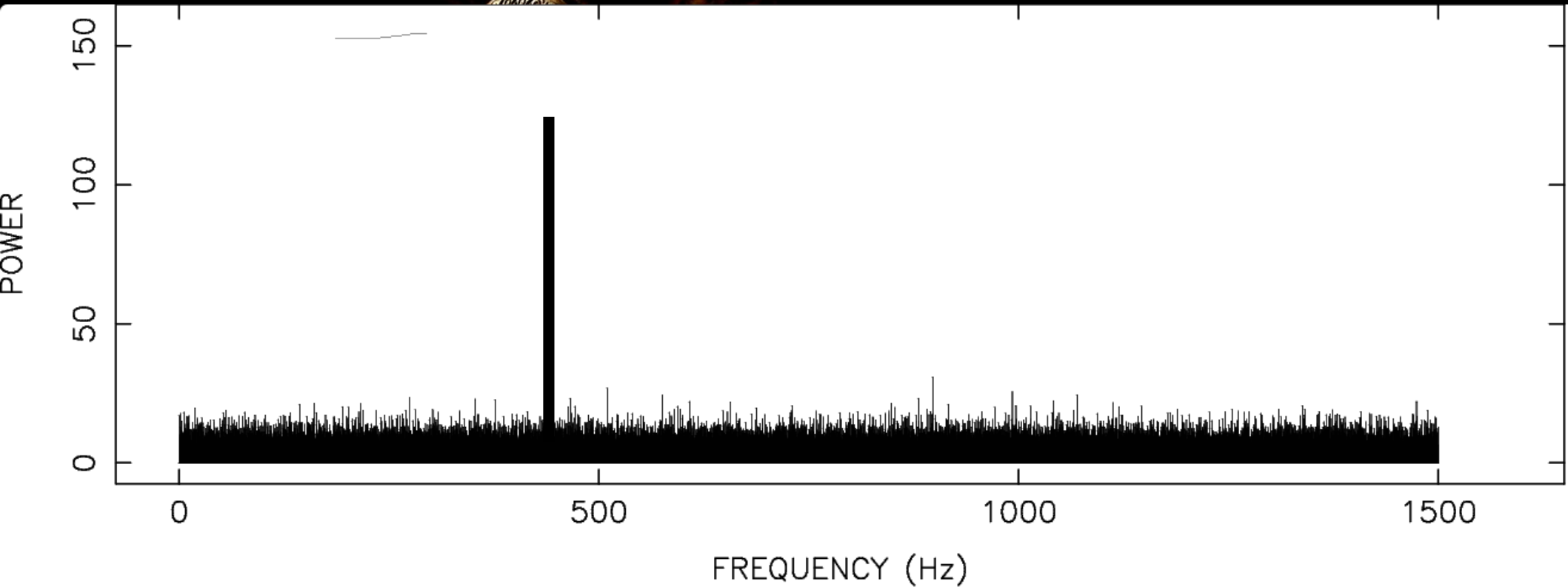
Informally, the probability of an event is the average number of times the event occurs in a sequence of trials. Another way of looking at that is to ask for an average number of trials before the first occurrence of the event. This could be formalized in terms of mathematical expectation.

(http://www.cut-the-knot.org/)

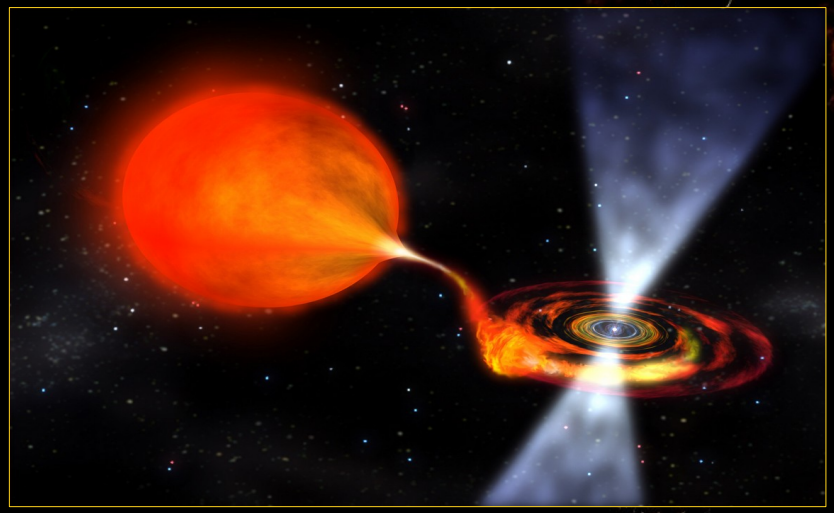
# *Dynamical Power spectrum*

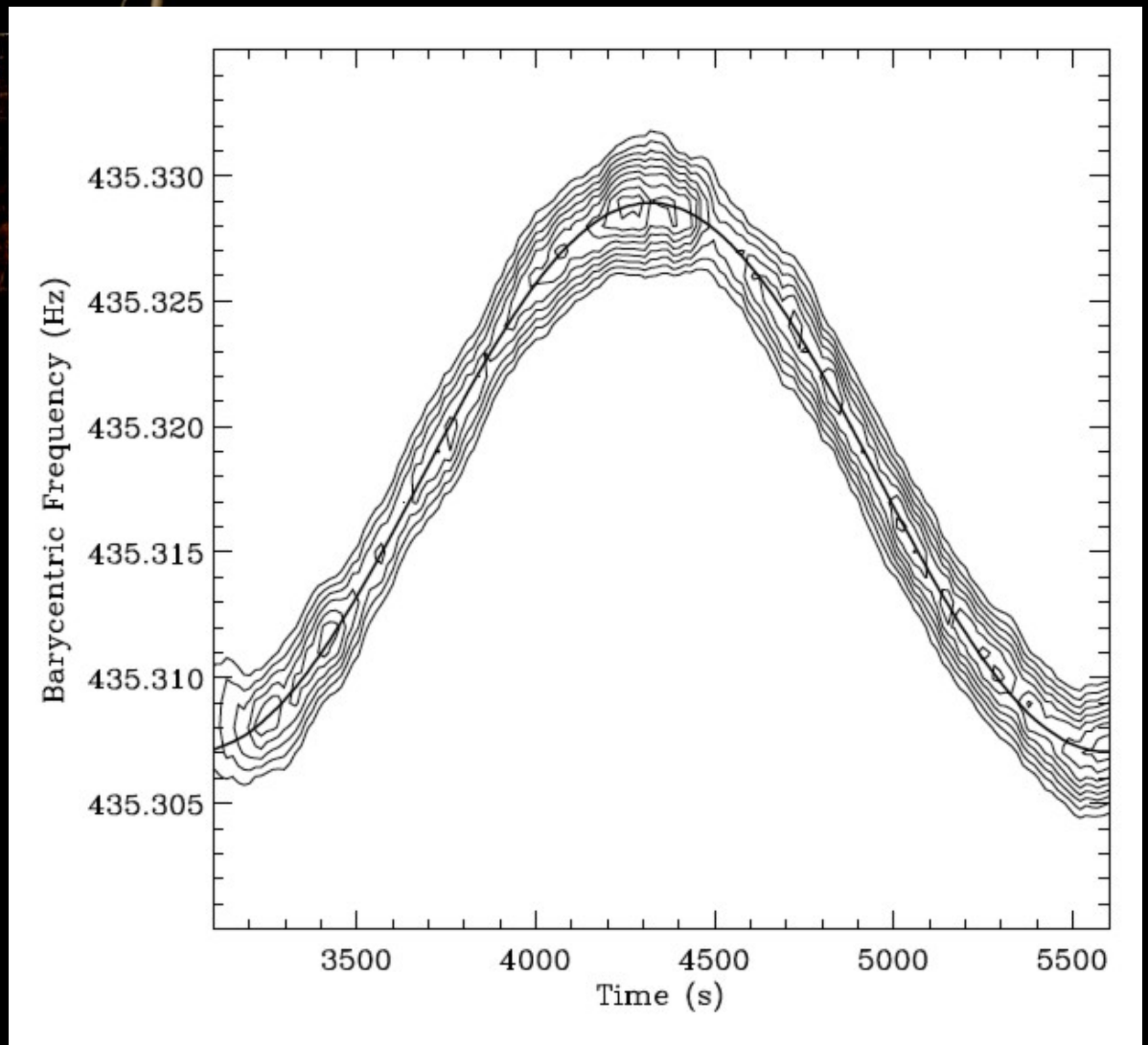




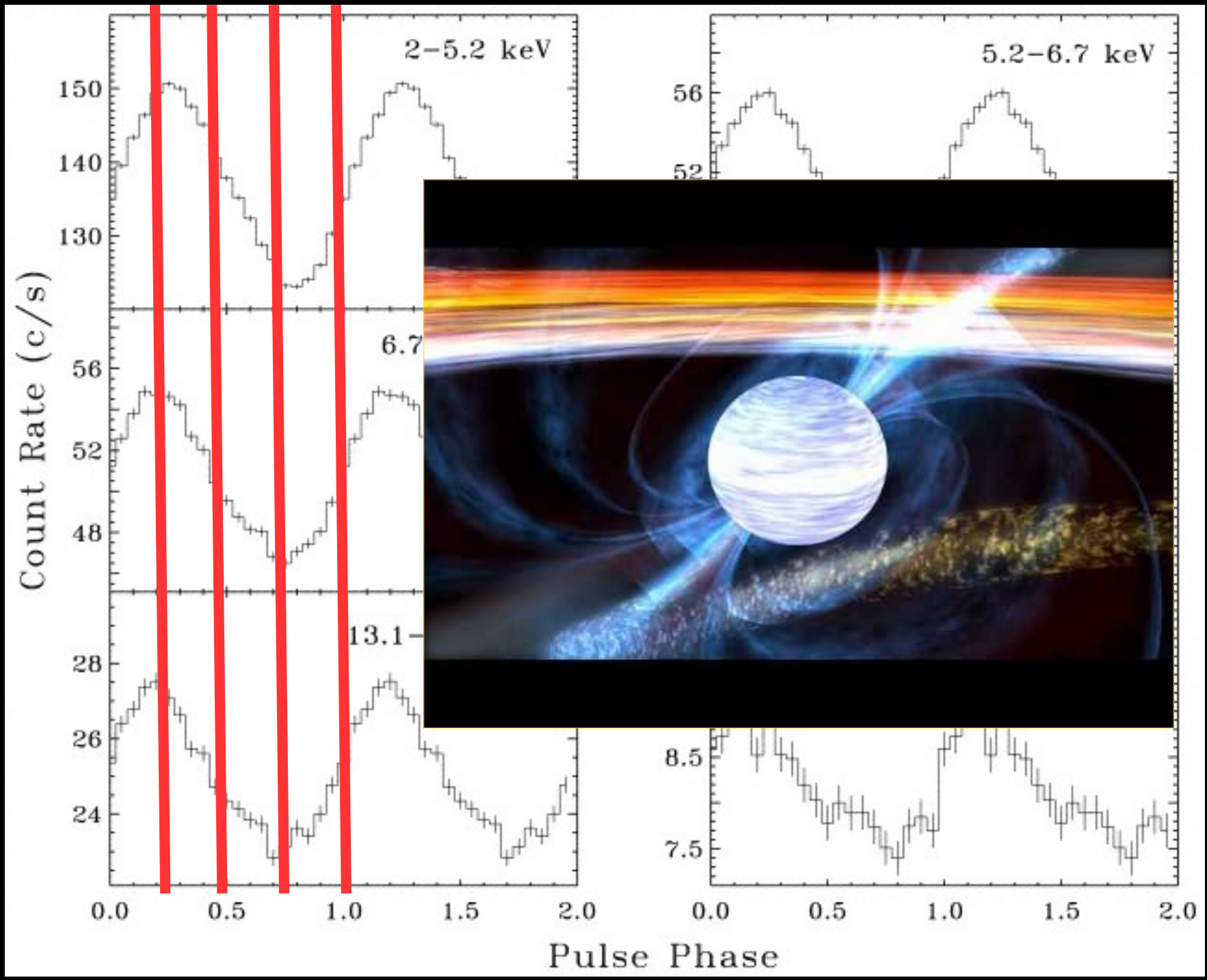

POWER
150
100
50
0
0
500
1000
1500
FREQUENCY (Hz)

*Dynamical Power spectrum --> Gives the orbital period!!*

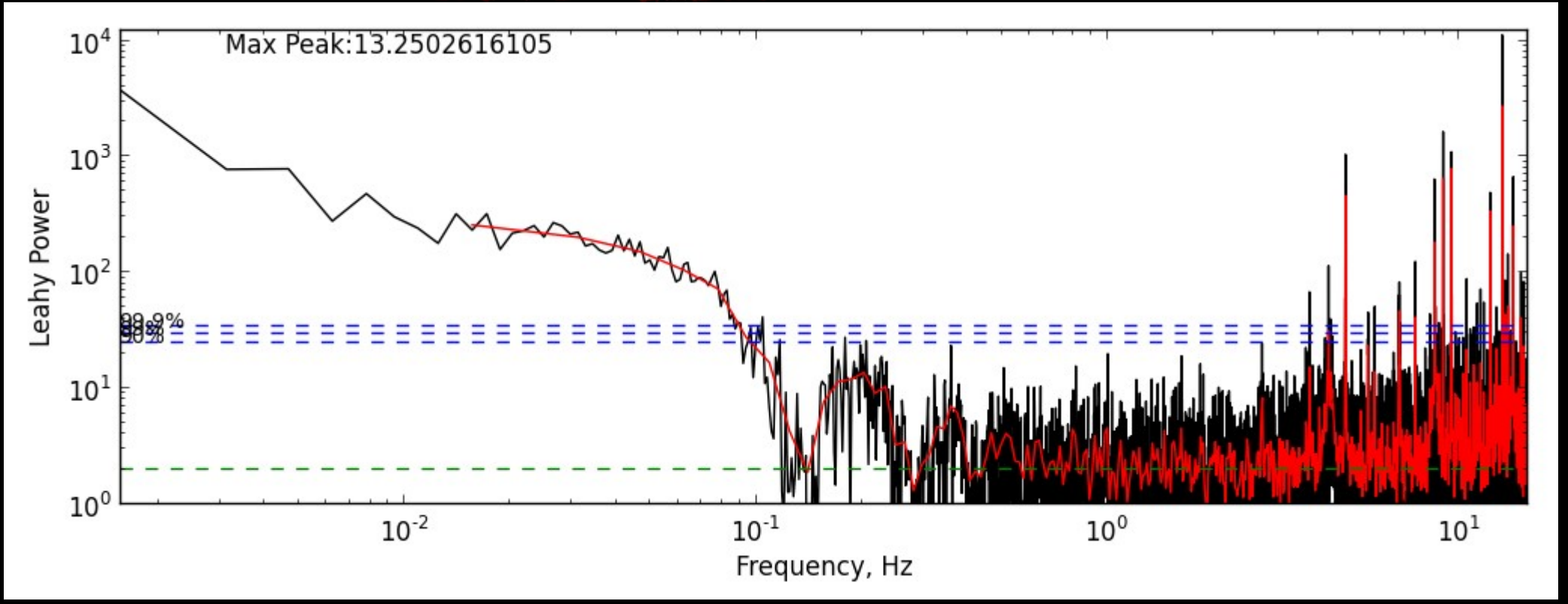





2–5.2
5.2–6.7 keV
6.7–8.9 keV
8.9–13.1 keV
13.1–19.7 keV
19.7–29.9 keV
Count Rate (c/s)
Pulse Phase
150
140
130
48
56
52
48
56
52
48
28
26
24
9.5
8.5
7.5
0.0
0.5
1.0
1.5
2.0

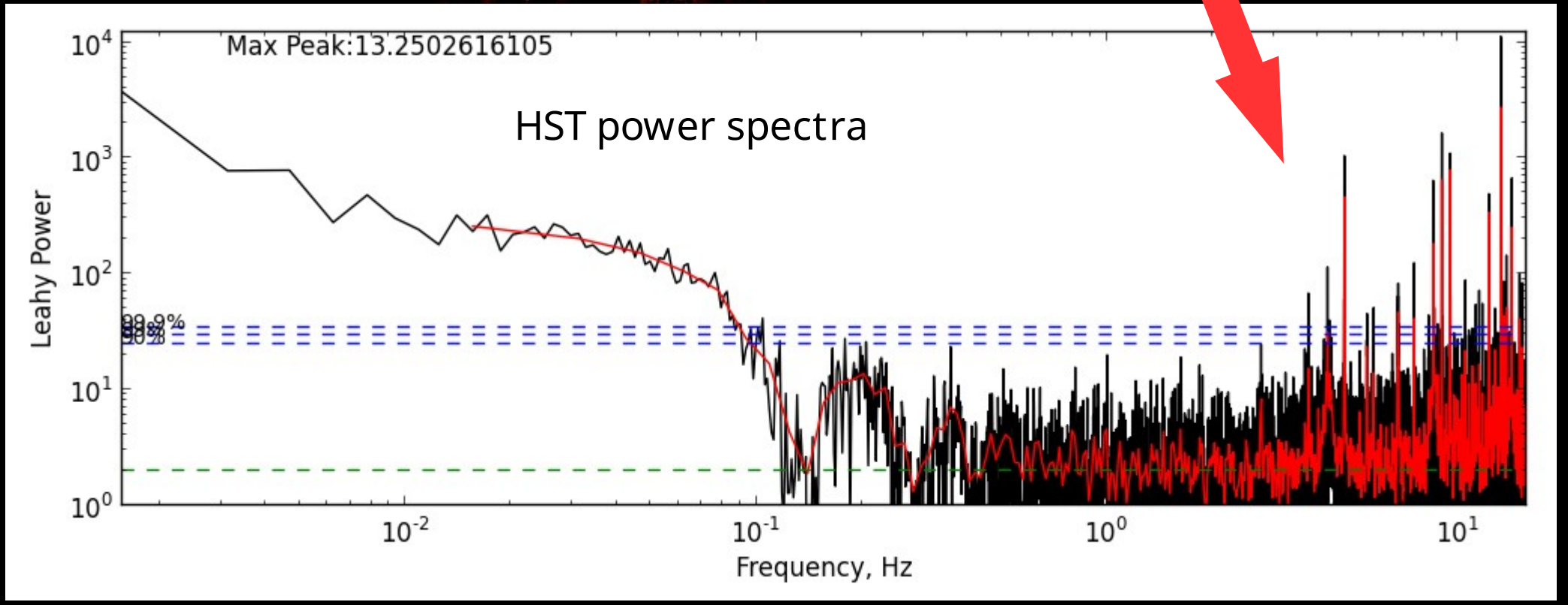

2–5.2 keV
5.2–6.7 keV
6.7
13.1
Count Rate (c/s)
Pulse Phase
150
140
130
56
52
48
28
26
24
8.5
7.5
0.0
0.5
1.0
1.5
2.0

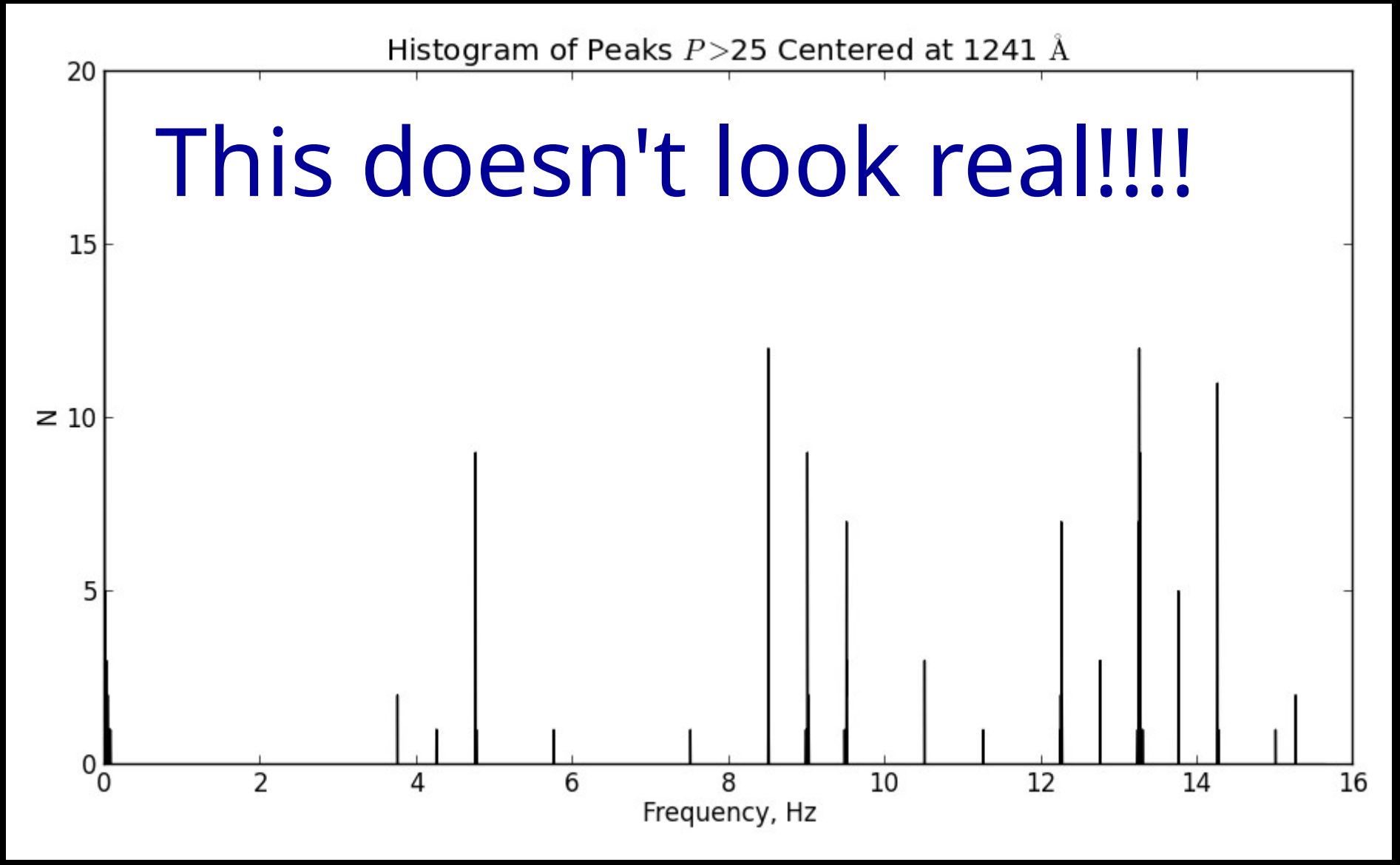
# With great power, comes great responsability

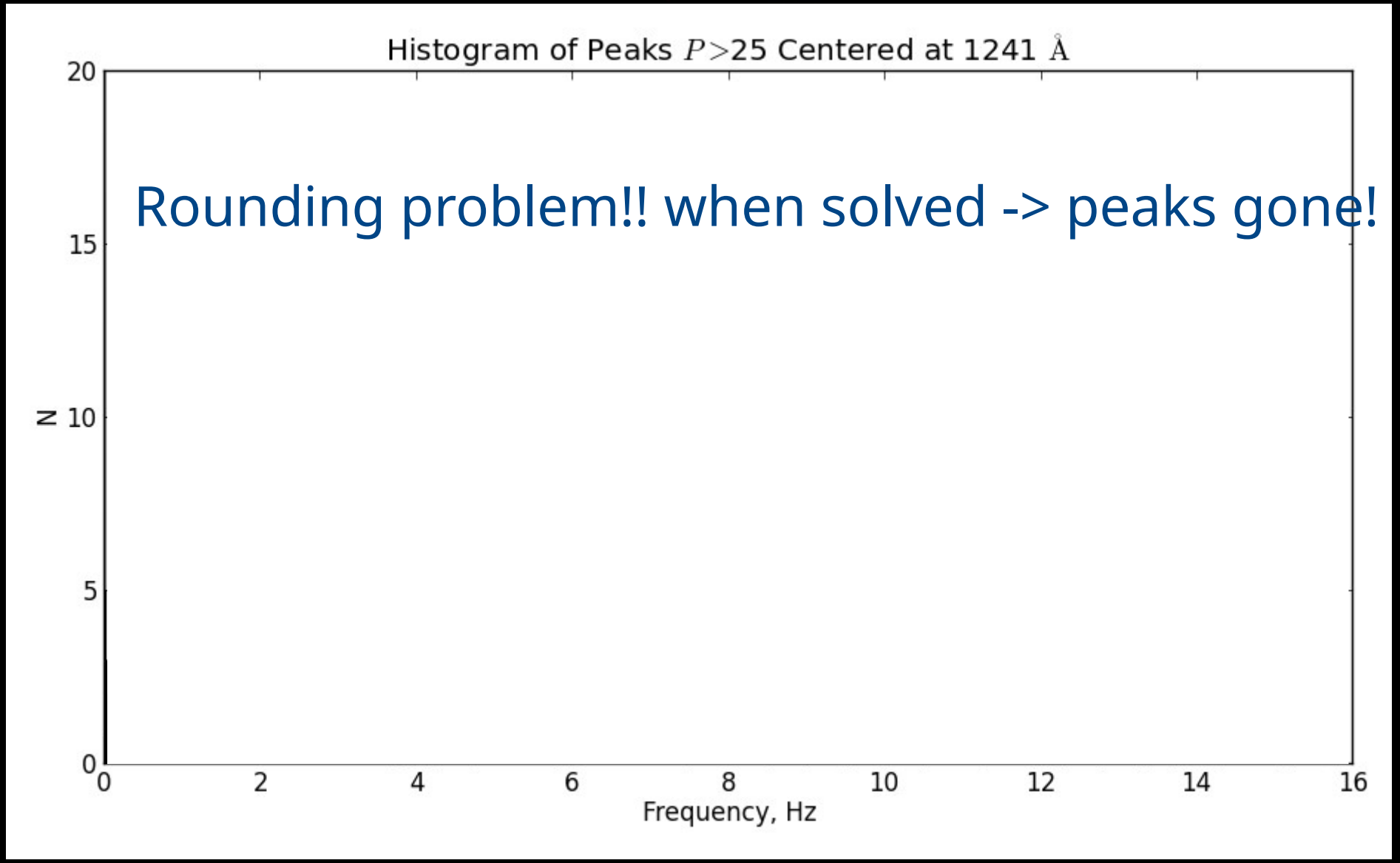


# With great power, it comes great responsability

Super nice result!!!!



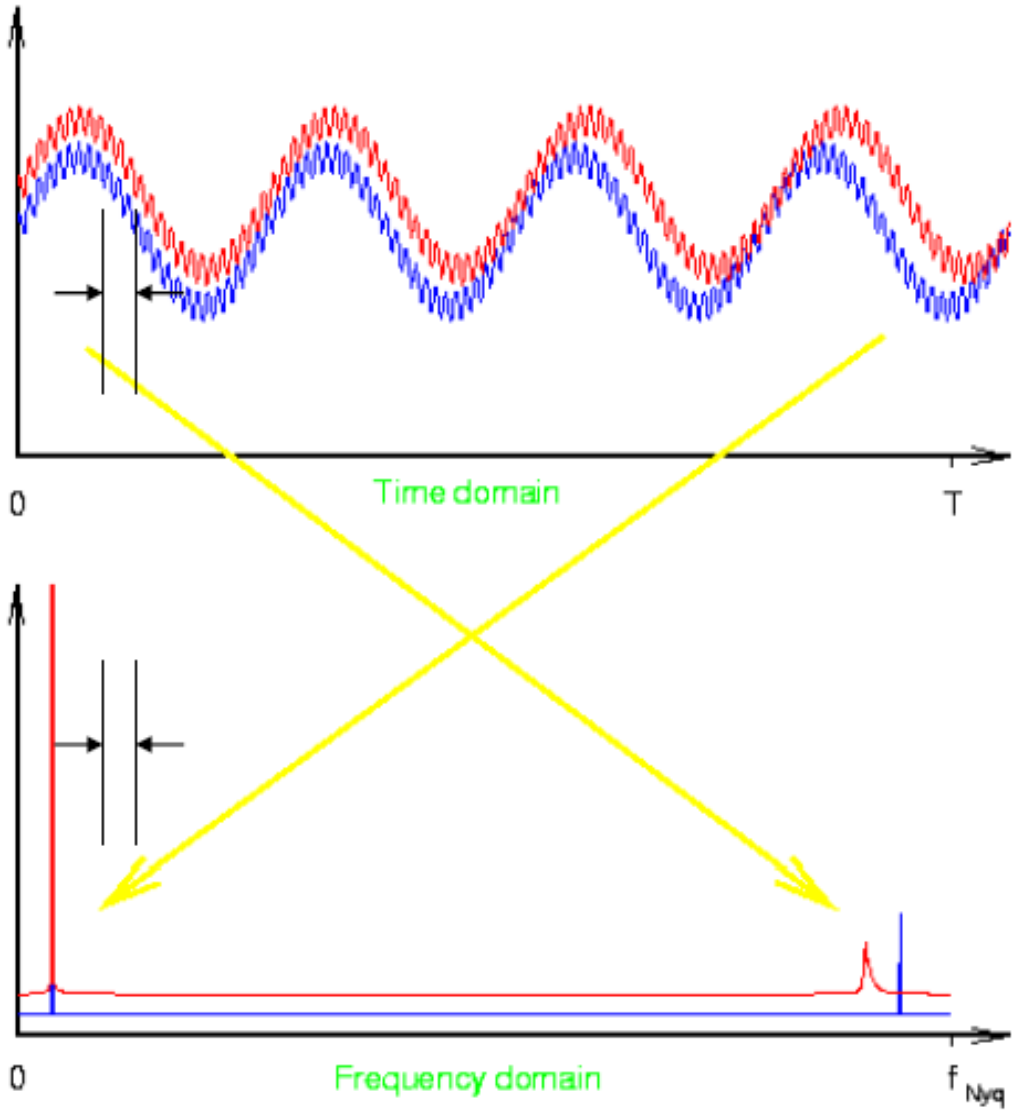

Histogram of Peaks $P>25$ Centered at 1241 Å
This doesn't look real!!!!
N
Frequency, Hz
0
5
10
15
20
0
2
4
6
8
10
12
14
16


Histogram of Peaks $P$>25 Centered at 1241 Å
Rounding problem!! when solved -> peaks gone!
N
Frequency, Hz
0
5
10
15
20
0
2
4
6
8
10
12
14
16

# Time and Frequency are "Duals"

Time Sampling $\Delta t$

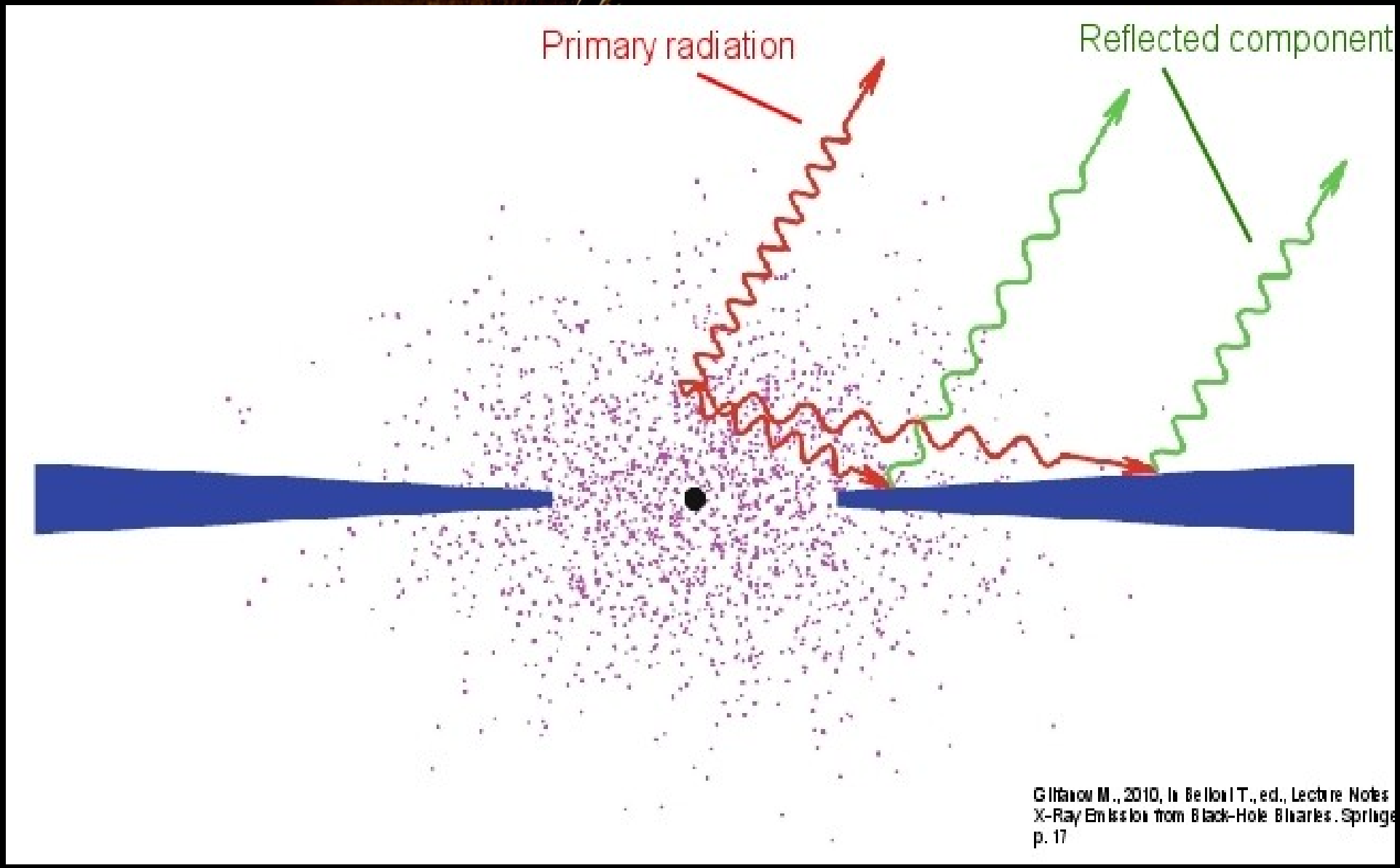
Frequency Sampling $\Delta f$




Time Span T

Nyquist Frequency $f_{max}$

# *Phase / Time Lags*



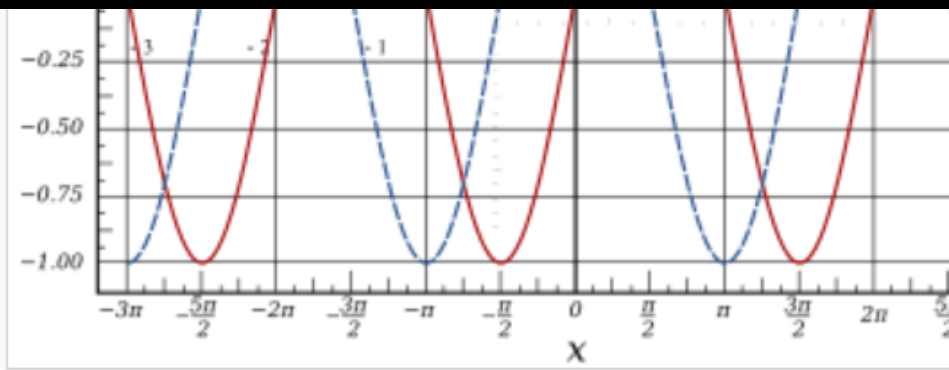

Gilfanov M., 2010, In Belloni T., ed., Lecture Notes
X-Ray Emission from Black-Hole Binaries. Springe
p. 17

# *Phase ... Phase ... Phase*

$$y(t) = A\sin(2\pi f t + \varphi) = A\sin(\omega t + \varphi)$$

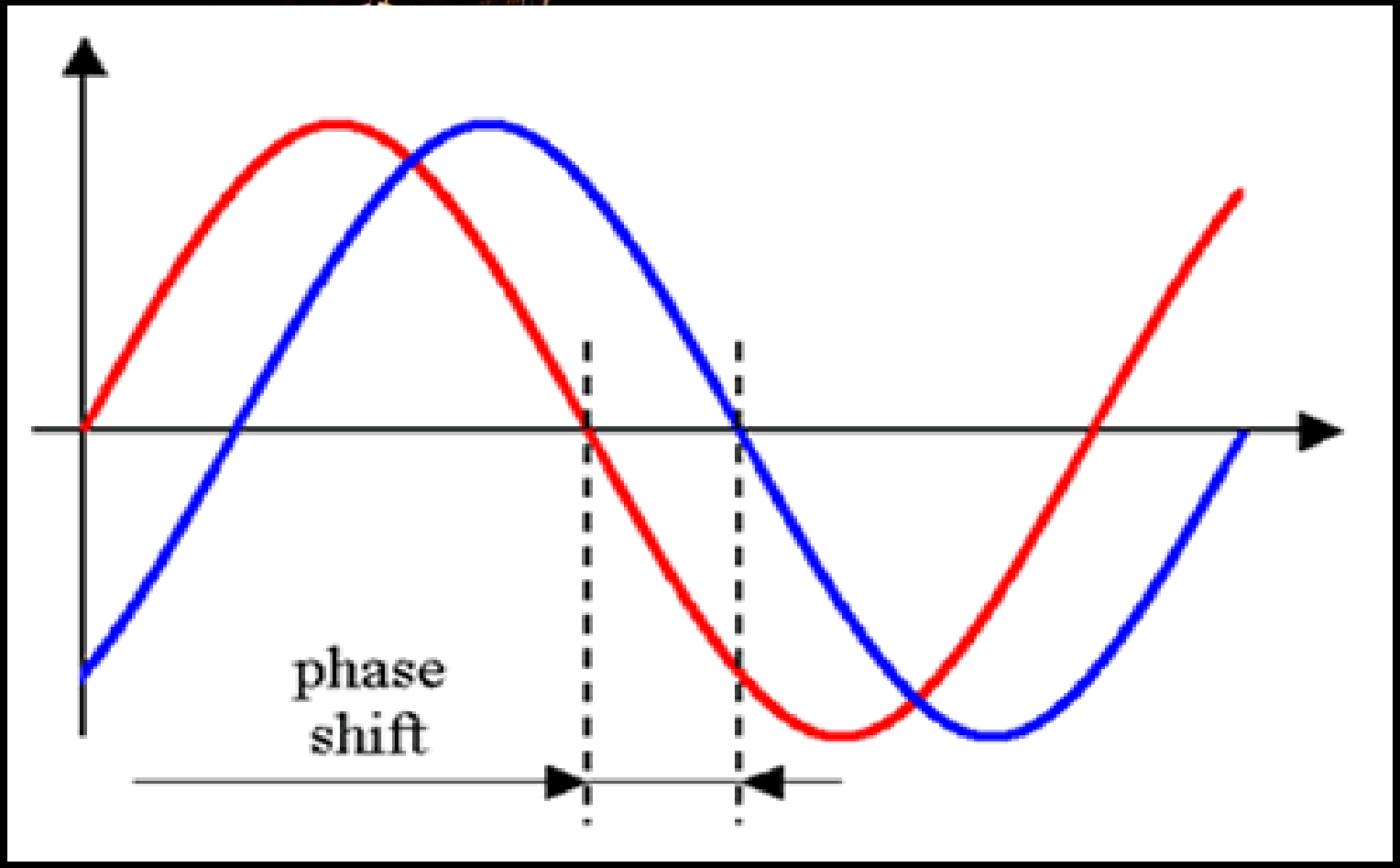
where:

- *A*, the *amplitude*, is the peak deviation of the function from zero.
- *f*, the *ordinary frequency*, is the *number* of oscillations (cycles) that occur each second of time.
- $\omega = 2\pi f$, the *angular frequency*, is the rate of change of the function argument in units of radians per second
- $\varphi$, the *phase*, specifies (in radians) where in its cycle the oscillation is at $t = 0$.
  - When $\varphi$ is non-zero, the entire waveform appears to be shifted in time by the amount $\varphi/\omega$ seconds. A negative value represents a delay, and a positive value represents an advance.

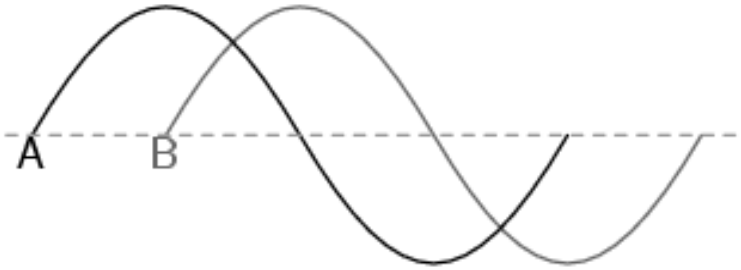



The graphs of the sine and cosine functions are sinusoids of different phases.

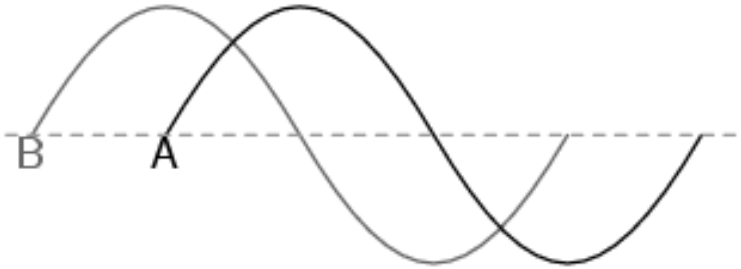
# *Phase ... Phase ... Phase*



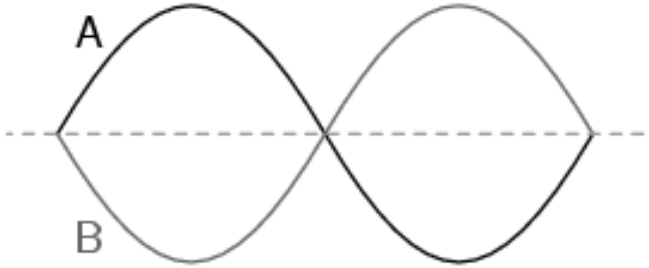
# *Phase / Time Lags*



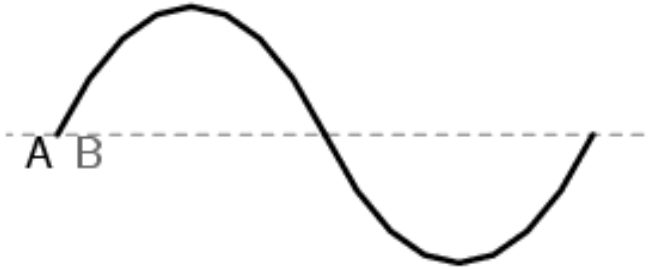

Phase shift = 90 degrees
A is ahead of B
(A "leads" B)




Phase shift = 90 degrees
B is ahead of A
(B "leads" A)

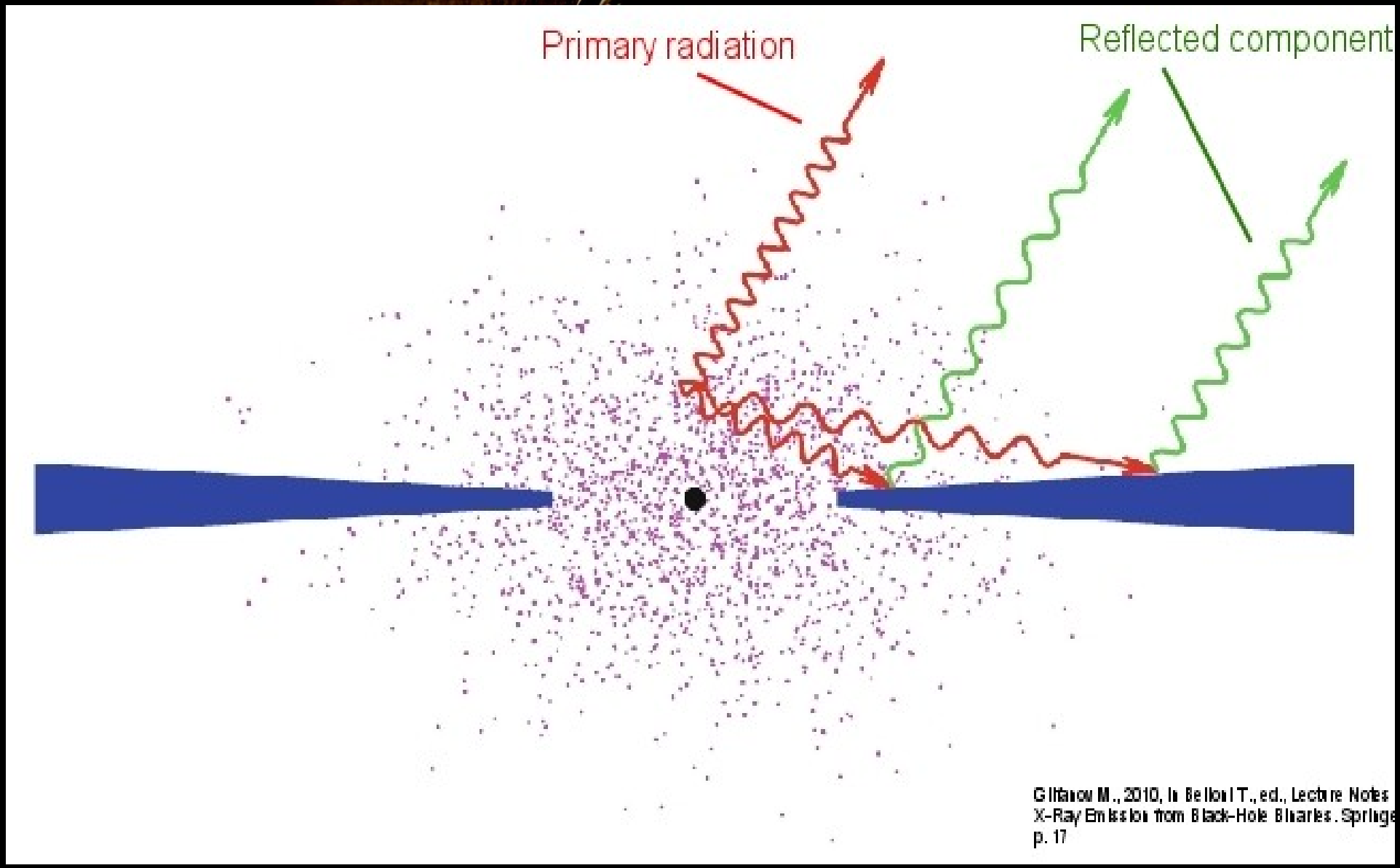



Phase shift = 180 degrees
A and B waveforms are
mirror-images of each other




Phase shift = 0 degrees
A and B waveforms are
in perfect step with each other

# *Phase / Time Lags*

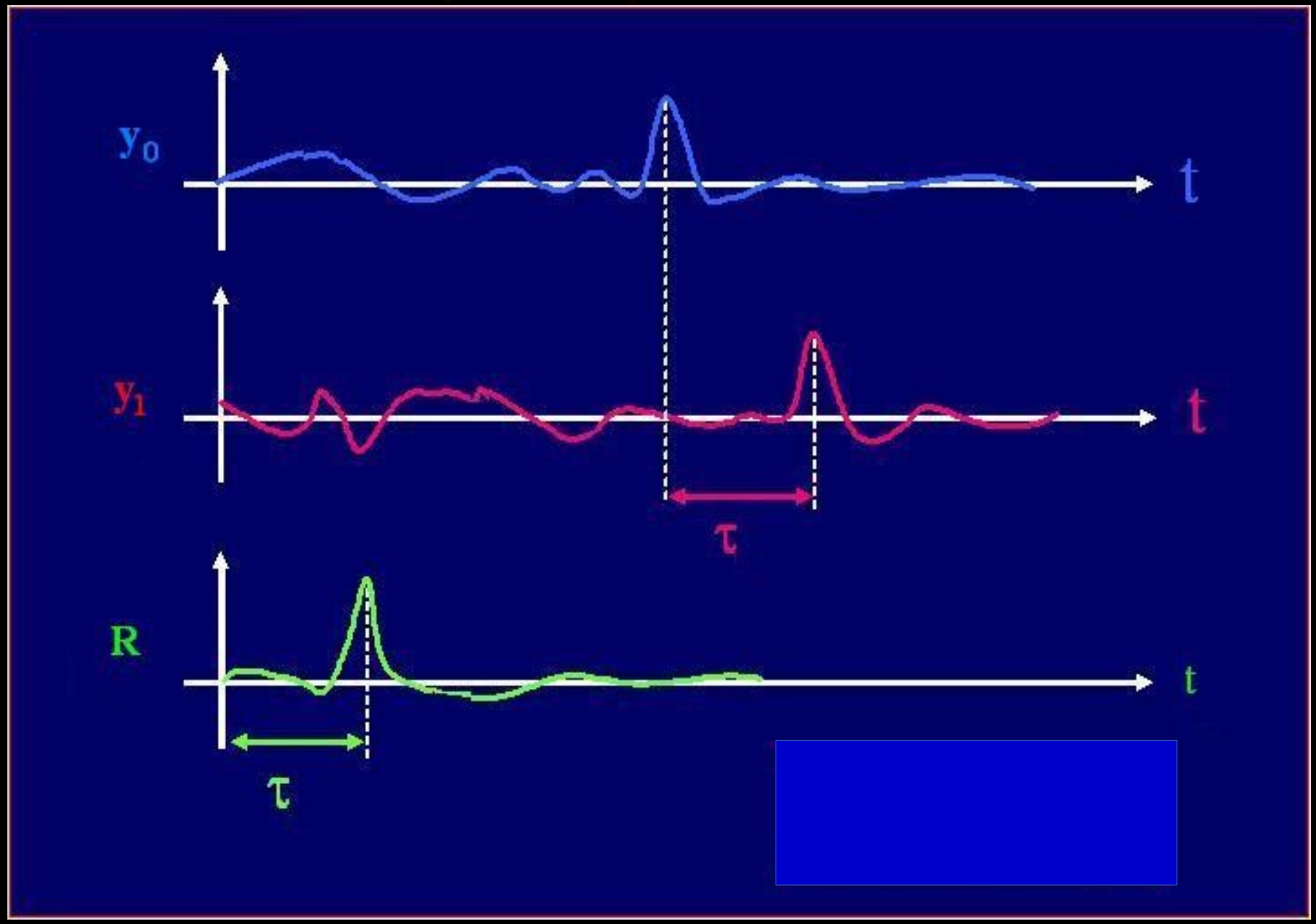


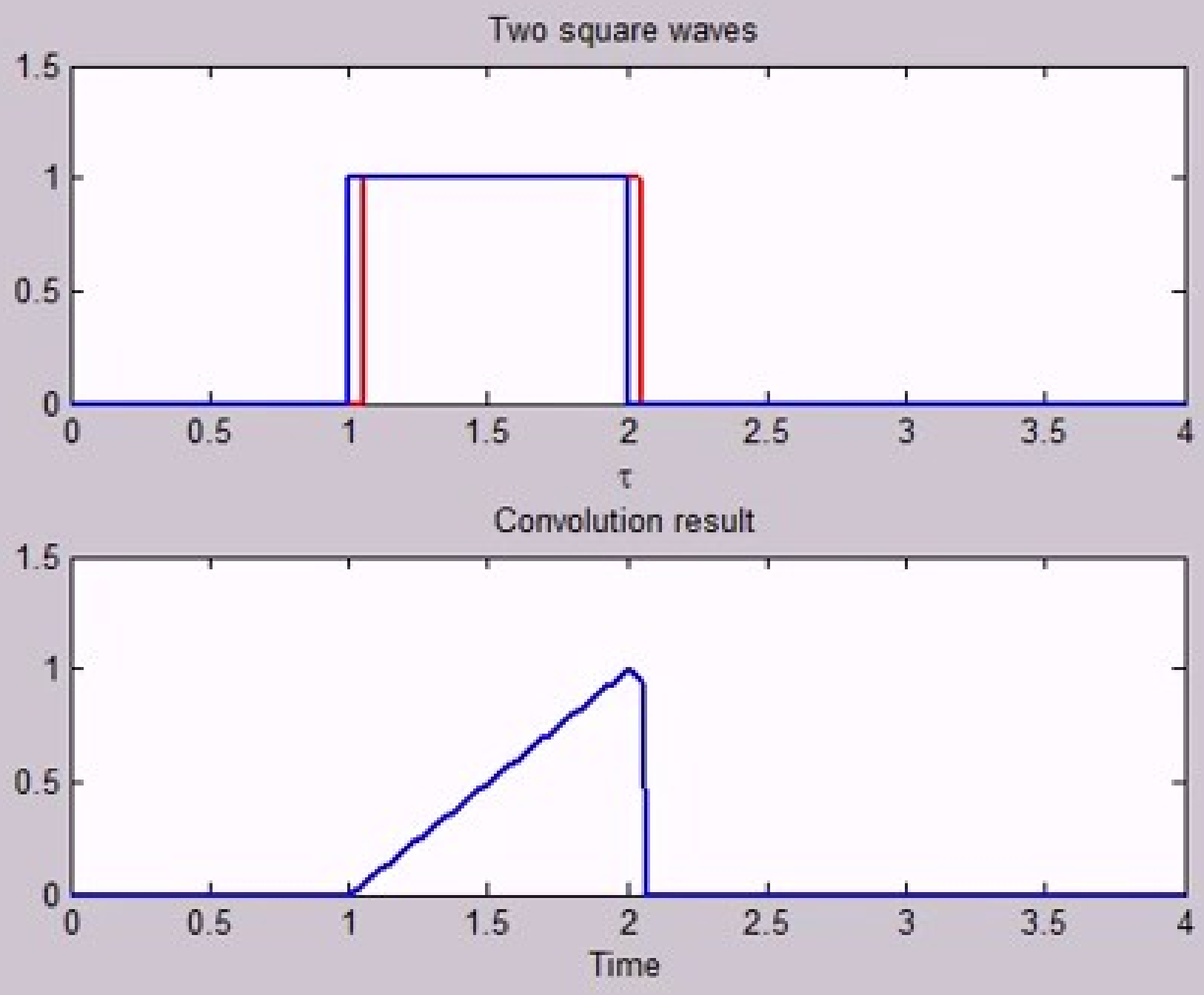

Gilfanov M., 2010, In Belloni T., ed., Lecture Notes
X-Ray Emission from Black-Hole Binaries. Springe
p. 17

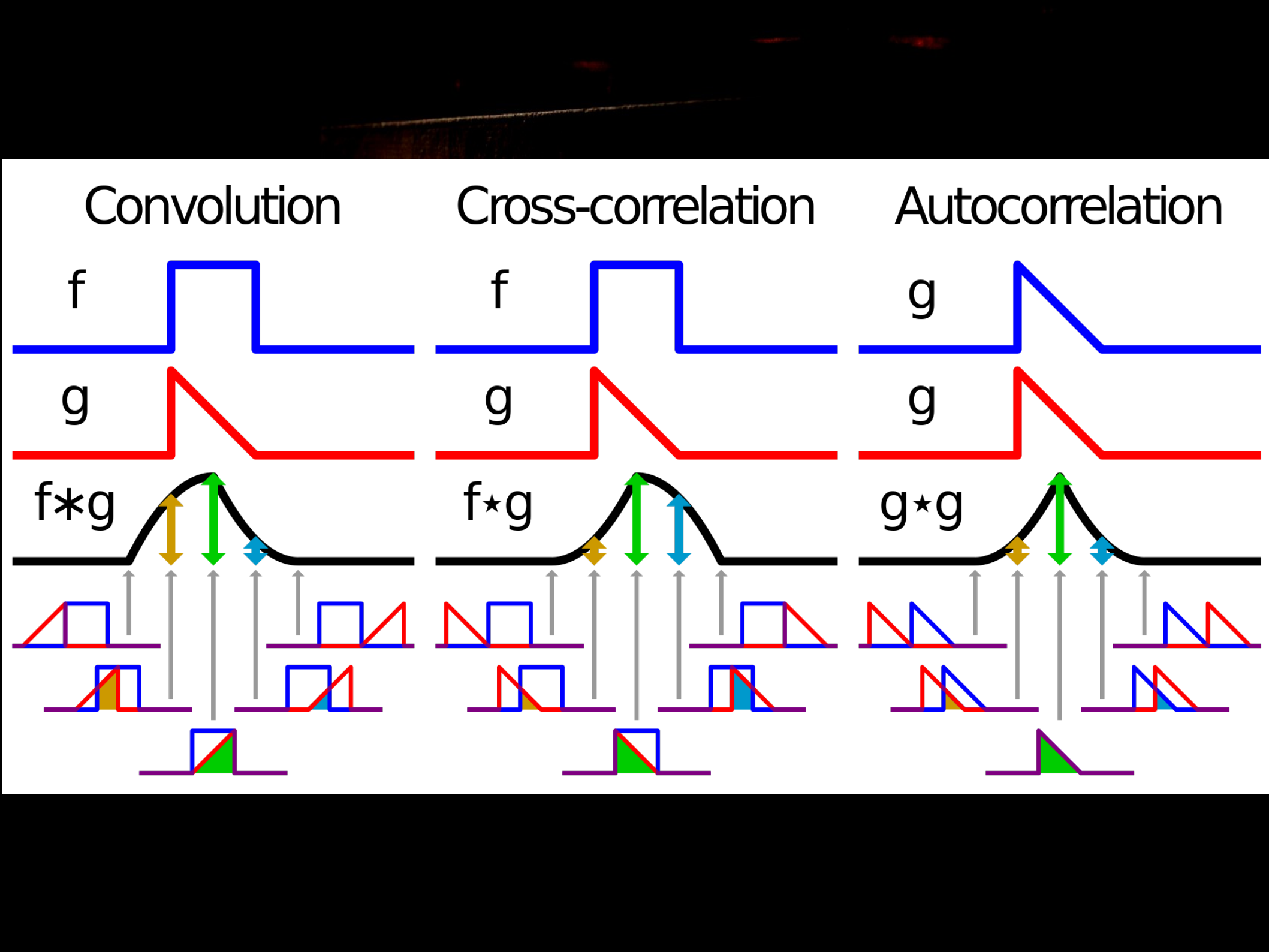
*MAGIC WORD:*

*cross-correlation!*

$$(f \star g)(\tau) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f^*(t)\, g(t+\tau)\, dt,$$


$y_0$
t
$y_1$
t
τ
R
t
τ


Two square waves
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
τ
Convolution result
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Time


Convolution
Cross-correlation
Autocorrelation
f
g
f∗g
f
g
f⋆g
g
g
g⋆g

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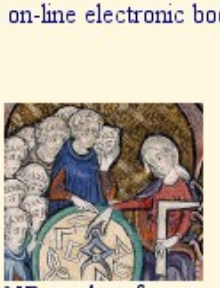
NR readers forum.

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Web, dating back to 1993 when there were only about 25,0
about 200,000,000.) In partnership with Cambridge Univers
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by a Numerical Recipes user. They are available to all other
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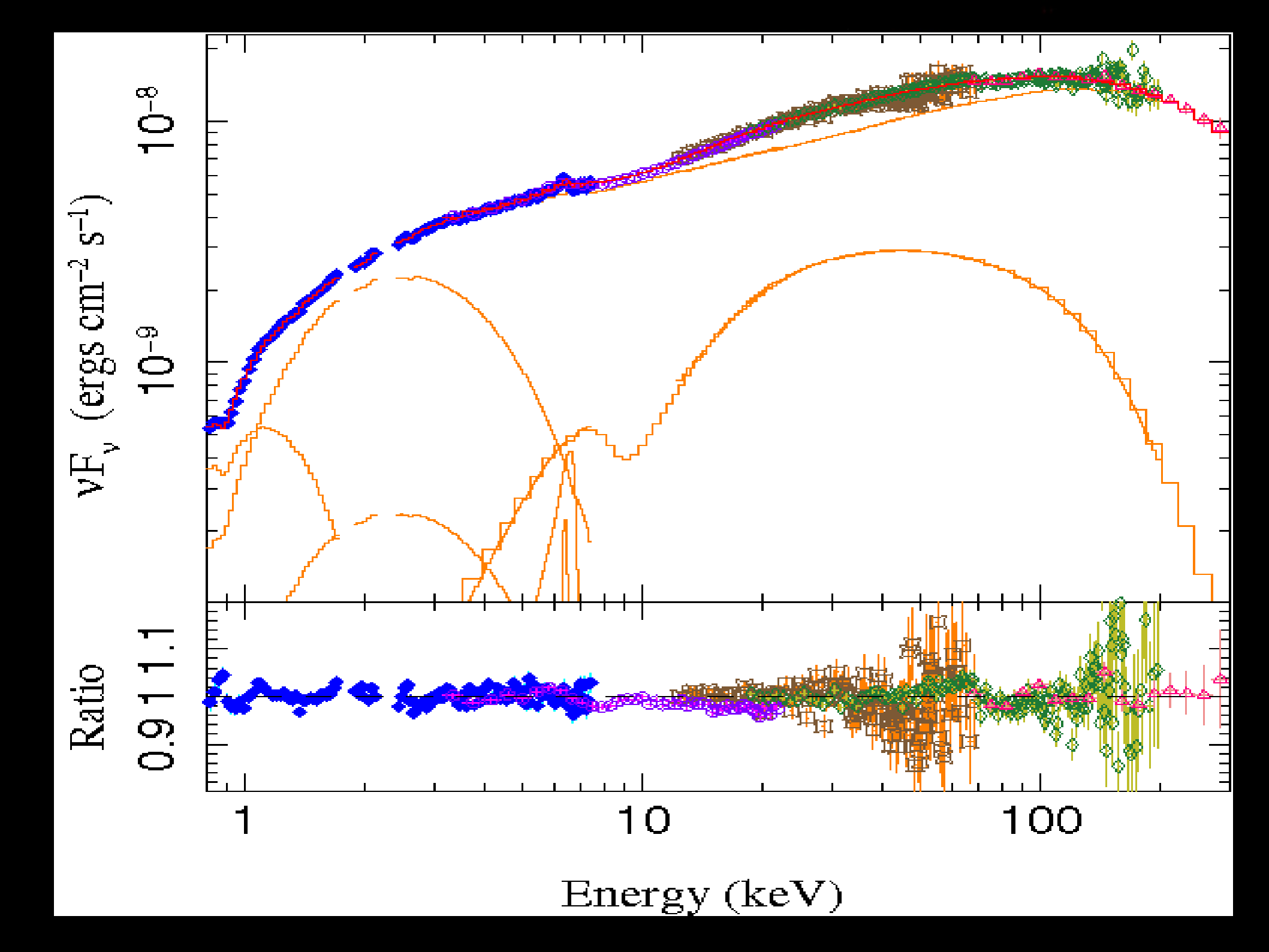
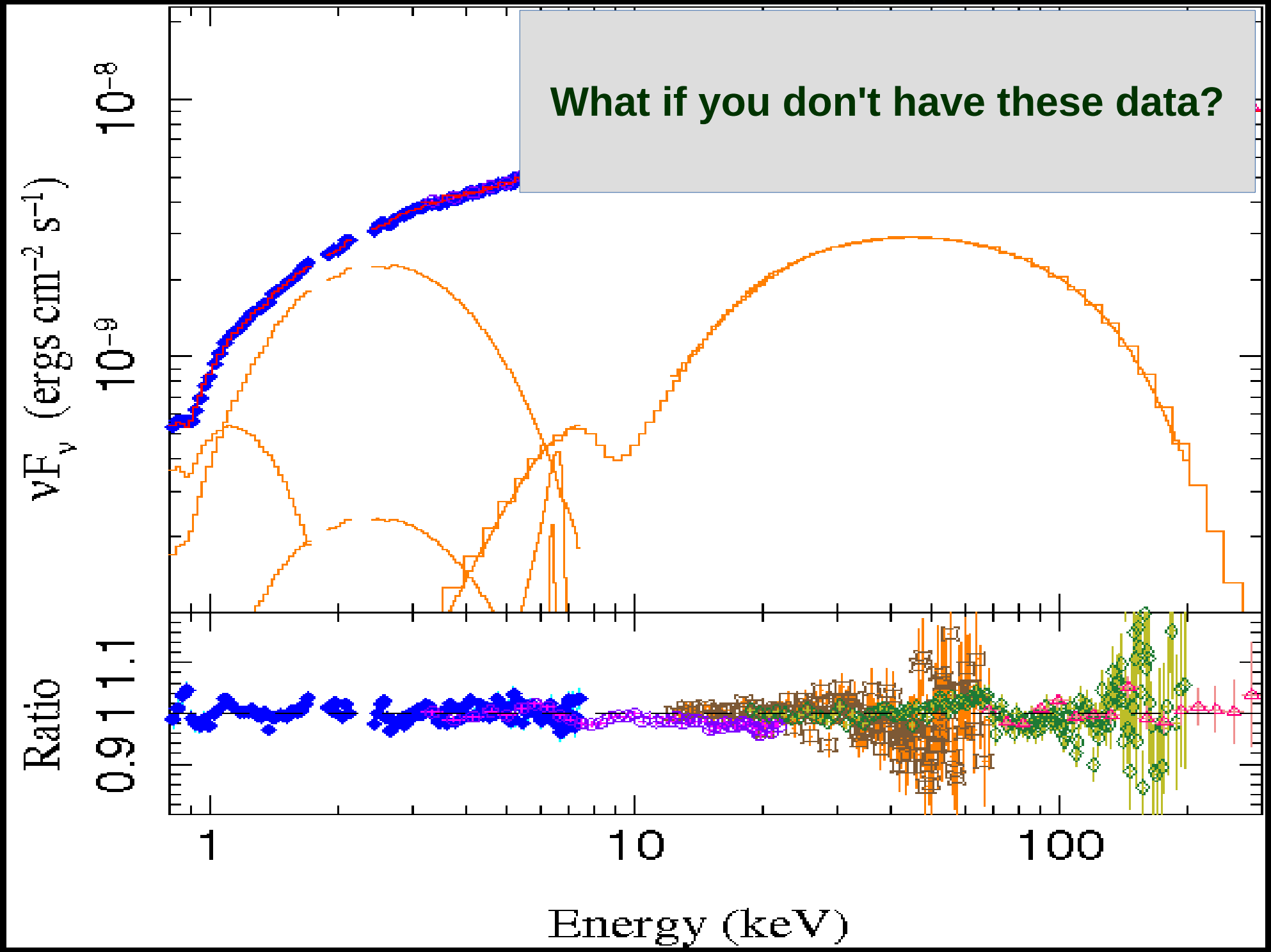
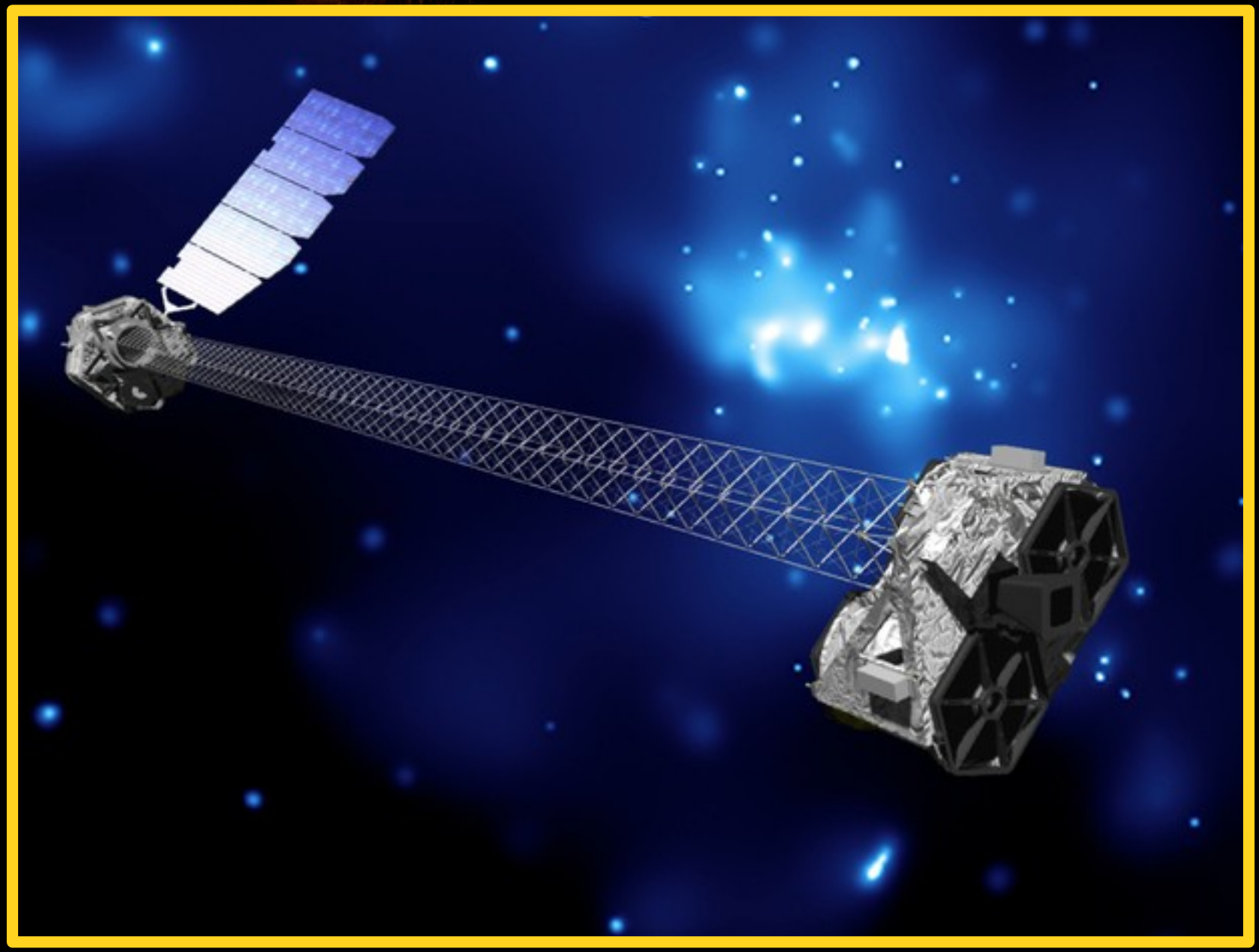
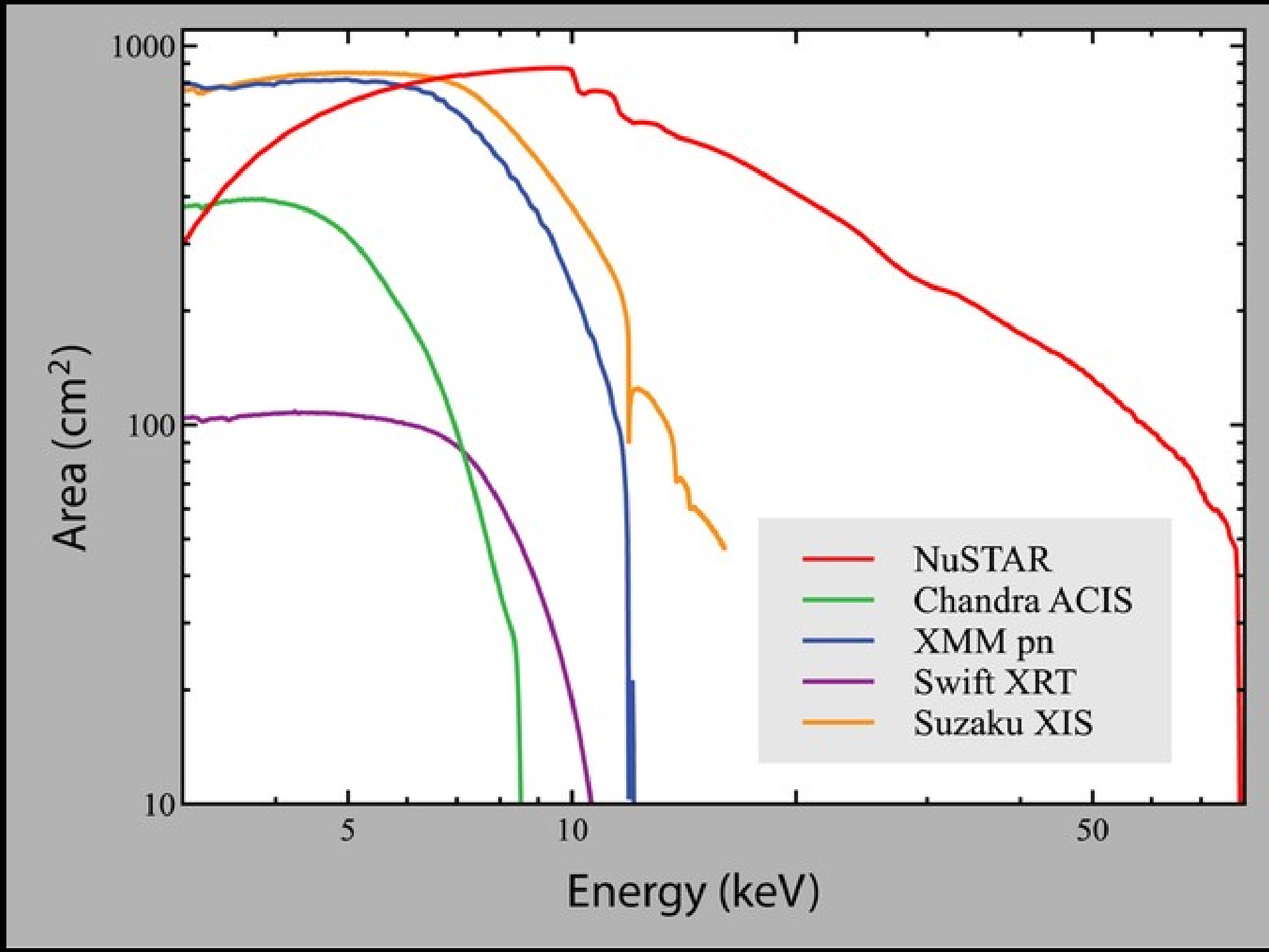
You can call Numerical Recipes routines (along with any oth
examples is here. A free interface file is here. This is an alpha


$10^{-8}$
$10^{-9}$
$\nu F_\nu$ (ergs cm$^{-2}$ s$^{-1}$)
Ratio
0.9
1
1.1
1
10
100
Energy (keV)


What if you don't have these data?
$10^{-8}$
$10^{-9}$
$\nu F_\nu$ (ergs cm$^{-2}$ s$^{-1}$)
Ratio
0.9
1
1.1
1
10
100
Energy (keV)

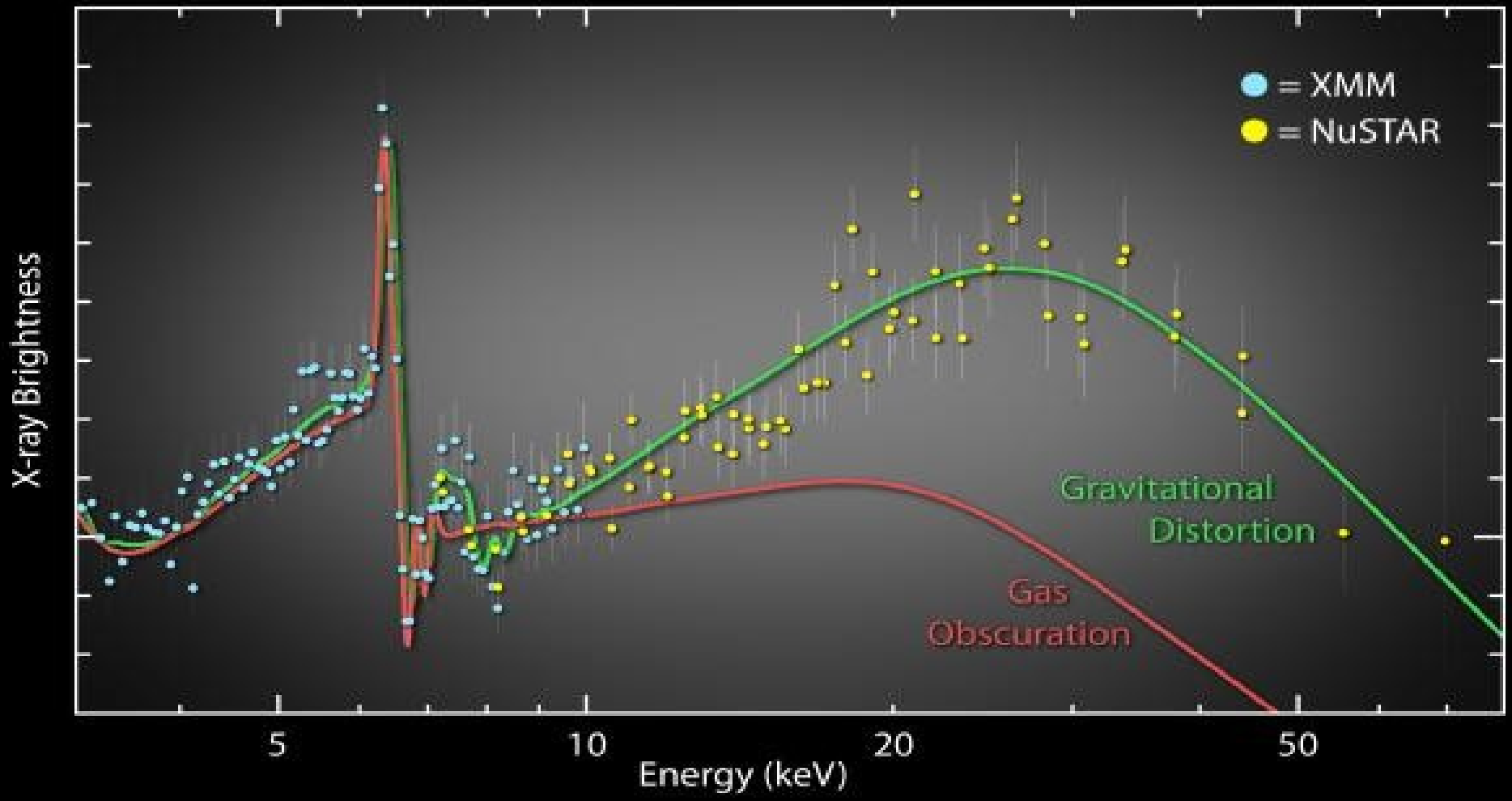
# NuStar



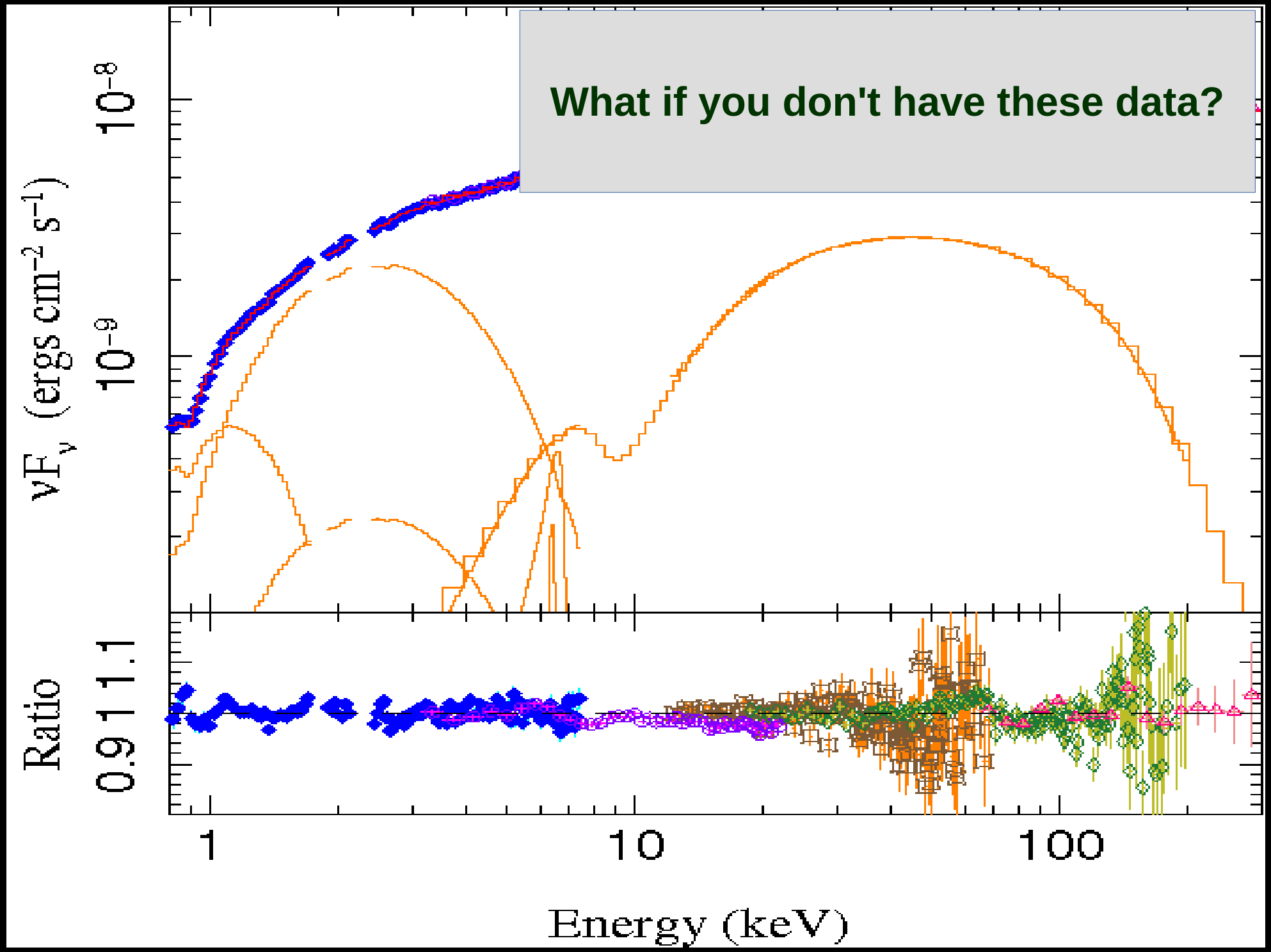

1000
100
10
Area (cm$^2$)
5
10
50
Energy (keV)
NuSTAR
Chandra ACIS
XMM pn
Swift XRT
Suzaku XIS

| | |
|---|---|
| **Energy Band** | 3 - 79 keV |
| **Angular Resolution** | 58" (HPD), 18" (FWHM) |
| **Focal Plane Size** | 12' x 12' |
| **Energy Resolution** | 0.4 keV at 6 keV, 0.9 keV at 60 keV (FWHM) |
| **Temporal Resolution** | 0.1 msec |
| **Maximum Flux Measurement Rate** | 10,000 cts/s |
| **ToO response** | < 24 hours |
| **Launch date** | June 13, 2012 |
| **Orbit** | 650 km x 610 km, 6 degree inclination |
| **Slew Rate** | 0.06 deg / sec |
| **Settle Time** | 142 sec |

No pile up!!! -- but you do have deadtime :-S




You can't imagine how important is to have a broad eneryg coverage!!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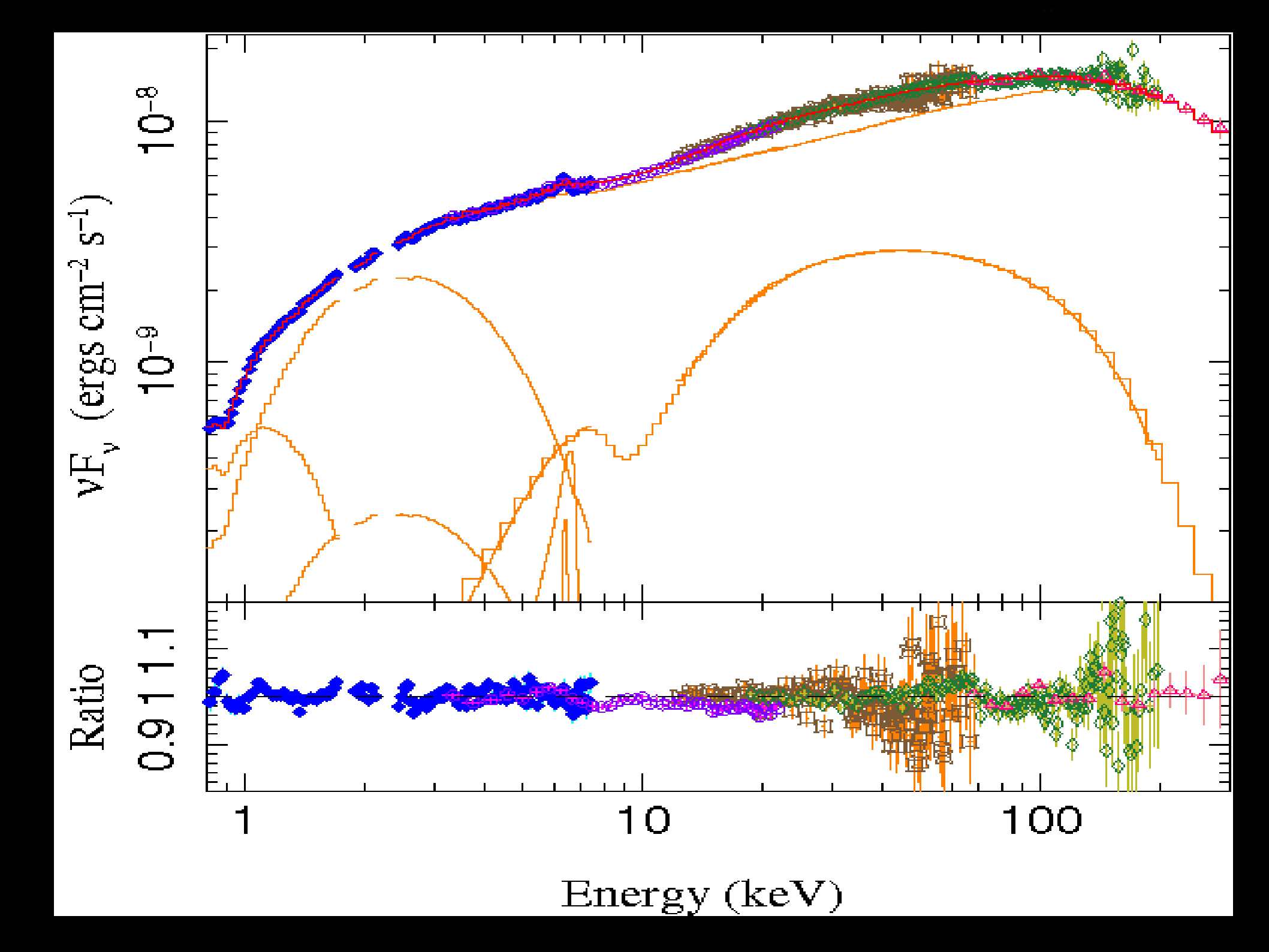
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