Mullard Space Science Laboratory
University College London

UCL

Observations of particle acceleration in the blast waves of Gamma Ray Bursts

Peter A. Curran

with
Rhaana Starling, Alexander van der Horst,
Ralph Wijers, Phil Evans, Mat Page

Discovery: Vela Satellites

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

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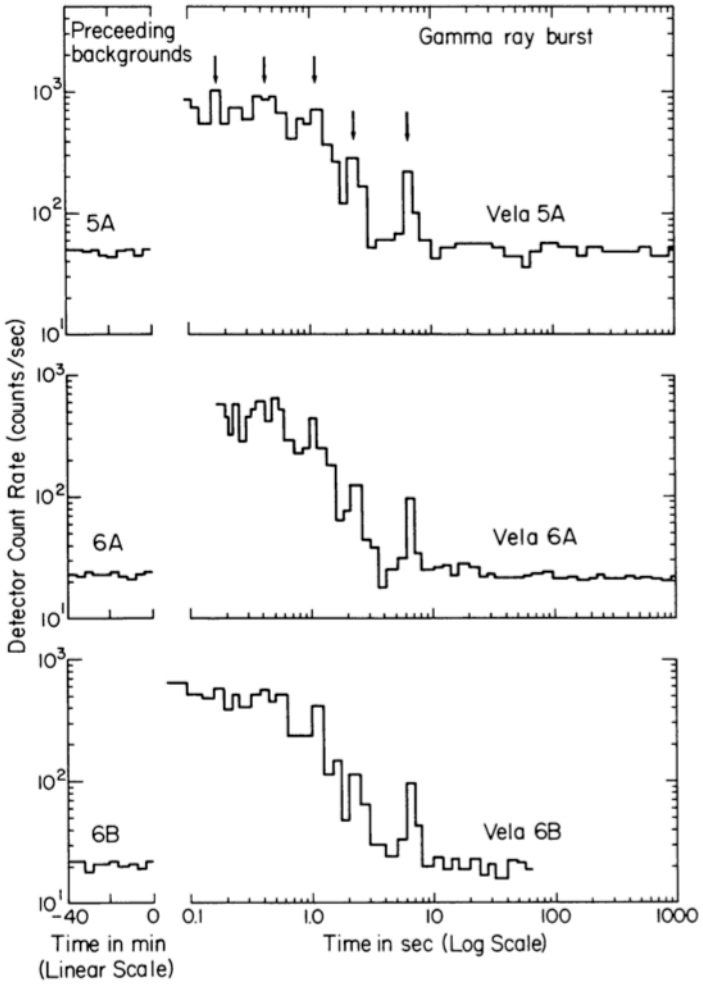
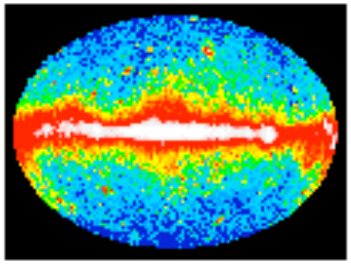
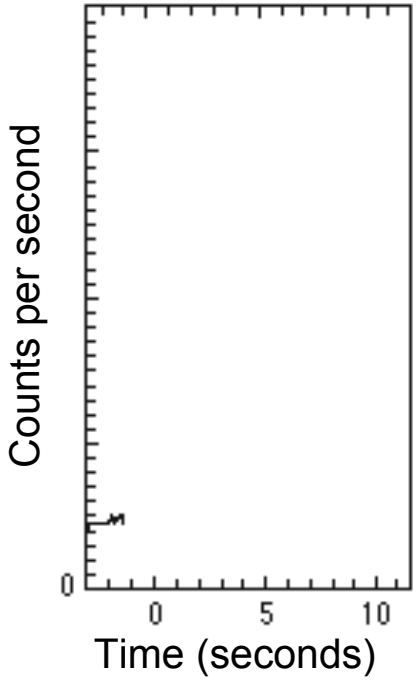


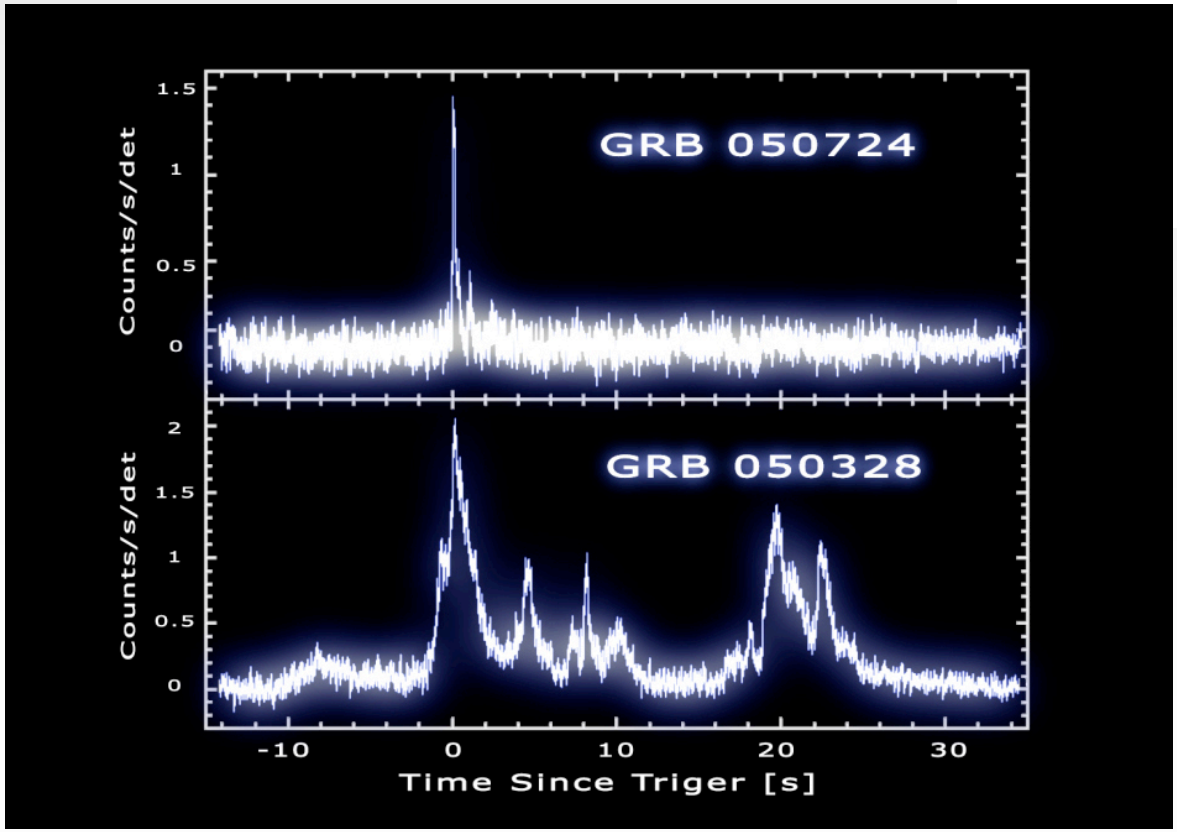
Prompt emission

Intense, short-lived, gamma-ray sources

Most luminous sources in the Universe… for a very brief period



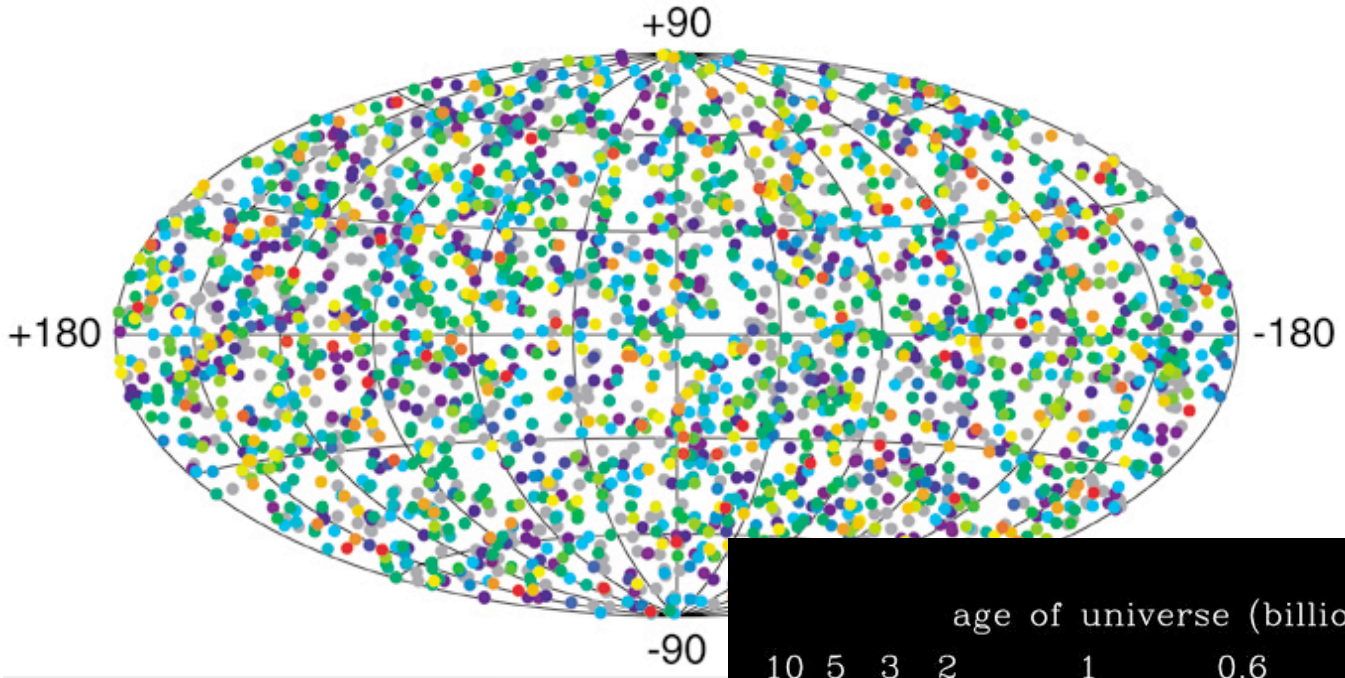




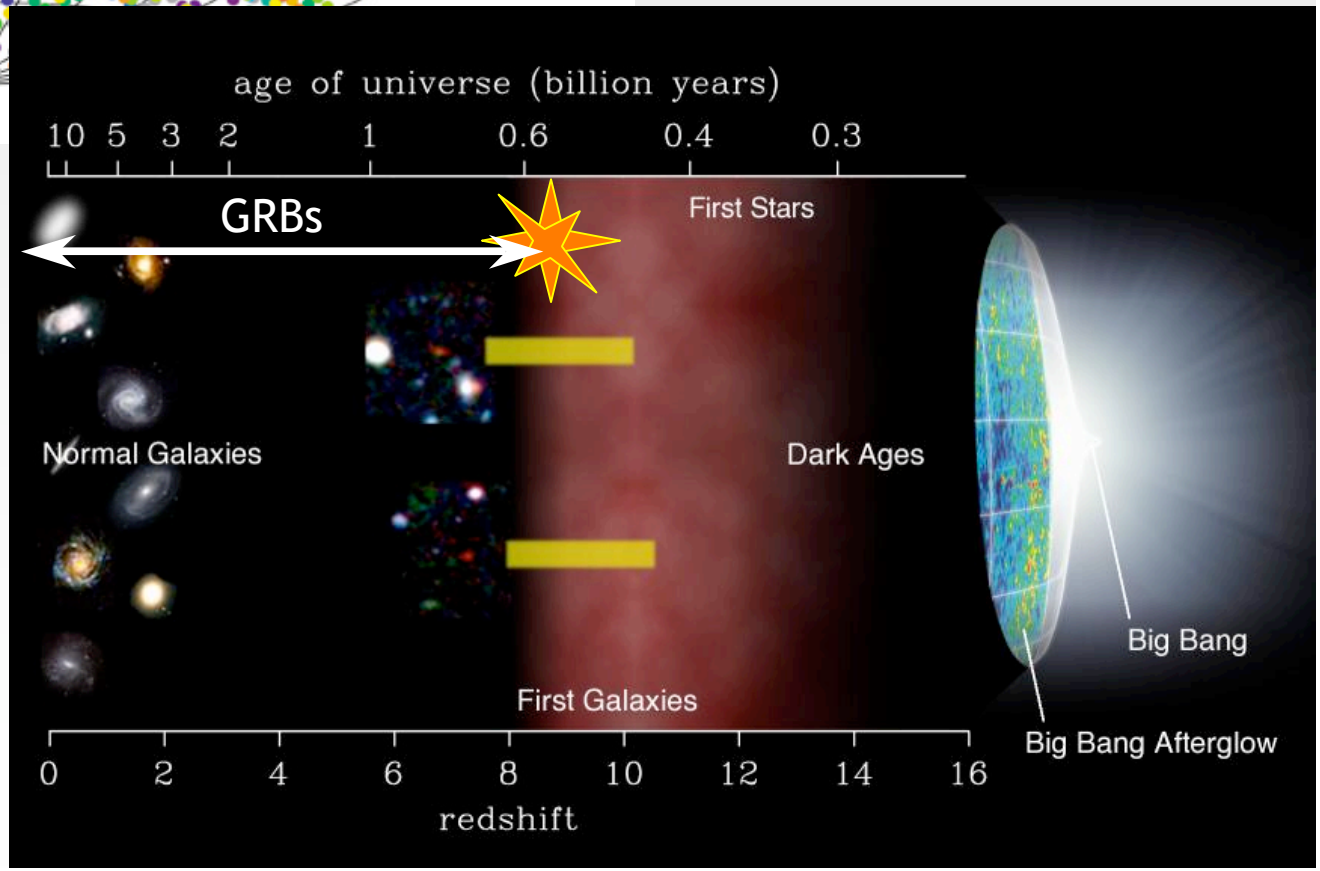
Rapid variability

$\Rightarrow$ small size (~ $c\,\Delta t$)

Cosmological sources

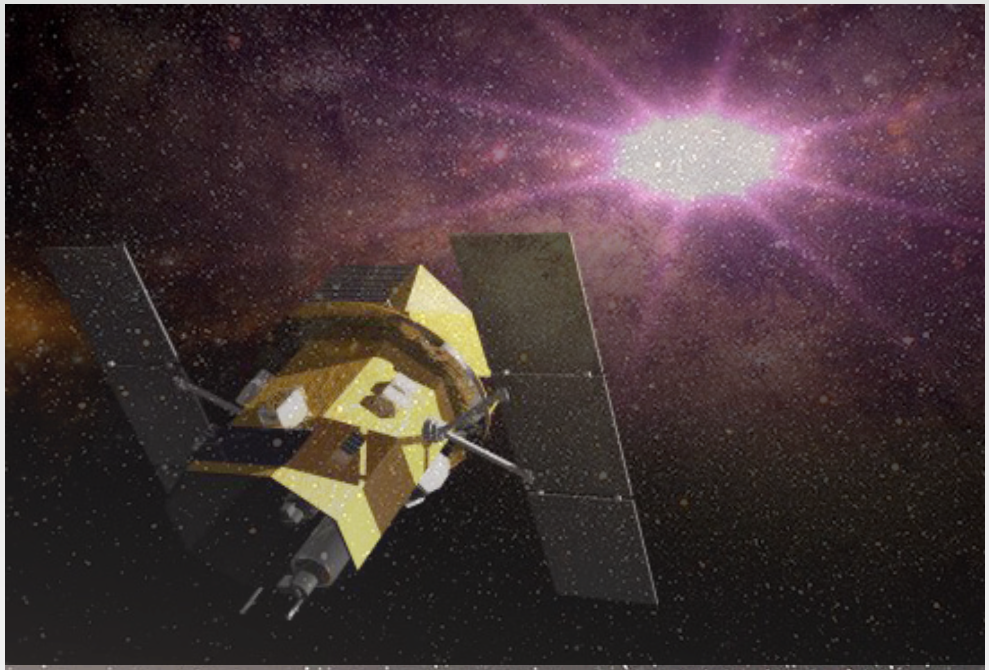


Isotropic distribution
& redshifts



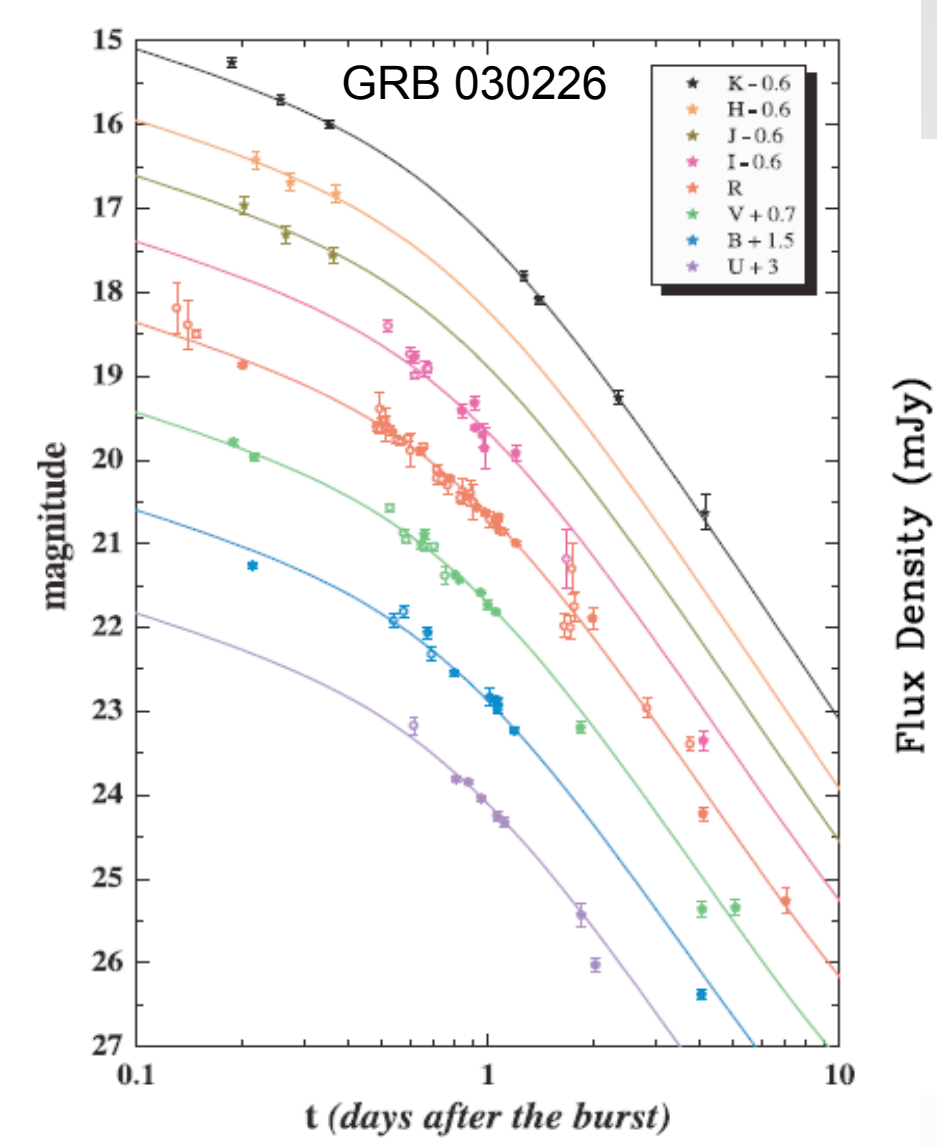
Multi-wavelength afterglows

Afterglow (X-ray – optical – radio) observable for weeks/months/years



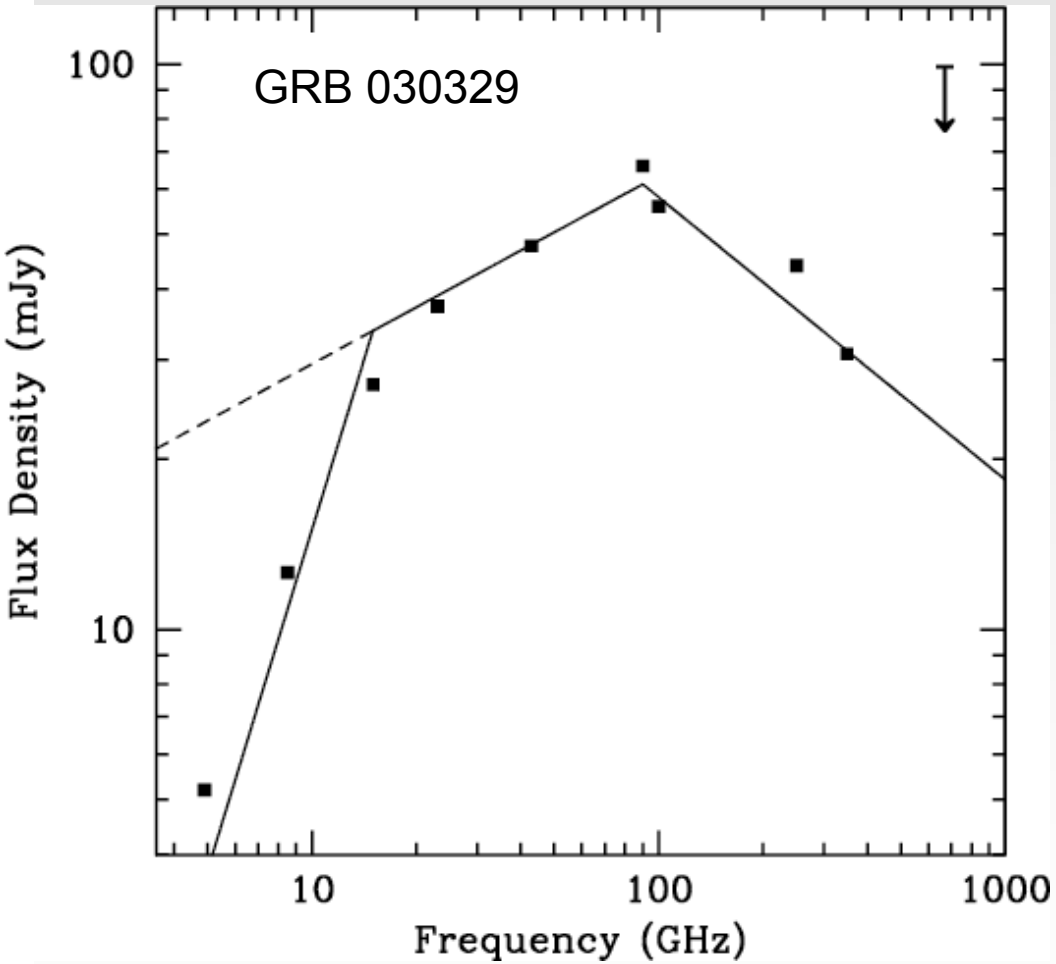
Multi-wavelength afterglows

Afterglow light curve



(Klose et al. 2004)

Afterglow spectra/SED



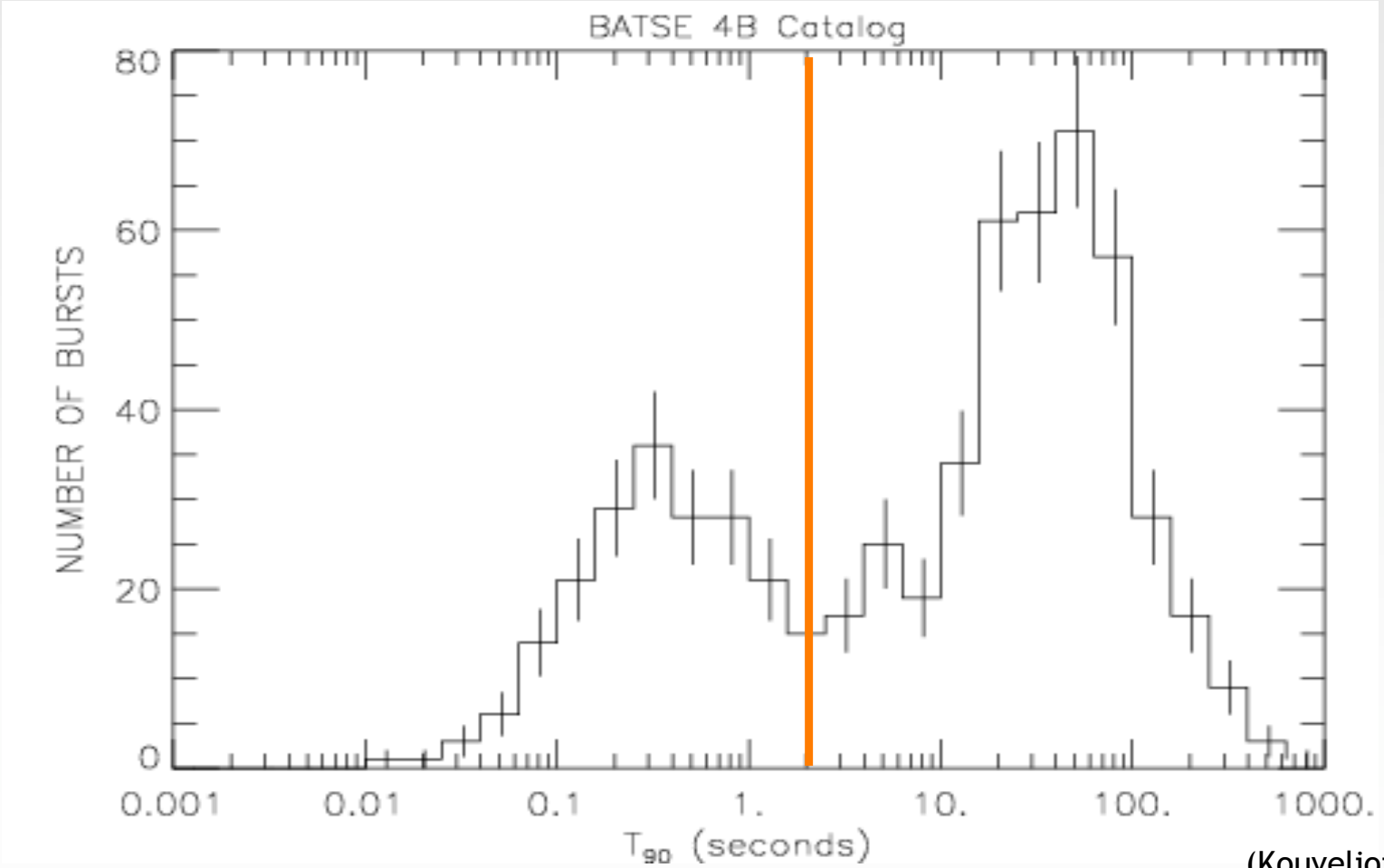
(Smith et al. 2005)

Note: log-log plots

Two (almost) distinct classes

Short/Hard bursts:
- Various host galaxies/No host
- Binary mergers (BH,NS)

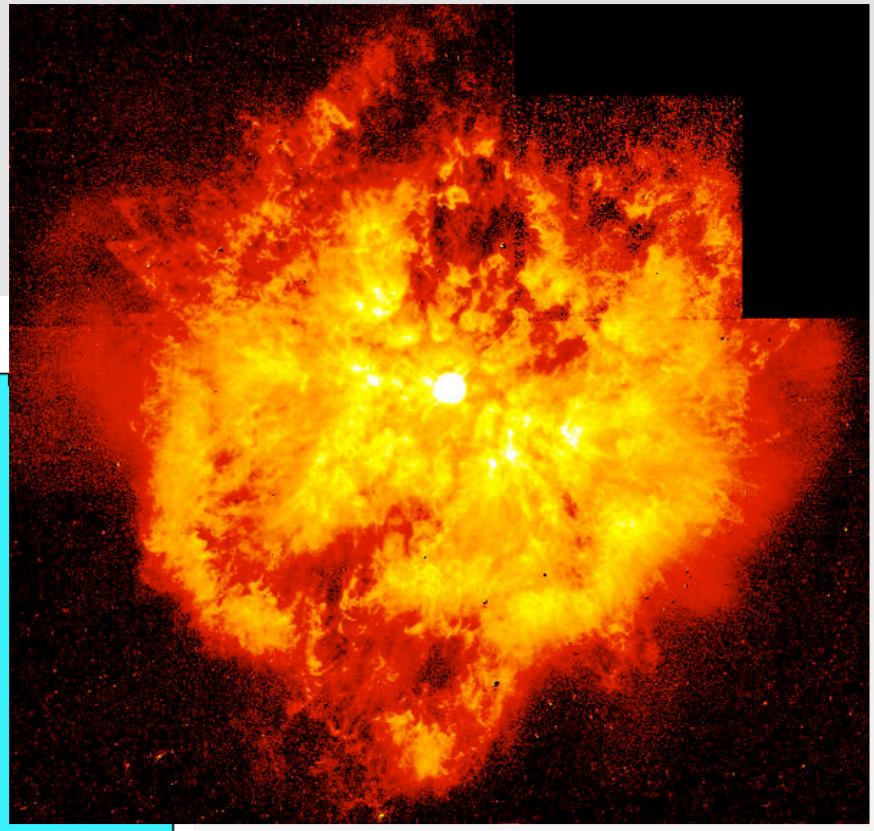
Long/Soft bursts:
- **Associated young host galaxies**
- **Core collapse supernova**
- **Massive, low-metalicity progenitors**

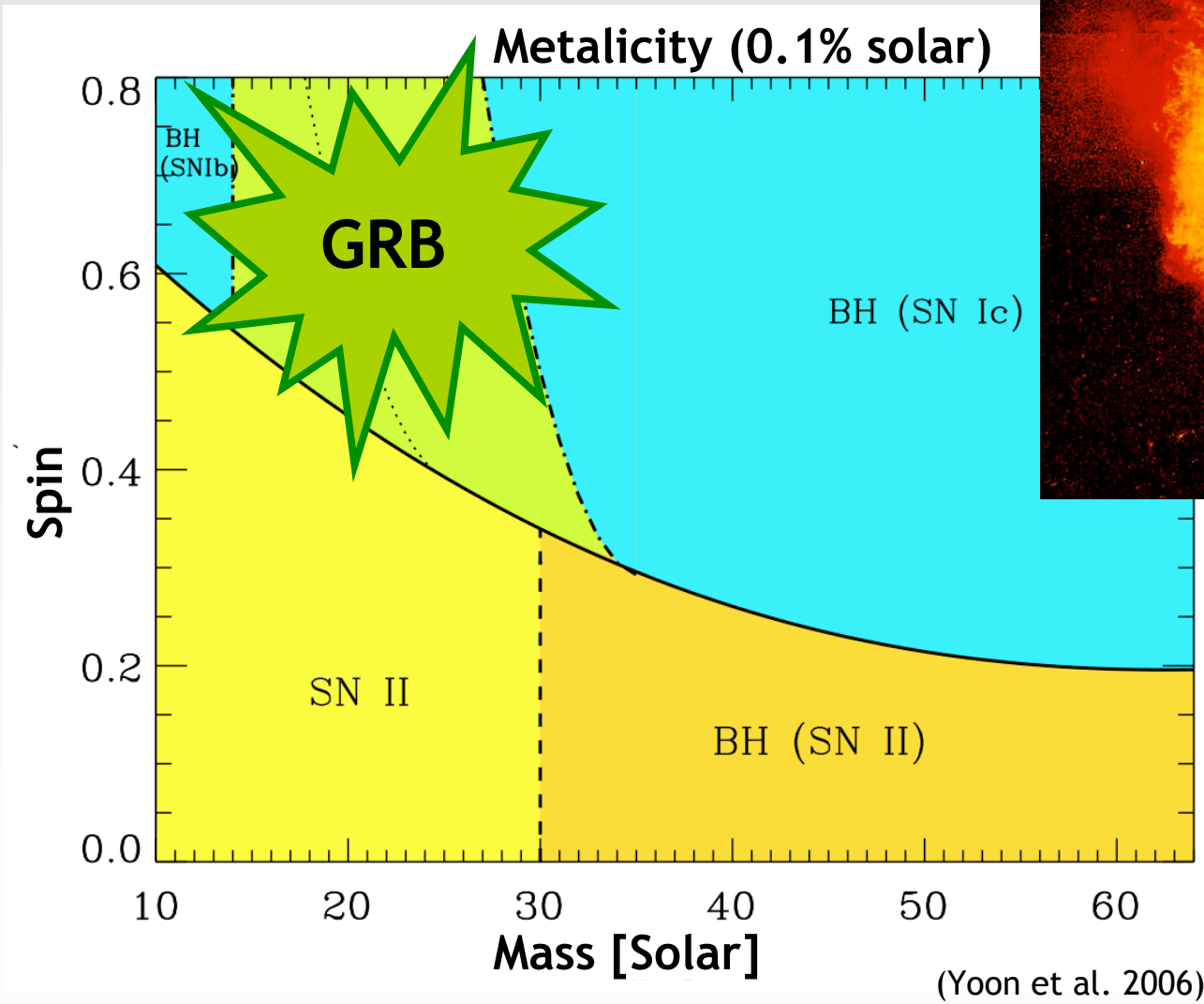


(Kouveliotiu et al. 1993)

Progenitors of long GRBs

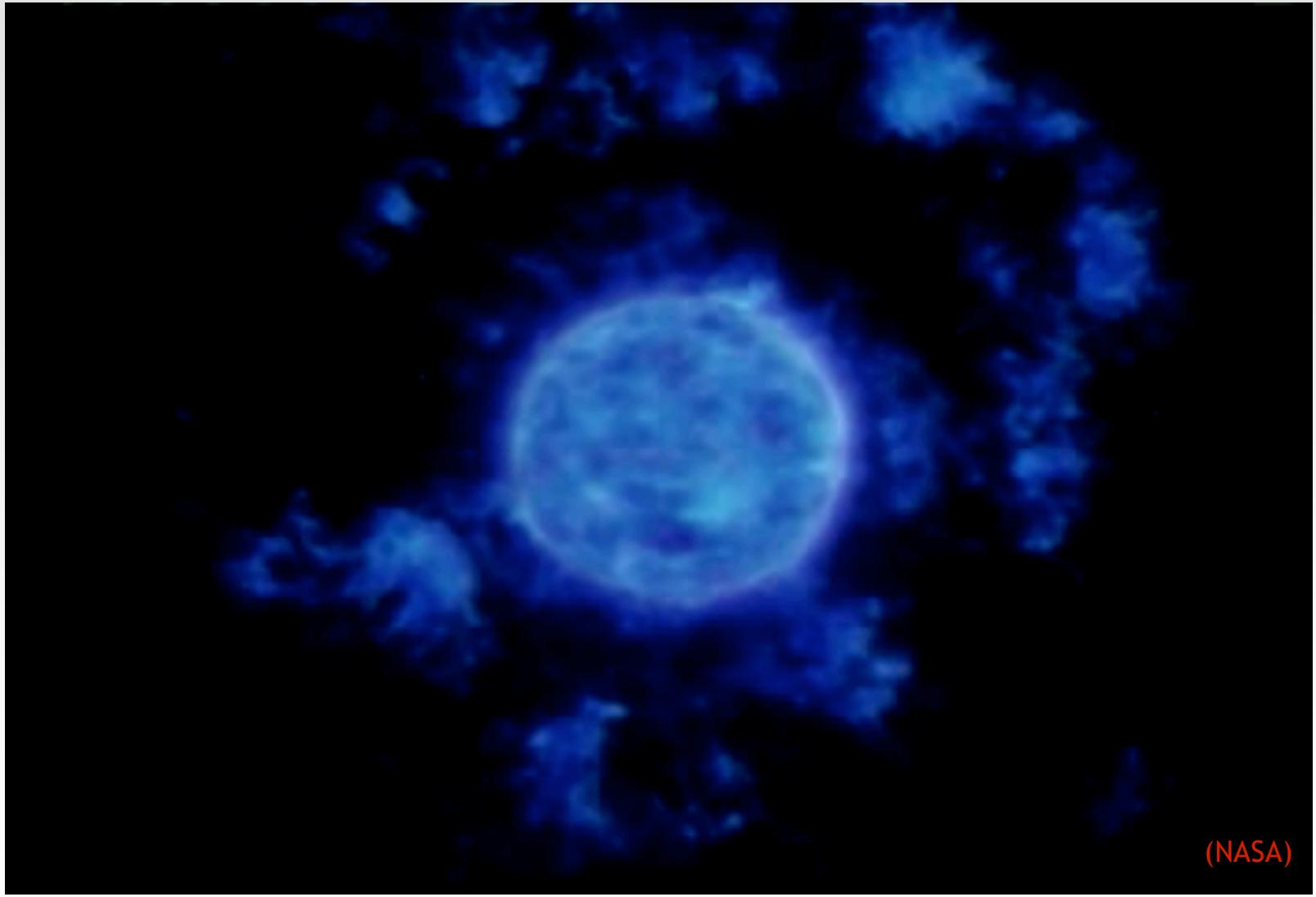
Collapse of massive, low-metalicity, rapidly-rotating **Wolf-Rayet stars** (Hot, massive, strong winds)



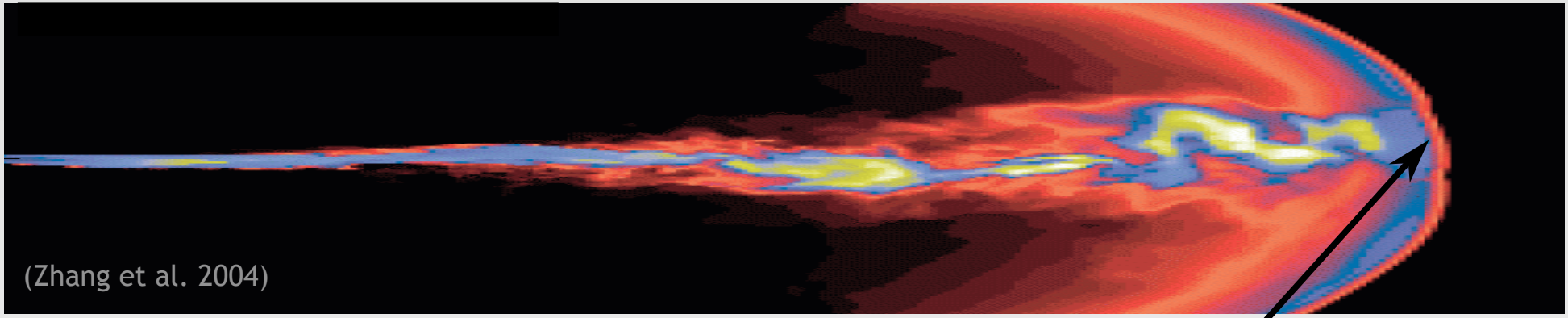


(Yoon et al. 2006)

Long GRBs: Collapsar & Supernova



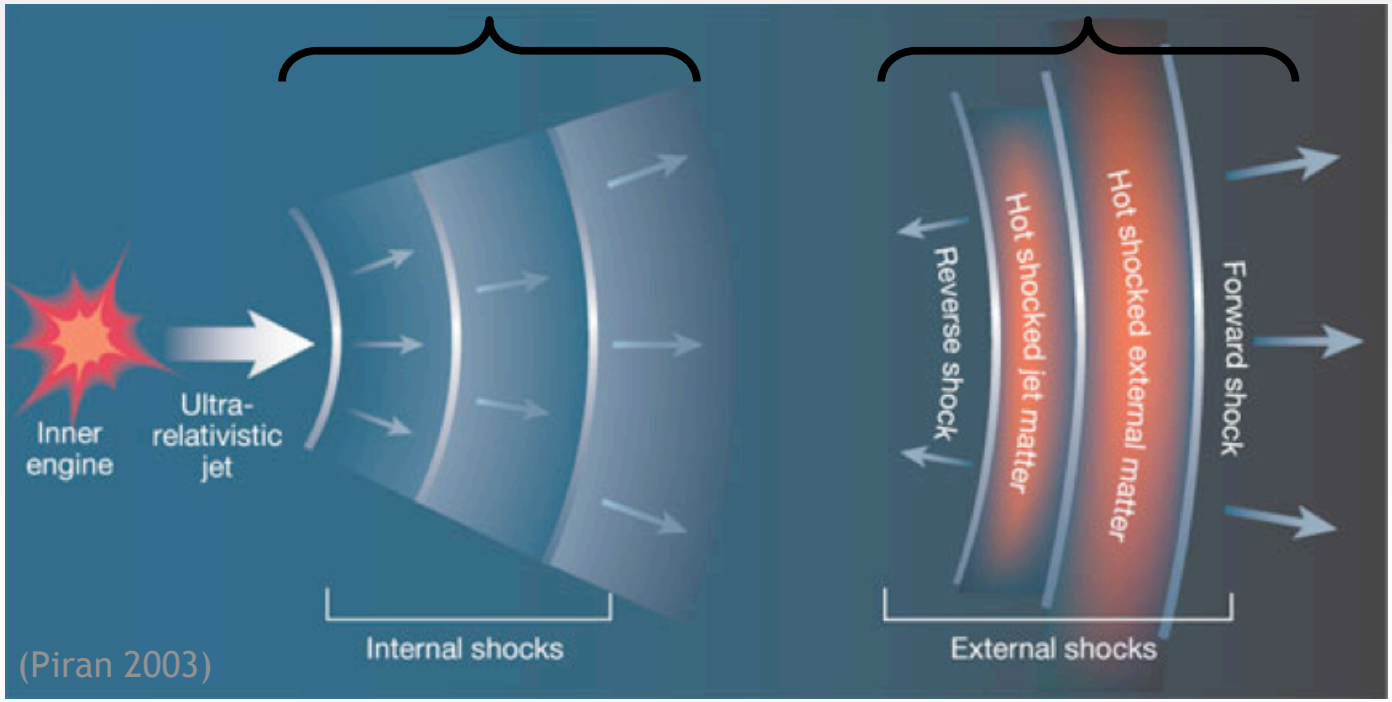
The blast wave



2 emission regions:

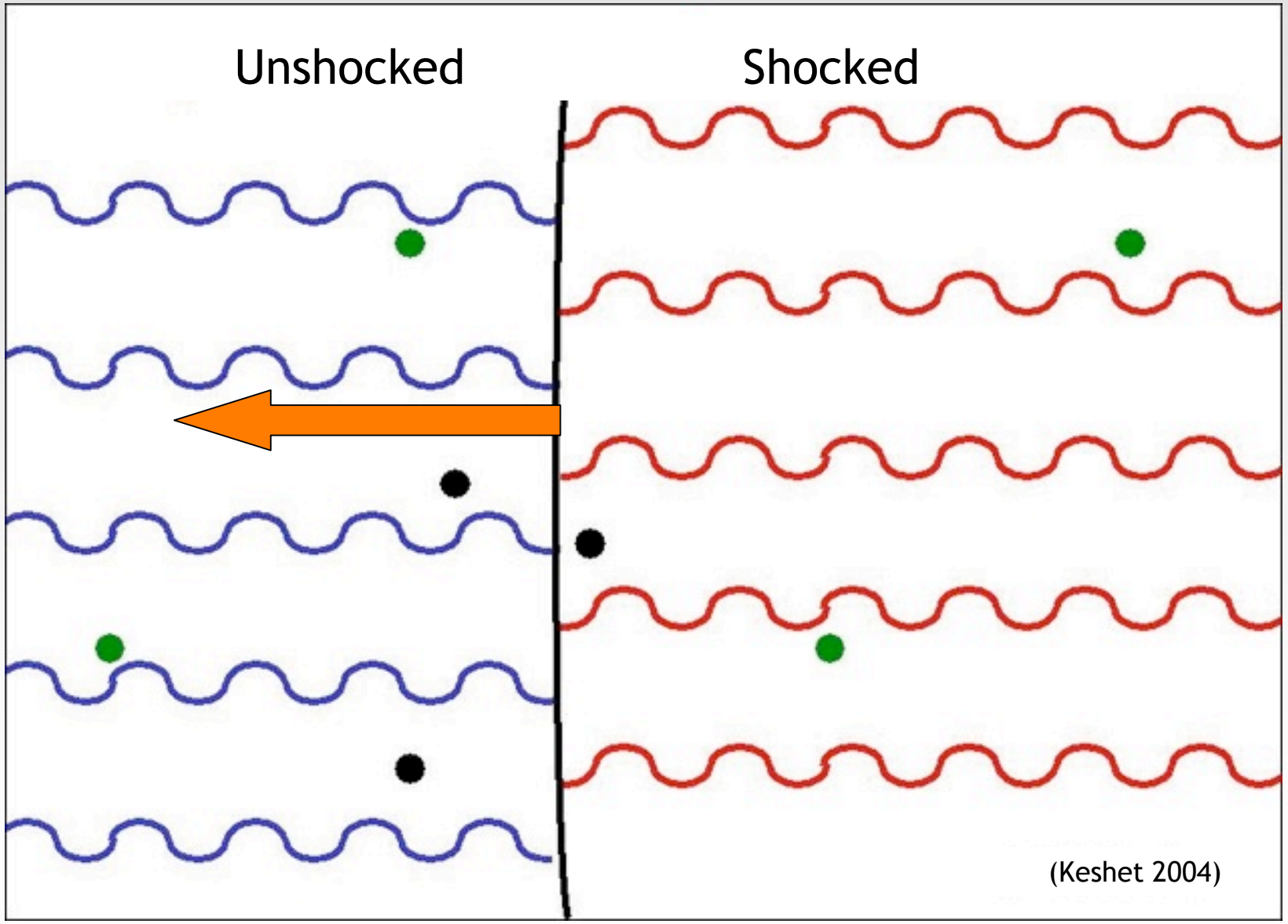
Internal shocks
γ-ray, X-ray

External shocks
X-ray, optical, radio



Fermi acceleration of electrons

Electrons are accelerated by shock…

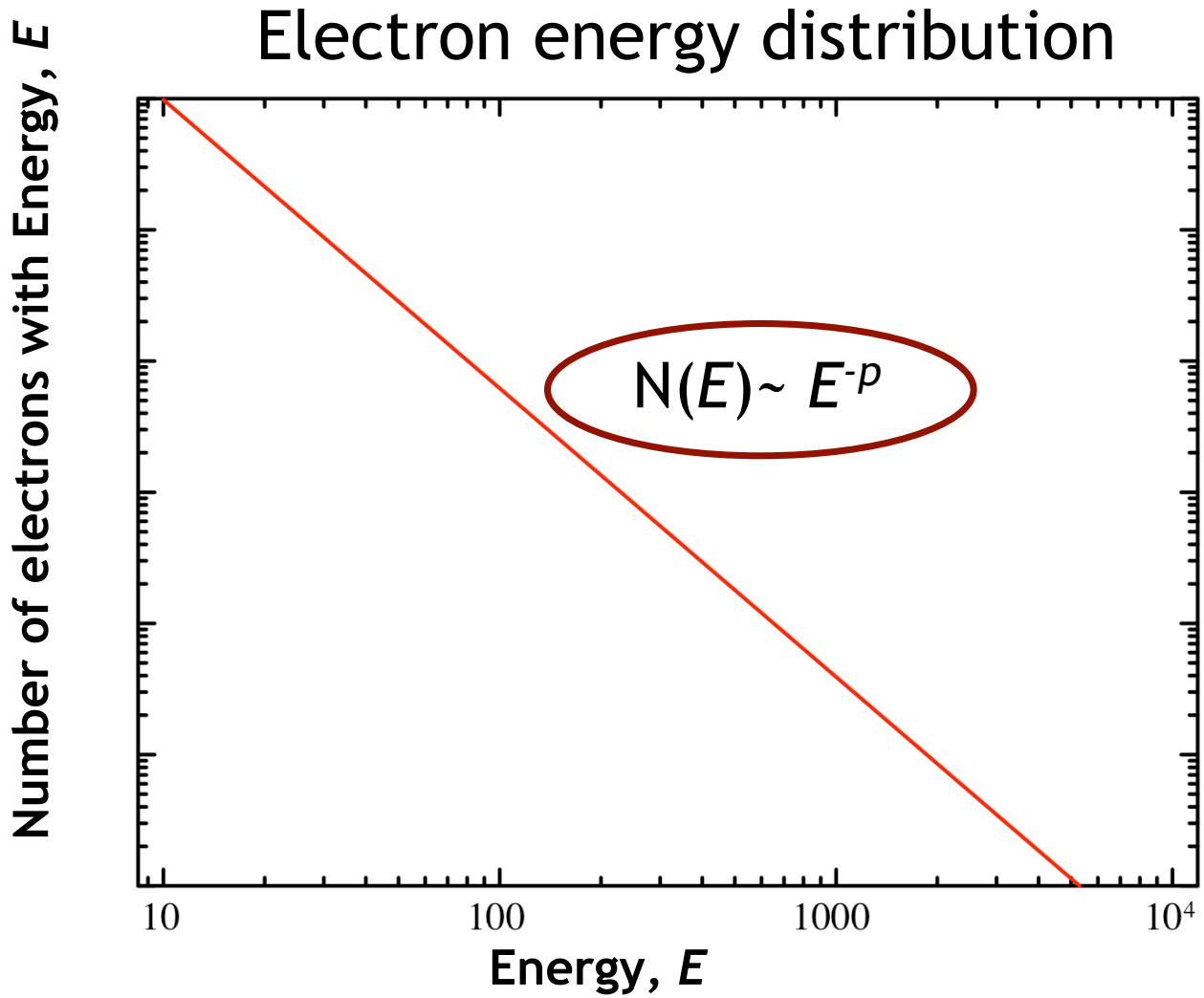


See http://www.cfa.harvard.edu/~ukeshet/Research.html for movie

Fermi acceleration of electrons

Electrons are accelerated by shock… to a certain distribution

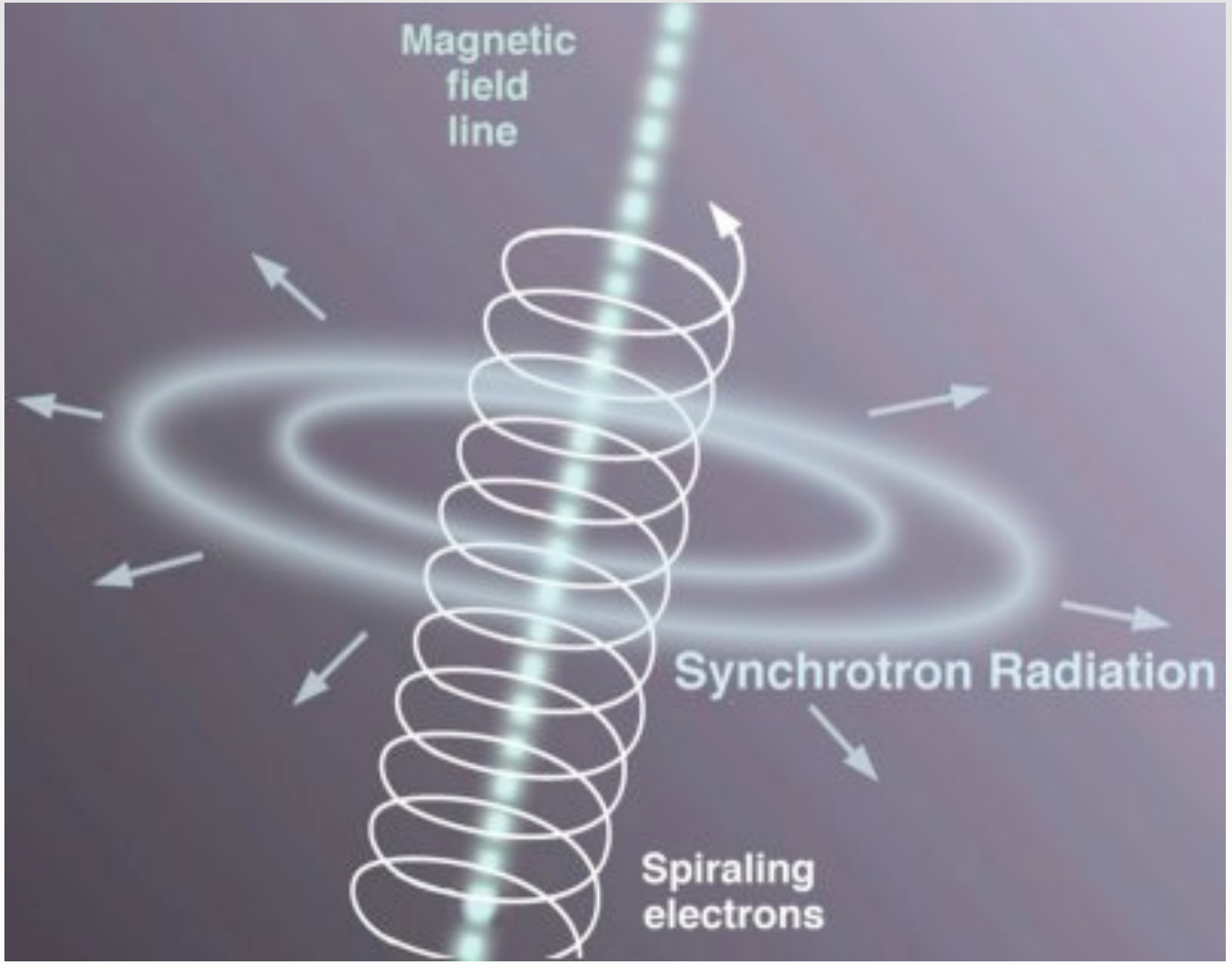
Value of *p* dependent on the underlying plasma physics!
Single value of *p*? Distribution of *p*? What distribution?



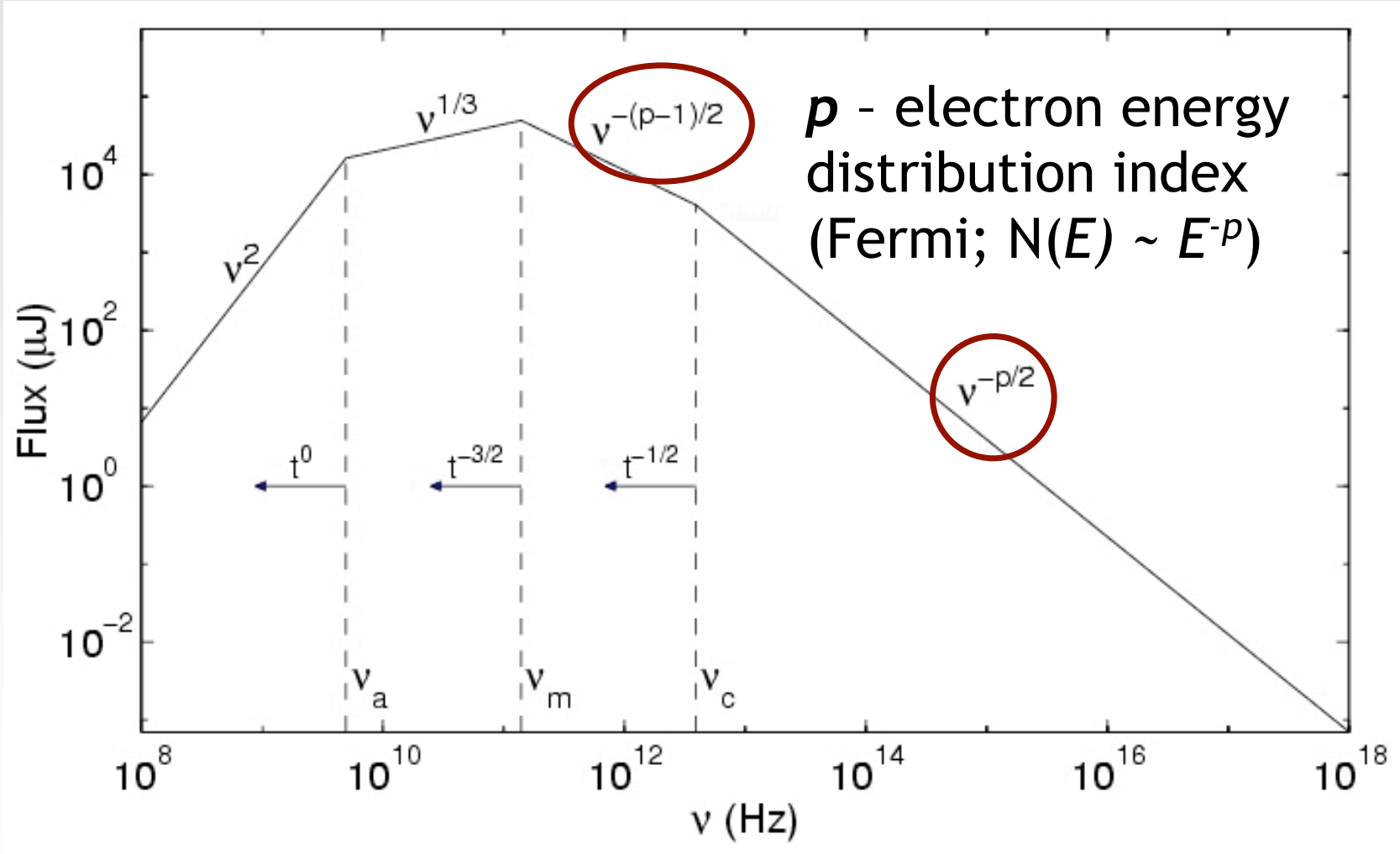
Synchrotron spectra

Accelerated electrons spiral in randomly structured magnetic field

$\Rightarrow$ emit via synchrotron radiation



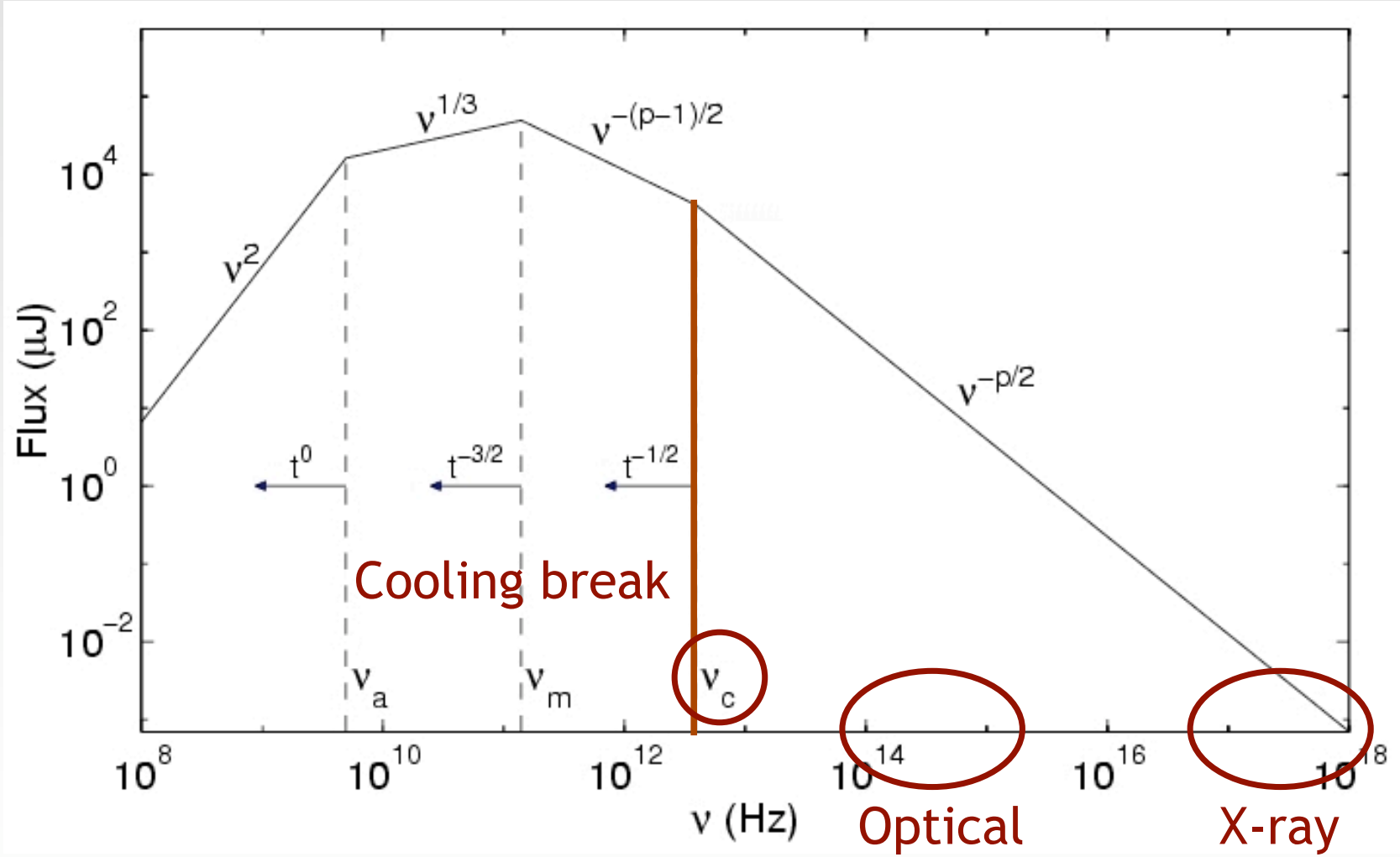
Synchrotron spectra



p – electron energy distribution index (Fermi; N(*E*) ~ E^{-p})

(Sari et al. 1998)

Synchrotron spectra



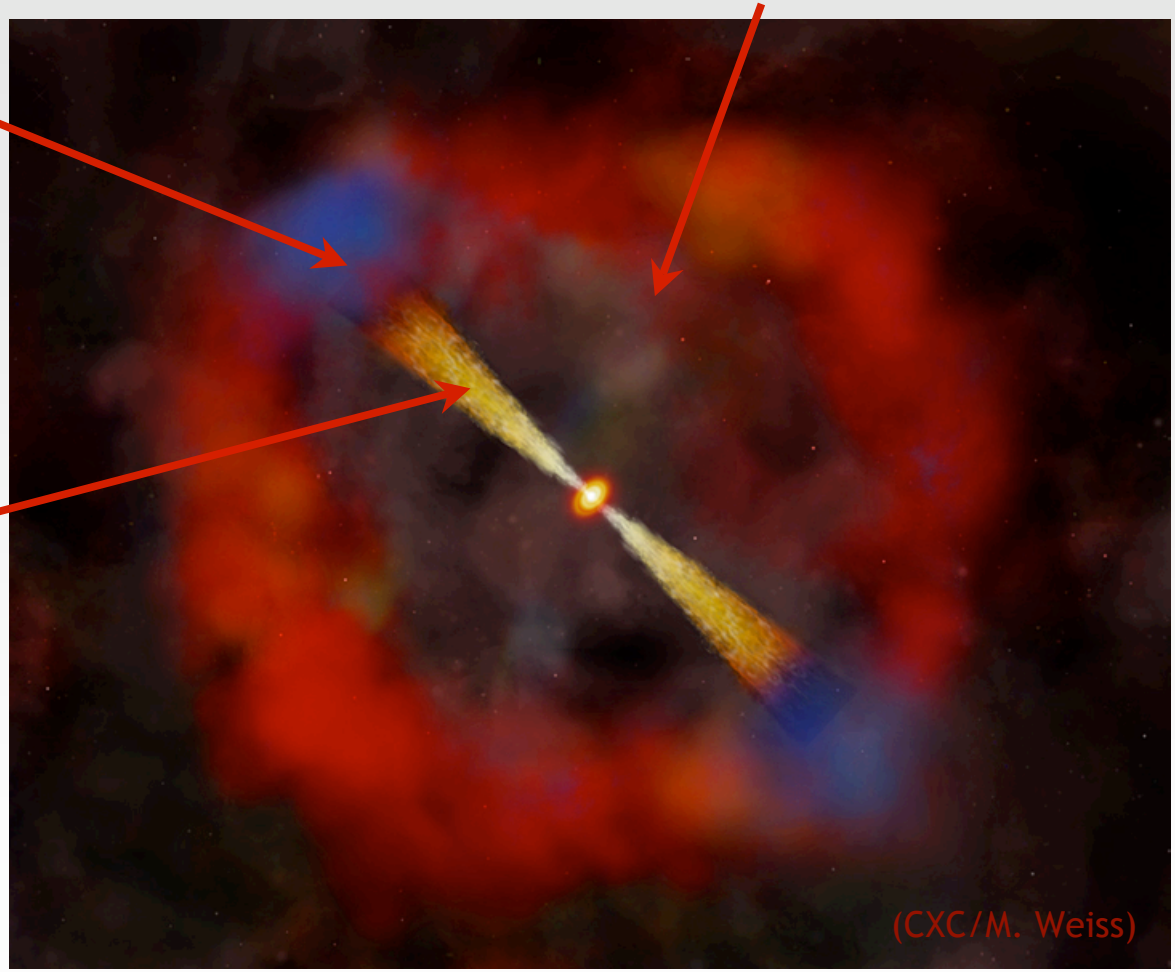
(Sari et al. 1998)

Other blast wave parameters

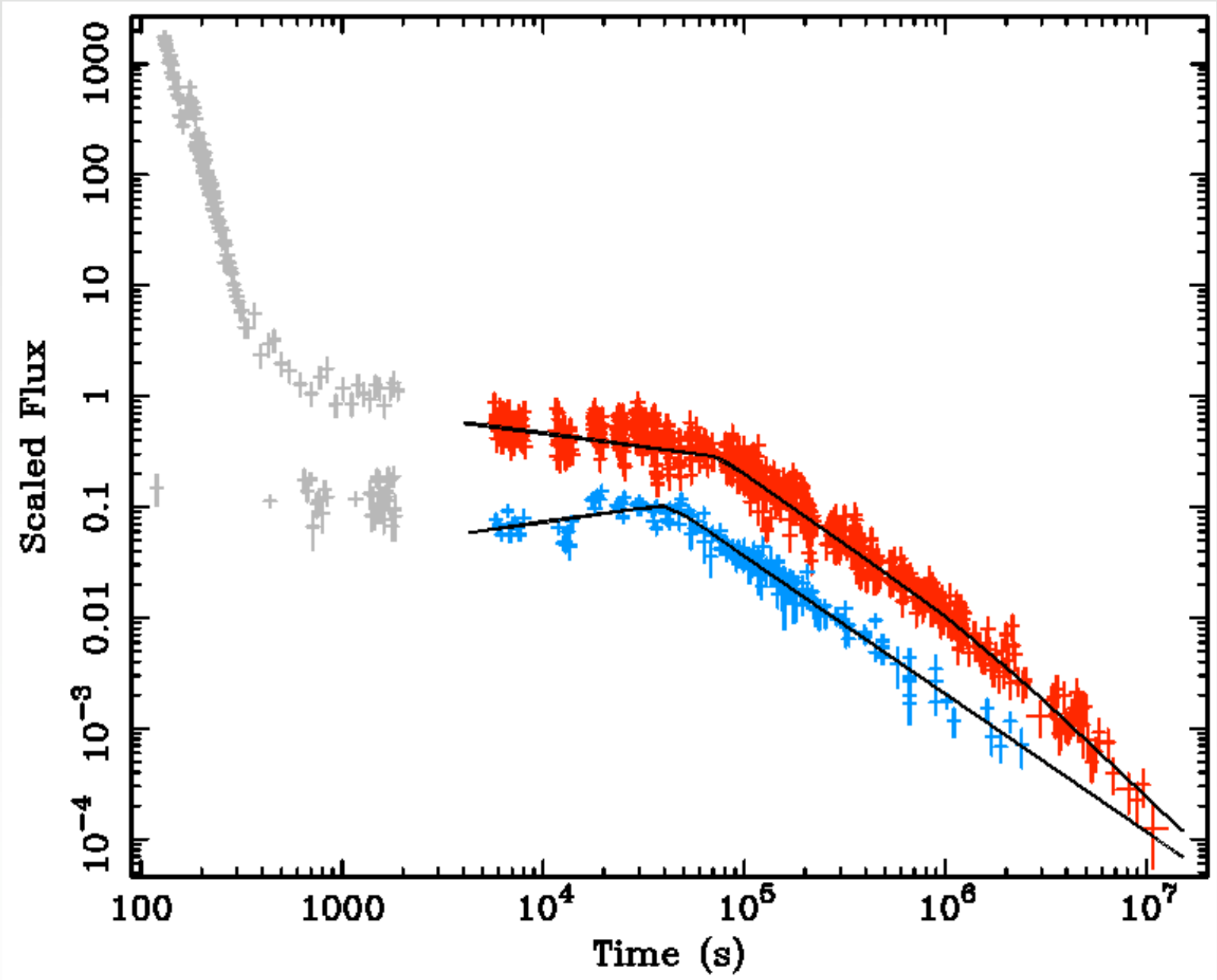
p – electron energy distribution index (Fermi; N(E) ~ E^{-p})

k – circumburst density profile ($\rho \sim r^{-k}$)

q – continued energy injection index ($E \sim t^{q}$)



Blast wave light curves



Derivation of p

Derivation of p

light curves → $p(\alpha, k, q)$ & accuracy of temporal fit

⇒ multiple options

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optical SED → $p(\beta_{opt},E_{B-V})$
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X-ray SED → $p(\beta_X,N_H)$
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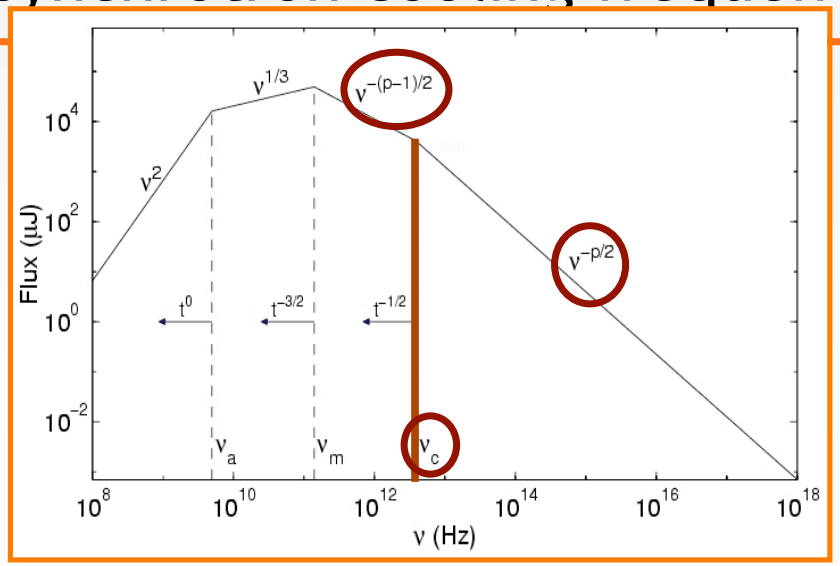
Derivation of p

light curves → $p(\alpha,k,q)$ & accuracy of temporal fit
⇒ multiple options

optical SED → $p(\beta_{opt},E_{B-V})$
⇒ multiple options

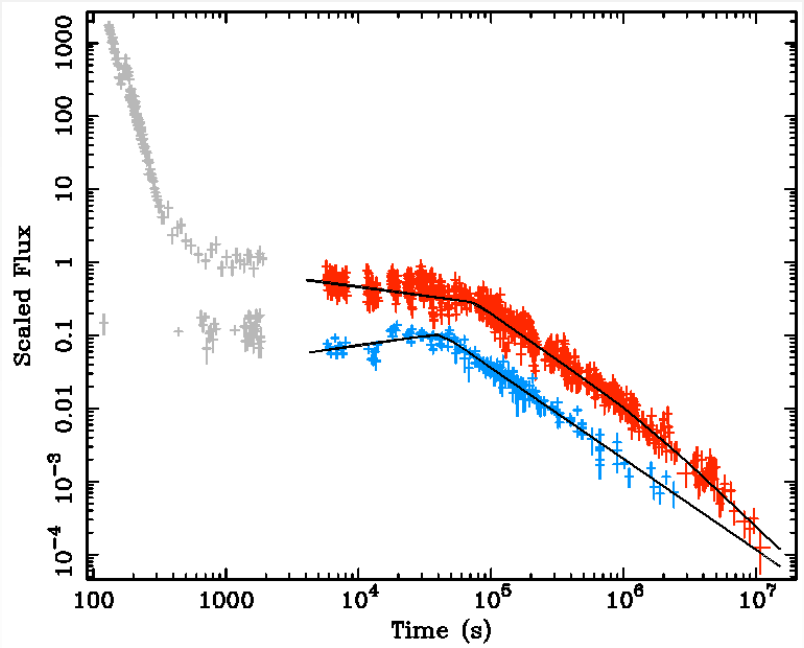
X-ray SED → $p(\beta_X,N_H)$
⇒ multiple options
⇒ synchrotron cooling frequency above/below



Predictions of p

Compare predictions of these values of *p* to light curves & spectra to:

- Decide which value of *p* is correct
- Test blast wave model
- Derive other blast wave parameters (*q*, *k*)

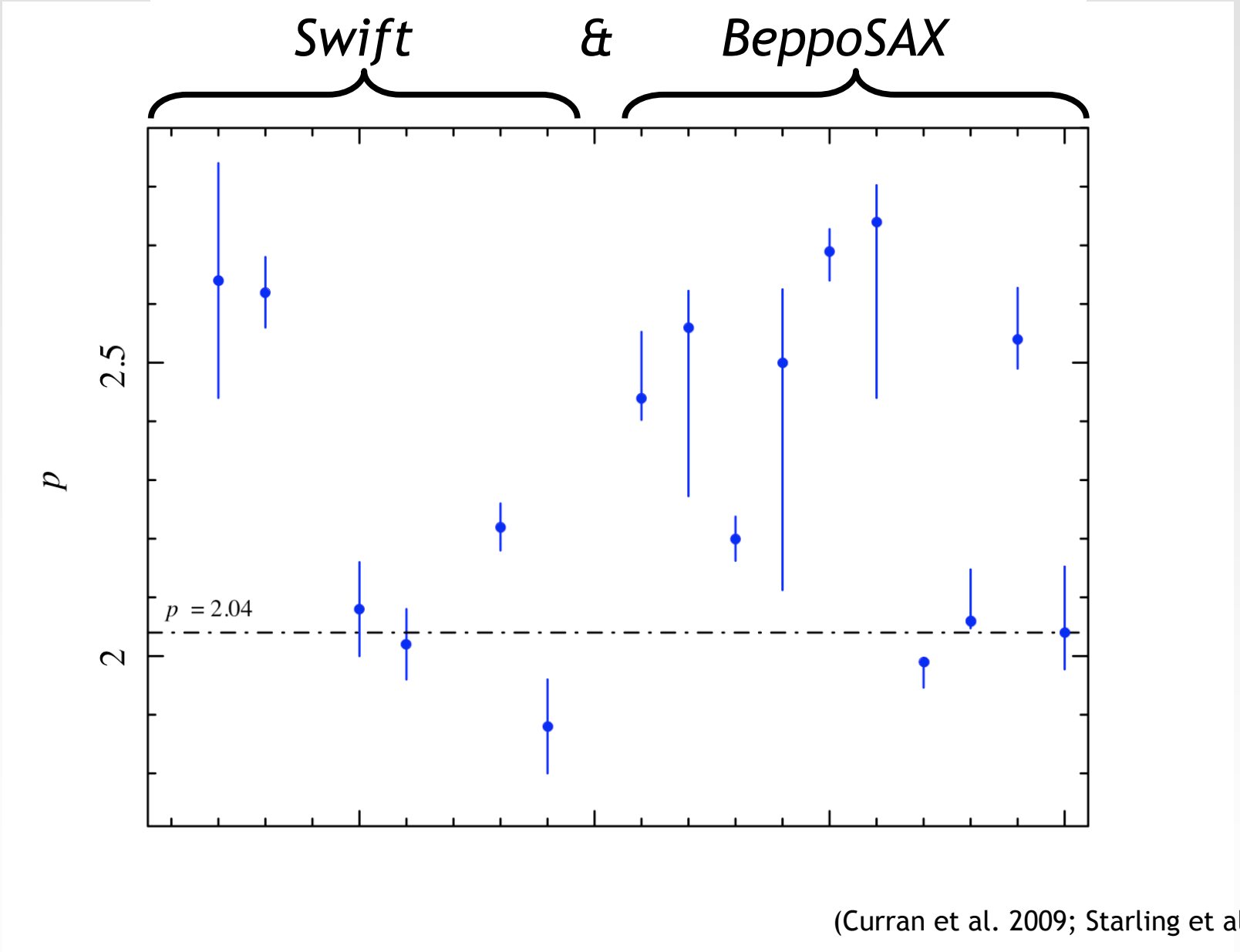


(Curran et al. 2009)

Electron energy distribution index, p

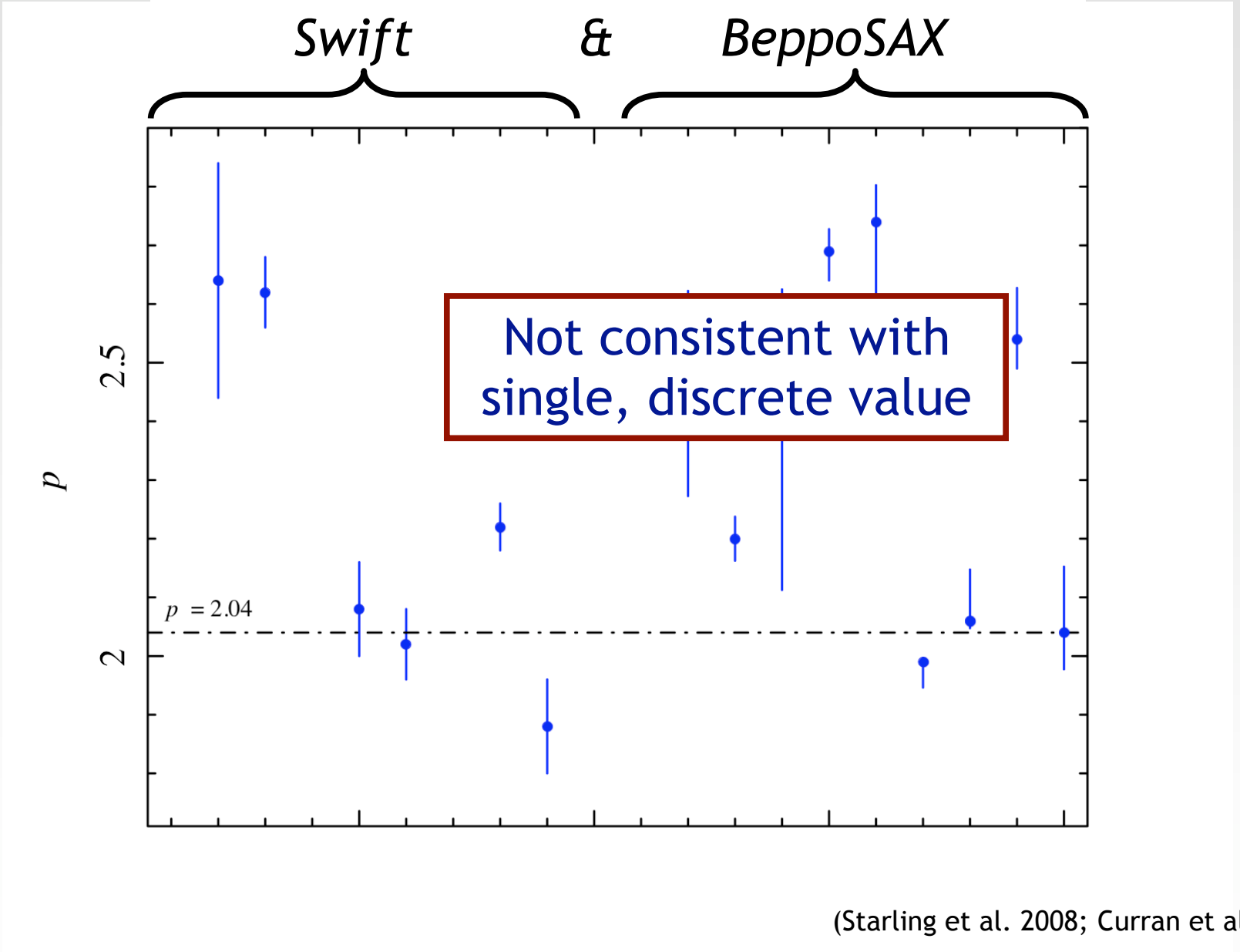
Discrete or distributed?

Distribution of p



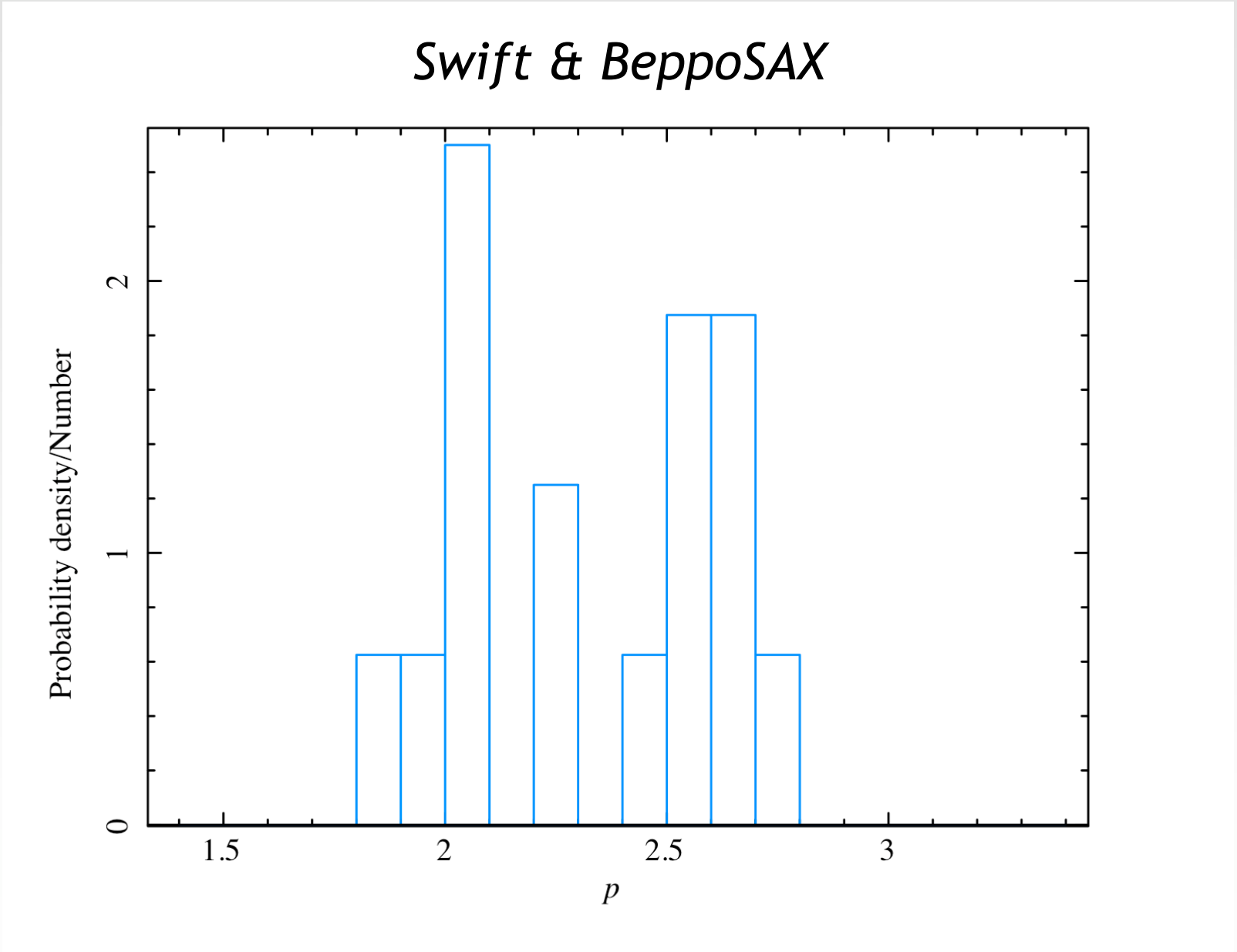
(Curran et al. 2009; Starling et al. 2008)

Distribution of p

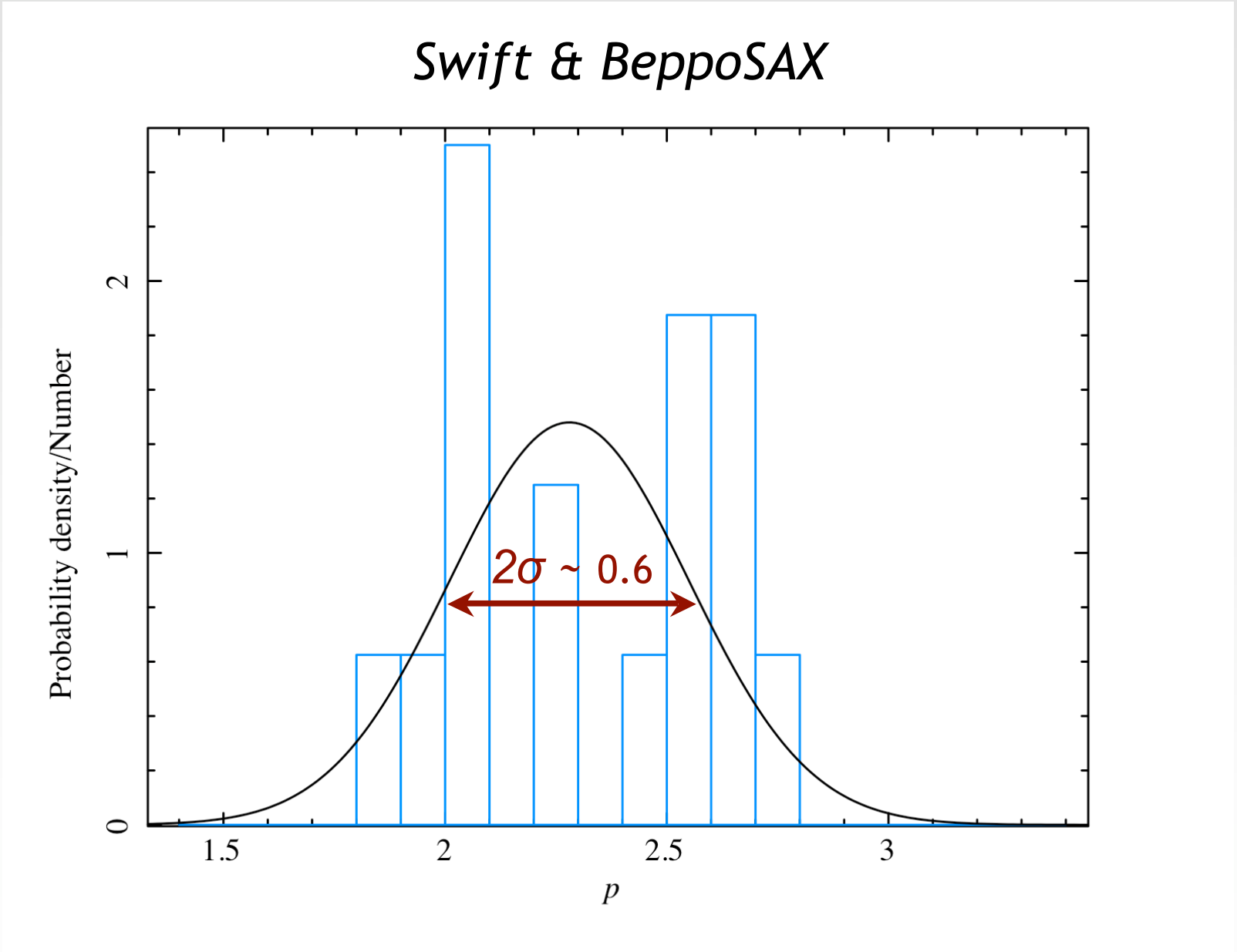


(Starling et al. 2008; Curran et al. 2009)

Distribution of p

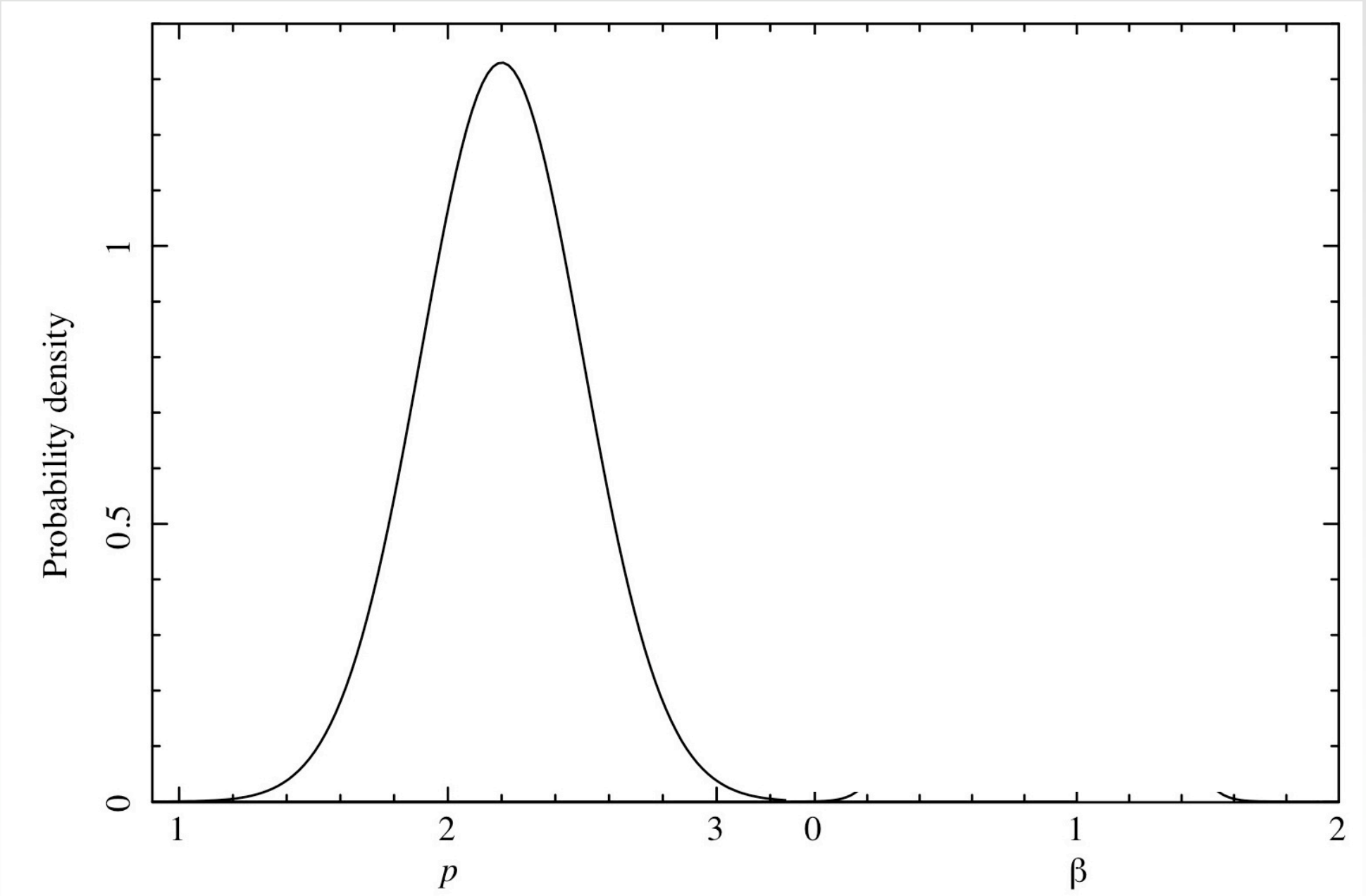


Distribution of p

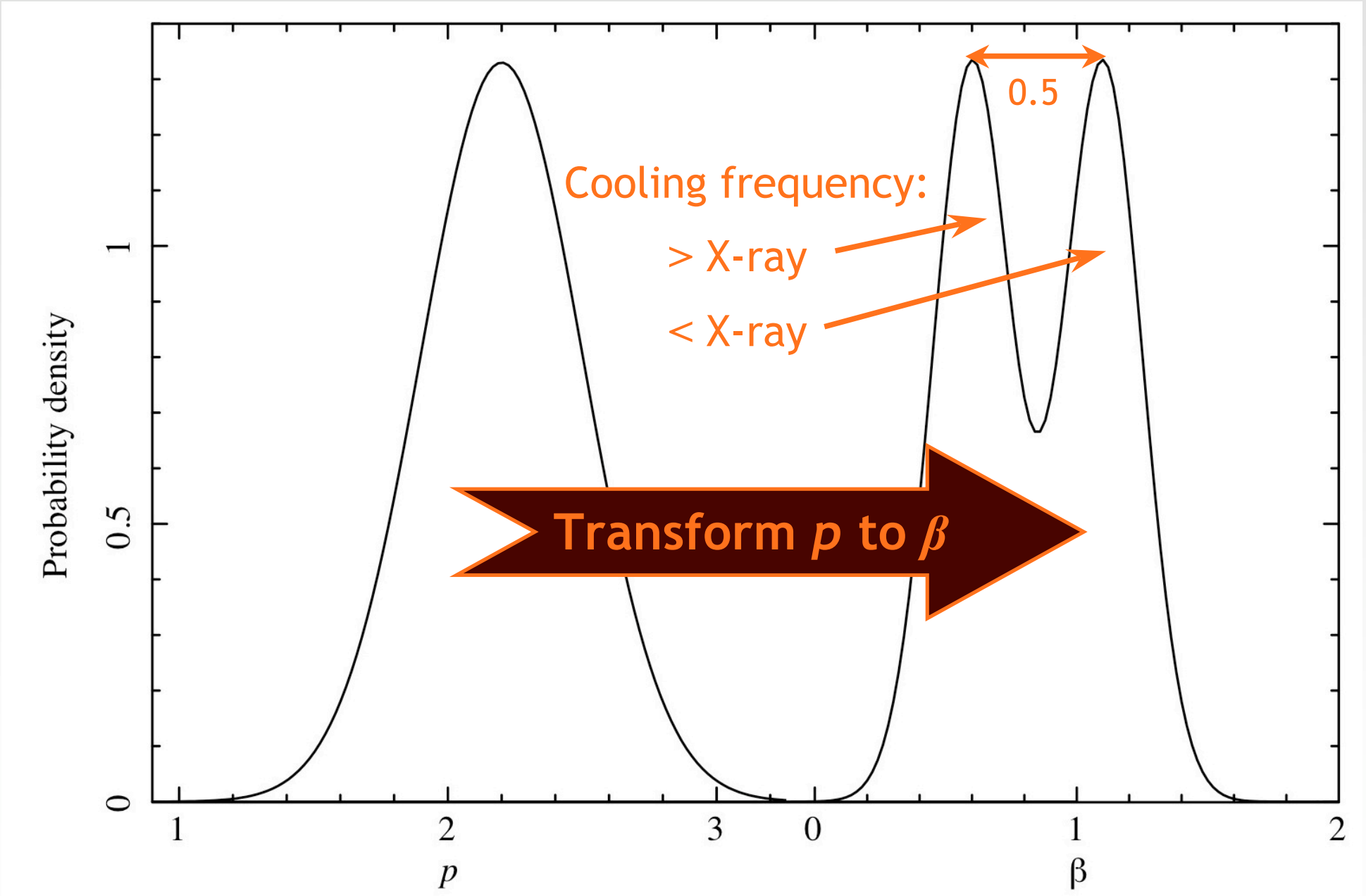


Distribution of X-ray spectral index, β_X

Transforming p to β_x

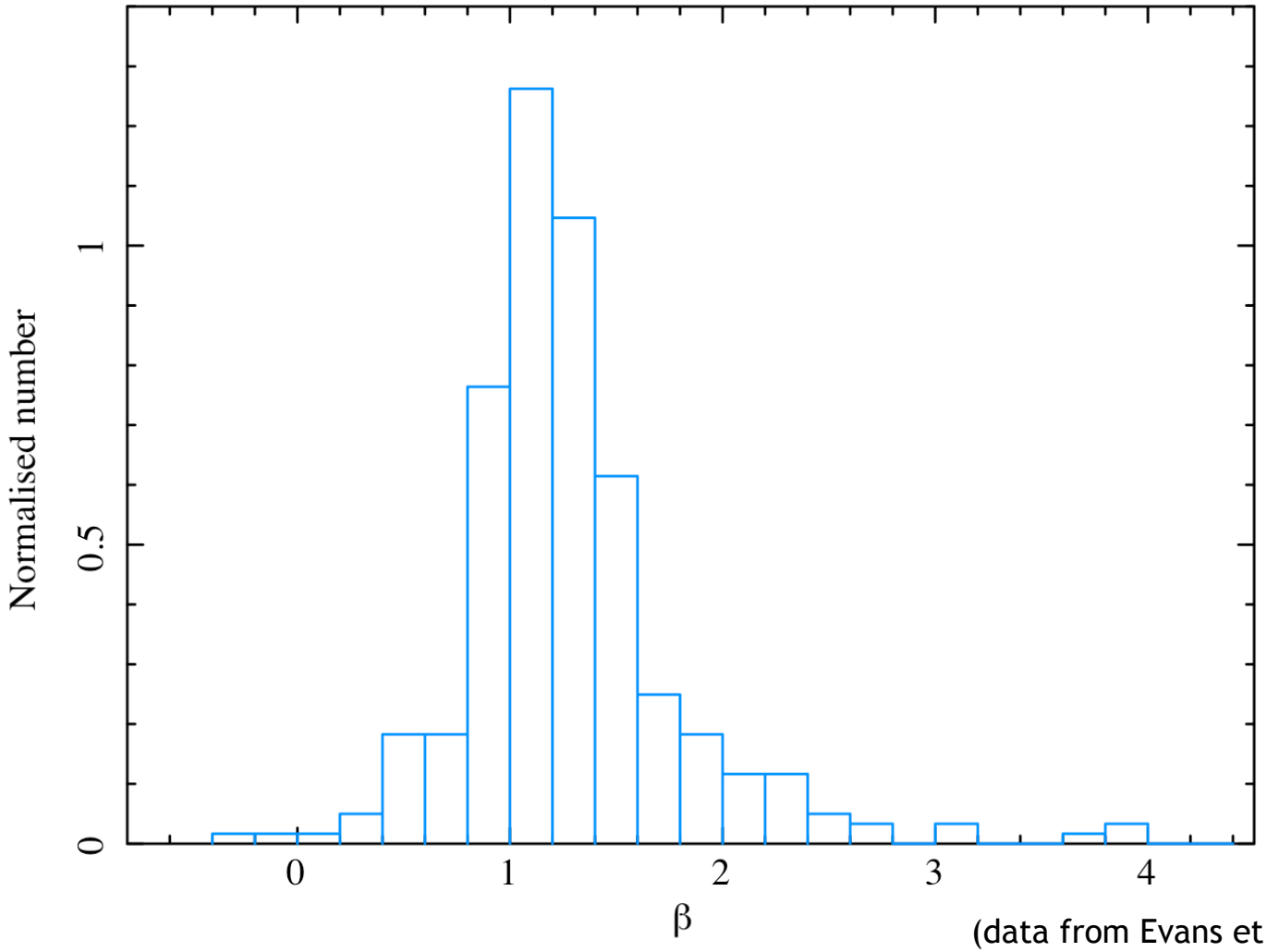


Transforming p to β_X



Distribution of spectral index, β_X

Swift XRT (~300 bursts)



(data from Evans et al. 2009)

Distribution of spectral index, β_X

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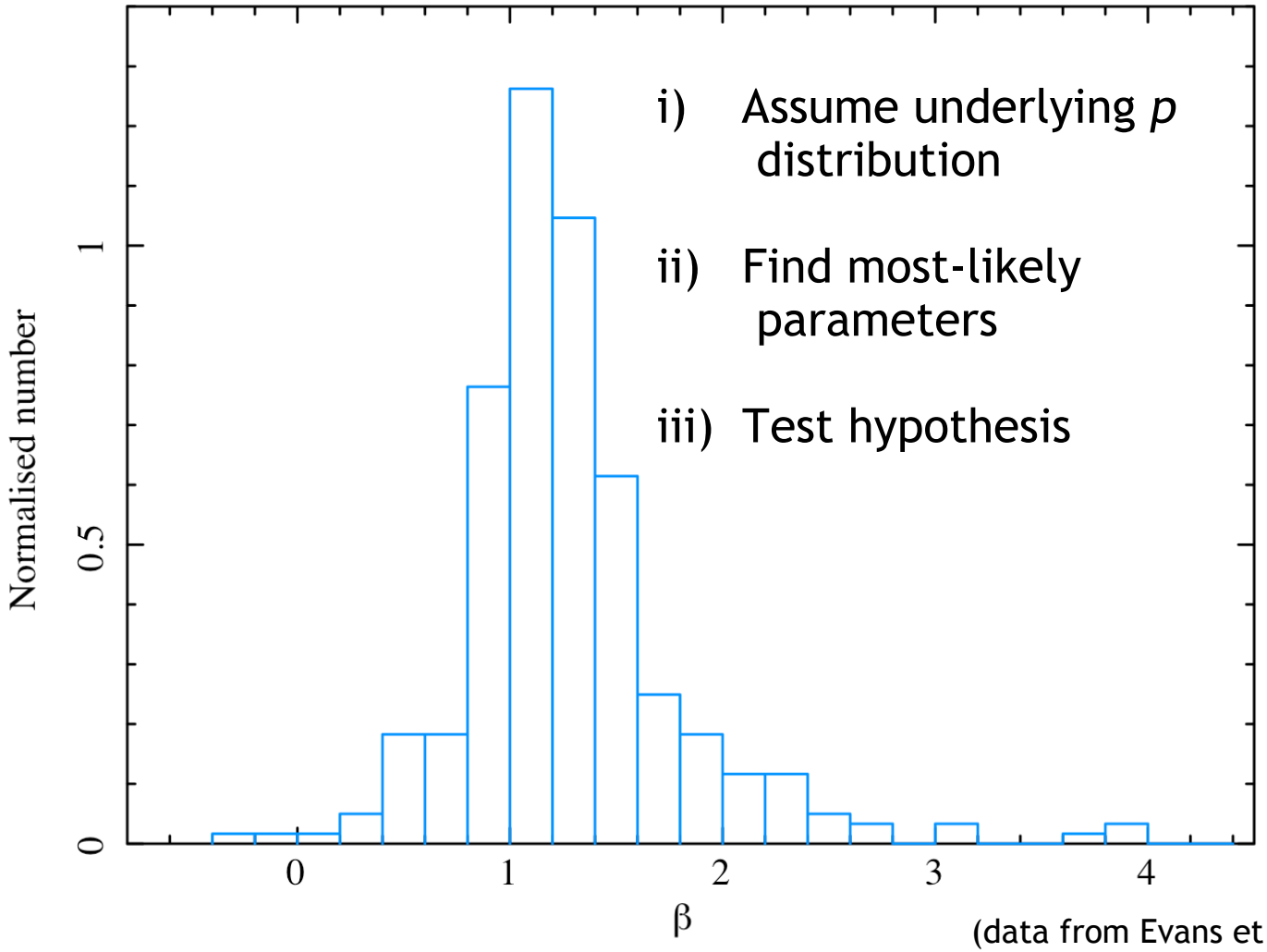

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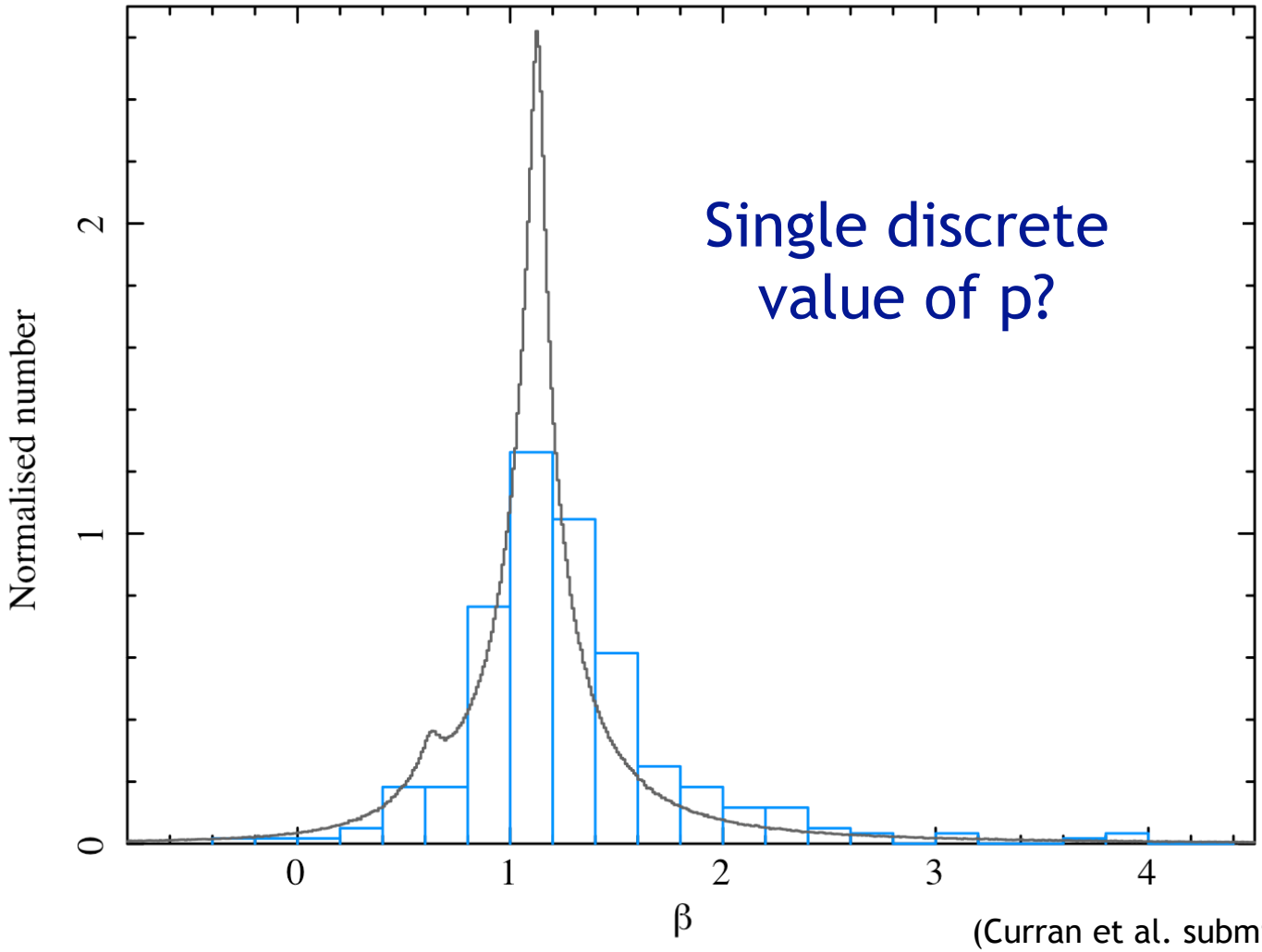

(Curran et al. submitted)

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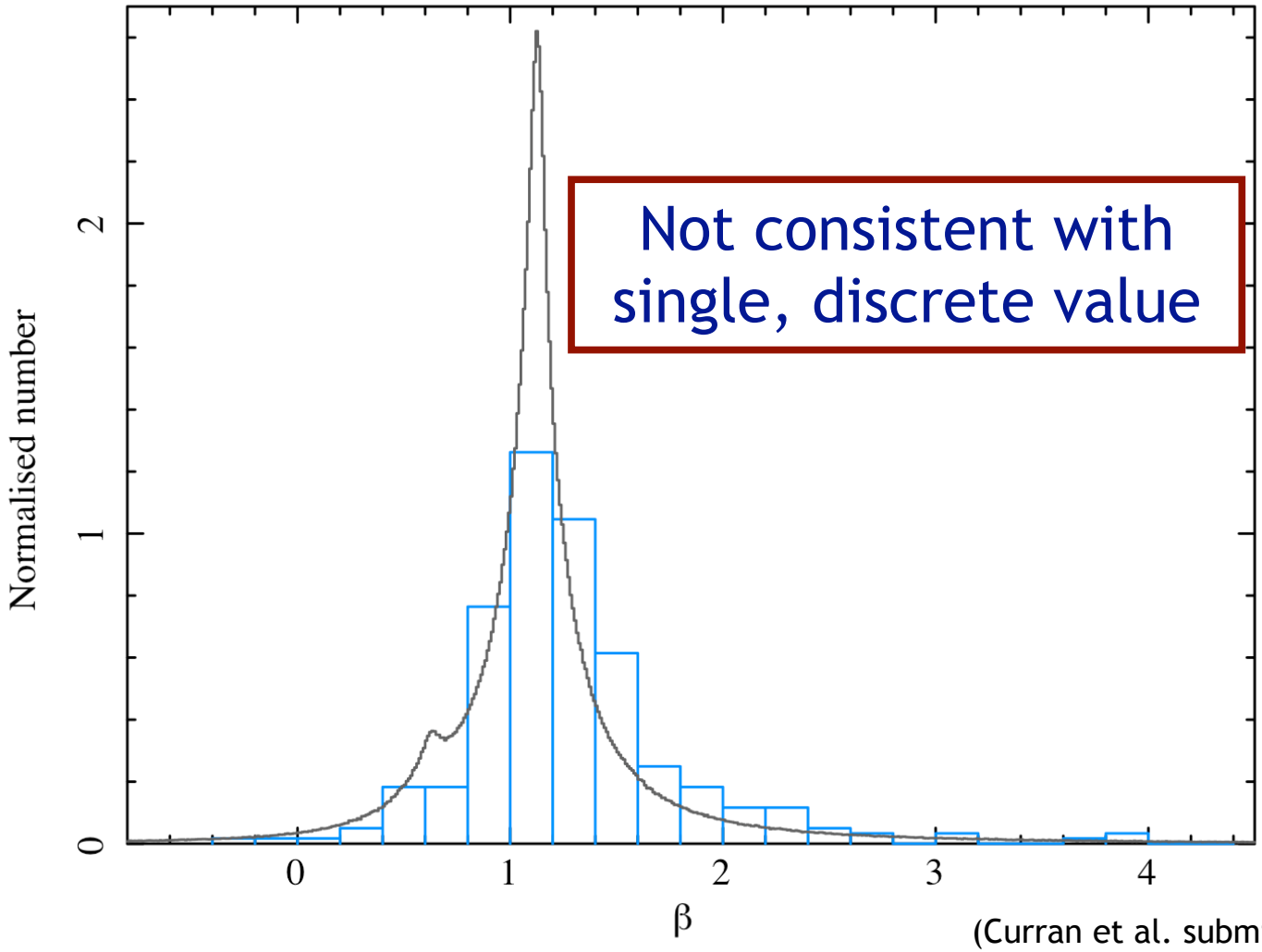

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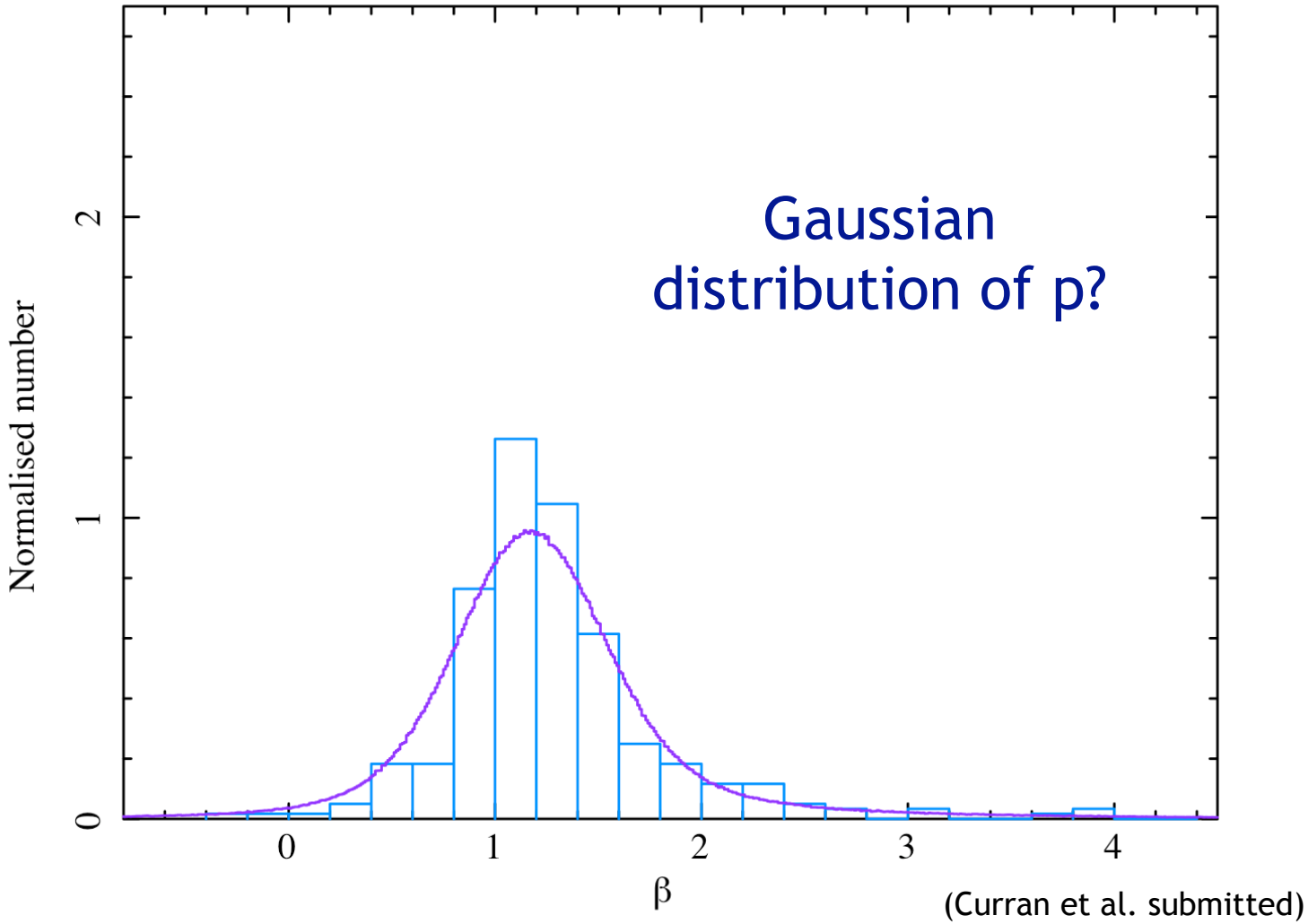

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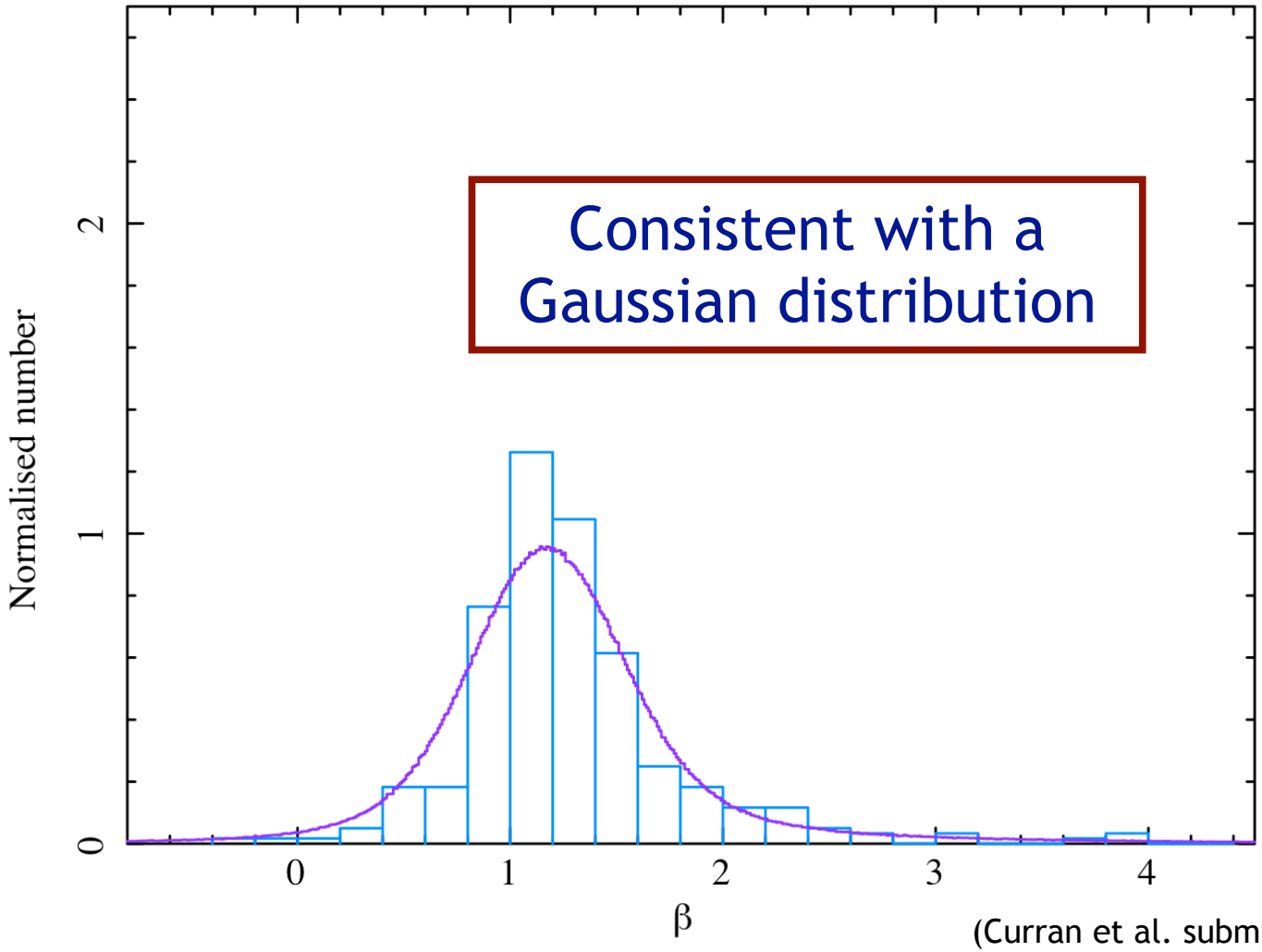
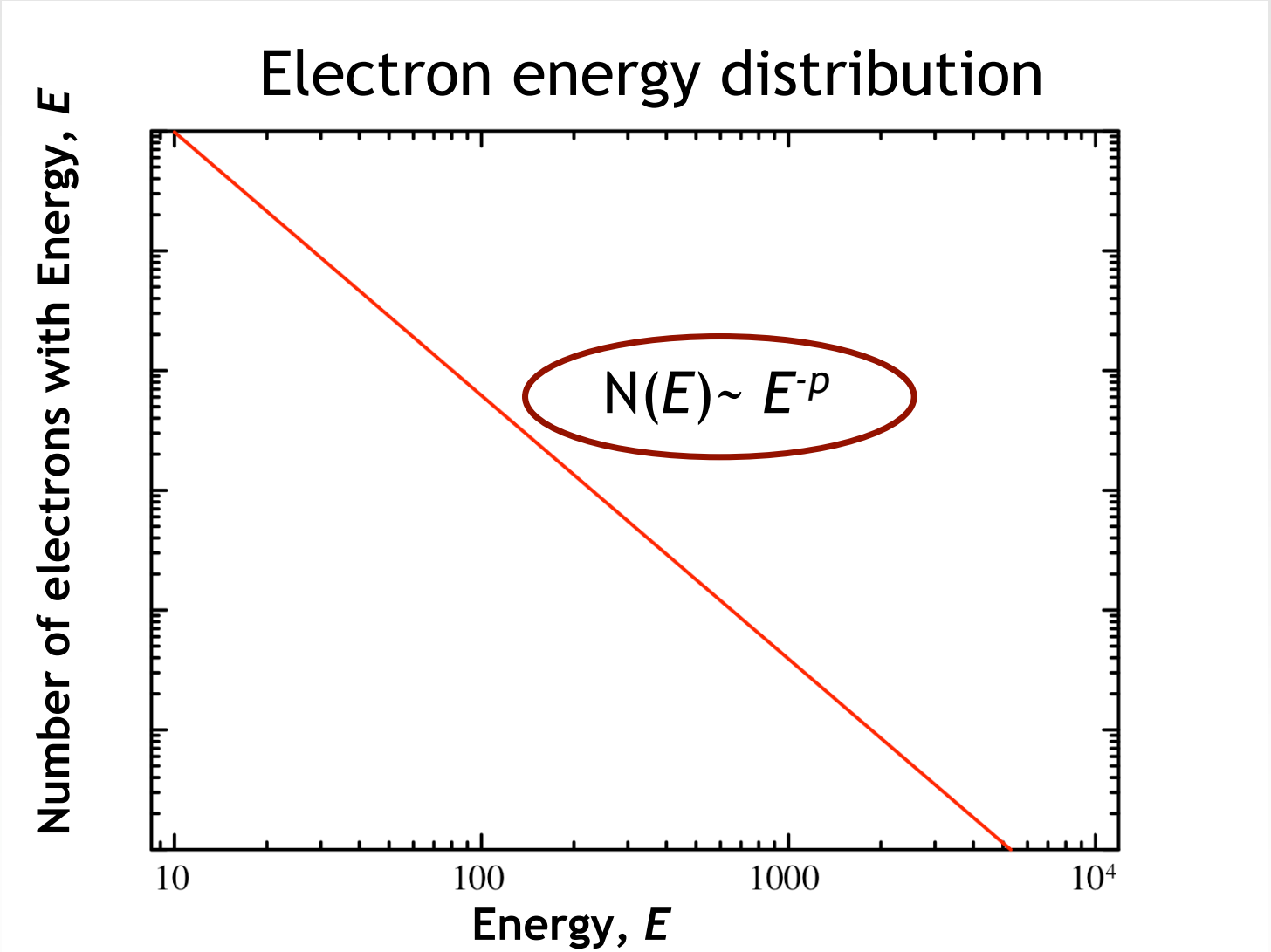


(Curran et al. submitted)

Fermi acceleration of electrons

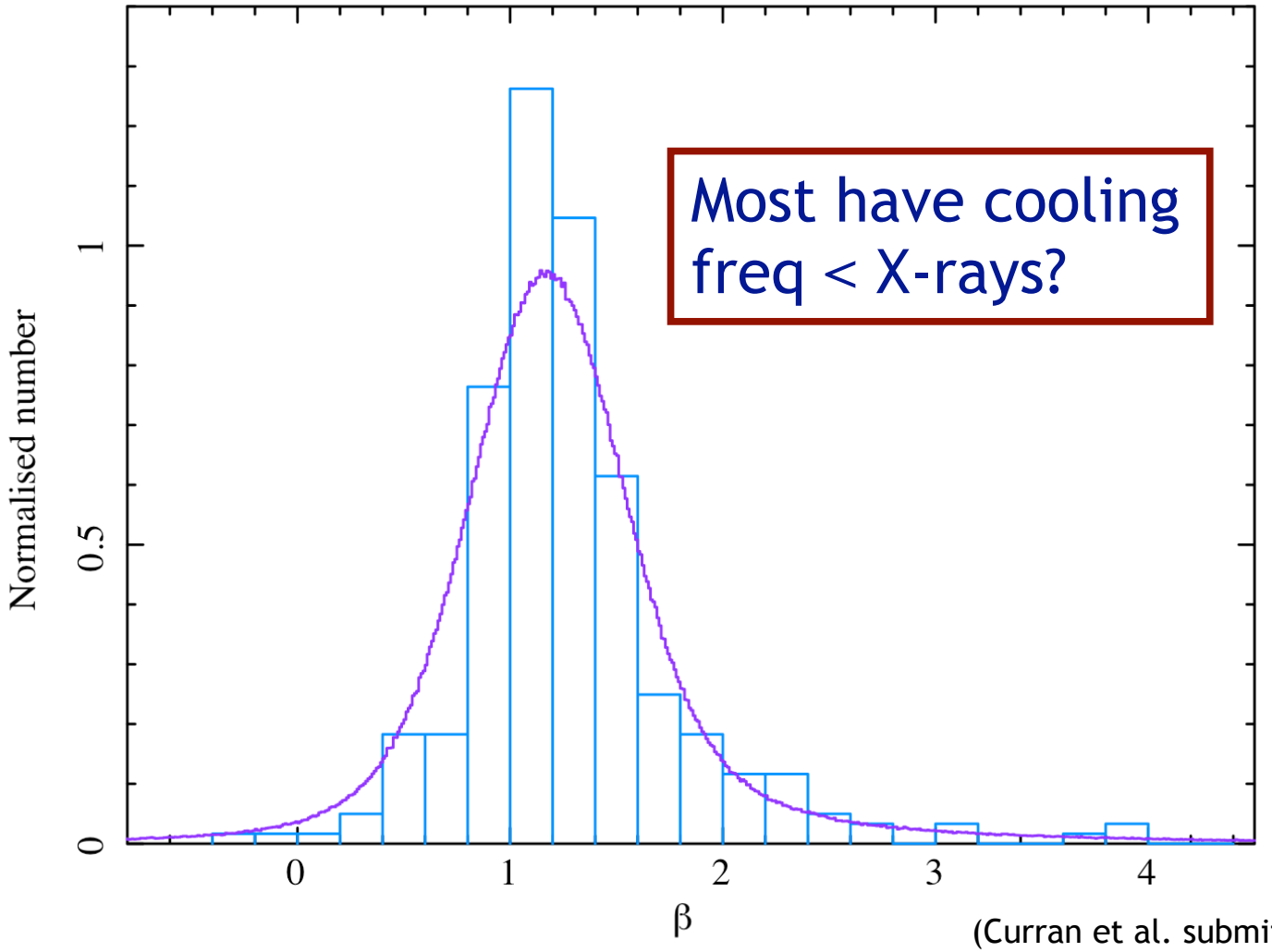
Q: Single value of *p*? Distribution of *p*? What distribution?

A: Gaussian distribution at p=2.39 and standard deviation, σ=0.6



Why only 1 peak?

Swift XRT (~300 bursts)



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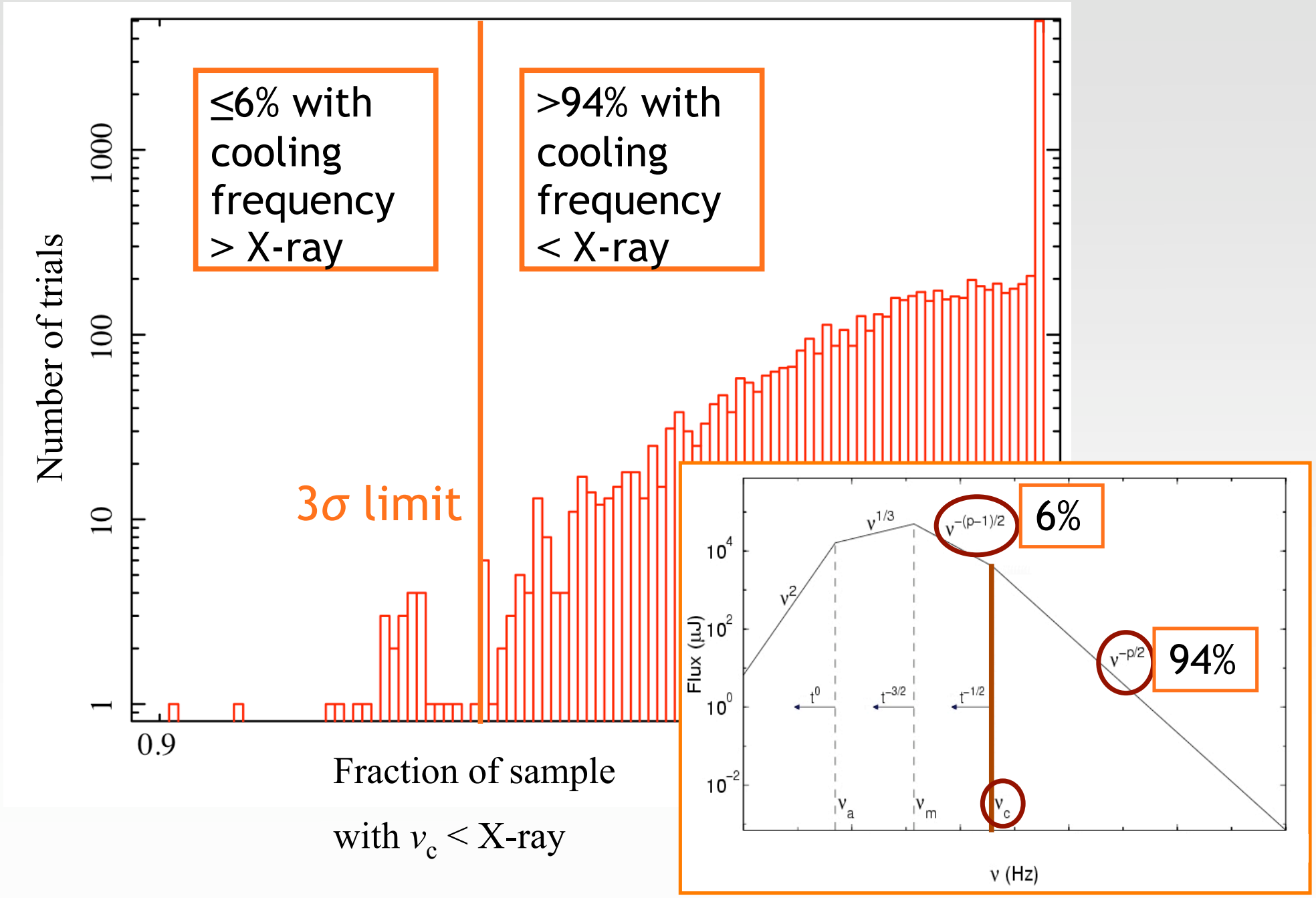
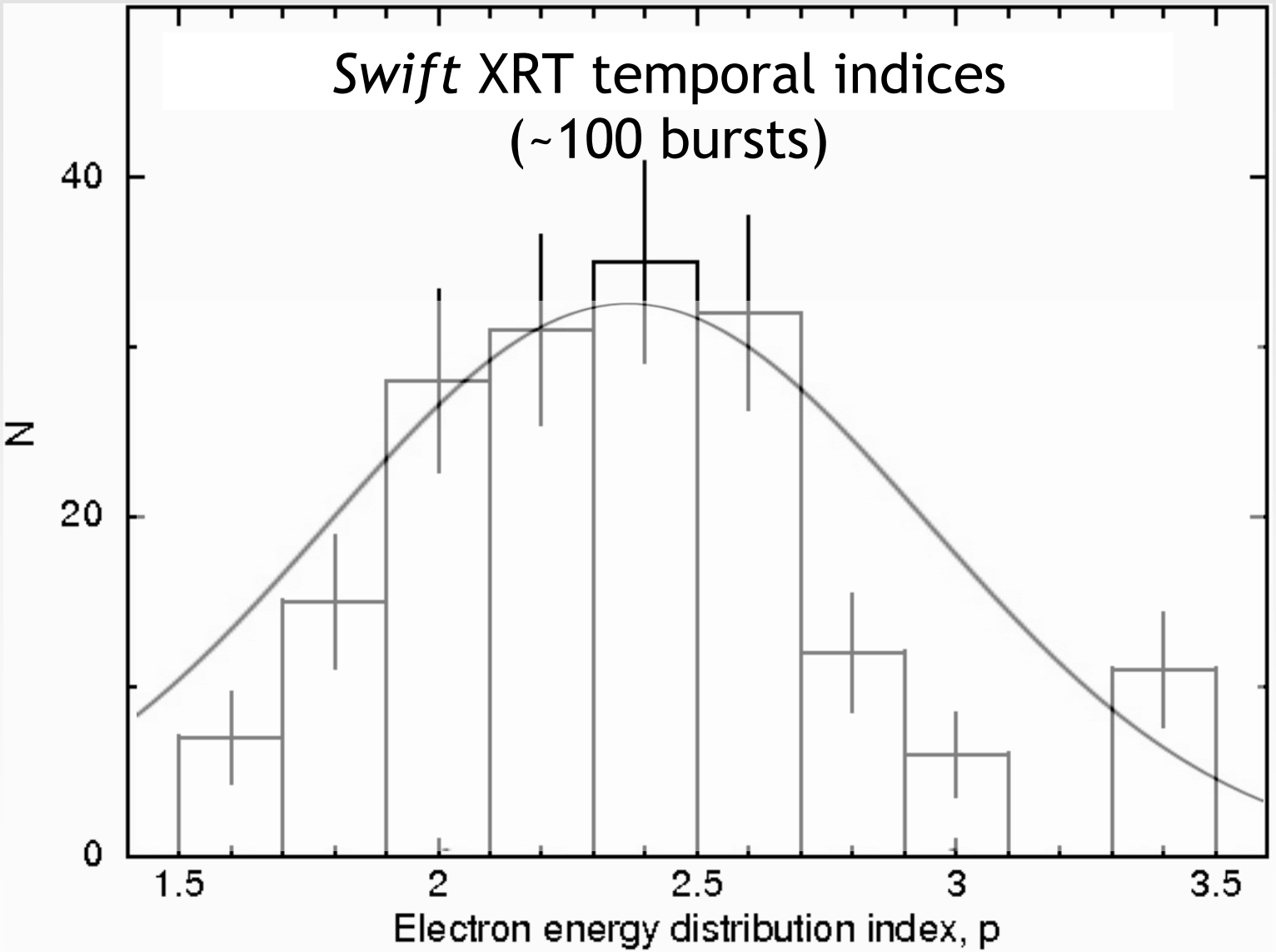


Distribution of p

…by a totally independent method



(Evans et al. in preparation)

Conclusions

- ***GRBs probe plasma physics 13 billion light years away… as well as general relativity, cosmology & electromagnetism!***
- *The blast wave model explains GRBs quite well*
- ***p** is <u>not</u> consistent with a single, discrete value*
- ***p** is consistent with Gaussian of $p \sim 2.35$, $\sigma \sim 0.6$*
- *94% of GRBs: cooling frequency below the X-rays?*