IACHEC XVI : 12-16 May 2024 : Parador de la Granja

On Pileup in *Chandra*/ACIS

Vinay Kashyap (CXC/CfA)

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Two approaches to improve spectral fitting

Vinay Kashyap (CXC/CfA)
Justina Yang (Harvard), Hector McKimm (Imperial), Daniela Huppenkothen (SRON), David van Dyk (Imperial), Rafael Martinez-Galarza (CXC/CfA), Diab Jerius (CXC/CfA), Terry Gaetz (CXC/CfA), Doug Finkbeiner (Harvard), Aneta Siemiginowska (CXC/CfA)

Pileup: Context

- If two or more photons arrive at the same detector pixel within the same frame time, they are read out as one photon with their energies compounded
- For ACIS, this begins to happen at count rates of ≈0.05 ct/frame. When this starts happening, the grade fractions change, with more bad grades and more instances of complex good grades
- XMM-Newton EPIC starts showing pileup effects at ≈5-50× the detector count rate
- AXIS threshold is similar, ≈7 ct/s, equivalent to a moderately bright source like AR Lac
- Even the Athena/WFI uses defocusing to get to 1% pileup for 1 Crab at 80% throughput (Meidinger et al. 2018)

PSR J0437−4715 pileup experiments with ACIS
00741 τ=0.441s N_ROW=128 ct/s=0.298 θ=3.95'
06154 τ=0.441s N_ROW=101 ct/s=0.238 θ=0.34'
06155 τ=3.041s N_ROW=1024 ct/s=0.168 θ=0.37'
06156 τ=1.541s N_ROW=512 ct/s=0.201 θ=0.37'
06157 τ=0.441s N_ROW=101 ct/s=0.228 θ=3.63'
06158 τ=10.041s N_ROW=1024 ct/s=0.071 θ=0.35'
06767 τ=0.241s N_ROW=101 ct/s=0.239 θ=0.39'
06768 τ=0.241s N_ROW=101 ct/s=0.247 θ=0.40'
07216 τ=6.041s N_ROW=1024 ct/s=0.115 θ=0.40'
0.20
0.15
0.10
0.05
0.00
−6
−4
−2
0
2
4
Δx
bin=0.25 pix

PSR J0437−4715 pileup experiments with ACIS
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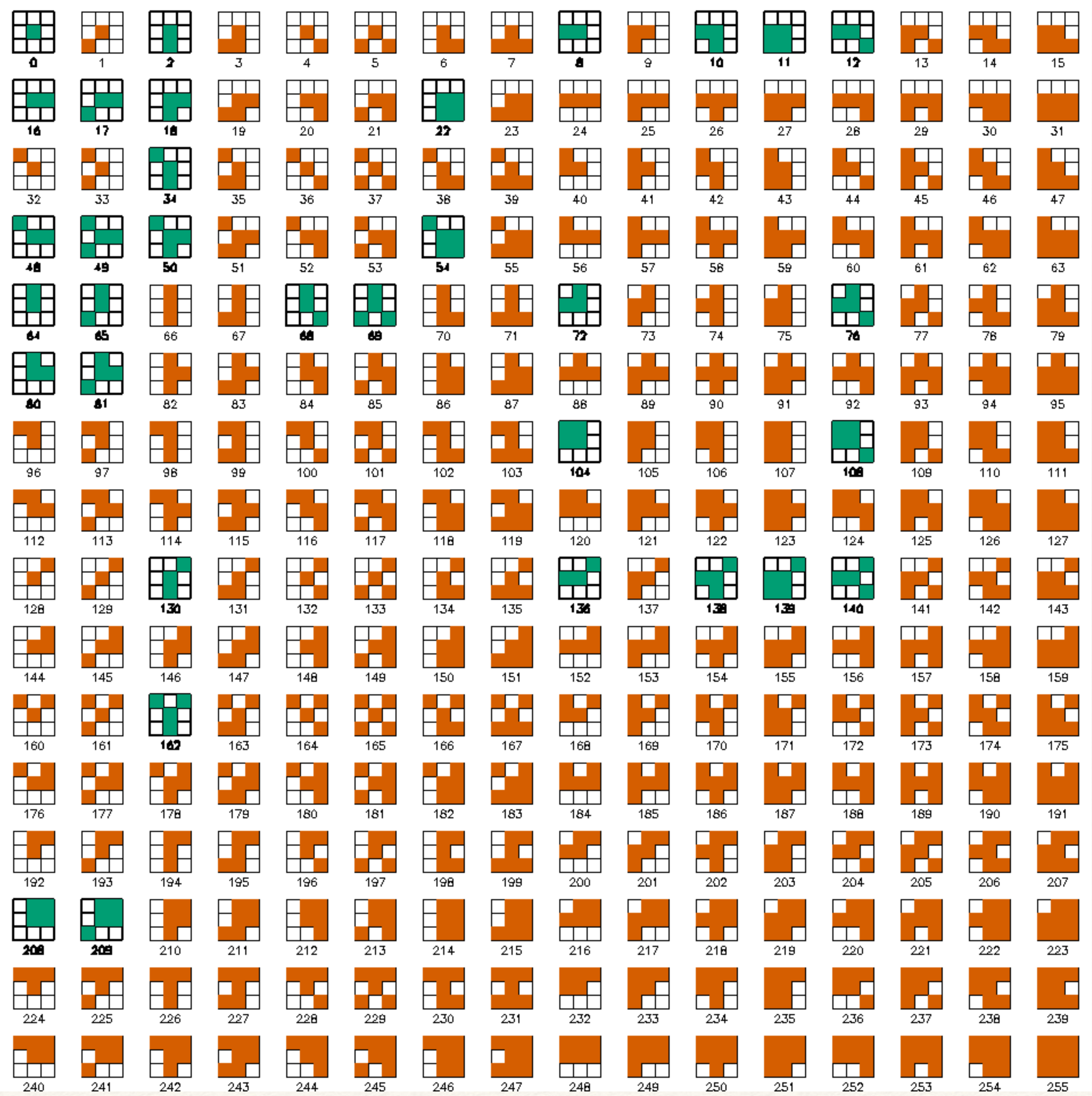
06768 τ=0.241s N_ROW=101 ct/s=0.247 θ=0.40'
07216 τ=6.041s N_ROW=1024 ct/s=0.115 θ=0.40'
1.0
0.8
0.6
0.4
0.2
0.0
200
400
600
800
PHA_RO
bin=5 smoothing -,+5

Chandra POG Fig 6.21 and Table 6.6

Bitwise grade assignments

32	64	128
8	0	16
1	2	4



Grade Migration : The John Davis Model

- The probability of n photons with good grades piling up yet resulting in a good grade: $\alpha^{n\text{-}1}$

AHELP for CIAO 4.16 Sherpa	**set_pileup_model**	Context: modeling

Synopsis

Include a model of the Chandra ACIS pile up when fitting PHA data.

Syntax

```
set_pileup_model(id, model=None)

id - int or str, optional
model - an instance of the jdpileup class
```

Description

Chandra observations of bright sources can be affected by pileup, so that there is a non-linear correlation between the source model and the predicted counts. This process can be modelled by including the `jdpileup` model for a data set, using the `set_pileup_model` .

pileup: CCD pile-up model for Chandra

CCD pile-up model used for brightish point sources observed by Chandra. This is an implementation of the fast pile-up algorithm proposed by John Davis (see http://space.mit.edu/~davis/papers/pileup2001.pdf). The frame time and maximum number of photons to pile up should be fixed. The grade morphing is expressed through a single parameter, alpha, which should be left as a free parameter. This model should be considered in beta test. Note that to calculate fluxes etc. for the model you must remove the pileup component. The pile-up model is similar to the operation of the convolution models, differing only in the treatment of the detector efficiency during the convolution. Note that renorm will not work with pileup since increasing the normalization does not linearly increase the predicted count rate. Therefore you should set renorm none prior to doing a fit with pileup.

par1	frame time (in seconds)
par2	maximum number of photons to pile up
par3	grade correction for single photon detection
par4	grade morphing parameter (good grade fraction is assumed proportional to par4 $^{(p-1)}$ where p is the number of piled photons)
par5	PSF fraction. Only this fraction will be treated for pile-up. Note that this is **not** the fraction of the PSF included in the extraction region but is the fraction of counts in the region which are from the point source whose pile-up is being modeled. For this model to work well the extraction region should be large enough to contain essentially all the PSF.
par6	Number of regions. The counts to be piled-up will be distributed among par6 regions, which will be piled-up independently.
par7	Value of FRACEXPO keyword in ARF.

https://cxc.cfa.harvard.edu/ciao/download/doc/pileup_abc.pdf

https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XSmodelPileup.html

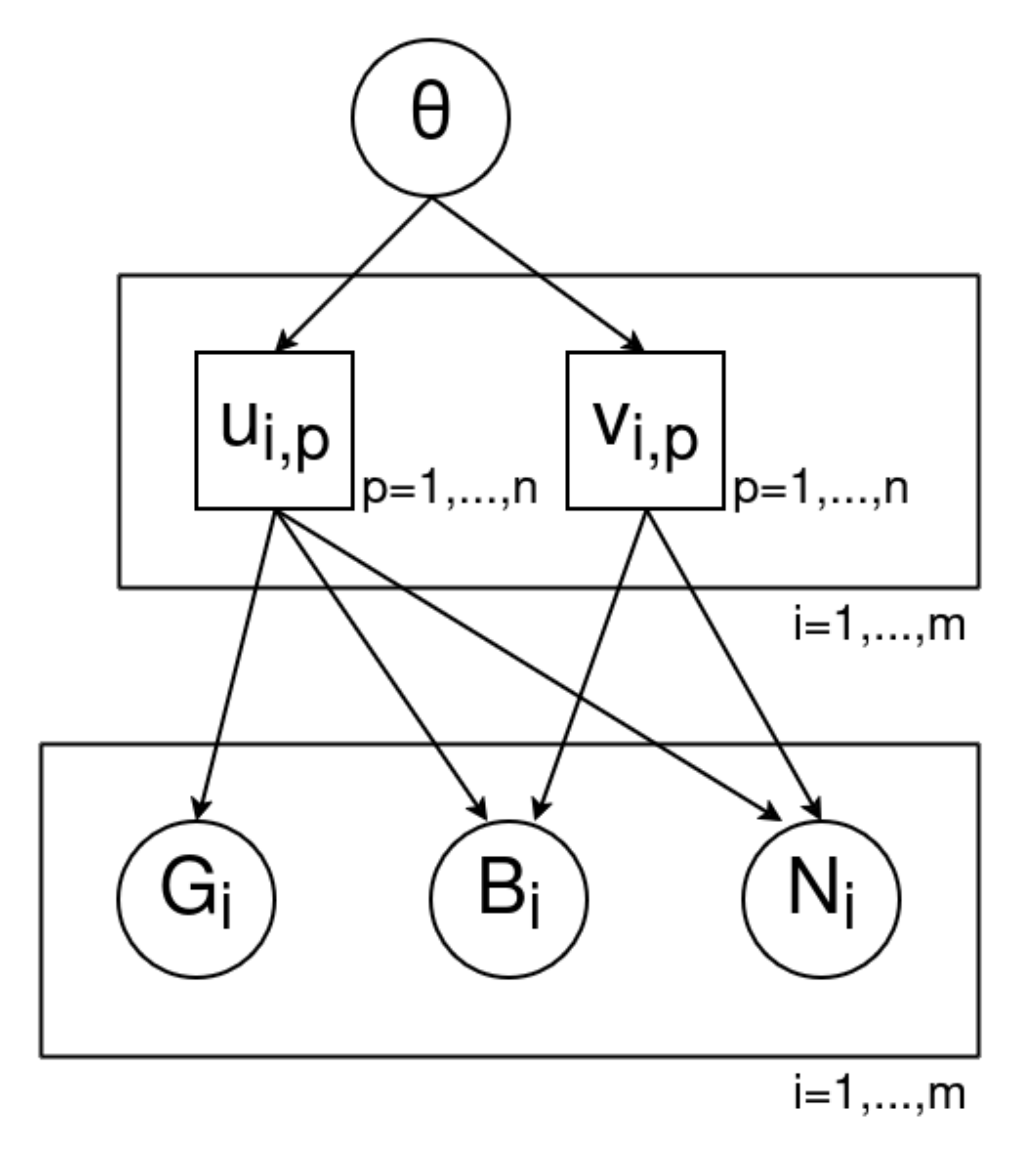
https://cxc.cfa.harvard.edu/sherpa/ahelp/set_pileup_model.html

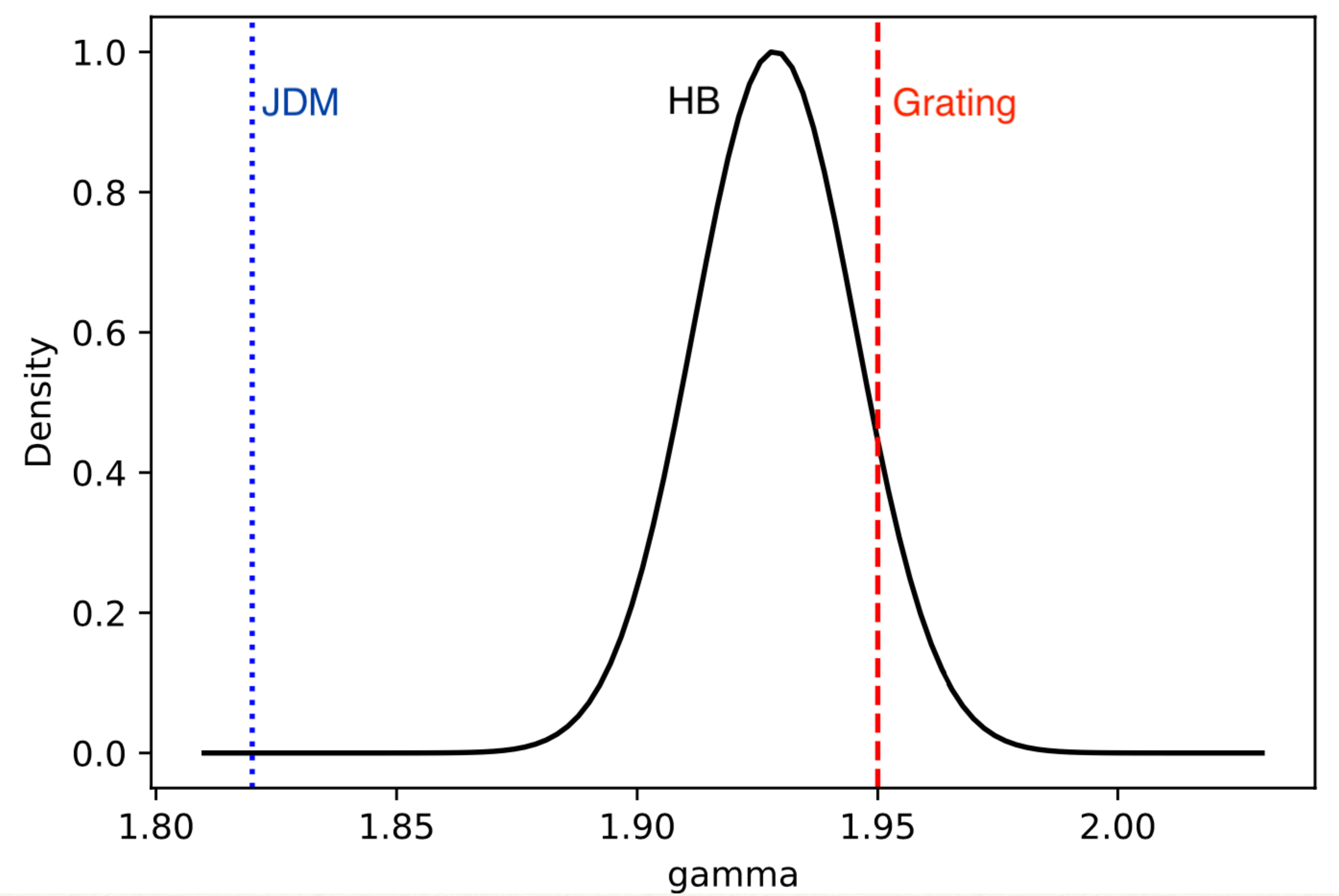
https://cxc.cfa.harvard.edu/sherpa/threads/pileup/

Grade Migration: The John Davis Model

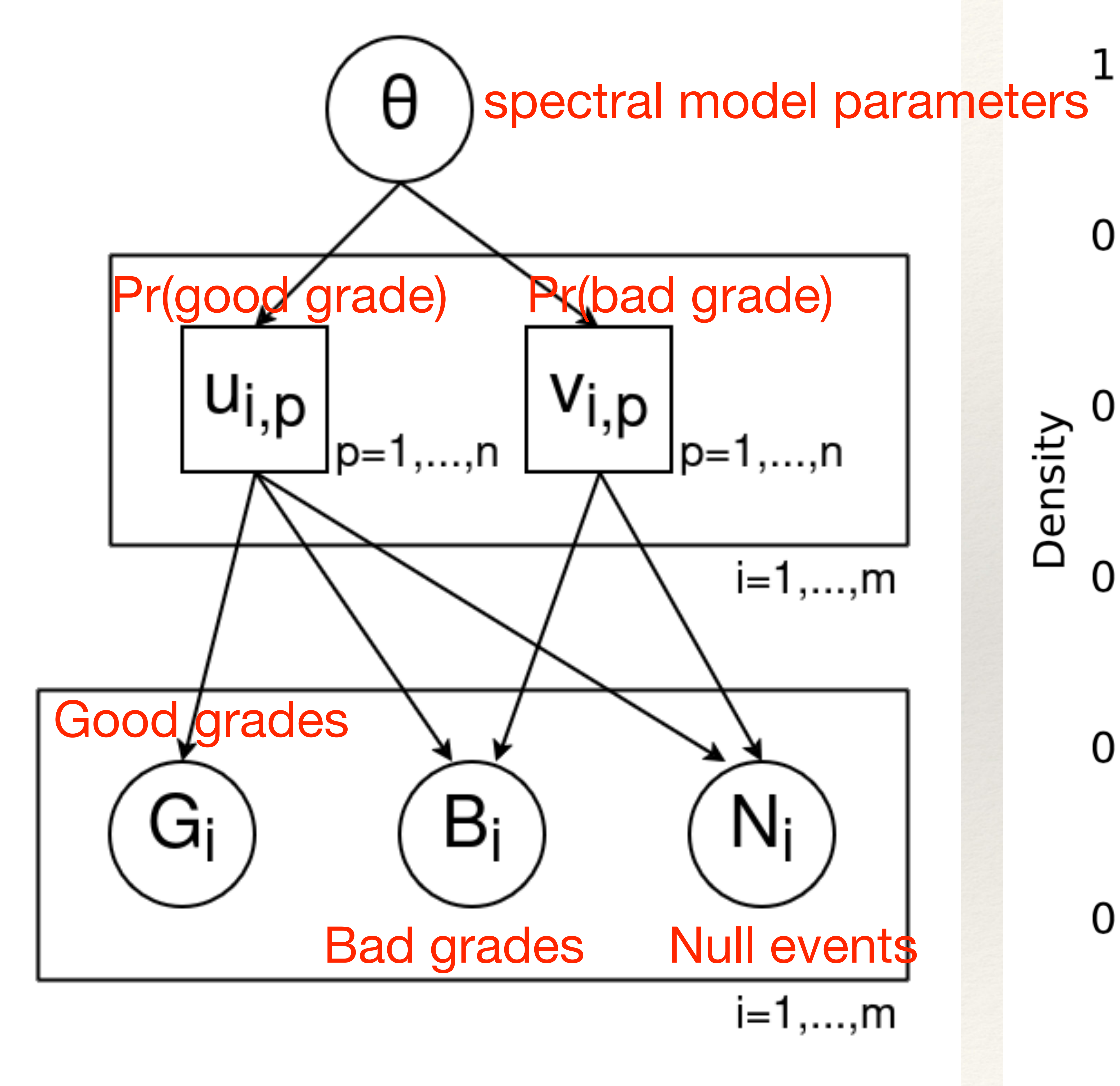
- The probability of n photons with good grades piling up yet resulting in a good grade: α^{n-1}
- Limitations:
  - ad hoc, with no connection to a likelihood
  - does not work well for large pileup fractions
  - does not use bad grade data
  - does not account for PSF shape

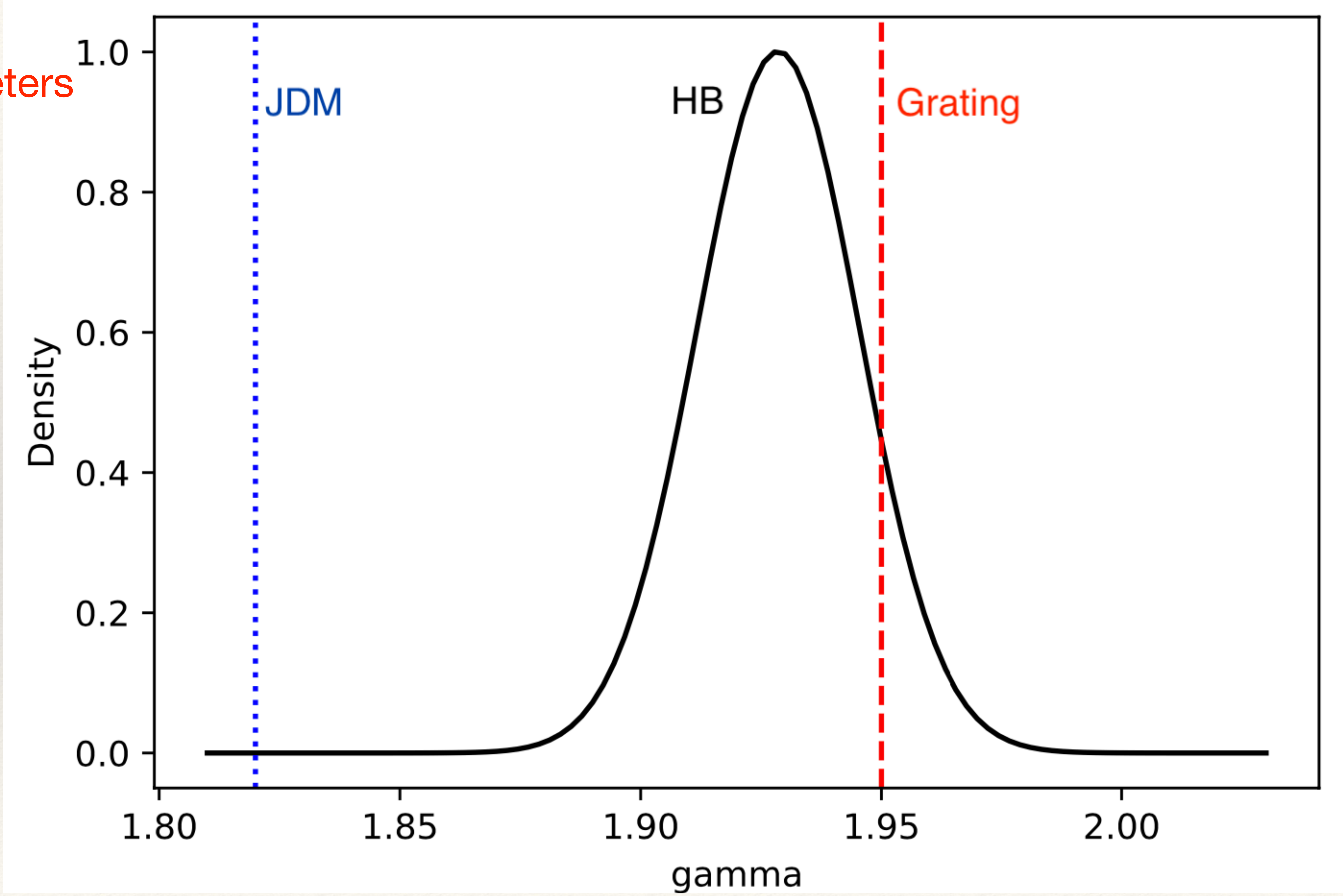
Hierarchical Bayesian Modeling



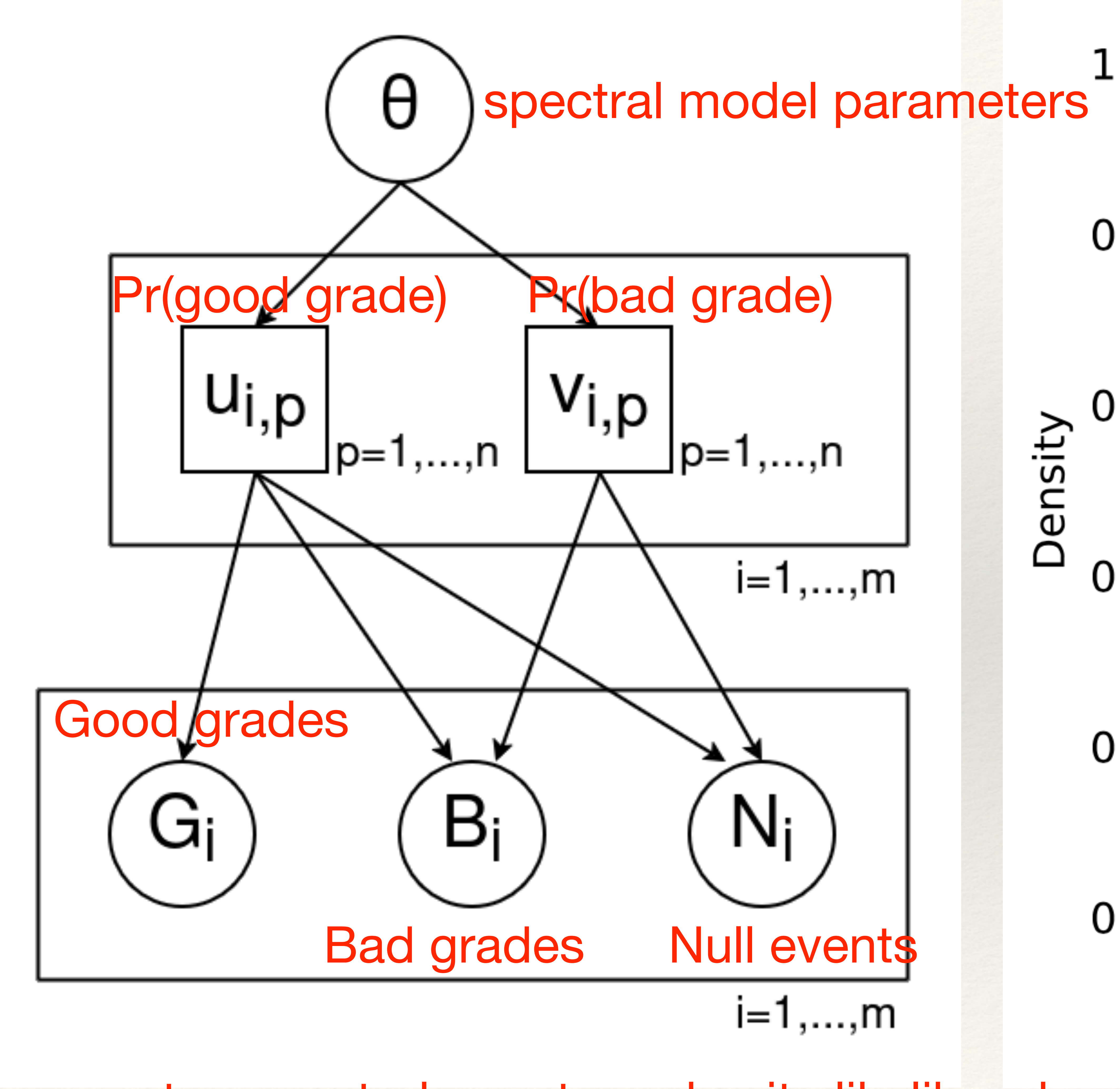


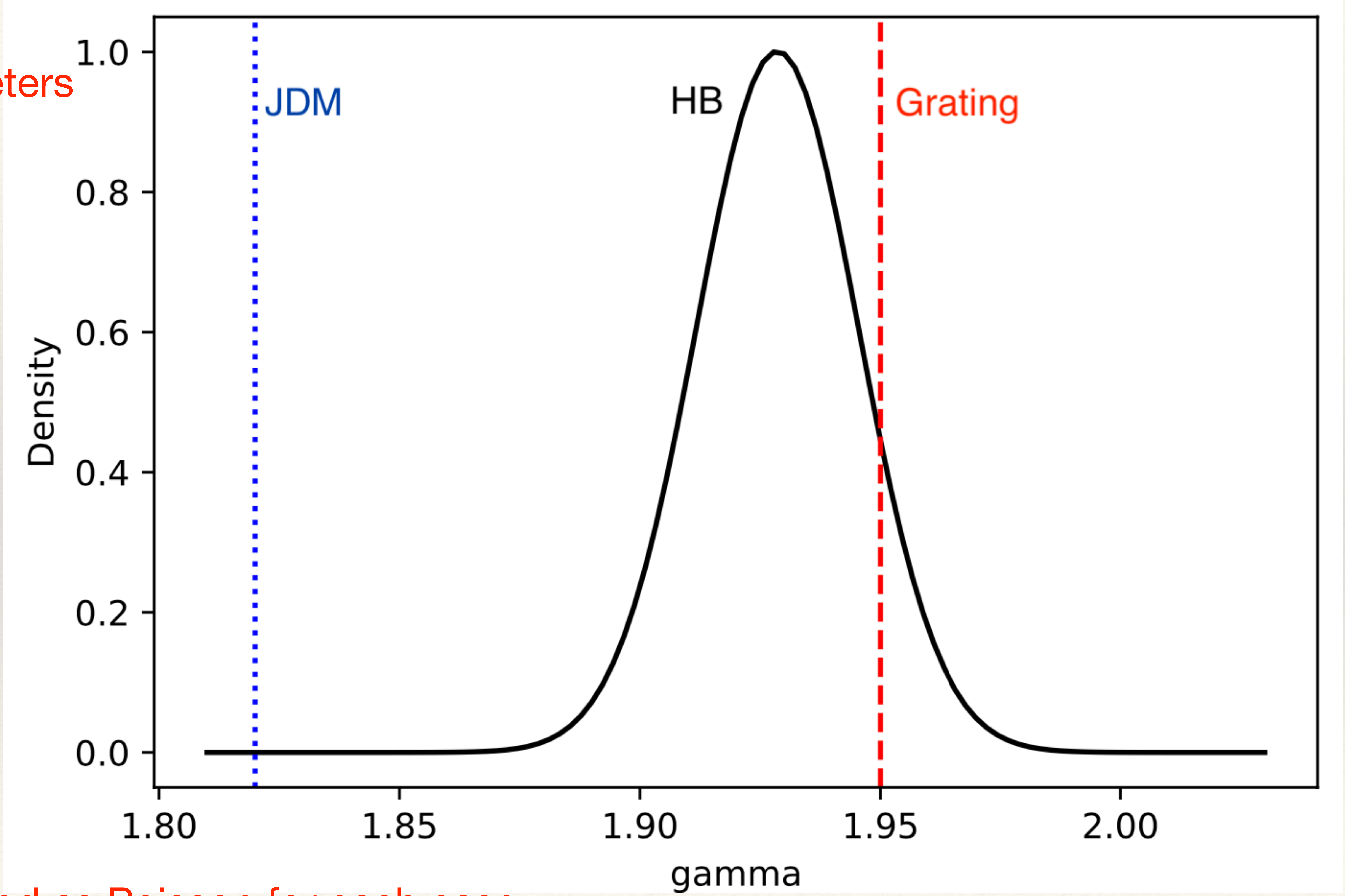
Hierarchical Bayesian Modeling





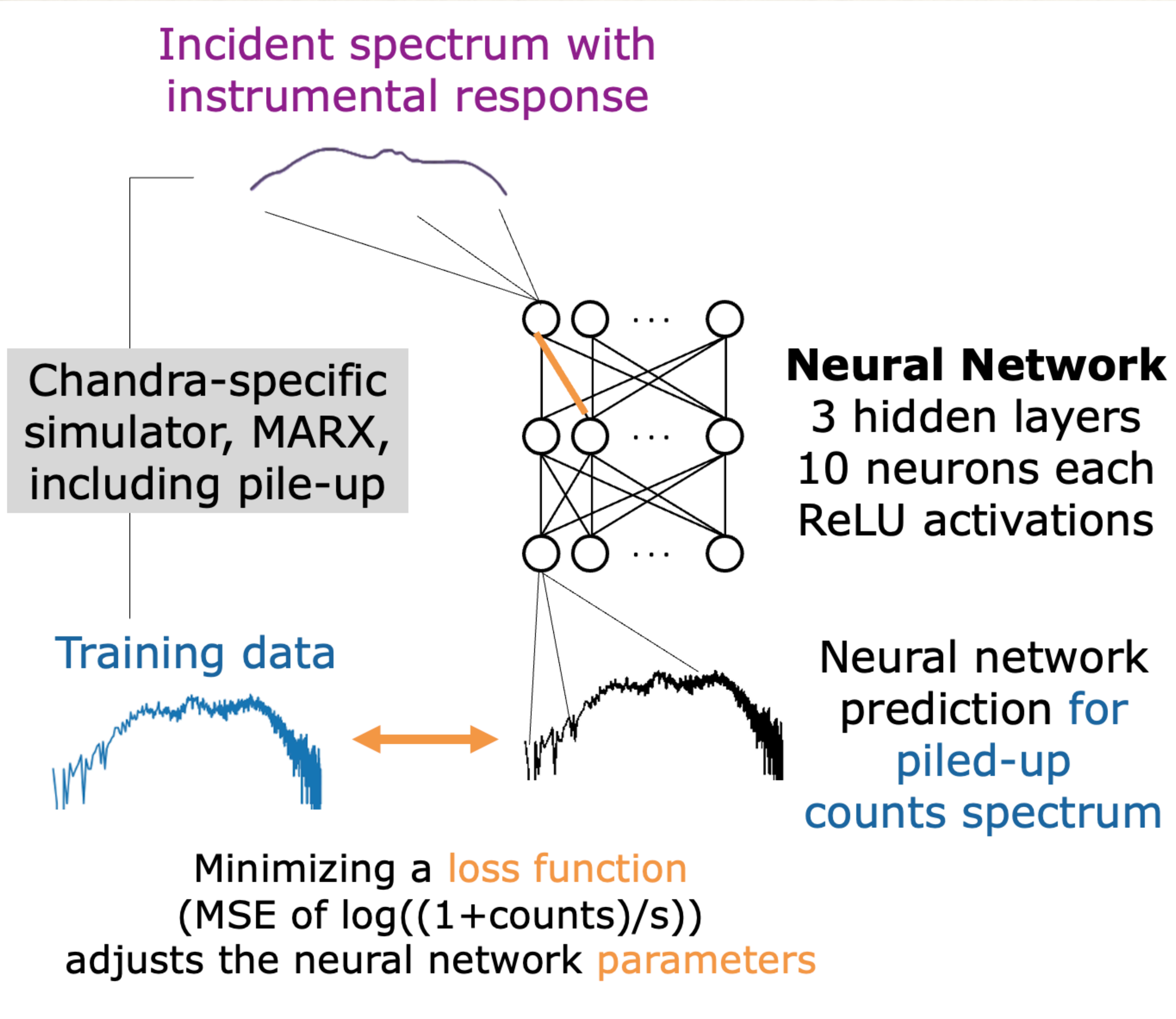
Hierarchical Bayesian Modeling

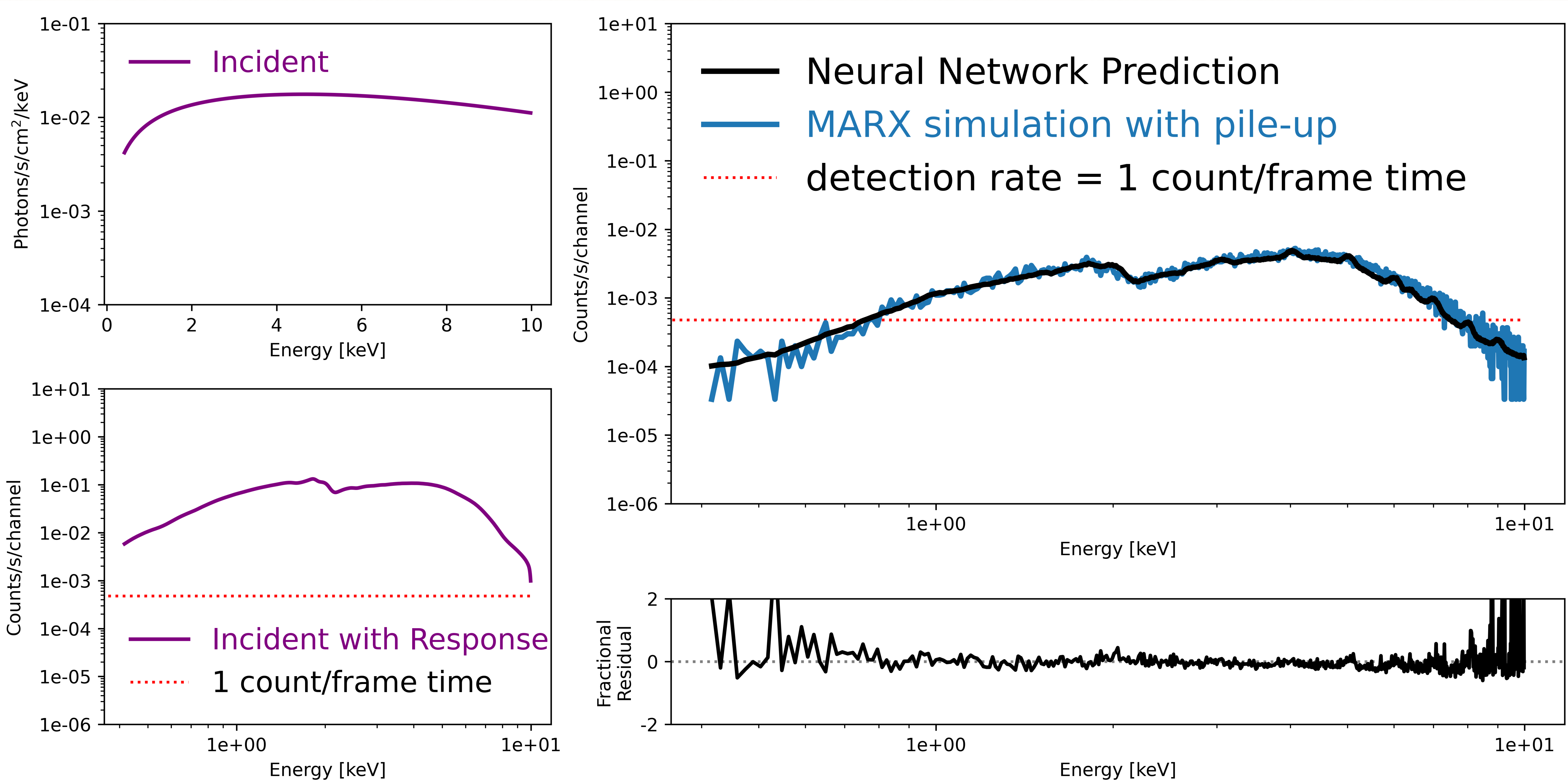




compute expected counts and write likelihood as Poisson for each case

Learning pileup from simulations and data





Yo quiero saber.. I want to know

Yo quiero saber.. I want to know

- What kind of process leads to pileup in <*your*> detector

Yo quiero saber.. I want to know

- What kind of process leads to pileup in <*your*> detector
- What is your strategy for dealing with pileup?

Yo quiero saber.. I want to know

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- What is your strategy for dealing with pileup?
- At what count rate does pileup (or some form of non-linearity) become important?

Yo quiero saber.. I want to know

- What kind of process leads to pileup in <*your*> detector
- What is your strategy for dealing with pileup?
- At what count rate does pileup (or some form of non-linearity) become important?
- What modifications should we make to our Bayesian model to handle specific cases?