IACHEC XV : 2023 Apr 27

Calibration Statistics Working Group

Vinay Kashyap (CfA/CXC) [vkashyap@cfa.harvard.edu]

CalStats WG Summary

Vinay Kashyap (CfA/CXC) [vkashyap@cfa.harvard.edu]

Forum for discussion of statistical, methodological, and algorithmic issues that affect calibration of instruments, how calibration data are used in data analysis and analysis results are interpreted.

iachec-calstats+subscribe@cfa.harvard.edu

https://iachec.org/calibration-statistics/

iachec.slack.com:#calstats

CalStats WG talks spanned two sessions on Apr 25

- Herman Marshall on devising a better system for fitting polarization data utilizing the information in event charge deposition ellipticities

Suggest: Updating XSPEC analysis

- New model is $Q_j(E,\Theta) = T\int A(E')\mathcal{Q}(E',\Theta)\mathcal{M}_j(E',E)dE', \quad U_j(E,\Theta) = T\int A(E')\mathcal{U}(E',\Theta)\mathcal{M}_j(E',E)dE'$
  - Index j refers to specific values of α_j
  - New detector mRMF is $\mathcal{M}_j(E',E) = \mu(\alpha_j,E')\epsilon(E')\phi(\alpha_j,E')R(E',E)$ New!
  - where $\sum_j \phi(\alpha_j,E') = 1$ and $\sum_j \mu(\alpha_j,E')\phi(\alpha_j,E') = \mu(E')$ (unweighted, uncut)
- Original: $\lambda(n_0,\Pi,\varphi;E,\psi) = [1+\Pi\mu_E\cos(2\psi+2\varphi)]n(E')A(E')TdE'd\psi$
  - gives MDP99 $= 4.29/\sqrt{\sum \mu_{E_i}^2 C(E_i)}$
  - Then $\lambda(n_0,\Pi,\varphi;E,\alpha_j,\psi) = \int dE'[1+\Pi\mathcal{M}_j(E',E)\cos(2\psi+2\varphi)]n(E')A(E')Td\psi$
  - and $\tilde{S}(q,u) = -2\sum_i \ln(1+q\mu(\alpha_i,E_i)\cos 2\psi_i + u\mu(\alpha_i,E_i)\sin 2\psi_i)$

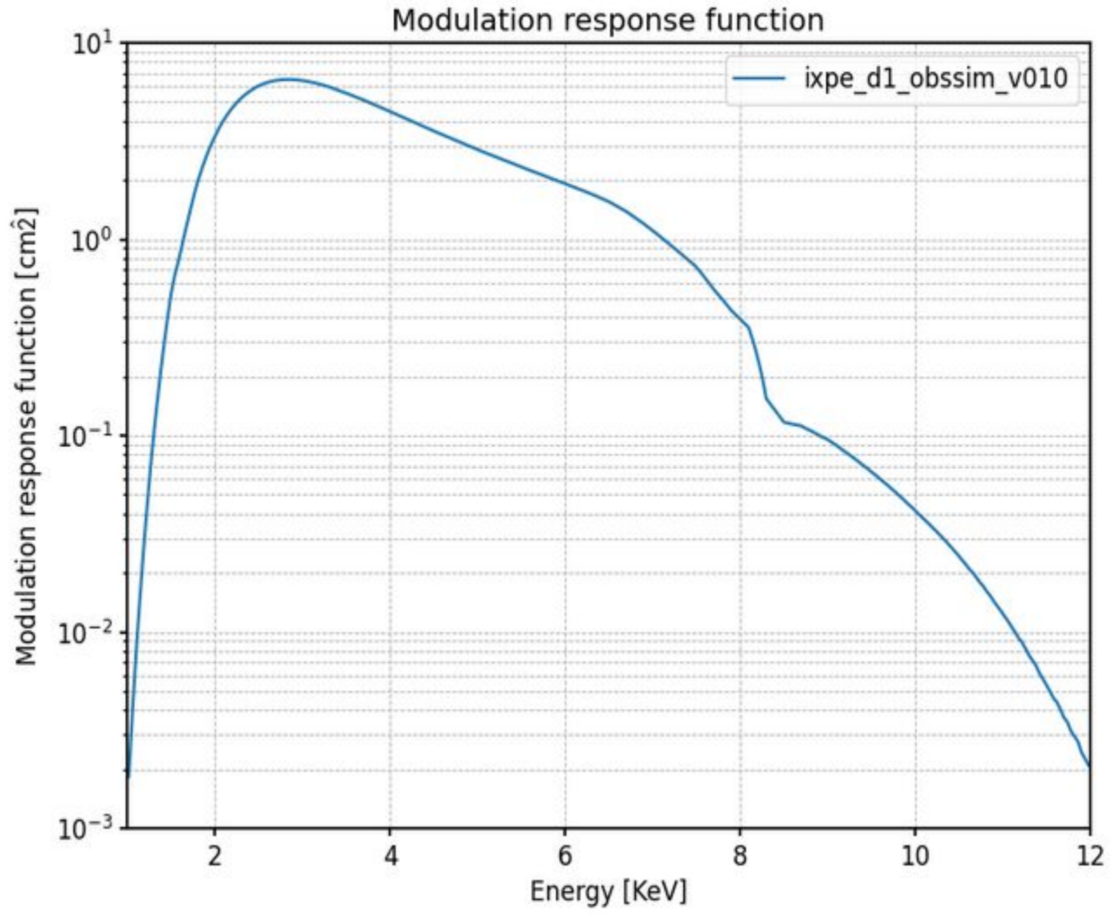
iachec-calstats@cfa.harvard.edu

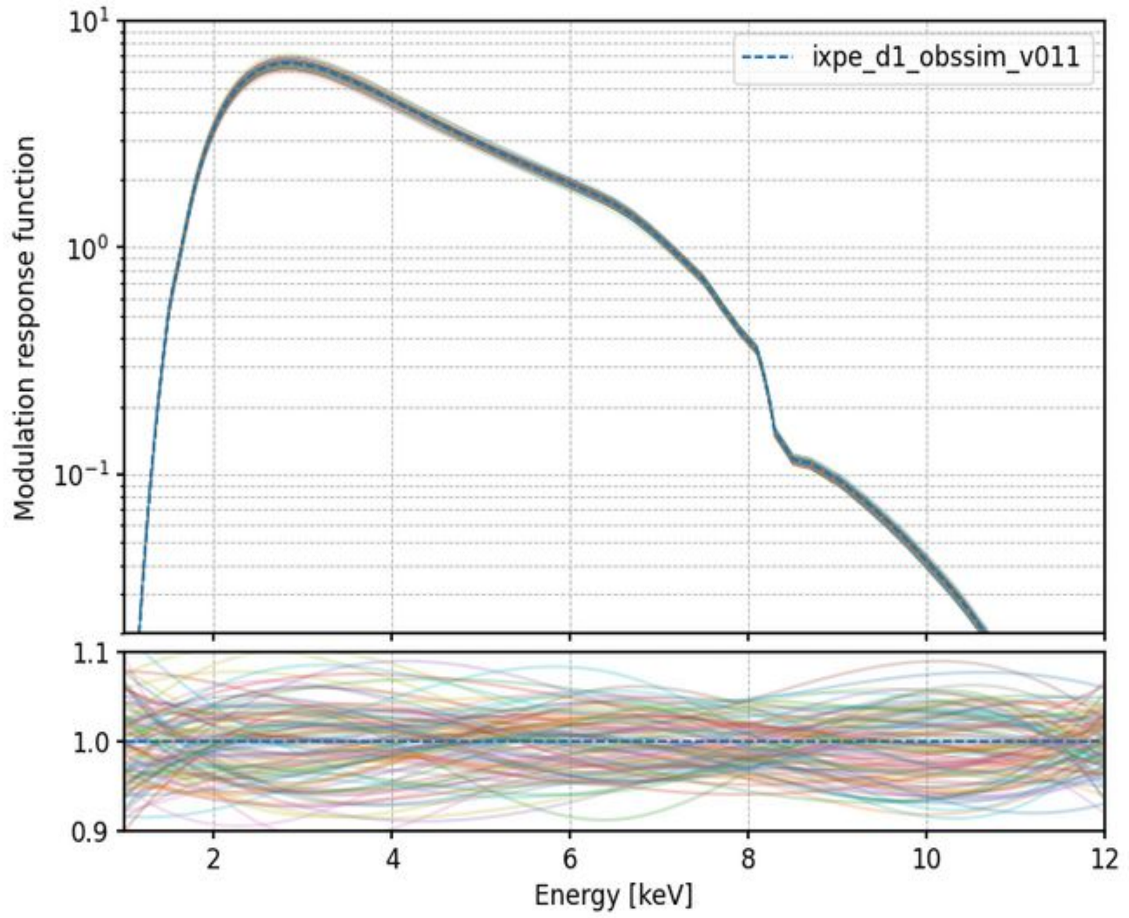
CalStats WG talks spanned two sessions on Apr 25

- Herman Marshall on devising a better system for fitting polarization data utilizing the information in event charge deposition ellipticities
- Stefano Silvestri on describing the effects of systematic uncertainties in IXPE effective areas combined with modulation factors

SYSTEMATICS III: MODULATION RESPONSE FUNCTION

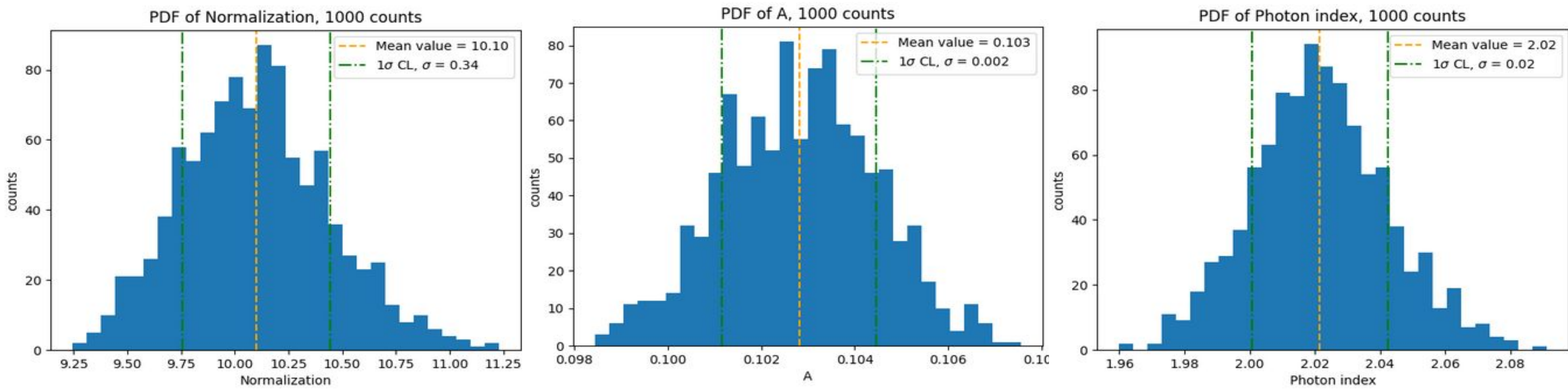
What happens when you put them together?





EFFECTS ON THE OBSERVABLES

We interpret the same simulated observation with all those different response functions and see the error induced in the parameters



Parameter	Target	Result	Systematic IRF
Ph. index	2	2.000 ± 0.001	2.02 ± 0.02
Normalization	10	10.00 ± 0.01	10.10 ± 0.35
Pol. degree	0.1	0.098 ± 0.0015	0.103 ± 0.002

iachec-calstats@cfa.harvard.edu

CalStats WG talks spanned two sessions on Apr 25

- Herman Marshall on devising a better system for fitting polarization data utilizing the information in event charge deposition ellipticities
- Stefano Silvestri on describing the effects of systematic uncertainties in IXPE effective areas combined with modulation factors
- Benjamin Schneider on CCD events energy calibration via correlations of synthetic vs raw ADU spectra

Advantages of ECC

- Very fast (ECC_{AMR}, Maier+20)
  - a few seconds for the 256 columns of MXT
- Better performance with **low count** spectrum
  - reduce data statistics required for calibration
- Able to consider **lines** and/or **background**
  - more robust and accurate calibration
- Also **flexible** method
  - possible to change intensity of lines to favor a part of the energy range
  - past calibrated spectrum as synthetic spectrum to monitor the gain evolution over time

Schneider+2022 arXiv:2212.09863

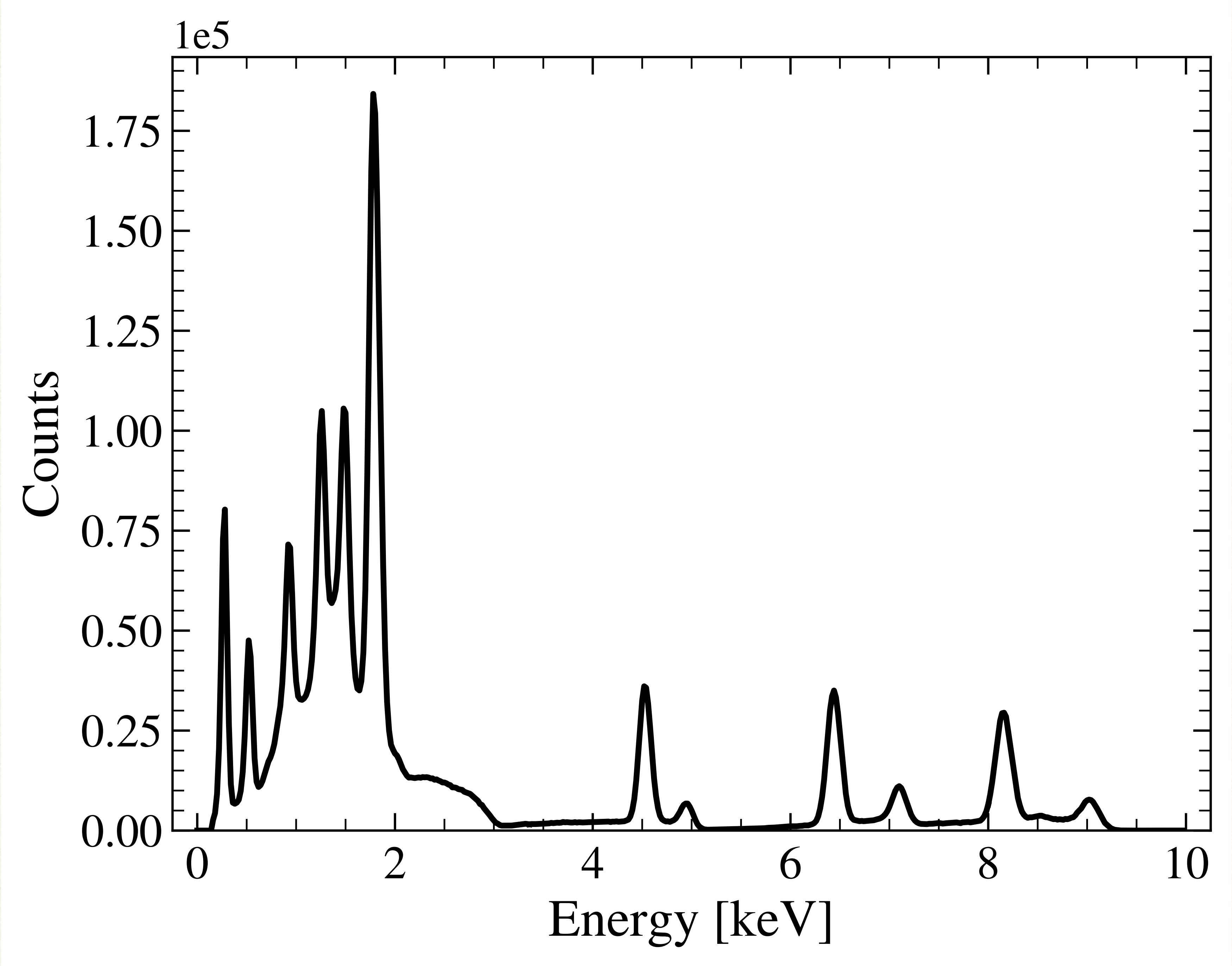


Fig. 3: Combined spectrum used to derive the energy calibration. Only well-resolved fluorescence lines produced by the Panter X-ray source (Table 2) are considered.

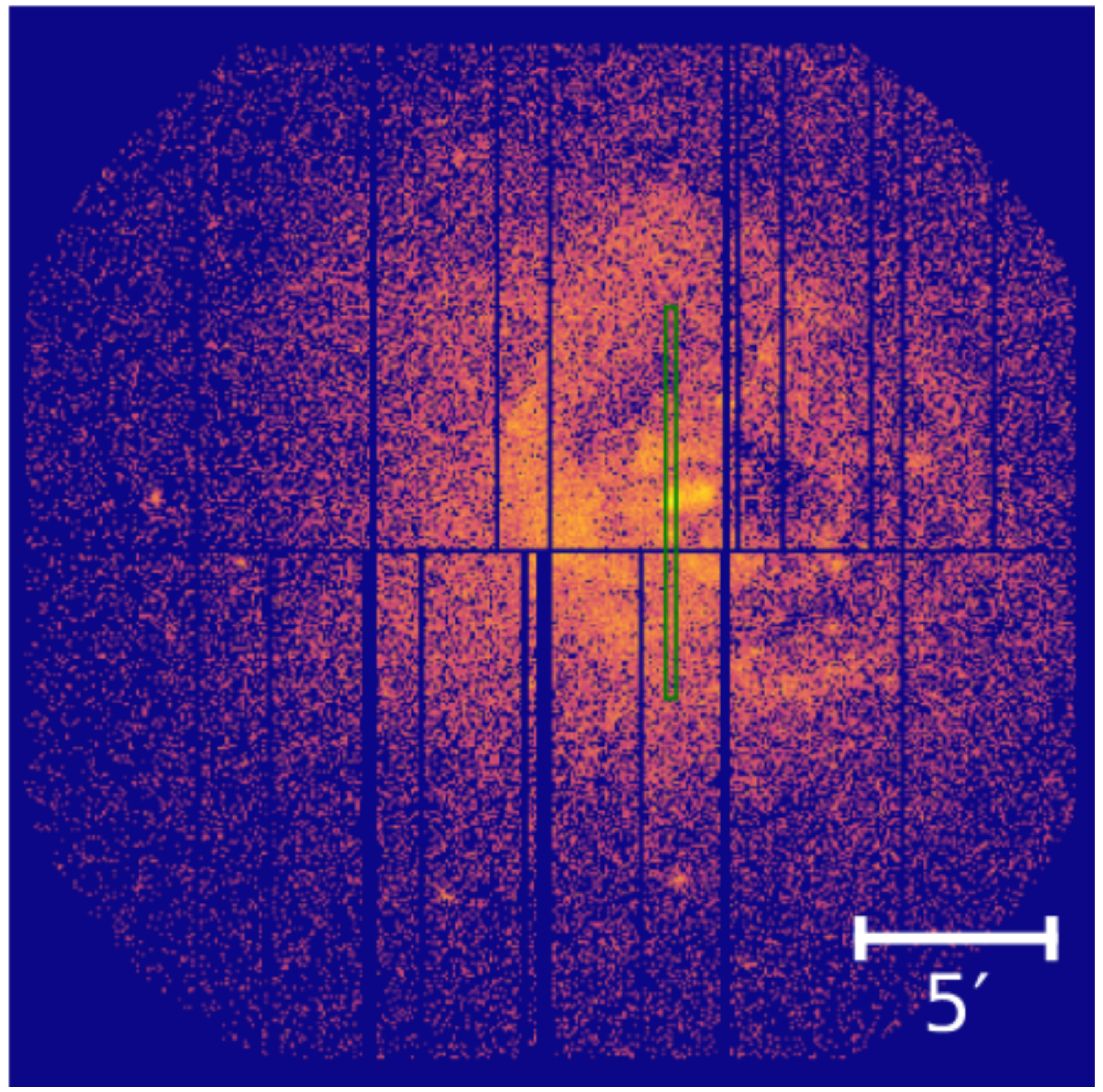
Element	Energy [eV]
C-K	277
O-K	525
Cu-L	930
Mg-K	1253
Al-K	1486
W-M	1774
Ti-Kα	4510
Ti-Kβ	4950
Fe-Kα	6400
Fe-Kβ	7053
Cu-Kα	8040
Cu-Kβ	8910

Table 2: Fluorescence lines produced by the Panter X-ray source and used for the spectral calibration. Energies are extracted from the X-Ray Data Booklet (Thompson et al., 2009).

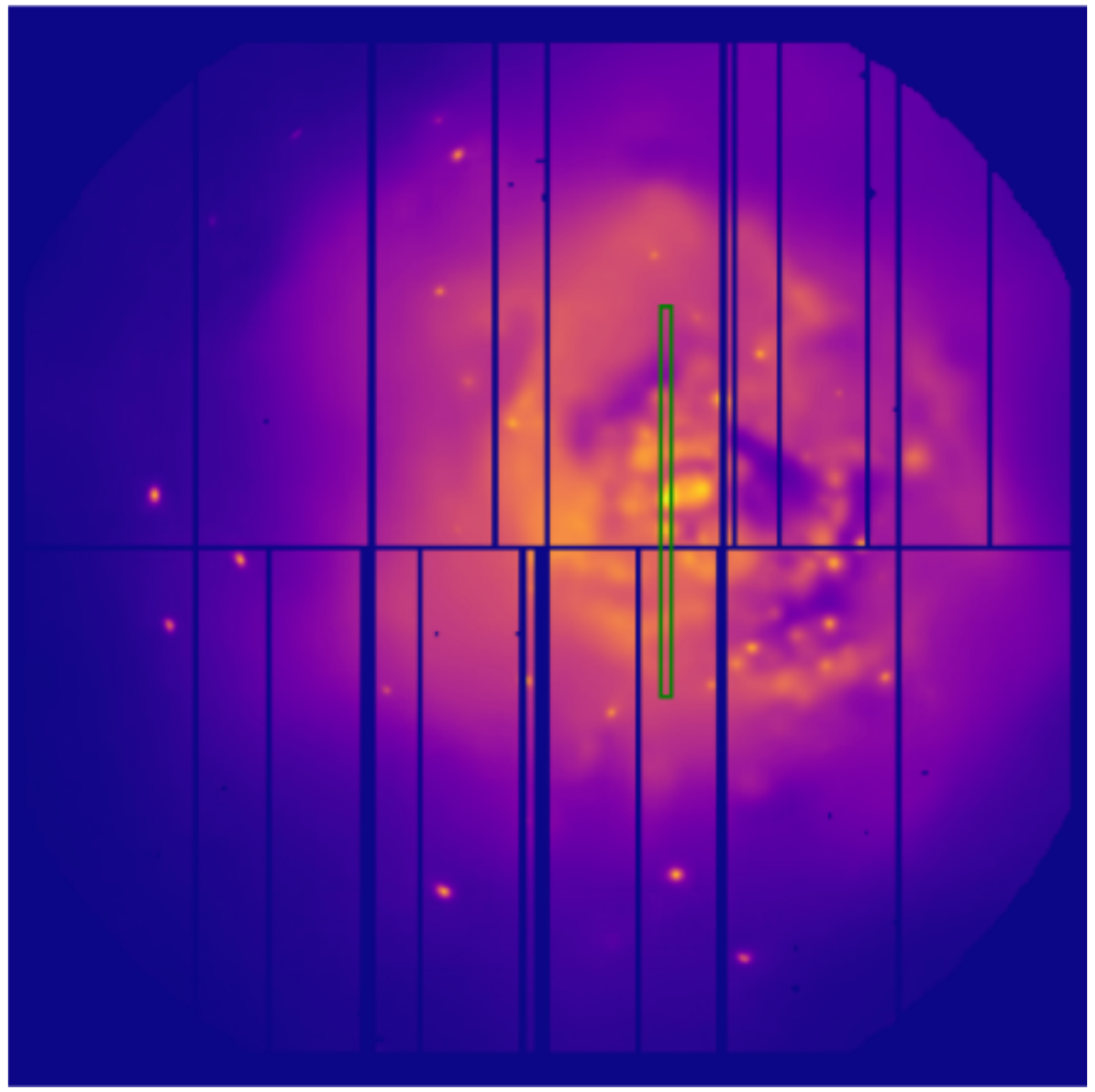
CalStats WG talks spanned two sessions on Apr 25

- Herman Marshall on devising a better system for fitting polarization data utilizing the information in event charge deposition ellipticities
- Stefano Silvestri on describing the effects of systematic uncertainties in IXPE effective areas combined with modulation factors
- Benjamin Schneider on CCD events energy calibration via correlations of synthetic vs raw ADU spectra
- Ivan Valtchanov on denoising and super-resolving XMM data by leveraging machine learning methods and training on simulations

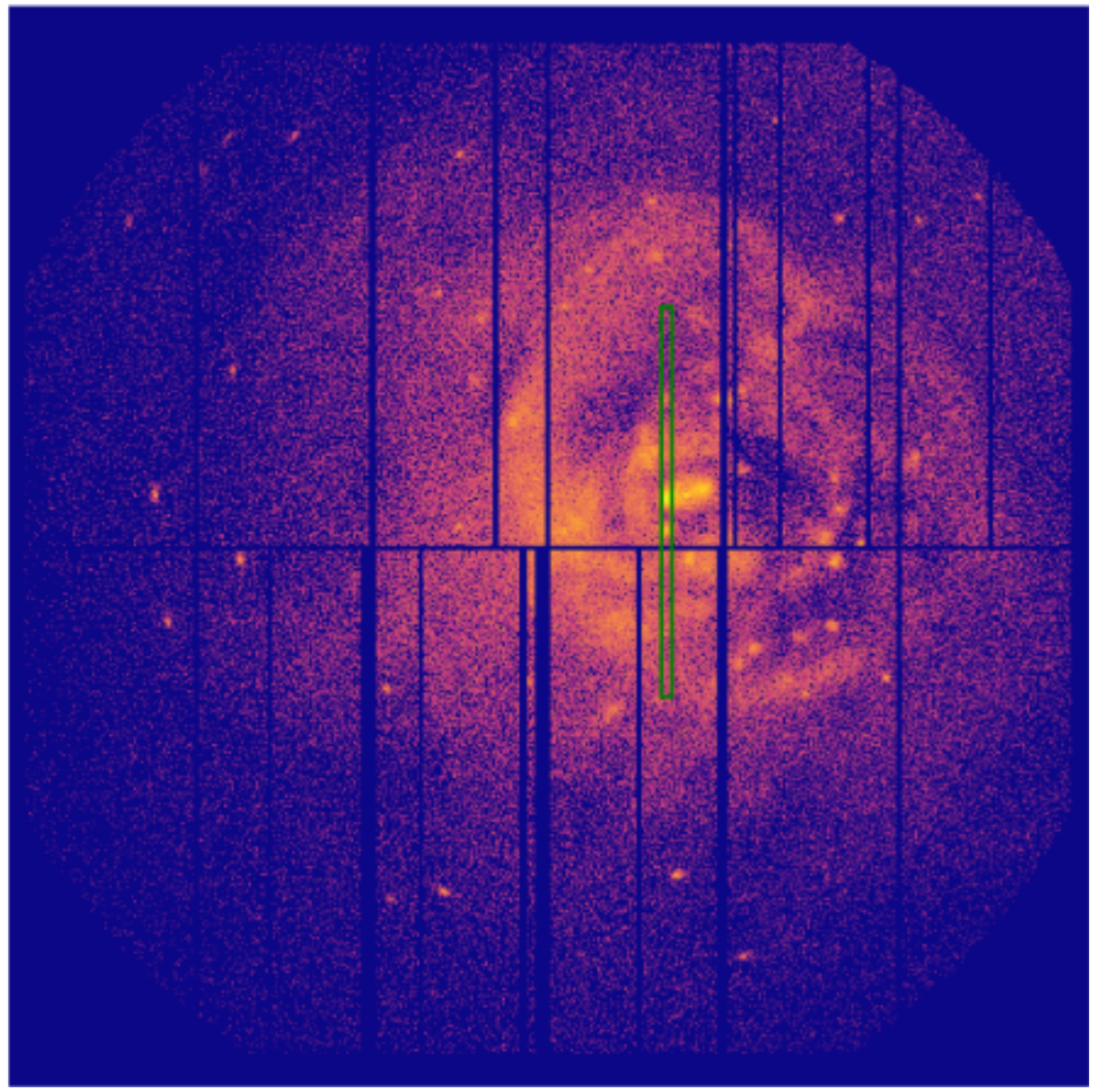
Strip Plot on Simulated Data



Input
1x resolution
20ks exposure



Predicted
2x resolution
100ks exposure



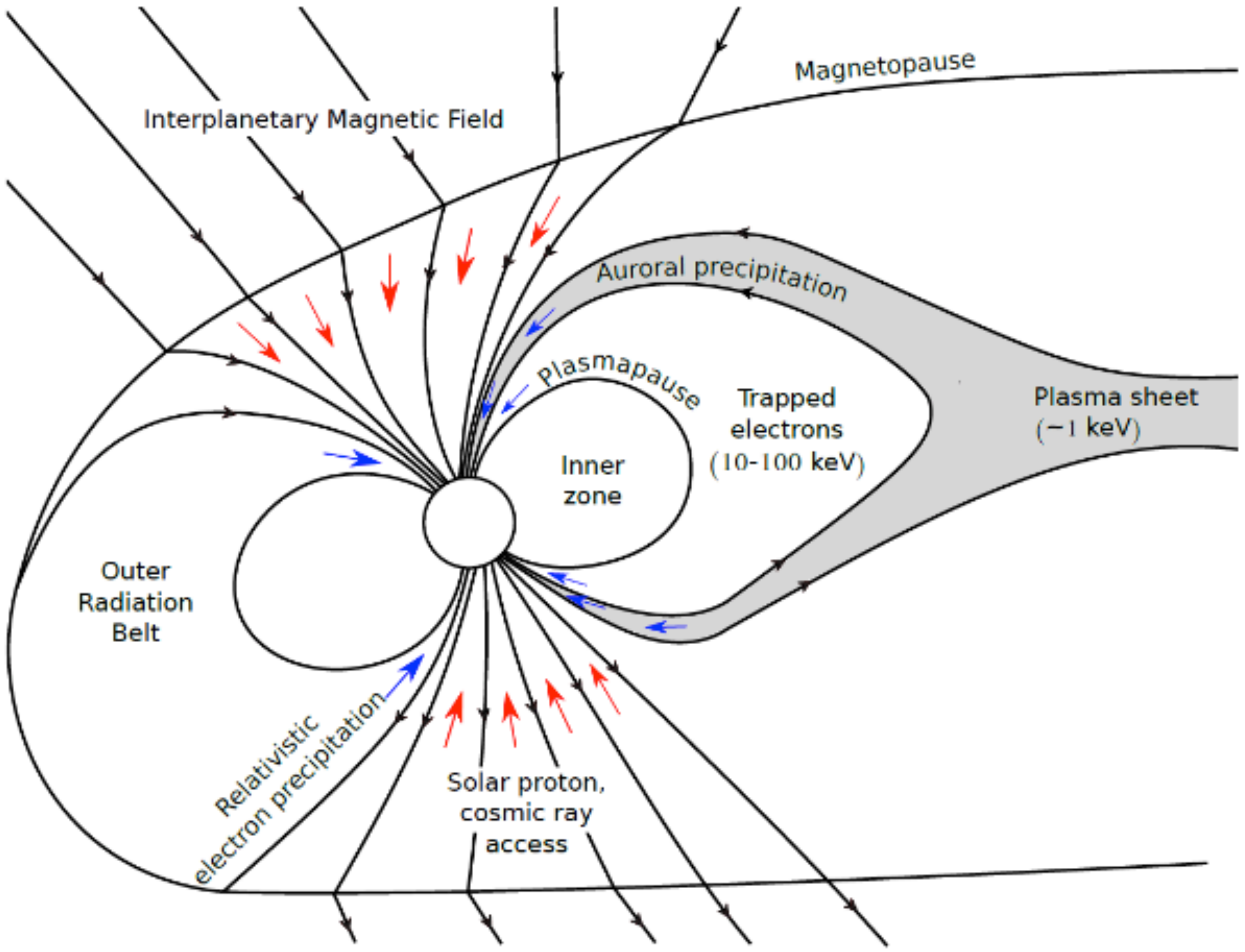
Target
2x resolution
100ks exposure

CalStats WG talks spanned two sessions on Apr 25

- Herman Marshall on devising a better system for fitting polarization data utilizing the information in event charge deposition ellipticities
- Stefano Silvestri on describing the effects of systematic uncertainties in IXPE effective areas combined with modulation factors
- Benjamin Schneider on CCD events energy calibration via correlations of synthetic vs raw ADU spectra
- Ivan Valtchanov on denoising and super-resolving XMM data by leveraging machine learning methods and training on simulations
- Craig Markwardt on the practical use of SCORPEON, the background model developed for NICER

SCORPEON Background Modeling

- SCORPEON Model
- Major goals
  - Break down background into physically-motivated components
  - Assume simple spectral shapes
  - Use HK to estimate norms
- Model is adjustable in XSPEC



Thorne et al 1980
Tyssoy presentation

We maintain a library of background models and scripts at the IACHEC wiki, see

https://wikis.mit.edu/confluence/display/iachec/Calibration+Statistics

CalStats WG talks spanned two sessions on Apr 25

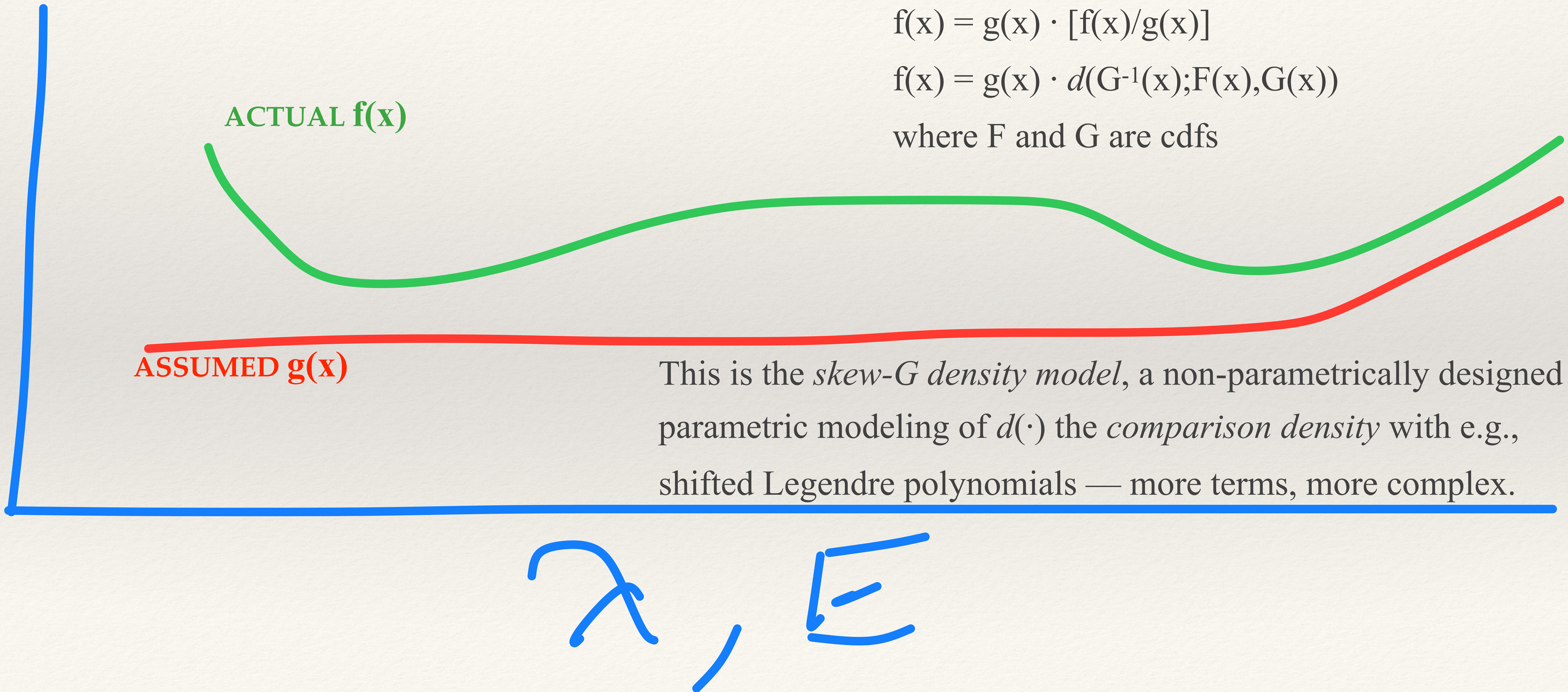
- Herman Marshall on devising a better system for fitting polarization data utilizing the information in event charge deposition ellipticities
- Stefano Silvestri on describing the effects of systematic uncertainties in IXPE effective areas combined with modulation factors
- Benjamin Schneider on CCD events energy calibration via correlations of synthetic vs raw ADU spectra
- Ivan Valtchanov on denoising and super-resolving XMM data by leveraging machine learning methods and training on simulations
- Craig Markwardt on the practical use of SCORPEON, the background model developed for NICER
- Vinay Kashyap on the difficulties arising from counts sparsity in high-resolution spectra with weak sources and a new method to characterize how good a model for the background is

how well do you know your background?

$f(x) = g(x) \cdot [f(x)/g(x)]$

$f(x) = g(x) \cdot d(G^{-1}(x); F(x), G(x))$

where F and G are cdfs



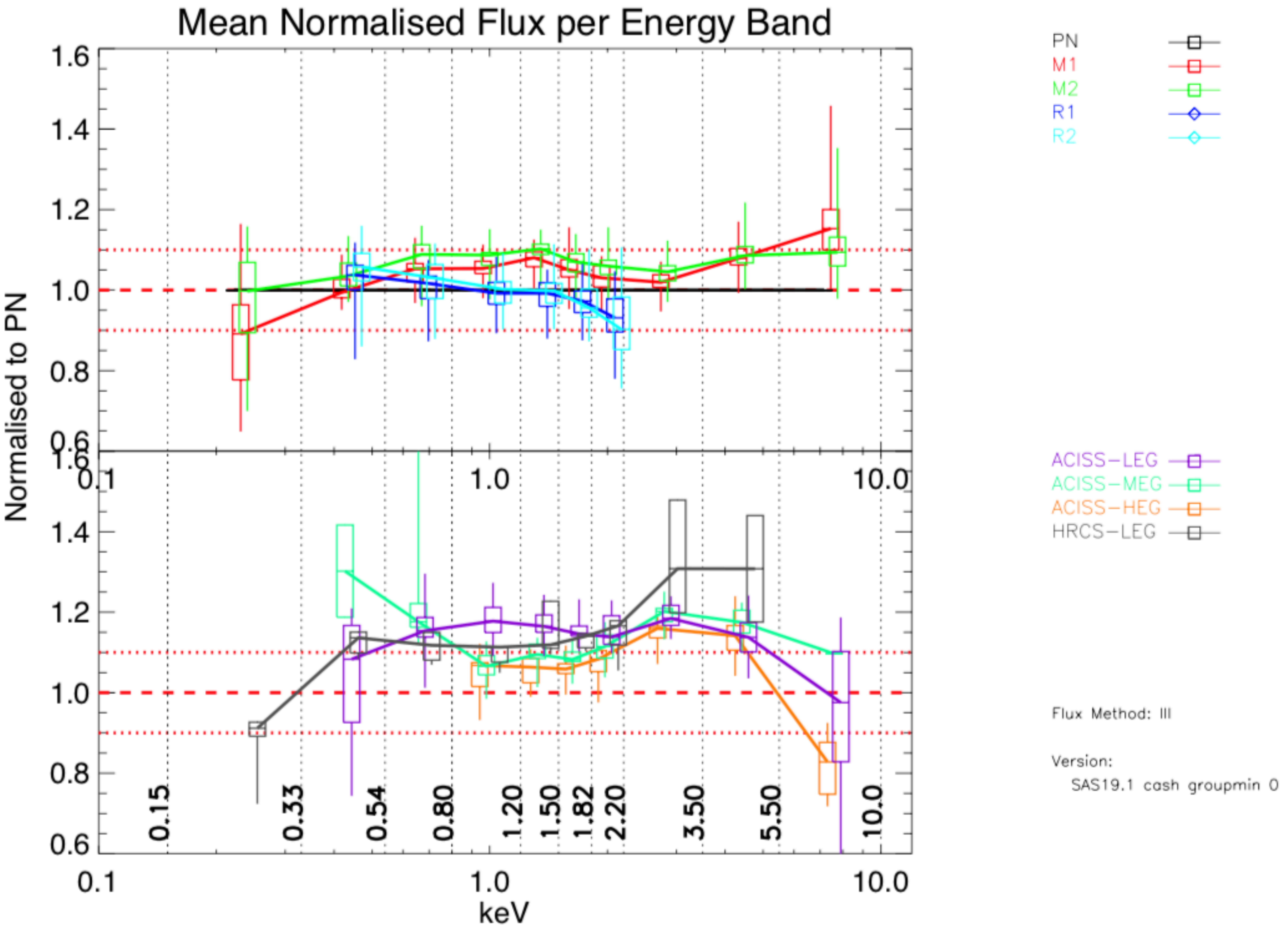
This is the *skew-G density model*, a non-parametrically designed parametric modeling of $d(\cdot)$ the *comparison density* with e.g., shifted Legendre polynomials — more terms, more complex.

iachec-calstats@cfa.harvard.edu

Two panel discussions on Apr 25

- Concordance [Herman Marshall (MIT), Yang Chen (Michigan)]
- C-stat and systematics [Yang Chen (Michigan), Max Bonamente (Alabama)]

Next: XMM/Chandra XCAL



Numerical Studies: A simple example

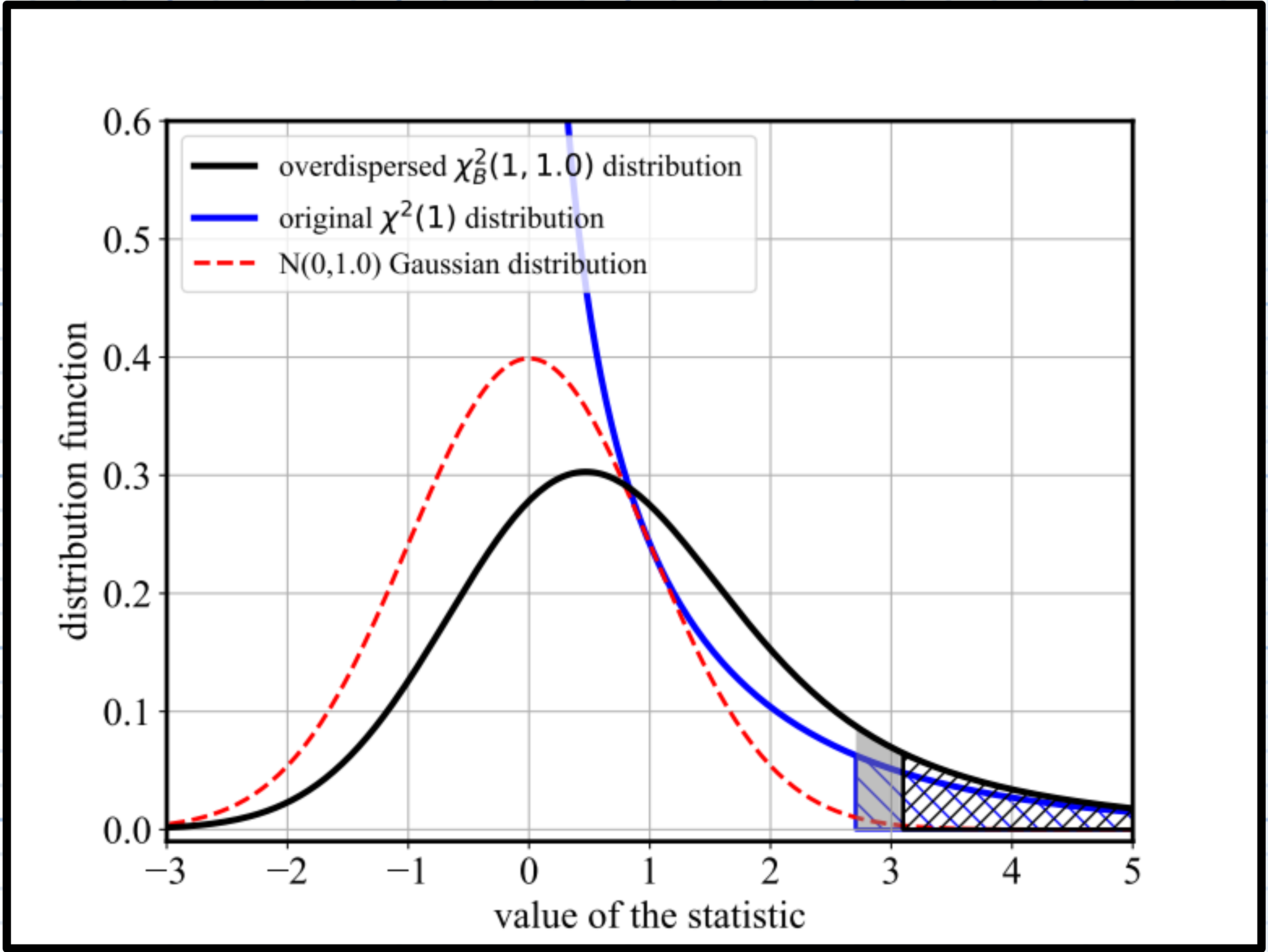
We consider this example: $n = 100$, $\theta_1 = 2$, $\theta_2 = 1$, and

$$s_i = \theta_1 \exp\left(\theta_2 \times i/n\right), \quad i = 1, \ldots, n.$$

Table 1: The p-values of five numerical studies, $\theta_1 = 2.0$.

Test	1	2	3	4	5
Bootstrap test	0.112	0.732	0.316	0.124	0.610
C_{min} test	0.109	0.730	0.302	0.113	0.649
χ^2 test	0.028**	0.184	0.063	0.025**	0.153

The ΔC fit statistic is also distributed as an overdispersed $\chi_B^2(m, \tilde{\sigma}_C^2)$ distribution, where m is the number of additional parameters in the nested component



Other talks likely of interest to CalStat WG members

- Daniel Wik (Mon), galaxy cluster temperature cross-telescope comparisons
- Jeremy Sanders (Mon), Chandra vs eROSITA flux comparisons
- Konrad Dennerl (Tue), modeling the arf/rmf of eROSITA
- Jukka Neveleinen (Wed), XMM-Chandra cluster-to-cluster scatter
- Christian Pommranz (Wed), CORRAREA to match EA of MOS to pn
- Jelle de Plaa (Wed), SPEX

CalStats Future Plans

- At least one virtual WG meeting before next IACHEC
- Virtual talks on an intermittent schedule, covering topics from statistics methods to machine learning applications
- Continue to maintain Library [https://iachec.org/calibration-statistics/#library] and backgrounds wiki [https://wikis.mit.edu/confluence/display/iachec/Calibration+Statistics]
- Continuing projects: calibration uncertainty, Concordance, polarization fitting methods, superresolution and deconvolution, spatio-spectral disambiguation, etc.