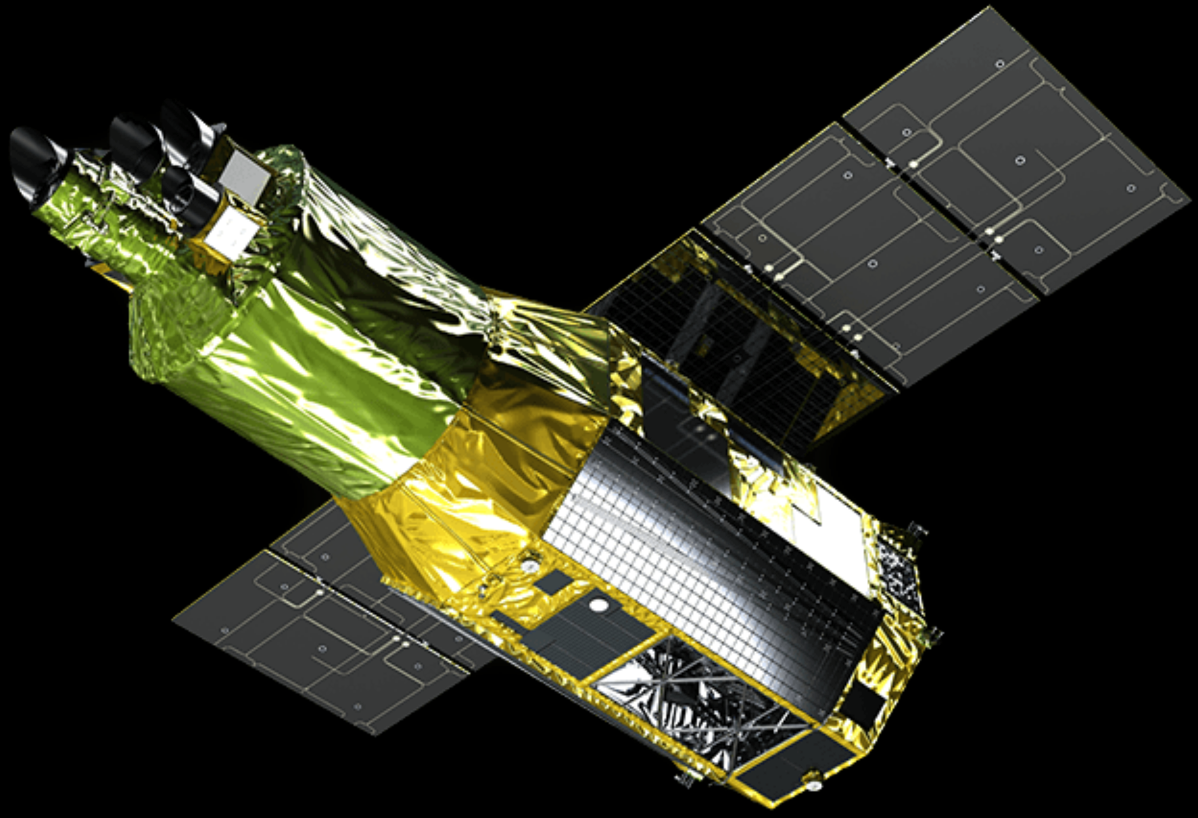
XRiSM X-Ray Imaging and Spectroscopy Mission

Planning in-flight calibration for XRISM



Eric D. Miller (MIT) for the XRISM Team

IACHEC April 2021 Plenary Sessions

The XRISM team

XRISM X-Ray Imaging and Spectroscopy Mission

XRISM Science Meeting 2, Ehime University, Japan, October 2019

JAXA(Japan Aerospace Exploration Agency)
NASA(National Aeronautics and Space Agency)

ESA(European Space Agency)
Tokyo Metropolitan University
Kanazawa University
Osaka University
University of Miyazaki
Saitama University

SRON(Neitherlands Institute for Space Research)
University of Geneva
Canadian Space Agency

Gravitation AstroParticle Physics Amsterdam
Canadian Light Source Inc.
University of Chicago
Chuo University
University of Durham
Ehime University

European Souther Observatory
Fujita Health University
Harvard-Smithsonian Center for Astrophysics
Hiroshima University
Kanto Gakuin University
Kwansei Gakuin University

Kyoto University
Lawrence Livermore National Laboratory
Leiden University
University of Maryland
Massachusetts Institute of Technology
University of Michigan

Nagoya University
Nara University of Education
Nara Women's University
Nihon Fukushi University
RIKEN
Rikkyo University

Saint Mary's University
Shibaura Institute of Technology
Shizuoka University
Tohoku Gakuin University
University of Tokyo
Tokyo University of Science

Waseda University
University of Waterloo
University of Wisconsin
Yale University

Outline

- Overview of the XRISM mission and instruments
- In-flight calibration planning team organization and guiding principles
- Calibration target list
- Specific in-flight calibration tasks and strategies

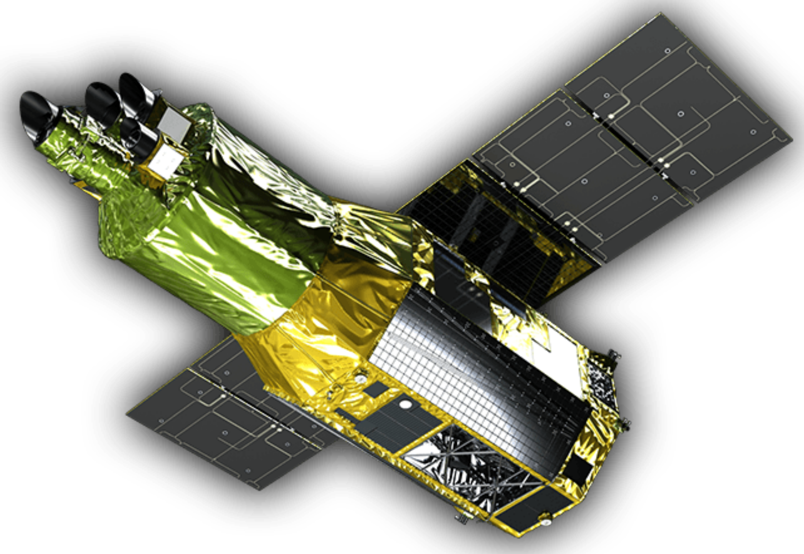
- Discussion

Science goals

XRISM — X-Ray Imaging and Spectroscopy Mission

XRISM is the “X-Ray Imaging and Spectroscopy Mission”:
High-spectral-resolution *imaging* spectrometer across a broad X-ray band

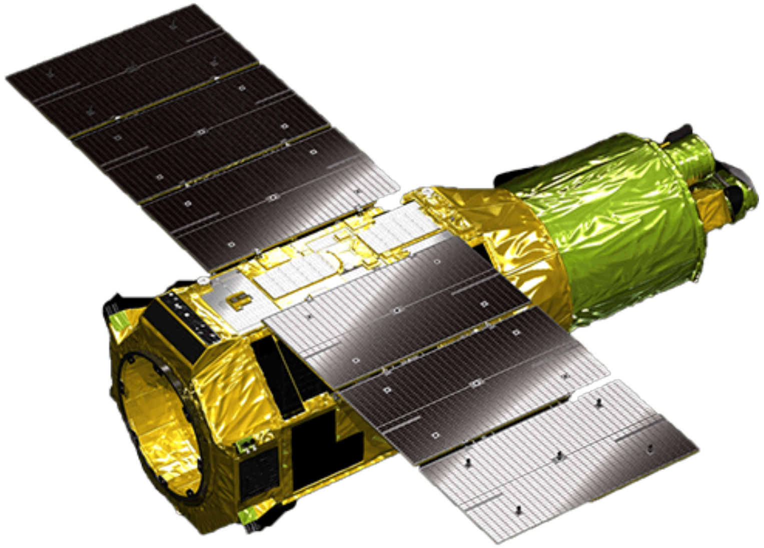
1. Formation and evolution of structure in the Universe
   - How do cluster mergers turn gravitational energy into thermal energy?
   - How much energy is distributed in ICM motion?
2. Circulation of baryonic matter in the Universe
   - How do supernova and AGN feedback distribute heavy elements?
3. Transport and circulation of energy in the Universe
   - How do galaxies and their supermassive black holes evolve together?
   - How do AGN and X-ray binary accretion flows and winds work?
4. New astrophysics
   - SNR plasma diagnostics, validation of laboratory measurements, dark matter.



XRISM will greatly expand a new era of spatially resolved X-ray spectroscopy begun by Hitomi.

Mission

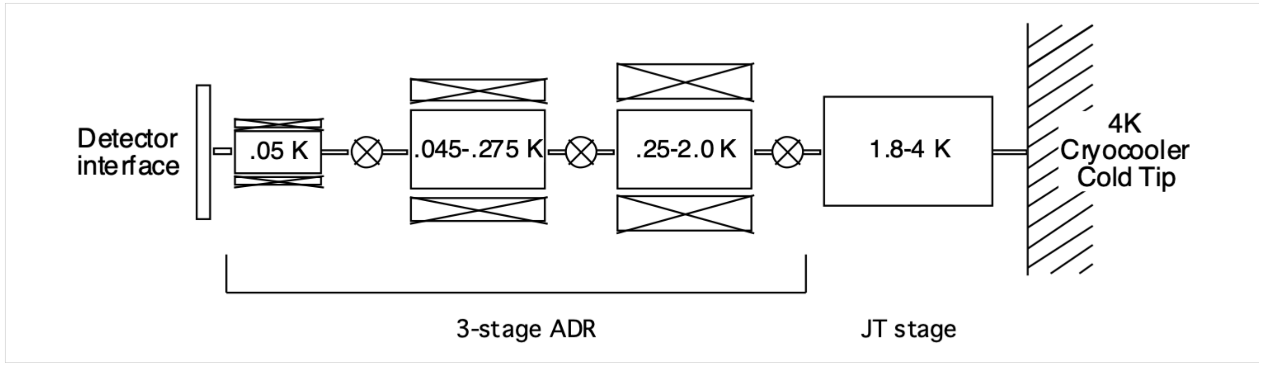
- XRISM is led by JAXA, with contributions from NASA and ESA
- 3-year nominal mission + cryogen-free mode
- Low Earth orbit, i = 31°
- Launch in JFY 2022 (Apr 2022–Mar 2023)
  - 0–3 months: initial phase (commissioning)
  - 3–9 months: calibration + PV phase
  - 9+ months: GO phase



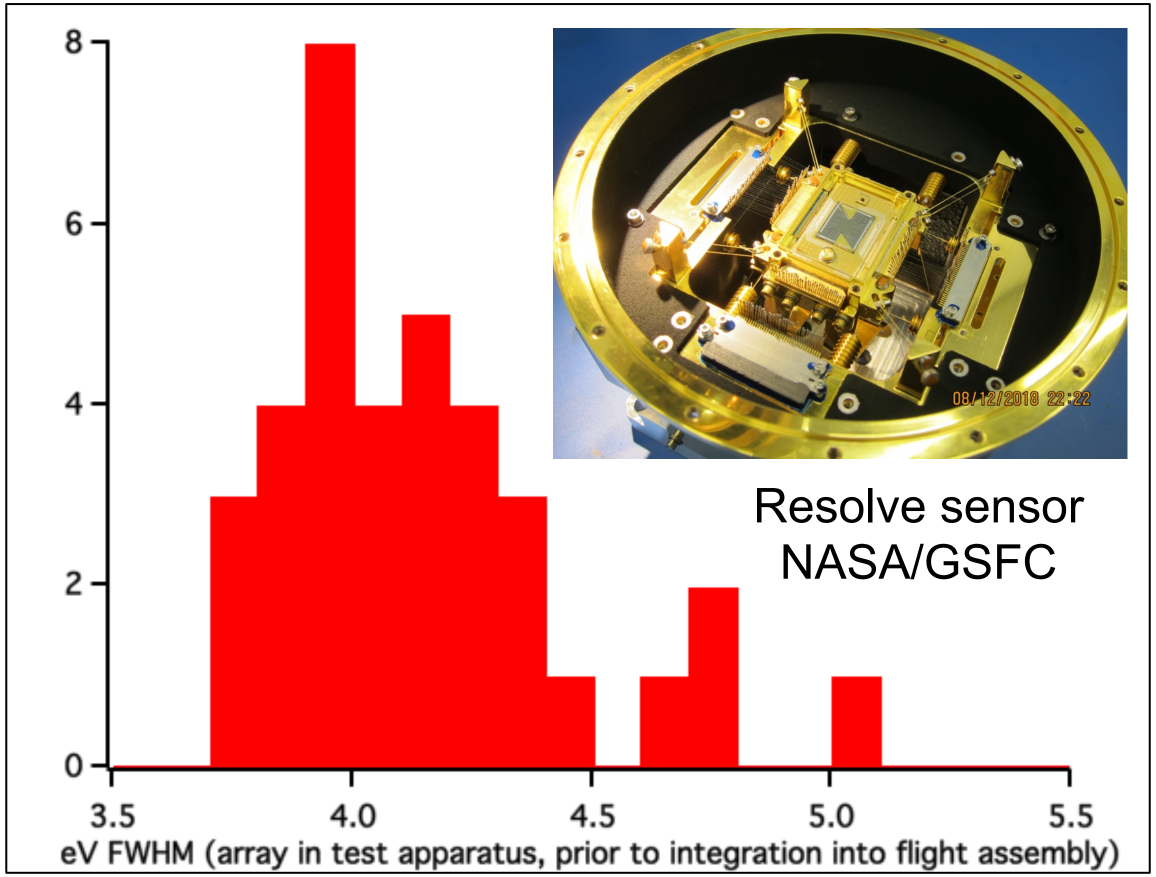
Instrument	FOV	PSF (HPD)	ΔE (FWHM @6 keV)	Energy band
Resolve	3′ × 3′ (6 × 6 pixels)	<1.7′	7 eV (goal 5 eV)	0.3–12 keV
Xtend	38′ × 38′	<1.7′	< 250 eV at EOL (< 200 eV at BOL)	0.4–13 keV

Resolve

- High-resolution imaging spectrometer, based on Hitomi SXS, including X-ray Mirror Assembly (XMA).
- Detector must be cooled to 50 mK.



- Flight detector has been integrated with flight dewar at SHI in Japan and is undergoing testing.
- Flight XMA in testing and calibration at GSFC.



Resolve sensor NASA/GSFC

Resolve requirements

XRISM X-Ray Imaging and Spectroscopy Mission

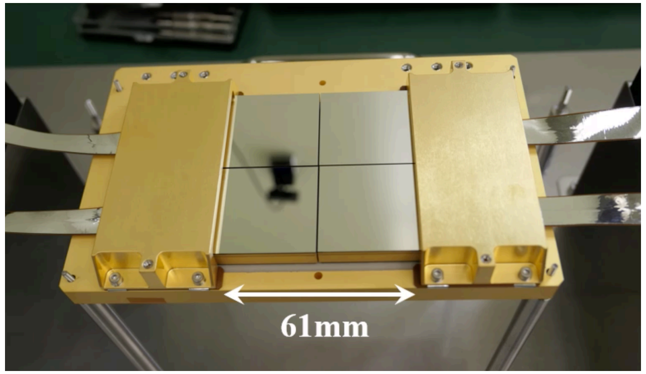
Parameter	Requirement	Hitomi Values
Energy resolution	7 eV (FWHM)	5.0 eV
Energy scale accuracy	± 2 eV	± 0.5 eV
Residual Background	2 x 10^{-3} counts/s/keV	0.8 x 10^{-3} counts/s/keV
Field of view	2.9 x 2.9 arcmin	same, by design
Angular resolution	1.7 arcmin (HPD)	1.2 arcmin
Effective area (1 keV)	> 160 cm^2	250 cm^2
Effective area (6 keV)	> 210 cm^2	312 cm^2
Cryogen-mode Lifetime	3 years	4.2 years (projected)
Operational Efficiency	> 90%	> 98%

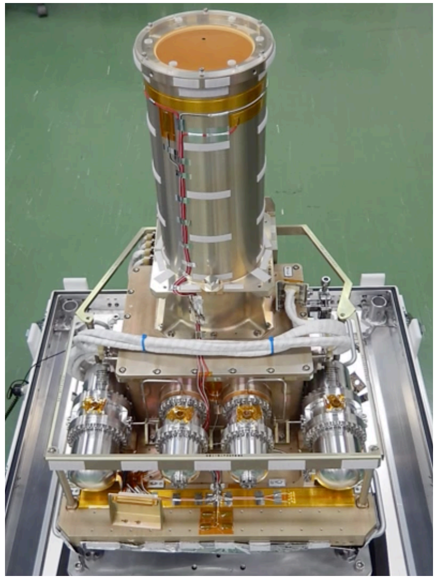
Xtend

XRISM X-Ray Imaging and Spectroscopy Mission

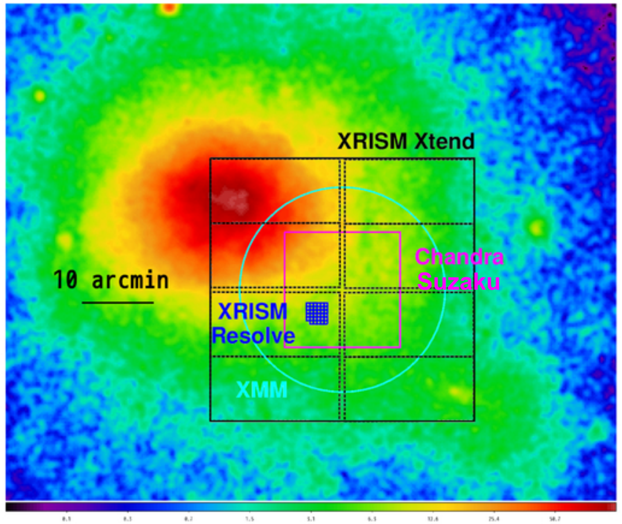
- Wide-field X-ray CCD imager, based on Hitomi SXI, including XMA.
- 4 × 200-μm thick BI CCDs
  - Good QE at soft and hard energies.
  - Low particle background.
  - 38′×38′ FOV allows detection of sources that might contaminate Resolve FOV, and monitoring for transients.

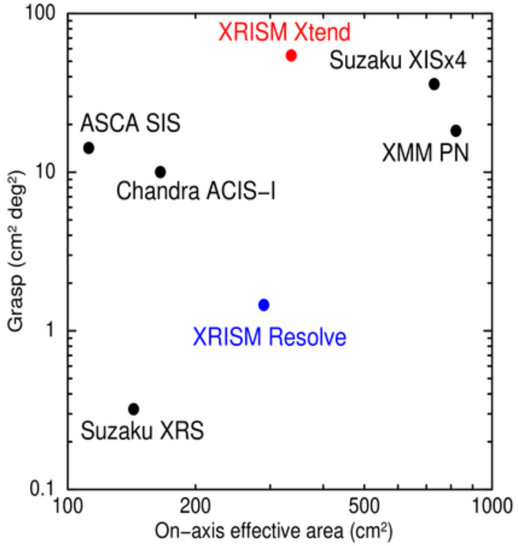
- Flight detector undergoing testing and calibration at Osaka U., MHI, and TKSC in Japan.
- Flight XMA in testing and calibration at GSFC.





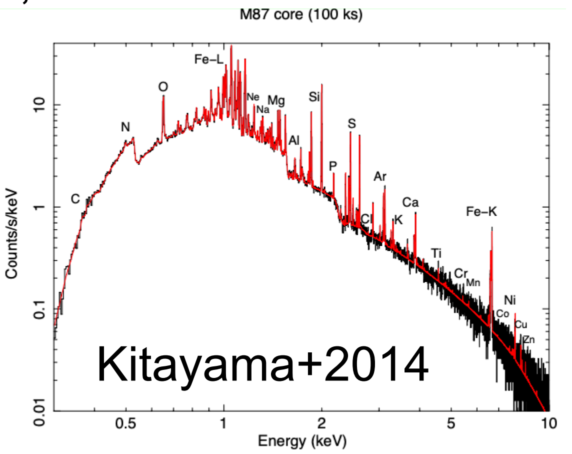
Nakajima+2020

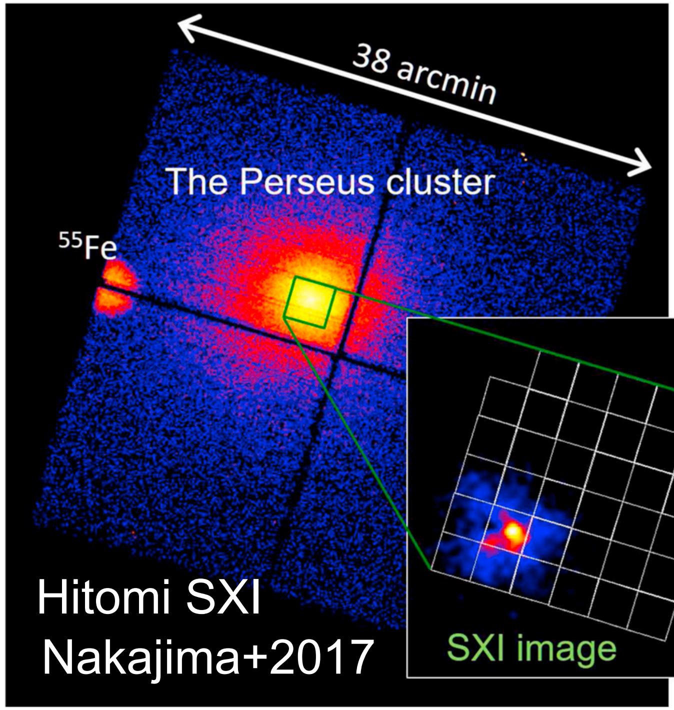


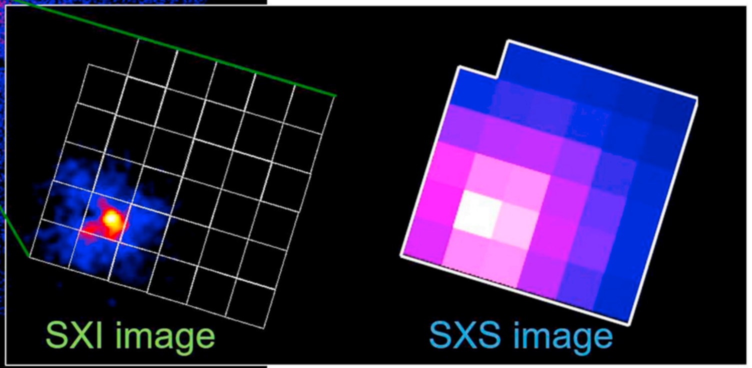


In-Flight Calibration Plan (IFCP)

- Ground calibration is underway, but things can change after launch and on-orbit.
  Porter+2020, Midooka+2020, Nakajima+2020, Yoneyama+2020
- In-flight calibration plan must:
  - Identify and prioritize calibration requirements for the instruments aboard XRISM;
  - Identify calibration targets and observing strategies;
  - Perform feasibility simulations.
- Calibration challenges for Resolve:
  - Unprecedented combination of spectral resolution, spectral coverage, and effective area.
  - Field of view ~ point spread function.
- Calibration challenges for Xtend:
  - Imaging fidelity over 38′ FOV.
  - Increased hard-band response compared to other X-ray CCD instruments.







IFCP team

Chair	Eric Miller *
Co-chair	Makoto Sawada *
Resolve Instrument Team	Megan Eckart Caroline Kilbourne Maurice Leutenegger Scott Porter Masahiro Tsujimoto Cor de Vries Takashi Okajima Takayuki Hayashi Keisuke Tamura Rozenn Boissay-Malaquin
Xtend Instrument Team	Hironori Matsumoto Koji Mori Hiroshi Nakajima Takaaki Tanaka
Science Operations Team	Yukikatsu Terada Mike Loewenstein Tahir Yaqoob
Science Management Office	Makoto Tashiro Richard Kelley Rob Petre Matteo Guainazzi * Brian Williams Hiroya Yamaguchi
Science Team	Marc Audard Ehud Behar Laura Brenneman Lia Corrales Renata Cumbee Teruaki Enoto Liyi Gu Edmund Hodges-Kluck Yoshitomo Maeda Maxim Markevitch * Paul Plucinsky Katja Pottschmidt Aurora Simionescu *

* IFCP sub-group lead.

IFCP team organization

- Broad membership drawn from Instrument Teams, Science Operations Team, and Science Team.
- Ensures necessary technical and astrophysical background to understand limits imposed by instrumentation and celestial sources.
- Ensures that all interested parties have a stake in proper calibration to reach the desired science goals.
- Greatly expands the workforce available to run complex simulations of different calibration strategies and review possible targets.

IFCP guiding principles

- Build in flexibility
  - Identify secondary calibration targets well in advance of launch in case of schedule changes.
- Plan ahead
  - Perform simulations of observations and strategies well before launch.
  - Learn from previous experience to prepare contingency plans (e.g. molecular contamination monitoring and calibration).
- Use the community
  - Capitalize on experience of IACHEC*, including standard candle definitions and multi-mission observation coordination.
  - XRISM IFCP borrows heavily from Hitomi IFCP, but with fewer instruments.

* International Astronomical Consortium for High-Energy Calibration, iachec.org

In-flight calibration requirements

XRISM X-Ray Imaging and Spectroscopy Mission

Calibration requirements are derived from mission science goals by the Instrument Teams.
Tashiro+2018, Tashiro+2020, Eckart+2018

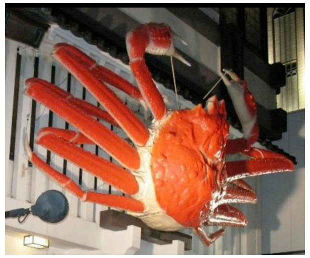
Table 1. XRISM calibration requirements to be verified in flight.[a]

Requirement	Resolve	Xtend
Energy scale	2 eV for each pixel [1 eV (0.05–12 keV), 3 eV (12–25 keV)]	5% (1 keV) 0.3% (6 keV)
Energy resolution (FWHM)	1 [0.5] eV for each pixel[b] [2 eV (12–25 keV)]	10% (1 keV)[c] 5% (6 keV)[c]
Abs. eff. area on-axis[d]	10% [5%]	10% [5%]
Abs. eff. area off-axis[d]	10% [5%] within 5′	15% [10%] within 10′
Rel. eff. area on-axis[d]	5% [3%] [5% (12–25 keV)]	5% [2%]
Rel. eff. area $< 2'$ off-axis[d]	5% [3%] [5% (12–25 keV)]	10% [5%]
Rel. eff. area 2′–5′ off-axis[d]	10% [10% (12–25 keV)]	10% [5%]
Rel. eff. area $> 5'$ off-axis[d]	N/A	10% [5%]
Rel. eff. area fine structure[d]	5% in 1 eV bins around C, N, O K edges[e]	15% at Si K edge
PSF on-axis[f]	5% [3% (0.3–25 keV)]	10%
PSF off-axis[g]	5% [5% (12–25 keV)]	[10%]
Absolute timing[h]	1.0 ms	10 ms
Relative timing[h]	0.5 ms	TBD
Aimpoint	Difference in the aimpoint and optical axis known to 30″	

IFCP boundary conditions

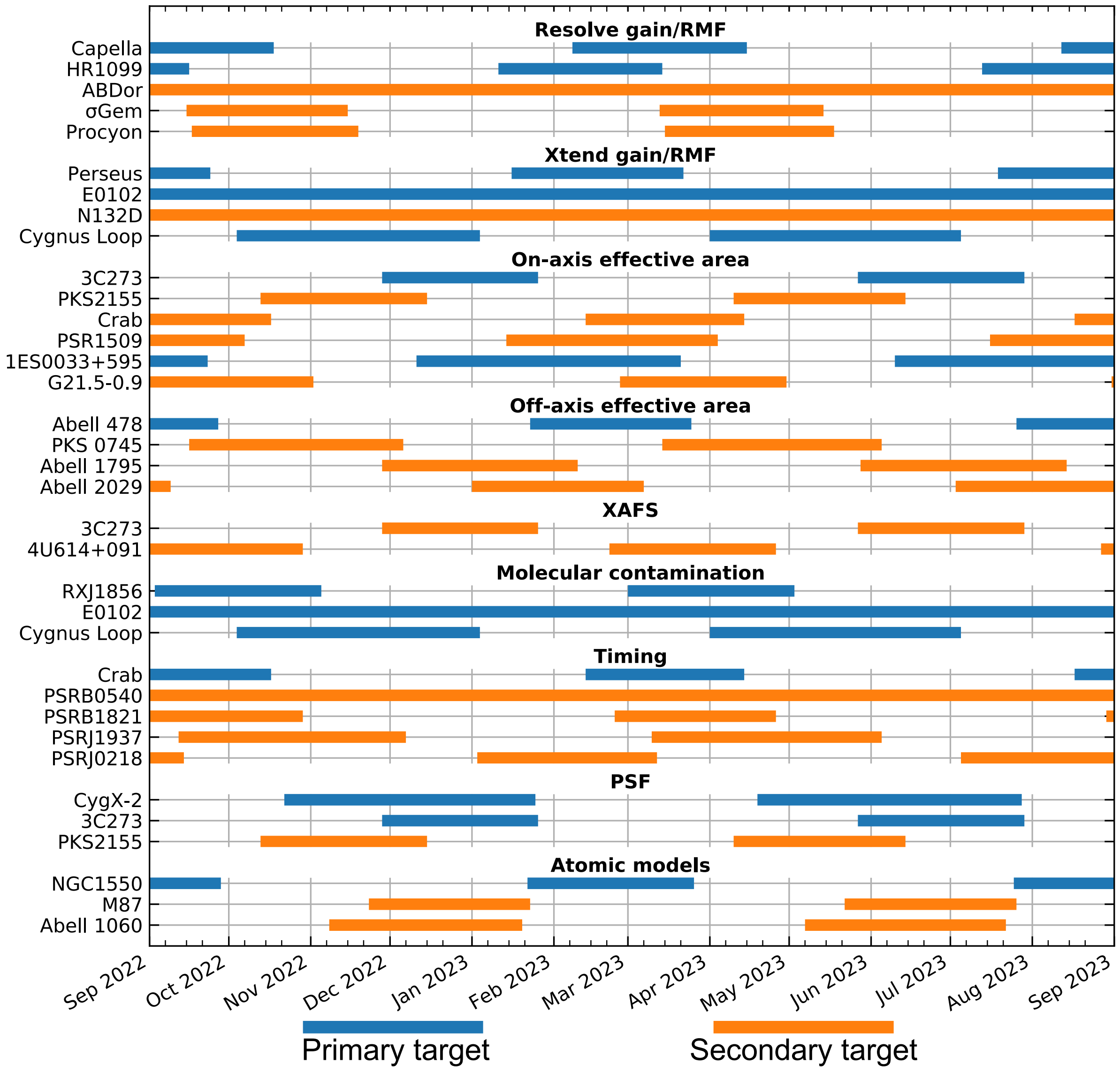
XRISM X-Ray Imaging and Spectroscopy Mission

- Available calibration time
  - Commissioning phase: 0 Msec
  - Calibration and PV phase: [1 mo + (0.05 × 6 mo)] * 0.43 = 1.4 Msec
  - GO phase: (0.05 × 12 mo) * 0.43 = 0.7 Msec
- Visibility constraints
  - 90-minute low-Earth orbit, 90°±30° Sun angle
  - Most sources are visible 2x per year, short windows for Ecliptic sources, high-Ecliptic latitude sources are always visible.
  - Roll constraints affect extended sources, raster scans, PSF measurements.
- Bright source limits
  - Resolve encounters issues with >10mCrab sources: reduced high-res fraction due to pulse overlap, electrical cross-talk degrading resolution, dead time from PSP overload. XRISM Bright Sources Study Group ("The 1 Crab Club"), Lead: E. Hodges-Kluck
  - Xtend suffers pile-up for >1mCrab sources. Tamba+2021



Preliminary Target List Visibility

XRISM X-Ray Imaging and Spectroscopy Mission

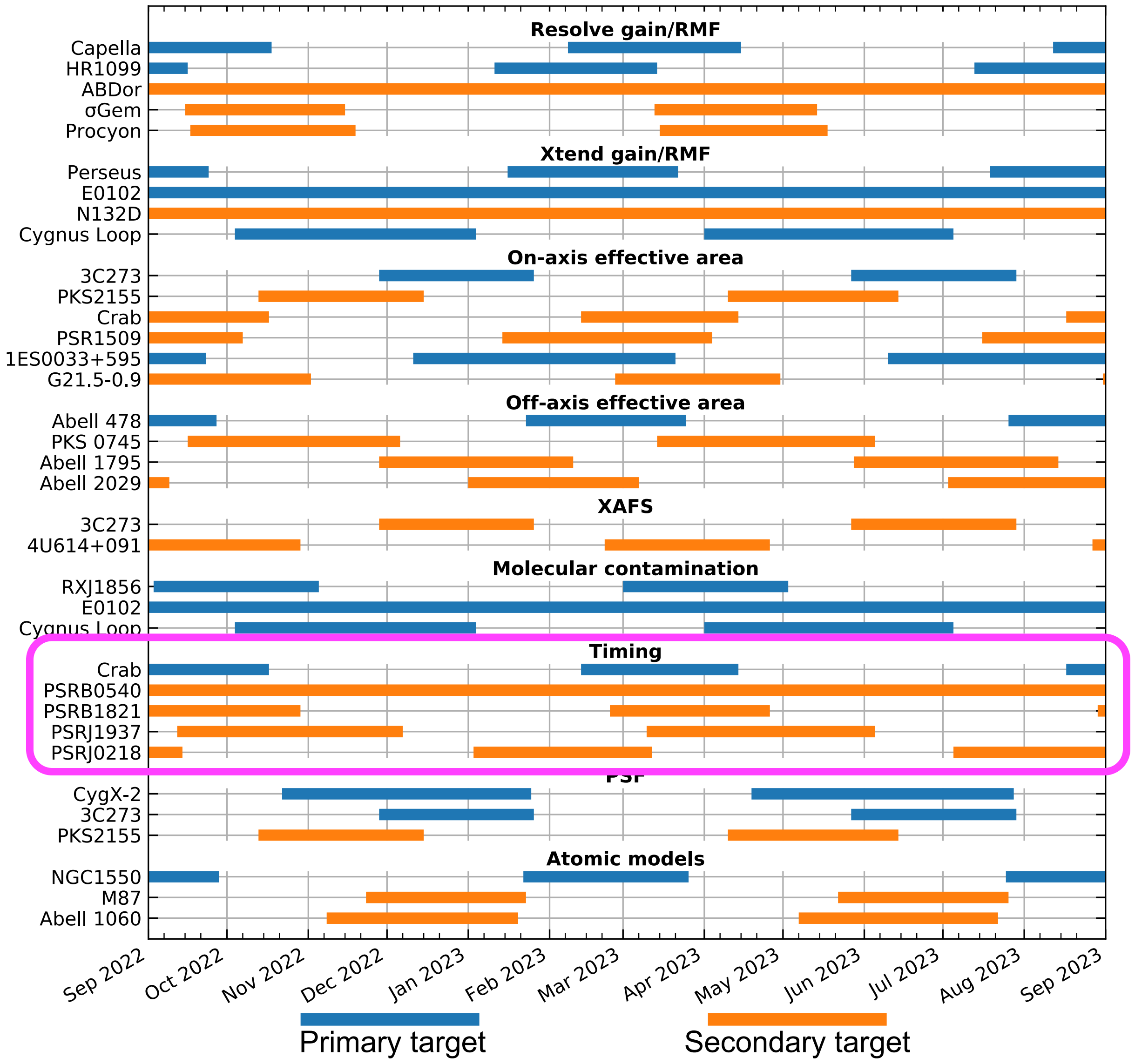


- Some calibration must be done early.
  1. Determination of the boresight and optical axis position of both instruments.
  2. Verification of the accuracy of time assignment.
  3. Verification of the accuracy of the Resolve energy scale and resolution.
  4. Contamination monitoring campaign of the Resolve and Xtend.
  5. First characterization of the overall effective area calibration.

- Target visibility and flexibility are key!

Preliminary Target List Visibility

XRISM X-Ray Imaging and Spectroscopy Mission



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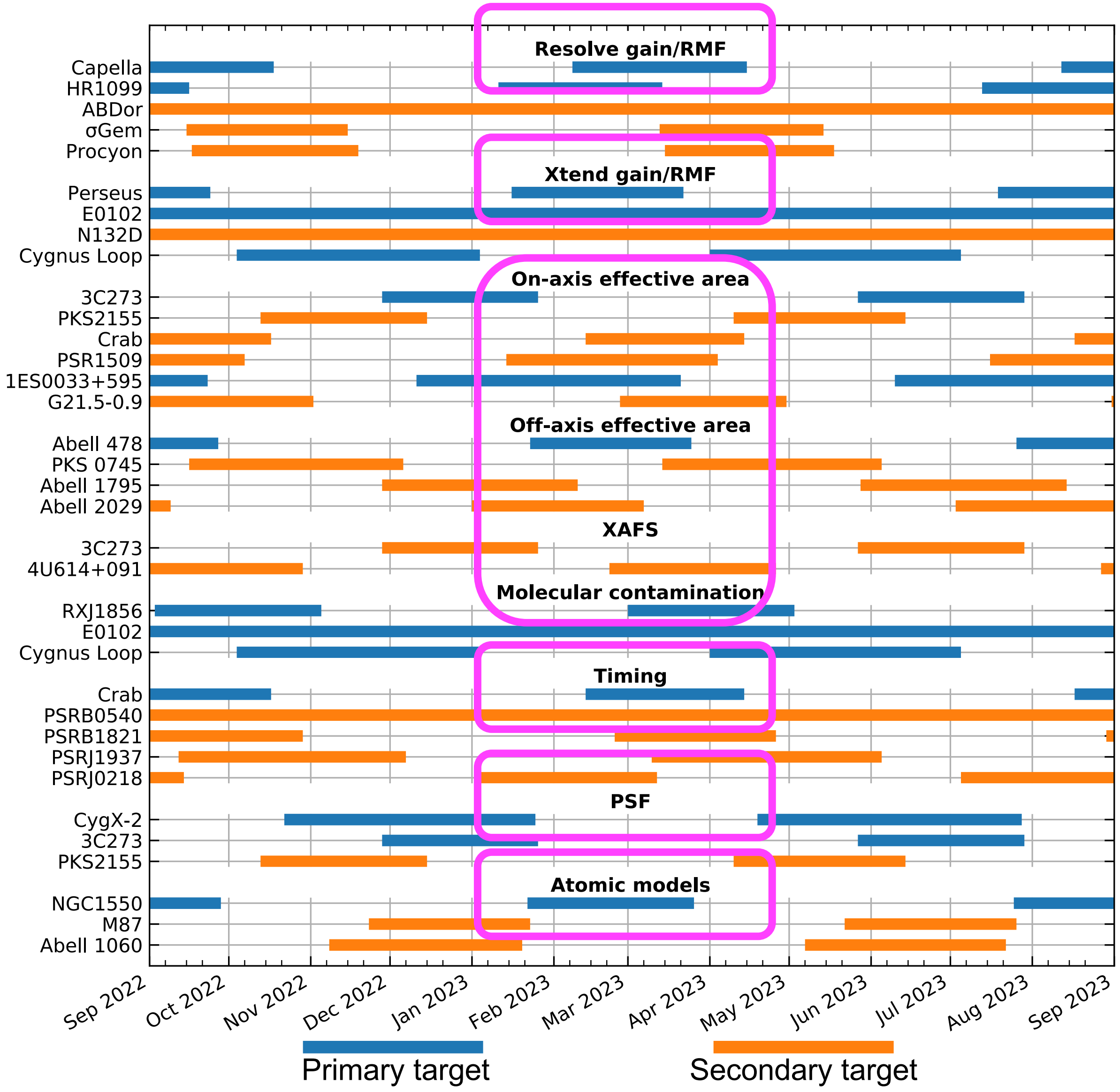
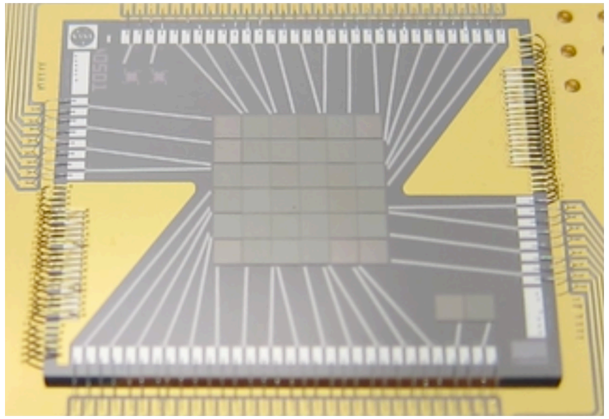
Preliminary Target List by Sub-group



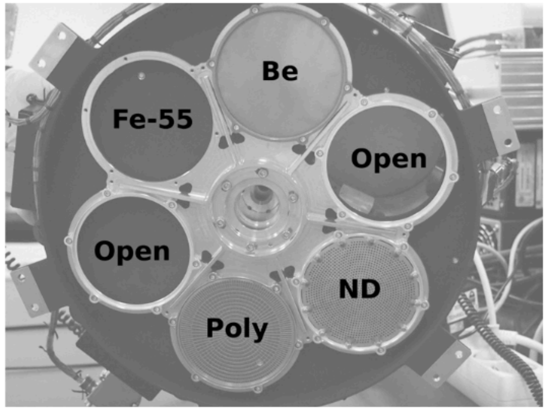
- IFCP Team has ~30 people. That's a lot.
- Sub-groups defined for detailed work.
  - Review specific XRISM in-flight calibration requirements.
  - Review Hitomi IFCP to identify changes:
    - New or stricter requirements for XRISM.
    - New or different operational constraints placed on XRISM compared to Hitomi.
    - Elimination of hard X-ray instruments.
    - New science goals for XRISM.
  - Perform simulations and plan strategies.

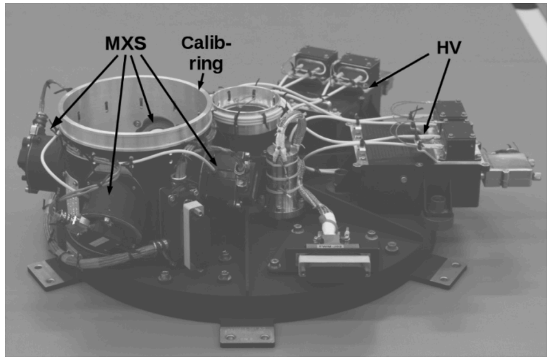
Resolve energy scale and spectral response

^{55}Fe-illuminated calibration pixel for overall energy scale, LSF trend.

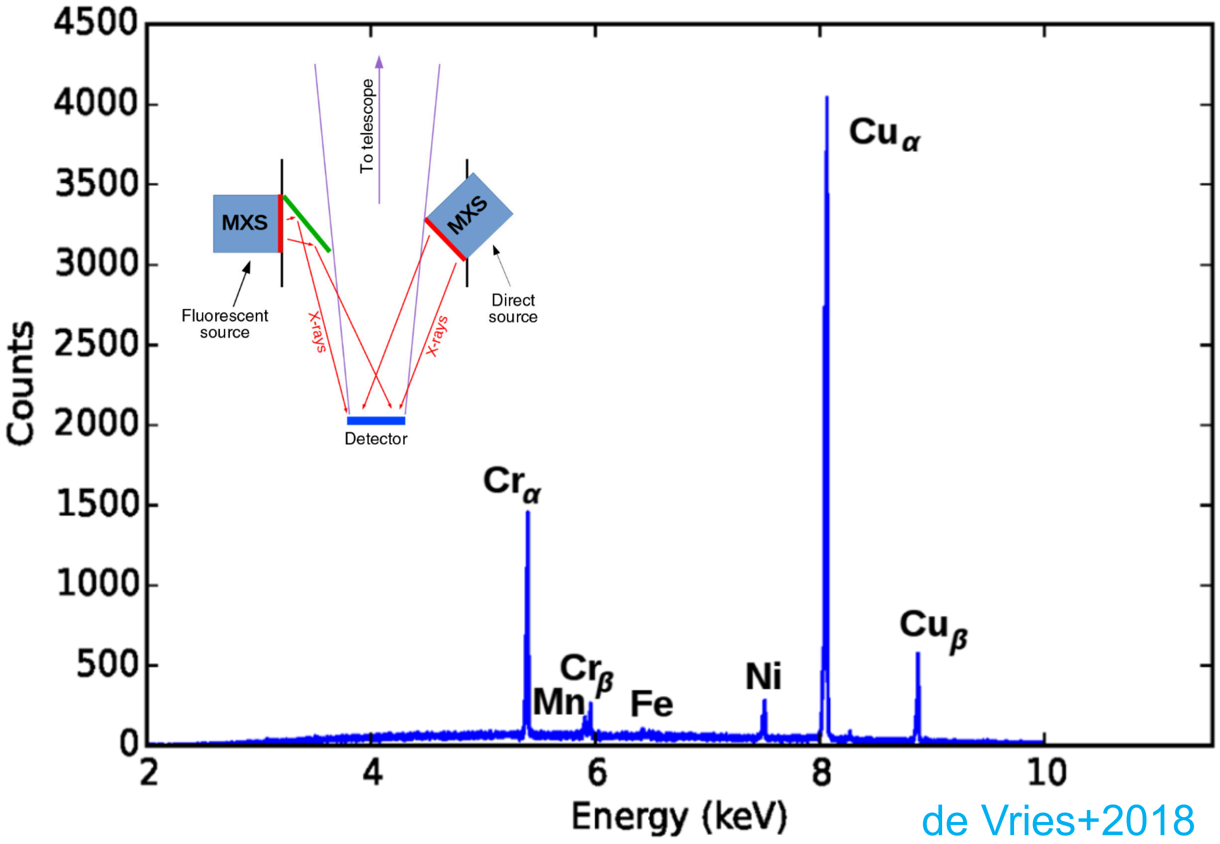


^{55}Fe filter wheel position to illuminate all pixels, 1 ct/s/pix @ 6 keV.





Modulated X-ray Source (MXS) can be pulsed at 1–3% duty cycle, 1–3 cts/s/pix

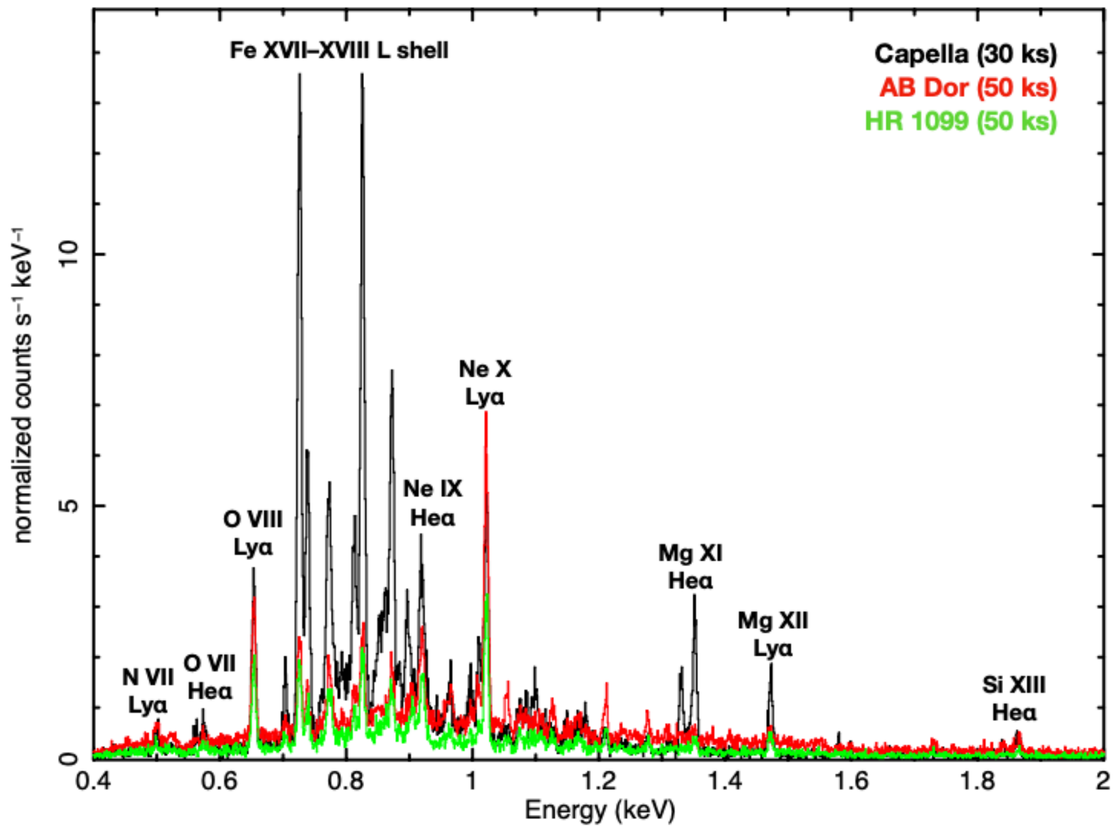


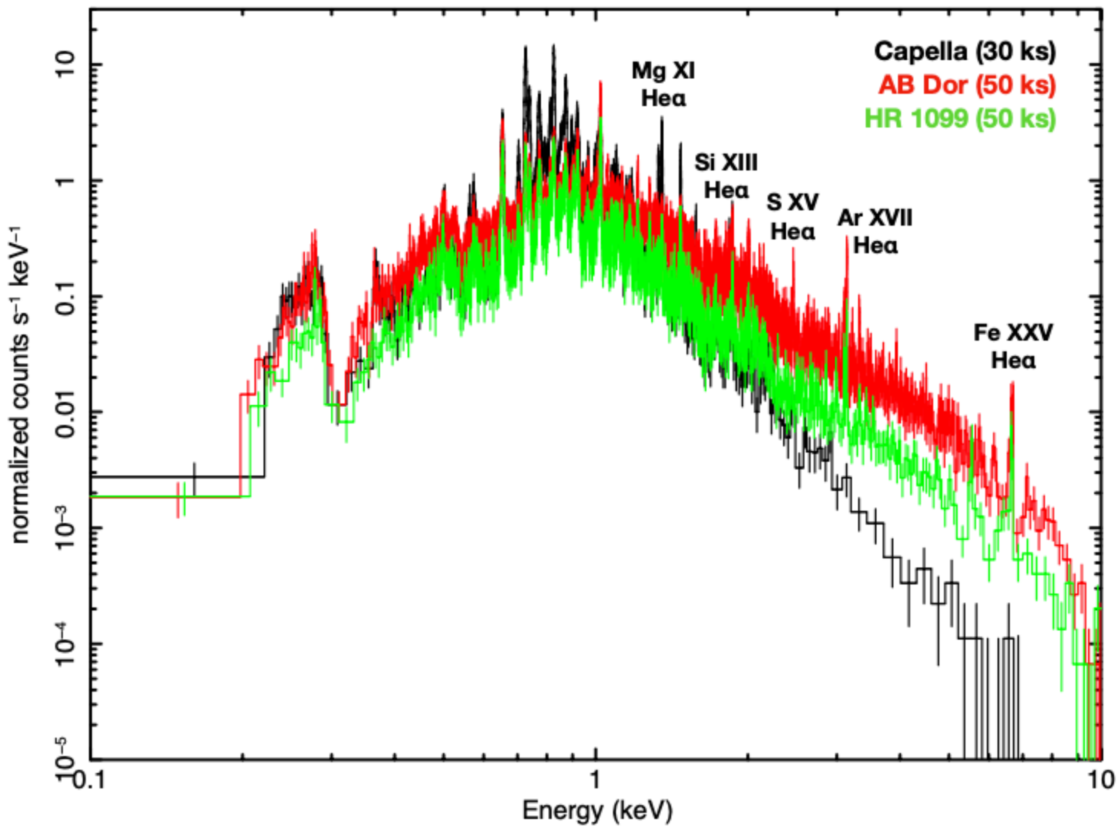
de Vries+2018

Resolve energy scale and spectral response

XRISM X-Ray Imaging and Spectroscopy Mission

- Coronal stars for on-axis energy scale, LSF < 5 keV. Exposure times driven by LSF calibration.

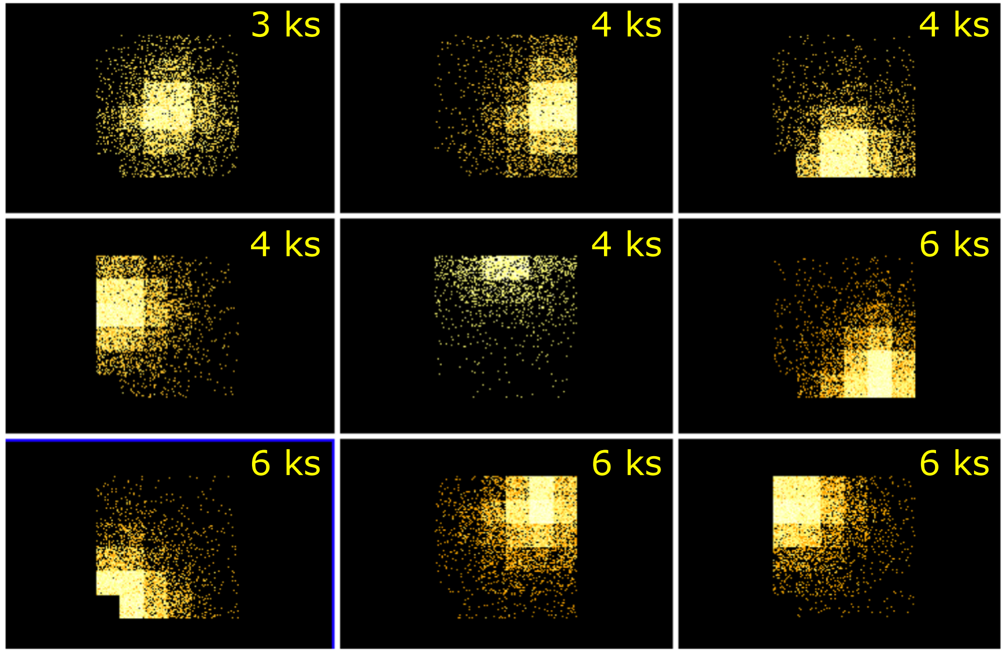


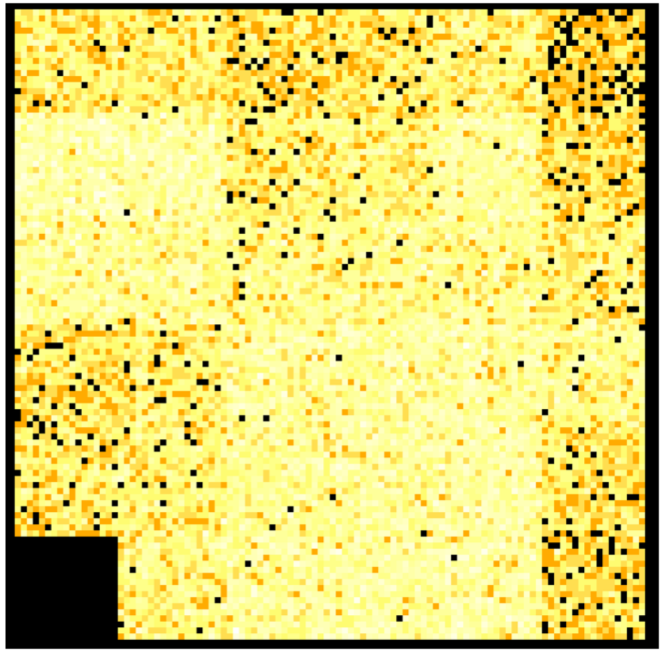


Simulations by M. Audard

Resolve energy scale and spectral response

- Capella raster scan to uniformly illuminate all Resolve pixels.
- Obtain >1000 counts in two Fe L lines (0.72 and 0.82 keV).
- Two modes (normal/forced mid-res) × three operating temperatures.





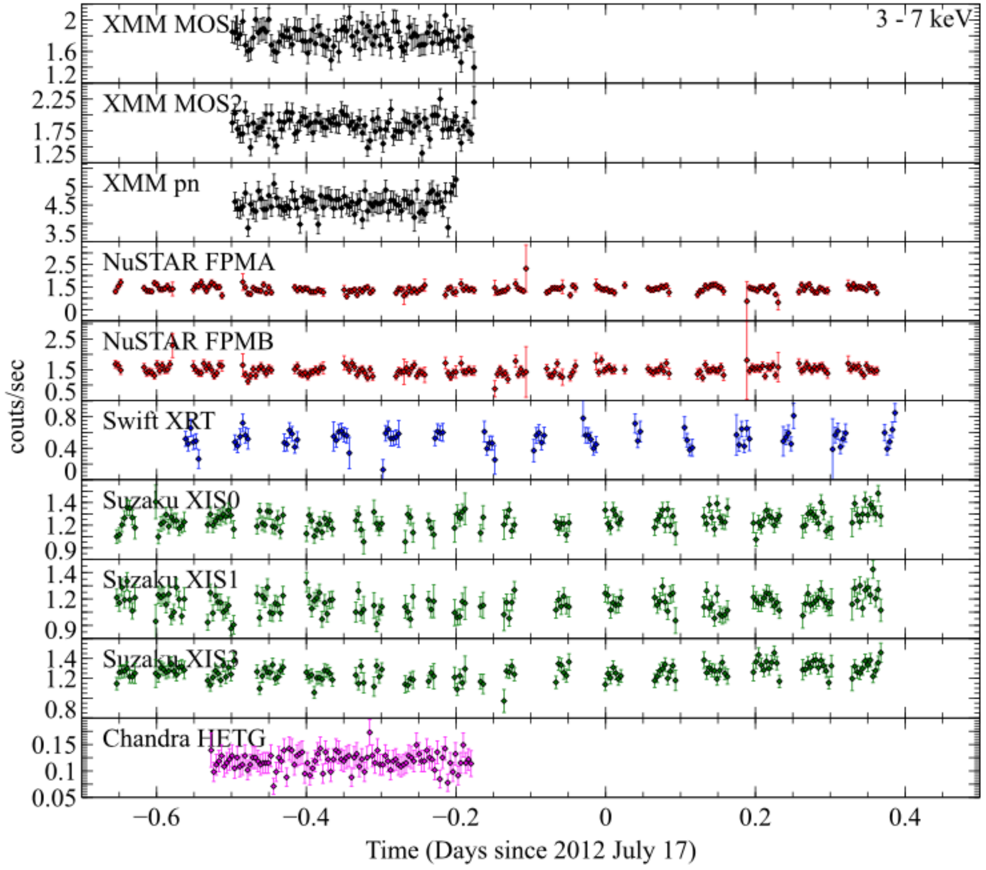
Total time allocation 43 ks x 5 = 215 ks (+ on-axis 50 ks)

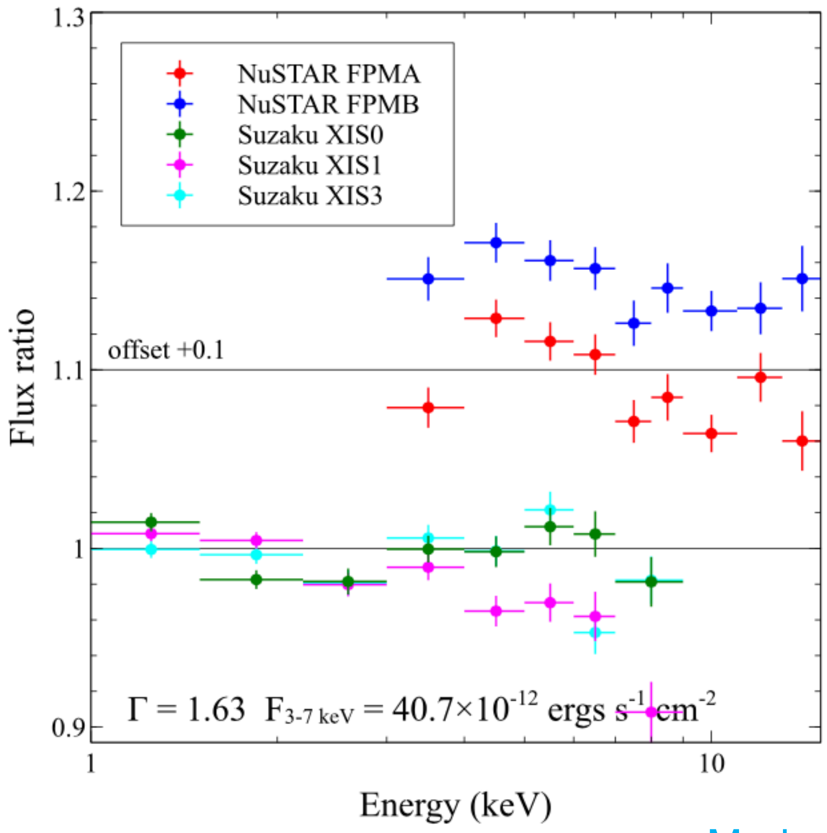
Simulations by M. Guainazzi

Resolve & Xtend effective area on-axis

XRiSM X-Ray Imaging and Spectroscopy Mission

- Bright blazars (3C273, PKS2155) for on-axis effective area (absolute and relative).
- Variable, so must be observed simultaneously with other instruments, especially NuSTAR.



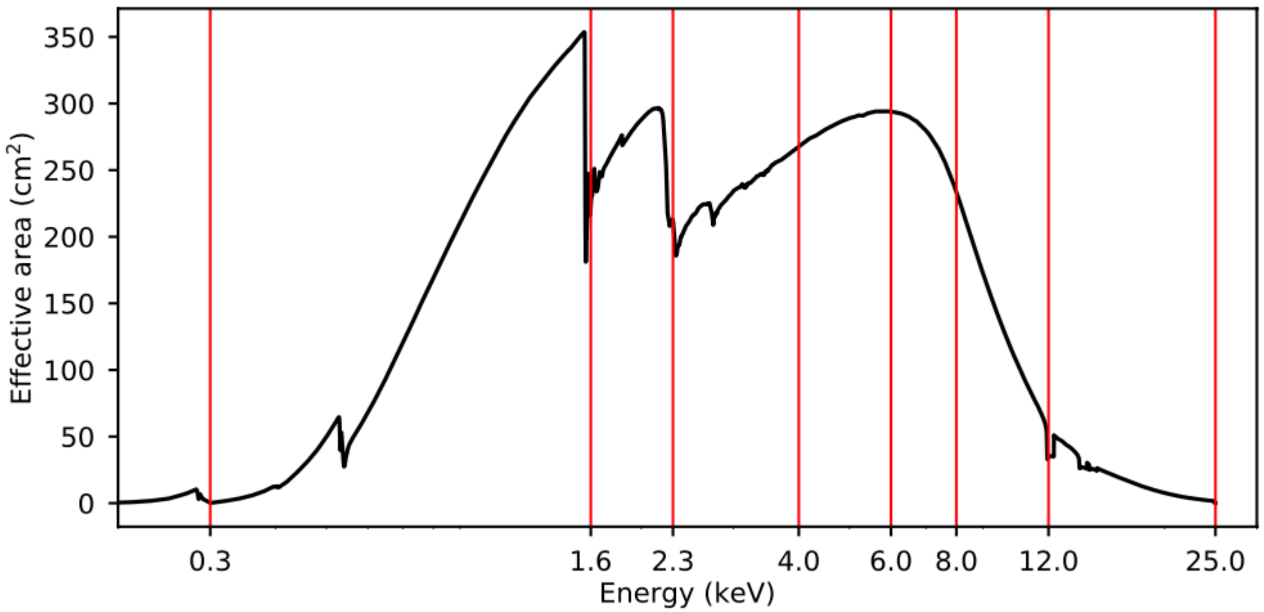


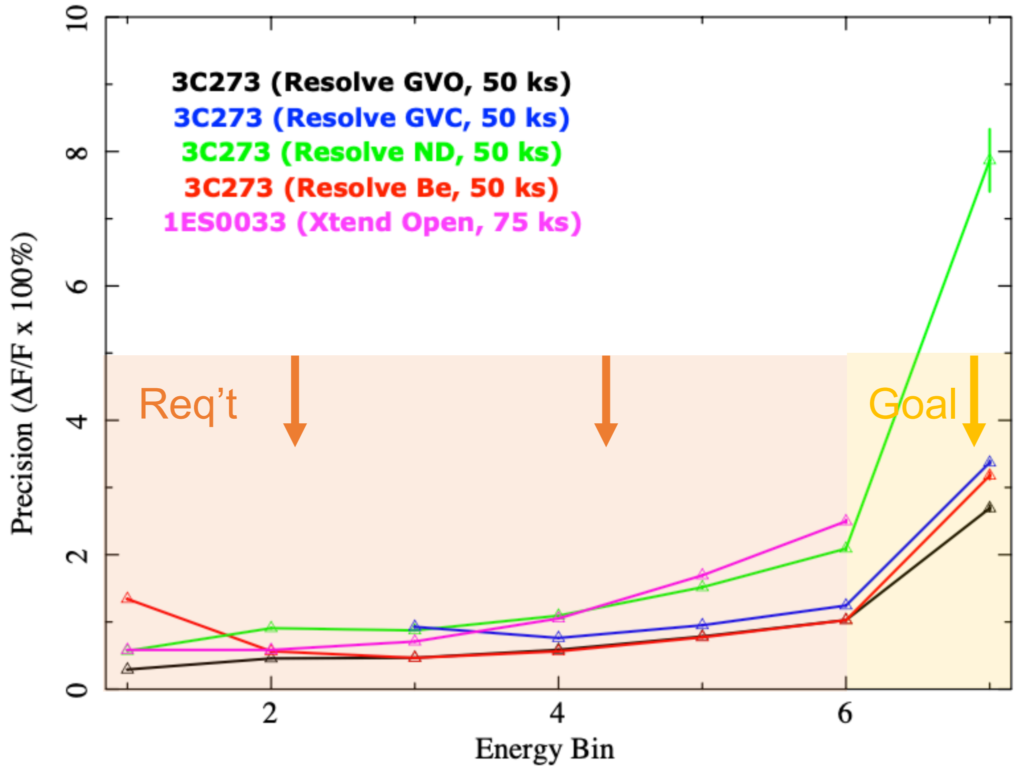
Madsen+2017

Resolve & Xtend effective area on-axis

XRiSM X-Ray Imaging and Spectroscopy Mission

- All filter and gate valve combinations must be calibrated for Resolve.
- Xtend must use a fainter source than Resolve due to pile-up, like 1ES0033.
- Observe E0102 to compare continuum-dominated and line-dominated sources, monitor contamination.
- Observe RXJ1856 to monitor contamination.



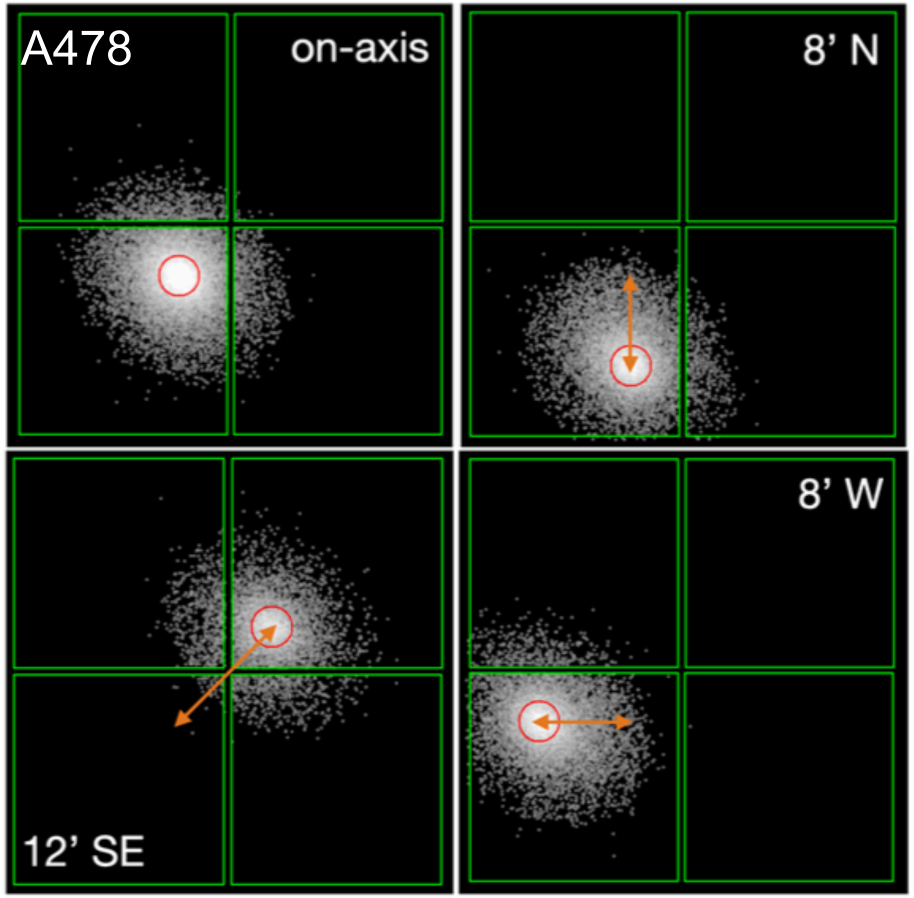


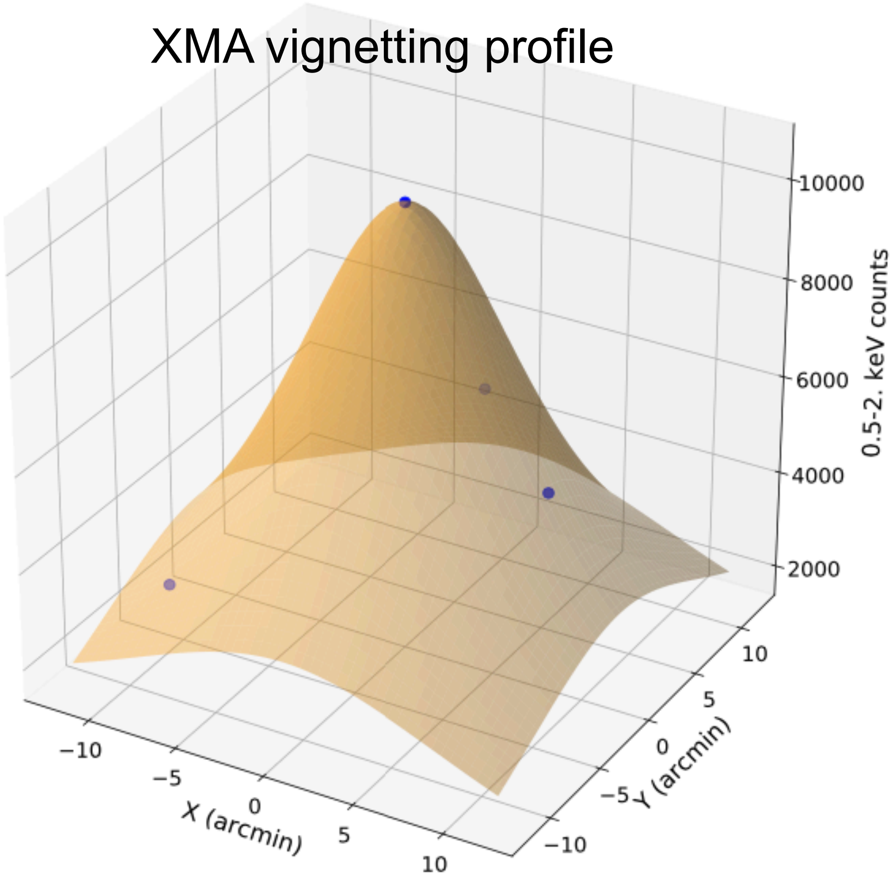
Simulations by L. Brenneman

Xtend effective area off-axis

XRISM X-Ray Imaging and Spectroscopy Mission

- 4×10 ksec raster scan of "peaky cluster" for Xtend XMA off-axis vignetting and optical axis.





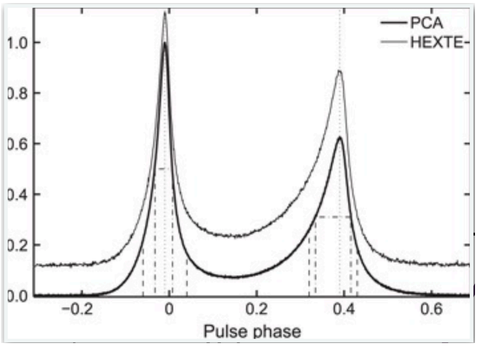
Simulations by A. Simionescu

Resolve timing

XRISM X-Ray Imaging and Spectroscopy Mission

- Resolve timing requirements are 1.0 ms absolute, 0.5 ms relative.
- Includes allocations for instrument and spacecraft.
- Crab pulsar is best source, but other sources can calibrate absolute timing if visibility is bad.

Crab



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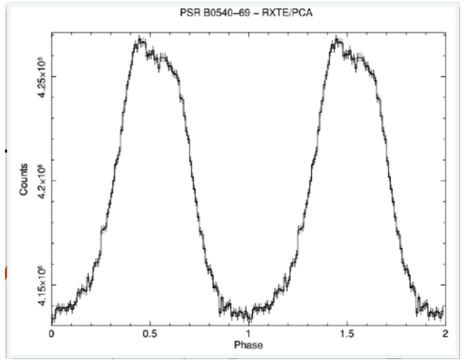
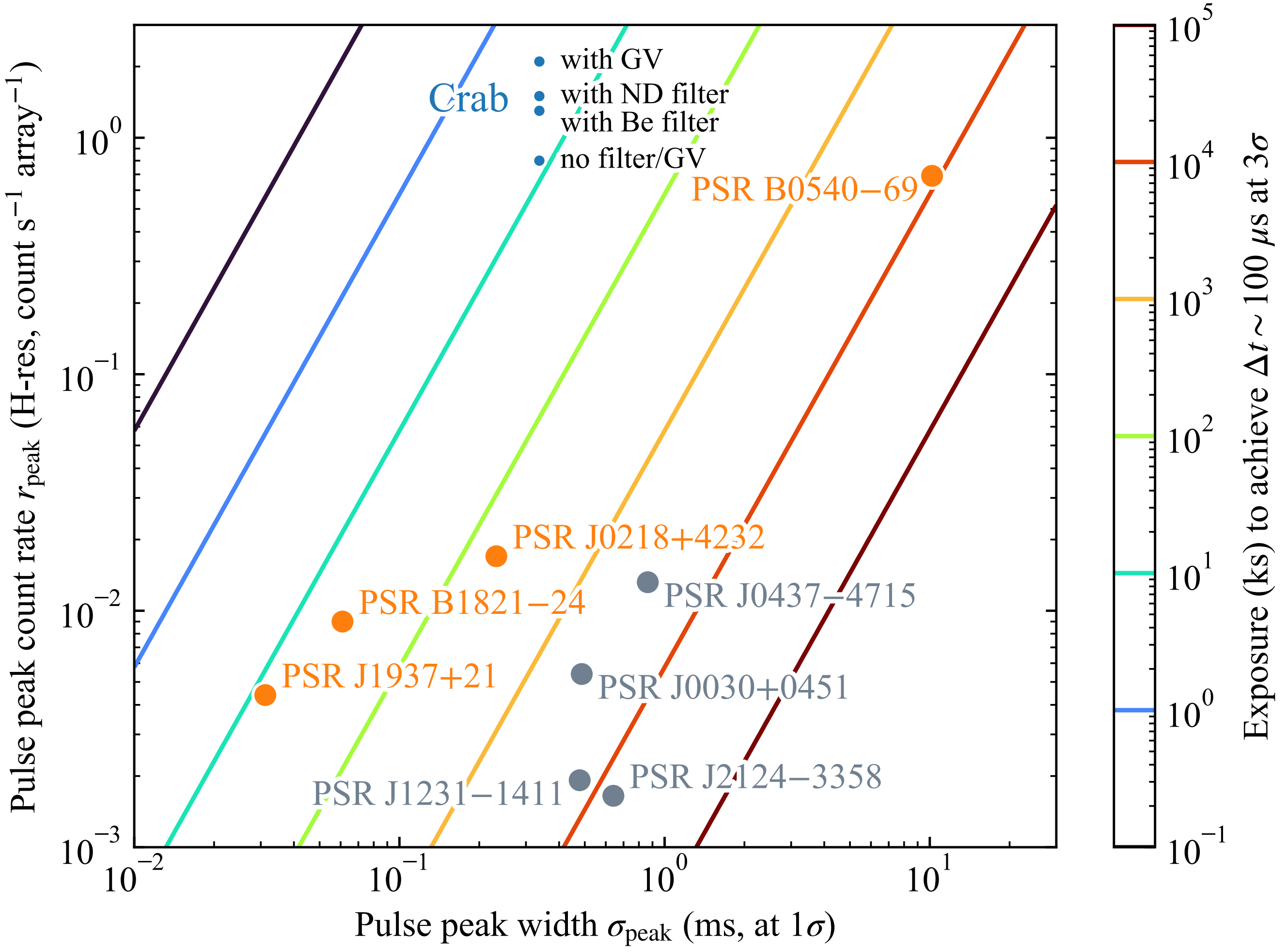
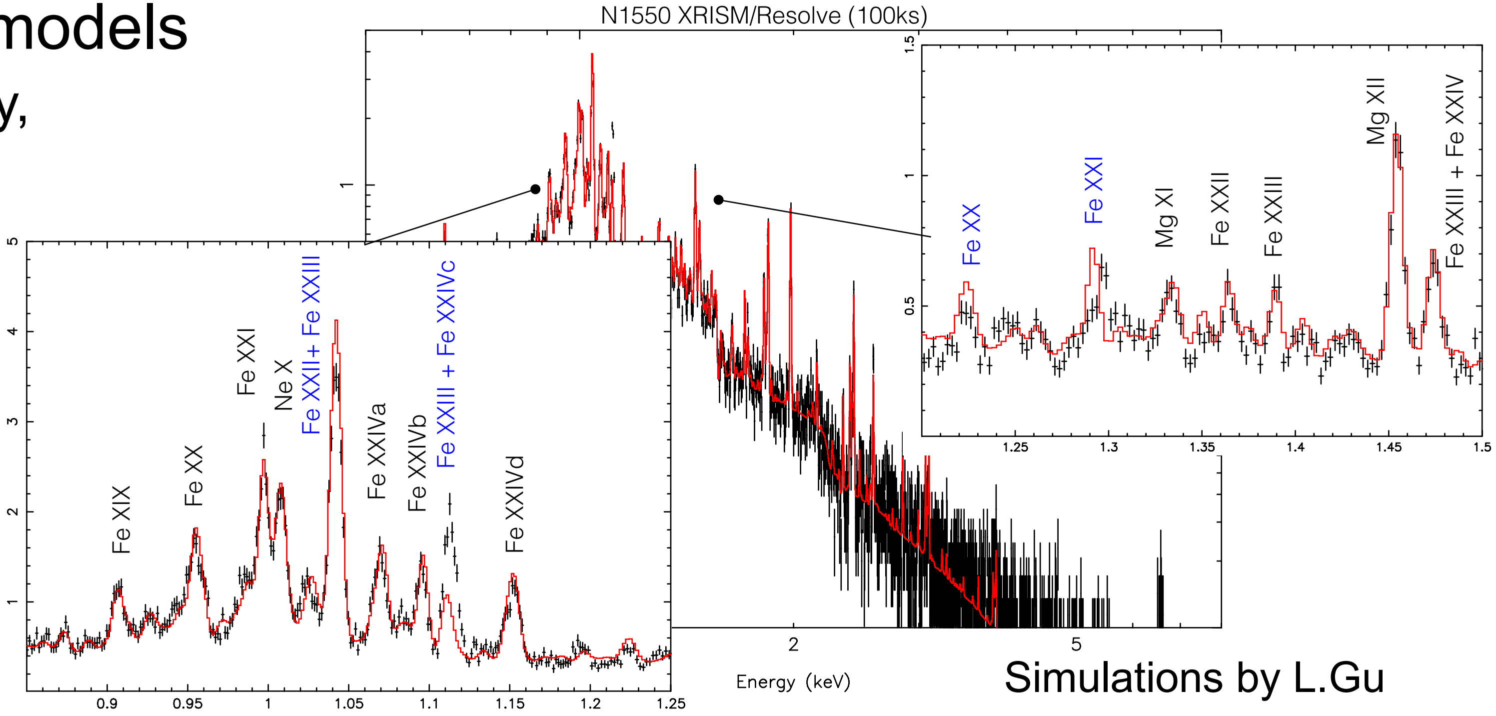




Simulations by M. Sawada

Science calibration: atomic modeling

- “Science calibration” targets are valuable for enabling the best XRISM science or performance, but do not directly address *instrument* calibration.
  - Enhance PV ***or*** GO phase science.
  - Require early observations (PV phase) to be of most use.
  - Enable or enhance science return on multiple categories of objects.
- Calibration of X-ray spectral models
  - transition energy, line emissivity, ionization balance
  - NGC 1550: 1.3 keV, L-shell lines of FeXX–FeXXIV, K-shell lines of O to Si.



Simulations by L.Gu

Summary

XRISM X-Ray Imaging and Spectroscopy Mission

- XRISM in-flight calibration plan builds on lessons learned.
- Team members have been performing simulations, planning strategies.
- Preliminary target list has been compiled, final simulations are underway and observing strategies are being planned.

- Thanks to hard work on ground calibration by instrument teams, we expect smooth in-flight verification, but we will be prepared!

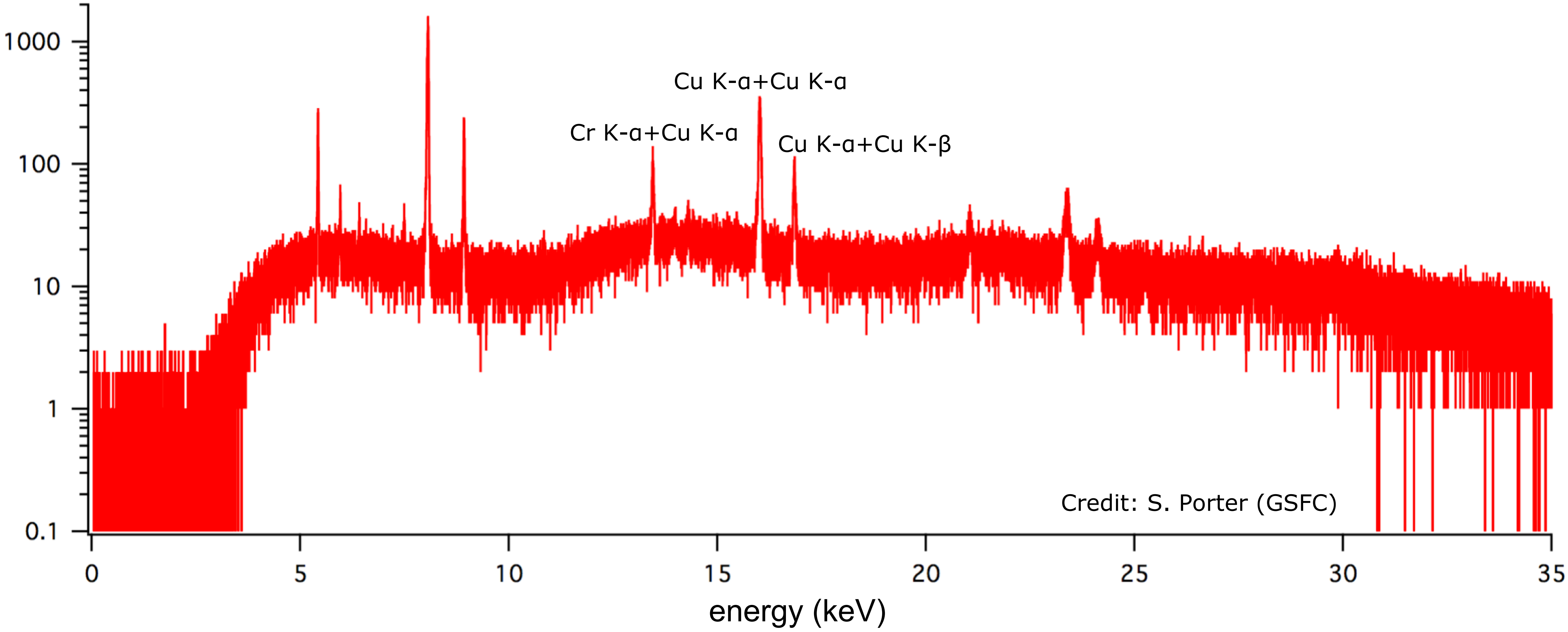
Thanks!

- Tashiro+2020, "Status of x-ray imaging and spectroscopy mission (XRISM)." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 1144422
- Porter+2020, "Initial ground calibration of the Resolve detector system on XRISM." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 1144424
- Midooka+2020, "X-ray transmission measurements of the gate valve for the x-ray astronomy satellite XRISM." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 114445C
- Nakajima+2020, "Soft x-ray imager (SXI) for Xtend onboard X-Ray Imaging and Spectroscopy Mission (XRISM)," Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 1144423
- Yoneyama+2020, "On-ground calibration of XRISM/Xtend CCD." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 11425
- Terada+2020, "Detail plans and preparations for the science operations of the XRISM mission." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 114445E
- Loewenstein+2020, "The XRISM science data center: optimizing the scientific return from a unique x-ray observatory." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 114445D
- Miller+2020, "Planning in-flight calibration for XRISM." Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 1144426
- Kilbourne+2018, "Design, implementation, and performance of the Astro-H SXS calorimeter array and anticoincidence detector," JATIS 4, 011214
- Ishisaki+2018, "In-flight performance of pulse-processing system of the ASTRO- H/Hitomi soft x-ray spectrometer," JATIS 4, 011217
- de Vries+2018, "Calibration sources and filters of the soft x-ray spectrometer instrument on the Hitomi spacecraft," JATIS 4, 011204

Resolve energy scale and spectral response

X-Ray Imaging and Spectroscopy Mission

Extended gain and LSF calibration using two-photon events!



Xtend energy scale and spectral response

- Strategy from Suzaku XIS: field-filling stable line sources.
  - Perseus Cluster @ 6 keV
  - Cygnus Loop @ < 2 keV
- Xtend has 4x the FOV of XIS.
  - Outer regions are expensive to calibrate.
  - But aimpoint will be self-calibrated by any line source thanks to Resolve!

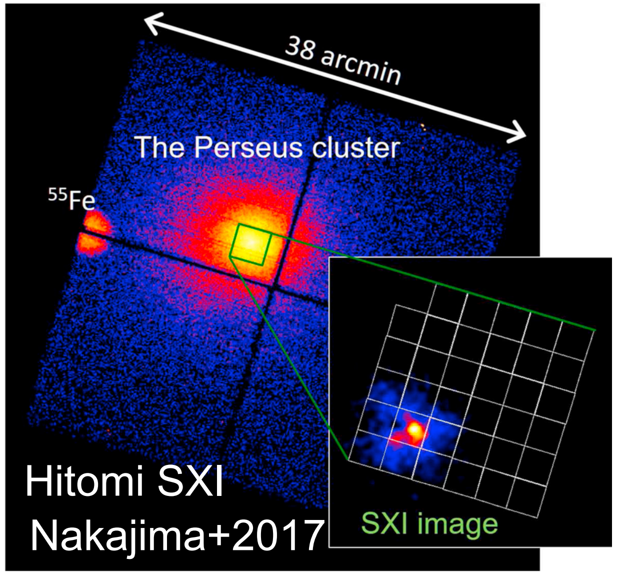


Table 2. Achievable gain calibration uncertainty for Xtend.

	Gain uncertainty	$t_{\rm exp}$ (ks)	Description
Case I	7 eV @ $r < 8'$ 18 eV @ $8' < r < 15'$ 60 eV @ $r > 15'$	80	Observed only on-axis to reach the same gain uncertainy as Suzaku/XIS.
Case II	7 eV on-axis chip 8 eV neighbor chips 9 eV opposite chips	320	Observed on each chip for the same exposure time and goal as Case I. Off-axis chips have higher uncertainty due to vignetting.
Case III	7 eV everywhere	640	Observed on each chip for exposure time that scales with vignetting, to reach the Suzaku/XIS gain uncertainty at all FOV locations.