Reflections on reflection

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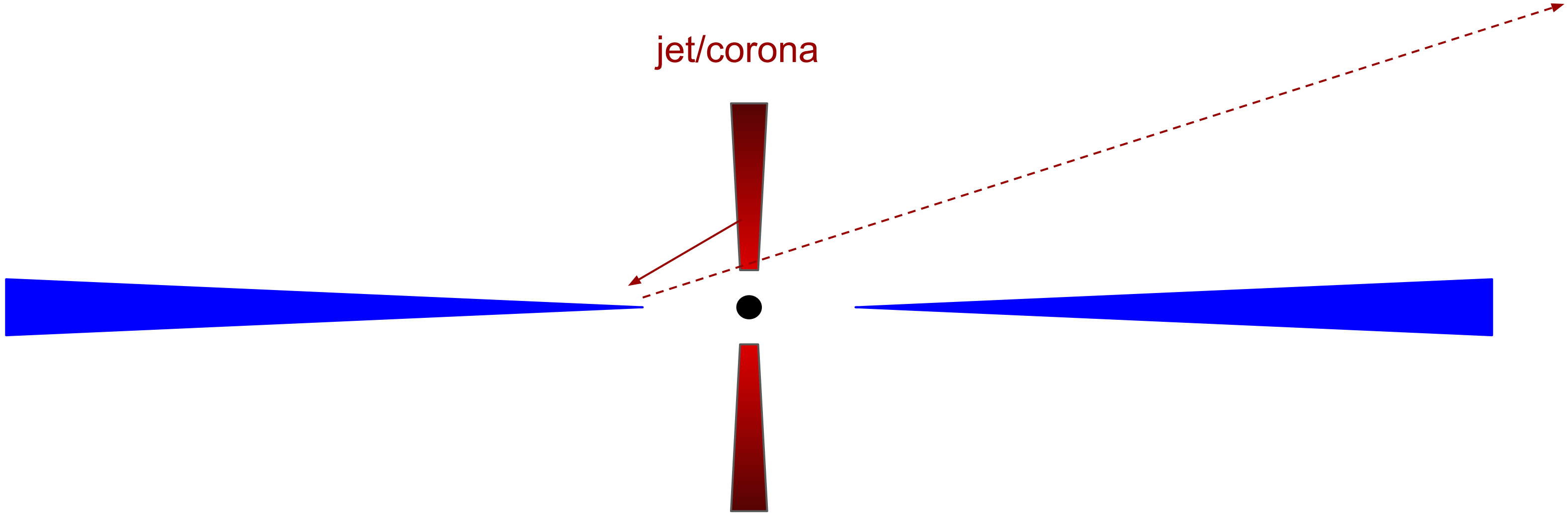
Outline

Praise for current models and efforts.

Recognition of the challenges posed by XRISM, Athena, Arcus, Lynx, etc.

An idea for the future.

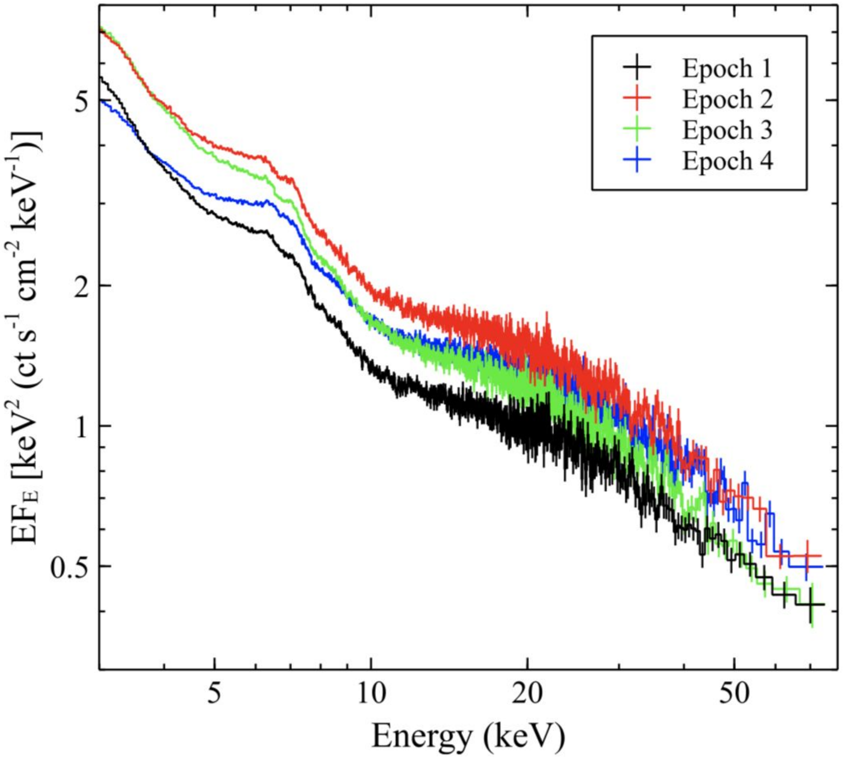
Stellar-mass black holes are likely simple

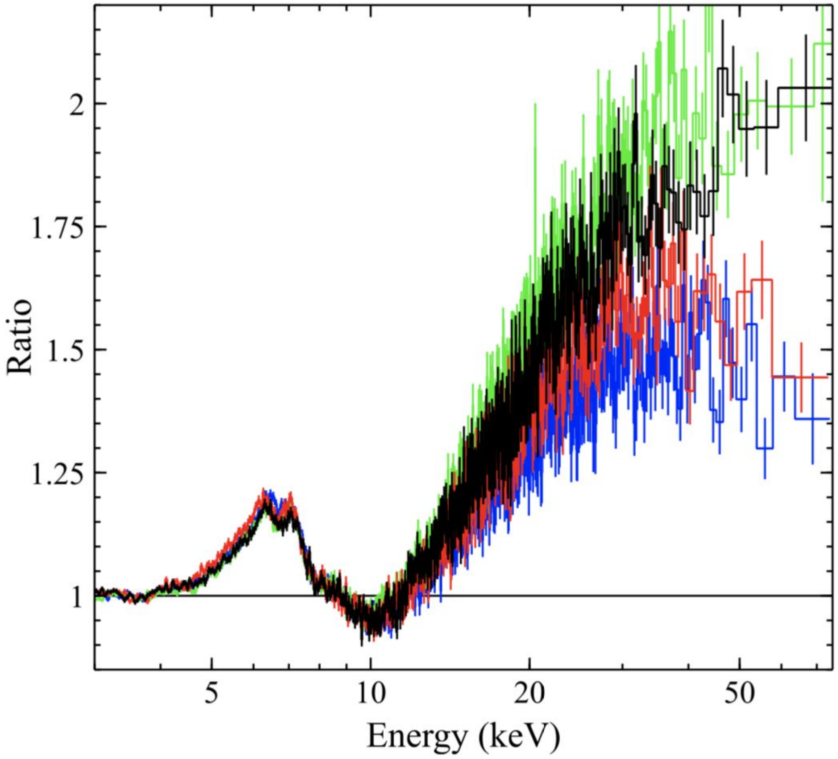


The time scales for variability and the energetics of the corona demand that it is typically very small, magnetic, and may well be the base of a jet → simple lamp-post geometries.

Cygnus X-1 with NuSTAR

Walton et al. 2016





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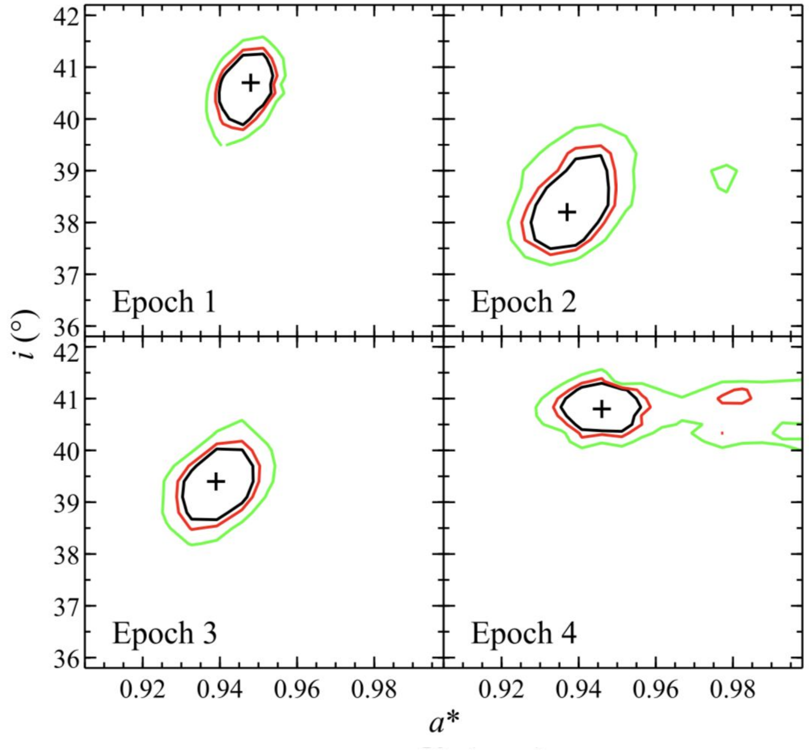

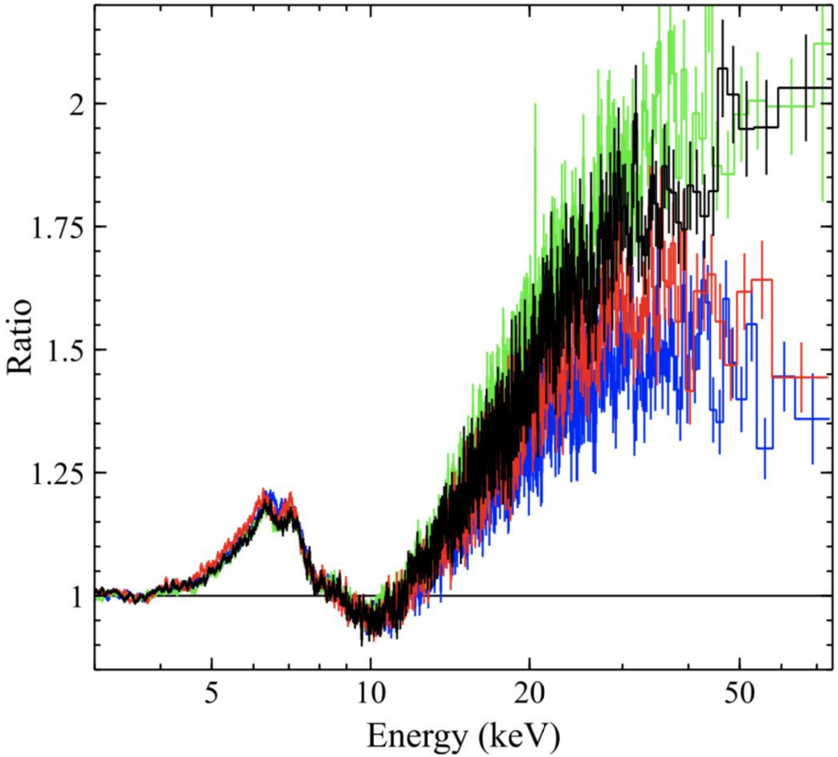

A golden era for reflection in X-ray binaries

NuSTAR offers unprecedented sensitivity across the 3-79 keV band.

Incredibly powerful, especially when paired with XMM-Newton or Swift.

Spin measurements via blurred reflection are possible in essentially every stellar-mass black hole that is observed.

A small range of input spectral forms, coronal geometries, etc., can be tested.

Credit to xillver & Javier Garcia and Thomas Dauser. Laura Brenneman & Chris Reynolds, Randy Ross, and many more.

Reflecting on the data and model

Blurring	2000 eV	(approximately)
NuSTAR energy resolution	400 eV	(at 6 keV)
Key Fe charge states sep. by	270 eV	(Fe XXV → Fe XXVI)
“xillver” energy resolution	20 eV	

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Key Fe charge states sep. by	270 eV	(Fe XXV → Fe XXVI)
“xillver” energy resolution	20 eV	
Chandra HEG 1st resolution	45 eV	(at Fe K)
Chandra HEG 3rd resolution	15 eV	(at Fe K)
XRISM expected resolution	5 eV	
Athena X-IFU exp. resolution	2.5 eV	

Reflecting on the data and model

Abundances: 4-10X solar.

Potentially an ionized disk atmosphere has distorted abundances owing to "magnetic levitation."

Might instead by an artifact of *density* (e.g. Tomsick et al. 2018).

Modeling with artificially low density may lead to artificially high abundances.

But, the situation might be more complicated (Zoghbi et al. 2019).

Reflecting on the data and model

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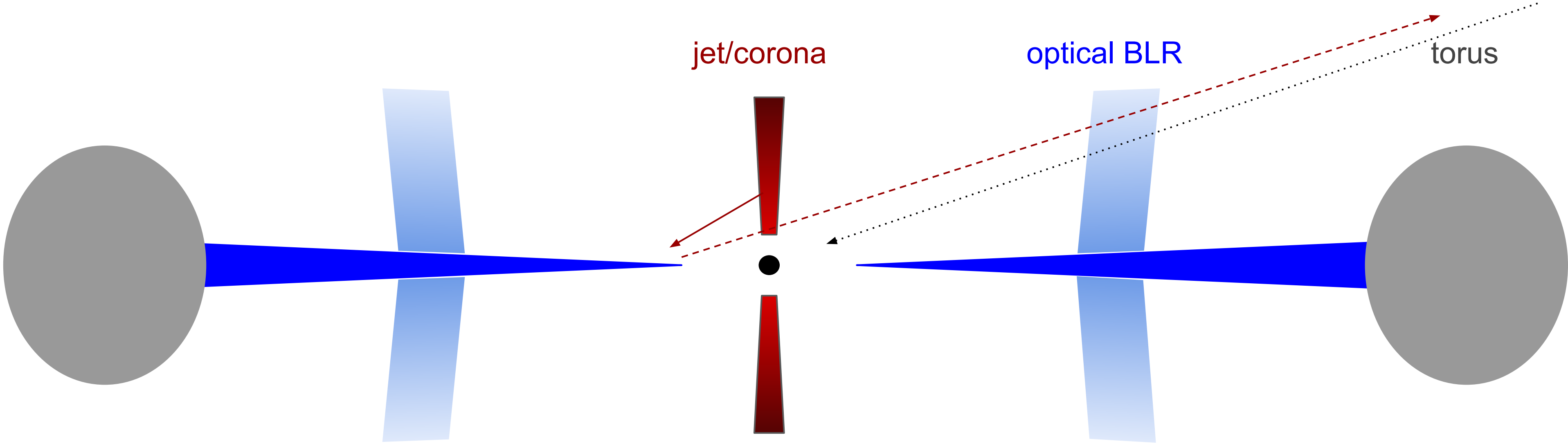
Modeling with artificially low density leads to artificially high abundances.

! Density as a smoothly varying parameter at high res. would increase file size.

! Calculations become very difficult at high density, log(n) ~ 19-20.

! Yet, these steps may be necessary.

AGN are far more complex … everything reflects



$10^{0\text{-}1}$ GM/c^2 = 0.2-2 ks

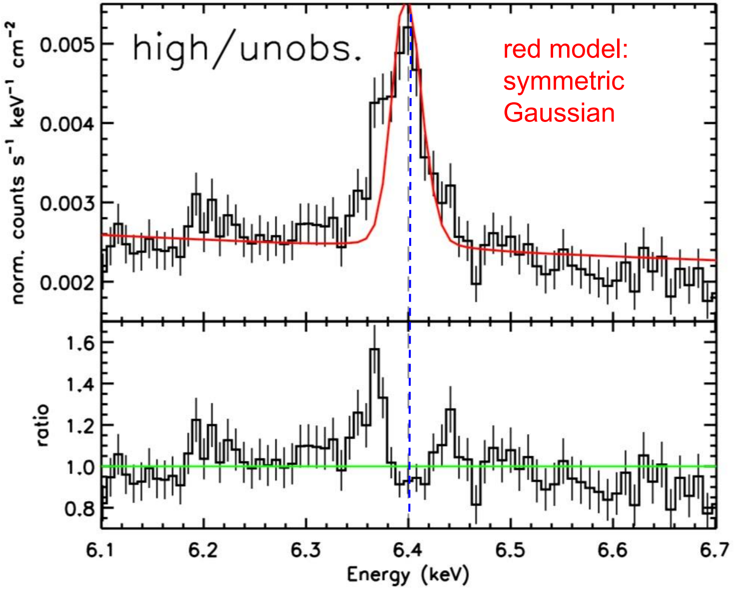
$10^{2\text{-}3}$ GM/c^2 = 20 ks - 3 days

$10^{6\text{-}7}$ GM/c^2 = 1-few pc = 1200 light-days/pc

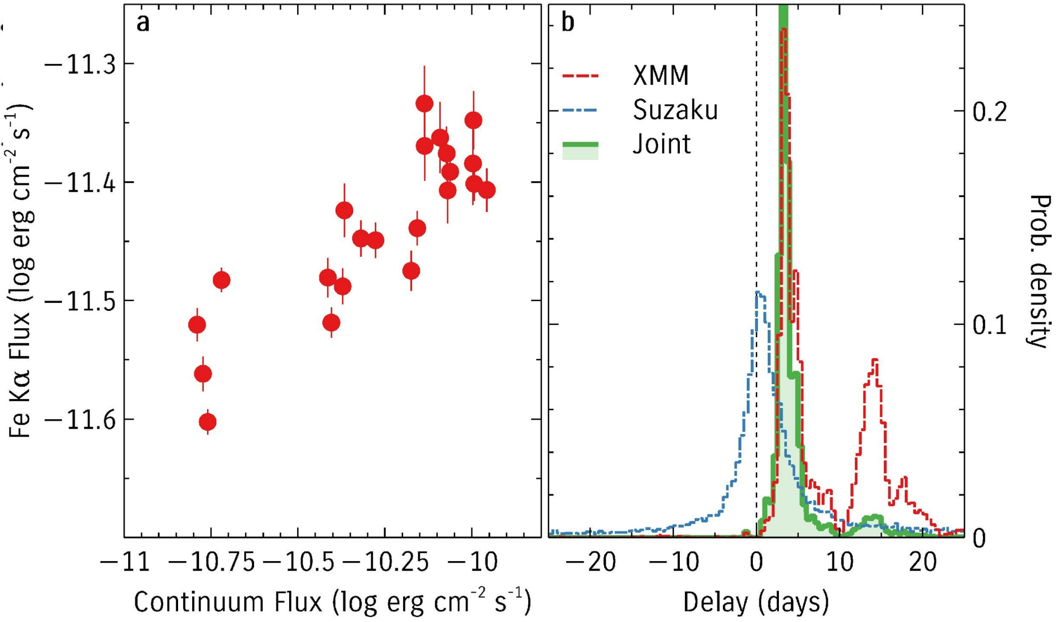
$10^{3\text{-}4}$ GM/c^2 = 6 light-days

Narrow Fe K reverberation in NGC 4151

Miller et al. 2018



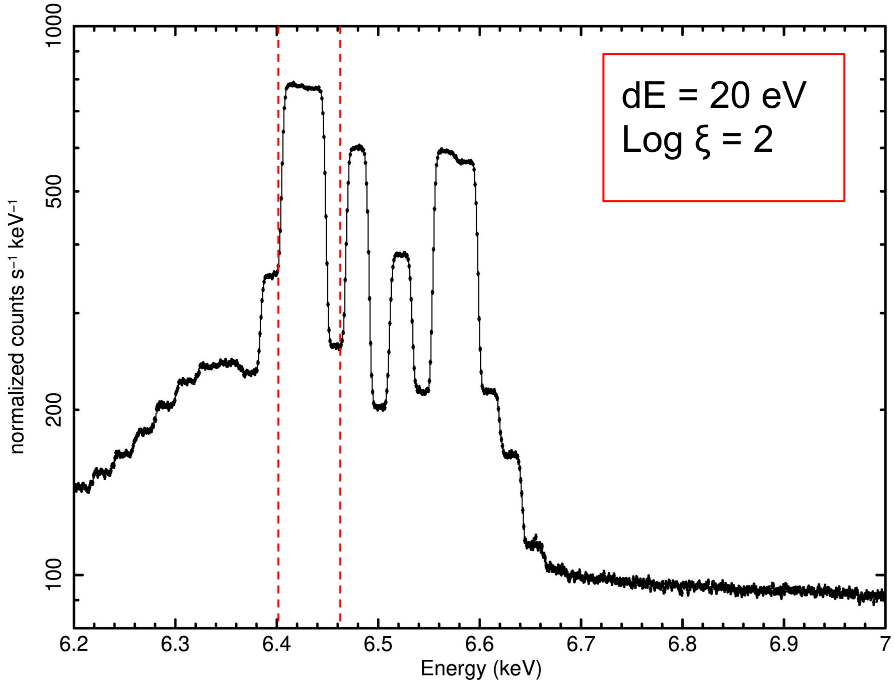
Zoghbi et al. 2019. Lag measured using the “Javelin” code for QSOs.

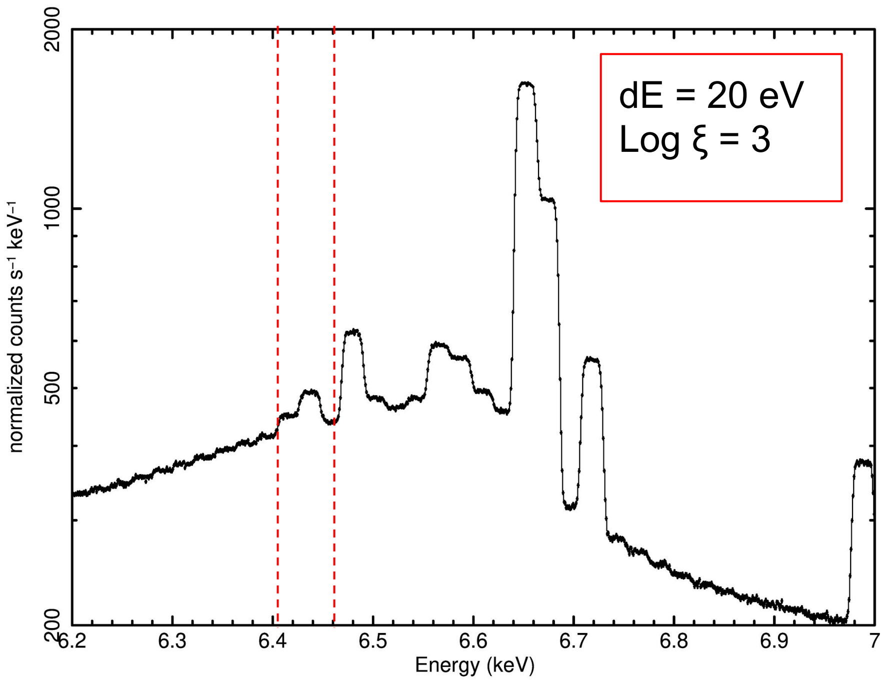


Chandra: line asymmetry, significant at 5σ.
not due to scattering.
R = 800 (+400,-200) GM/c^2

Fe K line varies by 20% on short time scales.
by ~2 on longer time scales.
τ = 3.3 (+1.8,-0.7) days = 1600 (+800,-400) GM/c^2

Ionized reflection models, simulated XRISM data

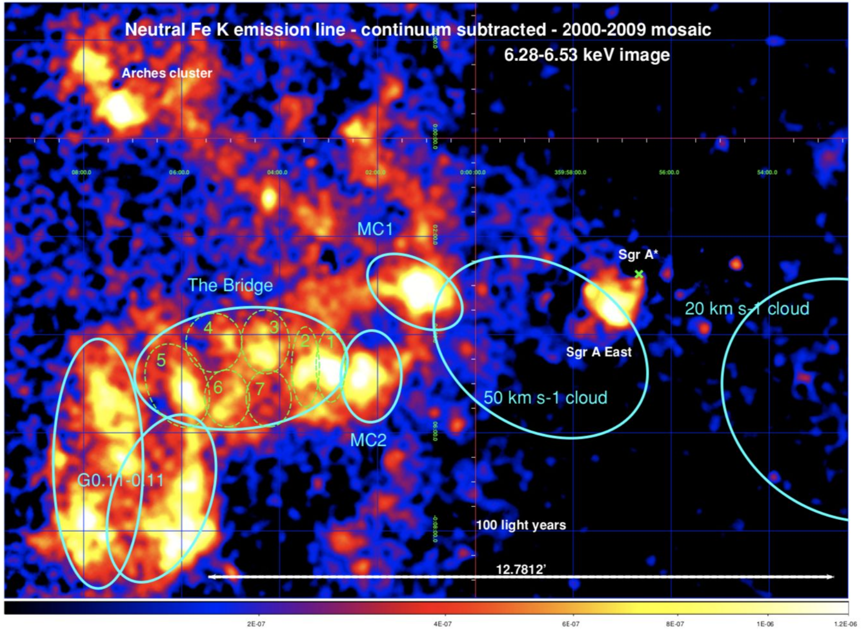




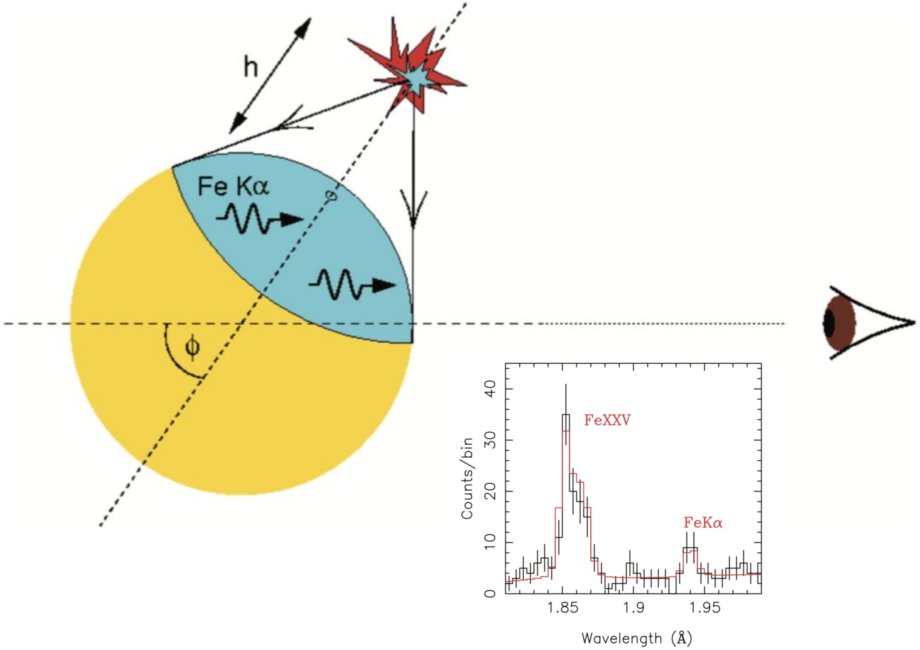
Recall: Fe I-XVII 6.40 → 6.43 keV, just 30 eV.
At ~20 eV model resolution, information is lost. If the gas is moving, even more is lost.

Reflection more broadly

Sgr A* reflection nebulae (Ponti et al. 2010)



Flare stars such as II Peg (Testa et al. 2008)



Preparing for XRISM (5 eV), Athena (2.5 eV)

	Xillver	mytorus*
Resolution	20 eV	4 eV
Ionization	yes	no.
Column density	Inf.	variable.
Density	log n<19	no
Continua	limited options	power-law only

*Murphy & Yaqoob 2009

We need a *facility*, not end-products

One size fits all will soon fit nothing very well.

Better data demands more variable parameters, more resolution, range, etc.

[To say nothing of variable incident continua….]

File size, fit minimization time, etc., could become untenable.

Future models need to be tailored to specific situations.

Proper input spectra.

Resolution where it makes sense, in the parameters that matter most.

We need a *facility*, not end-products

The field needs a generator like XSTAR or Cloudy.

Fine control over numerous parameter ranges and resolutions, spectra.

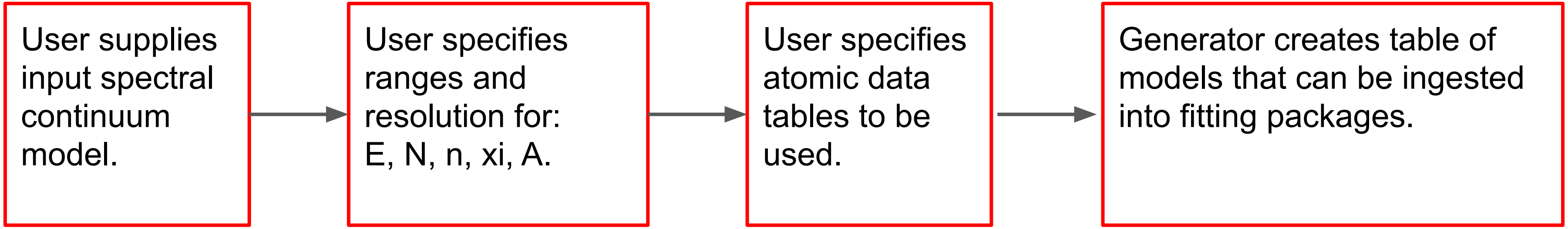
But, the inputs need to be more modular:

Users needs the flexibility to choose the atomic data that are used.

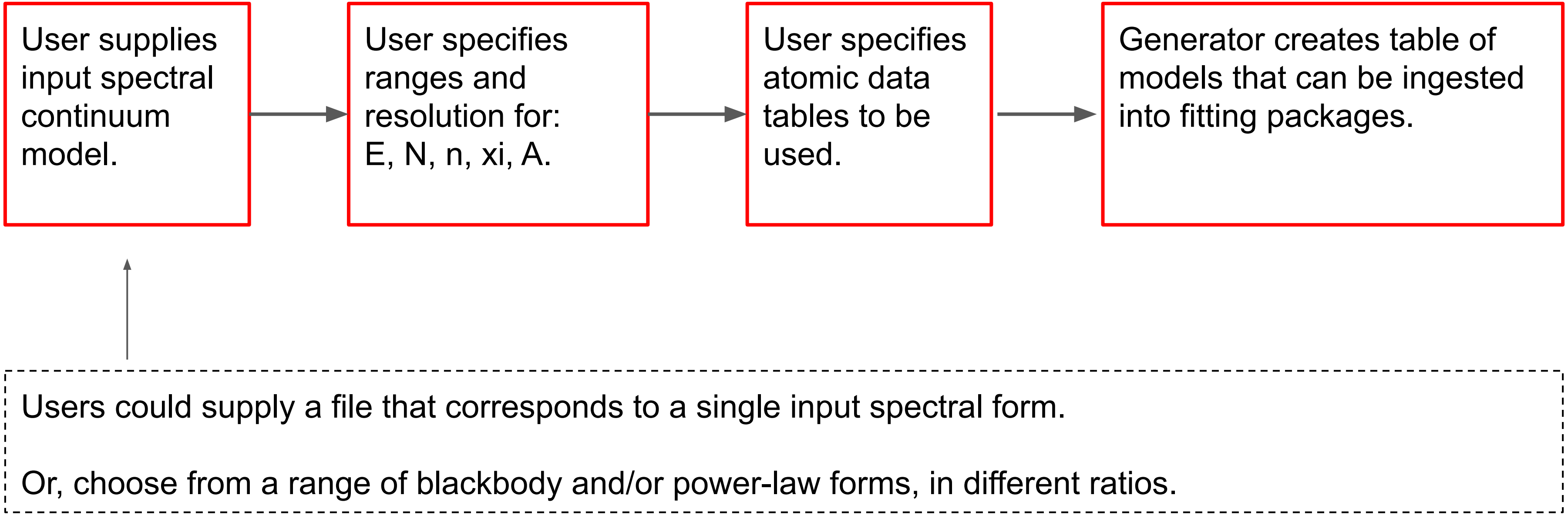
This requires standardization of atomic data inputs.

It may be necessary to reconsider whether “blurring” should be external.

Reflection facility



Reflection facility



Reflection facility

User supplies input spectral continuum model.

→

User specifies ranges and resolution for: E, N, n, xi, A.

→

User specifies atomic data tables to be used.

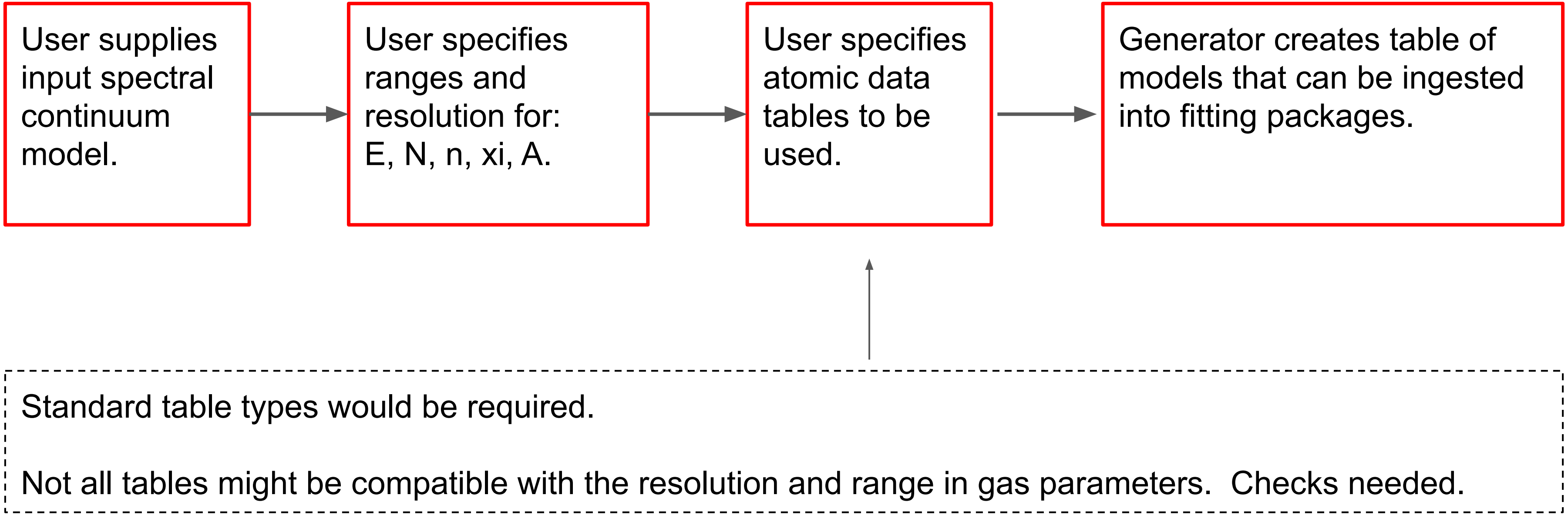
→

Generator creates table of models that can be ingested into fitting packages.

These could be tailored to mission energy resolution, and the specific geometries being considered.

Allowing the resolution to vary within each parameter would permit flexibility an optimization.

Reflection facility



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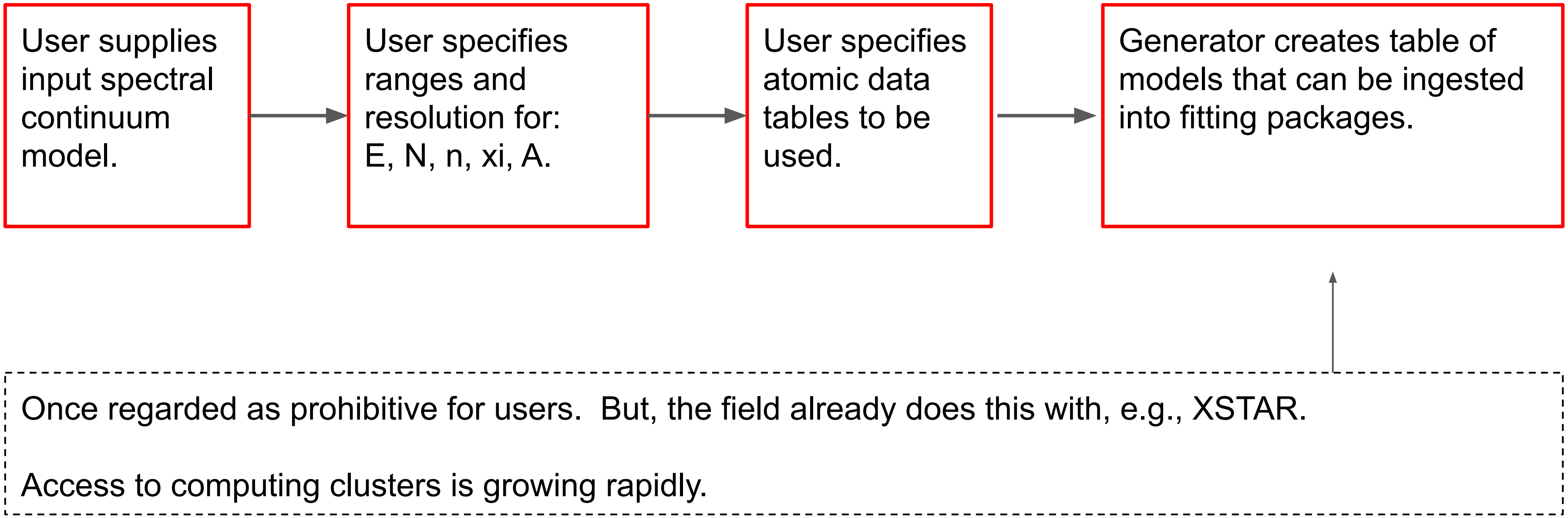

Reflection in the future

The energy resolution afforded by XRISM, Athena, Arcus, Lynx requires new high-res. reflection models, quickly. And maybe a new way of doing things.

Many key dimensions, plus density and abundance, and input spectral form, may need far more resolution and consideration.

It may be time for a community resource - a reflection *facility* - to be developed by NASA and other stakeholders. The facility would need a director and developers, community involvement and grants... *like a small mission*.

Constant density vs HSE might be regarded as different “instruments.”

On blurring

It might be best if convolution functions are developed separately.

Optimization of reflection, convolution models is not exactly the same.

If they are decoupled, this may free convolution models to explore a greater range of coronal geometries, ionization varying with radius, etc.