Soft Excess from Magnetized Coronae

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Outline

1) Soft X-ray Excess in AGNs

2) GRMHD shock heating in plunging region

3) Case Study ~ 7 Seyferts (preliminary)

4) Summary

Soft X-Ray Excess (SE)

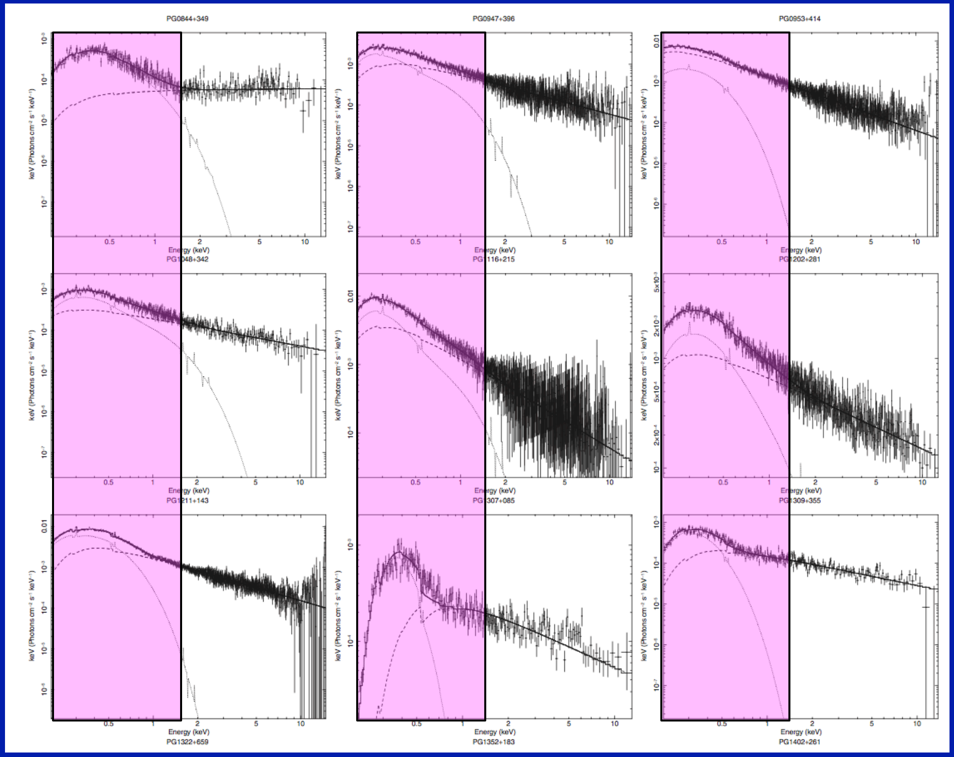
- Excess flux below ~2 keV above continuum flux
- Ubiquitous among NLS1s and PG QSOs
- Can be universally “fitted” by BB of ~100 – 200 eV

General Review:
Arnaud85, Boller+96, Leighly+99, Gierlinski+04
Crummy+06, Boissay+16…etc.

$$kT \sim 10\left(\dot{m}/M_8\right)^{1/4} \quad eV$$

Fact:
AGN SS-disk fails to be hot enough…

Zhong&Wang13



Outstanding Questions

- ✓ Region/Geometry?
- ✓ Physical process(es)?
- ✓ Expected Correlations?

Plausible Scenarios:

(1) Continuum absorbed by fast ionized winds

Schurch&Done(06,08), Gierlinski04, Middleton+07

(2) A series of (relativistically) blurred emission lines

Miniutti&Fabian04, Kara15, Ross&Fabian05, Crummy+06, Ponti+10
De Marco+13

(3) Comptonization

Petrucci+04, Mehdipour+11, Done+12, Zhong&Wang13, Di Gesu+14

Known(?) issues

(1) Continuum absorbed by fast winds

Schurch&Done06/08, Gierlinski04, Middleton+07

✓ *requires extreme relativistic speed (v/c < 0.9)*

Schurch&Done(06,08)

(2) A series of (relativistically) blurred emission lines

Miniutti&Fabian04, Kara15, Ross&Fabian05, Crummy+06, Ponti+10, De Marco+13

✓ *expecting correlation w/ hard X-rays* Vasudevan+14

✓ *No apparent correlation b/w SE and Reflection from a sample of 79 Seyferts with XMM-Swift/BAT* Boissay+16

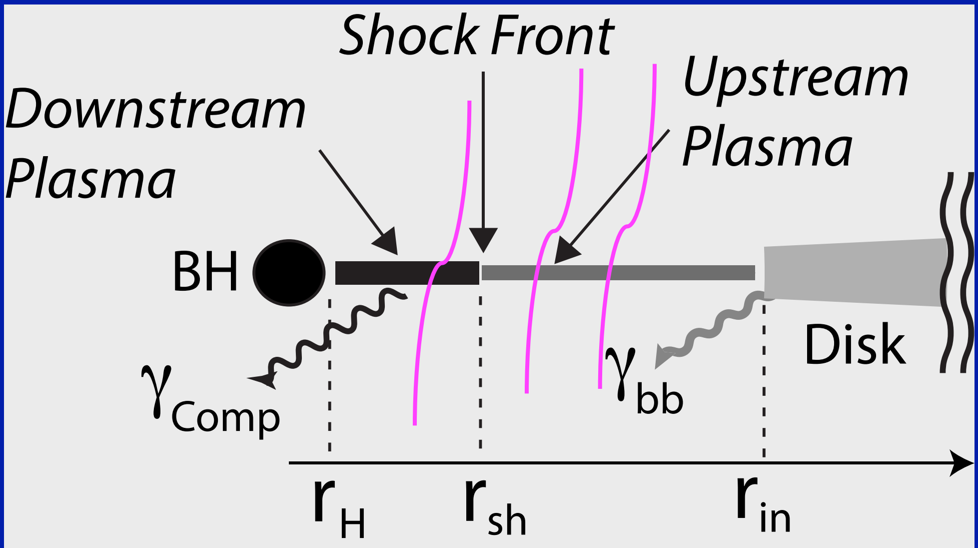
✓ *Soft/reflection lags don't (always) go together (multiple reflectors!?)*

✓ *Reflection not accounting for SE simultaneously*

Jin+13, Kara+14, Porquet+

Punch Line

Fukumura+16



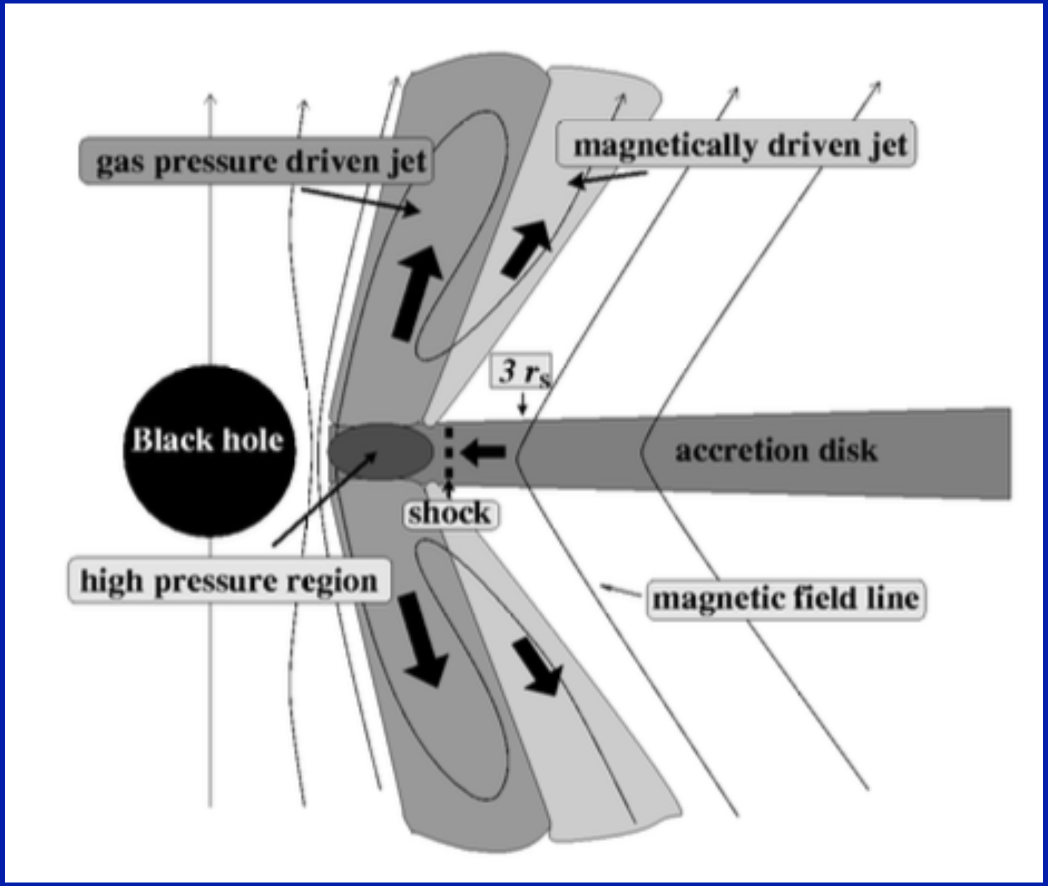
- Plasma
  - plunging in from "disk" (with V_r and V_ϕ)
  - forming a shock front within the plunging region
  - creating hot downstream

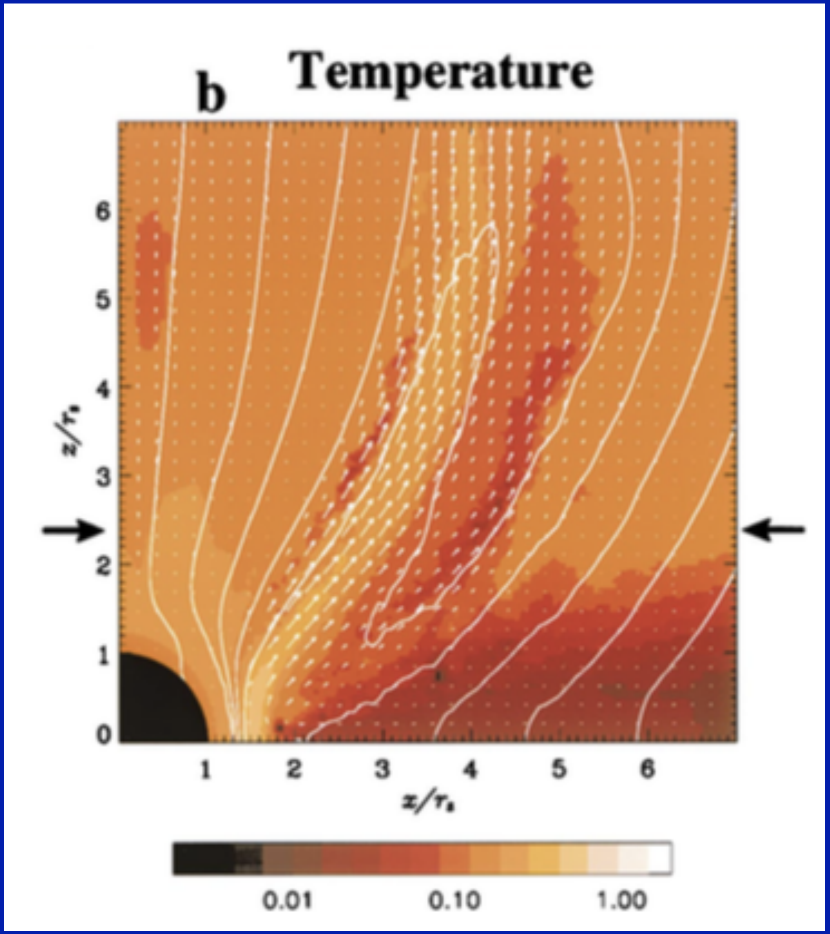
➔ compact magnetized "corona"

- Thermal Seed Photons
  - falling onto "corona" (aided by GR light bending)
  - Compton up-scattered by hot electrons ➔ producing soft excess

"Magnetized coronae in plunging region"

Coronae in GRMHD Simulations





Koide+(98,99,00)

Model Description

(1) Steady-state, axisymmetric ideal GRMHD under strong gravity

$$ds^2 = \left(1 - \frac{2Mr}{\Sigma}\right) dt^2 + \frac{4Mar\sin^2\theta}{\Sigma} dt d\phi - \frac{A\sin^2\theta}{\Sigma} d\phi^2 - \frac{\Sigma}{\Delta} dr^2 - \Sigma d\theta^2$$

$$E \equiv \mu u_t - \frac{\Omega_F B_\phi}{4\pi\eta}$$ ➔ Plasma energy

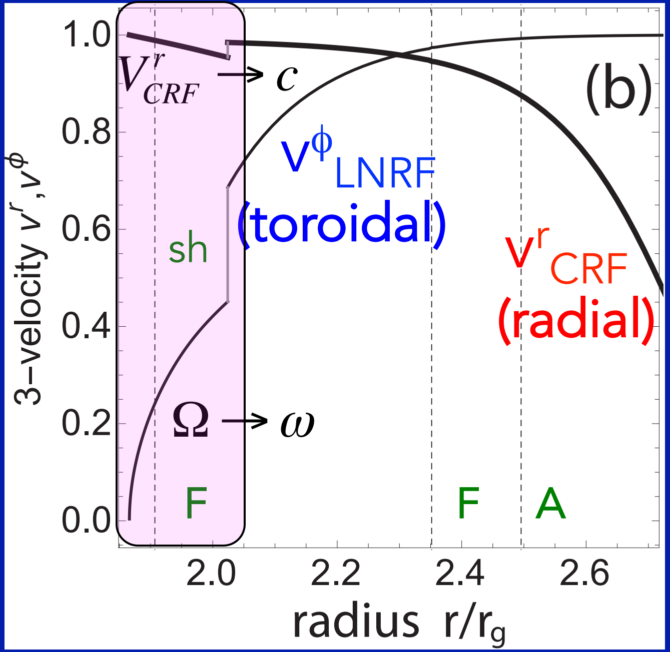
$$L \equiv -\mu u_\phi - \frac{B_\phi}{4\pi\eta}$$ ➔ Plasma angular momentum

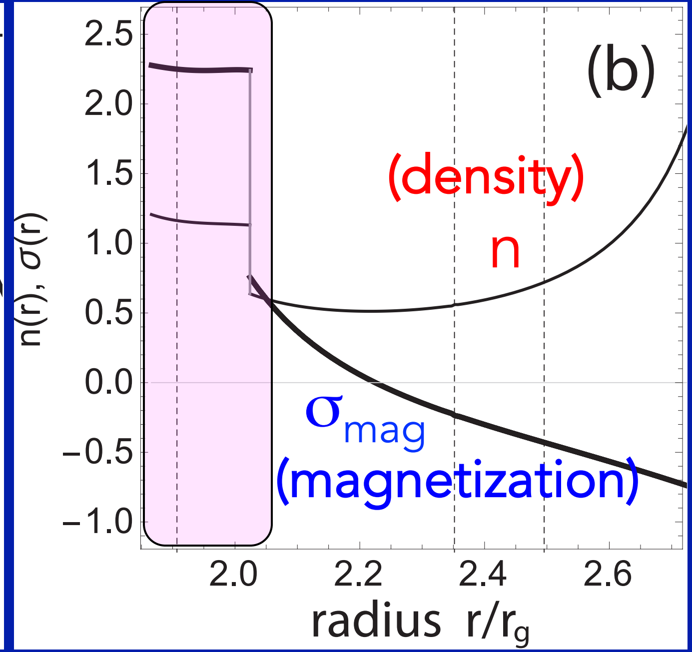
Fast MHD shock

BH spin: a/M = 0.5

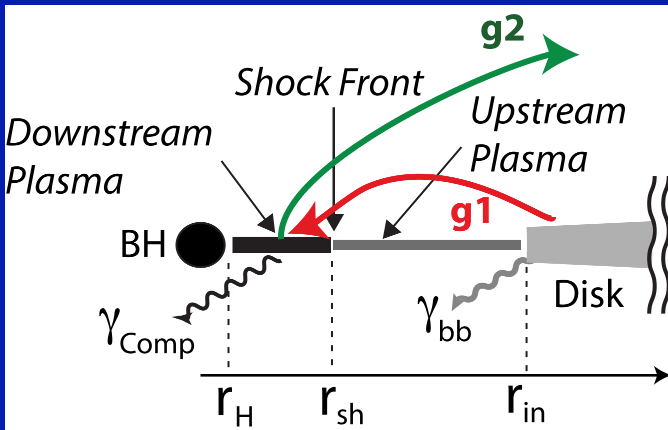
$$\frac{n_2}{n_1} = \frac{u_1^r}{u_2^r}$$

$$\sigma_{mag} \propto \frac{B_\phi}{\mu u^t}$$





Comptonization in Downstream



$$B_D(\epsilon, kT_{\rm in})d\epsilon = \frac{8\pi\epsilon^2}{h^2c^2}\frac{1}{e^{\epsilon/kT_{\rm in}}-1}d\epsilon$$ Thermal disk photons

EUV seed photons to be Comptonized by e$^-$:

Redshift factor

$$I_{\rm obs}(\epsilon_{\rm obs}, kT_{\rm in}) \propto \frac{g_1(r,\phi)^3 g_2(r,\phi)^3}{H_1(\beta_1,\beta_2)} \int \frac{B_D(\epsilon_{\rm pl}/g_1, kT_{\rm in})}{\epsilon_{\rm pl}} d\epsilon_{\rm pl}$$

Comptonized photon intensity

Comptonization

$$\frac{dF_{\rm obs}}{dr} \propto \int\int_{\rm downstream} I_{\rm obs}\left(\epsilon_{\rm obs}, kT_{\rm in}\right) d\Omega_{\rm obs}$$

➔ Integrating over Comptonizing region

Fukumura+16

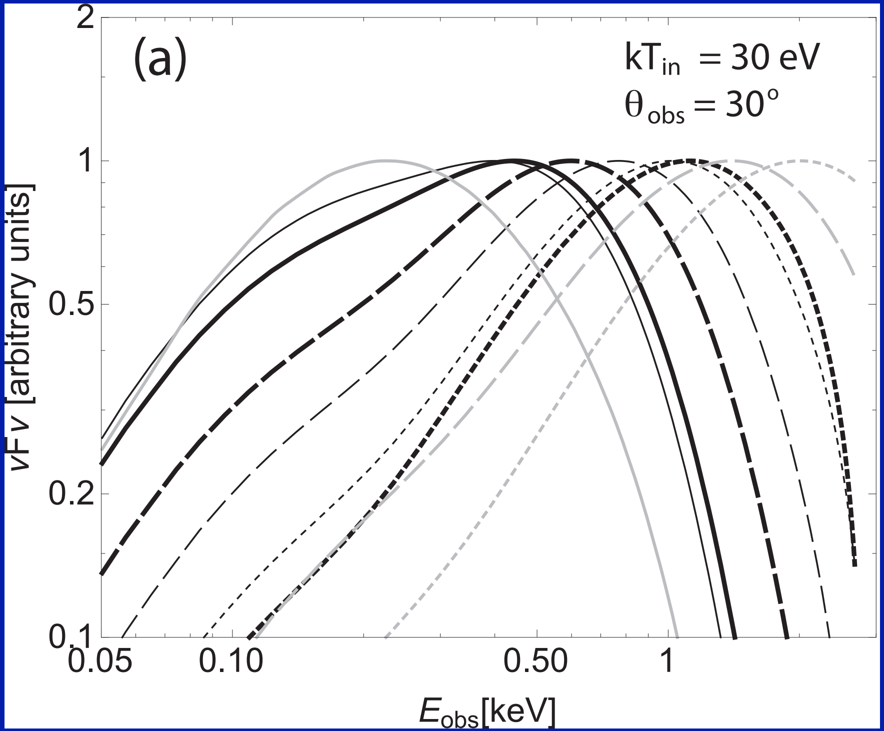
Shock heating in downstream plasma efficiently converted to electron energy

$$\Theta_e(r) \equiv \frac{kT_e}{m_ec^2} = K\rho_o^{\Gamma_p-1} = \frac{1}{1+N}\left(\frac{\mu}{m_ec^2}-1\right)$$ ➔ $$\beta(\Theta_e) \simeq \frac{\sqrt{\Theta_e(2+\Theta_e)}}{1+\Theta_e}$$ where $$\gamma \equiv \left(1-\beta^2\right)^{-1/2}$$

How does spectrum look like?

Comptonized Spectrum

Normalized Comptonized spectra (plasma rest frame) for kT_{in} = 30 eV & θ_{obs} = 30°



Shock location r_{sh} determines kT_e
➔ kT_e determines spectrum:

Gray:
33 keV, 250 keV, 378 keV for a/M = −0.5

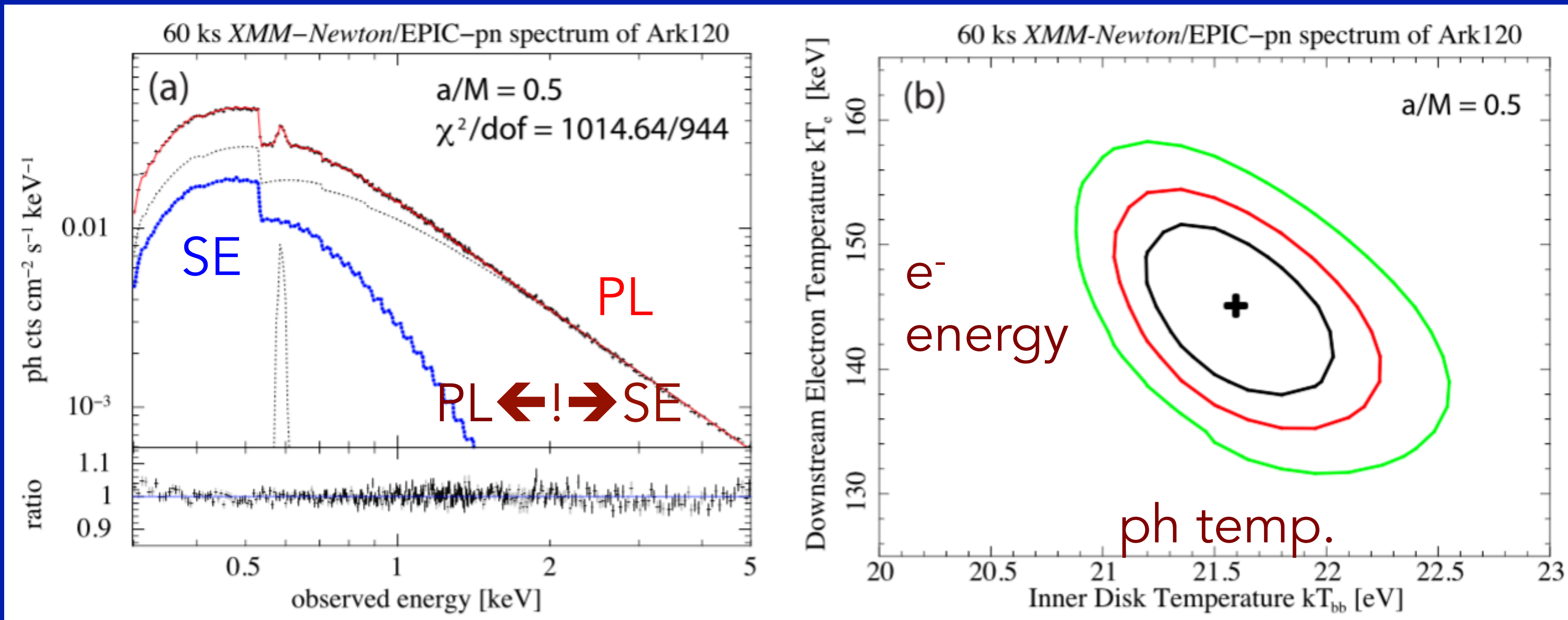
Thin black:
75 keV, 125 keV, 256 keV for a/M = 0

Thick black:
126 keV, 179 keV, 296 keV for a/M = 0.5

Primary Model Parameters: θ_{obs} , kT_e , kT_{in} for a given BH spin a

Case Study

Ark 120
"bare" AGN



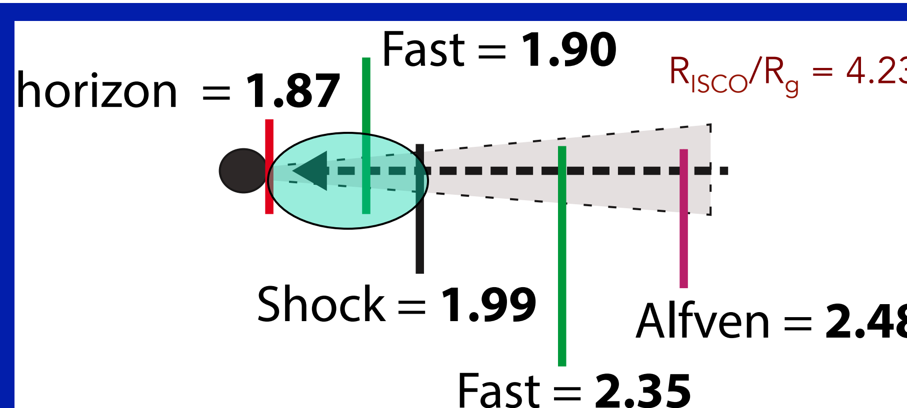
Best-fit model with a/M = 0.5

θ_{obs} = 36.6°

kT_{in} = 21.6 [eV]

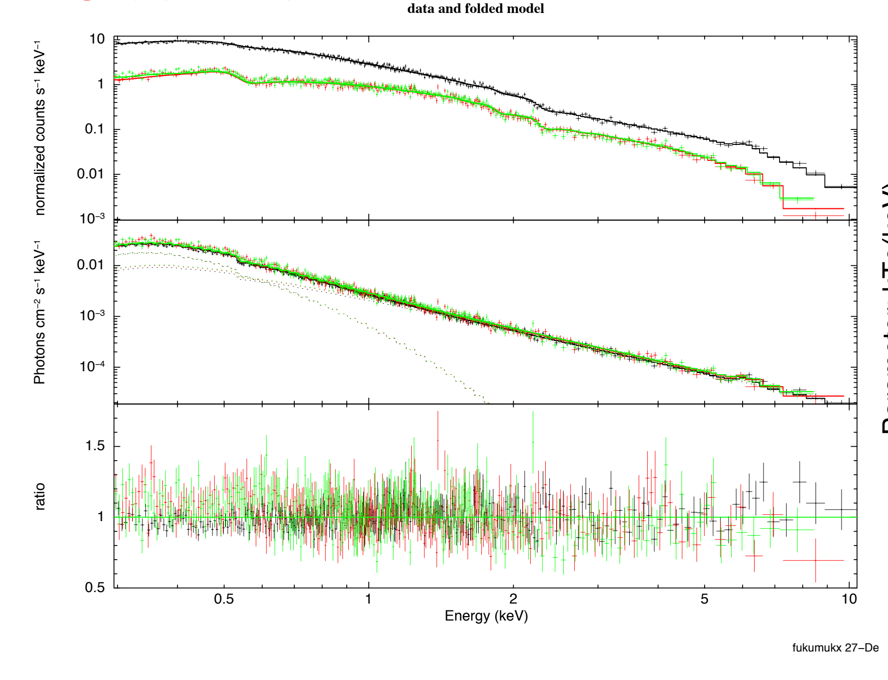
kT_e = 144.3 [keV]

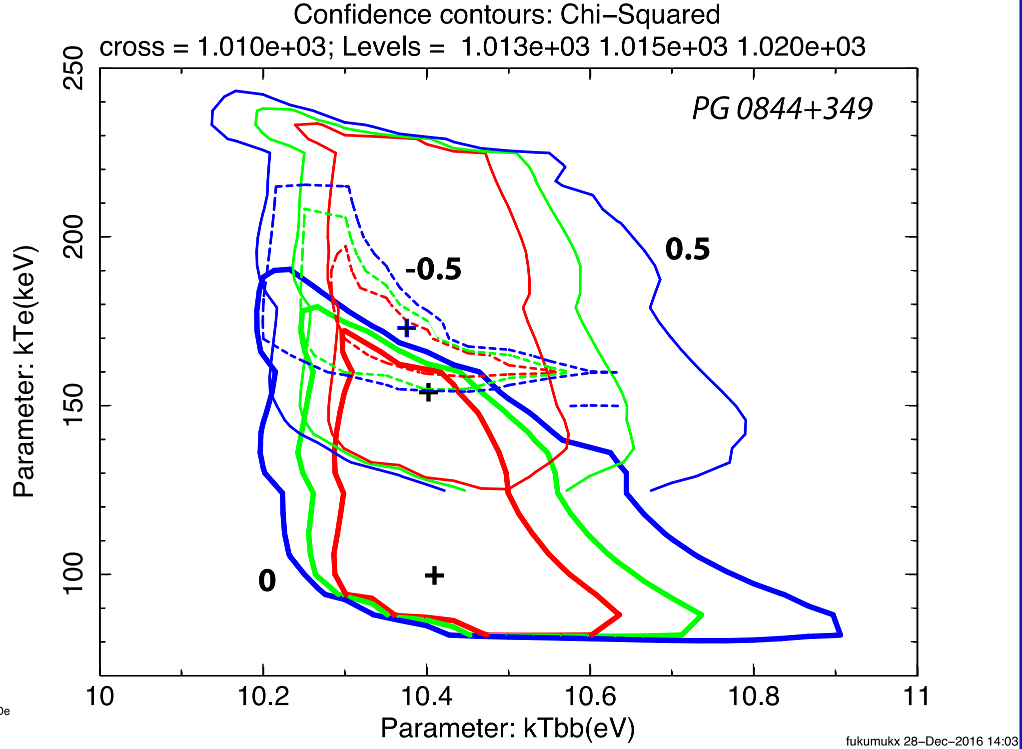
χ^2/dof = 1014.64/944



Preliminary Analysis

PG 0844+349



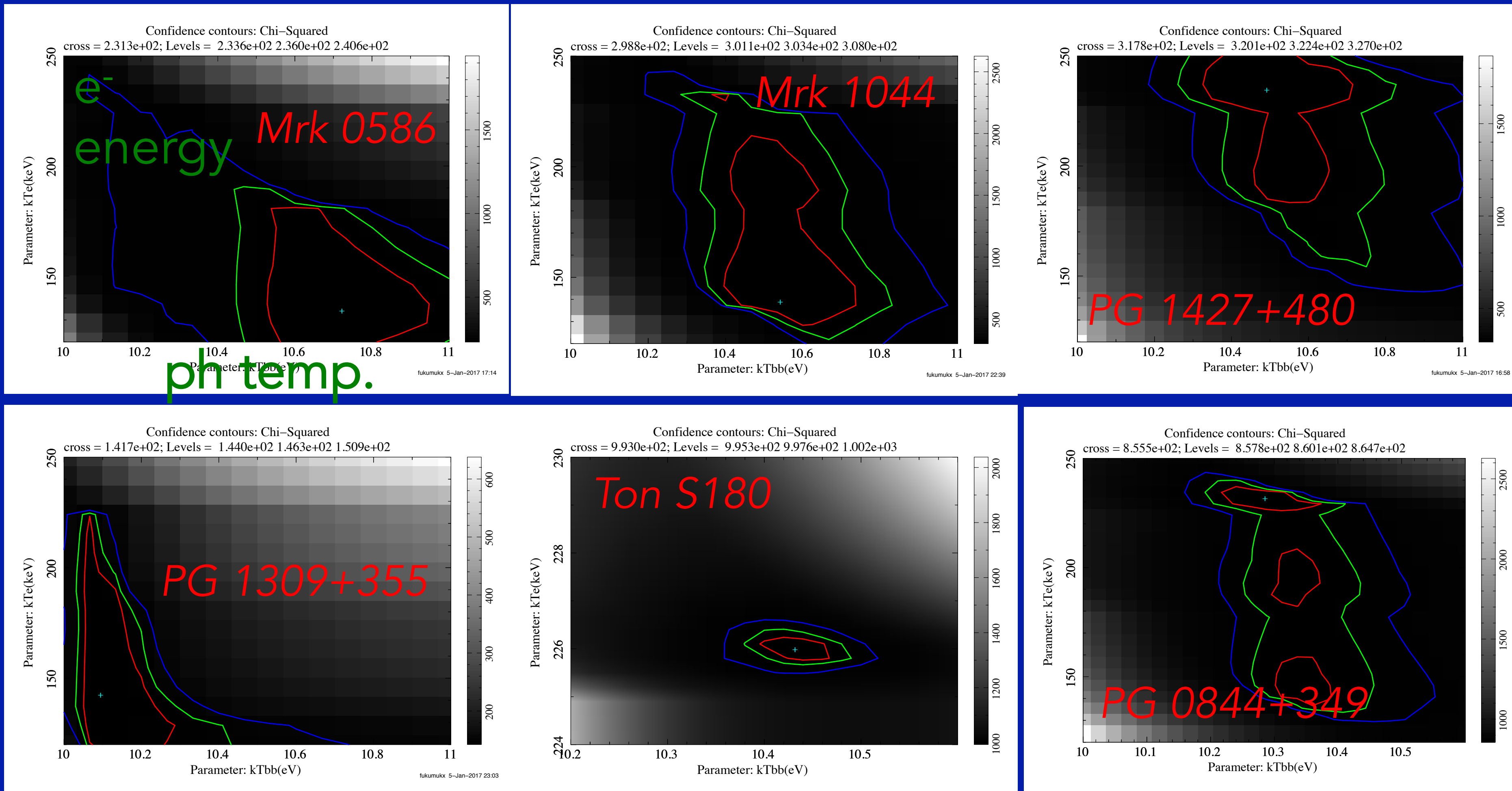


Best-fit model with a/M = 0.5

θ_{obs} = 19.9° , kT_{in} = 10.3 [eV] , kT_e = 231.7 [keV]

χ^2/dof = 855.47/882

More Preliminary Analysis



e.g. a/M = 0.5 case:

- ❑ Constrained reasonably well
- ❑ High e^- energy (~100-200 keV)
- ❑ Compact magnetized coronae (R/R_g ~ 2-5)

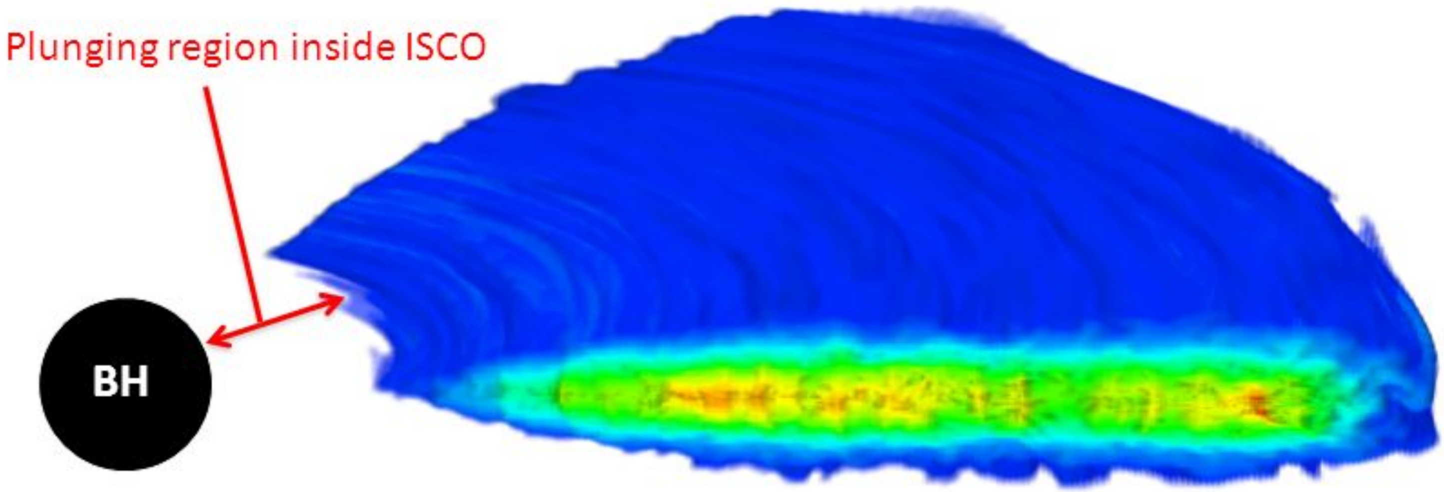
Take-Away

- We consider ideal GRMHD accretion
- Accretion developing into shocks
- Electron energy up to kT_e ~ 100 - 200 keV
- Disk photons to be Compton up-scattered
  → imprint the "soft excess" signature

- Possible to have a compact (R/R_g~2-5) magnetized "corona" near black hole
- Provides an independent Comptonizing region almost exclusively for SE
  → "independent of continuum/reflection"
- τ_e assumed to be smaller in the plunging region than Haardt&Maraschi 2-phase model (1993)
- PL continuum produced perhaps on disk surface(?)

END

Assumption of ISCO Truncation



3-D MHD simulation of a geometrically-thin accretion disk

Clearly shows transition at the ISCO which will lead to truncation in iron line emission

Reynolds & Fabian (2008)