Velocity diagnostics in distant galaxy clusters with *IXO*

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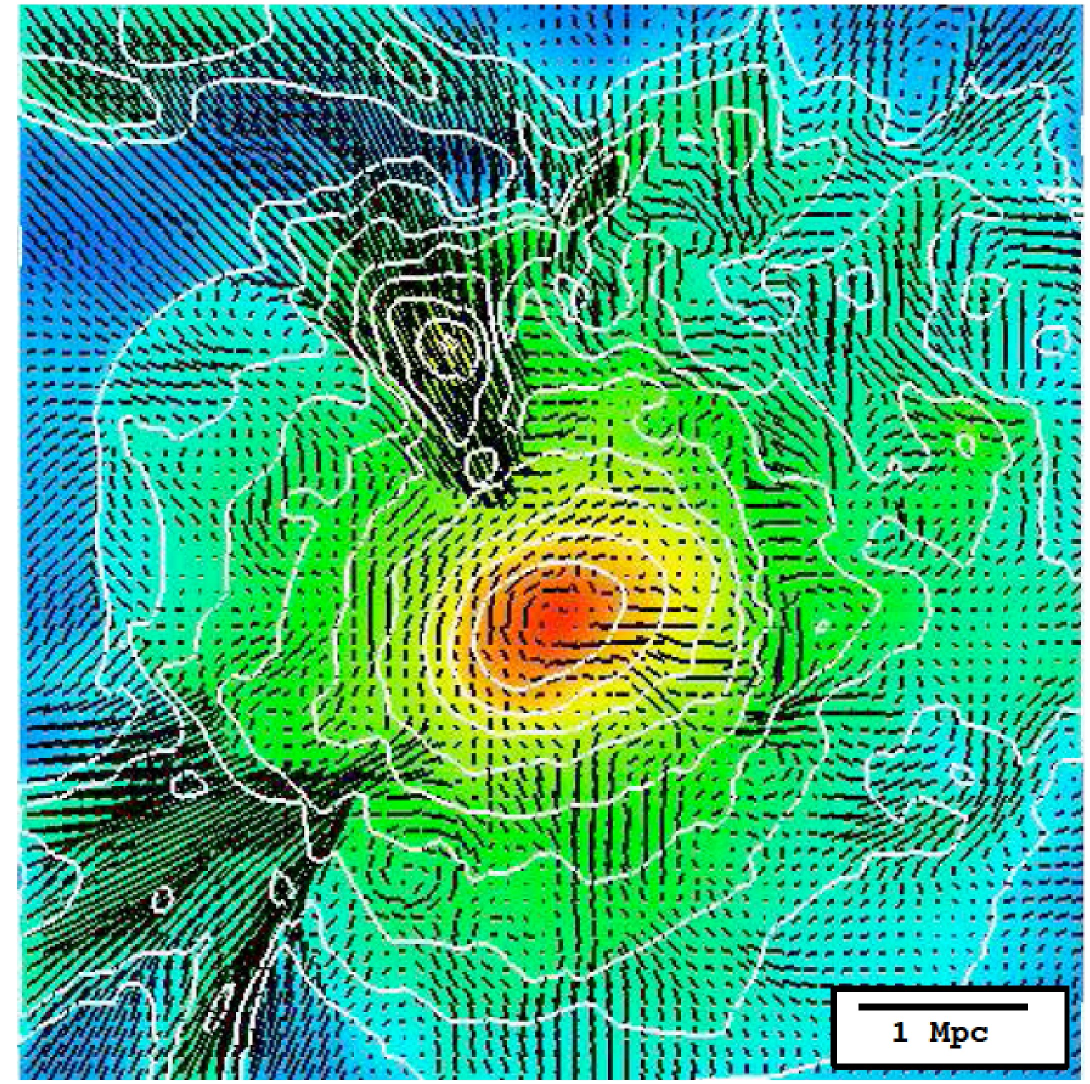
Outline

1. Motivation
2. Detectability of line broadening and shifting in distant clusters
3. Line of sight mergers
4. Summary

1. Motivation

___ Velocity vectors
Color & contours: gas density

- ✤ Dynamical evolution of clusters
  - Clusters have grown into the present shape via merging
  - ➡ Large-scale bulk/turbulent motions of ICM
  - Non-thermal pressure may contribute by ~20% (e.g., Schueker+04; Mahdavi+08)
- ✤ It's important to probe dynamical state of ICM in the distant universe for cluster mass estimation => the future precision cosmology



6.4Mpc

Velocity field (Norman & Bryan 98)

v~300-600 km/s @r<1Mpc

How precise can we measure the gas motions with TES microcalorimeters on IXO?

Measurement of gas motions with metal lines

1. Line shifting

•Bulk motion

$\Delta E_{bulk} = E_0 \, v_{bulk}/c$

$= 6.7\text{eV} \, (v_{bulk}/300 \text{ kms}^{-1})$ for 6.7keV

(Suzaku/XIS Δv_{bulk} <1400 km/s; Ota+07)

2. Line broadening

•Turbulent

$\Delta E_{turb} = E_0 \, v_{turb}/c$

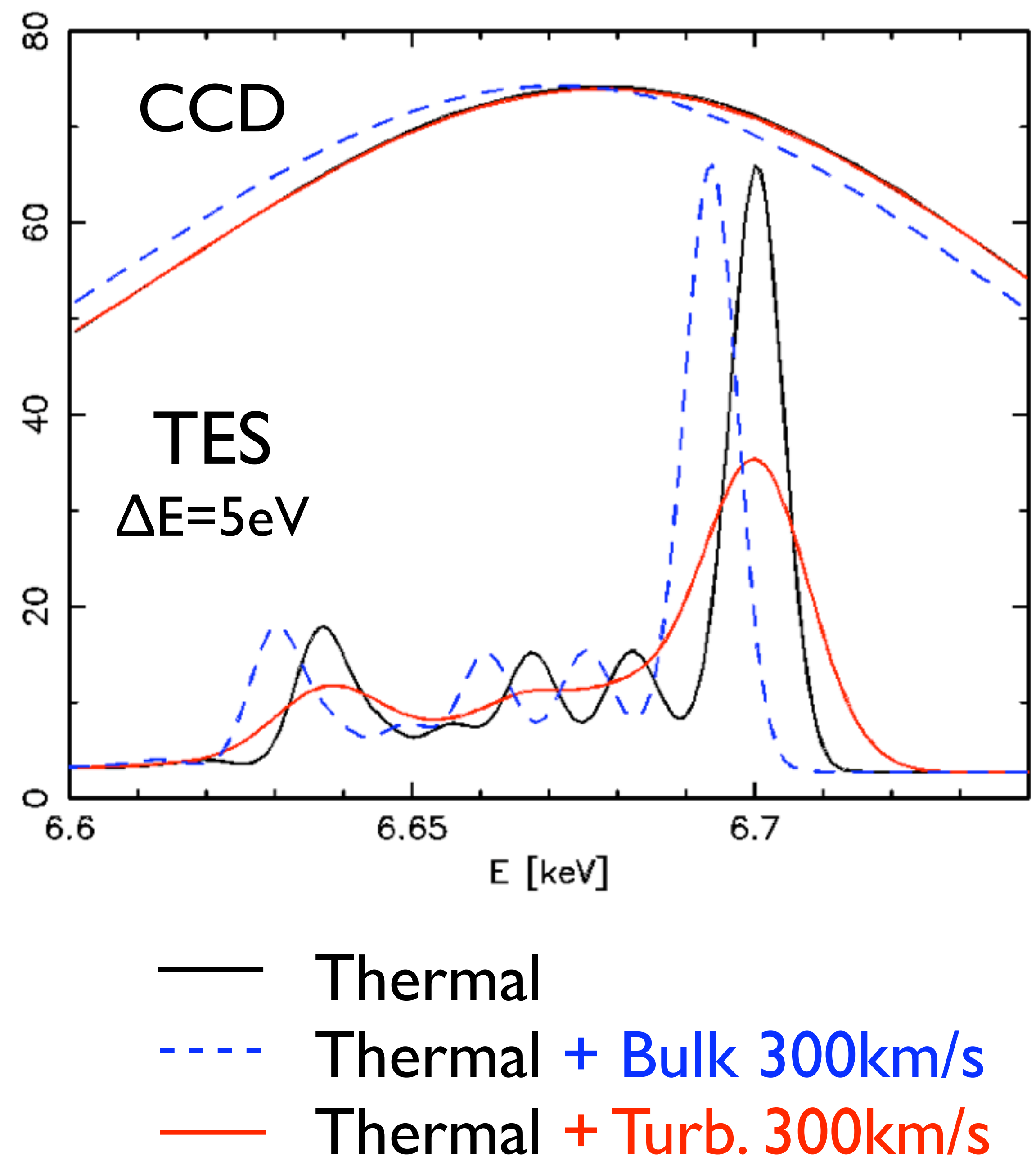
$= 6.7\text{eV} \, (v_{turb}/300 \text{ kms}^{-1})$ for 6.7keV

•Thermal

$\Delta E_{th} = E_0 (kT/m)^{1/2} /c$

$= 3\text{eV} \, (kT/5 \text{ keV})^{1/2}$ for 6.7keV

6.7 keV Fe XXV



m ↑ $\Delta E_{turb}/\Delta E_{th}$ ↑ ➡ Fe-K is the best,

Si-K, Fe-L, ... are also important

2. Detectability of line broadening/shifting

✤ Assumptions for spectral simulations

- log L_{bol}=45.5, kT=7.3 keV, Z=0.3 solar
- log L_{bol}=45.0, kT=5.0 keV, Z=0.3 solar
- log L_{bol}=44.5, kT=3.4 keV, Z=0.3 solar
- log L_{bol}=44.0, kT=2.3 keV, Z=0.3 solar

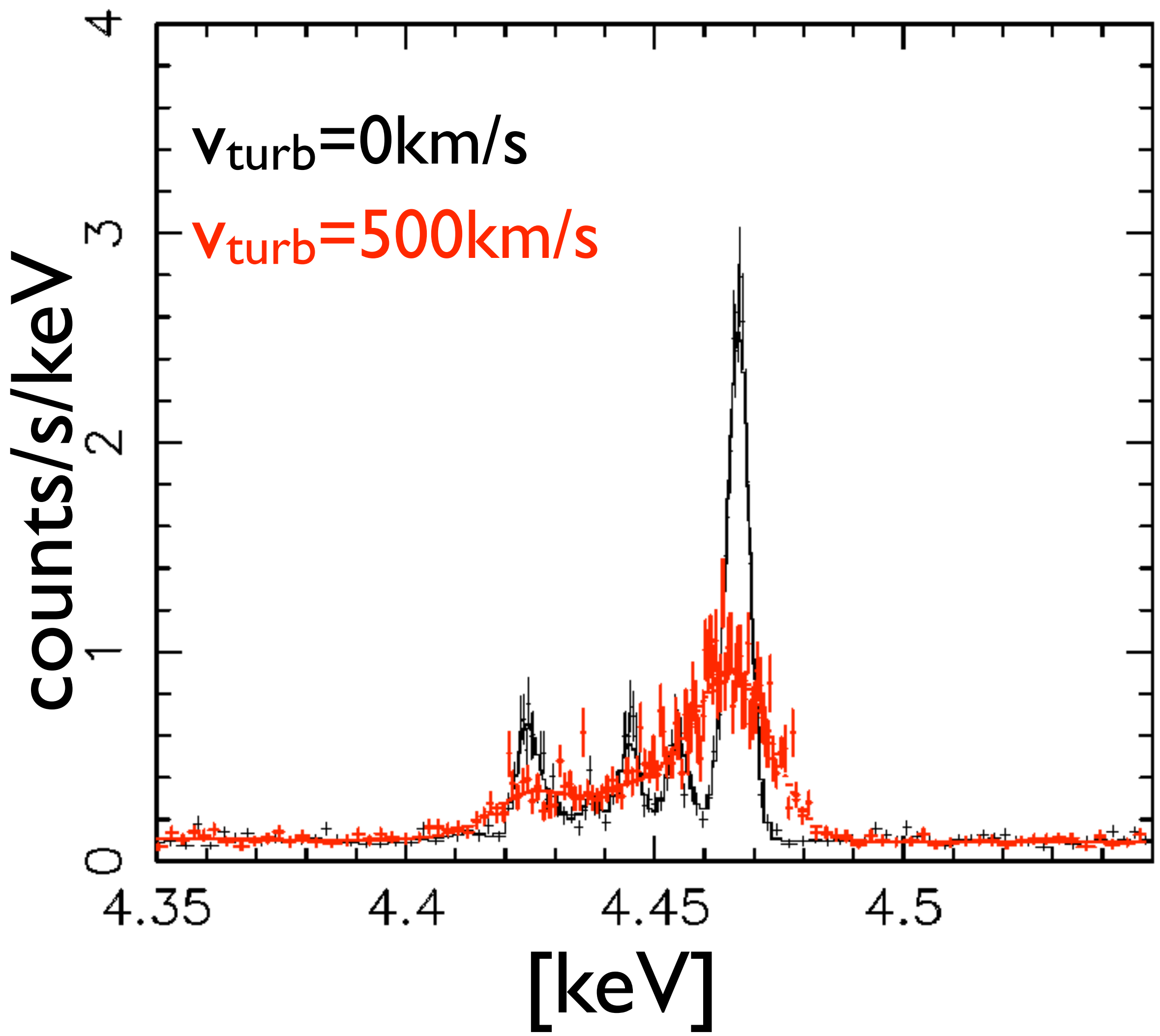
✤ XSPEC/fake

- Spectral model "BAPEC", v_{turb}=0, 100, .., 1000 km/s, z=0.1,0.5,..,2
- Energy response FWHM = 2.5eV
- Effective area 3m^2 @E <2 keV, 1m^2 @E >2 keV
- Background "bg_xeus_tes_ML_THINFILTER_10arcsec.fak"

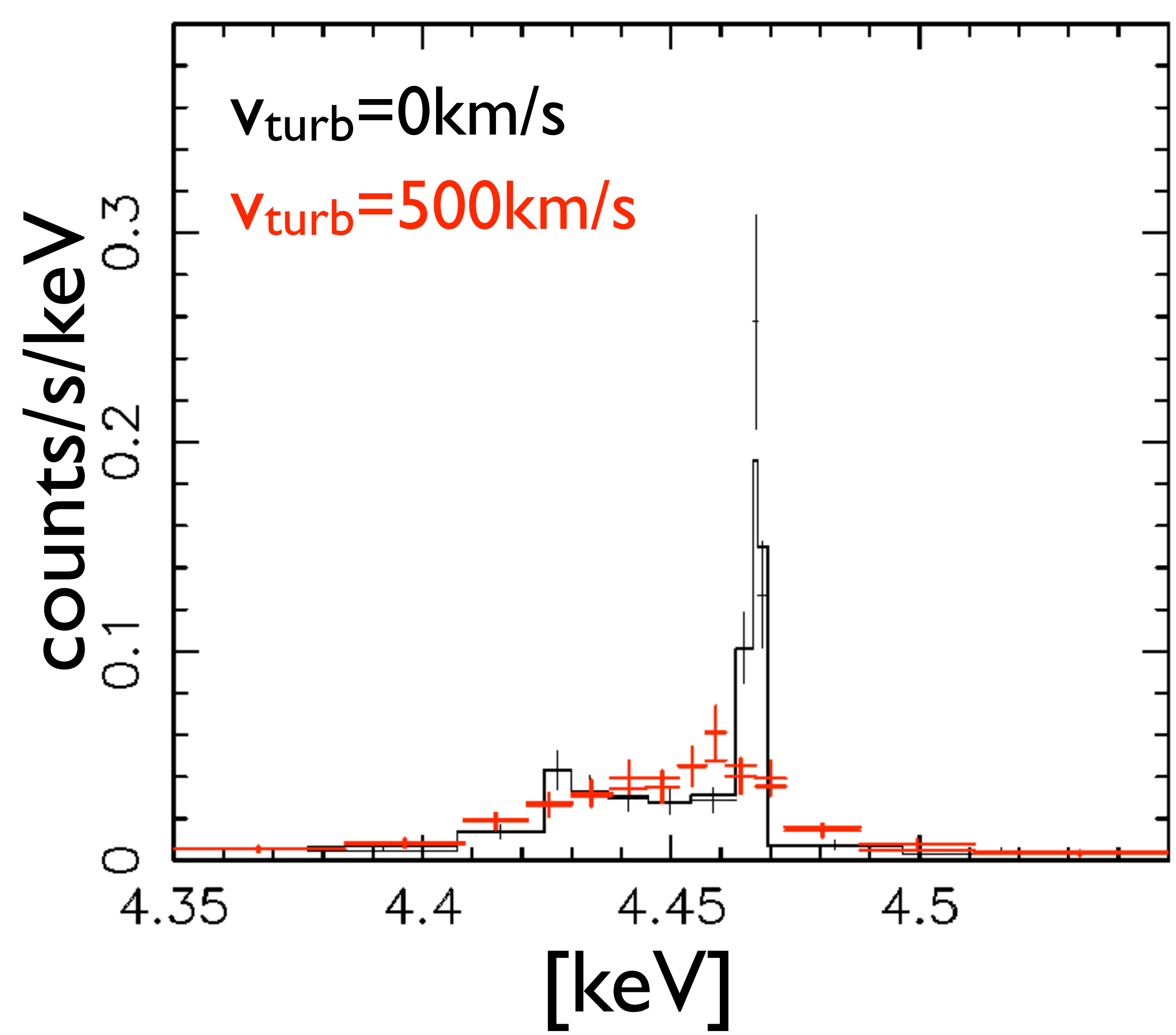
  Integration radius r_{500}~1Mpc$(T/5keV)^{0.5}[\Omega_M(1+z)^3+\Omega_\Lambda]^{-1/2}$
- Exposure 100 ksec

Simulated spectra: 6.7 keV Fe XXV

- 5keV cluster@ z=0.5

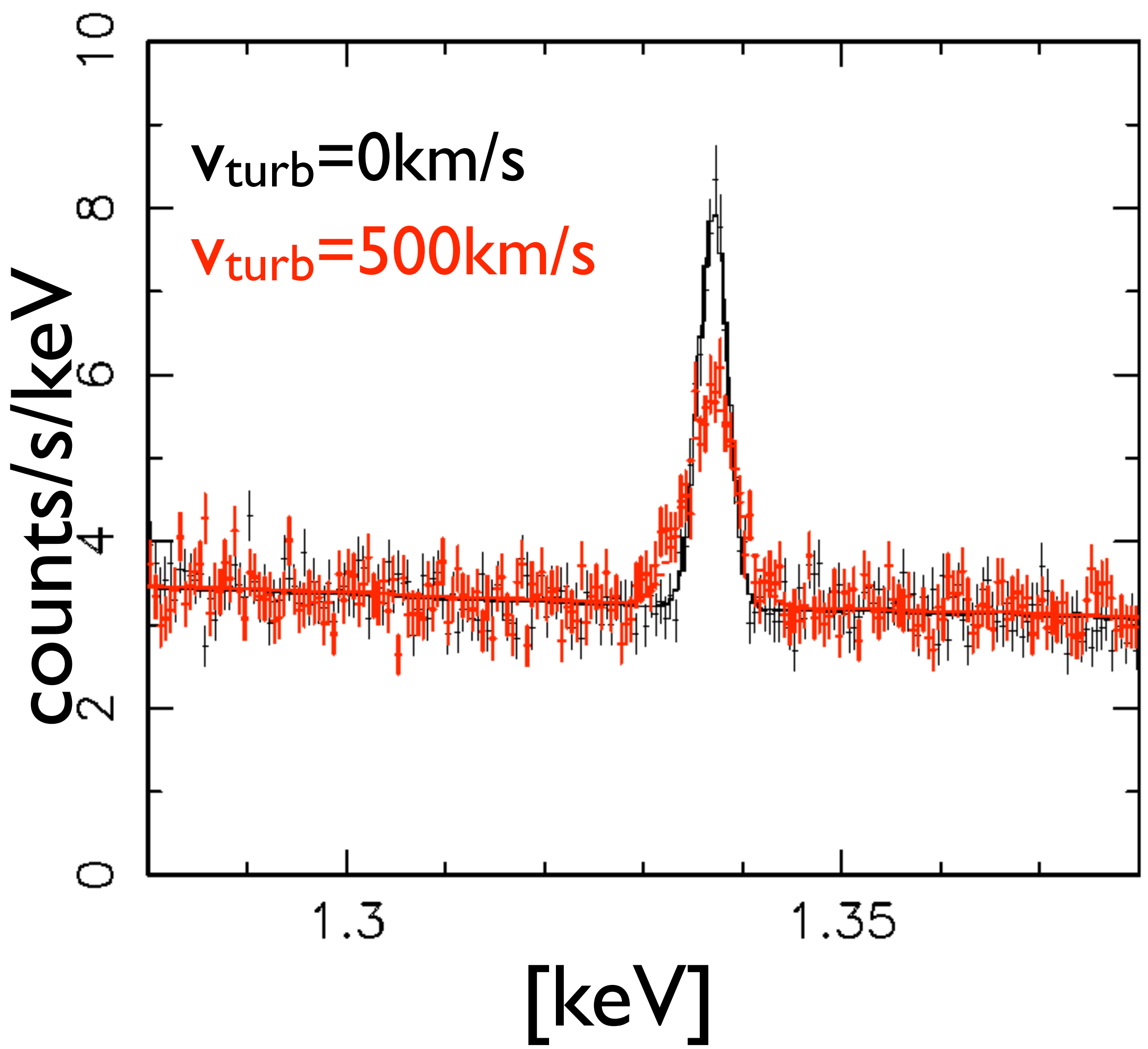


- 2.3keV cluster@ z=0.5

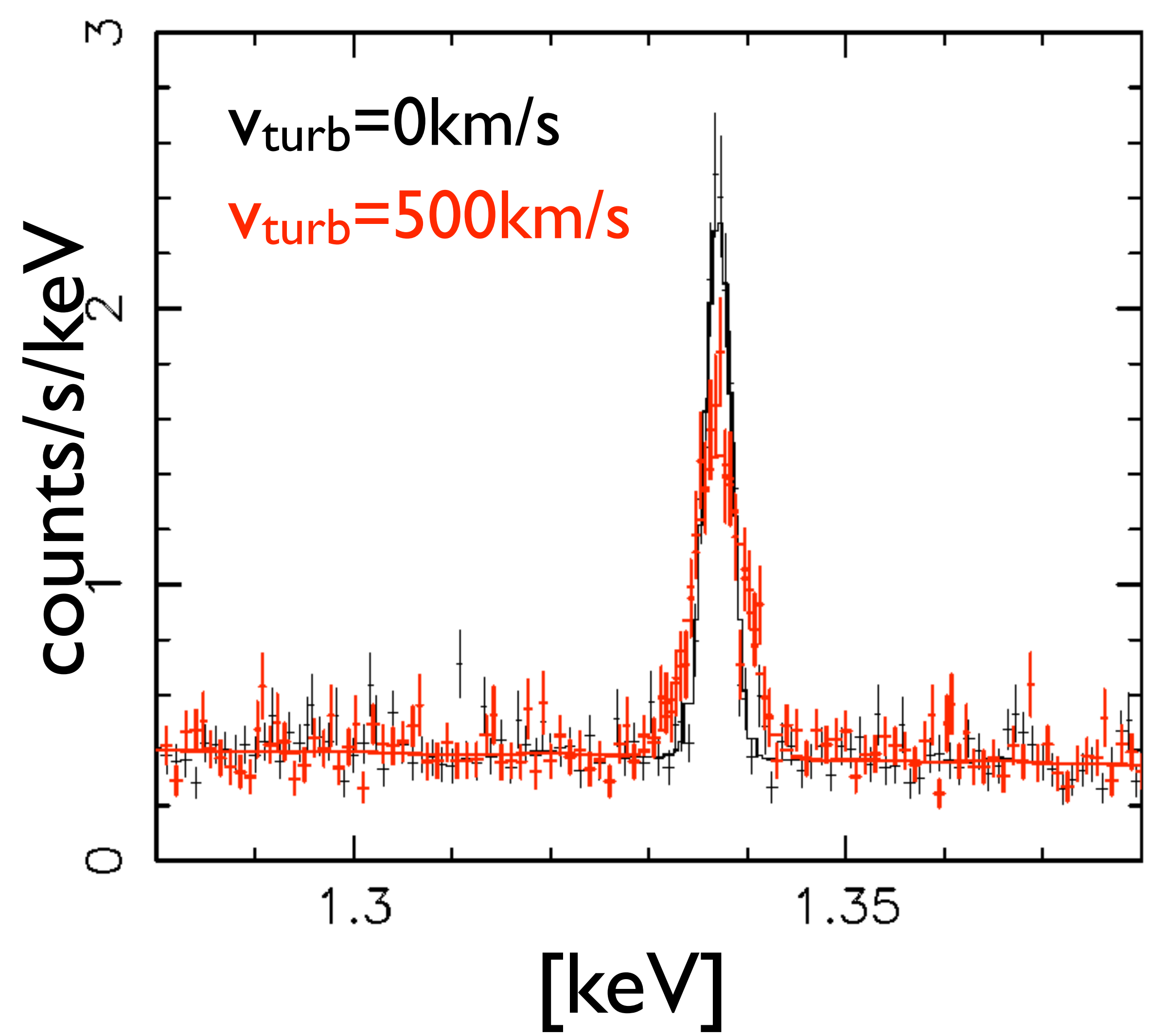


Simulated spectra: 2.0 keV Si XIV

✤5keV cluster@ z=0.5



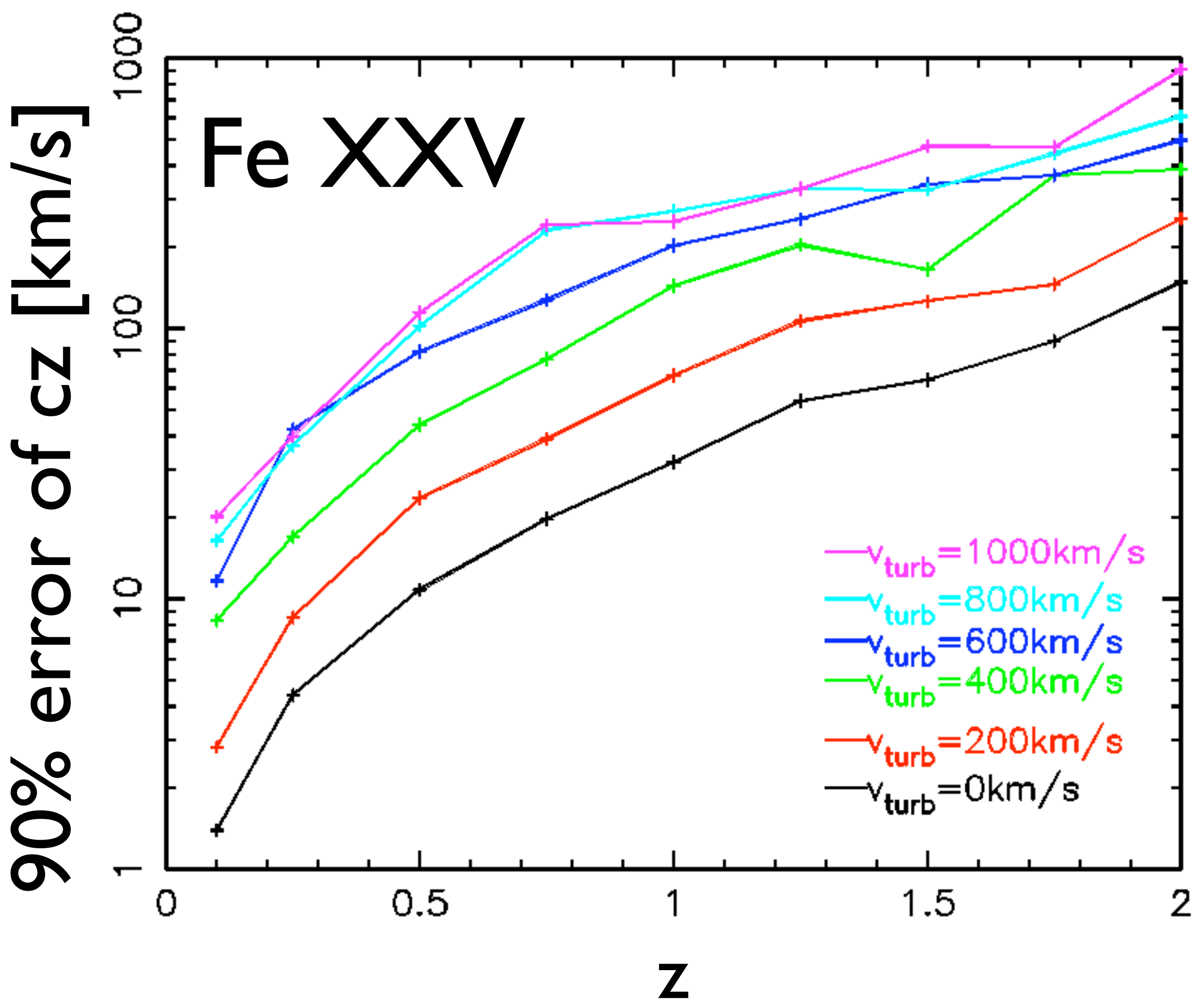
✤2.3keV cluster@ z=0.5



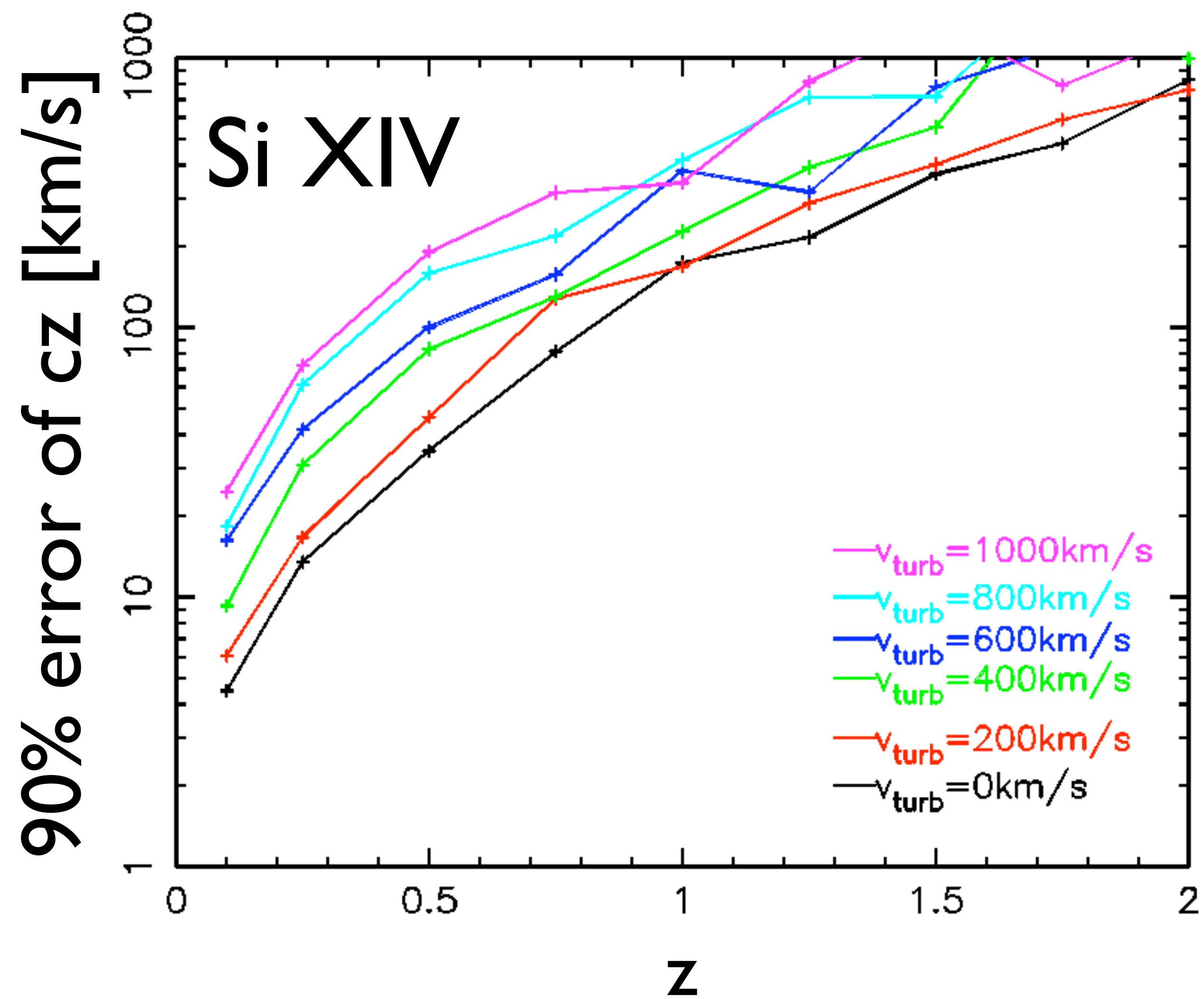
Fitting model: BAPEC
Free parameters: kT, Z, z, v_{turb}, Norm => Line shifting, broadening

Line shifting (or cz)

✤5keV cluster



✤2.3keV cluster



If v_{turb}=0km/s, $\Delta(cz)$ = 10km/s @ z=0.5
$\Delta(cz)$ = 30km/s @ z=1

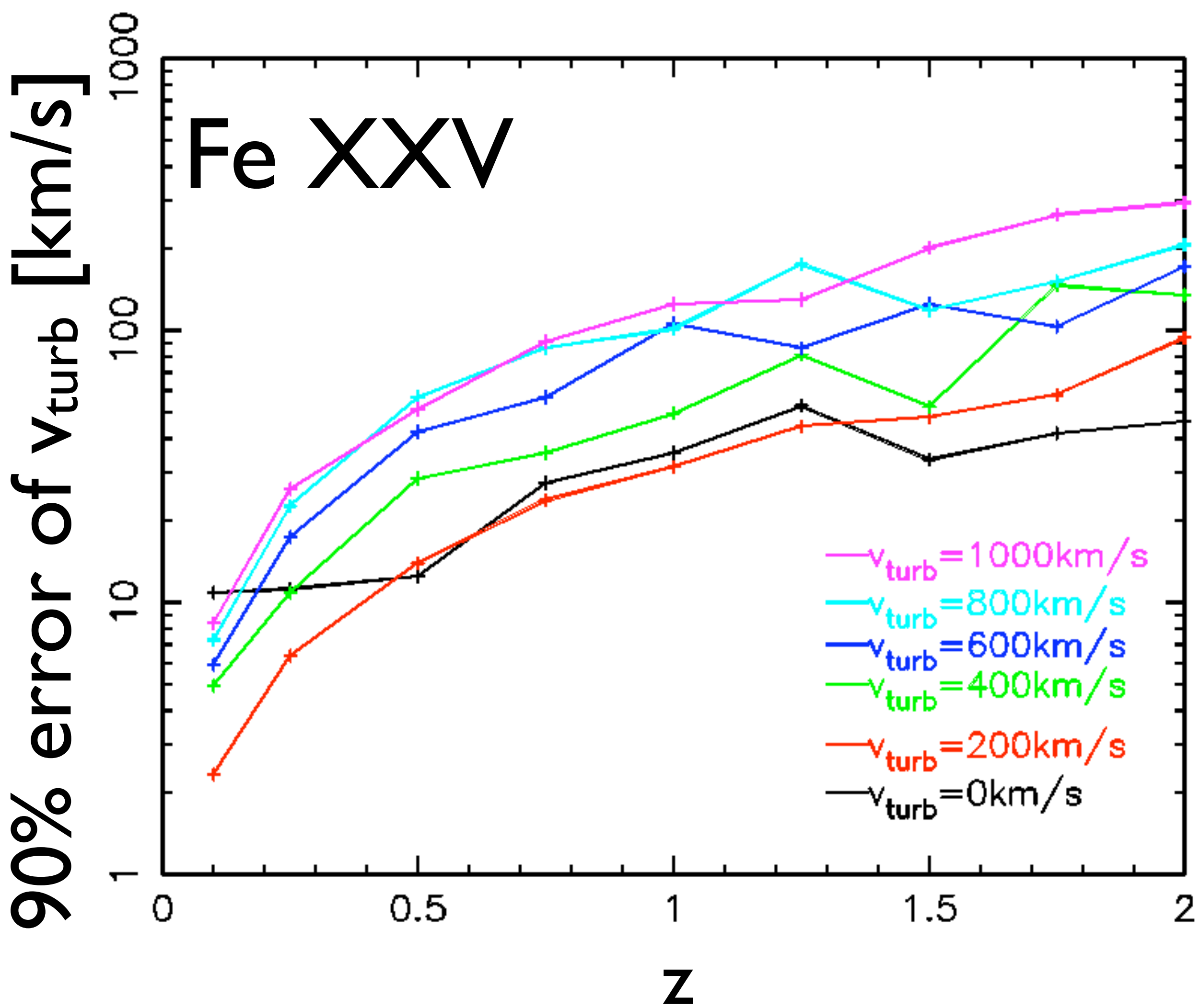
$\Delta(cz)/(cz) < 10^{-3}$ @ z<2

If v_{turb}=0km/s, $\Delta(cz)$ = 30km/s @ z=0.5
$\Delta(cz)$ = 170km/s @ z=1

$\Delta(cz)/(cz) < 3\times10^{-3}$ for z<2

Line broadening

✤5keV cluster

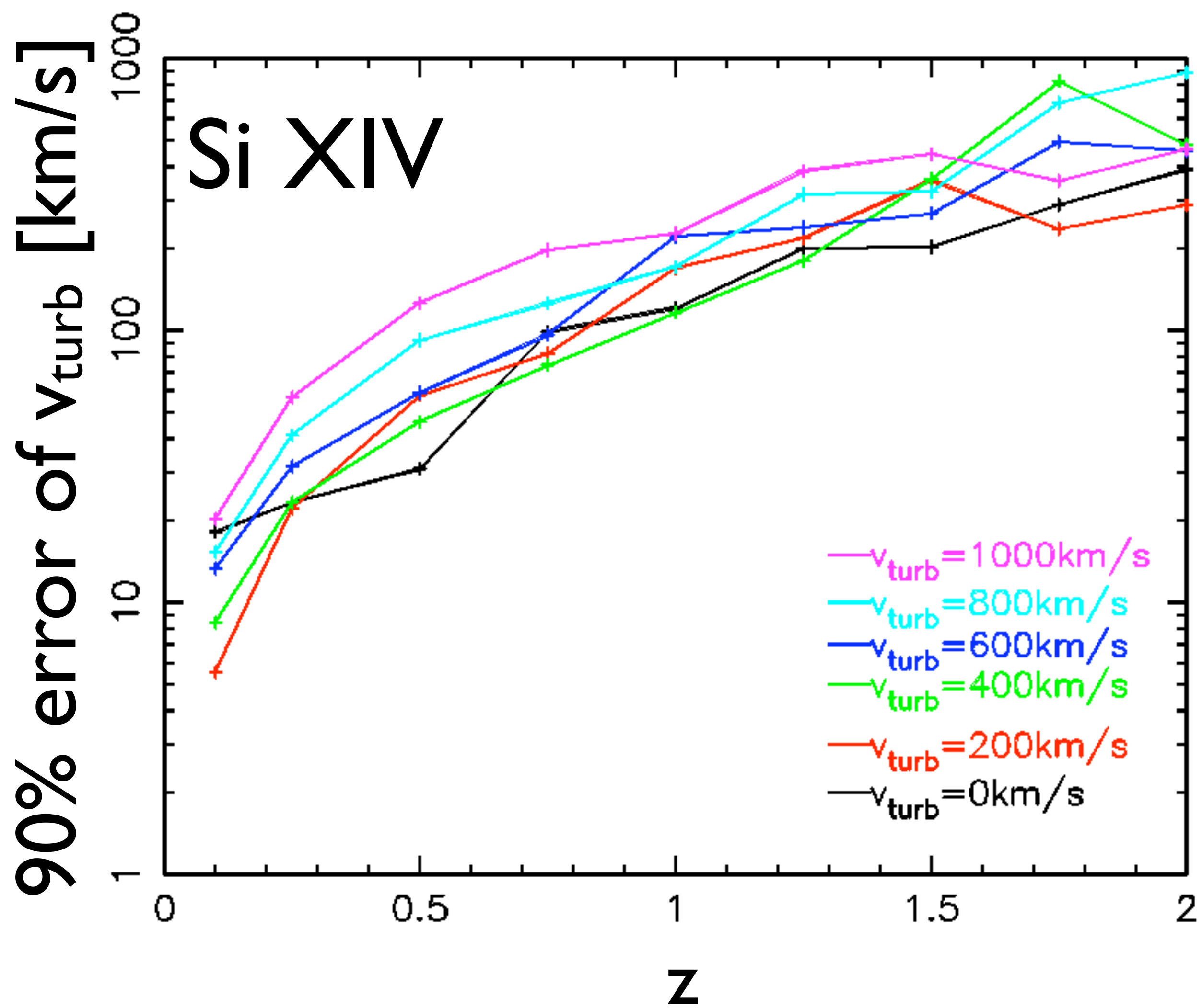


Δv_{turb} = 10-- 50 km/s @z=0.5

Δv_{turb} = 35--125 km/s @z=1

Δv_{turb} = 45--300 km/s @z=2

✤2.3keV cluster



Δv_{turb} = 30--120 km/s @z=0.5

Δv_{turb} = 120--230 km/s @z=1

Δv_{turb} = 390--460 km/s @z=2

Summary of results

✤ Redshift and flux for $\Delta v_{turb}/v_{turb} < 0.15$ (v_{turb}=500km/s)

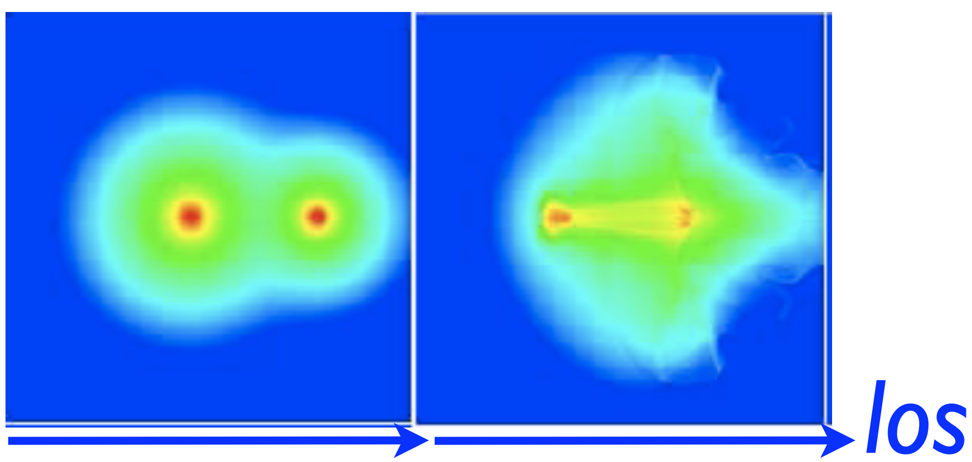
kT[keV]	Fe XXV		Si XIV	
	z	Flux*	z	Flux*
7.3	<1.75	$>1.2\times10^{-13}$	<0.5	$>2.7\times10^{-12}$
5.0	<1.25	$>1.0\times10^{-13}$	<0.5	$>8.6\times10^{-13}$
3.4	<0.5	$>2.6\times10^{-13}$	<0.75	$>9.8\times10^{-14}$
2.3	<0.25	$>5.1\times10^{-13}$	<0.75	$>2.9\times10^{-14}$

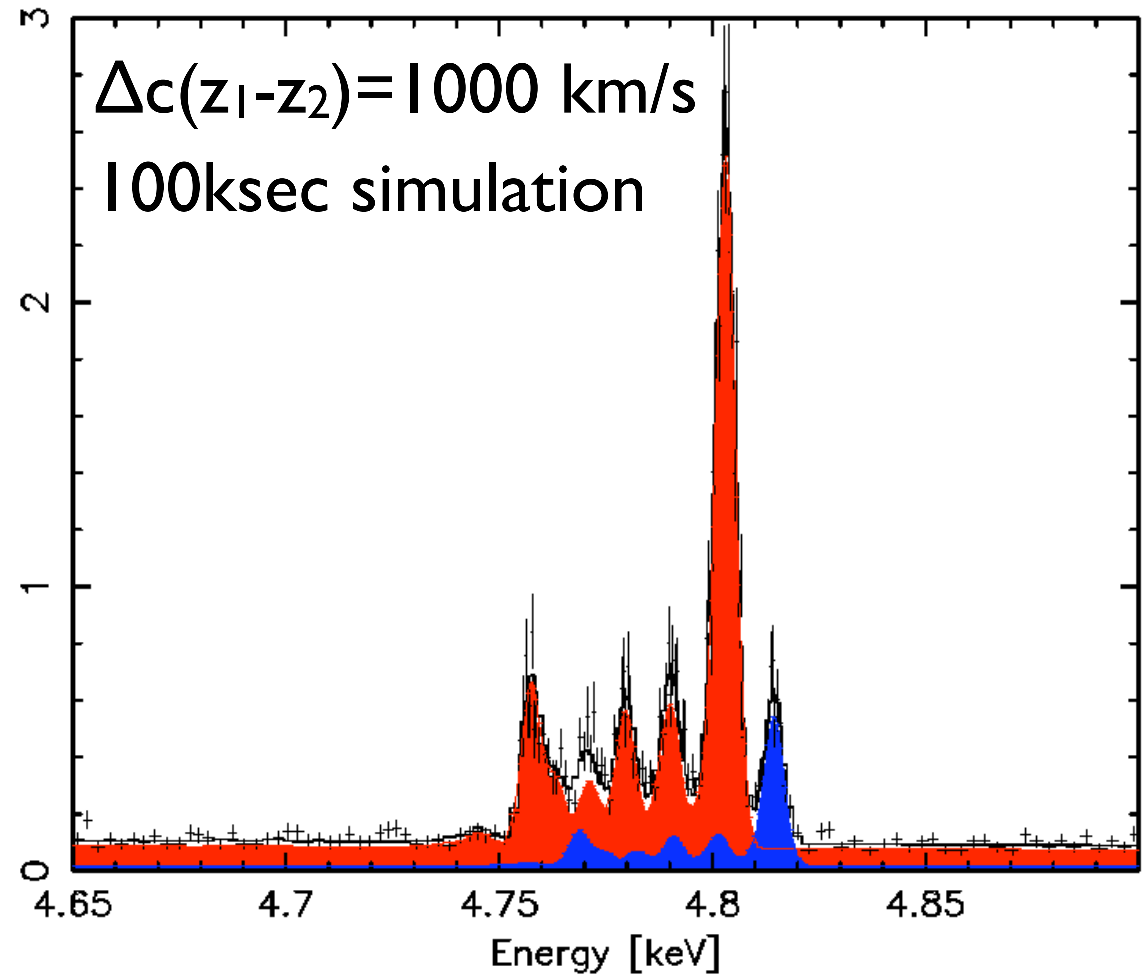
*0.3-10keV flux [erg/s/cm^2]

3. Can we resolve line-of-sight mergers?

✤ High speed (~3000km/s) collision is suggested for some systems

CL0024+17 @ z=0.4
(e.g., Ota+04; Czoske+02; ZuHone+08)





✤ Consider a superposition of two clusters

- APEC + APEC
  kT_1=4.5keV, kT_2=3.0keV,
  L_{bol1}=5.6x10^{44}erg/s,
  L_{bol2}=1.6x10^{44}erg/s,
  $Z_1=Z_2$=0.3solar

- If $\Delta c(z_1-z_2)$ >200 km/s, two components can be separated!

Summary

- Based on TES spectral simulations, we examined the detectability of cluster gas motions
  - Line shifting of Fe/Si can be constrained to < 0.1%/0.3% accuracy @z<2
  - Doppler broadening of Fe/Si can be measured up to z~1.75/1.25/0.75/0.75 with 15% accuracy for clusters with logLx=45.5/45/44.5/44, Z=0.3solar
  - Line of sight mergers can be resolved if the velocity separation is >200 km/s @z=0.4
- IXO will provide excellent opportunities to probe the dynamical evolution of clusters