X-ray signatures of AGN outflows:

multi-dimensional radiative transfer simulations

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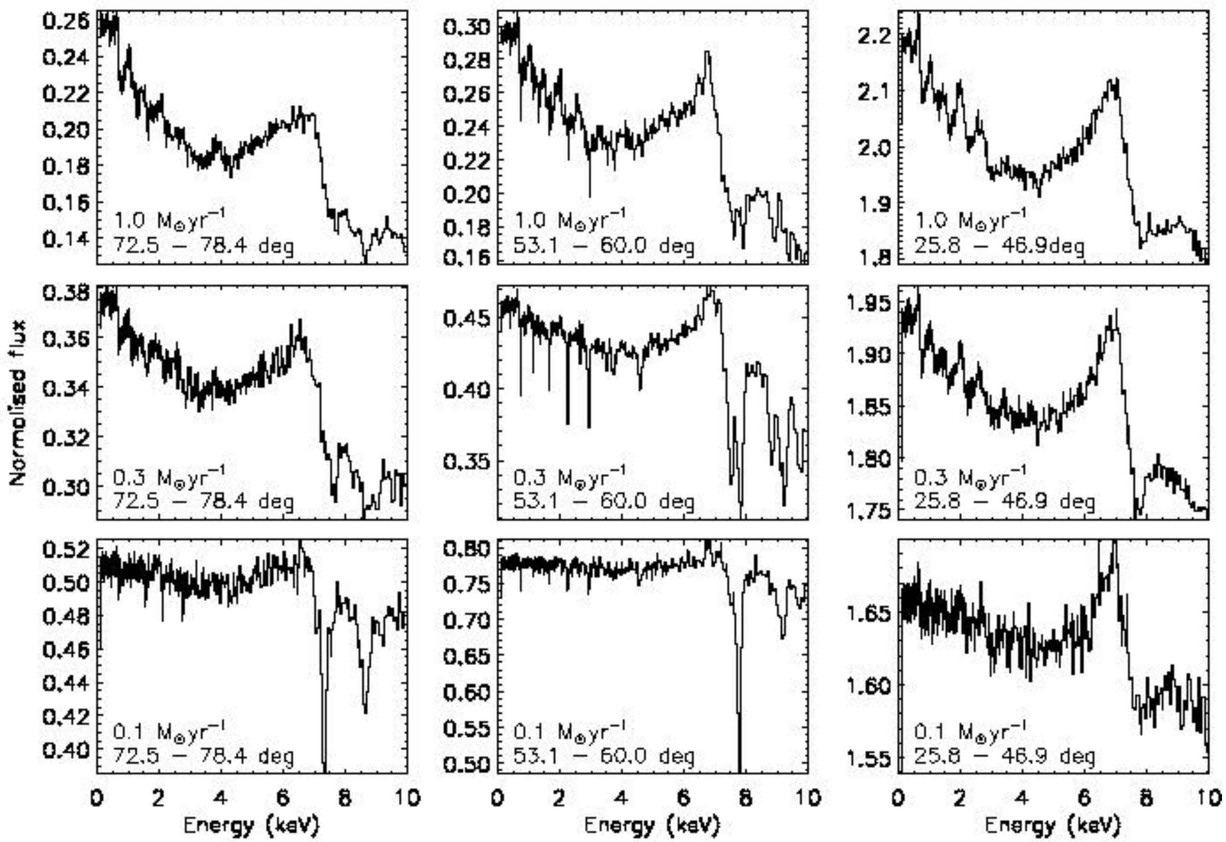


Overview (our project)

1. Motivation: complex outflow geometries

- Modelling of X-ray observations
- Hydrodynamical simulations

Need to consider multi-D effects

2. Two-pronged approach

- Synthetic spectra for hydro models

Predictions: no additional parameters in RT simulations

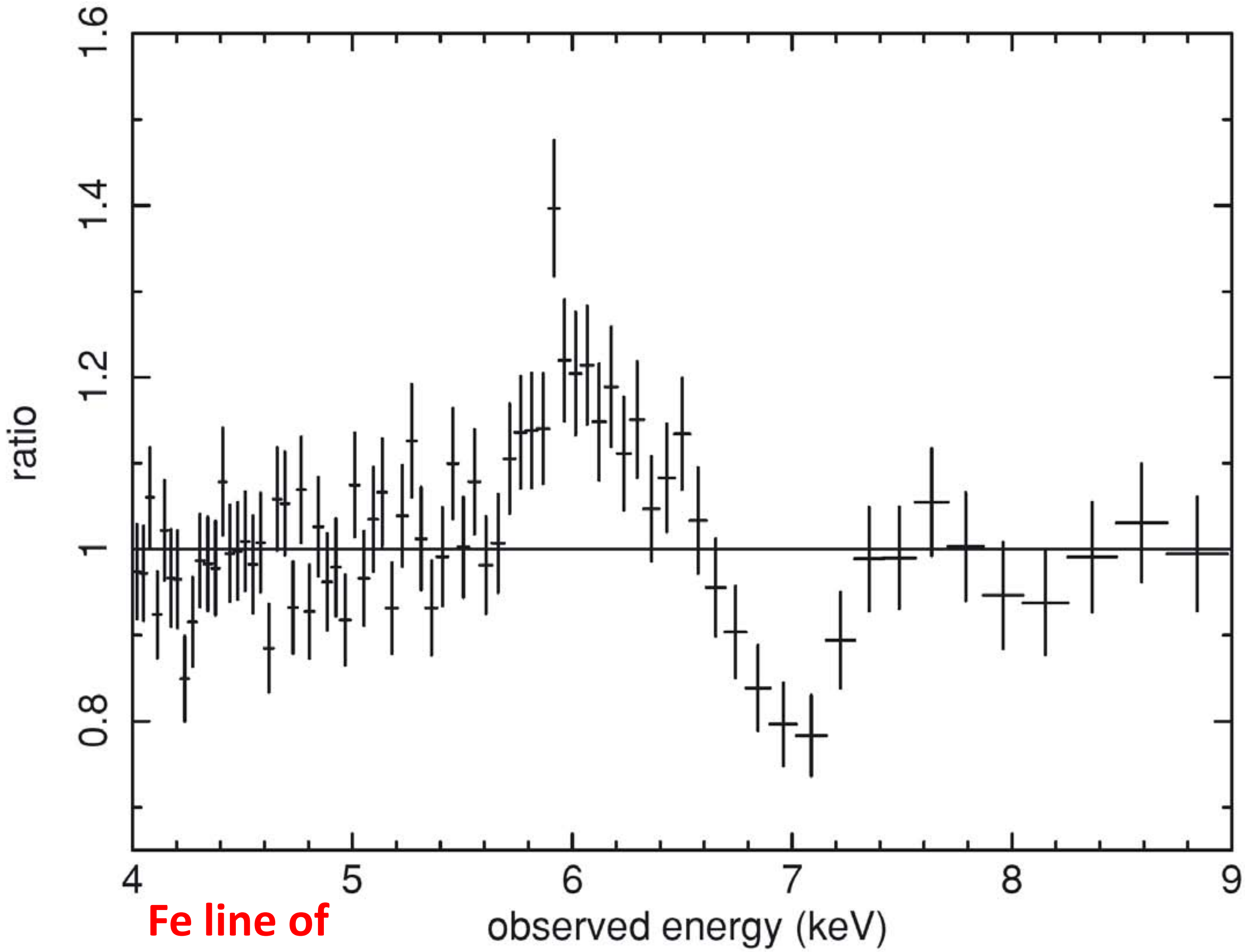
- Synthetic spectra for parametrized wind models

Allow fitting of data to determine wind properties

3. Interpretation of spectral features

- Blue-shifted absorption lines
- Broad emission lines

Winds can reproduce many important X-ray spectral features



Fe line of PG1211+143 (Pounds et al. 2009)

Overview (this talk)

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2. Two-pronged approach

- **Synthetic spectra for hydro models**

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3. Interpretation of spectral features

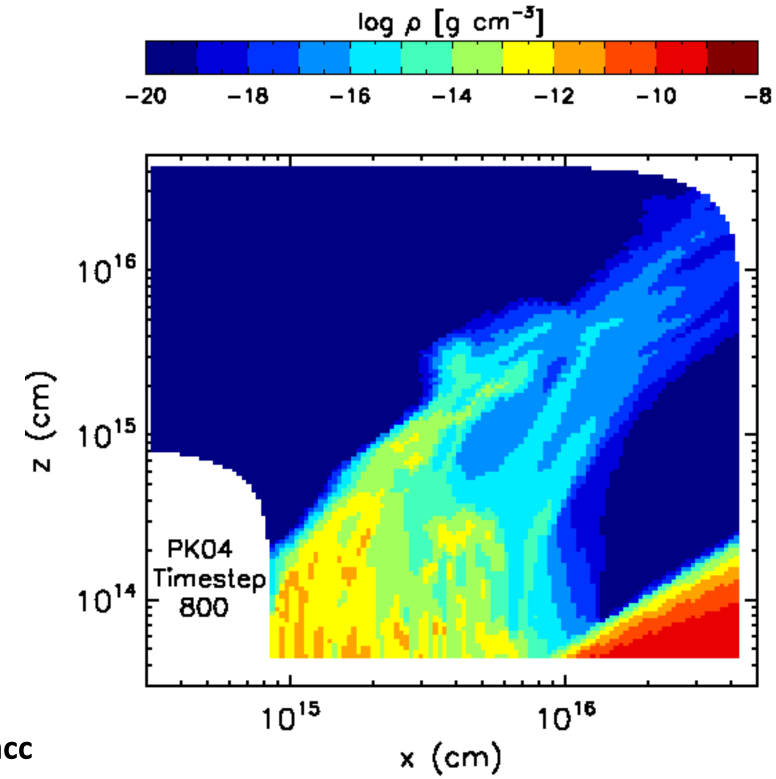
- **Blue-shifted absorption lines (some comments on UFOs)**
- **Broad emission lines**

Winds can reproduce many important X-ray spectral features

Simulations: line-driven wind

Results:

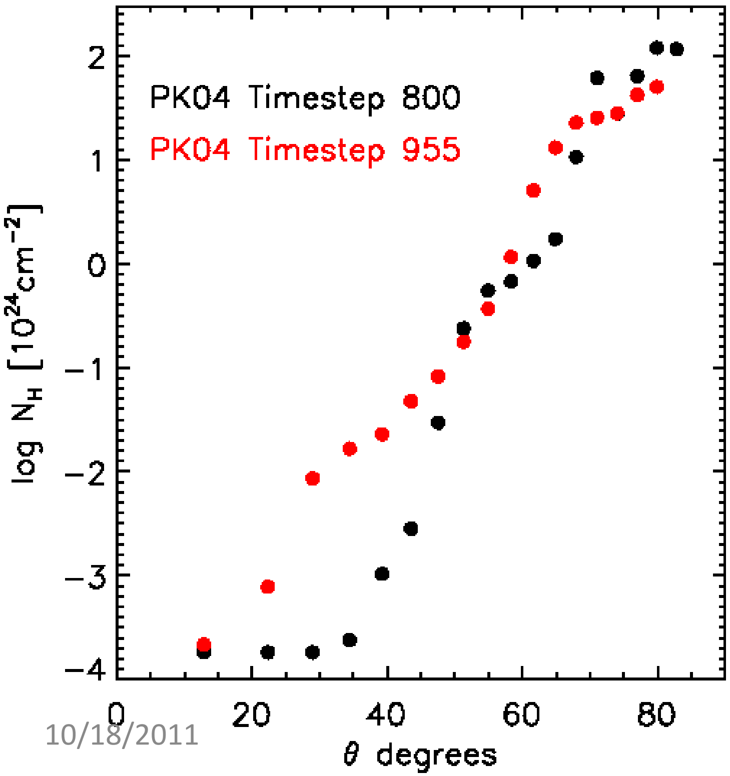
- Shielding can work
- Multi-component flow:
  - Low density polar flow
  - Slow equatorial outflow
  - Fast stream at intermediate angles (mildly relativistic)
  - Inner "failed wind" region – the shield
- Time variable flow
- Significant mass loss for luminous objects
  - For 0.5 L_{edd} sim., mass loss about 0.1 M_{acc}
- Wind not present for < 0.1 L_{edd}
  - Still develop failed wind region

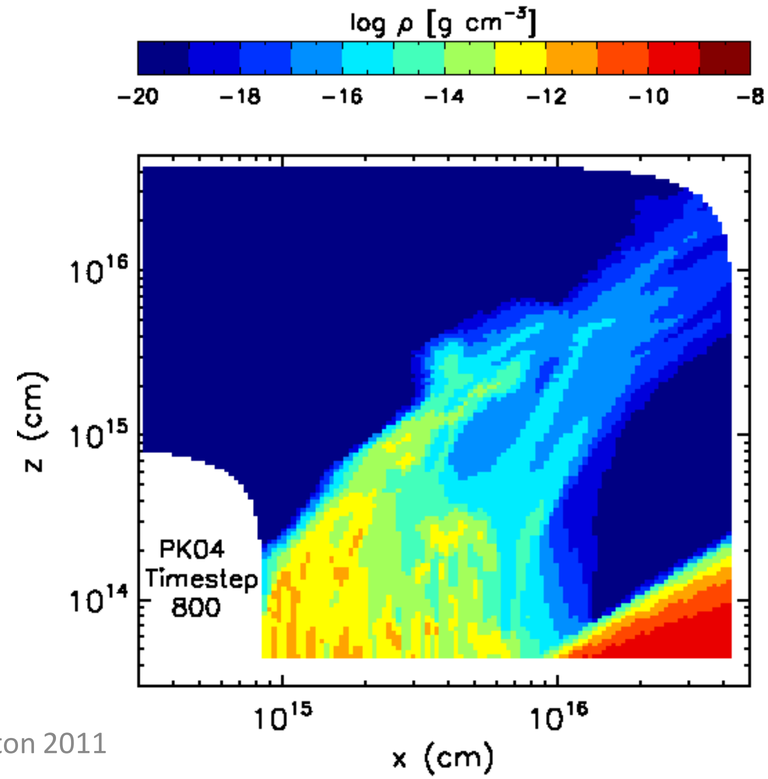


Proga et al. 2000, 2004

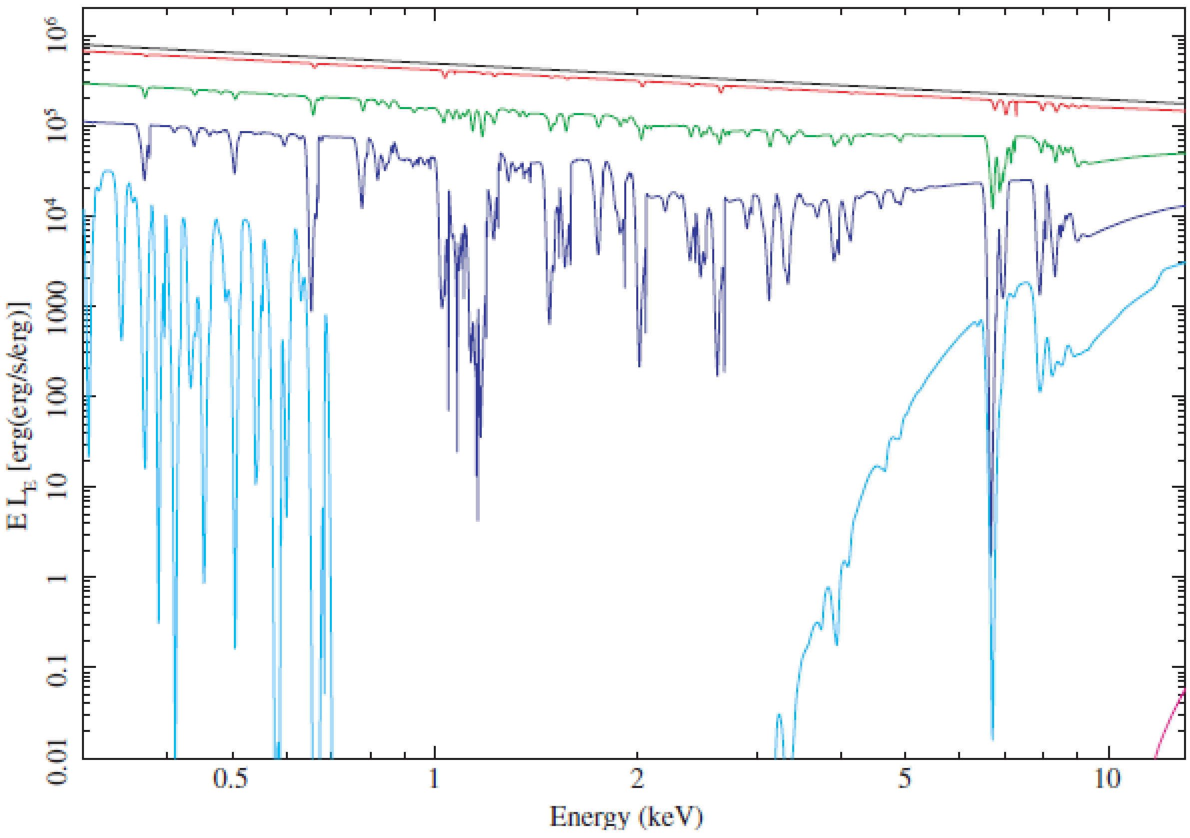
Observable signatures

If winds have high enough column density, they will imprint signatures on spectra.





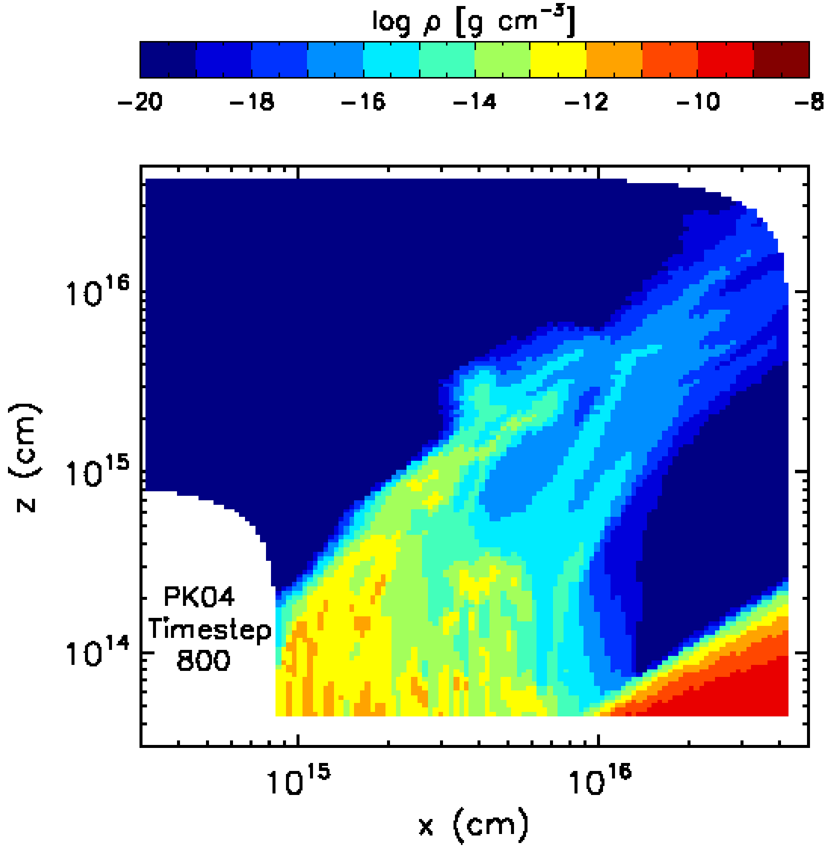
X-rays; Schurch, Done & Proga 2009



Synthetic X-ray absorption spectra

- 50, 57, 62, 65 and 67 degree orientations
- XSCORT spectra

Multi-D radiative transfer



1D methods great for transmission spectra but:

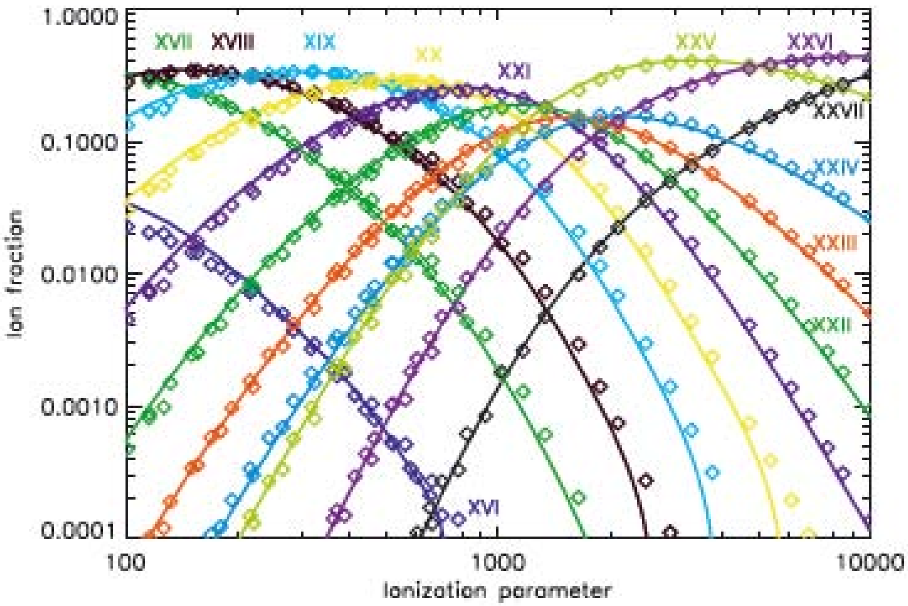
1. **Compton scattering will strongly affect radiation field (ionizing photons scattered)**
2. **Reprocessing/reflection by wind will produce spectral emission features**

Relatively easy to do accurately with Monte Carlo methods (Sim 05, 08, 10).

To compute synthetic spectra for realistic (disk wind) geometries.... need multi-D rad. Trans.

MC Radiative Transfer

- Monte Carlo method
  - + Simulate propagation of quanta representing radiative energy
  - + Not limited to resonance scattering – see Lucy 2002,2003 ...
  - + Easy for multi-D
- Solves for ionization balance
  - + Use MC estimators
  - + Approximate thermal balance
  - – Simple treatment of excitation
- Obtain l.o.s. spectra
  - + Both transmitted and scattered
  - + Feasible to do 2, 3-D
  - - Sobolev approximation for lines

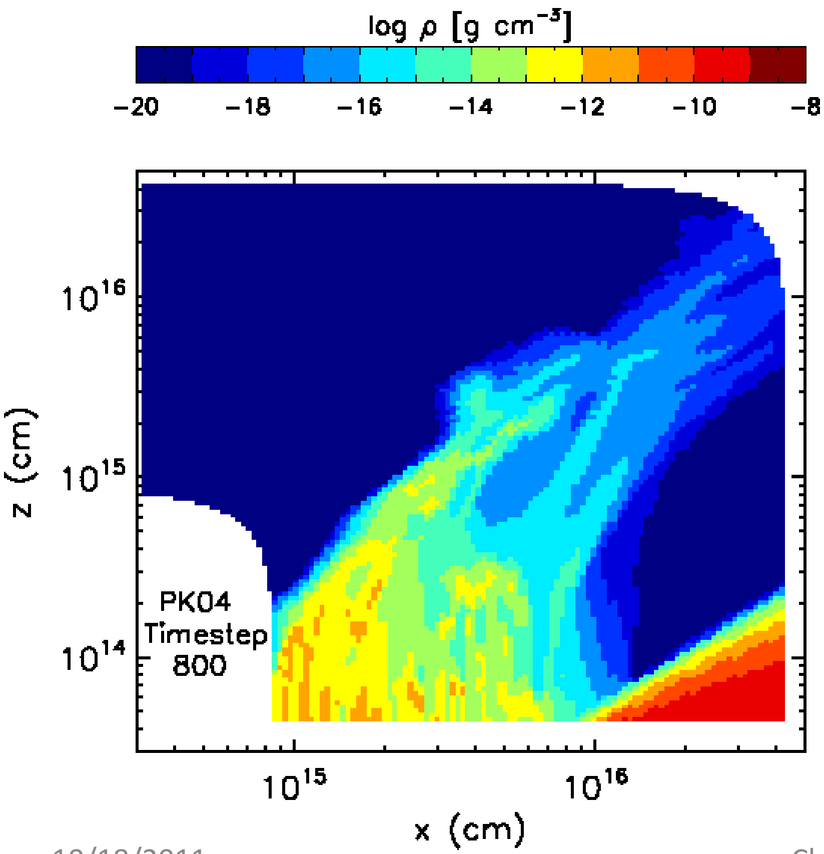


MC Radiative Transfer

- **Atomic Processes**
  - Bound-bound lines
  - Bound-free continua (and inner shell photo. abs)
  - Compton scattering (cold electrons)
  - Free-free
  - Auger effect
  - Electron collisions (ionization/excitation)
- **Data for K- and L-shell ions**
  - C, N, O, Ne, Mg, Si, S, Ar, Ca, Fe, Ni
  - High M-shell ions of Fe and Ni

See Sim et al. (2008,2010)

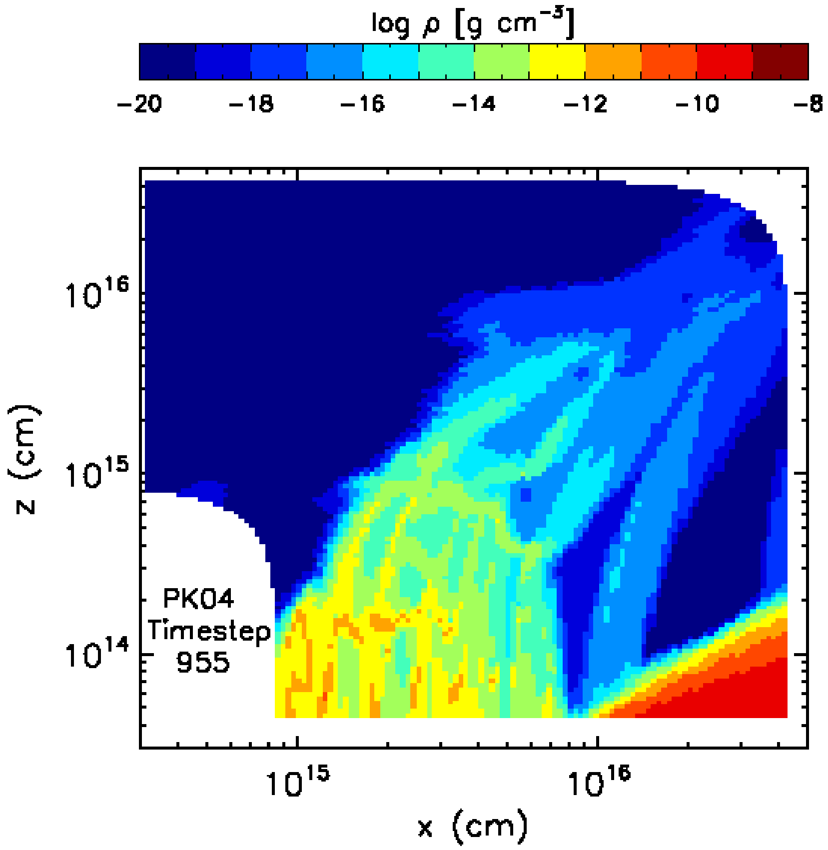
Proga 2004 line-driven wind

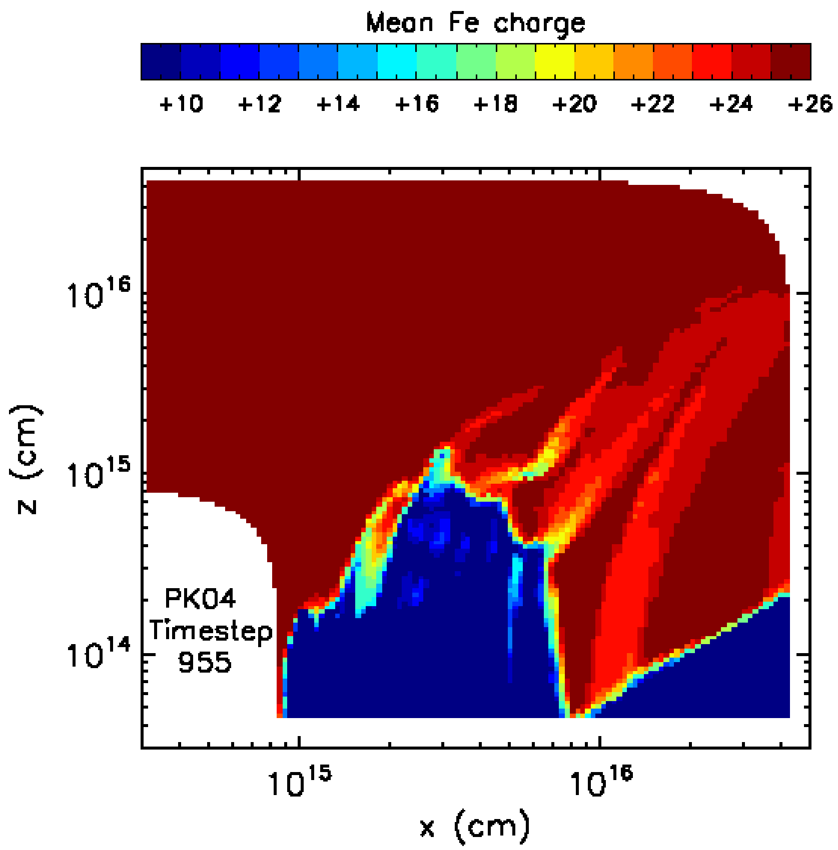


Compute synthetic spectra:

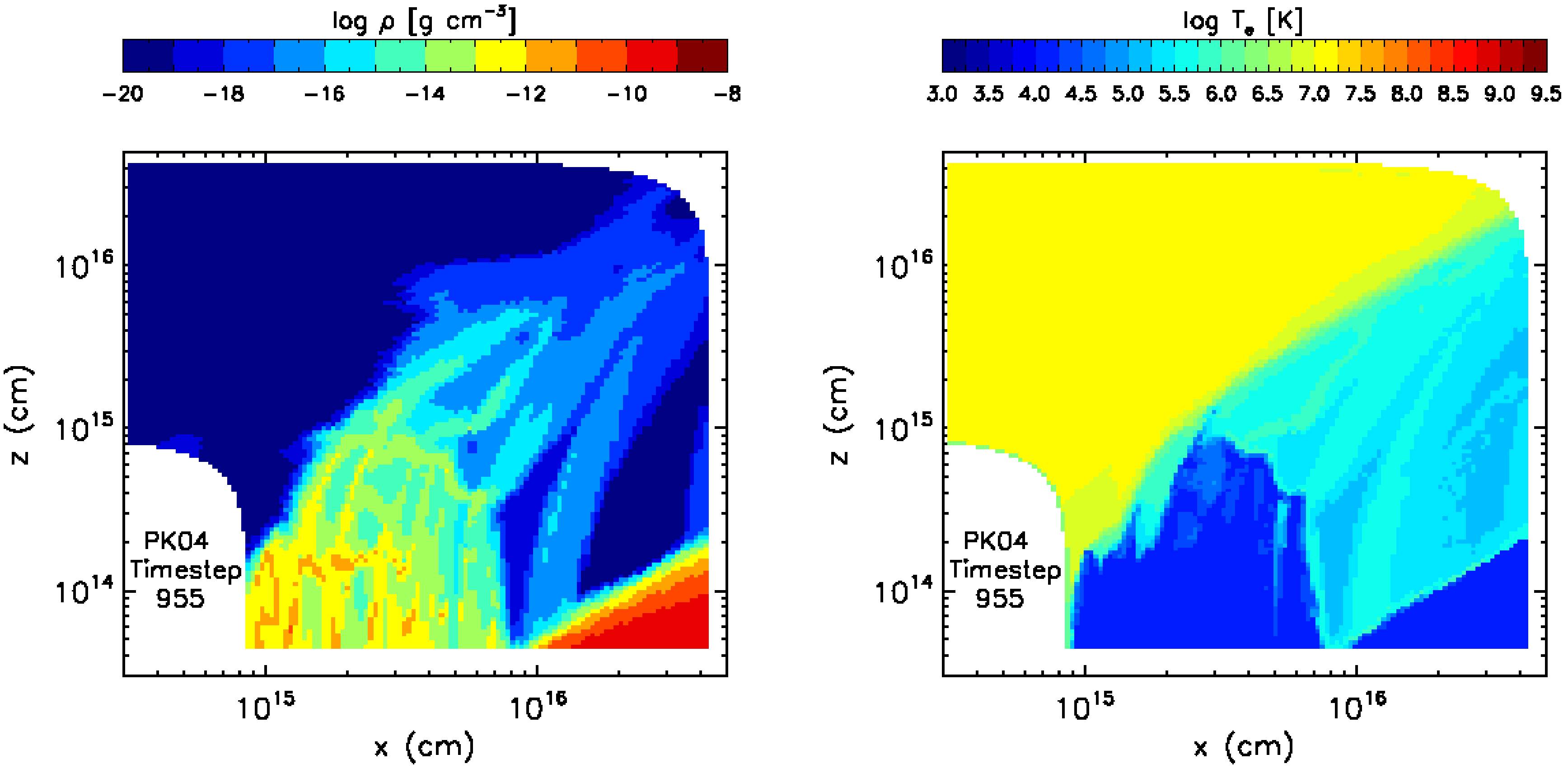
- **Central power-law X-ray source**
- **Compute ionization state**
- **Spectra for multiple orientations**
- **Broadly, 3 classes of spectra**

Ionization/temperature

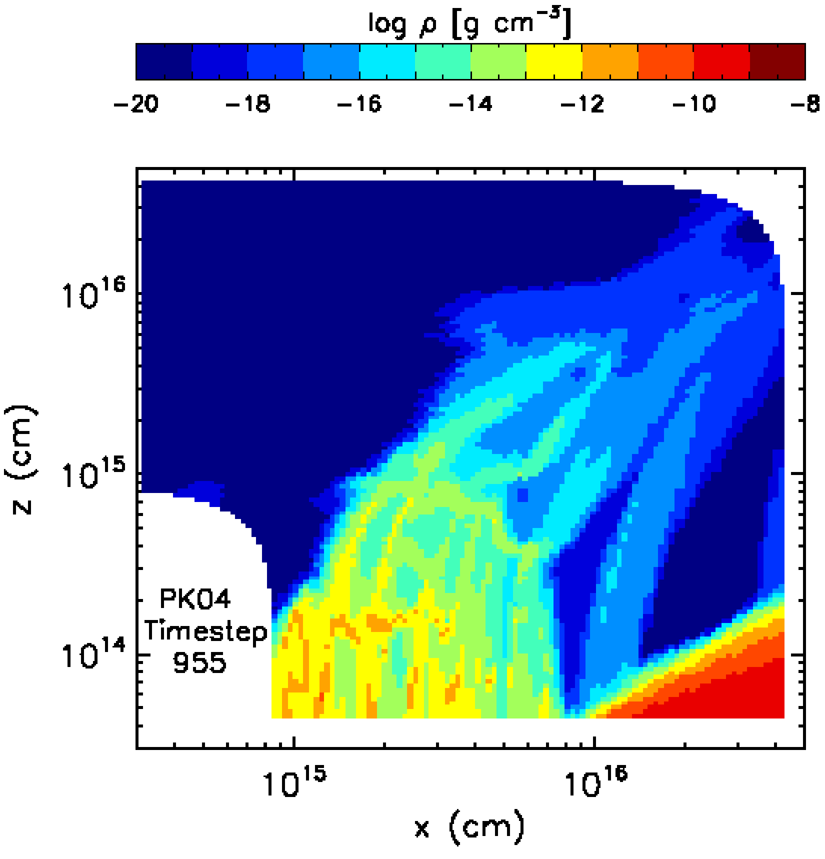


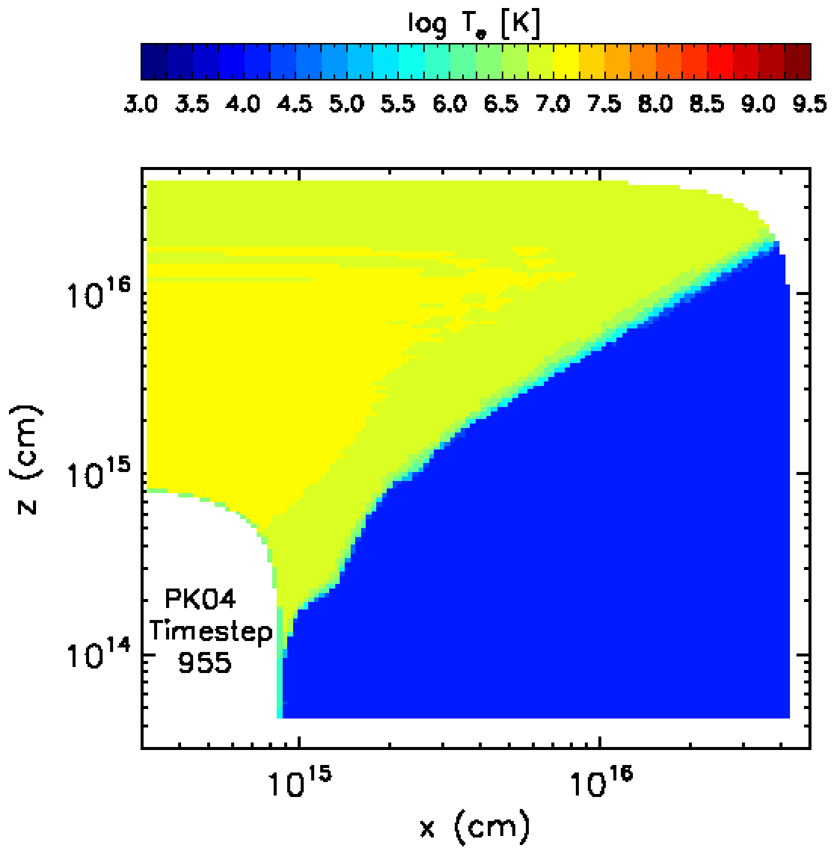


Ionization/temperature

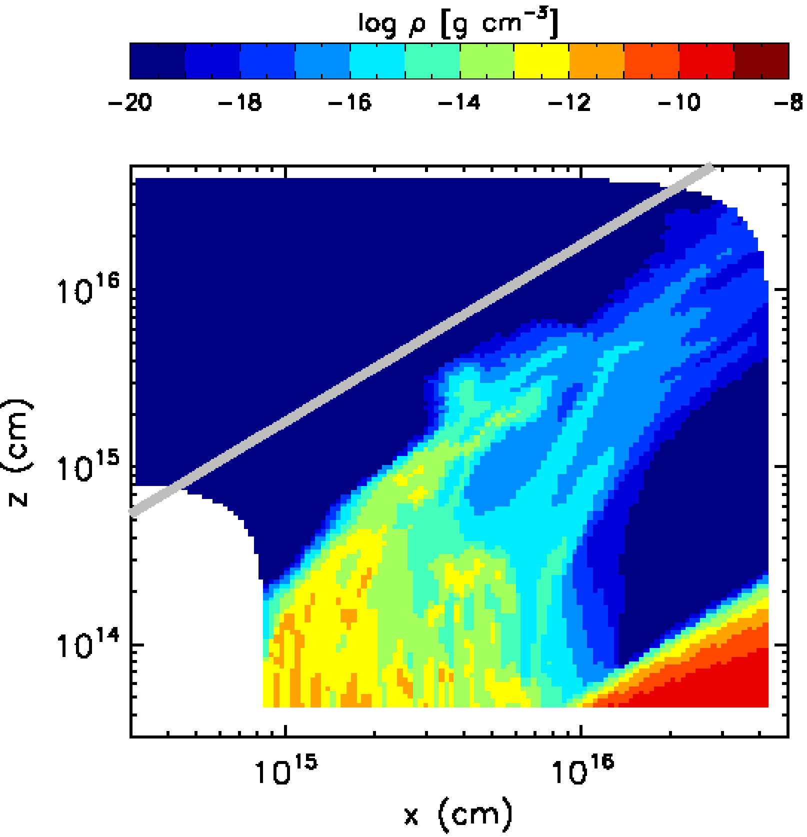


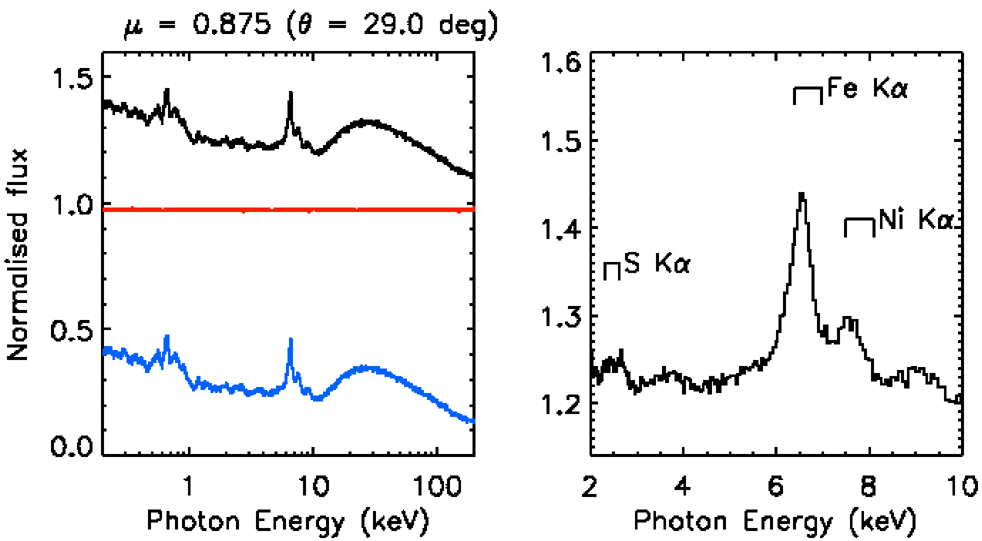
Ionization/temperature





Proga 2004 line-driven wind

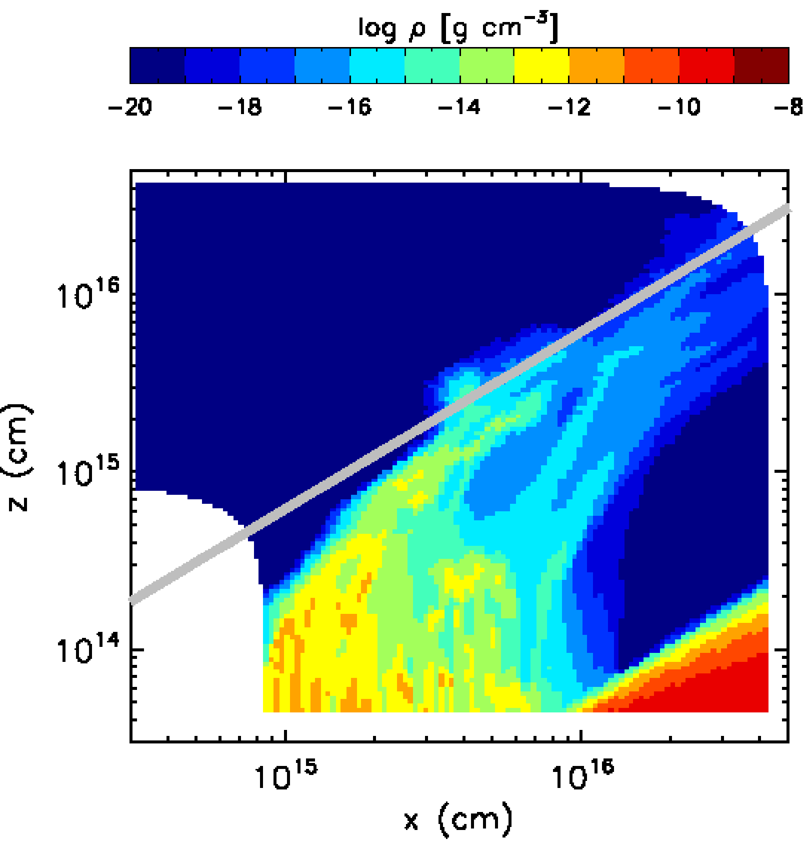


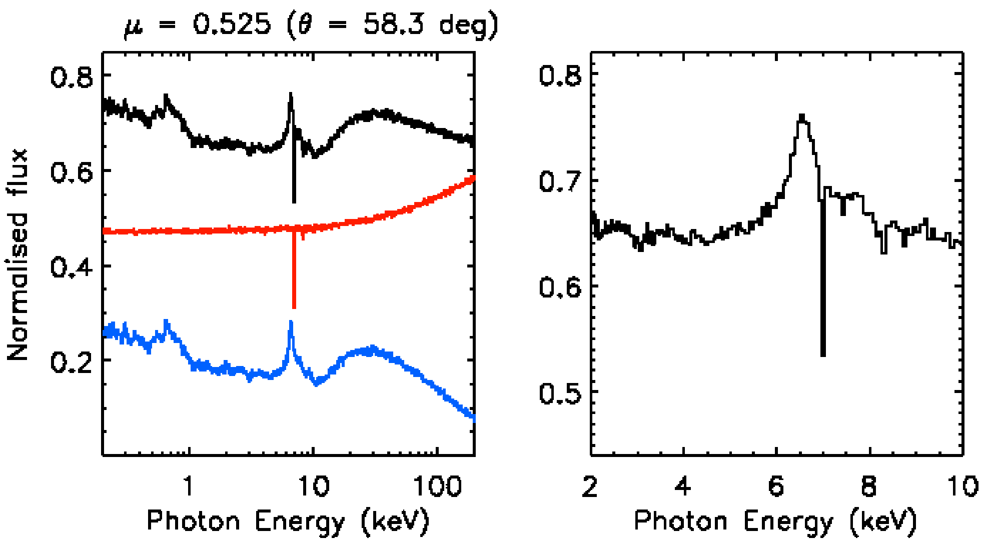


Polar observer:

- Direct continuum + Reflection
- Fe Ka emission + weak Comp. hump

Proga 2004 line-driven wind

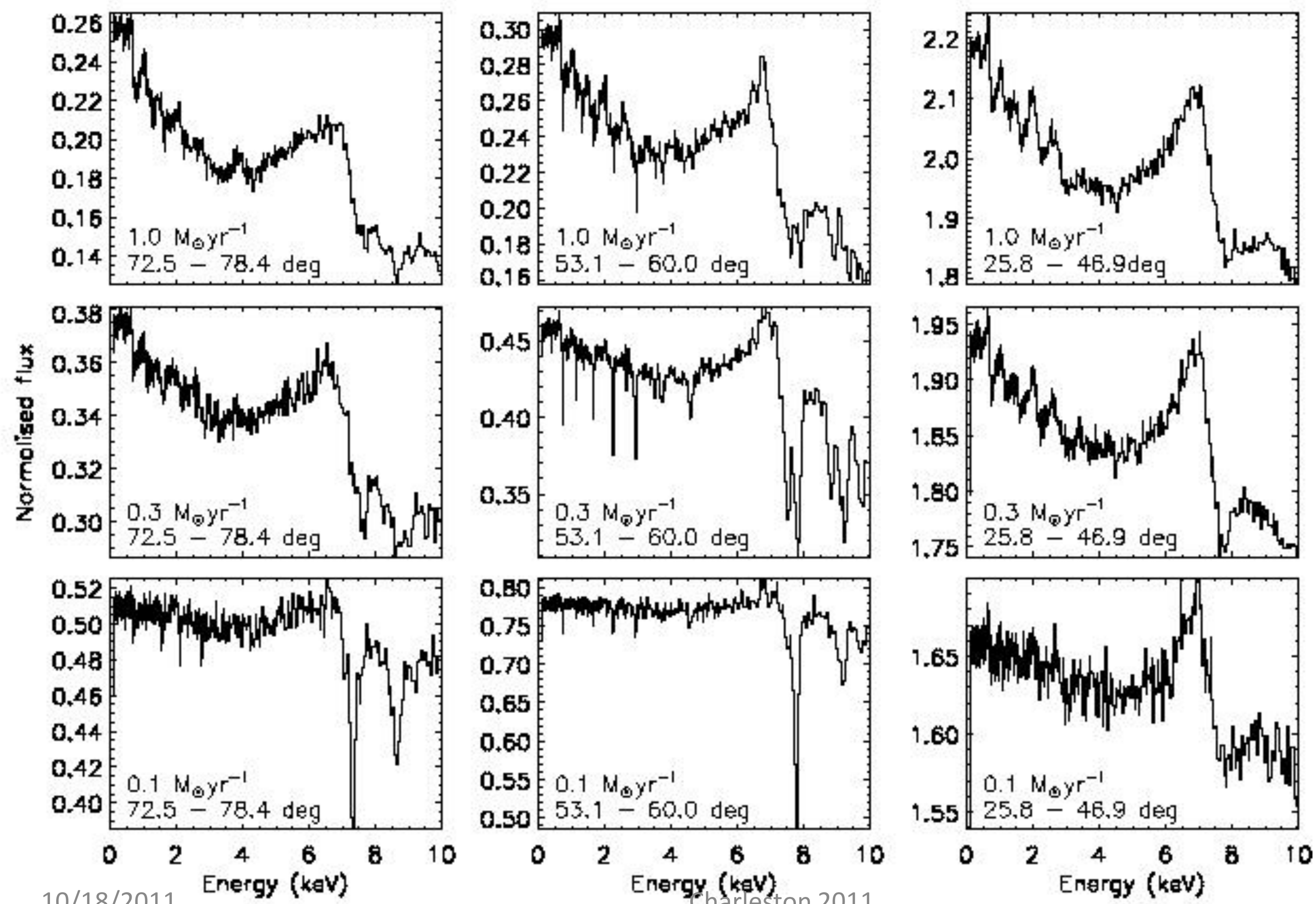




Intermediate orientation observer:

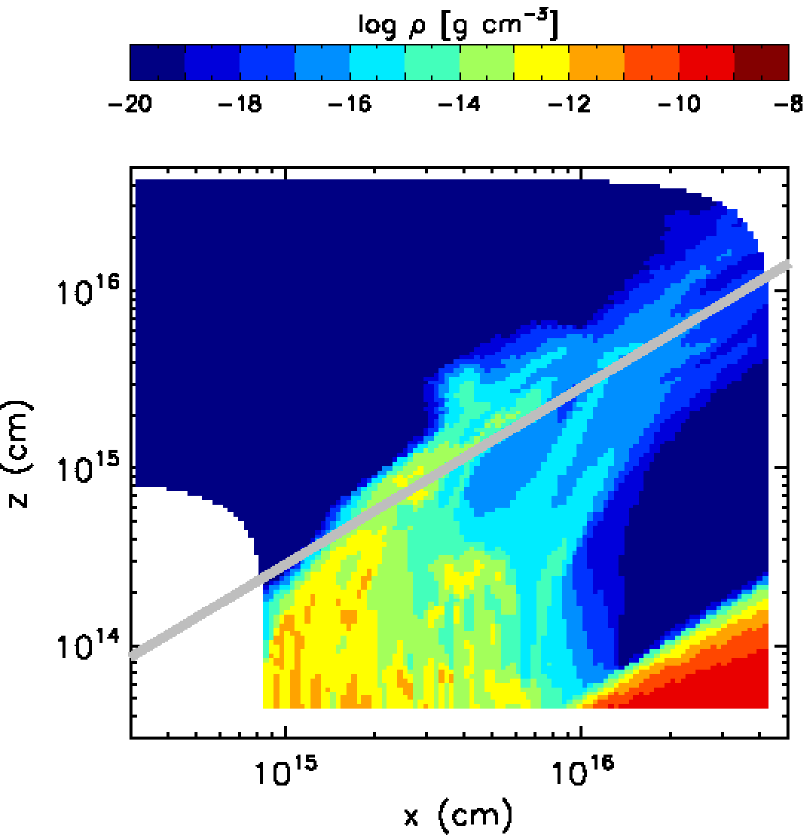
- Weaker continuum + Reflection
- Broad Fe Ka + weak Comp. Hump
- Narrow absorption lines

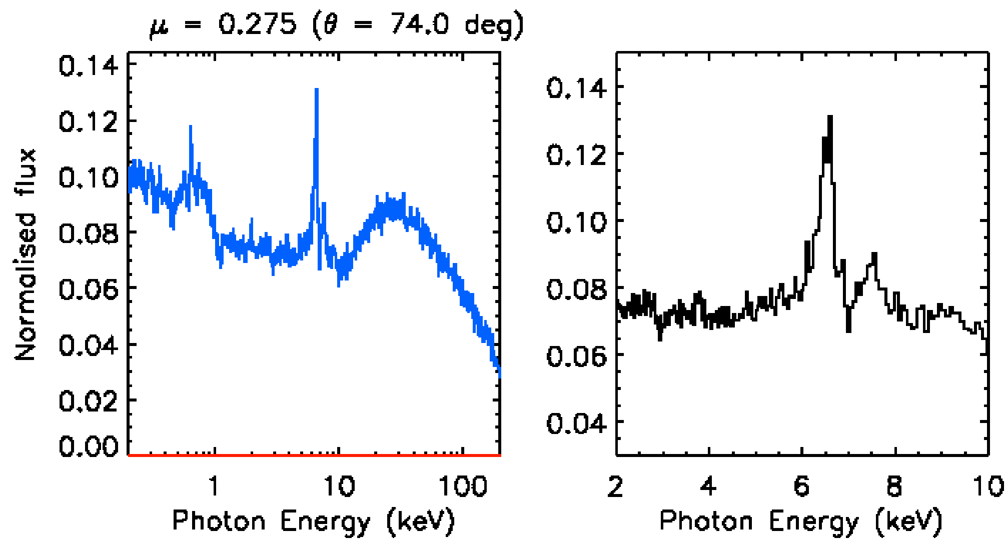
Parametrized models



Sim et al. 2008

Proga 2004 line-driven wind

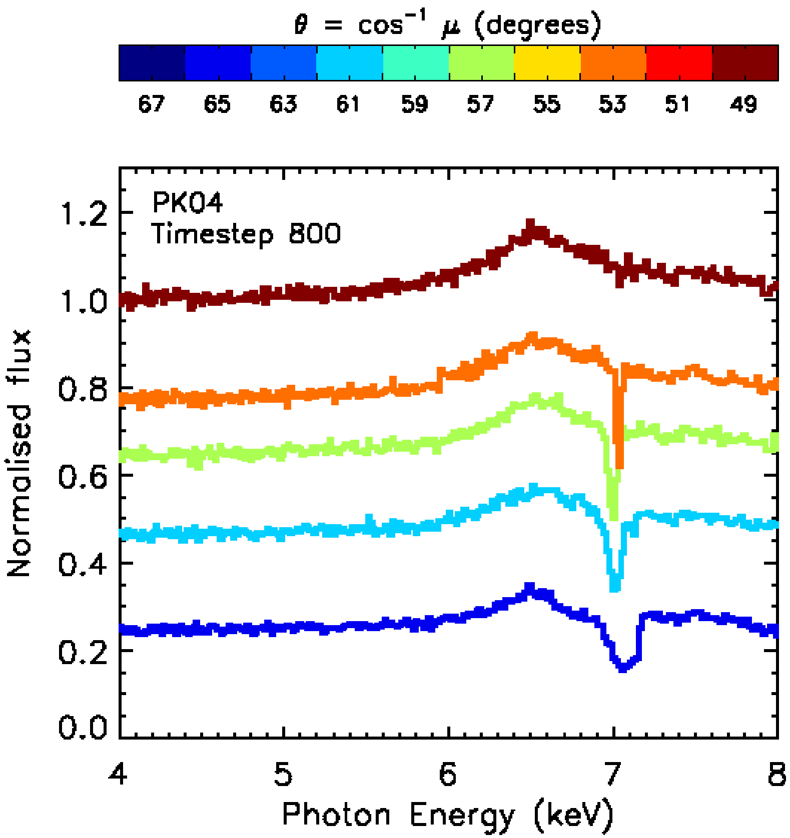




High orientation observer:

- Scattered/reprocessed spectrum
- Complex features
- No narrow absorption

On the occurrence of "UFOs"



Simulations **do** contain some **UFO-like** features:

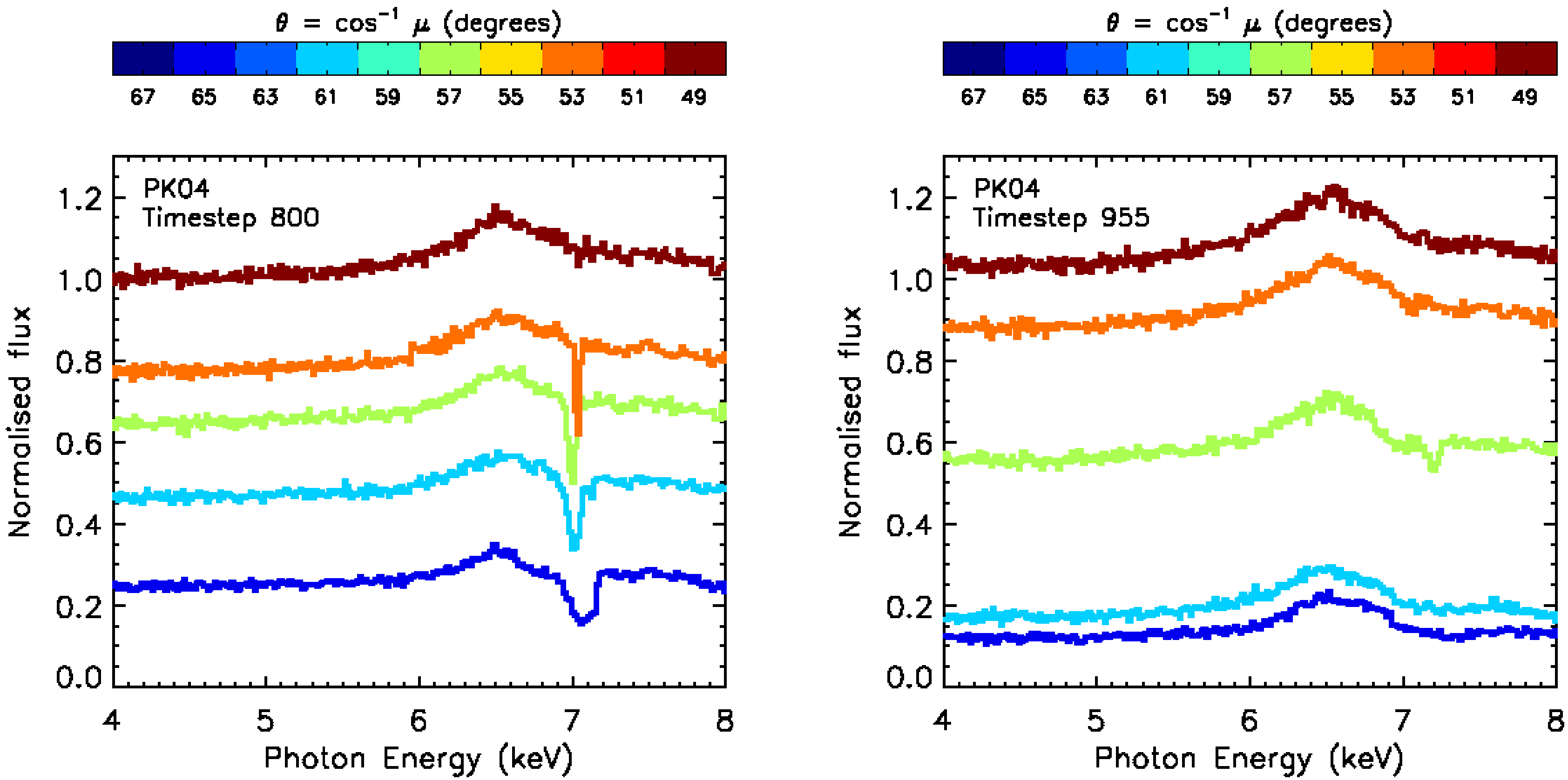
V < **0.06 c**

EW < **70 eV**

Fe XXVI/XXV K a present for small range of inclinations (**3 – 15 %** is isotropic)

Time variable

On the occurrence of “UFOs”



Significant absorption line variability: ~5 year time scale

Proga 2004 line-driven wind RT

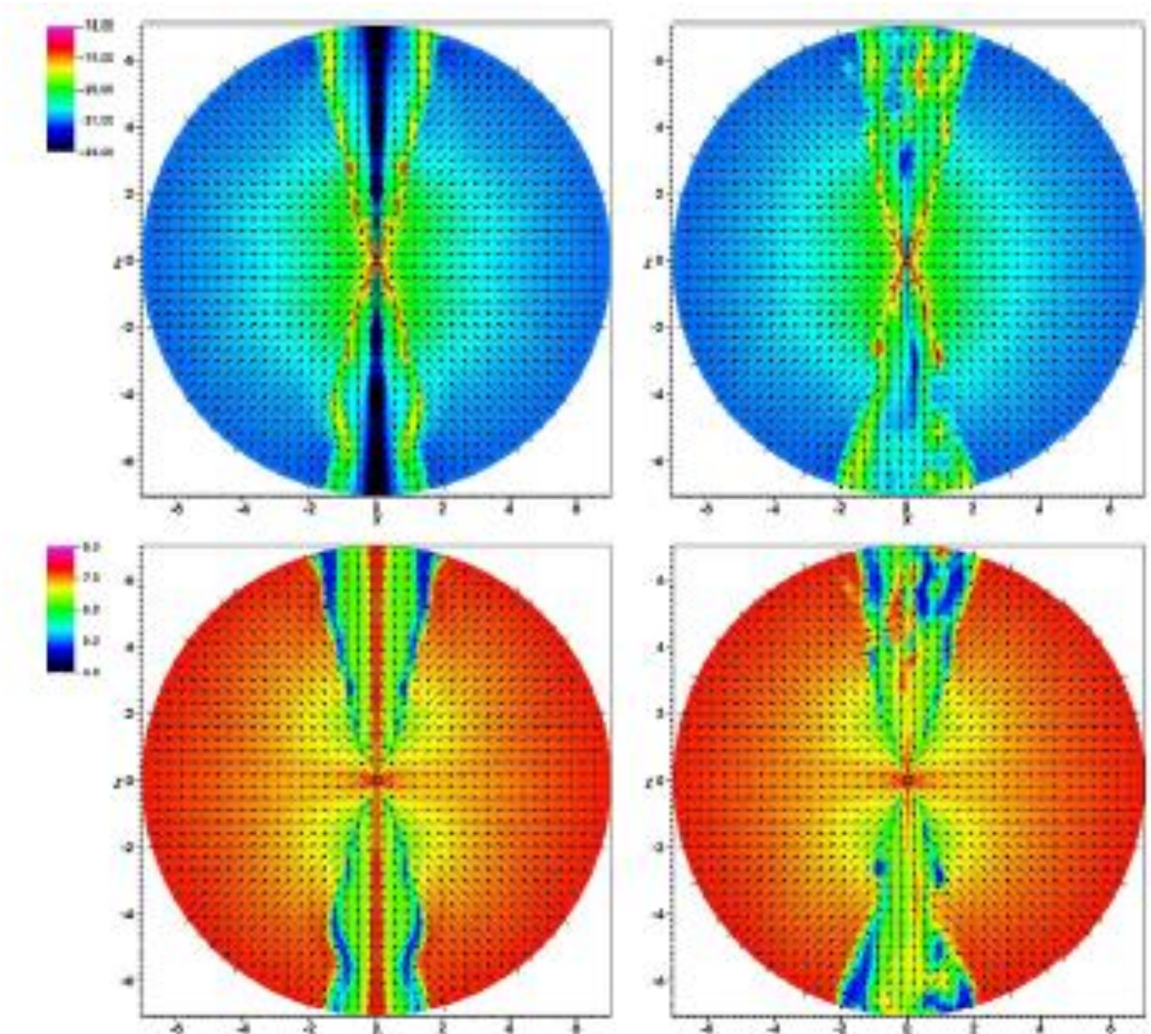
Summary (Sim et al. 2010):

- Fe Kα emission for all orientations
  - Significant EW (~150 eV up to ~400 eV)
  - Broad (FWHM > 700 eV; cf. MCG 5-23-115, Braito et al. ‘07)
  - Red-skewed wings (cf. Auer ‘72, Titarchuck et al. ‘03)
- Narrow Ka absorption lines
  - Up to EW ~70 eV and v ~0.06 c
  - Significant variability: ~5 year time scale
  - Present for ~ 5 – 12 deg range (3 – 15 %, isotropic)
- Compton hump/soft emission lines
- Scattered/reprocessed light critical – multi-D necessary!

Note:

- No tuning (also no improvement to model)
- Still 2D – no realistic clumping

Kurosawa & Proga 2009: wind blown from accretion flow



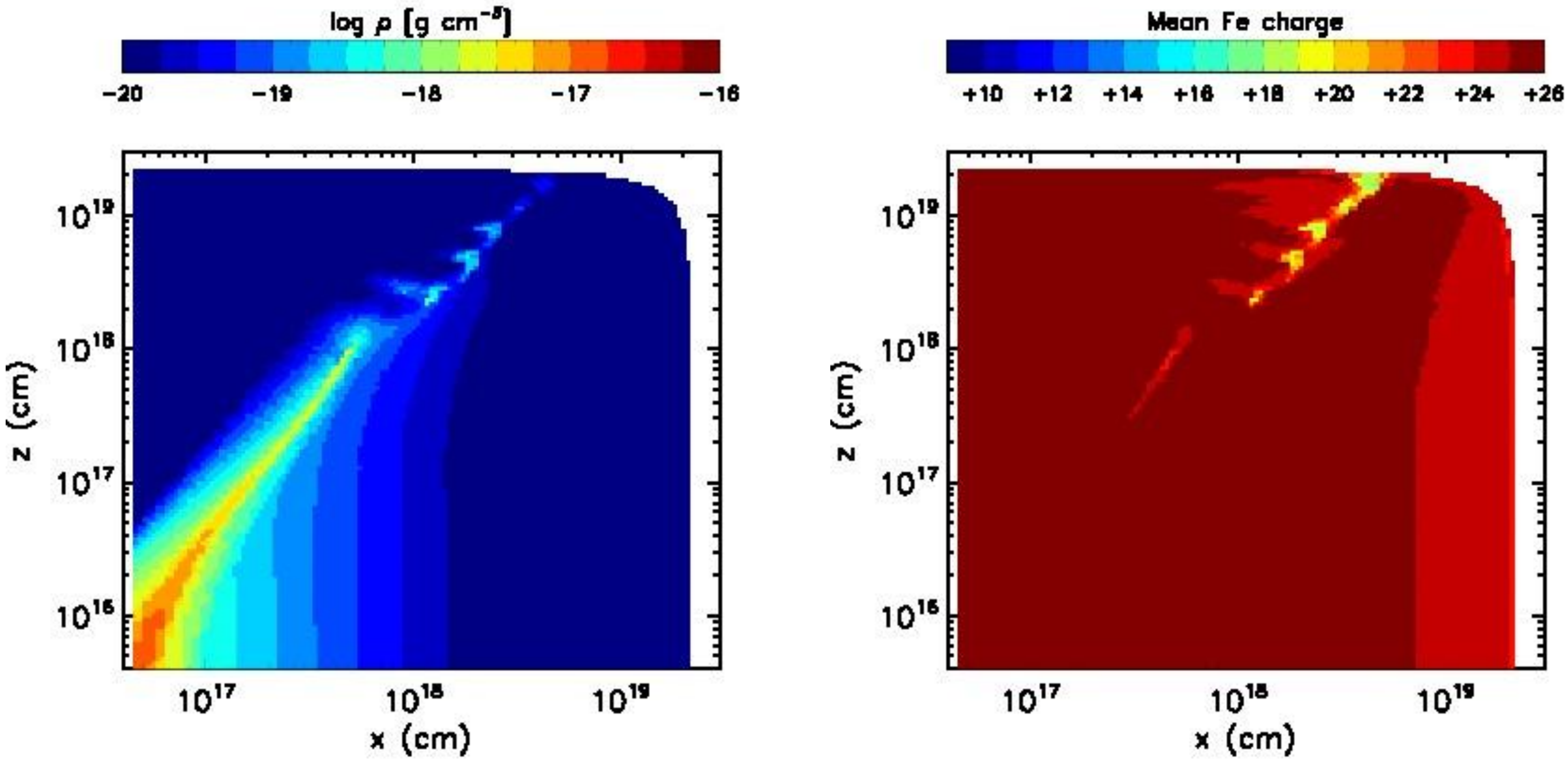
Outflow driven by irradiaton of accretion flow at large radii

Compared to disk wind

1. **Larger length scales**
2. **Lower columns**
3. **Lower densities**
4. **Lower velocities**

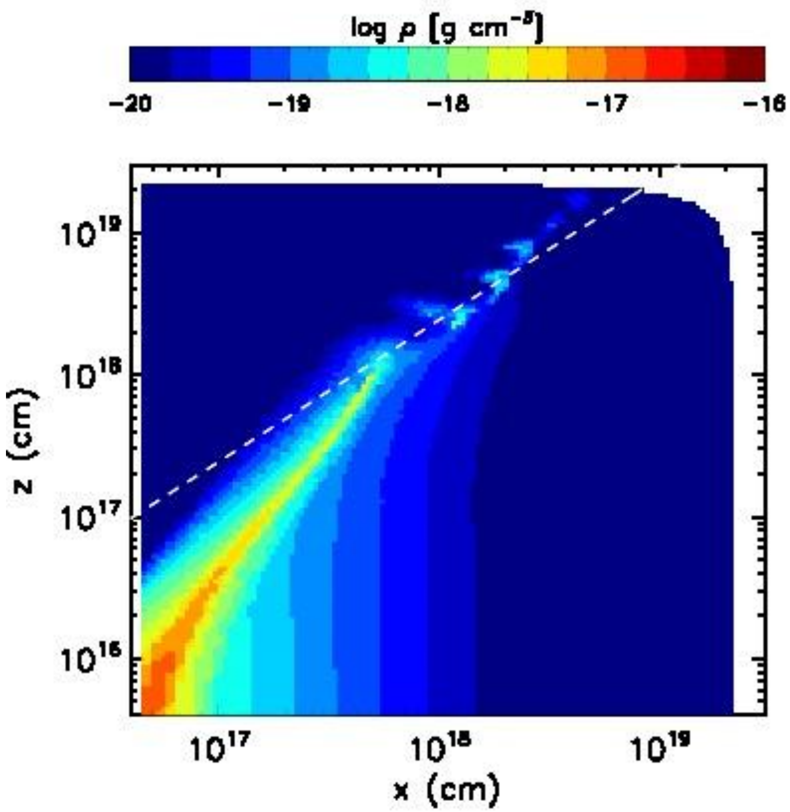
...but still observable

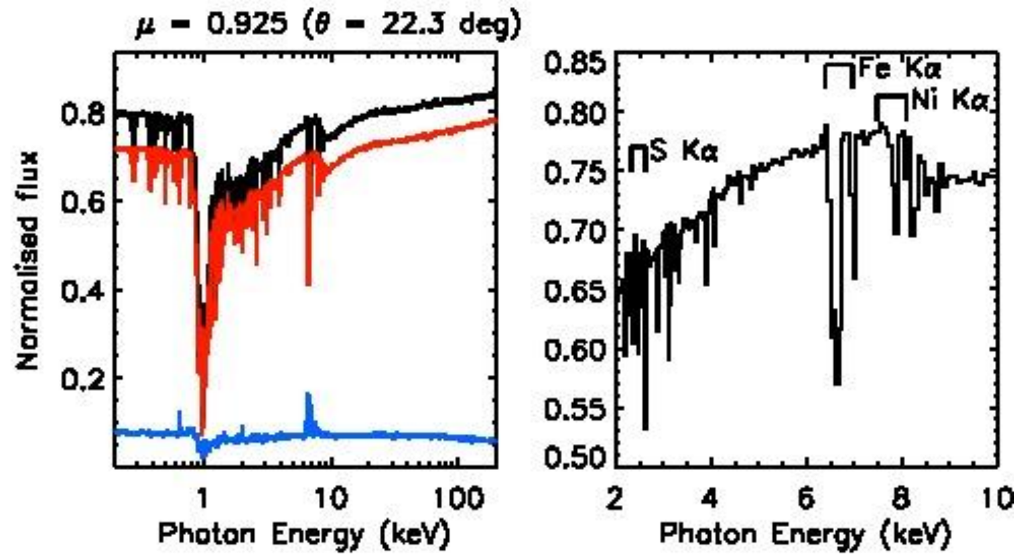
Kurosawa & Proga 2009: wind blown from accretion flow



Almost all is fully ionized, except for **dense knots/clouds in outflowing gas**

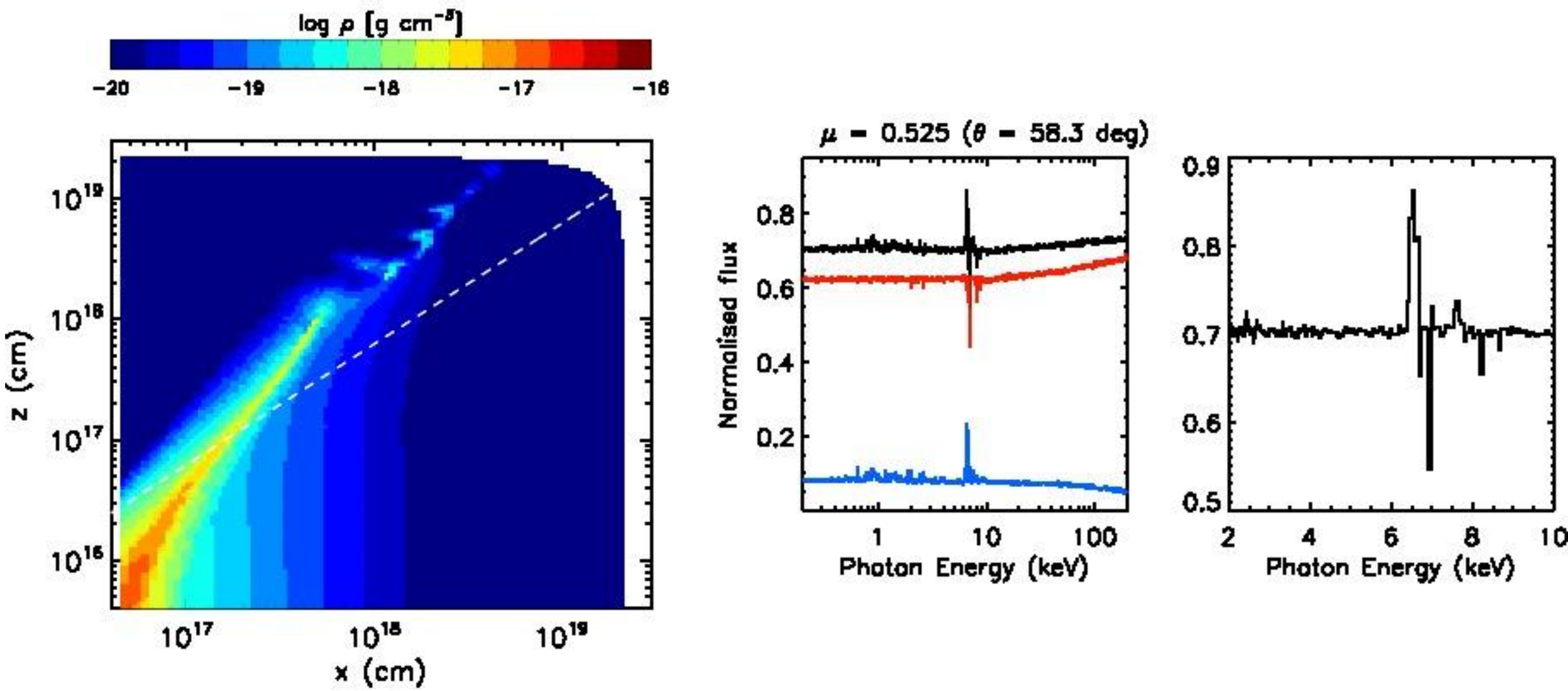
Kurosawa & Proga 2009: wind blown from accretion flow





Through the clouds get significant column of high ionization gas.
Absorption produced, narrow and low-velocity

Kurosawa & Proga 2009: wind blown from accretion flow

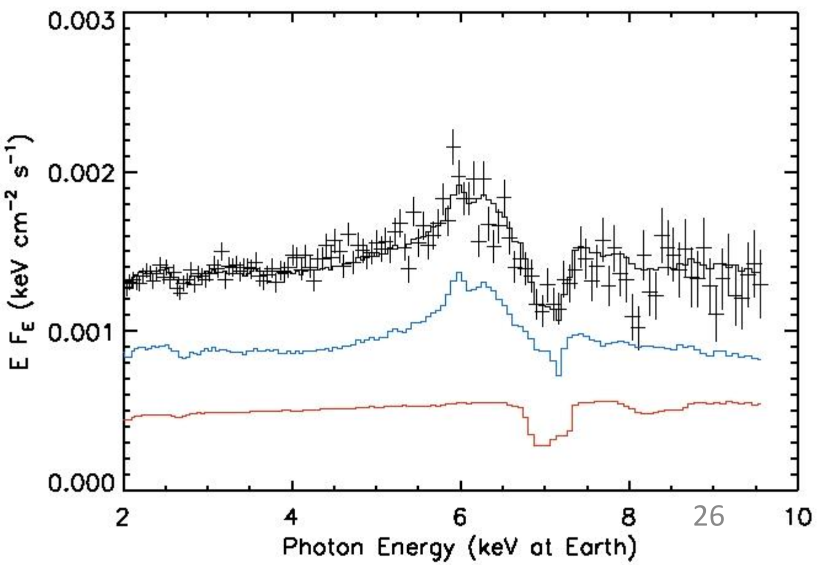


Other orientations have little absorption (very weak Fe XXVI Kα)

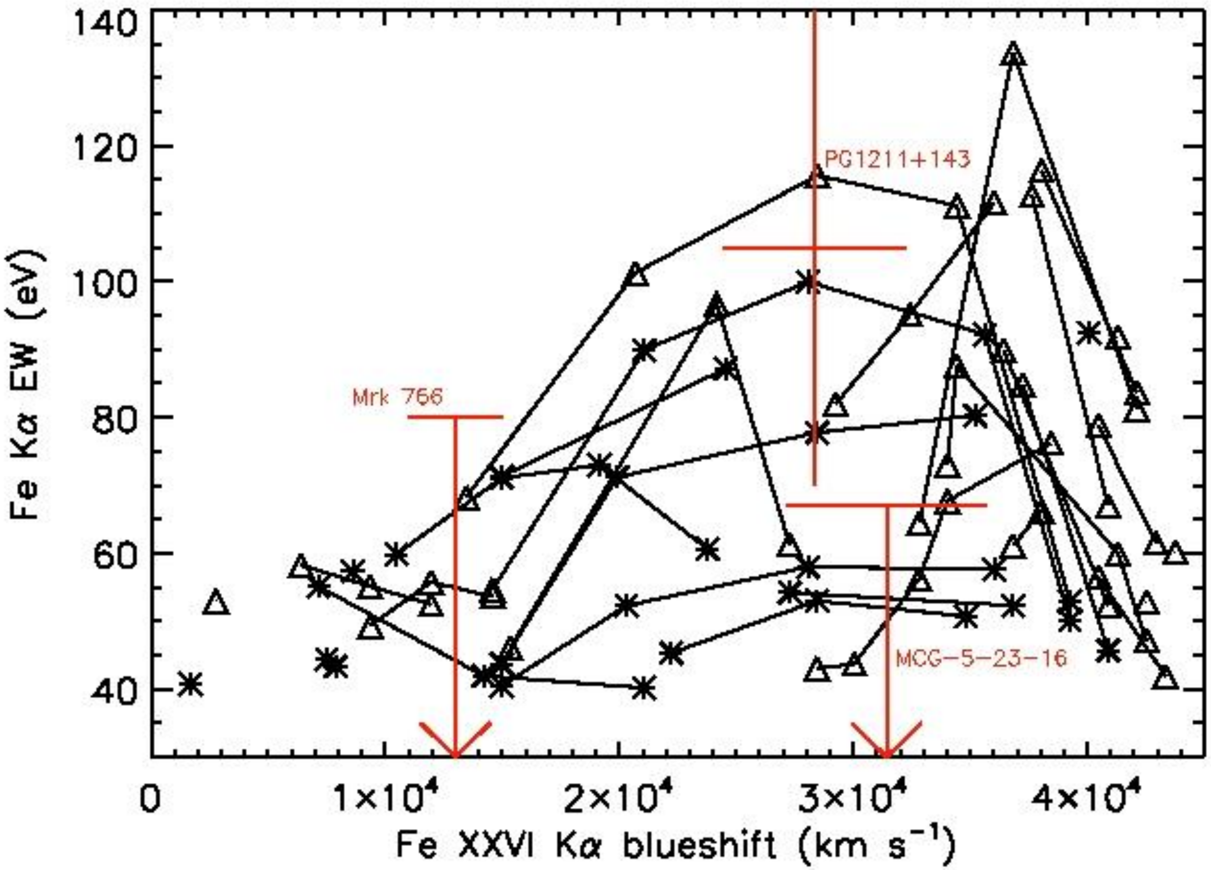
But Fe Kα emission produced, narrow and low-velocity

Summary

- **Need multi-D radiative transfer:**
  - AGN outflows are not expected to be spherical but may be Compton thick for some lines of sight
  - Need to model scattering/reprocessing to compute ionization state and synthetic spectra
- **Theoretical models predict observable signatures**
  - Disk winds: Blue-shifted absorption (the smoking gun); but beware projection/geometry
  - Disk winds: Broad emission (perhaps with red-skewed wings...electron scattering)
  - Large scale outflow: narrow emission; significant low-v absorption through clouds
- **Lots to do:**
  - Many missing elements of simulations: scattering in line-driven model, field geometry (MHD)
  - 3D structure, clumps etc.
  - Timing constraints
  - *Synthetic UV spectra*



Grids of models: blue-shifted Fe K absorption line



Models showed wide range of EWs and blueshifts

Pounds et al. 2003
Turner et al. 2007
Braito et al. 2007