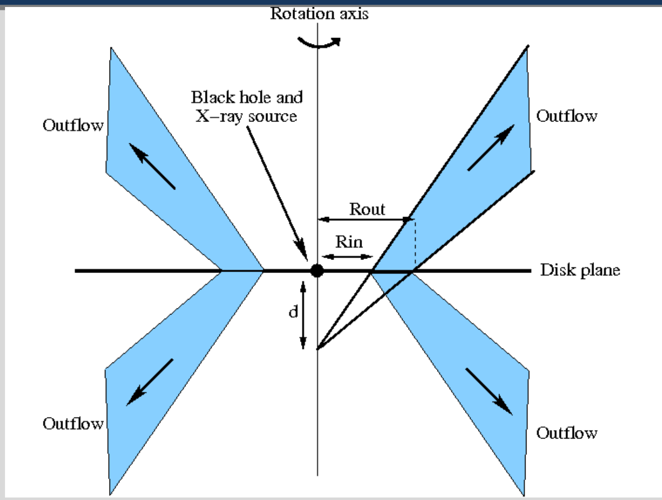
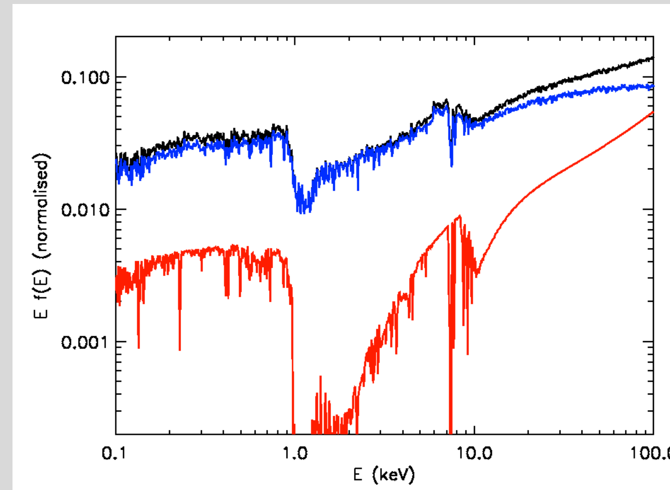
Signatures of AGN Accretion Disk Winds in X-ray spectra



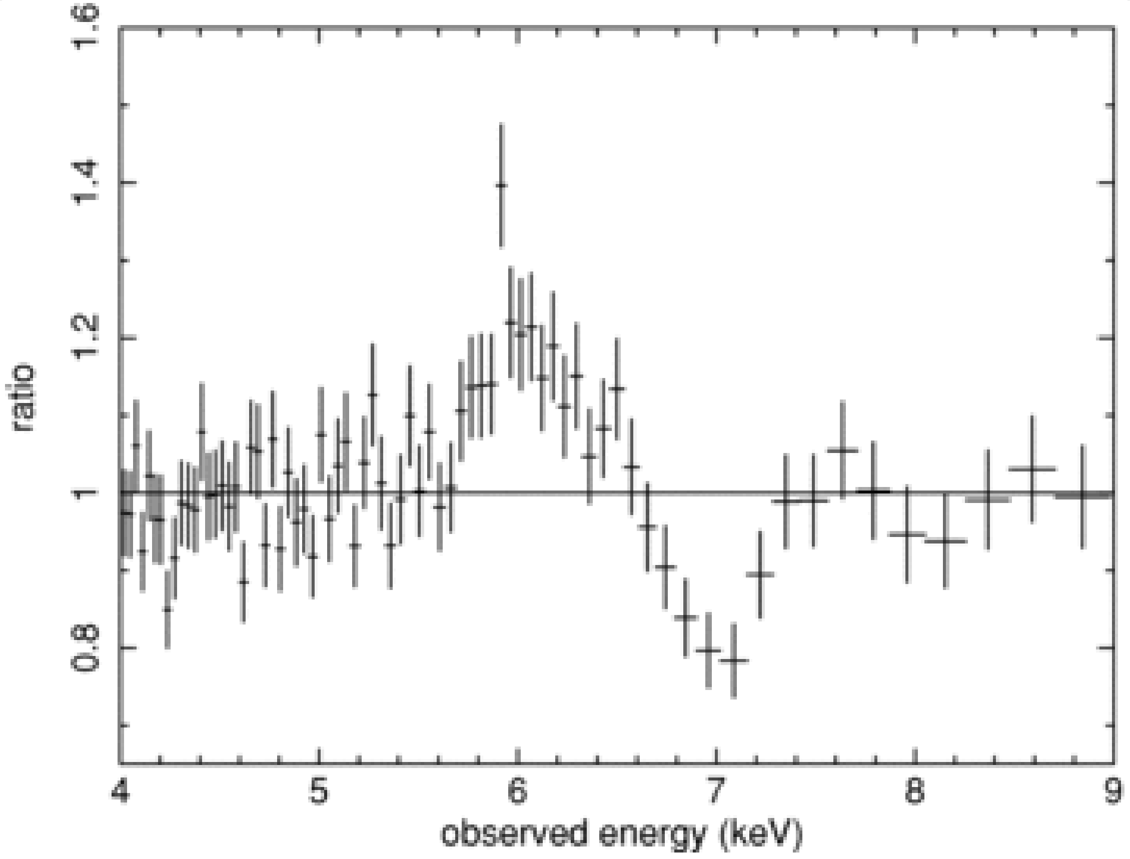


Stuart Sim

Lance Miller (Oxford), Daniel Proga (Las Vegas) Knox Long (STScI), Jane Turner (Maryland), James Reeves (Keele)

Max Planck Institute for Astrophysics

Observational motivation



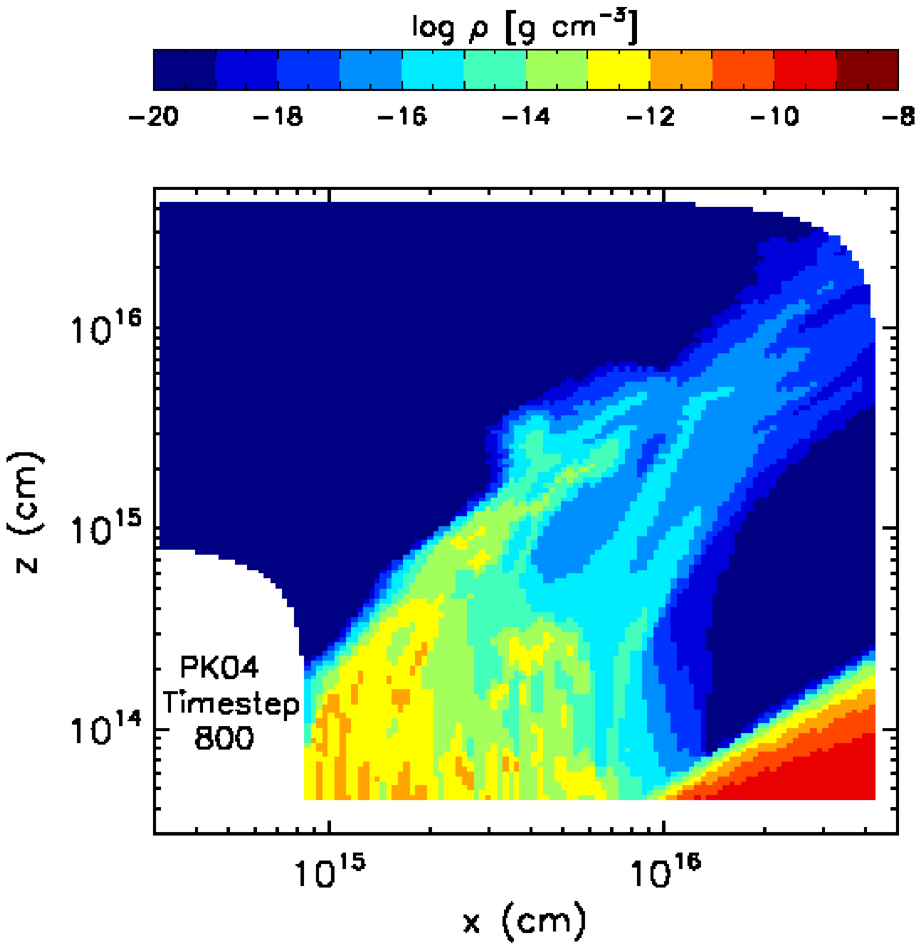
Blue shifted absorption features

Suggested origin in a disk wind

PG1211+143 (Pounds & Reeves 2009)

See also Tombesi et al. (2010)

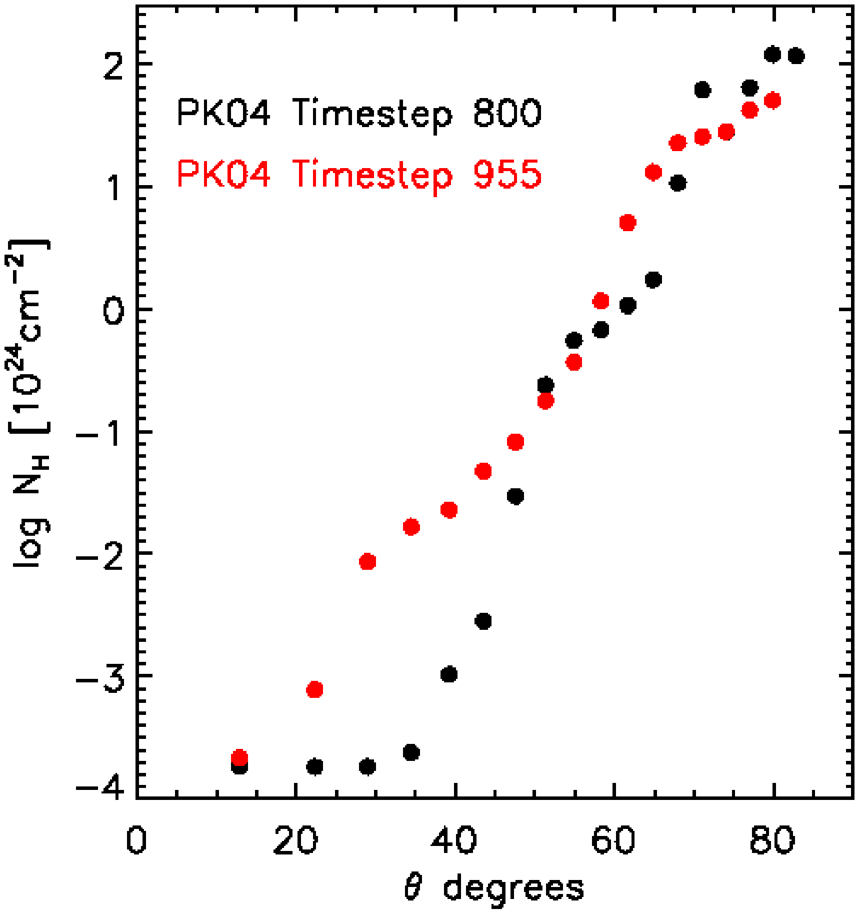
Theoretical motivation



- Mass loss expected for luminous disk
- Complex flow structure
- Time variable

Line driven wind
(Proga & Kallman 2004)

Theoretical motivation



- Mass loss expected for luminous disk
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Line driven wind

(Proga & Kallman 2004)

Questions:

- Does the disk wind geometry work for blue-shifted absorption lines?
  - Is profile shape/strength compatible?
  - How common should they be?
- What about cases without X-ray absorption lines?
  - What else should the wind do?
  - How might the wind complicate other diagnostics?

Want to be able to compute synthetic spectra for realistic disk wind geometries…. Requires multi-D rad. Trans.

Method: the code

- **Monte Carlo method (Lucy 2002, 2003)**
  - \+ Good for complex geometry/Compton scattering
  - \+ Parallelizable
  - – MC noise
- **Solves for ionization balance**
  - \+ Use MC estimators on computational grid
  - \+ Coupled to approximate thermal balance
  - – Very simple treatment of excitation
- **Obtain l.o.s. spectra**
  - \+ Both transmitted and scattered/reprocessed
  - \- Sobolev approximation for lines

Method: atomic processes

- **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)

Approach: two attack routes

1. **Forward modelling**
   - \+ Apply to theoretical models/hydro simulations
   - \+ Predictive power
   - \- Imperfect matches (few "fitable" parameters)

2. **Parameterised, semi-empirical model grids**
   - \+ Flexible geometric prescription
   - \+ Allows for quantitative comparison
   - \- Parameter degeneracy

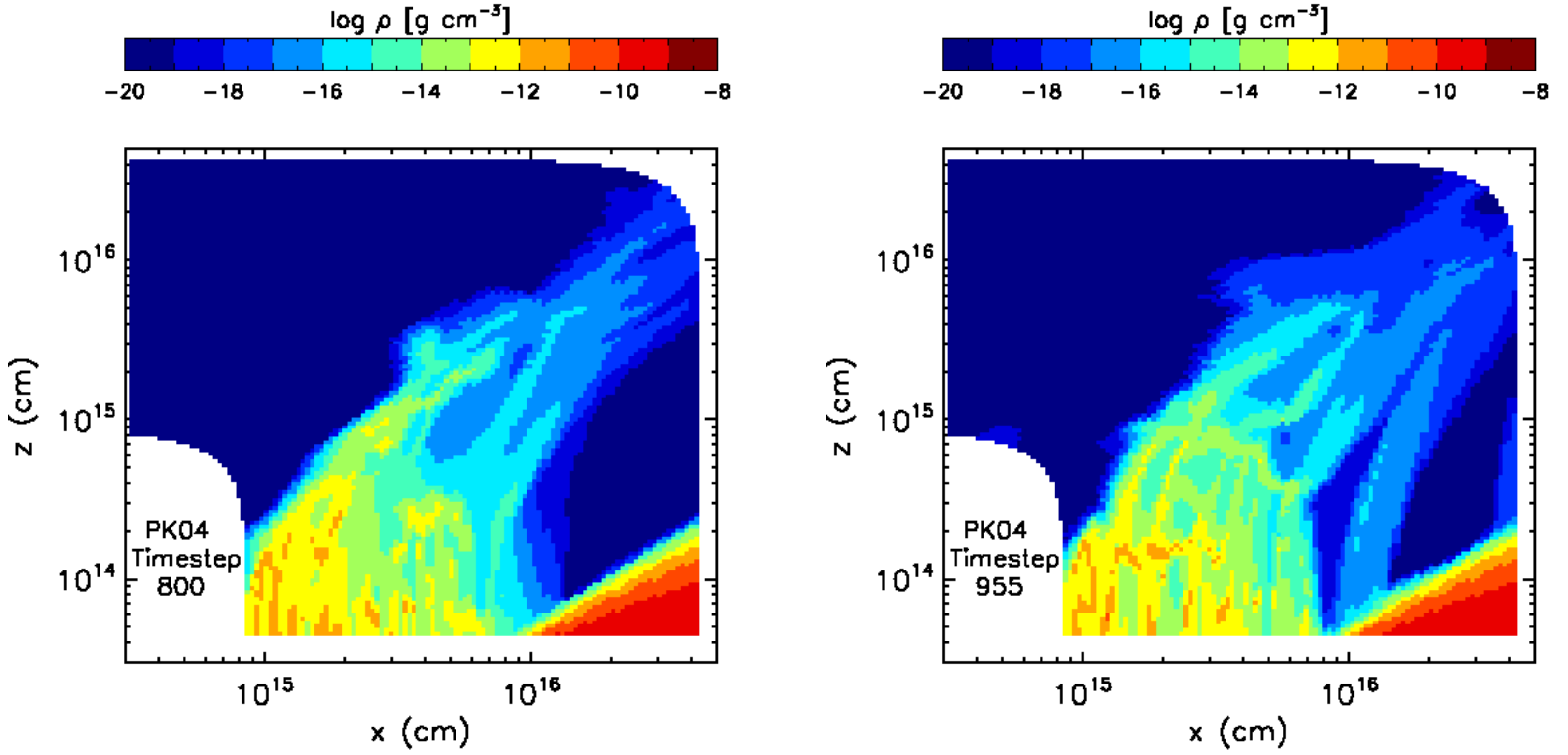
1) Forward modelling

(Sim, Proga et al. 2010)

Line driven wind

Consider two snapshots from Proga & Kallman (2004)

Separated in time by ~5 years



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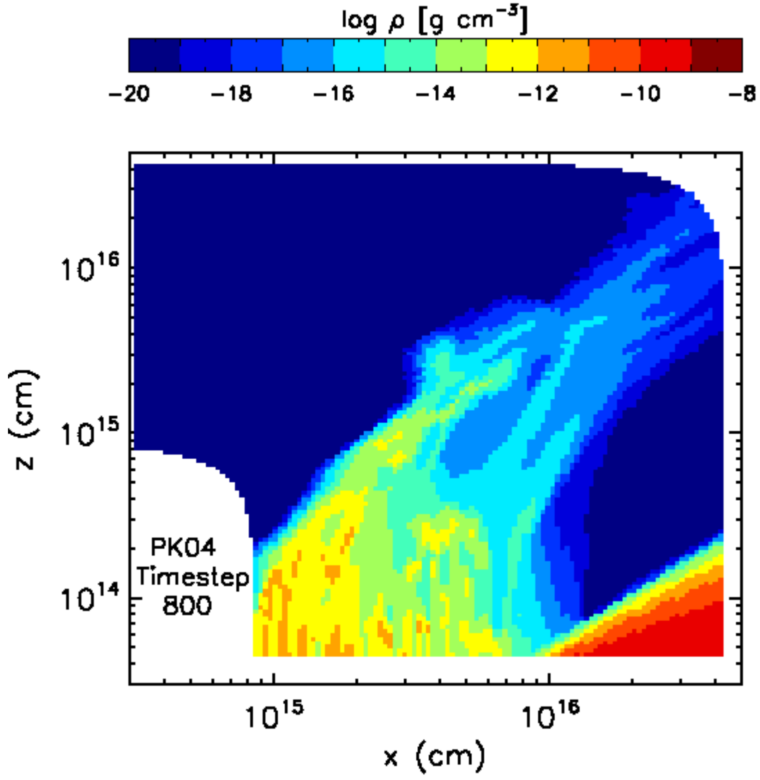

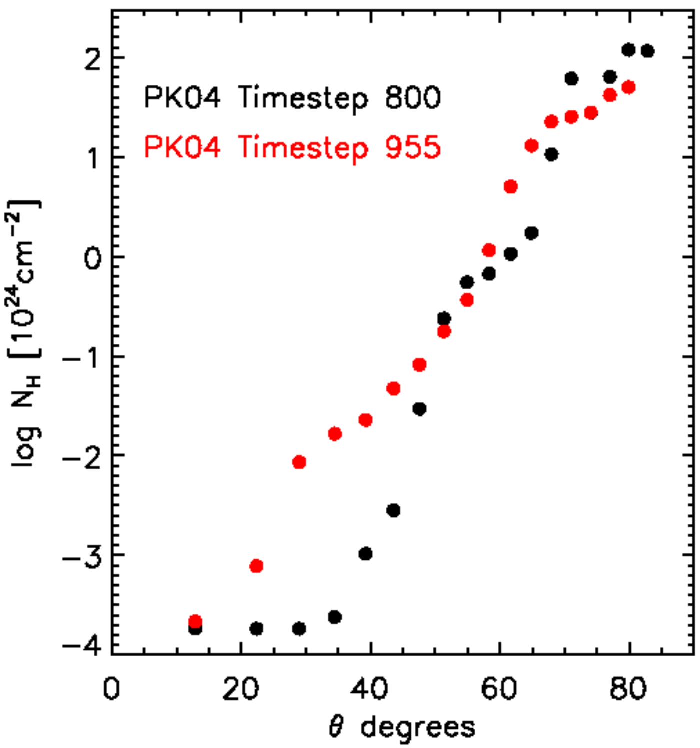

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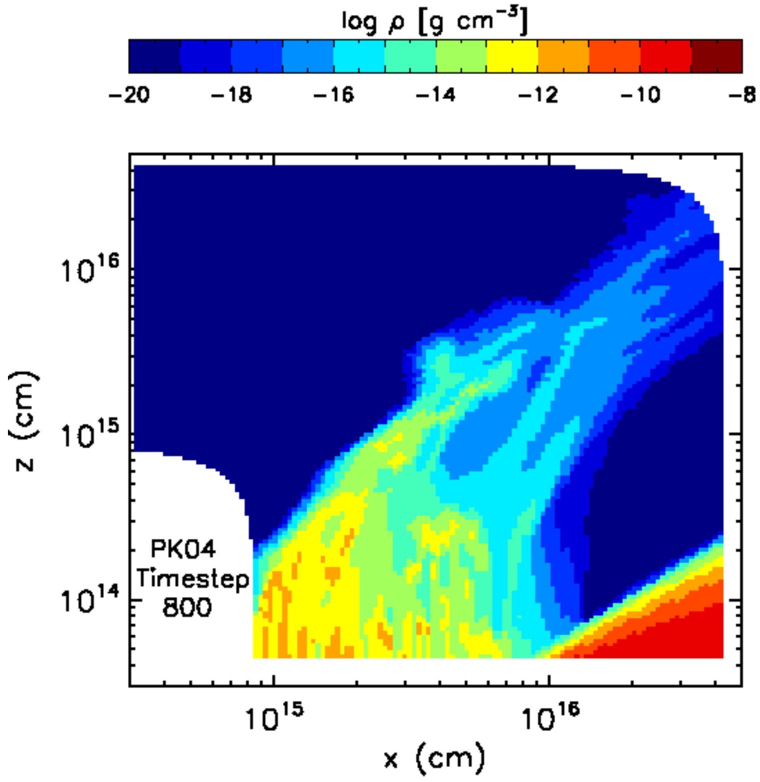
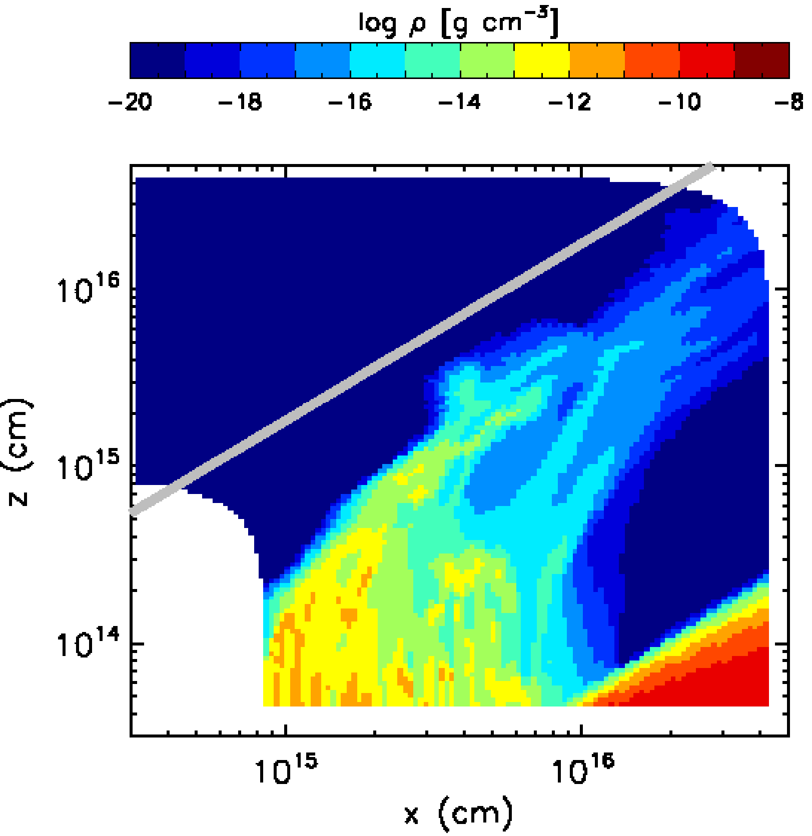
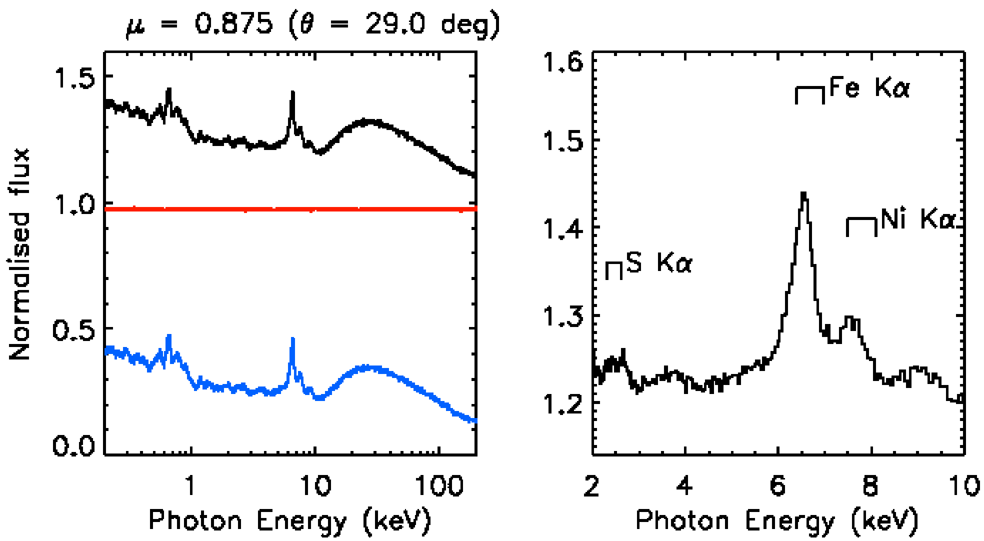


Compute synthetic spectra:

- **Central power-law X-ray source**
- **Both snapshots**
- **Multiple orientations**
- **Broadly, 3 classes of spectra**

Line driven wind: the spectra

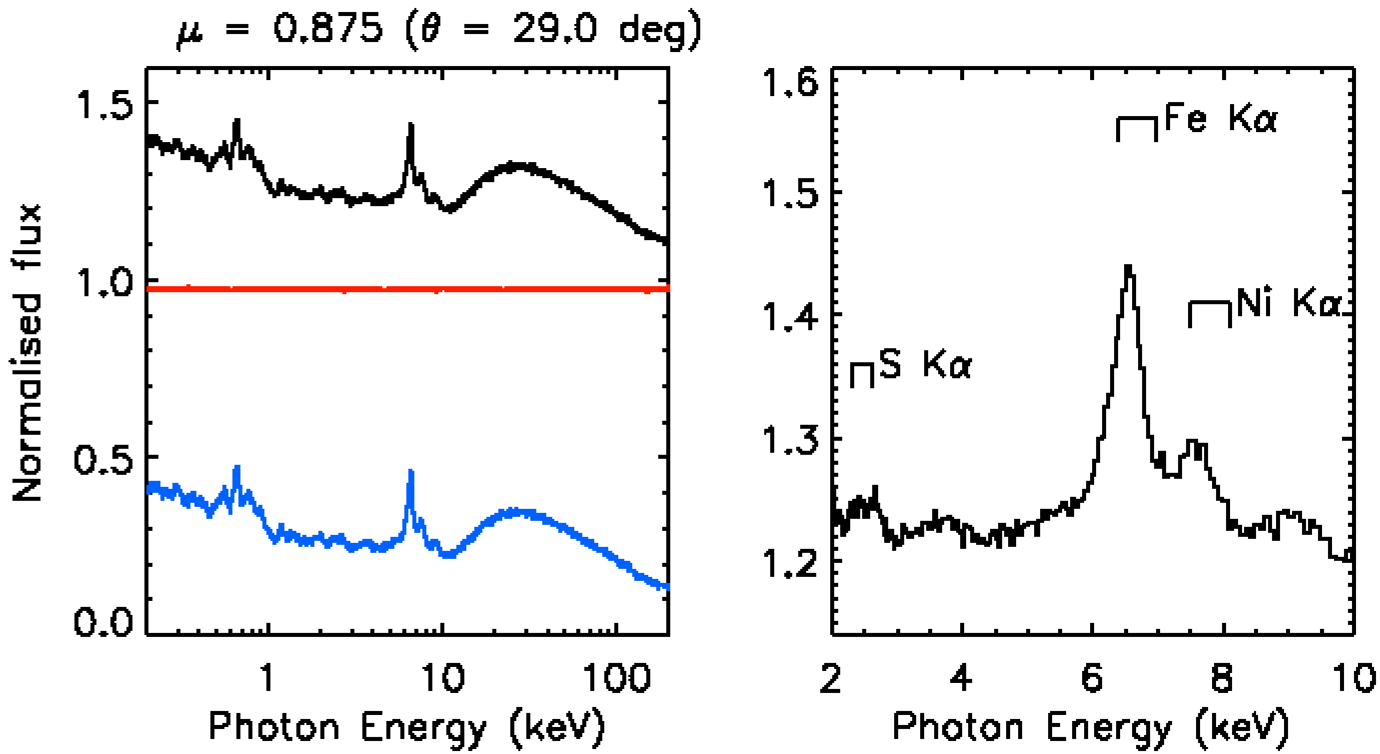




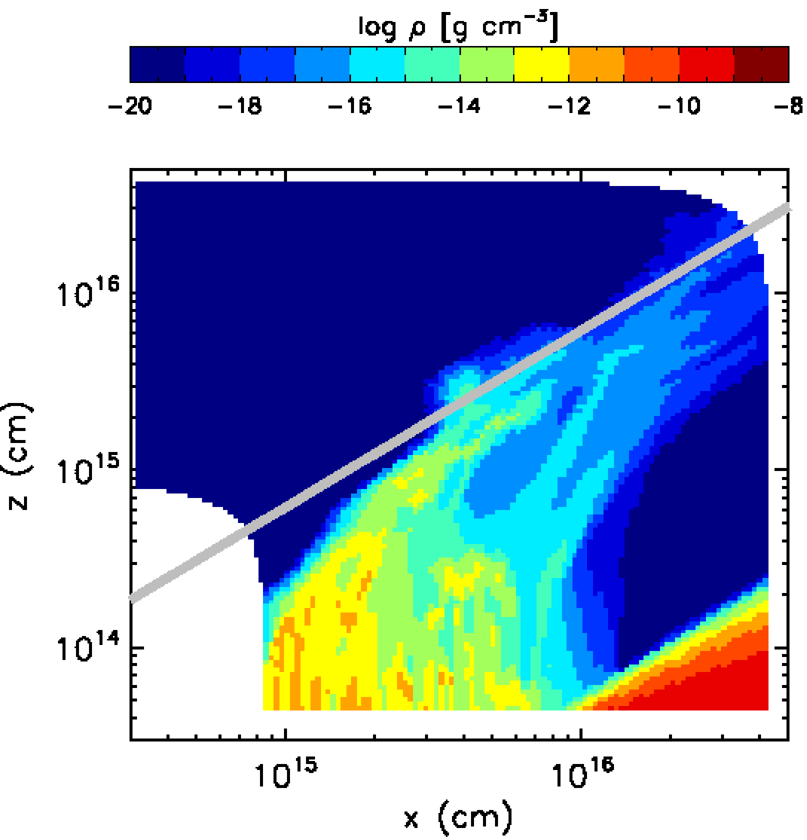
Polar observer:

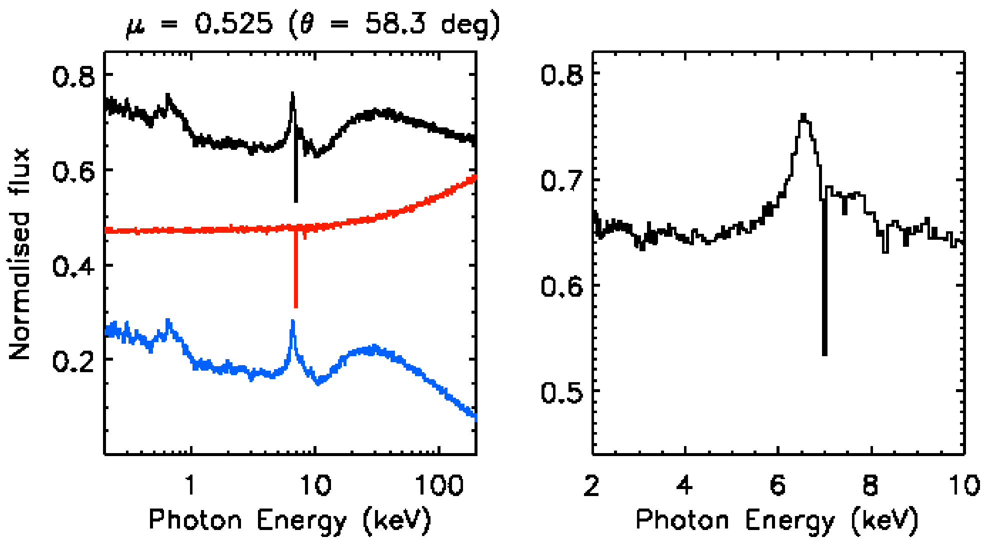
- Direct continuum + **Reflection**
- **Broad Fe Ka** + weak Comp. hump

Line driven wind: the spectra



Line driven wind: the spectra

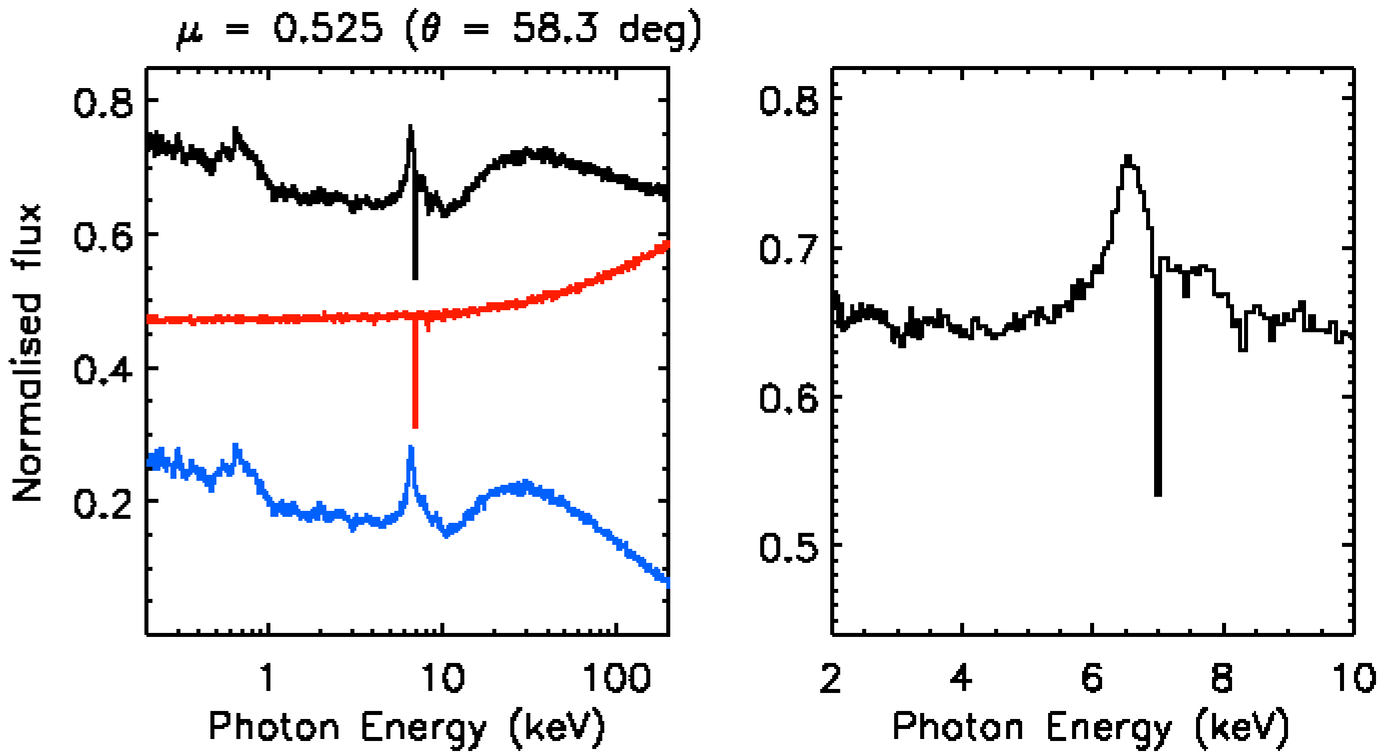




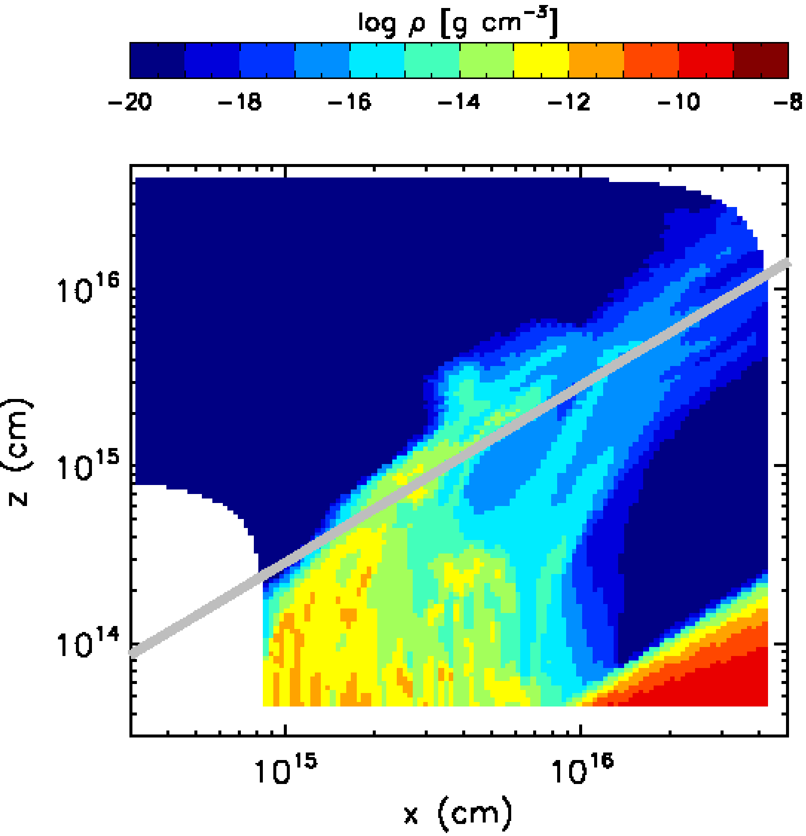
Intermediate orientation observer:

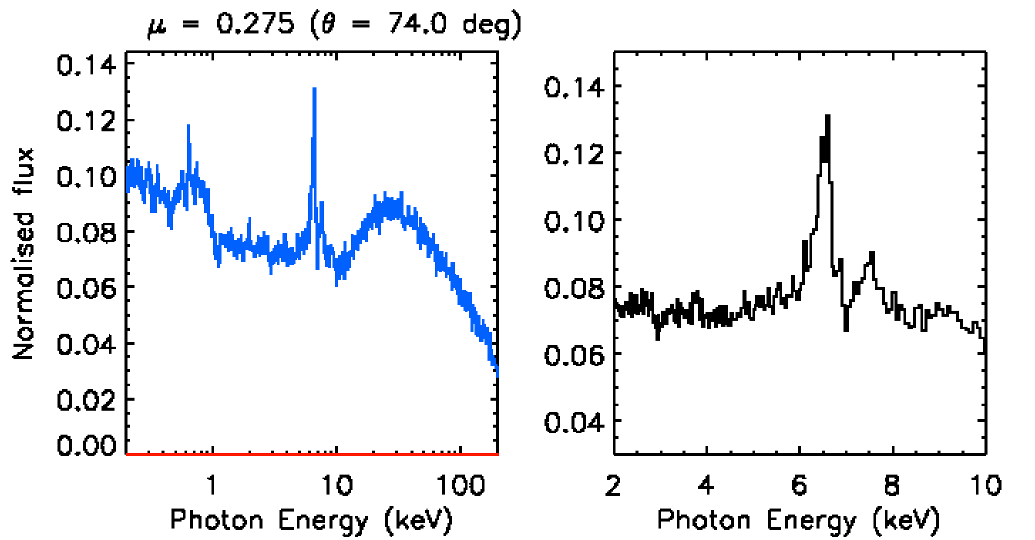
- Weaker continuum + Reflection
- Broad Fe Ka + weak Comp. Hump
- Narrow absorption lines

Line driven wind: the spectra



Line driven wind: the spectra

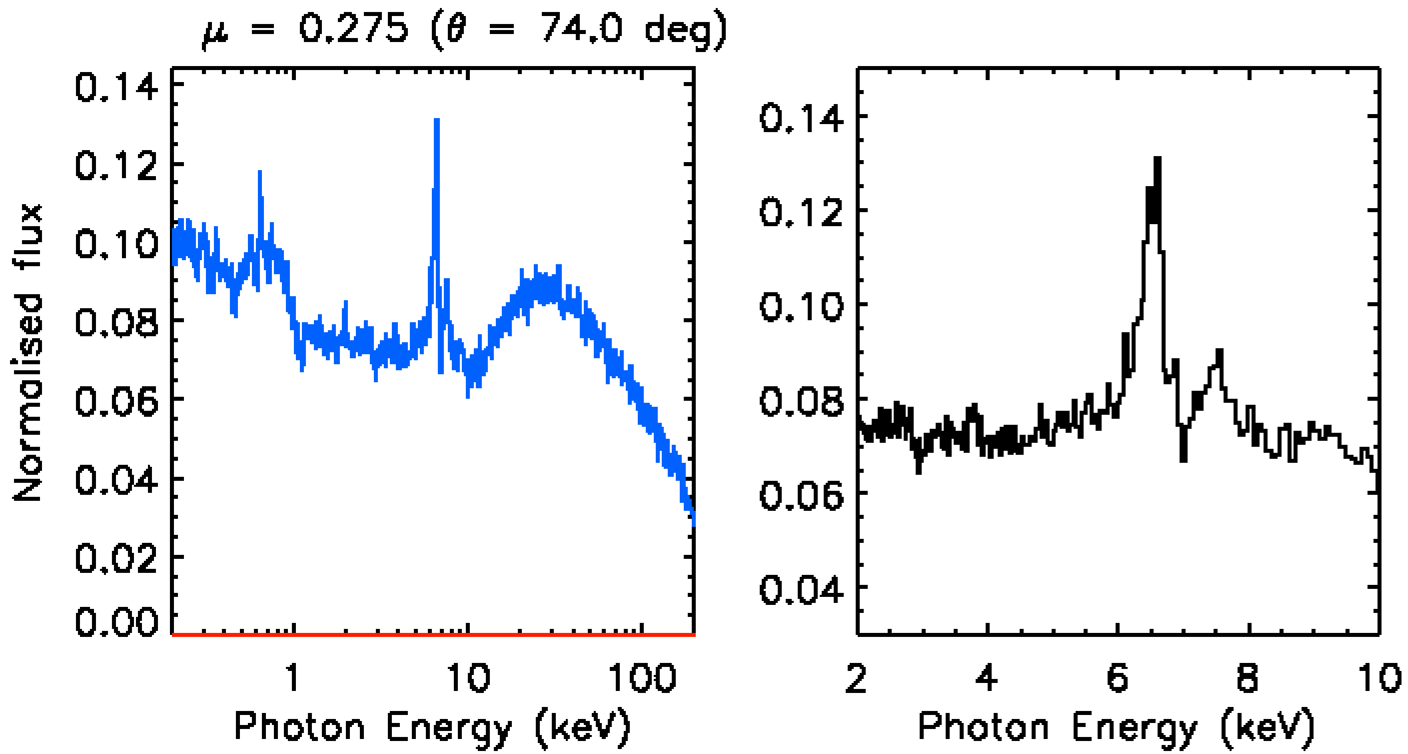




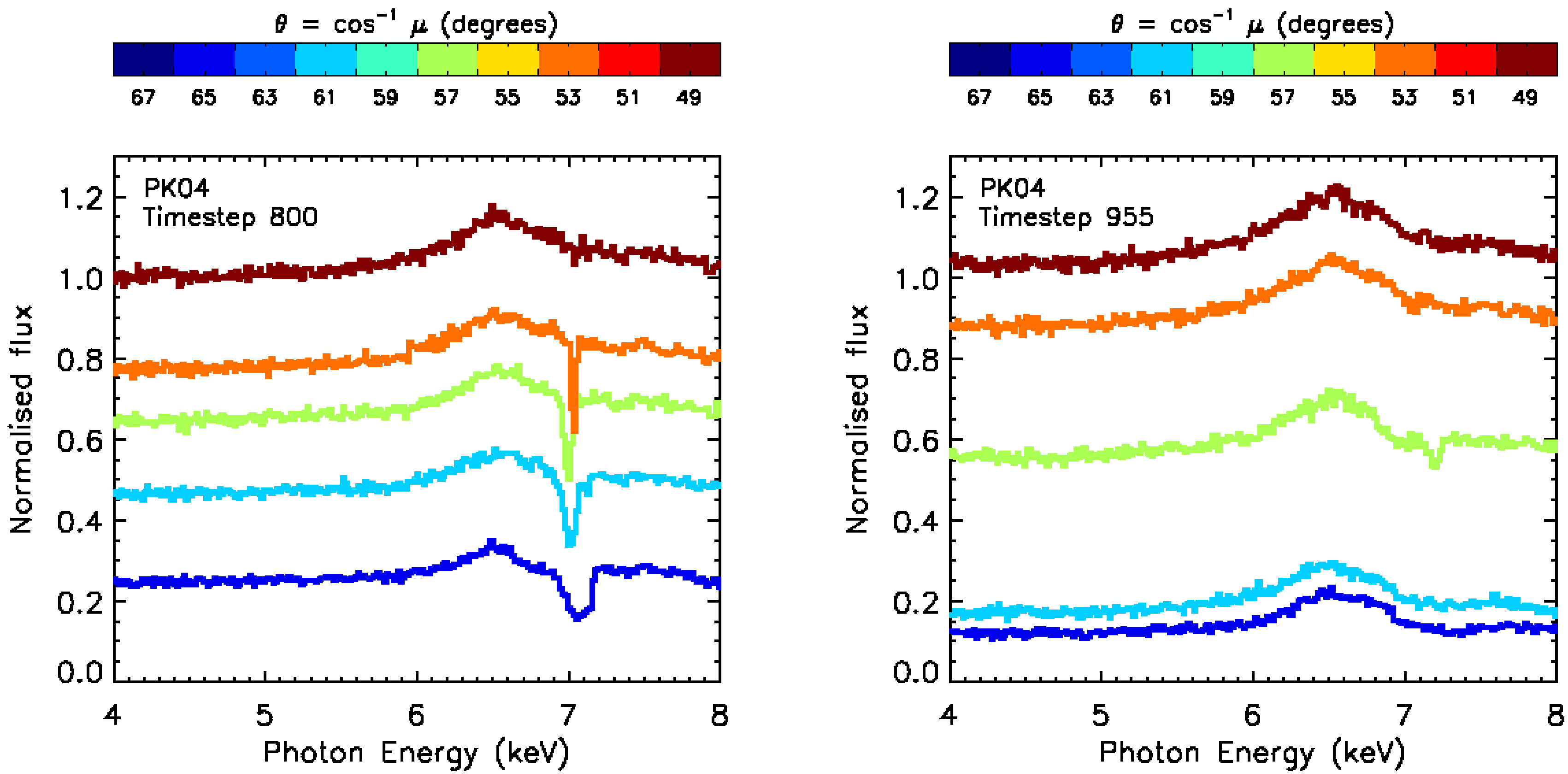
High orientation observer:

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

Line driven wind: the spectra



Line driven wind: time variability



Significant absorption line variability: ~5 year time scale

Line driven wind: some numbers

Summary (Sim et al. 2010):

- Fe Ka 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

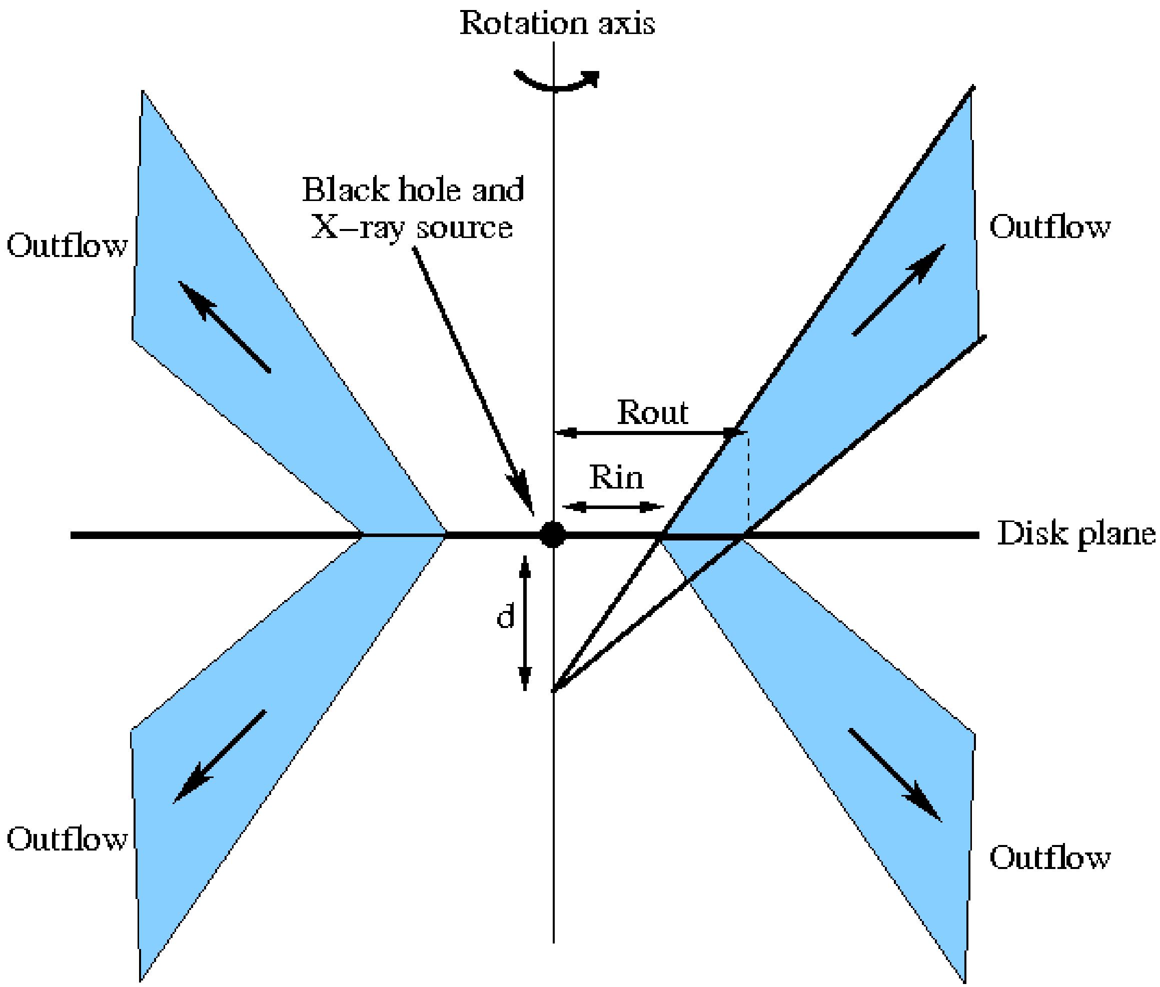
2) Parameterised modelling

(Sim, Long, Miller et al. 2008, 2010)

Parameterised model

- Perform radiative transfer simulations for model with fit parameters
  - Realistic disk wind scenario requires non-spherical geometry
  - Centrally concentrated power-law X-ray source
  - Include velocity law (outflow + rotation)
  - Smooth, stationary flow (described by $\dot{M}_{wind}$)

Adopted geometry



Standard KWD disk wind (Knigge et al. 95)

Defined by 3 parameters:

- ❑ r_{in}
- ❑ r_{out}
- ❑ d

...spectrum depends on

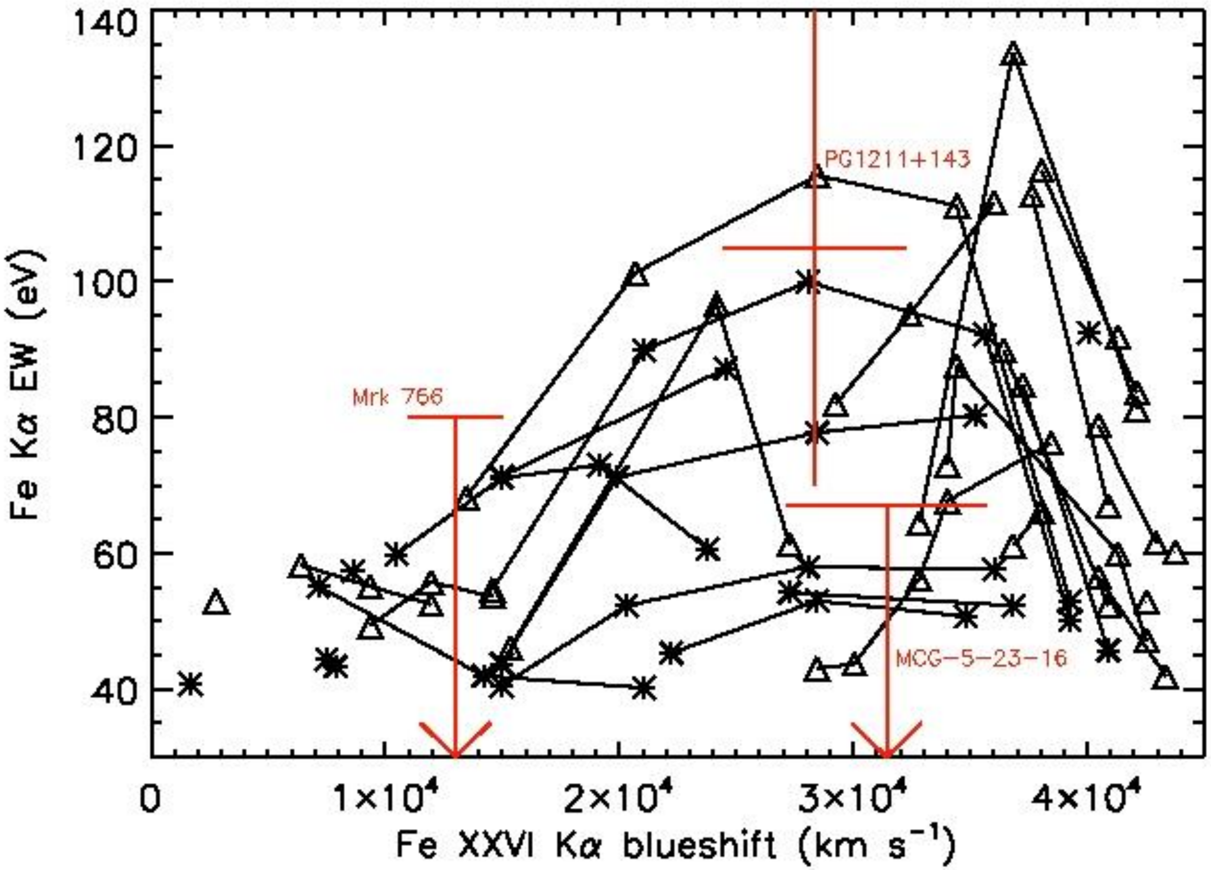
- ❑ $\mu = \cos^{-1} \theta$

1st Grid of models

- Focused on Fe K region (Sim et al. 2008)
  - Primarily concerned with narrow absorption lines
  - How are they determined by wind parameters?

- Preliminary grid of models
  - Explored mass-loss rate and geometry params
  - High ionization states only
  - 45 models in total

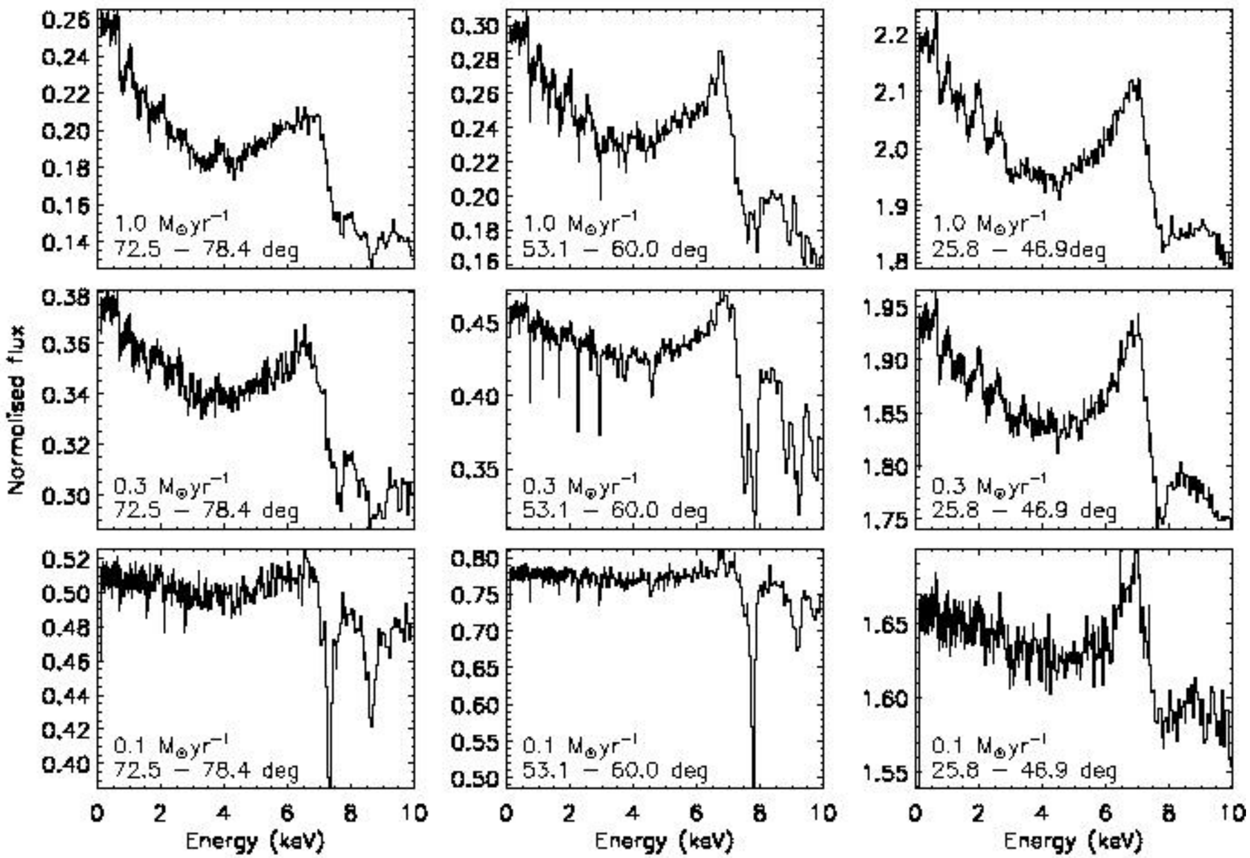
1st Grid of models



Models showed wide range of EWs and blueshifts

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

Grid of models



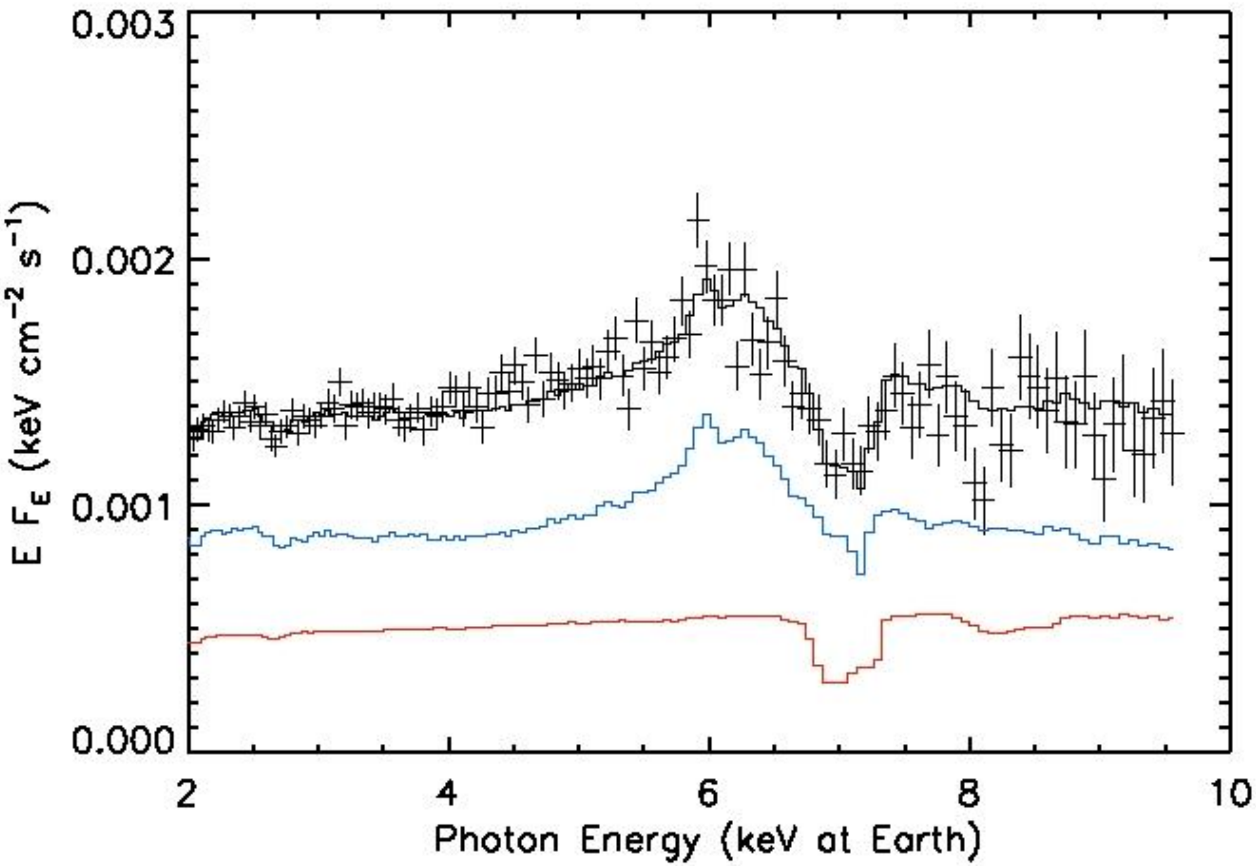
Also show a wide range of emission line shapes:

- **P Cygni profiles**
- **extended red wings**

Back to PG1211+143

- Attempt quantitative fits to Fe K region
  - Choose PG1211+143 for pilot study
  - Work with complete stacked data from multiple epochs (Pounds et al. 2009)
- Improved code version (Sim et al. 2010)
  - Less ionized material, self-consistent T_e
- Generated small grid of models
  - Fit model parameters to data with Xspec

Back to PG1211+143



Sim et al. 2010

Imperfect but good fit:

- ❑ P Cygni profile
- ❑ red wing
- ❑ weak S XVI

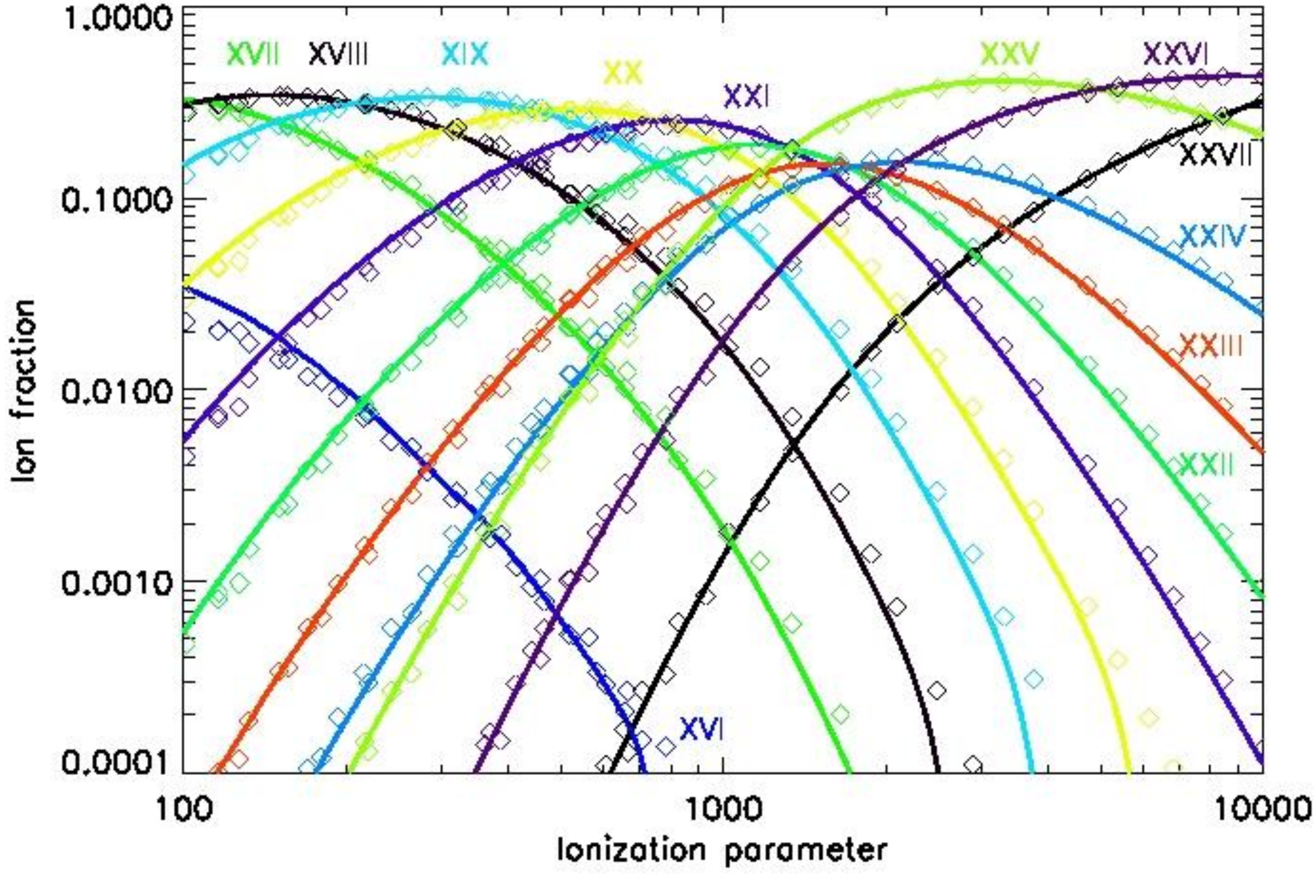
Broadly supports conclusions of Pounds & Reeves:

- ❑ wide angle flow

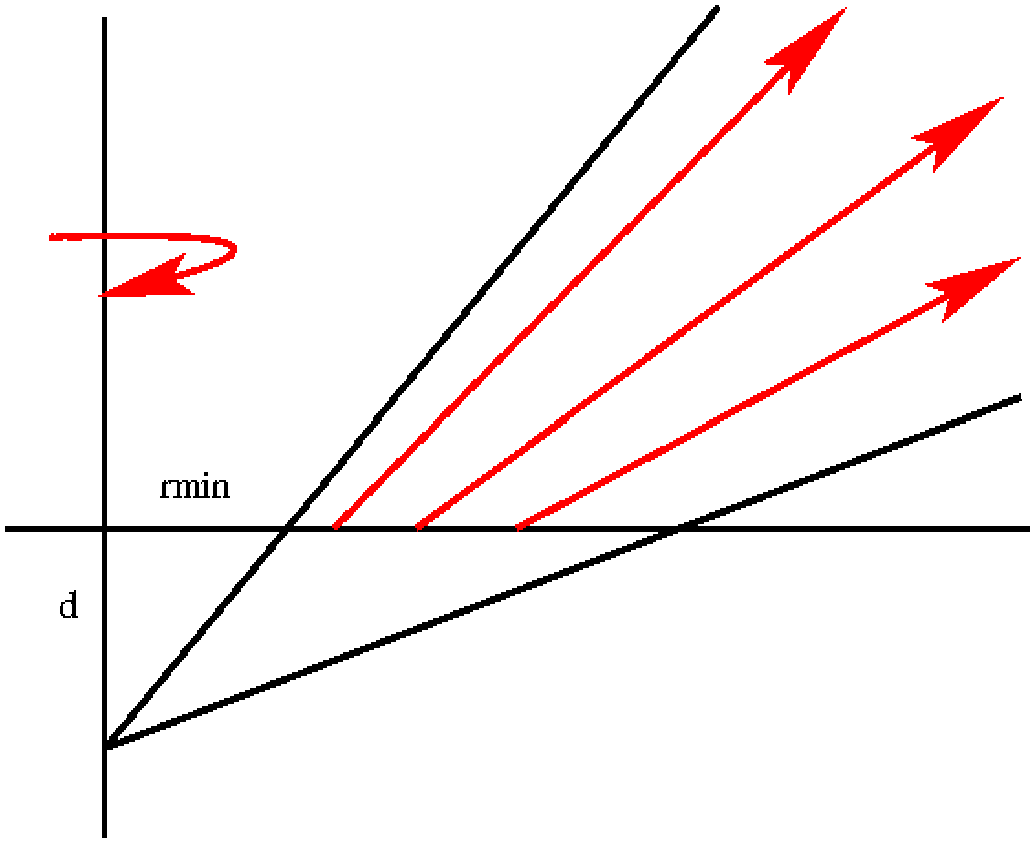
Conclusions and Prospects

- MC radiative transfer calculations for AGN outflows
  - Well-suited for transmitted/reprocessed radiation
  - Scattered light often critically important
- Wide range of features expected
  - Narrow blue-shifted absorption lines
  - Emission features with red wings
- Theoretical flow models predict observable features
  - Absorption line properties should vary in time
  - More quantitative work needed
- Plan to explore larger grids
  - Quantitative agreement in line profile possible (PG1211+143)
  - Working on bigger grids for XSPEC fitting

Method: the code



Adopted velocity



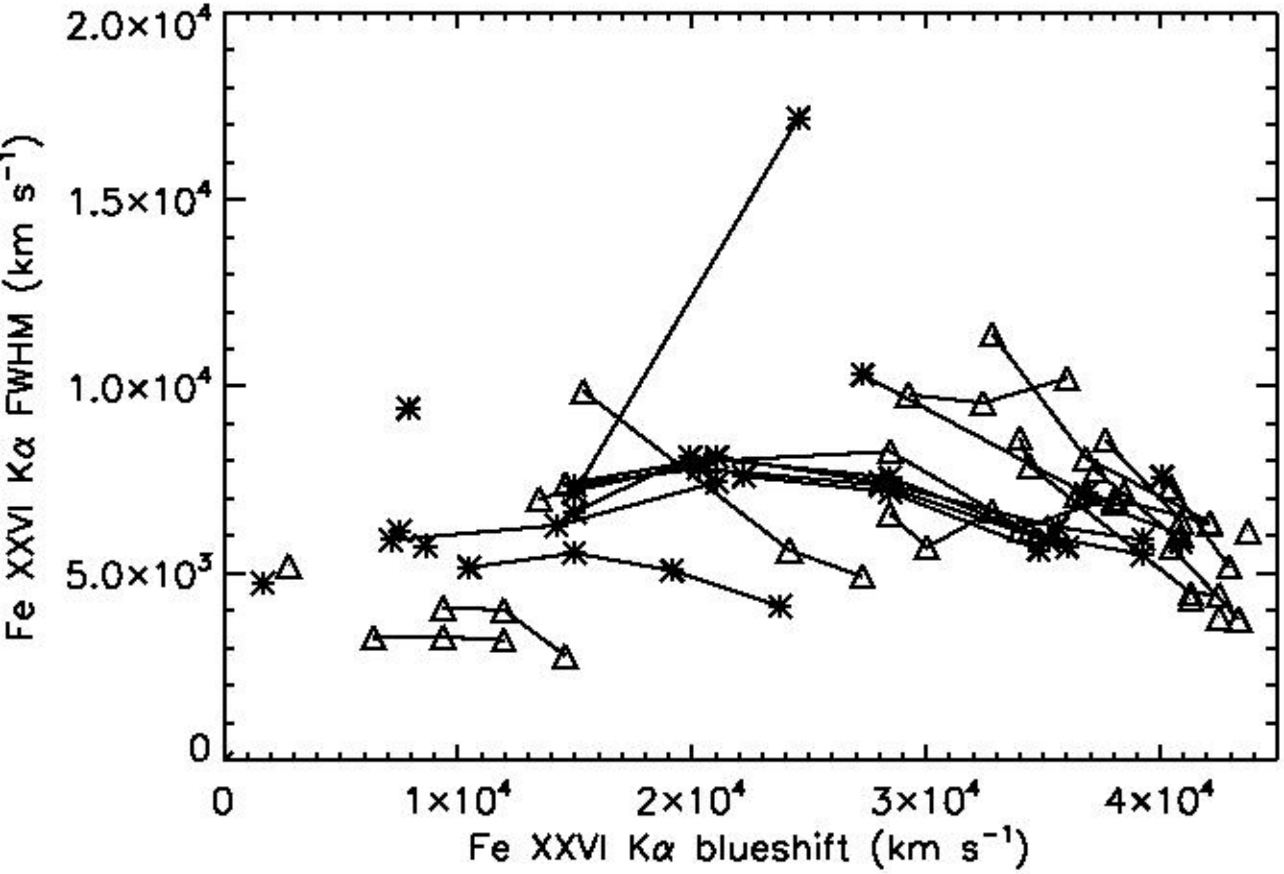
Standard KWD disk wind (Knigge et al. 95)

Keplerian rotation combined with outflow component of velocity:

$$v = v_{\infty}\left(1 - \frac{R_v}{l_s + R_v}\right)^{\beta}$$

Terminal velocity ~ **escape speed**

Grid of models



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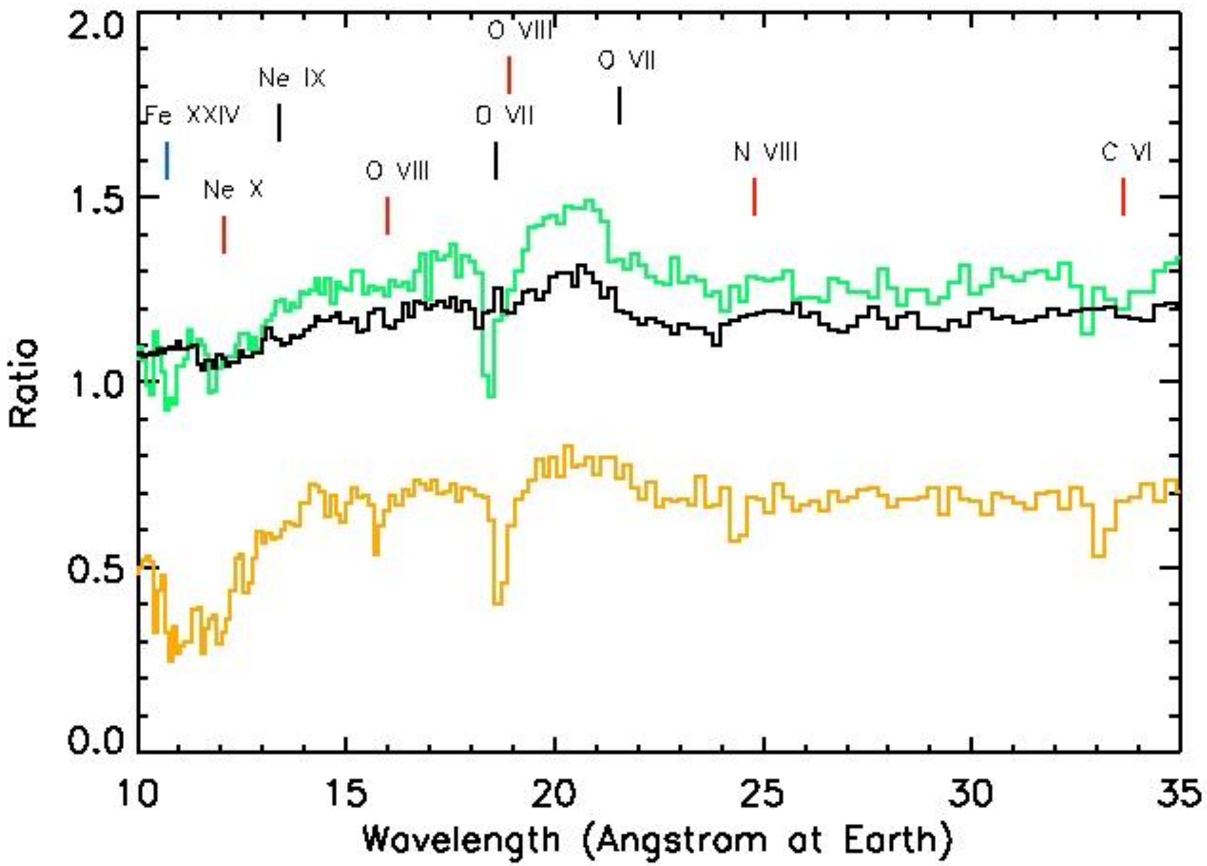

Wind model predicts additional features at lower energies:

- ❑ C, N, O & Ne
- ❑ comparison with RGS data to be done

Sim et al. 2009

Line driven wind

Role of scattered/reprocessed radiation on the temperature