A Chandra HETGS spectral study of the "Big Dipper" 4U 1624-490 and its associated X-ray dust scattering halo

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Abstract

We present a Chandra HETGS spectral study of the "Big Dipper" 4U 1624-490, and its associated X-ray dust scattering halo. Detailed spectral analysis and associated variability reveal a highly ionized (T~3.0x10^6 K) component associated with an extended accretion disk corona of radius R~3x10^{10} cm, and a less ionized (T~1.0x10^6 K) variable component coincident with the accretion disk rim, as well as a possible quasi-sinusoidal T~43 ks modulation that we attribute to changes in local obscuration. Based on these studies, a viewing geometry that is mapped to changes in plasma conditions over the 76 ks 4U 1624-490 orbital period is constructed. Further analysis of the associated X-ray dust scattering halo enabled significant improvements on the distance estimate to this source, and a first time determination of non-uniform dust distributions localized to the spirals arms in the Milky Way.

§1. Introduction

1. Source: 4U 1624-490: A Low Mass X-ray Binary (LMXB), also known as the "Big Dipper" because of its ~3 hr dip duration, long orbital period of ~21 hr and large obscuration covering ~90% of the compact object.

2. Dip: Thought to be due to occultations of the central source by gas from the accretions disk rim.

3. Observation: The source was observed with the *Chandra* High Energy Transmission Grating Spectrometer (HETGS) in timed graded mode on 2004 June 4 (ObsID: 4559) for 76 ks, covering one binary orbit (Fig. 1).

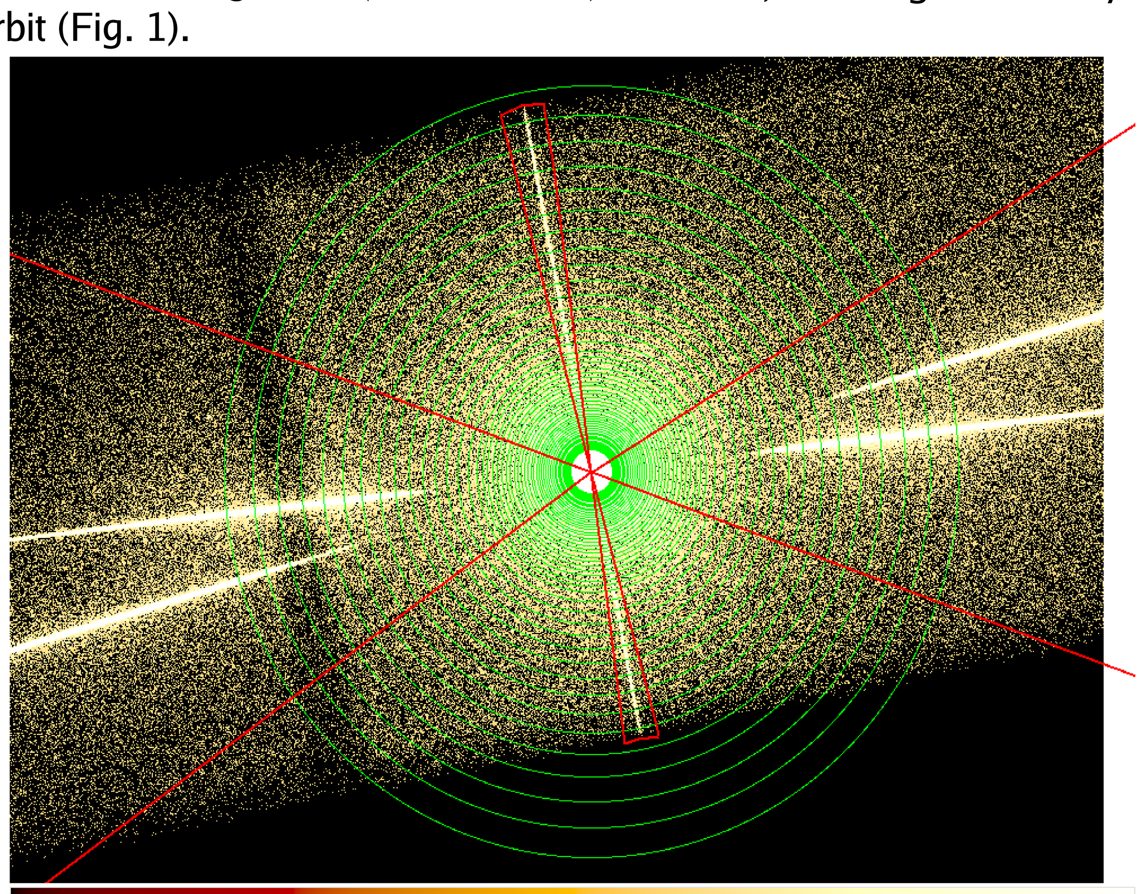

Fig.1 The Chandra HETG/ACIS-S image of 4U 1624-490. The data within the regions marked by the red lines are removed when we extract the halo radial profiles.

§ 2. Scattering Halos

Photons which have been scattered by dust along the LOS travel longer distances than the unscattered one. The delay time *dt* is given by

$$dt = 1.15\,h\,(D/1\,kpc)(\theta/1\,arcmin)^2\,\frac{x}{1-x}$$

Therefore the halo and binary light curves can be used to determine the distance to the point source (Fig 2).

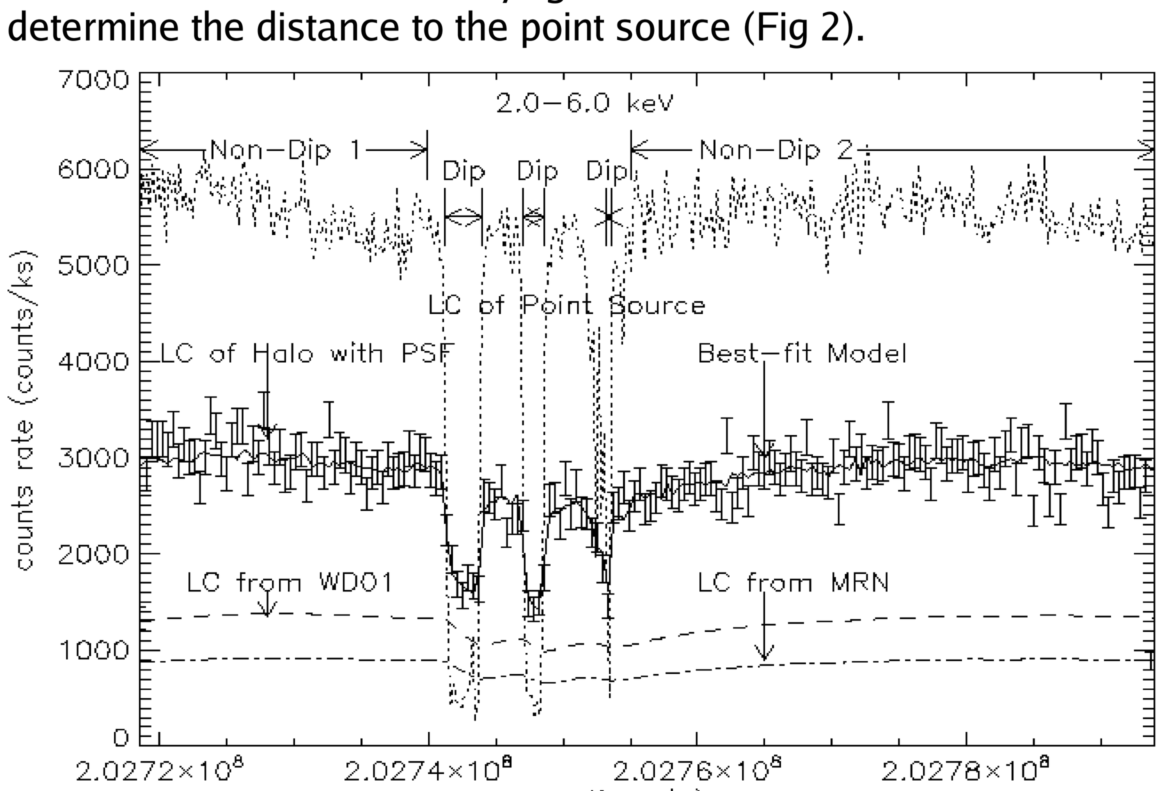

Fig. 2. ***We derive a distance D~15 kpc from fitting to the light curve of 4U 1624-490*** using the dust grain model WD01 [6], assuming uniformly distributed dust.

The observed first order scattering halo intensity $I_{sca}^{(1)}(\Theta, E)$ can be shown as:

$$I_{sca}^{(1)}(\theta,E) = F_X(E)\,N_H \int_{a_{min}}^{a_{max}} da\, n(a) \int_0^1 dx\, f(x)(1-x)^{-2} \times S(a,E,\theta_{sca})$$

So we can determine the spatial distribution of dust from the halo radial profiles. We assume a non-uniform dust distributions along the LOS. Fig. 3 shows the dust distribution along our LOS divided into three parts -- while the dust is assumed to be smoothly distributed in each of these regions, the quantity is allowed to vary independently within a given region.

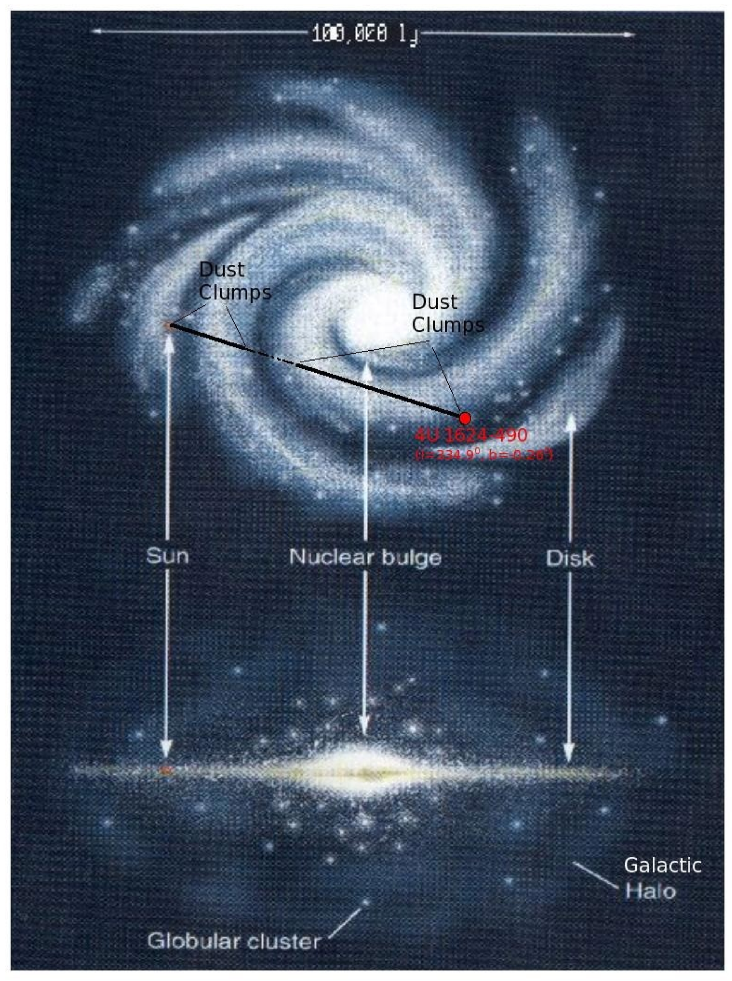

Fig. 3. The location of 4U 1624-490 and the spatial distribution of dust along the LOS.

§ 3. Evolving Broadband Continuum

While the light curves in persistent phase change little over duration of persistent phase (see Fig. 4 (I) seven phases: a, b, ..., and g, each of which lasts ~10 ks), the equivalent hydrogen column local to the system changes significantly when a partial covering model is used to fit these broadband continuum spectra (Fig, 4: II and III). The absorbed powerlaw flux changes significantly as well when a blackbody plus powerlaw model is used (Fig. 4: IV and V). Both models indicate that ***the observed orbital modulations are predominantly driven by absorption variations.***

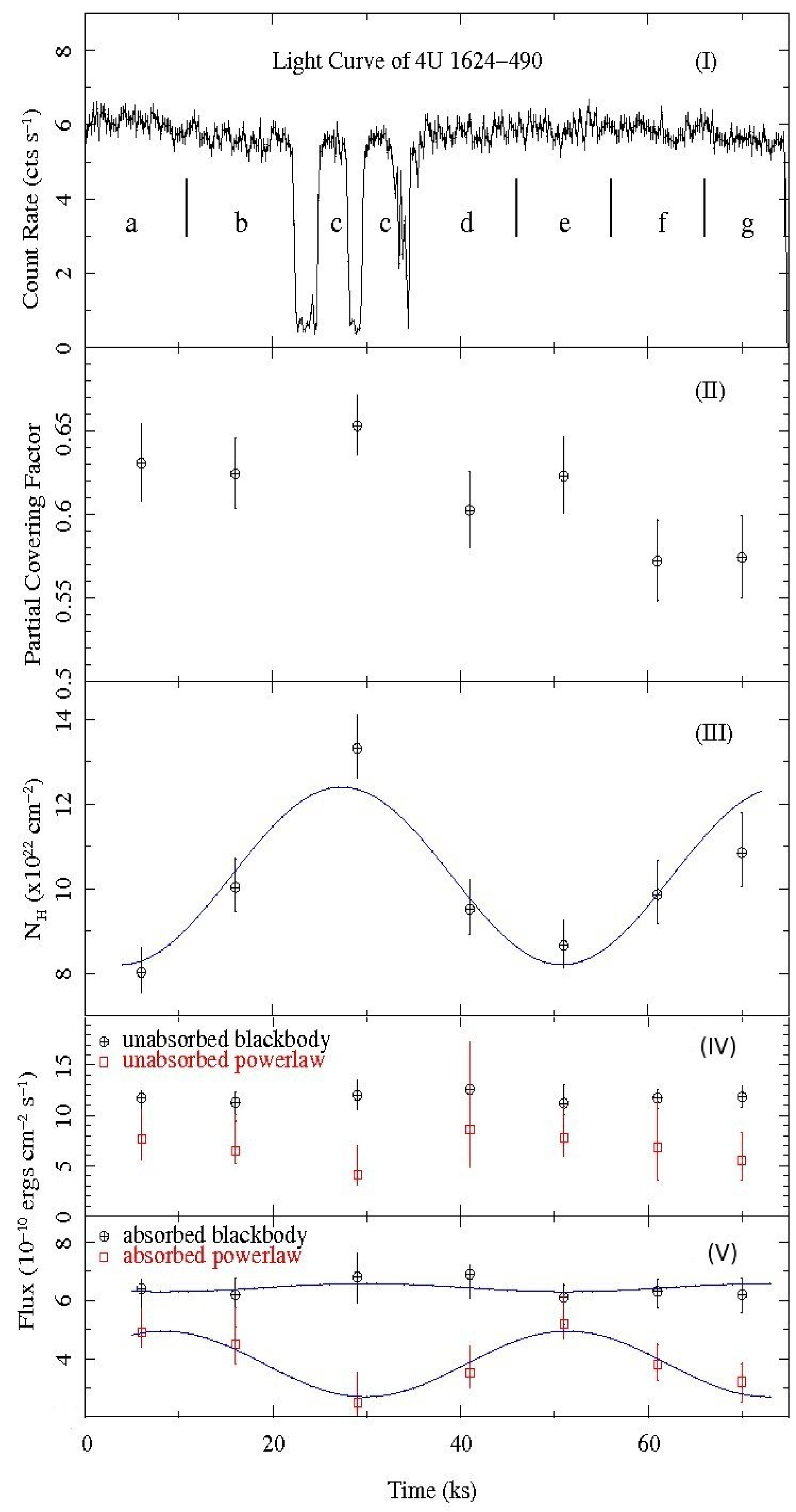

Fig. 4. Light Curves of 4U 1624-490. Seven phases are labeled with letters: a, b, c, d, e, f, and g.

Model 1: partial coverer + powerlaw (II + III)

Partial covering factor doesn't change significantly.

Equivalent hydrogen column local to the system shows a possible quasi-sinusoidal modulation with period P=47±7 ks

Model 2: blackbody + powerlaw (IV + V)

The absorbed powerlaw also shows a possible quasi-sinusoidal modulation with period $P=43^{+13}_{-9}$ ks while the unabsorbed flux changes little.

§ 4. Evolving Line Profiles with Phase

The ionized H-like and He-like Fe lines also show variability in both flux and wavelength (Fig. 5 and 6). The green lines indicate the laboratory wavelengths of Fe XXV (1.850 Å) and Fe XXVI (1.778 Å) resonant absorption.

As a first step, we assess spectral changes during phases far from the dip (*a+e+f+g*) and those immediately before and after (*b+c+d*) it by analyzing data which have been divided into these two categories.

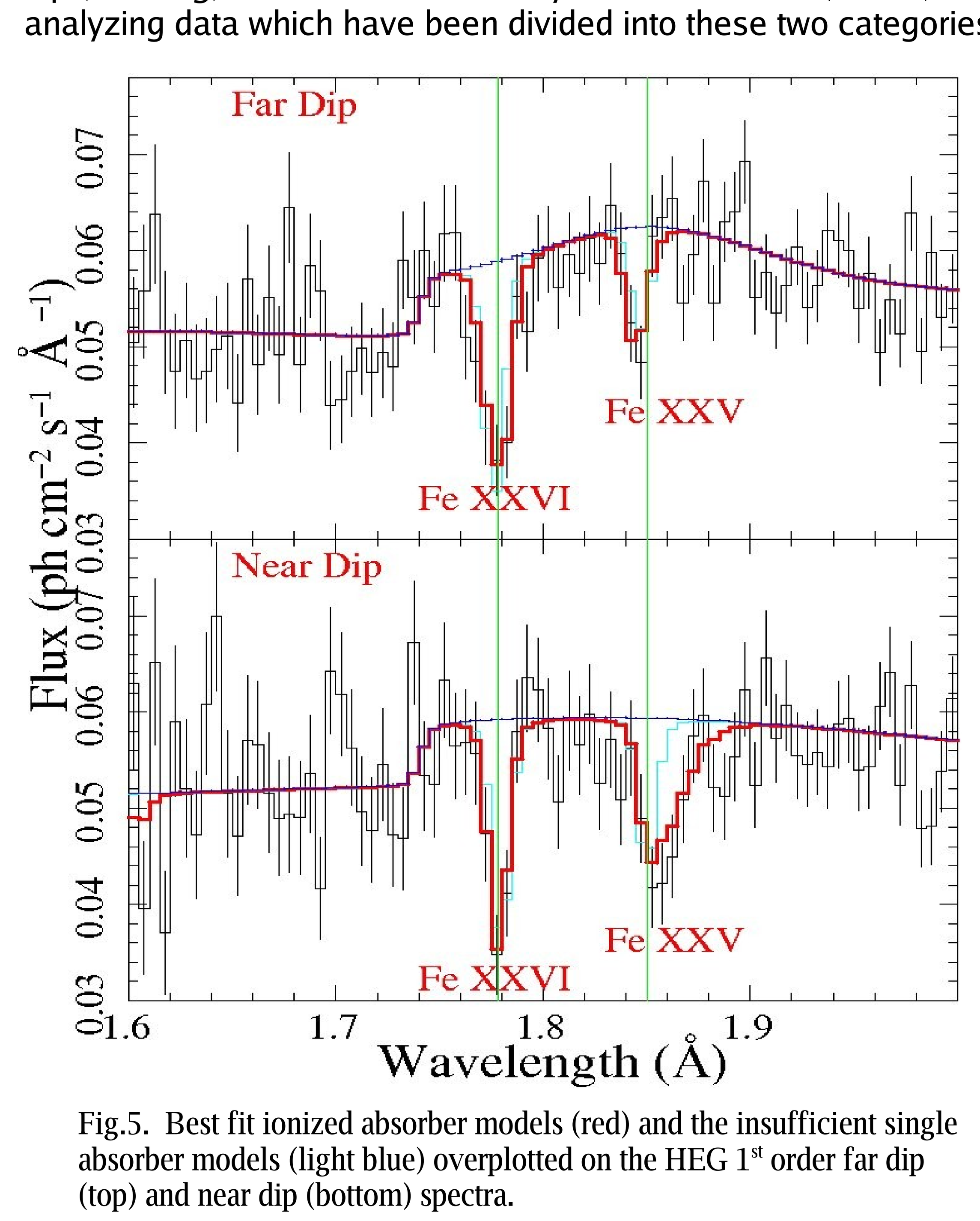

Fig.5. Best fit ionized absorber models (red) and the insufficient single absorber models (light blue) overplotted on the HEG 1st order far dip (top) and near dip (bottom) spectra.

A single absorber for fitting either of these spectra is not sufficient. Therefore, we use ***a dual absorber (one hot at T ~ 3 x 10^6 K and one less so T~ 10^6 K) to fully describe the observed lines.***

Using the relation between ionization parameter and the radius of plasma gas, we estimate the radius of ~3x10^{10} cm for the hot gas, which is consistent with the location of the Accretion Disk Corona (ADC) in 4U 1624-490 as determined by *Church et al 2004.* Similarly the ~10^{11} cm radius of less ionized gas is consistent with the truncation radius of the disk. Fig. 7 shows the location of these absorbers in the context of 4U 1624-490 geometry .

We also divided the persistent spectrum into 7 parts of ~10 ksec duration (Fig. 6). The Fe XXV and Fe XXVI line fluxes and profiles clearly evolve with phase.

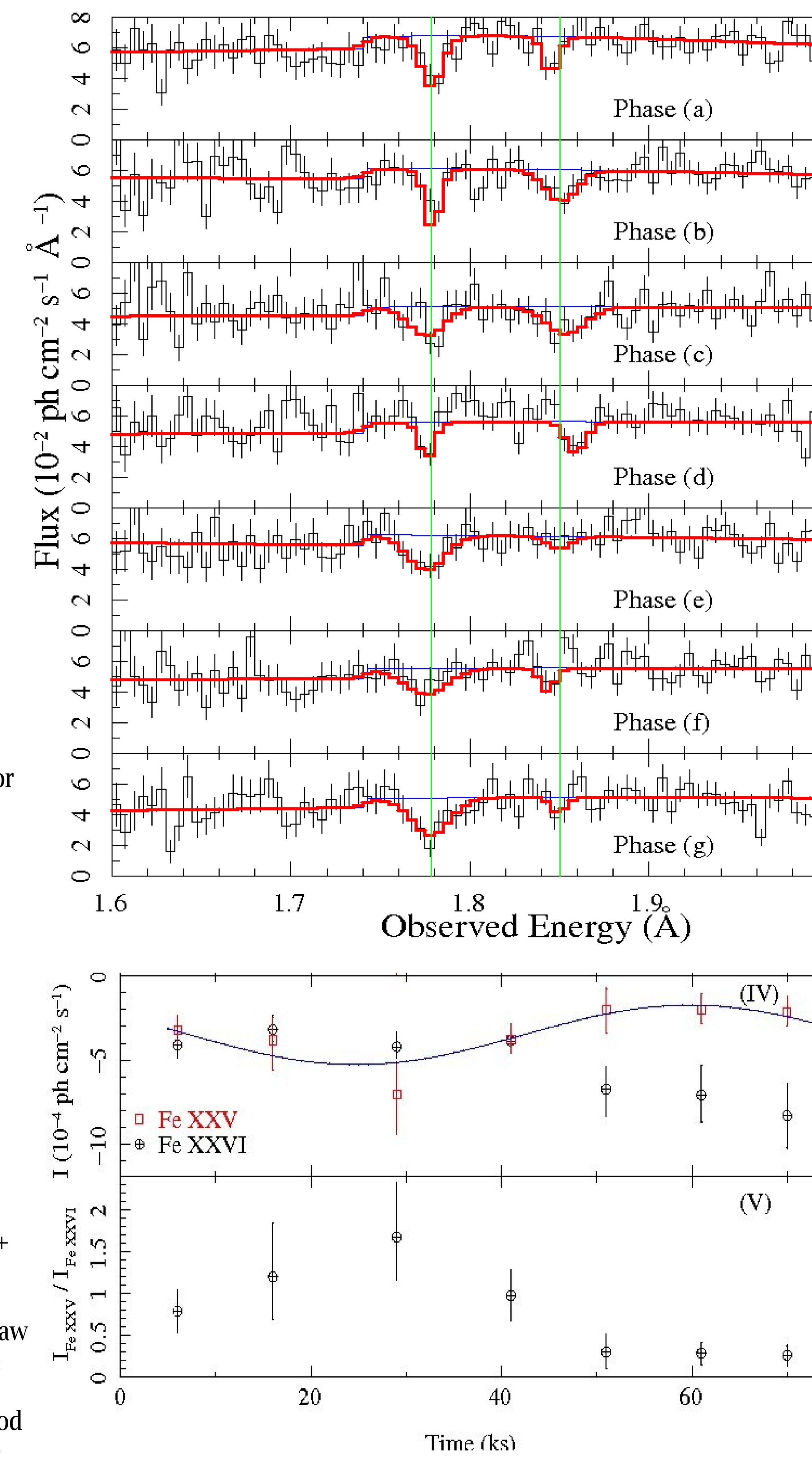

Fig. 6. The evolution of Fe XXV and Fe XXVI lines

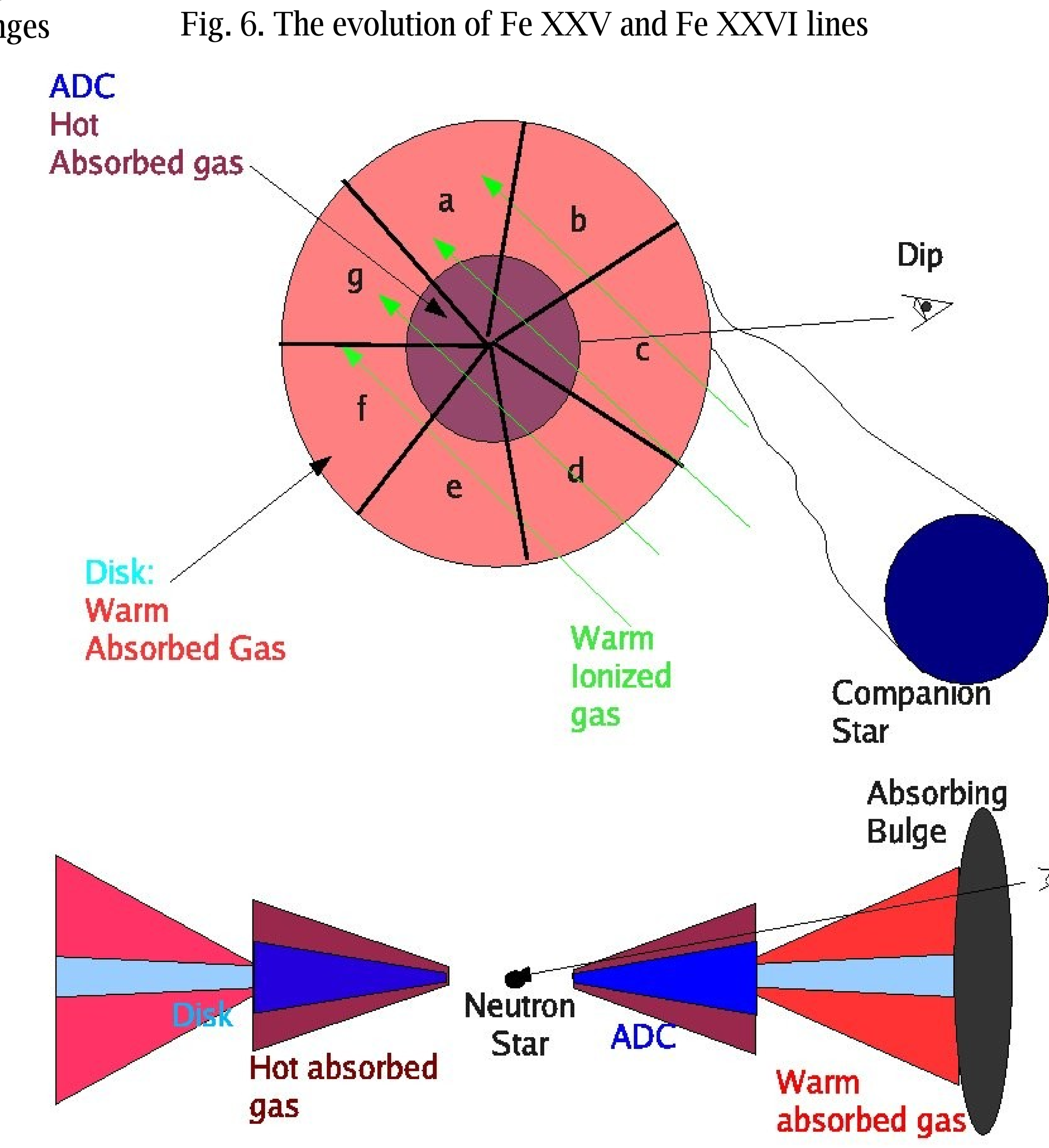

Fig. 7 Geometry of 4U 1624-490 showing the location of the two temperature ionized gas as it evolves with phase.

Conclusions:

(1) Xiang, Lee & Nowak 2007:

- We determine a distance $D_{4U1624-490} = 15.0^{+2.9}_{-2.6}$ kpc to 4U 1624-490 based on scattering halo studies.
- Varying dust distribution ***does*** affect the derived column densities along the LOS to 4U 1624-490. A simple estimate based on our halo fits imply the hydrogen particle density in the spiral arms is n~1.6 cm^{-3} and the one between two spiral arms n<0.3 cm^{-3}.

(2) Xiang, Lee, Nowak, Wilms & Schulz 2009:

- A possible quasi-sinusoidal modulation with period $P=43^{+13}_{-9}$ ks, are predominantly driven by changes in obscuration, rather than any intrinsic variation of the power-law or black-body components.
- Evolving iron absorption line profiles with orbital phase during the persistent phase of 4U 1624-490 are observed.
- The evolution of these lines can be modeled using the "XSTAR" photoionization code which places the location of the gas in the region of the ADC and disk.

Main References:

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