Time Dependent Photoionization of Gas Outflows in AGN

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Abstract

We study the dynamic effects of time varying UV ionizing continuum on radiation bounded photoionized outflows in AGN. We use a 1D hydrodynamics numerical code to verify the predictions of Bautista & Dunn (2010). It is seen that variations in the UV ionizing continuum yield non-equilibrium conditions in the plasma and create supersonic cooling and heating fronts that give the outflows. Thus, large pressure imbalances arise in the cloud, which are compensated by flow motions leading to fragmentation of the wind and dense shells at the leading ends of the outflowing clouds.

Introduction

BALQSO show complexes of narrow (of the order of a few hundred km s−1) absorption features from low ionization species, e.g. Fe II and Si II, which offer valuable diagnostics of the outflow. Such absorbers are unlikely to survive the journey from the supermassive black hole to their inferred location. Bautista and Dunn, 2009, studied the kinematic components in the troughs of the FeLoBAL of two quasars, QSO 2359–1241 and SDSS J0318–0600. These systems are made of a single main component and various smaller components with density of about one quarter of that of the main component. Moreover, all the components seems to be at the same distance from the central source. This suggests that all components maybe related to each other. But, the quasar optical and UV continue varies within time scales of the order of one year. Hence, it is important to study the effect of the varying radiation field on the structure of the FeLoBAL.

The effects of flux variations on FeLoBAL and dynamics of IF in outflowing clouds in AGN

The time variations of the ionizing flux are expected to have two kinds of effects: **(1)** in the region Δl just ahead of the IF the plasma departs from photoionization equilibrium. **(2)** because cooling of the plasma within the IF occurs simultaneously with the drop in ionization, the supersonically traveling IF is also a cooling front. Supersonic cooling fronts are accompanied by rarefaction waves and shocks, and these have important dynamical effects on the cloud as we see in the unmerical simulations below.

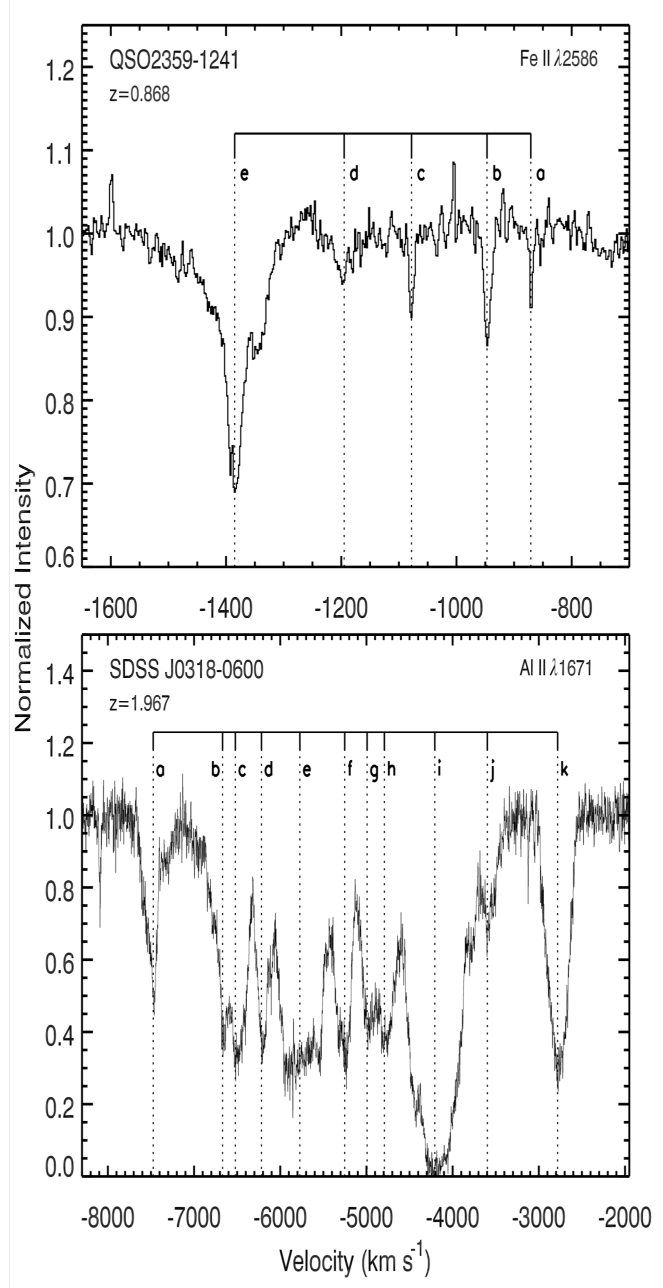

Fig. 2-a: Absorption troughs in QSO 2359-1241 (upper) and SDSS J0318-0600 (lower).

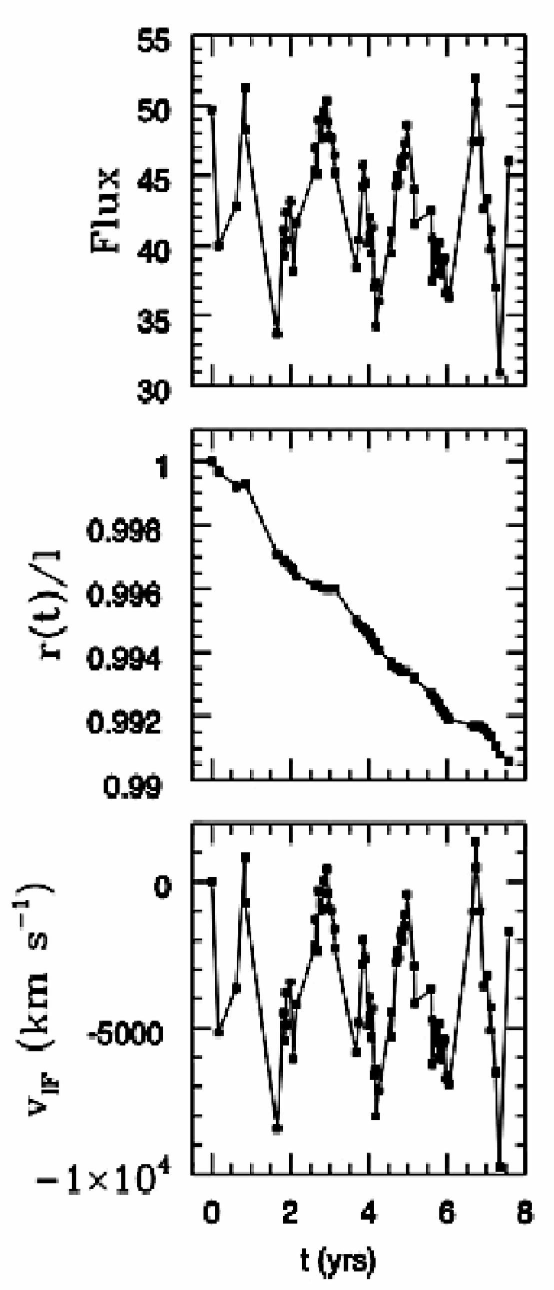

Fig. 2-b: flux, r(t), and v_{if} of PG0844 quasar observed by Kaspi et al. (2000) .

Cooling and recombination fronts are intrinsically interdependent. The supersonic change in temperature leaves a pressure step behind that creates a rearward-facing rarefaction wave and a forward-facing shock. The rarefaction wave creates a lower density region (with density ~ (1/4) n_H.

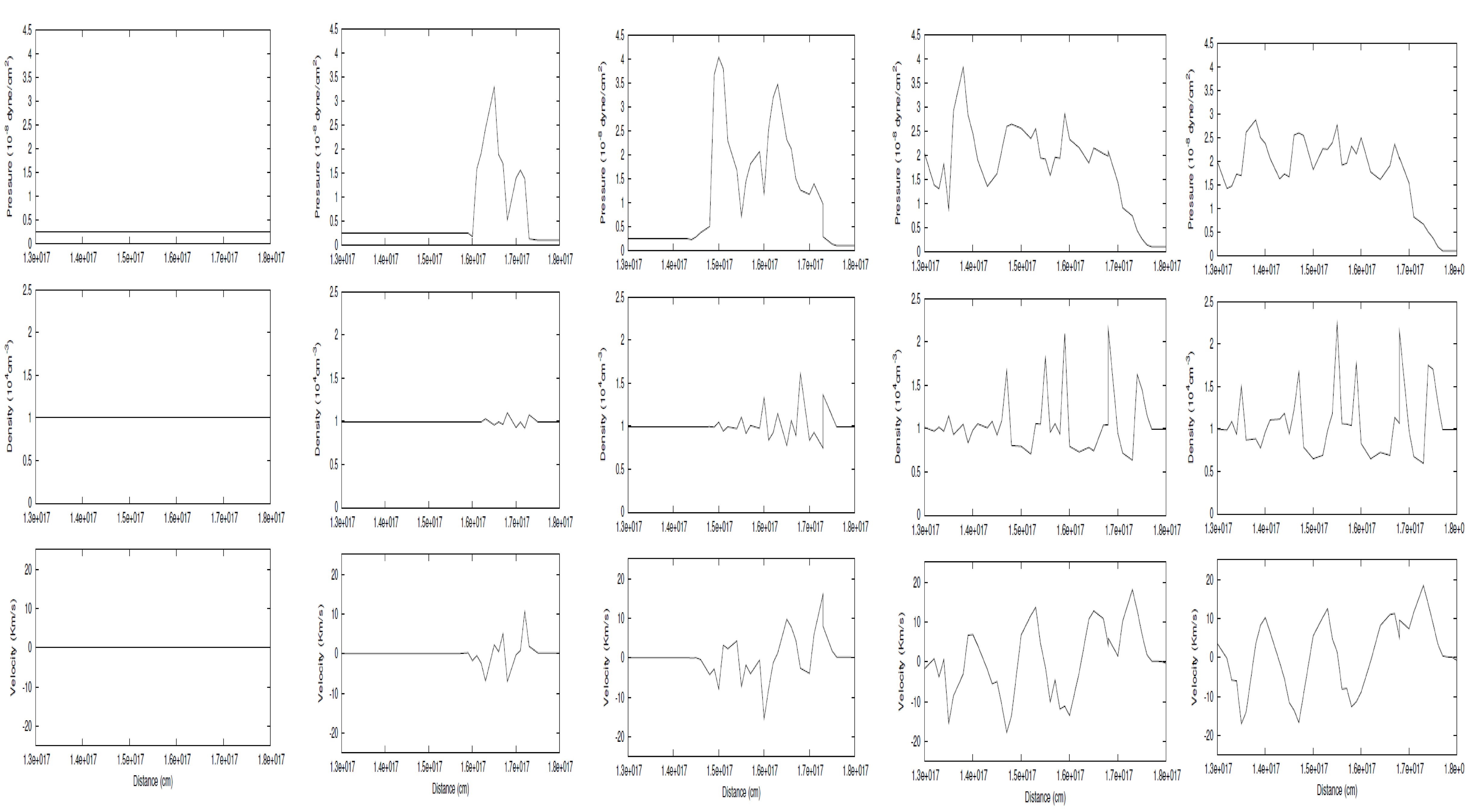

Fig 1: A time series of hydrodynamic effects on a cloud present in the time-dependent flux of PG0844 quasar observed by Kaspi et al., 2000. The top row is the pressure profile, the middle row is the density profile, and the bottom row is the velocity profile. The most left column represents the equilibrium state of the system at t=0.0, and the columns are 5 years apart. As we can see from the pressure profile, the flux variations yield large pressure imbalances that lead to flow motions clear in the velocity profile at the bottom row. These flow motions lead to fragmentation of the cloud with many components with smaller and larger densities than that of the parent cloud.

Hydrodynamic conservation laws

For simplicity we shall assume a 1-dimensional system entirely composed of hydrogen. The conservation equations of the mass, momentum, and energy can be expressed as Lagrangian differential equations with the internal energy of the system given by

$$\varepsilon = \frac{3}{2}KT,$$

and the mass conservation equation is,

$$\frac{\partial \rho}{\partial t} = -\rho\frac{\partial u}{\partial r},$$

where u is the fluid velocity and ρ is its mass density. The momentum conservation equation is given by,

$$\rho\frac{\partial u}{\partial t} = -\frac{\partial P}{\partial r},$$

The energy conservation equation indicates that the net thermal input of energy per unit volume per second equals the corresponding rate of thermal energy plus work done by the gas. Then the temperature of the system can be calculated from the energy conservation equation in the form,

$$n\frac{\partial}{\partial t}(\frac{3}{2}KT) = \sum_i(\Lambda_i - \Gamma_i) + KT\frac{\partial n}{\partial t}$$

where Λ and Γ are the heating and cooling rates due to physical processes under consideration.

Numerical simulation of time-dependent flux in FeLoBAL

The simulations presented here have been performed using hydrodynamic code used in this project developed from HYDRO code to study the effects of time-dependent flux on the FeLoBAL. A drop in the ionizing flux within ξ > 5% yield supersonic IF traveling through the cloud with speed vif as given by Bautista and Dunn 2010. The supersonic IF is accompanied by a cooling front that leaves a pressure step behind. This creates a shock wave in the direction of the IF and a rarefaction wave in the opposite direction. (Strachan & Ahlborn 1975). For simplicity, heating and cooling step functions are incorporated to the energy conservation equation to simulate the effects of instantaneous variation in the flux, rise and drop, respectively.

Figure 1 is a time series of the results of the effects of time-dependent flux on a cloud. It shows that rarefaction waves, originated by supersonic IF, yield fragments with different densities that detach from the main cloud with relative velocities of tens of km/s in the absence of magnetic fields. Higher detaching velocities can be achieved if the clouds sustain significant turbulent motions and magnetic fields that could be generated either from the accretion disc of the AGN itself or from dynamo-like effects in the plasmas, as predicted by Bautista and Dunn 2010.

Conclusions

We have confirmed the prediction of Bautista and Dunn, 2010, that time-dependent flux, which results in a supersonic IF accompanied by cooling fronts and rear-facing rarefaction wave traveling through the cloud, yields large pressure imbalances in the cloud. These pressure imbalances result in flow motions leading to fragmentation of the wind. Fragments detach from the main cloud with relative velocities of tens of km/s in the absence of magnetic fields, as predicted by Bautista and Dunn, 2010. Furthermore, our numerical simulations show that the density profile of the frgmentaions can be a diagnostic of the ionizing flux source properties and ages of the cloud.