Lyα Line Transfer in Starburst Galaxies

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- ApJ 554, 604 (June 10, 2001)
- J. Korean Ast. Soc., 33, 29 (2000)
- astro-ph/0111013 (ApJ, in press)
- A paper to be submitted soon

SOME BACKGROUNDS

- Lyα is the strongest resonance line
- Line center optical depth

$$\tau_0 = 1.41 \left(\frac{T}{10^4\,\mathrm{K}} \right)^{1/2} \left(\frac{N_{HI}}{10^{13}\,\mathrm{cm}^{-2}} \right)$$

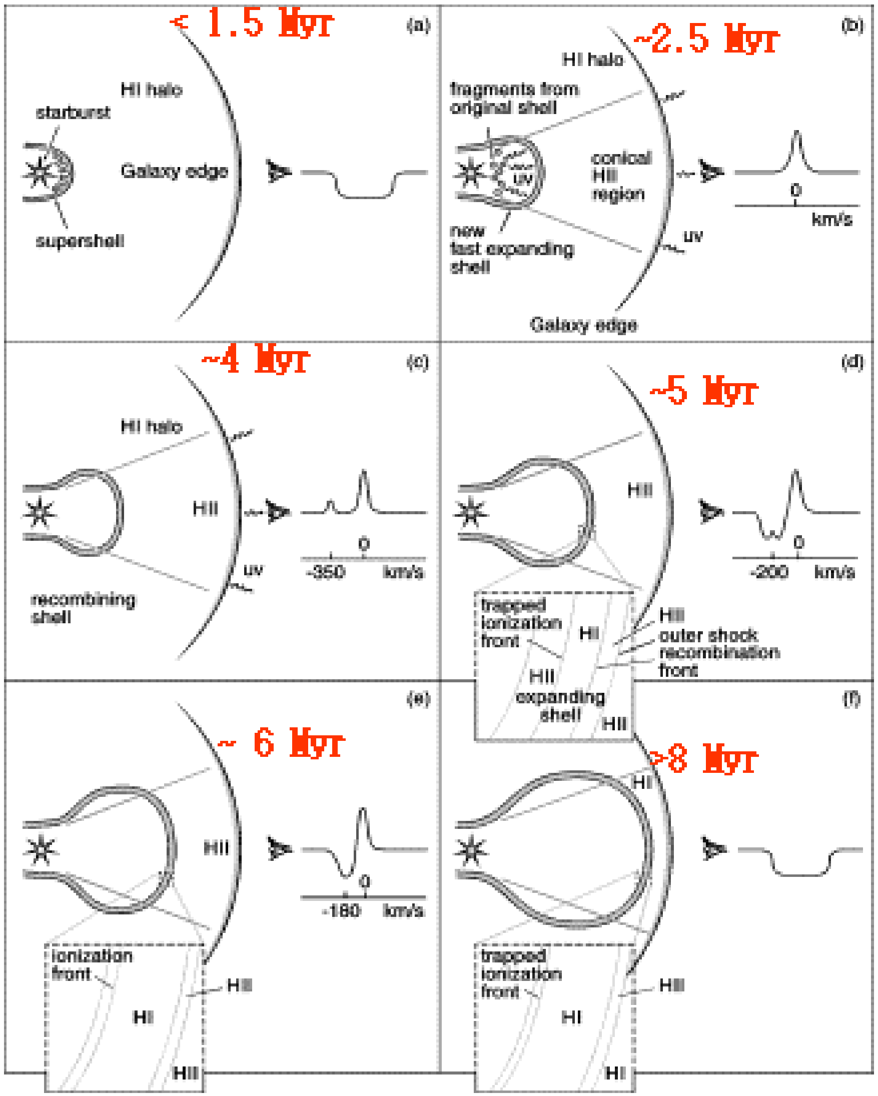
- Typical NHI across the galaxy: 10^{19}-10^{22} cm^{-2}

→Very Large Optical Depth!

Lyα and Dust

- Because of enormous optical depth of Lyα, the emission line can be easily destroyed
- However, Lyα emission lines are eventually observed even in rather dusty galaxies (Kunth et al. 1998) → The velocity structure of the absorbing medium could be important

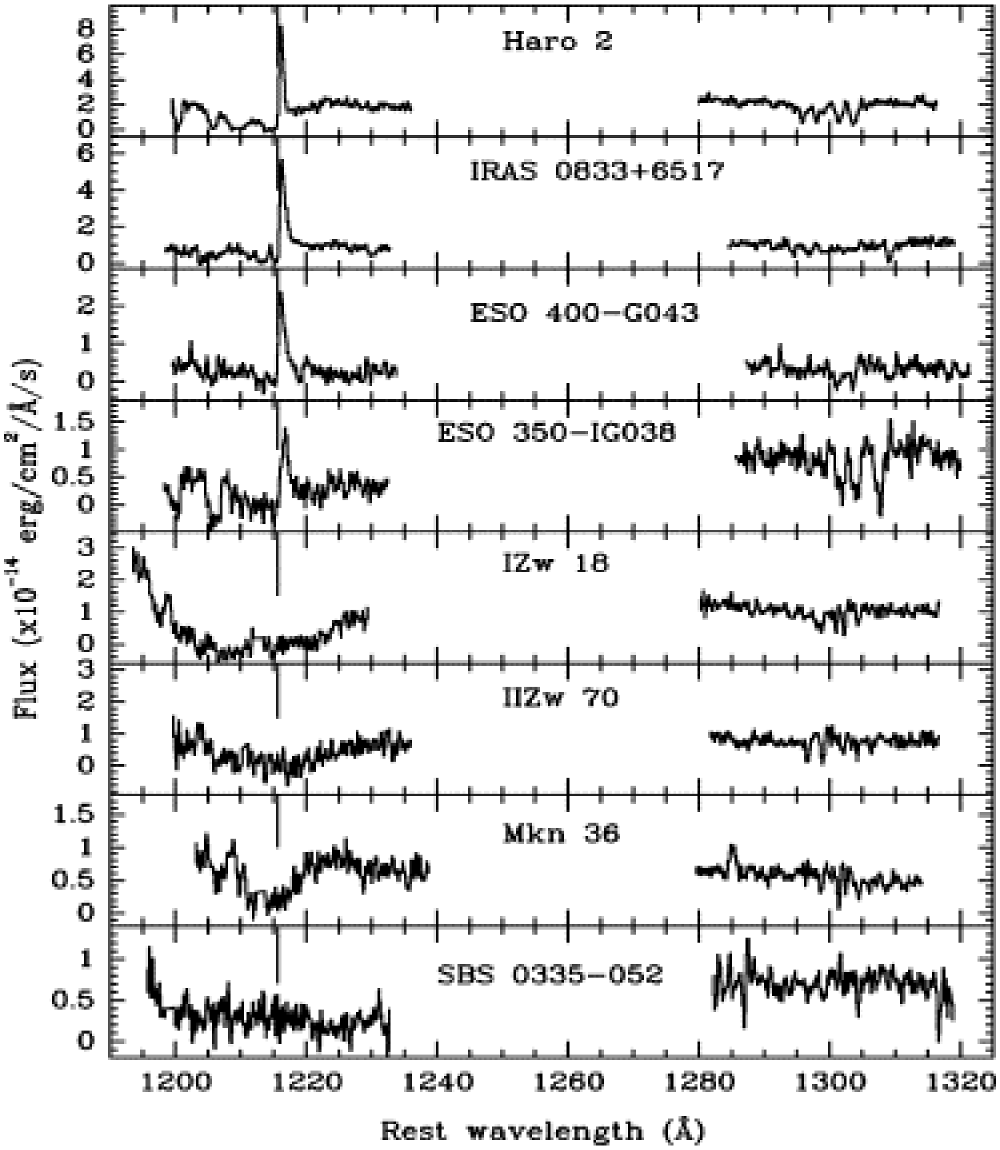
A SCHEMATIC MODEL FOR STARBURST(ing) GALAXIES



Tenorio-Tagle et al. 1999

Evolution of superbubbles and Lyα emission profile from star-forming galaxies

Lyα Profiles of star-forming galaxies



- Asymmetric P Cygni Type
- Broad damped absorption

Kunth et al. 1998: GHRS

Previous Works on Lyα Transfer

- Adams (1972): mean number of scattering

  $<N> \propto \tau_0$, rather than τ_0^2

  where τ_0 is the line center optical depth

- Harrington (1973), Neufeld (1990)

  Derived analytical solution for extremely thick case

Emergent mean intensity from a slab

$$J(\tau_0, x) = \frac{\sqrt{6}}{24} \frac{x^2}{a\tau_0} \frac{1}{\cosh[(\pi^4/54)^{1/2}(|x^3 - x_i|/a\tau_0)]}$$

a: damping constant

x: dimensionless frequency

Monte-Carlo Code for Lyα Transfer

- Incident Lyα photon
- Assumed geometry (plane parallel or shell)
- Assumed Voigt profile (combination of Doppler and natural broadening)
- Compute the propagation length of a photon

$$S = ts = \frac{t}{H(x,a) + \tau_d / \tau_0}$$

- The scattering direction is determined by underlying scattering phase function.

Voigt Profile

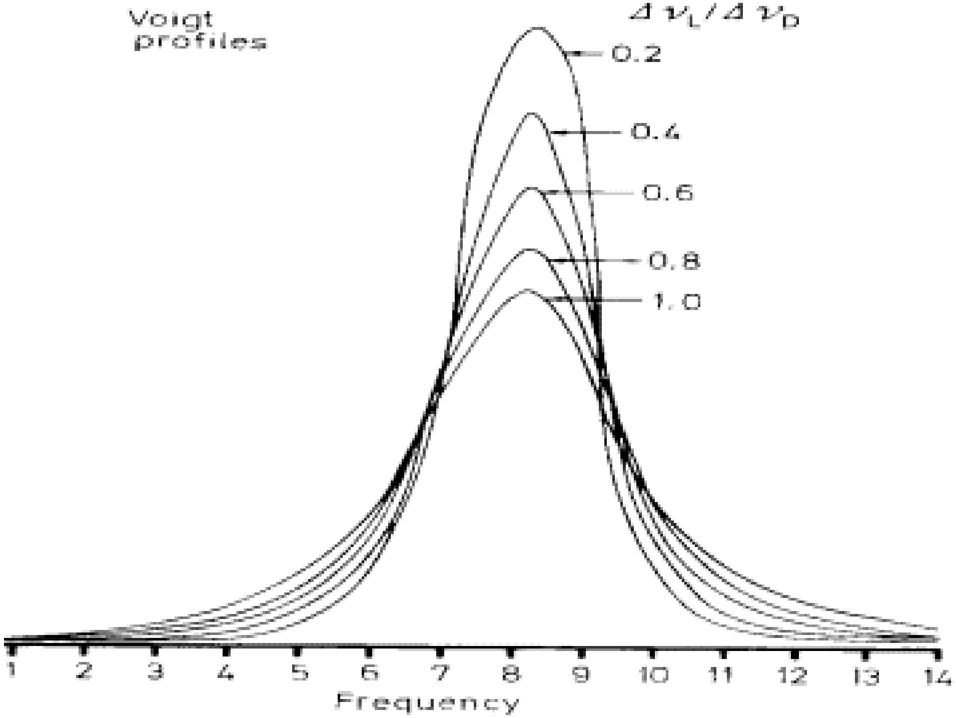
Optical depth at position *s* and frequency *x*

$$\tau_x(s) = 1.41\times10^{13}\,T_4^{-1/2}\,n_{HI}\,s\times H(x,a)$$

Γ is a damping const.

$$a = \frac{\Gamma}{4\pi\Delta\nu_D}$$

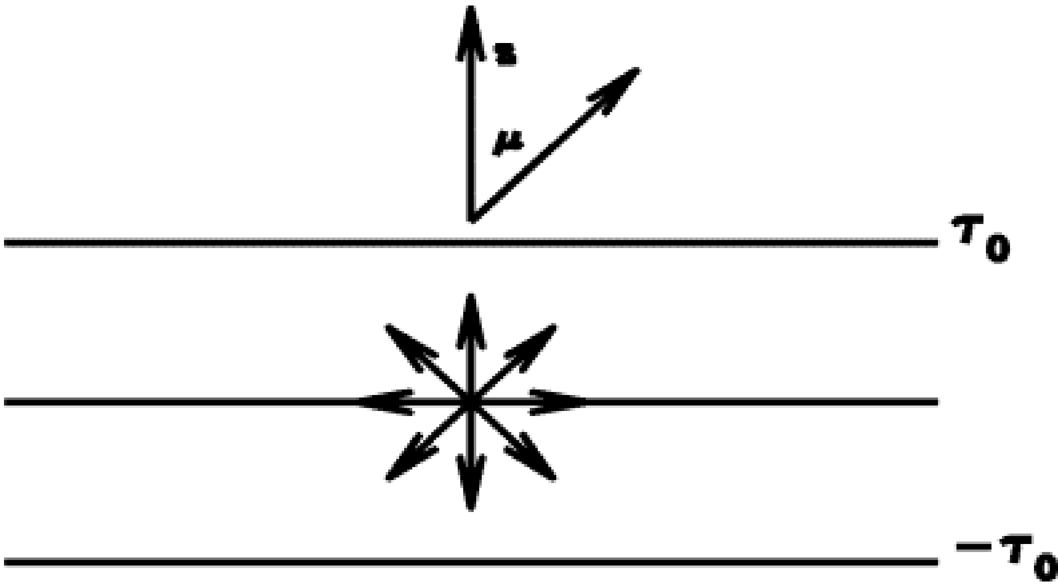
$$\Delta\nu_D = \frac{v_{th}}{c}\nu_0$$



Monte-Carlo Code (cont.)

- When $|z|>\tau_0$, the photons become emergent photons
- Continue until 1000 photons are collected in each frequency bin.

- Number of scatterings $\sim\tau_0$
- The frequency bin Δx = 0.25 ~ 1
- Plane parallel geometry (or spherical shell)



Physical Conditions

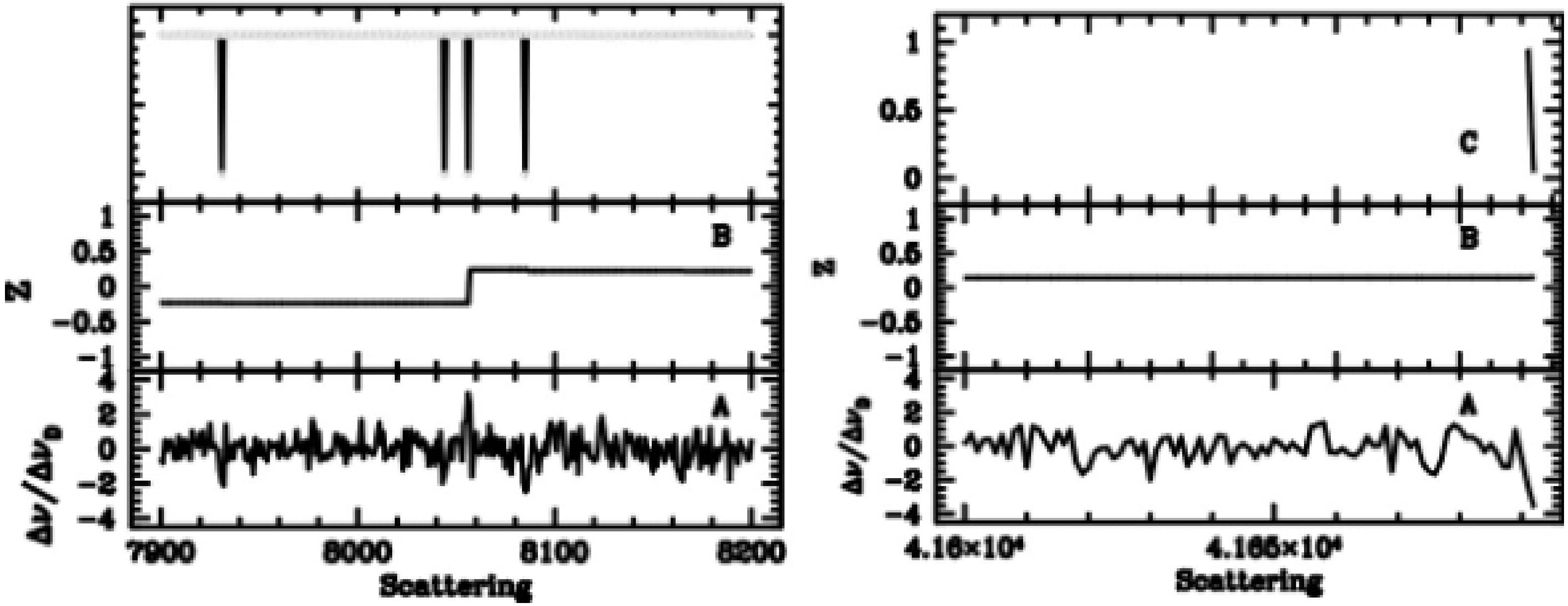
- Cold, neutral medium:

  T = 10, 100K
- Hot, ionized medium

  T=10,000K
- Turbulent medium
- Embedded line or continuum source (O,B stars, ionized medium)
- Static or expanding

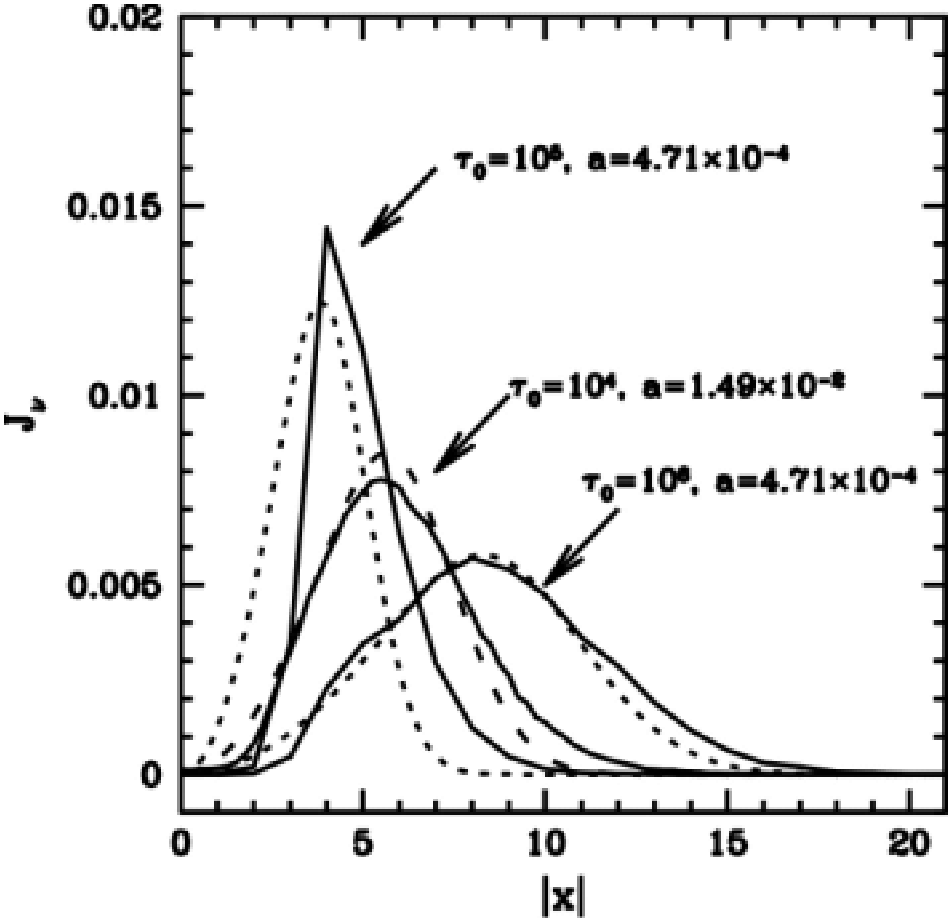
History of Escaping Photons

- **Single longest flight: a photon escapes after it becomes a wing photon**
- **Therefore, it is not a random walk process**



Comparison with Analytic Solutions

- Some discrepancy with analytic solution for small $\tau_{0.}$

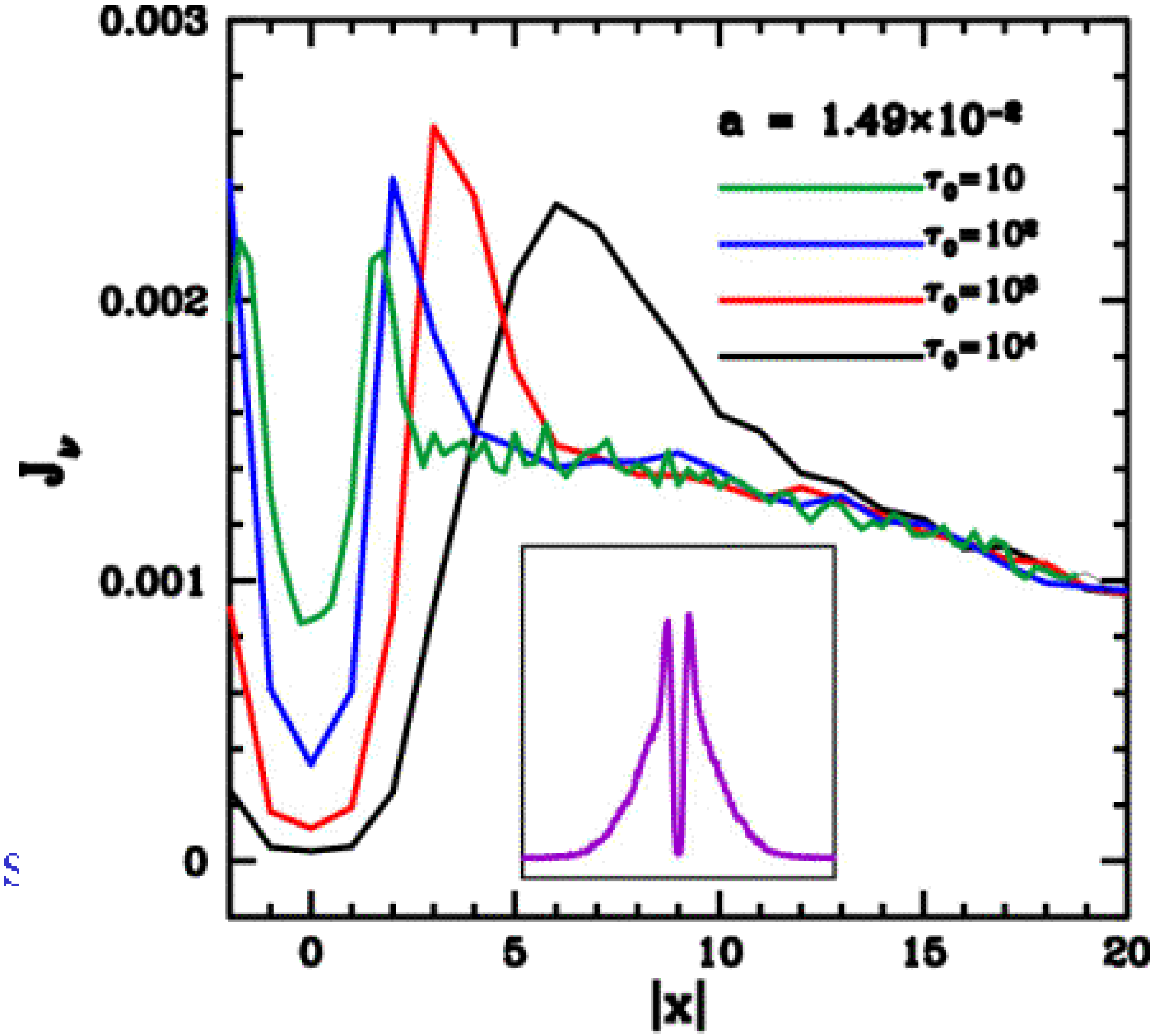


Solid: Monte-Carlo,
dotted: Neufeld (1990)

Line Profiles (1)

Hot broad line source surrounded by cold medium: initial phase of starburst

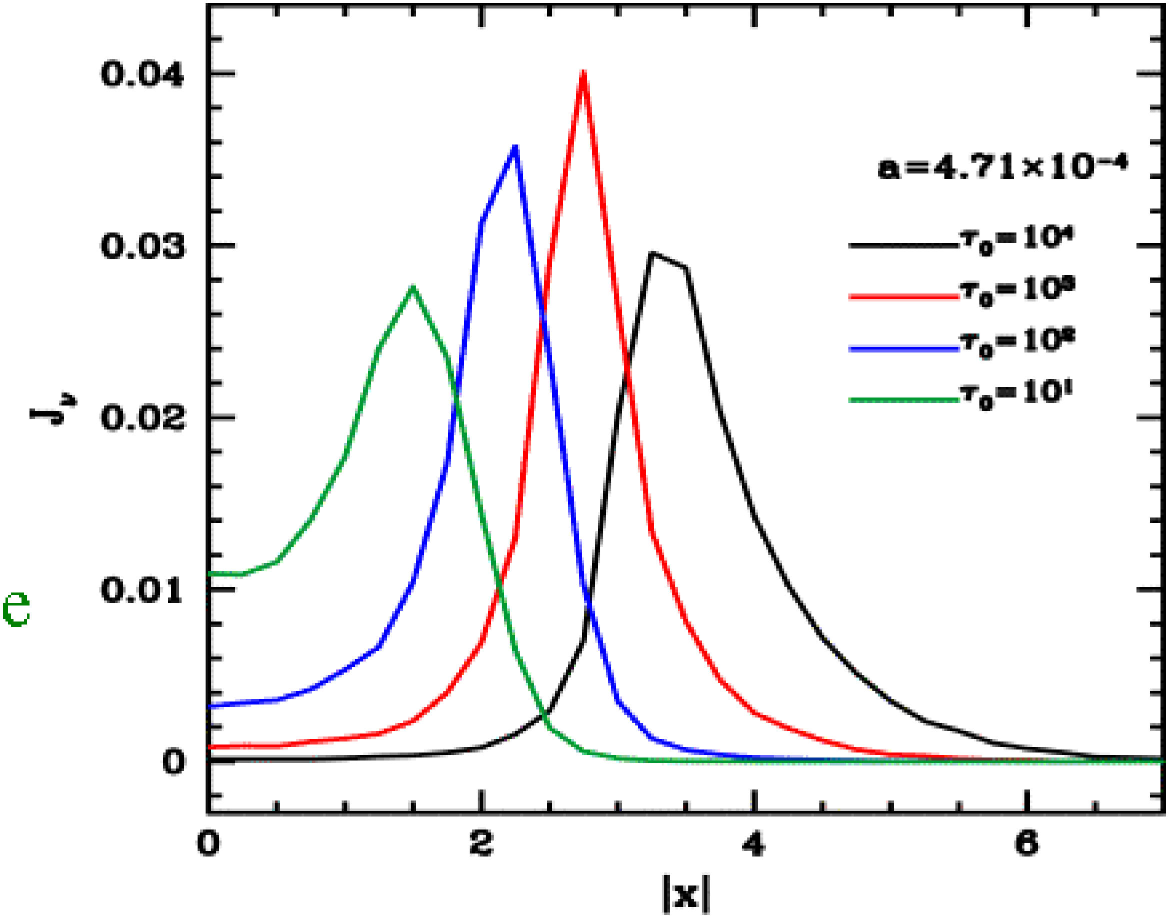
- Double peak and absorption trough
- Larger optical depth will give wider profiles
- Dust will destroy the peaks



$\Delta\lambda/\Delta x = 0.0016$A

Line Profiles (2)

Narrow line source surrounded by a hot medium ($T=10^4$ K)



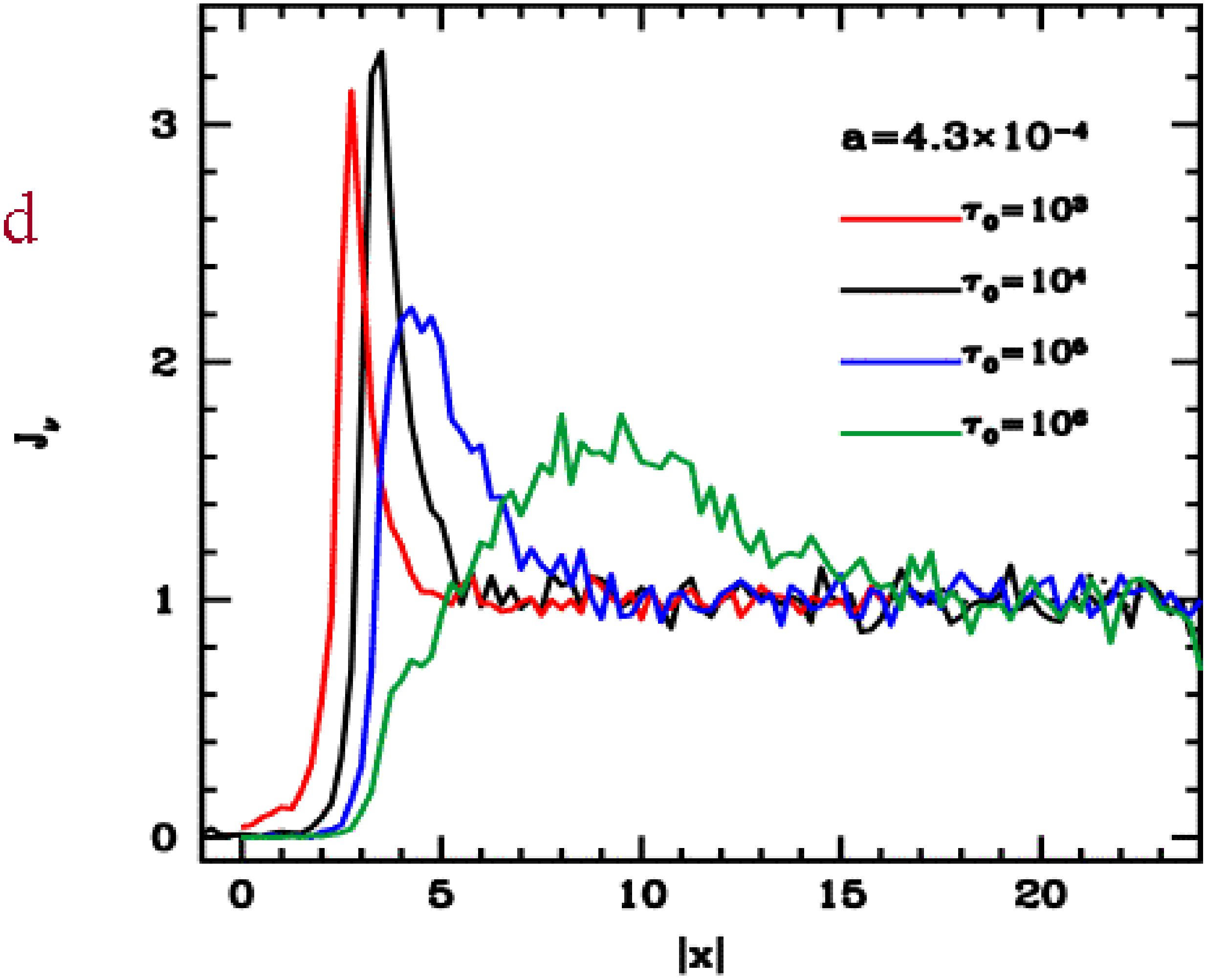
- Line formation in the surrounding medium is not considered
- Trough is very narrow: 0.3 A in rest frame

Line Profiles (3)

Continuum source at the center surrounded by hot ionized medium

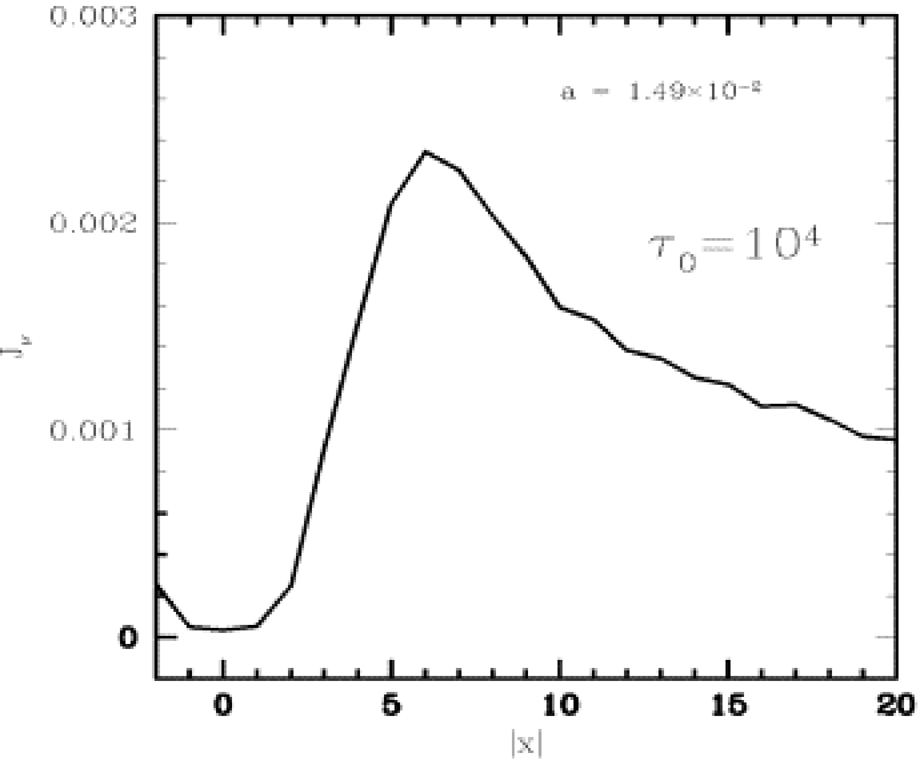
Broad absorption trough

$\Delta\lambda/\Delta x = 0.05$ A

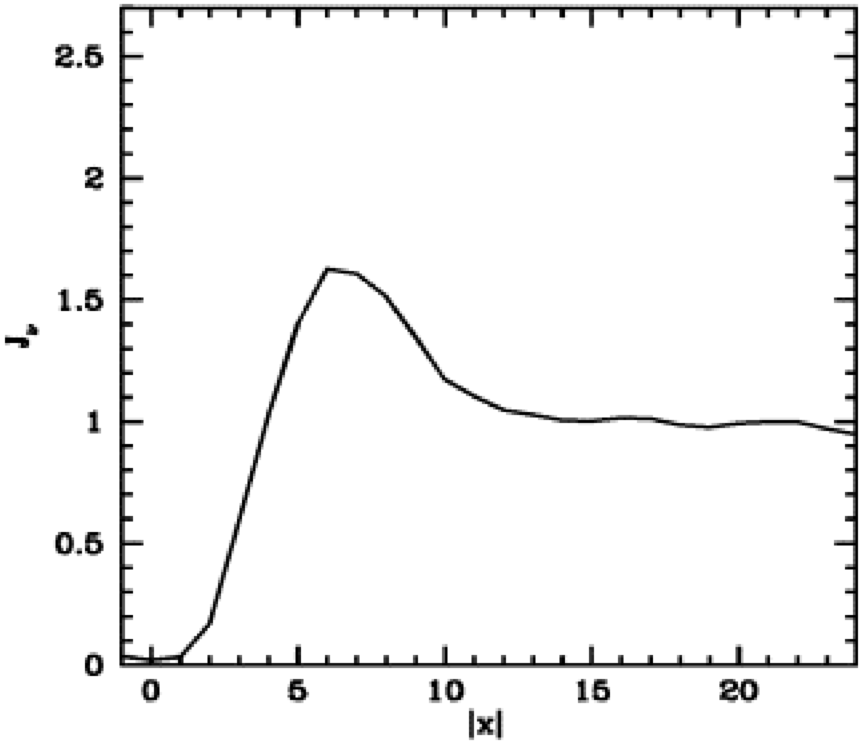


Application to Star-bursting Galaxies

Hot source with line + continuum in the center (early phase) → Trough + Double Peak



Line Source

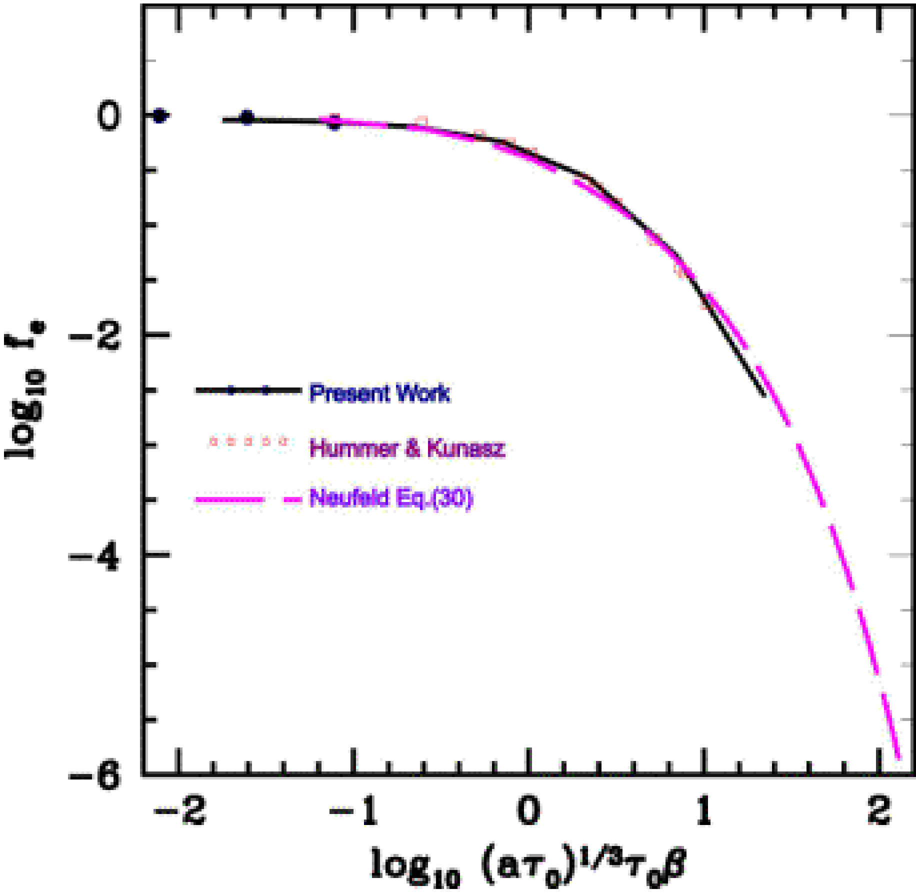


Continuum Source

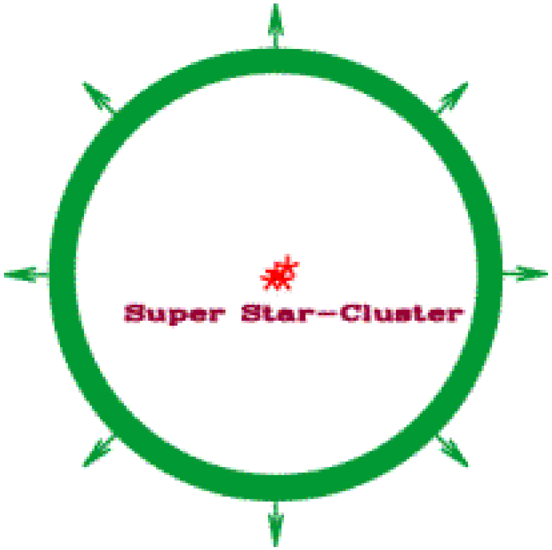
Effects of dusts

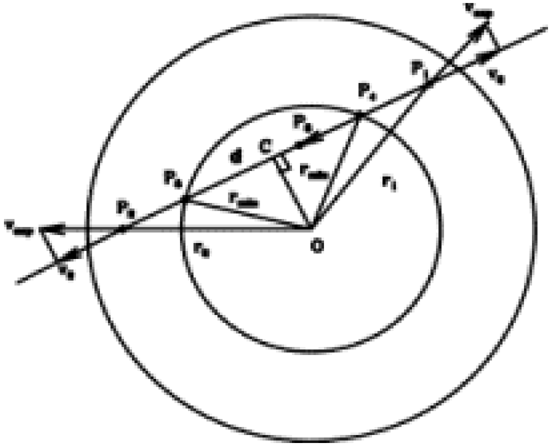
- Dust will probably destroy or significantly weaken the ‘double peak + trough’ components
- The kinematics should play important role in line shape as well as strengths

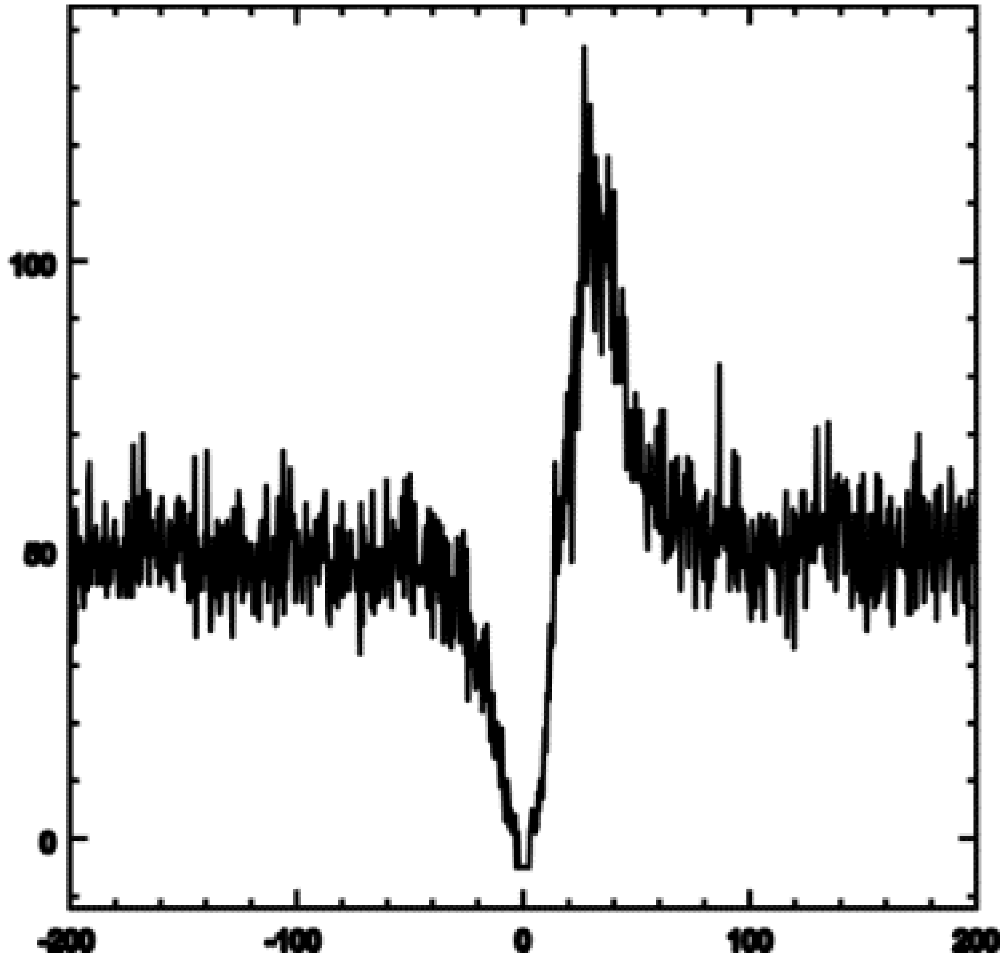
(P Cygni profiles are less prone to dust absorption)



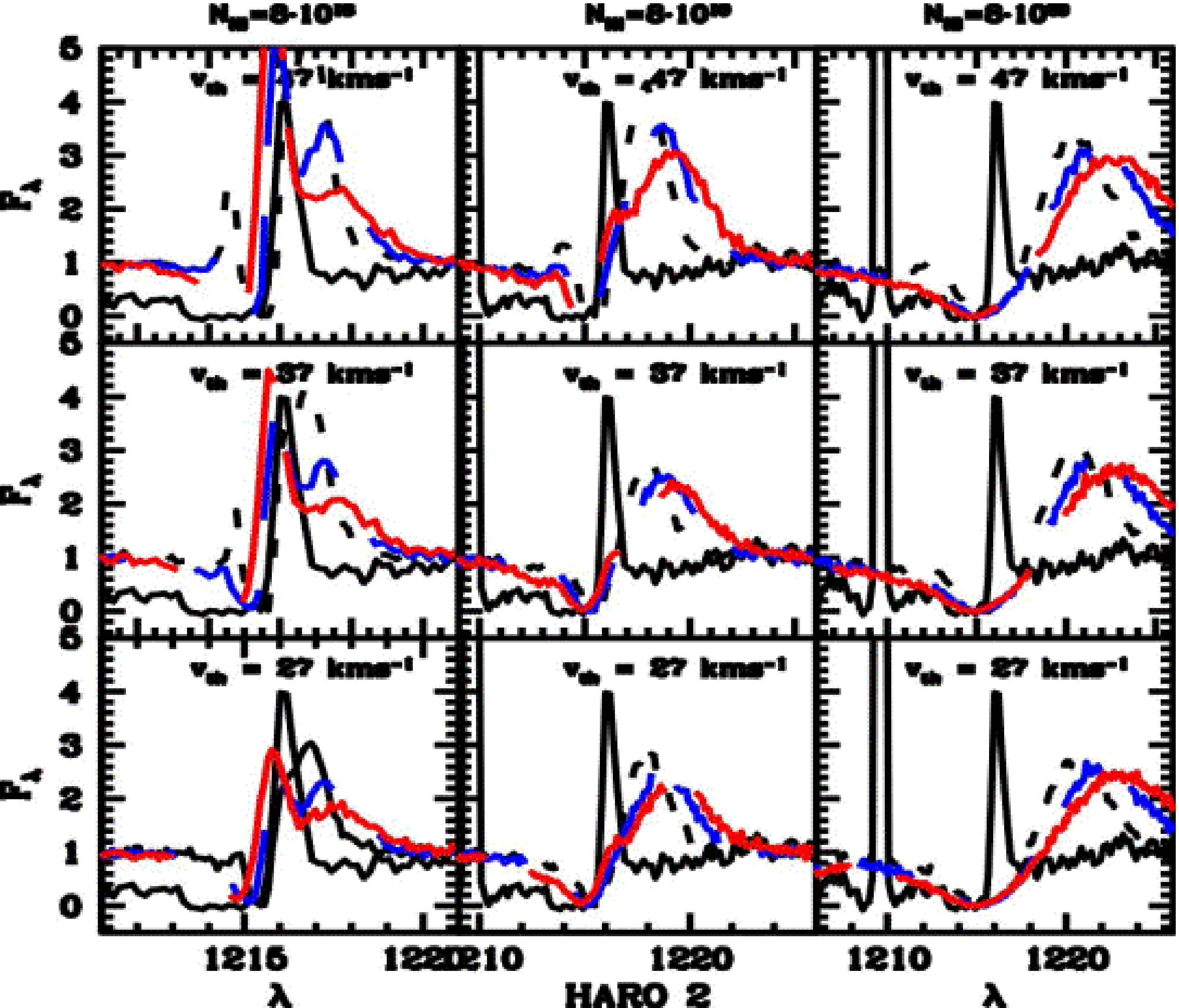
Lyα from expanding shell







Examples of Fitting



Parameters:

expansion vel, thermal width, and optical depth.

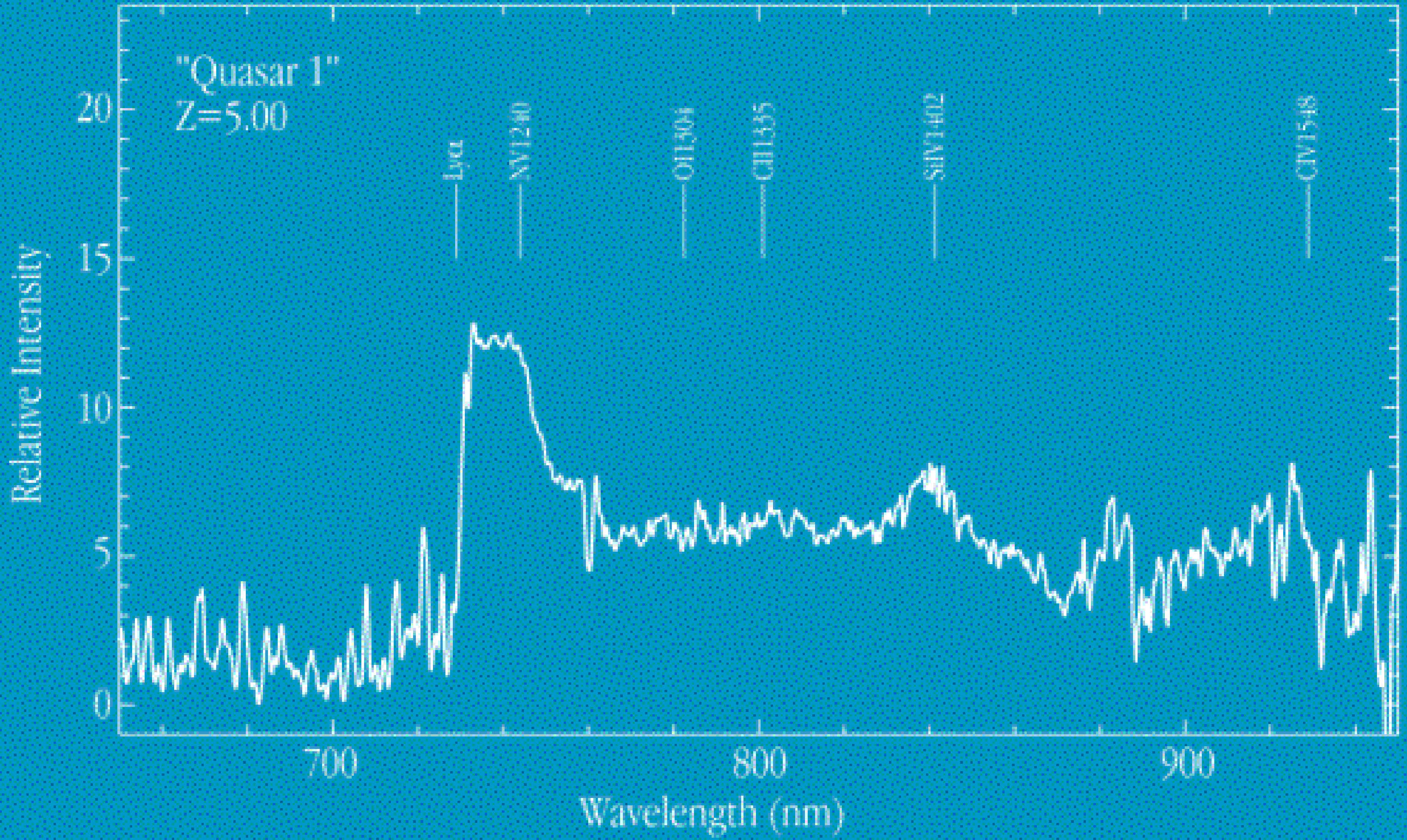
Red: 100 km/s

Blue: 200 km/s

Black: 300 km/s

Our best-fititng N_H is smaller than previous estimates

Blending or backscattering?



Spectrum of Quasar at Z=5.00 (VLT UT1 + FORS1)

ESO PR Photo 14c/99 (27 February 1999)

Summary and Future Works

- We have developed a ‘tool’ to compute the Lyα line transfer in thick medium
- The derived parameters are often quite different from simple fitting results
- Effects of dust should should be more carefully investigated
- Observed line profiles will be analyzed more carefully