Numerical simulation of line profile variation in roAp stars

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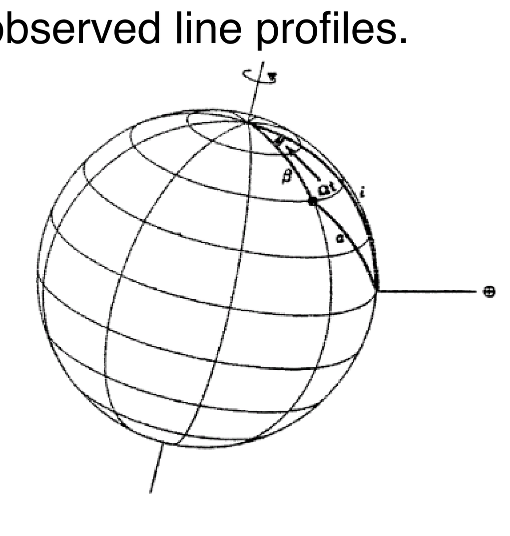
Introduction

Prior to the last decade, most observations of roAp stars have concerned the light variations. Recently some new, striking results of spectroscopic observations with high time resolution, high spectral dispersion, and high signal-to-noise ratio became available. Since the oscillations found in roAp stars are high overtones, the vertical wavelengths of the oscillations are so short that the amplitude and phase of variation of each spectroscopic line are highly dependent on the level of the line profile. Hence the analyses of variation of spectroscopic lines of roAp stars potentially provide us with new information about the vertical structure of the atmosphere of these stars. In order to extract such information, numerical simulation of line profile variation beyond a single-surface approximation is necessary. We carry out numerical simulation of line profile variation by taking account of finite thickness of the line forming layer. We demonstrate how effective this treatment is, by comparing the simulation with the observed line profiles.

Physical properties of the equilibrium model

$M/M_\odot$	$R/R_\odot$	$L/L_\odot$	$T_{\rm eff}$	X	Z
2.0	1.64	14.7	8800 K	0.73	0.02

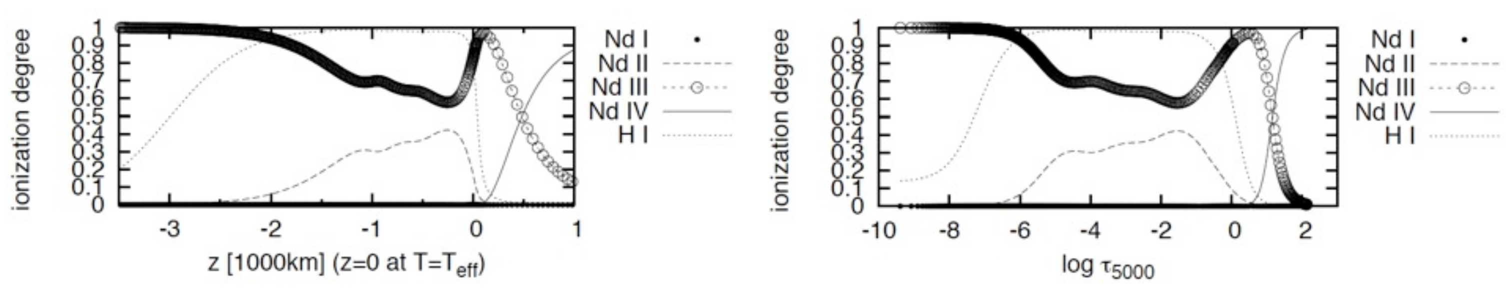
rotation period : 10 days
pulsation mode : l=1,m=0 (dipole mode)
oscillation period : 5~20min



i : rotation axis to observer
β : pulsation axis to rot. axis

Outline of procedure

step 1. Construct a static LTE model atmosphere (2Msun)

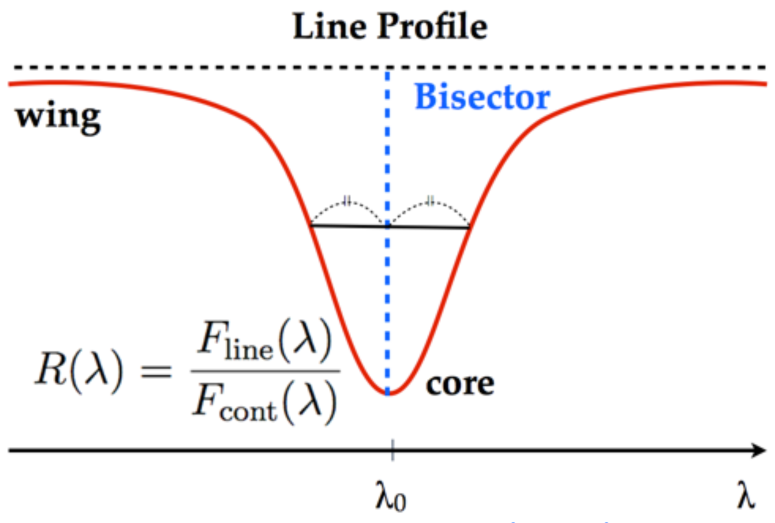


step 2. Solve the transfer eq. to compute spectral line shape

2a. compute continuum opacity

2b. choose a line and compute the line opacity

2c. calculate $R(\lambda)=F_{\rm line}(\lambda)/F_{\rm cont}(\lambda)$

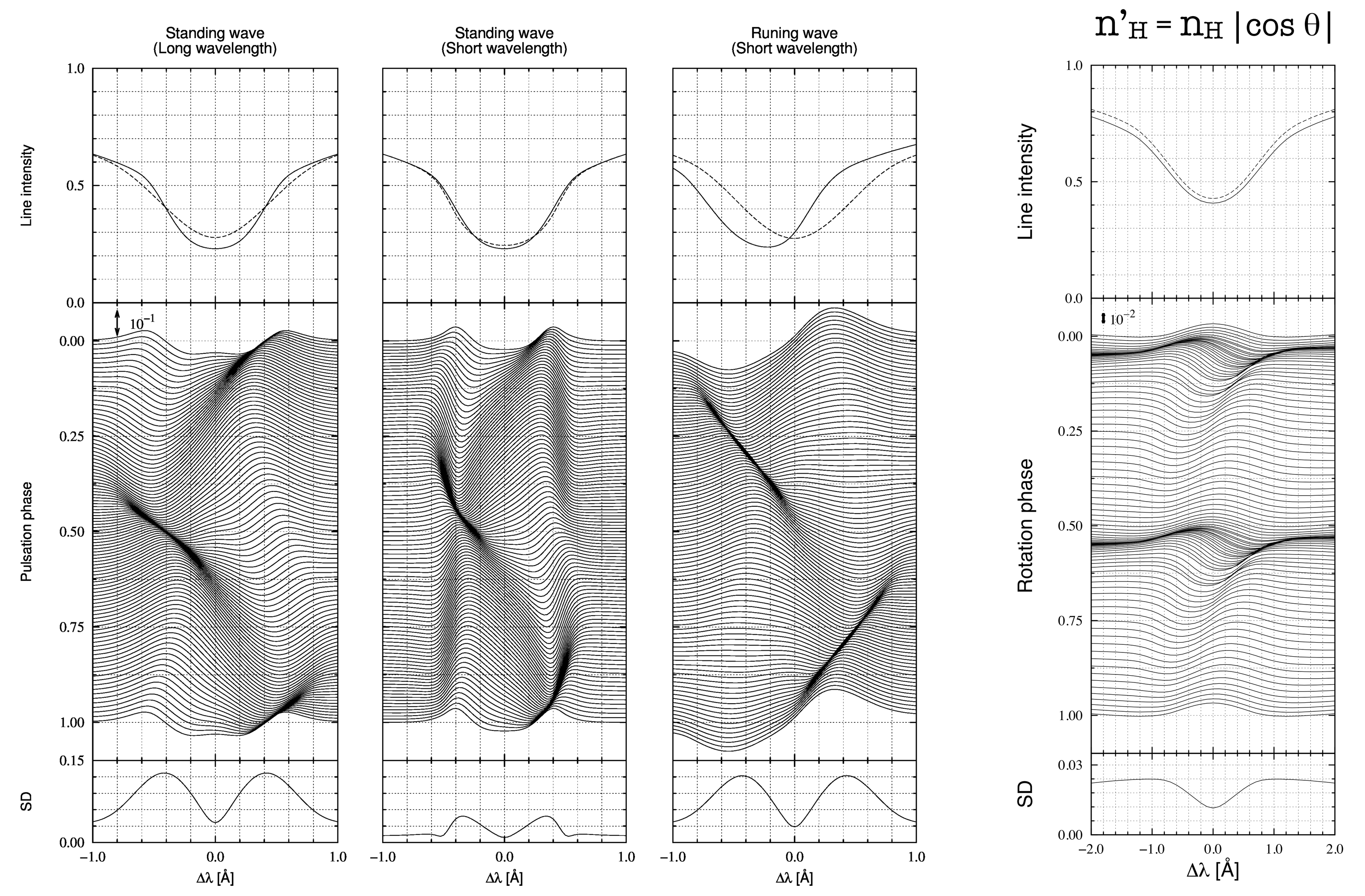


take account of
i) thermal broadening
ii) natural damping
iii) Stark effect
iv) macroscopic motion
v) Zeeman effect

step 3. take account of oscillation velocity field and lateral inhomogeneity

$V_{\rm osc}$ = sin(ωt) sin(ωt)cos(kz) sin(ωt-kz)

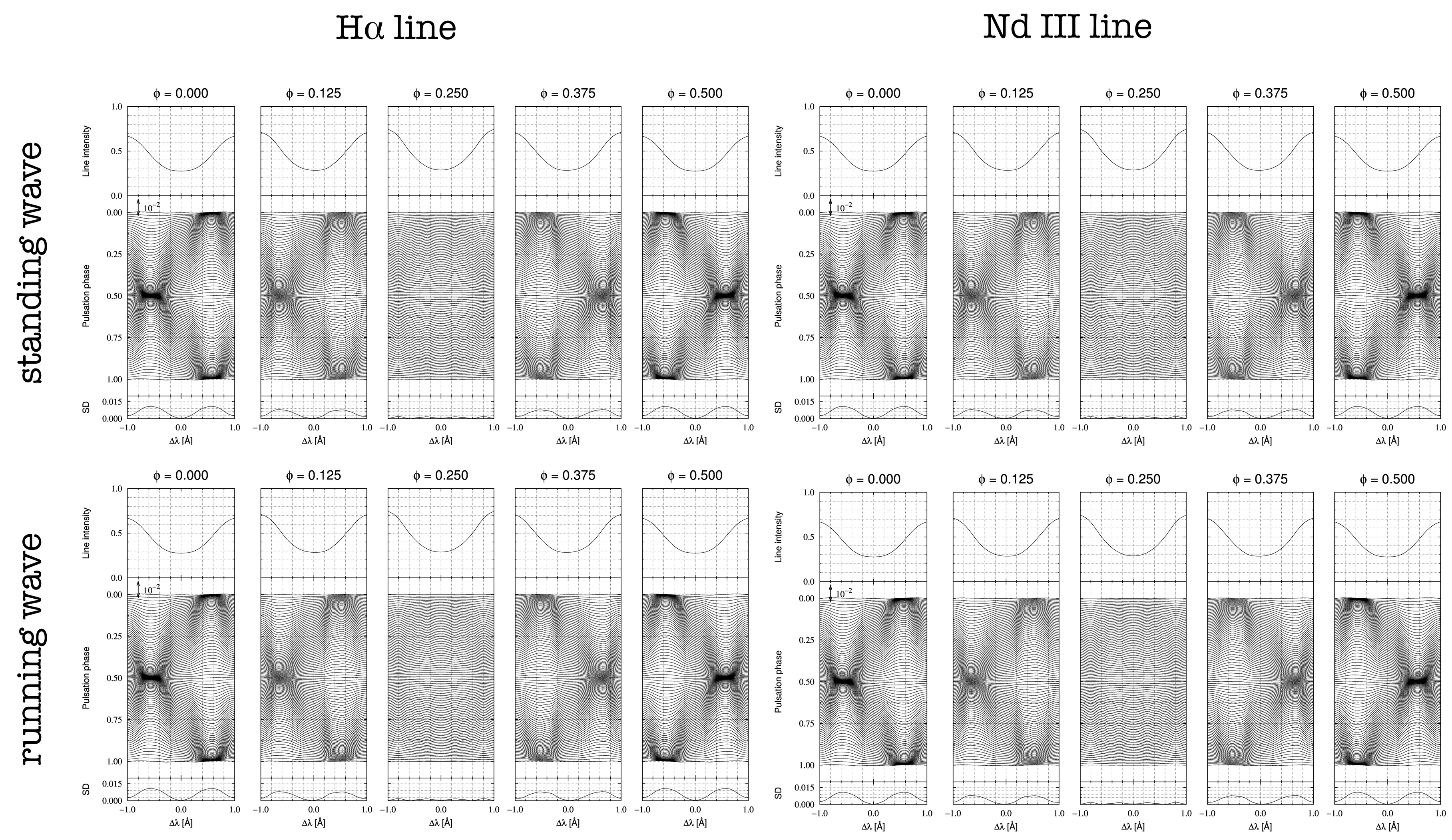
inhomogeneity
$n'_{\rm H} = n_{\rm H}\,|\cos\theta|$



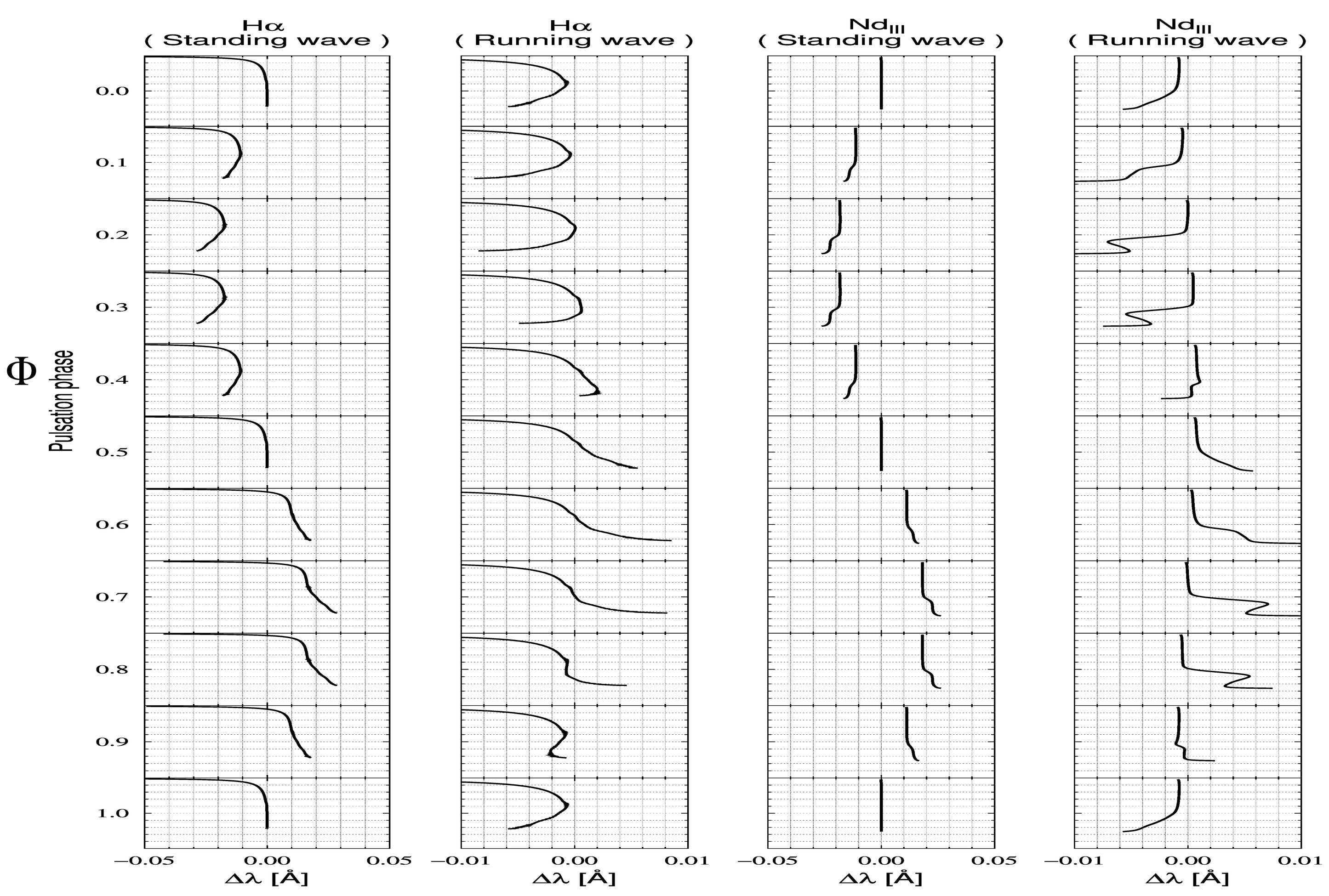
Results

Theoretically expected line-profile variation (LPV) of the Hα line(λ_0 = 6562.85[Å]), Nd III line (λ_0 = 6145.07[Å]) produced by an axisymmetric dipole mode (ℓ =1,m = 0) at a sequence of the rotation phase ϕ=0.0, 0.125, 0.25, 0.375 and 0.5 (from left to right).The rotation axis is assumed to be inclined with respect to the line-of-sight by 90°, and the symmetry axis of pulsation is assumed to be inclined with respect to the rotation axis of the star by 90°.In each panel, the differences between the individual profiles at a sequence of 100 pulsation phases and their mean are stacked with phase increasing downwards; above them is their mean, and below them is plotted their standard deviation. The abscissa is in units of angstrom. The left-hand ordinate scales refer to the phase of the oscillation, in units of the pulsation period.

Line profile variation & Bisector



Rotation phase Φ = 0.000



Summary

Simulation of LPV beyond single surface treatment is definitely necessary to get quantitative information of roAp stars from spectroscopic observations with high time resolution, high spectral dispersion, and high signal-to-noise ratio. This is a new information source of Ap stars, and is expected as a promising new tool of asteroseismology to probe 3-D structure of atmospheres of these enigmatic stars.

Goal

Our aim is to establish an inversion approach of LPV to probe Ap stars' atmosphere and pulsation.The present paper is the very first step for this purpose, and there is much room for improvement.

Road map to our goal.

- Levitation of chemical elements due to radiative pressure should be taken into account in model atmosphere.
- Zeeman effect should be taken into account in the calculation of line shapes of spectral lines.
- Nonadiabatic mode calculation should be done instead of adiabatic calculation.
- The effect of temperature perturbation should be taken into account in LPV calculation.
- More systematic calculation should be carried out for much more lines.