Physical properties of the BLR of AGN
Boltzmann-Plot vs. CLOUDY

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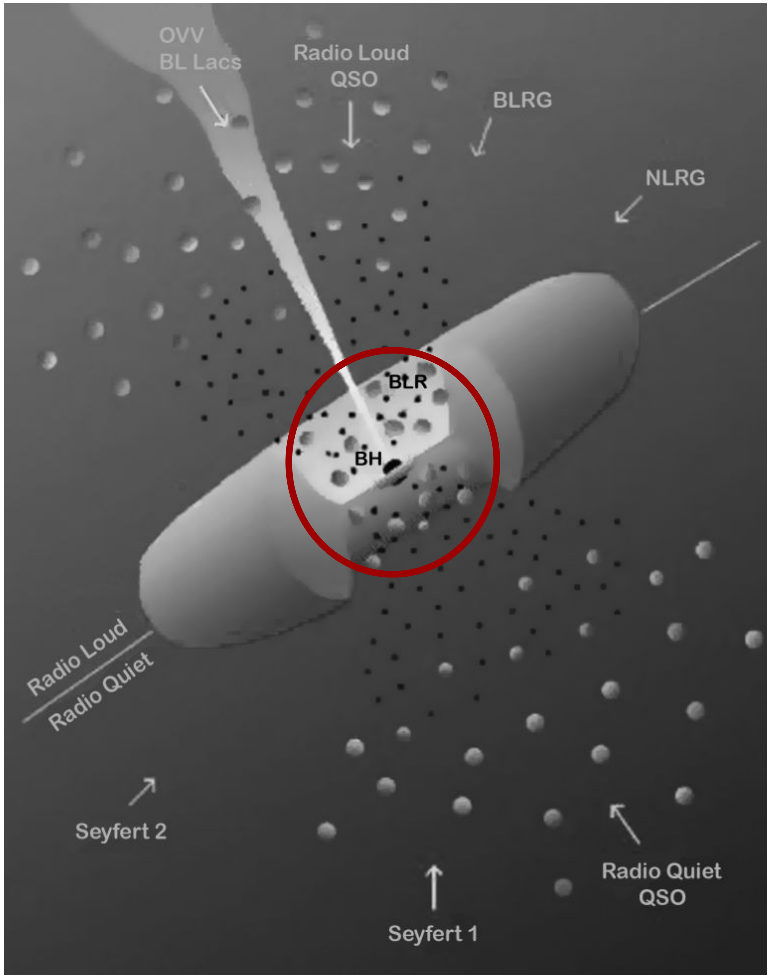
Active Galactic Nuclei (AGN)

- great luminosities
- emit on all λ
- strong emission lines
- consists of:
  - massive black hole
  - accretion disk
  - Broad Line Region BLR
  - Narrow Line Region NLR
  - torus and the jets



Problem to solve

- there is no **direct** method to measure T_e in the BLR of AGN!
- find such method (that would use only the observed spectrum) using theory, observations and numerical simulations
- photoionization code CLOUDY (Ferland 2006) – used for the numerical simulations

The Broad Line Region **(BLR)**

- **B**road **E**mission **L**ine
  (FWHM ~ up to 10,000 km/s
- dimensions ~ up to light-month
- photoionization (main heating source)
- $T_e \sim 10^4$ K $N_e \sim 10^9$-10^{12} cm^{-3}
- plasma conditions closer to stellar atmospheres than photoionized nebulae (Osterbrock 1989)

The Boltzmann Plot - **BP**

- optically thin plasma w/small changes in T_e & n_e (Griem 1997, Popović 2003, 2006)

$$I_{lu} \approx (hc/\lambda)\, g_u A_{ul}\, l\, (N_0/z)\, \exp(-E_u/kT_e)$$

- for lines from one spectral series (e.g.Balmer lines) if the population of upper states (n>3) has Boltzman distribution => T_e

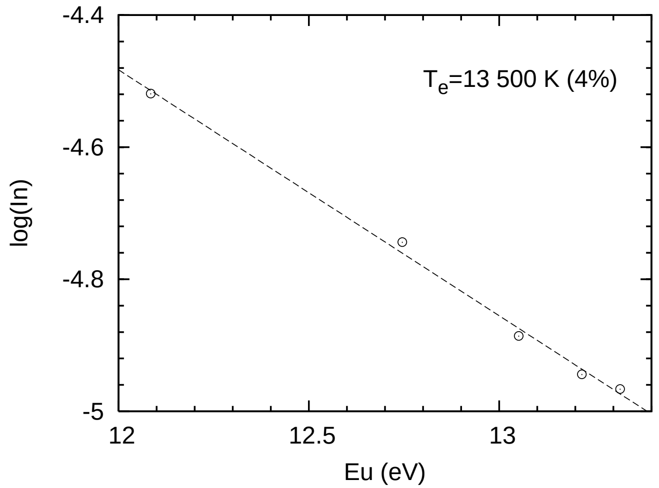
$$I_n = (F_{ul}\,\lambda)/(g_u A_{ul}) \quad => \quad \log(In) = B - A \cdot E_u$$

$$A = \log_{10} e/(k_B T_e)$$

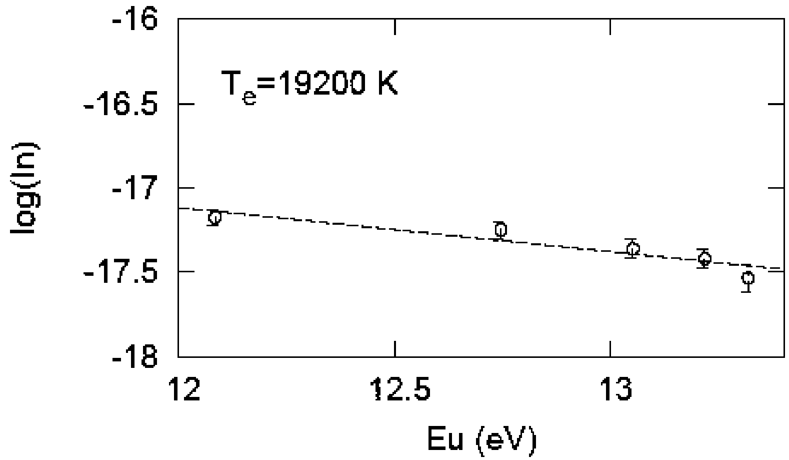
- assumption: lines are from the same region

The BP method – “cook book”

1. measure the emission line fluxes (e.g. 5 Balmer lines)
2. calculate the normalized intensities In
3. plot them versus E_u
4. if the fit error < 10-20%
   => Te from the slope
   => levels n>3 in PLTE



CLOUDY model



Ilić et al. 2006, MNRAS, 371, 1610

Our aims:

- to explore the parameter space with the CLOUDY code (Ferland 2006) and find the parameters for which the BP is a valid tool for temperature diagnostics

- to test the BP on the real data

The CLOUDY models

- produce grids of models for different pares of hydrogen gas density $n_H(cm^{-3})$ and hydrogen-ionizing photon flux $F_H(cm^{-2}s^{-1})$
- set a minimal number of input parameters
- apply BP on the model's results

The input parameters

- solar chemical abundances, constant hydrogen density, the code's AGN template for the incident continuum
- $\log n_H = [8, 12]$ $\log F_H = [17, 21]$
- fixed column density $N_H = 10^{23} cm^{-2}$

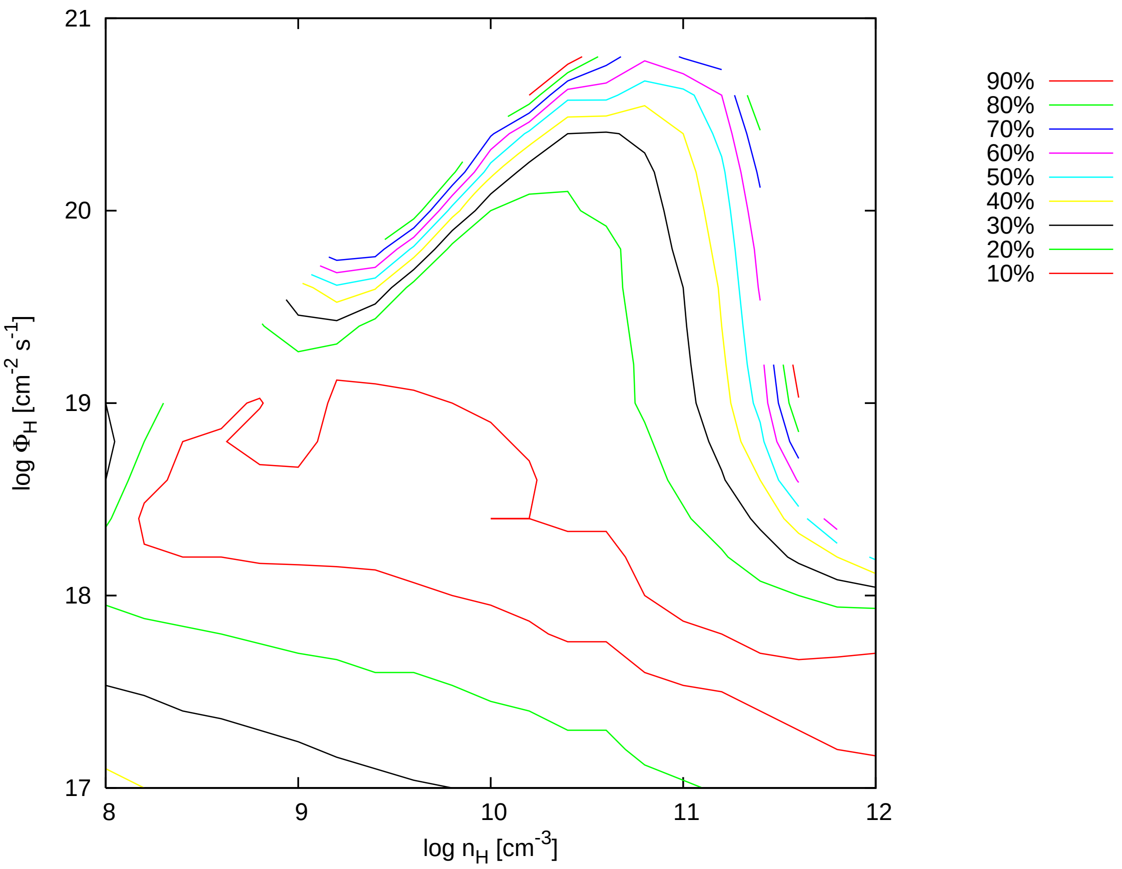
(Dumont et al. 1998, Korista & Goad, 2000, 2004)

The analysis

- take emission line generated by the code:
  - the Balmer lines,
  - HeII 4686, HeI 5876 (lines from two ionization states => their ratio is highly sensitive to T_e changes)
- apply the BP method on Balmer lines and calculate the BP temperature T_{BP}
- consider the average temperature T_{av} of the region (the value also given by the code)

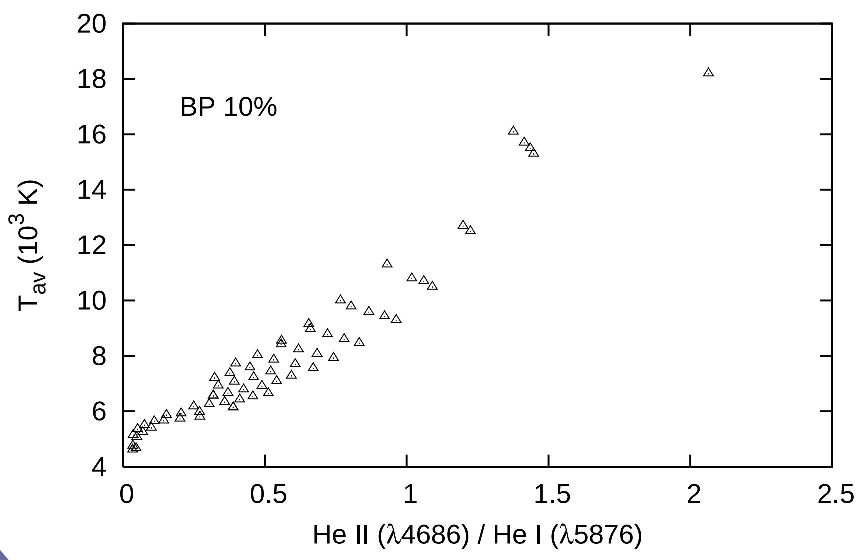
Results #1

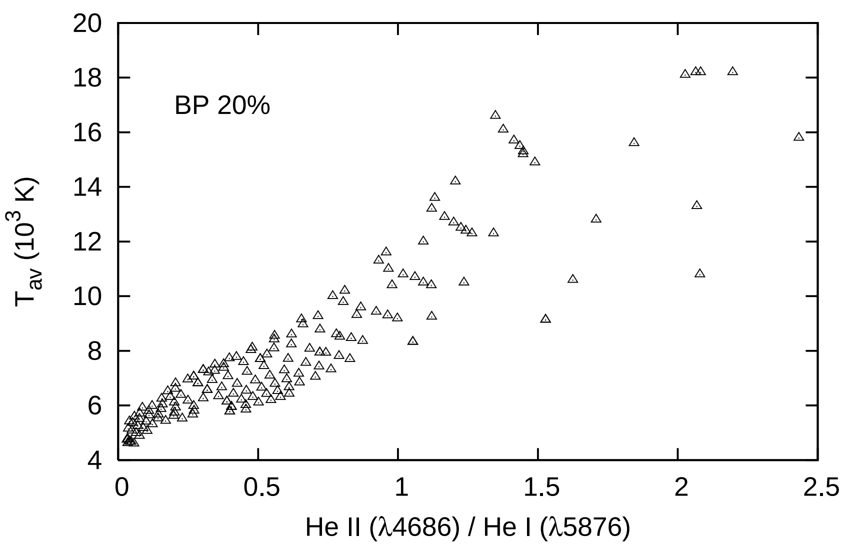
- χ^2 mapping
  (the error of the BP method applied on the model's results)



Results #2

- we then analyze only the results that have the BP error less then 20%
- T_{av} = A + B*R, where R=F(HeII)/F(HeI)

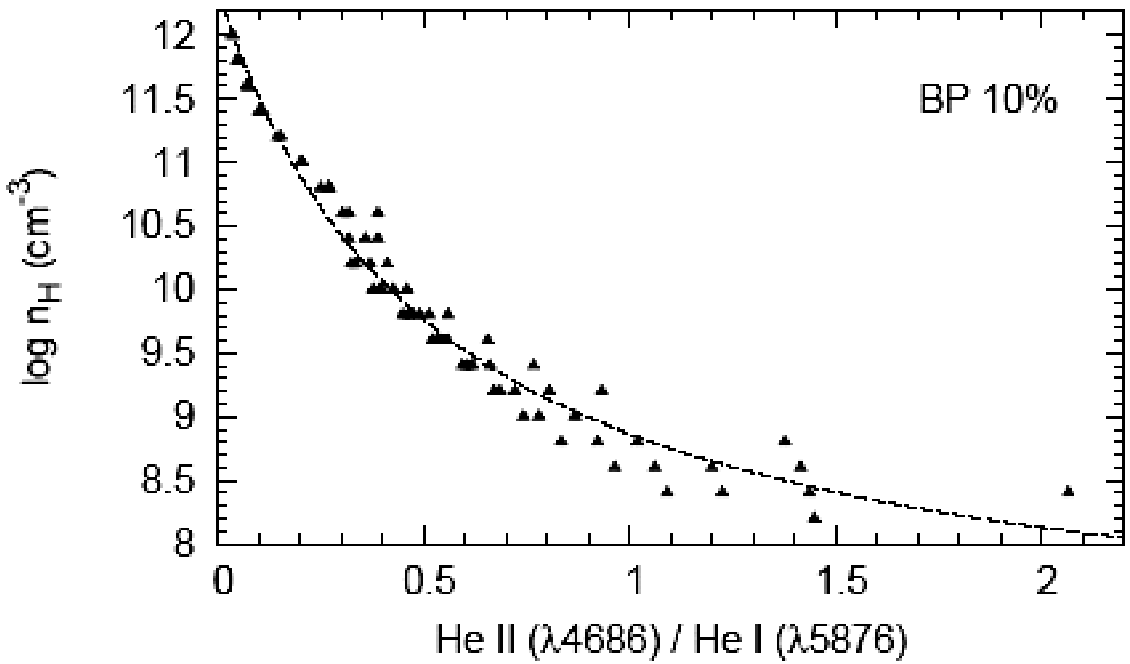




Results #3

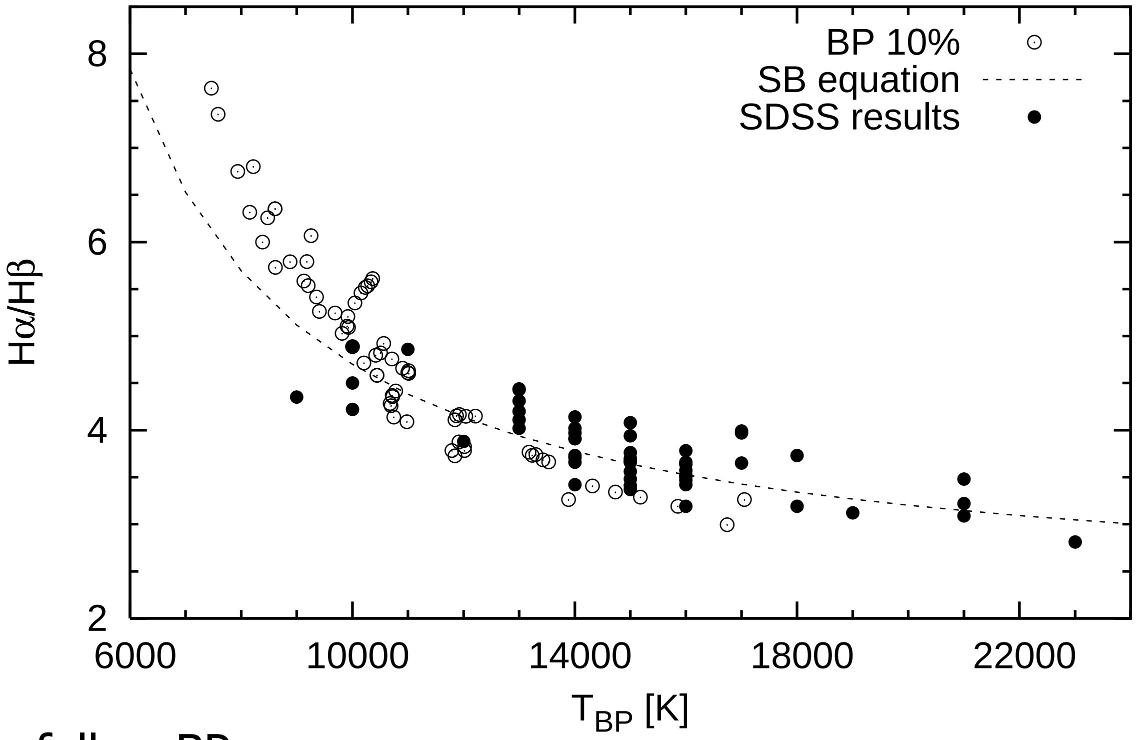
- $\log n_H = 7.00 + b/(c + R)$

R=F(HeII 4686)/F(HeI 5876)



Results #4

- $H\alpha/H\beta = f(T_{BP})$



1. BP 10%
2. Saha-Boltzmann eq.
3. 30% of SDSS sample follow BP
   (La Mura et al. 2007, sent to ApJ)

Some Conclusions

- **direct method**: from emission lines => T_e
- for a limited range of n_H - F_H parameter space the BP can be applied
- in the BLR could exists a thin zone described by Saha-Boltzmann equation where Balmer lines are forming
- **future work:** apply BP on real data (see how it correlates with other AGN properties)

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