

Radiative Transfer in Supernova and its application to Cosmic Recombination Epoch

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Basic Framework

- Radiative Transfer Equation (Mihalas, 1970)
 - ✓ Contains the distribution function for the photons.
 - ✓ Takes into account the scattering, emission and absorption in the system due to different atomic processes, which is together known more commonly as opacity.
- Rate Equations for different species
 - ✓ Coupled to Transfer Equation since Rates depend on the radiation intensity.
 - ✓ Simplifies to Saha Equation under local thermal

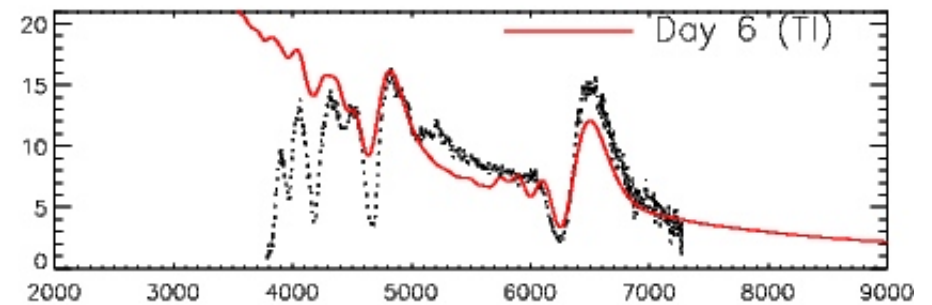
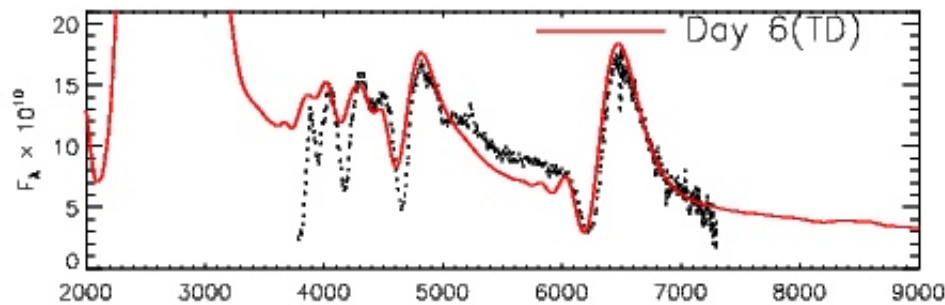
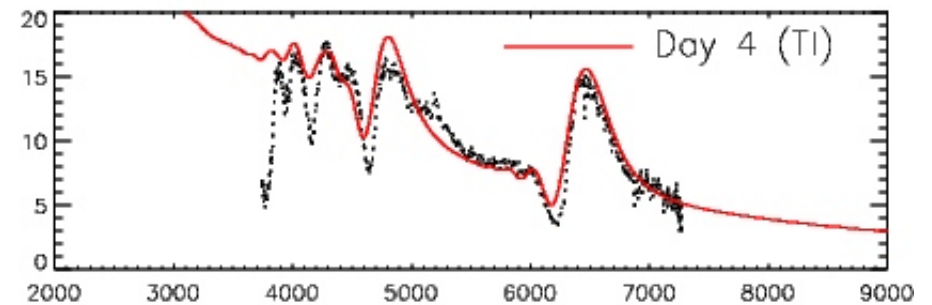
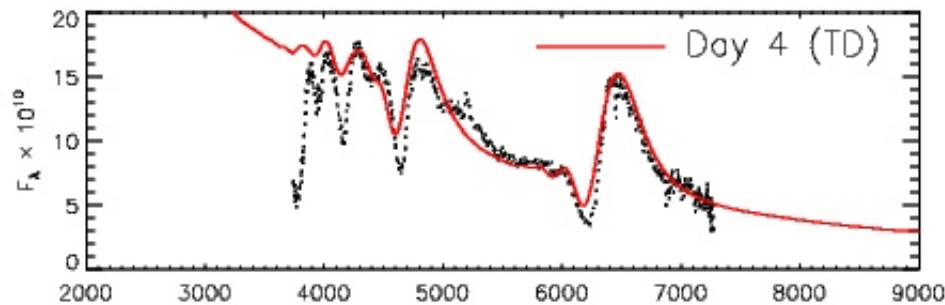
Motivation behind studying recombination time in supernova atmosphere

- Utrobin and Chugai (2005) proposed that time dependence in the rate equations of supernova is important due to the increase in the recombination time (compared to the age of the supernova) in supernova atmospheres.
- The recombination issue was probably first addressed by Peebles and Zeldovich in 1960s in the context of cosmology

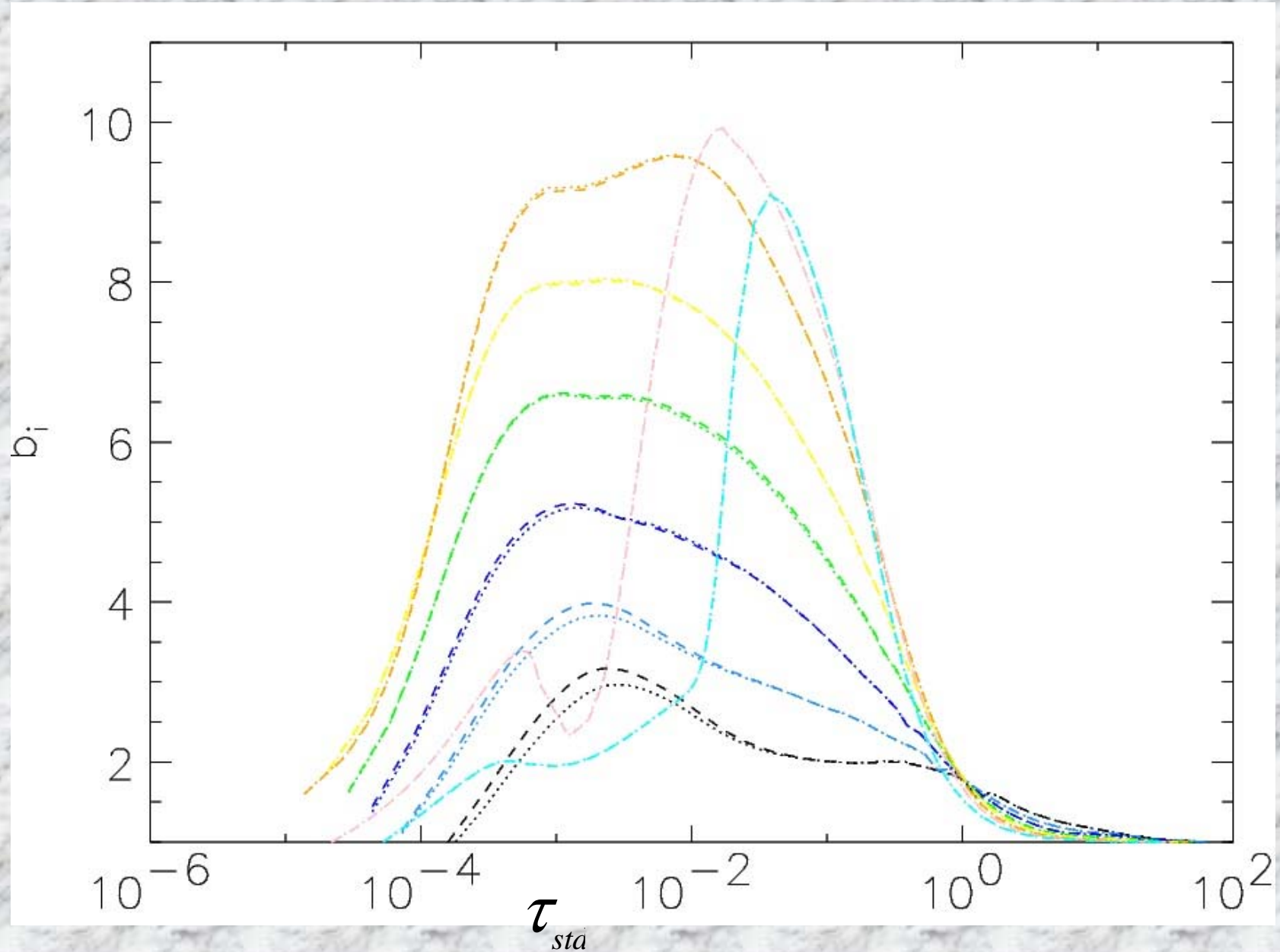
Outline of our work on supernova

- An advanced Generalized Model Atmosphere code (PHOENIX) has been developed over many years (by P. Hauschildt and E. Baron).
- Implemented time dependence in the Rate Equations for different species.
- Also included the non resonant processes between 2s and 1s processes that are important to the hydrogen recombination

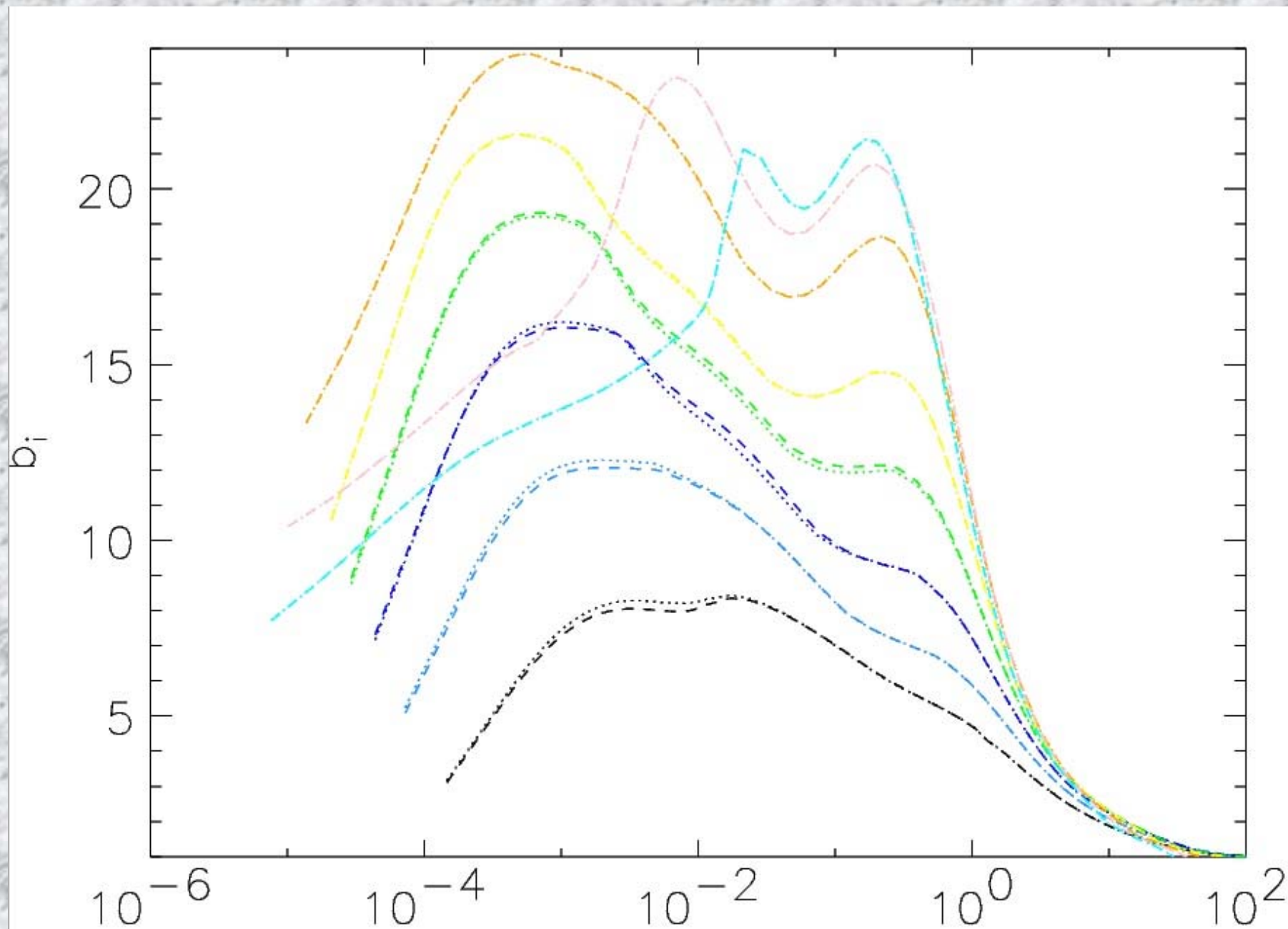
SN1987A Early Spectra (31 level Hydrogen in NLTE, metals in LTE) and Balmer profile



Results on Departure Coefficients (n=1)



Results on departure coefficients (n=2)



Conclusion on importance of time dependence in Supernova

- We generated synthetic time dependent spectra for SN1999em and SN1987A from the explosion to 40 days and 20 days respectively.
- Time dependence is important in the early phase of the supernova and this transient phenomena does not have significant effects in later times.
- Our result agrees with the claim of Utrobin and Chugai that time dependence has strongest effect in early time. Our results do not agree with more recent work by Dessart and Hillier (2008) who claim that time dependence is important as late as 48 days (since explosion in the case of SN1999em).
- Spectral features that were claimed to work better in late times only by introducing a time independent model could be generated using a modified density profile.

Transition to Cosmology

- We have a good Radiative Transfer code that is time dependent in both Transfer equation and Rate equation.
- This framework will follow the radiation field and the electron fraction as a function of time in the recombination era.
- One can hope to see detailed distortions in the CMB due to the details of recombination

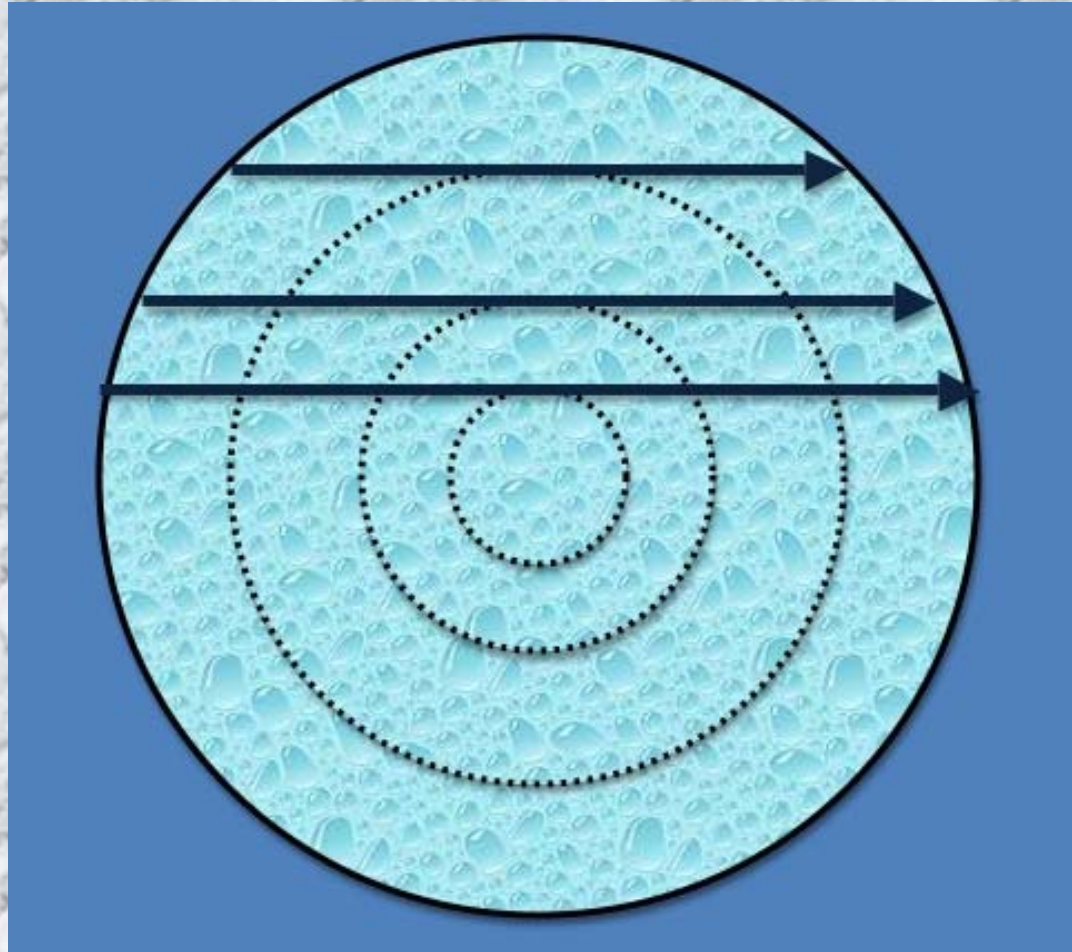
Basic Framework (Cosmology)

- **Time Dependent** Radiative Transfer Equation
 - ✓ Contains the distribution function for the photons.
 - ✓ Takes into account the scattering, emission and absorption in the system, or together known more commonly as opacity.
- **Time dependent** Rate Equations for different species
 - ✓ Coupled to Transfer Equation since Rates depend on the radiation intensity.
 - ✓ Simplifies to Saha Equation in LTE
- WMAP predicted geometry of the universe,

Looking at the Recombination Epoch

- Start at redshift much larger than that at recombination so that matter and radiation are strongly coupled and one can equate matter and radiation temperatures.
- Recombination will separate matter and radiation.
- Solve for the transfer equation to calculate the radiation temperature.
- Calculate the matter temperature using energy conservation.
- Move to the next time step inside the recombination era.

Begin to Solve for Radiation and Matter temperature (simplistic geometric picture)



How to get Matter Temperature from Radiation Temperature at z around z_{rec}

- Energy lost by Matter = Energy loss in line and Continuum transitions whose rates are calculated using J (and not B) +Compton scattering+Thompson scattering.
- Once one finds this matter temperature, solve for the transfer equation at a new time step.
- Get useful early universe signatures