Summary of the parallel session GB3

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In this proceedings, we give a brief general overview of the parallel session on photospheric emission in gamma-ray bursts (GRBs), which took place during the online 16$^{\text{th}}$ Marcel Grossmann Meeting. The session covered theoretical and observational aspects of photospheric emission. In particular, spectral, temporal and polarization properties were discussed.

Keywords: Gamma-ray bursts, Photospheric emission, Thermal emission, Non-thermal emission, Jet simulations.

1. State of the art

Photospheric emission models are seen as prime contenders to explain the prompt phase of gamma-ray bursts, see *e.g.*[1] for a review. This emission is produced when the expanding jet becomes optically thin to Compton scattering,[2] which is the dominant interaction mode for photon of comoving energy $\sim$ 1keV. Photospheric emission is a naturally expected process in the widely discussed fireball model.[3–6] It can be highly efficient if the transparency takes place at small radius, that is to say close to the transition radius between accelerating and coasting phase,[3,7–9] and it naturally predicts a clustering of the spectral peak energy around 500 keV.[10]

It has long been known that photospheric models in their simplest flavors fail to explain the shallow low energy spectral slope seen in most GRBs.[11–15] This picture changed in the past 15 years when it was realized that the spectra produced at the photosphere can be highly non-thermal due to 1- energy dissipation below the photosphere either via shocks,[16–18] magnetic reconnection[19–22] or neutron decay,[23] and 2- geometrical effects due to the structure of the jets[24,25] and the photon last scattering position.[11,14,23]

The aforementioned effects are difficult to study analytically, as any analysis depends on ad hoc assumptions on the geometry of the jet, dissipation mechanisms and their localization. In recent years, 3D (GR) MHD simulations coupled to Monte-Carlo radiative transfer calculations were designed to study photospheric emission in the context of GRBs solve those opens issues.[26–33] One of the most interesting finding is that the luminosity drop for off-axis observers is limited by the structure of the jet.

Moreover, the simulations were successful in reproducing correlations between observer position, luminosity, peak energy, and observed polarization. In particular, several important successes were obtained in explaining the Amati correlation[34] (between the isotropic total energy $E_{\rm iso}$ and the peak energy $E_{\rm p}$), the Yonetoku correlation[35] (between the isotropic luminosity $L_{\rm iso}$ and $E_{\rm p}$) and the Goletneskii relation[36] (between the luminosity and $E_{\rm p}$) by considering a distribution of off-axis observers.

Finally, the simulations permitted to obtain detailed polarization predictions. In particular, it was found from numerical simulations of photon propagation inside a jet that a high degree of time-resolved polarization requires off-axis observers, while the polarization for on-axis observers is lower.[37–39] Using a semi-analytical jet model, it was found that the polarization degree correlates to a substantial drop in luminosity.[37,40] Instead, recent hydrodynamical simulations[38,39] showed that the drop in luminosity for observer angles might be smaller than expected thanks to emission from the jet cocoon. Extending the analysis to lower frequencies it was shown that the polarization degree is larger at low energies, either thanks to the effect of synchrotron emission[41] or due to higher scattering angle towards the observer.[39]

Despite these many successes, the correlation analysis is limited to a few initial setups because of the large resources needed for each independent simulations and their post-processing analysis. In the forthcoming years, the reliability of the already obtained correlation results will be tested and refined against many more runs with different initial conditions and methods. In addition, the simulations are not yet mature enough to produce detailed spectral predictions, which could be confronted to observed data.

Concerning the spectral analysis in the context of photospheric emission, two different paths were explored in the past few years. First, detailed time-resolved spectral analysis of GBM data from many bursts were performed.[42–44] Specifically, the spectra were fitted with a cut-off power-law and the obtained low energy slope distribution were carefully investigated. It was realized that many bursts have one to several time bins with spectra harder than the limits from the synchrotron line of death. These studies concluded that photospheric emission should be the mechanism at work in those bursts, textbfsee however[45].

Second, simplified photospheric models, such as the DREAM model,[46,47] were directly fitted to observed GBM spectra[48] finding 1- good agreement for the bursts with the hardest low energy slope when considering the photospheric emission taking place at the transition between accelerating and coasting phase, and 2- good overall agreement with other bright bursts, when considering localized energy dissipation. It is expected that those studies will be extended to larger sample and refined models in the near future.

2. Talks at the session

The session was run in two blocks of three hours.

Asaf Pe'er delivered a review talk "Understanding prompt emission: where do we stand?" where he summarized basic observational information about the prompt emission and problems originating from misconceptions which are related to usage of models (including the progenitor, jet launching, dynamics and dissipation), the nature and dynamics of the outflow (e.g. baryonic vs. magnetic) and the radiation mechanisms (e.g. photospheric vs. synchrotron). He also discussed the spectral and polarization properties of non-dissipative photospheric emission, and its ability to explain observed correlation. Finally, he mentioned a new model of the prompt emission based on backscattering of the seed photons on a cold relativistic cork which appears natually in front of the jet in many progenitor models.

Ore Gottlieb presented a talk "Probing the jet launching mechanism from prompt emission of GRBs" where he described the ways to infer the information on the jet launching mechanism and its dynamics from the comparison of observations with numerical simulations of jet propagation and its the photospheric emission, focusing specifically on the role of magnetization of the jet. In particular, based on numerical hydrodynamic simulations, including self-consistent simulations within the collapsar model, he discussed and ability to produce jet tilt, intermittency, position of the magnetic dissipation region, and the role of different progenitors in jet launching and cocoon formation.

Gregory Vereshchagin reported a study "Diffusive photospheres in gamma-ray bursts" describing the results of the application of the theory of photospheric emission to the thermal radiation, detected in the early afterglows of some gamma-ray bursts. The inferred Lorentz factors of the outflow are clustered in two groups: few hundreds, indicating classical photospheric emission from ultrarelativistic outflow, and few tens, indicating diffusive regime of the photospheric emission, possibly from jet cocoons.

Tyler Parsotan delivered a talk "Monte Carlo Simulations of Photospheric Emission in Gamma Ray Bursts" in which he described the MCRaT code and its coupling to relativistic hydrodynamical simulations in order to obtain mock observations. He discussed how his code allows him to obtain predictions of the photospheric model, in particular prediction about optical prompt percursors of gamma-ray bursts.

Hirotaka Ito presented results on "Numerical simulations of photospheric emission in GRBs" focusing on the jet structure and its consequences for spectral shapes, polarization signal and correlations between observed quantities, based on hydrodynamical simulations and post processing with the radiative transport.

Yan-Zhi Meng reported the talk "Photosphere emission spectrum of hybrid relativistic outflow for gamma-ray bursts", considering both impulsive injection and continuous wind cases.

J. Michael Burgess in his talk "Spectroscopy of GRBs: Where are we now?" discussed how fitting physical models, instead of phenomenological ones, is important in order to infer physical information from observations. He mentioned several "myths" about the synchrotron emission model such as the line-of-death and width problem and showed how proper folding through the response function of the instruments demonstrates viability of this model.

Hüsne Dereli-Bégué presented a talk "Classification of Photospheric Emission in sGRBs" where she discussed the fit of a large sample of short GRBs with a phenomenological model based on a non-dissipative photosphere model. The main conclusions are that nearly one third of the spectra are consistent with purely thermal emission, and that a large fraction of bursts may come from subphotospheric dissipation.

Björn Ahlgren discussed "Subphotospheric dissipation evaluated using joint Fermi-Swift observations" and pointed out the importance of using XRT data in addition to the BAT data from the SWIFT satellite, in order to distinguish between photospheric and synchrotron mechanisms of emission in the context of fitting of dissipative photospheric model to the data, focusing specifically on the DREAM model.

Liang Li reported on "Bayesian Time-resolved Spectroscopy of Multipulse GRBs: Variations of Emission Properties among Pulses" where he discussed construction of the catalogue of multipulse bursts, the fitting procedure and the outcomes. In particular, he discussed different trends and correlations between observed quantities such as $F - \alpha$ and $F - E_p$.

The outcome of the discussion with participation of Gregory Vereshchagin, Pe'er Asaf, J. Michael Burgess and Damien Begue is that generally speaking about gamma-ray bursts, despite strong progress both in theory and in observations there are still many unresolved issues such as the origin of the jet, the mechanism of energy dissipation, and the nature of observed variability.

The field is observationally driven, with new recent observational results such as the "anomalous" X-ray behavior of GRB 170817A and the detection of very high energy emission from several sources such as GRB 190114C. However, there are some key observational results, which still need explanation from the theory, in particular the strong spectral evolution within each pulse, the power-law decay of the peak energy, the time evolution of the temperature and so on. From the observational viewpoint, one of the most promising direction is the study of polarization of gamma-ray bursts.

3. Conclusions

To conclude, many critical progresses were made and problem addressed in the past few years. In particular, theoretical and numerical predictions start to be mature enough to allow direct comparison to observations, either via direct spectral fitting or via comparison to the global population parameters. It is expected that this trend will continue, allowing for a refinement of the photospheric emission theories, a better understanding of the data and of gamma-ray bursts.

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