Final Report for Páll Jakobsson (01/10 2008 – 30/09/2011)

1. FINAL PUBLISHABLE SUMMARY REPORT

The research program focused on using gamma-ray bursts (GRBs), the most energetic cosmic explosions since the Big Bang, as probes of the high-redshift Universe, star-forming galaxies at various redshifts, and the star formation history of the Universe. Due to their immense brightness, GRBs can be seen across great distances, even through the dust and debris that can exist within their host galaxies. This implies we can use GRBs to locate galaxies and stars at the very edge of the Universe. Since light can only travel at a finite speed, this also means we are exploring the infant Universe. Hence, GRBs can actually provide us with information on when the first stars were born. One aspect of our research was focused on this subject: to systematically search for these far away GRBs and use them to probe the very early Universe and the start of star formation.

Originating in the core collapse of massive stars and visible to huge distances, GRBs offer a unique tool to probe the evolution of the early Universe. This project was aimed at better understanding the reionization of the Universe and the star formation over cosmic time. The *Swift* satellite and its ability to rapidly and accurately locate 100 GRBs/year made this feasible. It was complemented with comprehensive follow-up programmes on a number of telescopes, e.g. the Very Large Telescope (VLT).

To meet the goals of the proposal, we obtained more than 500 hours of observations on various telescopes, analyzed the data and published the results in more than 35 papers in peer-reviewed journals. Two of the key results were published in Nature and Science in 2009 and 2011, respectively:

GRB 090423: The Farthest Explosion Yet Measured. An explosion so powerful it was seen clear across the visible universe was recorded in gamma-radiation on 23 April 2009 by NASA's orbiting *Swift* observatory. Farther than any known galaxy, quasar, or optical supernova, this GRB was clocked at redshift 8.2, making it the farthest explosion of any type yet detected. Occurring only 630 million years after the Big Bang, GRB 090423 detonated so early that astronomers had no direct evidence that anything explodable even existed back then. The faint infrared afterglow of GRB 090423 was recovered by large ground telescopes within minutes of being discovered. An exciting possibility is that this GRB occurred in one of the very first generation of stars and announced the birth of an early black hole. Surely, GRB 090423 provides unique data from a relatively unexplored epoch in our Universe and a distant beacon from which the intervening universe can be studied.

A Supermassive Black Hole Caught Devouring a Star. On 28 March 2011 *Swift* detected an extremely luminous panchromatic outburst from the nucleus of a distant galaxy. The only explanation that so far fits the size, intensity, time scale, and level of fluctuation of the observed event, is that a massive black hole at the

very centre of that galaxy has pulled in a large star and ripped it apart by tidal disruption. The spinning black hole then created two jets one of which pointed straight to Earth. Originating 3.8 billion light years from Earth in the direction of the constellation of Draco, the beam consisting of high energy X-rays and gamma-rays remained brilliant for a period of weeks after the initial event. As more and more material from the doomed star crossed over the event horizon, bright flares erupted signaling its demise.

The main benefit of the project has simply been a better understanding of the nature and evolution of galaxies spanning a very broad redshift distribution. To be more specific:

- Our program has produced a well-defined, statistically useful sample of GRBs with measured distances, metallicities and extinction curves which in turn have lead to a considerable improvement in our understanding of the redshift distribution, luminosity function, energetics, and link to the star-formation history of the Universe.
- We have fully exploited the potential of the VLT and opened the way to securing high-quality spectra of crucially important events, GRBs at redshifts $z > 7$. Simply finding, and hence measuring the rate of, GRBs at high redshifts has provided a sample of host galaxies for future studies.