BlackHawk v1.2:
A tool for computing Black Hole evaporation
Tutorial session

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TOOLS 2020 Lyon – November 4th, 2020

1 Introduction

This is a (short) tutorial designed for the attendants of the TOOLS 2020 conference. Following this tutorial, you will be able to launch `BlackHawk` for two test runs (instantaneous and time-dependent). `BlackHawk` can be downloaded at

`https://blackhawk.hepforge.org`

Please make sure that you always use the latest version of the code as bugs are continuously solved by updates. The information given in this tutorial is very concise, more information can be found in the `BlackHawk` manual (A. Arbey and J. Auffinger, Eur. Phys. J. C79 (2019) 693, arXiv:1905.04268 [gr-qc]).

2 Installation

To install `BlackHawk`, you need to download the package on the webpage and to un-tar it (using the terminal or your favorite archive software). You obtain a folder called `blackhawk_v1.2`. You now need to move into this folder within your terminal to install it. For this, just execute the command

```
make
```

in the root folder. This may take several minutes. You just created the library `libblackhawk.a` which contains all the code routines.

3 First run: instantaneous spectra

3.1 Launching the run

First, we are going to use the instantaneous version of `BlackHawk`. You need to compile the program called `BlackHawk_inst` by executing the command

```
make BlackHawk_inst
```

This should be shorter than the first compilation. Let's now have a look at the `parameters.txt` file. It contains all the run parameters, some of which are of no interest for us for now. We will now modify some parameters, we *never* modify things out of this parameter file:

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- `destination_folder = test1` this will be our fist test
- `BHnumber = 1` we will simulate a single BH mass
- `Mmin = 1e+10` the BH mass will be 10^{12} g (corresponding to a temperature $T \sim 1$ TeV)
- `anumber = 1` we will simulate a single BH spin
- `amin = 0` the BH spin will be $a^* = 0$ (Schwarzschild BH)
- `spectrum_choice = 0` Dirac distribution for masses
- `spectrum_choice_a = 0` Dirac distribution for spins
- `Enumber = 1000` 1000 energies for optimal precision in the output
- `Emin = 5` the lower primary energy will be 5 GeV
- `Emax = 1e+5` the higher primary energy will be 10^5 GeV
- `grav = 1` we will compute the graviton spectrum
- `primary_only = 0` we will compute the hadronized spectra as well
- `hadronization_choice = 2` we will keep "cosmologically stable" particles

Now that the parameters are set, we can run `BlackHawk_inst` by executing

```
./BlackHawk_inst.x parameters.txt
```

the parameters file being given as an argument. This is what you should see:

```
$ ./BlackHawk_inst.x parameters.txt
         ############################
         #      BLACKHAWK v1.0      #
         #     HAWKING SPECTRUM     #
         #    COMPUTATION DEVICE    #
         ############################

[main] : STARTING EXECUTION...
[main] : READING THE RUN PARAMETERS IN 'parameters.txt'...              DONE
[main] : ESTIMATION OF THE MEMORY USE...

         Running this session will use around 38.420 MB of RAM and 0.055 MB of disc memory.

         Do you want to continue? (type y or n)
```

The program has estimated the amount of RAM and static memory used by the run you are launching. To go on just type `y` in the asked area. The launch should then go to its end without issue.

3.2 Exploitation of the results

We now want to have a look at the results. In the root folder, there is a subfolder called `/results`. Go into that folder and you will find your `destination_folder /test1` there. This folder contains 4 files:

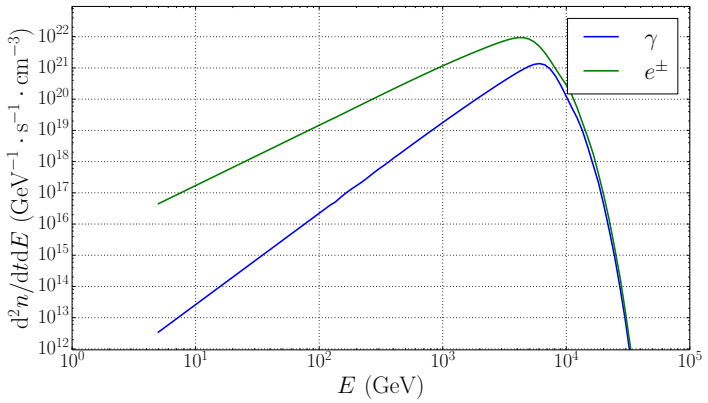
- `BH_spectrum.txt` contains the BH mass and spin distribution
- `instantaneous_primary_spectra.txt` contains the primary SM particles spectra
- `instantaneous_secondary_spectra.txt` contains the secondary hadronized spectra
- `parameters.txt` contains a copy of your parameters file, in case you erased or modified it in the root folder

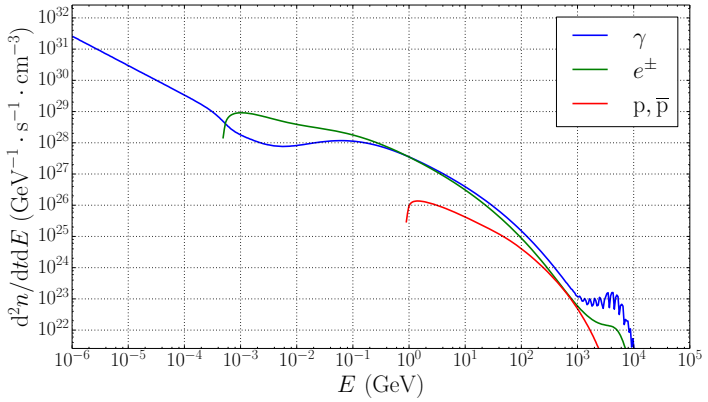
We can now plot the results, using `Pyhton` for example. For this purpose, proposition of plotting scripts are included in `BlackHawk`. You can of course modify them. Go into the subfolder `/scripts/visualization_scripts` and open `plot_inst.py`. You must now enter your personal path to the root folder of `BlackHawk` in the script, and the name of your run, as shown below:

```
## 2 - Folder definition

# Here put the BlackHawk path
BH_path = "[your path]/blackhawk_v1.2"
#
result_folder = BH_path + "/results/"
# Here put the name of the 'destination_folder'
data_folder = "test1"
folder = result_folder + data_folder + "/"
# Here put a path to some figures folder
fig_folder = folder
```

You may have to modify (or comment with `#`) the lines 115, 116, 215 and 216 as the titles are formatted in a way that may cause bugs. By running the cells 1 (package importations in `Python`) and 2, you must obtain the two figures below:





showing the primary photon and electron/positron spectra, and the secondary photon, electron/positron and proton/anti-proton spectra. The wiggles on the secondary photon spectrum come from the energy discretization. The figures are saved in the `/result/test1` subfolder.

You may play a little bit with this tutorial, for example by modifying the BH mass (don't forget to adapt the energy ranges `Emin` and `Emax` in that case) or spin, or display other particle spectra with the visualization scripts.

4 Second run: time-dependent spectra

4.1 Launching the run

Then, we are going to launch the time-dependent version of `BlackHawk`. You need to compile the program called `BlackHawk_tot` by executing the command

```
make BlackHawk_tot
```

in the root folder. We will have the same parameters compared to the first run at the exception of `destination_folder = test2` (this will be our second test). There is no conflict between the instantaneous and time-dependent files but this is clearer this way. Now that the parameters are set, we can run `BlackHawk_tot` by executing

```
./BlackHawk_tot.x parameters.txt
```

the parameters file being given as an argument. The run should be somewhat longer, with more information displayed on the screen: `BlackHawk` is computing the same information as before, but for all the BH evolution until evaporation, in a number of timesteps.

4.2 Exploitation of the results

We now want to have a look at the results. Go into the `/result` folder and you will find your `destination_folder /test2` there. This folder contains 5 types of files:

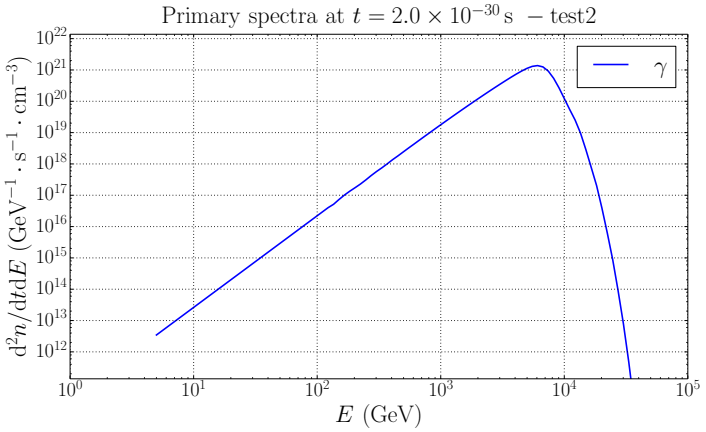
- `BH_spectrum.txt` contains the BH mass and spin distribution
- `*_primary_spectrum.txt` files contain the primary SM particles spectra
- `*_secondary_spectrum.txt` files contain the secondary hadronized spectra
- `life_evolutions.txt` contains the timestep of the BH mass and spin integration
- `parameters.txt` contains a copy of your parameters file, in case you erased or modified it in the root folder

You now need to open the visualization script `plot_tot.py`. You must still enter your personal path to the root folder of `BlackHawk` in the script, and the name of your run, as shown below:

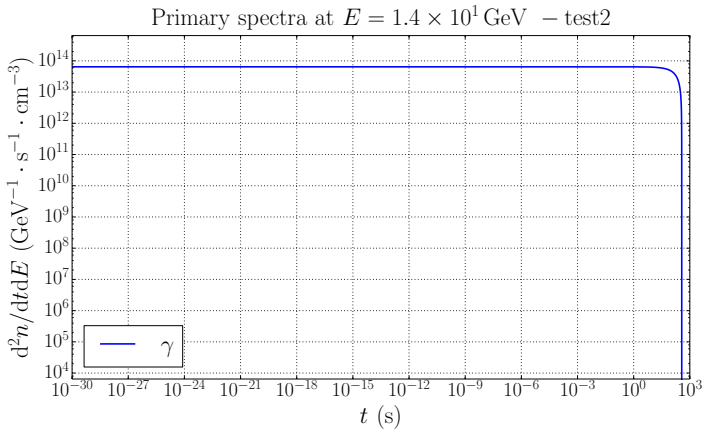
```
## 2 - Folder definition

# Here put the BlackHawk path
BH_path = "[your path]/blackhawk_v1.2"
#
result_folder = BH_path + "/results/"
# Here put the name of the 'destination_folder'
data_folder = "test2"
folder = result_folder + data_folder + "/"
# Here put a path to some figures folder
fig_folder = folder
```

By running cells 1, 2, 3, 5 and 6, you should obtain the instantaneous primary photon spectrum at the first timestep. This should be equal to the result of the instantaneous computation of the first part of this tutorial!



By running cell 7, you should obtain the rate of emission of photons at a fixed energy as a function of time:



You may play a little bit with this tutorial, for example by modifying the BH mass (don't forget to adapt the energy ranges `Emin` and `Emax` in that case) or spin, or display other particle spectra with the visualization scripts.

4.3 BH evolution

One secondary output of `BlackHawk_tot` is the global time evolution of the BHs. It is contained in the file `life_evolutions.txt`. You may want to have a look at the evolution of both mass and spin for different BH masses and spins in this file.

5 Tables: internal information

Finally, `BlackHawk` contains a number of tabulated quantities that an have an interest in other areas of physics. For example, the hadronization tables are of interest for the particle DM search community. You may have a look at those tables...

6 Conclusion

Thank you and have a good time using `BlackHawk`! You may contact me if you have any problem at my email address.