GammaMRI-simulator

Pablo Galve, Jose Manuel Udias, Joaquin Lopez-Herraiz, Luis Mario Fraile

Nuclear Physics Group, Universidad Complutense de Madrid & IPARCOS

Introduction

This document describes the main features of the gammaMRI-simulator software, developed by PhD Pablo Galve Lahoz at UCM.

There exist hyperpolarized nuclei in which the gamma emission distribution is defined by the direction of an external magnetic field. In this program, we simulate gamma emissions from an activity map of a hyperpolarized sample using a given spatiotemporal distribution of the magnetization vectors. The emission is determined using the probability distribution of figure 1, where *th* is the angle between the magnetization vector and the emission direction, and *a2* is parameter that defines the nuclear polarization (*a2=1* implies total polarization). The user may define a given number of detectors equally spaced over a cylinder, so that any photon that crosses the surface of one of them is recorded.

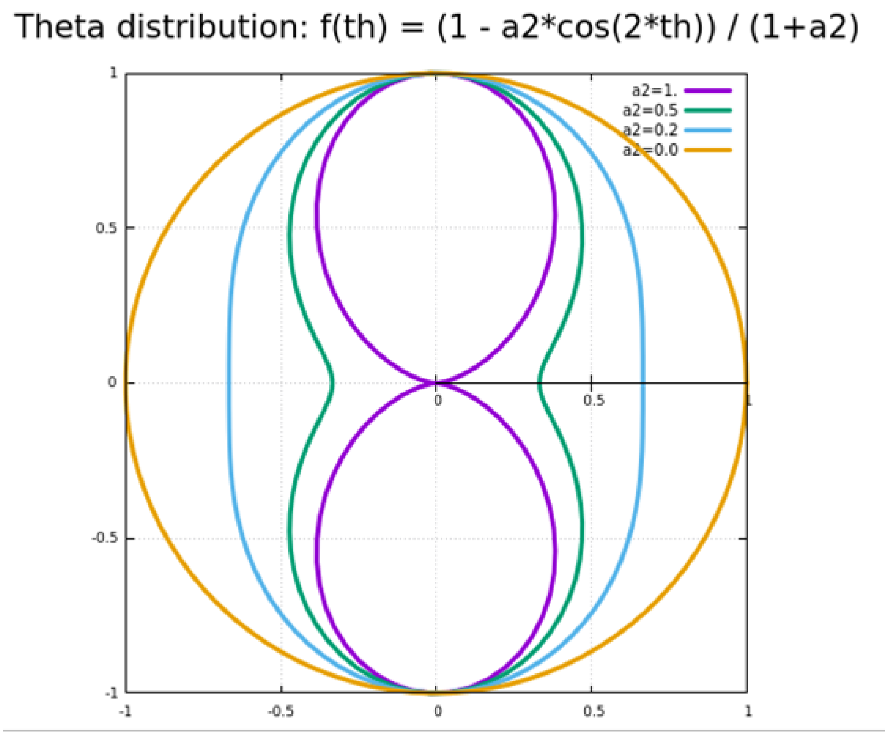

Figure 1. Polar graph of the gamma emission distribution of a hyperpolarized nucleus with different polarization values (*a2*).

Installation and execution

The code *gammaMRI-simulator.f* can be compiled without any special compiling option, using the Fortran compiler from Intel. The command-line used is:

```
ifort gammaMRI-simulator.f -o gammaMRI-simulator.x
```

We tested the code in the 2011 version of the *ifort* compiler. The command-line execution is:

```
./gammaMRI-simulator.x
```

Input files

All the input parameters and files are defined in the file "input_gammaMRI.inp":

```
7 #nx
7 #ny
5.65 #X-FOV size (cm)
5.65 #Y-FOV size (cm)
4 #Radius (cm)
0.6 #Detector size (cm)
8 #Number of detectors
10000000 #Initial activity (Bq)
767232 #Half life (s)
1.0 #Polarization (a2)
magnetizations.raw #Magnetization vectors file
0.00002 #Time step (s)
12001 #Number of time steps
unos_7x7.raw #Activity file
```

Line by line, the description of each parameter is shown in the following list:

1. Number of X bins in the activity map and in the magnetization vectors distribution.
2. Number of Y bins in the activity map and in the magnetization vectors distribution.
3. X field of view (X-FOV) size in centimeters.
4. Y field of view (Y-FOV) size in centimeters.
5. Radial distance from the detectors to the center of the FOV.
6. Detector size in centimeters. The detector surface covers a cylindrical section of arch length and axial length equal to this size.
7. Number of detectors. They are equally-spaced in the cylinder of radius given in point 5, in Z=0.
8. Initial activity in becquerels.
9. Isotope half life in seconds (e.g.: for the ^{129}Xe it is 8.8 days=767232 s).
10. Sample polarization. This value ranges from 0 to 1, and it defines the emission distribution of figure 1.

11. File with the spatiotemporal magnetization vectors distribution.
12. Time step used in the magnetization vectors file.
13. Total number of temporal steps in the magnetization vectors file.
14. File with the image activity distribution.

All the input files must be available in the execution folder.

The code also uses other constant parameters, such as the external magnetic field (without any gradient introduced) of B_0*=0.05 T*, or the gyromagnetic ratio of Xe γ*=1.37e6 Hz/T*.

Magnetization vectors file

This file defines a spatiotemporal grid of magnetization vectors in the rotating framework of the Larmor angular frequency. For every x-y-t point, 4 components must appear: the angular frequency due to an external magnetic gradient and the 3 components defining the magnetization vector in the rotating framework. The magnetization vectors are interpolated between every time bin using rotations.

This is a binary file, using float32 numbers. In the following code, we give a brief description of the Fortran code used to read it:

```
      real gvec(4), totgvec(nx,ny,nt,4)
      character*1000 file_magvectors

      print*,'Reading ',trim(file_magvectors)
      open(13,file=trim(file_magvectors),
     o form='unformatted',access='stream')

      do 333 ix=1,nx
      do 333 iy=1,ny
      do 333 it=1,nt
       read(13)gvec
       totgvec(:,ix,iy,it)=gvec(:)
333   continue
      close(13)
```

Where the four elements of gvec(4) correspond to the frequency due to the gradient in kRad/s, and sequentially the 3 XYZ components of the magnetization vector.

Activity distribution file

This file describes the relative activity of every pixel. For every decay, a random pixel is chosen following this distribution. We use a binary file with float32 numbers. In the following code, we give a brief description of the Fortran code used to read it:

```
 real act_img(nx,ny)
 character*1000 act_file

 open(13,file=trim(act_file),
o form='unformatted',access='stream')
 read(13)act_img
 close(13)
```

Output files

A few text and binary files have been prepared (all the images of this section correspond to the simulation details given in the Input files section):

list_det_gammaMRI.txt

This is a text file with a list of detected events line by line. Column, the following information is given:

1. Decay number.
2. Decay time.
3. Activity.
4. X pixel index of emission.
5. Y pixel index of emission.
6. X coordinate of emission (cm).
7. Y coordinate of emission (cm).
8. X coordinate of detection (cm).
9. Y coordinate of detection (cm).
10. Z coordinate of detection (cm).
11. Phi angle (*atan(Y/X)*) of detection (rad).
12. Detector idex (detector 1 is positioned at (x,y,z)=(-R, 0, 0) cm).

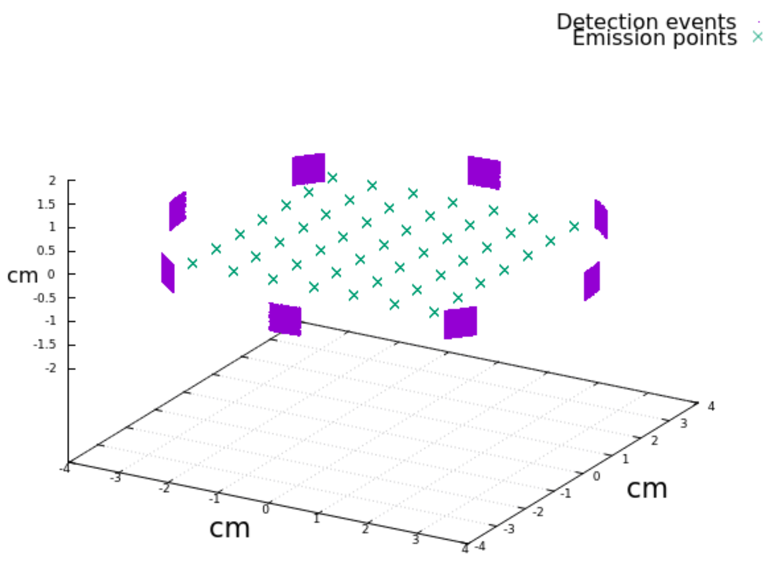

Figure 2. Plot of the columns 8:9:10 (Detection events) and 6:7 (Emission points) of file *list_det_gammaMRI.txt* for the parameters shown in section Input files.

events_per_detector.txt
Text file with the events per detector. Column by column description:

1. Detector index.
2. Angular position of the detector (in the center of the detector).
3. Total number of events in the detector.
4. Sensitivity (number of events / total number of decays).

activity_distribution.txt
Text file with the time distribution of the emitted activity:

1. Time bin (from 1 to 100).
2. Time (s).
3. Number of emitted events.
4. Activity (1/s).

emissions_image.raw
Binary image with the number of decays per pixel (same format of input activity image).

detections_image.raw
Binary image with the number of emitted decays which have been detected per pixel (same format of input activity image).

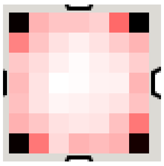

Figure 3. Example of the *detections_image.raw* for the parameters shown in section Input files.

detections_per_detector_image.raw
Binary image of the number of emitted decays which have been detected per pixel and detector, divided by the total number of decays. All detector images are concatenated by detector index order.

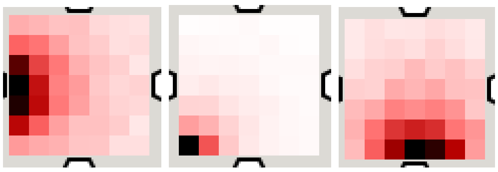

Figure 4. Example of the maps in *detections_per_detector_image.raw* for the 3 first detectors using the parameters shown in section Input files.

list_prob-map_gammaMRI.raw
Binary images of all the probabilities of emission of every pixel to the detector in which the detection took place following the emission formula given in figure 1. All the detection images are concatenated following the detection order. These maps might be very useful to perform image reconstruction.

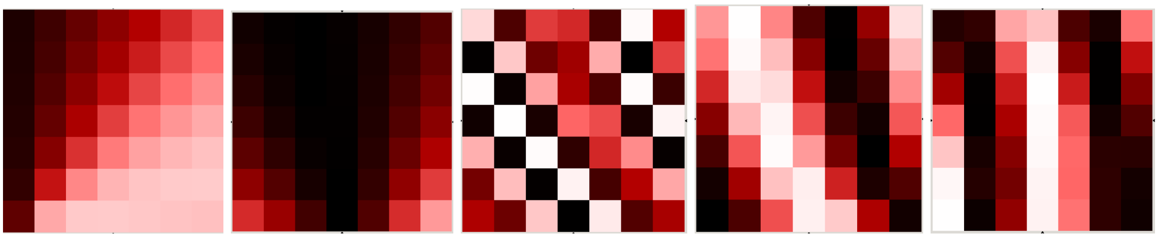

Figure 5. Example of 5 emission probability maps for 5 randomly selected events in the file *list_prob-map_gammaMRI.raw* using the parameters shown in section Input files.

Output obtained from the screen:

```
./gammaMRI-simulator.x
 ------------------------------------
 -------Gamma MRI generator----------
 ------------------------------------
 This code generates the output data from a distribution of
polarized nucleii.
 Let's read input file: input_gammaMRI.inp
 nx=           7
 ny=           7
 X-FOV size (cm)=   5.650000
 Y-FOV size (cm)=   5.650000
 Radius of detectors ring (cm)=   4.000000
 Detector size (cm)=  0.6000000
 Total number of detectors:            8
 Initial activity (Bq)=   10000000.0000000
 Isotope half life (s)=   767232.000000000
 Polarization (a2)=   1.00000000000000
 Magnetization vectors file:magnetizations.raw
 Time step (in magnetization file) (s)=
2.000000000000000E-005
 Number of time bins (in magnetization file) =       12001
 File with activity distribution: unos_7x7.raw
 Total time (s) =   0.2400200

 -------------------
 ---init_gvectors---
 -------------------
 Gyromagnetic ratio [gyro] (Hz/T)=   1370000.00000000
 Static magnetic field [B0] (T)=  5.000000074505806E-002
 Larmor frequency [gyro*B0] (Hz)=   68500.0010207295
 Reading magnetizations.raw

 -------------------------
```

```
---Starting simulation---
-------------------------
Total number of simulated decays =                 2401610
Total number of detected events =                    47039
Sensitivity =   1.9586444E-02
End time (s) =   0.240020054074153
End activity (Bq) =    9999996.87160917

----------------------------
---Enjoy your simulation!---
----------------------------
```