MSE-432: OOMMF Introduction

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13 March 2025

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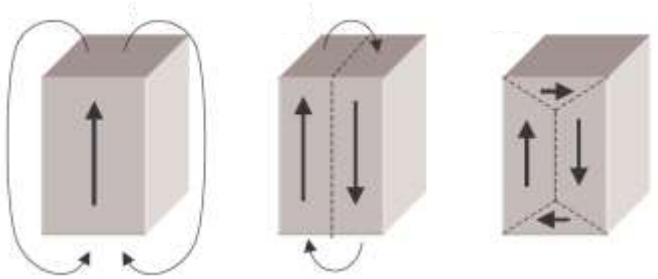
Proposed plan of the exercise classes: Spring 2025

	Date	Subject
E1	19/02 20/02	Lectures both days. Last 20 minutes: Introduction to exercise course
E2	26/02 27/02	Experiments for all groups (both days for exercises) Report Submission deadline: 07/03/2025
E3	06/03	Introduction to online seminars for flipped classroom on magnetic materials and devices.
E4	13/03	~~Feedback on experiments~~ **Introduction to OOMMF**
E5	20/03	Contact hours for Online seminars
E6	27/03	Student Talks: flipped classroom (Online seminars)
E7	03/04	Student Talks: flipped classroom (Online seminars)
E8	10/04	Feedback on experiments. Contact hours for OOMMF Report
E9	17/04	Contact hours for OOMMF Report Submission deadline: 15 May 2025

	Date	Subject
E10	24/04	Easter Holiday
E11	01/05	Student Talks: OOMMF
E12	08/05	Student Talks: OOMMF
E13	15/05	Problem set and solution discussion
E14	22/05	Question and answer / feedback session (with Prof. Grundler)
E15	28/05	Problem Set – 2 (Graded)
E16	29/05	Ascension day

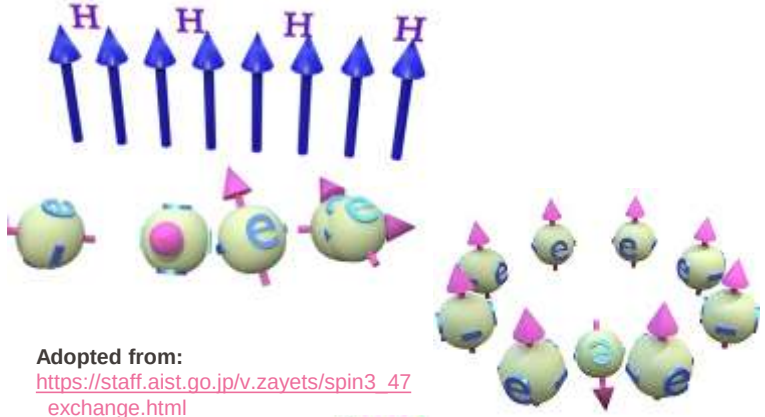
Grading:
- Submission of the experiments report: 10%
- Student's talk and abstract on seminars: 30%
- Talk and Report on OOMMF: 40%
- Submission of Problem Set 2: 20%

OOMMF simulation introduction

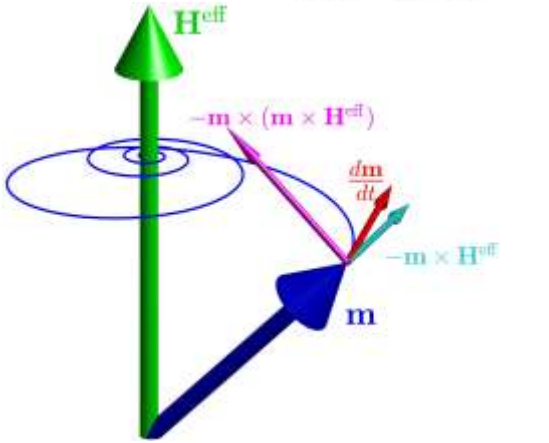


By Zureks - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=5155644

- Resources: https://math.nist.gov/oommf/oommf_tutorial/tutorial.html
- Micromagnetism:
  - State of ferromagnet by continuous vector, Magnetization *M(x,t)*
- Energy contributions (Magnetization statics):
  - Magnetostatic energy
  - Anisotropy
  - Exchange
  - Zeeman
- Landau-Lifshitz-Gilbert equation (Magnetization dynamics) is solved to evaluate the magnetization after relaxation at an applied magnetic field
- OOMMF:
  - Object Oriented Micromagnetic Frameworks
  - Finite Difference Method used to solve the LLG



Adopted from:
https://staff.aist.go.jp/v.zayets/spin3_47_exchange.html



Source: https://commons.wikimedia.org/wiki/File:LLG_constant.jpg

$$\frac{d\boldsymbol{m}}{dt} = -\frac{\gamma}{1+\alpha^2}\left(\boldsymbol{m}\times\boldsymbol{H_{eff}}\right) - \frac{\alpha\gamma}{(1+\alpha^2)M_s}\,\boldsymbol{m}\times\left(\boldsymbol{m}\times\boldsymbol{H_{eff}}\right)$$

OOMMF script

```
# MIF 2.1
# MIF Example File: imageatlas.mif
# Description: Example use of the Oxs_ImageAtlas class.

set pi [expr 4*atan(1.0)]
set mu0 [expr 4*$pi*1e-7]

Specify Oxs_ImageAtlas:atlas {
  xrange {0 480e-9}
  yrange {0 175e-9}
  zrange {0  50e-9}
  viewplane xy

    image "Dot.jfif"
  colormap {
     black    Py
     white    vacuum
  }
}

Specify Oxs_RectangularMesh:mesh {
  cellsize {20e-9 20e-9 50e-9}
  atlas :atlas
}
# Specify Oxs_UniformExchange:NiFe {
Specify Oxs_UniformExchange {
  A  9e-12
}
Specify Oxs_UZeeman [subst {
  multiplier [expr 0.001/$mu0]
  Hrange {
        { -500   0   0   -200    0    0    40}
        { -200   0   0    200    0    0   400}
        {  200   0   0   -400    0    0    40}
        {  500   0   0    200    0    0    40}
        {  200   0   0   -200    0    0   400}
        { -200   0   0   -500    0    0    40}
  }
}]

Specify Oxs_Demag {}

Specify Oxs_CGEvolve {}

Specify Oxs_MinDriver {
 basename test
 evolver Oxs_CGEvolve
 stopping_mxHxm 0.1
 mesh :mesh
 Ms { Oxs_AtlasScalarField {
   atlas :atlas
   values {
      Py 700e3
      vacuum 0
   }
 }}
 m0 {Oxs_RandomVectorField {
   min_norm 1.0
   max_norm 1.0
 }}
}

Destination archive   mmArchive
Schedule Oxs_MinDriver::Magnetization archive Stage 1
Schedule DataTable archive Stage 1
```

Defining Constants

Defining dimensions using Image

Defining material by color

Defining Cell Size

Exchange value (with a unit of J/m)

Defining Exchange Constant

Hysteresis Field Values

($\mu_0 H$ in mT)

Energy Minimization and Stopping Conditions

Defining Saturation Magnetization

Saturation magnetization value (with a unit of A/m)

Initial State (Random)

Save Output

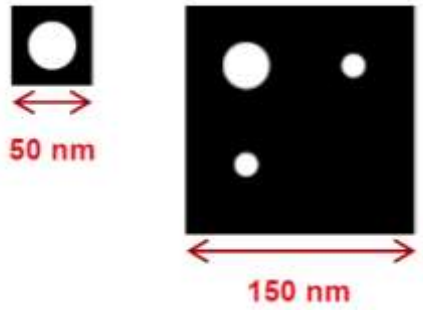
Image credits: Richa Agrawal

Problem sets

Compare: 2 (or 3) different geometries + 2 different materials

*You are free to choose the direction of the applied magnetic field

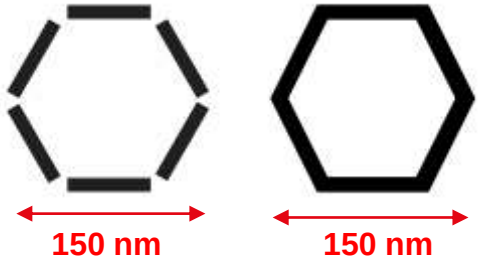
Group 1



Group 2

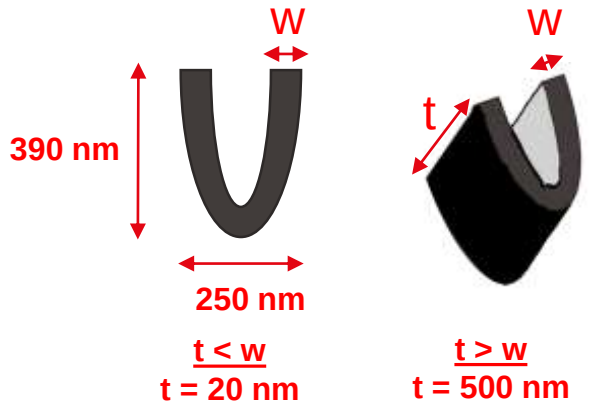
Group 3

Group 4



Group 5

Group 6



Material : Ni

PHYSICAL REVIEW LETTERS 123, 077201 (2019)

Thickness: **20 nm** (except for the groups 3 and 6)
Materials: **Ni and Co**

Material Parameters:

- Exchange energy $\mathbf{A_{ex}}$: **8 pJ/m** (Ni) and 31pJ/m (Co)
- Saturation magnetization $\mathbf{M_s}$: **490 kA/m** (Ni) and **1.44MA/m** (Co)

- Have a look at the paper from *J.M.D Coey, Magnetism and Magnetic Materials, Cambridge University Press, 2010, pp. 242*
- Good overview of each **energy term** that one must take into account when constructing the energy functional of the system
- Good practice when it comes to micromagnetic simulations (relevance of the **mesh size**, computation cost, etc.)

OOMMF simulation : expectations

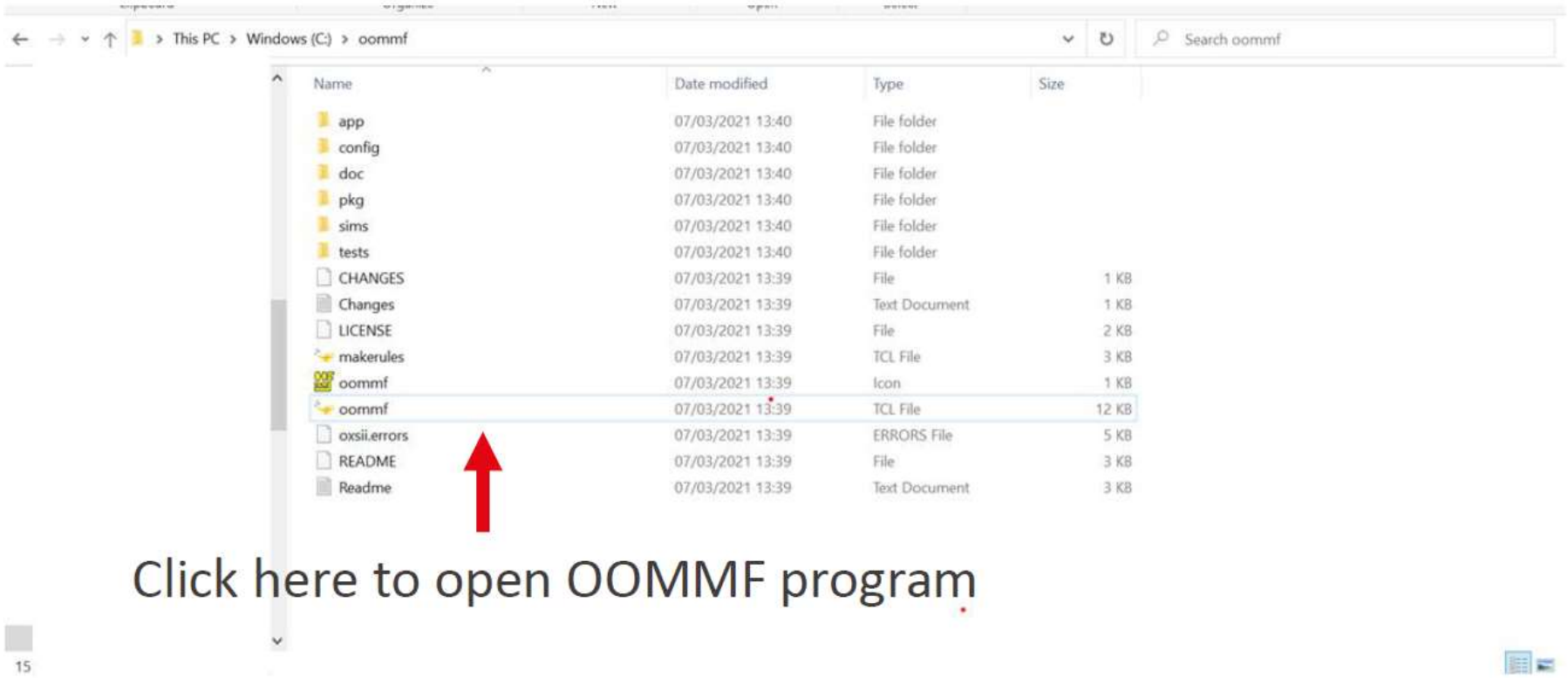
- Perform simulations for the given material parameters (dimensions, M_s, A_{ex})
- Understand the hysteresis loop and explain to your fellow classmates your observations during the group presentation:
  - Presentation of 15 min for a Group of 3 members and of 10 min for a Group of 2 members (i.e. 5 min per group member)
  - Explain briefly the problem statement, your approach, key observations, your understanding of these observations
- Prepare a report of *maximum 3 pages (Article format)*
- Each member of the group is expected to present a part of the presentation and answer questions related to that
- Cite the references, literature, and any online material you use in your presentations thoroughly (if needed)
- Questions and discussions from the fellow classmates are highly encouraged!

Exercise groups

Group	Participants	Seminar topic number	Date for Student Talks: flipped classroom	Date for Student Talks: OOMMF
1	Sven Jaquiéry	2	27/03	01/05
	Samuel Jaunin			
	Olivia Rouiller			
	Martin Sinègre			
2	Yohann Ansel	6		
	Hugo Joncquel			
	Eric Greulich			
3	María Murillo Acevedo	3		
	Pin-Ying Chen			
	Guillaume Lorenzini			
	Antoine Fotius			
4	Noé Paratte	4	03/04	08/05
	Thomas Bour			
	Davide Bréas			
	Andrea Filippo			
5	Jessie Staudenmann	1		
	Cécile Tran			
	Romaric Rager			
6	Melvin Arnold	5		
	Karl Abdelnour			
	Oliviero Gubelmann			
?	François Saulgeot	?		

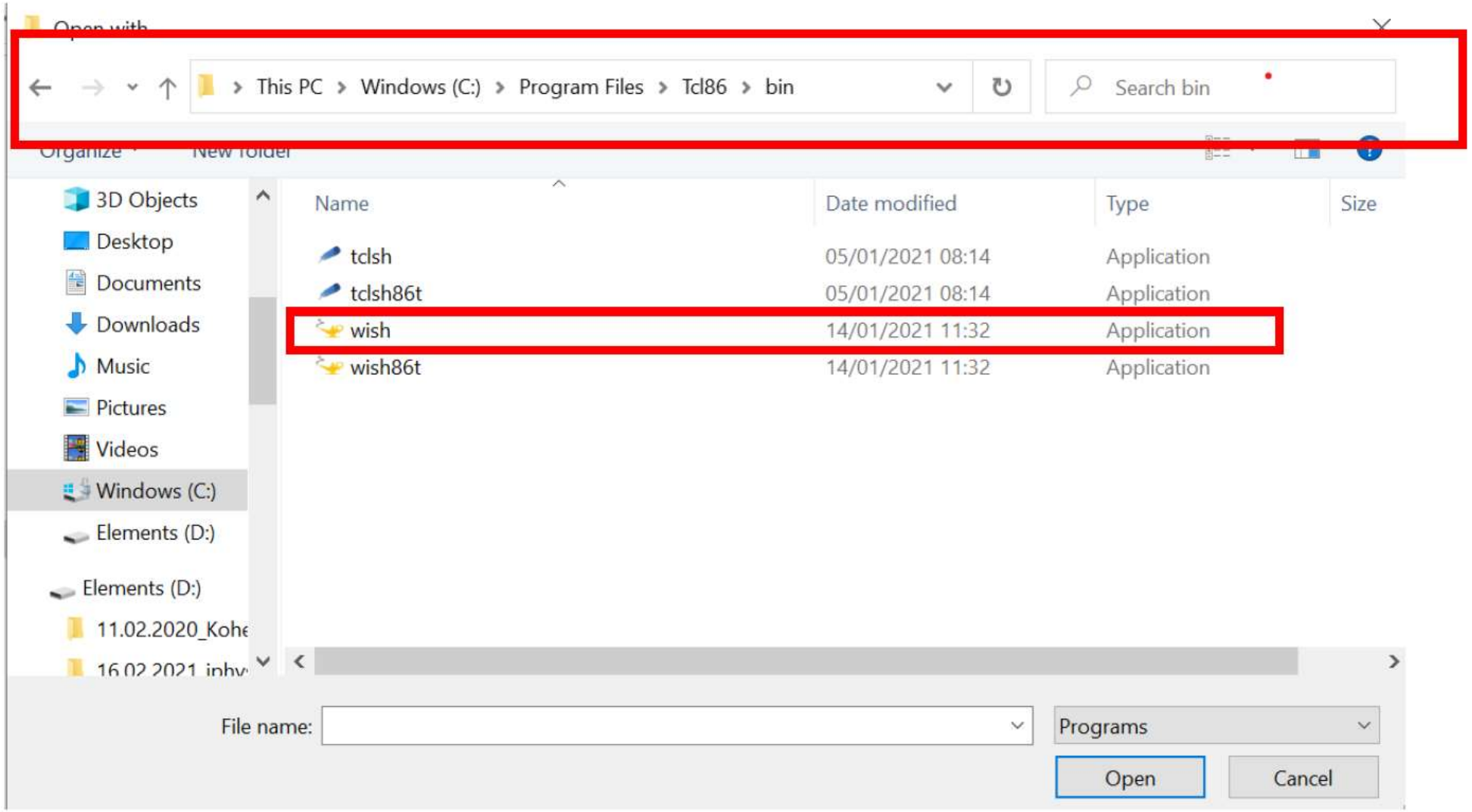
Running OOMMF script in MXF014

Running script in OOMMF



If you don't see your TCL file activated. Then go to **Open with > look for another app in this pc > Tcl86 > bin > wish (a screen shot is attached in the next slide)**

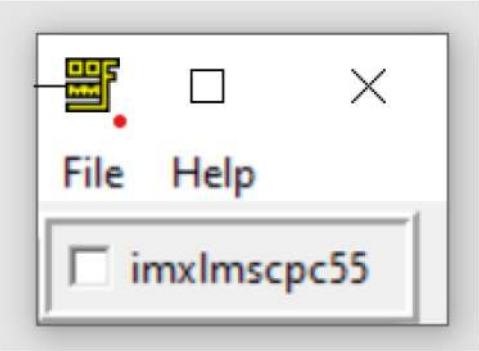
Running script in OOMMF



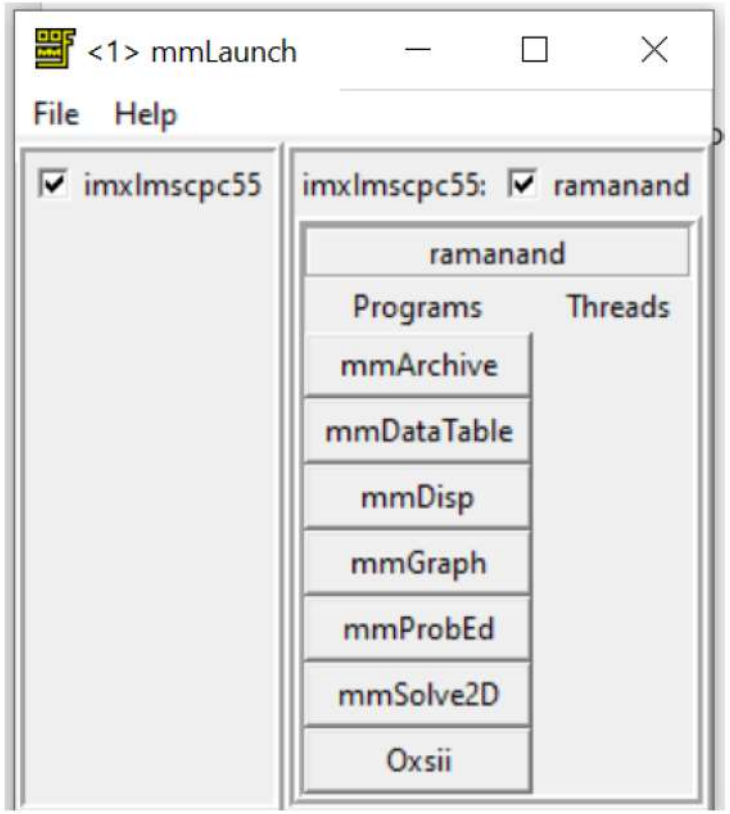
Running script in OOMMF

If everything goes fine your screen should look like the picture shown below after opening the Tcl file in OOMMF folder.

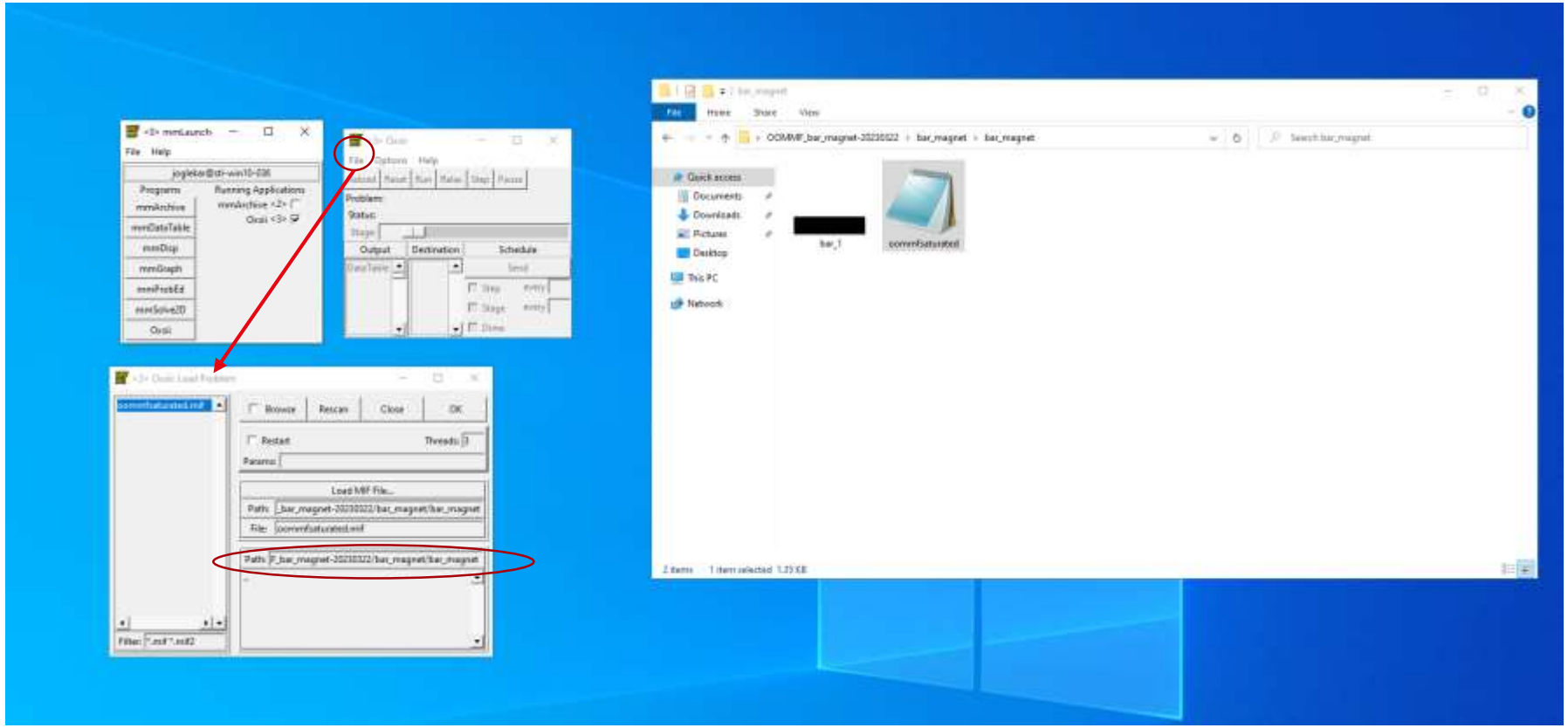
Step 1:



Step 2:



Running script in OOMMF

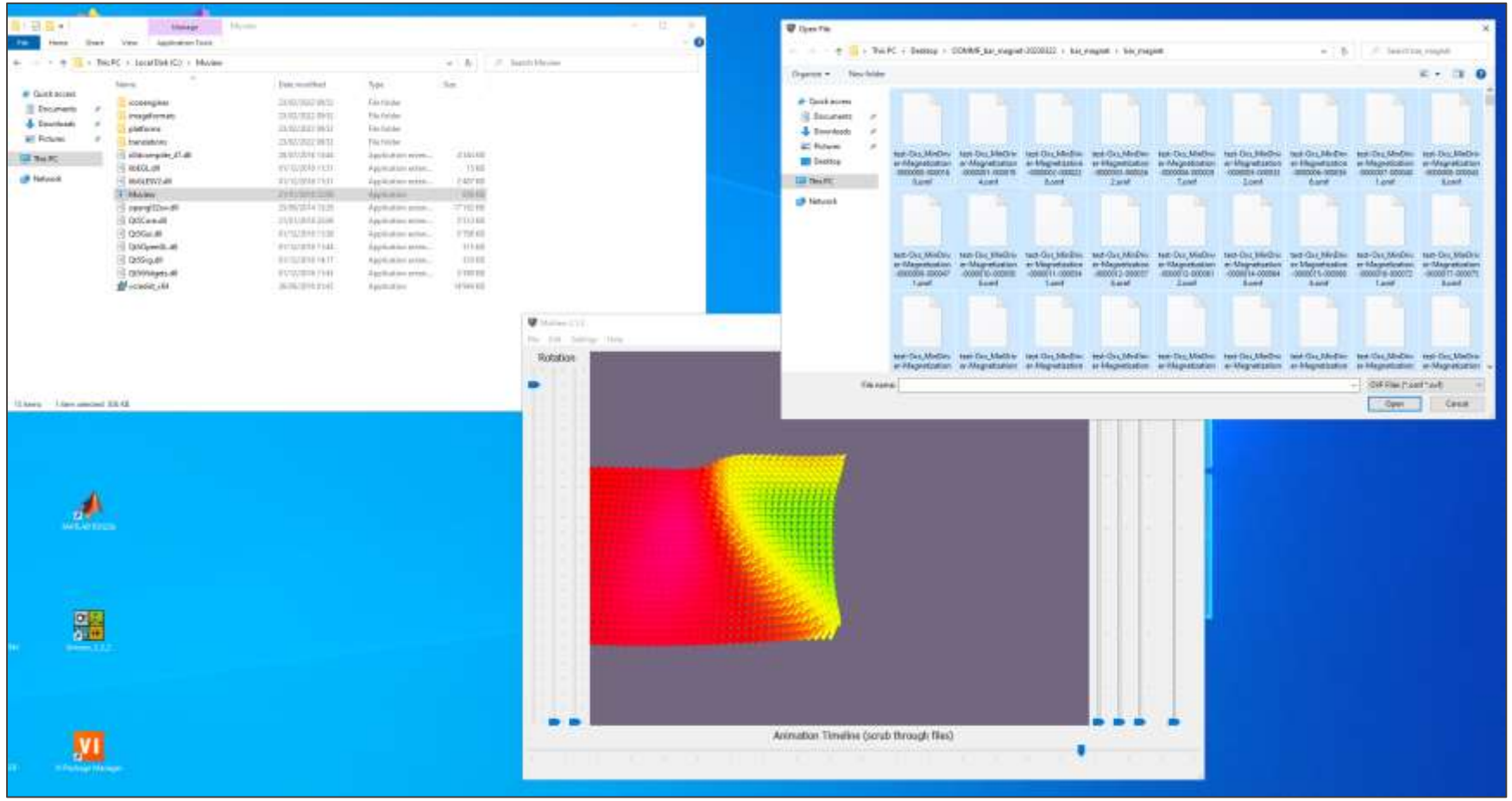


1. After clicking on Oxsii check-box, you would find a new window opened
2. Click on File (as shown with circle) and then on Load
3. The Oxsii load problem window will open. At *Path* window (highlighted), copy and paste the path of folder with simulation script and press enter.
4. In the left side, you will see .mif file "*oommfsaturated.mif*" as highlighted in blue. Click on it and Run the next window.

Visualizing results in Muview

Open C:/Muview software. Go to File – Load and select all the generated files by OOMMF in the folder. In Settings: you can adjust parameters to view spins corresponding to each pixel of your sample

Important:
Do organize these generated files in sub-folders when you run the next simulation. It will help separating the files simulated for different conditions/parameters



Contact us in case of questions.

Have fun!!