NARIT Radio Astronomy Summer School 2023

A brief manual for hands-on activity

Finding the period of maser flares in YSO: G107.298+5.639

using Lomb-Scargle periodogram

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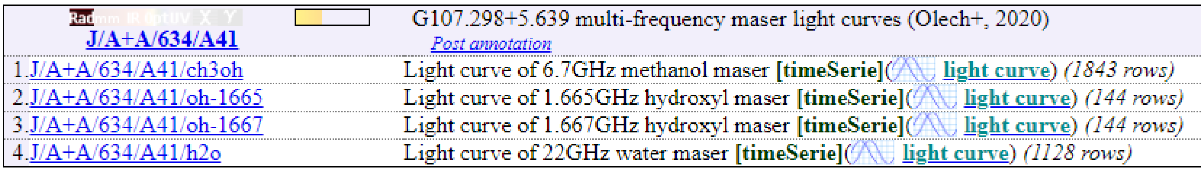
This activity will be followed the research of 2020A&A...634A..41O (Olech, M et al. 2020) which observed 4 maser emission lines e.g., 6.7 GHz (CH_3OH), 1.665 GHz (OH), 1.667 GHz (OH), and 22 GHz (H_2O) from the intermediate-mass young stellar object G107.298+5.639. In this activity, we will

- calculate the period of maser flares and discus the result,
- (optional) plot the VLBI data and discus the result.

1. Data extraction

Go to the vizier catalog (http://vizier.cds.unistra.fr/viz-bin/VizieR?-source=J/A+A/634/A41) and download the integrated flux density as a function of modify Julian day (MJD) (see Figure 1).



J/A+A/634/A41	G107.298+5.639 multi-frequency maser light curves (Olech+, 2020) Post annotation
1.J/A+A/634/A41/ch3oh	Light curve of 6.7GHz methanol maser **[timeSerie]**(light curve) *(1843 rows)*
2.J/A+A/634/A41/oh-1665	Light curve of 1.665GHz hydroxyl maser **[timeSerie]**(light curve) *(144 rows)*
3.J/A+A/634/A41/oh-1667	Light curve of 1.667GHz hydroxyl maser **[timeSerie]**(light curve) *(144 rows)*
4.J/A+A/634/A41/h2o	Light curve of 22GHz water maser **[timeSerie]**(light curve) *(1128 rows)*

Figure 1 An example of Vizier webpage

Click "light curve" of 6.7 GHz CH_3OH maser, it will create a new window which is shown in Figure 2.

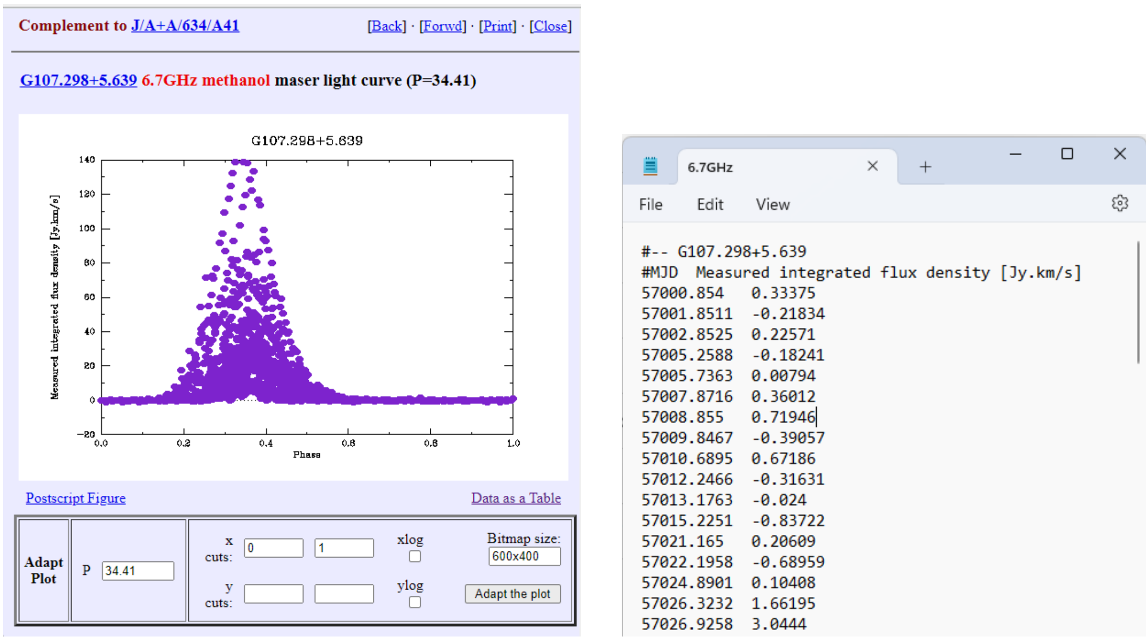


Figure 2 (left) light curve plot from vizier (right) MJD data from text file

At the adapt plot tool, edit P value from 34.41 to 0 (it will convert the x data type from phase to MJD), then click 'Adapt the plot' to change the plot, and click 'Data as a Table' then save the data to the text file with the name of frequency as '6.7GHz.txt'

Do it yourself: save the data for other maser lines 1.665 GHz (OH), 1.667 GHz (OH), and 22 GHz (H_2O).

2. Finding the period of maser lines using Python Libraries on Google colab

**If you have experiences with Python, please try by yourself on your machine/laptop. **

Go to your drive in google account, then create a google colaboratory. Click the folder tool on the left side and upload your data files to the directory. At the main screen, type the import module as follow in the first cell, then hold 'shift+enter' to run the cell

```
import matplotlib.pyplot as plt
import numpy as np
import scipy.signal as signal
import pandas as pd
import re
```

The screen will shows look like in Figure 3.

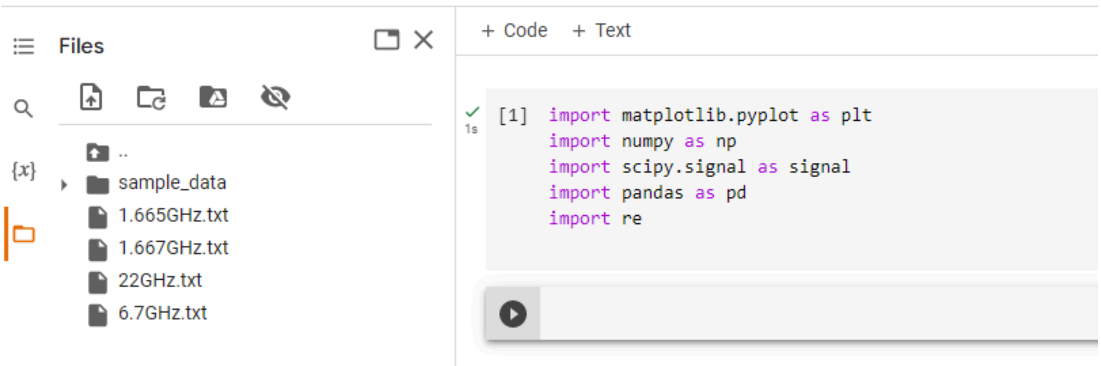


Figure 3 An example of the screen of colab

We need to input the data to our calculation; we define the function to call the data by type the code as follows to the new cell and then run it.

```
[illegible]
```

After run the cell, we need to set the maser name to the function, then it will give you a result of source name, MJD, and Integrated Flux density. Next, try to call the file name of ‘6.7GHz.txt’ with the following code and then run it.

```
maser='6.7GHz'
source, mjd, int_flux=callflux(maser)
```

The data of 6.7GHz will keep in parameters called ‘source’, ‘mdj’, and ‘int_flux’. Now, we need to look the integrated flux density with the observation time. We again define the function for plotting as follows code and then run it.

```
def plot(kind, title, x, y, w, h, fig_name):
    fig = plt.figure(figsize=(w,h))
    if kind=='scatter':
        plt.scatter(x[1], y[1])
    if kind=='plot':
        plt.plot(x[1], y[1])
    plt.title(title)
    plt.xlabel(x[0])
    plt.ylabel(y[0])
    plt.show()
    fig.savefig(fig_name,dpi=200)
```

The above function is use to plot the data of 2 parameters x and y in the form of scattering and line. Next, try to plot the integrated flux density as scatter, title='Time series of 6.7GHz', with the figure size of width and high as 12 and 4. Then save the image with the name 'time_series_of_6.7GHz.jpg' by using the code below.

```
title= 'Time series of '+maser
fig_name='time_series_of_'+maser+'.jpg'
plot('scatter', title, mjd, int_flux, 12, 4, fig_name)
```

Then, you may see the plot look like in Figure 4.

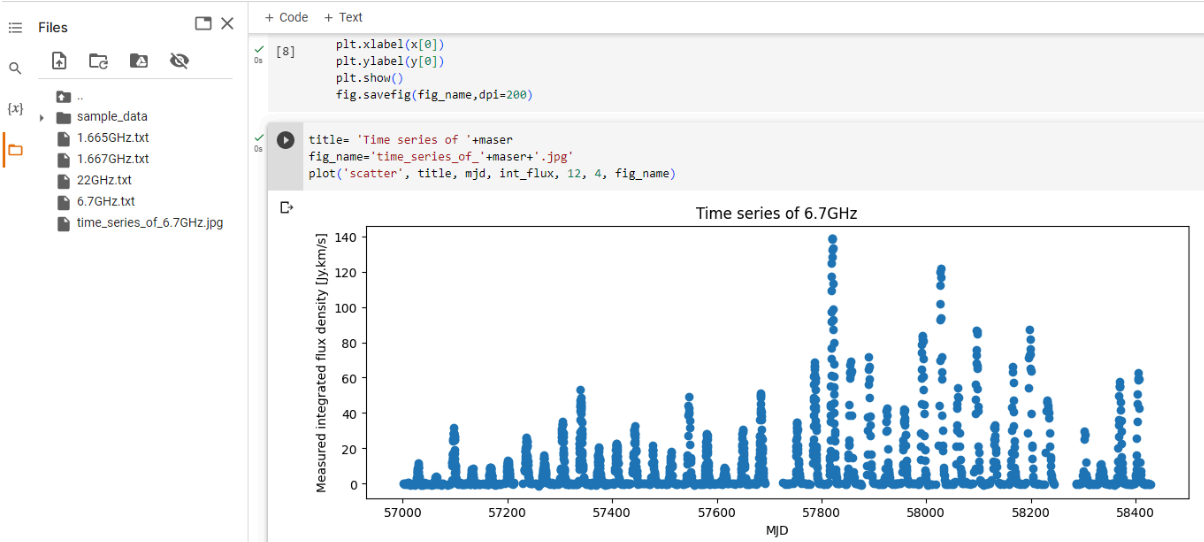


Figure 4 Time series of 6.7 GHz

Next, we will use the Lomb-Scargle periodogram to calculate the period of maser from time series data. This method can be imported from the module name 'scipy.signal'. We again set the function to find a period with the code.

```
def lombscargle(x, y, p_min, p_max, n):
    p = np.linspace(p_min, p_max, n)
    f = 2*np.pi/p
    amp = signal.lombscargle(x[1], y[1], f, normalize=True)
    P=['Period',p]
    Amp=['Amplitude',amp]
    max_a=max(amp)
    for i in range(n):
        if amp[i]==max_a:
            p_peak=p[i]
            break
    return P, Amp, p_peak
```

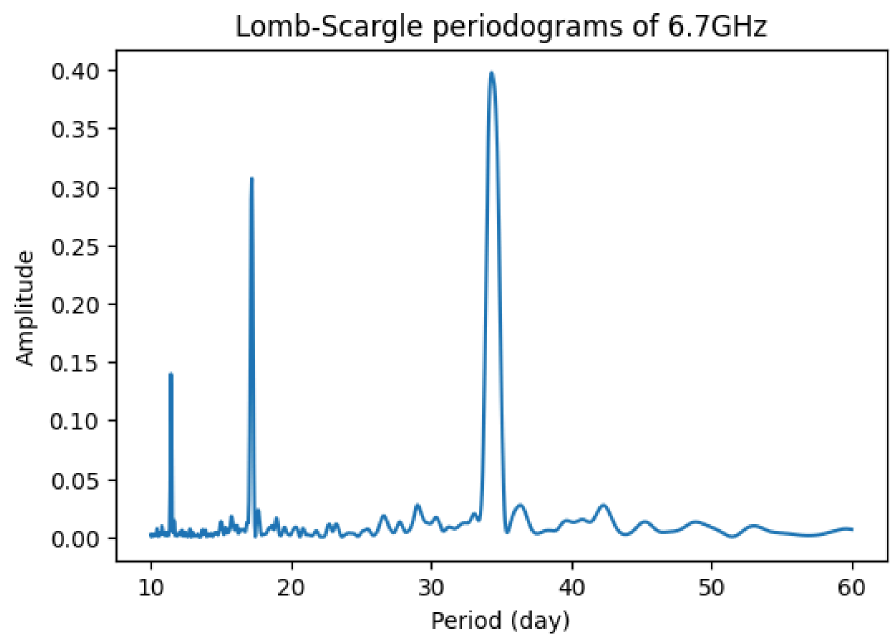
The above function will use x and y data to calculate the period with the condition by range of p_min and p_max for n bins. The above function will give you the period and the amplitude of each bin, and the period of maximum amplitude which means that the absolute time of flaring period. We try to calculate them, plot a result, and print the flaring period with the following code.

```
p, amp, p_peak=lombscargle(mjd, int_flux, 10, 60, 1000)

title= 'Lomb-Scargle periodograms of '+maser
fig_name='LombScar_of_'+maser+'.jpg'
plot('plot', title, p, amp, 6, 4, fig_name)

print('flraing period is : {:.2f} day'.format(p_peak))
```

Then, you may see the result look like Figure 5.




```
flraing period is : 34.32 day
```

Figure 5 Lomb-Scargle periodograms of 6.7GHz and text printing from the code.

Do it yourself:

- Call the data of 1.665GHz
- Plot the time-series of 1.665GHz
- Calculate the flaring period of 1.665GHz
- Do it again for 1.667GHz and 22GHz
- Discuss the flaring period from all maser emission lines.

Hint: you may use the function above to do it, but you need to change something like maser name

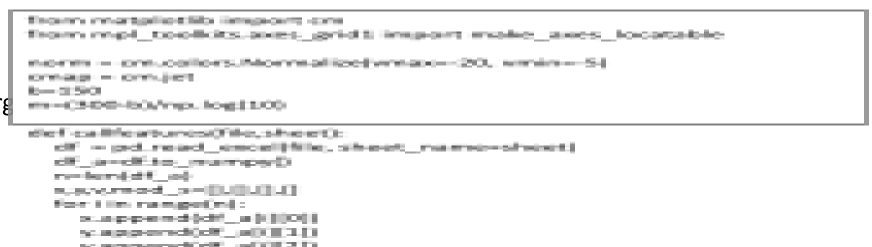
3. (Optional) Maser distribution from VLBI

In this part, we will use the data from VBLI (Very-long-baseline interferometry) observation. The data of maser from VLBI will be called as 'features', mase feature is calculated by using Gaussian Fitting. It will estimate the peak flux, flux, position offset, frequency and velocity from the spot of maser in particular area.

Unfortunately, the data of maser features is not available in the catalog, but we can take it from the main paper. The maser features data is available in the excel files named 'Features_Olech_2022.xlsx' with the description as follows.

Sheets : 22GHz, 6.7GHz, and 1.665GHz
Col.1 : offset position in x-axis (milli-arcsecond)
Col.2 : offset position in y-axis (milli-arcsecond)
Col.3 : Doppler velocity at the peak (km/s)
Col.4 : Maser brightness (Jy/beam)
Note: the center of position offset is RA(J2000) = 22h21m26.7730s and Dec(J2000) = 63'51'37.657''

First, you need to upload the excel file into the google colab directory. Then type the code new code at follow and run it.

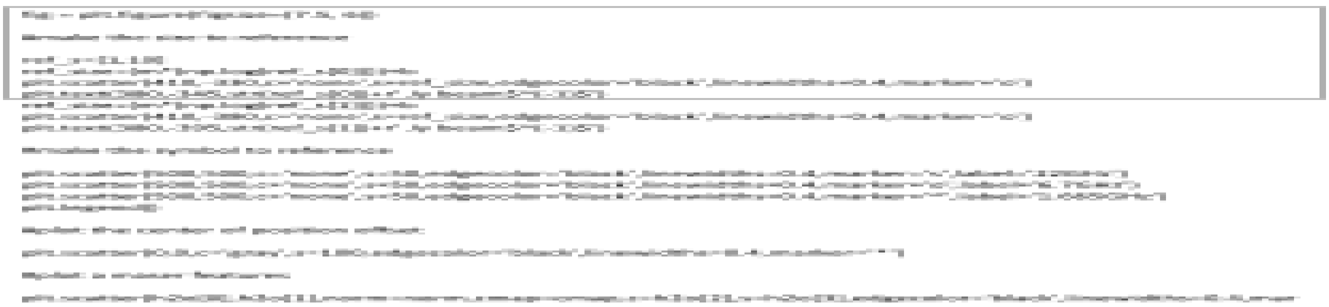


Next, call the features data from exel file and keep it in a different name with the following code.

```
excel_file='Features_Olech_2022.xlsx'

h2o=callfeatures(excel_file,'22GHz')
ch3oh=callfeatures(excel_file,'6.7GHz')
oh=callfeatures(excel_file,'1.665GHz')
```

Now, we will plot the maser features from VLBI data with



the size that refer to maser brightness, color refer to Doppler velocity, and symbol refer to a maser species. Use the following codes.

Finally, the result may look loke this.

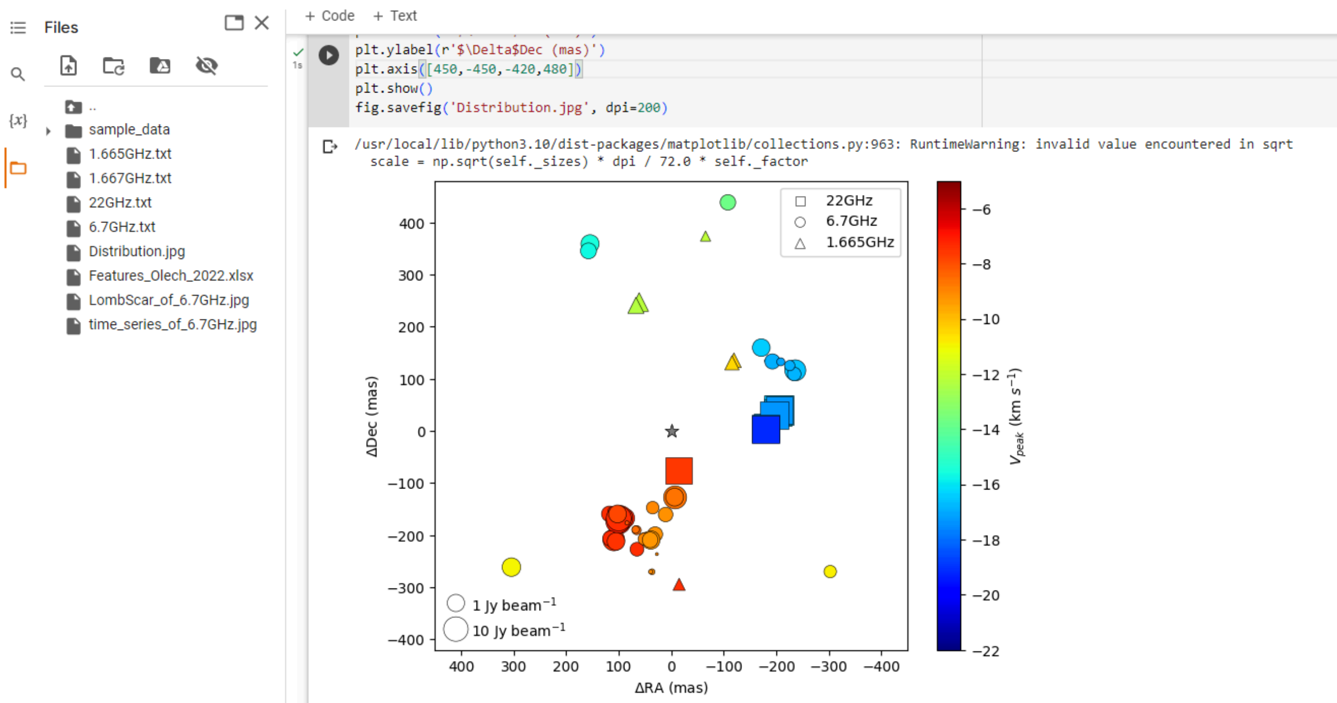


Figure 6 The distribution of various types of masers e.g., 22 GHz, 6.7 GHz and 1.665 GHz.

Do it yourself:

- According to the distribution and Doppler motion, what is the possible structure of this young stellar object? (Outflow, Disk, etc.?) why you think like that?
- Discuss your interpretation with a proper motion of 6.7GHz in the paper
- The distance of this object is about 0.76 kpc, so try to estimate the size of this object.

Note: Blue features mean moving towards the observer and red features mean moving away from the observer.

--- Good Luck ---