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Identifying Spectral Lines in JWST MIRI Data

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Abstract
This study utilizes data from the James Webb Space Telescope's Mid-Infrared Instrument (JWST MIRI) to analyze the Seyfert galaxy NGC 7469. By leveraging the integral field unit (IFU) capabilities of MIRI, we extracted and processed spectra from two distinct regions within the galaxy. Our analysis involved spectral smoothing, continuum modeling, and peak detection to identify emission lines, which were then compared to known mid-infrared lines. The results show notable differences in emission line profiles between the two regions, indicating variations in ionization conditions and dust properties. This research showcases the potential of JWST MIRI for spatially resolved spectroscopic studies of galaxies and provides insights into interpreting mid-infrared diagnostics in active galactic nuclei.

Contents

1. Introduction

1.1 Background on NGC 7469

NGC 7469 lies some 200 million light-years away in the Pegasus constellation. As an SAB(rs)a spiral galaxy showing Seyfert 1 activity, it boasts both a bright, variable active nucleus and a well-defined circumnuclear starburst ring. These dual characteristics offer a valuable laboratory for probing how black-hole feeding and surrounding star formation influence one another. At its center resides a supermassive black hole whose accretion of gas and dust produces the broad emission lines and luminous continuum typical of Seyfert 1 nuclei. Encircling this core is a roughly 1.5-kiloparsec-wide ring of vigorous star formation that shines strongly in ultraviolet and infrared light. NGC 7469's multiwavelength profile—from HST and Chandra to Spitzer and now JWST—has been mapped in exquisite detail.

1.2 Significance of Mid-Infrared Spectroscopy

Mid-infrared (MIR) spectroscopy, covering roughly 5–28μm, probes regions hidden at optical wavelengths. It uncovers molecular and ionic emission lines, maps thermal radiation from warm dust and gas, and penetrates dust-enshrouded environments. With JWST's MIRI instrument—an integral-field unit with four channels (4.9–7.65μm, 7.51–11.7μm, 11.55–17.98μm, 17.7–27.9μm)—astronomers now achieve

Table 1. Feature Details of NGC 7469

Feature	Details
Galaxy type	Seyfert 1, Barred Spiral (SAB(rs)a)
Constellation	Pegasus
Redshift (z)	0.0164
Distance	200 million light-years (61 Mpc)
Apparent magnitude	12.3 (V-band)
Radial velocity	4874 km/s
Right Ascension & Declination	345.815°, +8.8739°
Ring size	1.5 kpc in diameter
Central black hole mass	$(1\text{–}5) \times 10^7\,M_\odot$
Infrared luminosity	$10^{11}\,L_\odot$ (Luminous Infrared Galaxy)
Angular size	$1.3' \times 1.1'$
Other designations	Mrk 1514, UGC 12332, IRAS F23007+0836

high-resolution, spatially resolved MIR observations where each slice of the field is sampled at a slightly different wavelength.

Key Advantages and Scientific Contributions

I. **Penetration Through Dust:** MIR wavelengths traverse dense dust in star-forming clouds, AGN tori, and galactic nuclei, revealing sources opaque in optical or near-infrared bands. While shorter wavelengths are heavily absorbed and scattered, MIR light passes through, exposing embedded stellar nurseries and AGN environs.

II. **Tracing Thermal Emission:** Dust grains heated by young massive stars or by the AGN glow strongly in the mid-infrared. MIR spectroscopy captures this thermal signature, providing a direct tracer of star-formation rates and AGN heating effects—even when the underlying sources are completely obscured at shorter wavelengths.

III. **Diagnostic Emission Lines:** MIR spectra display fine-structure transitions—such as [Ne II], [Ne III], and [S III], which serve as precise probes of ionization levels, electron densities, and elemental abundances.

IV. **Polycyclic Aromatic Hydrocarbons (PAHs):** Emission bands from PAH molecules at 6.2, 7.7, 8.6, and 11.3μm highlight photodissociation regions in starburst environments and act as indicators of the star-formation rate.

V. **Molecular Signatures:** Absorption and emission from H_2, H_2O, CO_2, and silicate features reveal the chemical composition and physical conditions of the interstellar medium.

VI. **Local Galaxy Probing:** For nearby systems like NGC 7469 MIR spectroscopy achieves high signal-to-noise, spatially resolved observations that can dissect structures down to sub-kiloparsec scales.

2. Data and Analytical Tools

2.1 JWST MIRI IFU Spectral Cube Description

A spectral cube is a three-dimensional dataset that merges spatial and spectral information, making it ideal for exploring how light properties vary across both location and wavelength. Unlike conventional images that have two spatial dimensions, spectral cubes introduce a third spectral axis—typically representing wavelength, frequency, or velocity.

- **X-axis:** Right Ascension (RA) — spatial coordinate
- **Y-axis:** Declination (Dec) — spatial coordinate
- **Z-axis:** Spectral dimension — wavelength/frequency/velocity

By assembling two-dimensional slices at different wavelengths into a cube structure, researchers can effectively "slice through" a galaxy, unveiling hidden features and emission signatures that would remain obscured in traditional imaging[1].

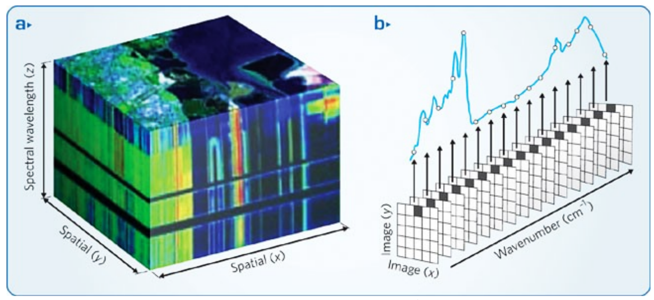

Figure 1. Data Cube

2.2 Software and Libraries Utilized

The analysis of JWST MIRI IFU data was carried out using a suite of Python-based libraries tailored for astrophysical research and visualization of spectral cubes. These tools offer flexibility in handling large data volumes, identifying spectral lines, preprocessing, and graphical representation.

- **Data Access:** FITS files were loaded and manipulated using `astropy.io.fits` and WCS utilities.
- **Spatial Extraction:** Circular regions for extracting localized spectra were defined using `SAOImageDS9`.
- **Visualization:** Raw and processed spectra were plotted using `matplotlib.pyplot` and `plotly.graph`, with key spectral features highlighted.

3. Methodology

3.1 Region Selection and Spectral Extraction

The spectral data cube was obtained from the Mikulski Archive for Space Telescopes (MAST). Using SAOImage DS9, two circular regions with radii of 0.5 arcseconds were designated—one

[1]The image below is credited to the original creator or copyright holder. All rights remain with the respective owner.

centered on the active nucleus and the other located on the surrounding starburst ring. These apertures were stored using the International Celestial Reference System (ICRS). Subsequent spectral extraction and analysis were performed using Python, where intensity as a function of wavelength was plotted for all four MIRI instrument channels.

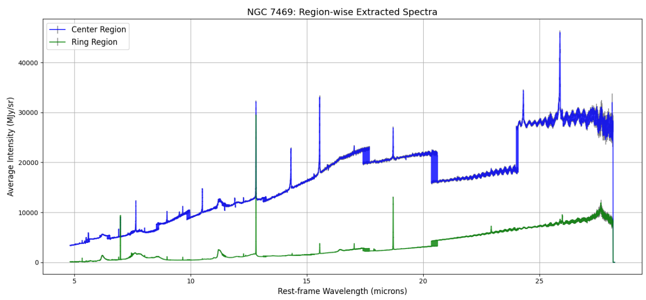

Figure 2. Intensity vs Wavelength graph

4. Results

4.1 Emission Line Identification

Spectral features were identified through the Jdaviz-Specviz platform. By cross-referencing the extracted data with a catalog of known mid-infrared transitions, we classified atomic, ionic, and hydrogen molecular emission lines present in both regions of interest.

4.2 Catalog of Detected Spectral Lines

A list of the identified emission lines—including species such as [Ne II], [Ne III], [S III], and H_2 transitions—was compiled to facilitate further interpretation of the physical conditions within NGC 7469 (See Table - 2 in the Appendix section).

5. Discussion

5.1 Physical Interpretation of Emission Lines

The mid-infrared spectrum of NGC 7469 reveals a rich assortment of emission lines that illuminate different physical components and excitation mechanisms within the interstellar medium (ISM). Below, the most notable lines are grouped by the gas phase they trace and the origin of their excitation.

Ionized Gas Tracers

- **[Ne II] 12.81 μm** – Emission from low-ionization H II regions excited by B- and late O-type stars; a reliable indicator of star formation. In AGN environments, the central engine may also contribute to its excitation.

- **[Ne III] 15.55 μm** – Requires higher-energy photons, implying the presence of young, hot O-stars or AGN influence. The [Ne III]/[Ne II] ratio serves as a proxy for ionization conditions and helps distinguish AGN-driven radiation from stellar processes.

- **[S IV] 10.51 μm and [S III] 18.71 μm** – Trace ionized gas and reveal stratified, decelerating outflows likely associated with AGN feedback. Their flux ratios inform the distinction between starburst and AGN sources.

- **[Ar II] 6.98 μm and [Ar III] 8.99 μm** – Sensitive to ionization structure; the [Ar III]/[Ar II] ratio independently probes the hardness of the radiation field.

- **[Mg VII] 5.50 μm** – A coronal line requiring photon energies above 180 eV. In NGC 7469, it shows broad, blueshifted profiles (FWHM 500–1100 km/s) and velocities up to 1700 km/s, confirming its AGN origin, as stellar processes cannot excite this transition.

Molecular Hydrogen (H_2) Lines

- **H_2 0–0 S(3) 9.66 μm, S(5) 6.91 μm, S(7) 5.51 μm** – Rotational transitions from warm molecular gas excited by:
  - UV photons in photodissociation regions (PDRs)
  - Shock waves from supernovae or AGN-driven outflows
  - X-ray heating in X-ray dominated regions (XDRs)

  Their line strengths help estimate excitation temperatures and infer dominant energy sources. A total H_2 mass of $\sim 1.2 \times 10^7$ $M_\odot$ is suggested in the analyzed region, with rotational motion apparent. Line widths (FWHM 125–330 km/s) reflect the gas dynamics.

Polycyclic Aromatic Hydrocarbon (PAH) Features

- **PAH bands at 6.2, 7.7, 8.6, 11.3, and 12.7 μm** – Emitted by large carbonaceous molecules excited by ultraviolet photons. These features are enhanced in star-forming zones but suppressed near AGN due to destruction by intense radiation. The PAH-to-continuum ratio is useful for gauging starburst versus AGN activity.

5.2 Limitations of the Current Approach

i) **Spectral Resolution:** MIRI's medium-resolution spectroscopic mode offers R $\sim$1500–3500 across 4.9–28 μm, enabling detection of lines spaced by $\sim$0.007 μm at 10 μm. However, this resolution may be inadequate for disentangling closely spaced or blended features, especially in complex emission regions.

ii) **Sensitivity of Diagnostic Ratios:** Ratios of spectral lines can infer physical conditions but are influenced by extinction, gas density, and metallicity. Without detailed photoionization modeling, it remains challenging to definitively separate AGN and stellar ionization contributions.

iii) **ISM Coverage Bias:** MIRI data are sensitive to warm dust and molecular/ionized gas, but not to colder components like CO-traced molecular clouds or atomic gas

(HI, [C II]), limiting the overall scope of ISM characterization.

iv) **Spatial Resolution Constraints:** Despite JWST's advanced capabilities, wavelength-dependent PSF broadening and the fixed integral-field spaxel size ($\sim$0.2 arcsec) hinder resolution of fine-scale structures—especially when differentiating nuclear and circumnuclear regions.

6. Future Work

To deepen our understanding of the interstellar medium and energetic activity in NGC 7469, future work should integrate multi-wavelength data. Submillimeter observations (e.g., ALMA) can trace cold molecular gas such as CO and HCN, which fuel star formation. Near-infrared IFU data (from JWST/NIRSpec or ground-based instruments) reveal hot dust, ionized gas, and hydrogen recombination lines. Far-infrared and radio measurements help detect thermal dust emission and synchrotron radiation from AGN jets or supernova remnants. Meanwhile, X-ray observations (e.g., Chandra, XMM-Newton) directly probe the AGN's high-energy output and hot gas components. This combined approach will connect different gas phases and provide broader context for the mid-infrared analysis.

Additionally, the full spatial coverage of the JWST/MIRI IFU data cube enables more detailed exploration beyond the nucleus and ring regions. A systematic mapping of line intensities and ionization conditions across the field can uncover spatial variations and transitions between AGN-dominated and starburst regions. Line-ratio diagnostics, such as [Ne III]/[Ne II] or [S IV]/[S III], will further clarify the physical processes shaping the galaxy. Expanding the spatial analysis in this way can significantly enrich our understanding of NGC 7469's internal dynamics and feedback mechanisms.

7. Acknowledgements

I would like to express my sincere gratitude to the academic mentors and faculty members whose guidance, encouragement, and thoughtful feedback were vital to the completion of this project. I am particularly thankful to our lecturers for their clear instruction and engaging discussions, which laid a strong conceptual groundwork for the analysis. I also appreciate the support of my fellow interns and peers, whose curiosity and insightful exchanges enriched the overall experience. Lastly, I extend my thanks to the broader scientific community, and especially the teams behind the James Webb Space Telescope (JWST) and its Mid-Infrared Instrument (MIRI), whose publicly available data enabled this research.

References

- Smith, H. A., et al. (2007): *Mid-Infrared Spectroscopy of Galaxies: Diagnostics for Starbursts and AGN*, Astronomical Journal, **133**(4).
- Galliano, F., et al. (2018): *Dust Emission Diagnostics in Galaxies*, Annual Review of Astronomy and Astrophysics, **56**, 673–713.
- García-Bernete, I., et al. (2022): *Mid-Infrared Integral Field Spectroscopy with JWST: Simulating the Spectra of AGN and Starburst Galaxies*, Monthly Notices of the Royal Astronomical Society, **513**(3).
- Armus, L., et al. (2021): *Infrared Diagnostics of Star-Formation and AGN in Galaxies*, Annual Review of Astronomy and Astrophysics, **59**, 209–265.
- Wright, G. S., et al. (2023): *The Mid-Infrared Instrument for the James Webb Space Telescope, I. Introduction*, Astronomy & Astrophysics, **655**, A52.
- Sturm, E., et al. (2020): *Probing the Circumnuclear Dust and Gas in Seyfert Galaxies with Mid-Infrared Spectroscopy*, Astrophysical Journal Supplement Series, **250**(1).
- GOALS-JWST Team (2022): *Tracing AGN Feedback on the Star-forming Interstellar Medium in NGC 7469*, Astrophysical Journal Letters.
- JWST User Documentation: `https://jwst-docs.stsci.edu/jwst-mid-infrared-instrument` *JWST Mid-Infrared Instrument (MIRI) provides imaging and spectroscopic observing modes from* $\sim$*5 to 28* μ*m.*
- Armus, L., et al. (2023): *GOALS-JWST: Mid-Infrared Spectroscopy of the Nucleus of NGC 7469*, Astrophysical Journal Letters.

Appendix: Code Snippets and Key Functions & Table - 2: Identified Emission Lines in JWST MIRI Channels

```python
# --- Imports ---
import numpy as np
import matplotlib.pyplot as plt
from astropy.io import fits
from astropy.wcs import WCS
from regions import Regions
import warnings
warnings.simplefilter('ignore')  # Suppress WCS warnings for clean output

# --- Redshift for rest-frame correction ---
z = 0.016268  # Redshift of NGC 7469

# --- File Paths to DS9 Region Masks ---
region_files = {
    "Center": r"...\Center_Region.reg",
    "Ring": r"...\Ring_Region.reg"
}

# List of JWST MIRI FITS cube file paths (C h 1 4 , short/medium/long)
file_paths = [
    fr"...\jw01328-c1006_t014_miri_ch{ch}-{part}_s3d.fits"
    for ch in range(1, 5)
    for part in ['short', 'medium', 'long']
]

# --- Dictionary to store Region Spectra ---
region_spectra = {}

# --- Main Loop: Spectrum Extraction per Region ---
for name, reg_path in region_files.items():
    region = Regions.read(reg_path, format='ds9')[0]
    wl_all, flux_all, err_all = [], [], []

    for path in file_paths:
        hdu = fits.open(path)
        cube, err_cube = hdu[1].data, hdu[2].data
        cube[cube < 0] = np.nan
        header = hdu[1].header

        mask = region.to_pixel(WCS(header).celestial).to_mask()
        spec, spec_err = [], []

        for i in range(cube.shape[0]):
            d = mask.multiply(cube[i])
            e = mask.multiply(err_cube[i])
            spec.append(np.nanmean(d) or 0)
            spec_err.append(np.sqrt(np.nanmean(e**2)) or 0)

        wl = ((np.arange(cube.shape[0]) - (header['CRPIX3'] - 1)) * header['CDELT3'] + header['CRVAL3']) / (1 + z)

        wl_all.extend(wl)
        flux_all.extend(spec)
        err_all.extend(spec_err)

    idx = np.argsort(wl_all)
    region_spectra[name] = {
        "wavelength": np.array(wl_all)[idx],
        "spectrum": np.array(flux_all)[idx],
        "error": np.array(err_all)[idx]
    }

# --- Plotting ---
plt.figure(figsize=(12, 6))
for idx, (name, data) in enumerate(region_spectra.items()):
    plt.errorbar(data["wavelength"], data["spectrum"],
                 yerr=data["error"], label=name, alpha=0.8)

plt.xlabel("Rest-frame Wavelength ( m )")
plt.ylabel("Flux (MJy/sr)")
plt.title("NGC 7469: Extracted Spectra from IFU Regions")
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```

Table - 2: Identified Emission Lines in JWST MIRI Channels

Channel	Range	Transition	Wavelength (μm)	Intensity (MJy/sr)	Center / Ring
CH1	Short	H 0–0 S(8)	5.052	3656	98
		[FeII] $a^4F_{9/2} - a^6D_{9/2}$	5.340169	4345	527
		[MgVII] $^3P_1 -^3 P_2$	5.5033	4501	150
		H 0–0 S(7)	5.511	4846	204
		[MgV] $^3P_1 -^3 P_2$	5.6098	5694	230
	Medium	H 0–0 S(6)	6.108	5382	453
	Long	H 0–0 S(5)	6.909	6548	799
		[ArII] $^2P_{1/2} -^2 P_{3/2}$	6.985274	8868	7965
CH2	Short	[NeVI] $^2P_{3/2} -^2 P_{1/2}$	7.6524	11250	1819
		H 0–0 S(4)	8.025	6823	1280
	Medium	[ArIII] $^3P_1 -^3 P_2$	8.99138	10004	1019
		H 0–0 S(3)	9.664	11000	714
	Long	[SIV] $^2P_{3/2} -^2 P_{1/2}$	10.51049	14556	723
CH3	Short	H 0–0 S(2)	12.279	12912	1536
		[NeII] $^2P_{1/2} -^2 P_{3/2}$	12.81354	29648	19165
	Medium	[ClII] $^3P_1 -^3 P_2$	14.3678	15101	1741
		[NeV] $^3P_2 -^3 P_1$	14.5546	22493	1445
	Long	[NeIII] $^3P_1 -^3 P_2$	15.55505	33020	3462
		[CoIII] $a^4F_{5/2} - a^4F_{7/2}$	16.391	20572	2448
		H 0–0 S(1)	17.035	22777	3200
CH4	Short	[SIII] $^3P_2 -^3 P_1$	18.71303	26912	13018
	Medium	[FeIII] $^5D_3 -^5 D_4$	22.925	18004	6476
	Long	[NeV] $^3P_1 -^3 P_0$	24.3175	33549	6985
		[OIV] $^2P_{3/2} -^2 P_{1/2}$	25.8903	46001	8586
		[FeII] $a^6D_{7/2} - a^6D_{9/2}$	25.98839	30544	9485

🔭Identifying spectral lines in MIRI JWST data

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In this project, we will analyse the MIRI spectral cubes collected from JWST data for the source NGC 7469. We will analyse how to extract spectra from spectral cube. We will also identify emission lines from the source.

📡 JWST:

JWST has four main science instruments, each designed for specific types of imaging, spectroscopy, and coronagraphy across the infrared spectrum.

Instrument	Full Name	Primary Capabilities	Wavelength Range
NIRCam	Near-Infrared Camera	Imaging, weak lensing, coronagraphy	0.6 – 5.0 μm
NIRSpec	Near-Infrared Spectrograph	Multi-object spectroscopy, IFU, high-res spectra	0.6 – 5.3 μm
MIRI	Mid-Infrared Instrument	Mid-IR imaging, spectroscopy, coronagraphy	5.0 – 28.5 μm
FGS/NIRISS	Fine Guidance Sensor / Near-Infrared Imager and Slitless Spectrograph	Target acquisition, slitless spectroscopy, exoplanet transit observations	0.6 – 5.0 μm

We will analyse data collected by MIRI for the galaxy NGC 7469.

💡 JWST MIRI wavelength range & different channels:

In [8]:
```
from IPython.display import Image, display
display(Image(filename="Screenshot 2025-06-28 015402.png", width=900))
```

FOV name λ-range (μm)	FOV (arcsec)	Pixel size (arcsec)	Sub-band name	λ-range (μm)	Resolving power (λ/Δλ)
Channel 1 4.9–7.65	3.2 × 3.7	0.196	SHORT (A) MEDIUM (B) LONG (C)	4.90–5.74 5.66–6.63 6.53–7.65	3,320–3,710 3,190–3,750 3,100–3,610
Channel 2 7.51–11.7	4.0 × 4.8	0.196	SHORT (A) MEDIUM (B) LONG (C)	7.51–8.77 8.67–10.13 10.01–11.70	2,990–3,110 2,750–3,170 2,860–3,300
Channel 3 11.55–17.98	5.2 × 6.2	0.245	SHORT (A) MEDIUM (B) LONG (C)	11.55–13.47 13.34–15.57 15.41–17.98	2,530–2,880 1,790–2,640 1,980–2,790
Channel 4 17.7–27.9	6.6 × 7.7	0.273	SHORT (A) MEDIUM (B) LONG (C)	17.70–20.95 20.69–24.48 24.40–27.90	1,460–1,930 1,680–1,770 1,630–1,330

🌠 NGC 7469:

It is a Barred Spiral Galaxy, having a central bar-shaped structure of stars. NGC 7469 is located about 200 million light-years away from Earth, which means, given its apparent dimensions, that NGC 7469 is approximately 142,000 light-years across. NGC 7469 is a type I Seyfert galaxy, characterised by its bright nucleus. It is also a luminous infrared source with a powerful starburst embedded into its circumnuclear region. It has been observed in: JWST (MIRI + NIRSpec), Spitzer IRS, ALMA, HST (UV/optical imaging), Chandra (X-ray).

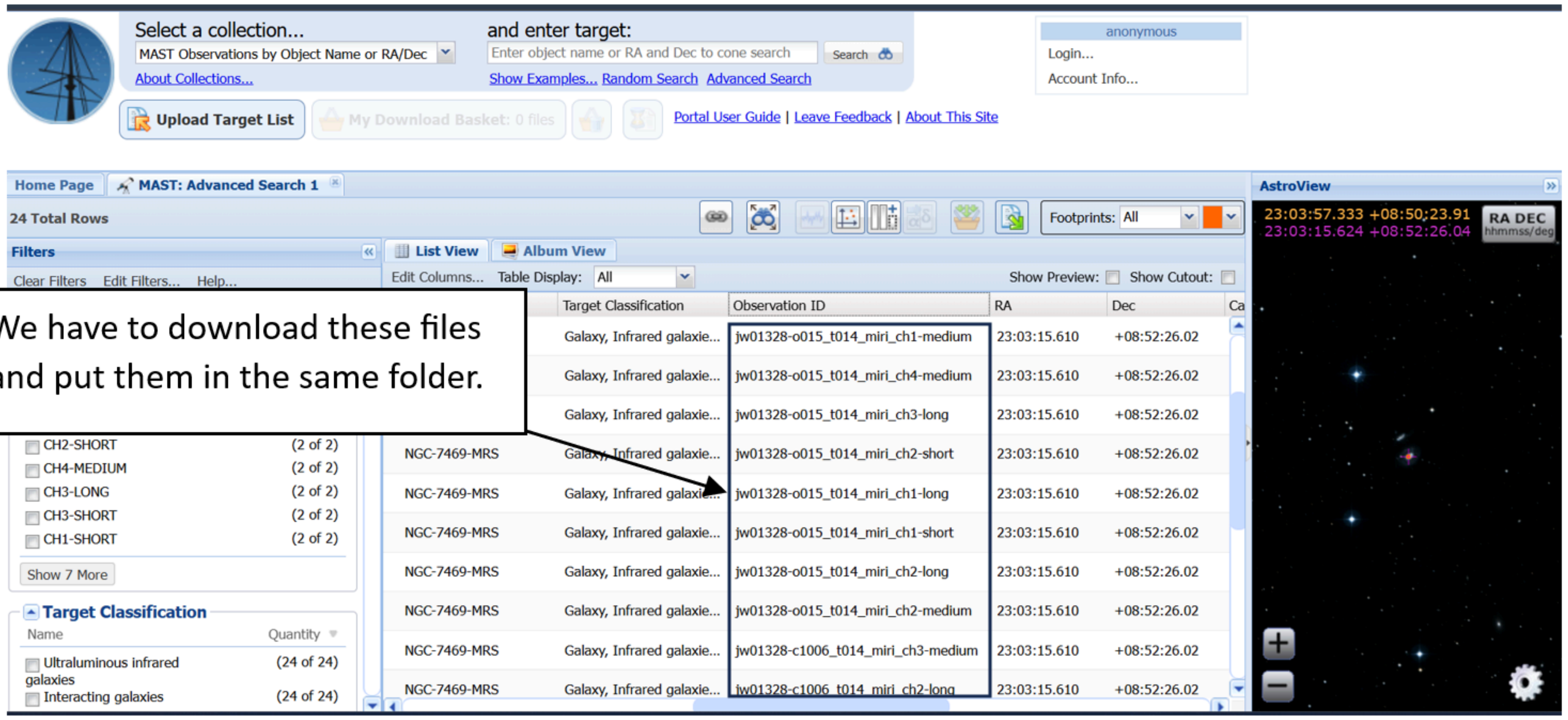
Property	Value / Description
Galaxy Name	NGC 7469
Other Designations	Mrk 1514, UGC 12332, IRAS F23007+0836
Galaxy Type	Seyfert 1 Galaxy with a Circumnuclear Starburst Ring
Morphological Type	(R')SAB(rs)a (intermediate barred spiral with ring and spiral structure)
Constellation	Pegasus
Redshift (z)	0.016268
Distance	68–70 Mpc (220 million light-years)
Radial Velocity	4874 km/s
Apparent Magnitude (V)	12.3
Angular Size	1.3 × 1.1 arcminutes
Physical Size	28,000 light-years across

⬇️ Steps about how to download data:

First go to the MAST portal (https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html). Then go to advanced search. There, give the following input:

1. Object Name: NGC 7469
2. Observation Type: science
3. Mission: JWST
4. Instrument: MIRI/IFU
5. Product Type: cube

In [9]:
```
display(Image(filename="Screenshot 2025-06-28 023621.png", width=900))
```



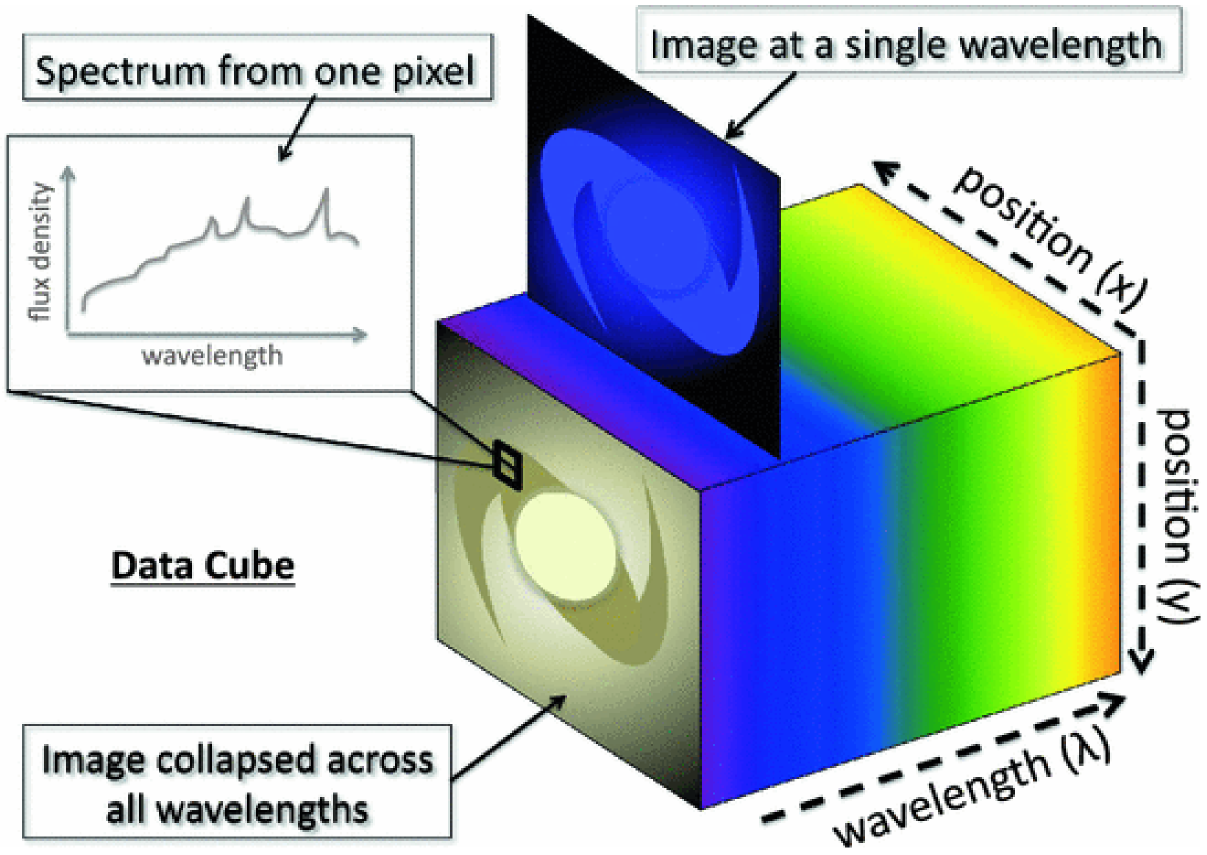
Spectral Cube:

A spectral cube is a three-dimensional (3D) astronomical data structure used in spectroscopy. It combines both spatial and spectral information into a single dataset, enabling detailed analysis of how light varies across position and wavelength. Unlike image that has 2 spatial axis, this has one spectral axis too. It can be in wavelength,frequency or velocity.

X-axis: spatial position (Right Ascension)
Y-axis: spatial position (Declination)
Z-axis: wavelength (or frequency or velocity)

JWST MIRI/MRS, NIRSpec IFU, ALMA, MUSE, and VLT SINFONI all produce spectral cubes.

In [3]:
```
display(Image(filename="Data Cube.png", width=600))
```



🔬 Regions:

Regions is an in-development coordinated package of Astropy for region handling.

The Regions package provides classes to represent:

```
Regions defined using pixel coordinates (e.g., CirclePixelRegion)
Regions defined using celestial coordinates, but still in an Euclidean geometry (e.g., CircleSkyRegion)
To transform between sky and pixel regions, a world coordinate system object (e.g., astropy.wcs.WCS) is needed.
```

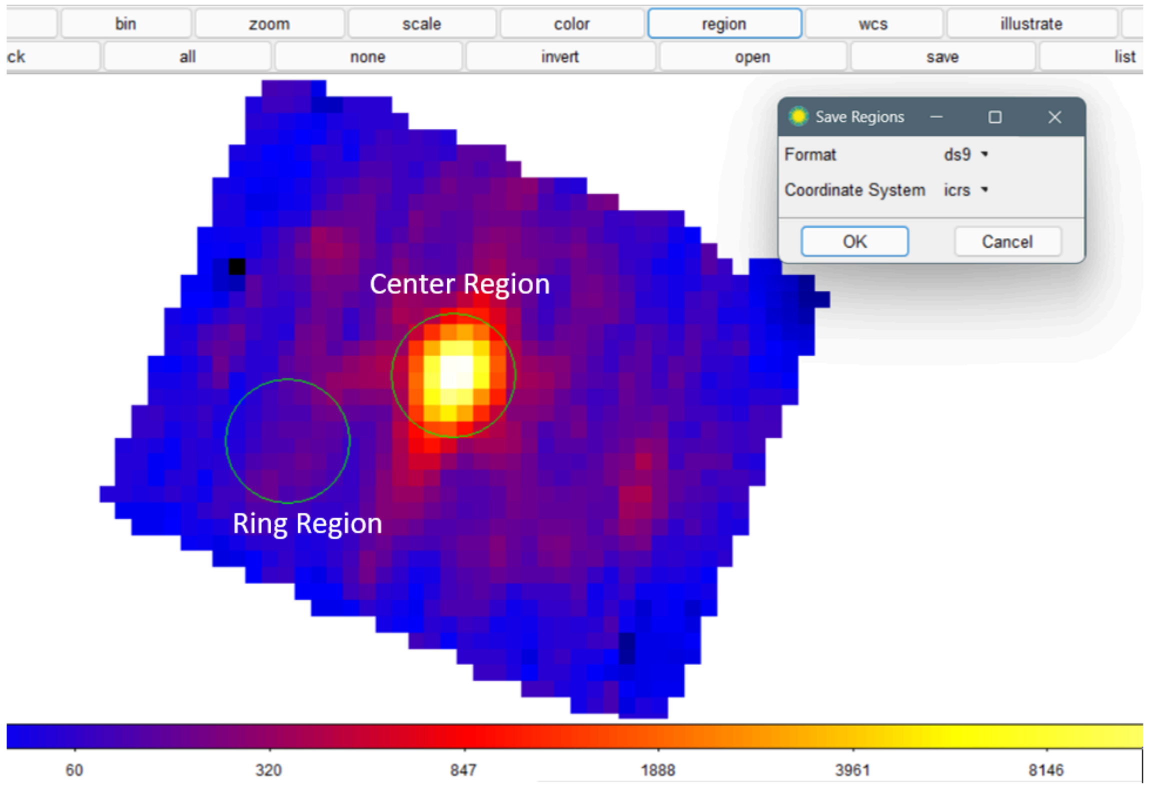
Regions also provides a unified interface for reading, writing, parsing, and serializing regions data in different formats, including the DS9 Region Format, CRTF (CASA Region Text Format), and FITS Region Binary Table format.

Further Reference: https://astropy-regions.readthedocs.io/en/stable/shapes.html

🧮 DS9:

SAOImage DS9 is a widely-used astronomical imaging and data visualization tool developed by the Smithsonian Astrophysical Observatory. It is primarily used to display and analyze FITS files (Flexible Image Transport System), which is the standard format for astronomical data. It is very usefull to creat Overlays (regions, contours, catalogs, coordinate grids). It has World Coordinate System (WCS) support.
Open the file "ch1_short" and make the regions as shown figure with radius = 0.5 arcsec. Save the region file as .reg file with format ‘ds9’ and coordinate system as 'icrs' respectively.

In [4]:
```
display(Image(filename="Screenshot 2025-06-28 025716.png", width=600))
```



📝 Python Code to extract spectra from data cube:

We have selected this two regions and will iterate it over all FITS file for all 4 channels. We can proceed further and extract the spectra from each of the file and plot the final spectrum from it.

In [1]:
```
# Import necessary libraries
import numpy as np
import warnings
import matplotlib.pyplot as plt
from astropy.io import fits
from astropy.wcs import WCS
from regions import Regions

warnings.filterwarnings("ignore", category=UserWarning, append=True)
```

In [2]:
```
# Define the redshift for NGC 7469
# NGC 7469 is a Seyfert galaxy with a redshift of approximately 0.016268
# This value is used to convert observed wavelengths to rest-frame wavelengths.
# The redshift value can be obtained from various astronomical databases like NED (NASA/IPAC Extragalactic Database).

# Redshift value
z = 0.016268

# Region file paths
region_files = {
    "Center Region": r"F:\PROJECTS\JWST MIRI\Region\Center Region.reg",
    "Ring Region": r"F:\PROJECTS\JWST MIRI\Region\Ring Region.reg"
}
print(region_files)
# FITS cube file paths
file_paths = []
for ch_num in range(1, 5):
    for part in ['short', 'medium', 'long']:
        #file_path = fr"F:\PROJECTS\JWST FITS\jw01328-c1006_t014_miri_ch{ch_num}-{part}_s3d.fits"
```

```python
        file_path = fr"F:\PROJECTS\JWST MIRI\FITS\jw01328-c1006_t014_miri_ch{ch_num}-{part}_s3d.fits"

        file_paths.append(file_path)

# Dictionary to store results per region
print(file_paths)
region_spectra = {}
```

```
{'Center Region': 'F:\\PROJECTS\\JWST MIRI\\Region\\Center Region.reg', 'Ring Region': 'F:\\PROJECTS\\JWST MIRI\\Region\\Ring Region.reg'}
['F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch1-short_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch1-medium_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01
328-c1006_t014_miri_ch1-long_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch2-short_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch2-medium_s3d.fit
s', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch2-long_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch3-short_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw0
1328-c1006_t014_miri_ch3-medium_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch3-long_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch4-short_s3d.fit
s', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch4-medium_s3d.fits', 'F:\\PROJECTS\\JWST MIRI\\FITS\\jw01328-c1006_t014_miri_ch4-long_s3d.fits']
```

In [4]:

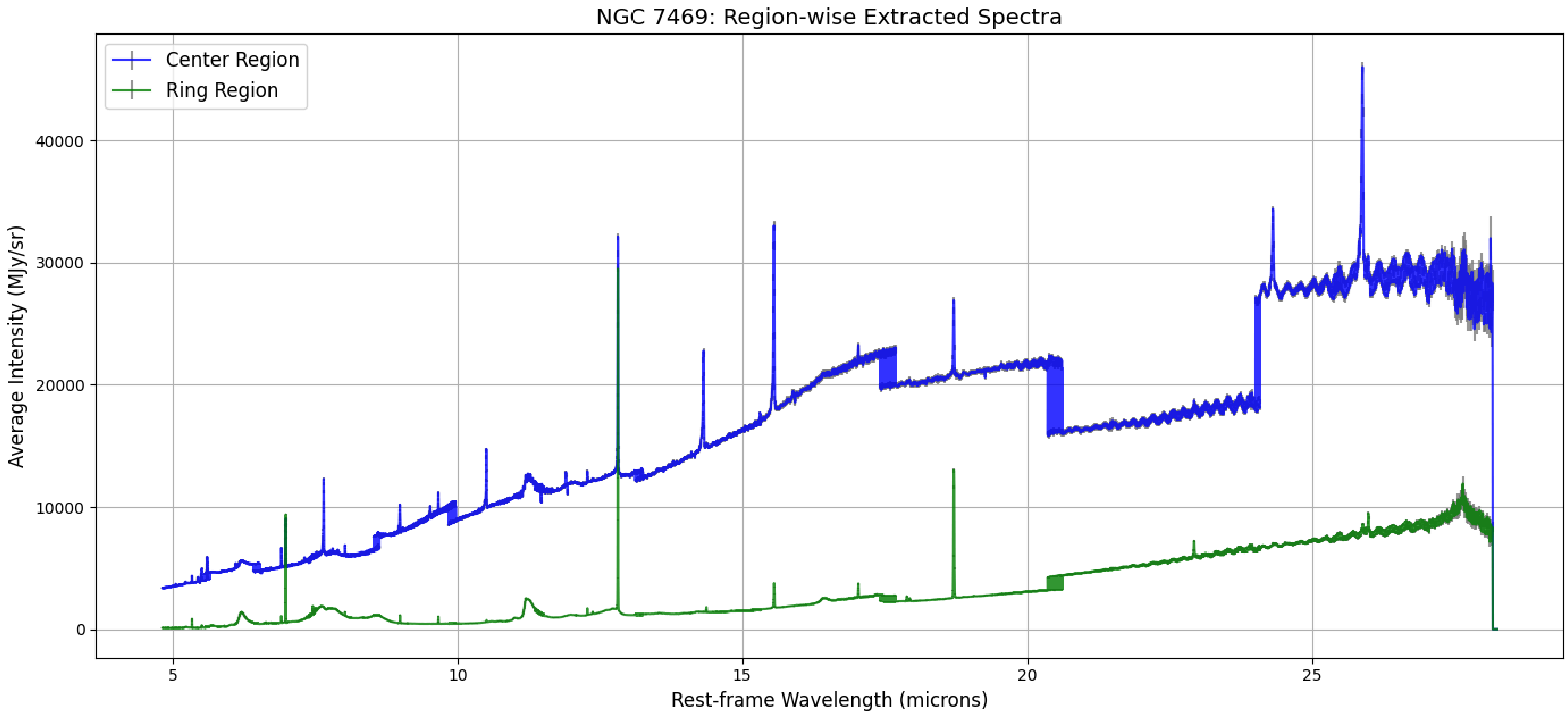
```python
# Loop over each region
for region_name, reg_path in region_files.items():
    regions = Regions.read(reg_path, format='ds9')

    # Use two region files
    region = regions[0]

    # Initialize lists to store the spectrum and wavelength for all channels
    spectrum_all = []
    spectrum_all_err = []
    wavelength_all = []

    for file_path in file_paths:
        # Read data
        data = fits.open(file_path)[1].data      # 1 contain the 3D data cube
        data[data < 0] = np.nan                  # Reject those data having intensity less than 0, which occures for instrumental malfunction
        data_err = fits.open(file_path)[2].data  # 2 contain the error cube

        # Open the FITS file and get the WCS information to make mask of the region
        # Mask means the region of interest in the image - other parts are ignored
        header = fits.open(file_path)[1].header
        wcs = WCS(header)
        mask = region.to_pixel(wcs.celestial).to_mask()  # Convert the region from celestial to pixel coordinates then make a mask

        # Get the shape of the data
        num_channels, ny, nx = data.shape
        spectrum = []
        spectrum_err = []

        # Loop over each channel (wavelength)
        for i in range(num_channels):
            # Extract the 2D image from channels
            masked_data = np.array(mask.multiply(data[i, :, :]), dtype=float)
            masked_data_err = np.array(mask.multiply(data_err[i, :, :]), dtype=float)

            avg_intensity = np.nanmean(masked_data)
            avg_intensity_err = np.sqrt(np.nanmean(masked_data_err ** 2))

            if np.isnan(avg_intensity):
                avg_intensity = 0
            if np.isnan(avg_intensity_err):
                avg_intensity_err = 0

            spectrum.append(avg_intensity)
            spectrum_err.append(avg_intensity_err)
```

```python
        # Extract the WCS information from the header to get the wavelength values
        # CRVAL3, CDELT3, and CRPIX3 are WCS keywords that define the wavelength axis

        # Wavelength axis
        crval3 = header['CRVAL3']   # CRVAL3 is the reference value of the wavelength axis
        cdelt3 = header['CDELT3']   # CDELT3 is the increment in the wavelength axis
        crpix3 = header['CRPIX3']   # CRPIX3 is the reference pixel of the wavelength axis

        wavelength = (np.arange(num_channels) - (crpix3 - 1)) * cdelt3 + crval3
        wavelength = wavelength / (1 + z) # Convert to rest-frame wavelength

        wavelength_all.extend(wavelength)
        spectrum_all.extend(spectrum)
        spectrum_all_err.extend(spectrum_err)

    # Sort all arrays by wavelength
    wavelength_all = np.array(wavelength_all)
    spectrum_all = np.array(spectrum_all)
    spectrum_all_err = np.array(spectrum_all_err)
    sort_idx = np.argsort(wavelength_all)

    region_spectra[region_name] = {
        "wavelength": wavelength_all[sort_idx],
        "spectrum": spectrum_all[sort_idx],
        "error": spectrum_all_err[sort_idx]
    }

import warnings
from astropy.wcs import FITSFixedWarning
warnings.simplefilter('ignore', category=FITSFixedWarning)
```

📈 Plotting the Intensity vs Wavelength data for selected two regions:

In [5]:

```python
# PLOT COMPARATIVE SPECTRA FOR REGION 1 & 2
plt.figure(figsize=(14, 6.5))
colors = ['blue', 'green']
for idx, (region_name, data) in enumerate(region_spectra.items()):
    plt.errorbar(data["wavelength"], data["spectrum"],
                 yerr=data["error"],
                 label=region_name,
                 color=colors[idx], ecolor='gray', alpha=0.8)

plt.xlabel('Rest-frame Wavelength (microns)', fontsize=12)
plt.ylabel('Average Intensity (MJy/sr)', fontsize=12)
plt.title('NGC 7469: Region-wise Extracted Spectra', fontsize=14)
plt.grid(True)
plt.legend(fontsize=12)
plt.tight_layout()
plt.show()
```

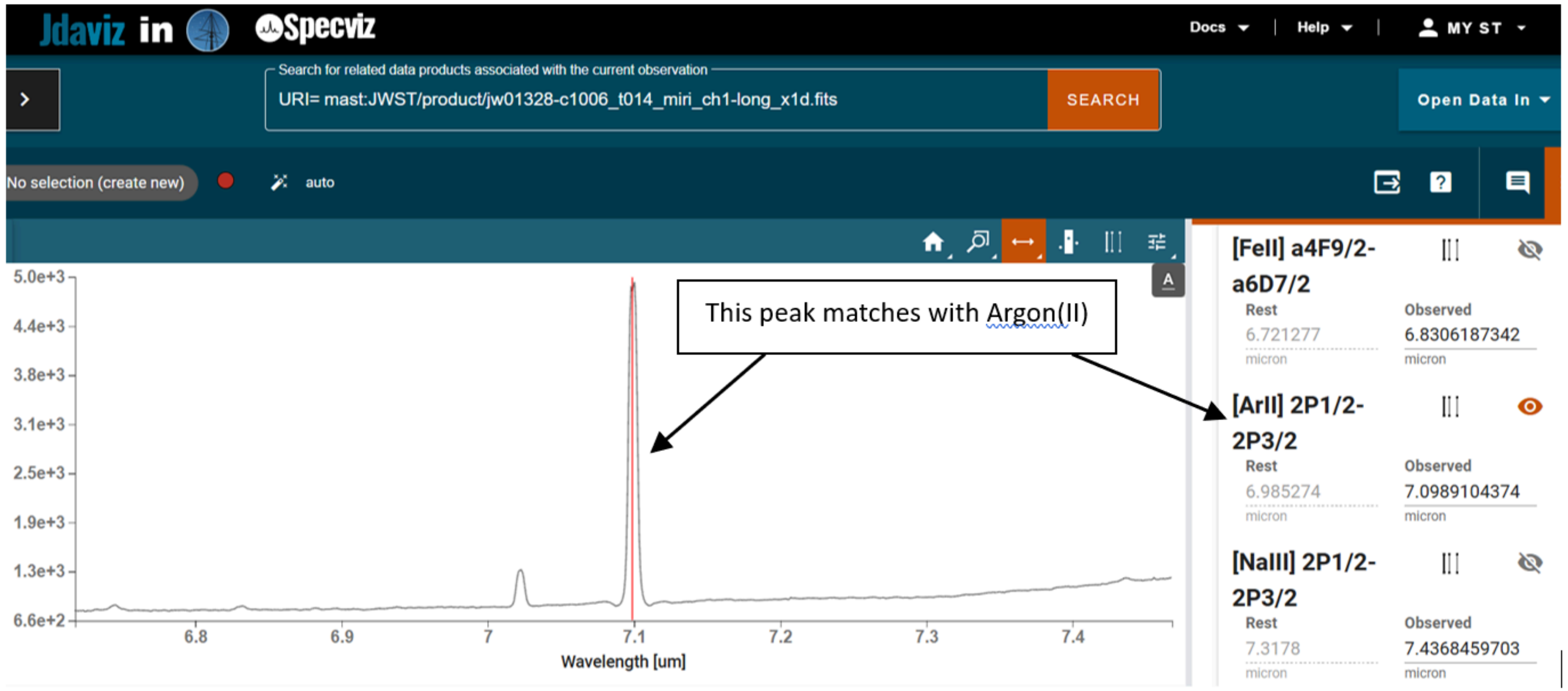


🌈 Identifying the spectrum:

We will now identify the peaks that appear in the above graph. These peaks indicate the abundance of different elements in the galaxy.
We will use **Jdaviz/Cubeviz** database. We have to enter the redshift value of this galaxy and then we will check spectrum of each channel.

Fore more Info: https://jdaviz.readthedocs.io/en/stable/cubeviz/index.html

In [5]:
```
display(Image(filename="Screenshot 2025-06-28 211813.png", width=900))
```



✅ List of observed peaks and corresponding wavengths (in microns) for each channels:

In [6]:
```
display(Image(filename="Screenshot 2025-06-28 222016.png", width=700))
```

Channel	Range	Transition	Wavelength(μm)
CH1	Short	H 0– 0 S(8) [FeII] a4F9/2-a6D9/2 [MgVII] 3P2–3P1 H 0 – 0S(7) [MgV]3P1 – 3P2	5.052 5.340169 5.5033 5.511 5.6098
	Medium	H 0 – 0S(6)	6.108
	Long	H 0 – 0S(5) [ArII] 2P1/2 – 2P3/2	6.909 6.985274
CH2	Short	[NeVI] 2P3/2 – 2P1/2 H 0 – 0S(4)	7.6524 8.025
	Medium	[ArIII] 3P1 – 3P2 H 0 – 0S(3)	8.99138 9.664
	Long	[SIV] 2P3/2-2P1/2	10.51049
CH3	Short	H 0 – 0S(2) [NeII] 2P1/2-2P3/2	12.279 12.81354
	Medium	[ClII] 3P1-3P2 [NeV] 3P2-3P1	14.3678 14.5546
	Long	[NeIII] 3P1 – 3P2 [CoIII] a4F5/2 – a4F7/2 H 0 – 0S(1)	15.55505 16.391 17.035
CH4	Short	[SIII] 3P2-3P1	18.71303
	Medium	[FeIII] 5D3-5D4	22.925
	Long	[NeV] 3P1-3P0 [OIV] 2P3/2-2P1/2 [FeII] a6D7/2-a6D9/2	24.3175 25.8903 25.98839

📈 Plotting the spectral lines:

In [6]:

```
import plotly.graph_objects as go
import numpy as np

# Initialize figure
fig = go.Figure(layout=dict(
    width=1280,
    height=600,
    template='plotly_white'
))

colors = ['blue', 'green', 'orange', 'purple', 'red']  # Add more if needed

# Plot region-wise spectrum and error bands
for idx, (region_name, data) in enumerate(region_spectra.items()):
    wavelength = np.array(data["wavelength"])
    spectrum = np.array(data["spectrum"])
    error = np.array(data["error"])

    # Add spectrum line
```

```
    fig.add_trace(go.Scatter(
        x=wavelength,
        y=spectrum,
        mode='lines',
        line=dict(color=colors[idx % len(colors)], width=1.5),
        name=region_name,
        hovertemplate='λ: %{x:.3f} µm<br>Intensity: %{y:.2f} MJy/sr<extra></extra>'
    ))

    # Add uncertainty band
    fig.add_trace(go.Scatter(
        x=np.concatenate([wavelength, wavelength[::-1]]),
        y=np.concatenate([spectrum + error, (spectrum - error)[::-1]]),
        fill='toself',
        fillcolor='rgba(31, 119, 180, 0.2)' if colors[idx % len(colors)] == 'blue' else 'rgba(150, 150, 150, 0.2)',
        line=dict(color='rgba(255,255,255,0)'),
        hoverinfo='skip',
        name=f'{region_name} Uncertainty',
        showlegend=False
    ))

# Define features
features = {
    'PAHs': {'PAH 6.2': 6.2, 'PAH 7.7': 7.7, 'PAH 8.6': 8.6, 'PAH 11.3': 11.3, 'PAH 12.7': 12.7, 'PAH 16.4': 16.4, 'PAH 17.4': 17.4,},
    'H₂': {'H₂(1)': 17.035, 'H₂(2)': 12.279, 'H₂(3)': 9.664, 'H₂(4)': 8.025, 'H₂(5)': 6.909, 'H₂(6)': 6.108, 'H₂(7)': 5.511, 'H₂(8)': 5.052 },
    'Neon': {'Ne(II)': 12.81354, 'Ne(III)': 15.55505, 'Ne(V)(3P2-3P1)': 14.32168, 'Ne(V)(3P1-3P0)': 24.3175, 'Ne(VI)': 7.6524,},
    'Iron': {'Fe(III)': 22.925, 'Fe(II)(a6D7/2-a6D9/2)': 25.98839, 'Fe(II)(a4F9/2-a6D9/2)': 5.340169,},
    'Suphur': {'S(III)': 18.71303, 'S(IV)': 10.51049,},
    'Argon': {'Ar(II)': 6.985274, 'Ar(III)': 8.99138,},
    'Magnesium': {'Mg(V)': 5.6098, 'Mg(VII)': 5.5033,},
    'Other': {'Cl(II)': 14.3678, 'O(IV)': 25.8903, 'Co(III)': 16.391,},
}

# Feature line colors
colors_features = {
    'PAHs': '#FF7F0E',
    'H₂': "#002E50",
    'Neon': "#D62728",
    'Iron': "#601303",
    'Suphur': '#E377C2',
    'Argon': "#6009B2",
    'Magnesium': '#56FF01',
    'Other': '#17BECF',
}

# Add vertical lines and annotations
for category, lines in features.items():
    for name, wl in lines.items():
        fig.add_vline(
            x=wl,
            line=dict(
                color=colors_features[category],
                width=1.5 if category == 'PAHs' else 1,
                dash='solid' if category == 'PAHs' else 'dot'
            ),
            annotation=dict(
                text=name,
                yanchor='bottom',
                font=dict(size=10, color=colors_features[category]),
                yshift=10 if category == 'PAHs' else 0
```

```python
            )
        )

# Highlight PAH bands as shaded regions
for wl in [6.2, 7.7, 8.6, 11.3, 12.7, 16.4, 17.4]:
    fig.add_vrect(
        x0=wl - 0.15, x1=wl + 0.15,
        fillcolor=colors_features['PAHs'],
        opacity=0.1,
        line_width=0
    )

# Final layout
fig.update_layout(
    title='<b>NGC 7469 JWST/MIRI IFU Region-wise Spectra with Molecular and Atomic Features</b>',
    xaxis_title='<b>Wavelength (μm)</b>',
    yaxis_title='<b>Intensity (MJy/sr)</b>',
    hovermode='x unified',
    legend=dict(
        orientation='h',
        yanchor='bottom',
        y=1.02,
        xanchor='right',
        x=1
    ),
    margin=dict(l=50, r=50, b=50, t=80)
)

# Show figure
fig.show()
```

💡 Intensity of observed peaks for Center region and Ring region:

In [10]:

```python
import numpy as np
import pandas as pd

# Define spectral lines of interest
features = {
    'PAHs': {'PAH 6.2': 6.2, 'PAH 7.7': 7.7, 'PAH 8.6': 8.6, 'PAH 11.3': 11.3, 'PAH 12.7': 12.7, 'PAH 16.4': 16.4, 'PAH 17.4': 17.4},
    'H₂': {'H₂(1)': 17.035, 'H₂(2)': 12.279, 'H₂(3)': 9.664, 'H₂(4)': 8.025, 'H₂(5)': 6.909, 'H₂(6)': 6.108, 'H₂(7)': 5.511, 'H₂(8)': 5.052},
    'Neon': {'Ne(II)': 12.81354, 'Ne(III)': 15.55505, 'Ne(V)(3P2-3P1)': 14.32168, 'Ne(V)(3P1-3P0)': 24.3175, 'Ne(VI)': 7.6524},
    'Iron': {'Fe(III)': 22.925, 'Fe(II)(a6D7/2-a6D9/2)': 25.98839, 'Fe(II)(a4F9/2-a6D9/2)': 5.340169},
    'Sulfur': {'S(III)': 18.71303, 'S(IV)': 10.51049},
    'Argon': {'Ar(II)': 6.985274, 'Ar(III)': 8.99138},
    'Magnesium': {'Mg(V)': 5.6098, 'Mg(VII)': 5.5033},
    'Other': {'Cl(II)': 14.3678, 'O(IV)': 25.8903, 'Co(III)': 16.391},
}

# Flatten feature list
all_lines = [(cat, name, wl) for cat, lines in features.items() for name, wl in lines.items()]

# Extract intensities separately for Center and Ring regions
region_tables = {}

for region in ['Center Region', 'Ring Region']:
    if region not in region_spectra:
        print(f"Region '{region}' not found in data.")
        continue
```

```
    data = region_spectra[region]
    wl_arr = np.array(data["wavelength"])
    flux_arr = np.array(data["spectrum"])
    err_arr = np.array(data["error"])

    # Collect rows
    rows = []
    for category, line_name, target_wl in all_lines:
        idx = np.abs(wl_arr - target_wl).argmin()
        matched_wl = wl_arr[idx]
        intensity = flux_arr[idx]
        uncertainty = err_arr[idx]

        rows.append({
            "Category": category,
            "Line": line_name,
            "Target λ (µm)": target_wl,
            "Matched λ (µm)": matched_wl,
            "Intensity (MJy/sr)": intensity,
            "Error (MJy/sr)": uncertainty
        })

    # Save table for this region
    region_tables[region] = pd.DataFrame(rows)

# Access tables like this:
center_table = region_tables["Center Region"]
ring_table = region_tables["Ring Region"]

# (Optional) Display preview
print("Center Region Sample:")
print(center_table.head(5))
print("\nRing Region Sample:")
print(ring_table.head(5))

# Export Center Region intensities to CSV
center_table.to_csv("NGC7469_CenterRegion_Intensities.csv", index=False)

# Export Ring Region intensities to CSV
ring_table.to_csv("NGC7469_RingRegion_Intensities.csv", index=False)
```

```
Center Region Sample:
  Category      Line  Target λ (µm)  Matched λ (µm)  Intensity (MJy/sr)  \
0     PAHs   PAH 6.2            6.2        6.200333         5558.678740
1     PAHs   PAH 7.7            7.7        7.699987         6239.918955
2     PAHs   PAH 8.6            8.6        8.599651         7862.196742
3     PAHs  PAH 11.3           11.3       11.299726        12097.524902
4     PAHs  PAH 12.7           12.7       12.699652        12719.077447

   Error (MJy/sr)
0       66.958839
1       63.252575
2       60.507728
3       77.815018
4      115.769391

Ring Region Sample:
  Category      Line  Target λ (µm)  Matched λ (µm)  Intensity (MJy/sr)  \
0     PAHs   PAH 6.2            6.2        6.200333         1365.219747
1     PAHs   PAH 7.7            7.7        7.699987         1637.012349
2     PAHs   PAH 8.6            8.6        8.599651         1145.460820
3     PAHs  PAH 11.3           11.3       11.299726         2123.961496
4     PAHs  PAH 12.7           12.7       12.699652         1649.023417

   Error (MJy/sr)
0       21.945997
1       19.481871
2       15.262571
3       19.902725
4       14.821774
```

🚀 Extracting spectra to a data-frame in pandas and exporting it into a CSV file:

In [7]:

```python
import pandas as pd
from functools import reduce

# List to collect all individual region DataFrames
df_list = []

for region_name, spec_data in region_spectra.items():
    # Build DataFrame for this region
    df = pd.DataFrame({
        "Wavelength (µm)": spec_data["wavelength"],
        f"Flux ({region_name})": spec_data["spectrum"],
        f"Error ({region_name})": spec_data["error"]
    })

    df_list.append(df)

# Merge all DataFrames on "Wavelength (µm)"
# This assumes the wavelength arrays are identical or nearly identical
df_merged = reduce(lambda left, right: pd.merge(left, right, on="Wavelength (µm)", how="outer"), df_list)

# Optional: sort by wavelength if not already
df_merged = df_merged.sort_values("Wavelength (µm)")

# Save to a single CSV
combined_csv_path = "combined_spectra_all_regions.csv"
df_merged.to_csv(combined_csv_path, index=False)
```

```python
print(f"\n✅ Combined spectra saved to: {combined_csv_path}")


from IPython.display import FileLink

# Display a clickable download link
FileLink("combined_spectra_all_regions.csv")
```

✅ Combined spectra saved to: combined_spectra_all_regions.csv

Out[7]: combined_spectra_all_regions.csv

📌 Output CSV Format Example:

Wavelength (µm)	Flux (Central)	Error (Central)	Flux (Ring)	Error (Ring)
5.100	1.23	0.05	1.01	0.06
5.105	1.20	0.04	1.00	0.05
...	...	...	...	...

❔ Questions:

1. What is the catagory and the subcatagory of the object?

🌀 The galaxy NGC 7469 has an active star formation and an active galactic nucleus (AGN). Type of galaxy is Seyfert Galaxy.
Subcatagories:
• Barred spiral galaxy
• Circumnuclear starburst ring
• Luminous Infrared Galaxy (LIRG)
• Composite system: AGN + nuclear starburst

A Seyfert galaxy is an active galaxy with a supermassive black hole at the center, has strong emission lines from ionized gas, and a bright core that can outshine the rest of the galaxy in X-ray and UV.

2. What does this category typically mean in the context of extragalactic astronomy?

🌌 In extragalactic astronomy, the category and subcategory of a galaxy provides crucial information about its structure, activity, evolution, and the physical processes occurring within it. Morphological Classification of NGC 7469 is (R')SAB(rs)a.

SAB:--- Weakly barred spiral (bar-like structure in the core).
R':--- Pseudo-ring formed by tightly wound spiral arms.
rs:--- Intermediate between a full ring and spiral arms.
a:--- Early-type spiral: large bulge, tightly wound arms.

Interpreted as a disk galaxy with both spiral and ring features, showing signs of internal dynamics (i.e. bar-driven gas inflow).

Circumnuclear Starburst Ring is a ring (typically ~1 kpc scale) of intense star formation encircling the galaxy nucleus. It is fed by inflowing gas, often driven by the galaxy's bar. These rings coexist with AGN and may be linked to AGN fueling via secular processes.

3. Why MIRI is important for studying objects like NGC 7469 and helps reveal hidden structures that Optical/NIR cannot?

Mid-Infrared (MIR) imaging is critical for studying galaxies like NGC 7469, especially those with active galactic nuclei (AGN) and circumnuclear starburst regions, because it allows astronomers to penetrate dense dust clouds and reveal structures that are invisible in Optical and Near-Infrared (NIR) wavelengths.

Optical and NIR light are strongly absorbed and scattered by dust, making many regions (like galactic centers) opaque at these wavelengths. Whereas MIRI wavelengths (5–28 microns) pass through dust, allowing astronomers to see inside dusty star-forming regions and around AGN. MIR captures thermal radiation from dust grains heated by young, massive stars or AGN. These emissions trace star formation, even when stars themselves are obscured.

4. After plotting the spectra for both regions, is there any vertical shift in the spectra?

When plotting intensity vs. wavelength, the entire central spectrum is vertically shifted upward compared to the ring. I have selected two regions, one at the galaxy center(AGN), 'Center Region' and one at the circumnuclear ring (star-forming ring), 'Ring Region'.

📌 Reasons for the Vertical Shift:

1. 🔥 Intrinsic Brightness Difference:
   AGNs produce strong thermal continuum from hot dust, heated by the AGN's radiation field.
   The ring is primarily star-forming, emitting PAH features and molecular lines, but with a weaker MIR continuum.
   So, there is a true physical difference in brightness.

2. 🧪 Continuum Emission vs. Line Emission
   Central regions: Strong continuum + high-ionization lines ([NeV], [OIV]).
   Ring regions: Weaker continuum, more PAH features and H_2 lines.
   Because of the stronger continuum, the central region's spectrum appears elevated across all wavelengths.

5. Why we selected these two particular regions to analyse?

The reason is to Compare two Key Physical Environments in the Galaxy, the AGN and the Circumnuclear starbrust ring. Central AGN produces hard UV/X-ray radiation high-ionization lines, warm dust continuum. Ring is rich in gas and young stars → produces PAH bands, low-ionization lines, and H_2 emission.

6. Apart from any vertical shift, is there any differences in the spectral features between these two regions? List all the differences.

Feature Type	Spectral Feature	Difference	Interpretation
PAH features	6.2, 7.7, 8.6, 11.3 µm	Stronger in **ring**	PAHs trace **star formation**; UV-excited
High-ionization lines	[Ne V] 14.3, [O IV] 25.9 µm	Stronger in **center**	Require **hard radiation**, i.e., AGN
Low-ionization lines	[Ne II] 12.8, [S III] 18.7, [Ar II] 6.98	Visible in both, maybe stronger in ring	**Photoionized gas** from stars or AGN
Molecular hydrogen	H_2 0-0 S(1) to S(7)	Present in **both**, possibly stronger in ring	Warm **molecular gas**, UV/shocks excited
Continuum emission	Full MIR continuum	Brighter in **center**	Hot dust emission from AGN
Line widths	Narrow lines in ring, possible broadening in center	Possibly different	Could indicate **outflows or shocks** from AGN

7. What could be the possible physical or astrophysical reasons behind these differences?

Feature	Central Region (AGN)	Ring Region (Starburst)	Physical/Astrophysical Explanation
Continuum brightness	Strong, rising continuum in MIR	Weaker continuum	**Hot dust** heated by AGN in the center
PAH features (e.g., 6.2, 7.7, 11.3 µm)	Weaker or suppressed	Strong and broad	PAHs are **destroyed by AGN radiation**, but survive in **PDRs** near young stars
[Ne V], [O IV], [Ne VI] lines	Strong	Absent or very weak	Require **very high-energy photons** — only an **AGN** produces these
[Ne II], [S III], [Ar II] lines	Present	Also present, sometimes stronger	Trace **H II regions** — found in both AGN and starburst environments
H_2 rotational lines (S(1) to S(7))	Present, possibly weaker	Stronger in some bands	Excited by **UV photons**, **PDRs**, or **shocks**; strong in star-forming regions

Feature	Central Region (AGN)	Ring Region (Starburst)	Physical/Astrophysical Explanation
Line widths	May be broader	Narrow	Central outflows or **turbulence** from AGN can **broaden** emission lines
Line ratios ([Ne III]/[Ne II])	Higher	Lower	Higher ratio = **harder radiation field** (AGN)
Spectral structure	More atomic/narrow lines	Mix of PAHs + atomic lines	AGN affects gas more; star-forming regions emit broader PAH features

8. As we move from Channel 1 to Channel 4 and towards longer wavelengths, do we notice any change in the spectral features?

Yes, as we move from (CH1) to (CH4), there are several notable trends in both the spectral features and the data quality.

Channel	Wavelength Range	Spectral Feature Trends
CH1	5–7 μm	- Dense clustering of lines (e.g., [Fe II], H_2 S(7), [Ar II]) - Strong PAH at 6.2 μm
CH2	7–11 μm	- Strong PAH features at 7.7, 8.6, 11.3 μm - H_2 S(4), [S IV], [Ar III]
CH3	11–18 μm	- Fewer but strong atomic lines (e.g., [Ne II], [Ne III]) - PAHs at 11.3, 12.7 μm
CH4	18–28 μm	- Sparse features, mostly [S III], [O IV], [Fe II] - Broader continuum - H_2 S(1)

🔍 Number of identifiable features tends to decrease with wavelength. Line spacing increases — atomic fine-structure lines are fewer in CH4. PAH emission drops off in CH4; replaced by atomic cooling lines ([OIV], [NeV]).

Channel	Trend in Noise and Errors
CH1–CH2	Higher resolution, denser sampling — spectra look smoother but show more features
CH3–CH4	Errors increase slightly, especially beyond 22 μm - Occasional oscillations - Flux calibration edge effects may appear

📉 Reasons: Detector sensitivity drops toward longer MIR wavelengths. Background subtraction is harder in CH4 due to increasing thermal background. Edges of each MIRI channel can show increased uncertainties or artifacts.

9. Is this change likely to be due to an instrumental effect or a real astrophysical property?

✔️ The answer is: Both — but mostly a real astrophysical property, with some instrumental influence. These changes reflect real variations in the physical conditions (temperature, ionization, star formation vs. AGN). As well as some of the instrumententional reason as mentioned above.