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REDUCTION AND ANALYSIS OF ULTRAVIOLET POLARIMETRIC DATA FROM HUBBLE SPACE TELESCOPE OF ACTIVE GALACTIC NUCLEI

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INTRODUCTION

- Description of the internship :

  - The goal of the internship is the study of active galactic nuclei in the UV spectral range with a polarimetric information.

  - Collect data from Hubble's Faint Object Camera (FOC), this data contains images with a supplementary polarimetric information.

  - Reduce the data through a code written in Python.

  - Analyse the polarisation maps obtained.

- Summary of the presentation :

  - Briefs definitions (AGN, polarisation) and description of the code.

  - Emphasis on error propagation.

  - Results through 2 examples : NGC 1068 and IC 5063.

ACTIVE GALACTIC NUCLEI (AGN)

- Extremely luminous objects in almost all spectral range (radio, IR, optical, UV, X-ray). Observed during first half of the 20th century.
- Radiation is theoretically supposed to come from the accretion of a dusty torus by a supermassive black hole.
- Some accretion discs produce also relativistic jets. We call radio loud galaxies which such jets and radio quiet the others.
- AGN type depends on the inclination of the galaxy compared to us :

  - Radio loud : blazar (jets direction), quasar (face-on), radiogalaxy (edge-on).

  - Radio quiet : Seyfert type I (face-on), Seyfert type II (edge-on).

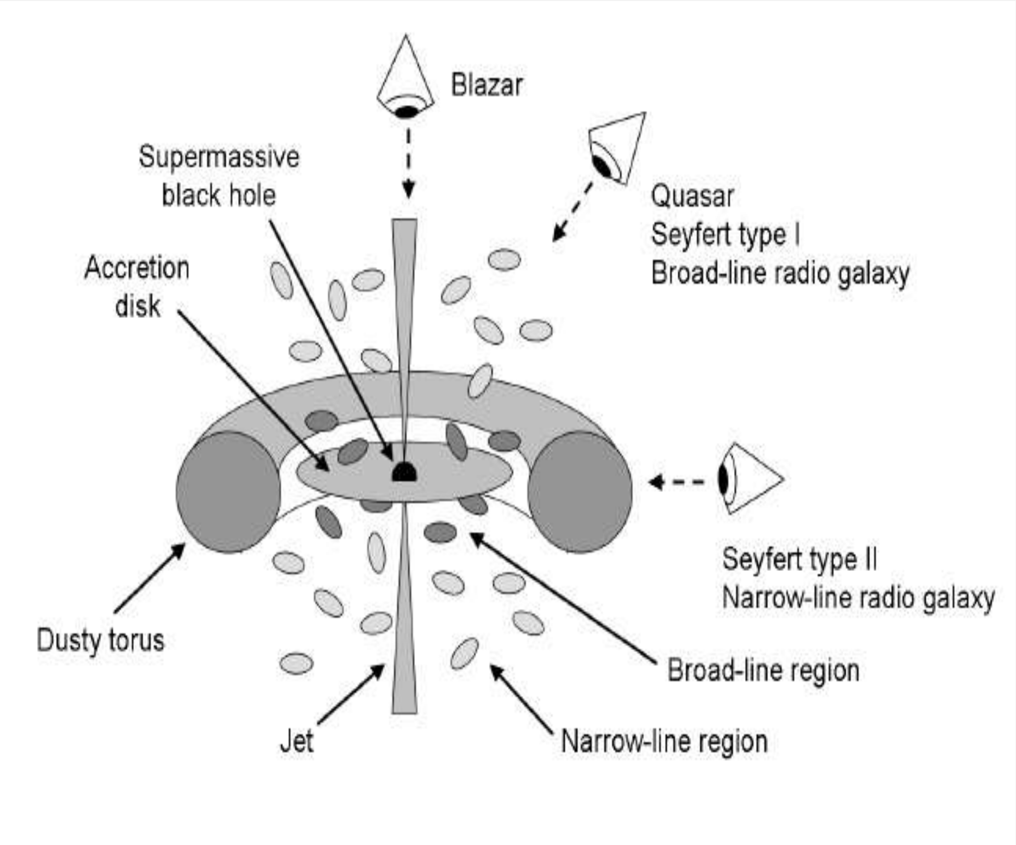


Figure - Theoretical model of unified AGN

POLARIZATION

- Property of electromagnetic waves that specifies the geometrical orientation of the electric field oscillations.
- Linear polarization : field oscillates in a static plane.
- Circular and elliptical polarisation : field oscillates in a rotating plane.
- We use Stokes parameters to describe polarized radiation in term of intensities.
- We also define the polarization degree P and polarization angle θ_{PA} :

$$P = \frac{\sqrt{Q^2 + U^2}}{I},$$
$$\theta_{PA} = \frac{1}{2} \arctan \frac{U}{Q}.$$

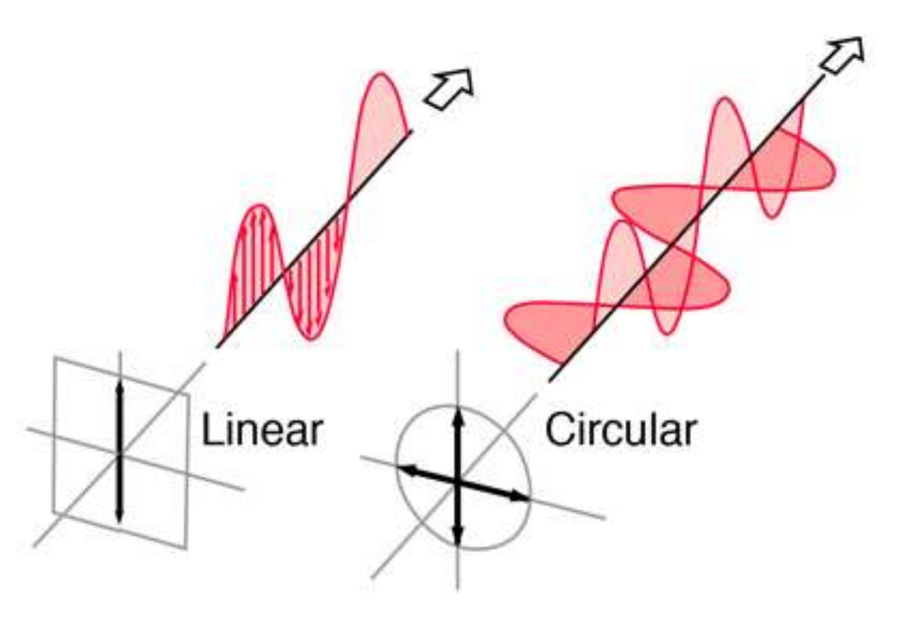
$$S_0 = I = E_x^2 + E_y^2$$ Total intensity

$$S_1 = Q = E_x^2 - E_y^2$$

$$S_2 = U = 2E_x E_y \cos\delta$$ Linearly polarized intensity

$$S_3 = V = 2E_x E_y \sin\delta$$ Circularly polarized intensity

V=0 for AGN



CODE (PYTHON)

- The goal of the code is to produce polarization map of the AGN using the data given by HST. To do so we use functions to reduce the data step by step. The goal of the reduction is to increase the SNR :

  - Extract the data from the FITS files. Very common format in astronomy, allows to store very large quantity of data.

  - Crop the parts with neither flux nor polarization.

  - Bind pixels together to increase the flux of each pixel.

  - Merge images of a same polarizer. FOC has 3 polarizers : 60°, 120° and 180°.

  - Compute I,Q,U, P and θ and errors using the data of each polarizer.

  - Merge images of different polarizers. We obtain a final image.

  - Add on this image the polarization vectors.

$$f_i = \frac{1}{2} t_i (I - k_i \cos 2\theta_i \cdot Q - k_i \sin 2\theta_i \cdot U),$$

Flux through polarizer i where t_i, k_i and θ_i are each polarizer's transmittance, efficiency and axis. We need 3 polarizers to calculate I,Q,U.

ERROR PROPAGATION

- A lot of uncertainties are considered in the code, we'll focus on the error propagation due to the angle of the polarizer's axis.
- Main issue of the code giving results way above the other uncertainties.

  - Error on P multiplied by 9 by axis error.

  - Error on θ_{PA} multiplied by 10 by axis error.
- Implementation of another way to calculate the axis error, following Kishimoto et al (1999).
- This computation gives better results :

  - Error on P and θ_{PA} in the same range of other uncertainties

Kishimoto et al (1999)

$$(\sigma_P^{\text{axis}})^2 = \sum_{i=1}^{3} \left(\frac{\partial P}{\partial \theta_i}\right)^2 \sigma_{\theta_i}^2,$$

$$(\sigma_{PA}^{axis})^2 = \sum_{i=1}^{3} (\frac{\partial \theta_{PA}}{\partial \theta_i})^2 \sigma_{\theta i}^2$$

where we take σ_{θ_i} to be 3°

$$\frac{\partial P}{\partial \theta i} = \frac{\sqrt{Q^2+U^2}}{I} (\frac{Q\frac{\partial Q}{\partial \theta i} + U\frac{\partial U}{\partial \theta i}}{Q^2+U^2} - \frac{1}{I}\frac{\partial I}{\partial \theta i})$$

$$\frac{\partial \theta_{PA}}{\partial \theta_i} = \frac{1}{2(U^2+Q^2)} (Q\frac{\partial U}{\partial \theta_i} - U\frac{\partial Q}{\partial \theta_i})$$

$$I = \frac{1}{\Lambda}(f_1' k_2 k_3 sin(-2\theta_2 + 2\theta_3) + f_2' k_1 k_3 sin(2\theta_1 - 2\theta_3) + f_3' k_1 k_2 sin(-2\theta_1 + 2\theta_2))$$

$$Q = \frac{1}{\Lambda}(f_1'(-k_2 sin2\theta_2 + k_3 sin2\theta_3) + f_2'(-k_3 sin2\theta_3 + k_1 sin2\theta_1) + f_3'(-k_1 sin2\theta_1 + k_2 sin2\theta_2))$$

$$U = \frac{1}{\Lambda}(f_1'(k_2 cos2\theta_2 - k_3 cos2\theta_3) + f_2'(k_3 cos2\theta_3 - k_1 cos2\theta_1) + f_3'(+k_1 cos2\theta_1 - k_2 cos2\theta_2)) \quad (1)$$

$$\Lambda = k_2 k_3 sin(-2\theta_2 + 2\theta_3) + k_1 k_3 sin(-2\theta_3 + 2\theta_1) + k_1 k_2 sin(-2\theta_1 + 2\theta_2)$$

$$f_i' \equiv \frac{2}{t_i} f_i,$$

RESULTS

<u>NGC 1068</u>

- Already very studied AGN in all spectral range. Distance of 10 Mpc.

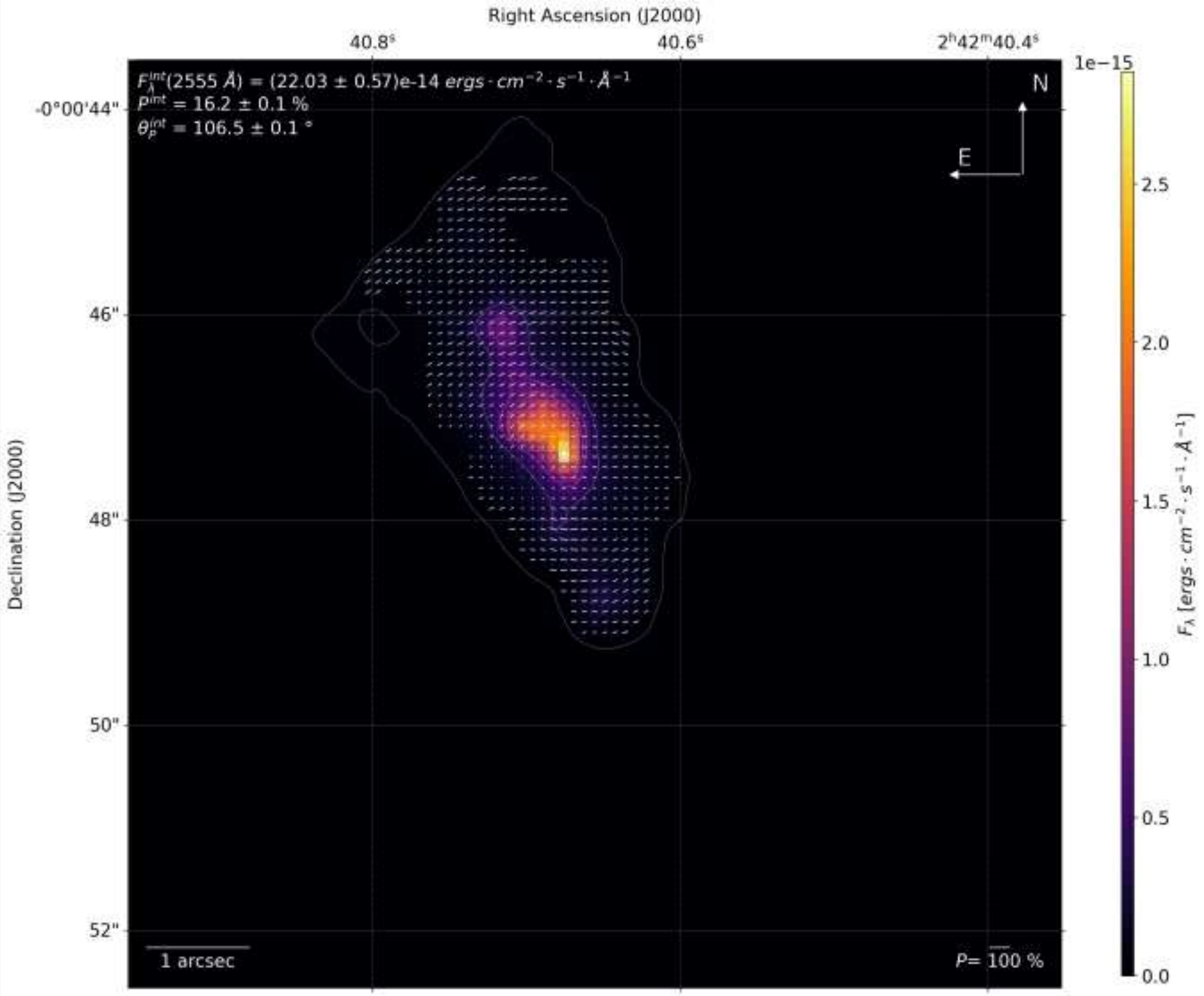
- Used to verify the code.

- Seyfert galaxy type II (no jets, edge-on)

- Polarization gives us information where there is no flux.

- The degree of polarization is typically in the range that we expect for this type of AGN : between 10-20%.

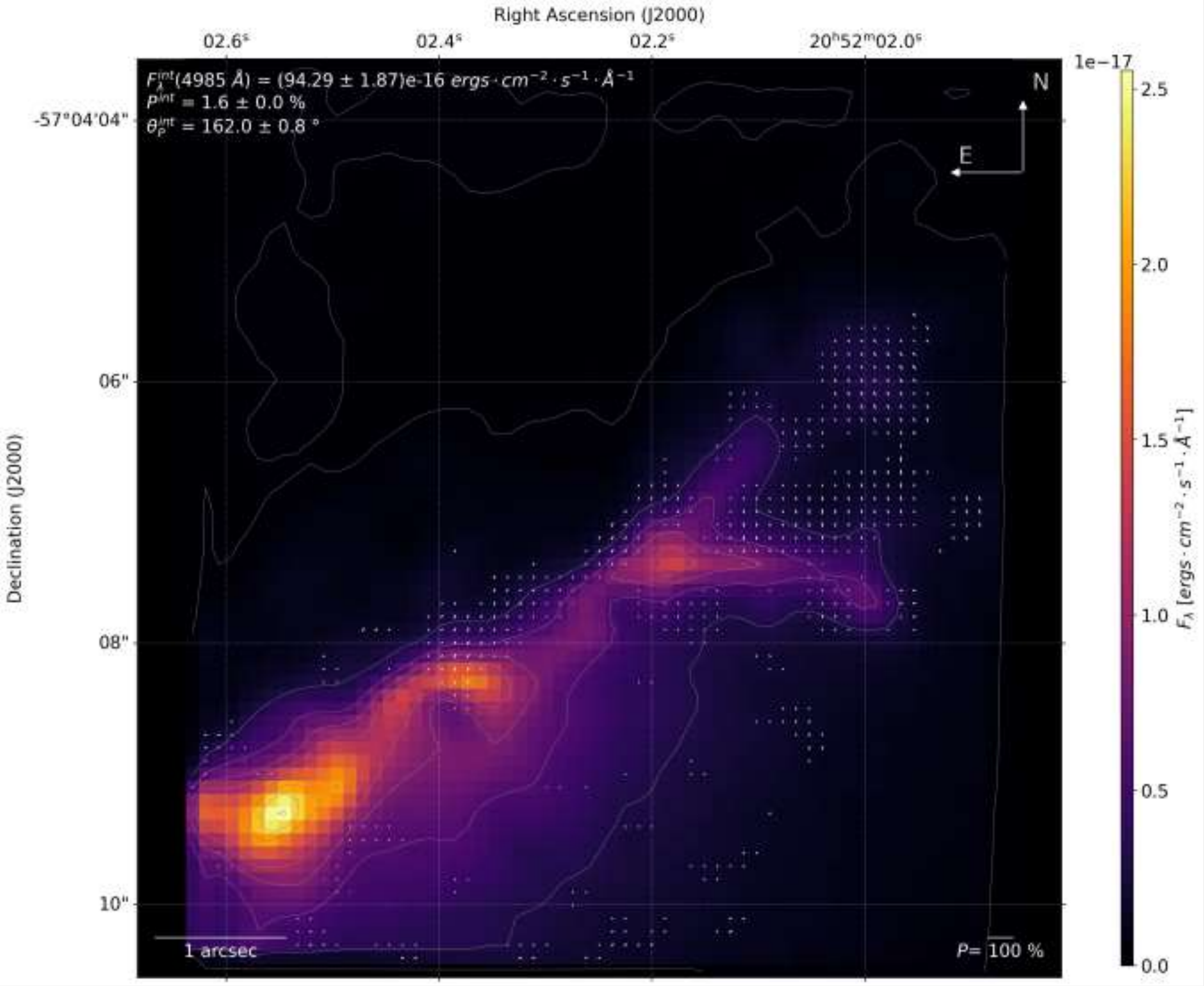
- The center of the circular polarization pattern isn't the brightest pixel. It is a bit shifted because of scattering in the hot plasma above the accretion disk.

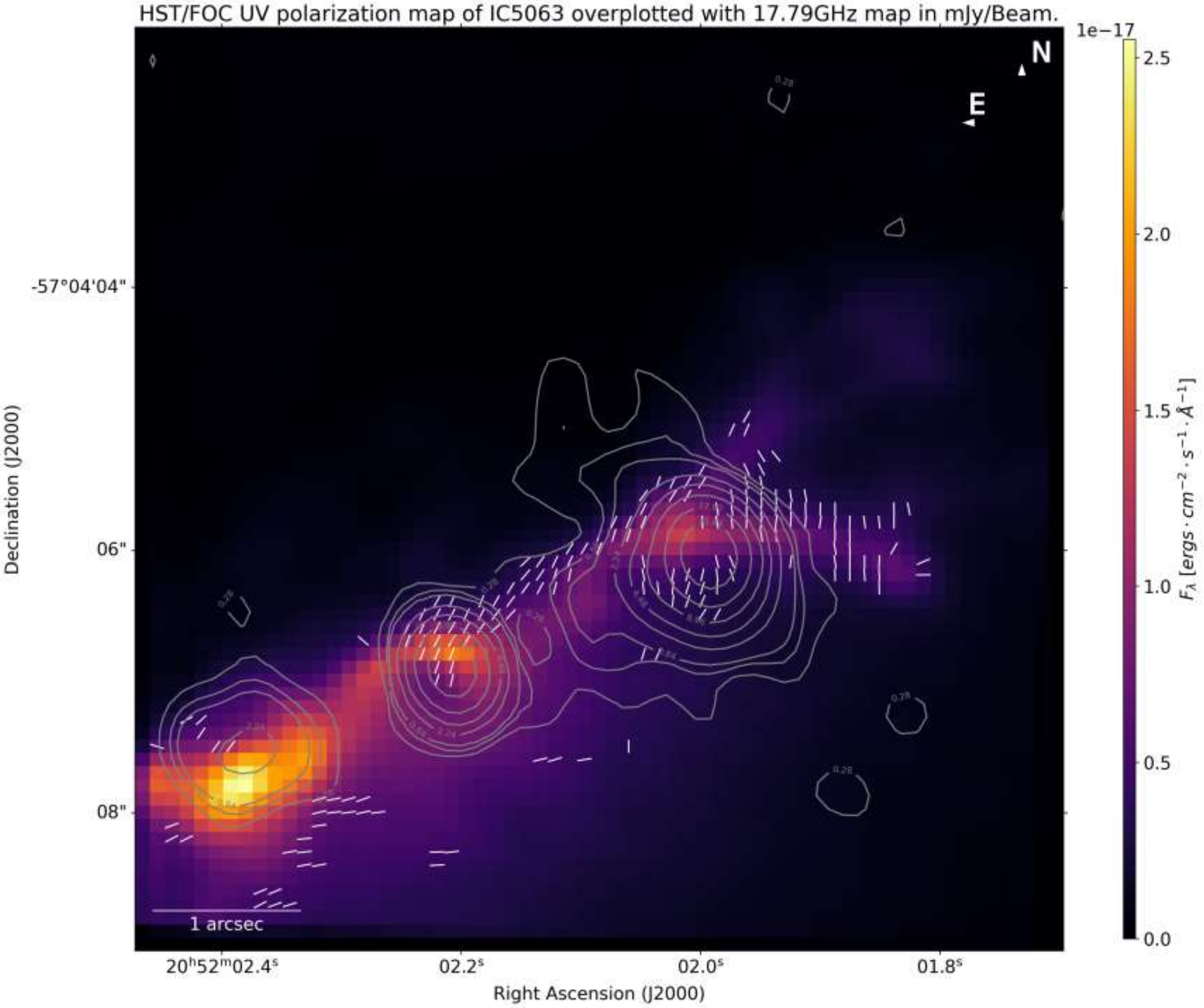


RESULTS

IC 5063

- Less studied galaxy, especially in UV spectral range. Seyfert type II galaxy as well. Distance of 48Mpc.
- Will be the object of a publication paper by Frédéric Marin.
- Degree of polarization : 10-20% for the NW blob decreasing to 1-3% in the SE blob. No global degree of polarization.
  No global polarization pattern. Local pattern maybe.
- Triple structure AGN, with most of the flux in the SE blob.
- We can overplot radio maps on UV maps (example with Morganti et al (2007) radio map).





HST/FOC UV polarization map of IC5063 overplotted with 17.79GHz map in mJy/Beam.
N
E
1 arcsec
-57°04'04"
06"
08"
Declination (J2000)
20h52m02.4s
02.2s
02.0s
01.8s
Right Ascension (J2000)
1e−17
2.5
2.0
1.5
1.0
0.5
0.0
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$]

CONCLUSION

- AGN are very interesting objects and are yet to be understand completely. Some objects that compose AGN (jets, supermassive blackhole, accretion disk,…) are keys in the understanding of galaxies and in general cosmology.
- Polarization is a useful tool in astronomy, it gives supplementary information compared to the flux. We can make polarization maps of astronomical objects.
- UV is an interesting spectral range for AGN because it allows to focus the light emitted by heated object such as the accretion disk. We can overplot different spectral range maps to improve the analysis.