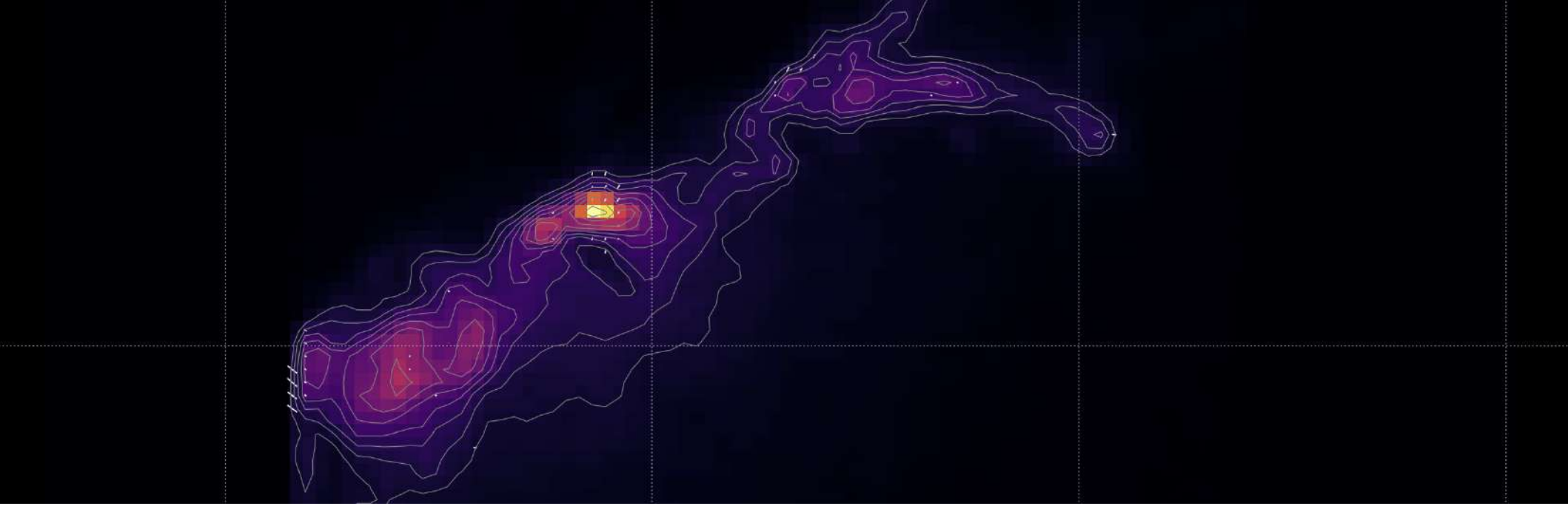


Ultraviolet polarization of quasars: forgotten treasures and future instruments

Frédéric Marin, Thibault Barnouin, Enrique Lopez-Rodriguez

Observatoire astronomique de Strasbourg | ObAS

Université de Strasbourg

Journées du PNHE, September 14 – 16, 2021

Quasars in the UV

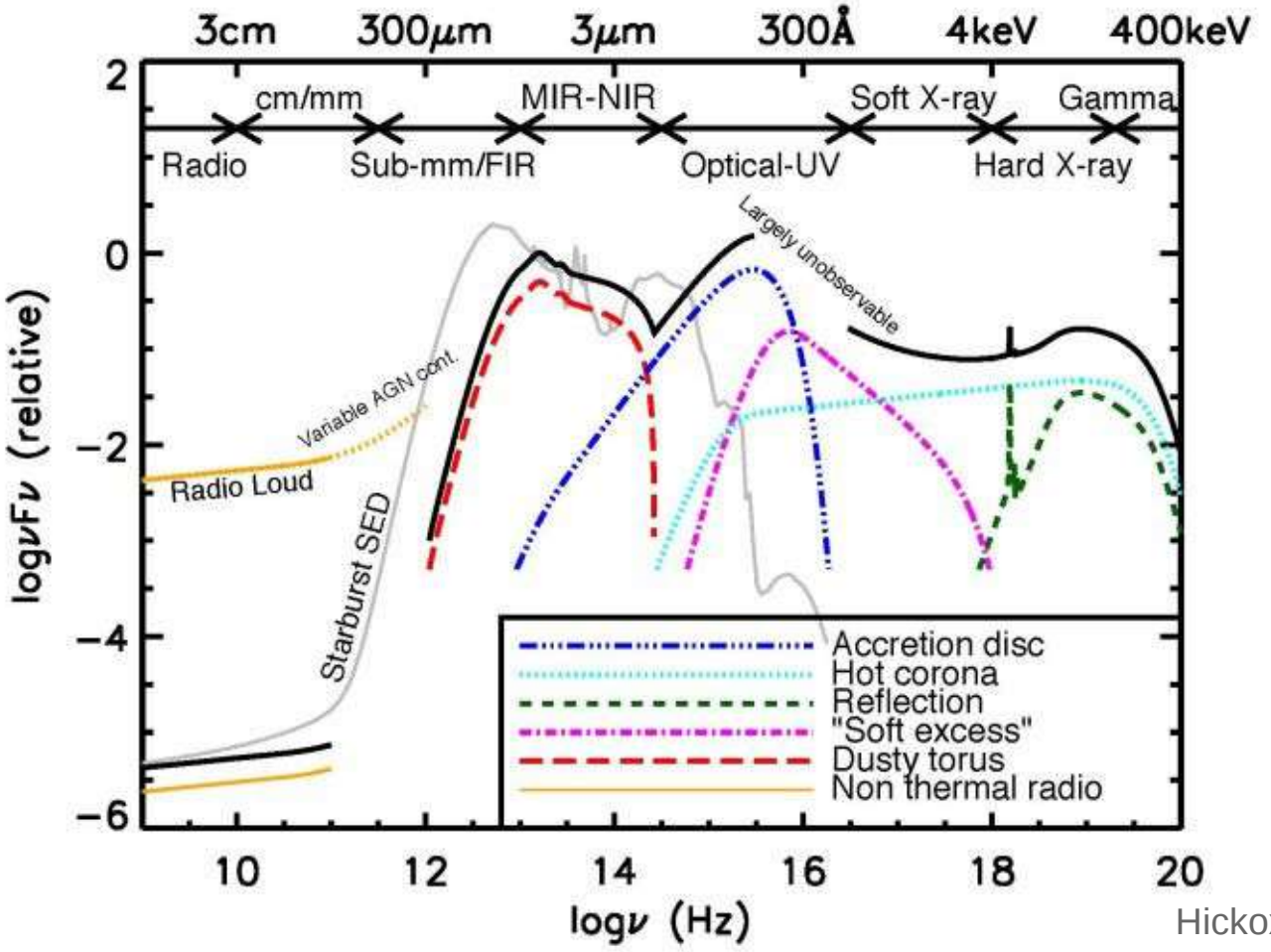
Quasars (AGN) are the brigthest and more persistent sources of light in the Universe

→ high redshift: allow us to study the formation and evolution of galaxies

→ bright in almost all wavebands: allow us to probe a wide range of physical processes

→ compact: a challenge for observations (even interferometry)

→ UV-band is the best waveband to probe the innermost regions of quasars

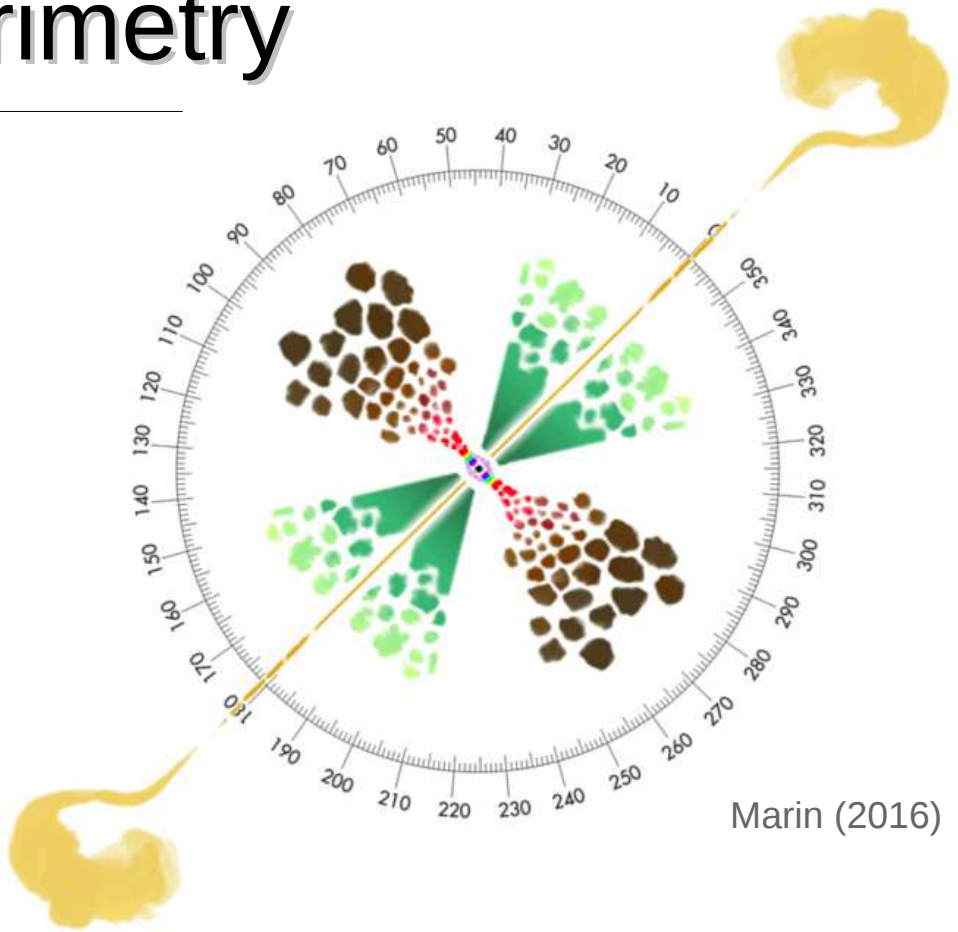


Hickox & Alexander (2018)

UV polarimetry

A large fraction of quasars are highly inclined objects
- → dust absorbtion by the circumnuclear torus
- → starlight dilution
- → low fluxes (relative to non-obscured AGNs)

They are hard to detect and there innermost regions are hidden
- → but not with polarimetry !



Marin (2016)

1 – The polarization degree and position angle are geometry and composition-dependent

2 – Scattered light can be detect, while direct light is absorbed by the torus

3 – Starlight intensity decreases in the UV: higher polarimetric contrast

4 – Dust scattering depends on λ^4

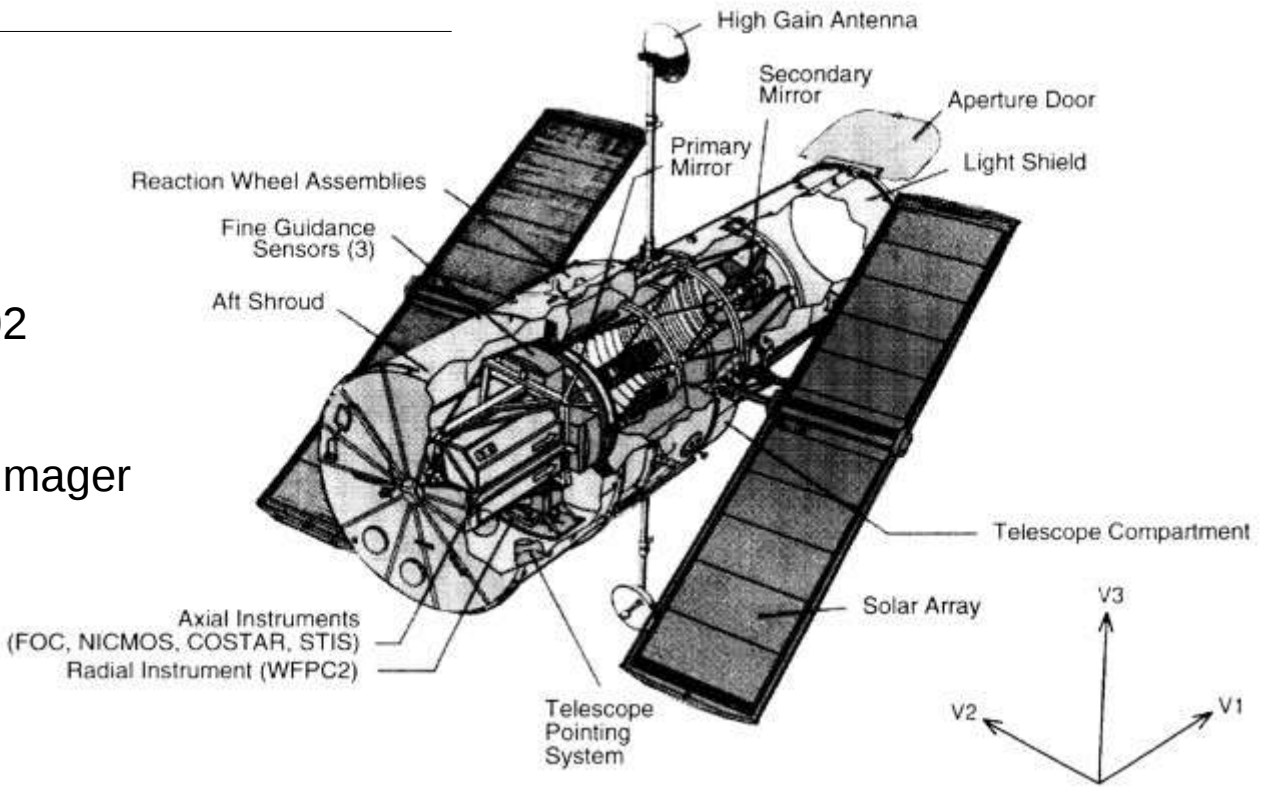
=> UV polarimetry brings high constrast, periscopic views of AGN cores

HST/FOC

Remember HST ?

→ In 2021, the HST is celebrating its 31 years of operation

→ 3 UV polarimeters (imaging and spectro) between 1990 and 2002



Let's focus on the HST/FOC

- long-focal-ratio, photon-counting imager
- wavelength range: 1150 - 6500 Å
- field-of-view (FOV): 7" x 7"
- pixel size: 0.014" x 0.014"
- 3 polarizing filters (0°, 60°, 120°)
- removed in 2002

Looking at the HST/FOC archives:

- 615 datasets (27 quasars)

→ 15% of the whole sample has no associated paper

Most of the old reduced observations are dispersed throughout the literature, with different analyses and approaches, making it difficult to fully interpret the HST/FOC AGN sample

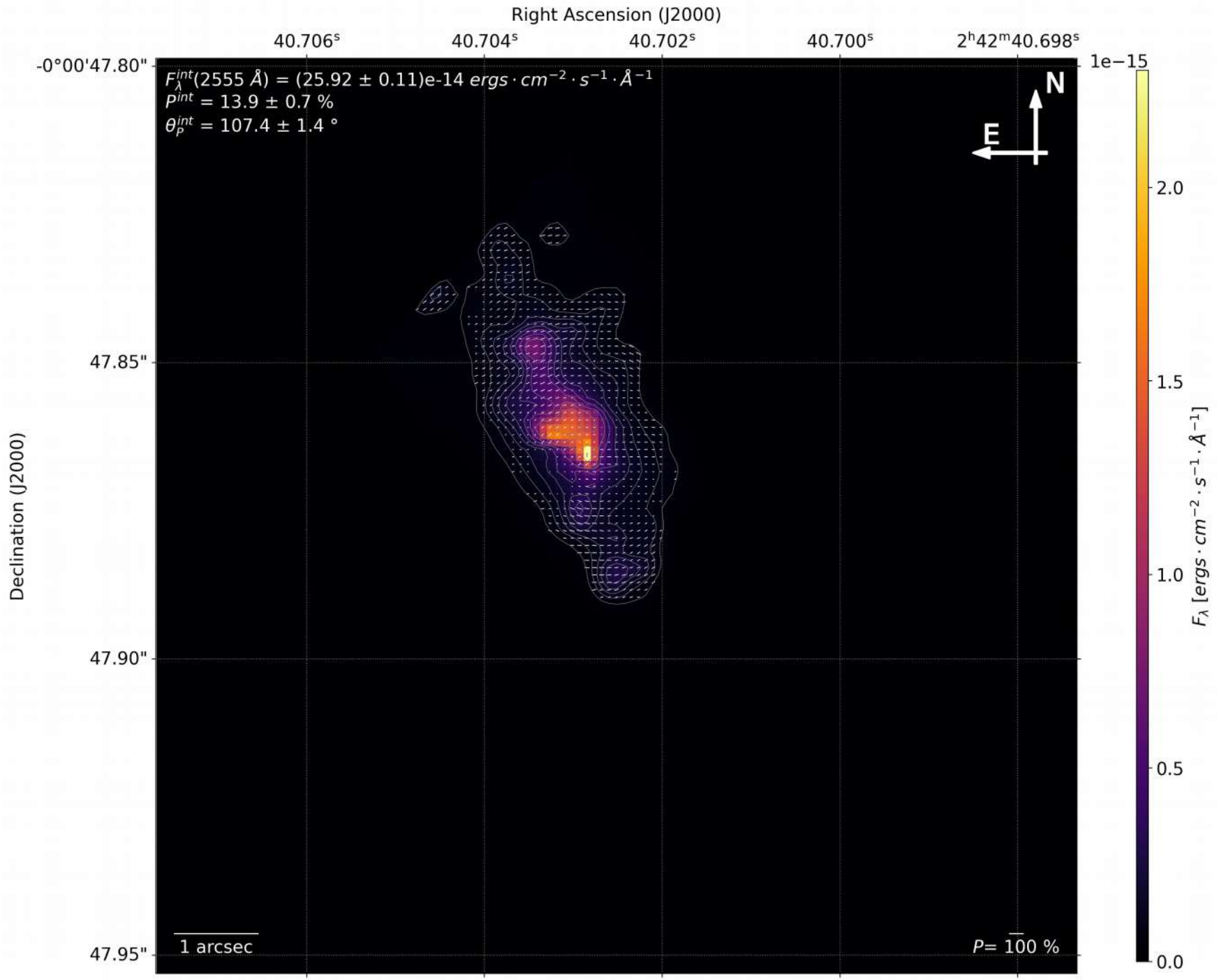
→ development of a consistent, standardized and open-access reduction pipeline

REDUCTION PIPELINE

A standardized procedure for all observations

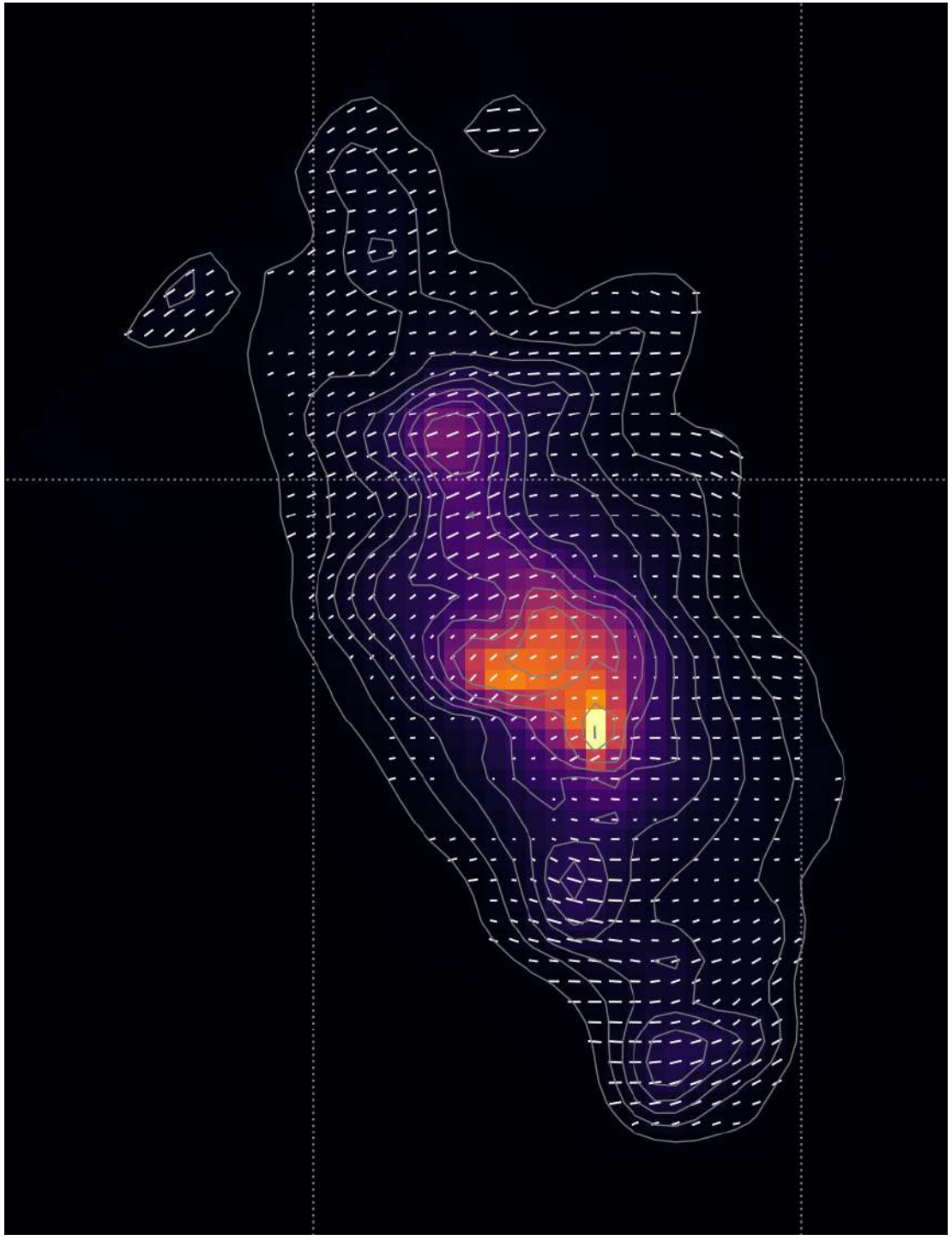
1- Import and crop data to optimal region of interest (Graham scan)
2- Estimate errors on raw data (the propagate)
3- Rebin to user-defined arcsec or pixel sizes
4- Align images
5- Possibility to deconvolve data for fine structure studies (Richardson-Lucy algorythm)
6- Smooth data to user defined kernel or using image combination.
7- Compute Stokes parameters
8- Derive polarization degree and angle
9- Apply celestial rotation
10- Unit conventions
11- Display results (polarization maps)
12- Save reduced data in FITS files

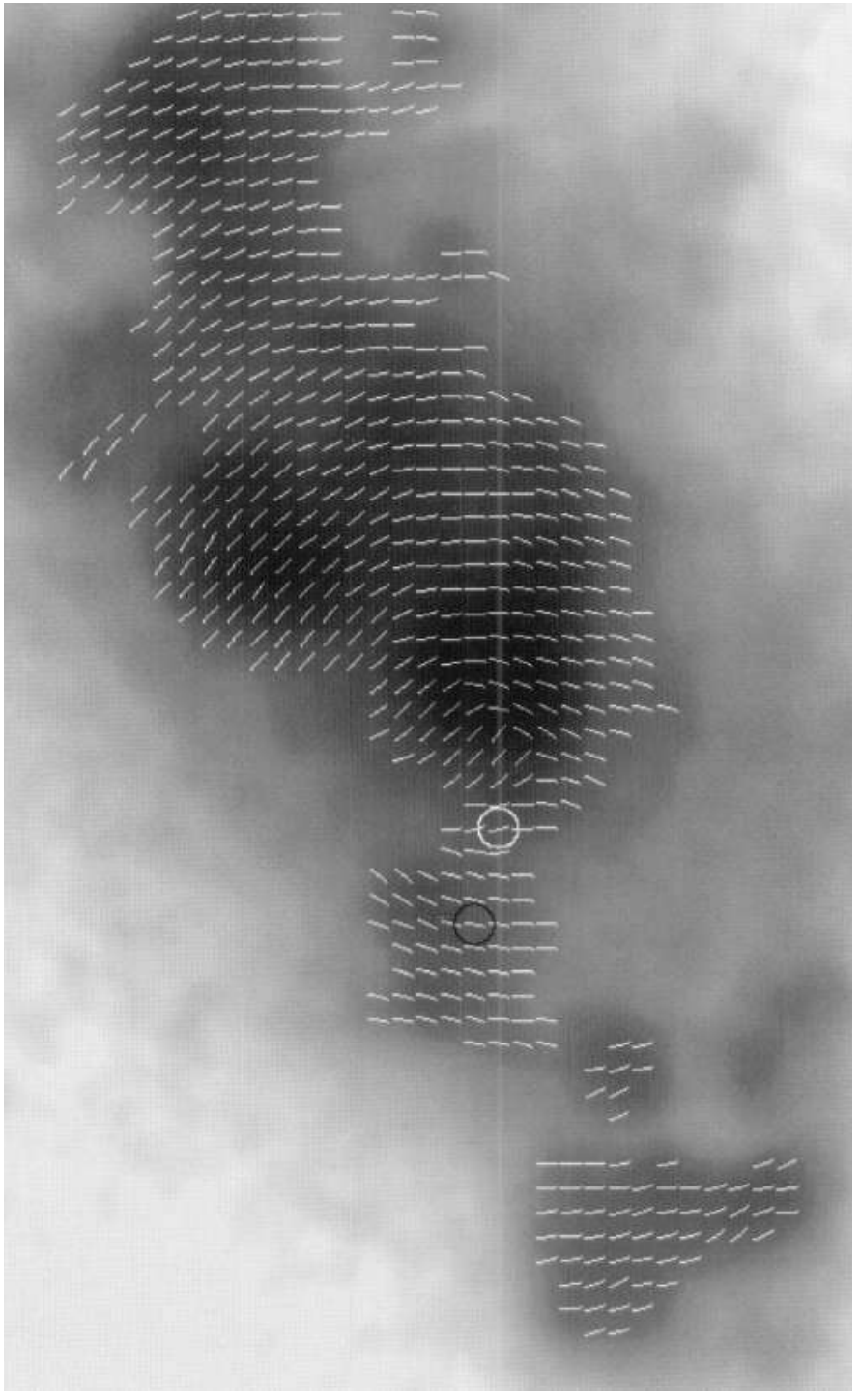
NGC 1068


Right Ascension (J2000)
40.706ˢ
40.704ˢ
40.702ˢ
40.700ˢ
2ʰ42ᵐ40.698ˢ
-0°00'47.80"
47.85"
47.90"
47.95"
Declination (J2000)
$F_\lambda^{int}(2555\ \AA)$ = (25.92 ± 0.11)e-14 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot \AA^{-1}$
P^{int} = 13.9 ± 0.7 %
θ_P^{int} = 107.4 ± 1.4 °
N
E
1 arcsec
P= 100 %
1e−15
2.0
1.5
1.0
0.5
0.0
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot \AA^{-1}$]

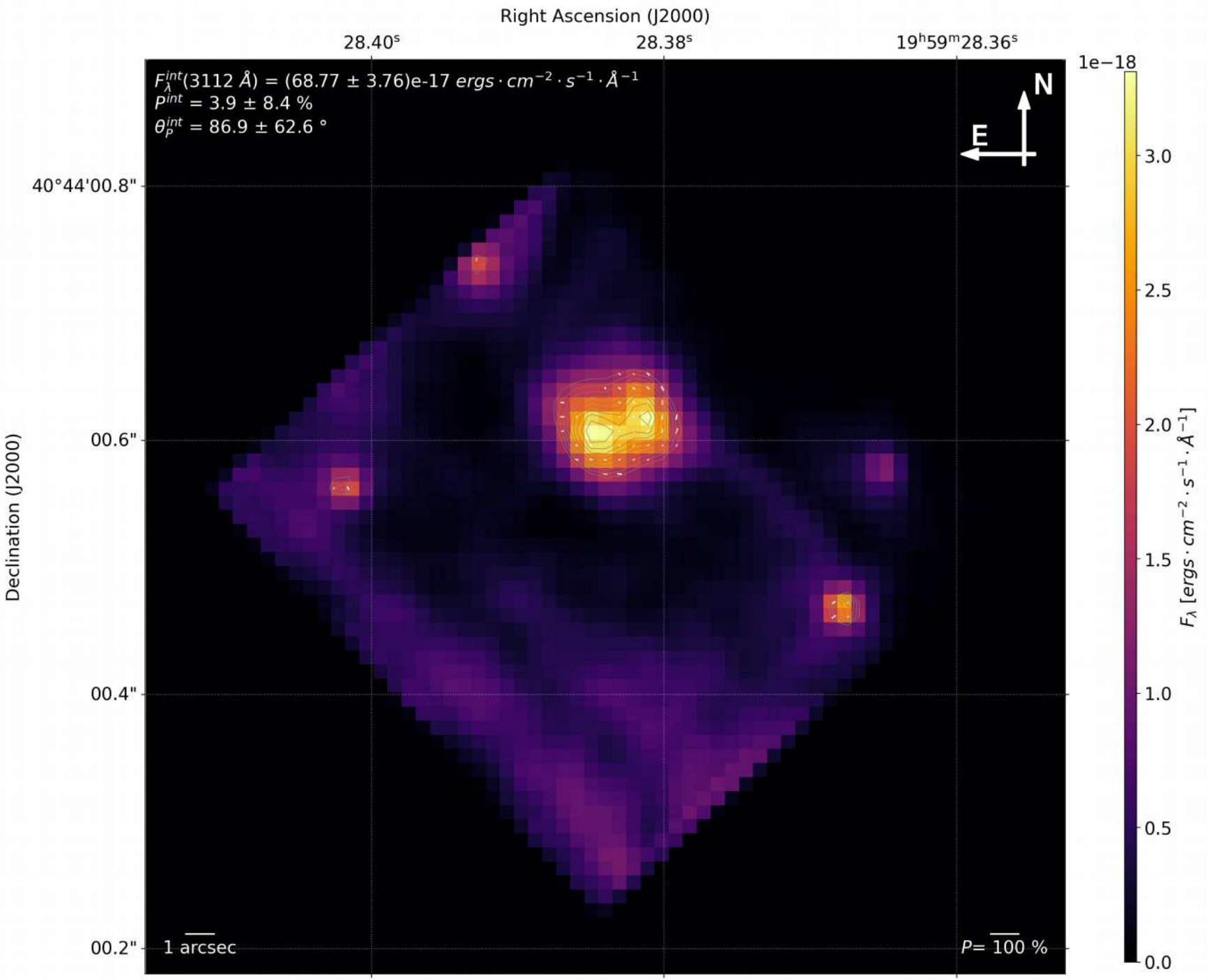
NGC 1068

Capetti et al. (1995)

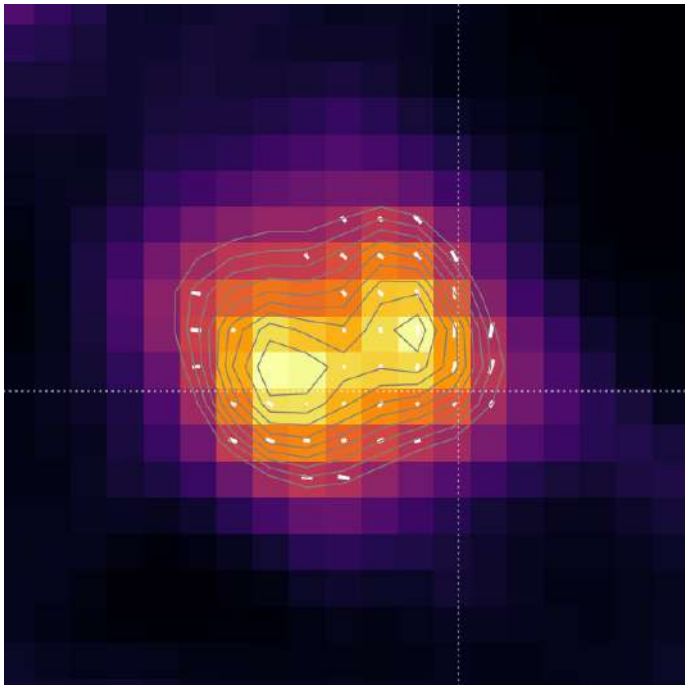


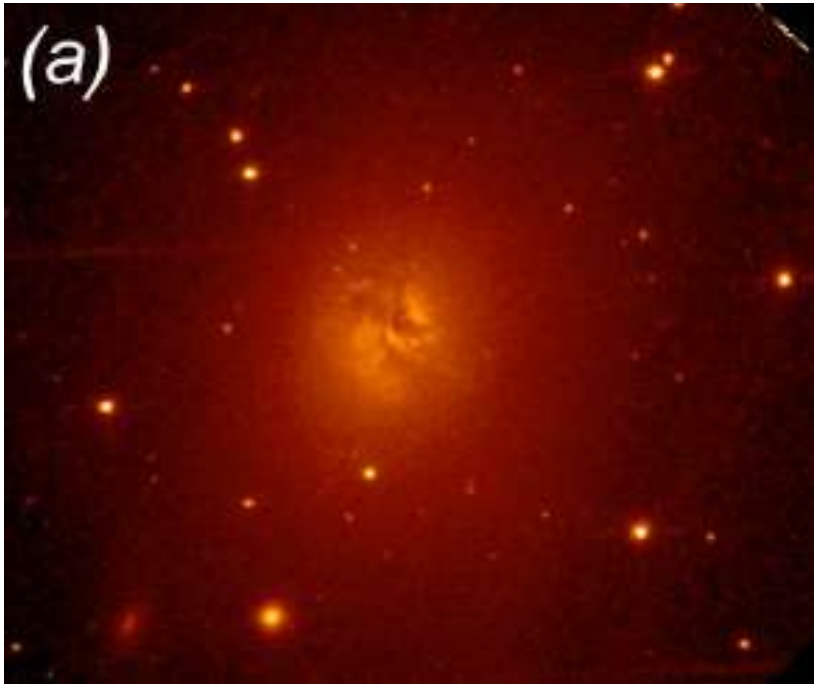


CYGNUS A


Right Ascension (J2000)
28.40ˢ
28.38ˢ
19ʰ59ᵐ28.36ˢ
F_λ^{int}(3112 Å) = (68.77 ± 3.76)e-17 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$
P^{int} = 3.9 ± 8.4 %
θ_P^{int} = 86.9 ± 62.6 °
N
E
40°44'00.8"
00.6"
00.4"
00.2"
Declination (J2000)
1 arcsec
P= 100 %
1e−18
3.0
2.5
2.0
1.5
1.0
0.5
0.0
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$]

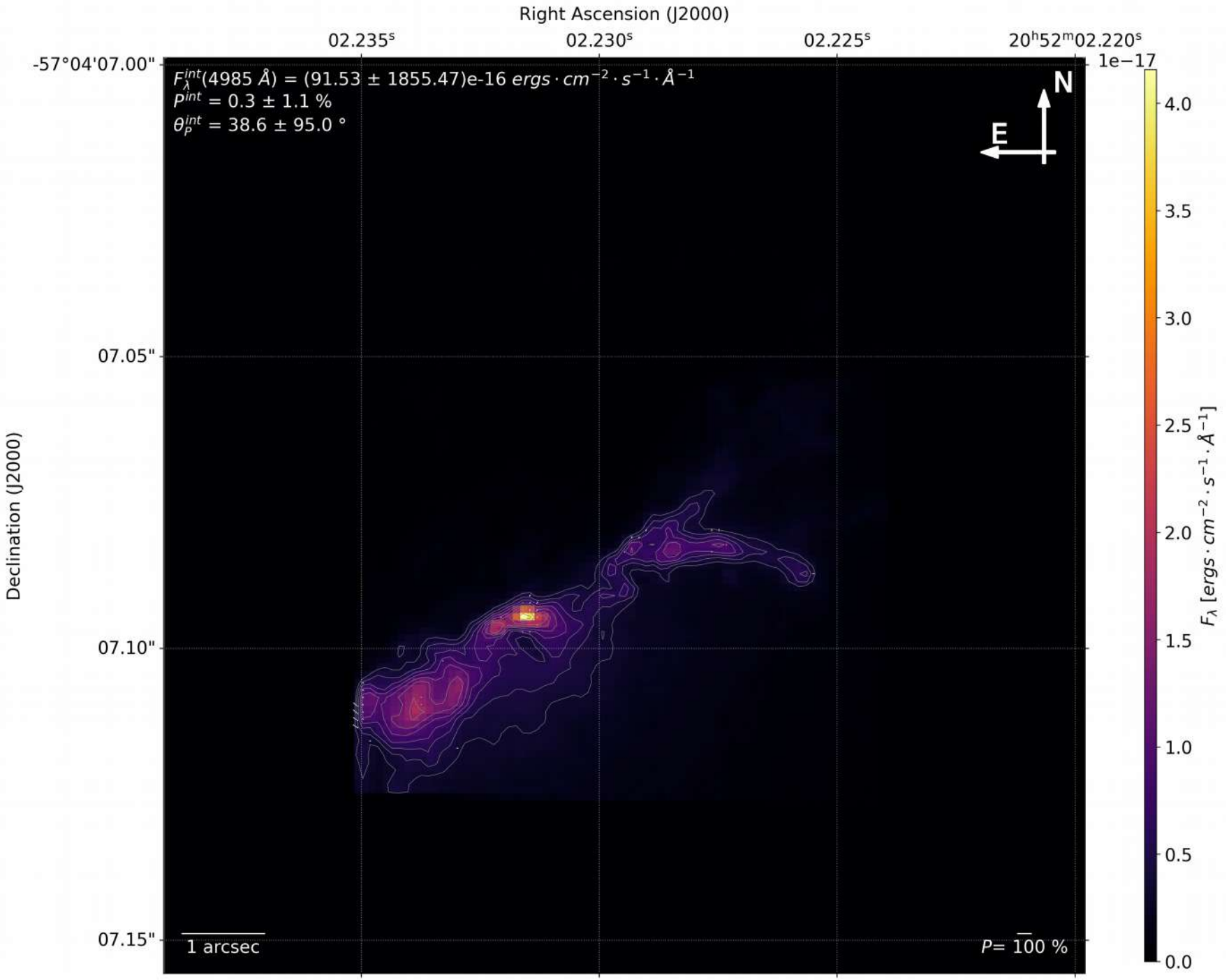
CYGNUS A



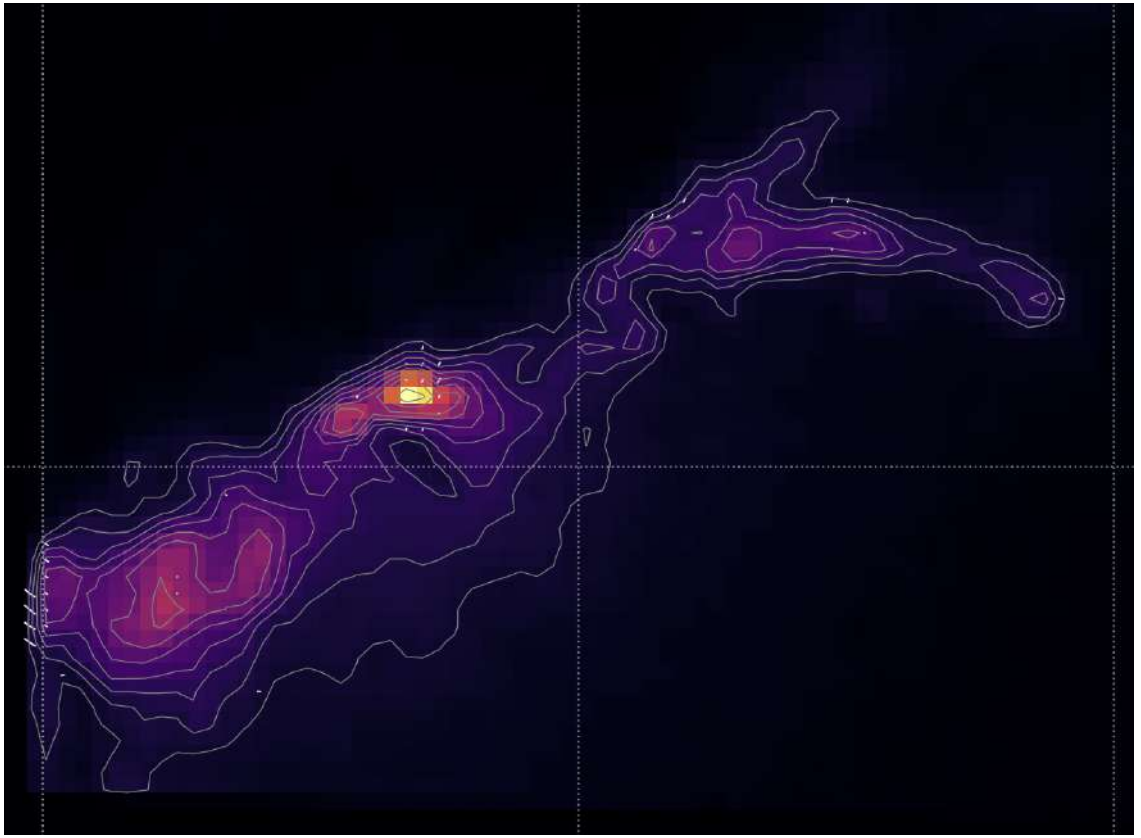


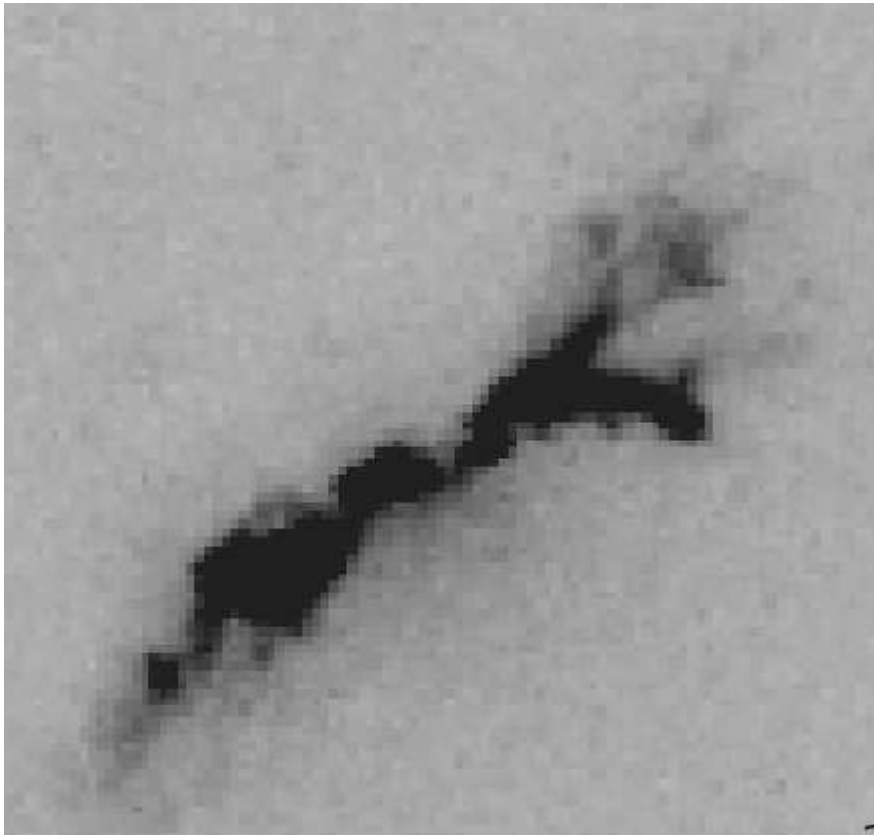
Optical images of 3C 405 (Cyg A) taken in the V band (0.55 mm) with HST / ACS
Labadie et al. (2014)

IC 5063


Right Ascension (J2000)
02.235ˢ
02.230ˢ
02.225ˢ
20ʰ52ᵐ02.220ˢ
-57°04'07.00"
07.05"
07.10"
07.15"
Declination (J2000)
$F_\lambda^{int}(4985\ \AA) = (91.53 \pm 1855.47)\text{e-}16\ ergs \cdot cm^{-2} \cdot s^{-1} \cdot \AA^{-1}$
$P^{int} = 0.3 \pm 1.1\ \%$
$\theta_P^{int} = 38.6 \pm 95.0\ °$
N
E
1 arcsec
P= 100 %
1e−17
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda\ [ergs \cdot cm^{-2} \cdot s^{-1} \cdot \AA^{-1}]$

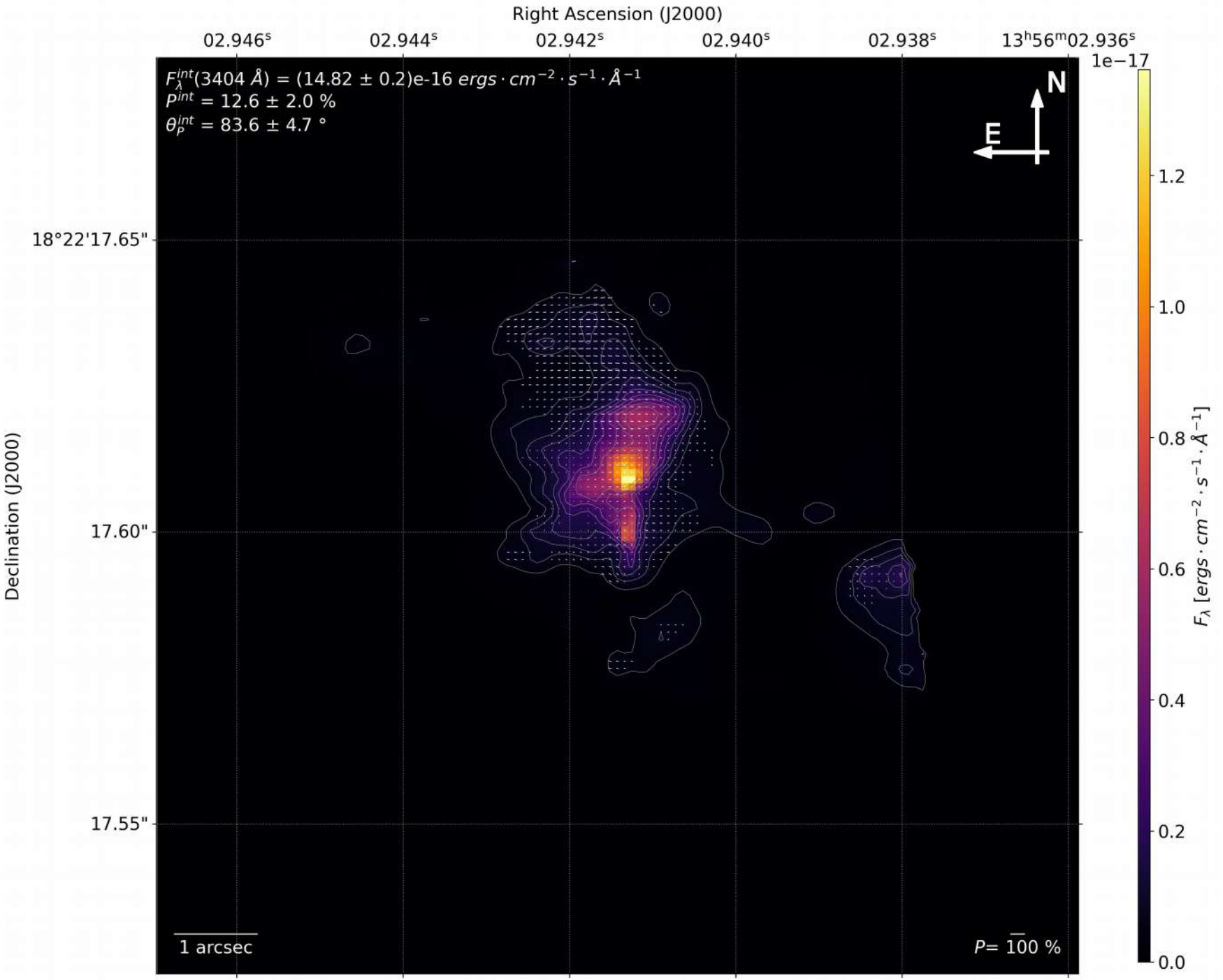
IC 5063



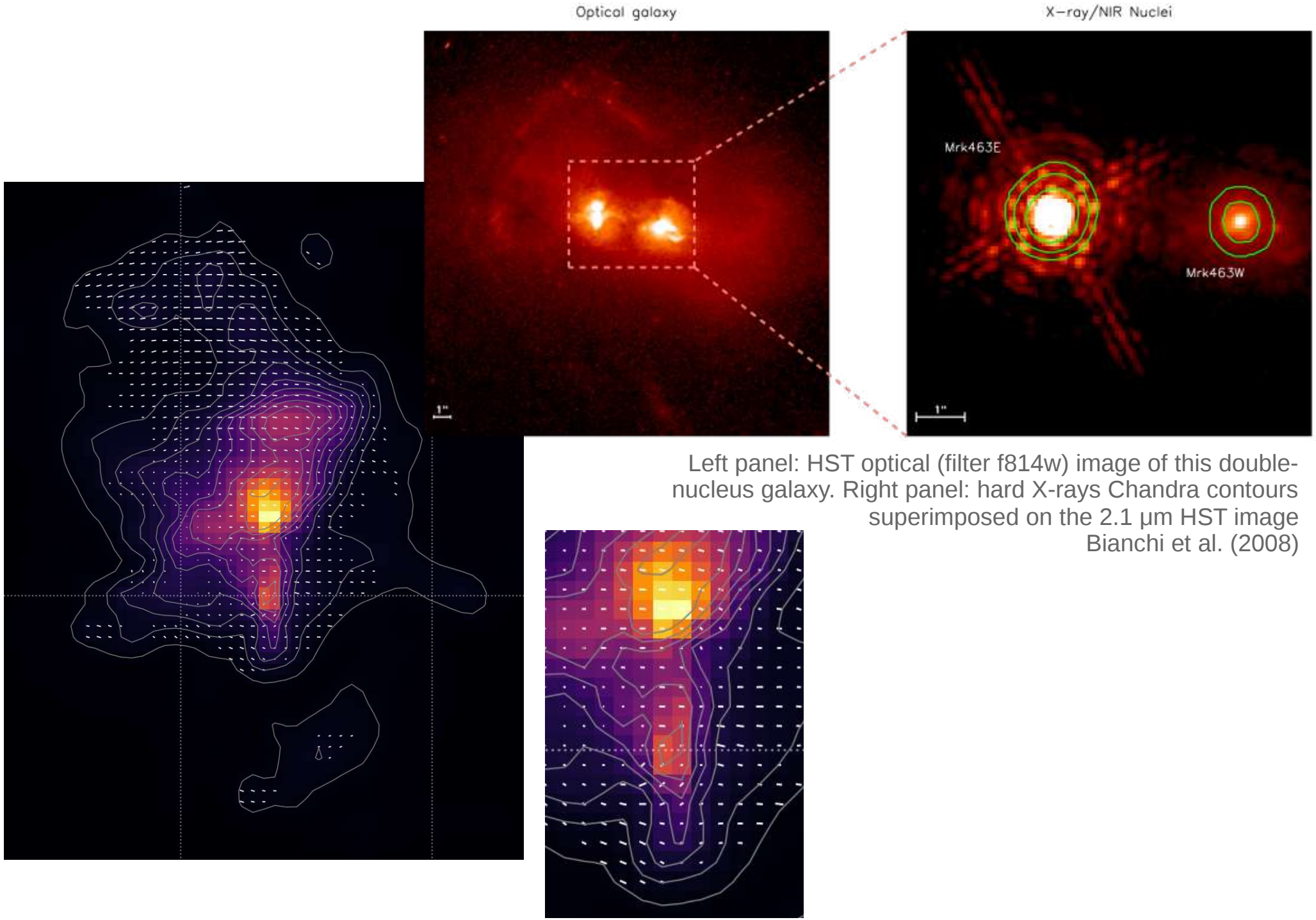


IC 5063 taken with the F606W filter of the Wide Field and Planetary Camera 2 (WFPC2) of the HST
Congiu et al. (2017)

MRK 463E


Right Ascension (J2000)
02.946s
02.944s
02.942s
02.940s
02.938s
13h56m02.936s
Declination (J2000)
18°22'17.65"
17.60"
17.55"
$F_\lambda^{int}(3404\ Å) = (14.82 \pm 0.2)$e-16 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$
$P^{int} = 12.6 \pm 2.0$ %
$\theta_P^{int} = 83.6 \pm 4.7$ °
N
E
1 arcsec
P= 100 %
1e−17
1.2
1.0
0.8
0.6
0.4
0.2
0.0
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$]

MRK 463E



Left panel: HST optical (filter f814w) image of this double-nucleus galaxy. Right panel: hard X-rays Chandra contours superimposed on the 2.1 μm HST image
Bianchi et al. (2008)

Results and impacts

NGC 1068

→ circular pattern that pinpoints the source of emission despite being hidden by dust
→ plateau of UV polarization: electron scattering in the first 1” (no dust)
→ various hot-spots: clumps in the polar winds (3D geometry feasible)

Cygnus A

→ extended source, very faint
→ 4 foreground contaminating sources
→ two lobes resolved, polarization angle perpendicular to jet direction (source localization)

IC 5063

→ triple structure !
→ very low polarization degree: either chaotic magnetic topology or low inclination
→ hard to determine if synchrotron emission dominates over scattering

Mrk 463E

→ a merging system consisting of Mrk 463E (East) and Mrk 463W (West)
→ Mrk 463E: dust enshrouded quasar
→ HST/FOC reveals a bright, subarcsec optical jet extending south of the nucleus
→ determining the physical nature of the mirror: electron scattering as the reflection mechanism (centro-symmetric pattern)

Conclusions

The HST/FOC archives contain many treasures that are yet to be explored and analyzed
→ 7 objects to be investigated with high priority
→ reduce the whole AGN sample in a standardized and consistent way

The HST/FOS and HST/ACS archives also have uncharted quasar data !!!

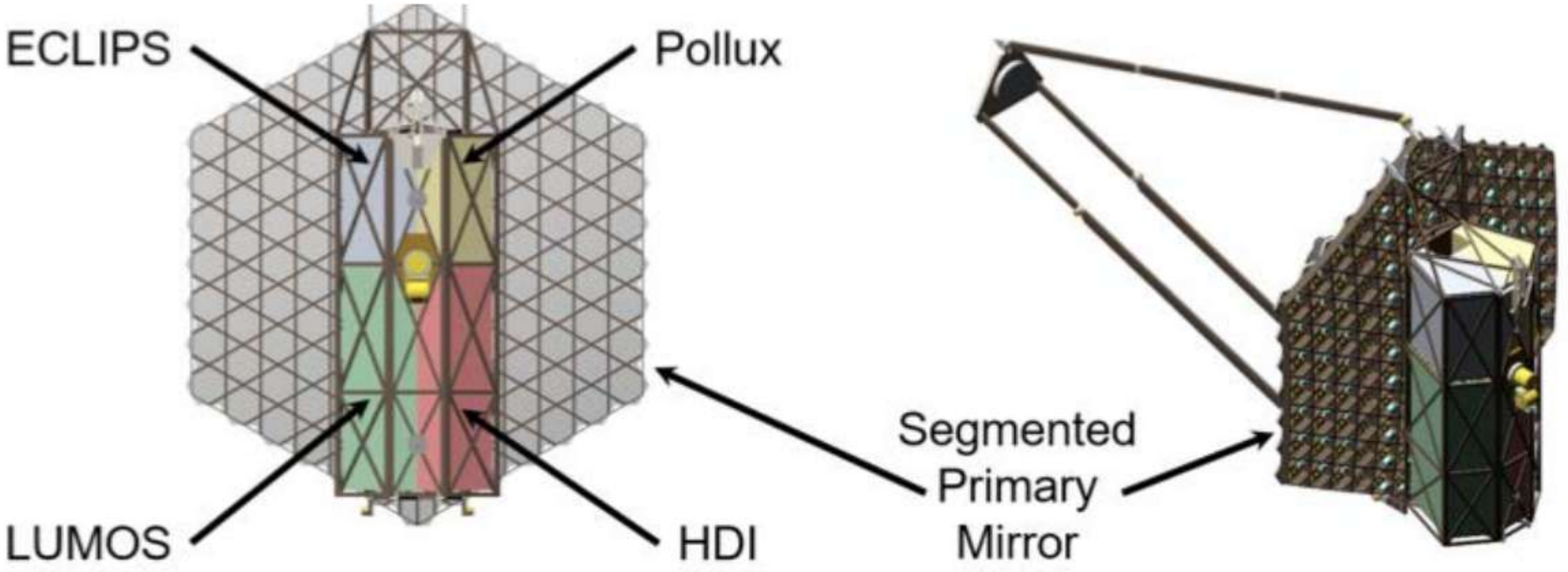
OUR PIPELINE WILL BE FREELY ACCESSIBLE FOR ALL UNEXPLORED HST POLARIMETRIC DATA OF EXTENDED SOURCES

Some examples?
HST/FOC supernovae SN1960L, SN1980K or SN1957D data have not yet been analyzed

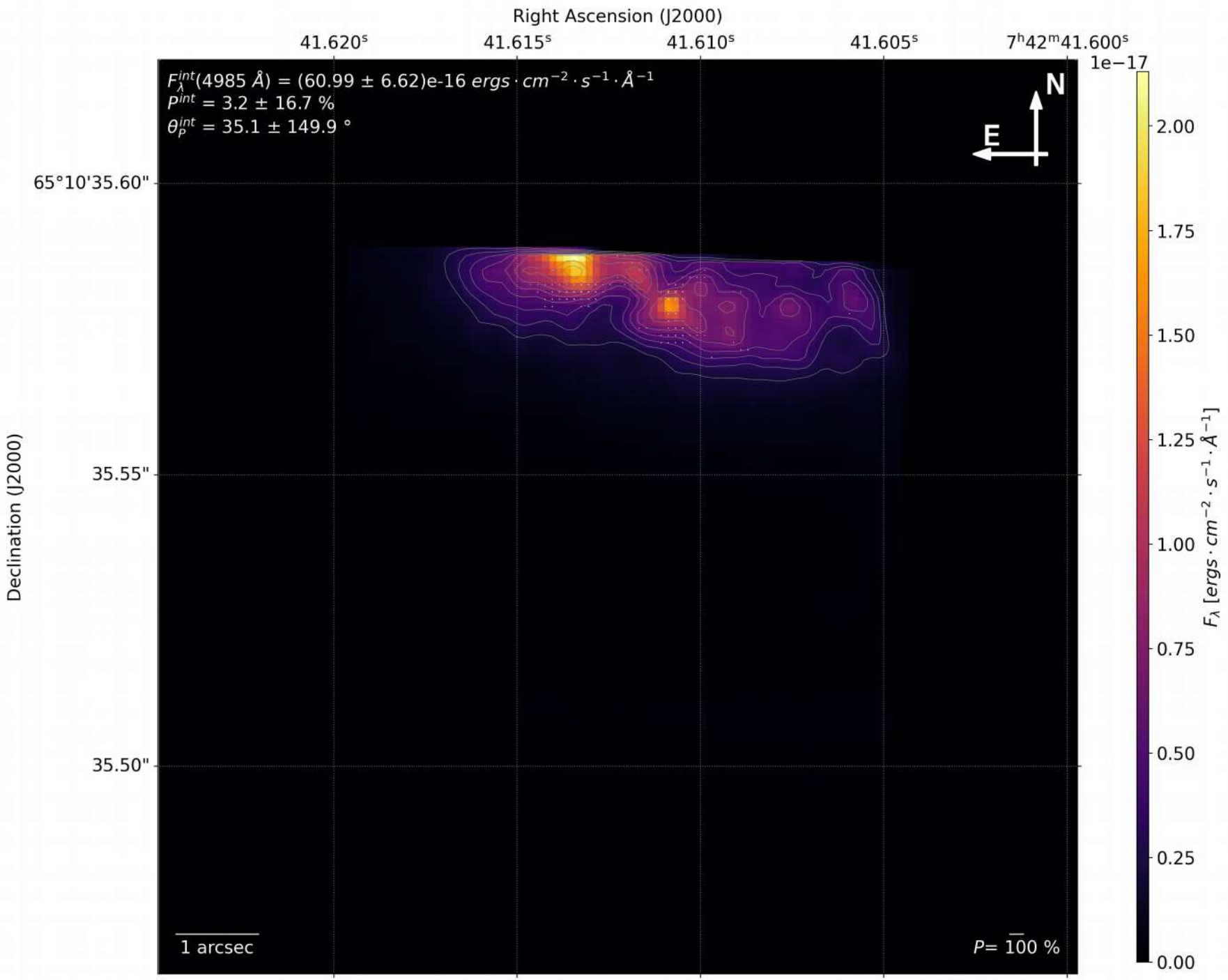
Conclusions

Such work will provide strong scientific requirements and objectives for the potential ultra-high-resolution UV spectropolarimeter POLLUX that might equip the LUVOIR mission

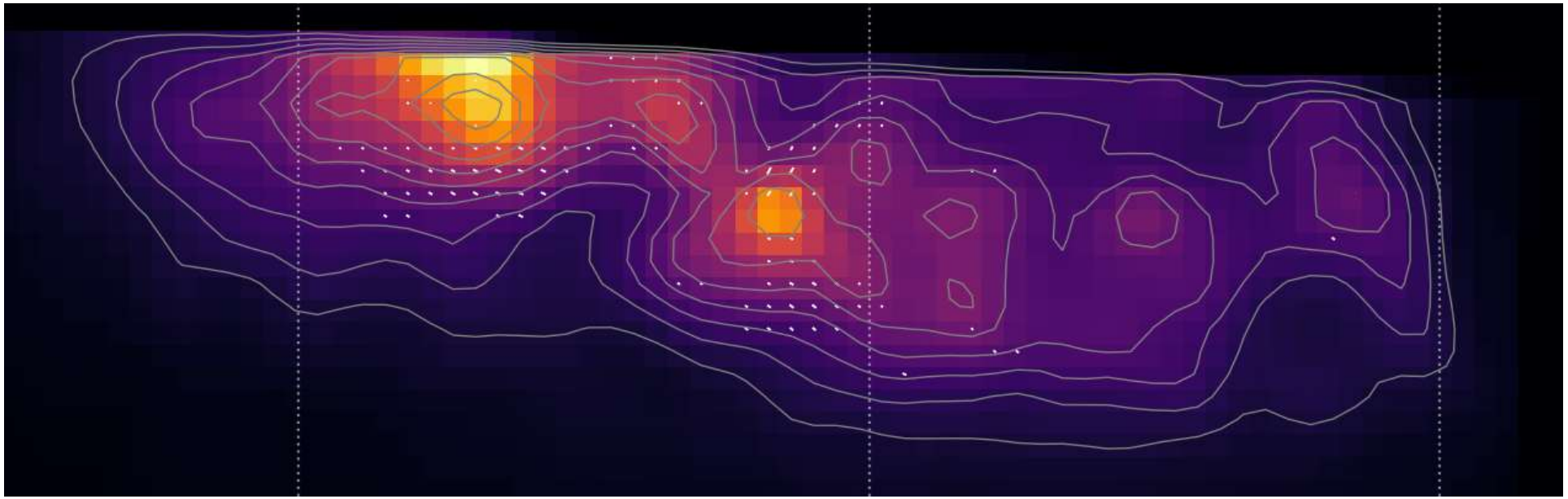
- waveband: 900 - 3900 Å
- spectral resolving power: 200 000
- spectral length ≥6 nm
- aperture size 0.01”
- polarization modes: circular+linear (QUV)

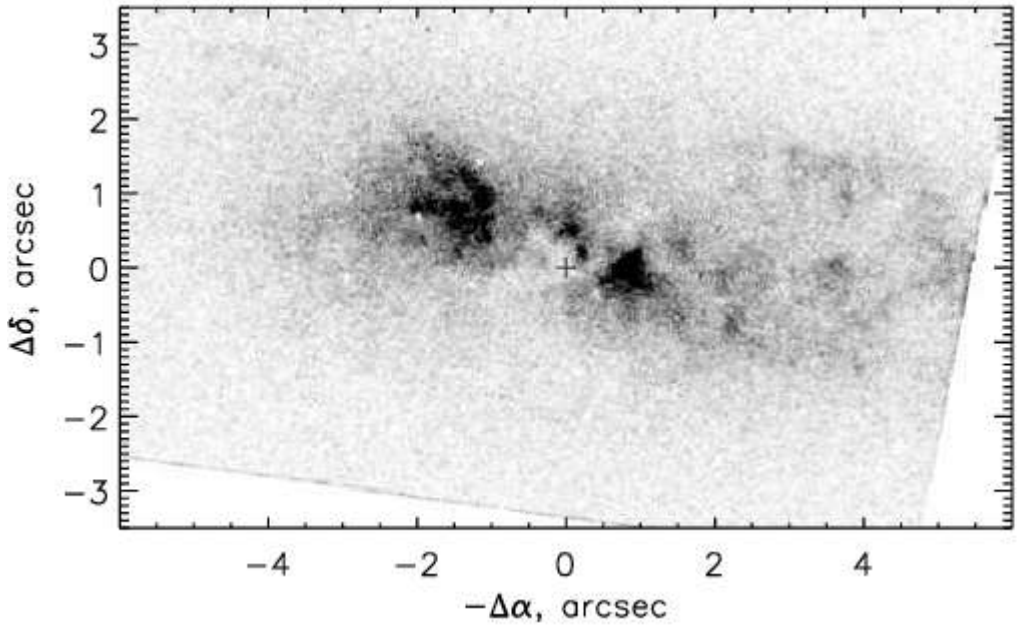


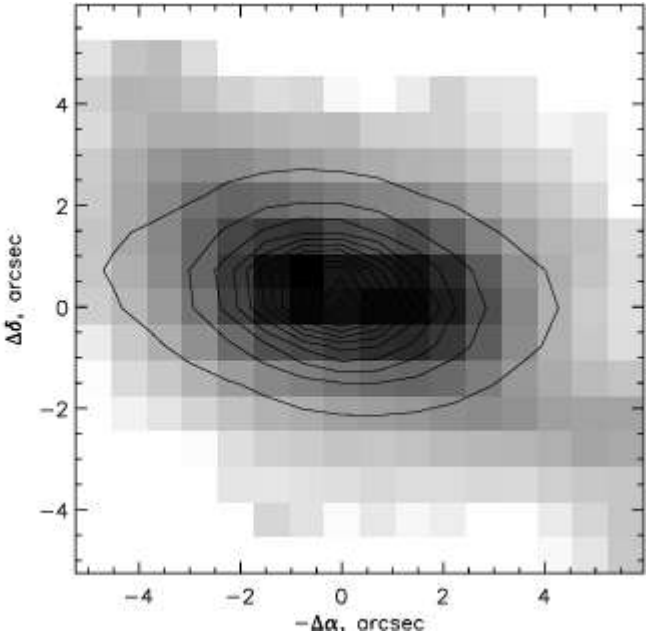
MRK 78


Right Ascension (J2000)
41.620ˢ
41.615ˢ
41.610ˢ
41.605ˢ
7ʰ42ᵐ41.600ˢ
1e−17
F_λ^{int}(4985 Å) = (60.99 ± 6.62)e-16 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$
P^{int} = 3.2 ± 16.7 %
θ_P^{int} = 35.1 ± 149.9 °
N
E
65°10'35.60"
35.55"
35.50"
Declination (J2000)
1 arcsec
P= 100 %
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$]

MRK 78

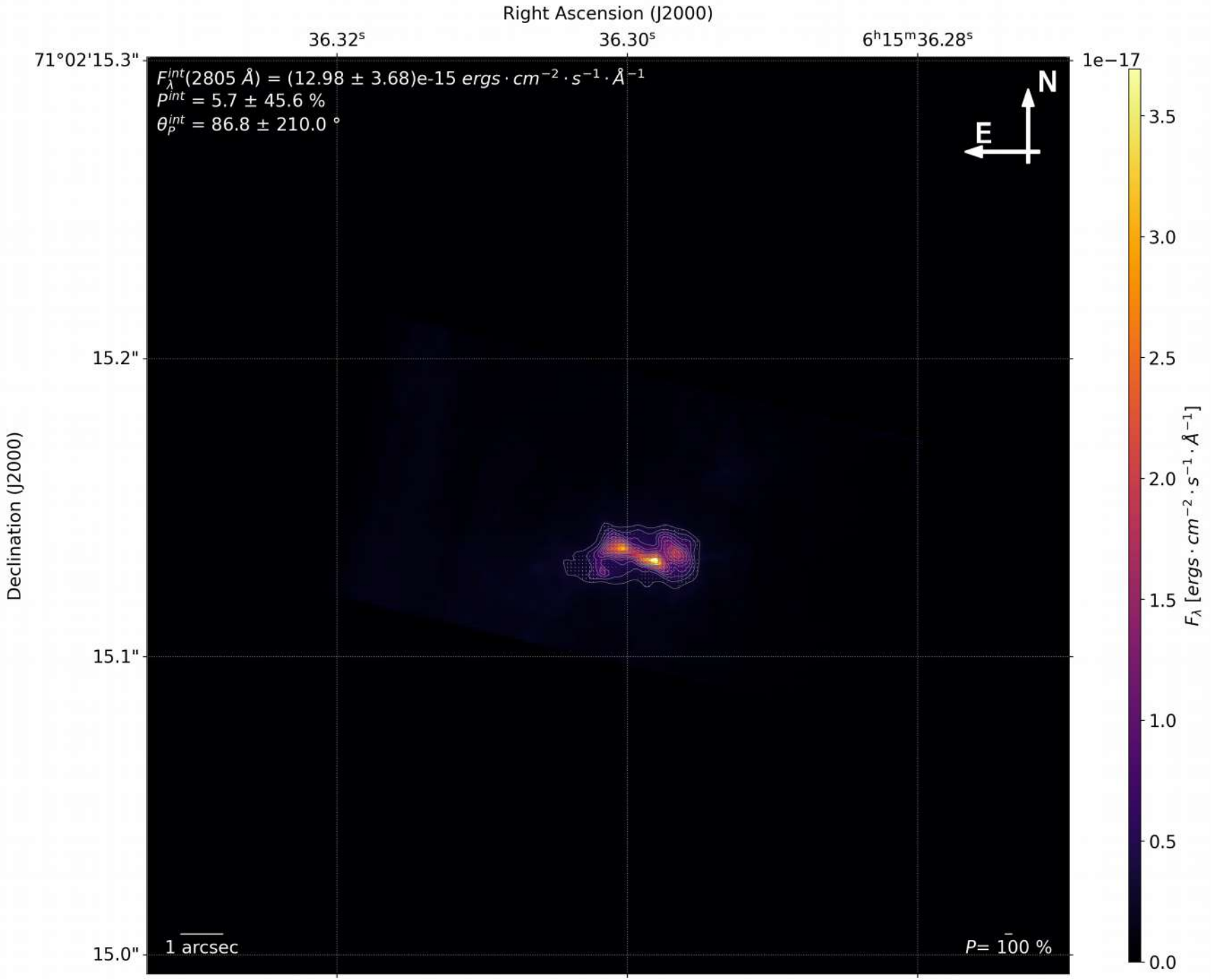




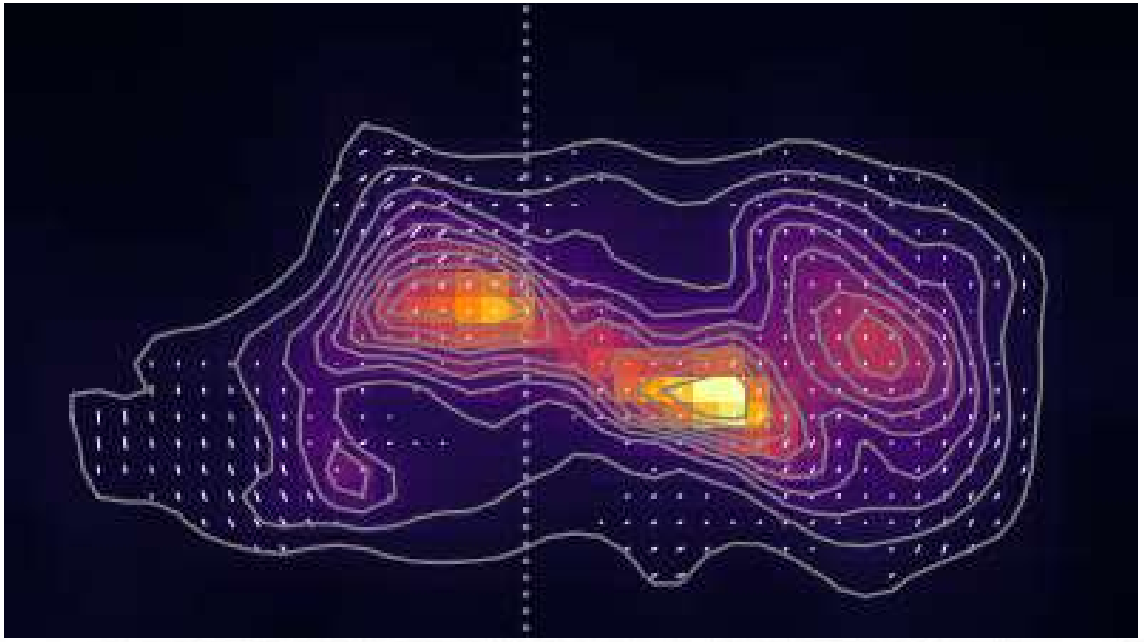


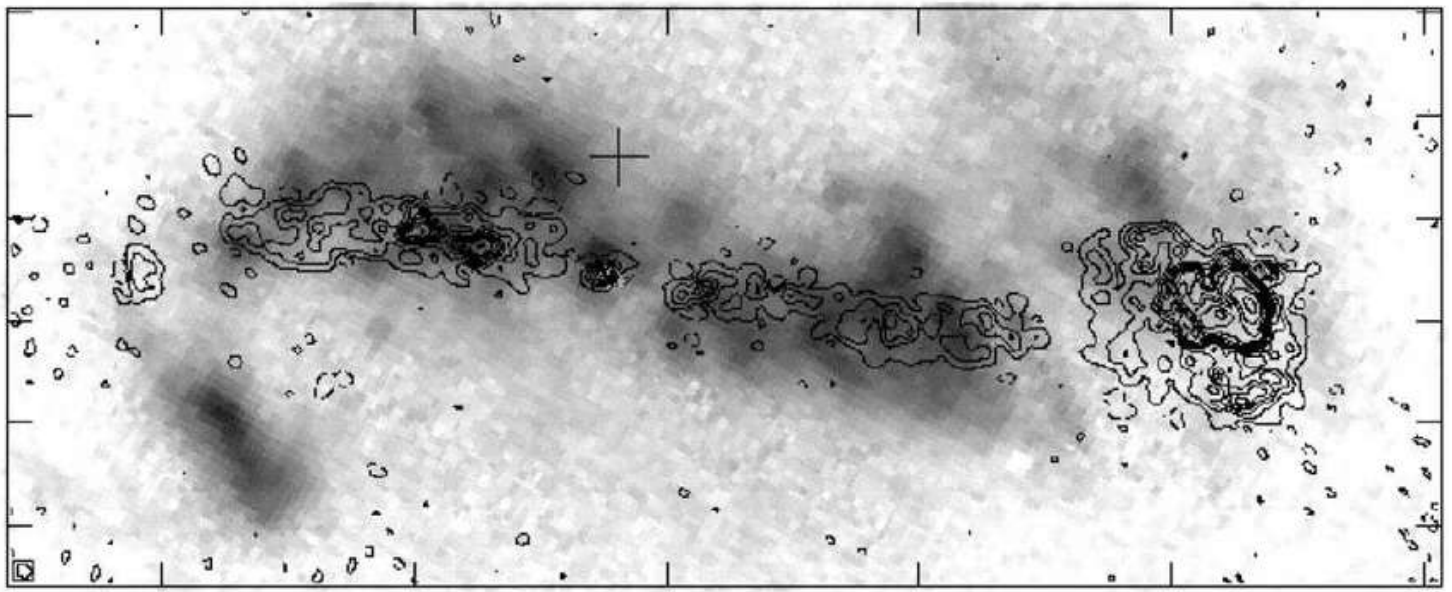
Left: the HST/FOC image with the F520M filter, shows the [OIII] emission (see Fischer et al., 2011)
Right: the MPFS image in the [OIII]λ5007 line with the superimposed continuum isophotes
Kozlova et al. (2020)

MRK 3


Right Ascension (J2000)
36.32ˢ
36.30ˢ
6ʰ15ᵐ36.28ˢ
71°02'15.3"
15.2"
15.1"
15.0"
Declination (J2000)
F_λ^{int}(2805 Å) = (12.98 ± 3.68)e-15 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$
P^{int} = 5.7 ± 45.6 %
θ_P^{int} = 86.8 ± 210.0 °
N
E
1 arcsec
P= 100 %
1e−17
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$]

MRK 3

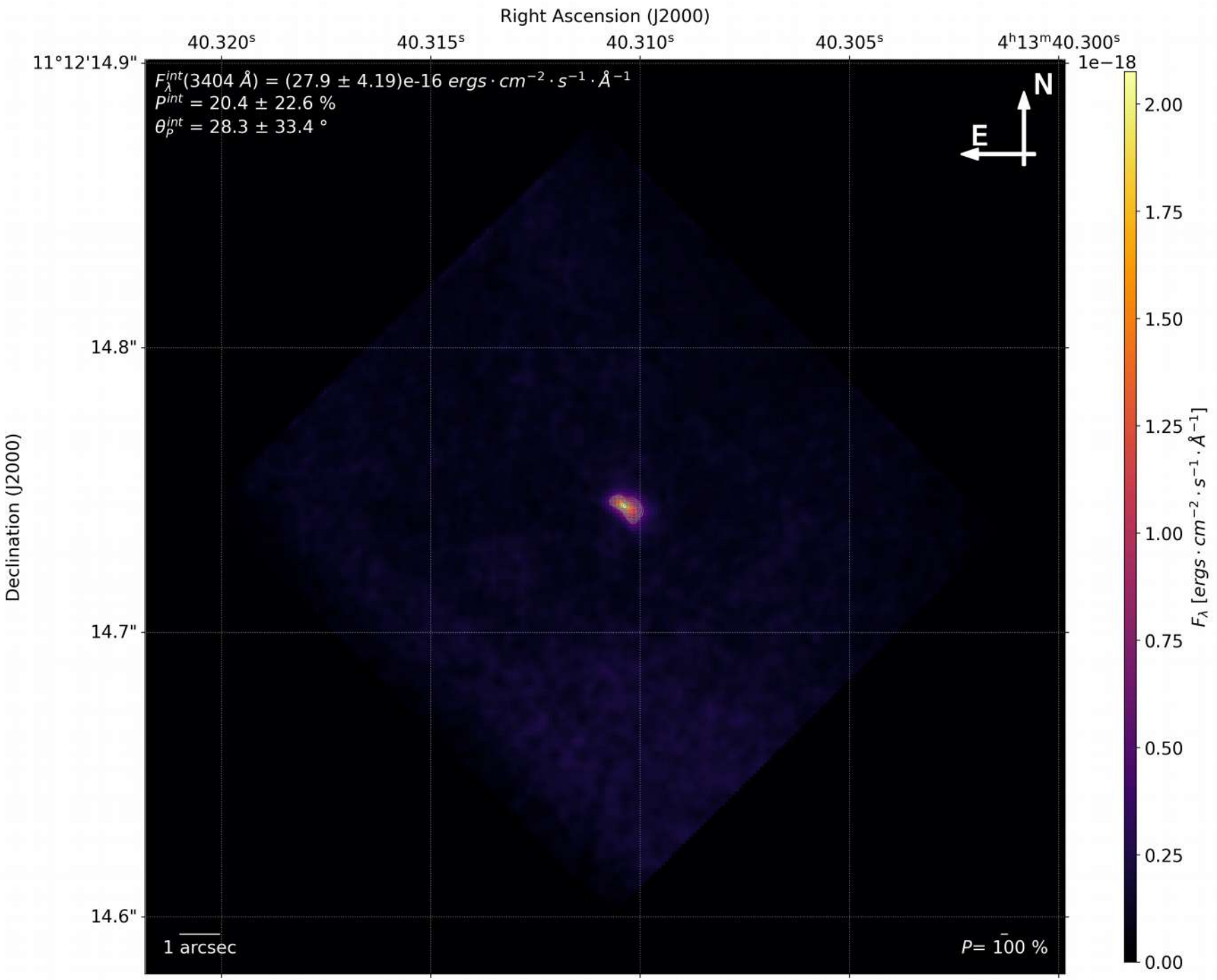




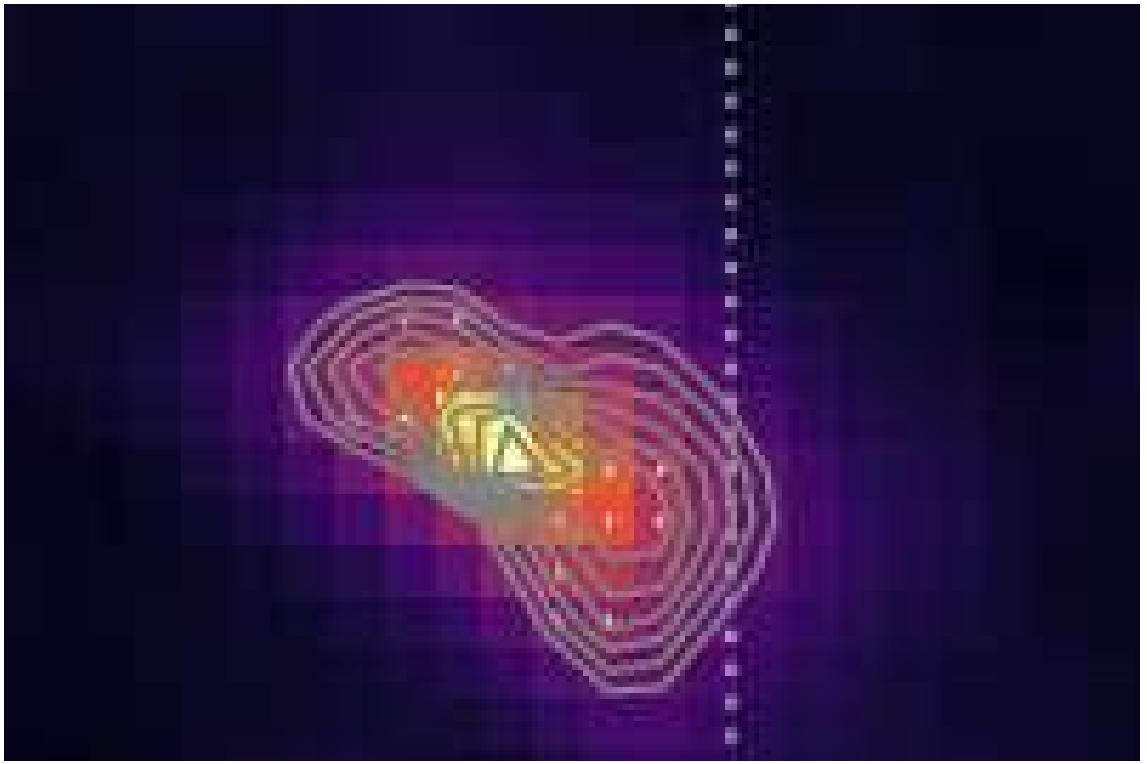
[O III] image (greyscale) of the NLR in Mrk 3 from the HST Faint Object Camera, with radio 18 cm emission (contours) superimposed, from Kukula et al. (1999). Tick marks on the vertical axis are separated by ∼0″.2

Crenshaw et al. (2009)

3C 109


Right Ascension (J2000)
40.320ˢ
40.315ˢ
40.310ˢ
40.305ˢ
4ʰ13ᵐ40.300ˢ
11°12'14.9"
14.8"
14.7"
14.6"
Declination (J2000)
F_λ^{int}(3404 Å) = (27.9 ± 4.19)e-16 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$
P^{int} = 20.4 ± 22.6 %
θ_P^{int} = 28.3 ± 33.4 °
N
E
1 arcsec
P= 100 %
1e−18
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
F_λ [$ergs \cdot cm^{-2} \cdot s^{-1} \cdot Å^{-1}$]

3C 109



SDSS archives
(Simbad, CDS)