PCA Tomography and its application to nearby galactic nuclei

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Principal Component Analysis - PCA

- Data cubes have huge number of pixels (6×10^6). How can we extract information?
- PCA tomography:
- Not a set of objects; a set of spatial pixels of the same data cube. The wavelength pixels are the properties.
- Linear transformation to a new system of coordinates
- The coordinates are orthogonal
- Dimensional reduction
- A lot of redundancy!
- Noise reduction – background subtraction
- Data organization and analysis

From a datacube to a data matrix

- The datacube has n = $\nu x \mu$ spatial pixels and m spectral pixels.
- The mean intensity $$Q_\lambda = \frac{1}{n} \cdot \sum_{i=1}^{\mu} \sum_{j=1}^{\nu} \left(I_{ij\lambda} \right)_O$$
- The intensity adjusted $$I_{ij\lambda} = \left(I_{ij\lambda} \right)_O - Q_\lambda$$
- The data cube $I_{ij\lambda}$ has to be transformed into a matrix, $I_{\beta\lambda}$

were $\beta = \mu(i-1) + j$

PCA — Principal Component Analysis

- Covariance matrix $$C_{\mathrm{cov}} = \frac{\left[I_{\beta\lambda}\right]^T \cdot I_{\beta\lambda}}{n-1}$$
- Properties $$C_{\mathrm{cov}} = \left[C_{\mathrm{cov}}\right]^T$$
- PCA transformation: $$T_{\beta k} = I_{\beta\lambda} \cdot E_{\lambda k}$$
- D must be diagonal: $$D_{\mathrm{cov}} = \frac{\left[T_{\beta k}\right]^T \cdot T_{\beta k}}{n-1}$$

The diagonal elements of D are the eigen-values Λ_k

Eigen-spectra and Tomograms

- $E_{\lambda k}$ are the eigen-spectra

and, (transforming β into ij)

- T_{ijk} are the tomograms

Analysing both ***together*** may reveal a wealth of information!

- Λ_k are the eigenvalues

Reconstruction, Compression Cosmetics

- Reconstructing the datacube with relevant eigenvectors to k=r.

$$I'_{\beta\lambda}(\leq r) = T_{\beta k}(\leq r) \cdot \left[E_{\lambda k}(\leq r)\right]^T$$

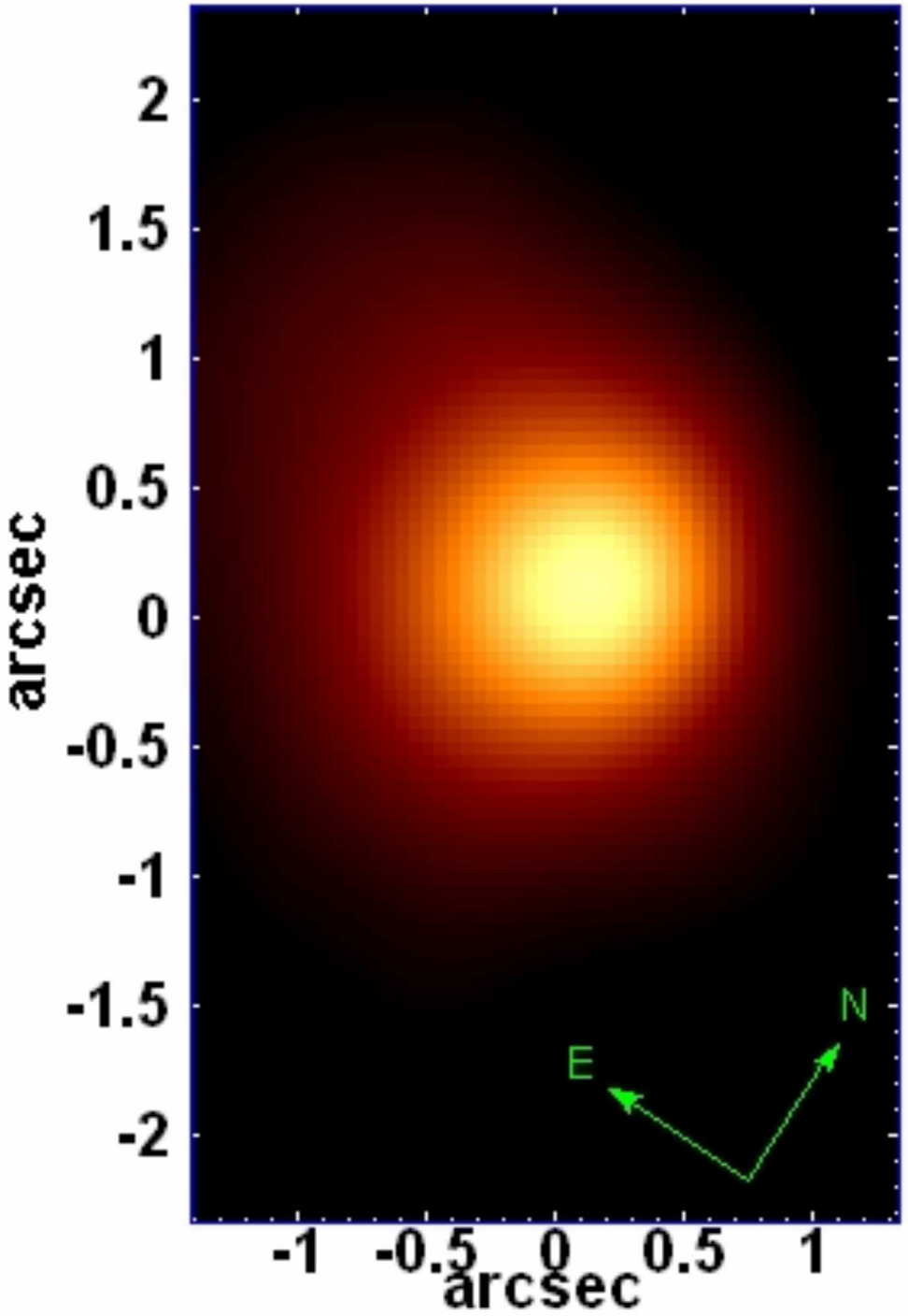
- Callibrating flux back

$$\left(I'_{ij\lambda}(\leq r)\right)_O = I'_{ij\lambda}(\leq r) + Q_\lambda$$

- Noise may be evaluated as

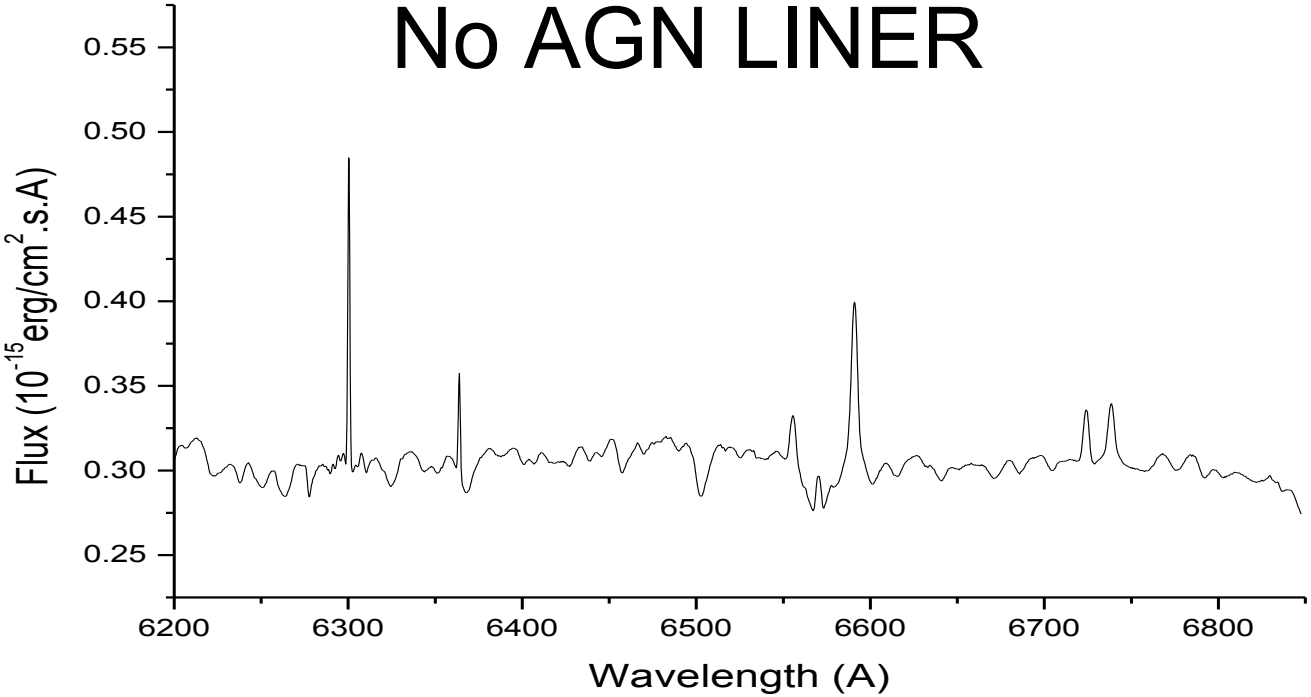
$$\sigma^2 = \sum_{k=r+1}^{k=m} \Lambda_k$$

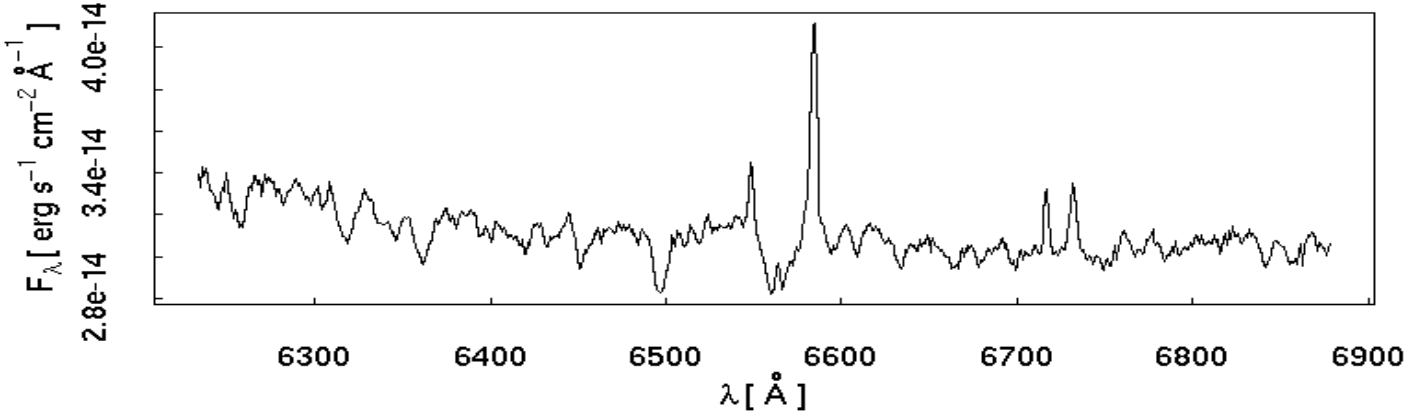
NGC 4736 (5 Mpc)
GMOS – IFU



NGC 4736 – Gemini 8m x Palomar 5m

No AGN LINER



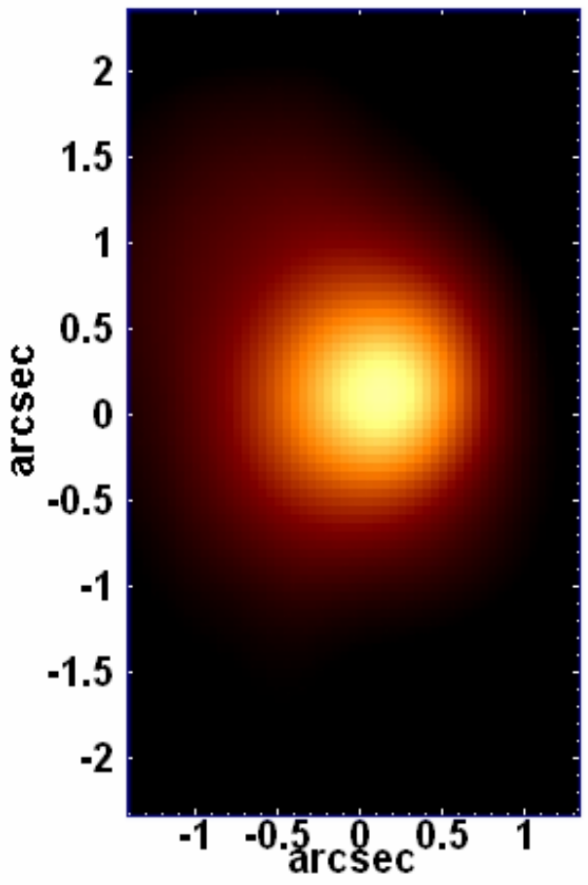


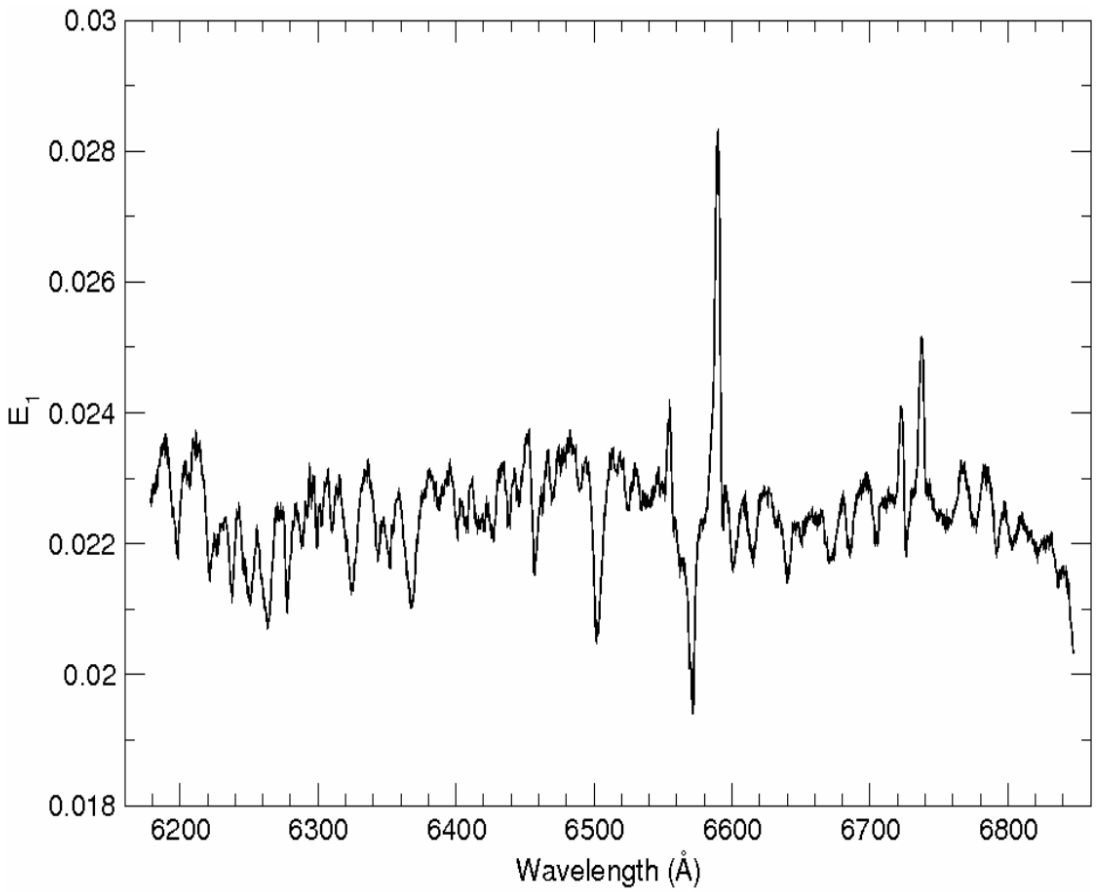
Eigenvalues and variance explained

(Huge redundancy)

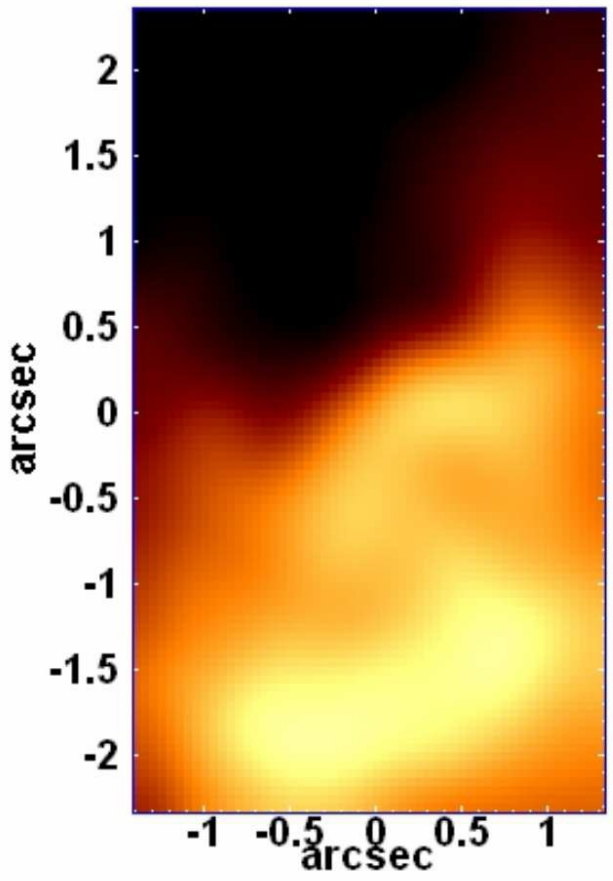
Eigenvector E_k	Eigenvalue (% of the variance)	Accumulated fraction (% of the variance)
E_1	99.7443	99.7443
E_2	0.0883	99.8326
E_3	0.0325	99.8651
E_4	0.0129	99.8781
E_5	0.0084	99.8864
E_6	0.0048	99.8912
E_7	0.0039	99.8952
E_8	0.0027	99.8979

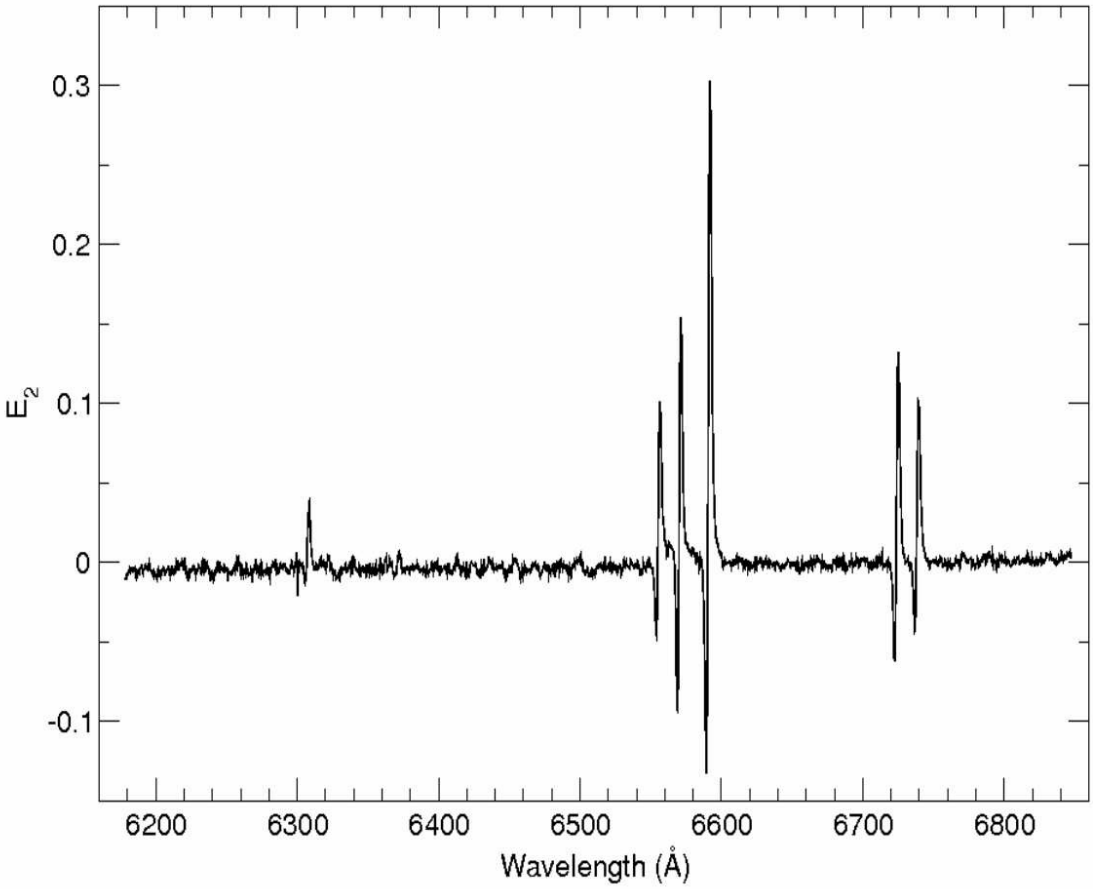
Tomogram 1 and eigenspectrum 1



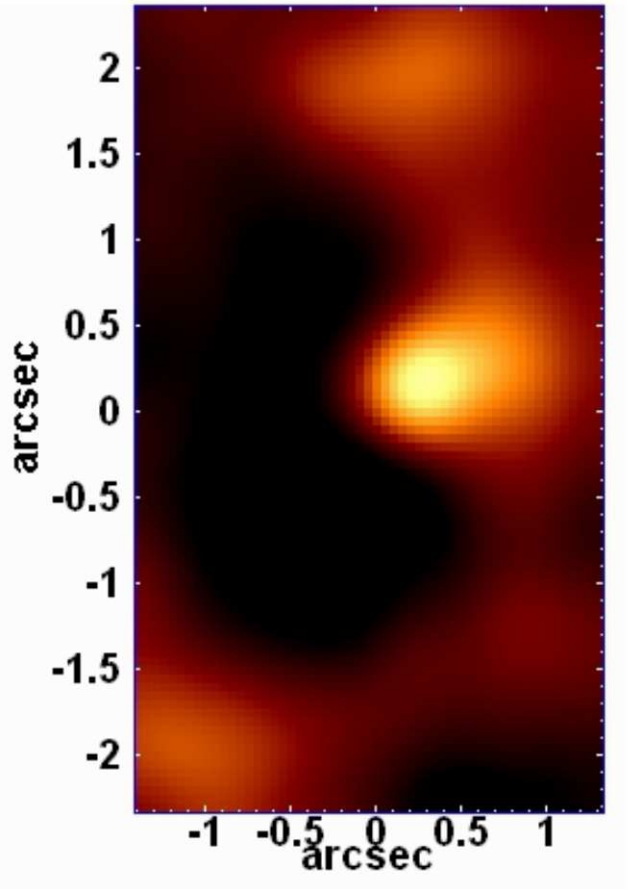


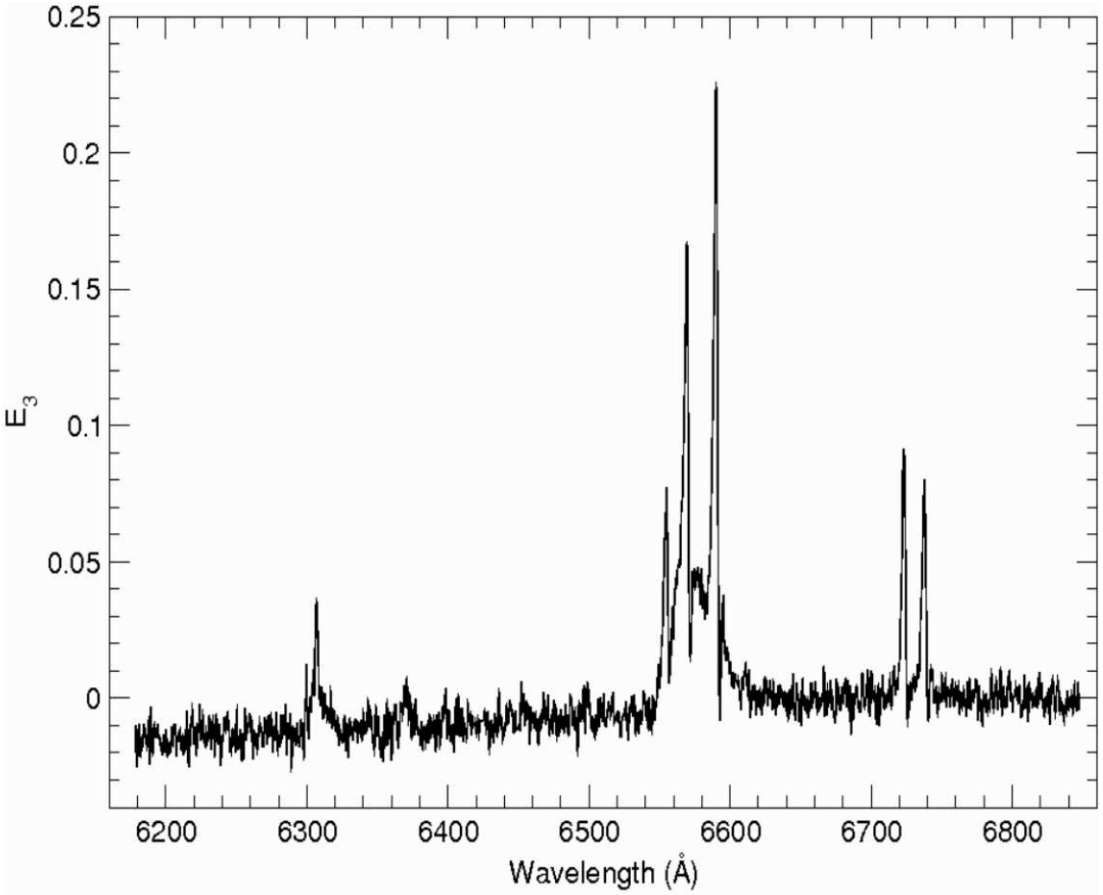
Tomogram 2 and eigenspectrum 2

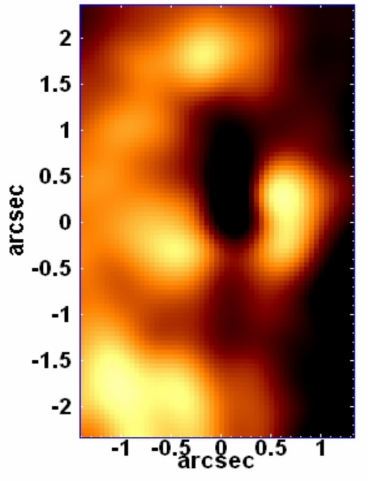


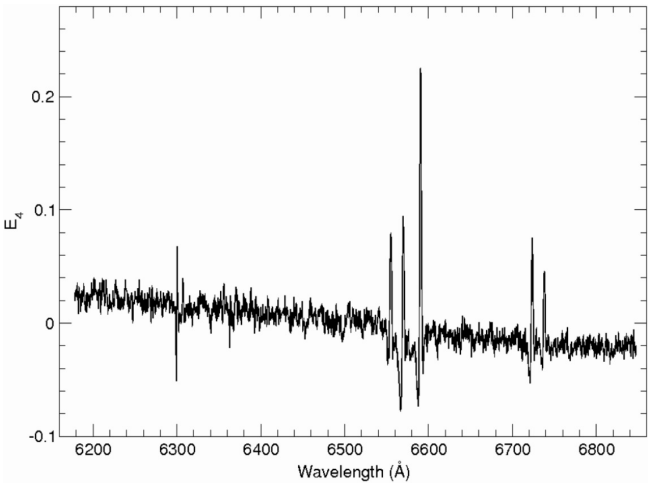


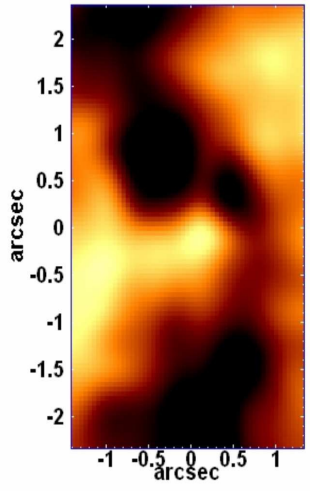
Tomogram 3 and eigenspectrum 3






arcsec
arcsec


E4
Wavelength (Å)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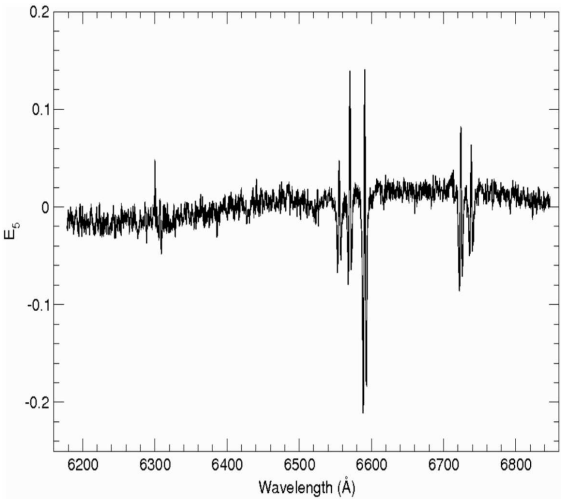
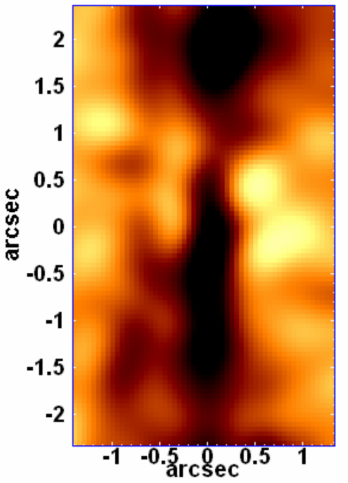

E5
Wavelength (Å)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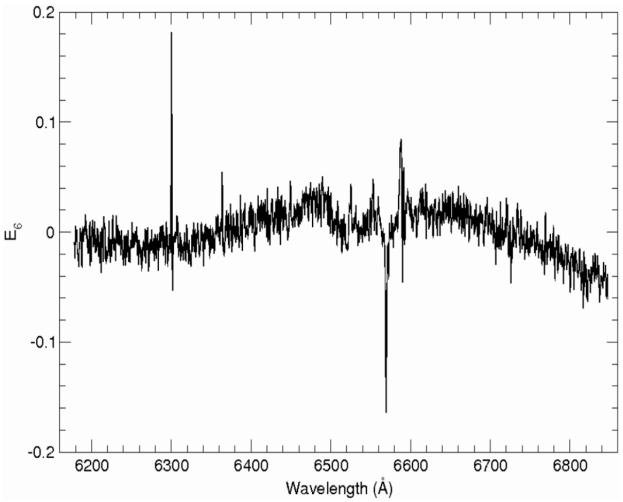
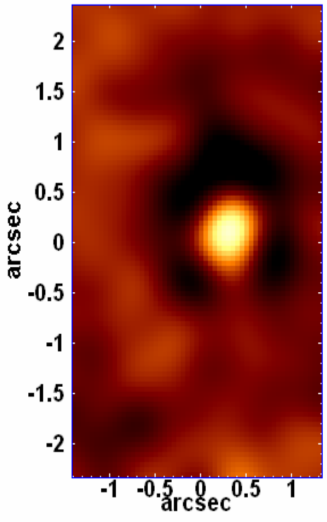

E6
Wavelength (Å)


arcsec
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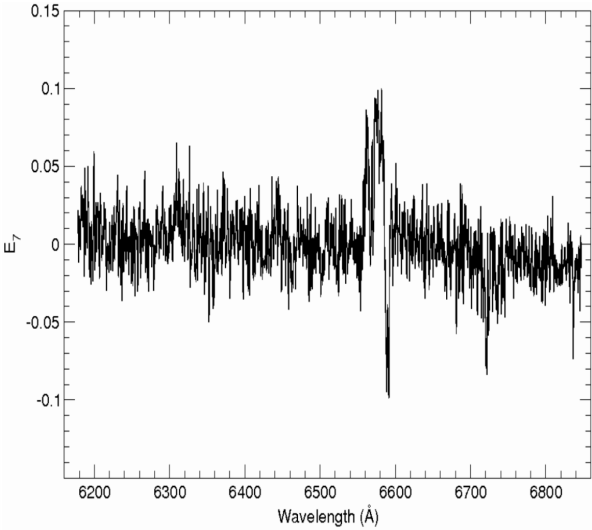
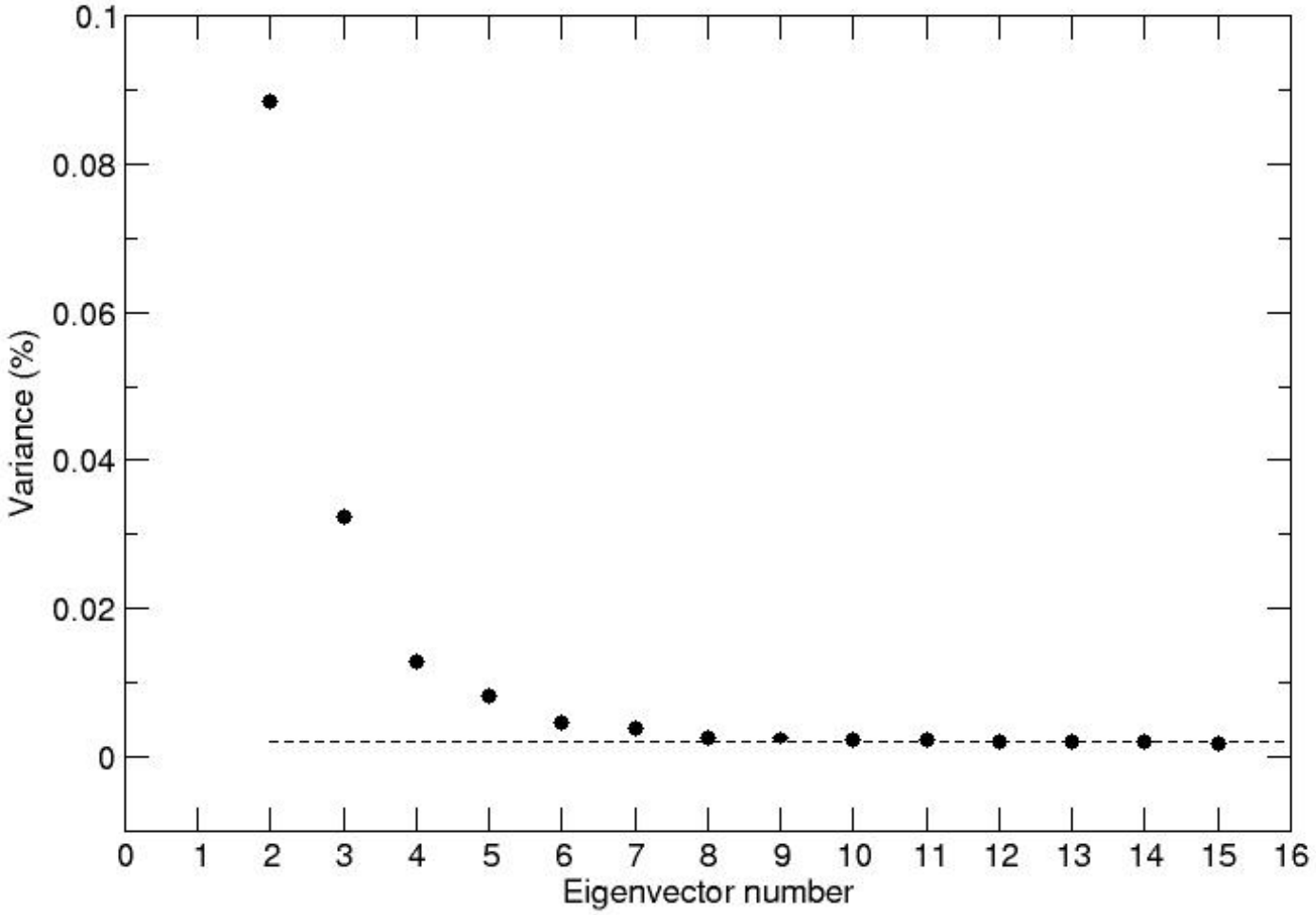
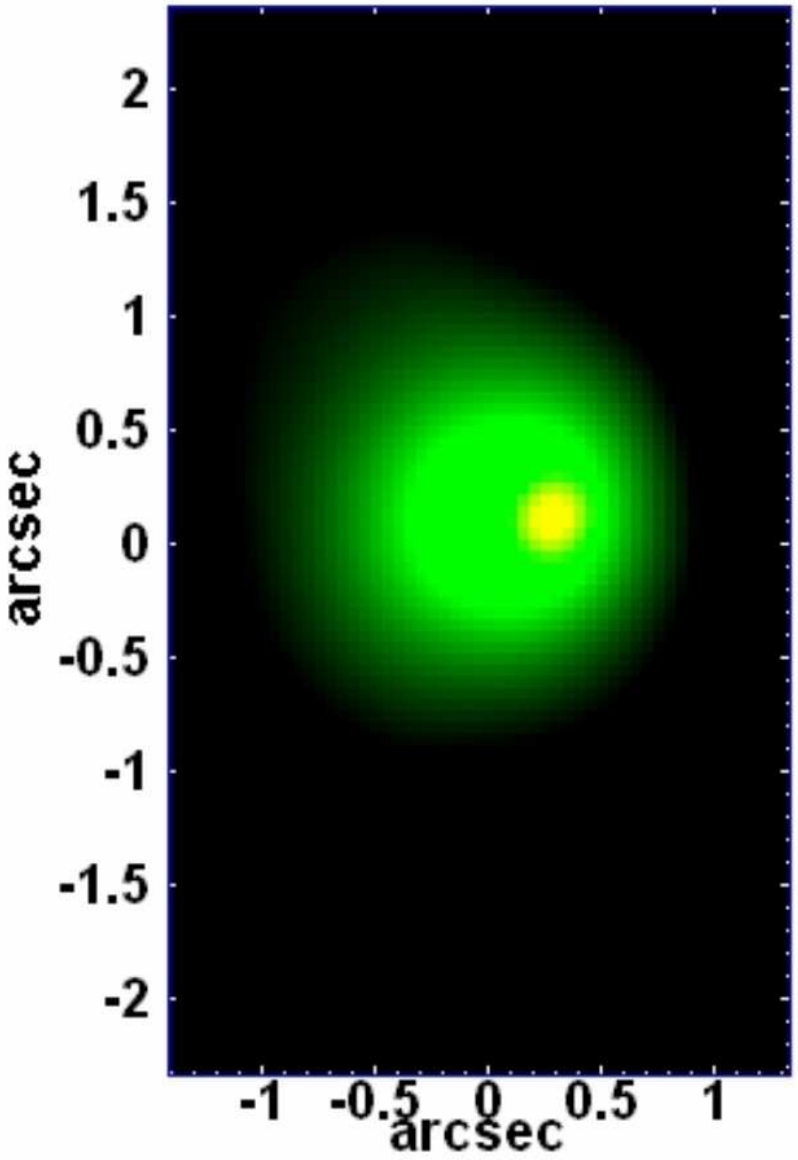

E7
Wavelength (Å)

The “scree test”



Tomogram 1 (green) + 2 (yellow)

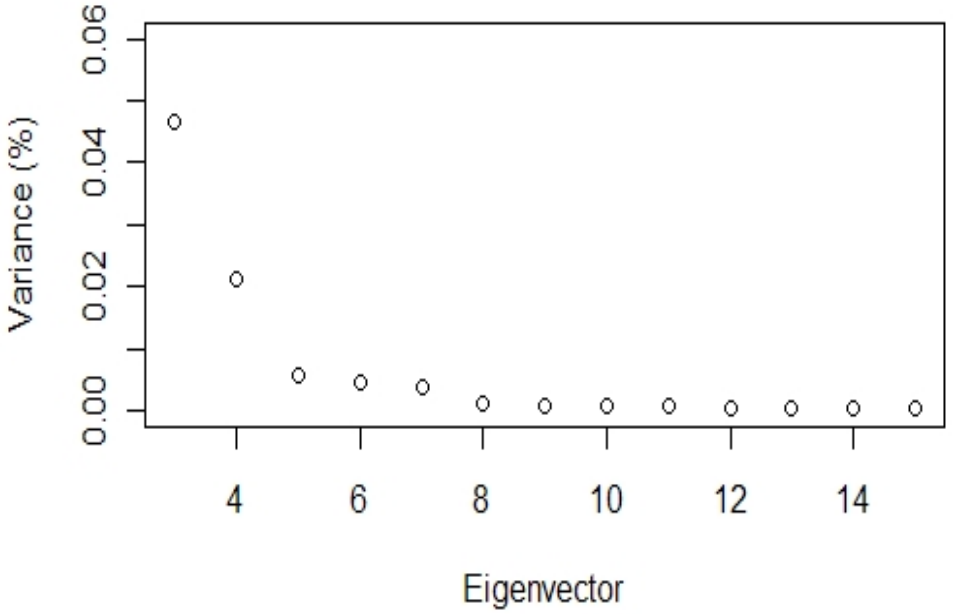
The stellar bulge and the BLR



NGC 7097 (E; 30 Mpc) - GMOS IFU data

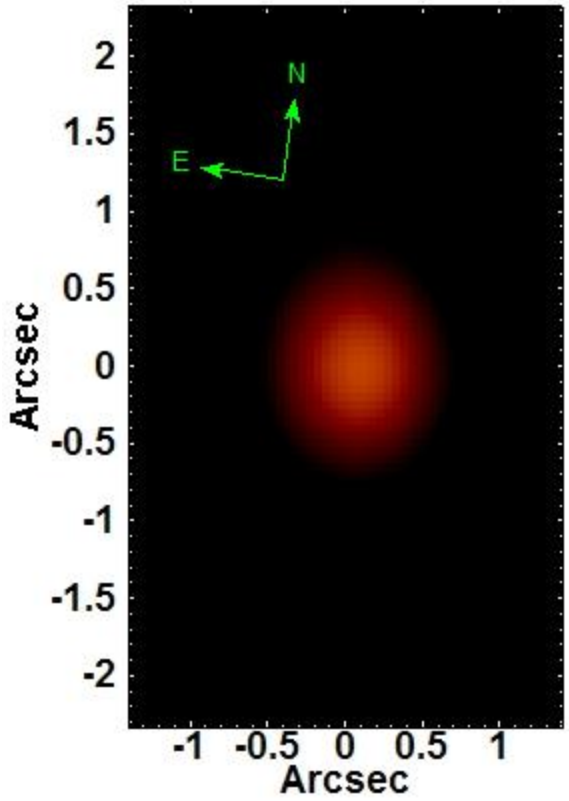
Eigenvector	Variance (%)
1	99.5256
2	0.3849
3	0.0464
4	0.0212
5	0.0059
6	0.0046
7	0.0038
8	0.0012
9	0.0009
10	0.0008

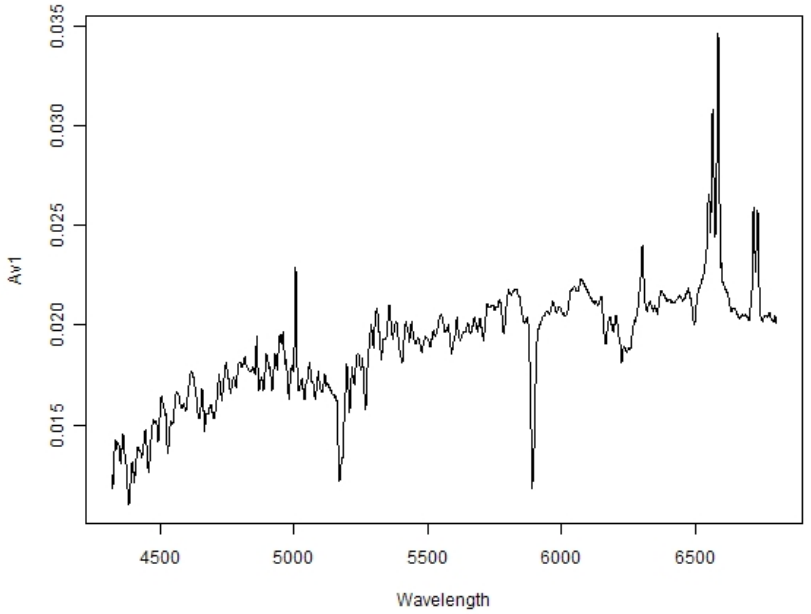
Scree test – Indicates that until Eigenvector 8 we have useful results



NGC 7097: Eigenvector 1 (99.52%):

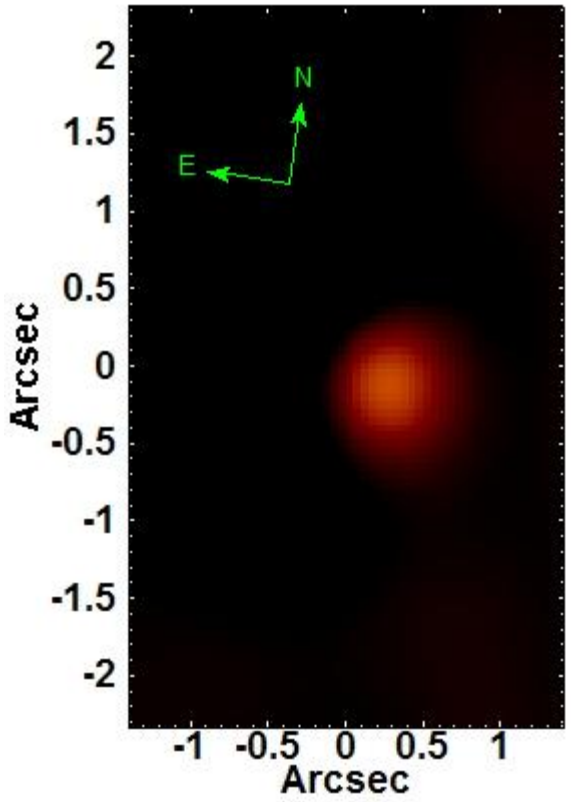
Mainly the galaxy Bulge

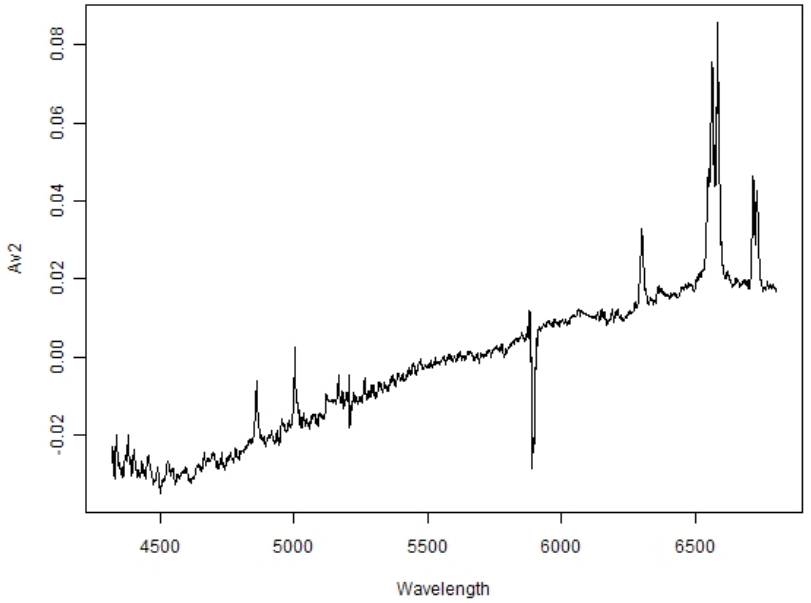




NGC 7097: Eigenvector 2 (0.38%):

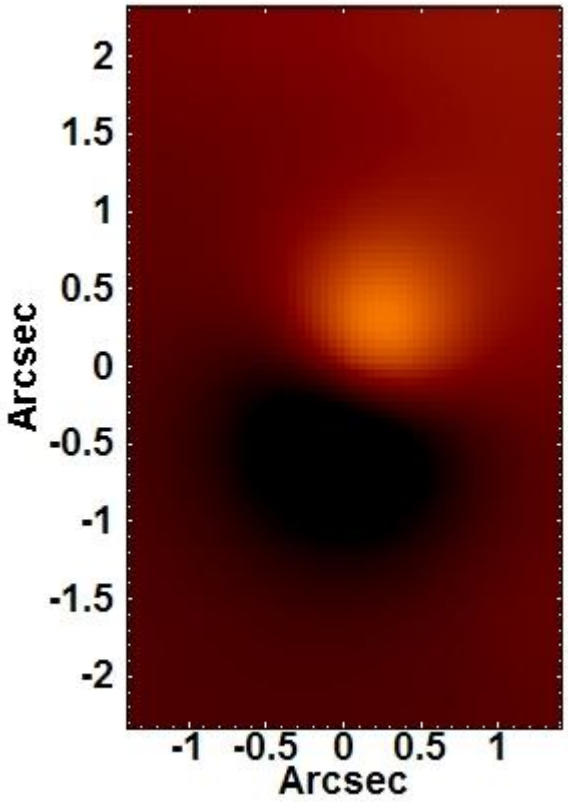
LINER signature. Red component correlated with the emission line features. Interstellar gas (Na I) in the line of sight to the AGN.

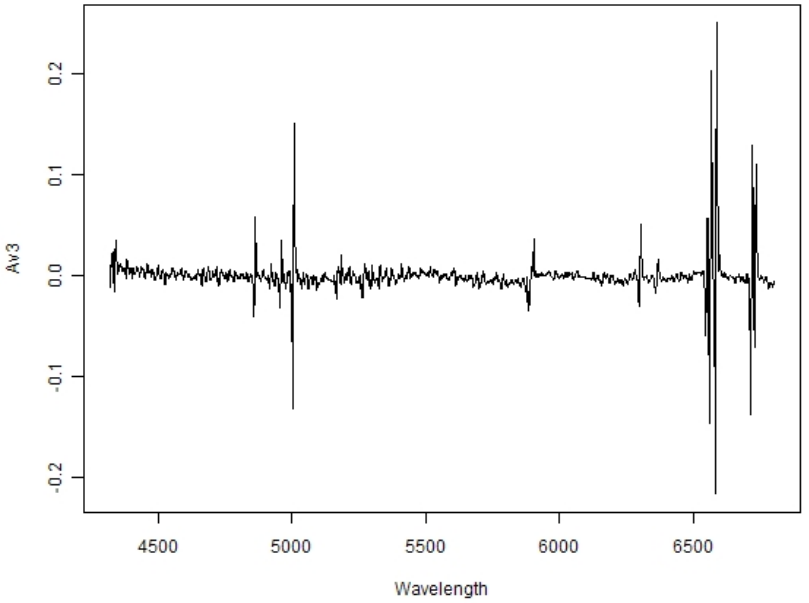




NGC 7097: Eigenvector 3 (0.046%):

Positive correlation is the red component of the line features.
Negative correlation is the blue component of the line features.
Rotating gaseous disc.

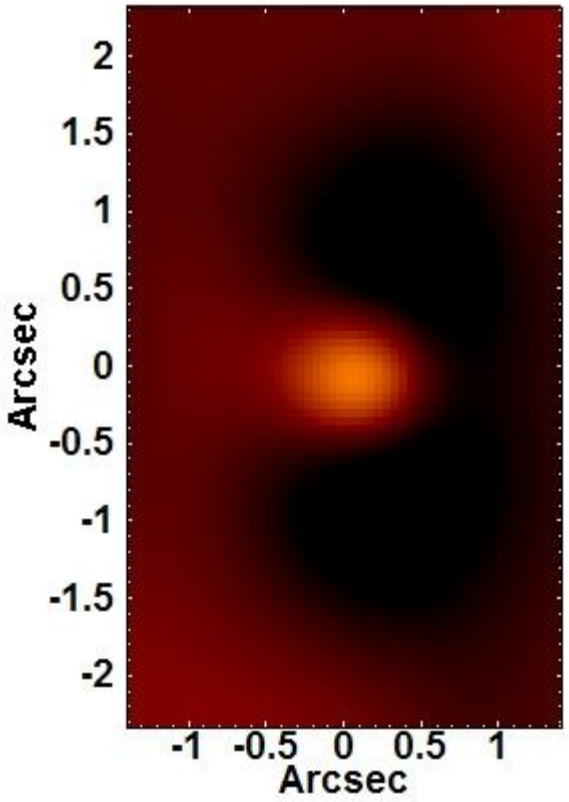


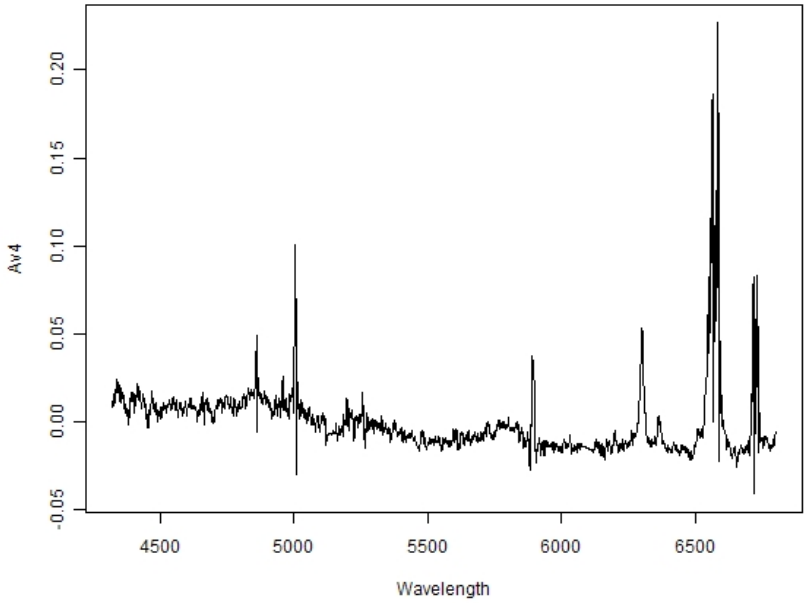


NGC 7097: Eigenvector 4 (0.021%):

A second LINER, but bluer than the one found in Eigenvector 2 and displaced 0.15’’ eastward. Absence of Na I absorption.

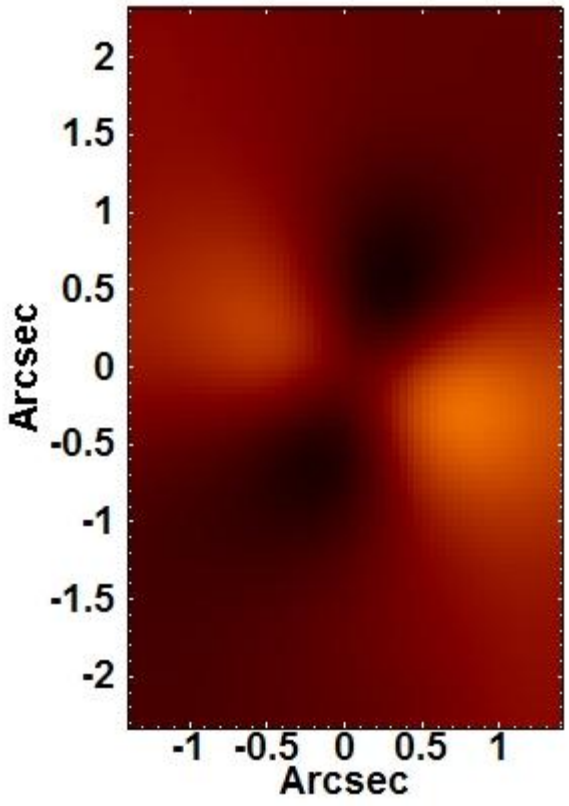
Same redshift as the first one.

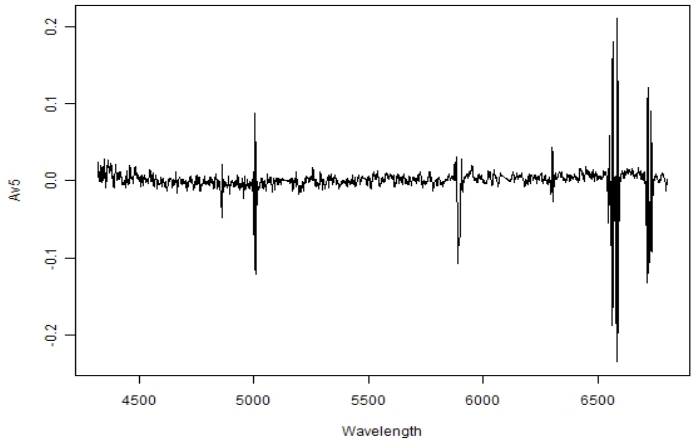


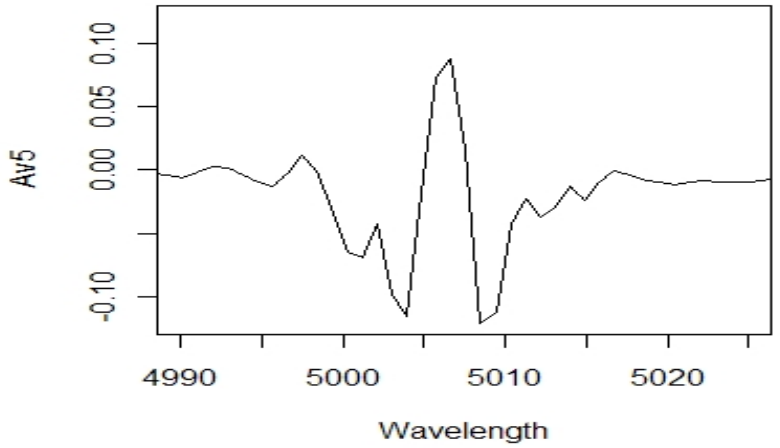


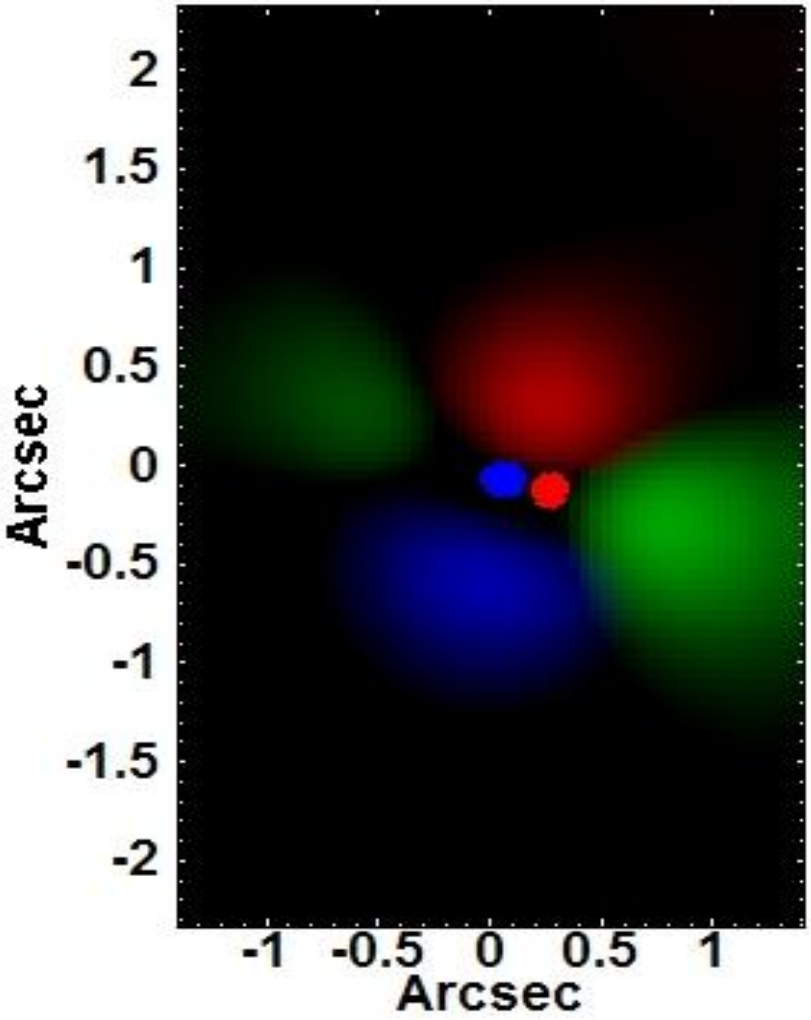
NGC 7097: Eigenvector 5 (0.0059%):

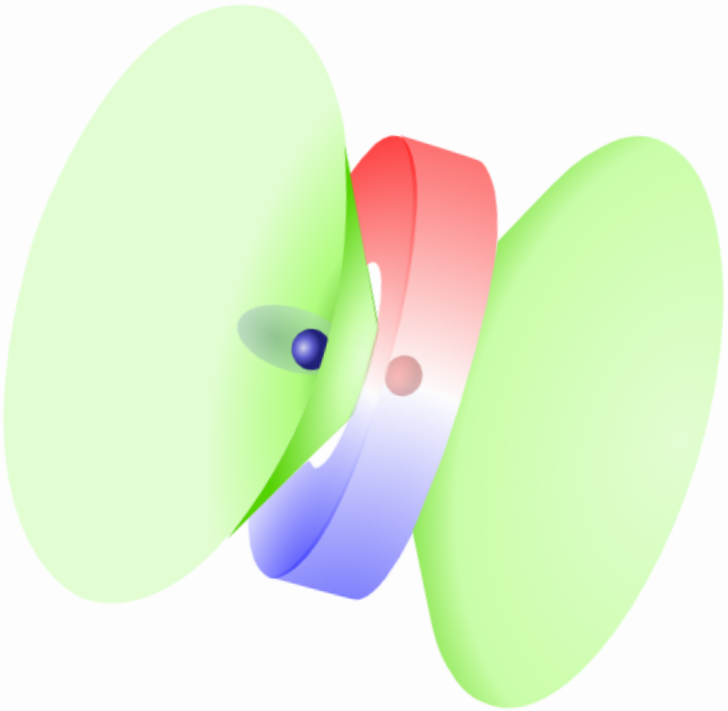
- The central component of the emission line features is anti-correlated with their blue and red components.
- Ionization cone (correlated) and rotating disc (anti-correlated).







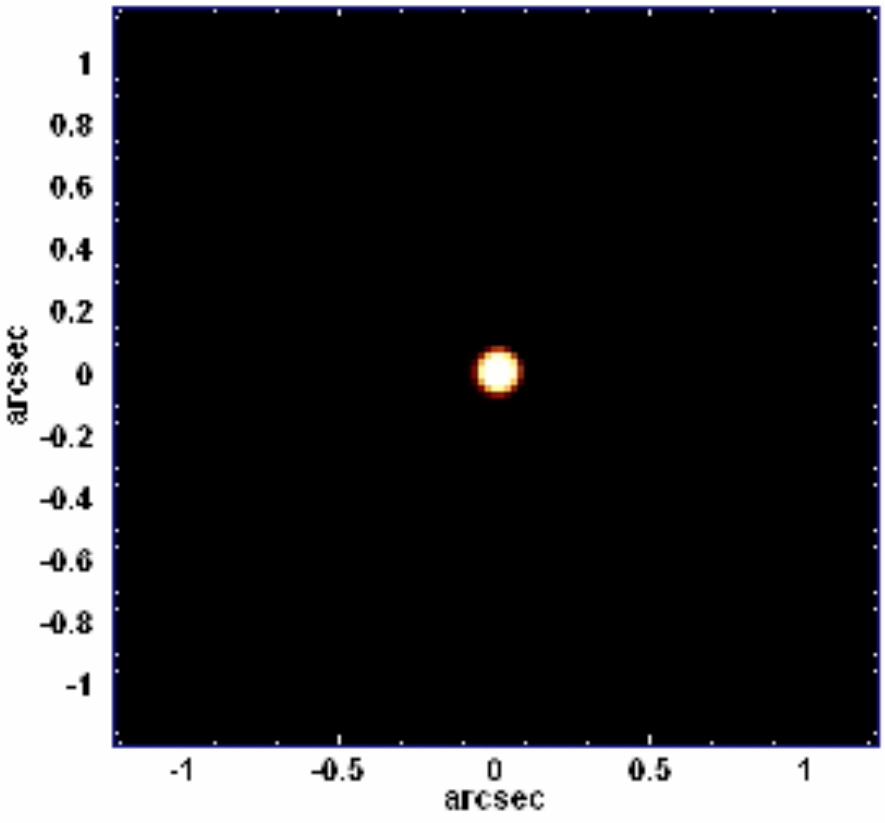


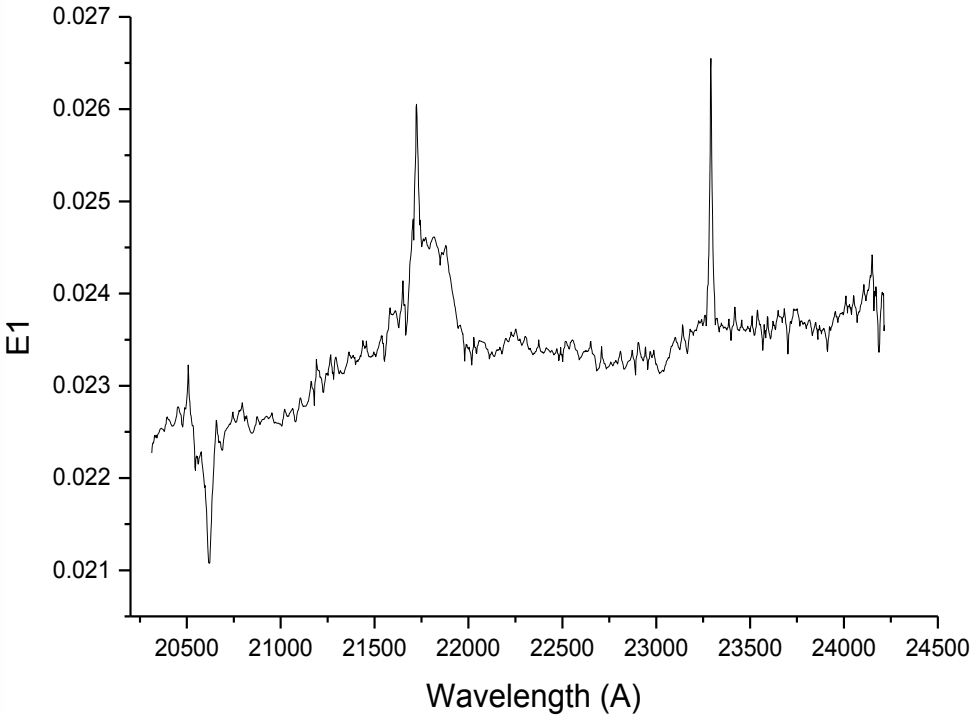


- The LINER is viewed directly through the disc, reddened by dust.
- The same LINER is reflected by the clouds in the ionization cone.
- We predict that the blue component has polkarized light polarized.

NGC 4151 NIFS data (Storchi-Bergmann et al 2009)

-Re-sample the data to a pixel of 0.021”
-Butterworth filter in Fourier space to remove high spatial frequencies
-Tomogram 1 can be used as a reliable PSF of the AGN (point source)
-It can be used to deconvolve the data cube
-Strehl ratio before deconvolution = 0.05
-Strehal ratio after deconvolution = 0.15





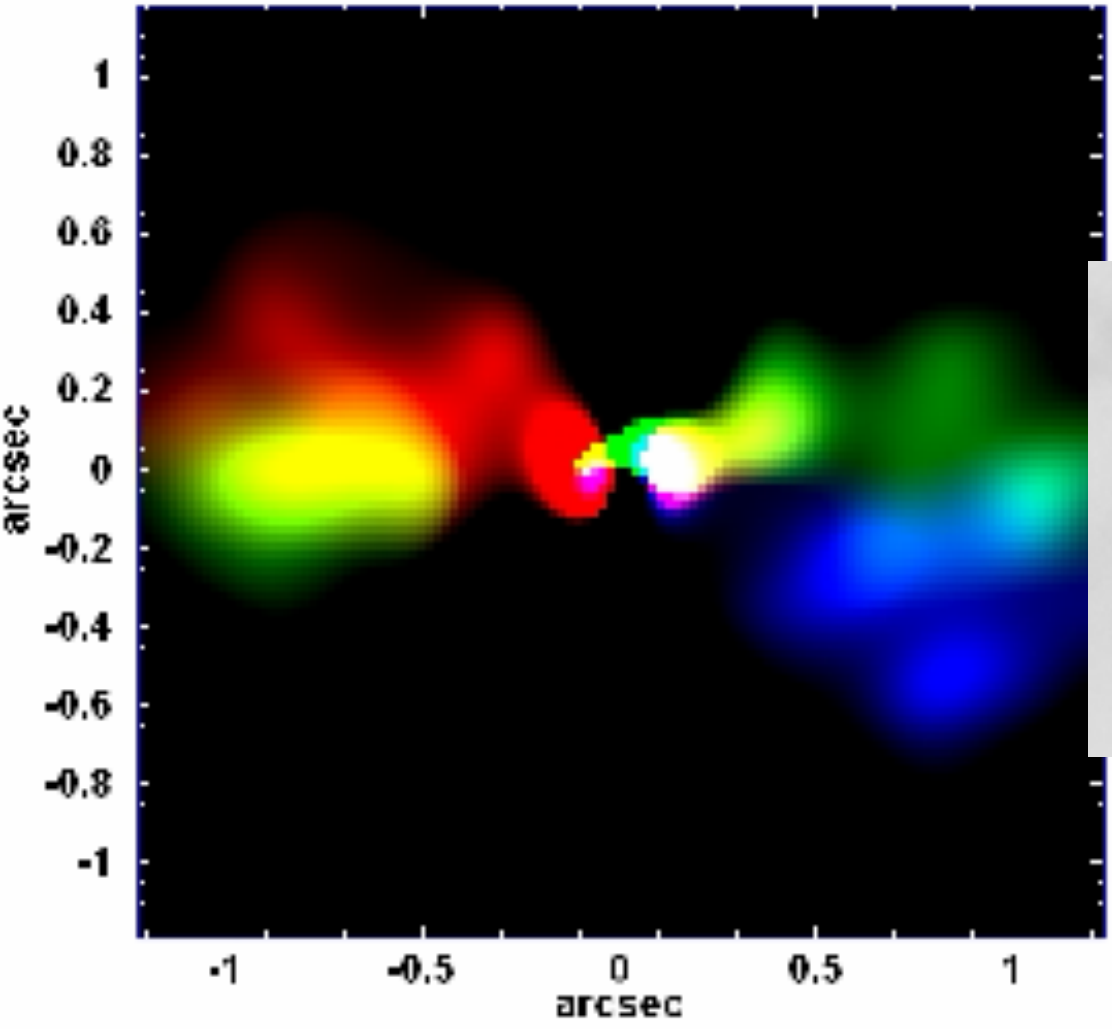
Feature supression and enhancement

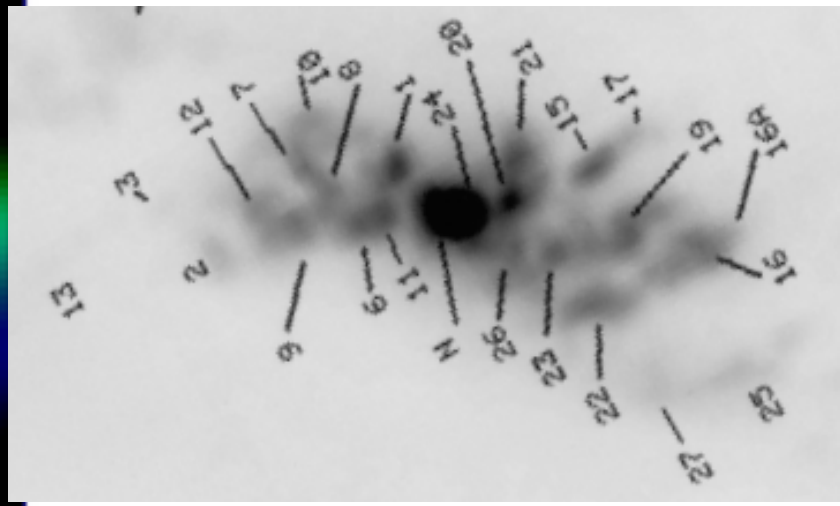
- Defining an object “A”: $\Gamma_k(A) = 1;0$
- Cube with enhanced feature: $I'_{ij\lambda}(A) = \sum_k \left[\left(I'_{ij\lambda}(k) \right) \cdot \Gamma_k(A) \right]$
- Or directly $I'_{\beta\lambda}(A) = T_{\beta k} \cdot \left[\left(E_{\lambda k} \right)_\Gamma \right]^T$

NGC 4151-NIFS observations (Storchi-Bergmann et al 2009)

“software coronagraph”
Br γ after switching-off PC1+PC2

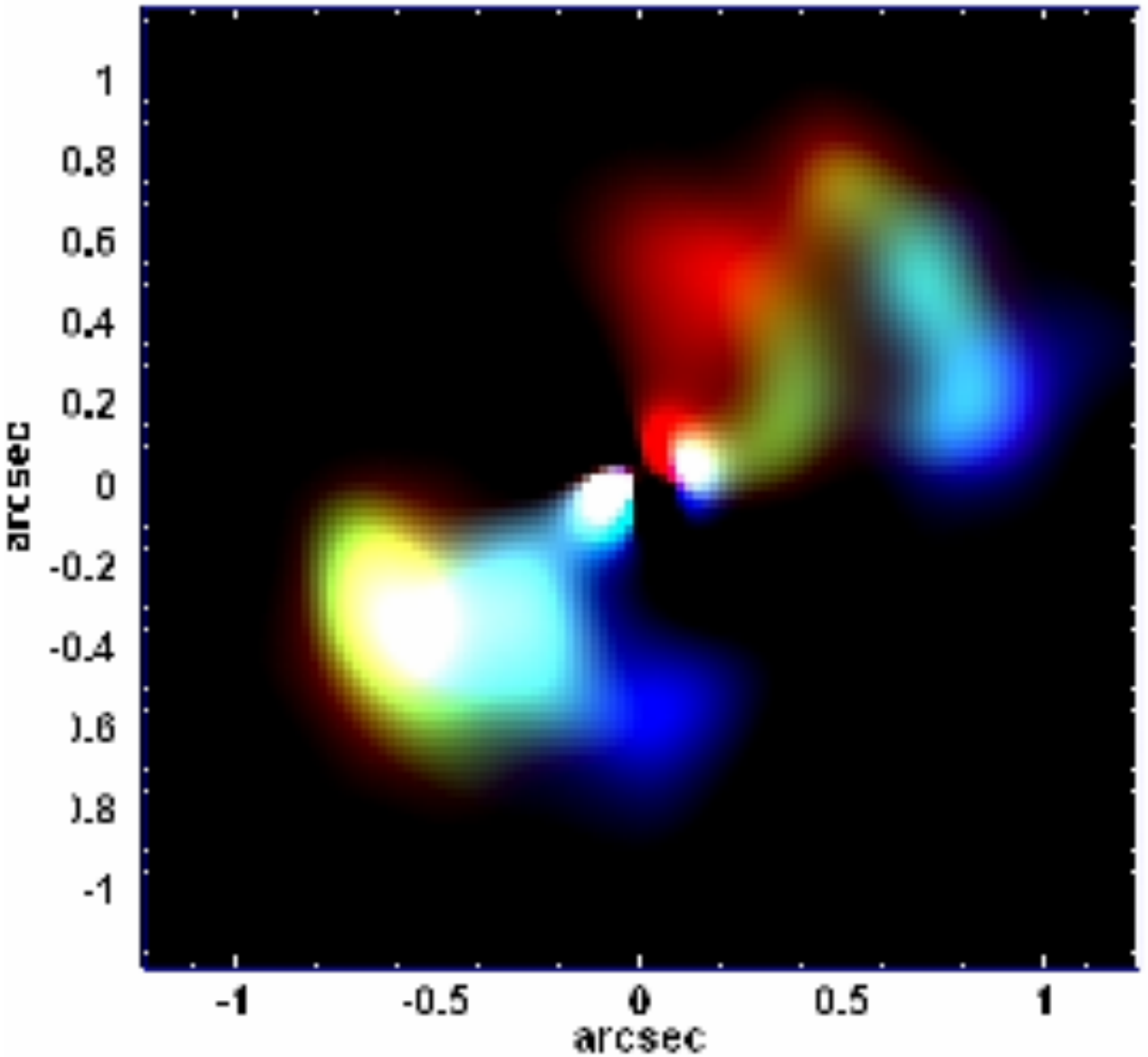
HST observations





NGC 4151 – NIFS observations (Storchi-Bergmann et al 2009)

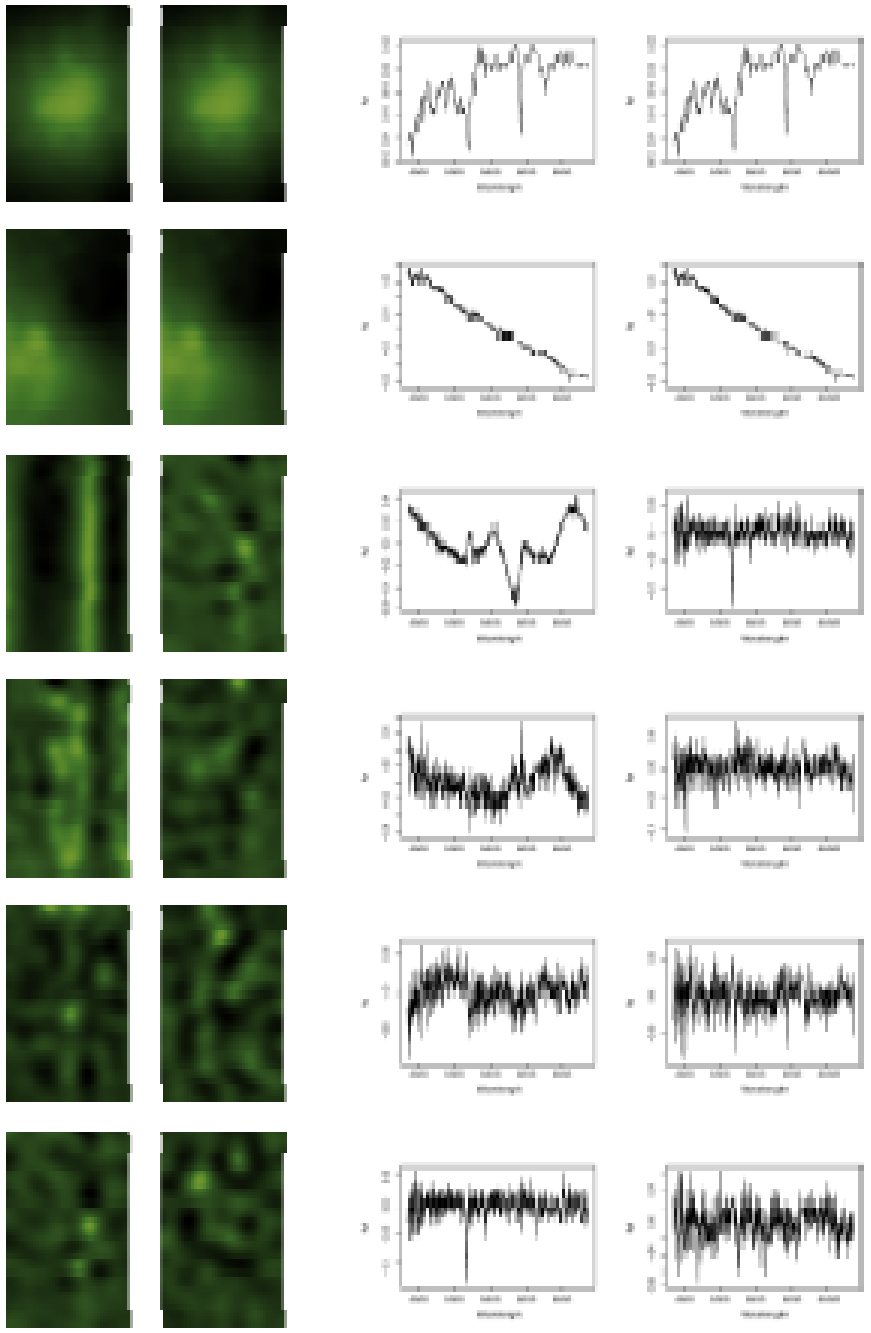
H2 lines – after switching-off PC1+PC2

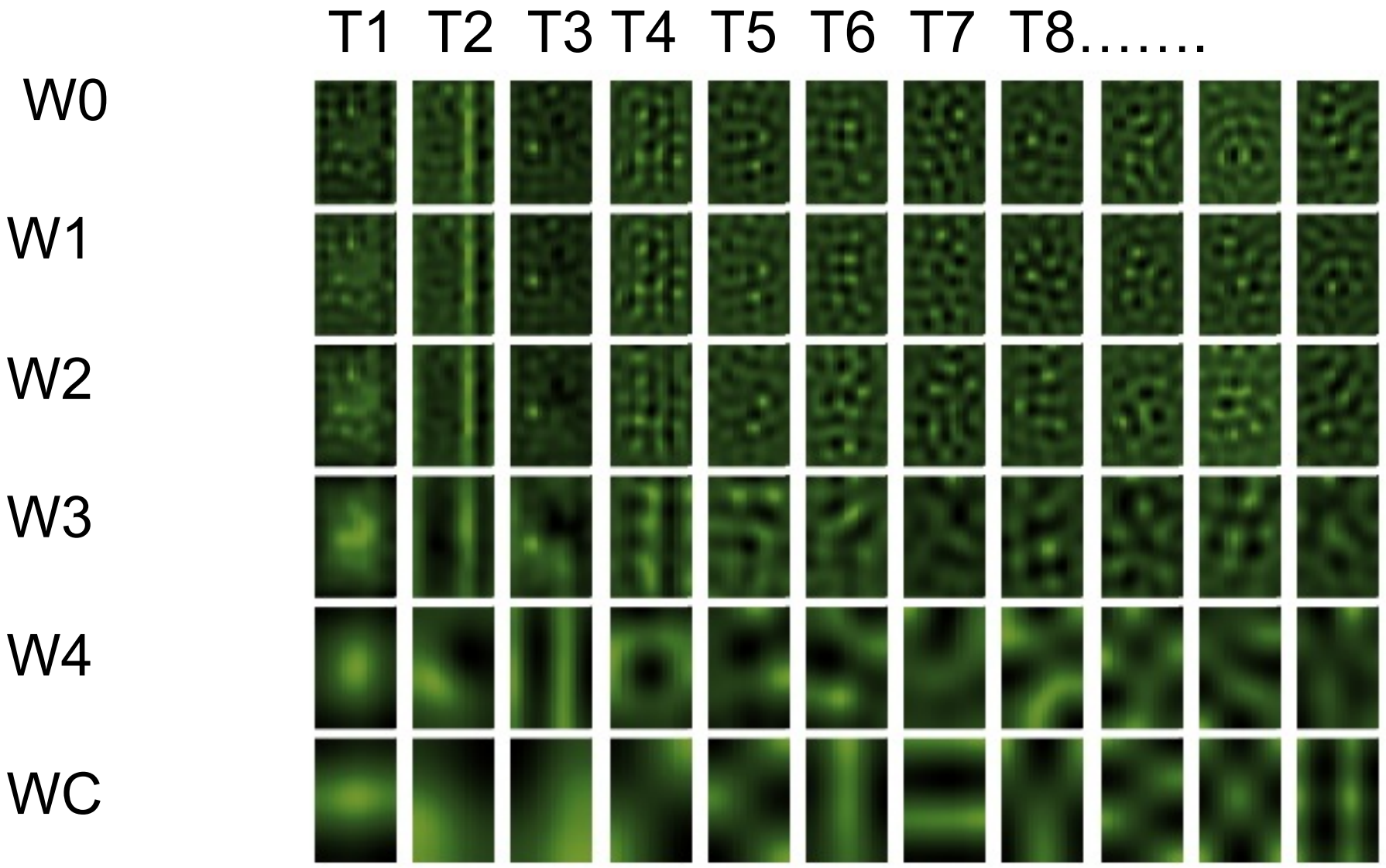


NGC 1399

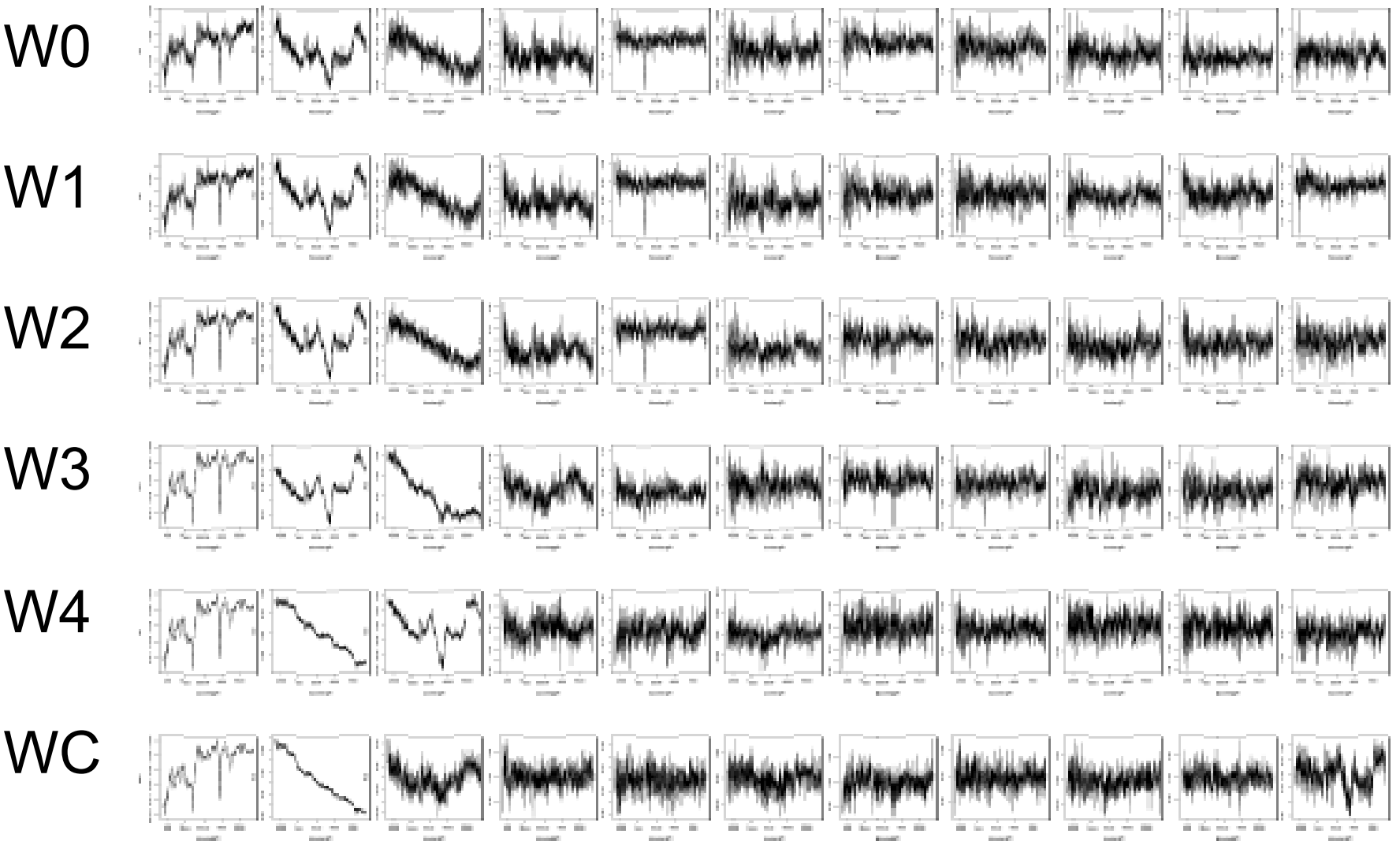
GMOS IFU

Instrument “fingerprint”




T1 T2 T3 T4 T5 T6 T7 T8.....
W0
W1
W2
W3
W4
WC

E1 E2 E3 E4 E5 E6 …….



Steiner et al (2009) MNRAS 395, 64

Relevant software can be found at
WWW.astro.iag.usp.br/~pcatomography