Outflow morphology in the active galactic nucleus of Circinus galaxy

PROMIS project BOWIE, PI Marko Stalevski

Science Fund
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ASTRONOMICAL OBSERVATORY

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Kakkad et al., 2023, MNRAS, 519, 5324

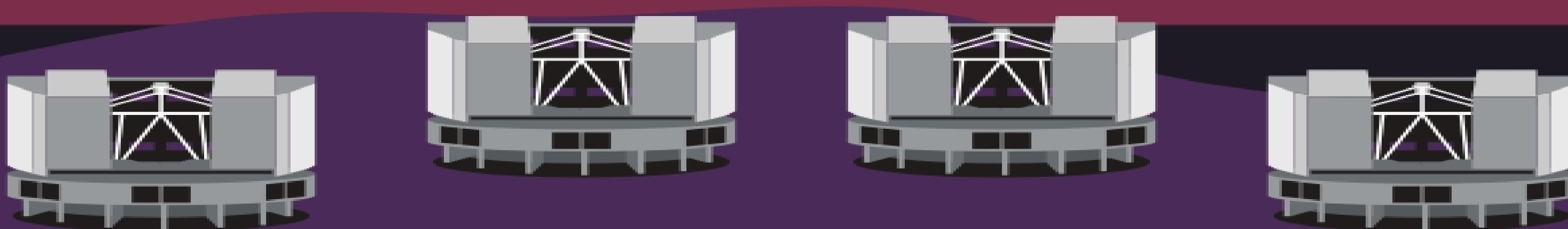
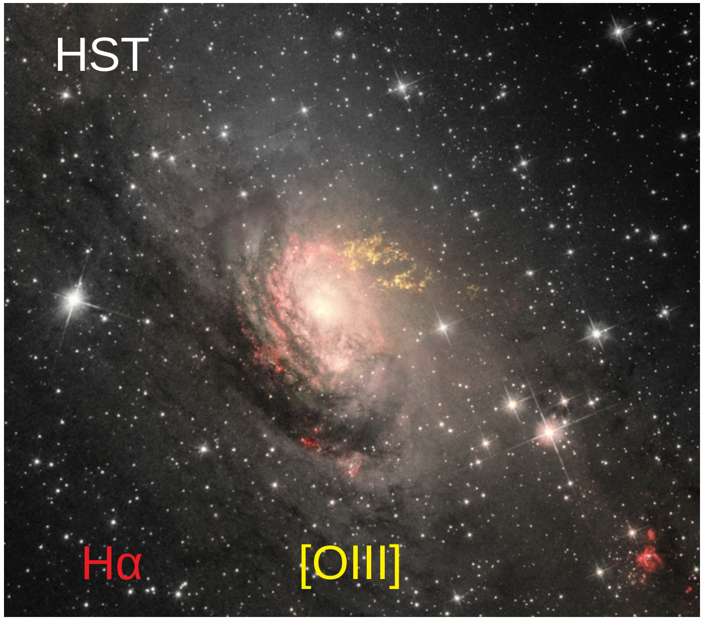


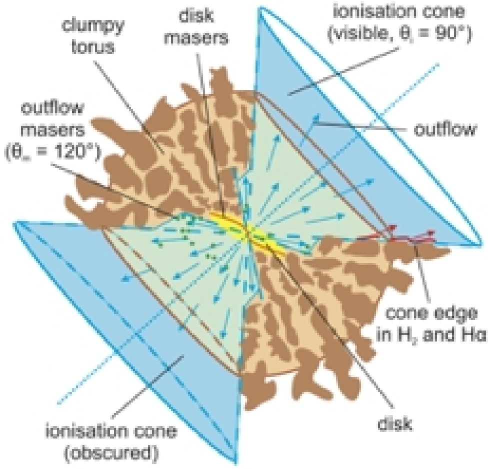
Illustration: Monika Lang

Circinus galaxy

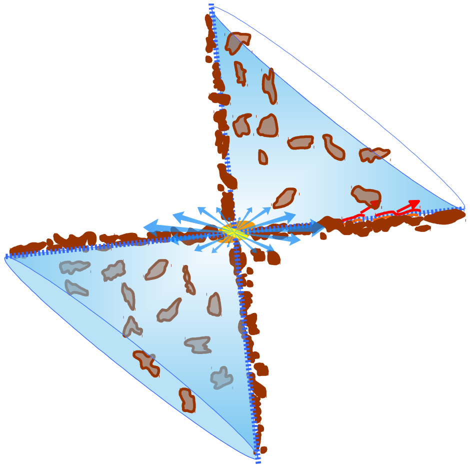


Credit: Schmidt J.

Equatorial torus-like dust model **VS** Polar dust wind model



Credit: Tristram K.

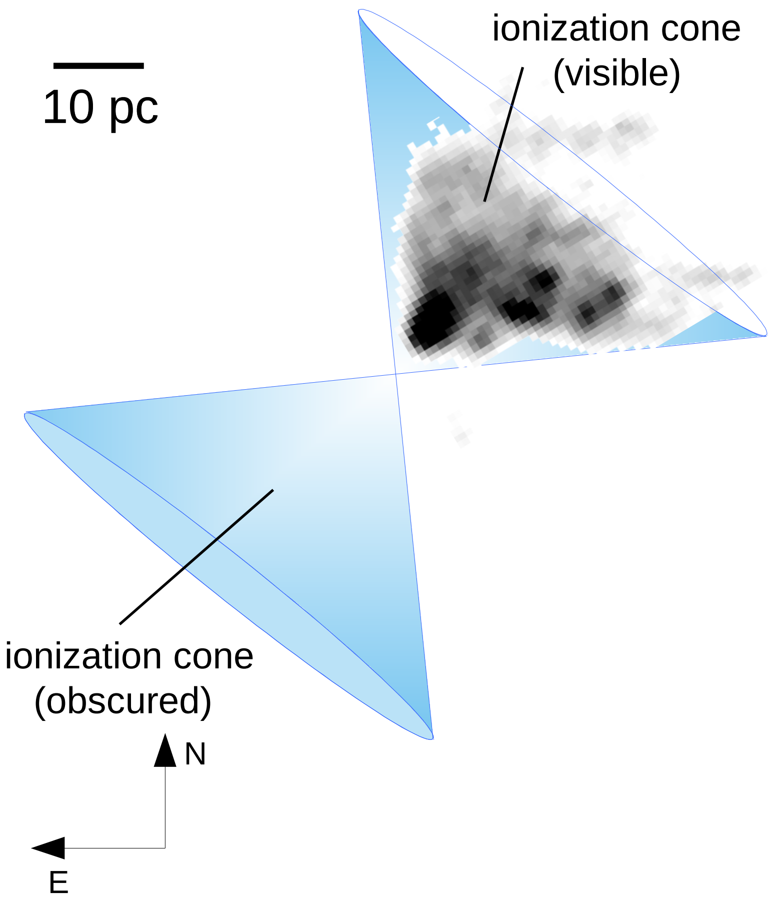


Credit: Stalevski M.

- Distance: 4.2 Mpc
- Closest Seyfert 2 galaxy.
- Circinus inclination of 65°.
- Best candidate to disentangle and understand polar dust and gas structure in AGN.

Circinus: a prototype for polar dust AGN population

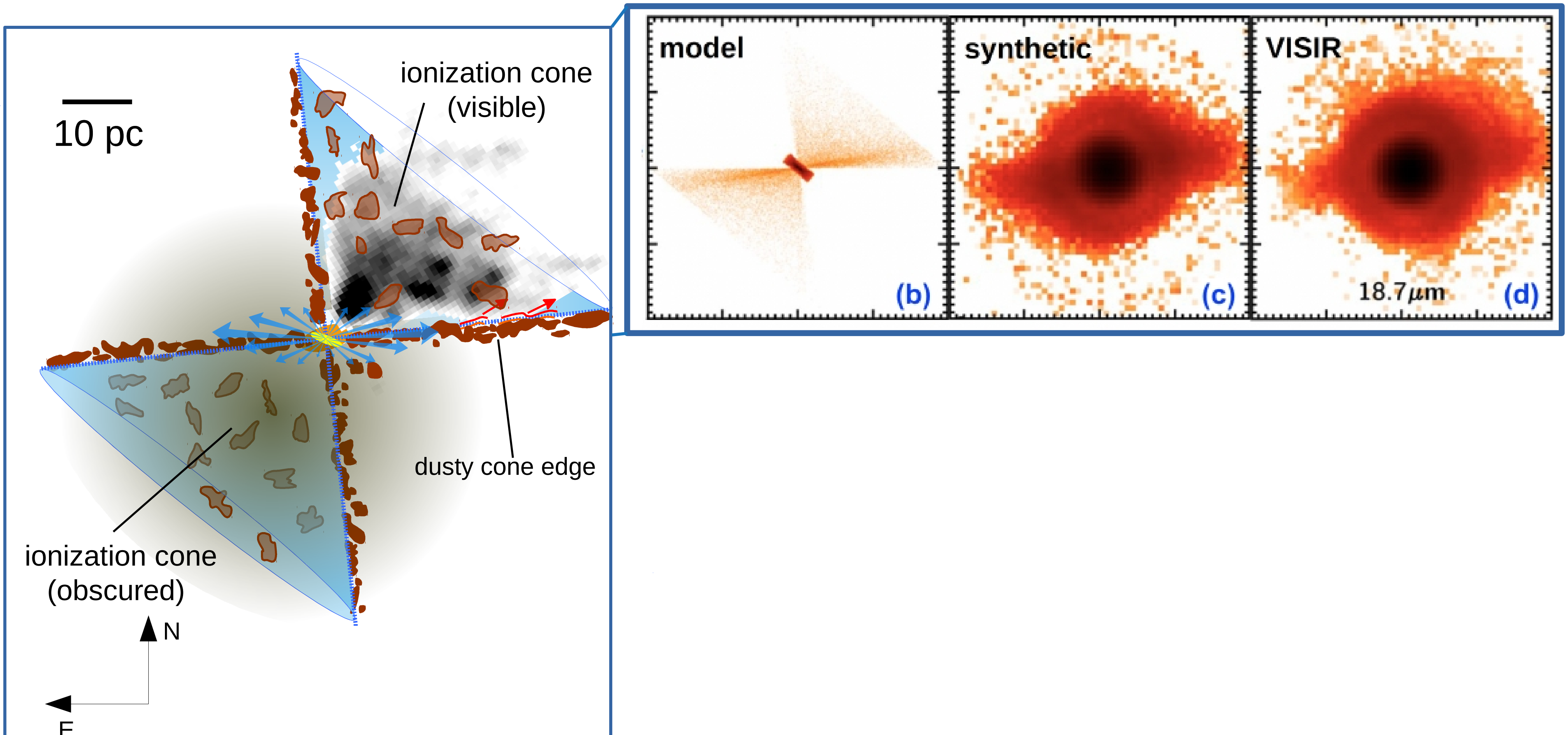
- Optical observations (HST, MUSE WFM): a one-sided and a wide-angled kpc-scale ionization cone traced by [OIII] λ5007 (Wilson et al., 2000, ApJ, 120, 1325; Mingozzi et al., 2019, A&A, 622, A146).



Circinus: a prototype for polar dust AGN population

- IR observations (Polar emission dominating the total IR budget of the AGN):

i. VLT/VISIR (~40 pc): polar IR emission in the form of a thin bar along the edge of the ionization cone (Asmus et al., 2016, ApJ, 822,109).



Circinus: a prototype for polar dust AGN population

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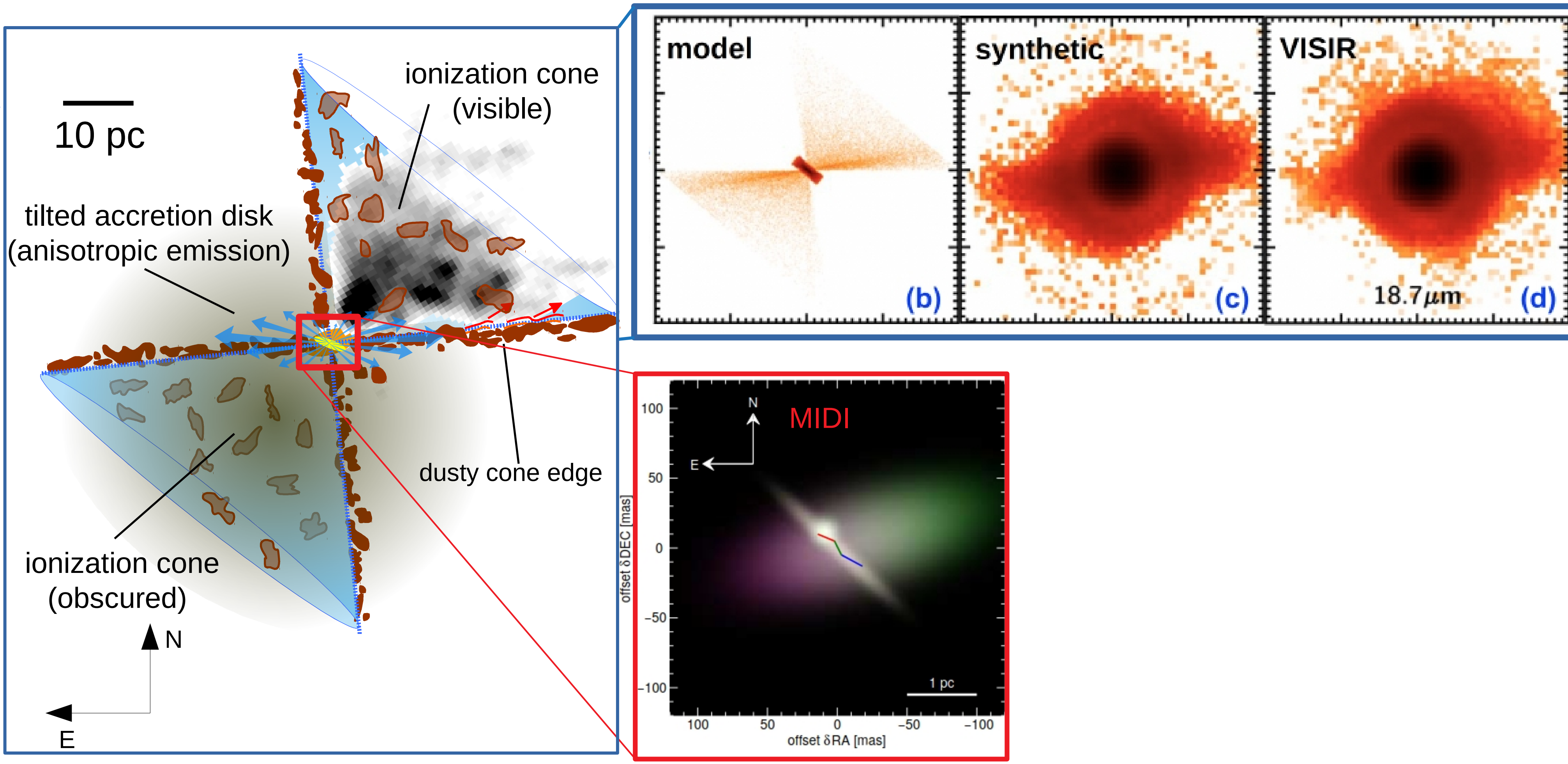
i. VLT/VISIR (~40 pc): polar IR emission in the form of a thin bar along the edge of the ionization cone (Asmus et al., 2016, ApJ, 822,109).

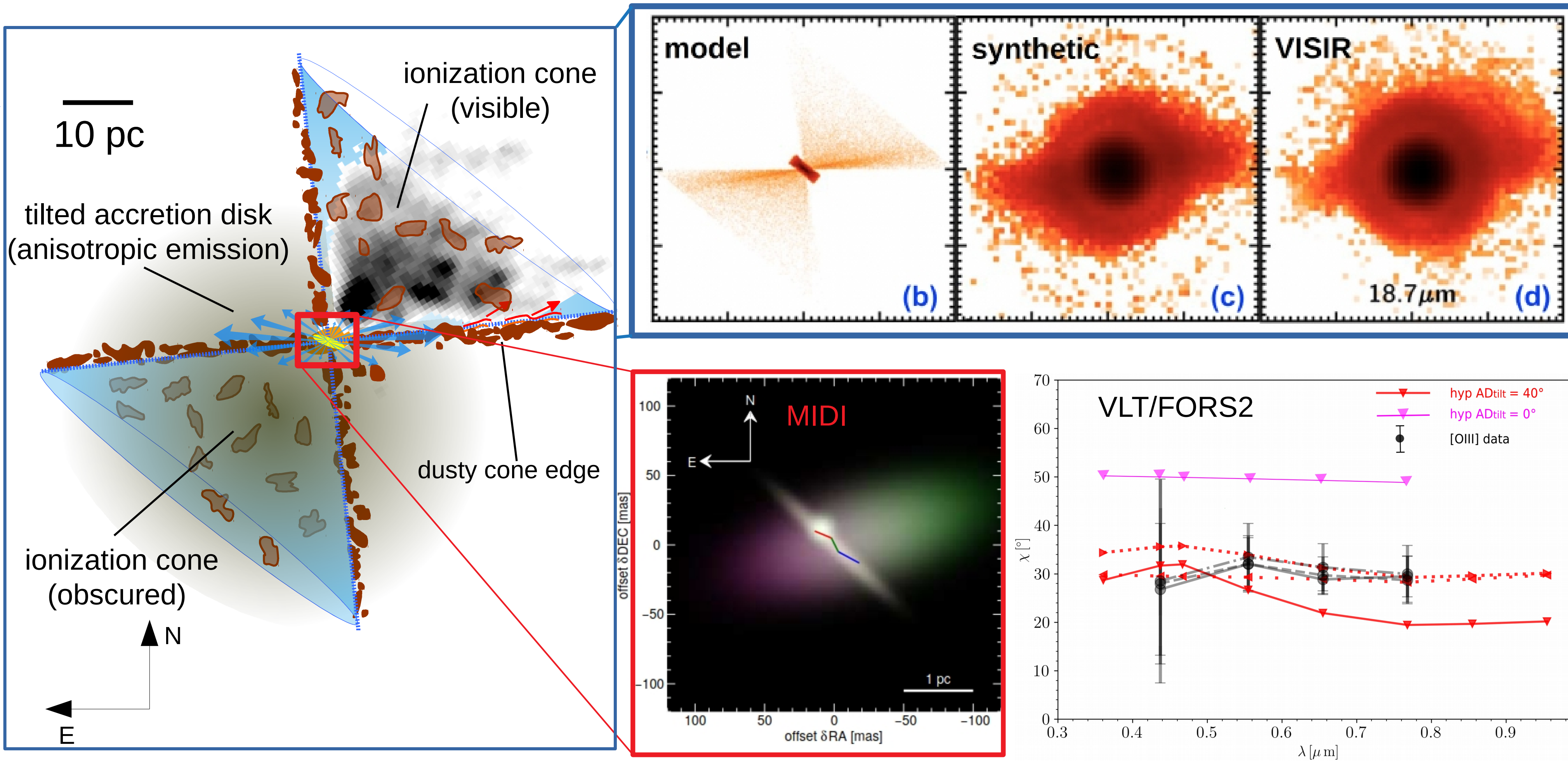
ii. VLTI/MIDI (pc-scale): thin edge-on disk in the equatorial plane (dusty extension of the accretion disk) and a larger polar-elongated structure (Tristram et al., 2014, A&A, 563, A82).



Circinus: a prototype for polar dust AGN population

- VLT/FORS2 polarimetry (Stalevski et al., 2023, MNRAS, 519, 3237): dusty cone (hyperboloid with an half-opening angle of 40°) illuminated by a tilted accretion disk (R~3pc, geometrically thin – width ~ 5°).

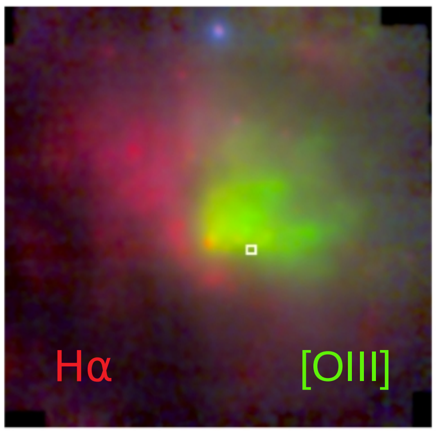
- 3D radiative trasfer modelling (Stalevski et al., 2017, MNRAS, 472, 3854; 2019, MNRAS, 484, 3334): all observations can be explained with a **dusty wind forming a hollow cone which is anisotropically illuminated by the tilted accretion disk**.



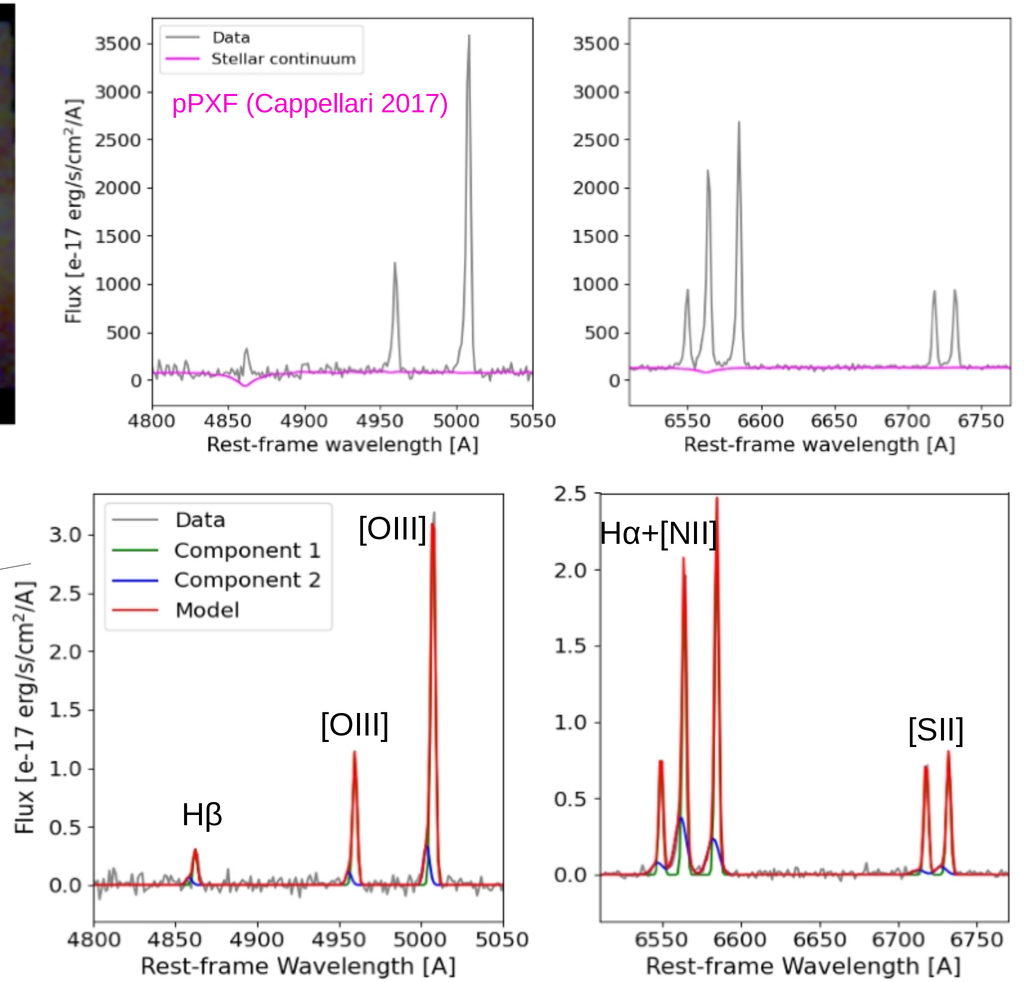
Dissecting the Circinus with VLT/MUSE-NFM

- Observations with AO, on-source ~ 1.1h ; FoV: 7.5”x7.5”
- Spatial sampling 0.025” and spatial resolution (PSF) 0.1” (~ 2pc)
- Spectral coverage 4800 – 9300Å, spectral resolution ~ 150km/s (at [OIII] λ5007)

MUSE NFM



Kakkad et al. (2023)



continuum subtracted data

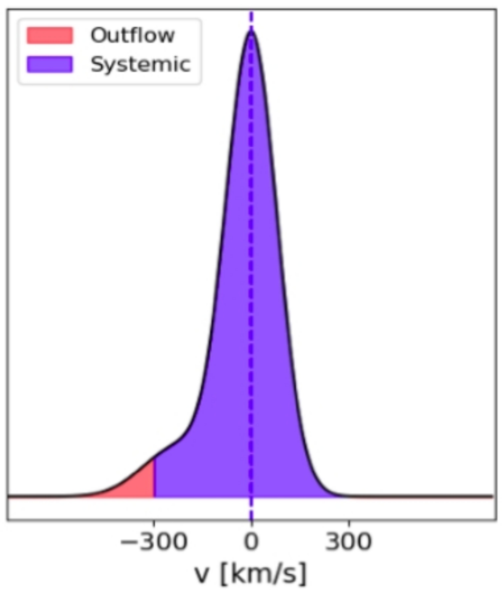
Fitting 1 or 2 Gaussians:
[OIII], [SII], [NII], Hα, Hβ.

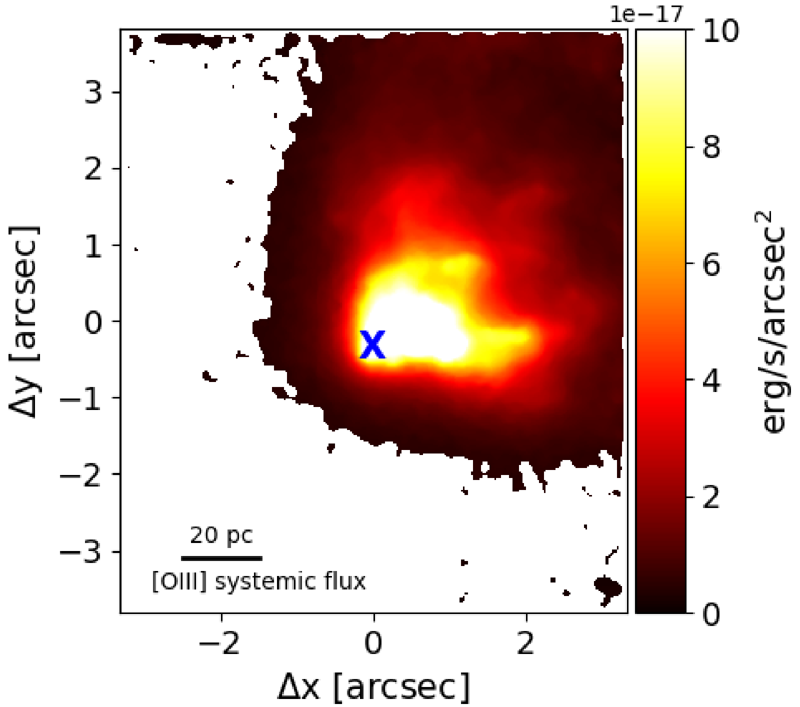
Analysis & Results

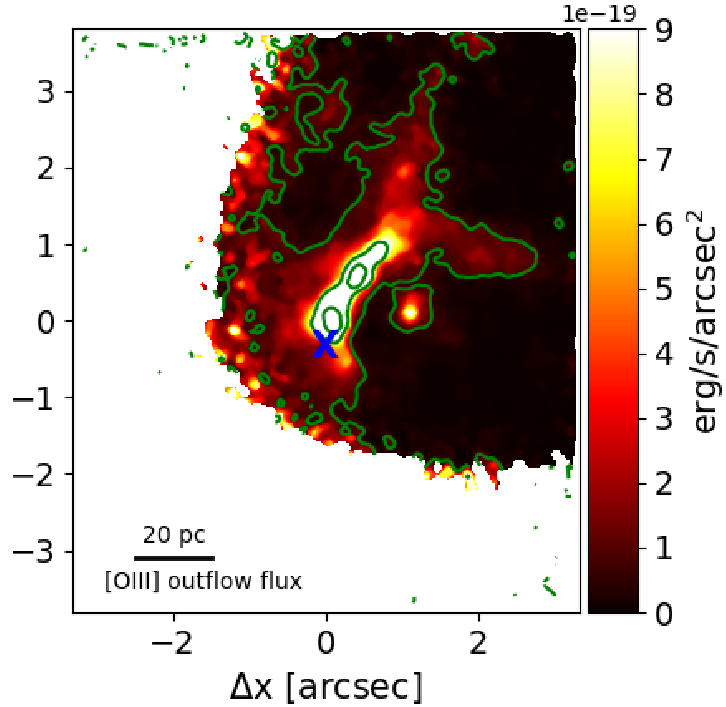
- Non-parametric analysis:

a) systemic flux (|v| < 300 km/s) & outflow flux (|v| > 300 km/s);
b) v10 = blue-shifted velocity containing 10% of the overall line flux;
c) w80 = width containing 80% of the line flux.

- AIM: mapping the morphology and kinematics of the ionized gas, tracing the dust extinction, determining the dominating source of ionization.

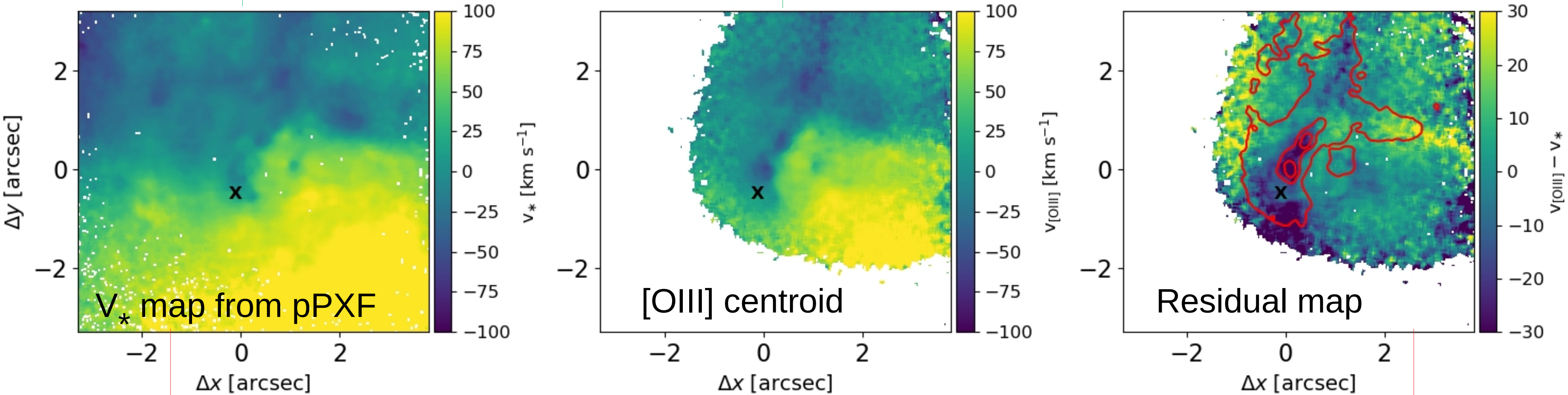






Velocity maps

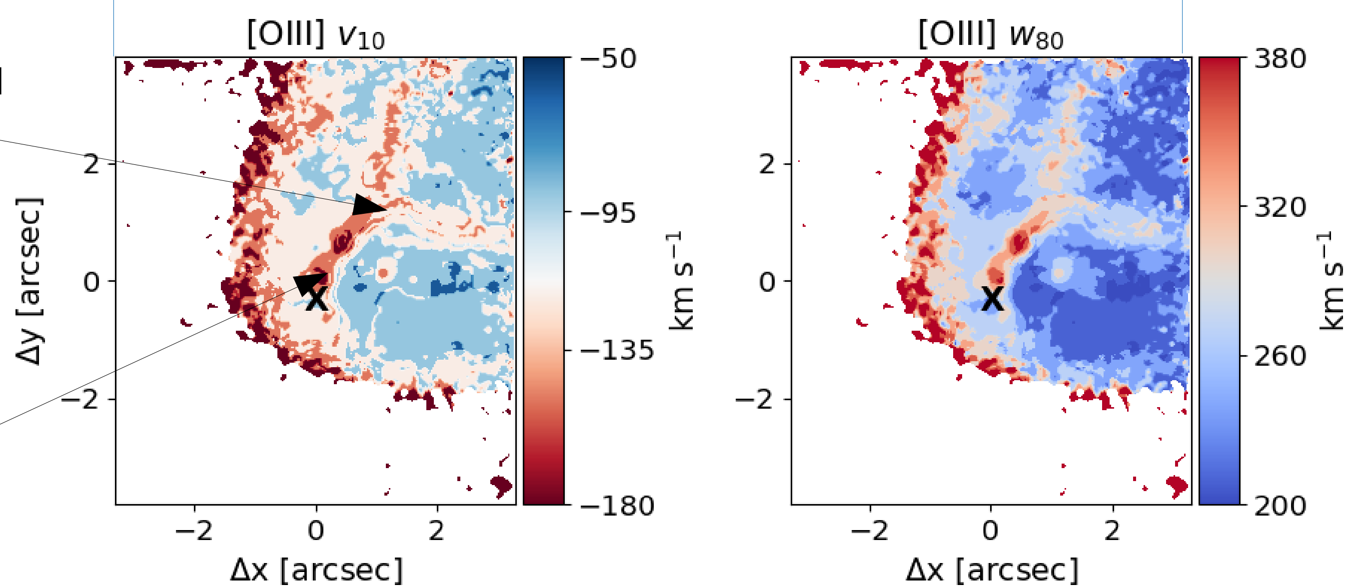
The ionized gas co-rotates with the host galaxy.



The fork co-rotates with the host galaxy and the ionization cone.

Blue-shifted and high velocity collimated outflow.

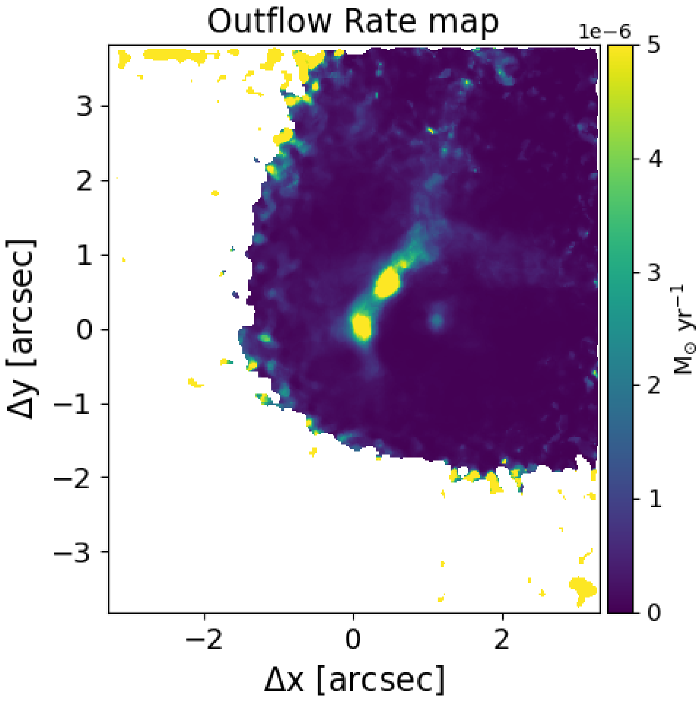
1.5” (30 pc) from AGN



0.4”(8 pc) from AGN

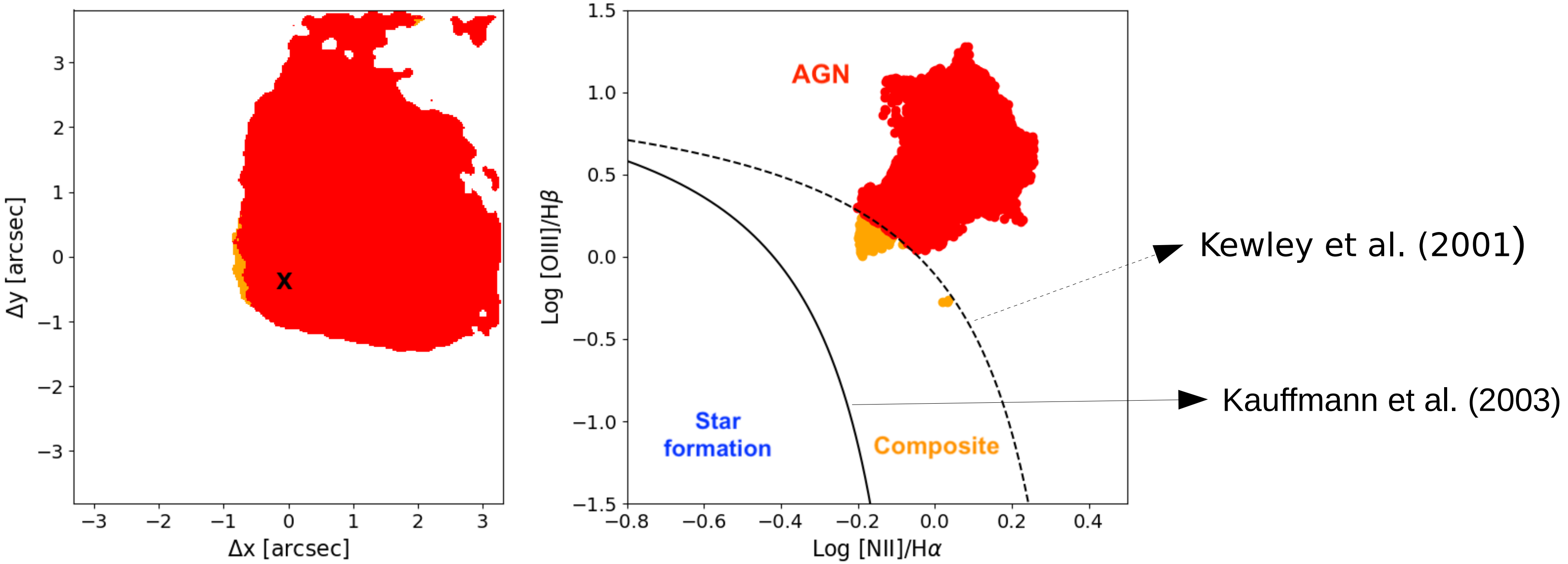
Mass outflow rate

- Derived from [OIII] λ5007.
- Instantaneous mass outflow rate: $M_{inst} = \Sigma_{pix} M_{out} v_{out} / \Delta R = 0.01\ M_{\odot} yr^{-1}$
- Time-averaged mass outflow rate: $M_{Tavg} = M_{tot\_out} \langle v_{out} \rangle / R = 10^{-4}\ M_{\odot} yr^{-1}$
- [SII] λ6716,6731 outflow flux ratio gives outflow density of ~ 200 cm^{-3} (median).



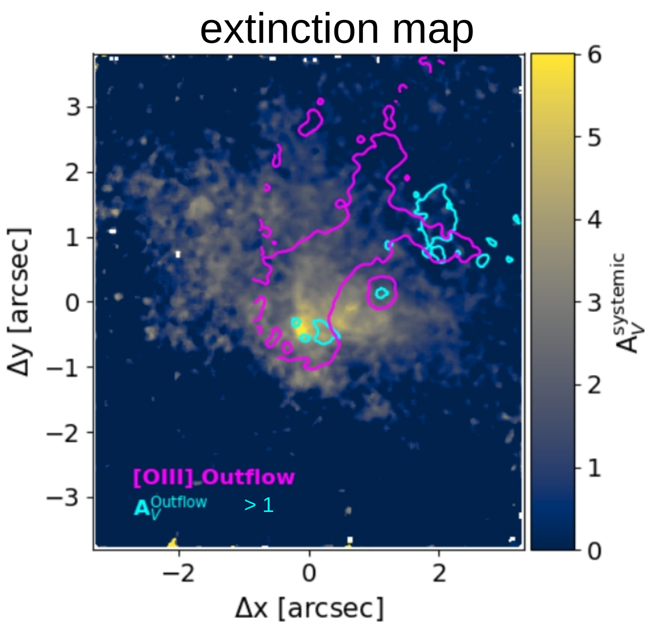
Star formation rate in Circinus 3-8 $M_{\odot} yr^{-1}$ (literature)
--> the observed ionized outflow not expected to shut down star formation in pc scale.

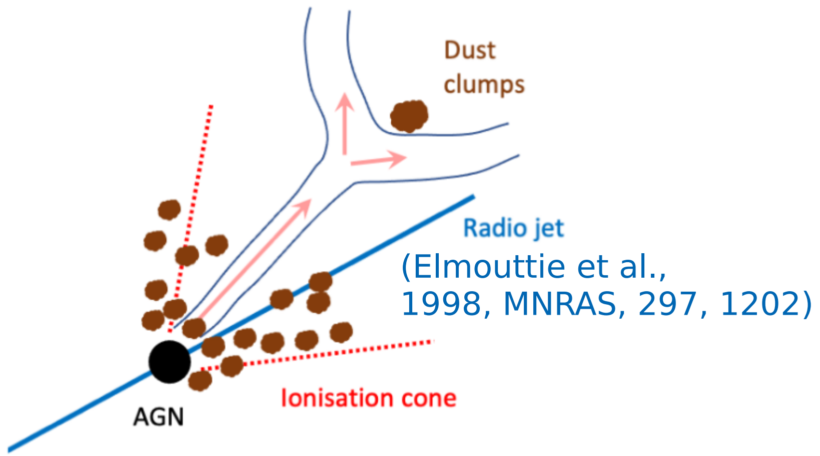
Baldwin, Phillips & Terlevich (BPT) diagram



- AGN is the dominant source of ionization.
- Ionization by star formation (SF) is negligible.
- Current observations show no evidence of outflows triggering SF activity in the vicinity of the AGN.

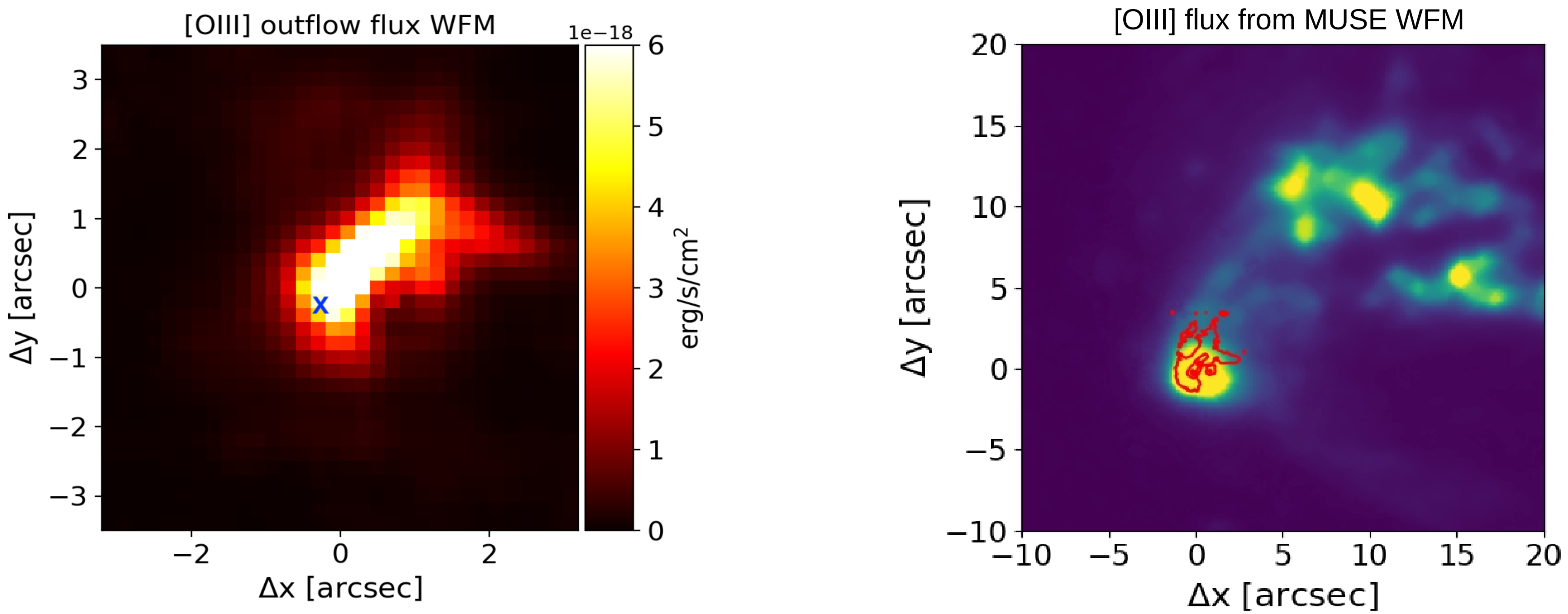
Dust extinction map





- Dust extinction map derived from Balmer decrement.
- Assumed Calzetti et al. (2000) dust attenuation law with R_V=4.05 and T_e=10 000K (typical for NLR).
- A_V systemic reveals conical morphology.
- The origin of the collimated outflow could be due to a pc-scale radio jet that changes direction as it propagates through the ISM.
- The splitting of the collimated structure might be caused by a dust clump at this location.

Comparison to MUSE WFM observations



- Tuning fork not seen in MUSE WFM with lower spatial resolution ~ 0.5”.
- The origin of the kpc-scale filaments might be in the fragmented arms of the tuning fork.

Summary

- Presented **VLT/MUSE NFM** observations that **resolved the regions close to the AGN torus** (spatial resolution 2 pc).
- We derived the properties of the **ionized gas outflow using the [OIII] λ5007** emission line.
- **The systemic [OIII] flux shows conical morphology**. The ionized gas co-rotates with the host galaxy.
- **"Tuning fork" structure** seen for the first time in the flux distribution of the outflowing component of the [OIII], v10 and w80. **Outflow is blue-shifted**.
- **The ionized gas outflow is not expected to regulate star formation within a radius of ~100 pc** from the AGN location.
- Systemic Balmer decrement shows **the dust distribution concentrated along the ionization cone**, while the outflowing shows **a clump at the fragmentation site**.
- Possible origin of the collimated outflow: **small scale radio jet interaction with ISM.**

THANK YOU FOR YOUR ATTENTION.