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New insights into the study of the clumpy torus of AGN using near-infrared polarimetry

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SUMMARY

Attempting to estimate the magnetic field strength of the clumpy torus in AGN

Developing of a polarimetric model with several mechanisms of polarization

- Estimation of the extinction to the central engine of the AGN
- Estimation of the contribution of each mechanism of polarization

Estimation of the intrinsic polarization through the torus

Magnetic field strength of the torus can be estimated

Context

Torus of AGN

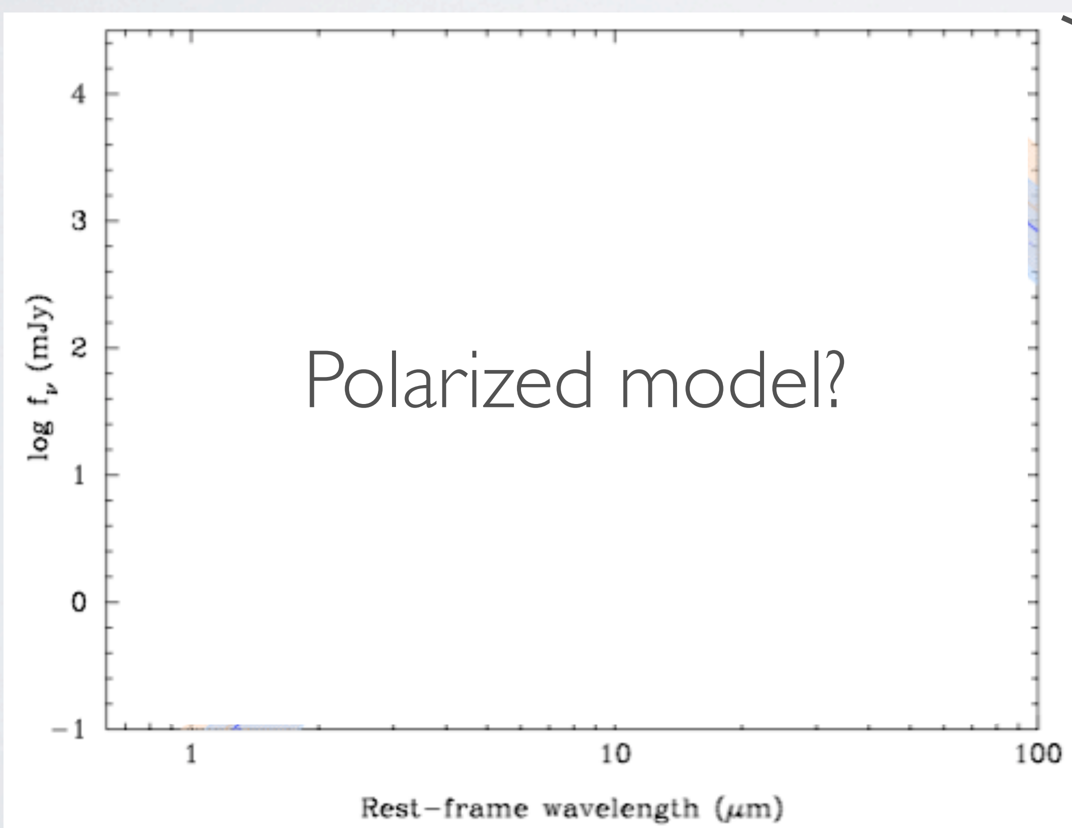
Optically and geometrically thick, clumpy and dusty torus Nenkova et al. (2008a,b)

Scales of a few ten parsecs Tristram et al. (2007) Jaffe et al. 2004, etc.

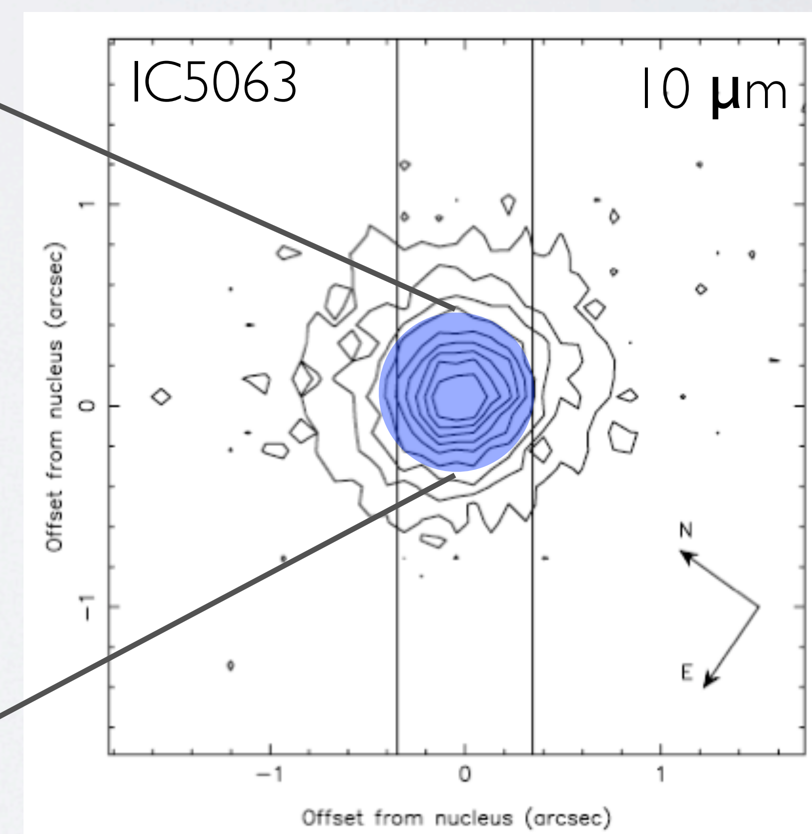
Isolate the torus from:
- Host galaxy
- Surrounding star formation

→ SED from high-spectral observations

Polarimetry



Alonso-Herrero et al. (2011)



Young et al. (2007)

NIR polarization of IC5063

IC5063

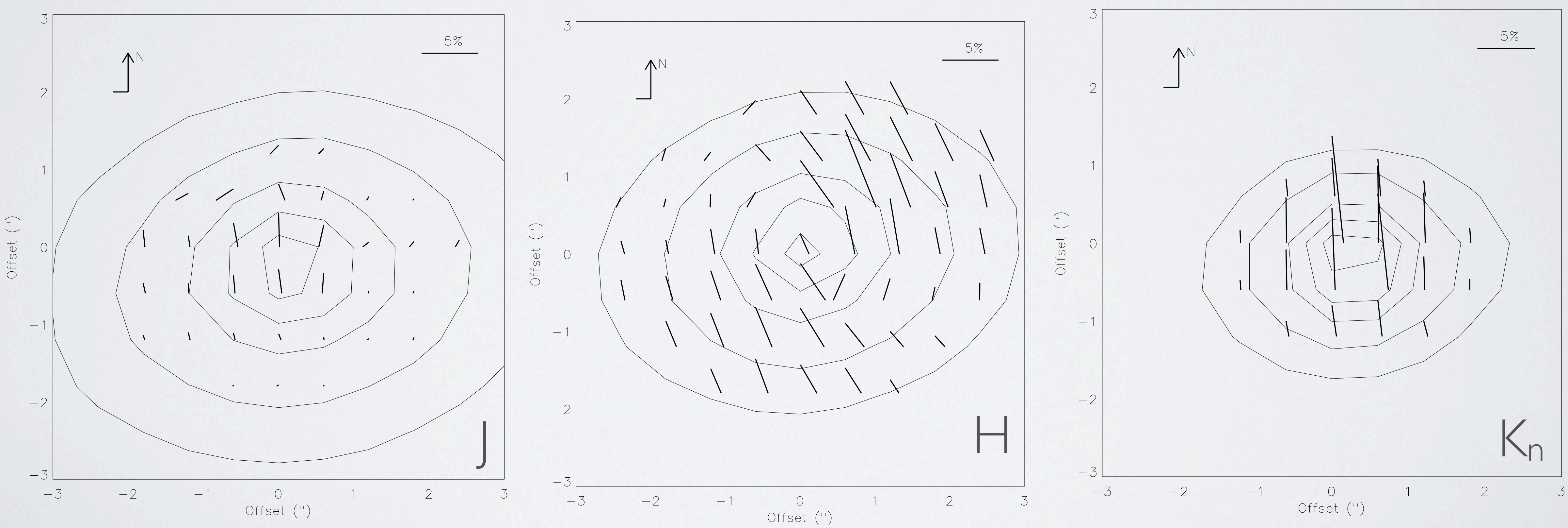
NIR polarimetry observations of IC5063

Observations on the 4-m AAT

Pixel scale 0.6''/px

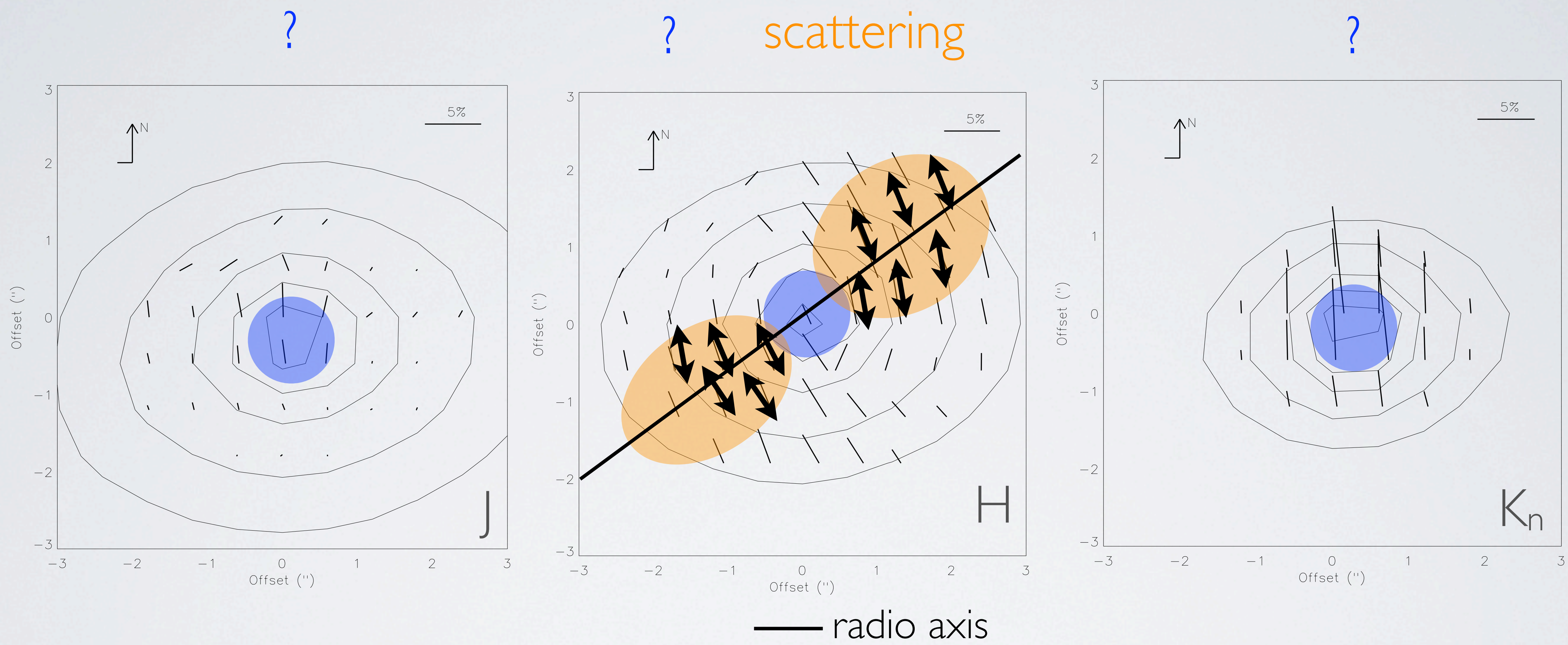
Standard NIR reduction

Stokes parameters, I, Q, U were obtained



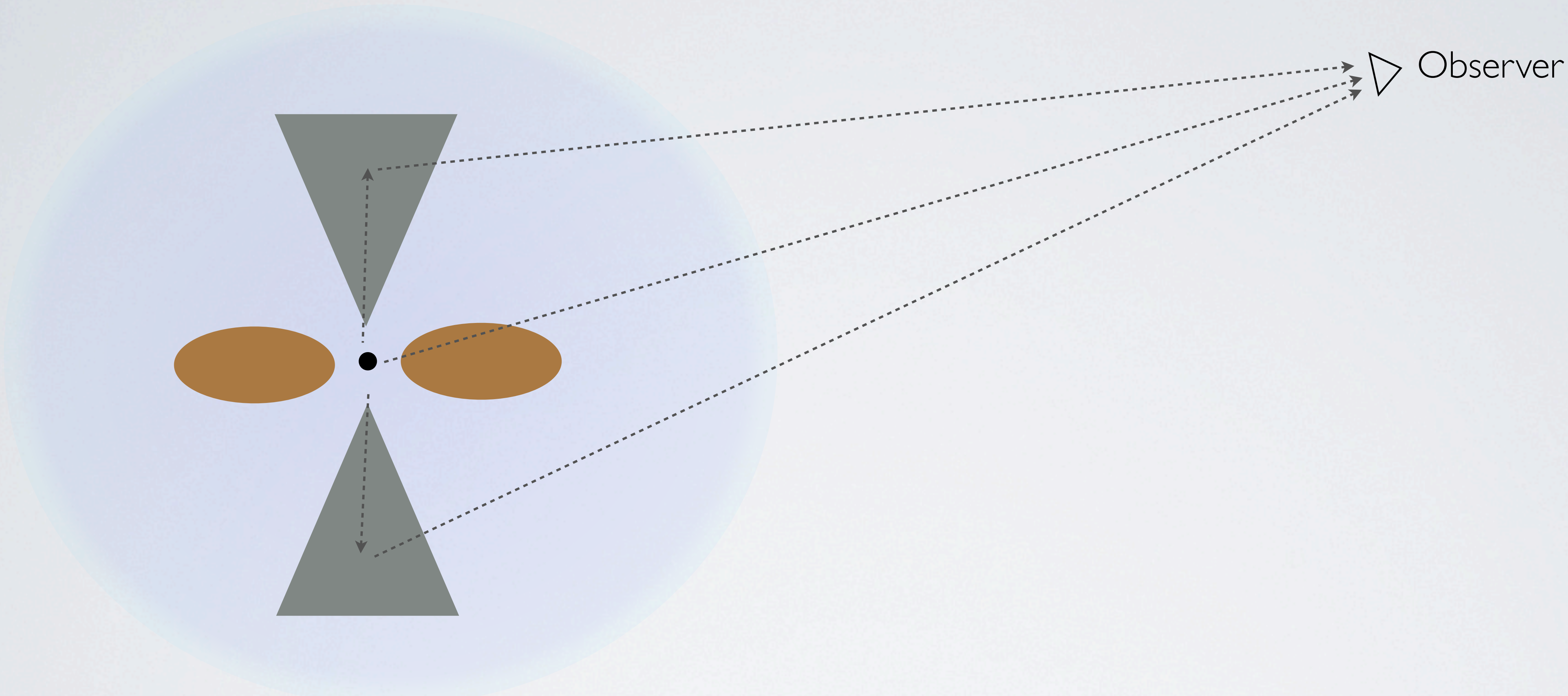
IC5063

Mechanisms of polarization



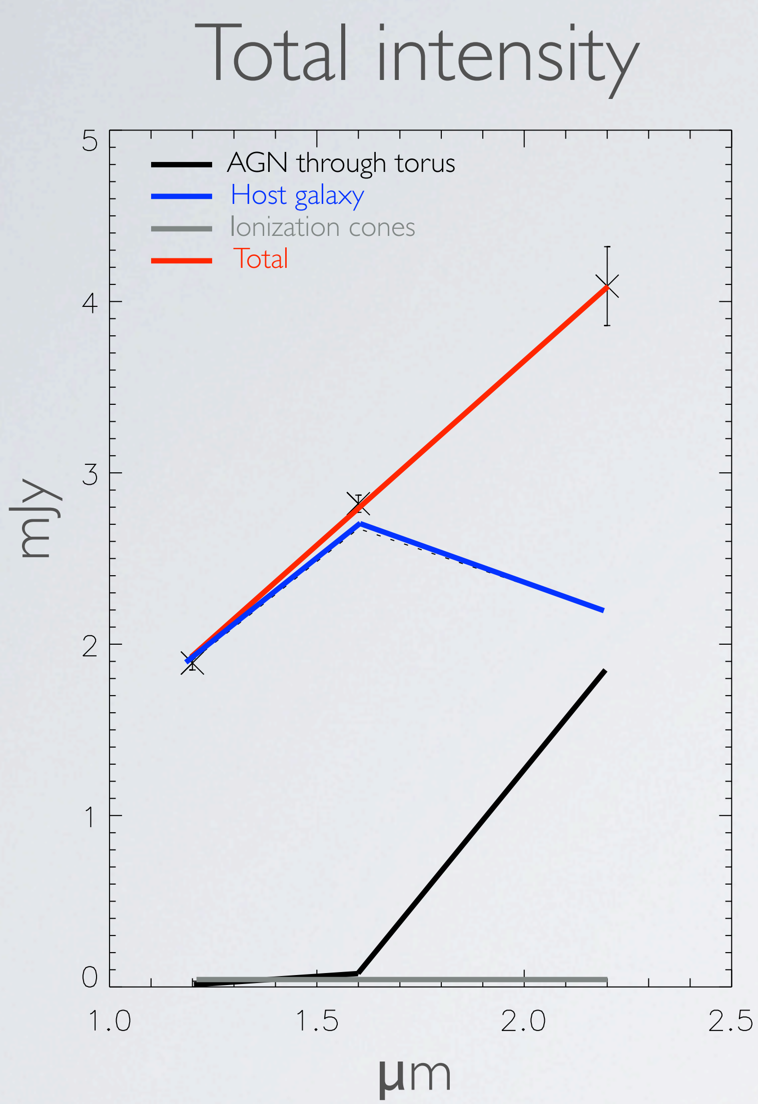
Polarization model

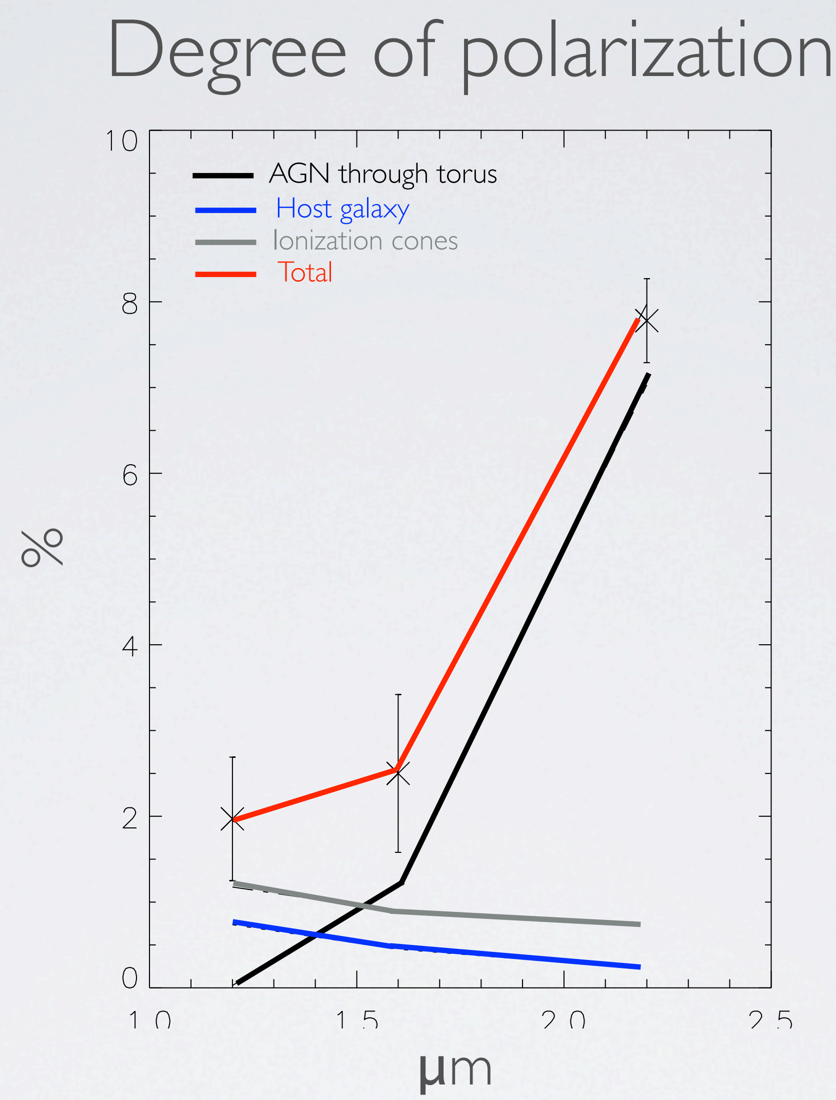
Polarization model

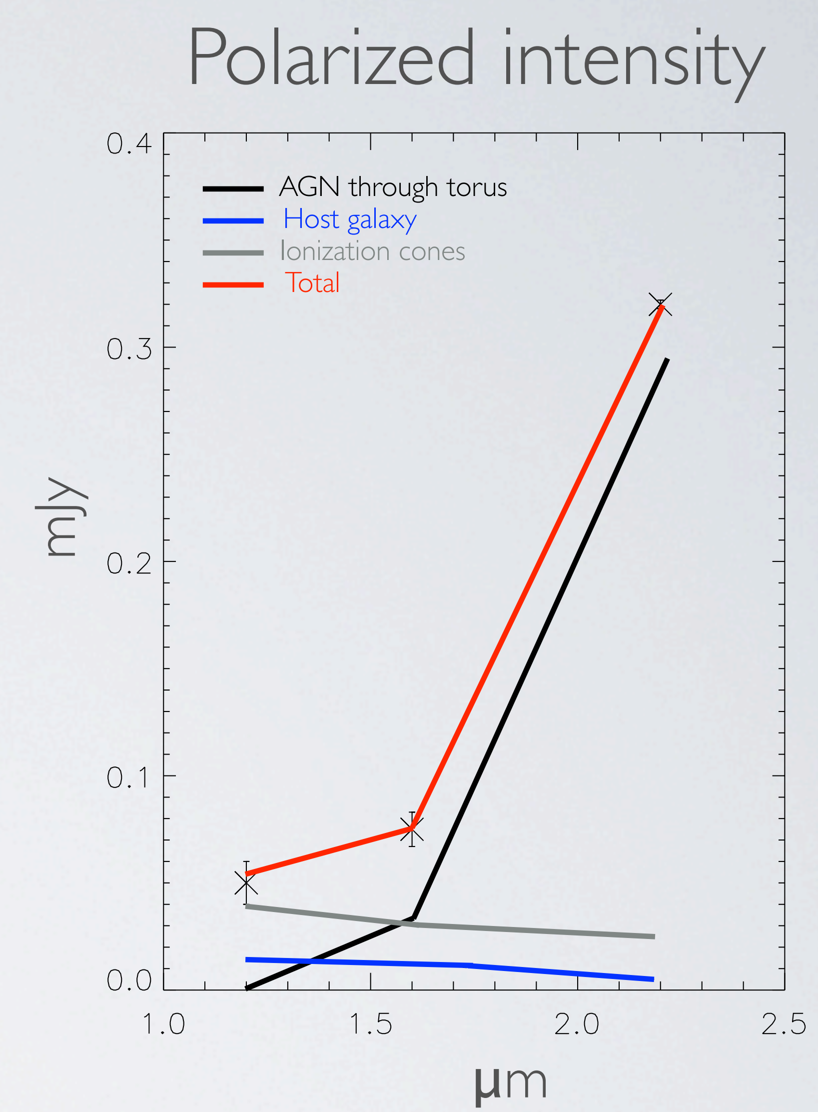


Central engine	Torus	Ionization cones	Host galaxy
unpolarized power-law	Dichroic absorption	Electron scattering	Dichroic absorption
$F_\nu \propto \nu^{-0.5}$	$P_\lambda \propto A_\lambda \times \lambda^{-\gamma}$	$P_\lambda = \lambda^0$	$P/P_{max} = \exp(-\ln(\lambda/\lambda_{max})^2)$
	Extinction: A_v(tor)		Extinction: A_v(gal)

Polarization Model







	Host galaxy	$A_V(gal) = 6 \pm 2$ mag.
Extinction	Torus	$A_V(tor) = 48 \pm 2$ mag.
	Total	$A_V = A_V(tor) + A_V(gal) = 54 \pm 4$ mag.

From literature:

Host galaxy	$A_V(gal) = 7$ mag.	Heisler & De Robertis (1999)
Total	$A_V = 64 \pm 15$ mag.	Simpson et al. (1994)

Intrinsic polarization

Observed polarization at K_n in a 1.2'' aperture $P_{obs} = 7.8 \pm 0.5$ %

Remove host galaxy and dust lane from observed degree of polarization

From PSF-subtraction the contribution of Starlight is 57 ± 3 %

AGN is 43 ± 3 %

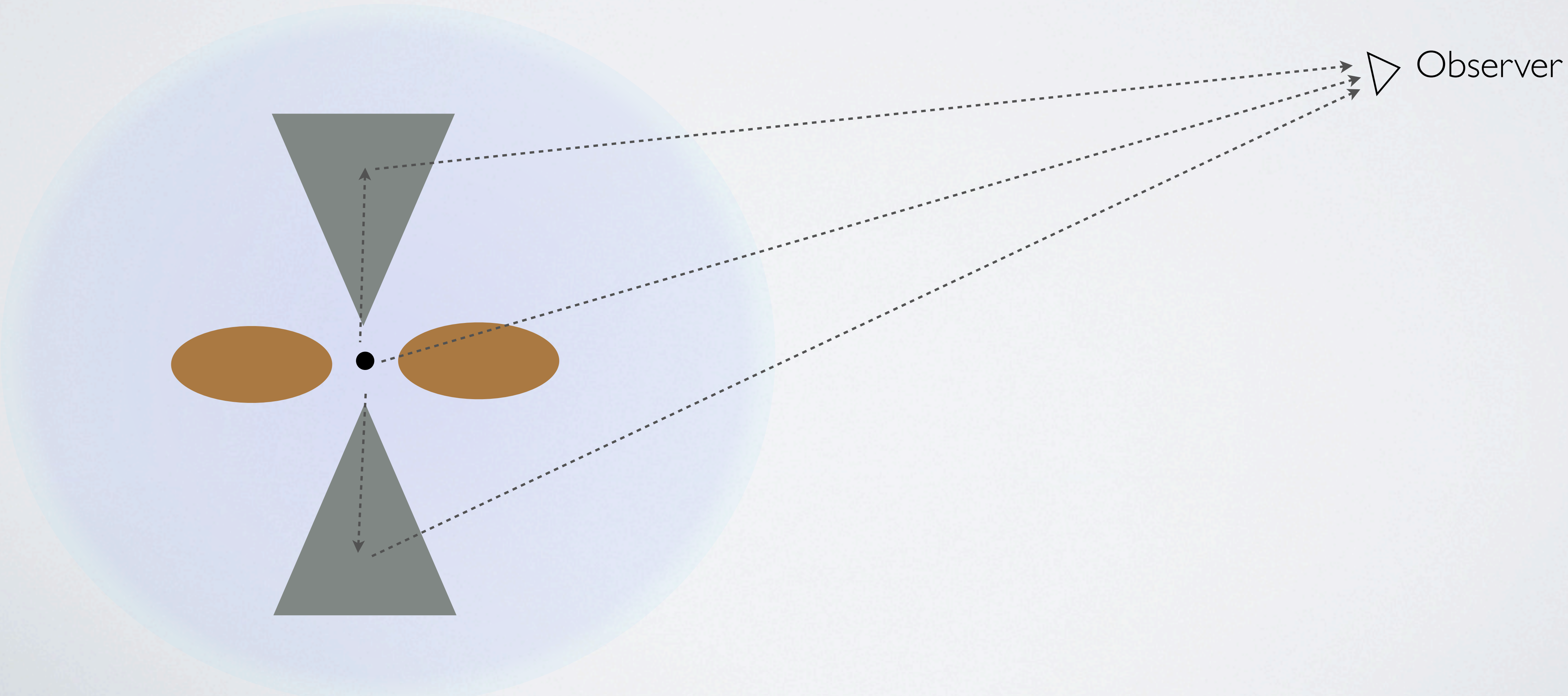
From polarization model 89% dichroic absorption through aligned dust grains within the torus

Intrinsic polarization in a 1.2'' aperture at K_n $\mathbf{P_{int} = 12.5 \pm 2.7}$ **%**

Total extinction to the AGN

Estimates of the extinction at several wavelengths

Method	Av (mag)
Polarization model	54 ± 4



Total extinction to the AGN

Method	Av (mag)
Polarization model	54 ± 4
NIR polarization	59 ± 5

Assuming polarization arises from dichroic absorption

$P_K = 2.23\ \tau_K^{3/4}$

$\tau_K = 0.09\ A_v$

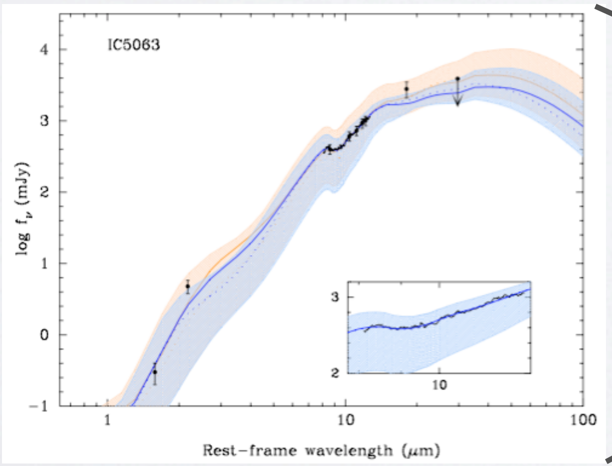
Jones (1989)

Total extinction to the AGN

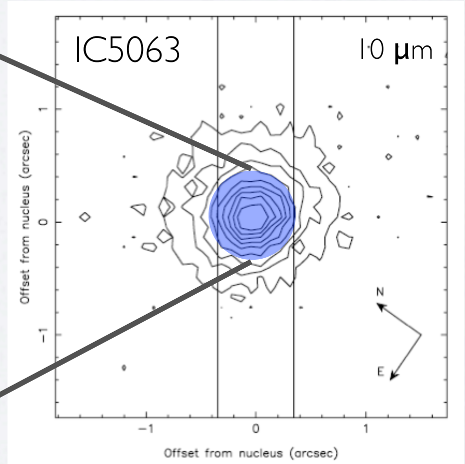
Method	Av (mag)
Polarization model	54 ± 4
NIR polarization	59 ± 5
Clumpy torus model	1800^{+200}_{-270}

Bayesian approach using NIR and MIR photometry and MIR spectra

Alonso-Herrero et al. (2011)



Alonso-Herrero et al. (2011)



Young et al. (2007)

Total extinction to the AGN

Method	Av (mag)
Polarization model	54 ± 4
NIR polarization	59 ± 5
Clumpy torus model	1800^{+200}_{-270}
X-Ray	131 ± 4

Assuming standard galactic ratio $A_V/N_H = 5.23\ 10^{-22}$ mag cm^2

Bohlin et al. (1978)

Total extinction to the AGN

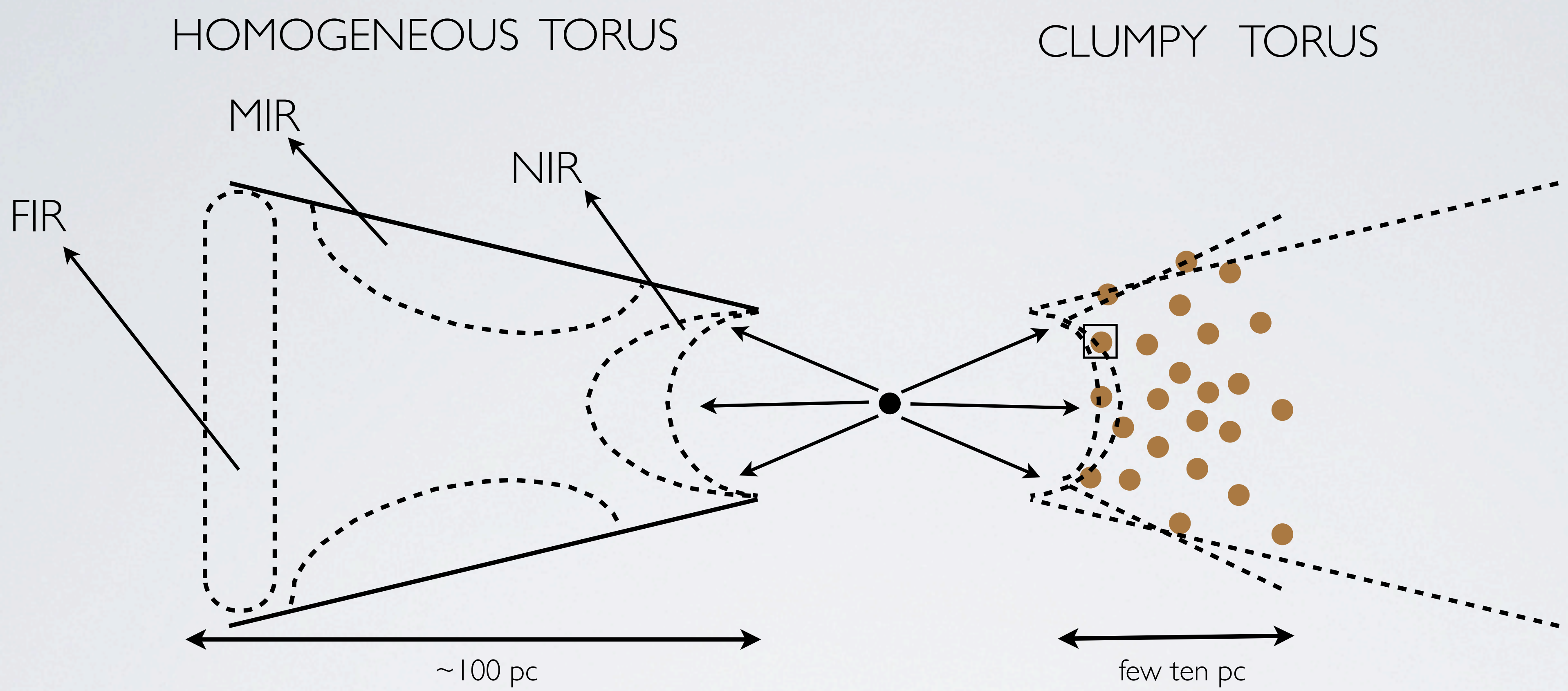
Method	Av (mag)
Polarization model	54 ± 4
NIR polarization	59 ± 5
Clumpy torus model	1800^{+200}_{-270}
X-Ray	131 ± 4

Obscuration depends strongly of the wavelength and/or model used

Interpretation

Nuclear extinction: *Interpretation*

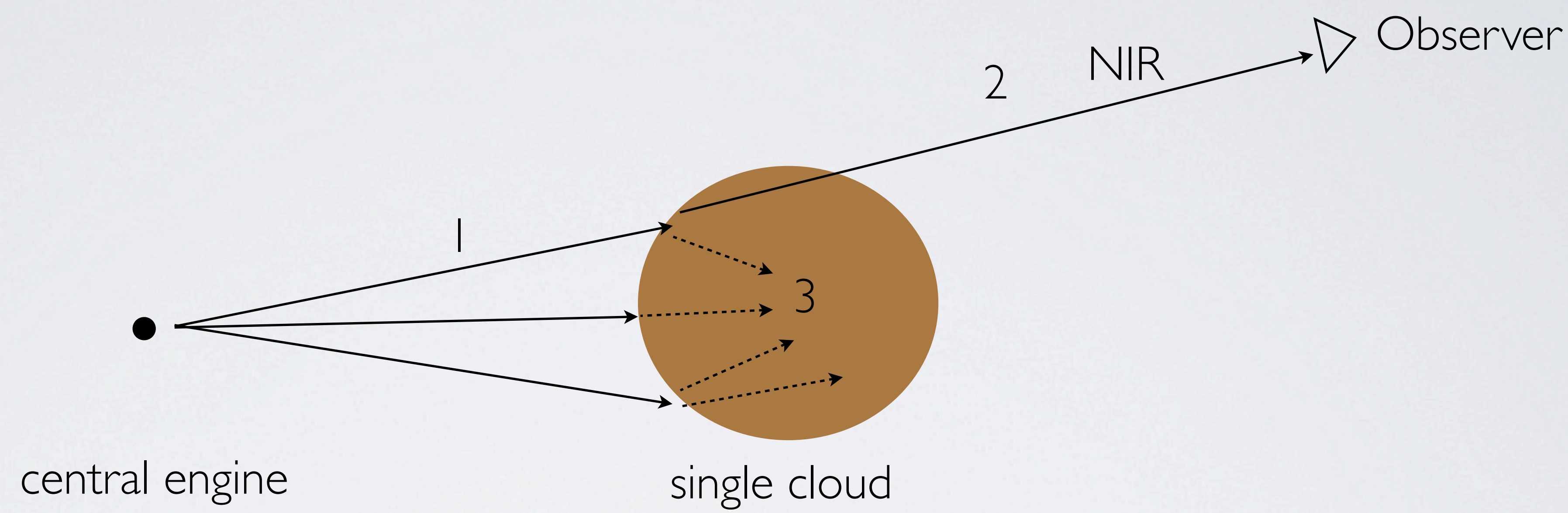
Each wavelength penetrates different depths into the obscuring torus



1. NIR total flux is emitted from inner facing clumps
2. MIR total flux is emitted from the warm dust of a single cloud

NIR polarization in the torus: *Interpretation*

NIR polarization produced by the passage of light through the aligned dust grains in the clumps of the torus



1. Radiation from the central engine

2. Passage of light through the aligned dust grains to the observer

3. Complete extinguished radiation to the dense regions of the cloud

Magnetic field in the torus

Magnetic fields in the torus

We want to relate:

$$\frac{P(\%)}{A_V} \propto B^n$$

Magnetic fields in the torus

Best model in literature by Vrba, Coyne & Tapia (1981) for molecular clouds, tested in optical and IR wavelengths!!!

$$\frac{P(\%)}{A_v} = \frac{67}{75}\frac{B^2}{an}\frac{\chi''}{\omega}\left(\frac{2\pi}{m_H K T_{gas}}\right)^{1/2}(\gamma - 1)\left(1 - \frac{T_{gr}}{T_{gas}}\right)$$

Physical conditions and environment of the gas and dust within the torus

Description	Parameter	Value
Gas temperature	T_{gas}	10^4 K
Grain temperature	T_{gr}	800-1500 K
Grain size	a	10^{-6} - 10^{-5} cm
Column density in the cloud	n	10^4 - 10^5 cm $^{-3}$

Other parameters are dependent of these four ones.

Estimated an **intrinsic polarization** of **12.5 ± 2.7 %**

Estimated a torus obscuration of **A_v(tor) = 48 ± 4 mag.**

Magnetic fields in the torus of IC5063

Magnetic field for the torus of IC5063 is calculated to be:

B = 12 - 128 mG

Note the model is for a quite and stable molecular cloud in the torus

Lower-limit of the magnetic field is estimated!!!

Literature:

1. Water vapor maser clouds in NGC 4258 at 0.2 pc B ~ 90 mG

Modjaz (2005)

Summary

Building a polarimetric model with different mechanisms of polarization

Electron scattering
(dust scattering can be included)
Dichroic absorption
(dichroic emission can be included)

Synchrotron can be included

Attempting to estimate the magnetic field strength of the clumpy torus in AGN

Through IR polarimetry we are attempting to characterize the magnetic field structure below the spatial resolution of the telescope

Wavelength coverage is crucial

Lopez-Rodriguez et al. (2012) prepared to be submitted in ~2-3 weeks

Near future work

Survey using:

MMT-POL at the 6.5m MMT with AO system → New data at K !!!

Cygnus-A

NGC1068

Packham et al. (2012, SPIE)

Wavelength: 1-5 μm

Pixel scale: 0.04''-0.19'' per pixel

Future Work

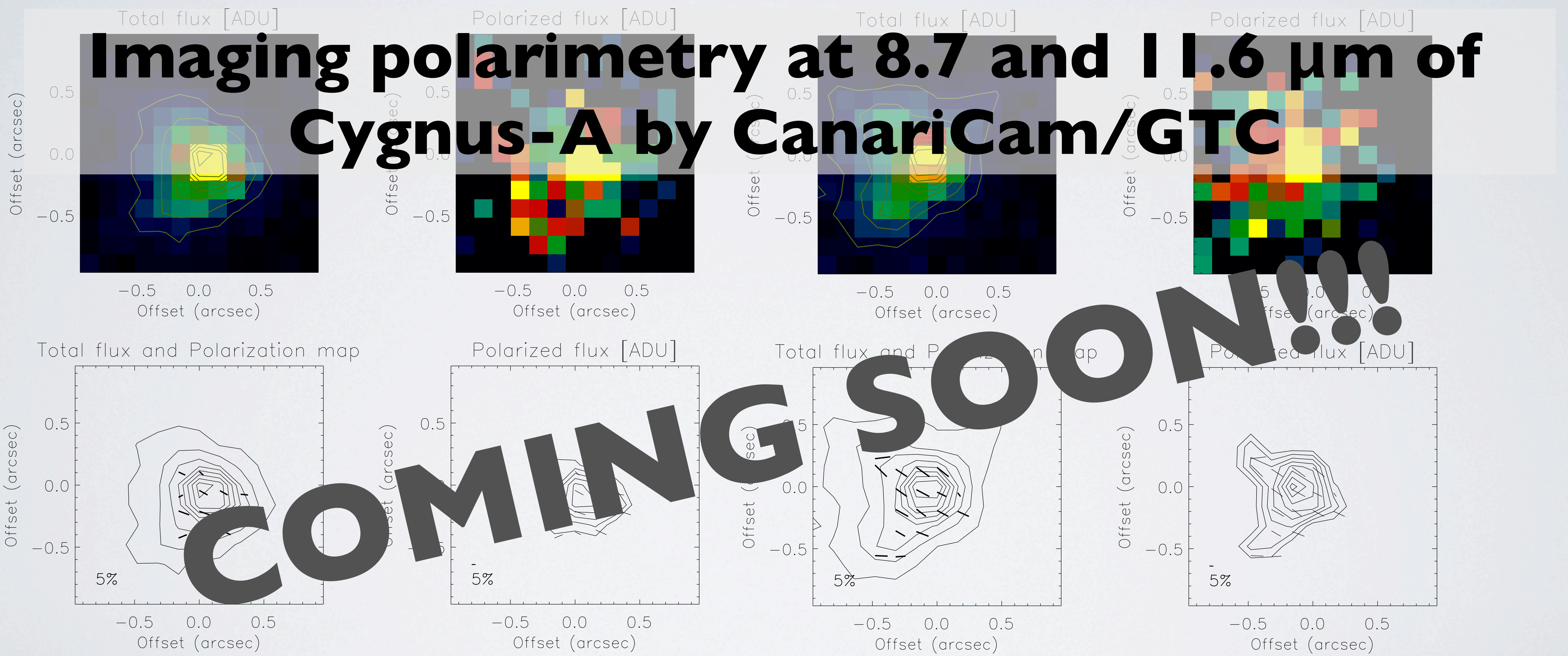
Survey using:

- MMT-POL at the 6.5m MMT with AO system
- CanariCam at the 10.4-m GTC
    - Polarimetry mode by Packham et al. (2005, SPIE)
    - Polarimetry mode fully commissioned
    - Wavelength: 7.5-13 μm
    - Pixel scale: 0.08" per pixel

Future Work

Survey using:

- MMT-POL at the 6.5m MMT with AO system → New data !!!
- CanariCam at the 10.4-m GTC → New data !!!



Thanks!