Models of thick turbulent gas disks with magnetocentrifugal winds in AGN and their application to Circinus and NGC 1068

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M. Schartmann: 3D radiative transfer
L. Burtscher: IR emission/visibilities
F. Marin, R. Goosmann: 3D polarization model
S. Hönig, R. Davies

Vollmer et al. 2017, A&A, 615, 164

Massive turbulent thick gas disks

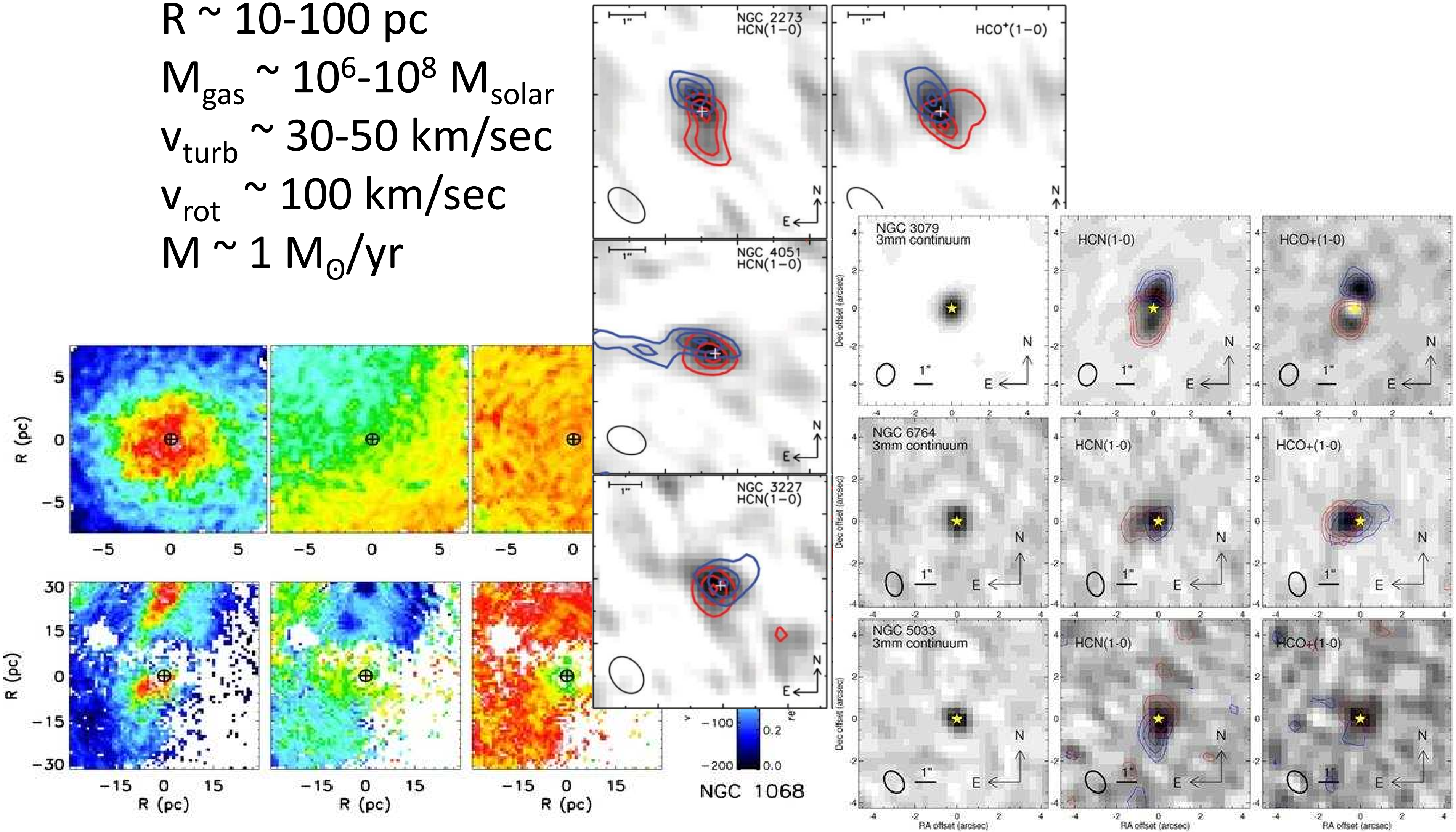
$R \sim 10\text{-}100$ pc

$M_{gas} \sim 10^6\text{-}10^8\ M_{solar}$

$v_{turb} \sim 30\text{-}50$ km/sec

$v_{rot} \sim 100$ km/sec

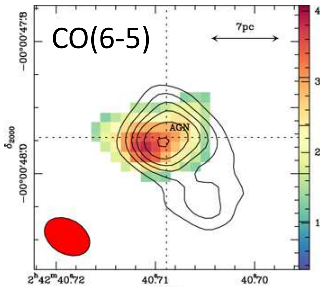
$M \sim 1\ M_{\odot}$/yr

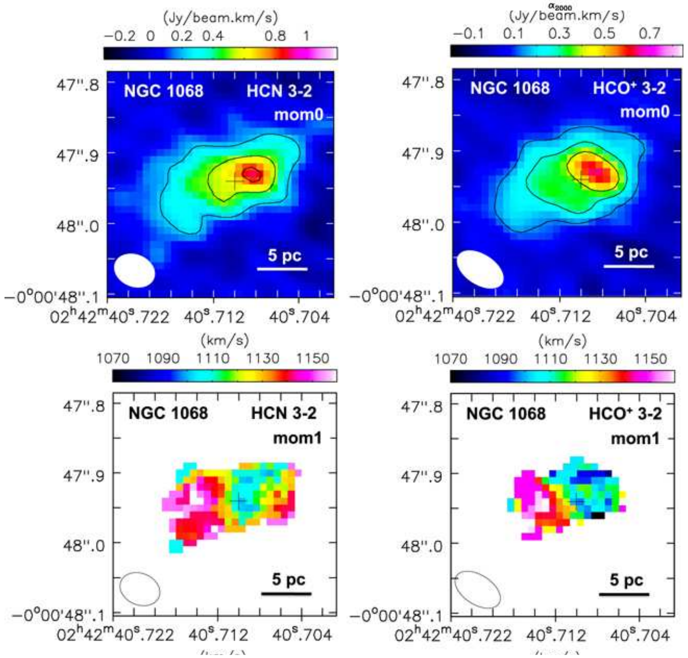


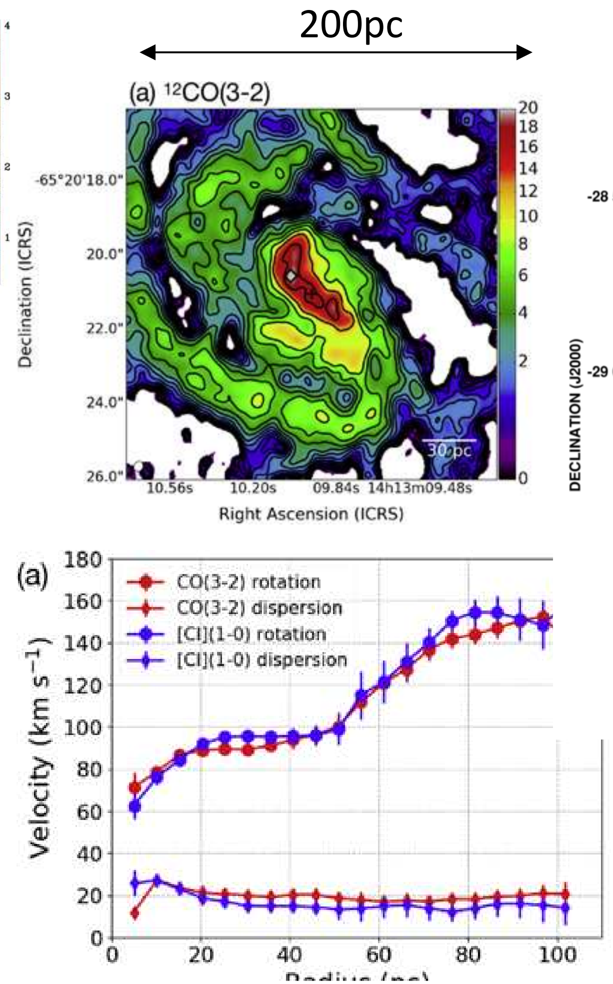
warm H_2 (Hicks et al. 2009) HCN/HCO+ (Sani et al. 2012) HCN/HCO+ (Lin et al. 2016)

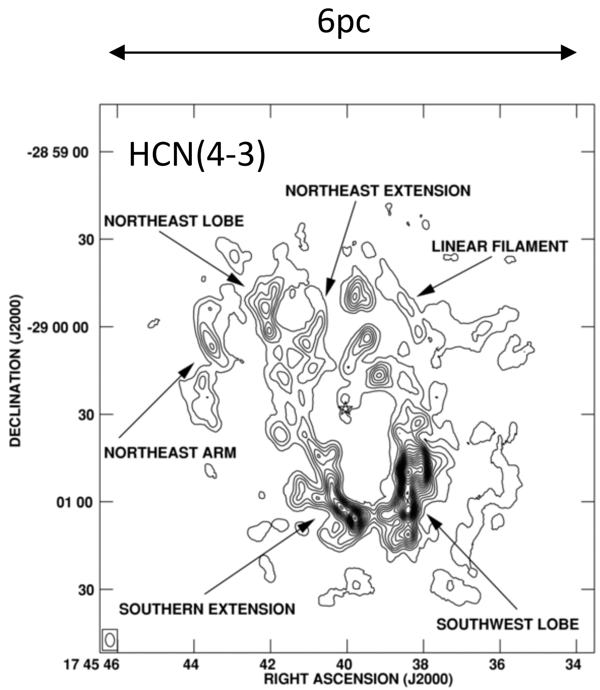
Massive turbulent thick gas disks close to the central black hole

Garcia-Burillo et al. (2016)









NGC 1068 (Imanishi et al. 2018) Circinus (Izumi et al. 2018) CND Galactic Center (Castano-Montero et al. 2009)

What can a massive thick disk do for you?

- Scale: 1 – 10 pc
- Obscuration of the central engine (vertical disk stratification)
- High mass accretion rates (~ 1 $M_{\odot}$/yr)
- No violent starburst
- Viscous heating leads to T_{gas} ~ few 100 K at high densities
- Compton-thick reflector at inner edge (~ 1 pc)
- Transition to thin maser disk at R $\lesssim$ 1 pc
- Necessity of a molecular/dusty wind/outflow to remove angular momentum and mass ->

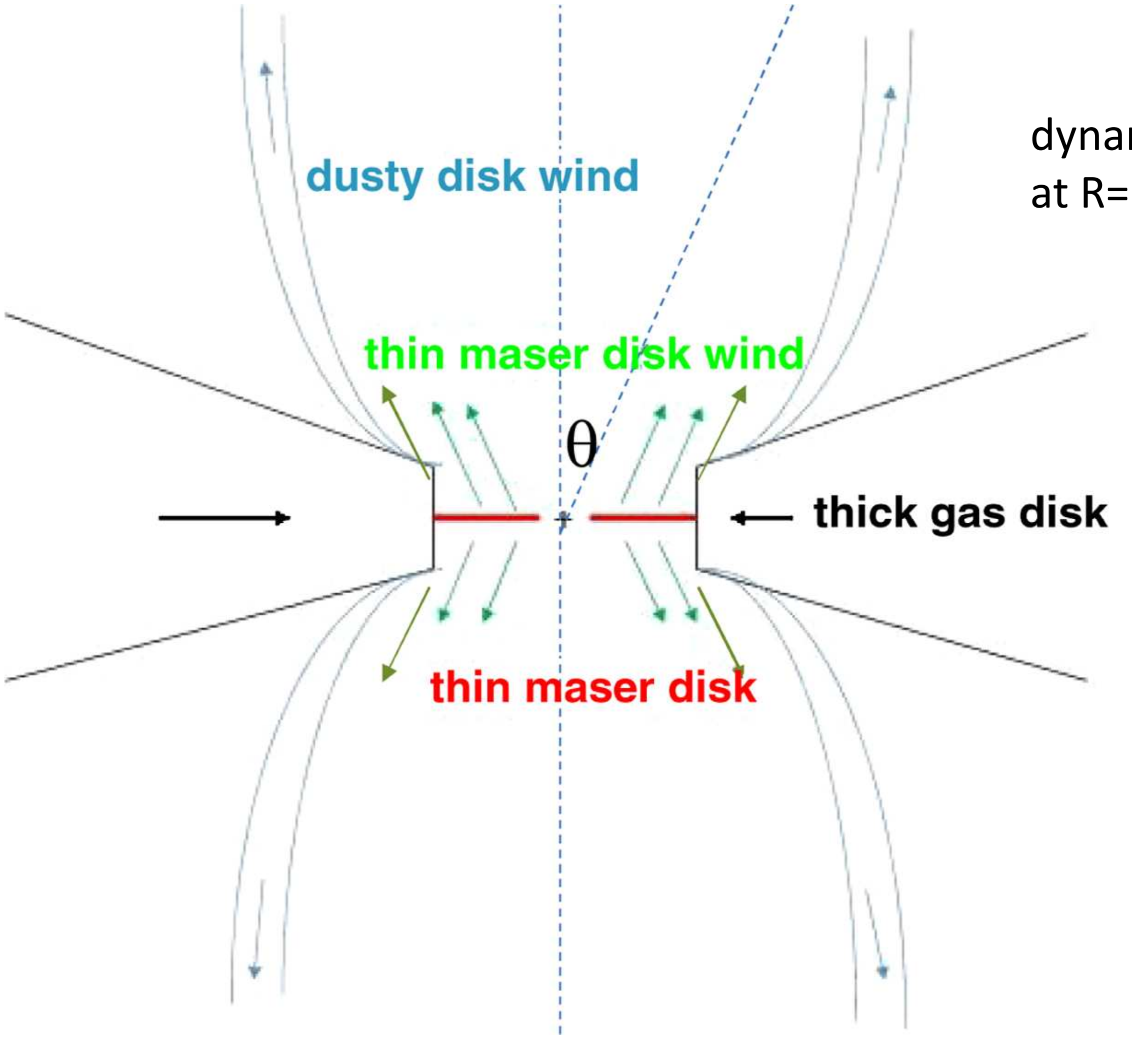
  decrease of the mass accretion rate toward the center

(slide from Torus2015 workshop)

The gas accretion scenario

- Event of high external mass accretion (from $\geq$100 pc)
- Possibility of a pre-existing circumnuclear disk/ring
- Disk has to increase its viscosity to cope with the gas infall via turbulent adiabatic compression
  -> turbulent clumpy thick gas disk
- Magnetocentrifugal wind sets in where the polar magnetic field is bent by at least 30^{o} -> magnetic diffusivity = viscosity (Lubow et al. 1994) or bending through radiation pressure
- Angular momentum taken away by the wind -> gas disk becomes thin
- Mass flux conservation: $\dot{M}_{\rm thick\ disk} - \dot{M}_{\rm wind} - \dot{M}_{\rm thin\ disk} = 0\ ,$

The model geometry



dynamical timescale at R=1pc: t_{dyn}~10^4 yr

Our **smooth** winds have optical depths of a few

Model assumptions

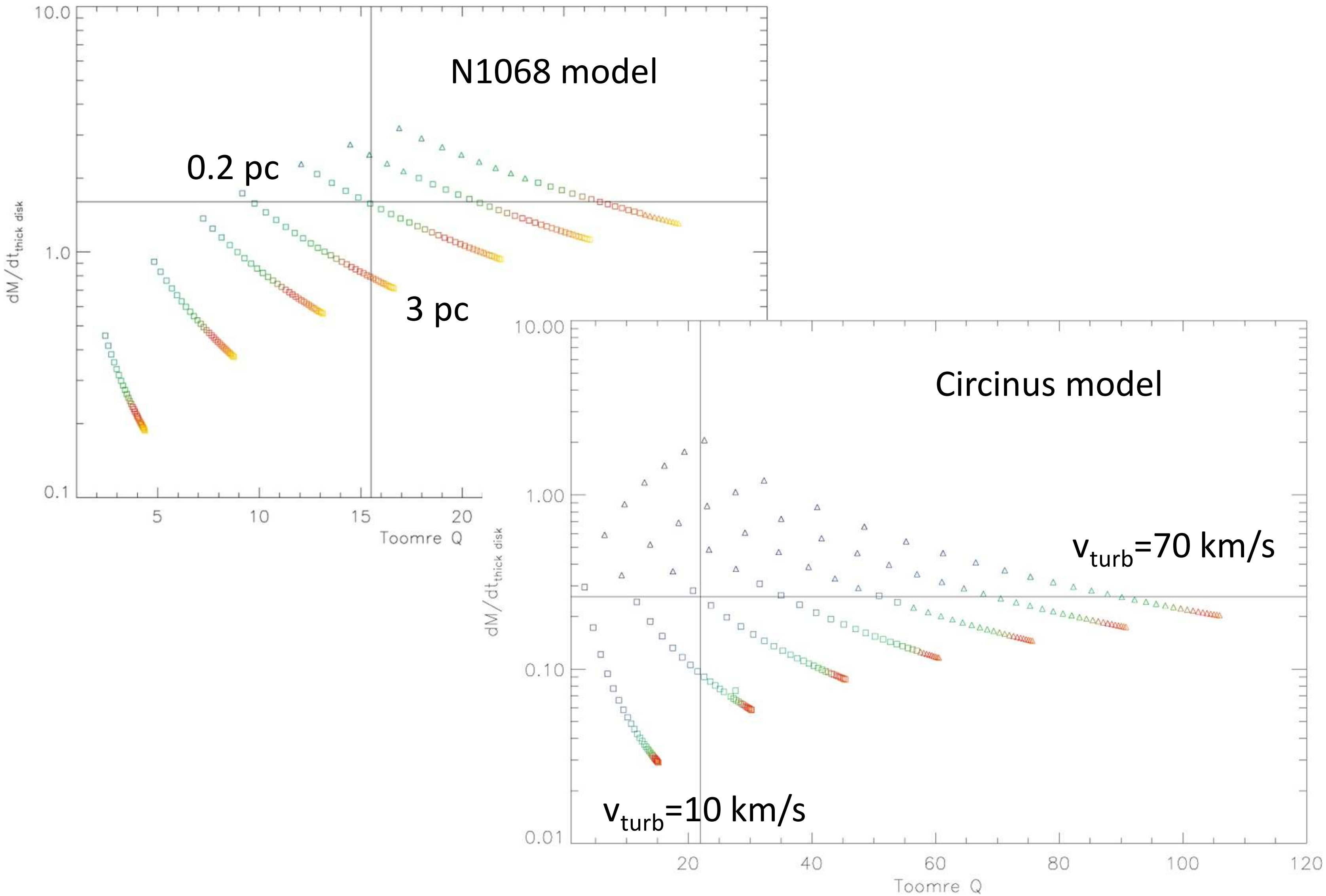
- Axial symmetry, smooth gas distribution
- Strongly magnetized gas disk (energy density equipartition)
- Regular B field is about 1/3 of the total B field
- Massive gas disk not strongly affected by radiation pressure
- Wind might be shaped by radiation pressure, but magnetocentrifugal forces dominate
- Radius where the wind sets in is determined by mass flux conservation

Results

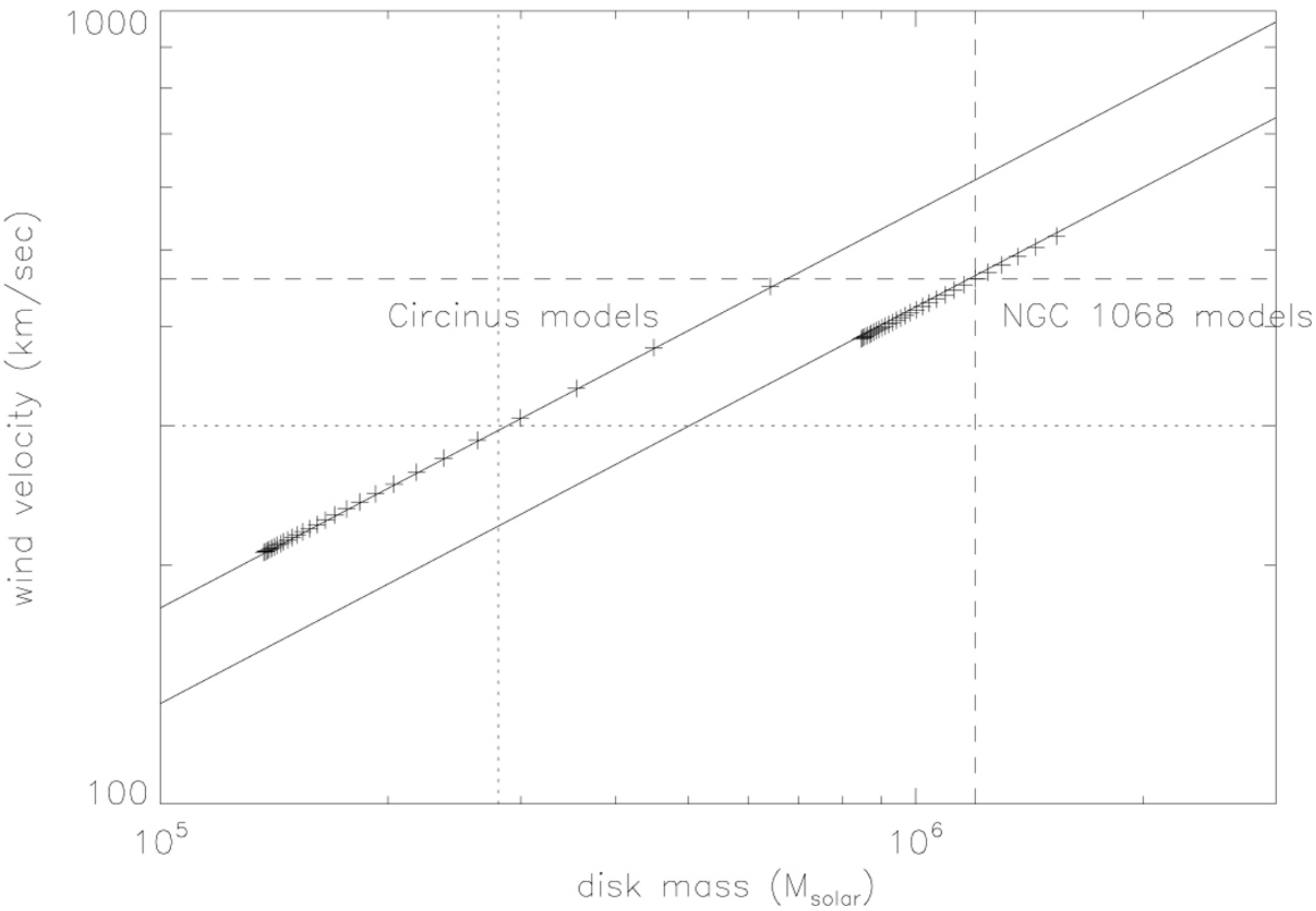
	D	$L_{\mathrm{bol}}^{\mathrm{a}}$	M_{BH}	M_{*}^{b}	$v_{\mathrm{rot}}^{\mathrm{c}}$	$v_{\mathrm{turb}}^{\mathrm{d}}$	Ω^{e}	$r_{\mathrm{wind}}^{\mathrm{f}}$
	(Mpc)	(erg s^{-1})	($M_{\odot}$)	($M_{\odot}\,\mathrm{pc}^{-\frac{5}{4}}$)	(km s^{-1})	(km s^{-1})		(pc)
Circinus	4.2	3×10^{43}	1.6×10^{6}	1.0×10^{6}	100	30	0.022	0.53
NGC 1068	14.4	3×10^{44}	8.6×10^{6}	3.0×10^{6}	170	50	0.022	1.5

	$M_{\mathrm{gas}}/M_{\mathrm{dyn}}$	Q	Φ_{A}	$B_{\mathrm{p}}^{\mathrm{a}}$	r_{A}	$\dot{M}_{\mathrm{thick\ disk}}$	$\dot{M}_{\mathrm{wind}}$	$\dot{M}_{\mathrm{thin\ disk}}$	$p_{\mathrm{B}}(r_{\mathrm{wind}})$	$p_{\mathrm{rad}}(r_{\mathrm{wind}})$
				(mG)	(pc)	($M_{\odot}\,\mathrm{yr}^{-1}$)	($M_{\odot}\,\mathrm{yr}^{-1}$)	($M_{\odot}\,\mathrm{yr}^{-1}$)	(erg cm^{-3})	(erg cm^{-3})
Circinus	0.010	22	0.45	14	0.85	0.26	0.14	0.12	7.4×10^{-6}	5.1×10^{-6}
NGC 1068	0.016	15	0.42	15	2.4	1.57	0.85	0.73	8.5×10^{-6}	6.2×10^{-6}

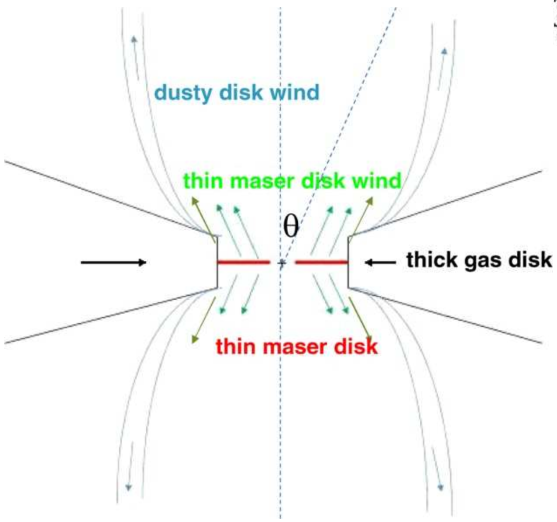
Viable magnetocentrifugal winds

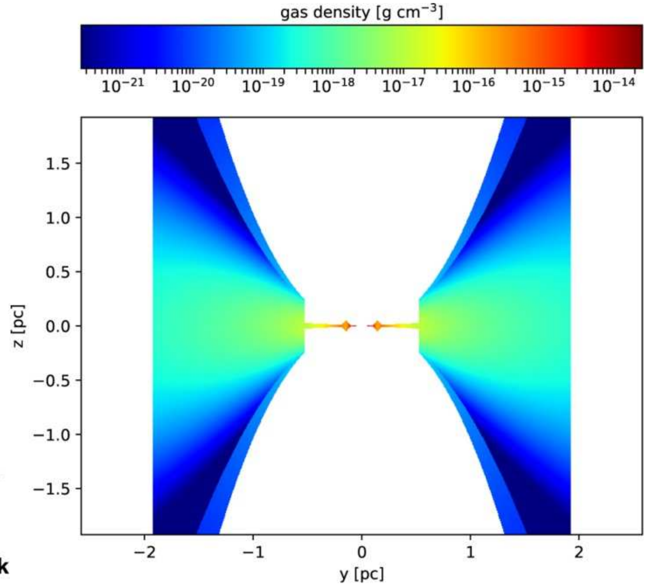


Terminal wind velocities

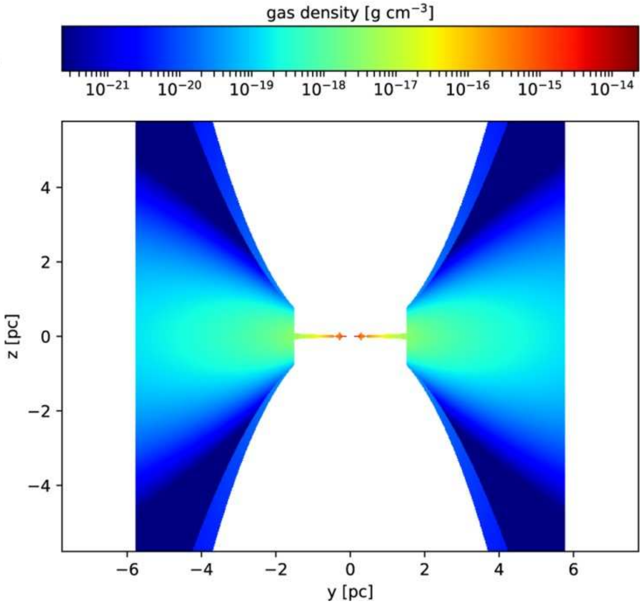


Radiative transfer models





Circinus model

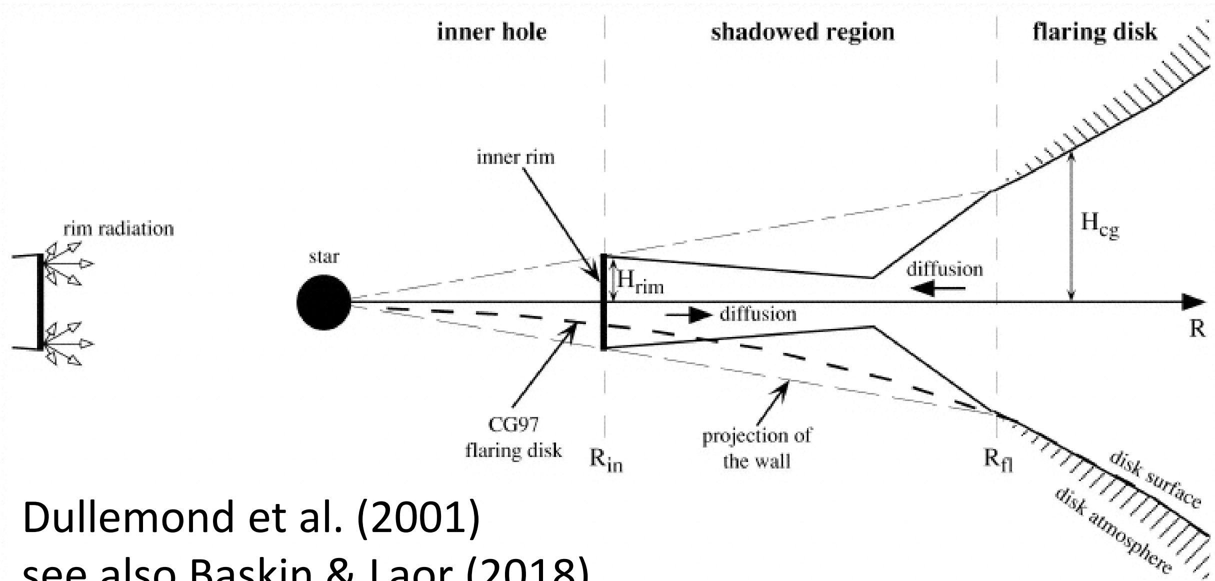


NGC 1068 model

The inner puff-up

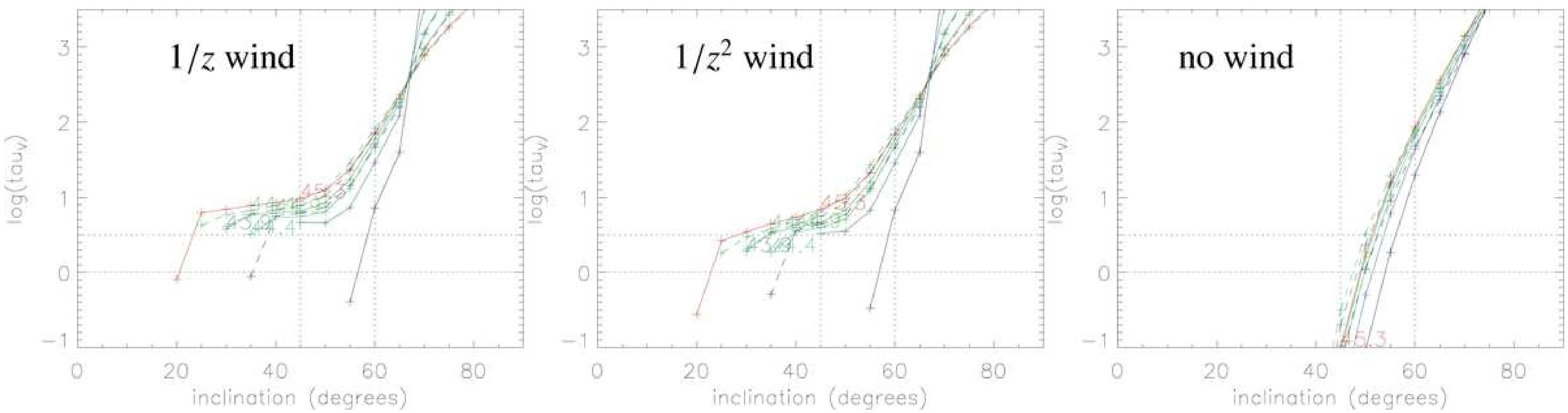
- Postulated ad-hoc in our model
- Needed for the NIR emission
- Observed in Young Stellar Objects

(e.g. Monnier et al. 2006)



Dullemond et al. (2001)
see also Baskin & Laor (2018)

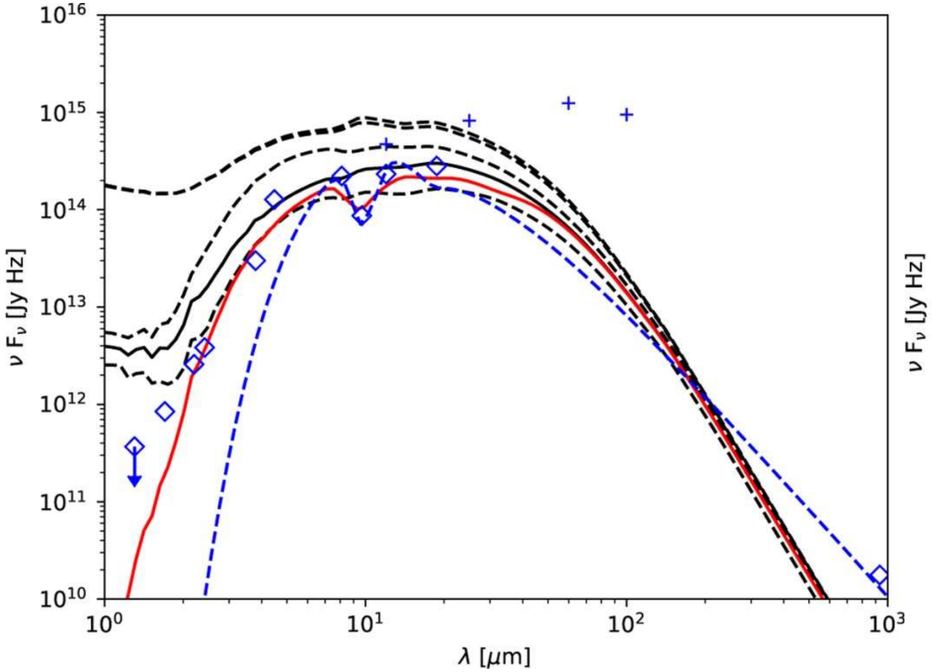
The central extinction



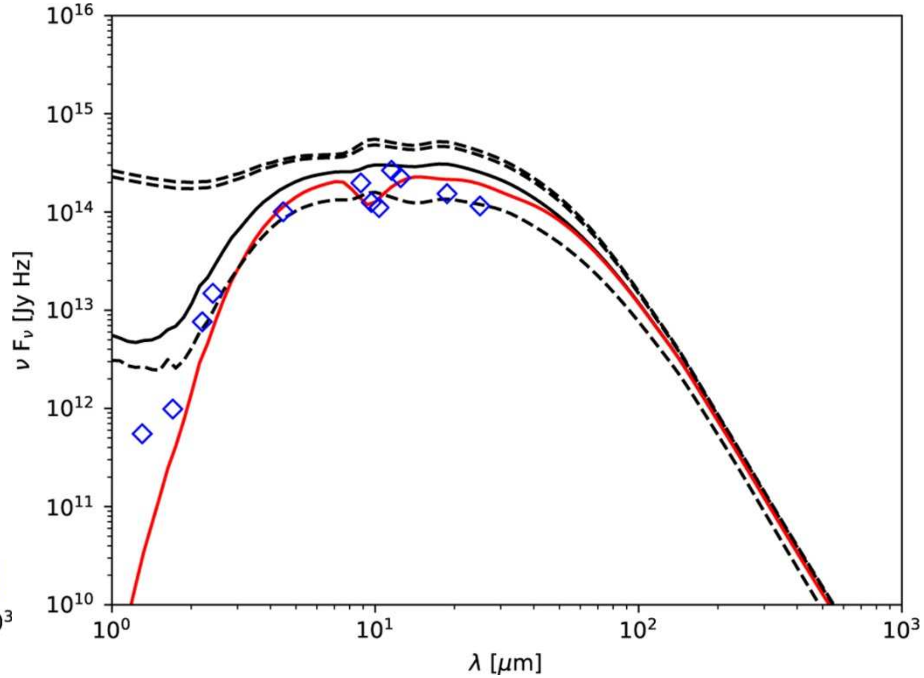
Sy 1.5: <= 3 mag
Sy 1.8-1.9: 4 – 8 mag
Sy 2: > 10 mag

SEDs

Circinus



NGC 1068



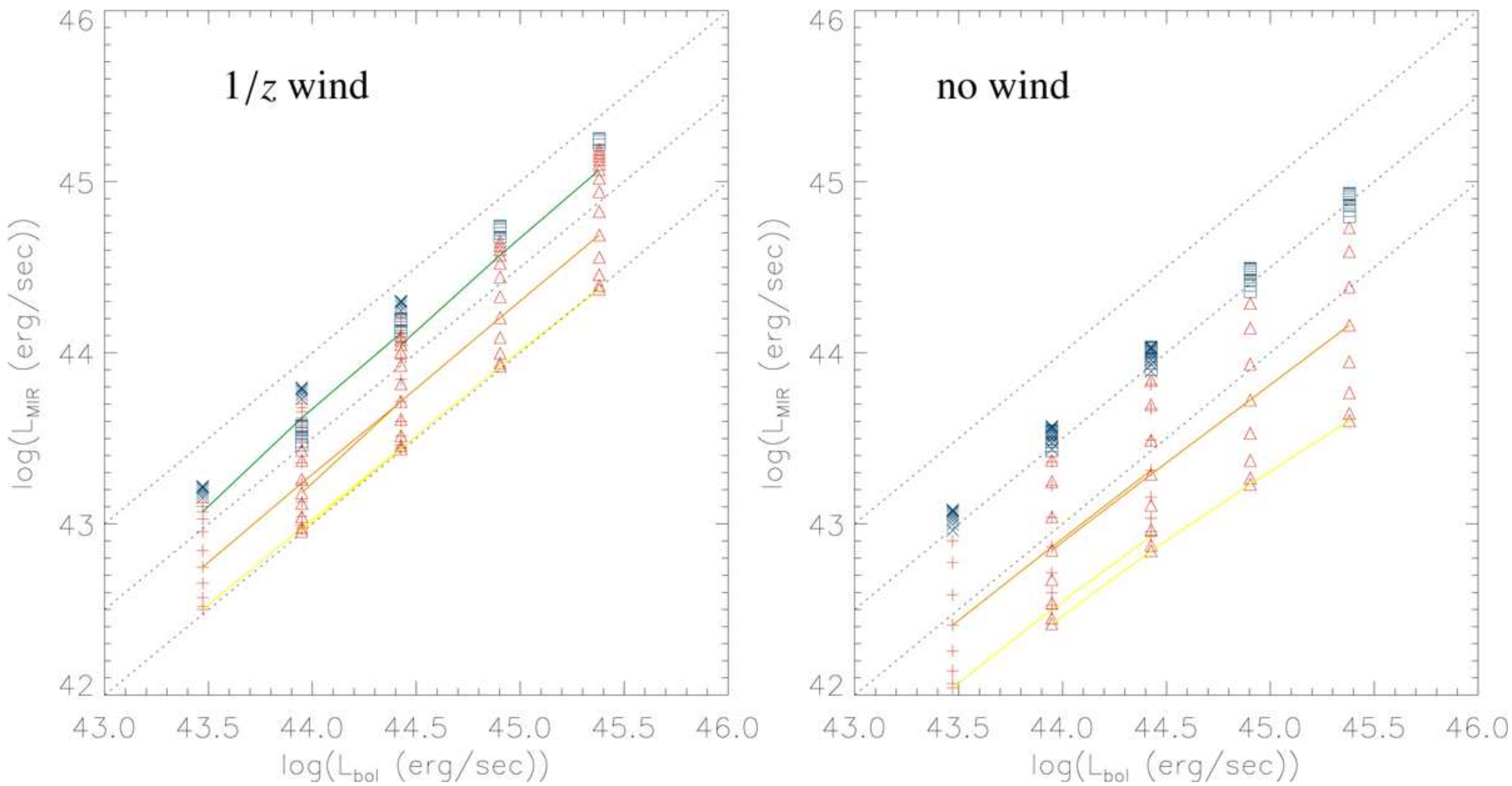
Blue dashed line: Tristram et al. (2014)
Blue diamonds: Prieto et al. (2010)
Blue pluses: IRAS

Blue diamonds: Prieto et al. (2010)

Red model curves: additional screen with τ_V=20

MIR luminosities

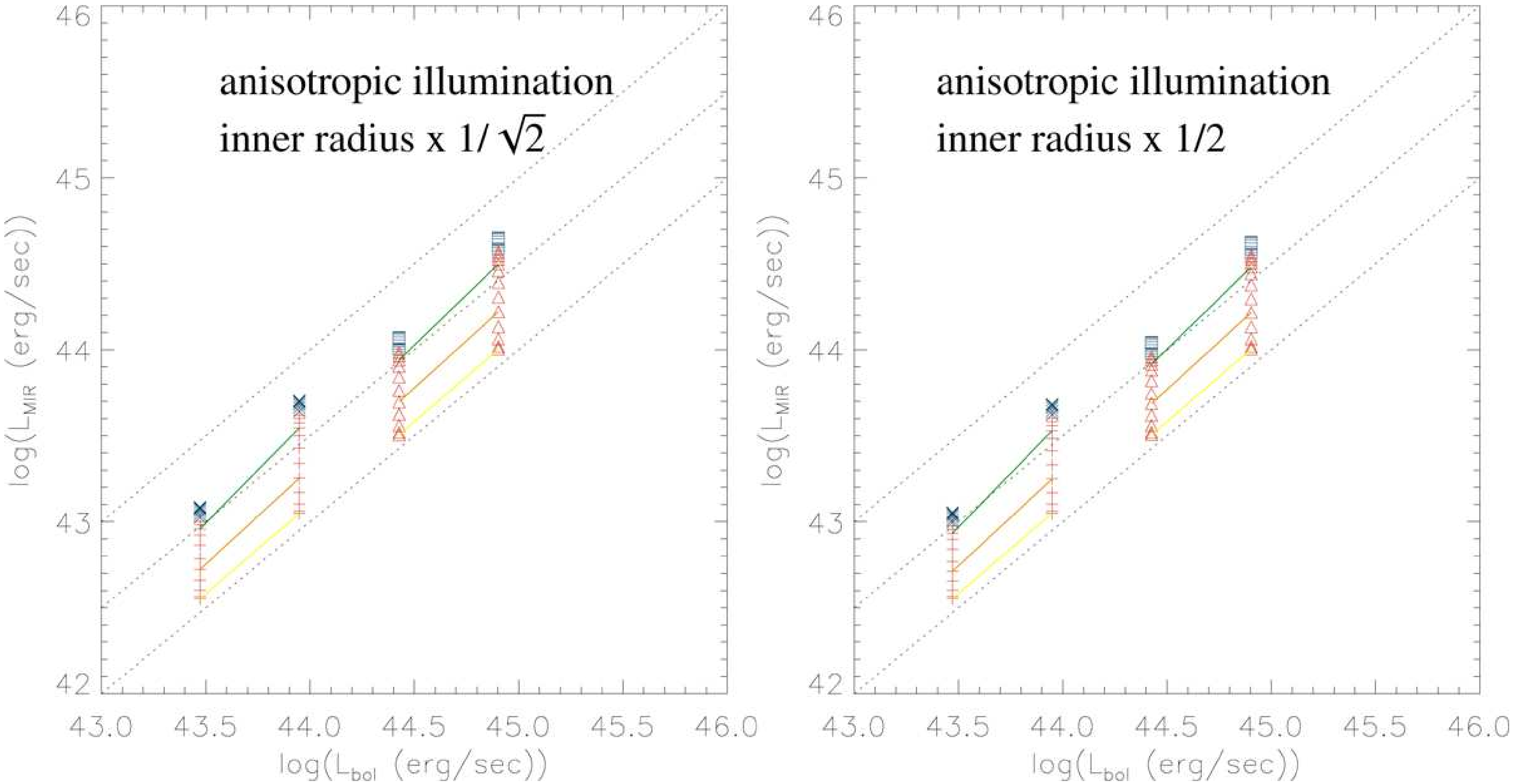
Isotropic illumination



Crosses/pluses: Circinus model squares/triangles: NGC 1068 model

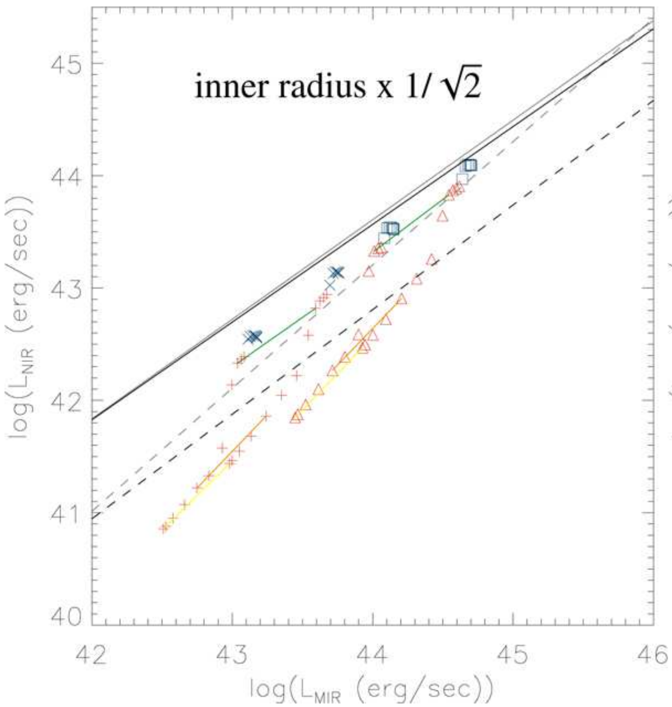
green: i=50º orange: i=70º yellow: i=90º

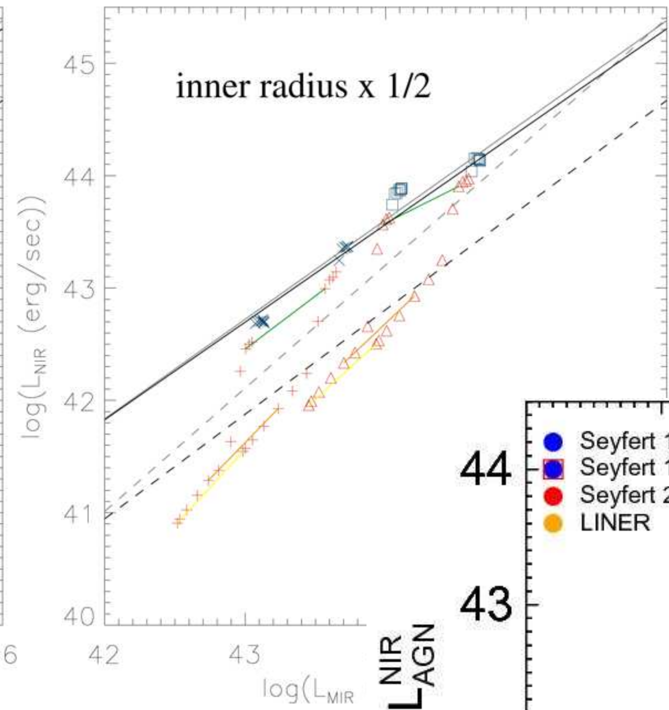
MIR luminosities



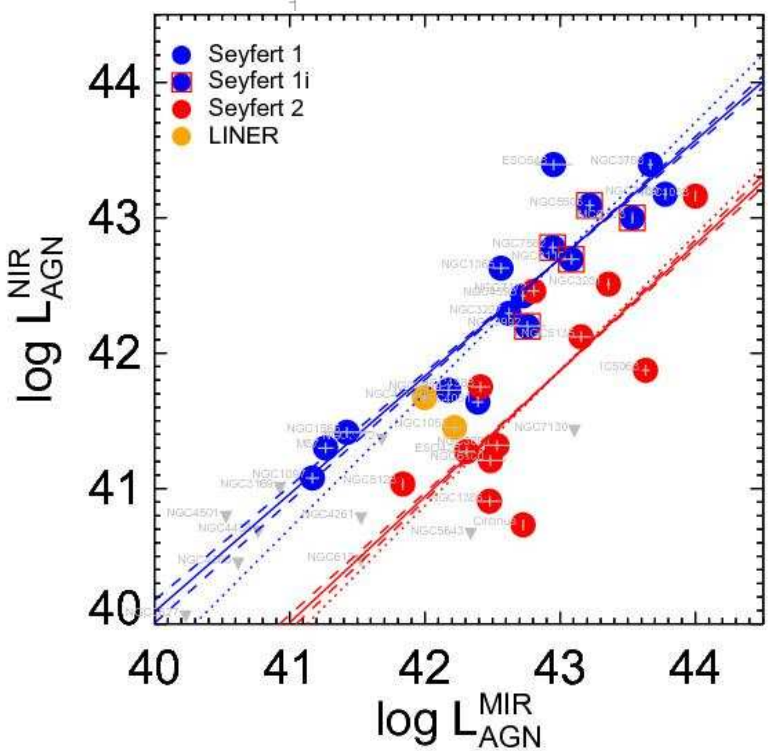
Torus covering factor of 51 Sy1 galaxies: f_c=0.3$\pm$0.17 (Ezhikode et al. 2017)
-> anisotropic illumination is preferred

NIR luminosities



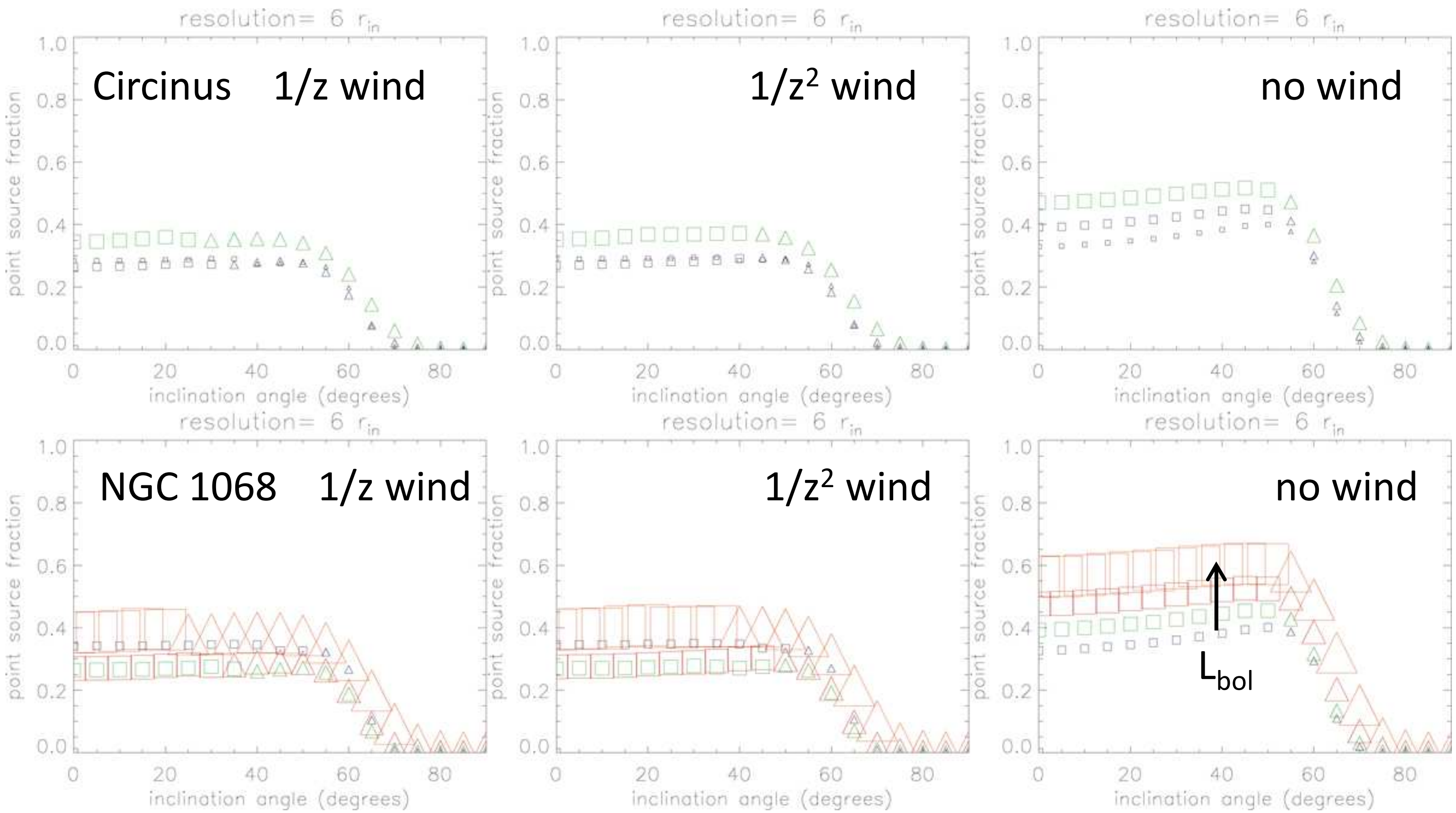


Burtscher et al. (2015)

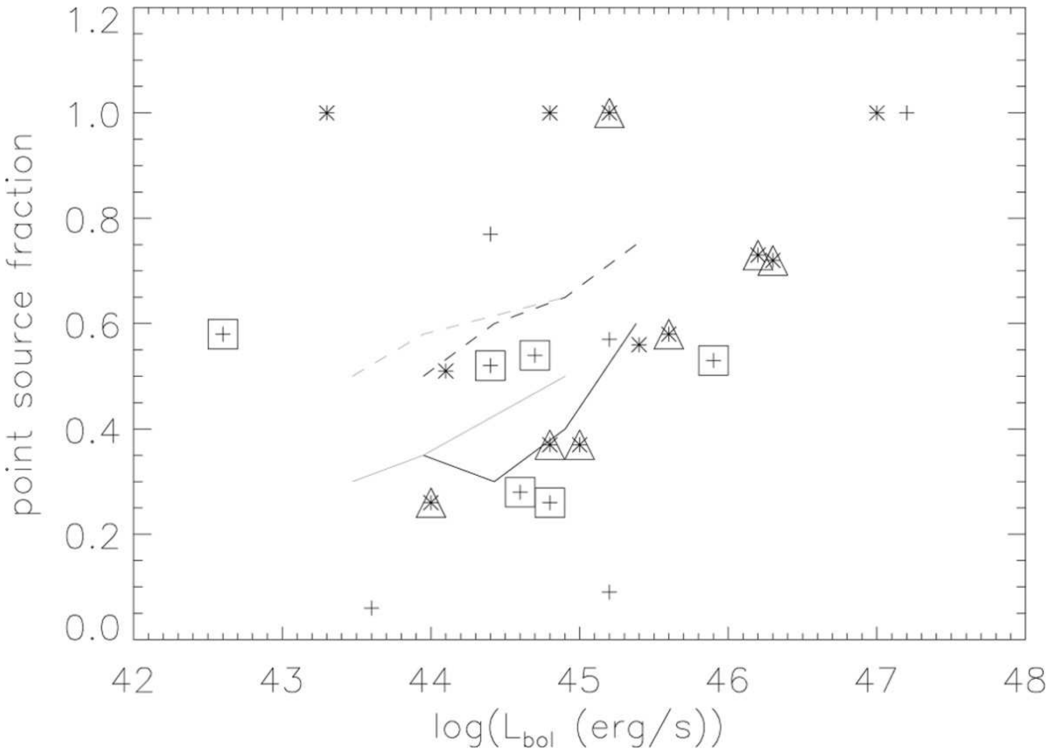


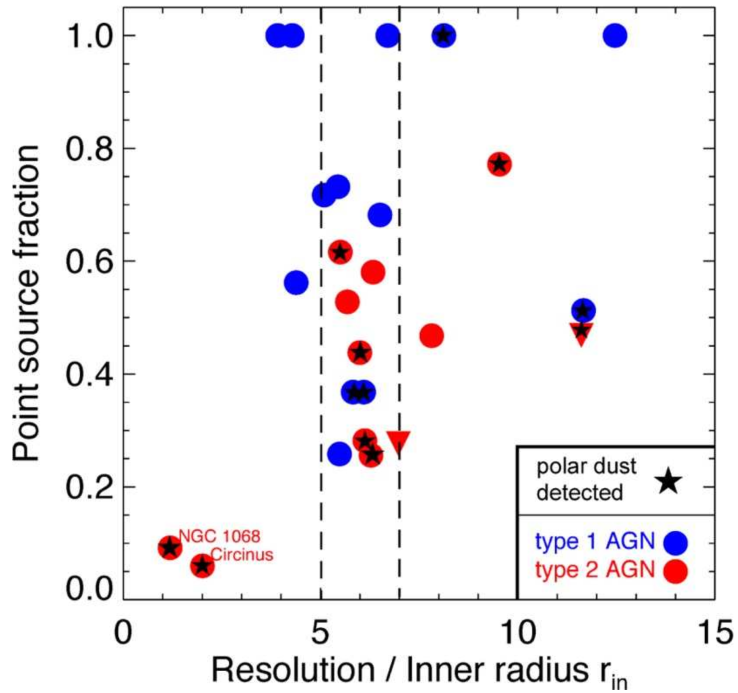
Point source fraction (interferometry)

= flux density within $N \times r_{sub}$ divided by the total flux density



Point source fraction



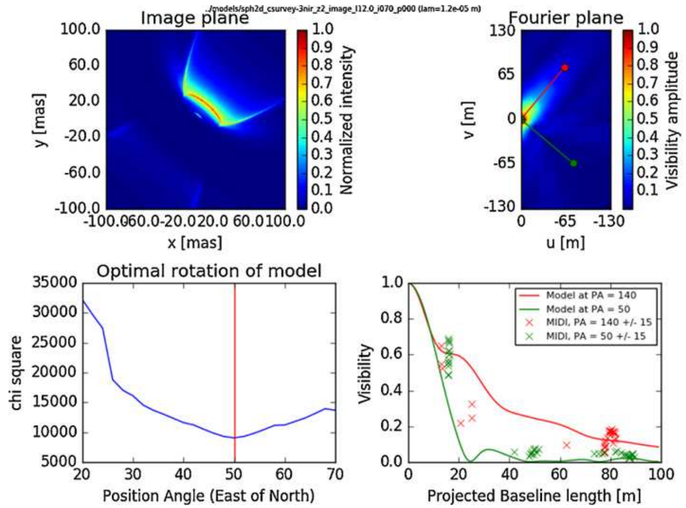


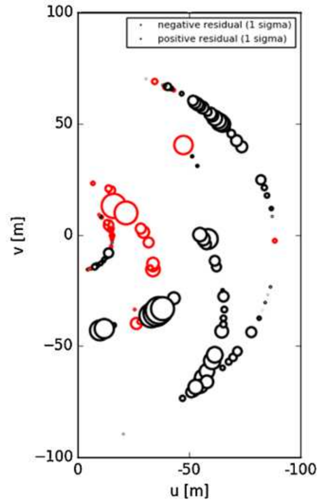
Stars: Sy1 Pluses: Sy2
Triangles: Sy1 Squares: Sy2 with $(6 \pm 1)\times\ r_{sub}$

Burtscher et al. (2013)

MIR interferometry of Circinus

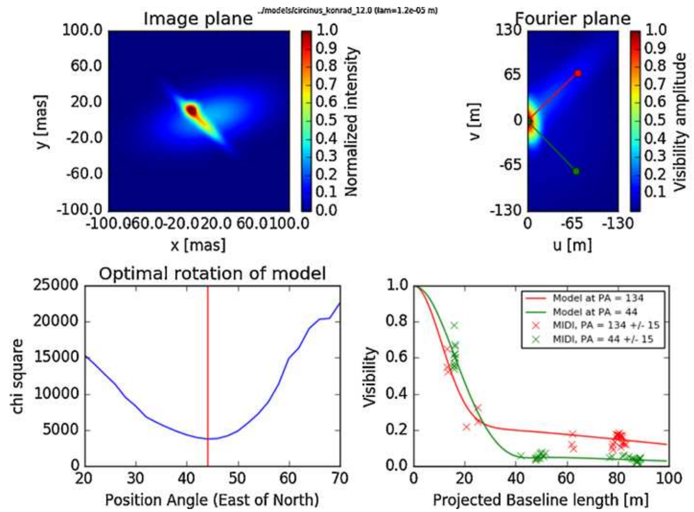
Vollmer et al. (2017)

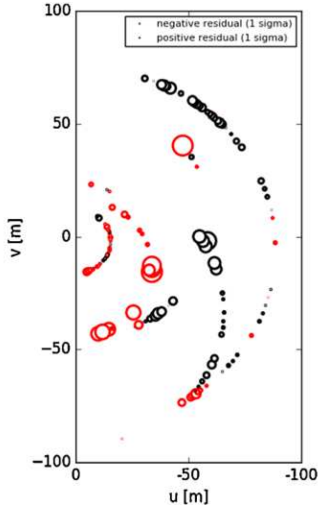




$2.5\times\ \chi^2_{Tristram}$

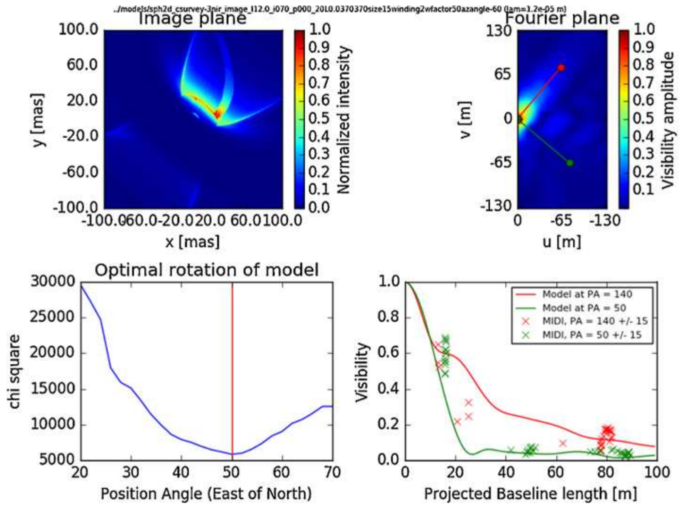
Tristram et al. (2014)

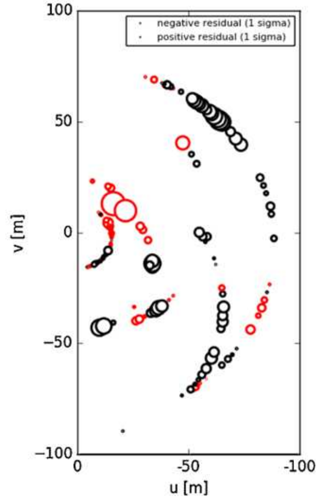




MIR interferometry of Circinus

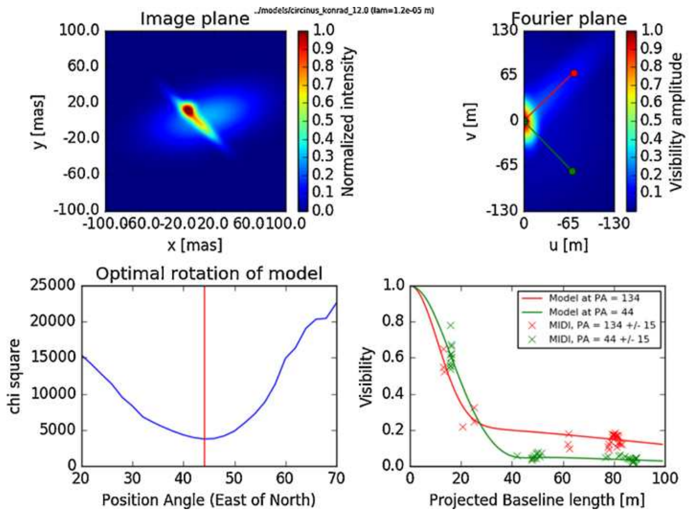
Vollmer et al. (2017)

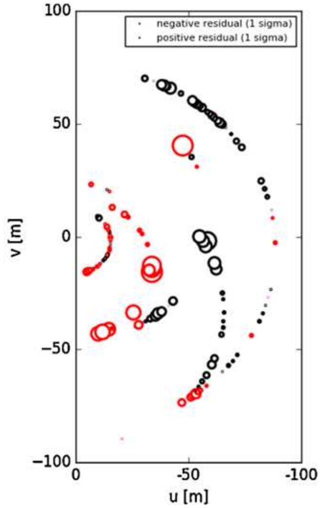




$2.2\times\,\chi^2_{Tristram}$

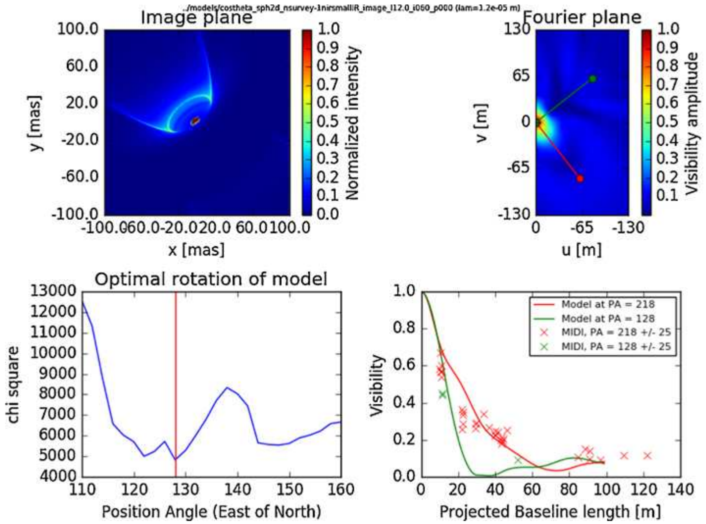
Tristram et al. (2014)

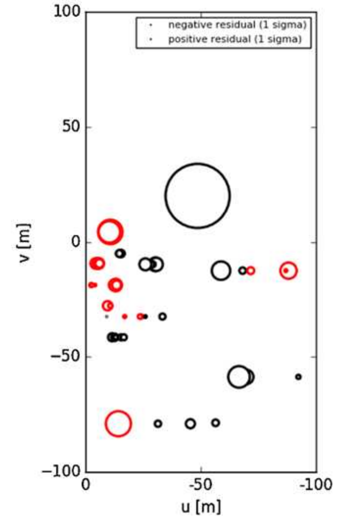




MIR interferometry of NC 1068

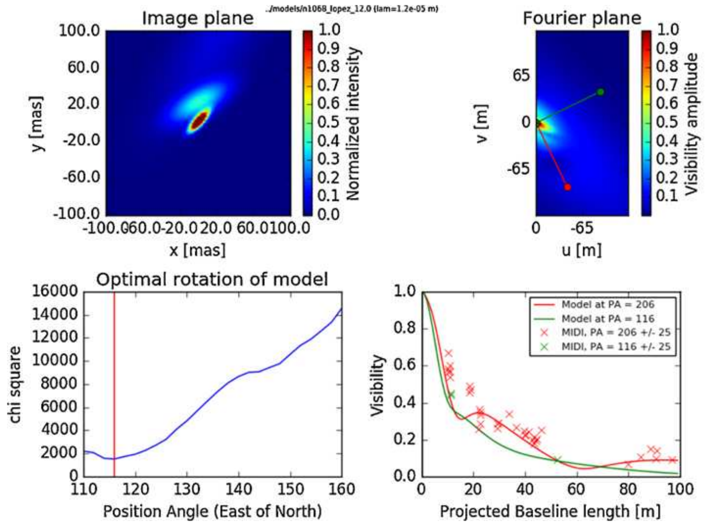
Vollmer et al. (2017)

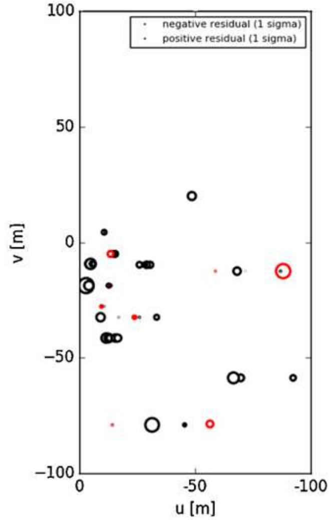




$2.8\times\chi^2_{LG}$

Lopez-Gonzaga et al. (2014)

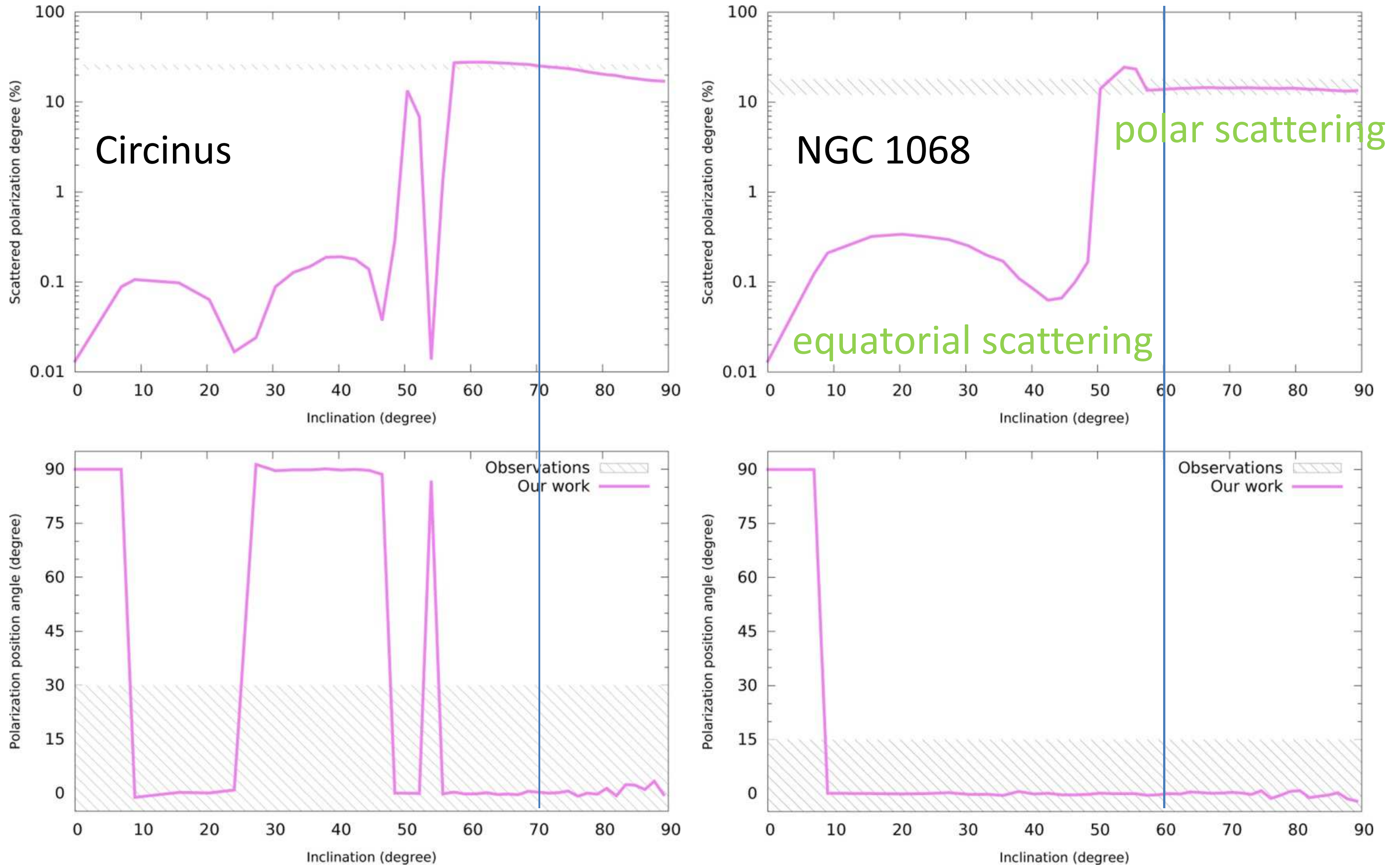




Optical polarization

degree of polarization

polarization angle



nuclear screen included

STOKES code (Gossmann & Gaskell 2007, Marin 2012)

Conclusions

- Thick gas disks + magnetocentrifugal winds are viable
- Key ingredient: directly illuminated inner wall of the thick gas disk + wind
- cos(θ) illumination is prefereed
- About half of the MIR is emitted by the wind (depends on optical depth)
- Puff-up (and A_V~20) screen are needed
- Central extinction, SED, L_{MIR}/L_{bol}, L_{NIR}/L_{MIR}, point source fraction, MIR interferometry, polarization
- Open questions: influence of clumpiness, what is the screen, where does the thick gas disk become thin, magnetic field strength, rotation of gas in the wind, wind optical depth -> AGN statistics