Radio constraints on the volume filling factors of AGN winds

Alexander Blustin

STFC Postdoctoral Fellow
Institute of Astronomy, University of Cambridge

and Andy Fabian (IoA)

JENAM, University of Hertfordshire, 20/04/09

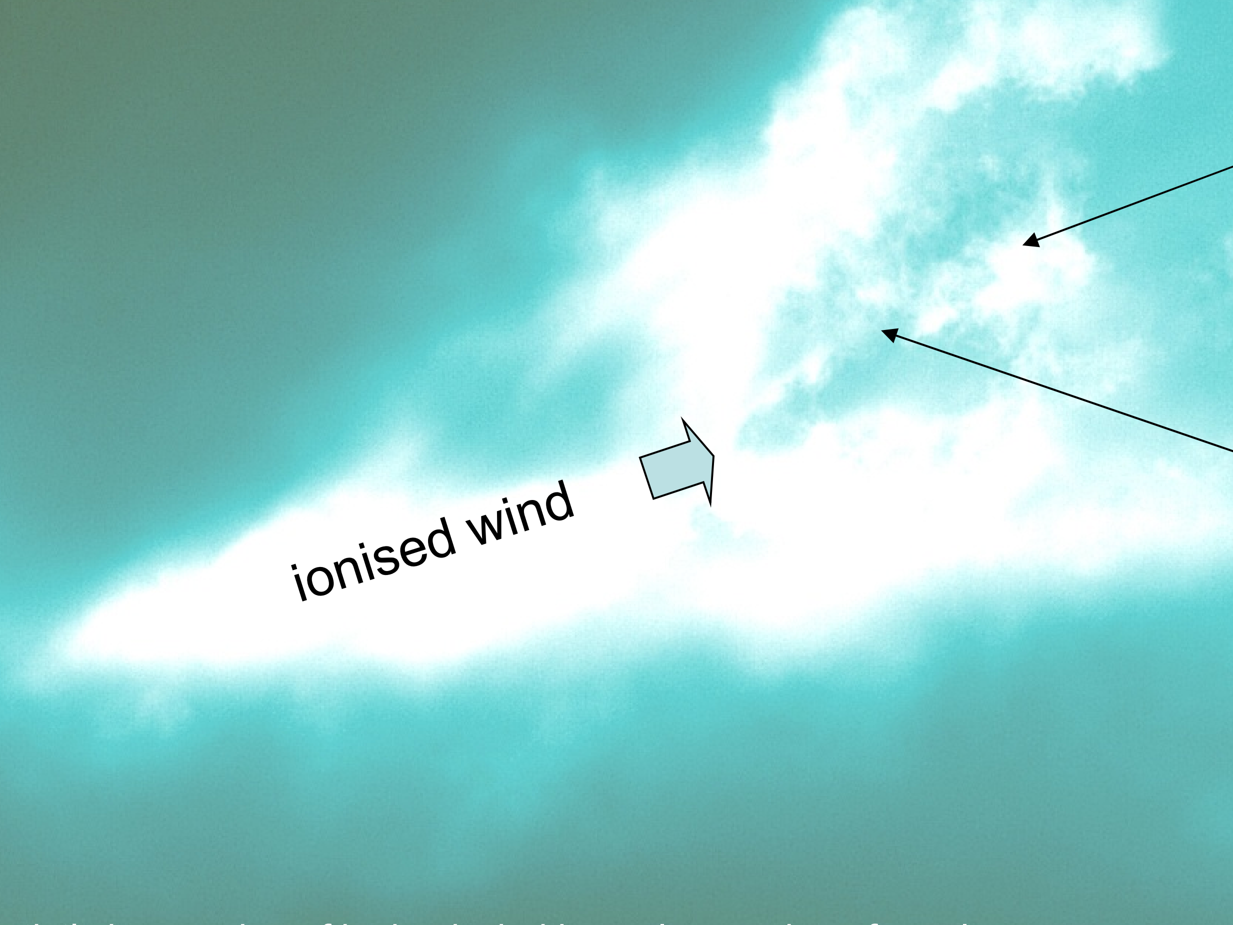
Cambridge
X-Ray Astronomy

Observing AGN winds

The winds are studied through X-ray and UV spectroscopy.

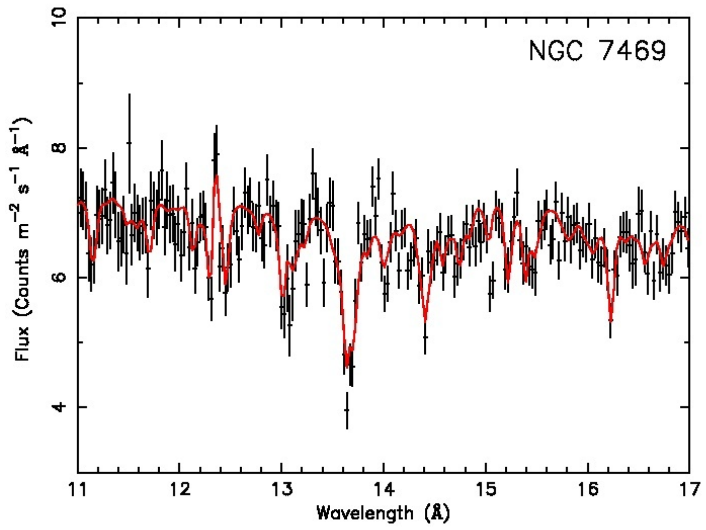
They contain gas at a range of velocities and ionisation levels.

Multiple origins: torus/NLR, accretion disc?



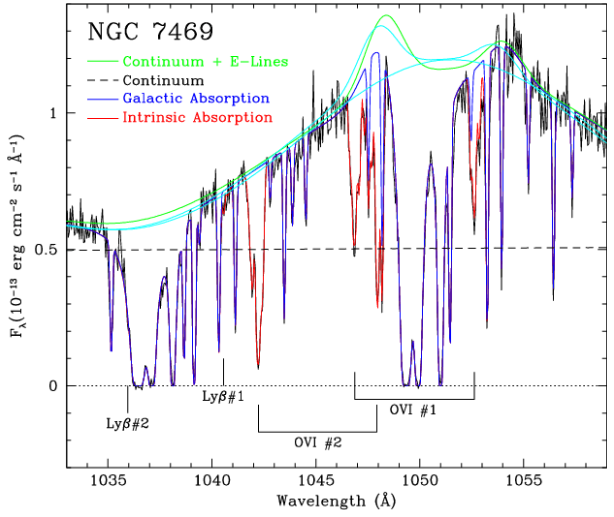
Artist’s impression of ionised wind in nuclear region of a galaxy

X-ray absorption – more ionised



Blustin et al. 2007, A&A, 466, 107

UV absorption – less ionised



Kriss et al. 2003, A&A 403, 473

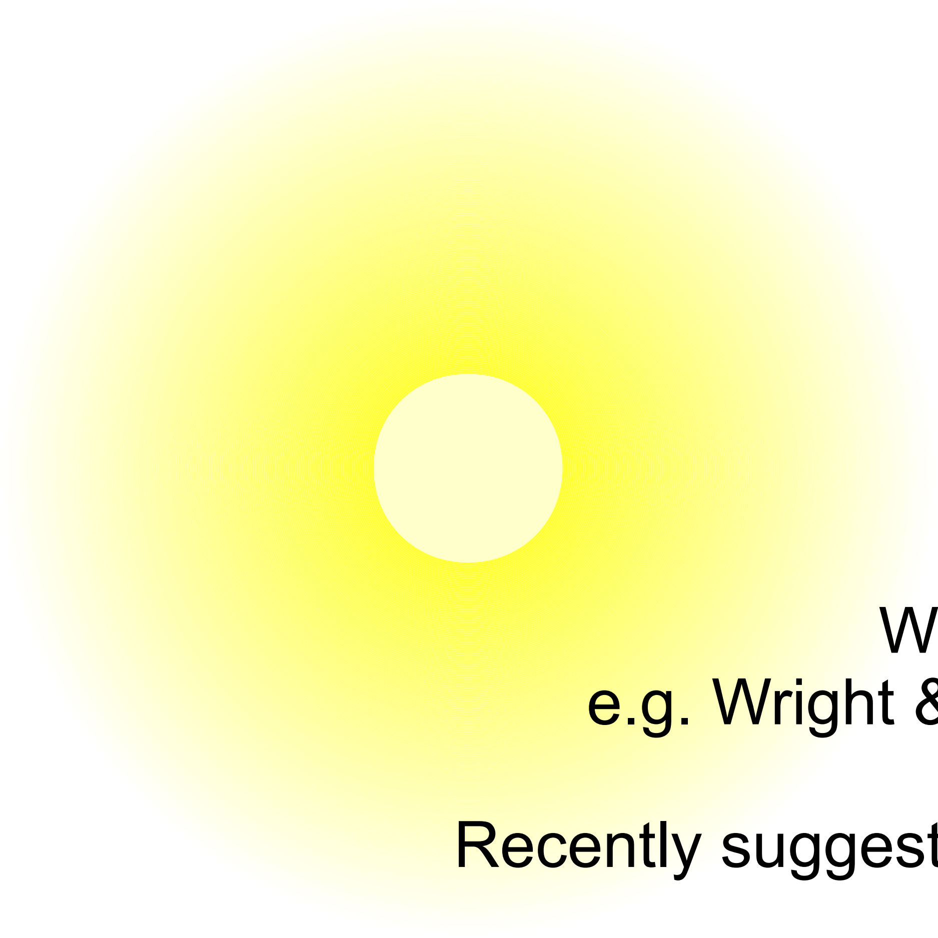
What role do AGN winds play in feedback?

How much mass and energy is carried by AGN winds?

What are their volume filling factors?

Probably small (see Blustin et al. 2005, A&A 431 111), but direct observational evidence lacking

Need a new observational window: radio free-free (bremsstrahlung) emission from wind?

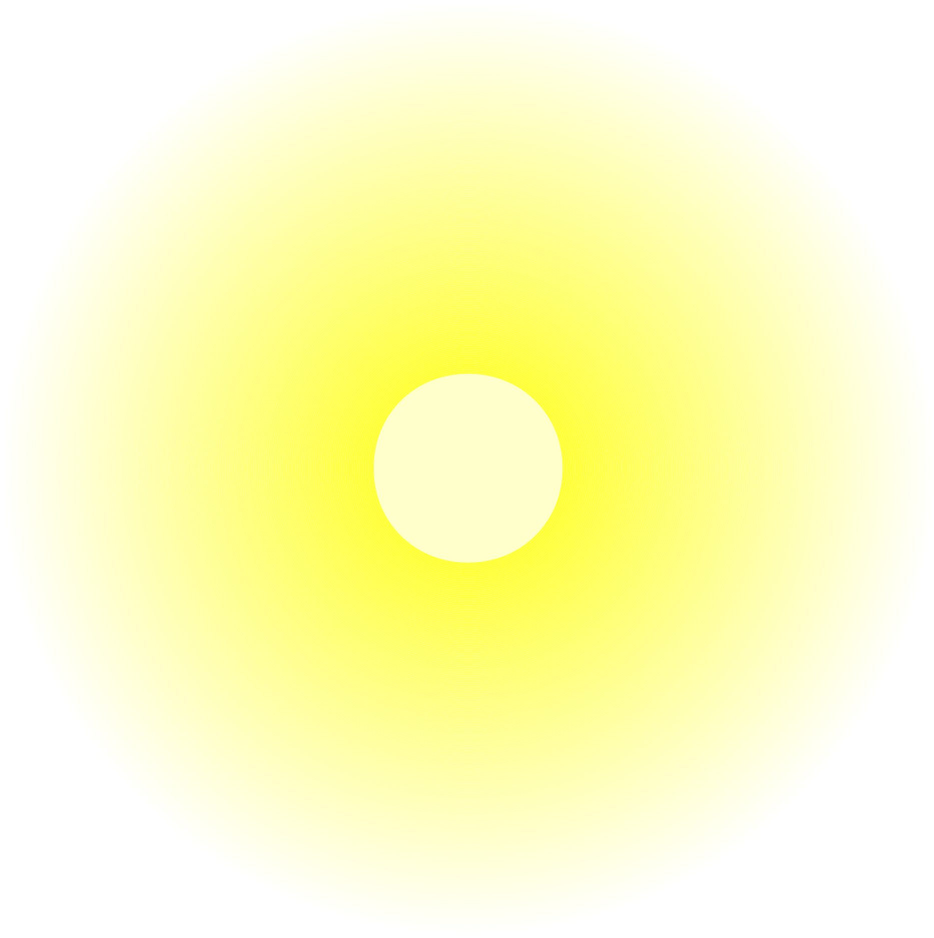


Well-known diagnostic of stellar winds
e.g. Wright & Barlow 1975, Panagia & Felli 1975

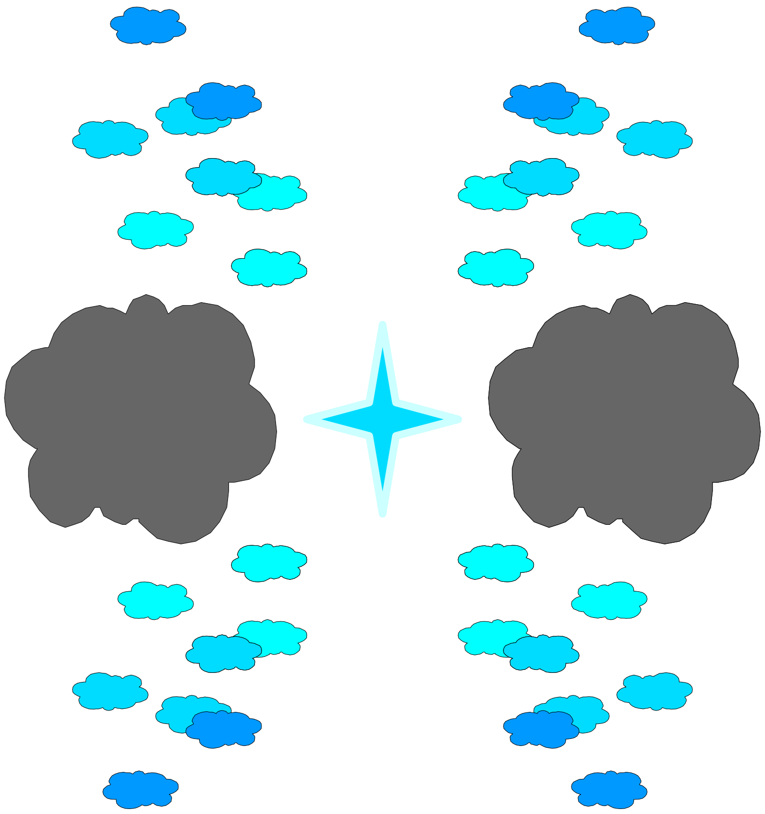
Recently suggested for AGN: Blundell & Kuncic 2007

We have now applied this to winds in a group of nearby AGN

Stellar: uniform spherical wind



AGN wind: partially covering, clumpy



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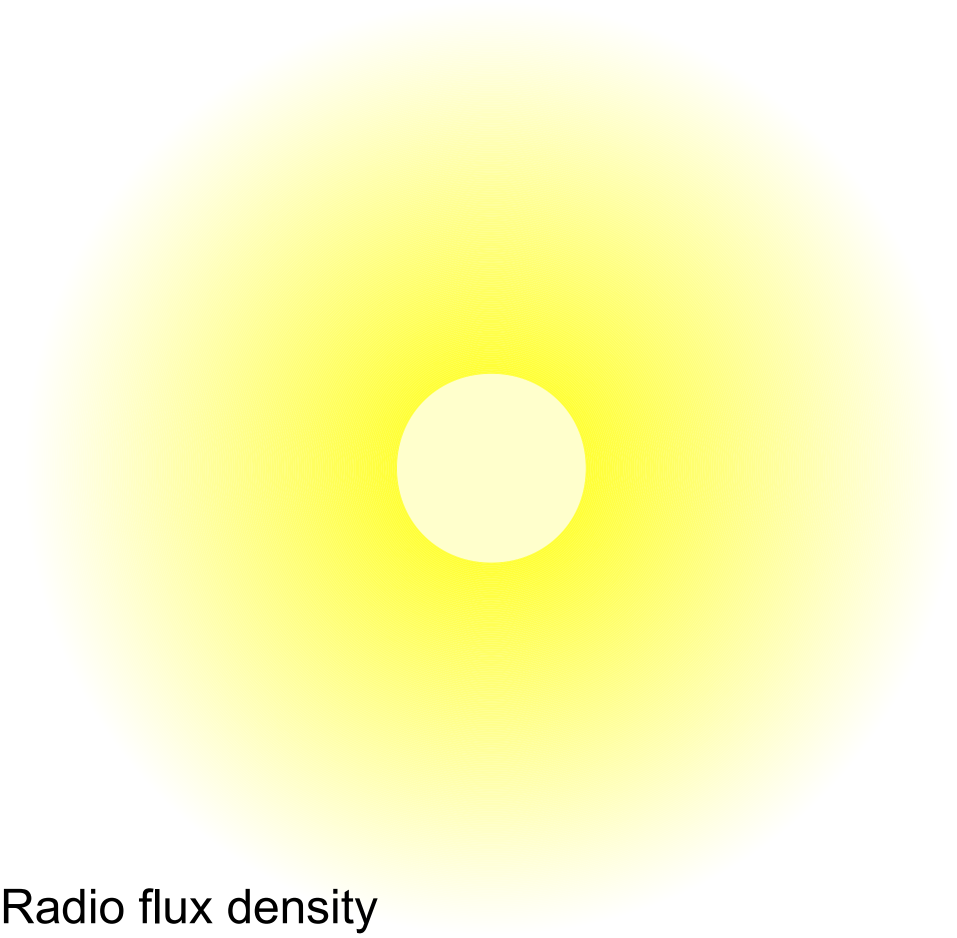


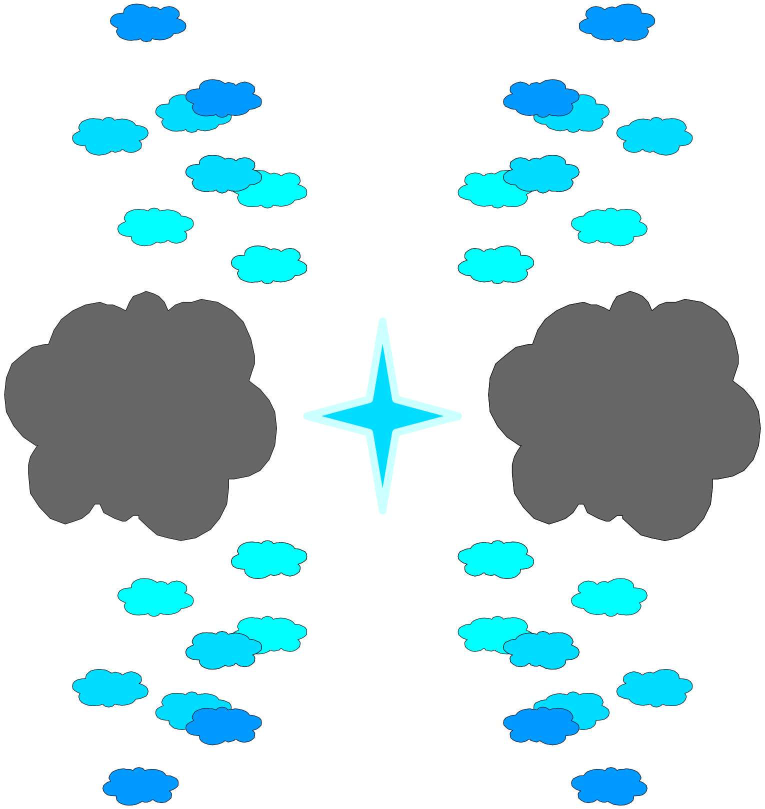
Radio flux density

$$S_{\nu,4\pi} \propto \dot{M}_{4\pi}^{4/3}$$

Mass outflow rate

Wright & Barlow 1975
Panagia & Felli 1975

AGN wind: partially covering, clumpy



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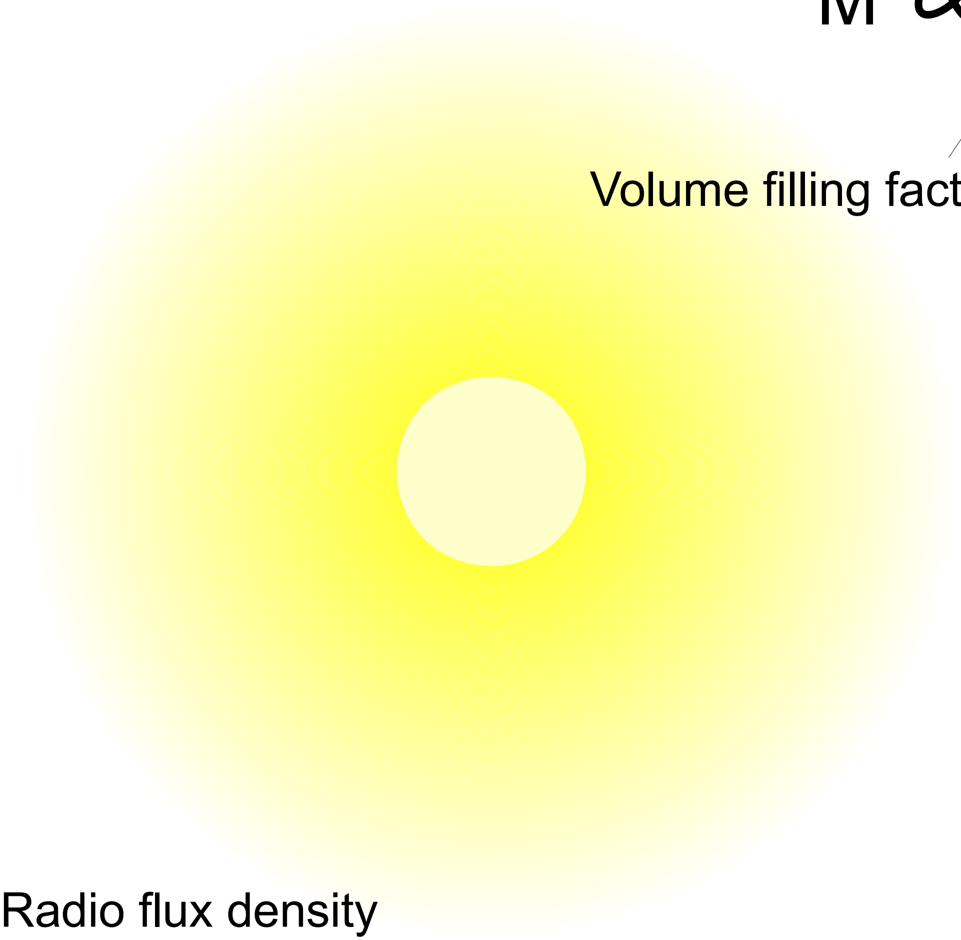

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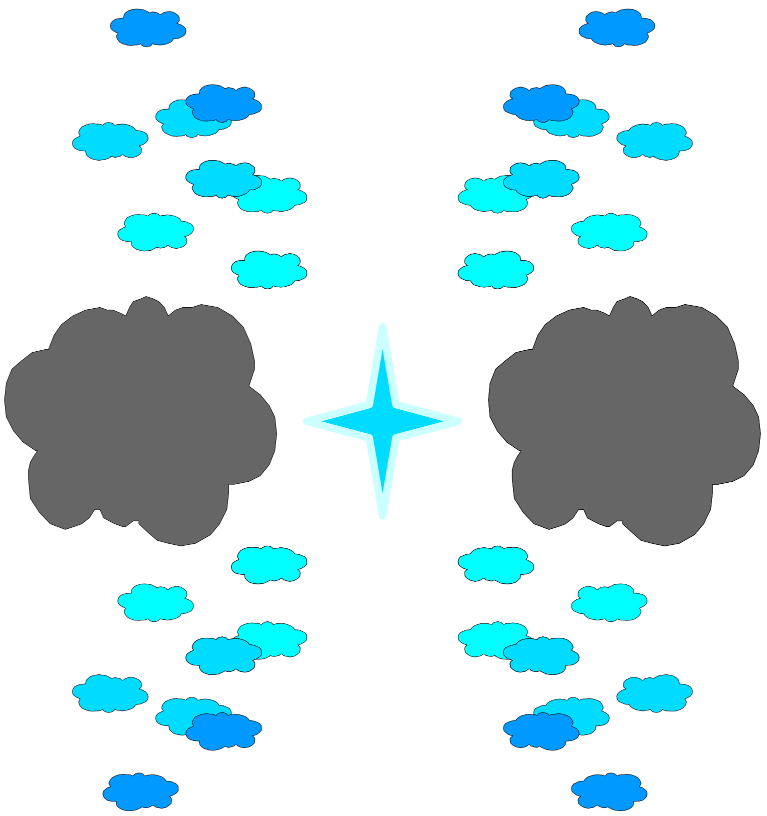
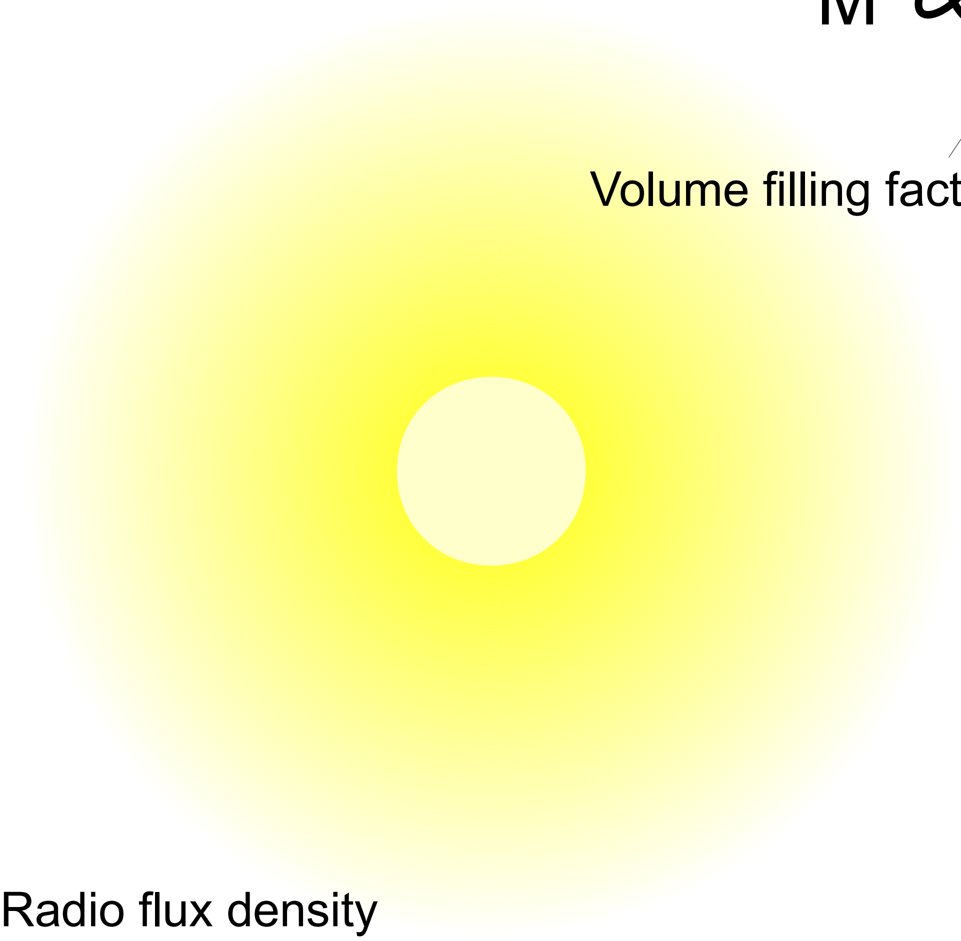
Covering factor

$$\dot{M} \propto C_v \Omega$$

Volume filling factor



Stellar: uniform spherical wind



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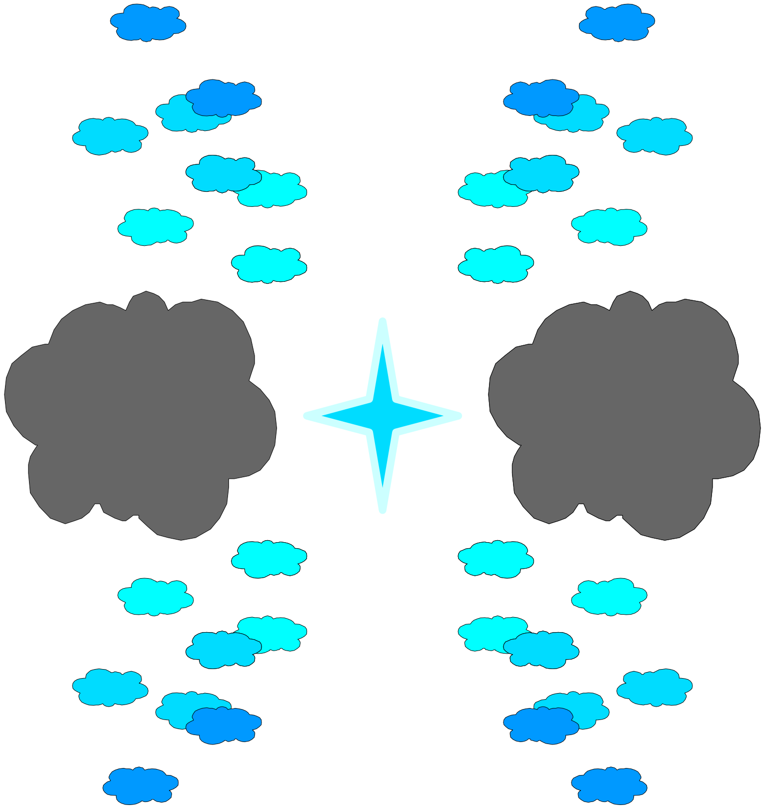
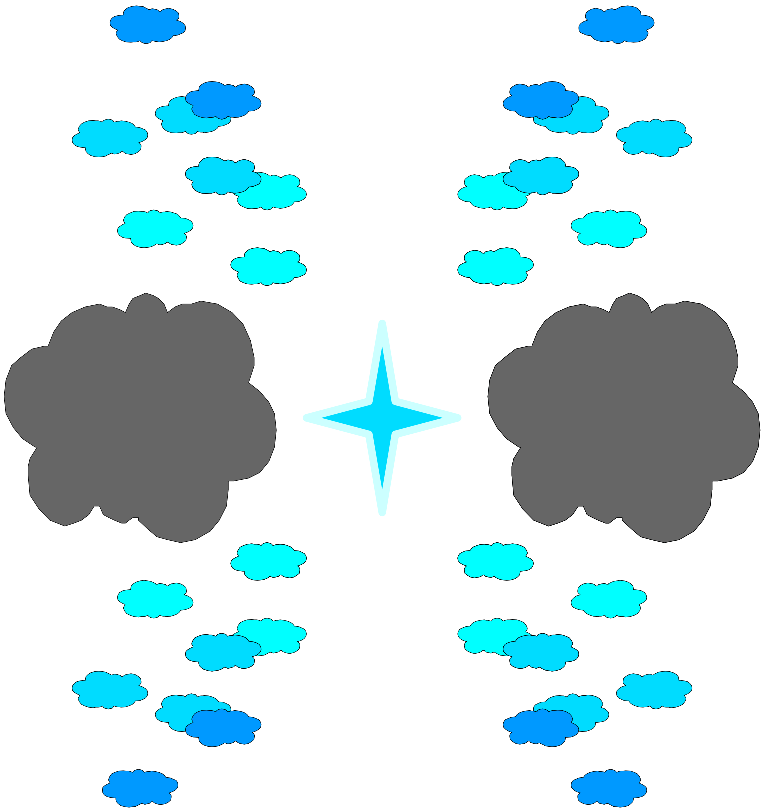
Volume filling factor



$$\boxed{S_{\nu,\mathrm{obs}} \propto (C_v \Omega)^{4/3} \dot{M}_{4\pi}^{4/3}}$$



Observed AGN 1.4 GHz
radio flux density

Covering factor

$$C_v \Omega = \left(\frac{S_{\nu,obs}}{S_{\nu,4\pi}} \right)^{\frac{3}{4}}$$

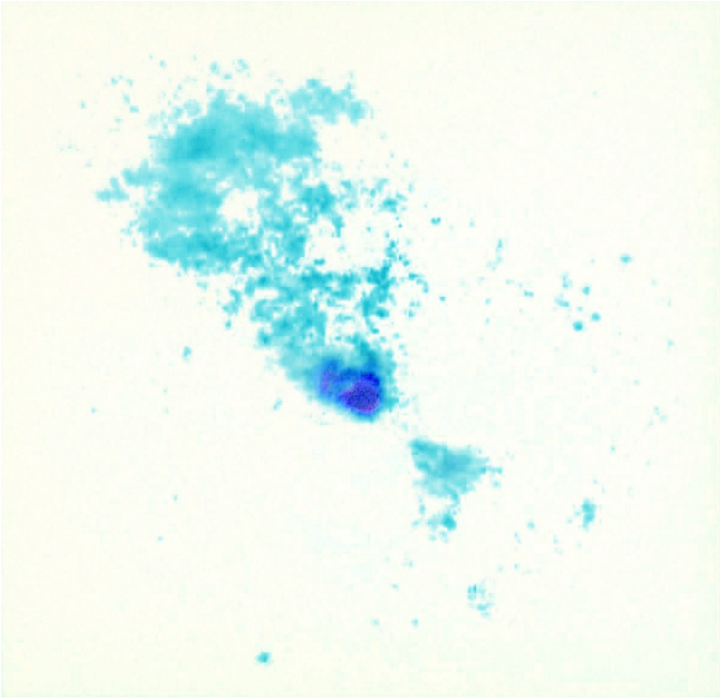
Volume filling factor

AGN 1.4 GHz radio flux density
predicted for a spherical uniform wind

What is the value of global covering factor Ω?

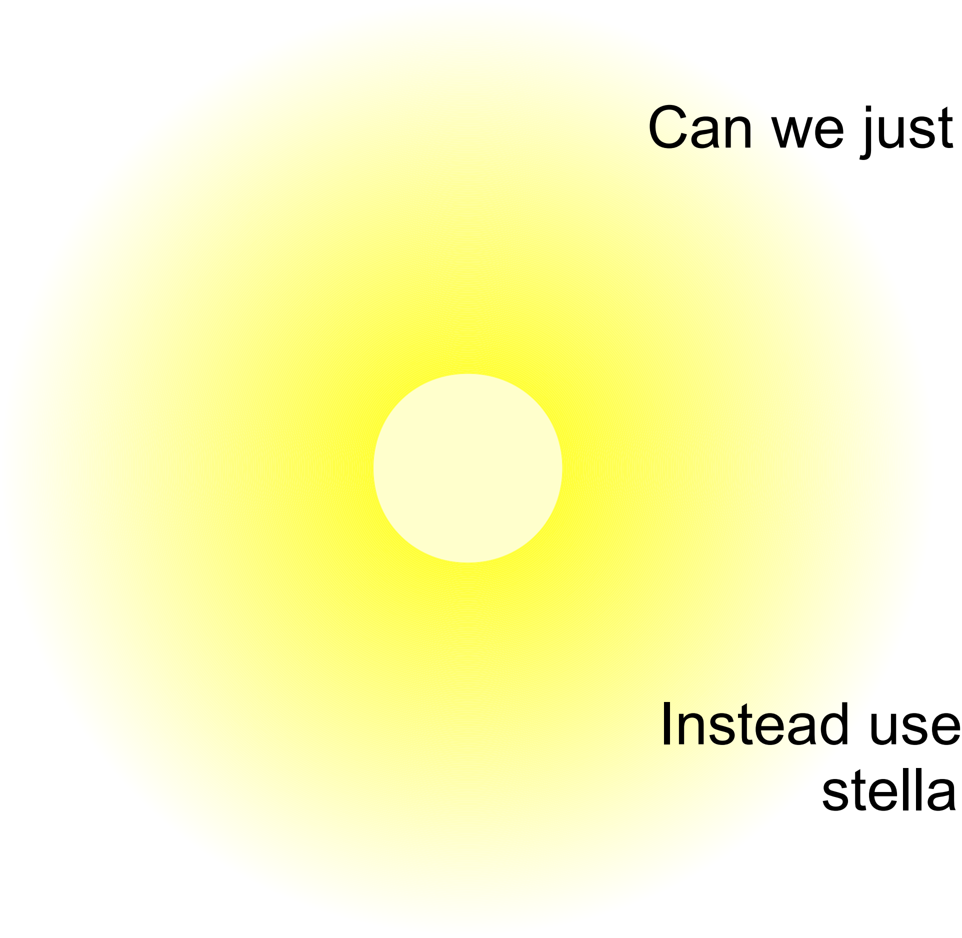
50% of nearby Seyferts have warm absorbers,
so could be $4\pi/2 = 2\pi$

BUT



if the winds are related to the (base of) the NLR, it has to be smaller than this: 2π x (solid angle of torus hole=proportion of unobscured AGN=25%) = 1.6

Calculating the radio flux density $S_{\nu,4\pi}$



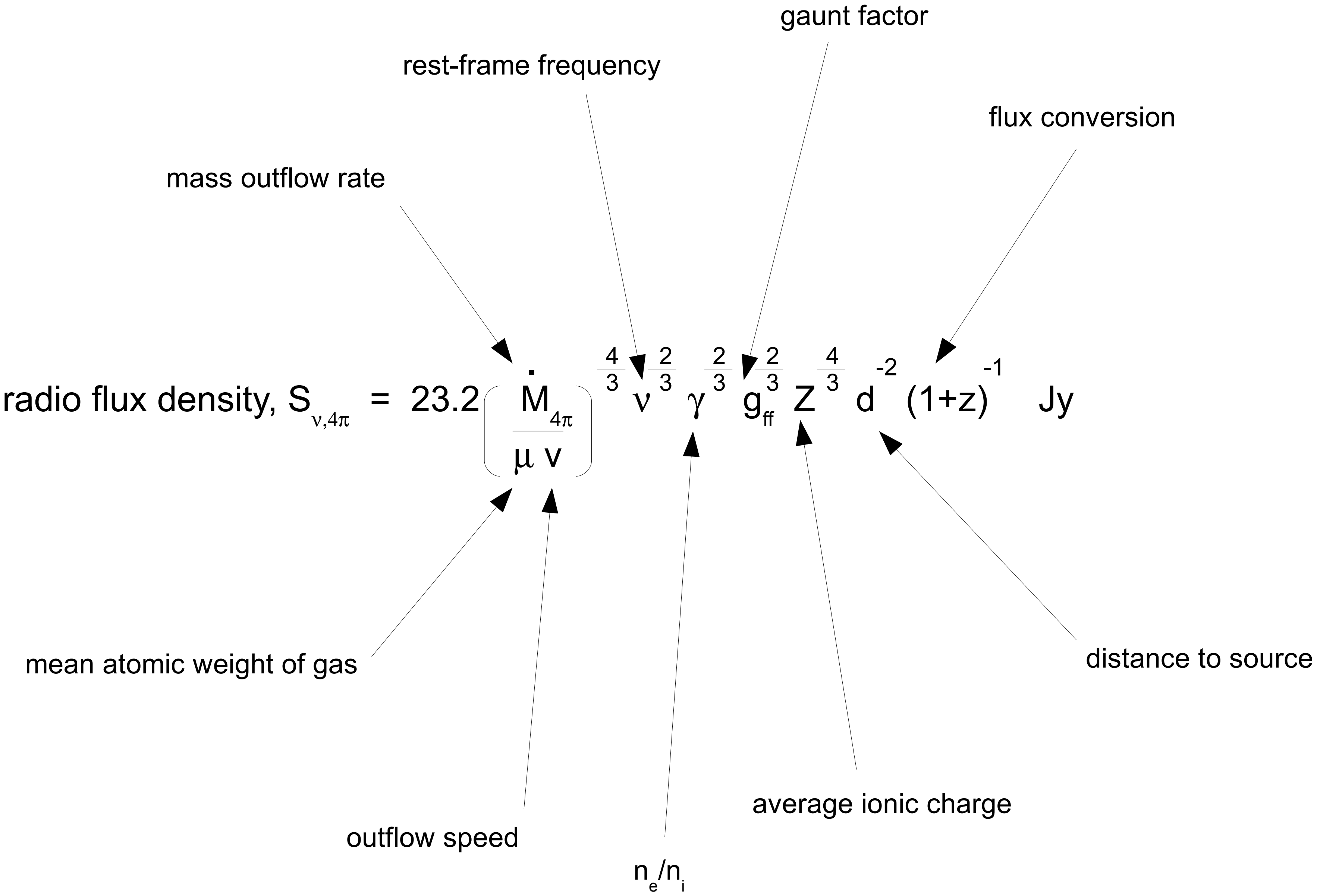
Can we just integrate over bremstrahlung emission?
i.e. optically thin?

No ($\tau >> 1$).

Instead use modified expressions for optically-thick stellar wind emission (Wright & Barlow 1975):

$S_\nu \sim \int$ [blackbody flux x bremsstrahlung absorption] dr

Full expression for S_ν:



gaunt factor

rest-frame frequency

flux conversion

mass outflow rate

$$\text{radio flux density, } S_{\nu,4\pi} = 23.2 \left(\frac{\dot{M}_{4\pi}}{\mu\, v}\right)^{\frac{4}{3}} \nu^{\frac{2}{3}} \gamma^{\frac{2}{3}} g_{ff}^{\frac{2}{3}} Z^{\frac{4}{3}} d^{-2} (1+z)^{-1} \quad \text{Jy}$$

distance to source

mean atomic weight of gas

average ionic charge

outflow speed

n_e/n_i

based on Wright & Barlow 1975

Mass outflow rate for a uniform wind:

$$\dot{M}_{4\pi} = \frac{4\,\pi\, \overset{\text{ionising luminosity}}{L_{ion}}\, \mu\, \overset{\text{proton mass}}{m_p}\, v}{\underset{\text{ionisation parameter}}{\xi}}$$

(For non-outflowing ionised absorber, use substitution:

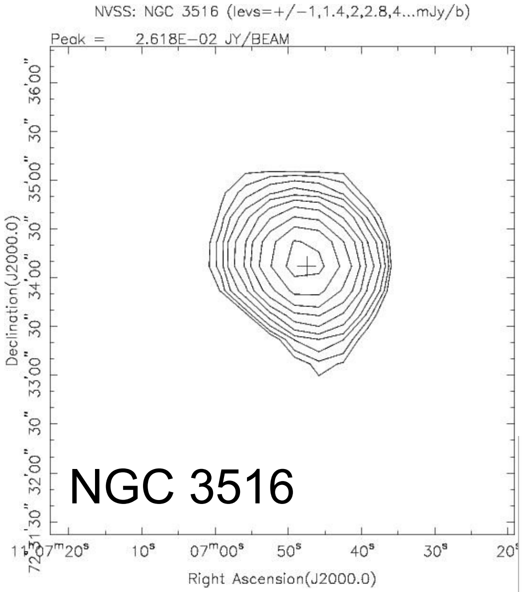
$$\frac{\dot{M}_{4\pi}}{\mu\, v} = 4\,\pi\, m_p\, \frac{L_{ion}}{\xi}$$

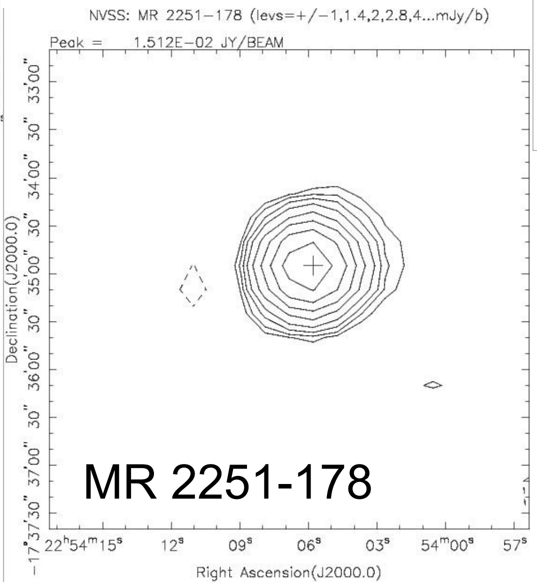
assuming $n \propto r^{-2}$ and ξ is constant)

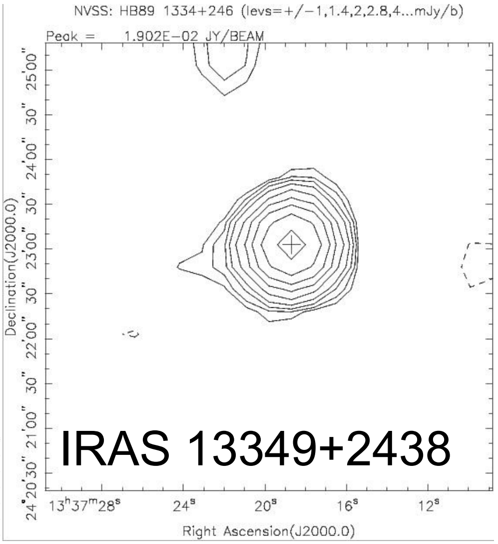
The AGN sample

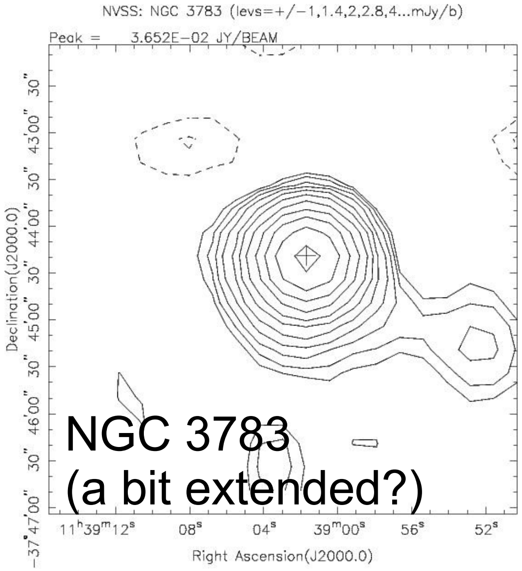
Requirements: ➡ point-like radio source in NVSS image (no host contamination)

➡ Sufficiently well-spectroscopically-studied X-ray absorbing wind


NGC 3516


MR 2251-178


IRAS 13349+2438


NGC 3783
(a bit extended?)

Also MCG-6-30-15 (no NVSS image, but unresolved in VLA; Ulvestad & Wilson 1984)

Upper limits for volume filling factors

Assuming Ω is in range 1.6 - 2π:

		C_v upper limit
NGC 3516	→	0.0002 - 0.3
IRAS 13349+2438	→	0.01 - 0.5
MR 2251-178	→	0.04 - 0.1
MCG-6-30-15	→	0.006 - 0.02
NGC 3783	→	(none; predicted radio flux lower than observed; host galaxy emission from extended source?)

(Not all phases predicted to produce sufficient flux to obtain an upper limit to C_v)

Conclusion

When calculating the mass outflow rate of an AGN wind, we can't safely assume a volume filling factor of unity;

This will cause us to overestimate the wind's contribution to feedback.

For more details, see:

Blustin & Fabian 2009, MNRAS in press, arXiv/0904.0209