The Circinus Galaxy

Shedding X-ray light on the energetics of AGN outflows

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The X-ray Universe 2011, Berlin

University of Hertfordshire

Outline

- Why?
- Where?
- How?
- What?
- When?

Why?
Where?
How?
What?
When?

Bubbles and shocks (small sources)

- Jet → ISM E transfer
  - Age ~ 10^6-10^8 yr
  - E ~ 10^56 erg
- Overpressure, T jump

  → shocks
  - M ~ 3-6

•Energetics (Jet + lobes/bubbles + shock)

•Timescales

•Feedback, SF triggering/quenching

•Power/mass scaling

•Morphology dependence

Centaurus A
(Kraft et al. 2003, Croston et al. 2009)

Why?
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What?
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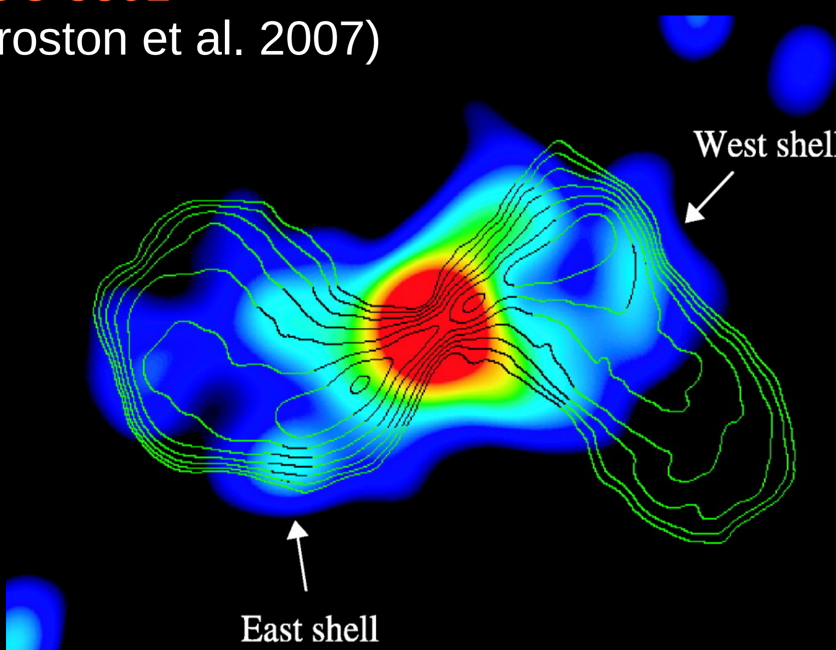
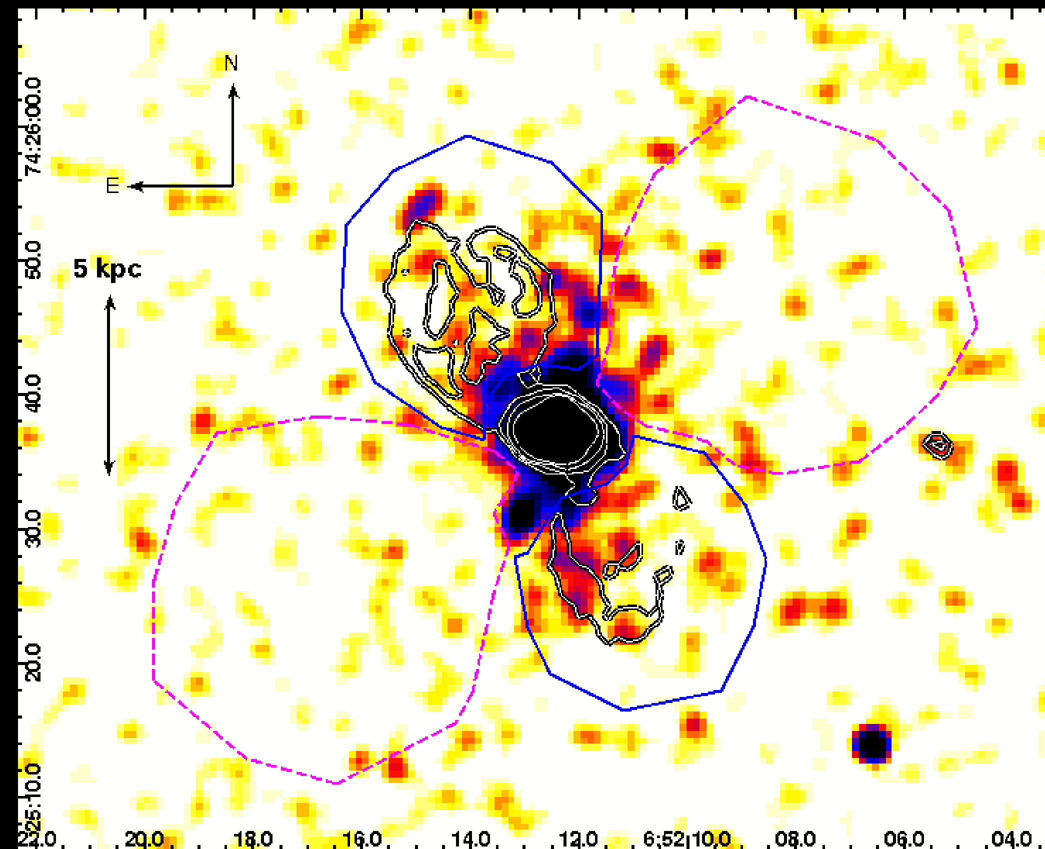
Bubbles and shocks (small sources)

NGC 3801
(Croston et al. 2007)



Markarian 6
(Mingo et al. 2011)



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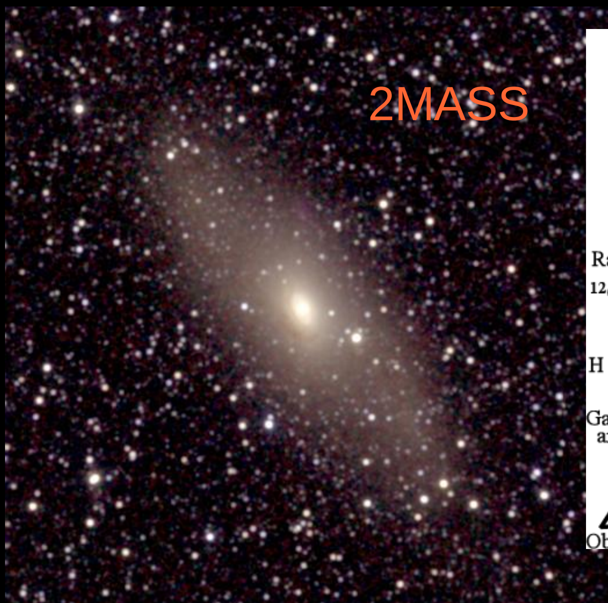
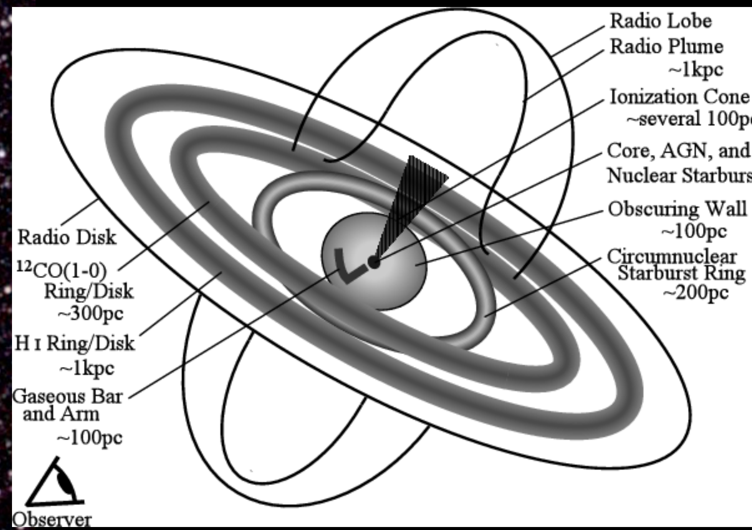
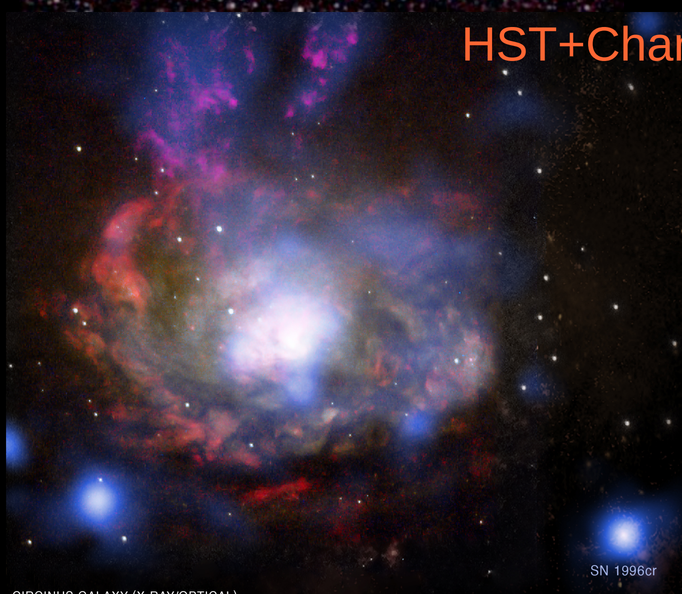
The Circinus galaxy

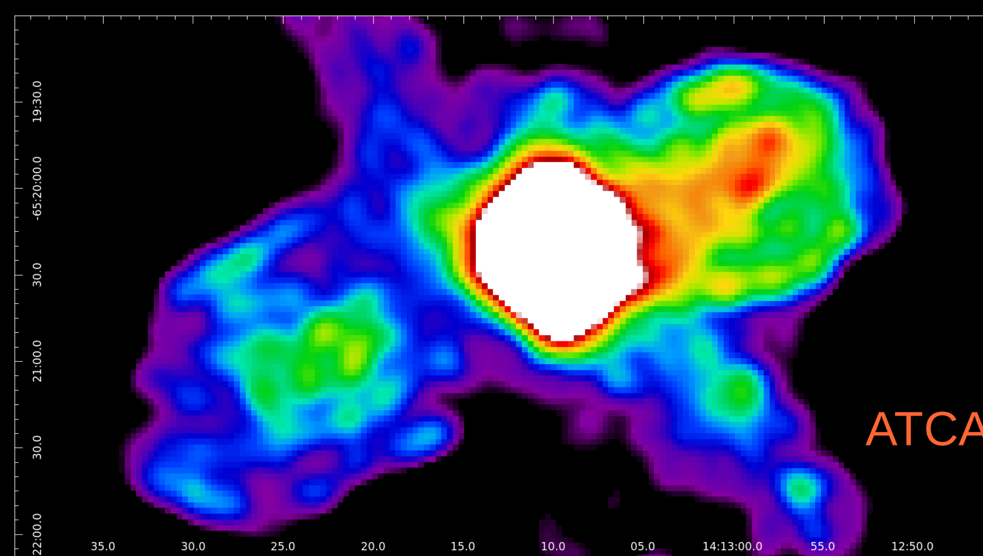




Ohsuga & Umemura 2001

- D ~4Mpc
- Sy 2
- $L_{(1.4GHz)}$ =2.2x10^20 W Hz^-1 sr^-1
- M ~10^11 M_{Sol}





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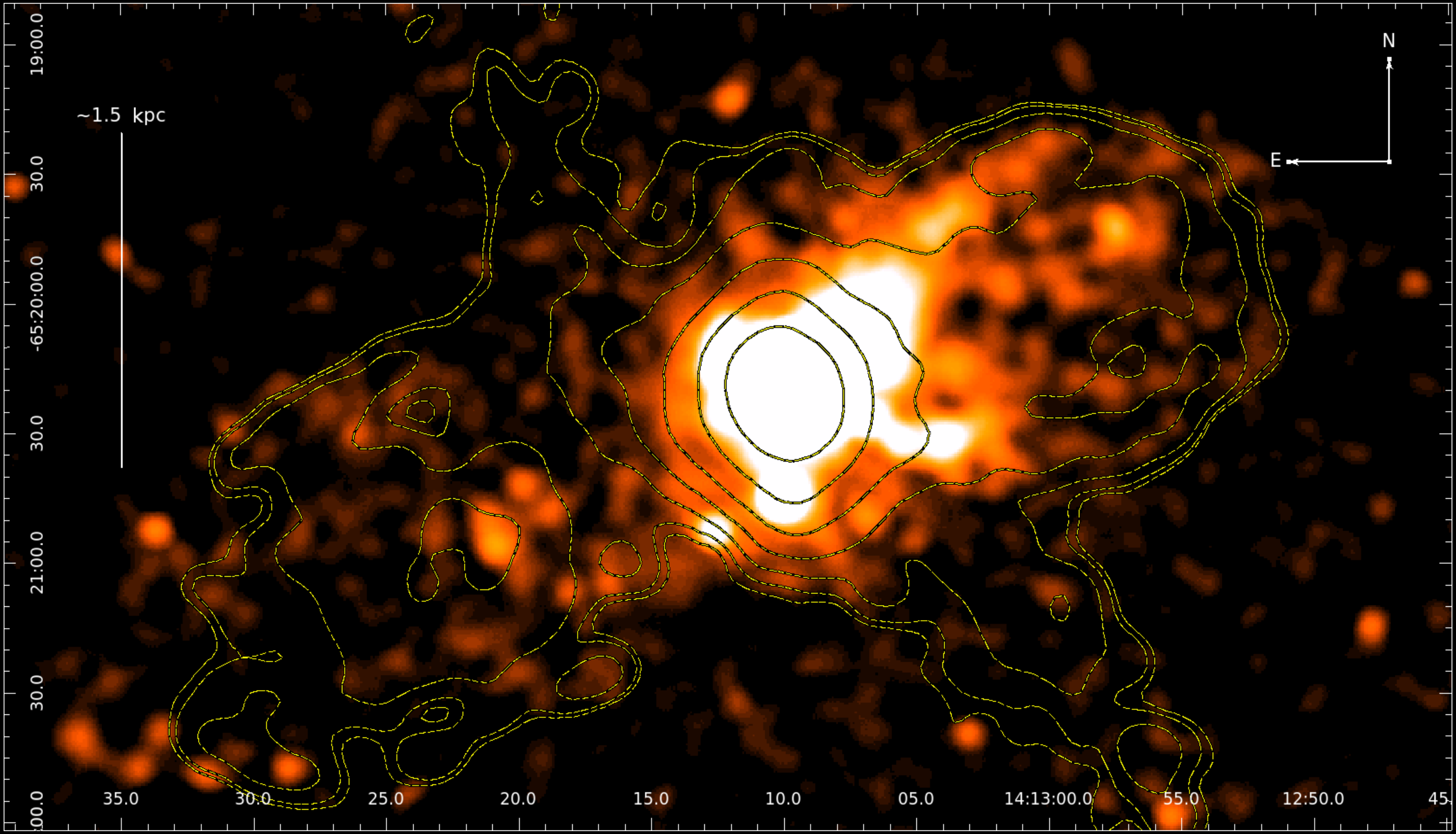
The Circinus galaxy



The Circinus galaxy

Shock heating $\frac{\rho_{out}}{\rho_{shell}} \rightarrow \frac{\Gamma+1}{\Gamma-1}=4$

$$M=\sqrt{\frac{4(\Gamma+1)(T_{shell}/T_{out})+(\Gamma-1)}{2\Gamma}}$$

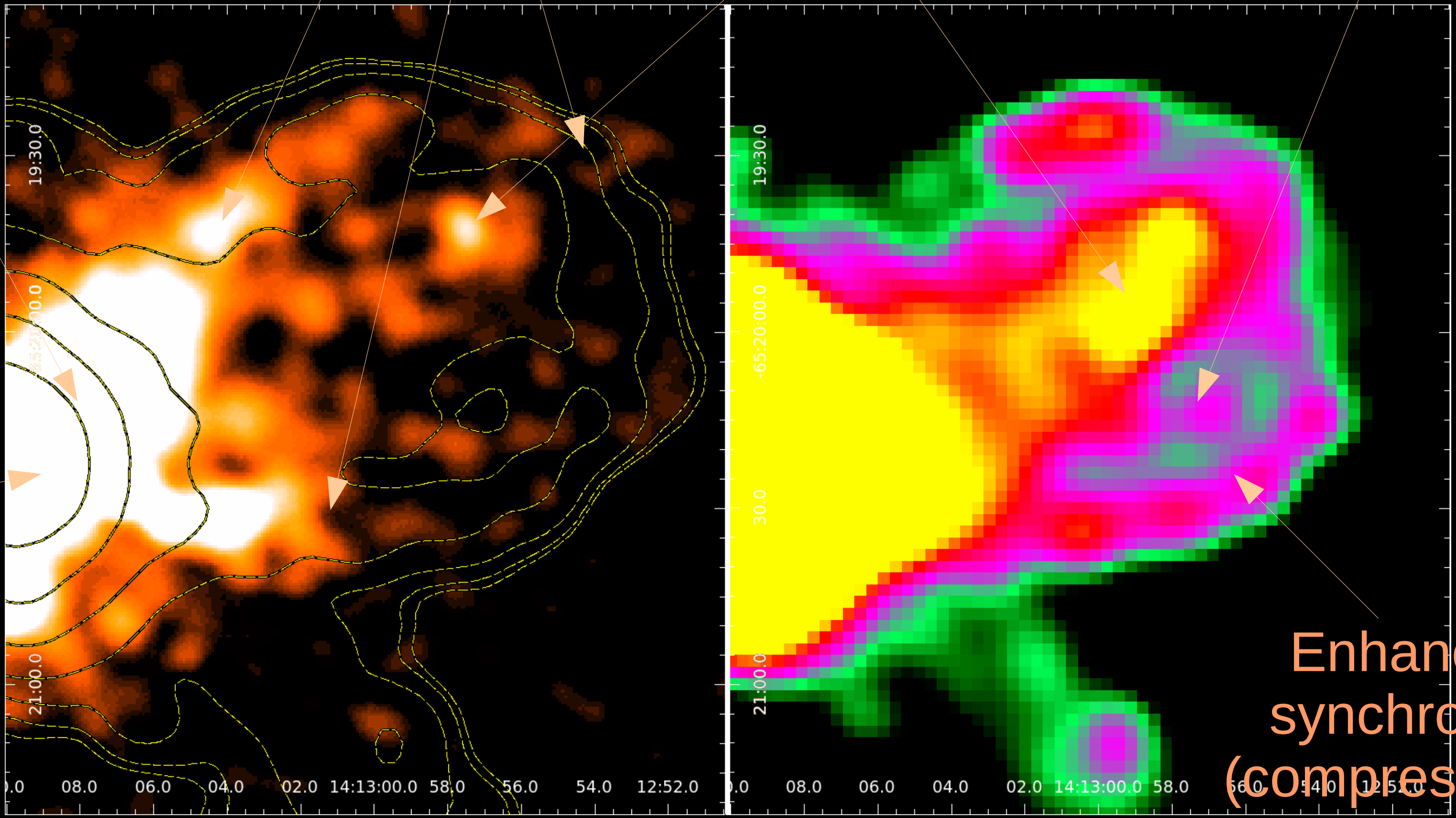
Synchrotron

$$\nu_s=\frac{\gamma^2 e B}{2\pi m_e c} \qquad \tau=\frac{5\times10^8}{B^2\gamma}\ s$$

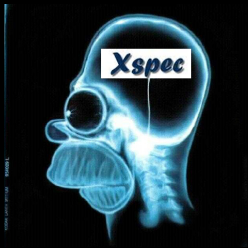
Photoionization

Hotspot (?)

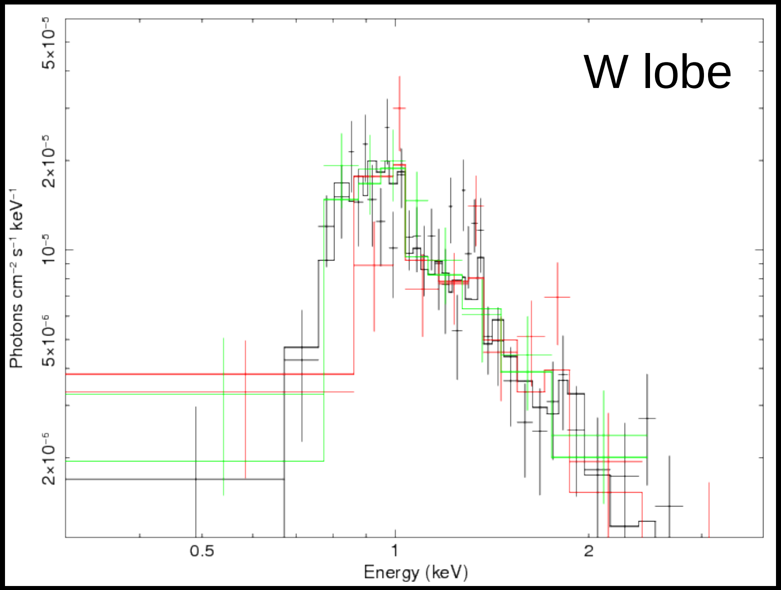
AGN

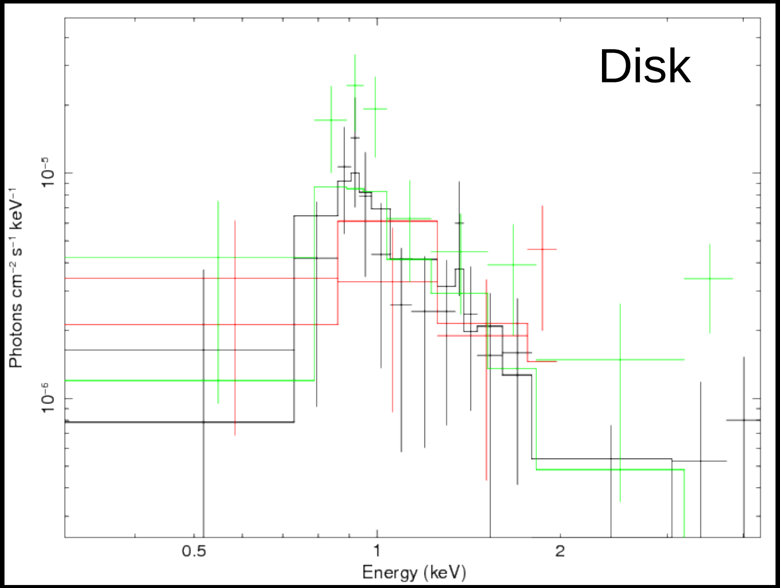


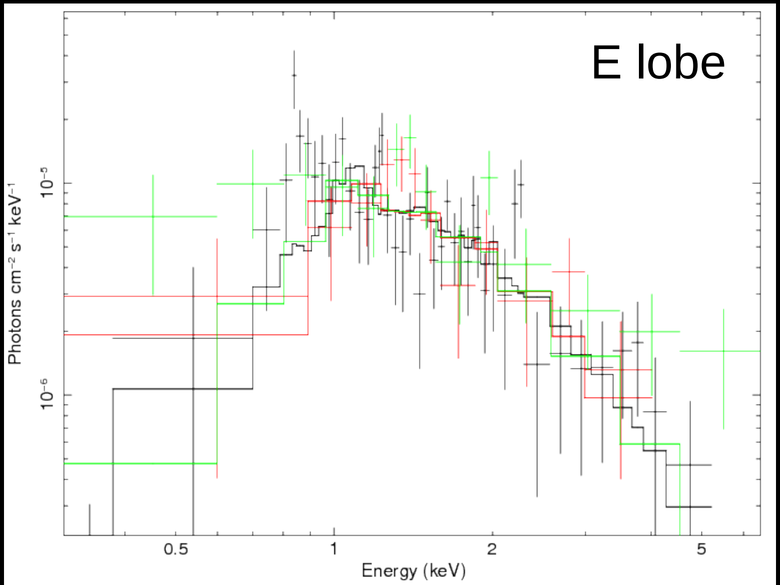
Enhanced synchrotron (compression + B amplification)



Analysis







The emission from the halo gas is too faint!

→ Radial luminosity profile

→ Constraints on luminosity and temperature of the halo gas from statistical studies of halos of spiral galaxies (e.g. Tullmann et al. 2006)
+ known properties of Circinus (Elmouttie et al. 1996, 1997; Wilson et al. 2000; Curran et al. 2008)

→ Consistent with a strong shock ?

Results - shells

- Shocked shells: ellipsoids with two equal axes
  - W: $R_{int,min}$=0.51 kpc; $R_{int,maj}$=0.89 kpc; $R_{ext,min}$=0.60 kpc; $R_{ext,maj}$=1.05 kpc → V=6.05x10^8 pc^3
  - E: $R_{int,min}$=0.61 kpc; $R_{int,maj}$=0.93 kpc; $R_{ext,min}$=1.03 kpc; $R_{ext,maj}$=1.57 kpc → V=5.50x10^9 pc^3
- Normalization for *apec*:

$$\frac{10^{-14}}{4\pi[D_A(1+z)]^2}\int n_e n_H \, dV$$

$$n_e \sim 1.18\, n_p$$

Results - shells

Table 1: Results for the shells of Circinus, for the temperatures discussed in the text. The columns, from left to right, show the shell, temperature, model normalization, electron density, mass, pressure, total thermal energy, work available from the gas filling the shells and total kinetic energy.

Shell	kT	Norm	N_e	M	P	E	PV	K
	keV	$\times 10^{-4}$ cm^{-5}	$\times 10^{-2}$ cm^{-3}	$\times 10^{36}$ Kg	$\times 10^{-12}$ Pa	$\times 10^{54}$ erg	$\times 10^{54}$ erg	$\times 10^{53}$ erg
W	$0.74^{+0.07}_{-0.05}$	$1.39^{+0.24}_{-0.13}$	$4.41^{+0.20}_{-0.21}$	$1.06^{+0.05}_{-0.05}$	$9.22^{+0.44}_{-0.46}$	$2.46^{+0.12}_{-0.12}$	$1.64^{+0.08}_{-0.08}$	$2.78^{+0.13}_{-0.14}$
E	0.8	$1.30^{+0.12}_{-0.12}$	$4.07^{+0.19}_{-0.18}$	$1.03^{+0.04}_{-0.05}$	$9.64^{+0.46}_{-0.46}$	$23.4^{+1.1}_{-1.1}$	$15.6^{+0.7}_{-0.8}$	$2.90^{+0.14}_{-0.14}$
E	1.8	$1.08^{+0.12}_{-0.12}$	$3.70^{+0.21}_{-0.20}$	$0.93^{+0.06}_{-0.05}$	$19.7^{+1.1}_{-1.0}$	$21.3^{+1.1}_{-1.2}$	$31.9^{+1.8}_{-1.7}$	$2.64^{+0.14}_{-0.14}$

Mingo et al. (in prep.)

W shell is much larger!

- What is contributing to the large residuals?
- What is the nH column?

Results – external medium

Table 2: Results for the external medium. The columns, from left to right, show the low/high values of the gas temperature, model normalization, electron density, luminosity and gas pressure.

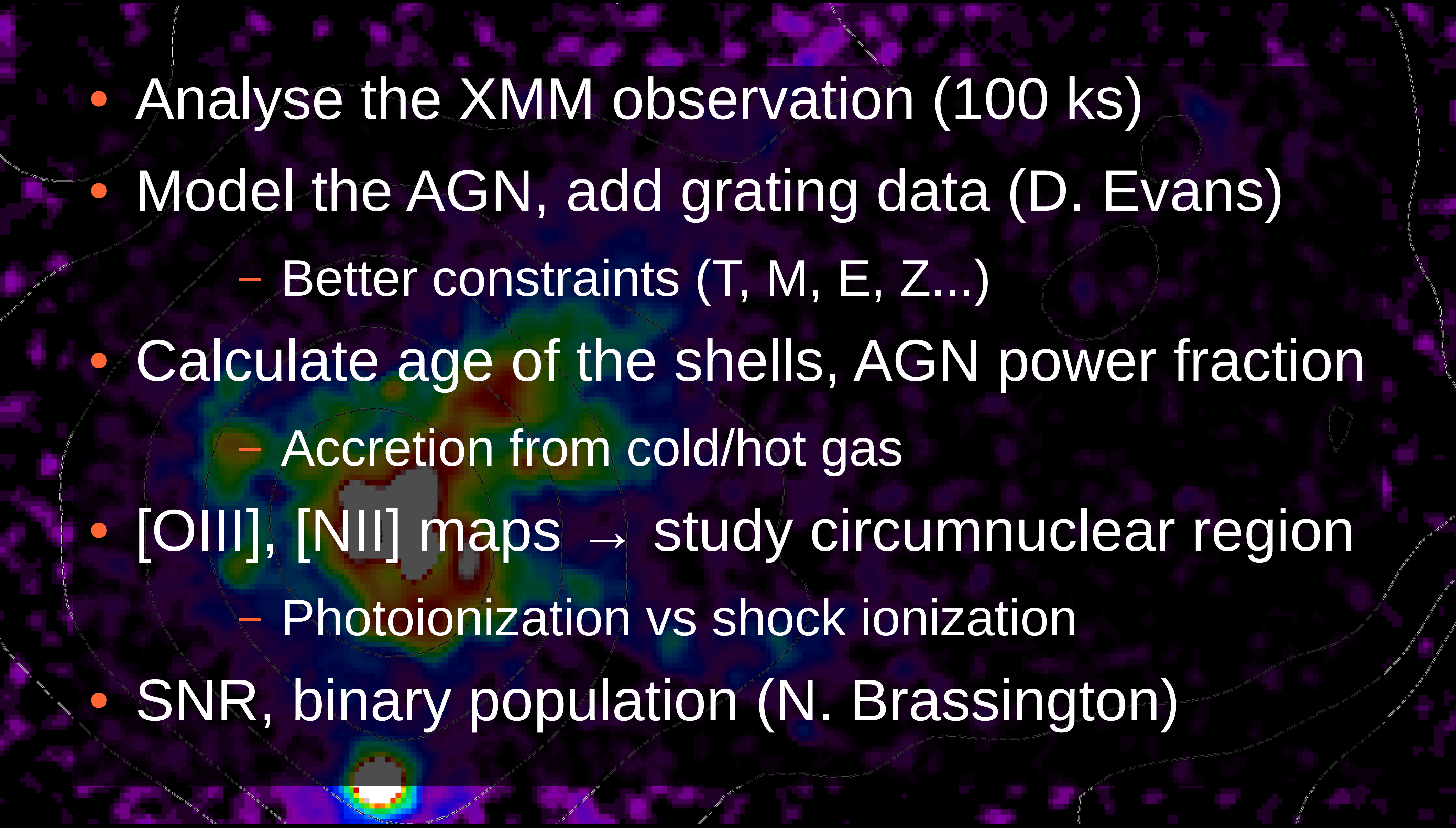
kT	Norm	N_e	$L_{0.2-3keV}$	P
keV	$\times 10^{-2}$ cm^{-5}	$\times 10^{-2}$ cm^{-3}	$\times 10^{38}$ erg s^{-1}	$\times 10^{-12}$ Pa
0.1	2.80/5.70	2.35/3.35	0.71/1.45	0.70/0.99
0.2	1.00/2.10	1.40/2.03	5.30/10.70	0.83/1.20
0.3	0.33/0.66	0.80/1.14	5.04/10.07	0.72/1.01

Mingo et al. (in prep.)

- W: M~2.6-3.6; c~260 km/s; v=915 km/s
- E: M~2.8-5.3; c~260 km/s; v=950 km/s

Shock scenario works!

Future work



- Analyse the XMM observation (100 ks)
- Model the AGN, add grating data (D. Evans)
  - Better constraints (T, M, E, Z...)
- Calculate age of the shells, AGN power fraction
  - Accretion from cold/hot gas
- [OIII], [NII] maps → study circumnuclear region
  - Photoionization vs shock ionization
- SNR, binary population (N. Brassington)

Conclusions

- Radio galaxies are our friends
- Circinus is (most likely) shocking, with M~2.5-5
  - Photoionization / stellar superwinds unlikely
- Results are compatible with Cen A, NGC 3801, and Mrk 6, with power scaling
- Radio/X-ray match suggests that the shock is powering synchrotron emission in the shells → seen in SNR, expected for radio galaxies, but not observed before! → would explain what is observed at larger distances (e.g. Mrk 6)