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Feeding and Feedback in Radio Galaxies and Mergers: an X-ray Perspective

Francesco Tombesi

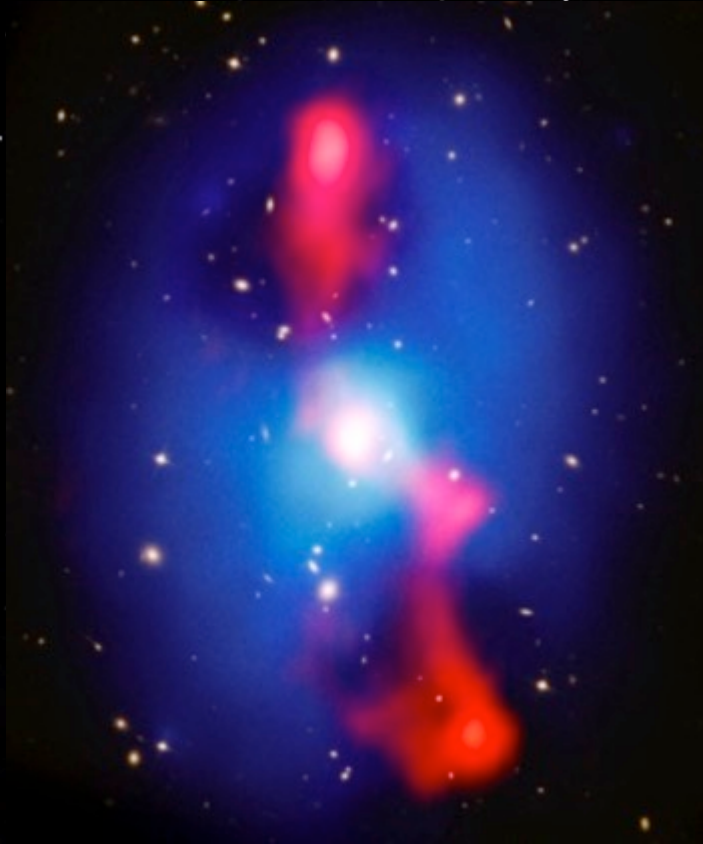
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NASA - Goddard Space Flight Center

University of Maryland, College Park

Flavors of black hole feedback

Relativistic jets

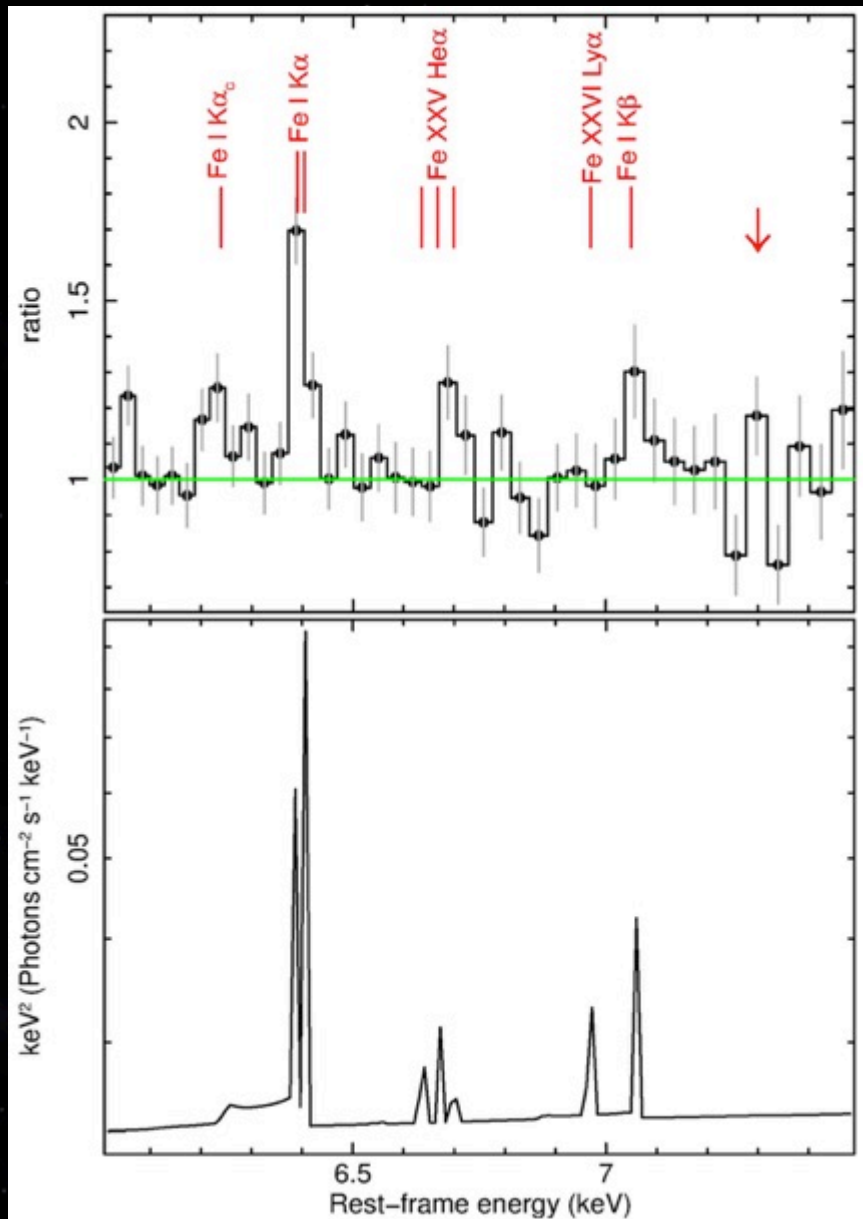


Disk winds



- Large program Chandra HETG, 3C 390.3, 3C 120, 3C 111
- Most radio-loud AGN are (minor) mergers (Chiaberge et al. 2015)

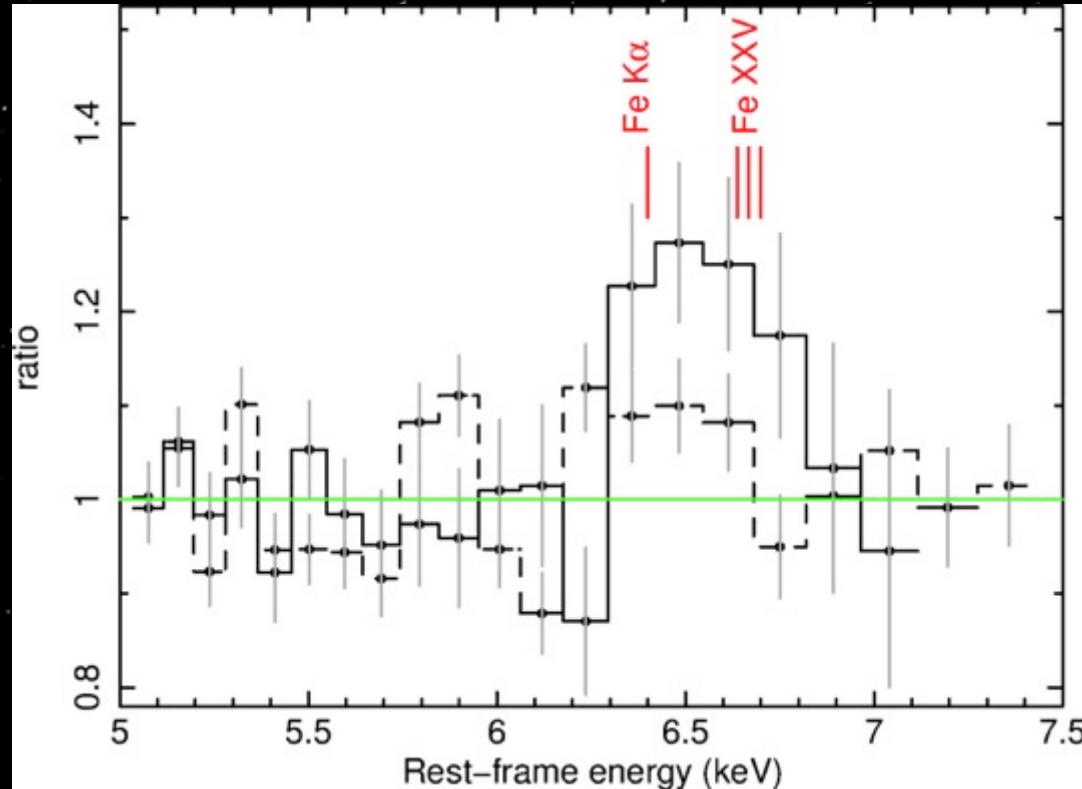
Feeding: Fe K emission lines in 3C 120



- Series of neutral/ionized Fe K lines (including Fe K Compton shoulder)
- Fe K α FWHM $\sim$ 2,300 km/s, comparable to optical BLR ($i\sim 20^\circ$)
- $R=0.22\pm 0.04$, $N_H > 6 \times 10^{24}$ cm⁻²
- Compton thick equatorial clumps?
- Ionized emitter $\log \xi \sim 3.7$ at $< \sim 2$ pc
- Ionized absorber $v_{\text{out}} \sim 20,000$ km/s, $\log \xi \sim 3.5$ erg s⁻¹ cm, $N_H \sim 3 \times 10^{21}$ cm⁻²
- Emission/absorption from disk wind?

(Tombesi et al. 2017)

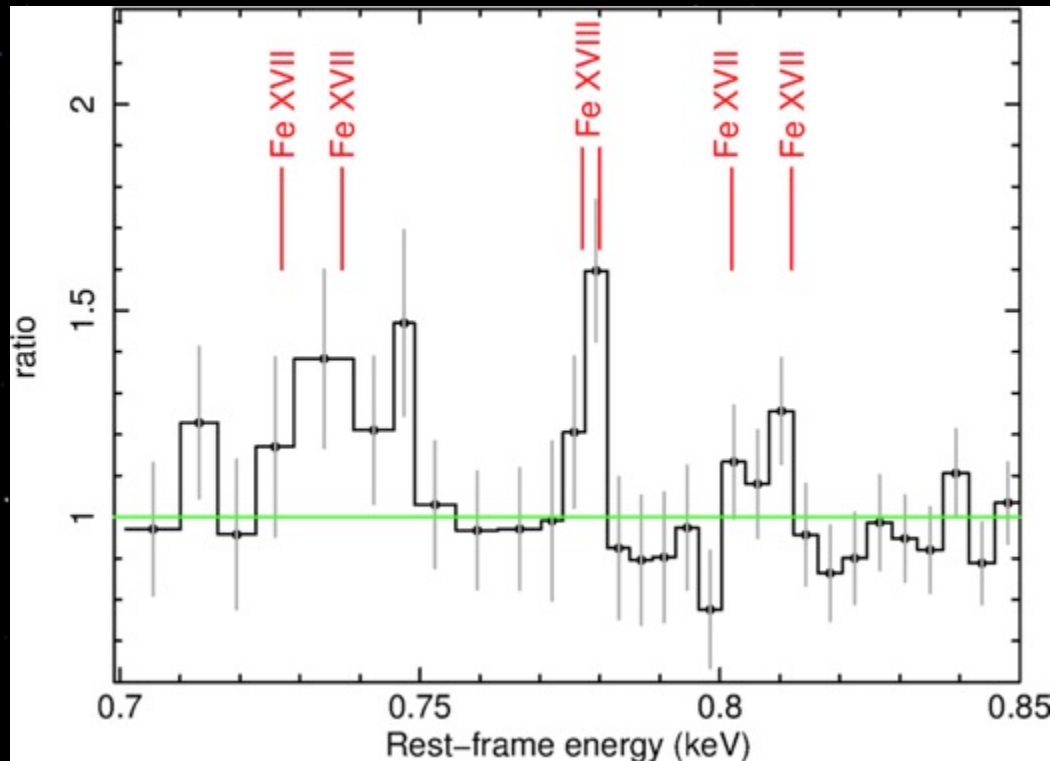
Feeding: Fe K emission lines in 3C 390.3



(Tombesi et al. 2016)

- Fe K α $E=6.40\pm0.4$ keV, $\text{FWHM}=8,300\pm3,300$ km/s
- Lowly ionized, high column (*xillver*) reflection $\log\xi=1.3\pm0.3$ erg s $^{-1}$ cm
- Line width consistent with optical H α , origin in BLR or outer accretion disk?

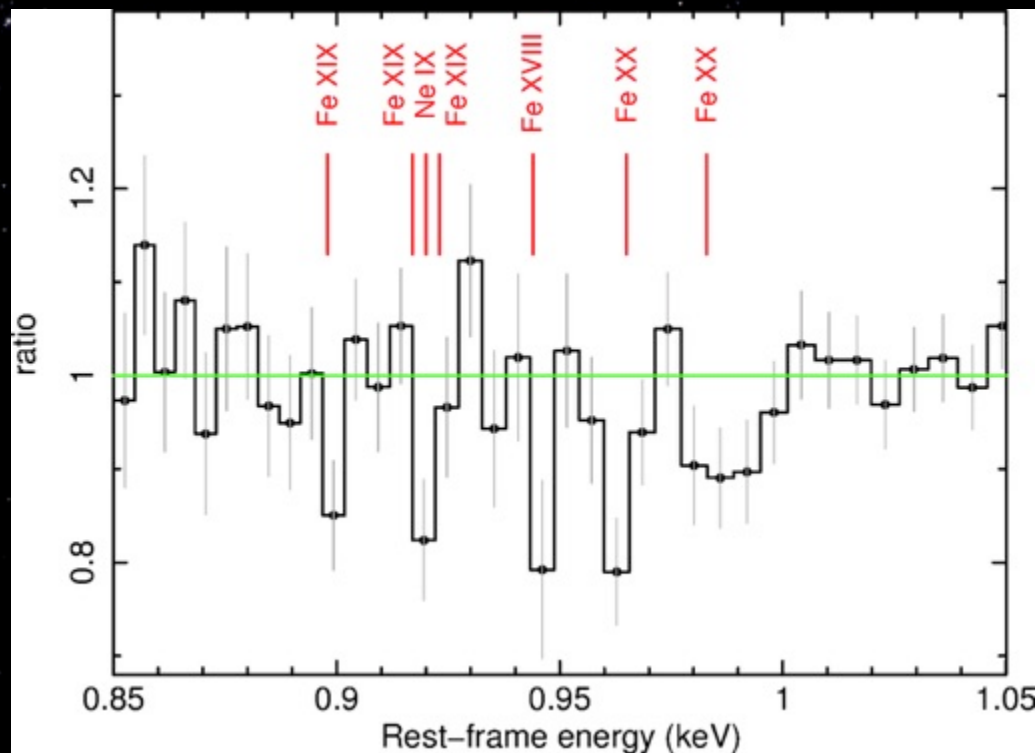
Feedback: soft X-ray emission lines in 3C 390.3



(Tombesi et al. 2016)

- Series of emission lines due to Fe L transitions (Fe XVII-XVIII)
- Hot ISM emission, $kT=0.5\pm0.1$ keV, FWHM $\sim 3,000$ km/s
- Luminosity $L_{\text{ISM}} \sim 3 \times 10^{42}$ erg/s, $t_{\text{cool}} \sim 10^{7-8}$ yrs. What is the heating source?
- Mechanical energy from AGN jet/disk wind is $L_K \sim 10^{44-45}$ erg/s

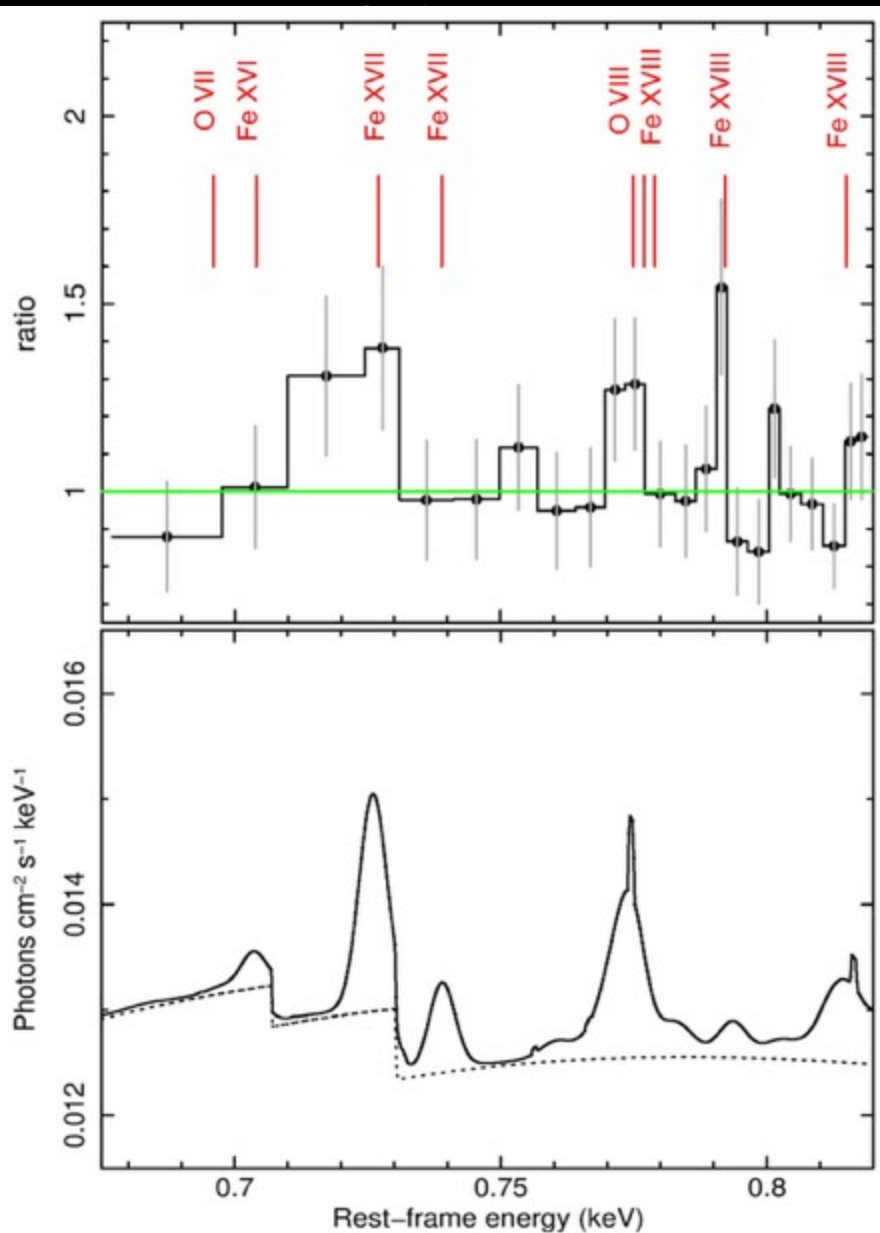
Feedback: soft X-ray absorption lines in 3C 390.3



(Tombesi et al. 2016)

- Series of absorption lines from higher Fe L transitions (Fe XVIII, Fe XIX, Fe XX)
- Warm absorber? $\log N_H = 20.7 \pm 0.1 \text{ cm}^{-2}$, $\log \xi = 2.3 \pm 0.5$, $v_{\text{out}} < 150 \text{ km s}^{-1}$
- $R \sim 3.5 \text{ pc} - 3.5 \text{ kpc}$, $P_{\text{wa}} \sim 0.001\% L_{\text{bol}}$

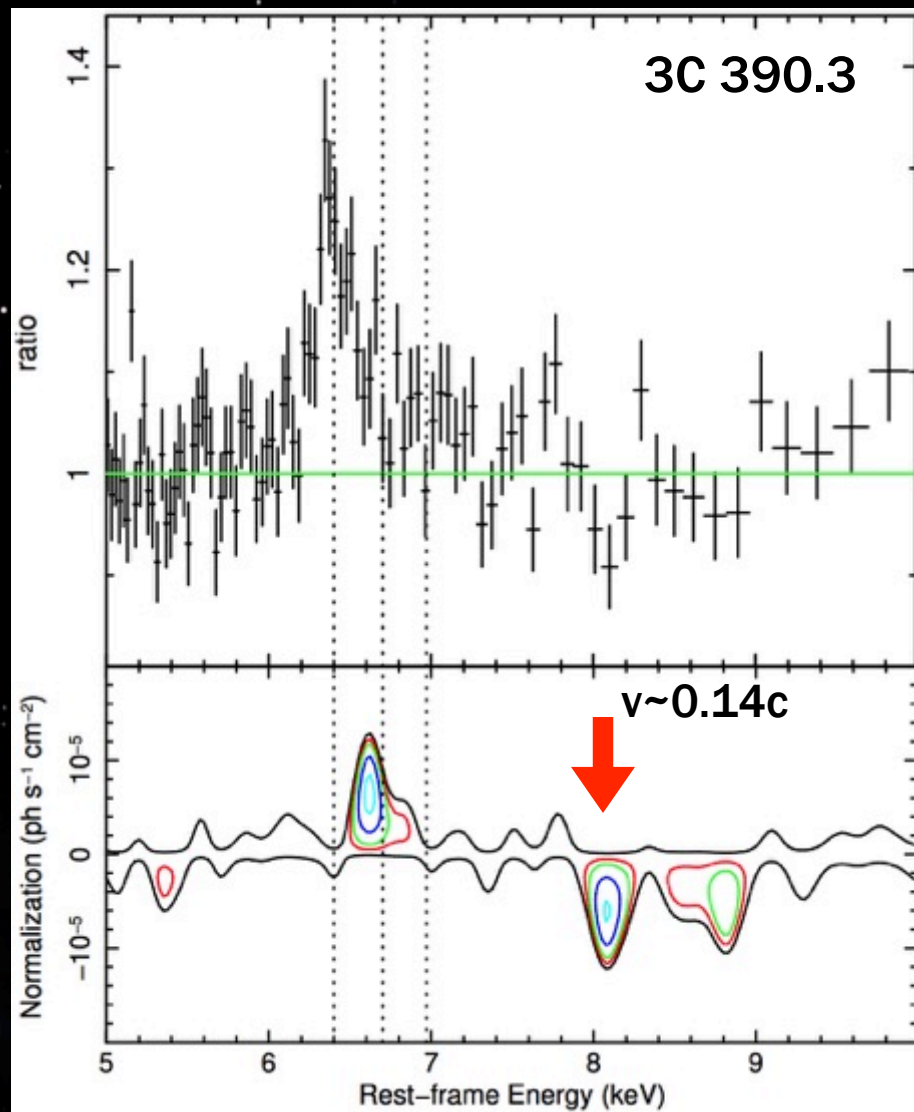
Feedback: soft X-ray emission lines in 3C 120



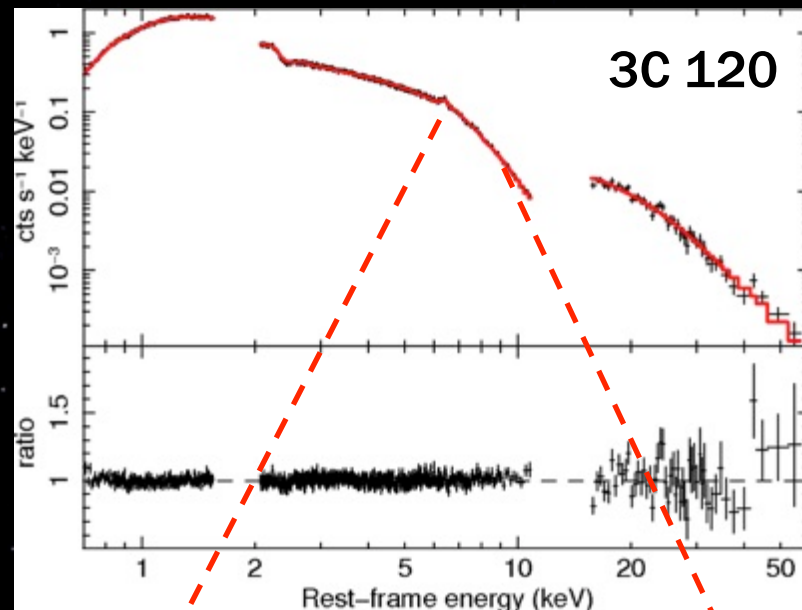
- Emission lines, possibly from OVII/VIII and Fe L (Fe XVI/XVII/XVIII)
- Hot gas $T \sim 10^7$ K, broad emission line FWHM ~ 2400 km/s
- $L_{\text{hot}} \sim 1.5 \times 10^{42}$ erg/s, $t_{\text{cool}} \sim 10^{6-7}$ yrs
- Consistent with expanding $\sim$ kpc scale hot bubble with shock velocity ~ 1000 km/s
- Bubble inflated by AGN winds/jets?

(Tombesi et al. 2017)

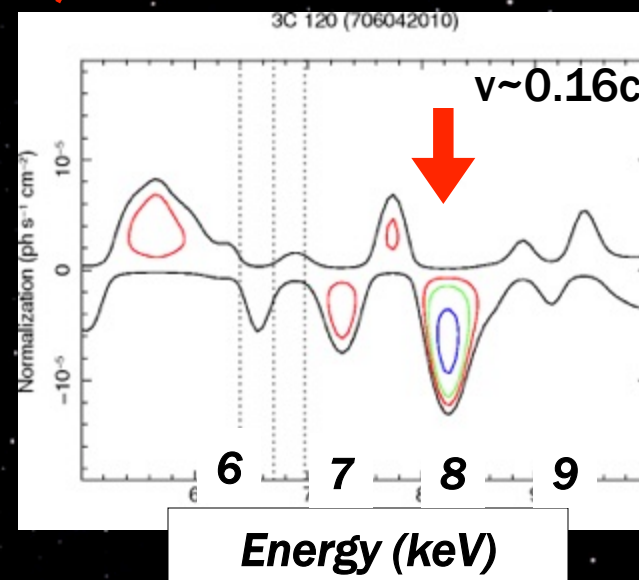
Ultrafast outflows in radio galaxies



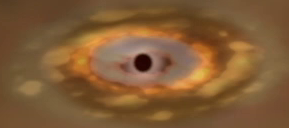
(Gofford et al. 2013)



(Tombesi et al. 2014)

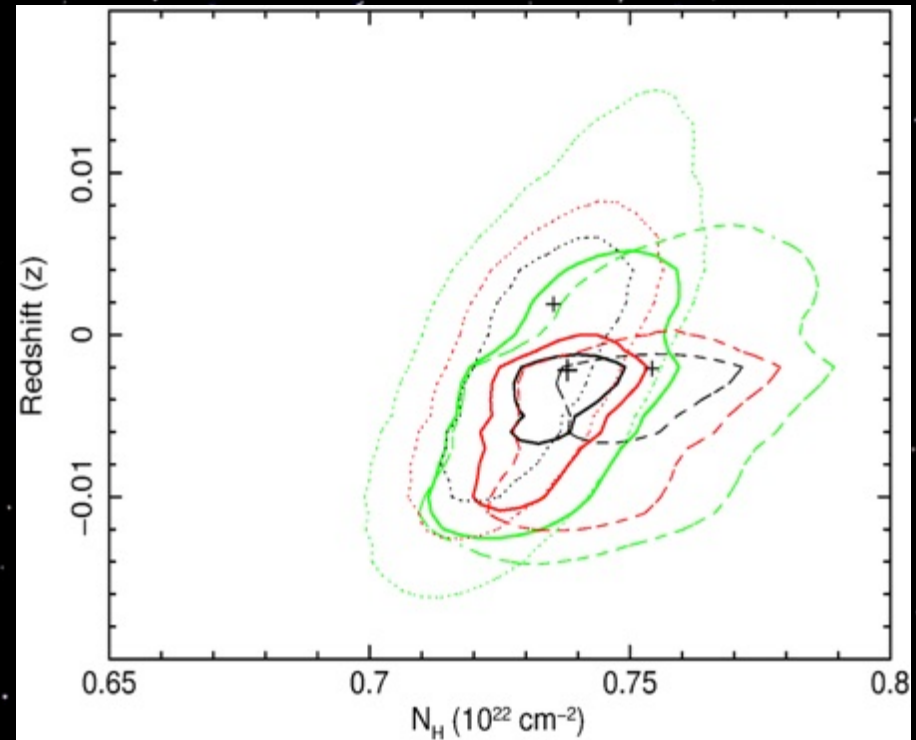
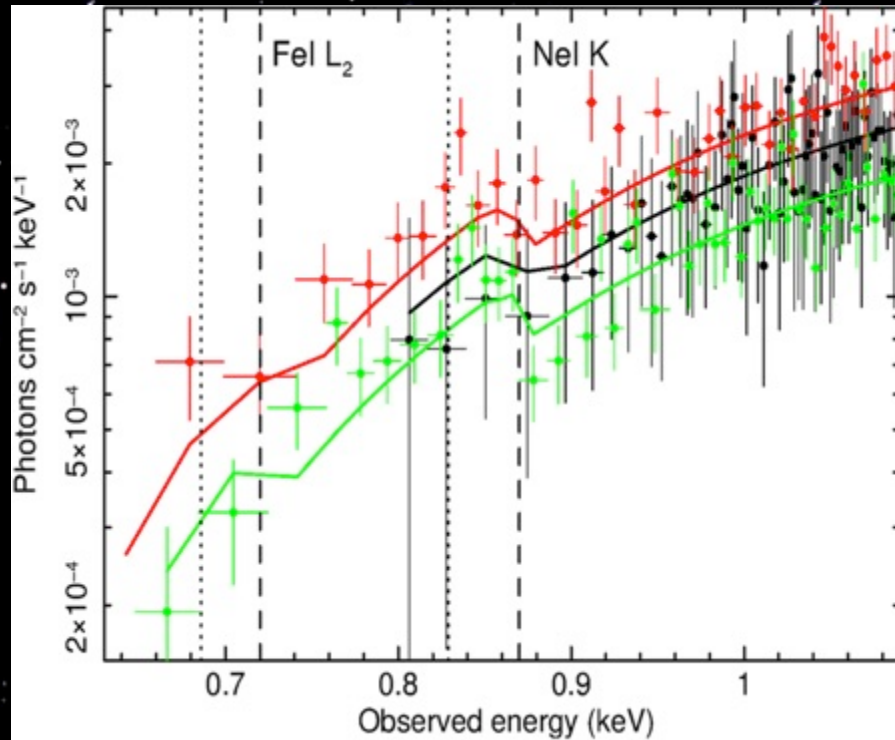


Hot bubble inflated by black hole winds/jets?



(credit: NASA/GSFC)

Excess Galactic Molecular Absorption in 3C111



(Tombesi et al. 2017)

- Atomic HI from radio surveys $N_{\text{H}} = 3 \times 10^{21} \text{ cm}^{-2} + \text{extra } N_{\text{H}} = 4.4 \times 10^{21} \text{ cm}^{-2}$
- Line of sight absorption from the Taurus molecular cloud in the Milky Way
- Need to consider total Galactic column density of $N_{\text{H}} = 7.4 \times 10^{21} \text{ cm}^{-2} !!$

Active Galaxy

Jet

Wind

Supermassive
Black Hole

Thank you for your attention!

