Effects of GR in accretion flows

... in strong gravity

Vladimír Karas

Astronomical Institute of the Czech Academy of Sciences

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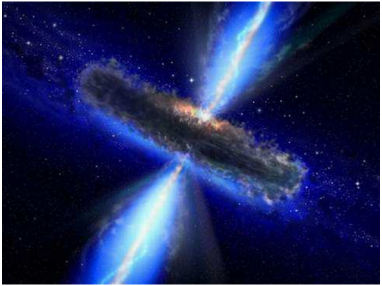
Introduction – the main ingredients of AGN model

- Accretion disc and an obscuring torus
- Supermassive black hole
- Wind outflow and/or a collimated jet
- Nuclear star cluster



$$R_{\rm g} = \frac{2GM}{c^2} \approx 10^{-5} M_8 \quad [\mathrm{pc}], \qquad t_{\rm g} = \frac{2GM}{c^3} \approx 10^3 M_8 \quad [\mathrm{s}],$$

$$M_8 \equiv \frac{M}{10^8\,M_\odot}.$$

Range	Wavelength [m]	Energy [keV]	Frequency [MHz]	Temperature [K]
γ-ray	$< 10^{-11}$	$> 10^3$		
Hard X-ray	$\approx 10^{-10}$	≈ 100		$\approx 10^8$
Soft X-ray	$< 10^{-8}$	< 1		$< 10^6$
Far UV	$> 10^{-8}$	> 1		$> 10^6$
Ultraviolet	$\approx 10^{-7}$	≈ 0.1		$\approx 10^5$
Near IR	$\approx 10^{-6}$			$\approx 10^4$
IR	$\approx 10^{-5}$			$\approx 10^3$
Far IR	$\approx 10^{-4}$			≈ 100
Millimetre	$\approx 10^{-3}$		$\approx 10^5$	≈ 10
Microwave	$\approx 10^{-1}$		$\approx 10^3$	≈ 1
Short wave	$\approx 10^2$		≈ 1	
Medium wave	$\approx 10^3$		≈ 0.1	
Long wave	$\approx 10^4$		≈ 0.01	

Time variability

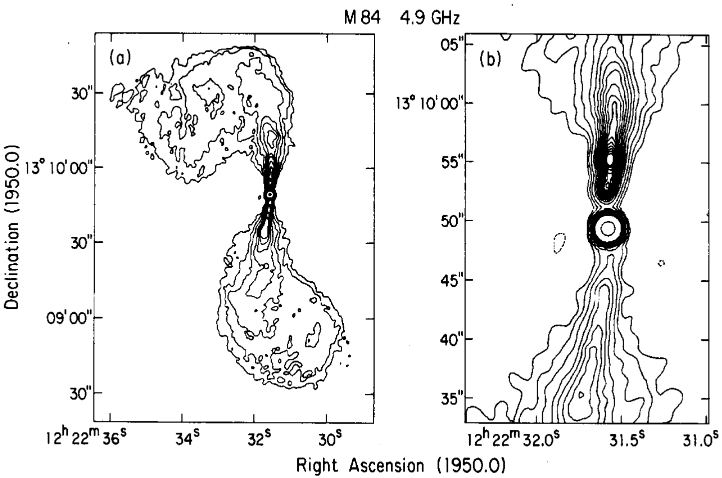
Featureless variability is seen in X-rays. At frequencies $\omega \approx (10^{-2}$–$10^{-5})$ Hz, variability exhibits a complex behaviour. The power spectrum of the variable signal can be represented by a power-law in the form $F(\omega) \propto \omega^{-\alpha_s}$ with $1 \lesssim \alpha_s \lesssim 2$.

Large radio-sources must be over 10^8 years old. Otherwise they could not reach observed sizes of $\approx (10^2$–$10^3)$ kpc in the course of their existence. The typical time-scale for radiation losses of electrons is given by the cooling time, provided they radiate due to electron synchrotron emission:

$$t_{\mathrm{cool}} \approx 6 \times 10^8 \left(\frac{1\ \mathrm{G}}{B_\perp}\right)^{3/2} \left(\frac{1\ \mathrm{MHz}}{\omega_{\mathrm{crit}}}\right)^{1/2} \quad [\mathrm{s}].$$

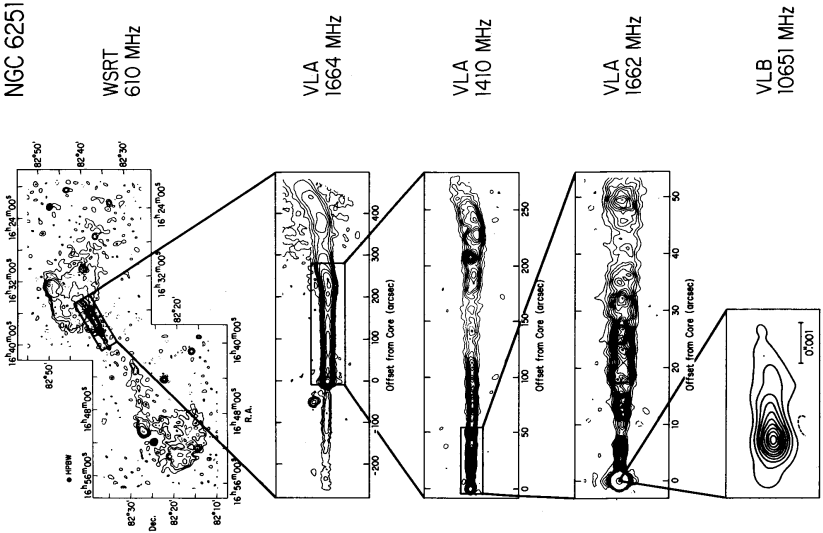
$[\omega_{\mathrm{crit}} \propto$ (*magnetic field intensity*) $\times$ (*electron energy*)^2].

Large radio sources

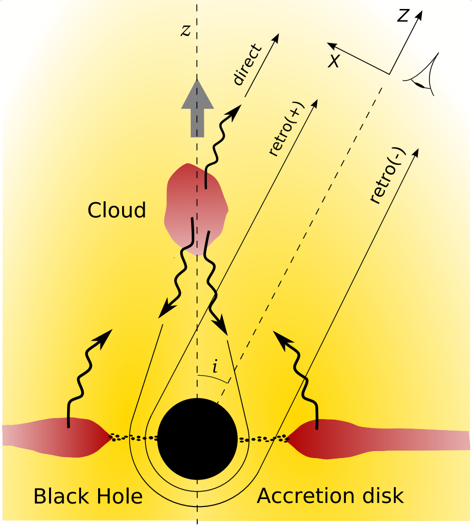


(Bridle & Perley 1984)

Large radio sources

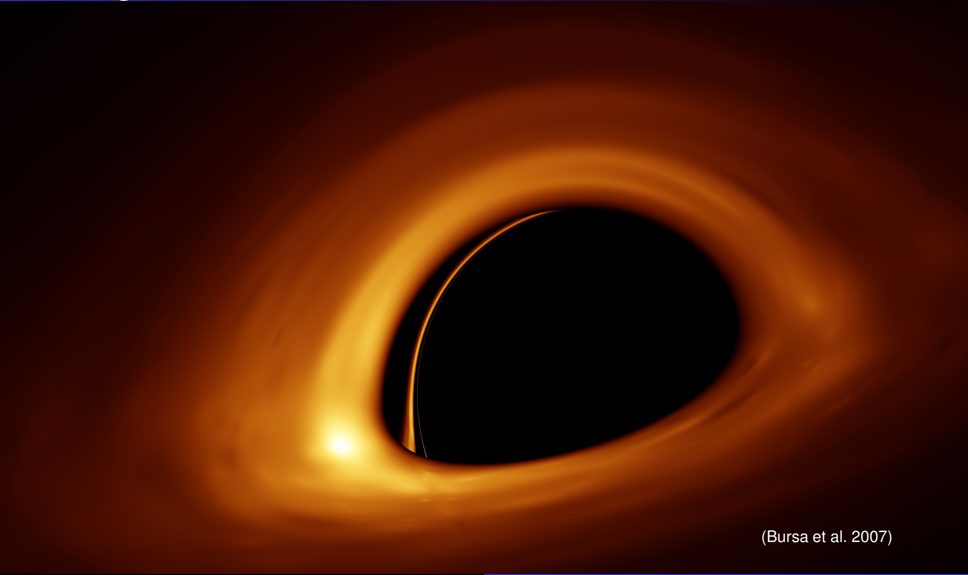


Going close to the center – GR effects



(Horák & Karas 2006)

Going close to the center – GR effects



(Bursa et al. 2007)

High-frequency elmg. waves

Basic equations – vacuum case:

$$F^{\mu\nu}{}_{;\nu} = 0, \qquad {}^{\star}F^{\mu\nu}{}_{;\nu} = 0.$$

$$E^{\alpha} = F^{\alpha\beta} u_{\beta},\ {}^{\star}F_{\mu\nu} \equiv \tfrac{1}{2}\varepsilon_{\mu\nu}{}^{\rho\sigma} F_{\rho\sigma}$$

An electromagnetic wave is an approximate test-field solution of the Maxwell equations:

$$F_{\alpha\beta} = \Re e \left[u_{\alpha\beta}\ e^{\Im S(x)} \right].$$

A fixed background geometry is asssumed.

- Phase $S(x)$ ... rapidly varying function
- Amplitude $u_{\alpha\beta}$ ... slowly varying function
- Wave vector $k_{\alpha} \equiv S_{,\alpha}$ ... paralel transport, null geodesics

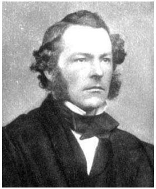
$$k_{\alpha;\beta}\, k^{\beta} = 0, \quad k_{\alpha} k^{\alpha} = 0.$$

Polarization tensor

- Polarization tensor ... $J_{\alpha\beta\gamma\delta} \equiv \frac{1}{2}\langle F_{\alpha\beta}\bar{F}_{\gamma\delta}\rangle$
- In observer's rest-frame ... $J_{\alpha\beta} \equiv J_{\alpha\beta\gamma\delta}\, u^{\gamma}\, u^{\delta} = \langle E_{\alpha}\bar{E}_{\beta}\rangle$
- Four parameters ... $S_A \equiv \frac{1}{2}(k_{\alpha}u^{\alpha})^2 F_A \quad (A = 0, \ldots, 3)$

(F_A ... constructed by projecting onto a tetrad $e^{\alpha}_{(i)}$)

"On the composition and resolution of streams of polarized light from different sources"



References: [1] Sir George Stokes (1852), Trans. Cambridge Phil. Soc., 9, 399

[2] Chandrasekhar (1950), *Radiative Transfer* (Oxford: Clarendon)

[3] Cocke & Holm (1972), Nature, 240, 161

[4] Jauch & Rohrlich (1955), *The Theory of Photons and Electrons* (Reading: Wesley)