Synchrotron Radiation in Astrophysics

Jana Połedniková

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1. Introduction
2. Basic properties
   - Physical point of view
   - Mathematicians would say ...
3. Astrophysics
   - What do we observe?
   - Explanations?
4. Conclusions
5. References

Outline of the talk

Why synchrotron radiation?

- Non-thermal processes essentials for cutting edge astrophysics.
- High energies $\Rightarrow$ probes of the distant ('old') universe.
- Present in many astrophysical processes (to be discussed later).

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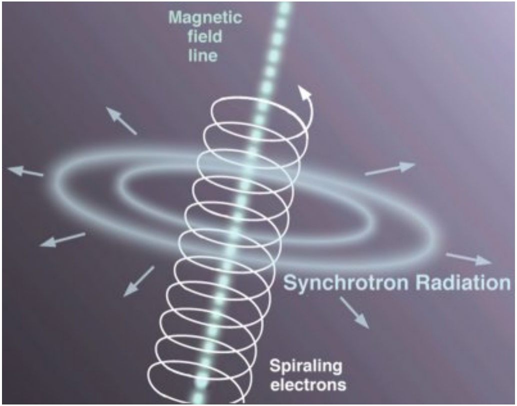
How does this work?

Synchrotron radiation is a caused by electrons moving in a magnetic field in the speeds close to the speed of light c (so called ultrarelativistic electron, because relativistic effects have to be taken into account).
The electrons are travelling along the curved paths and due to relativity, theirs frequency is affected by Lorentz factor γ.
We can observe strong polarization (circular or eliptical), strong beaming and energy spectrum accelerated to x-rays and even further.

Image worths thousands words



Outline of the talk

Some handy expressions I

Radiation loss rate

$$-\left(\frac{\mathrm{d}E}{\mathrm{d}t}\right)_{\mathrm{rad}} = \frac{q^2|\dot{\vec{v}}|}{6\pi\epsilon_0 c^3}$$

Electron moves in a spiral path at constant pitch angle Θ. $\vec{v} = const$ along the field lines, whilst it gyrates about the lines direction with gyrofrequency

$$v_g = \frac{eB}{2\pi\gamma m_e}$$

The total radiation loss rate is hence

$$-\left(\frac{\mathrm{d}E}{\mathrm{d}t}\right) = \frac{\gamma^4 e^2}{6\pi\epsilon_0 c^3}|a_\perp| = \frac{e^4 B^2}{6\pi\epsilon_0 c m_e^2}\frac{v^2}{c^2}\gamma^2 \sin^2\Theta$$

Some handy expressions II

Beaming angle can be computed following considerations: accelerated electron emits the usuall dipole pattern, relativistic aberation takes place $\Rightarrow$ beaming in the direction of motion within an angle $-\frac{1}{\gamma} < \phi < \frac{1}{\gamma}$.
Observed energy distribution is power-law

$$N(E)\mathrm{d}E = \kappa E^{-p}\mathrm{d}E$$

$N(E)\mathrm{d}E$ stands for the number of electrons per unit volume in interval $(E + \mathrm{d}E)$. Derivation in literature (too long).

Outline of the talk

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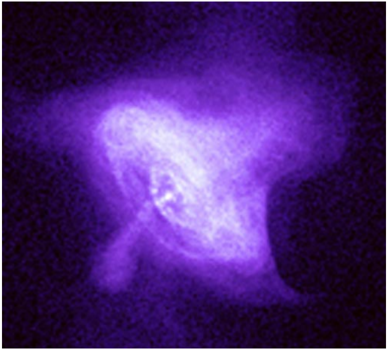
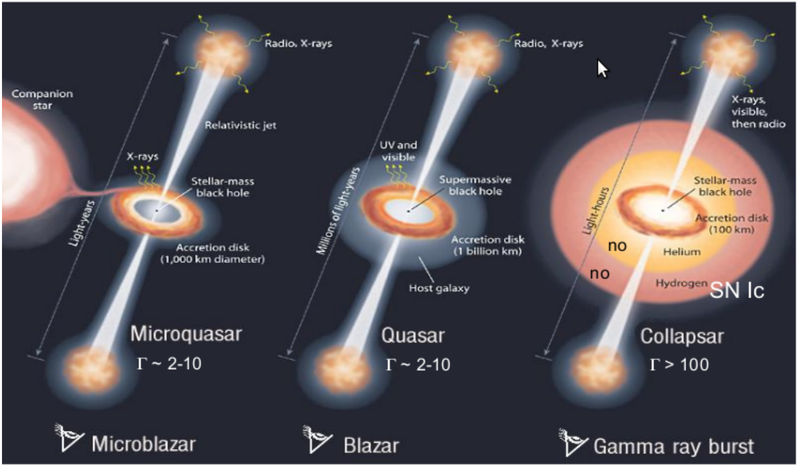
Jets et all.



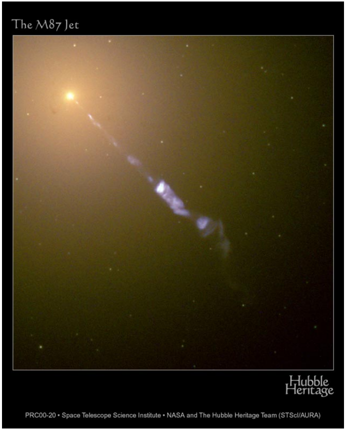
- Pulsar wind driven nebulae (i.e. M1)
- Active galactic nuclei
- Black holes
- Gamma-ray bursts

Jets of all scales



Outline of the talk

How this works?



- Mechanism of the jets still unknows ('black box where magic happens').
- Observational angle plays a big role (i.e. superluminal motions, x-ray flares etc.).
- Nowadays waiting for better observational techniques (currently observing up to 300 GeV with Fermi, higher energies in Cherenkov observatories)

Outline of the talk

Conclusions

- Synchrotron radiation plays a huge role in high energy astrophysics.
- The nonthermal relativistic electrons can be found in many kinds of astronomical objects.
- From the mathematical point of view, power-law distribution desribes the radiation rather well (incl. broken power law etc.).
- Synchrotron radiation is quite well understood, though the processes leading to its creation around BHs are not
- Real challenge for contemporary high energy astrophysics.

The last one . . .

In any field, find the strangest thing and then explore it.

–John A. Wheeler

Thank you for your attention!

Outline of the talk

References

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