Measurement of AGN BH mass by *TeV gamma-rays*

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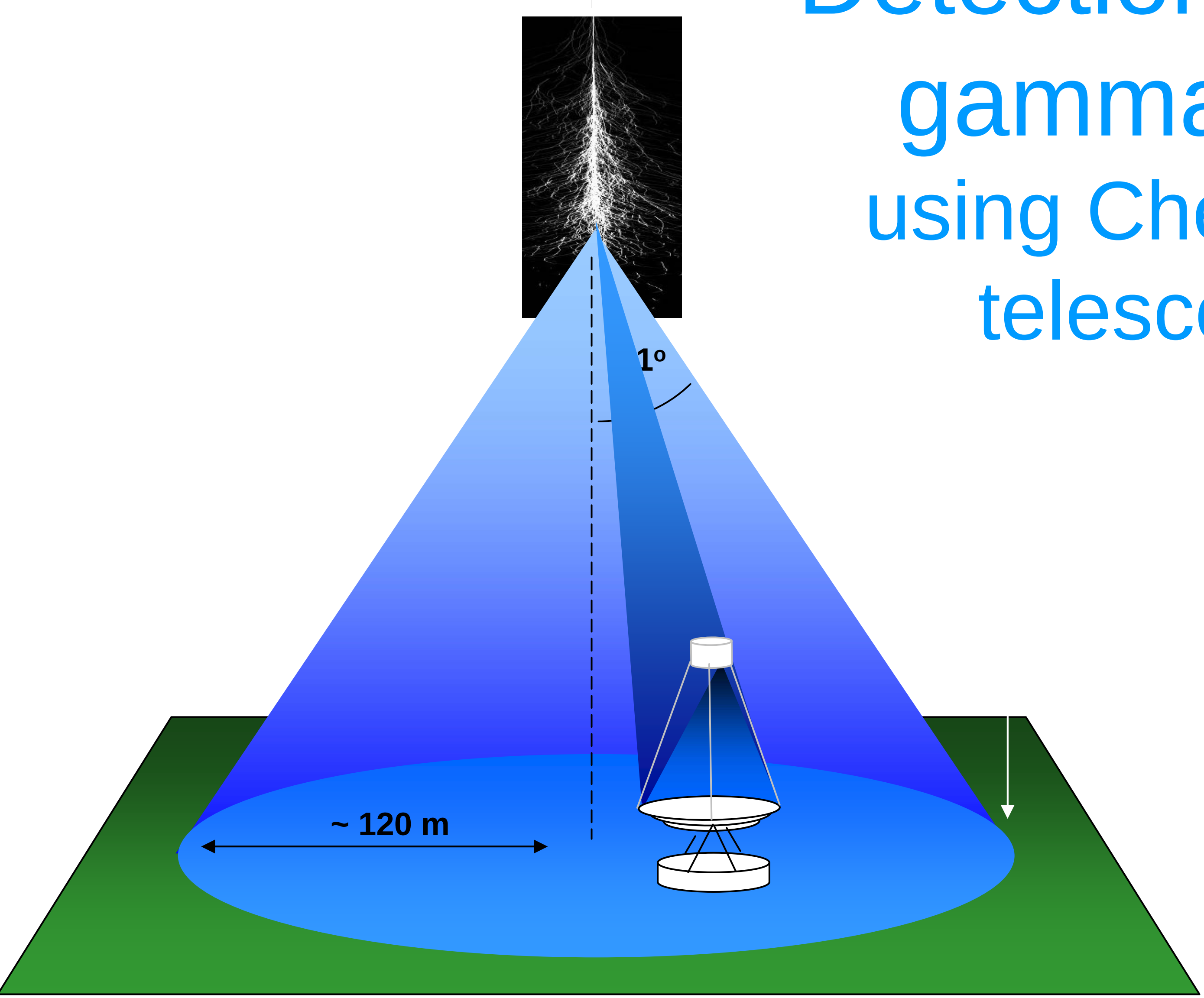
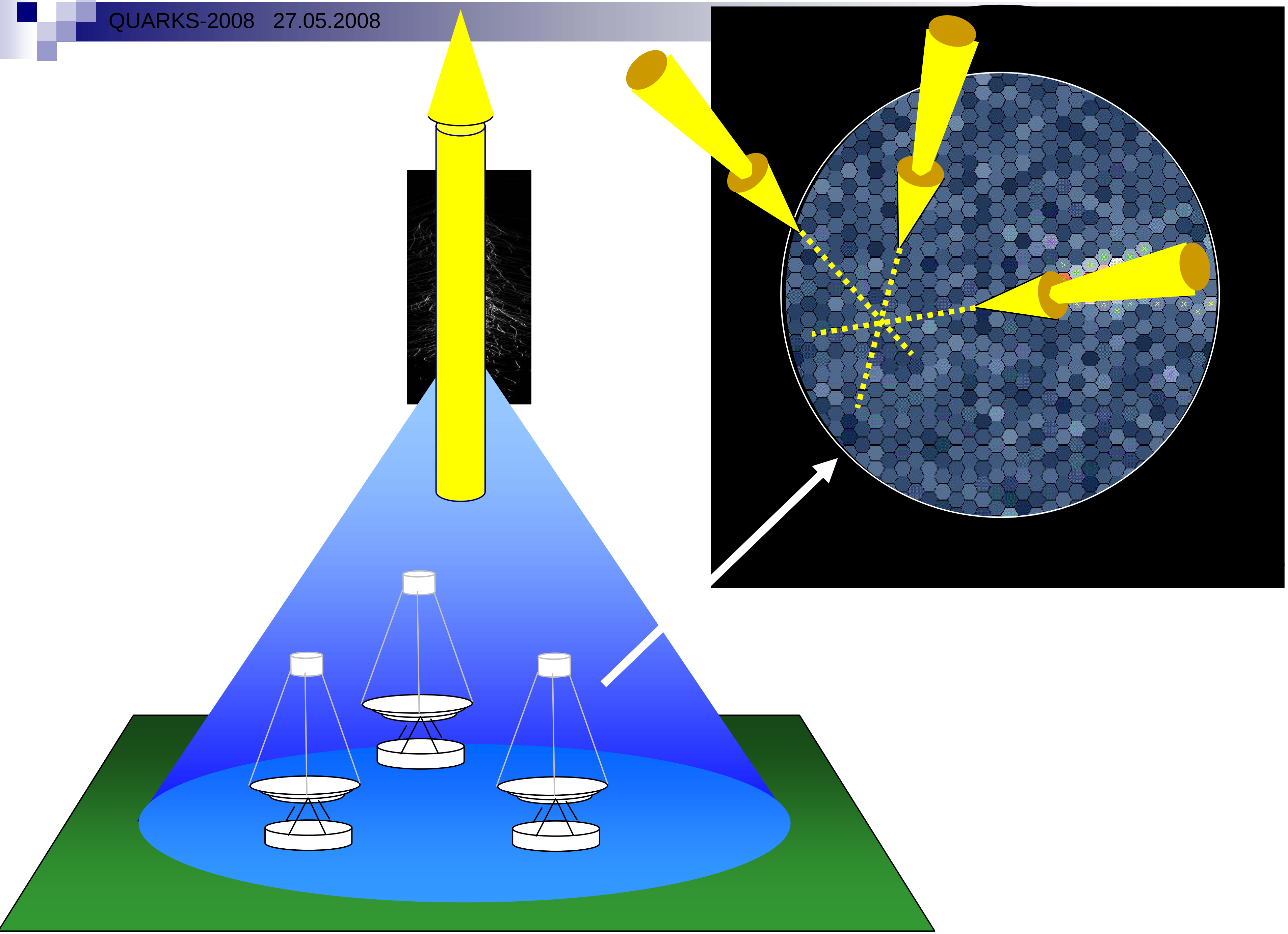
Overview:

- Introduction: TeV gamma-ray astronomy
- AGN core model
- Production of TeV gamma-rays by protons
- Flare signal periodicity and BH mass
- Conclusions

TeV gamma-ray astronomy

Detection of TeV gamma rays using Cherenkov telescopes



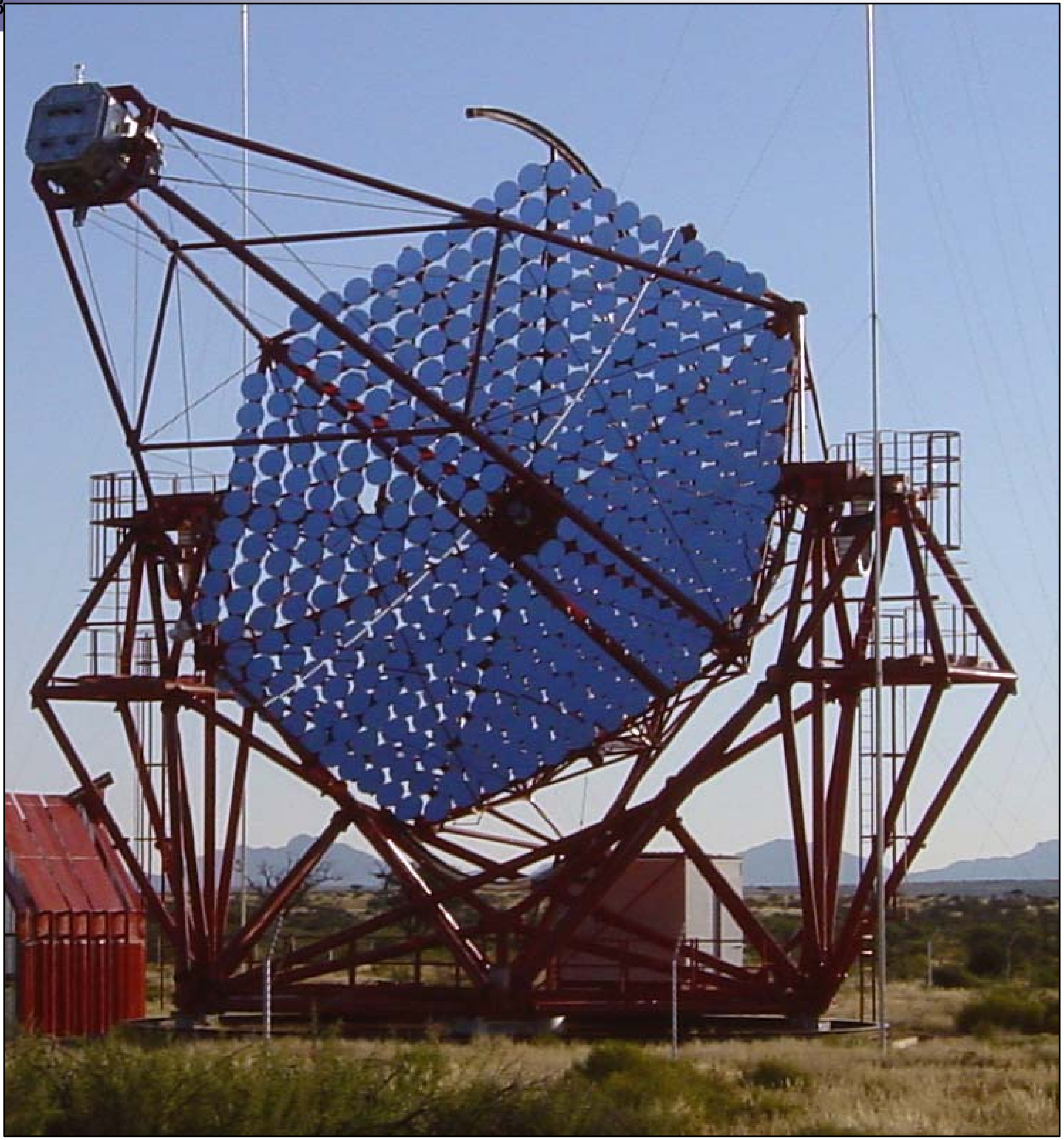


Whipple 1968

Detection of the Crab Nebula 1989:

50 h observation time for 5σ signal

H.E.S.S.
2003



Detects Crab-like source in

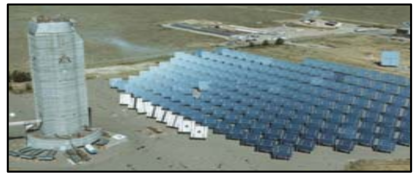
30 seconds

1% Crab in 25 h

VHE γ detectors

MILAGRO

STACEE



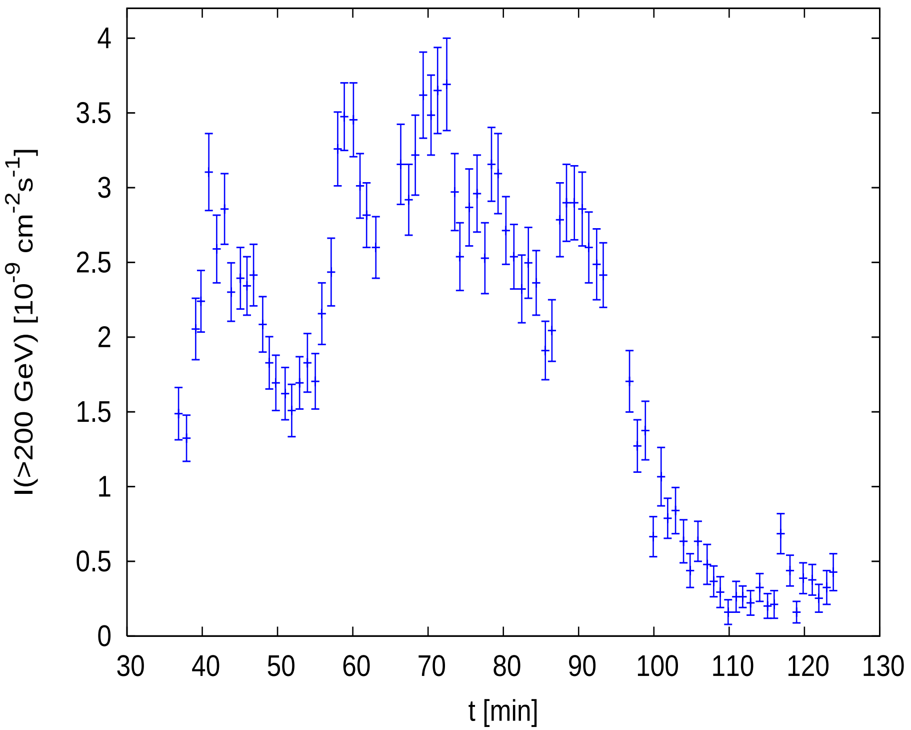
MAGIC

TIBET

Timing
PKS 2155-304 with
TeV gamma-rays

Giant flare of PKS 2155-304

- On July 2006 H.E.S.S. observed giant flare from PKS 2155-304
- Independent 2 min bins for E>200 GeV
- Sub-flares at 10 min scale
- Total time 90 min

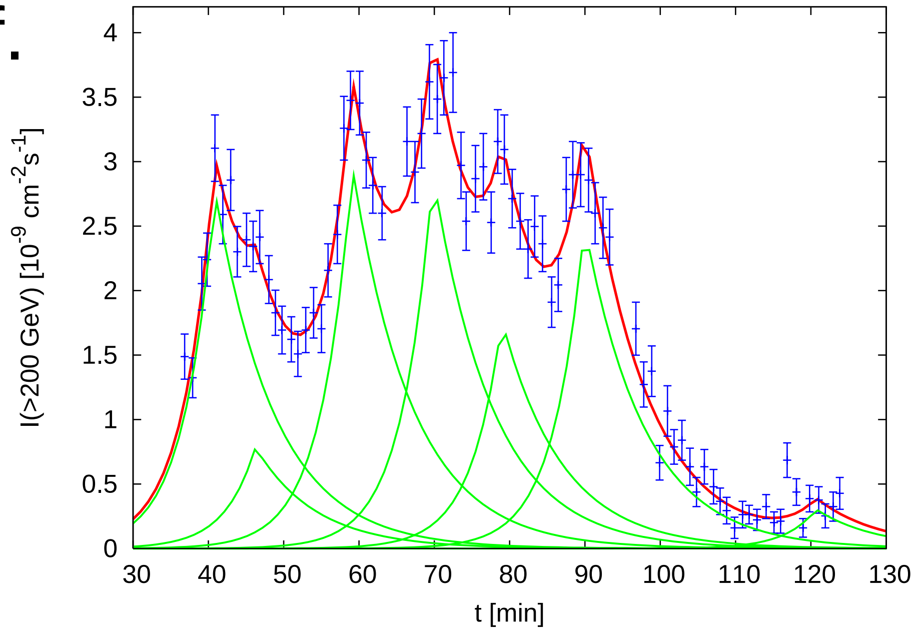


Sub-flare profile

$$I_k(t) = \begin{cases} N_k \exp\left[\dfrac{t - t^k{}_{\max}}{t_{rise}}\right] & \mathrm{t} < \mathrm{t}^{\mathrm{k}}{}_{\max} \\ N_k \exp\left[-\dfrac{t - t^k{}_{\max}}{t_{decay}}\right] & \mathrm{t} > \mathrm{t}^{\mathrm{k}}{}_{\max} \end{cases}$$

Results of fit:

- 5 flares $\chi^2 = 106/70$ d.o.f.
- 6 flares $\chi^2 = 86/68$ d.o.f.
- 7 flares $\chi^2 = 76/66$ d.o.f.



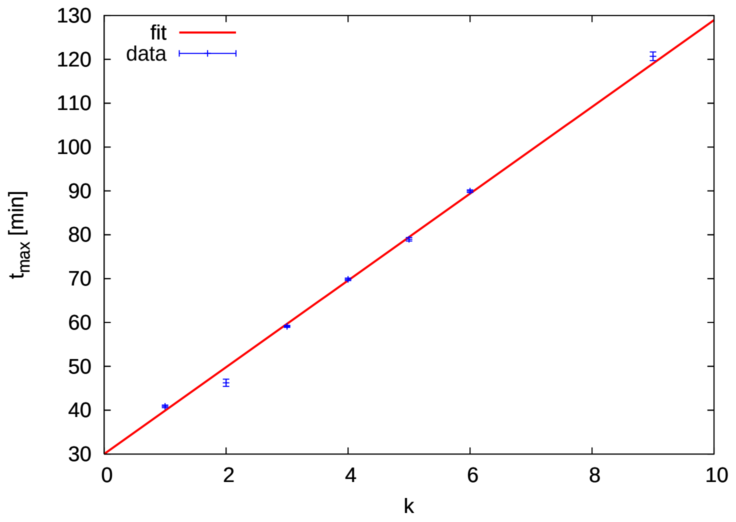
$$t_{rise} = (2.5 \pm 0.2) \cdot 10^2 s$$

$$t_{decay} = (4.9 \pm 0.5) \cdot 10^2 s$$

Arrival times as function of number

- Approximate linear law:

$$t^{k}_{\max} = t_0 + k \cdot T$$



- Period:

$$T = (5.9 \pm 0.15) \cdot 10^{2} s$$

$$\Delta t \approx 10^{2} s$$

- Probability by chance: $P = 1.3 \cdot 10^{-3}$

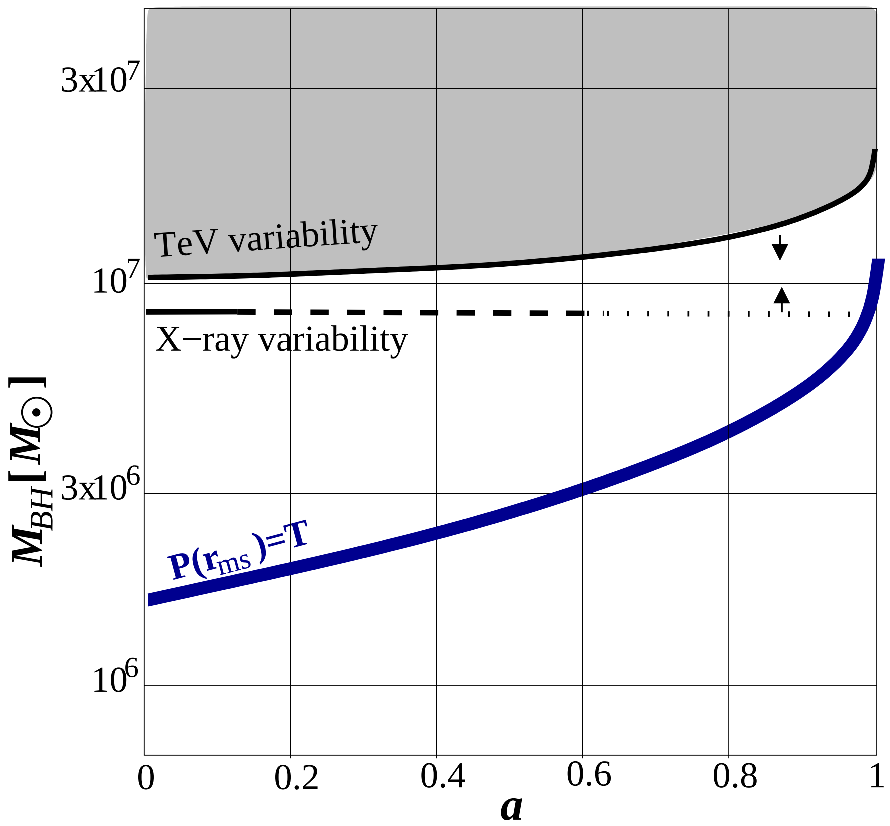
Minimal variability time scale

$$t_{lc} = 2\left(R_g + \sqrt{R_g^2 - a^2}\right)/c = \begin{cases} 10^2\left[\dfrac{M_{BH}}{10^7 M_{sun}}\right] \mathrm{s} & \mathrm{a} = R_g \\ 2\cdot 10^2\left[\dfrac{M_{BH}}{10^7 M_{sun}}\right] \mathrm{s} & \mathrm{a} = 0 \end{cases}$$

Rotation around last stable orbit

$$P(r) = 2\pi \frac{r^{3/2} \pm a R_g^{1/2}}{c R_g^{1/2}} = \begin{cases} 4\pi R_g / c = 630 \left[\dfrac{M_{BH}}{10^7 M_{sun}} \right] s & \mathrm{a} = R_g \\ 12\sqrt{6} R_g / c = 4600 \left[\dfrac{M_{BH}}{10^7 M_{sun}} \right] s & \mathrm{a} = 0 \end{cases}$$

Parameters of BH from TeV lightcurve



AGN core toy model

RIAF models

- Radiation Inefficient Accretion Flow (RIAF)

$$\dot{M} << \dot{M}_{Edd} = 0.2\left[\frac{M_{BH}}{10^7 M_{sun}}\right] M_{sun} / year$$

- Two-temperature plasma mildly-relativistic electrons and ions. Radiation produced only by electrons.

Accretion disk: matter and B

- Electrons

$$\langle \gamma_e^2 \rangle = 10 \left(\frac{T_e}{m_e} \right)^2$$

- Matter

$$n(R) = 10^{10}\, cm^{-3} \left[\frac{R_g}{R} \right]^{\alpha} \qquad \alpha = 0.5 \div 1.5$$

- Magnetic field

$$B(R) = 10^4 \beta^{-0.5} \left[\frac{R_g}{R} \right]^{1/2} \left[\frac{n(R)}{10^{10}\, cm^{-3}} \right]^{1/2} G$$

Synchrotron radiation of disk

- Synchrotron radiation $\varepsilon_{synch} = \frac{eB}{m_e}\left\langle \gamma_e^2 \right\rangle = 5 \cdot 10^{-3}\left[\frac{B}{10^4 G}\right]\left[\frac{T_e}{1MeV}\right]^2 eV$
- Self-absorption $\varepsilon_{SA} = 37\varepsilon_{synch} = 0.2eV$
- Total radiation

$$L_{synch} = 3.2 \cdot 10^{39}\left[\frac{M_{BH}}{10^7 M_{sun}}\right]^2\left[\frac{B}{10^4 G}\right]^3\left[\frac{T_e}{1MeV}\right]^7 erg/s$$

- Scale R~R$_g$

$$n_{synch} = \frac{L_{synch}}{4\pi R^2{}_{synch}\varepsilon_{SA}} \approx 10^{16} cm^{-3}\left[\frac{L_{synch}}{10^{39} erg/s}\right]\left[\frac{R_g}{R_{synch}}\right]^2 \frac{0.2eV}{\varepsilon}$$

IC radiation of disk

- Inverse Compton radiation

$$\varepsilon_{IC} = \varepsilon_{SA}\left\langle \gamma_e^2 \right\rangle = 4\left[\frac{B}{10^4 G}\right]\left[\frac{T_e}{1MeV}\right]^4 eV$$

- Scale

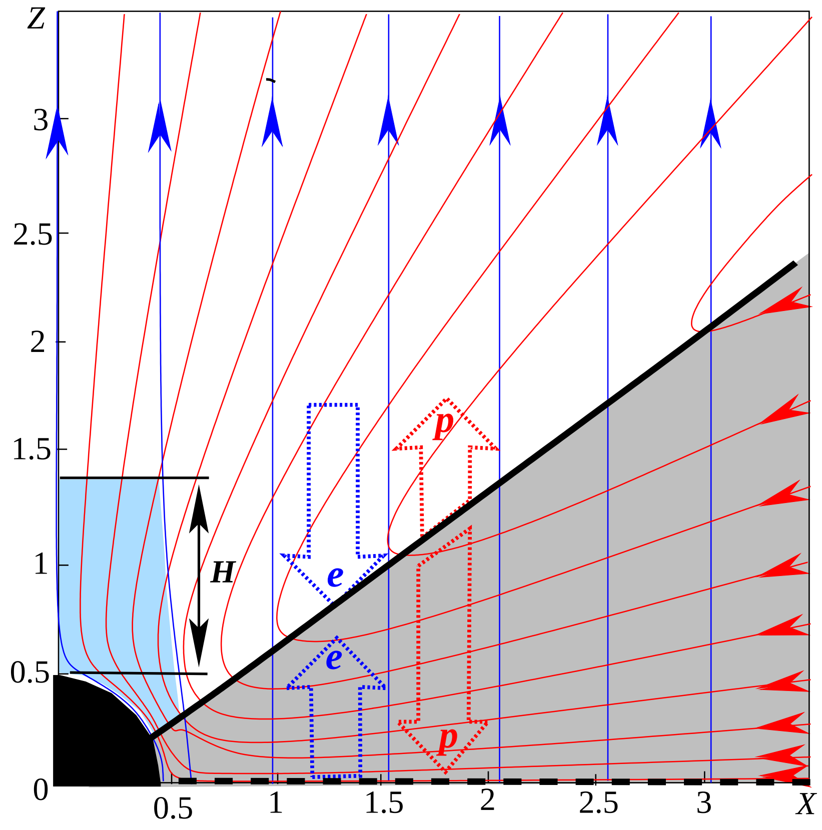
$$R \sim 100 R_g$$

- Total radiation

$$L_{IC} = 0.1\cdot 10^{39}\left[\frac{L_{synch}}{10^{39} erg/s}\right]\left[\frac{n_e(R_{IC})}{10^8 cm^{-3}}\right]\left[\frac{R_{IC}}{100 R_g}\right]\left[\frac{T_e(R_{IC})}{0.5 MeV}\right]^2 erg/s$$

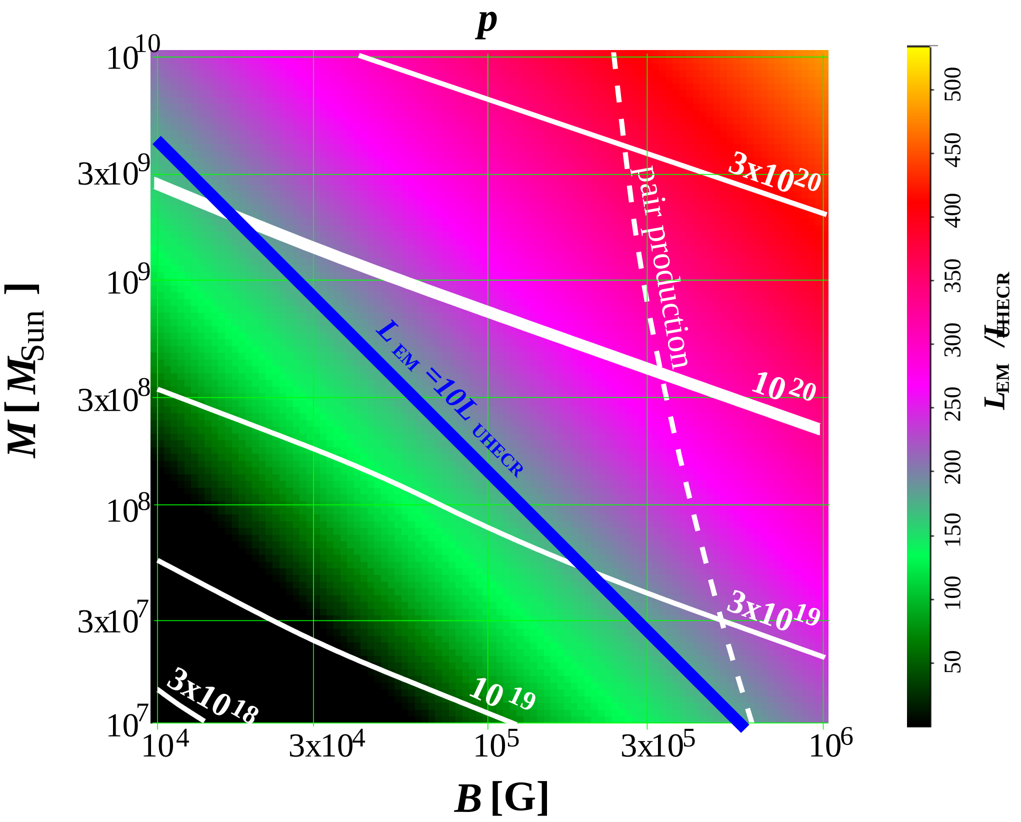
$$n_{IC} = \frac{L_{IC}}{4\pi R^2{}_{IC}\varepsilon_{SA}} \approx 5\cdot 10^9 cm^{-3}\left[\frac{L_{IC}}{10^{38} erg/s}\right]\left[\frac{R_g}{100 R_g}\right]^2 \frac{4eV}{\varepsilon}$$

Acceleration of protons

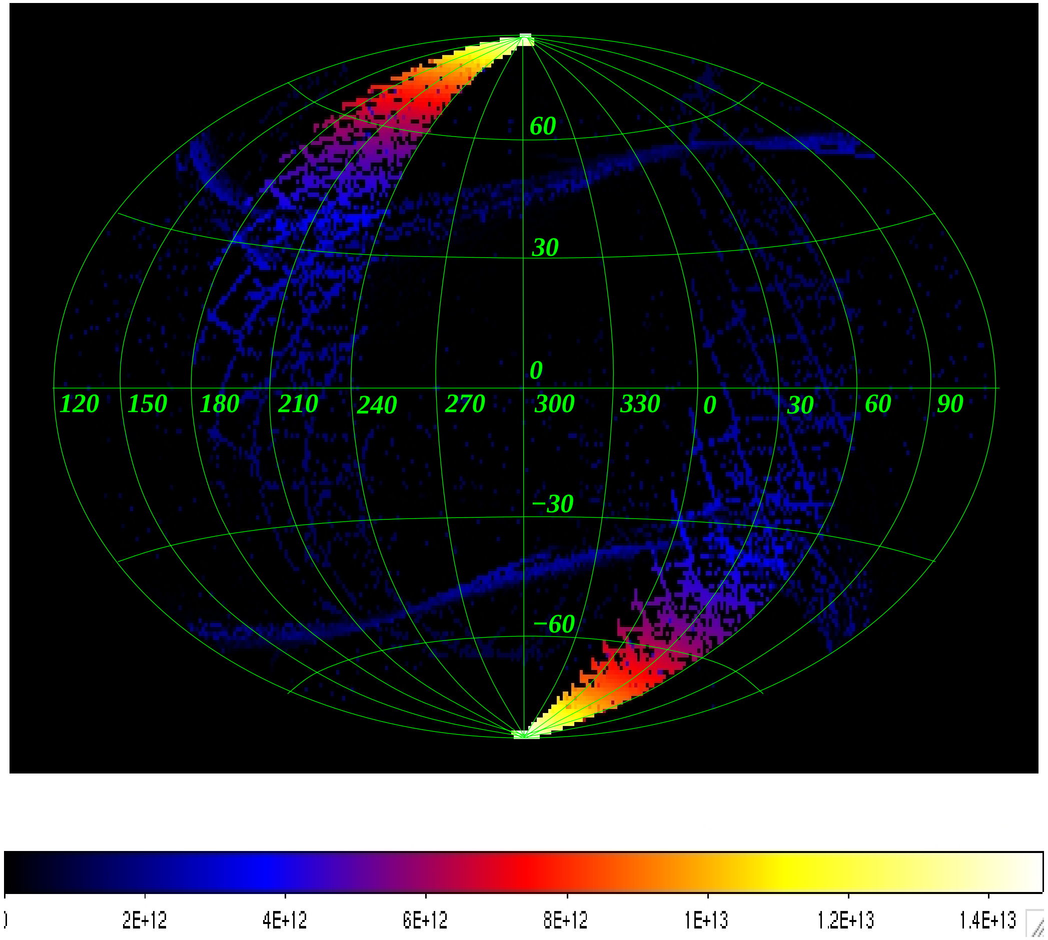


$$\frac{E}{m} \leq 2\cdot 10^{9}\left[\frac{M_{BH}}{10^{7}M_{sun}}\right]^{1/2}\left[\frac{B}{10^{4}G}\right]^{1/4}$$

Acceleration of protons to E>1 EeV energies



Maximum losses at direction of jet



TeV gamma rays emitted in direction of jet

Escape of TeV gamma-rays

- Production of pairs
- On synchrotron near BH

$$E_\gamma \varepsilon \geq m_e^2$$

$$\tau_{synch}(\gamma) = n_{synch} R_{synch} \sigma_{\gamma\gamma} = 10^3$$

$$E_\gamma(\max) = 5 \frac{0.2eV}{\varepsilon} TeV$$

- On IC at 100 R_g

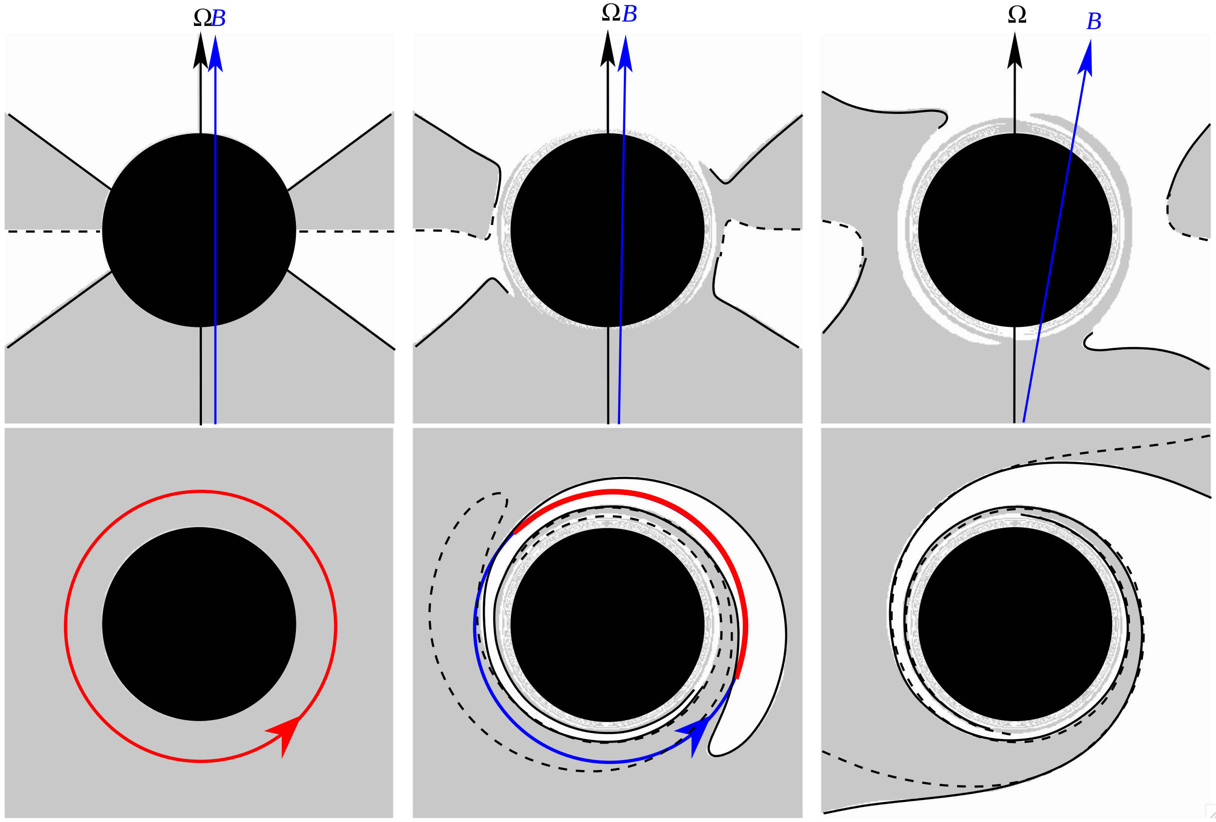
$$\tau_{IC}(\gamma) = n_{IC} R_{IC} \sigma_{\gamma\gamma} = 0.2$$

$$E_\gamma = 1 \frac{4eV}{\varepsilon} TeV$$

Cascade in PKS 2155-304

- TeV gamma-rays can escape from production region near BH in RIAF models
- Gamma-rays with E>2-3 TeV produce pairs and start cascade this cascade produce relativistic blob with high gamma-factor at 100 R_g from BH.
- Gamma-rays with E<2-3 TeV directly go to observer and give information about BH

Configuration of force-free surfaces allow to produce emission with period T



CONCLUSIONS:

- TeV gamma-ray telescopes can resolve time structures on the scales of BH size
- Giant flare of PKS 2155-304 give information about BH mass and rotation moment.
- We can connect this flare with acceleration of protons near BH and present a toy model for BH central engine