Karlsruhe Institute of Technology

EAS detection through molecular bremsstrahlung radiation in the GHz regime

Theory and current research on microwave emissions of extended air showers

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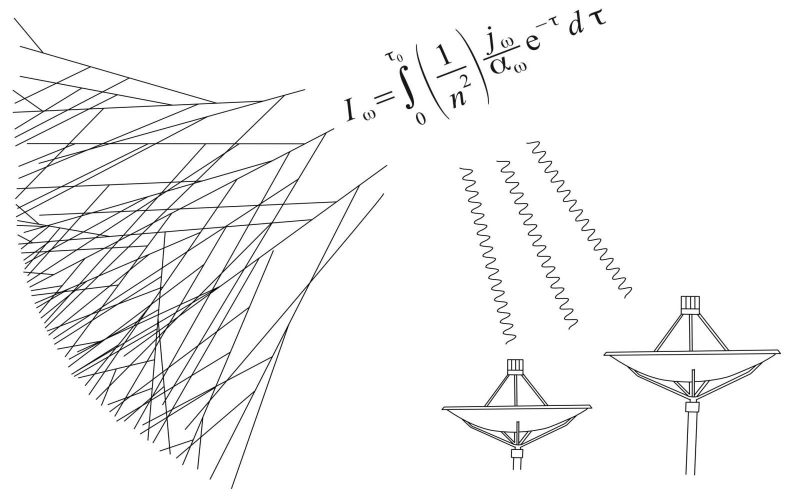


GHz radiation - motivation

Observation of isotropic shower emissions can be used to Isotropically emitted radiation (e.g. fluorescence) allows non directional observation.

Current experiments (e.g. Auger FD, Fly´s Eye, HiRes) suffer from a severely constrained duty cycle.

Solution: move to a different, preferably low-noise, wavelength,

GHz radiation - motivation

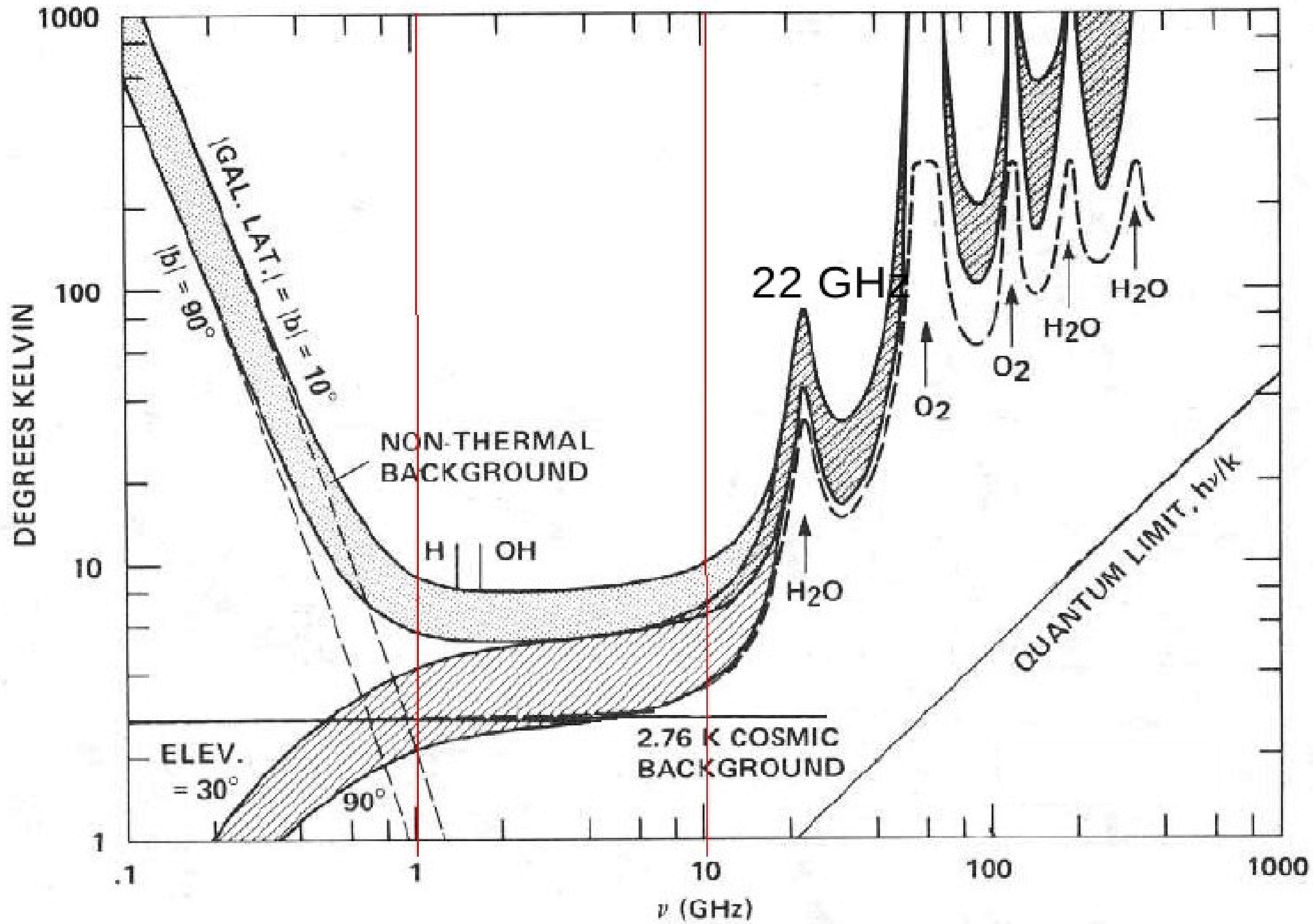
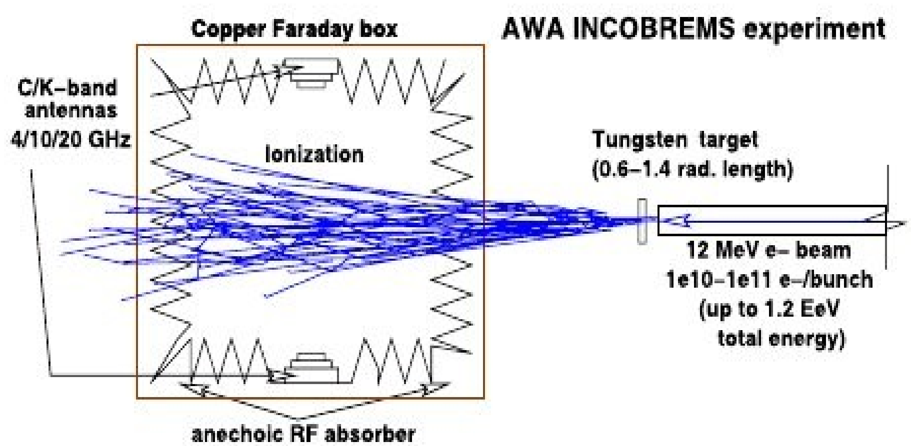


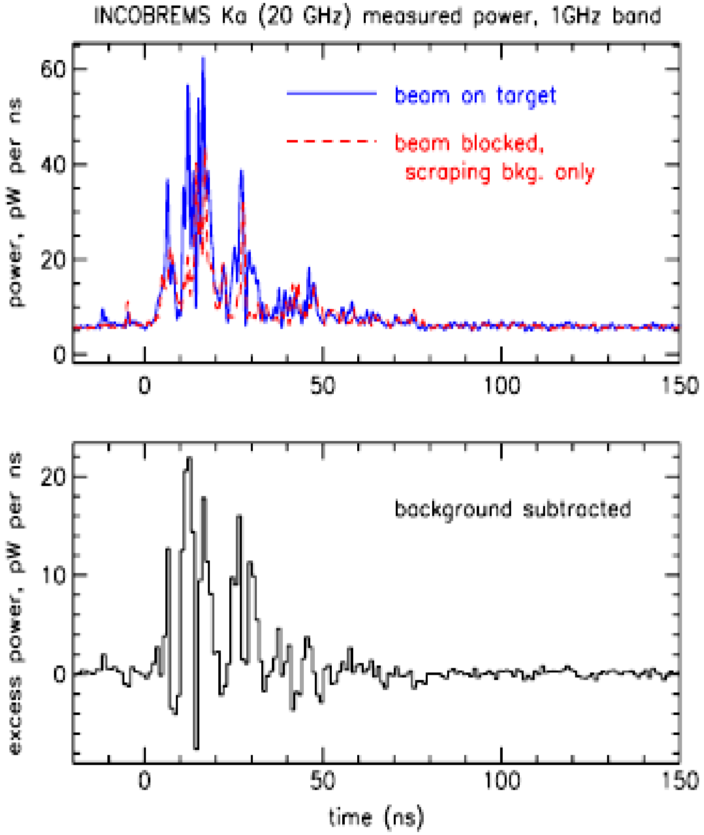
Figure: Smida, ICRC 2011

GHz radiation – where to look?

- Extended air showers trailed by short lived plasma cloud, lifetime ~10 ns
- Plasma is weakly ionized, mixed with neutral atmosphere
- Average electron energies ~35 eV
- Collision processes between electrons and atmospheric neutrals cause emission of bremsstrahlung
- Signal may be isotropic, unpolarized and incoherent (depending on electron velocity distribution)

Experiments: INCOBREMS





Figures: P. W. Gorham *et al.*,Physical Review D 78, 032007 (2008)

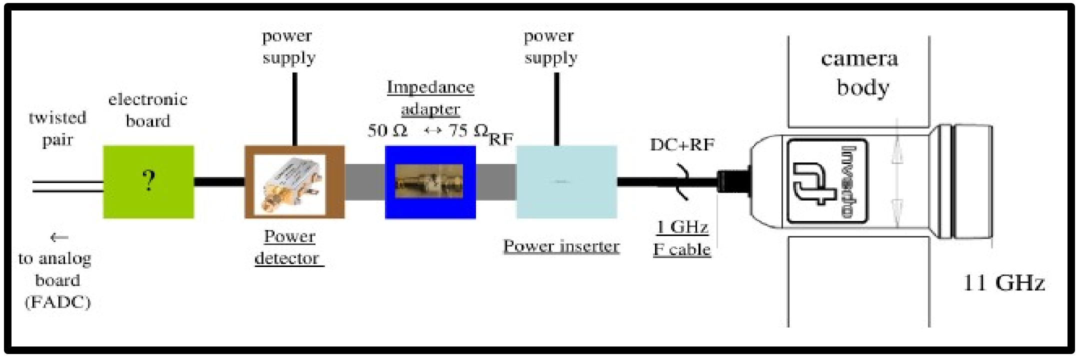
Experiments: CROME

- located inside KASCADE-Grande array
- Readout triggered by high energetic showers (>10^{16} eV)

Experiments: Proposed and operating

MIDAS

FDWave



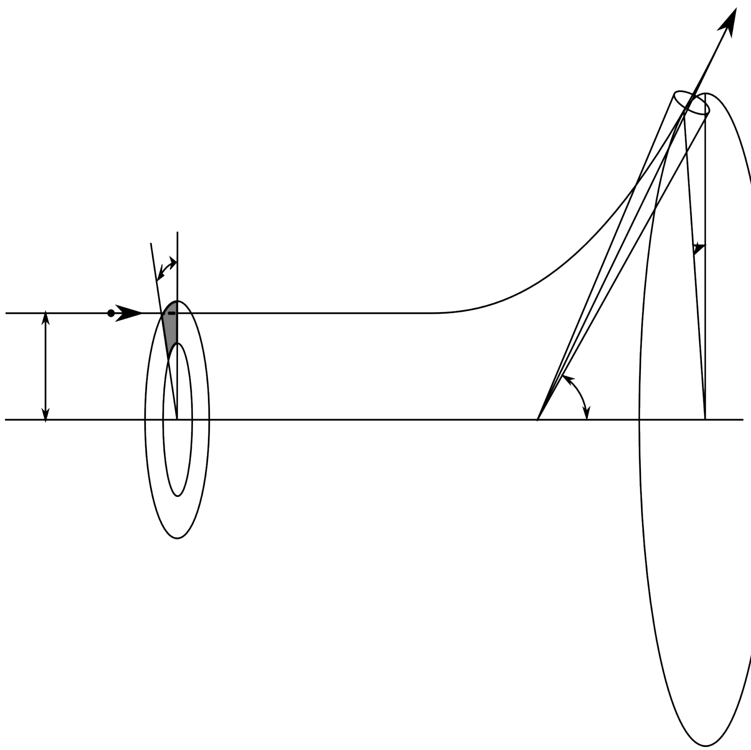
AMBER

EASIER

Theoretical model: Bremsstrahlung

Bremsstrahlung = EM-emission through acceleration of charged particles in two-body interaction

$$\phi(\vec{r},t)=\frac{e}{4\pi\epsilon_0}\left[\frac{1}{gR}\right]_{t'} \; ; \; \vec{A}(\vec{r},t)=\frac{e}{4\pi\epsilon_0 c}\left[\frac{\beta}{gR}\right]_{t'} \text{ where } \vec{\beta}=\frac{\vec{v}}{c} \; ; \; g=(1-\hat{\vec{q}}\cdot\vec{\beta}) \text{ and } t'=t-\frac{R(t')}{c}$$



Source function

$$S_\omega=\frac{1}{n_r^2}\frac{j_\omega}{\alpha_\omega}$$

Intensity emitted per unit angle

$$I_\omega=\int_0^{\tau_0} S_\omega(\tau)e^{-\tau}\,d\tau$$

Open questions

- More precise form of electron velocity distribution?
- Coherent emission possible? Effects?
- Plasma lifetime?

- Non-time-stationary effects?
- Potential anisotropies in plasma leading to corrections in emission patterns?
- Effects of collision cross sections of atmospheric neutrals being dependent on electron velocity?
- Effects of shower disk curvature?

Open questions - velocity distribution

- Source function very obtainable for maxwellian velocity distribution
  Problem: Injection probably dominated by shower velocity distribution
  ↓
  Power law

- Isotropic emission immediately follows for isotropic velocity distribution
  Problem: Linear motion of shower disk might introduce anisotropies
  ↓
  Corrections to emission patterns?

Open questions – coherent emission

Coherent emission of bremsstrahlung in gas discharge plasmas experimentally observed.
Condition (necessary, not sufficient):

$$-E\frac{\partial \sigma_M}{\partial E} > 2\sigma_m$$

for isotropic emission

$$\vec{E}=\sum_{j=1}^{N_e}\vec{\epsilon}(\vec{v})\exp(-i\vec{k}\cdot x_j+\phi_j)$$

Potential effects:

$$P/A=|\vec{E}|^2/Z_0$$

$$\vec{E}=\sum_{j=1}^{N_e}\vec{\epsilon}(\vec{v})=N_e\vec{\epsilon}(\vec{v})$$ Instead of $$|\vec{E}|^2=N_e|\vec{\epsilon}(\vec{v})|^2$$

→ Time-density function has to be derived

σ_M=experimental electron-molecular nitrogen momentum transfer cross section

Open questions – plasma lifetime

Signal strength strongly dependent on plasma lifetime.

Dominant effects:

- Electron attachment
- Recombination
- Thermalization

$$\frac{dn_e}{dt} = N_e^0 - \alpha_e n_e^2 - \beta_e n_e$$

recombination coefficient (α_e)

attachment coefficient (β_e)

Effects highly dependent on atmospheric conditions

→ Parameterization of plasma lifetime complicated

Summary

- Fundamental theory for thermal bremsstrahlung emission in stationary plasmas available and well understood
- Experiments have been proposed, built, and are taking data

But:

- No adequate signal has been measured as of yet
- Theoretical models insufficient to describe present problem
- Energy and density distribution not well known

Thank you for your time.

References

- G. Bekefi, Radiation Processes in Plasmas (Wiley, NewYork, 1966).
- P. W. Gorham *et al.*,Physical Review D 78, 032007 (2008)