MAGNETOSPHERIC FORMATION PROCESSES OF THE DIFFUSE AURORA

International Space Weather Camp 2024

Katja Stoll

DLR

Outline

1. Diffuse aurora
2. Plasma waves, wave-particle interactions
3. Calculation of wave-induced diffusion coefficients
4. Results from event study

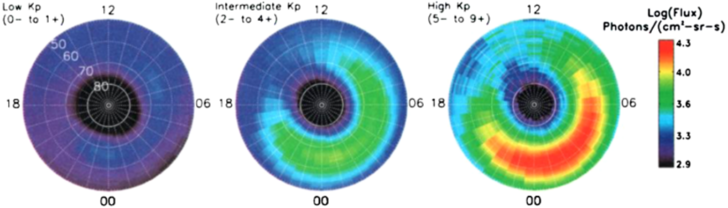
Image Credit: NASA

Different types of aurora

- Discrete aurora
  - Localized regions of intense auroral arcs
  - Associated with field-aligned currents and acceleration of the electrons
- Diffuse aurora
  - Broad regions of lower intensity emissions
  - Precipitation of magnetospheric plasma involving wave-particle interactions

Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center

Diffuse aurora

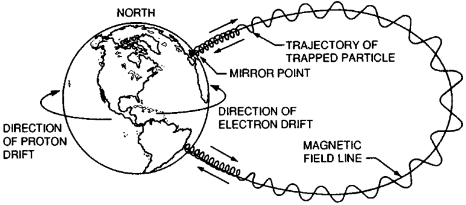


Petrinec et al. (1999)

- Diffuse auroral precipitation = major source of energy input to upper nightside atmosphere
- Latitudinal range and peak energy flux location varies with solar wind conditions and seasonal changes

Adiabatic invariants

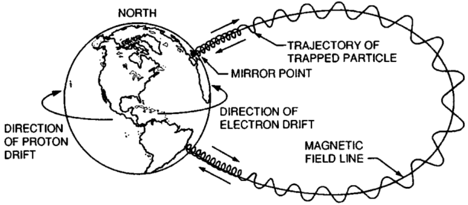
- 3 types of cyclic motion for particles trapped in the geomagnetic field:
  - Gyration around magnetic field line
  - Bounce motion between the mirror points
  - Azimuthal drift around the Earth
- Approximate conservation law associated with each cyclic motion: adiabatic invariants



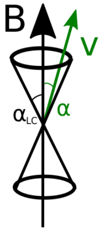
Walt (1994)

Adiabatic invariants

- 3 types of cyclic motion for particles trapped in the geomagnetic field:
  - Gyration around magnetic field line
  - Bounce motion between the mirror points
  - Azimuthal drift around the Earth
- Approximate conservation law associated with each cyclic motion: adiabatic invariants
- Electrons with $\alpha > \alpha_{\mathrm{LC}}$ remain trapped
- Electrons with $\alpha < \alpha_{\mathrm{LC}}$ are lost to the atmosphere: precipitation



Walt (1994)

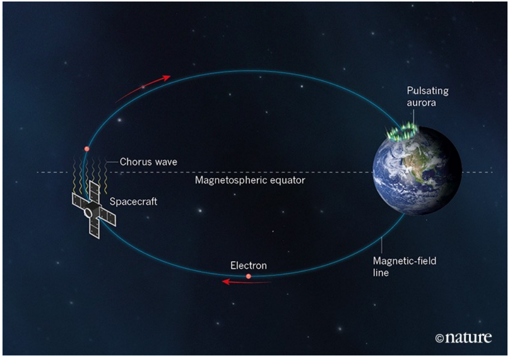


Plasma waves

- Waves can interact resonantly with particles: $\omega - k_\parallel v_\parallel = \frac{n\Omega_\sigma}{\gamma}$, $\Omega_\sigma = \frac{|q|B}{mc}$
- Describe the effect of wave-particle interactions on the particle distribution by quasi-linear diffusion
- Diffusion coefficient $D_{\alpha\alpha}$ captures the effects of pitch-angle scattering
- Dominant source population for the diffuse aurora: central plasma sheet electrons of $\sim 100\ \mathrm{eV} - 10\ \mathrm{keV}$

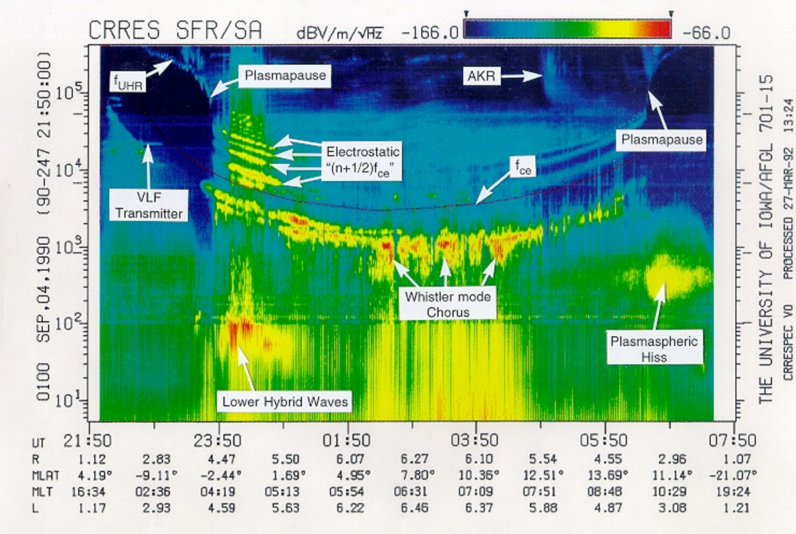
Plasma waves

Violation of first adiabatic invariant by plasma waves
$\Rightarrow$ Pitch-angle scattering into the loss cone and precipitation



Jaynes (2018)

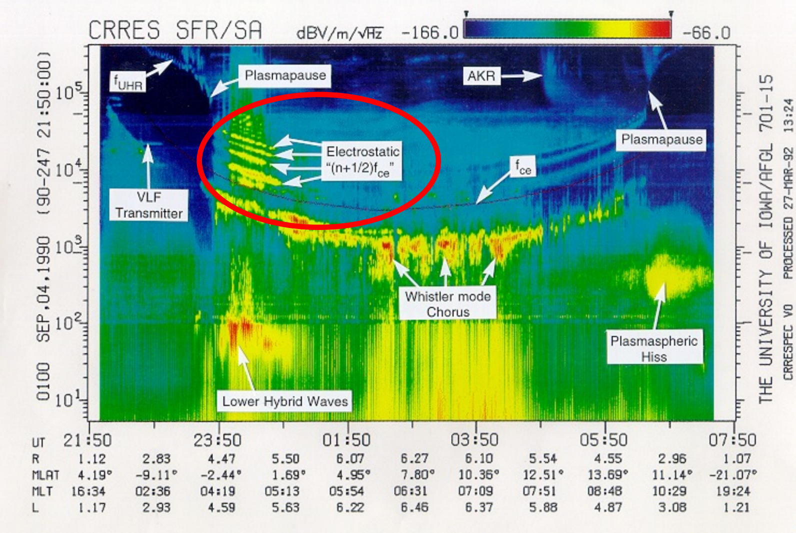
Plasma waves



Magnetospheric waves contributing to diffuse aurora

- **Upper- and lower-band chorus waves:** intense on nightside and in the inner magnetosphere, weaker on dayside
- **Lower band chorus waves:** pulsating aurora
- **Electrostatic electron cyclotron harmonic (ECH) waves:** nightside, outer magnetosphere (beyond $\sim 8\ \mathrm{R_E}$), pulsating aurora
- **Electromagnetic ion cyclotron (EMIC) waves:** ion precipitation

Electrostatic electron cyclotron harmonic waves



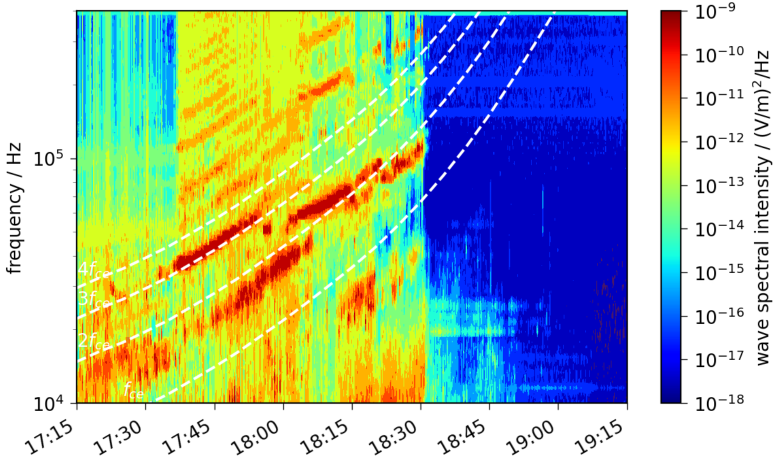
Calculation of ECH wave-induced diffusion coefficients

- Use **Full Diffusion Code** to calculate bounce-averaged momentum and pitch angle diffusion coefficients (Ni et al., 2008; Shprits et al., 2009)

- Solve the hot plasma **dispersion relation** along with the **resonance condition**

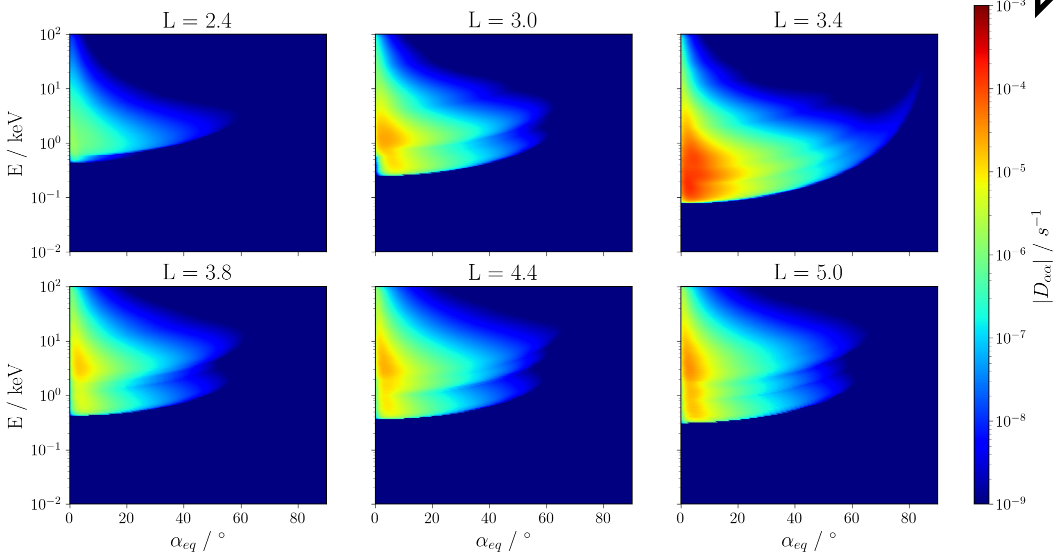
- Detailed information about the magnetospheric waves is required:
  - Wave power spectrum
  - Wave normal angle distribution
  - Number of resonances
  - Background magnetic field
  - Plasma density
  - Properties of the hot plasma sheet electrons responsible for wave excitation

ECH wave event on 17 March 2013



L	4.9	4.3	3.4	2.9	2.4	1.5	1.2
MLT	2.8	3.2	4.0	4.6	5.4	8.2	13.7
λ	-2.6	-1.5	0.4	2.0	4.2	9.9	7.2

ECH wave-induced diffusion coefficients



Summary

- Precipitation of electrons with $0.1 - 10$s keV produces diffuse aurora
- Resonant wave-particle interactions $\Rightarrow$ Pitch-angle scattering into the loss cone
- Model the process by quasi-linear theory $\Rightarrow$ calculate diffusion coefficients
- Diffusion coefficients depend on several wave and plasma properties
- Calculate event-specific diffusion coefficients