RESONANCE
Project for Studies of Wave-Particle Interactions in the Inner Magnetosphere

Anatoly Petrukovich and Resonance team
Resonance

Inner magnetospheric mission

- **Space weather**
  Ring current, outer radiation belt, plasmasphere

- **Resonant wave-particle interactions**
  Magnetospheric cyclotron maser

- **Auroral region acceleration**
  Small-scale active zones, precipitation

- Two pairs of spacecraft

- Magneto-synchronous orbit

**To be launched in 2014**

**2011: Engineering models delivery**
Resonance team

- **Russia** – Space Research Institute, NPO S.A. Lavochkin, Institute of Applied Physics, IZMIRAN, PGI, NIRFI, ...
- **Austria** – Space Research Institute
- **Bulgaria** – Space Research Institute
- **Czech Republic** – Institute of Atmospheric Physics
- **Finland** – Oulu University
- **France** – LPC2E/CNRS, CESR/CNRS
- **Germany** – MPI Lindau
- **Greece** – Thrace University
- **Poland** – Center for Space Research
- **Slovakia** – Institute of Experimental Physics
- **Ukraine** – Lviv center, Space Research Inst., Inst. of Astronomy
- **USA** – Maryland University

**Project Leader**
Prof. L.M. Zelenyi

**Project Scientist**
Dr. M.M. Mogilevsky
Orbit design

Goal: corotation with a flux tube

Magnetosynronous orbits

Apogee: ~28 000 km,
Perigee: ~ 500 km,
Period: ~ 8 hours
Inclination: +63.4° and -63.4°
Three sample orbits: corotation up to 3 hours
Zones along orbit

- inner radiation belt
- auroral zone
- outer radiation belt, corotation
- RESONANCE 1 orbit
- RESONANCE 2 orbit
Separation strategy with four spacecraft

Resonance 1A и 1B

~ 1-100 km

~ 5-15 000 km

~ 1- 5 000 km

Resonance 2A и 2B
### Preliminary strategy of satellite separation

<table>
<thead>
<tr>
<th>Phase</th>
<th>First pair (1A/1B)</th>
<th>Second pair (2A/2B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; phase (1-9 months)</td>
<td>1-10 km</td>
<td>1-10 km</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; phase (9-18 months)</td>
<td>1-10 km</td>
<td>10-100 km</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; phase (18-27 months)</td>
<td>10-100 km</td>
<td>100-1000 km</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; phase (27-36 months)</td>
<td>100-1000 km</td>
<td>1000-9600 km</td>
</tr>
</tbody>
</table>
RESONANCE instruments

Electric and magnetic sensors
Wave analyzer and interferometer
DC – 10 MHz

Plasma sensors
Cold plasma
Suprathermal plasma
Energetic particles
Relativistic electrons
### Scientific instrumentation

<table>
<thead>
<tr>
<th>EM field and wave measurements</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Flux-gate magnetometer**    | 3 components of B field, DC – 10 Hz  
~ 2.1 kb/s                      |
| **ULF electric field receiver** | 3 components of E field, DC – 10 Hz  
~ 1.4 kb/s                      |
| **VLF receiver**              | 3 electric and 3 magnetic components of EM field, 10 Hz – 20 kHz  
~ 5.76 Mb/s                     |
| **HF receiver**               | 3 electric and 3 magnetic components of EM field, 5kHz – 1 MHz,  5 MHz, 15 MHz  
~ 2.16 Gb/s                    |
| **Space radio interferometer** | 5-15 MHz    |
# Scientific instrumentation

## Plasma and particle measurements

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Energy Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold plasma analyzer</td>
<td>0 – 20 eV</td>
</tr>
<tr>
<td>Suprathermal electron spectrometer</td>
<td>10 eV – 15 keV</td>
</tr>
<tr>
<td>Suprathermal ion spectrometer with composition</td>
<td>10 eV – 30 keV</td>
</tr>
<tr>
<td>Fast electron analyzer (10 ms)</td>
<td>5 keV – 50 keV</td>
</tr>
<tr>
<td>Ring current ions and energetic electrons spectrometer</td>
<td>20 keV – 0.4 MeV</td>
</tr>
<tr>
<td>Relativistic electrons</td>
<td>300 keV – 5 MeV</td>
</tr>
</tbody>
</table>
Some issues to be resolved

Verification of chorus generation theory
Existing theories of chorus generation connect characteristics of chorus (frequency sweep-rate, time interval between chorus elements) with chorus amplitude which, in turn, depends on cold plasma density, plasma inhomogeneity, and resonant electron distribution function.

Electron pitch-angle diffusion and precipitation
Various wave-modes (whistlers, whistler-mode chorus, electromagnetic and electrostatic ion cyclotron waves, upper hybrid waves) have been suggested.

Proton precipitation with the operation of ground-based VLF transmitters

Nature of particle energization (acceleration) via wave-particle interactions

RESONANCE mission measures all necessary quantities simultaneously in the magnetic flux tube of effect
Magnetospheric maser

Active substance:
Energetic electrons > 5 keV

Electrodynamical system:
magnetic tube with cold plasma, ionosphere as mirrors

Operating modes:
whistler and ion cyclotron waves

Important for acceleration of MeV electrons
History

Discovery of radiation belts
*Sputnik 3, Explorer 1 (1958)*

First observations of ELF/VLF el.-m. waves
*Alcock, Martin (1956)*
*Duncan, Ellis (1959)*

CM in the Earth magnetosphere
*Brice (1964); Dungey (1963); Trakhtengerts (1963); Andronov and Trakhtengerts (1964); Kennel and Petchek (1966)*

Electronics
*Gaponov-Grekhov (1959)*
*Andronov, Zheleznyakov, and Petelin (1964)*

Plasma Physics
*Zheleznyakov (1960)*
*Sagdeev and Shafranov (1960)*
*Vedenov, Velikhov, and Sagdeev (1961)*
**Particles and fields**

**ELF/VLF chorus**

Frequency, kHz

- Waveform capability for E and B up to 10-40 kHz
- Energy, keV
- Pitch-angle
- Latitude = 30°

**Energetic electrons**

Time, s

- Electron distribution in keV range
- ~10 ms sampling, dE/E ~ 1%

Theory by V. Trakhtengerz & A. Demekhov
Ring current, radiation belt, plasmasphere

- Injection development
- MeV electron dynamics
- Ring current formation
- Wave-particle interaction
- Plasmasphere refilling and loss
Auroral acceleration region

FAST electric fields and electrons

AKR onboard INTERBALL-2
International inner magnetospheric constellation
2012-2015

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Altitude</th>
<th>Inclination</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESONANCE</td>
<td>27000 km</td>
<td>63 deg</td>
</tr>
<tr>
<td>ERG</td>
<td>4-5 Re</td>
<td>near-equatorial</td>
</tr>
<tr>
<td>RBSP</td>
<td>30000 km</td>
<td>near-equatorial</td>
</tr>
</tbody>
</table>

+ geostationary satellites, MMS, THEMIS, KUAFU-auroral

- Collaborative science topics in which synergy is possible?
- Orbital conjunctions?
Resonance - HAARP

- Artificial electromagnetic waves
- Modification of precipitation particles
- Modification of the reflection coefficient from the ionosphere