Venus Express Radio Science Experiment VeRa

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and the VeRa Team

“Venus Express Legacy Session”

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The VeRa Team and Partners

- Universität der Bundeswehr, Germany (B. Häusler, T. Andert)
- University Cologne, Germany (M. Pätzold, S. Tellmann)
- University Bonn, Germany (M. Bird)
- Stanford University (G. L. Tyler, R.A. Simpson, D. Hinson)
- Royal Observatory Belgium, Brussels (V. Dehant, P. Rosenblatt)
- JAXA, Japan (T. Imamura)
- NASA-JPL/DSN (S. Asmar, T. Thompson)
- ESA – ESTEC/ ESOC/ ESAC (H. Svedhem, D. Titov, F. Jansen, S. Remus)

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Thanks to all who have supported VeRa!
VeRa – Science Topics

- Atmosphere
- Ionosphere
- Surface
- Gravity Anomalies
- Solar Corona
VeRa-VEX Status Early in the Mission

• First occultation season 2006

• Begin of S-band anomaly (considerable drop in radiated power)
  ~ August 4, 2006  DOY216

VeRa experiments affected: SCO, OCC, BSR

• VEX thermal problems resulted in a revision of thermal rules, affecting also VeRa

• Consequence:
  • No more BSR experiments (confirmation of the existence of a thin conductive layer at Maxwell Montes missing for the next decades)
  • No more SCO experiments
  • Limitations in further OCC experiments (sun illumination, S/C body rates)
Note: Active Sun during Aug.-Nov. 2011 and during Feb.-March 2012.

VEX mission

Aerobraking

ISES Solar Cycle F10.7cm Radio Flux Flux Progression
Observed data through Aug 2014
Mission Operations Summary
Data Analysis

CL receiver mode:

VeRa retrieved so far more than 800 profiles of

- Temperature
- Neutral number density
- Pressure
- Electron Density

Occultation season # 16 (last radio science pass DOY 082, 23 March, 2014)

OL receiver mode:

- Data analysis still in progress both at RIU/Cologne and JAXA.
- Detection of very thin structures (< 1 km) in Venus mesosphere now possible.
Mission Operations Summary

Archiving

- Level 2 data archived until 2014.
- Selected temperature profiles available on request.
- Complete level 4 data set available on Saturn Server @ RIU by end of September 2016 (EURO Venus project)
Instrument – Experimental Techniques
VeRa Experiment

Ultrastable Oscillator (USO)

Quartz USO connected to X/S-band transponder
Serves as ultrastable reference frequency source

Allan Deviation $\approx 3 \cdot 10^{-13}$

1.5 kg 5 W
Manufact. TIMETECH
Venus Express transmitted Frequency (X-Band USO)

Note: X5.4 Flare occurred on orbit #2147  March 7, 2012

Oct. 9 2014 in orbit # ~ 3100
Two frequencies are needed to separate dispersive effects (plasma) from non-dispersive effects (orbit, neutral atmosphere)
Receiving Techniques Used

Closed Loop Recording (CL):
Groundstation receives a dynamically limited the carrier signal with a PLL and requires S/N: ~ 12dB

Open Loop Recording (OL):
Groundstation samples incoming signal with 150 ksamples per second. Special digital processing techniques allow to recover a highly dynamic carrier signal out of noise. S/N: ~ 0 dB
Amount of data for a typical occultation: ~ 4 GByte
Radio Science Occultation Technique:
Principle: Ray Bending in Neutral Atmosphere

It is the bending angle $\alpha$ which carries the information about the refraction index $n(r)$.

Sensitivity: $\Delta \alpha \sim 10^{-8}$ rad

next iteration step
The Radio Occultation Technique
Conducting an Experiment

At Venus - in order to maximize receiving power - one has to dynamically steer the radio beam in 3 axes through the atmosphere to compensate for the ray bending effect (Bending angle < 7°, 3dB opening angle of antenna beam 1.7°)

Dedicated software (Matlab/Simulink based simulator) including a model atmosphere was developed for this purpose by the Radio Science team. This allowed to calculate the HGA pointing angles expressed by quaternions for the 3-axis pointing maneuvers to guide the microwave ray through the atmosphere.

Pointing had also to obey the „thermal rules“.

First done by an experiment in an ESA mission. Flawless operations.
Carrier Power in a Typical „Deep“ Occultation Pass CL-Receiver
Both Channels Normalized in Power

Loss of carrier power in the atmosphere due to defocusing and absorption

~ - 50 dB (X-band)!
VeRa was the first planetary Radio Science mission detecting the carrier signal throughout a complete occultation.

The carrier could be detected during times with the planetary disk occulting completely the satellite.

Loss of carrier power in the atmosphere due to defocusing and absorption

~ - 50 dB (X-band)!
Achievements in Science

Characterized by an excellent cooperation within in the VEX Team including the Akatsuki Team

Very competent support in the fields of mission/experiment planning and ground station operations
VeRa turned out to be an extremely versatile instrument: Precise time and frequency measurements with microwaves allowed to characterize, determine, detect, discover:

- The ionospheric structure of Venus
- Particles of meteoric origin in ionospheric plasma
- Structure of Venus middle atmosphere
- Zonal wind distribution of Venus middle atmosphere (VeRa, VIRTIS)
- Cloud top structure (VeRa, VIRTIS)
- Polar vortex
- Planetary waves
- Ubiquitous distribution of gravity waves in the atmosphere
- Saturation of gravity wave power spectra (gravity wave breaking)
- Thin-layered near neutral structure of Venus mesosphere
- Thin inversion layer at tropopause (~ 1 km, ~ 10K)
- H2SO4 g distribution in atmosphere
- Dielectric properties of surface aereas and gravity properties
- Solar corona effects
Structure of the Venus Ionosphere

Discovery of Meteor Layer

Pätzold et al., GRL, 2009
Global Thermal Structure of Venus Middle Atmosphere
Latitude vs. Pressure, Zonally Averaged

Anomalous thermal structure at high latitudes above 70 km

~ 80 km

~ 70 km

~ 60 km

Tellmann et al., 2015
Averaged Zonal Wind Velocity Based on Cyclostrophic Approximation. Derived from VeRa and VIRTIS Data

A. Piccialli et al., Icarus, 217, 2012
Static Stability of Venus Middle Atmosphere as Observed by VeRa

Gravity wave propagation
Wave breaking

Thin inversion layer
~ 1 km

Convective region
with strong vertical gradients of velocity

Tellmann et al., JGR 2009
Global distribution of the *Potential Energy* $E_p$ of gravity waves (altitude range 65-80 km) detected by VeRa. Background: Topography measured by Magellan.

Tellmann et al., Icarus, 2012
OL Processing of Multipath Effects Based on Wigner-Ville Transformation (see also Herrmann et al. Thursday presentation)

Mattei, Remus, 2010

1 km "thick" Inversion layer not detected every pass – but almost.
Discovery of Saturated Gravity Wave Spectra and Turbulence in the Upper Mesosphere

Power Spectral Density of vertical wave number spectra divided by $N^4$ in the altitude interval 65-80 km and 75-90 km in selected latitude intervals. Shown also semi-empirical saturation curve (dotted).

Vertical diffusion coefficient: 2.7-31 (m2s-1)

Ando et al., JAS, 72, 2015
Thin, near-neutral layers are frequently found above ~60 km altitude in the high-resolution static stability profiles obtained by FSI in the middle and high latitude. Indication for turbulence.

Miyamoto et al., 2015
~ 4 Day Variations at Constant Latitude and Local Time

Presence of Planetary Wave
(possibly vert. propag. Rossby/Kelvin Wave)
- see Presentation by Tellmann et al. (Thursday) -

Temperature at lat: -35°, local time: 3-4 h

Origin of large scale structure still not clear:
Baroclinic instability? And/or possibly turbulent processes acting transferring small scale structures into large scale structures?
Solar Induced Effects above Tropopause at 75° - 85° Lat.
Presence of Wave # 2 Structure

Coldest temperatures located at the subsolar and antisolar points.

Tellmann et al., JGR, 2009
Model is being developed supporting the picture of a meridional transport of H2SO4 g condensing into droplets in the upward branch and evaporating again in the downward branch of the Hadley cell assuming a significant polar depression.

350 Profiles between 2006 and 2014

J. Oschlisniok et al., 2016
Background: VeRa temperature field
Crosses: VIRTIS (near IR)
Filled and open circles: Venera 15 (mid-IR)

Data suggest an increase of particle size in the upper cloud from equator to pole

Lee et al., Icarus, 2012
Simulation of Barotropic Instability in the Venus Atmosphere - Polar Vortex
- Presentation by H. Ando this Thursday -

Instability criteria met
Change of sign of dq/dφ

Circumpolar temperature distribution as simulated by AFES

Ando et al., 2016
Instability criteria must be met. Unstable modes can develop in regions of low static stability with large gradients of zonal velocity creating planetary scale waves.

Häusler, Andert, 2010

Piccialli, 2010
Thank You
For Your Attention