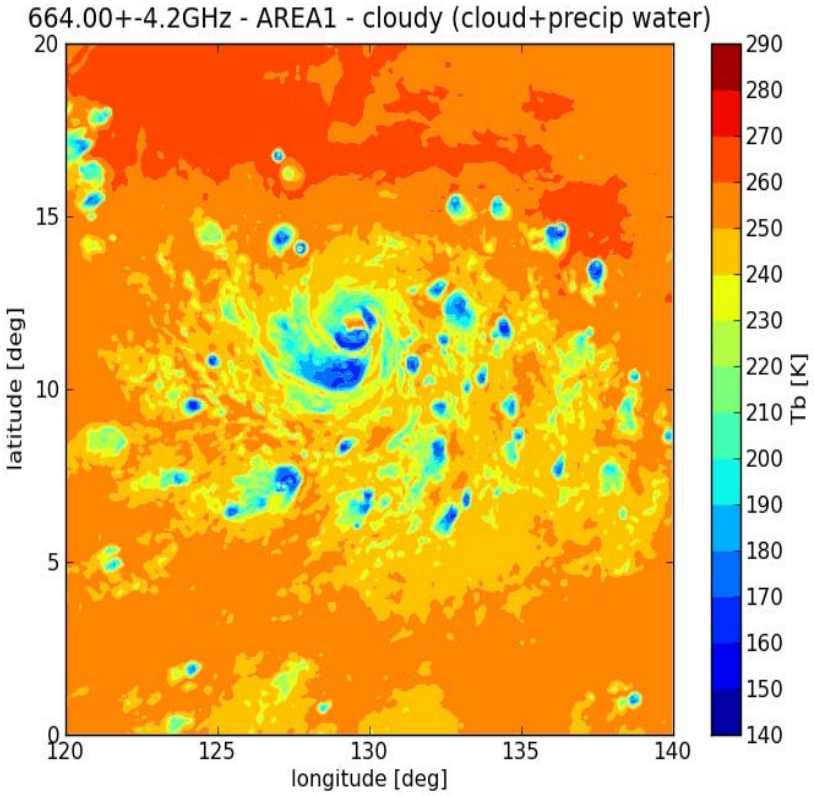
SRS Annual Meeting
Kiruna, March12th 2013



ARTS+
A toolbox for microwave atmospheric radiative transfer in solar system planets

Jana Mendrok
Luleå University of Technology

Contents

- Intro
  - Radiative Transfer – what is it? what for?
- ARTS
  - applications
  - capabilities
  - new features for planetary RT
- Summary

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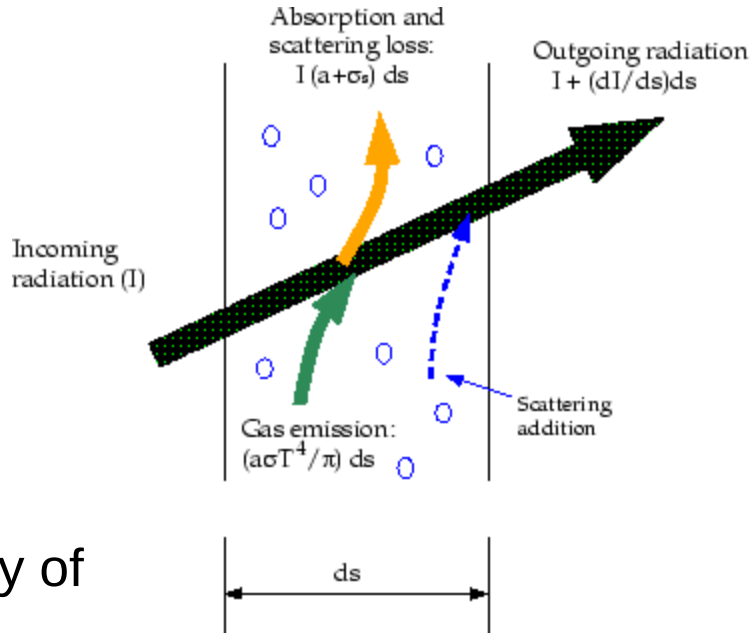
Intro

- Radiative transfer (RT) / Propagation modeling?

- what for do we do it?
  - predict signals: detectability of features/processes, measurability of parameters ⇨ instrument design, preparatory studies
  - sensor calibration
  - data analysis, retrieval



courtesy: ANSYS Inc.
(https://www.sharcnet.ca/Software/Fluent12/html/th/node111.htm)

ARTS

- **A**tmospheric **R**adiative **T**ransfer **S**imulator
  - applications
  - capabilities
  - new features for planetary RT

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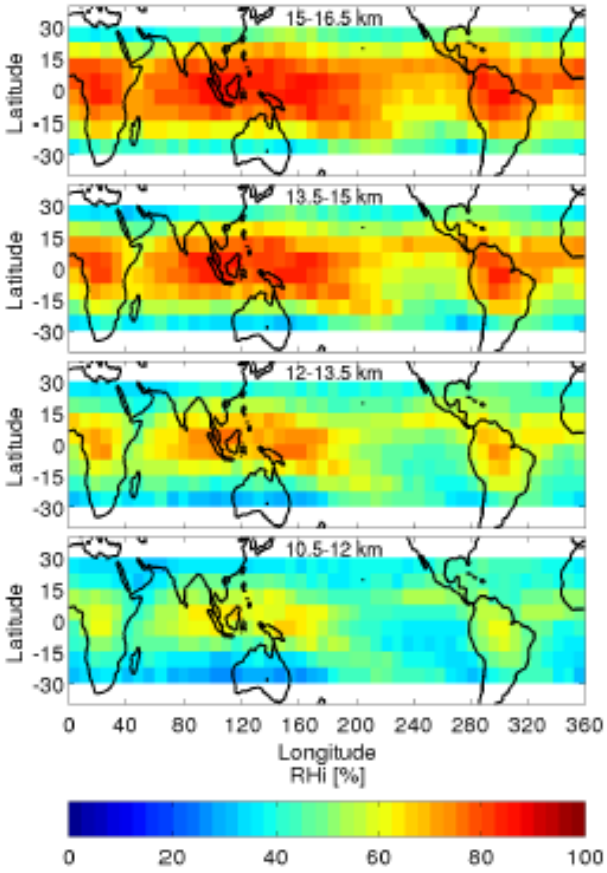
ARTS – Application examples

- (sub)mm-wave limb observations of Earth atmosphere for stratospheric chemistry
  - preparatory sensor studies
  - data analysis

⇨ **Odin-SMR**

⇨ JEM-SMILES



courtesy: Rydberg et al., 2009

Odin-SMR multi-year means of (upper tropospheric) relative humidity

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ARTS

- focus (but not exclusively limited):
  - mostly Earth atmosphere
  - environmental and climate related applications
- basic philosophy:
  - general and **based on physical principles**

    (as far as feasible!)
  - modular, (easily) extendable
  - flexible (“scripting language” control files as user interface)

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ARTS – Application examples

- (sub)mm-wave limb observations of Earth atmosphere for stratospheric chemistry
  - preparatory sensor studies
  - data analysis

- Data analysis
  - groundbased MW radiometers (O3, H2O, winds, …)
  - Upper tropospheric humidity (UTH) from MW & IR satellite sensors (climate monitoring)
- Validation
  - Radiosonde measurements
  - UTH from operational meteo satellites (Calib)
- …

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ARTS – Application examples

- examples of space science/astronomy applications:
  - "Characterization of the atmosphere above a site for millimeter wave astronomy" (DOI:10.1007/s10686-011-9214-9)
  - "Observing cosmic microwave background polarization through ice" (DOI:10.1111/j.1365-2966.2007.11464.x)
  - "Sub-millimeter observations of the terrestrial atmosphere during an Earth flyby of the MIRO sounder on the Rosetta spacecraft" (subm. to Plan. Space Sci.)

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ARTS – Application examples

>80 papers (and counting) from ARTS applications

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ARTS – Capabilities

- Polarization (1-4 Stokes elements)
- 1D, 2D or 3D
- ellipsoidal planet and surface topography
- all observation geometries allowed

- state-of-the-art absorption models (line-by-line (HITRAN & other catalogs) and various continua and full absorption models)
- scattering (2 different methods available)
- arbitrarily shaped, arbitrarily oriented (scattering) particles

- analytical or semi-analytical Jacobians

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ARTS – What it can't do (yet?)

- no collimated beam source (solar source)
- no absorption models for UV/VIS
  - **microwave to thermal infrared only**

- non-LTE

- sophisticated surface models (also: no absent surface)
- extremely fast calculations (e.g. for broadband flux calculations)
- …

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ARTS

- **A**tmospheric **R**adiative **T**ransfer **S**imulator
  - community model

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ARTS – a community model

- "Fathers" of the project
  - ***Stefan Buehler***
  - ***Oliver Lemke***
  - ***Patrick Eriksson***

LULEÅ TEKNISKA UNIVERSITET
FORSKNING OCH UTBILDNING I VÄRLDSKLASS

CHALMERS

- many more contributors/developers
  - Cory Davis
  - Claudia Emde
  - ***Mattias Ekström***
  - Sreerekha T.R.
  - Thomas Kuhn
  - ***Richard Larsson***
  - Axel von Engeln
  - ***Mathias Milz***
  - ***Carlos Jimenez***
  - ***Daniel Kreyling***
  - ***Jana Mendrok***
  - and several more

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ARTS

- **A**tmospheric **R**adiative **T**ransfer **S**imulator
  - community model
  - open source (GNU public license, C++)
  - available from ***www.sat.ltu.se/arts/***

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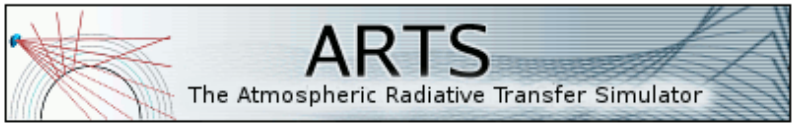
ARTS

- available from ***www.sat.ltu.se/arts/***

Satellite Atmospheric Science Group

KIRUNA SPACE CAMPUS
LULEÅ UNIVERSITY OF TECHNOLOGY
SRT - Division of Space Technology
IRF



ARTS - The Atmospheric Radiative Transfer Simulator

- What is ARTS?
- Science with ARTS
- Getting ARTS
- Documentation / Support
- Related Tools
- Automated builds
- Previous versions (ARTS 1.0)

News

Show all news

2012-05-07: Pont des Arts

ARTS

- available from ***www.sat.ltu.se/arts/***
  - download & installation info

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Getting ARTS

Code of Conduct

If you use data generated by ARTS or Qpack in a scientific publication, then please mention this and cite the most appropriate of the ARTS publications that are summarized on the Documentation page.

Subversion Access

The latest stable ARTS version can be checked out through Subversion with the following command:

```
svn co https://www.sat.ltu.se/svn/rt/arts/branches/arts-2.0
```

Although we recommend to use Subversion to stay up to date with the latest changes, you can download a snapshot of ARTS from http://www.sat.ltu.se/arts/misc/download/stable/2.0/.

The latest development version can be checked out with:

```
svn co https://www.sat.ltu.se/svn/rt/arts/trunk arts
```

Although we recommend to use Subversion to stay up to date with the latest changes, you can download a snapshot of ARTS from http://www.sat.ltu.se/arts/misc/download/trunk/.

To build ARTS you need the following tools:

* cmake (>=2.8.3)

ARTS

- available from ***www.sat.ltu.se/arts/***
  - documentation

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Documentation

Online Docs

Stable Version

Please note that the crosslinks between the PDF documents only work if you download all three books and save them in the same directory.

* ARTS User Guide PDF: Guide for ARTS users.
* ARTS Developer Guide PDF: Guide for ARTS developers.
* ARTS Theory PDF: Describes the theoretical basis of many ARTS algorithms.
* ARTS built-in documentation browser: This is the preferred way of accessing the ARTS built-in documentation. It provides a browsable HTML version of the documentation including all workspace methods, variables, agendas and groups. You can also run it locally on your own computer with `arts -s`.

Development Version

* ARTS User Guide: Guide for ARTS users.
* ARTS Developer Guide: Guide for ARTS developers.
* ARTS Theory: Describes the theoretical basis of many ARTS algorithms.
* ARTS built-in documentation browser

Articles

Going a step further: Planets

- ⇨ sophisticated, well-validated RT model
- ⇨ extend to further planets

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Going a step further: Planets

- (Microwave) Propagation Toolbox for Planetary Atmospheres:
  - Radiative Transfer/Propagation Model
    - (upcoming slides: updates & upgrades)
  - Data Collection
    - atmospheric scenarios for Earth, Mars, Venus, Jupiter (T, z, gas VMRs, cloud/dust fields, B, Ne)
    - spectroscopic catalogue
    - cloud/dust optical properties

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Going a step further

- Radiative Transfer Model: **generalisations** for planetary applications

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Going a step further

- Radiative Transfer Model: **generalisations** for planetary applications – **air = 79% N2 + 21% O2 ? Well, nope!**

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Going a step further

- Radiative Transfer Model: **generalisations** for planetary applications – **air = 79% N2 + 21% O2 ? Well, nope!**
  - spectroscopy
    - new catalogue format (pressure broadening and pressure shifts for 6 major species: N2, O2, CO2, H2, He, H2O)
    - newly compiled catalogue

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    - newly compiled catalogue
  - line absorption
    - pressure broadening and shifts acc. to actual air mixture

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Going a step further

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  - spectroscopy
    - new catalogue format (pressure broadening and pressure shifts for 6 major species: N2, O2, CO2, H2, He, H2O)
    - newly compiled catalogue
  - line absorption
    - pressure broadening and shifts acc. to actual air mixture
  - refraction
    - acc. to actual air mixture (considering 5 major species: N2, O2, CO2, H2, He; extendable)

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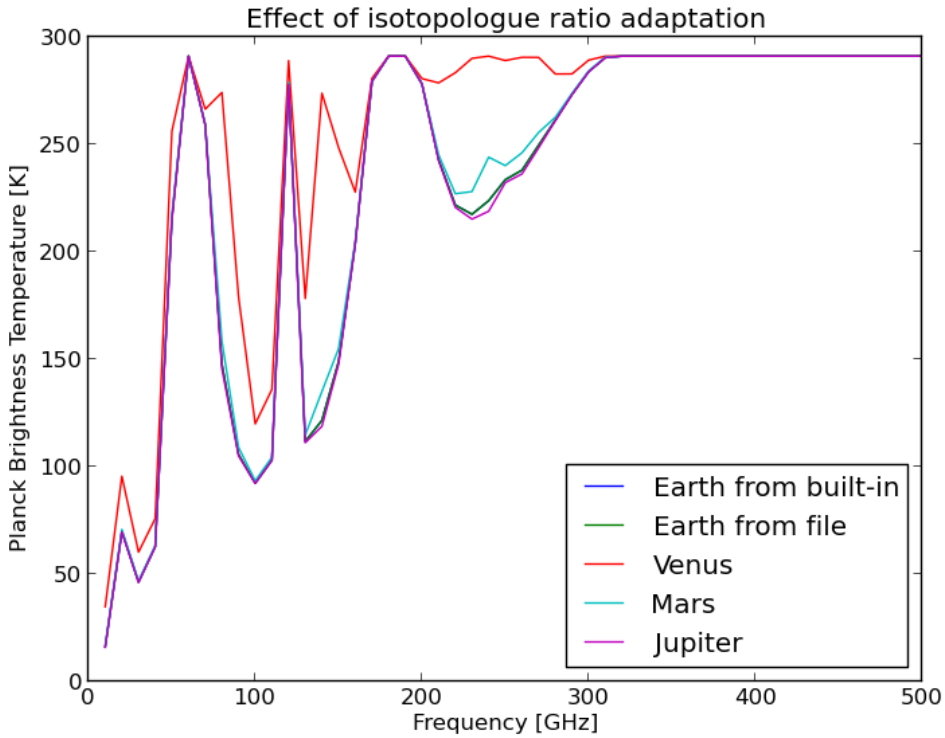
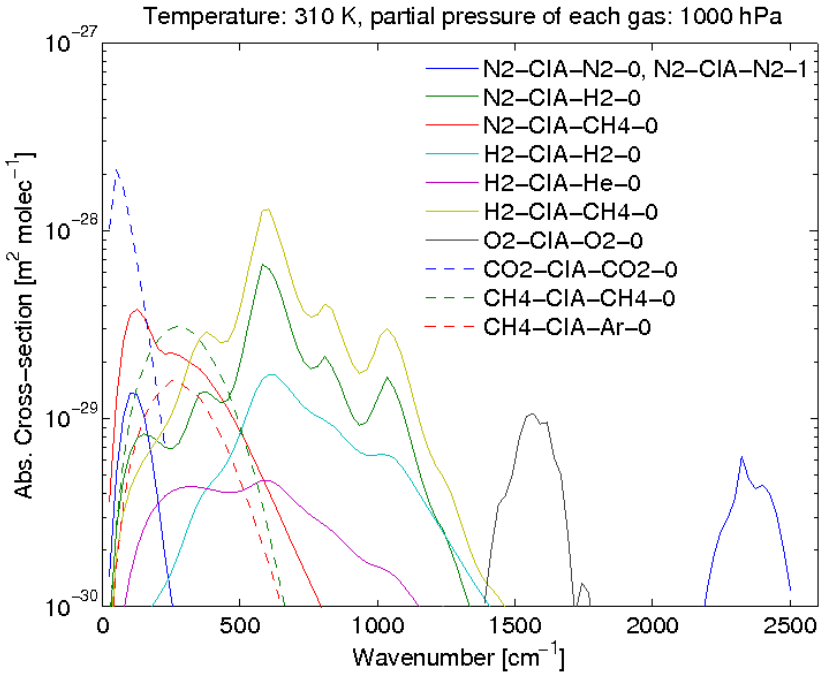
Going a step further

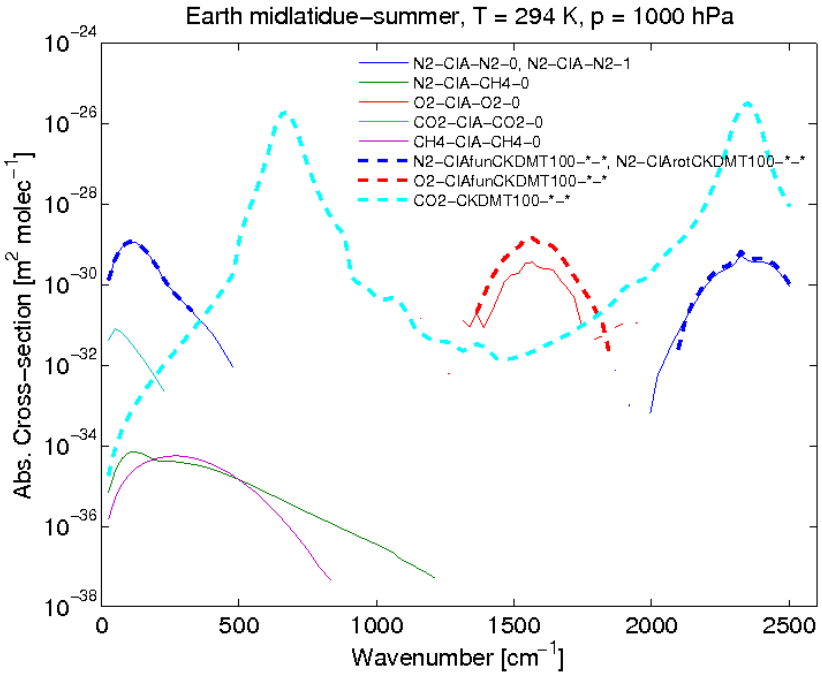
- Radiative Transfer Model: generalisations for planetary applications
  - isotopologue ratios (de-hardwired; now a set of input parameters)



Going a step further

- Radiative Transfer Model: **new features**
  - additional continuum models
    - collision induced absorption (data source: HITRAN; particularly relevant in high-pressure atmospheres)





courtesy: Stefan Buehler

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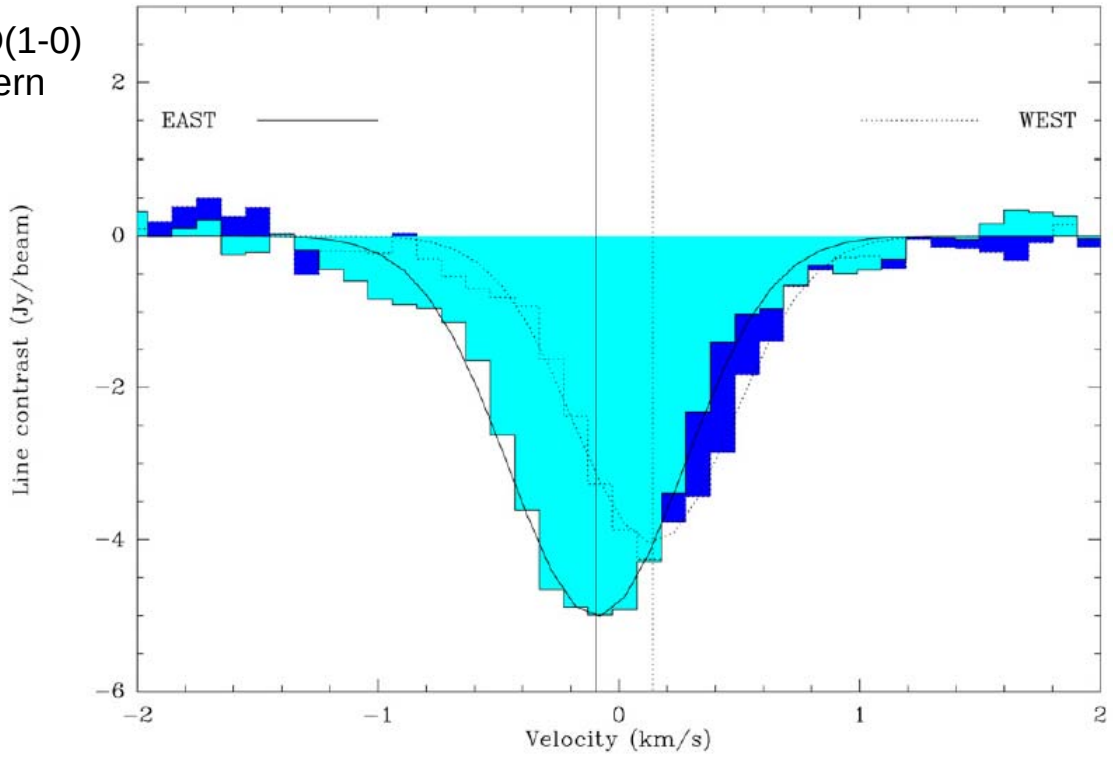
Going a step further

- Radiative Transfer Model: **new features**
  - Doppler shifts:
    - wind (up to 3D wind fields)
    - planet rotation (neglecting altitude dependency; relevant for full-disk obs., wind meas. at East/West limb)

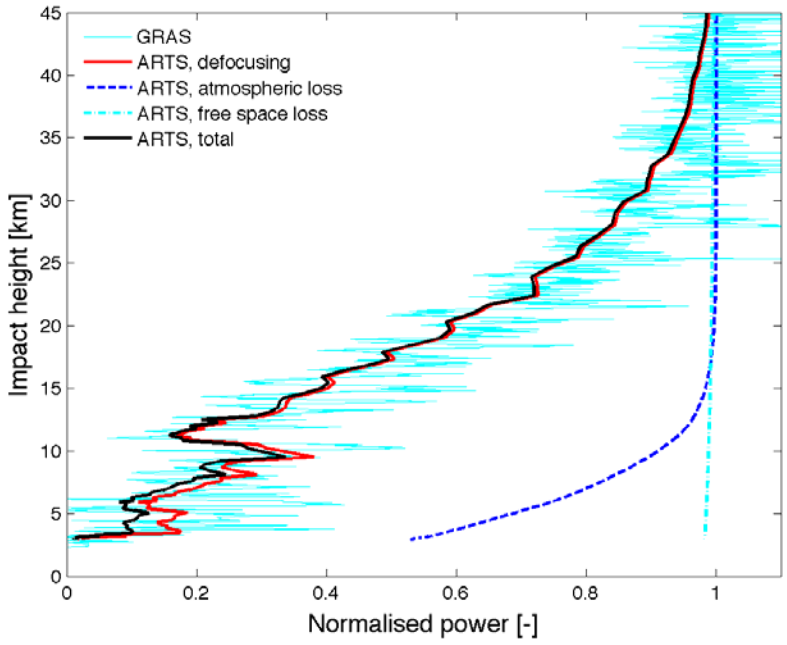
IRAM observation of CO(1-0) transition in Venus Eastern and Western limb. Uncorrected for planet rotation.

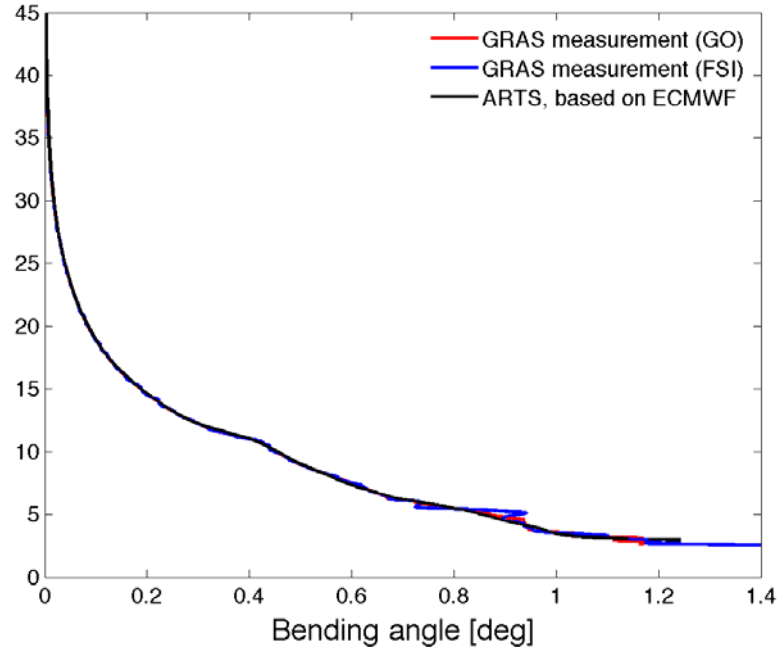


courtesy: Moreno et al., 2009

Going a step further

- Radiative Transfer Model: **new features**
  - active measurement techniques:
    - radio occultation (attenuation incl. atmo. and free space loss and defocusing, path delay/bending angles; transmitter-to-receiver path tracing)





courtesy: Patrick Eriksson

Going a step further

- Radiative Transfer Model: **new features**
  - active measurement techniques:
    - radio occultation (attenuation incl. atmo. and free space loss and defocusing, path delay/bending angles; transmitter-to-receiver path tracing)
    - radio links

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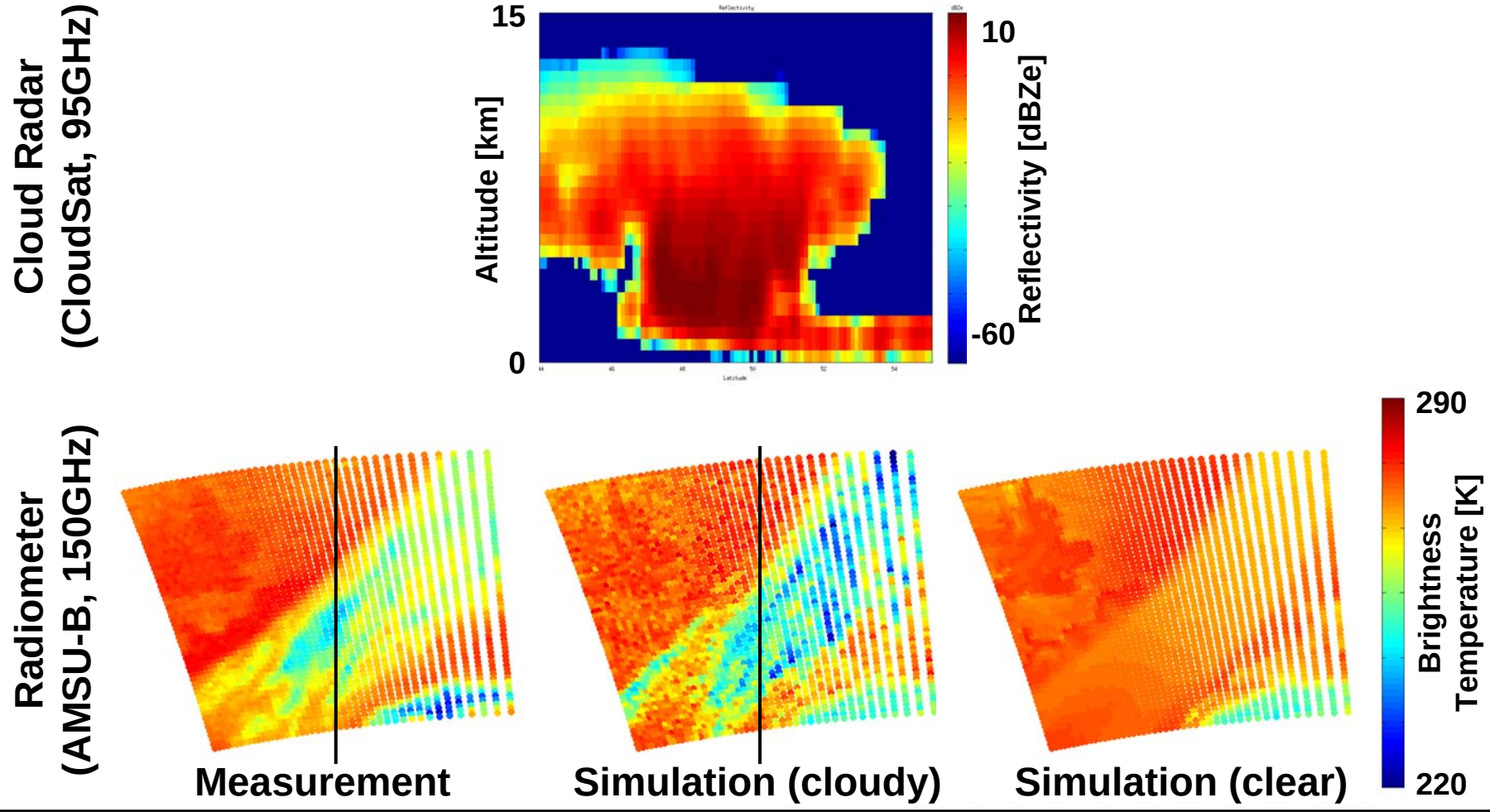
Going a step further

- Radiative Transfer Model: **new features**
  - active measurement techniques:
    - cloud radar (reflectivity)



courtesy: Victoria Galligani & Patrick Eriksson

Going a step further

- Radiative Transfer Model: **new features**
  - Free electron (ionospheric) effects
    - Refraction
    - Faraday rotation: polarization change due to charged particles (electrons) in presence of magnetic field

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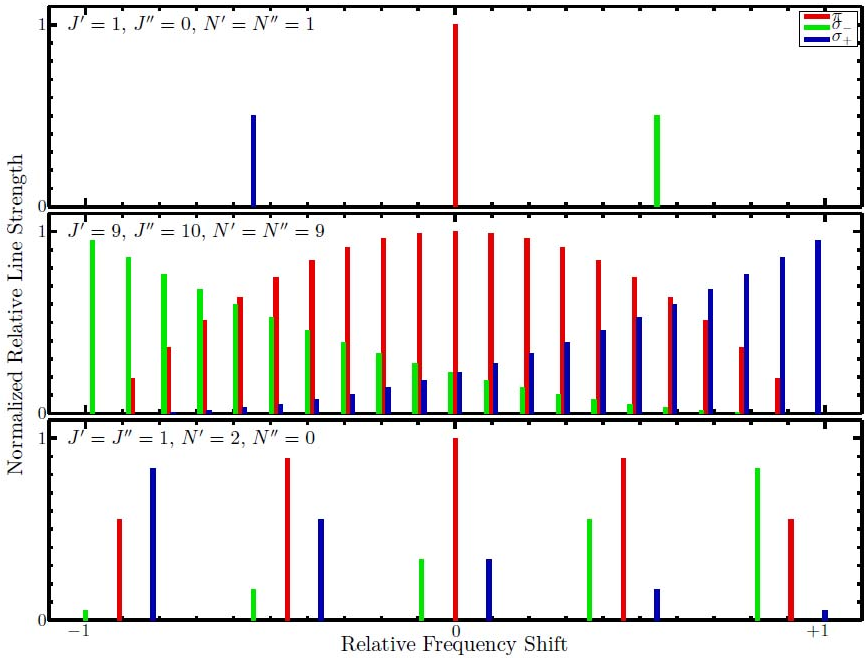
Going a step further

- Radiative Transfer Model: **new features**
  - magnetic field effects
    - Zeeman splitting: splitting of an energy level (of a molecule/atom with total electron spin !=0) into several sub-levels in interaction with external magnetic field



courtesy: Larsson et al., 2013

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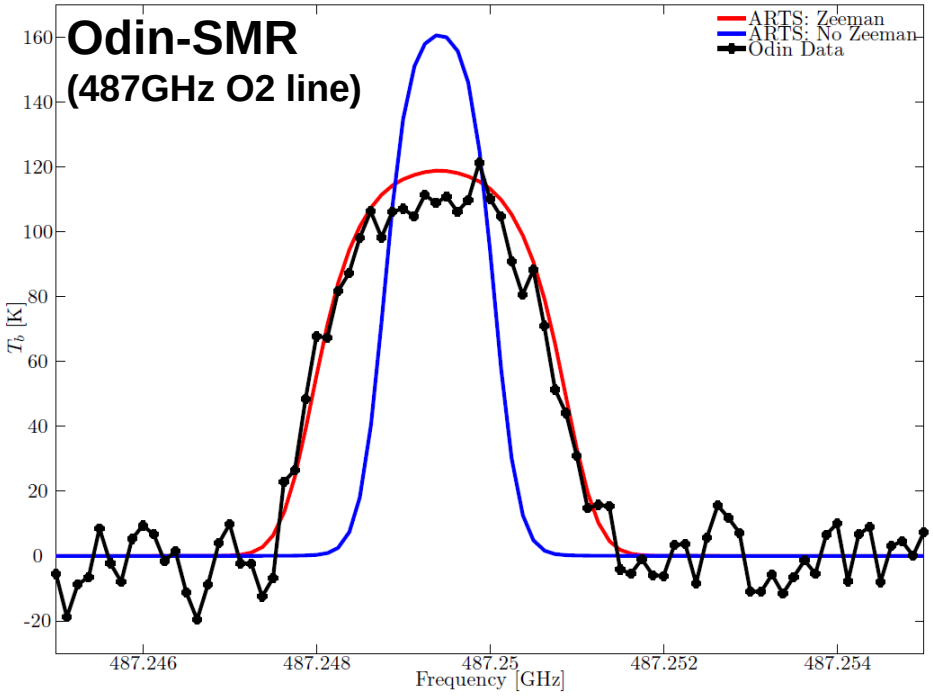
Going a step further

- Radiative Transfer Model: new capabilities
  - magnetic field effects
    - Zeeman splitting:
      - splitting of an absorption line into sub-lines, shifted away from the original line position (virtual line broadening)
      - polarized absorption/emission, depending on magnetic field orientation



courtesy: Larsson et al., 2013

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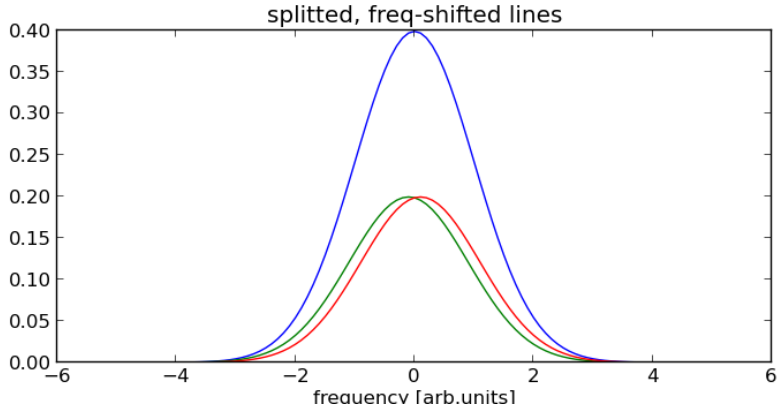
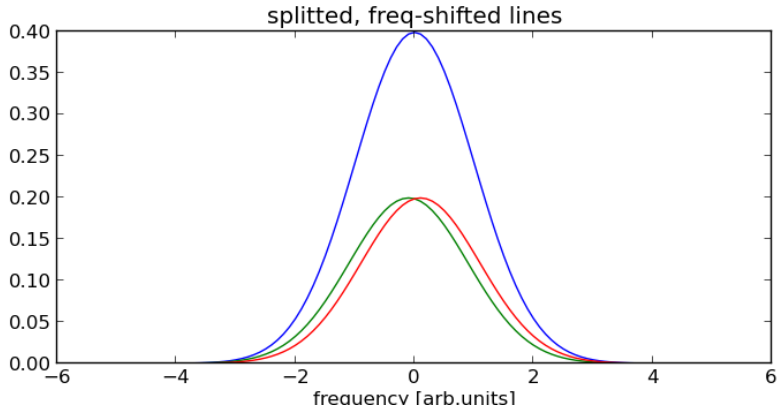
Going a step further

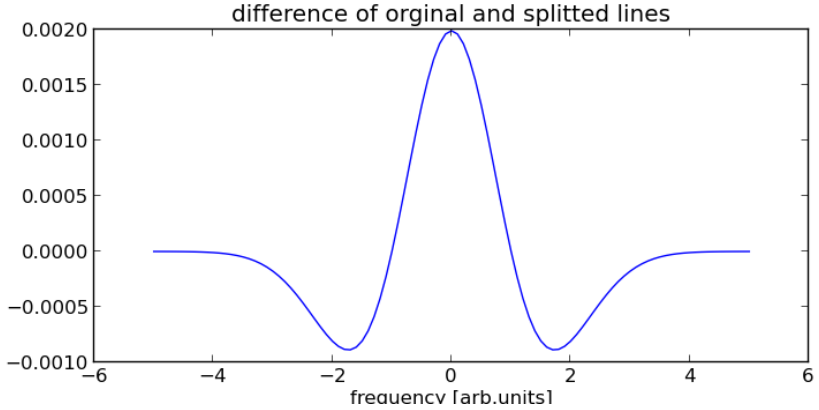
- Radiative Transfer Model: new capabilities
  - Zeeman splitting: measure magnetic field, e.g. Mars
    - Zeeman shift is small (few Hz/nT)



Going a step further

- Radiative Transfer Model: new capabilities
  - Zeeman splitting: measure magnetic field, e.g. Mars
    - Zeeman shift is small (few Hz/nT)
    - maximum signal difference at $(\nu_0 - \nu)^2 \approx (\Delta\nu_D)^2 + \left(\frac{\gamma}{4\pi}\right)^2$.





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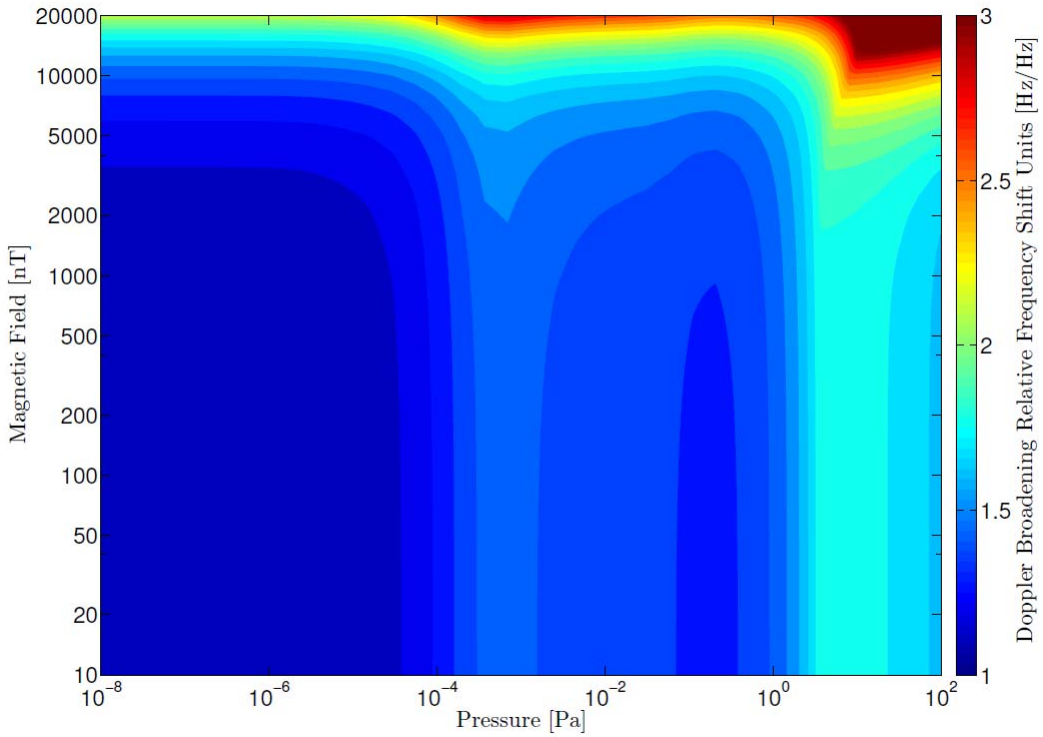

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Summary

- ARTS as a tool for planetary science (+space science, astronomy)

  You're welcome!

  - to apply ARTS for your projects
  - to contribute to development (or suggest/ request new features/applications)

www.sat.ltu.se/arts/

Acknowledgments: Planetary toolbox development financed by ESA.

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