Synthetic spectra with the Reference Forward Model (RFM)

IRDAS-EXP
The presence of methane in the atmosphere of an extrasolar planet

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The extrasolar planet atmosphere and exosphere: Emission and transmission spectroscopy

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![Graph showing absorption spectrum vs wavelength](image-url)
VENUS

- Sulfuric acid cloud layers
- Sulfuric acid haze
- Troposphere

Diagram showing the vertical distribution of temperature and pressure on Venus.
Since I have failed with Exoplanets, and with the Solar system, why not to look at the Mythology

The Birth of Venus

Botticelli

Mars

Velázquez

Cronus

Goya
One slide about PHOENIX

- http://www.hs.uni-hamburg.de/EN/For/ThA/phoenix/index.html
- General purpose radiative transfer code for HR-diagram starts, Ttauri stars, novae, supernovae, brown dwarfs and extrasolar giant planets
- Thesis dissertation by Mariana Wagner:
  “Reflectance Spectra of Earth-Like Exoplanets” June 2011
The Reference Forward Model (RFM)

- Many thanks to Anu Dudhia (AOPP University of Oxford)
- web page: www.atm.ox.ac.uk/RFM/
- Line-by-line transfer model based on GENLN2 model by D. P. Edwards (1992)
- Started as a limb line-by-line model link to MIPAS studies but now it is a quite general line-by-line model
ENVISAT

- ESA
- Sun Synchronous Polar Orbit (800 km)
- 98.55° inclination
- Period 101 minutes, 14.25 Orbits per day
- Launched in 2002
MIPAS

Michelson Interferometer for Passive Atmospheric Sounding

- Fourier Transform Spectrometer
- Spectrum 685-2410 cm\(^{-1}\) (14.6-4.15 \(\mu\)m) at 0.035 cm\(^{-1}\) resolution in 4.5s
- Limb scan in 17 steps from 150-6km in 85s (~500km)
- 72 profiles per orbit
- ~1000 profiles per day
RFM applications

- Simulating atmospheric emission/transmission spectra
- Modelling cell transmittances for spectroscopy
- Flux calculations for radiative forcing
- Generating look-up tables of absorption cross-section
- Atmospheric path ray-tracing and integrations
RFM Geometries

Cell Transmittance

Atmospheric Transmittance

Flux Calculations

Limb Radiance
What RFM can do part I

- Spherical or plane-parallel atmospheres, homogeneous paths
- Field-of-View & Instrument Line Shape convolutions
- $\text{CO}_2$ line mixing
- Curtis-Godson approximation
- Continua for $\text{H}_2\text{O}$, $\text{O}_2$, $\text{N}_2$ and $\text{CO}_2$
- Non-LTE
What RFM can do part II

- Jacobians for p, T, VMR, line-of-sight pointing and surface temperature and emissivity
- Satellite/Balloon & Aircraft/Ground-based viewing geometries
- Surface reflections
- Output spectra of radiance, transmittance, absorption, cooling rates, optical depth and brightness temperature
What RFM can do part III

- Output diagnostics from ray-tracing
- Can do horizontal structure of the atmosphere
- Flux calculations
- Different isotopic mixing ratio profiles
- Compatible with HITRAN 2008 and HITRAN cross-sections for heavier molecules such as CFCs and $\text{N}_2\text{O}_5$
What RFM can not handle

- Scattering
- Instrument line shape wider than around 1 cm$^{-1}$

But I like it quite a lot because it is really easy to install and to use.
Radiance

Path Transmittance: \[ \tau = \prod_j \tau_j \]

Radiance: \[ R = \int B \, d\tau = \sum B_i \Delta \tau_i \quad (\text{+} \; B_s \tau) \]
Transmittance

Absorption Coefficient: \( k(v) = \sum_i S_i(T) F(v-v_{0i}, p, T) \)

Transmittance: \( \tau_i(v) = \exp(-k \rho s) \)

Multiple absorbers \( j \): \( \tau_i(v) = \prod_j \tau_{ij} \)
The continua

For more on continuum refer to University of Reading, CAVIAR project
http://www.met.reading.ac.uk/caviar/background.html
Curtis-Godson approximation

- For Lorentzian absorption the effective pressure and temperature for an heterogeneous path:

\[ \bar{p} = \frac{1}{m} \int p \rho \, dz \]
\[ \bar{T} = \frac{1}{m} \int T \rho \, dz \]
\[ m = \int \rho \, dz \]
Curtis-Godson approximation in the “strong” limit is exact as it is in the “weak” limit

\[ \tau = e^{-\int \frac{S}{\pi} \frac{\alpha_L}{(\nu - \nu_0)^2} \rho \, dz} \]

\[ \alpha_L \sim \alpha \cdot \frac{p}{p_0} \]

\[ \tau = e^{-\frac{-S}{\pi} \frac{\alpha_0}{(\nu - \nu_0)^2} \bar{p} m \, p_0} \]
# The molecules included

<table>
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## Key

- Standard HITRAN line molecules
- HITRAN line Molecules also represented as cross-sections
- Additional GEISA line molecules (RFM-specific IDs)
- Extinction cross-section [km⁻¹] (RFM-specific IDs)
- Molecular cross-section [cm²/molec] (RFM-specific IDs)
- Dummy names for extra cross-section molecules (RFM-specific IDs)
Installation

- In Linux/Unix with a Fortran77 compiler
- Source code is distributed as a tar file:
  - rfm_v4.28.tar.gz
  - Unpack tar -xzf rfm_v4.28.tar.gz
- With ifort: ifort -O3 -o rfm *.for
Input files: Driver table

*HDR
RFM run for IRDAS studies
*FLG
TRA
*SPC
4029.104610 4029.114610 0.00001
*GAS
3
*ATM
/home/gga500/atmfascodes/tro.atm ! Atmospheric conditions, TROPICAL
*TAN
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58
59 60
*HIT
/home/gga500/HITRAN08.bin
*TRA
../out/tro.atm/Target_Species_Transmission/I01/RFM_*.tra
*GRD
!/export/home/ndca500/RFM-source/fov.rfm !mipas.fov
*END
Input files: Atmospheric profile

! FASCOD Model 6 U.S. Standard Atmosphere
! Transformed to RFM .atm file format by program USARFM v.23-AUG-96

1  ! No.Levels in profiles
*HGT  [km]
   2.0
*PRE  [mb]
   7.950E+02
*TEM  [K]
   275.20
*H2O  [ppmv]
   4.631E+03
*CO2  [ppmv]
   3.300E+02
*O3   [ppmv]
   3.237E-02
*N2O  [ppmv]
   3.200E-01
*CO   [ppmv]
   1.399E-01
*CH4  [ppmv]
   1.700E+00
*O2   [ppmv]
   2.090E+05
*END
HITRAN08.bin

- It is a binary version of the HITRAN database compatible with the GENLN2 input format
- It can be created starting with the HITRAN ASCII *.par file using hitbin.f program
MIPAS spectral range radiance 15 km
Something about ACE-FTS

- Solar occultation FTS
- 0.02 cm\(^{-1}\)
- Spectral range 750-4400 cm\(^{-1}\)
- “High” signal to noise ratio, usually above 300
ACE-FTS region RFM radiance spectra
ACE-FTS region transmission spectra
Formic acid

1 !Driver table for lecture HCOOH
2 *HDR
3 RFM run using Driver Table SAO 1 (19/03/2012)
4 *FLG
5 TRA ABS RAD !Transmission, absorption and radiance
6 *SPC
7 FullACE 750.0 4400 2.0 !To have a full picture
8 RetrACE 1100 1110 0.02 !Where it was actually done
9 *GAS
10 32
11 *ATM
12 /home/ggonzale/TOOLS/RFM/atmospheres/hgt_std.atm
13 /home/ggonzale/TOOLS/RFM/atmospheres/std.atm
14 /home/ggonzale/TOOLS/RFM/atmospheres/minor.atm
15 /home/ggonzale/TOOLS/RFM/atmospheres/HCOOH.atm
16 *TAN
17 1 5 10 17 40
18 *HIT
19 /home/ggonzale/TOOLS/RFM/HITRAN08/HITRAN08.bin
20 *ABS
21 /home/ggonzale/TOOLS/RFM/HCOOH_1/efm_*.abs
22 *TRA
23 /home/ggonzale/TOOLS/RFM/HCOOH_1/efm_*.tra
24 *RAD
25 /home/ggonzale/TOOLS/RFM/HCOOH_1/efm_*.rad
26 *END
27
An example: HCOOH
Formic acid, used microwindow
ACE-FTS spectra with HCOOH residual
Line selection

CO$_2$ region

Transmission

Wavenumbers cm$^{-1}$

4766 4768 4770 4772 4774 4776 4778 4780
Project 2

!Driver table for lecture project_2
2 *HDR
3 RFM run using Driver Table SAO 2 (16/04/2012)
4 *FLG
5 TRA ABS RAD OBS!Transmission, absorption and radiance
6 *SPC
7 !OH 118 119 0.0002 !Project second
8 HCl 2923.00 2926.00 0.0005 ! Project first
9 !MIPAS 685 2410 2.0 !To have a full picture
10 !RetrACE 1100 1110 0.02 !Where it was actually done
11 *GAS
12 15
13 !13 13 !H2O O3 OH
14 !1 3 6 10 15 !H2O O3 CH4 NO2 HCl
15 *ATM
16 /home/ggonzale/TOOLS/RFM/atmospheres/hgt_std.atm
17 /home/ggonzale/TOOLS/RFM/atmospheres/std.atm
18 /home/ggonzale/TOOLS/RFM/atmospheres/minor.atm
19 /home/ggonzale/TOOLS/RFM/atmospheres/HCOOH.atm
20 !*TAN
21 !25 30 35 40 45
22 *ELE
23 45
24 *OBS
25 0.0 !Observer in ground
26 *HIT
27 /home/ggonzale/TOOLS/RFM/HITRAN08/HITRAN08_22.bin
28 *XSC
29 /home/ggonzale/TOOLS/RFM/CX/f12.xsc_h2k !52 CFC-12 cross section
30 /home/ggonzale/TOOLS/RFM/CX/f22.xsc_h2k !56 HCFC-22 cross section
31 /home/ggonzale/TOOLS/RFM/CX/f134.xsc_h2k !79 HFC-143a cross section
32 *ABS
33 /home/ggonzale/TOOLS/RFM/PROJECT_2/rfm_*.abs
34 *TRA
35 /home/ggonzale/TOOLS/RFM/PROJECT_2/rfm_*.tra
36 *RAD
37 /home/ggonzale/TOOLS/RFM/PROJECT_2/rfm_*.rad
38 *END