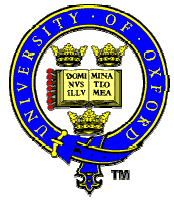

Infrared Limb Sounding
MIPAS and HIRDLS

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MIPAS

Michelson Interferometer for Passive Atmospheric Sounding

- Fourier Transform Interferometer
- Launched on Envisat 1st March 2002
- ~1 000 profiles per day

HIRDLS

High Resolution Dynamics Limb Sounder

- Filter Radiometer
- To be launched on Aura early 2004
- ~10 000 profiles per day

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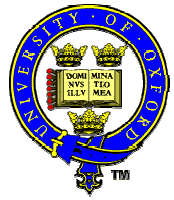
- Introduction
- Limb Viewing Geometry
- Channel Selection
- Radiative Transfer Modelling
- Retrieval Schemes



Limb-sounders compared to nadir-sounders

- Better vertical resolution – 3km MIPAS, 1km HIRDLS
- Better upper vertical range – mesosphere
- Worse horizontal resolution – 100s km
- More sensitive to cloud – fewer gaps in limb view

Also: radiative transfer & retrieval more complicated (2D)

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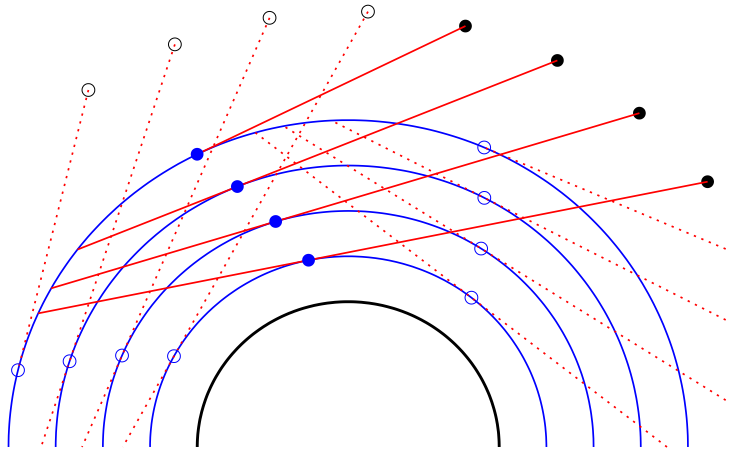
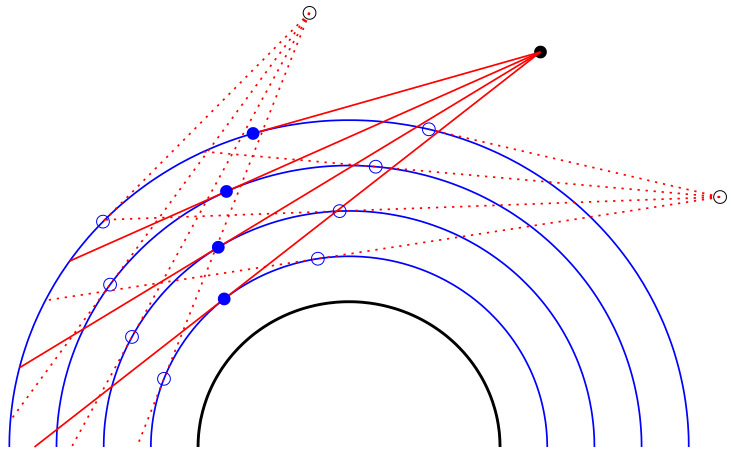
Limb Viewing Geometry

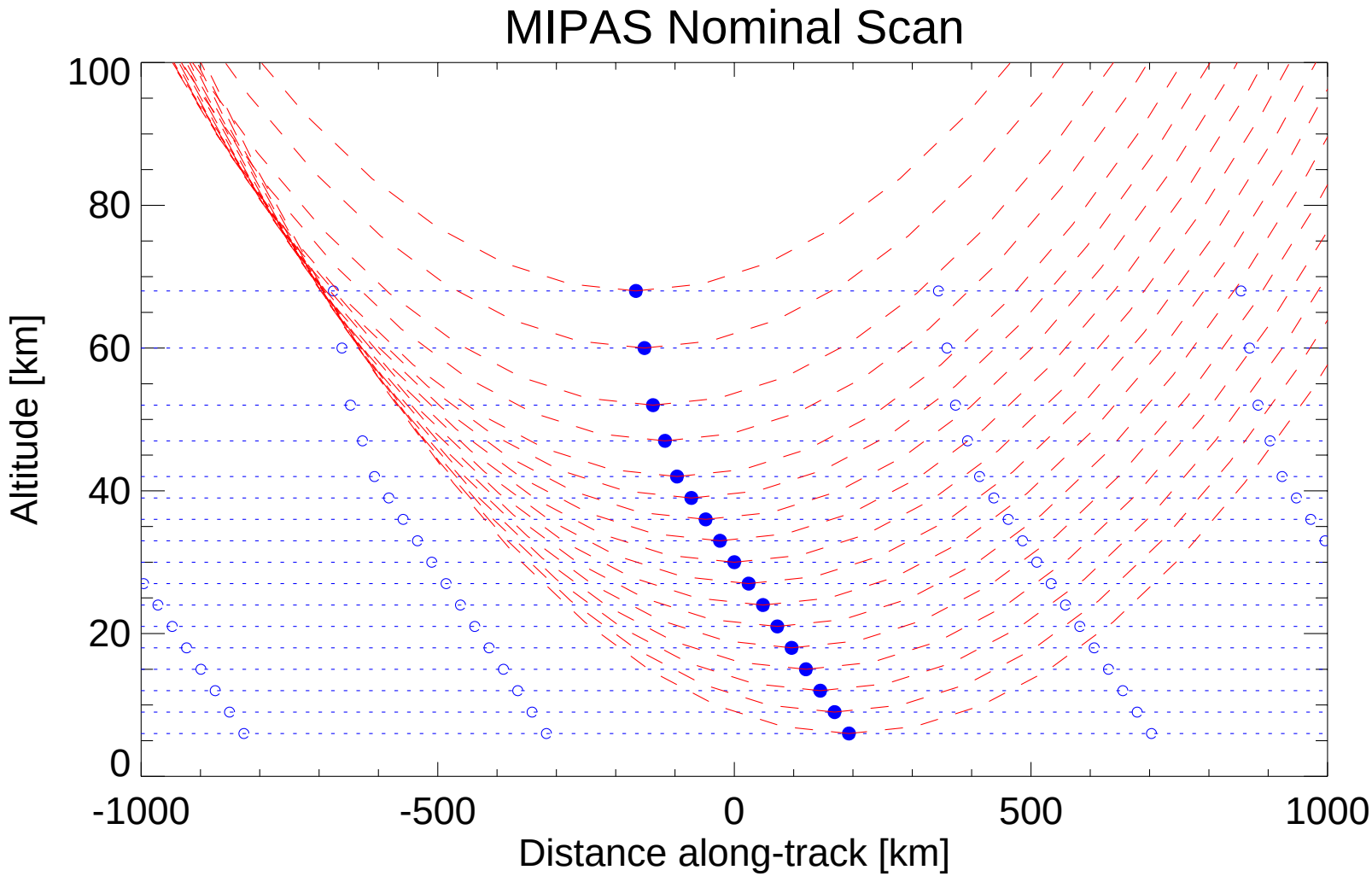
(satellite moving clockwise in both figures)

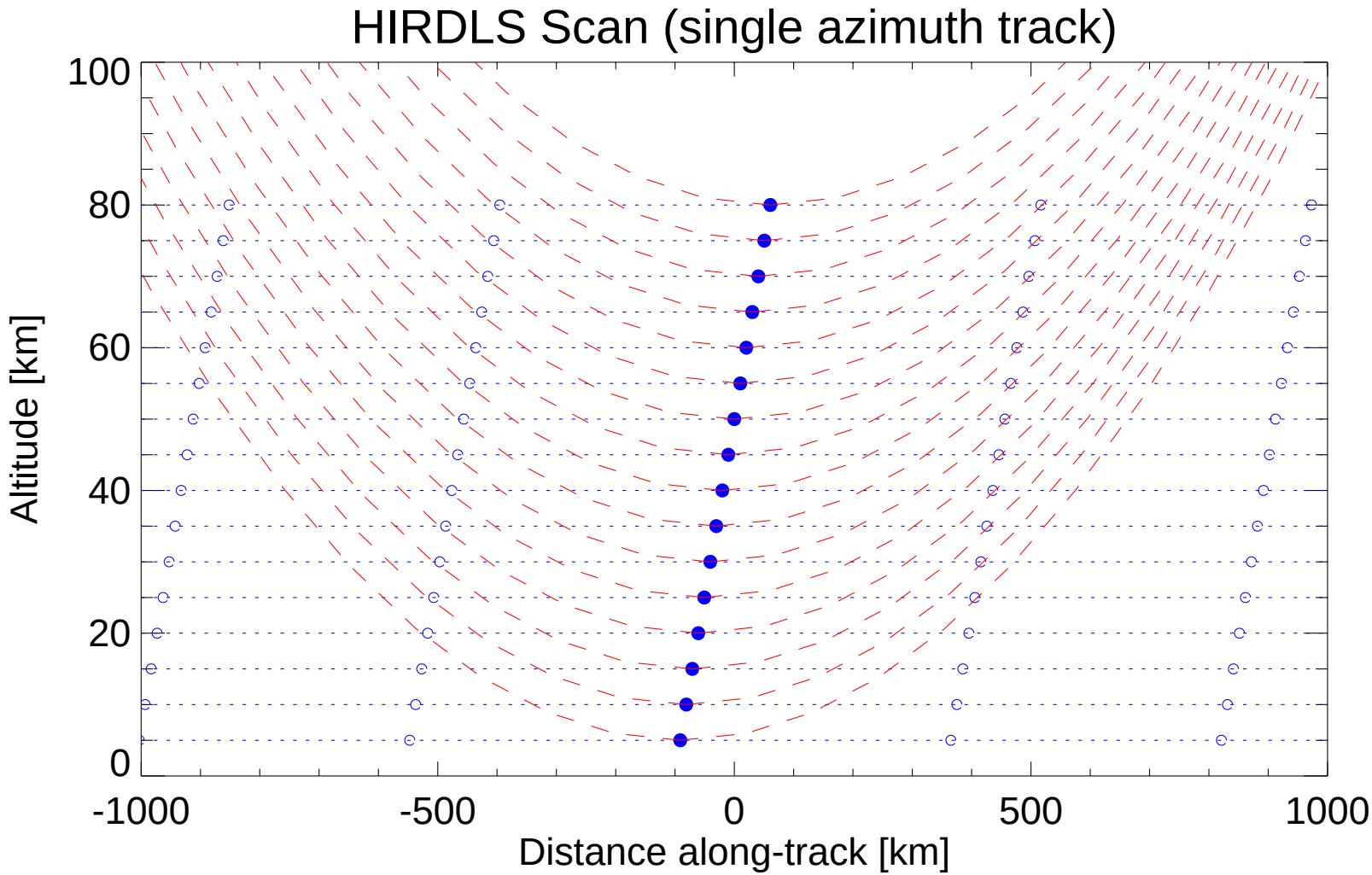


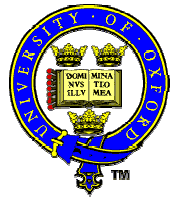


MIPAS – slow limb scan
Tangent point slopes downwards following satellite

HIRDLS – fast limb scan
Tangent point slopes upwards towards satellite


MIPAS Nominal Scan
Altitude [km]
100
80
60
40
20
0
-1000
-500
0
500
1000
Distance along-track [km]


HIRDLS Scan (single azimuth track)
Altitude [km]
100
80
60
40
20
0
-1000
-500
0
500
1000
Distance along-track [km]



Spectral Coverage

MIPAS

685-2410cm^{-1} at 0.025cm^{-1} spacing, 5 bands

2-7 Microwindows up to 3cm^{-1} width selected for each species

HIRDLS

21 filter channels from 570-1600cm^{-1}

1-4 Filters up to 120cm^{-1} width assigned to specific species

Infrared Limb Sounding MIPAS and HIRDLS

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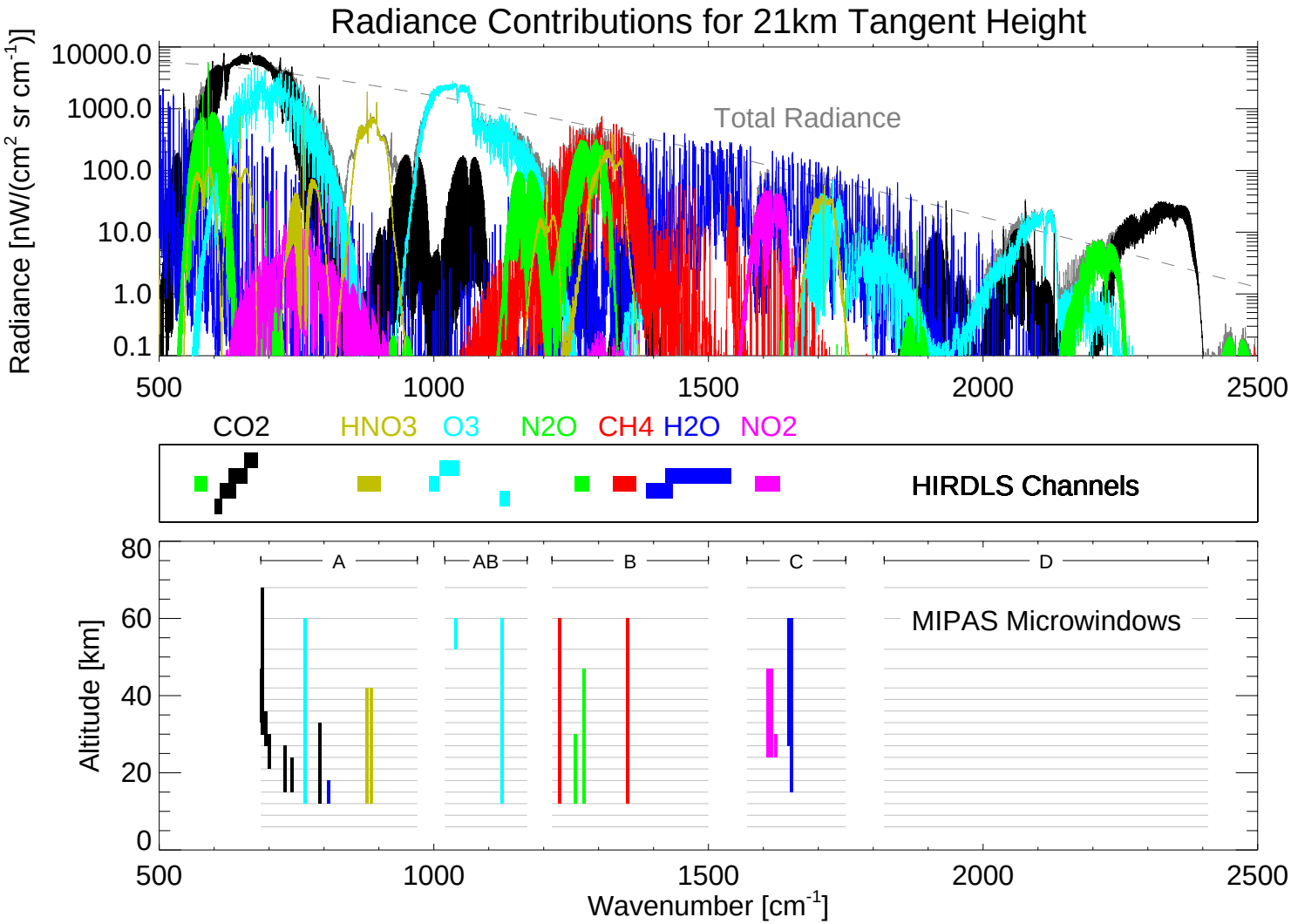

Infrared Limb Sounding MIPAS and HIRDLS

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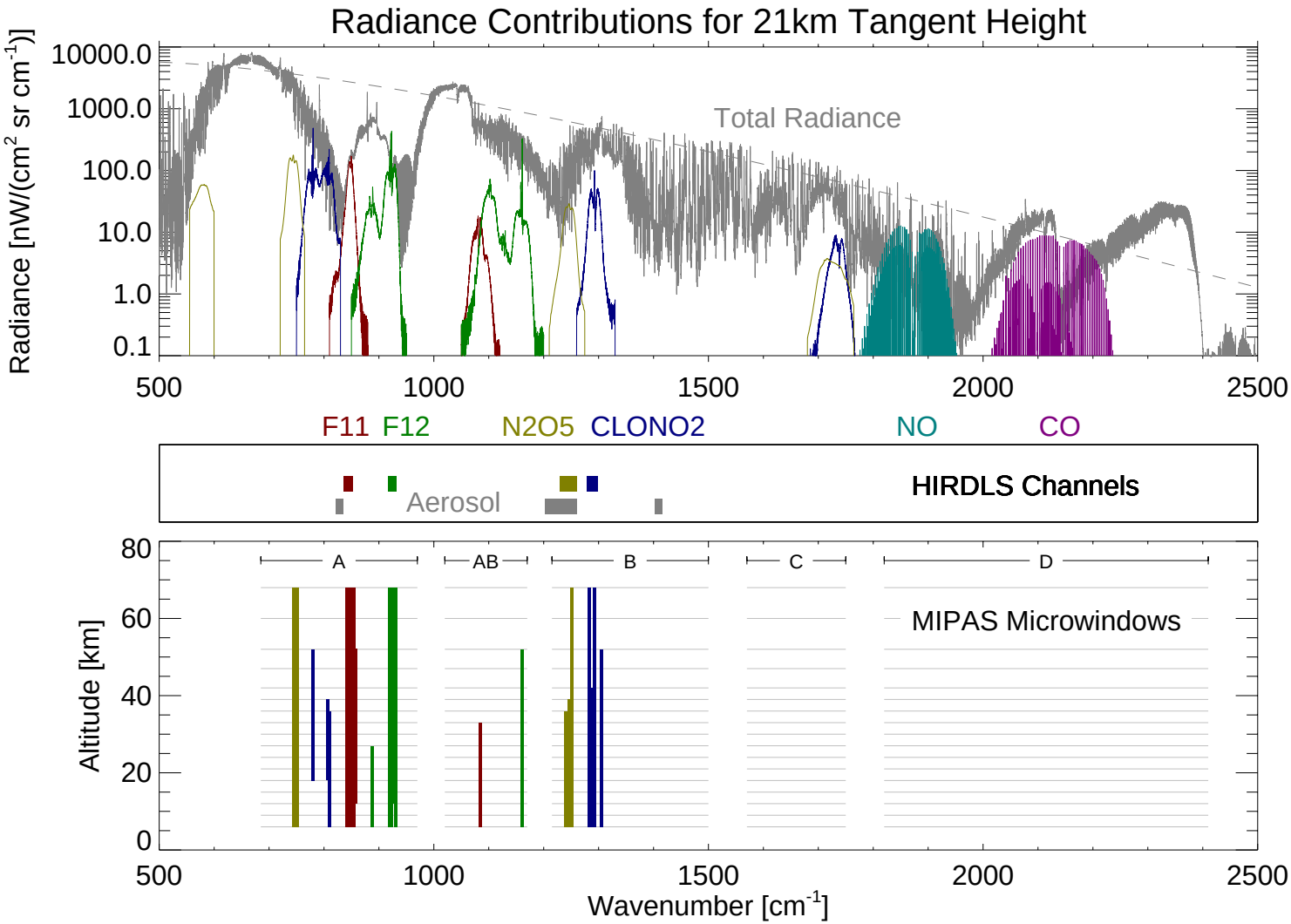

MIPAS Microwindows

- Selected to minimise total retrieval error for given CPU cost
- Use spectral masks to exclude measurements
- Computer, rather than human, selection
- Also results in systematic error budget

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PT__0004 Microwindow

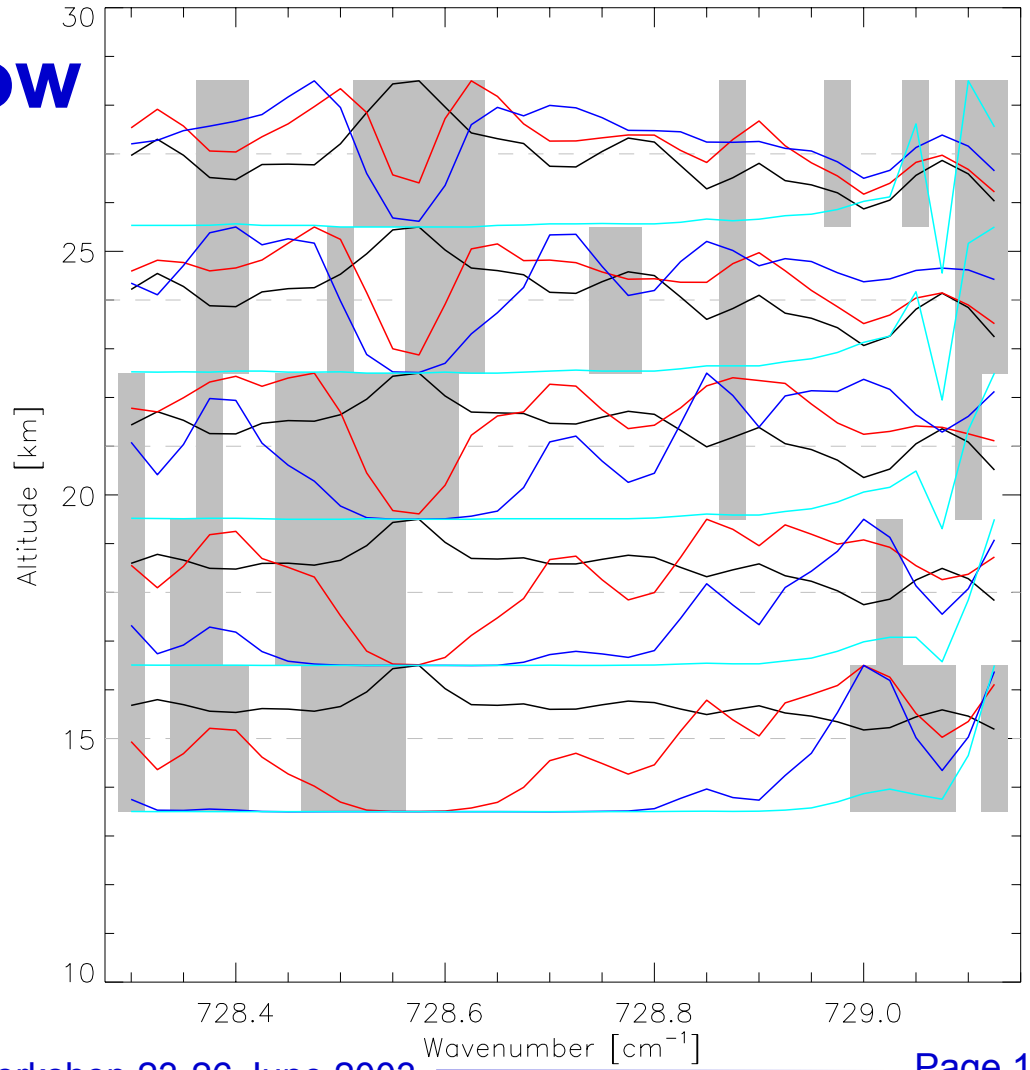
Radiance spectrum

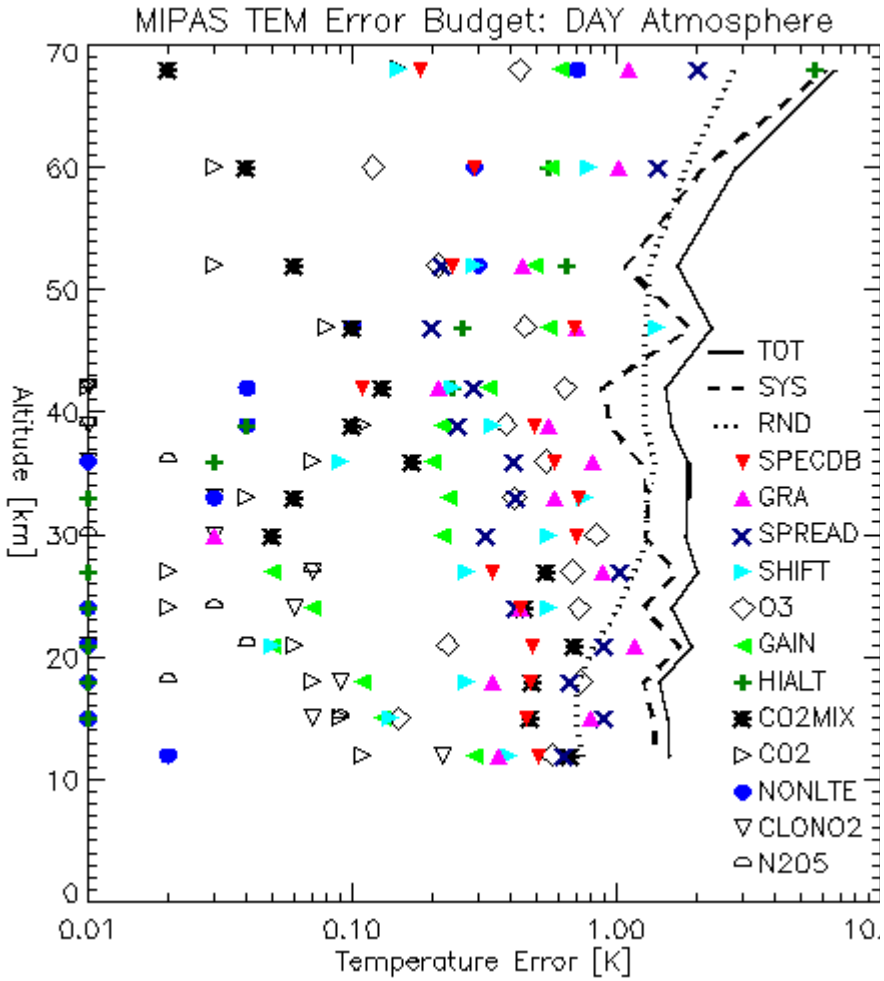
Temperature Jacobian

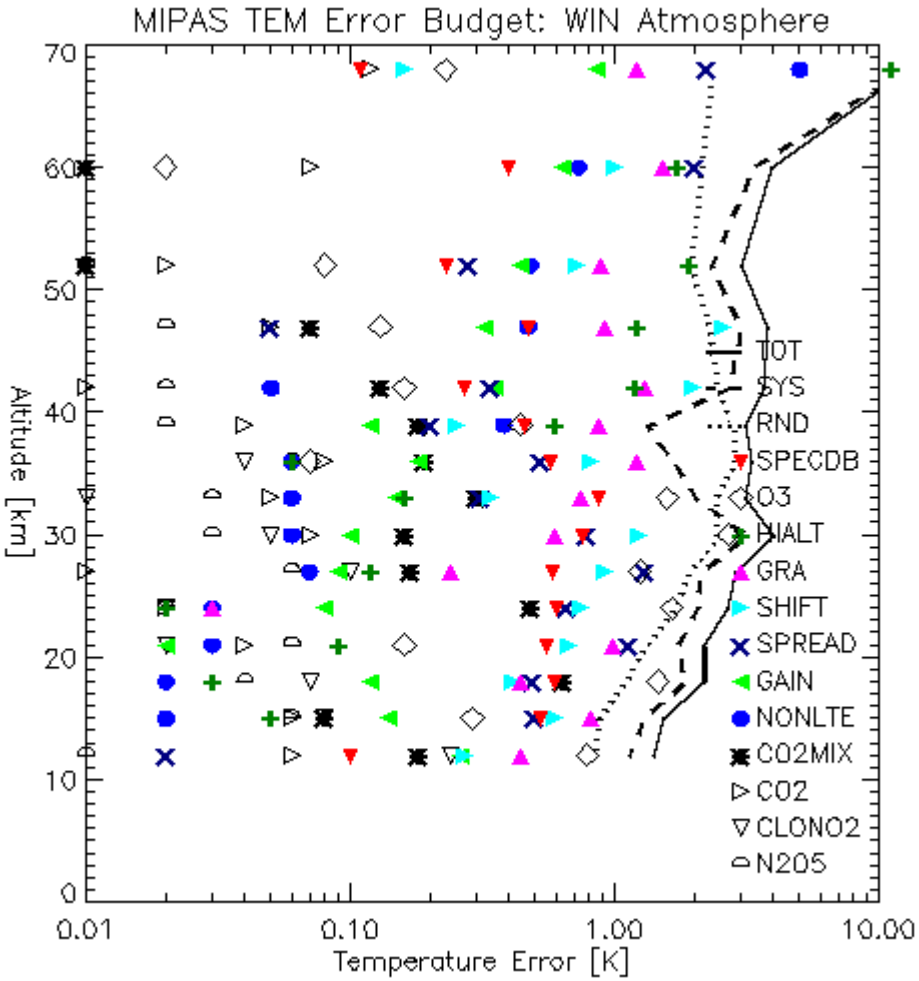
Pressure Jacobian

H2O Interference

Spectral masks




MIPAS TEM Error Budget: DAY Atmosphere
Altitude [km]
Temperature Error [K]
0.01
0.10
1.00
10.
0
10
20
30
40
50
60
70
TOT
SYS
RND
SPECDB
GRA
SPREAD
SHIFT
O3
GAIN
HIALT
CO2MIX
CO2
NONLTE
CLONO2
N2O5


MIPAS TEM Error Budget: WIN Atmosphere
Altitude [km]
Temperature Error [K]
0.01
0.10
1.00
10.00
0
10
20
30
40
50
60
70
TOT
SYS
RND
SPECDB
O3
HIALT
GRA
SHIFT
SPREAD
GAIN
NONLTE
CO2MIX
CO2
CLONO2
N2O5

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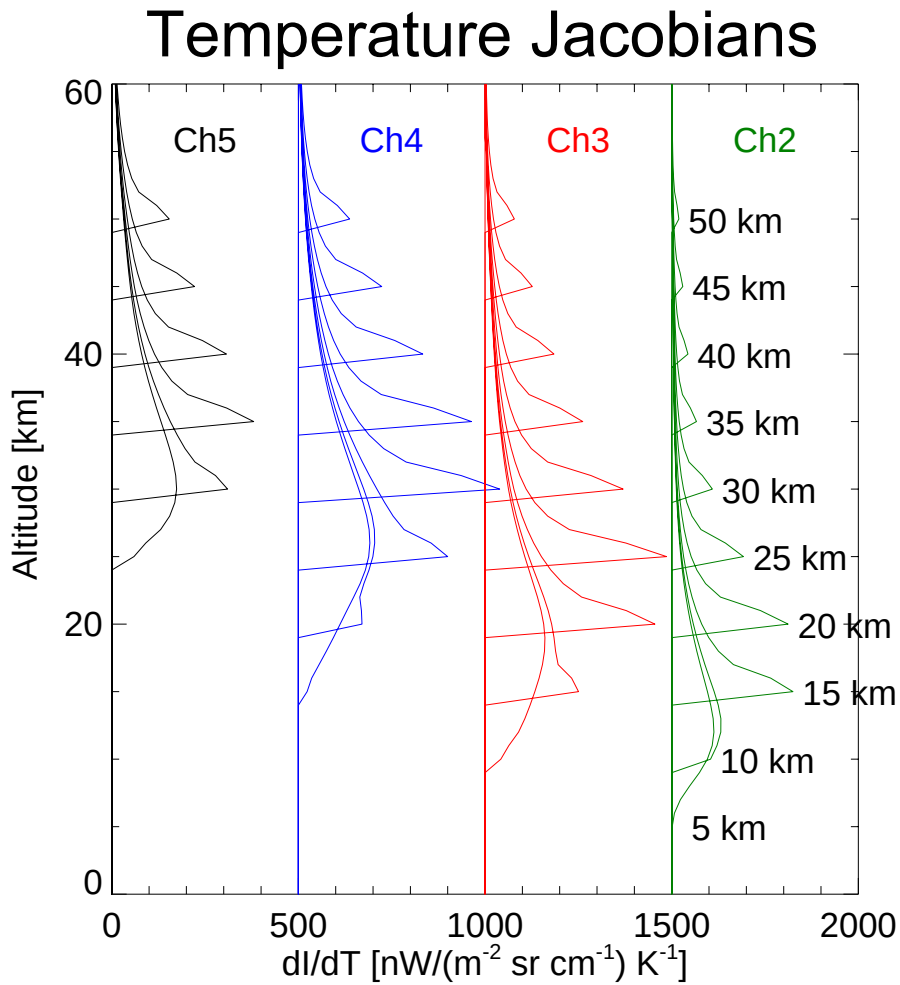
HIRDLS pT Channels

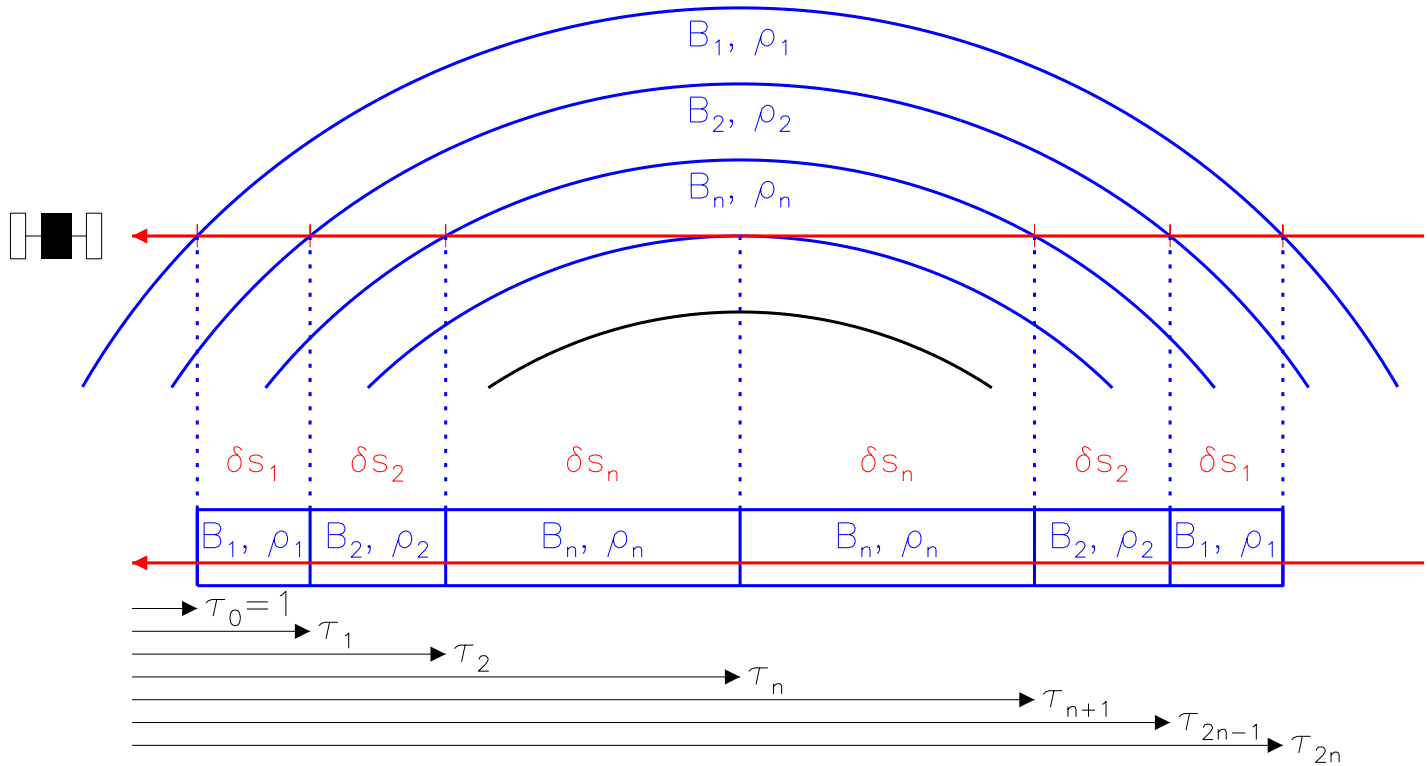
Large area = good S/N

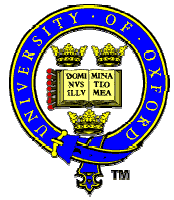
Sharp peak = good resolution

- Require 4 CO2 Channels to cover complete vertical profile



Radiance Modelling





Ray Tracing

- No analytical solution for limb geometry
  - numerical integration required
- Usually adequate to consider atmosphere locally spherical
  - radius of curvature varies by ±0.5% around orbit
- Refraction is significant
  - deflection 70m at 25km, increases in proportion to density

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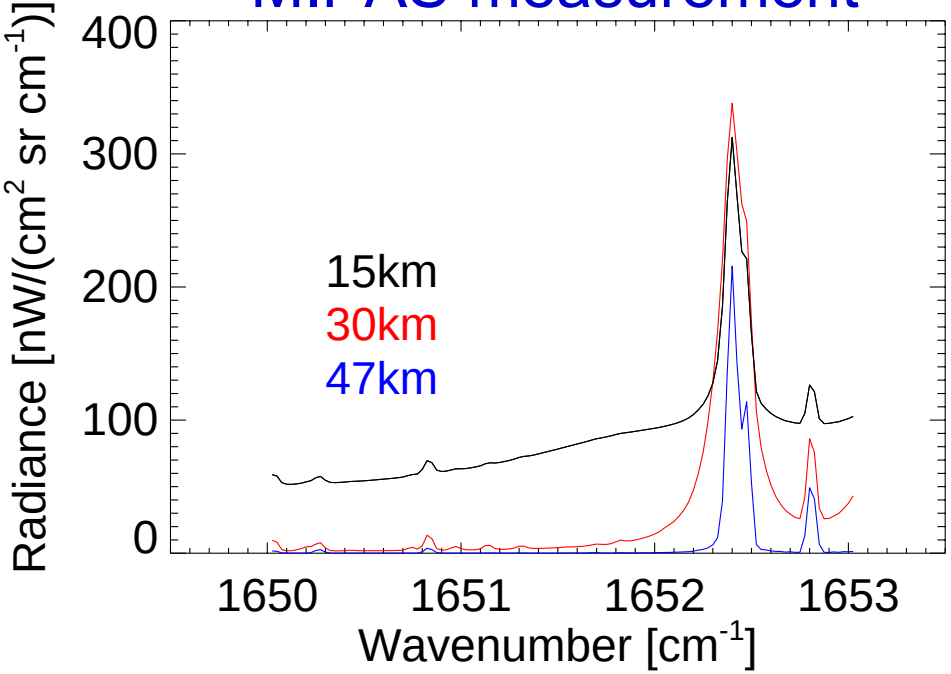
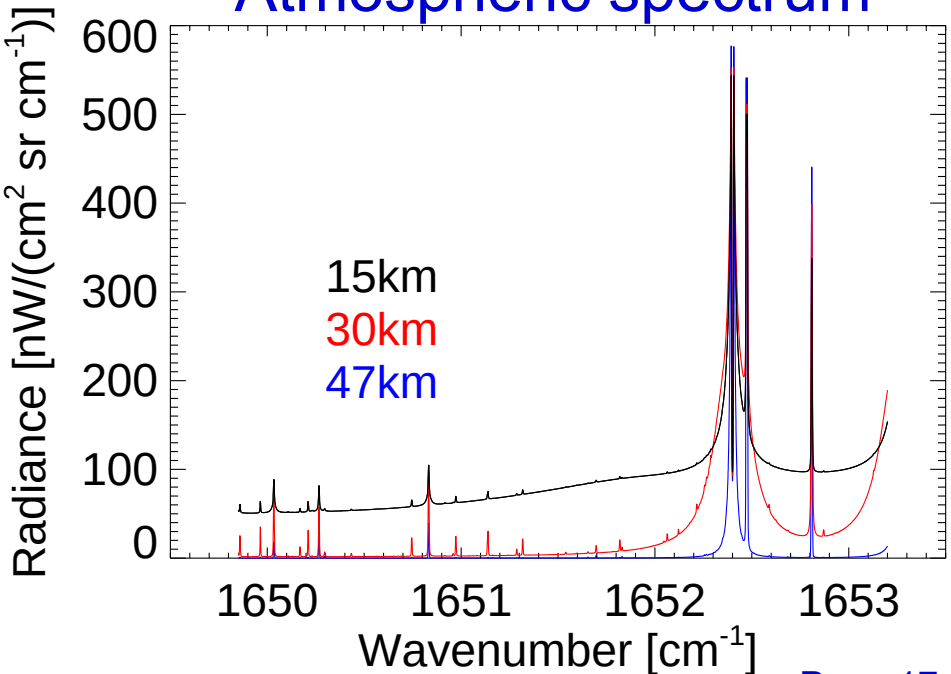
Transmittance Calculations

Limb viewing requires high spectral resolution calculations
- typically 0.0005cm^{-1} to capture Doppler broadened lines

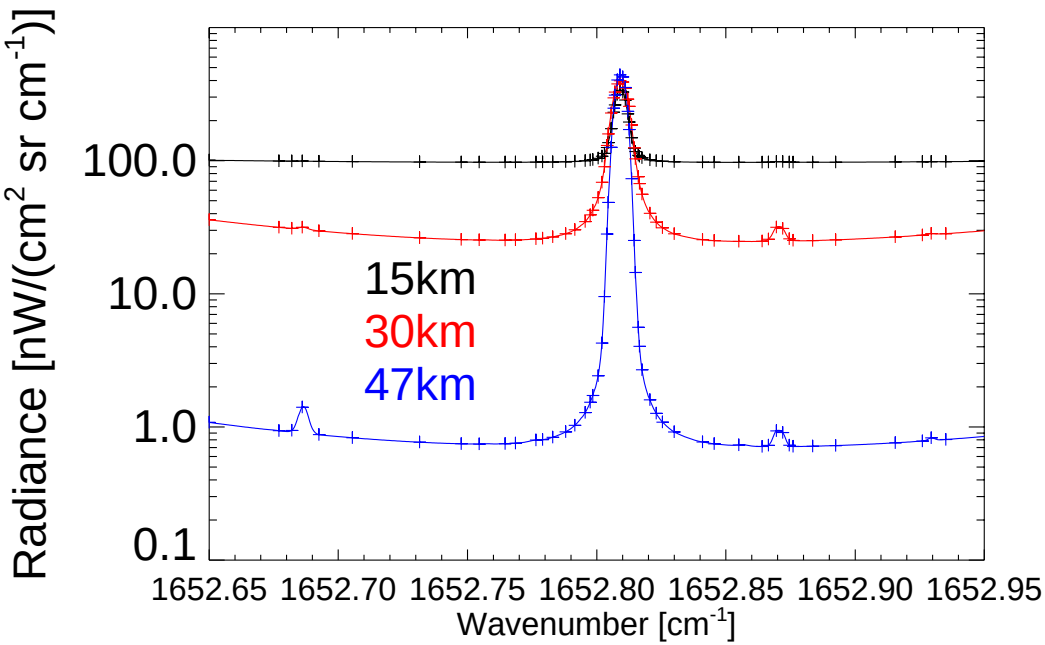
MIPAS measurement



Atmospheric spectrum



Irregular Grids



MIPAS solution is to compute radiative transfer only at a subset of fine grid points, determined from spectral structure in each microwindow

Look Up Tables

MIPAS uses look-up tables of absorption coefficient k(v,p,T) for transmittance of each cell, containing absorber amount u

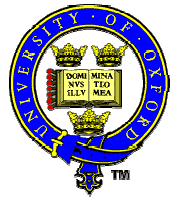
$$\tau^c = \exp (- k\, u)$$

Path transmittance is then product of cell transmittances (Beer's Law)

$$\tau = \prod \tau^c$$

Finally radiance is convolved with instrument line shape Ψ

$$R = \int \int B\, \Psi\, d\tau\, d\, v$$



Band Model

HIRDLS solution is to use channel-averaged transmittances

$$\int \int B \, \Psi \, d\tau \, d\nu \approx \int \underline{B} \, d\underline{\tau}$$

where $\underline{\tau} = \int \Psi \, \tau \, d\nu$ and $\underline{B} = \int B \, \Psi \, d\nu$, Ψ is channel spectral response

Band transmittances are pretabulated $\underline{\tau}(u,p,T)$ where p,T are path-averaged quantities (Beer's Law not valid for $\prod \underline{\tau}^c$)

This removes the spectral integration from the retrieval forward model, but has limited accuracy.

Pressure-Temperature Retrieval

Infrared radiances are highly sensitive to temperature (4%/K) and pressure (1-2% / %)

Nadir sounders retrieve T(p) directly, but limb-viewing gives T(z) or p(z)

- Always start with joint pT retrieval for profiles p(z),T(z),

Use CO2 channels since concentration is known

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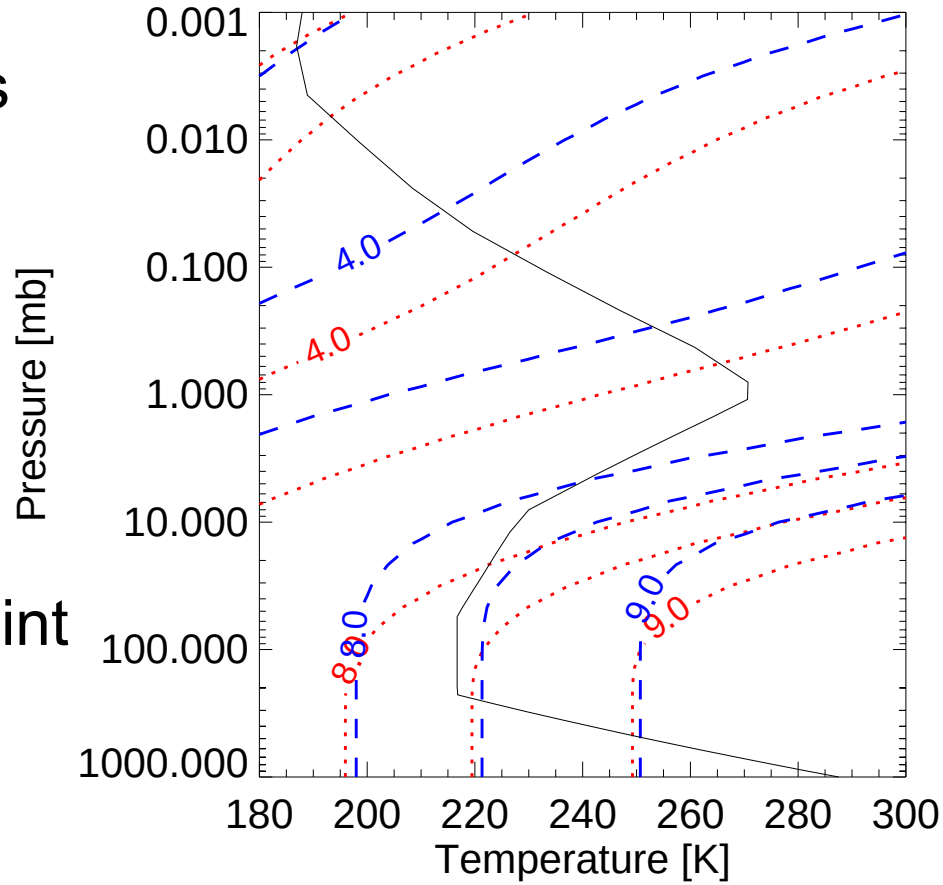
Hydrostatic Constraint

- Retrieving two parameters requires at least two independent pieces of information.
- Difficult at high/low altitudes
- Usually use some relative pointing knowledge and hydrostatic constraint

$$d \ln p = -(gM/RT)\, dz$$

HIRDLS Ch3 Ch4

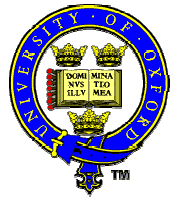


Current MIPAS Retrieval

- Least Squares Fit
  - no explicit a priori or regularisation
- One dimensional
  - assume no horizontal gradients
- Sequential
  - pT, then H2O, O3, HNO3, CH4, N2O, NO2

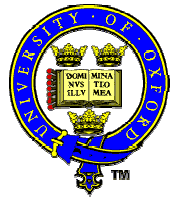
Baseline HIRDLS Retrieval

- Optimal Estimation
  - loose climatological a priori constraint
- 1D retrieval, 2D forward model
  - 2 passes, model gradients in 2nd pass
- Sequential/Joint
  - pT, Aerosol, H2O, O3, NO2, (HNO3+F11+F12), (CH4+N2O+ClONO2+N2O5)



Future MIPAS Retrieval ?

- Optimal Estimation
  – otherwise too many indeterminate parameters!
- 2D forward model
  – tomographic retrieval of complete orbit
- Joint
  – pT+all species, including additional gases



Summary

- Infrared limb sounding provides good vertical resolution and measurements of additional species
- Main disadvantages are poor horizontal resolution and cloud sensitivity
- Limb viewing geometry generally adds another dimension to the complexity of radiance modelling
- Someday someone *will* assimilate limb radiances …