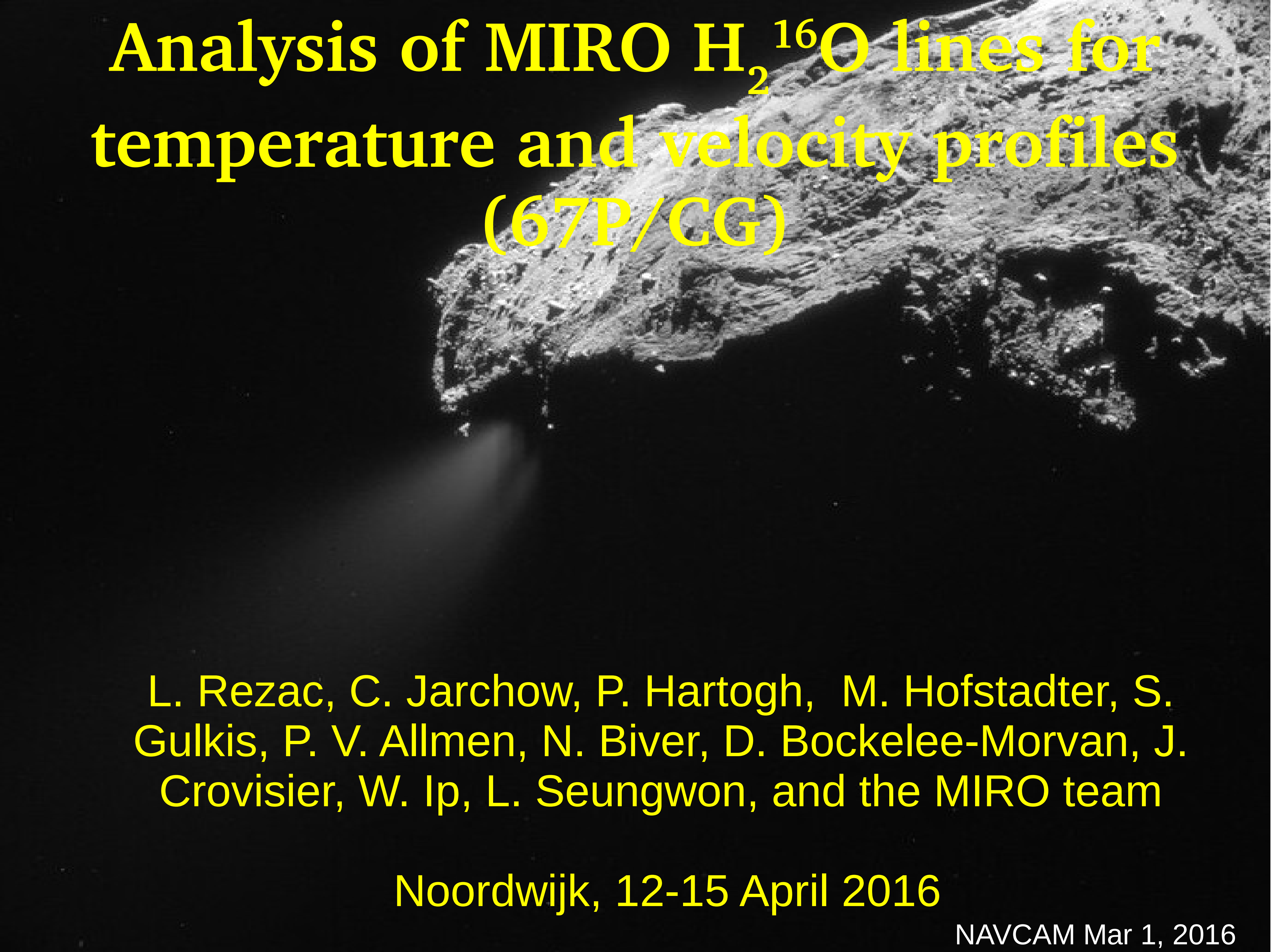
Analysis of MIRO $H_2{}^{16}O$ lines for temperature and velocity profiles (67P/CG)



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Noordwijk, 12-15 April 2016

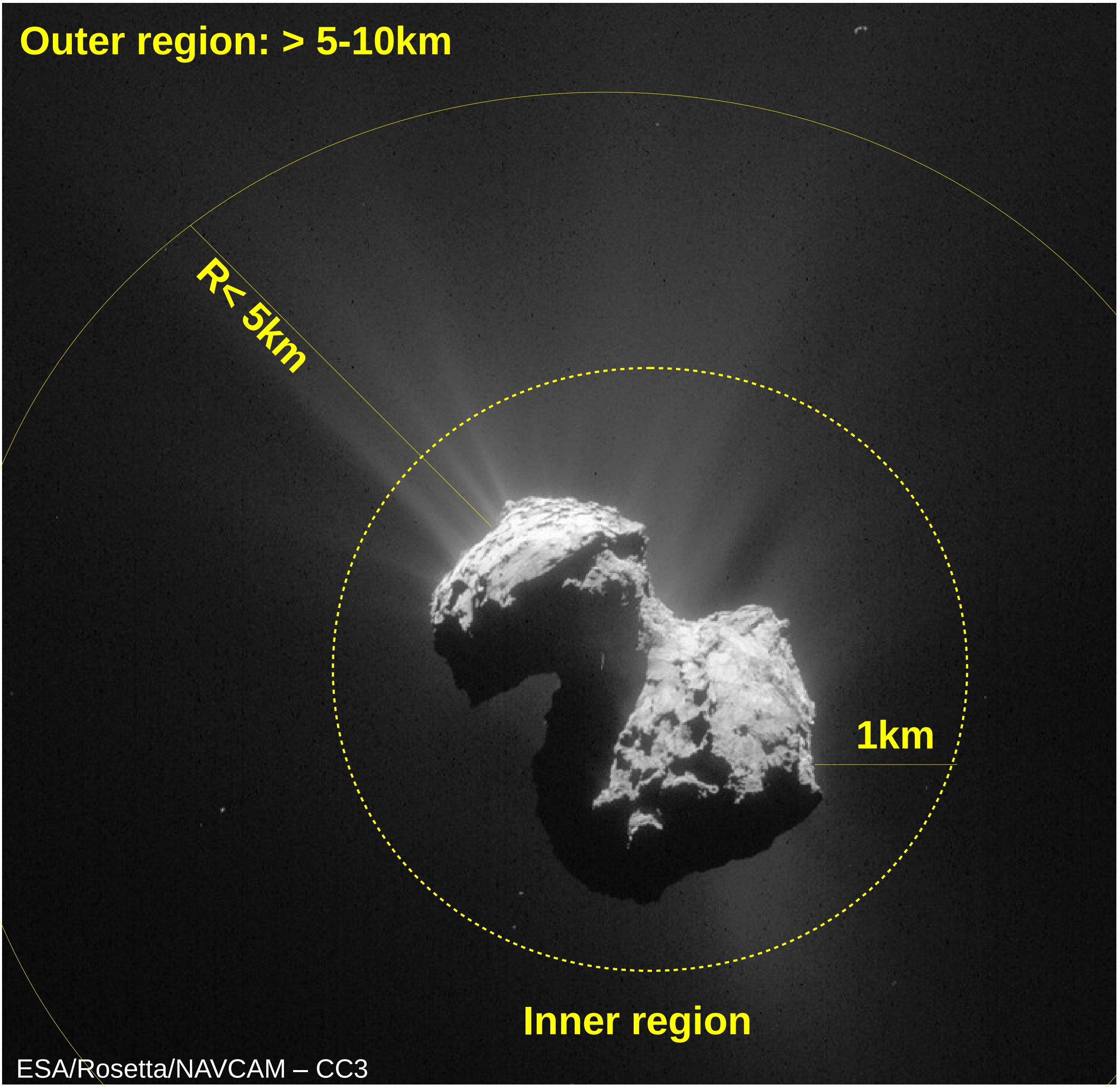
NAVCAM Mar 1, 2016

Outline

• Goal of this talk:
MIRO is a “natural” near nucleus sounder, and proper line shape fitting (16 H_2O) allows one to obtain accurate line-of-sight altitude profiles for T, Vexp.

- MIRO and the measurements
- $H_2{}^{16}O$ line shape and radial profile information
- Retrieval methodology –approach/self-consitency
- Summary

Why is this interesting...?



- Inner region never before probed.

- Inner region fields expected to be highly affected by topography, source distribution, D-G interactions.

- Outer region is expected to be spherical like (Haser like) for typical activity (although ...)

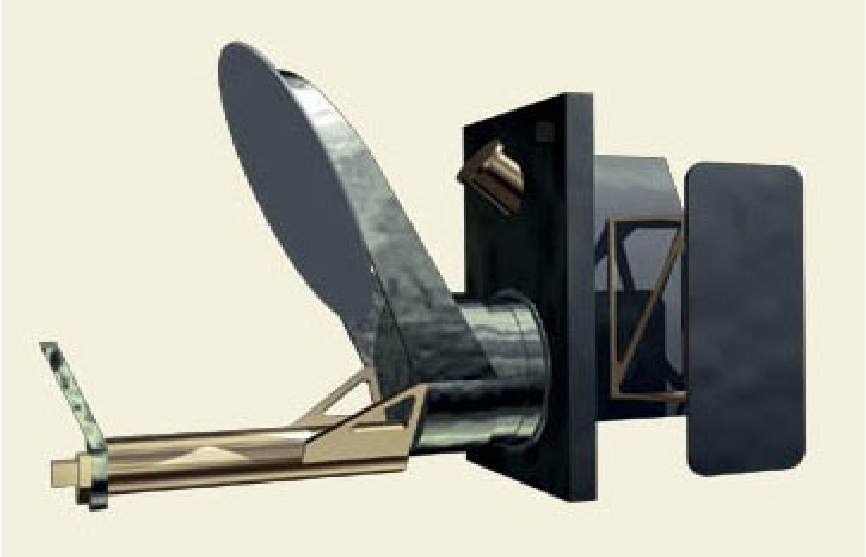
- <u>MIRO unique measurement of a unique region – need to get this information out..</u>.

ROSETTA/MIRO

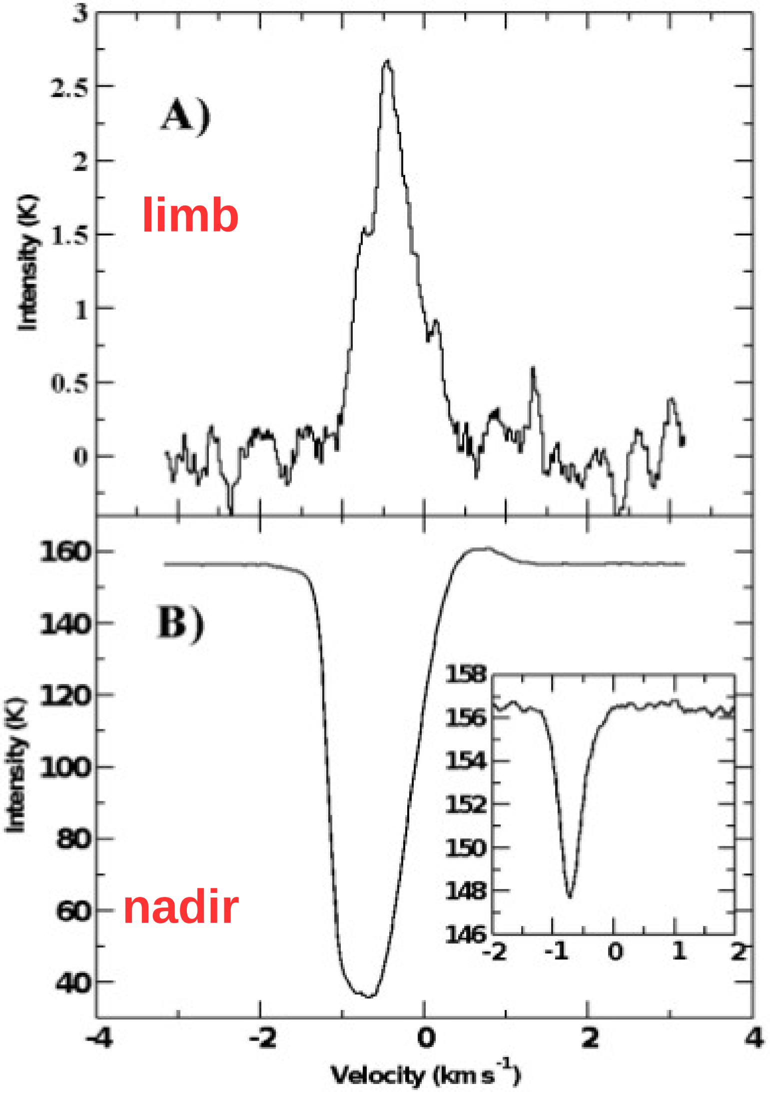
Table 3
Performance parameters of MIRO instrument

	Millimeter	Submillimeter
Telescope		
Diameter	30 cm	30 cm
Beam-width (FWHM)	23.8 arc min	7.5 arc min
Foot-Print (@ 2 km)	15 m	5 m
Spectral characteristics		
Frequency	188.5–191.5 GHz	547.5–580 GHz
IF Continuum bandwidth	550 MHz	1100 MHz
Spectral resolution		44 KHz
Spectral bandwidth		180 MHz
No. channels		4096
Radiometer		
DSB noise temp	800 K	3800 K
Data rates	Combined with submillimeter	0.1–1.92 kbps

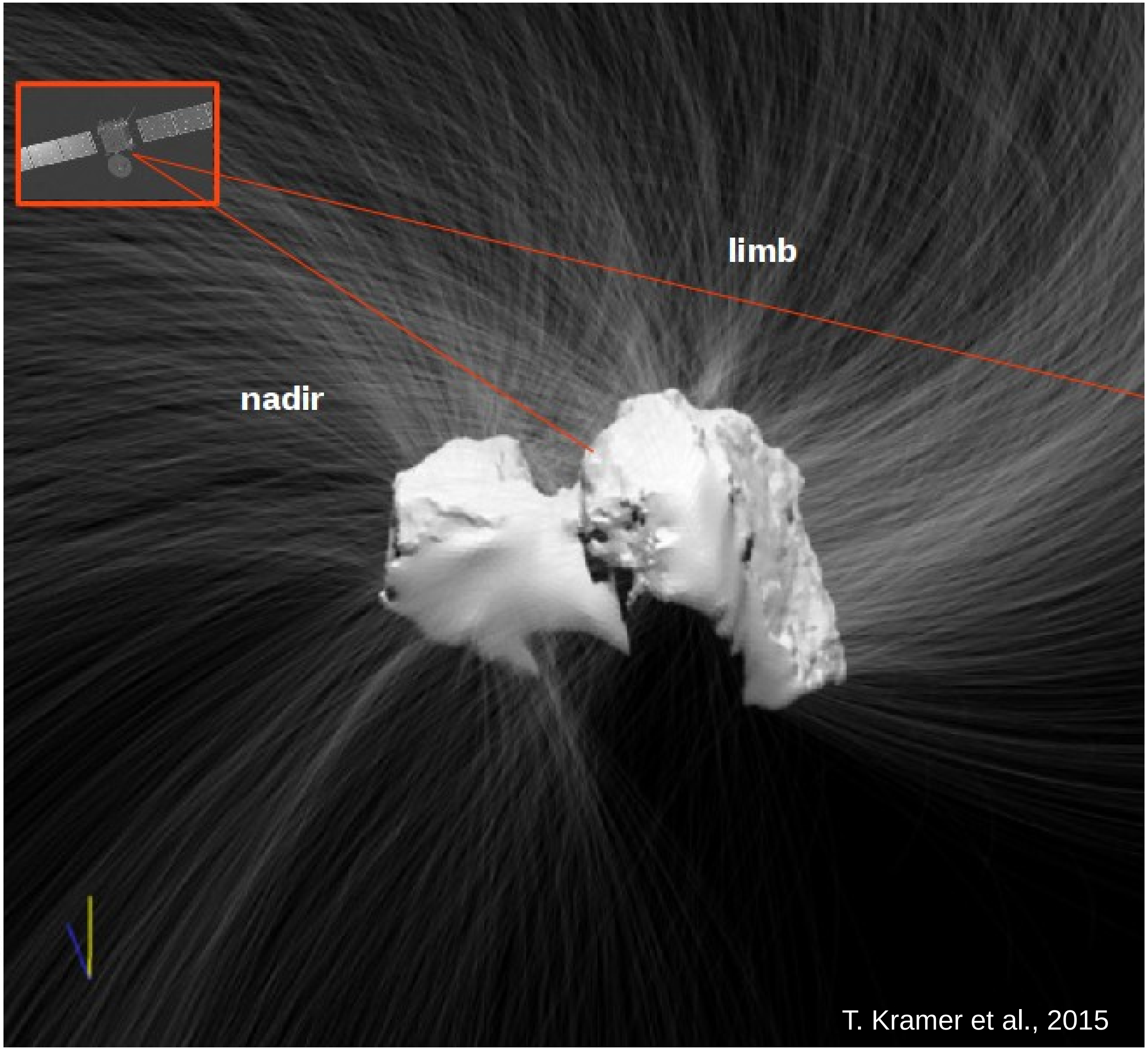
- **o-$H_2{}^{16}O$ 557 GHz + 18, 17 water as well**
- **NH_3, CO, and CH_3OH**



MIRO measurement



Gulkis et al., 2015



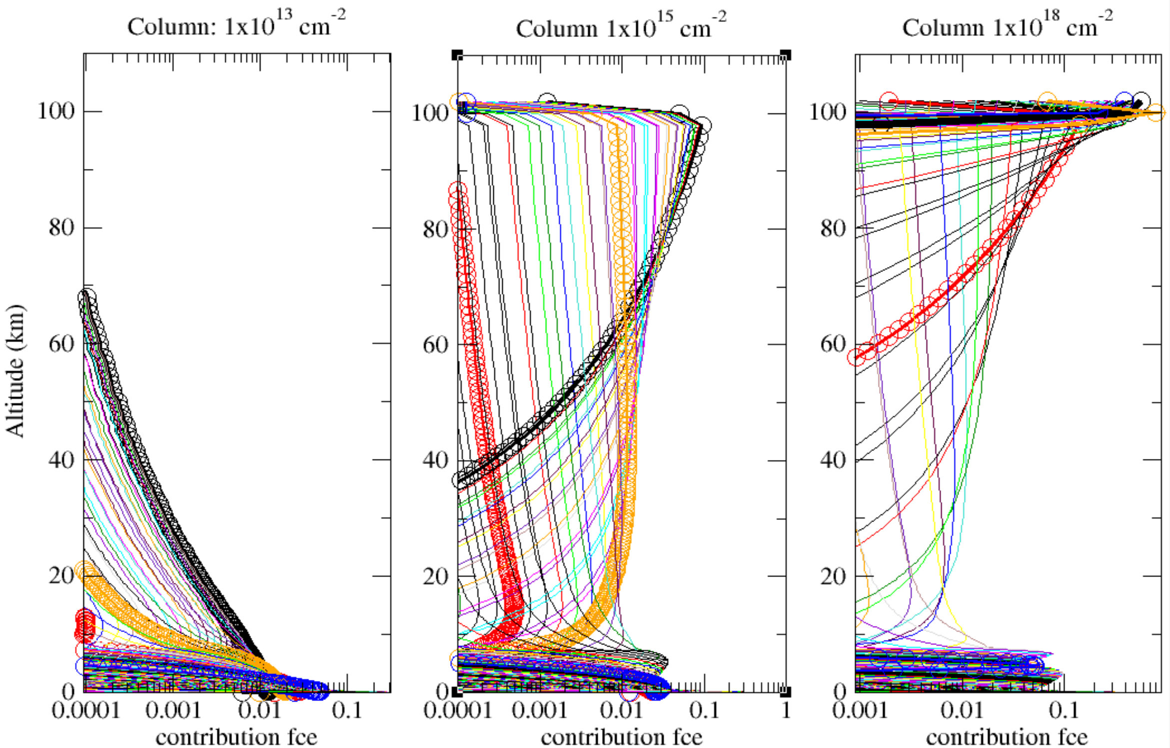
MIRO direct measurable(s)

- Line Doppler shift (expansion velocity along LOS)
  - Great for purely Doppler broadened line (ie, optically thin + rather fast expansion)

- Integrated line area (column density along LOS)
  - Good for optically thin, isothermal gas - analytical solution ! Good choice for unresolved coma lines.
  - Numerical fit of line area needs extra care: non-unique solutions are the norm in the [n(r), V(r), T(r)] space.

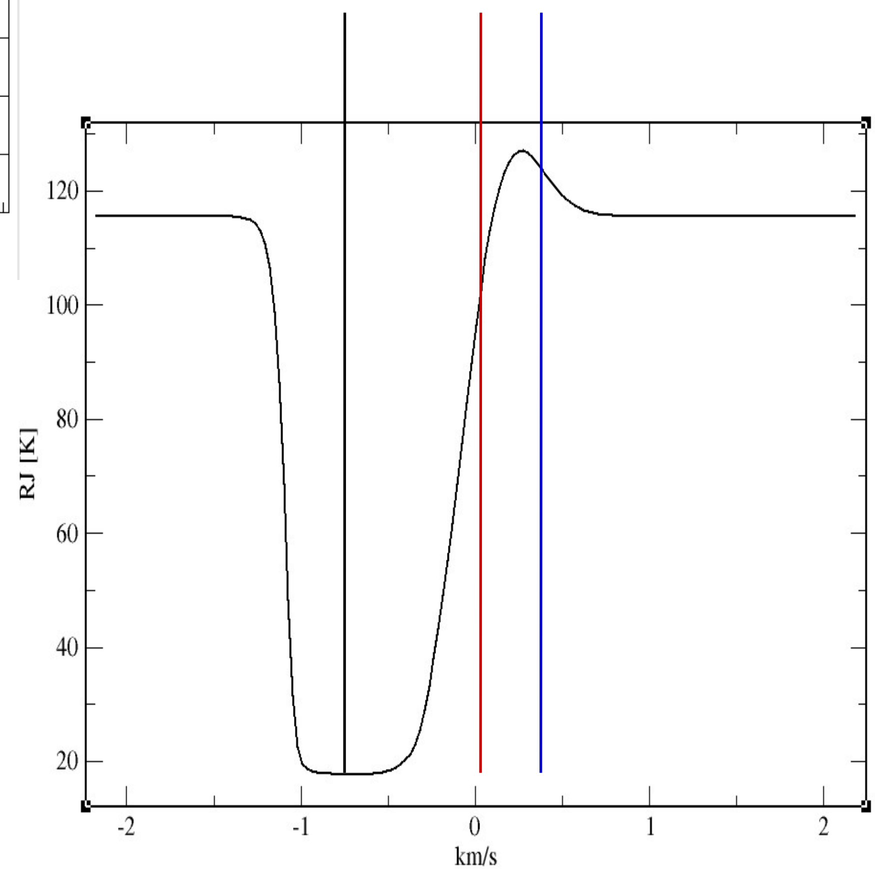
- Line shape (number density, temperature, velocity radial profiles, albeit smoothed version of reality)
  - Line shape + scanning (slewing) (additional radial information !)
  - Combining line shapes of different molecules + different view angles is the ultimate goal – (allows slicing 3D structure, ensures consistency)

MIRO: natural near nucleus sounder: exploiting line shapes



Analysis of line profiles along LOS: <u>independence</u> of the 3D coma structure and nucleus shape

Column 3e15 cm-2



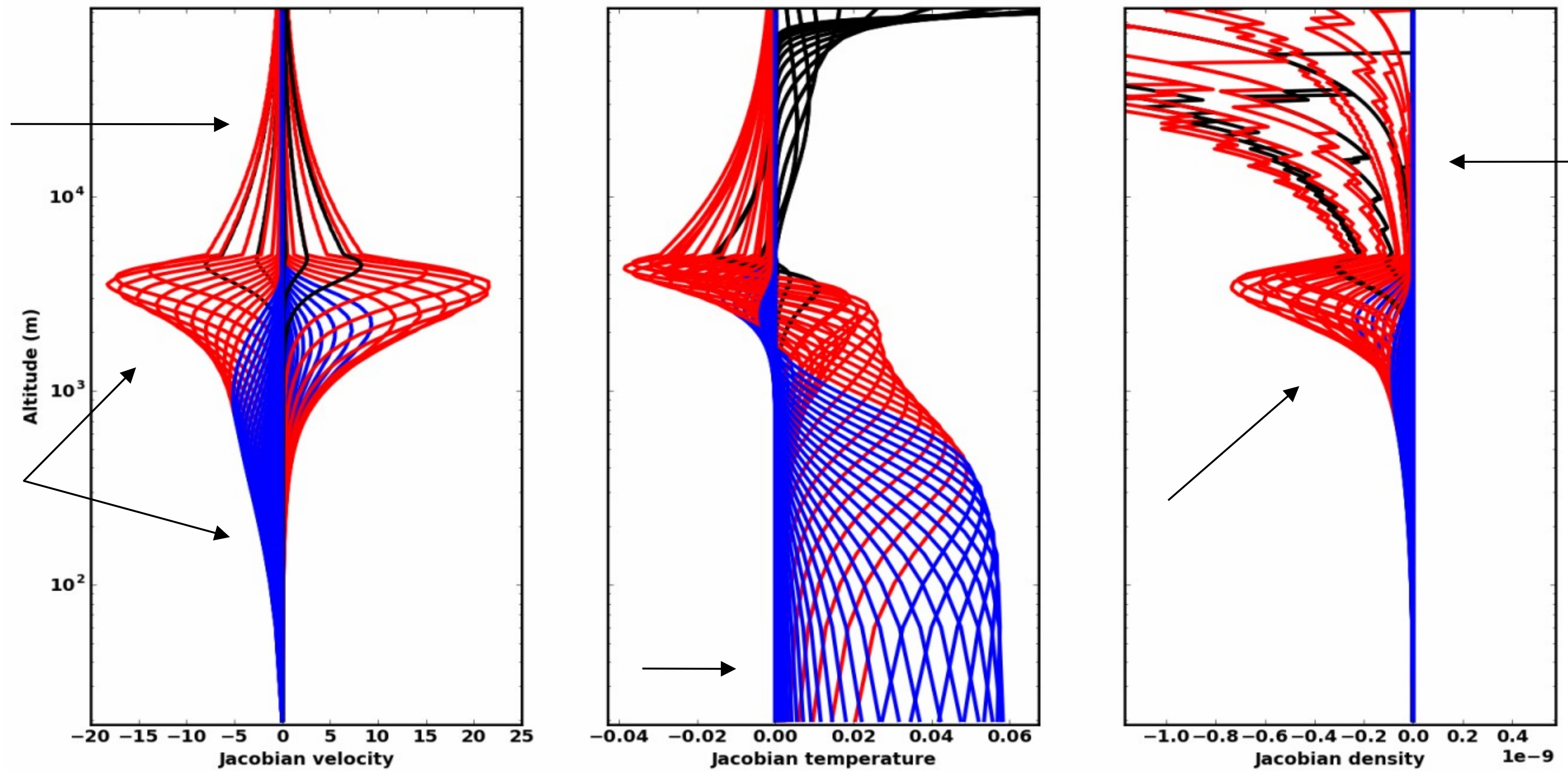
<u>Nadir contribution function</u> : from where does the radiation come along LOS (depends on optical depth.

<u>Similarly: limb</u> LOS retrieval should be processed, and not rely on spherical coma assumption!

MIRO line shape information content

- How sensitive is the measurement to the desired parameters (Jacobians)?
- Understand qualitatively and quantitatively information content of MIRO, needed for both: algorithmic and/or parametric fit.

Line core **Line wing** **Far wing**



Problem statement

- Obtain T(r), v(r) and n(r)-scaling from measured $H_2{}^{16}O$ line + $H_2{}^{18}O$(scaling only of n(r)).
- Ensure stable inversion of spectra with solid error analysis applicable to all observations.
- Investigate self-consistency on physical examples and the uniqueness of the solution.

Inversion methodology

Method: Solve a constrained LS problem minimizing:

$$J(\mathbf{x}) = (\mathbf{y} - \mathbf{F}(\mathbf{x}))^T \mathbf{S_e^{-1}} (\mathbf{y} - \mathbf{F}(\mathbf{x})) + (\mathbf{x} - \mathbf{x_a})^T \mathbf{S_a^{-1}} (\mathbf{x} - \mathbf{x_a})$$

- Iterate to handle the strong non-linearity
- Regularization is applied (deal with null-space)

$$\mathbf{x_{i+1}} = \mathbf{x_a} + \mathbf{S_a^{-1} K_i^T} (\mathbf{K_i S_a^{-1} K_i^T} + \mathbf{S_e^{-1}}) (\mathbf{F}(\mathbf{x}) - \mathbf{y} - \mathbf{K_i}(\mathbf{x_a} - \mathbf{x_i}))$$

Solution covariance matrix

$$\hat{\mathbf{S}}^{-1} = \mathbf{K}^T \mathbf{S}_y^{-1} \mathbf{K} + \mathbf{S}_a^{-1}$$

One more thing: how to represent the radial profile?

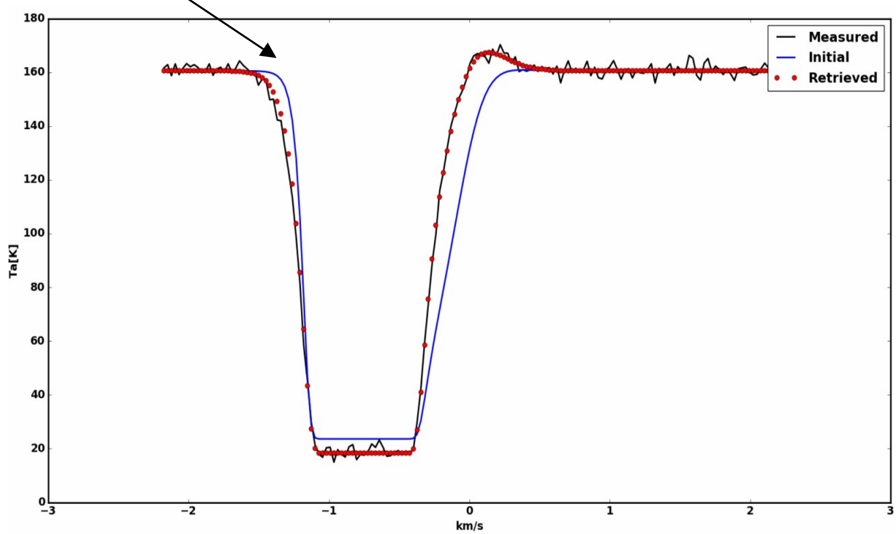
- Retrieve set of numbers in radial grid
    - Regularization (numerical)
    - Physics related regularization
- Parametrization of vertical profiles:
    - Power law approaches (fast, but crude)
    - Basis functions
        - EOFs (using physical DSMC results)
        - Polynomial representation

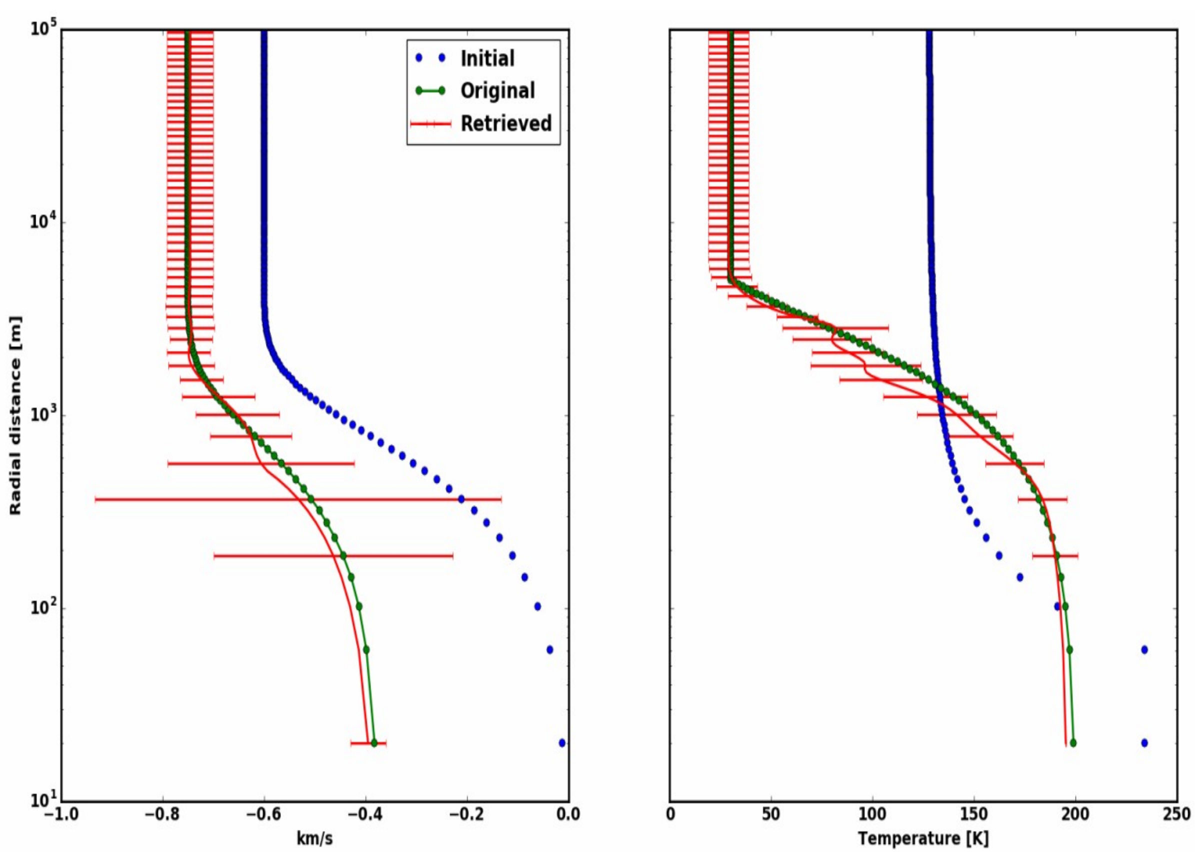
There is a trade off – we want a flexible enough parametrization to capture possible LOS variations in T, v, but still maintain reasonably determined solution by the measurement.

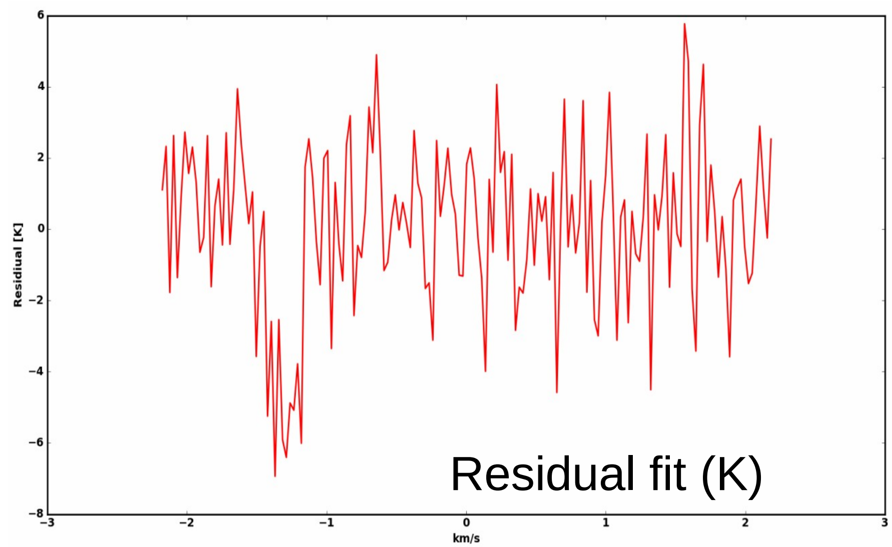
Self-consistency study: 1

- 2-step procedure (broken power law) – get closer in profile space, then constrained LS on a grid to really adequate fit of spectra.

- Temperature,very well determined by the data, velocity accuracy reliable z>500 m, lower sensitivity below.





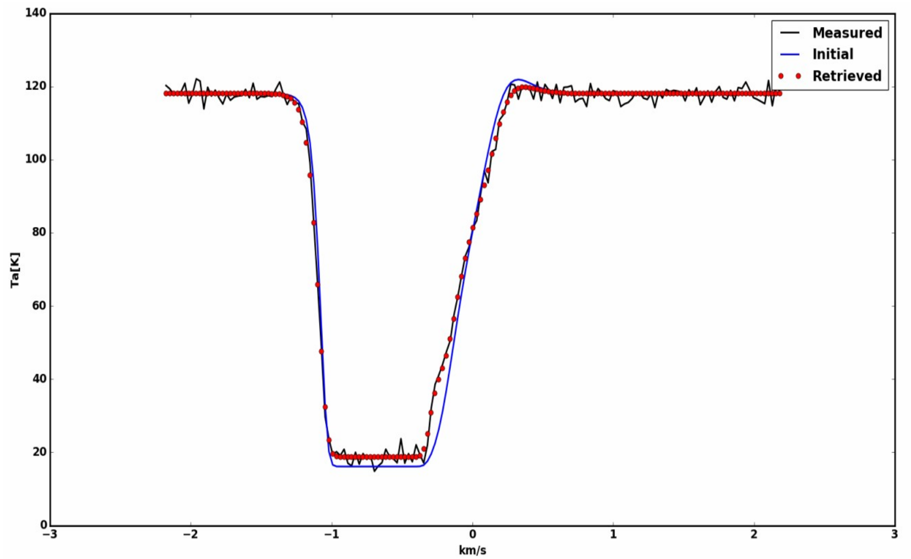


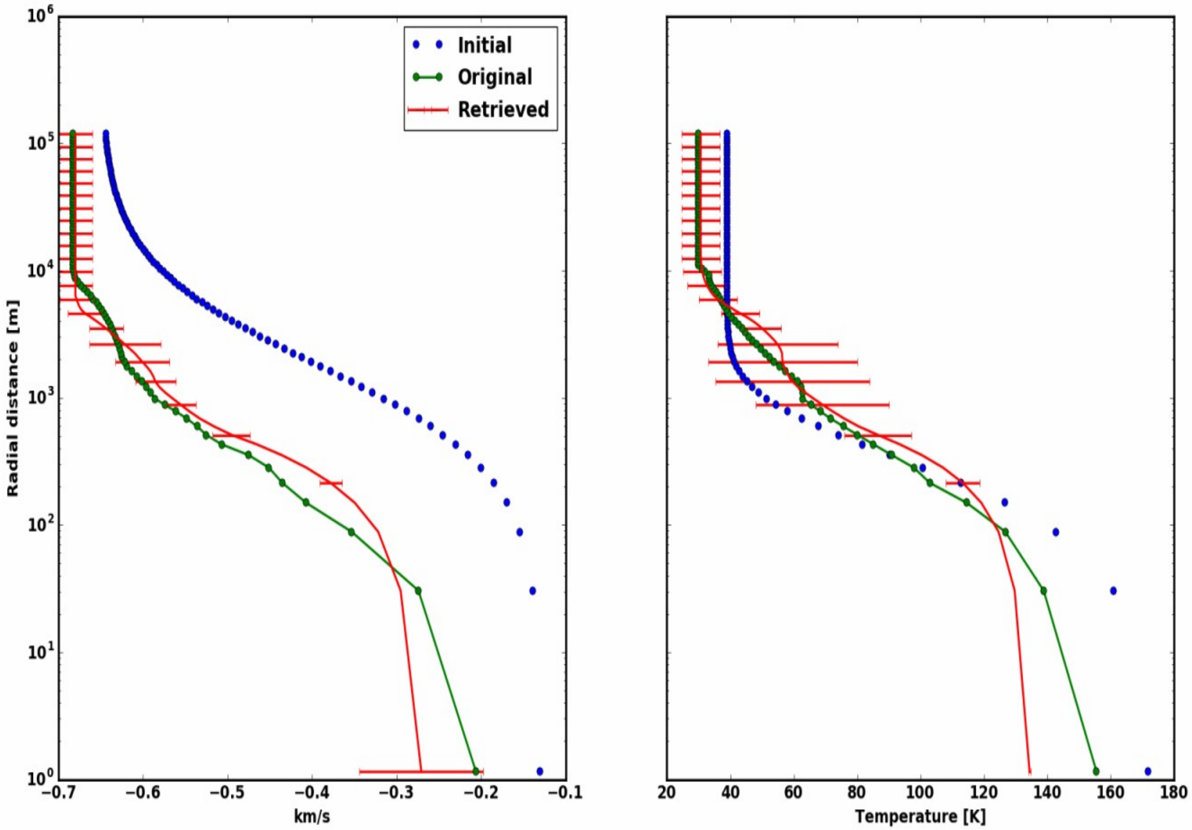
Self-consistency study: 2

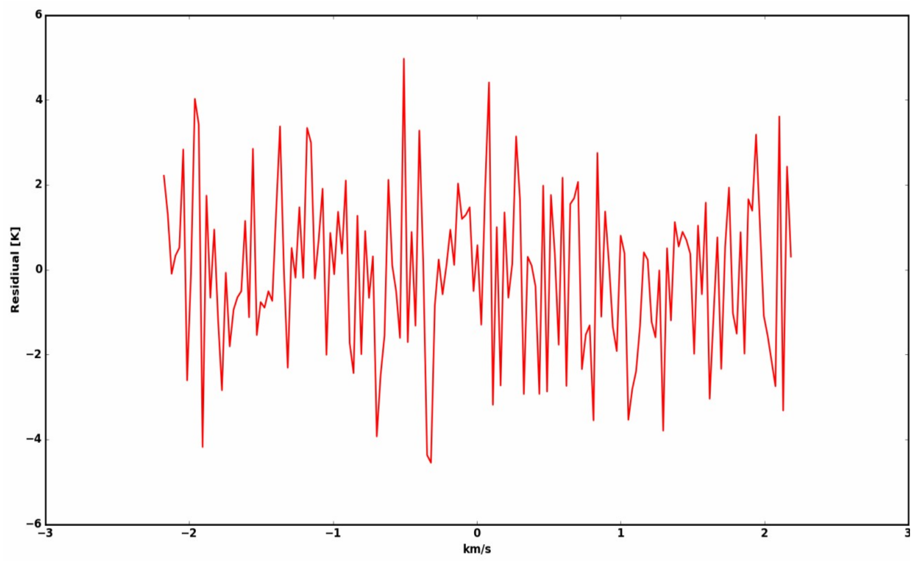
- Similar story as before; case with lower S/N, less dense grid, slow decay profile, higher density density

- Excellent fit and retrieval quality for both Tkin and Vexp. Temperature can be well determined below 1km within (does depend on S/N).

- Results very weakly dependent on initial profile (next slide)

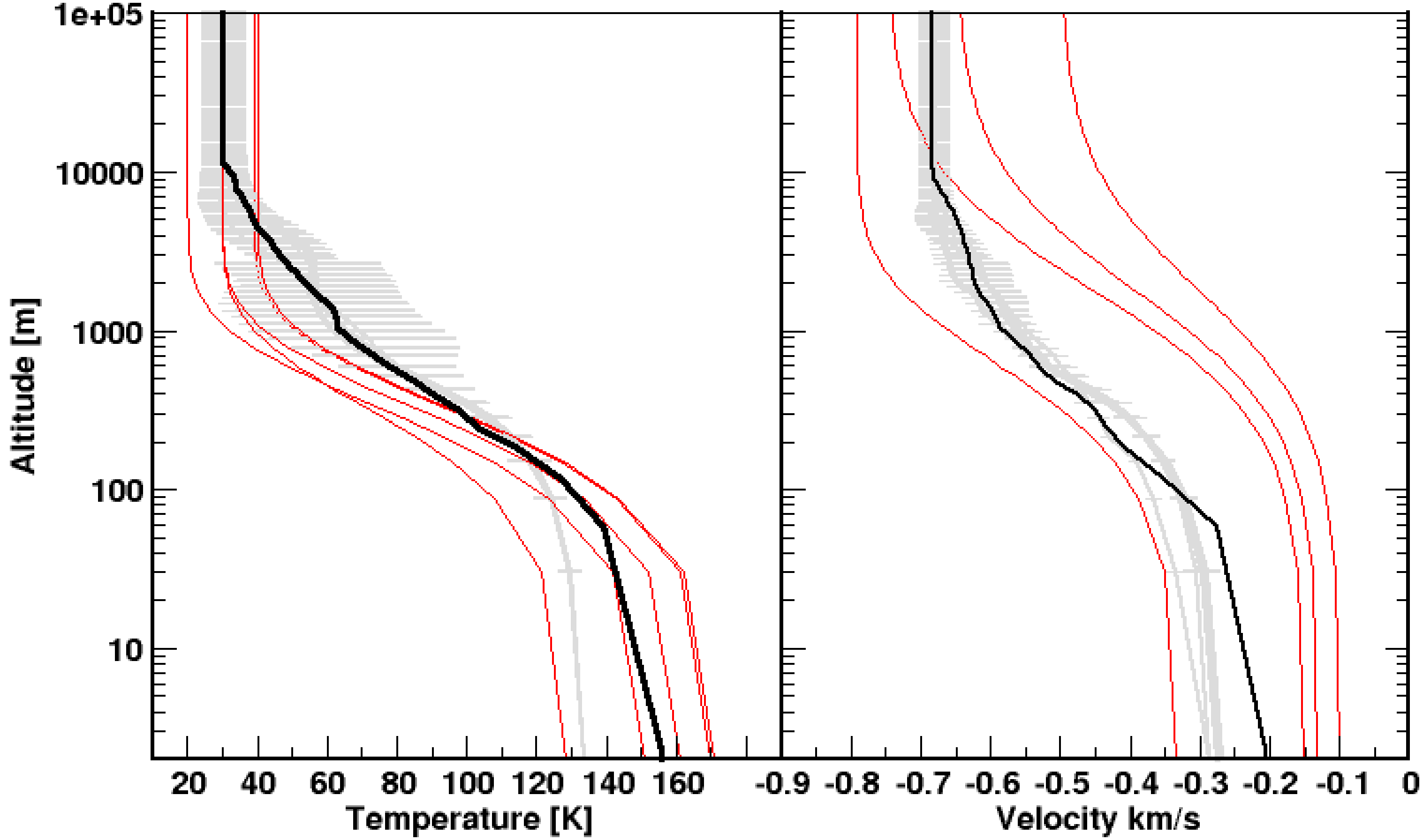






Initial condition and bias check

* Summary plot for different initial profiles for T, V
* Density bias of 35% applied
* Gray profiles: retrieved profiles (initial profile independence + density bias independence)



Summary

(1) The optically thick 557 GHz water line measured by MIRO contains information on the vertical profile (LOS) for T and Vexp.

(2) Solving the associated inverse problem is possible in a robust way.

(3) Since the $H_2{}^{16}O$ line is thick (since early on in mission) there are plenty study cases. It is demonstrated that ware are very weakly dependent on knowledge of H_2O density (35-40 % accuracy is sufficient). Also the inversion is weakly dependent on initial profile (good).

(4) Applying the inversion to many cases we can start deriving science by interpreting the vertical profiles

   (1) Dust to gas interaction

   (2) Topography effects on gas flow

   (3) Locating active areas (high spatial resolution..)

(5) Finally, while promising this work is a first step: ultimate goal is combining nadir view, nadir + limb, and combining detectable molecules allowing much improved determination of the vertical profiles.

Slicing 3D coma with MIRO (tomography vs 2D inversion)