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# OUT-OF-EQUILIBRIUM HYPERSONIC JET SPECTROSCOPY



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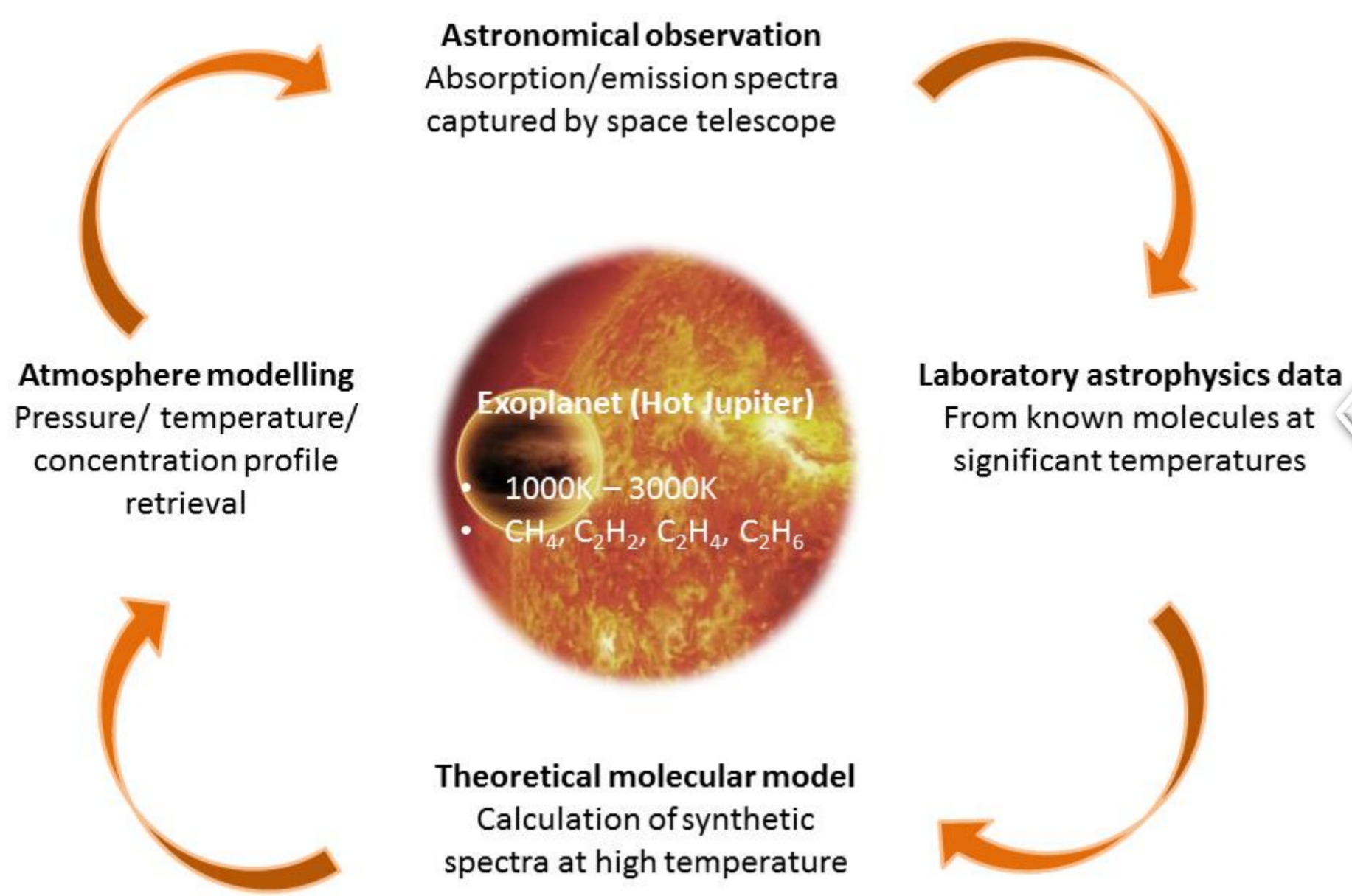
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## Introduction



## Out-of-equilibrium hypersonic jet spectroscopy

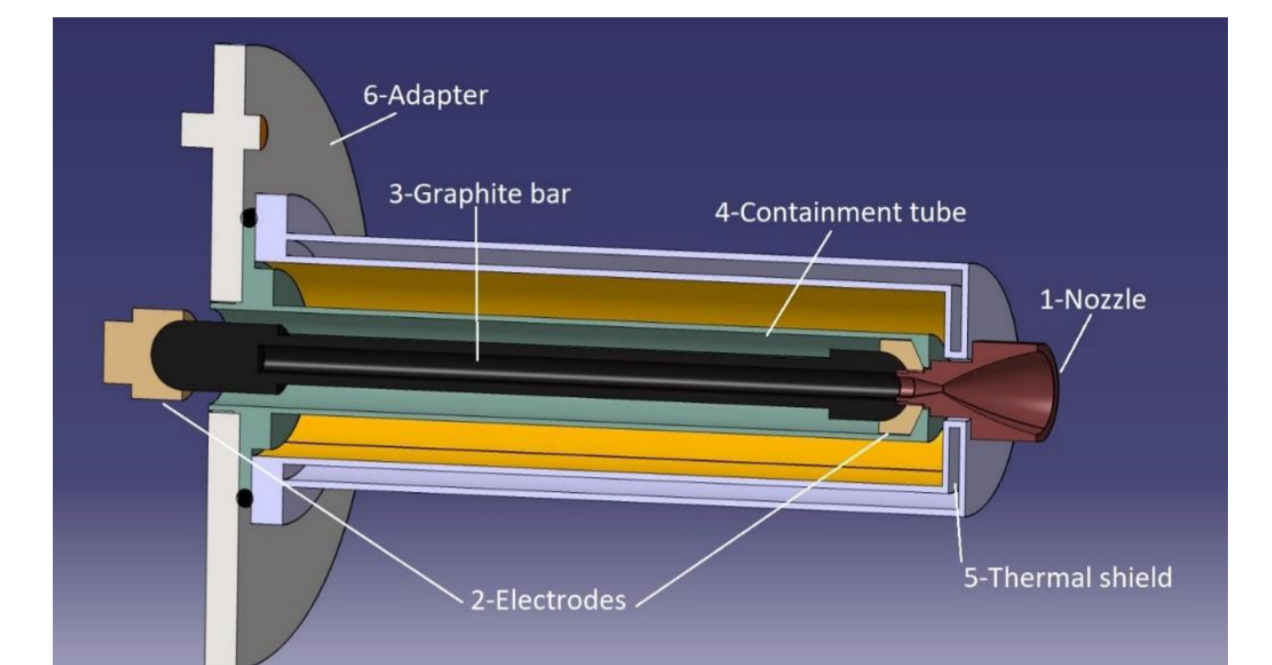
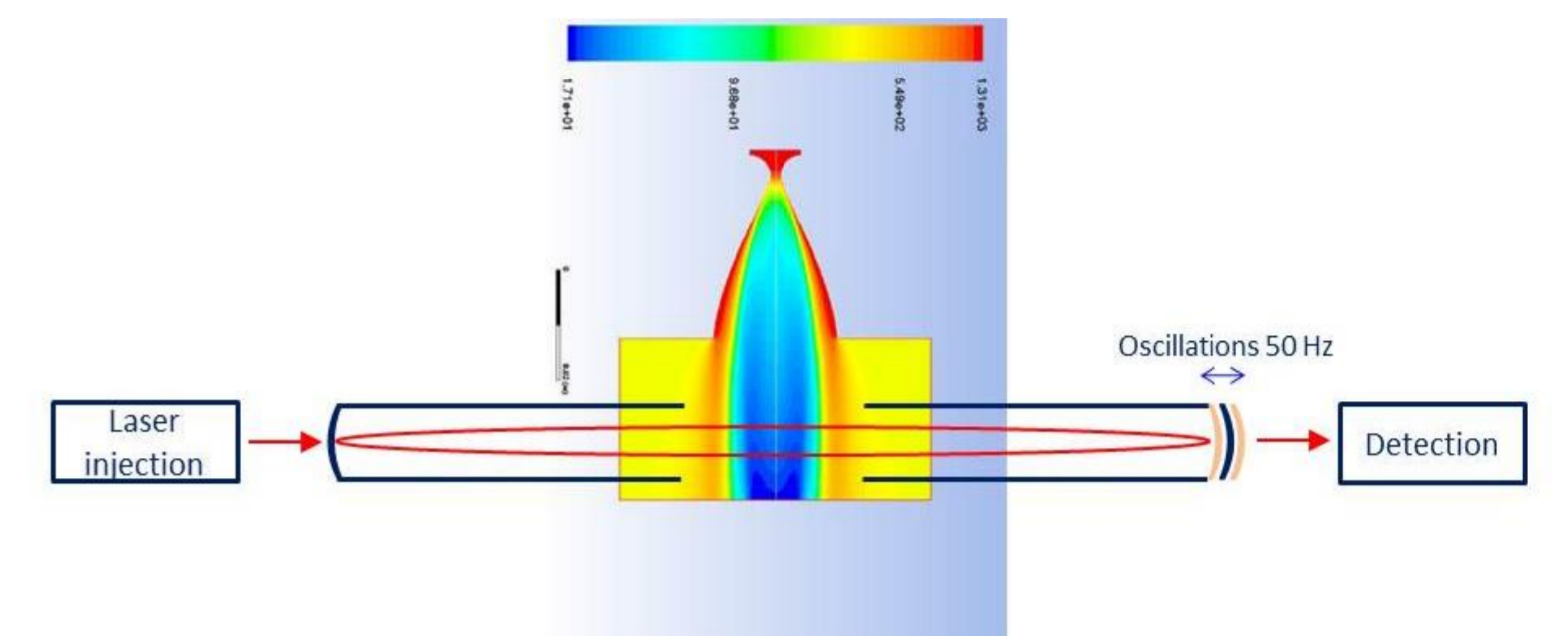
### Hypersonic jet

- initially heated up to 2000 K
- sudden drop of molecular collisions
- strong decoupling of the internal degrees of freedom of the molecules
- uniform shape with isentropic core
  - rotational temperature relaxes rapidly
  - vibrational temperature remains very close to the initial one
  - relative high density
  - hot shear layer
  - several hundreds Kelvin

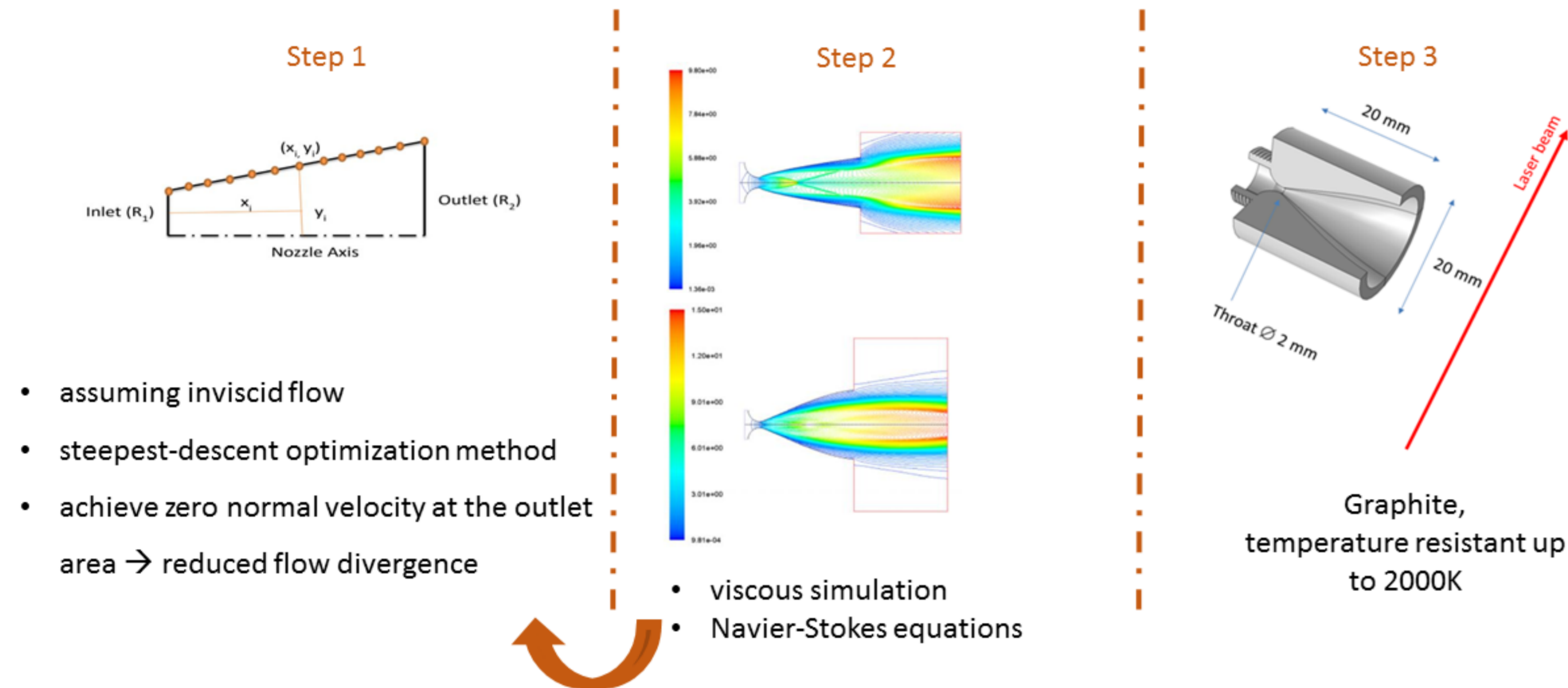
### Cavity Ring-Down Spectroscopy

- ultra-sensitive technique
  - 675 m optical path
  - high-finesse optical cavity
- IR spectrum (1.5 μm range)
- fibred DFB butterfly laser diode
- laser diameter: 0.5 mm
- ring-down time: 180 μs
- resolution max.: 10<sup>-4</sup> cm<sup>-1</sup>

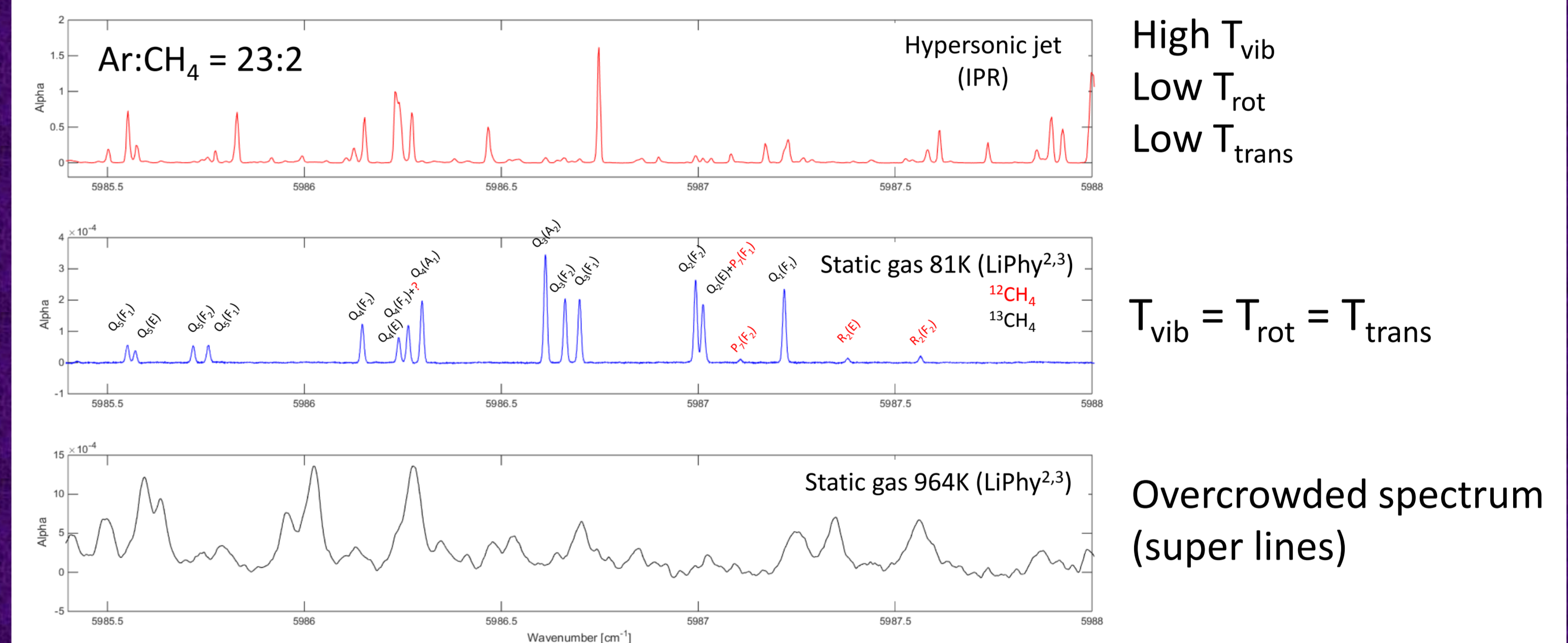
## Experimental setup



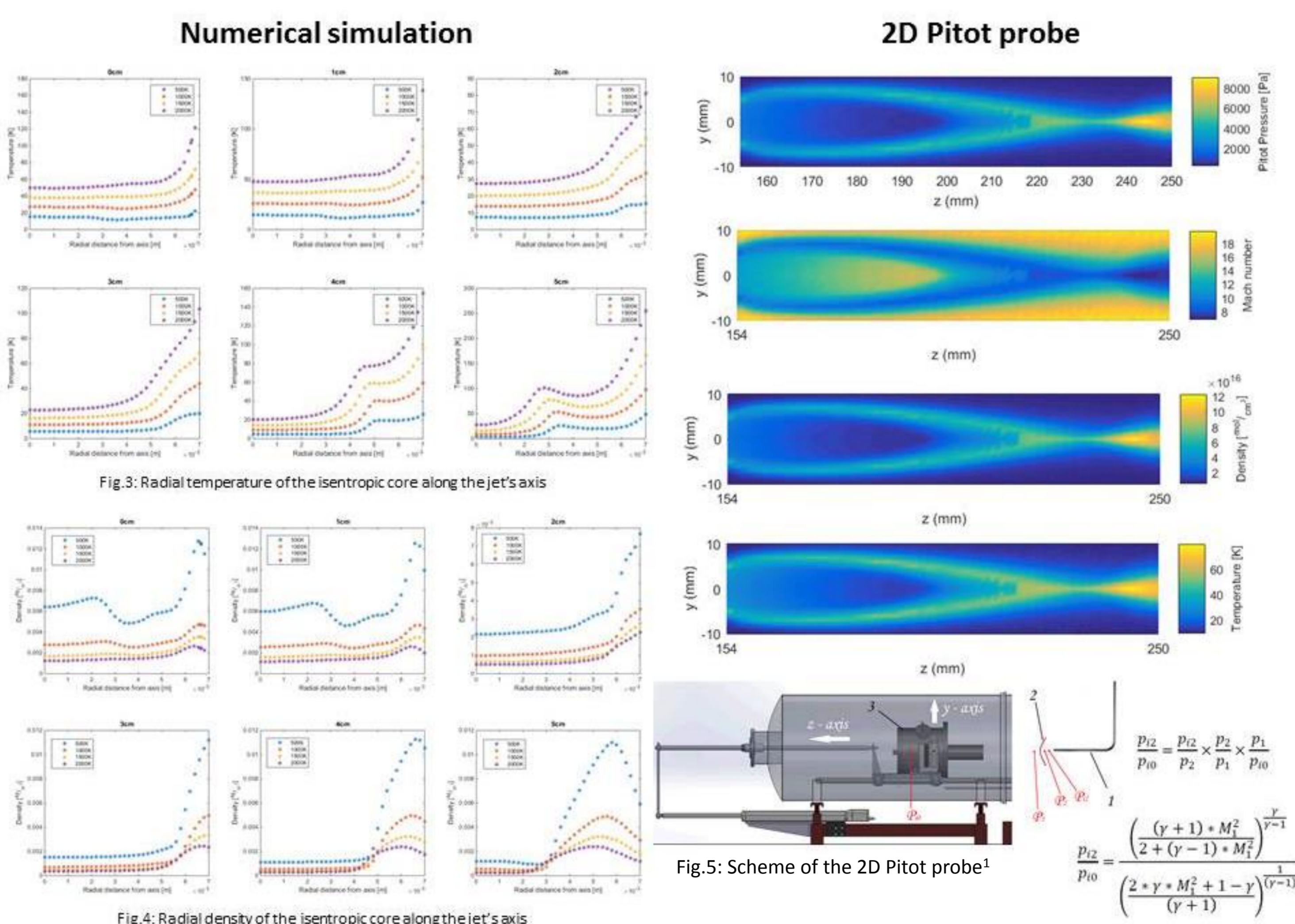
## Design of small dimensional de Laval nozzle



## Cavity Ring-Down Spectroscopy



## Characterization of the flow



### Advantages

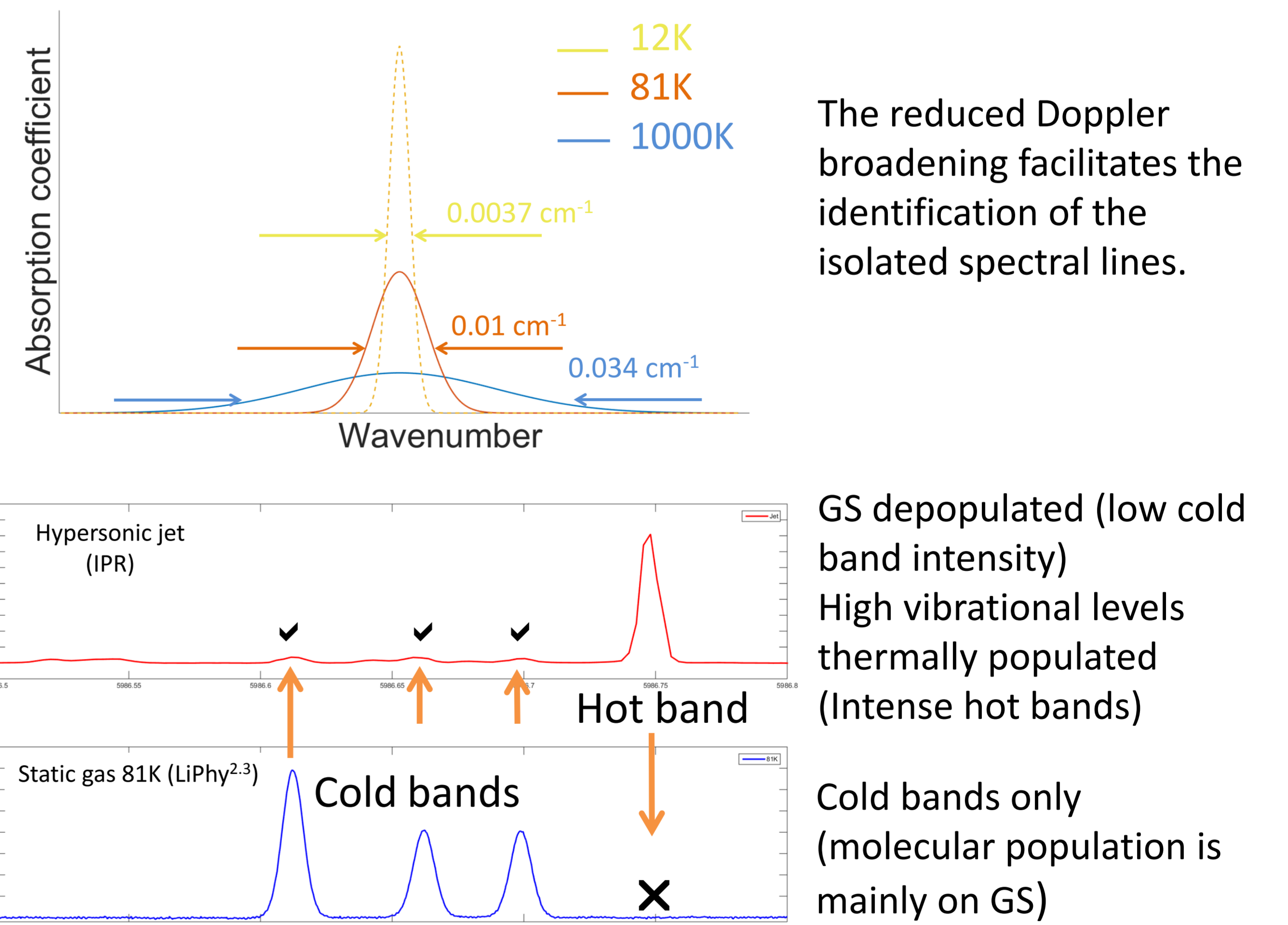
- Low temperature in the isentropic core
- Relatively high density (few 10<sup>16</sup> cm<sup>-3</sup>)
- Radially uniform core over Ø15 mm
- Tunable initial reservoir temperature and pressure

### To be improved

Unwanted shear layer absorption (rotationally hot gas)

Design of a planar nozzle for reducing the shear layer effect and for lengthening the optical path by a factor of 10

## Performance



## Discussion:

- simplified rotational structure of the hypersonic spectrum (1.5 μm range)
- without depopulating the highly excited vibrational energy levels whose analysis is really challenging under equilibrium conditions
- in progress: implementation of a planar nozzle

## Acknowledgements

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## References

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<sup>2</sup>M. Konefal, M. Ghysels, D. Mondelain, S. Kassi, A. Campargue The absorption spectrum of 13CH<sub>4</sub> at 80 K and 296 K near 1.73 μm 2018  
<sup>3</sup>M. Ghysels, S. Vasilchenko, D. Mondelain, S. Béguier, S. Kassi, A. Campargue Laser absorption spectroscopy of methane at 1000 K near 1.75 μm: A validation test of the spectroscopic databases