INAF - Osservatorio Astronomico di Capodimonte

INFN Istituto Nazionale di Fisica Nucleare

ET EINSTEIN TELESCOPE

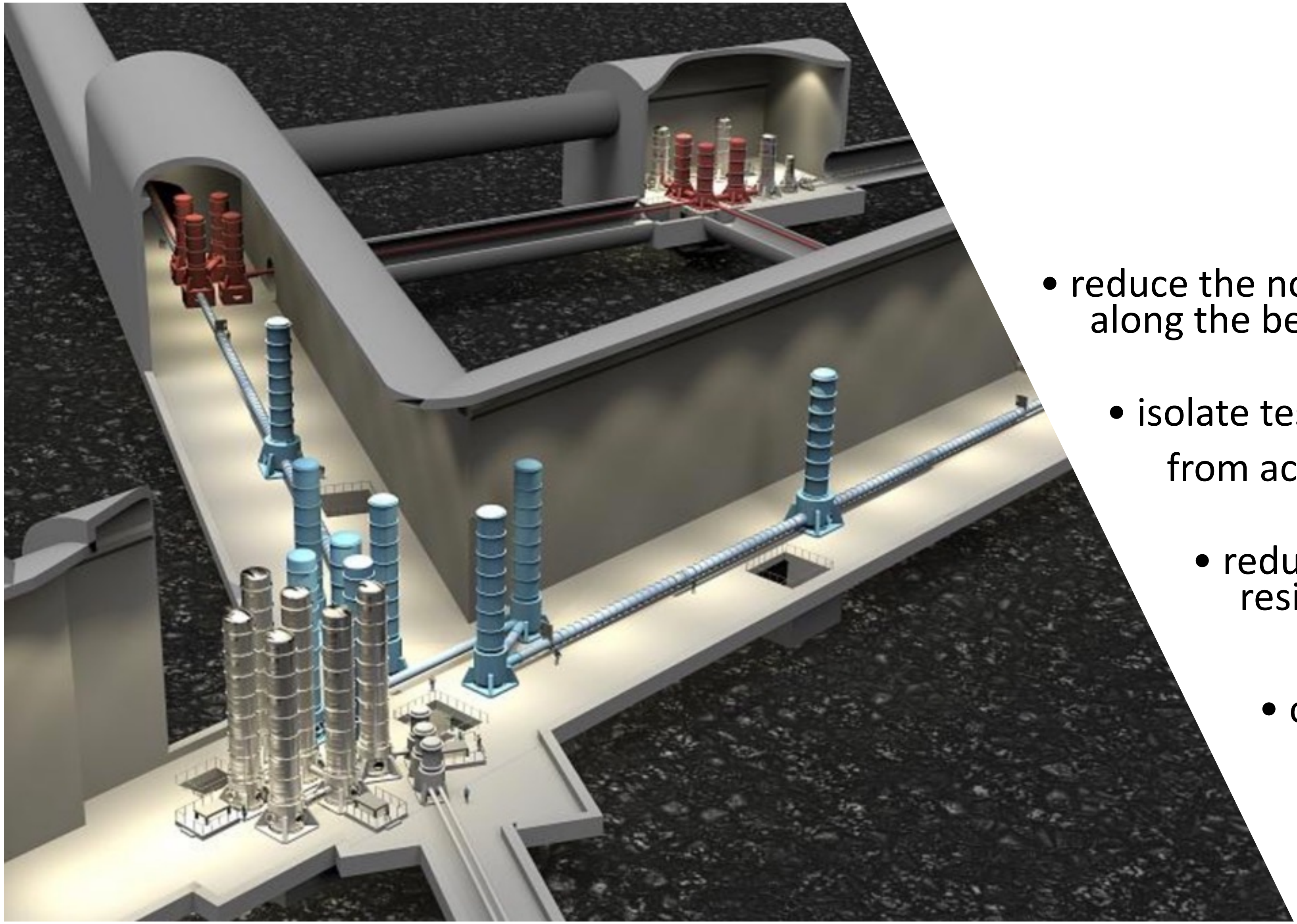
Einstein Telescope

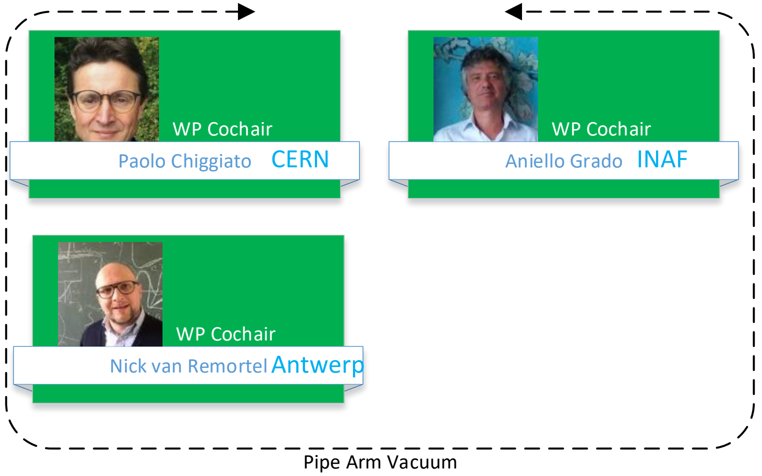
The Einstein Telescope beam pipe vacuum system activities

Aniello Grado
INAF/INFN

2023-06-22 EGO- INAF-IFAE Collaboration

ET: why under vacuum?





- reduce the noise due to residual gas fluctuations along the beam path to an acceptable level;
- isolate test masses and other optical elements from acoustic noise;
- reduce test mass motion excitation due to residual gas fluctuations,
- contribute to thermal isolation of test masses and of their support structures;
- contribute to preserve the cleanliness of optical elements.

Agreement with CERN

The beam pipe vacuum system is under direct responsibility of the ET Directorate.

In 2022 an agreement among INFN, Nikhef and CERN has been signed. Main goals are:

- **Coordinate the effort of ET collaborators** interested in the same technical objectives.
- Coordinate the contact and sharing of information with **Cosmic Explorer in the field of vacuum technology**.
- Re-evaluate **the baseline solution** (Virgo/LIGO) with minor modifications imposed by the new requirements.
- Design and test **technical solutions** that fulfil the ET requirements and are **less expensive** than the baseline. The required **technical infrastructure** will be evaluated and optimized as well.
- Manufacturing, assembly and commissioning of a **pilot sector**.
- Write the **technical design report**, including **cost estimations**.

The requirements of the beam pipe vacuum system is under the ISB responsibility

ET beampipes requirements

- Since January we have regular by-weekly teleconf
- We are writing a requirement document on beampipe

https://www.overleaf.com/read/xxhqmbzyqwk

Huge work done by Mario and his group on light scattering

- tube diameter
- Baffles size and distribution in the beampipe

EINSTEIN TELESCOPE

Beampipe vacuum system

ET-XXXXA-23
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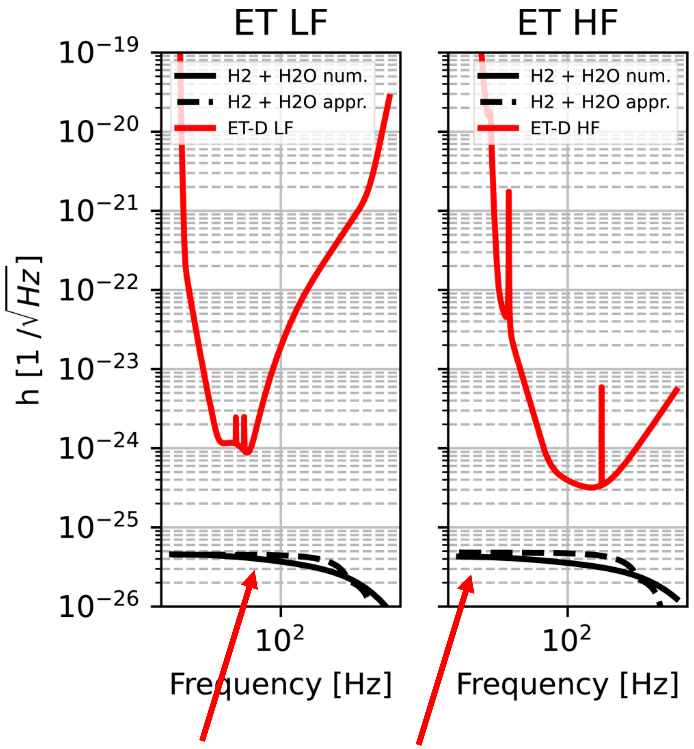
ET beampipes requirements

- Tube diameter ~ 1m
- Total lenght 120 km

Surface: 3.8×10^5 m^2
Volume: 9.4×10^4 m^3

- Material ?(2G detectors: SS 304L or 316L, 3G ?)
- Life time: 50 years
- Cost: ~ 560 Meuro (only the beam pipe vacuum system)



Contribution of the residual gas to the ET noise

A. Grado et al. J. Vac. Sci. Tech. B 41 024201 (2023)

ET requirements: beampipe partial pressure for gas species

Gas species	Outgassing rate	Max pressure	Noise HF	Margin
	$mbar\, l/s\, cm^2$	mbar	$1/\sqrt{Hz}$	
H_2	1×10^{-14}	5.3×10^{-11}	1.7×10^{-26}	18.7
H_2O	1.5×10^{-15}	9.5×10^{-12}	1.6×10^{-26}	20
N_2	5×10^{-16}	5.6×10^{-12}	1.4×10^{-26}	22.7
CO	2×10^{-16}	2×10^{-12}	1×10^{-26}	31
CO_2	1.5×10^{-16}	2×10^{-12}	1×10^{-26}	26
C_2H_4	1×10^{-16}	1×10^{-12}	1.5×10^{-26}	21

Table 1: Noise contribution to ET-HF due to residual gas fluctuations. The gas composition is supposed to be made of all the species listed in the table. The distance among pumps is assumed to be 500 m. The chosen specific outgassing and pumps capacity and distribution give a ratio ET-D/total gas noise of 9 for ET-HF.

Gas species	Outgassing rate	Pressure max	Noise LF	Margin
	$mbar\, l/s\, cm^2$	mbar	$1/\sqrt{Hz}$	
H_2	1×10^{-14}	4.7×10^{-10}	4.2×10^{-26}	21
H_2O	1×10^{-15}	1.1×10^{-10}	4.1×10^{-26}	21
N_2	5×10^{-16}	7×10^{-11}	3.7×10^{-26}	24
CO	2×10^{-16}	2.8×10^{-11}	2.7×10^{-26}	33
CO_2	1.5×10^{-16}	2.6×10^{-11}	3.2×10^{-26}	27
C_2H_4	1×10^{-16}	1.4×10^{-11}	4×10^{-26}	22

Table 2: Noise contribution due to residual gas fluctuations. The gas composition is supposed to be made of all the species listed in the table. The distance among pumps is assumed to be 2000 m. The chosen specific

ET-HF: 5000 l/s pumps
500 m pumps distance

ET-LF: 5000 l/s pumps
2000 m pumps distance

Interferometer arm lenght

Gas optical polarizability

$$S_L(f) = \frac{(4\pi\alpha)^2}{v_0} \int_0^L \frac{\rho(z)\, \exp\left[-2\pi f\, w(z)/v_0\right]}{w(z)}\, dz$$

Power spectral density fluctuations of optical path

Average molecules speed

Molecules number density

Laser beam gaussian radius

Study on materials: the hydrogen problem

Material	H content	H diffusivity	Corrosion resistence	price
Austenitic	High	Low	high	high
Wild steel	Low	High	low	low
Ferritic	Low	High	Can be high	intermediate

different H trapping mechanisms

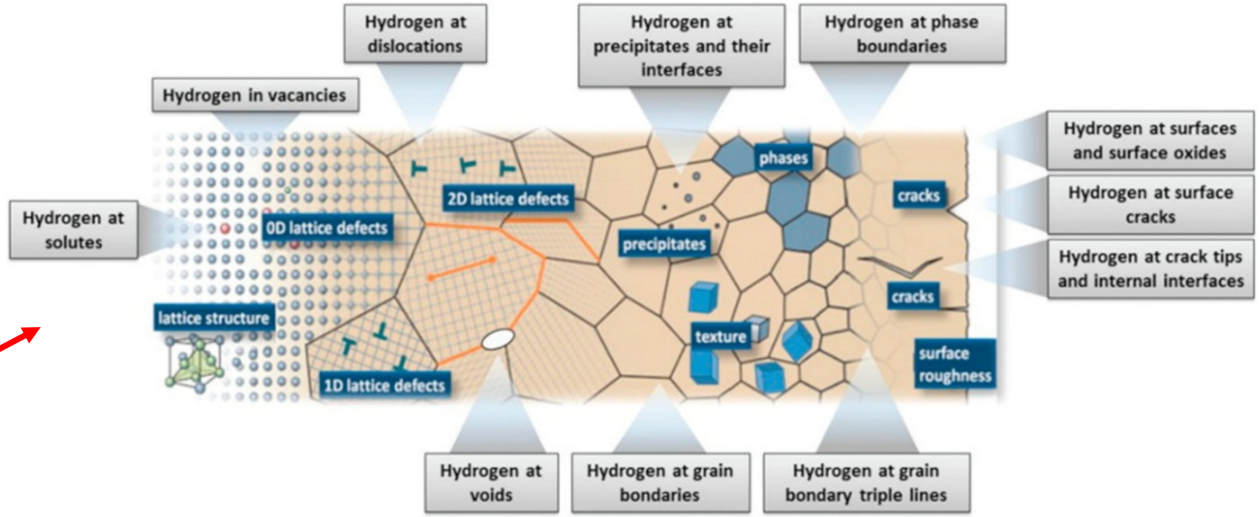


Figure 14: Illustrative representation of different hydrogen trapping mechanisms due to lattice defects in steels. Picture adapted from [Koyama 2017].

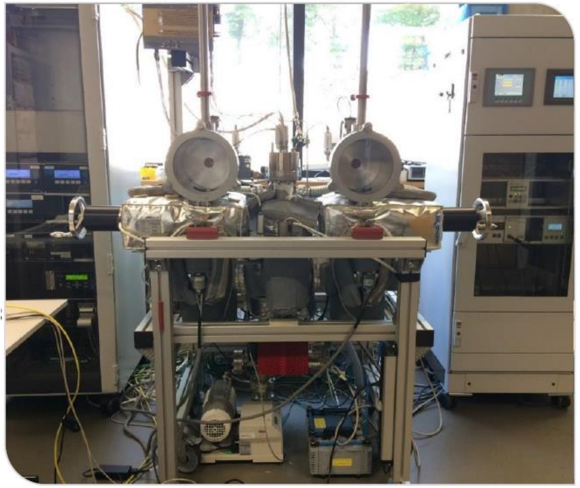
On going project on ET beampipe materials

Outgassing and (cryo) pumping at KIT (Karlsruhe)

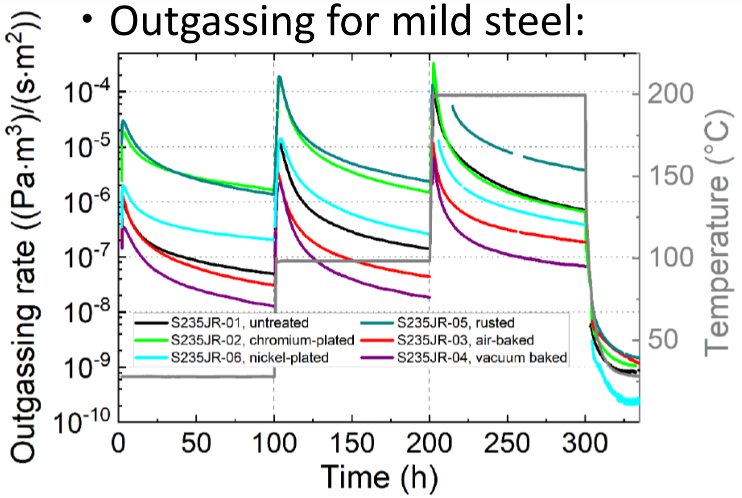
K. Battes, Chr. Day, S. Hanke, …

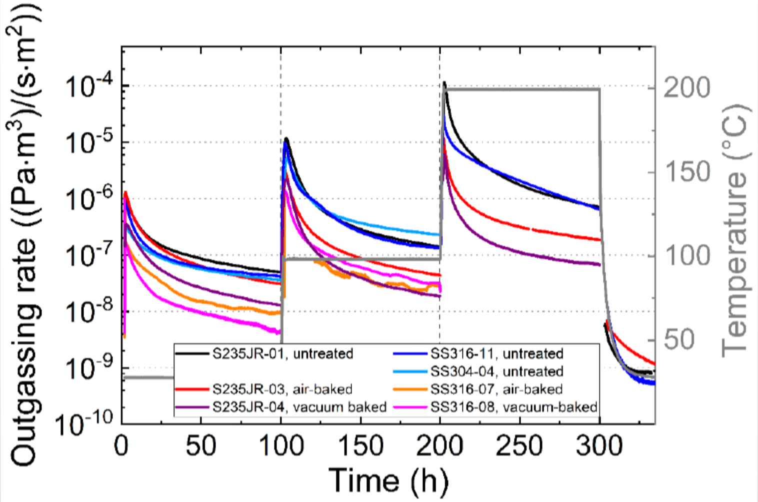
- **Modified throughput method** with second identical chamber to directly subtract background
- Specific outgassing rates from about 10^{-2} to 10^{-9} Pa $m^3/(s\ m^2)$
- Temperatures from 20 to 300 °C
- Quadrupole mass spectrometer

- Outgassing test facility: OMA



- Outgassing for mild steel:





Ongoing activities:

- Comparison out outgassing rates with those measured at CERN
- Exchange of samples between CERN and KIT
- Asessment of pumping speed vs outgassing rate

On going project on ET beampipe materials

Material properties and selections @ NIKHEF

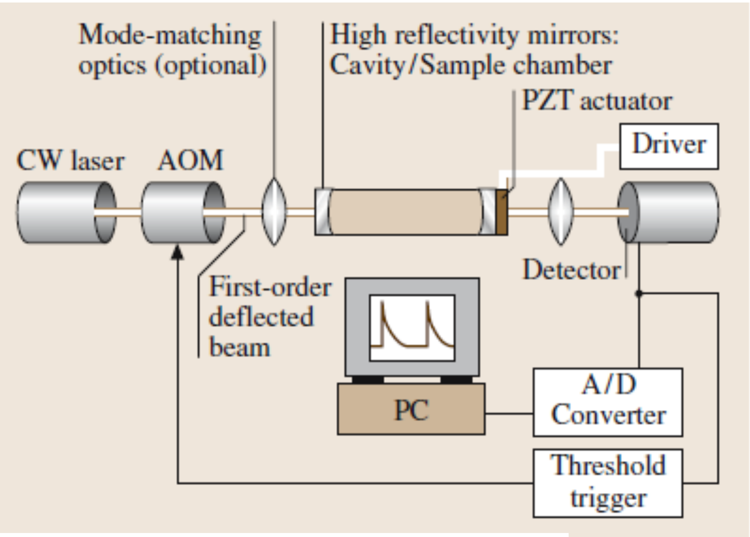
- Financed R&D project between NIKHEF, TATA steel and VDL ETG
- Material inventory and selection:
  - Stainless steel
  - Low carbon steel
  - Aluminium

Metal	Grade	Thickness (mm)
Stainless steel	SS304L	3.0
Low-Carbon Steel	IF01	3.4
Low-Carbon Steel	ULC01	2.53
Low-Carbon Steel	LC01	3.06
Low-Carbon Steel	LC01	3.7
Aluminium	6061, T6	3.17
Aluminium	6061, T651	6.1

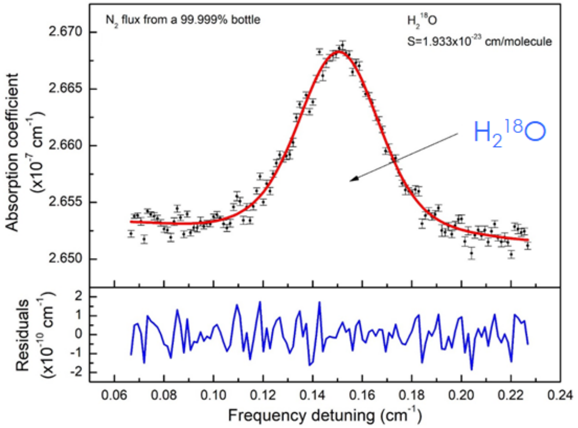
Outgassing test method	Required sample dimensions (mm x mm)
• Thermal desorption analysis (TDA, Kratos)	10 mm x 10 mm
• Thermal desorption spectroscopy (TDS, Bruker)	120 mm x 25 mm
• Throughput method (NIKHEF)	Maximum size Ø 105 mm x 47 mm Maximum weight = 1 kg

ETIC-CALATIA – Vanvitelli: R&D on new method to measure hydrocarbon partial pressure

Prof. L. Gianfrani, Prof. A. Castrillo, E. Fasci, E. Tofani, A. Grado

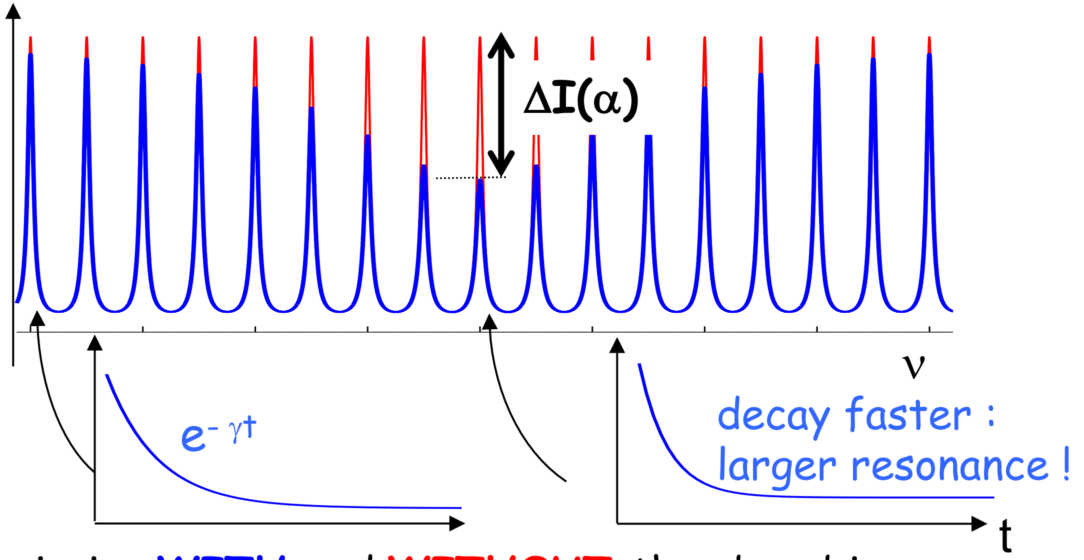


Simplified scheme



CRDS detection of $H_2{}^{18}O$ in nitrogen at the ppb level

Selective and sensitive measurements of trace amounts of hydrocarbons in UHV environments by means of comb-assisted Cavity Ring-Down Spectroscopy (CRDS)



Cavity transmission **WITH** and **WITHOUT** the absorbing gas sample

$$\alpha(\nu) = \frac{\tau_0 - \tau}{c\tau_0\tau} \rightarrow N\ (\text{molecules/cm}^3)$$

ETIC-CALATIA: Study of hydrocarbon contamination on surfaces in UHV systems

V. Mennella, A. Grado, F. Cozzolino, E. Zona

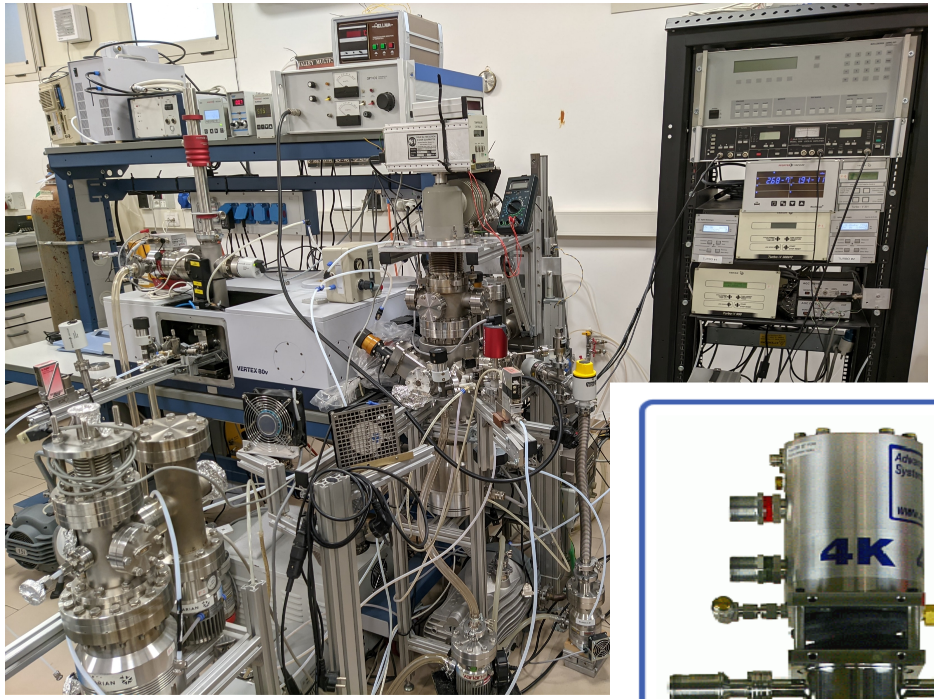
Cosmic Physics Laboratoy - INAF OAC Naples

- Of relevance in cosmic dust studies is the attribution of the so called 3.4 μm band due C-H aliphatic bonds, observed in the ISM, comets and meteorites. A similar band is also characteristic of hydrocarbon contamination in UHV systems.

Goals of the project

- ***define a method/procedure to asses the hydrocarbon contamination of the steel used to build the beampipe***
- ***Measure the sticking factor to study the ice formation on cold surface in ET-LF***

Setup where the cryostat will be installed

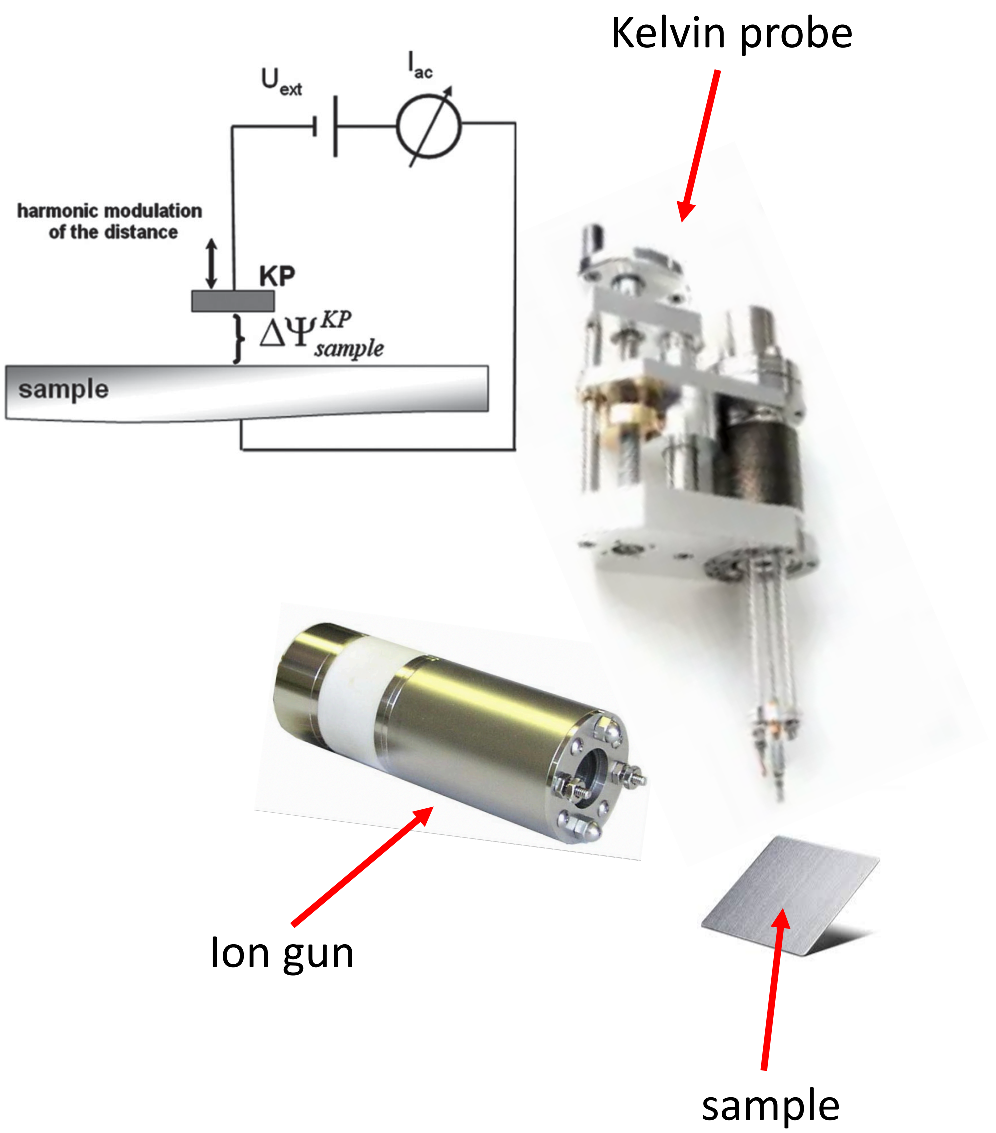


ETIC-CALATIA - Evaluation of Surface Contamination

A. Grado, L. Limatola, F. Getman, F. Cozzolino

The RMS of the work function of surfaces depends on their contamination (Patch effect).

We aim to develop a surface work function measuring system made of a cleaning device (using an ion gun) and a work function measurement device (using a Kelvin Probe) to determine at which level the patch effect can assess the surface contamination.

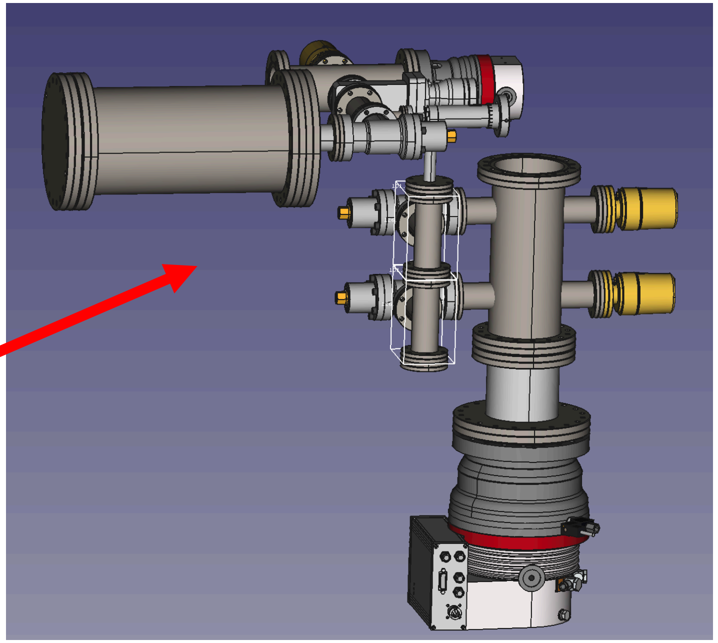


ET-Italia/INAF: Study of low outgassing materials suitable for UHV vessel

- Degassing stations @ EGO - A. Pasqualetti, J. Gargiulo
- Set up of a degassing station at the Astronomical Observatory in Naples (INAF OAC) to study materials for the beampipe
  – A. Grado, V. Mennella, F. Cozzolino,

Investigation of steel with low H_2 outgassing rate in order to reduce/avoid air-firing that would be too expensive for ET

Expected first results in the next 6 months



Outgassing station currently under construction @ INAF Capodimonte

Outgassing station @EGO
Courtesy A. Pasqualetti

Thank you for the attention

Scanning Kelvin Probe to map hydrogen content

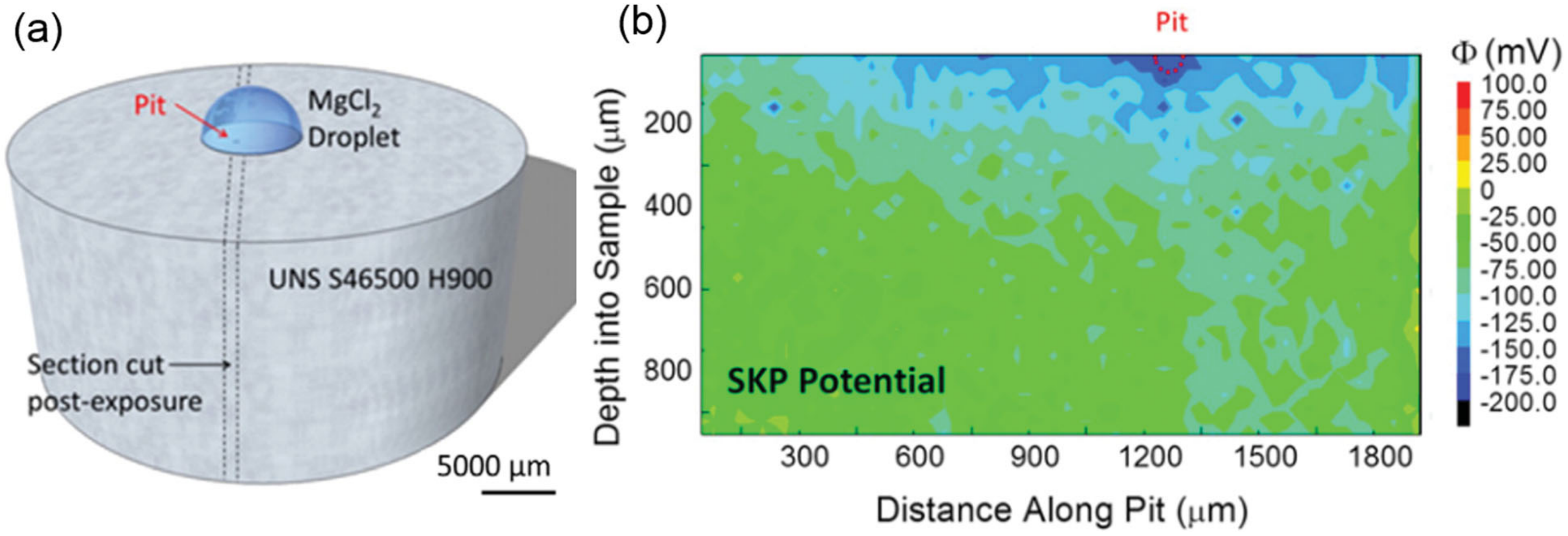


Figure 6. Diffusible hydrogen distribution at a pit visualised by SKP [50]. (a) The schematic shows a droplet pre-exposure on a surface with the location of the cross-section cut depicted in (b). (b) SKP potential map obtained on a UNS S46500 precipitation-hardened stainless steel. The SKP measurement was carried out on a cross-sectional area of the specimen containing the pit as shown in (a). 'Reproduced with permission from *Electrochem. Comm.*, **63**, 6-7 (2016). Copyright 2016, Elsevier'.

Recent progress in microstructural hydrogen mapping in steels. Koyama et al. 2017, Materials Science and Technology, 33:13, 1481-1496