# Spectroscopic measurements and analyses of water and air molecules in glow plasma discharges for fusion application

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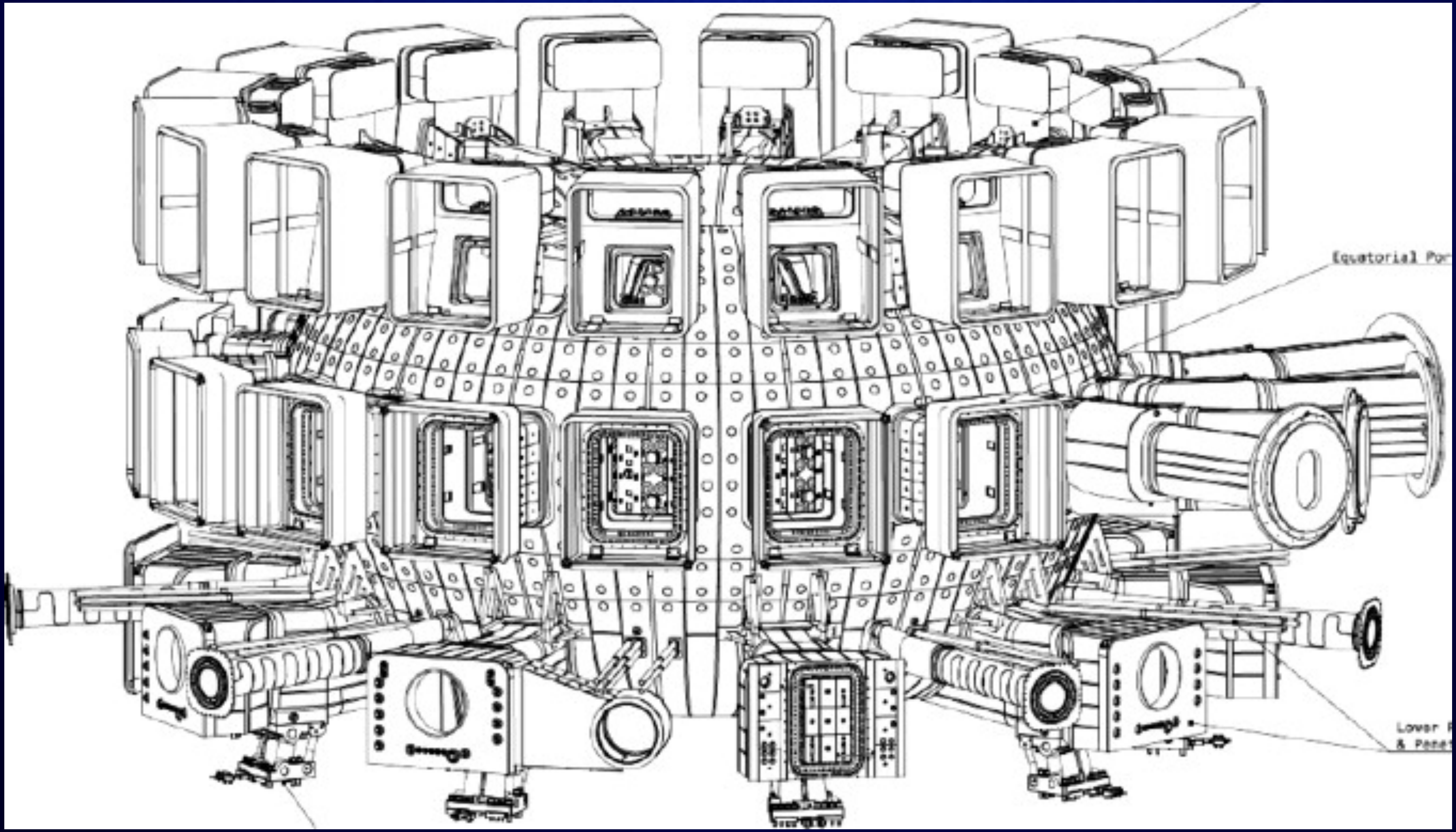
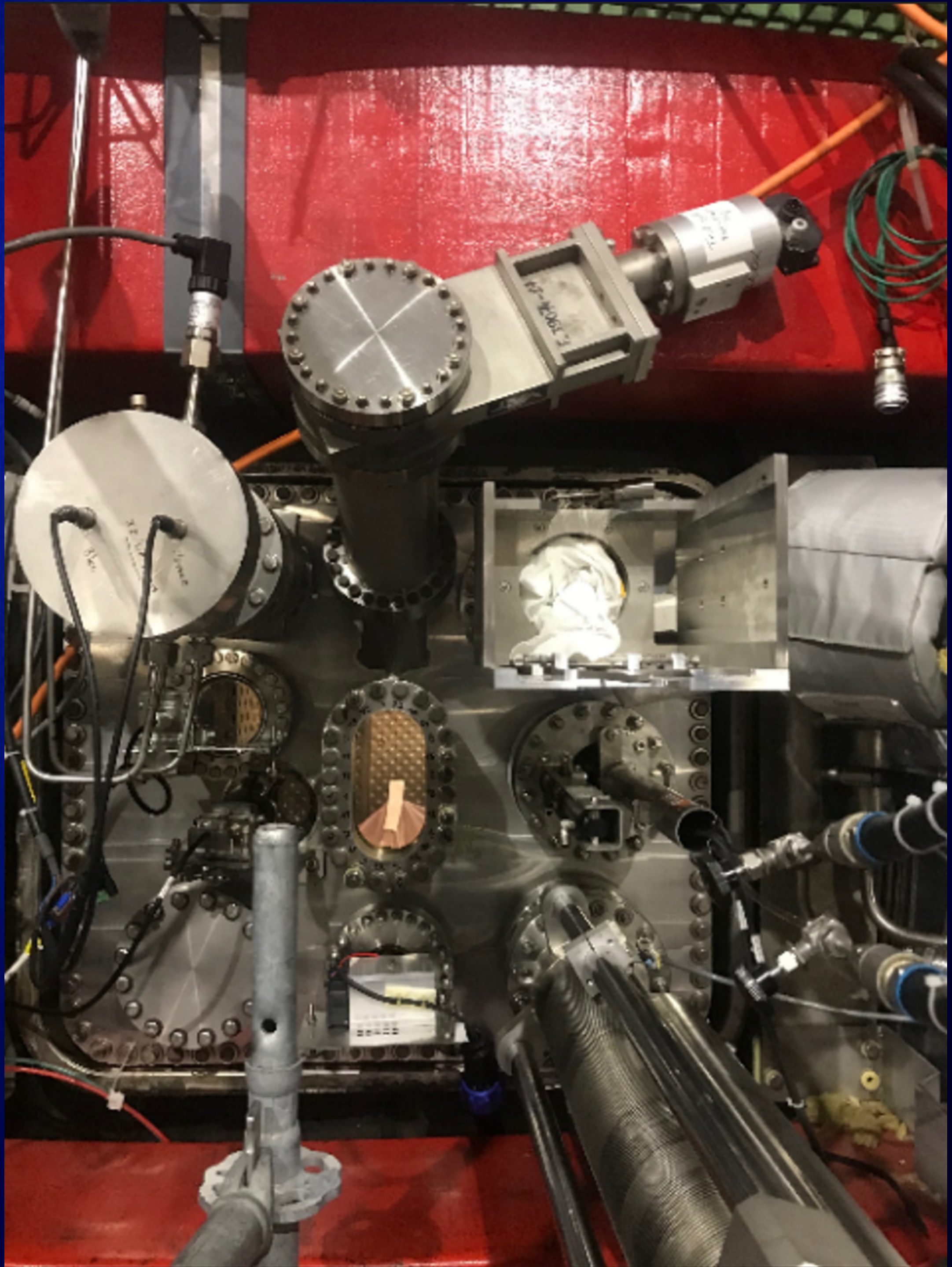
# Tokamak as a complex system of ports, each could contain multiple flanges, and each flange is a source of air leak.

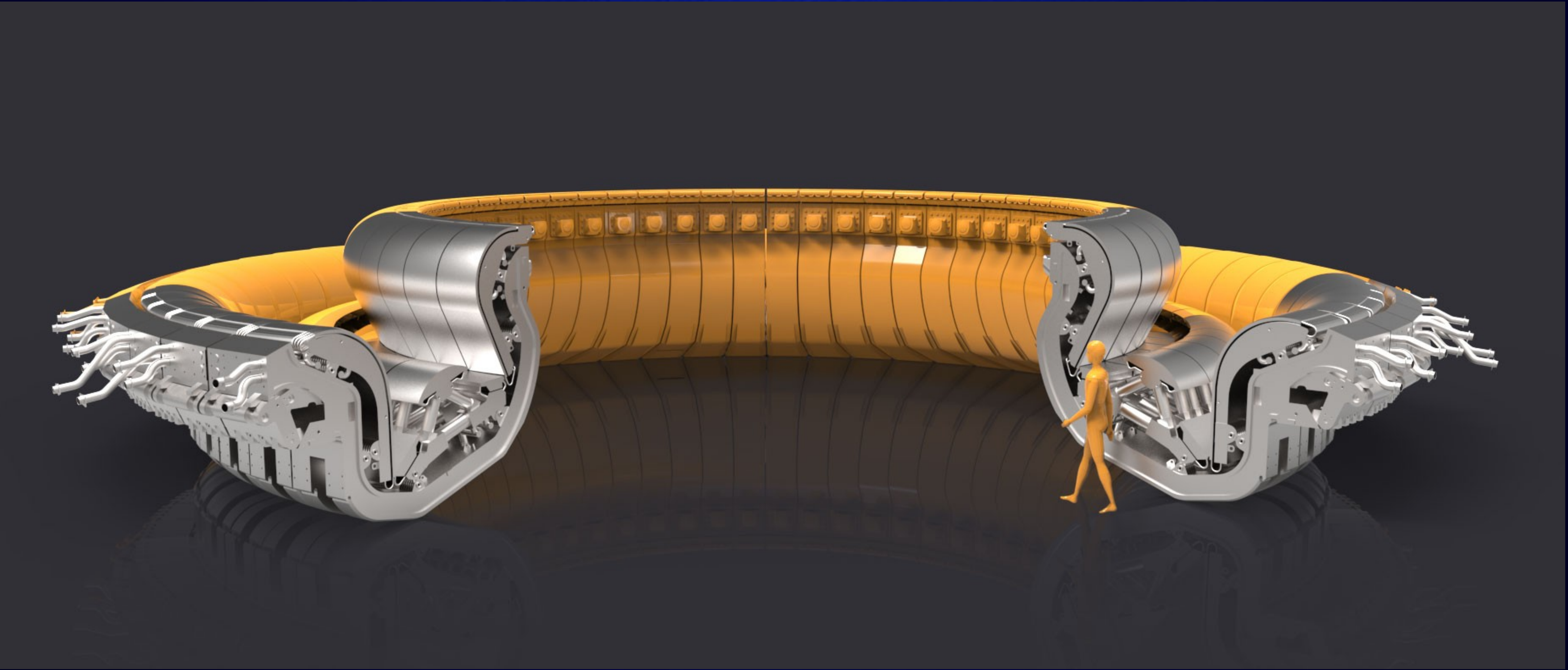


# Flanges on the midplane section on WEST (France)

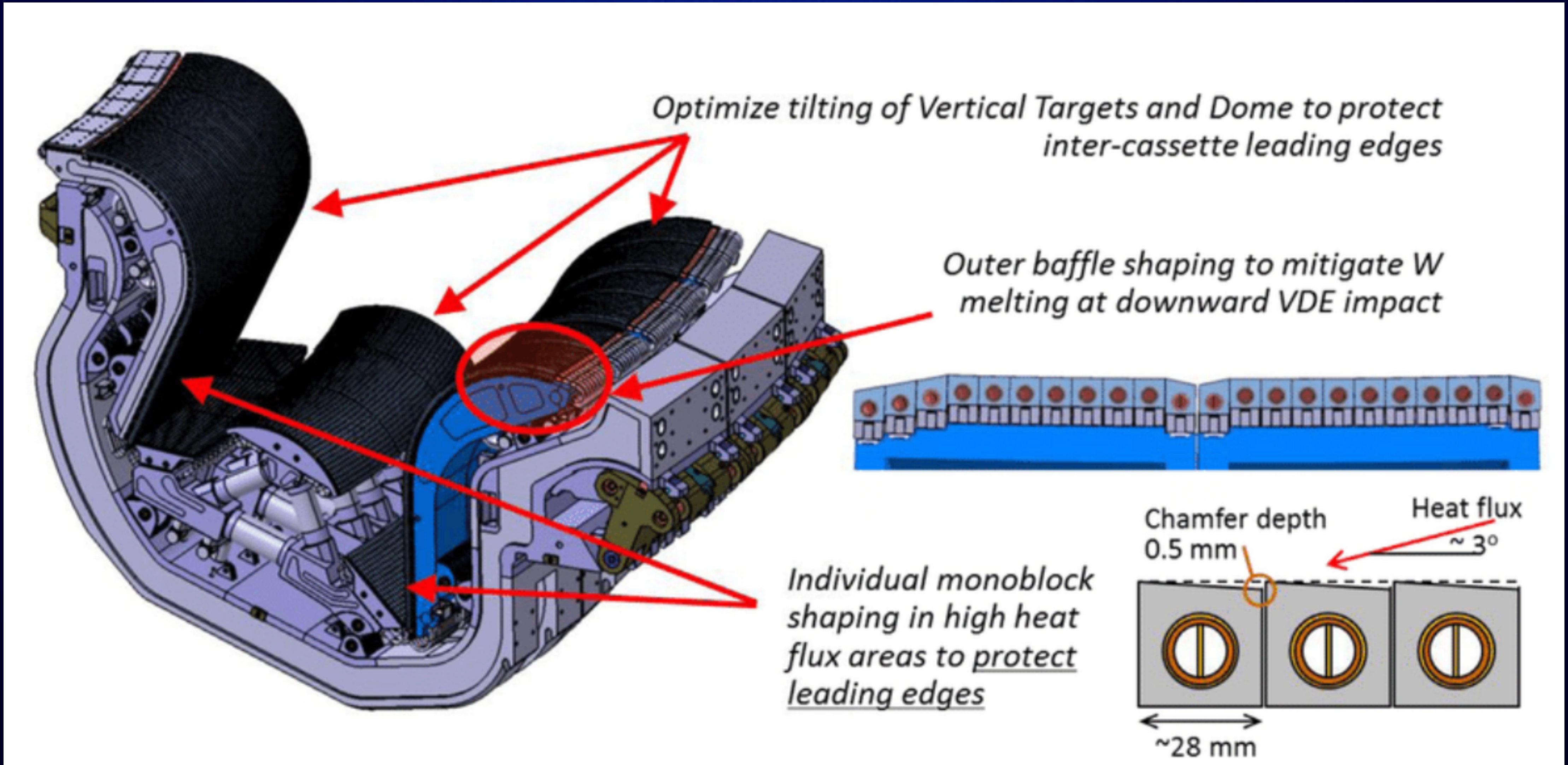
Each flange is a possible source of air leak into the tokamak vacuum chamber



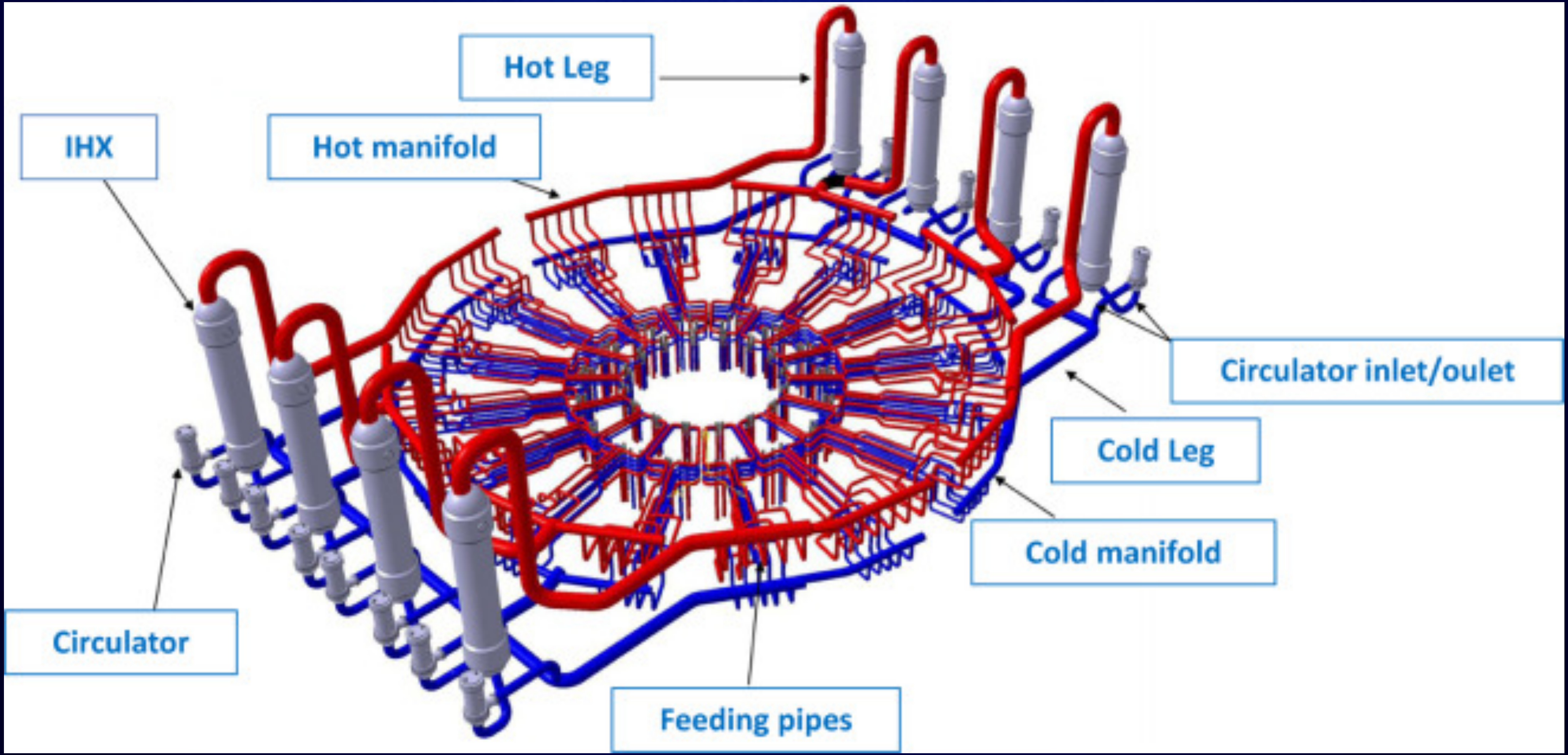
# ITER water-cooled divertor



# Water cooling inside the tokamak is another source of leak



# Water cooling in ITER

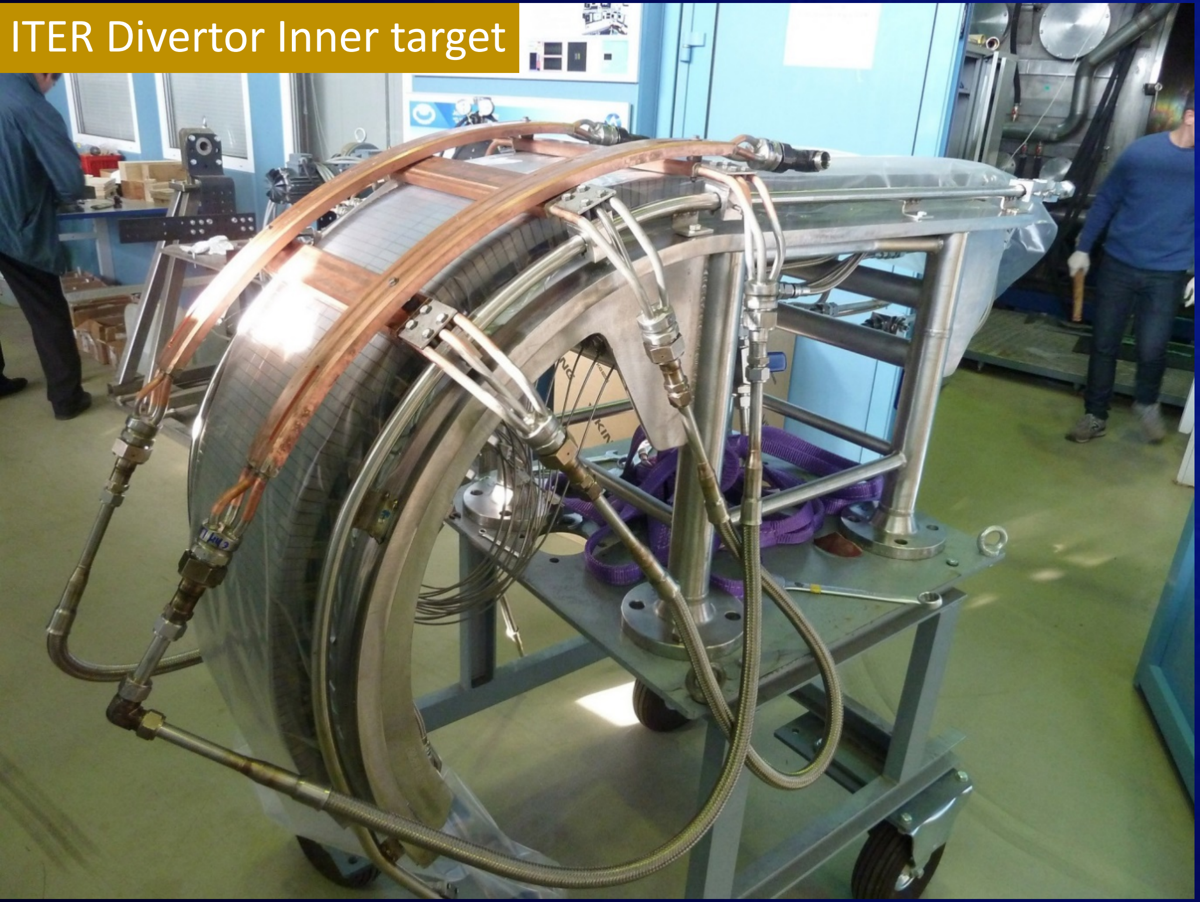


# Water cooling to be used on ITER

[26PHs945]

| Parameter | VV PHTS** | IBED PHTS | NBI PHTS |
|---|---|---|---|
| Conductivity @25ºC, µS/ cm | <= 1.0 | <= 0.2 | <= 0.1 |
| pH @25 ºC | 6.5 - 8.0 | 7.0 - 9.0 | 6.5 - 7.5 |
| Sodium, ppb | <= 25 | <= 5 | <= 5 |
| Cloride, ppb | <= 25 | <= 5 | <= 5 |
| Hydrogen***, ppb | - | <= 350 | <= 100 |
| Catalyzed Hydrazine****, ppb | - | <= 30 | - |
| Ammonia****, ppb | <= 300 | <= 1,000 | - |
| Oxygen, ppb | <= 100 | <= 10 | <= 10 |
| ORP@25 ºC, mV | Info | (-400) - (-100) | (-400) - (-100) |
| Iron*****, ppb | <= 12 | <= 10 | <= 10 |
| Copper*****, ppb | <= 10 | <= 10 | <= 10 |

# Many Sources of air and water leaks





**Molecules inside tokamaks because of leaks are OH, $H_2O$, $N_2$, $O_2$ and $H_2$ etc.**

# Motivation

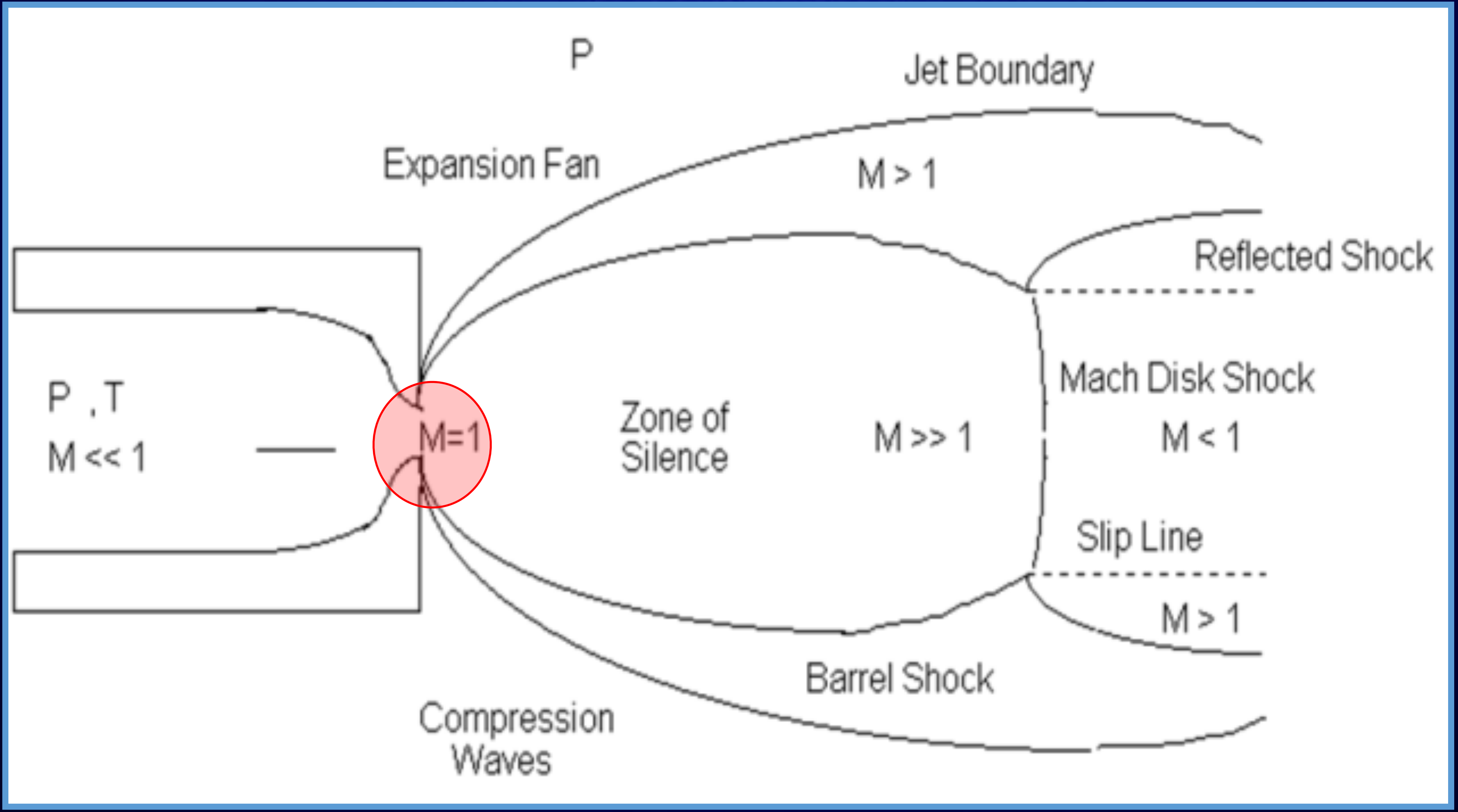
- Air and/or water leaks always occur in tokamaks and, in addition to the fact that it is not possible to safely operate, one may need several weeks to determine their spatial location(s).

- This aspect is going to be even more critical and more time-consuming in bigger tokamaks such as ITER or DEMO.

- This project is to determine the leak(s) spatial position swiftly using a combination of visible imaging techniques, glow discharges, and adequate image processing.

- To select the filters that ought to be inserted in front of the camera, dedicated spectroscopic measurements and simulation will be done to outline the signature of the rays that exist during different types of glow discharges followed by those that exist during air or water leaks.

# Gas Jet Free Expansion into vacuum from a point source leak



# Physical Quantities put as a Function of the Mach number *M*

- $PV^{\gamma}$ = Constant (adiabatic process)
- $P = (R/W)nT$ (ideal gas)

$$\frac{P_0}{P^\star} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{-\frac{\gamma}{\gamma-1}} ,$$

$$\frac{n_0}{n^\star} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{-\frac{1}{\gamma-1}} ,$$

$$\frac{T_0}{T^\star} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{-1} ,$$

$$\frac{A_0}{A^\star} = \frac{1}{M}\left(\frac{(\gamma+1)/2}{1+(\gamma-1)M^2/2}\right)^{\frac{\gamma+1}{\gamma-1}} .$$

- Once the variation of $M$ determined, the evolution of $P_0$, $n_0$, $T_0$ and $A_0$ are obtained.

# The Mach number dependence on distance to the leak source (or the nozzle)

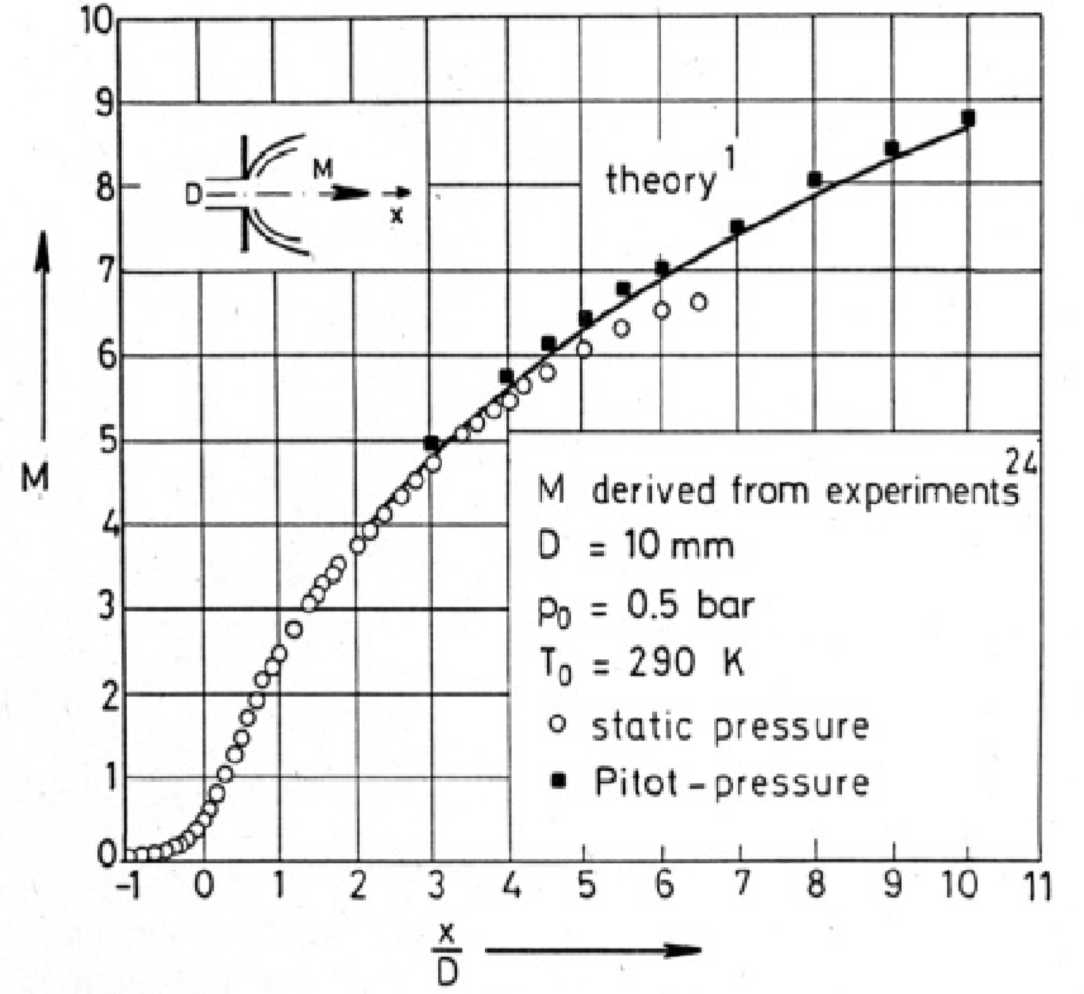
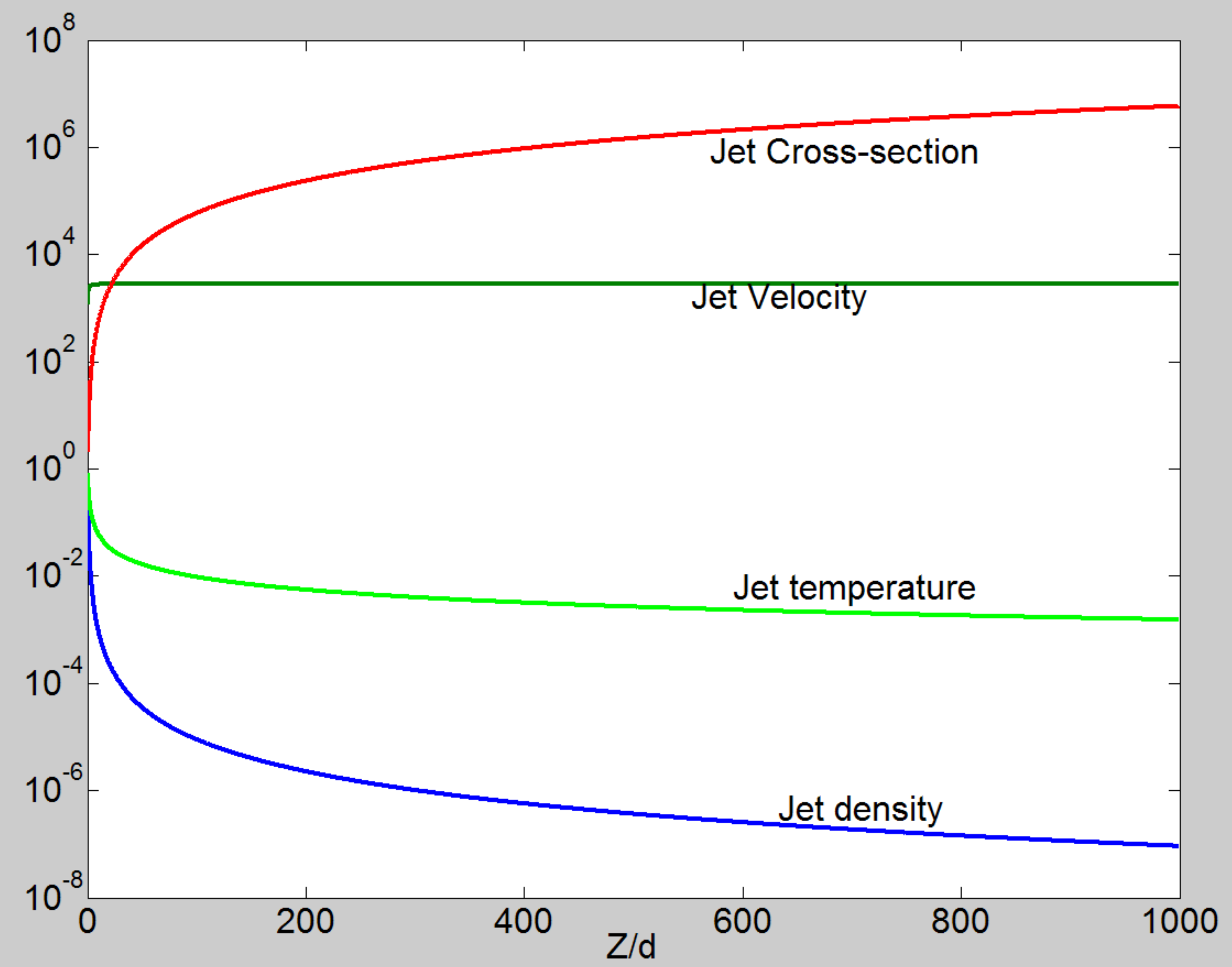
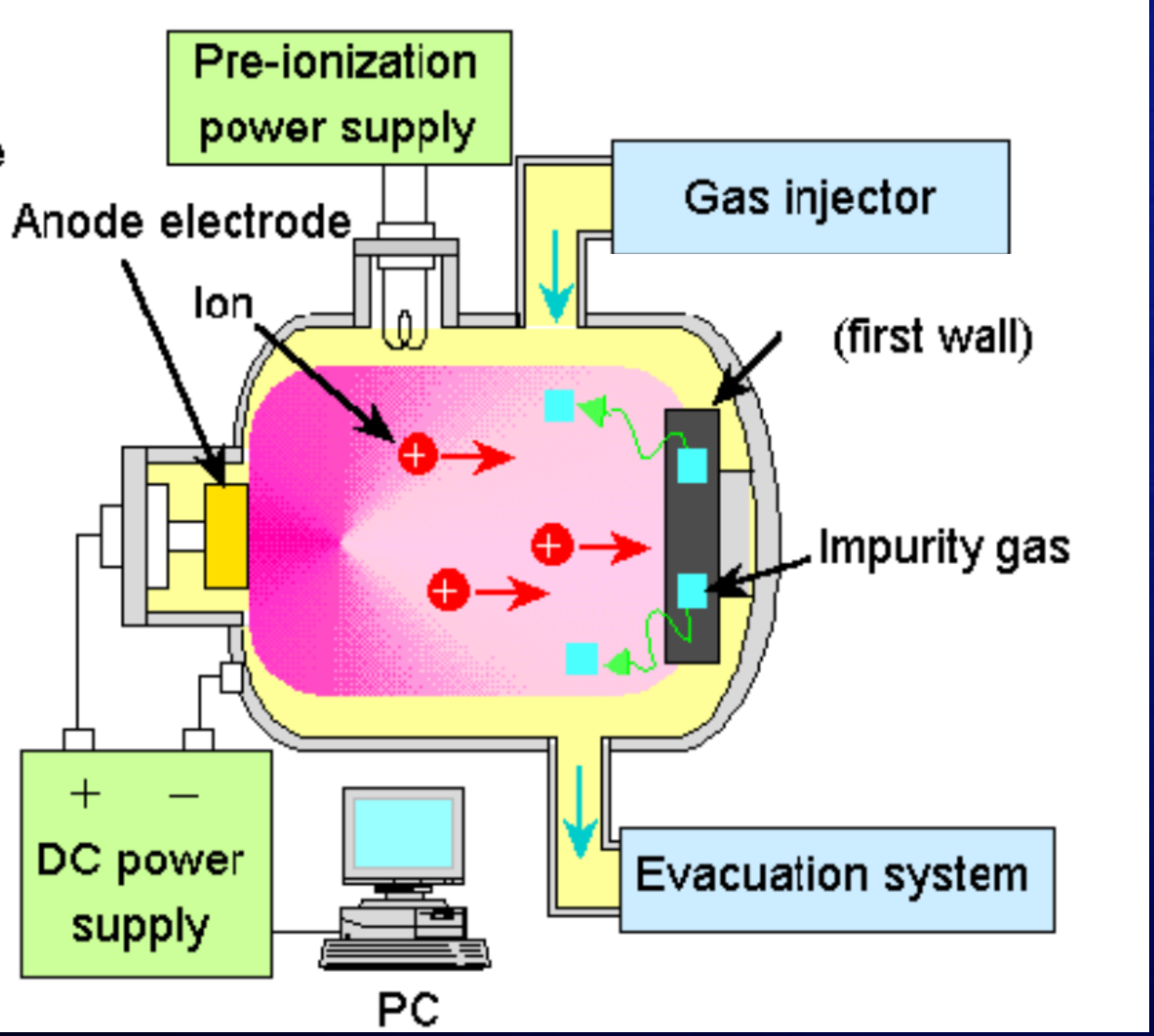



**Figure 2.** Sub- and transsonic free jet measurements: supersonic theory,[1] $\kappa = 1.40$.

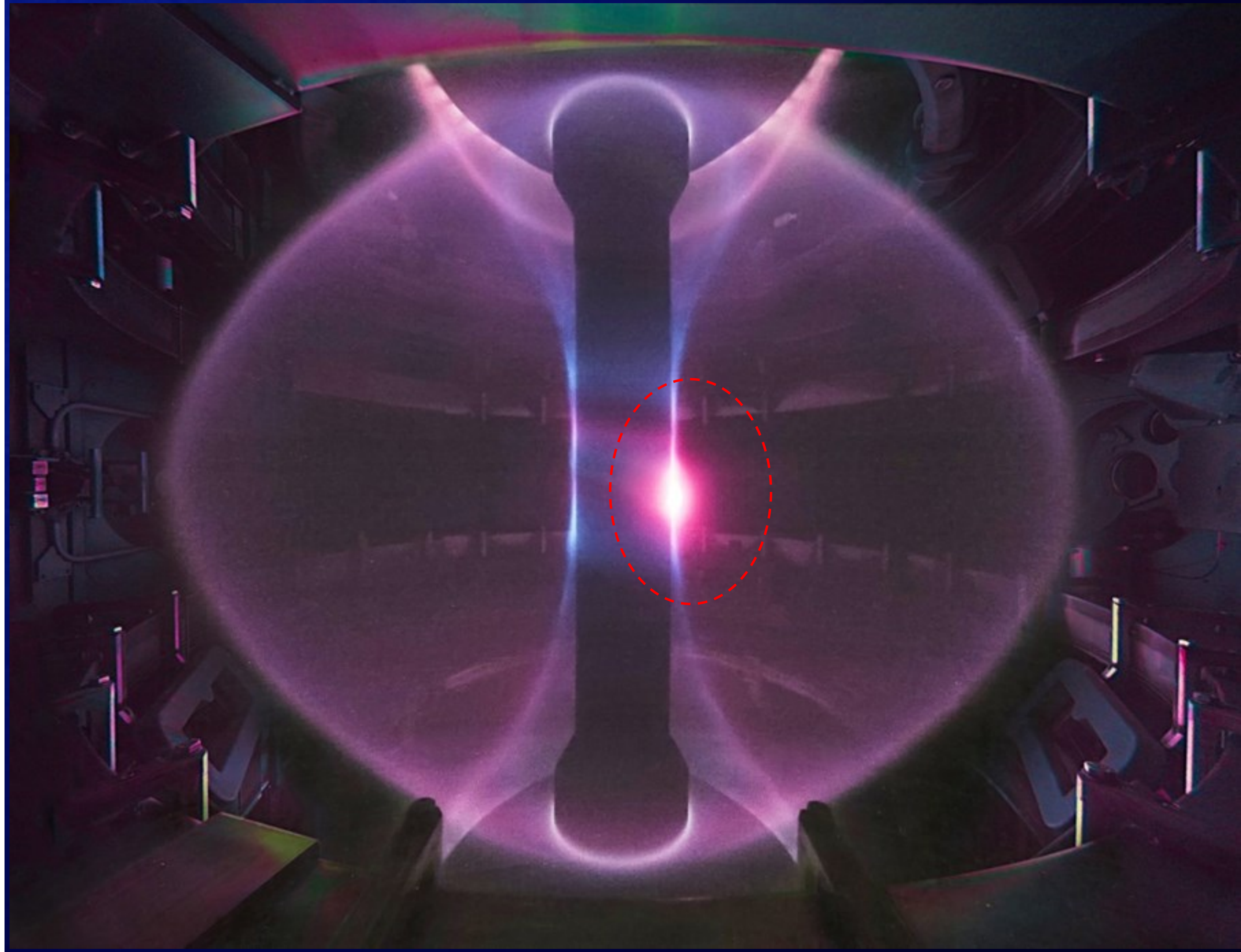
# As the neutral jet cross-section increases, the density and temperature decrease strongly



# A glow discharge occurs in all tokamaks




# Visible imaging also occurs inside tokamaks



# Our Goal:

**Determine the spatial location of the leak inside the tokamak during the Glow Discharge cleaning phase with adequate imaging system and image processing technique**

# The Way

- Spectroscopic measurements in the **visible range** will be conducted during glow discharges.
- The spectra for Air and water leaks will be studied experimentally
- The various lines will feed theoretical models
- The effects of the type of the glow gas will be assessed using Ar and H gas.
- The effects of the discharge parameters (type, power…) on the spectra will be studied.
- Possible seeding elements will be investigated for the water leaks inspired by previous studies.

# Methodology of the leak detection

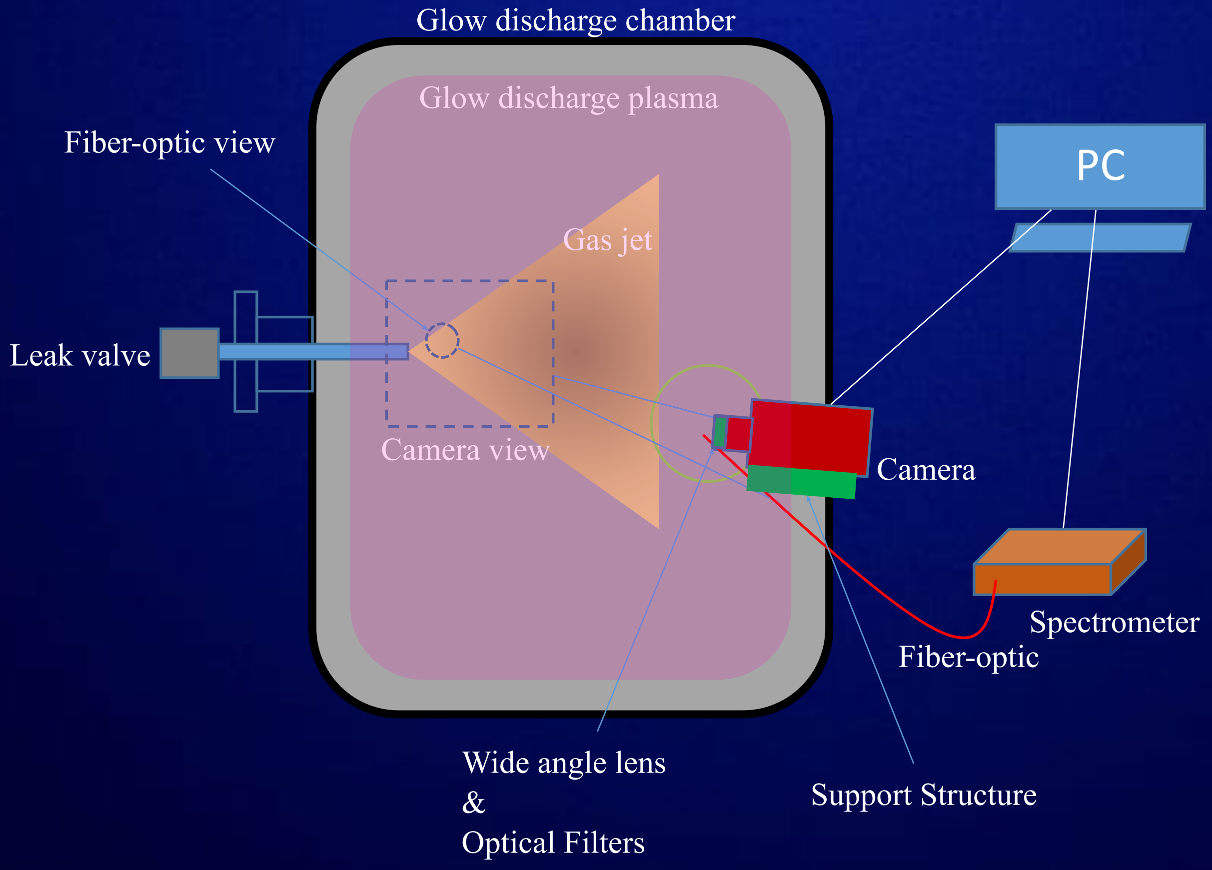
Leaks can be very small and consequently their amount of radiation. This is worsened by the filter(s) presence in front of the camera. To enhance the detectability of these leaks, we propose to proceed in three steps:

1. The use of one or different several filters should also be investigated
   a) **This is to decrease the background light intensity and select the lines that are most emitted.**

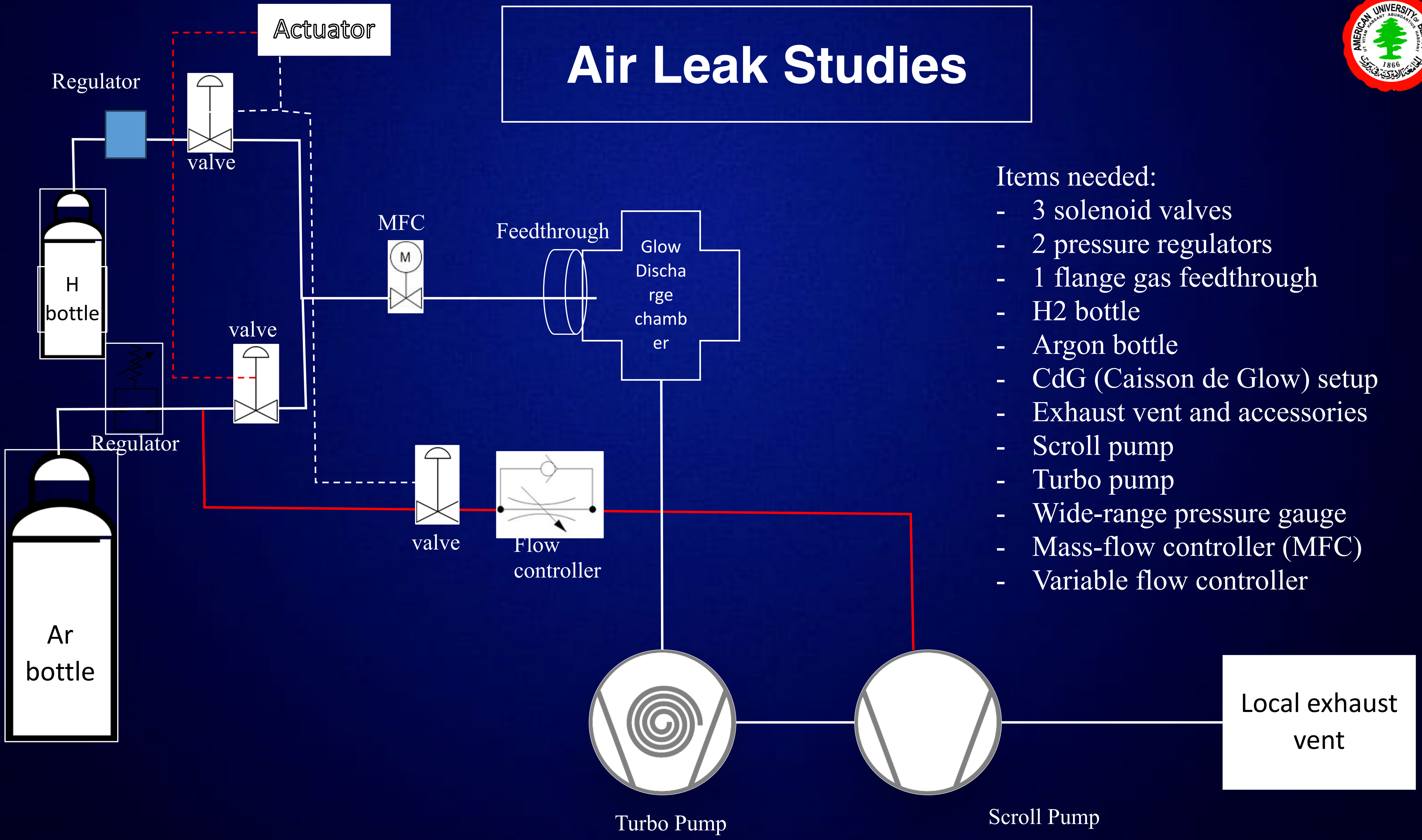
2. Change the integration time of the camera in order to integrate the light coming from the leak and thus enhance its intensity. Since GDCs occur for relatively a long time, this should not be a problem.
   b) **We thus need to determine the dependence of the minimum detectable leak from the light intensity of the camera as a function of its integration time.**

3. Use of adequate yet automated image processing techniques.
   c) **We aim at using the difference in the images between a global source of light and a local one to define the adequate image processing.**

# Schematic of the experiment that simulates water and air leaks in an Ar or H DC glow discharge plasma



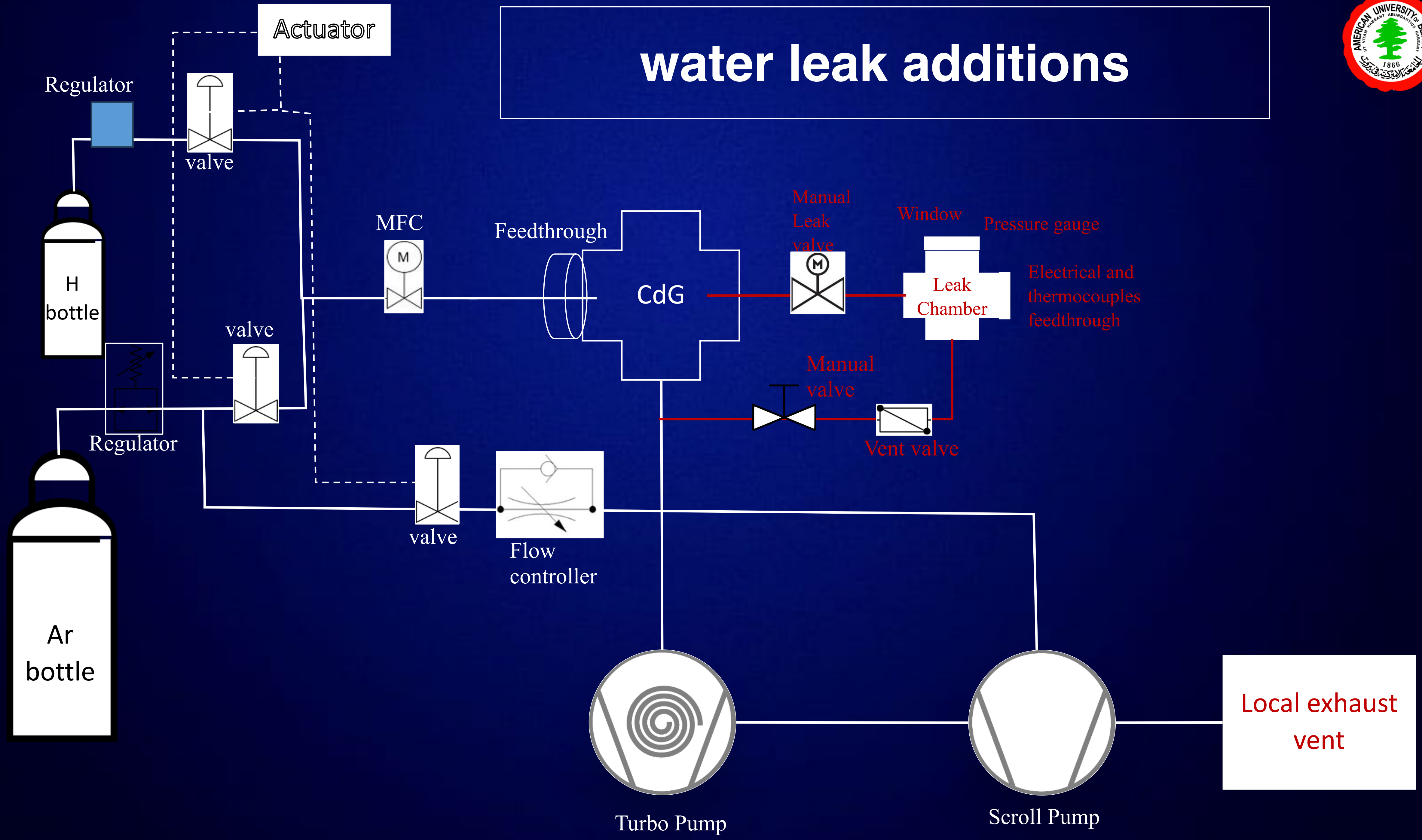
# Air Leak Studies




Items needed:

- 3 solenoid valves
- 2 pressure regulators
- 1 flange gas feedthrough
- H2 bottle
- Argon bottle
- CdG (Caisson de Glow) setup
- Exhaust vent and accessories
- Scroll pump
- Turbo pump
- Wide-range pressure gauge
- Mass-flow controller (MFC)
- Variable flow controller

# water leak additions



# List for the gas and water leaks equipment

- Support structure of the new chamber
- 6-way reducing cross with conflat flanges (DN100CF)
- Conflat-ISO converter flange
- Flexible hose to link the new chamber to the vacuum system
- Window
- Empty flange
- Manual leak valve
- Manual valve
- Vent valve
- Heater element with its controller
- Wide-range pressure gauge

# Water molecules used to enhance emission in the UV range

Nikolai TIMOFEEV*, †, Georges ZISSIS** and Dmitry MIKHAYLOV*, Journal of Science and Technology in Lighting Vol.41, 2017

Under some discharge conditions water molecules give hydroxyl molecules OH that produce very intensive UV emission 306.4 nm. It is shown that regarding all rare gases enhanced emission of the OH 306.4 nm band is registered from the discharge of Ar mixed with water vapor

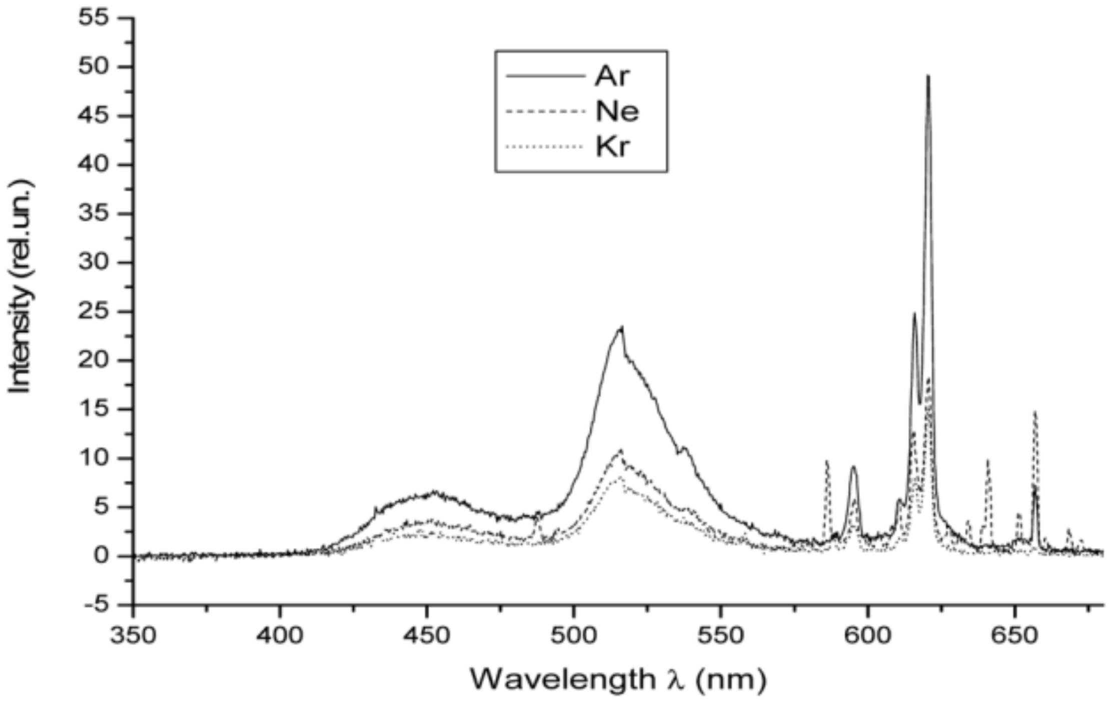
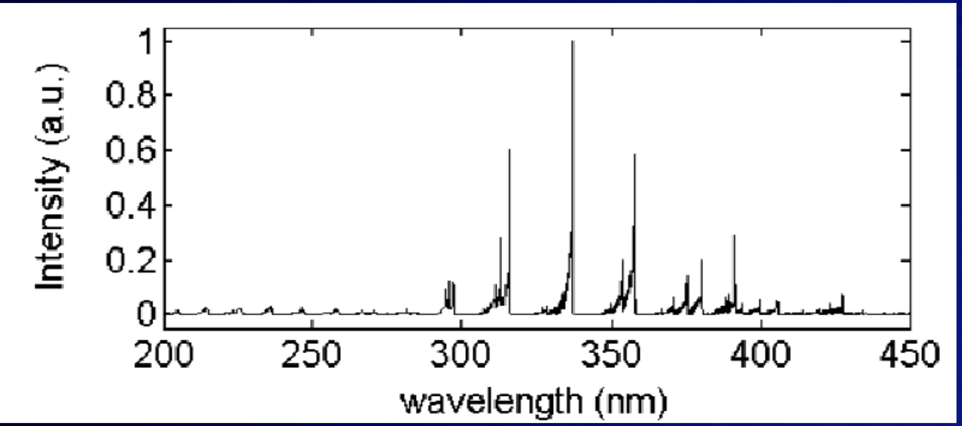
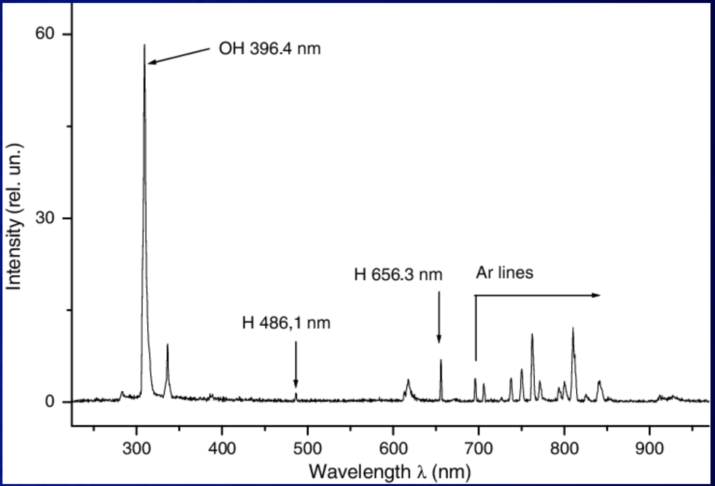


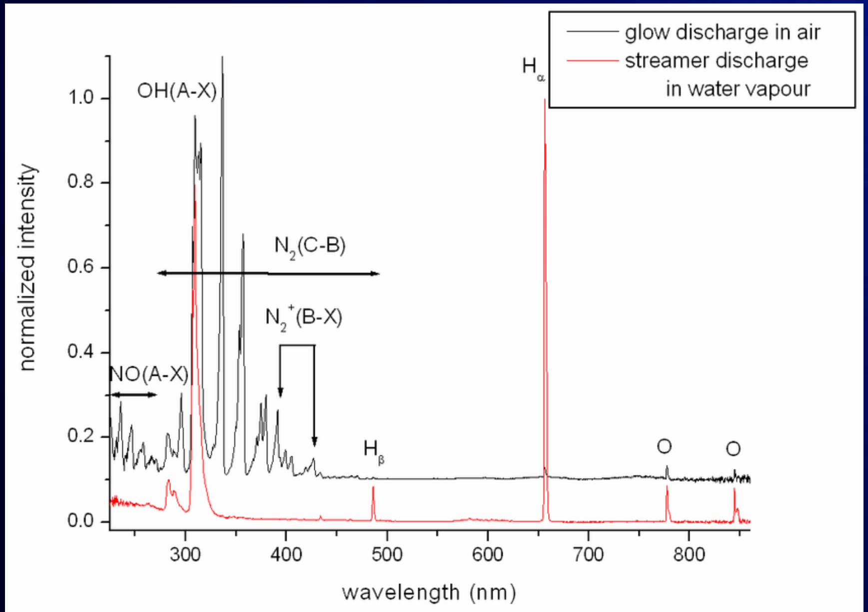

Figure 1 Spectra of the $(Ar+H_2O)$- (solid), $(Ne+H_2O)$- (dash) and $(Kr+H_2O)$-discharge (dot). Tube wall temperature $T$=80°C, pressure of a rare gas $P_{Rg}$=1.0 Torr, electric current $i$=0.3 A.



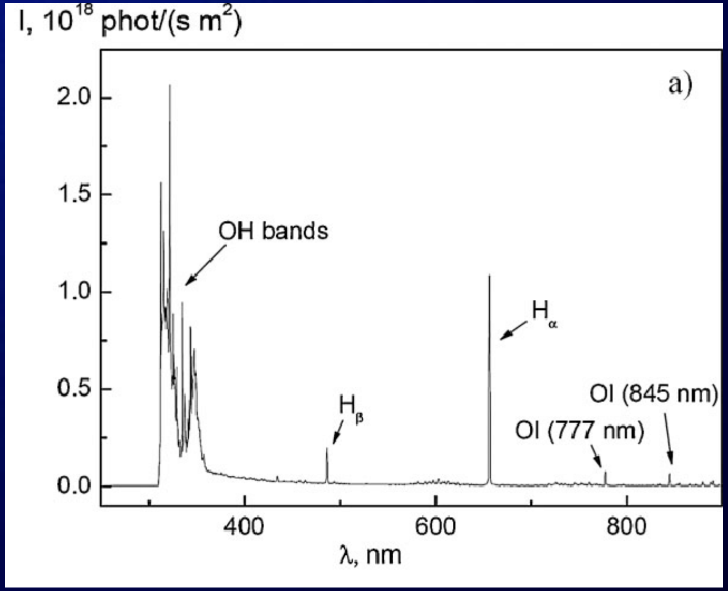

Optical emission spectra from a glow discharge in air by David Staack et al.




The spectrum of an Ar-water vapour discharge in a quartz body. DC regime, $P_{Ar}$ = 1330 Pa, discharge current I = 200 mA, discharge voltage U = 180 V. by N. A. Timofeev et al

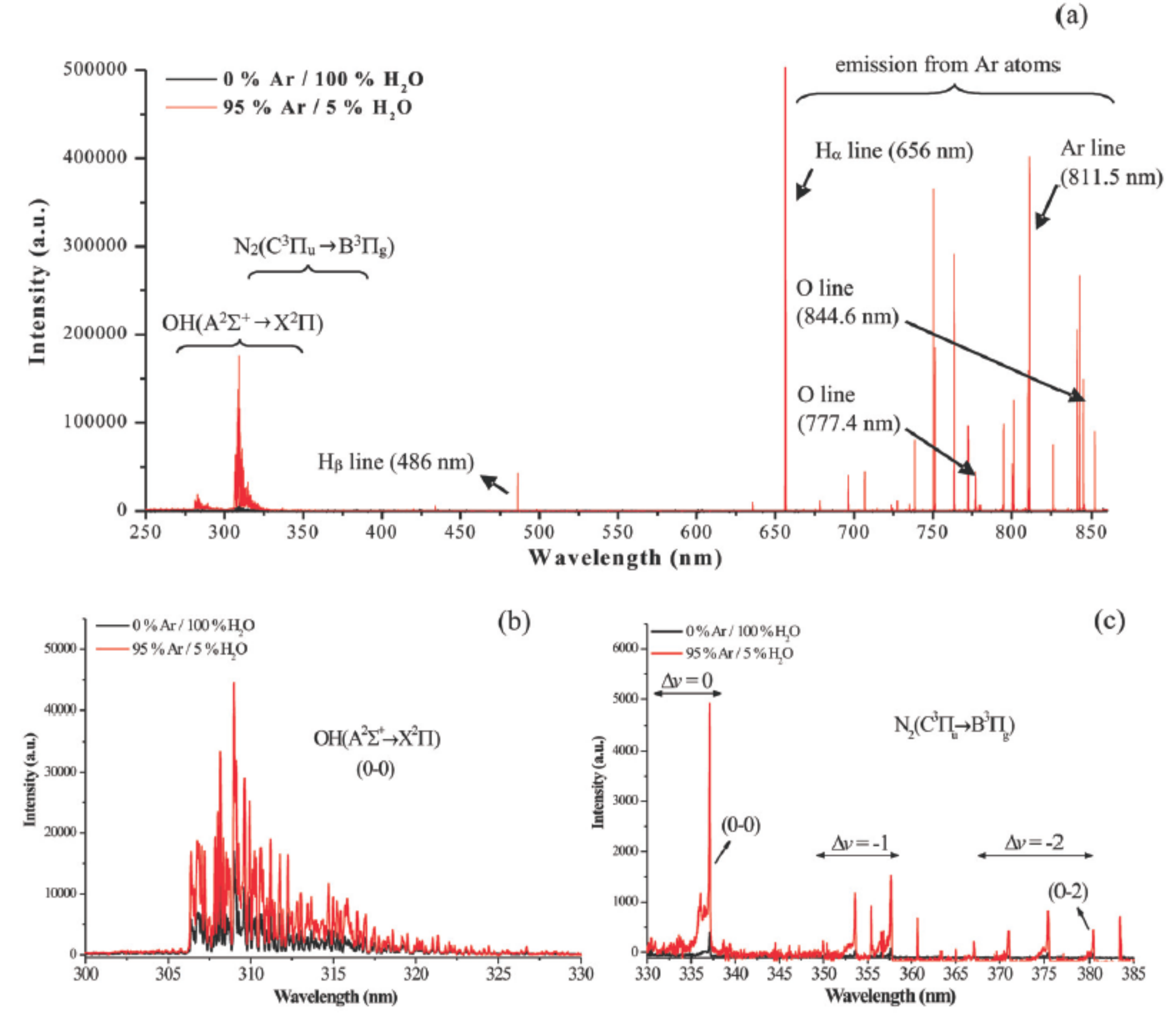



Overview emission spectra of an atmospheric pressure glow discharge in air and a streamer discharge in water vapour by Peter Bruggeman et al.

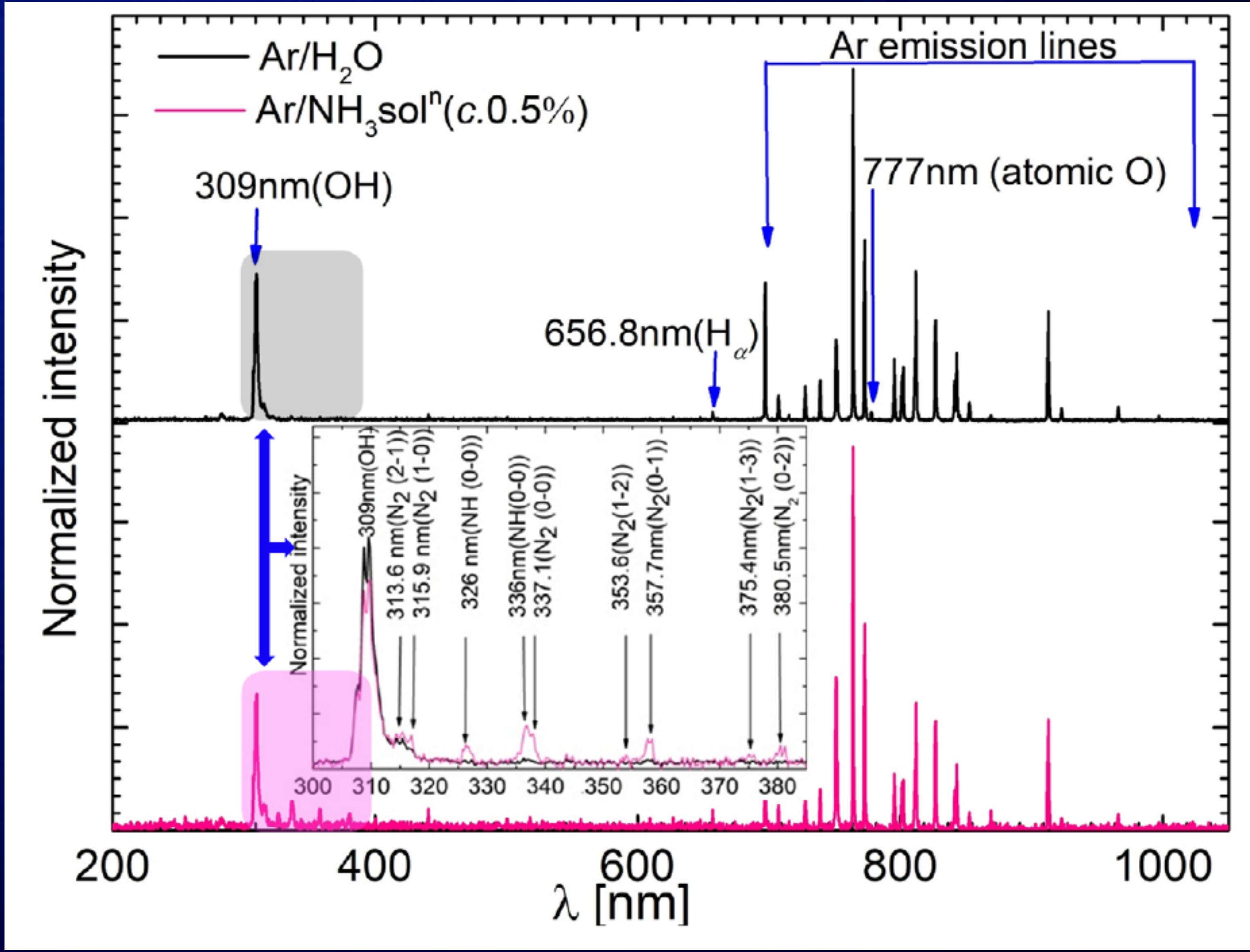



Overview of (a) water-vapor plasma discharge spectrum. V. V. Rybkin et al.

# Emission spectra from Ar/H2O DC plasma discharge



# Normalized OES of the water mixed argon plasma and its comparison with ammonia mixed argon plasma.

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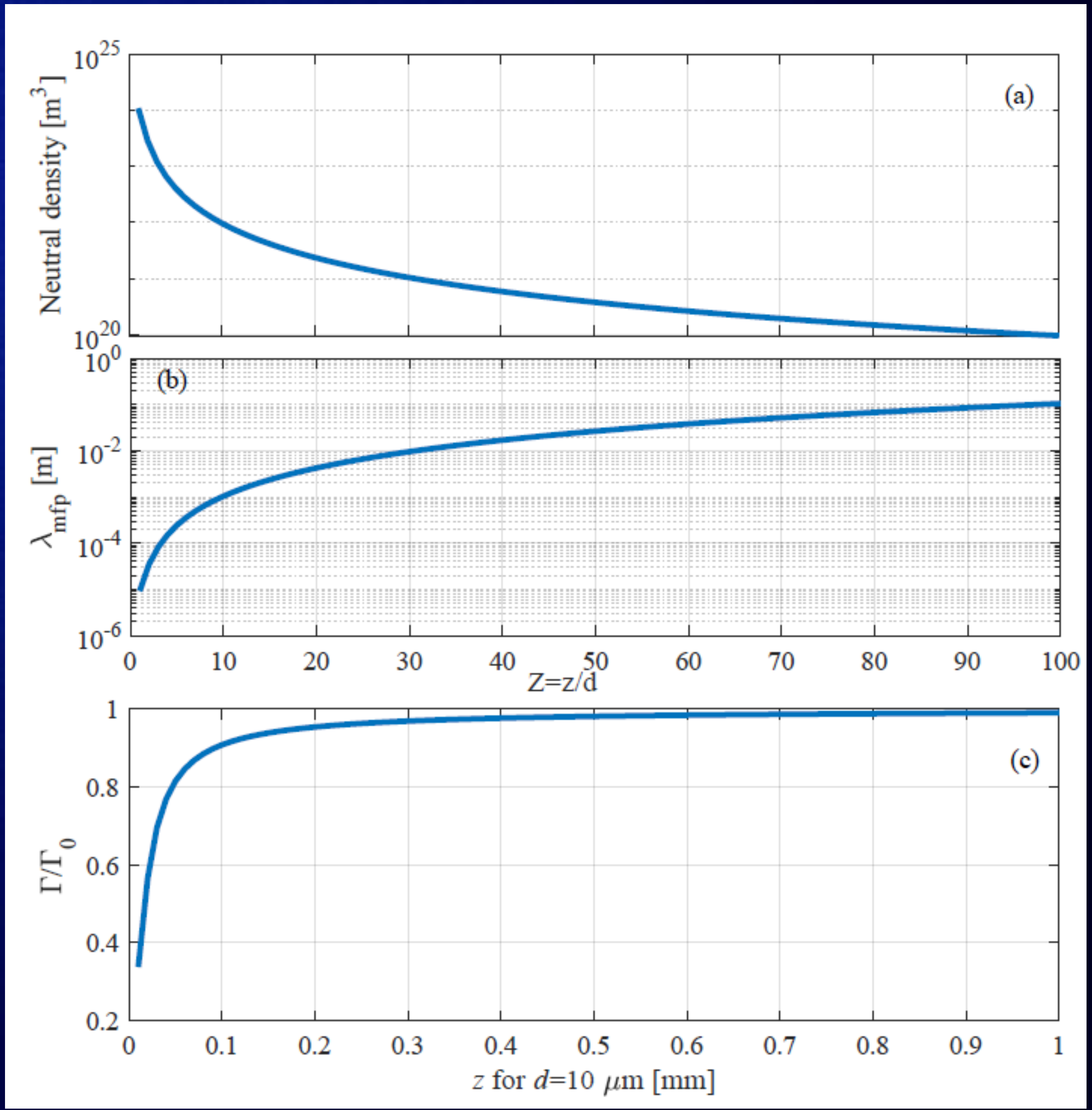
# Simulating the leak properties from a point source

- This means that the gas rapidly spread into the vacuum chamber with density decreasing with the distance to the source.

- This means that the mean free path of electron-neutral collision increases strongly, thus decreasing the possibility to observe the radiation induced by the electron collisions with the molecules.

- The ratio Γ/Γ0 shows that at distances far from 0.1 mm from the leak the electron density is that of the background almost unaffected by its presence.



# Experiments could be done in Polaris linear plasma at AUB for controlled experiments

- Length 3.5 m
- Diameter of the source 6 cm
- Diameter of the vacuum chamber: 30 cm
- Axial Magnetic field <700 G
- RF source + Matching Network <2000 W
- Operation type: steady state

# Research Plan AUB+CEA+ITER

| | Task description |
|---|---|
| Task 1 | Identification of hardware and procurement of hardware |
| Task 2 | Development of methodology to calibrate the leak valve |
| Task 3 | Assembly, commissioning and testing of the experimental setup |
| Task 4 | Spectroscopic measurement and filter selection (use Ar then H GDC) |
| Task 5 | Camera integration time optimization study |
| Task 6 | Development of data processing approach |
| Task 7 | Test on simulated leaks |

# Hope