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About Gas Fluxes in the Subsurface and Sampling: from Science to Technology

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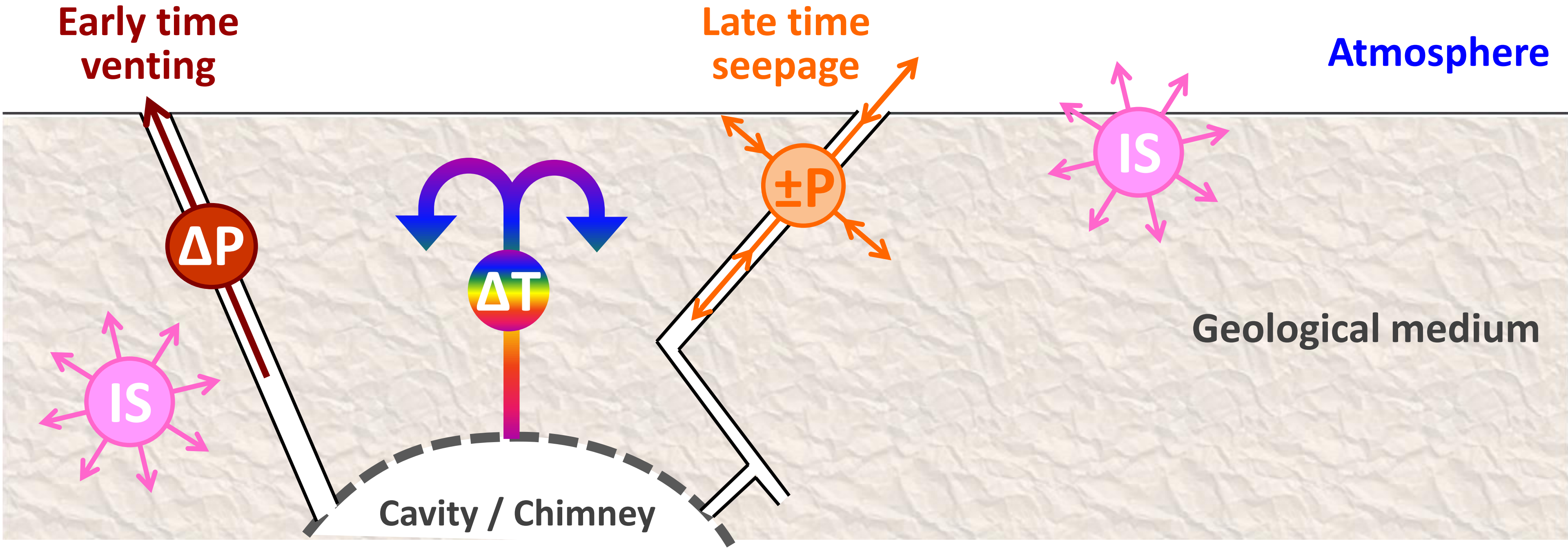
Expected Gas Fluxes following an Underground Nuclear Explosion

Remote Detection by International Monitoring System (^{131m}Xe, ^{133}Xe, ^{133m}Xe, ^{135}Xe)

Local Detection by On-Site Inspection (^{37}Ar)



ΔP Cavity gas advection in fractures along **Overpressure Gradient**

ΔT Cavity gas migration along **Thermal Gradient with phase change**

±P Cavity gas advection-diffusion in fractured porous media by **Barometric Pumping**

IS **In-situ Gas Production:** ^{37}Ar by neutron activation

See also: SnT17 Poster T1.3-P8 Pili et al.

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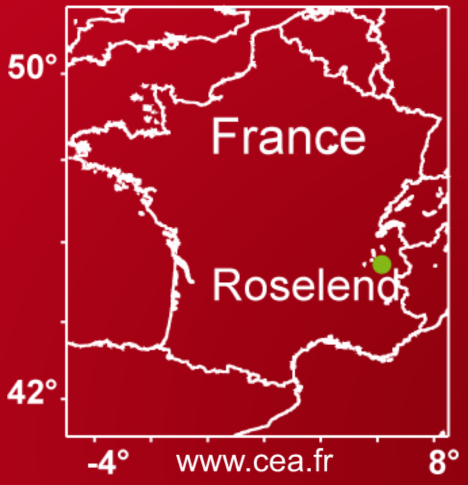
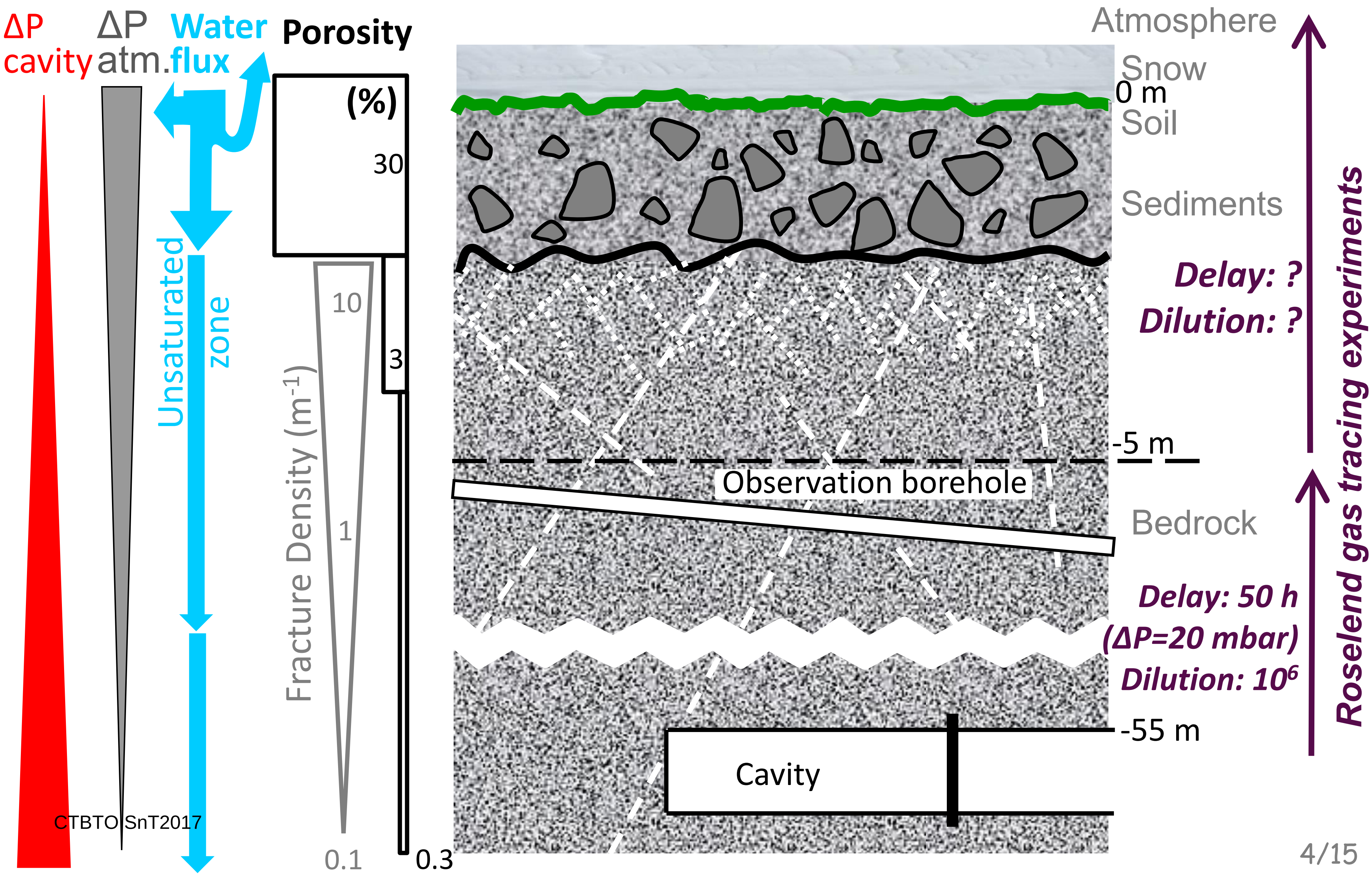
Gas fluxes at the Ground Surface?

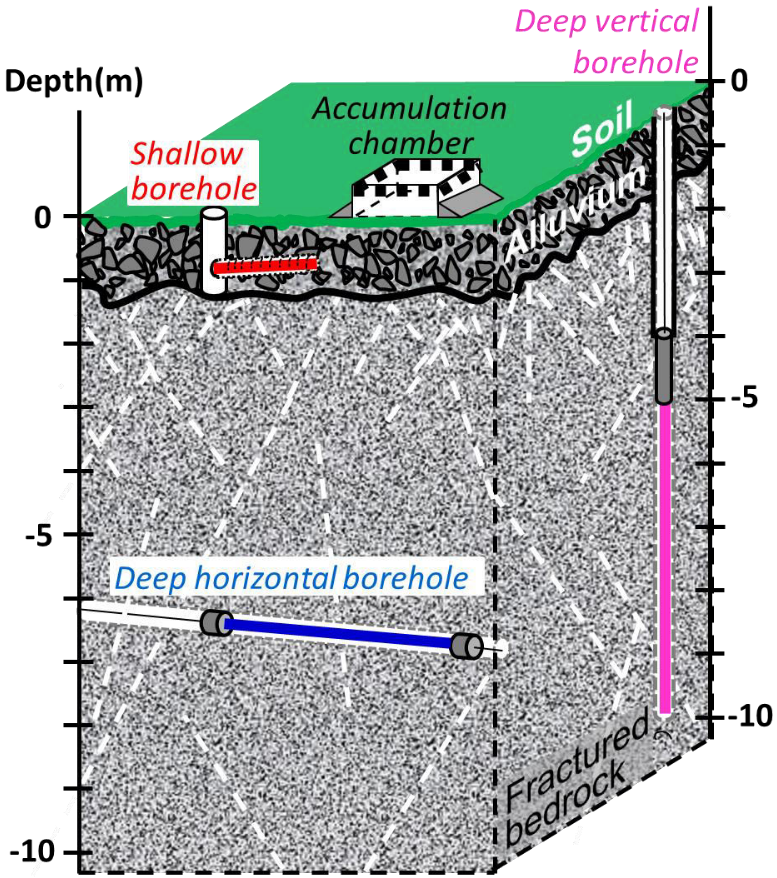


Provost et al. (2004)

Earth is a Complex System, Complexity Increases towards the Surface



Equipment for Subsurface Gas Monitoring at the Roselend Natural Laboratory

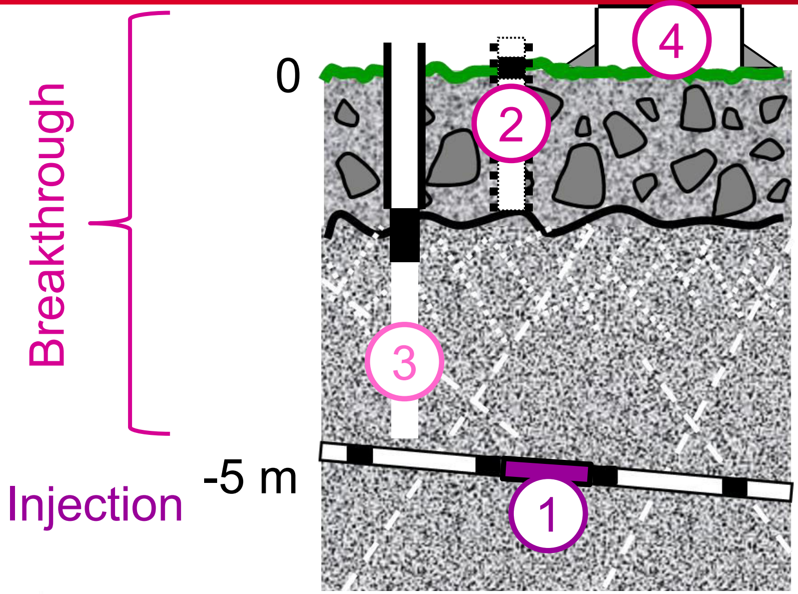


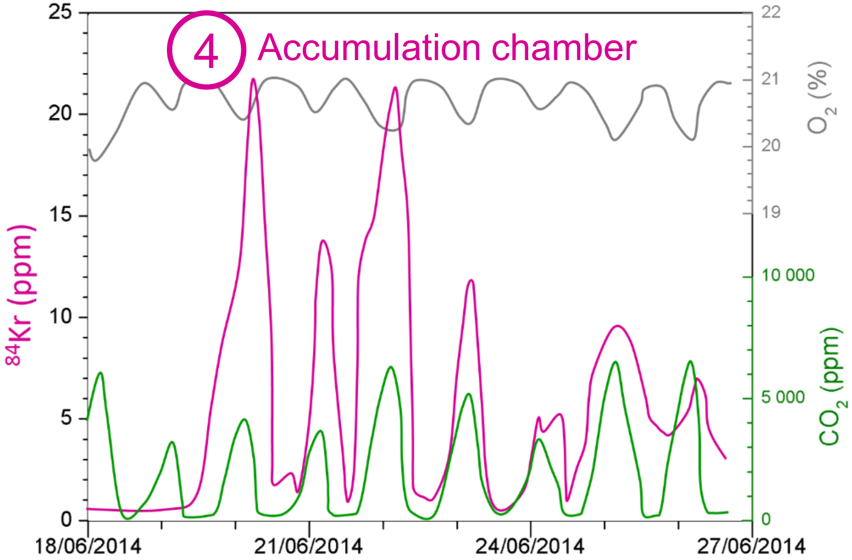
✓ Monitoring of gas concentrations from:
- Accumulation chamber at the ground surface,
- Packed-off boreholes at various depths (porous vs. fractured media).

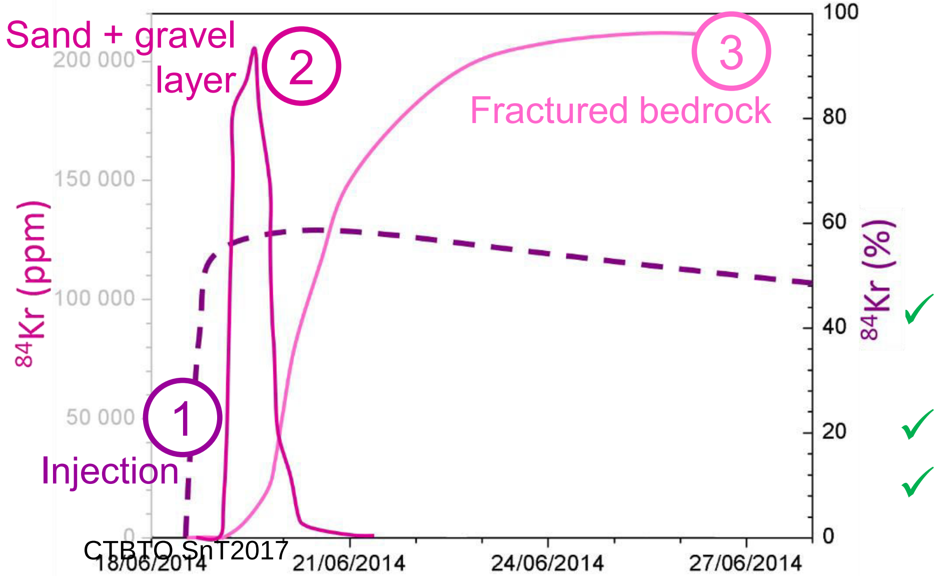
✓ Magnetic-sector mass-spectrometer (Thermo Prima Pro) for continuous, on-line, multi-gas analyses, including atmospheric heavy noble gases (Kr, Xe)

Guillon, S., Gréau, C., Pili, E., 2016. Continuous Monitoring of the Vadose Zone Gas Phase by Mass Spectrometry. Vadose Zone Journal, 15(8): 6.

Subsurface Tracing Experiment with Krypton



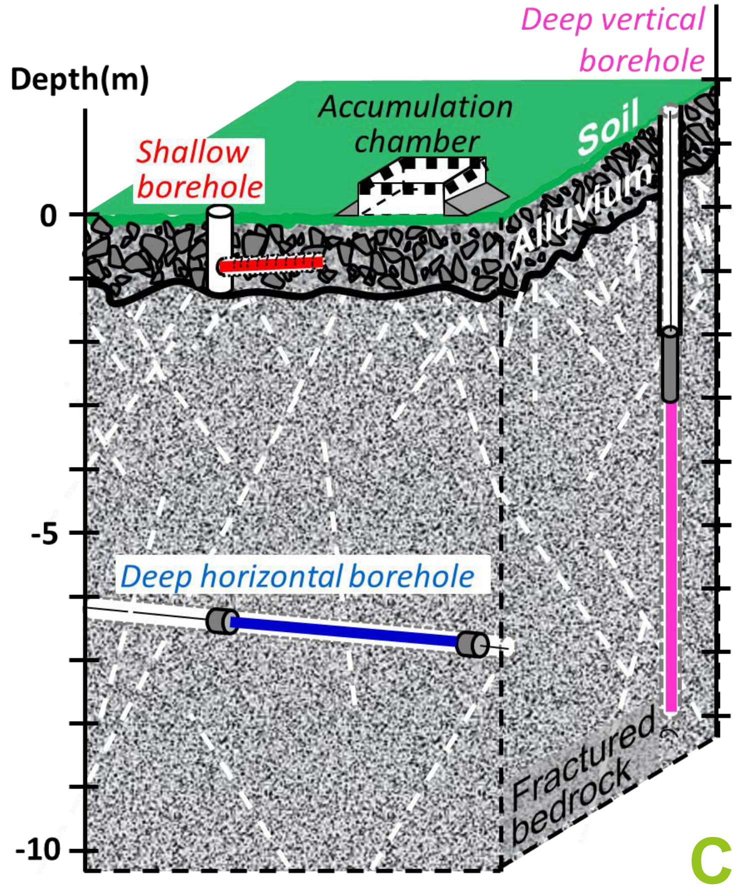


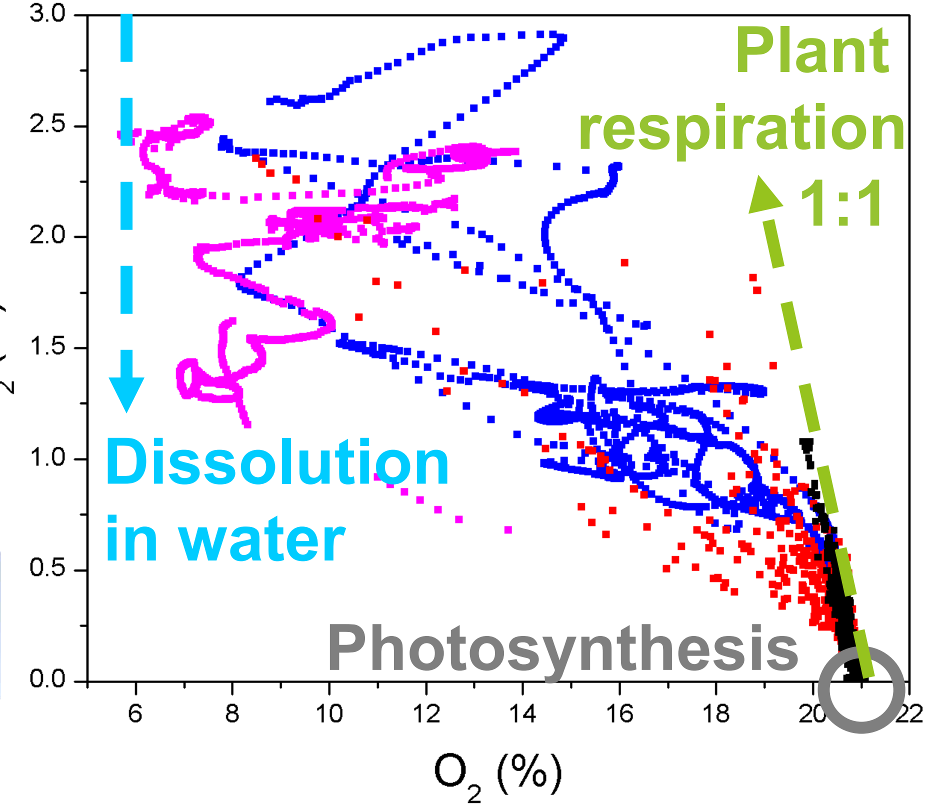


Tracer	Kr
Detect. limit (ppm)	1
Dilution	10^3
First apparition (h)	2-30

- ✓ Multiple paths in porous media & selectivity of percolating fracture networks in bedrock.
- ✓ Surface ventilation by the atmosphere.
- ✓ Kr signal at the surface controlled by plant respiration & photosynthesis.

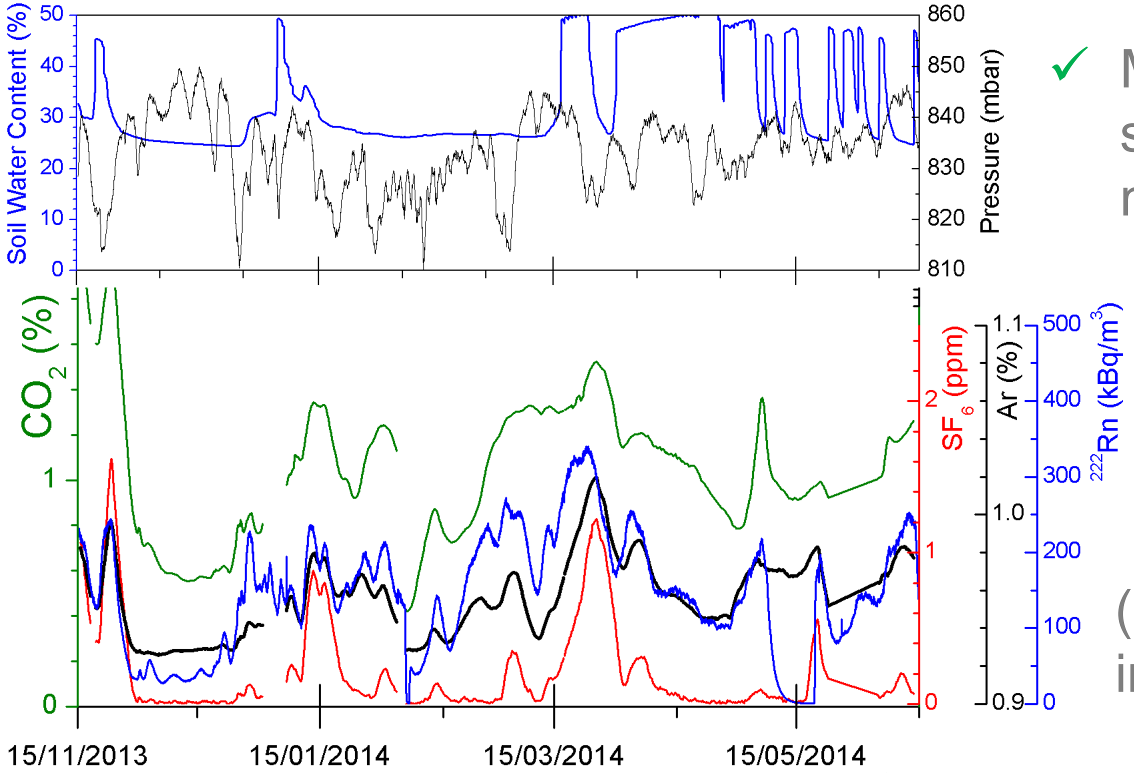
Dynamics of CHON Gas Species: Biogeochemical Reactions Drive Gas Migration





- ✓ **Respiration** (organic matter degradation) + **differential dissolution** of gas species = biogeochemical reactions, control partial pressures of CHON gases, hence pressure and concentration gradients that drive migration of all gas species, incl. noble gases.

Naturally-Occurring Gas Species, Pressure and Water Controls on Gas Flux



- ✓ Monitoring of various gas species in a borehole (5-10 mbgl).

(SF_6 injected 2.5 years earlier in the cavity 50 m underneath)

- ✓ Naturally occurring gas species: **proxies easy to monitor** vs. ^{37}Ar or ^{133}Xe.
- ✓ **Atm. pressure** fluctuation & **precipitations** (rainfall, snowmelting) control gas fluxes

- ✓ **Water** especially important**:**
  - ✓ **Isolation** from the atmosphere (O_2),
  - ✓ **Stimulation** of biogeochemical reactions,
  - ✓ Differential **dissolution** of gas species
  - ✓ Gas displacement by **piston effect**,
  - ✓ Control on **^{37}Ar background.**

See also: Guillon, S. Sun, Y., Purtschert, R., Raghoo, L., Pili, E., Carrigan, C.R. 2016. Alteration of natural ^{37}Ar activity concentration in the subsurface by gas transport & water infiltration. Journal of Environmental Radioactivity, 155–156: 89-96.

Sampling Gas Fluxes at the Surface by Means of Tarps: Then and Now

Before

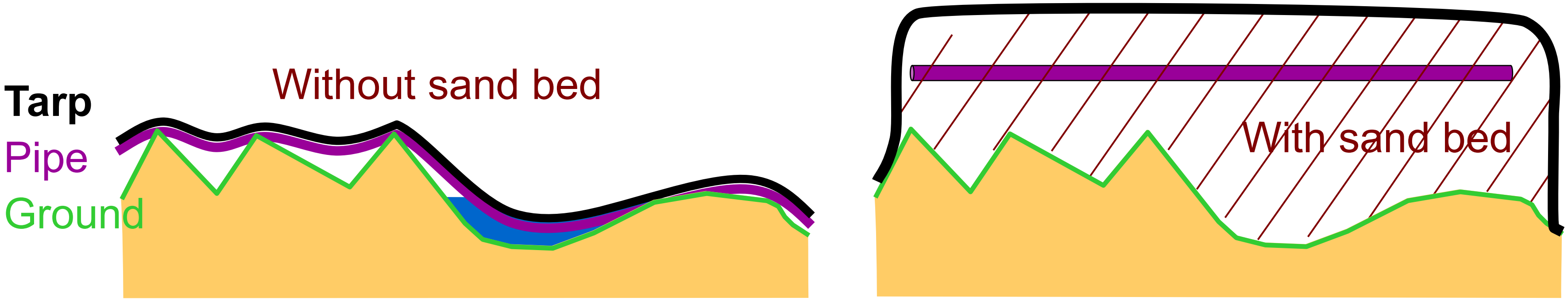
Pipe directly on ground

After

Sand bed + pipe

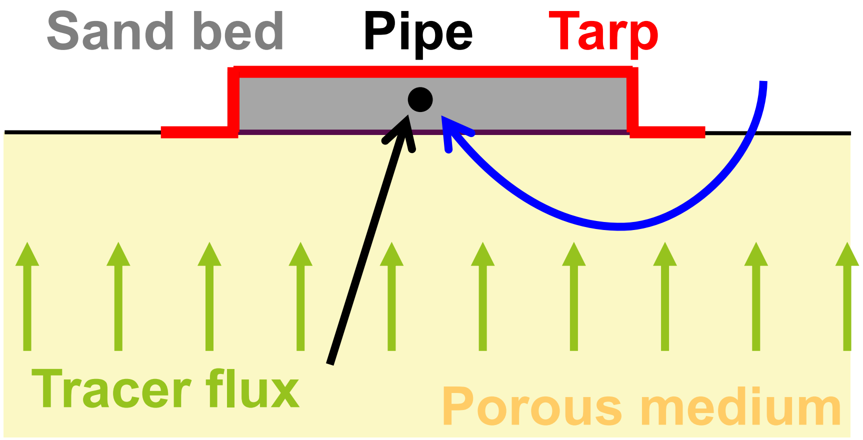
Pipe sandwiched in sand bed + tarp

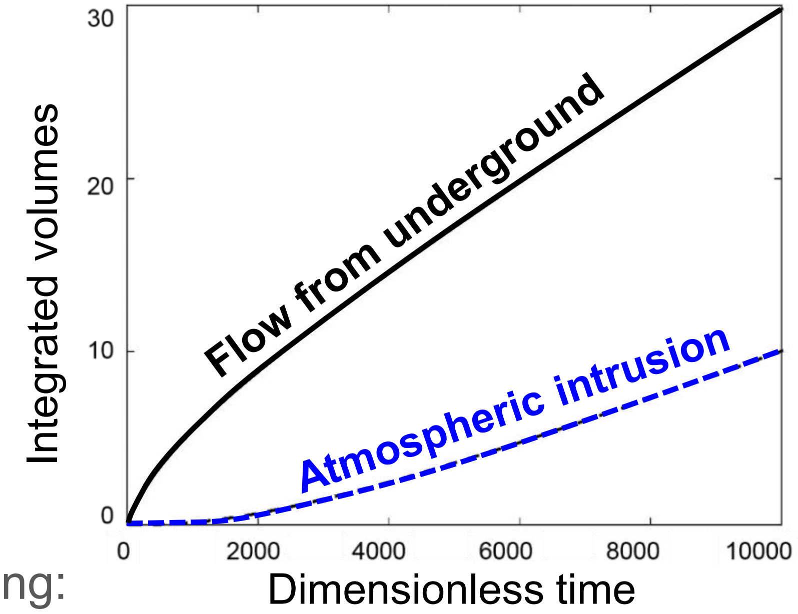
Multiple Advantages of Tarp with Sand Bed



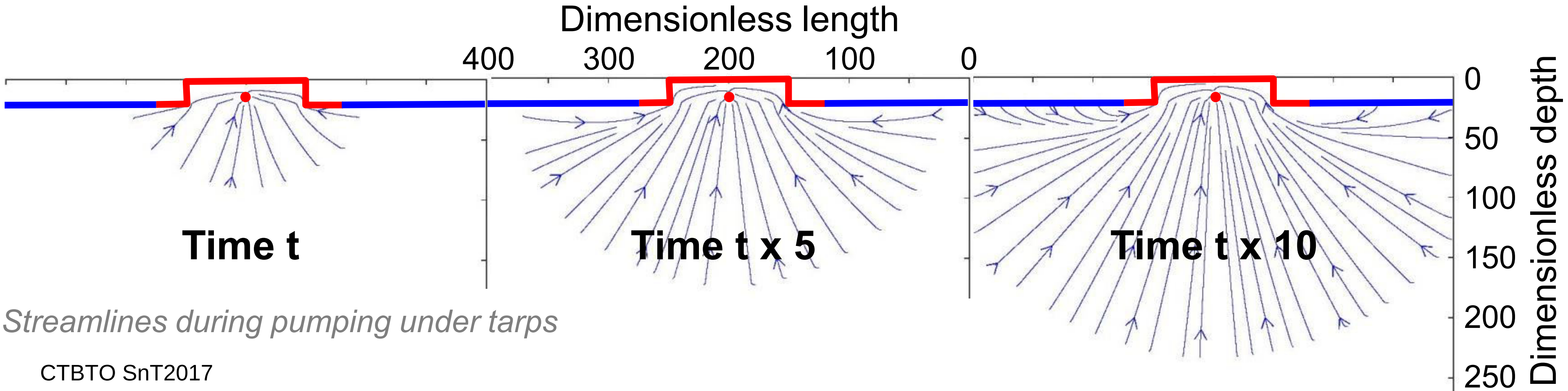
- ✓ **Sand bed ensures:**
  - ○ **mechanical protection** (surface roughness, operator steps, wildlife),
  - ○ **thermal protection** against overnight freezing,
  - ○ better control on runoff water, **no water around / in the pipe,**
  - ○ **continuity of porous media** from natural ground to pipe,
  - ○ **inertia** of sand porosity:
    - **increased persistence** of signals (less chance to miss signal),
    - **limited ventilation** and dilution (wind or atm. pressure fluctuations).
- ✓ **Equivalent to a borehole without drilling:**
  - ○ cheaper, faster, longer pipe length than with a borehole
- ✓ **Sand available anywhere:**
  - ○ Typically: 5 x 5 x 0.2 m^3 = 5 m^3 ~ 9 tons (1.5 m^3 of storage porosity).

Model-based Optimization of Gas Sampling using Sand Bed + Pipe + Tarp





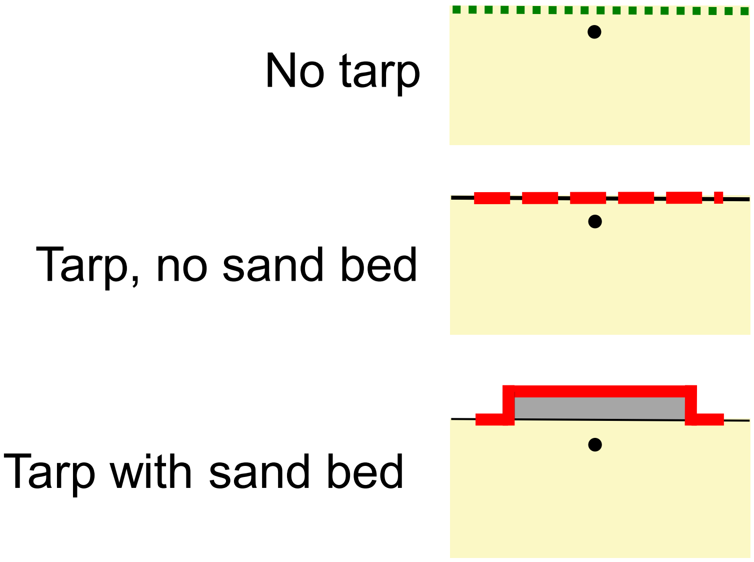
- ✓ Minimize atmospheric intrusion during sampling: Influence of tarp, sand and pumping parameters?

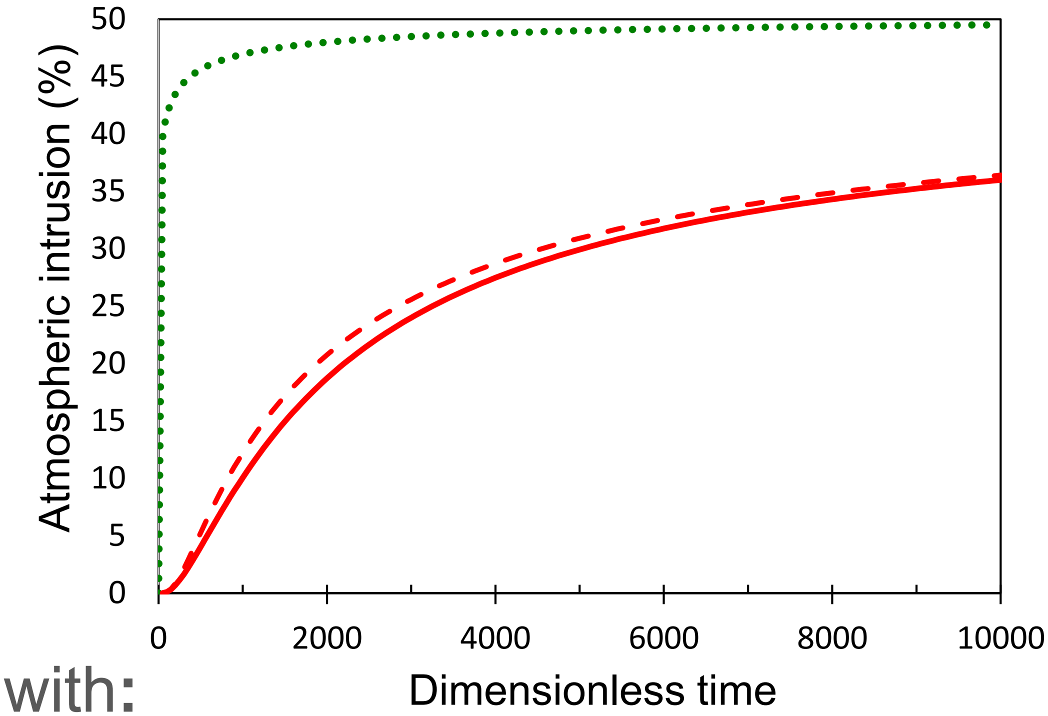


Streamlines during pumping under tarps

Pili E. and P. M. Adler (in prep.)

Optimizing Subsurface Gas Sampling with Tarps





- **Best efficiency** obtained with:
  - ✓ **Tarp + sand bed,**
  - ✓ **Pipe within sand** bed,
  - ✓ Pumping at **low flowrate for longer time**,
  - ✓ Waiting for gas flux to **accumulate** in sand bed before pumping
  - ✓ **Model-based optimization** of Sand + Tarp + Pipe parameters.

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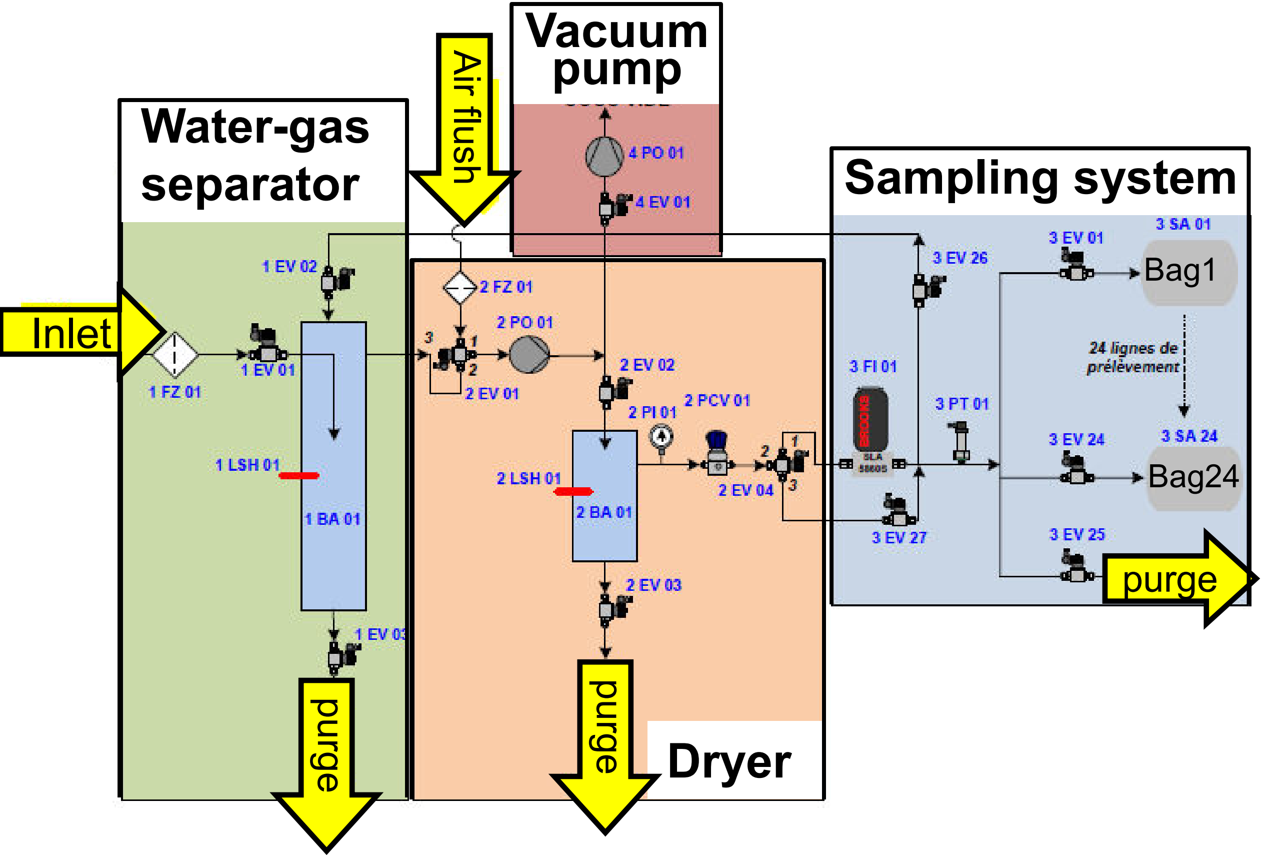
Pili E. and P. M. Adler (in prep.)

Controlled & Reliable SubSurface Air Sampler: the CoRSSAir system

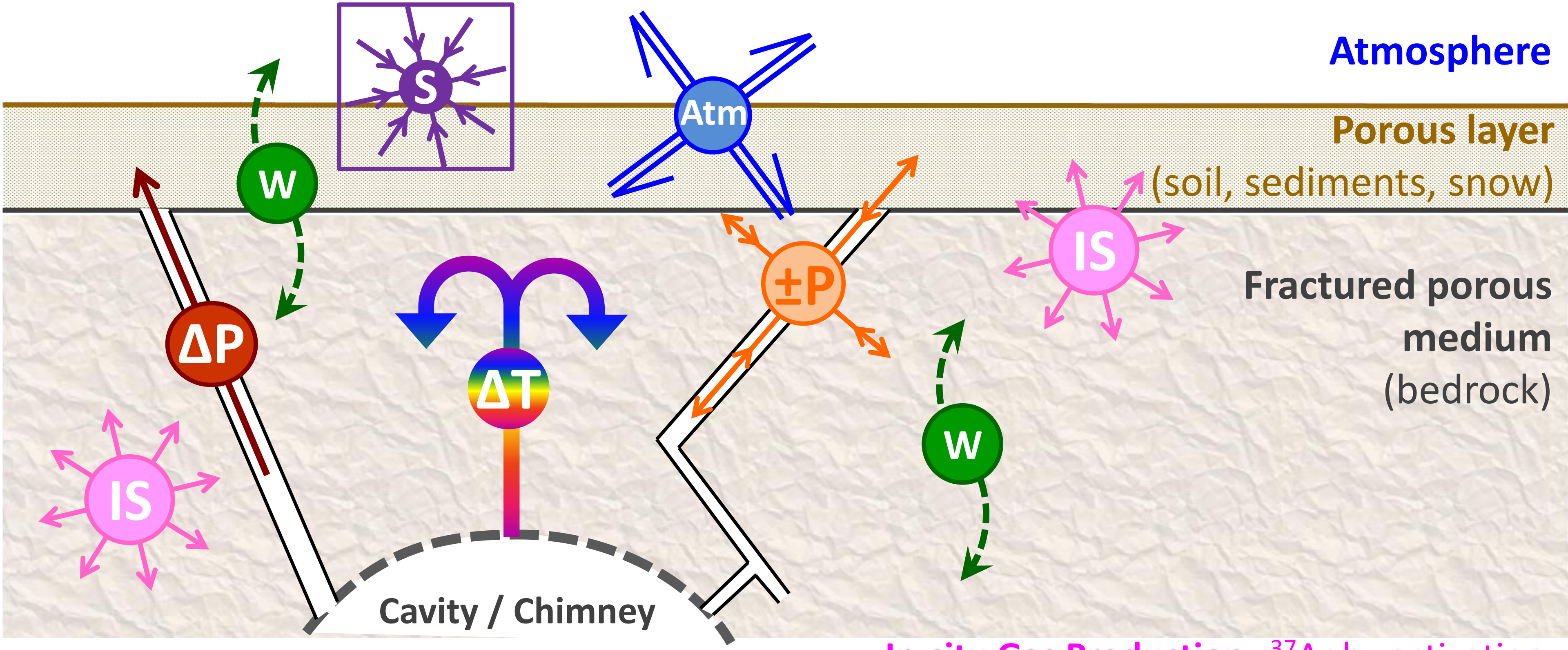


24 VDC, Ethernet, 40 kg

The CoRSSAIR sampler handles:

- ✓ **Fully automated** sampling and preparation cycles,
- ✓ **Water at inlet** and humid gas,
- ✓ **Low to no flow** from sampled boreholes,
- ✓ **Sample integrity** (water purge, air flush, vacuum, leak test).

Summary: More Complete Picture of Gas Fluxes in the Subsurface



ΔP Cavity gas migration in fractures along **Overpressure Gradient**

ΔT Cavity gas migration along **Thermal Gradient with phase change**

±P Cavity gas migration in fractured porous medium by **Barometric Pumping**

IS **In-situ Gas Production:** ^{37}Ar by activation, spontan. fission Xe, ^{222}Rn from U-series, CHON gases by biogeochemical reactions

W **Water piston effect**

Atm **Ventilation & Exchange** with atmospheric gas species

S **Pumping** by sampling device

Conclusion: Gas Fluxes in the Subsurface Need to be Understood as a Whole

- **Large diversity of gas fluxes in the subsurface:**
  - ✓ Variety of **gas sources**, including naturally occurring ones,
  - ✓ Variety of **migration mechanisms** and **driving forces**.

- **Numerous controls on gas fluxes in the subsurface:**
  - ✓ Atmospheric **pressure fluctuations**,
  - ✓ **Water** (rainfall, snowmelt, evaporation…): **displacement + dissolution**

- **Chemistry is as important as Physics:**
  - ✓ **Biogeochemical reactions** control advection-diffusion of all RN gases,
  - ✓ Naturally occurring gas species **proxies** for RN gas of interest.

- **Improved techniques validated in the field:**
  - ✓ **Optimized tarping** with **pipe sandwiched in a sand bed,**
  - ✓ **Continuous on-line analysis** of multiple gaseous species,
  - ✓ **Controlled and Reliable SubSurface Air sampling** (CoRSSAIR).

- **Relevant not only for OSI but also for IMS as well as testbed experiments carried out at the Roselend Natural Laboratory, NNSS, IFExx.**

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