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Muriel Joly, Mariline Theveniot, Frédéric Mathonat, Raphaëlle Peguilhan, Florent Rossi, et al..
Twenty years of elucidating diversity and function of cloudborne microorganisms: from lab studies to
biotechnological applications. *Microbes* 2024, Oct 2024, Lille, France. hal-04858048

HAL Id: hal-04858048

<https://hal.science/hal-04858048v1>

Submitted on 29 Dec 2024

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Twenty years of elucidating diversity and function of cloudborne microorganisms: from lab studies to biotechnological applications

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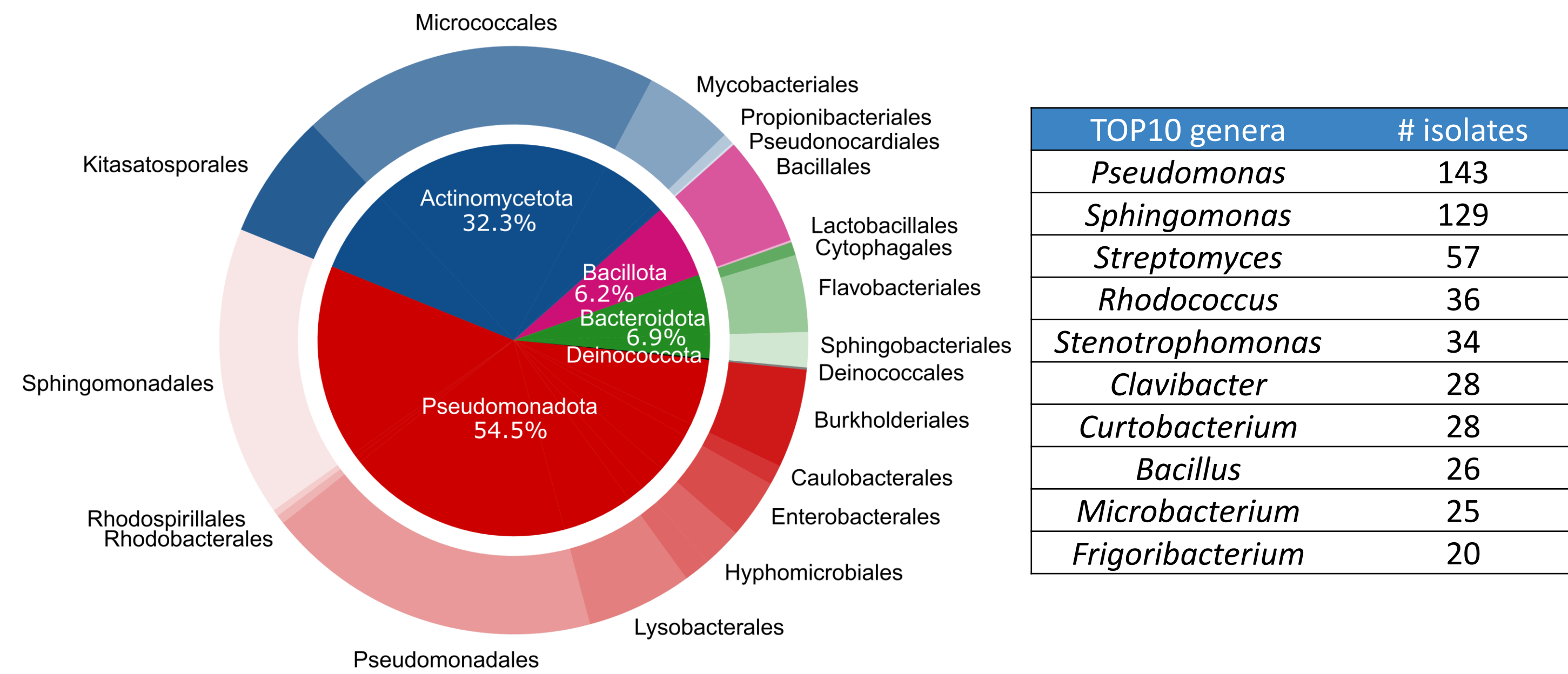
Contact: muriel.joly@uca.fr



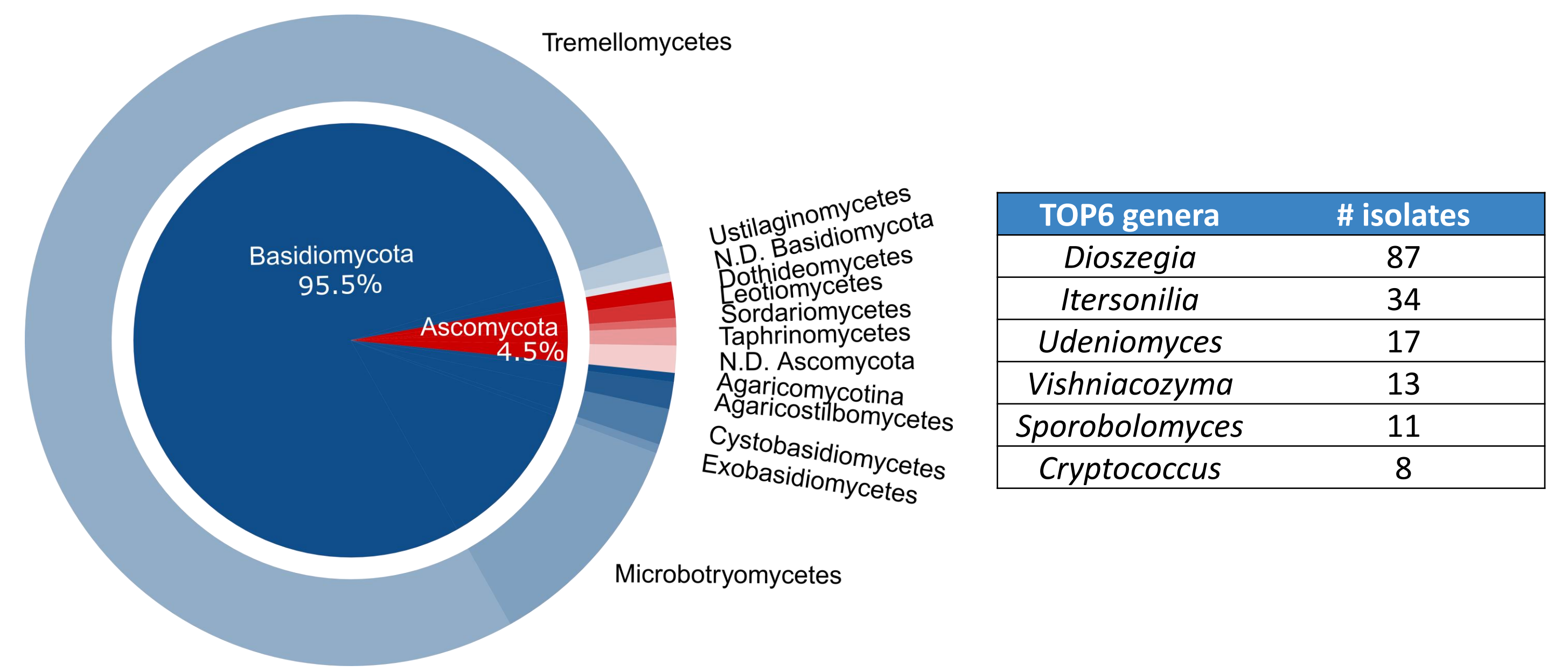
Microbial diversity in the ICCF cloudborne culture collection

- **827 bacterial strains and 223 fungal strains** were isolated from cloud water sampled at the top of the puy de Dôme (Auvergne) or the Maïdo (Reunion island, Indian ocean) mountains to form a **unique culture collection**

Bacteria

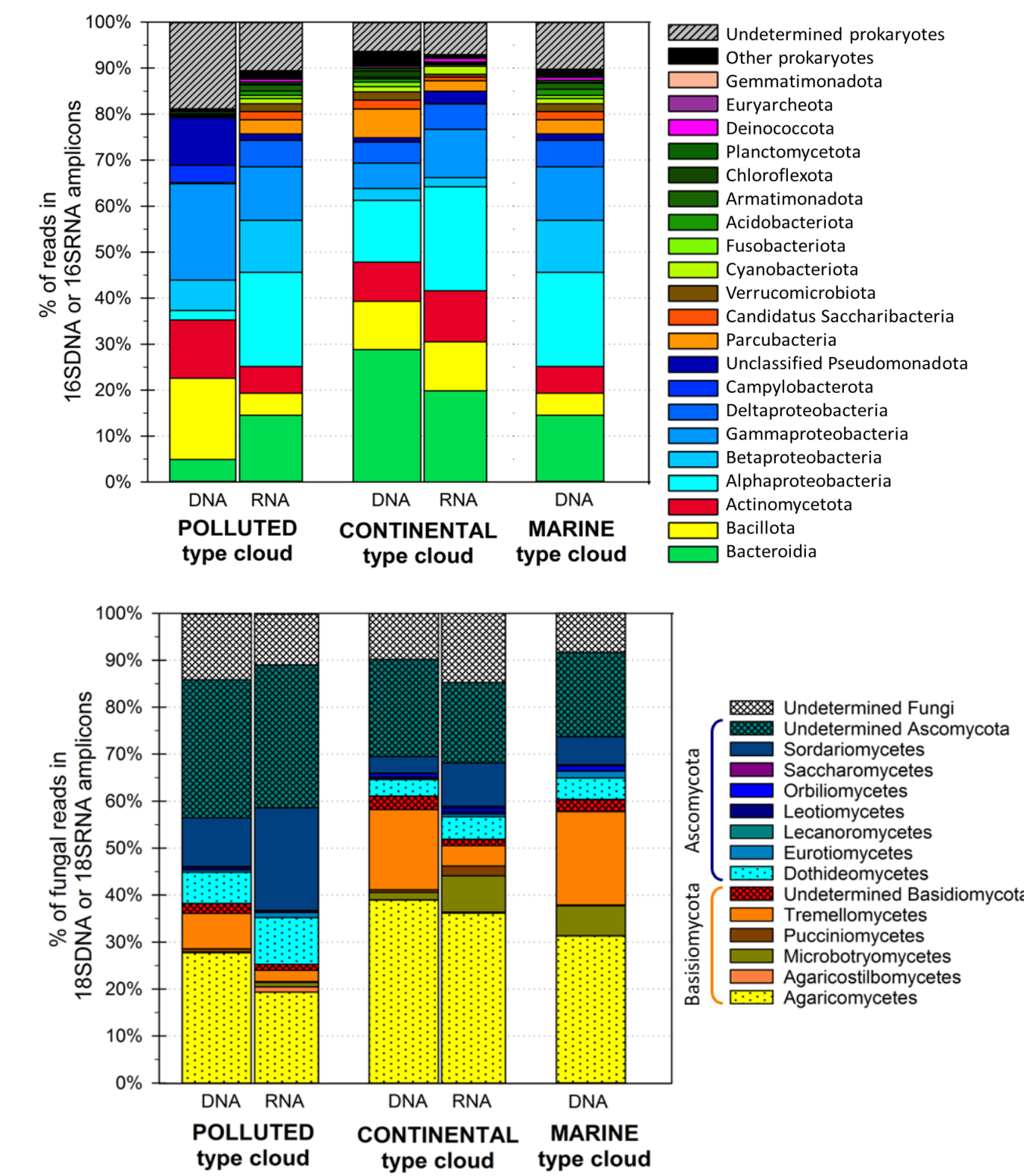


Fungi



Metabarcoding of total and active communities

- Cloud water is a rich environment with > 28 000 OTU_{97%} for bacteria and > 2600 OTU_{95%} for fungi
- Pseudomonadota and Bacteroidota phyla dominate total prokaryotic community while Ascomycota and Basidiomycota dominate fungi community
- Active orders (based on 16S or 18S rRNA) comprise Sphingomonadales, Rhodospirillales, Hyphomicrobiales, Burkholderiales and Pseudomonadales for prokaryotes



Updated from Amato et al., PlosOne (2017) doi.org/10.1371/journal.pone.0182869



Cloud water, a source of undescribed species

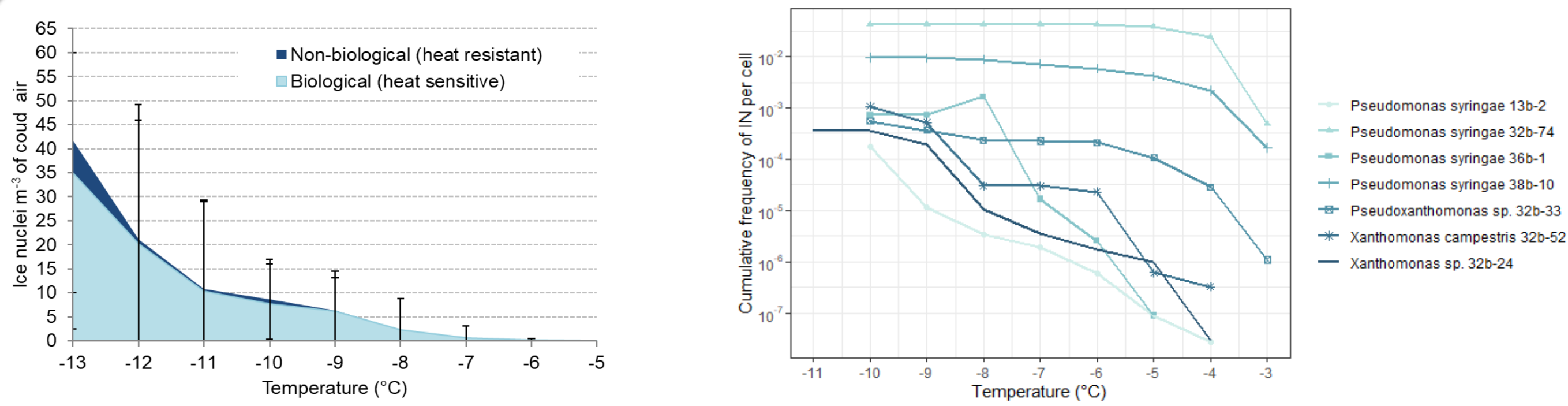
- ~ 1% of bacterial isolates share < 97% of identity with the closest type strain rDNA 16S sequence
- ~ 4% of yeast isolates share < 97% of identity with the closest type strain rDNA 18S sequence and ~3% have < 95% of similarity with their closest neighbor)
- **Cloud water is poorly explored for its biodiversity and potentially contains new species never described before**

Strain identifier	Most probable affiliation	Maximal percentage identity (16S/18S rDNA)
MAIDO-R6b-21	Micrococcaceae bacterium	96.7%
PDD-58b-27	<i>Flavobacterium</i> sp.	96.0%
PDD-23b-17	<i>Hymenobacter</i> sp.	96.6%
PDD-54b-11	Hymenobacteraceae bacterium	96.3%
PDD-69b-30	Burkholderiales bacterium	96.5%
PDD-70b-11	Burkholderiales bacterium	96.7%
PDD-26b-32	Leotiomyces yeast	96.9%
PDD-23b-2	Sordariomycota yeast	93.9%
PDD-77b-8	Agaricomycotina yeast	93.8%
PDD-33b-4	Microbotryomycetes yeast	95.6%
PDD-26b-29	Pucciniomycotina yeast	93.5%
PDD-24b-25	<i>Itersonilia</i> sp.	93.5%
PDD-26b-11	Tremellomycetes yeast	94.7%
PDD-77b-14	Tremellomycetes yeast	92.2%

Unpublished data - BlastN against nr/nt nucleotide collection - 2021

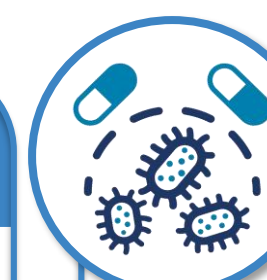


Ice nucleating bacteria, possible rainmakers



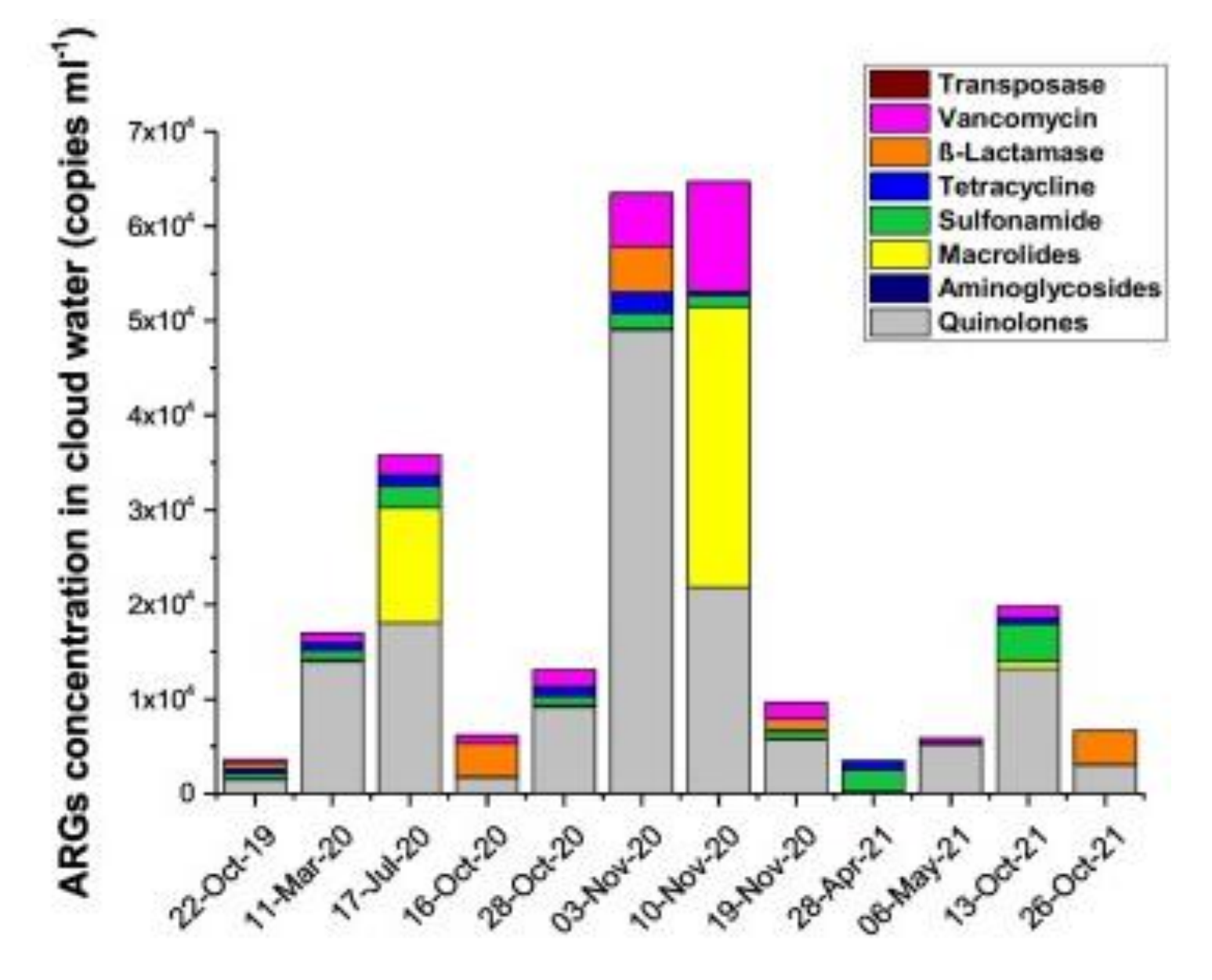
- Biological particles participate in ice nucleation at high temperature in cloud water sampled at the puy de Dôme mountain
- 7 bacterial strains of our cloud collection belonging to *Pseudomonas* and *Xanthomonas* genera were identified as ice nucleation active at near 0°C temperatures. They are among the most active identified to date
- **Bacteria could contribute to cloud evolution by triggering precipitation at temperatures close to 0°C**

Adapted from Joly et al., Atm Env (2013), doi.org/10.1016/j.atmosenv.2013.01.027 and Joly et al., ACP (2014), doi:10.5194/acp-14-8185-2014



Antibiotic resistance genes (ARGs) dissemination via clouds

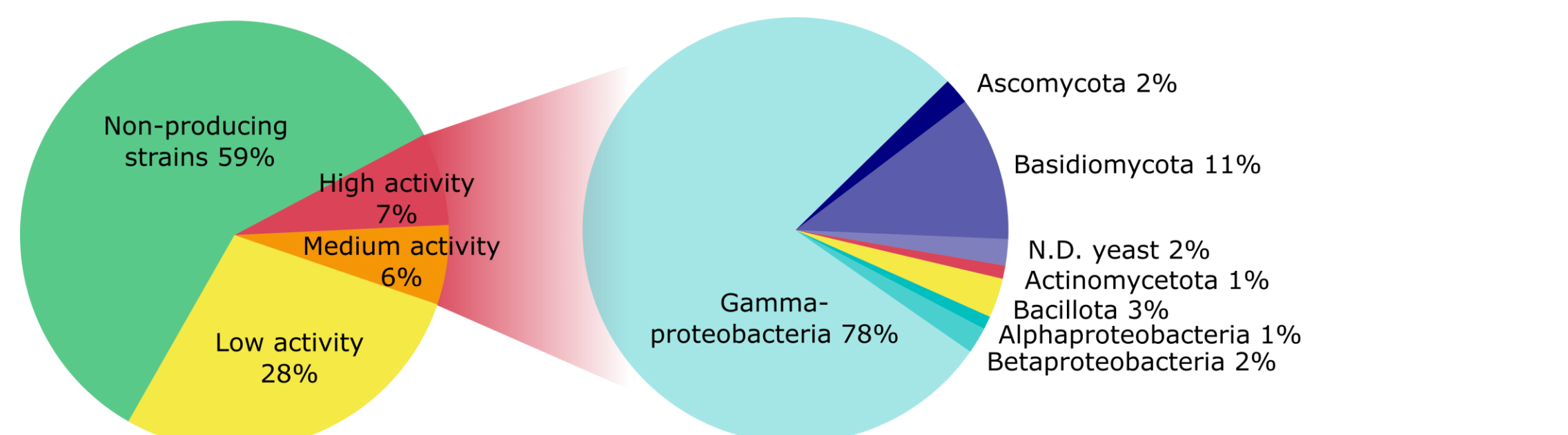
- 29 different ARGs subtypes were detected by qPCR on cloud water sampled at the puy de Dôme
- ~10³ to 10⁴ copies of ARGs per m³ were quantified
- Air mass origin influenced the prevalence of ARGs subtypes
- **Cloudborne microorganisms participate in ARGs dissemination at large scales**



Rossi et al., STOTEN (2023), doi.org/10.1016/j.scitotenv.2022.161264



Surfactant-producing microorganisms to facilitate droplet formation



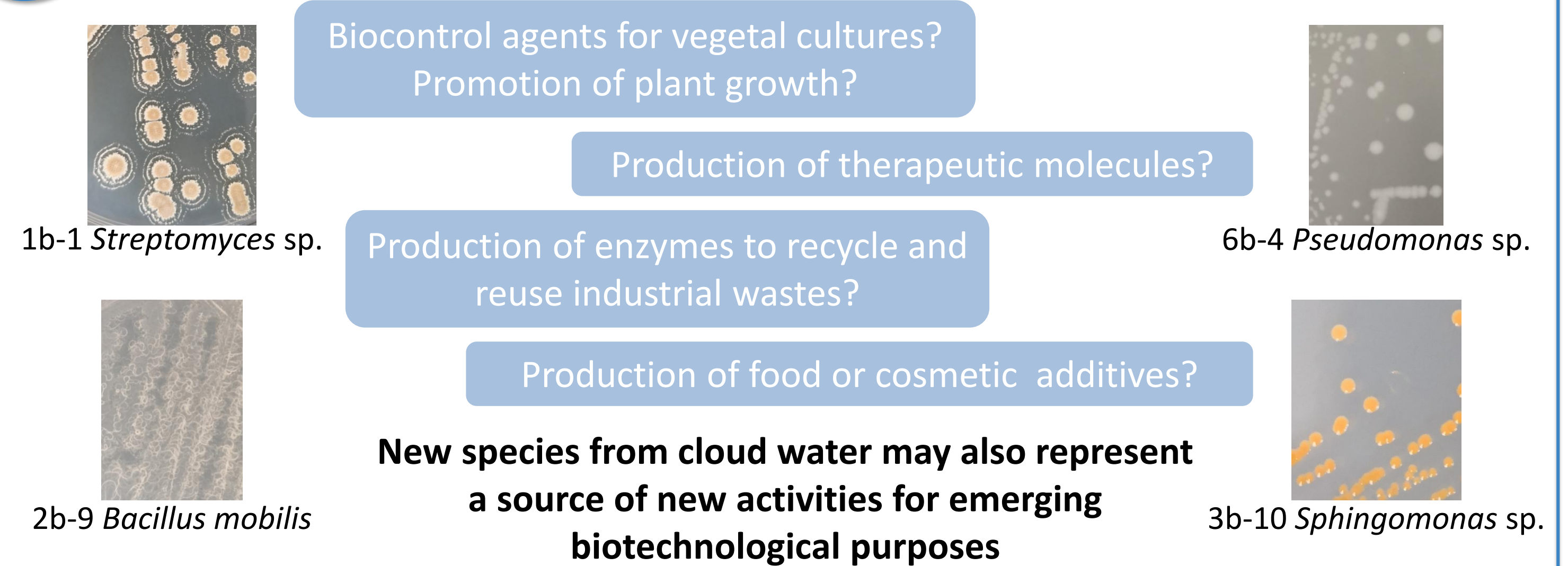
- Surfactants in the atmosphere may facilitate the formation of cloud droplets by reducing water surface tension
- ~41% of strains isolated from cloud water are active producers of biosurfactants, 7 % are extremely active

Adapted from Renard et al. ACP (2016), doi:10.5194/acp-16-12347-2016



Towards biotechnological applications

- Biocontrol agents for vegetal cultures? Promotion of plant growth?
- Production of therapeutic molecules?
- Production of enzymes to recycle and reuse industrial wastes?
- Production of food or cosmetic additives?
- **New species from cloud water may also represent a source of new activities for emerging biotechnological purposes**



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