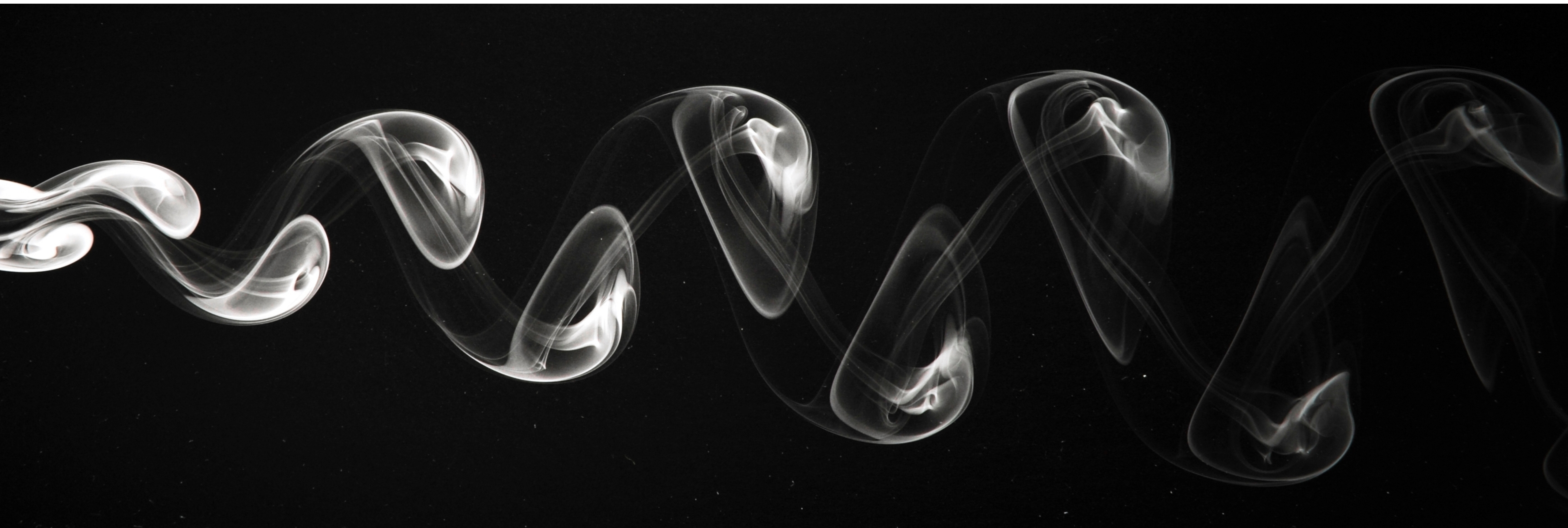
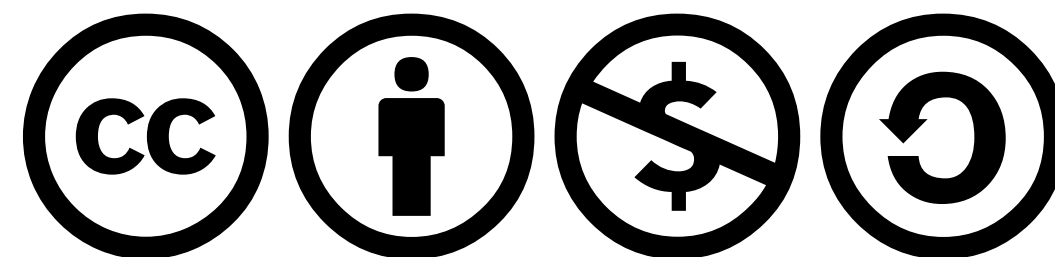


Odor Movement 101



Jürgen Wagner, Wikimedia

Lindsay D. Waldrop, Ph.D.
Schmid College of Science and Technology
Chapman University



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Contact:
waldrop@chapman.edu
<https://waldroplab.com>

As we begin...

- I am not a professional dog handler/trainer.
- I can't (and won't) tell you how to work your dog.
- I am an amateur dog handler in NACSW Nosework™.
- I am an expert in biological fluid dynamics.
- I am here because I am funded by your tax dollars!
(Office of Naval Research)
- Together, I hope we can come up with some strategies for helping your working team find odor sources!

Download these slides!



Goals of this seminar

- Describe the physical process of odor-plume formation.
- Describe how odor is released from a source.
- Explain why, how, and where air moves to transport odor.
- Describe the three principles of qualitative flow visualization of odor plumes.
- Discuss how to improve training and search success based on fluid flow.

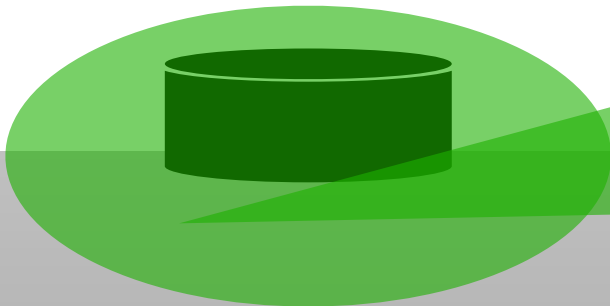
Anatomy of an odor plume

Planar laser-induced fluorescence

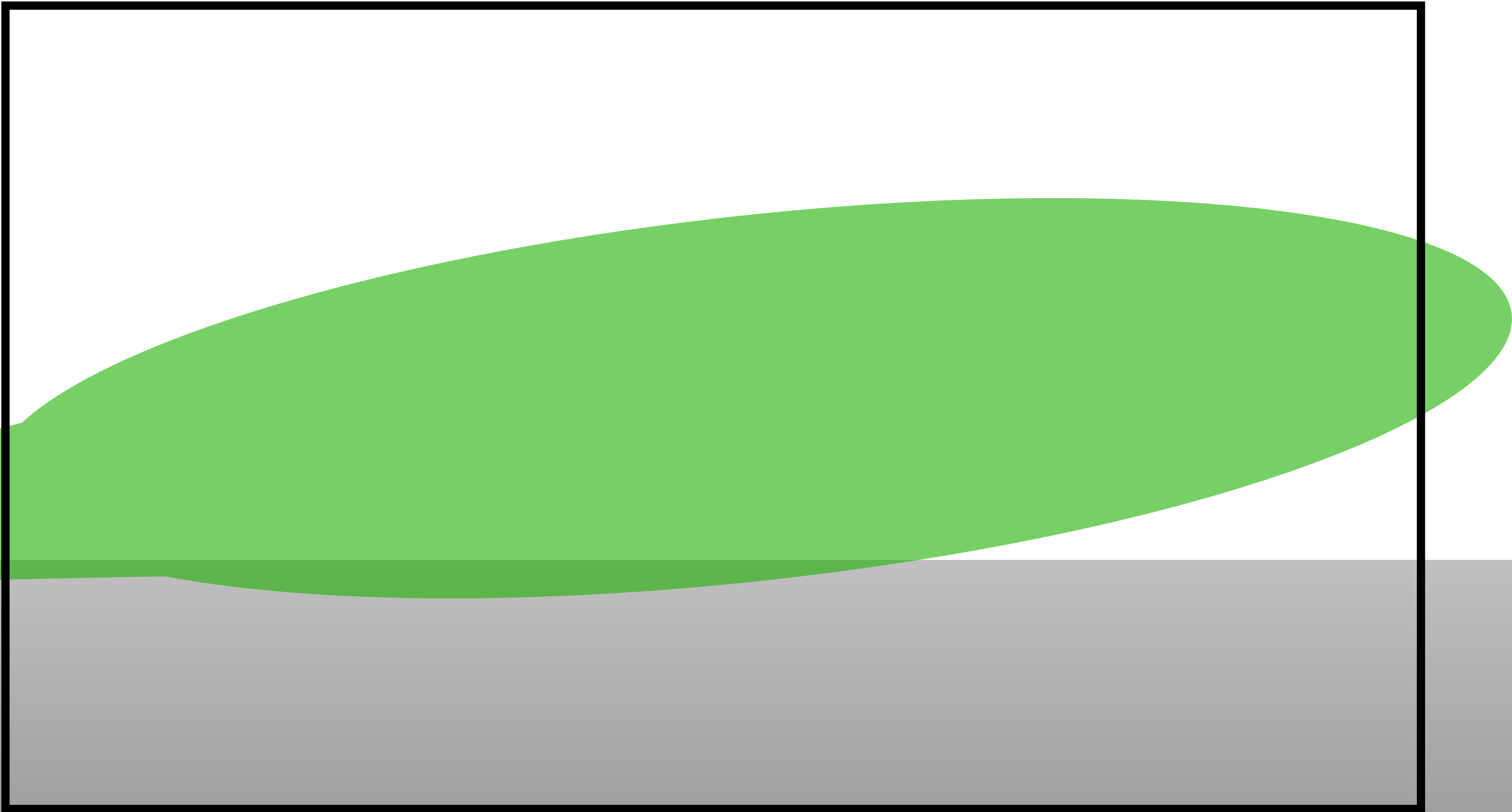
2. Air movement



Source



1. Odor release



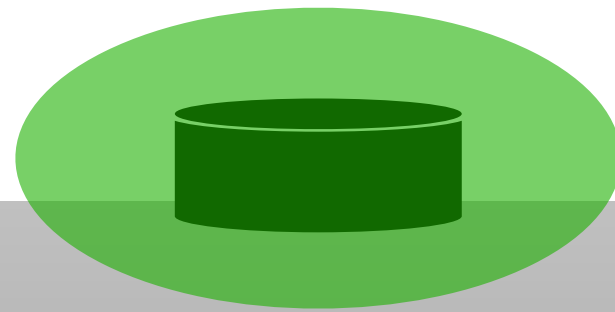
Anatomy of an odor plume

Planar laser-induced fluorescence

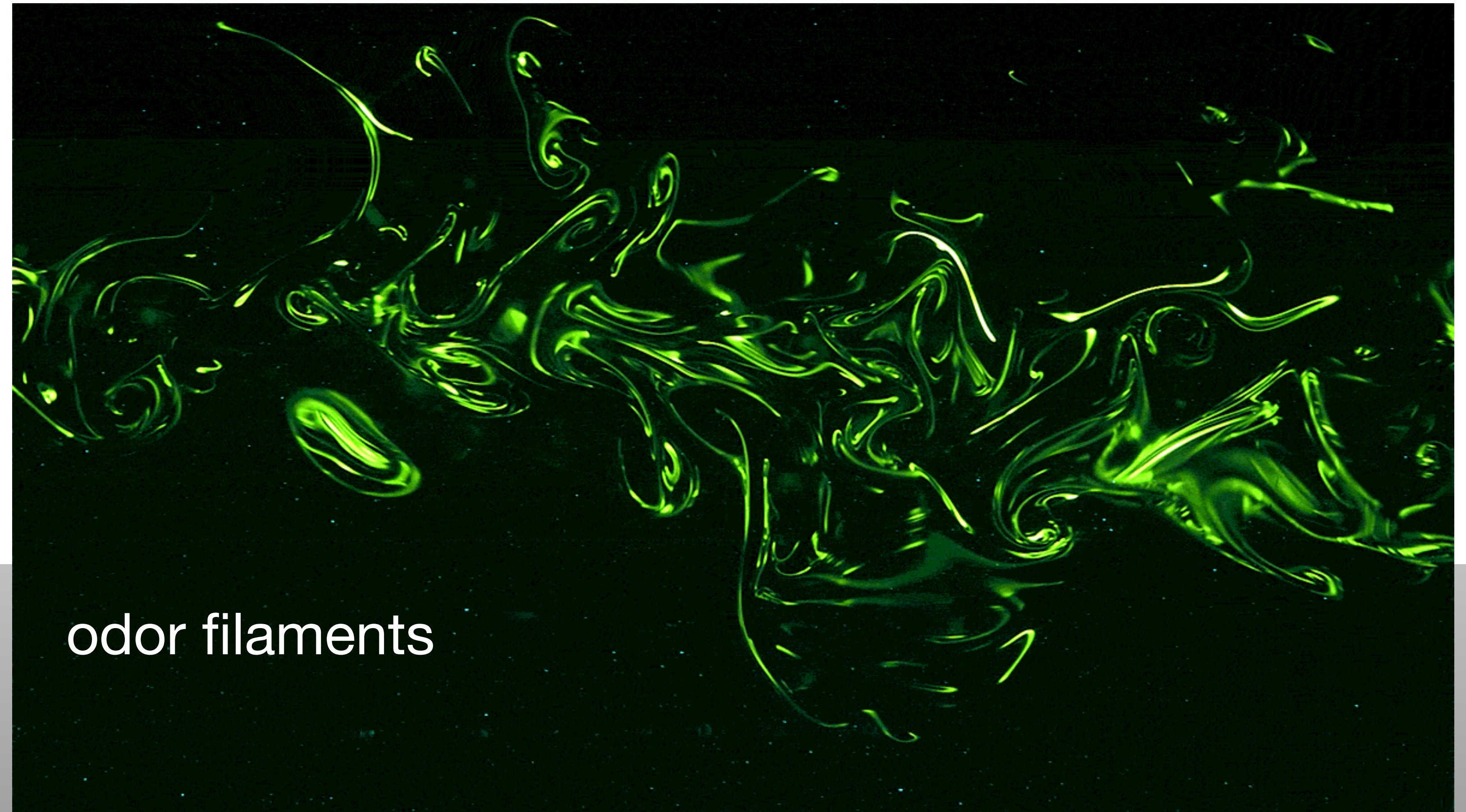
2. Air movement



Source

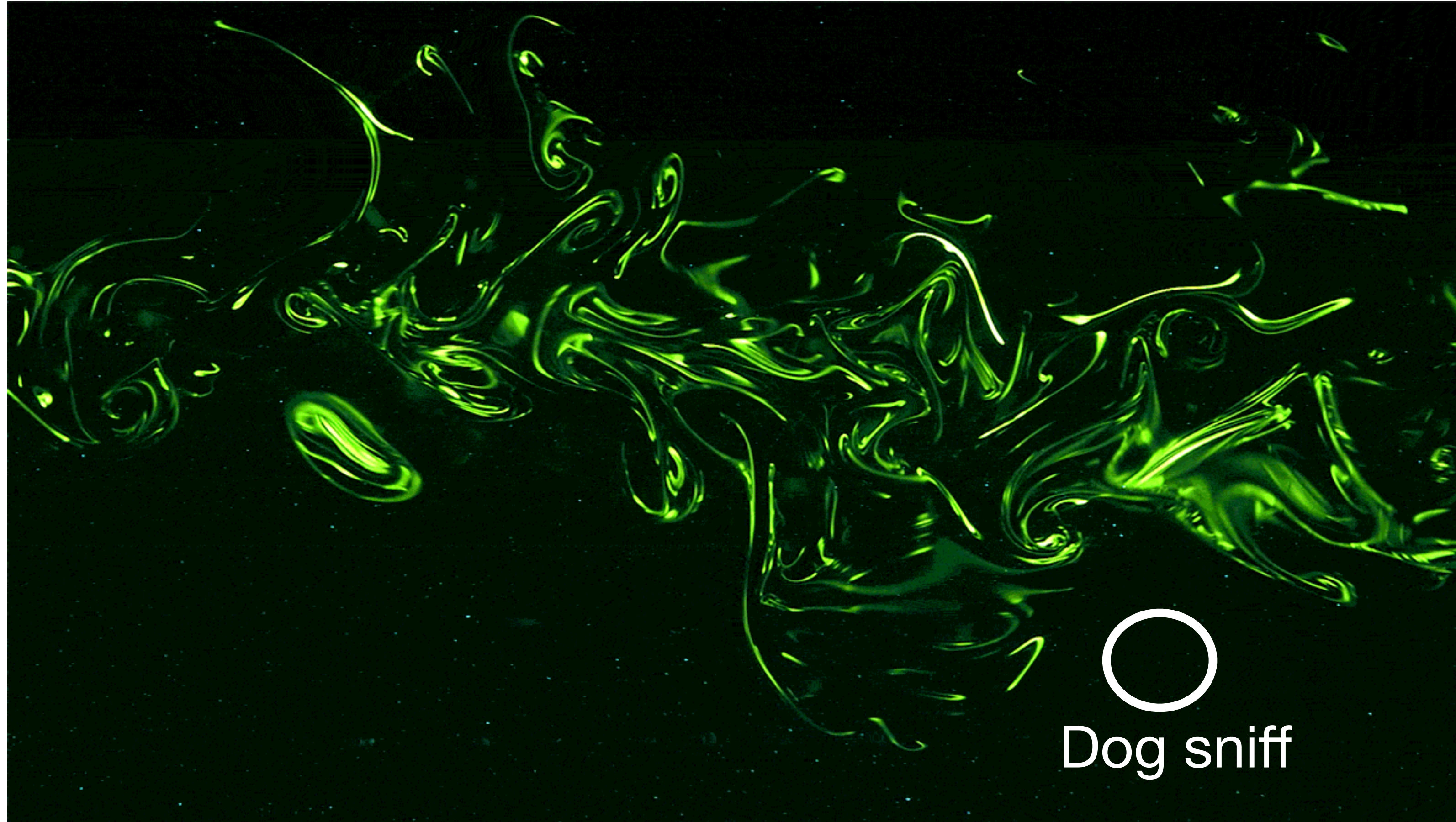


1. Odor release



Brian Gill, Univ. of
Colorado, Boulder

Anatomy of an odor plume



- Odor release and air movement create ***odor filaments***
- Arrangement and locations of odor filaments vary based on conditions
- Dogs search ***discontinuous signals*** within a plume

Knowing the ***structure*** of an odor plume is important for understanding how dogs search it!

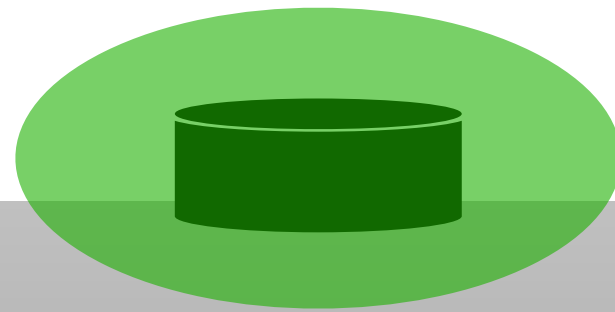
Anatomy of an odor plume

Planar laser-induced fluorescence

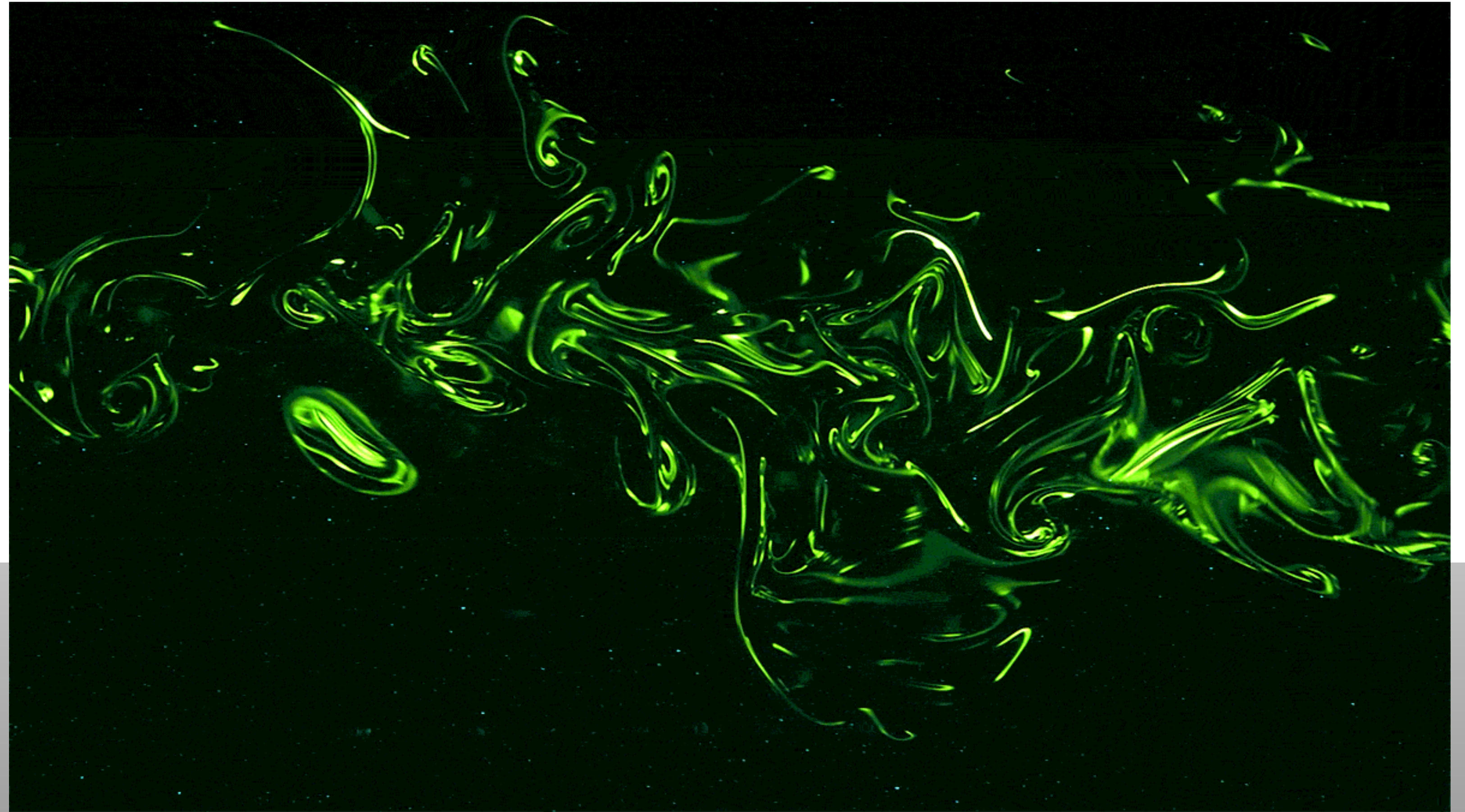
2. Air movement



Source



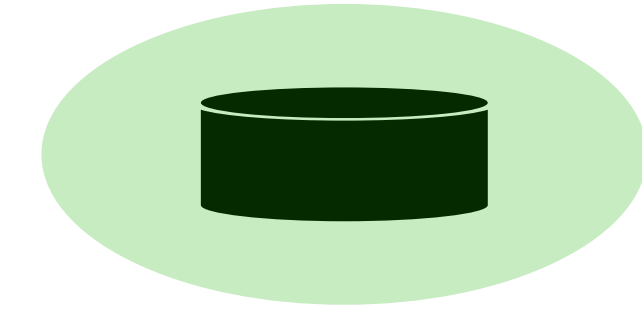
1. Odor release



Brian Gill, Univ. of
Colorado, Boulder

1. How odor enters the air

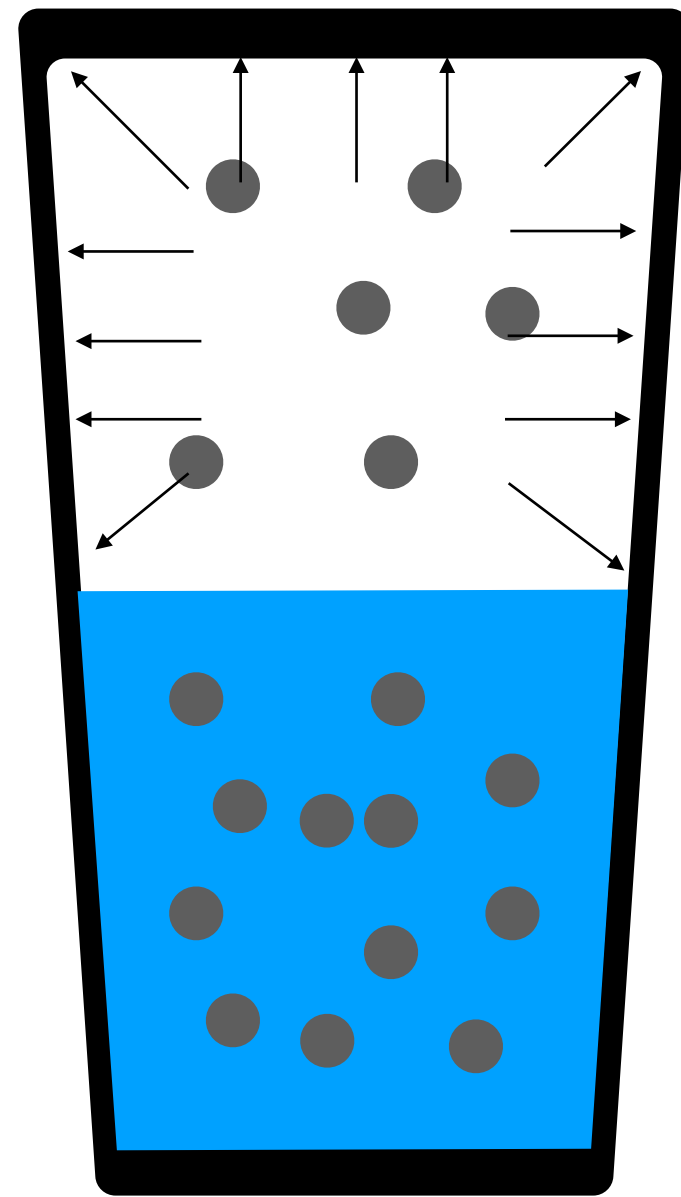
Odor release from a source is dependent on several features:



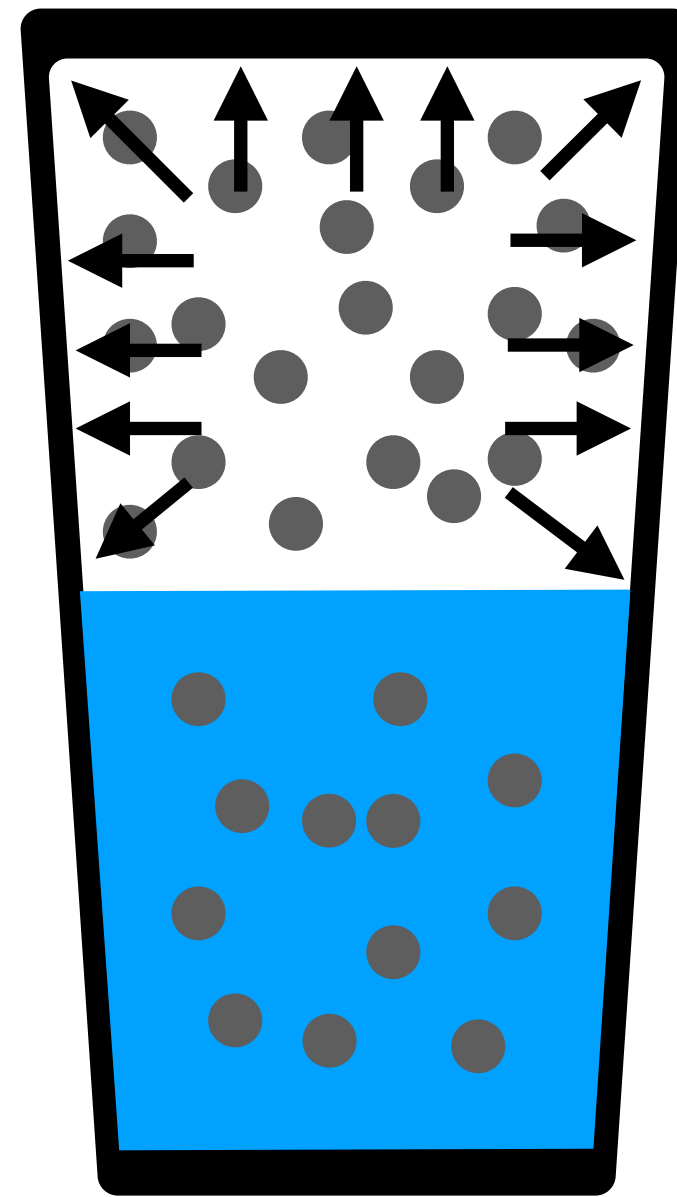
- Chemical properties of the material
 - ➡ Vapor pressure
 - ➡ Diffusion coefficient
- Properties of the training aid
 - ➡ Surface area of the material
 - ➡ Containment of the material

More info: [Sloan et al. 2025 Frontiers](#)

How odor enters the air: Vapor Pressure

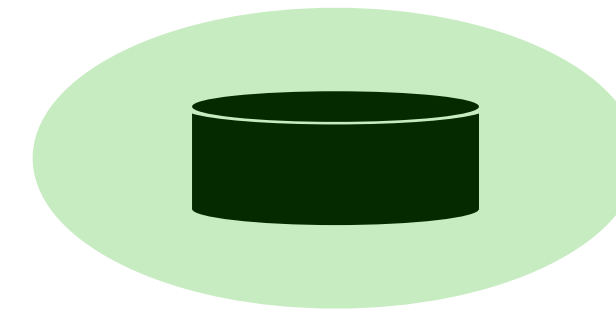


Low vapor pressure

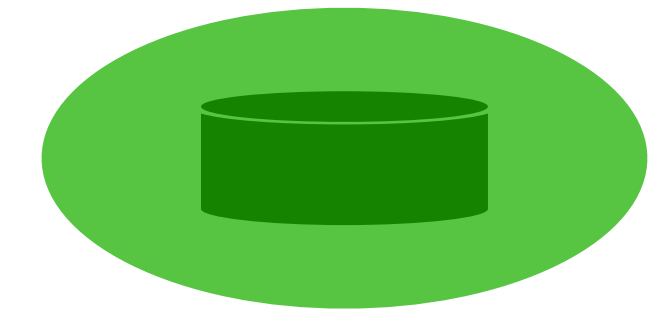


High vapor pressure

Low vapor pressure



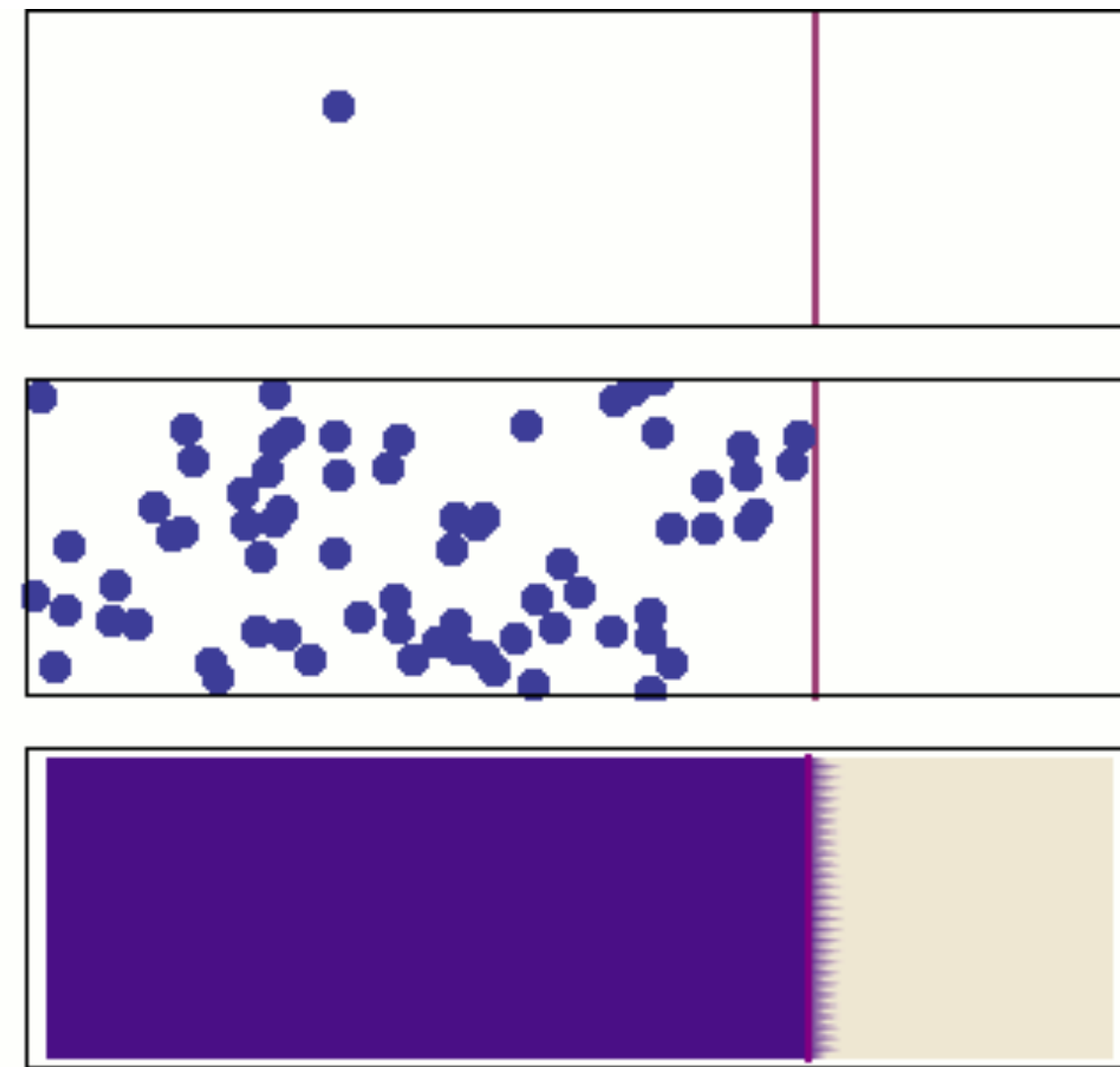
High vapor pressure



more mass in same volume = higher concentration

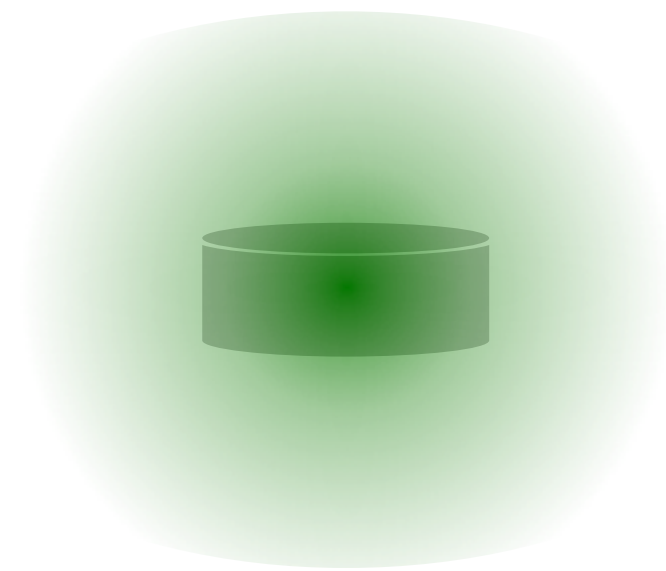
Vapor pressure can be dependent on *temperature* and *humidity*.

How odor enters the air: Diffusion

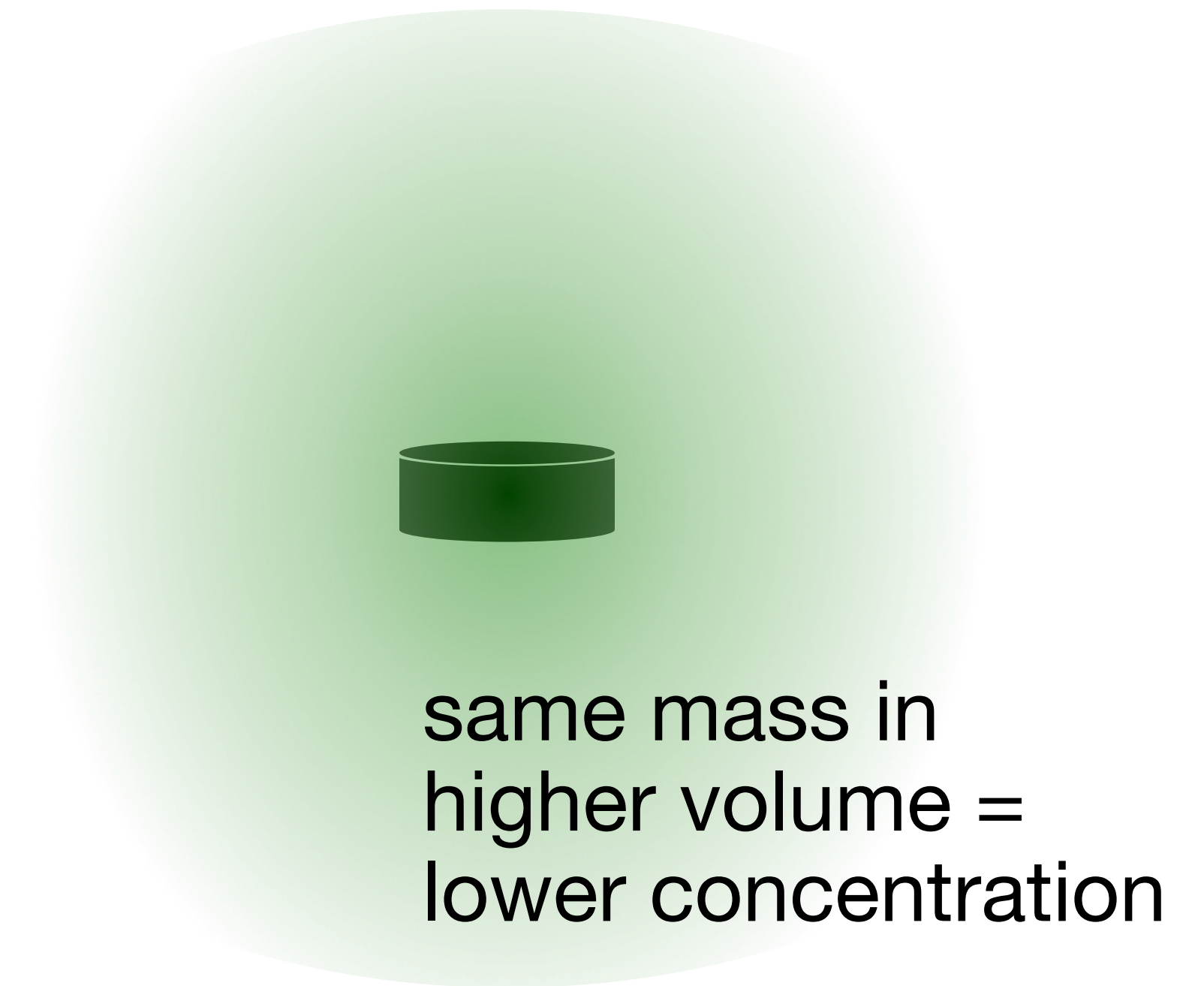


Wikipedia, Fick's Law

Low
diffusion
coefficient

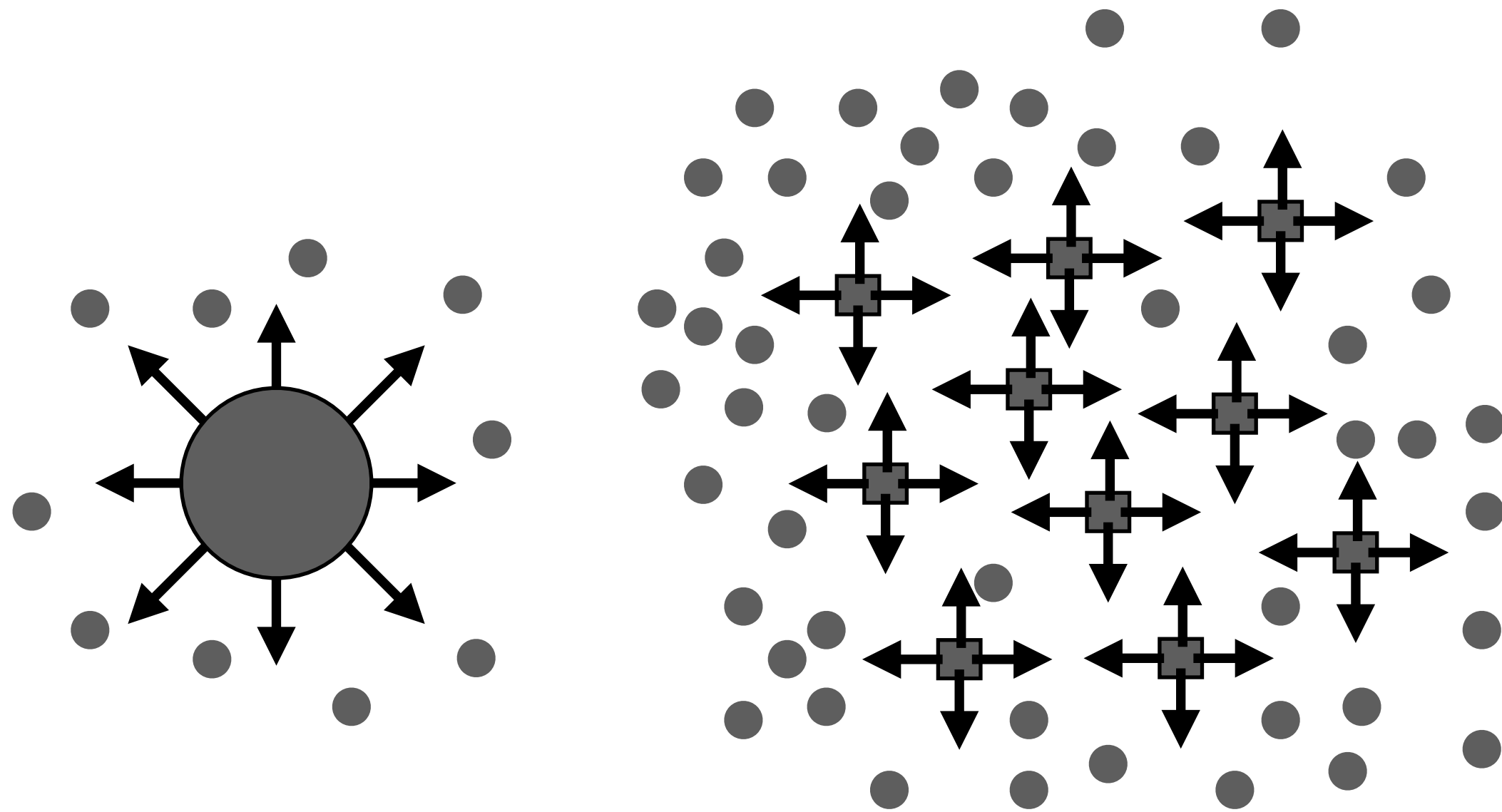


High
diffusion
coefficient

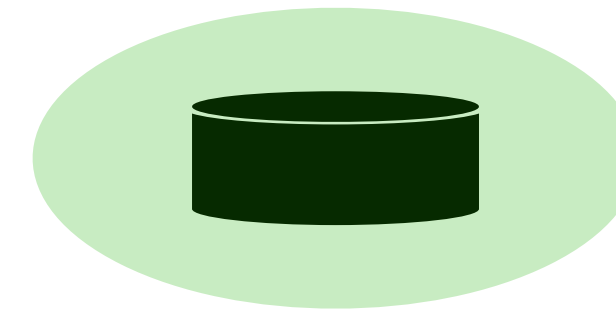


Diffusion can be dependent on *temperature*
and *humidity*.

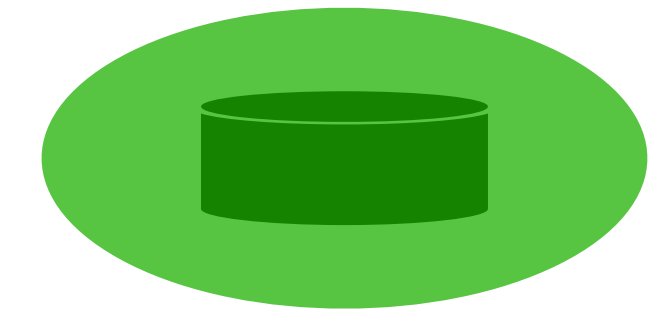
How odor enters the air: Surface Area



Low surface
area



High surface
area

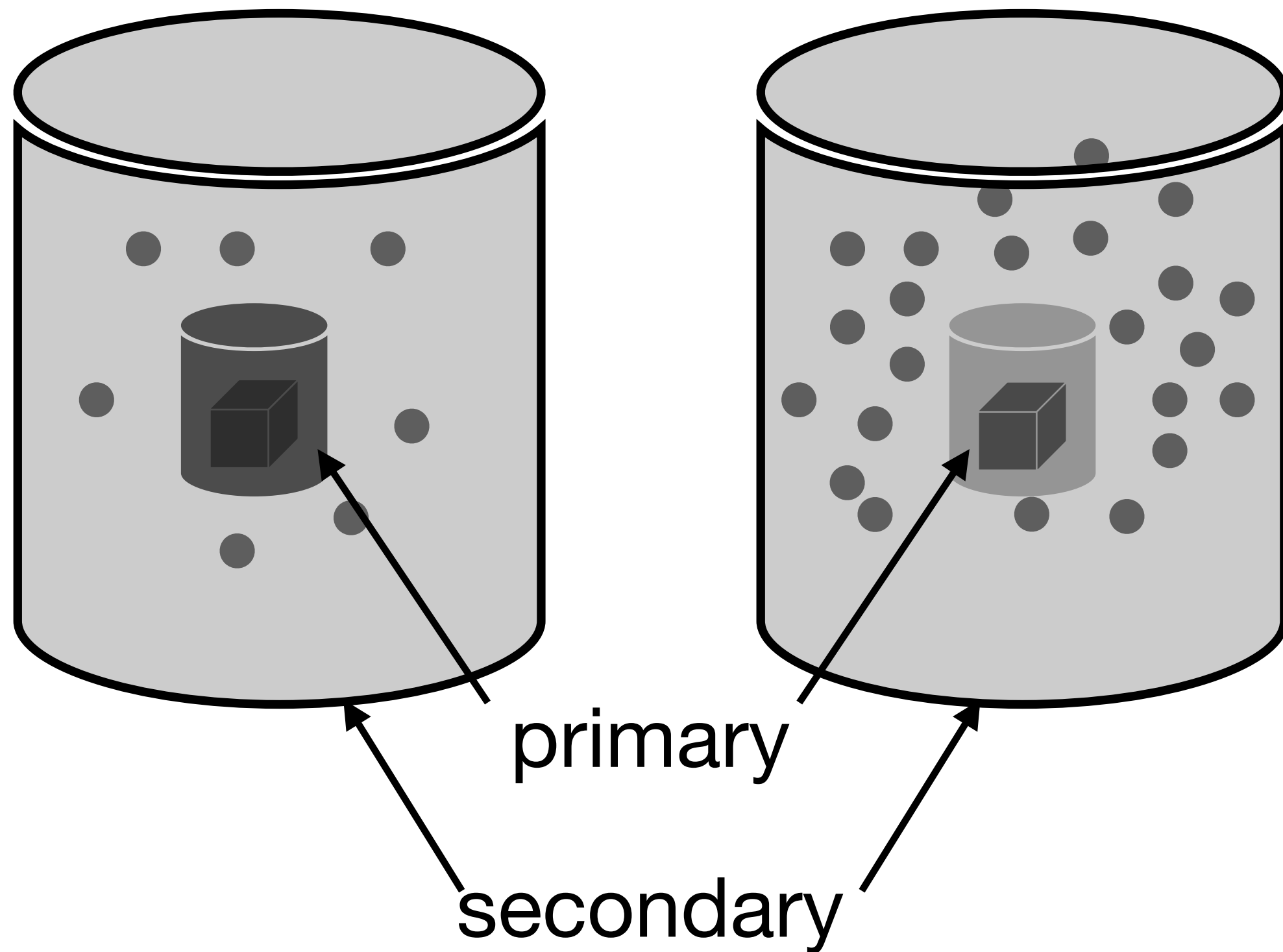


more mass in same
volume = higher
concentration

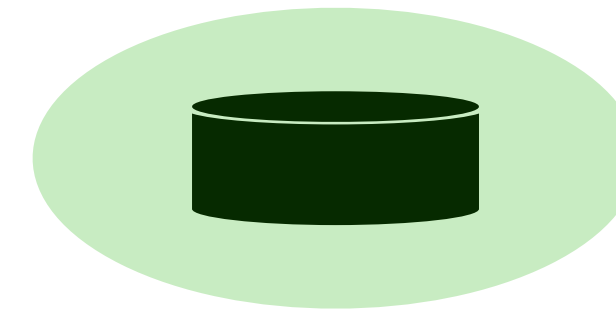
Odor release is proportional to the
surface area of the source material,
not mass.

How odor enters the air: Containment

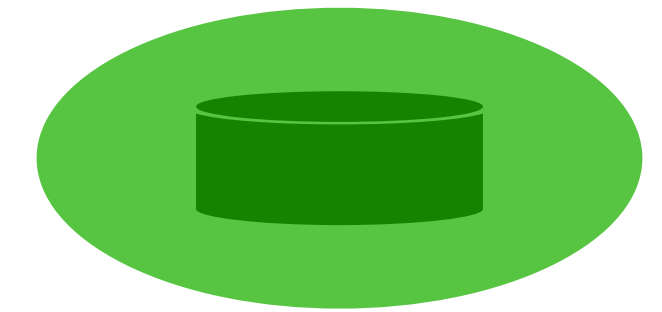
Permeability



Low permeability



High permeability



more mass in same volume = higher concentration

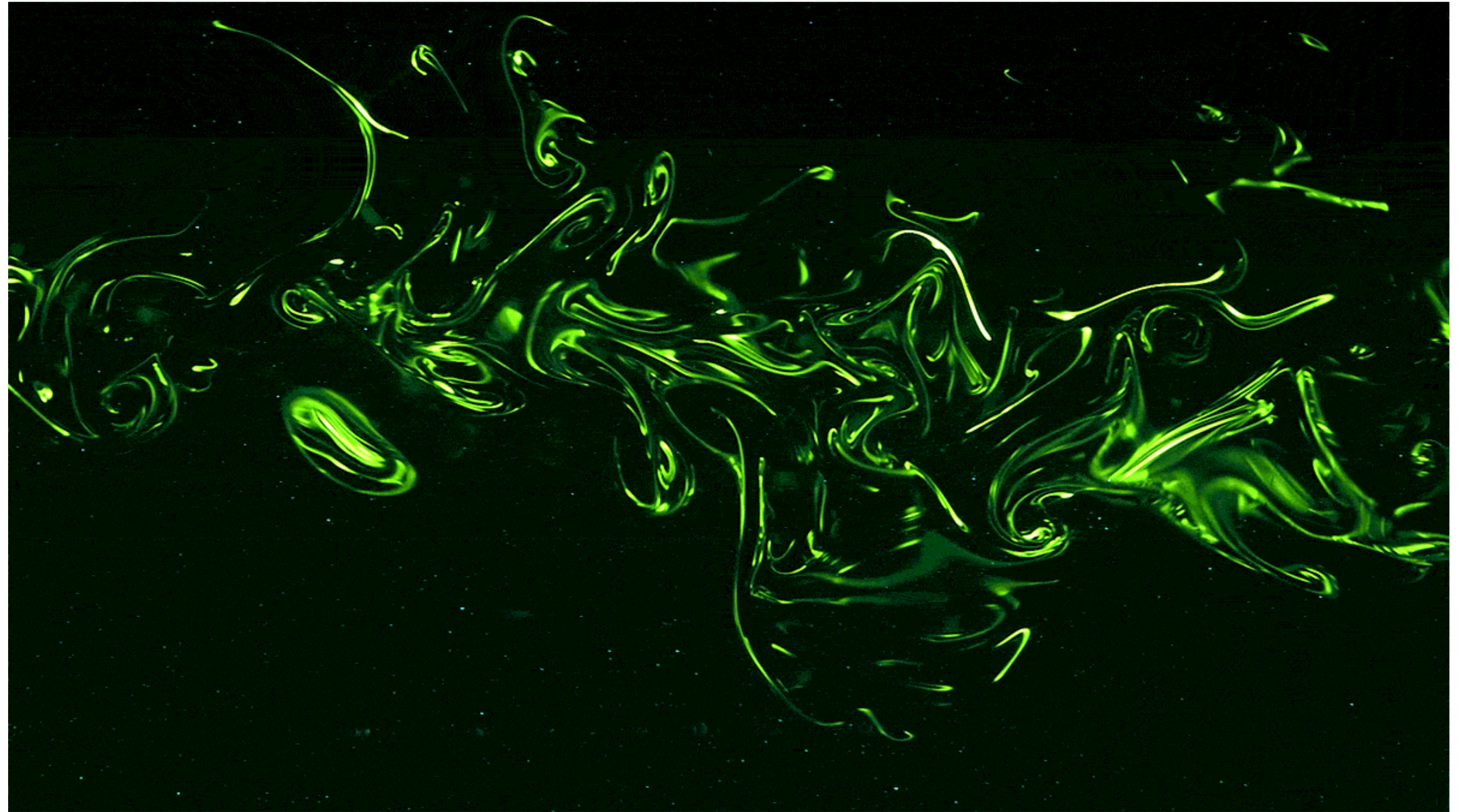
Odor release depends on the *permeability* of the materials' containment and concealment.

2. Air Movement

***Why* does air move?**

***How* does air move?**

***Where* does air move?**



Brian Gill, Univ. of
Colorado, Boulder

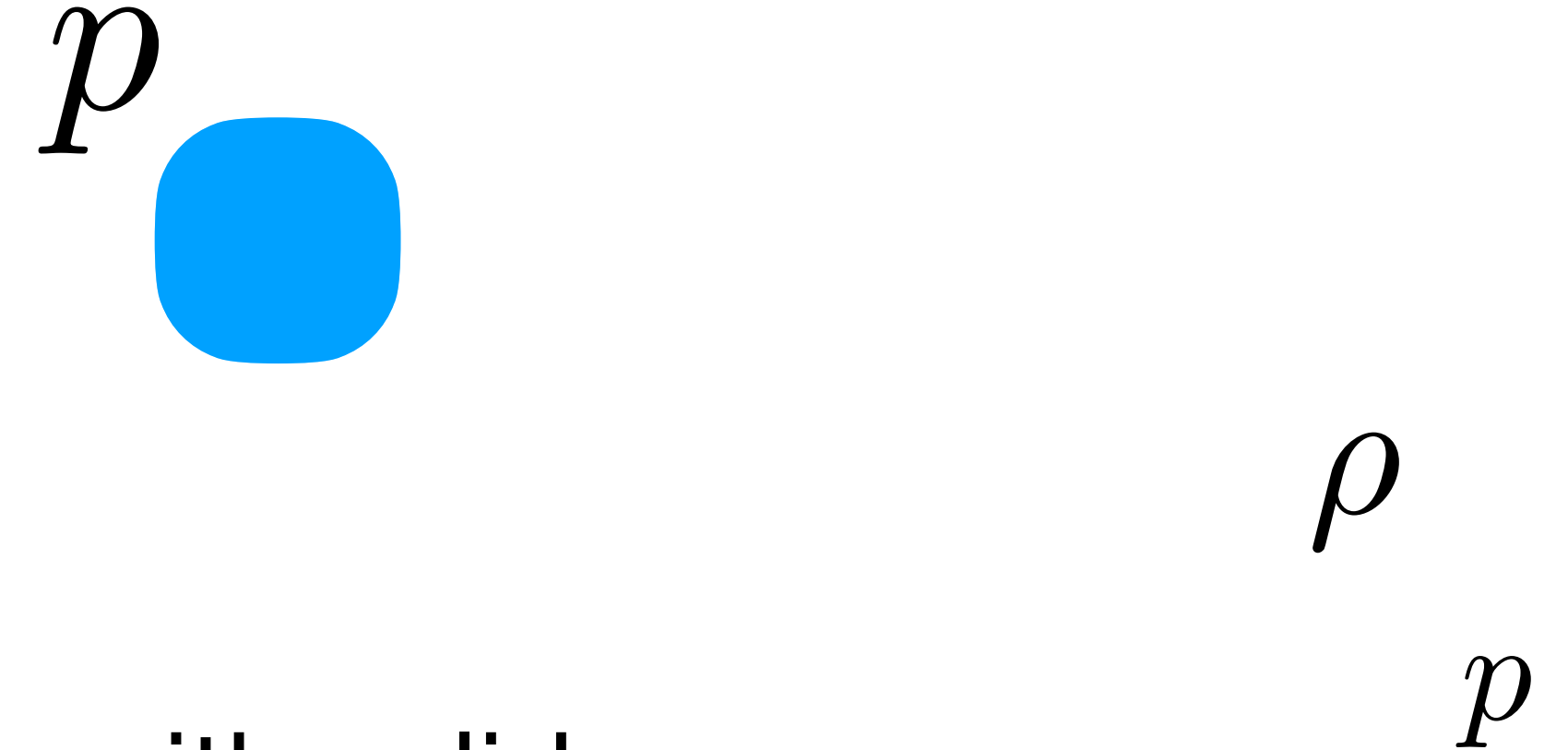
Why does air move?

- Movement of fluids is dictated by the same rules as solids: air moves in response to applied forces.

Movement of solid object

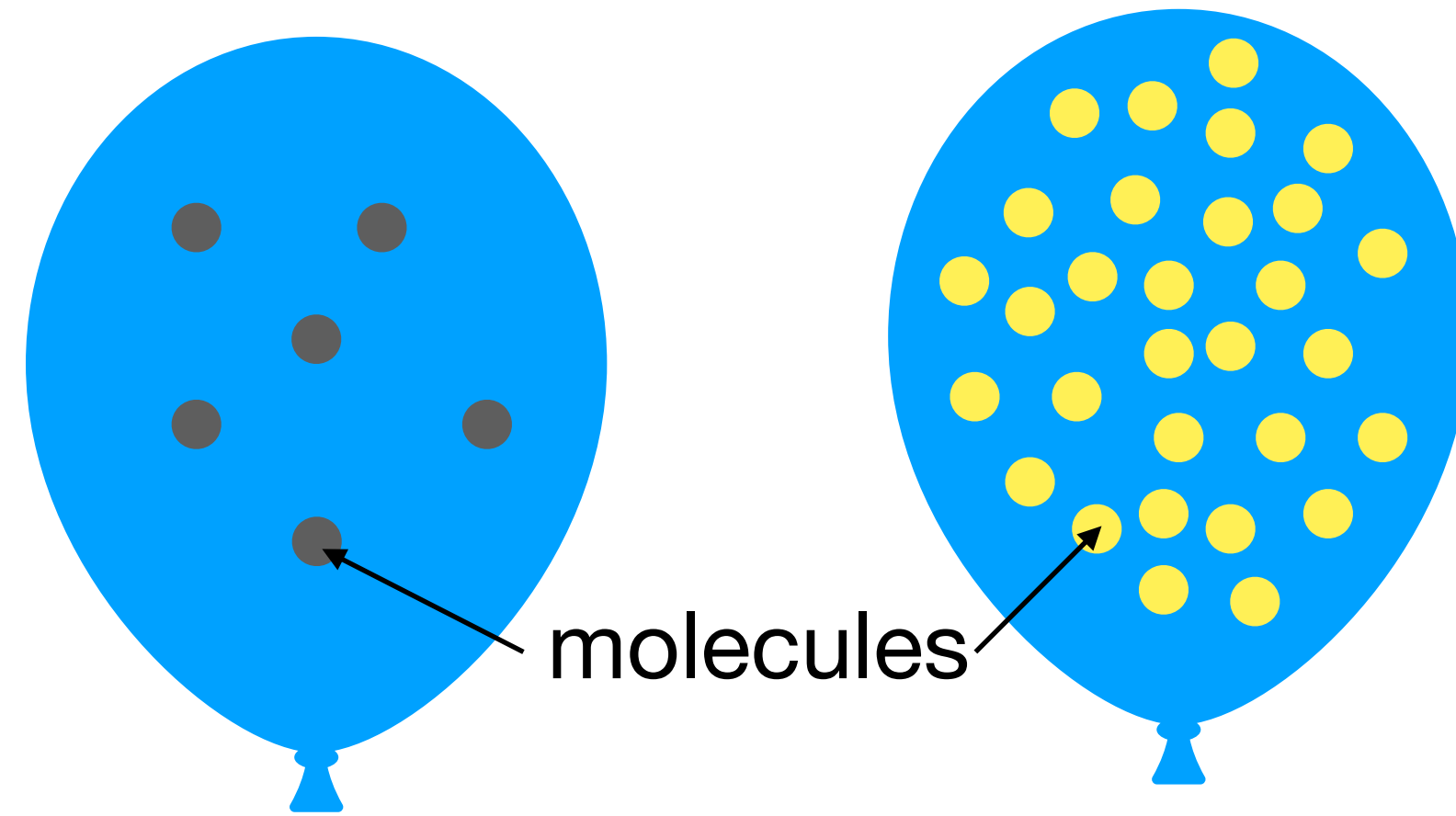


Movement of fluid



- We describe these forces a little differently than with solids
 - ➔ Instead of Mass, we can describe *Density*
 - ➔ Instead of Force, we can describe *Pressure*

Density



lower
density

higher
density

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Density affects
buoyancy.

Differences in
buoyancy can
drive motion.

What can affect fluid density in air?

Density differences drive flow

Different chemical makeup

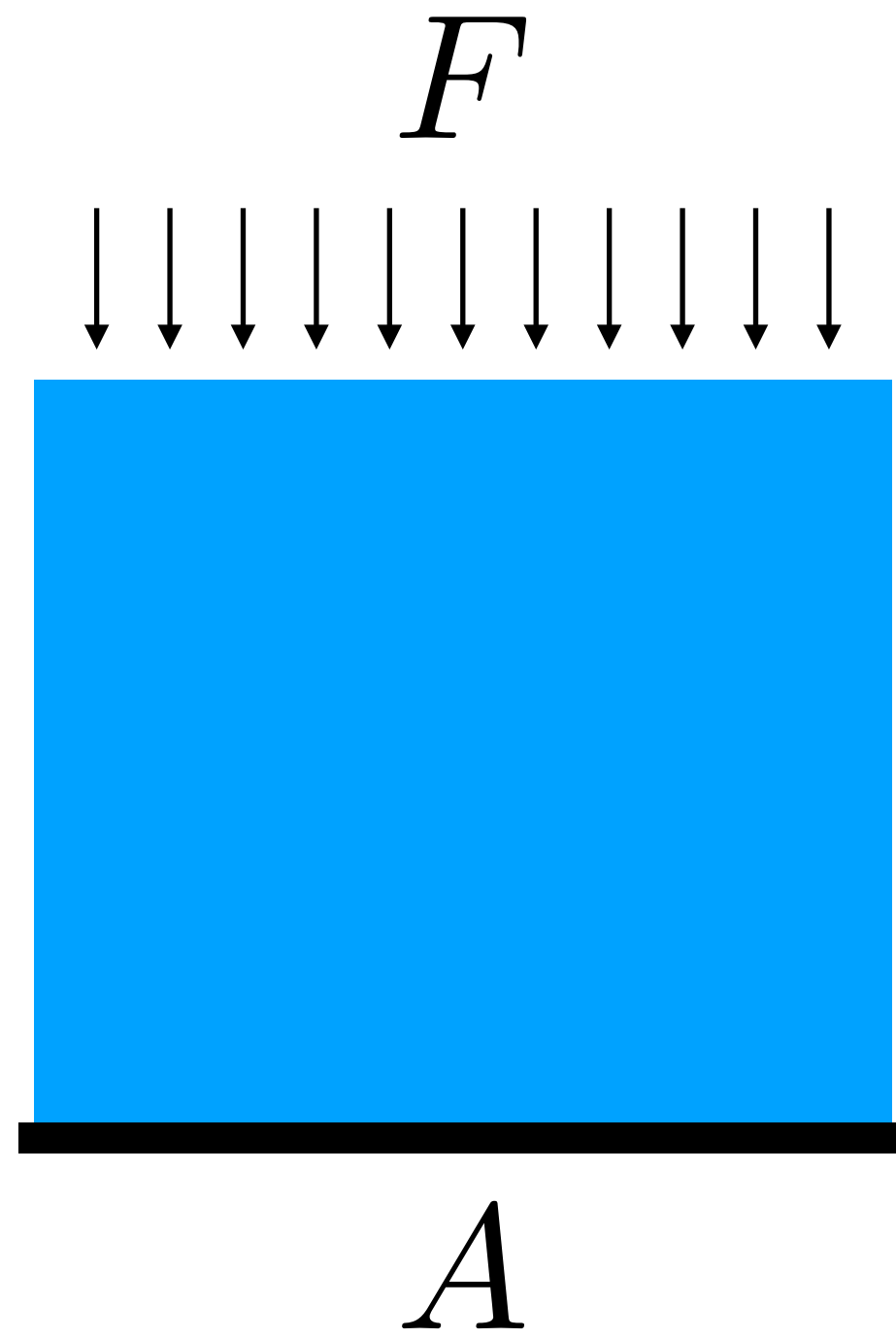


Temperature



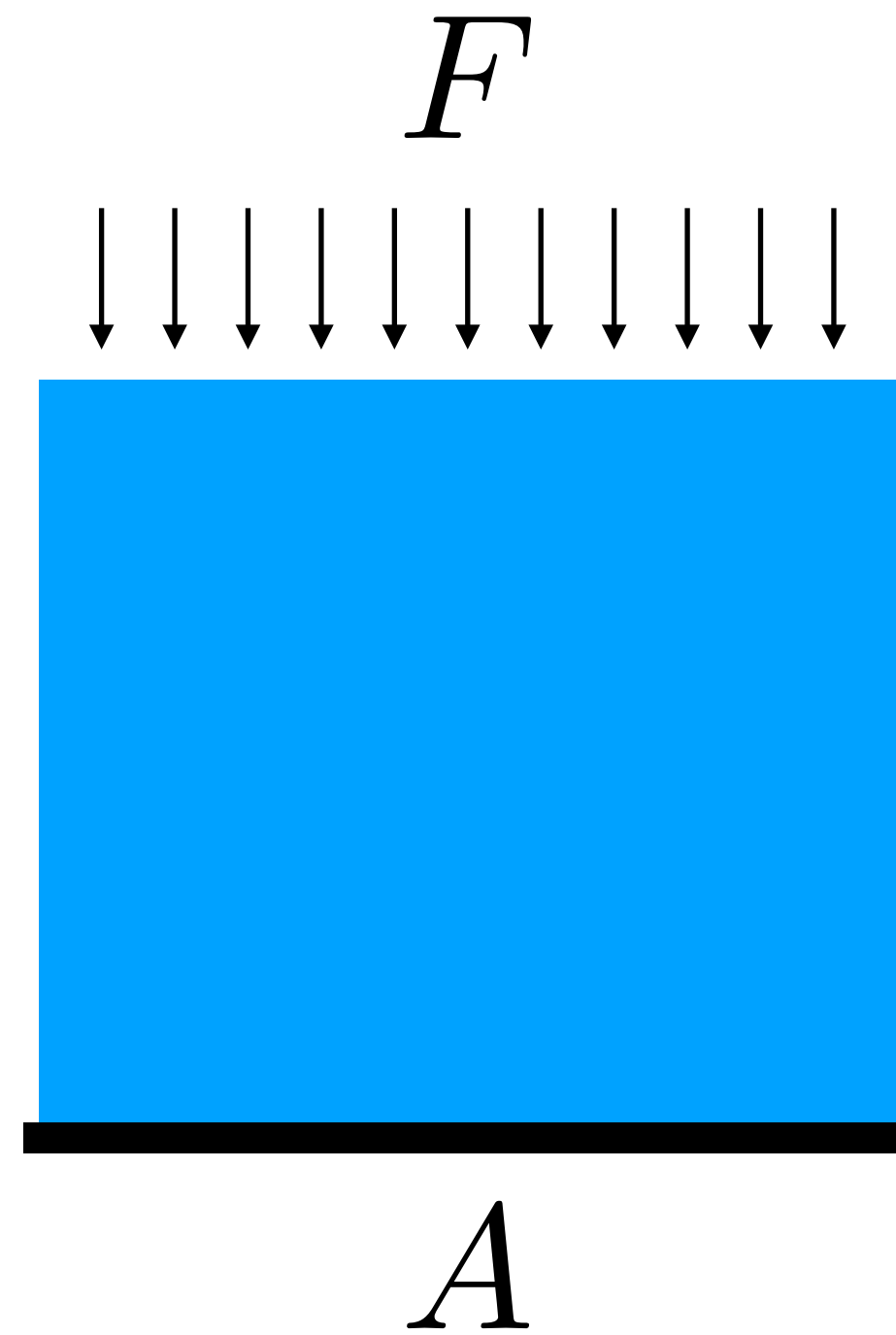
Settles 2005 *J Fluids-Engineering*

Pressure



$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

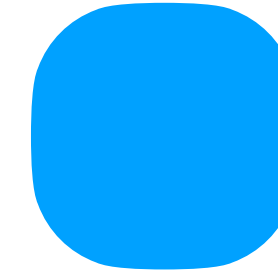
Pressure



$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

Movement of fluid

High p



Low p

Sources of pressure changes:

- wind
- fans
- HVAC systems
- moving objects
- traffic
- people and dogs

Pressure differences drive flow

Movement of a person will cause large-scale air movement

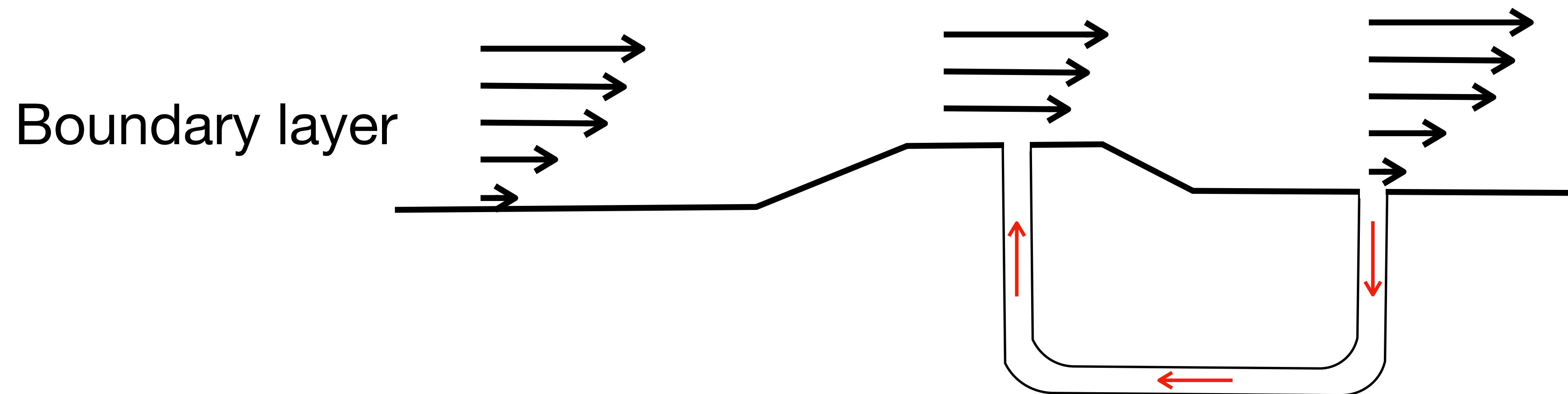
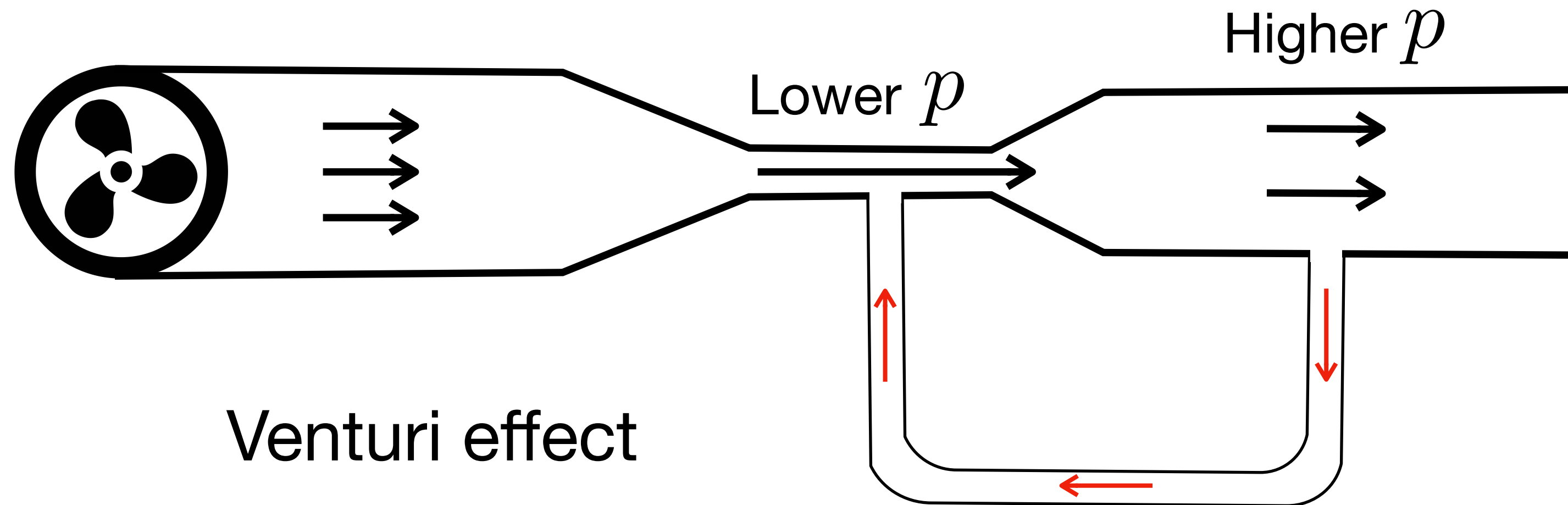


Settles 2005 *J Fluids-Engineering*

Dogs sniffing will also affect the odor plume structure by sniffing/moving



Pressure differences drive flow



Geometrically
induced passive
flow

Why air moves: takeaways

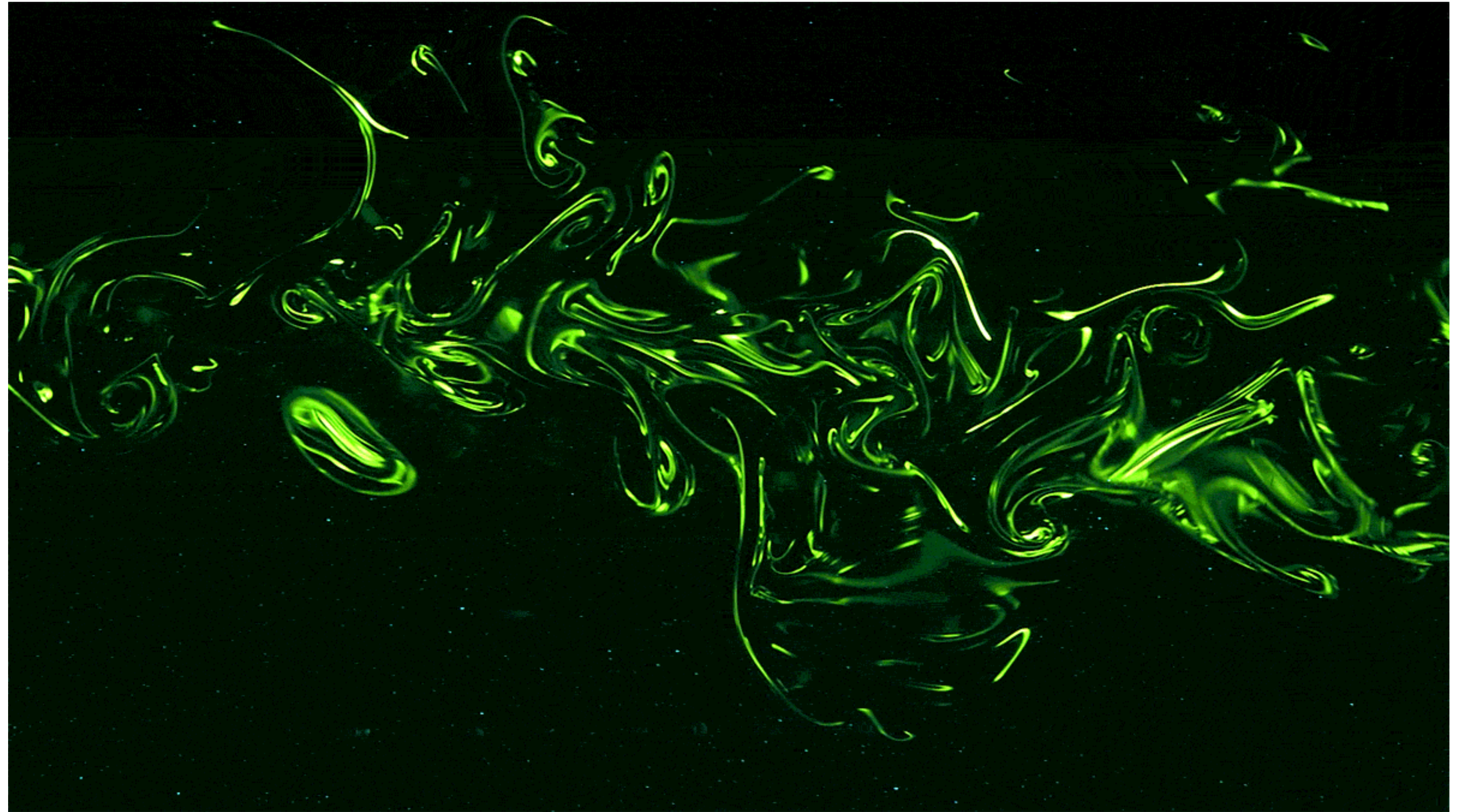
- Fluid moves in response to applied force in the form of ***density*** or ***pressure*** differences.
- Movement due to density can include differences in ***temperature*** and ***chemical composition*** of vapor.
- Pressure differences can be created by ***fans***, ***wind***, ***objects in motion***, and ***passively*** through geometry.

2. Air Movement

Why does air move?

How does air move?

Where does air move?



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Colorado, Boulder

Think like a Fluid Dynamicist



What do you think about when you flush a toilet?

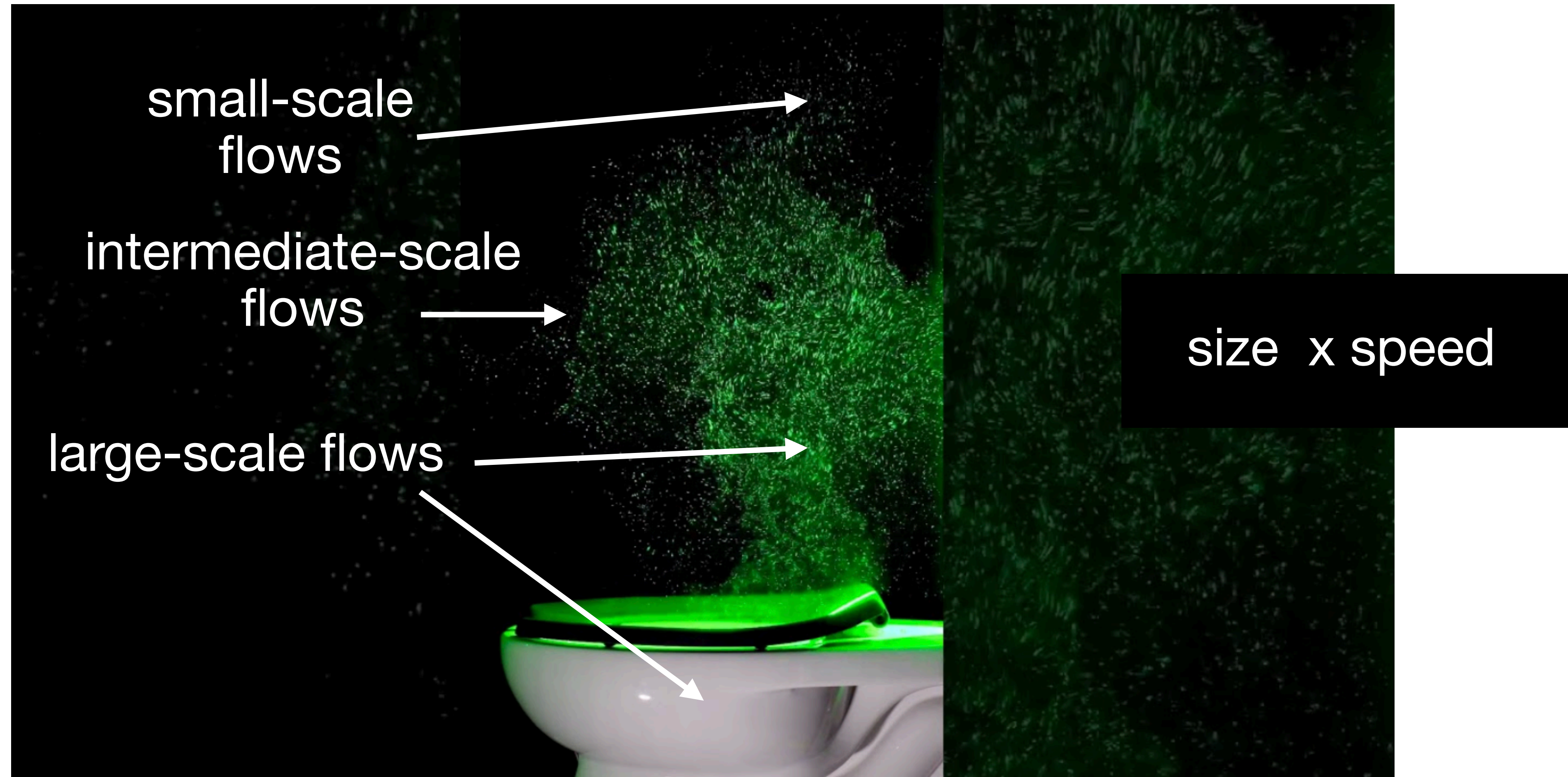
Think like a Fluid Dynamicist



J. Crimaldi, Univ of Colorado Boulder

What I think about when I flush a toilet

Scales of fluid flow



J. Crimaldi, Univ of Colorado Boulder

How does air move? Why does it matter?

Small-scale flows:

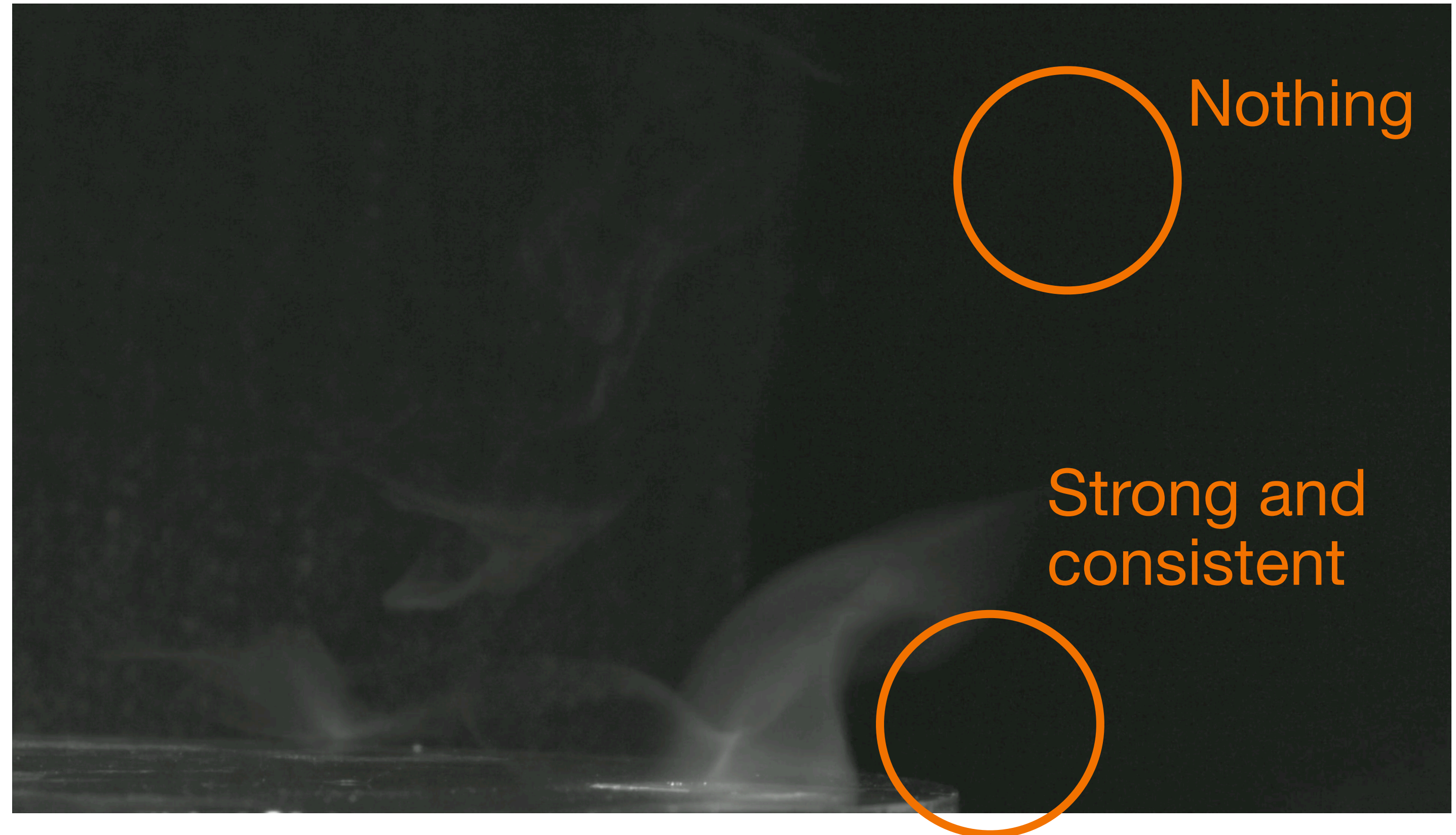
- determine the local *intensity* of odor signal

Intermediate-scale flows:

- determine how *well mixed* the odor signals become away from the source

Large-scale flows:

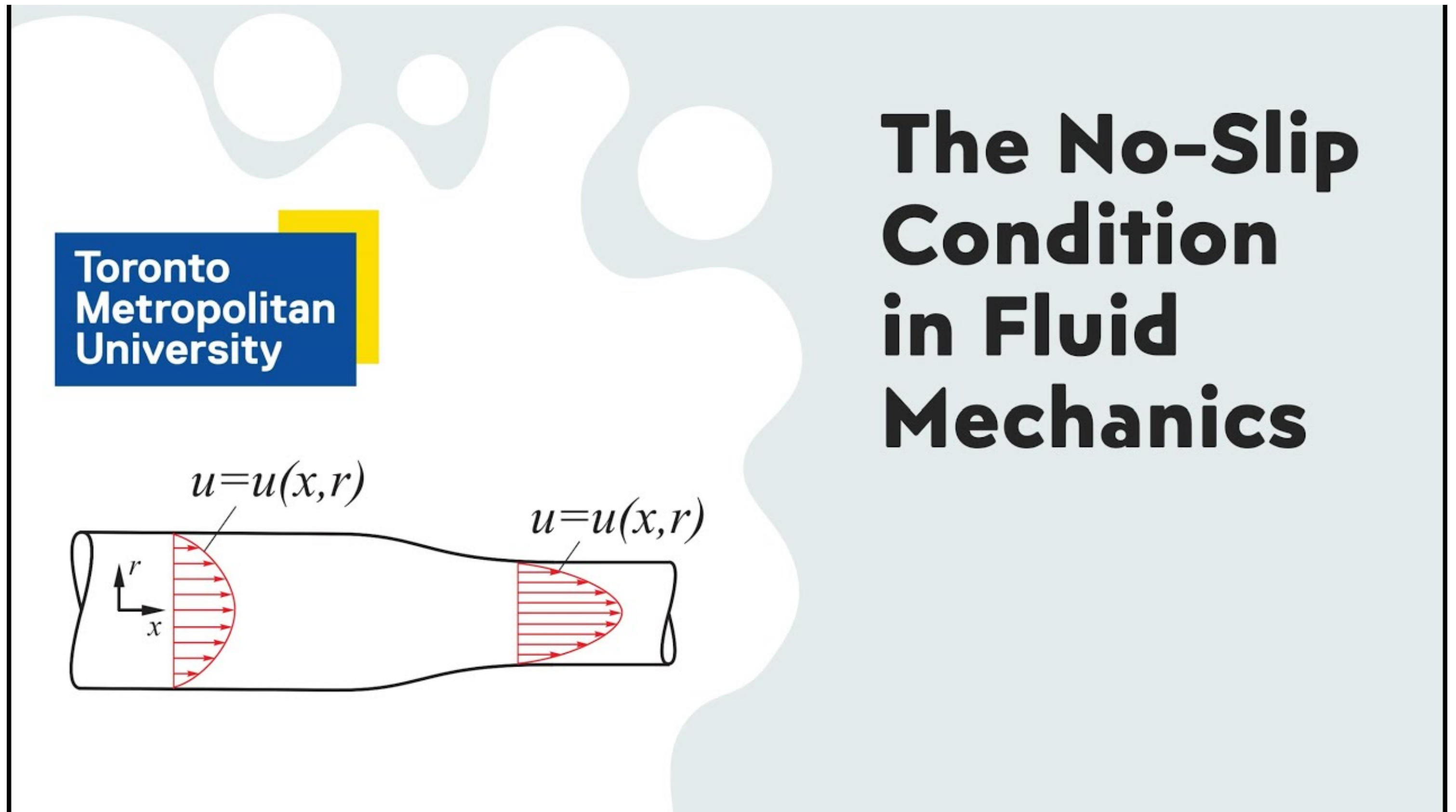
- determine where in a large space odor ends up



Dog sniffing at 500 frames per second

Setting the scene: solid objects and fluids

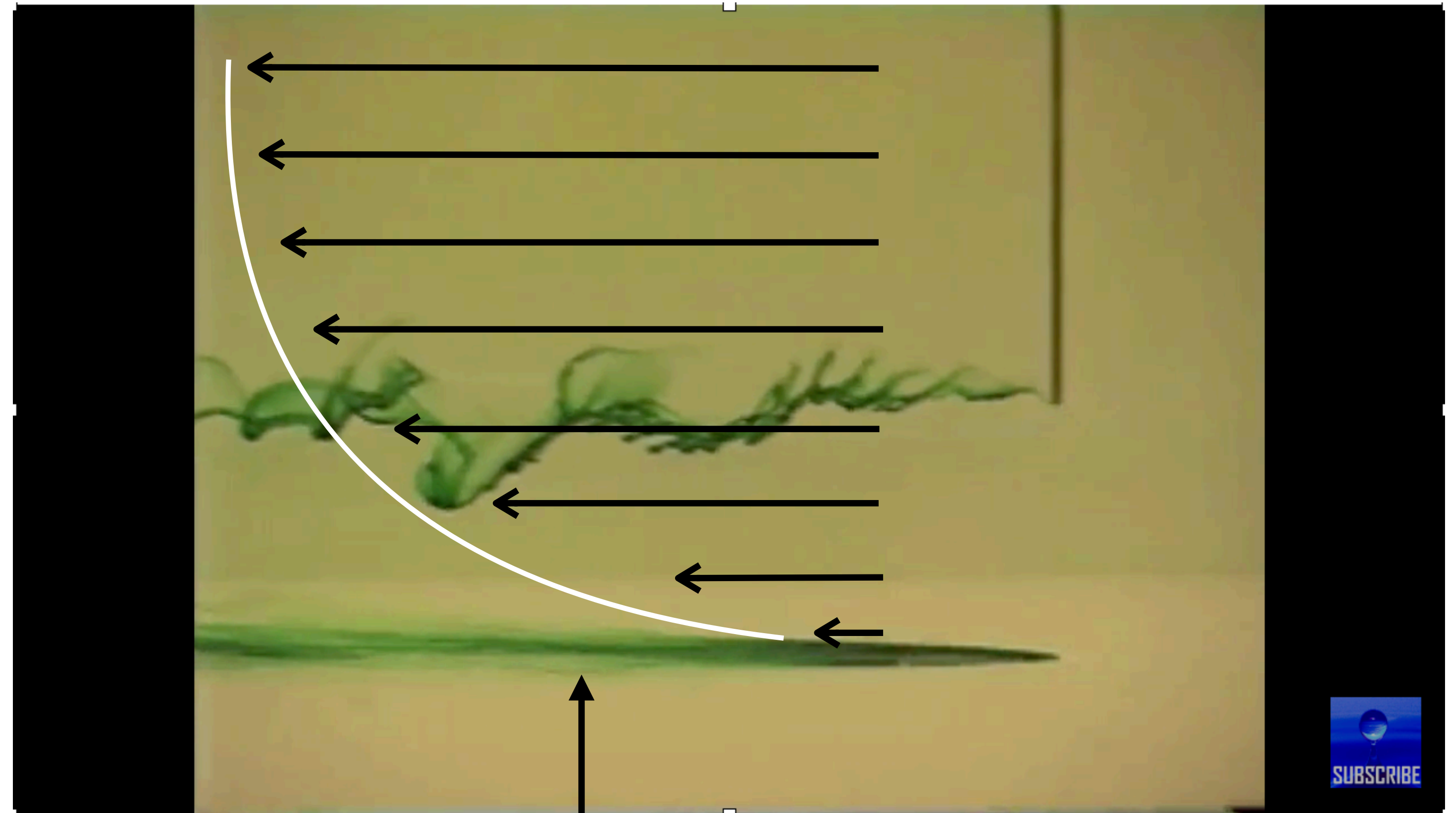
- All fluids will *stick* to a solid object, in a very small layer (“No-slip condition”)
- This causes ***shear*** between free flows and the solid surface (where speed is *zero*)
- The resulting gradient of speeds from 0 to free stream is called the ***boundary layer***



D. Naylor, Toronto
Metro Univ

The boundary layer

- The velocity profile is always a curve, dropping sharply close to the surface.
- Odor patterns will look ***very different*** depending on where the source is in the boundary layer!



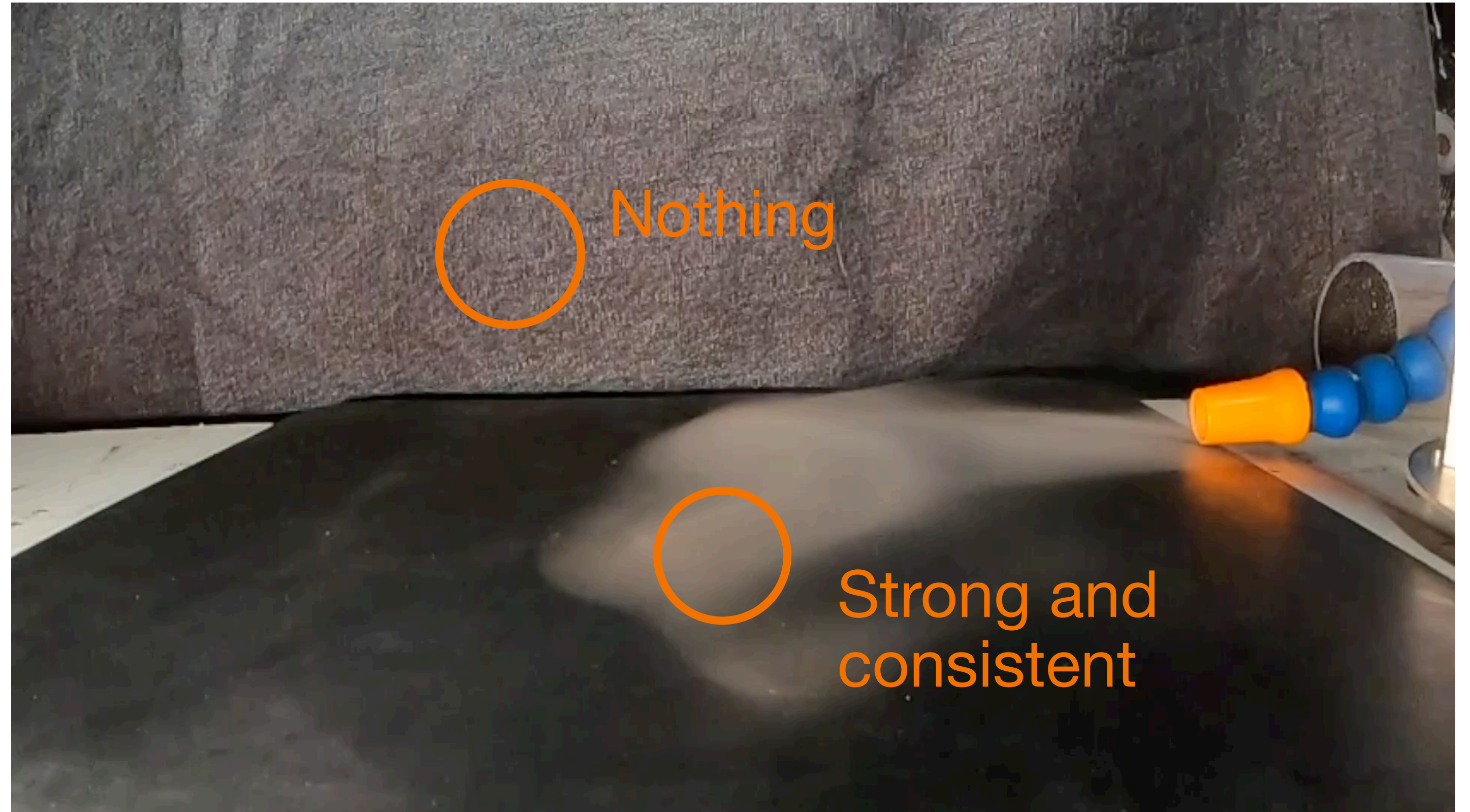
Viscous sublayer

D. Naylor, Toronto
Metro Univ



Odor pools in the viscous sublayer

- Very low air flow + very close to the surface
- Vapor is slightly more dense than the air, so is negatively buoyant
- Vapor largely pools and spreads along the surface



2x speed playback

How would odor make it out of the sublayer?

Escape from the viscous sublayer

- Inertia in flow overwhelms bottom layers in shear, trips over into “hairpin” vortices

Hairpin bursts

Fan producing slow, steady flow

- This happens even at **very low** flow speeds!

Low flows cause dramatically different odor patterns

Weak but consistent

- Flows can be so low you may not even notice them!

Strong but inconsistent

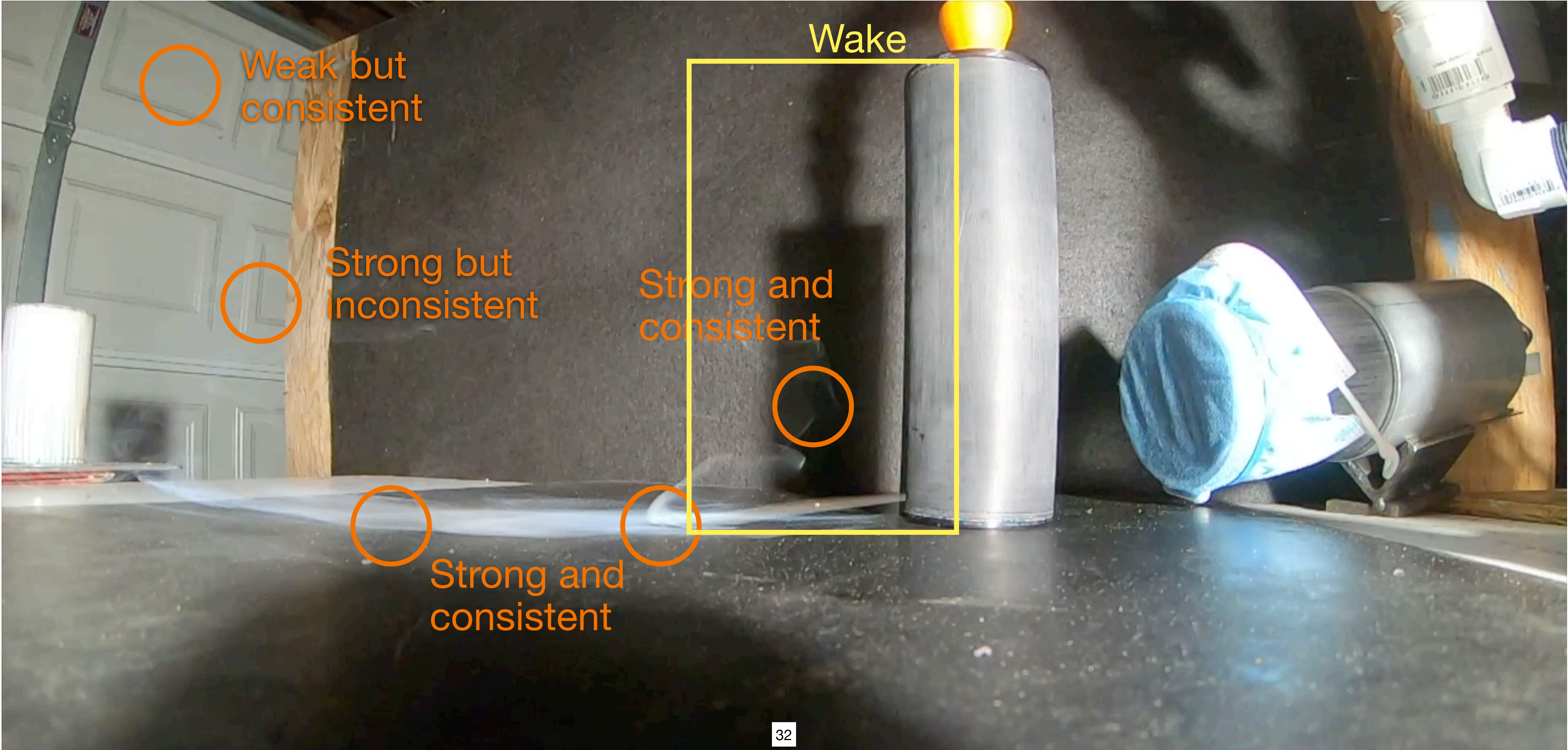
Nothing

Strong and consistent

- The **same** flow speeds can produce different patterns!

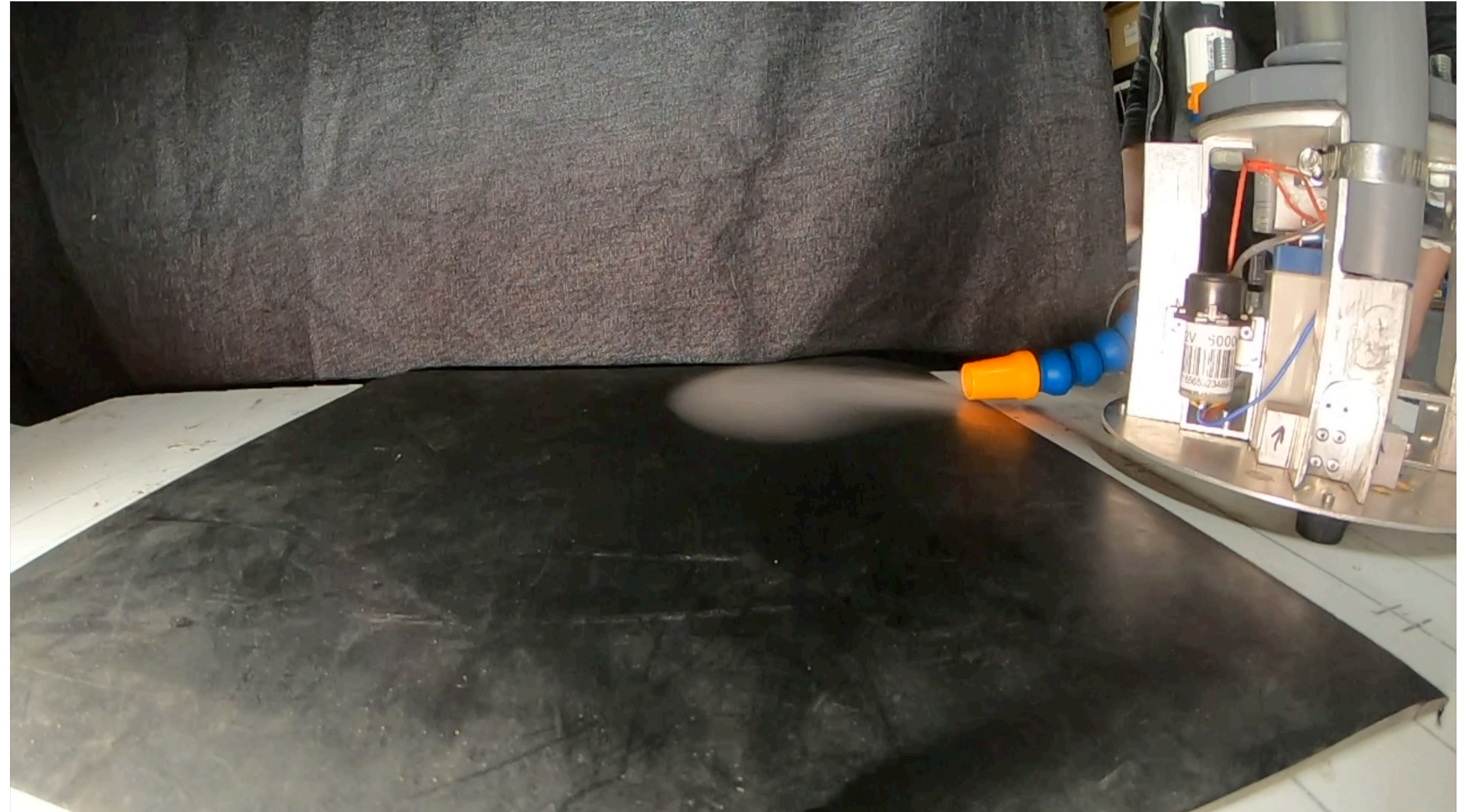
An errant puff of air trips this into unsteady flow!

Wakes drive vertical movement of odor & mixing



Beware YOUR wake!

- Slow flows are **unstable** and prone to dramatic change based on **small inputs!**
- My wake was enough to drag this odor pool onto the floor!



2x speed playback

Turbulence mixes and transports odor

○ Weak but consistent

○ Nothing

○ Strong and consistent

Factors that influence turbulent mixing:

- air speed
- objects and vegetation
- surface roughness
- uneven heating
- surface terrain

How air moves: takeaways

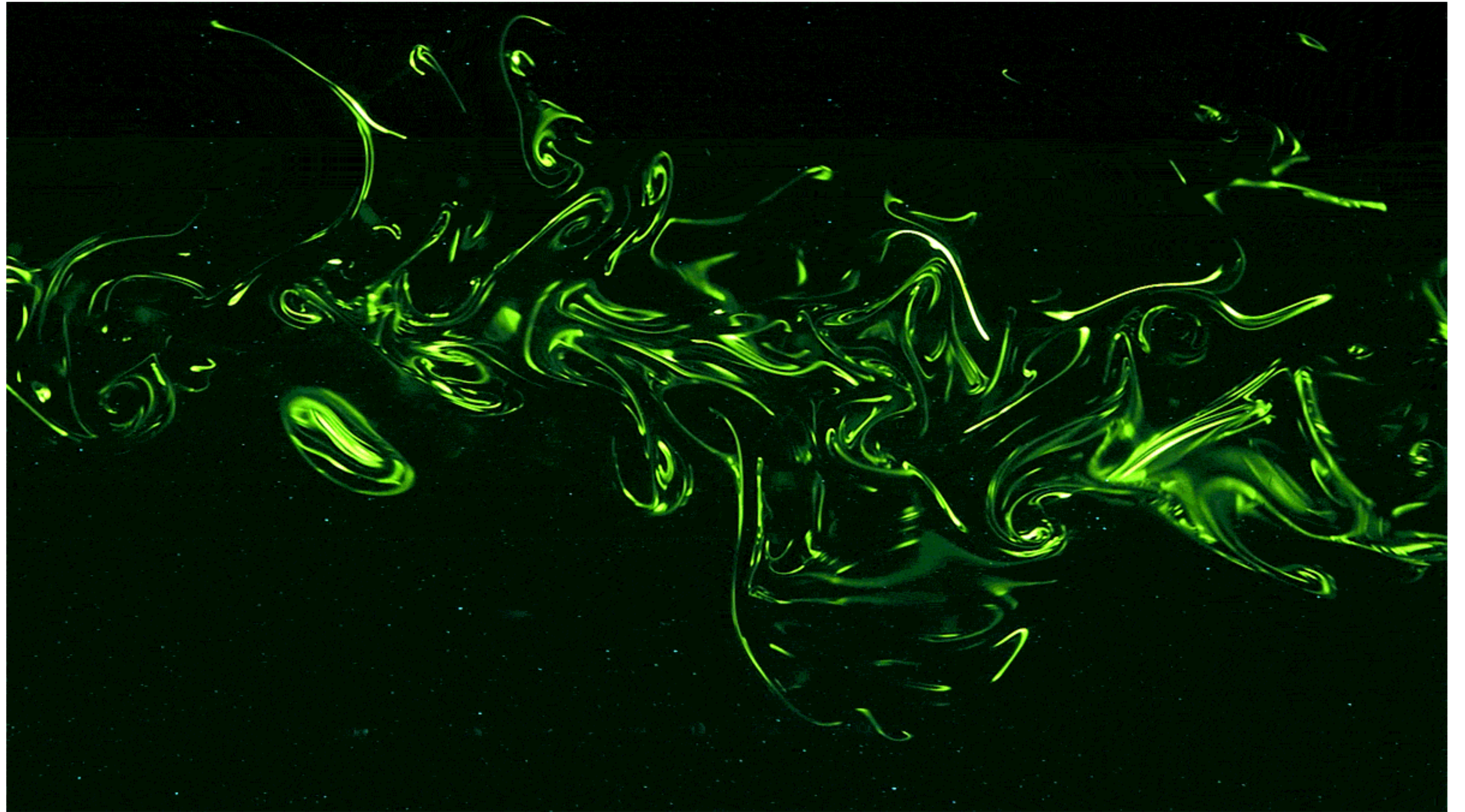
- Fluid behaves ***differently at different scales***, each scale affects the **intensity, mixing, and transport of odor**.
- Fluid sticks to solid surfaces creating a **boundary layer**. The layer can collect odor, but it is ***very unstable and sensitive to small flows***.
- Solid objects can create **wakes**, which ***vertically transport*** and ***mix odor***.
- **Turbulent** flows ***mix*** and ***transport*** odors.

2. Air Movement

***Why* does air move?**

***How* does air move?**

***Where* does air move?**



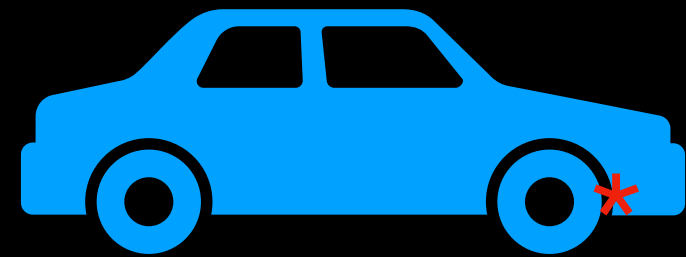
Brian Gill, Univ. of
Colorado, Boulder

Where does air move odor?

- **Probably not where you think!**
- Scenarios to challenge your understanding of odor movement:
 - ➡ Scenario 1: Vehicle hide in a parking lot
 - ➡ Scenario 2: Single source hide in a room
 - ➡ Scenario 3: Elevated hide in a room

Scenario 1: Vehicle search in a parking lot

- Sunny day in large parking lot with blacktop, no wind
- Hide under front wheel well near base of car, inaccessible



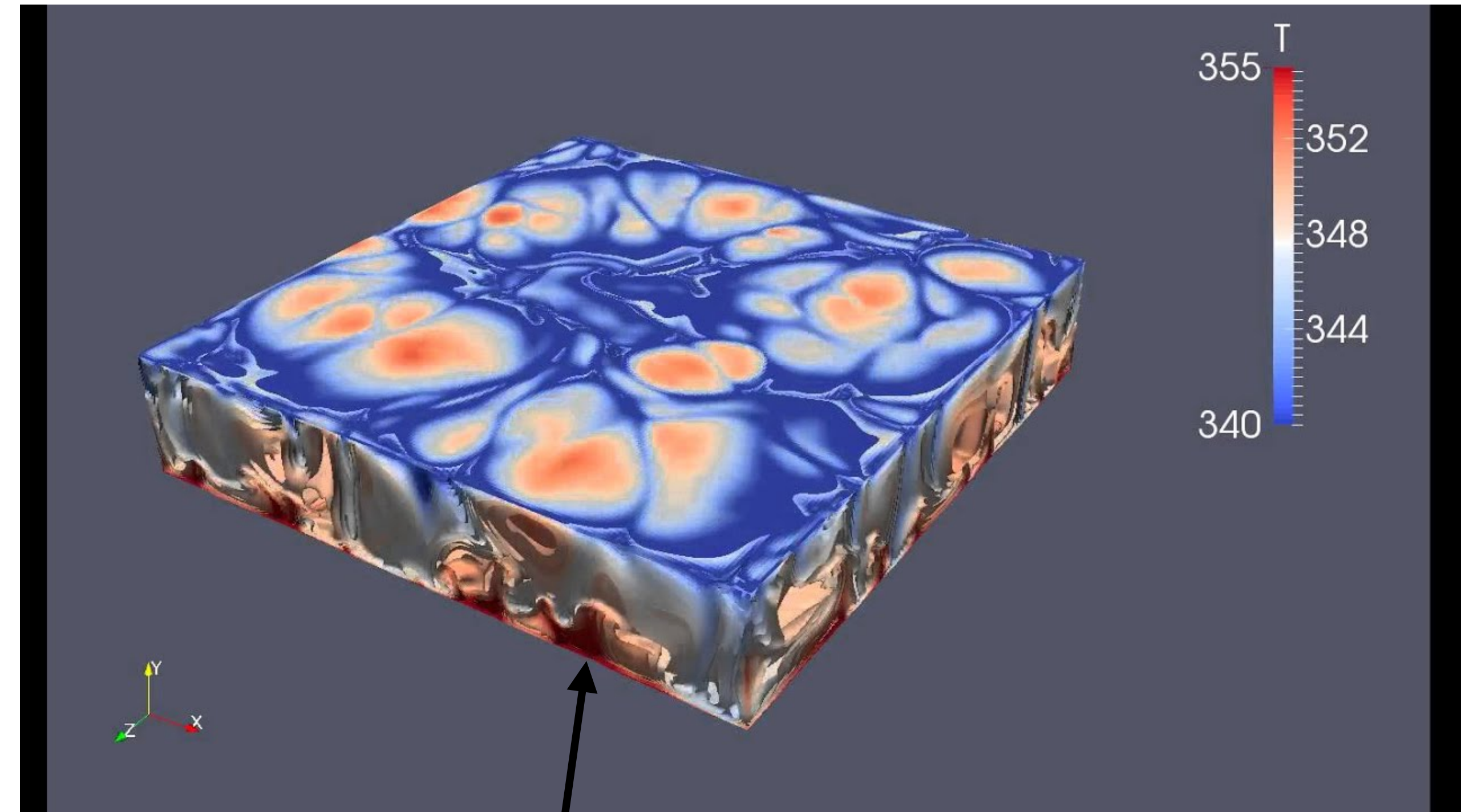
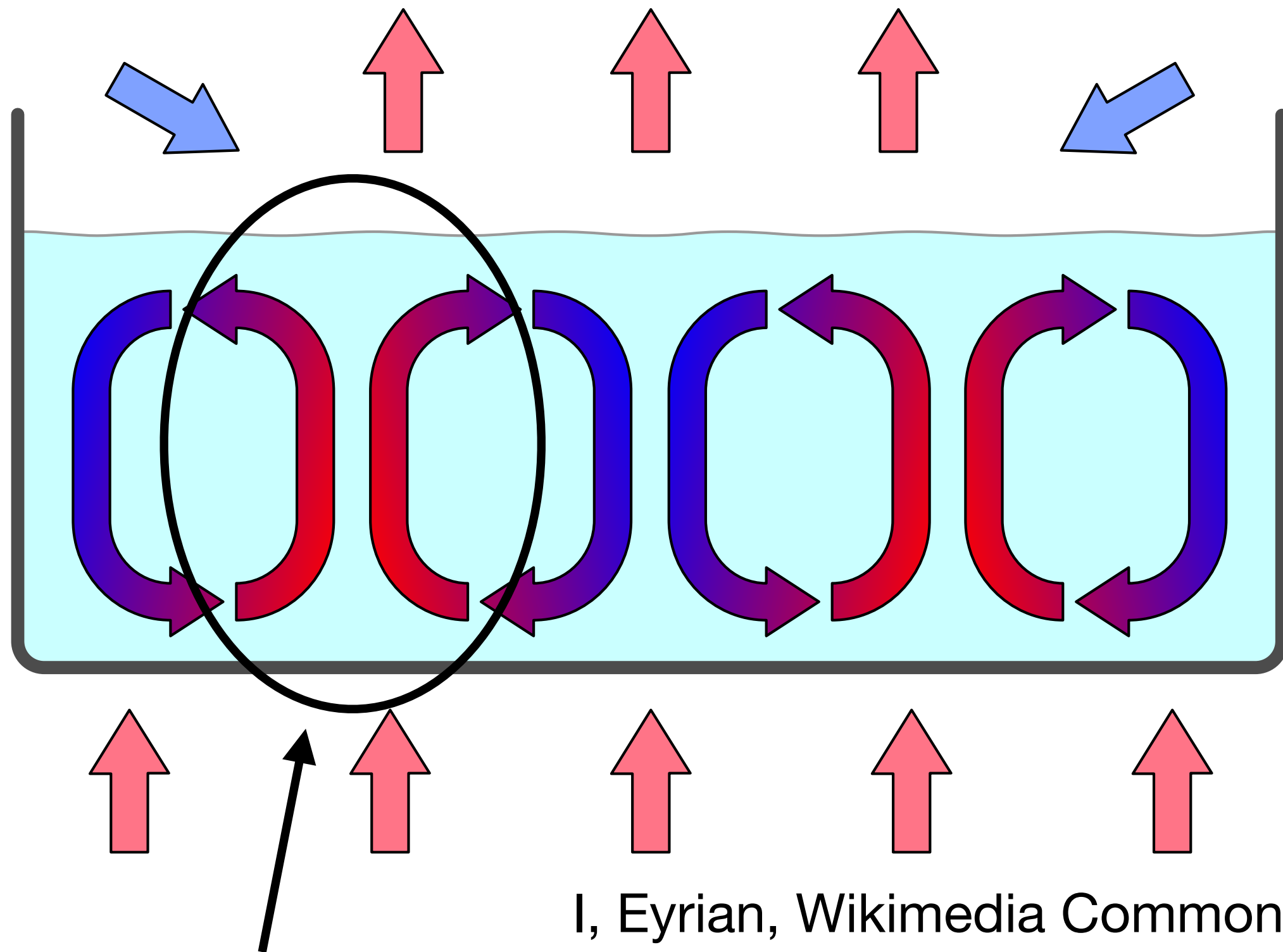
Scenario Analysis:

Where is the odor traveling?

Where is the dog most likely to pick it up initially?

Flow driven by temperature differences

Surface heating can drive Rayleigh-Bénard convection



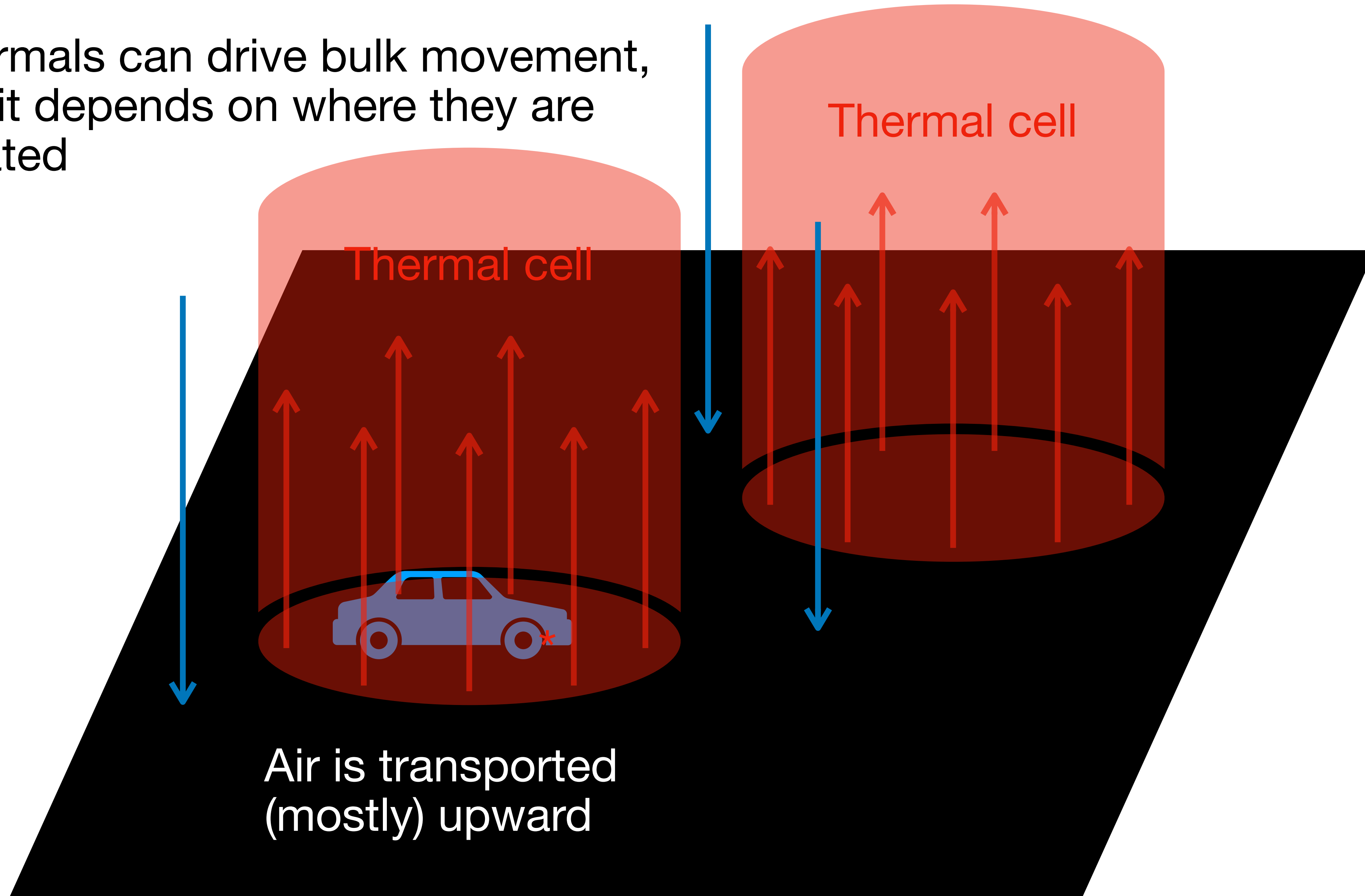
Thermals occur over:

- Parking lots
- Dark-color ground
- Dirt fields

Local air movement can be counterintuitive and unstable

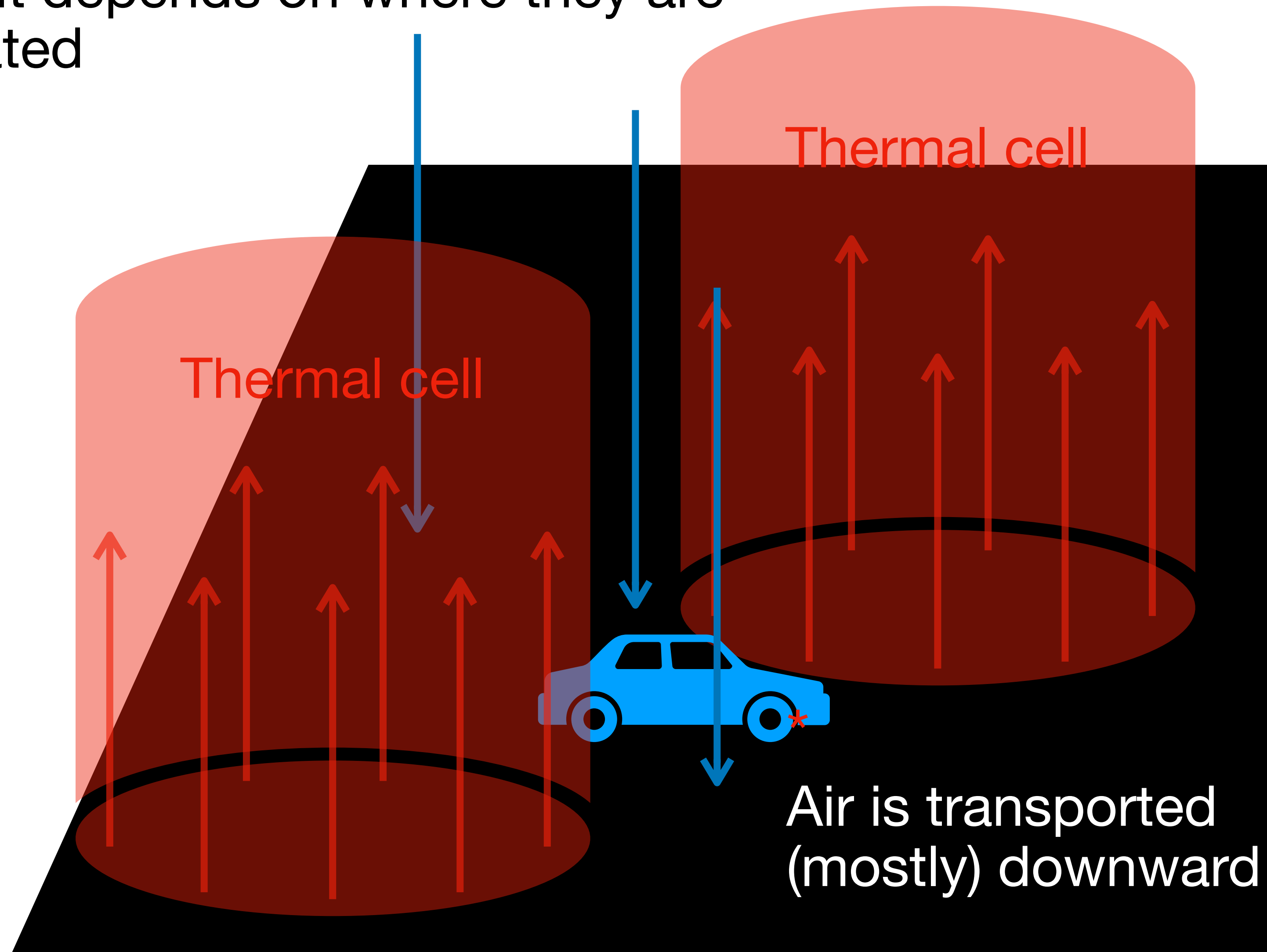
Large-scale flow: in a parking lot

- Thermals can drive bulk movement, but it depends on where they are located



Large-scale flow: in a parking lot

- Thermals can drive bulk movement, but it depends on where they are located

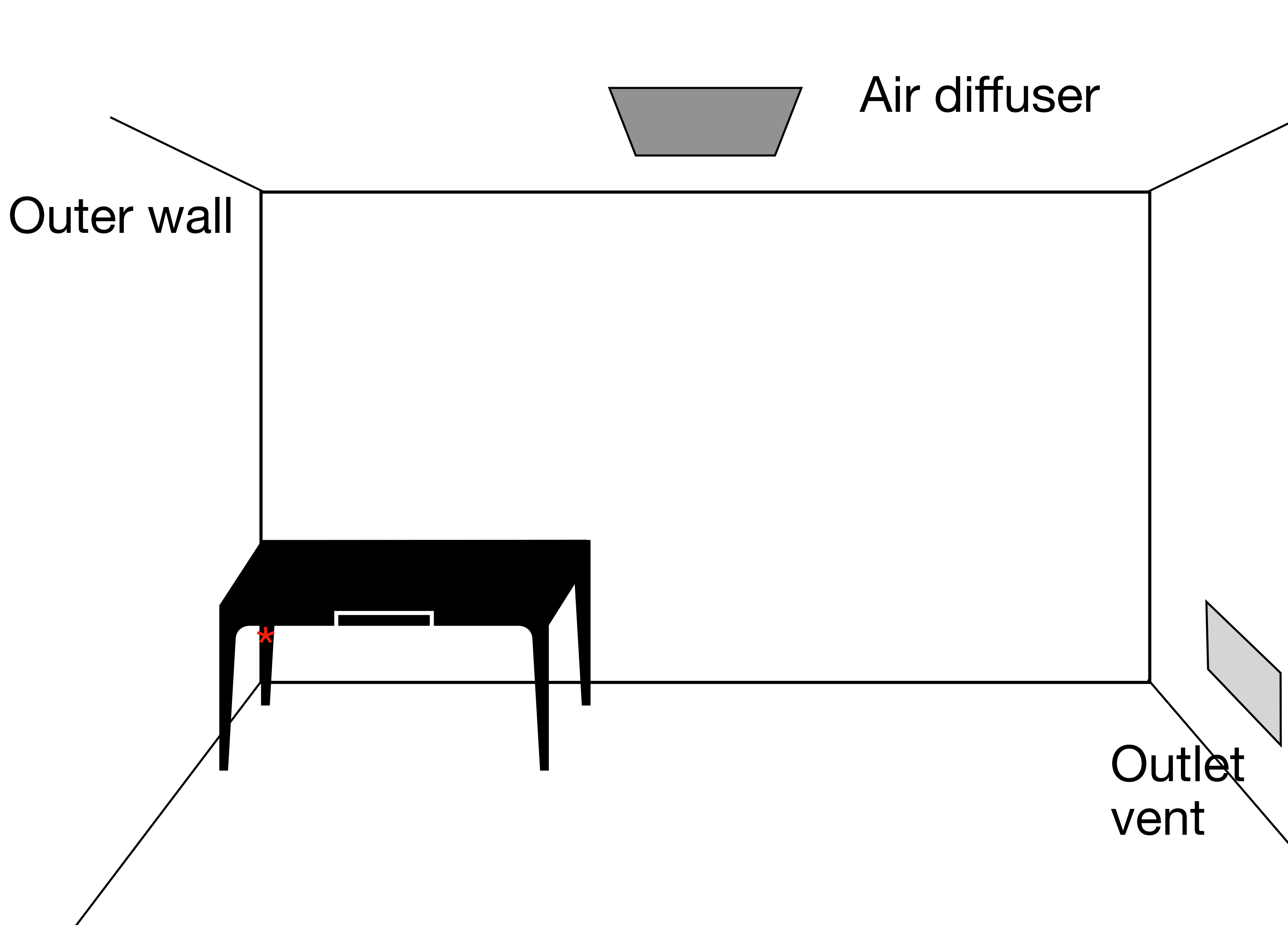


Scenario Analysis:

Depends on many factors.

Likely unable to predict.

Scenario 2: Single source hide in a room



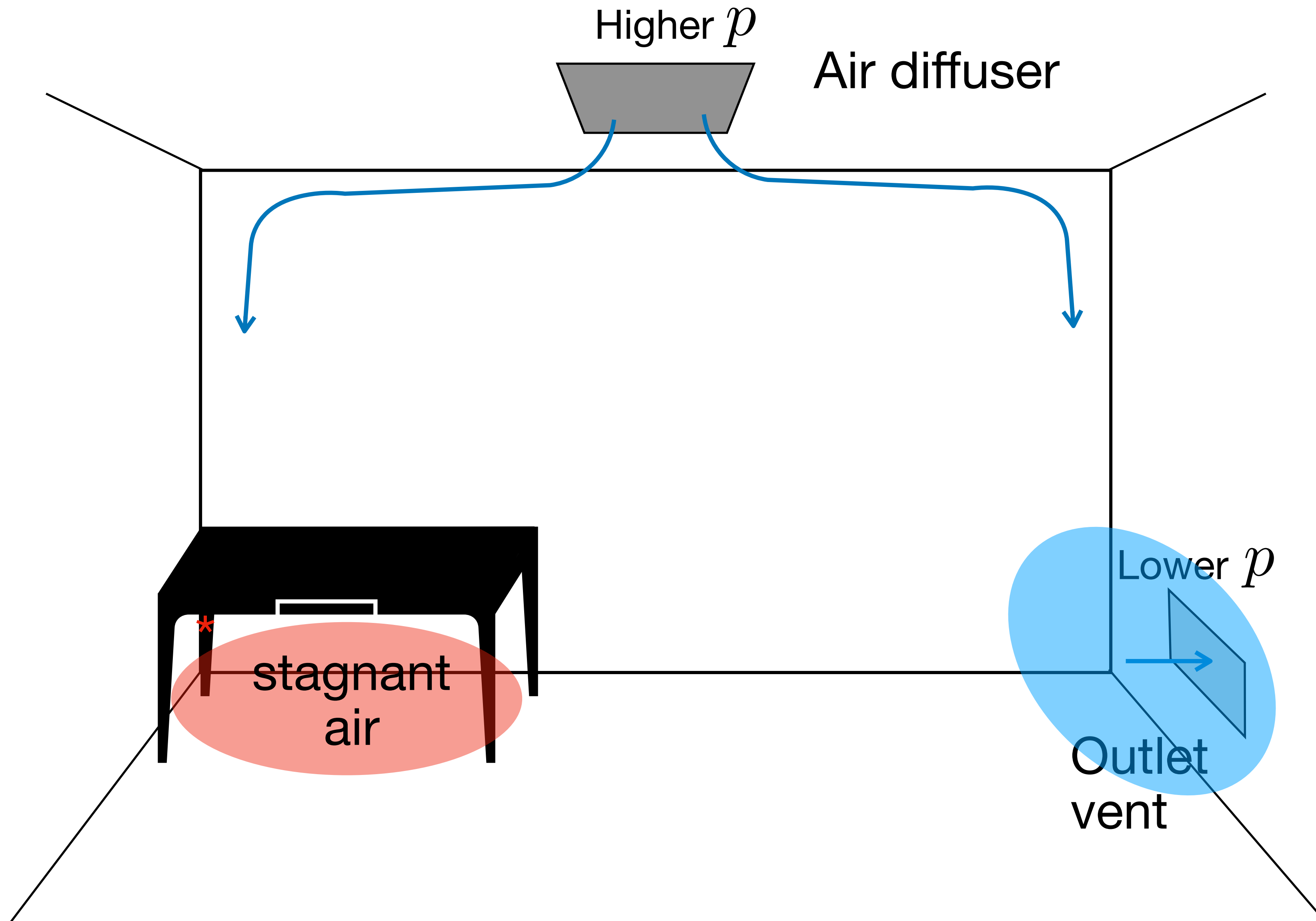
- Single source in a room, underneath table in corner
- HVAC is on
- Room shares a wall with the south-facing outer building wall

Scenario Analysis:

Where is the odor traveling?

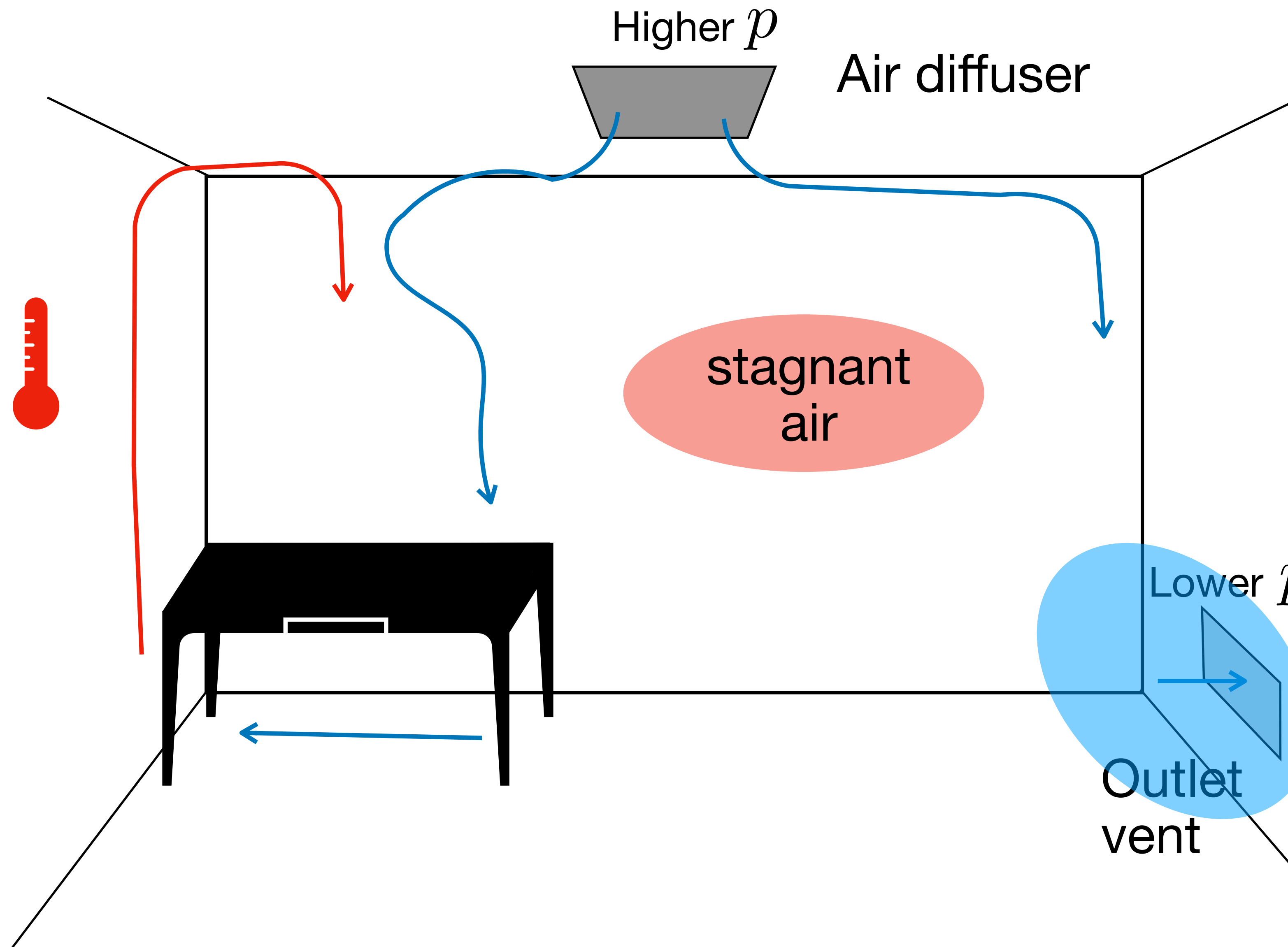
Where is the dog most likely to pick it up initially?

Scenario 2: Single source hide in a room



- HVAC systems are generally designed to minimize stagnant air, but results may vary!
- Variables like **diffuser shape, outlet placement, furniture placement, and wall temps** can influence bulk flow
- Stagnant air may collect odor like a container

Scenario 2: Single source hide in a room



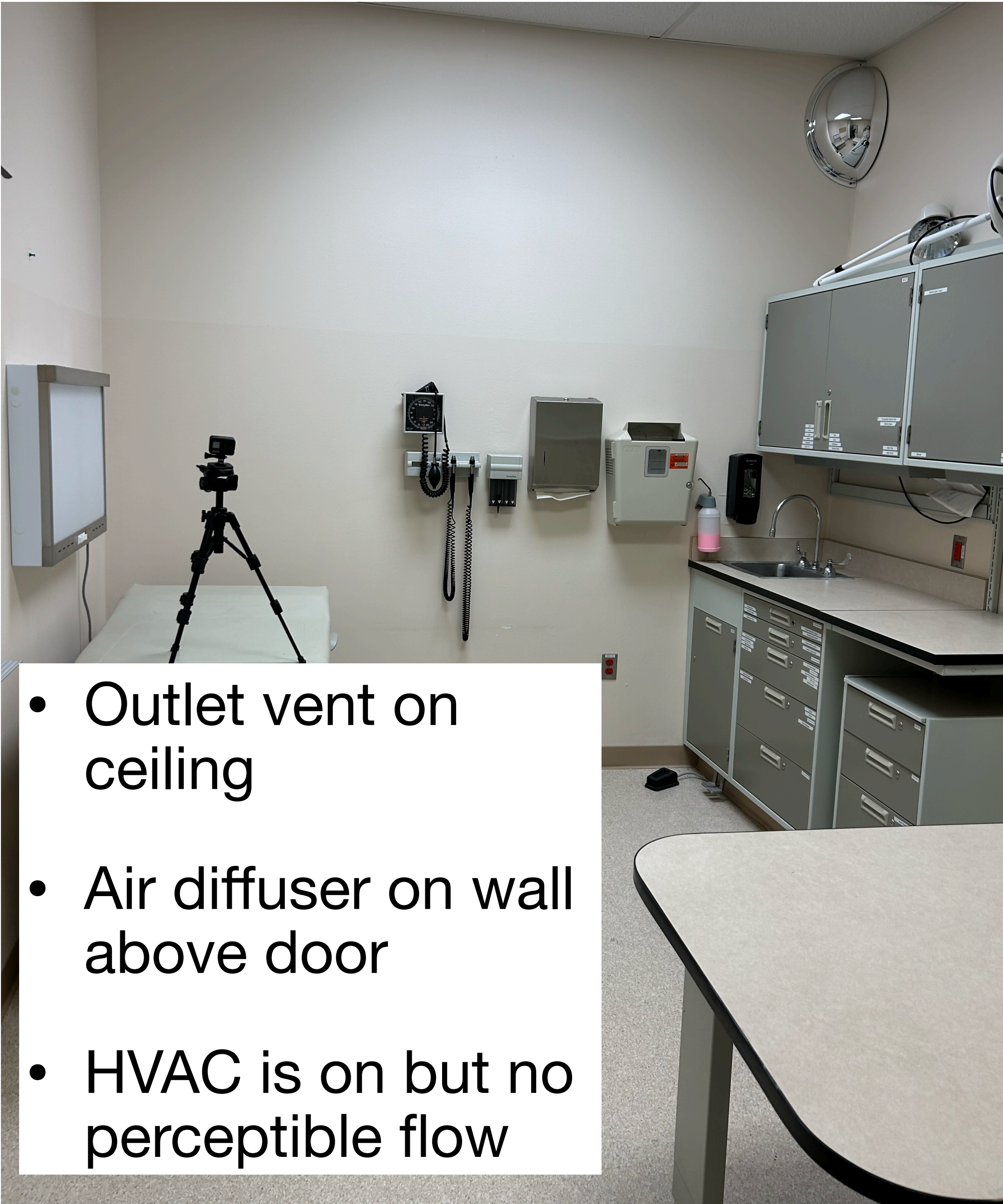
- Outer wall heating will change flow patterns drastically!

Scenario Analysis:

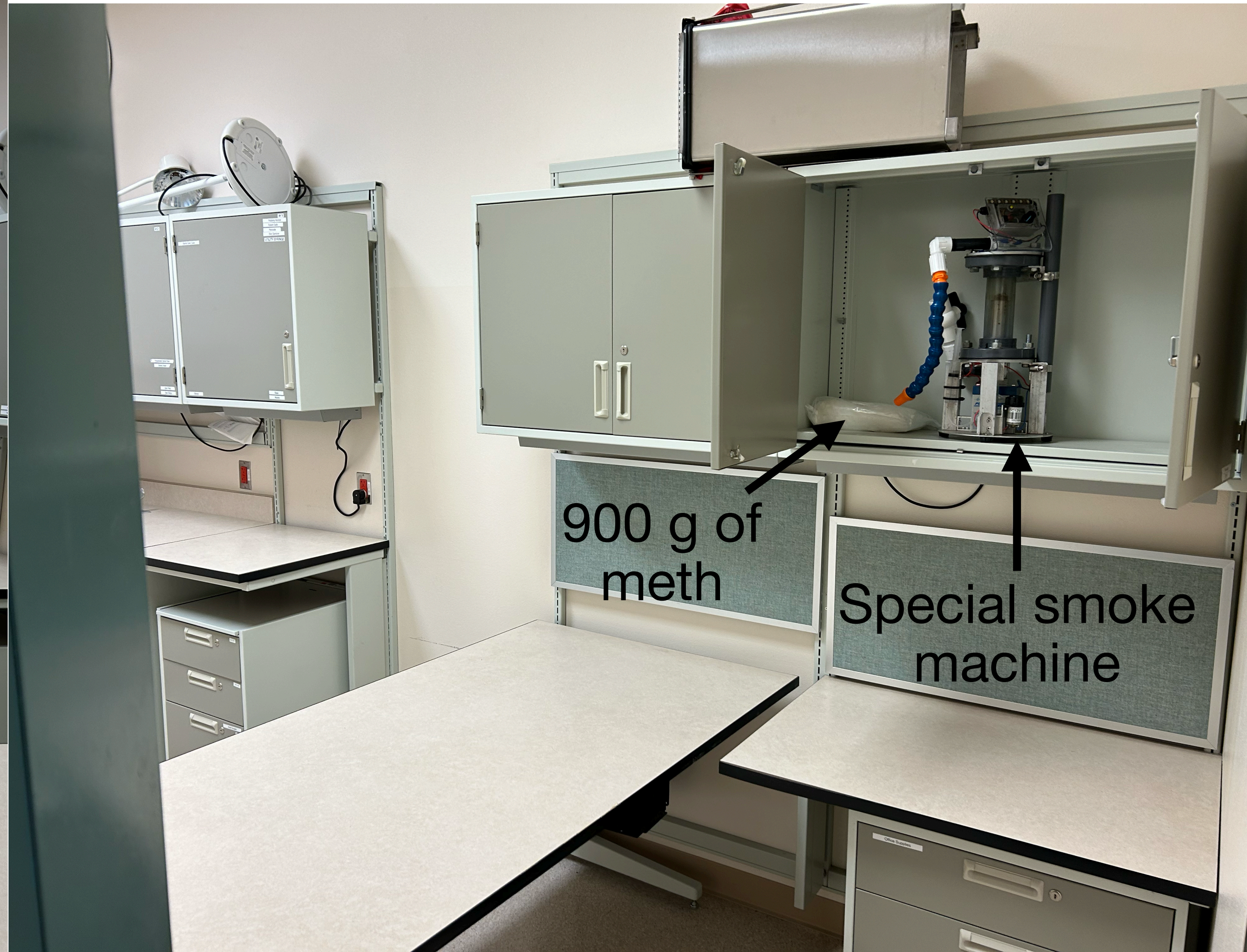
Depends on many factors.

Likely unable to predict.

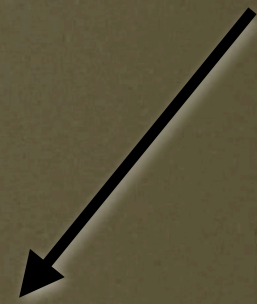
Scenario 3: Elevated hide in a room



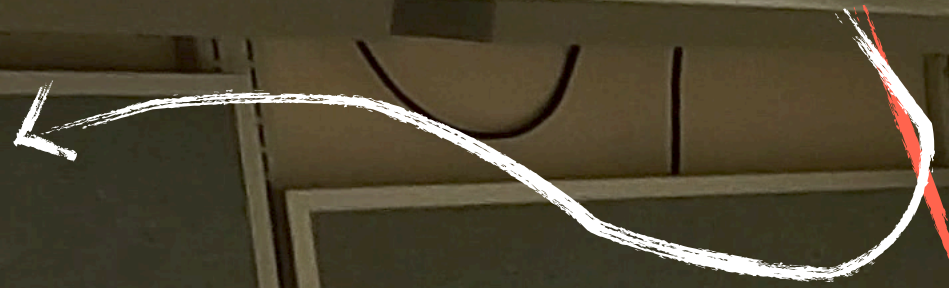
- Outlet vent on ceiling
- Air diffuser on wall above door
- HVAC is on but no perceptible flow



Hide is here



where smoke moves



where we thought
the odor would go



Scenario Analysis:

Where is the odor traveling?

Where is the dog most likely
to pick it up initially?

Hide is here



Where does air move odor?

- Probably not where you think!
- Each scenario has challenging aspects that make predictions exceptionally difficult.
- Two takeaways from this:
 1. You ***already*** have a good intuitive sense of where odor is from watching dog behavior. They are your sensors!
 2. Avoid telling stories about odor movement.

Where does air move odor?

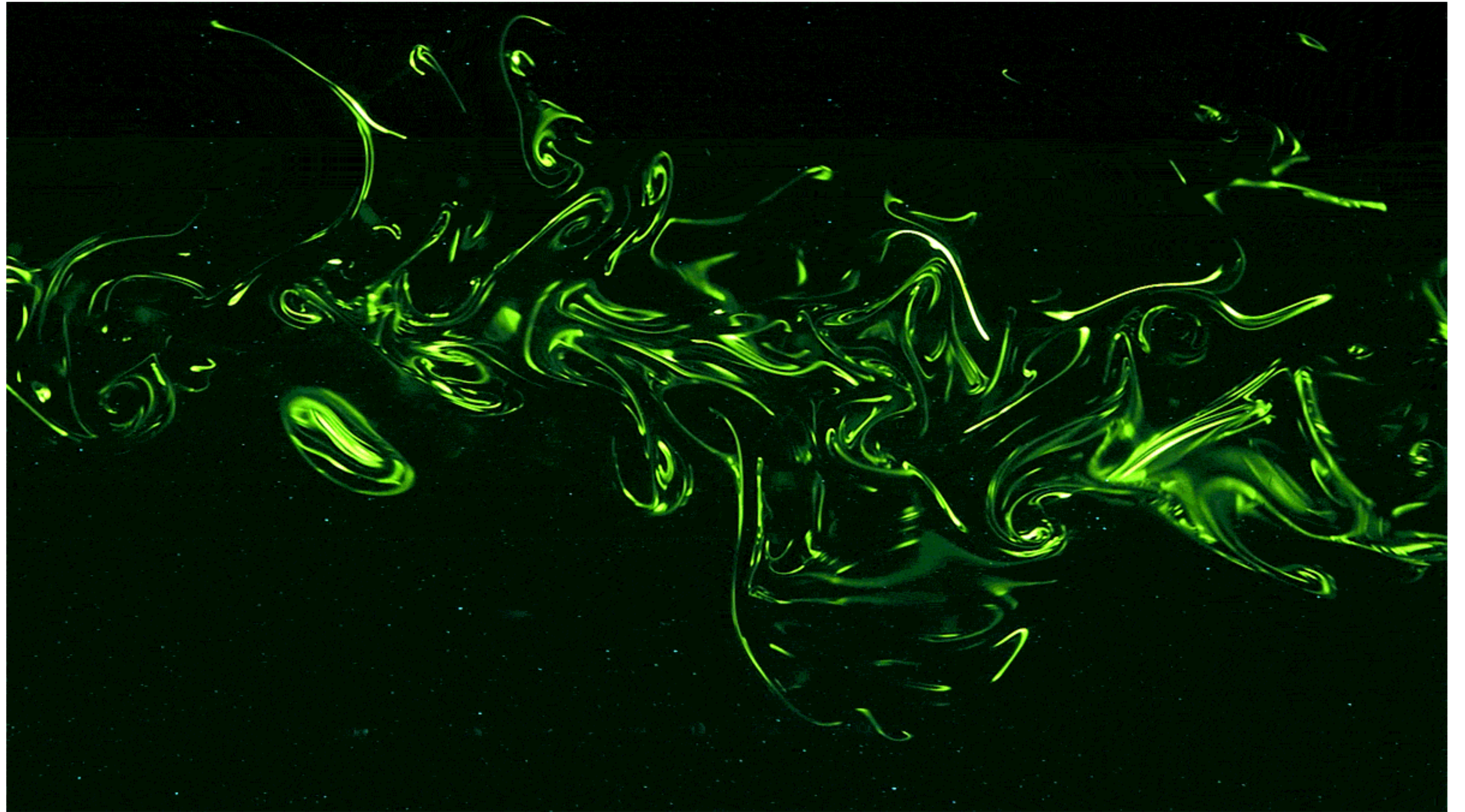
- Advice for training and running your dog:
 - During training:
 - ➡ ***Exposure***: work different flow scenarios into your training.
 - ➡ ***Flow visualization***: will help ensure that you understand your dog's behavior
 - During runs:
 - ➡ ***Flow visualization***: basic information is helpful but not the end of the story.
 - ➡ ***Hypothesis testing***: treat ideas about odor movement as hypotheses that your dog can test for you.

2. Air Movement

Why does air move?

How does air move?

Where does air move?



Brian Gill, Univ. of
Colorado, Boulder

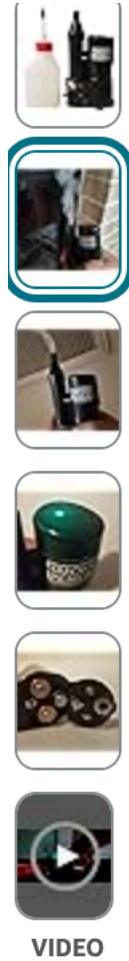
Let's talk flow visualization!

Flow visualization

- **Qualitative** flow visualization is important to set up training scenarios and gather basic information during searches.
- Basic idea: add something we can see to the movement of air that's relevant to odor.
- Covered in this section:
 - ➡ **Tools to help you visualize flow**
 - ➡ **Guidelines for using the tools in different conditions.**

Flow visualization tools and options

BEST Options: Smoke/vape machines



- Unlikely to set off smoke alarms (when used judiciously)

- Smoke Pencil for HVAC leak detection: \$36
<https://www.amazon.com/Smoke-Pencil-ONE-Leak-Detection/dp/B09MJMYZNG>

- LENS GO Smoke Machines: \$80-128
<https://www.amazon.com/LENSGO-Hand-held-Portable-Photography-Disinfection/dp/B0CKHG23YR/>

- Capable of producing cool smoke appropriate buoyancy

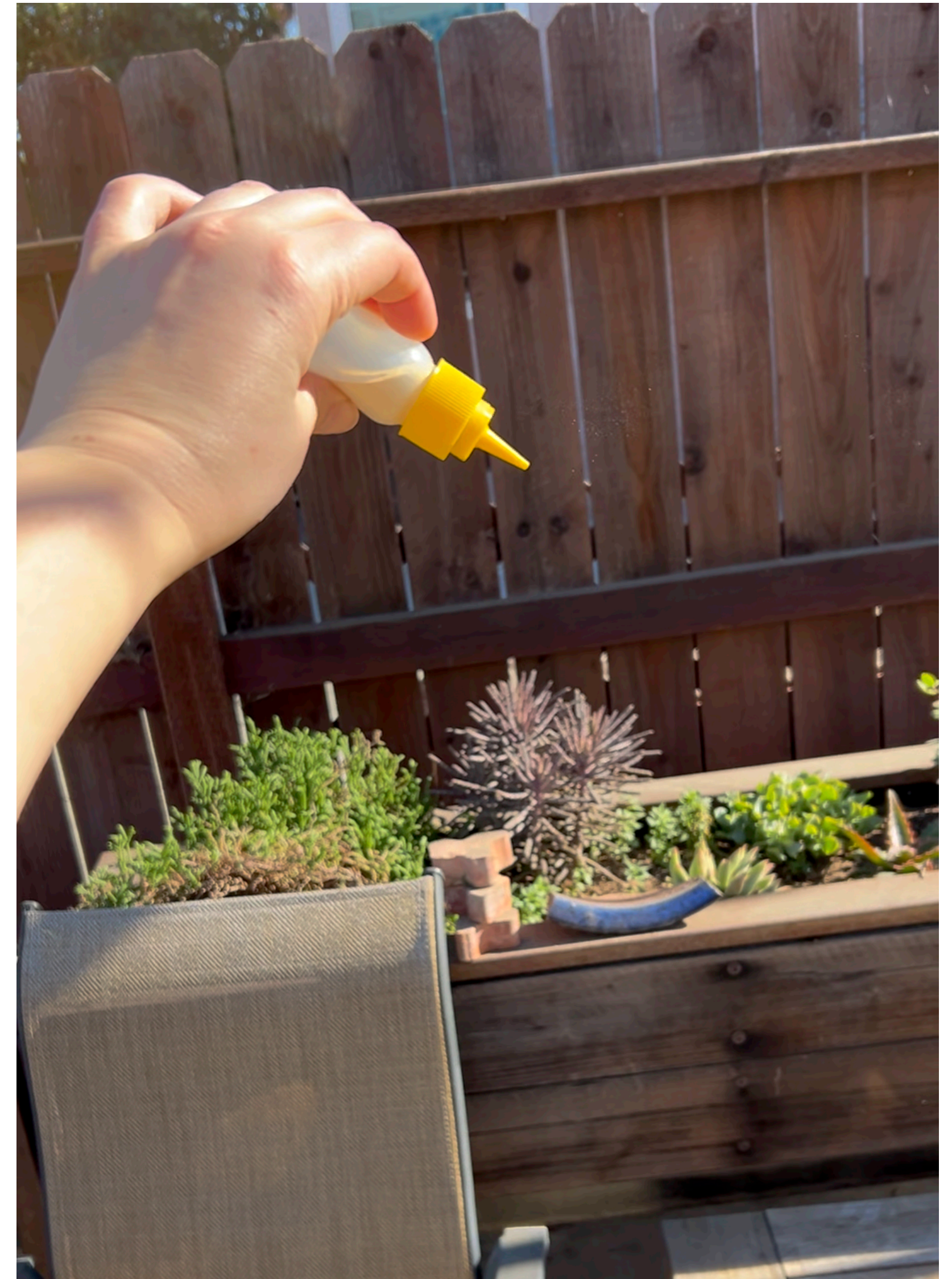


Flow visualization tools and options

OK Options: light-weight powders



- Lycopodium powder (club moss spores): \$18
<https://www.amazon.com/CHEMICALSTORE-COM-Lycopodium-Powder-40-grams/dp/B0D8BWSKYQ/>
- good for basic wind direction/strength
- limited use beyond this

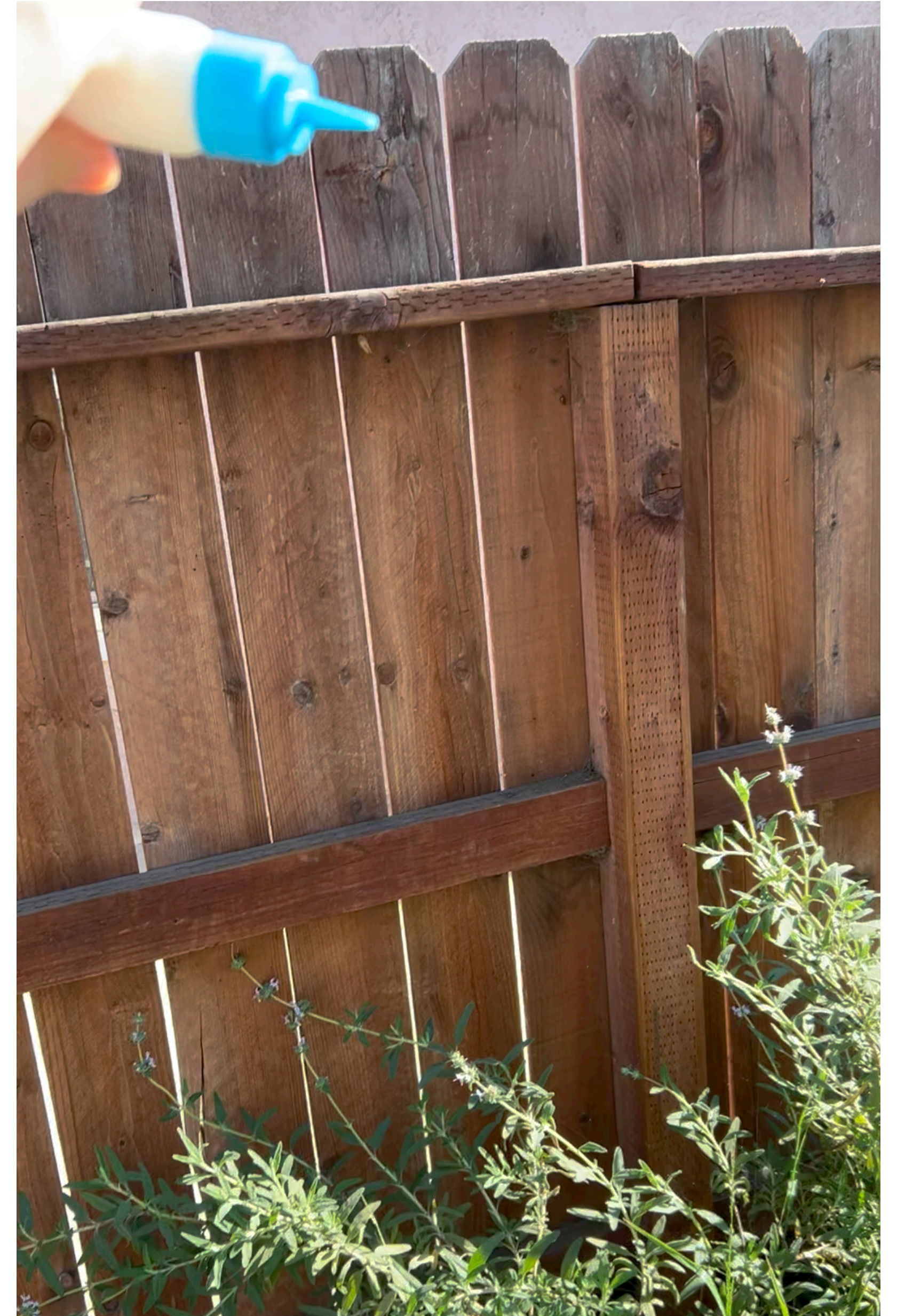


Flow visualization tools and options

OK Options: light-weight powders



- Corn starch ~\$1.50 (any grocery store)
- good for basic wind direction/strength
- limited use beyond this



Flow visualization tools and options

NOT Recommended: smoke bombs



- Orixia Smoke Pellets: \$34
<https://www.amazon.com/ORIXA-Pellets-Photography-Parties-Dramatic/dp/B0D8G876MM/>
- good for high wind speeds and visualizing long distances
- not recommended for other uses!

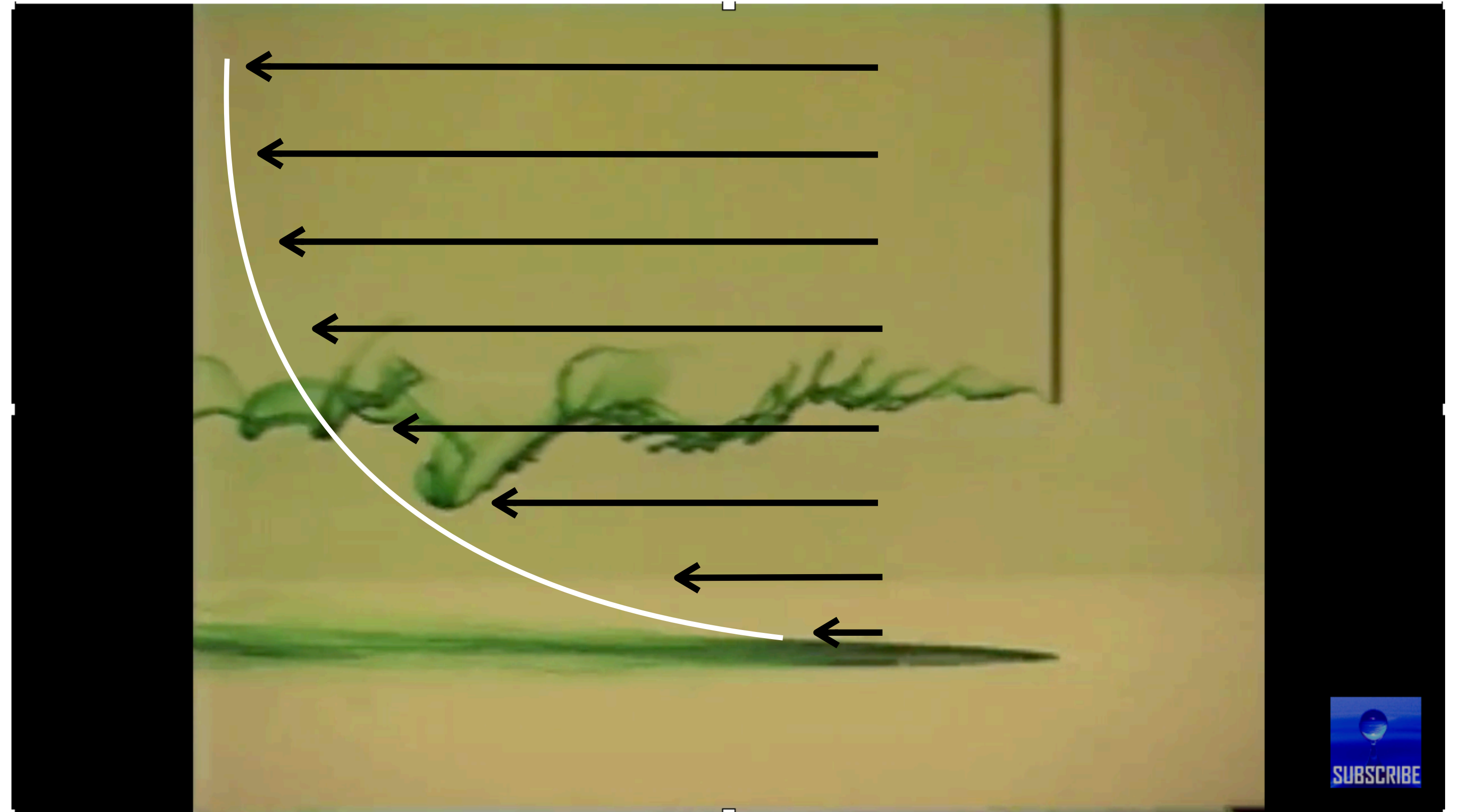


Flow visualization Guidelines

- Accurately visualizing odor movement depends on ***three*** factors:
 1. **Position of source in boundary layer**
 2. **Buoyancy of visualization material**
 3. **Relative speed of flow**

1. Position in the boundary layer

- Odor patterns will look ***very different*** depending on where the source is in the boundary layer!
- Where odor ends up will also be very different!



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Metro Univ

**Position your visualization material/device at
the same position as the source!**

2. Buoyancy of viz material

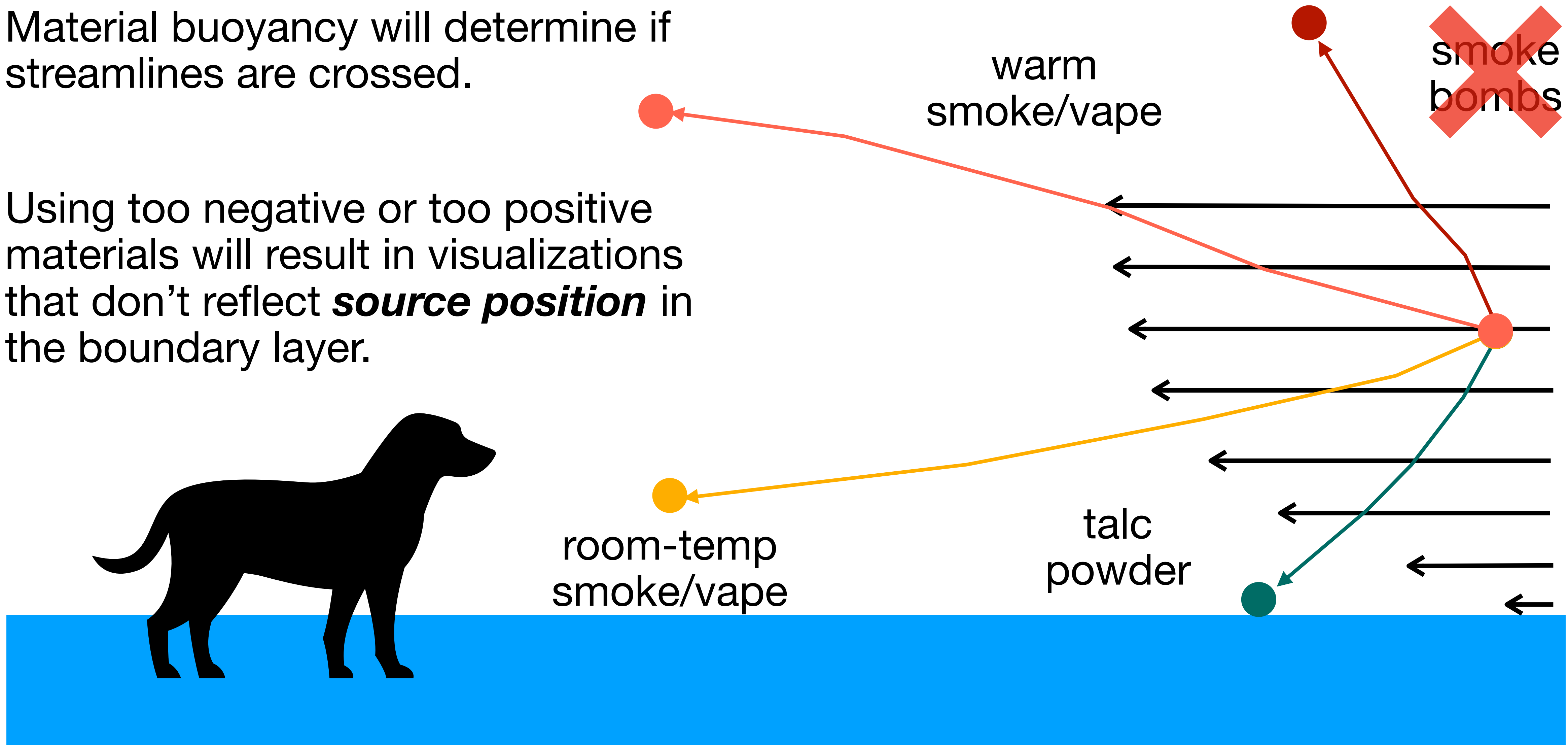
Very negative

Slightly negative

Very positive

Slightly positive

- Material buoyancy will determine if streamlines are crossed.
- Using too negative or too positive materials will result in visualizations that don't reflect **source position** in the boundary layer.



Good buoyancy matches



Bad buoyancy matches



3. Relative flow speed

- Relative to what? Buoyancy of material!
 - The slower the flow the ***more important*** it is to match buoyancy of the viz material to source odor.
 - The faster the flow the ***less important*** it is to match buoyancy of the viz material to source odor.

Low wind speed



Smoke machine (cooled)



Smoke bomb

Variable wind speed



- As wind speed increases, there is a smaller difference in the travel of the two materials.

Smoke machine (cooled)



Smoke bomb

Flow visualization done right!

- Accurately visualizing odor movement depends on ***three*** factors:
 1. **Position of source in boundary layer**
 2. **Buoyancy of visualization material**
 3. **Relative speed of flow**
- All three should be taken into account when choosing a visualization tool and/or material!
- ***There is no one-size-fits-all recommendation!***

Bringing It Together

- Odor plumes have a complex structure over space and time, presenting dogs with a discontinuous signal to track.
- Odor movement is a combination of factors including physical factors and fluid movement.
- Fluid movement is a complex problem that has several scales.
- Fluid visualization requires appropriate tools and deployment to accurately understand odor movement.
- Improving search success will depend on taking into account fluid flow during training and deployment.

Thank you for attending!

If you would like to download these slides as a PDF, go to <https://waldroplab.com/downloads> or use this QR code:



Please provide me feedback on the seminar so I can improve for next time!

You are welcome to contact me directly: waldrop@chapman.edu

Or fill out this anonymous survey: <https://forms.gle/E6nFrbyhBSXDPve49>



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