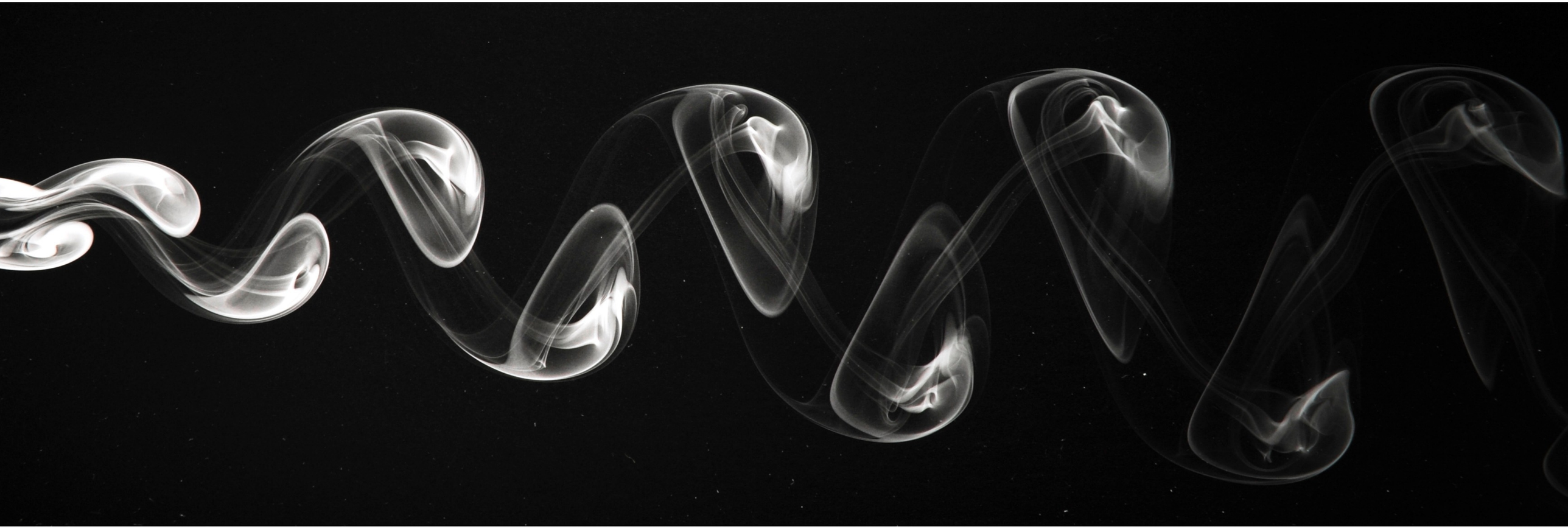
Odor Movement 101



Jürgen Wagner, Wikimedia

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https://waldroplab.com

As we begin…

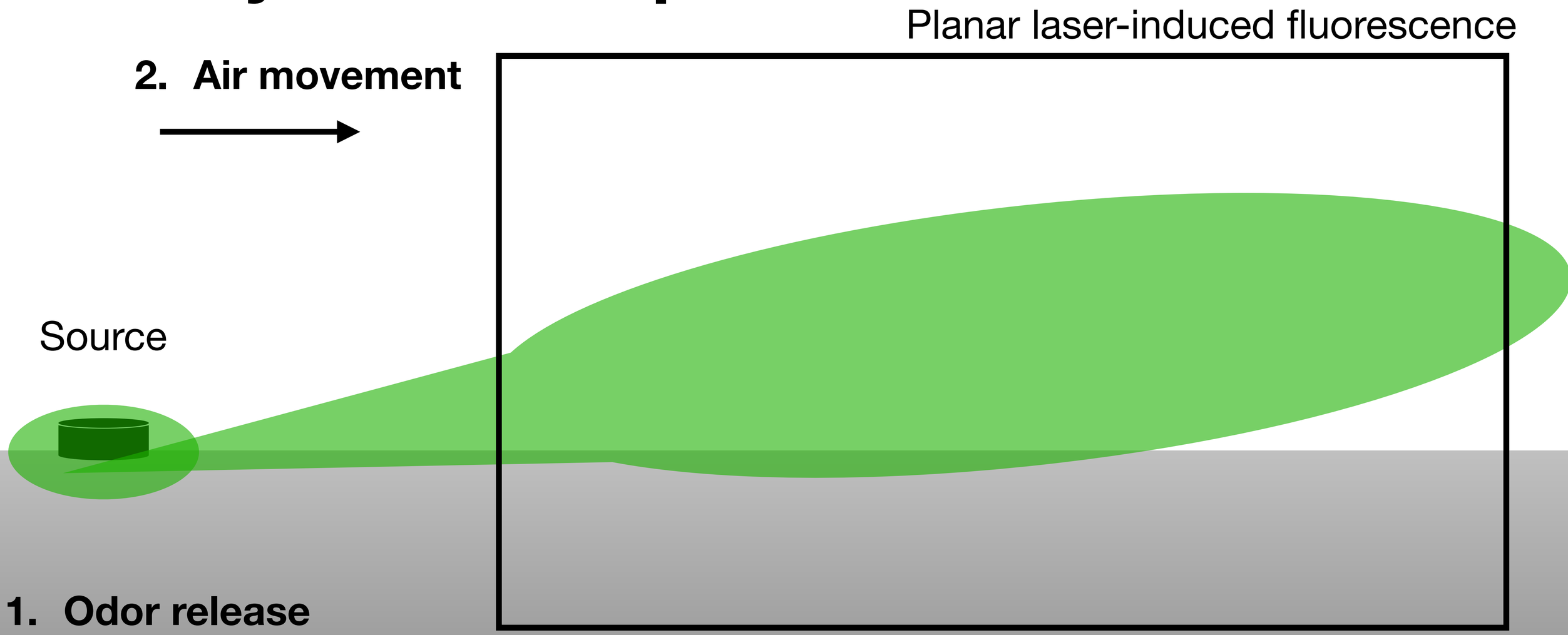
Download these slides!

- 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!

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

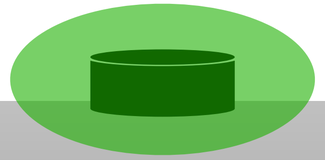


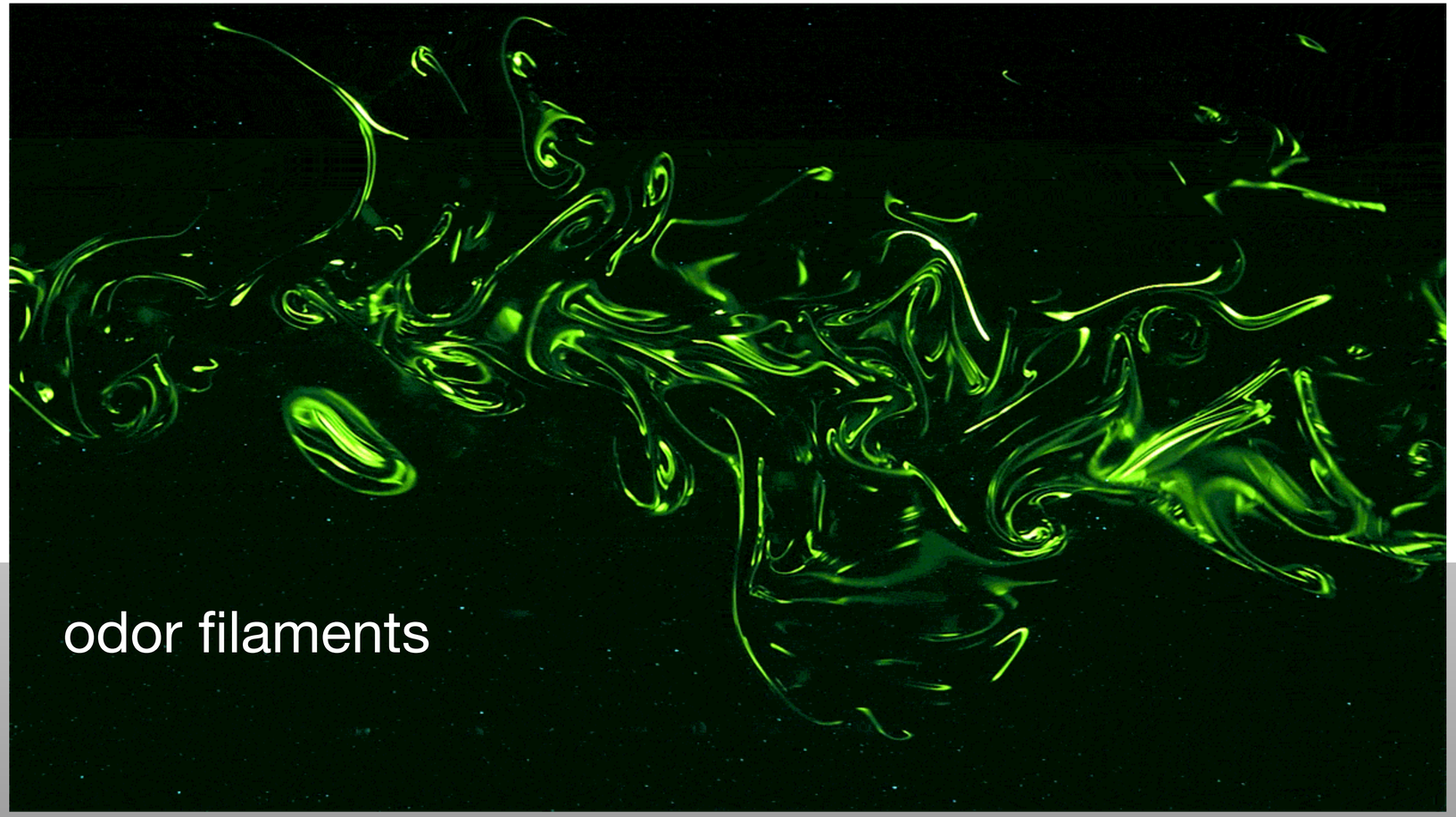
Anatomy of an odor plume

Planar laser-induced fluorescence

2. **Air movement**

Source

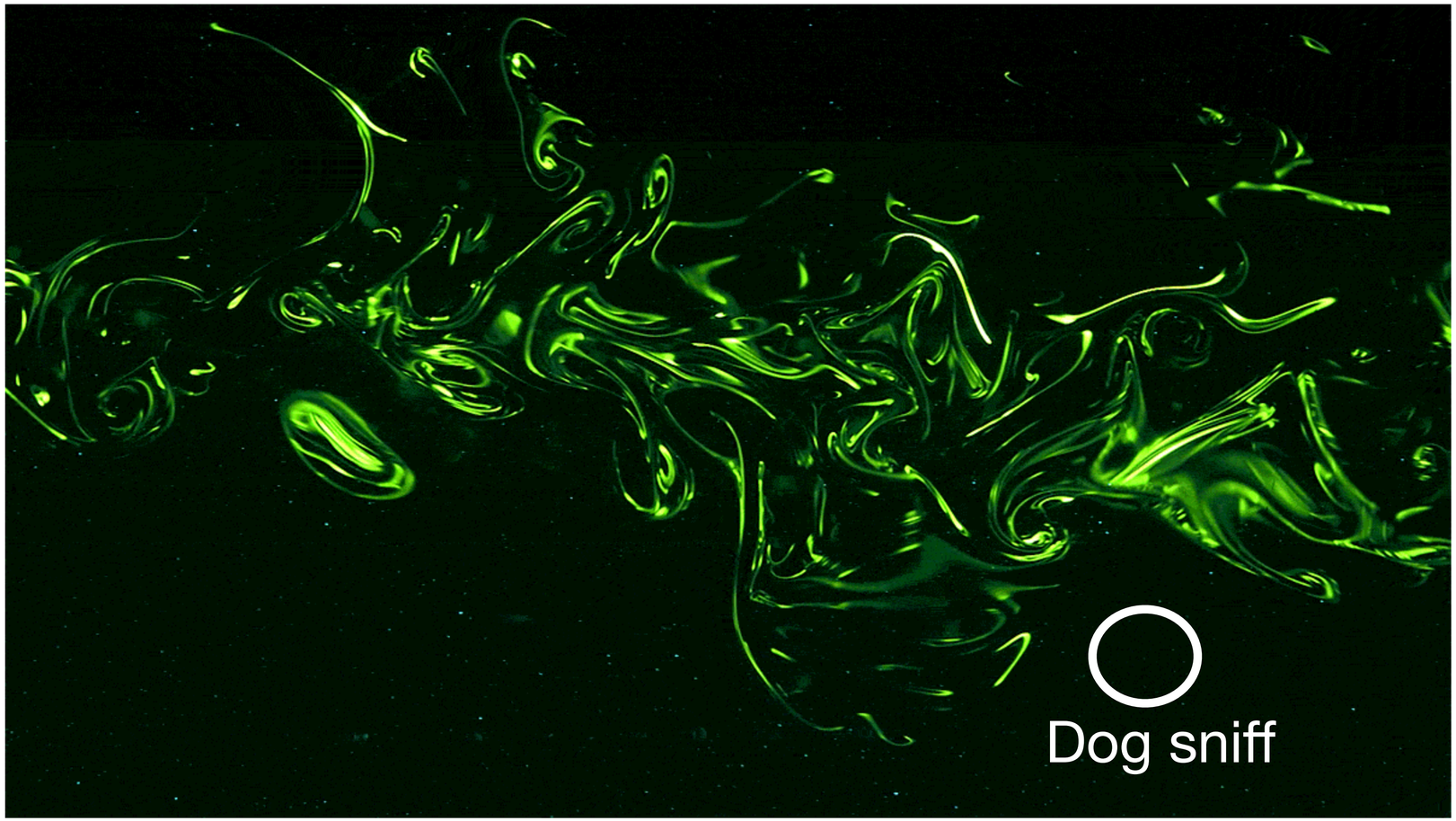




1. **Odor release**

Brian Gill, Univ. of Colorado, Boulder

Anatomy of an odor plume



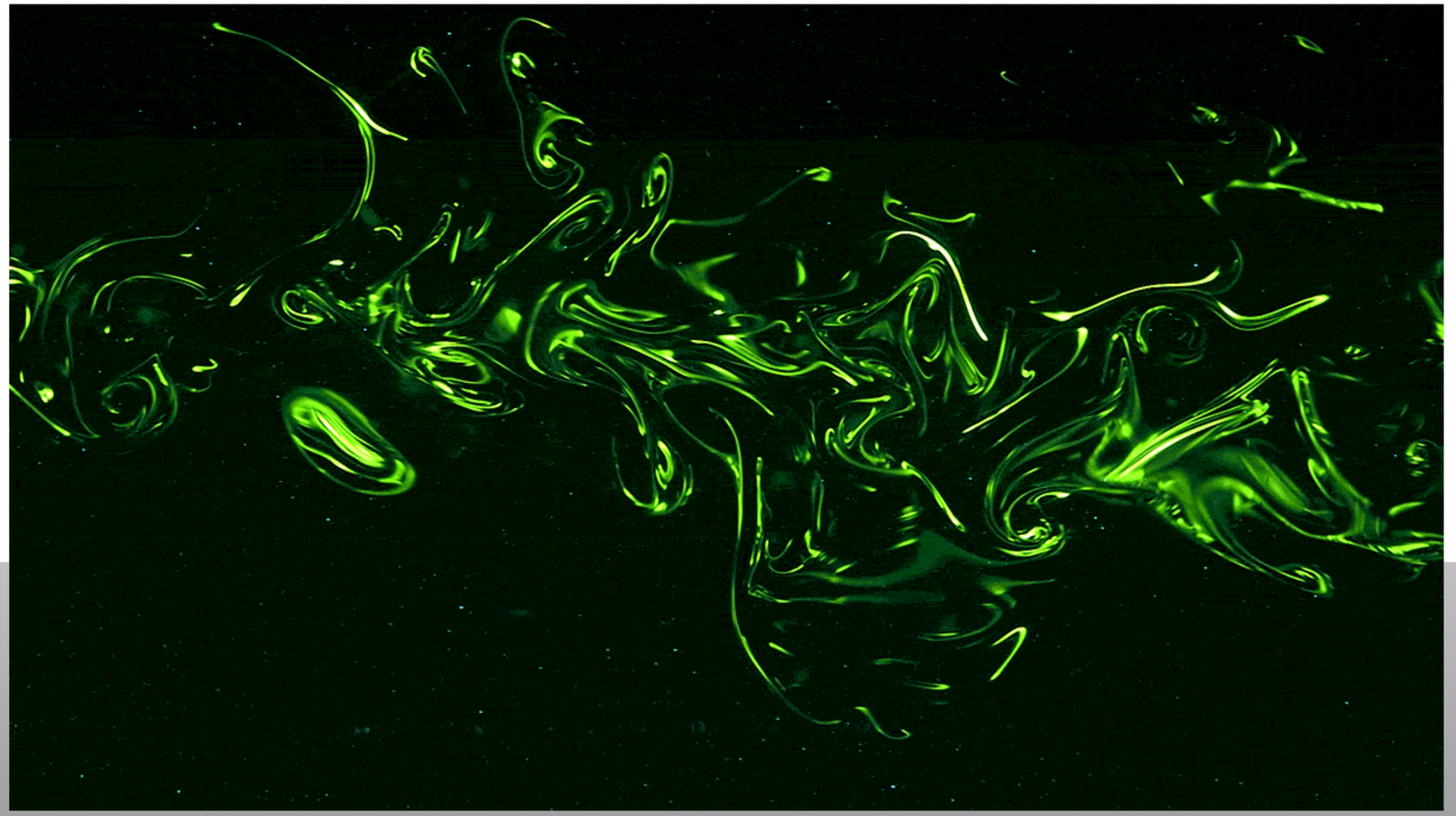
- Odor release and air movement create ***odor filaments***
- Arrangement and locations of odor filaments vary based on conditions
- Dogs search ***discontinuous signals*** within a plume

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

Anatomy of an odor plume

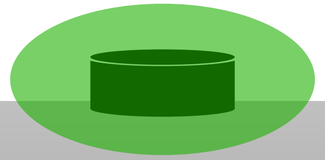
Planar laser-induced fluorescence

2. Air movement



Brian Gill, Univ. of Colorado, Boulder

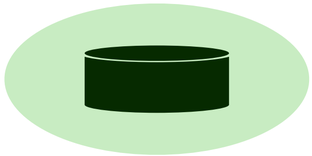
Source



1. Odor release

1. How odor enters the air

Odor release from a source is dependent on several features:



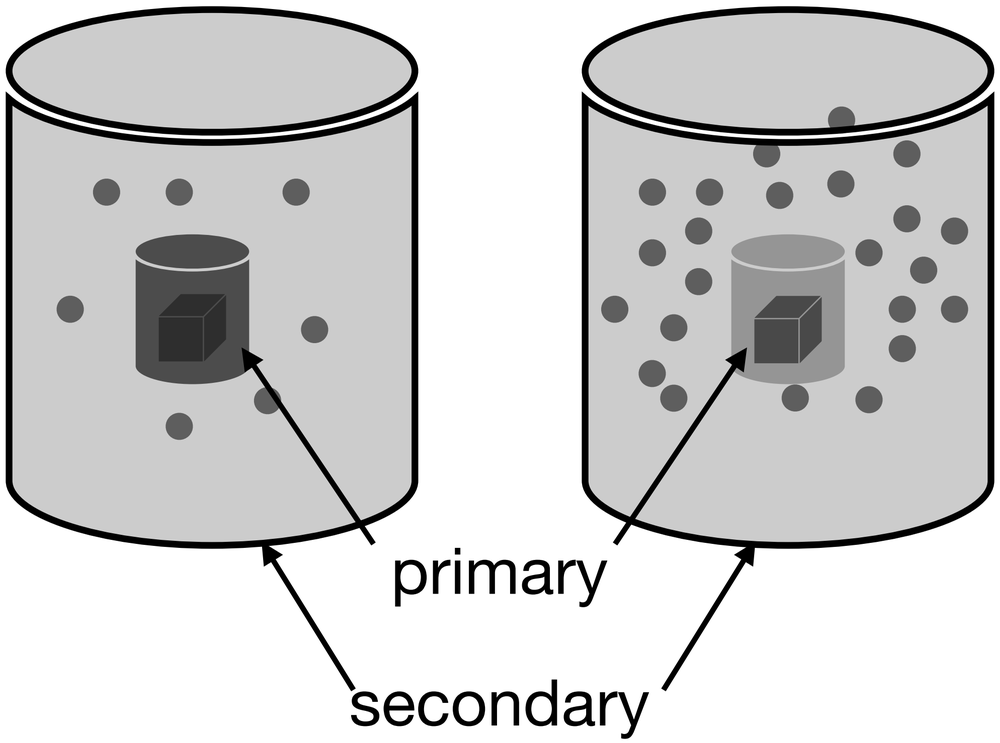
- Chemical properties of the material
  - ➡ Vapor pressure
  - ➡ Diffusion coefficient
- Properties of the training aid
  - ➡ Surface area of the material
  - ➡ Containment of the material

More info: Sloan et al. 2025 Frontiers

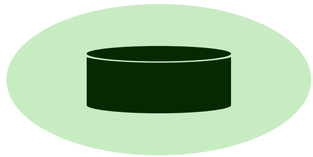
1. How odor enters the air

Containment

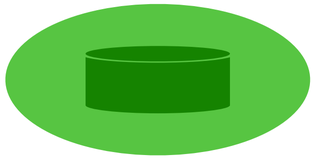
Permeability



Low permeability



High permeability



more mass in same volume = higher concentration

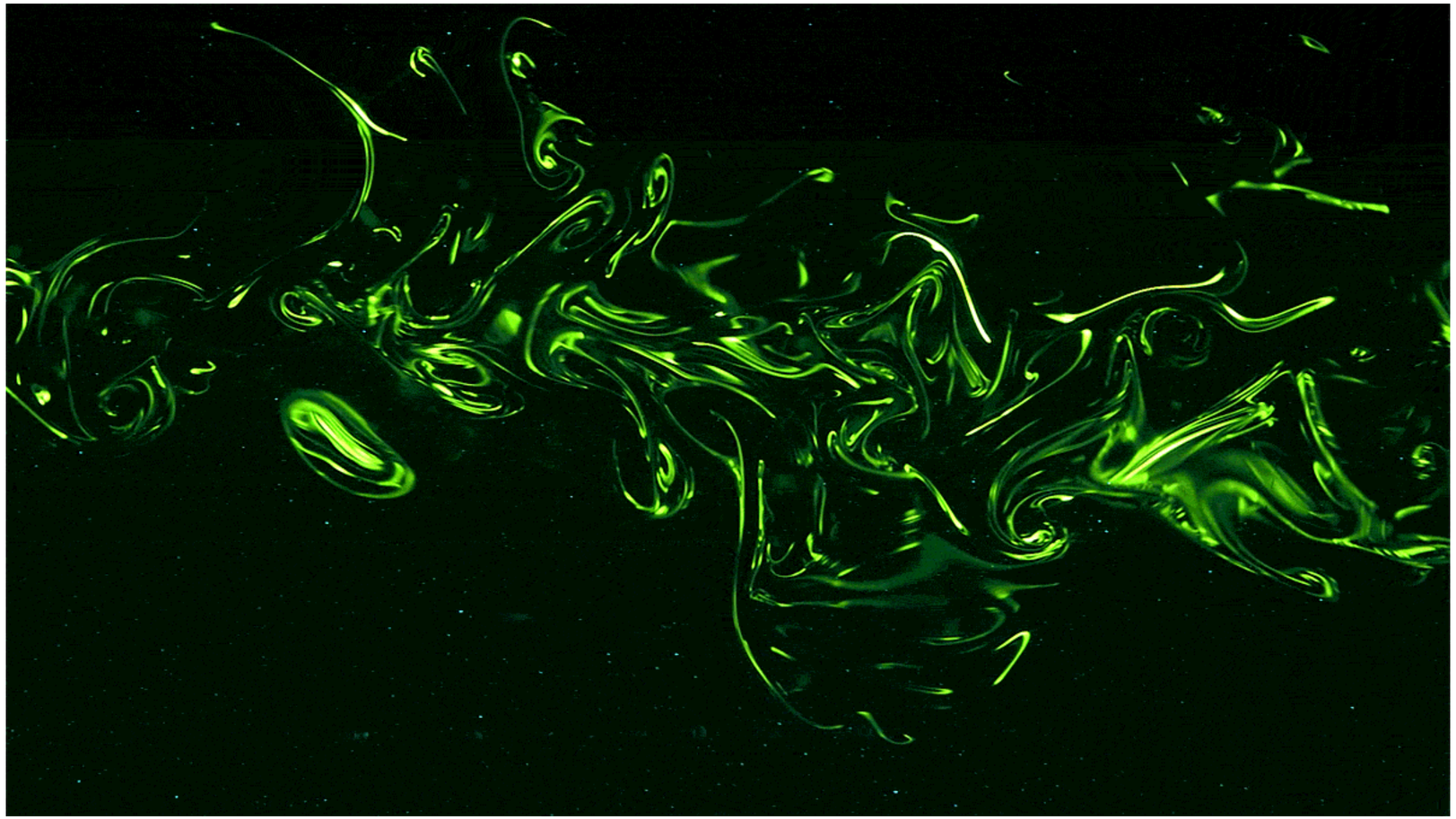
Odor release depends on the *permeability* of the materials' containment and concealment.

2. Air Movement

Why **does air move?**

How **does air move?**

Where **does air move?**



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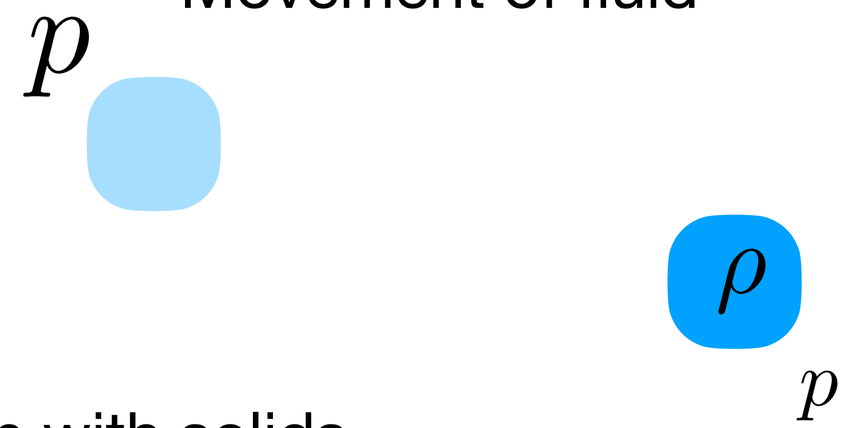
Why does air move?

- 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

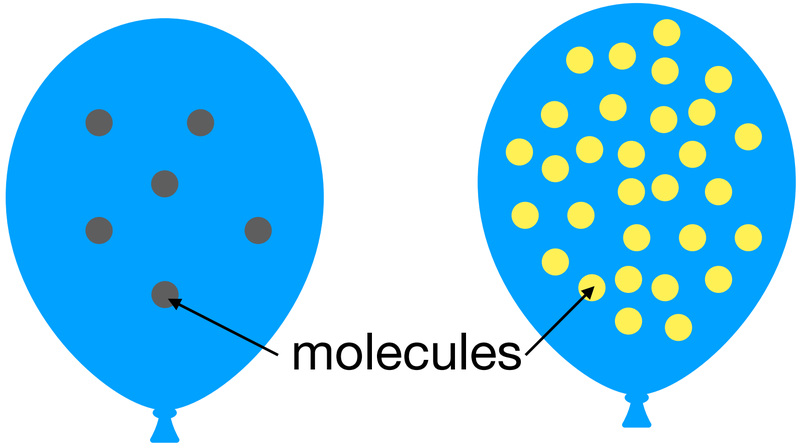


- We describe these forces a little differently than with solids

➡ Instead of Mass, we can describe *Density*

➡ Instead of Force, we can describe *Pressure*

Density



lower density

higher density

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

Density affects *buoyancy*.

Differences in buoyancy can drive motion.

What can affect fluid density in air?

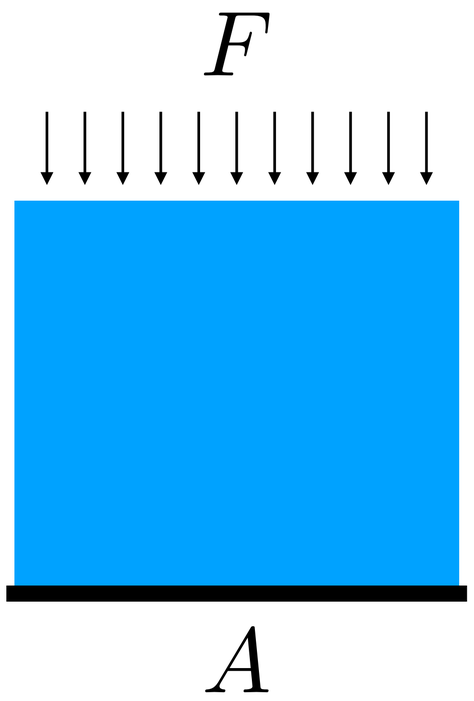
Density differences drive flow

Different chemical makeup

Temperature

Settles 2005 *J Fluids-Engineering*

Pressure



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

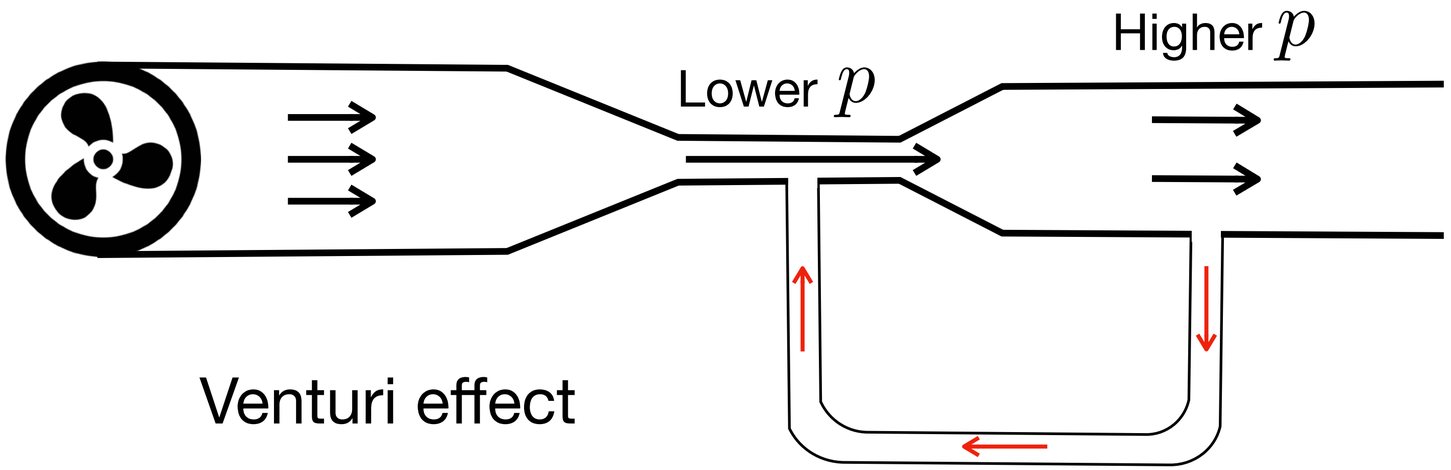
Pressure differences drive flow

Movement of a person will cause large-scale air movement

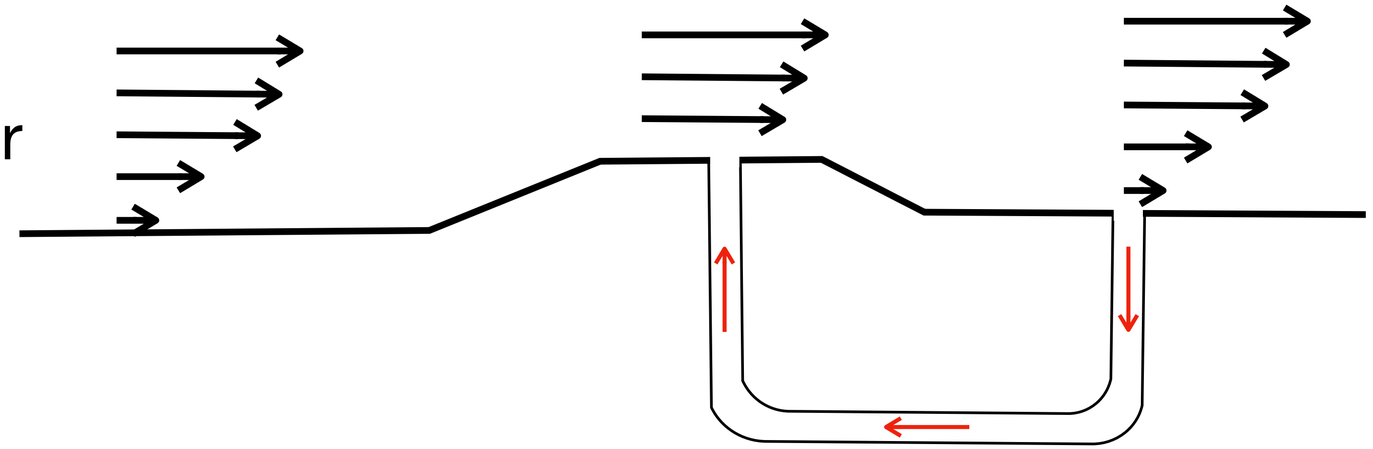
Settles 2005 *J Fluids-Engineering*

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

Pressure differences drive flow



Venturi effect



Boundary layer

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.

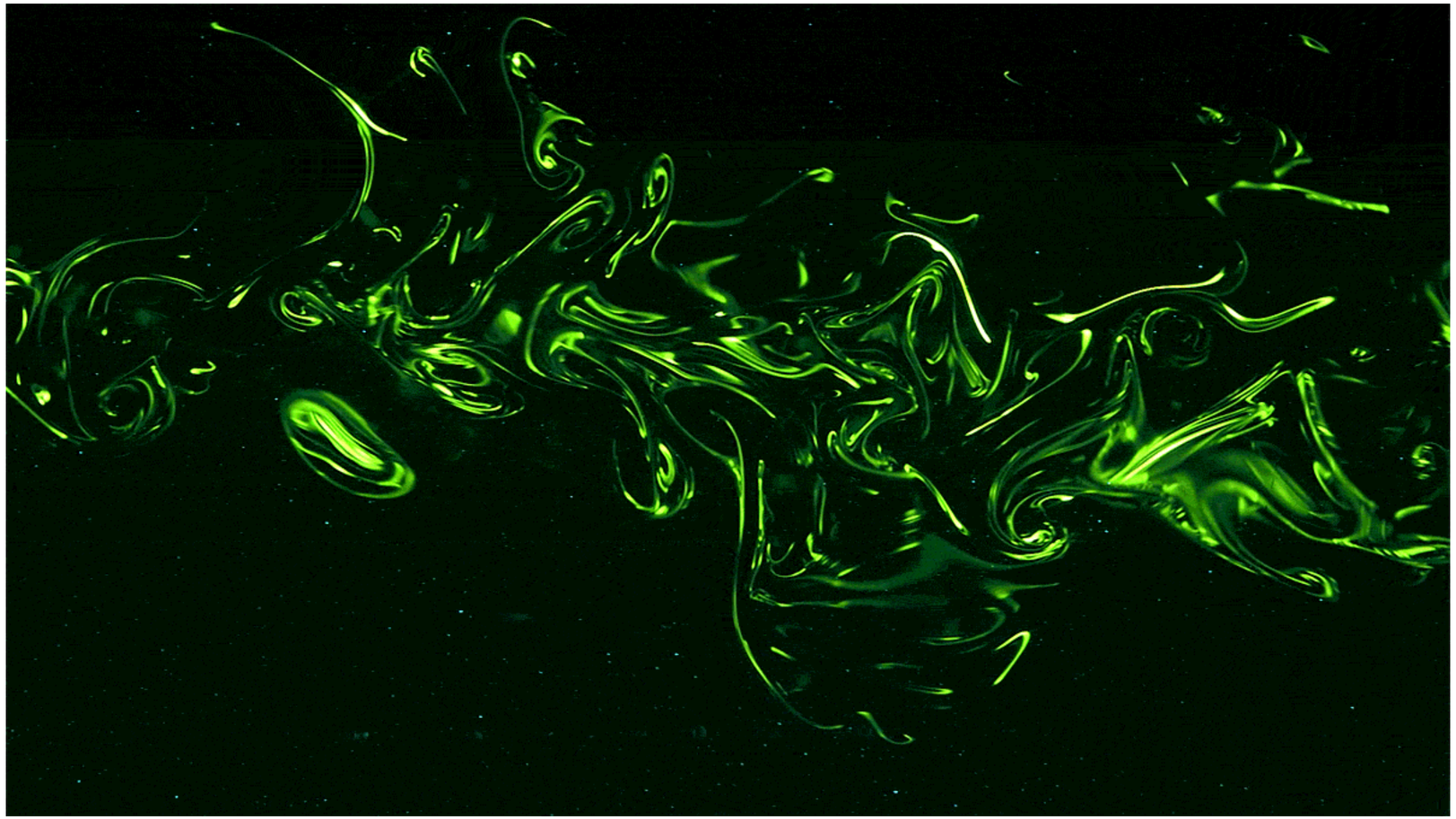
- Pressure differences can be created by ***fans***, ***wind***, ***objects in motion***, and ***passively*** through geometry.

2. Air Movement

Why **does air move?**

How **does air move?**

Where **does air move?**



Brian Gill, Univ. of Colorado, Boulder

Think like a Fluid Dynamicist

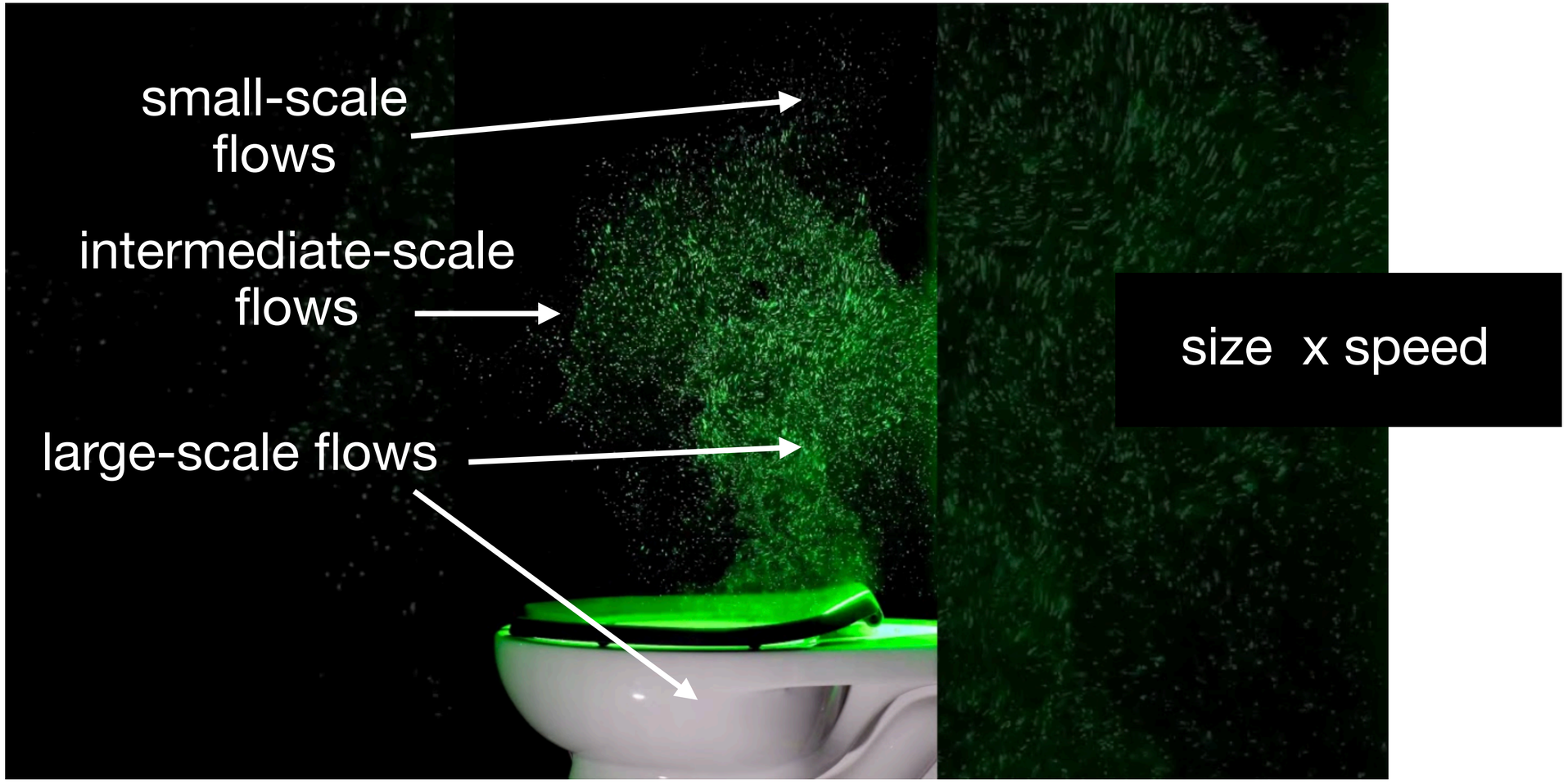
What do you think about when you flush a toilet?

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:

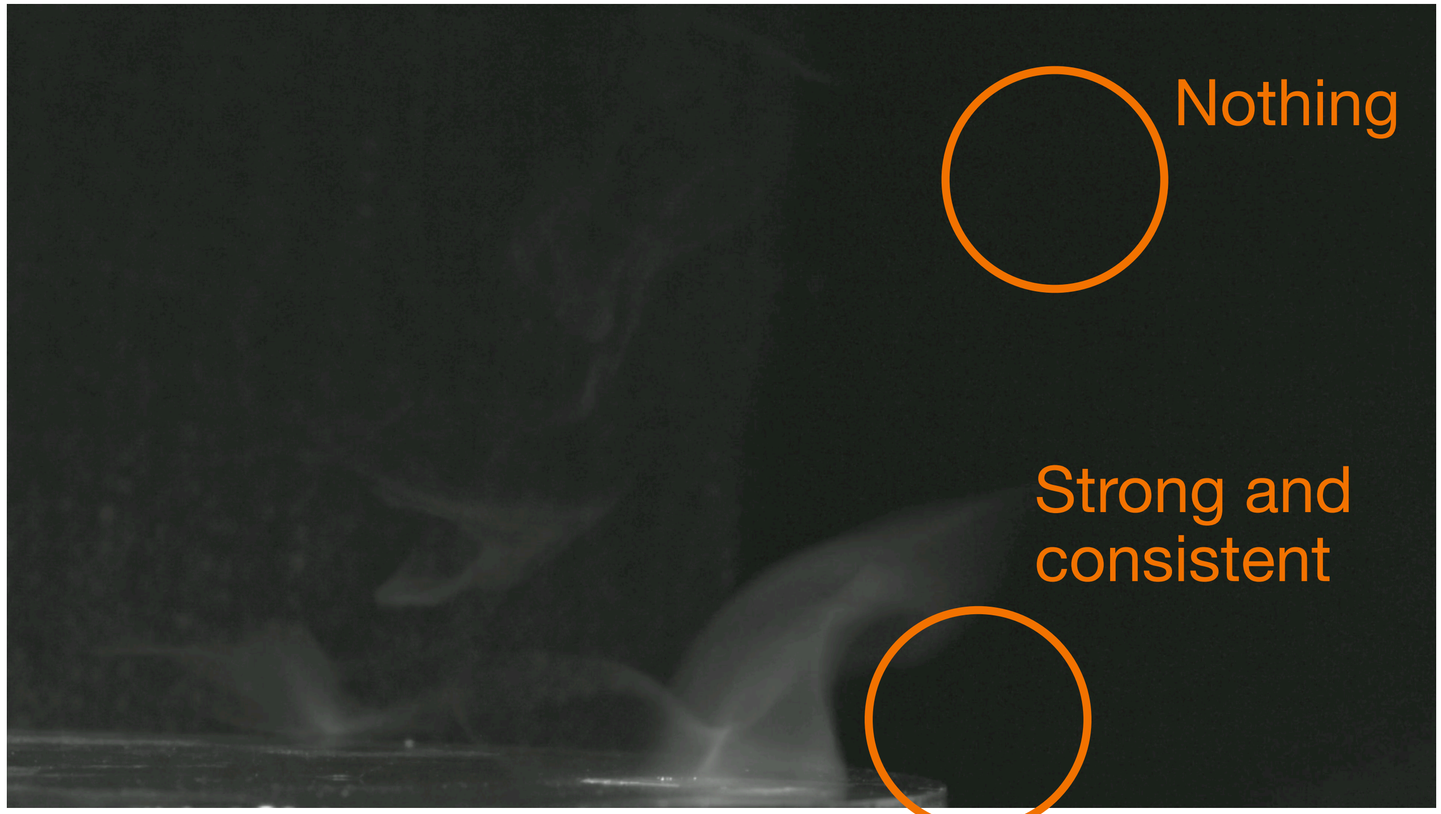
- determine the local *intensity* of odor signal

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



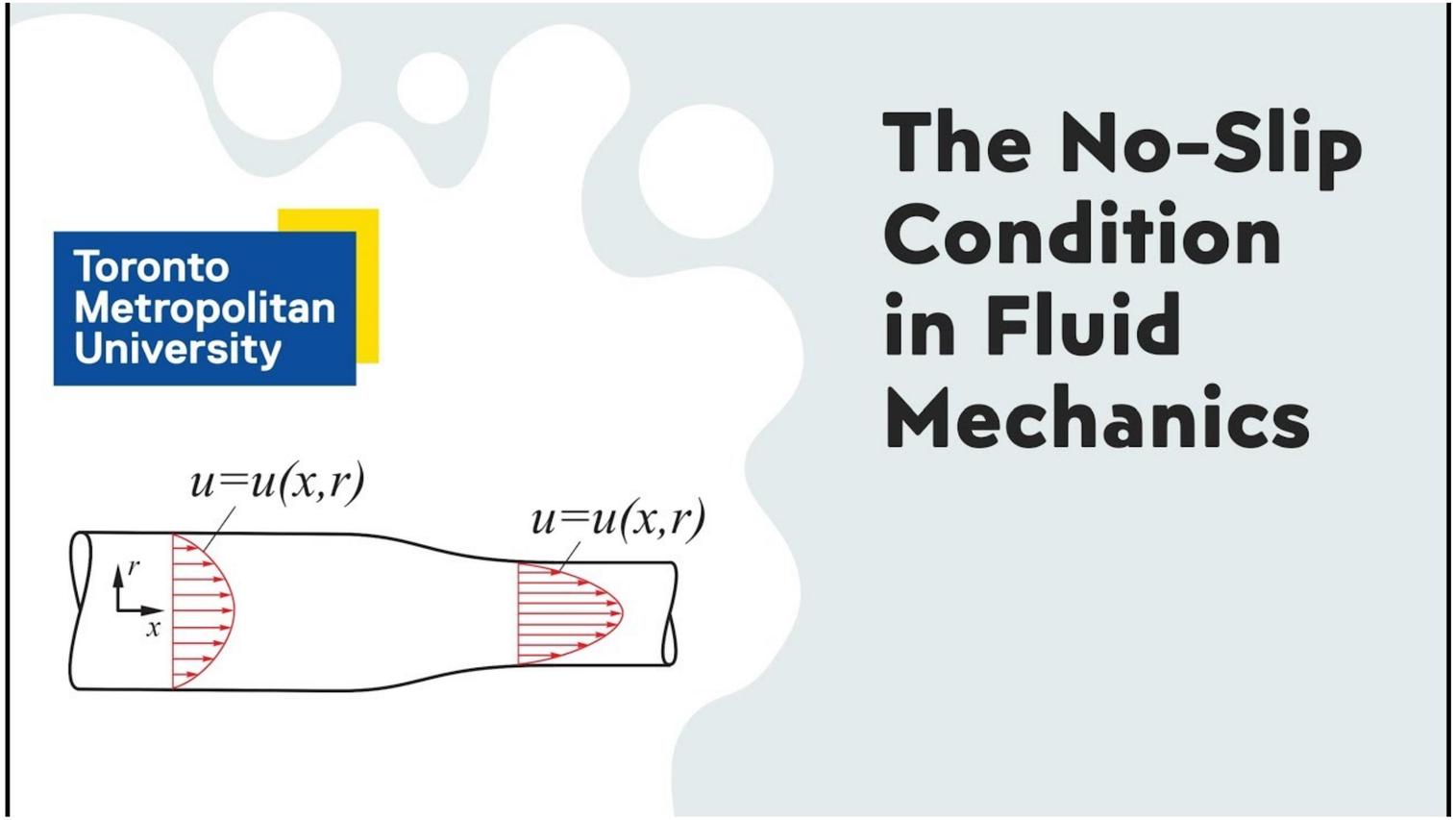
Dog sniffing at 500 frames per second

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***

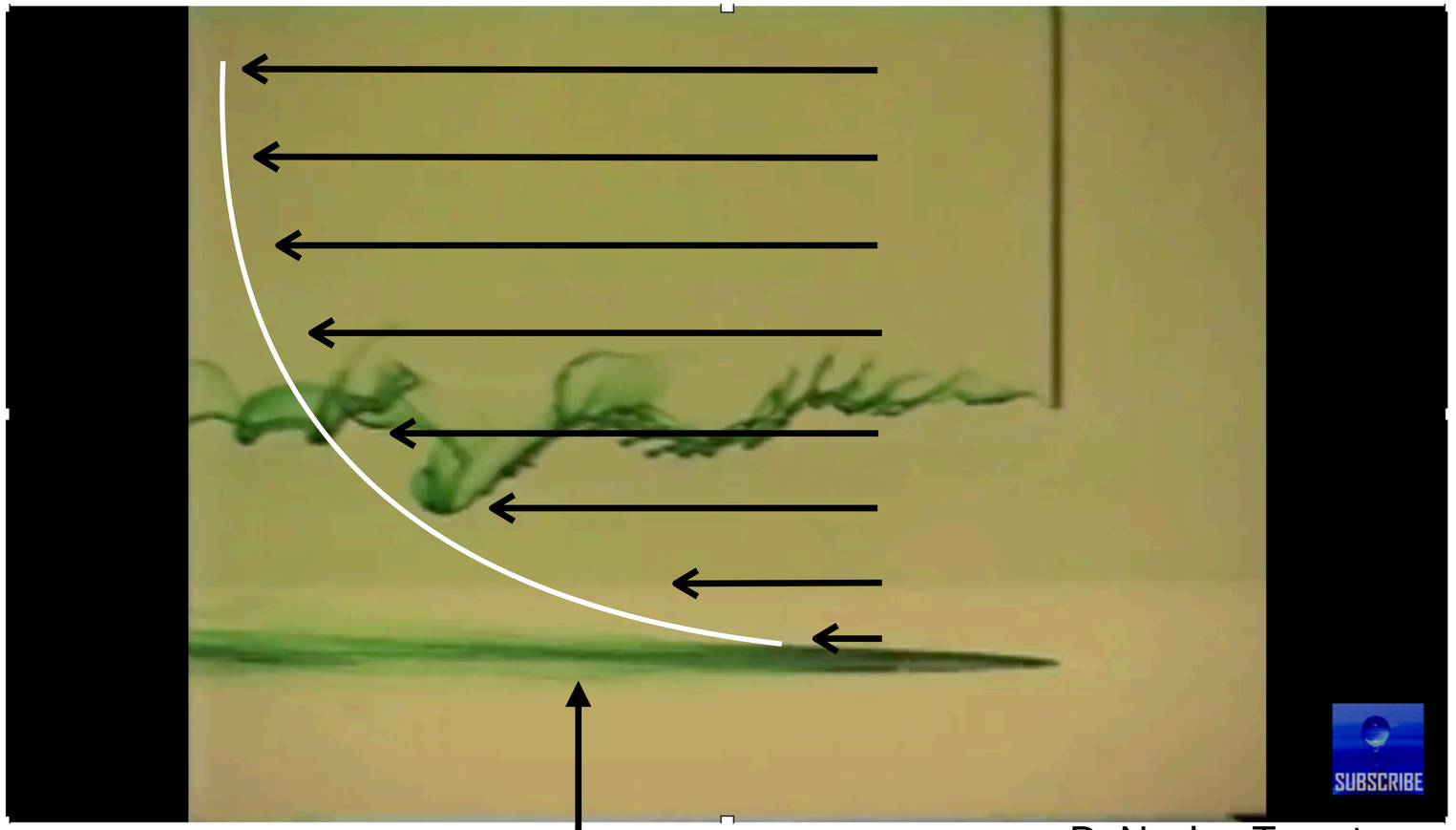


D. Naylor, Toronto Metro Univ

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!

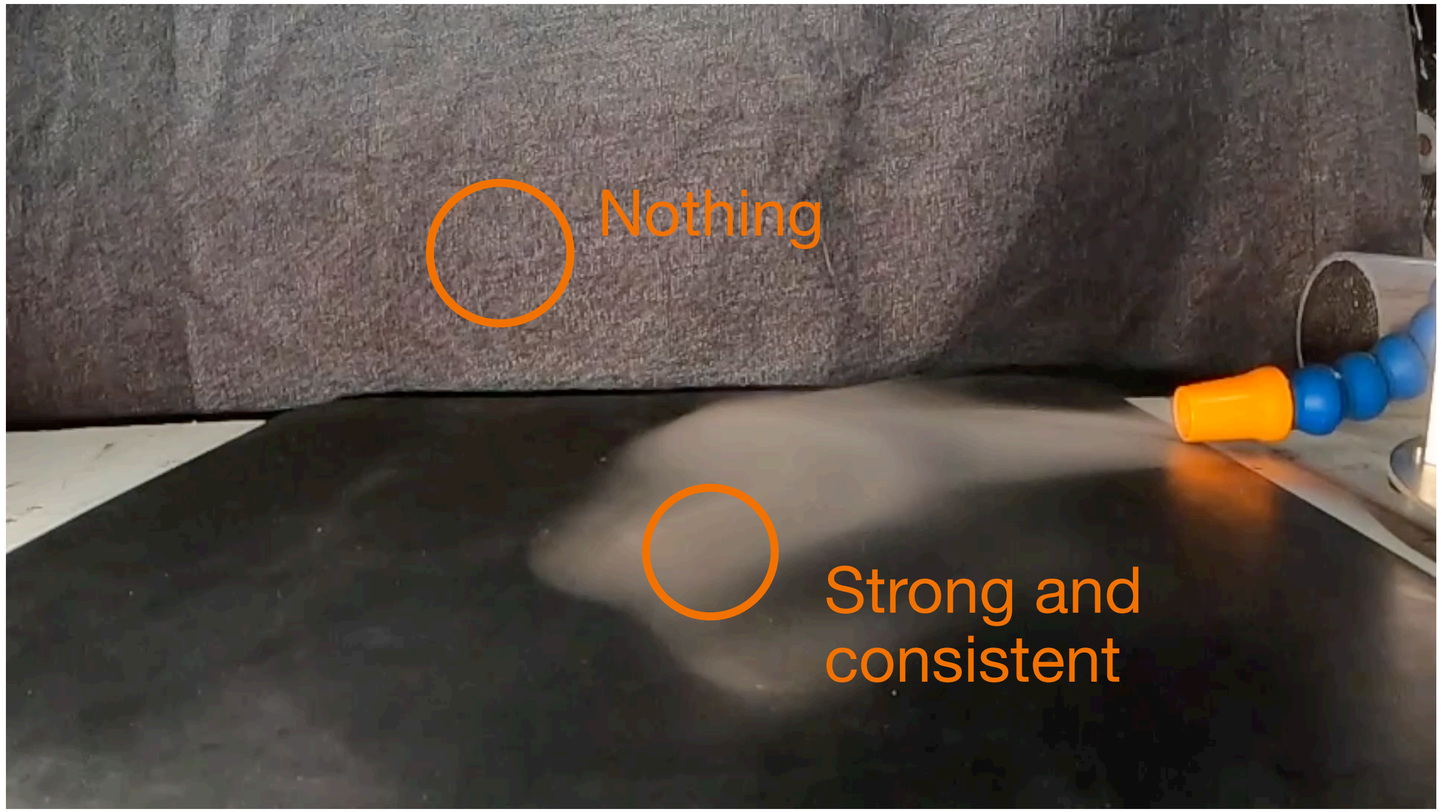


D. Naylor, Toronto Metro Univ

Viscous sublayer

Odor pools in the viscous sublayer

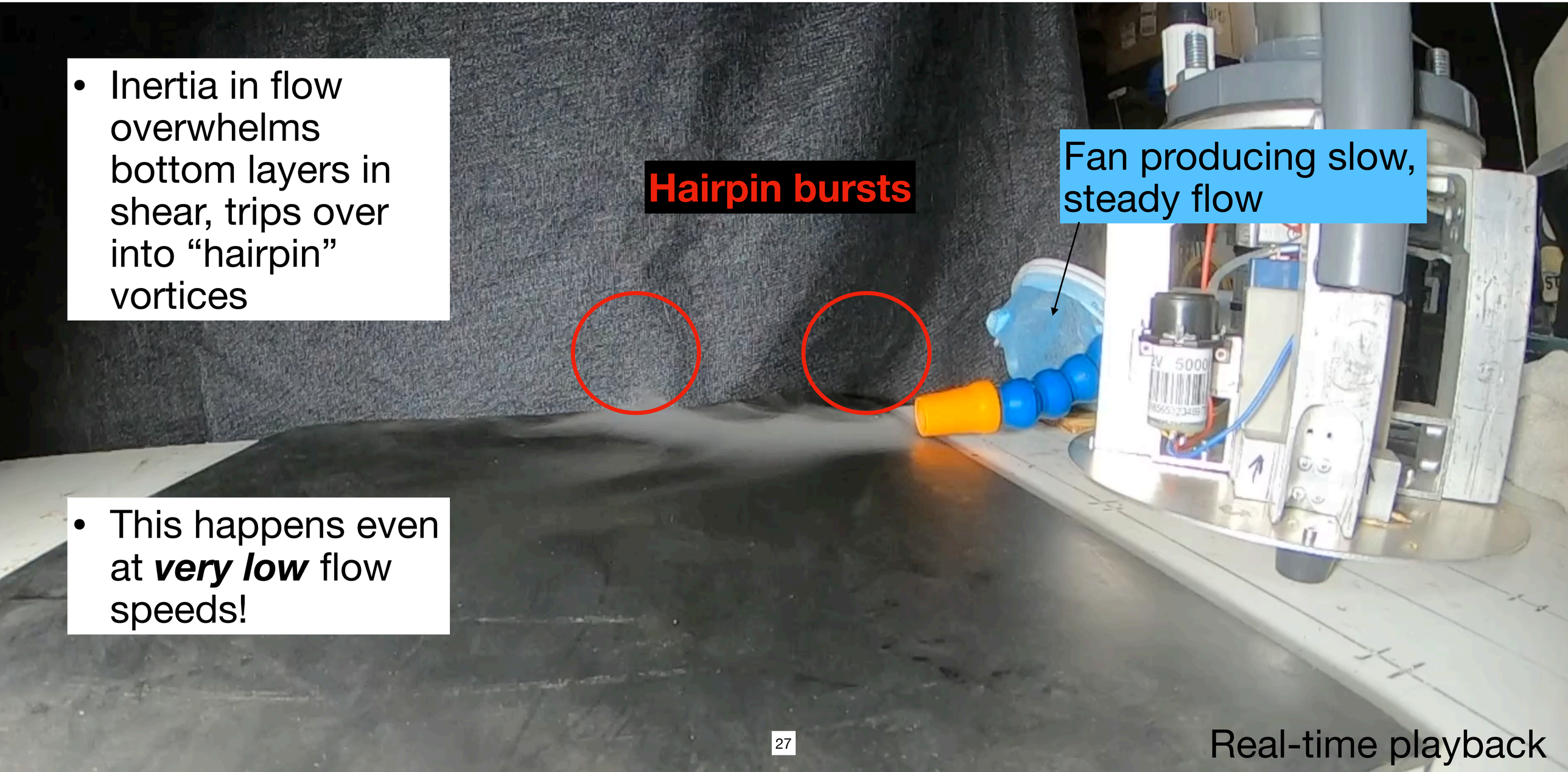
- Very low air flow + very close to the surface
- Vapor is slightly more dense than the air, so is negatively buoyant
- Vapor largely pools and spreads along the surface



2x speed playback

How would odor make it out of the sublayer?

Escape from the viscous sublayer

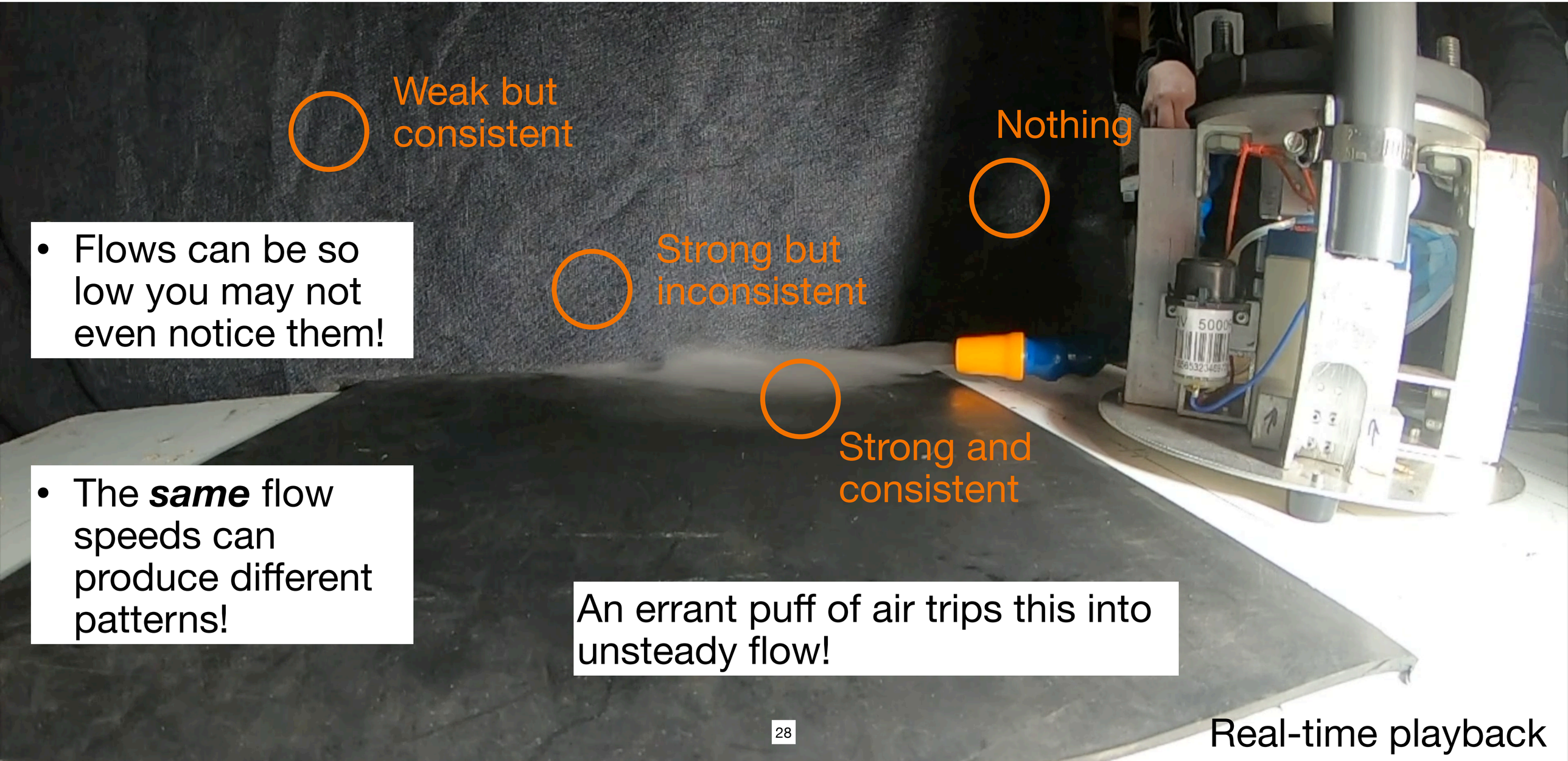


- Inertia in flow overwhelms bottom layers in shear, trips over into “hairpin” vortices

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

Real-time playback

Low flows cause dramatically different odor patterns



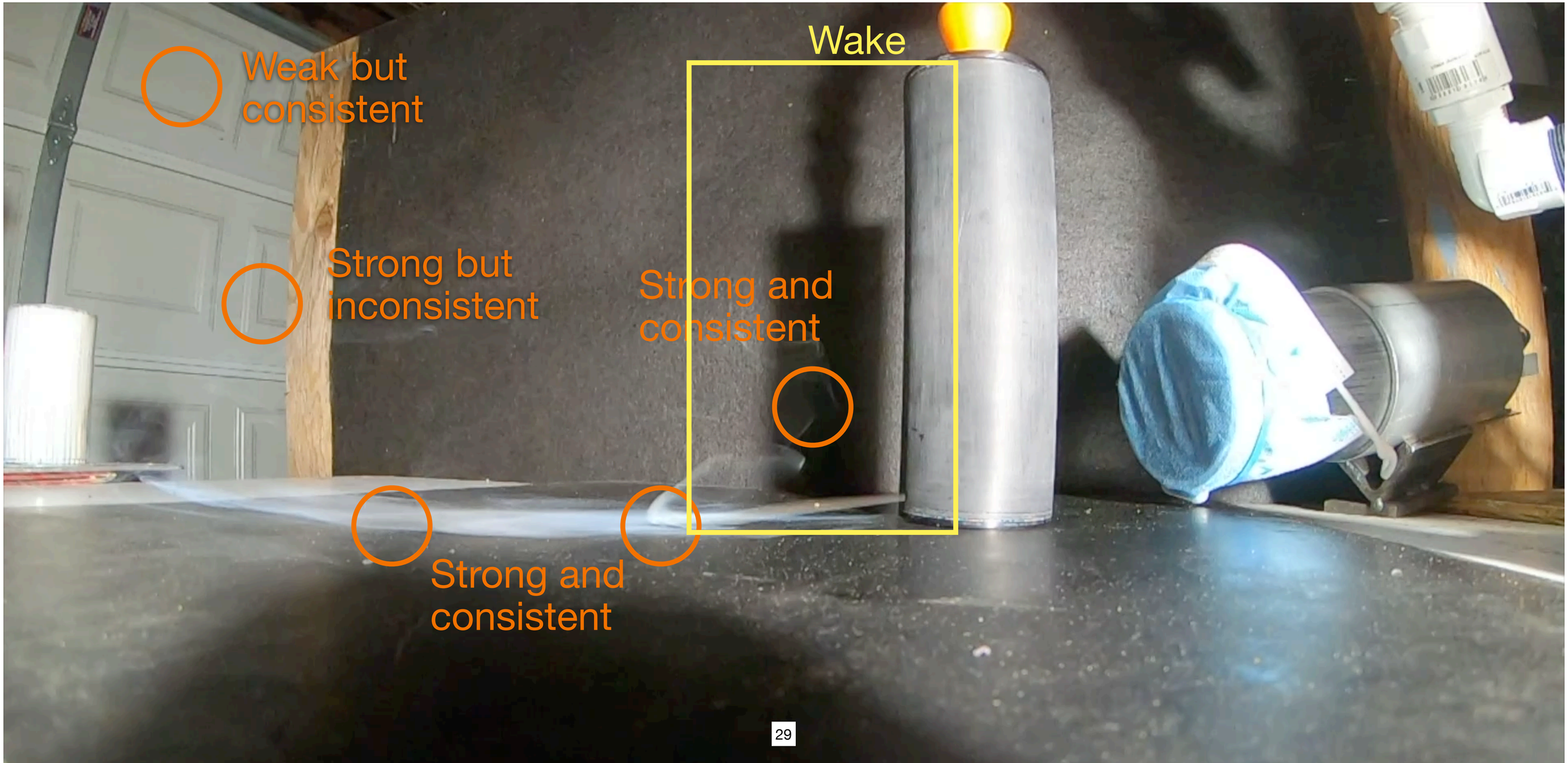
- Flows can be so low you may not even notice them!

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

An errant puff of air trips this into unsteady flow!

Real-time playback

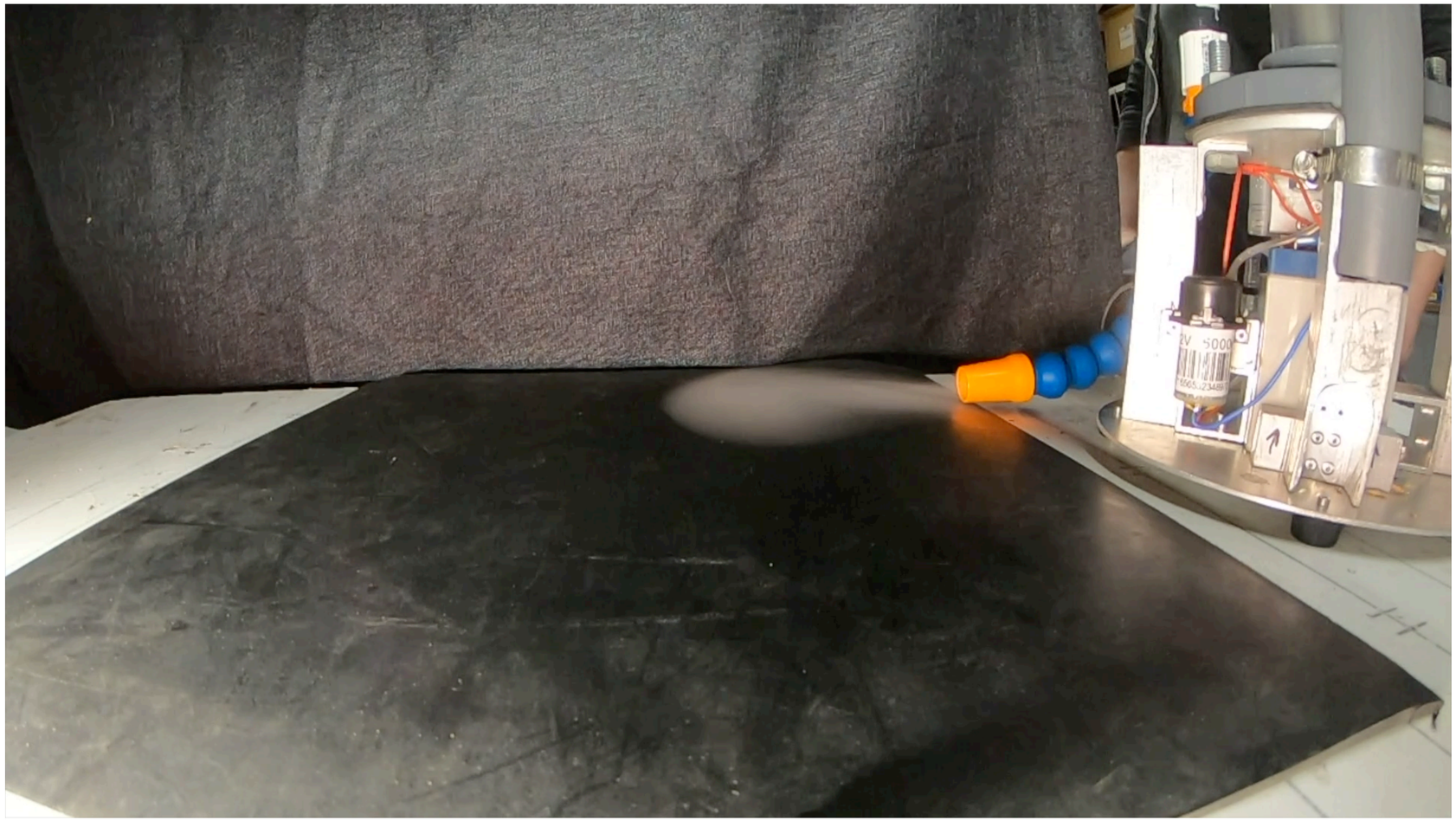
Wakes drive vertical movement of odor & mixing



Beware YOUR wake!

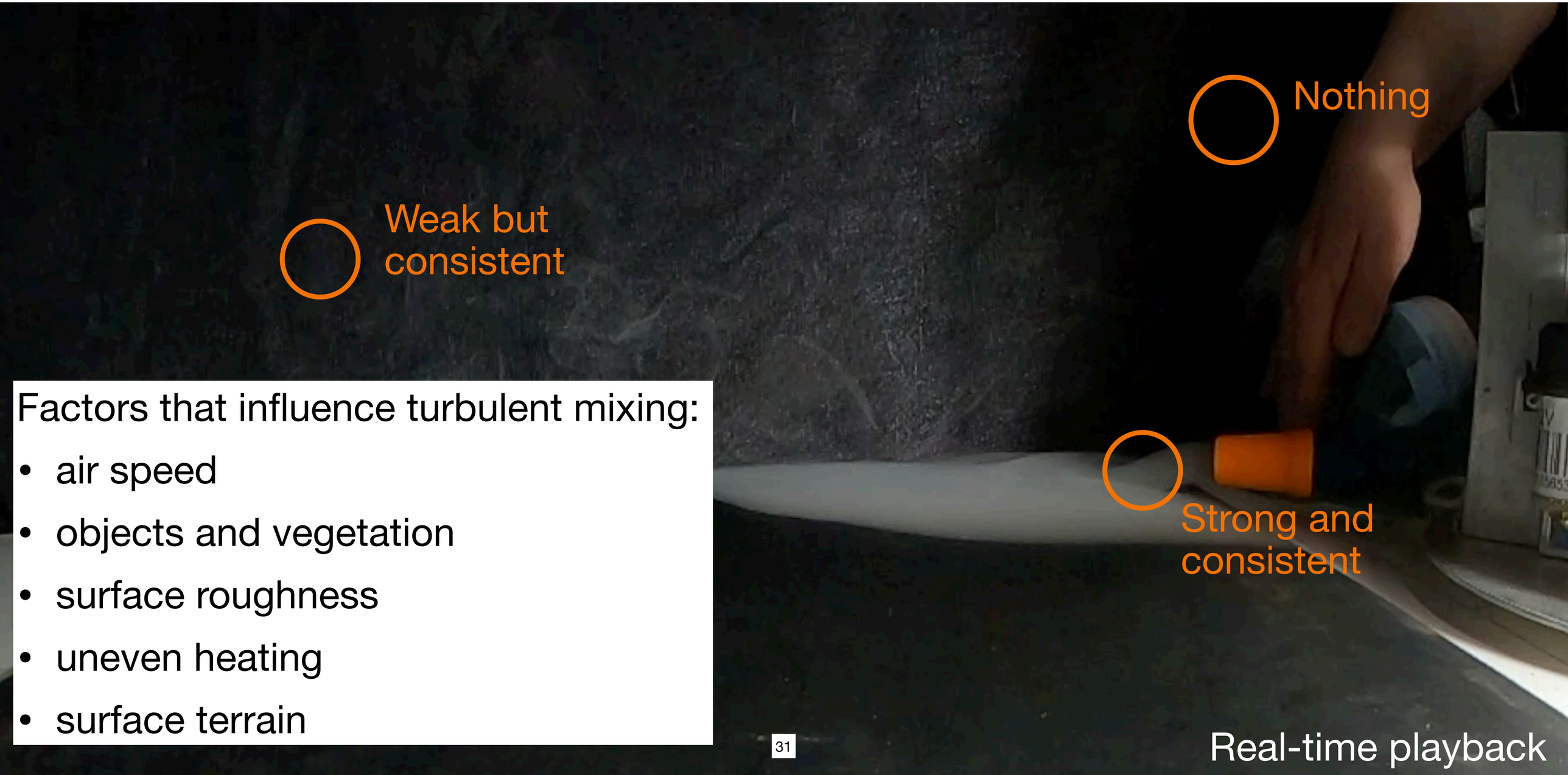
- Slow flows are **unstable** and prone to dramatic change based on **small inputs!**

- My wake was enough to drag this odor pool onto the floor!



2x speed playback

Turbulence mixes and transports odor



Factors that influence turbulent mixing:

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

Real-time playback

How air moves: takeaways

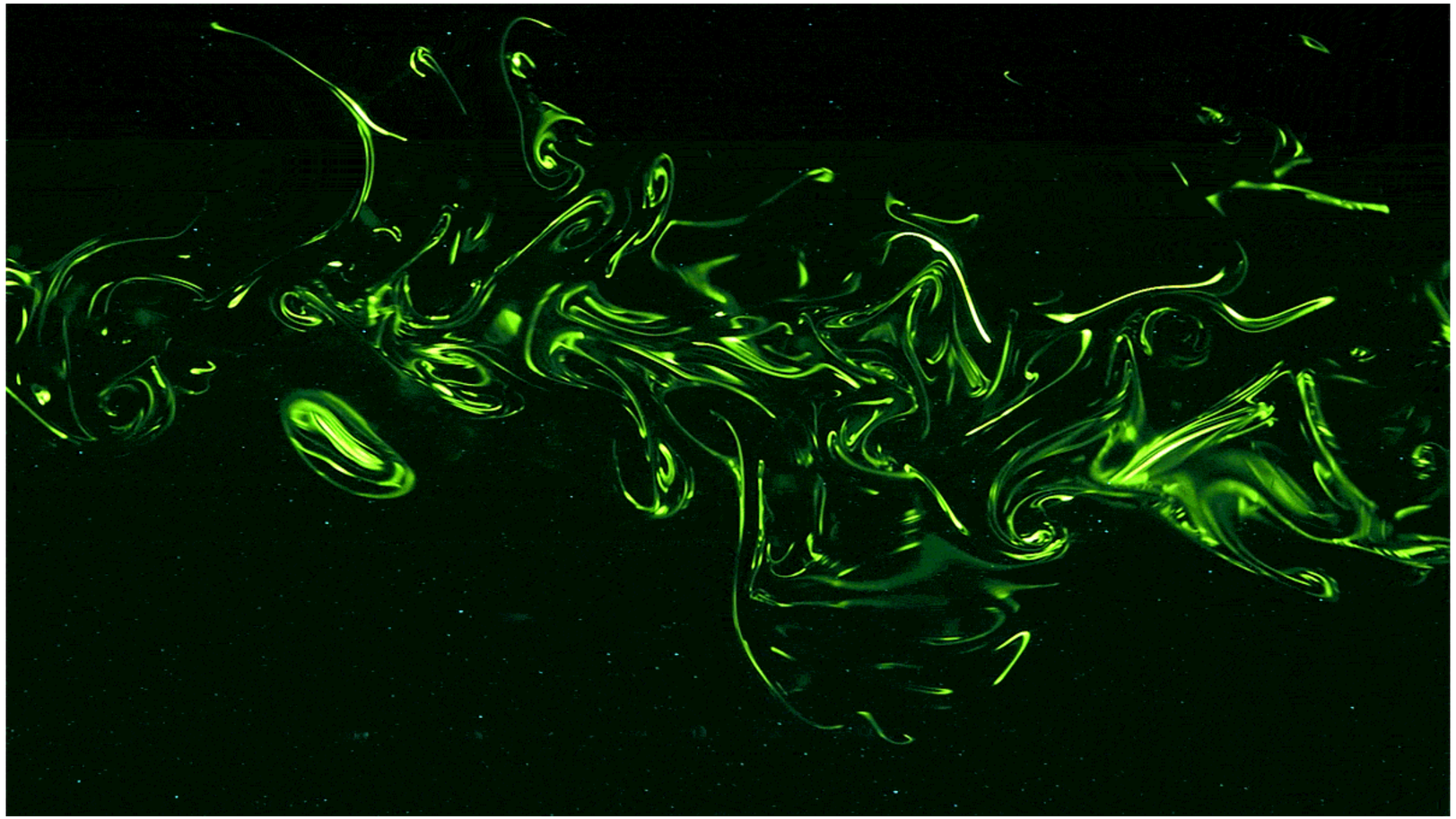
- Fluid behaves ***differently at different scales***, each scale affects the **intensity**, **mixing**, and **transport of odor.**
- Fluid sticks to solid surfaces creating a **boundary layer.** The layer can collect odor, but it is ***very unstable and sensitive to small flows.***
- Solid objects can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



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Where does air move odor?

- **Probably not where you think!**

- Scenarios to challenge your understanding of odor movement:

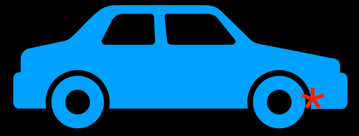
  ➡ Scenario 1: Vehicle hide in a parking lot

  ➡ 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



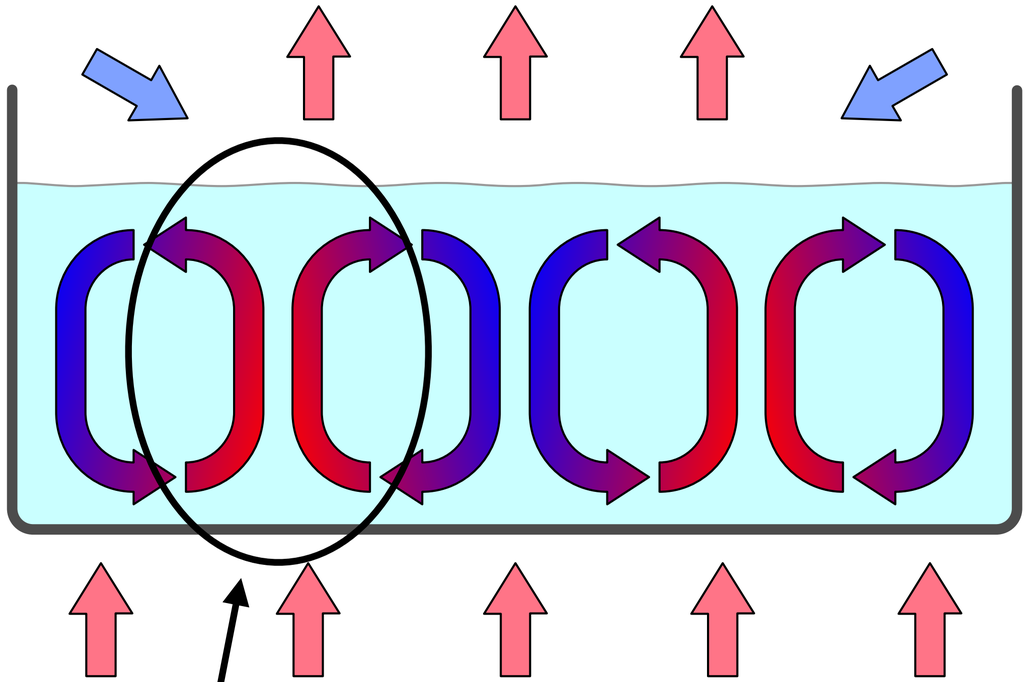
Scenario Analysis:

Where is the odor traveling?

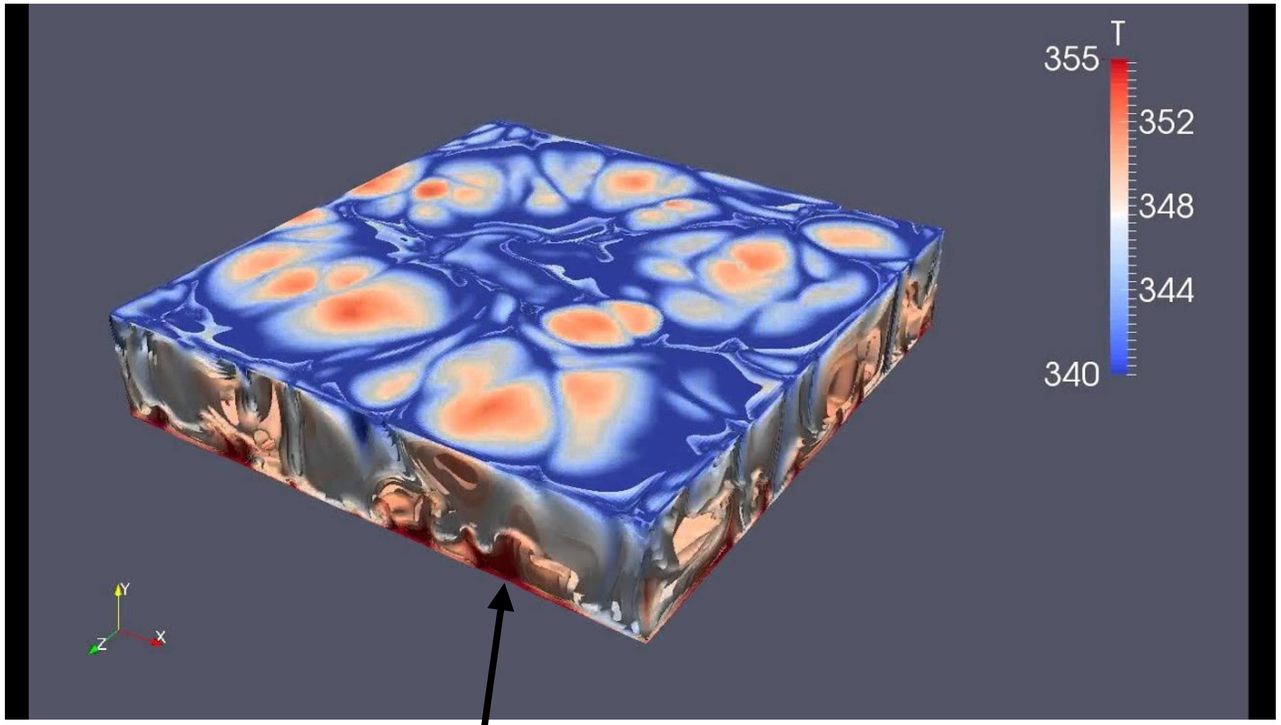
Where is the dog most likely to pick it up initially?

Flow driven by temperature differences

Surface heating can drive Rayleigh-Bénard convection



I, Eyrian, Wikimedia Commons



/dev /null, Youtube

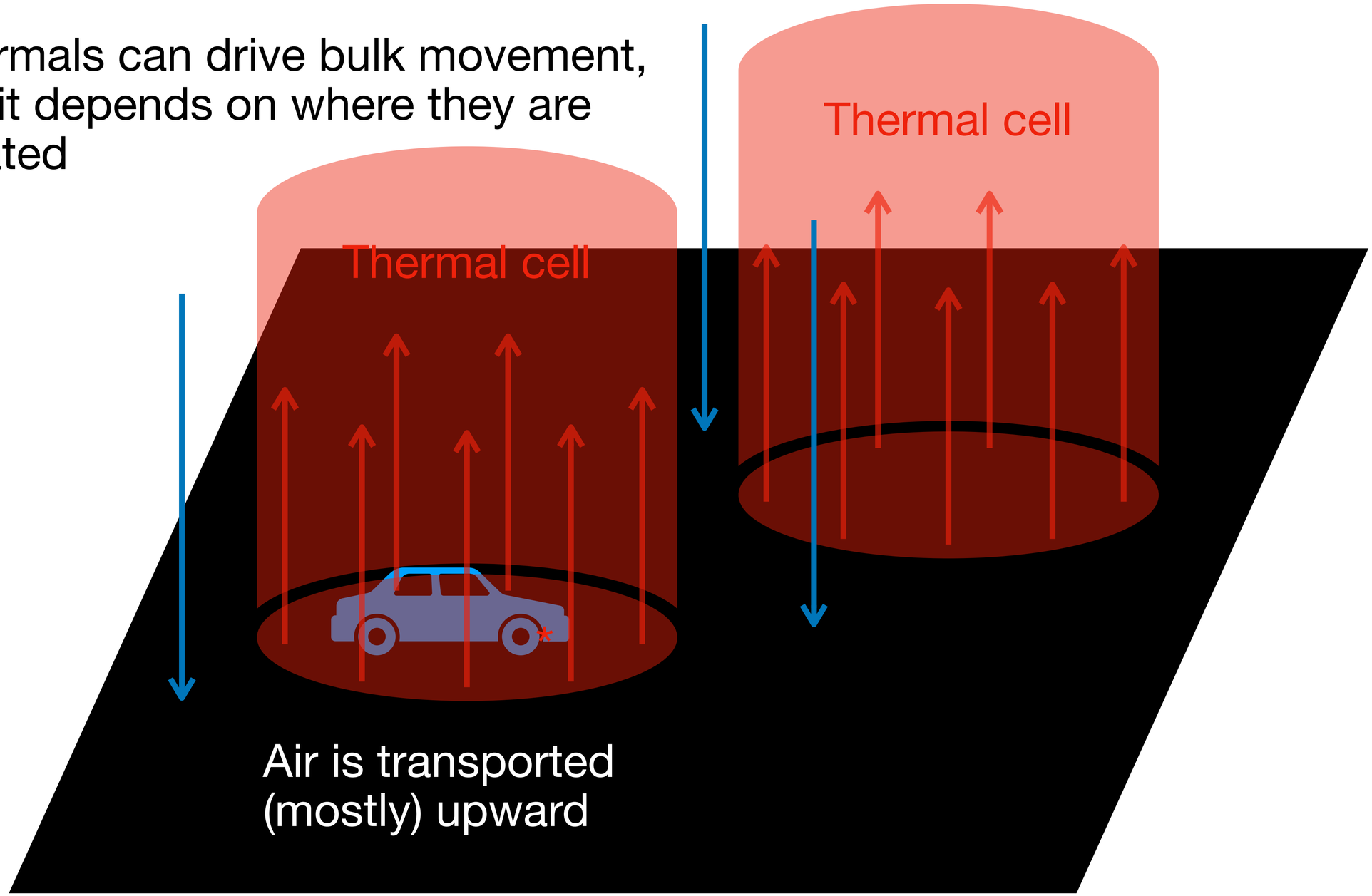
Thermals occur over:

- Parking lots
- Dark-color ground
- Dirt fields

Local air movement can be counterintuitive

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

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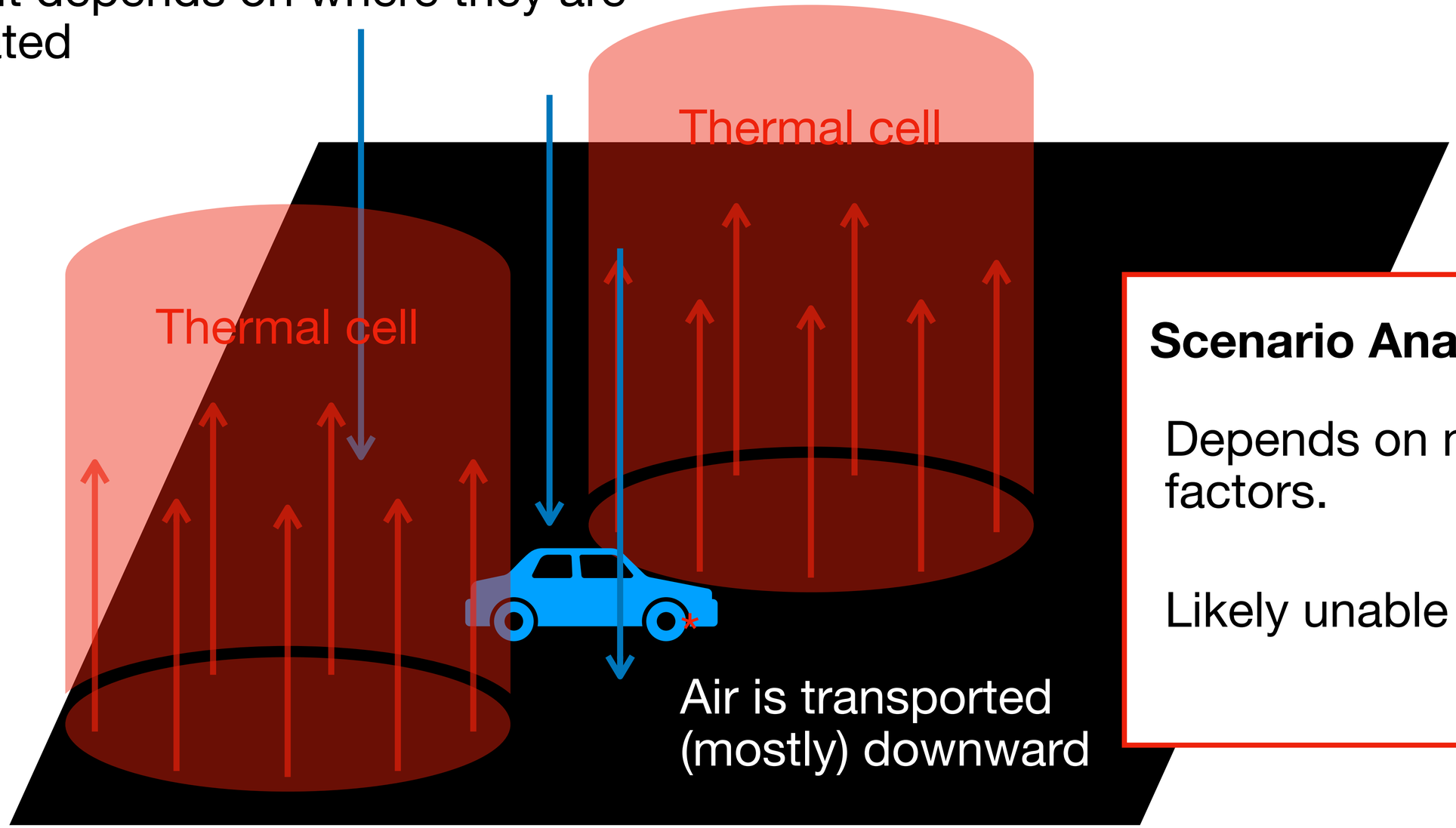
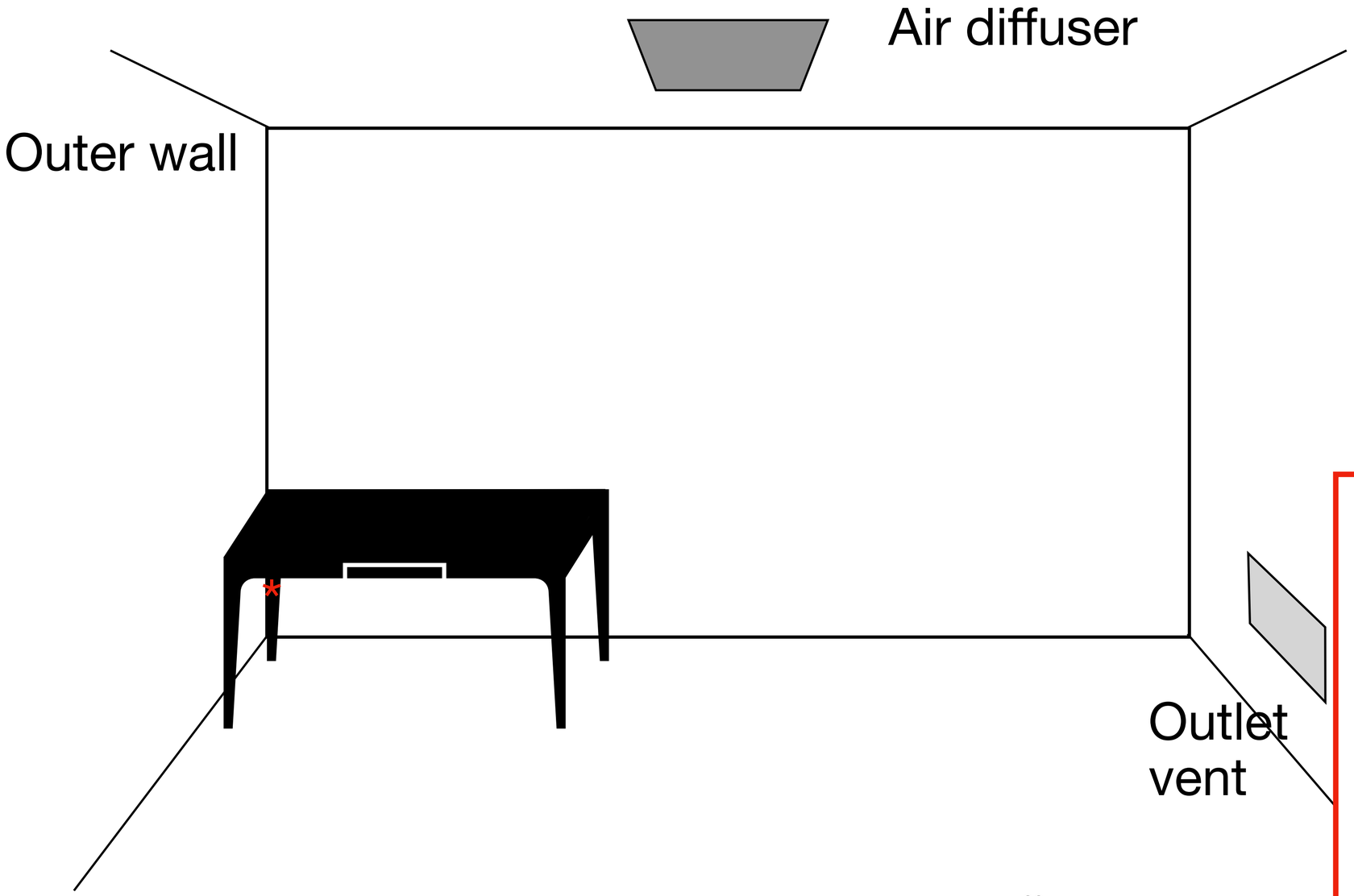


Scenario Analysis:

Depends on many factors.

Likely unable to predict.

Scenario 2: Single source hide in a room



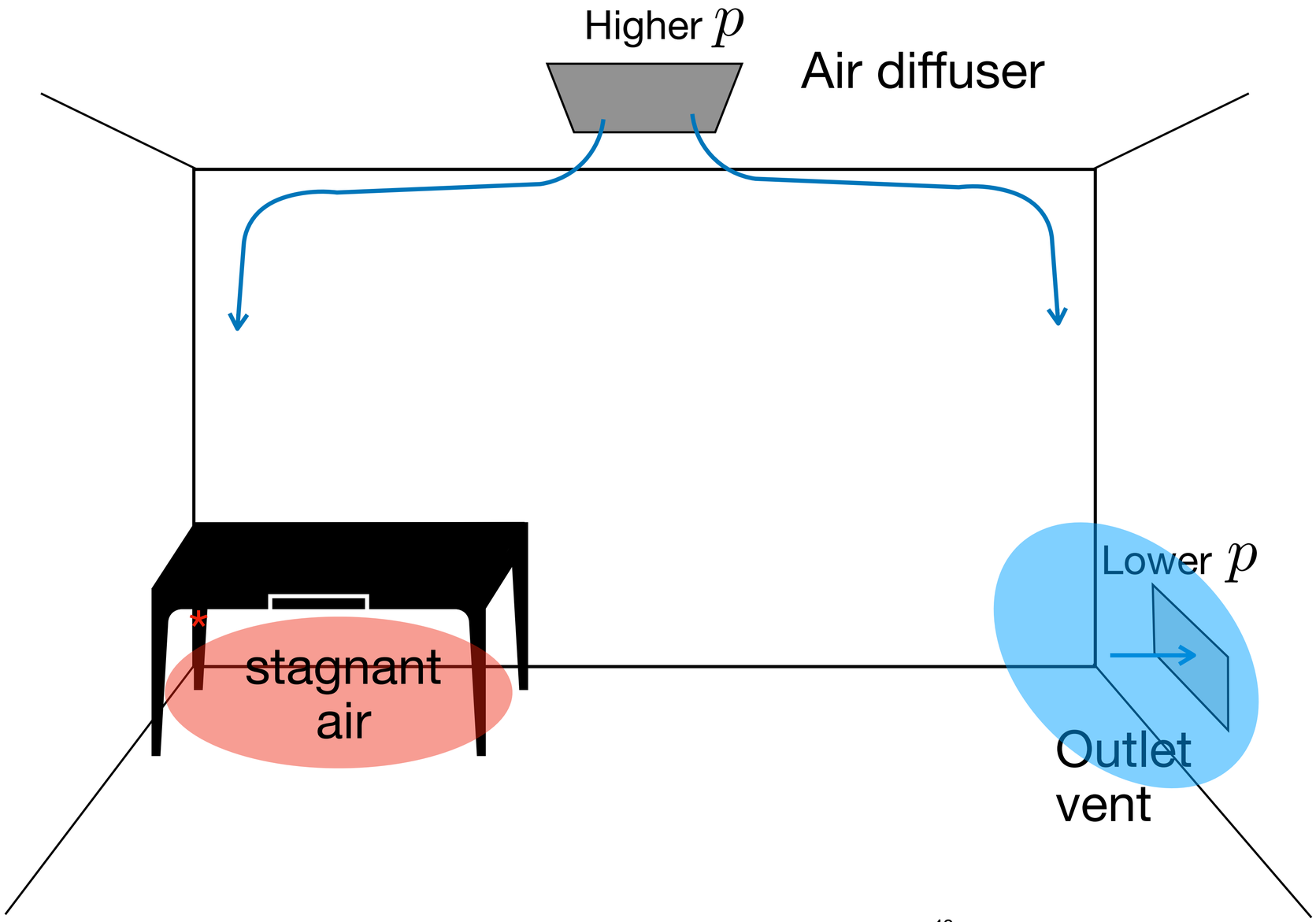
- Single source in a room, underneath table in corner
- HVAC is on
- Room shares a wall with the south-facing outer building wall

Scenario Analysis:

Where is the odor traveling?

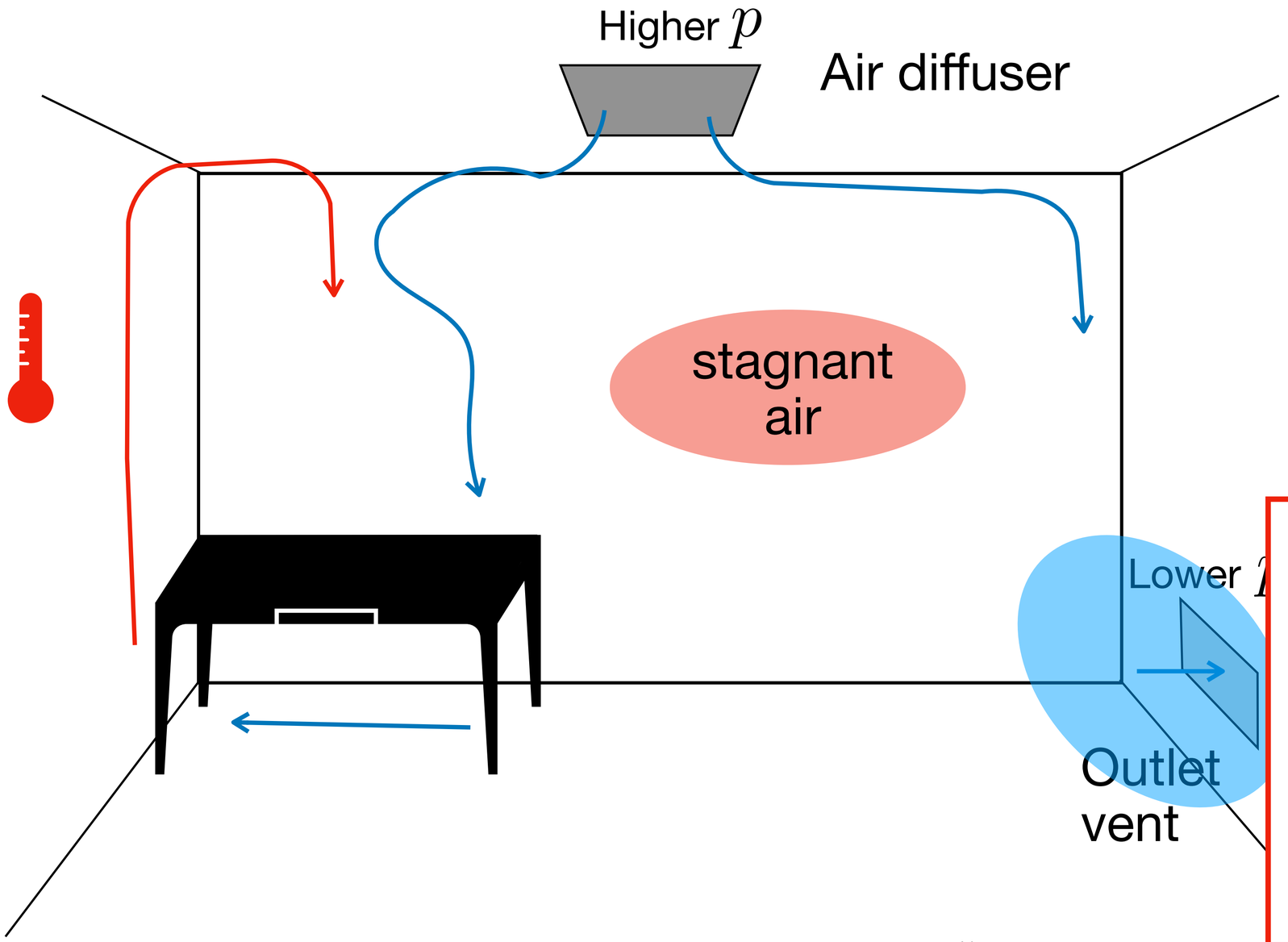
Where is the dog most likely to pick it up initially?

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



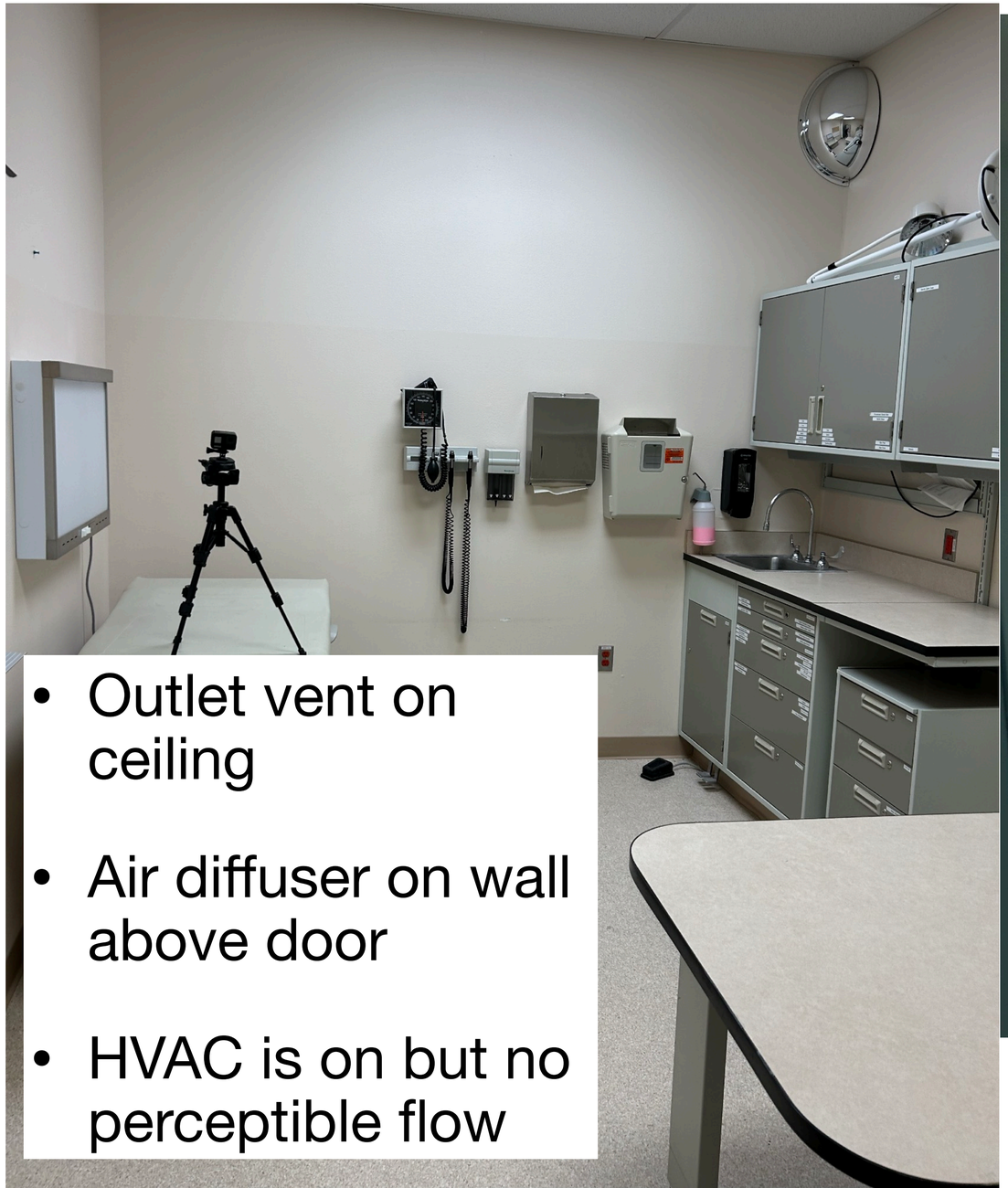
- Outer wall heating will change flow patterns drastically!

Scenario Analysis:

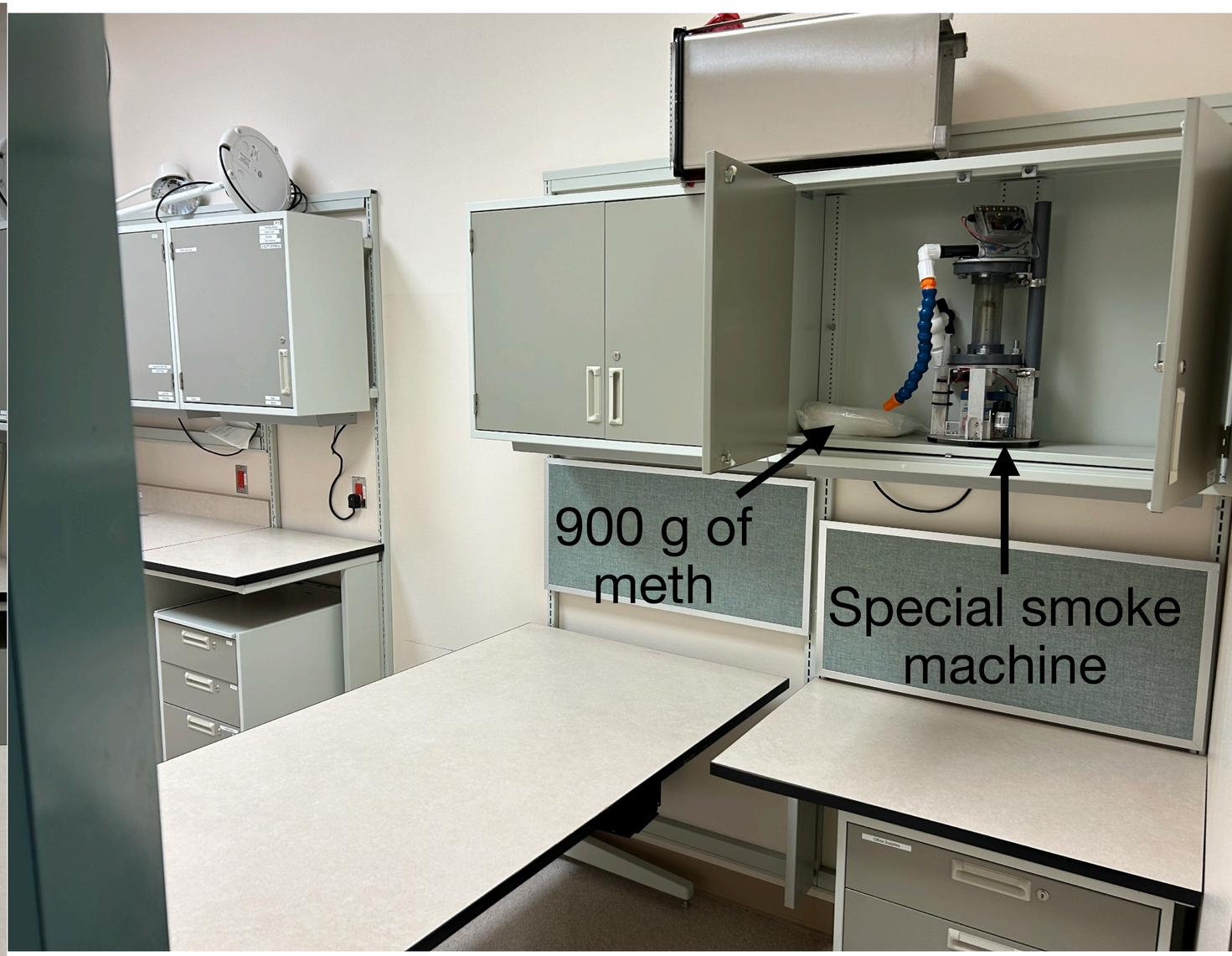
Depends on many factors.

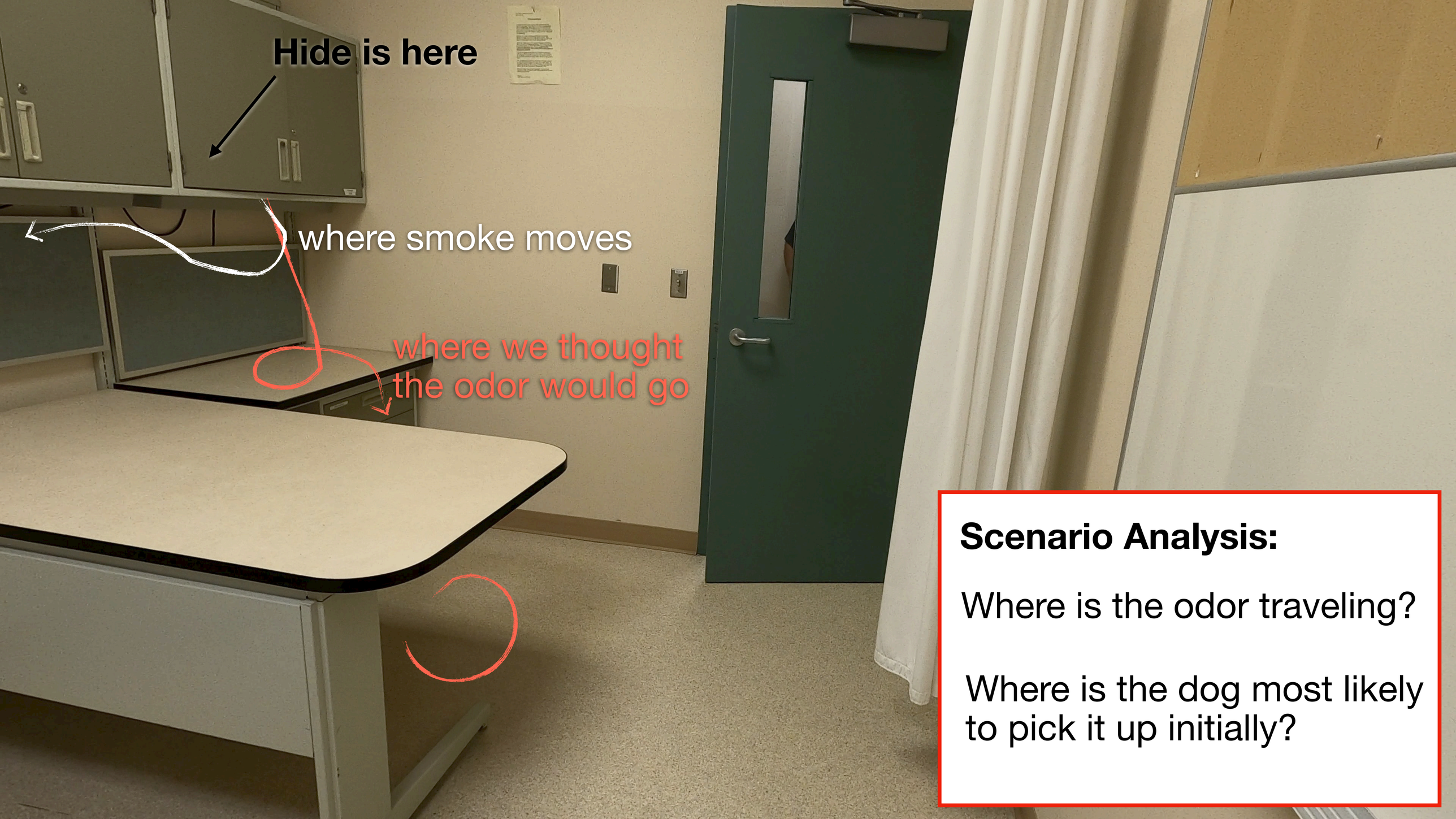
Likely unable to predict.

Scenario 3: Elevated hide in a room



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





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?

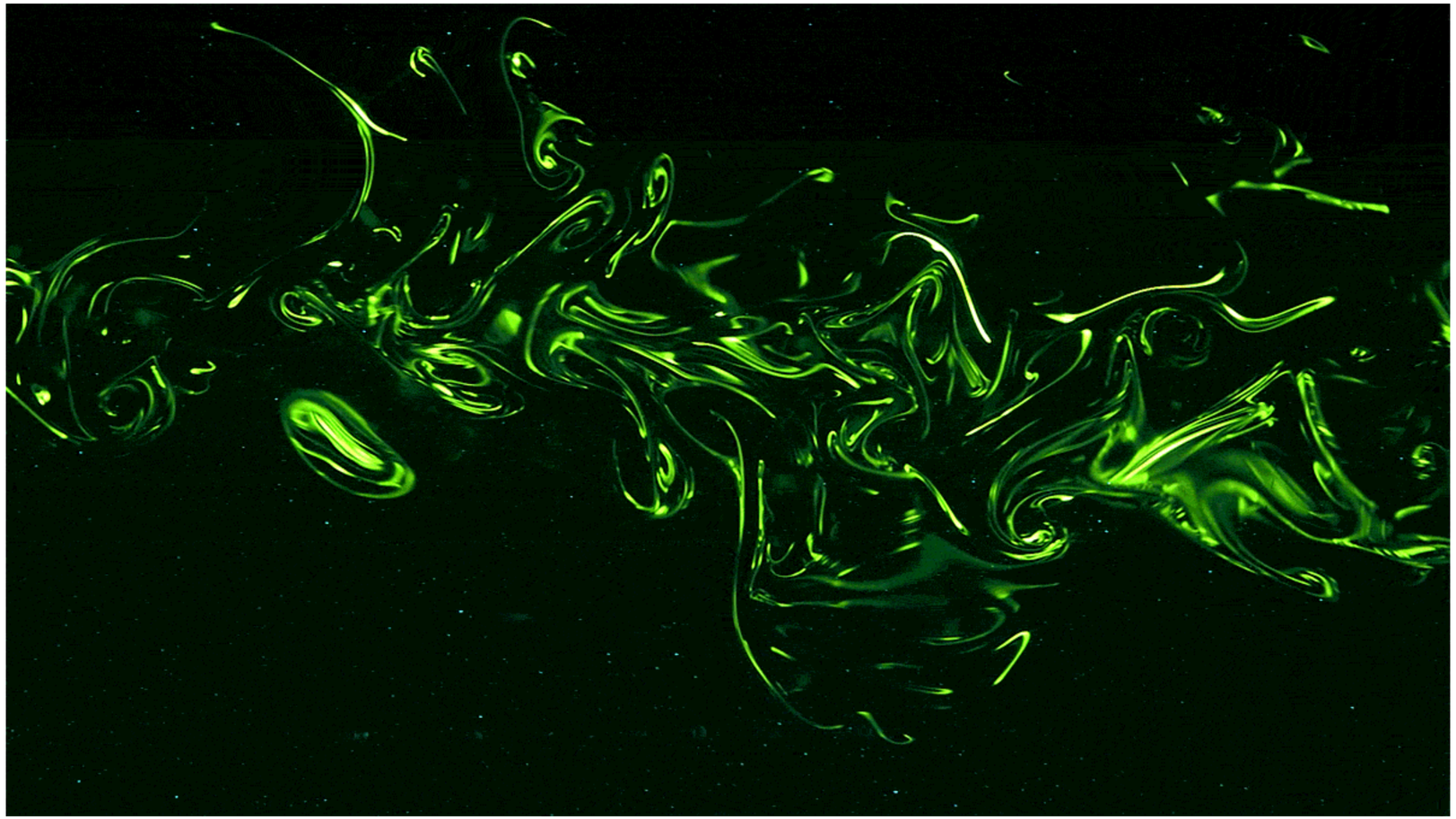
- Advice for training and running your dog:
  - During training:
    - ➡ ***Exposure***: work different flow scenarios into your training.
    - ➡ ***Flow visualization***: will help ensure that you understand your dog's behavior
  - During runs:
    - ➡ ***Flow visualization***: basic information is 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.

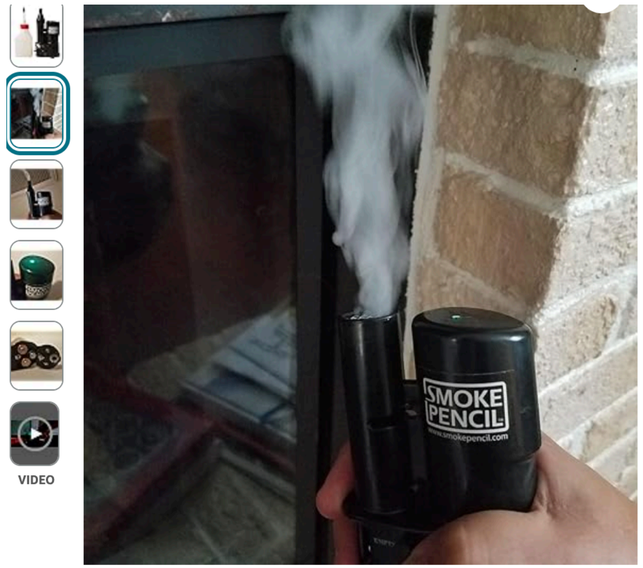
- Covered in this section:

  ➡ **Tools to help you visualize flow**

  ➡ **Guidelines for using the tools in different conditions.**

Flow visualization tools and options

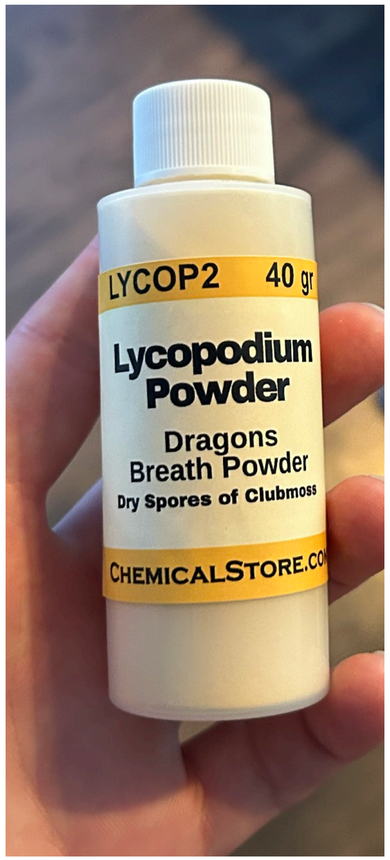
BEST Options: Smoke/vape machines



- Smoke Pencil for HVAC leak detection: $36 https://www.amazon.com/Smoke-Pencil-ONE-Leak-Detection/dp/B09MJMYZNG
- Capable of producing cool smoke appropriate buoyancy
- Unlikely to set off smoke alarms (when used judiciously)
- LENSGO Smoke Machines: $80-128 https://www.amazon.com/LENSGO-Hand-held-Portable-Photography-Disinfection/dp/B0CKHG23YR/

Flow visualization tools and options

OK Options: light-weight powders

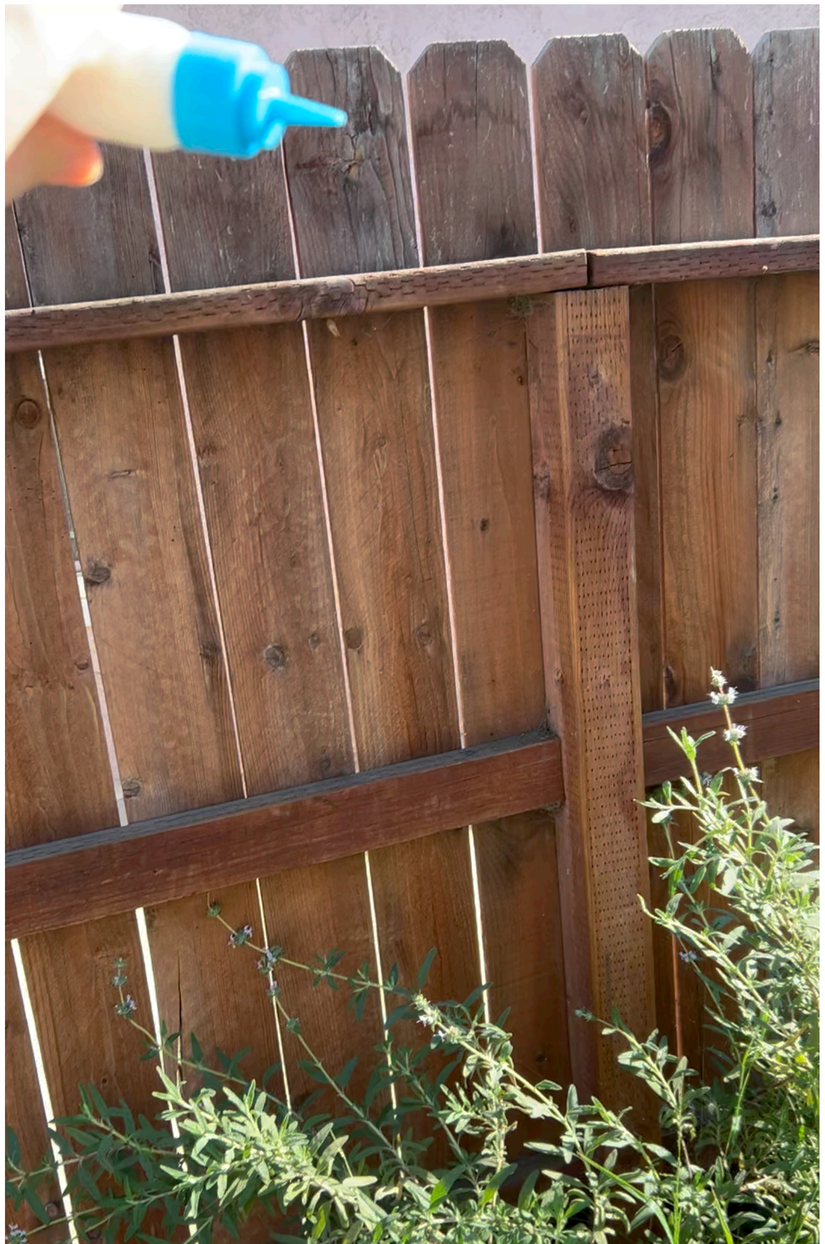


- Lycopodium powder (club moss spores): $18 https://www.amazon.com/CHEMICALSTORE-COM-Lycopodium-Powder-40-grams/dp/B0D8BWSKYQ/
  - good for basic wind direction/strength
  - limited use beyond this

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

- Orixa 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

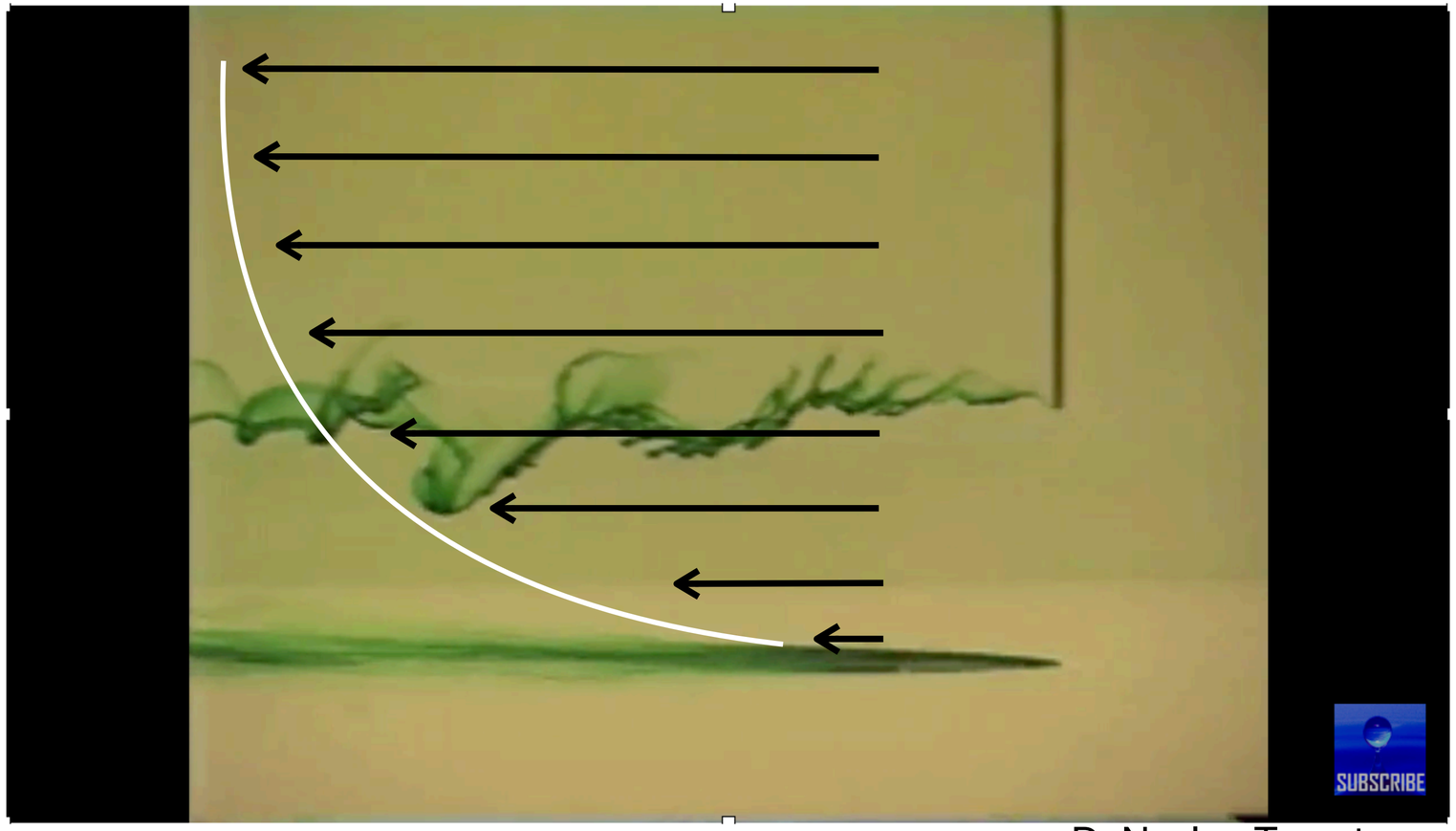
- Accurately visualizing odor movement depends on ***three*** factors:

    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!



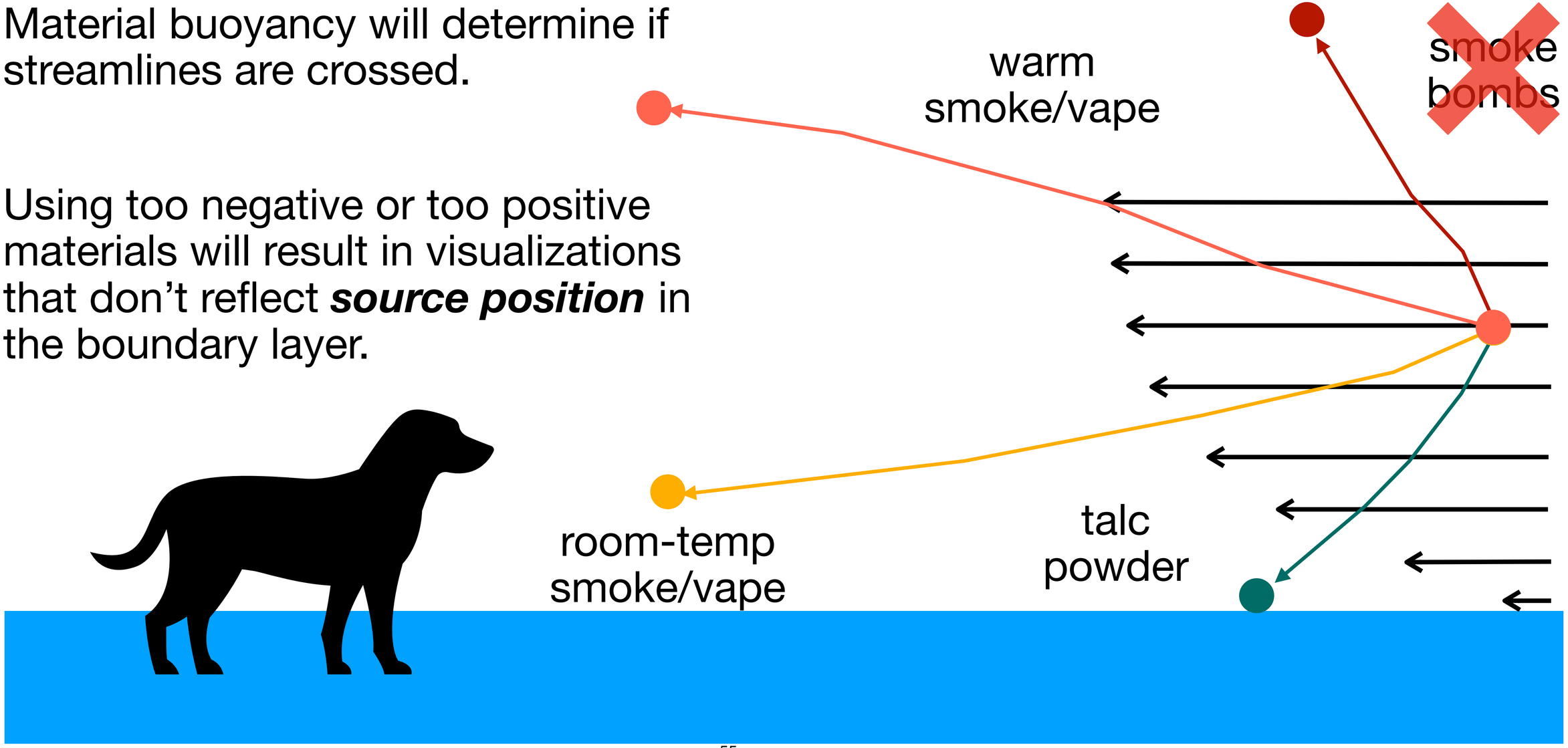
D. Naylor, Toronto Metro Univ

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

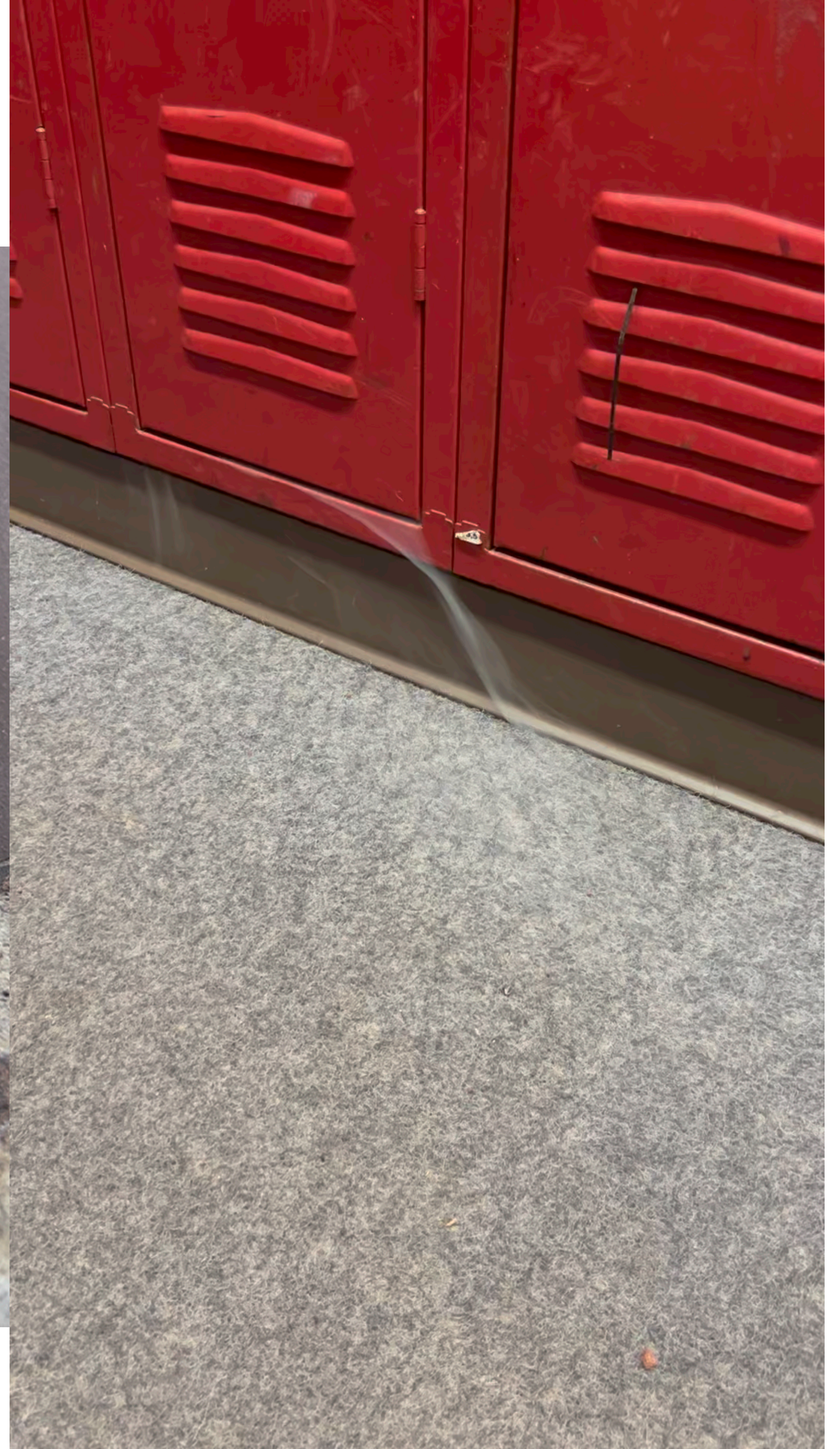
2. Buoyancy of viz material

- 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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