Applying optimal search to Dyson Minds

V. Hunter Adams
2025 Penn State SETI Symposium
Dyson Minds breakout session
August 19, 2025

What I’ve been thinking about . . .

- If the observability of a Dyson Mind couples with its motivation, we benefit from both a physics-up and a philosophy-down approach to search.

What I’ve been thinking about . . .

- If the observability of a Dyson Mind couples with its motivation, we benefit from both a physics-up and a philosophy-down approach to search.
- Minimizing the expected time to discovery requires the rapid and properly-weighted incorporation of a *huge* amount of information and opinions.

What I’ve been thinking about . . .

- If the observability of a Dyson Mind couples with its motivation, we benefit from both a physics-up and a philosophy-down approach to search.
- Minimizing the expected time to discovery requires the rapid and properly-weighted incorporation of a *huge* amount of information and opinions.
- How do we weigh the opinion of a philosopher against that of a computer engineer or a physicist? How do we take the opinions of folks who aren’t astronomers and rapidly apply them to astronomical search?

What I've been thinking about . . .

- If the observability of a Dyson Mind couples with its motivation, we benefit from both a physics-up and a philosophy-down approach to search.
- Minimizing the expected time to discovery requires the rapid and properly-weighted incorporation of a *huge* amount of information and opinions.
- How do we weigh the opinion of a philosopher against that of a computer engineer or a physicist? How do we take the opinions of folks who aren't astronomers and rapidly apply them to astronomical search?
- We may take inspiration from folks that make their living doing very high-stakes search. This is a presentation about how they do what they do, and how we might apply their approach to this problem.

What I’d like to discuss . . .

- Introduction to optimal search by way of a terrestrial example
- Mapping that terrestrial example to our celestial problem
- Proposed course of action

What I'd like to discuss . . .

I *think* this is both clearest, and most fun!

- Introduction to optimal search by way of a terrestrial example
- Mapping that terrestrial example to our celestial problem
- Proposed course of action

Walking through an example

Terrestrial problem statement: A tiny object (a “chipsat”) has descended from space and landed somewhere in or near Cayuga Lake, and we'd like to find it.

Celestial problem statement: A Dyson Mind exists somewhere in the universe, and we’d like to find it.

Walking through an example

We start with the assumption that what we're looking for *is out there*.

The algorithm that I'm about to describe maintains this assumption.

Walking through an example

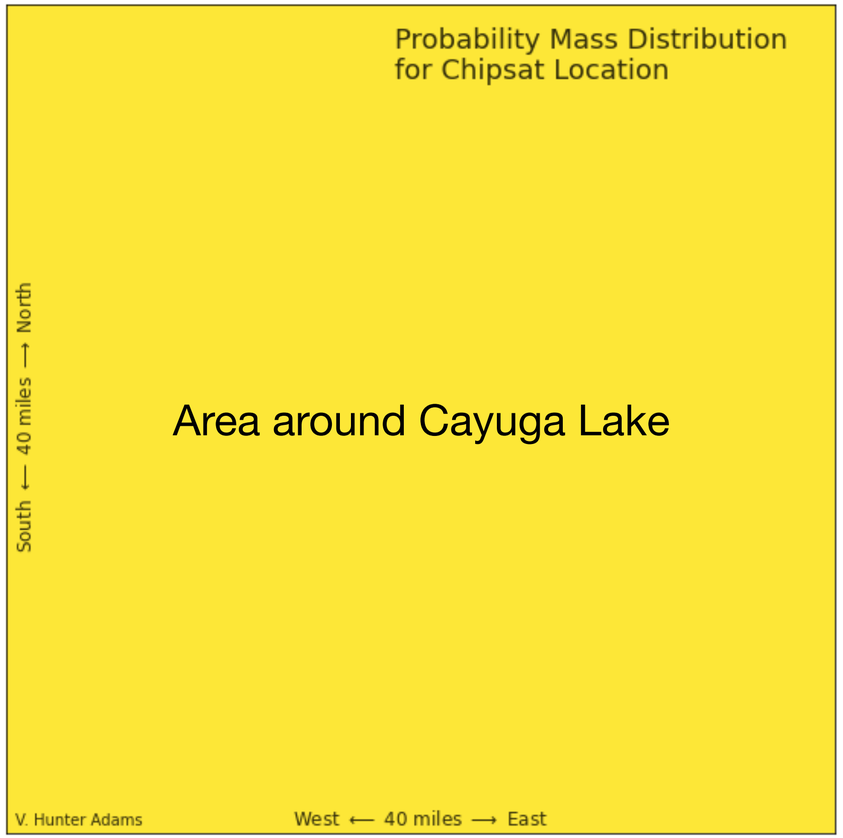
With *only* these problem statements, we've no reason to prefer any location to another in our search.

Our initial probability mass distributions for the locations of the objects we seek are *uniform*.

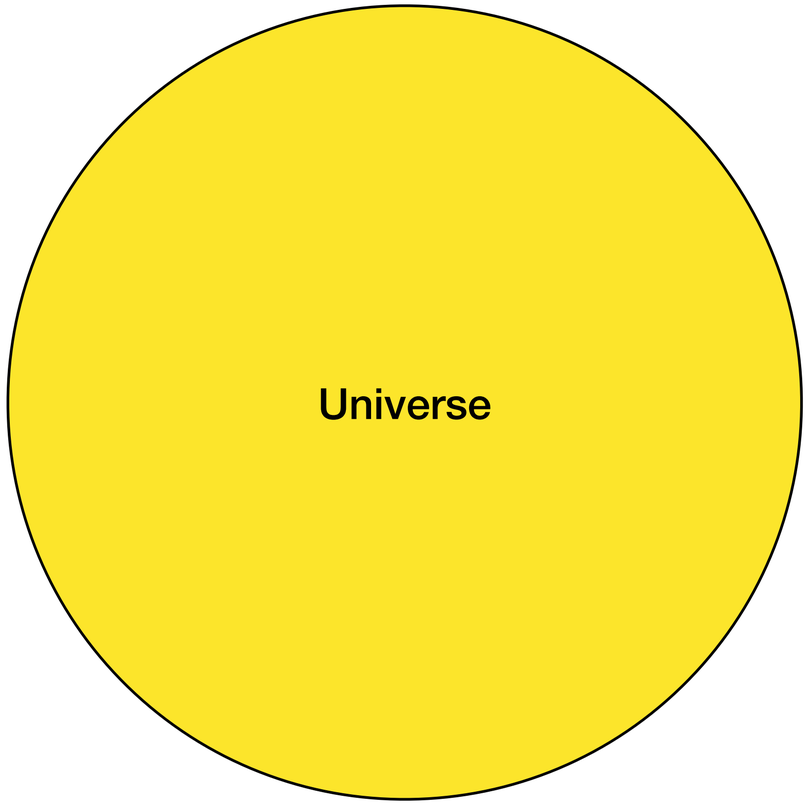
Walking through an example

Start with ignorance → Generate priors → Estimate searchability → Prioritize search → (Search!) → Update priors → A north wind blows

Terrestrially



Celestially



V. Hunter Adams

Walking through an example

Before we even start looking, we can apply some things that we know about the problems that we're solving.

Walking through an example

Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Search! → Update priors → A north wind blows

Terrestrially

$p(\text{chipsat is in this cell})$

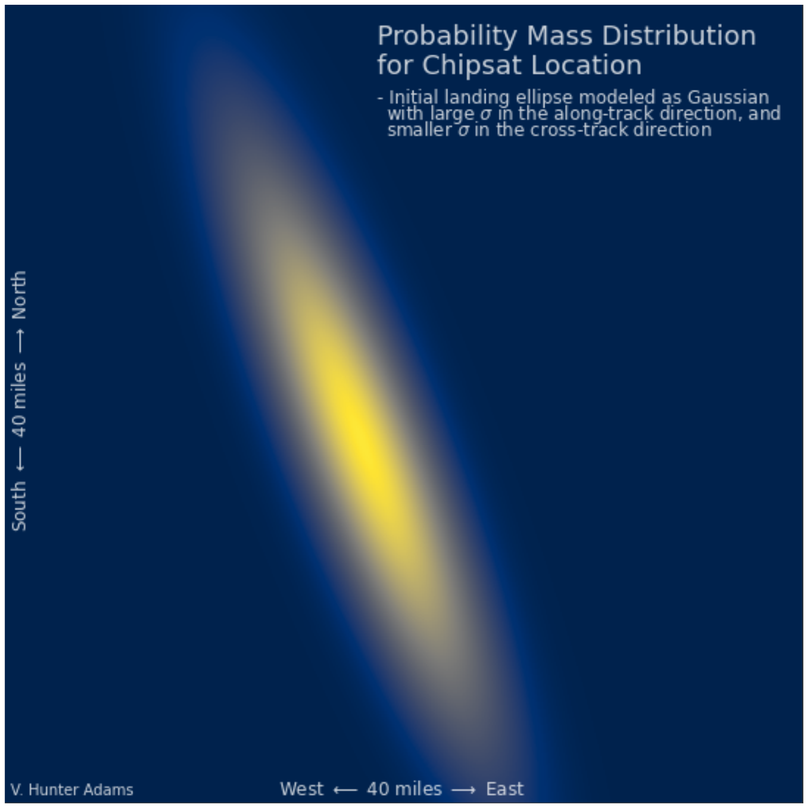
Let's suppose we know:

- The position and velocity of the chipsat when it hit the top of the atmosphere.
- Orbital mechanics, aerodynamics, a little about the weather, etc.

Walking through an example

Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Search! → Update priors → A north wind blows

Terrestrially



p(chipsat is in this cell)

(Total probability mass normalized to 1)

Let's suppose we know:

- The position and velocity of the chipsat when it hit the top of the atmosphere.
- Orbital mechanics, aerodynamics, a little about the weather, etc.

Walking through an example

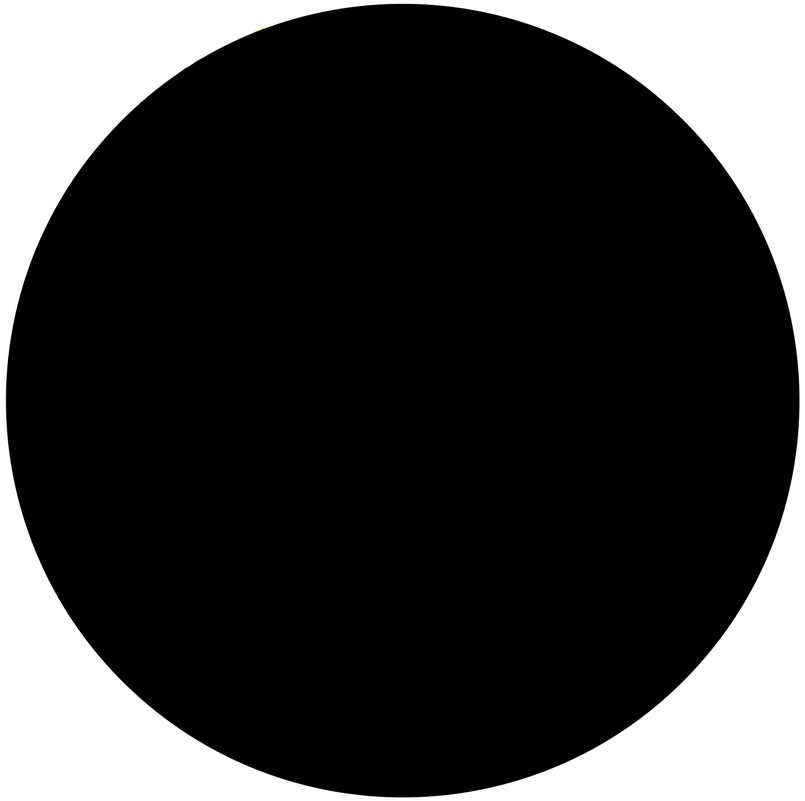
Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Update priors → A north wind blows

Search!

Let's suppose we know:

- The opinions of folks/groups of relevance about where they *think* Dyson Minds are likely located.
- The strength of their opinions, in units of probability mass.

Celestially



$p(\text{Dyson Mind is in this cell})$

V. Hunter Adams

Walking through an example

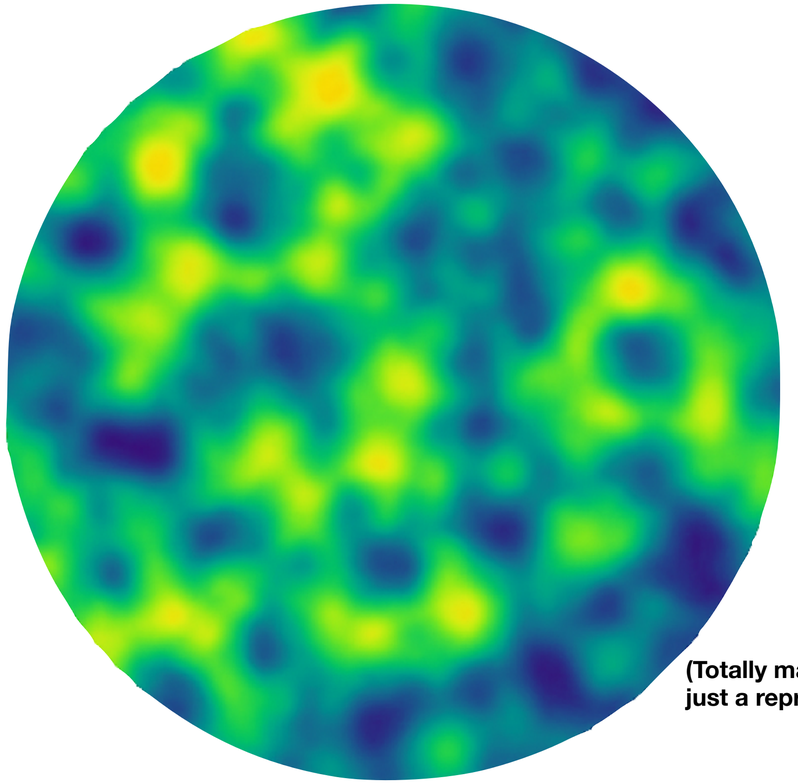
Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Update priors → A north wind blows

(Search! → Prioritize search; Update priors → A north wind blows)

Let's suppose we know:

- The opinions of folks/groups of relevance about where they *think* Dyson Minds are likely located.
- The strength of their opinions, in units of probability mass.

Celestially



(Totally made up data, just a representation)

p(Dyson Mind is in this cell)

V. Hunter Adams

Walking through an example

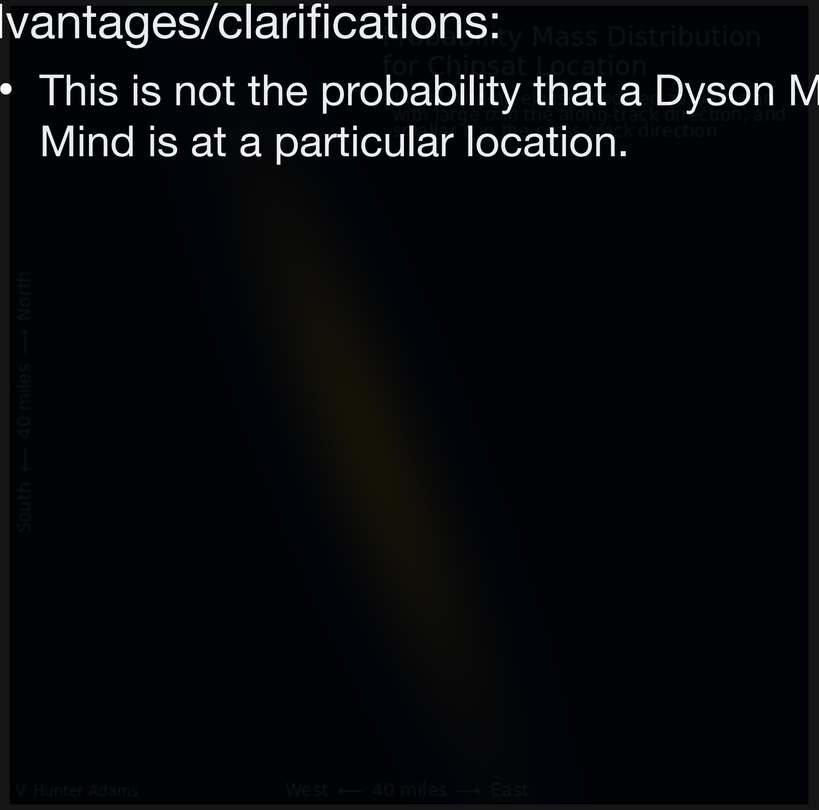
Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Search! → Update priors → A north wind blows

Terrestrially

Celestially

Advantages/clarifications:

- This is not the probability that a Dyson Mind is at a particular location, it's the *strength of your opinion* that the Dyson Mind is at a particular location.



p(chipsat location)

(Totally made up data, just a representation)

p(Dyson Mind is in this cell)

Walking through an example

Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Update priors → A north wind blows

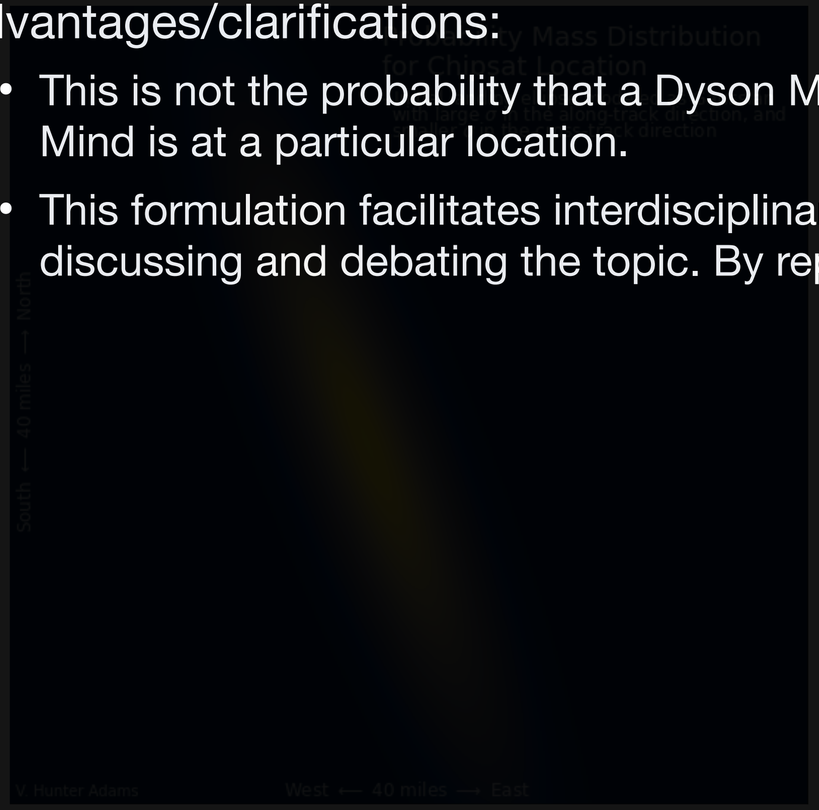
Search!

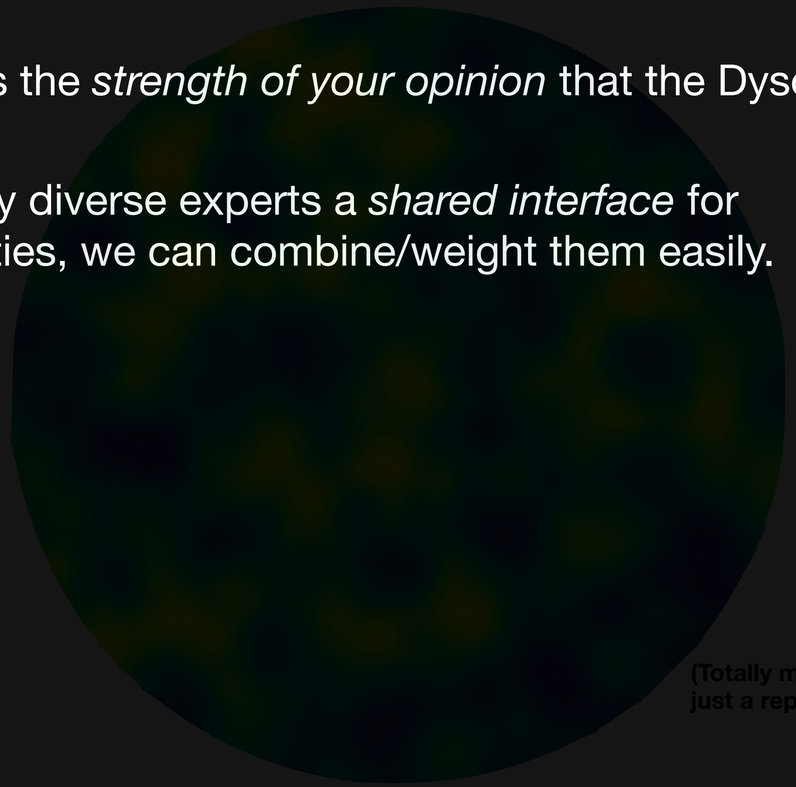
Terrestrially

Celestially

Advantages/clarifications:

- This is not the probability that a Dyson Mind is at a particular location, it's the *strength of your opinion* that the Dyson Mind is at a particular location.
- This formulation facilitates interdisciplinary conversation by offering highly diverse experts a *shared interface* for discussing and debating the topic. By representing opinions as probabilities, we can combine/weight them easily.





(Totally made up data, just a representation)

p(chipsat location)

p(Dyson Mind is in this cell)

V. Hunter Adams

Walking through an example

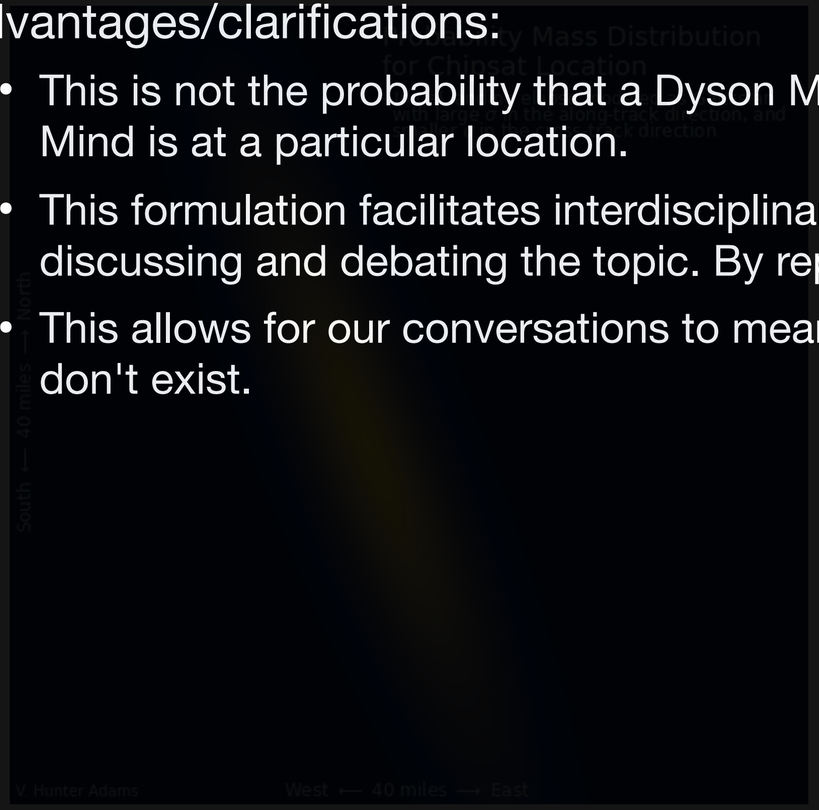
Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Search! → Update priors → A north wind blows

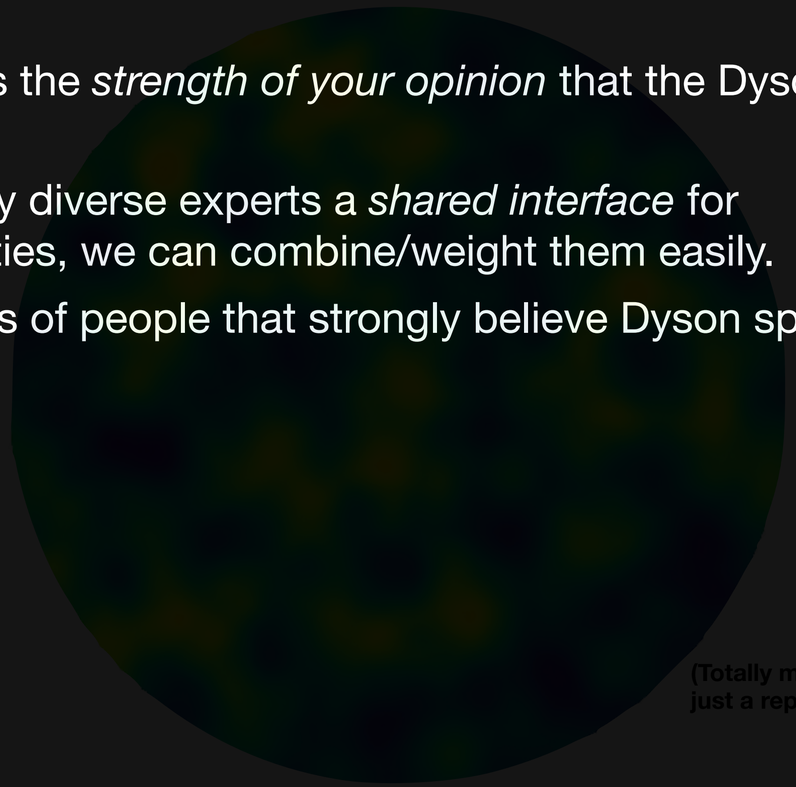
Terrestrially

Celestially

Advantages/clarifications:

- This is not the probability that a Dyson Mind is at a particular location, it's the *strength of your opinion* that the Dyson Mind is at a particular location.
- This formulation facilitates interdisciplinary conversation by offering highly diverse experts a *shared interface* for discussing and debating the topic. By representing opinions as probabilities, we can combine/weight them easily.
- This allows for our conversations to meaningfully include the perspectives of people that strongly believe Dyson spheres don't exist.





(Totally made up data, just a representation)

p(chipsat location)

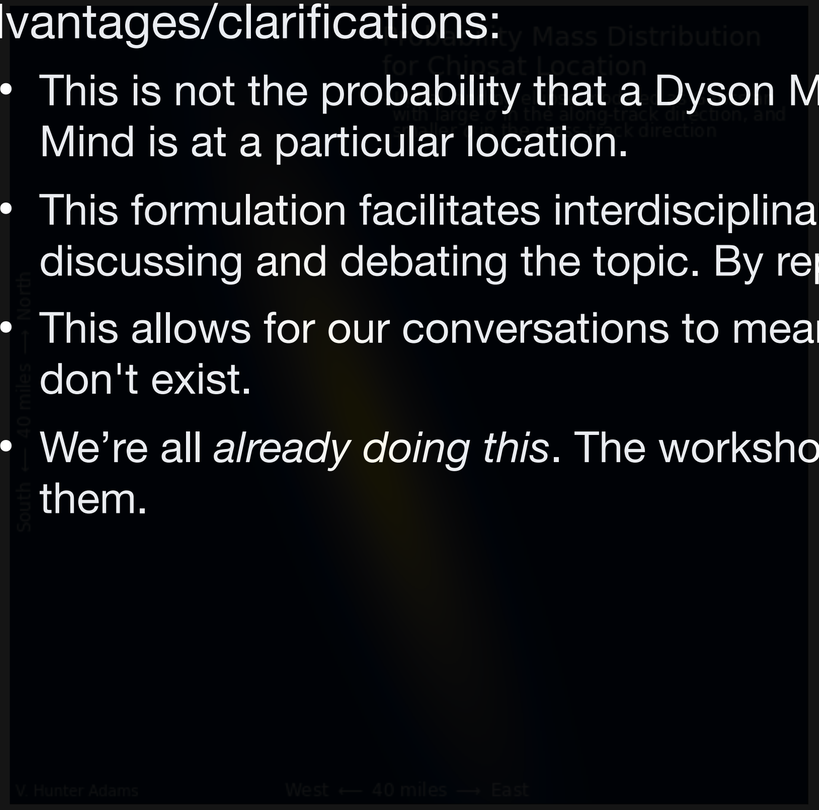
p(Dyson Mind is in this cell)

V. Hunter Adams

Walking through an example

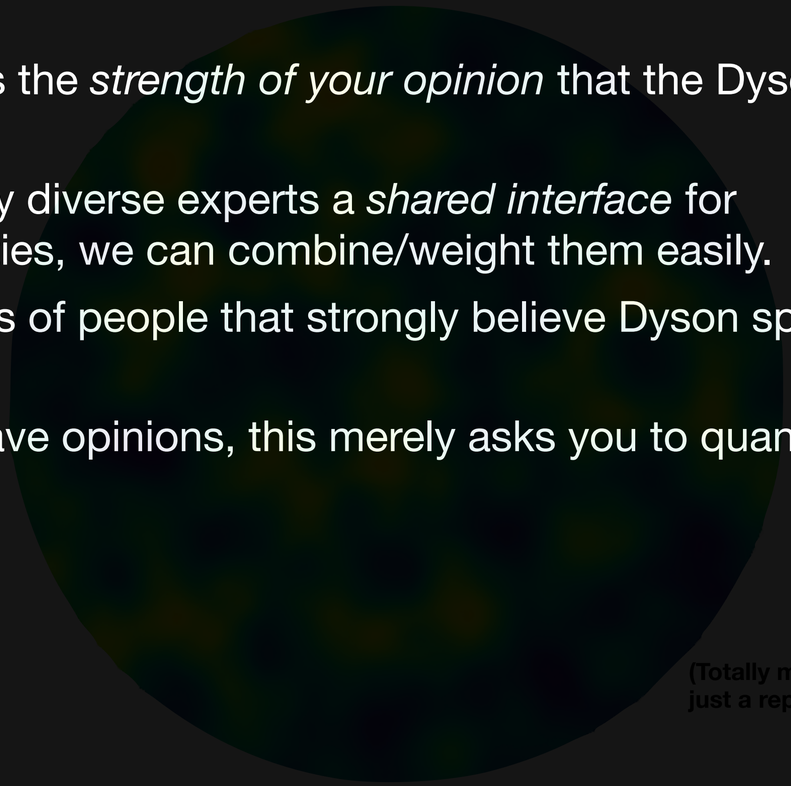
Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Search! → Update priors → A north wind blows

Terrestrially



p(chipsat location)

Celestially



(Totally made up data, just a representation)

p(Dyson Mind is in this cell)

Advantages/clarifications:

- This is not the probability that a Dyson Mind is at a particular location, it's the *strength of your opinion* that the Dyson Mind is at a particular location.
- This formulation facilitates interdisciplinary conversation by offering highly diverse experts a *shared interface* for discussing and debating the topic. By representing opinions as probabilities, we can combine/weight them easily.
- This allows for our conversations to meaningfully include the perspectives of people that strongly believe Dyson spheres don't exist.
- We're all *already doing this*. The workshop revealed that folks certainly have opinions, this merely asks you to quantify them.

V. Hunter Adams

Walking through an example

Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → (Search!) → Update priors → A north wind blows

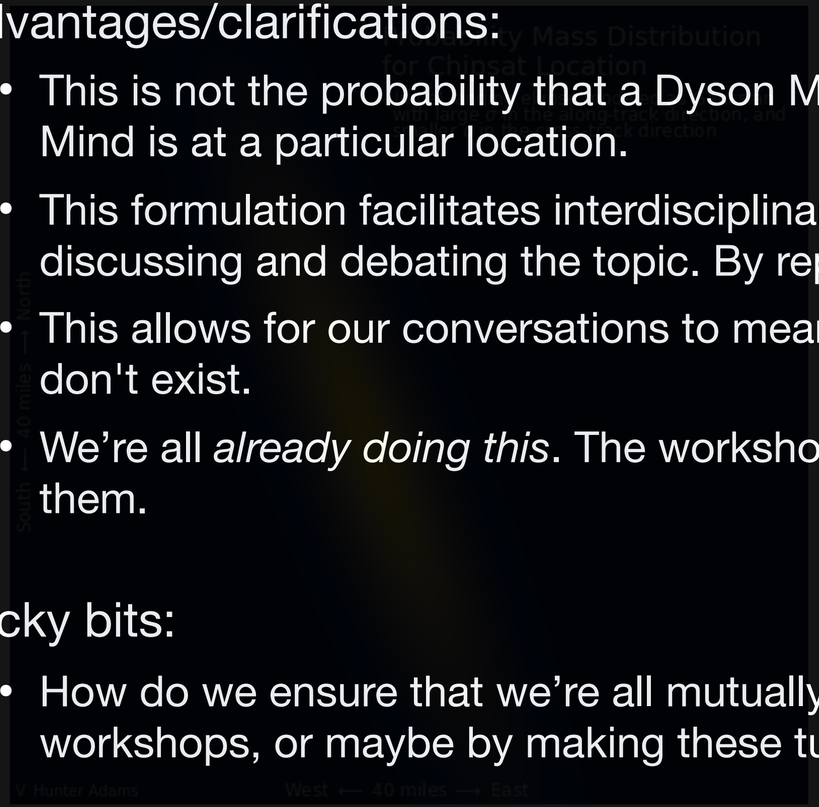
Terrestrially | **Celestially**

Advantages/clarifications:

- This is not the probability that a Dyson Mind is at a particular location, it's the *strength of your opinion* that the Dyson Mind is at a particular location.
- This formulation facilitates interdisciplinary conversation by offering highly diverse experts a *shared interface* for discussing and debating the topic. By representing opinions as probabilities, we can combine/weight them easily.
- This allows for our conversations to meaningfully include the perspectives of people that strongly believe Dyson spheres don't exist.
- We're all *already doing this*. The workshop revealed that folks certainly have opinions, this merely asks you to quantify them.

Tricky bits:

- How do we ensure that we're all mutually calibrated in our assignment of probabilities? Maybe by way of domain-specific workshops, or maybe by making these tunable parameters in a database (more on this in a moment).



p(chipsat location)

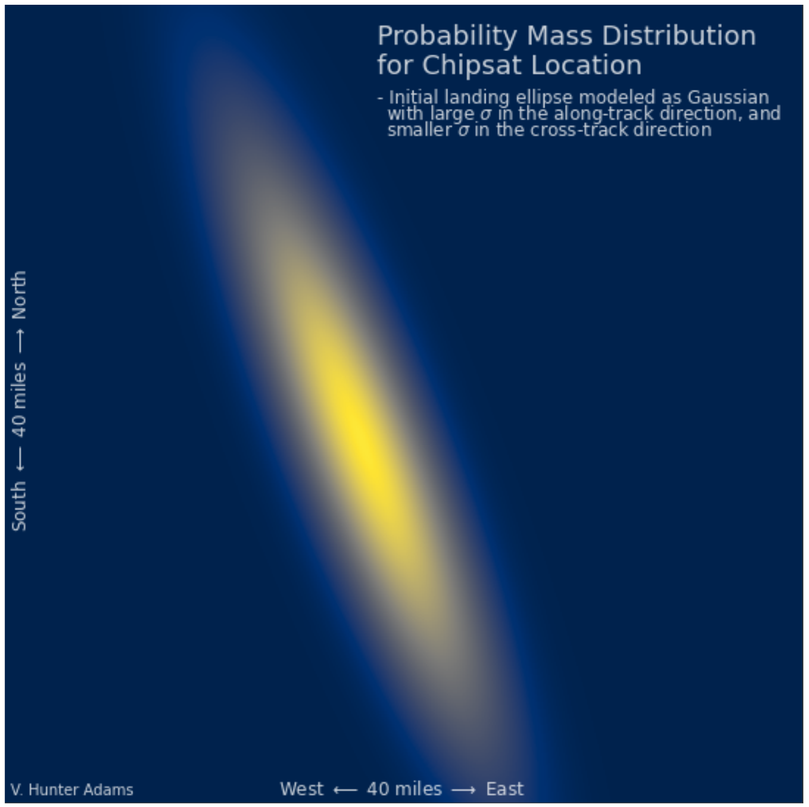
p(Dyson Mind is in this cell)

(Totally model agnostic, just a representation)

Walking through an example

Start with ignorance → **Generate priors** → Estimate searchability → Prioritize search → Search! → Update priors → A north wind blows

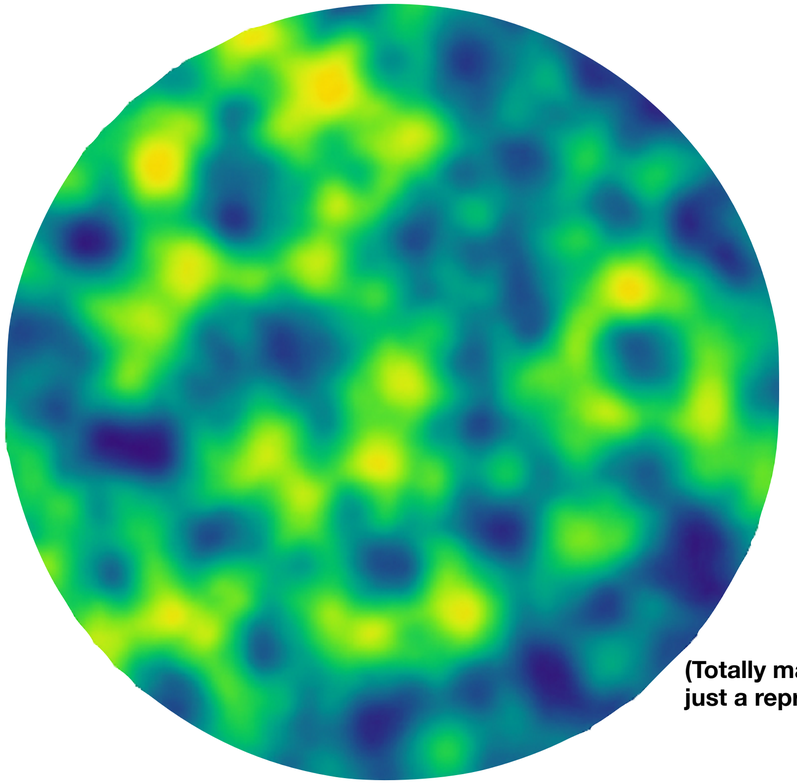
Terrestrially



p(chipsat is in this cell)

After having applied what we know, before we search.

Celestially



(Totally made up data, just a representation)

p(Dyson Mind is in this cell)

V. Hunter Adams

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → Search! → Update priors → A north wind blows

But our search space is not uniformly searchable!

Terrestrially, some areas of our search space include deep gorges and treacherous terrain.

Celestially, some regions of the universe are really hard to observe.

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → Search! → Update priors → A north wind blows

Suppose that which we seek is in a particular cell, and suppose we look for it in that cell, what is the probability that we don't see it?

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → Search! → Update priors → A north wind blows

Terrestrially

For purposes of this discussion, let's suppose:

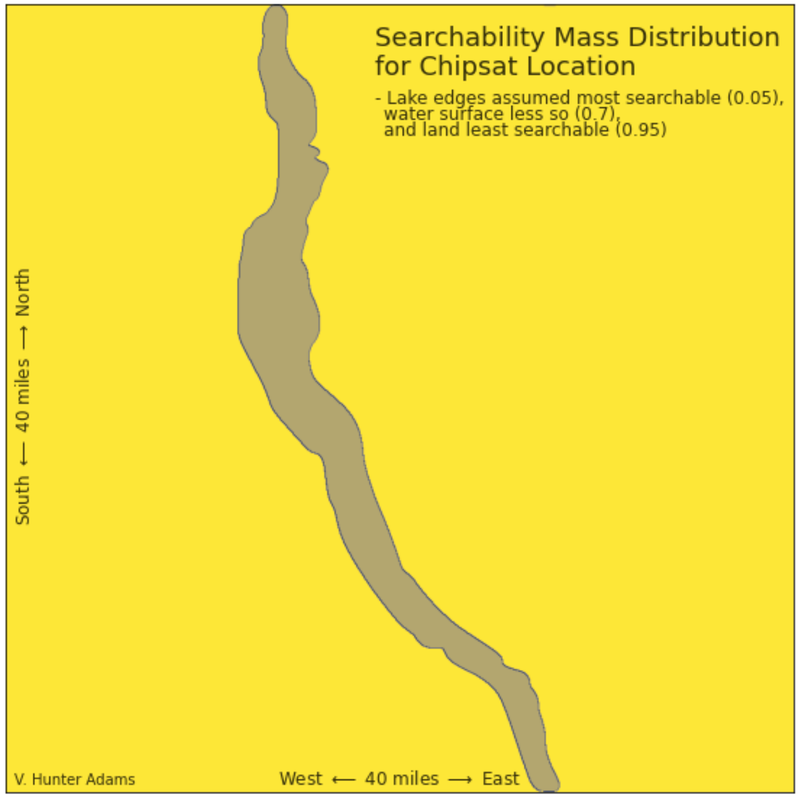
- The shores of the lake are very searchable (it's easy to find a chipsat on the beach)
- The water itself is moderately searchable
- Land has poor searchability (challenging terrain, hard to access, etc.).

p(not finding chipsat in cell | chipsat is located in that cell)

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → (Search!) → Update priors → A north wind blows

Terrestrially



For purposes of this discussion, let's suppose:

- The shores of the lake are very searchable (it's easy to find a chipsat on the beach)
- The water itself is moderately searchable
- Land has poor searchability (challenging terrain, hard to access, etc.).

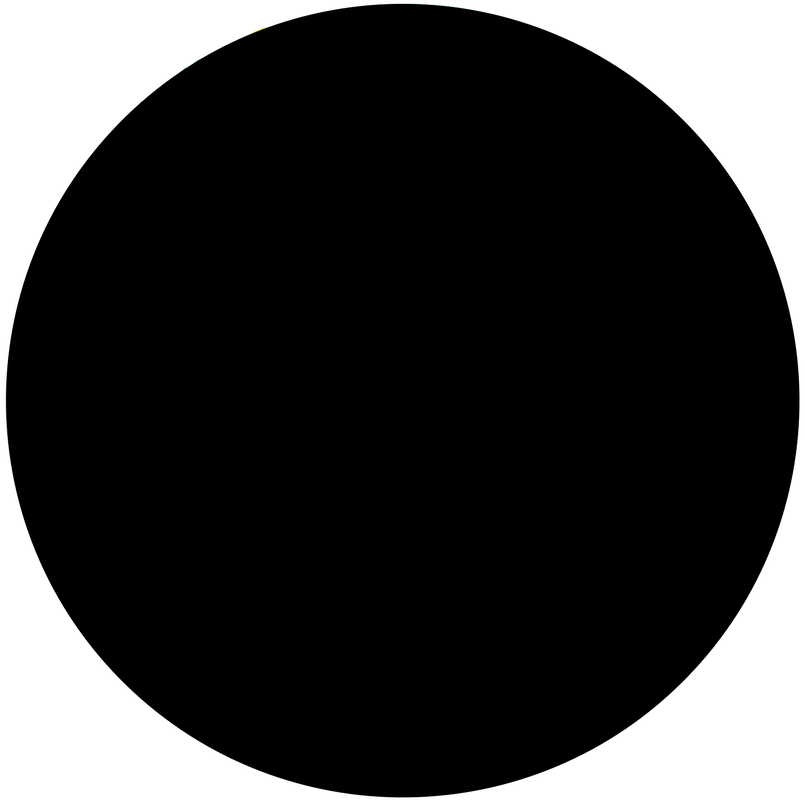
p(not finding chipsat in cell | chipsat is located in that cell)

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → Update priors → A north wind blows

Search!

Celestially



Searchability for Dyson Minds

- We ask **two** questions when quantifying the searchability of a universe cell for Dyson Minds. Supposing that a Dyson Mind exists in a particular cell:
  - What is the probability that we can gather data from that cell?
  - Given that we have gathered data, what is the probability that we *don't* notice the Dyson Mind?

$p(\text{We don't see a Dyson Mind in a particular cell} \mid \text{a Dyson mind exists in that cell})$

Expands to

$p(\text{Gathering data from that cell}) \cdot p(\text{Not seeing the Dyson Mind in that data})$

V. Hunter Adams

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → Update priors → A north wind blows

Search!

Searchability for Dyson Minds

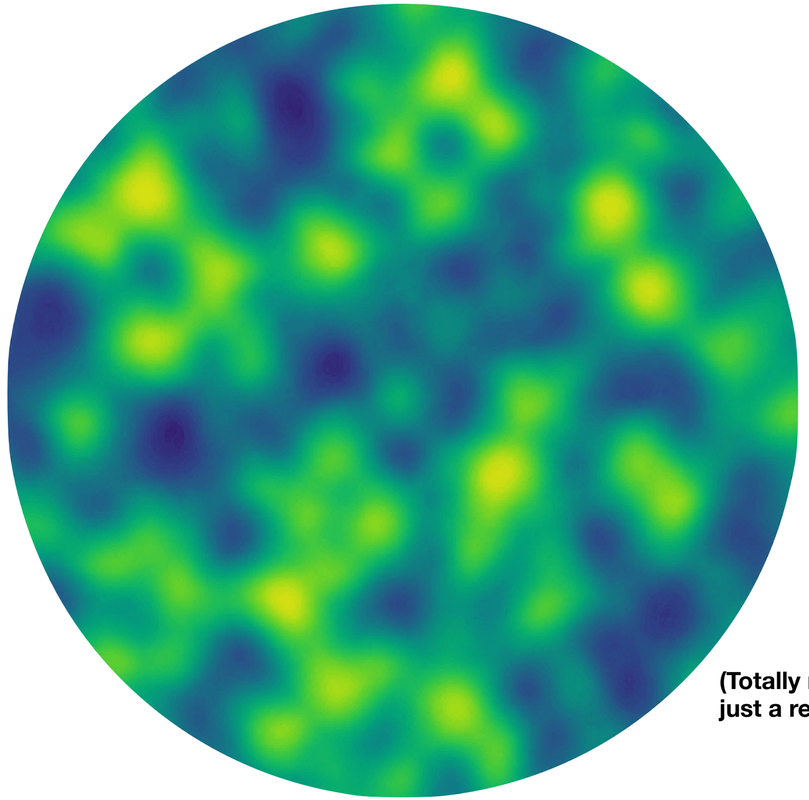
- We ask **two** questions when quantifying the searchability of a universe cell for Dyson Minds. Supposing that a Dyson Mind exists in a particular cell:
  - What is the probability that we can gather data from that cell?
  - Given that we have gathered data, what is the probability that we *don't* notice the Dyson Mind?

$p(\text{We don't see a Dyson Mind in a particular cell} \mid \text{a Dyson mind exists in that cell})$

Expands to

$p(\text{Gathering data from that cell}) \cdot p(\text{Not seeing the Dyson Mind in that data})$

Celestially



(Totally made up data, just a representation)

Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → (Search!) → Update priors → A north wind blows

Celestially

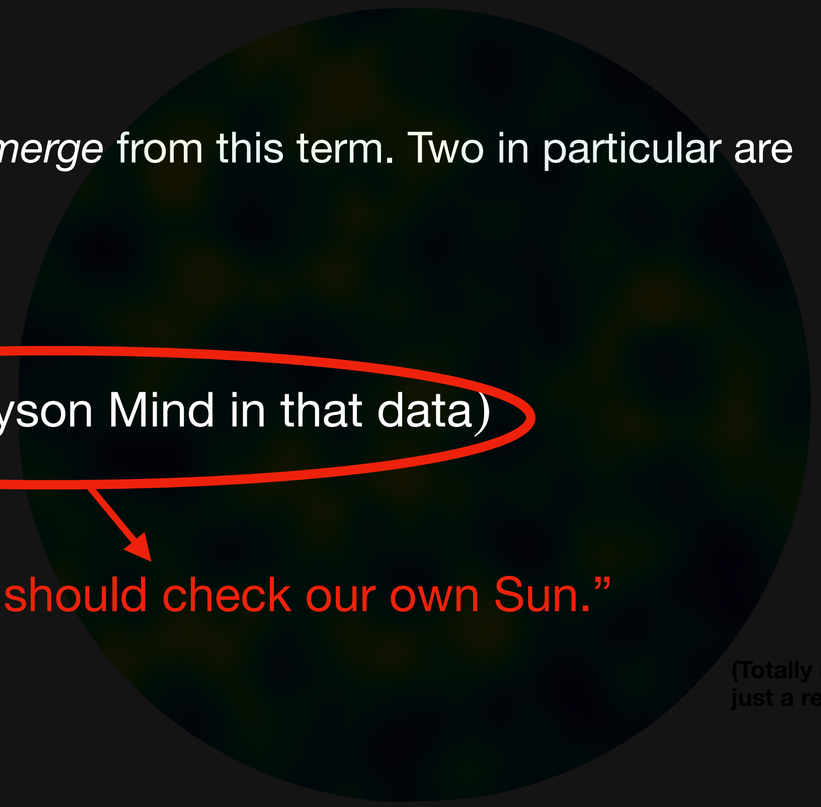
Some thoughts about searchability:

- Here is where we recruit the expertise of our friends in astronomy!!
- Some intuitions which were articulated at the Dyson Minds workshop *emerge* from this term. Two in particular are illustrated below.

$$p(\text{Gathering data from that cell}) \cdot p(\text{Not seeing the Dyson Mind in that data})$$

"We should check the data that we already have."

"We should check our own Sun."



(Totally made up data, just a representation)

$p(\text{We don't see a Dyson Mind in a particular cell} \mid \text{a Dyson mind exists in that cell})$

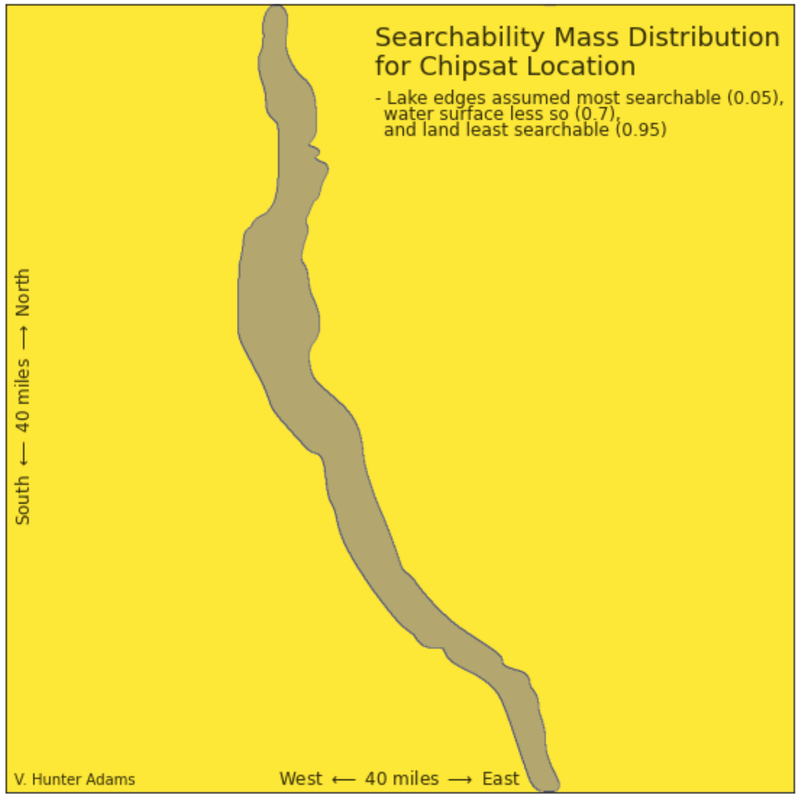
Expands to

$p(\text{Gathering data from that cell}) \cdot p(\text{Not seeing the Dyson Mind in that data})$

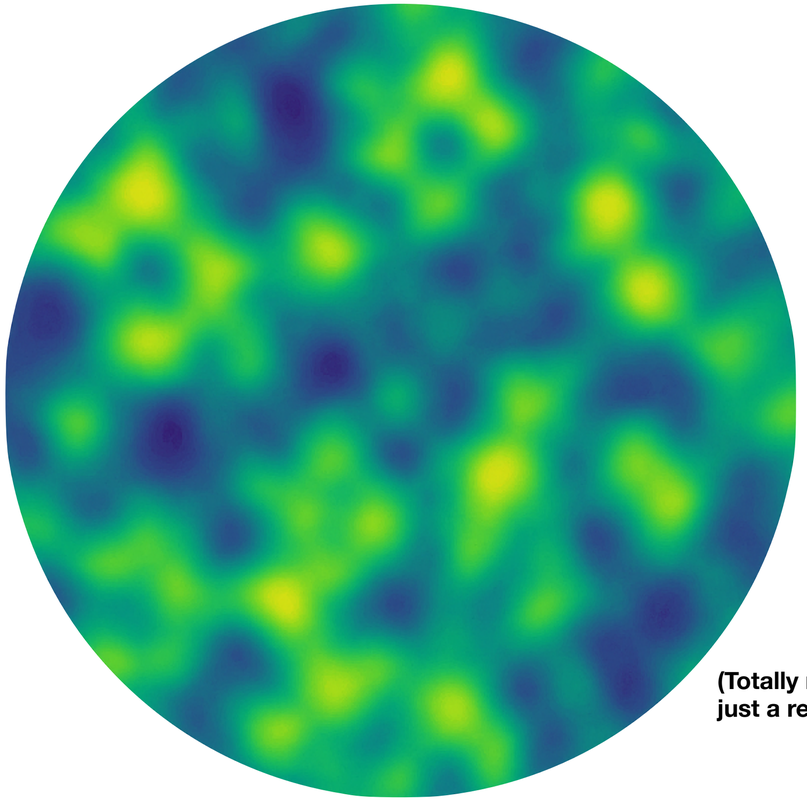
Walking through an example

Start with ignorance → Generate priors → **Estimate searchability** → Prioritize search → Search! → Update priors → A north wind blows

Terrestrially



Celestially



(Totally made up data, just a representation)

p(not seeing what we're looking for in this cell | we're looking in the correct cell)

V. Hunter Adams

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → **Prioritize search** → Search! → Update priors → A north wind blows

We don’t want to search in the places where what we’re looking for is most likely to be located.

We want to search in the places that we’re most likely to find what we’re looking for.

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → **Prioritize search** → (Search!) → Update priors → A north wind blows → (back to Prioritize search)

For each cell, we can compute how likely we are to find what we're looking for in that cell.

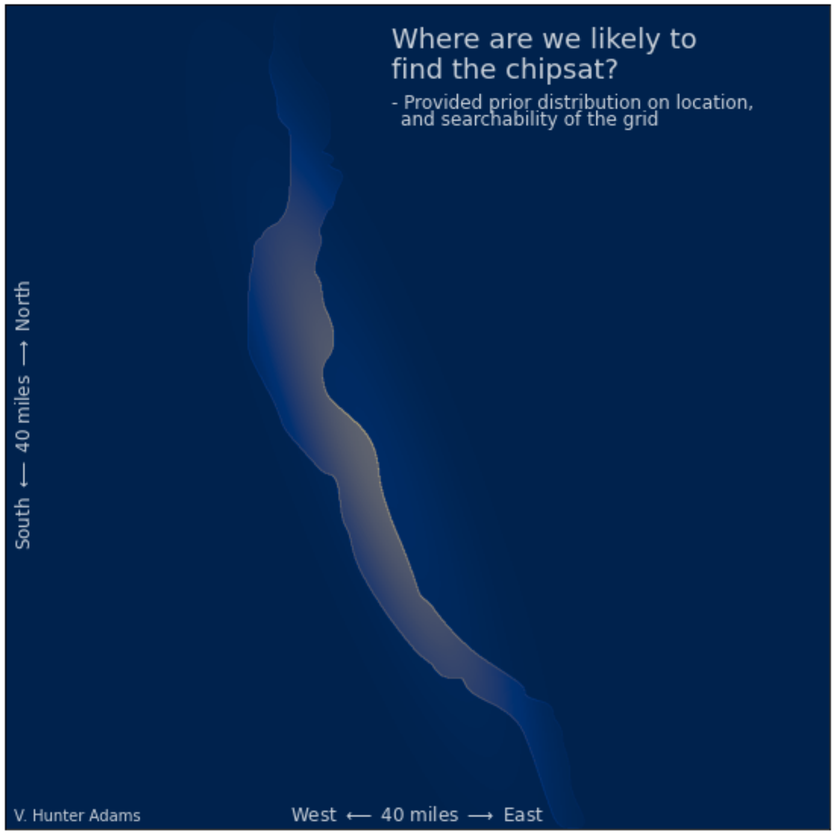
These are the places where we should begin our search.

$$p(\text{we're looking in the right cell}) \cdot \left(1 - p(\text{not seeing what we're looking for} \mid \text{we're looking in the right cell})\right)$$

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → **Prioritize search** → (Search!) → Update priors → A north wind blows

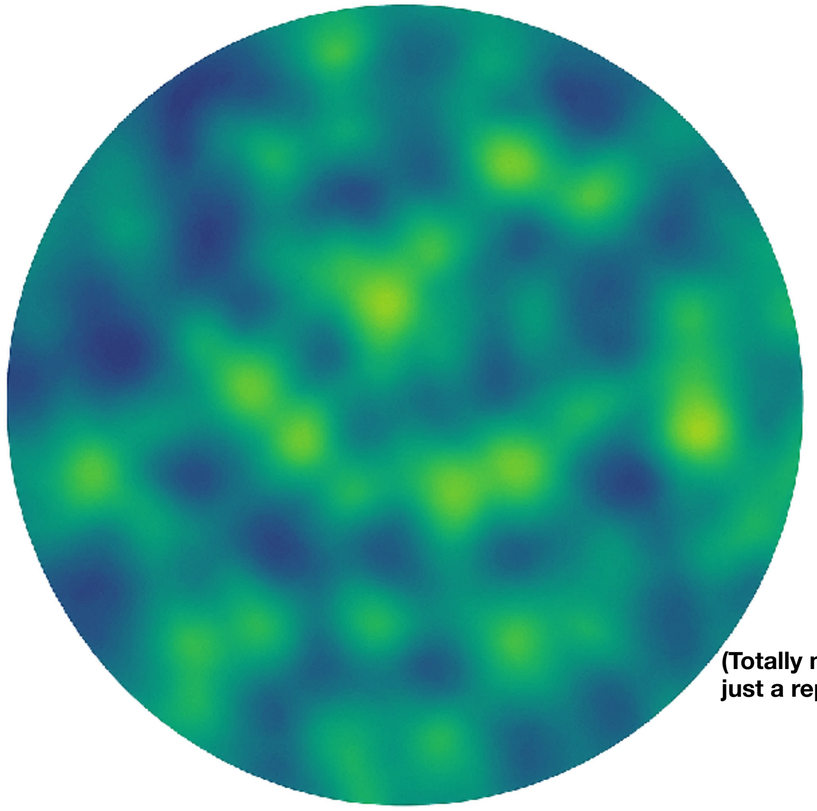
Terrestrial



← Search the shores and water.

Search the data we already have (e.g. EHT), and places where we're likely to see what we're looking for. →

Celestial



(Totally made up data, just a representation)

V. Hunter Adams

Walking through an example

Look for what you're trying to find! Start in the cells you've identified as being most promising.

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → Prioritize search → Search! → **Update priors** → A north wind blows

Every time you *don't* find what you're looking for in a single cell, you can update your entire map by way of the equation below (just Bayes' Rule).

$$p(\text{What I'm seeking is in this cell} \mid \text{I did not find it in this cell}) = \frac{p(\text{it's in this cell}) \cdot p(\text{not seeing it in this cell} \mid \text{it's in this cell}))}{p(\text{not seeing what I'm looking for})}$$

Let's suppose we search the *whole* map, and we don't find anything.

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → Prioritize search → Search! → **Update priors** → A north wind blows

Every time **you *don't*** **find what you're looking for in a single cell, you can update your entire map by way of the equation below (just Bayes' Rule).**

Talked about this already

Talked about this already

$$p(\text{What I'm seeking is in this cell} \mid \text{I did not find it in this cell}) = \frac{p(\text{it's in this cell}) \cdot p(\text{not seeing it in this cell} \mid \text{it's in this cell}))}{p(\text{not seeing what I'm looking for})}$$

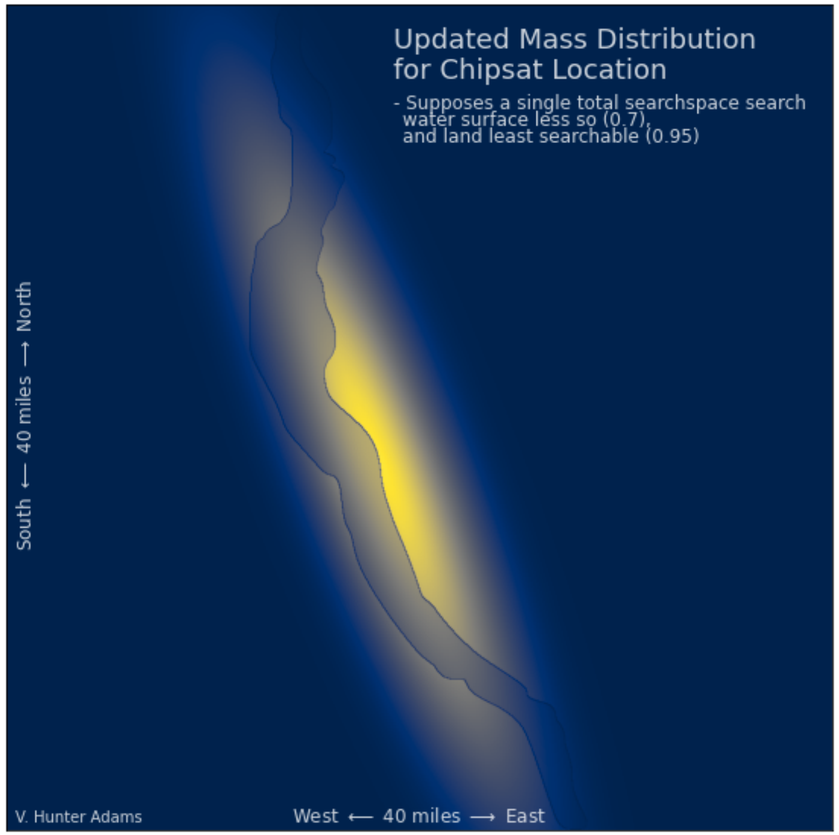
Just normalize over the search space

Let's suppose we search the *whole* map, and we don't find anything.

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → Prioritize search → Search! → **Update priors** → A north wind blows

Terrestrial

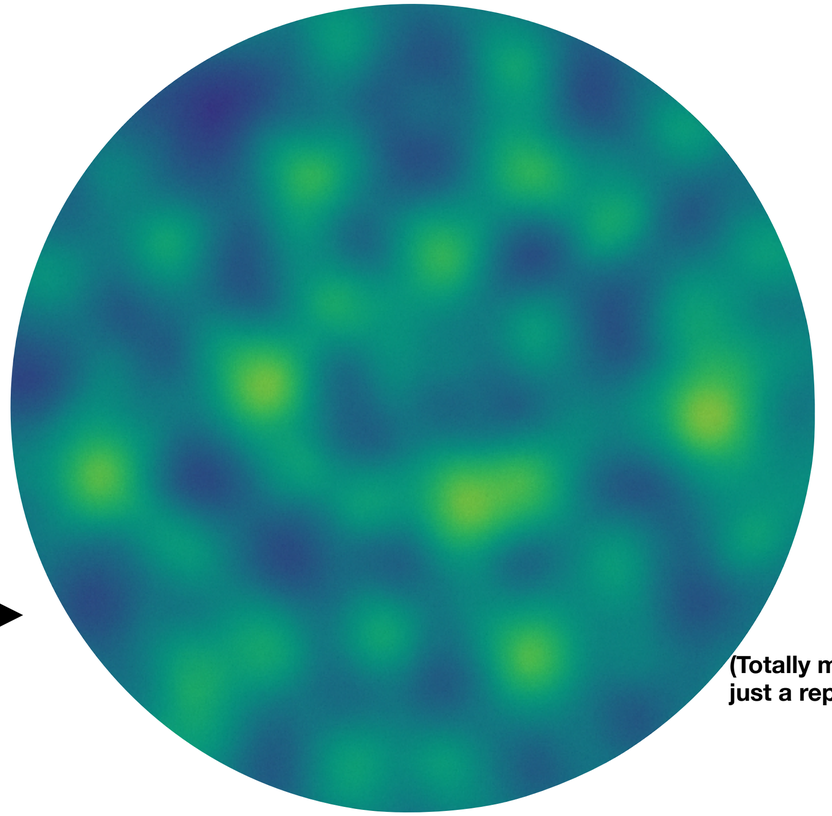


(Total probability mass automatically stays normalized to 1)

← Decreased confidence that the object is in the lake or on a shore (we'd probably have seen it). Increased confidence it's on land.

→ A **new** map, based on what we didn't find.

Celestial



(Totally made up data, just a representation)

(Total probability mass automatically stays normalized to 1)

V. Hunter Adams

Walking through an example

Let us suppose something happens which changes our understanding of the search space.

Terrestrially, perhaps a north wind blows.

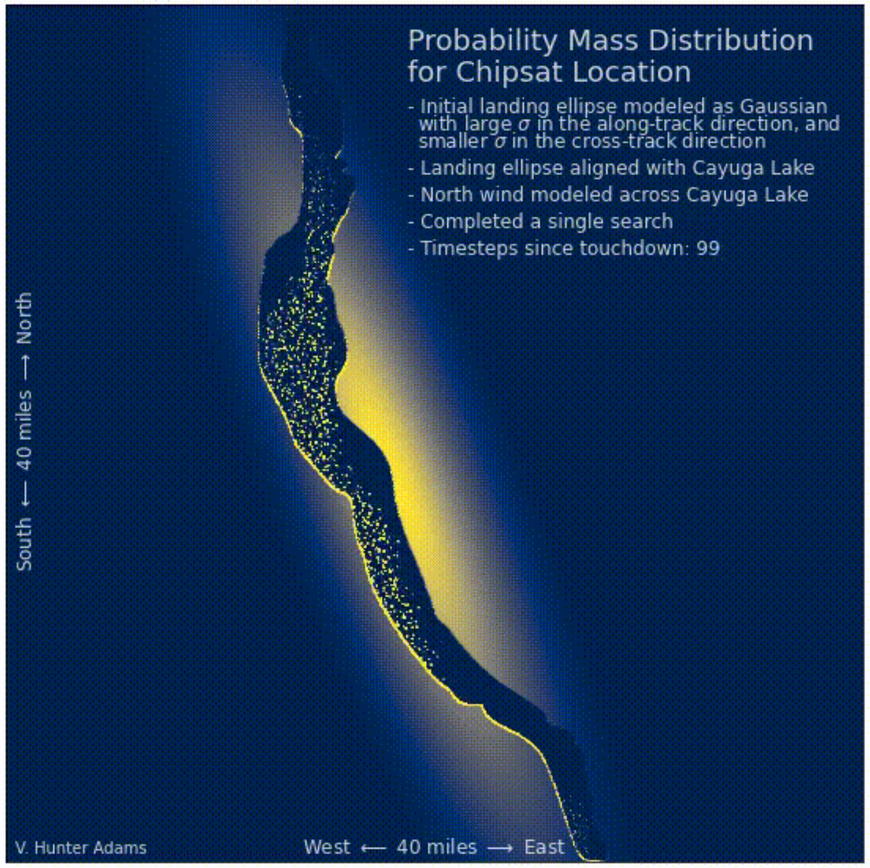
Celestially, perhaps a new paper comes out that improves our understanding of the likelihood for a Dyson Mind being at particular places on the map.

That’s ok! We just update and carry on.

Walking through an example

Start with ignorance → Generate priors → Estimate searchability → Prioritize search → (Search!) → Update priors → **A north wind blows**

[Click here for a gif!]



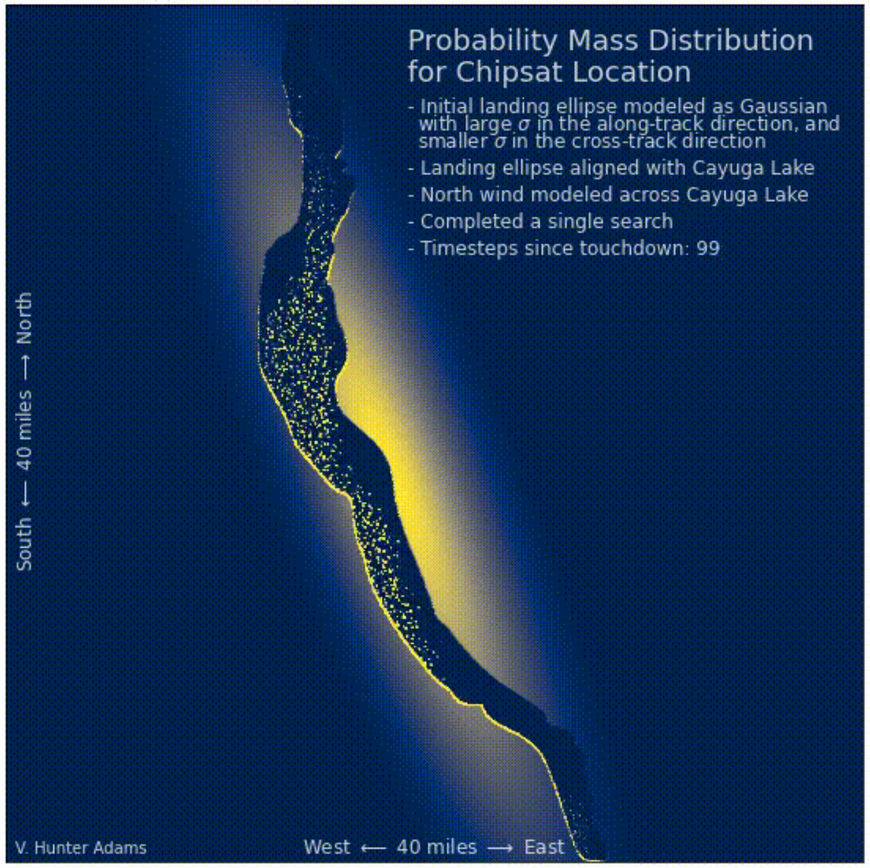
A north wind moves probability mass on the *surface* of the lake south. It accumulates on north-facing shores.

V. Hunter Adams

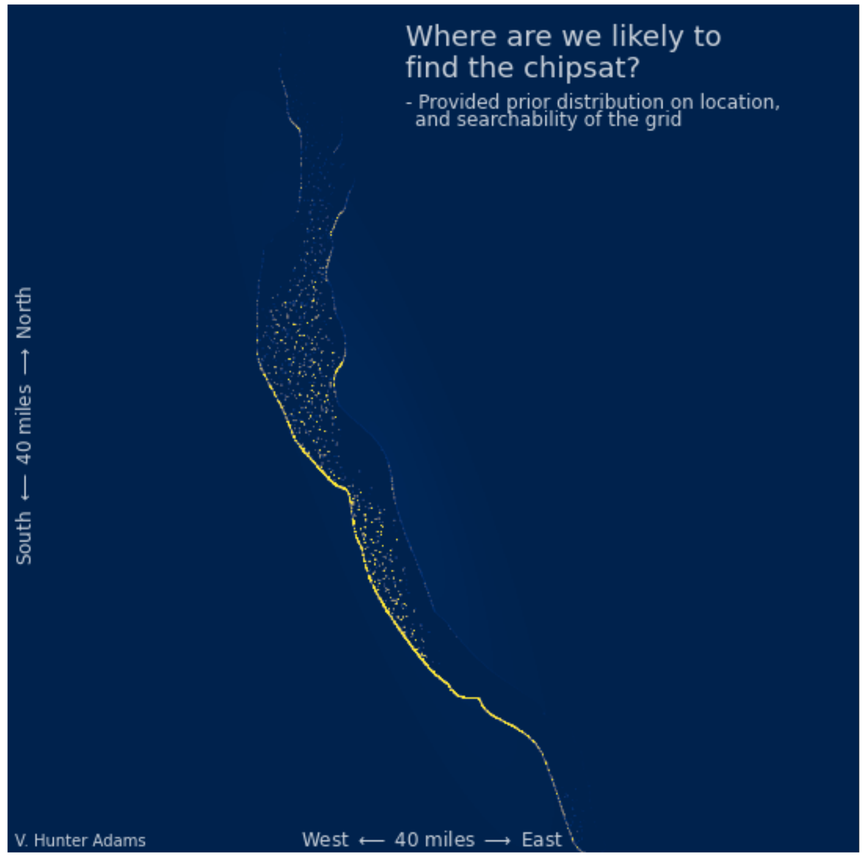
Walking through an example

Start with ignorance → Generate priors → Estimate searchability → **Prioritize search** → (Search!) → Update priors → A north wind blows

Click here for a gif!



We should check the south shores again, even though we already looked there. →



V. Hunter Adams

What could this offer?

- A shared interface for folks from a variety of backgrounds to debate and discuss, and that allows for an easy synthesis of their opinions

What could this offer?

- A shared interface for folks from a variety of backgrounds to debate and discuss, and that allows for an easy synthesis of their opinions
- A visual representation of progress in the form of an evolving heat map. Every time a new paper is published or a new opinion is expressed, we get a new map.

What could this offer?

- A shared interface for folks from a variety of backgrounds to debate and discuss, and that allows for an easy synthesis of their opinions
- A visual representation of progress in the form of an evolving heat map. Every time a new paper is published or a new opinion is expressed, we get a new map.
- A mechanism for always directing new thoughts and information instantly at the problem of *search*.

What could this offer?

- A shared interface for folks from a variety of backgrounds to debate and discuss, and that allows for an easy synthesis of their opinions
- A visual representation of progress in the form of an evolving heat map. Every time a new paper is published or a new opinion is expressed, we get a new map.
- A mechanism for always directing new thoughts and information instantly at the problem of *search*.
- The opportunity for highly-targeted future workshops, which focus on a particular term in the Bayes' equation

What could this offer?

- A shared interface for folks from a variety of backgrounds to debate and discuss, and that allows for an easy synthesis of their opinions
- A visual representation of progress in the form of an evolving heat map. Every time a new paper is published or a new opinion is expressed, we get a new map.
- A mechanism for always directing new thoughts and information instantly at the problem of *search*.
- The opportunity for highly-targeted future workshops, which focus on a particular term in the Bayes' equation
- A democratization of the search for Dyson Spheres

How does this happen?

- We generate (or augment?) a database of all the objects in the sky, along with their positions.

How does this happen?

- We generate (or augment?) a database of all the objects in the sky, along with their positions.
- Build an interface to that database which allows for users to input their opinions, quantified as probabilities, as to the likelihood of a Dyson Mind existing and/or being seen at particular locations.

How does this happen?

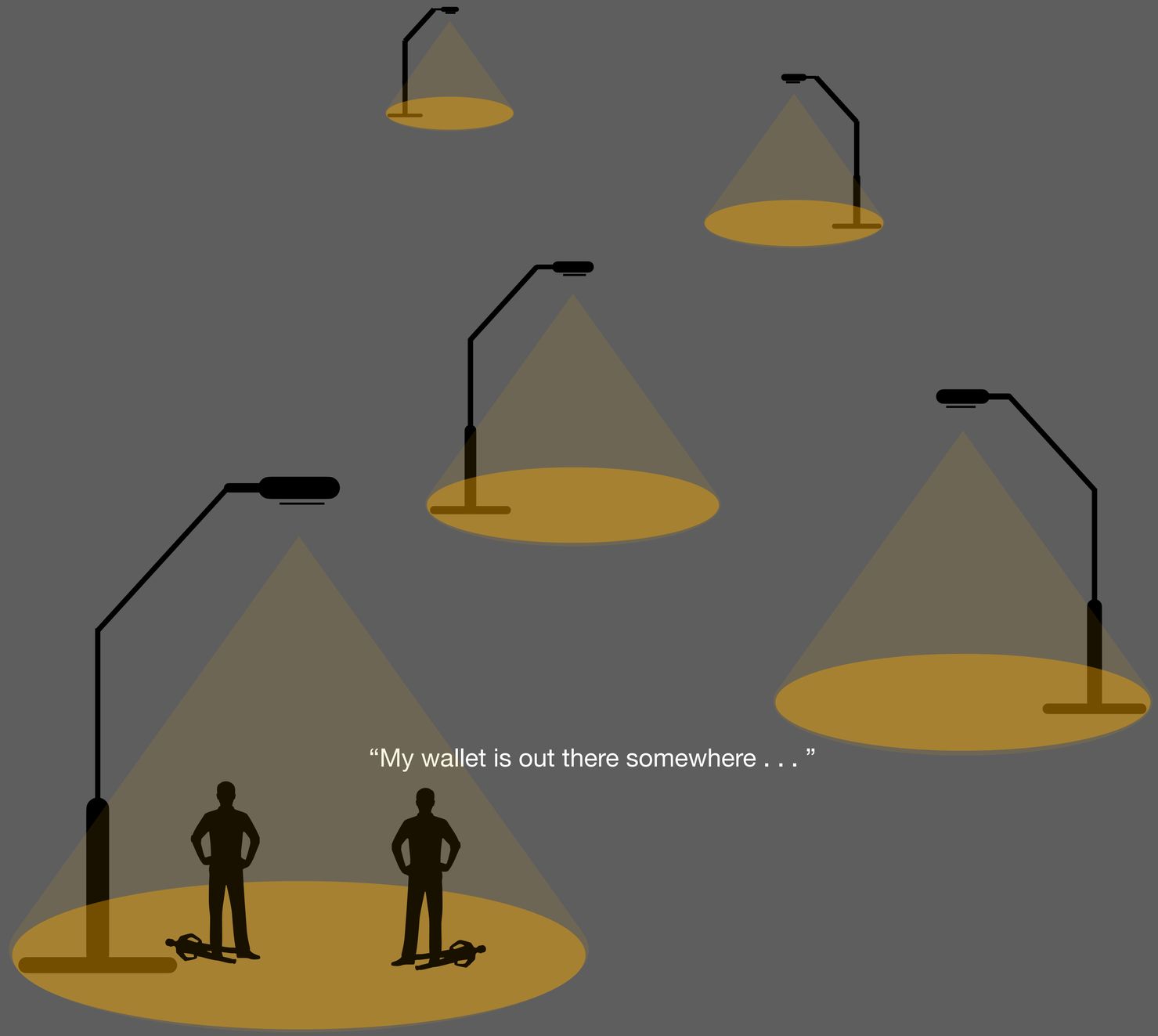
- We generate (or augment?) a database of all the objects in the sky, along with their positions.
- Build an interface to that database which allows for users to input their opinions, quantified as probabilities, as to the likelihood of a Dyson Mind existing and/or being seen at particular locations.
- An association with each object in the database to papers/data of relevance.

How does this happen?

- We generate (or augment?) a database of all the objects in the sky, along with their positions.
- Build an interface to that database which allows for users to input their opinions, quantified as probabilities, as to the likelihood of a Dyson Mind existing and/or being seen at particular locations.
- An association with each object in the database to papers/data of relevance.
- An interface that allows for playing with the weights of users' opinions. What happens when we trust the computer engineers a little more? Or the astronomers? Or the philosophers? Do any regions of the map "stay hot" even as these parameters are adjusted? These would be the places to direct our attention.

How does this happen?

- We generate (or augment?) a database of all the objects in the sky, along with their positions.
- Build an interface to that database which allows for users to input their opinions, quantified as probabilities, as to the likelihood of a Dyson Mind existing and/or being seen at particular locations.
- An association with each object in the database to papers/data of relevance.
- An interface that allows for playing with the weights of users' opinions. What happens when we trust the computer engineers a little more? Or the astronomers? Or the philosophers? Do any regions of the map "stay hot" even as these parameters are adjusted? These would be the places to direct our attention.
- If there is a taxonomy of Dyson spheres/minds, each species will have its own map.



V. Hunter Adams