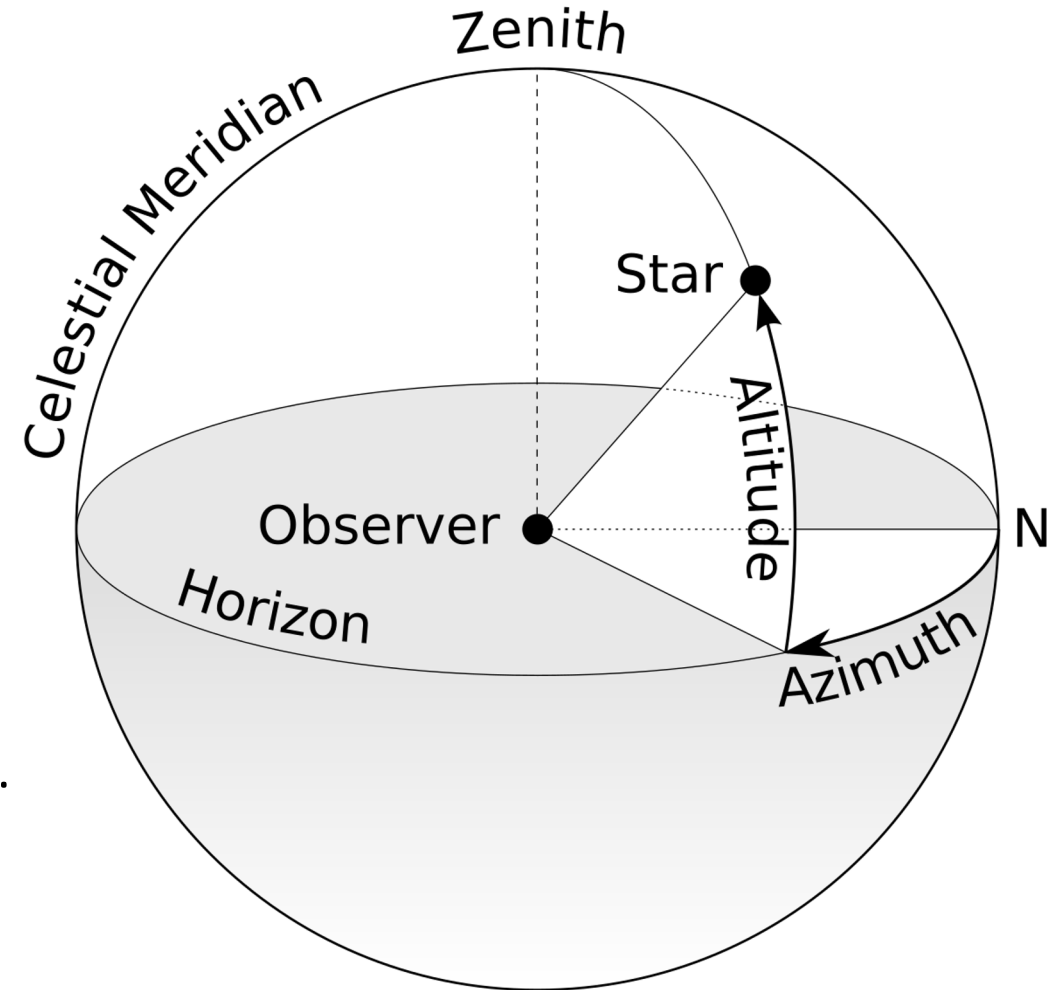


# How we locate a point in the sky

## The Observer and the Sky

- Imagine the sky as a giant dome surrounding the observer.
- The observer stands at the center.
- The point straight above your head is the zenith.
- In astronomy, the astronomical horizon is defined as the intersection between the celestial sphere and a plane perpendicular to the zenith axis of the observer.
  - This is a geometrical reference plane used to define celestial coordinates.
  - It does not coincide with the place where the sky appears to meet the Earth. That would only be true if the Earth were flat.
  - The line where the sky seems to touch the ground is instead called the visual horizon, which depends on the observer's position and on the curvature of the Earth.



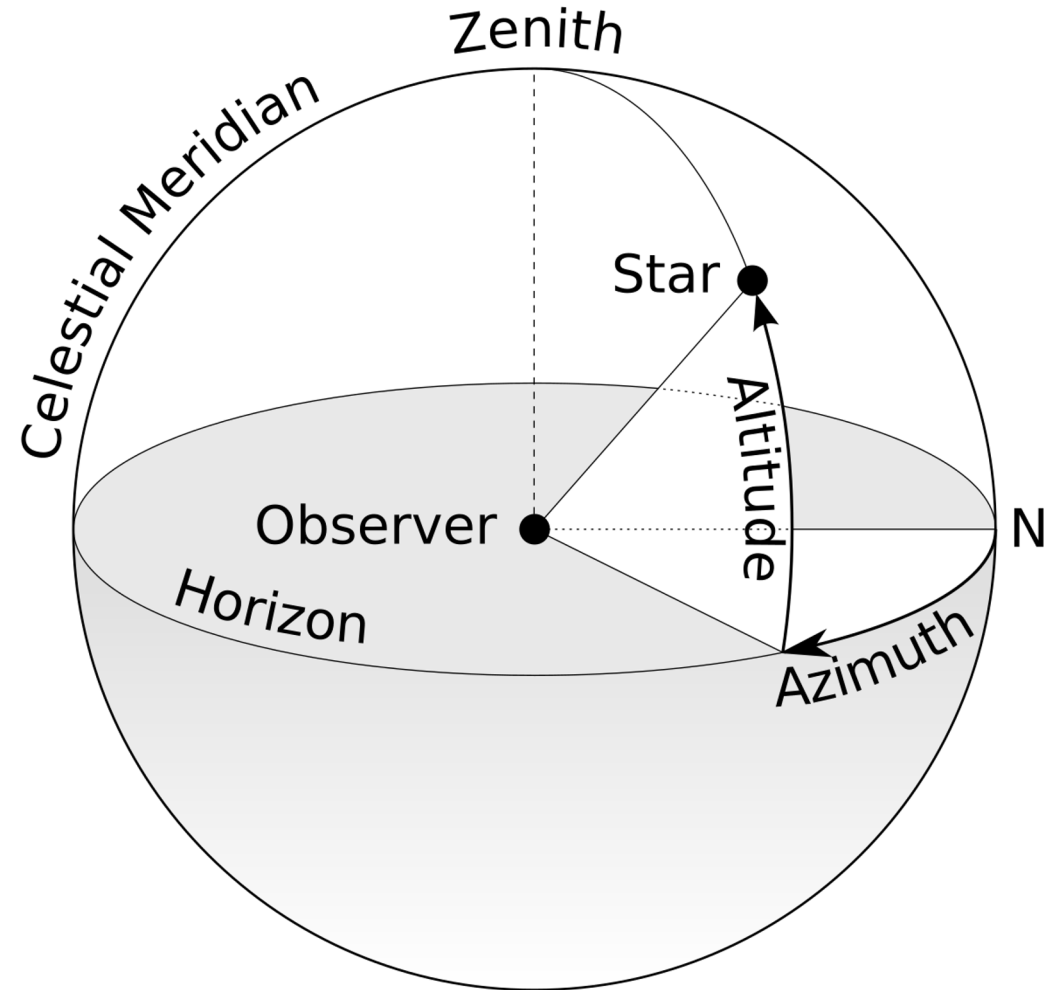
# How we locate a point in the sky

Altitude = “Sky Latitude”

- Altitude tells us how high an object is in the sky.
- It is measured upward from the horizon.
  - $0^\circ \rightarrow$  object is on the horizon
  - $90^\circ \rightarrow$  object is at the zenith (straight overhead)

Analogy:

Like latitude on Earth, which tells how far North or South a location is.



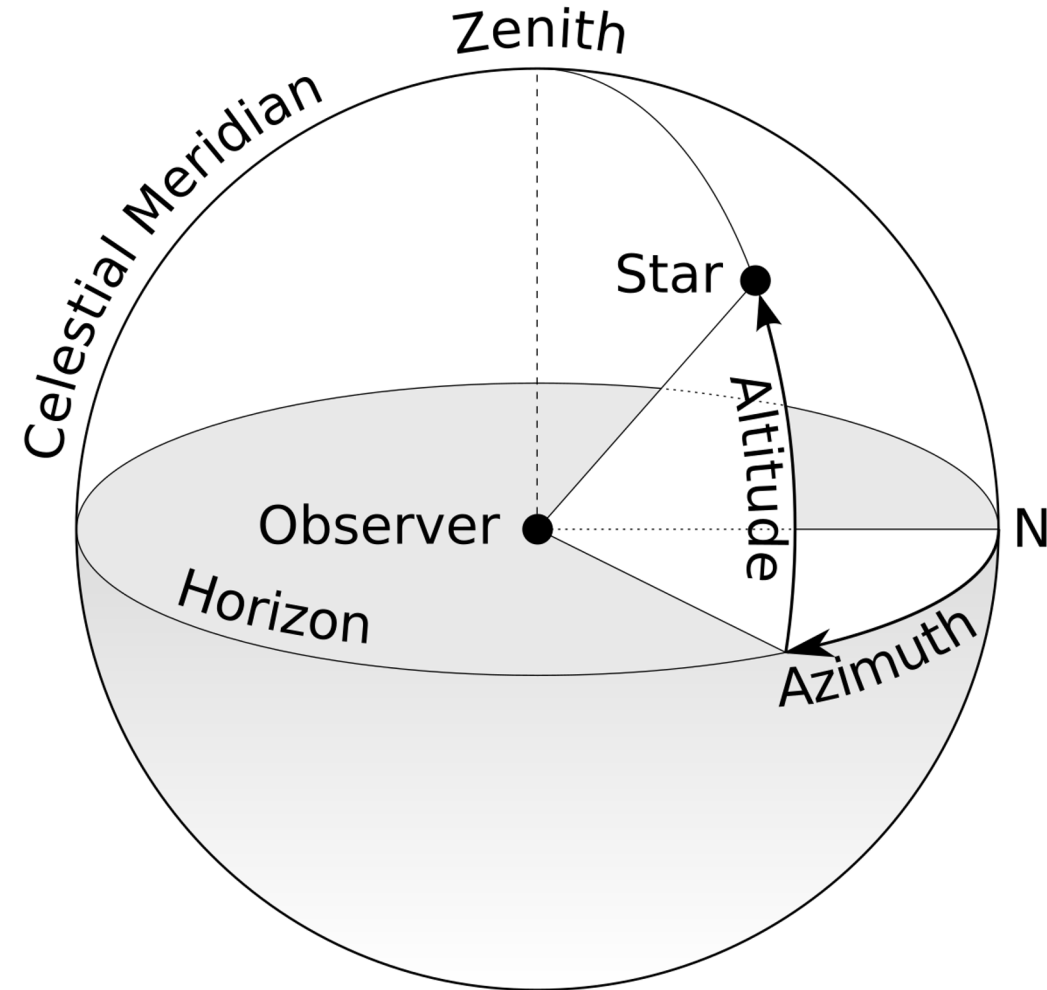
# How we locate a point in the sky

Azimuth = “Sky Longitude”

- Azimuth tells us which direction to look along the horizon.
- It is measured around the horizon, starting from North.
  - North =  $0^\circ$
  - East =  $90^\circ$
  - South =  $180^\circ$
  - West =  $270^\circ$

Analogy:

Like longitude on Earth, which tells how far East or West a location is.

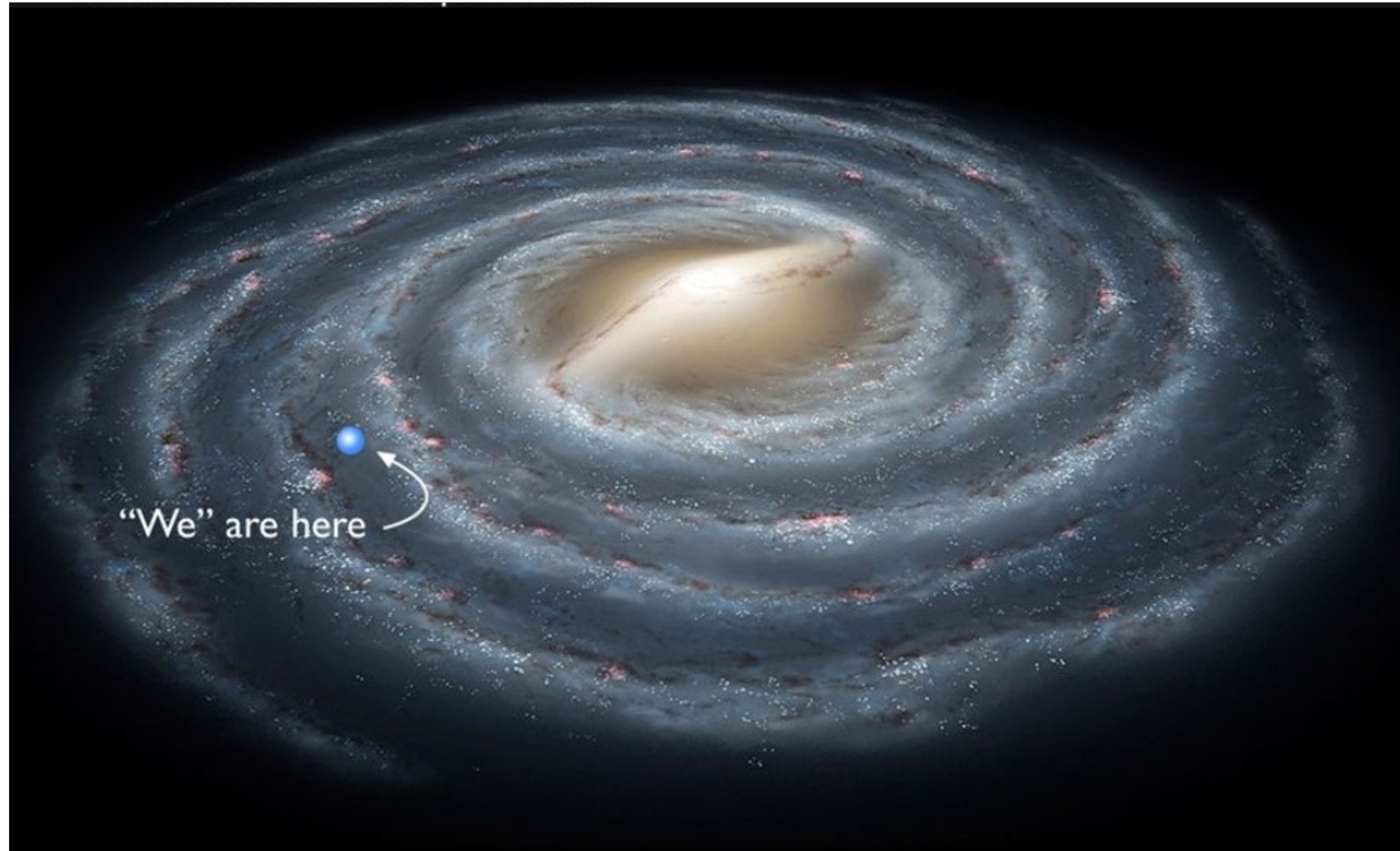


# What we can try to measure with KM3NeT in a local coordinate sky map

- Above the horizon (altitude  $> 0^\circ$ ):
  - mainly the huge contribution of atmospheric muons (background)
  - atmospheric and cosmic neutrinos are completely overwhelmed by muons
- Slightly below the horizon ( $-10^\circ < \text{altitude} < 0^\circ$ )
  - many poorly reconstructed downgoing muons that decrease more and more as we move to more negative altitude (background)
  - atmospheric and cosmic neutrinos are still significantly overwhelmed by muons
- Below the horizon (altitude  $< -10^\circ$ )
  - No atmospheric muons (muons cannot cross the Earth to reach the detector from below)
  - some atmospheric neutrinos (background)
  - a few cosmic neutrinos (signal!)

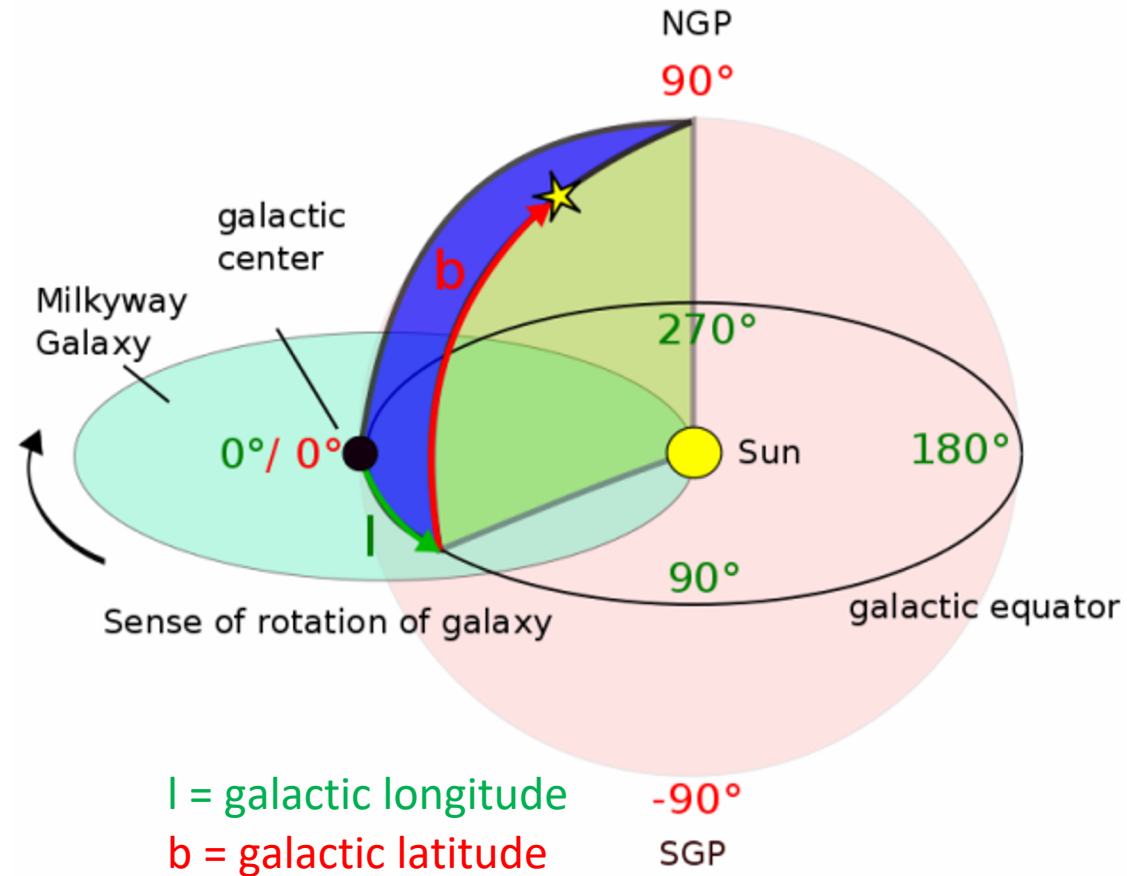
# Galactic coordinates

- The Milky Way is shaped like a flat disk (like a giant pancake).
- We live inside this disk, not outside it.



# Galactic coordinates

- The Sun is our reference point (yellow dot).
- The galactic centre is the middle of the galaxy (black dot).



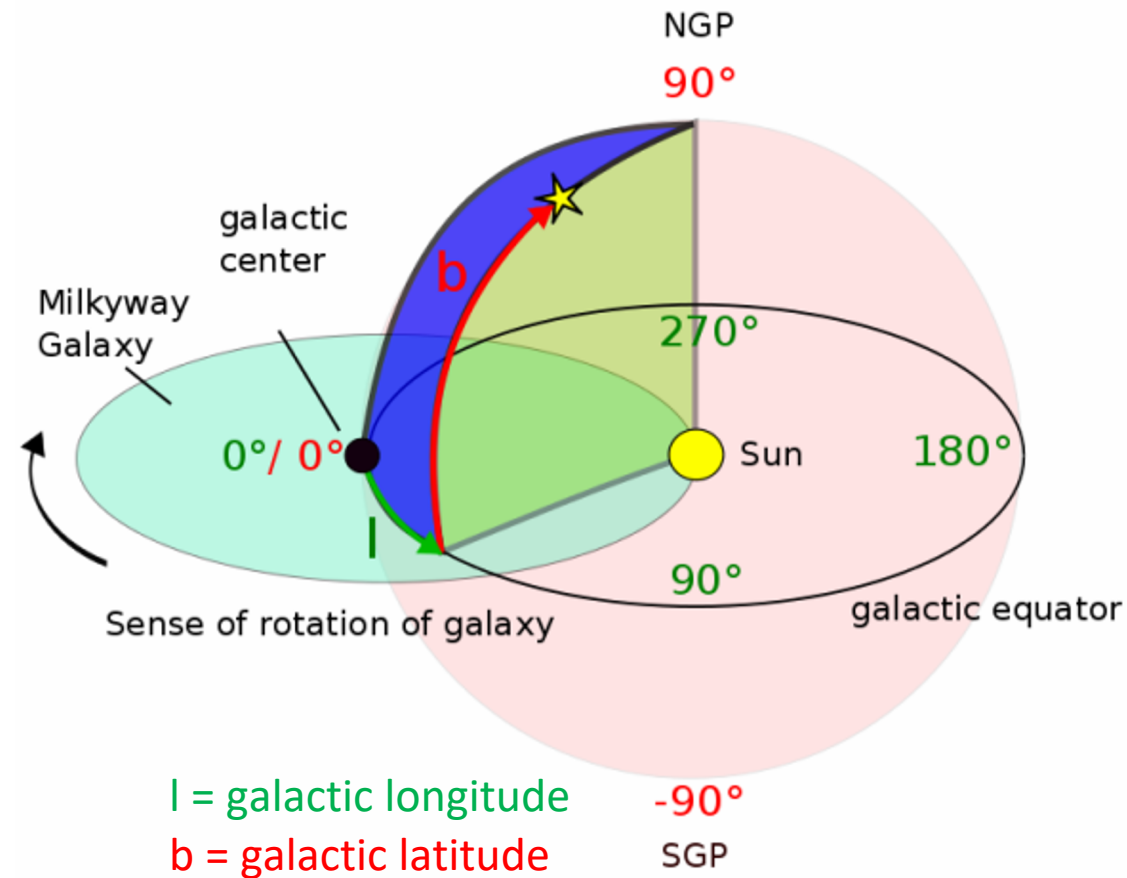
# Galactic coordinates

## Galactic Longitude (Gal Lon)

- Galactic longitude tells us which direction we look within the galaxy.
- It is measured around the galactic disk:
  - $0^\circ \rightarrow$  toward the galactic center
  - $90^\circ, 180^\circ, 270^\circ \rightarrow$  other directions around the galaxy

## Analogy:

Like longitude on Earth, measuring East–West position.



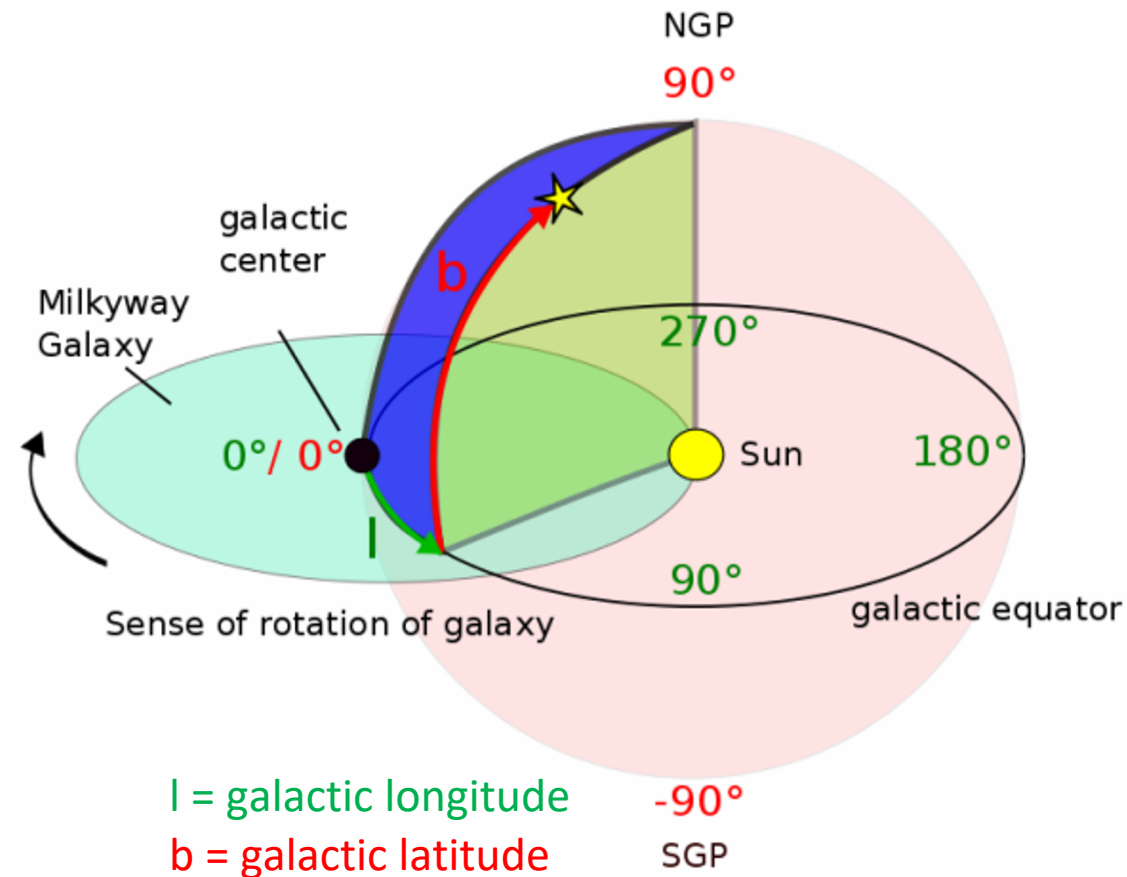
# Galactic coordinates

## Galactic Latitude (Gal Lat)

- Galactic latitude tells us how far above or below the galactic disk an object is.
- It is measured up or down from the galactic equator:
  - $0^\circ \rightarrow$  inside the galactic disk
  - $+90^\circ \rightarrow$  North Galactic Pole (NGP)
  - $-90^\circ \rightarrow$  South Galactic Pole (SGP)

## Analogy:

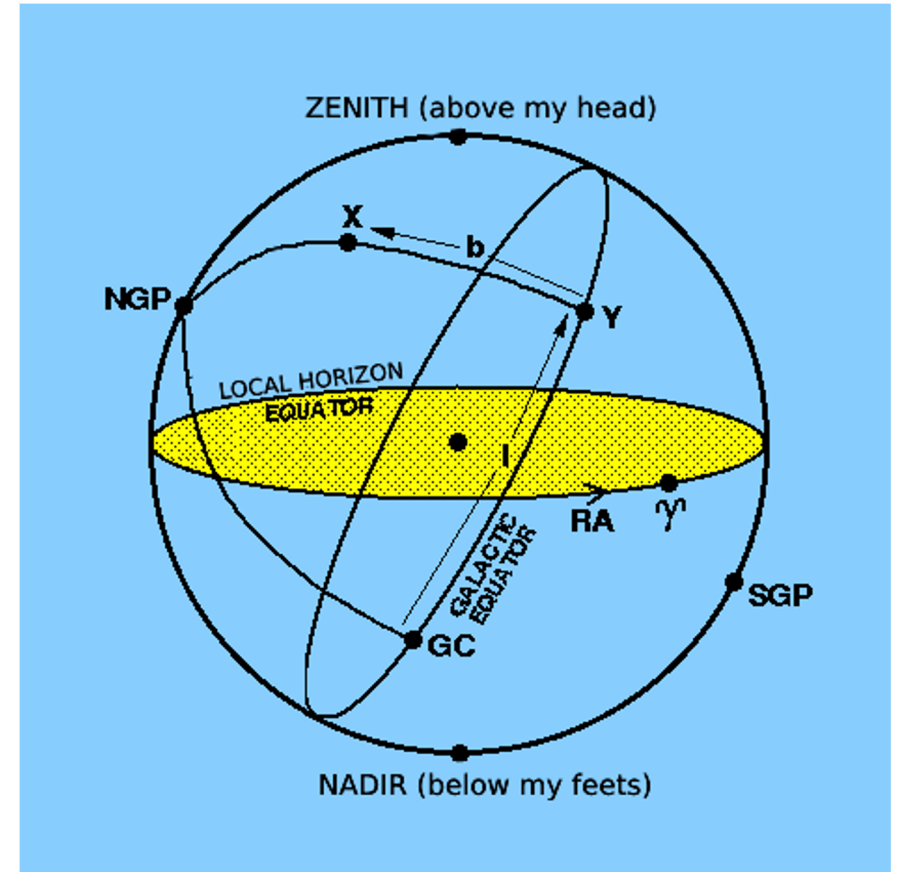
Like latitude on Earth, measuring North–South position.



# Local coordinates vs Galactic coordinates

The celestial sphere does not change!

- All stars are projected onto the same celestial sphere
- What changes is how we draw the reference plane on that sphere
- The picture shows different planes crossing the same sphere

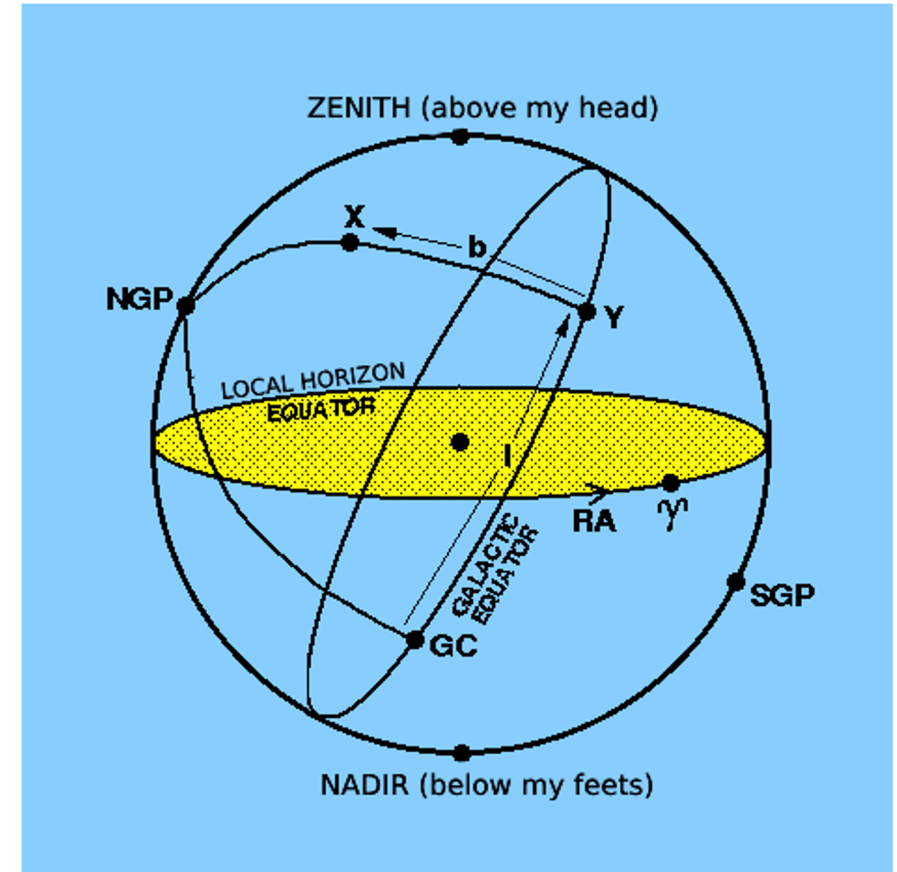


# Local coordinates vs Galactic coordinates

A star stays in the same position in space

But its coordinates change because:

- We rotate the reference plane (Earth rotates!)
- Mathematically, this is like rotating the coordinate system, not moving the star



# Local coordinates vs Galactic coordinates

## Local Coordinates (Altitude & Azimuth)

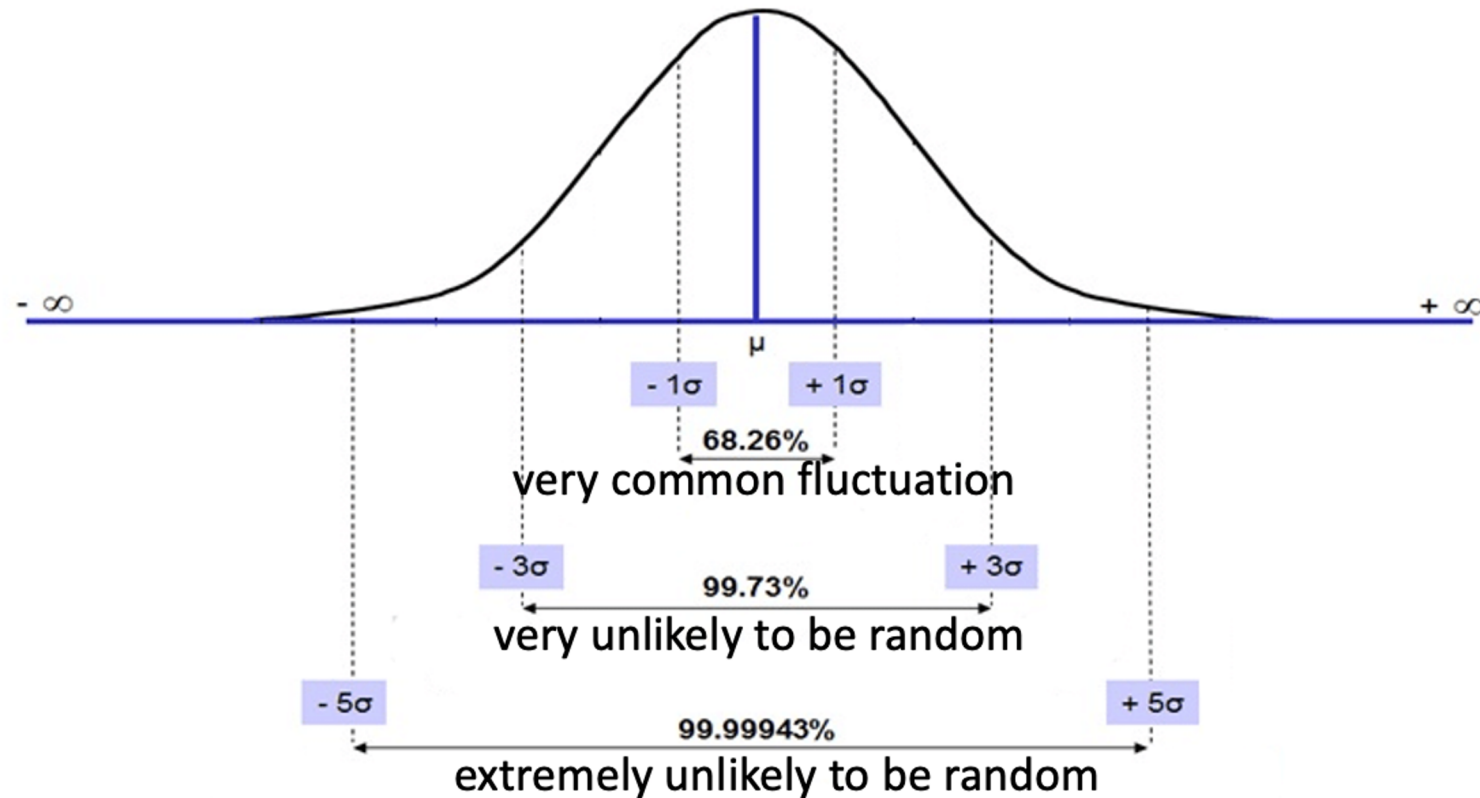
- Based on where you are standing on Earth
- Dependant on:
  - Your location
  - The time of day
- Great for:
  - Pointing a telescope
  - Saying “Look there, above the horizon!”
- Problem:
  - The same star has different coordinates for different observers
- They answer the question:
  - “Where is the object in my view right now?”

## Galactic Coordinates (Galactic Lat/Lon)

- Based on the structure of the Milky Way
- Independent of:
  - The observer
  - The time
- Ideal for:
  - Making sky maps
  - Sharing scientific data
- Advantage:
  - Everyone measures the same coordinates
- They answer the question:
  - “Where is the object in the universe?”

# What is “statistical significance”?

- When we measure something, the result is never exactly the same
- Small differences come from:
  - Random fluctuations
  - Measurement errors
- Statistics helps us decide:
  - Is this result real, or just random chance?



$3\sigma \rightarrow$  evidence

$5\sigma \rightarrow$  discovery

# Significance estimation with ON/OFF zones

- Neutrino detectors see many events
- Most of them are background (not from a source)
- We need a way to tell if a source is really producing neutrinos
- ON zone:
  - a  $0.3^\circ$  circle around the astrophysical source
  - If the source emits neutrinos, extra events should appear here
- OFF zone:
  - the rest of the sky outside the ON zone (at the same altitude)
  - It is assumed to contain:
    - Only background neutrinos
    - No contribution from the source
  - It tells us how many background events we expect

# Significance estimation with ON/OFF zones

- Compare ON and OFF
  - Count events in the ON zone
  - Use the OFF zone to estimate the background
  - Ask: “Are there more events in the ON zone than those expected *by chance*?”
- Statistical significance
  - If ON zone events  $\approx$  expected background  $\rightarrow$  no detection
  - If ON zone events  $>$  background by  $3\sigma$   $\rightarrow$  evidence of a signal
  - If ON zone events  $>$  background by  $5\sigma$   $\rightarrow$  discovery of a source

# Significance estimation with likelihood

Why go beyond ON/OFF?

- ON/OFF counts how many events we see
- But it ignores where exactly the events are inside the region
- Likelihood uses all the information we have
- Signal hypothesis
  - Cosmic neutrinos come from the source direction
  - Signal centered on the source
  - Signal width  $\rightarrow$  KM3NeT angular resolution
  - Events closer to the source are more likely signal
- Background hypothesis
  - Background events come from everywhere
  - Their directions are uniformly spread
  - Same probability everywhere in the region

# Significance estimation with likelihood

- For each detected event, we ask:  
    “Is this event more likely signal or background?”
- We combine all events together
- We estimate the amount of signal that best explains the data
- We compute the significance of our observation

# Analysis instructions

- Open the analysis webpage [link](#)
- Upload a calibration file
- Click on 'run analysis'
- The plots will be shown in the browser
- If you are not satisfied with the result (or the calibration plots), you can try to improve the calibration and repeat the analysis.

# Candidate sources

In this exercise, we will investigate four sources belonging to two different categories:

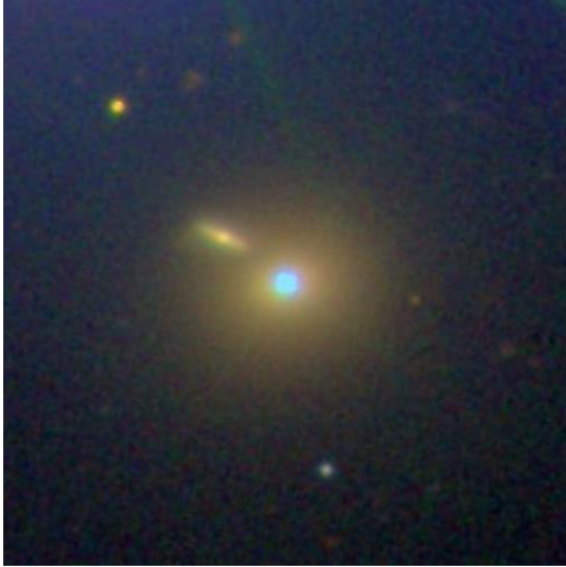
## **Blazars**

- Blazars are extremely energetic galaxies with a supermassive black hole at their center.
- The black hole launches powerful jets of particles moving close to the speed of light.
- When one of these jets points toward Earth, we observe very strong radiation across many wavelengths (from radio waves to gamma rays).
- They are among the brightest and most variable objects in the universe.

## **Pulsar Wind Nebulae (PWN)**

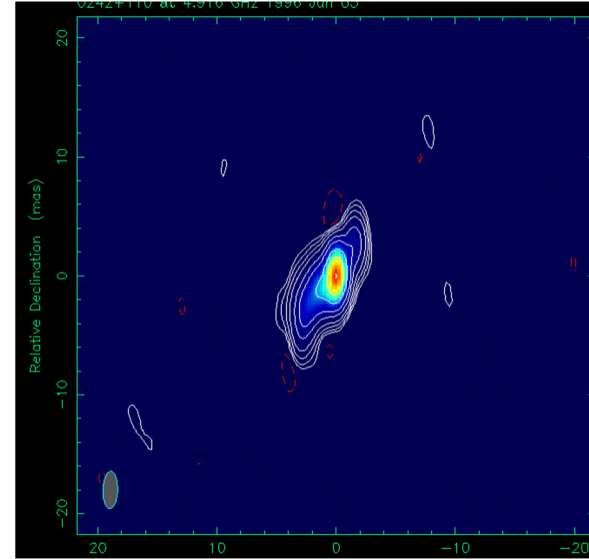
- A pulsar wind nebula forms around a pulsar, which is a rapidly spinning neutron star left after a supernova explosion
- The pulsar emits a wind of very energetic particles.
- These particles interact with the surrounding material and magnetic fields, creating a glowing nebula. PWNe are important sources of high-energy radiation such as X-rays and gamma rays.

# Candidate sources



**A - Markarian 421**

Blazar



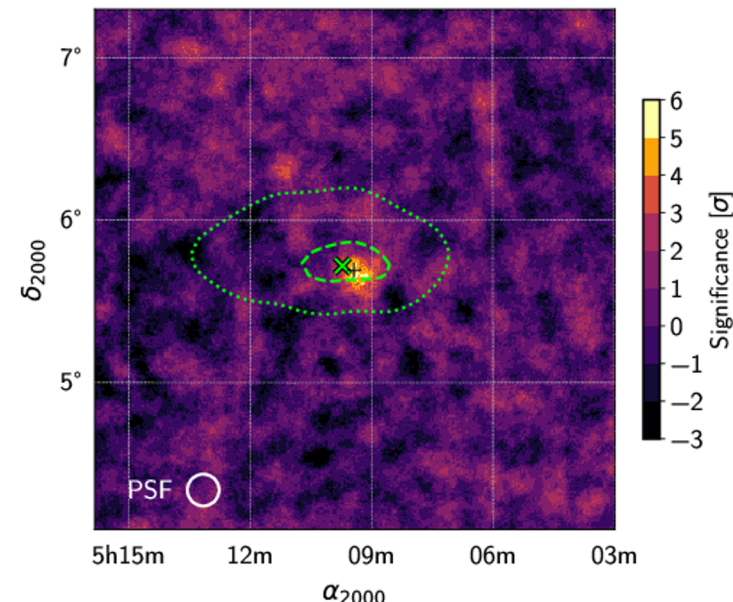
**B - PKS 0239+108**

Blazar



**C - Vela X**

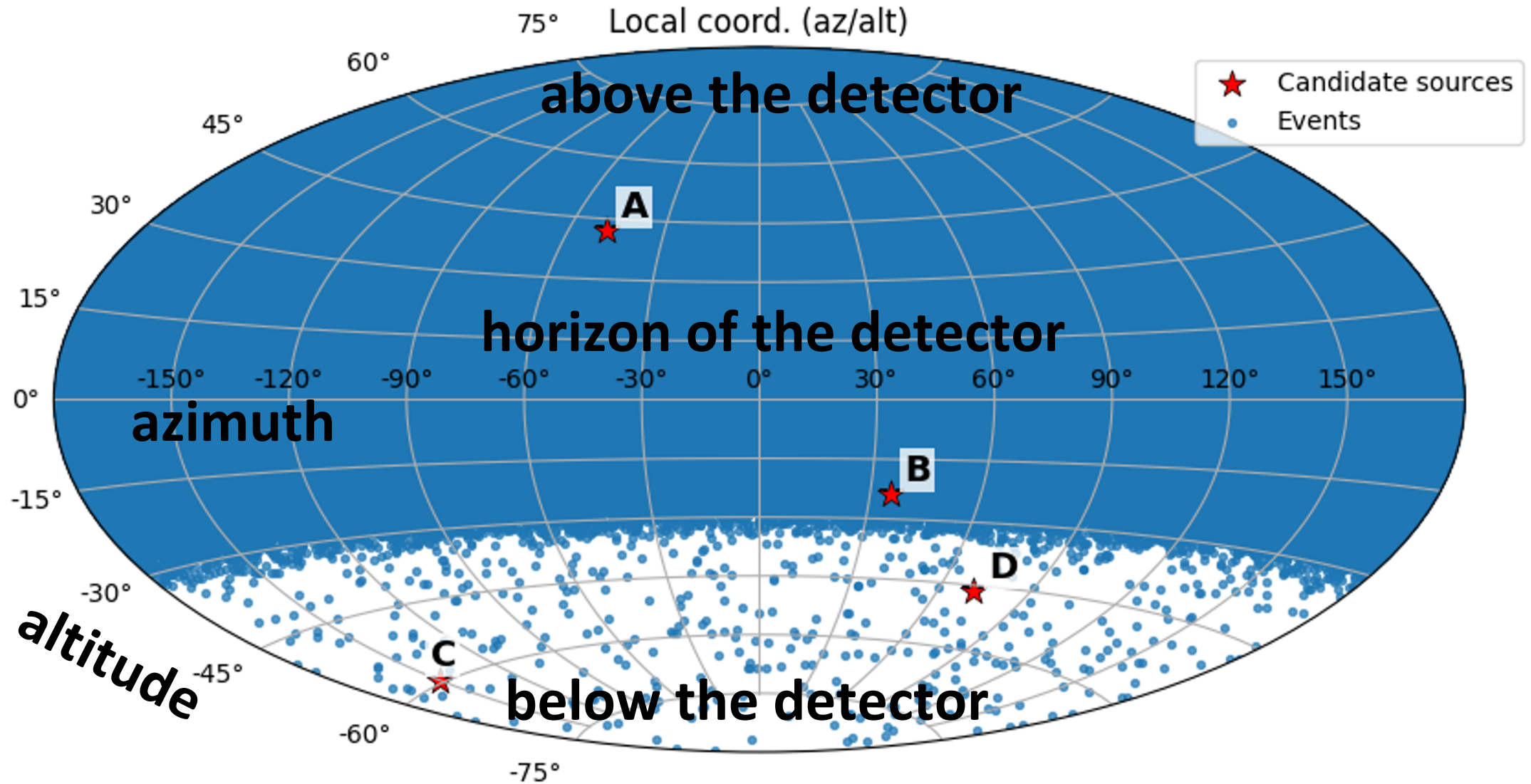
Pulsar wind nebula



**D - TXS 0506+056**

Blazar

# How to interpret the plots



# How to interpret the plots

