# Superluminal Jets and Lorentz Symmetry Violations


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## *Theory/Background*

**Background**

Lorentz Symmetry: Transformations between inertial reference frames preserve symmetry.

Principle of special relativity: According to Lorentz symmetry, all laws of physics are the same in inertial reference frames.

Speed of light maximum: Result of the principle of relativity, light travels at the same speed in all frames. The speed of light is also the speed limit of matter.

**Theory**

Spacetime's 4 dimensions include 3 spatial coordinates $\vec{r} = (x, y, z)$ & 1 temporal coordinate $t$.

In conventional relativity, light propagates according to the "metric equation":

$$\Delta s^2 = \Delta t^2 - \Delta \vec{r}^2 = 0$$

In the "bumblebee" model, the matter "speed limit" remains the same, but light propagates according to an "effective metric":

$$\Delta \tilde{s}^2 = \Delta t^2 - \Delta \vec{r}^2 + \delta(B_0 \Delta t + \vec{B} \cdot \Delta \vec{r})^2 = 0$$

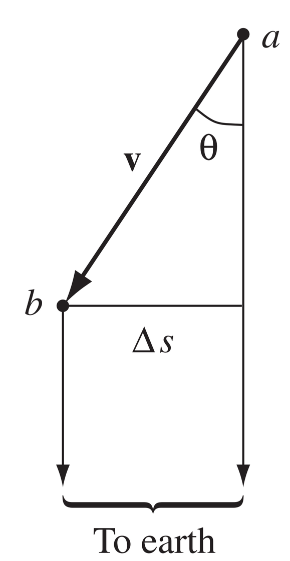
**Superluminal jets**

Relativistic glob of electrons from active galactic nuclei.

Observed motion $v_t$ appears faster than light, due to signal delay, angle discrepancies, and the angle of observation.

Transverse velocity exceeds c due to signal delays.

Geometric reasoning: $v_t = \dfrac{v \sin \theta}{1 - \frac{v}{c} \cos \theta}$




**Fast light & Slow light**

We postulate two different cases for the project.

Fast Light is when $v_c > 1$; Slow Light is when $v_c < 1$

**Isotropic vs anisotropic**

If light moves at the same speed in all directions, the model is **isotropic**; otherwise it is **anisotropic**.

In the bumblebee model, $\vec{B} = 0$ gives us the isotropic model; only one free parameter rather than four.

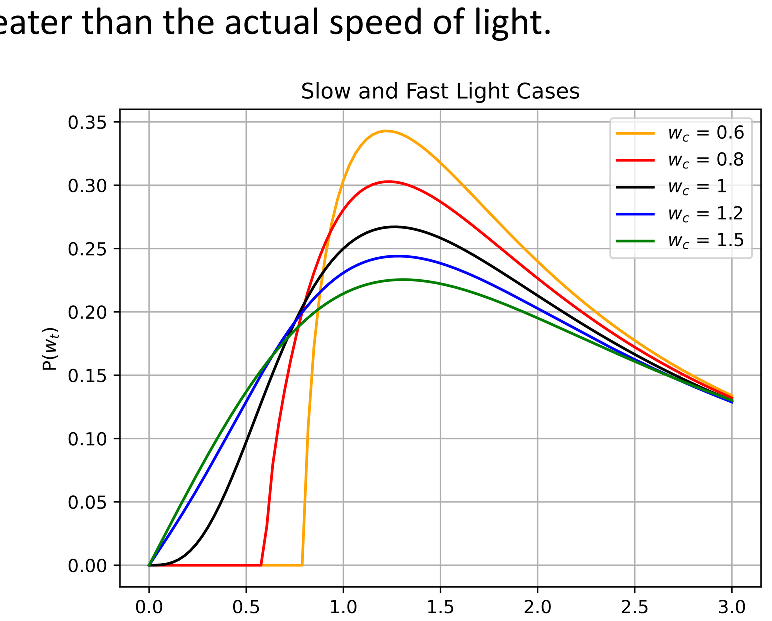
**Log likelihood distributions**

We used them to facilitate the Markov chain Monte Carlo (MCMC) simulation.

In our likelihood functions, we make the assumptions that active galactic nuclei are equally likely to emit sources in all directions in space. We also assume that the true velocities of these jets are uniformly distributed between 0 and 1, with Cherenkov radiation causing a drop in speed for jets traveling at greater than the actual speed of light.

The graph on the right shows likelihood of $w_t$ values for various $w_c$ values.

$$w_t = \frac{1}{v_t} \qquad w_c = \frac{1}{v_c}$$




## *Markov Chain Monte Carlo*

Markov chain Monte Carlo (MCMC) is used to draw conclusions from random samples of a probability distribution.

MCMC performs a "random walk" through possible solutions, spending more time in high-probability areas of our likelihood function to accurately represent the target distribution.

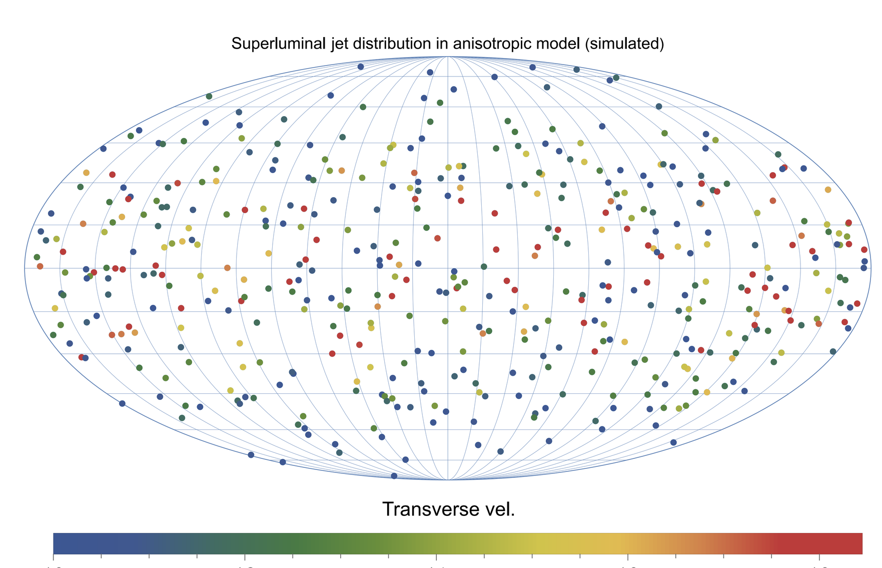
MCMC approximates the most likely parameter, representing the deviation of a value from the speed of light (0 indicates no deviation, and non-zero values indicate some kind of deviation). The results allow us to find what values of our parameters are more and less likely to occur given the provided input.

## *Simulating Data*

To facilitate the testing of our code, we went about generating a variety of different artificial samples of superluminal jets.

This allows us to test the code with a certain expected result, so that we are able to debug the code properly. Otherwise, we wouldn't be able to tell whether we're getting useful results or not.

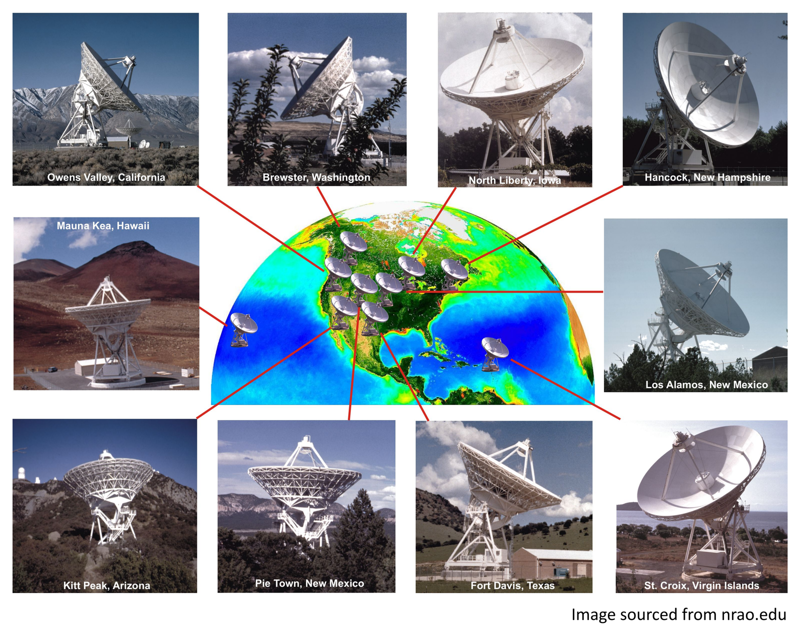
Below is a graphic depicting the distribution of superluminal jets in a simulated anisotropic model.




## *Sourcing Data*

We created some code that we used to import data from the MOJAVE (Monitoring of Jets in Active Galactic Nuclei with VLBA Experiments) program, which monitors radio brightness and polarization variations in jets from active galaxies that are visible in the northern sky.

The MOJAVE program uses the Very Long Baseline Array (VLBA) which is a network of 10 radio telescopes spread out in and around the United States. Locations of VLBA telescopes are below.

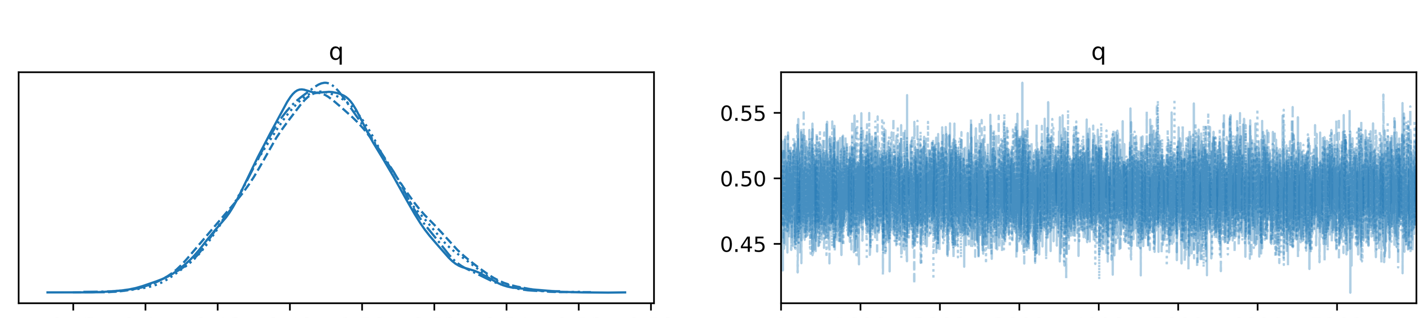



## *Results*

We ran our isotropic model on the MOJAVE dataset and received some unexpected results.

$q = w_c - 1$; $q = 0$ implies that conventional physics applies.

The non-zero q value implies that the speed of light is significantly slower than what it is known to be; this is a fairly nonsensical result.

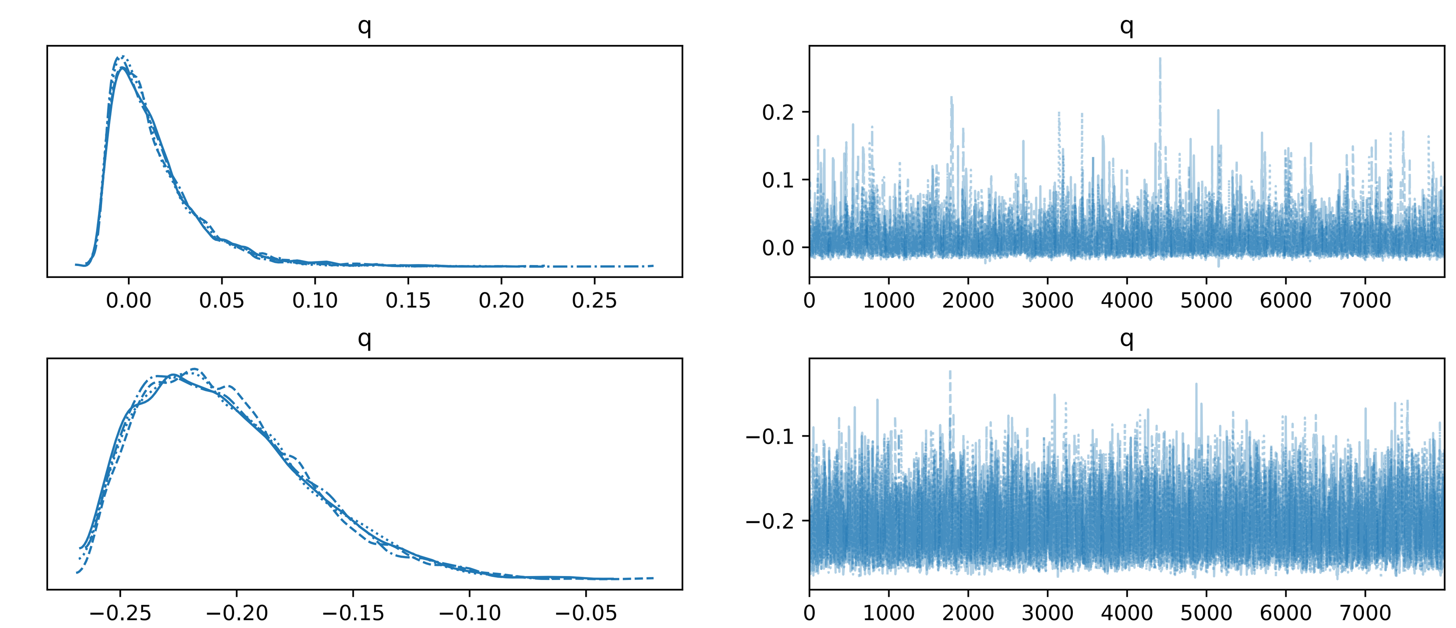



## *Results, cont.*

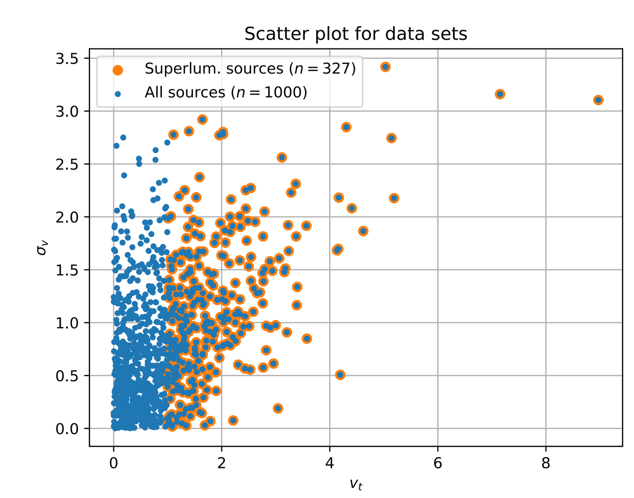
There appears to be a bias due to a "selection effect" where our results are affected by having mostly data from superluminal jet sources.

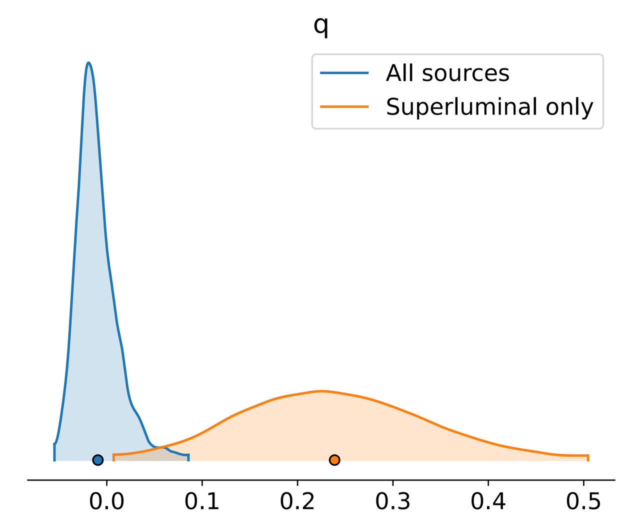
These come up more in observations due to relativistic beaming, where jets that appear to be going faster also shine brighter than others, leading to easier detection.

In contrast to the MOJAVE dataset runs, the simulated runs below are coming out as expected using $q = 0$ and $q = -0.20$ parameters respectively.




When analyzing only superluminal sources from simulated data, we get a shift in the results that deviate from what we expect. This simulation provides evidence that there is some sort of selection effect occurring.




## *Future Work*

We would be interested in implementing the anisotropic model and seeing what results we can obtain when using it.

We want to look into more about the selection effect that we are experiencing, so that we can try to account for it in the model.

## *Acknowledgments*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