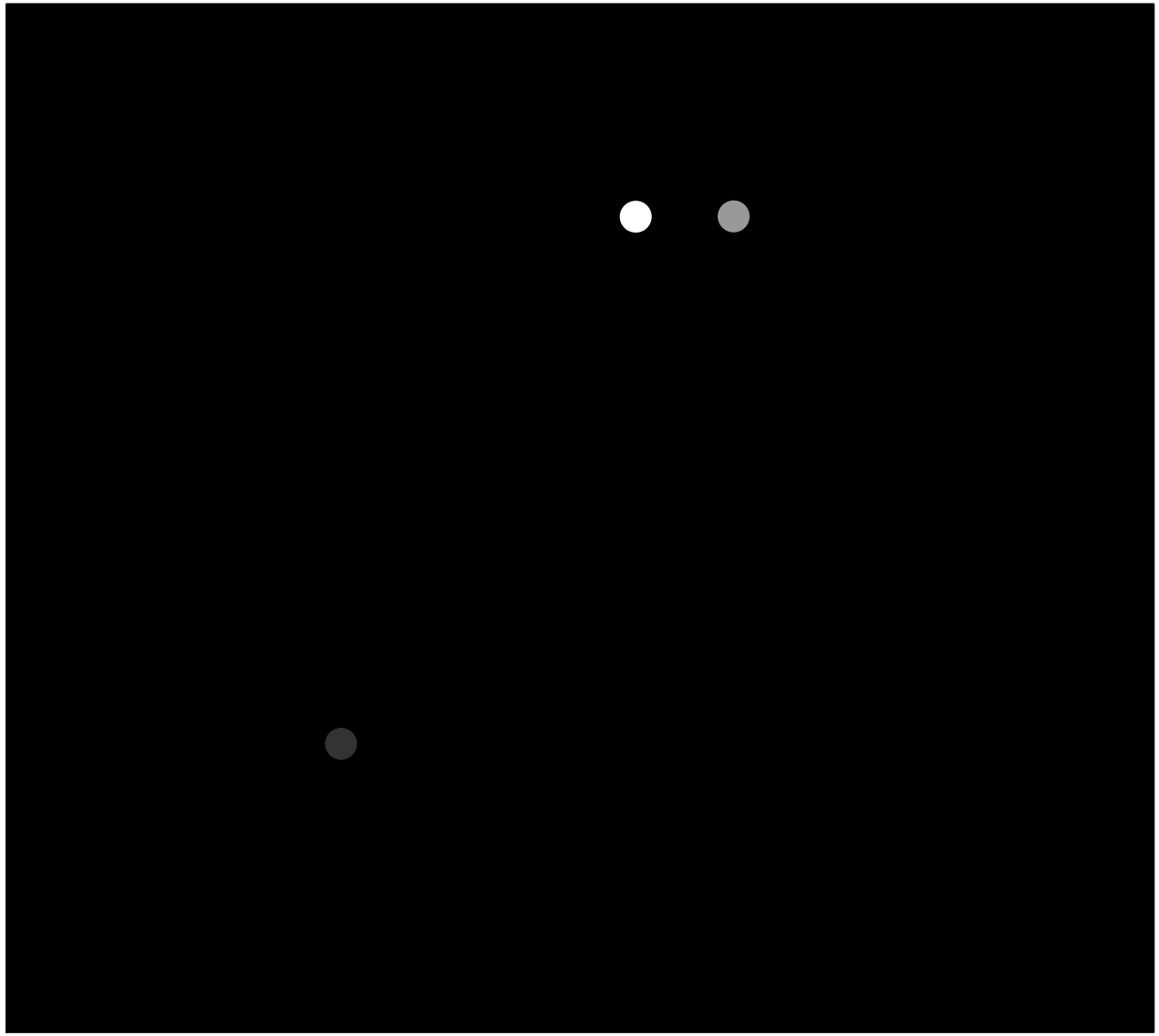
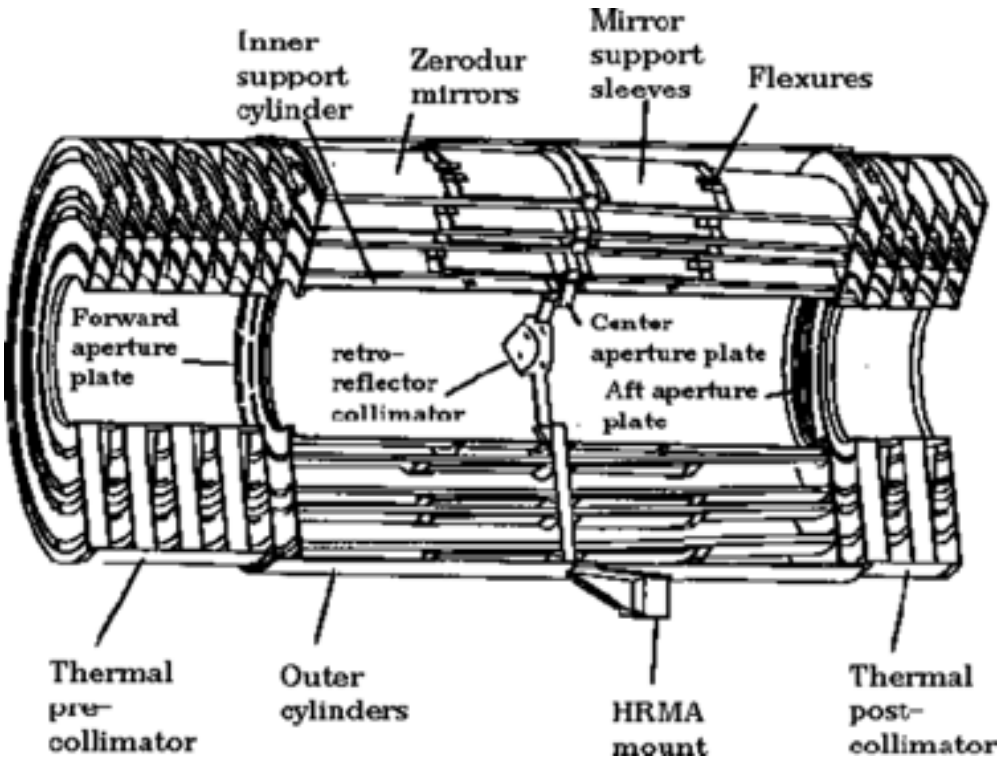
Disambiguating Sources II
an alternative and an extension

Luis Campos (with David Jones, David van Dyk, Aneta Siemiginowska, Vinay Kashyap, Xiao-Li Meng)

April 18, 2017



X-Ray Telescope: Chandra and psf



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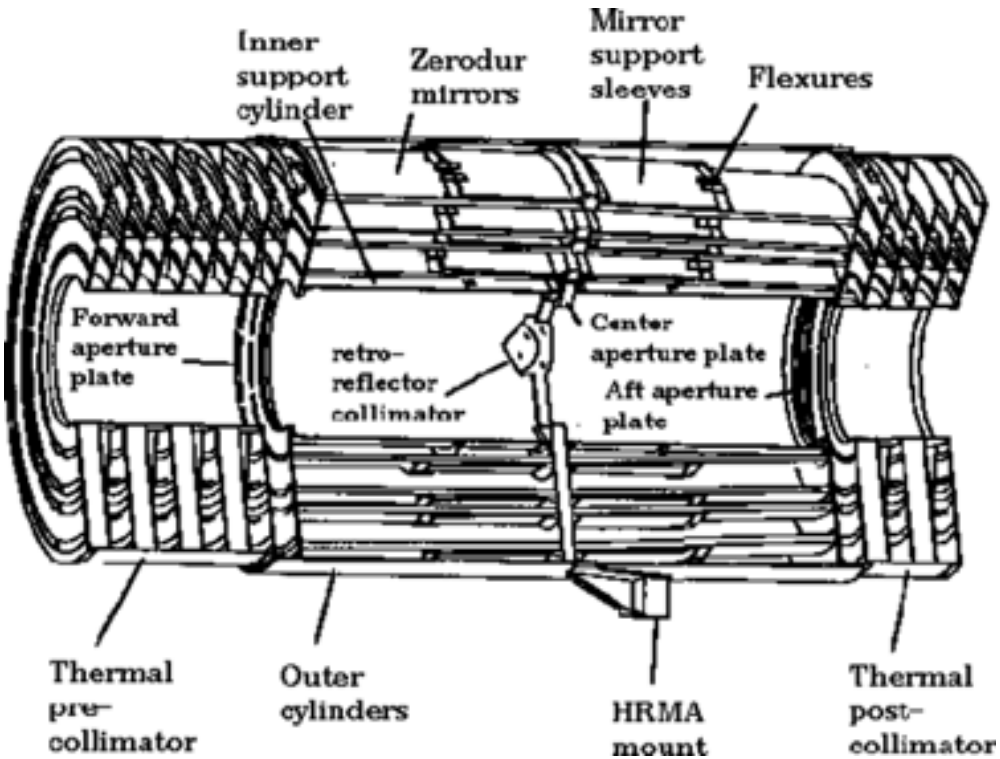
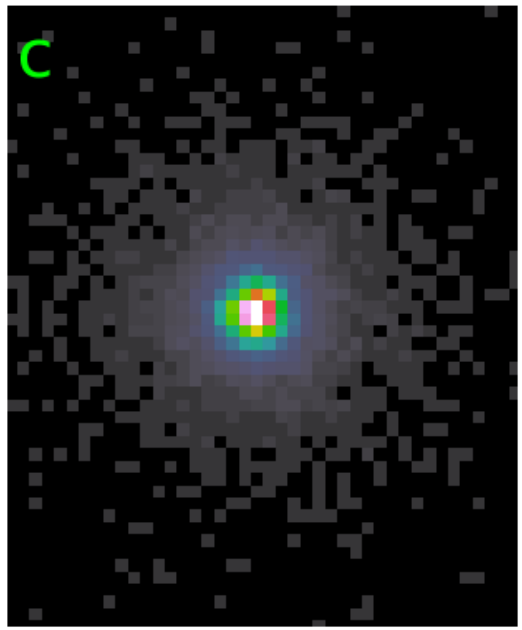
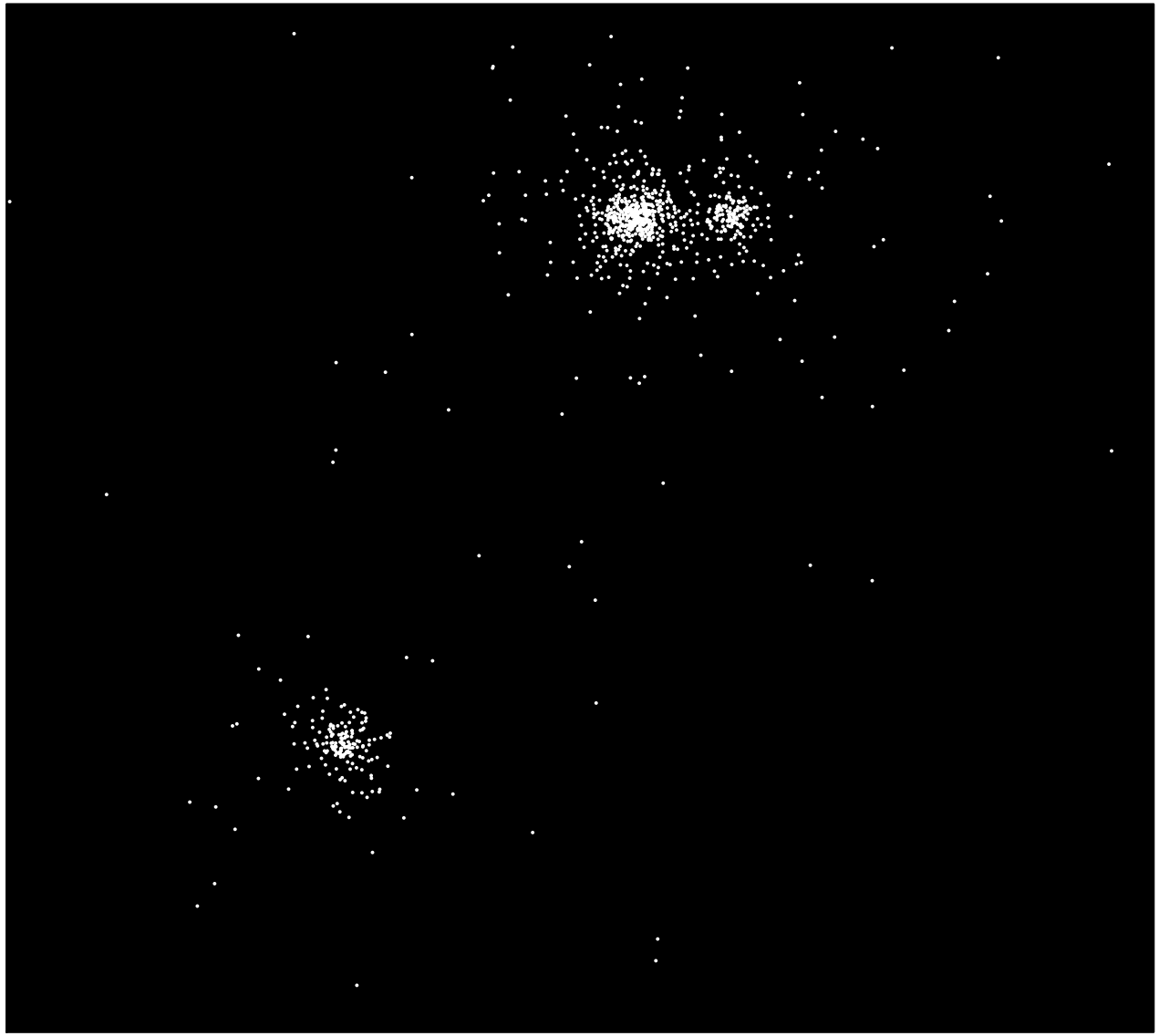
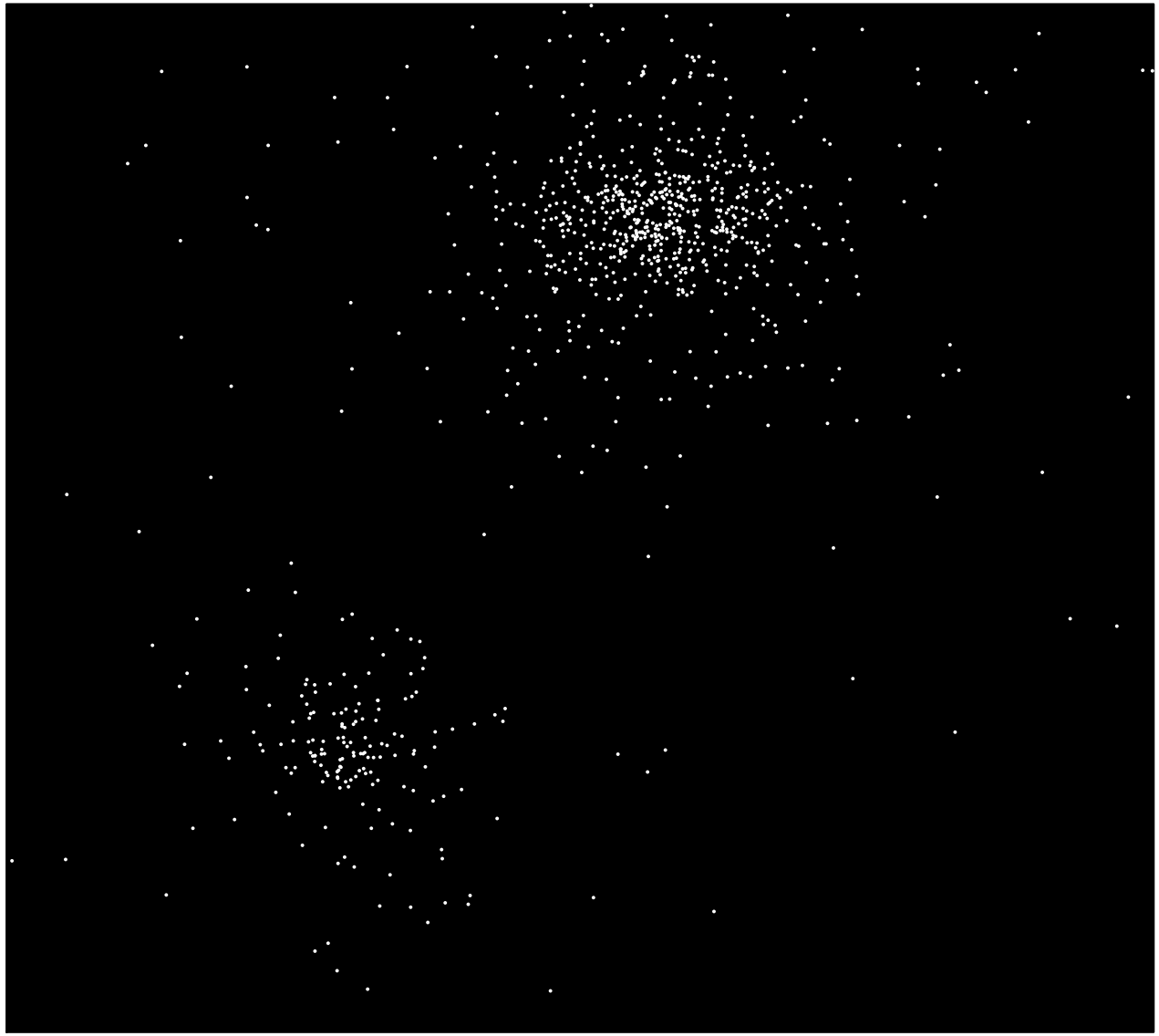
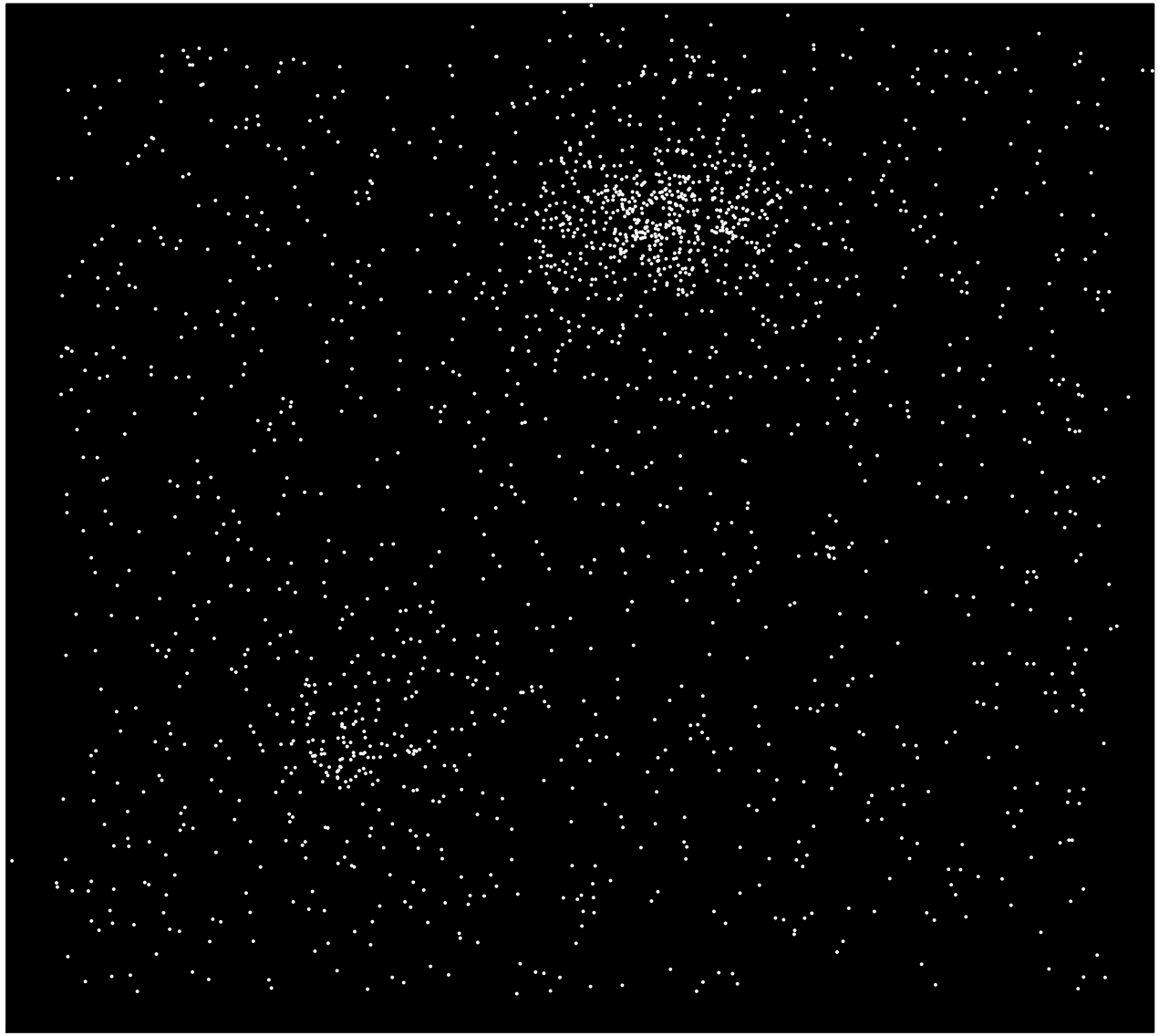




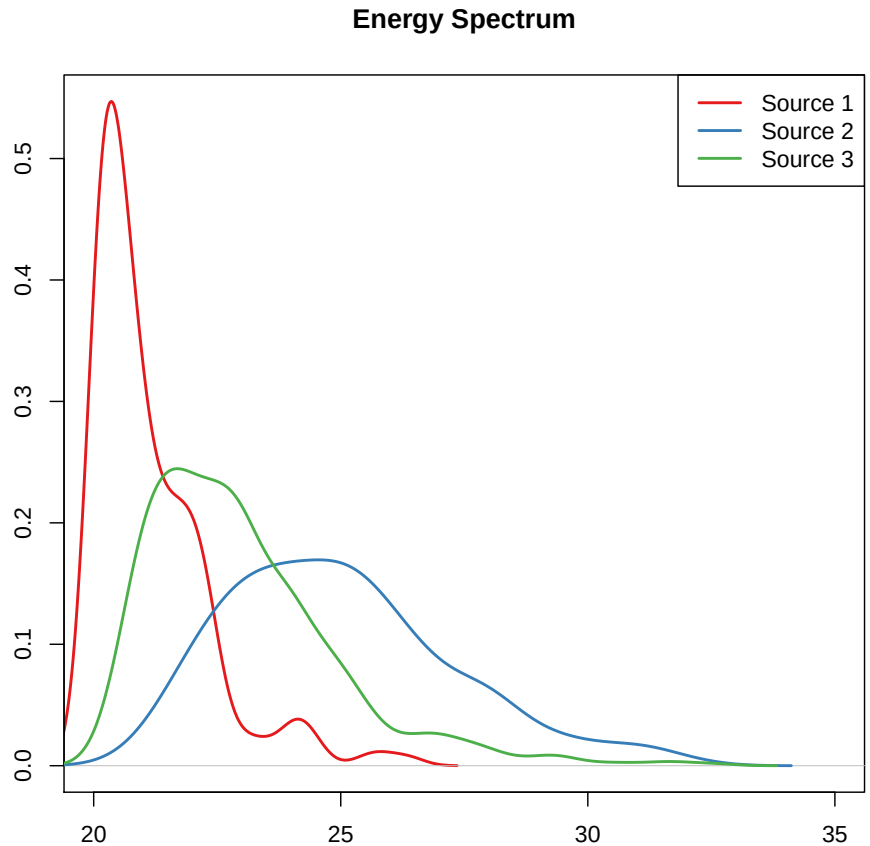






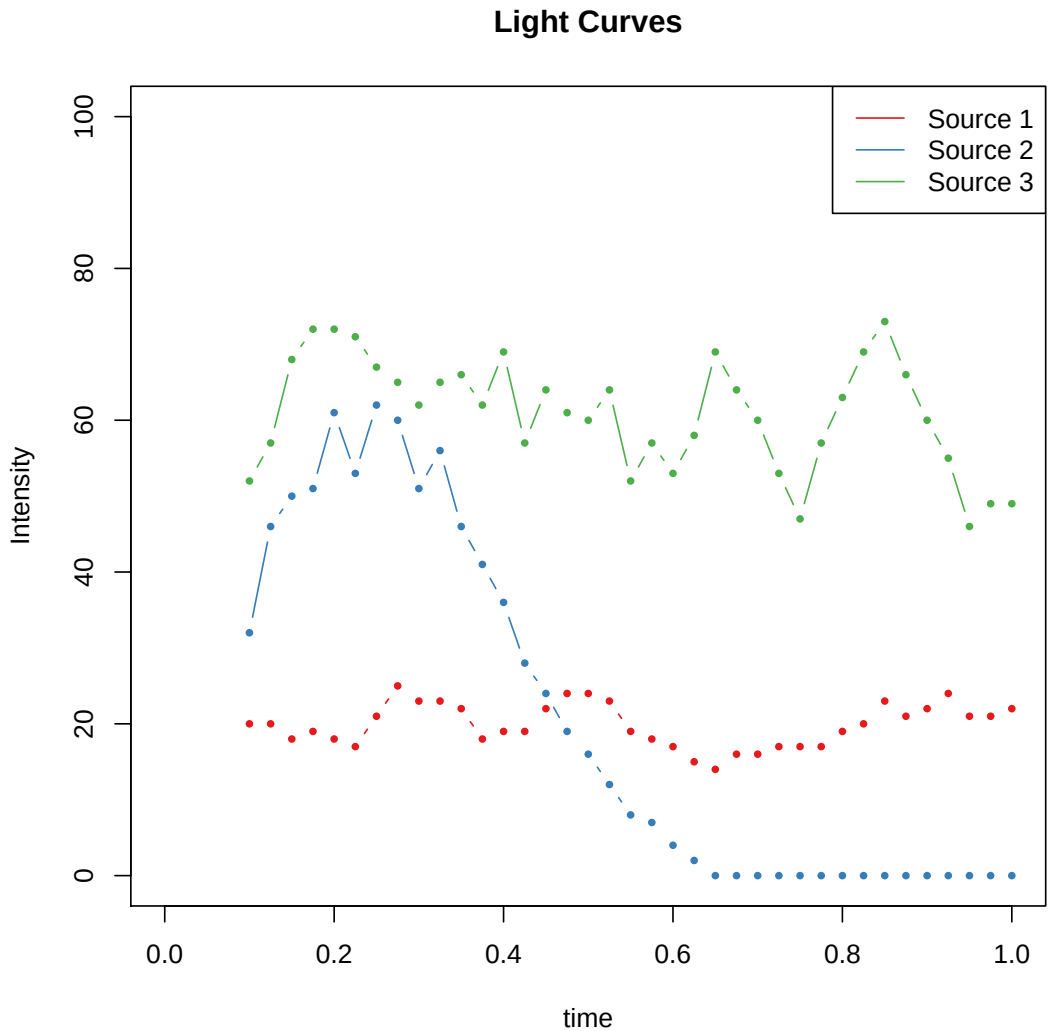
When Spatial Information is not enough.

Spectral Energy Distribution



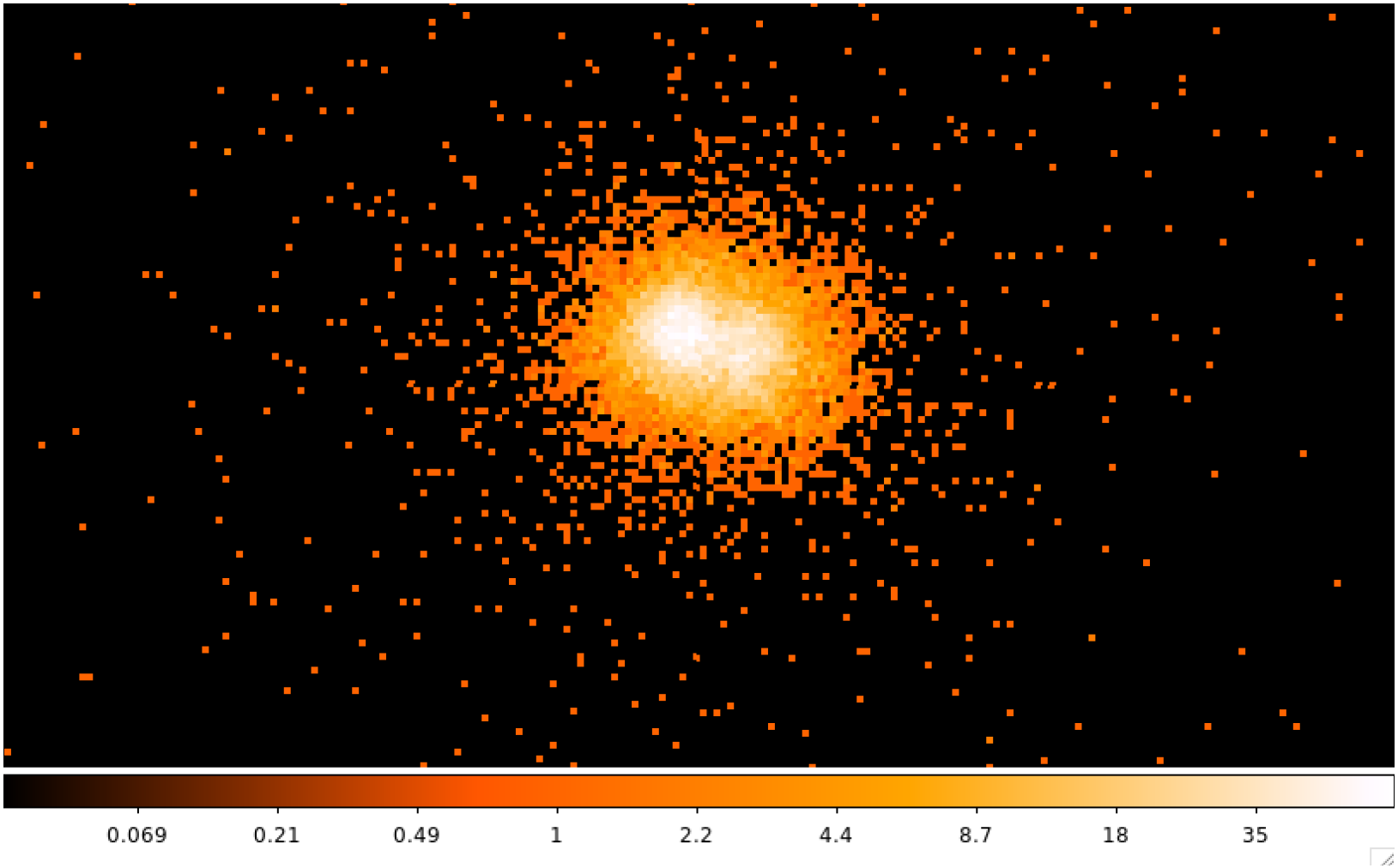
David E. Jones, Vinay L. Kashyap, and David A. van Dyk (2015) "Disentangling Overlapping Astronomical Sources using Spatial and Spectral Information" The Astrophysical Journal

Time Arrival Information



Luis F. Campos, et.al (2017? 2018?)

Illustrative Example: HBC515



Illustrative Example: HBC515

- Part of a system of multiple young stellar objects
- Discovered in 2012
- **Difficult to Study**: One study pulished in 2016 Principe, et.al. 'The Multiple Young Stellar Objects of HBC 515: An X-ray and Millimeter-wave Imaging Study in (Pre-main Sequence) Diversity'

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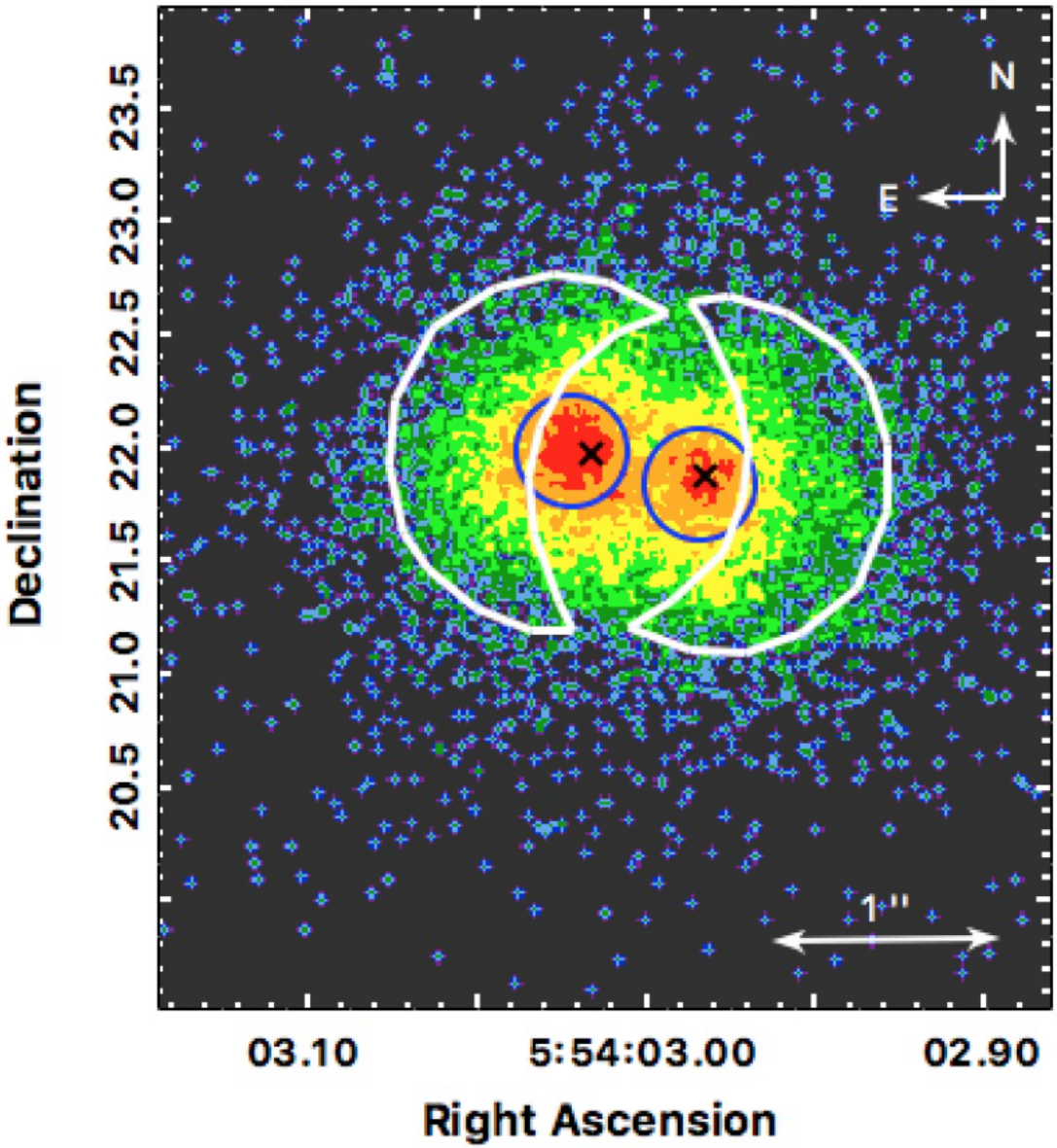
Methods:

- "The point spread functions of the two binary components overlap significantly, however, complicating their photometric and spectral decomposition."
- "Hence, we used two spectral extraction regions for each of the component sources"

Illustrative Example: HBC515



Problem Setup

Given:

- (x_i, y_i, E_i, t_i): photon-level information
- S: number of sources (assume known for now)

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$\downarrow\downarrow$

- distance between sources
- source intensities
- better understand source spectral information
- better models for time arrival (O-U process, flares), etc.

Problem Setup

Overarching plan:

- Jones, et.al. used (x_i, y_i, E_i) with *unknown* number of sources
- First use (x_i, y_i, t_i) with fixed number of sources (MVP)
- Extend to *unknown* number of sources
- Then combine with Jones, et.al.

Photon Allocation Model

$$p(z_i = s|x_i, y_i, t_i) = \frac{p(x_i, y_i, t_i|z_i = s)\ p(z_i = s)}{p(x_i, y_i, t_i)}$$

Photon Allocation Model

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Assume photon location distribution can be modeled the same accross time.

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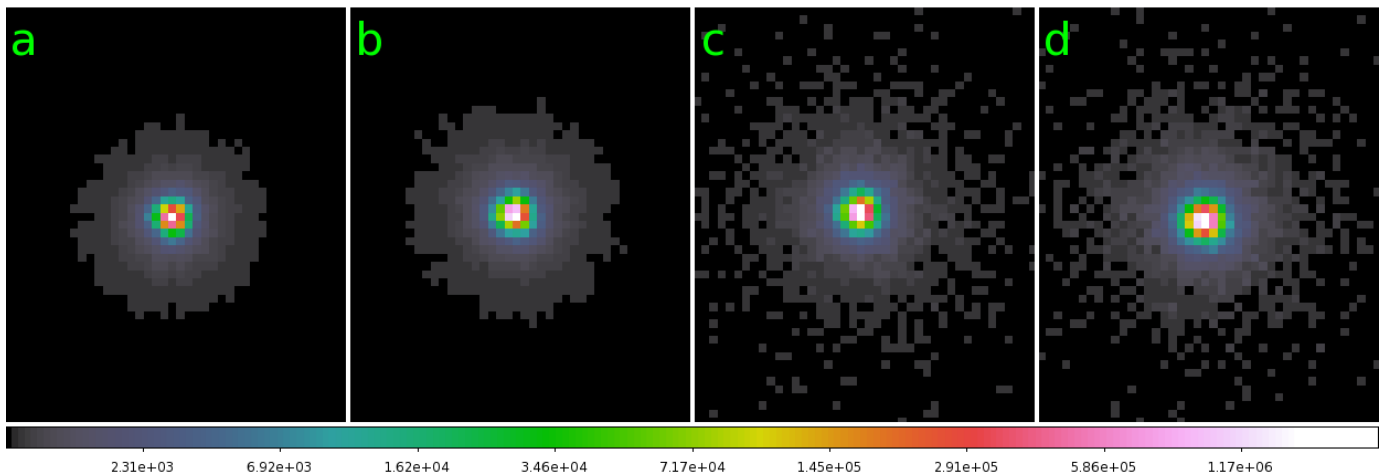


Photon Allocation Model

Onward!

$$p(z_i = s|x_i, y_i, t_i) \propto p(x_i, y_i|z_i = s)\ p(t_i|z_i = s)\ p(z_i = s)$$

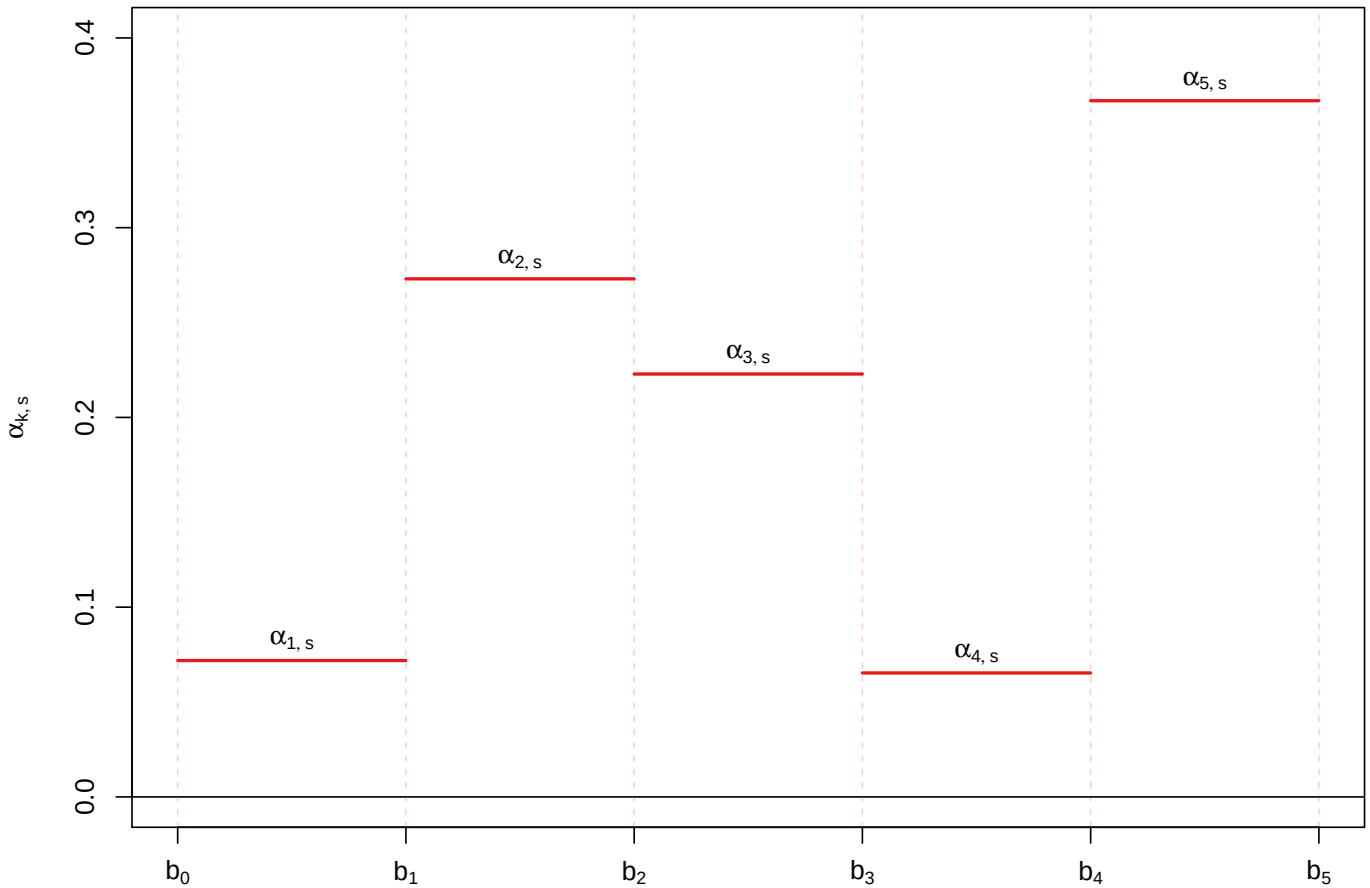
Photon Allocation Model

Onward!

$$p(z_i = s|x_i, y_i, t_i) \propto p(x_i, y_i|z_i = s)\ p(t_i|z_i = s)\ p(z_i = s)$$

- $p(x_i, y_i|z_i = s)$: Can use the King Profile (a 2-d Cauchy)
- $p(z_i = s)$: Can use a Dirichlet distribution.
- $p(t_i|z_i = s)$?

A Simple Time Model



$$p(t_i \in [b_{k-1}, b_k] | z_i = s) = \alpha_{k,s} \quad \textit{and} \quad \sum_k \alpha_{k,s} = 1$$

A Simple Time Model

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Model Considerations:

- Number of breakpoints K
- Breakpoint locations $\{b_k\}_{k=1}^{K}$

A Simple Time Model

$$p(t_i \in [b_{k-1}, b_k] | z_i = s) = \alpha_{k,s} \quad \textit{and} \quad \sum_{k=1}^{K} \alpha_{k,s} = 1$$

Overarching answer:

- Goal: allocation
- Models should capture some overall structure
- Err on the side of caution

A Simple Time Model

$$p(t_i \in [b_{k-1}, b_k] | z_i = s) = \alpha_{k,s} \quad \textit{and} \quad \sum_{k=1}^{K} \alpha_{k,s} = 1$$

Model Choices:

- K same across sources, relatively small (10, 15).
- $\{b_k\}_{k=1}^{K}$ are fixed and evenly spaced across sources.

Simulated Data

We want to study:

1. Should we even use time?
2. How does the distance between sources affect out ability to distinguish them?

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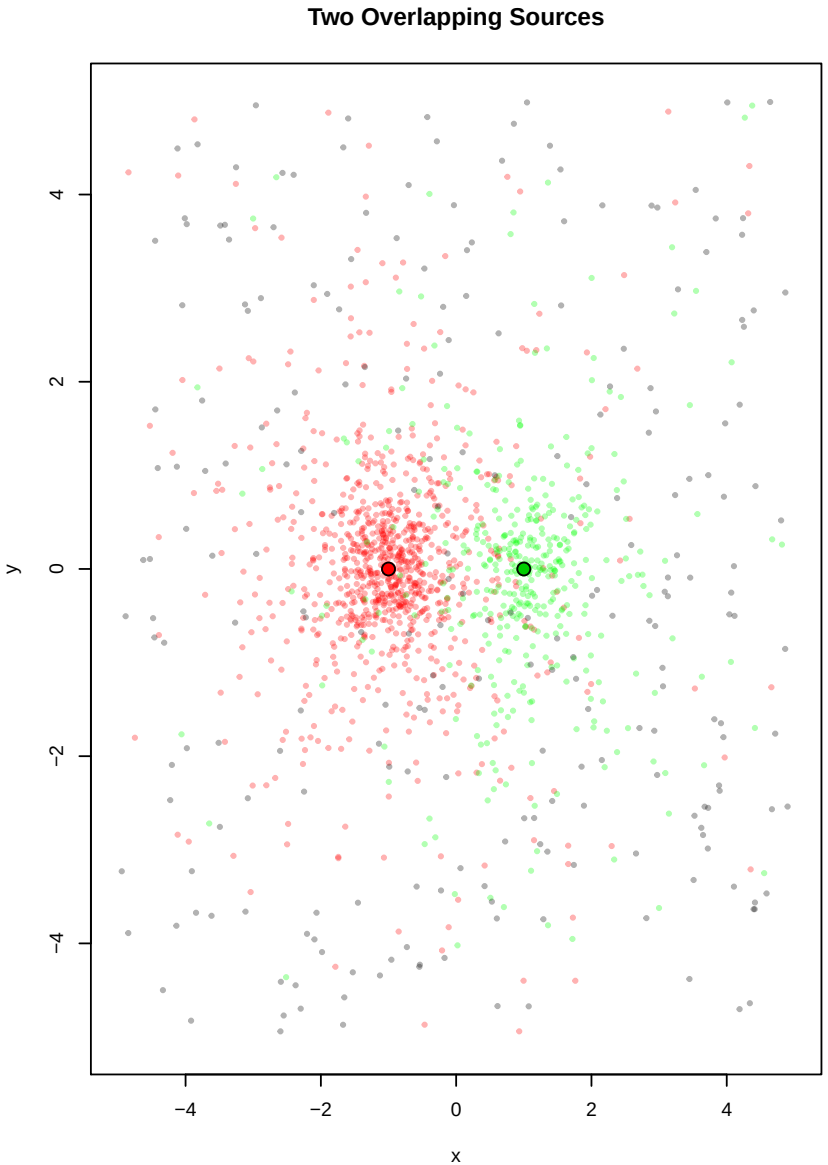
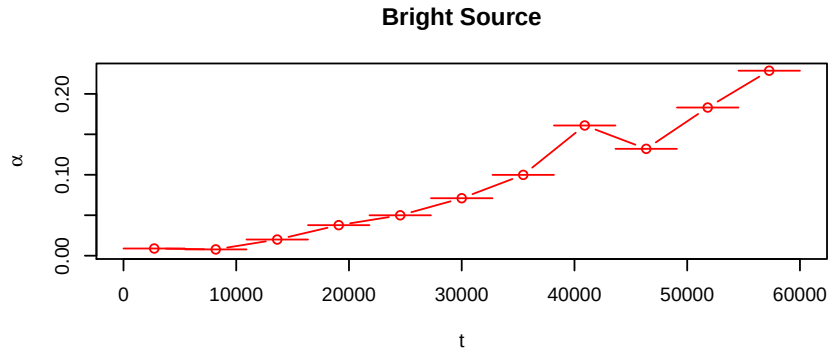
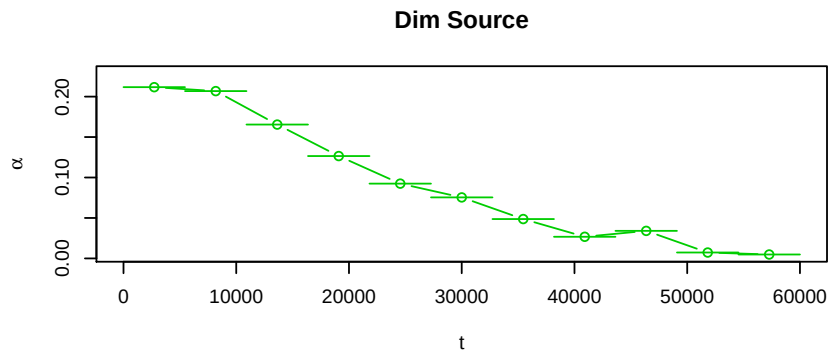
Simulation:

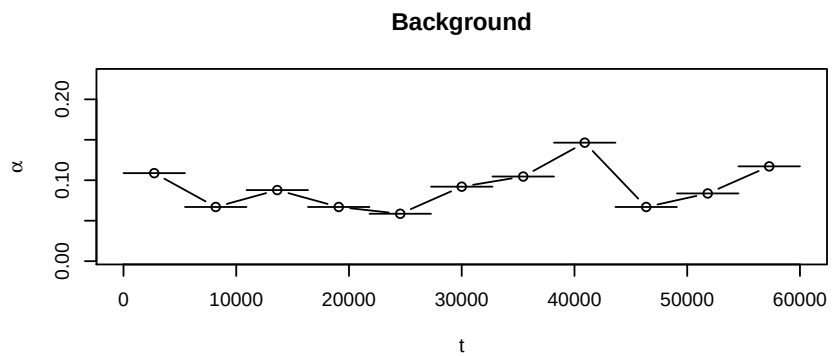
1. Two sources with background
2. Source separation $(0.5, 0.6, 0.75, 1, 1.5, 2)$
3. Ideal time arrival distributions (for now)

Simulated Data (separation = 2)

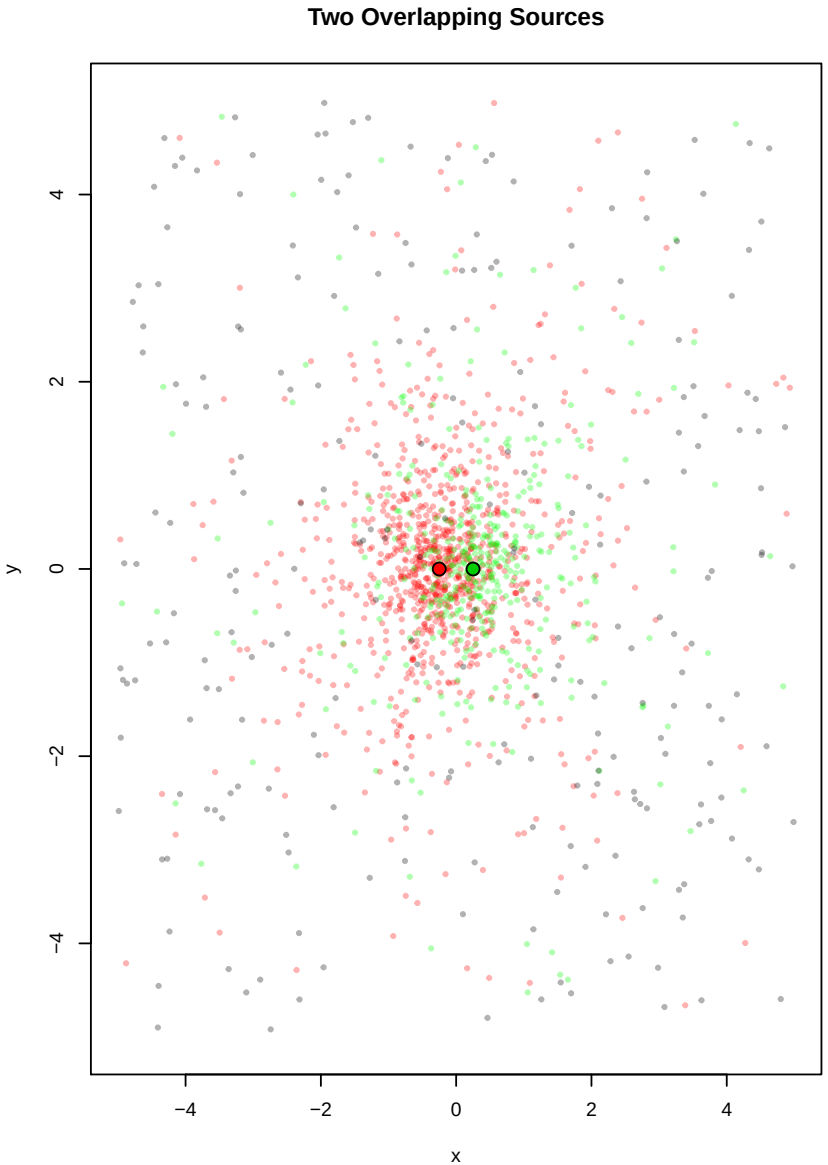


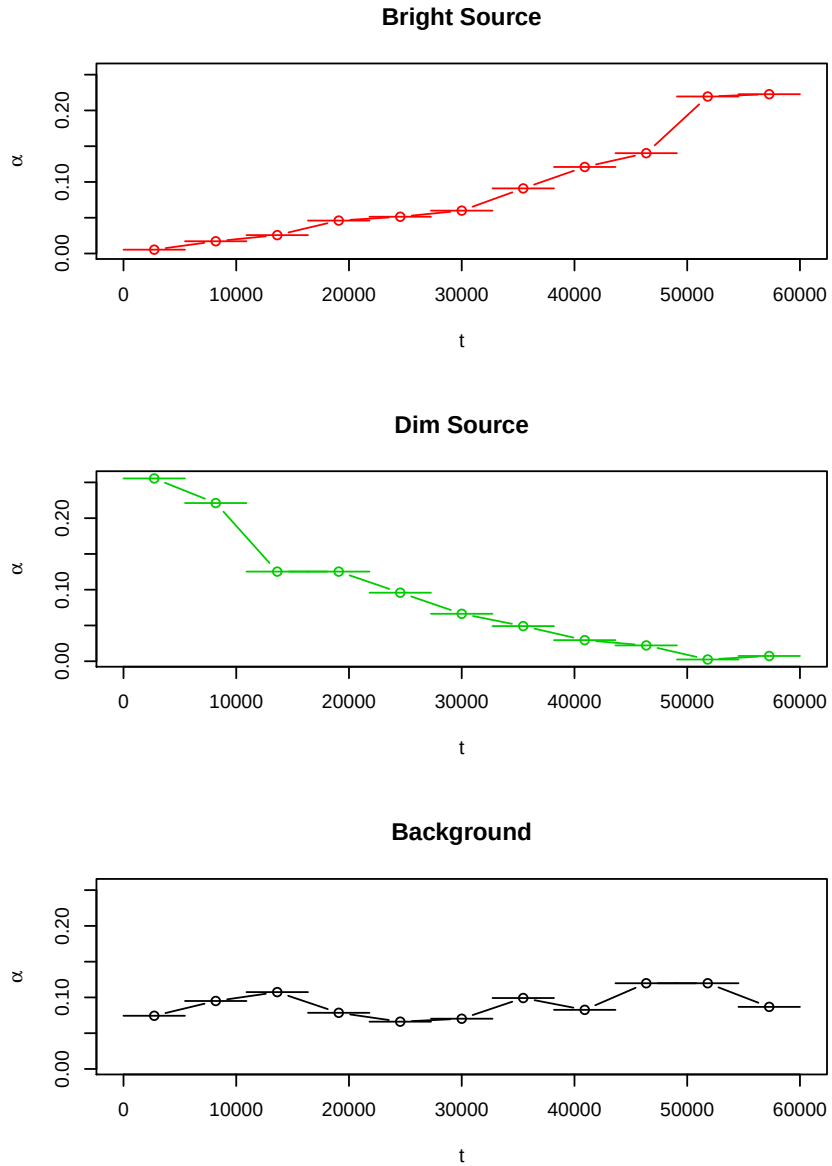




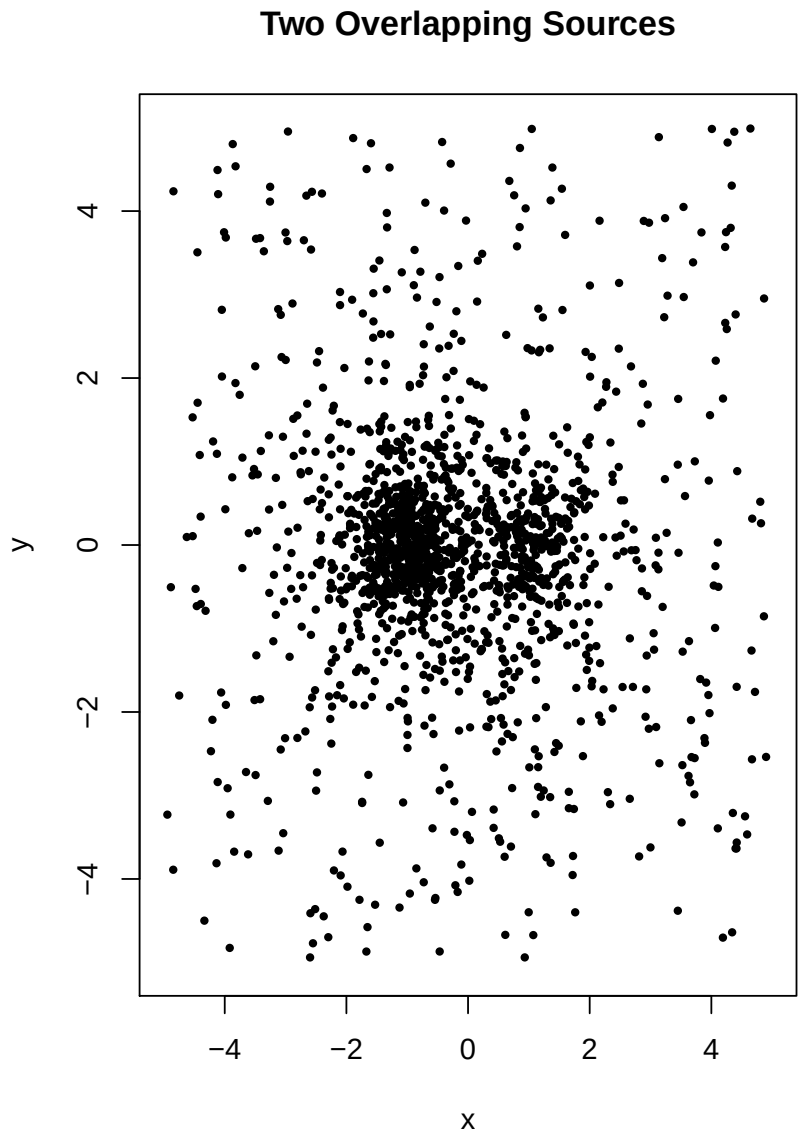


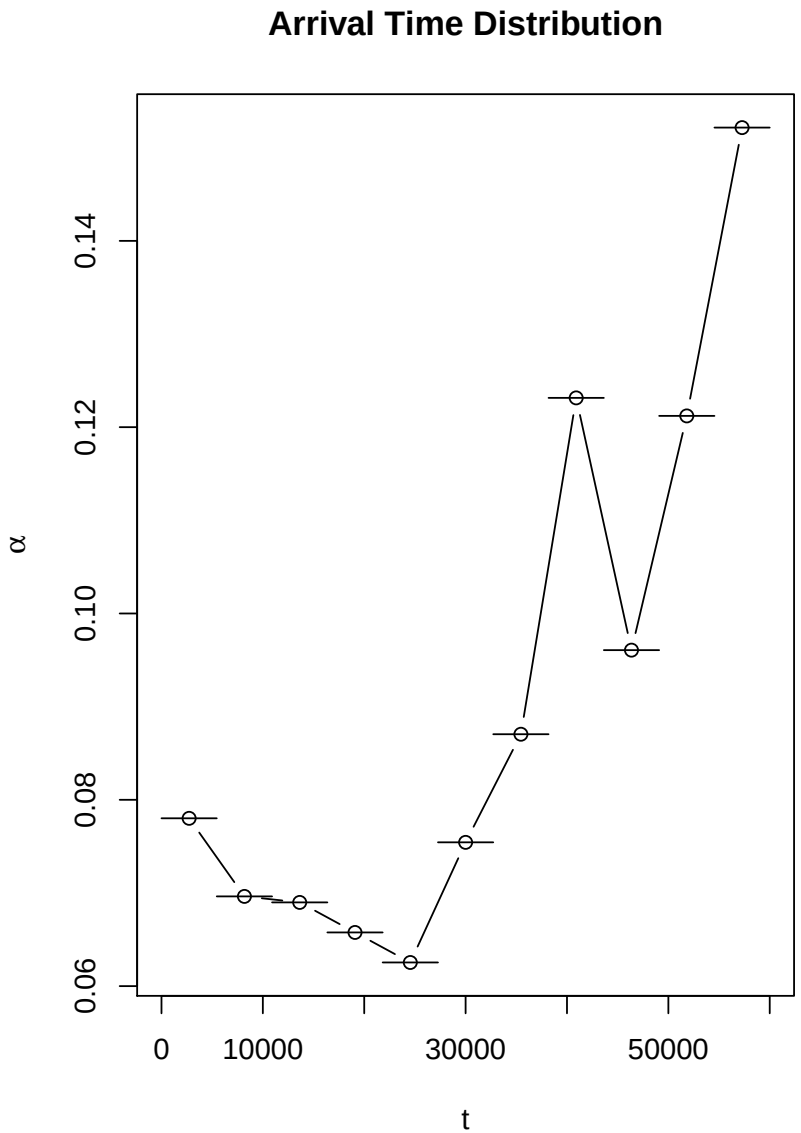
Simulated Data (separation = 0.5)





What we have to work with (separation = 2)





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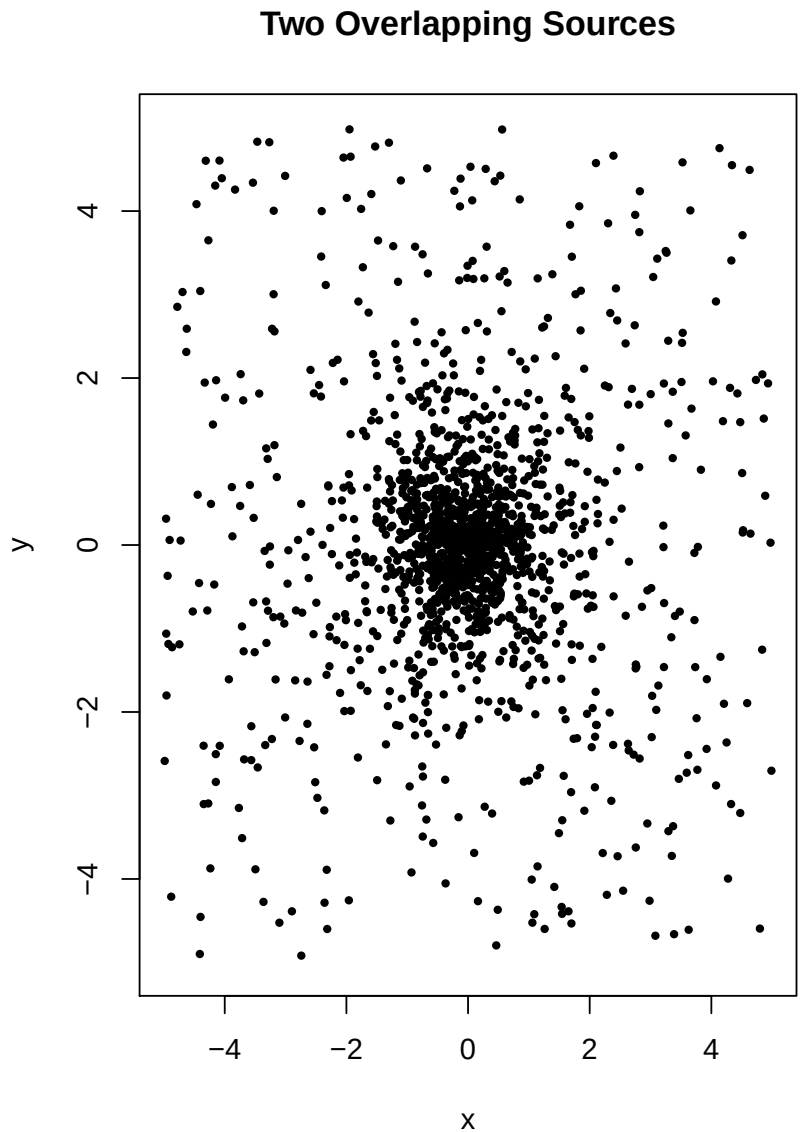
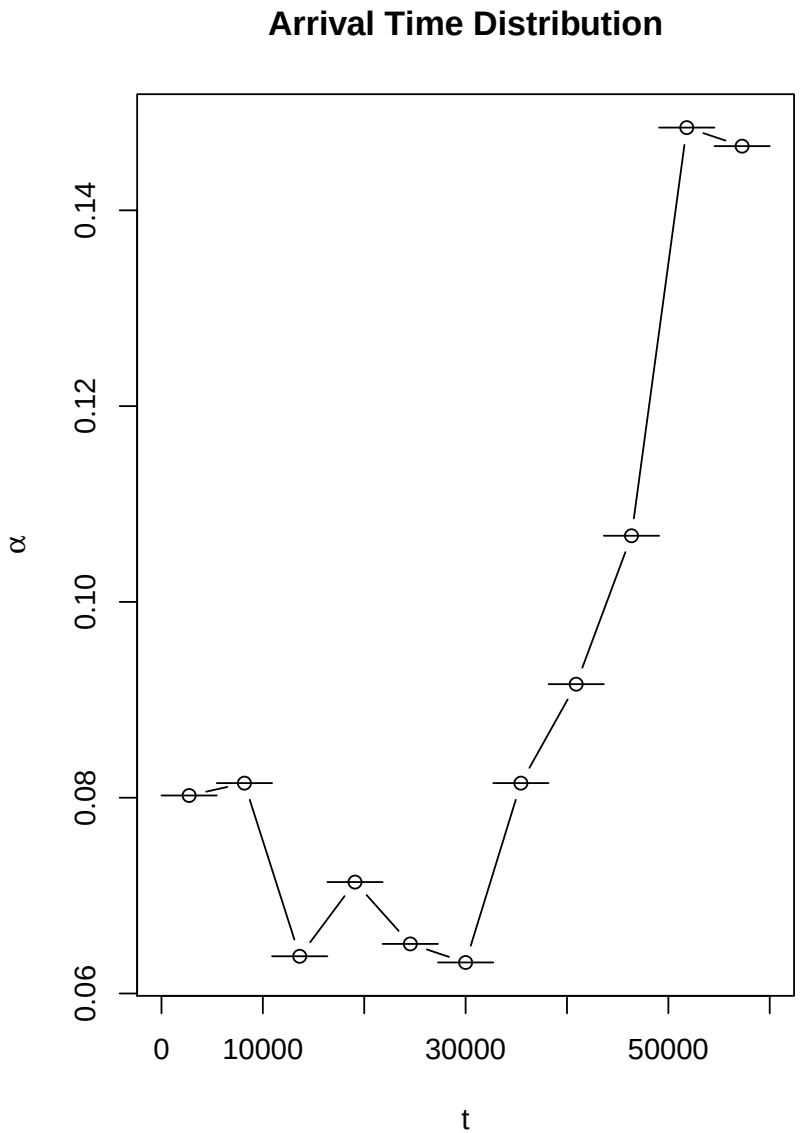
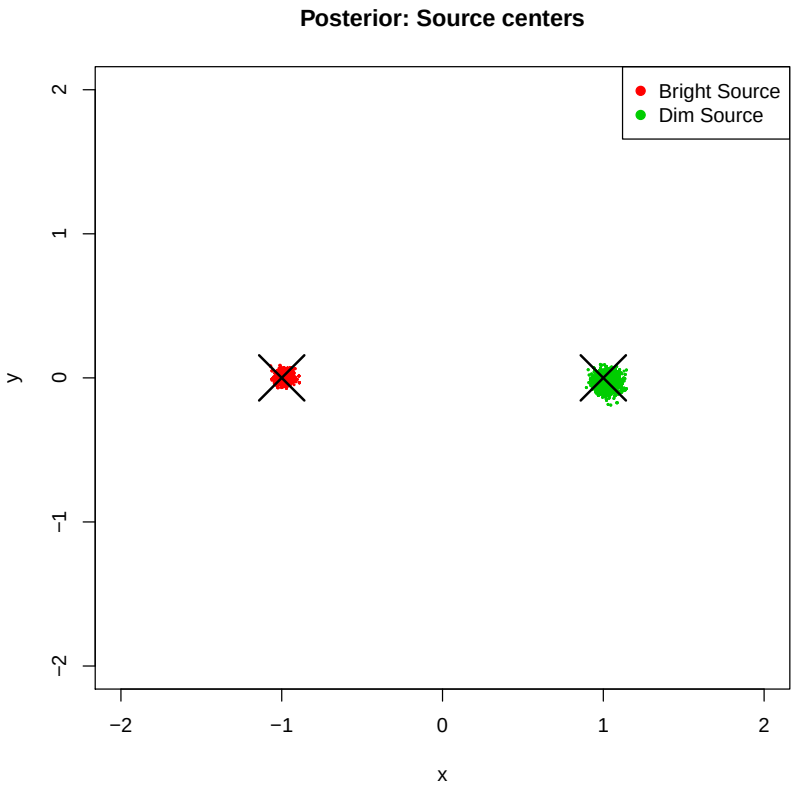
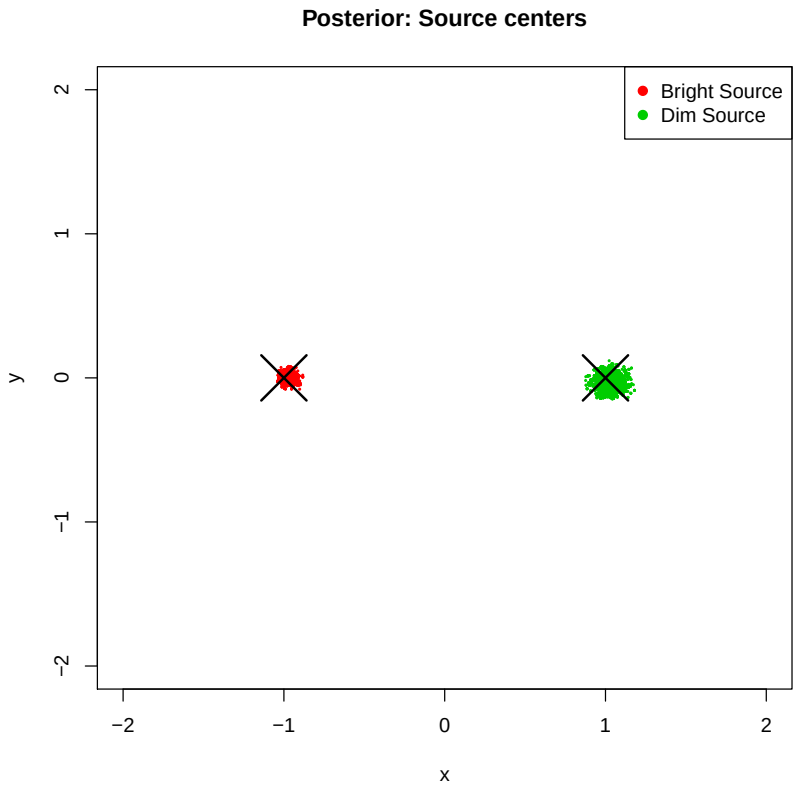




Source Location (separation = 2)

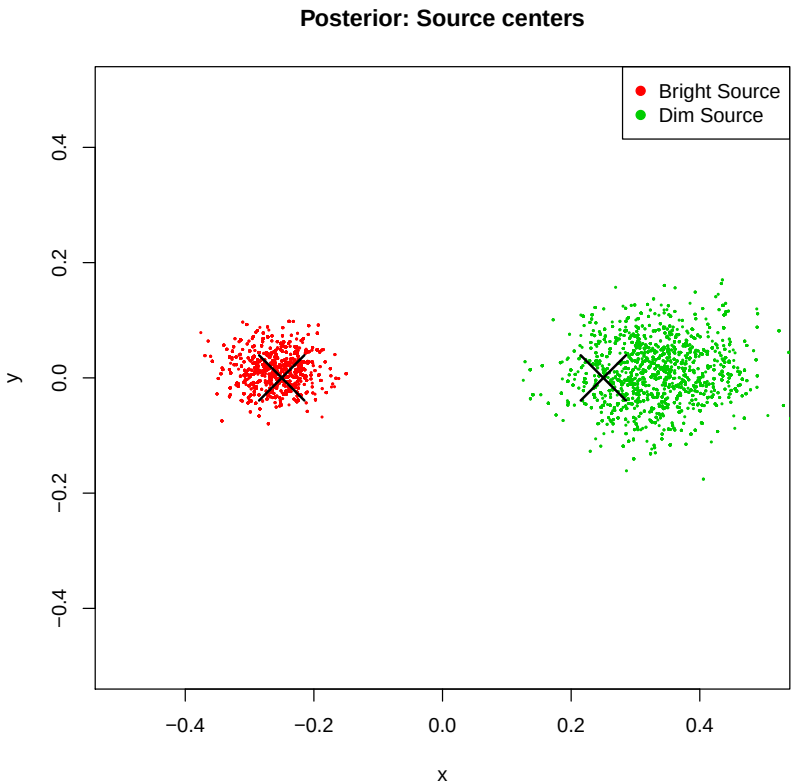


(a) Location and Time Model

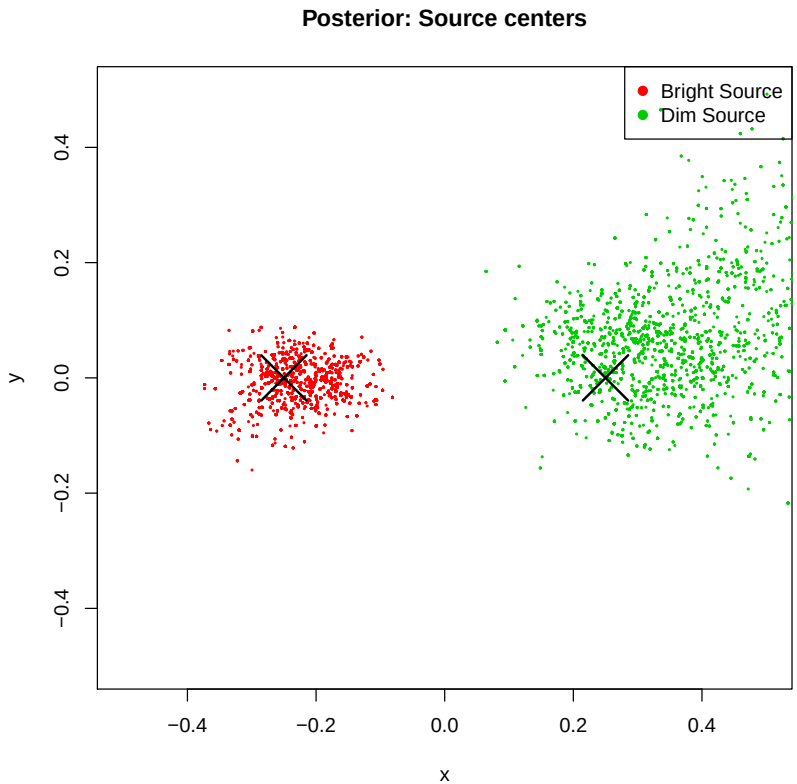


(b) Location Only Model

Source Location (separation = 0.5)

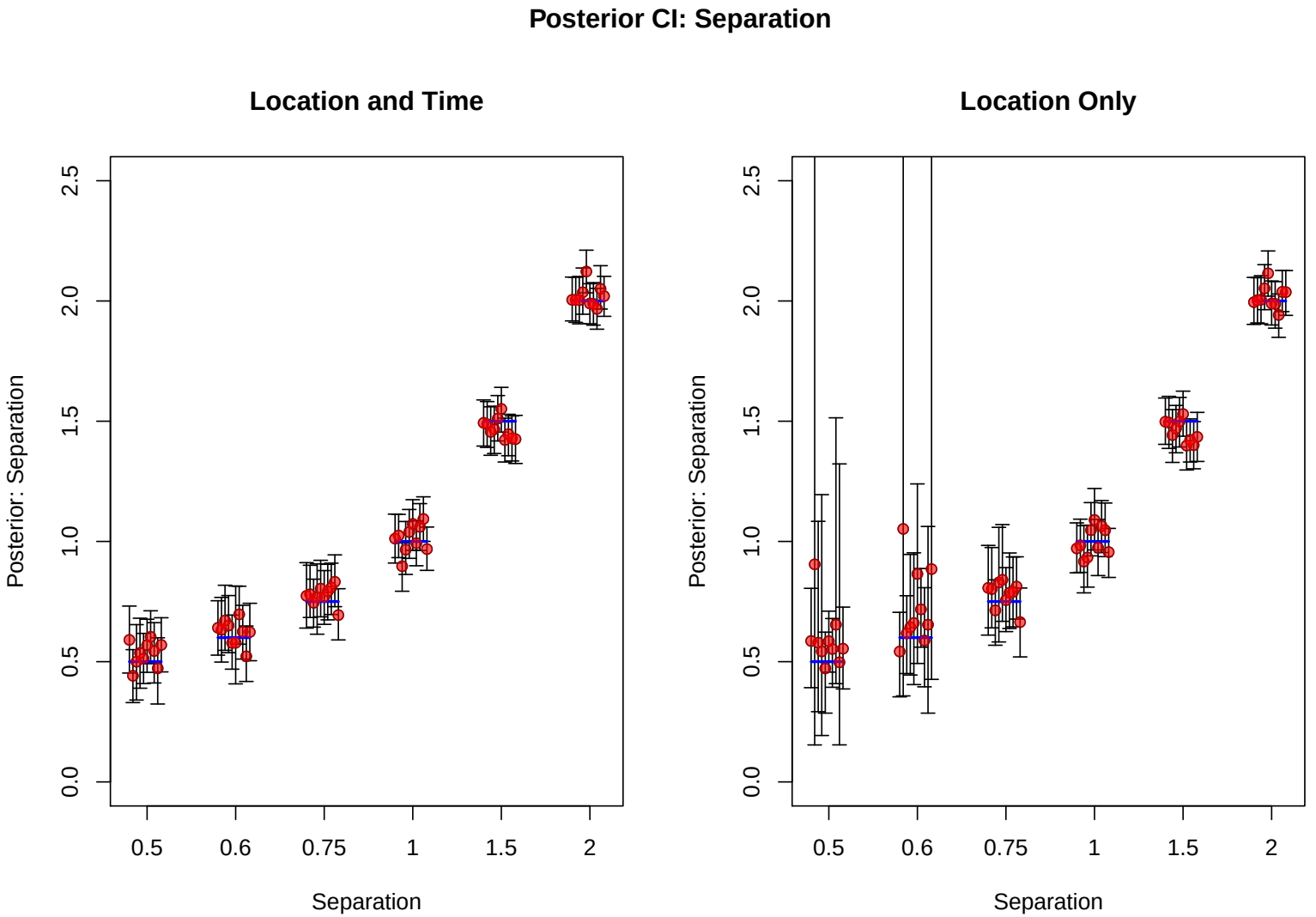


(c) Location and Time Model

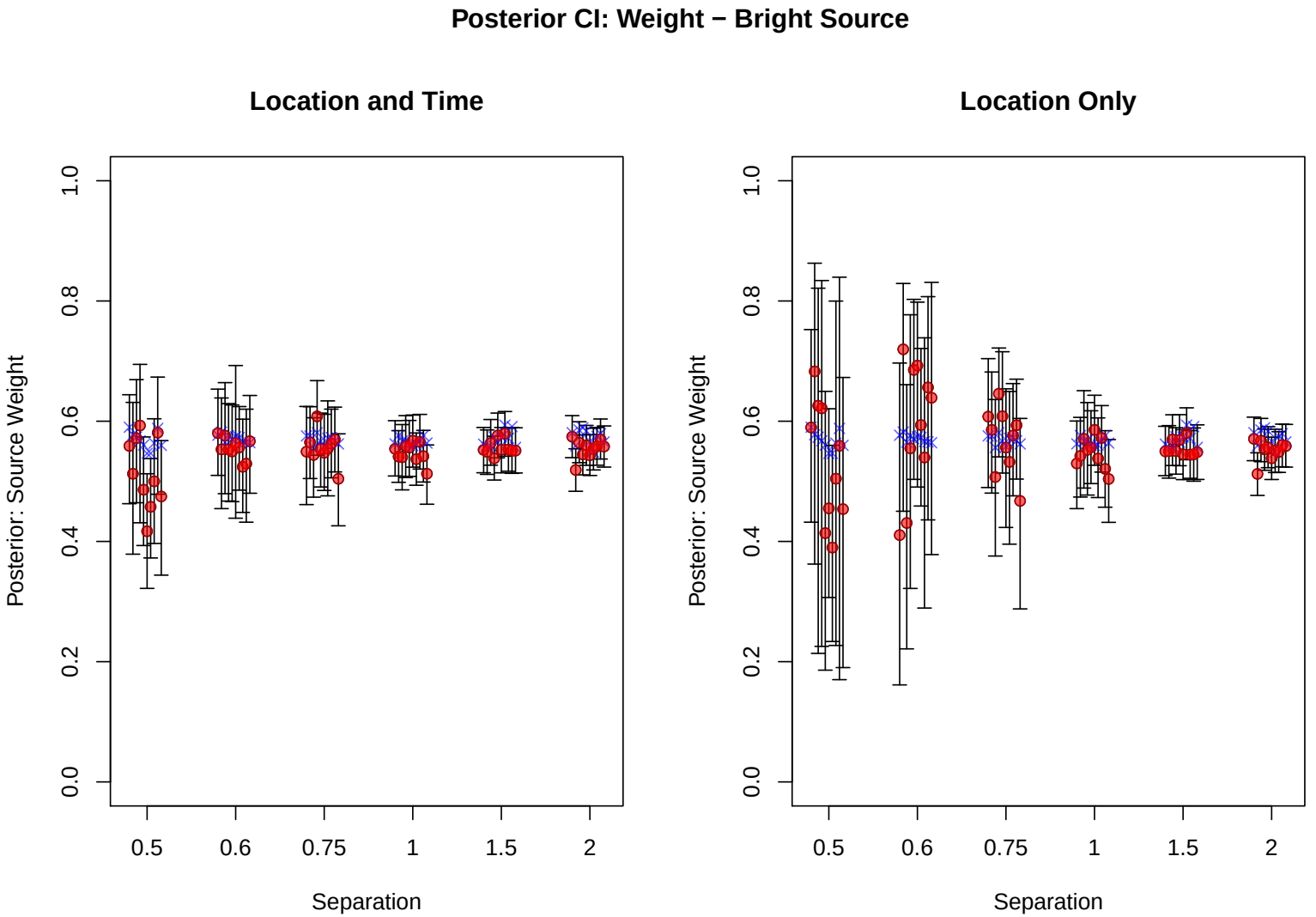


(d) Location Only Model

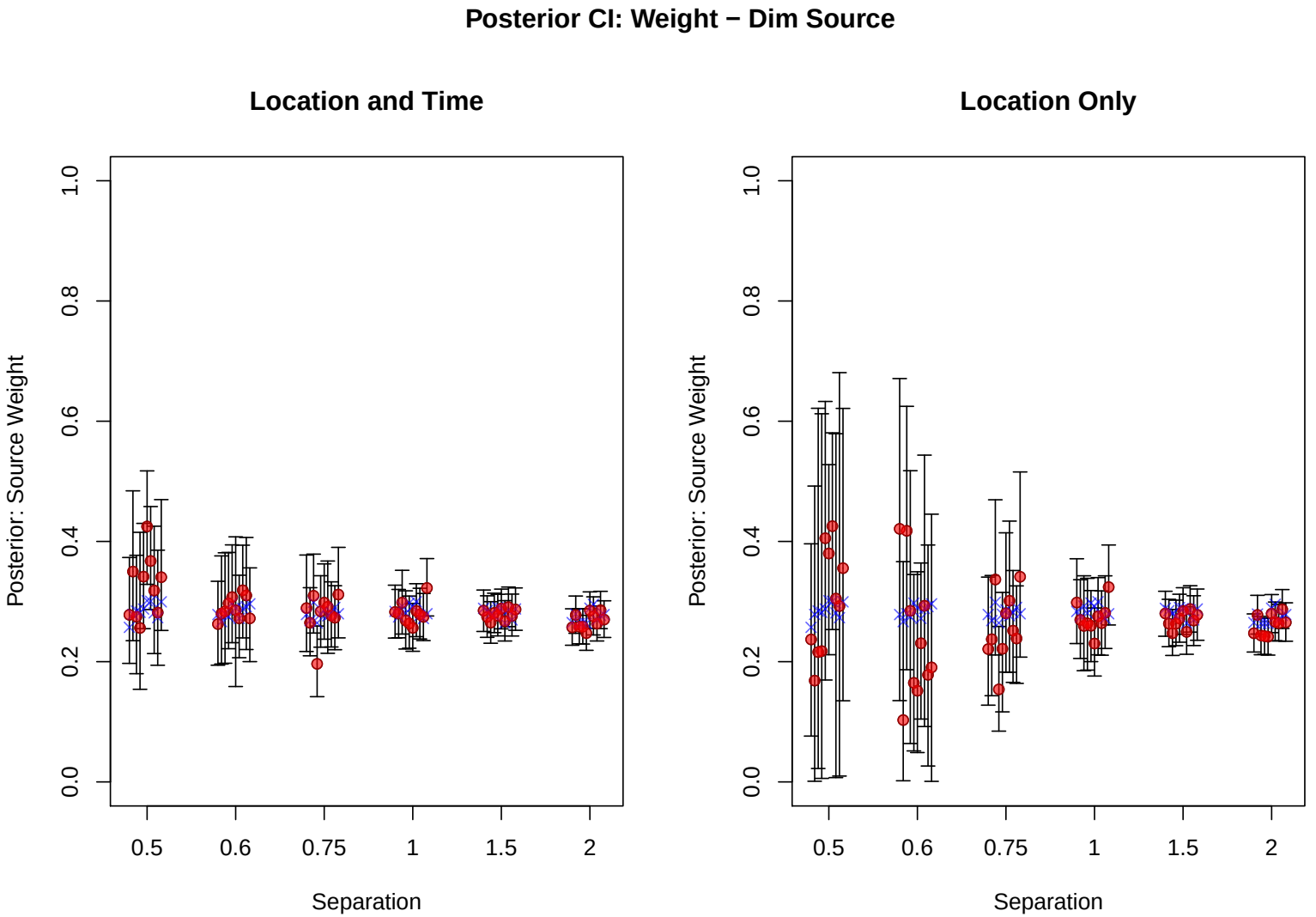
Source Separation (with replicates)



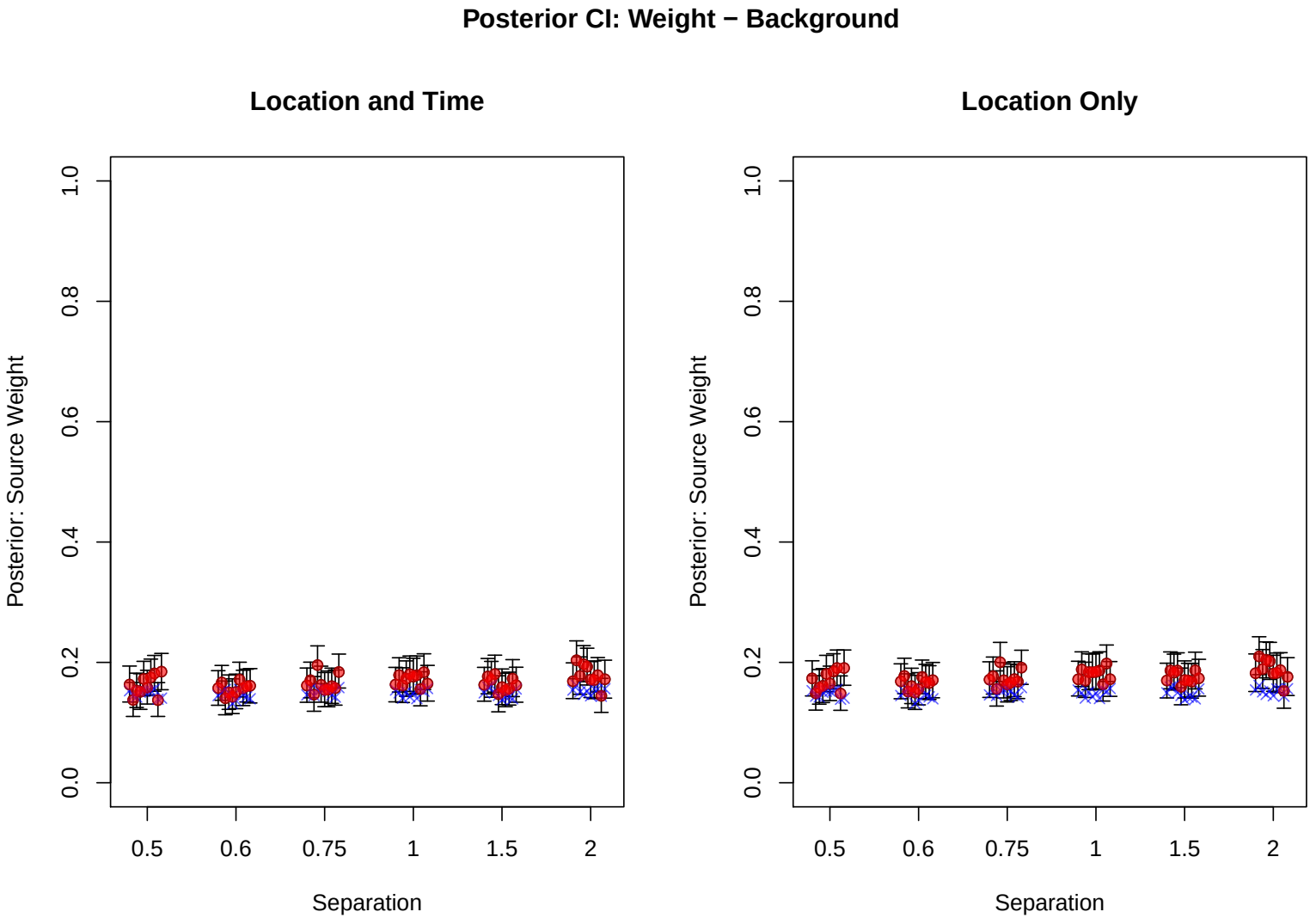
Source Intensity: Bright Source (with replicates)



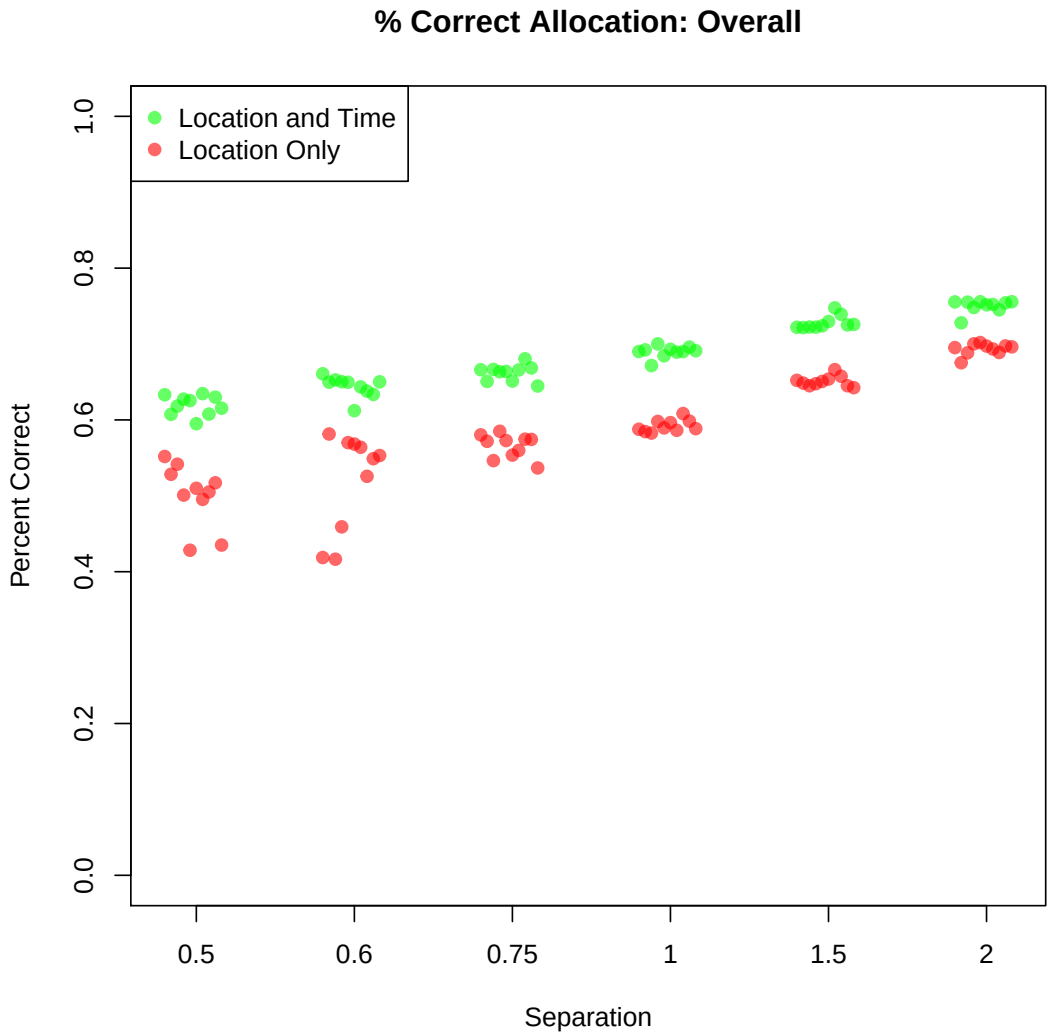
Source Intensity: Dim Source (with replicates)



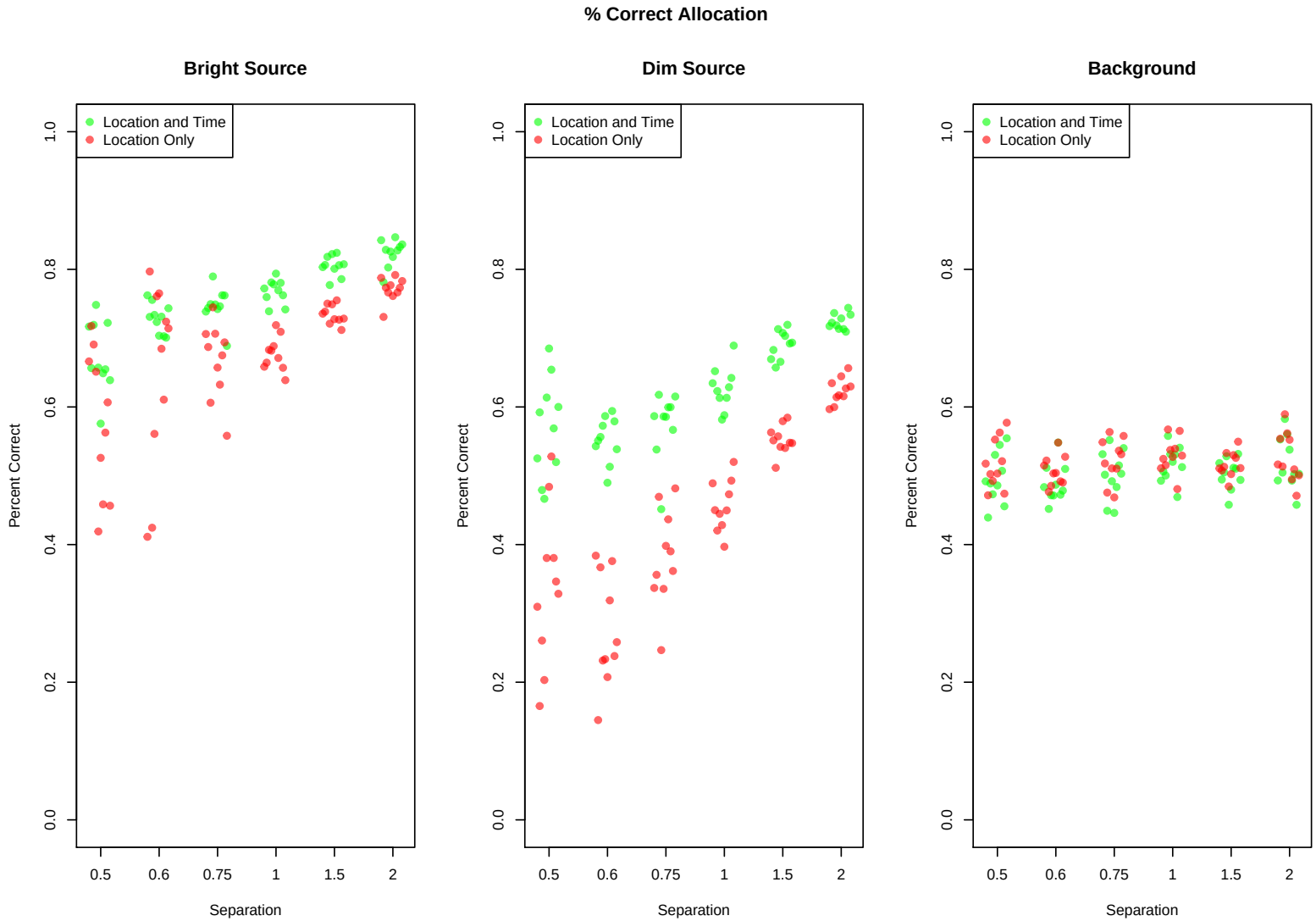
Source Intensity: Background (with replicates)



Average Correct Source Allocation (with replicates)



Average Correct Source Allocation by Source (with replicates)



Where do we go from here?

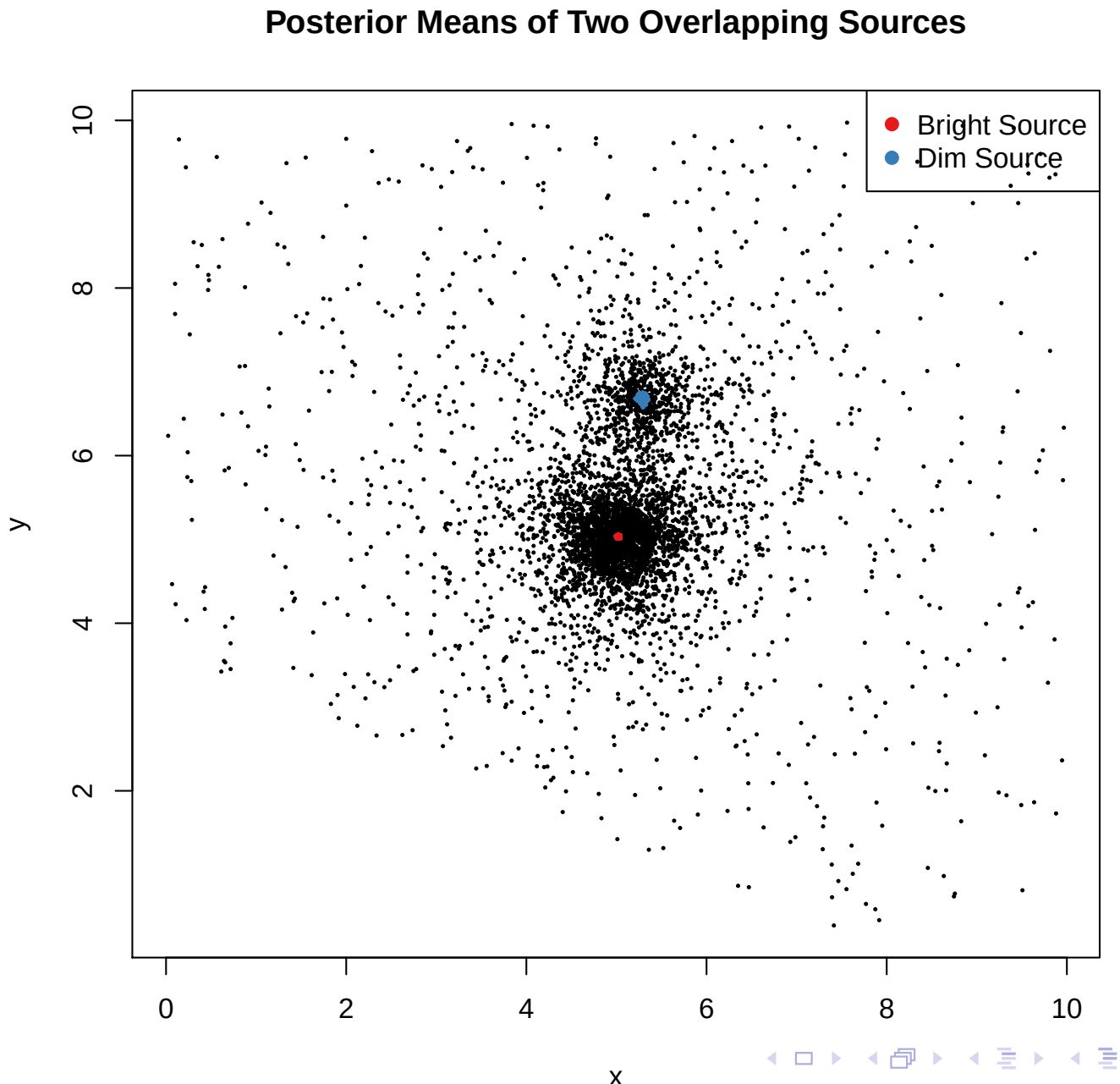
What we've done:

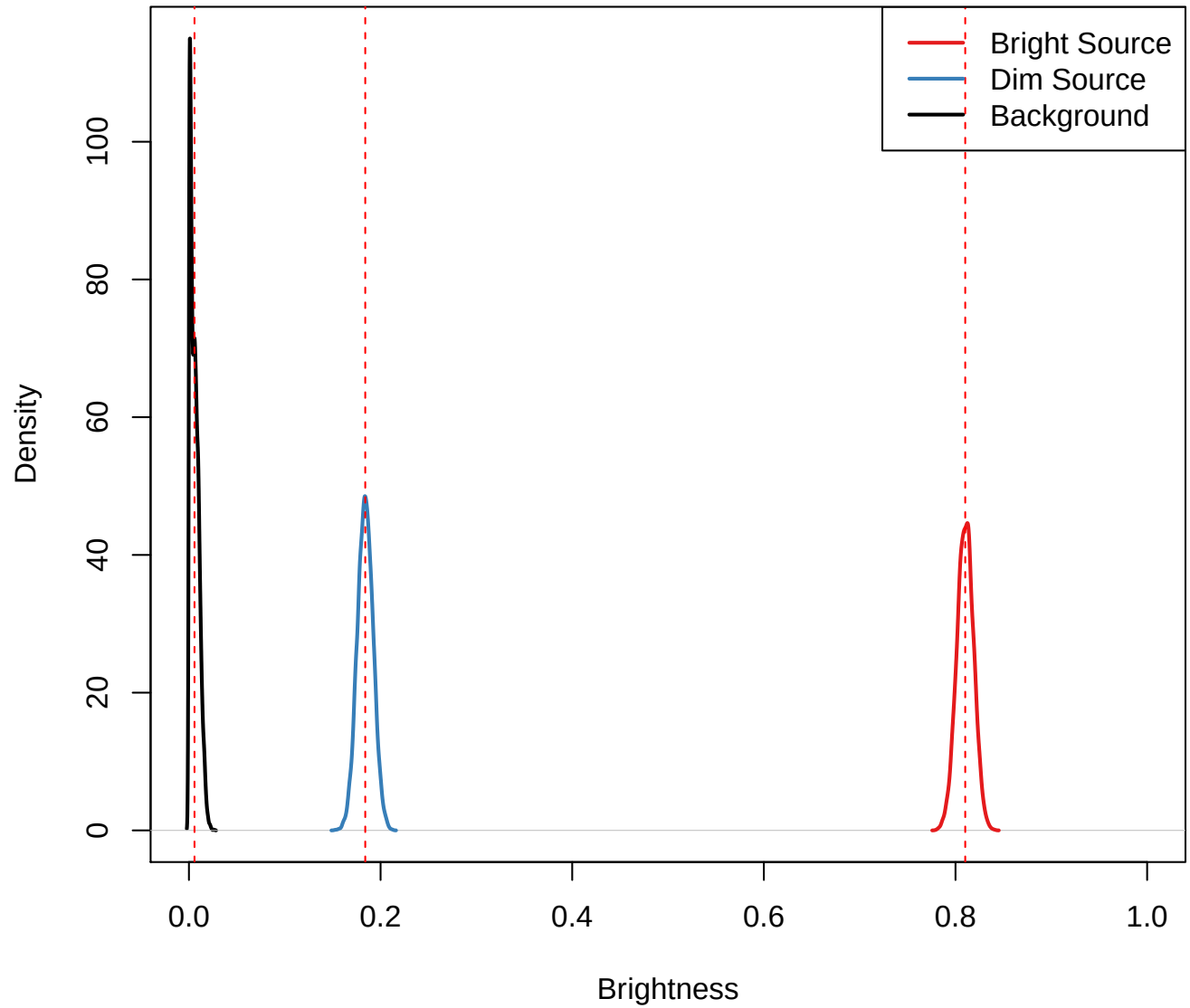
- We've shown that using time **can** help disambiguate sources.
- Even simple models (constant functions) can prove useful.

Future directions:

- Real light curve shapes (mine were too simple)
- Reversible Jump MCMC for unknown number of sources
- Merge with spectral energy models.

Data Analysis (time permitting)




Posterior: Relative Brightness
Bright Source
Dim Source
Background
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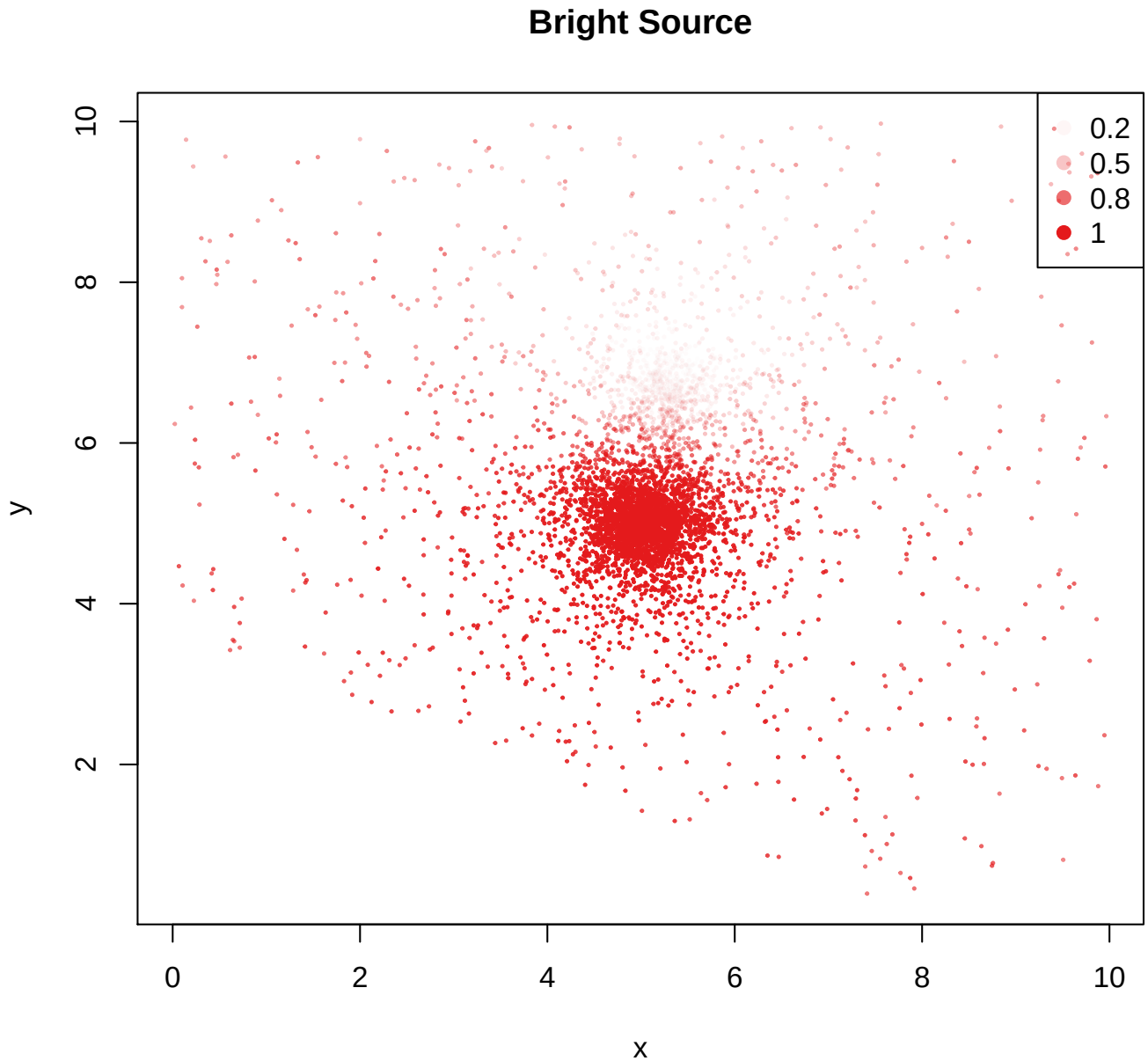
Brightness


Bright Source
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0.5
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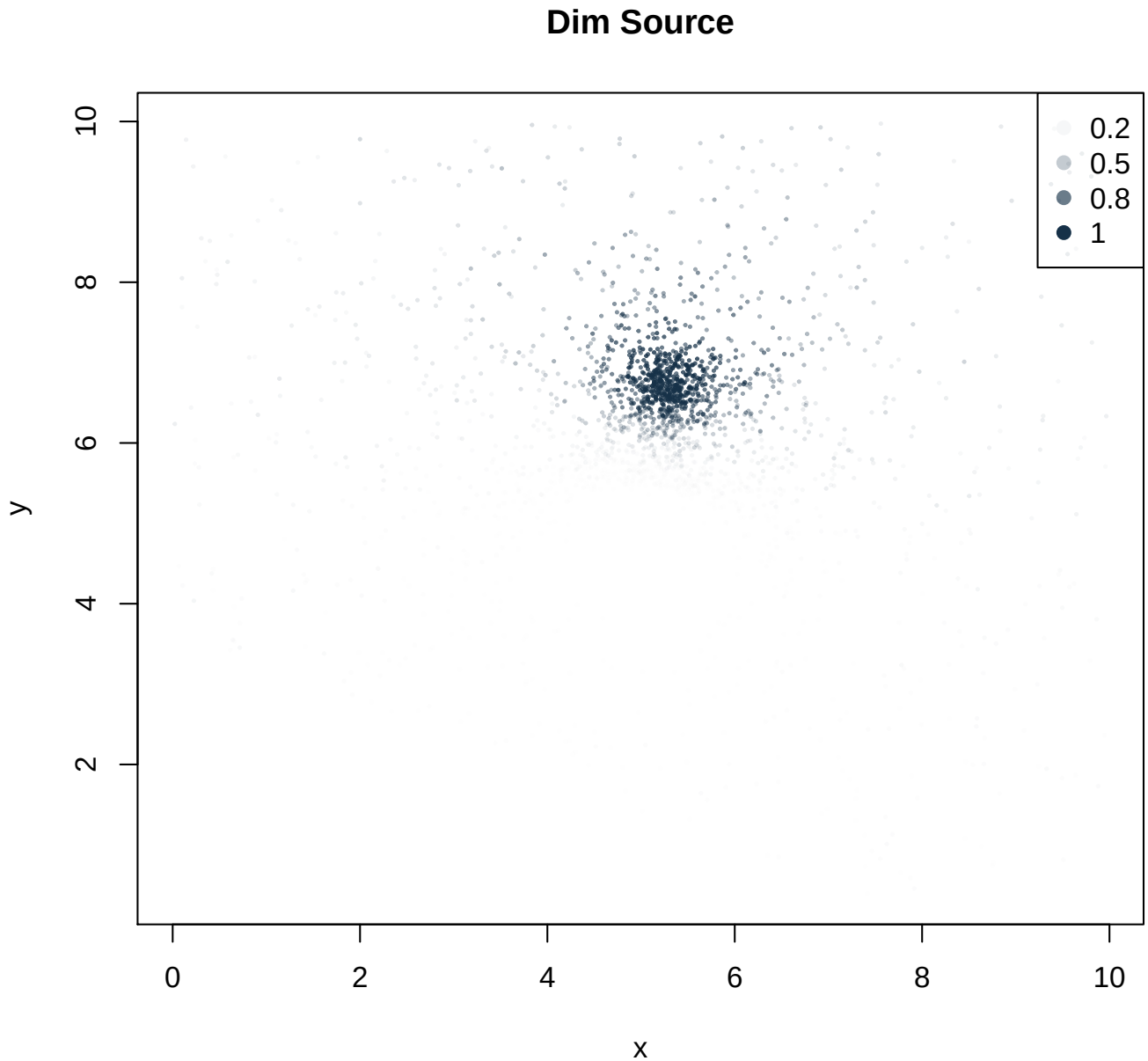
Dim Source
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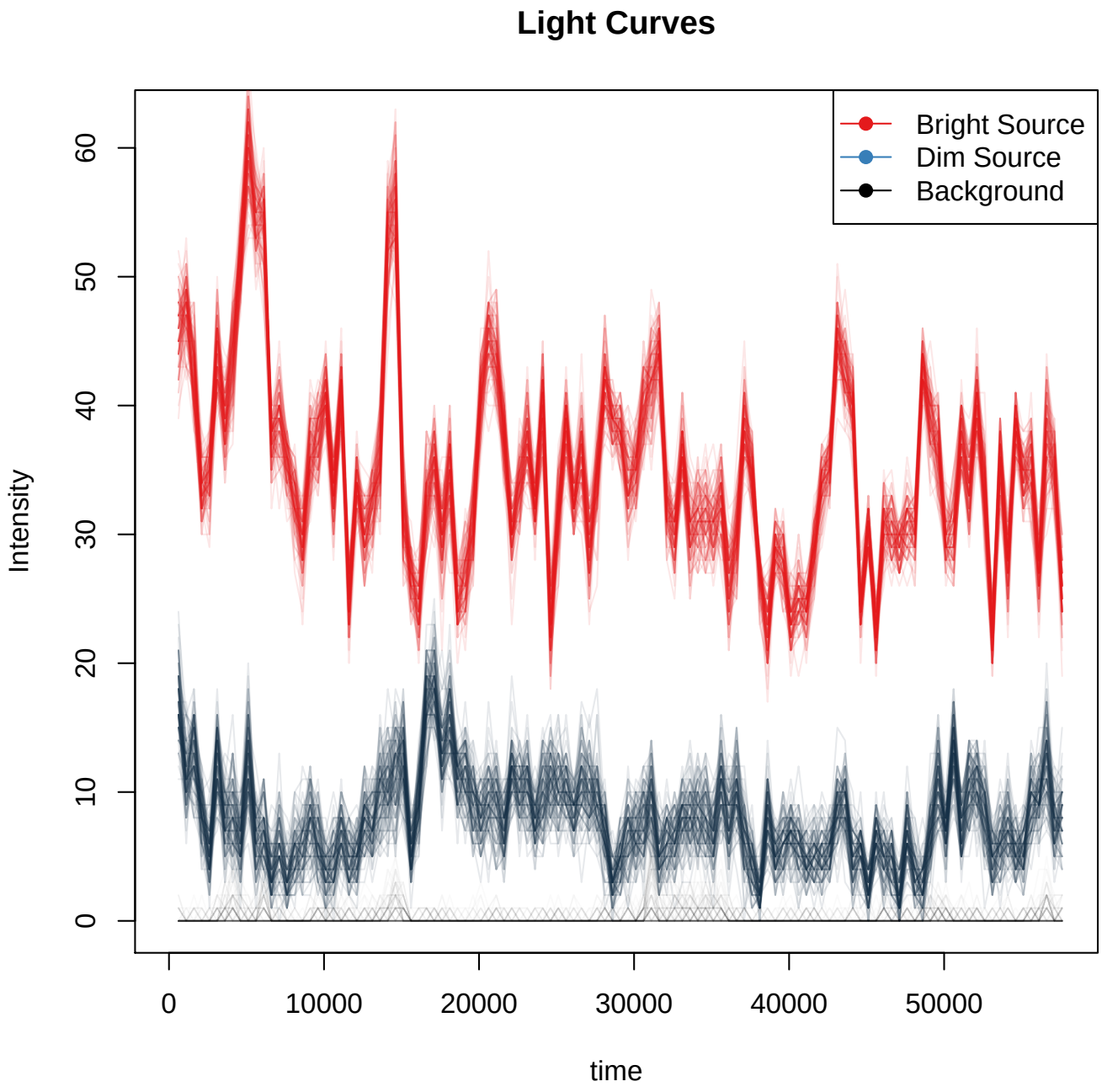
Light Curves
Bright Source
Dim Source
Background
Intensity
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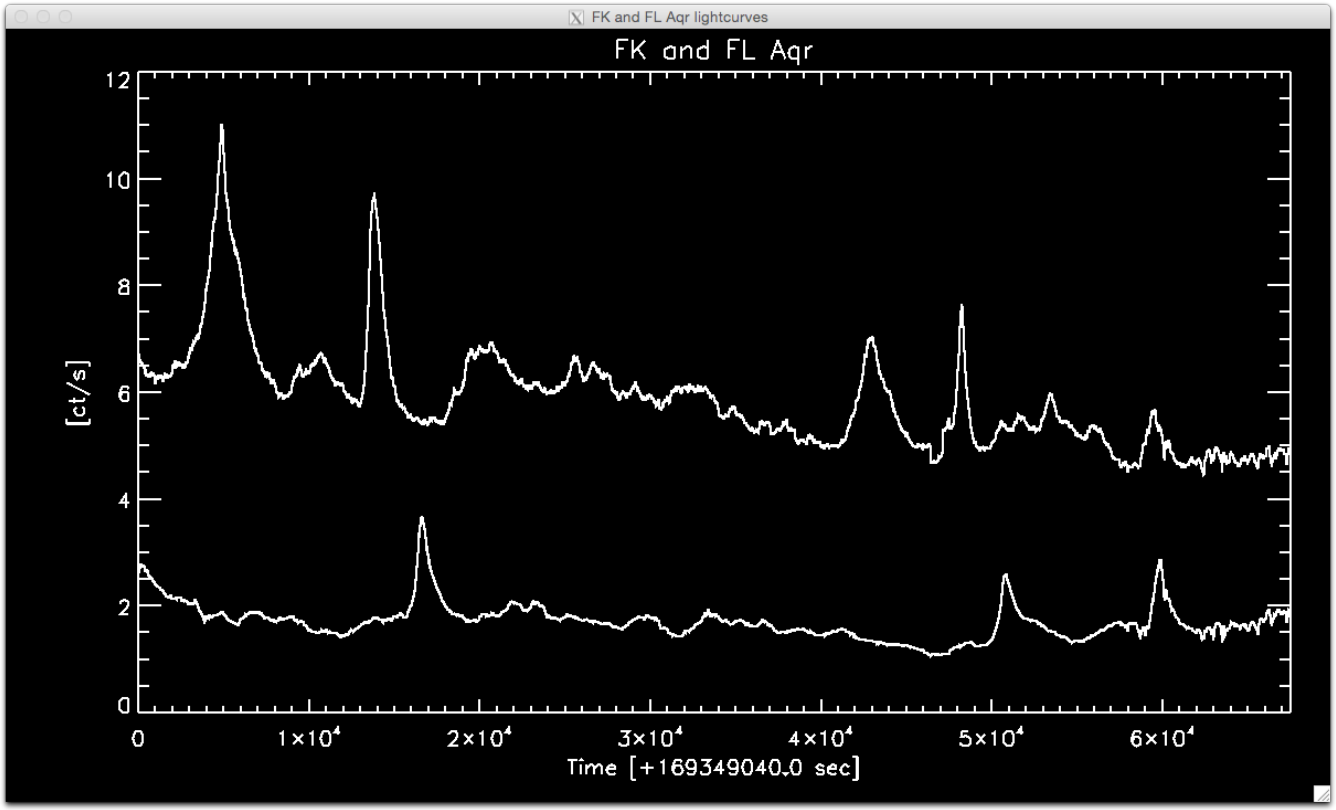
Thank you!


FK and FL Aqr lightcurves
FK and FL Aqr
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