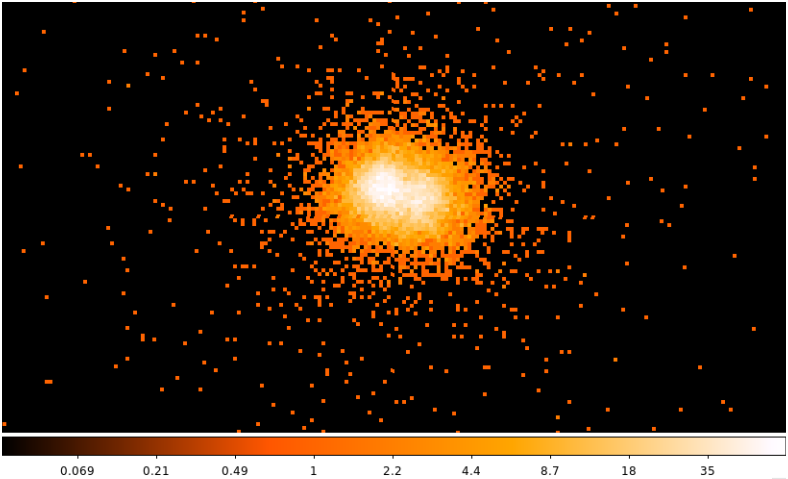
Disambiguating Sources II
Valentine's Day Edition

Luis Campos (with David Jones)

February 14, 2017

Illustrative Example: HBC515



Illustrative Example: HBC515

- Discovered in 2012
- Part of a system containing multiple young stellar objects (YSOs)
- Difficult to Study: One study pulished in 2017 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”

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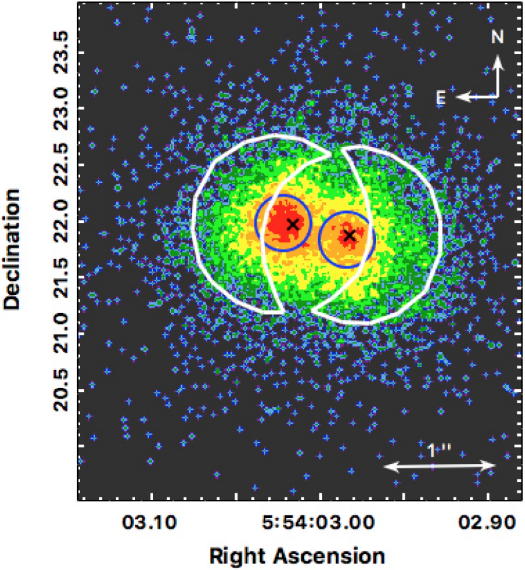

Problem Setup

Given:

- (x_i, y_i): photon-level location information
- E_i: photon-level Energy information
- t_i: photon-level time-arrival info.
- S: number of sources (assume known for now)

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

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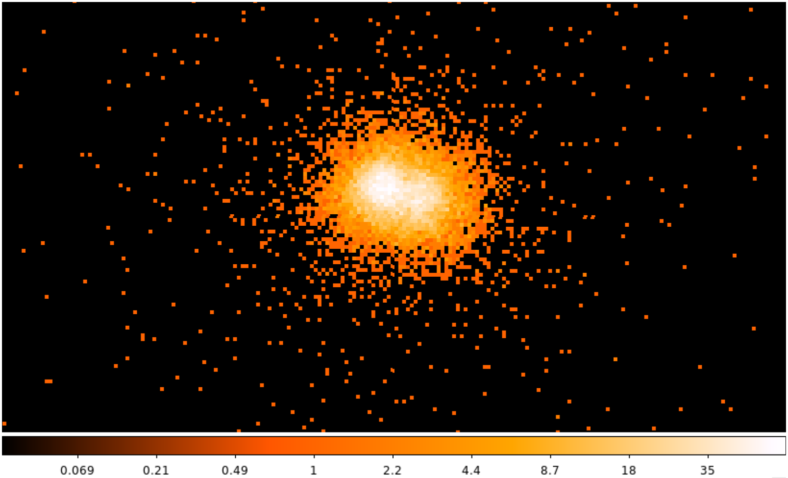

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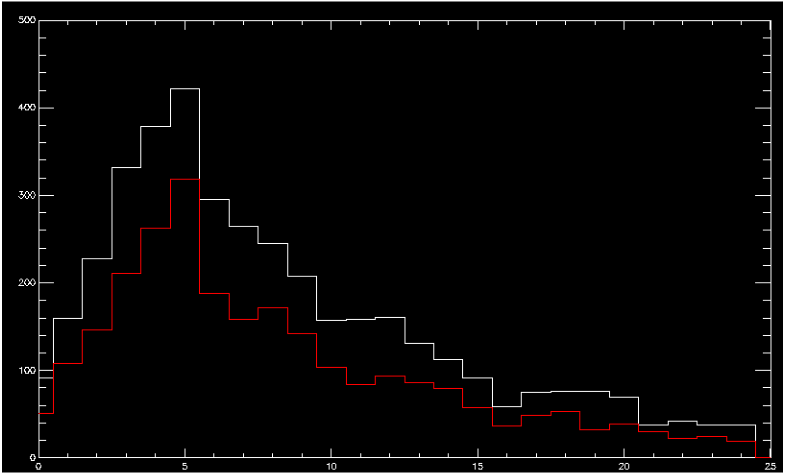

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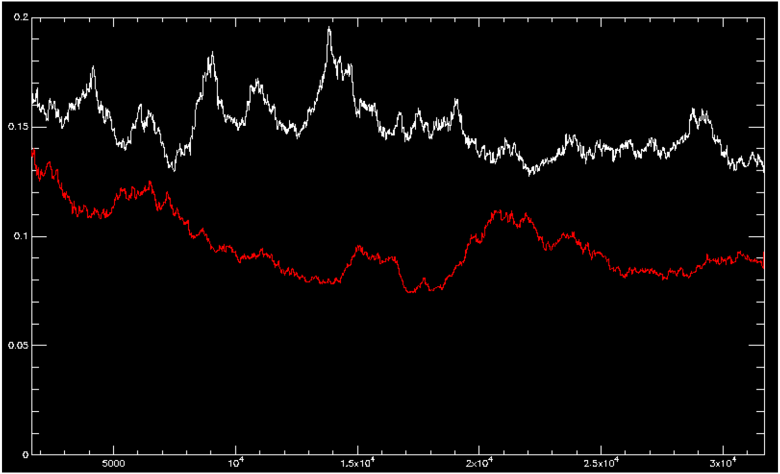
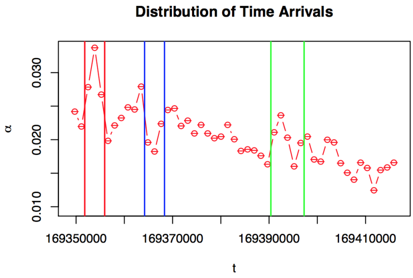
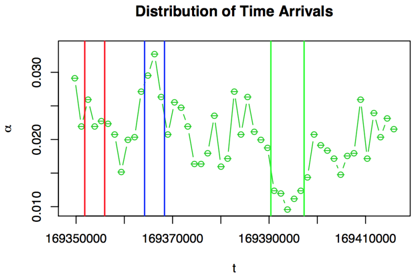


Using time-arrival?





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$$\begin{aligned} p(z_i = s | x_i, y_i, t_i = t) &\propto p(x_i, y_i, t_i = t | z_i = s) p(z_i = s) \\ &= p(x_i, y_i | z_i = s) p(t_i = t | z_i = s) p(z_i = s) \end{aligned}$$

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\end{aligned}
$$

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

A Simple Time Model

Model the time-arrival as piece-wise constant. For each source (s):

- n_s: number of photons from source s
- Break time into K bins (fixed)
- ... at fixed locations $(b_0, b_1, ..., b_K)$
- $n_{s1}, n_{s2}, ..., n_{sK}$: photon counts in each bin.
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$$(\alpha_{s1}, ..., \alpha_{sK})|n_s \sim Dir(n_{s1} + \tilde{\alpha}_s, n_{s2} + \tilde{\alpha}_s, ..., n_{sK} + \tilde{\alpha}_s)$$

- Time arrival parameters: $(\alpha_{s1}, ..., \alpha_{sK})$, for $s = 1, .., S$
- Prior on arrival dist: α_s, for $s = 1, .., S$

A Simple Time Model

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- $p(z_i = s | t_i = t)$?

We'll assign the probabilities as follows, for each photon:

- Find k such that $b_{k-1} < t_i < b_k$
- Assign the probabilities

$$p(z_i = 1 | t_i = t) = \frac{\alpha_{1k}}{\sum_{s=1}^{S} \alpha_{sk}}$$
$$p(z_i = 1 | t_i = t) = \frac{\alpha_{2k}}{\sum_{s=1}^{S} \alpha_{sk}}$$
$$\vdots$$
$$p(z_i = S | t_i = t) = \frac{\alpha_{Sk}}{\sum_{s=1}^{S} \alpha_{sk}}$$

Simulated Data

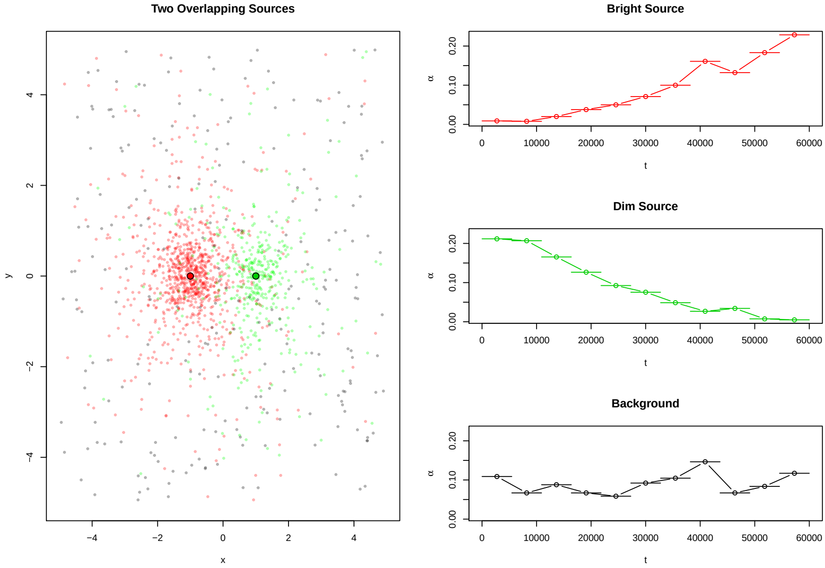
We want to first study a few simple things:

1. If we incorporate time, will we do better than not incorporating?
2. If (1), at what point do our gains fall apart?
3. A simple example for (2), how does the distance between the sources affect out ability to distinguish them?

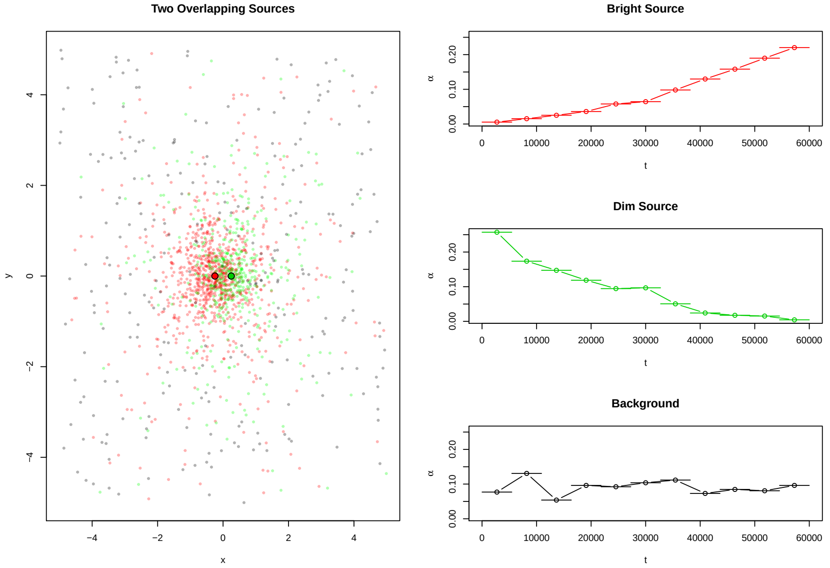
Simulation:

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

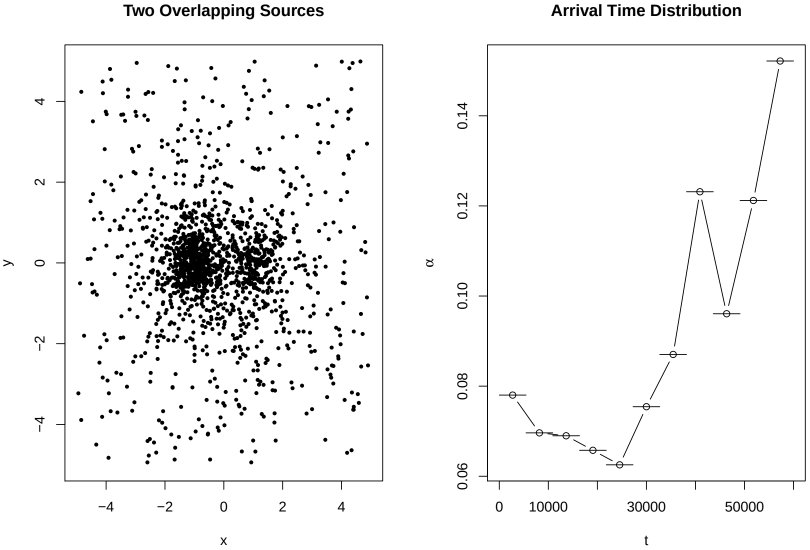
Simulated Data (separation = 2)



Simulated Data (separation = 0.5)



What we have to work with (separation = 2)



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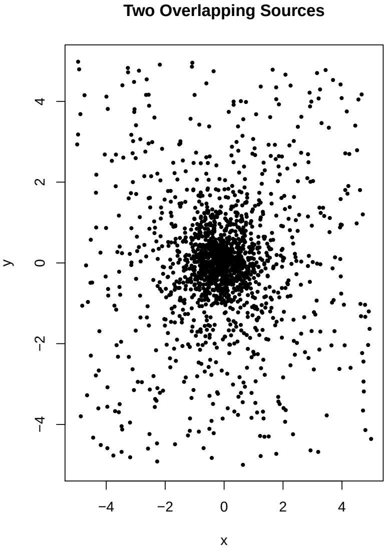
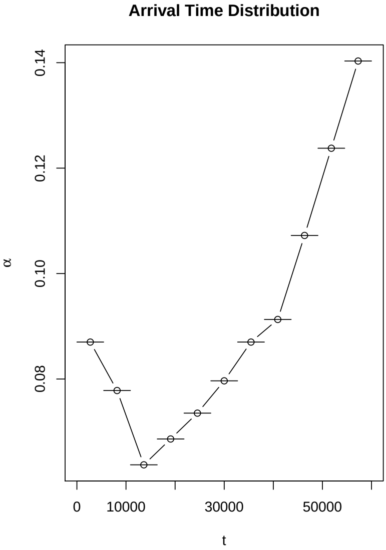
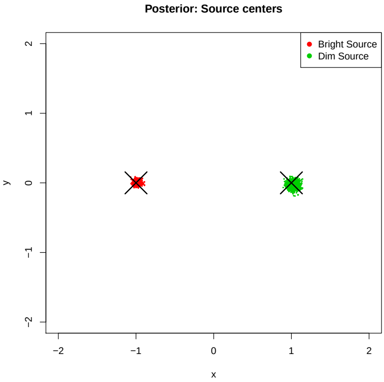
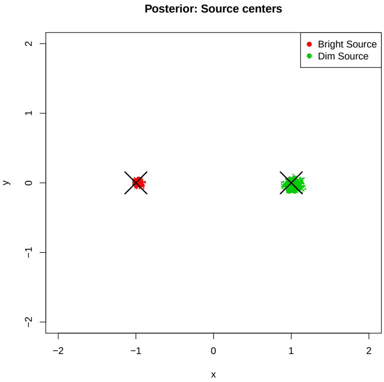




Source Location (separation = 2)

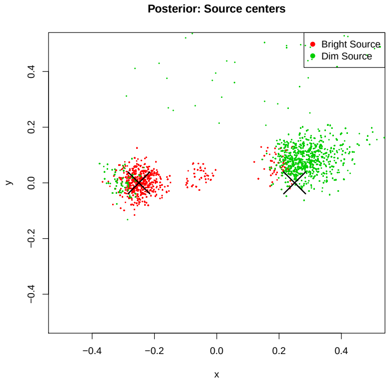


(a) Location and Time Model

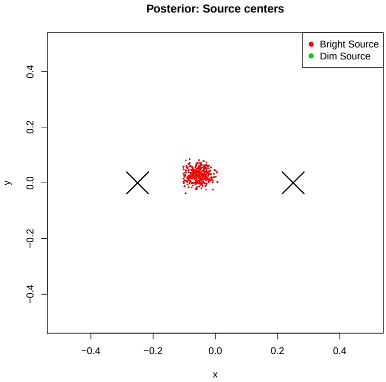


(b) Location Only Model

Source Location (separation = 0.5)

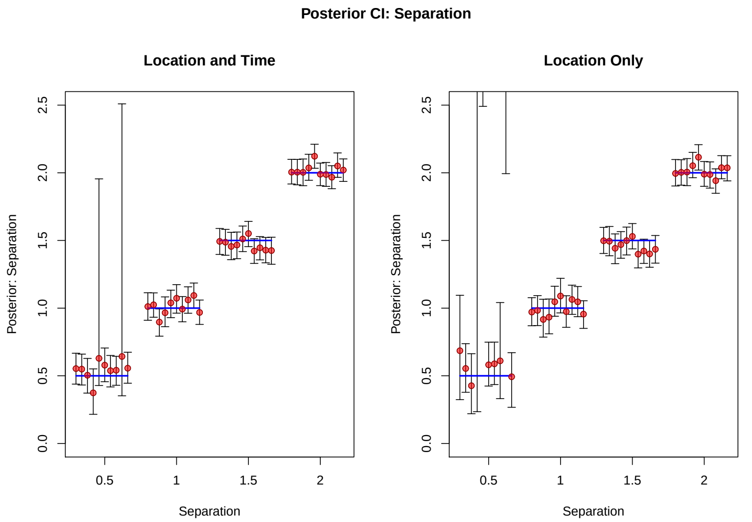


(c) Location and Time Model

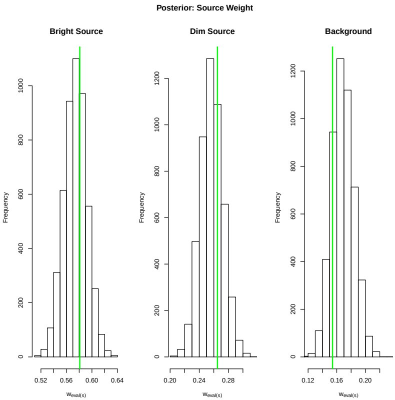


(d) Location Only Model

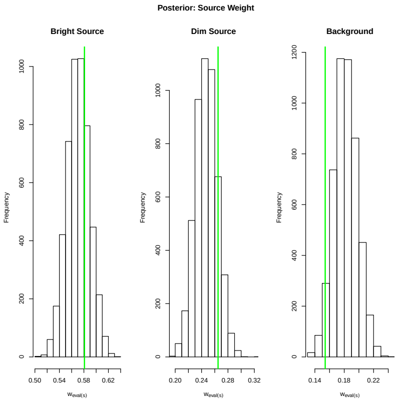
Source Separation (with replicates)



Source Intensity (separation = 2)

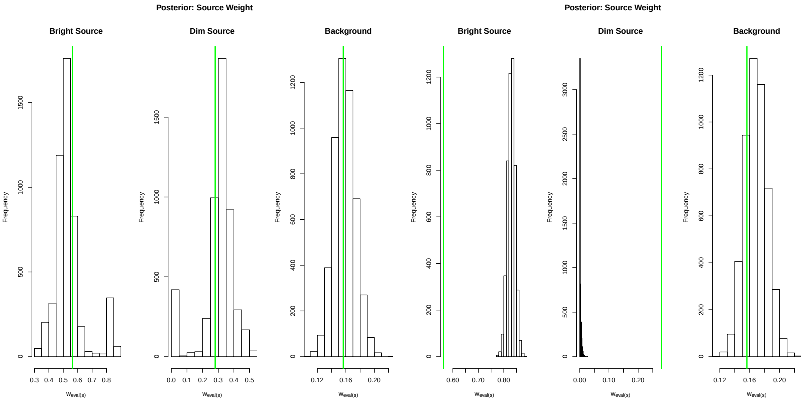


(e) Location and Time Model



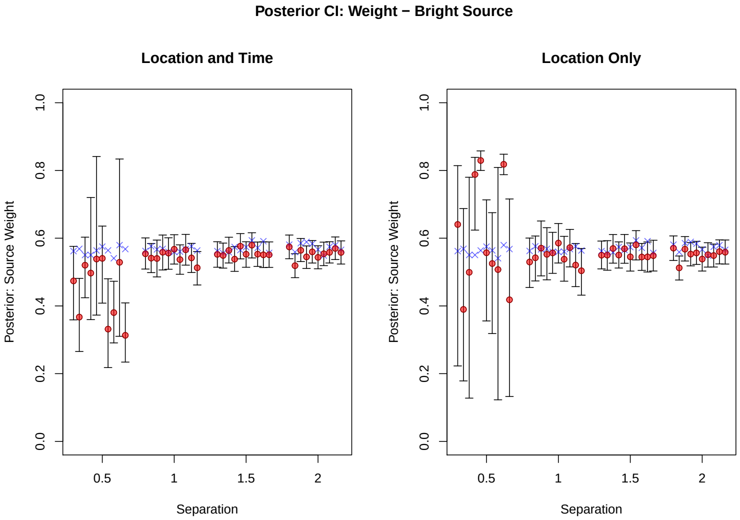
(f) Location Only Model

Source Intensity (separation = 0.5)

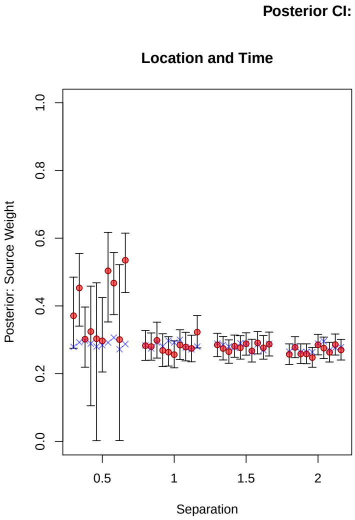


(g) Location and Time Model (h) Location Only Model

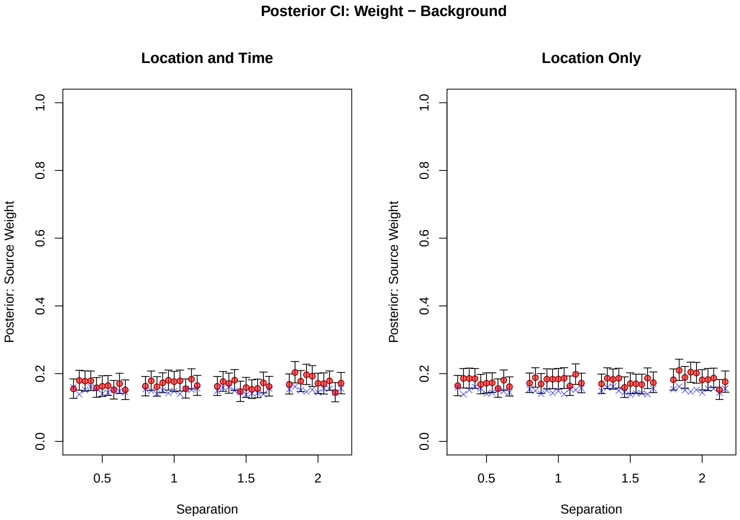
Source Intensity: Bright Source (with replicates)



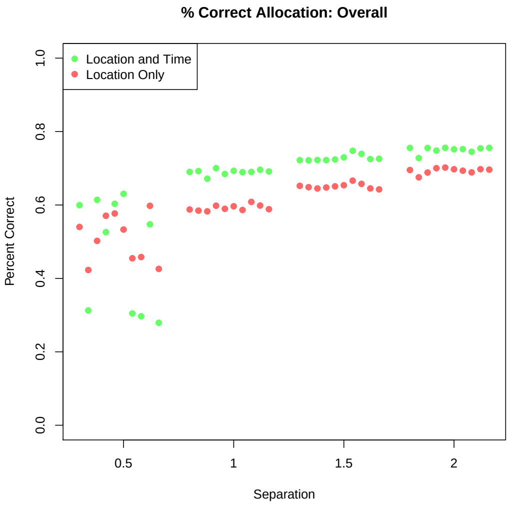
Source Intensity: Dim Source (with replicates)



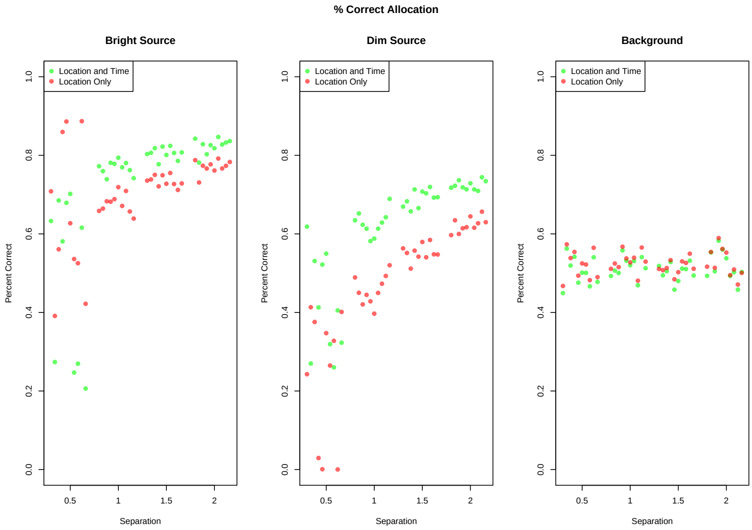
Source Intensity: Background (with replicates)



Average Correct Source Allocation (with replicates)



Average Correct Source Allocation by Source (with replicates)



Where do we go from here?

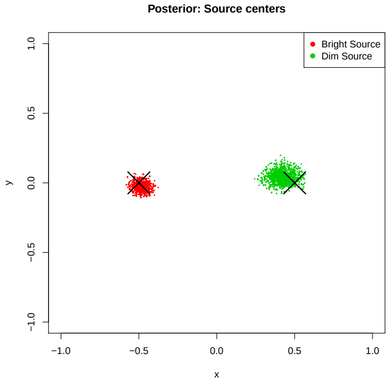
What we've done:

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

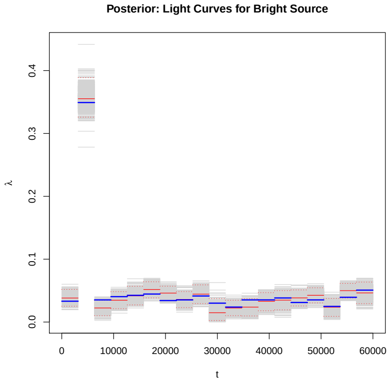
Future directions:

- Real light curve shapes (mine were too simple)
- More complex time models?
  - vary cut-offs per source
  - more comlex models per source

Light Curves with Spikes (Seperation = 1)



(i) Source Centers



(j) Light Curve Posterior (bright)

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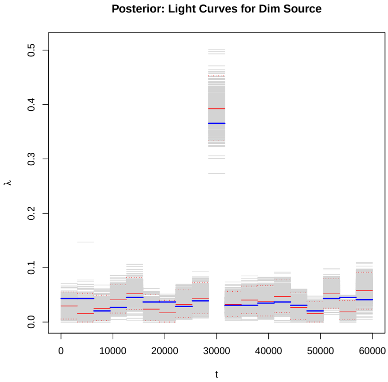
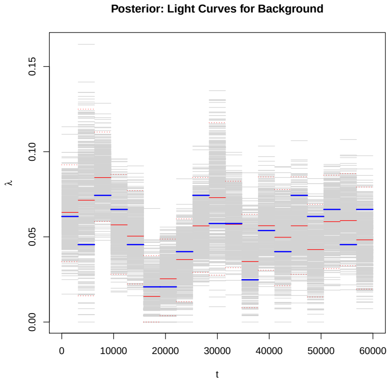
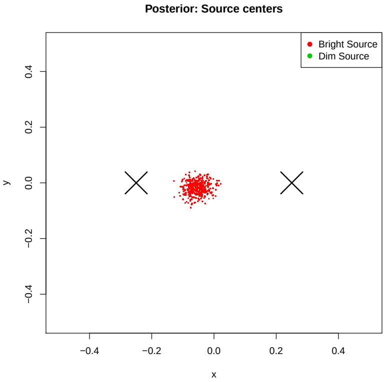


(k) Light Curve Posterior (dim)

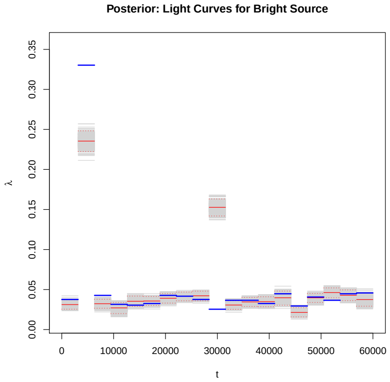


(l) Light Curve Posterior (bg)

Light Curves with Spikes (Seperation = 0.5)



(m) Source Centers



(n) Light Curve Posterior