How the Statistical Analysis of Magnetic Structures Will Help Us Usher a New Generation of Solar Cycle Predictions

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NSF REU program

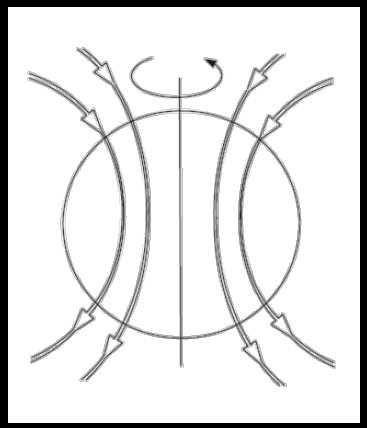
Solar Cycle Propagation and Prediction

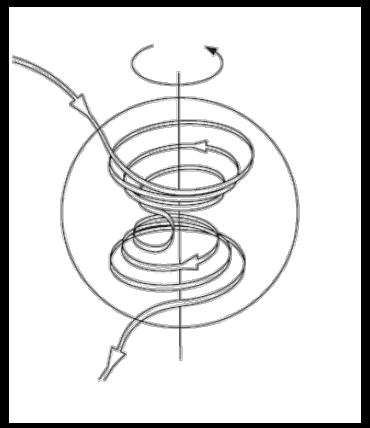
Muñoz-Jaramillo et al. ApJL & PRL (2013)

Poloidal
r - θ

Differential Rotation →

Toroidal
ϕ





Credit: J. J. Love

Polar Fields

Sunspot Numbers/Area

Solar Cycle Propagation and Prediction

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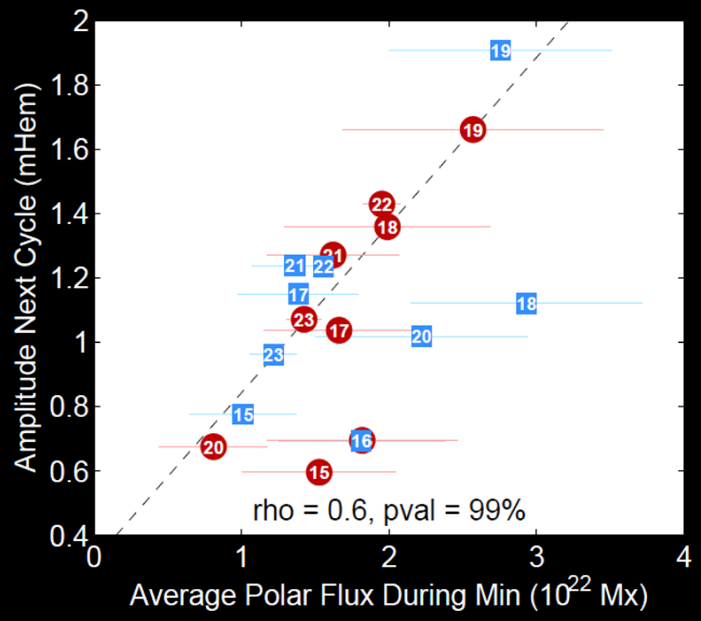
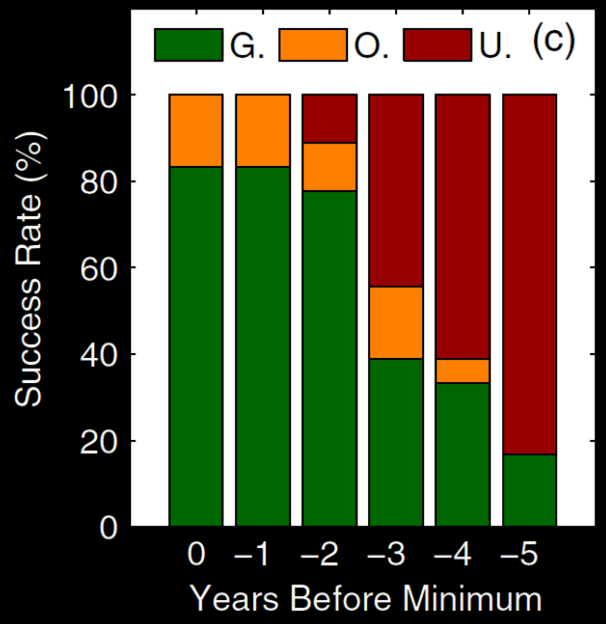
Poloidal $r - \theta$ $\xrightarrow{\text{Differential Rotation}}$ Toroidal ϕ





Predictions based on the polar fields are successful only within two years of solar minimum.

Solar Cycle Propagation and Prediction

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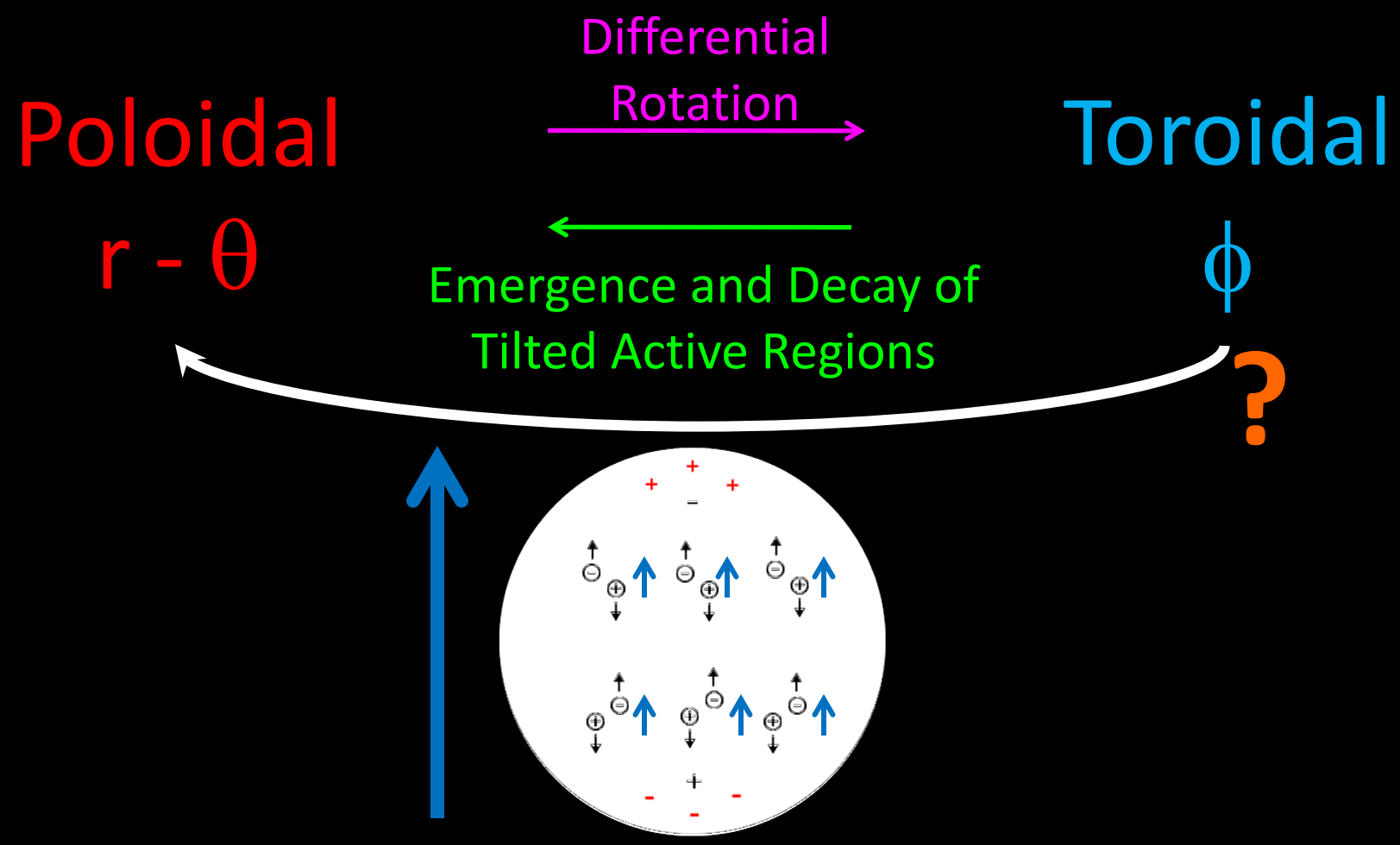

Solar Cycle Propagation and Prediction

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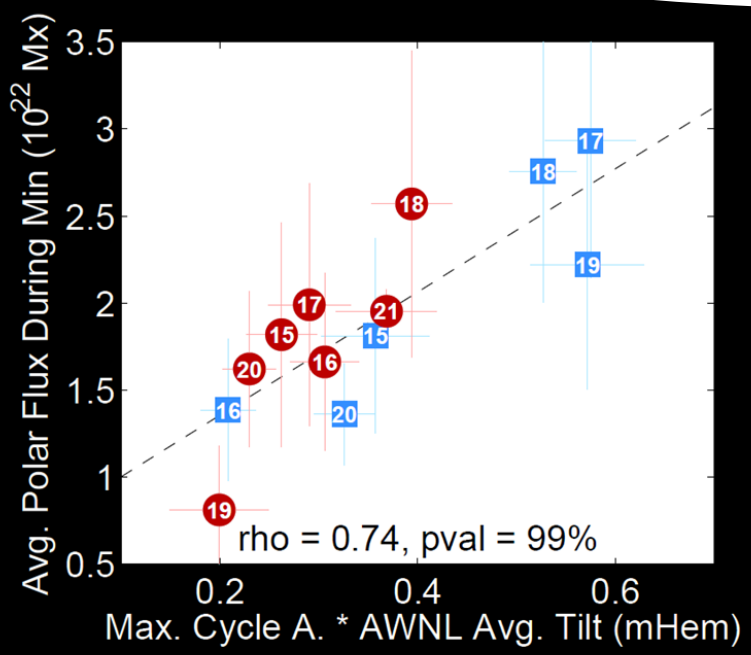
Poloidal $r - \theta$ $\xrightarrow{\text{Differential Rotation}}$ Toroidal ϕ

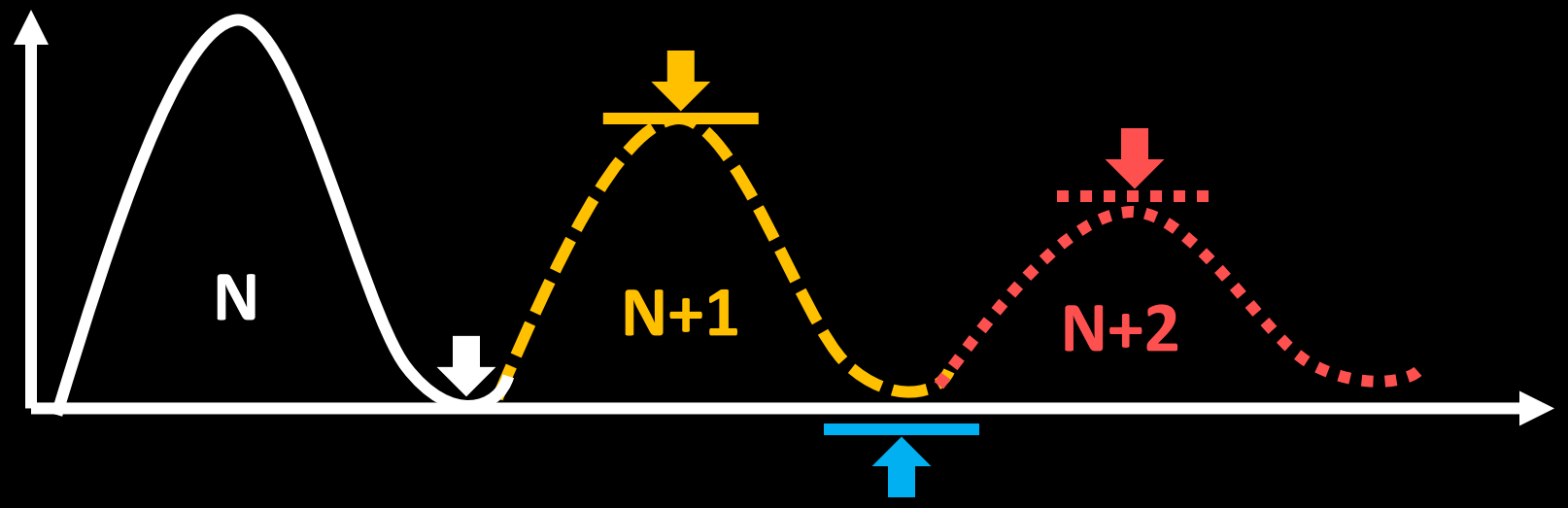
$\longleftarrow$ Emergence and Decay of Tilted Active Regions

?



- This is a stochastic process.
- Both flux and tilt are necessary to obtain a correlation between toroidal and poloidal proxies.

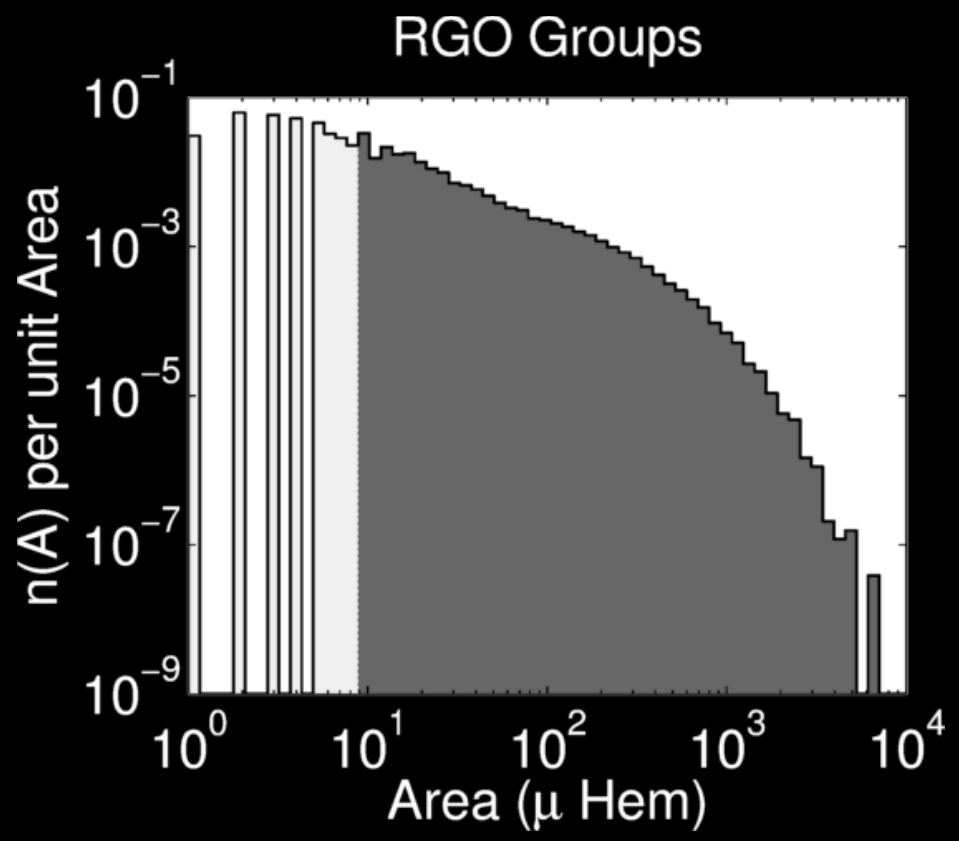
How to enhance cycle prediction using statistics?



- Using polar flux at the end of cycle N, you can predict what the amplitude of cycle N+1 is going to be.
- Using only this information can we predict what polar flux at the minimum of cycle N+1 is going to be (and predict N+2)?
- We need to create many representative synthetic sets of active regions to be used as input for simulations.

Size-Flux distribution. How many of each flux/size?

Muñoz-Jaramillo et al. ApJ, in press (2014)



- This characterization has been revisited 15 times in the last 30 years with inconclusive results (different studies fit data using different distributions)

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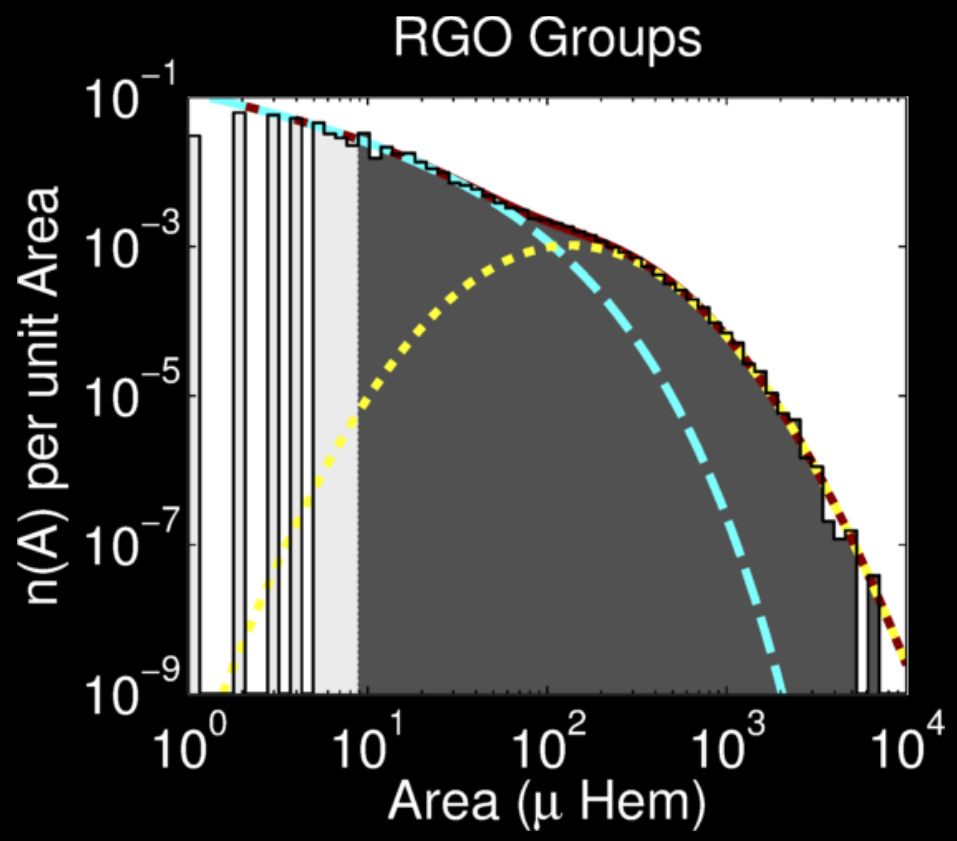

- We find that a combination of Weibull and Log-normal distributions fits the data best.

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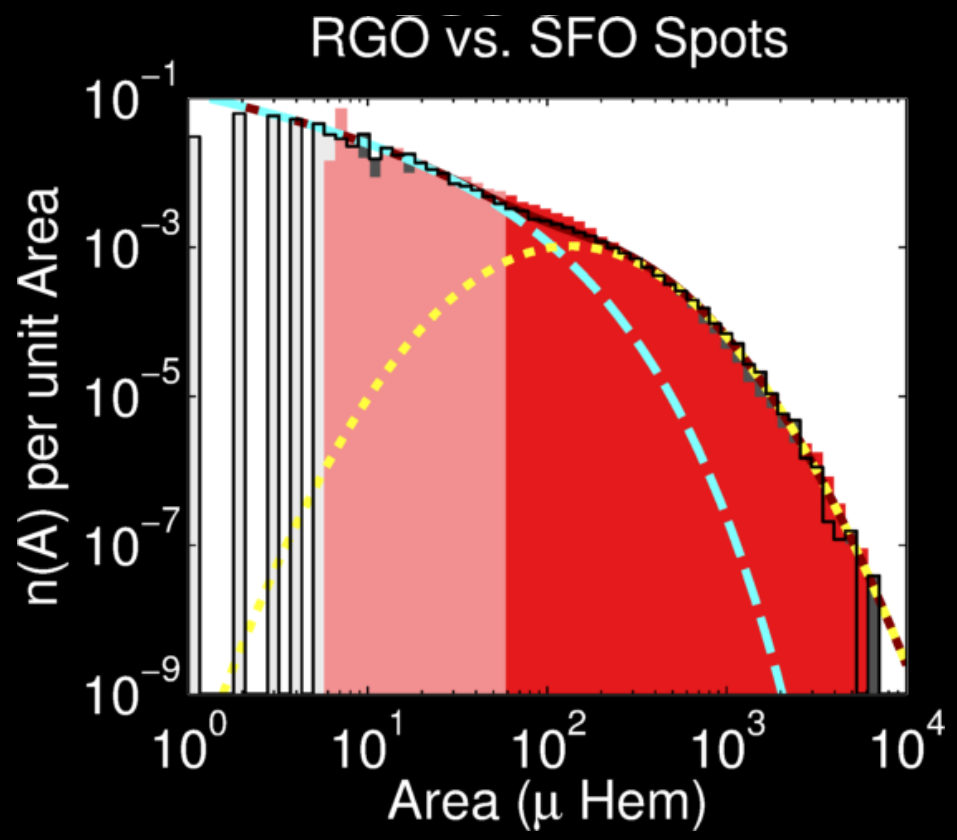

- All our databases can be made consistent by using a proportionality constant. Conflicting results arise from different data types sampling different part of this distribution.

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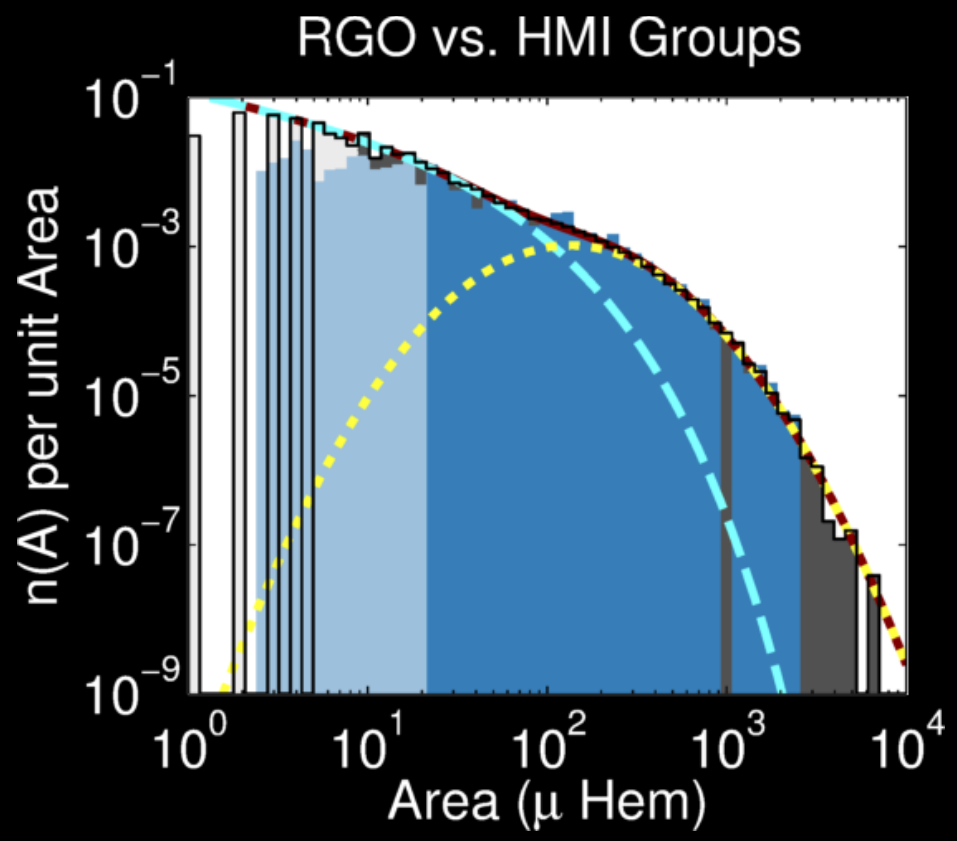

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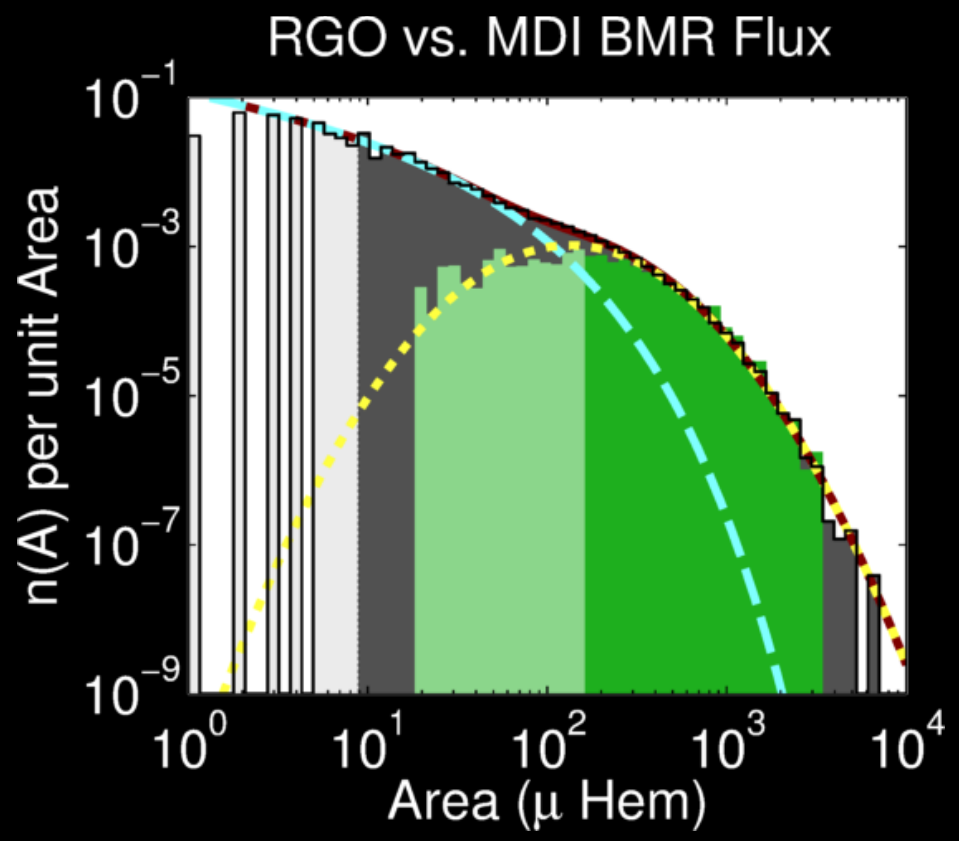

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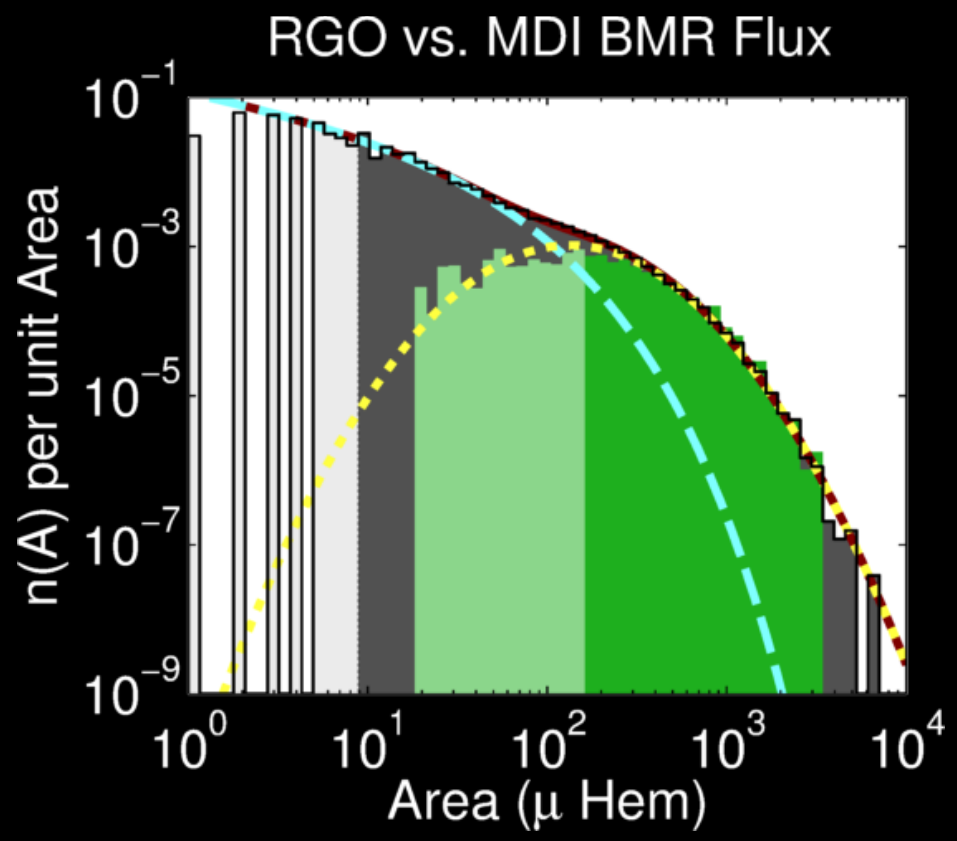


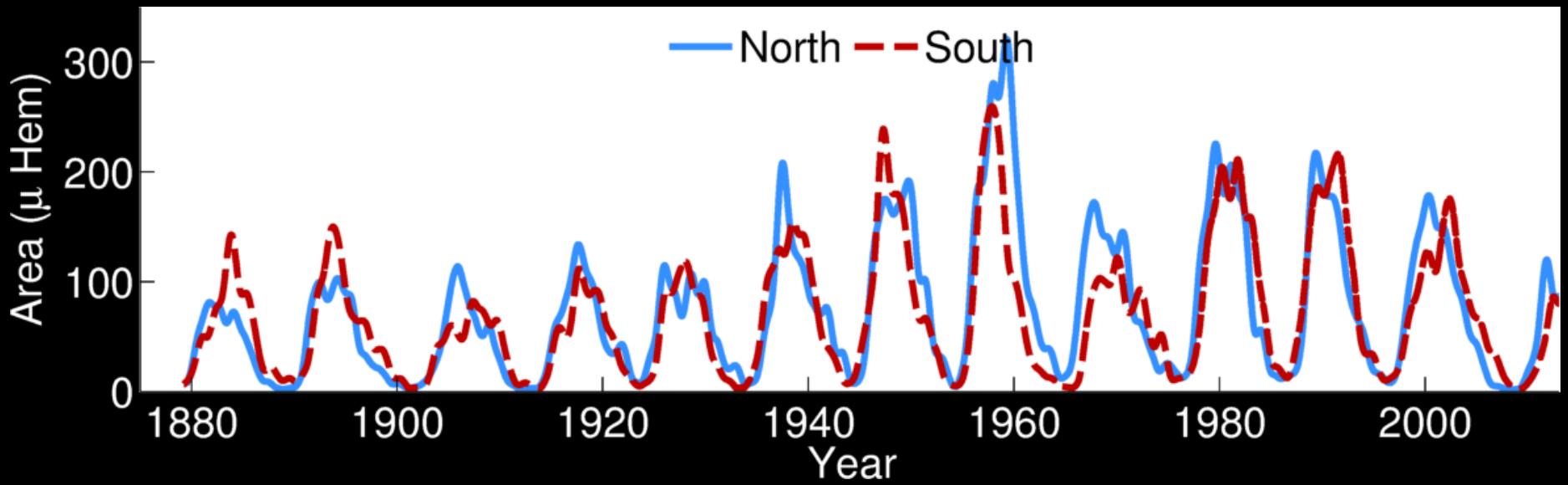
- Our results suggest that photospheric magnetic structures arise from two different mechanisms (global vs. small-scale components of the dynamo).

WHAT ABOUT CYCLE DEPENDENCE?

Muñoz-Jaramillo et al., *in Preparation*, 2014

Activity Level: A New Way of Binning Data

Muñoz-Jaramillo et al. in preparation(2014)

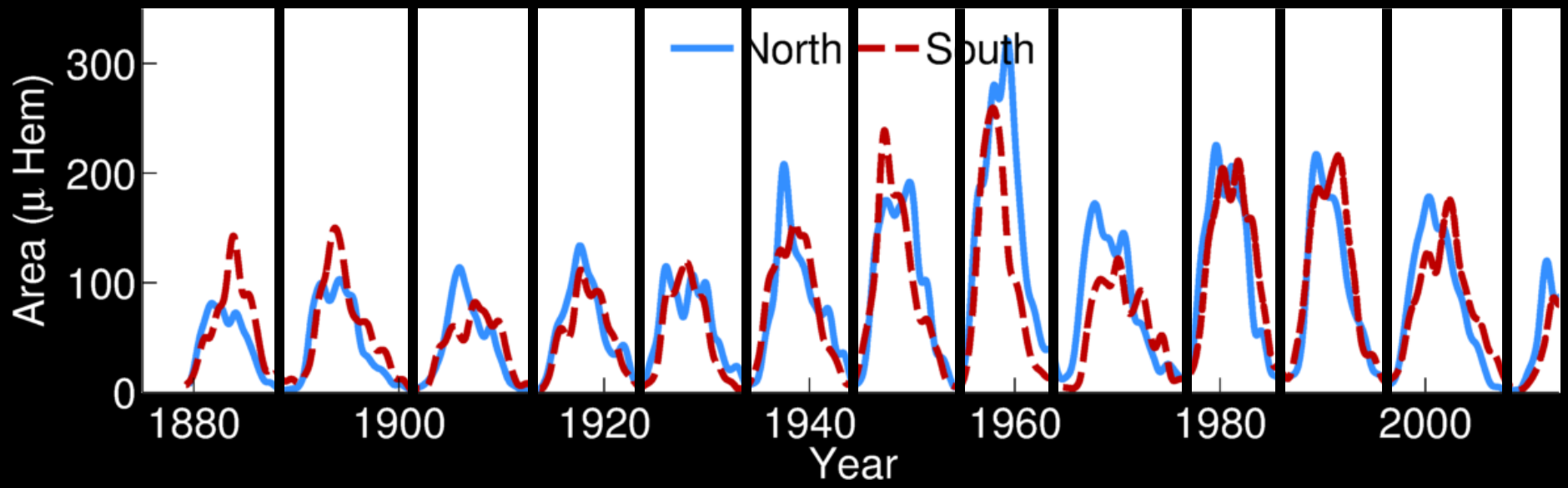


- Cycle evolution of active regions and sunspots is normally done by comparing separate cycles or phases (minimum vs. maximum).

- This approach is conceptually incorrect. Why?

Activity Level: A New Way of Binning Data

Muñoz-Jaramillo et al. in preparation(2014)



- **The lifetime of an active region is but an instant compared with the cycle.**
- **Assumption: The global properties of a cycle are irrelevant for determining the properties of active regions. Only activity level is important.**

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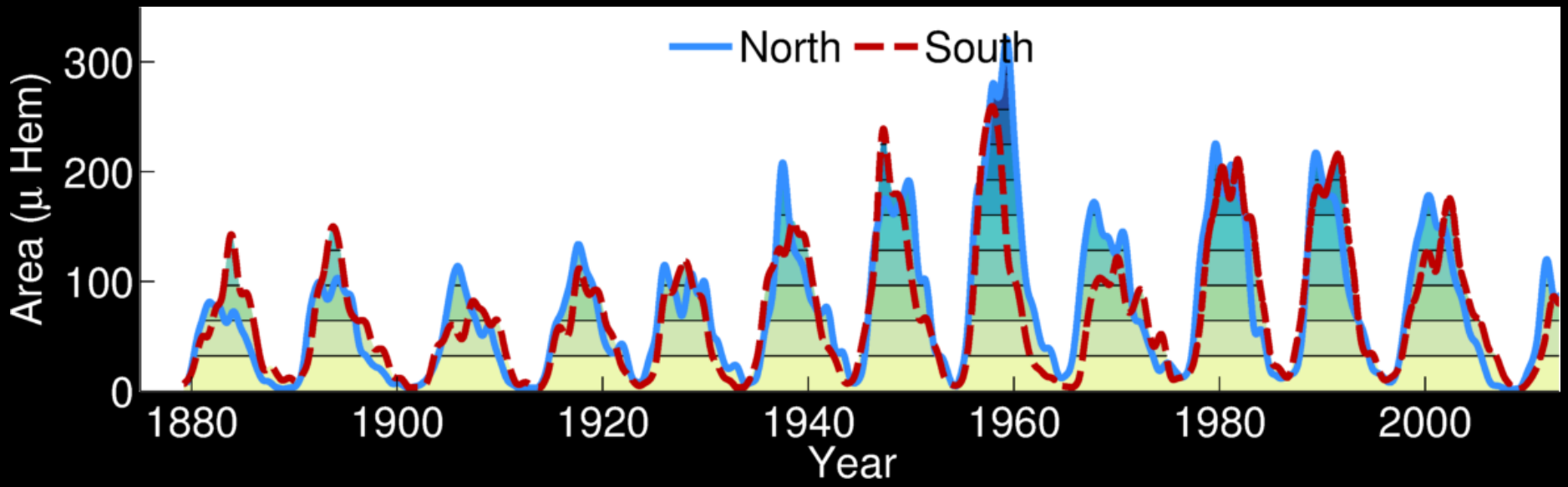

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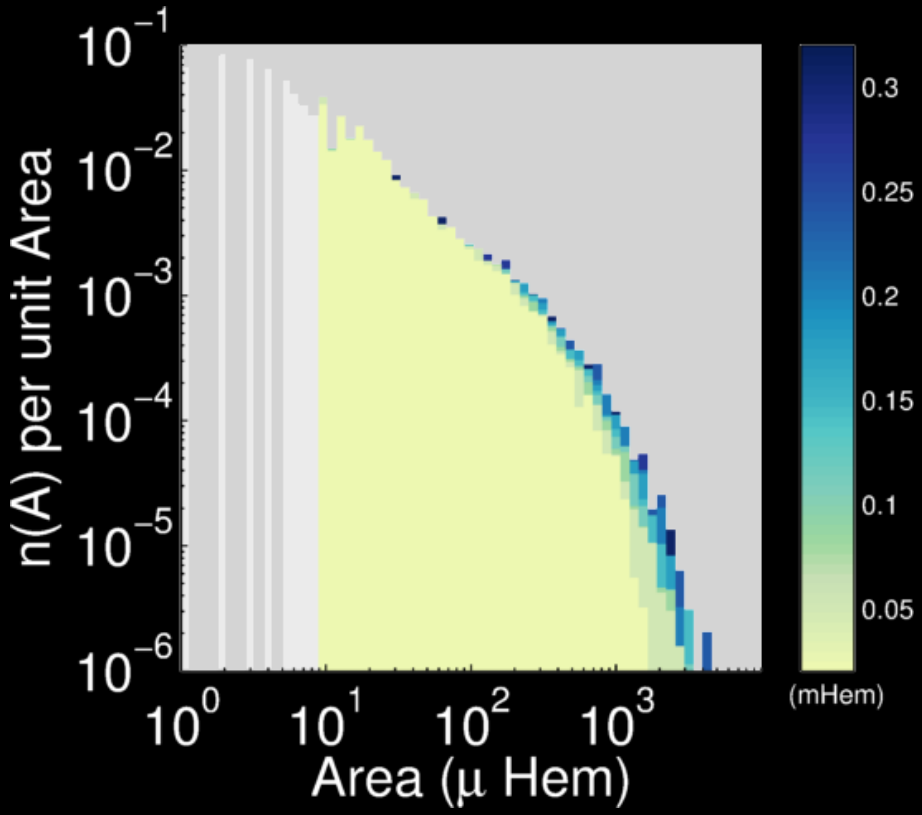
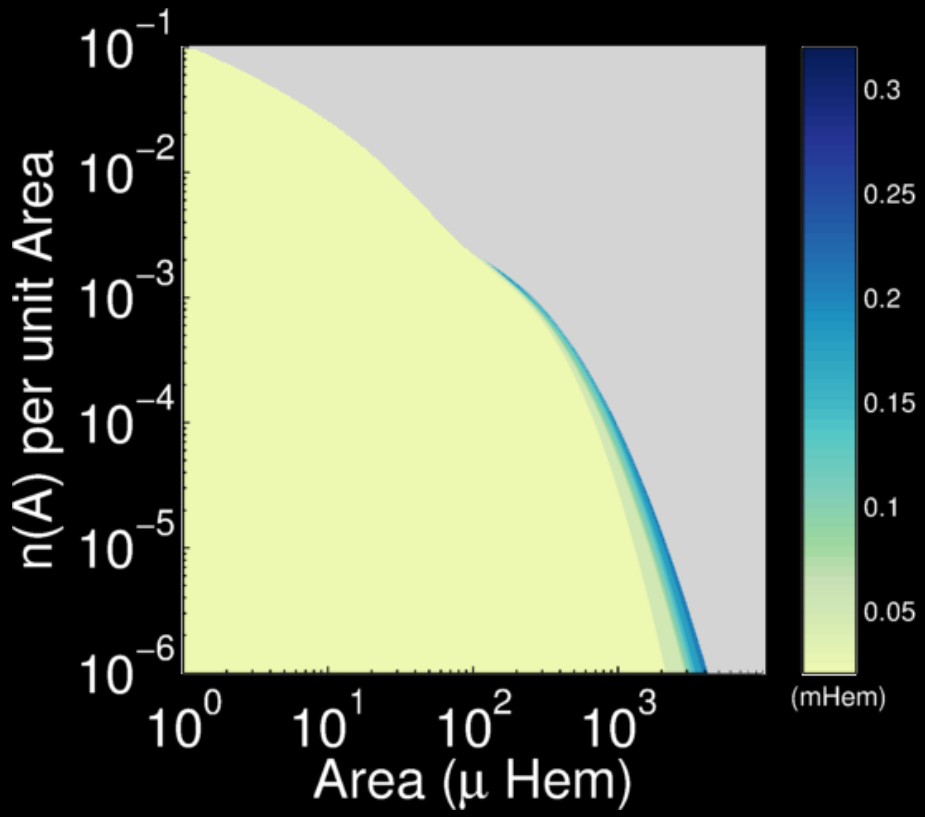
Activity Level and the size-flux distribution function

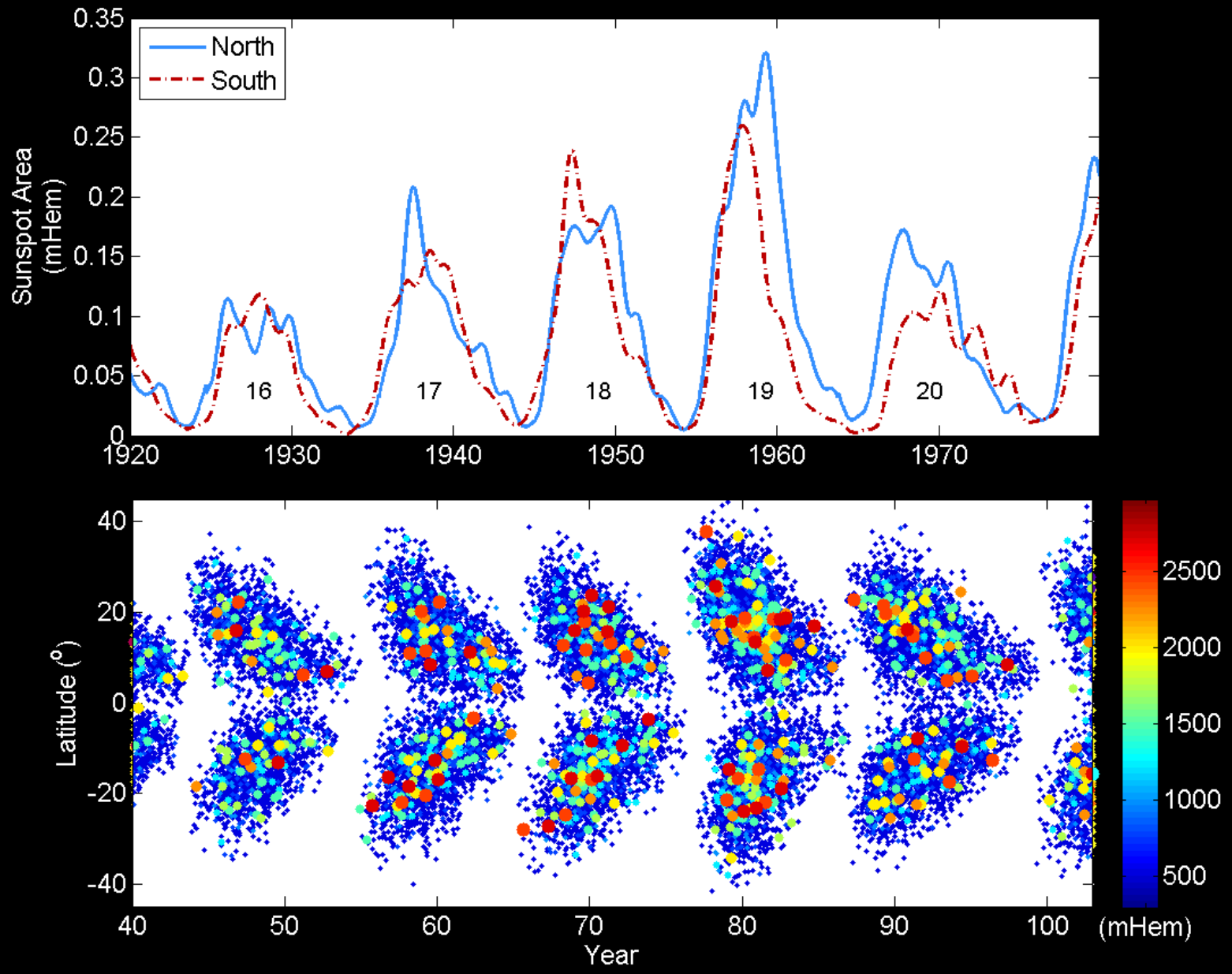
Muñoz-Jaramillo et al. in preparation(2014)





- **We can use established relationships between cycle phase and amplitude, and the shape of the butterfly diagram to create synthetic sets.**

Synthetic vs. Observed Cycles



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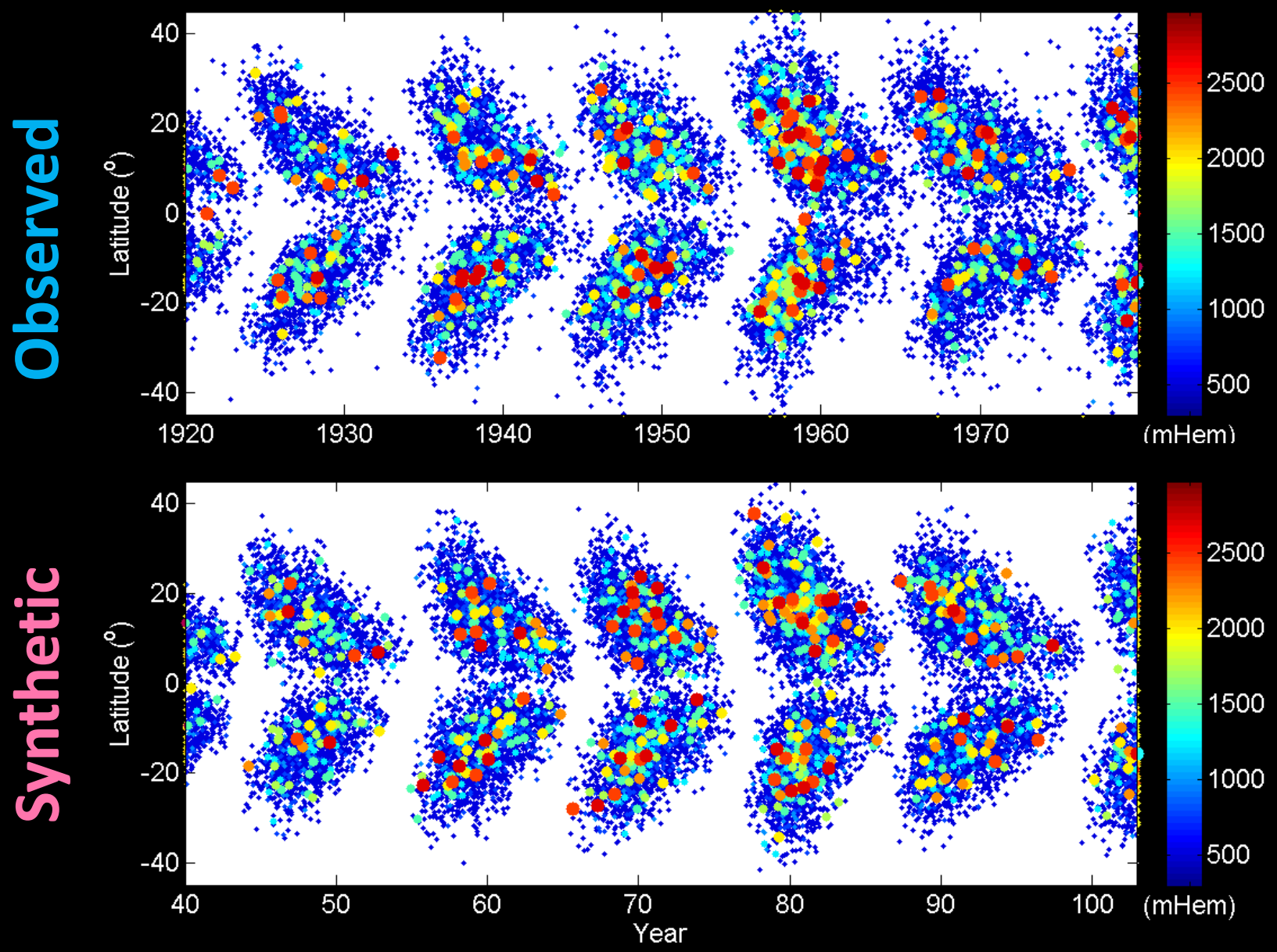


Concluding Remarks

- Cycle prediction based on the polar fields is effective only within 2 years of solar minimum.
- We need to understand the statistical properties of bipolar active regions (tilt and flux) in order to develop next generation predictions.
- The solar size-flux distribution is a composite of Weibull and log-normal distributions. A very simple modulation of its parameters captures cycle dependence.
- Analysis of tilt, and model assimilation of synthetic sets are still pending. However, initial results show great promise.

EXTRA SLIDES

Our Data

- Sunspot Group Area:
  - Royal Greenwich Observatory (RGO). 1874 - 1976.
  - Solar Observing Optical Network (SOON). 1985 - present.
  - Pulkovo's catalogue of solar activity (PCSA). 1938 - 1991.
  - Kislovodsk Mountain Astronomical Station (KMAS). 1954 - present.
  - SDO/HMI. 2010 - present.
- Sunspot Area:
  - SOHO/MDI. 1996 - 2010.
  - SDO/HMI. 2010 - present.
  - San Fernando Observatory (SFO). 1983 - present.
- Bipolar Magnetic Region Flux:
  - KPVT. 1976 - 1986.
  - SOHO/MDI. 1996 - 2010.
  - KPVT/SOLIS. 1996 - present.

Which distribution to use?

Power Law

$$f(x\,|\,\alpha) = \frac{\alpha - 1}{x_{\min}}\left(\frac{x}{x_{\min}}\right)^{\alpha}$$

Zharkov et al. (2005)
Meunier (2003)
Parnell et al. (2009)

Log-Normal

$$f(x\,|\,\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}}e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$$

Bogdan et al. (1988)
Baumann & Solanki (2005)
Zhang et al. (2010)
Schad & Penn (2010)

Weibull

$$f(x\,|\,k,\lambda) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^{k}}$$

Parnell (2002)

Exponential

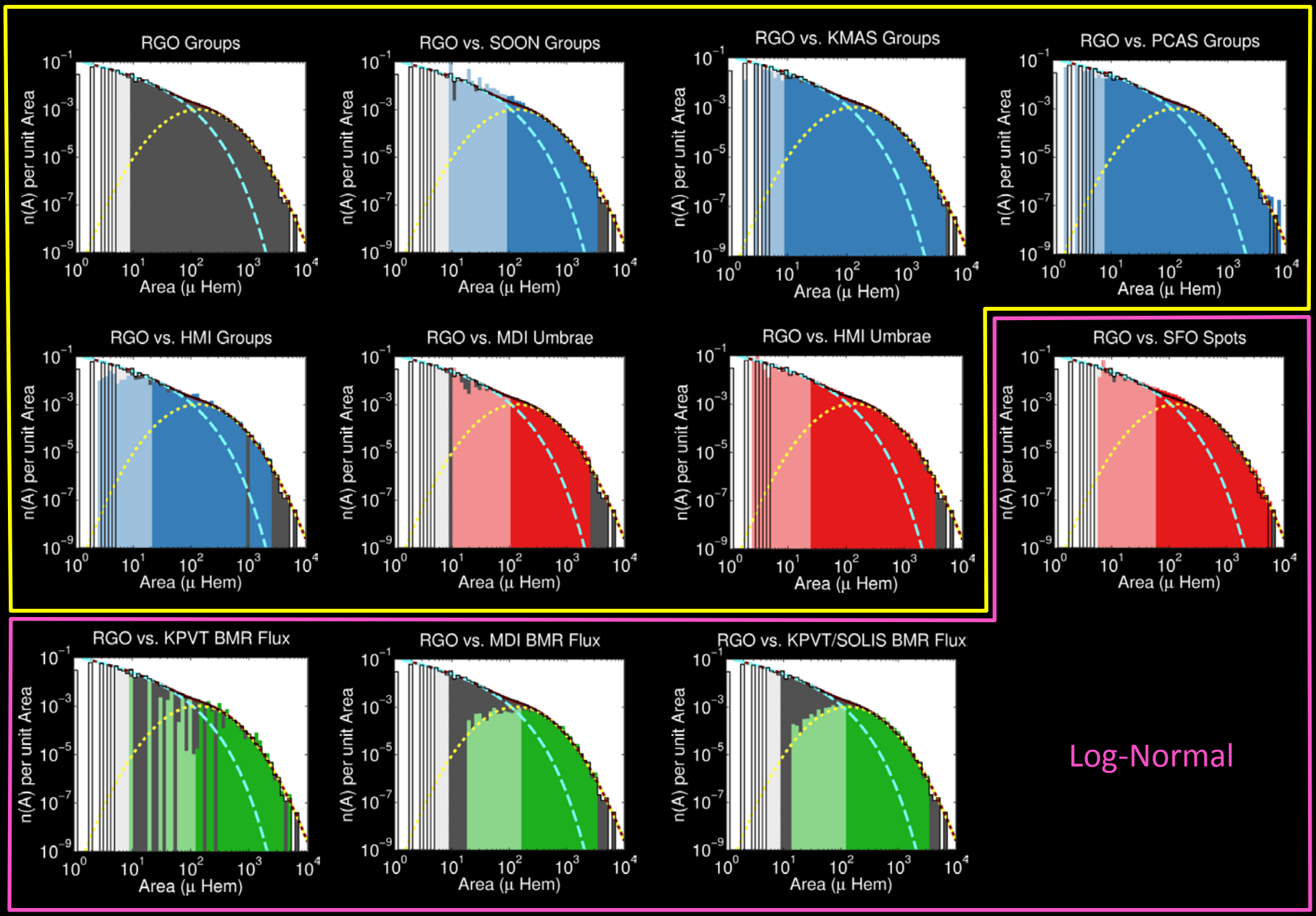
$$f(x\,|\,\lambda) = \frac{k}{\lambda}e^{-\left(\frac{x}{\lambda}\right)}$$

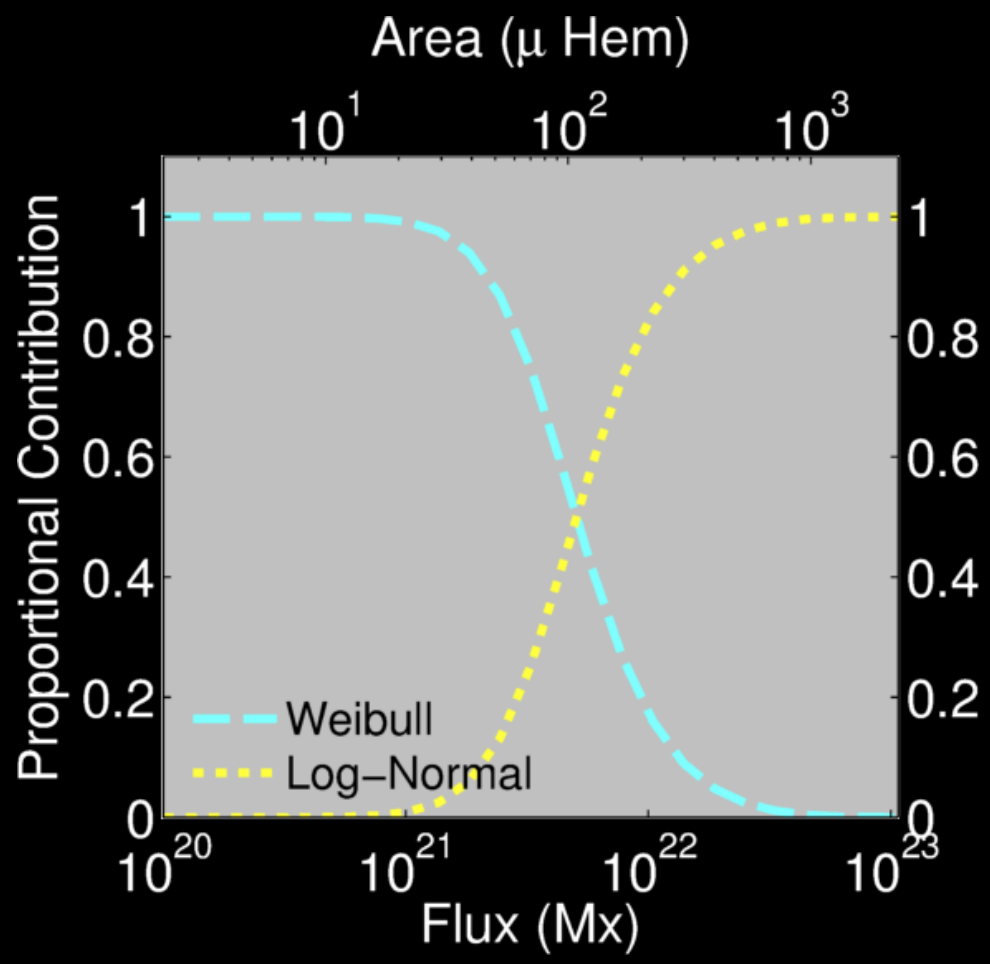
Tang et al. (1984)
Schrijver et al. (1997)

Composite Distributions

Kuklin (1980) Harvey & Zwaan (1993) Jiang et al. (2011) Nagovitsyn et al. (2012)

Weibull



Log-Normal

Transition between distributions