

# Invisible sunspots and implications for the monitoring of Solar Active Regions

Silvia Dalla<sup>(1)</sup>, Lyndsay Fletcher<sup>(2)</sup> and Nicholas Walton<sup>(3)</sup>

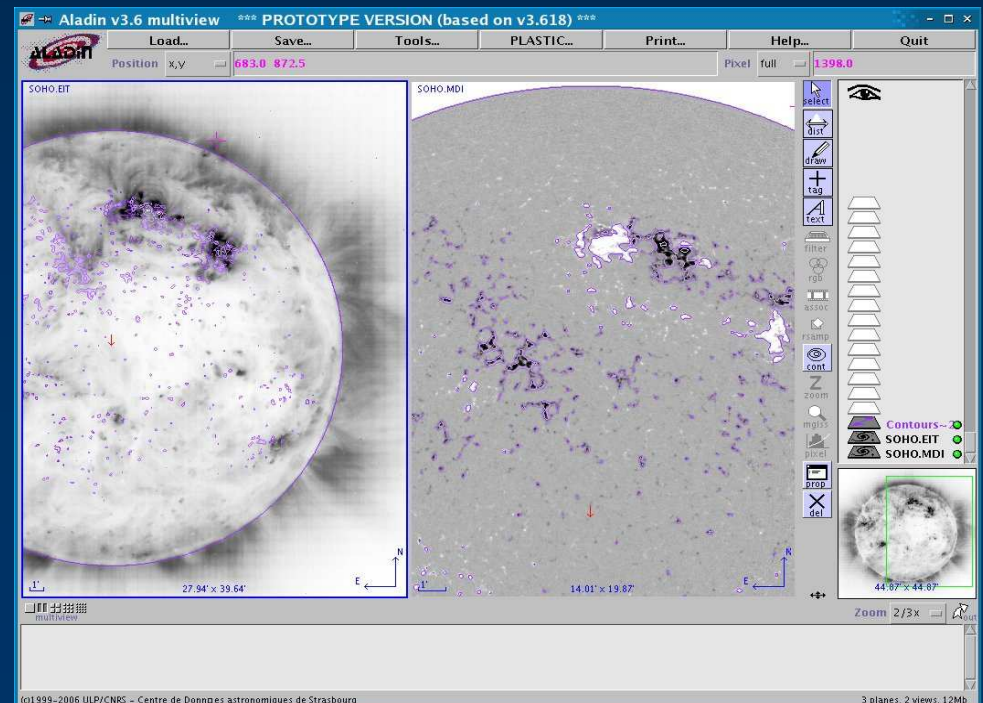
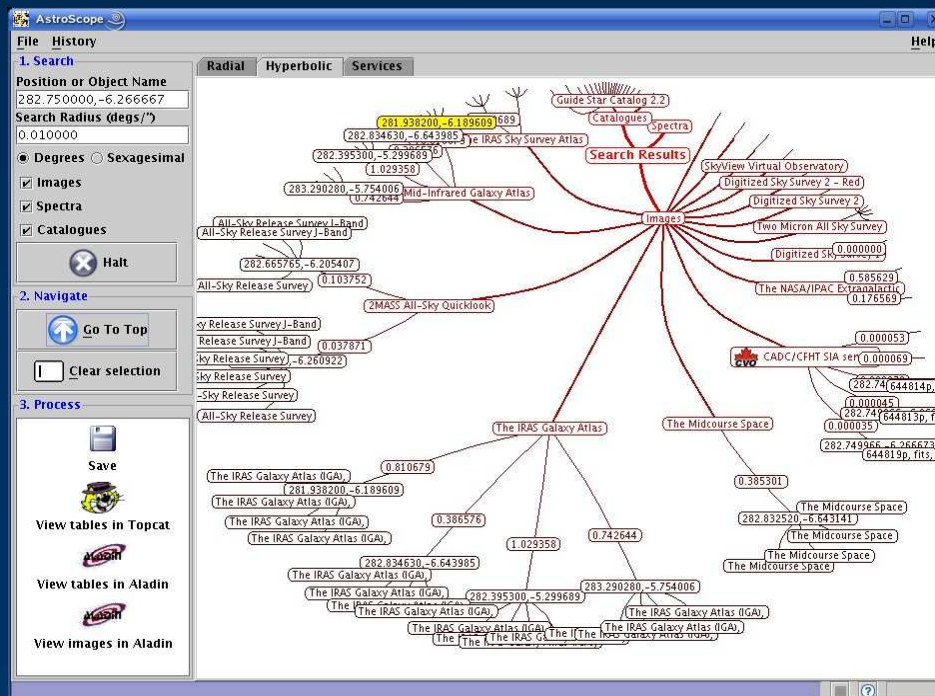
<sup>(1)</sup> Centre for Astrophysics,  
University of Central Lancashire, Preston, UK

<sup>(2)</sup> Dept of Physics and Astronomy, University of Glasgow, UK

<sup>(3)</sup> Institute of Astronomy, University of Cambridge, UK

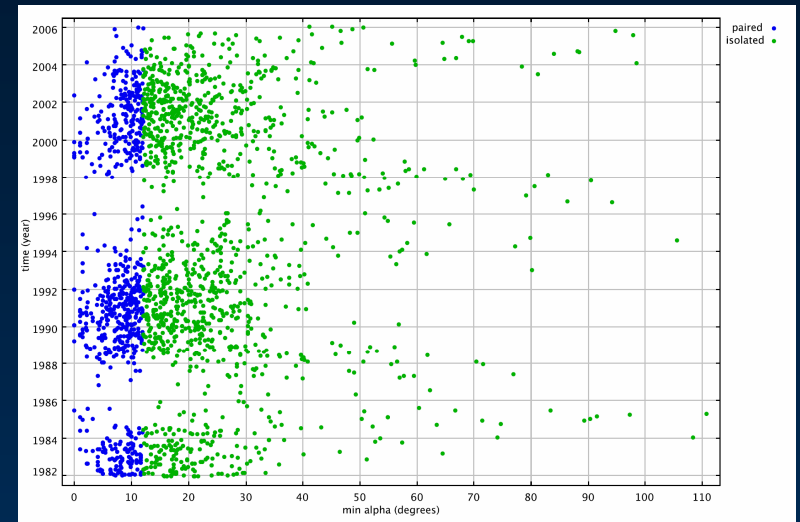
# AstroGrid study of region emergence and flare productivity

- AstroGrid – UK Virtual Observatory project – [www.astrogrid.org](http://www.astrogrid.org)
- Making integration and comparison of data from diverse sources transparent
- Enabling access and manipulation of large datasets and catalogues



# Flare productivity of newly emerged paired/isolated Active Regions

- Use workflows to cross match catalogues of solar active regions and flares, to answer the question: Does emergence of a new region near another one increase flare productivity?
- AstroGrid workflows analysing USAF/Mt Wilson + GOES data: only small increase in flare productivity for paired regions (Dalla et al A&A 468, 1103, 2007)



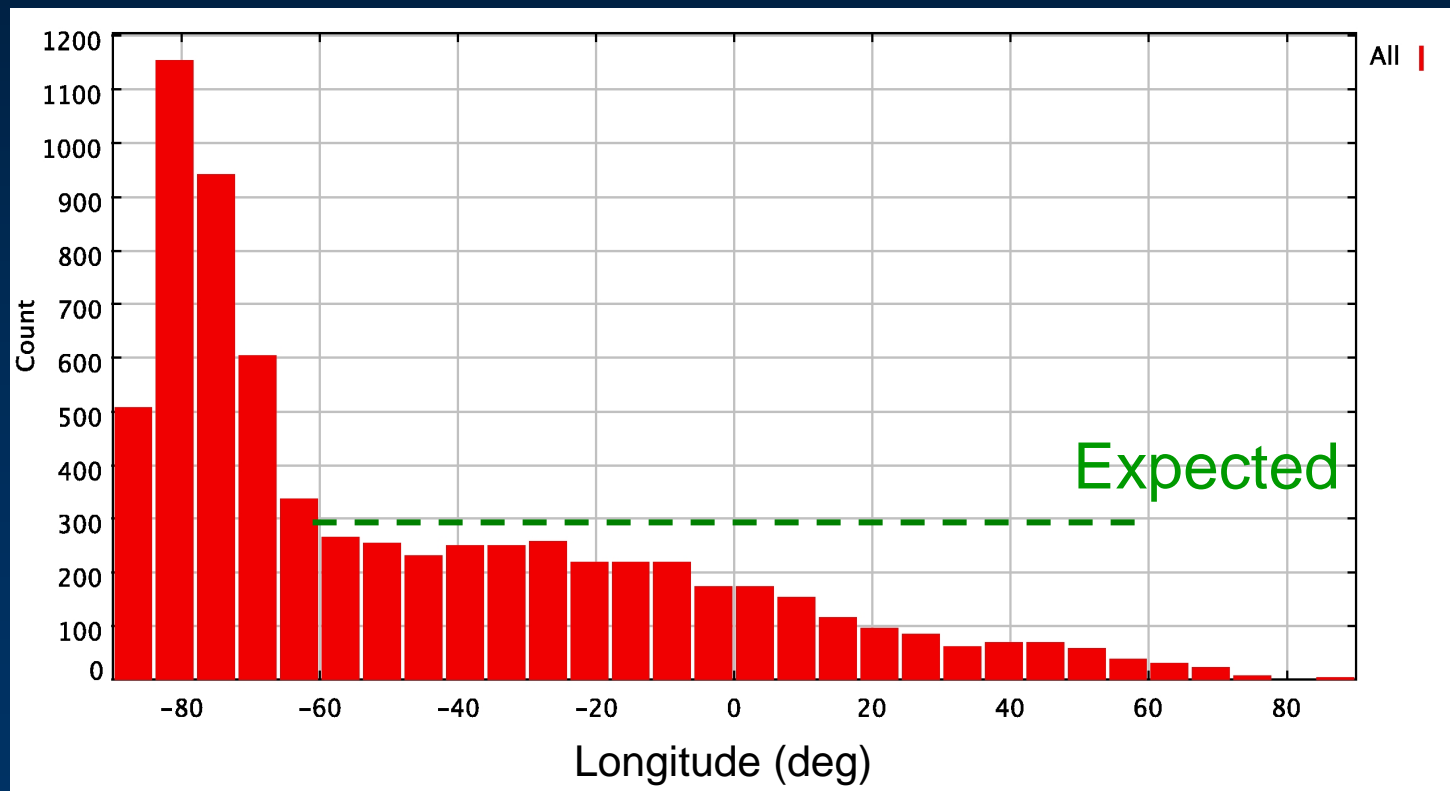
Subset	n of regions	$P$ (%)	$F$ (flares/4 days)
NERs	2115	$21.7 \pm 1.0$	$0.639 \pm 0.017$
NERs paired	675	$24.3 \pm 1.9$	$0.696 \pm 0.032$
NERs isolated	1440	$20.5 \pm 1.1$	$0.613 \pm 0.020$
companions	676	$39.3 \pm 2.4$	$1.745 \pm 0.051$
old regions	1516	$39.7 \pm 1.6$	$1.689 \pm 0.033$

$P$  = % of regions with flares

$F$  = mean flare number

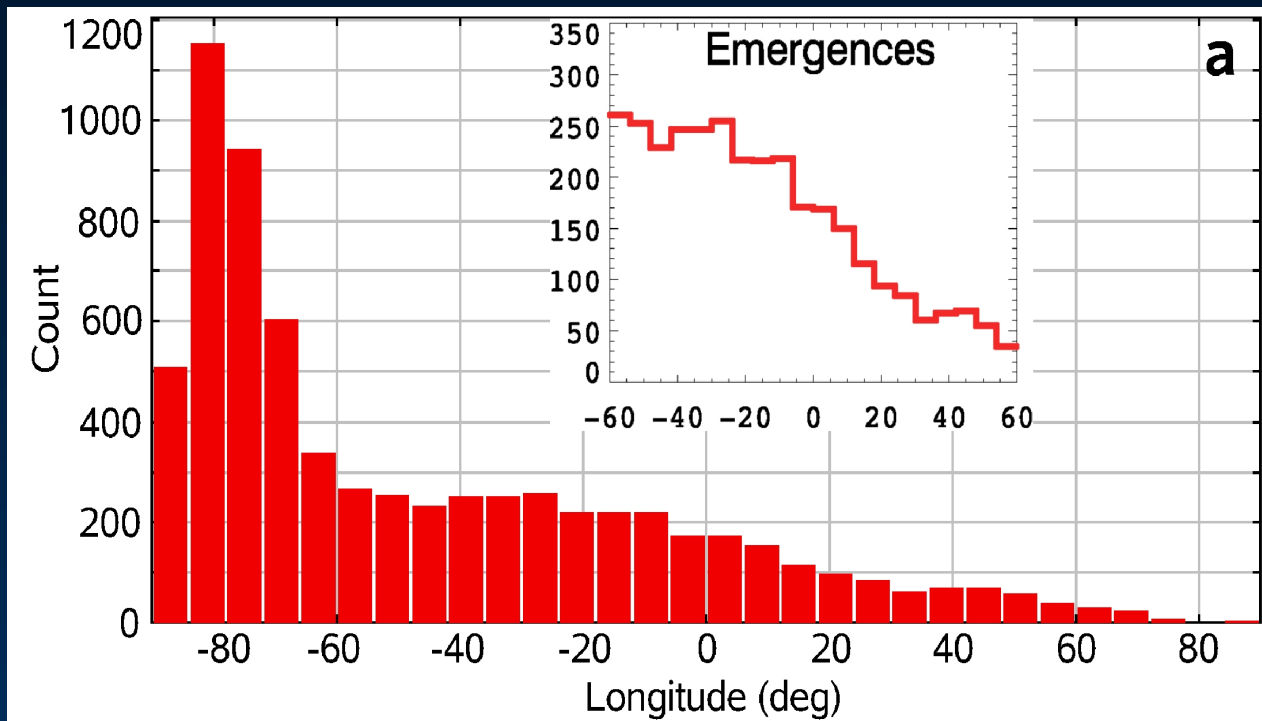
# Location of emergence of new regions

- USAF/Mt Wilson catalogue of sunspot groups for 24 years (Dec 1981- Dec 2005) - 6862 regions
- For each NAR identify where/when region was **first** observed

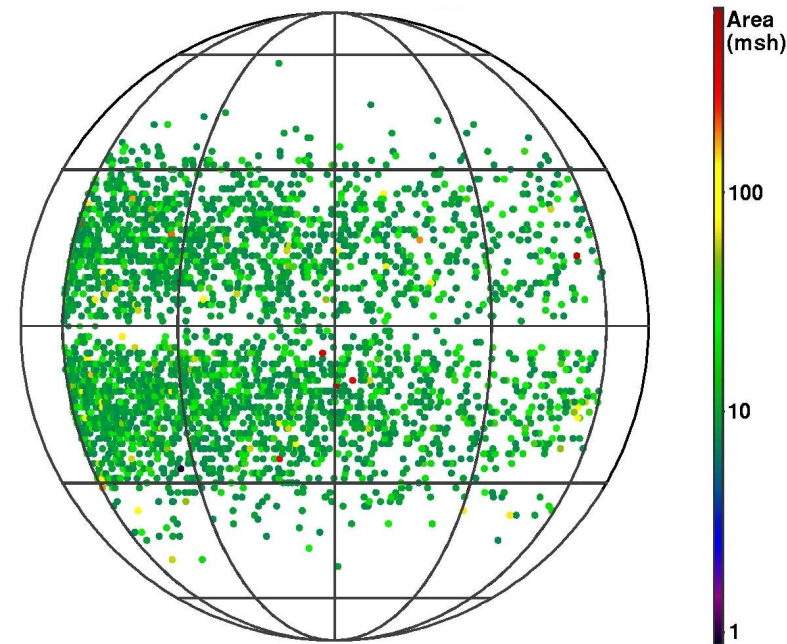


- Displays strong East-West asymmetry

# East-West asymmetry

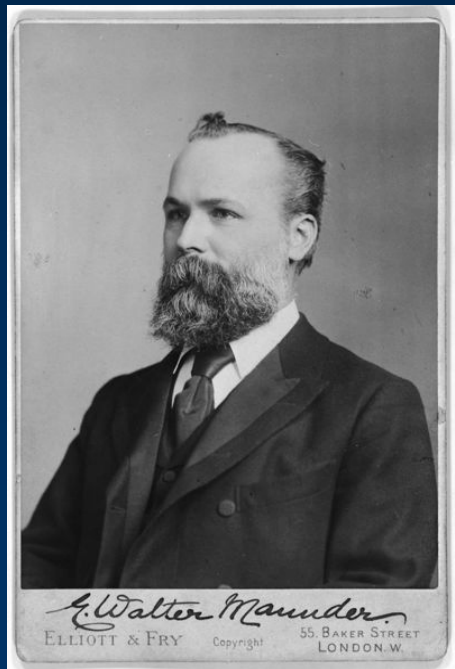


- 825 new regions in  $[-60, -40]$
- 177 new regions in  $[+40, +60]$



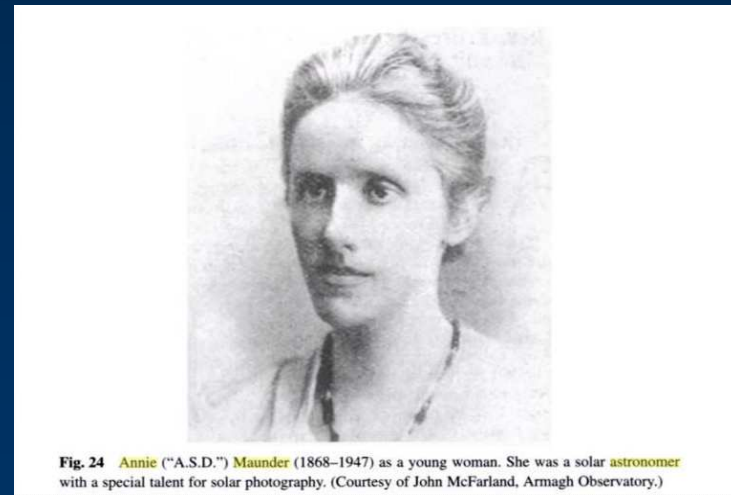
# Maunder paper (1907)

- First report of an East-West asymmetry in the location of emergence of sunspots: A.S.D. Maunder, 1907
- East-West asymmetry in sunspot areas also reported in the paper



[Image:  
Greenwich  
Royal  
Observatory]

E. Walter Maunder



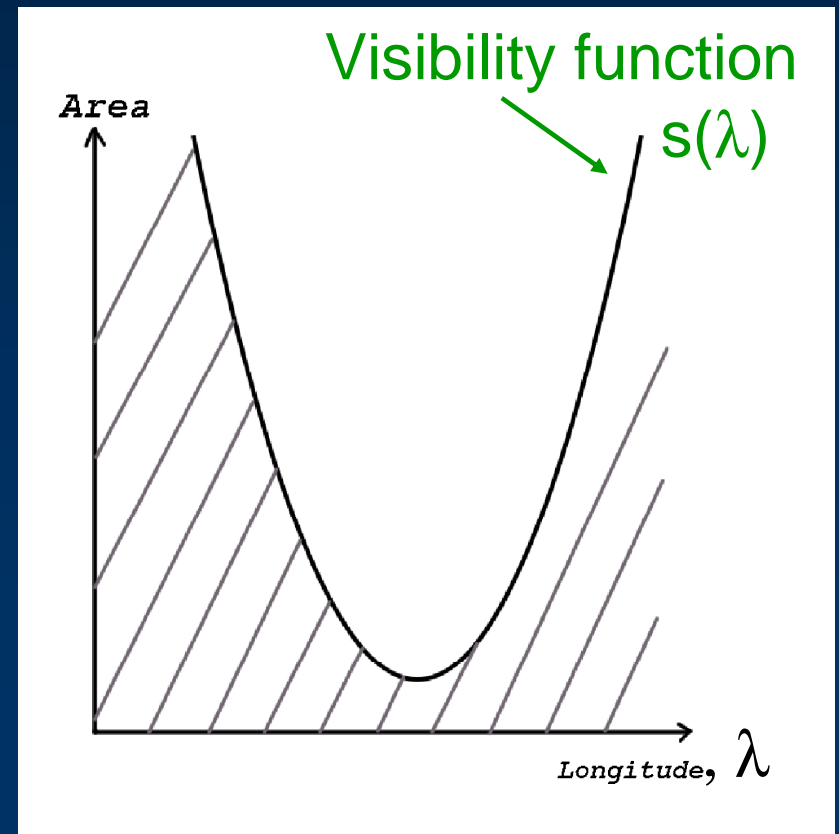
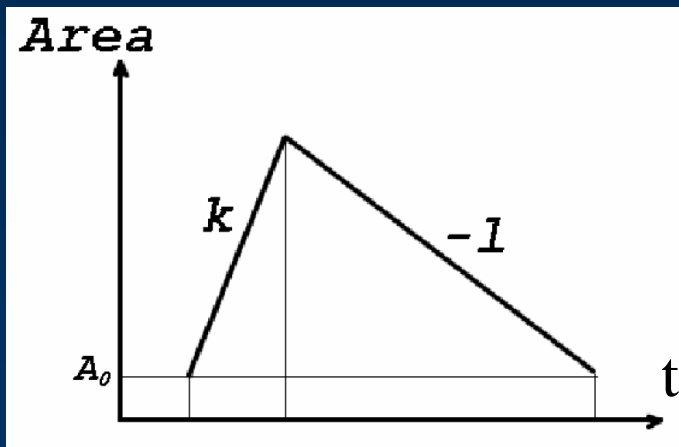
Annie Maunder

[Image from  
book: "The  
Maunder  
Minimum and  
variable Sun-  
Earth  
connection",  
Soon and  
Yaskell, 2004]



# East-West asymmetry explained

- Schuster (1911) explained Maunder's data as a **visibility effect**
- Minnaert (1939) introduced a graphical representation that makes the cause of the asymmetry clear:



# Visibility function and number of regions observed

- $N(\lambda)$ =number of regions *observed* to emerge in a unit bin at longitude  $\lambda$
- $N_1$ =*actual* (constant) number of regions emerging in unit bin=actual rate of new region emergence
- $N(\lambda)$  depends on the gradient of the visibility function  $s'(\lambda)$  and on the growth rate  $k$  of sunspot regions' area

$$N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right]$$

Schuster, 1911



# Recent assumptions on visibility

- Results by Maunder and Schuster appear to have been forgotten in recent times – East-West asymmetry often ascribed to observer bias
- Furthermore, since Minnaert, it has been *assumed* that the visibility function is:

$$s(\lambda) = 1/\cos(\lambda) = \sec(\lambda)$$

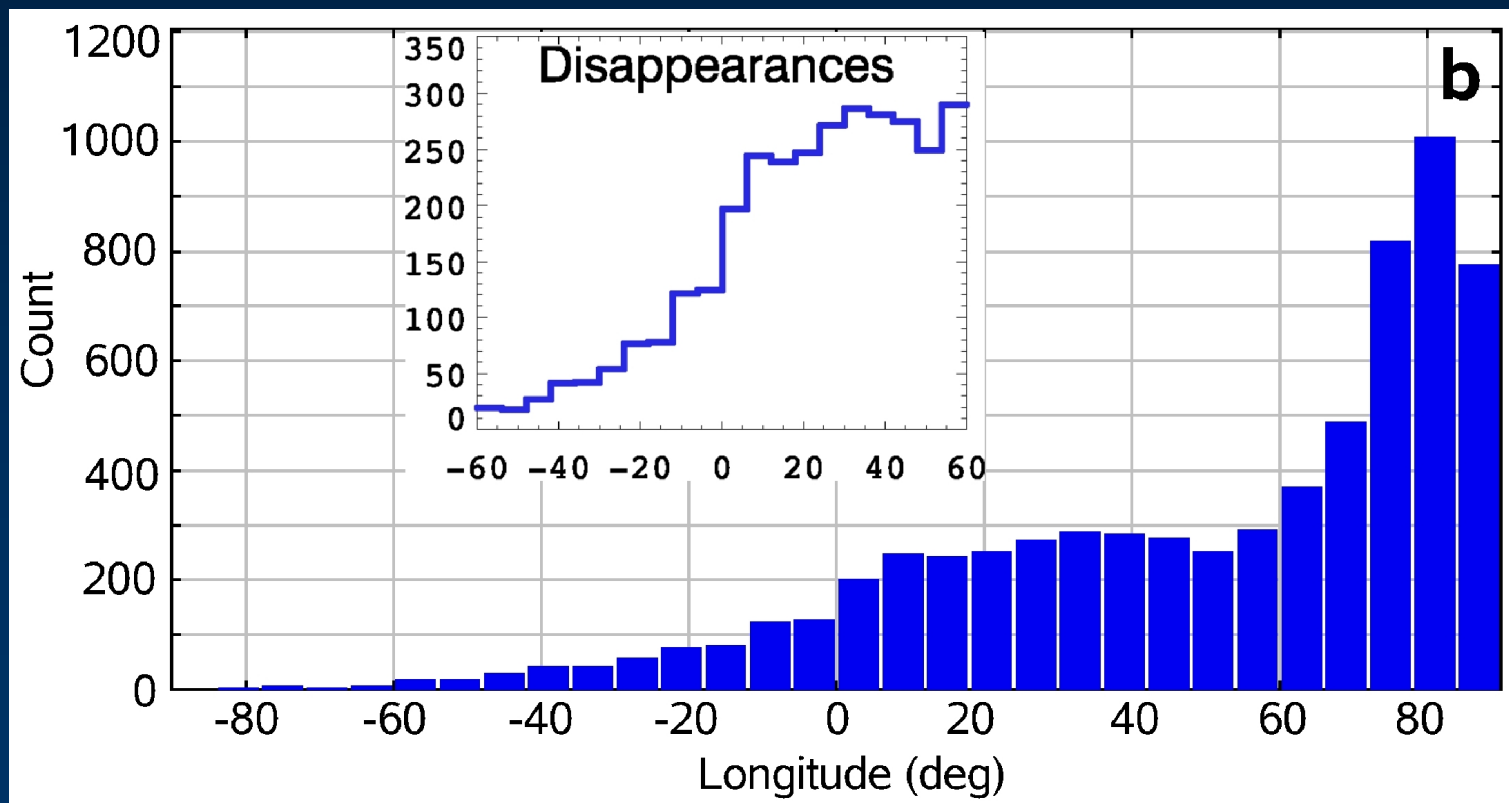
- *geometric (foreshortening) visibility function*: very flat near  $\lambda=0$

# Our work

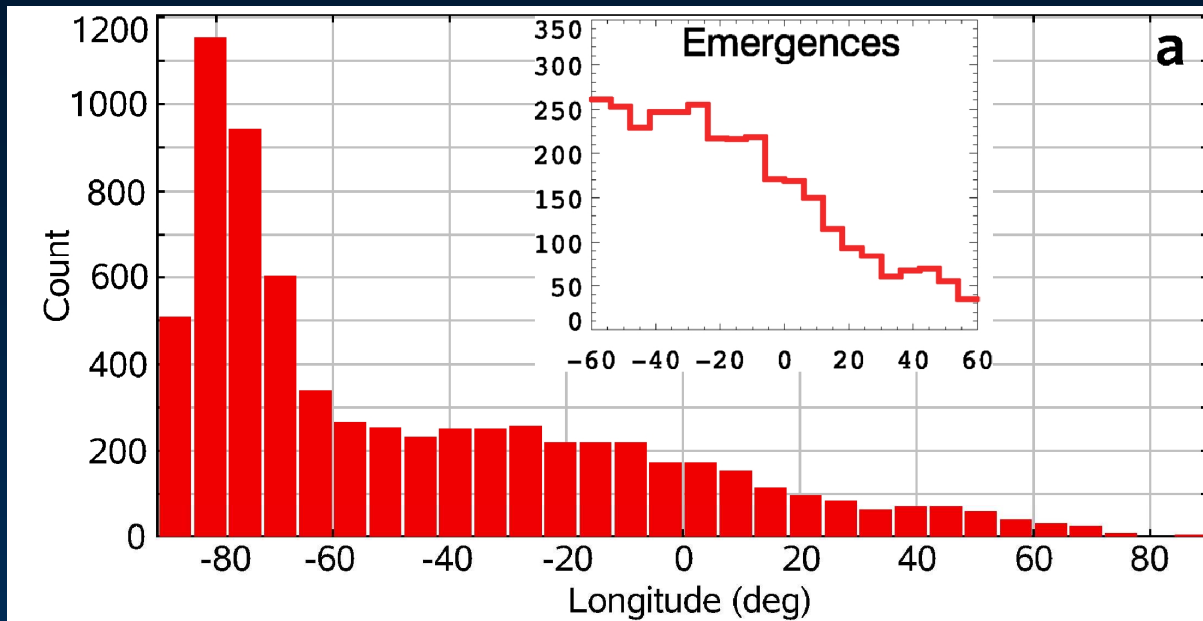
- Confirm that Schuster's theory is in quantitative agreement with the data
- Use our asymmetry data to derive:
  - Visibility function
  - Growth rate/decay rate of sunspot regions
  - Quantify how many new emergences go completely undetected as a result of the visibility effect (invisible sunspots)

# Locations of sunspot disappearances

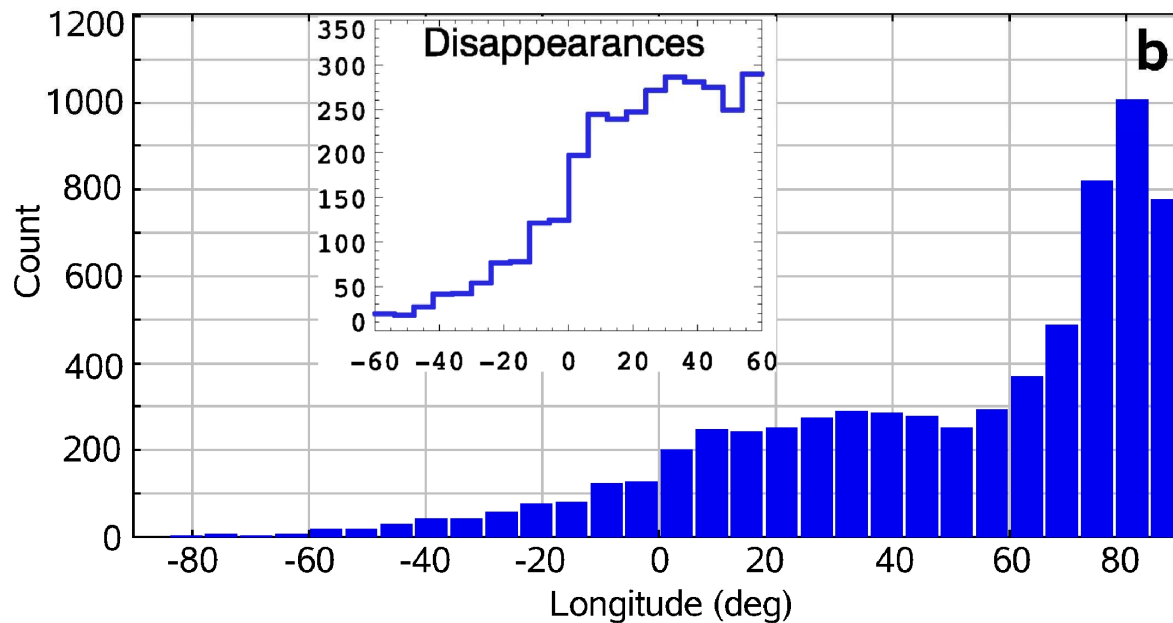
- If the asymmetry in emergences is the result of poor visibility, a similar effect must be present for sunspot disappearance locations



# Emergences + disappearances



$$N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right]$$



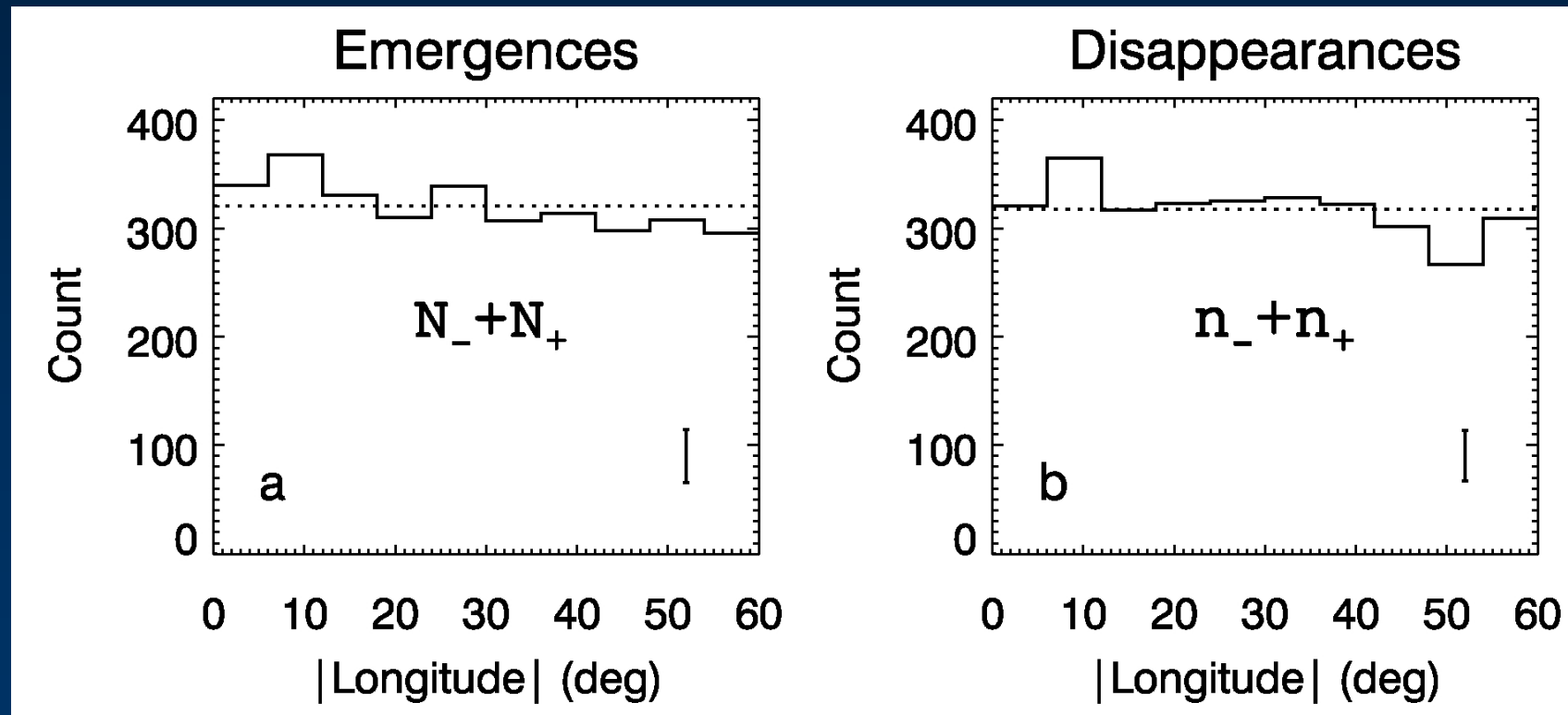
$$n(\lambda) = n_1 \left[ 1 + \frac{\Omega}{l} s'(\lambda) \right]$$

# Actual rate of region emergence

- For a symmetric visibility function, the following relations are expected to hold:

$$N_+ + N_- = 2 N_1$$

$$n_+ + n_- = 2 n_1 = 2 N_1$$



$$N_1 = 160.55 \pm 11.41$$

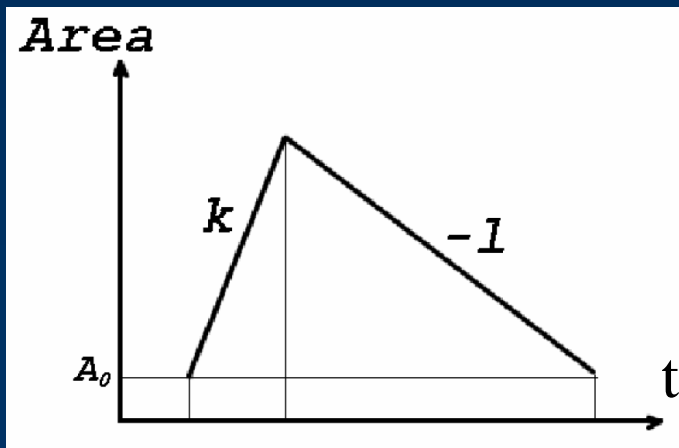
$$N_1 = 158.95 \pm 12.19$$

# Ratio of growth/decay rates

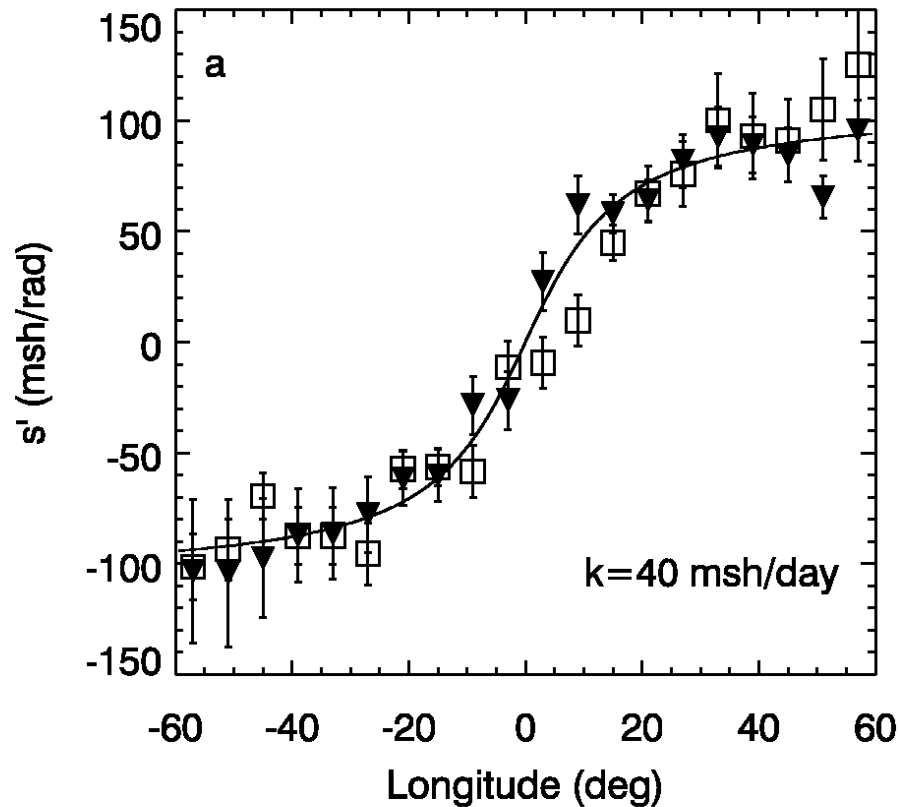
$$N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right]$$

$$n(\lambda) = n_1 \left[ 1 + \frac{\Omega}{l} s'(\lambda) \right]$$

- $k / l = 1.37 \pm 0.26$  (from 16 longitude bins)
- On average, decay phase is only  $\sim 1.4$  times longer than rise phase
- Fast rise + slow decay might be an observational effect



# Derivative of visibility function



⊠ Emergences  
▼ Disappearances

- Obtain  $s'$  separately from emergences and disappearances data
- Requires an assumption on the growth rate of sunspot regions  $k$

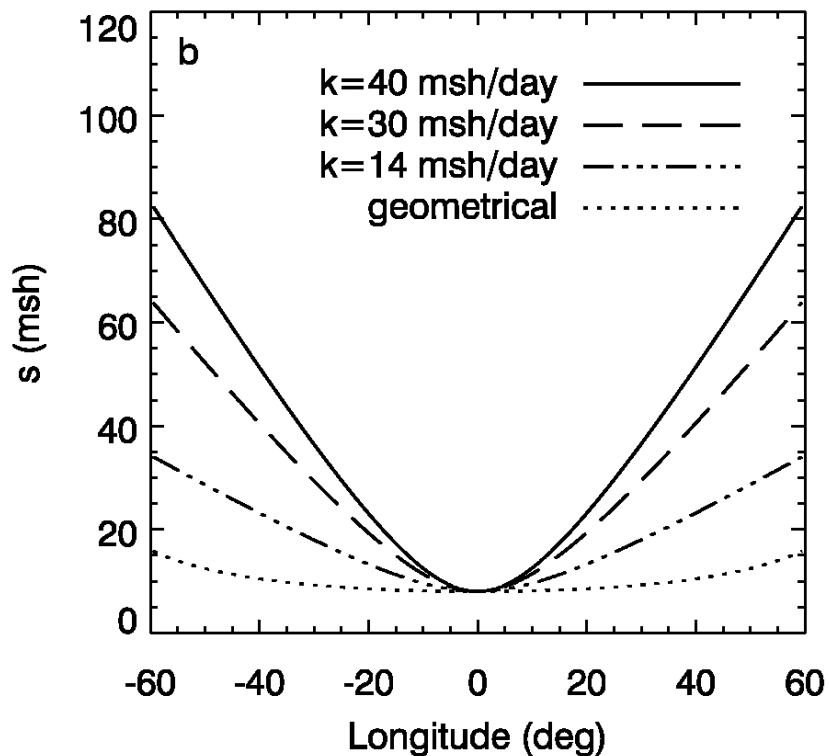
$$N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right]$$

$$n(\lambda) = n_1 \left[ 1 + \frac{\Omega}{l} s'(\lambda) \right]$$



# Visibility function

- Fit  $s'$  expression  $s'(\lambda) = c_1 \tan^{-1}(c_2 \lambda)$
- Integrate to find  $s(\lambda) = c_1/c_2 [x \tan^{-1} x - 1/2 \ln(1 + x^2)] + A_{\min}$   
 $x = c_2 \lambda$



- Strong center-to-limb variation of visibility of small spots
- Visibility is much worse than expected from projection effects (geometrical,  $\sec \lambda$ )

# Invisible sunspots

- 44% of **new** sunspots emerging between 0 and +60 are invisible
- The corresponding Active Regions are not given an Active Region number (unless they produce a flare) and are not monitored

An Active Region number is assigned to a region that satisfies one of the following criteria: (1) the region has been reported to have a sunspot group with first digit of its Modified Zurich Classification of C, D, E, F or H; (2) two or more reports confirm the presence of a Modified Zurich class A or B sunspot group; (3) the region produces a solar flare; or (4) the region is bright in  $H_{\alpha}$  and exceeds 5 heliographic degrees in either latitude or longitude.

- Systematic bias affecting Western Active Regions
- Need for additional data for AR cataloguing

# Apparent vs actual age of sunspots

- For the sunspots that are detected, actual times of emergence and decay can differ considerably from those that are observed
- Sunspot's lifetime is often underestimated – eg regions crossing in and out of the visibility curve
- Distributions of sunspot lifetimes and decay times may need revising (Note: decay time distribution is used to infer mechanism of sunspot decay eg Martinez-Pillet et al, 1993).

# Further questions

- Cause of the strong centre-to-limb variation of visibility – 3D structure of sunspots
- Will the same physical mechanism also affect larger spots and how?
- Visibility effects in magnetogram data?