Sunspot group classifications

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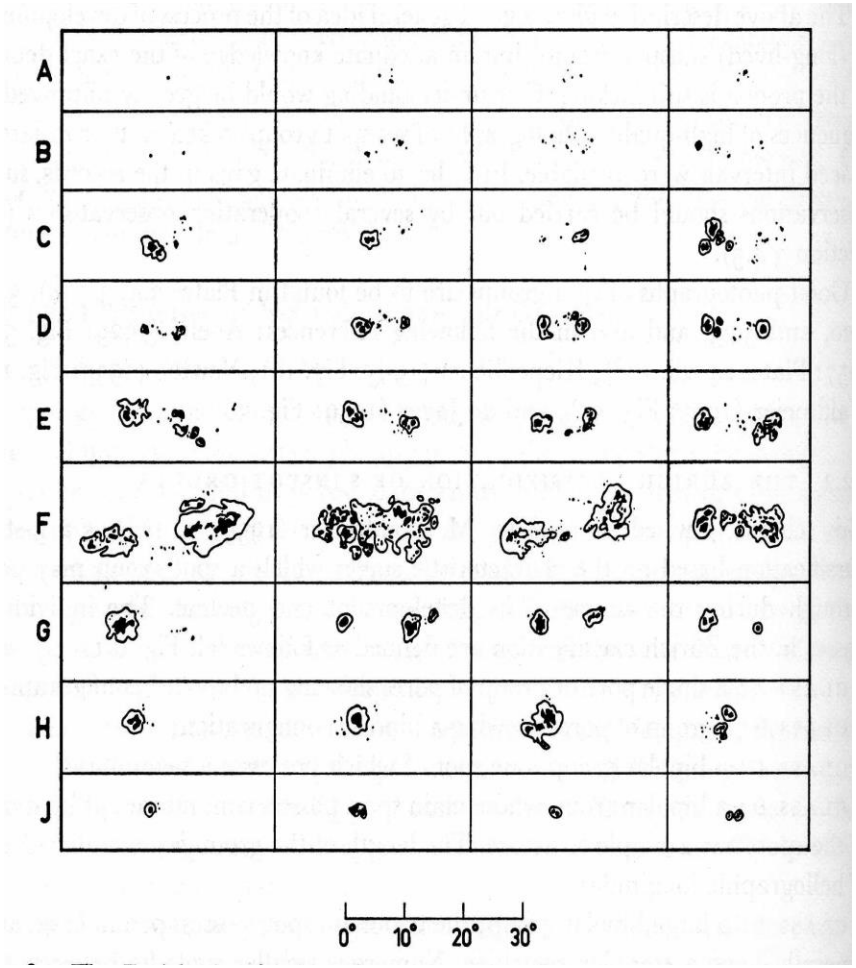
Purpose of a classification

- Sunspots as a measurement tool:
  - Sunspot contrast and size proportional to magnetic field
  - Sunspot group topology reflects the magnetic field distribution
- Input to solar dynamo models:
  - global statistics (long-lat distribution, rotation rates): global dynamo mechanism
  - group properties and evolution scenarios: flux rope emergence, flux dispersion, magnetic helicity (intrinsic or buildup)
- Flaring probability: given by the magnetic flux concentration, magnetic gradients
- Group evolution: mid-term activity predictions
- Sunspot deficit component for total solar irradiance models

The Zürich classification (M. Waldmeier, 1938)

- Based on a typical temporal evolution scenario
- NB: most groups don't evolve through the whole sequence

- **A**: unipolar spot or group of small spots without penumbra (appearance)
- **B**: symmetrical dipolar group with small spots without penumbra
- **C**: asymmetrical dipolar group with a penumbra on one side
- **D**: dipolar group with penumbrae on both sides. At least one of the principal spots has a simple structure. Extent < 10°
- **E**: like D but more complex structure and extent >10°, < 15°
- **F**: like E but extent > 15° and often many secondary spots and penumbrae between the main spots (maximum development)
- **G:** large dipolar group with simple structure and no small secondary spots between the principal spot: Extent > 15° (decline of types F)
- **H**: unipolar group with a single big spot with penumbra: extent > 2.5° (decline)
- **J**: like H but extent < 2.5° (decline)



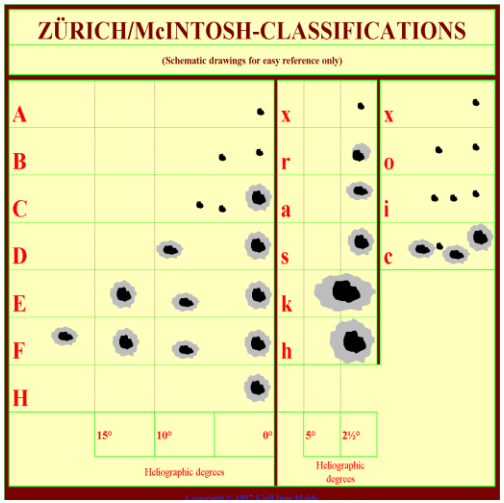
Type	Bipolar	Penumbra	Morphology	History
A		No | tiny	Small spots, scattered randomly	Early or very late stage of evolution Growth to B.
B	X	No | tiny	Small spots, 2 clusters along E-W axis	Early or very late stage of evolution Growth to C, decay to A
C	X	1	Like B, with penumbra present on one side	Growth from type B Decay to B or J
D	X	≥ 2	2 clusters with penumbrae on both sides. One of the main spots has a simple structure. E-W extent < 10°	Growth from types B or C Further growth to E Or decay to C, B or J
E	X	≥ 2	Larger version of D. Extended main penumbrae, many spots between mains spots, possibly with penumbra E-W extent > 10° and < 15°	Large complex group. Growth from type D. Further growth to F or decay to G or H
F	X	≥ 2	Larger version of E, very large penumbrae, space between poles filled with spots and secondary penumbrae, sometimes bridging the main spots E-W extent > 15°	Largest category. Maximum development. Growth from types D and E. Can only decay towards types G or H
G	X	≥ 2	Large bipolar group with penumbrae on both main spots but without small spots between the main spots. Extent > 15°	Decay of type F Decay to C, H or J
H		1 large	Single large spot with extended penumbra, alone or surrounded by a few randomly scattered spots. Penumbral extent > 2.5°	Decay of types E , F or G Further decay to J or dipolar to C
J		1 small	Similar to H but with penumbral extent < 2.5°.	Decay of type D, E, F, G or H Most often types D or H Further decay to A or dipolar to C

Mc Intosh classification (1990)

- Rationale:
  - Better discrimination between « active » and « inactive » groups (occurrence rate of X-ray flares)

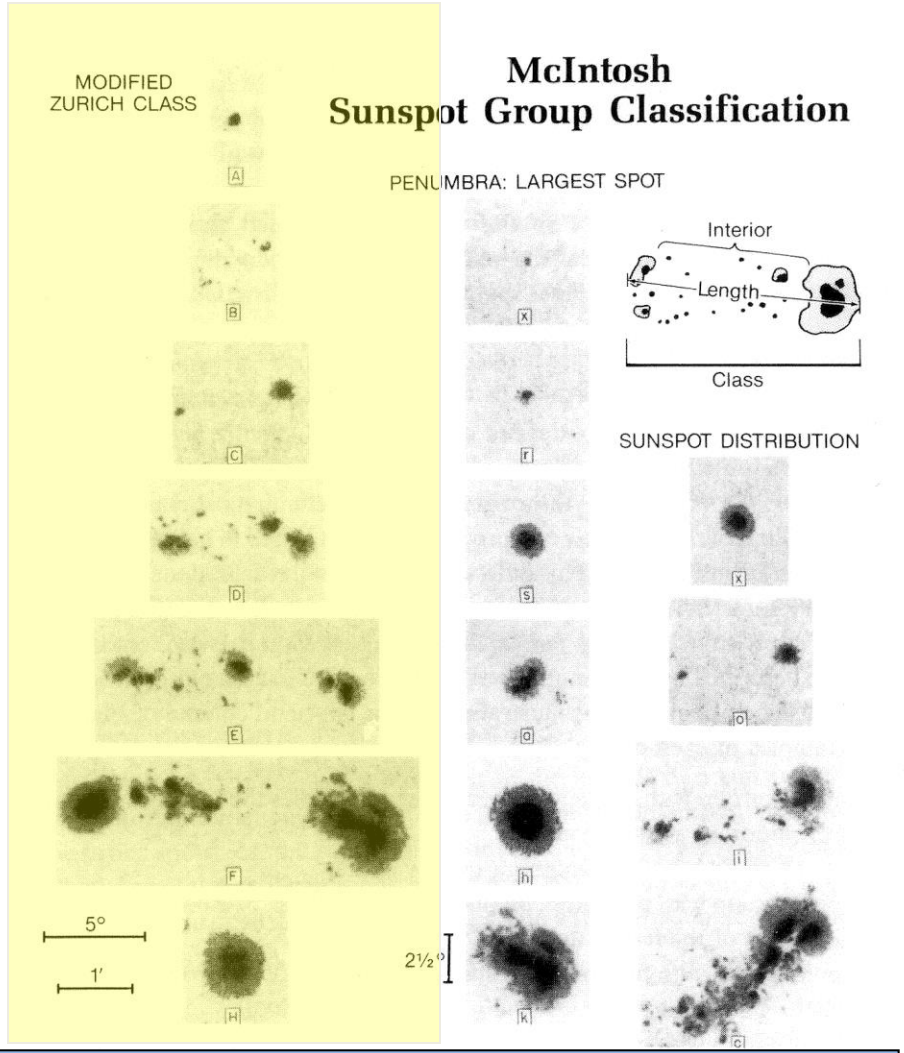
- Extension of the Zürich scheme:
  - Introduction of two additional "qualifiers" (Zpc):
    - "Z ": the Zürich class
    - "p": descriptor for the penumbra of the main spot.
    - "c": descriptor of the distribution of spots inside the group.

- Suppressions of class G:
  - Difficult identification (dependant on past evolution)
  - Merged into E and F classes (via "c" descriptor)
- Suppression of class J:
  - No real difference between unipolar classes H and J
  - Merged with H (via "p" descriptor)



Modified Z class

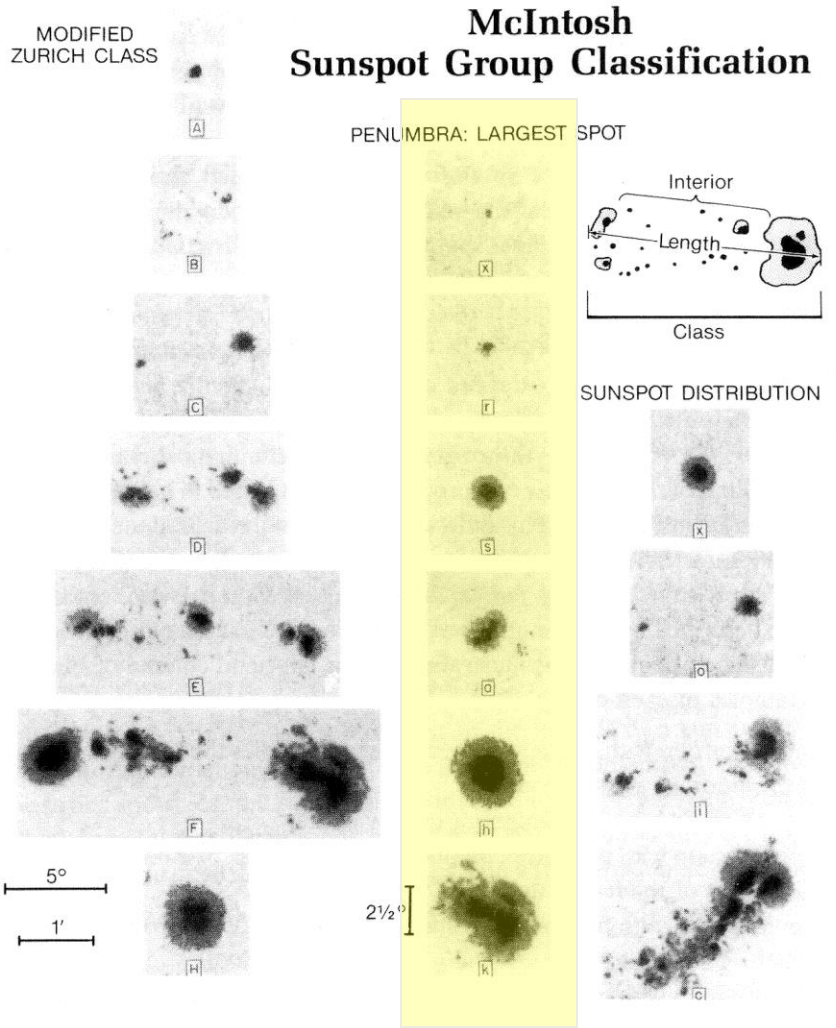
Z class	Description	E-W size
A	Small unipolar spot	S < 3°
B	Dipolar group without penumbra	
C	Dipolar group. Penumbra on one side	
D	Dipolar group. Penumbrae on both sides	S < 10°
E	Large dipolar group. Penumbrae on both sides	10°<S<15°
F	Very large dipolar group. Penumbrae on both sides	S > 15°
H	Unipolar group with large penumbra	



- A group is considered unipolar if the longitudinal separation between the extreme spots is < 3°
- A new group appearing next to an H group is considered as a new separate group

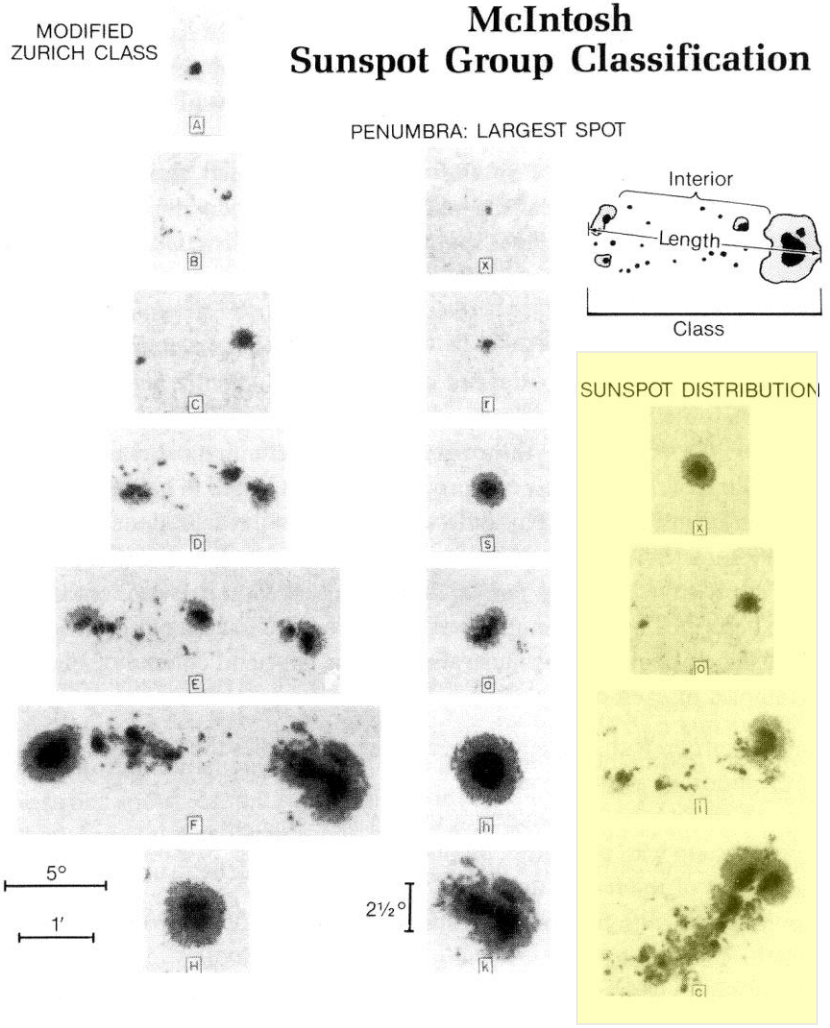
p : development stage of main penumbra

p sub-class	Description	Diameter
x	No penumbra (Z=A or B)	
r	Rudimentary or fragmentary penumbra	< 3 arcsec
s	Small and symmetrical, regular outline (cf. Zürich type J)	< 2.5° (N-S)
a	Small and asymmetrical, containing several umbrae (cf. Zürich type J)	< 2.5° (N-S)
h	Large and symmetrical (cf. Zürich type H)	> 2.5° (N-S)
k	Large and asymmetrical	> 2.5° (N-S)



C: distribution of spots within group

c sub-class	Description
x	Undefined (for classes A and H)
o = open	No spots or few small spots between main spots (Eo and Fo contain the Zürich class G)
i = intermediate	Many small spot between main spots, but none with developed penumbra
c = compact	Many spots between main spot, and at least one with penumbra. The whole group may be contained in a single huge penumbra



Zürich-Mc.Intosh equivalence table

Z \ Mc	A	B	C	D	E	F	H
A	p=x c=x						
B		p=x c=o,i					
C			p=r,s,a c=o,i				
D				p=r,s,a,h,k c=o,i,c			
E					p=s,a,h,k c=i,c		
F						p=h,k c=i,c	
G			p=h,k c=o,i	p=h,k c=o,i	p=s,a,h,k **c=o,i**	p=h,k **c=o,i**	
H							p=h,k c=x
J							**p=s,a** c=x
Nb Combinations	1	2	6	12	12	6	4

Zürich-McIntosh equivalences

- Zürich type J: unipolar group with penumbra in the main spot, with diameter < 2.5°
  - = types Hsx, Hax
- Zürich type H: unipolar group with penumbra in the main spot, with diameter > 2.5°
  - = types Hhx, Hkx
- Zürich type G: large non-compact bipolar group with at least one large sunspot with penumbra and resulting from the decay of a large sunspot group (type, E,F). Different kinds possible:
  - Large dipole spacing > 10°, with the largest spot <2.5° or >2.5°
    = types Eko, Eki, Eho,Ehi,Eao, Eai, Eso,Esi,Fko,Fki,Fho,Fhi (+Fao,Fai,Fso,Fsi?)
  - Strongly asymmetric dipole (<10° or >10°)with a main large spot with penumbra and diameter > 2.5° (other pole: small spots without penumbra or with small penumbrae)
    = types Cho,Chi,Cko,Cki,Dho,Dhi,Dko,Dki

Sources of ambiguities

- **Splitting of neighboring sunspot groups** (no magnetic polarity information).
  - Dominant source of random fluctuations at **high activity**
- **Distinction between smallest spots and pores** (minimum size is ill defined).
  - Dominant source of random fluctuations at **low activity**
- **Multiple umbrae in the same big penumbra** (light bridges, no magnetic information).

Group splitting

- Non-bipolar groups: all spots within 5°x5° (60,000 x 60,000 km)
- Bipolar groups: possible only up to 20° extension.
  - *A test: are both ends of a possible big group obviously unipolar?*
    - *Yes: then single large group*
- Rules for marginal cases *(Ref. Kunzel 1976)*:
  - Two spots up to 15° apart form a single group if they are the remainder of a large extended group
  - A bipolar collection of spots forms one group if the dipole is parallel to the solar equator or if the leading spot is closer to the equator than the trailing spot:
    Lat(West) ≤ Lat(East)
    - Typical tilt angles: 1-2° at 10° latitude, 4° at 30° latitude
- Parallel sunspot evolution: e.g. in decaying groups,
  - The trailing spot disappears first by fragmentation into multiple small spots
  - The leading spot disappears last (H type) by shrinking.