Coronal Holes and SWx

Michael S.F. Kirk
[NASA GSFC | ASTRA]
Hole-y Corona!

These are the first images that conclusively discovered low density, dark patches in the solar corona.

Waldmeier is the modern discoverer of coronal holes in 1957. However it wasn’t until photographs of the Sun from above the Earth’s atmosphere, they were identified as 3D structures in their own right.

Skylab’s Apollo Telescope Mount x-ray images from June 1973 revolutionized high temperature solar imagery.
A Vacant Corona

“Coronal holes” simultaneously refer to three different phenomena:

1. Dark patches in x-ray or EUV images representing a lack of emitting coronal plasma.
2. “Open” magnetic field lines emanating from the solar surface.
3. Low emission off the limb of the sun.
Dark Patches: Coronal Hole Zoology

Current observations are made in X-ray and EUV (and He I Triplet).
Open Field Lines: Coronal Hole Theory

(a) Magnetic field lines organize in the inter-granular lanes as flux tubes.
(b) A fraction of these lines organize in the lanes of supergranules.
(c) Large mono-polar regions extend into the corona and are ‘open.’

Megameter (Mm) = 1,000,000 m
Low Emission: Ground-based Imaging

530.3 nm “Green line” images from natural or man-made eclipses were the only observations of coronal holes until the space age.

These images are rarely used in modern coronal hole studies but are an essential link to historic datasets.
A less-than-solved problem...

EUV X-Ray Images  Ground-based Observations  Theory

Hinode XRT  Druckmüller, Fe XIV  PFSS Magnetic Field Model

All of these features are related, yet a one-to-one mapping between features has never been successful.
The Fast Solar Wind

- **Speed:** 400 – 800 km s\(^{-1}\)
- **Density:** \(n_p \sim 3 \text{ cm}^{-3}\)
- **Composition:** \(~ 95\% \text{ H}; 5\% \text{ He}; \) some ions
- **Temperature:** \(T_p \sim 2 \times 10^5 \text{ K}\)
- **Magnetic Field:** \(~ 5 \text{ nT}\)
- **Characteristics:** Alfvénic (EM) fluctuations

Origin In Coronal Holes

(Bothmer and Zhukov, 2007)
Coronal Holes and Space Weather

- Fast solar wind comes from coronal holes.
- Define the quiescent heliospheric environment.
- Direct connection to transition region plasma.
Coronal Holes and Space Weather
Coronal Holes to Earth

A high-speed stream can cause an energetic electron flux enhancement and magnetic field disturbances on Earth.

K-index quantifies disturbances in the horizontal component of earth's magnetic field.
Hole Measurements, what are they good for?

- Current forecasts are highly dependent on coronal hole size and location (ENLIL, ADAPT).
- Geoeffective impacts of equatorial holes and CMEs are embedded in the quiescent solar wind.
- A solar cycle measurement that is not activity dependent.
- Measurements of the global rearrangement of magnetic field at solar minimum.

WSA-ENLIL  Solar Wind Prediction
Evolution of the Holes

Polar Coronal Hole Size

Northern Hole

Southern Hole

Kirk et al. 2017
Current Measurement Techniques

Kirk et al. 2009

Examples of automated techniques for identifying coronal hole boundaries.

Arge et al. 2017
Coronal Holes: A Summary

- Regions of low emission in x-ray and EUV images.
  - Characterized as regions of *open* magnetic field lines.
  - The primary source of the fast solar wind.
Want to know more?


...or michael.s.kirk@nasa.gov

(and various other methods: slack, riot.im, twitter, skype, facebook, google hangouts, WhatsApp, dialing a phone, etc....)