# Effects of the Solar Cycle on Interstellar Hydrogen Rates Observed by IBEX


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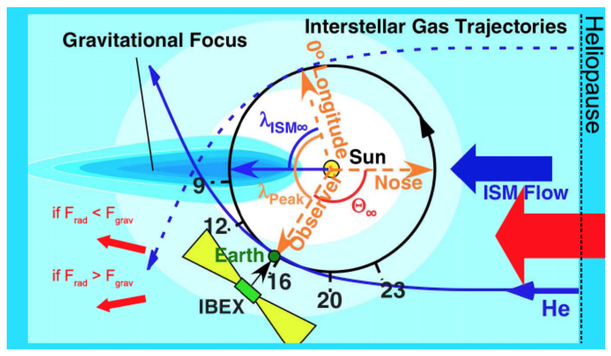
## Introduction

- As the sun moves through the LISM, neutral atoms travel through the heliosphere and can be detected by the Interstellar Boundary Explorer (IBEX).
- Interstellar hydrogen (ISH) atoms, with a presumed drifting Maxwellian distribution function, travel on hyperbolic trajectories and are subject to solar gravity and solar radiation pressure as well as ionization processes.
- The radiation pressure likely overcompensates for the gravitational force, which makes the ISH atoms decelerate on their trajectories and shifts in the observational longitude of the peak of the ISH flow.
- We studied the effect of the solar parameters on the ratio of ISH fluxes in the two lowest energy channels of IBEX-Lo.
- We applied corrected ISH flux to study hydrogen signal variations over ten years of IBEX observations and the effect of radiation pressure on that.

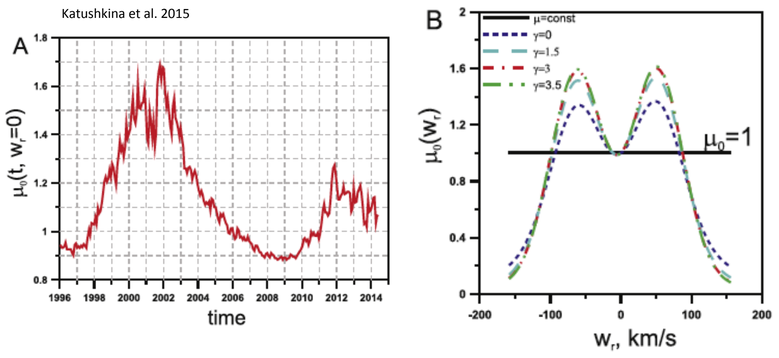



Gali et al. 2018

## Solar Cycle and Radiation Pressure

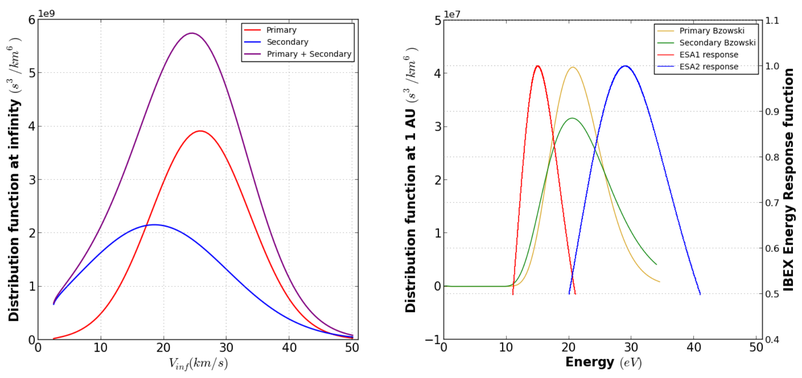
- The distribution function of the ISH is modified by the Sun's gravity and radiation pressure.
- The dimensionless parameter $\mu(t, \vartheta, v_r) = \boldsymbol{F_{rad}} / \boldsymbol{F_g}$ is a function of time, heliolatitude and the radial velocity of the ISH atoms.

Katushkina et al. 2015

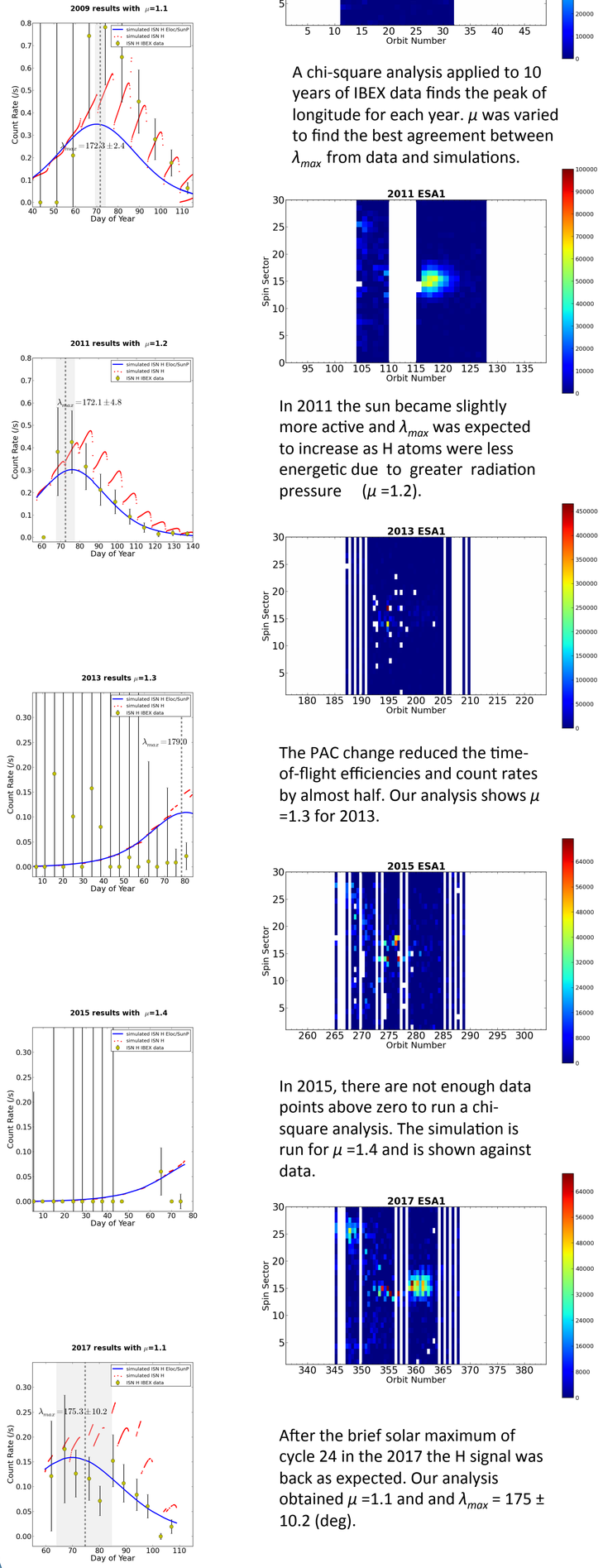



## Interstellar Hydroen

- Charge exchange at the heliospheric interface leads to filtration of the primary ISH and creation of the secondary ISH with a much hotter and slower distribution function. In turn, the selective filtration of the primary population makes it faster and cooler.
- The charge exchange processes that occur further inside the heliopause, along with photoionization, lead to the loss of neutral particles and update both distribution functions.
- Neutrals that pass through IBEX-Lo collimator are filtered based on energy and accelerated through an electrostatic analyzer (ESA) with eight energy steps ( ESA 1 and 2 for ISH atoms).
- Since the distribution peak of the ISH falls between the two energy channels, its signal is very sensitive to variation of solar parameters and calibration coefficients of the instrument.




## Results



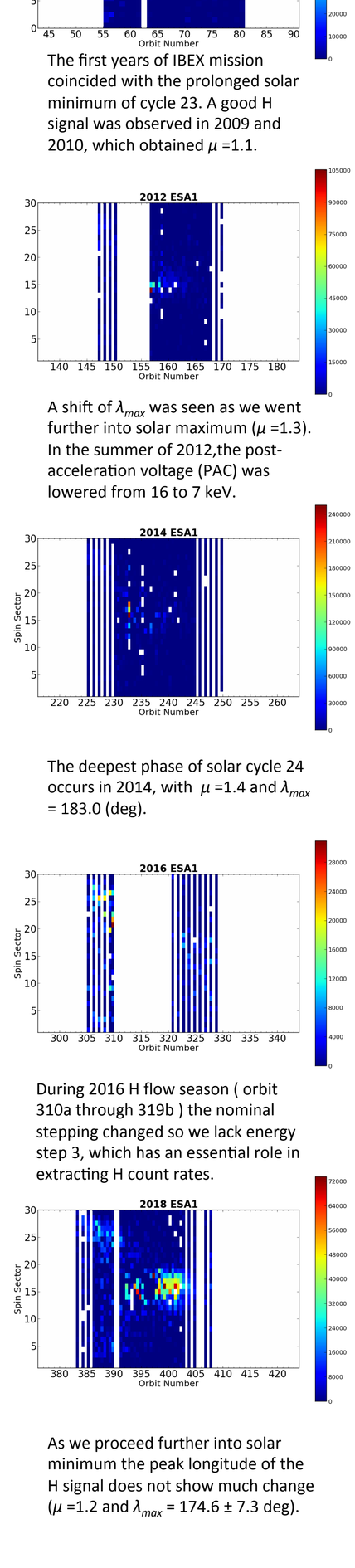

A chi-square analysis applied to 10 years of IBEX data finds the peak of longitude for each year. $\mu$ was varied to find the best agreement between $\lambda_{max}$ from data and simulations.

In 2011 the sun became slightly more active and $\lambda_{max}$ was expected to increase as H atoms were less energetic due to greater radiation pressure ($\mu$ =1.2).

The PAC change reduced the time-of-flight efficiencies and count rates by almost half. Our analysis shows $\mu$ =1.3 for 2013.

In 2015, there are not enough data points above zero to run a chi-square analysis. The simulation is run for $\mu$ =1.4 and is shown against data.

After the brief solar maximum of cycle 24 in the 2017 the H signal was back as expected. Our analysis obtained $\mu$ =1.1 and and $\lambda_{max}$ = 175 ± 10.2 (deg).




The first years of IBEX mission coincided with the prolonged solar minimum of cycle 23. A good H signal was observed in 2009 and 2010, which obtained $\mu$ =1.1.

A shift of $\lambda_{max}$ was seen as we went further into solar maximum ($\mu$ =1.3). In the summer of 2012,the post-acceleration voltage (PAC) was lowered from 16 to 7 keV.

The deepest phase of solar cycle 24 occurs in 2014, with $\mu$ =1.4 and $\lambda_{max}$ = 183.0 (deg).

During 2016 H flow season ( orbit 310a through 319b ) the nominal stepping changed so we lack energy step 3, which has an essential role in extracting H count rates.

As we proceed further into solar minimum the peak longitude of the H signal does not show much change ($\mu$ =1.2 and $\lambda_{max}$ = 174.6 ± 7.3 deg).

| Year | $\lambda_{max}$ | $\mu$ |
|---|---|---|
| 2009 | 172.3 ± 2.4 | 1.1 |
| 2010 | 169.5 ± 4.6 | 1.1 |
| 2011 | 172.1 ± 4.8 | 1.2 |
| 2012 | 182.0 ± 18.0 | 1.3 |
| 2013 | 179.0 | 1.3 |
| 2014 | 183.0 | 1.4 |
| 2017 | 175.3 ± 10.2 | 1.1 |
| 2018 | 174.6 ± 7.3 | 1.2 |

## Summary and Conclusions

- We used Analytical Full Integration Model (aFINM), which is:
  - limited to the boundaries of the heliosphere
  - Stationary, Axisymmetric (using averaged values for ionization and radiation parameters)
  - Based on conservation of energy (using radiation pressure as a conservative force)
- We Performed a chi-square analysis to fit aFINM to IBEX-Lo count rates of the ISH in order to obtain the same peak longitude for each season by varying radiation pressure parameter.
- We showed how radiation pressure affects hydrogen signal expansion and decline over different phases of solar cycle over the course of an almost full solar cycle.
- In this analysis we solely focused on ESA1 data and left the ESA2 and the qualitative difference between predicted and observed flux (discrepancy between the ratio of the rates in energy step 1 and 2) for future work. We plan to resolve this issue by applying a new method of incorporating the geometric factor.

## References:


Schwadron et al. (2013), DOI: 10.1088/0004-637X/775/2/86

Katushkina et al. (2015), DOI: 10.1088/0067-0049/220/2/33

Lee et al. (2012), DOI: 10.1088/0067-0049/198/2/10

Gali et al. (2018), In Work



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