Gravitational Lens Statistics with Herschel-ATLAS

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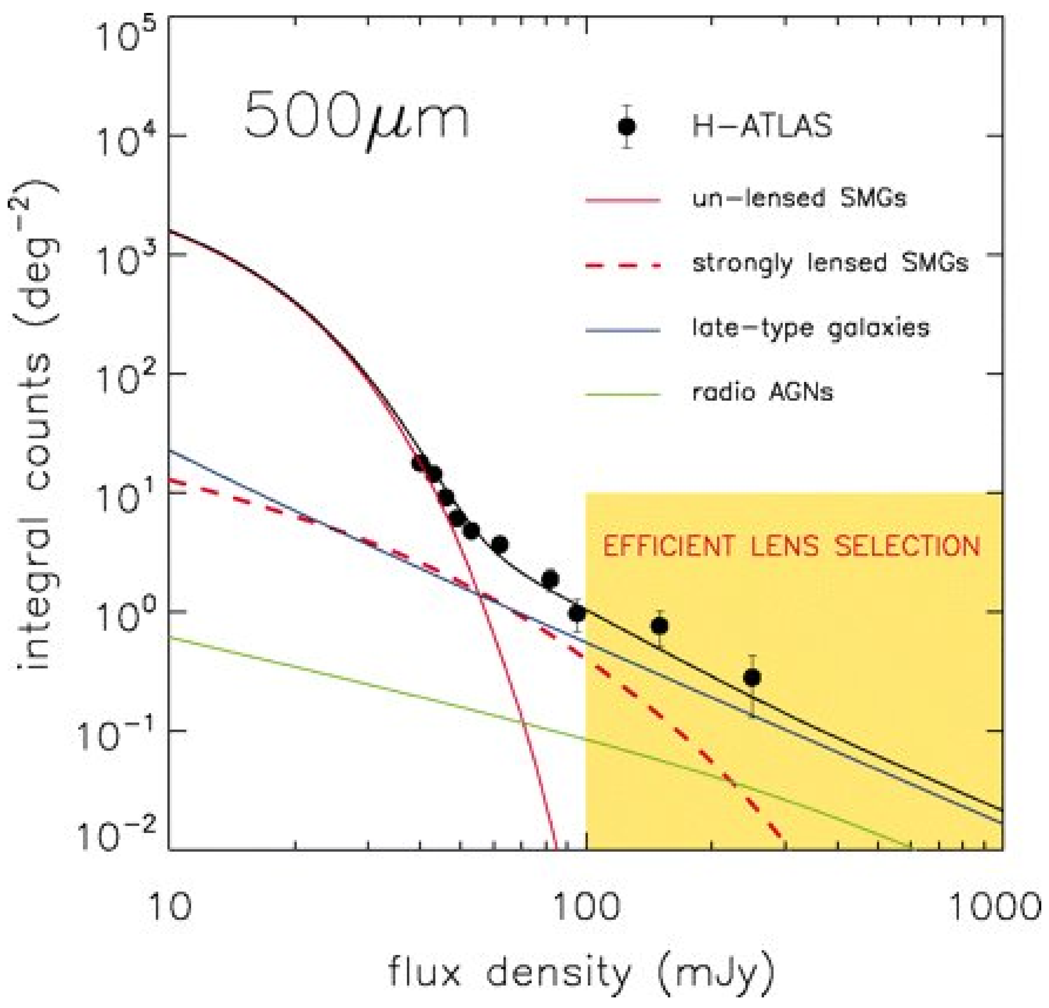
Statistical Methods + Sub-mm Observations = Predicted Lens distributions for H-ATLAS

Herschel Space Observatory

- First space-based **far-infrared** to **sub-millimetre** telescope.
- Launched in 2009, expected to finish in 2013.
- SPIRE instrument images at 250, 350, 500 μm.
- Aim: to investigate cold/dusty objects.

Herschel-Astrophysical Terahertz Large Area Survey

- Largest extragalactic *Herschel* survey (1/80th sky or 550 deg^2).
- Science Demonstration Phase (SDP) covers 3% total (16 deg^2).



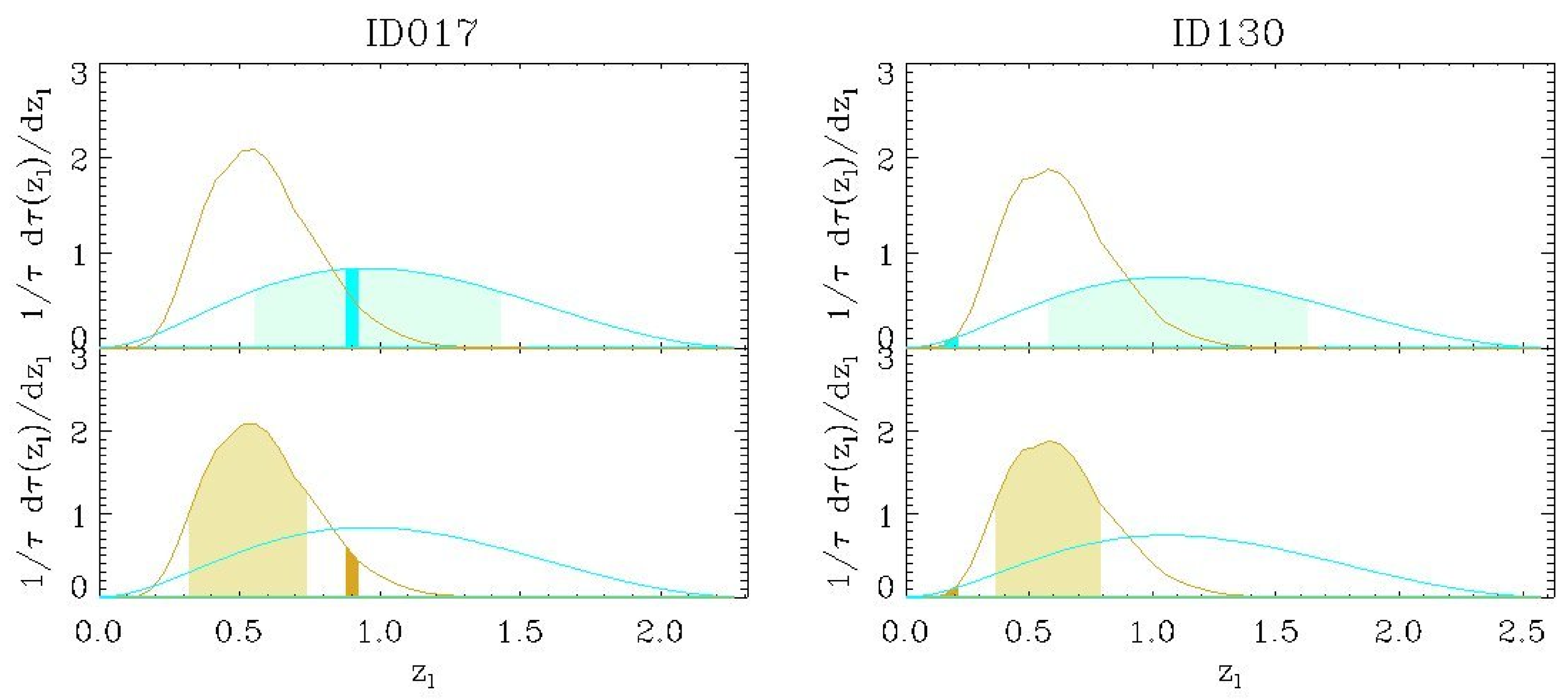
Negrello et al. (2010)

- Negrello et al. (2010) demonstrated an **efficient lens selection** technique.
- Sources counts at 500μm are expected to fall off quickly with flux, therefore sources with fluxes above a given cut-off are very likely to be lenses.

- Five candidate lens were identified in the SDP data; around 100 are expected with the full data set.
- González-Nuevo et al. (2012) have extended the technique, utilising flux measurements from the other wavebands, and expect to find around 1000 lenses.

Results: $\tau(z_l)$ compared to SDP data

- These plots show the probability of finding a lens ($\tau(z_l)/\tau$) as a function of the lens redshift (z_l), given there exists a source at redshift z_s that has been lensed, for two of the five H-ATLAS SDP candidate lenses.



Lines coloured cyan use the SIS cross section; yellow lines use the NFW cross section estimate. Shading is the $\sim 1\sigma$ (68%) confidence interval. Vertical lines indicate the estimated location of gravitational lenses found by Negrello et al. (2010).

- A likelihood analysis using all five lenses shows a slight preference for the SIS profile over the NFW profile ($L_{SIS} = 0.014$ and $L_{NFW} = 0.012$).

Gravitational Lensing

- Gravitational lensing occurs when light from a background source is distorted by foreground mass.
- **Strong gravitational lensing** occurs when this lensing effect is sufficient to generate multiple images.
- Here we consider the statistics of these strong gravitational lenses i.e. how many we expect to occur, at what redshift, magnification and image separation .

Lens Statistics Methodology

- The probability of a source being strongly lensed, or the **lensing optical depth**, depends on:
  - the **mass function** (n) which describes the halo number density in the the physical comoving volume element at a given redshift; and
  - the **lensing cross-section** (σ) which is the area in the source plane where a source would be strongly lensed.

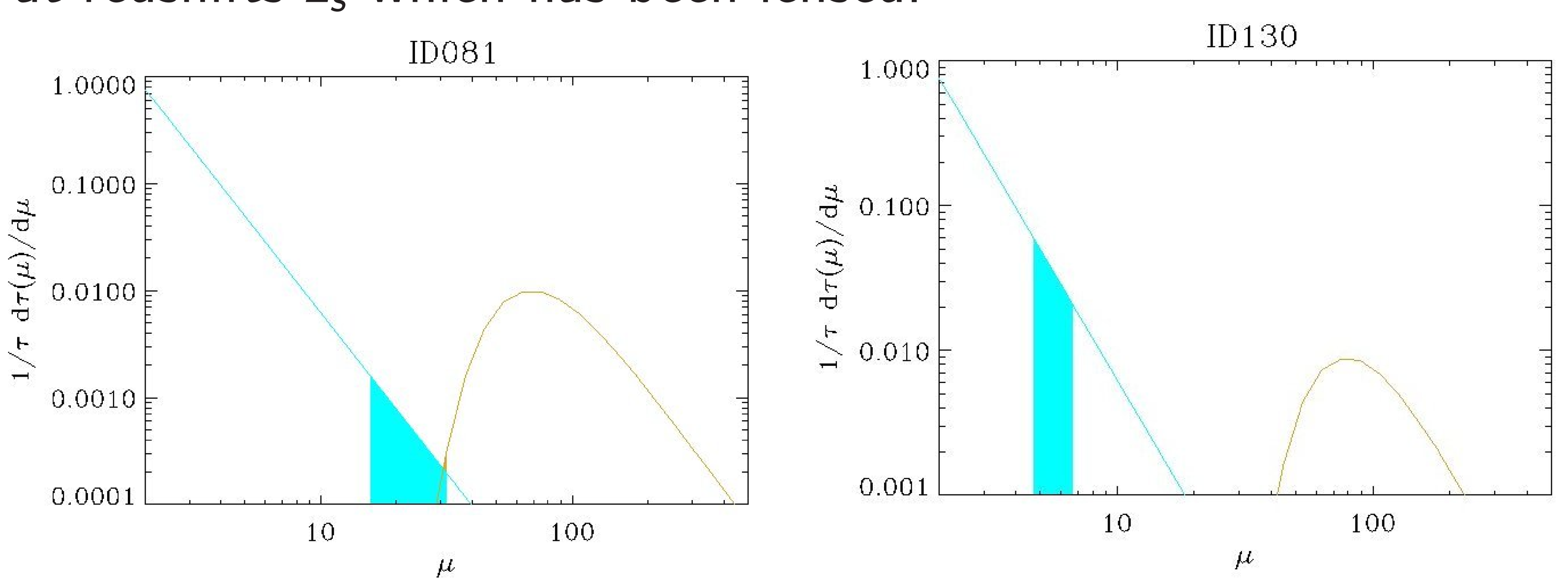
$$\tau(z_s, \ldots) = \int\int n(m, z_l)\,\sigma(m, z_l, z_s, \ldots)\frac{dD_l}{dz_l}\,dm\,dz_l$$

Trends as a function of z_l and μ

- **Dark Energy Density:**
  - $\tau(z_l, \mu, \theta)$ decreases with increasing Ω_Λ (for a flat universe).
- **Lens Density Profile:**
  - $\tau(\mu)$ favors higher μ for shallower central density profiles.
- **Mass Function:**
  - $\tau(\theta)$ favours higher θ for mass functions which predict more higher mass halos.

Results: $\tau(\mu)$ compared to SDP data

- These plots show the probability of finding a lens ($\tau(\mu)/\tau$) as a function of the lens magnification (μ) given there exists a source at redshifts z_s which has been lensed.



Lines coloured cyan use the SIS cross section; yellow lines use the NFW cross section estimate. Vertical lines indicate the estimated magnification of two gravitational lenses found by Negrello et al. (2010).

- A likelihood analysis of the two lenses for which magnifications are available shows that the SIS profile is preferred over the NFW profile ($L_{SIS} = 9\times 10^{-5}$ and $L_{NFW} = 4\times 10^{-14}$).

Conclusions & Future work

- So far there have been just five lenses identified the the H-ATLAS SDP data. However with the full data set there should be 100-1000 lenses.
- This is only enough data to look at the density profile and the data suggest that the SIS density profile is preferred over the NFW profile.
- However with the full data set, and more follow-up information, we will be able to learn a lot more about different astrophysical and cosmological parameters.

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