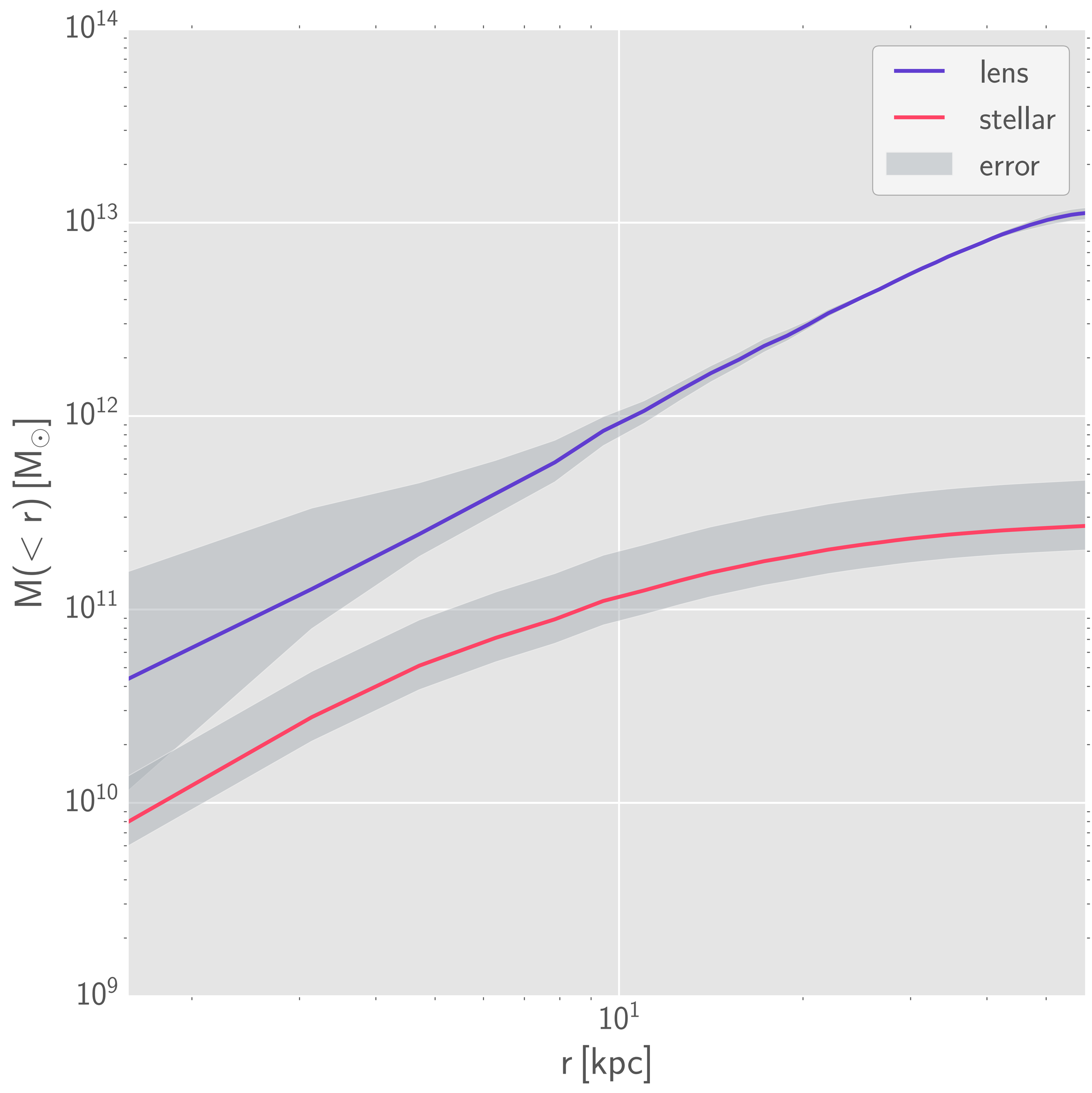
Unveiling Dark Matter through Gravitational Lensing

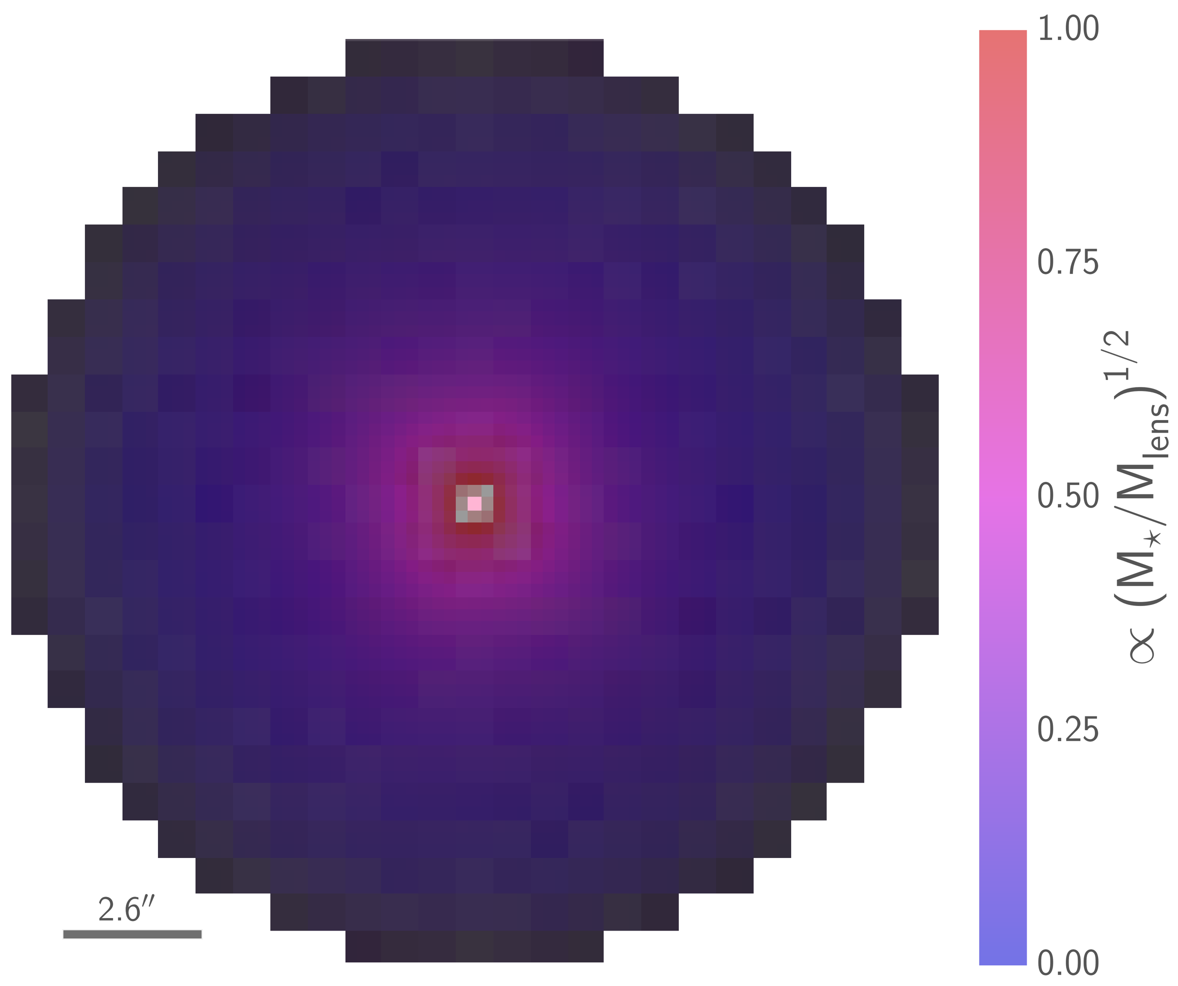
Philipp Denzel, Rafael Küng, Prasenjit Saha

Universität Zürich[UZH]

in collaboration with Elisabeth Baeten, Jonathan Coles, Claude Cornen, Ignacio Ferreras, Christine Macmillan, Phil Marshall, Anupreeta More, Lucy Oswald, Aprajita Verma, Julianne K. Wilcox

Galaxies have been observed in great numbers and variety. The detected light from galaxies is almost exclusively related to their mass in stars. But the gravitational fields are dominated by some exotic non-baryonic matter. This was first noticed in 1933 by Fritz Zwicky who called it simply 'Dunkle Materie' or '**Dark Matter**'.





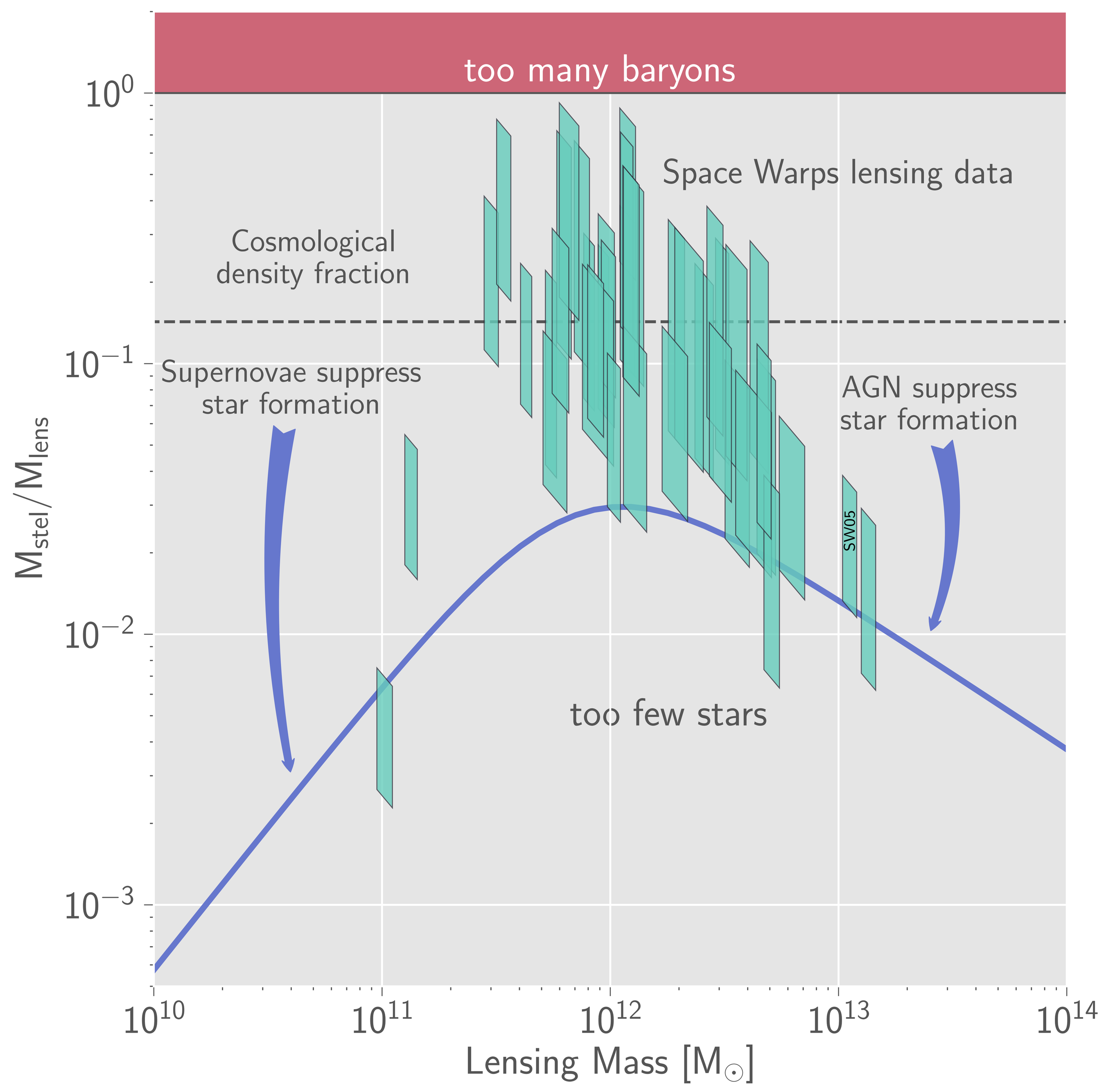
We are using **gravitational lensing** to measure the total mass content of a galaxy, that is the baryonic as well as the dark matter. Why is it called gravitational lensing? A lens is basically a glass sheet of varying thickness which delays light by an amount proportional to the local thickness. In gravitational lensing the same effect is produced by a gravitational field.

$$\nabla^2 t_{\rm grav} = -(1+z_{\rm L})\frac{8\pi G}{c^3}\Sigma(x,y)$$

- $t_{\rm grav}$ Time delay due to gravity
- Σ Surface density
- $z_{\rm L}$ Redshift of the lens

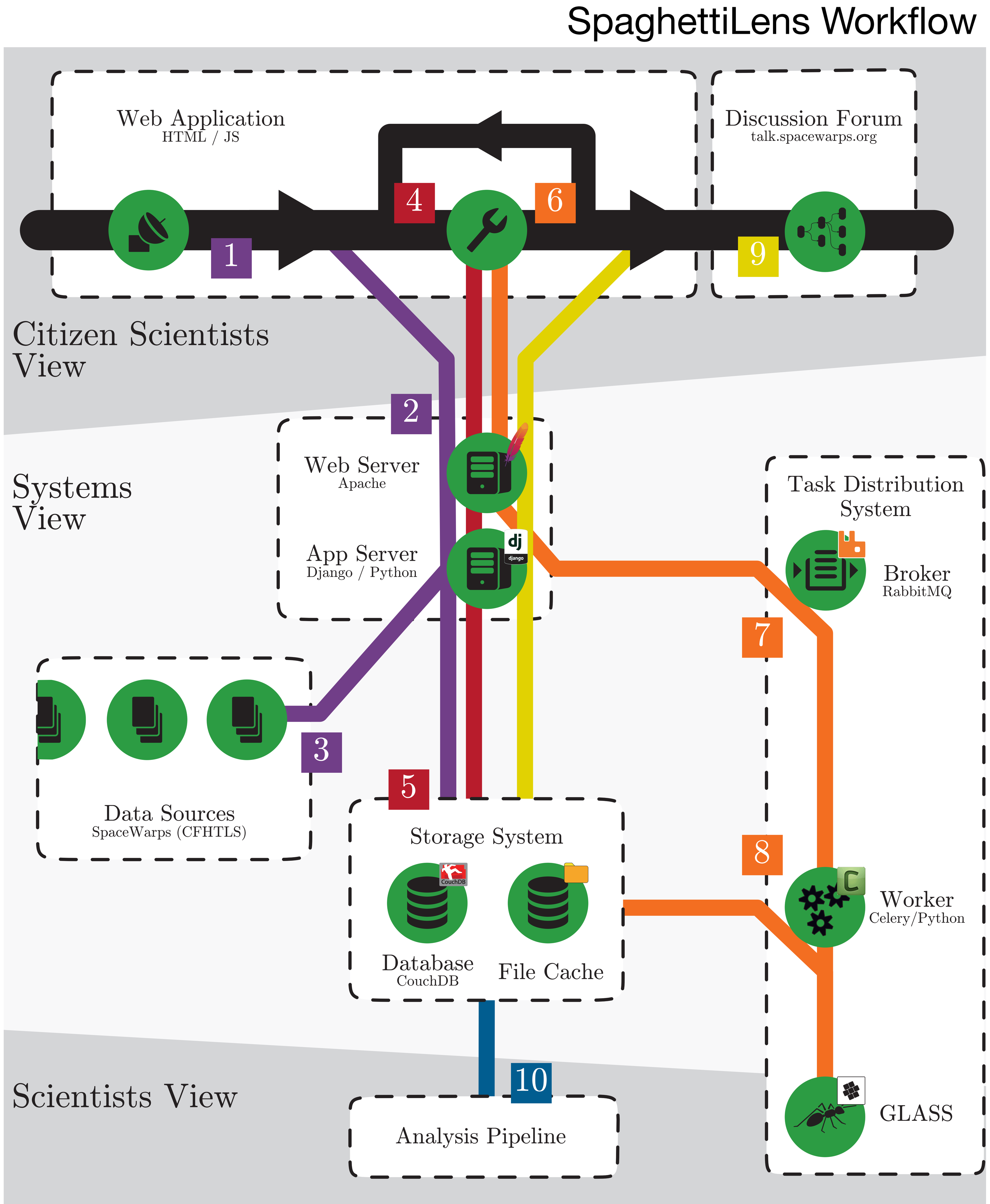
Here we see an example of an inner region dominated by baryons and an outer region dominated by dark matter.

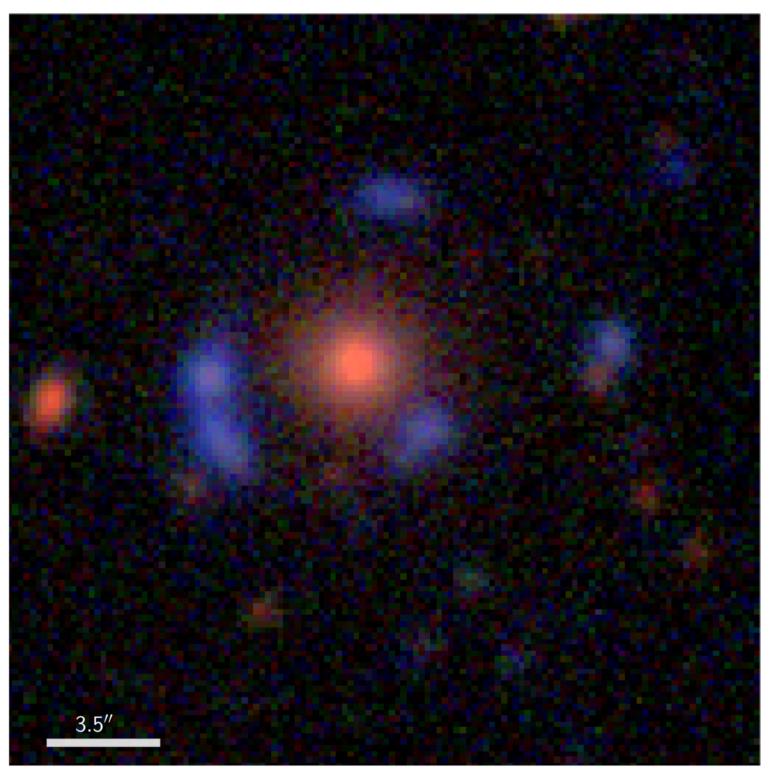
Current cosmological models estimate a **baryonic-to-total mass ratio** of $\Omega_b/\Omega_m \sim 0.14$. If light traces mass this cosmological average would hold for galaxies of all masses.
Galaxy formation simulations which include baryonic as well as dark matter however show that on small scales light does no longer simply trace mass and predict the star formation of galaxies to be suppressed at both the low and high ends of the mass spectrum due to various feedback effects such as tidal stripping, Supernovae and AGNs.
In summary, having more concentrated baryonic matter (e.g. stars) will increase the stellar-to-lens mass fraction whereas feedback which disperses baryonic matter decreases it.

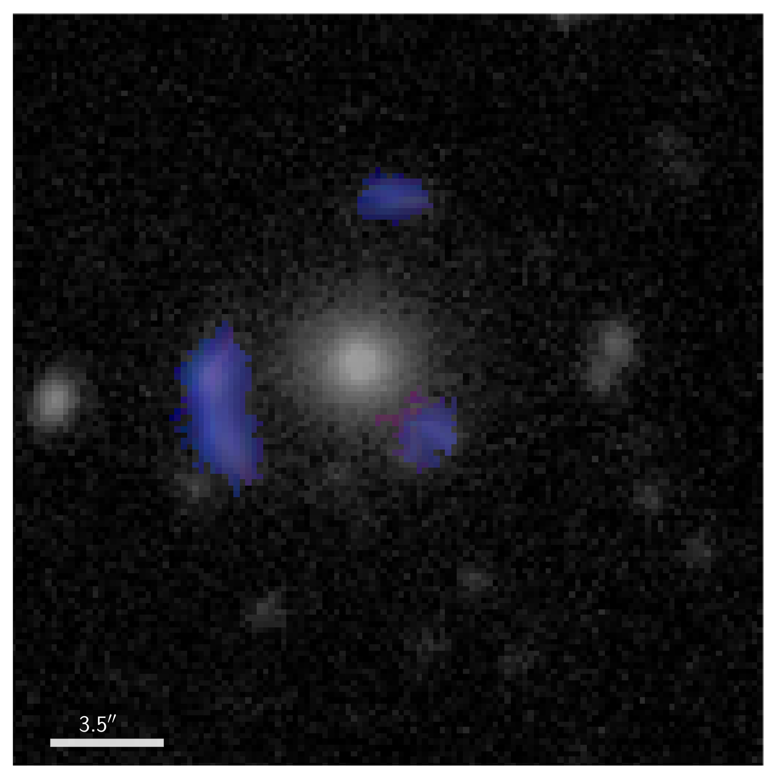


The **Space Warps** endeavour is a citizen science project in which volunteers, or citizen scientists, were asked to spot lensed features in images from the Canada-France-Hawaii Telescope Legacy Survey. In the course of 8 months more than 37'000 volunteers made 29 promising discoveries (59 in total).
A few candidates such as SW05 (above and on the bottom right) seem particularly interesting, because they represent the extremes in the mass spectrum and are expected to have a high dark matter content.

SpaghettiLens Workflow







In a second phase, a small group of non-professional enthusiasts were asked to use **SpaghettiLens** (RK 2015), an analytical framework for modelling gravitational lenses, to do in-depth analysis of the previously discovered lenses.
They computed various lens models, compared the models' synthetic images to the real pictures (see above: original left, synthetic image right), and posted their results on an online forum, where they discussed their findings with professional astrophysicists or got advice.
Confirmed gravitational lenses are still quite rare (only a few hundred), but in the future with the commissioning of new improved telescopes able to cover much bigger patches of the sky, we expect discoveries to increase by $\sim 10^4$, which makes having reliable analytical tools and help from volunteers indispensable.
If you're interested and maybe want to contribute, please feel free to come and talk to us!

Email: phdenzel@physik.uzh.ch

FNSNF Swiss National Science Foundation