Astrophysical probes of dark matter

Nitsan Bar
Weizmann Institute of Science, Israel

Helmholtz-Weizmann MMS School - Annual Meeting
August 2020

Dark matter can be many many things, how do we proceed?

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Primordial
black holes
$m \sim 100\, M_\odot \sim 10^{68}$ eV

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Ultralight dark matter
(ULDM, "fuzzy")
$m \sim 10^{-22}$ eV

Primordial
black holes
$m \sim 100\, M_\odot \sim 10^{68}$ eV

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Ultralight dark matter
(ULDM, "fuzzy")
$m \sim 10^{-22}$ eV

$\sim$ GeV
WIMPs

Primordial
black holes
$m \sim 100\, M_\odot \sim 10^{68}$ eV

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Ultralight dark matter
(ULDM, "fuzzy")
$m \sim 10^{-22}$ eV

Axion-like

$\sim$ GeV
WIMPs

Primordial
black holes
$m \sim 100\, M_\odot \sim 10^{68}$ eV

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Ultralight dark matter (ULDM, "fuzzy")
$m \sim 10^{-22}$ eV

Axion-like

$\sim$ GeV
WIMPs

Primordial black holes
$m \sim 100\, M_\odot \sim 10^{68}$ eV

Gravity-only constraints, minimal theoretical prejudice.

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Ultralight dark matter (ULDM, "fuzzy")
$m \sim 10^{-22}$ eV

Axion-like

$\sim$ GeV WIMPs

Primordial black holes
$m \sim 100\, M_\odot \sim 10^{68}$ eV

Gravity-only constraints, minimal theoretical prejudice.

No guarantee of SM-DM non-gravitational interaction.

Dark matter can be many many things, how do we proceed?

If it's a "simple" gravitationally interacting particle: mass spectrum

Ultralight dark matter (ULDM, "fuzzy") $m \sim 10^{-22}$ eV

Axion-like

$\sim$ GeV WIMPs

Primordial black holes $m \sim 100\, M_\odot \sim 10^{68}$ eV

Gravity-only constraints, minimal theoretical prejudice.

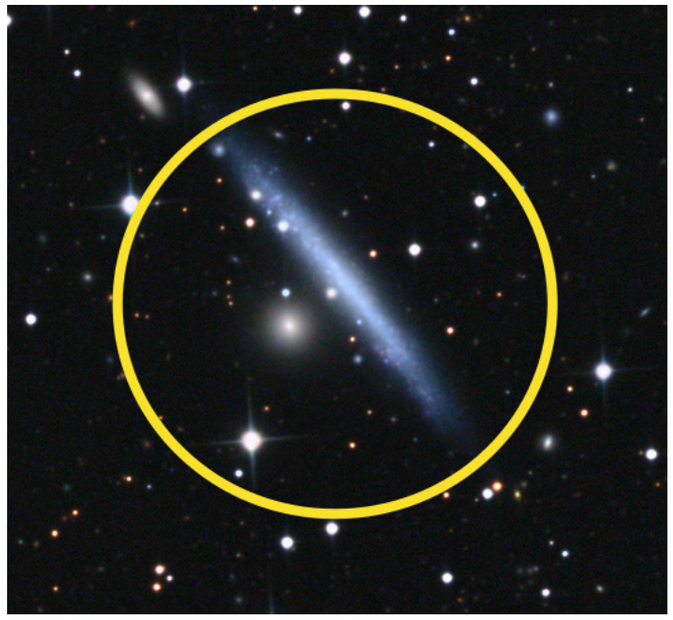
No guarantee of SM-DM non-gravitational interaction.

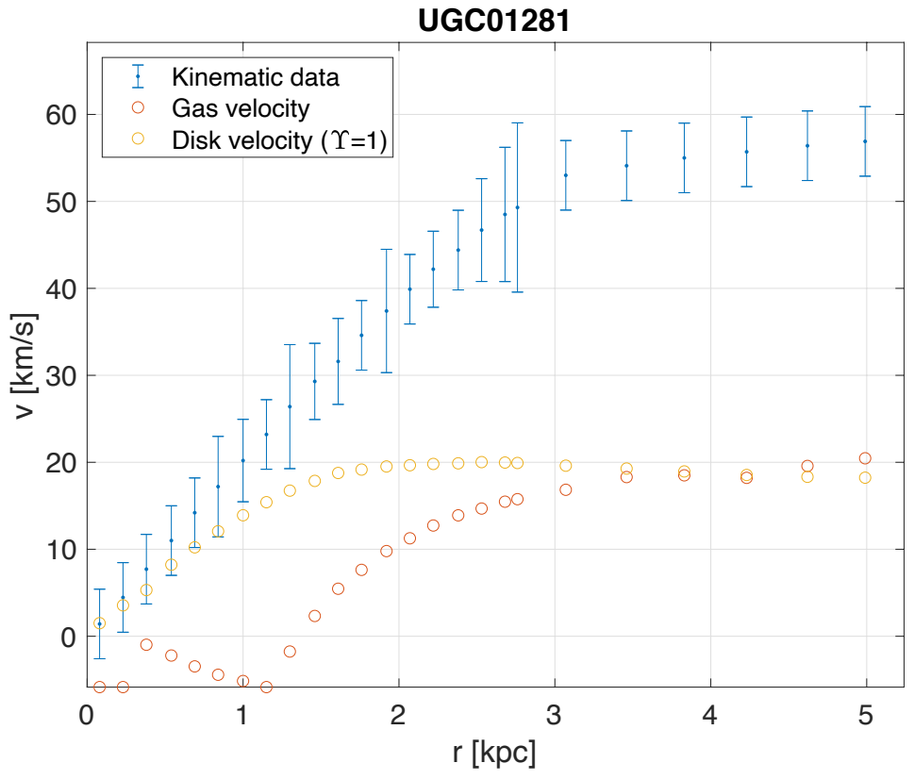
We can and we should fully explore the gravity-only astronomical arena.

We can learn more about the properties (or lack of properties) of dark matter from “indirect” astronomy

We can learn more about the properties (or lack of properties) of dark matter from "indirect" astronomy

- Galaxies as test beds, as predictions of dark matter models sharpen.





We can learn more about the properties (or lack of properties) of dark matter from "indirect" astronomy

- Galaxies as test beds, as predictions of dark matter models sharpen.

- Newly discovered galaxies like dwarf galaxies in the vicinity of the Milky Way.

We can learn more about the properties (or lack of properties) of dark matter from "indirect" astronomy

- Galaxies as test beds, as predictions of dark matter models sharpen.

- Newly discovered galaxies like dwarf galaxies in the vicinity of the Milky Way.

- Better astrometric data in our galaxy, e.g. from the Gaia sattelite.

We can learn more about the properties (or lack of properties) of dark matter from "indirect" astronomy

- Galaxies as test beds, as predictions of dark matter models sharpen.

- Newly discovered galaxies like dwarf galaxies in the vicinity of the Milky Way.

- Better astrometric data in our galaxy, e.g. from the Gaia sattelite.

We can learn more about the properties (or lack of properties) of dark matter from "indirect" astronomy

- Galaxies as test beds, as predictions of dark matter models sharpen.

- Newly discovered galaxies like dwarf galaxies in the vicinity of the Milky Way.

- Better astrometric data in our galaxy, e.g. from the Gaia sattelite.

- Measurements based on gravitational lensing.

Case-study: Ultralight dark matter in the centres of galaxies

$$\lambda_{dB} = \frac{h}{mv} = 1.2 \left(\frac{10^{-22}\ \mathrm{eV}}{m} \right) \left(\frac{100\ \mathrm{km/s}}{v} \right)\ \mathrm{kpc}$$

Case-study: Ultralight dark matter in the centres of galaxies

$$\lambda_{dB} = \frac{h}{mv} = 1.2 \left(\frac{10^{-22}\ \mathrm{eV}}{m} \right) \left(\frac{100\ \mathrm{km/s}}{v} \right)\ \mathrm{kpc}$$

$\gg \Delta x \equiv n^{-1/3}$ the inter-particle spacing.

Can be shown that the equations of motion reduce to Schrödinger-Poisson in the non-relativistic limit.

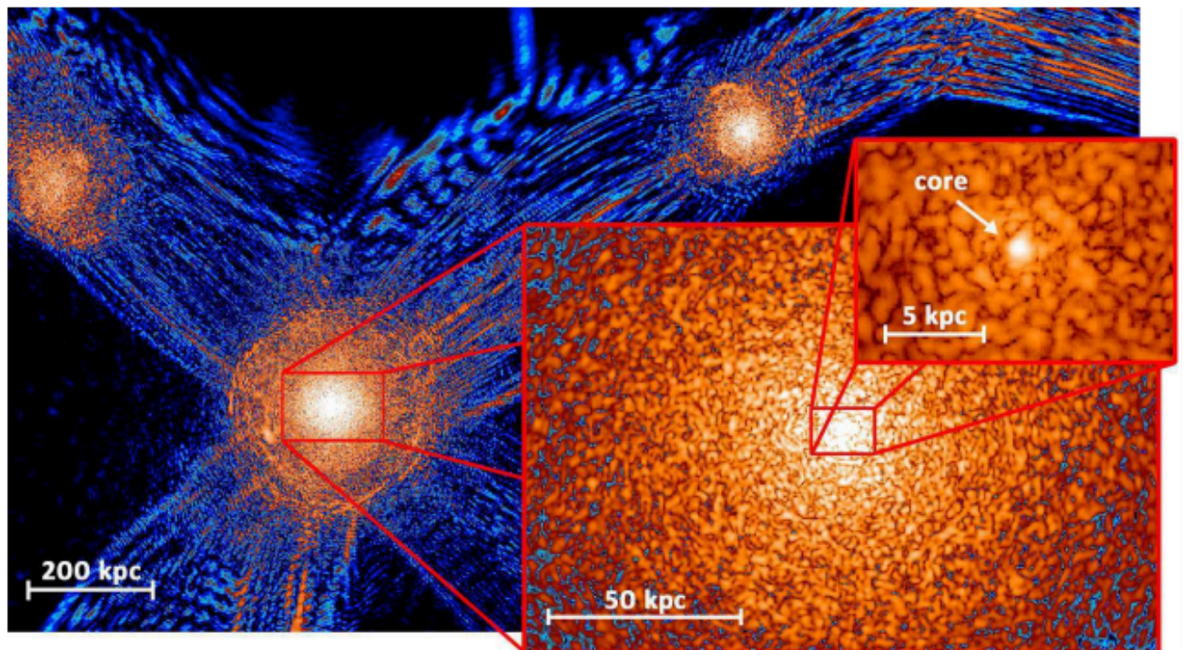
Case-study: Ultralight dark matter in the centres of galaxies

$$\lambda_{dB} = \frac{h}{mv} = 1.2 \left(\frac{10^{-22}\ \mathrm{eV}}{m} \right) \left(\frac{100\ \mathrm{km/s}}{v} \right)\ \mathrm{kpc}$$

$\gg \Delta x \equiv n^{-1/3}$ the inter-particle spacing.

Can be shown that the equations of motion reduce to Schrödinger-Poisson in the non-relativistic limit.

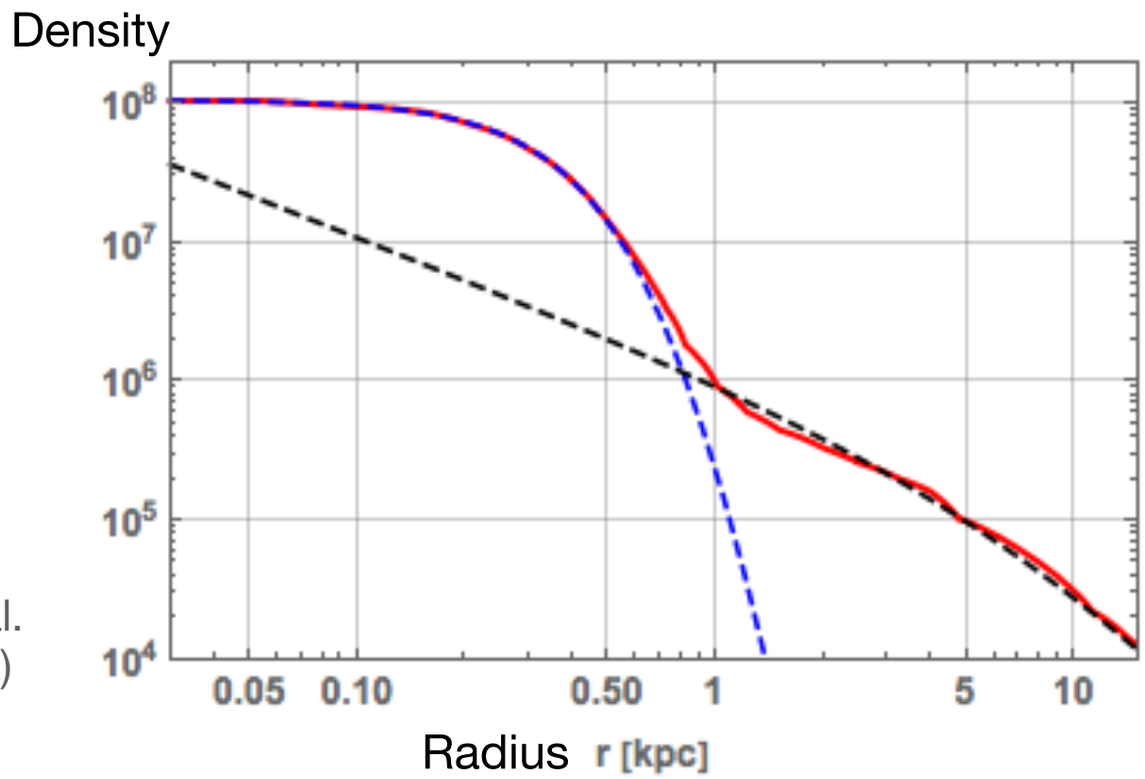
Simulations show:
Distinct core feature that we can look for in the centres of galaxies.



Schive et al.
Nat. Phys. (2014)

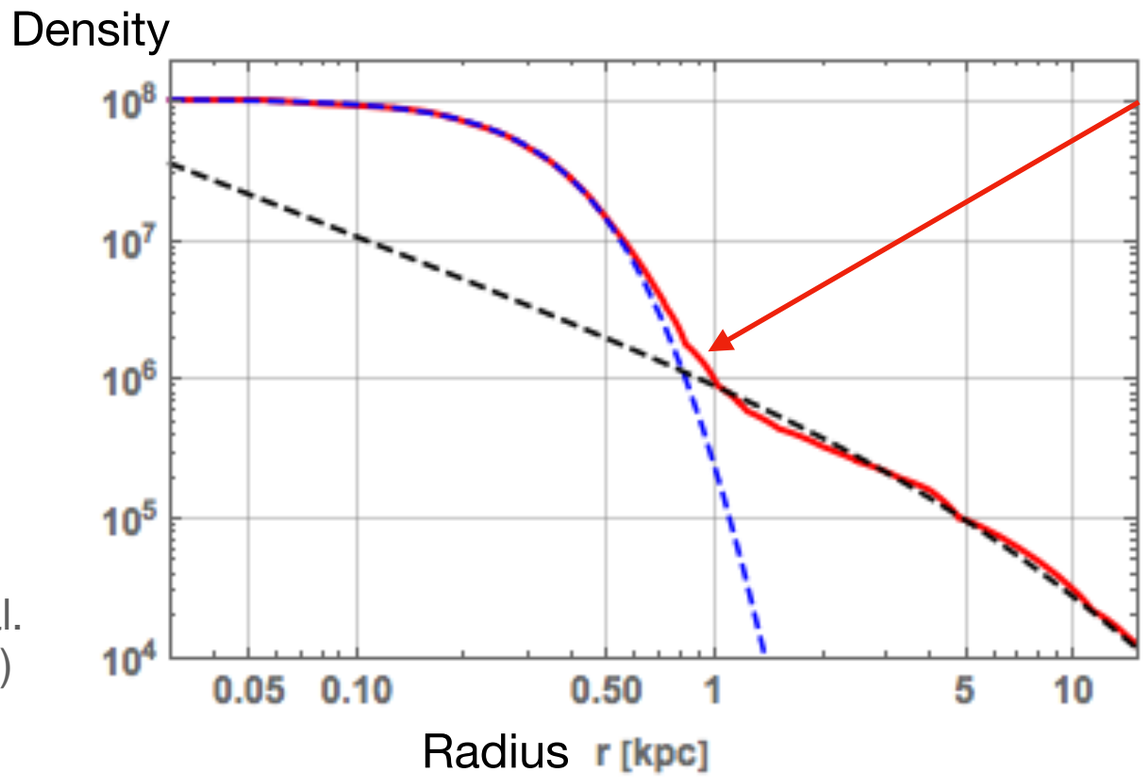
Core feature of ultralight dark matter confronted with low-surface brightness galaxies

Core feature of ultralight dark matter confronted with low-surface brightness galaxies



Schive et al.
PRL (2014)

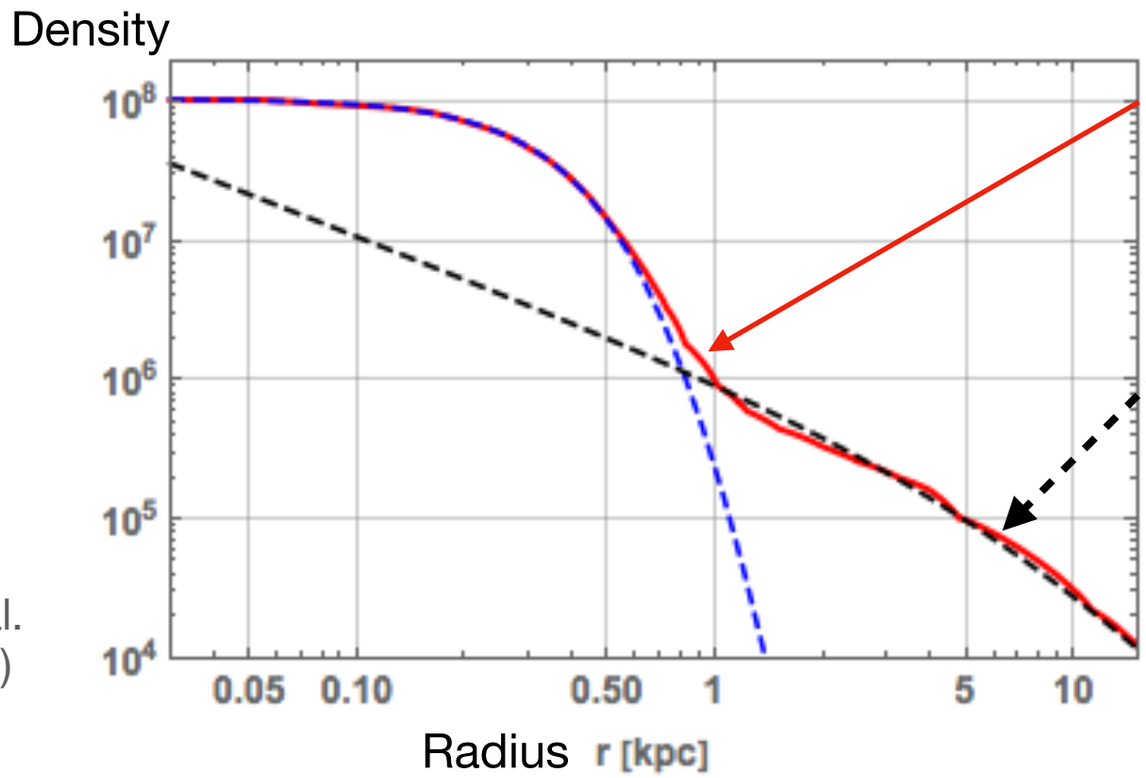
Core feature of ultralight dark matter confronted with low-surface brightness galaxies



Example of simulated halo profile

Schive et al. PRL (2014)

Core feature of ultralight dark matter confronted with low-surface brightness galaxies

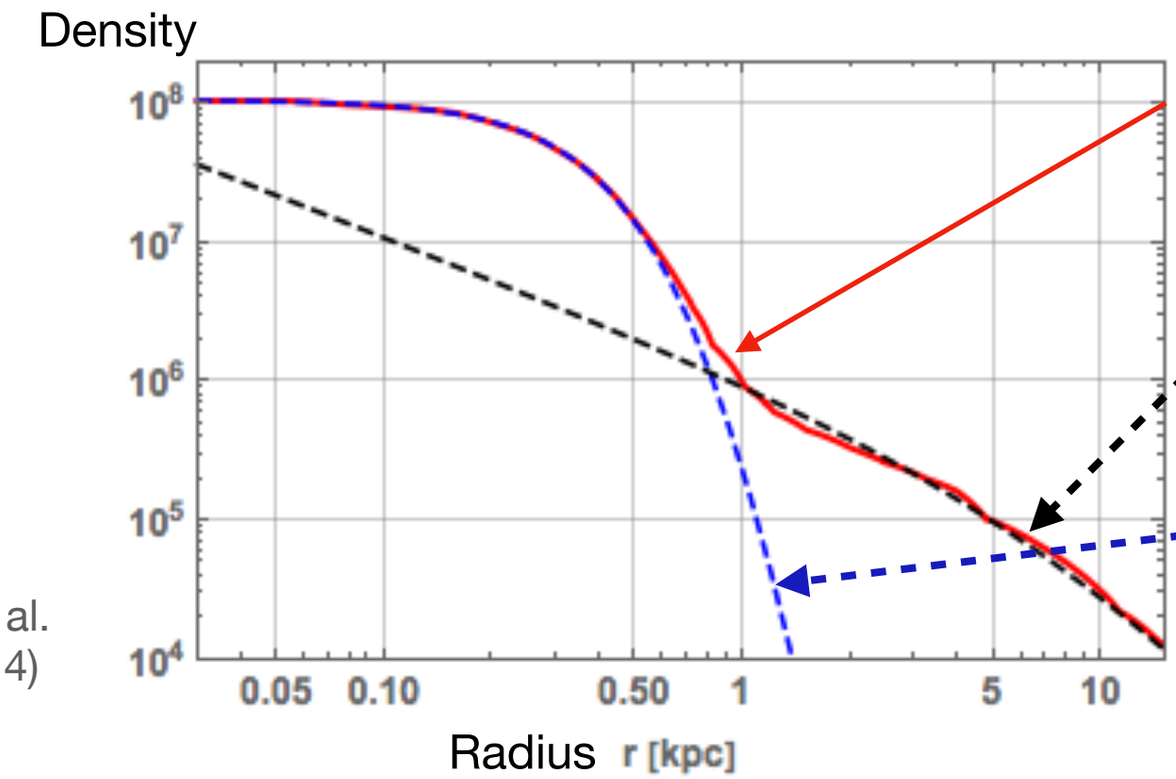


Example of simulated halo profile

NFW fit: Behaves like cold dark matter on large scales

Schive et al. PRL (2014)

Core feature of ultralight dark matter confronted with low-surface brightness galaxies



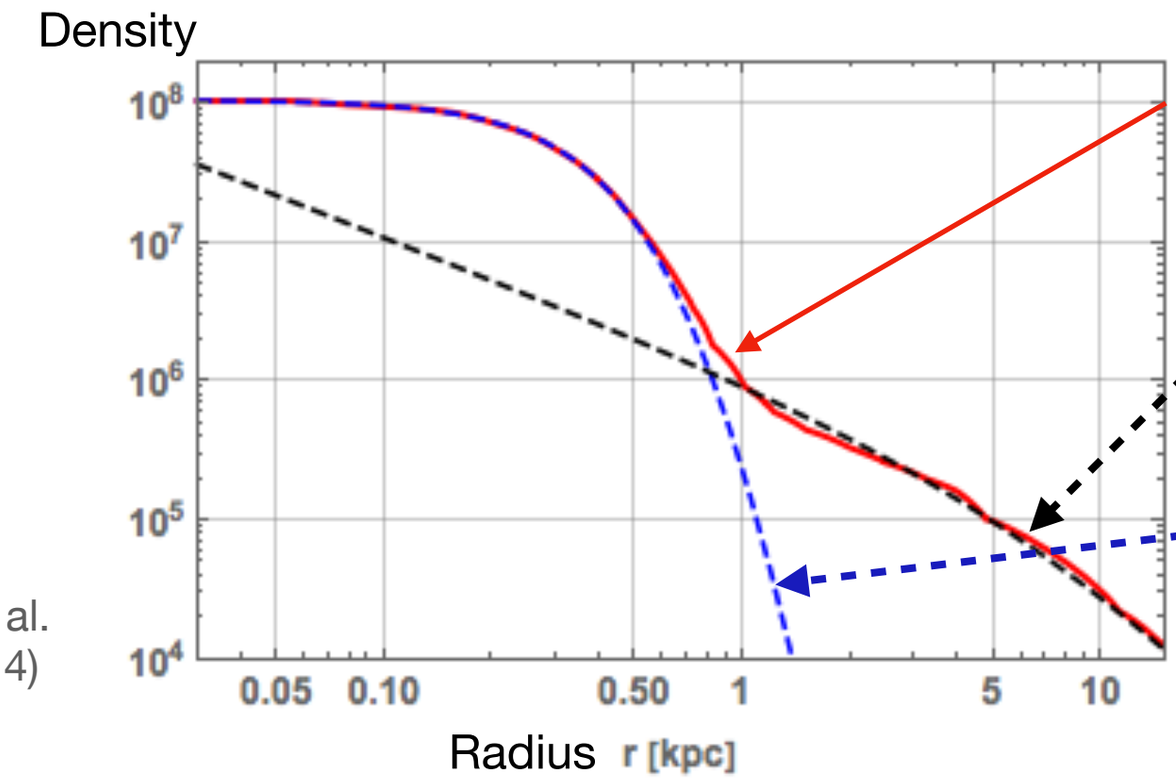
Example of simulated halo profile

NFW fit: Behaves like cold dark matter on large scales

- **Very dense core at de-Broglie scale**
- **Cores agree with ground-state solution - “soliton”. Predictive.**

Schive et al. PRL (2014)

Core feature of ultralight dark matter confronted with low-surface brightness galaxies



Example of simulated halo profile

NFW fit: Behaves like cold dark matter on large scales

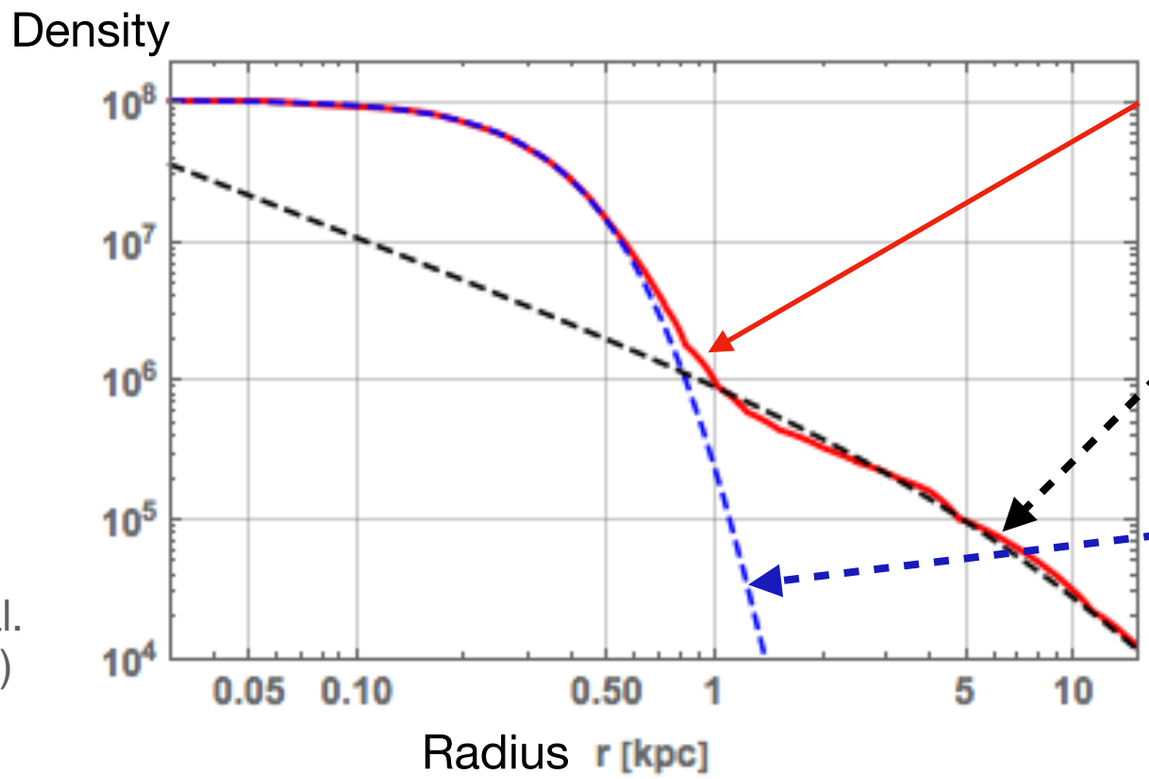
- **Very dense core at de-Broglie scale**
- **Cores agree with ground-state solution - "soliton". Predictive.**

Schive et al. PRL (2014)

Predict soliton using:

$$\max V_{\mathrm{circ,soliton}} \approx \max V_{\mathrm{circ,halo}}$$

Core feature of ultralight dark matter confronted with low-surface brightness galaxies



Example of simulated halo profile

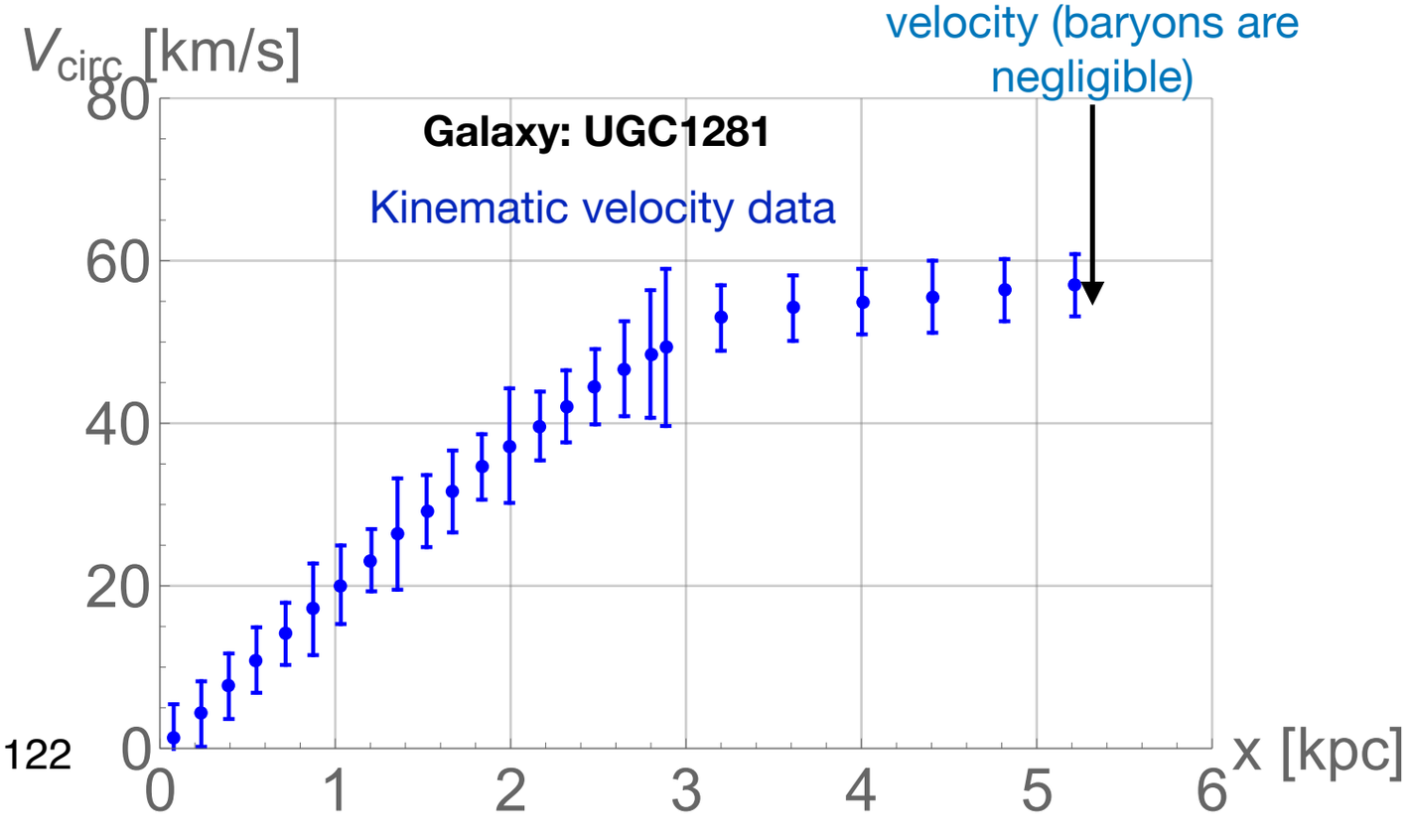
NFW fit: Behaves like cold dark matter on large scales

- **Very dense core at de-Broglie scale**
- **Cores agree with ground-state solution - "soliton". Predictive.**

Schive et al. PRL (2014)

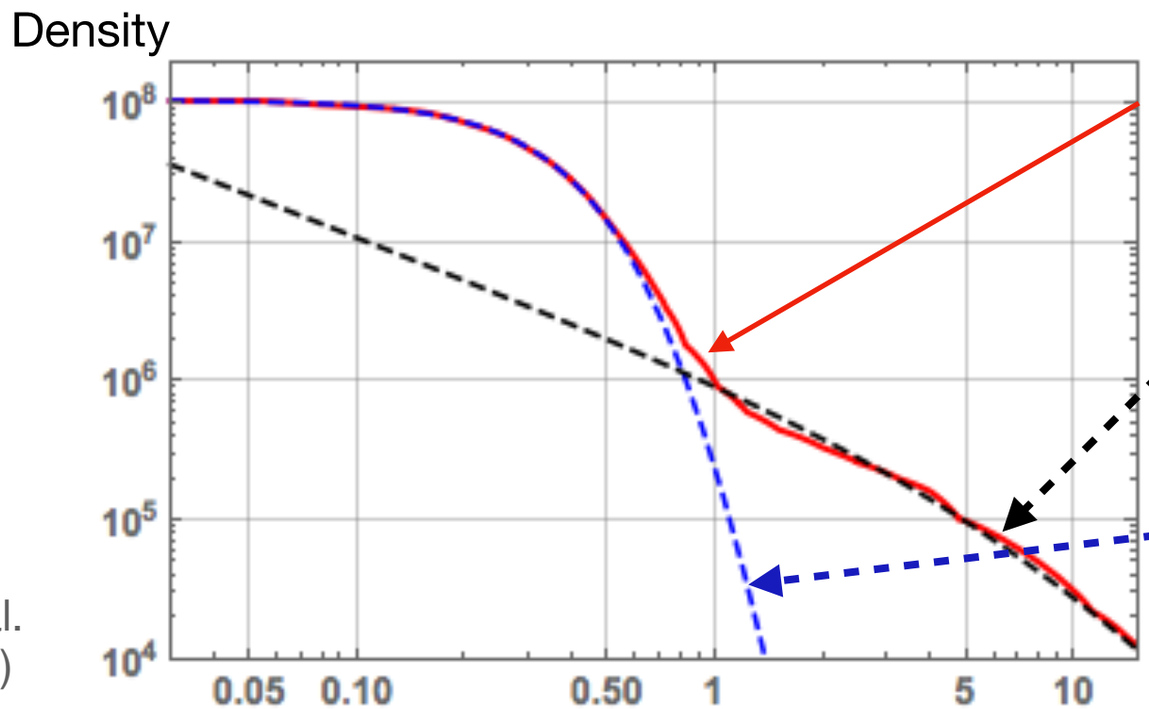
Predict soliton using:

$$\max V_{\mathrm{circ,soliton}} \approx \max V_{\mathrm{circ,halo}}$$



NB, Blas, Blum, Sibiryakov, 1805.00122

Core feature of ultralight dark matter confronted with low-surface brightness galaxies



Example of simulated halo profile

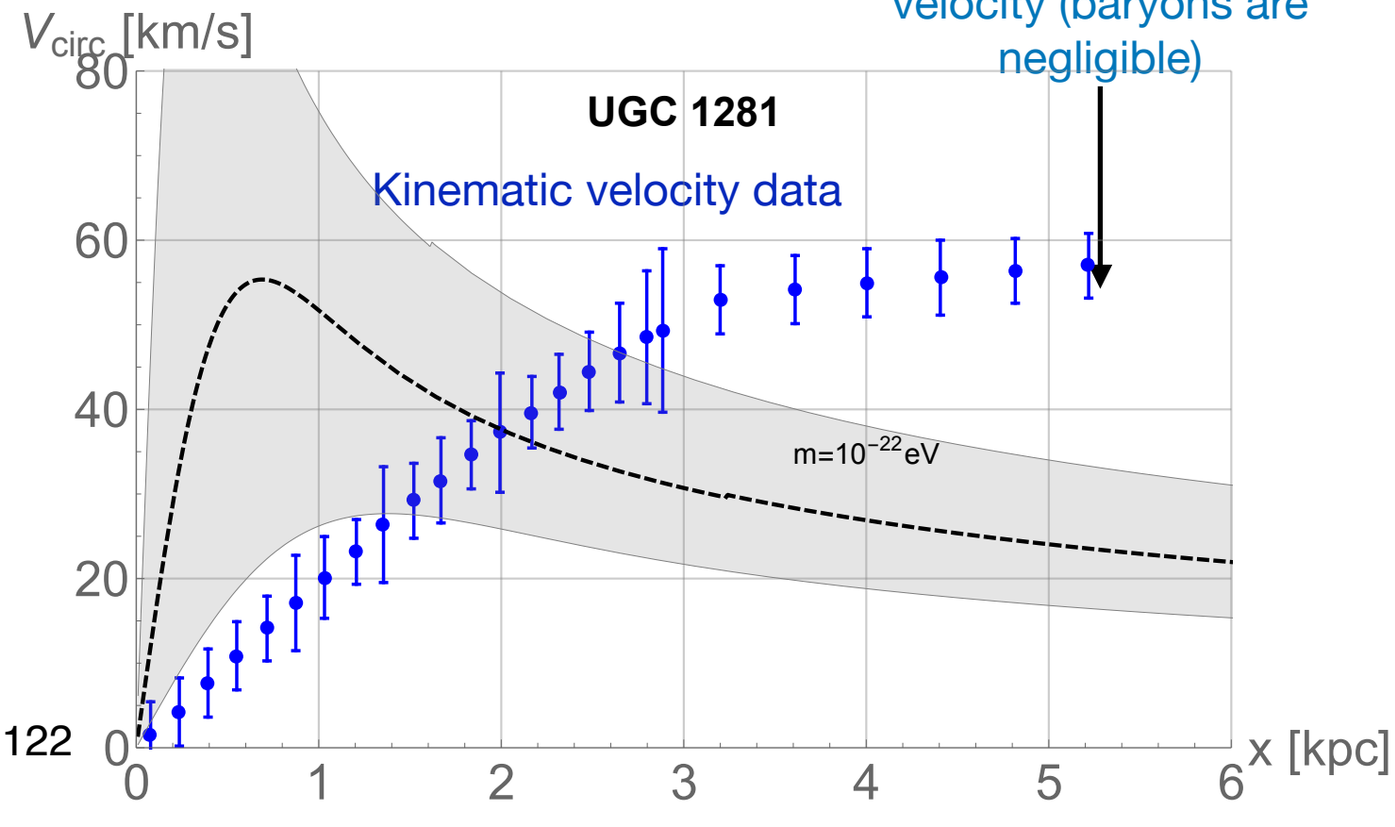
NFW fit: Behaves like cold dark matter on large scales

- **Very dense core at de-Broglie scale**
- **Cores agree with ground-state solution - "soliton". Predictive.**

Schive et al. PRL (2014)

Predict soliton using:

$$\max V_{\mathrm{circ,soliton}} \approx \max V_{\mathrm{circ,halo}}$$



NB, Blas, Blum, Sibiryakov, 1805.00122

Case-study: Ultralight dark matter - conclusions

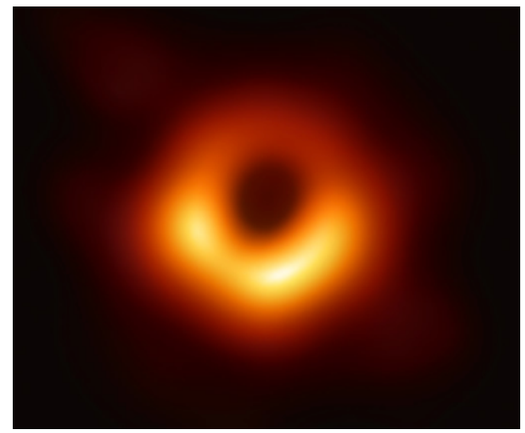
Case-study: Ultralight dark matter - conclusions

- Data on rotation curves disfavour crucial parameter space, $m \approx 10^{-22} - 10^{-21}\, eV$
  NB, Blas, Blum, Sibiryakov 1805.00122

Case-study: Ultralight dark matter - conclusions

- Data on rotation curves disfavour crucial parameter space, $m \approx 10^{-22} - 10^{-21}\, eV$
  NB, Blas, Blum, Sibiryakov 1805.00122

- The core feature can be sought for in smaller-scales, even near supermassive black holes
  NB, Blum, Lacroix, Panci 1905.11745



Case-study: Ultralight dark matter - conclusions

- Data on rotation curves disfavour crucial parameter space, $m \approx 10^{-22} - 10^{-21}\, eV$
  NB, Blas, Blum, Sibiryakov 1805.00122

- The core feature can be sought for in smaller-scales, even near supermassive black holes
  NB, Blum, Lacroix, Panci 1905.11745

- Bound is complementary to Lyman-alpha probe.
  Kobayashi et al. (2017), etc.

Outlook

Outlook

- In another project in this theme - we look into the “timing problem” in the Fornax dwarf galaxy and look into dynamical friction in non-CDM classes of dark matter.

Ongoing, w/ Diego Blas, Kfir Blum, Hyungjin Kim

Outlook

- In another project in this theme - we look into the “timing problem” in the Fornax dwarf galaxy and look into dynamical friction in non-CDM classes of dark matter.
  Ongoing, w/ Diego Blas, Kfir Blum, Hyungjin Kim

- I’m also interested in coming up with observables that reflect the nature of dark matter in our galaxy and can be tested with *Gaia* data.