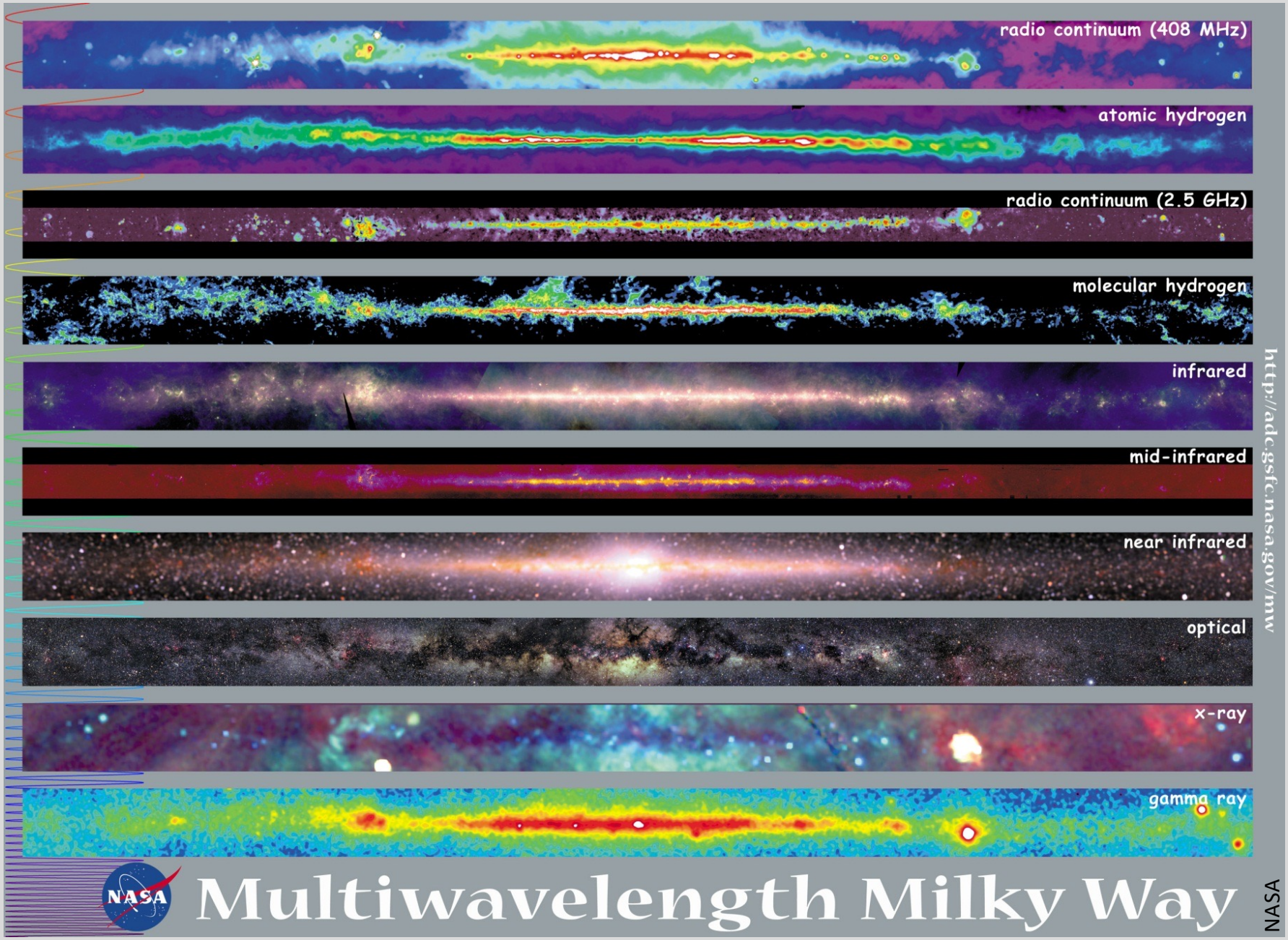
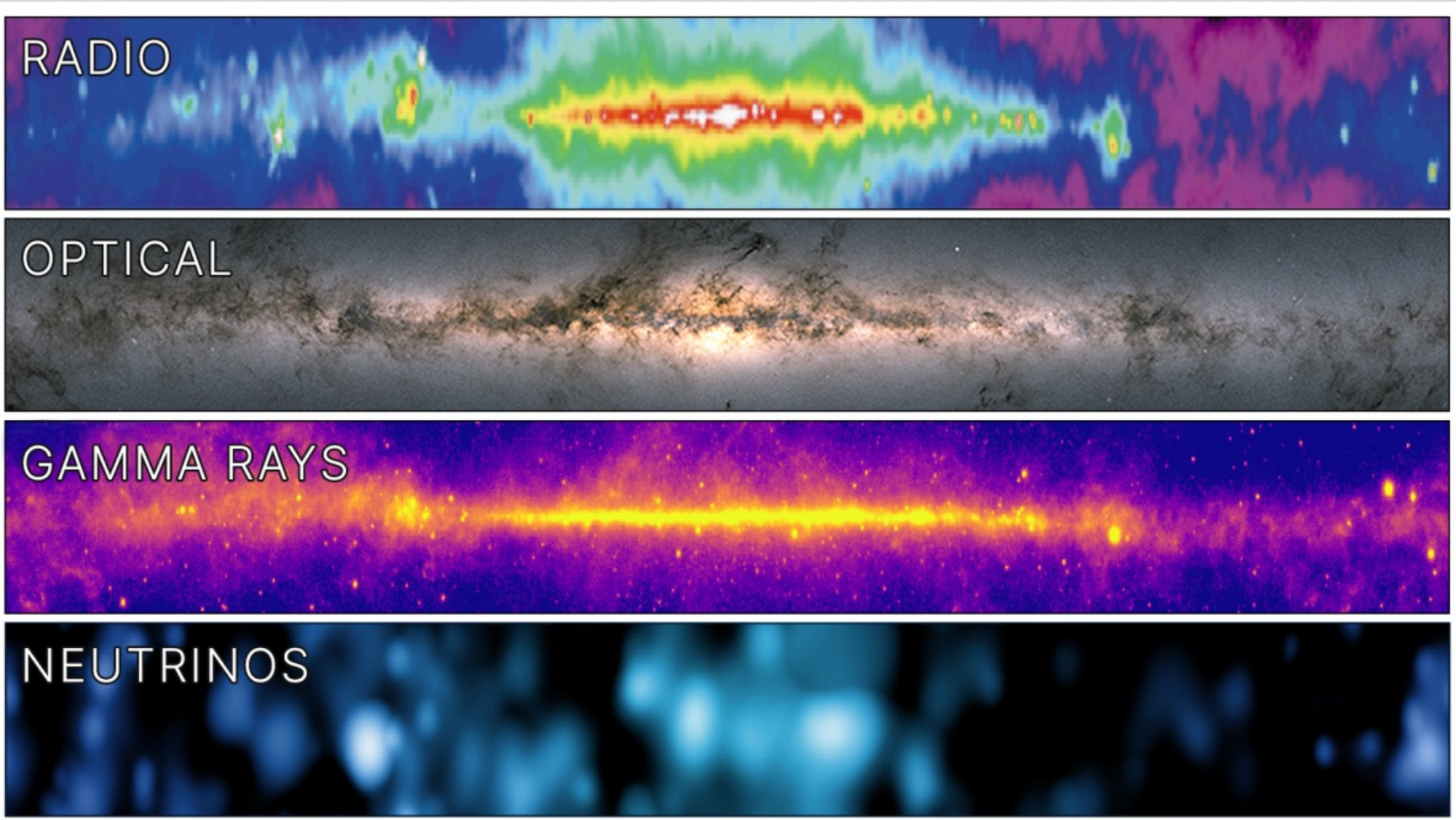

From darkness to light:
indirect searches for dark matter
Dominik Elsässer
TU Dortmund
DFG CRC 1491 General Assembly 2023
06.11.2023
SFB1491
ESO


ESO


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
Multiwavelength Milky Way
http://adc.gsfc.nasa.gov/mw/
NASA



IceCube Collaboration

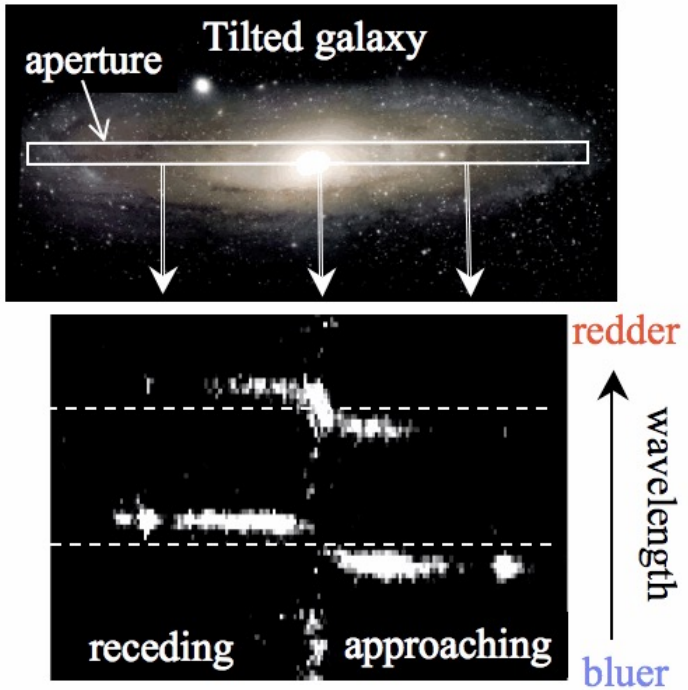
- IceCube Collaboration et al., „Observation of high-energy neutrinos from the Galactic plane“, SCIENCE Vol 380, Issue 6652, pp. 1338-1343 (2023), DOI: 10.1126/science.adc9818
- PhD thesis M. Hünnefeld within CRC 1491 (2023)

$$\mathrm{KE}_{\mathrm{avg}} = -\frac{1}{2}\ \mathrm{GPE}_{\mathrm{avg}}$$

Fritz Zwicky, *Helv. Phys. Acta*, 1934

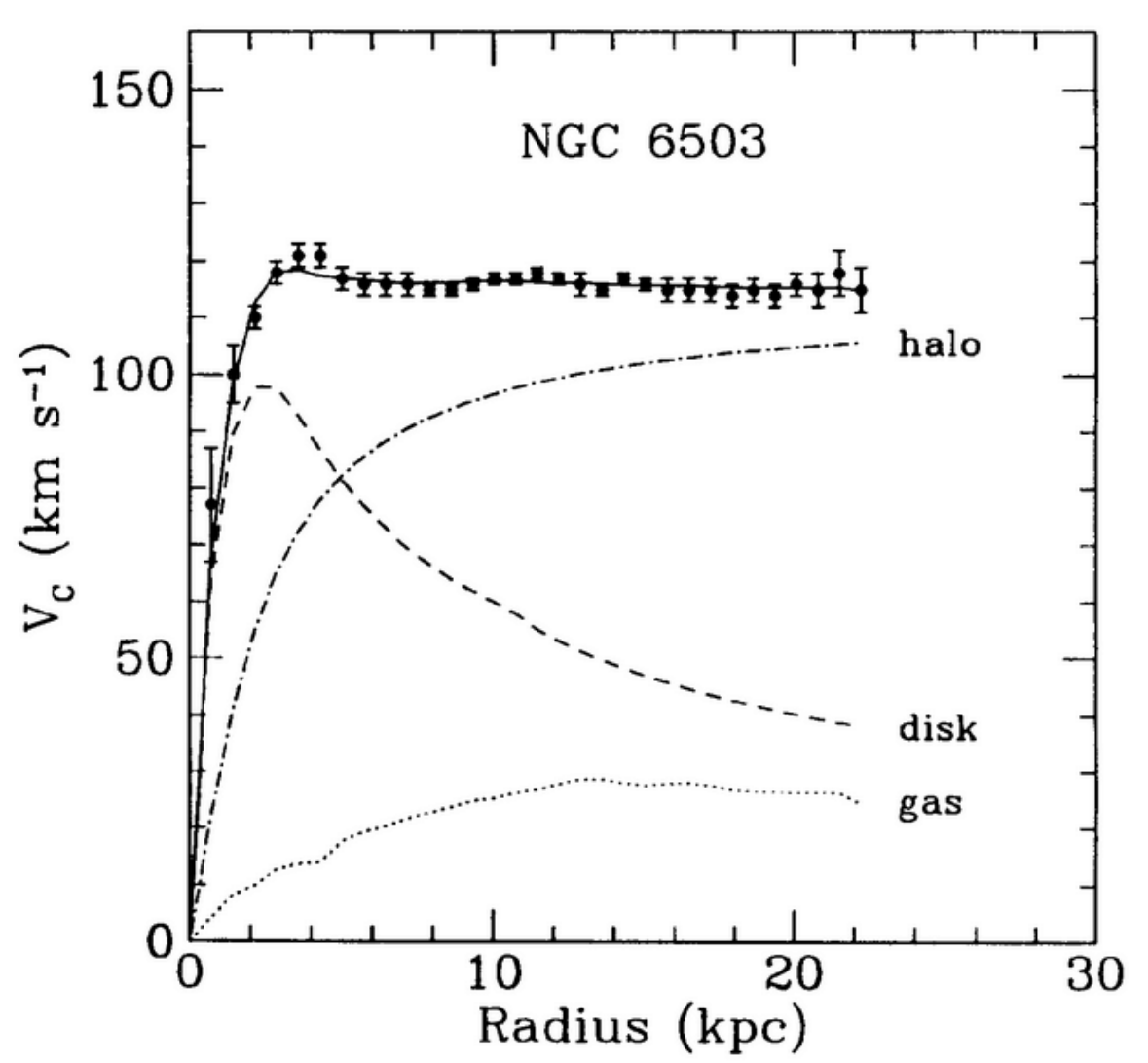
Vera Rubin ca. 1970

Vera Rubin measuring galaxy rotation curves (~1970)



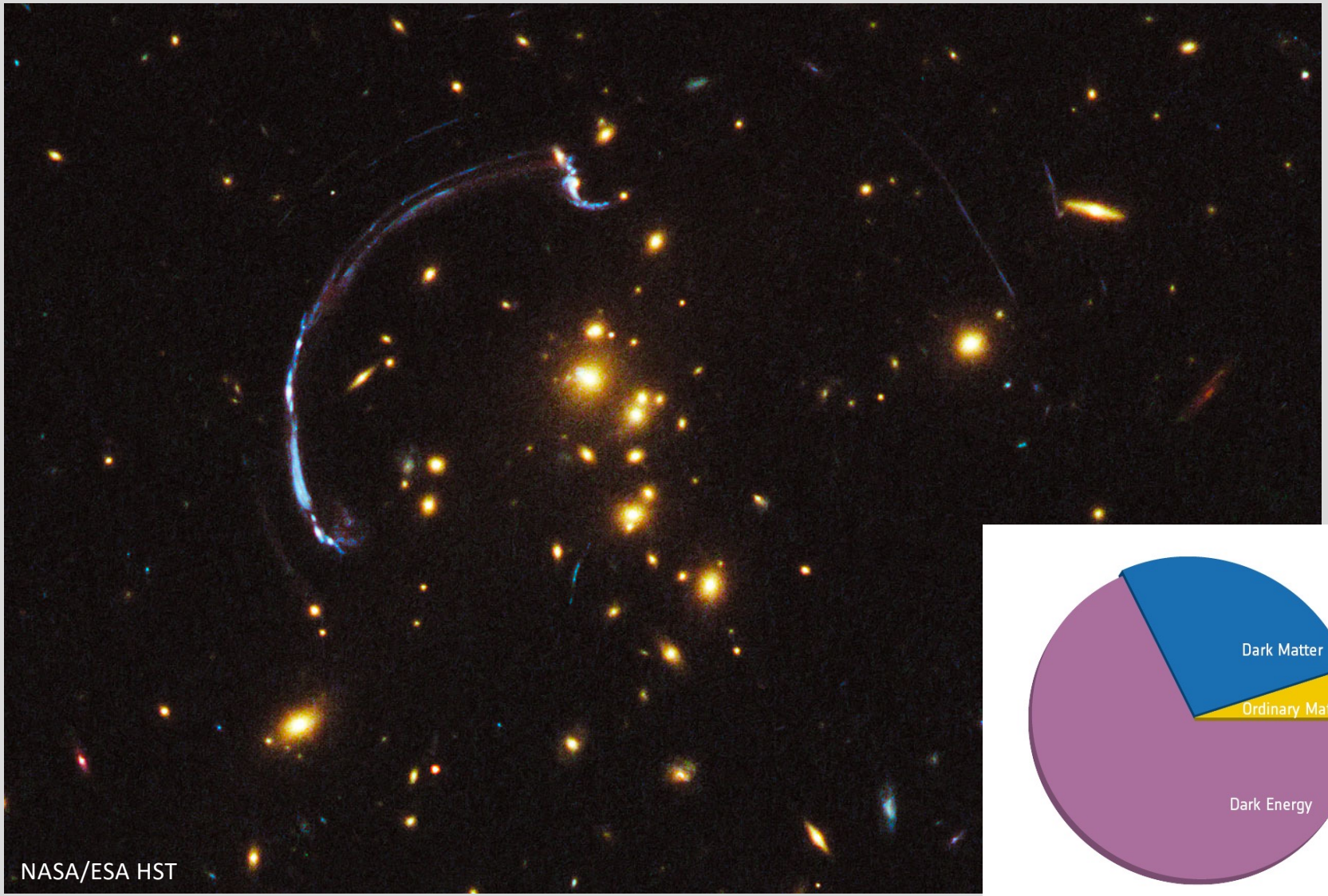
Resulting spectrum of light within aperture

Typical rotation curves of spiral galaxies often display dynamical dominance of DM



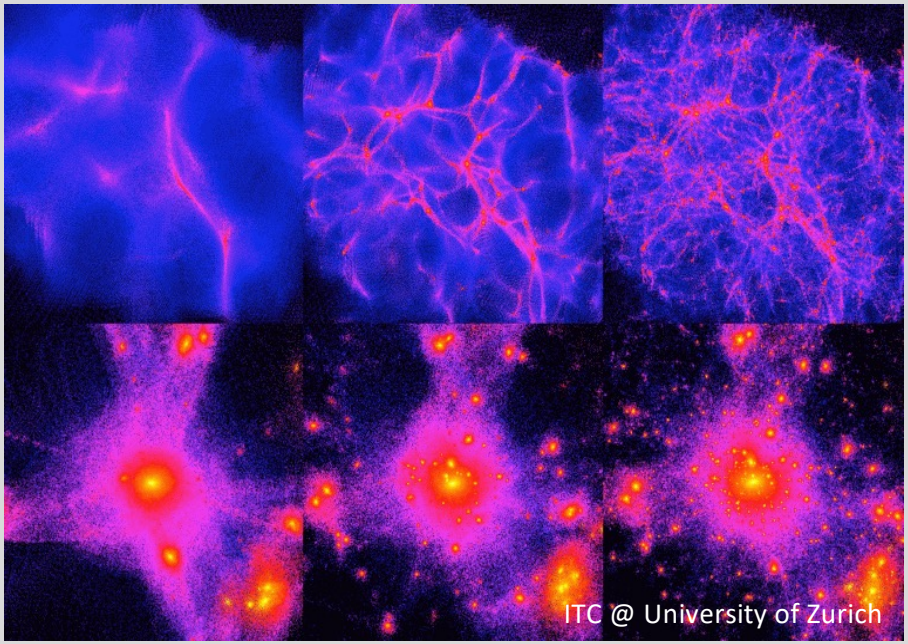
Katherine Freese

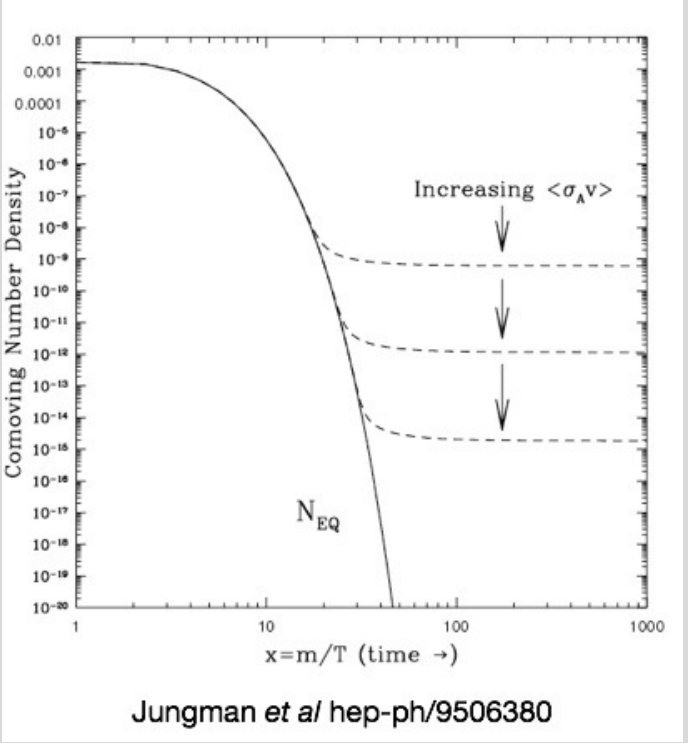
Dynamics of matter, pathways of light



Why are we so often talking about WIMP DM?

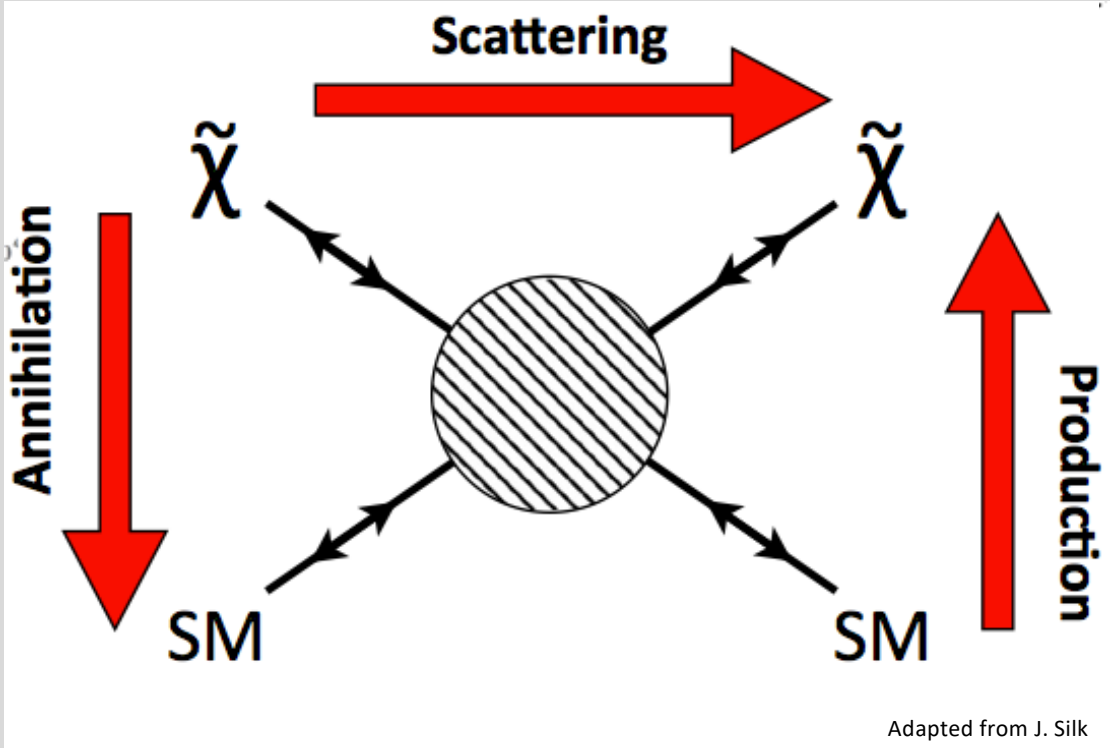
- No plausible candidates from the Standard Model of particle physics
- Massive astrophysical objects in the Galaxy constrained by microlensing
- Thermal freeze-out of weakly interacting particles with masses of order electroweak scale can reproduce the observed DM density
- Large-scale structure as a probe
- Not exclusive: there may be room e.g. for Axion DM, sterile neutrino DM...





Jungman *et al* hep-ph/9506380

Toolkit for WIMP – searches



Indirect searches

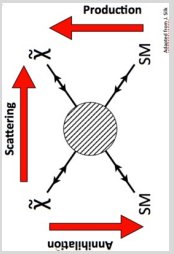
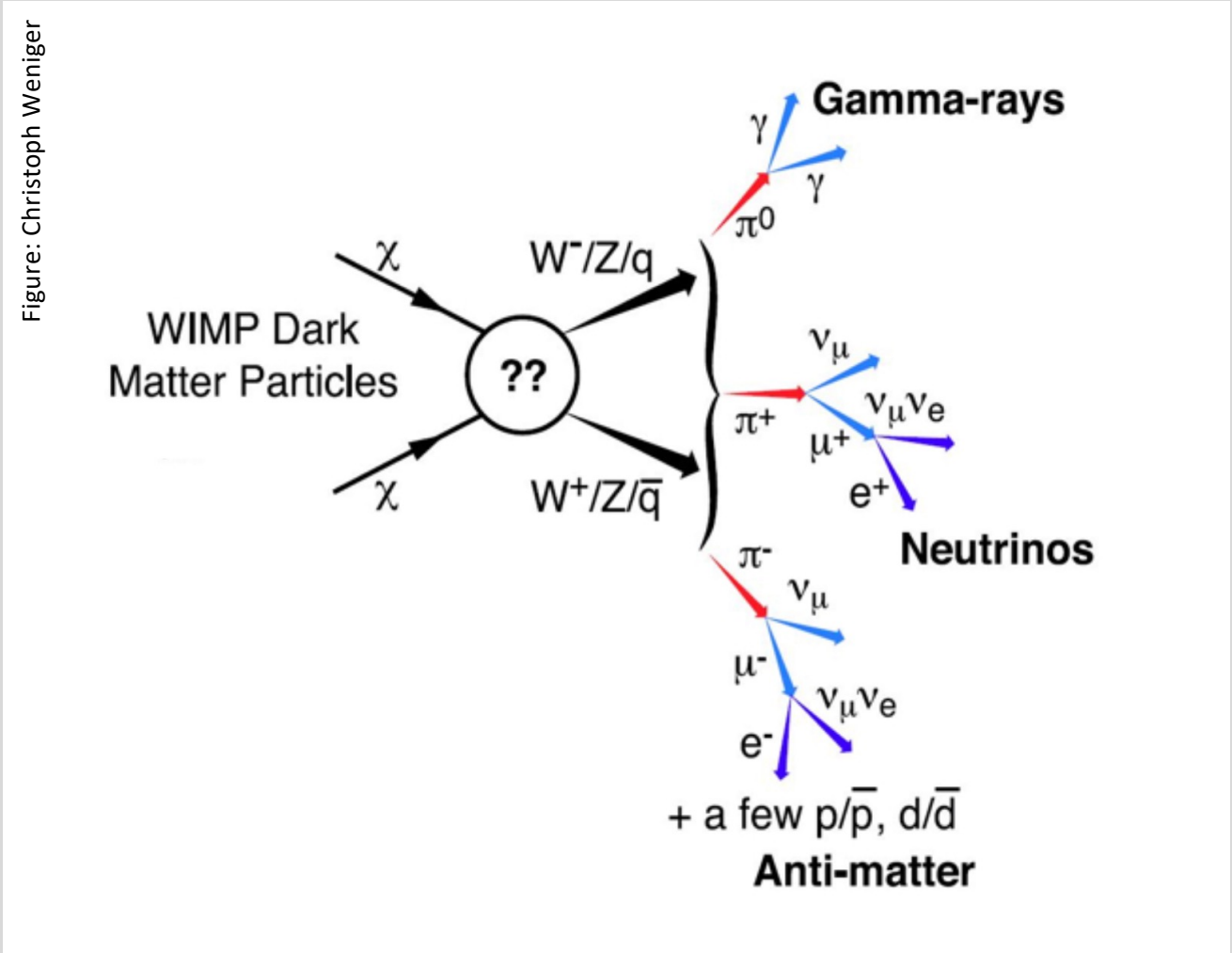
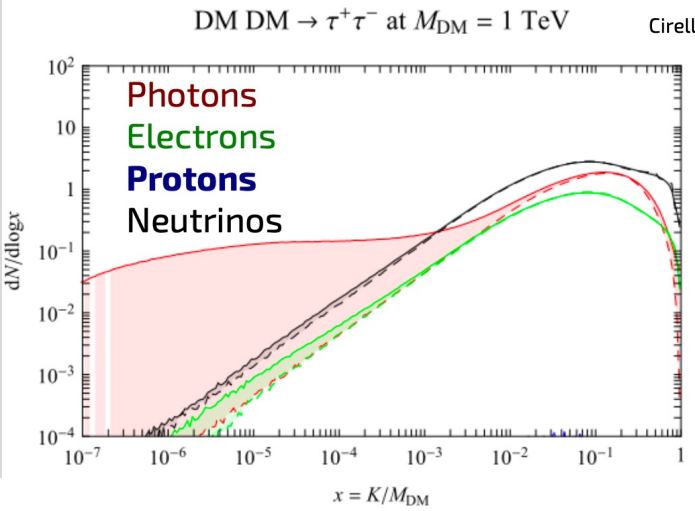


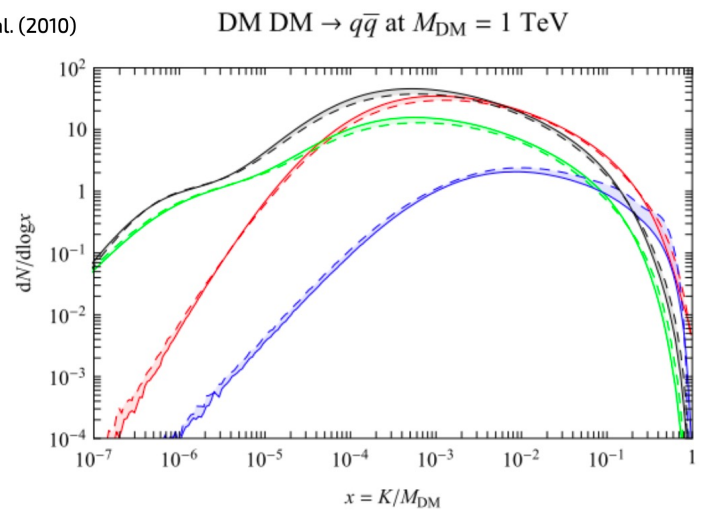
Figure: Christoph Weniger



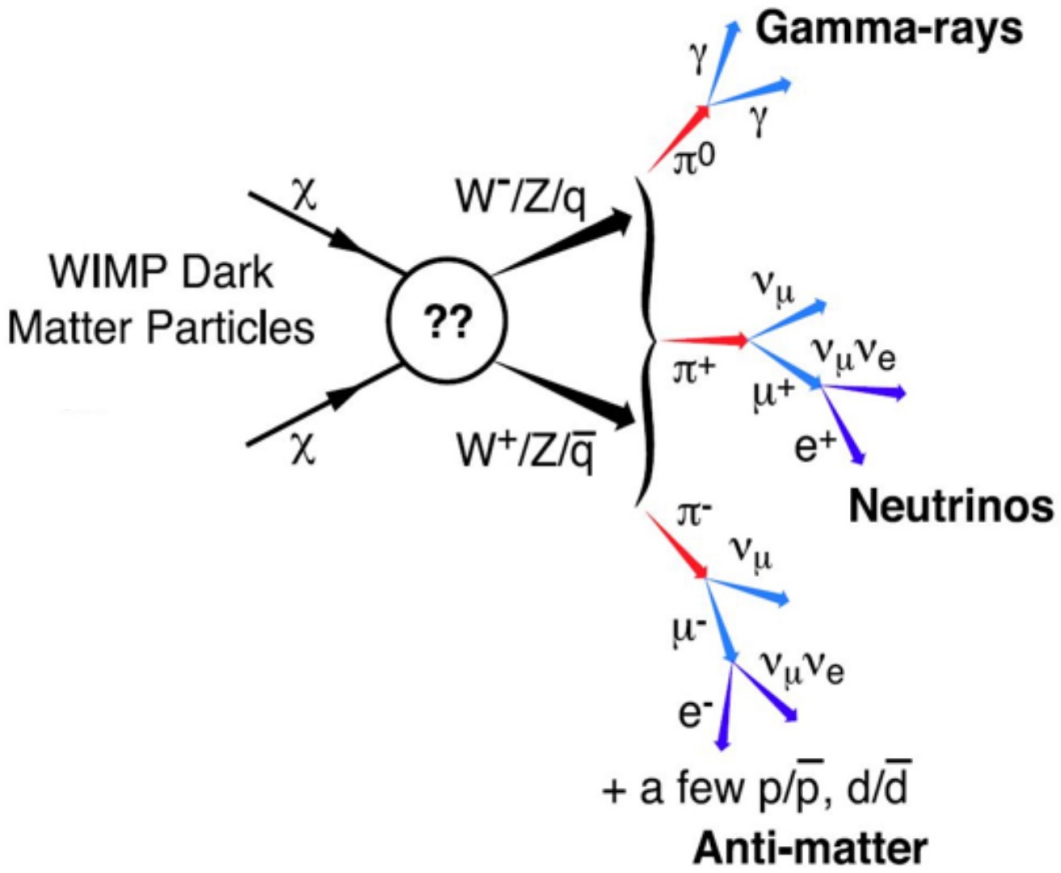
- Basic idea: we look out for photons, neutrinos, or charged SM particles from annihilation or decay of WIMPs
- Dark truth: we have to do that without knowing the exact channels and ratios
- Input from particle physics towards precision is highly valuable



Cirelli et al. (2010)



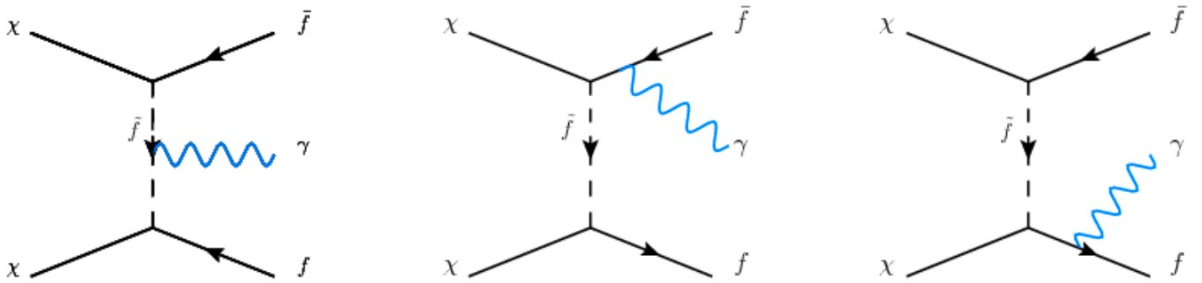
Figures: Christoph Weniger



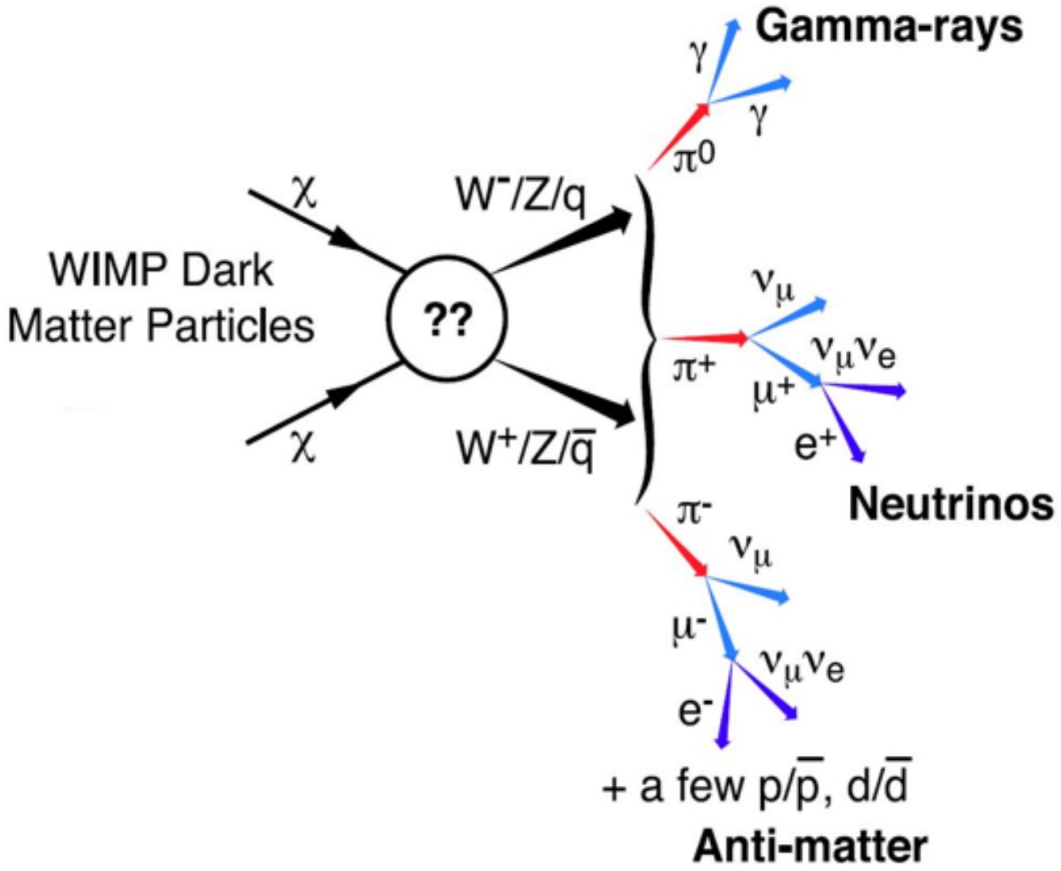
- Naive expectation: relatively „soft“ pion decay spectra; maxima at $O(0.001 — 0.1\ m_{DM})$
- Heavy competition from non-DM astrophysical processes

Figures: Christoph Weniger

$$\chi\chi \to \bar{f} f \gamma$$

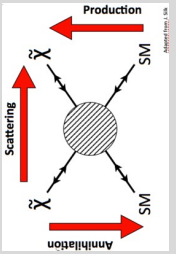


[e.g. Bringmann, Bergström & Edsjö (2008)]



- Naive expectation: relatively „soft“ pion decay spectra; maxima at $O(0.001 — 0.1\ m_{DM})$
- Heavy competition from non-DM astrophysical processes
- Examples for aforementioned input: better understanding of the relevance of internal Bremsstrahlung and FSR

Indirect searches

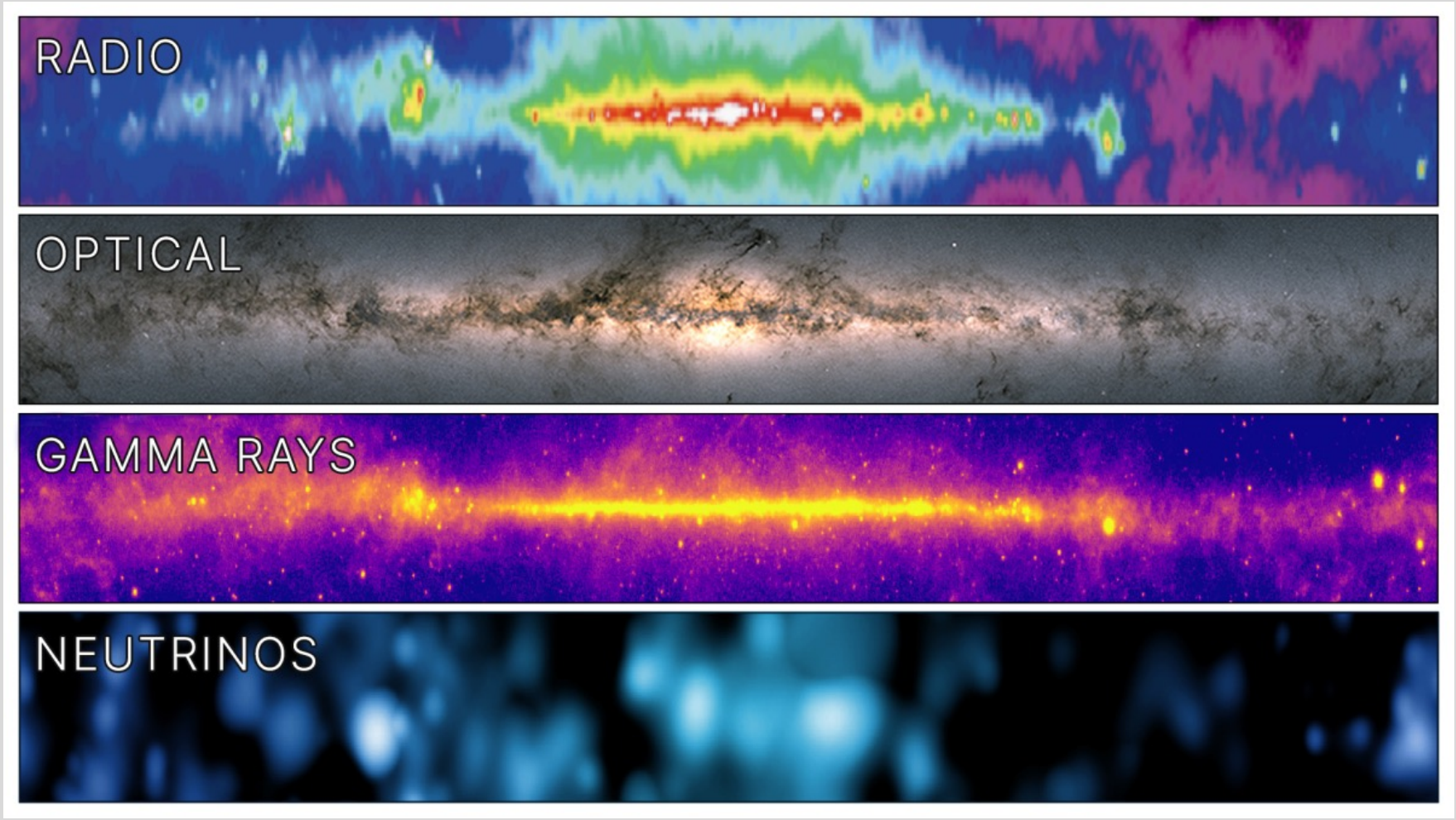


- Until a detection is made, task is to extract limits to constrain parameter space
- Expected fluxes governed by astro- and particle physics

$$\frac{\mathrm{d}\Phi\left(\Delta\Omega, E_\gamma\right)}{\mathrm{d}E_\gamma} = \underbrace{\mathcal{J}\left(\Delta\Omega\right)}_{\text{Astrophysics}} \cdot \underbrace{\frac{1}{4\pi} \frac{\langle\sigma_{ann} v\rangle}{2m_\chi^2} \sum_i \mathrm{BR}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma}}_{\text{Particle physics}}$$

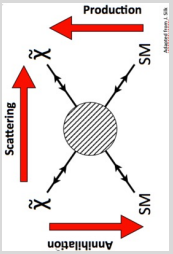
$$\mathcal{J}\left(\Delta\Omega\right) = \int_{\Delta\Omega} d\Omega' \int_{\text{l.o.s.}} dl\, \rho^2(l, \Omega')$$

- Very important addition: transport and backgrounds → plasma-(astro)physics



IceCube Collaboration

Indirect searches



$$\frac{\mathrm{d}\Phi\left(\Delta\Omega, E_\gamma\right)}{\mathrm{d}E_\gamma} = \underbrace{\mathcal{J}\left(\Delta\Omega\right)}_{\text{Astrophysics}} \cdot \frac{1}{4\pi} \underbrace{\frac{\langle\sigma_{ann}v\rangle}{2m_\chi^2} \sum_i \mathrm{BR}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E_\gamma}}_{\text{Particle physics}}$$

$$\mathcal{J}\left(\Delta\Omega\right) = \int_{\Delta\Omega} d\Omega' \int_{\text{l.o.s.}} dl\, \rho^2(l, \Omega')$$

- Cosmological surveys are powerful tools for unravelling DM distribution on a range of scales
- CRC 1491 Project F5

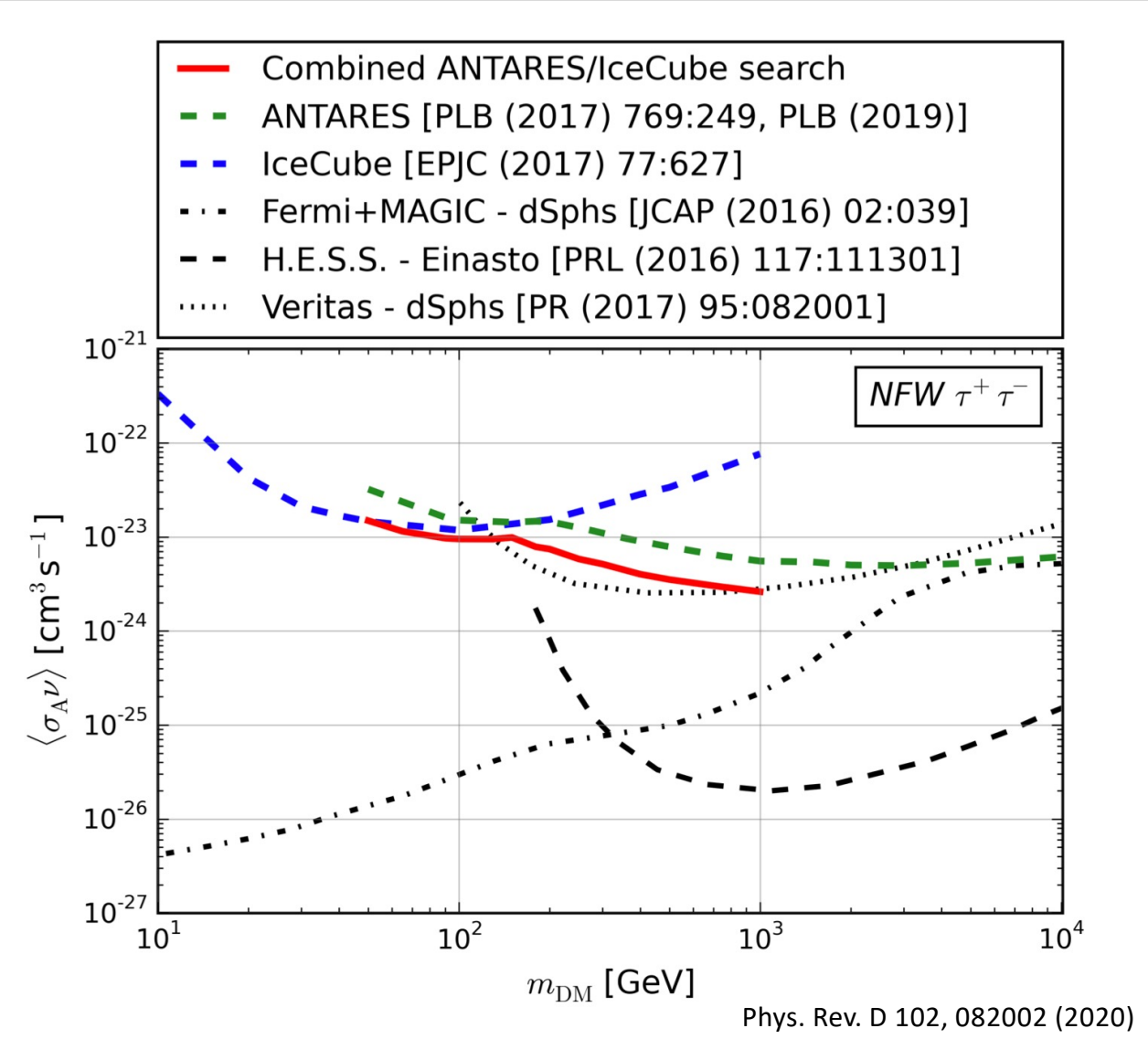
$$\rho(r) = \frac{\rho_0}{(r/r_s)(1 + r/r_s)^2}$$

Navarro, Frenk & White 1996

Some highlight targets

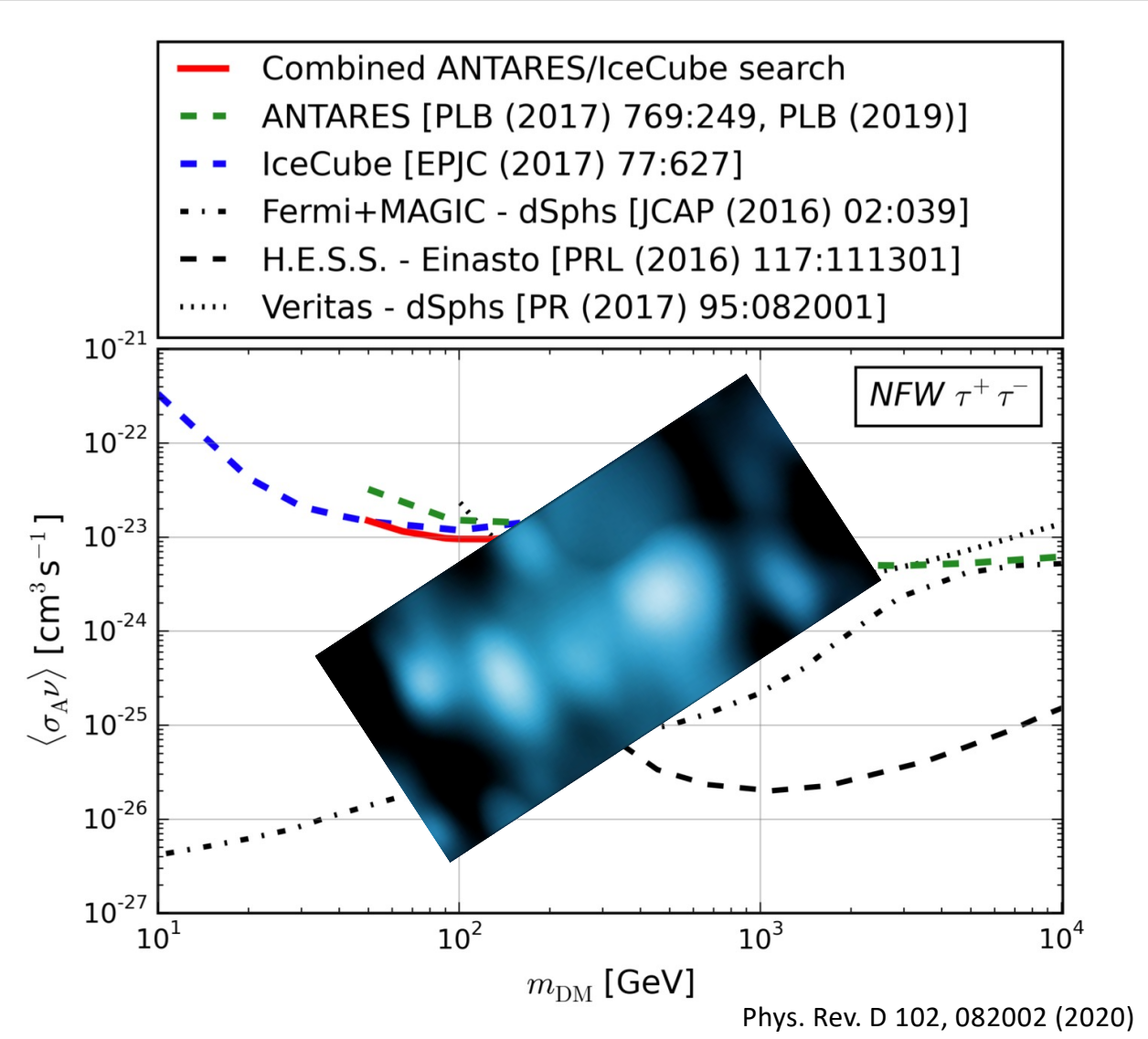
- Galactic center
- Nearby clusters of galaxies
- Large-scale structure
- Dwarf galaxies

Galactic center: multi-messenger searches



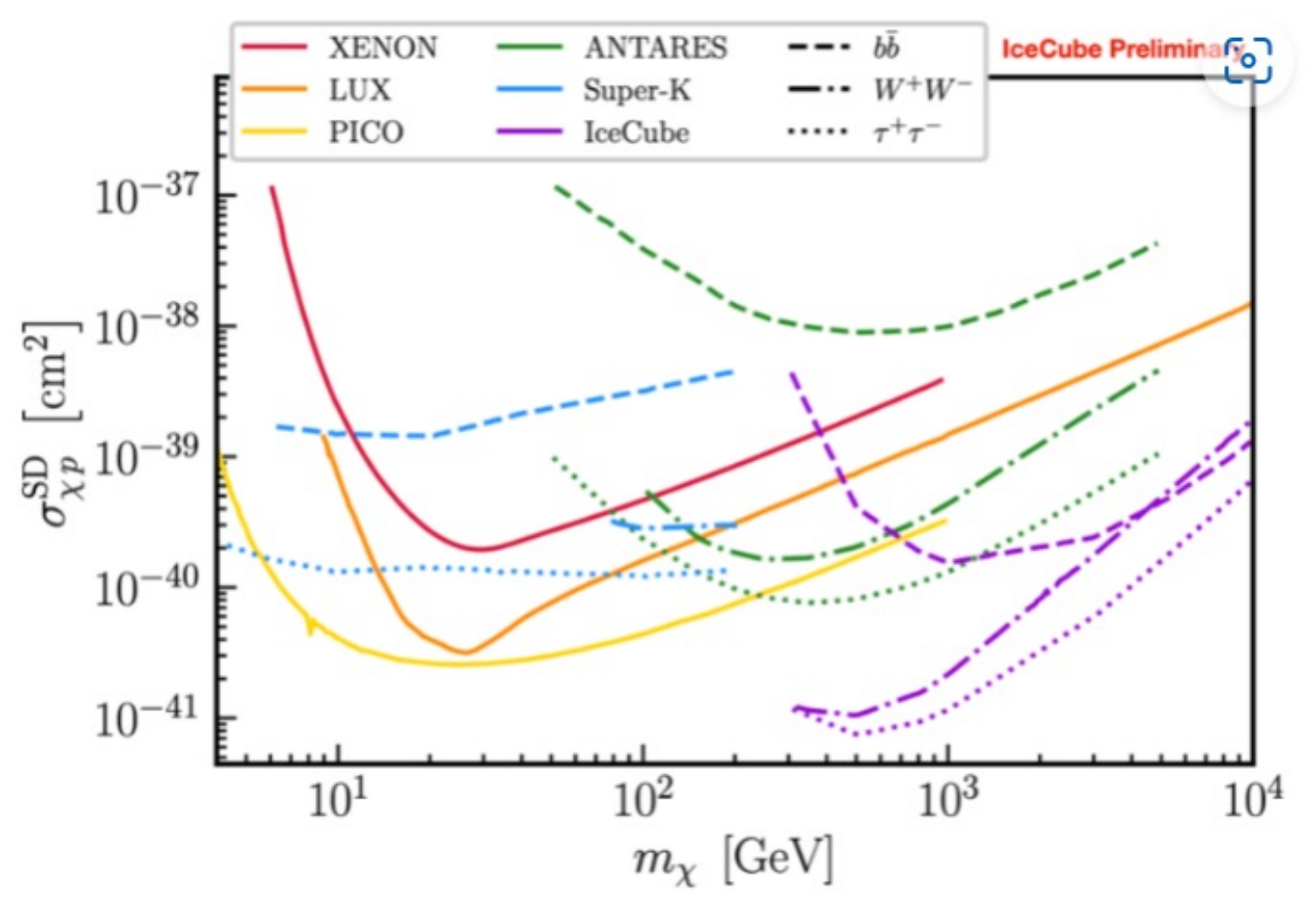
Phys. Rev. D 102, 082002 (2020)

Galactic center: multi-messenger searches



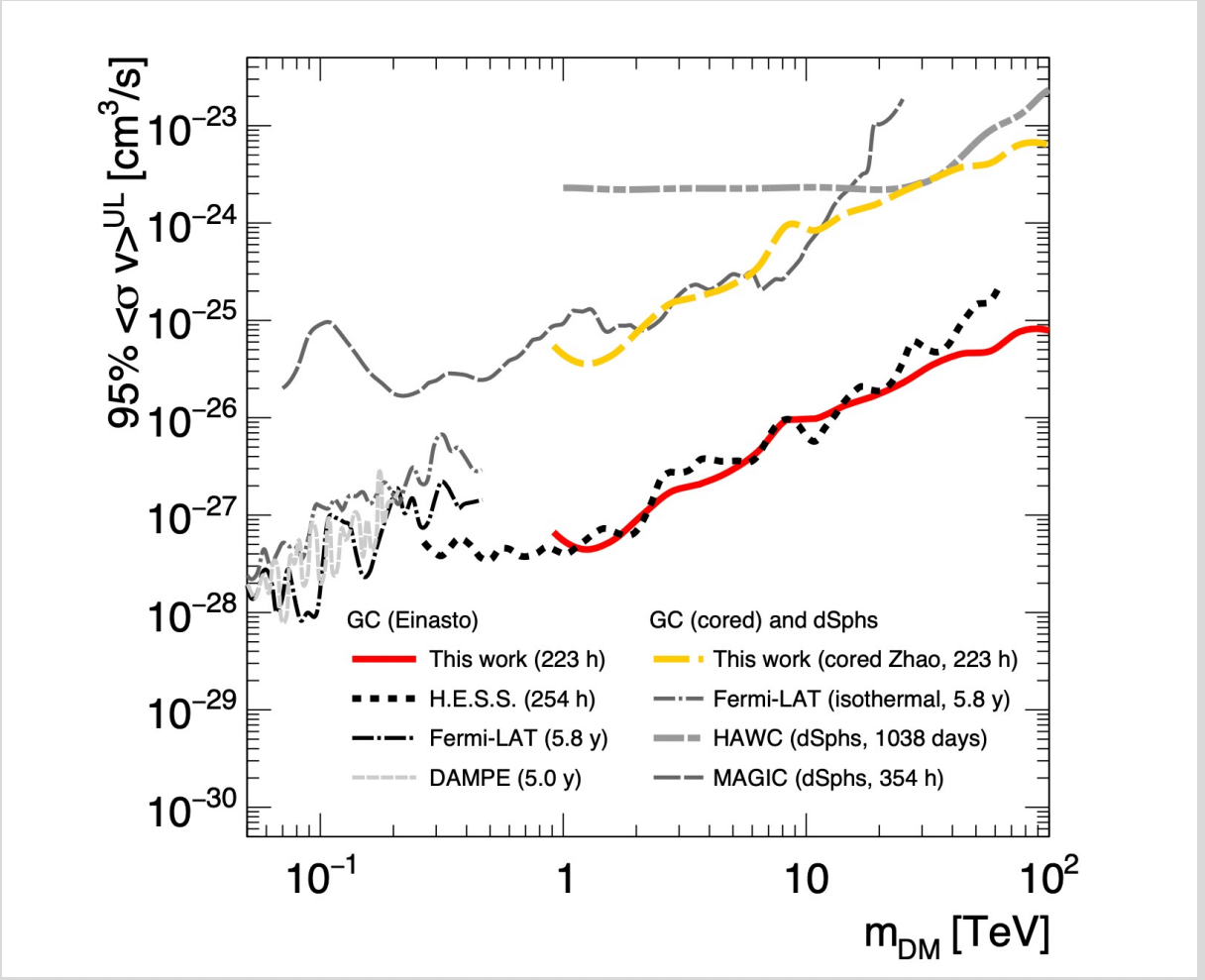
Phys. Rev. D 102, 082002 (2020)

Centers of Sun and Earth: scattering cross-sections with IceCube



Searches for gamma-ray lines from DM annihilation

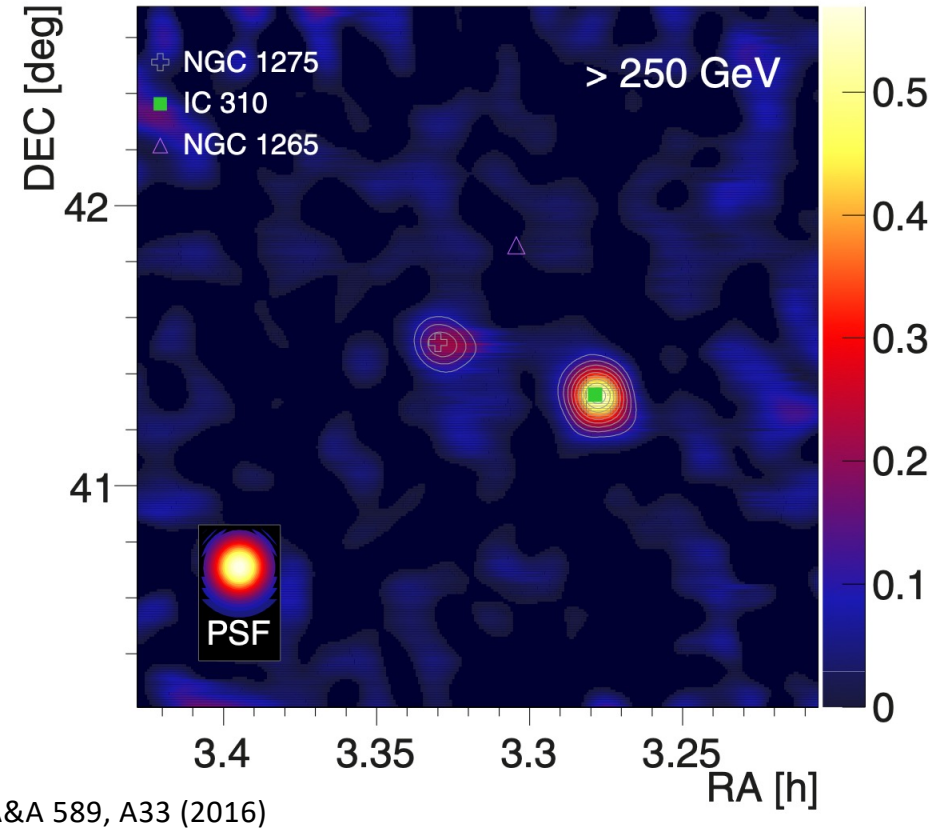
- In addition to the pion-decay spectra, VHE lines may arise from loop-level annihilation directly to photos
- Imaging air-Cherenkov telescopes are powerful tools to search for this processes
- Backgrounds less critical (but understanding still needed!) → Galactic center an outstanding target
- Close connection to CRC 1491 project A1

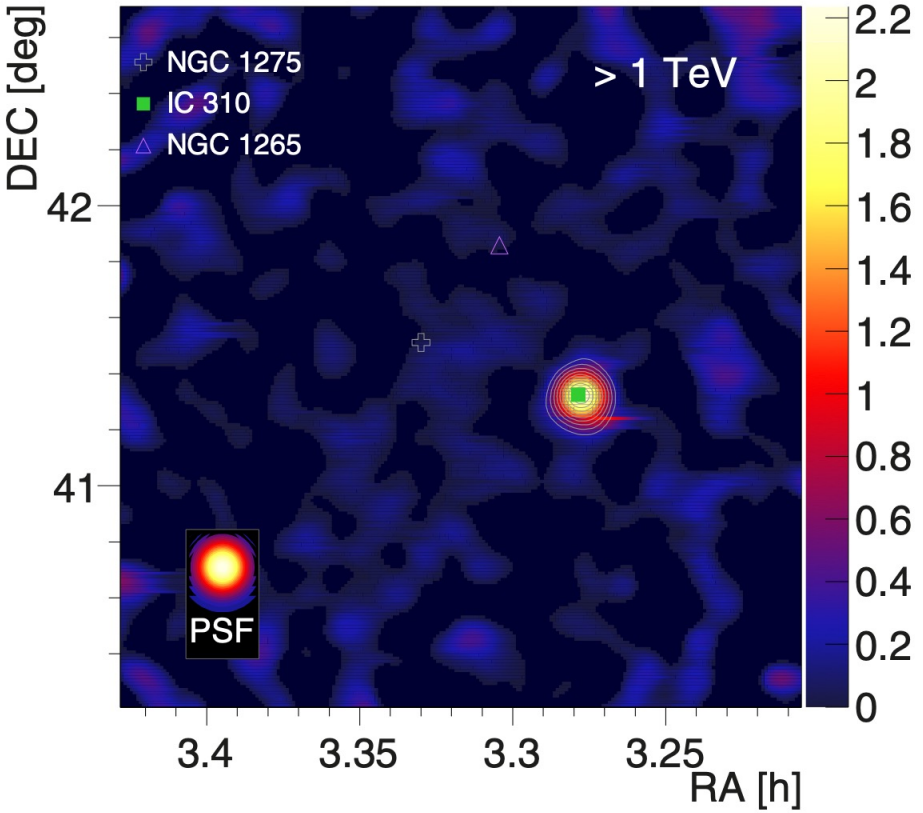


H. Abe et al. (MAGIC Collaboration)
Phys. Rev. Lett. 130, 061002 – Published 10 February 2023

Deep MAGIC observations of the Perseus field: a long-term project

85h + 168h

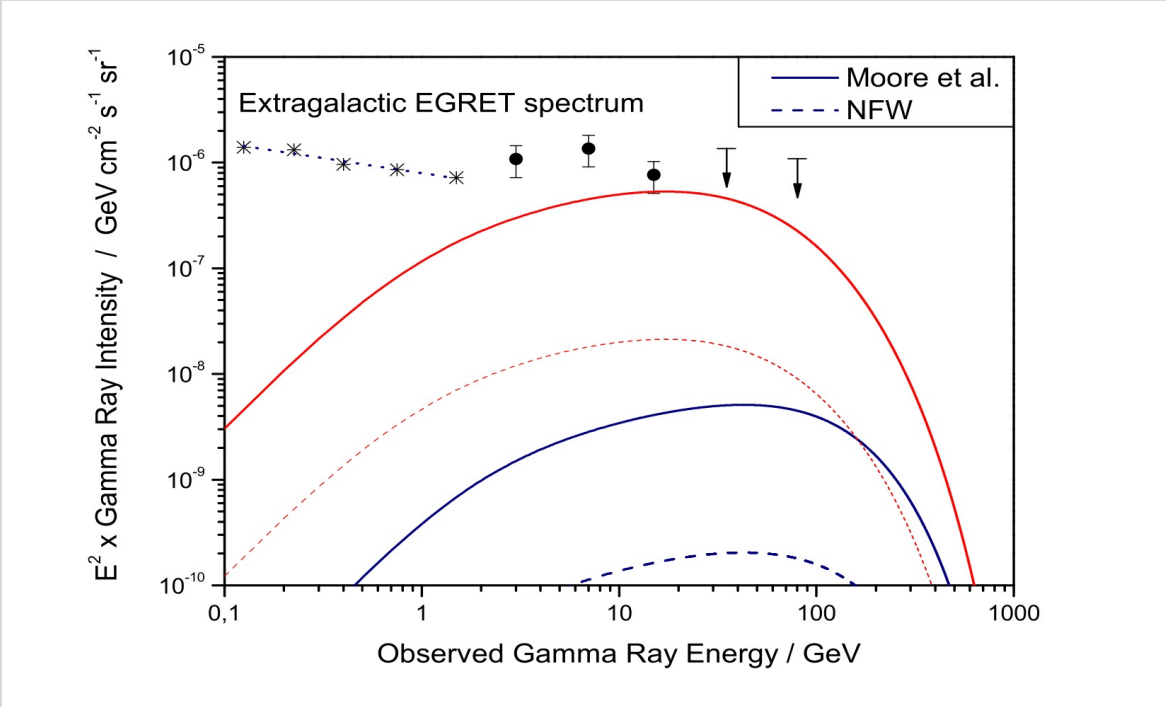




A&A 589, A33 (2016)

Large-scale structure

- Idea: as dark matter is the dominant mass component in the Universe, it is also the component globally dominating weak lensing
- If there is a contribution to the extragalactic gamma-ray background from DM annihilation/decay, the EGB intensity should thus be correlated with the lensing signal
- Problem, again: of course also e.g. AGN trace overall mass...
- **Preparatory studies done in the M. Sc. thesis of Tristan Gradetzke (2023)**

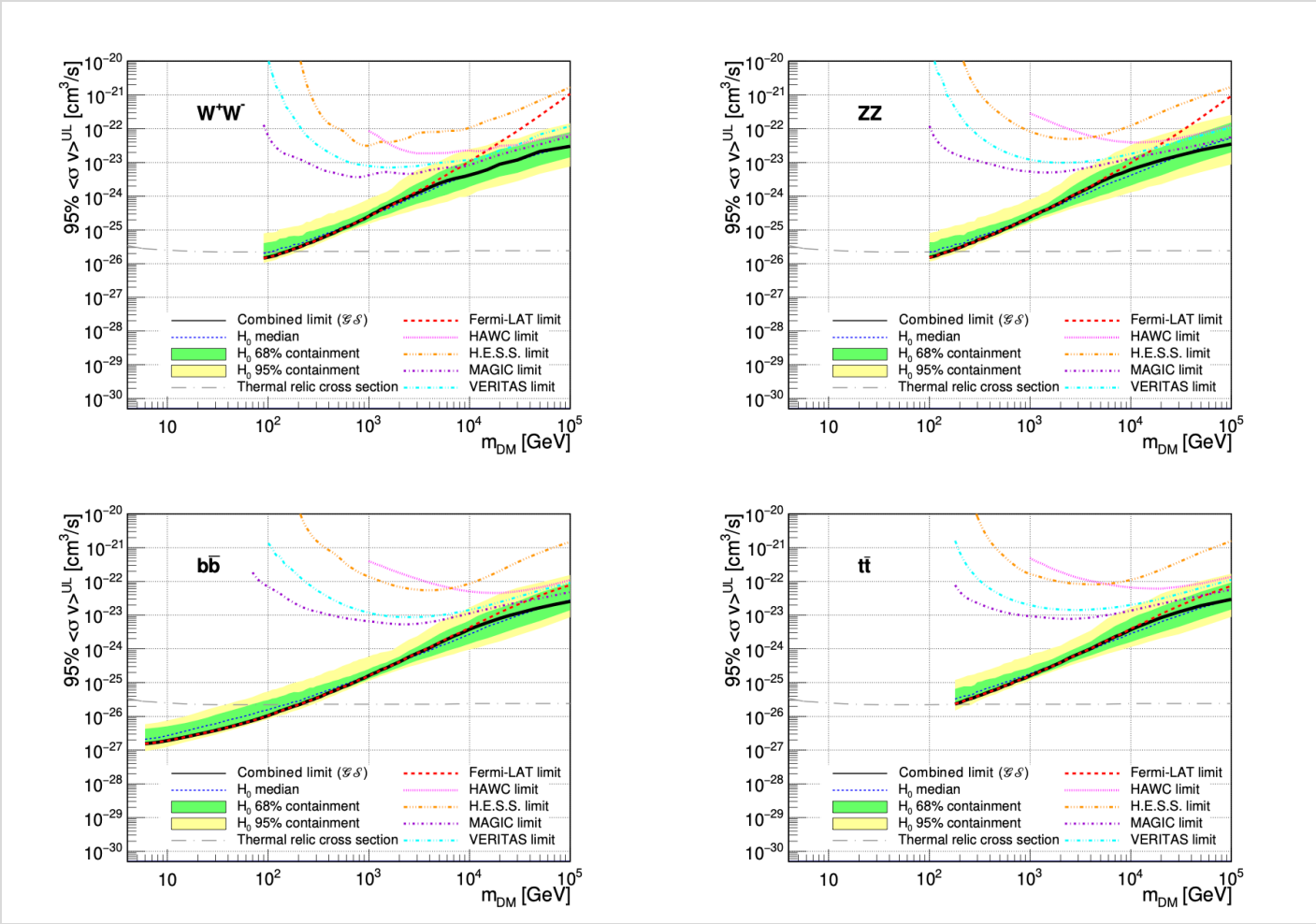


Elsaesser & Mannheim, Astropart.Phys.22:65-72 (2004)

Dwarf spheroidal galaxies

Source name	Experiments
Boötes I	VERITAS (14h), HAWC, *Fermi*-LAT
Canes Venatici I	HAWC, *Fermi*-LAT
Canes Venatici II	*Fermi*-LAT
Carina	H.E.S.S. (23h), *Fermi*-LAT
Coma Berenices	H.E.S.S. (11h), HAWC, *Fermi*-LAT
Draco	HAWC, *Fermi*-LAT
Fornax	H.E.S.S. (6h), *Fermi*-LAT
Hercules	HAWC, *Fermi*-LAT
Leo I	HAWC, *Fermi*-LAT
Leo II	HAWC, *Fermi*-LAT
Leo IV	HAWC, *Fermi*-LAT
Leo T	*Fermi*-LAT
Leo V	*Fermi*-LAT
Sculptor	H.E.S.S. (12h), *Fermi*-LAT
Segue I	MAGIC (158h), VERITAS (92h), HAWC, *Fermi*-LAT
Segue II	*Fermi*-LAT
Sextans	HAWC, *Fermi*-LAT
Ursa Major I	HAWC, *Fermi*-LAT
Ursa Major II	MAGIC (95h), HAWC, *Fermi*-LAT
Ursa Minor	*Fermi*-LAT

Until “the one“ target may be found: combine limits!



Fermi, HAWC, H.E.S.S., MAGIC, VERITAS et al., *in preparation*

Dark matter in dwarf galaxies
@ CRC 1491: background treatment still decisive

- Talk by Athy

„Dark matter in dwarf galaxies: astrophysical foreground and dark-matter background “

today, 17:15

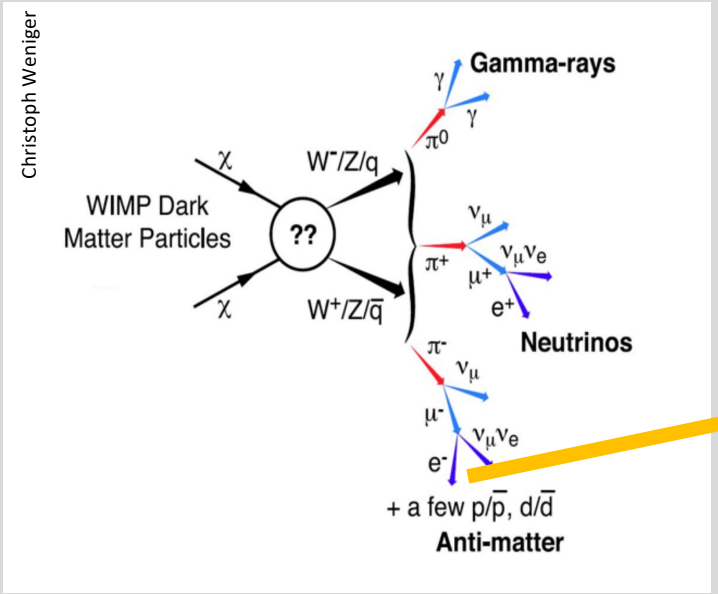
- Talk by Stefan

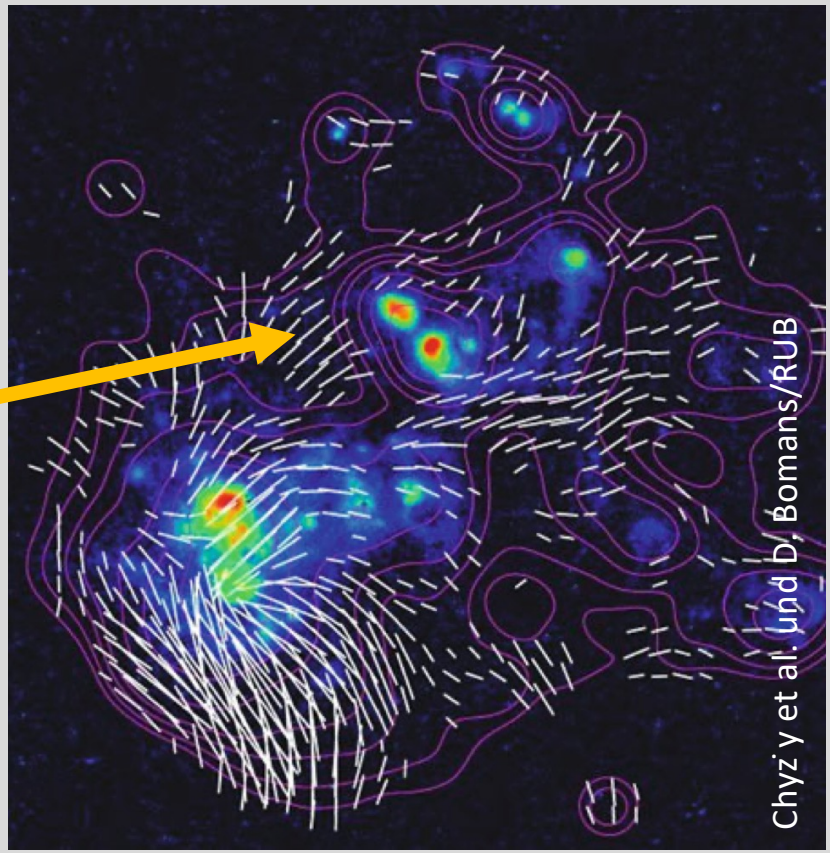
„Asimov datasets for gamma-ray astronomy “

tomorrow, 14:00


In the meantime: preparing for MAGIC + LST-1 observations e.g. of Coma dSph
CTA

Radio: The LOFAR2.0 Dark Matter eXperiment (LoDMaX)

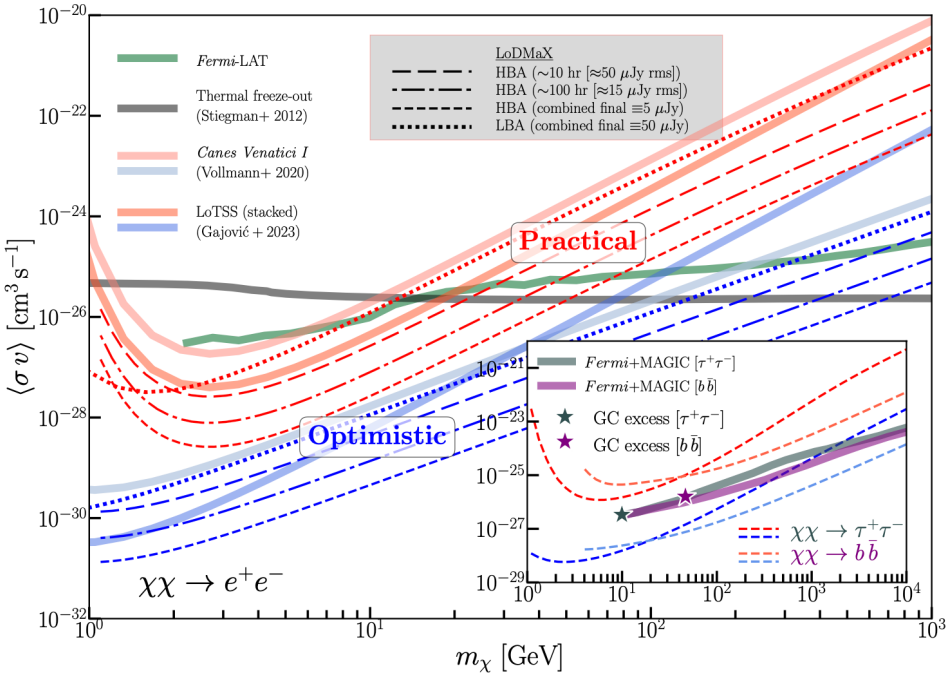




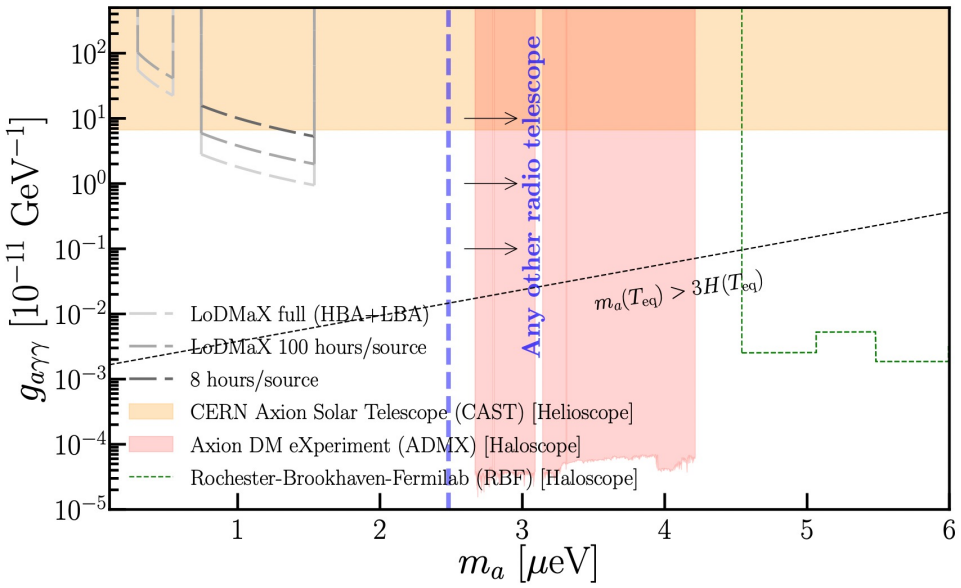
- Idea: search for synchrotron losses of charged leptons from annihilation
- Needs precise treatment of magnetic fields in dwarf galaxies (and...of backgrounds)

- Ideal synergy with CRC 1491 project A2
- LOFAR (2.0) ideal instrument to search for this signature
- **TU Dortmund group will become co-operator of Jülich LOFAR station**

The LOFAR2.0 Dark Matter eXperiment (LoDMaX)



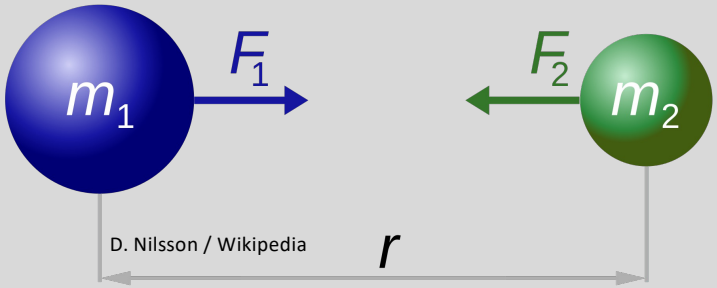
LoDMaX EoI (incl. CRC 1491 participants) Submitted in 2023!



Summary

- Indirect dark matter search remains one of the central pillars on which hopes for a discovery rest
- Very soon, observational limits will improve substantially
- Unlike in the past, astro- and plasma-physics will be absolutely central for the scientific harvest of those datasets
- CRC 1491 bringing together key expertise

MOND?



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

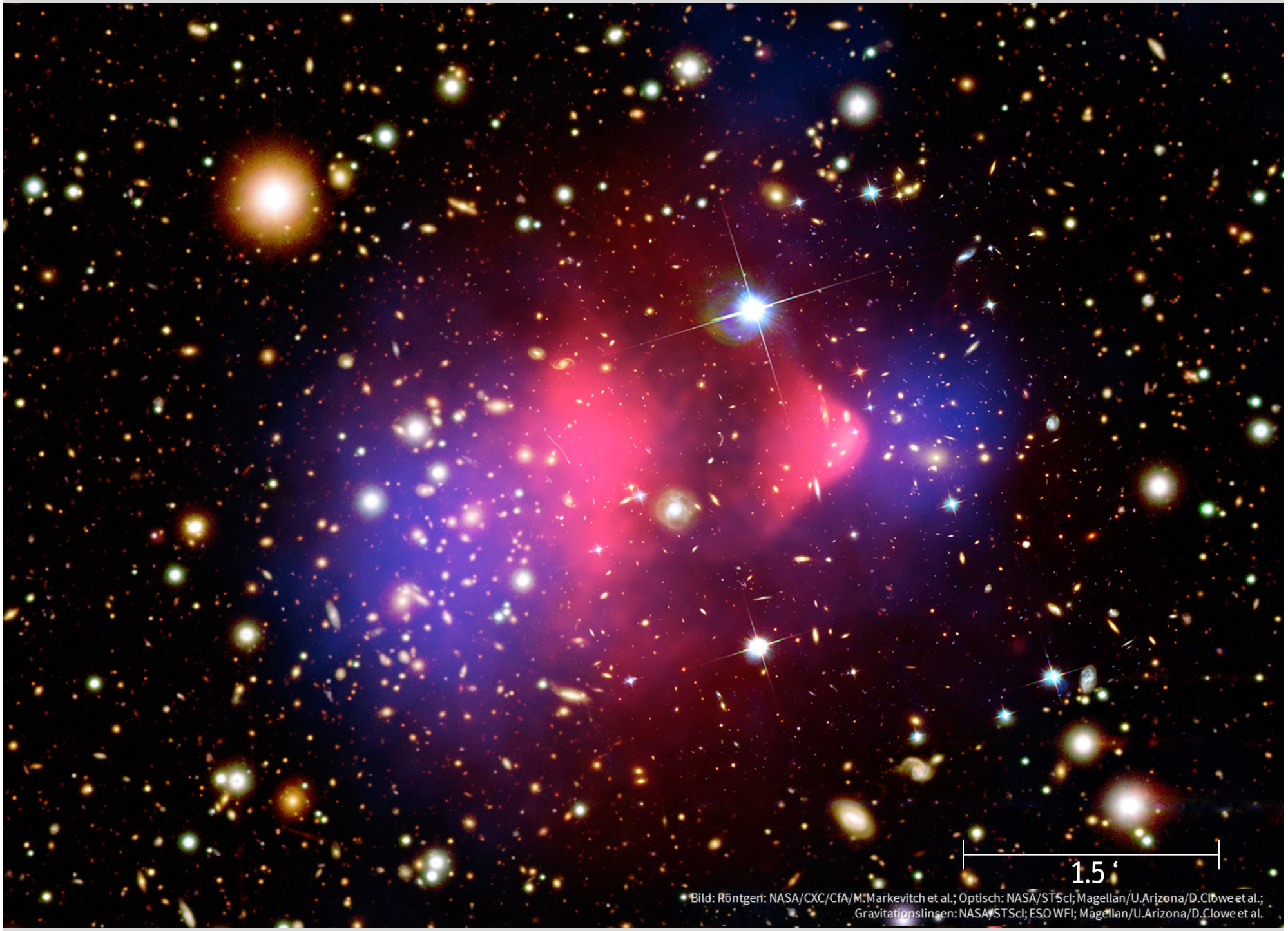


Bild: Röntgen: NASA/CXC/CfA/M.Markevitch et al.; Optisch: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Gravitationslinsen: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.