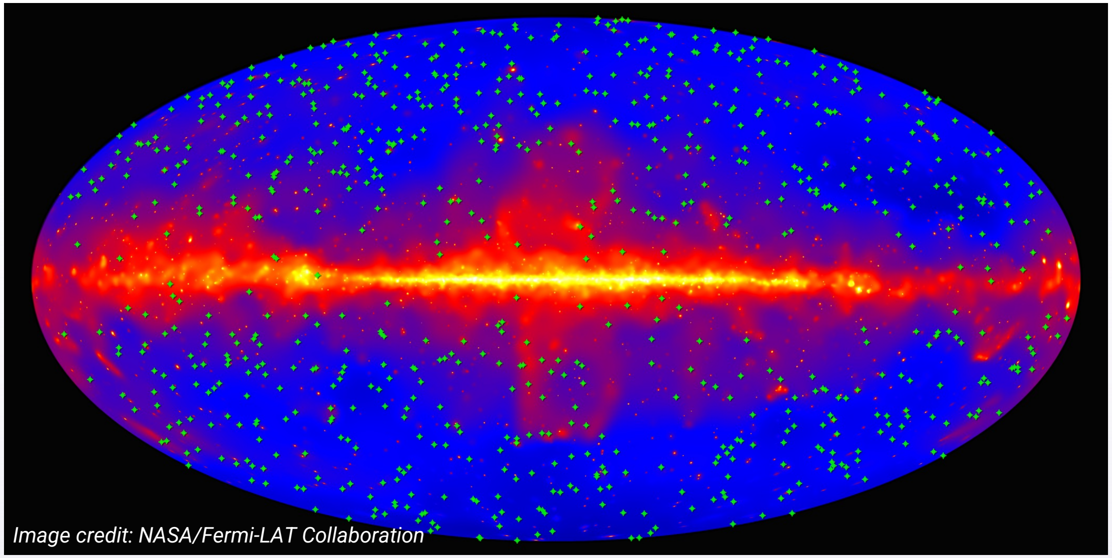
Understanding the GeV-TeV signatures of star-forming galaxies in the EGB

Presentation meeting of the ICRR Inter-University Research Program, FY2022



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Budget, intended purpose and constraints

- Approved budget: 300,000 JPY
  - 22 day visit to ICRR CTA group (3 days were possible in Dec 2022) to set up EGB simulations, understand instrument and analysis approaches to inform signal extraction pipelines
  - 3 day visit to attend CTA-Japan meeting at ICRR to present interim results to gamma-ray community
- Progress very constrained by travel situation
- Taiwan border closed until mid-October 2022; travel not possible from NTHU
- Amount used: 80,000 JPY (CTA-Japan 2022 meeting; 3 day visit to ICRR CTA group)
- Carry-over requested: 220,000 JPY – now in Osaka U; no travel restrictions

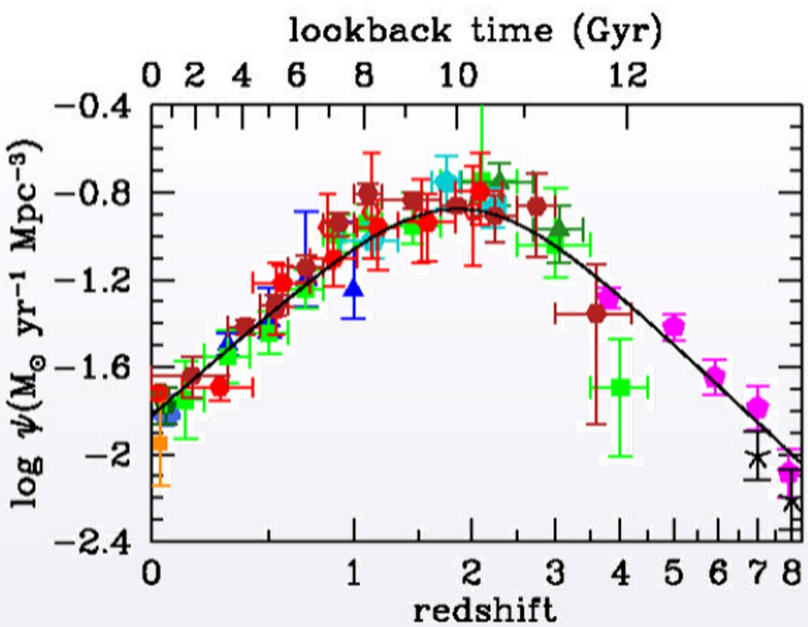
Alternative activities

- Independent theoretical studies:
  - Forward modeling to determine possible extra-galactic gamma-ray background (EGB) signatures
  - Useful as a starting point for EGB simulations and prototype pipelines
  - Identify areas where model refinement is needed (transport modeling)

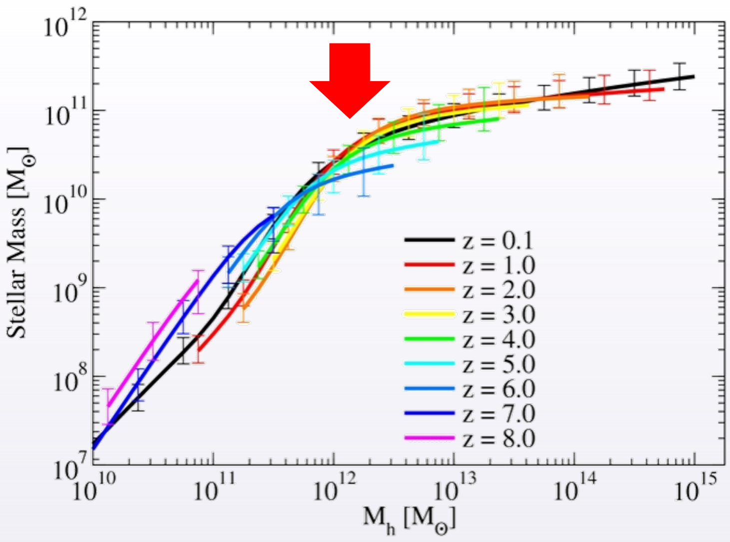
- Publications:
  - *Characterizing the signatures of star-forming galaxies in the extragalactic gamma-ray background*. MNRAS 506, 1, 52, doi: 10.1093/mnras/stab1707
  - *The extragalactic gamma-ray background: imprints from the physical properties and evolution of star-forming galaxy populations*. MNRAS 513, 2, 2335, doi: 10.1093/mnras/stac1079

Galaxy formation/evolution

- Galaxy self-regulation (feedback) mainly modelled thermally/mechanically; some treatment of radiation – SNe/AGN etc.
- Picture not yet complete, massive, highly star-forming or high-z galaxies presenting particular ~~problems~~ opportunities



(Madau & Dickinson 2014)



(Behroozi+2013)

Cosmic ray feedback and γ-ray production

Hadronic interactions (pp dominates over p-gamma in galactic settings)

$$
\mathrm{p} + \mathrm{p} \rightarrow \begin{cases} \mathrm{p} + \mathrm{p} + \pi^0 \\ \mathrm{n} + \mathrm{p} + \pi^+ \\ \mathrm{p} + \mathrm{p} + \pi^+ + \pi^- \end{cases}
$$

+ pion multiplicities at higher energies

$$\pi^0 \rightarrow 2\gamma$$

electromagnetic decay

$\tau_{\mathrm{em}} \approx 8.5 \times 10^{-17}\mathrm{s}$

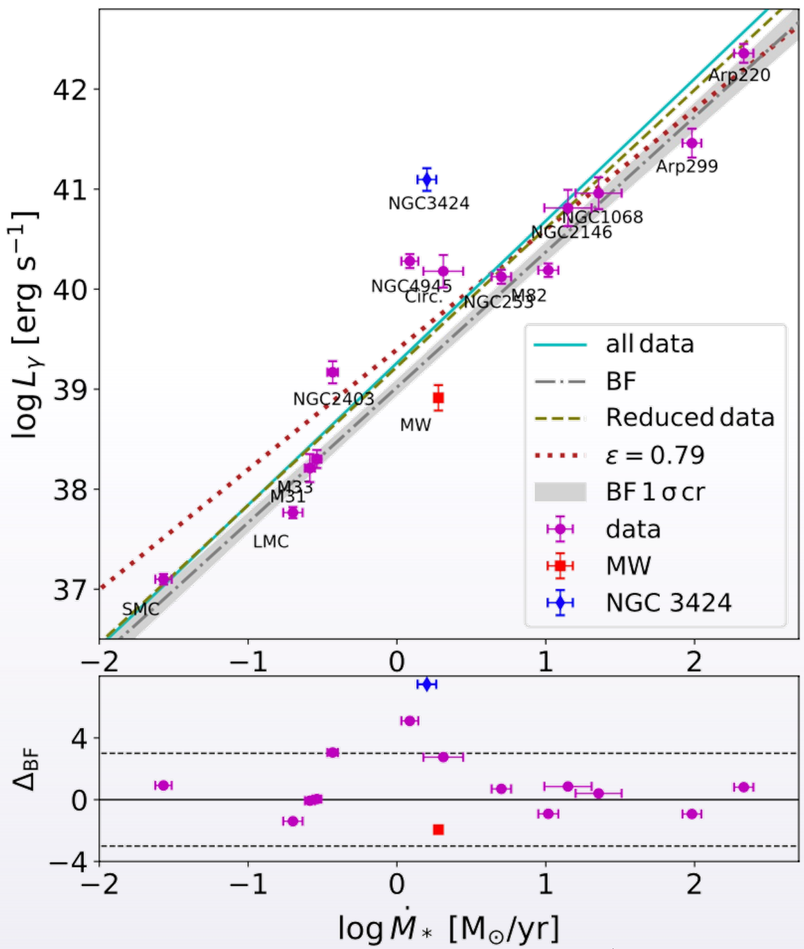
$$\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \bar{\nu}_\mu \nu_\mu$$

$$\pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \nu_\mu \bar{\nu}_\mu$$

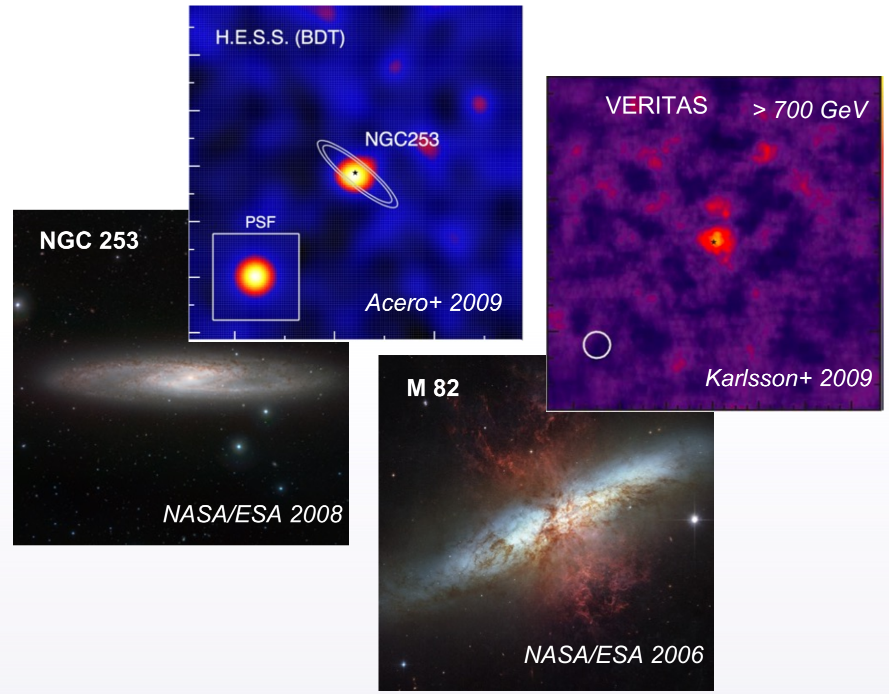
weak decay

$\tau_{\mathrm{weak}} \approx 2.6 \times 10^{-8}\mathrm{s}$

γ-ray emission from starbursts



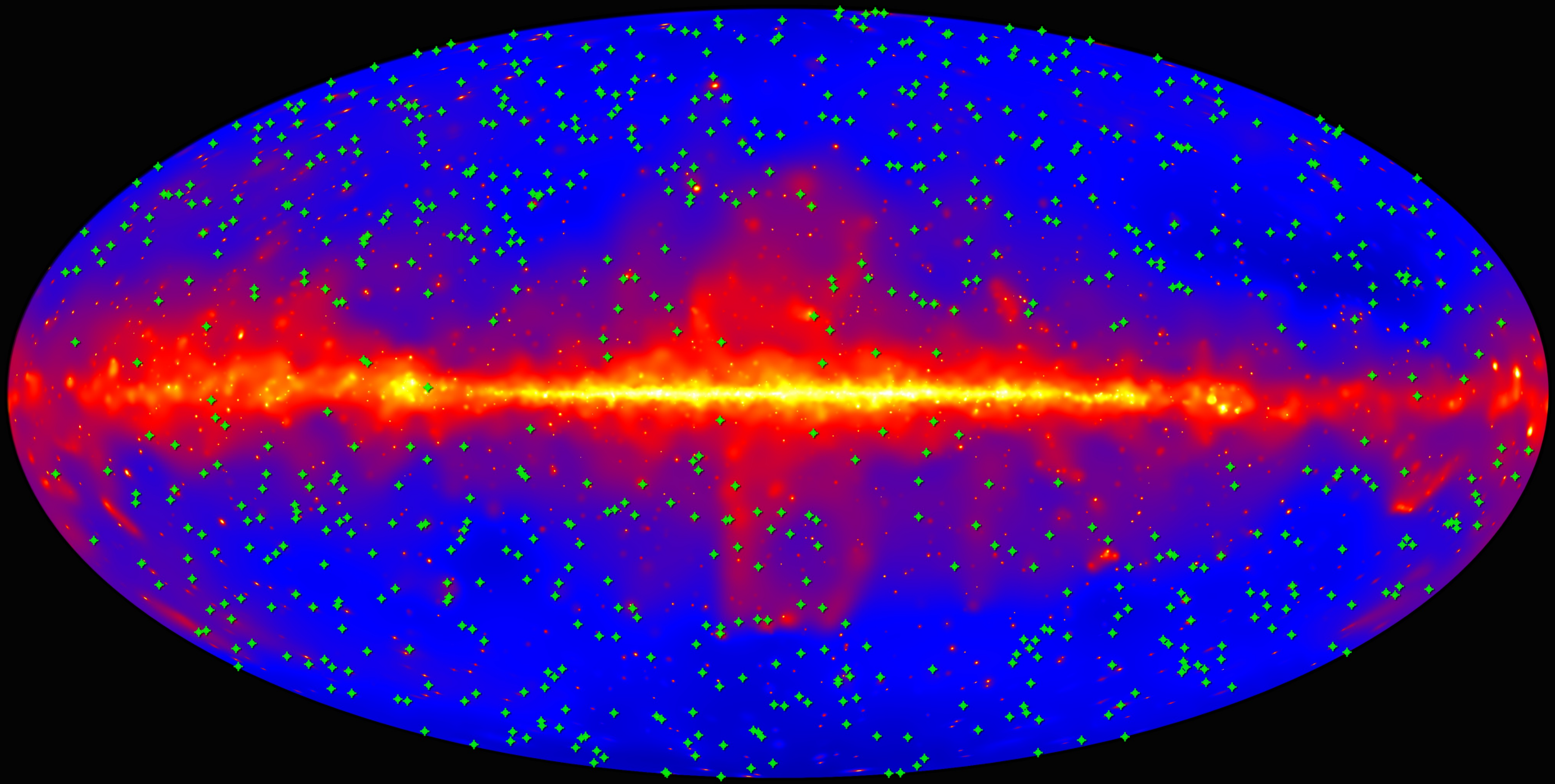
(Kornecki+2020)



Gamma-ray luminosity is a proxy for cosmic ray luminosity (later)

The extra-galactic γ-ray background

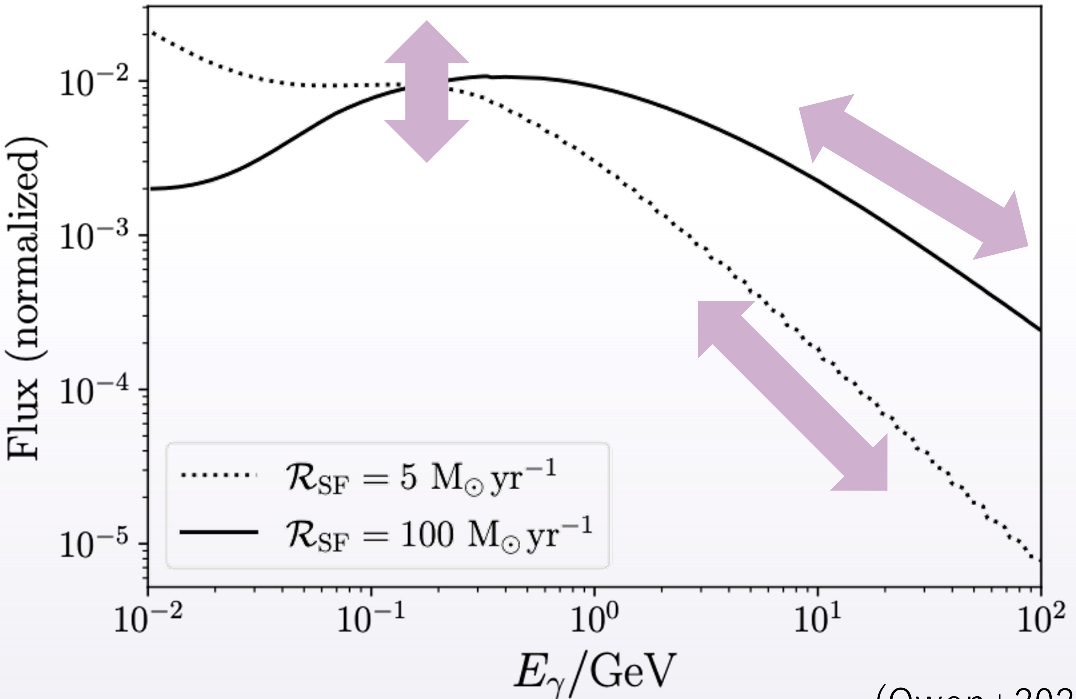
10 years of Fermi-LAT
E>10 GeV



NASA/*Fermi*-LAT collaboration

Prototype galaxy model: γ-ray production

$U_{\rm CR} \propto \mathcal{R}_{\rm SN} \propto \mathcal{R}_{\rm SF}$



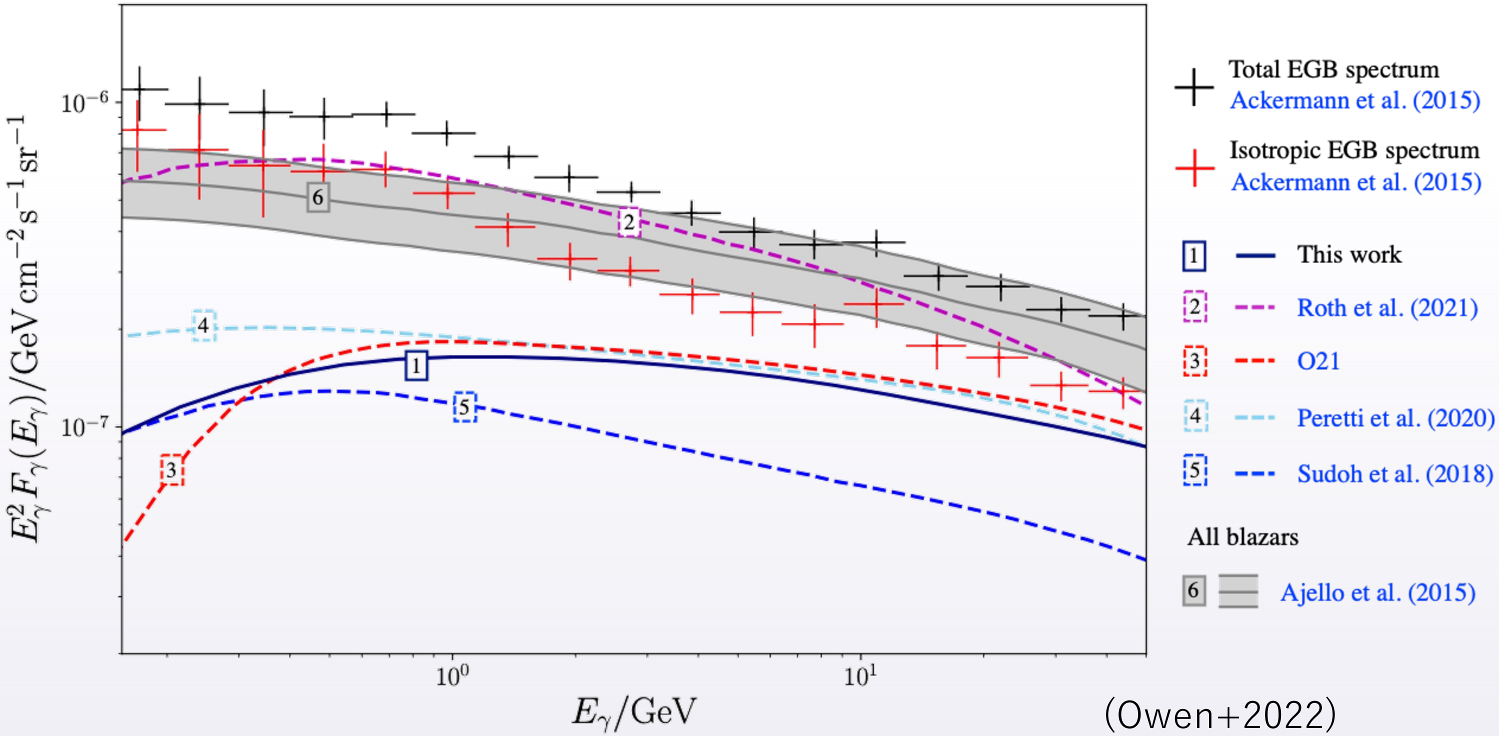
(Owen+2022)

CR injection spectrum $\propto T_{\rm p}^{-\Gamma}$

Include treatment of CR propagation; diffusion/leaking gives different spectral slopes with SF rate

EGB spectrum

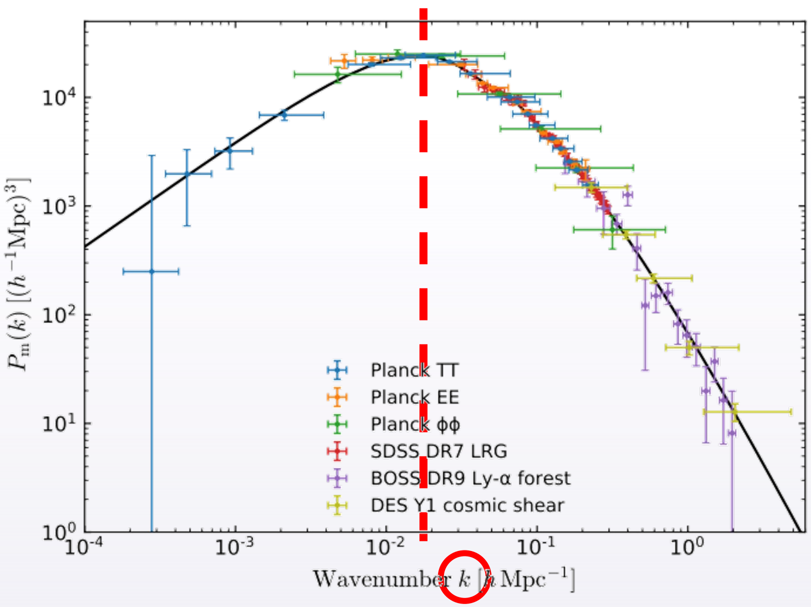
Galaxies can contribute a few tens of percent (depends slightly on CR spectrum in sources; also works by Abrosome+2021)



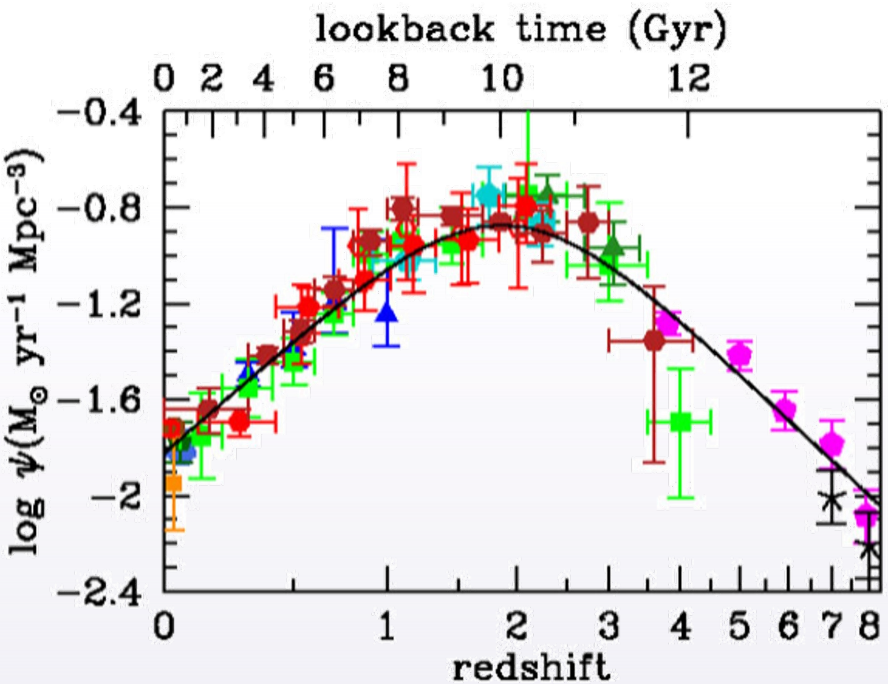
(Owen+2022)

Source population distribution

Intensity distribution; imprints at a preferred (peak) angular scale



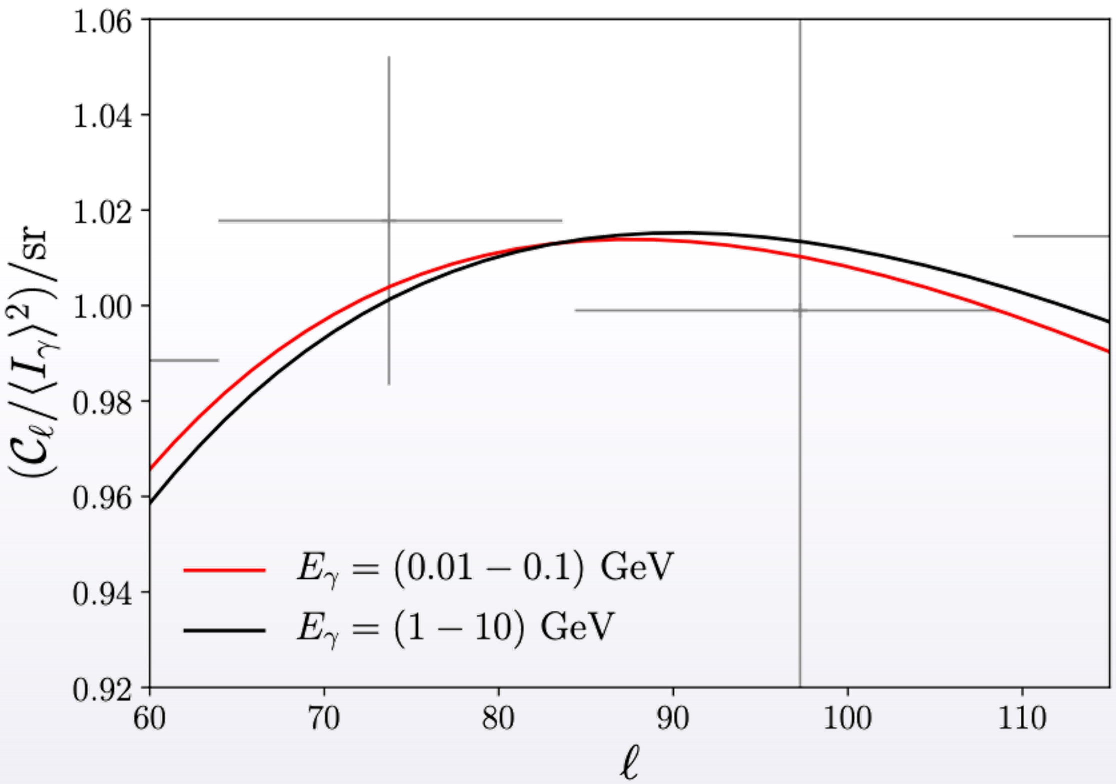
(Planck Collaboration+2018)



(Madau & Dickinson 2014)

EGB anisotropy modeling

Redshift evolution imprints spatial signature in EGB



(Owen+2022)

Future capabilities

(1) Higher angular resolutions, so detailed anisotropy signatures more accessible, so better **redshift information**

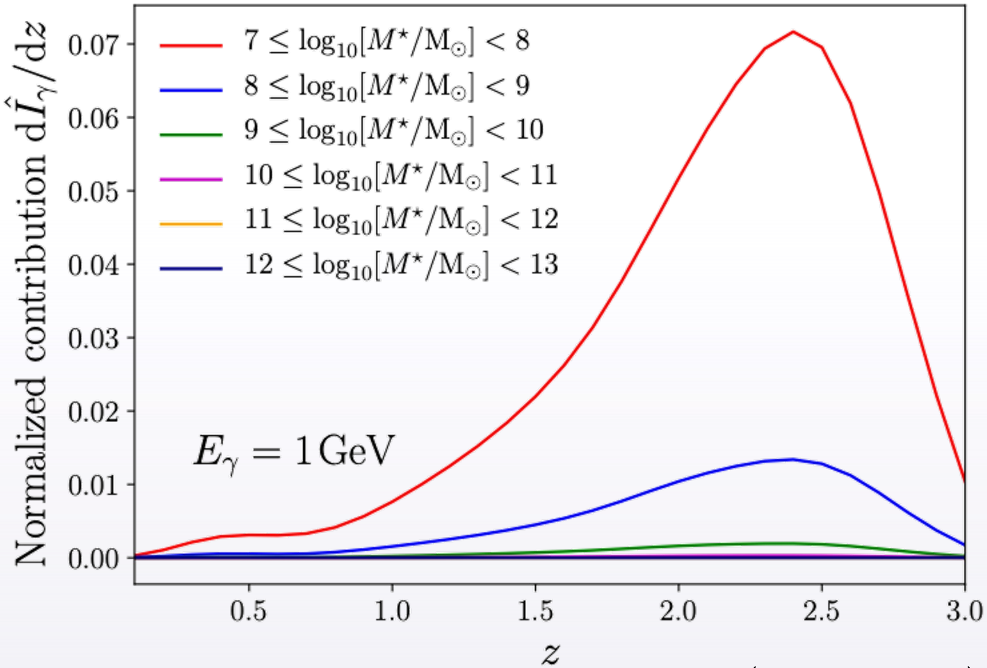
(2) Access higher multipoles for **wider redshift range**

(3) More data at **higher energies**, so can test CR containment/feedback in galaxy populations (Ambrosone+2022)

Osaka University Theoretical Astrophysics

Mass separation and model biases

Relative contributions



(Owen+2022)

80% from low mass intense starbursts

Is this **realistic**?

- Intense starbursts with low mass most likely to develop strong nuclear outflows
- Advection of CRs
- Self-consistent feedback needed (not post processing)

Project status

- Substantial delays by Covid-19 pandemic
- Preliminary models complete using prototype techniques; effectively "post-processing" (Owen et al. 2021, 2022)

Next steps in FY2023

- Self consistent treatment of hydrodynamics and particle transport in progress (improving normalization and understanding of particle advection/containment)
- Modeling realistically accessible signatures for the CTA era with guidance from the ICRR-CTA group (after new models)
- Development of testbed simulations and proof-of-concept analysis pipelines suitable for future analyses (FY 2023)