Gamma-ray Emission from Starburst, Main Sequence, and Dead Galaxies

Contributions to Extragalactic Isotropic Backgrounds

3rd September, 2024: Gamma2024, Milan, Italy

Ellis R Owen

JSPS Fellow; Theoretical Astrophysics Group, Osaka University

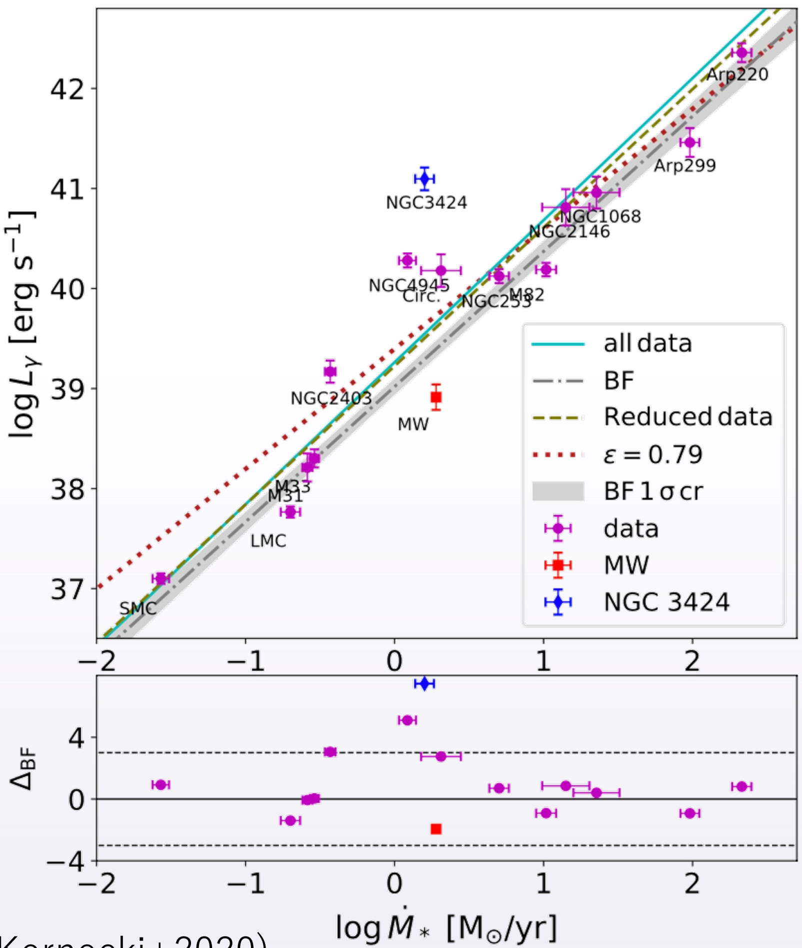
Collaborators: Y. Inoue (Osaka U), T. Fujiwara (Osaka U), A. K.-H. Kong (NTHU), K.G. Lee (IPMU, U Tokyo)

erowen@astro-osaka.jp ellisowen.org

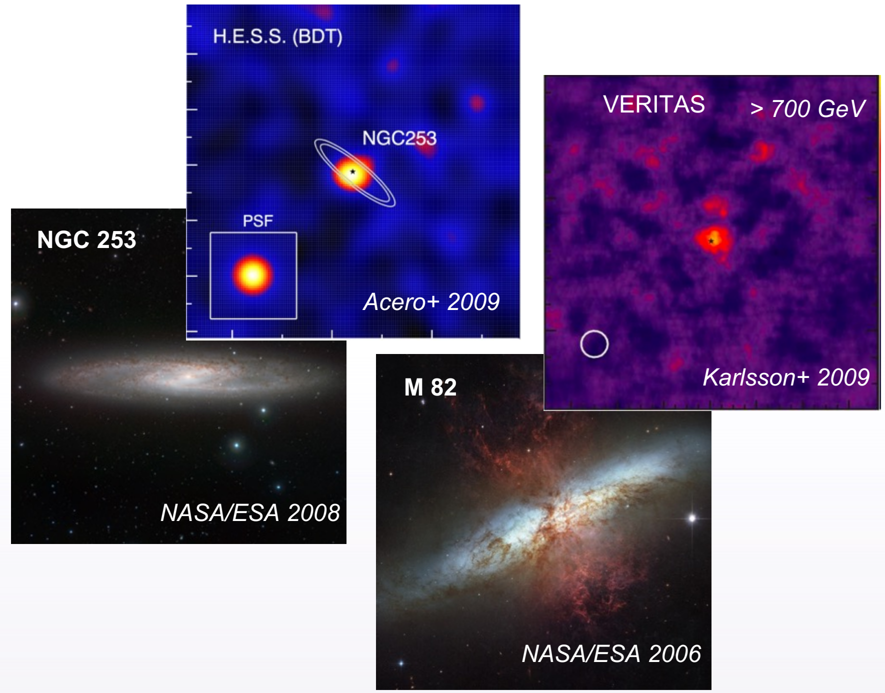
Outline

- High energy emission from galaxies
- Star-forming, normal and quiescent galaxies
- A new prototype gamma-ray emission model
- Semi-analytic modeling of galaxy populations
- Contribution to the Isotropic Gamma-ray Background

γ-ray emission from galaxies



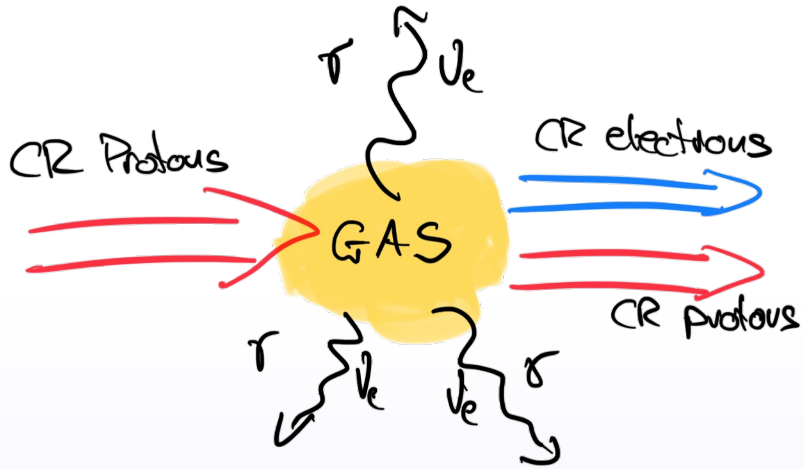
(Kornecki+2020)



Gamma-ray luminosity has a close relation with tracers of star-formation rate

Hadronic/Lepto-hadronic processes

pp interaction



Messengers:

Gamma-rays

Neutrinos

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

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

electromagnetic decay $\tau_{\rm em} \approx 8.5 \times 10^{-17}\,{\rm s}$

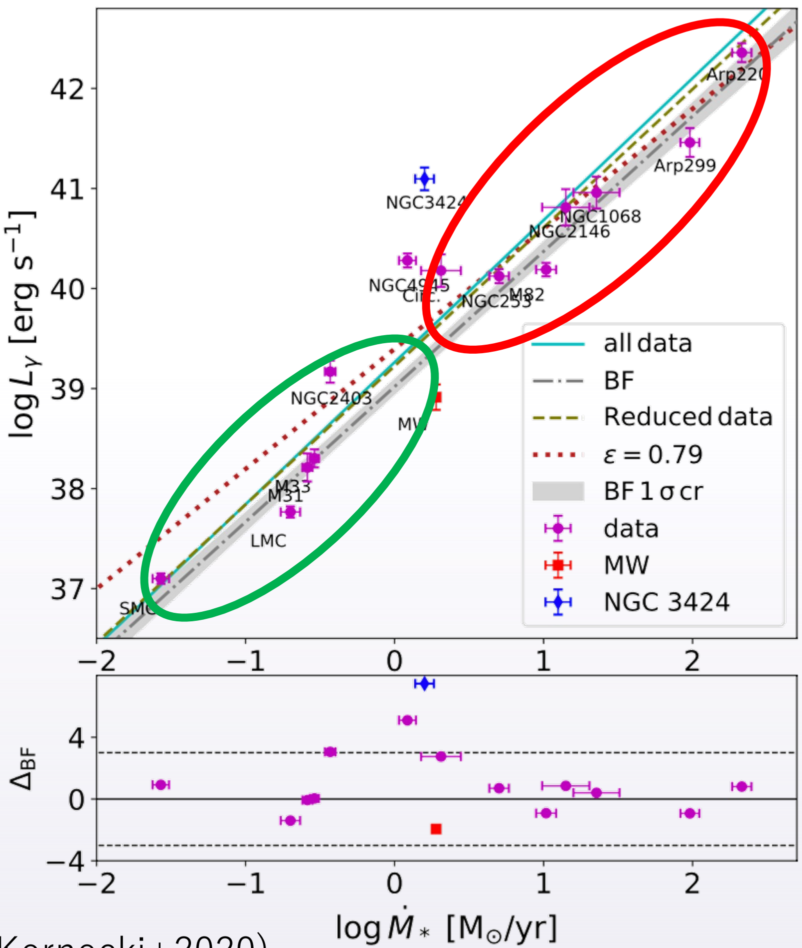
$$\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \bar{\nu}_\mu \nu_\mu$$

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

weak decay $\tau_{\rm weak} \approx 2.6 \times 10^{-8}\,{\rm s}$

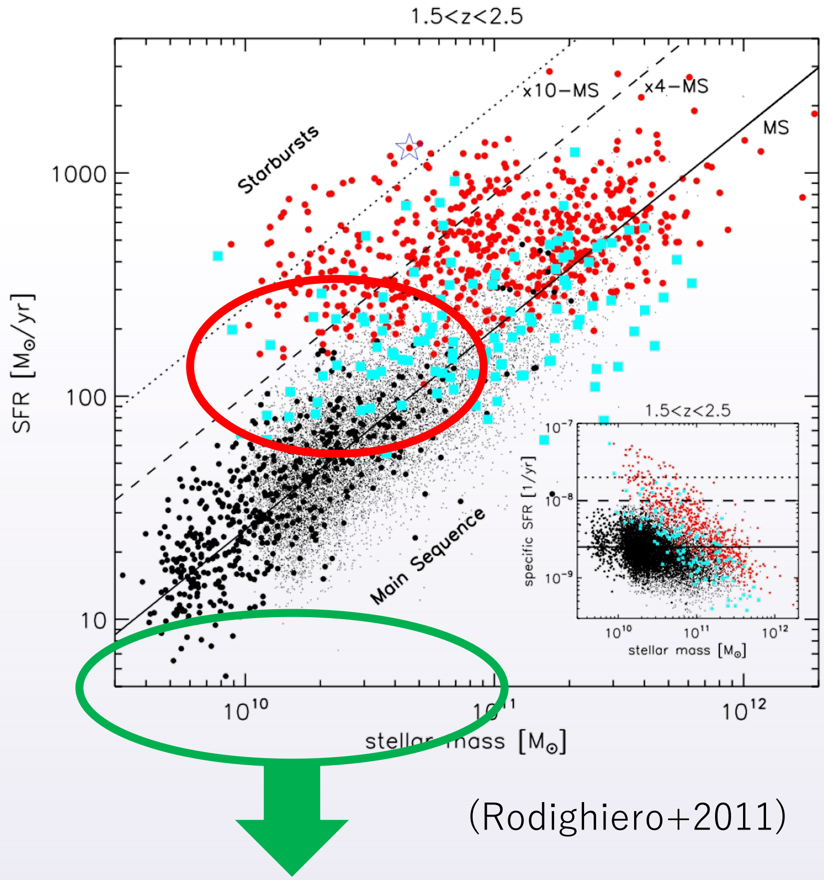
+ pion multiplicities at higher energies

γ-ray emission from galaxies



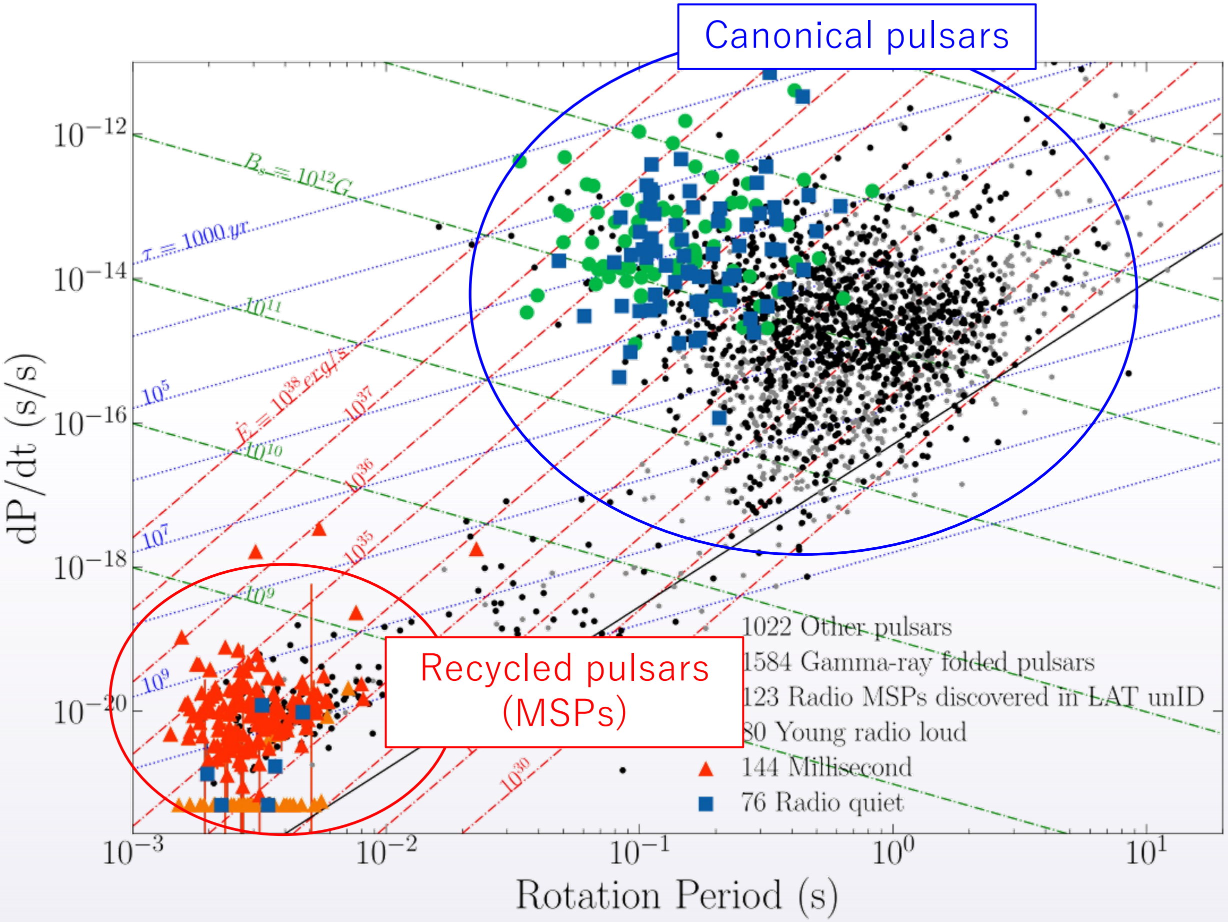
(Kornecki+2020)

Gamma-ray emitting galaxies are not all the same



(Rodighiero+2011)

Gamma-ray pulsar populations



(Smith et al. 2023)

10^{32}-10^{37} erg/s

Potential to be a major contributor in an older galaxy

2 types of pulsars can contribute gamma-rays in different ways

Pulsar contribution: population

Population evolution model:

$$\frac{\partial n(L_\gamma, t)}{\partial t} + \boxed{\frac{\mathrm{d}L_\gamma}{\mathrm{d}t}\frac{\partial n(L_\gamma, t)}{\partial L_\gamma}} = \boxed{-\kappa n(L_\gamma, t)} + \boxed{f(L_\gamma, t)}$$

fading (ageing) — destruction (death) — formation (birth)

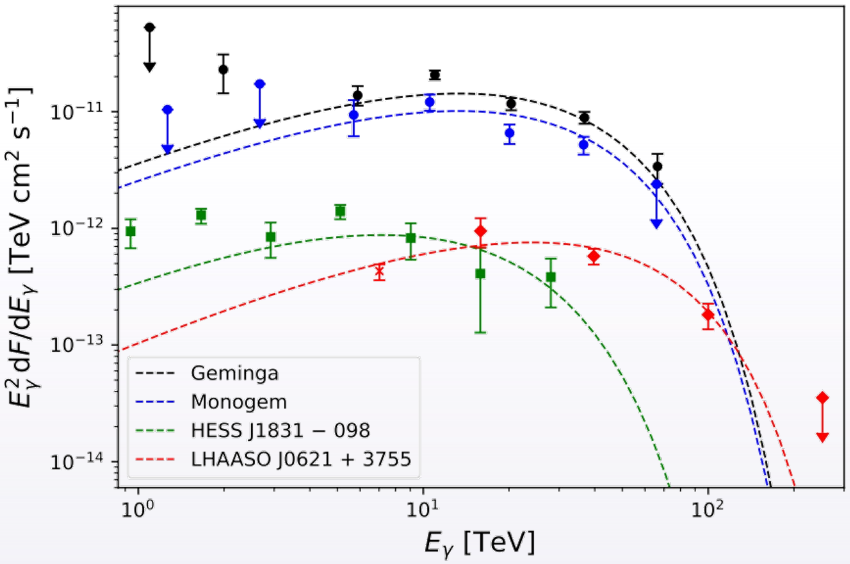
Canonical pulsars/halos:
- Birth: following SFR
- Ageing: Spin-down power evolution
- Death: Death line (empirical)

MSPs:
- Birth: 1 Gyr delay from SFR
- Ageing: Effectively none (very slow)
- Death: Death line (empirical)

Pulsar contribution: spectrum

Canonical pulsars/halos

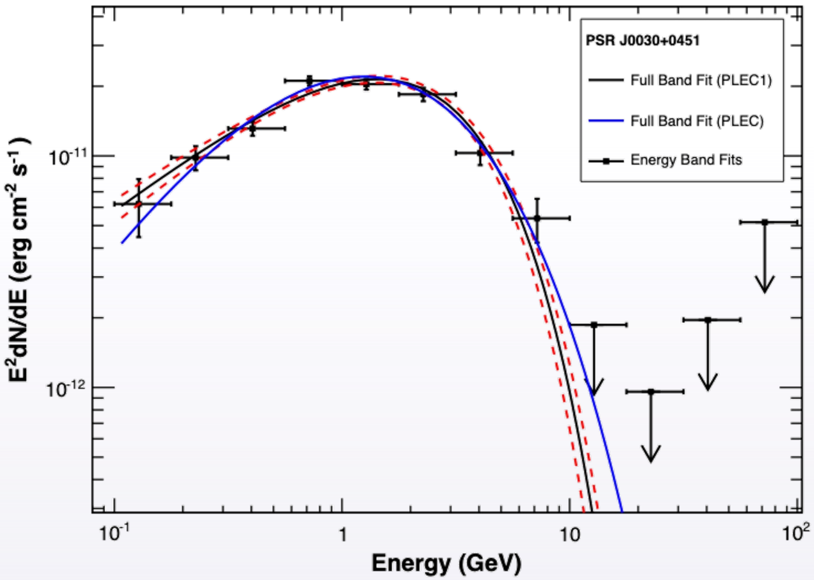
One-zone model (lower energy emission sub-dominant)



Main contribution at 10s of TeV

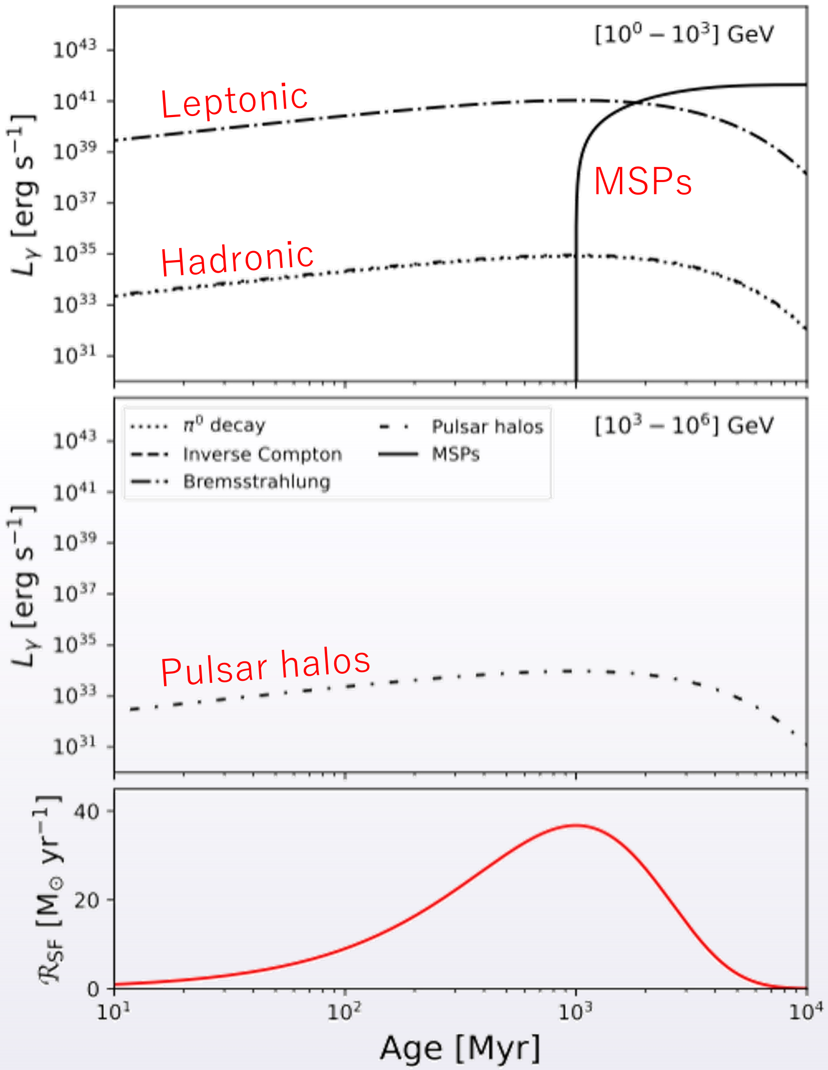
MSPs

Empirical model



Main contribution at < 10 GeV

Prototype model: evolution



Example massive MW-like galaxy

Low energy gamma-rays

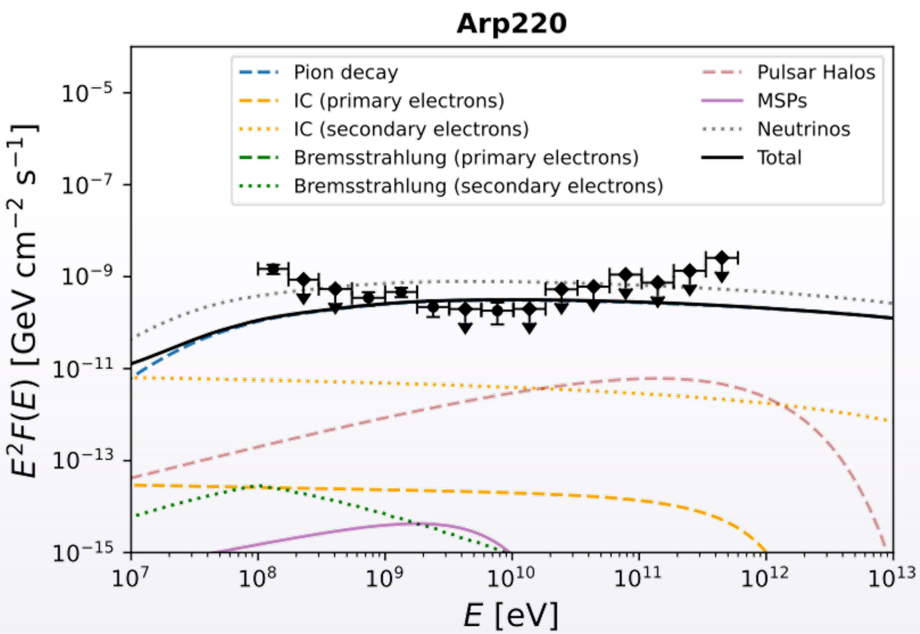
High-energy gamma-rays

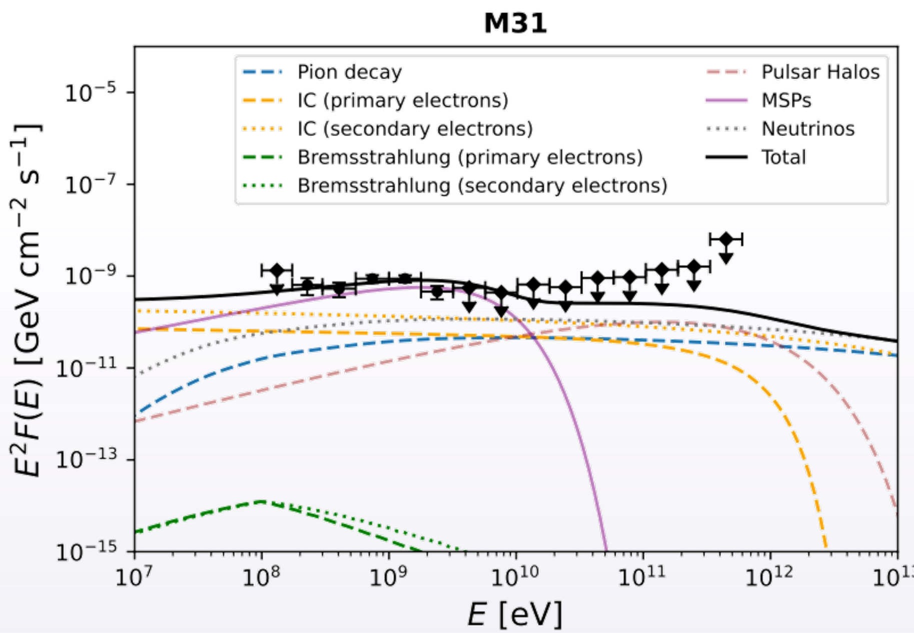
Star-formation rate

Prototype model

Standard parameters adopted

Starburst vs. quiescent galaxies are both consistent



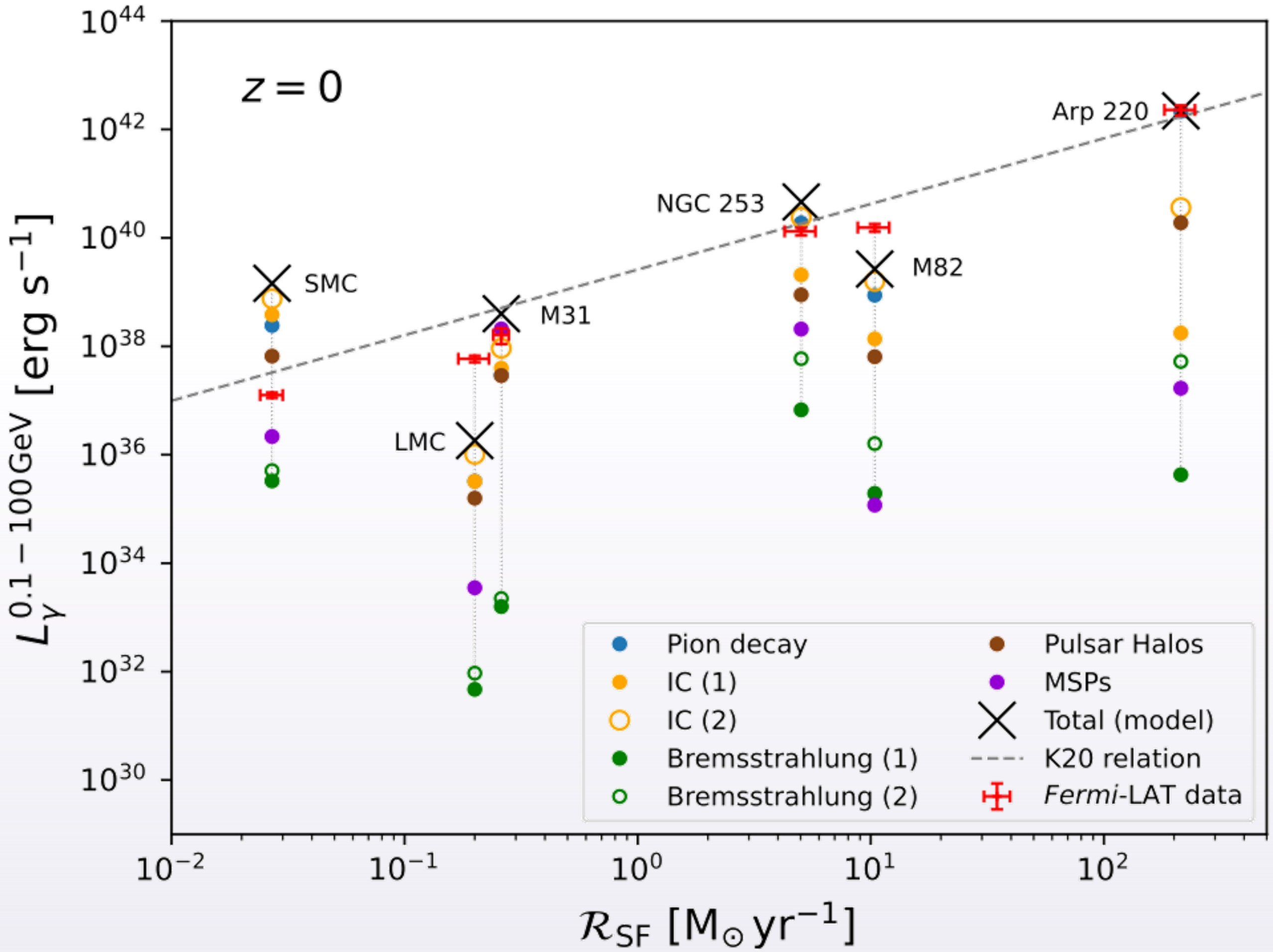


Primary CRe to CRp ratio of 2%

Fermi-LAT data from Ajello et al. 2020

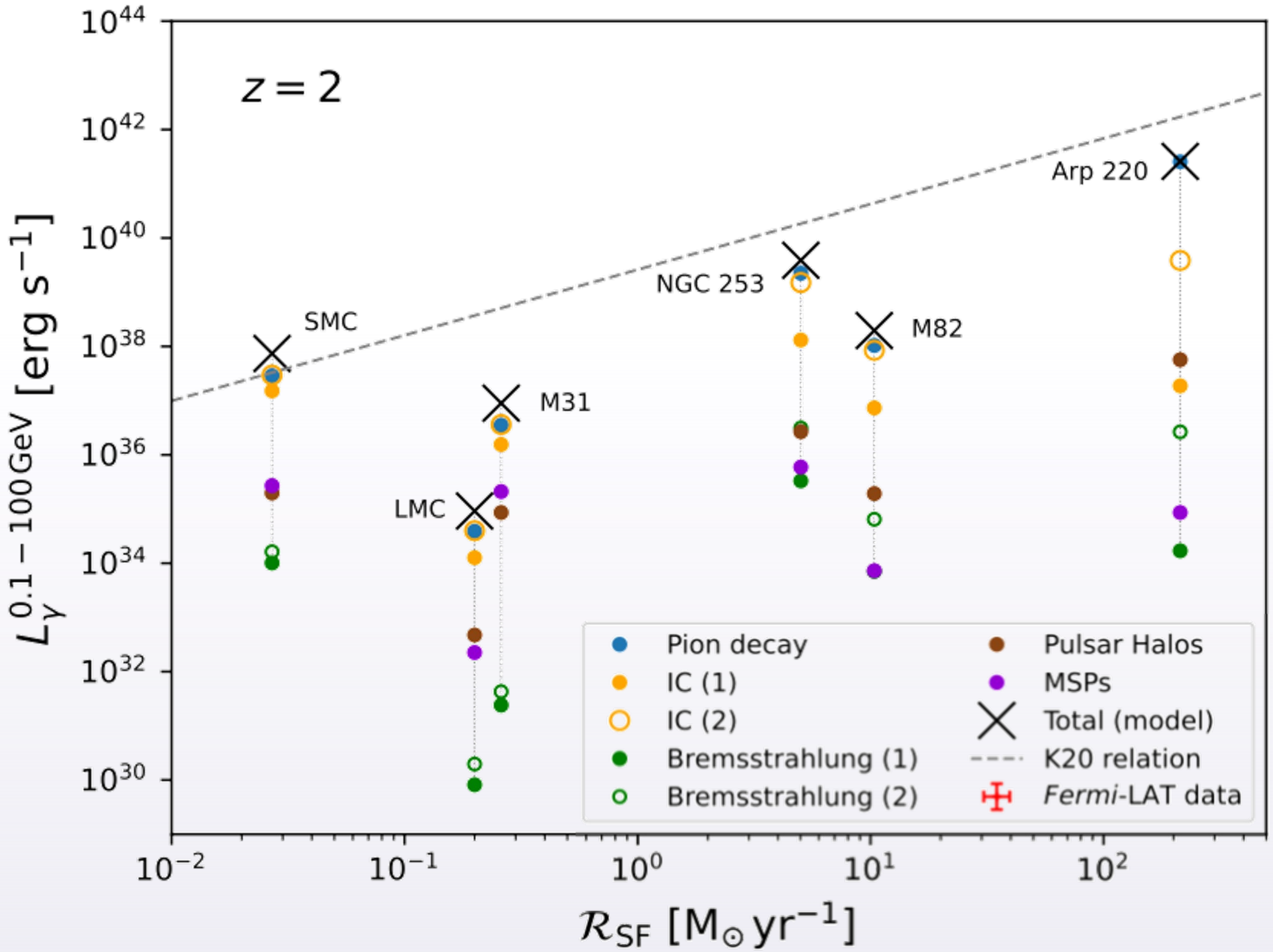
Prototype model

Total emission from most nearby galaxies can be captured by the prototype



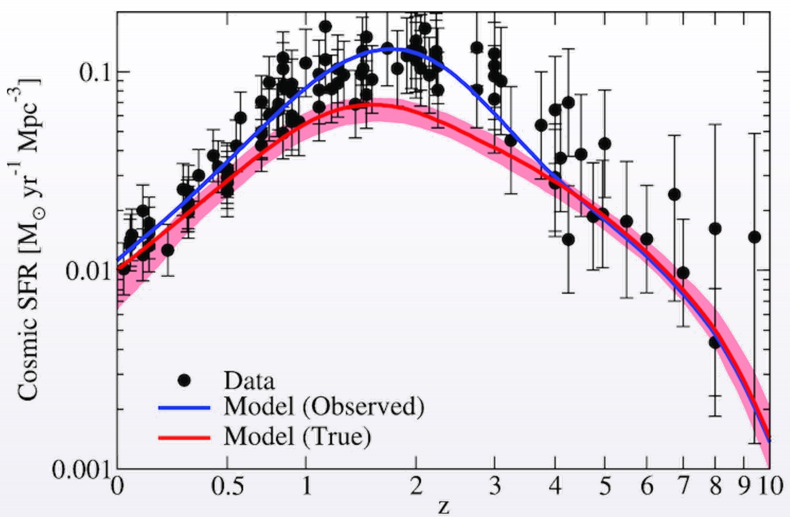
Prototype model at cosmic noon

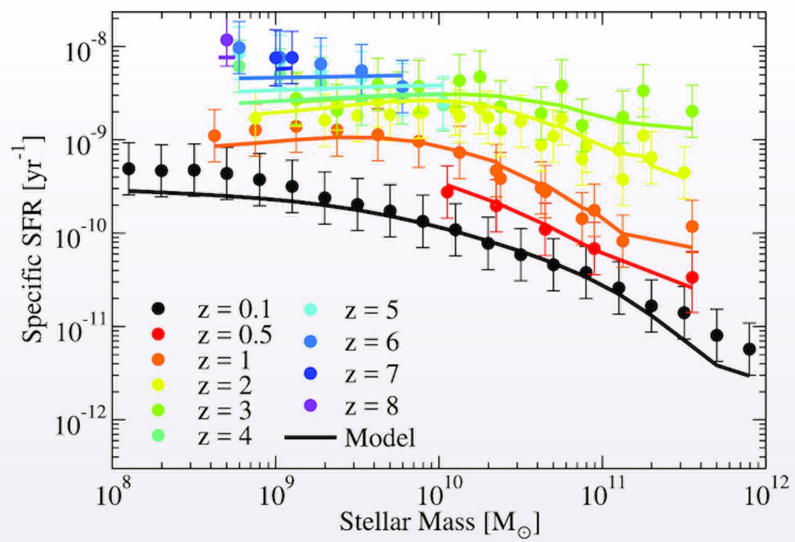
Properties evolve substantially with cosmic time



UniverseMachine

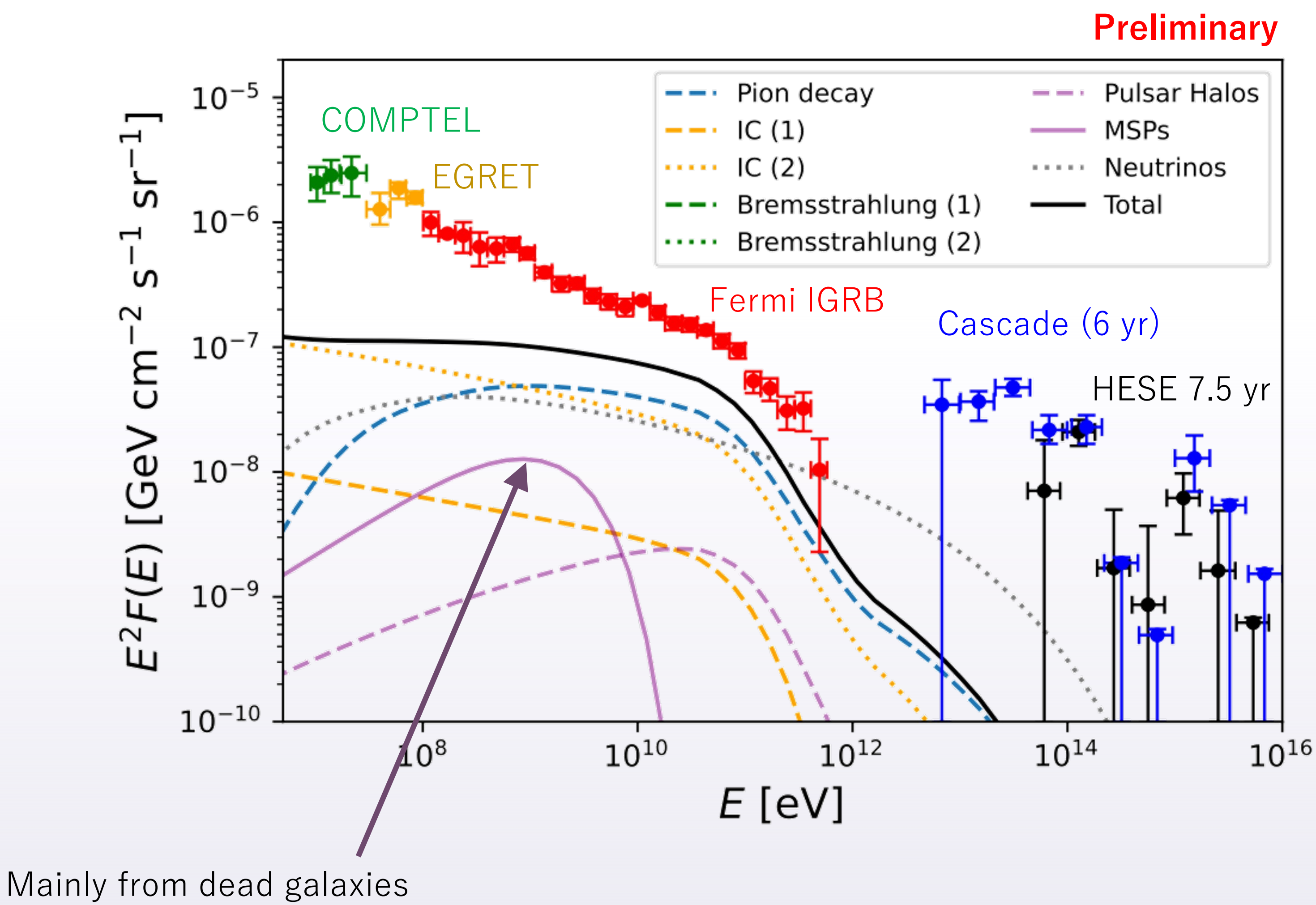
- **Semi-analytic model** of galaxy formation/evolution linking galaxy growth to halo growth
- **Empirically informed**: Many universes simulated; predicted observables compared to data to calculate likelihood of chosen parameters





Behroozi et al. 2019

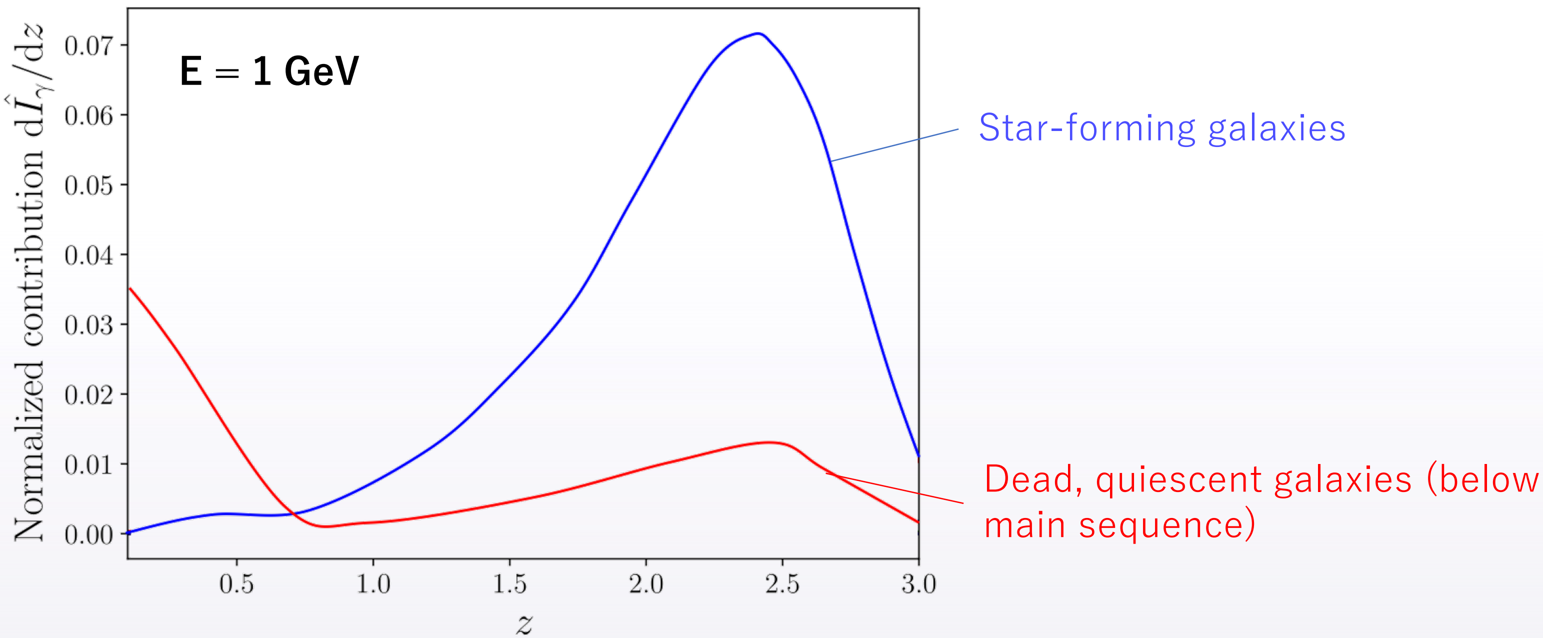
Isotropic high-energy backgrounds



Redshift contributions

- MSPs drive a boost in late time gamma-ray emission from massive galaxies

Preliminary



- Testing this model: small-scale anisotropies – correlation term
  - Hard to detect, foregrounds may contaminate
  - Cross-correlation with galaxy surveys to boost signal

Conclusions

- **Multiple components** in the extra-galactic isotropic gamma-ray background
- Gamma-ray emission from galaxies may be **more leptonic** (e.g. MSPs @ GeV energies, pulsar halos @ TeV energies), with old quiescent galaxies emerging as a possible source population
- Gamma-ray emission from normal and star-forming galaxies correlates with their star-formation rate, and follows the cosmic star-formation rate density
- Dead galaxies develop gamma-ray emission Gyrs after the end of their star-formation
- Different evolutionary timescales could allow their relative contributions to be tested observationally

See paper on arXiv next month for details…