Particle acceleration in star clusters

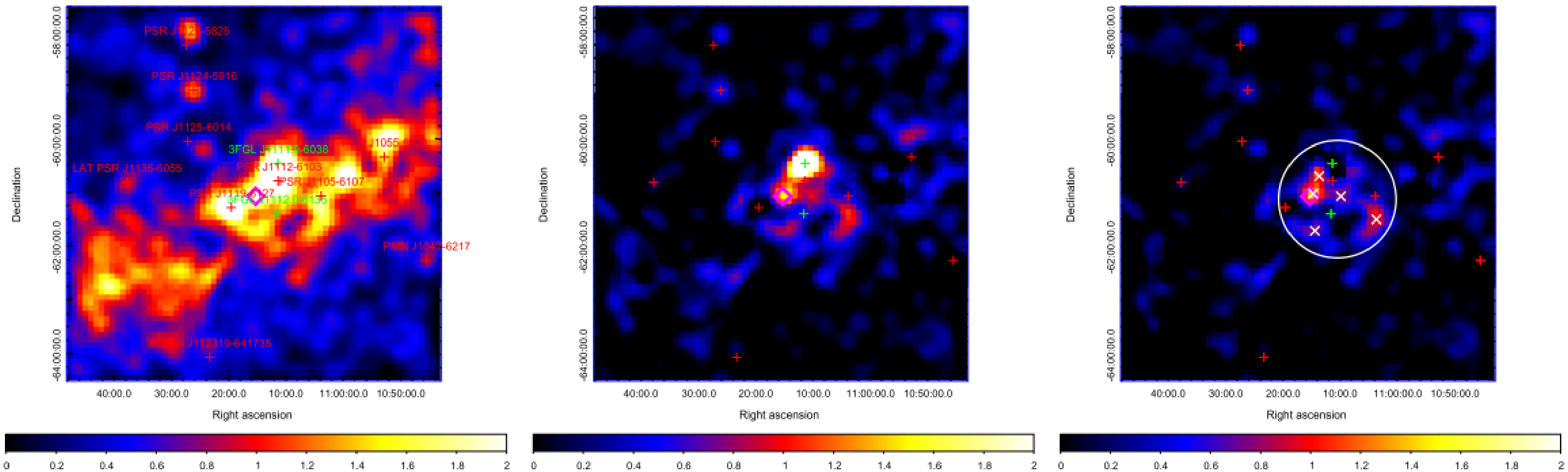


Fig. 1: *left* γ-rays counts map above 10 GeV in the inner 5° around NGC 3603. The identified 3FGL catalog sources are labeled as red crosses. The two unassociated catalog sources are labeled as green cross. The position of NGC 3603 is marked as a magenta diamond. *middle* : The residual map after subtracting all the identified catalog source and the diffuse background. *right* : The residual map after subtracting all the identified catalog source and the diffuse background, as well as the unassociated catalog source 3FGL 1111.9-6038. Also shown is the best fit gaussian disk (white circle, the radius is corresponding to the 1 σ of the Gaussian) and the position of the five point sources (white "x") used to test the hypothesis that the extended emission comes from several independent point sources.

Yang & Aharonian (2016)

- Young star clusters and associations are potential sites of cosmic ray acceleration
- eg. Westerlund 2 (Yang+ 2017), NGC 3603 (Yang & Aharonian 2016), Cygnus OB2 (Ackermann+ 2011)

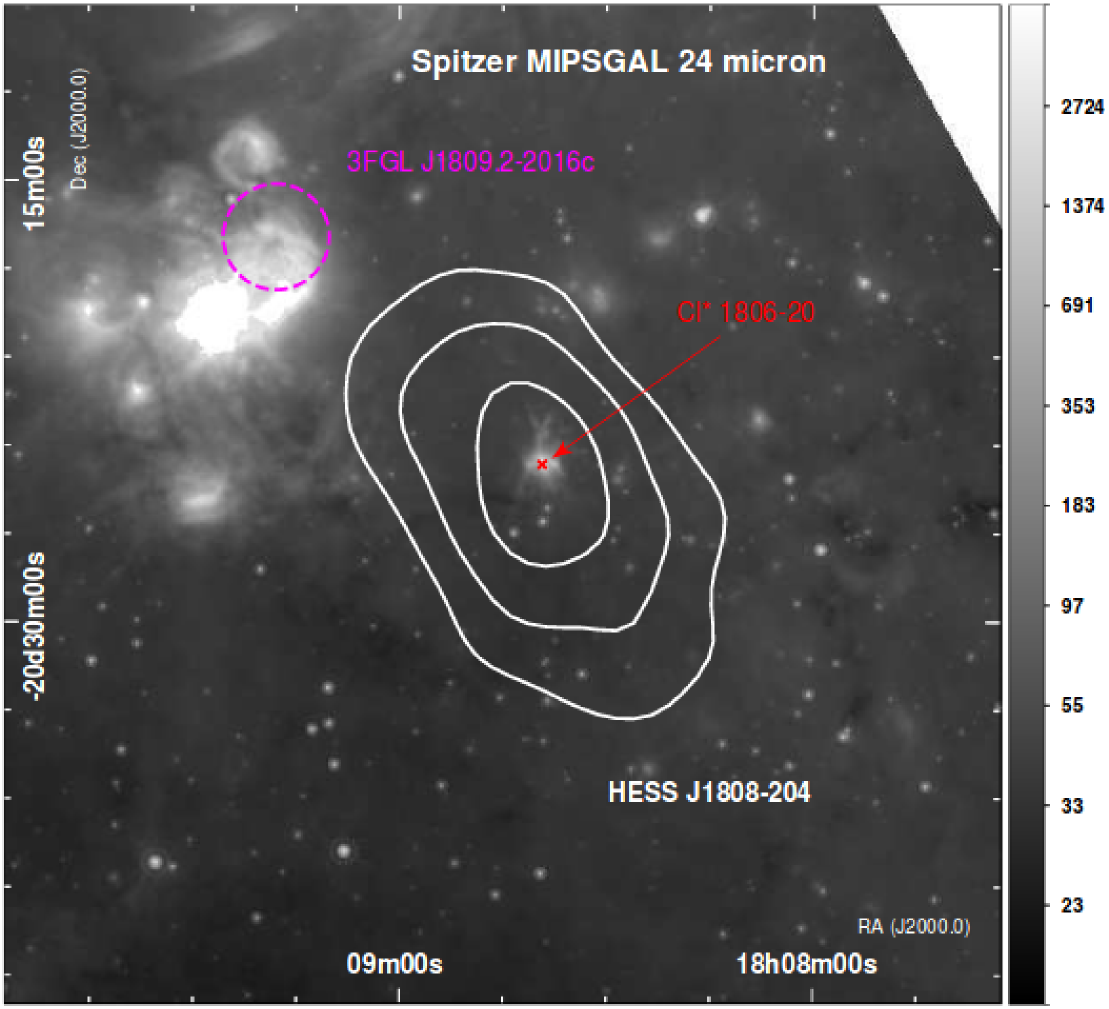


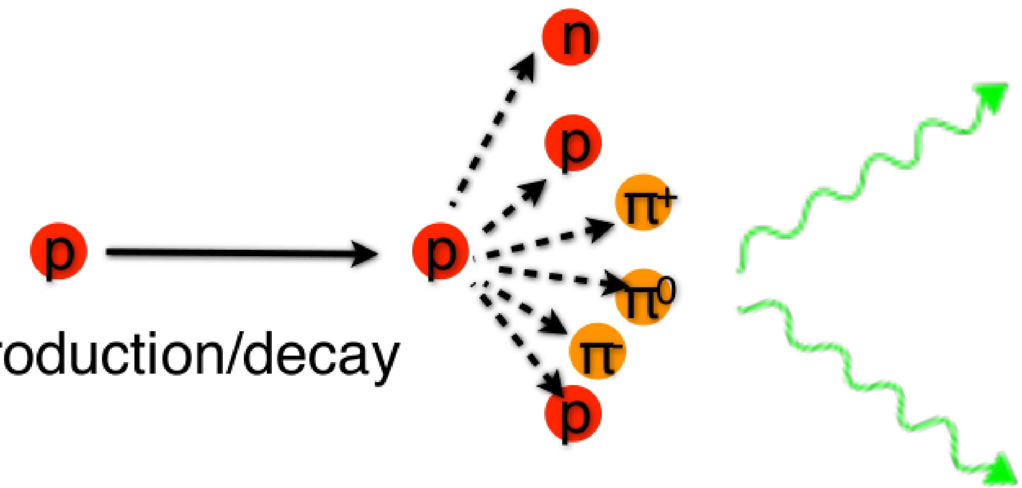
Fig. A.1. *Spitzer* MIPSGAL 24 μm image in MJy/sr units with HESS J1808−204 excess significance contours (6, 5, 4 σ as for Fig. 1) overlaid as solid white lines. Locations of the stellar cluster Cl* 1806−20 (containing SGR1806−20 and LBV 1806−20) and the *Fermi-LAT* GeV source 3FGL J1809.2−2016c (68% location error) are indicated. The bright infrared feature to the north-east towards the *Fermi-LAT* source is the W31 giant HII star formation complex.

H.E.S.S. Collaboration (2018)

- Collective effect of multiple shocks from supernovae and the winds of massive stars provide sufficient energy for cosmic ray acceleration.
- γ-ray production due to accelerated cosmic rays interacting with surrounding interstellar medium (hadronic processes?)

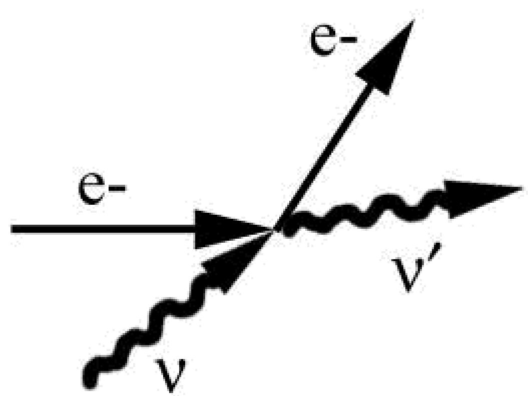
Emission processes

Neutral pion production/decay



$$\pi^0 \rightarrow 2\gamma$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$
$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$
$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

Inverse Compton scattering



$\nu' > \nu$

High energy e- initially

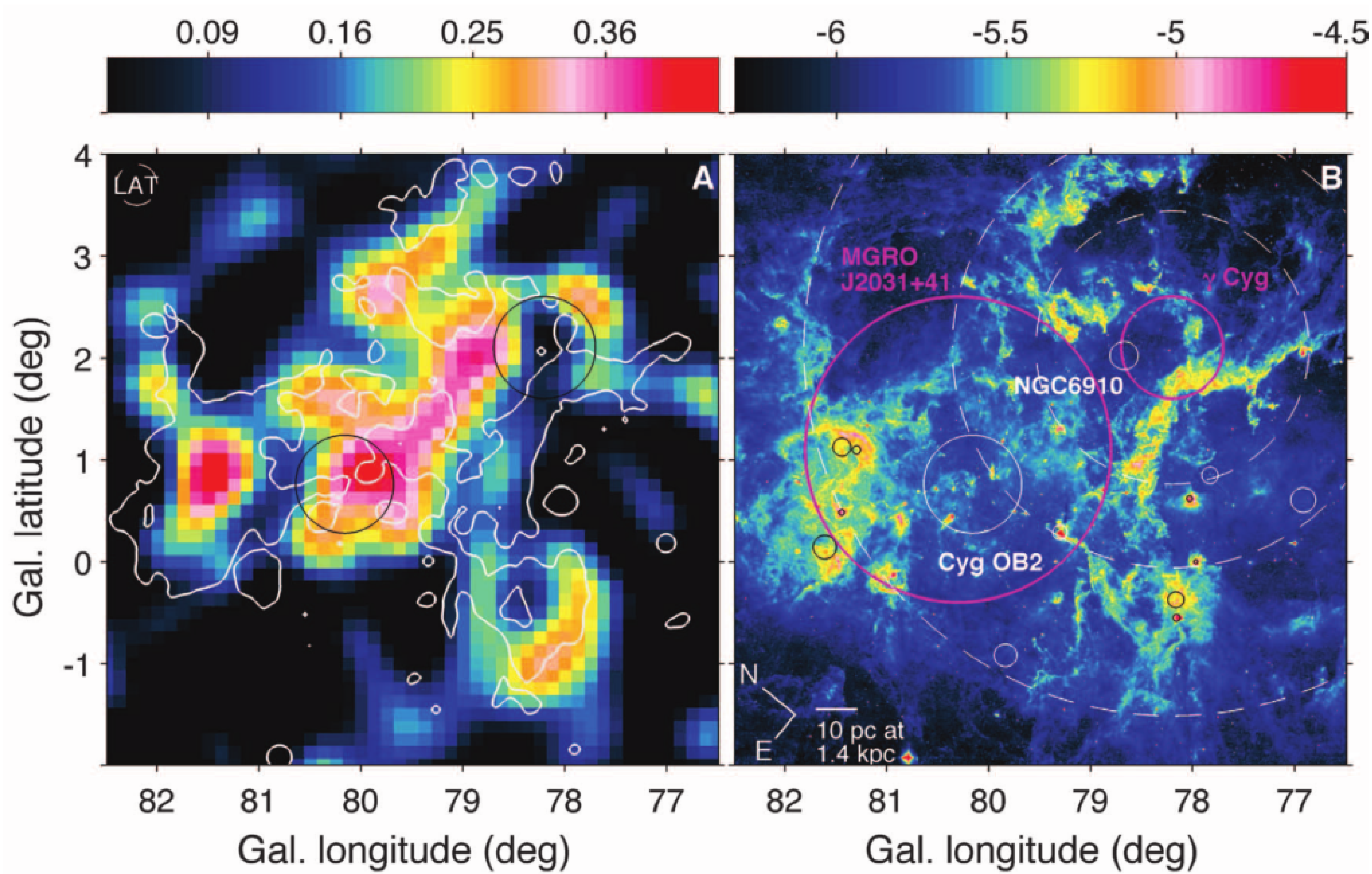
e- loses energy

Why do we care?

- CRs are an important constituent of the ISM (energy density ~ 1eV/cm^3 – slightly larger than starlight, CMB, or Galactic B field)
- Crucial role for ISM physics and chemistry because they dominate the ionisation of dense ISM clouds where the gas is shieded from the UV radiation field
- Ions couple the gas to magnetic field → changes the dynamics of the cloud, protoplanetary discs, complex molecule creation
- CRs detected indirectly through radiation processes
- Star clusters and associations are particle acceleration sites → ^{60}Fe abundance in CRs, correlation with Galactic diffuse γ-ray emission

Cygnus OB2 association

Fig. 3. (**A**) Photon count residual map in the 10- to 100-GeV band (*30*), smoothed with a $\sigma = 0.25°$ Gaussian kernel, and overlaid with the $10^{-5.6}$ W m^{-2} sr^{-1} white contour of the 8-µm intensity. The typical LAT angular resolution above 10 GeV is indicated. The black circles mark γ Cygni and Cyg OB2. (**B**) An 8-µm map and solid circles for γ Cygni and stellar clusters, as in Fig. 1. The large magenta circle marks the location and extent of the source MGRO J2031+41 (*14*); dashed circles give upper limits to the diffusion lengths of 10, 10^2, and 10^3 GeV particles after 5000 years of travel time using the standard interstellar diffusion coefficient. Their origin from the position of the rim of γ Cygni 5000 years ago is purely illustrative.



Ackermann+ (2011)