the Fermi Bubbles

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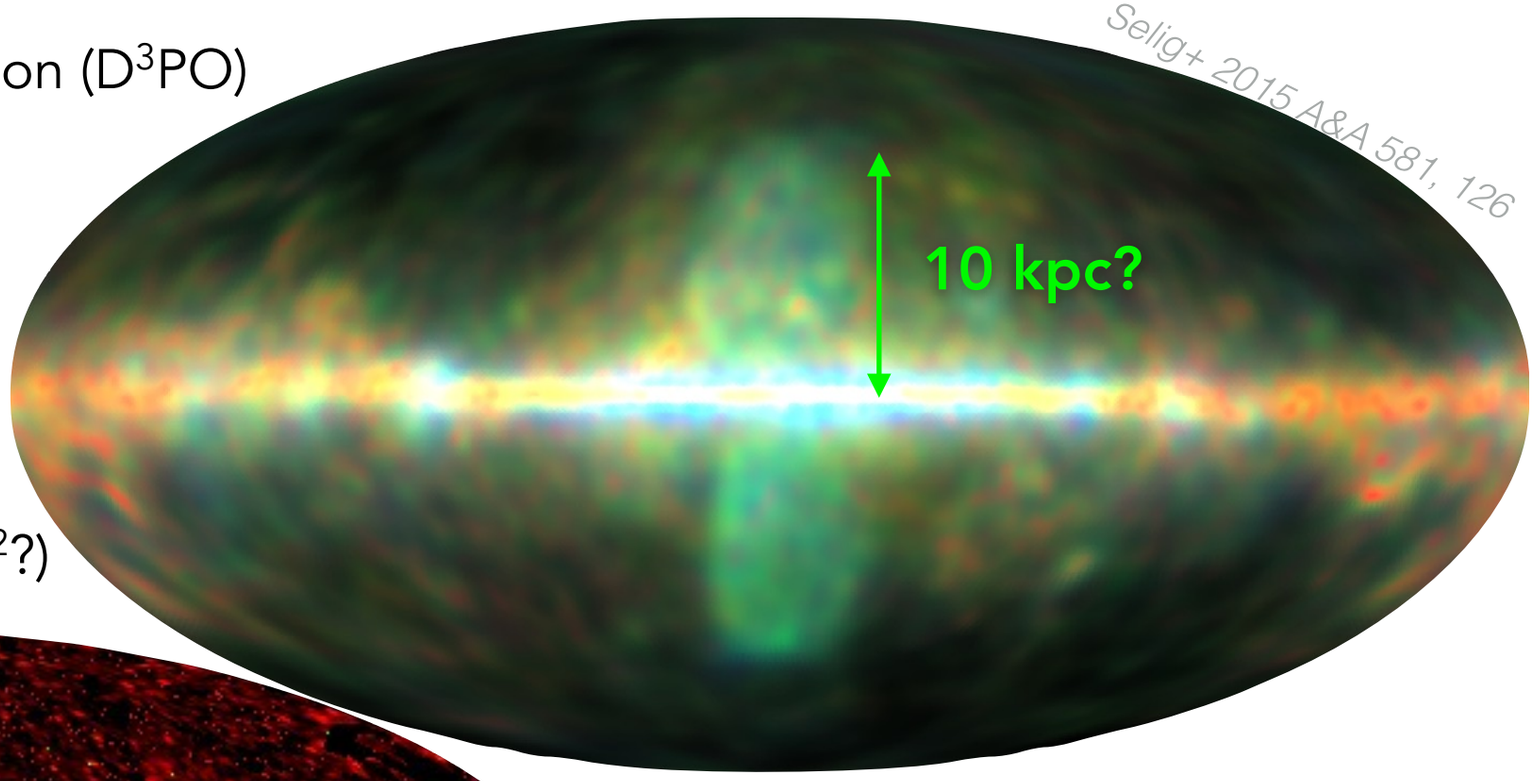
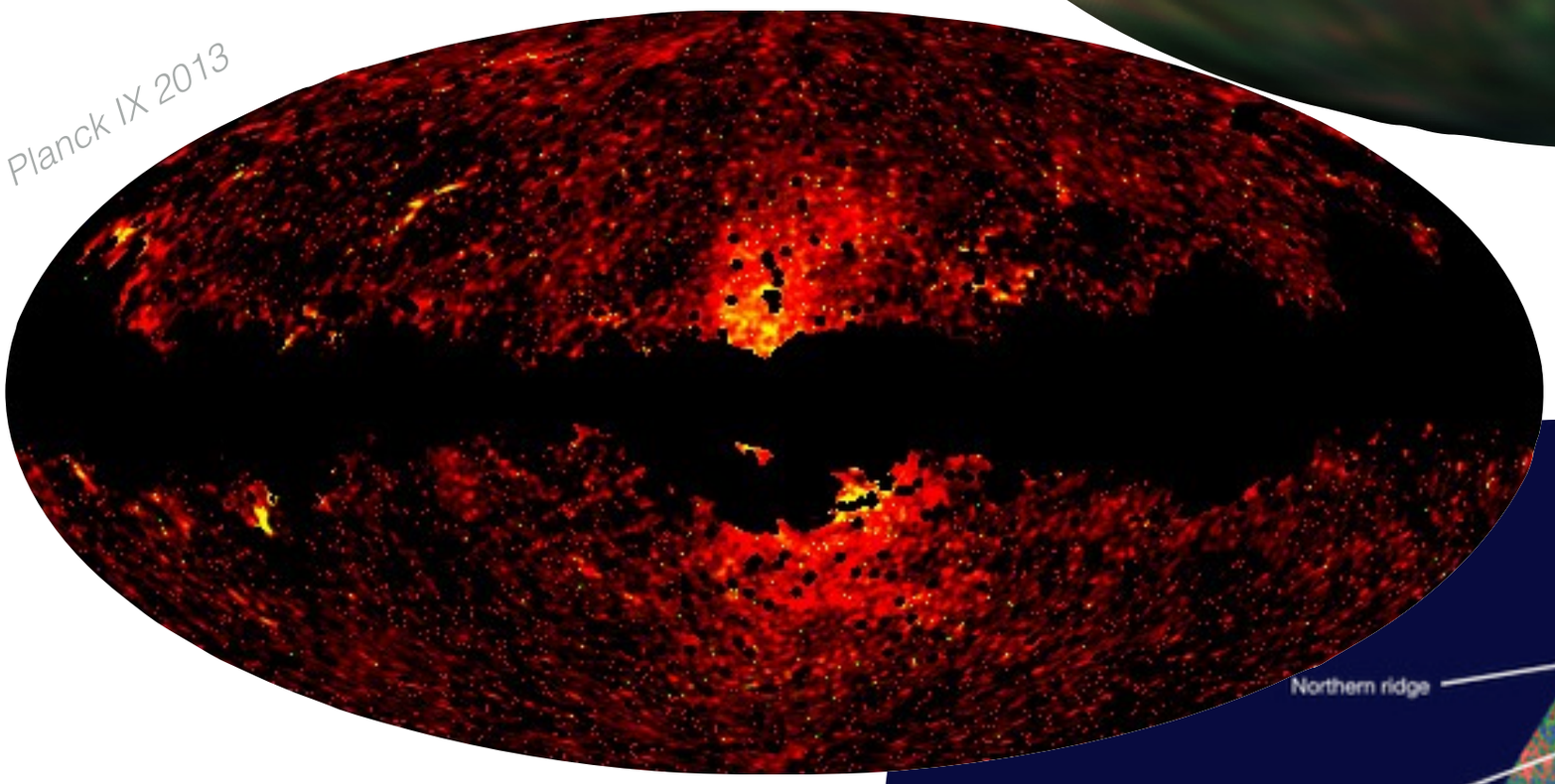
Fermi Bubbles

- spectro-spatial component separation (D^3PO)
  - 5.5 yrs > 600 MeV
  - redder cloud-like emission
  - bluer emission from Loop I + Bubbles
- Planck haze at 30 GHz
  - $T_b \propto \nu^{-2.56}$ (synchrotron from $E_e^{-2.2}$?)

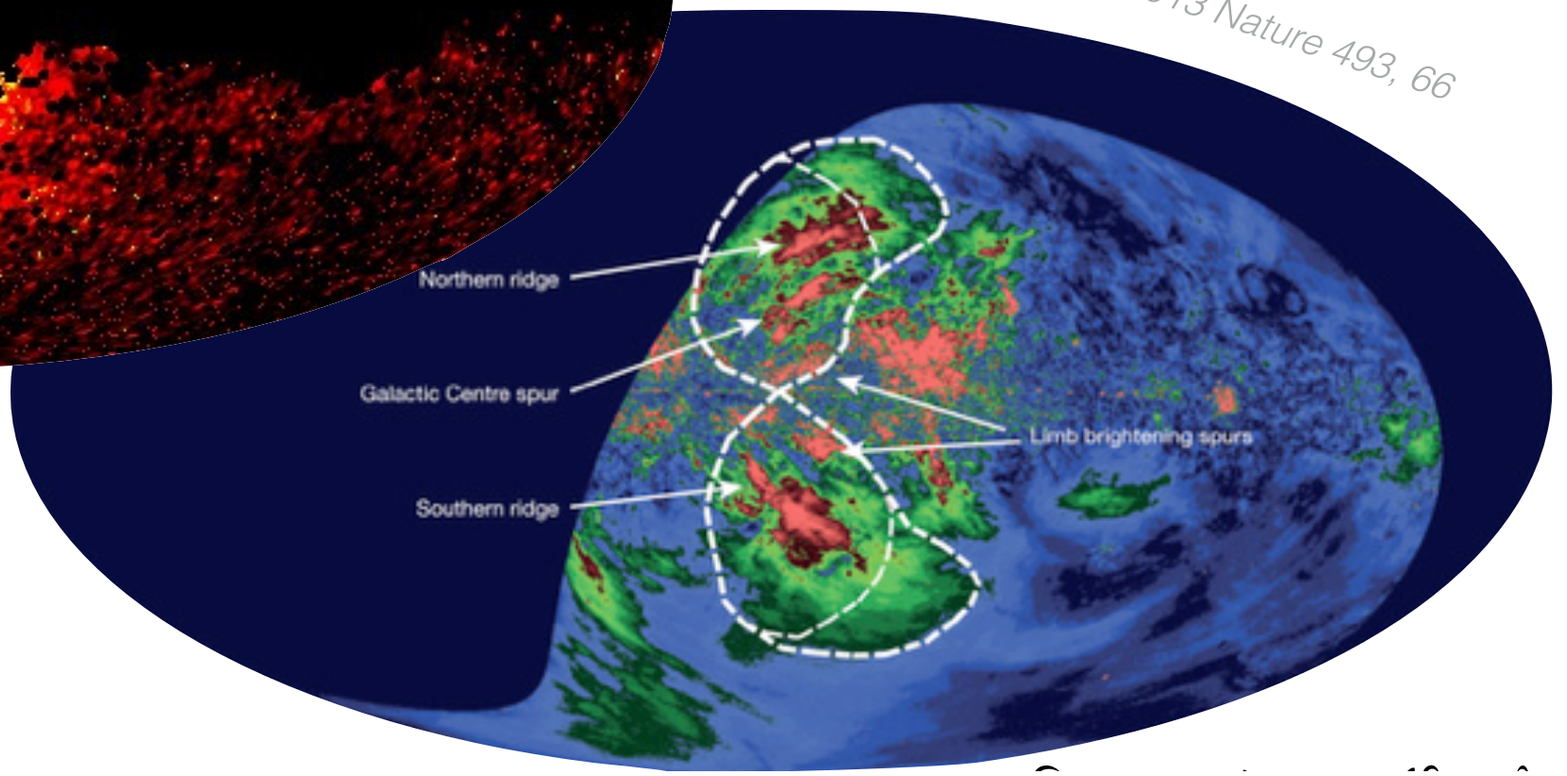


Selig+ 2015 A&A 581, 126



Planck IX 2013

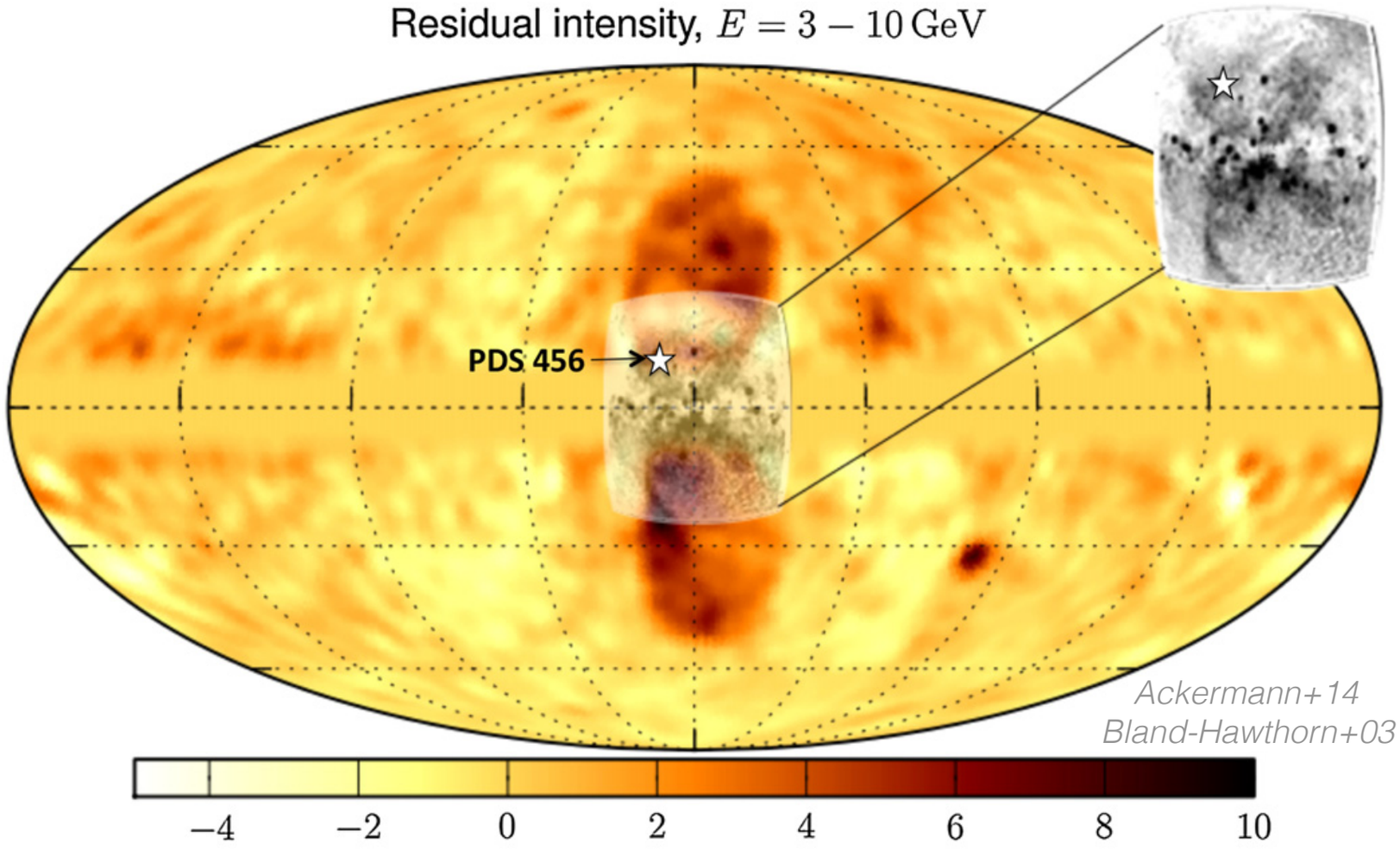
- linearly-polarized intensity at 2.3 GHz
  - distorted by MWay motion



Carretti+ 2013 Nature 493, 66

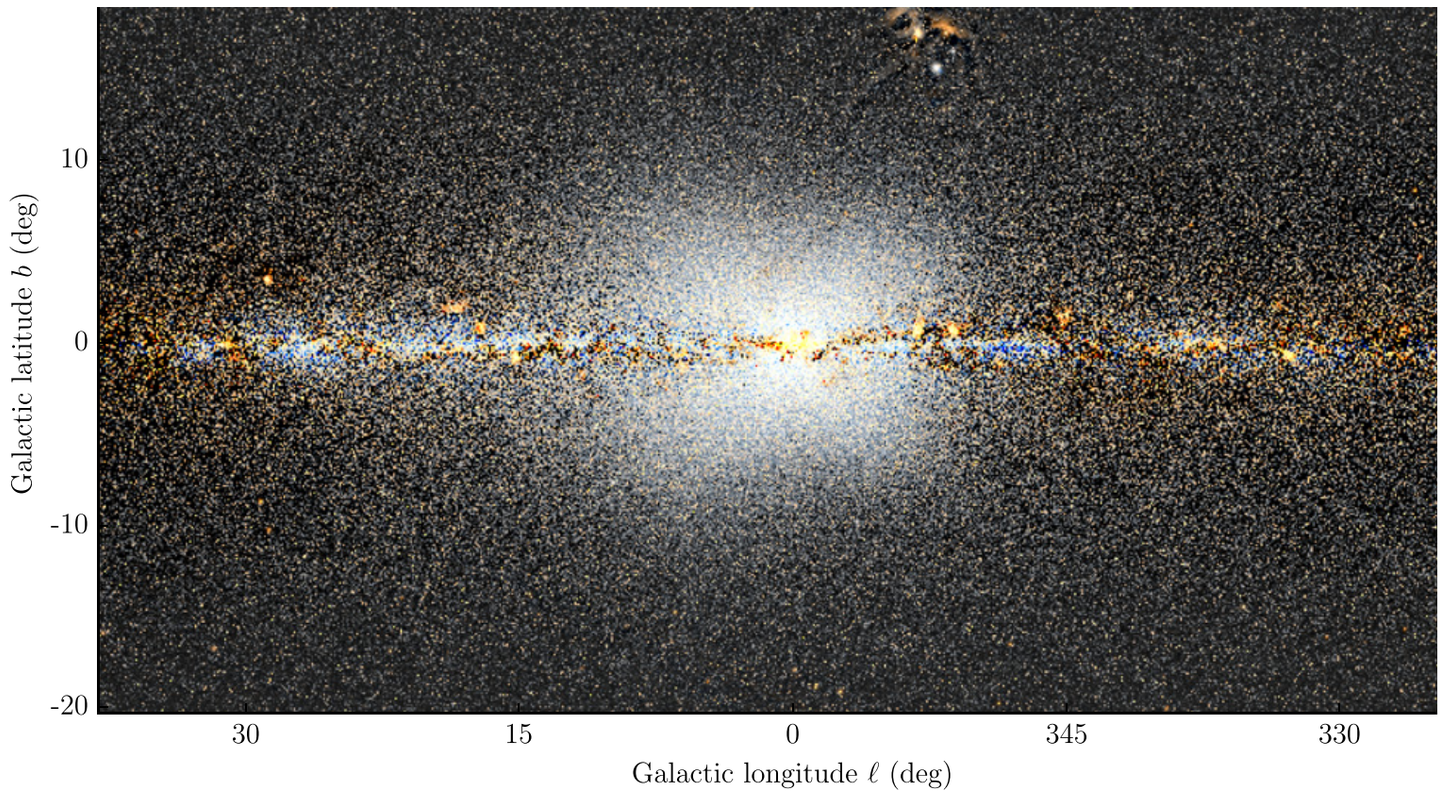
extent at low latitudes?

- ROSAT 1.5 keV

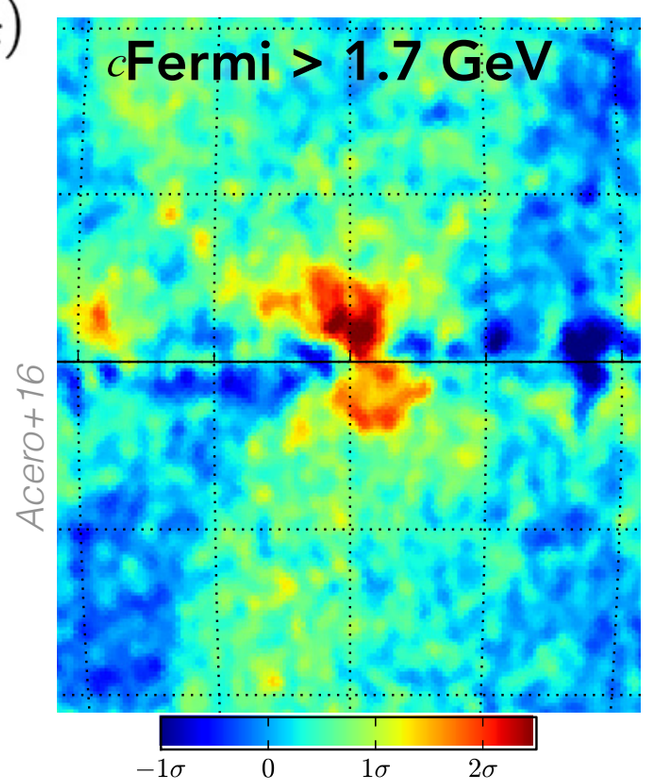


Ackermann+14
Bland-Hawthorn+03

- X-shaped bulge stars (WISE)
  - IC + pulsars + LMXBs …



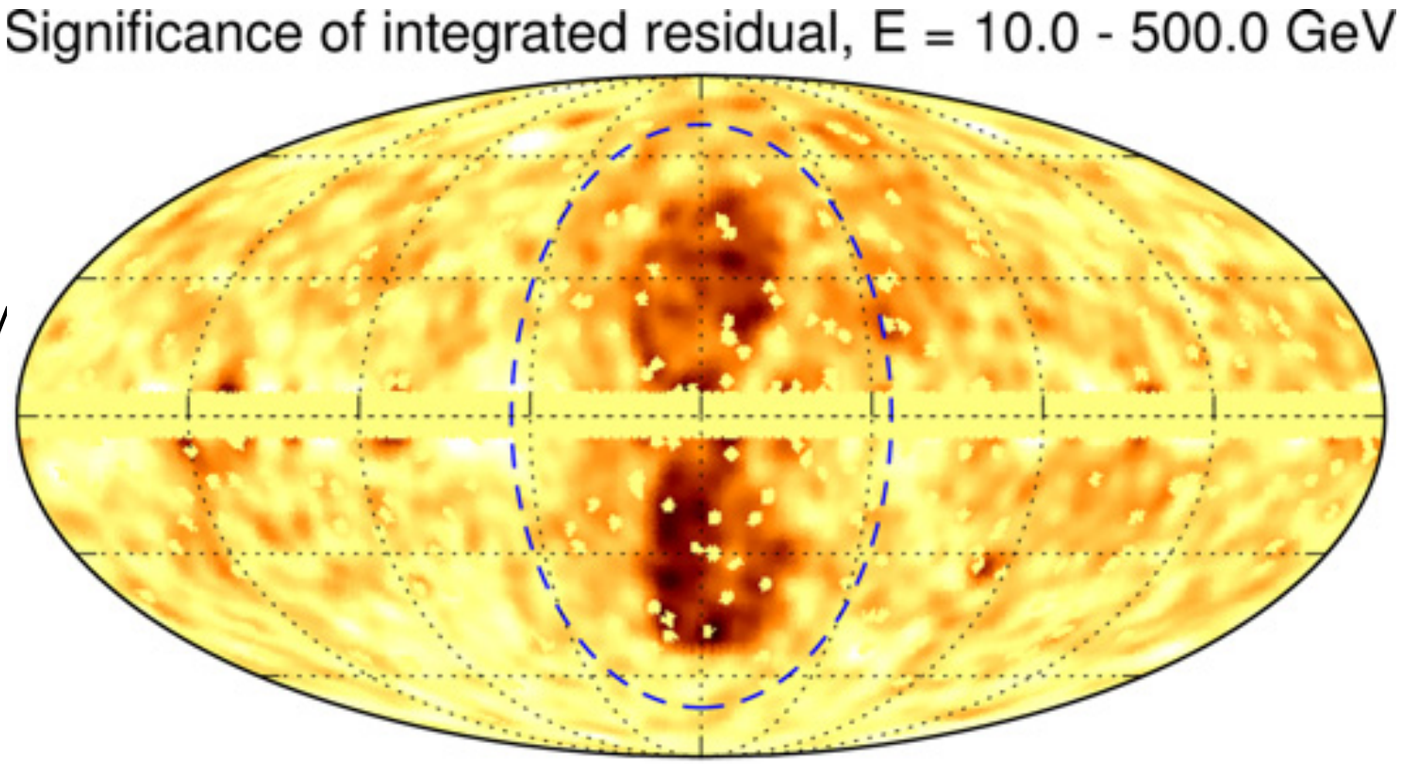
Ness & Lang 2016



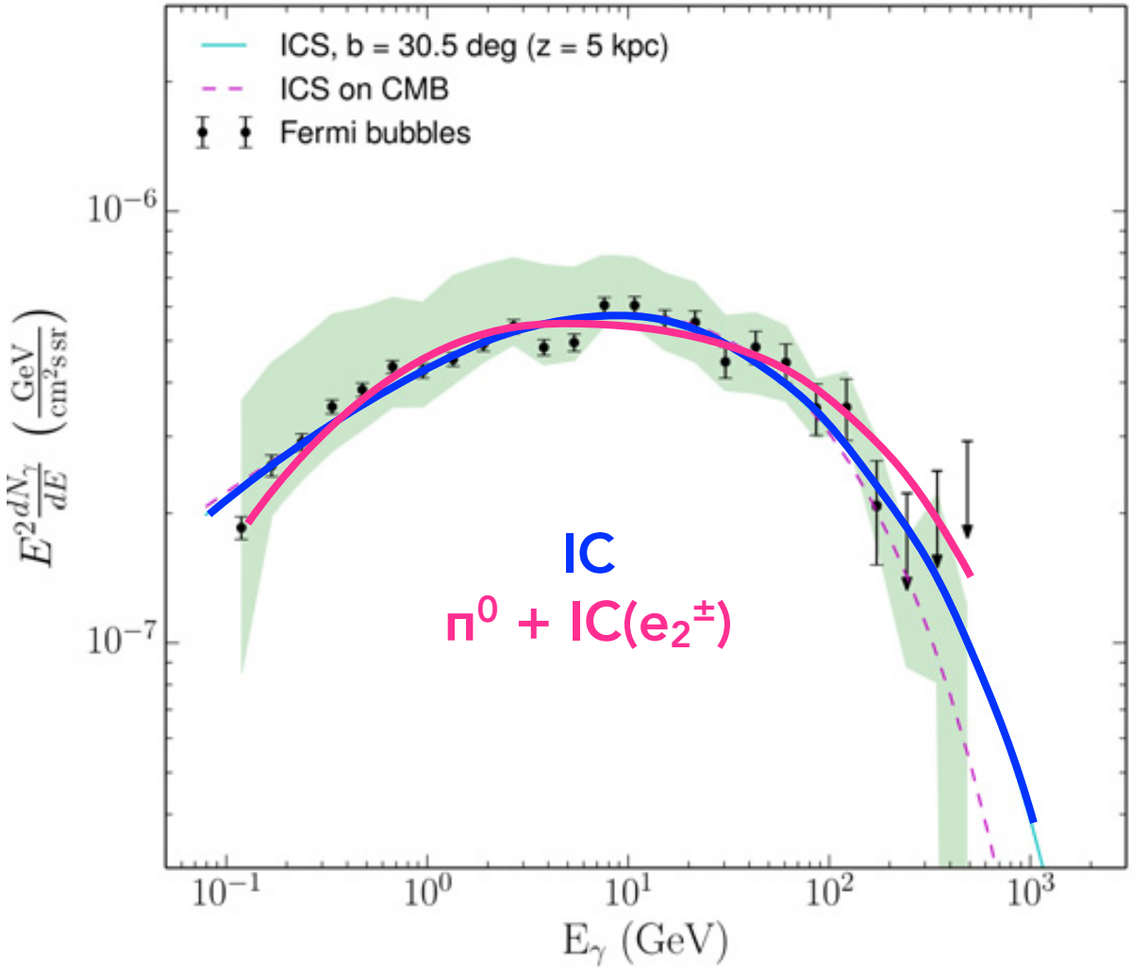
Acero+16

γ-ray properties

- 4.2 yr of Fermi-LAT data > 100 MeV
  - $L_{0.1\text{-}500\ GeV} = (44 \pm 0.1^{+2.4}_{-0.9})\ 10^{37}$ erg/s
  - index $-1.87 \pm 0.02^{+0.14}_{-0.17}$ above 1 GeV
    $E_{cut} = 113 \pm 19\ ^{+45}_{-53}$ GeV
  - uniform with latitude or intensity
  - no central jet



Ackermann+14

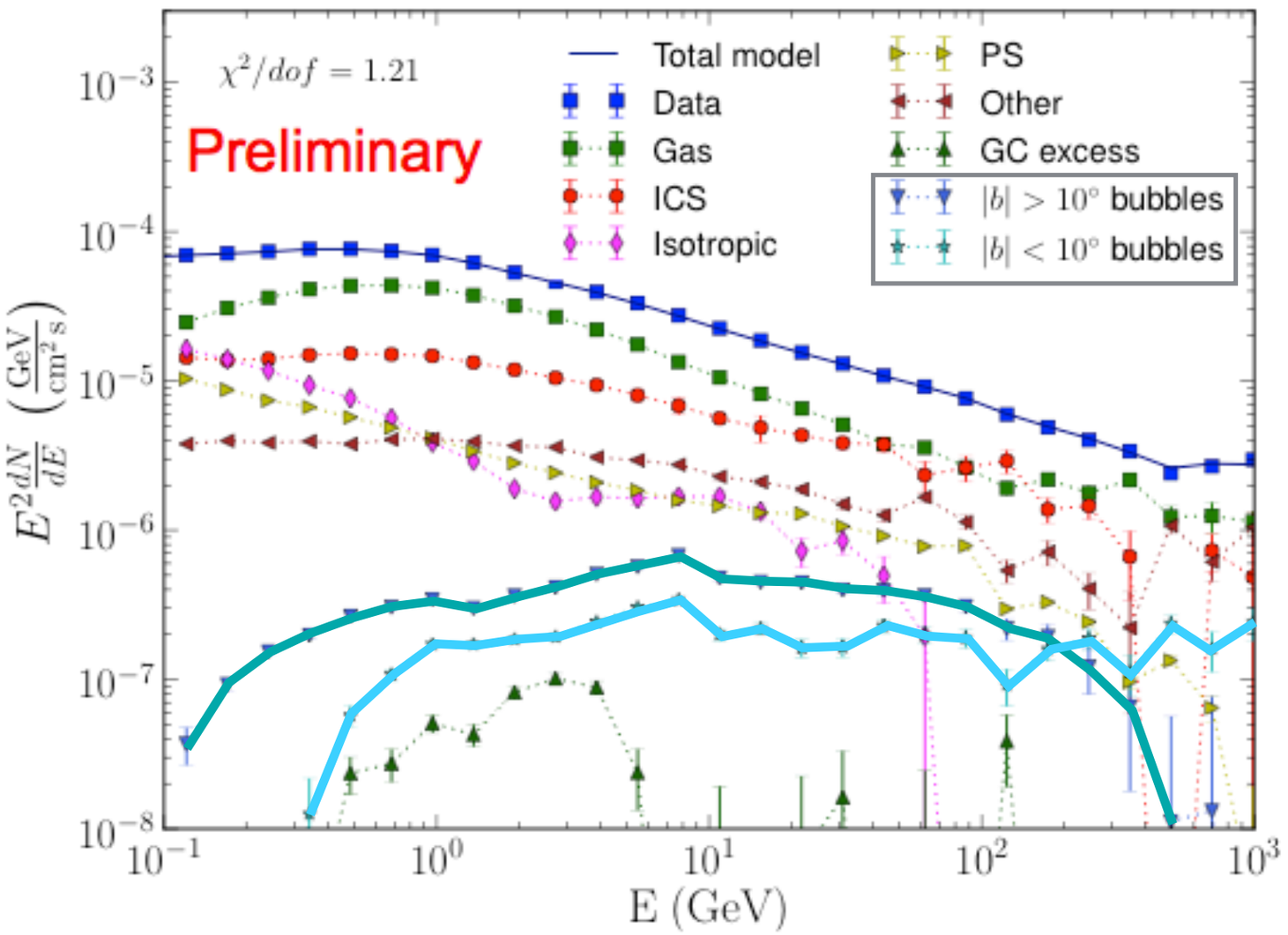


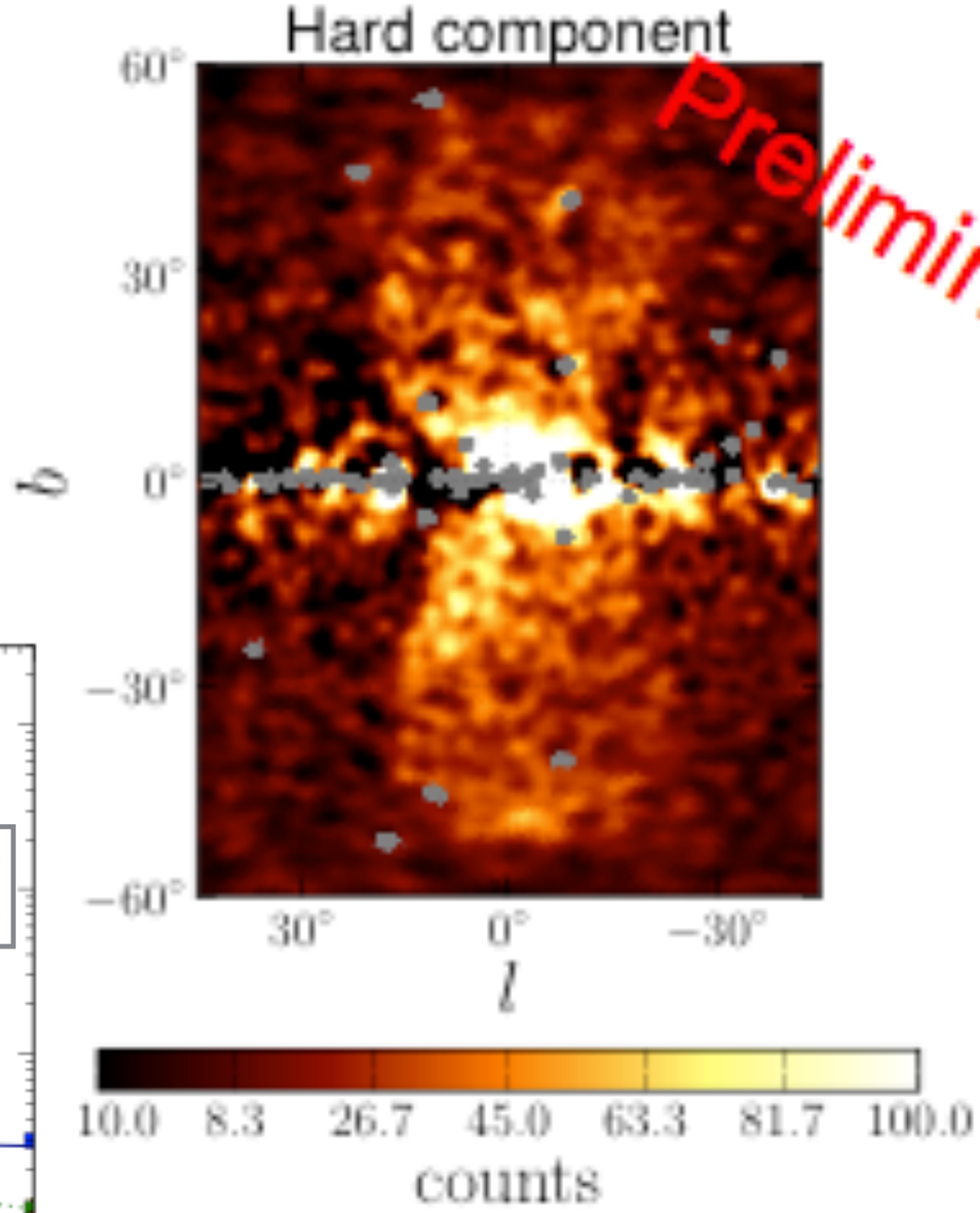
Ackermann+14

- IC model with E-2.2 electrons cutting off at ~1 TeV, holding ~10^{52} ergs above 1 GeV
  - ok with synch haze
- π^0 model with E-2.1 protons cutting off at ~ 14 TeV, holding ~3 10^{55} ergs above 1 GeV
  - requires other electron source for haze
- spectrally indistinguishable

extended analysis

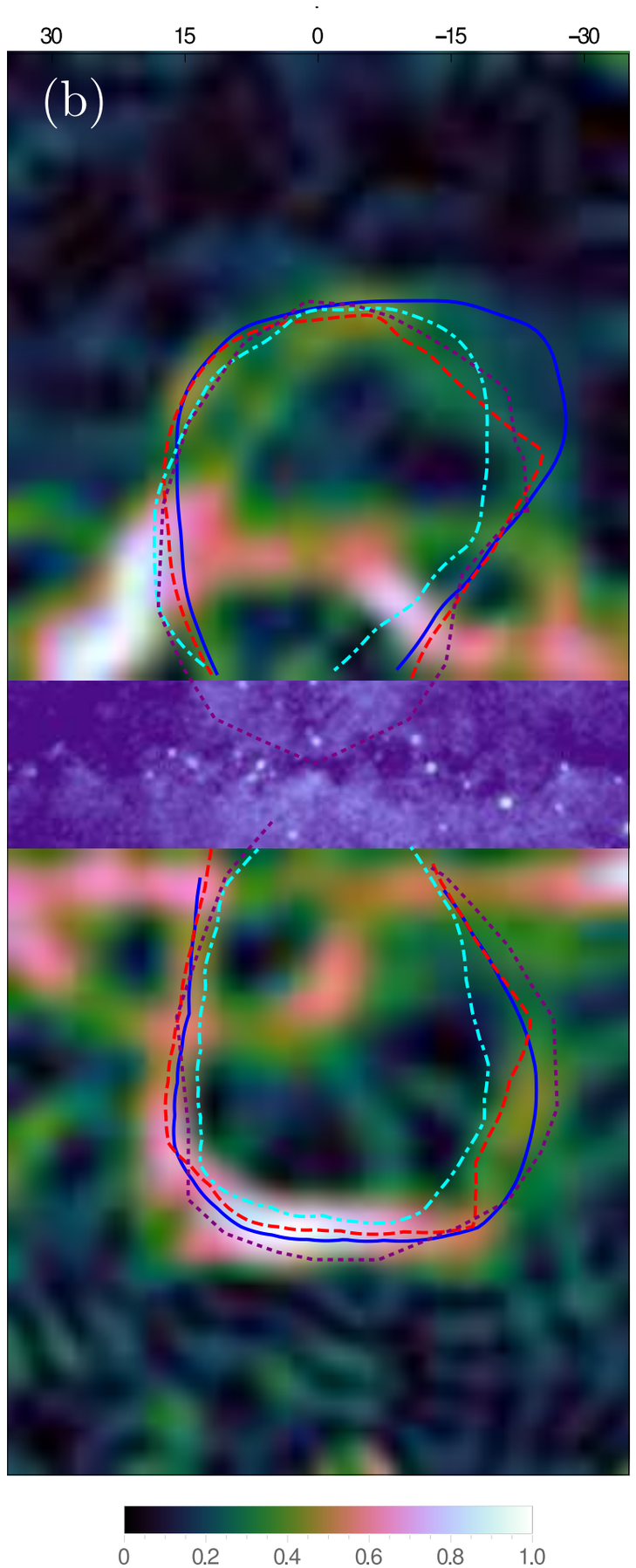
- 6.5 yrs of Pass 8 Fermi ultra clean data > 100 MeV
- spectral component analysis & extension to |b| < 10° assuming the same $E^{-1.9}$ spectrum as at high latitude
- indeed similar spectra below & above 10° (except above 400 GeV ???…)





sharp edges

- edges connect to the ROSAT base (?)
- edge vs. integrated spectrum: softened by only $\Delta\gamma = 0.2\text{-}0.3$ =>
  - CRs injected at shock & diffuse away faster at high energy
  - $D(E) \approx 10^{29.5}\,(E/10\ \mathrm{GeV})^{0.48\pm0.02}\ \mathrm{cm}^2\ \mathrm{s}^{-1}$ if electrons
    $D(E) \propto (E/10\ \mathrm{GeV})^{0.24\pm0.01}$ if protons
  - rather uniform edge spectrum despite varying Mach number along the edges => Mach > 5
- favours
  - in-situ acceleration over injection from GC
  - forward rather than termination shock



Keshet & Guruch 2017

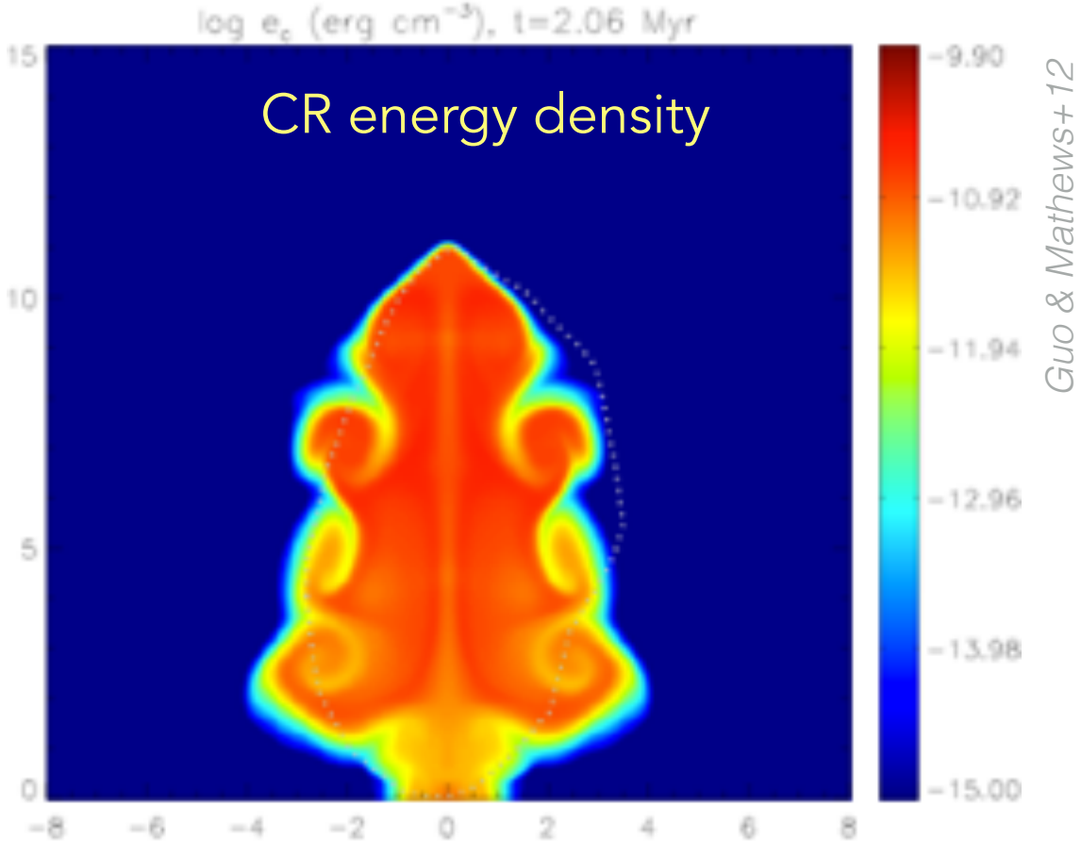
AGN driven bubbles

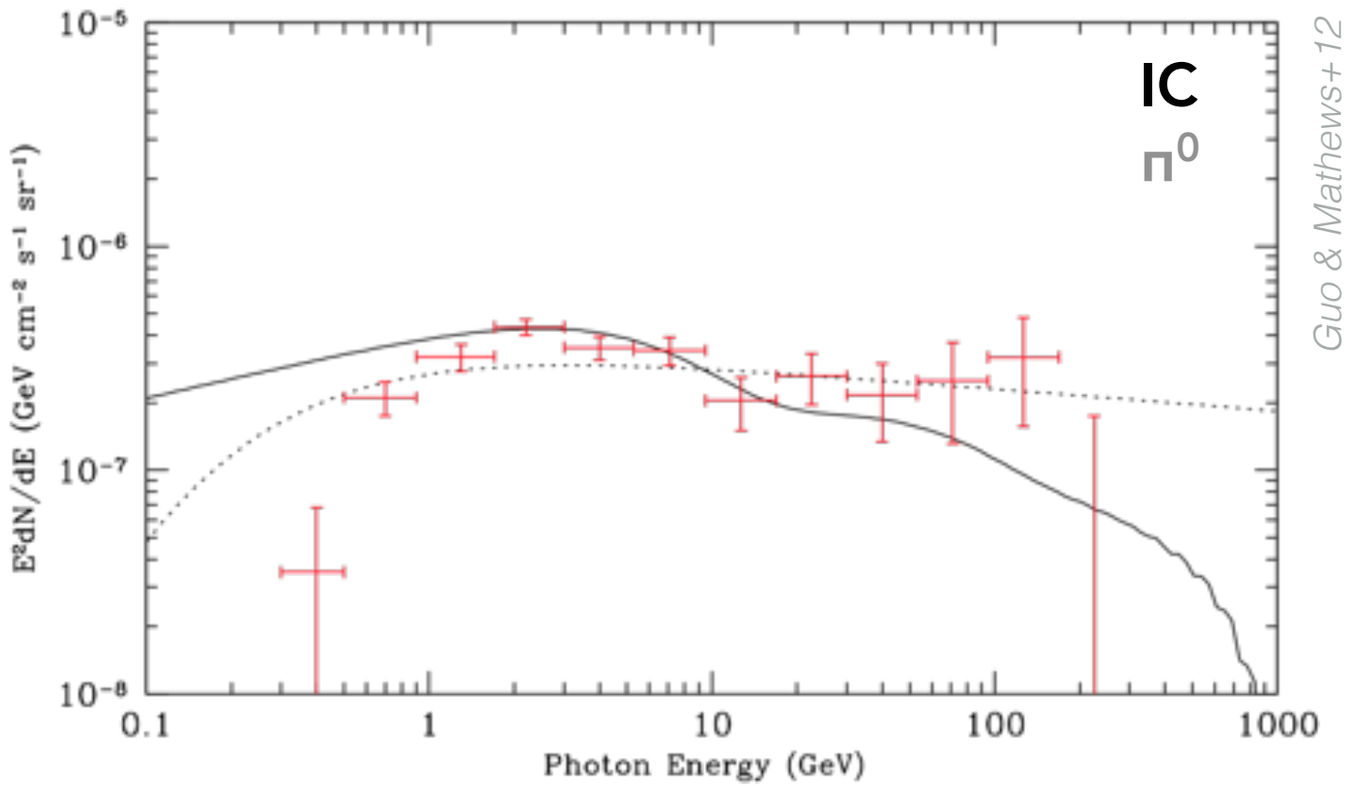
- inflated by AGN jets Guo 2012
  - jet ok for location, size, shape, sharp edges
  - jet active for 0.1-0.5 Myr, 1-3 Myr ago
  - requires $10^{55\text{-}57}$ ergs, $\dot{M}_{accr} = 10^{2\text{-}4}\ M\odot$
  - smooth brightness => suppressed RT and KH instabilities downstream of the bow shock
  - sharp edges => suppressed CR diffusion across the shock
  - IC or π^0 emission ???
    if IC $p_e \ll p_{th}$, if π^0 $p_{CR} > p_{th}$ probably
  - pb: 0.3 L_{Edd}(SgrA*) and age too young unless continuous reaccelerating of IC electror

Zubovas & Nayakshin 2012

- AGN wind
  - spherical expansion, 0.1 c,
  - confined by CMZ
  - 6 Myr

- tidal disruption events

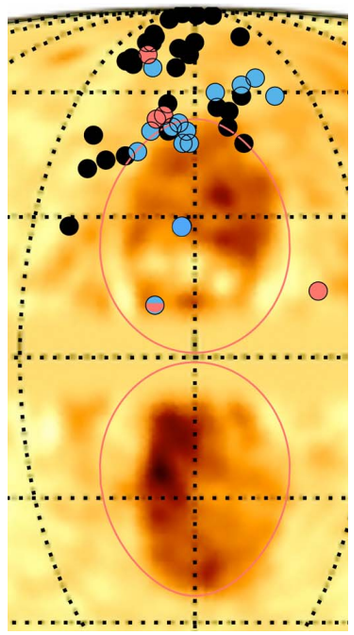


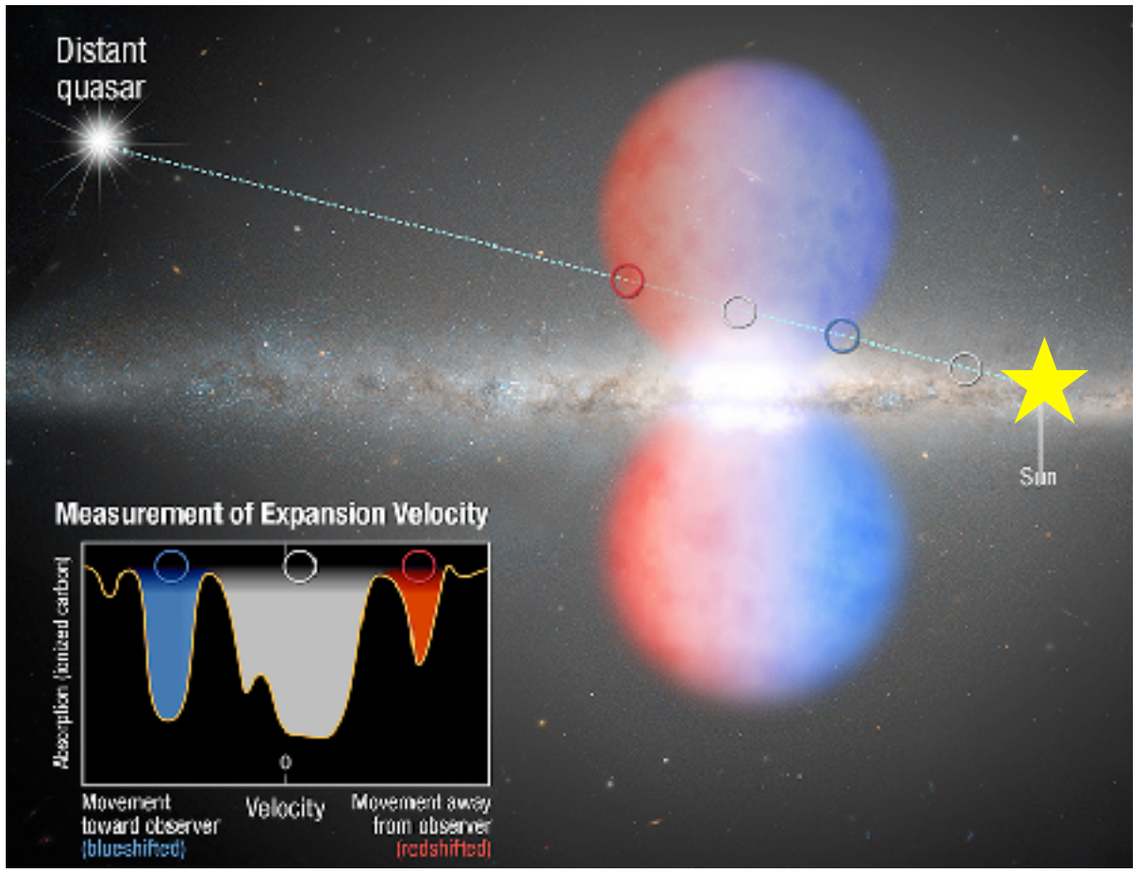


The average spectrum of the Bubbles

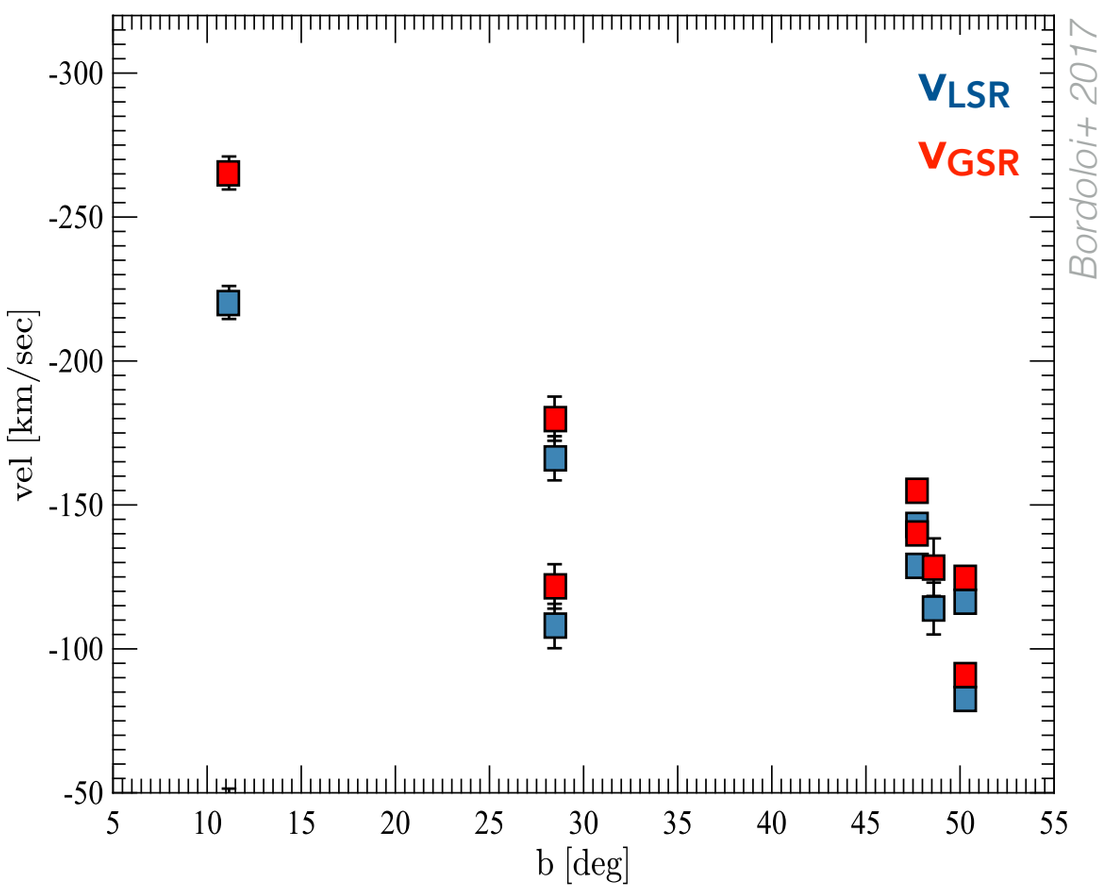
association with central warm outflows

- 2 UV absorption lines (HST):
  - WIM 10^4 K gas entrained in a biconical outflow with $v_{out} \sim 900$ km/s, opening angle $\sim 110°$
  - not the hot wind plasma
- UV absorption mapping (HST):
  - $v_{GSR} \downarrow$ with z and R_{Gal}
  - not constant E injection but 2 bursts at 1000 & 1300 km/s 4 and 6 Myr ago
  - or AGN jet constantly active for 5-6 Myr

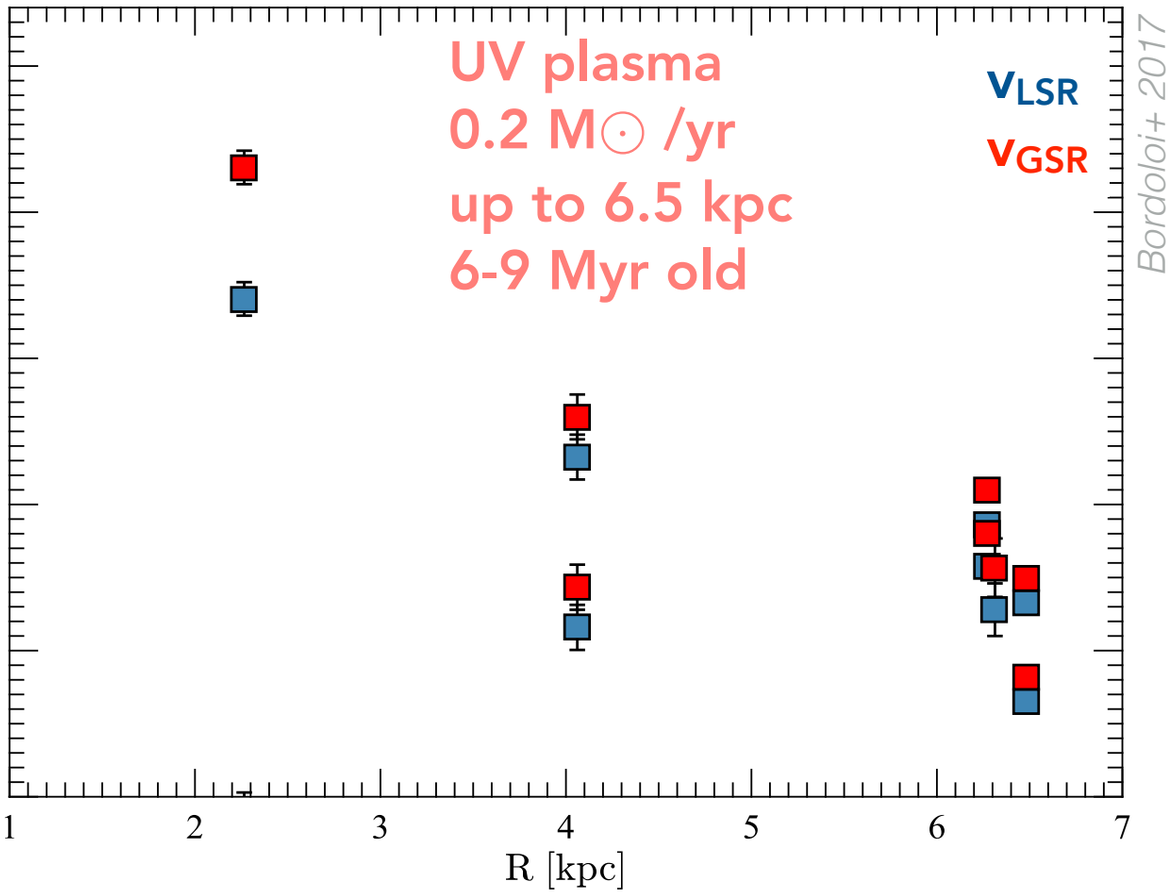




Fox+ 2015 ApJ 799, L7



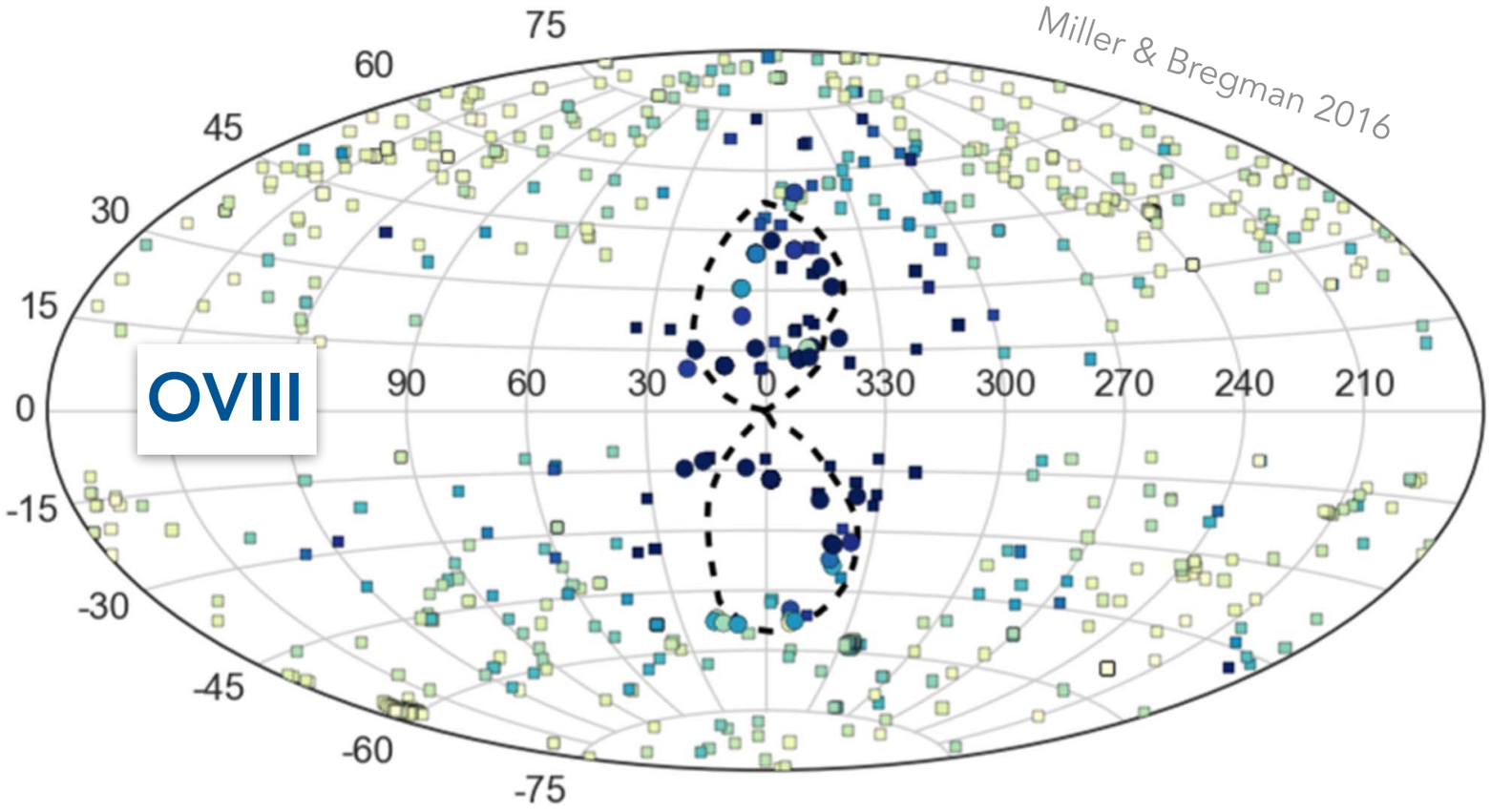
Bordoloi+ 2017

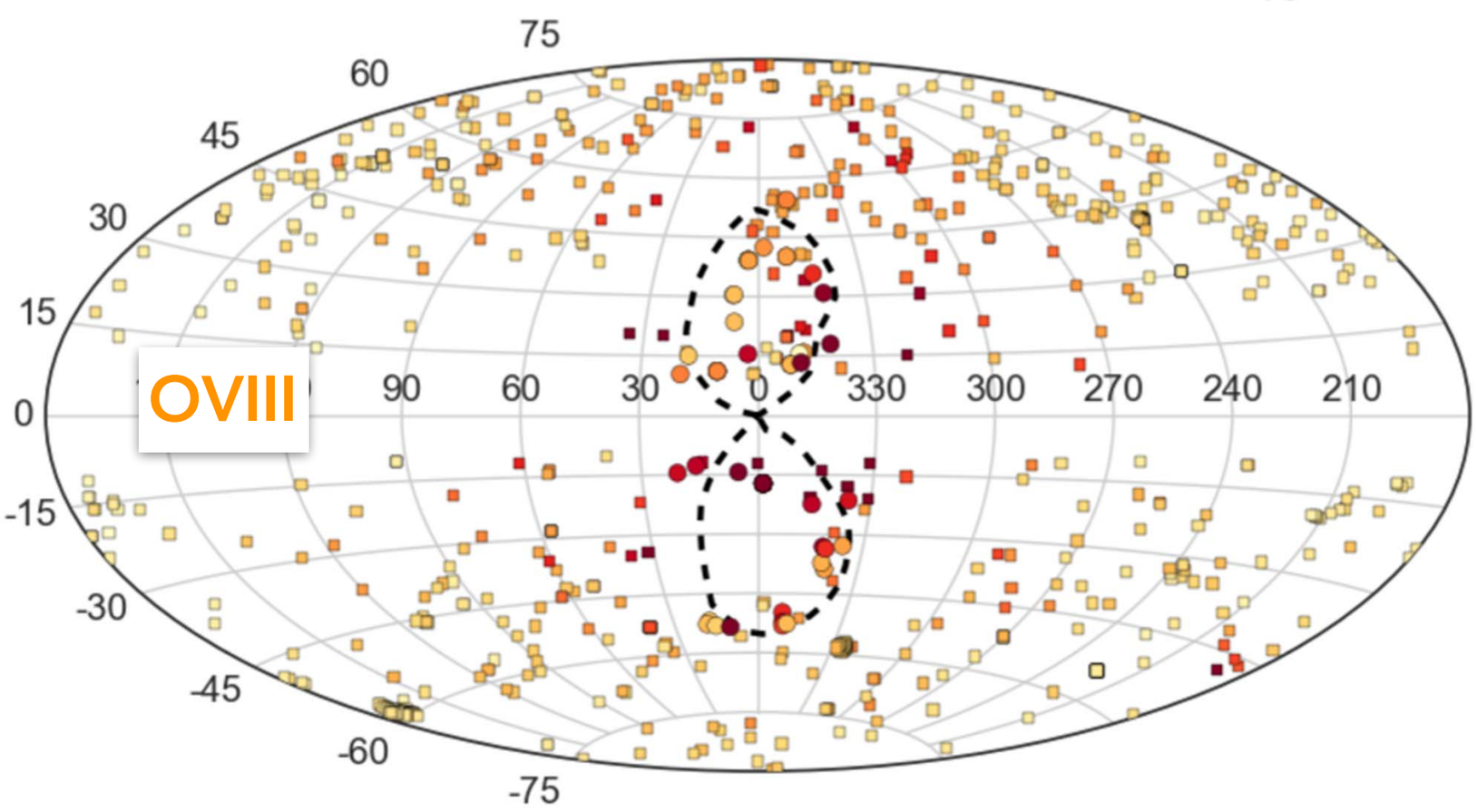


Bordoloi+ 2017

association with a central hot outflow

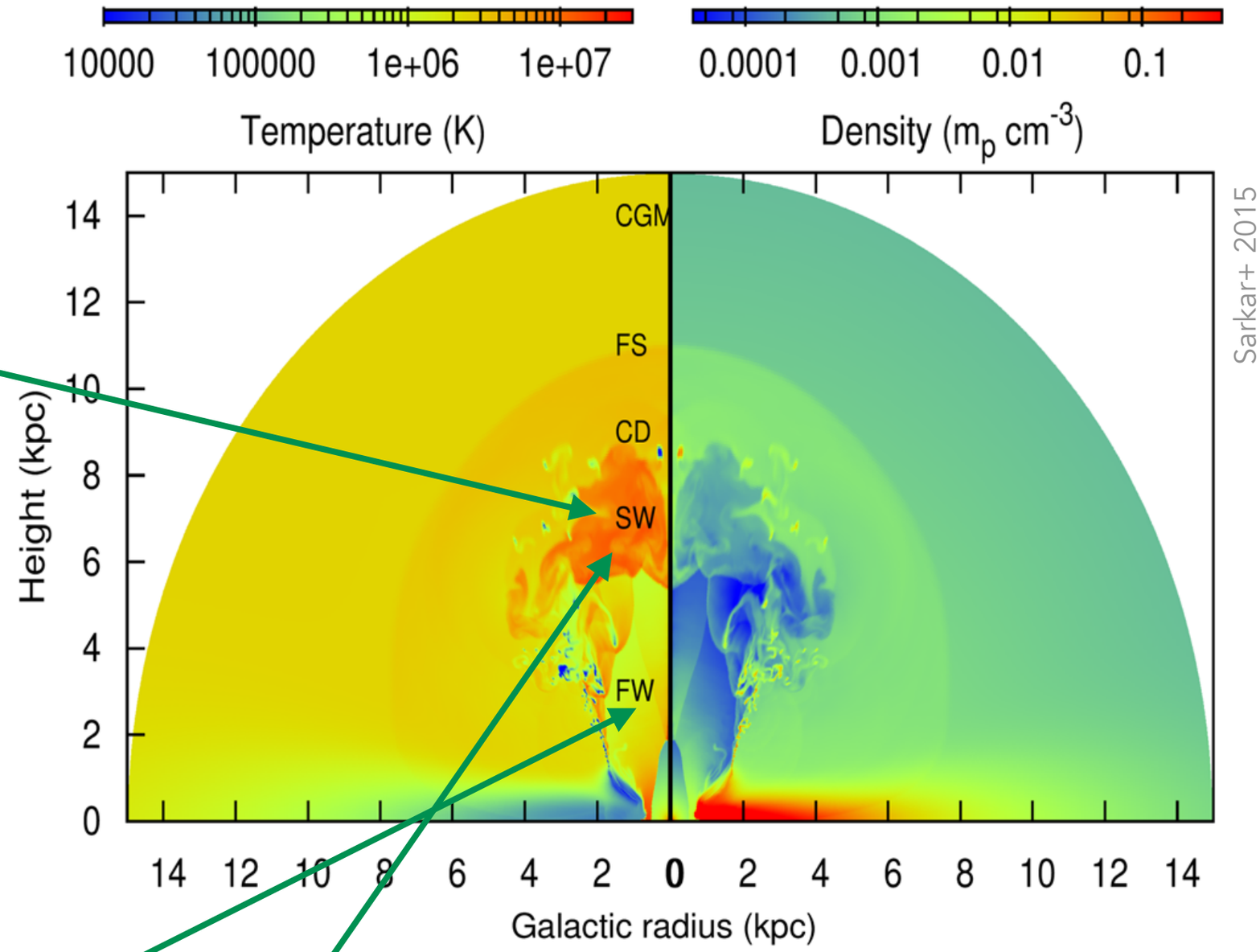
- X-ray OVII & OVIII lines
  - ~ 4.5 MK, 10^{-3} cm^{-3} gas,
  - flowing out at 490^{+230}_{-77} km/s
  - age of $4.3^{+0.8}_{-1.4}$ Myr
  - power of $2.3^{+5.1}_{-0.9}$ 10^{42} erg/s
  - favours accretion-driven event over Gal. wind





Galactic wind outflow

- continuous E(SNe) injection
  - over 50 Myr,
    SFR < 0.5-0.7 M⊙/yr
  - haze = synch (3-5 μG)
    from e- accelerated at TS
  - IC γ rays ok
  - X-ray emission “parachute”
    outside the CD, 20° beyond
    the γ-ray edge



- variant by Crocker et al. 2015
  - haze = synch from CR electrons
    reaccelerated at the reverse shocks,
    only 300 pc downstream => weak IC emission
  - γ rays: CR nuclei reaccelerated at the reverse shocks & further compressed near the CD
    where dense gas to produce pions

prospects for e-ASTROGAM

- e-ASTROGAM + Fermi
  + SKA absorption line & RRL surveys

- why so uniform inside & along edges?
  - resolve sub-structures
    at ~GeV energies
  - search for spectral changes along
    the edges

- increased level-arm in energy for a
  better separation of
  - bulge
  - CMZ
  - Bubbles' base
  - GC excess
- still very difficult…

- hard X-ray emission from the
  shocked gas
- MeV brem from low-energy electrons
- sensitivity for M31 bubbles???