

High Energy γ -Rays from Galactic Accretion Events and Implications for Unidentified GeV-TeV Sources

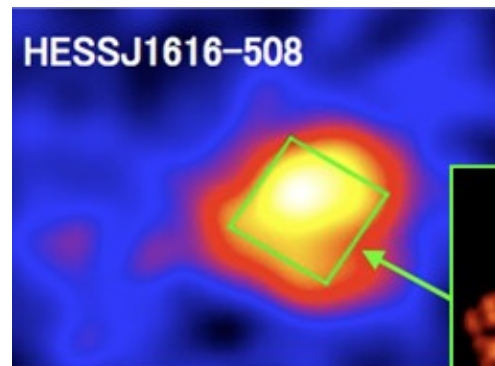
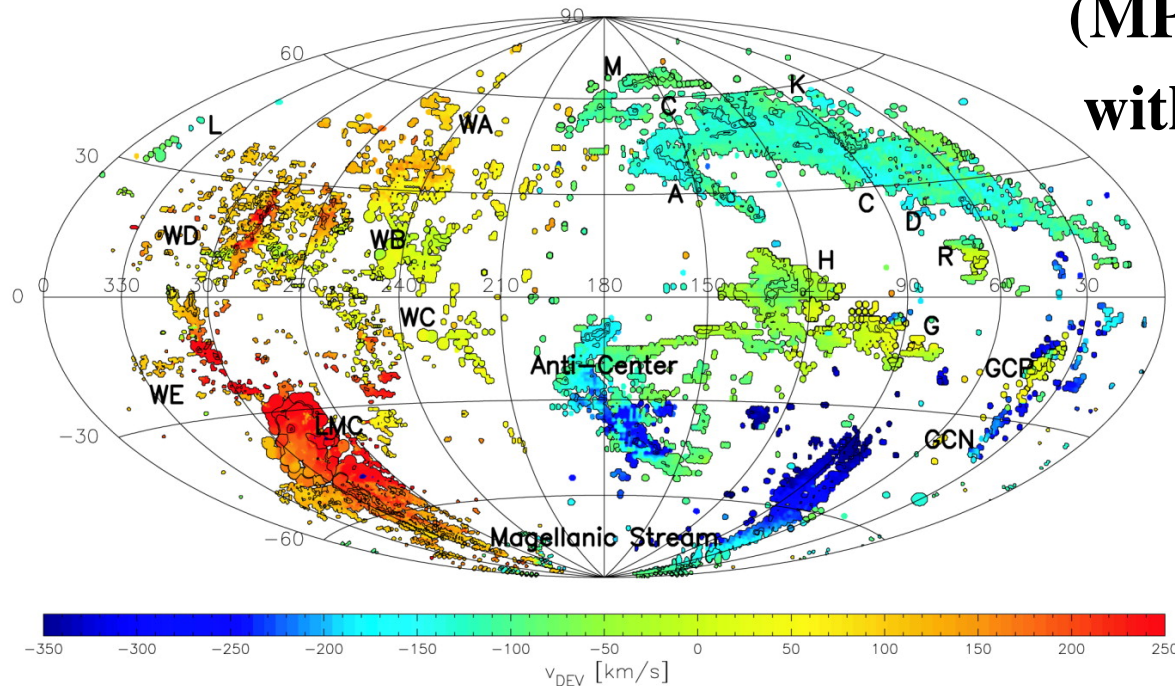
Susumu Inoue

(MPP Munich/ICRR, U. Tokyo)

with Y. Uchiyama, M. Renaud

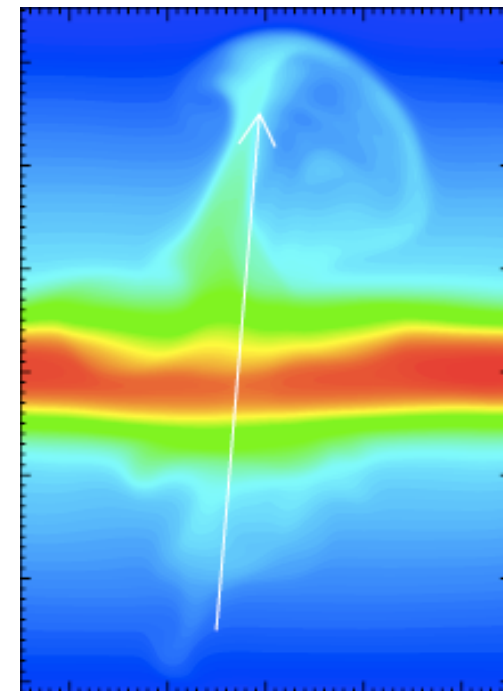
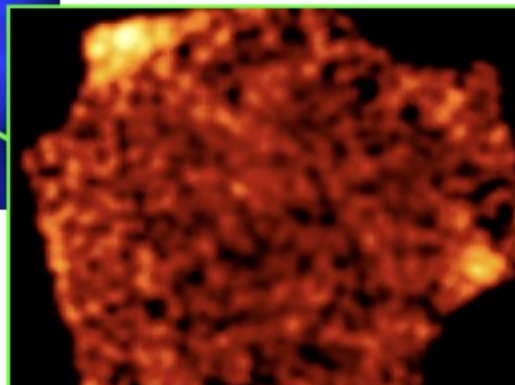
C. H. Baek, K. Wada

high velocity cloud+
Galactic disk collisions



TeV

keV



high velocity clouds

large deviations from Galactic rotation

HI emission (and/or absorption)

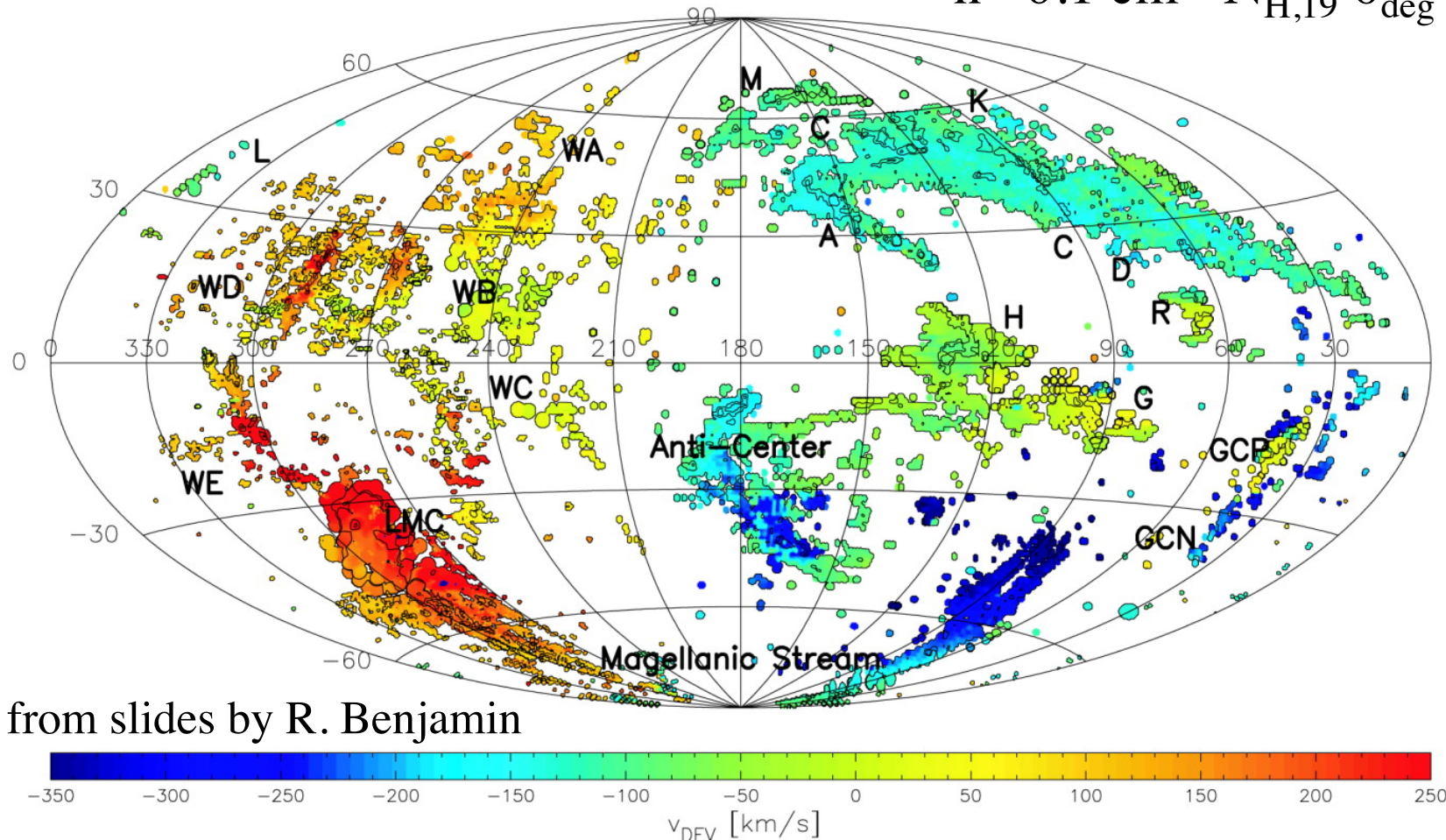
$$|V_{\text{LSR}}| > 90 \text{ km/s}$$

$v \sim \text{few } 100 \text{ km/s}$, no excess stars

for some HVCs $D \sim 5\text{-}15 \text{ kpc}$ $M \sim < 10^5\text{-}10^6 M_{\odot}$, $Z \sim < 0.2 Z_{\odot}$

also in M31, M33, etc.

$$n \sim 0.1 \text{ cm}^{-3} N_{\text{H},19} \theta_{\text{deg}}^{-1} D_{10\text{kpc}}^{-1}$$



from slides by R. Benjamin

Contours in above HI image at $\sim 2, 20, 40 \times 10^{18} \text{ cm}^{-2}$ (Wakker et al 2003)

high velocity clouds

large deviations from Galactic rotation

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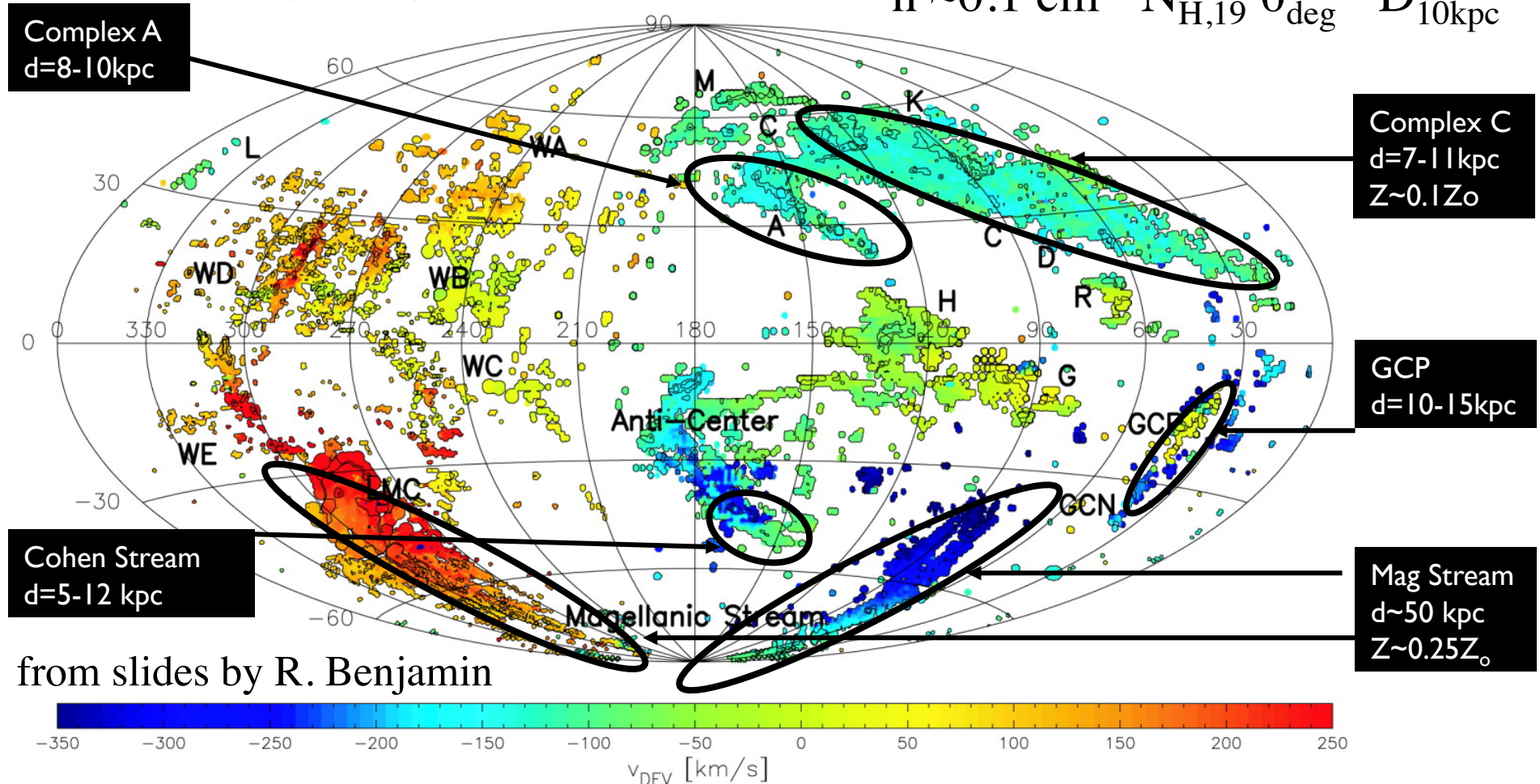
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high velocity clouds: ongoing Galactic accretion?

Oort 70

dark-matter dominated systems in Local Group?

gas streams stripped from infalling satellites

clouds from thermal instability in Galactic halo

cold accretion from external filaments

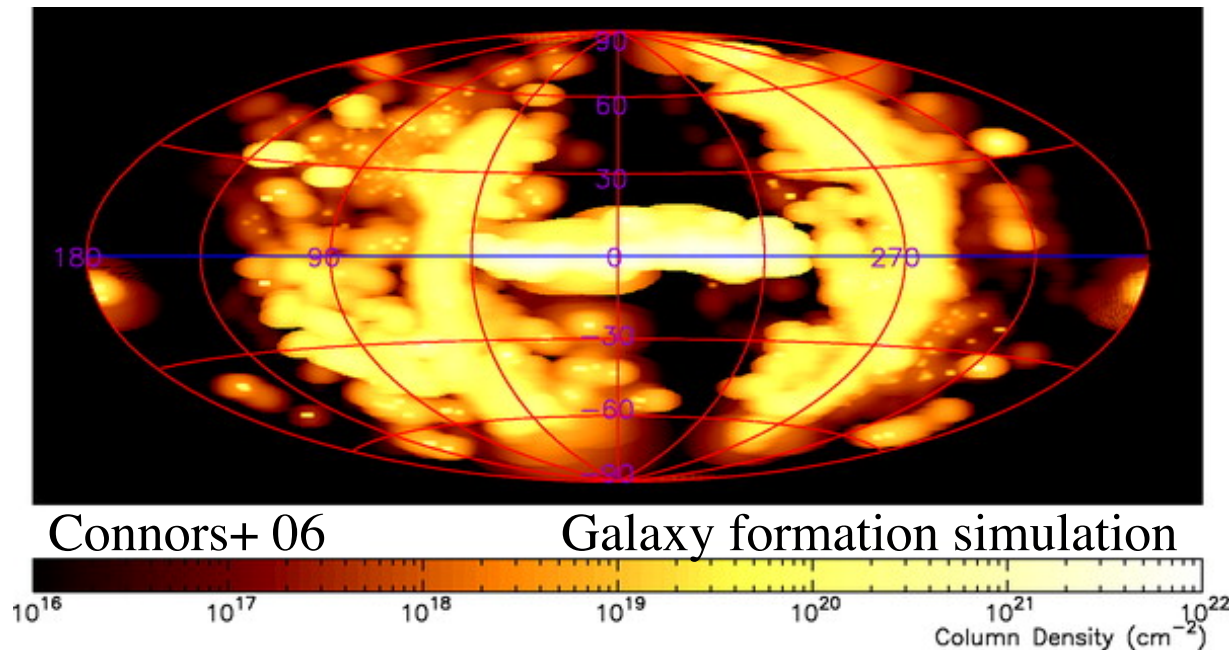
important role in
Galaxy evolution

Blitz+ 99

Maller & Bullock 04

Kaufmann+ 04

Peek+ 07



$$\dot{M} \sim 1 M_{\odot} / \text{yr}$$

- fresh (low Z) fuel for star formation (G-dwarf problem)
- source of ISM turbulence

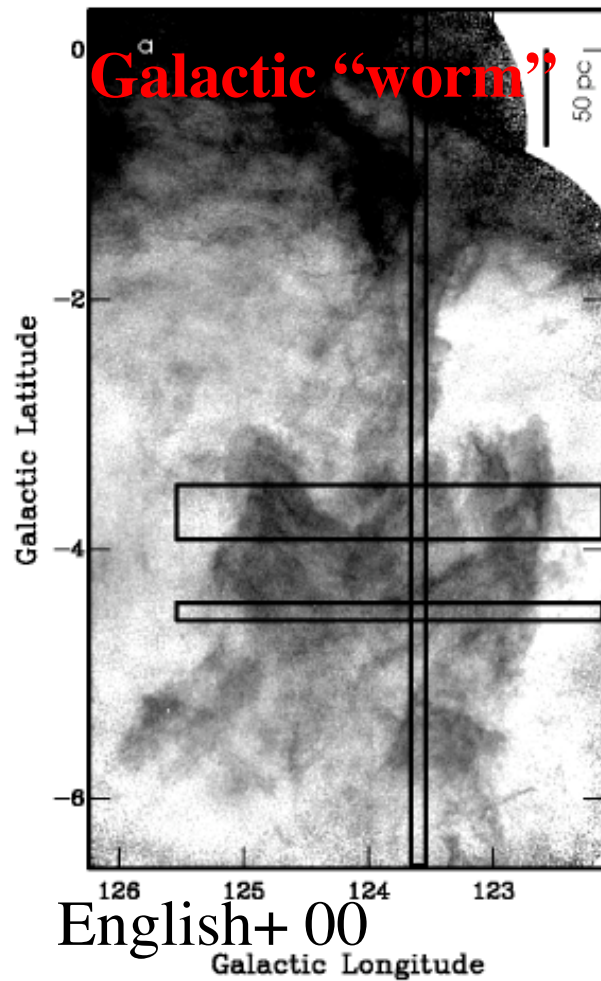
SN-driven fountains?

Shapiro & Field 76

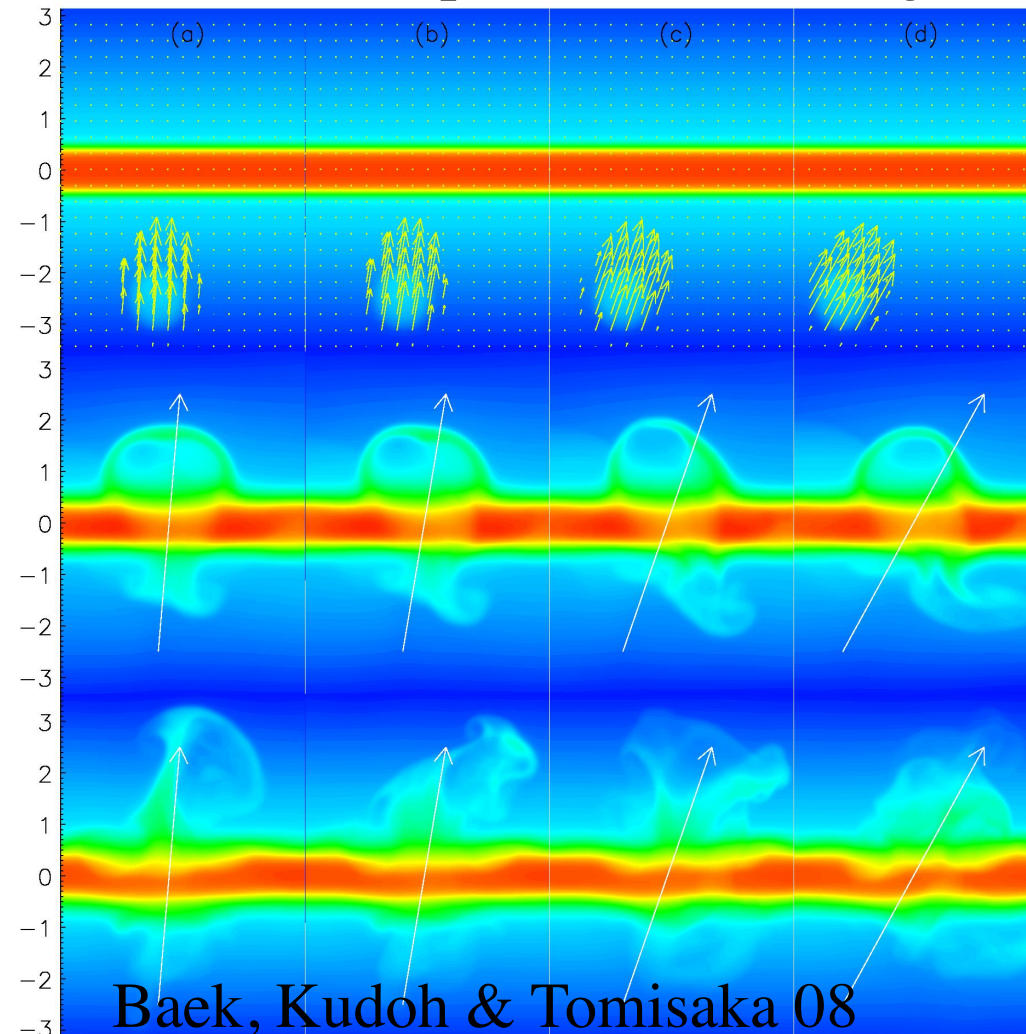
Booth & Theuns 07

$v < 100 \text{ km/s}$ expected -> **intermediate velocity clouds**

HVC+disk collisions: origin of Galactic filament structure?



worms, shells, loops ... Tenorio-Tagle+ 86,87



$v \sim 100-300$ km/s $\rightarrow$

$T \sim 10^5-10^6$ K (UV-soft X)

thermal emission is dark

strong reverse shock

shock lifetime $t_s \sim h/v \sim 3 \times 10^6-10^7$ yr

$\rightarrow$ radiative, isothermal

Galactic accretion events as cosmic ray/gamma-ray sources

SI, Uchiyama, Renaud, Baek, Wada+, to be submitted

velocity $v_{\text{acc}} \sim v_{\text{HVC}} \sim 100\text{-}300 \text{ km/s}$ $T_{\text{HVC}} \sim 50\text{-}300 \text{ K}$ $\mathcal{M} \sim 10\text{-}30$

accretion rate $\dot{M} \sim 1 M_{\odot} / \text{yr}$

accretion power $L_{\text{acc}} \sim (1/2) \dot{M} v_{\text{acc}}^2 \sim 3 \times (10^{39}\text{-}10^{40}) \text{ erg/s}$

$\leftrightarrow L_{\text{SN}} \sim E_{\text{SN}} R_{\text{SN}} \sim 3 \times 10^{41} \text{ erg/s}$

large HVC mass $M_{\text{HVC}} \sim < 10^5\text{-}10^6 M_{\odot}$

large HVC kin. energy $E_{\text{HVC}} \sim (1/2) M_{\text{HVC}} v_{\text{HVC}}^2 \sim < 10^{52}\text{-}10^{54} \text{ erg}$

CR acceleration $t_{\text{accel}} = (10/3) \eta (E/Z e B) (c/v_s^2) = t_s$

$v_s \sim 100\text{-}300 \text{ km/s}$, $t_s = 3 \times 10^6\text{-}10^7 \text{ yr}$

$\rightarrow E_{p,\text{max}} \sim 100 \text{ TeV} (v_s/300 \text{ km/s})^2 (B/3 \mu\text{G}) (\eta/10)^{-1} (t_s/3 \times 10^6 \text{ yr})$

c.f. ion-neutral damping limit $v > \sim 100 \text{ km/s}$ Bykov+ 00

pp $\pi^0 \gamma$ flux $f_{\pi^0} \sim 10^{-12} \text{ erg/cm}^2/\text{s} (E_{\text{CR}}/10^{51} \text{ erg}) (n_{\text{gas}}/1 \text{ cm}^{-3}) (D/10 \text{ kpc})^{-2}$

number $N \sim (\dot{M}/M_{\text{HVC}}) t_s \sim 10\text{-}100$

Galactic accretion events=unID TeV sources?

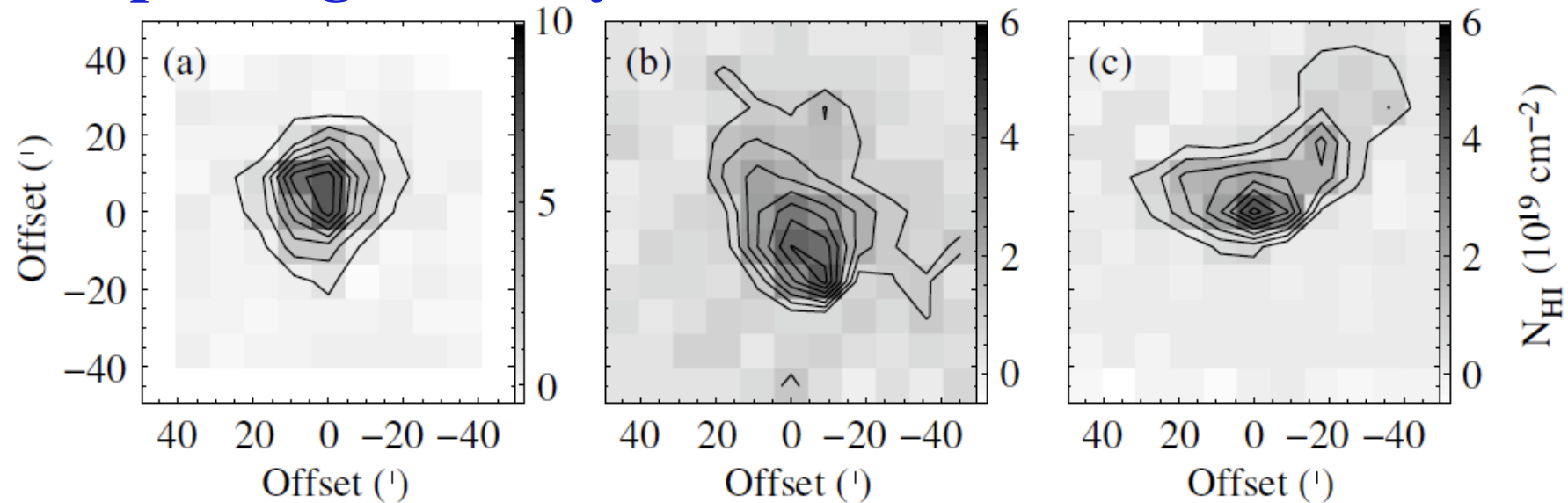
- thermal UV-soft X: **dark** (heavily absorbed)
- primary electron sync.: $E_{\text{syn,max}} \sim < 1 \text{ eV } (v_s/100 \text{ km/s})^2$

angular size -> compact HVCs?
or inhomogeneities in large HVCs?

secondary syn.+IC?

$$p_{\text{CR}} + p_{\text{gas}} \rightarrow \pi^0, \pi^{\pm} \quad \pi^0 \rightarrow 2\gamma, \pi^{\pm} \rightarrow e^{\pm} 3\nu \quad e^{\pm} + B \rightarrow \text{syn}, e^{\pm} + \gamma \rightarrow \text{IC}$$

compact high velocity clouds



Westmeier+ 05

Figure 1. H I Column density maps of a) spherically symmetric CHVC 148-82, b) head-tail CHVC 040+01, and c) bow-shock shaped CHVC 172-60. Contour levels range from $N_{\text{H I}} = 5 \times 10^{18} \text{ cm}^{-2}$ ($1 \times 10^{19} \text{ cm}^{-2}$ in (b)) in steps of $5 \times 10^{18} \text{ cm}^{-2}$.

angular size $< 2 \text{ deg}$

$D < 100 \text{ kpc}$

$$n \sim 3 \text{ cm}^{-3} N_{\text{H},20} \theta_{0.2\text{deg}}^{-1} D_{3\text{kpc}}^{-1}$$

$$M \sim 400 M_{\odot} N_{\text{H},20} \theta_{0.2\text{deg}}^2 D_{3\text{kpc}}^2$$

$$E_{\text{kin}} \sim 4 \times 10^{50} \text{ erg } N_{\text{H},20} \theta_{0.2\text{deg}}^2 D_{3\text{kpc}}^2 v_{300}^2$$

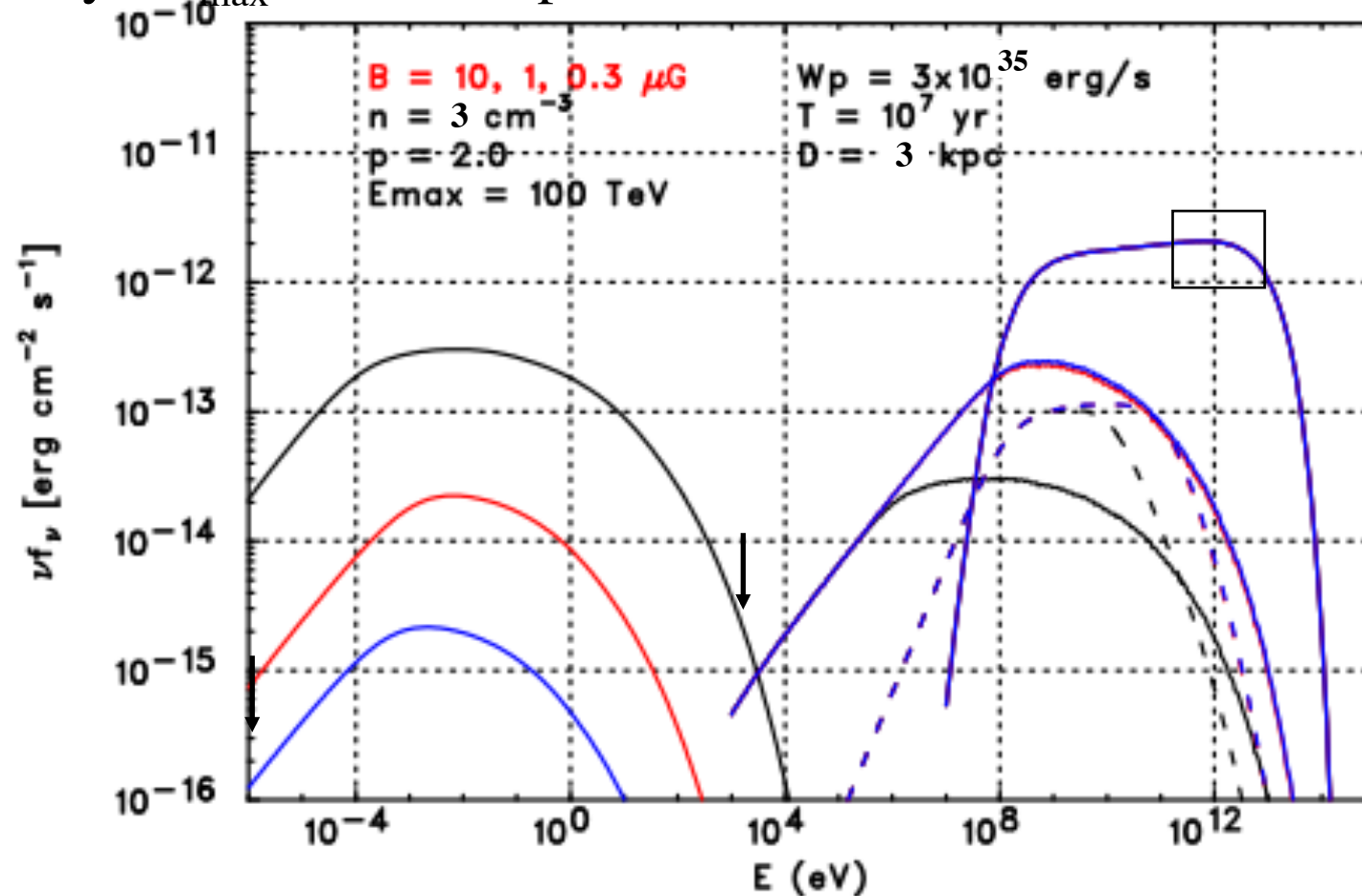
$$f_{\text{TeV}} \sim 10^{-12} \text{ erg/cm}^2/\text{s } N_{\text{H},20}^2 \theta_{0.2\text{deg}} D_{3\text{kpc}}^{-1} v_{300}^2$$

spectra from HVC shocks

p-p γ +secondary (syn.+IC+brems.)

$$L_p = 10^{50} \text{ erg}/10^7 \text{ yr} = 3 \times 10^{35} \text{ erg/s}, n = 3 \text{ cm}^{-3}, R = 10 \text{ pc}, D = 3 \text{ kpc}$$

$$t = 10^7 \text{ yr}, E_{\text{max}} = 100 \text{ TeV}, p = 2$$



upper limits for HESS J1616-508

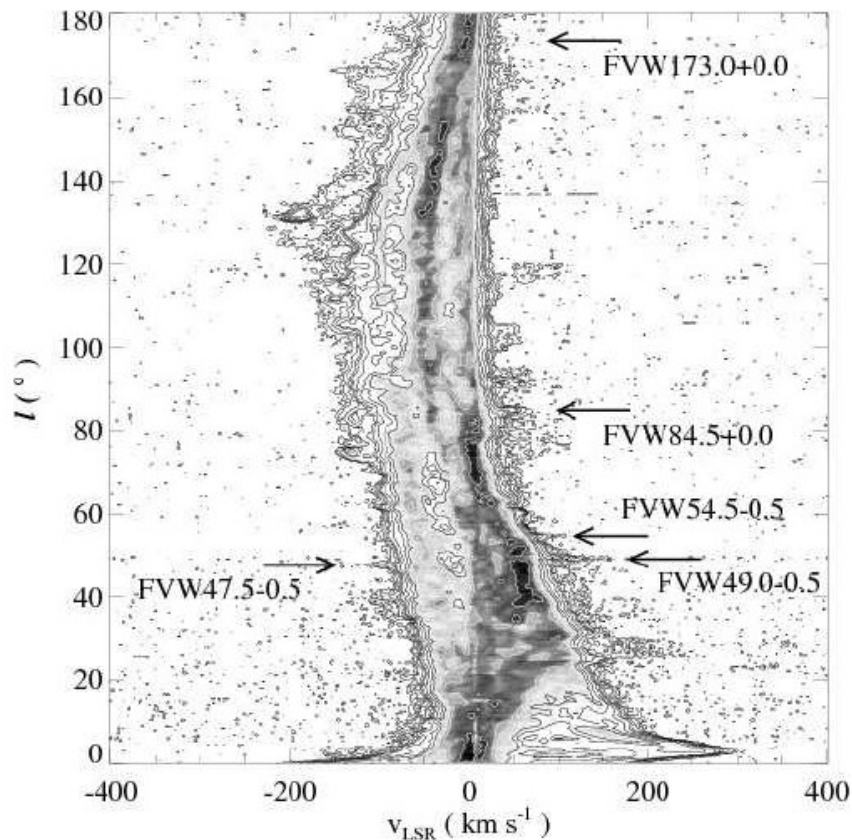
Suzaku keV

Molonglo 843MHz

TeV source associated with a forbidden velocity wing

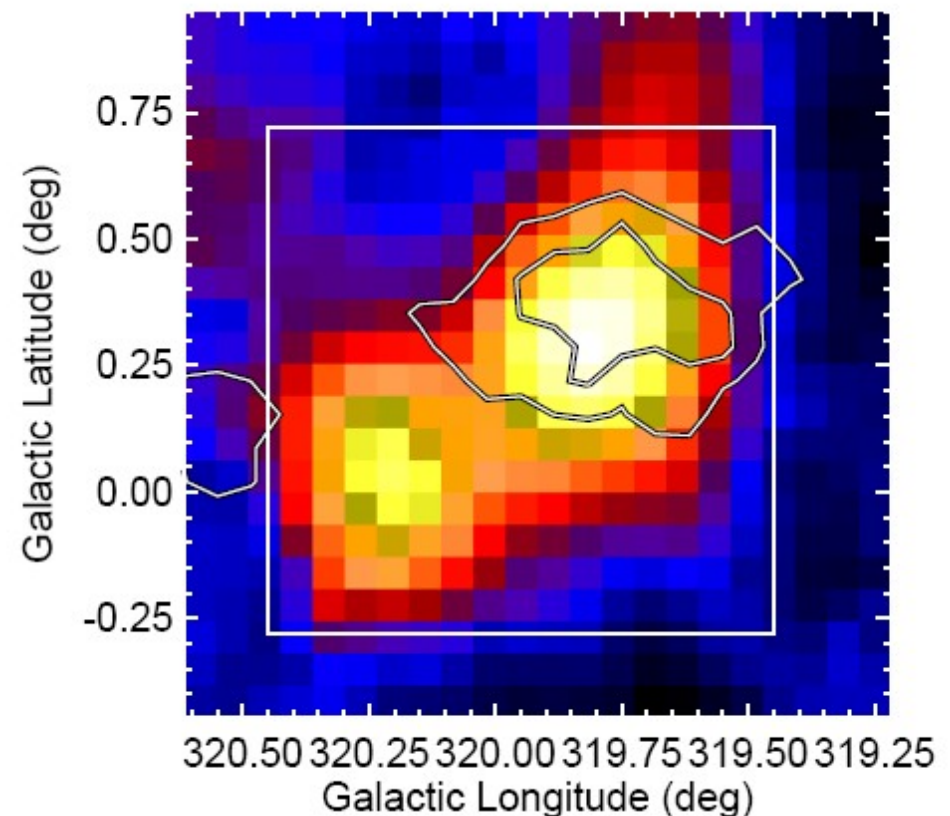
-> (compact) HVC decelerated by disk collision?

“forbidden velocity wings”: anomalous HI structure in Galactic plane
localized deviations from Galactic rotation $|dv| > 20$ km/s Kang & Koo 07
87 objects, only few correlated with known objects (e.g. 3 HVCs)



HESS J1503-582

Renaud+ 08



some predictions/speculations

- $E_{\gamma, \text{max}} \sim < 100 \text{ TeV}$ $\rightarrow$ deeper higher E obs. CTA
- π^{+-} secondary sync.+IC (+brems.) $\rightarrow$ deeper radio+X obs.
- locations not necessary correlated with star forming regions
possible even outside stellar disk
BUT star formation may be induced? Franco+ 88, Izumi+ 11
- some correlation with planar and/or extraplanar HI

implications interesting information on Galaxy/ISM evolution

probe accretion rate, distribution of mass, velocity, location...

IACT, Fermi outer Galaxy
+radio-X-ray followup

CTA M31?

summary high velocity cloud + Galactic disk interaction

potential GeV-TeV gamma-ray sources

(GeV if acceleration less efficient)

(compact) HVC+disk may explain some unID TeV sources

larger HVC+disk detectable with Fermi?

future tests

GeV-TeV: search outer Galaxy (M31?), non-SF regions

radio-IR-X-ray: deeper followup

correlations with HI structure (inside/outside Gal. plane)

implications for Galaxy/ISM formation+evolution

GeV-TeV gamma-rays may provide us with interesting information by illuminating Galactic accretion interface points in the disk (thermal emission is dark)