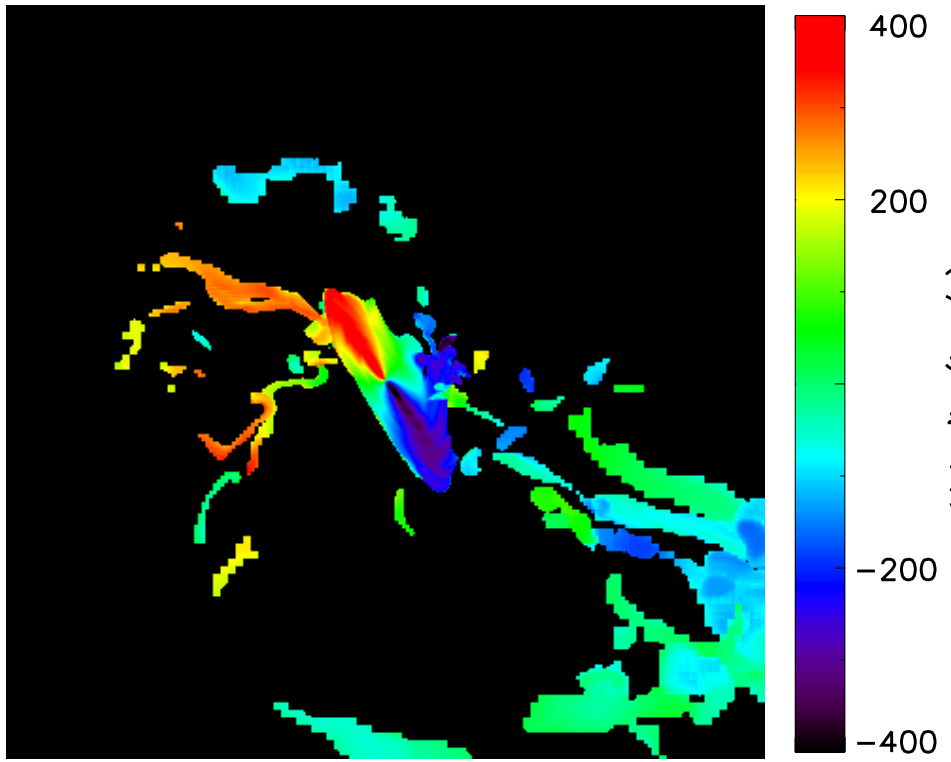
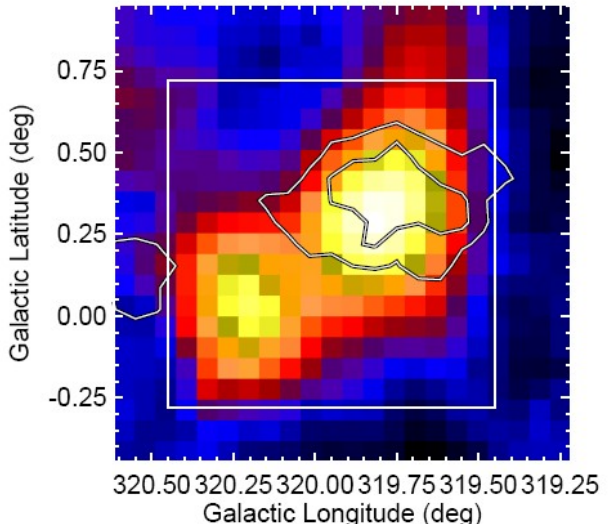
Cosmic Rays and Non-thermal Emission Induced by Accretion of Cool Gas onto the outer Galactic disk

Susumu Inoue (RIKEN) in collaboration with
Yasunobu Uchiyama, Masanori Arakawa (Rikkyo)
Matthieu Renaud (Montpellier), Keiichi Wada (Kagoshima)

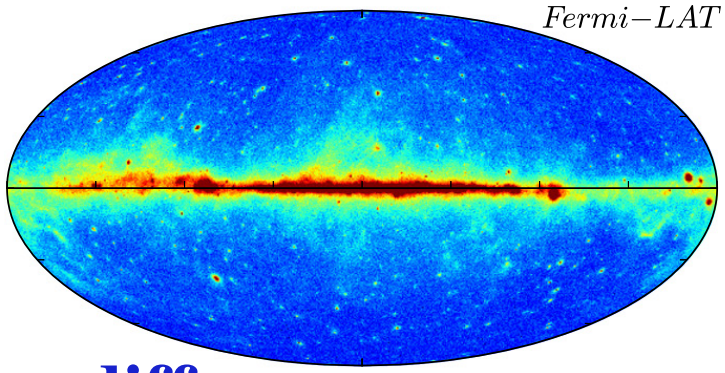
ApJ, close to accepted
arXiv:1708.08574

cool gas accretion onto Milky Way disk





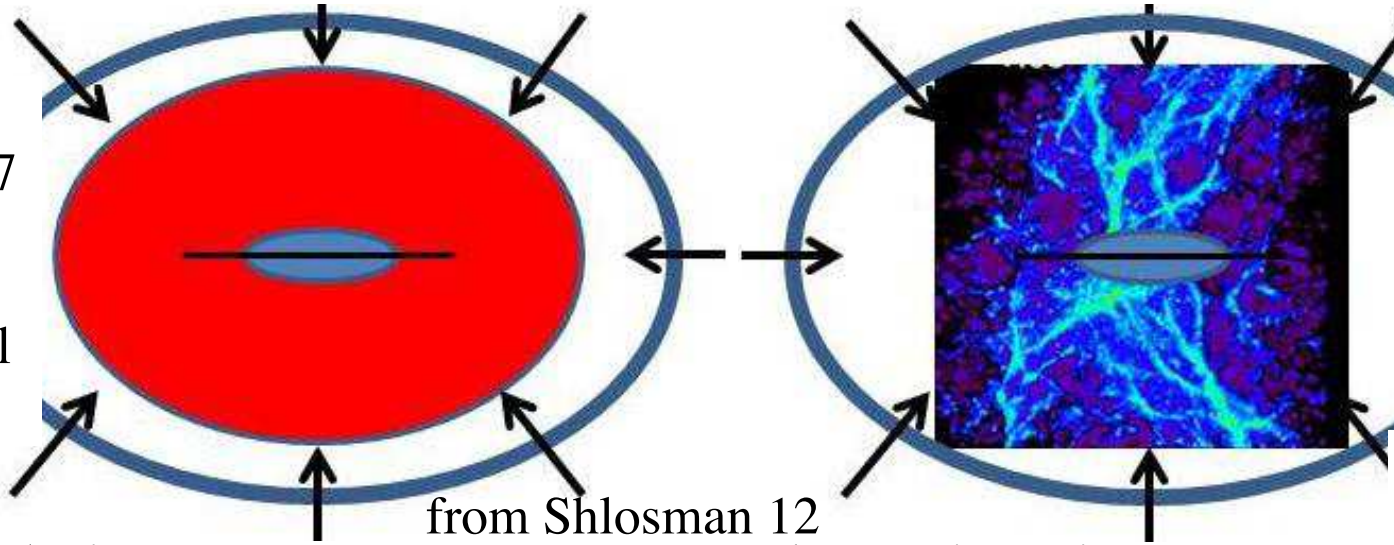
unID GeV-TeV sources



diffuse gamma excess in outer Galaxy

formation+evolution of disk galaxies: theory

Rees & Ostriker 77
White & Rees 78…
Blumenthal + 84



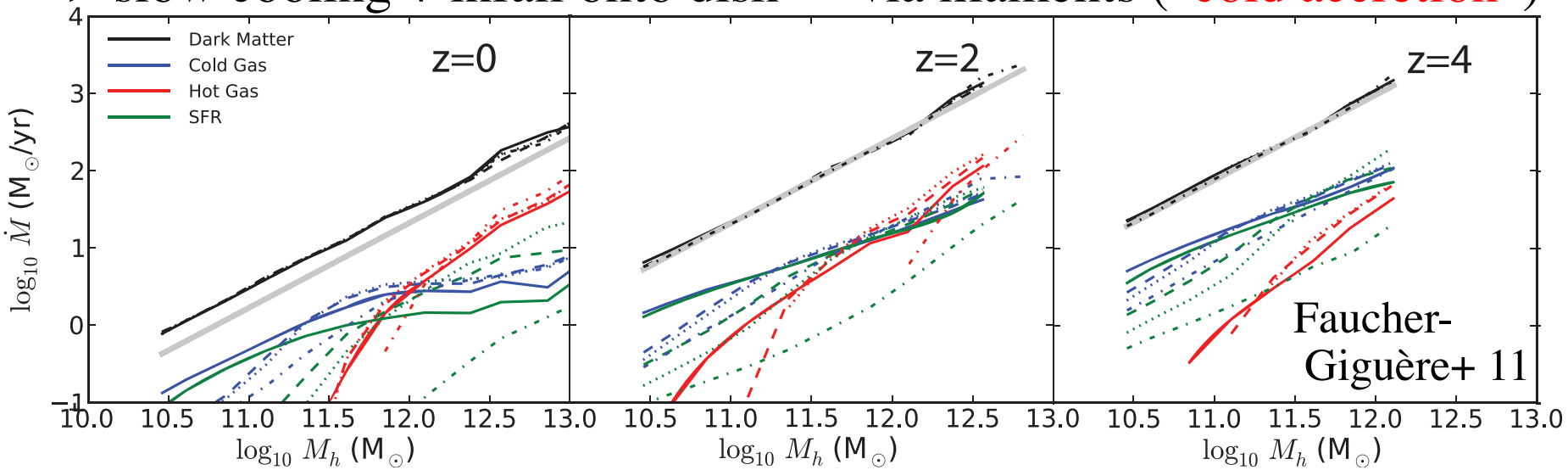
from Shlosman 12

Binney 77
Dekel & Birnboim 03
Keres+ 05…

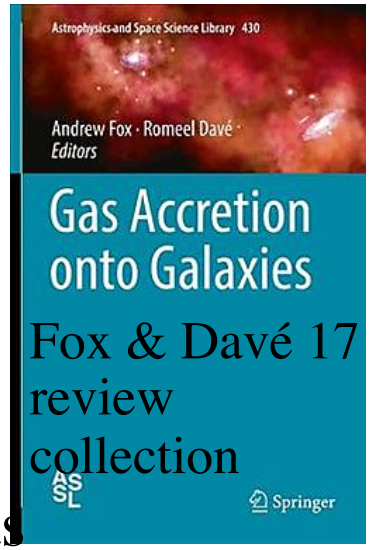
see however Nelson+ 13

<u>classical picture</u>
virial shock heating
-> pressure-supported hot halo
-> slow cooling + infall onto disk

<u>alternative picture</u>
part virial shock heating -> hot halo
part direct cooling+infall onto disk
via filaments ("cold accretion")



gas accretion onto disk galaxies



Fox & Davé 17 review collection

observational requirements

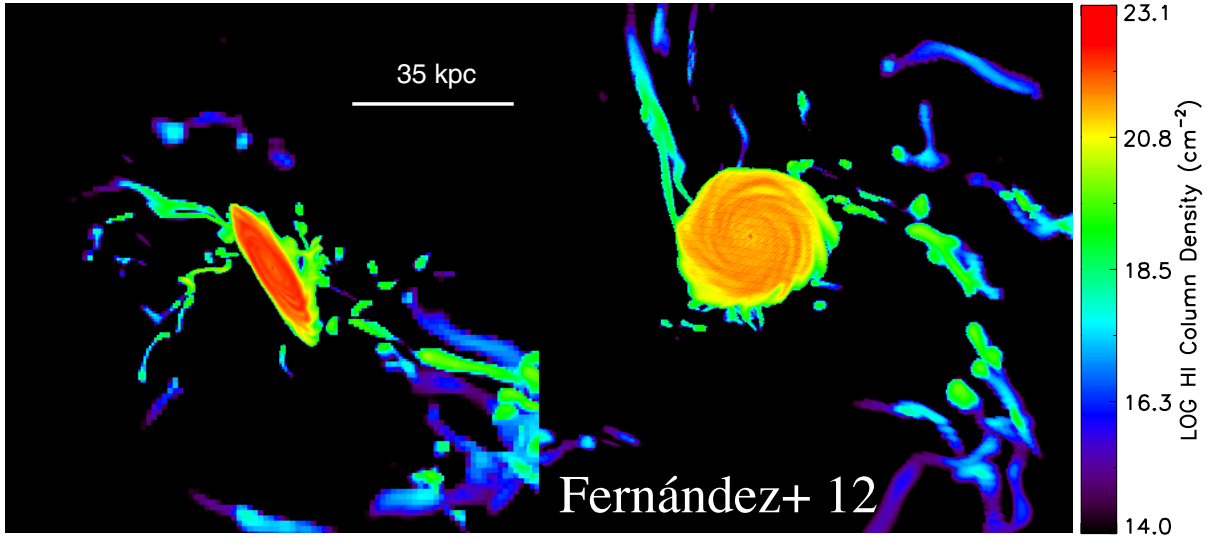
- $\dot{M}_{acc}$~1-3 $M_\odot$/yr to sustain star formation for >Gyr
- $Z/Z_\odot$ ~0.1 to explain stellar metallicity distribution

potential sources

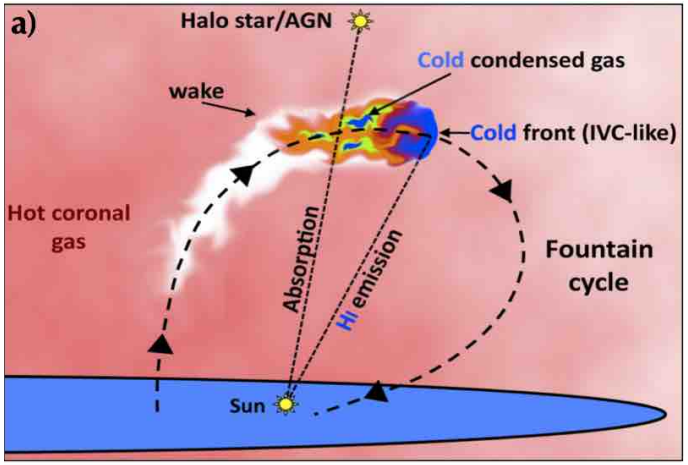
- filamentary accretion from IGM
- gas stripped from satellites
- SN(SMBH)-driven fountains/outflows mixed with halo gas

destination: primarily outer galaxy

- larger target area
- higher angular momentum of accreting gas relative to disk
- survival against disruption in hot halo or outflows from disk
- subsequent radial inflow due to e.g. mergers



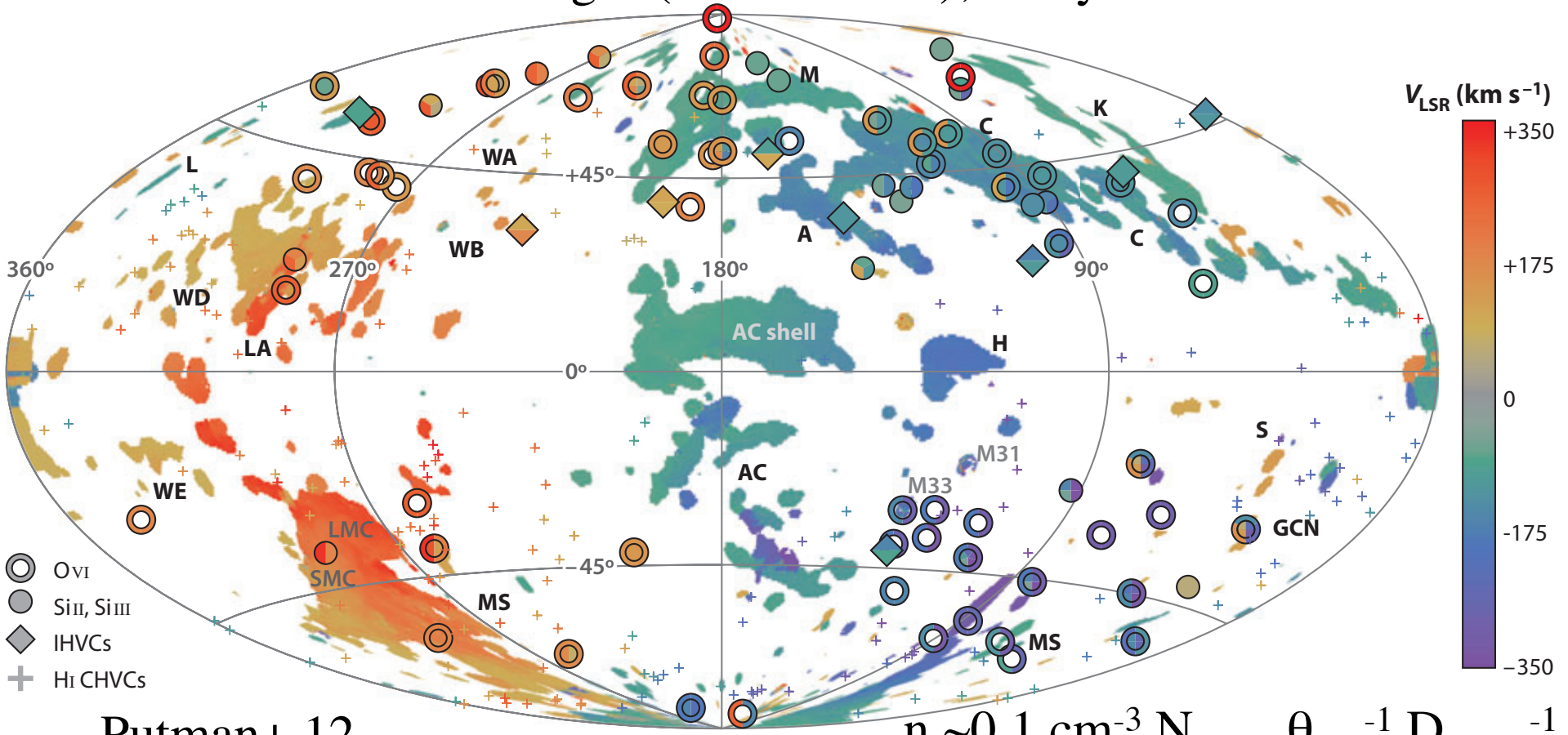
Fernández+ 12



Fraternali 17

high velocity clouds in the Milky Way

- HI emission (and/or absorption, T~<10^4 K), N_{HI} ~ 10^{17}-10^{20} cm^{-2}
- large deviations from Galactic rot. $|V_{LSR}|$>90 km/s, v_{3D}~few 100 km/s
- HVC complexes: D~2-15 kpc, M_{HI}~10^5-5×10^6 $M_\odot$, Z~0.1-0.5 $Z_\odot$
- Magellanic Stream: D>~55 kpc, M_{HI}~3×10^8 $M_\odot$ D_{55kpc}^2, Z~0.1-0.3 $Z_\odot$
- compact HVCs: θ~<2°
- associated warm ionized gas (T~10^4-10^5 K), likely dominant in mass



Putman+ 12

n ~0.1 cm^{-3} $N_{HI,20}$ θ_{deg}^{-1} D_{10kpc}^{-1}

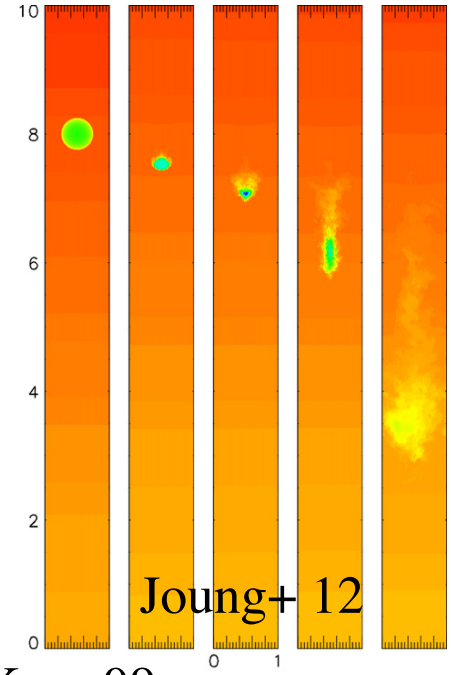
high velocity clouds: fuel for star formation?

accretion rate $\dot{M}_{acc}$ inc. both cold+warm

- no MS, low warm: 0.1-0.4 $M_\odot$/yr -> too low for SF? Putman+ 12
- no MS, high warm: 0.45-1.40 $M_\odot$/yr -> just right? Lehner & Howk 11
- inc. MS: >5 $M_\odot$/yr -> more than enough? Richter 17

HVC disruption in ambient hot halo ($T>\sim10^6$ K)

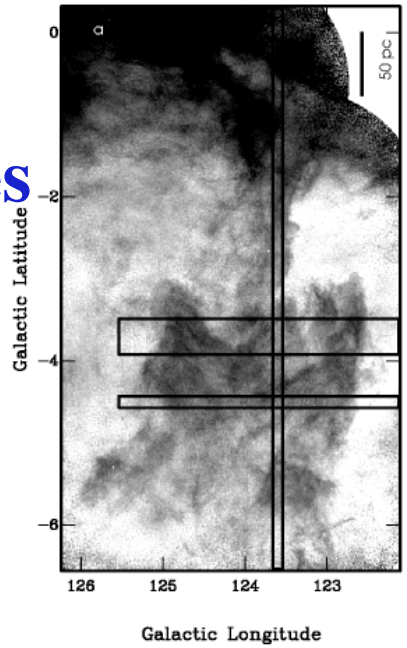
- deceleration+disruption+ablation via RT+KH inst. unless $M>\sim10^{4.5}\,M_\odot$
- origin of warm component of HVCs?
- possible mitigation by B fields, thermal conduction, DM confinement, etc…



Joung+ 12

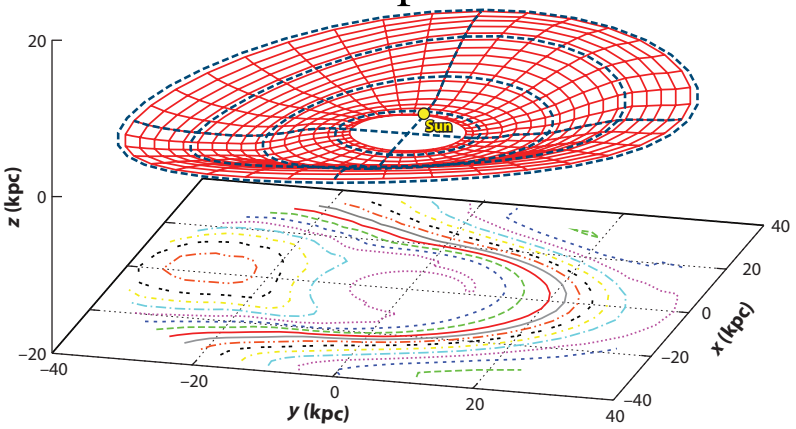
high velocity clouds: potential consequences of accretion onto disk

- gigantic HI structure: shells, loops, worms
- warps, lopsidedness of outer disk structure



English+ 00

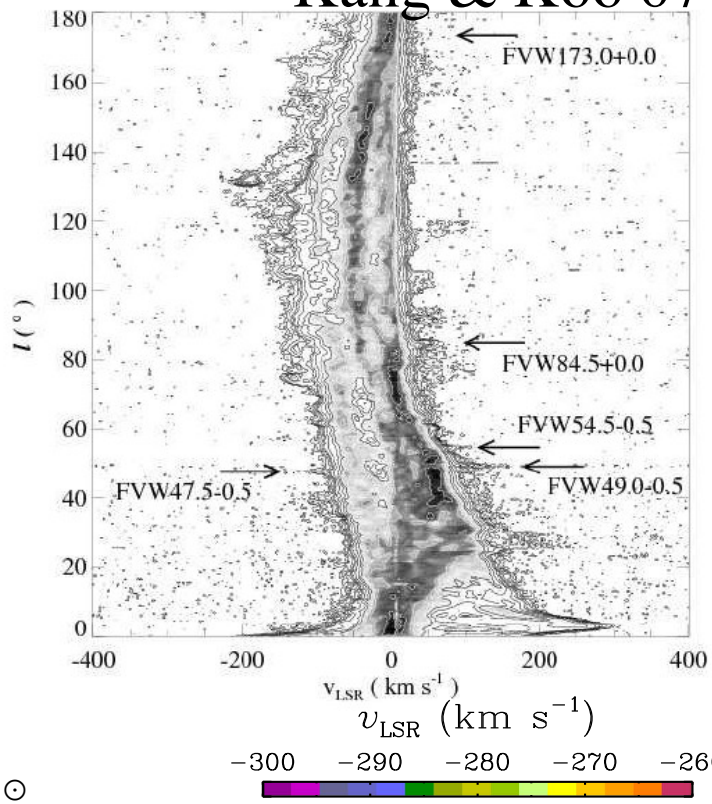
Kalberla & Kerp 09



forbidden velocity wings (FVWs)

- localized HI structure in Gal. plane, deviations from Gal. rotation |dv|>20 km/s
- 87 objects, nature of most unknown

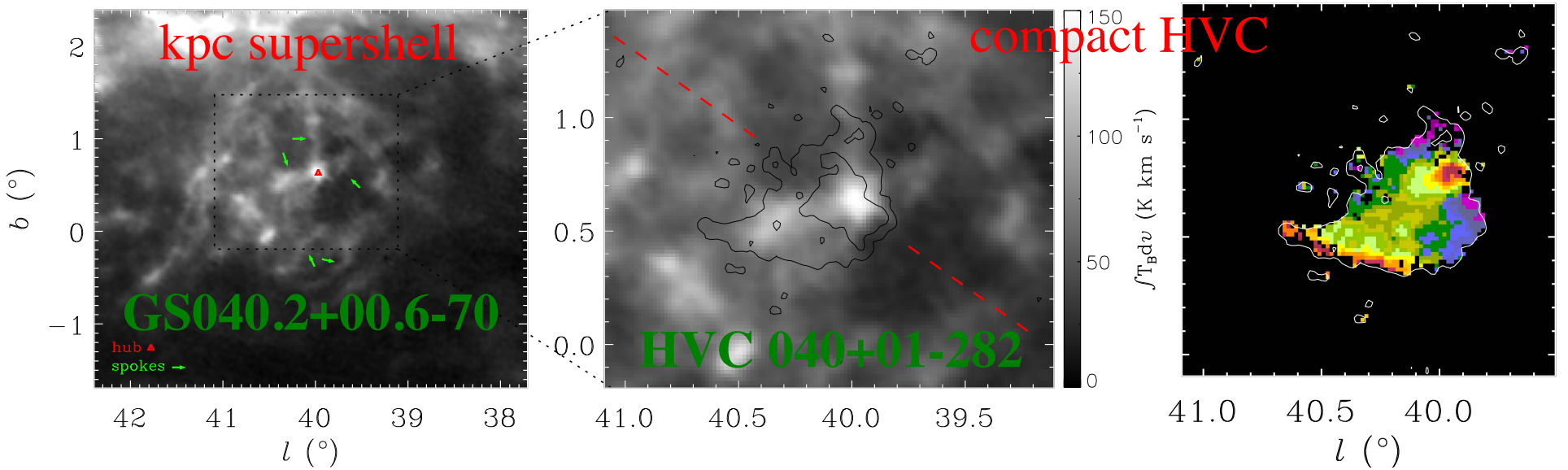
Kang & Koo 07



discovery of direct HVC accretion event

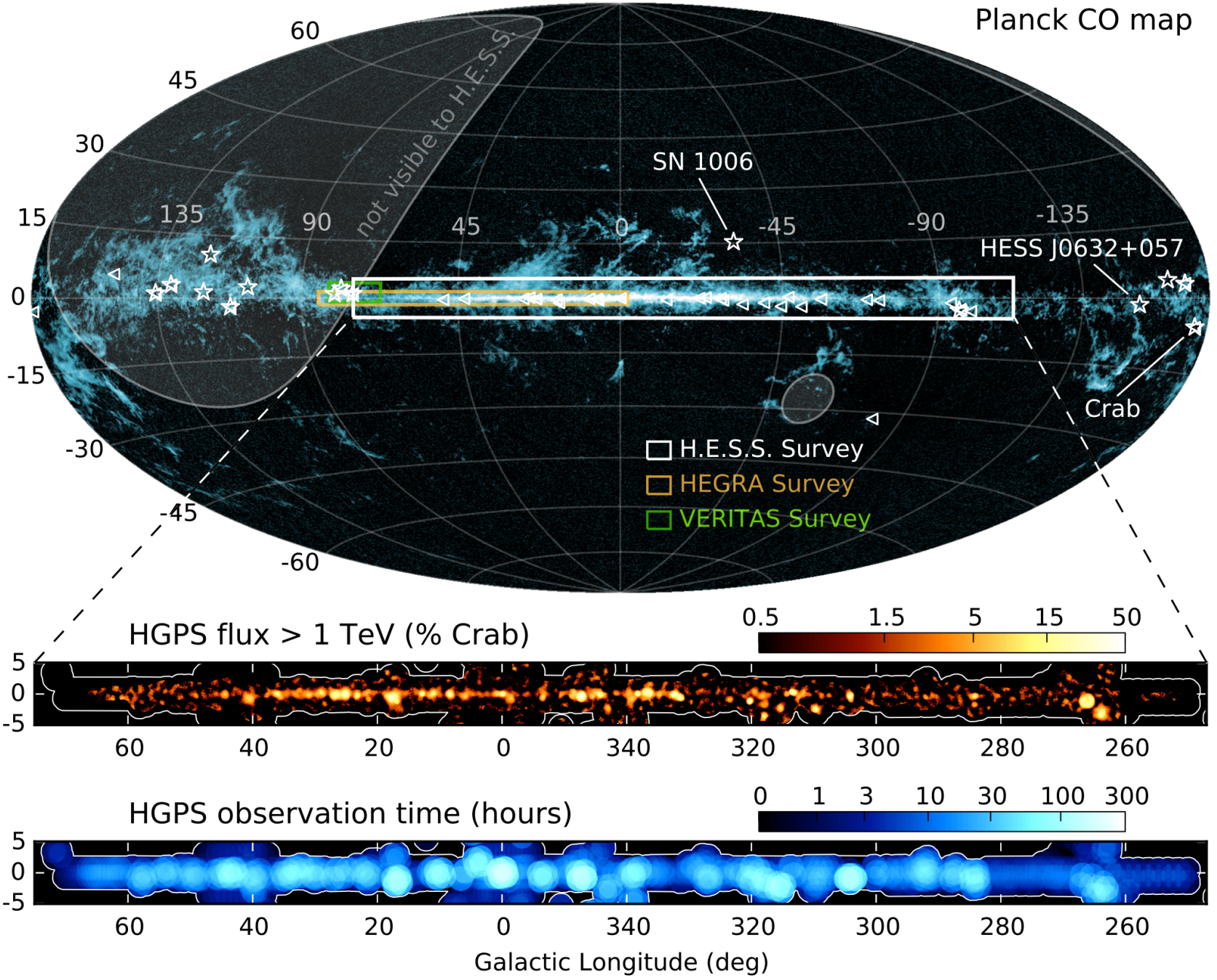
Park+ 16

- high res. HI obs. of FVW 40.0+0.5
  -> kpc-scale supershell + CHVC at center
- favored distance D~20kpc (R~15 kpc)
- CHVC size 210 x 320 pc, M_{HI}~6x10^3 $M_\odot$
- inferred pre-collision:
  v_{rel}~ 240 km/s, E_{kin}~7x10^{52} erg, M~6x10^4 $M_\odot$



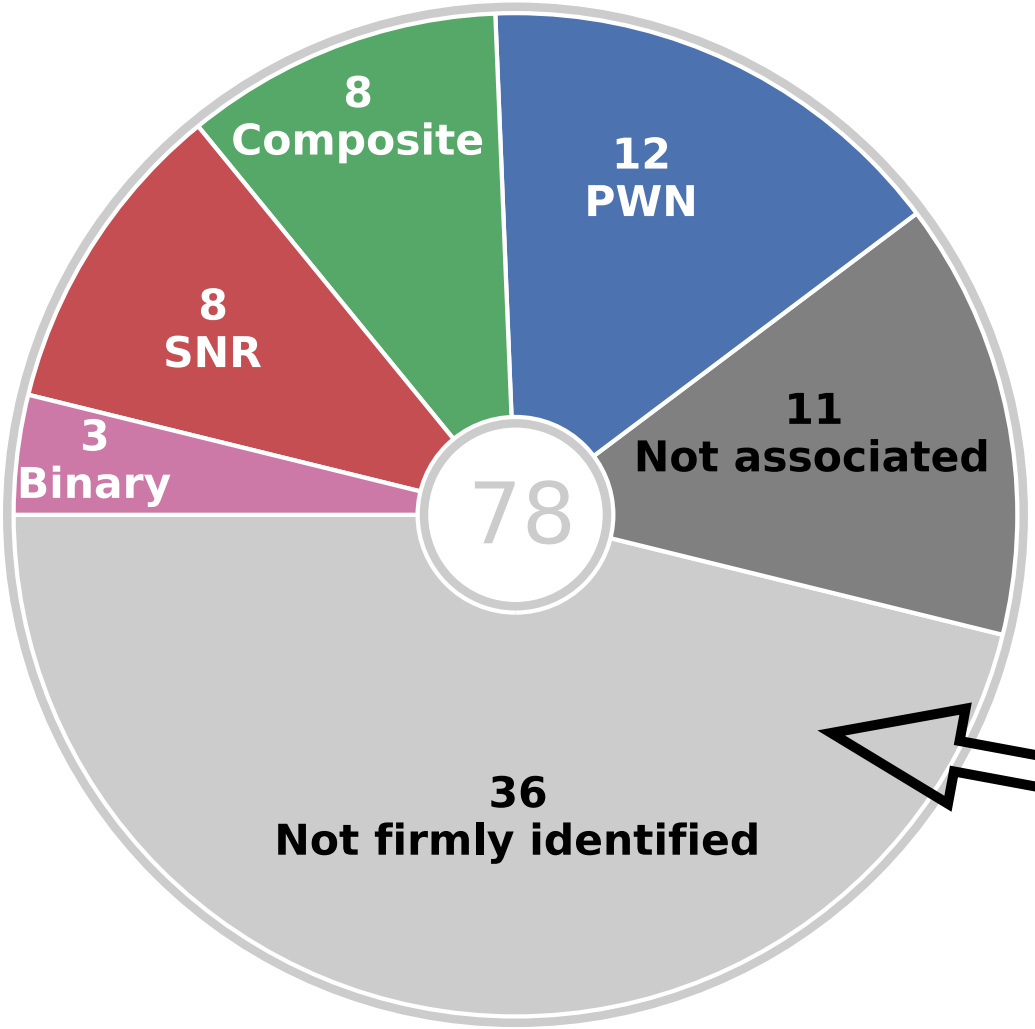
Galactic gamma-ray sources: HESS

Parsons, ICRC 2017



Galactic gamma-ray sources: HESS

Parsons, ICRC 2017



78 sources discovered in total

Most do not have strong strong associations with known MWL sources

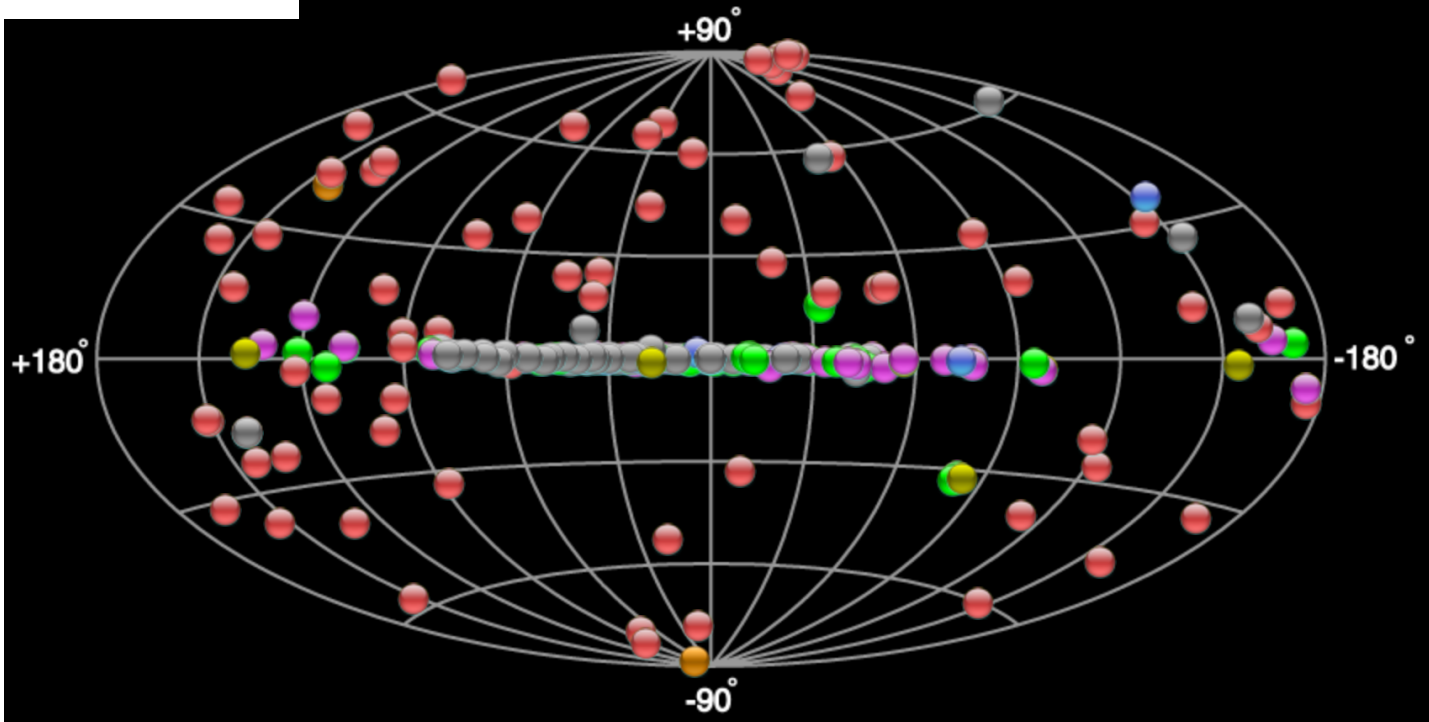
Of the known sources PWN are the most numerous class

May have multiple potential counterparts

TeVCat

Welcome to TeVCat!

http://tevcat.uchicago.edu



Try TevCat 2.0 Beta!

Table Control | Map Control | Tools | Legend

Table Columns
- ☐ TeVCat Name ☑ Name ☑ RA
- ☑ Dec ☑ Type
- ☐ Discoverer
- ☑ Date ☑ Distance
- ☑ Catalog

Select

Catalogs

- Default Catalog
- Newly Announced
- Other Sources
- Source Candidates

☑ Filter by Catalog

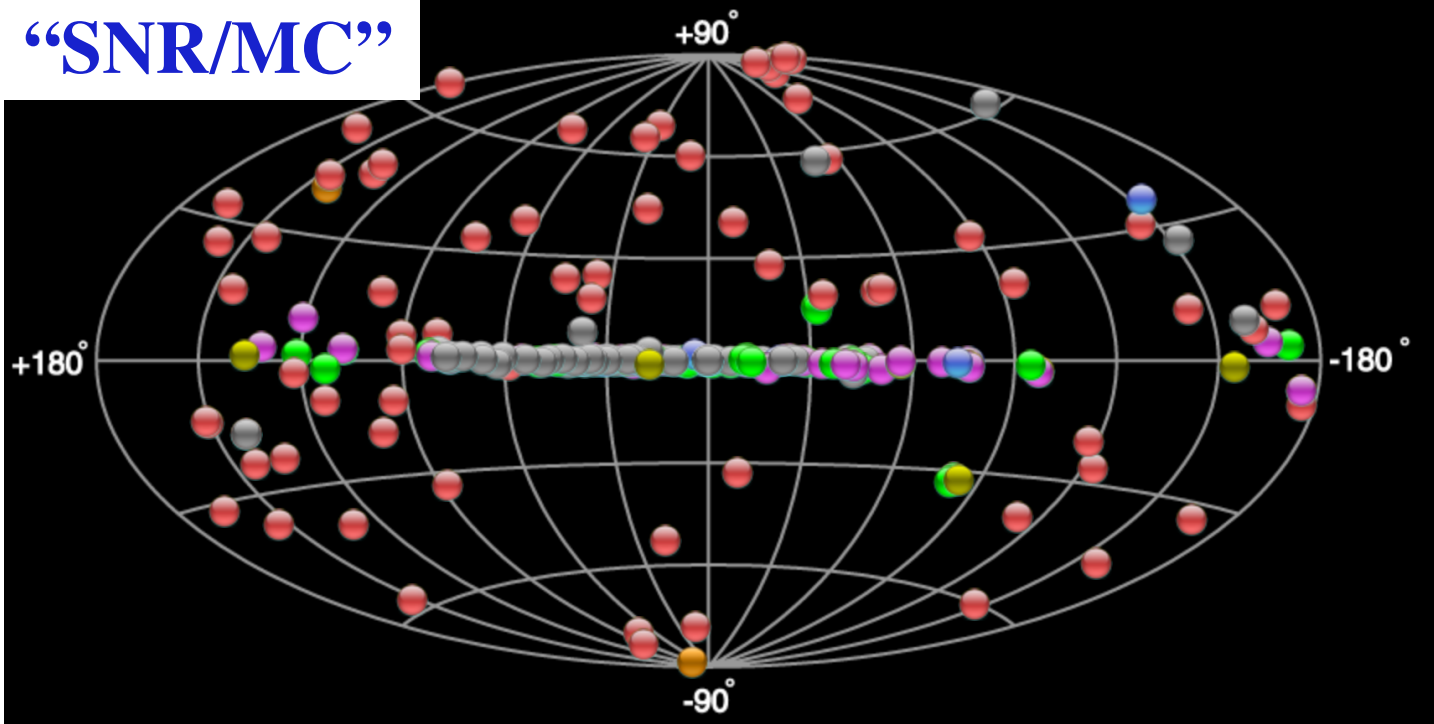
Select All | Unselect All | Plot Selected | Plot All | Plot UnSelected | Filter Selected | Clear Filters

Reg Exp: OK

Name	RA	Dec	Type	Date	Dist	Catalog
			...			...
CTA 1	00 06 26	+72 59 01.0	PWN	2011.10	1.4 kpc	Default Catalog
SHBL J001355.9-185406	00 13 52.0	-18 53 29	HBL	2010.11	z = 0.095	Default Catalog
Tycho	00 25 21.6	+64 07 48	Shell	2010.05	3.5 kpc	Default Catalog
KUV 00311-1938	00 33 34.2	-19 21 33	HBL	2012.07	z = 0.61	Newly Announced
1ES 0033+595	00 35 16.8	+59 47 24.0	HBL	2011.10	z = 0.467	Default Catalog
NGC 253	00 47 34.3	-25 17 22.6	Starburst	2009.07	2500 kpc	Default Catalog
S2 0109+22	01 12 05.8	+22 44 39	IBL	2015.07		Newly Announced
RGB J0136+391	01 36 32.5	+39 06 00	HBL	2012.07		Newly Announced
RGB J0152+017	01 52 33.5	+01 46 40.3	HBL	2008.02	z = 0.08	Default Catalog
3C 58	02 05 31	+64 51 00	PWN	2014.05	2 kpc	Default Catalog
S3 0218+35	02 21 05.5	+35 56 14	FSRQ	2014.07	z = 0.954	Default Catalog
3C 66A	02 22 41.6	+43 02 35.5	IBL	1998.03		Default Catalog
MAGIC J0223+403	02 23 12	+43 00 42	UNID	2009.02		Default Catalog
1ES 0229+200	02 32 53.2	+20 16 21	HBL	2006.12	z = 0.1396	Default Catalog
LS I +61 303	02 40 34	+61 15 25	Binary	2006.06	2 kpc	Default Catalog
PKS 0301-243	03 03 23.49	-24 07 35.86	HBL	2012.07	z = 0.2657	Default Catalog

TeVCat "SNR/MC"

Welcome to TeVCat!



Try TevCat 2.0 Beta!

Table Control | Map Control | Tools | Legend

Table Columns
- ☐ TeVCat Name ☑ Name ☑ RA
- ☑ Dec ☑ Type
- ☐ Discoverer
- ☑ Date ☑ Distance
- ☑ Catalog

Select

Catalogs

Default Catalog
Newly Announced
Other Sources
Source Candidates

☑ Filter by Catalog

Select All | Unselect All | Plot Selected | Plot All | Plot UnSelected | Filter Selected | Clear Filters

Reg Exp: OK

Name	RA	Dec	Type	Date	Dist	Catalog
			SNR/Molec. Cloud			...
LMC N132D	05 25 02.20	-69 38 39.0	SNR/Molec. Cloud	2014.10	50 kpc	Default Catalog
SNR G318.2+00.1	14 57 46	-59 28 00	SNR/Molec. Cloud	2010.12		Newly Announced
CTB 37A	17 14 19	-38 34 00	SNR/Molec. Cloud	2008.11	7.9 kpc	Default Catalog
SNR G349.7+00.2	17 17 57.8	-37 26 39.6	SNR/Molec. Cloud	2013.07	11.5 kpc	Default Catalog
HESS J1745-303	17 45 02.10	-30 22 14.00	SNR/Molec. Cloud	2006.01		Default Catalog
HESS J1800-240C	17 58 51.6	-24 03 07.2	SNR/Molec. Cloud	2008.04	2 kpc	Source Candidates
HESS J1800-240B	18 00 26.4	-24 02 20.4	SNR/Molec. Cloud	2008.04	2 kpc	Default Catalog
W 28	18 01 42.2	-23 20 06.0	SNR/Molec. Cloud	2008.04	2 kpc	Default Catalog
HESS J1800-240A	18 01 57.8	-23 57 43.2	SNR/Molec. Cloud	2008.04	2 kpc	Default Catalog
W 49B	19 11 07.3	09 09 37.0	SNR/Molec. Cloud	2010.12		Default Catalog
W 51	19 22 55.2	+14 11 27.6	SNR/Molec. Cloud	2008.10	4.3 kpc	Default Catalog

1-11

TeVCat "PWN"

Select All | Unselect All | Plot Selected | Plot All | Plot UnSelected | Filter Selected | Clear Filters

Reg Exp: OK

RA	Dec	Type	Date	Dist	Catalog
		PWN			...
CTA 1	00 06 26	+72 59 01.0	PWN	2011.10	1.4 kpc	Default Catalog
3C 58	02 05 31	+64 51 00	PWN	2014.05	2 kpc	Default Catalog
Crab	05 34 31.1	+22 00 52	PWN	1989.07	2 kpc	Default Catalog
LHA 120-N 157B	05 37 44	-69 09 57	PWN	2012.01	50 kpc	Default Catalog
0FGL J0631.8+1034	06 31 49.22	+10 34 12.7	PWN	2009.04	6.55 kpc	Source Candidates
Geminga	06 32 28	+17 22 00	PWN	2009.04	0.169 kpc	Default Catalog
Vela X	08 35 00	-45 36 00	PWN	2006.03	0.29 kpc	Default Catalog
HESS J1018-589 B	10 16 31	-58 58 48	PWN	2010.08		Default Catalog
HESS J1026-582	10 26 38.4	-58 12 00	PWN	2011.01	2.3 kpc	Default Catalog
SNR G292.2-00.5	11 19 00	-61 24 00	PWN	2009.07	5 kpc	Newly Announced
HESS J1303-631	13 02 48.0	-63 10 39	PWN	2005.09	6.6 kpc	Default Catalog
HESS J1356-645	13 56 00	-64 30 00	PWN	2008.12	2.4 kpc	Default Catalog
Kookaburra (Rabbit)	14 18 04	-60 58 31	PWN	2006.09	5.6 kpc	Default Catalog
Kookaburra (PWN)	14 20 09	-60 45 36	PWN	2006.09	5.6 kpc	Default Catalog
HESS J1458-608	14 58 09.6	-60 52 38	PWN	2012.04		Newly Announced
MSH 15-52	15 14 07	-59 09 27	PWN	2005.05	5.2 kpc	Default Catalog
SNR G327.1-01.1	15 54 36	-55 05 05	PWN	2012.01	9 kpc	Newly Announced
HESS J1616-508	16 16 24.0	-50 54 00	PWN	2005.03	6.5 kpc	Default Catalog
HESS J1632-478	16 32 09.6	-47 49 12	PWN	2006.01		Default Catalog
HESS J1640-465	16 40 43.2	-46 31 48	PWN	2005.03	8.6 kpc	Default Catalog
HESS J1708-443	17 08 11	-44 20 00	PWN	2009.07	2.3 kpc	Default Catalog
HESS J1718-385	17 18 07	-38 33 00	PWN	2007.09	4.2 kpc	Default Catalog
SNR G000.9+00.1	17 47 23.2	-28 09 06	PWN	2005.03	8.5 kpc	Default Catalog
HESS J1813-178	18 13 36.0	-17 50 24	PWN	2005.03	4.7 kpc	Default Catalog
HESS J1825-137	18 25 41	-13 50 20	PWN	2005.03	3.9 kpc	Default Catalog
HESS J1831-098	18 31 25	-09 54 00	PWN	2011.10		Newly Announced
HESS J1833-105	18 33 32.5	-10 33 19	PWN	2007.10	4.8 kpc	Newly Announced
HESS J1837-069	18 37 38.4	-06 57 00	PWN	2005.03	6.6 kpc	Default Catalog
HESS J1846-029	18 46 24.1	-02 58 53	PWN	2007.10	6.3 kpc	Newly Announced
IGR J18490-0000	18 49 01.63	-00 01 17.2	PWN	2008.07	7 kpc	Newly Announced
MAGIC J1857.2+0263	18 57 13.0	02 37 31	PWN	2014.11		Default Catalog
SNR G054.1+00.3	19 30 32	+18 52 12	PWN	2009.07	6.2 kpc	Default Catalog
0FGL J1958.1+2848	19 58 07.61	+28 48 11.9	PWN	2009.04		Source Candidates
MGRO J2019+37	20 18 35.03	+36 50 00.0	PWN	2007.03		Default Catalog
0FGL J2021.5+4026	20 21 35.77	+40 26 20.8	PWN	2009.04		Source Candidates
TeV J2032+4130	20 32 07	+41 30 30	PWN	2002.10	1.8 kpc	Default Catalog
Boomerang	22 28 44	+61 10 00	PWN	2009.04	0.8 kpc	Default Catalog

1-37

TeVCat "UNID"

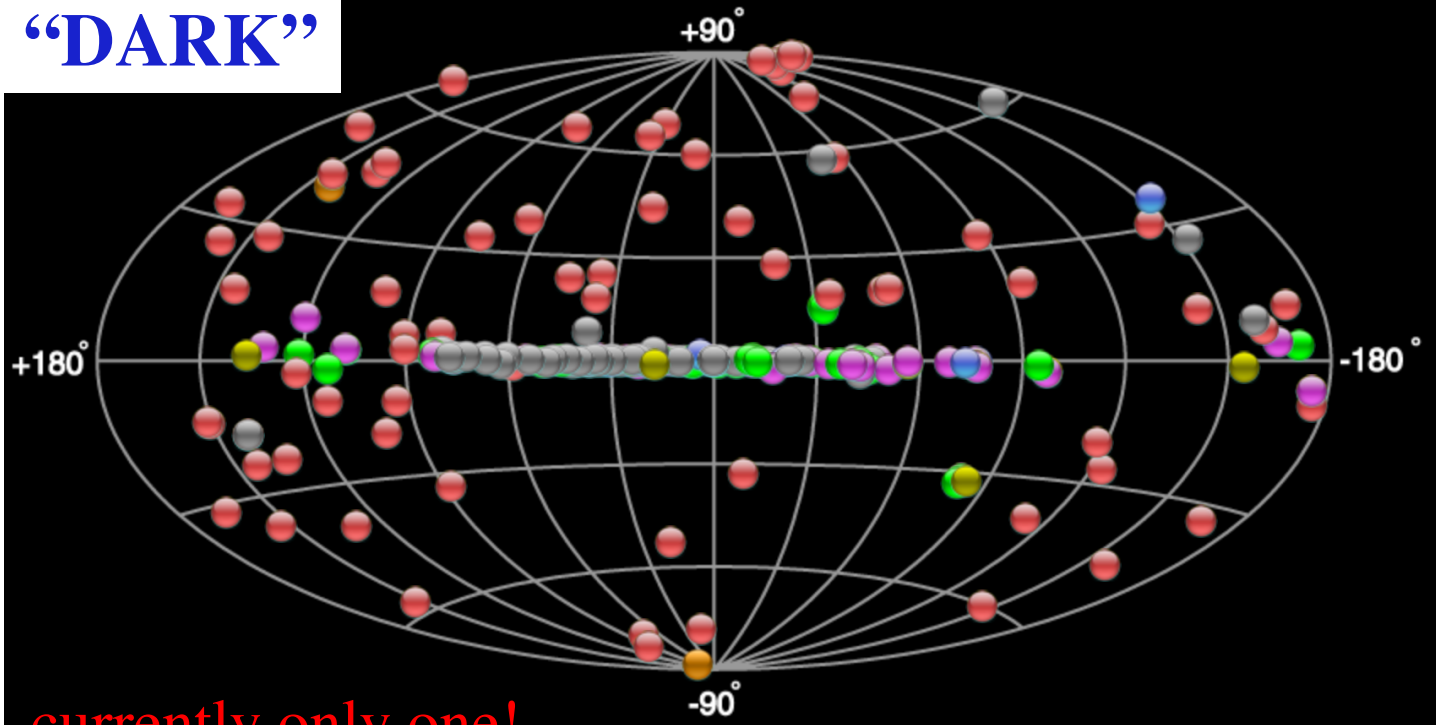
~55 at |b|<10°

Name	RA	Dec	Type	Date	Dist	Catalog
			UNID			...
2HWC J0700+143	07 00 28.8	14 19 12	UNID	2017.02		Newly Announced
2HWC J0819+157	08 19 55.2	+15 47 24	UNID	2017.02		Newly Announced
2HWC J1040+308	10 40 52.8	+30 52 12	UNID	2017.02		Newly Announced
2HWC J1309-054	13 09 14.4	-05 29 24	UNID	2017.02		Newly Announced
2HWC J1829+070	18 29 21.6	+07 01 48	UNID	2017.02		Newly Announced
2HWC J1852+013*	18 52 02.4	+01 22 48	UNID	2017.02		Newly Announced
2HWC J1902+048*	19 02 02.4	+04 51 36	UNID	2017.02		Newly Announced
2HWC J1907+084*	19 07 09.6	+08 30 00	UNID	2017.02		Newly Announced
2HWC J1914+117*	19 14 43.2	+11 43 12	UNID	2017.02		Newly Announced
2HWC J1921+131	19 21 12	+13 07 48	UNID	2017.02		Newly Announced
2HWC J1928+177	19 28 36	+17 46 48	UNID	2017.02		Newly Announced
2HWC J1938+238	19 38 58	+23 48 36	UNID	2017.02		Newly Announced
2HWC J1949+244	19 49 40.8	+24 27 36	UNID	2017.02		Newly Announced
2HWC J1953+294	19 53 02.4	+29 28 48	UNID	2017.02		Newly Announced
2HWC J1955+285	19 55 19.2	+28 35 24	UNID	2017.02		Newly Announced
2HWC J2006+341	20 06 12	+34 10 48	UNID	2017.02		Newly Announced
MAGIC J1746.4-2853	17 46 25	-28 52 55	UNID	2016.11		Newly Announced
1HWC J1904+080c	19 04 24	08 00 00	UNID	2015.09		Source Candidates
1HWC J1842-046c	18 42 00	-04 36 00	UNID	2015.09		Source Candidates
HESS J1813-126	18 13 21.66	-12 41 13.6	UNID	2015.08		Newly Announced
VER J1746-289	17 46 19.71	-28 57 58.4	UNID	2015.07		Newly Announced
HESS J1826-130	18 26 00.2	-13 02 00.0	UNID	2015.07		Newly Announced
HESS J1828-099	18 28 58.72	-09 59 33.8	UNID	2015.07		Newly Announced
HESS J1832-085	18 32 31.75	-08 30 35.4	UNID	2015.07		Newly Announced
HESS J1844-030	18 44 41.22	-03 05 34.6	UNID	2015.07		Newly Announced
HESS J1746-285	17 46 23.86	-28 52 33.4	UNID	2015.07		Default Catalog
MAGIC J1857.6+0297	18 57 35.6	02 58 02	UNID	2014.11		Default Catalog
VER J2019+368	20 19 25	+36 48 14	UNID	2014.04		Default Catalog
ARGO J1910+0720	19 10 36	+07 21 00	UNID	2013.11		Source Candidates
ARGO J0409-0627	04 09 24	-06 27 00	UNID	2013.11		Source Candidates
HESS J1641-463	16 41 02.1	-46 18 13	UNID	2012.10		Default Catalog
HESS J1808-204	18 08 37.3	-20 25 36.3	UNID	2012.07		Default Catalog
VER J2016+371	20 16 02	37 11 52	UNID	2011.08		Default Catalog
HESS J1852-000	18 52 13	-00 00 23	UNID	2011.08		Newly Announced
HESS J1729-345	17 29 35	-34 32 22	UNID	2011.05		Default Catalog
HESS J1507-622	15 06 52.8	-62 21 00.0	UNID	2009.12		Default Catalog
VER J2019+407	20 20 04.8	+40 45 26	UNID	2009.11		Default Catalog
0FGL J1844.1-0335	18 44 08.87	-03 35 21.4	UNID	2009.04		Source Candidates
0FGL J1900.0+0356	19 00 02.21	+03 56 48.3	UNID	2009.04		Source Candidates
MAGIC J0223+403	02 23 12	+43 00 42	UNID	2009.02		Default Catalog
HESS J1741-302	17 41 00	-30 12 00	UNID	2008.07		Newly Announced
HESS J1843-033	18 43 00	-03 18 00	UNID	2008.07		Newly Announced
HESS J1809-193	18 10 31	-19 18 00	UNID	2007.09	3.7 kpc	Default Catalog
MGRO J1908+06	19 07 54	+06 16 07	UNID	2007.08		Default Catalog
MGRO J2031+41	20 28 43.2	+41 18 36	UNID	2007.08		Default Catalog
HESS J1626-490	16 26 04	-49 05 13	UNID	2007.07		Default Catalog
HESS J1427-608	14 27 52	-60 51 00	UNID	2007.07		Default Catalog
HESS J1841-055	18 40 55	-05 33 00	UNID	2007.07		Default Catalog
HESS J1857+026	18 57 11	+02 40 00	UNID	2007.07		Default Catalog
HESS J1858+020	18 58 20	+02 05 24	UNID	2007.07		Default Catalog
Galactic Centre Ridge	17 45 39.6	-29 00 22	UNID	2006.02	8.5 kpc	Default Catalog
HESS J1634-472	16 34 57.6	-47 16 12	UNID	2006.01	8.6 kpc	Default Catalog
HESS J1702-420	17 02 44	-42 00 57	UNID	2006.01		Default Catalog
HESS J1708-410	17 08 24	-41 05 24	UNID	2006.01		Default Catalog
MilagroDiffuse	20 20 00	+38 00 00	UNID	2005.12		Default Catalog
HESS J1804-216	18 04 31.2	-21 42 00	UNID	2005.03	6 kpc	Default Catalog
HESS J1834-087	18 34 45.6	-08 45 36	UNID	2005.03	4 kpc	Default Catalog
Galactic Centre	17 45 39.6	-29 00 22	UNID	2004.05	8.5 kpc	Default Catalog
Vela Region	08 33 39	-45 00 10	UNID	1997.09		Other Sources

1-59

TeVCat "DARK"

Welcome to TeVCat!



Try TevCat 2.0 Beta!

Table Control | Map Control | Tools | Legend

Table Columns
- ☐ TeVCat Name ☑ Name ☑ RA
- ☑ Dec ☑ Type
- ☐ Discoverer
- ☑ Date ☑ Distance
- ☑ Catalog

Select

Catalogs

Default Catalog
Newly Announced
Other Sources
Source Candidates

☑ Filter by Catalog

currently only one!

Select All | Unselect All | Plot Selected | Plot All | Plot UnSelected | Filter Selected | Clear Filters

Reg Exp: OK

Name	RA	Dec	Type	Date	Dist	Catalog
			DARK			...
HESS J1503-582	15 03 38	-58 13 45	DARK	2008.12		Newly Announced

1-1

[What's New?] [TeVCat FAQ] [TeV Astrophysics] [Bug Report or Feature Request] [Admin]

TeVCat is brought to you by Scott Wakely And Deirdre Horan and is partially supported by NASA and the NSF --- Best Viewed with

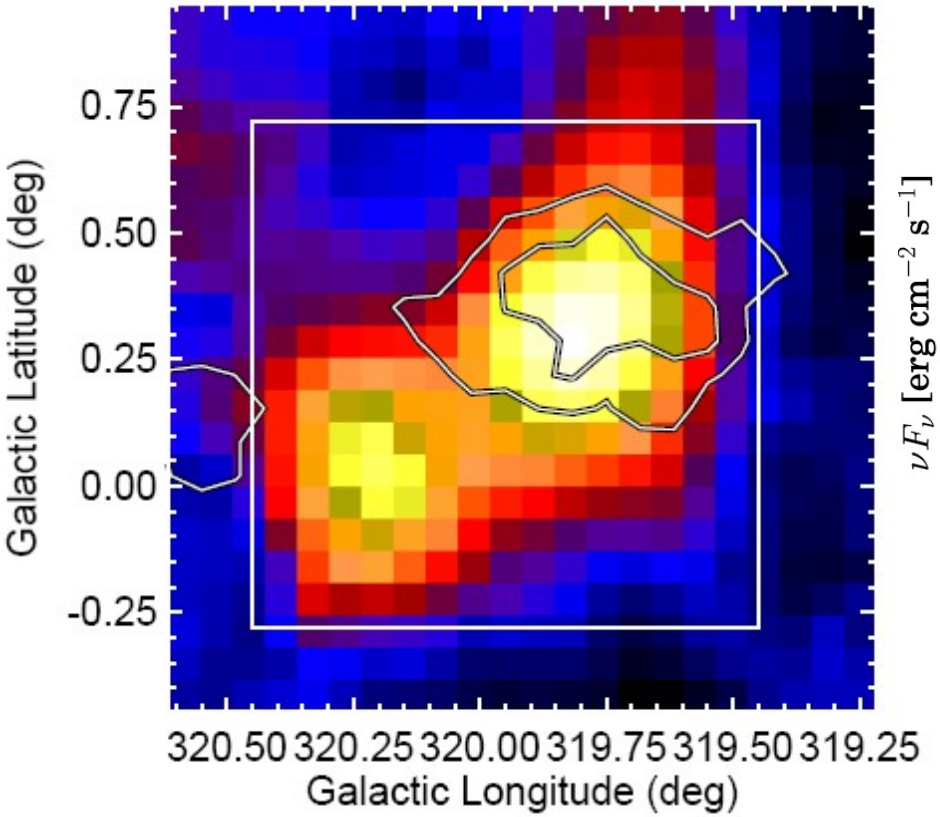
Current Catalog Version: 3.400

Read the TeVCat Terms and Conditions

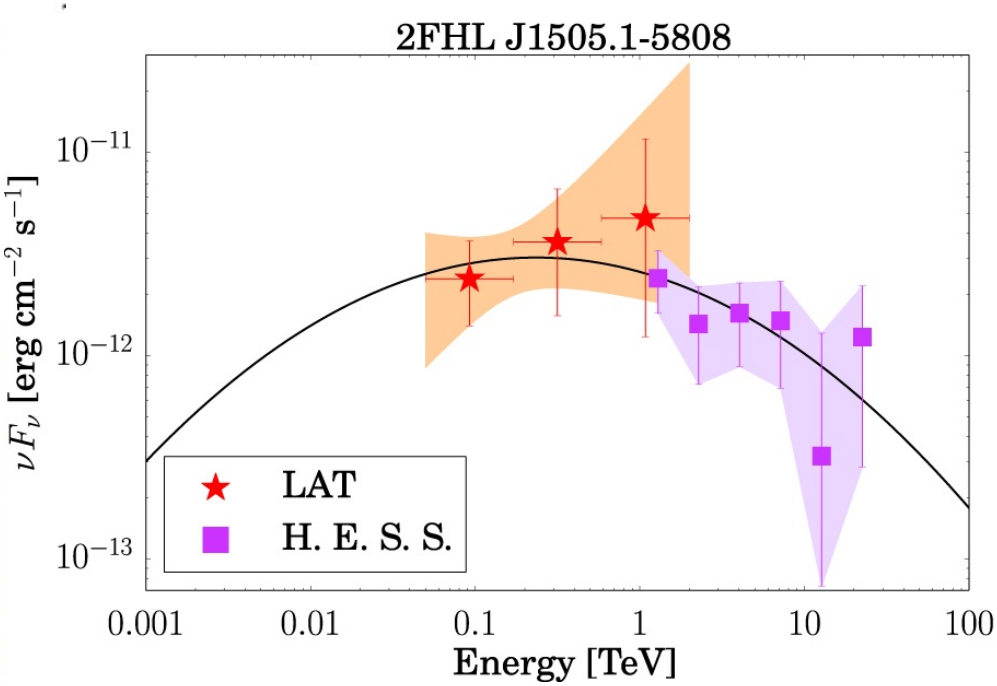
The Tooltip code used on this page is from dyn-web.com

HESS J1503-582: “dark” source associated with a FVW

Renaud+ 08 **HESS J1503-582**



Ackermann+ 16

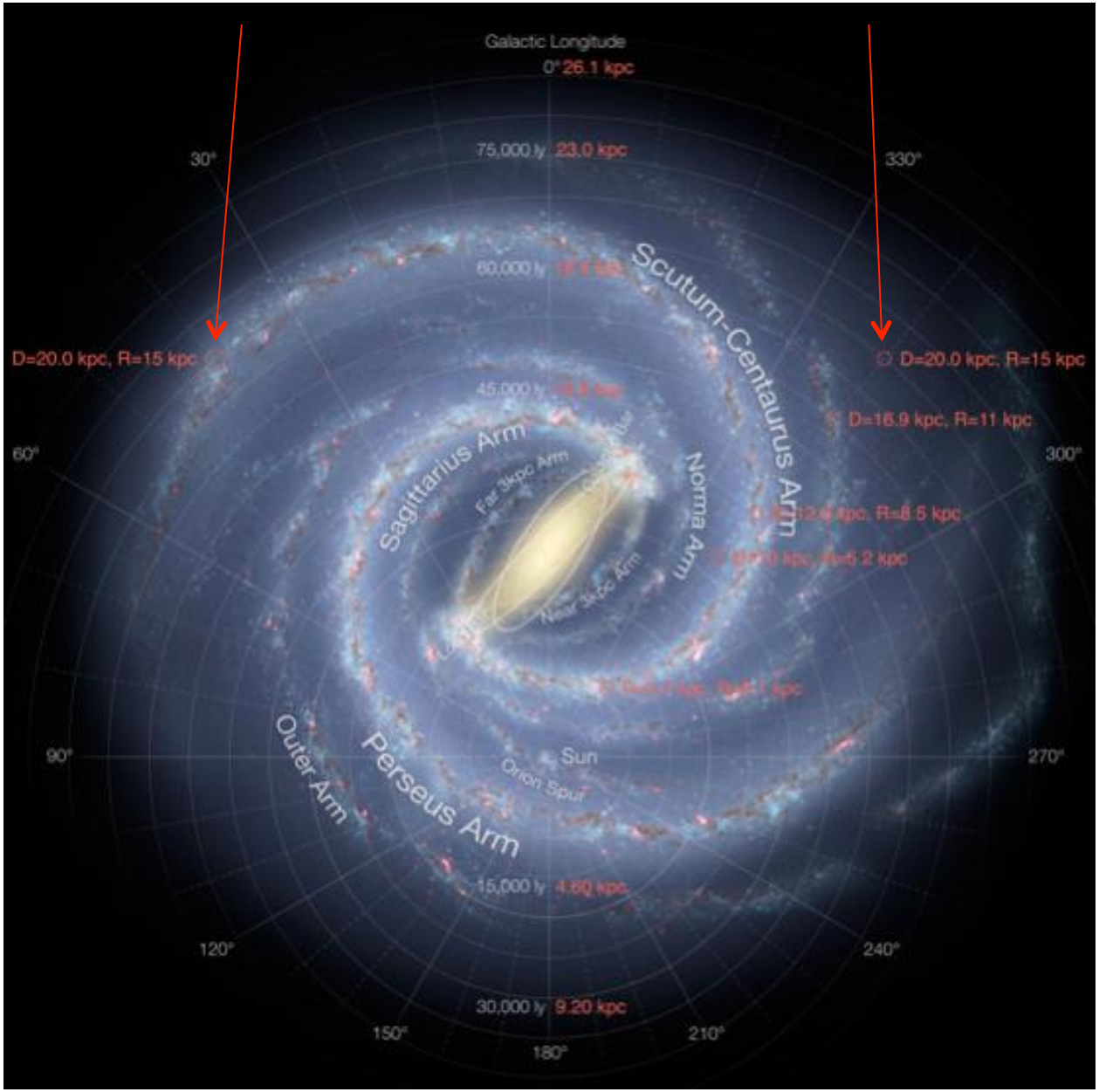


- no obvious counterparts in radio, IR or X
  only “dark” source in TeVCat
- 2FHL (50 GeV – 2 TeV) counterpart
- potential association with FVW 319.8+0.3 of unknown nature

-> direct HVC accretion event?

Galactic Plane geography

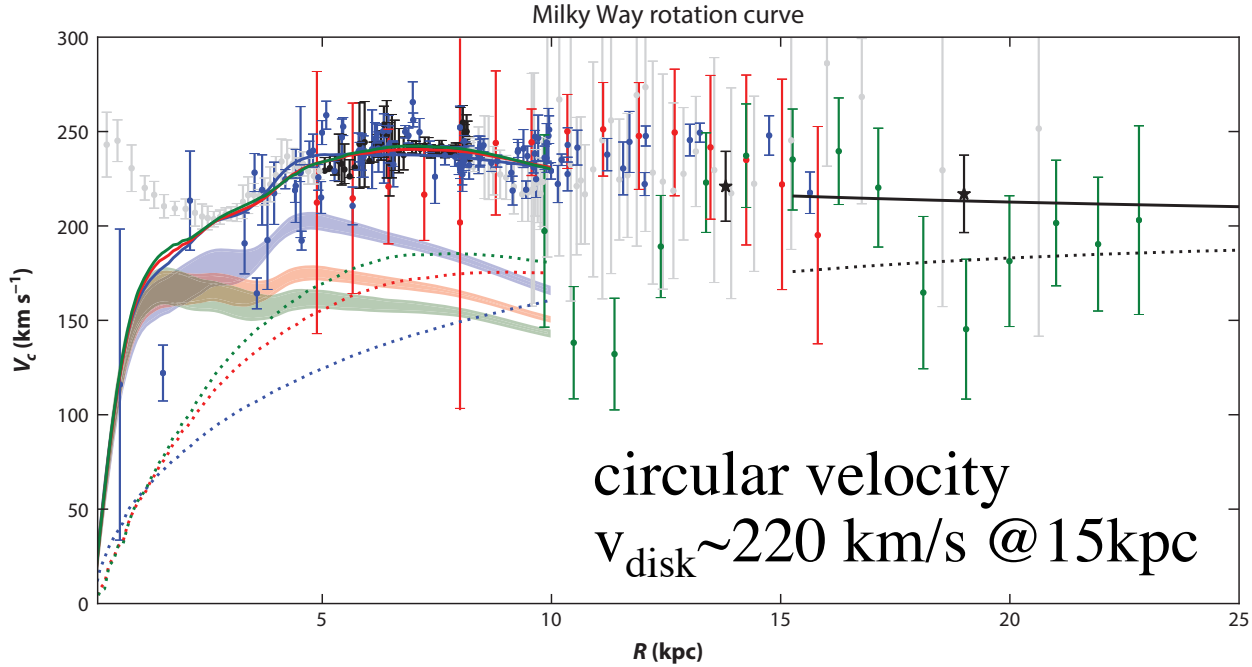
HVC 040+01-282 **HESS J1503-582?**

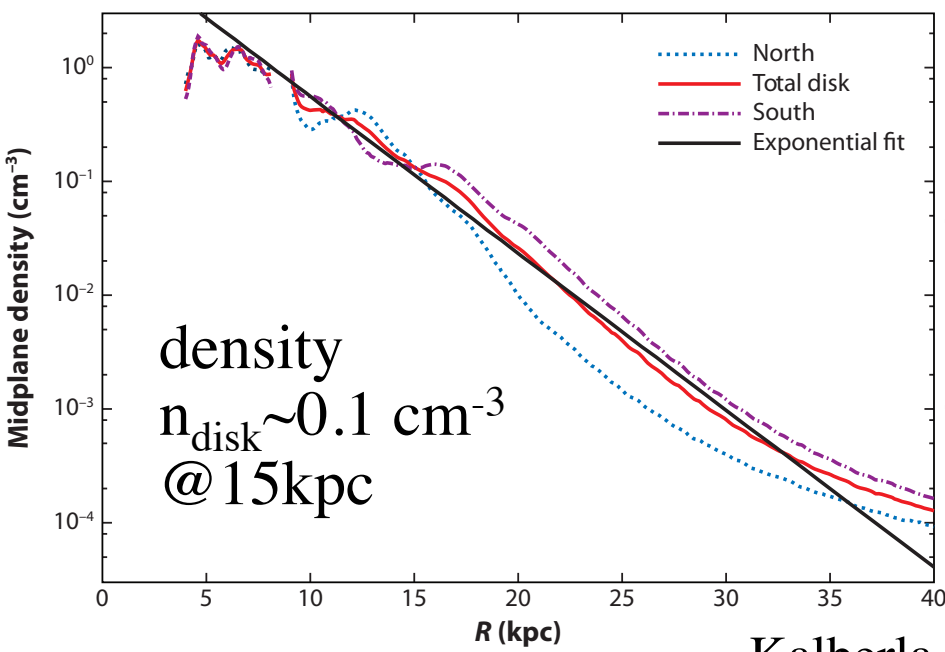


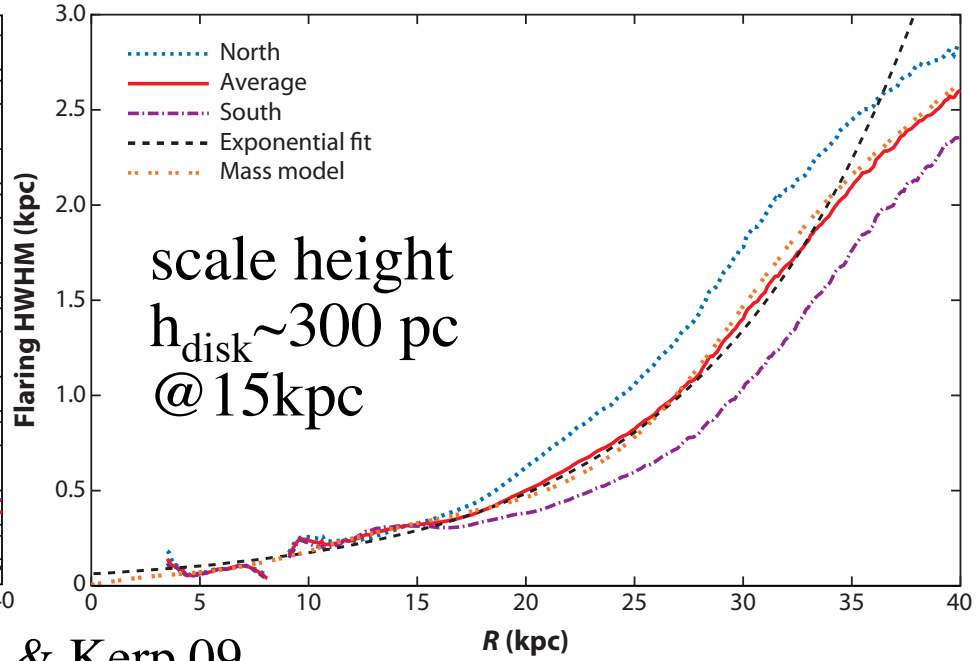
fiducial location
R=15 kpc

Galactic disk properties

fiducial location R=15 kpc



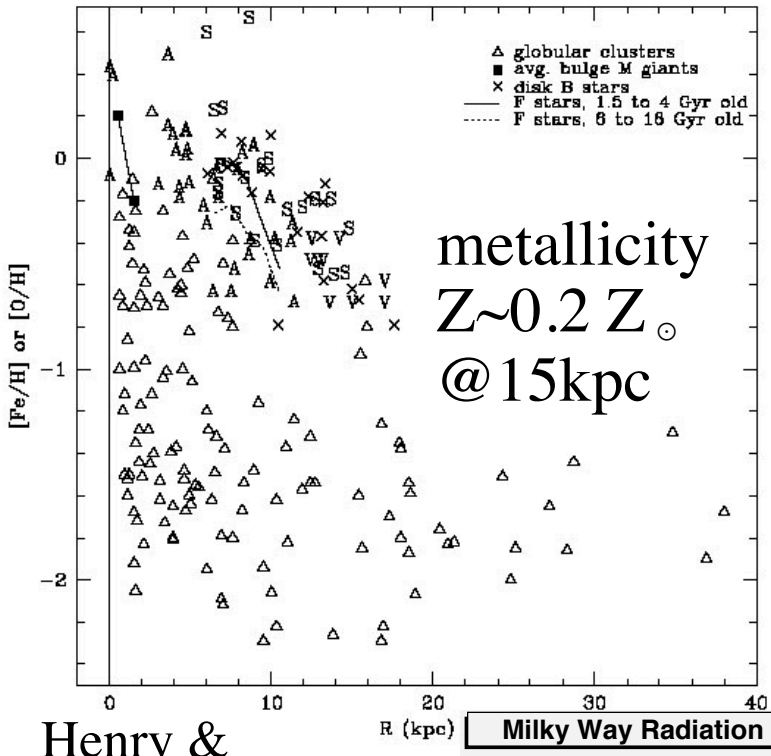




Kalberla & Kerp 09

Galactic disk properties, cont'd

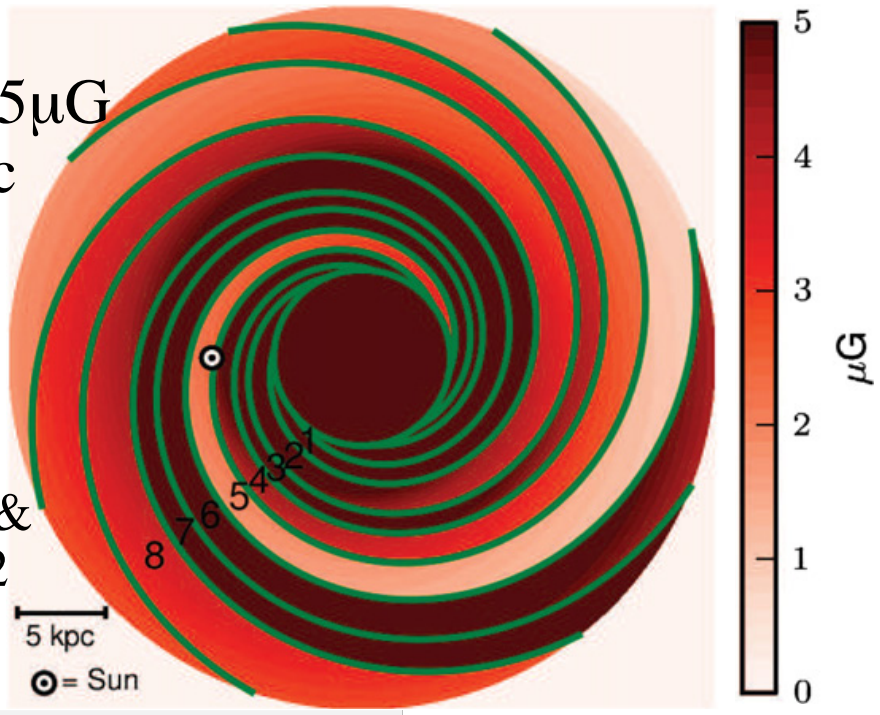
fiducial location R=15 kpc



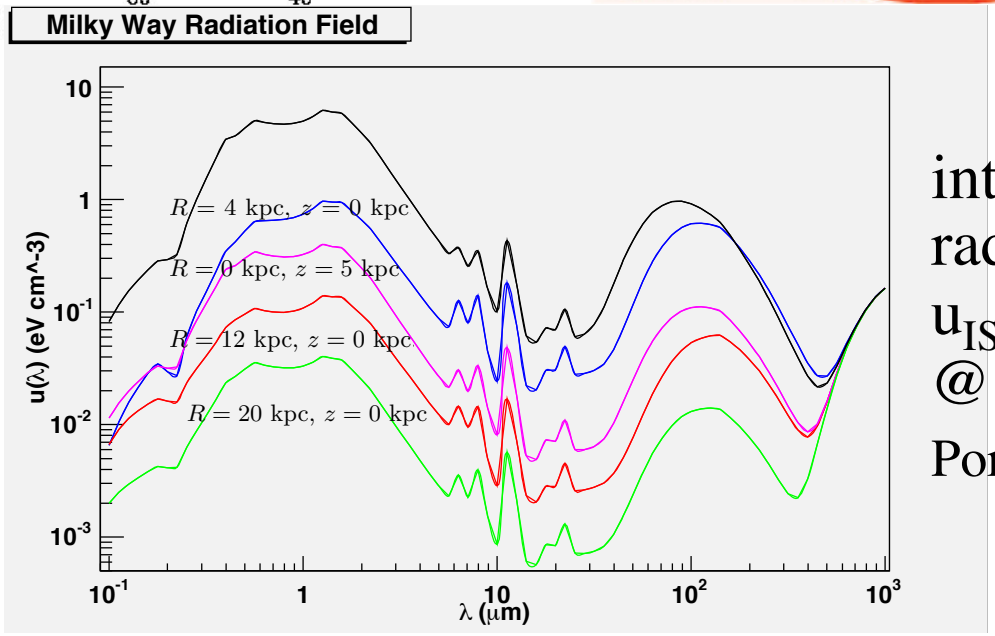
metallicity
$Z \sim 0.2\ Z_\odot$
@15kpc

Henry & Worthey 99

B field
B~ 0.3-5μG
@15kpc



Jansson & Farrar 12



interstellar radiation field
$u_{ISRF} \sim 0.1$ eV cm^{-3}
@15kpc

Porter+ 05

HVC accretion events: shock properties

SI+ 1708.08574

HVC mass, density: fiducial $M_{HVC}=10^5\ M_\odot$, $n_{HVC}=0.1 cm^{-3}$

shock velocity: fiducial $v_s = 300$ km/s

Mach no. $\mathcal{M}_s \simeq 20.1 \left(\frac{v_s}{300\ \mathrm{km\ s^{-1}}}\right)\left(\frac{T_0}{10^4\ \mathrm{K}}\right)^{-1/2}$ post-shock $T_s \simeq 1.3\times10^6\ \mathrm{K}\left(\frac{v_s}{300\ \mathrm{km\ s^{-1}}}\right)^2$

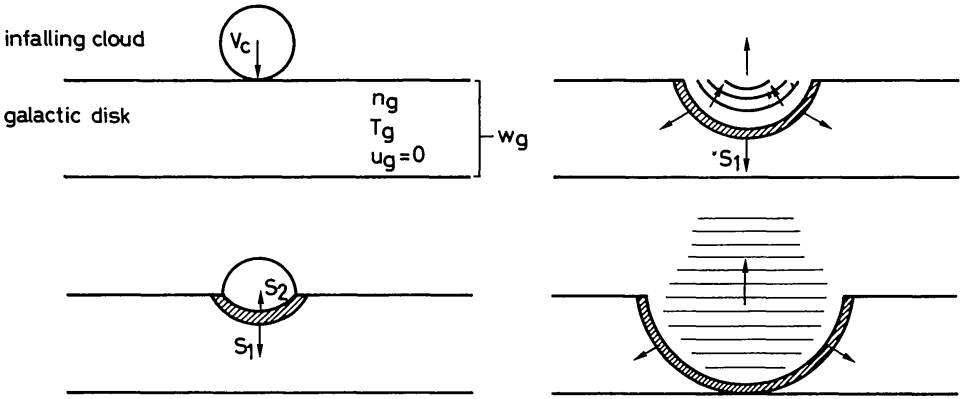
shock lifetime (adiabatic, constant v_s phase) $\tau_s \sim \min[\tau_{\rm disk}, \tau_{\rm HVC}, \tau_{g,\rm rad}]$

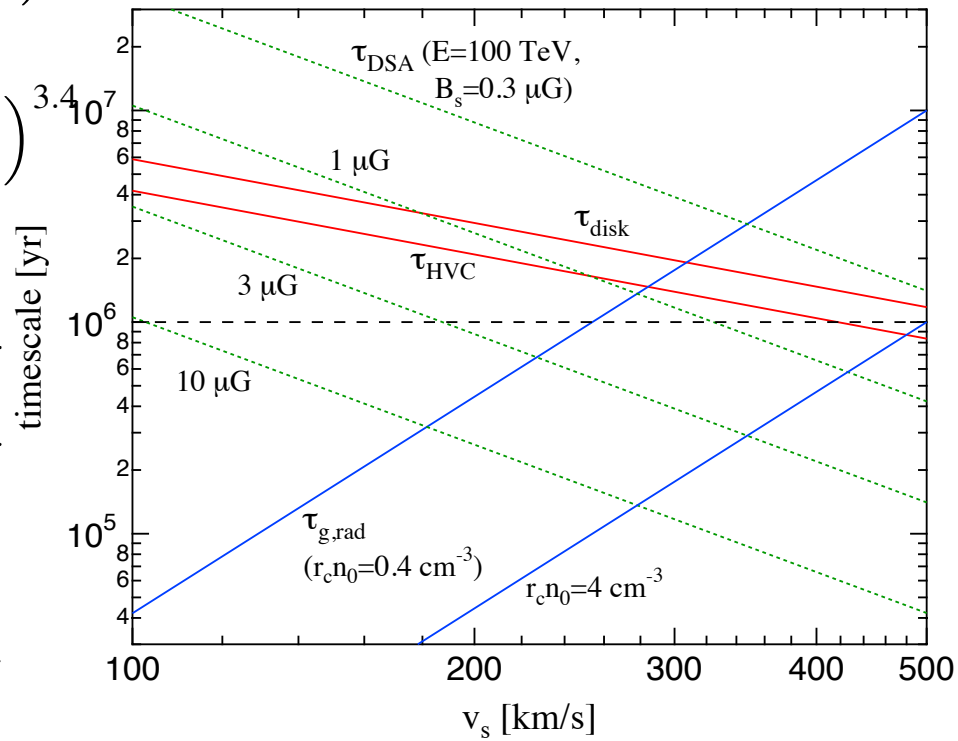
$t_s \sim 10^6$ yr

$$\tau_{\rm HVC} \approx \frac{2r_{\rm HVC}}{v_{s,r}} \simeq 1.4\times10^6\ \mathrm{yr}\left(\frac{n_{\rm HVC}}{0.1\ \mathrm{cm^{-3}}}\frac{M_{\rm HVC}}{10^5\ \mathrm{M_\odot}}\right)^{1/3}\left(\frac{v_s}{300\ \mathrm{km\ s^{-1}}}\right)^{-1}$$

$$\tau_{\rm disk} \approx \frac{2h_{\rm disk}}{v_{s,f}\cos\theta} \simeq 2.0\times10^6\ \mathrm{yr}\frac{1}{\cos\theta}\left(\frac{h_{\rm disk}}{300\ \mathrm{pc}}\right)\left(\frac{v_s}{300\ \mathrm{km\ s^{-1}}}\right)^{-1}$$

$$\tau_{g,\rm rad} \simeq 1.8\times10^6\ \mathrm{yr} \times \left(\frac{r_c n_0}{0.4\ \mathrm{cm^{-3}}}\right)^{-1}\left(\frac{Z}{0.2\ Z_\odot}\right)^{-0.8}\left(\frac{v_s}{300\ \mathrm{km\ s^{-1}}}\right)^{3.4}$$





Tenorio-Tagle 80

HVC accretion events: particle acceleration

SI+ 1708.08574

B fields

disk: B~0.3-5μG? HVC: ? c.f. B~6-8μG measured in 2 HVCs

post-shock magnetic field: fiducial B_s=3μG (0.3-10μG) B_{eq}~14 μG

acceleration time, max energy

$$\tau_{\rm DSA} \approx \frac{10}{3}\frac{\eta c E}{e B_s v_s^2} \simeq 3.9\times10^3\ {\rm yr}\ \eta \left(\frac{E}{1\ {\rm TeV}}\right)\left(\frac{B_s}{3\ \mu{\rm G}}\right)^{-1}\left(\frac{v_s}{300\ {\rm km\ s^{-1}}}\right)^{-2}$$

$$E_{p,\rm max} \approx \frac{3}{10}\frac{e B_s v_s^2 \tau_s}{\eta c} \simeq 256\ {\rm TeV}\ \eta^{-1}\left(\frac{B_s}{3\ \mu{\rm G}}\frac{\tau_s}{10^6\ {\rm yr}}\right)\left(\frac{v_s}{300\ {\rm km\ s^{-1}}}\right)^{2}$$

~30 TeV-1 PeV

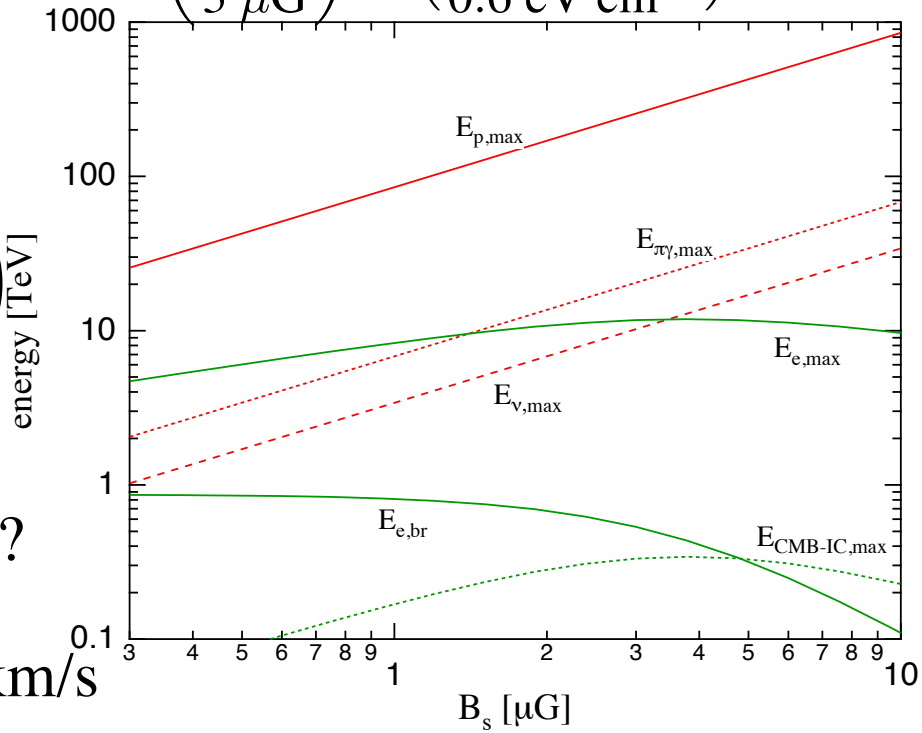
$$E_{e,\rm max} \approx \frac{3 m_e c v_s}{2}\left(\frac{e B_s}{10\eta(u_B+u_{\rm ph})}\right)^{1/2} \simeq 11.5\ {\rm TeV}\ \eta^{-1/2}\left(\frac{B_s}{3\ \mu{\rm G}}\right)^{1/2}\left(\frac{u_B+u_{\rm ph}}{0.6\ {\rm eV\ cm^{-3}}}\right)^{-1/2}$$

injection

$$Q_p(p) \equiv \frac{dN_p}{dp dt} = Q_{p0}\left(\frac{p}{p_0}\right)^{-\alpha}\exp\left(-\frac{p}{p_{p,\rm max}}\right)$$

$$Q_e(p_e) \equiv \frac{dN_e}{dp_e dt} = Q_{e0}\left(\frac{p_e}{p_0}\right)^{-\alpha}\exp\left(-\frac{p}{p_{e,\rm max}}\right)$$

fiducial e/p @1GeV/c K_{ep}=0.01



neutral particles in pre-shock medium?

moderately radiative ->

likely photoionized unless v_s > 120 km/s

HVC accretion events: energetics, number

SI+ 1708.08574

HVC kinetic energy $\mathcal{E}_{\rm HVC} = \frac{1}{2} M_{\rm HVC} v_{\rm HVC}^2 \simeq 9.0 \times 10^{52}\ {\rm erg} \left(\frac{M_{\rm HVC}}{10^5\ {\rm M}_\odot}\right) \left(\frac{v_{\rm HVC}}{300\ {\rm km\ s^{-1}}}\right)^2$

HVC accretion power

$\mathcal{L}_{\rm acc,HVC} \approx \frac{1}{2} f_{\rm acc} \dot{M}_{\rm acc,HVC} v_{\rm acc}^2 \simeq 2.9 \times 10^{40}\ {\rm erg\ s^{-1}}\ f_{\rm acc} \left(\frac{\dot{M}_{\rm acc,HVC}}{1\ {\rm M}_\odot\ {\rm yr^{-1}}}\right) \left(\frac{v_{\rm acc}}{300\ {\rm km\ s^{-1}}}\right)^2$

vs SN power

$\mathcal{L}_{\rm SN} = \mathcal{E}_{\rm SN} \mathcal{R}_{\rm SN} \simeq 9.5 \times 10^{41}\ {\rm erg\ s^{-1}} \left(\frac{\mathcal{E}_{\rm SN}}{10^{51}\ {\rm erg}} \frac{\mathcal{R}_{\rm SN}}{0.03\ {\rm yr^{-1}}}\right)$

$\mathcal{L}_{\rm acc,HVC}$ fiducially ~<3% of SN, optimistically ~<15% of SN

number of active adiabatic HVC shocks

$N_s \approx f_{\rm s} (\dot{M}_{\rm acc,HVC}/M_{\rm HVC}) \tau_s \simeq 10\ f_{\rm s} \left(\frac{\dot{M}_{\rm acc,HVC}}{1\ {\rm M}_\odot\ {\rm yr^{-1}}} \frac{\tau_s}{10^6\ {\rm yr}}\right) \left(\frac{M_{\rm HVC}}{10^5\ {\rm M}_\odot}\right)^{-1}$

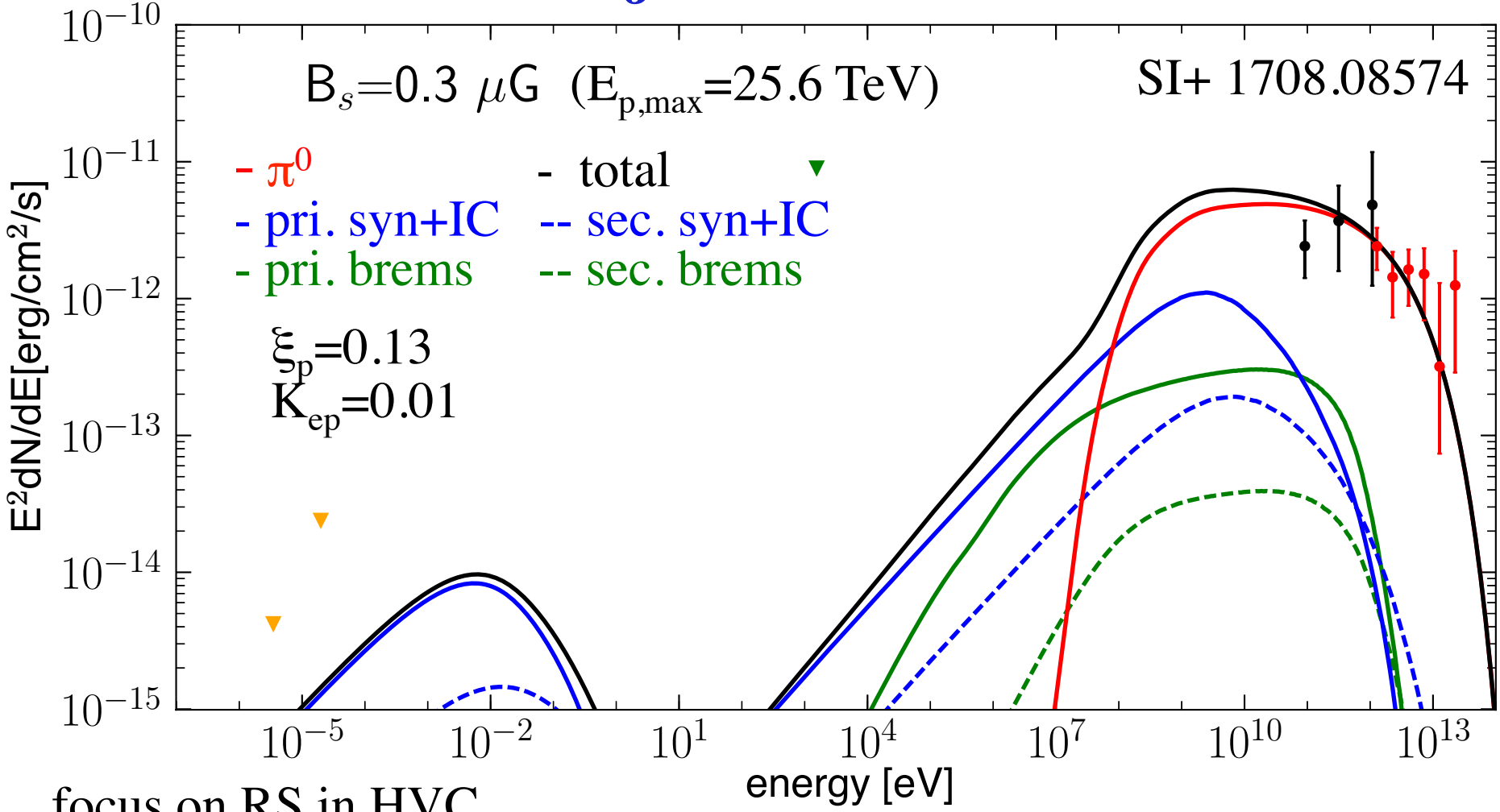
fiducially $N_s \sim 10$

can be larger if:

$M_{\rm HVC} < 10^5\ M_\odot$ can survive

radiative phase considered (acceleration to GeV energies?)

dark TeV source HESS J1503-582 as HVC accretion event



focus on RS in HVC

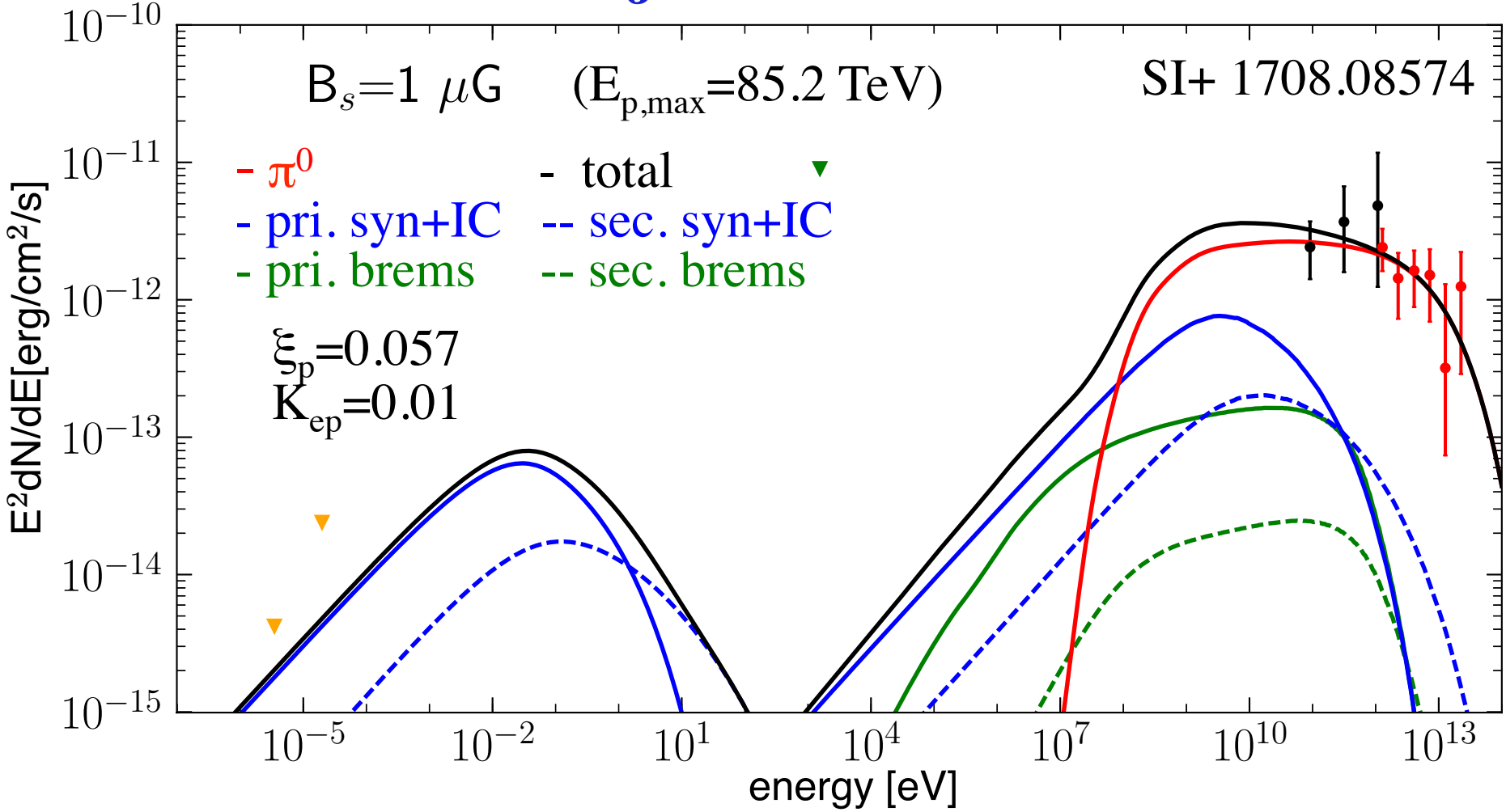
v_s=300 km/s, M_{HVC}=10^5 $M_\odot$, n_{HVC}=0.15 cm^{-3} (t_s=1.2x10^6 yr)

D=20 kpc (R=15 kpc, u_{ISRF}=0.1 eV cm^{-3})

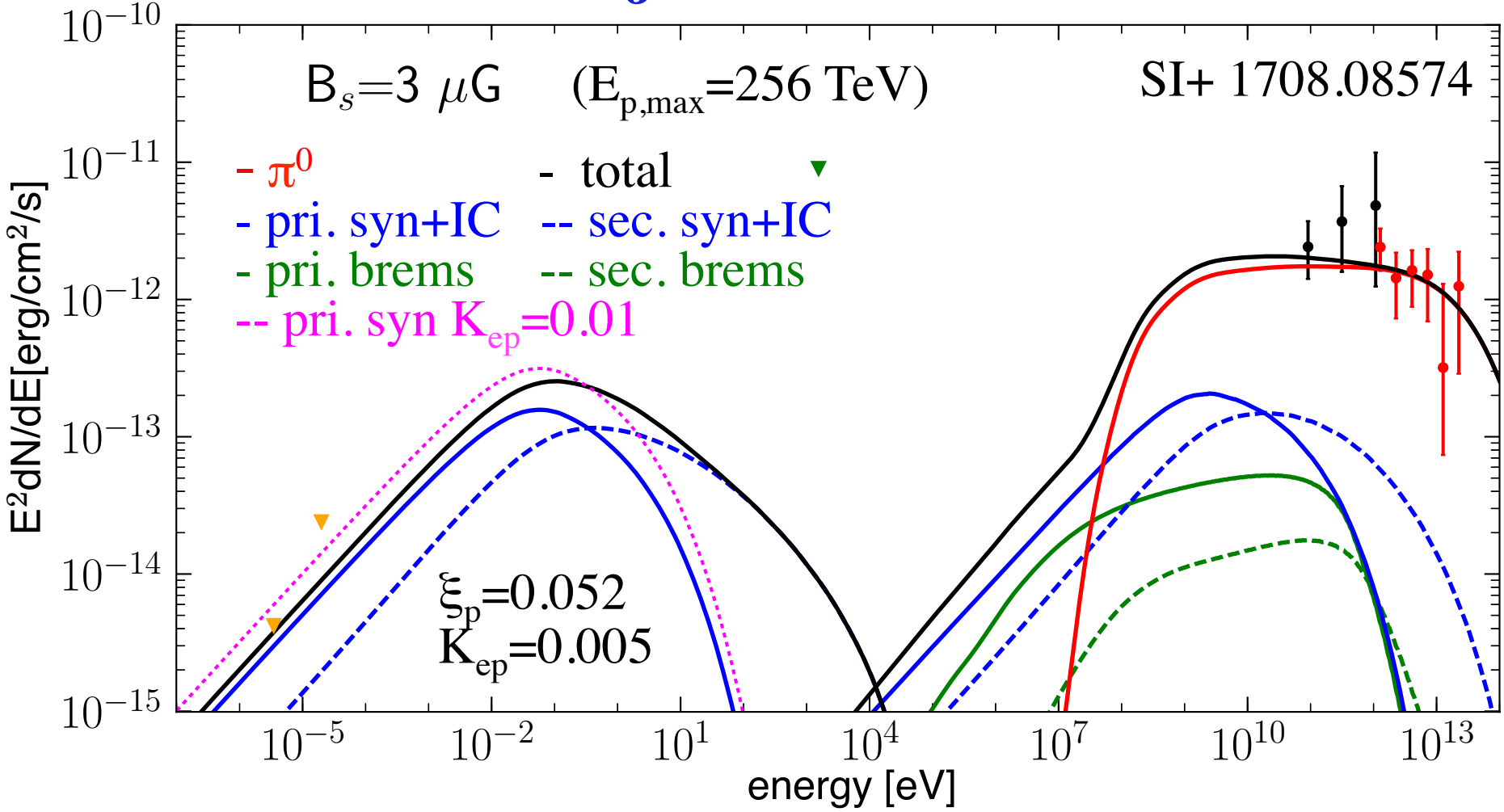
η=1, α=2

- B_s<0.3μG disfavored due to TeV spectrum

dark TeV source HESS J1503-582 as HVC accretion event

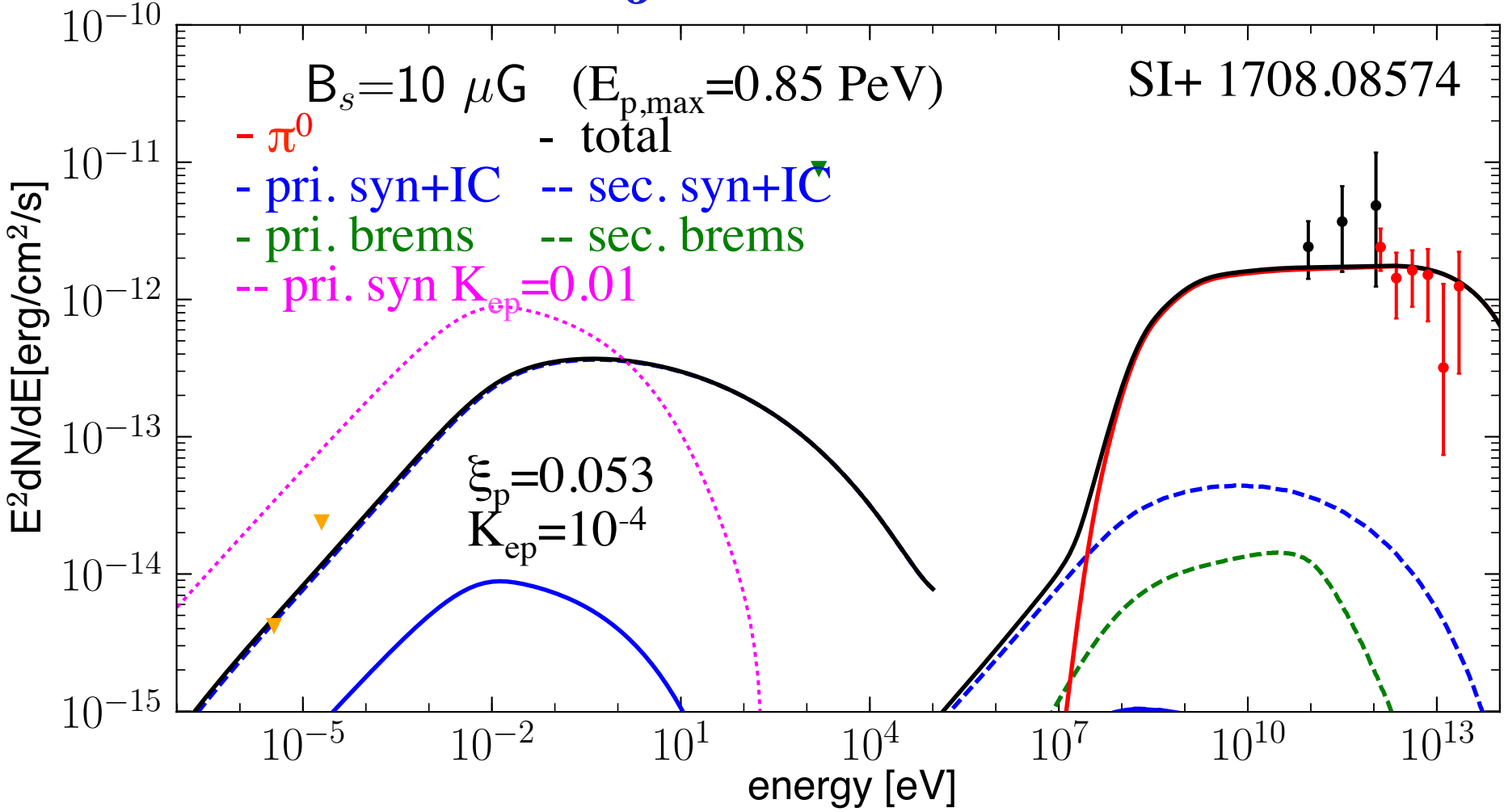


dark TeV source HESS J1503-582 as HVC accretion event



- X-rays from secondary sync. may be detectable by deeper observations

dark TeV source HESS J1503-582 as HVC accretion event



- B_s>10μG disfavored due to radio upper limits
- radio/X-rays from sec. sync. may be detectable by deeper observations
  -> constrain B_s

further observational tests

SI+ 1708.08574

HI observations

- morphology, kinematics: signs of HVC+disk interaction
- distance: larger energetics compared to SNR, PWNe
- location: weak, little, or opposite correlation with star forming regions
  IGM/satellite gas ignorant of disk conditions
  disruption due to SN-driven outflows from disk

GeV-TeV: sub-PeV cutoff, π^0 bump

non-thermal radio, X-ray

secondary electrons (indep. of K_{ep}): constrain B_s

thermal

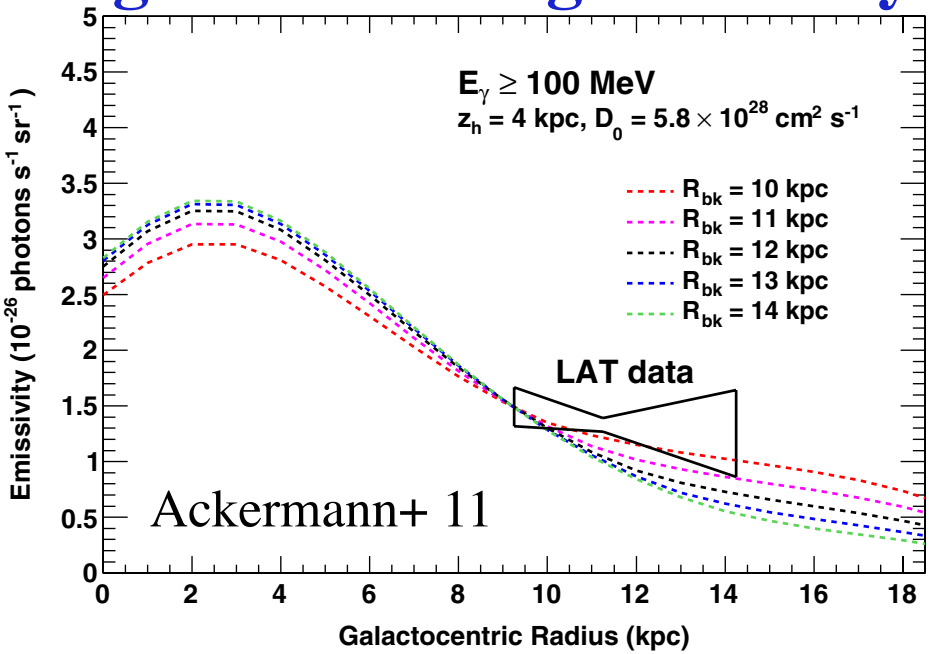
- free-free continuum: heavily attenuated (e.g. $N_H \sim 1.5 \times 10^{22}$ cm^{-2} for HESS J1503-582), but possibly detectable if nearer sources exist
- emission lines from Fe, Si?

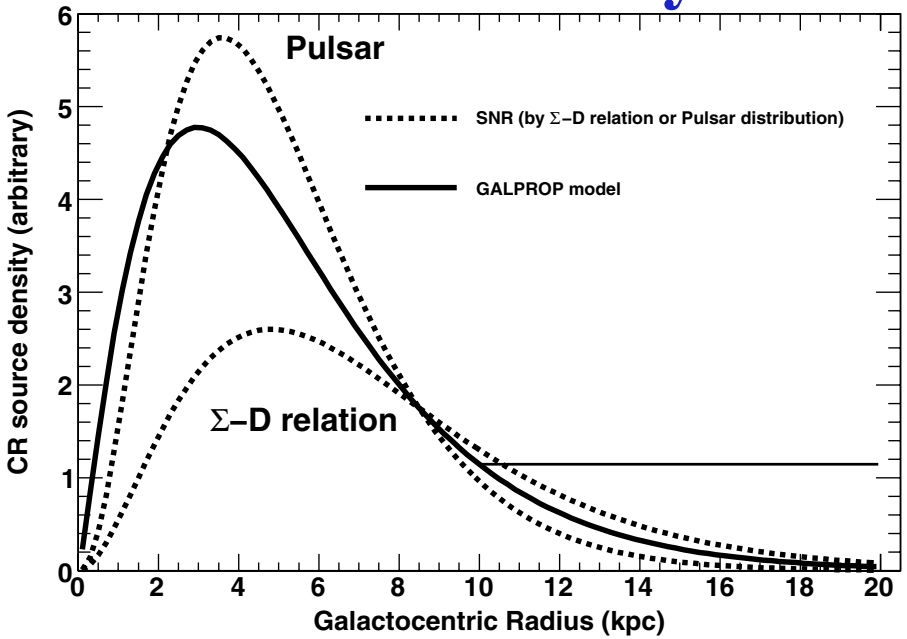
HE neutrinos: detectable by KM3NeT

search for more sources

- HESS, Fermi, HAWC… vs FVWs, HI shells…
- CTA: HVC accretion events in M31?

origin of diffuse gamma-ray excess in outer Galaxy?

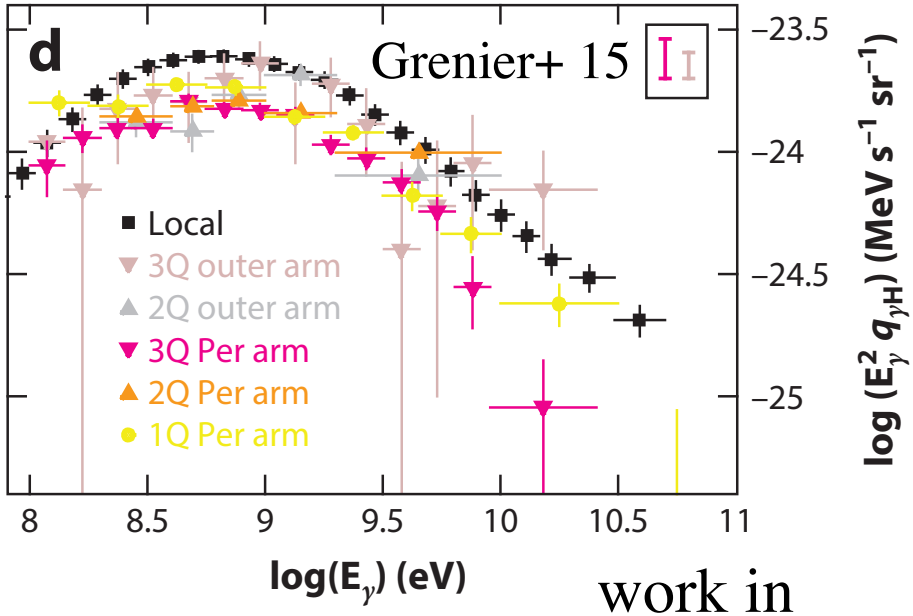




long-standing problem:
non-standard diffusion?
undetected "dark" gas?

cool gas accretion?

- preferential injection of CRs in outer Galaxy from IGM/satellite gas accretion
- advective confinement due to inflow
- generation of turbulence in non-star-forming regions



work in progress

summary

observational facts

- ongoing accretion of low-metallicity gas onto Galactic disk at rate of order $\dot{M}_{acc} \sim 1\ M_\odot$/yr
- at least partly via direct accretion of HVCs with mass $\sim 10^5\ M_\odot$ and velocity few 100 km/s
- numerous unidentified GeV-TeV sources in Galactic Plane
- at least one "dark" source with no counterparts except FVW

plausible consequences

- with magnetic fields of order few μG in HVC accretion shocks, acceleration of protons to sub-PeV, electrons to multi-TeV during 10^6 yr lifetime -> π^0 gamma-ray emission (+ some IC)
  -> origin of dark unID GeV-TeV sources
- locations un- or anti-correlated with star formation
- testable with further observations in HI, radio, X-rays, neutrinos…

further implications

- origin of diffuse gamma excess in outer Galaxy?
- other observable effects?
- potential signposts illuminating gas accretion interface?