

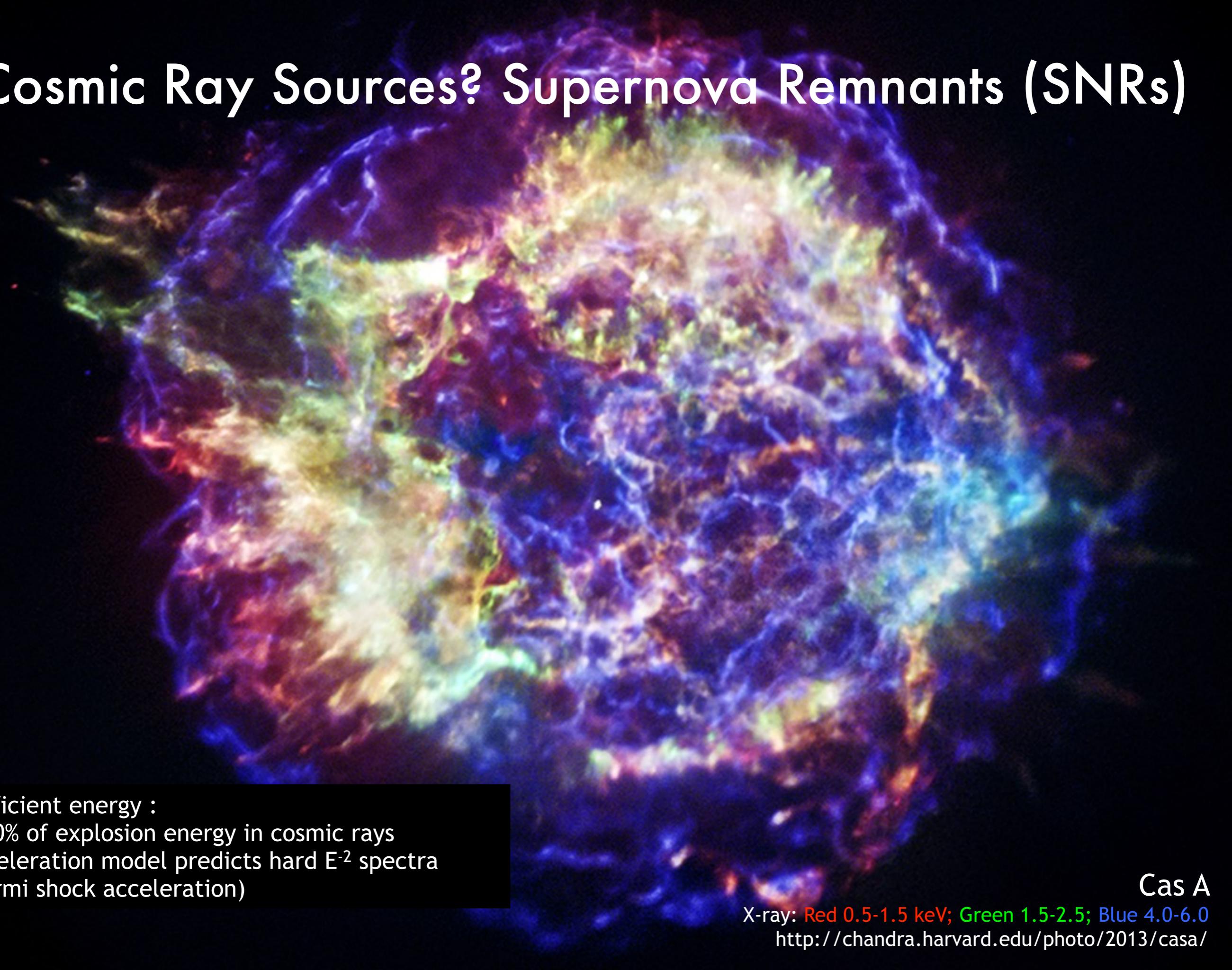


Upper limits on gamma-ray emission from supernovae observed with H.E.S.S.

R.Simoni, N.Maxted, J.Vink, M.Renaud
On behalf of the H.E.S.S. collaboration



Cosmic Ray Sources? Supernova Remnants (SNRs)



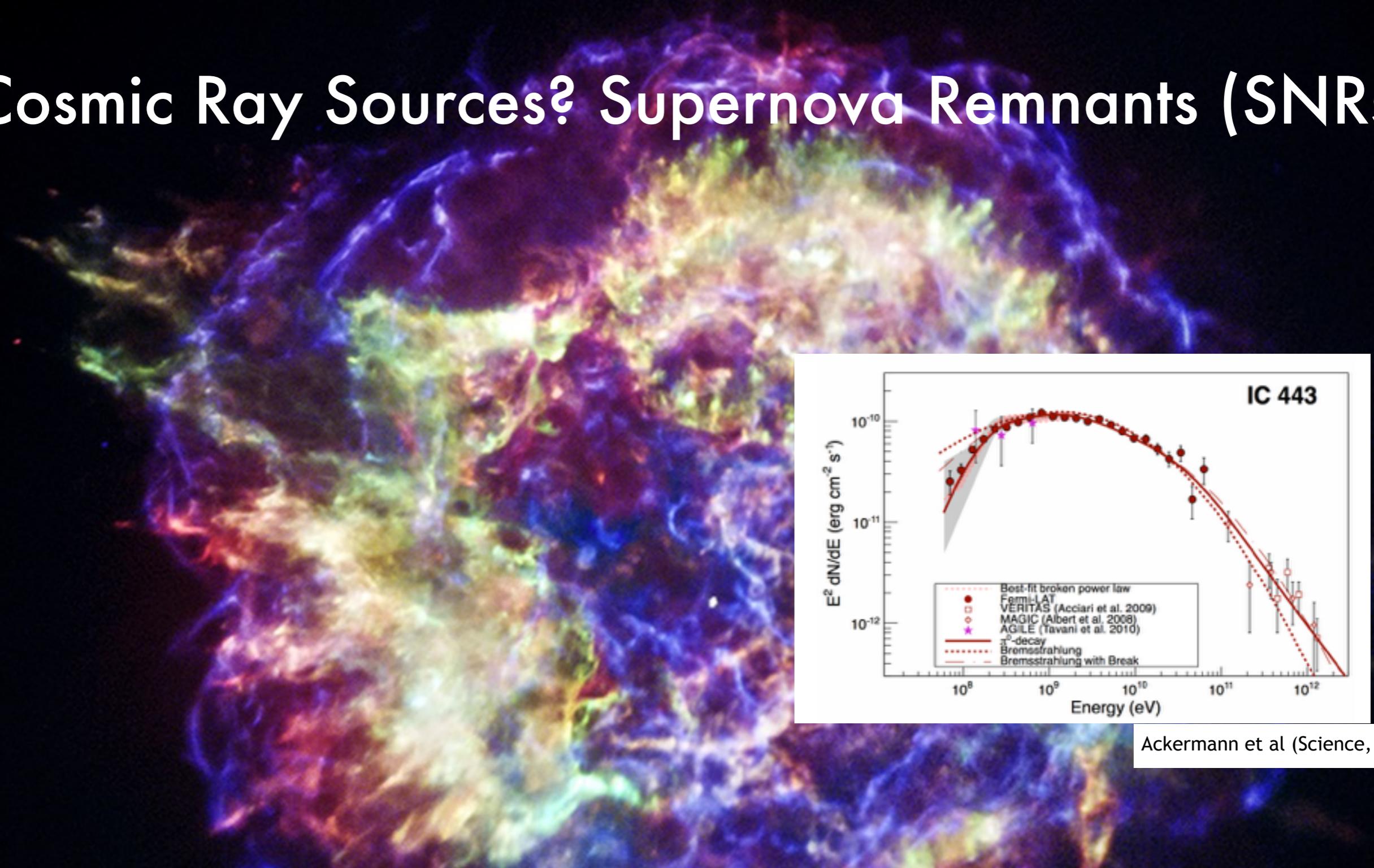
Sufficient energy :

5-10% of explosion energy in cosmic rays
Acceleration model predicts hard E^{-2} spectra
(Fermi shock acceleration)

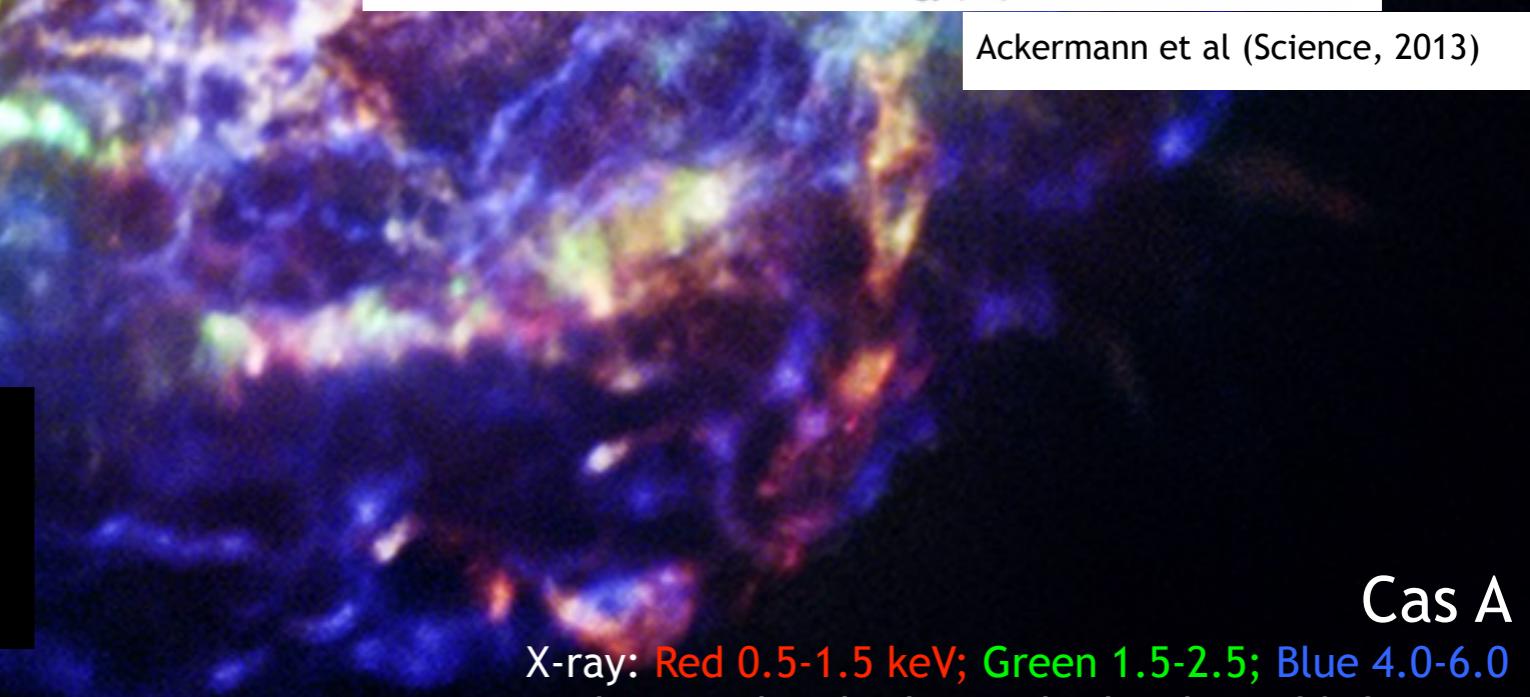
Cas A

X-ray: Red 0.5-1.5 keV; Green 1.5-2.5; Blue 4.0-6.0
<http://chandra.harvard.edu/photo/2013/casa/>

Cosmic Ray Sources? Supernova Remnants (SNRs)



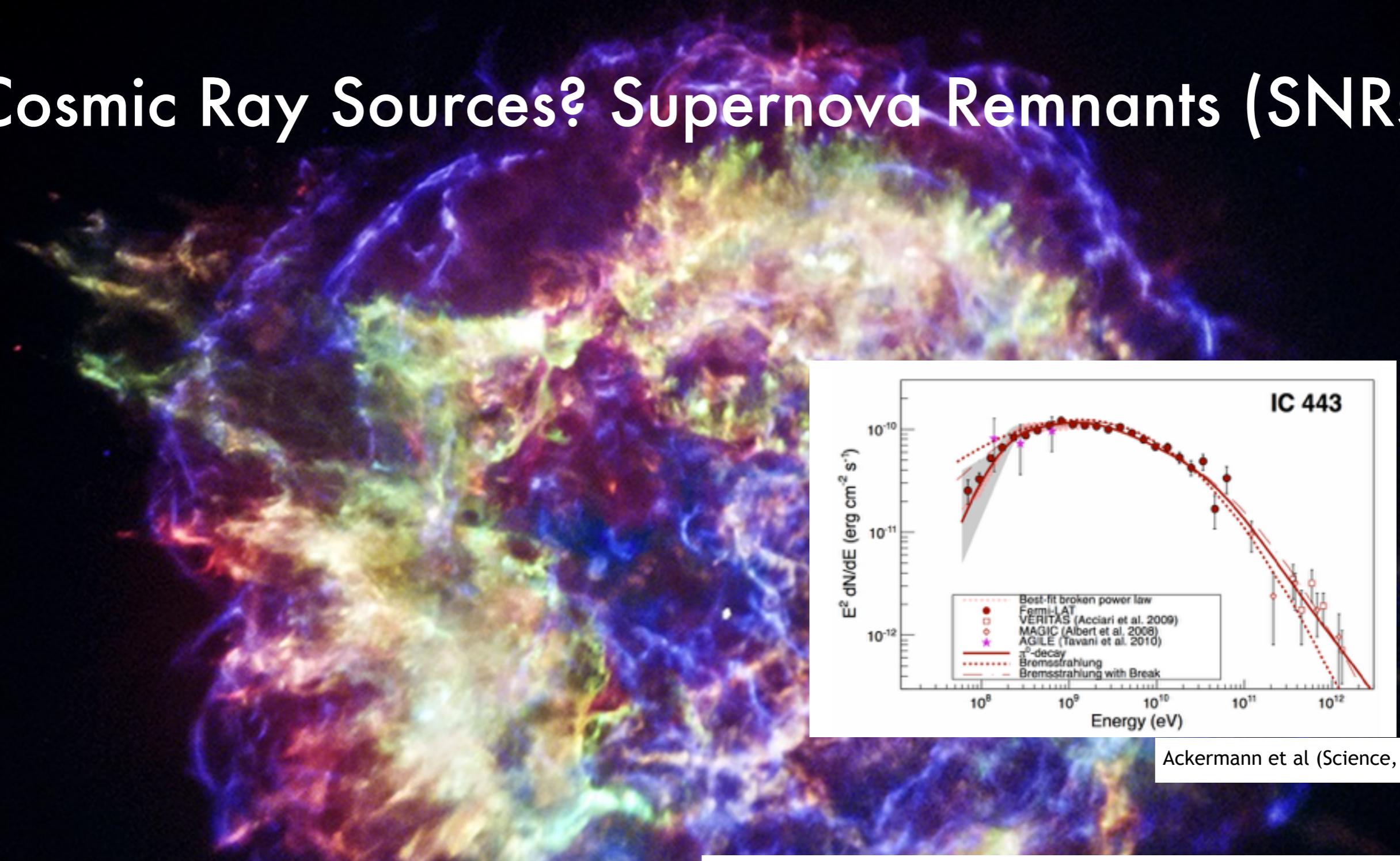
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Cosmic Ray Sources? Supernova Remnants (SNRs)



But no evidence of PeV emission from SNR
has been found yet.

Sufficient energy :
5-10% of explosion energy in cosmic rays
Acceleration model predicts hard E^{-2} spectra
(Fermi shock acceleration)

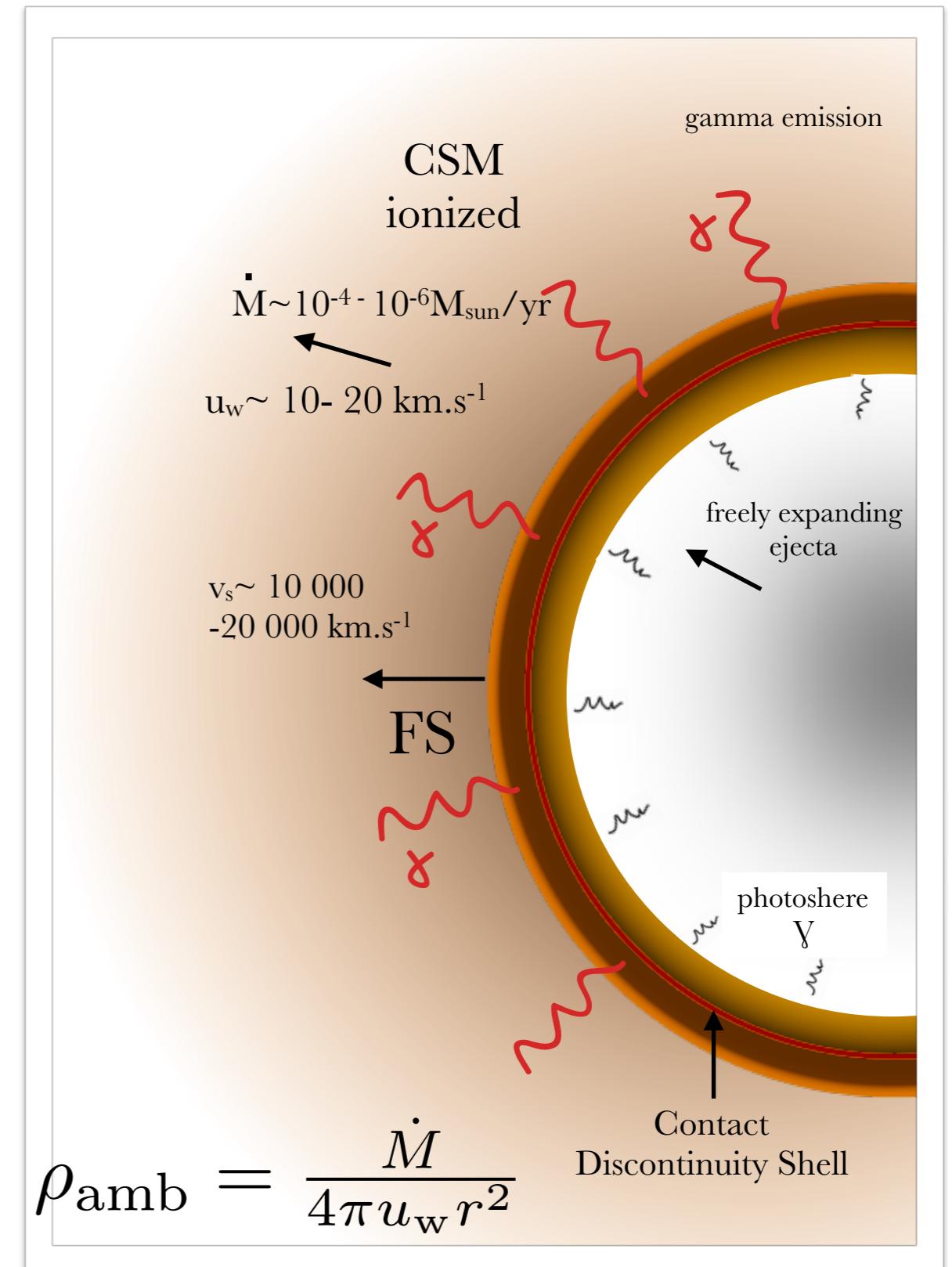
Cas A

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CR acceleration by Supernovae (SNe)

- Need very dense environment (progenitor wind).
- Fast magnetic field amplification (Bell 2004).
- High density: more p-p collisions
→ gamma-ray emission
- Best candidates are core-collapse SNe.

(e.g. Marcowith et al. 2014, Cardillo et al 2015, Murase et al 2011, Katz et al 2011.)



Modelling

We use a semi-analytical model
(Dwarkadas 2013):

$$v_{\text{sh}} = 10\,000 \text{ km.s}^{-1}$$

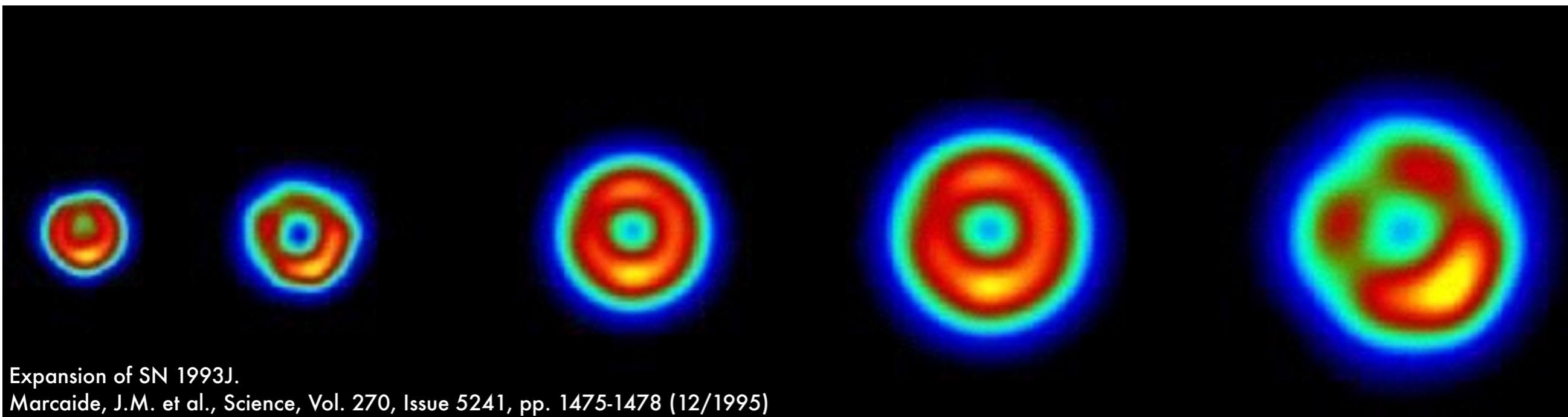
And considering an index of 2

$$\underline{F_\gamma(> 1\text{TeV}) = 5.14 \times 10^{-12}}$$

$$\left[\frac{\dot{M}_{-5}}{u_{w,10}} \right]^2 \left(\frac{1}{t_{\text{days}}} \right) \left(\frac{1}{d_{\text{Mpc}}^2} \right).$$

for $t > 5$ days

SN 1993J is a prime example



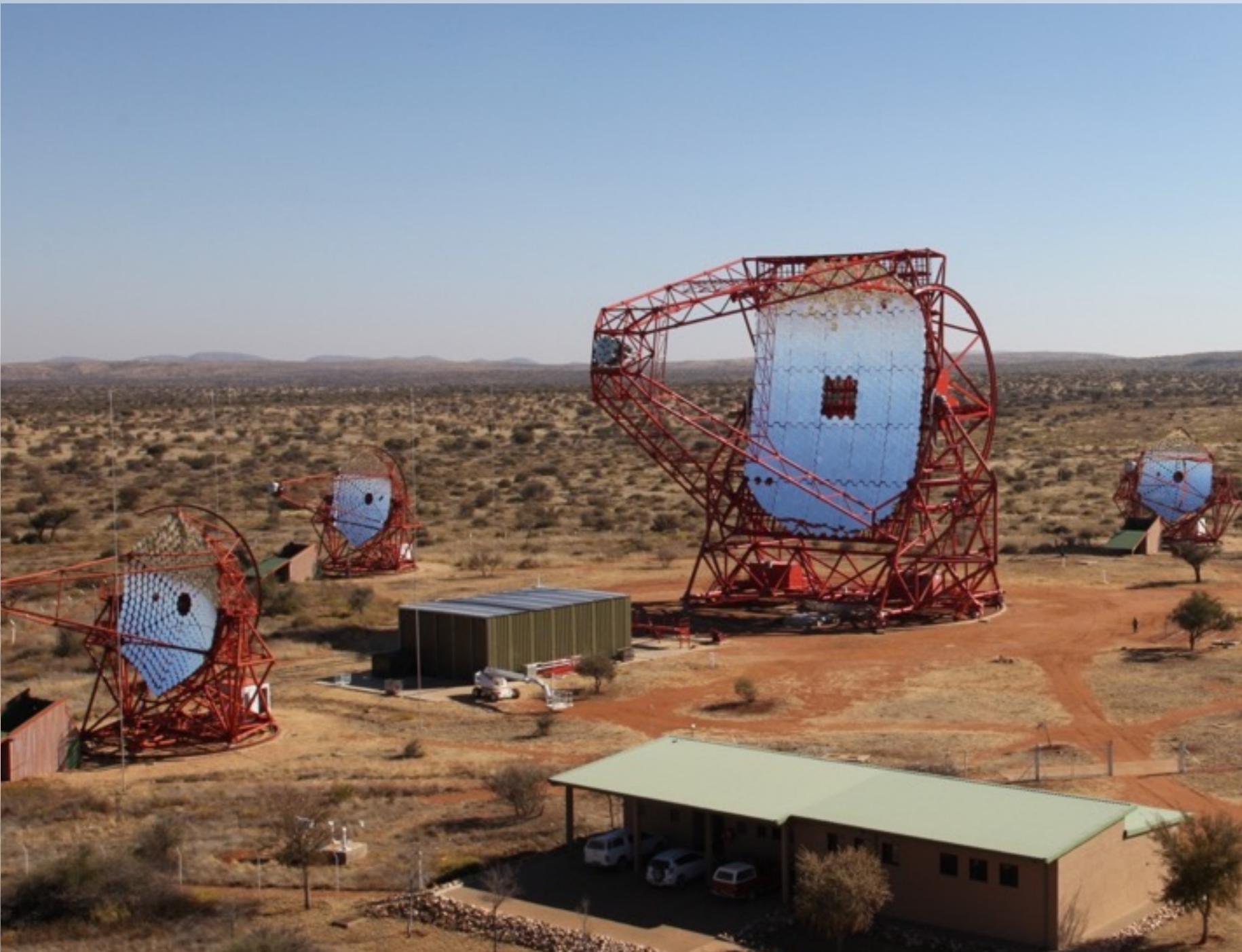
- Bright radio nearby SNe
- Very high Magnetic field 1G-100G (Fransson & Björnsson 1998 and Tatischeff 2009).
- Very high shock speed ($\sim 20\,000 \text{ km.s}^{-1}$)
- TeV Gamma ray emission should have been detected, on a timescale of weeks after the outburst (Tatischeff 2009, Markowitz et al 2018)

**Core-collapse Supernovae occurring
in a dense environment are possible
candidates for PeV cosmic-ray
acceleration.**



H.E.S.S.

High Energy Stereoscopic System



Khomas Highland Namibia
1800m

Operating since 2003 :
HESSI : 4 small telescope CT1-4
 $\varnothing 12\text{ m}, 107\text{ m}^2$

HESSII : 2012->CT5
 $\varnothing 28\text{ m}, 600\text{ m}^2$

Energy range 50 GeV–100 TeV
Angular resolution up to 0.05°
Field of view $5^\circ/3.2^\circ$

1000 h / year

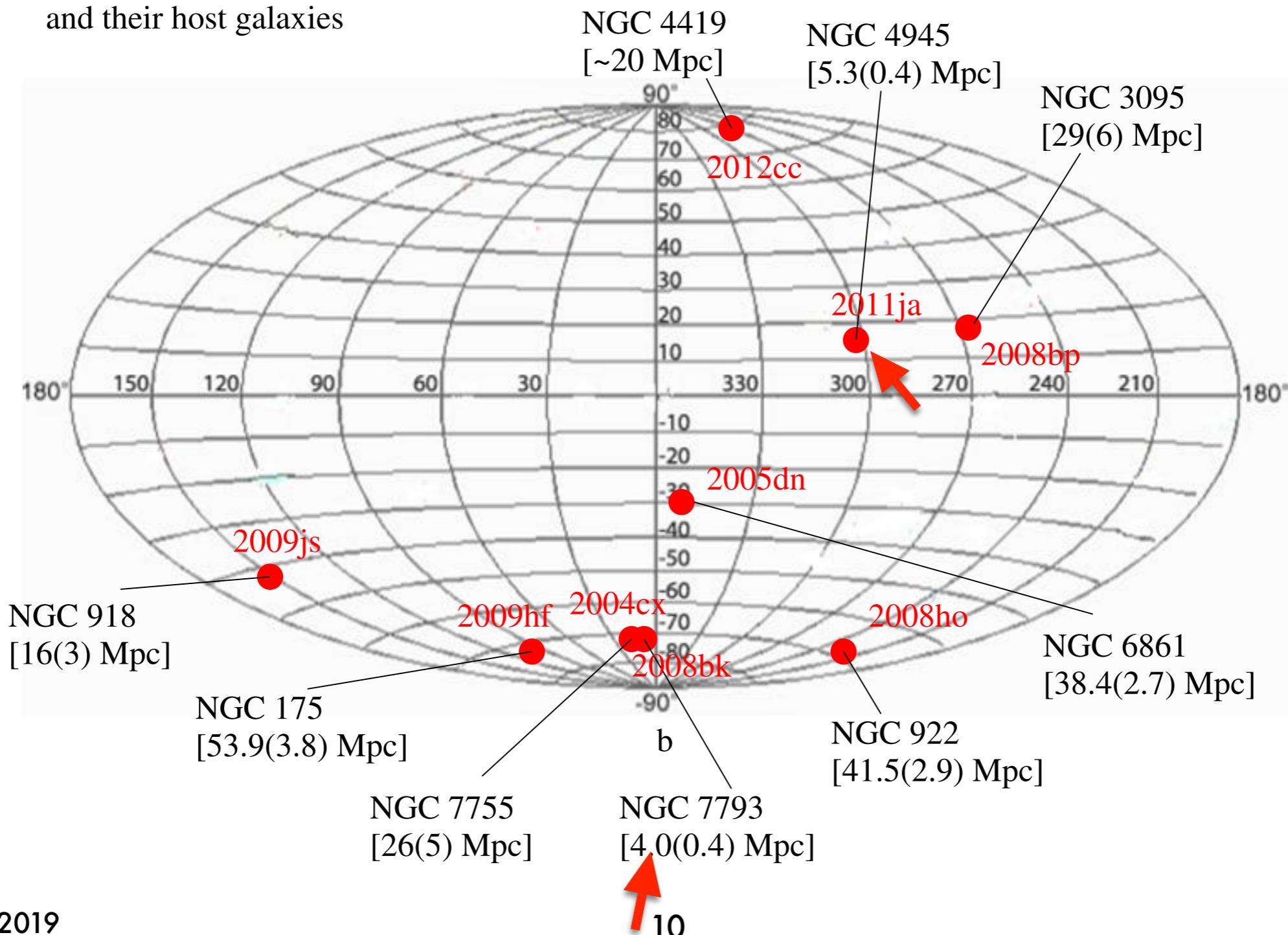
source catalogue of 83 sources

More information on <https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/sources/>

Candidate selection

9 SNe were observed "serendipitously"

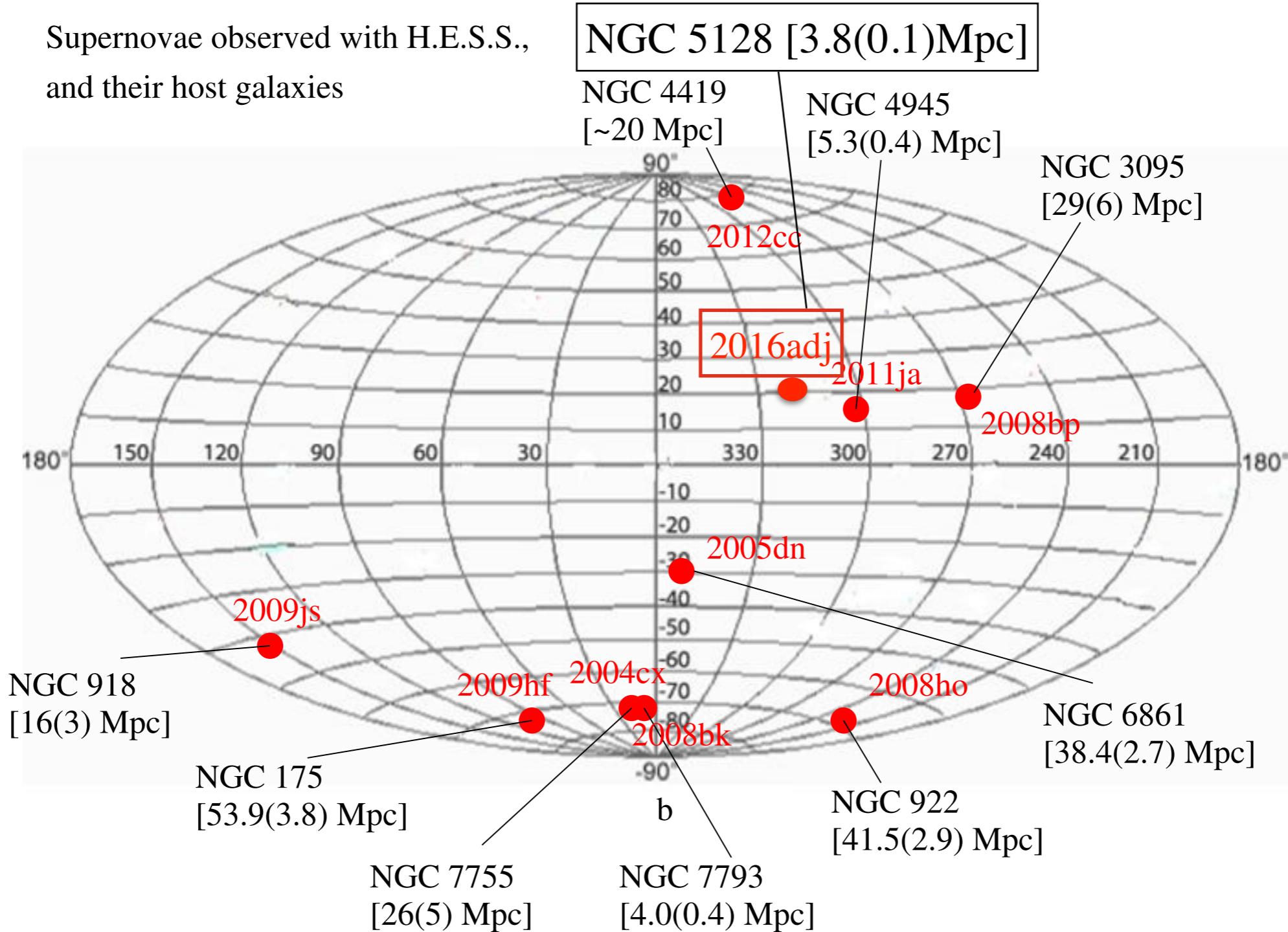
Supernovae observed with H.E.S.S.,
and their host galaxies



Candidate selection

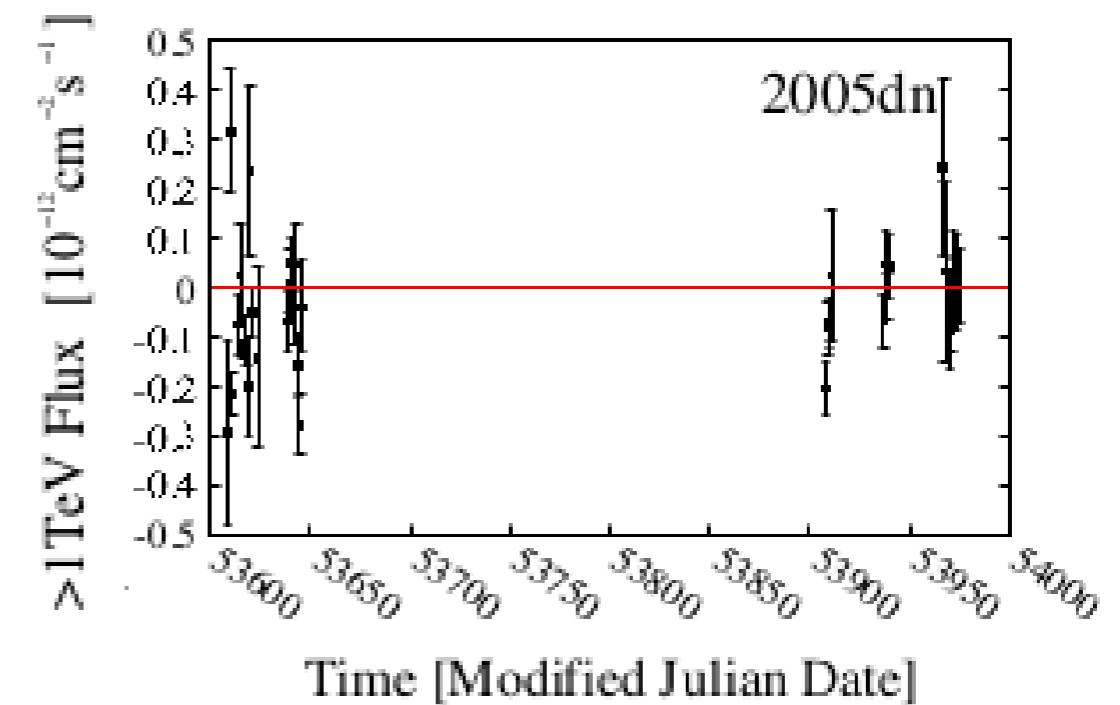
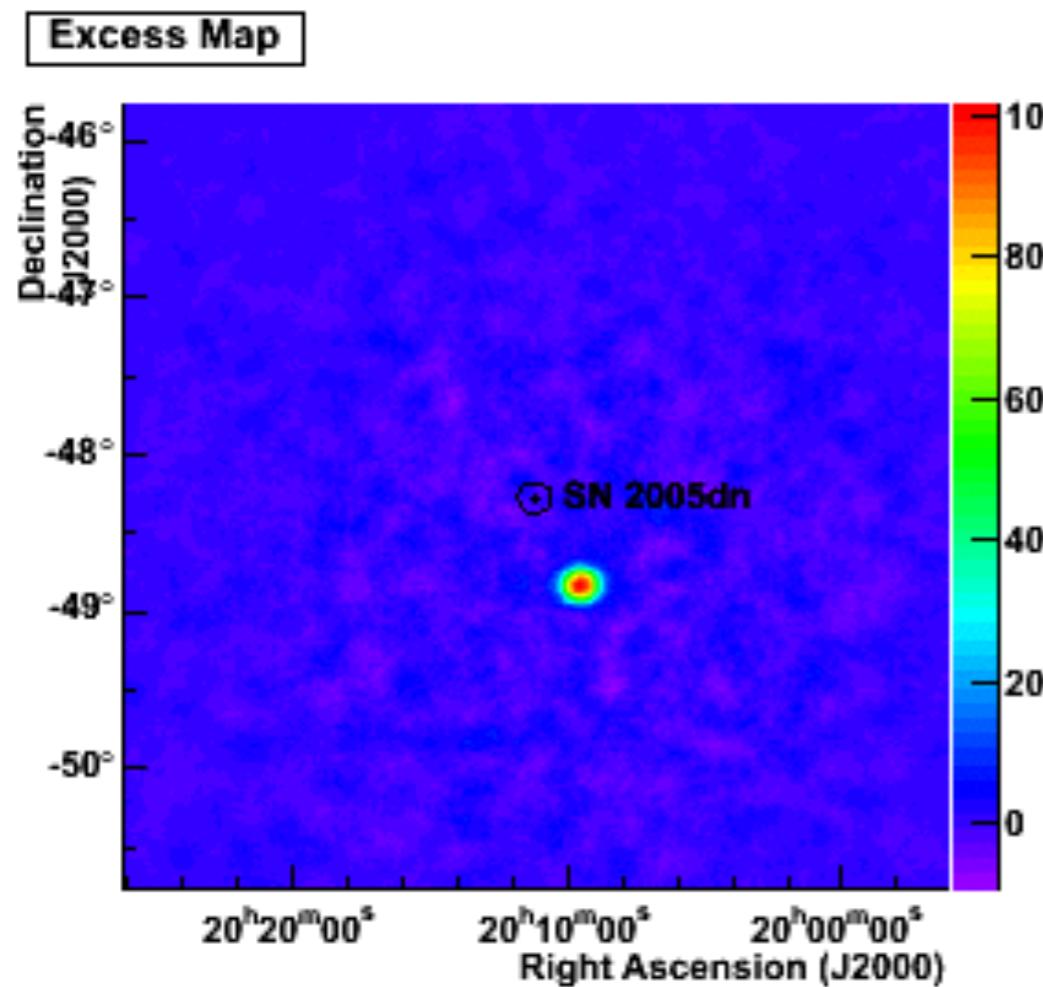
A final sample of 10 type II SNe was selected.

Supernovae observed with H.E.S.S.,
and their host galaxies



Results - Upper Limits

example SN 2005dn



Nightly Binned Lightcurve for SN 2005dn

$E_{\text{th}} = 0.21 \text{ TeV}$

Flux (95%CL) $< 2.2 \cdot 10^{-13} \text{ cm}^{-2} \text{s}^{-1}$

Luminosity $< 6.2 \times 10^{40} \text{ erg s}^{-1}$

Complete results : H.E.S.S. Collaboration, *Astronomy & Astrophysics* 626 (2019) A57

Results

What can we learn from this non detection?

Our main conclusion is that for selected objects the environment before outburst was not dense enough.

$$\underline{F_\gamma(> 1 \text{TeV})} = 5.14 \times 10^{-12}$$

$$\left[\frac{\dot{M}_{-5}}{u_{w,10}} \right]^2 \left(\frac{1}{t_{\text{days}}} \right) \left(\frac{1}{d_{\text{Mpc}}^2} \right).$$

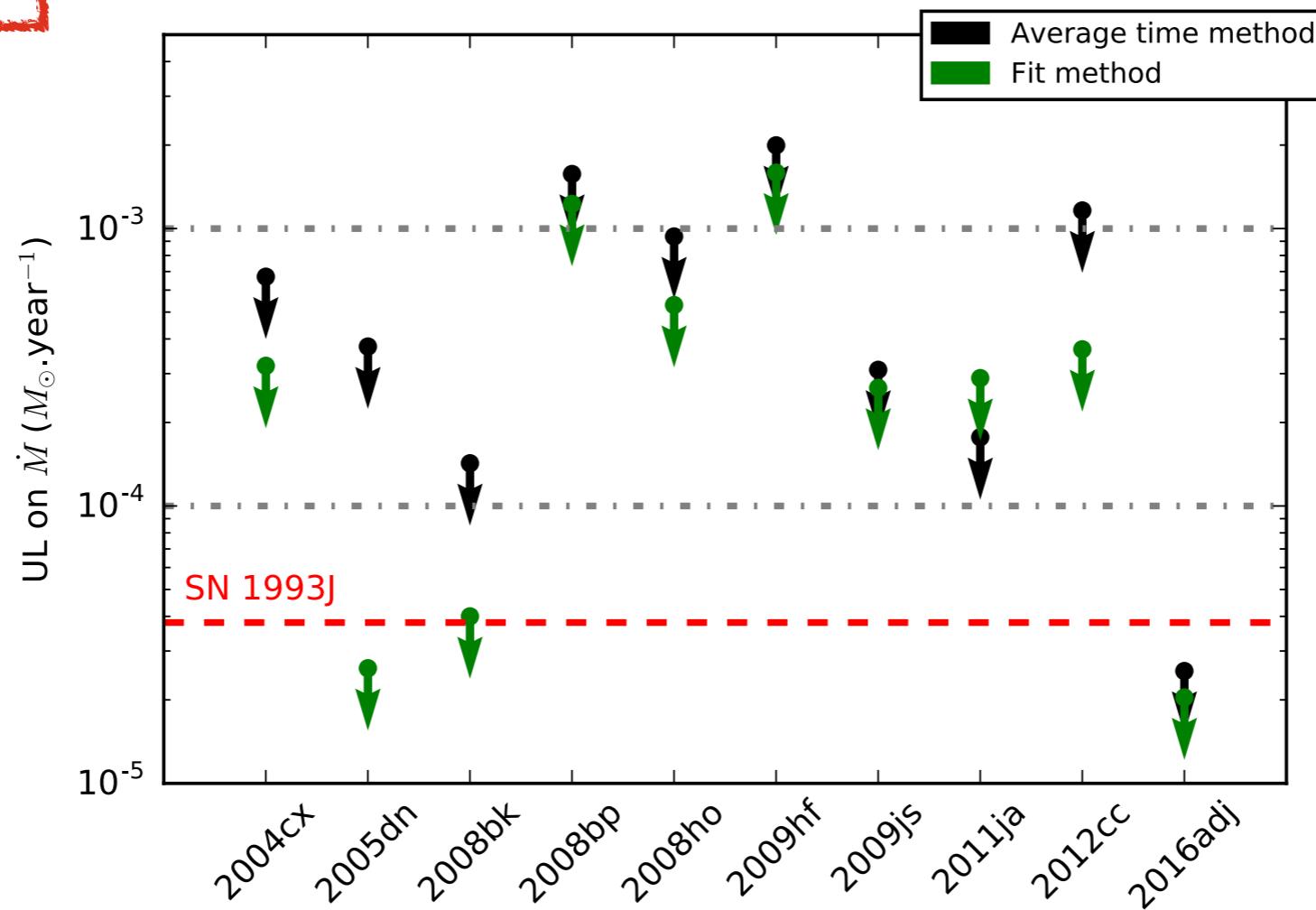
(Dwarkadas 2013)

$t > 5$ days

UL on the Mass Loss Rate

$$v_{sh} = 10\,000 \text{ km.s}^{-1}$$

$$u_w = 10 \text{ km.s}^{-1}$$

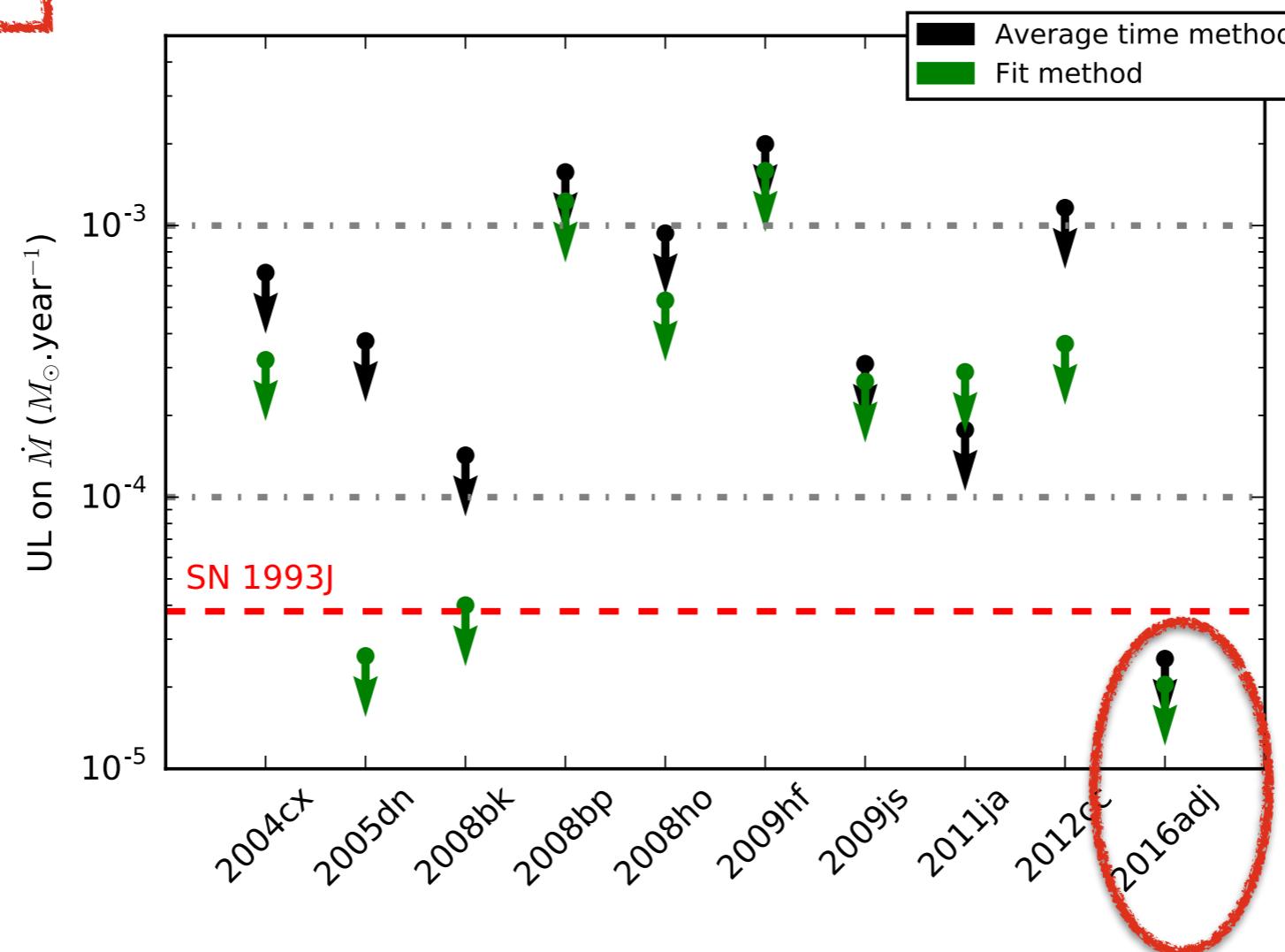


Upper Limits on \dot{M} considering $u_w = 10 \text{ km.s}^{-1}$
and comparison to the mass loss rate estimation for SN 1993J derived by Tatischeff 2009

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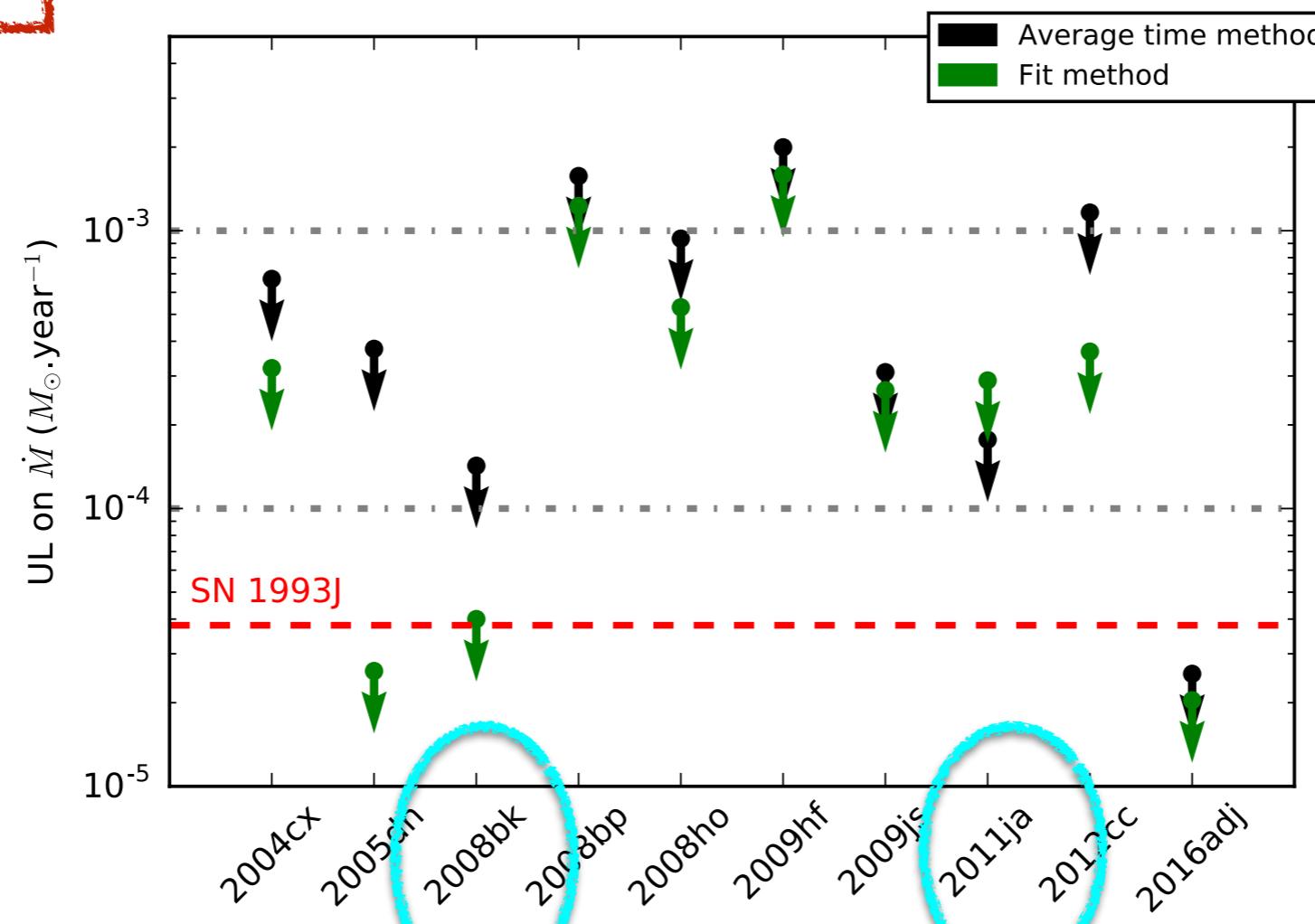
First constraining value on SN 2016adj progenitor mass loss rate

Upper Limits on \dot{M} considering $u_w = 10 \text{ km.s}^{-1}$
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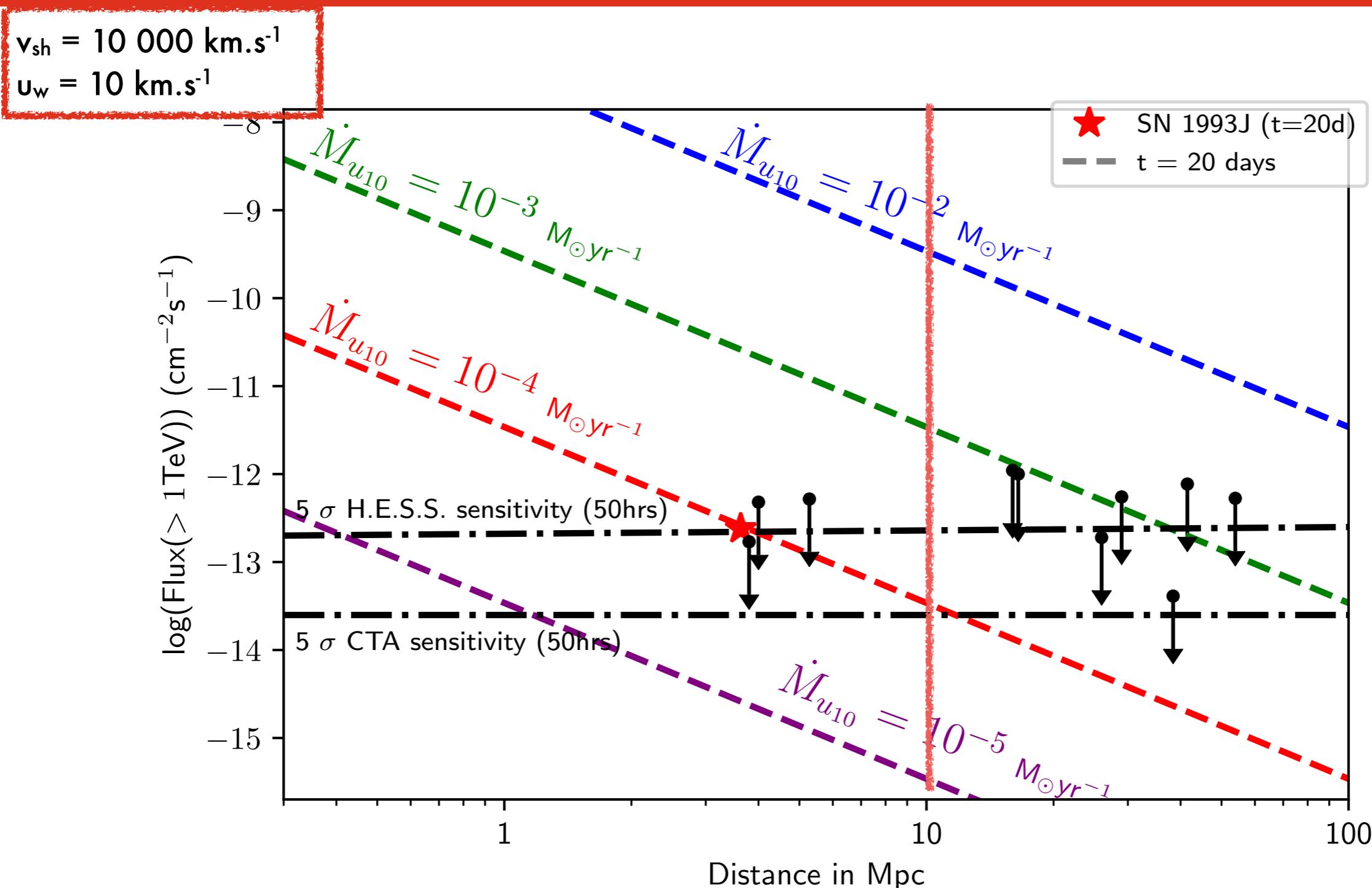
previous studies

SN 2008bk
 $\sim 10^{-6.3}$ Solar Mass/yr
 (Davies & Beasor 2018)

SN 2011ja
 $\sim 10^{-6}$ Solar Mass/yr
 (Chakraborti et al. (2013))

Upper Limits on \dot{M} considering $u_w = 10 \text{ km.s}^{-1}$
 and comparison to the mass loss rate estimation for SN 1993J derived by Tatischeff 2009

Expected Flux vs Distance



Predicted Flux(> 1 TeV) using the model, represented as a function of the distance to the source.

Conclusion

- Upper limits: provides strong constraints on progenitor's mass loss rates.
- 1st constraint for SN 2016adj: consistent with radio observations (in preparation).
- Good prospects for detections by CTA.
- Now regular trigger for nearby SNe in place for H.E.S.S.

**Core-collapse Supernovae occurring
in a dense environment are possible
candidates for PeV cosmic-ray
acceleration.**

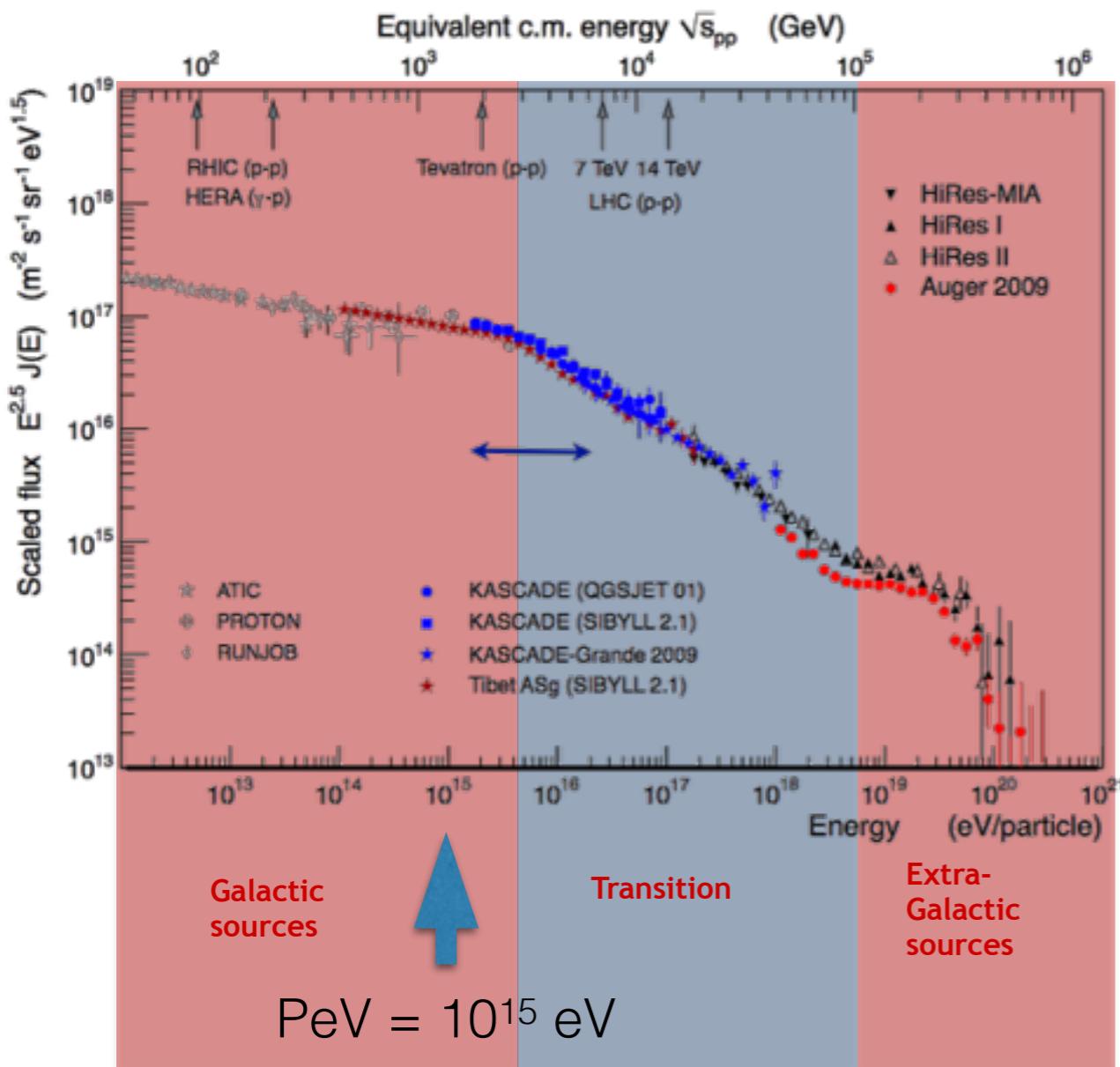
July 2019 H.E.S.S. Source of the Month
<https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2019/07/>

Paper : H.E.S.S. Collaboration, *Astronomy & Astrophysics* 626 (2019) A57

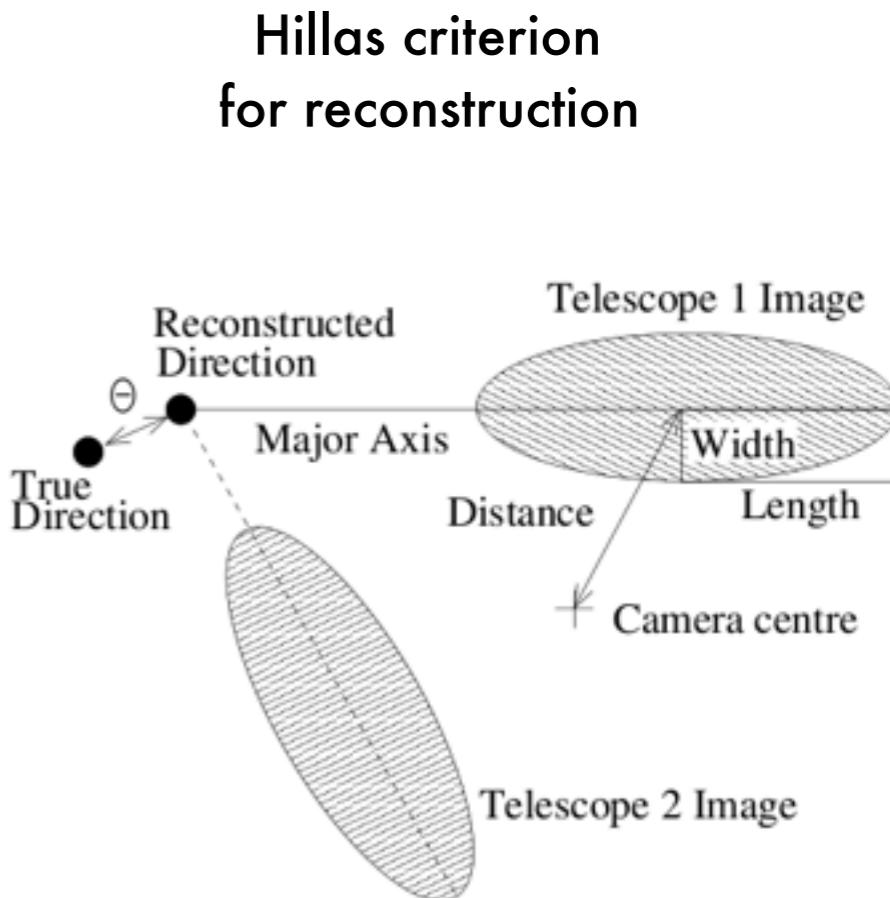
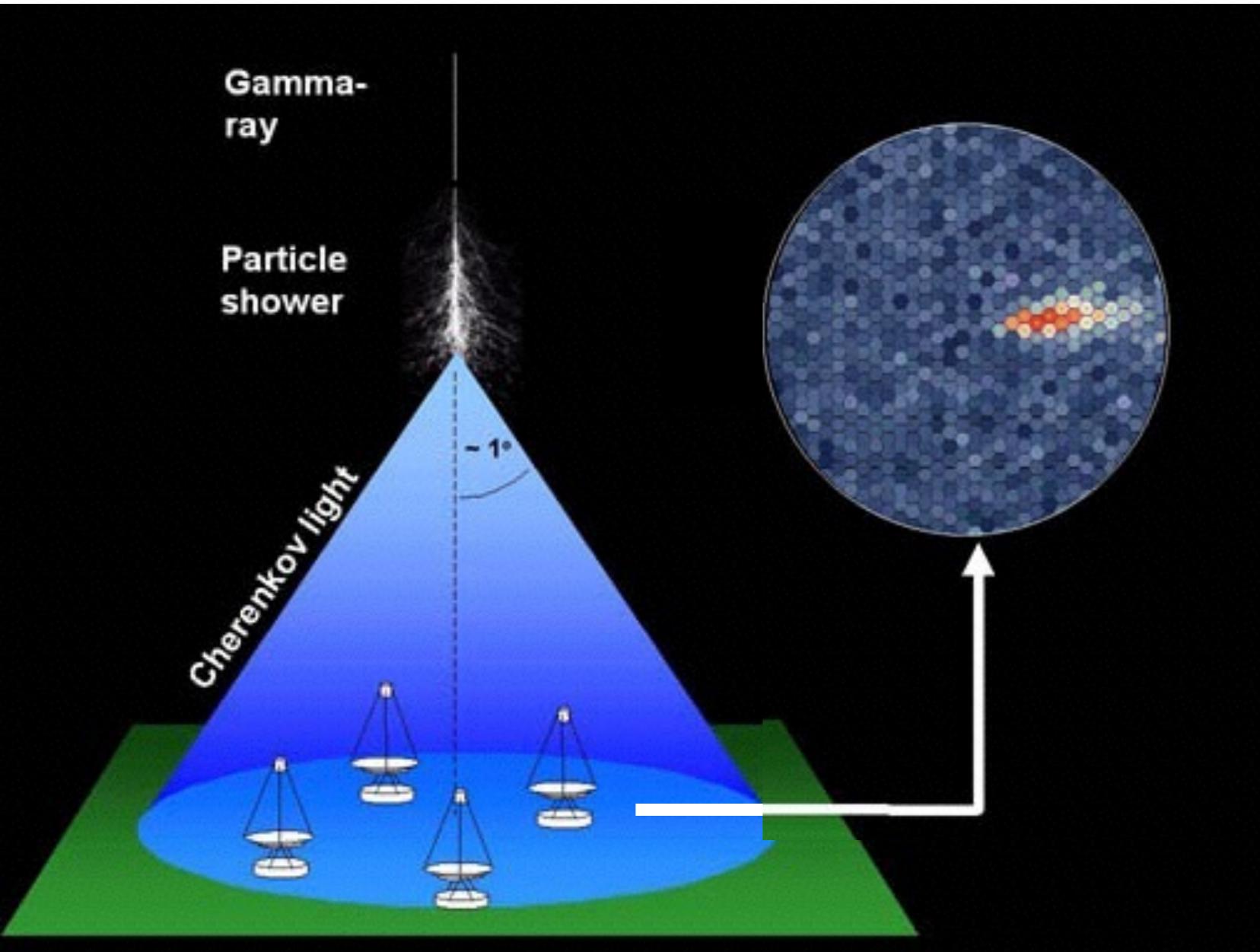
Back up

Cosmic ray sources

Cosmic Ray Spectrum



Imaging Air shower Cherenkov Telescope



Now the analysis chains are using 2D ellipse LLH fitting method

Candidate selection

All SNe CBAT catalogue (~3600 SNe) were compared to NED catalogue to select only nearby host galaxies ($z < 0.01$).

Then 10 years of HESS data were compared to select candidates observed 1 week before or within the year after the SNe explosion.

A final sample of 9 type II SNe was selected.

SN Name	Host galaxy	RA [J2000]	DEC [J2000]	Dist. [Mpc]	Type	Disc. date
SN 2004cx	NGC 7755	23h47m52.86s	$-30^{\circ}31'32.6''$	26 ± 5	II	2004-06-26
SN 2005dn	NGC 6861	20h11m11.73s	$-48^{\circ}16'35.5''$	38.4 ± 2.7	II	2005-08-27
SN 2008bk	NGC 7793	23h57m50.42s	$-32^{\circ}33'21.5''$	4.0 ± 0.4	IIP	2008-03-25
SN 2008bp	NGC 3095	10h00m01.57s	$-31^{\circ}33'21.8''$	29 ± 6	IIP	2008-04-02
SN 2008ho	NGC 922	02h25m04.00s	$-24^{\circ}48'02.4''$	41.5 ± 2.9	IIP	2008-11-26
SN 2009hf	NGC 175	00h37m21.79s	$-19^{\circ}56'42.2''$	53.9 ± 3.8	IIP	2009-07-09
SN 2009js	NGC 918	02h25m48.28s	$+18^{\circ}29'25.8''$	16 ± 3	IIP	2009-10-11
SN 2011ja	NGC 4945	13h05m11.12s	$-49^{\circ}31'27.0''$	5.28 ± 0.38	IIP	2011-12-18
SN 2012cc	NGC 4419	12h26m56.81s	$+15^{\circ}02'45.5''$	16.5 ± 1.1	II	2012-04-29
SN 2016adj	NGC 5128	13h25m24.11s	$-43^{\circ}00'57.5''$	3.8 ± 0.1	IIb	2016-02-08

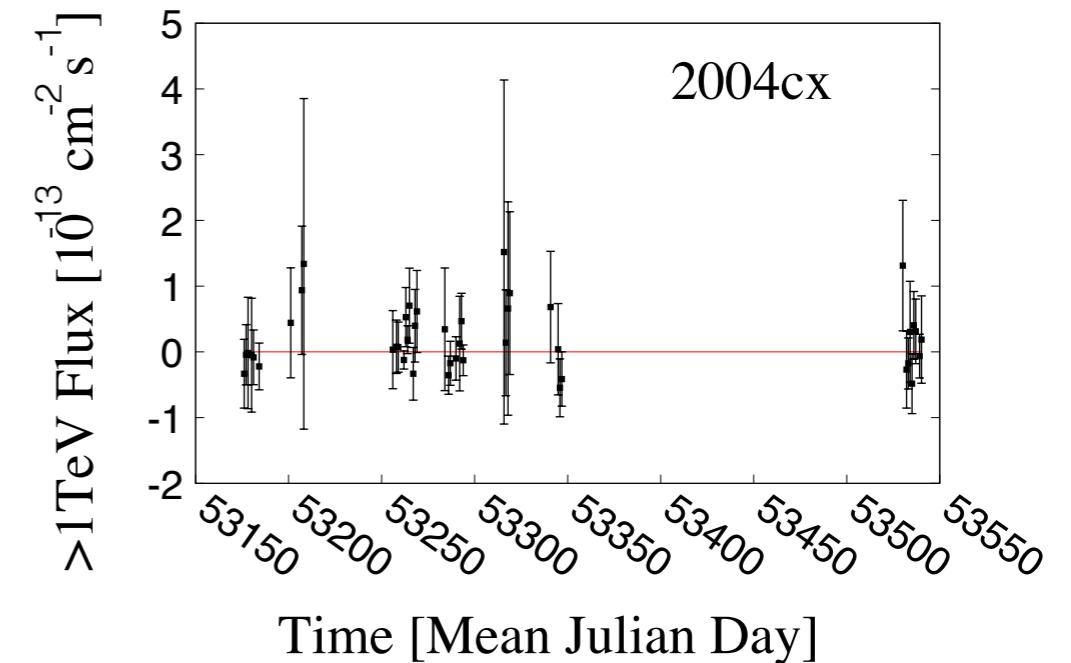
SN positions tested for HESS gamma-ray excess emission.

Results - No detection

Upper Limits on the Flux

Supernovae	Upper Limit (95%) Flux > 1 TeV (10^{-13} phot.cm $^{-2}$ s $^{-1}$)
SN2004cx	1.9
SN2005dn	0.41
SN2008bk	4.8
SN2008ho	7.7
SN2008bp	5.5
SN2009js	11
SN2009hf	5.3
SN2011ja	5.2
SN2012cc	10
SN2016adj	1.7

H.E.S.S. Collaboration, Astronomy & Astrophysics 626 (2019) A57



Nightly Binned Lightcurve for SN 2004cx

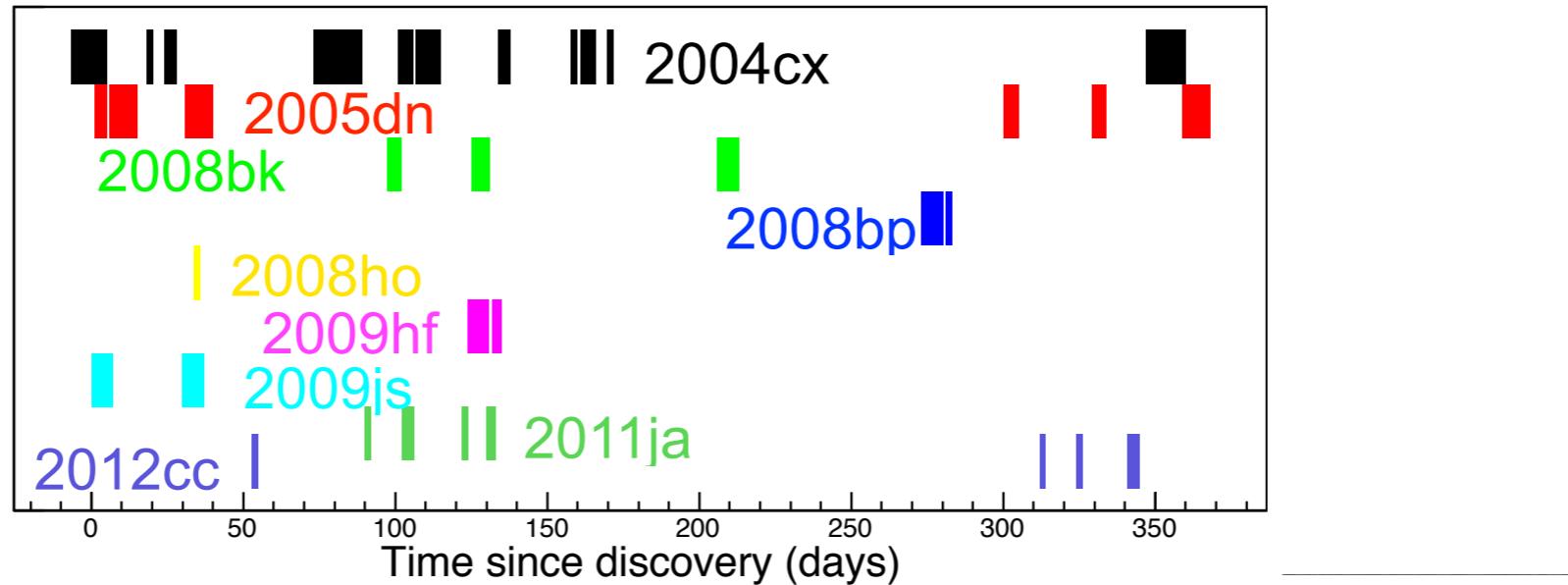
Luminosity range $\sim 2 \times 10^{39}$ erg s $^{-1}$ to $\sim 1 \times 10^{42}$ erg s $^{-1}$

Fluence within 1 year

Corresponding to ~ 0.06 - 3 % of the canonical energy of 10^{51} erg.s $^{-1}$

Data-set

Fig.2 : Data-set for each SNe spread over one year after discovery

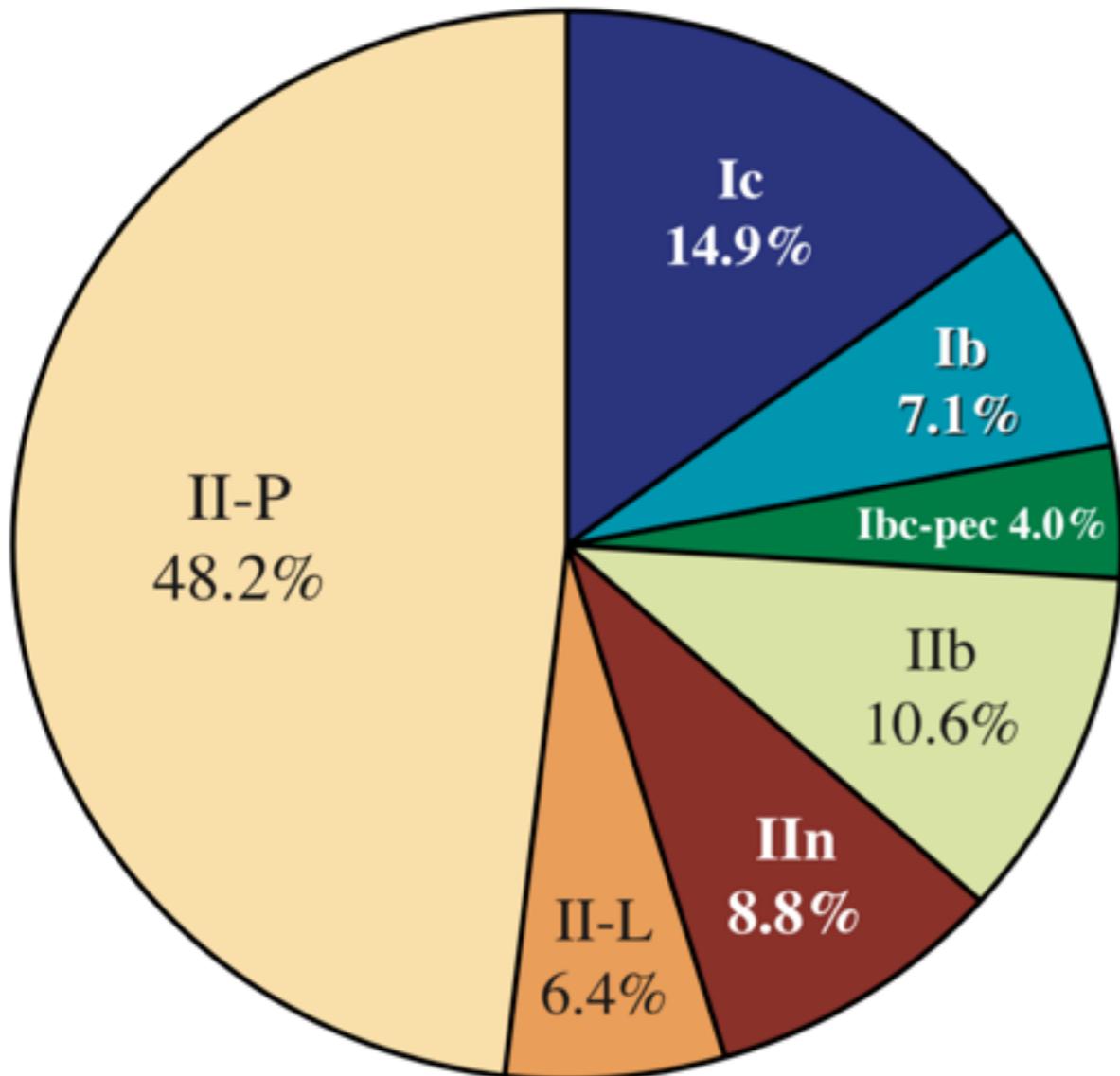


main analysis M++ std cuts
crosschecked with ImPACT_std

Statistic for the sample

SNe	N _{on}	N _{off}	α	N _{excess}	Sig	Livetime (hrs)	Obs. coverage (days)	Average time (days)
SN 2004cx	169	10387	0.015	8.7	0.7	40	-6 - 359	180
SN 2005dn	571	11452	0.053	-39	-1.5	53	-3 - 364	120
SN 2008bk	50	3652	0.018	-18	-2.3	9.6	98 - 211	136
SN 2008bp	32	1860	0.017	1.1	0.2	4.7	272 - 282	282
SN 2008ho	9	369	0.030	-2.3	-0.7	1.4	34 - 34	34
SN 2009hf	43	1404	0.029	3.3	0.5	4.0	124 - 134	133
SN 2009js	14	711	0.015	3.4	1	4.8	1 - 35	17.5
SN 2011ja	37	620	0.053	4.51	0.75	3.4	91 - 131	111
SN 2012cc	7	660	0.013	-1.9	-0.7	3.0	53 - 343	255
SN 2016adj	624	8573	0.070	22	0.9	13	3 - 10	7

cc SNe Rate



Core-Collapse SN fractions

Smith and al. 2011

60 Mpc/80 CCSNe

Table 1. Volume-limited core-collapse SN fractions.

SN type	Fraction (per cent)	Error (per cent)
Ic	14.9	+4.2/-3.8
Ib	7.1	+3.1/-2.6
Ibc-pec	4.0	+2.0/-2.4
IIb	10.6	+3.6/-3.1
IIn	8.8	+3.3/-2.9
II-L	6.4	+2.9/-2.5
II-P	48.2	+5.7/-5.6
Ibc (all)	26.0	+5.1/-4.8
Ibc+IIb	36.5	+5.5/-5.4

Gamma-Gamma attenuation

Interaction of gamma-ray photons with the low energy photon of the shock photosphere.

Complete modelling doesn't exist yet. Also very dependant of the photospheric condition of each object.

Modelling for the case of SN 1993J in Marcowith , Renaud et al. (2014)

At TeV energies, absorption can be important but only a very short time after outburst (~5 days). The final gamma-ray flux is hence the unabsorbed flux $F_{\gamma,un}$ times an attenuation factor $\exp(-\tau_{\gamma\gamma}(E_\gamma))$ in the anisotropic scenario.

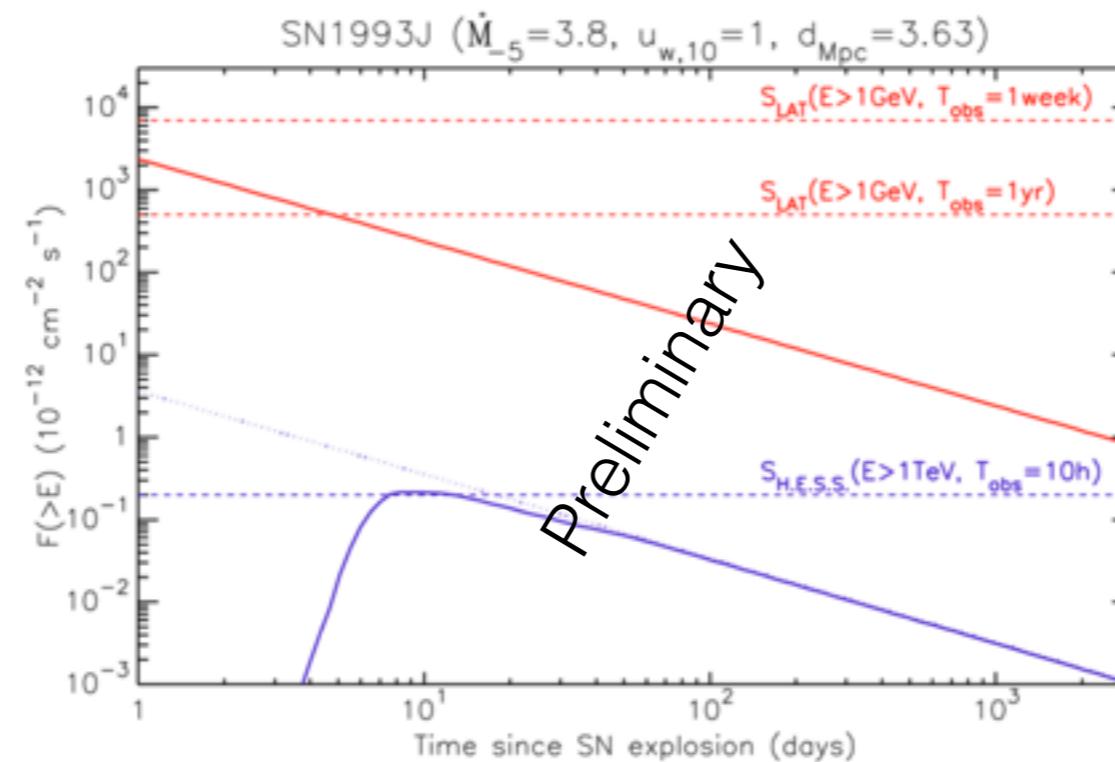


Figure 1: Time evolution of the expected gamma-ray flux above 1 GeV (red) and above 1 TeV (blue) from SN 1993J [5, 18]. The dotted blue line gives the unabsorbed flux above 1 TeV (see text), while the horizontal dashed lines show the 5 σ point-source sensitivities of Fermi-LAT and H.E.S.S.-I.

Discussion - choice of parameters

m = expansion parameter

$$(0.7 < m < 0.9) \quad m = 0.85$$

β = Fraction of the shocked volume which produces gamma emmission

$$\beta = 0.5$$

$$\left[\frac{\dot{M}}{u_w} \right]^2 \leq F_\gamma (> 1TeV) \frac{32\pi^2(3m-2)\beta\mu m_p d^2}{3q_\alpha \xi v_{sh} m^2 t}$$

G-ray emissivity

(normalized to the CR energy density...)

$$q_\alpha (> 1 \text{ TeV}) = 1.02 \times 10^{-17} \text{ s}^{-1} \text{ erg}^{-1} \text{ cm}^{-3} (\text{H-atom})^{-1}$$

(Drury Aharonian Voelk 1994)

Shock velocity

$$V_{sh} = 10\,000 \text{ km.s}^{-1}$$

Efficiency of the CR acceleration

$$\xi = 0.1$$