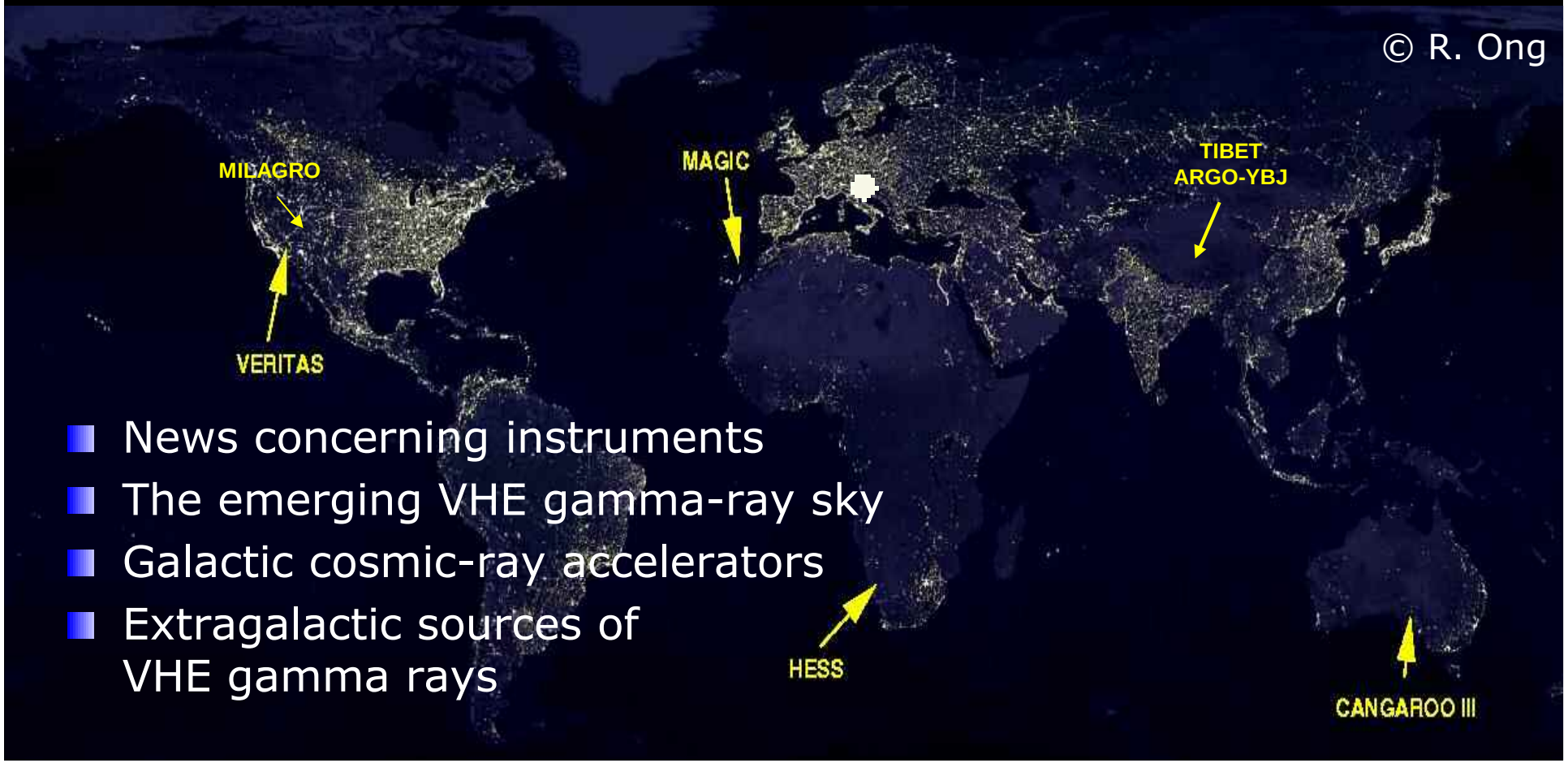
Latest results from ground based gamma-ray telescopes

W. Hofmann, MPI Heidelberg

TeVPA 2007, Venice



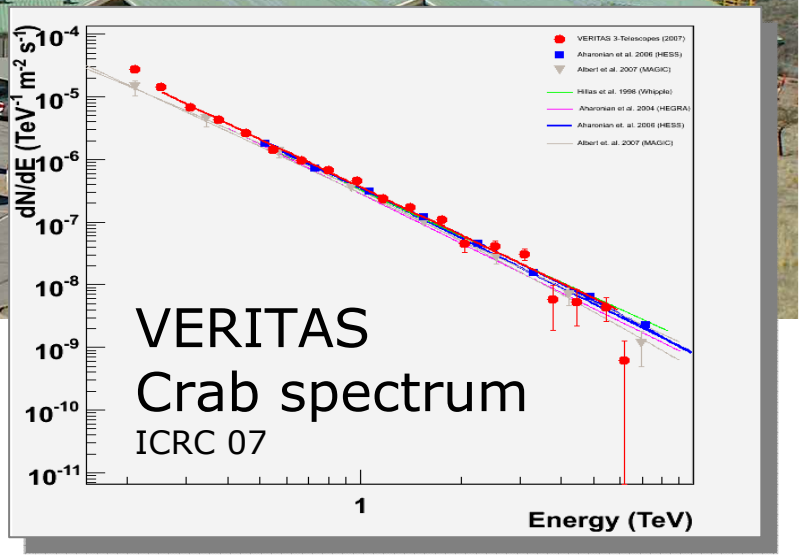
- News concerning instruments
- The emerging VHE gamma-ray sky
- Galactic cosmic-ray accelerators
- Extragalactic sources of VHE gamma rays

VERITAS operational

▶ T. Ergin

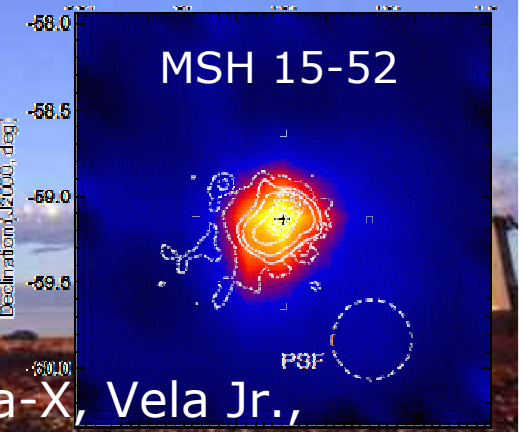
Sensitivity

1% Crab in 50 h



News:

Problems in CANGAROO I, II analyses mostly sorted out
CANGAROO III results consistent with H.E.S.S.



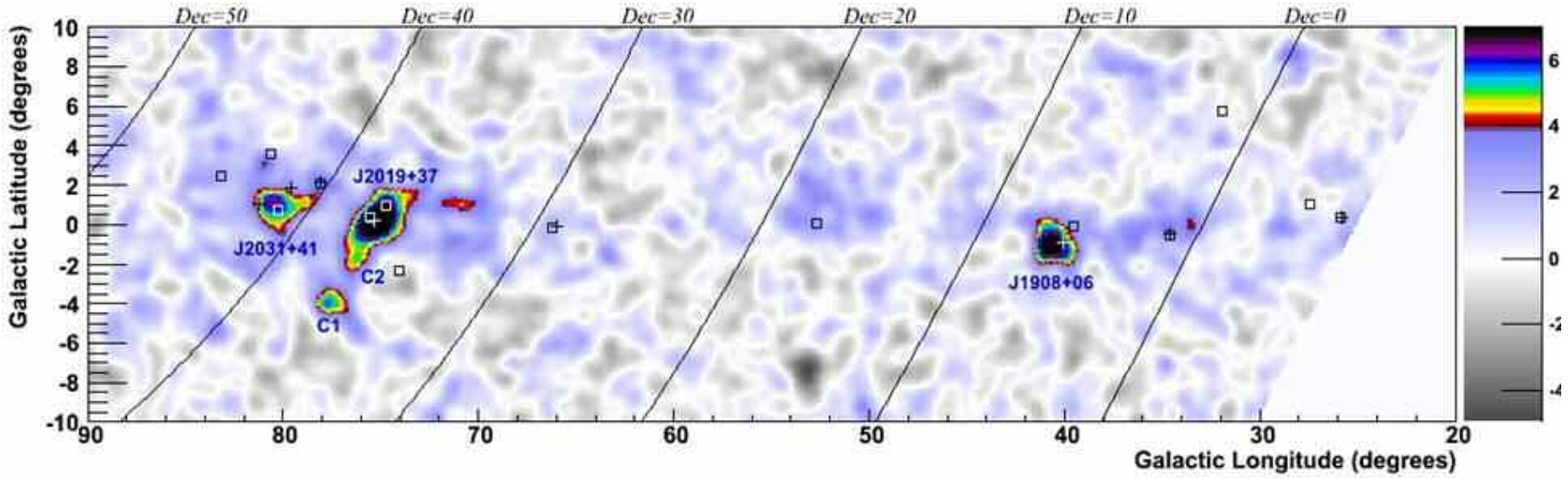
CANGAROO revived ▶ T. Nakamori

Detections: MSH 15-52, Vela-X, Vela Jr., PKS 2155, HESS J1303-631, HESS J1804-216,....

MILAGRO: new analysis

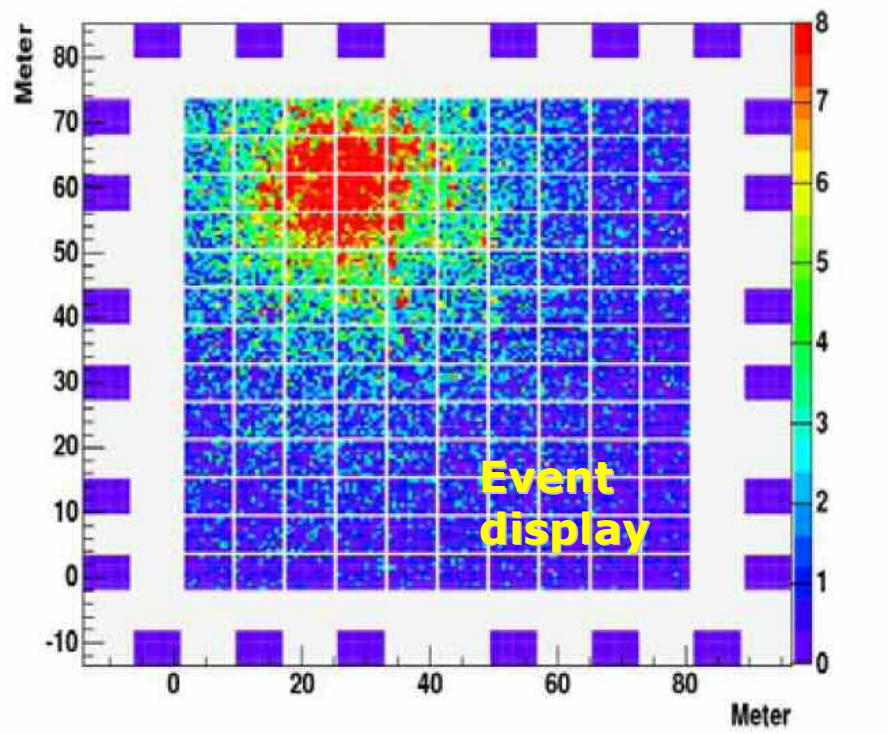
- **J. Goodman**
- **L. Dury**

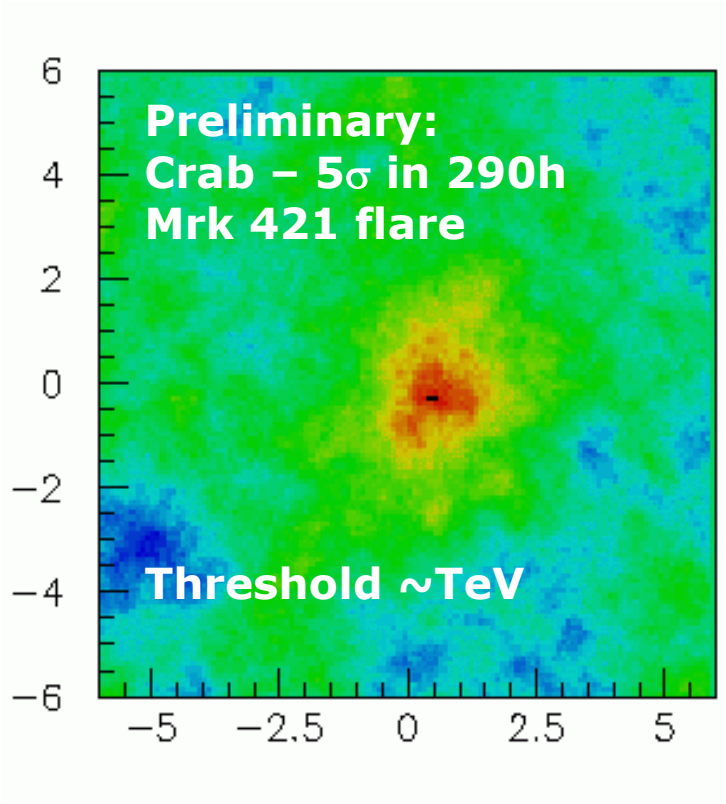
Crab:
15σ in 6 years
(3 years with outriggers)
Median energy ~20 TeV

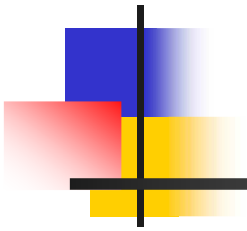


ARGO-YBJ: operational

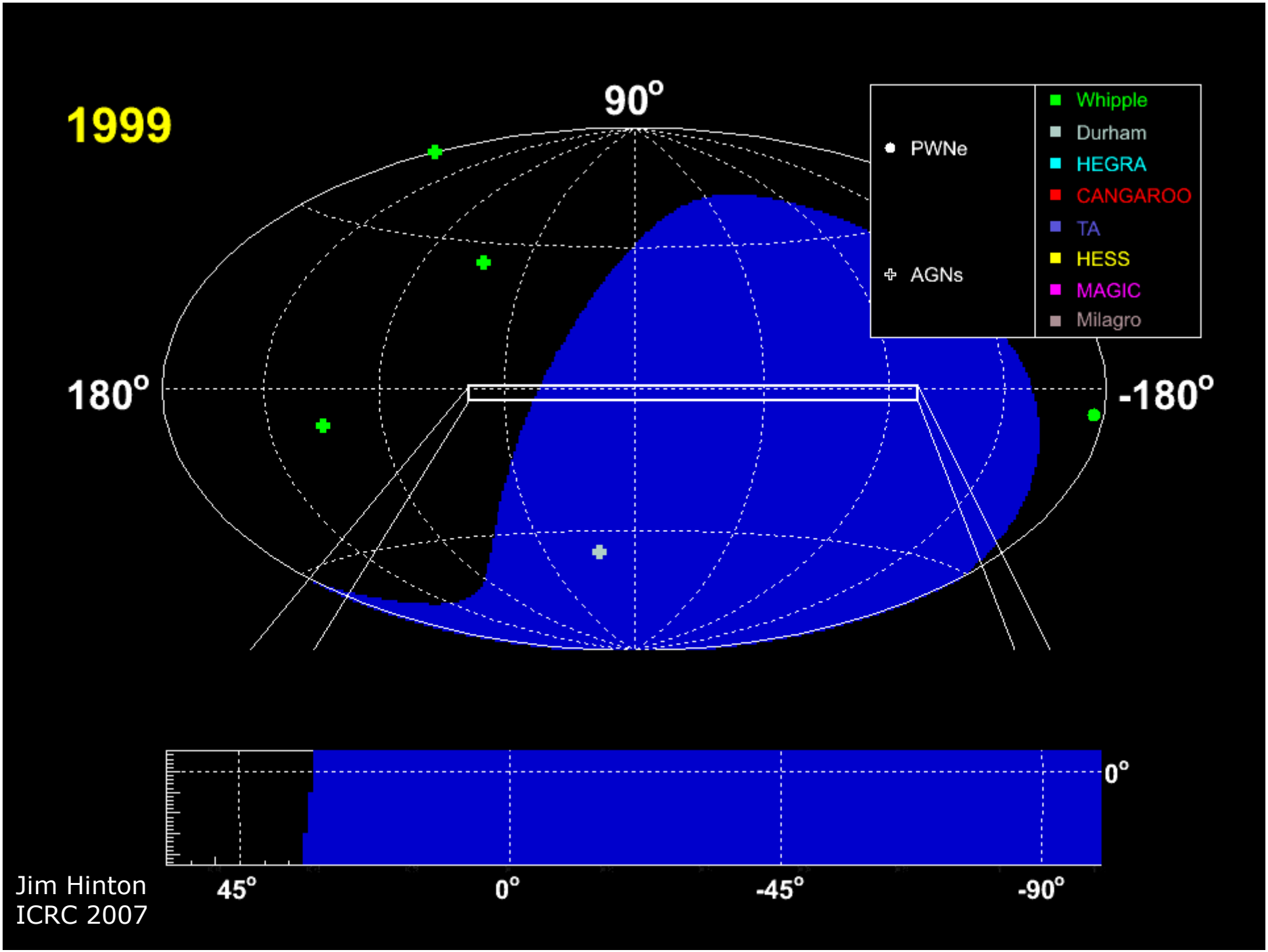
▶ I. DeMitri

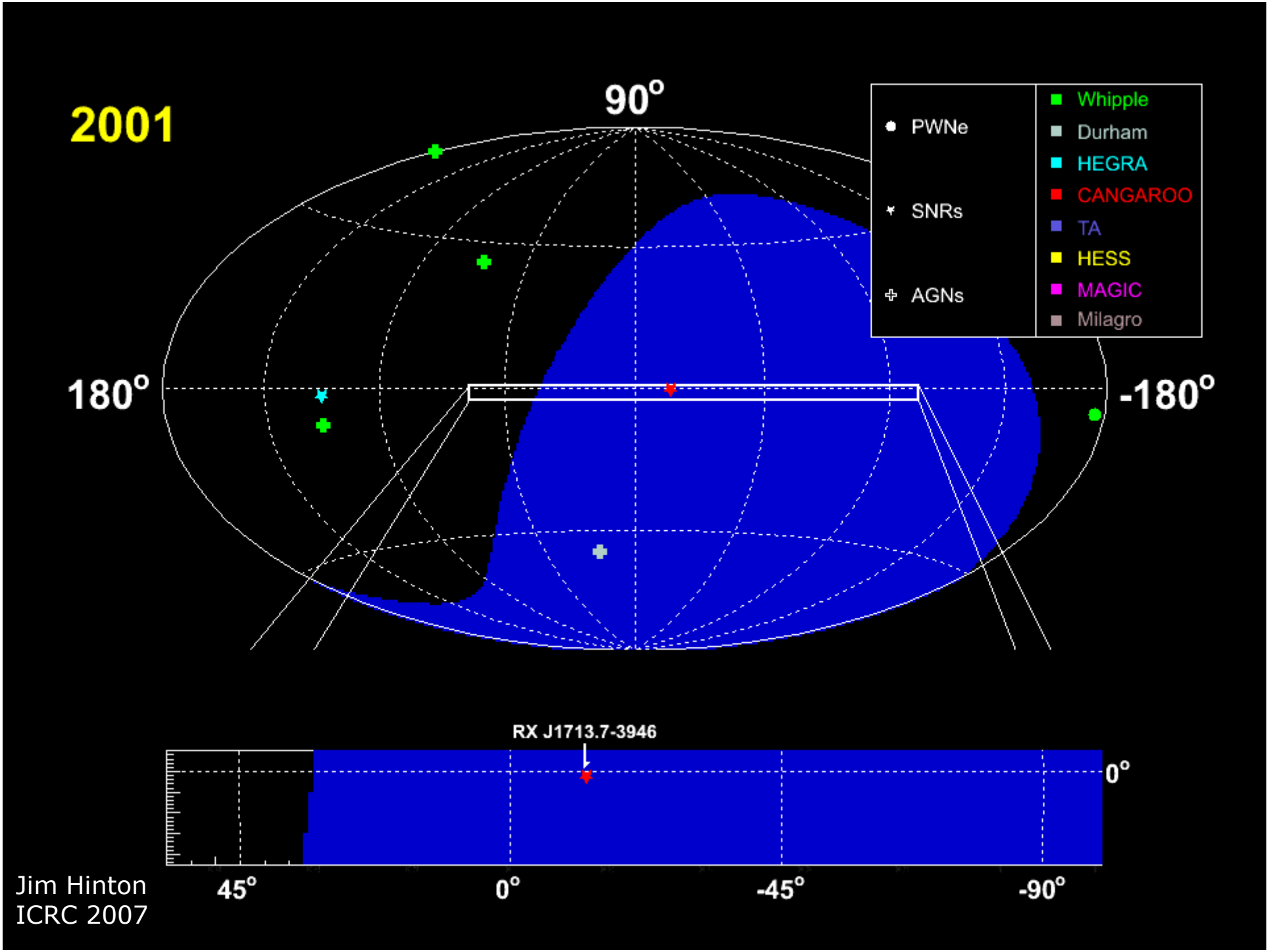


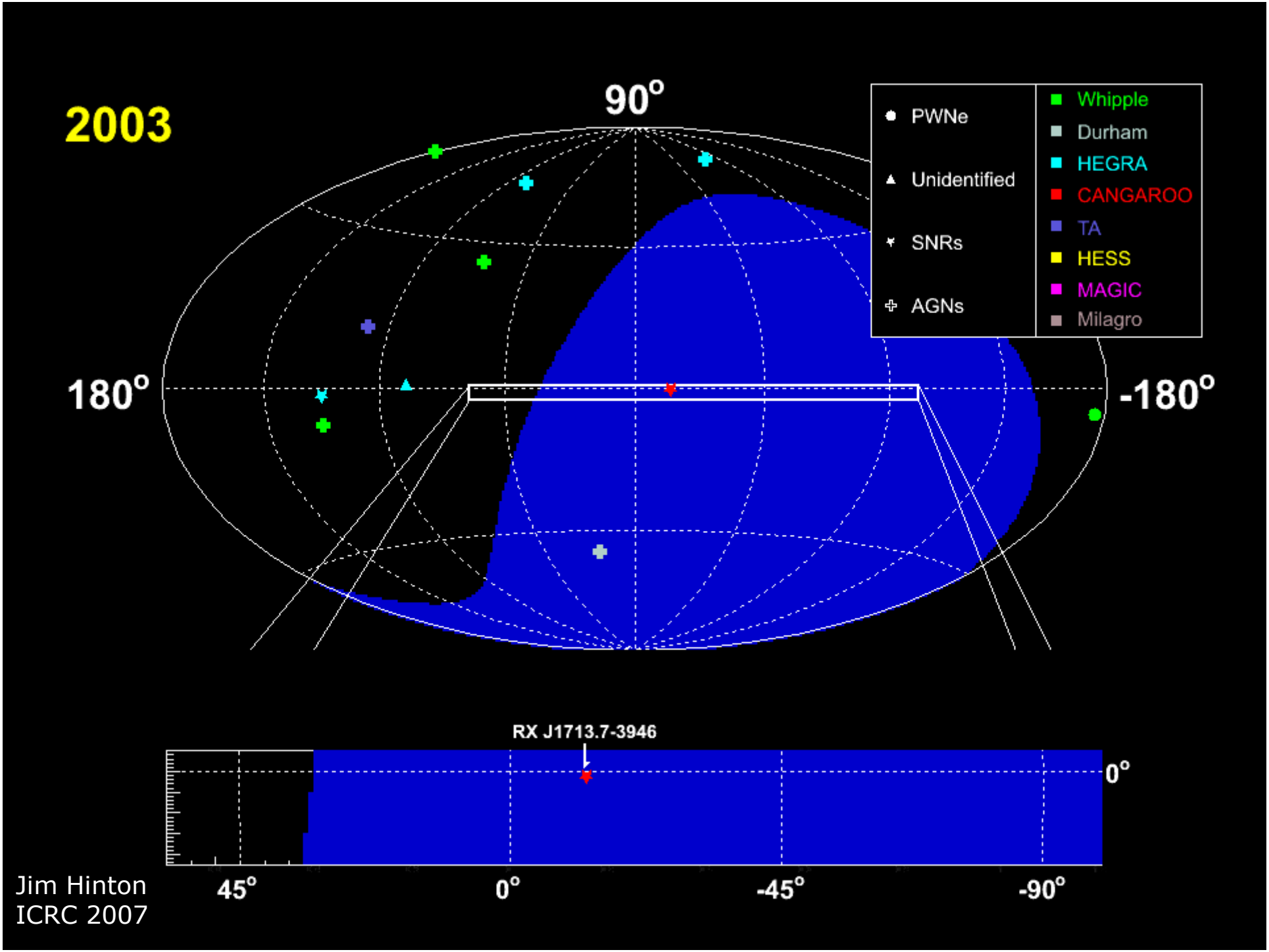


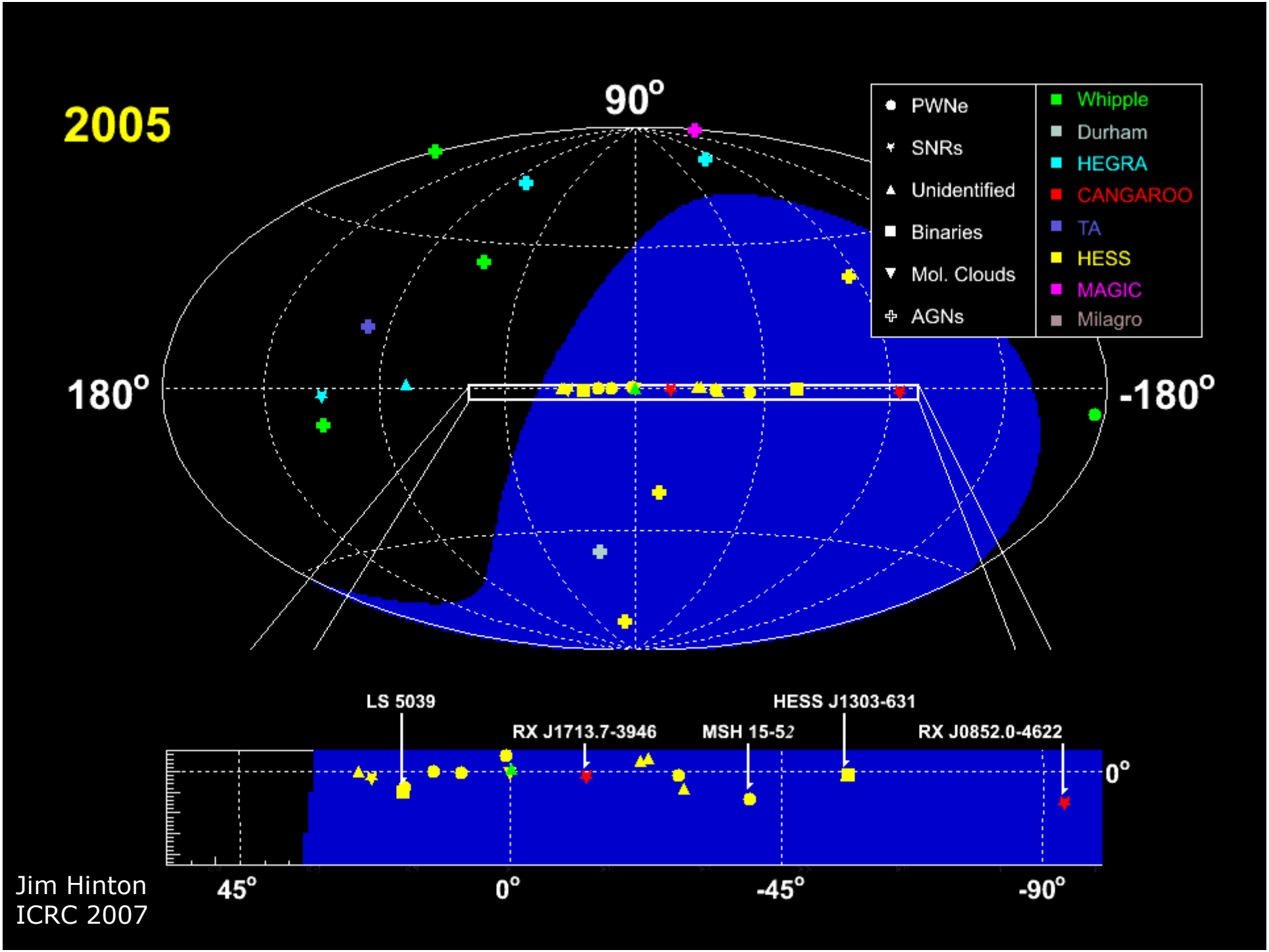


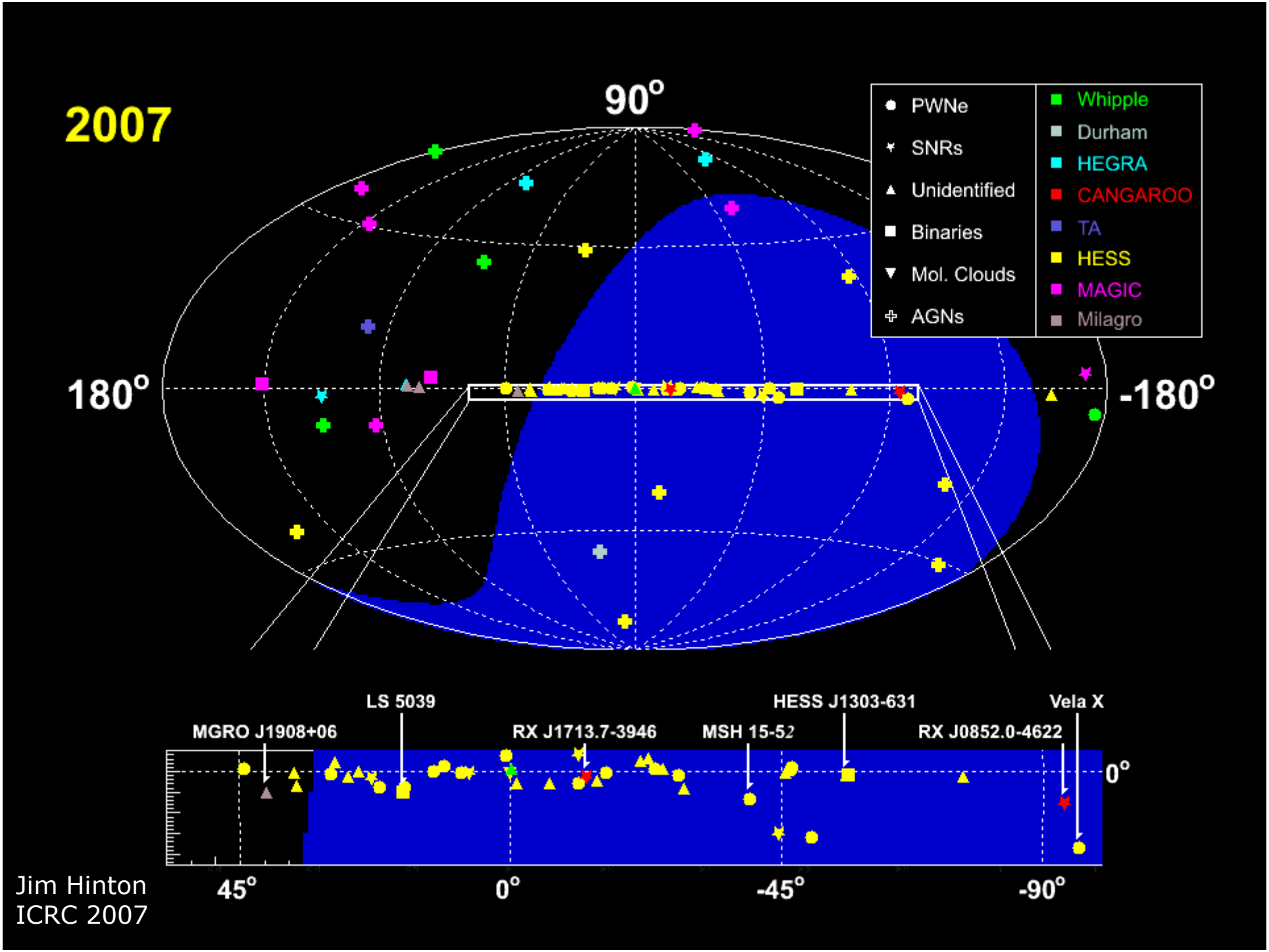
The emerging VHE gamma-ray sky

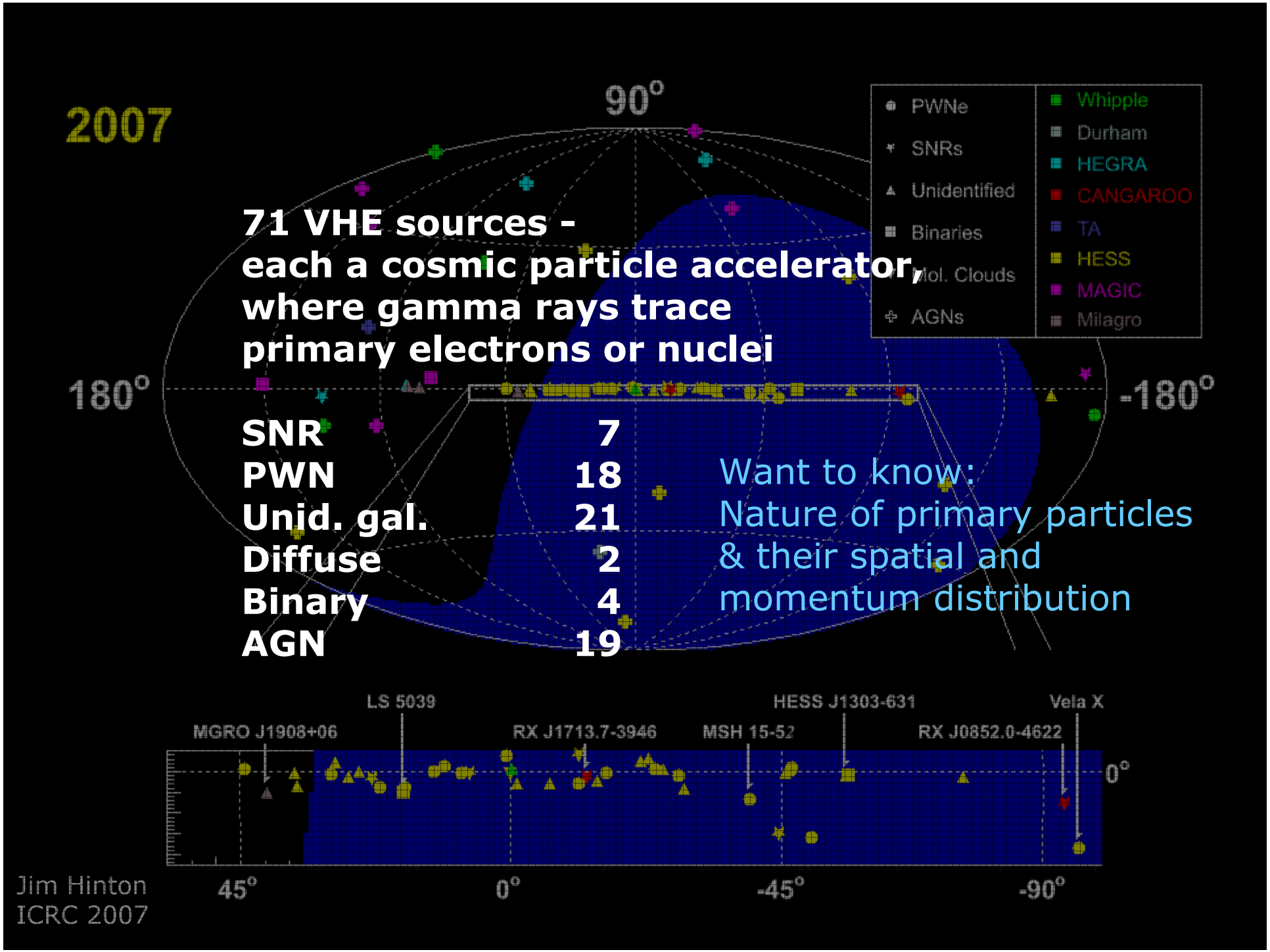

1999
90°
180°
-180°
PWNe
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

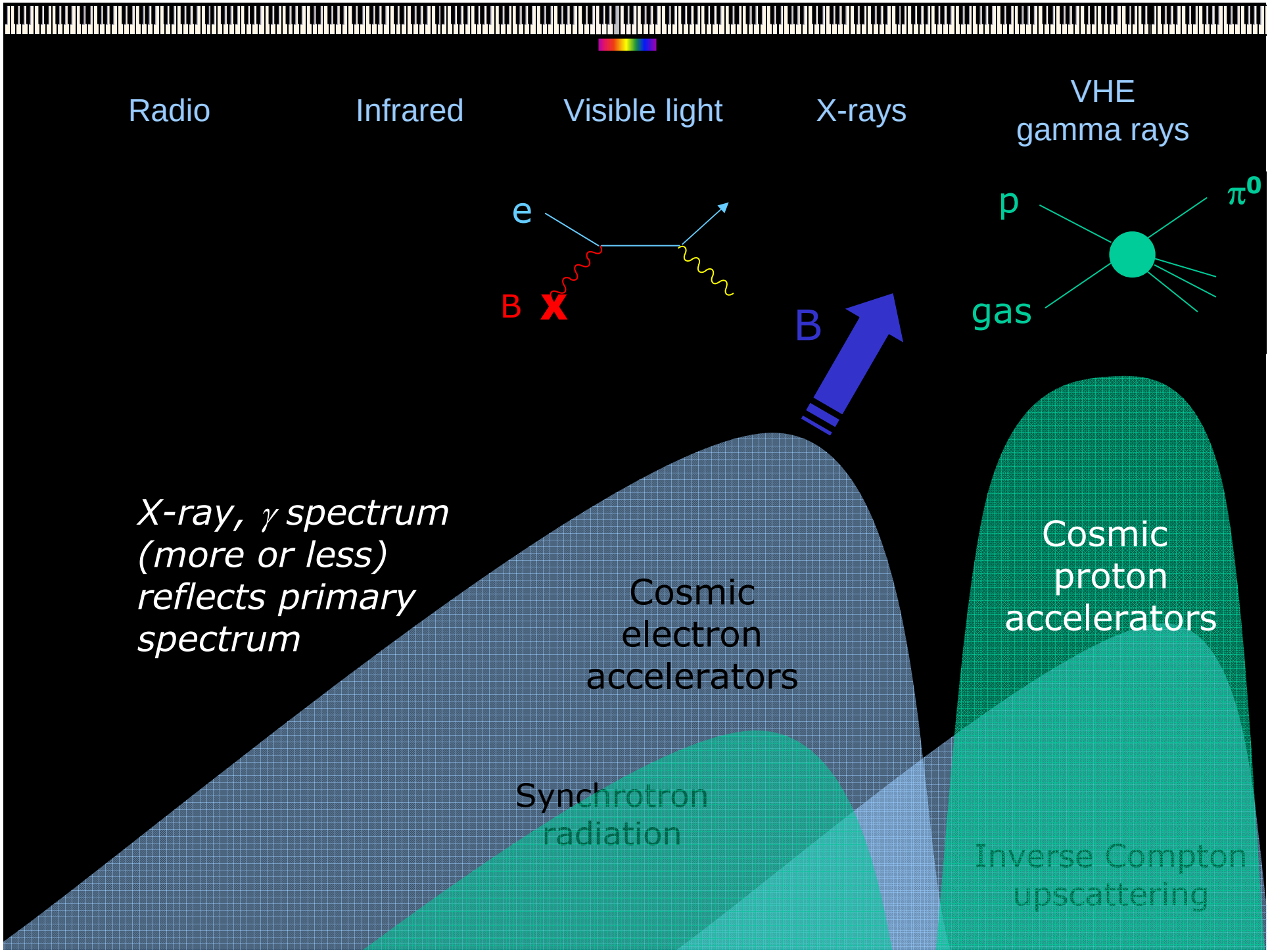

2001
90°
180°
-180°
PWNe
SNRs
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
RX J1713.7-3946
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

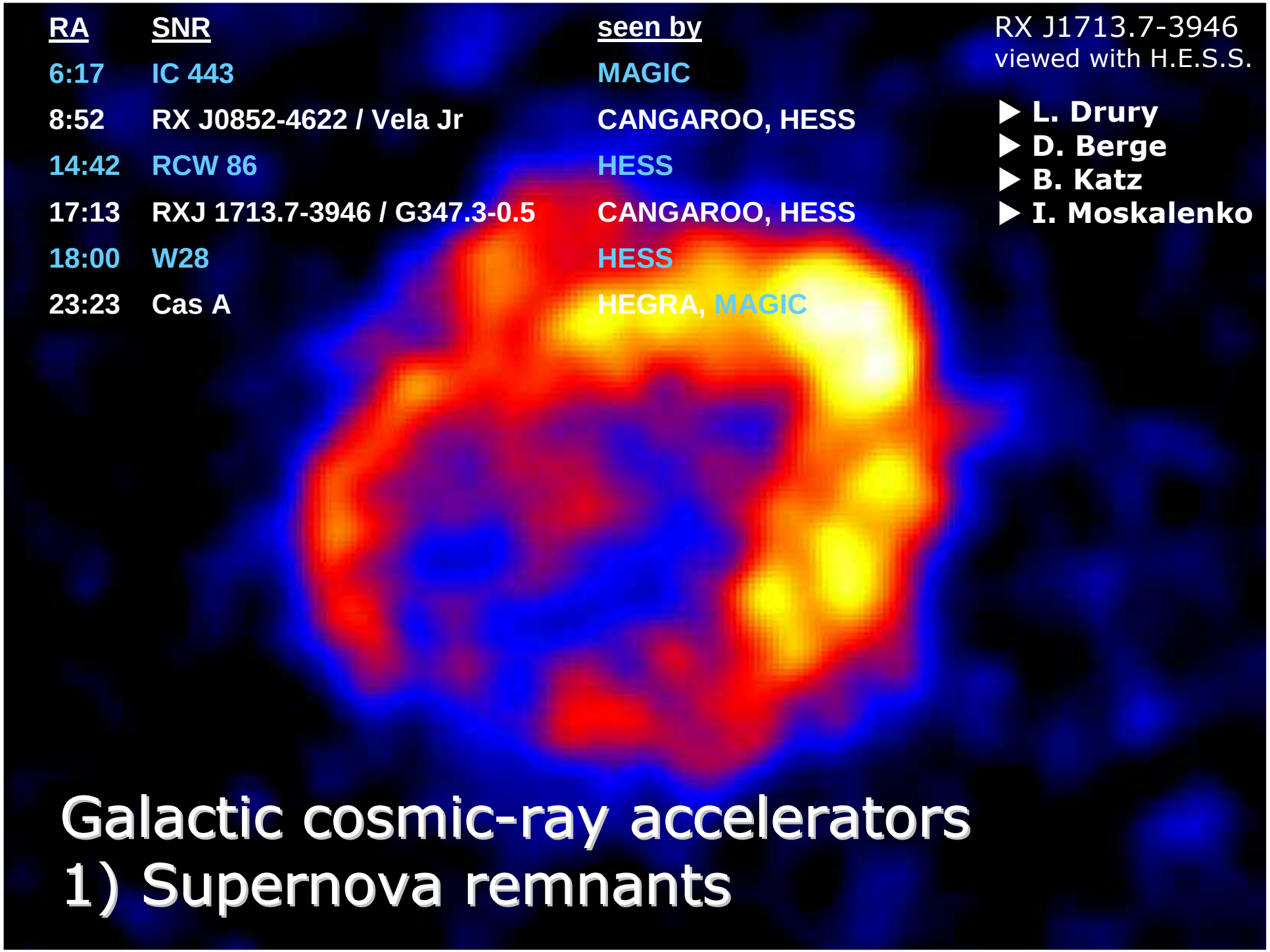

2003
90°
180°
-180°
PWNe
Unidentified
SNRs
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
RX J1713.7-3946
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

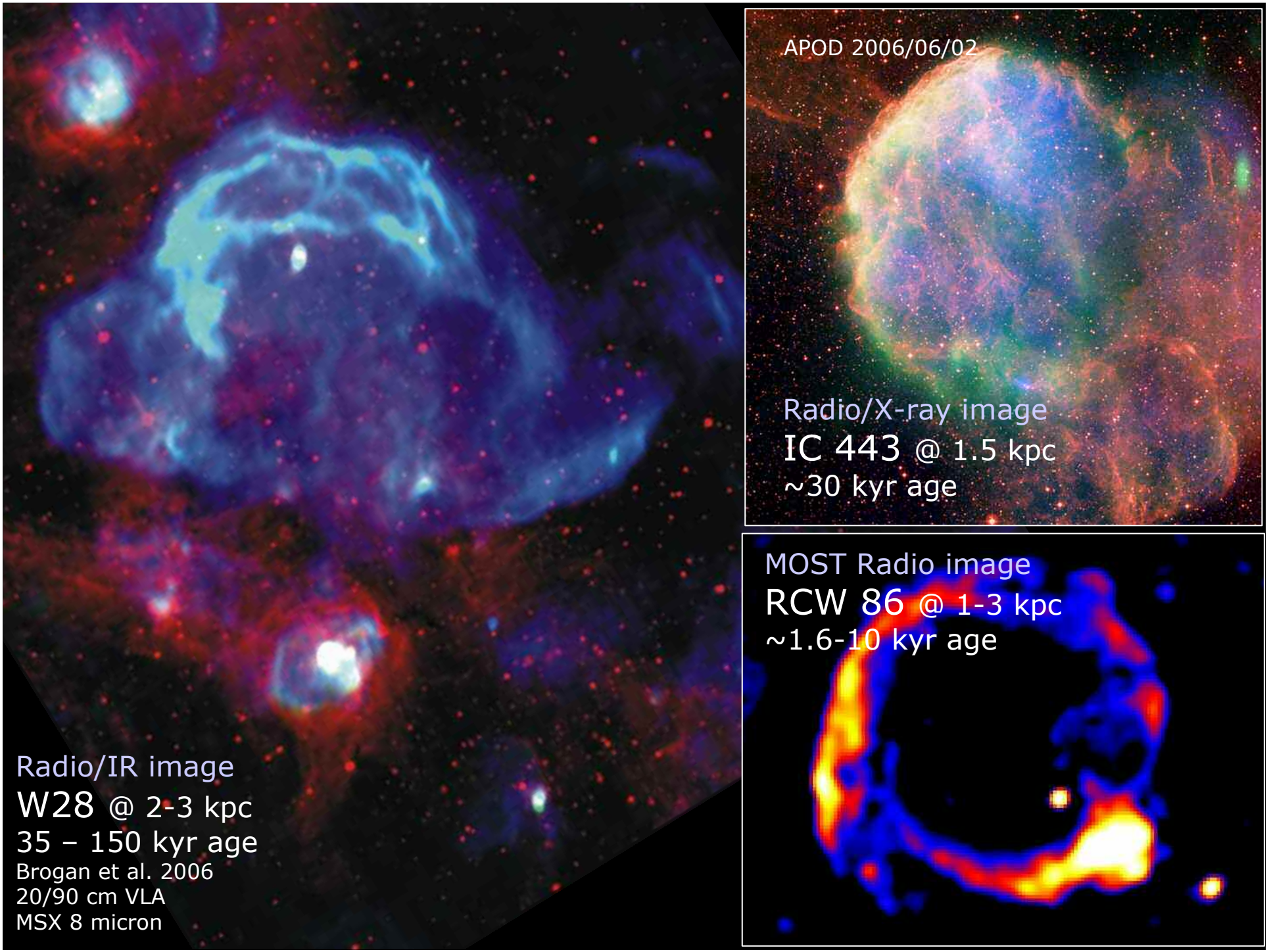

2005
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007


2007
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
HESS J1303-631
Vela X
MGRO J1908+06
RX J1713.7-3946
MSH 15-52
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

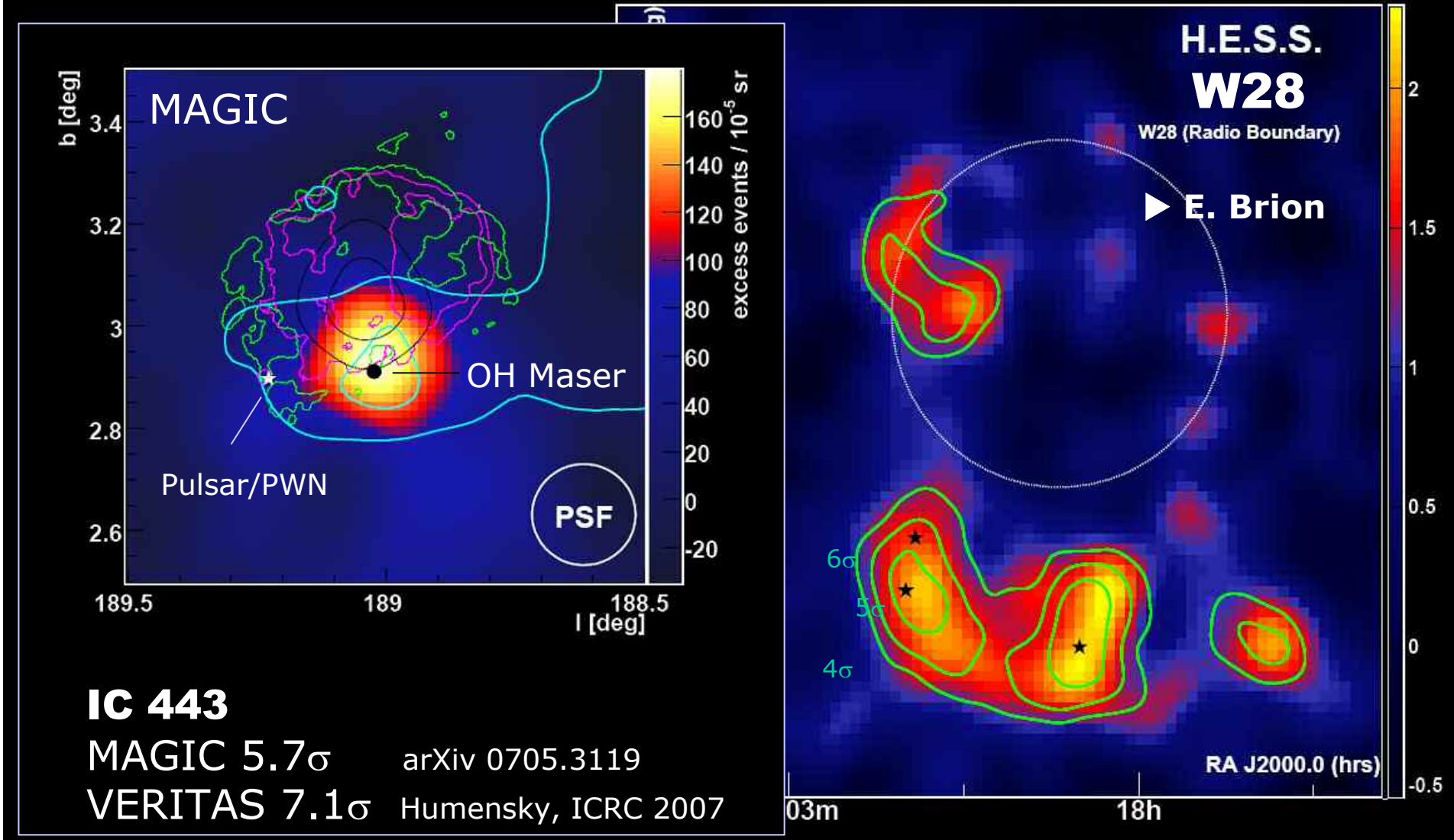

2007
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
71 VHE sources -
each a cosmic particle accelerator,
where gamma rays trace
primary electrons or nuclei
SNR 7
PWN 18
Unid. gal. 21
Diffuse 2
Binary 4
AGN 19
Want to know:
Nature of primary particles
& their spatial and
momentum distribution
LS 5039
HESS J1303-631
Vela X
MGRO J1908+06
RX J1713.7-3946
MSH 15-52
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007


Radio
Infrared
Visible light
X-rays
VHE
gamma rays
e
B
X
B
p
gas
π0
X-ray, γ spectrum
(more or less)
reflects primary
spectrum
Cosmic
electron
accelerators
Cosmic
proton
accelerators
Synchrotron
radiation
Inverse Compton
upscattering


RA SNR seen by
6:17 IC 443 MAGIC
8:52 RX J0852-4622 / Vela Jr CANGAROO, HESS
14:42 RCW 86 HESS
17:13 RXJ 1713.7-3946 / G347.3-0.5 CANGAROO, HESS
18:00 W28 HESS
23:23 Cas A HEGRA, MAGIC
RX J1713.7-3946
viewed with H.E.S.S.
L. Drury
D. Berge
B. Katz
I. Moskalenko
Galactic cosmic-ray accelerators
1) Supernova remnants


APOD 2006/06/02
Radio/X-ray image
IC 443 @ 1.5 kpc
~30 kyr age
MOST Radio image
RCW 86 @ 1-3 kpc
~1.6-10 kyr age
Radio/IR image
W28 @ 2-3 kpc
35 – 150 kyr age
Brogan et al. 2006
20/90 cm VLA
MSX 8 micron

Protons interacting with cloud(s)?

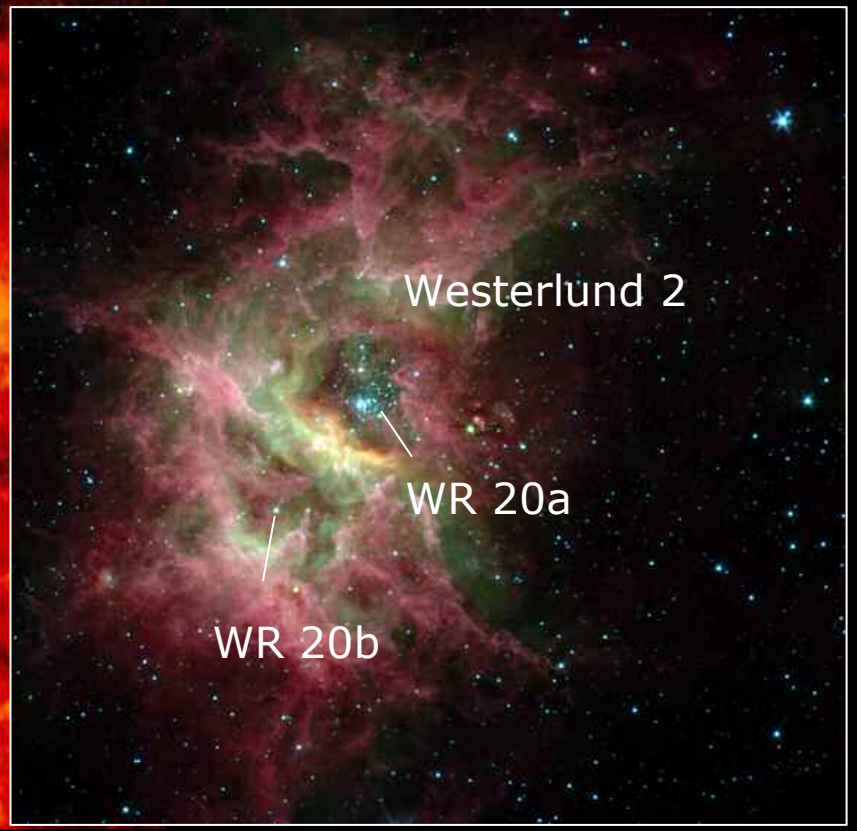


IC 443

MAGIC 5.7σ arXiv 0705.3119

VERITAS 7.1σ Humensky, ICRC 2007

RCW 49:
Stellar Winds as Cosmic Accelerators

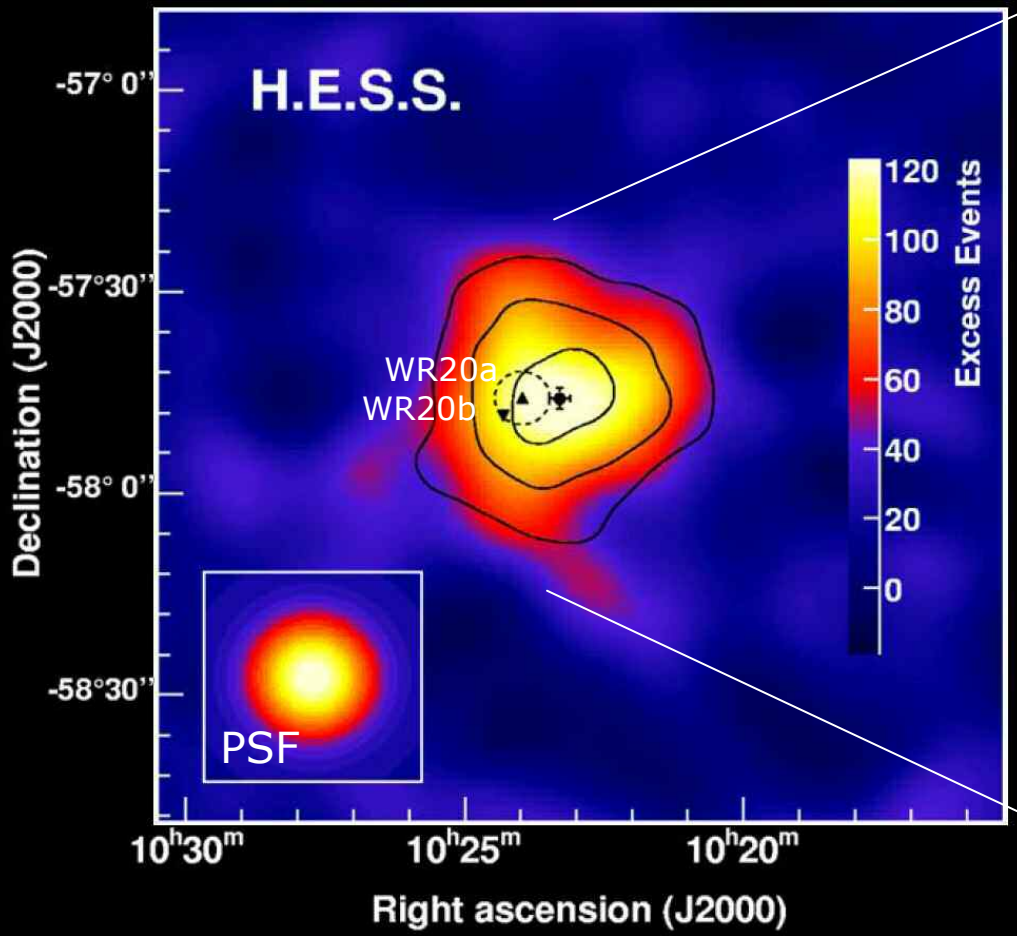


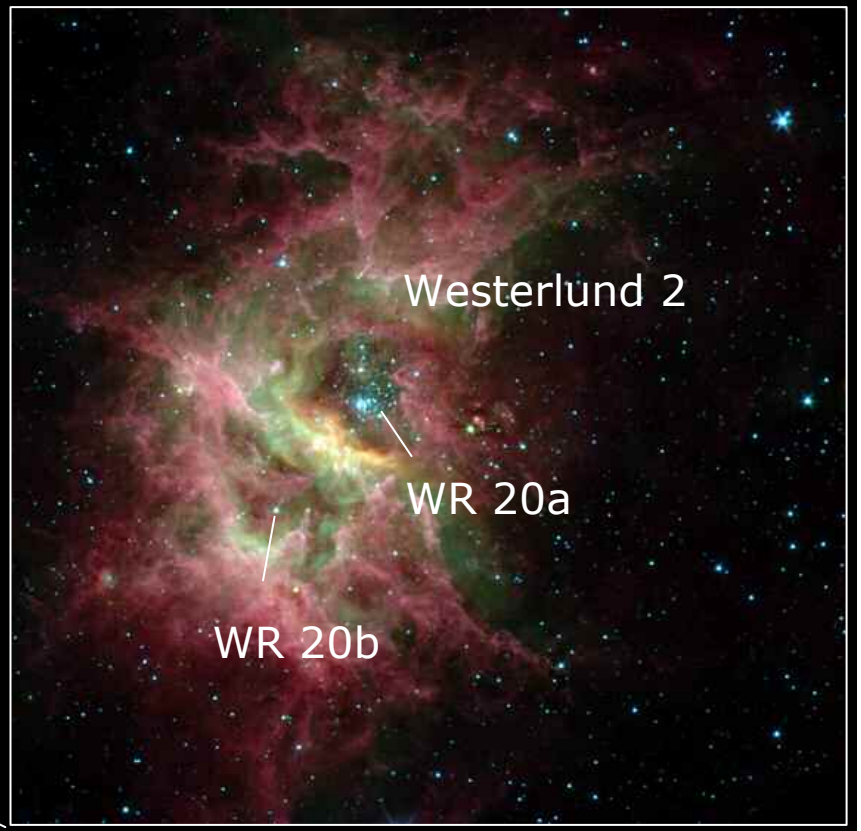
Star Formation in RCW49 Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / E. Churchwell (Univ. of Wisconsin) ssc2004-08a

WR20a:
Two ~70 $M_\odot$ WR stars
in 3.7 d orbit

RCW 49: Stellar Winds as Cosmic Accelerators

HESS J1023-575

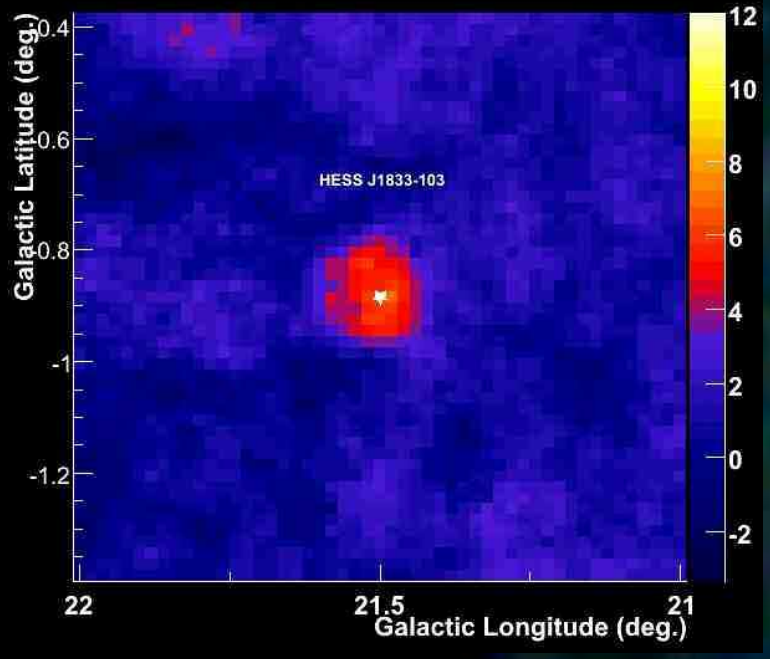




A&A 467, 1075 (2007)
also M. Butt, Nature 446, 986 (2007)

G21.5-0.9
Chandra / H.Matheson & S.Safi-Harb

HESS J1833-103

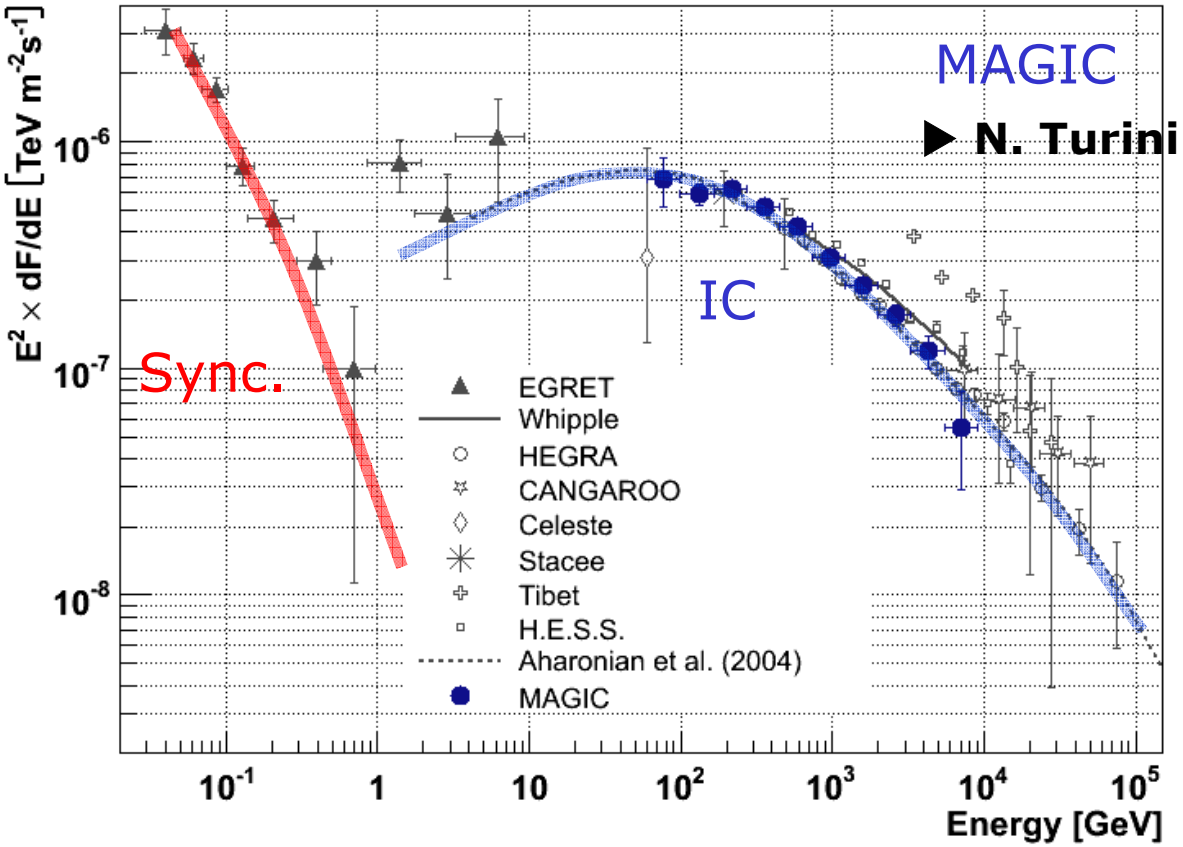


4′

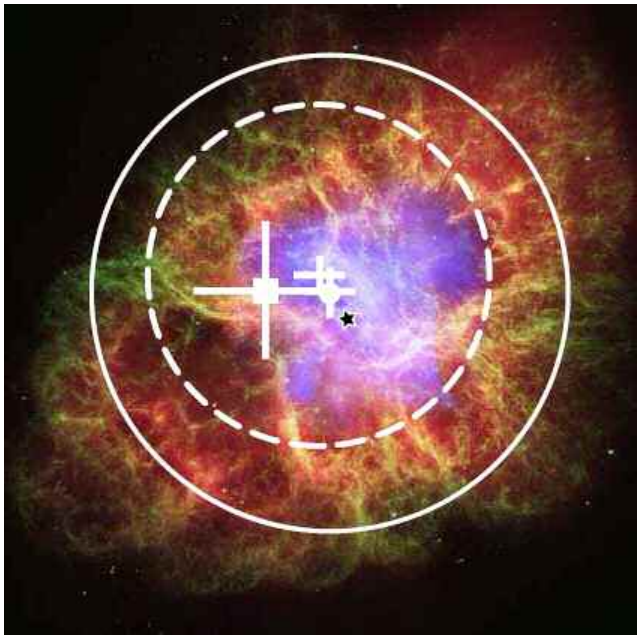
Galactic cosmic-ray accelerators
2) Pulsar wind nebulae

Best studied: the Crab Nebula

Crab seen also by
MILAGRO
Tibet AS-γ
ARGO YBJ



Turn-over of SED starts to be visible ar ~100 GeV
MAGIC arXiv:0705:3244



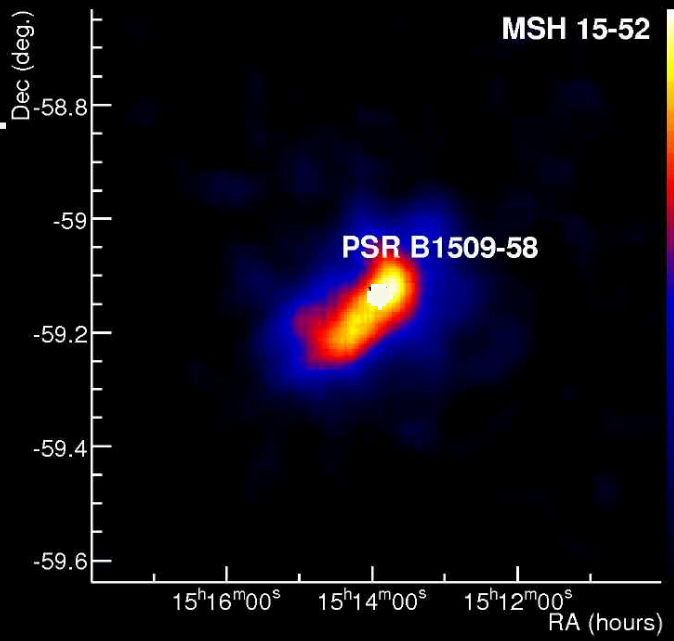
Source size @ 500 GeV < 1.6'

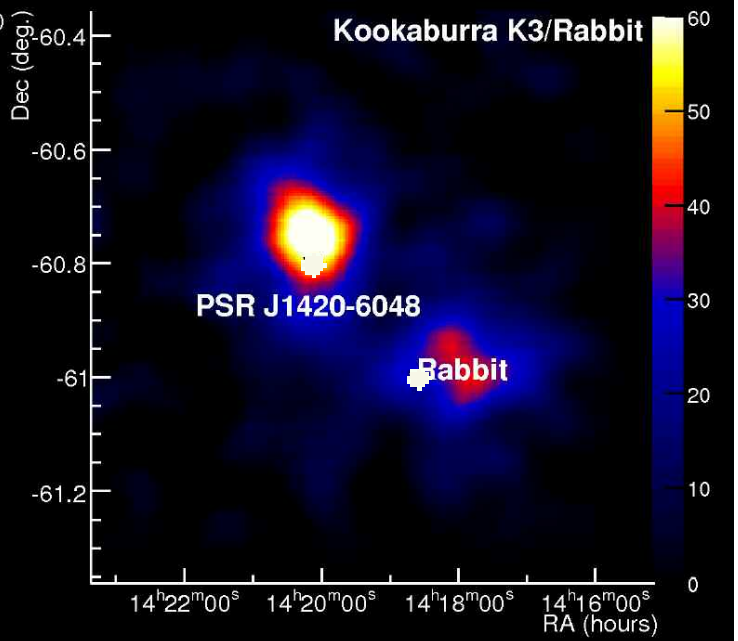
PWN

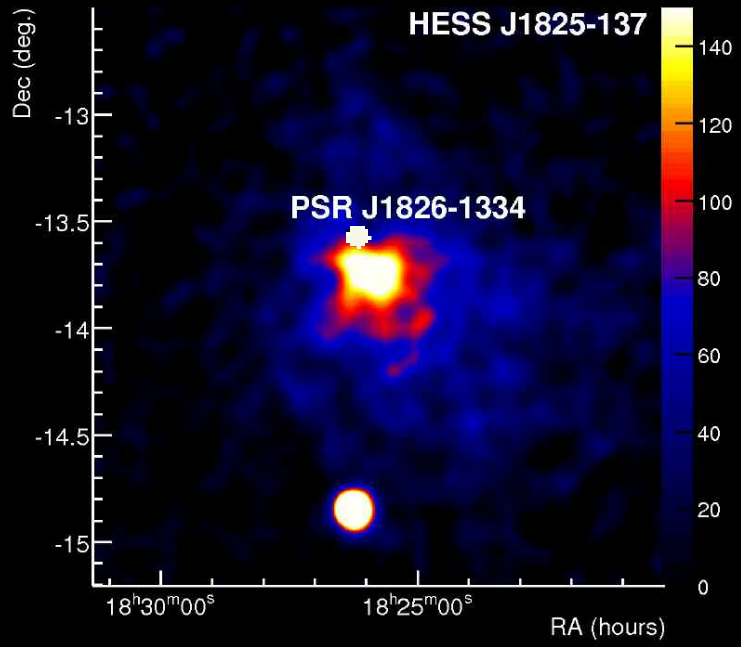
as seen by H.E.S.S.

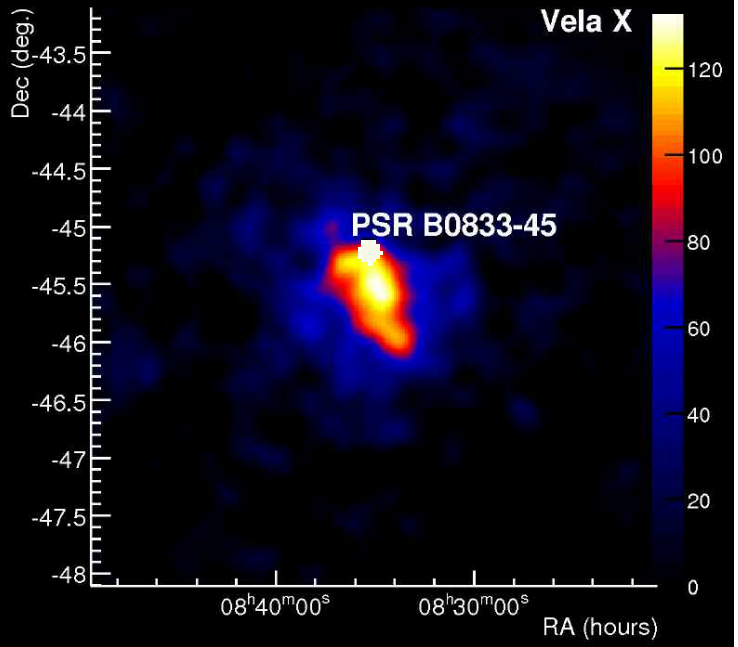
γ-ray sources are

- extended O(10 pc)
- displaced from pulsar

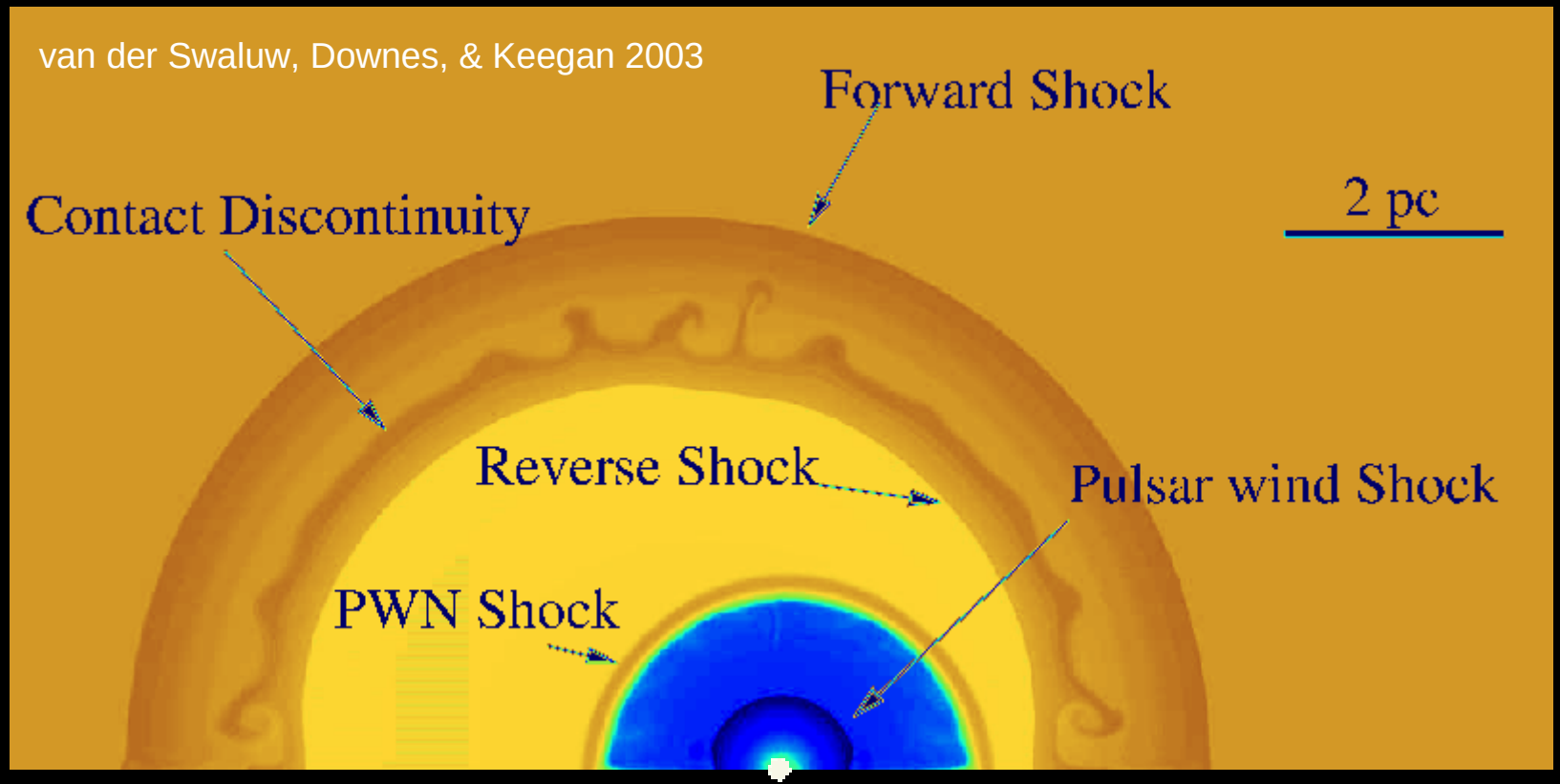






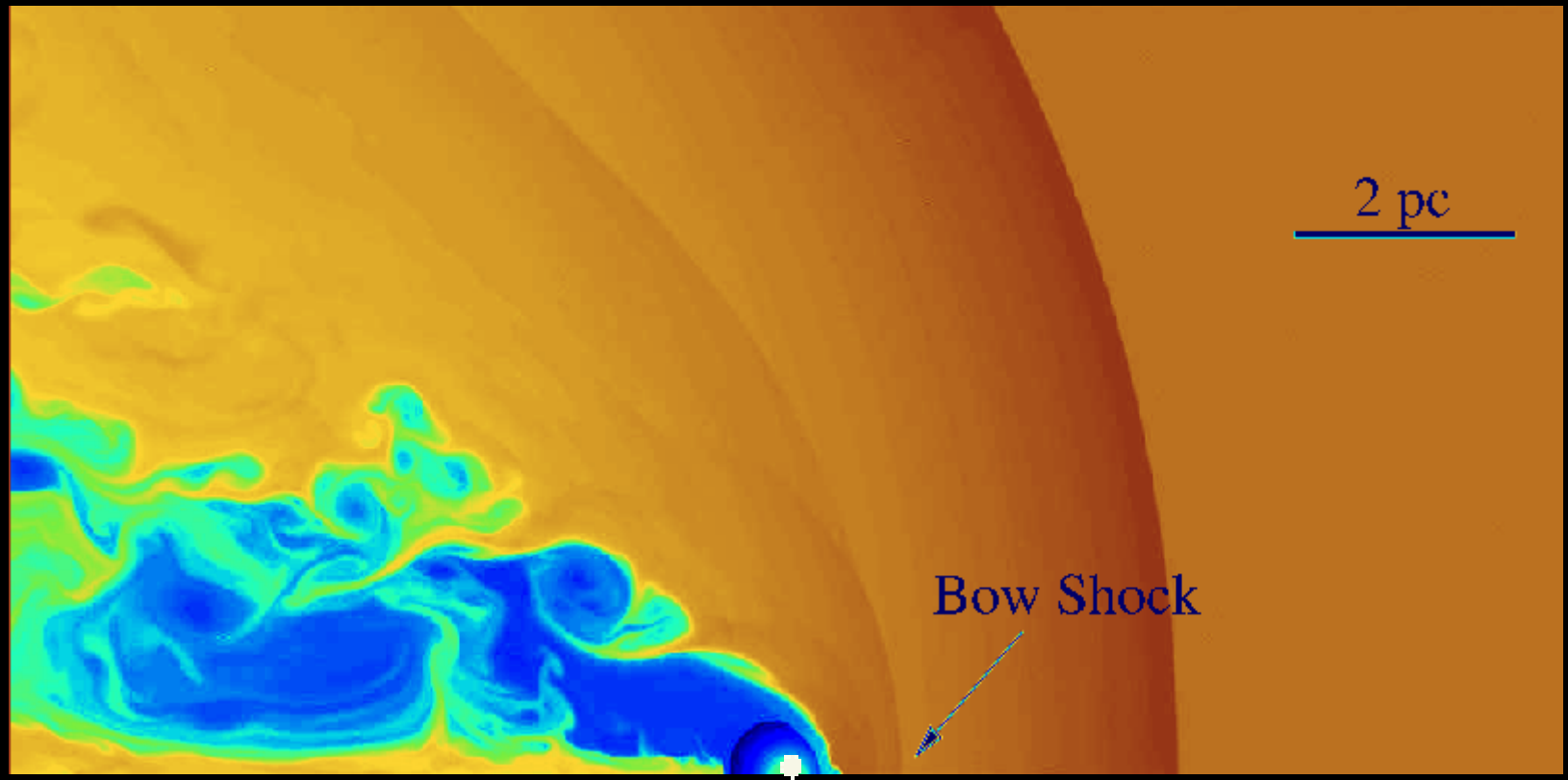


Hydrodynamics simulations of PWN inside SNR

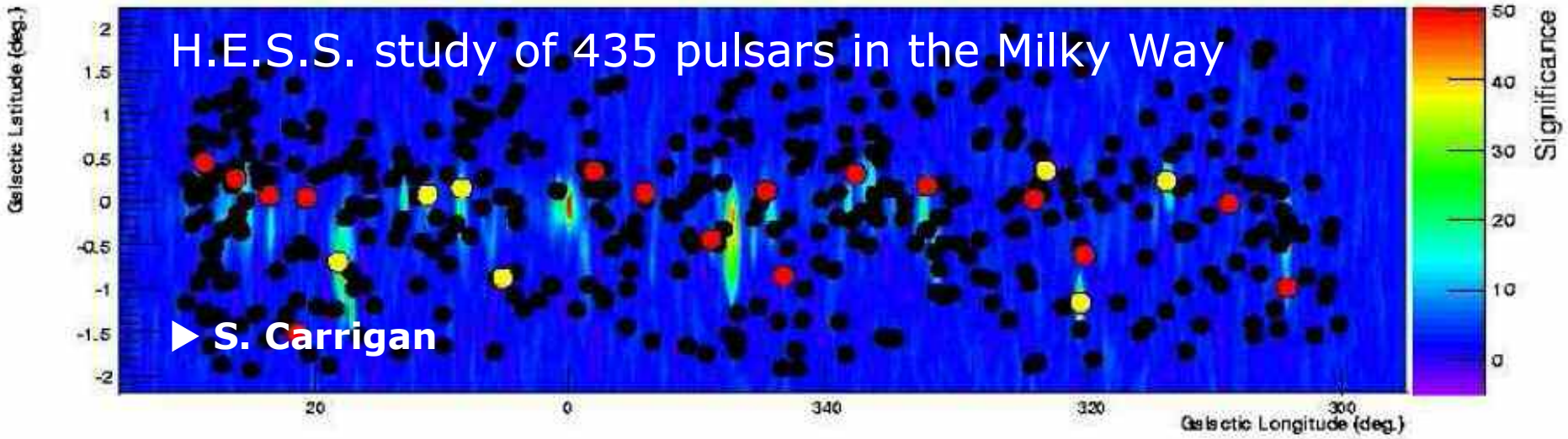


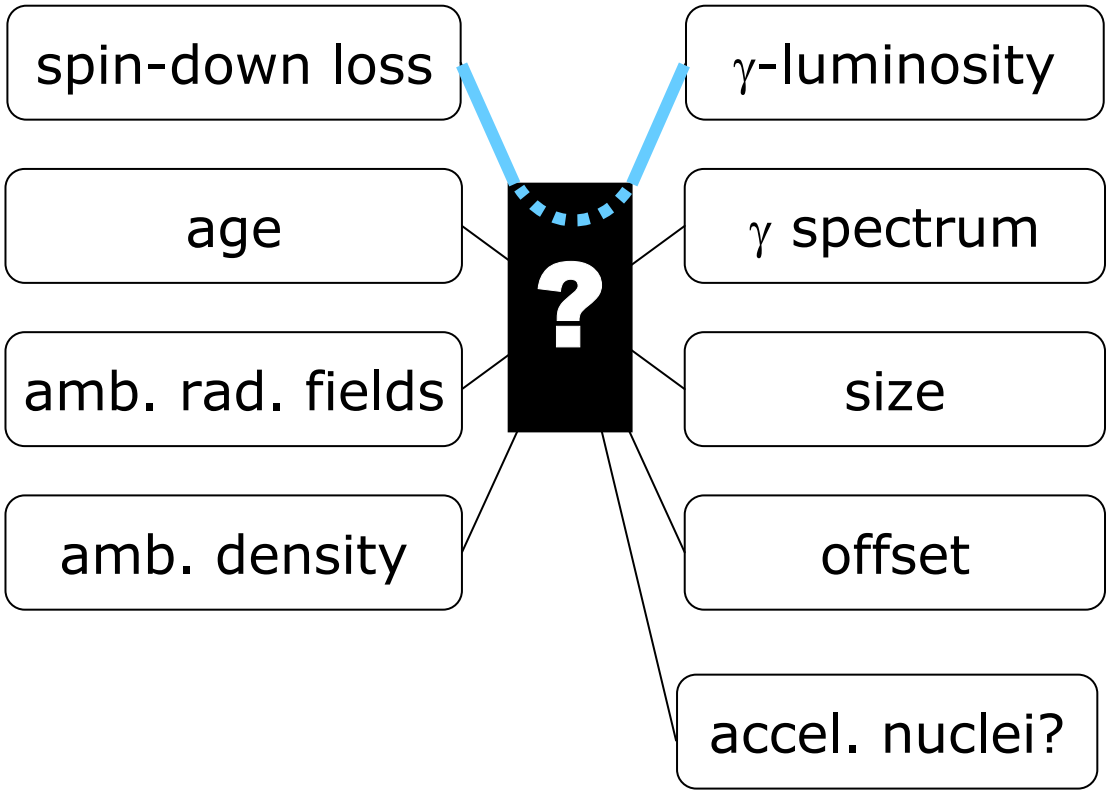
Displacement due to pulsar kick ?

Hydrodynamics simulations of PWN inside SNR



… similar effects due to inhomogeneity of ambient medium



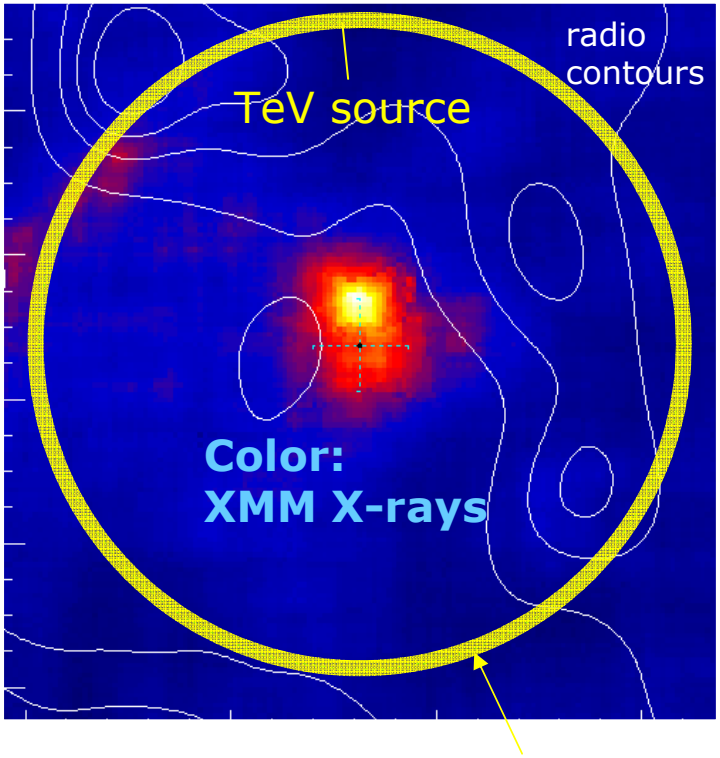


5 of 7 Pulsars with spin-down energy flux $\dot{E}/d^2 > 10^{35}$ ergs/kpc^2 (●) detected; no signif. detections below 10^{34} (●)

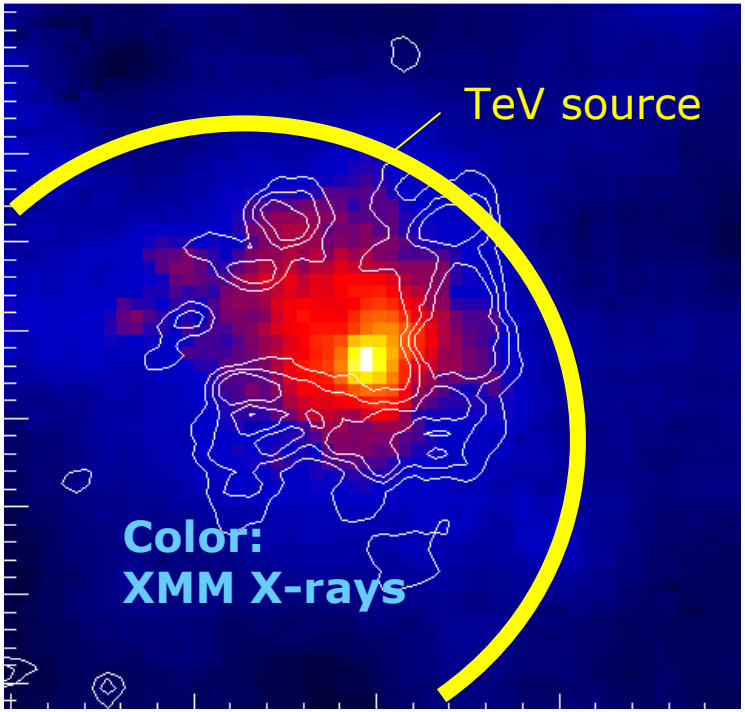
O(1%) of spin-down energy loss goes into VHE gamma rays
(give or take a factor of a few)

X-ray PWN discovered in VHE sources

HESS J1640-465
Funk et al., astro-ph/0701166



HESS J1813-178
Funk et al., astro-ph/0611646

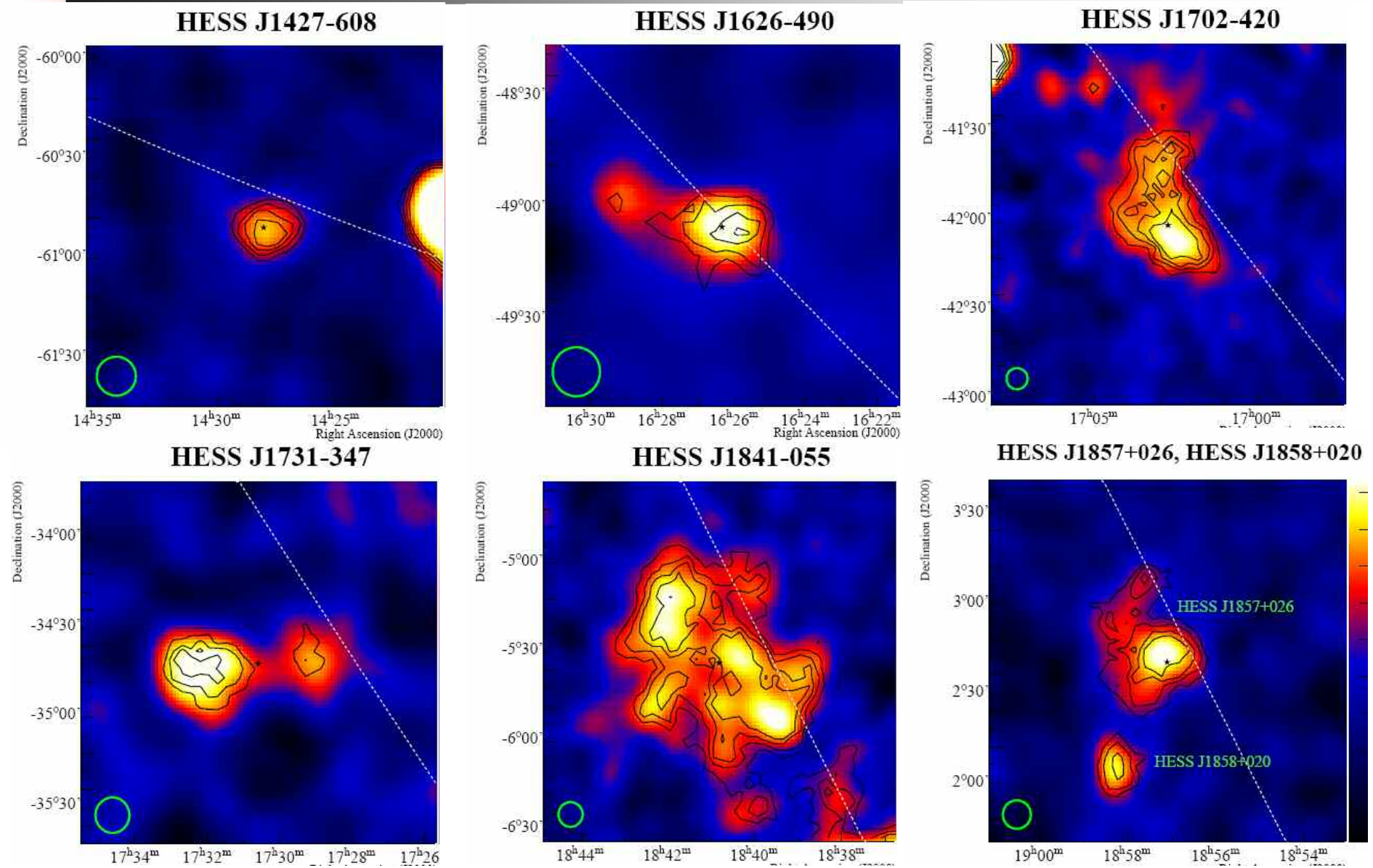


Radio shell
Helfand et al., astro-ph/0505392
Brogan et al., astro-ph/0505145

Galactic cosmic-ray accelerators
4) Mystery sources and *Cygnus region*

Radio image
Y. English
APOD February 18, 2002

Examples of sources without compelling X-ray / radio counterparts

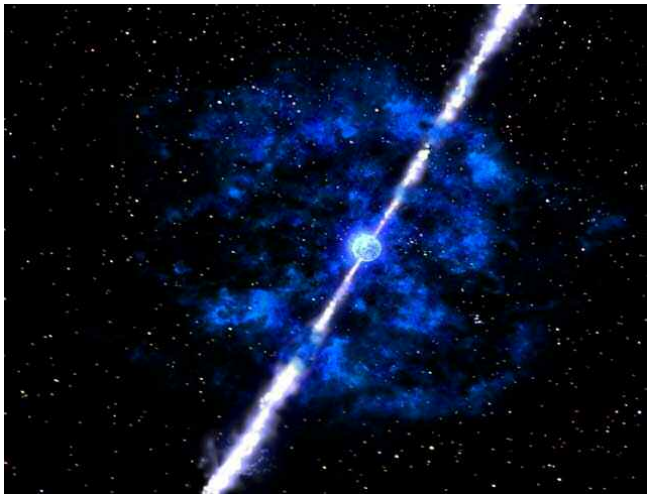


"Dark sources"

What are they?

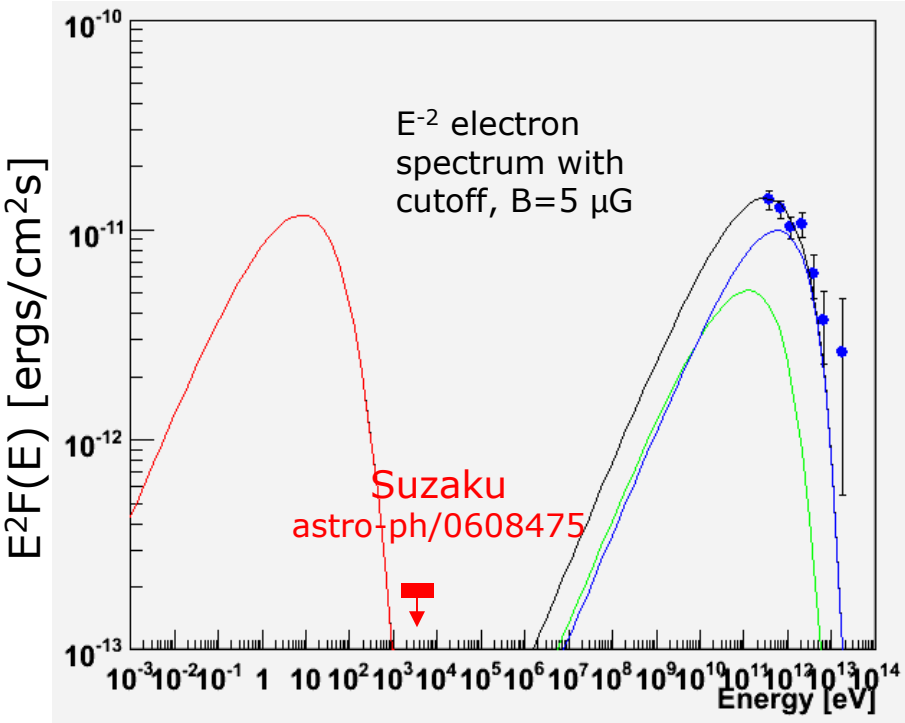
(a) Sources "without" electrons:

- GRB remants (Atoyan et al.)

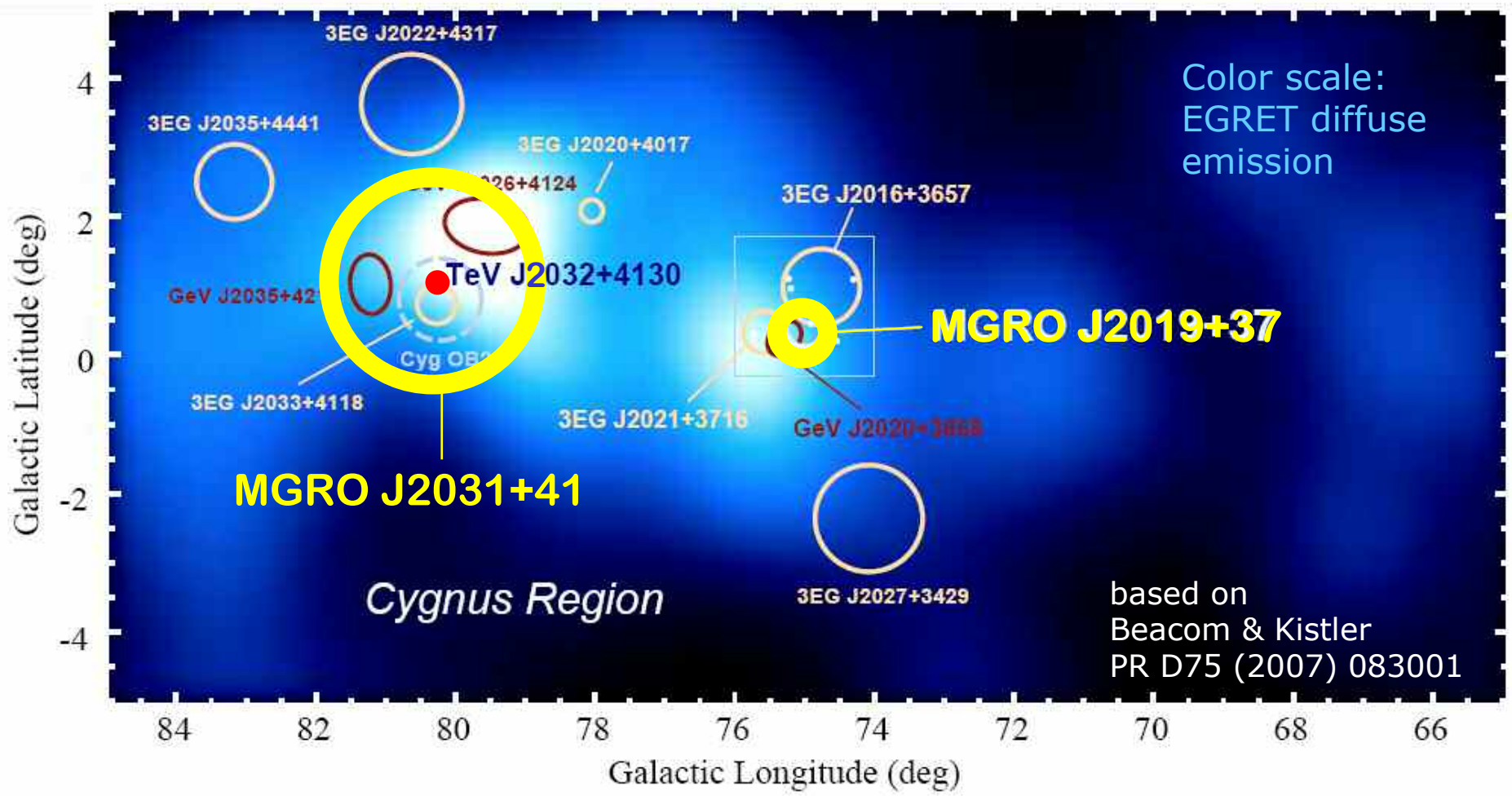


- Old supernova remnants (Yamazaki et al.)
- Stellar clusters / stellar winds / OB assoc.

(b) "hidden" electrons?
e.g. HESS J1616-508

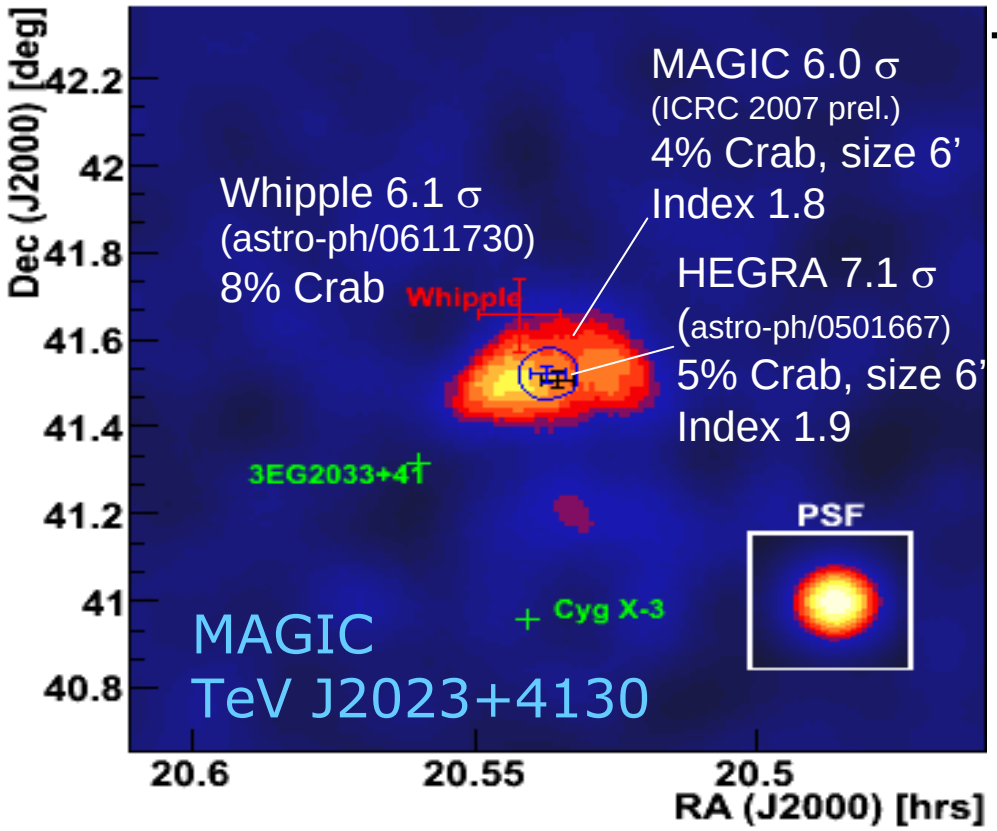


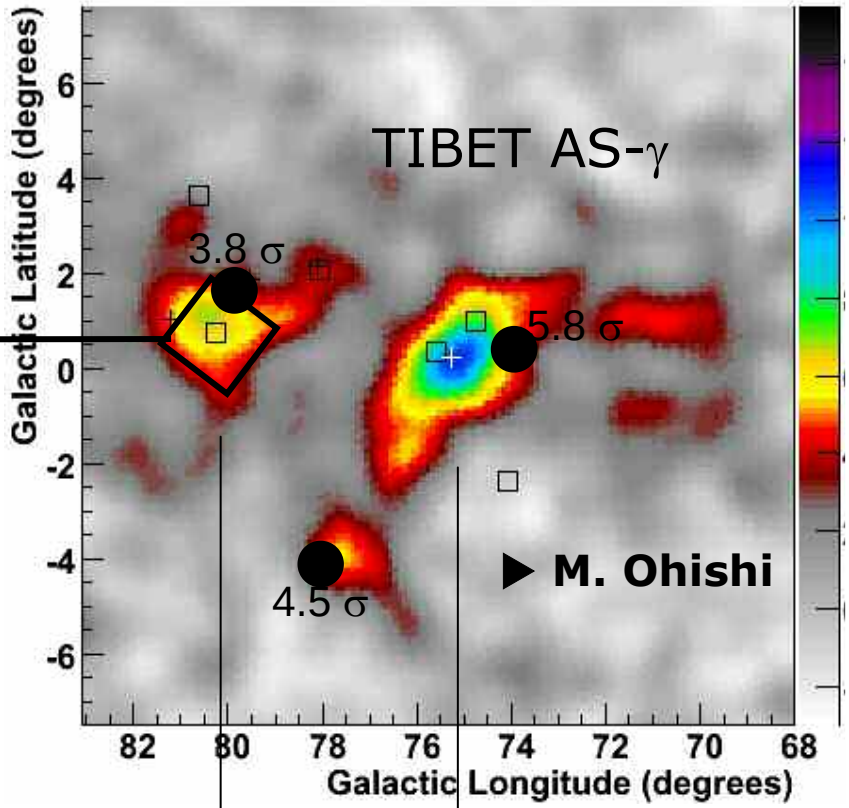
Where it all started: Cygnus region



TeV J2032+4130 and MGRO J2031+41, MGRO J2019+37

MILAGRO
Aldo et al. ApJL 658, L33



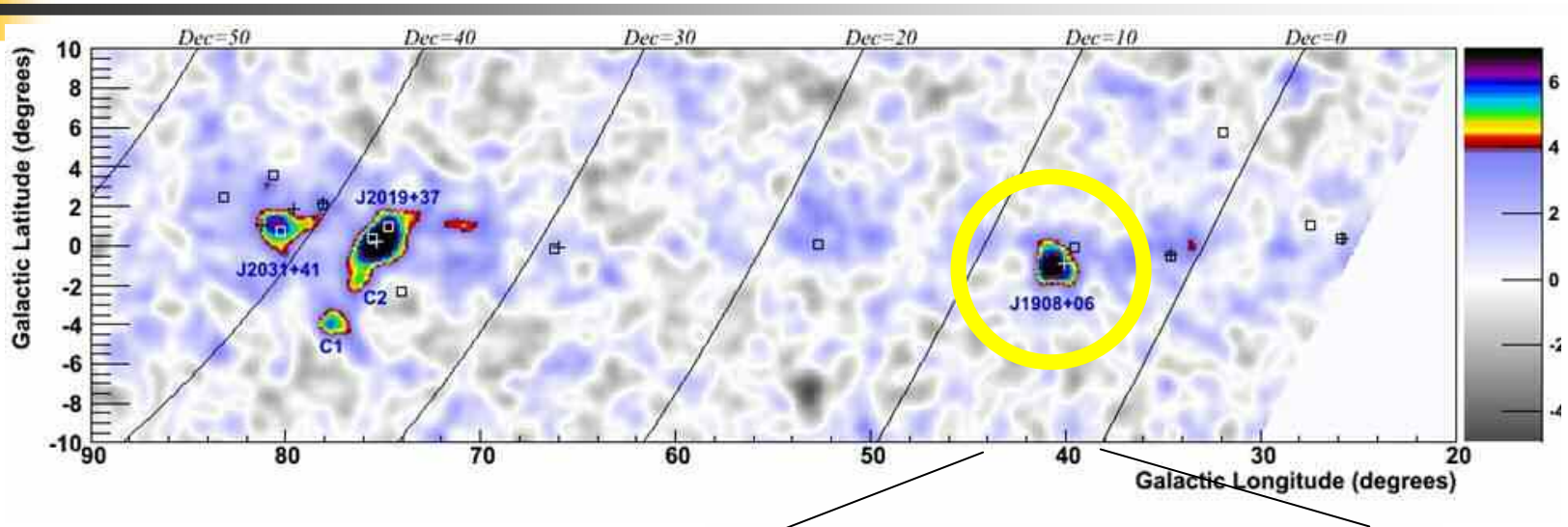


MGRO J2031+41
6.6 / 4.9 σ

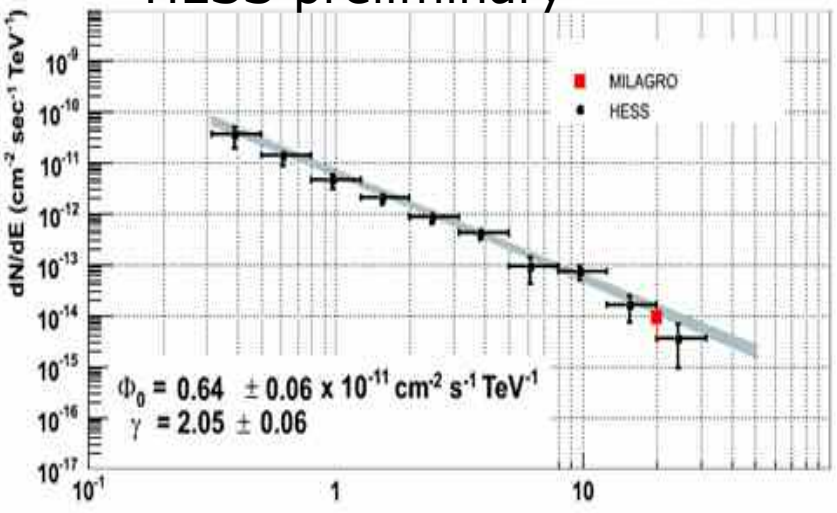
MGRO J2019+37
10.4 / 9.3 σ

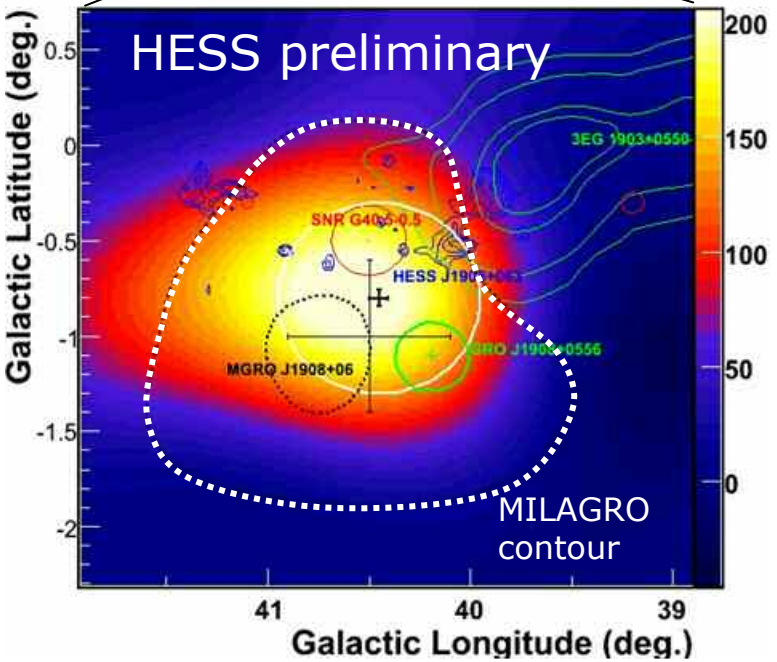
TIBET AS-γ
5.8 σ (ICRC 2007)

Unidentified: MGRO 1908+06

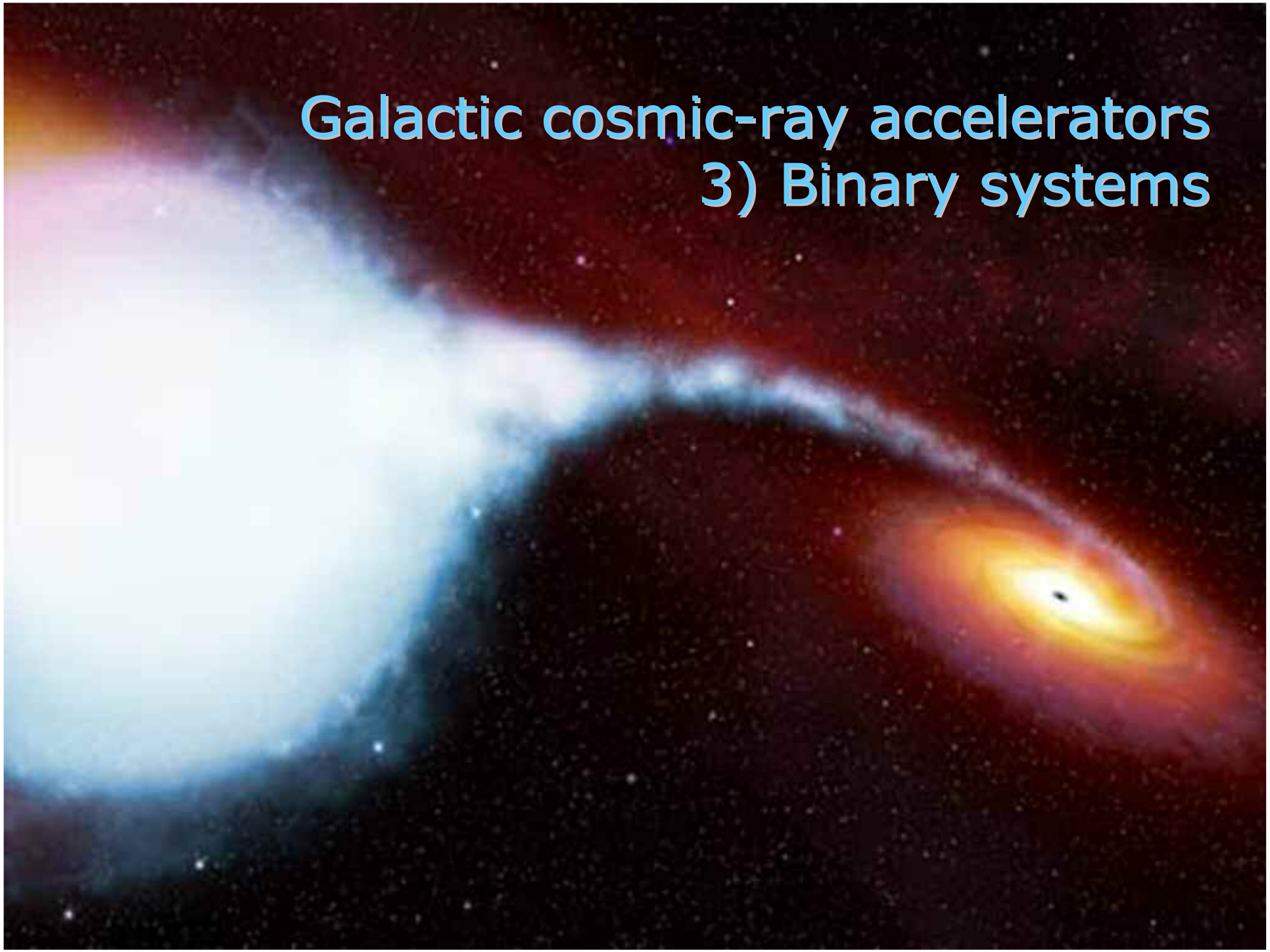


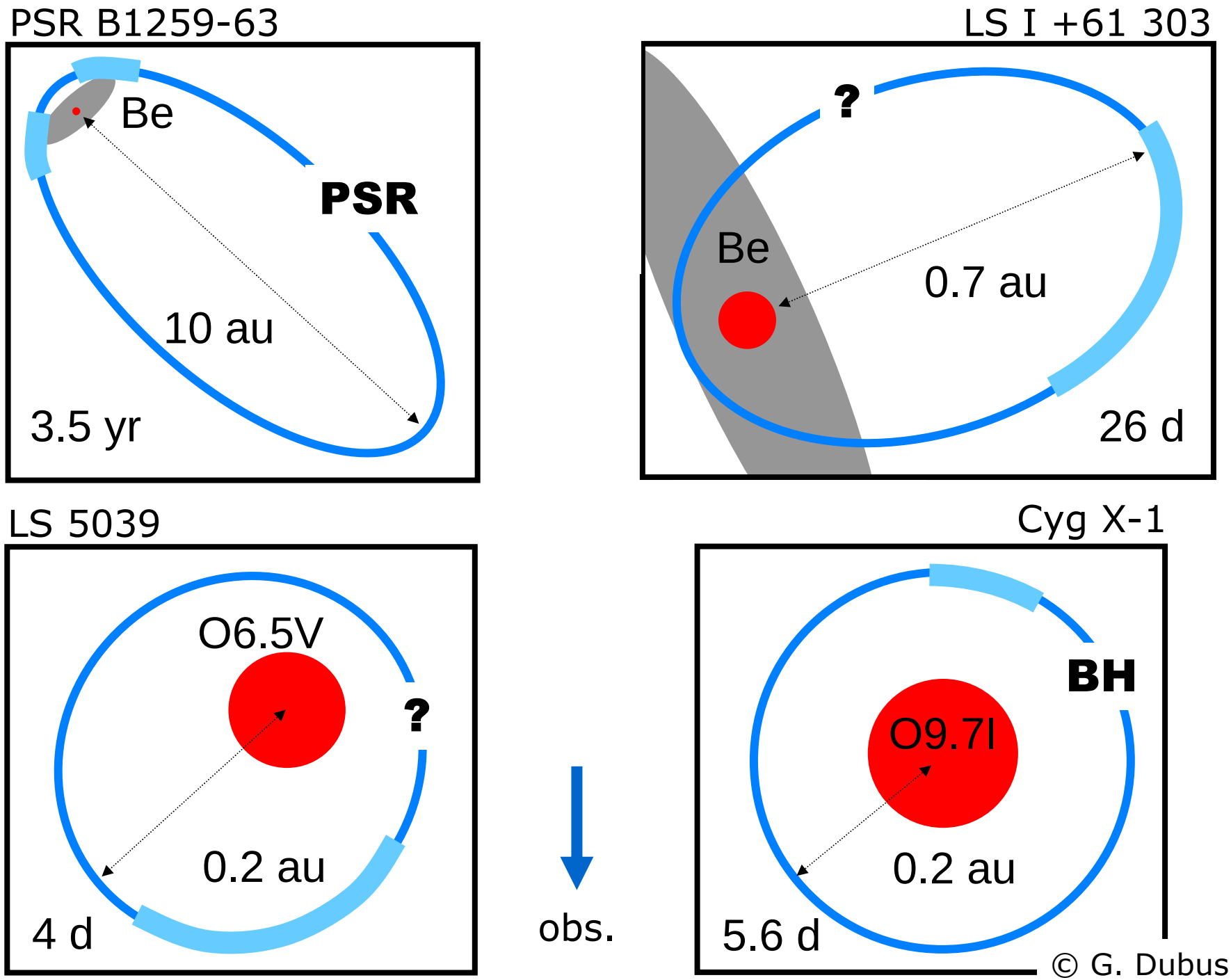
HESS preliminary



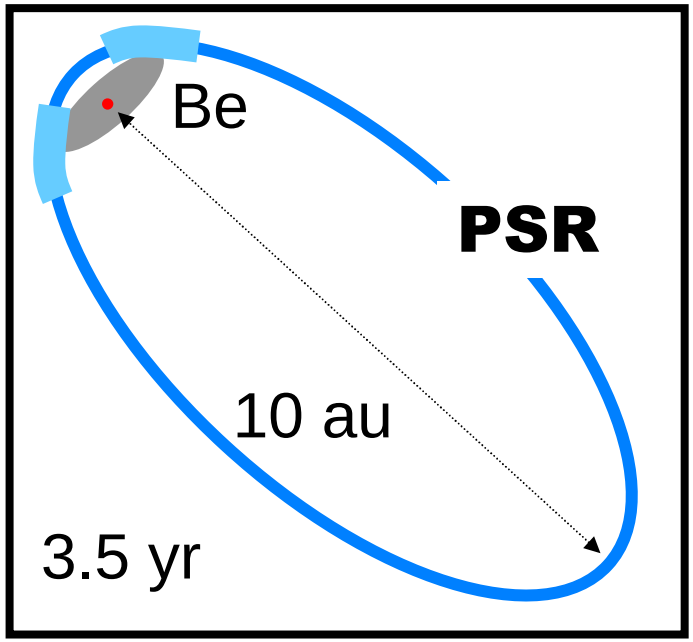


Galactic cosmic-ray accelerators
3) Binary systems



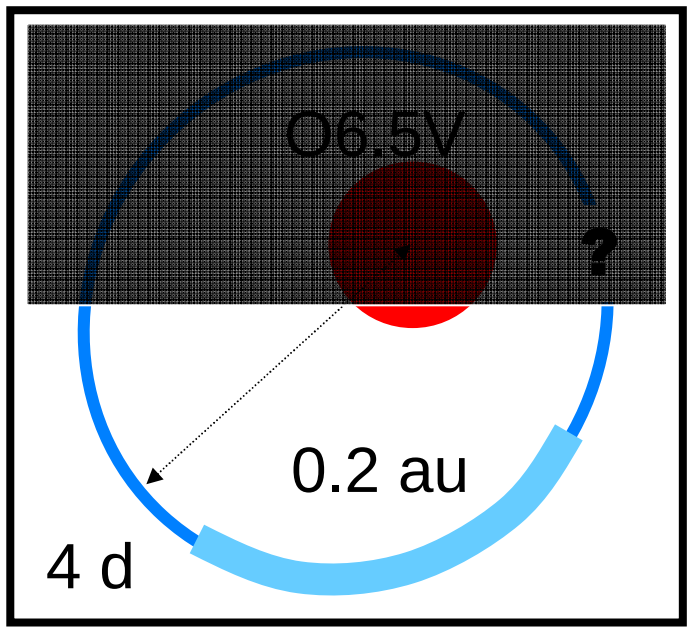

PSR B1259-63
Be
PSR
10 au
3.5 yr
LS I +61 303
?
Be
0.7 au
26 d
LS 5039
O6.5V
?
0.2 au
4 d
obs.
Cyg X-1
BH
O9.7I
0.2 au
5.6 d
© G. Dubus

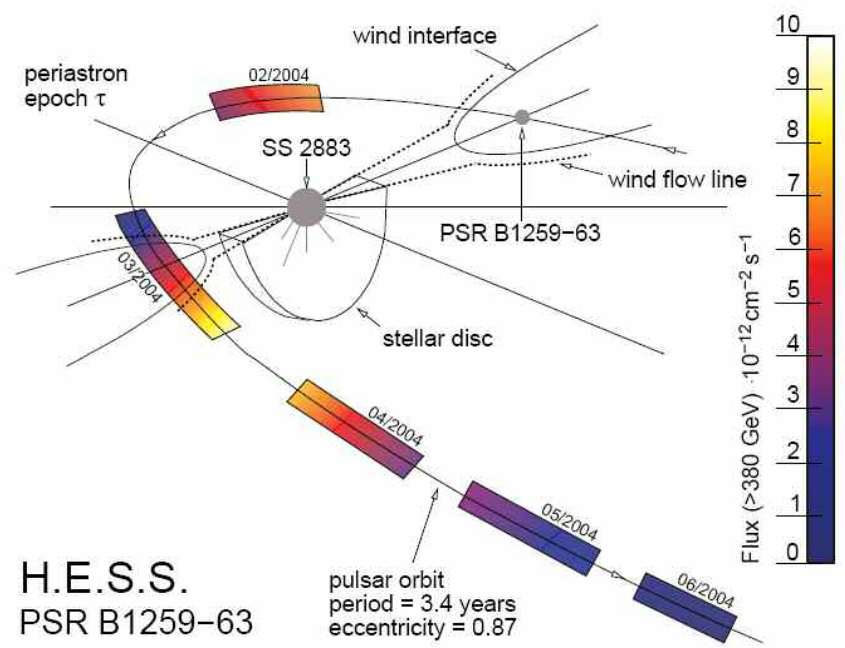
PSR B1259-63

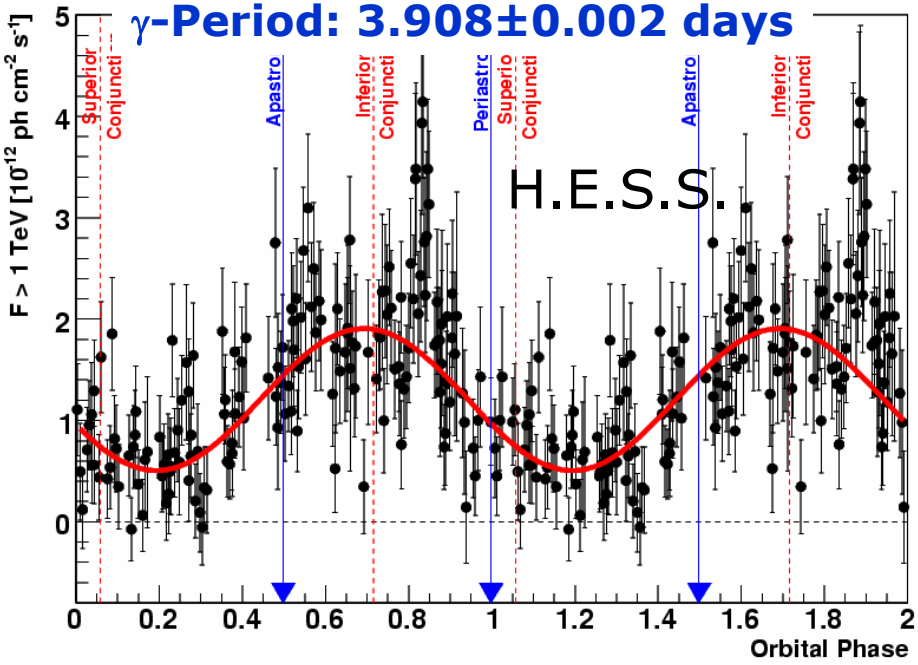


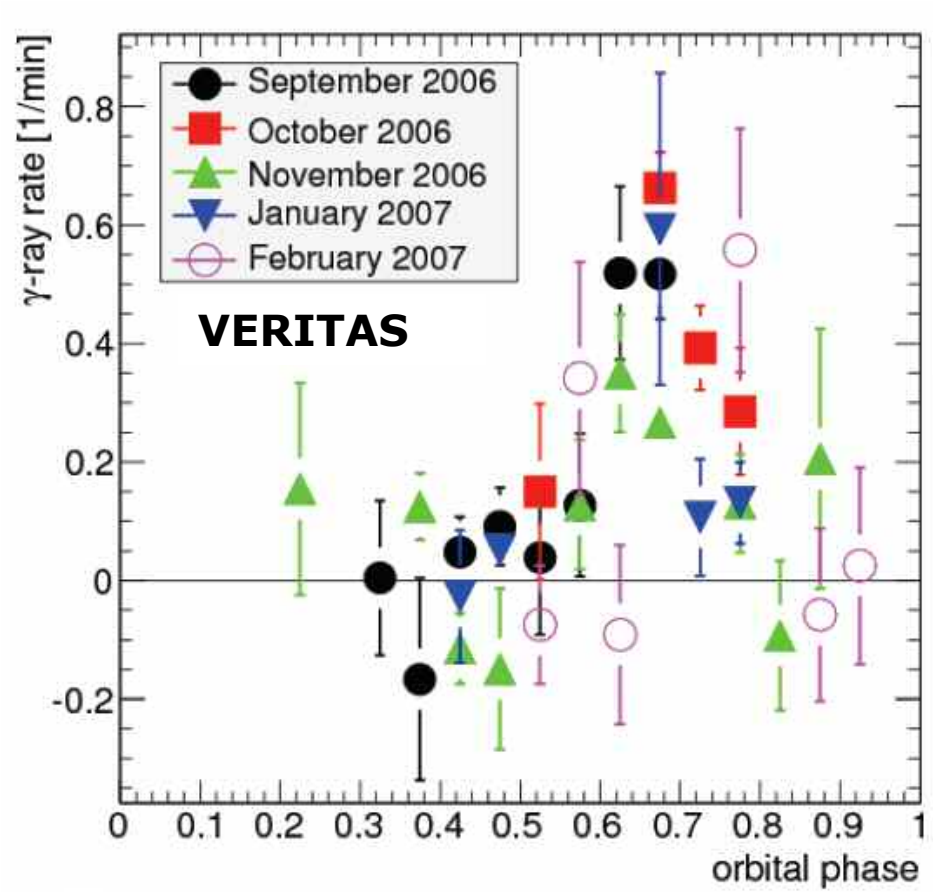
obs.

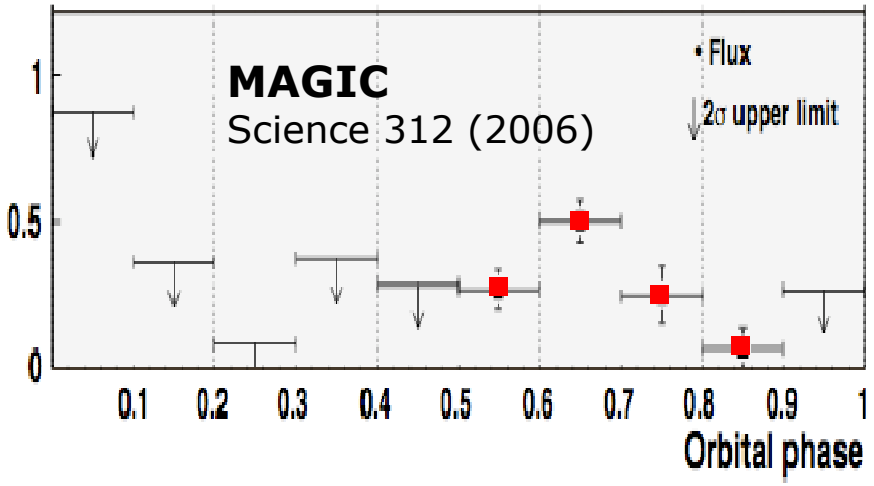
LS 5039



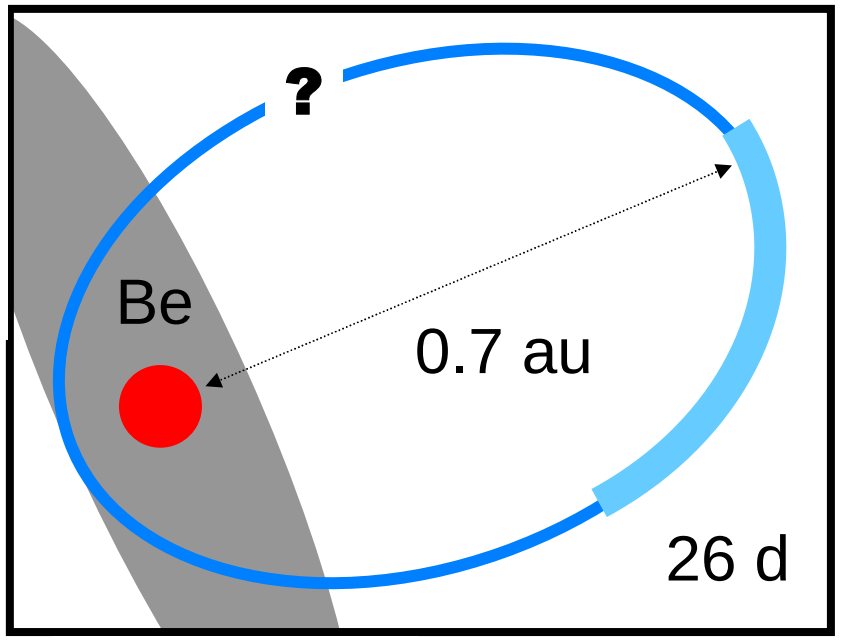








LS I +61 303



- **N. Turini**
- **T. Ergin**

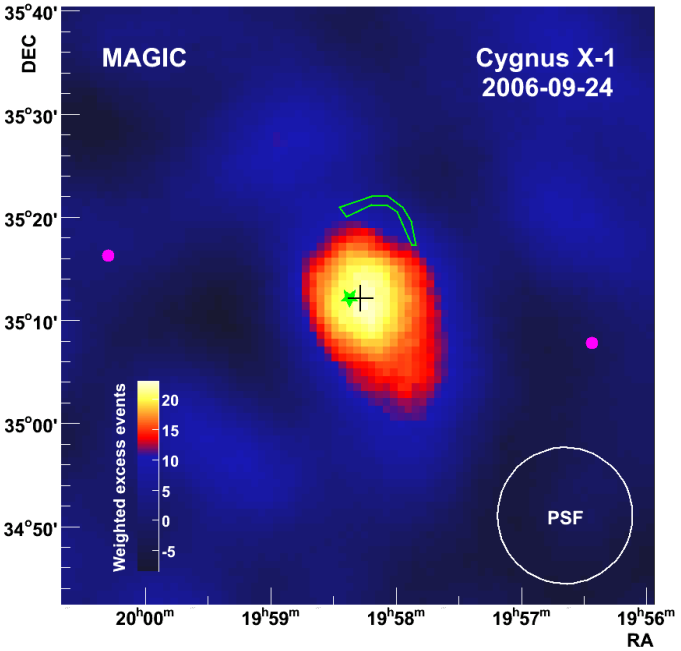
▶ **N. Turini**

MAGIC: Cyg X-1
arXiv:0706.1505

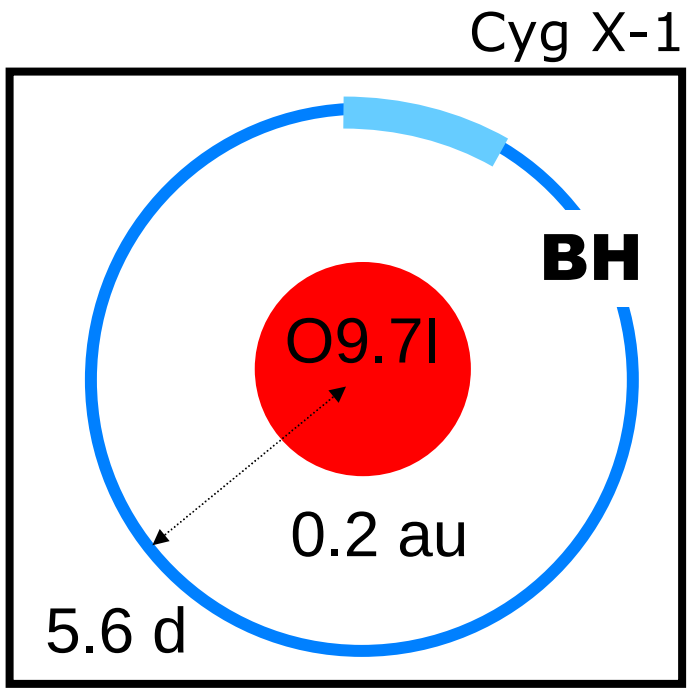
40 h in 26 nights

Night of 2006-09-24
first 76 min: 0.5 σ
second 79 min: 4.9 σ
(4.1 σ for 52 trials)

Coincident with X-ray flare



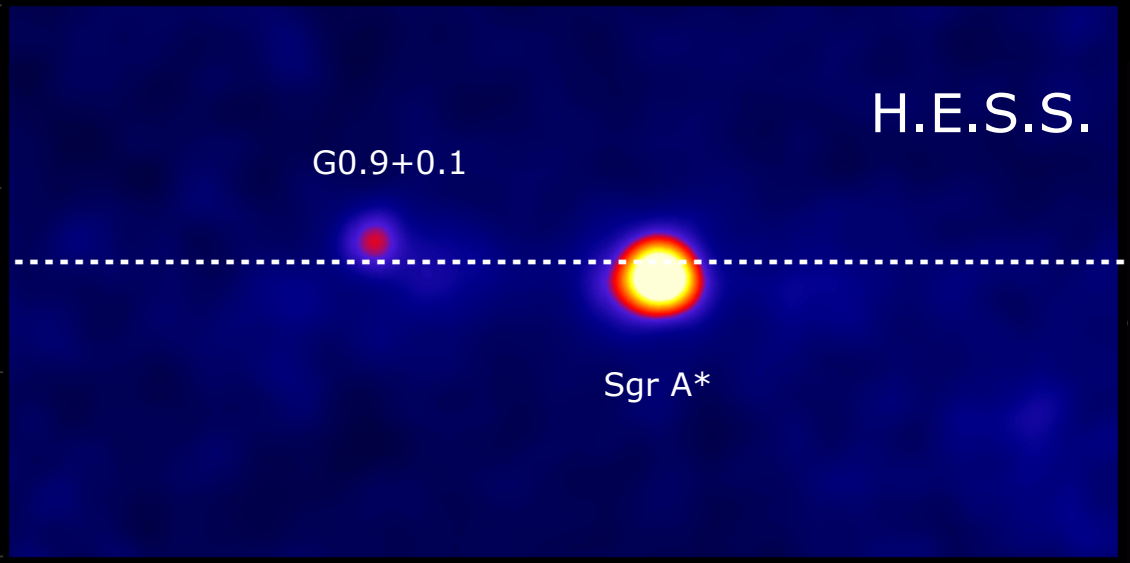
obs.



Galactic cosmic-ray accelerators

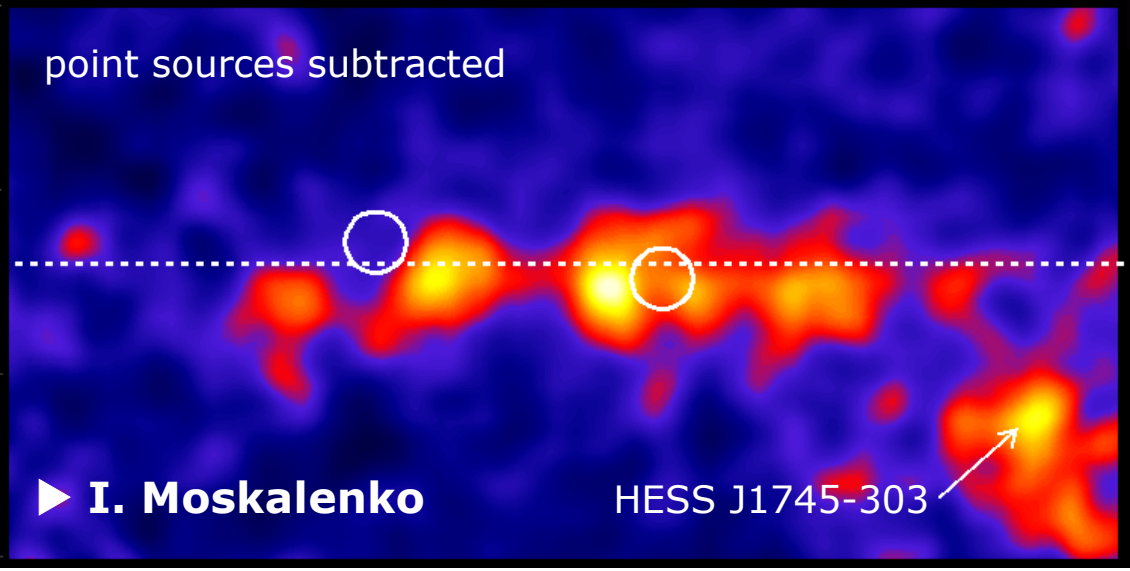
5) Galactic Center

The center of our Galaxy



Point source G0.9+0.1

Point source near Sgr A*

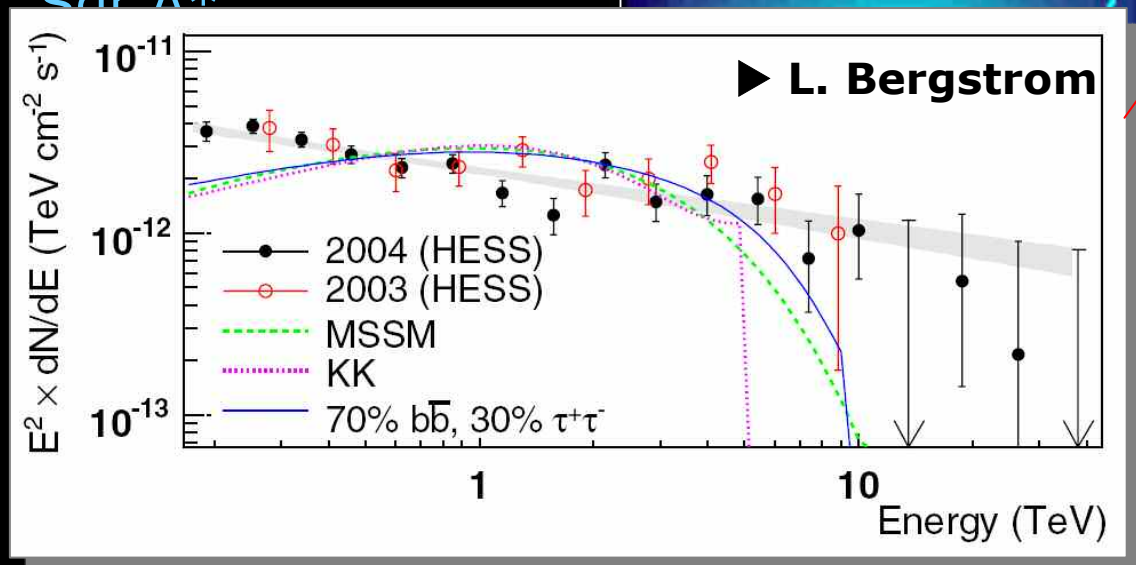


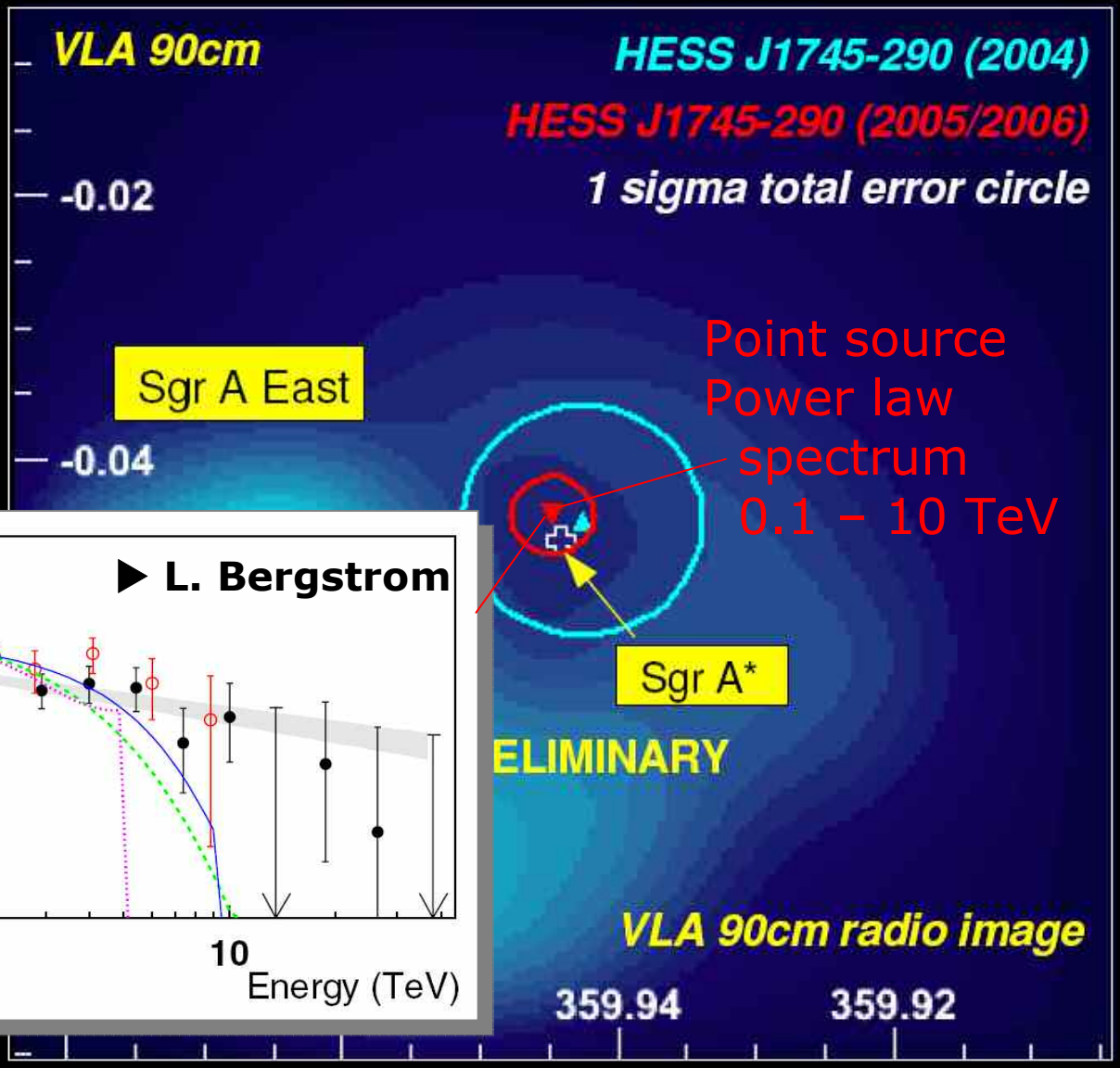
Diffuse emission from clouds; spectrum like Sgr A* source

GC source location

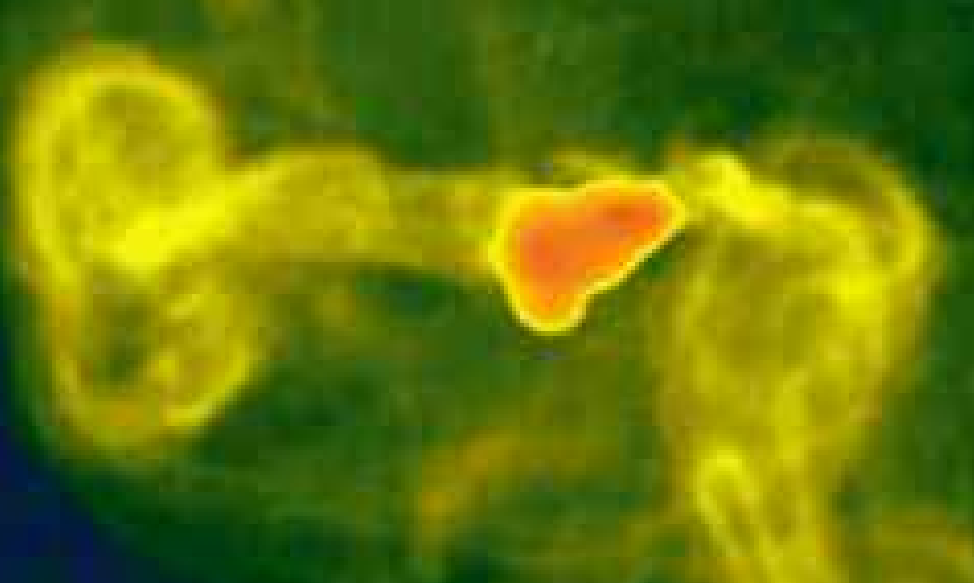
Position of GC source now with 6” syst., 6” stat. error (HESS, ICRC)

Consistent with Sgr A*





Extragalactic sources of VHE gamma rays



M87

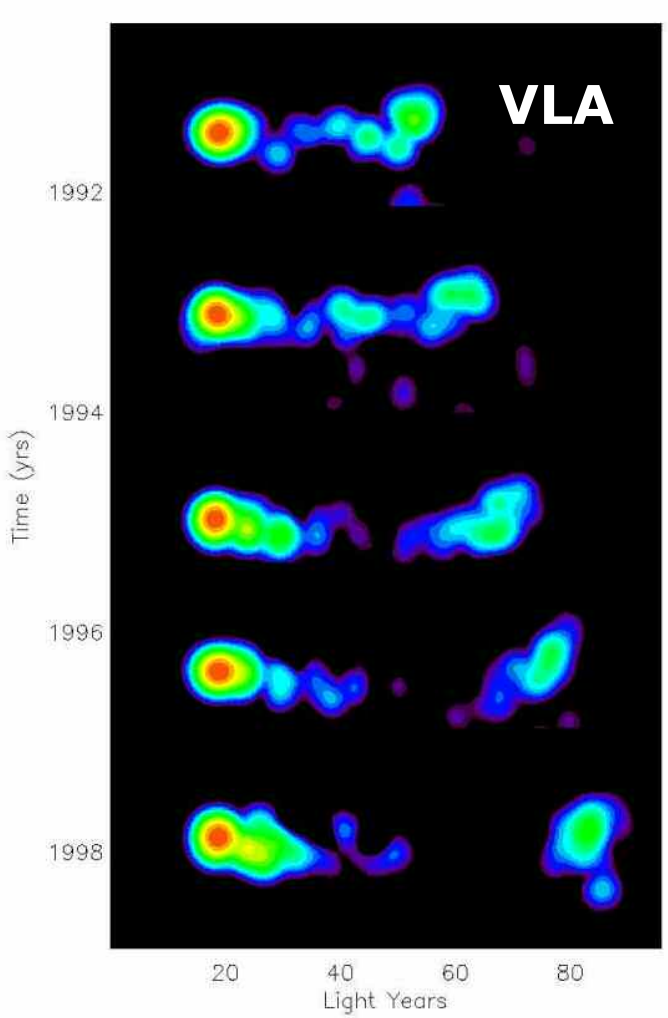
- Observations I: New sources and source types
- Observations II: Rapid variability
- Source physics
- Propagation physics I: Quantum gravity limits
- Propagation physics II: Extragalactic background light

Observations I: New sources and source types

▶ N. Turini

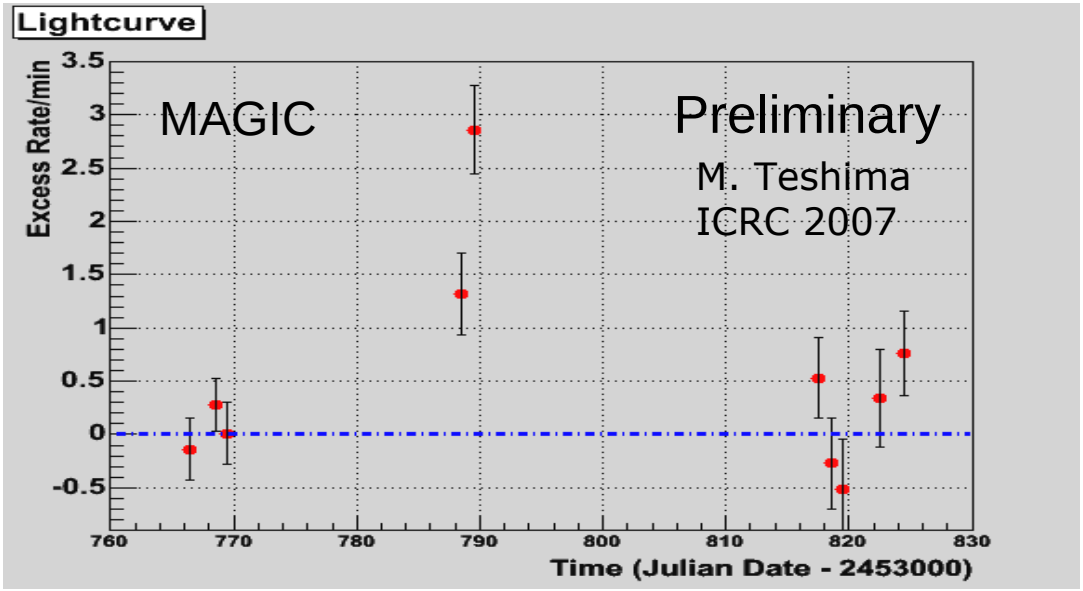
Name	Type	Redshift	Signif.	Discovered	
			***: >10		
M 87	FR I	0.004	***	HEGRA	
Mrk 421	BL Lac	0.031	***	Whipple	
Mrk 501	BL Lac	0.034	***	Whipple	
1ES 2344+514	BL Lac	0.044	***	Whipple	
Mrk 180	BL Lac	0.046	5.5	MAGIC	optical trig.
1ES 1959+650	BL Lac	0.047	***	TA	
BL Lac	BL Lac	0.069	5.1	MAGIC	
PKS 0548-322	BL Lac	0.069	5.8	HESS	
PKS 2005-489	BL Lac	0.071	***	HESS	
PKS 2155-304	BL Lac	0.116	***	Durham	
H 1426+428	BL Lac	0.129	7.5 / 5	Whipple	
1ES 0229+200	BL Lac	0.14	6.6	HESS	
H 2356-309	BL Lac	0.165	***	HESS	
1ES 1218+304	BL Lac	0.182	9 / 6.4	MAGIC	
1ES 1101-232	BL Lac	0.186	***	HESS	
1ES 0347-121	BL Lac	0.188	***	HESS	
1ES 1011+496	BL Lac	0.212	***	MAGIC	optical trig.
PG 1553+113	BL Lac	?	***	HESS/MAGIC	
3C 279	FSRQ	0.536	~8 (trials?)	MAGIC	

The most distant: MAGIC - 3C 279 (z=0.536)



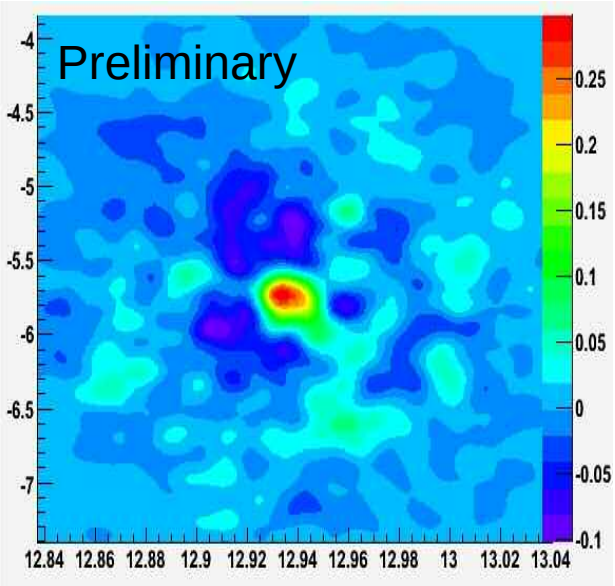
Wehrle et al., ApJSS 133 (2001) 297

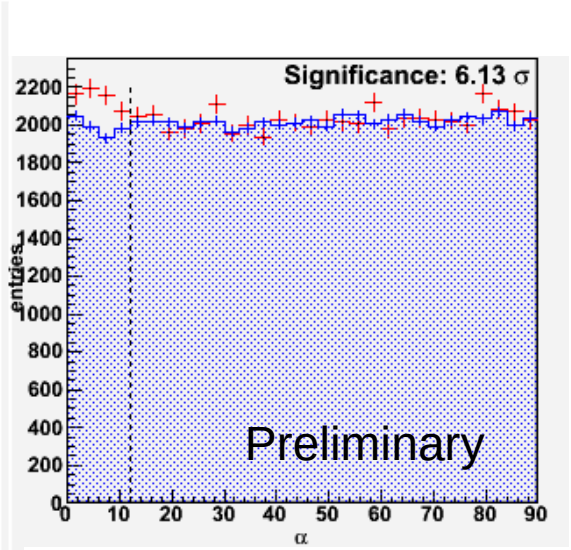
Flat spectrum radio quasar (FSRQ)
Strong and flaring EGRET blazar
Superluminal motion
$\beta > 0.99c$, jet angle 2^o-4^o δ=12-21
Piner et al, ApJ 588 (2003) 716

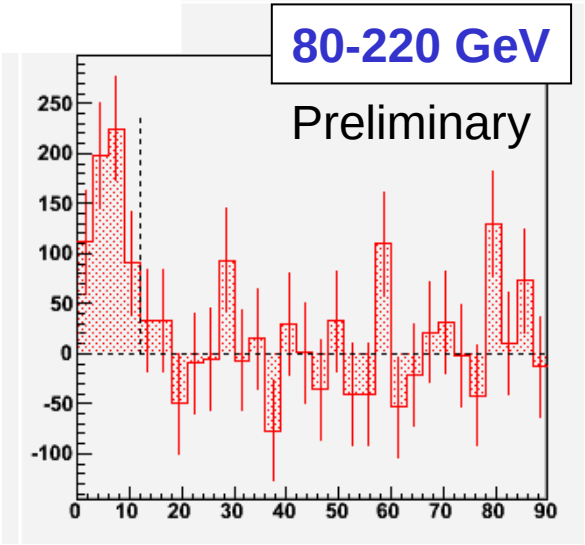


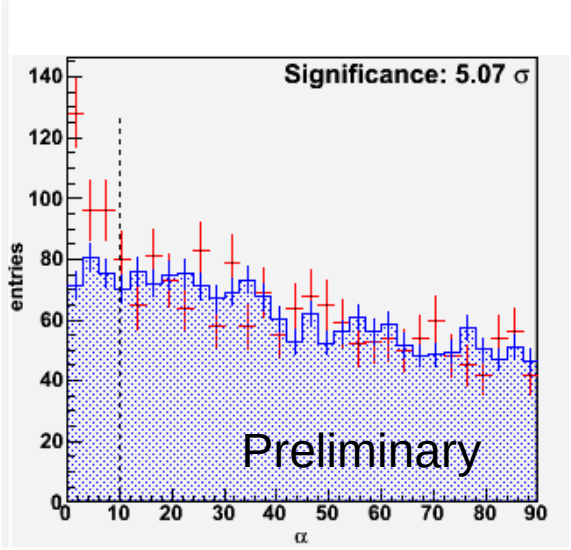
The most distant: MAGIC - 3C 279

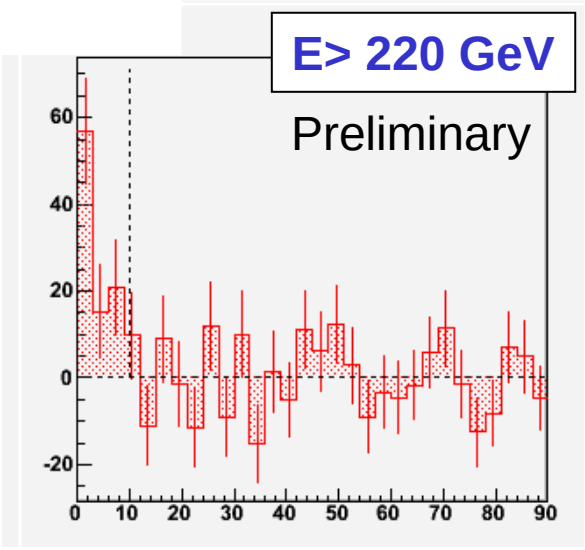
Sky map for
Feb 23, 2006





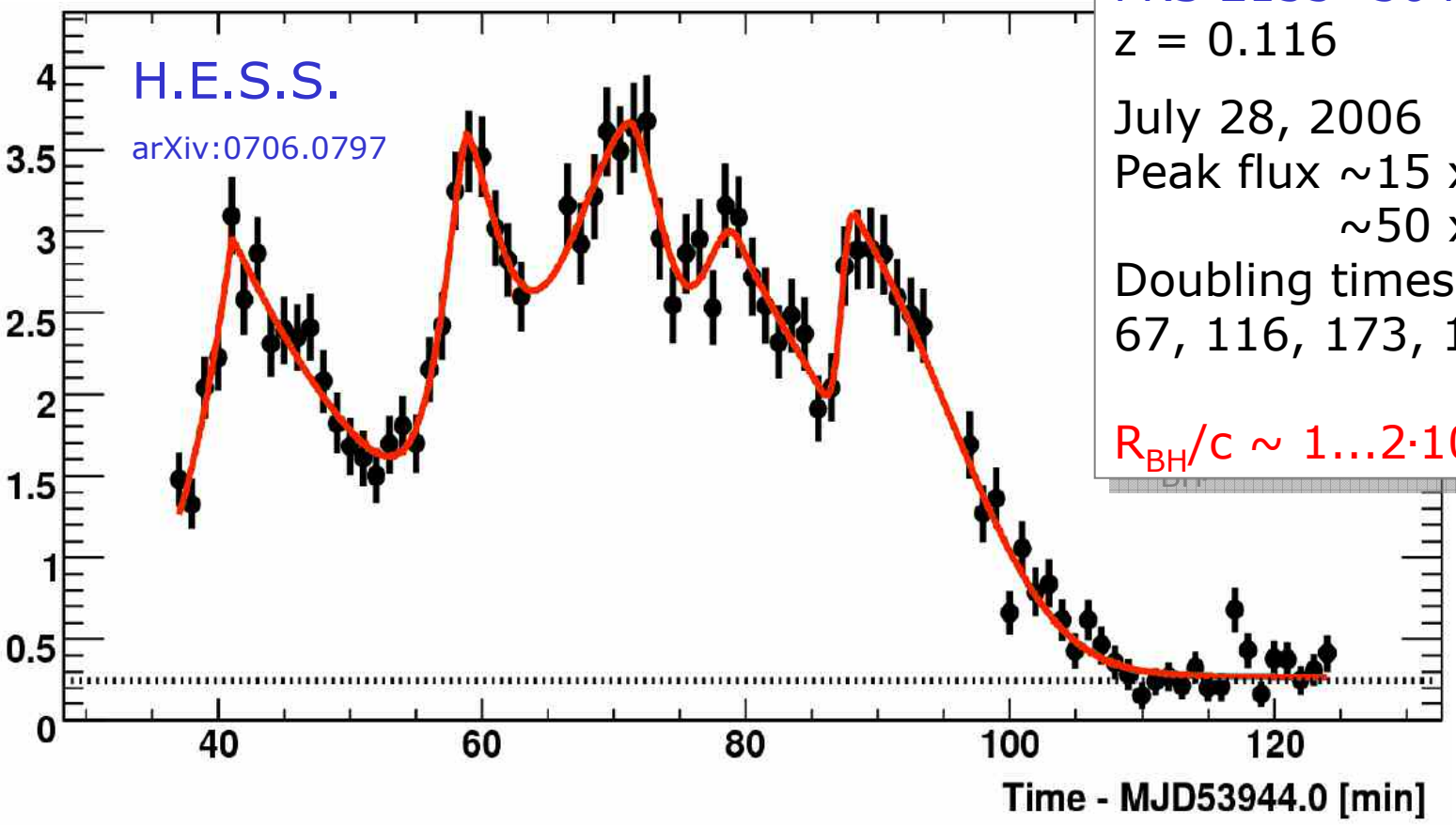






M. Teshima
ICRC 2007

Observations II: Rapid variability



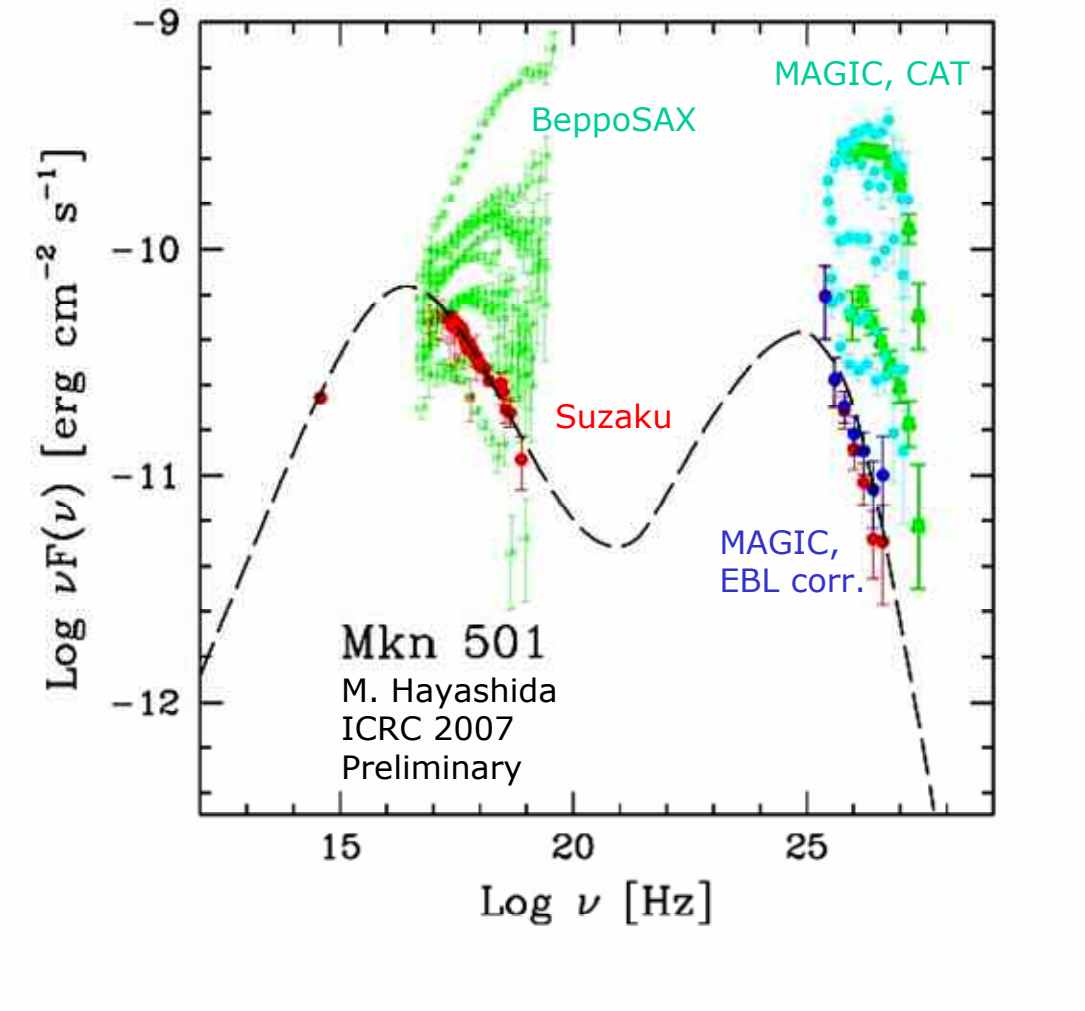
PKS 2155−304
z = 0.116

July 28, 2006
Peak flux ~15 x Crab
~50 x average
Doubling times
67, 116, 173, 178 ±50 s

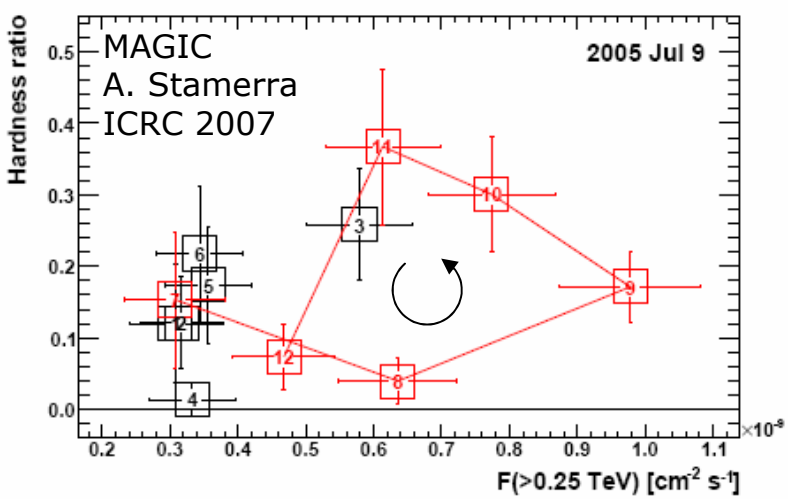
$R_{BH}/c \sim 1...2 \cdot 10^4$ s

Source physics

- N. Turini
- D. Paneque

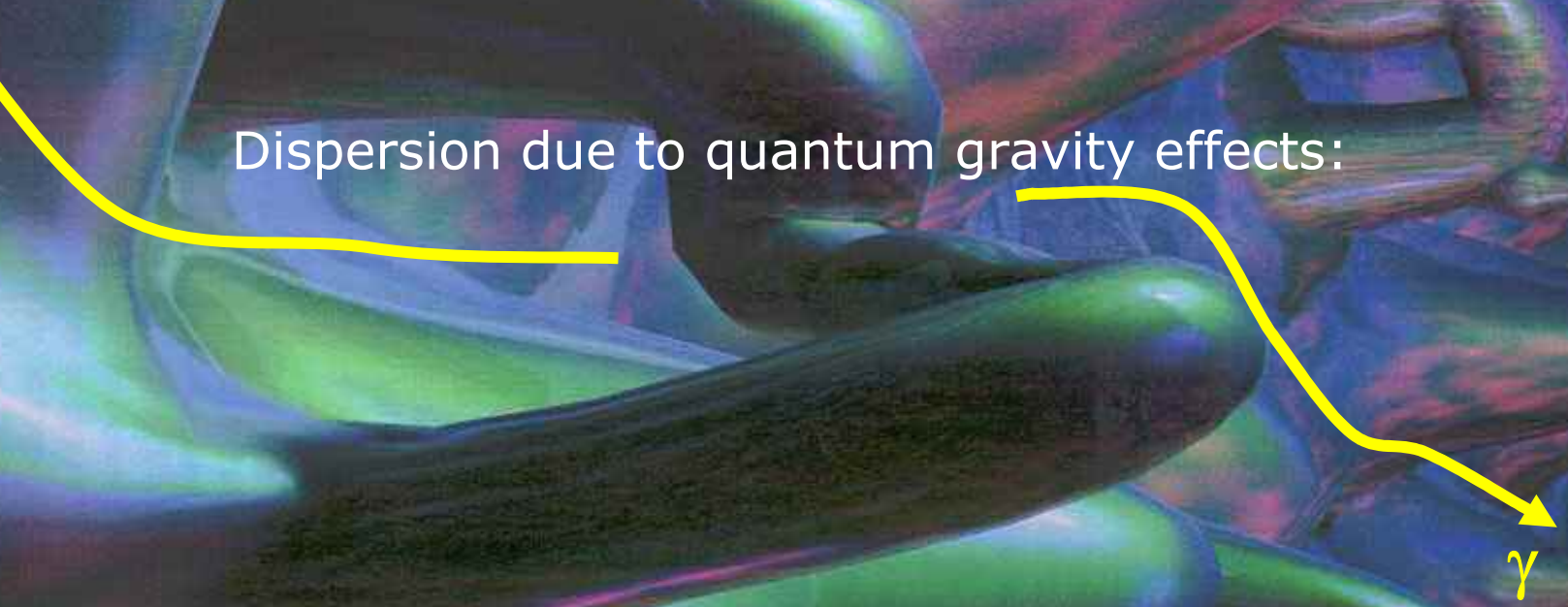


- Single-zone SSC models fit bulk of data
- Real model selectivity from time dependence/ delay of X-ray, VHE-γ flux and index



Propagation physics

Dispersion due to quantum gravity effects:



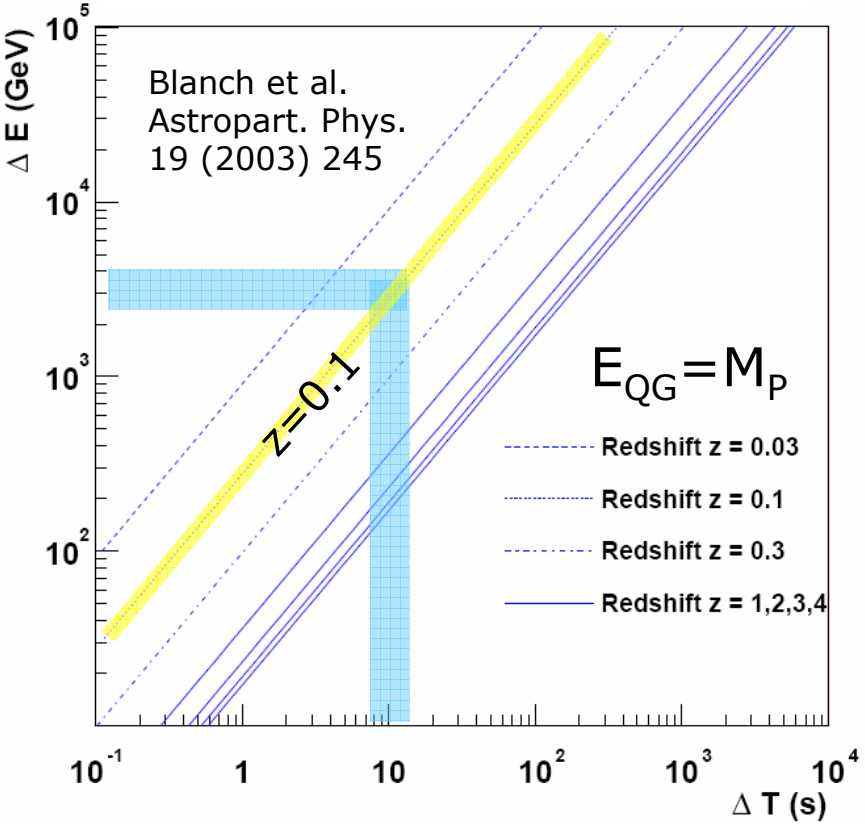
Absorption:

visible/infrared light accumulated by all stars in history of Universe

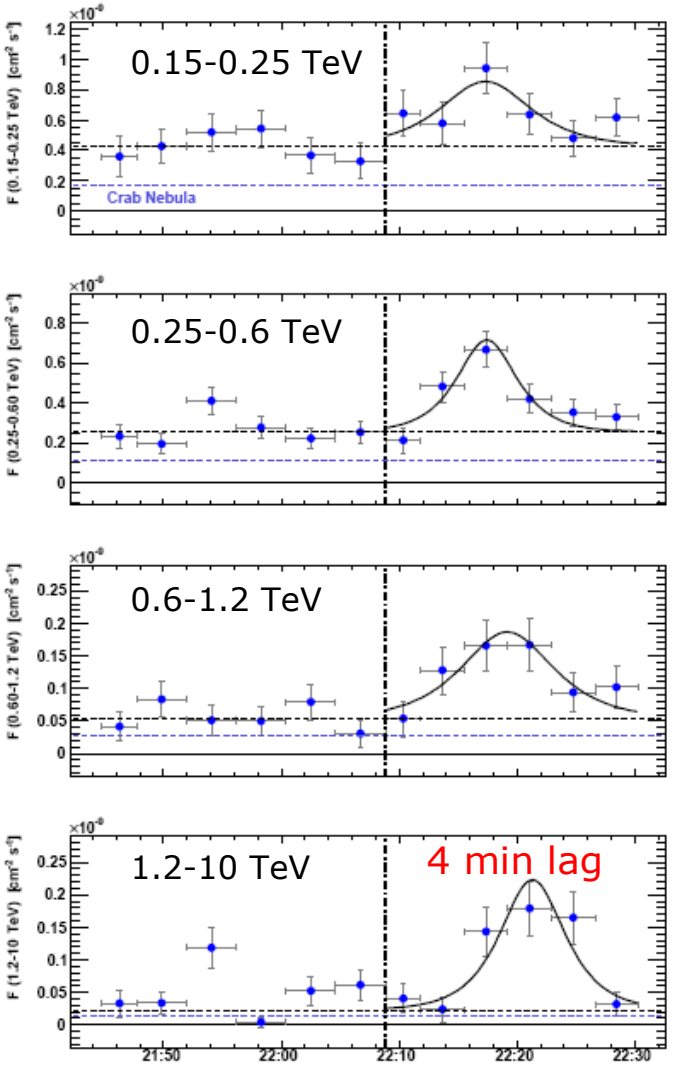
Propagation physics I: Quantum gravity limits

- **S. Wagner**
- **A. Sakharov**

$$\Delta t \sim \xi \frac{E}{E_{QG}} \frac{z}{H_0} = \xi \frac{E}{E_{QG}} \frac{L}{c}$$

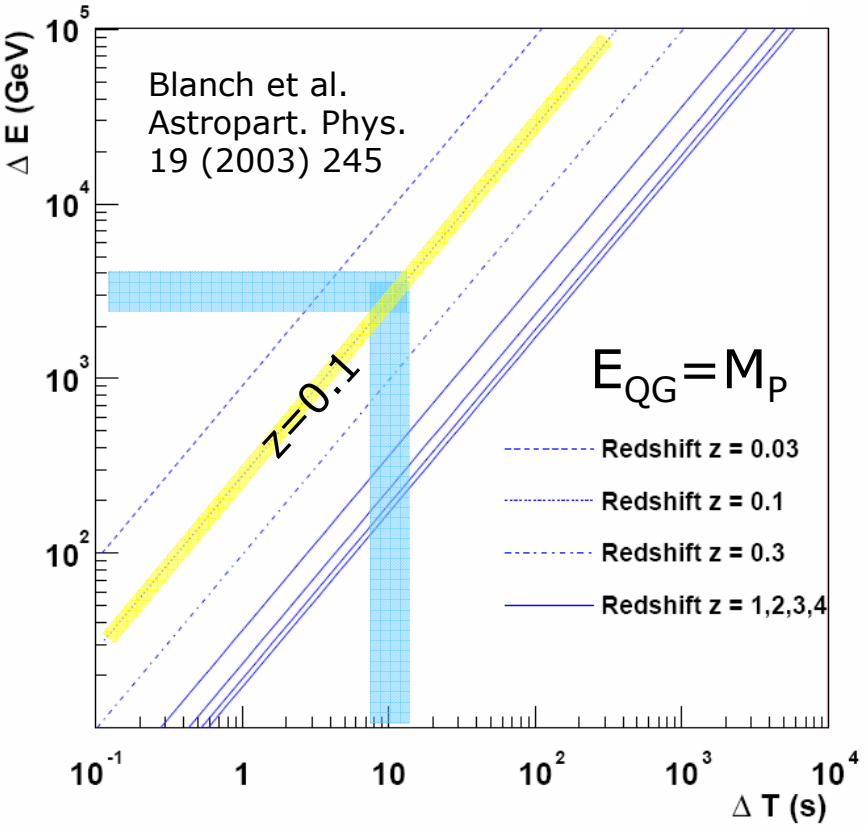


Mrk 501,
MAGIC, astro-ph/0702008



Propagation physics I: Quantum gravity limits

$$\Delta t \sim \xi \frac{E}{E_{QG}} \frac{z}{H_0} = \xi \frac{E}{E_{QG}} \frac{L}{c}$$



MAGIC Mrk 501, arXiv:0708.2889

$E_{QG} \sim 0.03\ M_P$

$E_{QG} > 0.02\ M_P$

HESS PKS 2155, ICRC 2007 prel.

$E_{QG} > 0.04\ M_P$

Whipple 1999, PRL 83(1999)2108

$E_{QG} > 0.005\ M_P$

GRB X-ray limits:

$E_{QG} > 0.001 \ldots 0.01\ M_P$

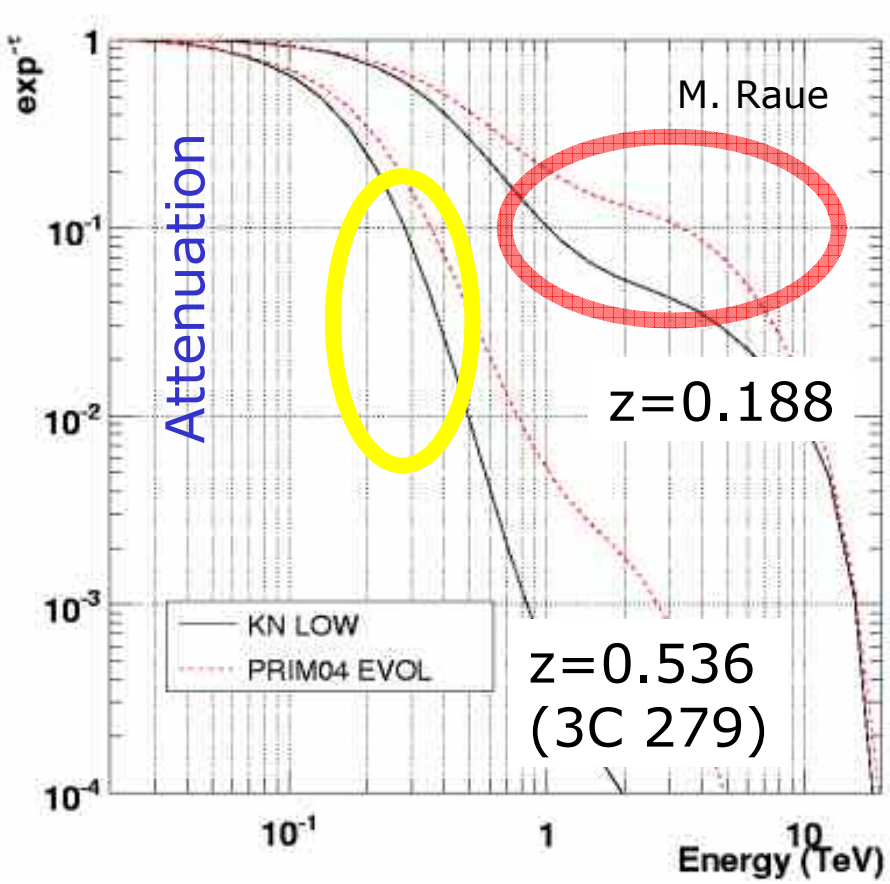
… but in most scenarios

$\Delta t \sim (E/E_{QG})^{\alpha}$, $\alpha > 1$

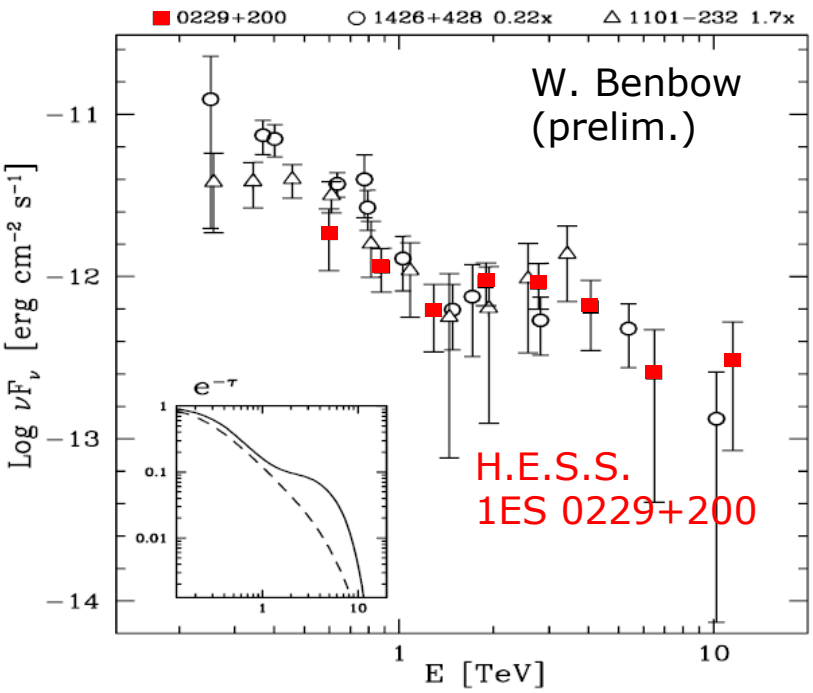
- VHE gamma rays even better
- Mrk 501: $E_{QG} > 3 \cdot 10^{-9}\ M_P$, $\alpha = 2$

Propagation physics II: Extragalactic background light

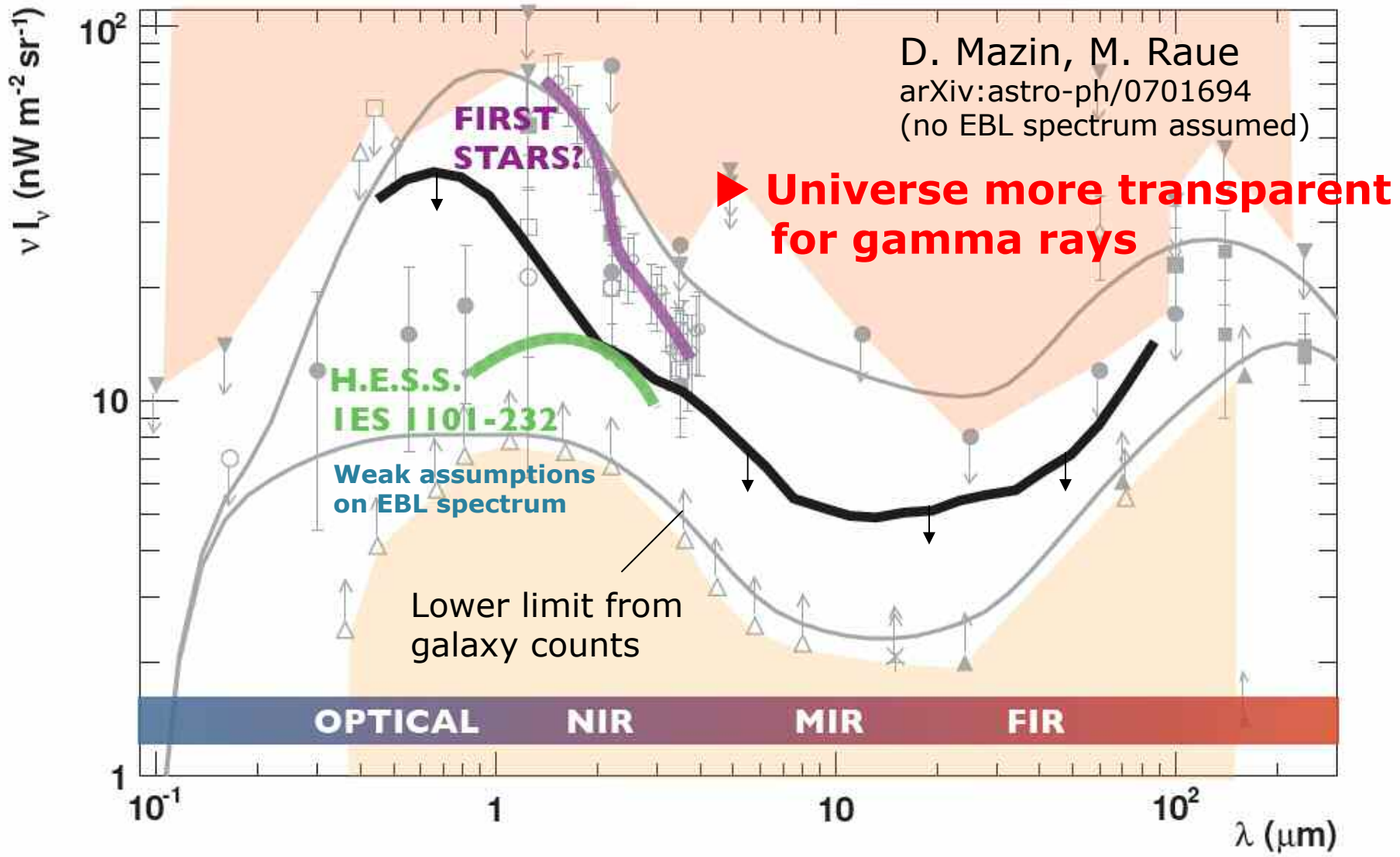
3C 279 spectrum at >0.2 TeV should be very VERY steep …



Shape of multi-TeV spectra probe EBL slope at mid-IR



Propagation physics II: Extragalactic background light



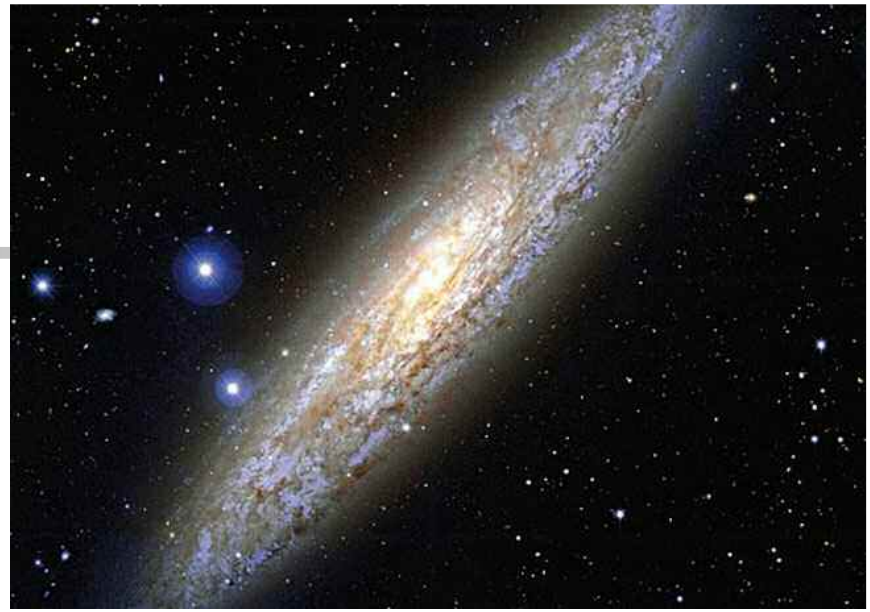
Limits

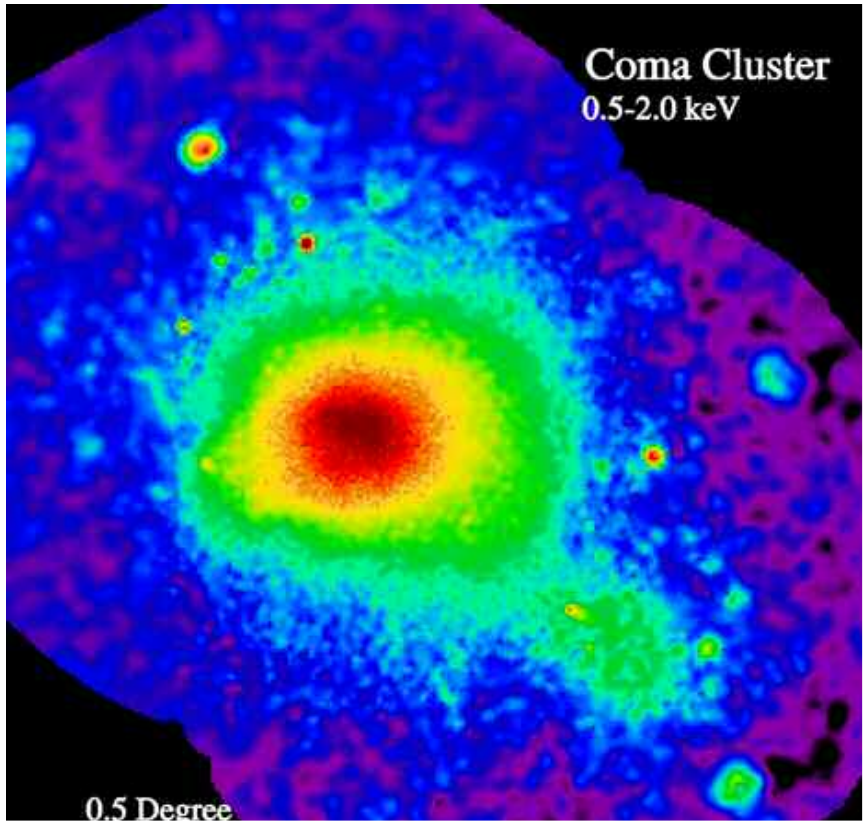
Object classes with upper limits:

- Dwarf galaxies & DM
- Starbust galaxies (NGC 253, M83)
- Ultraluminous IR galaxies (Arp 220)
- Galaxy clusters (Abell 496, 2029, 3667, 4038, Coma, Perseus…)
- GRBs
  - MAGIC: 23 follow-ups of GRBs
  - HESS: 17 follow-ups, 1 prompt GRB obs: GRB060602b
  - MILAGRO
  - AS-γ
  - …

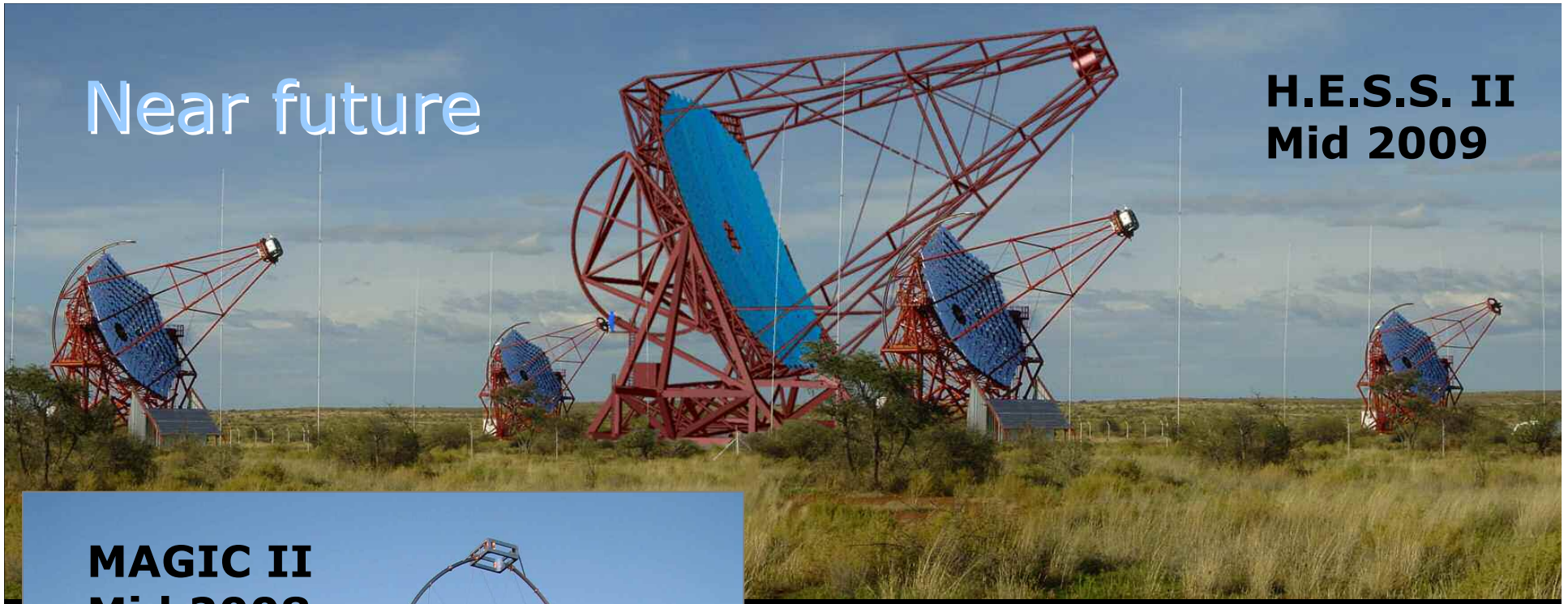
Limits often not far from predictions

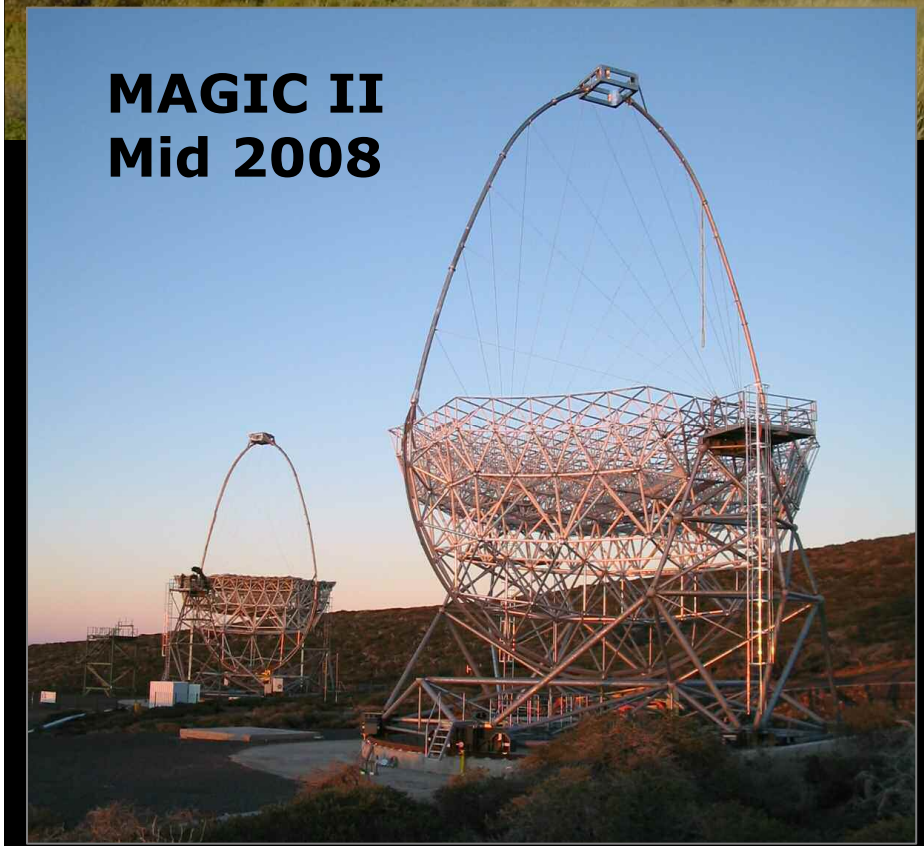
But no strong constraints on models (yet)





Near future





Longer-term future

- CTA Observatory
- AGIS
- HAWC
- …

▶ L. Drury