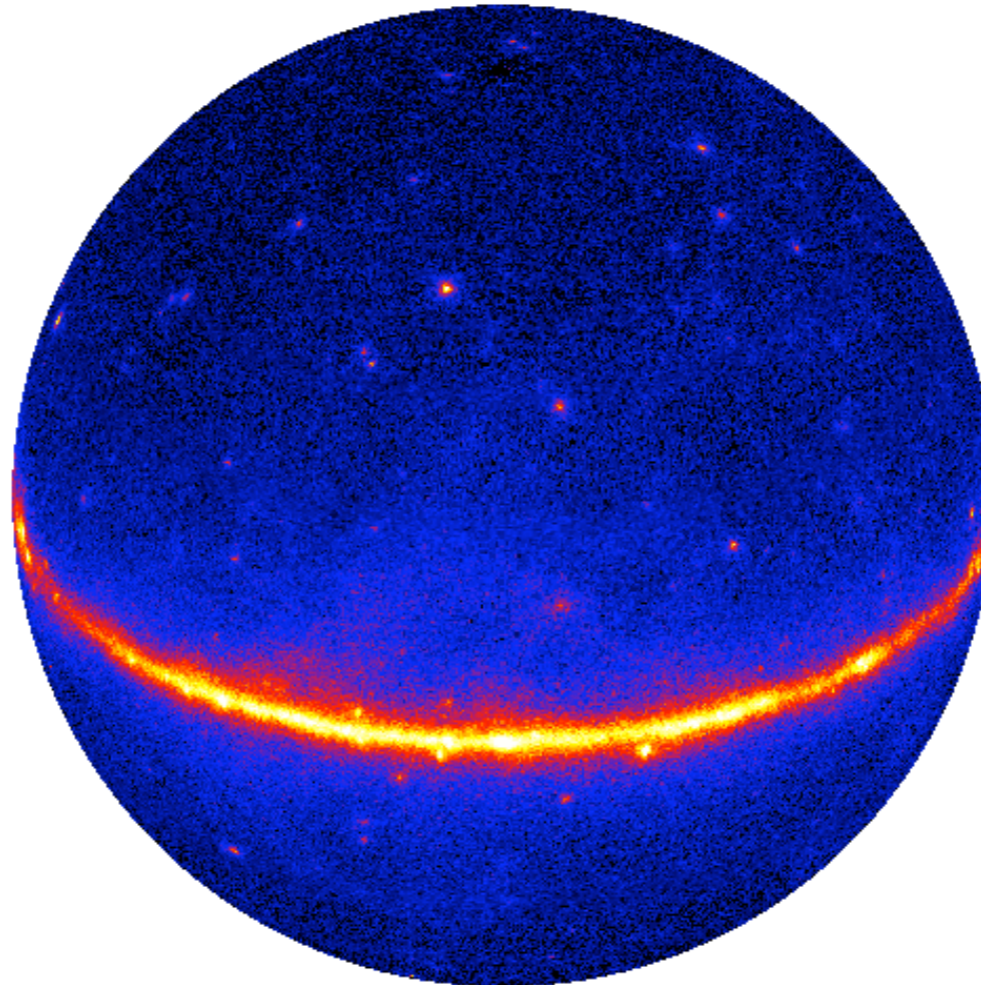


the animated GeV sky by Fermi

Isabelle Grenier
Université Paris Diderot
& CEA Saclay

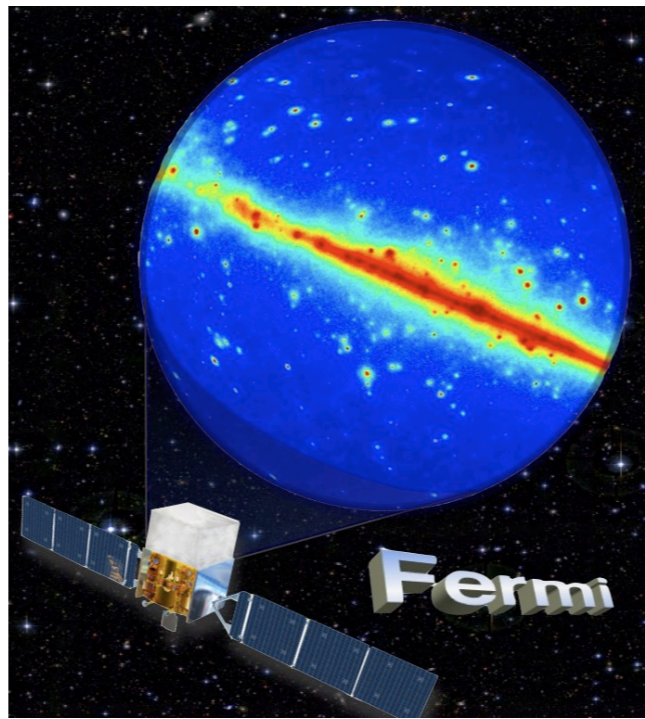


on behalf of
the Fermi-LAT
collaboration

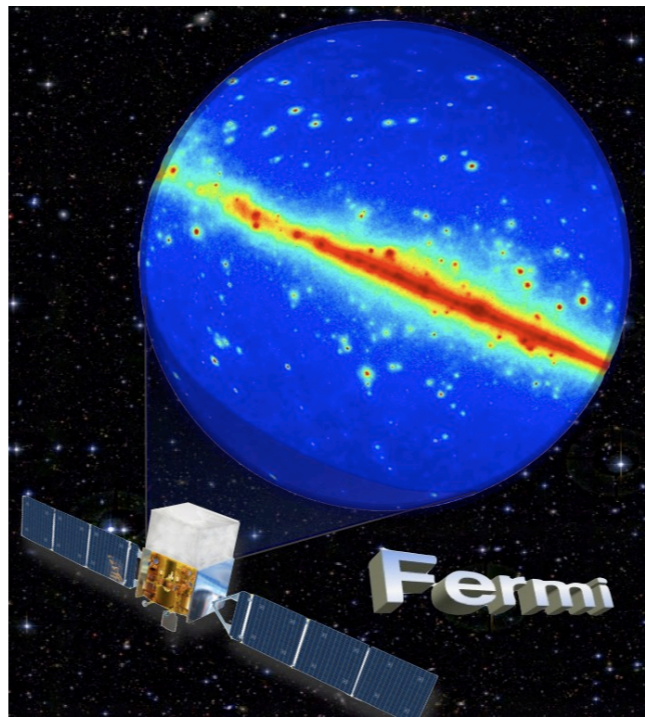
Fermi instruments

- launched in June 2008
 - lifetime 5 + 5 years
- Large Area Telescope (LAT)
 - 20 MeV – 300 GeV
- GLAST Burst Monitor (GBM)
 - 8 keV – 30 MeV
 - all sky not occulted by Earth

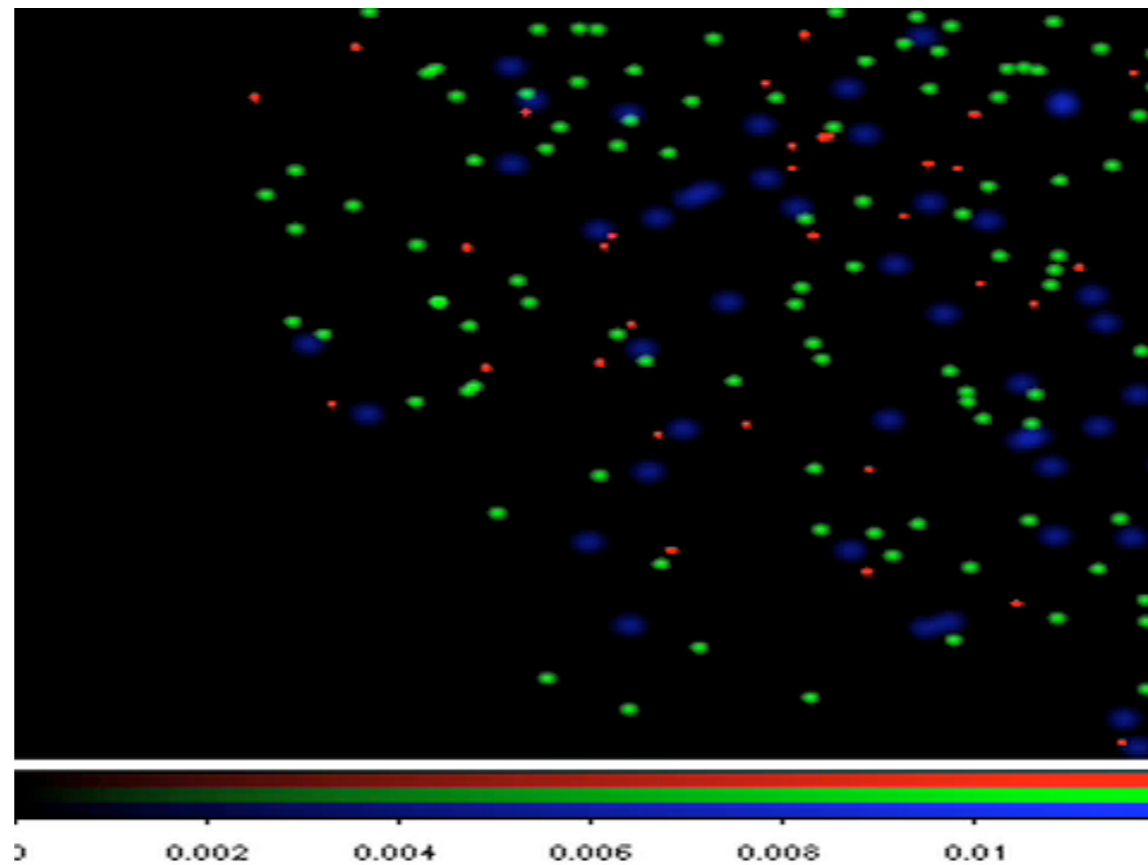




γ -ray bursts



γ -ray bursts



a short one

so far: > 160 GBM events, > 5 LAT events

GRB081024B

- first short GRB with $\gamma > \text{GeV}$

- delayed and longer-lasting emission at high energy

- single Band spectrum

- $\gamma + \gamma \rightarrow e^\pm$ constraints

$\Gamma > 150$ at $z = 0.1$

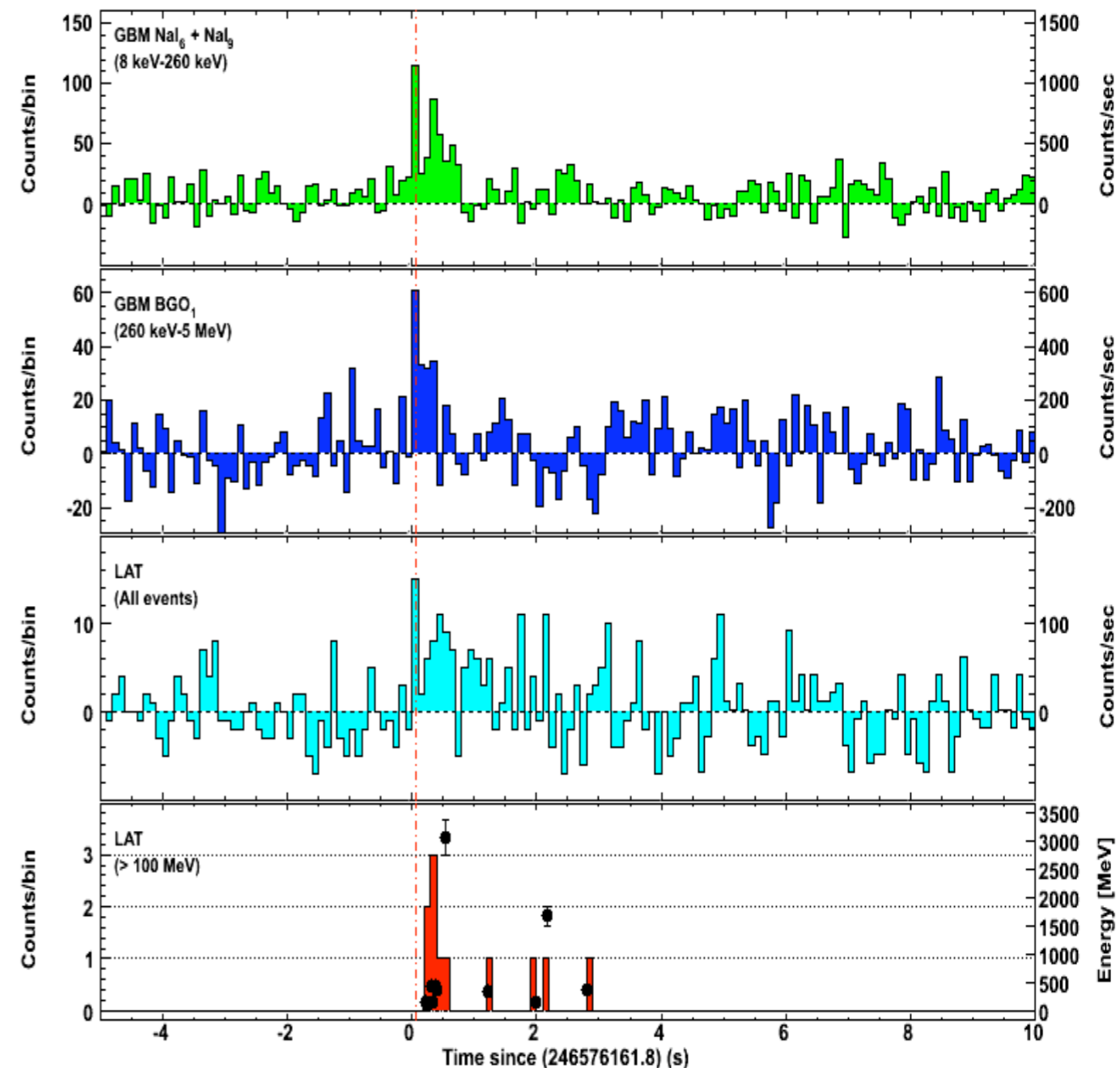
$\Gamma > 900$ at $z = 3.0$

- origin of lasting HE γ rays?

- why with 2nd GBM peak?

- why delayed after sub-MeV?

PRELIMINARY

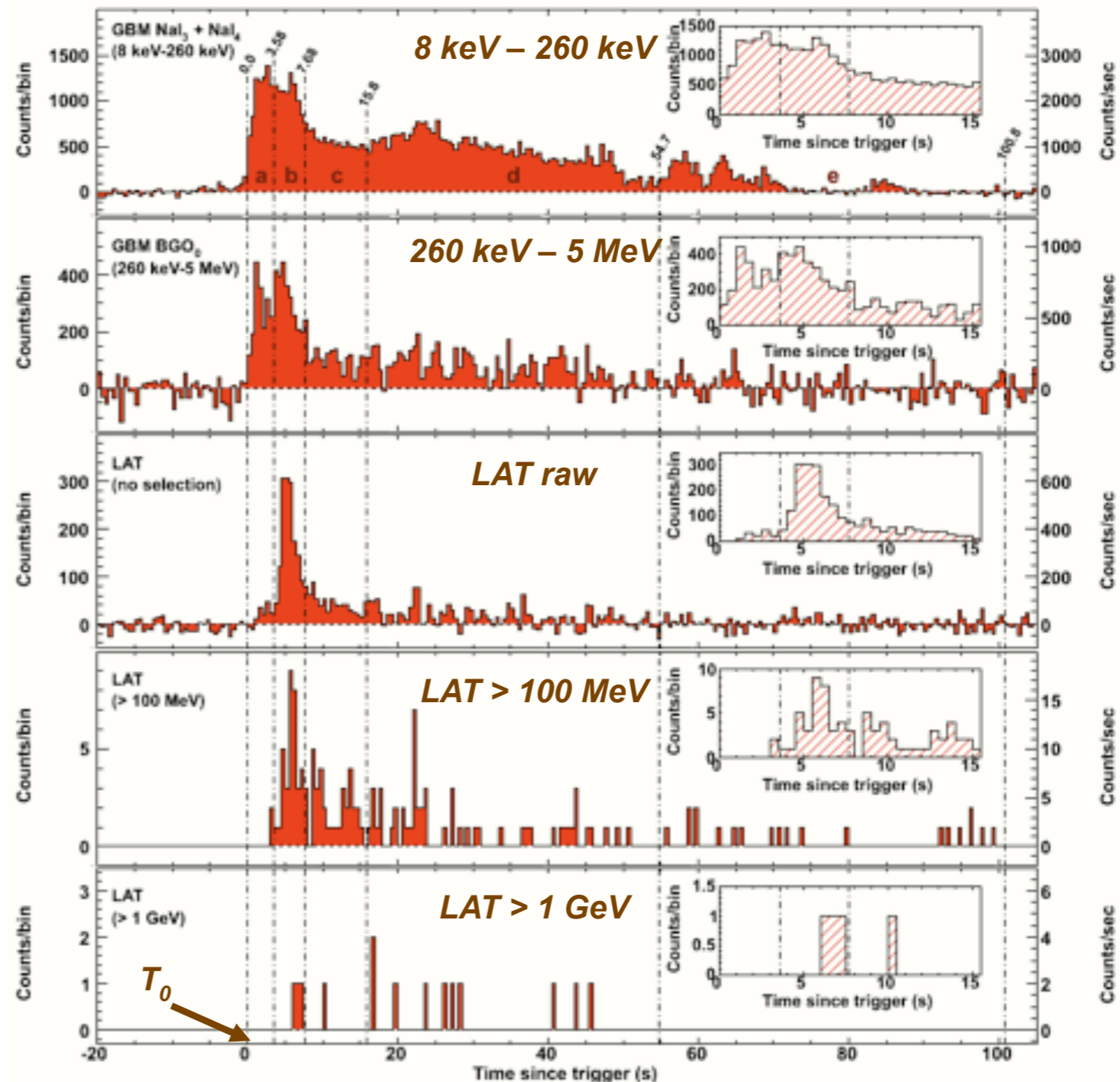


a long one

GRB080916C: $z = 4.35 \pm 0.15$ (GROND)

- delayed and 23mn-lasting γ rays
- Band spectrum $E_\gamma \leq 13$ GeV ($E_{\text{rest}} \leq 170$ GeV)
- $E_{\text{iso}} = 8.8 \cdot 10^{47} \text{ J} = 4.9 M_\odot c^2$
- beamed: $\Gamma > 890 \pm 20$
- X-ray afterglow after 17h

PRELIMINARY

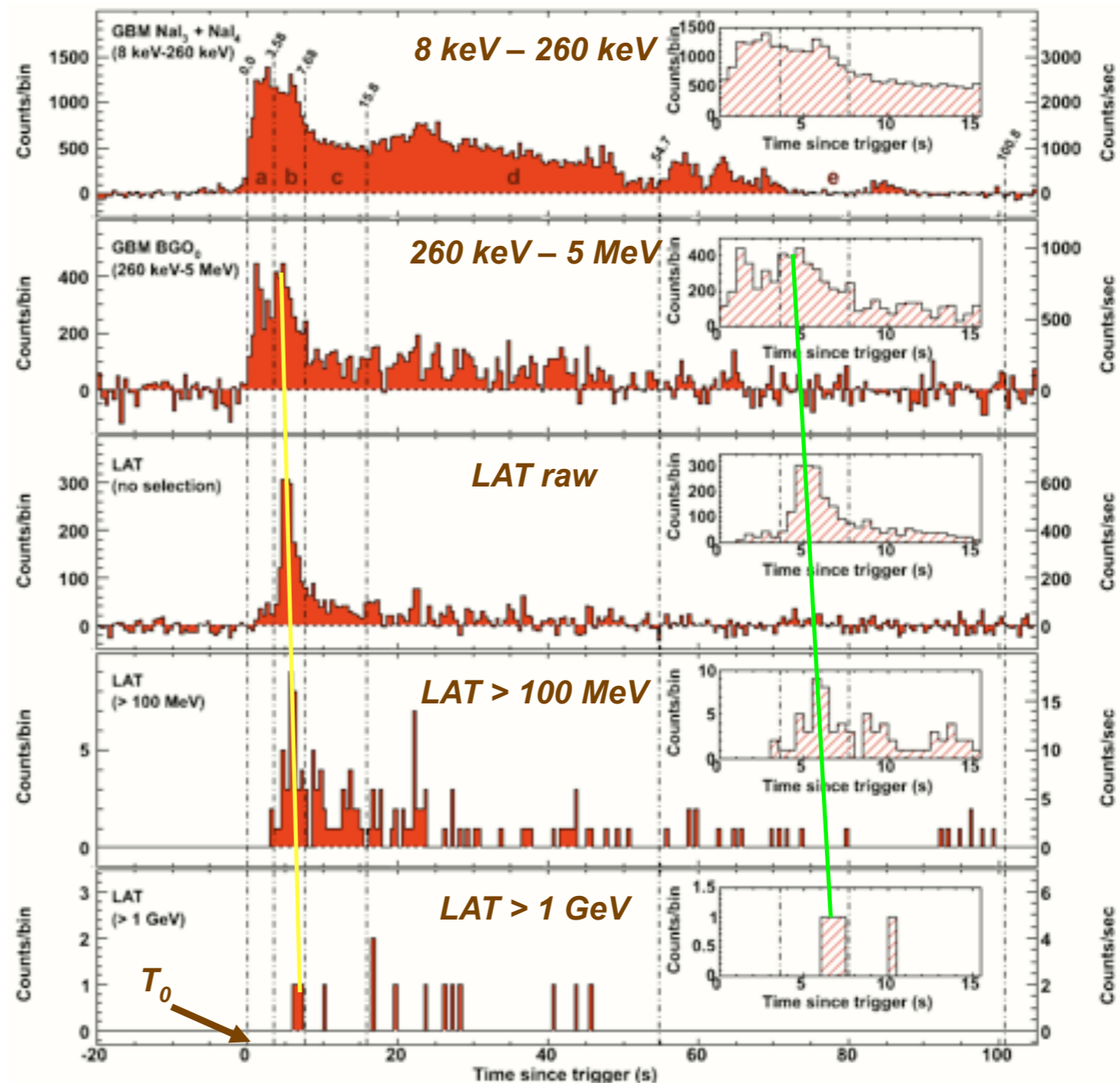


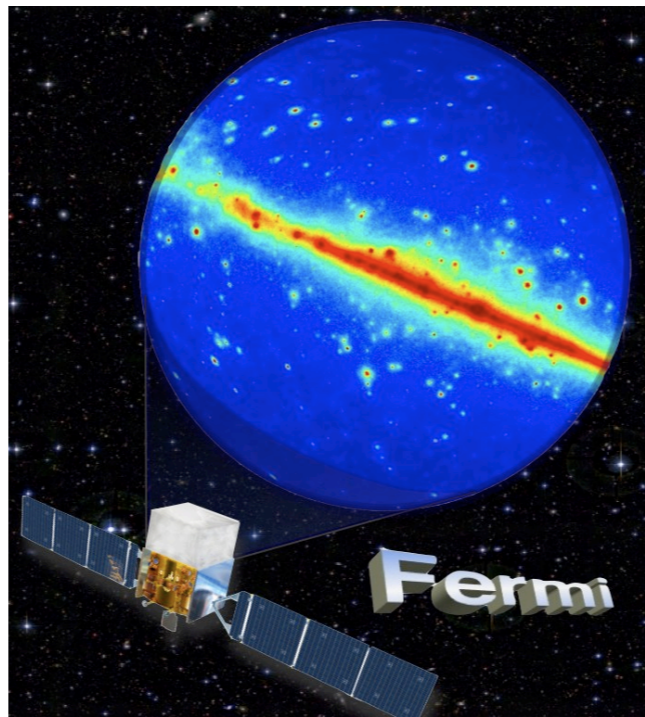
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PRELIMINARY





the animated GeV sky

the LAT telescope

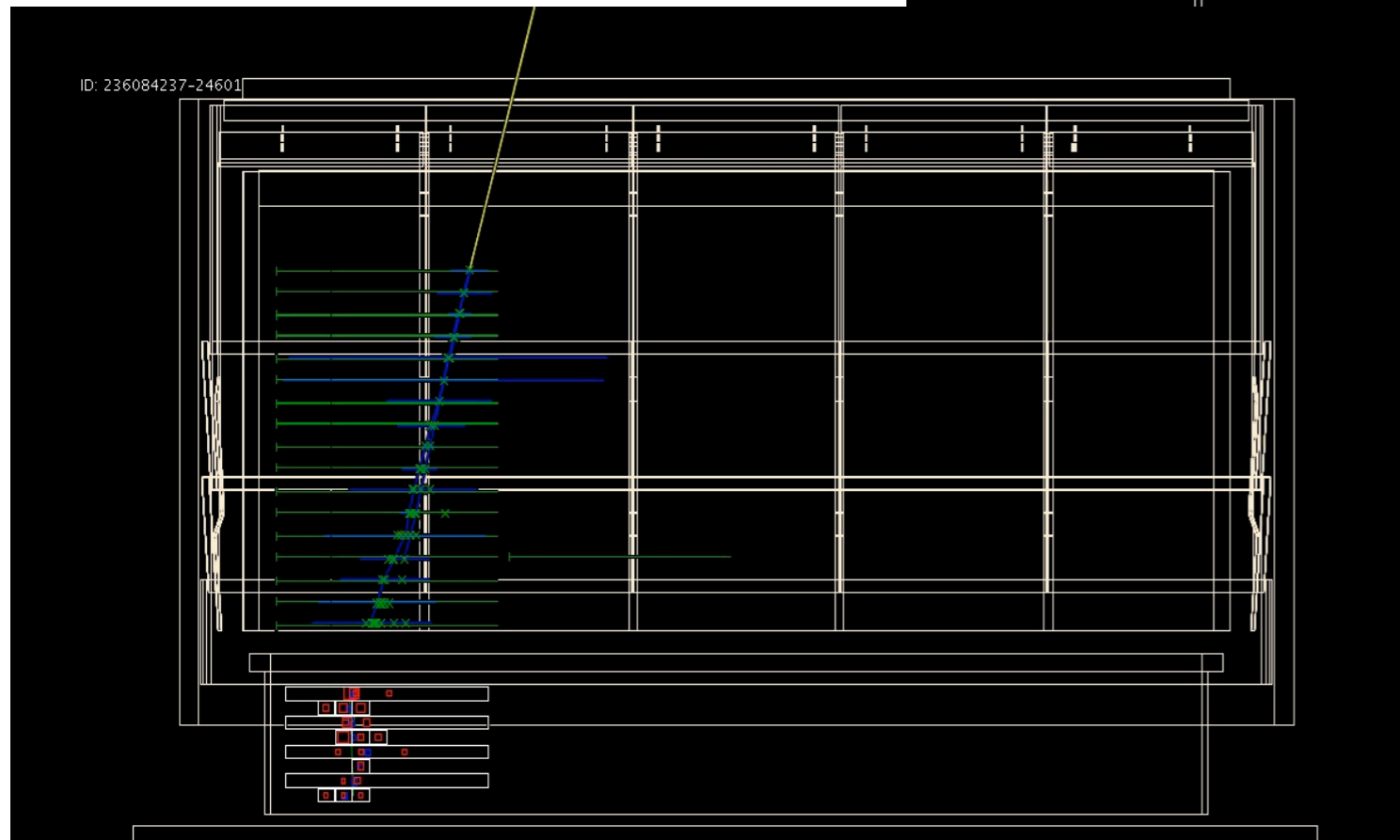
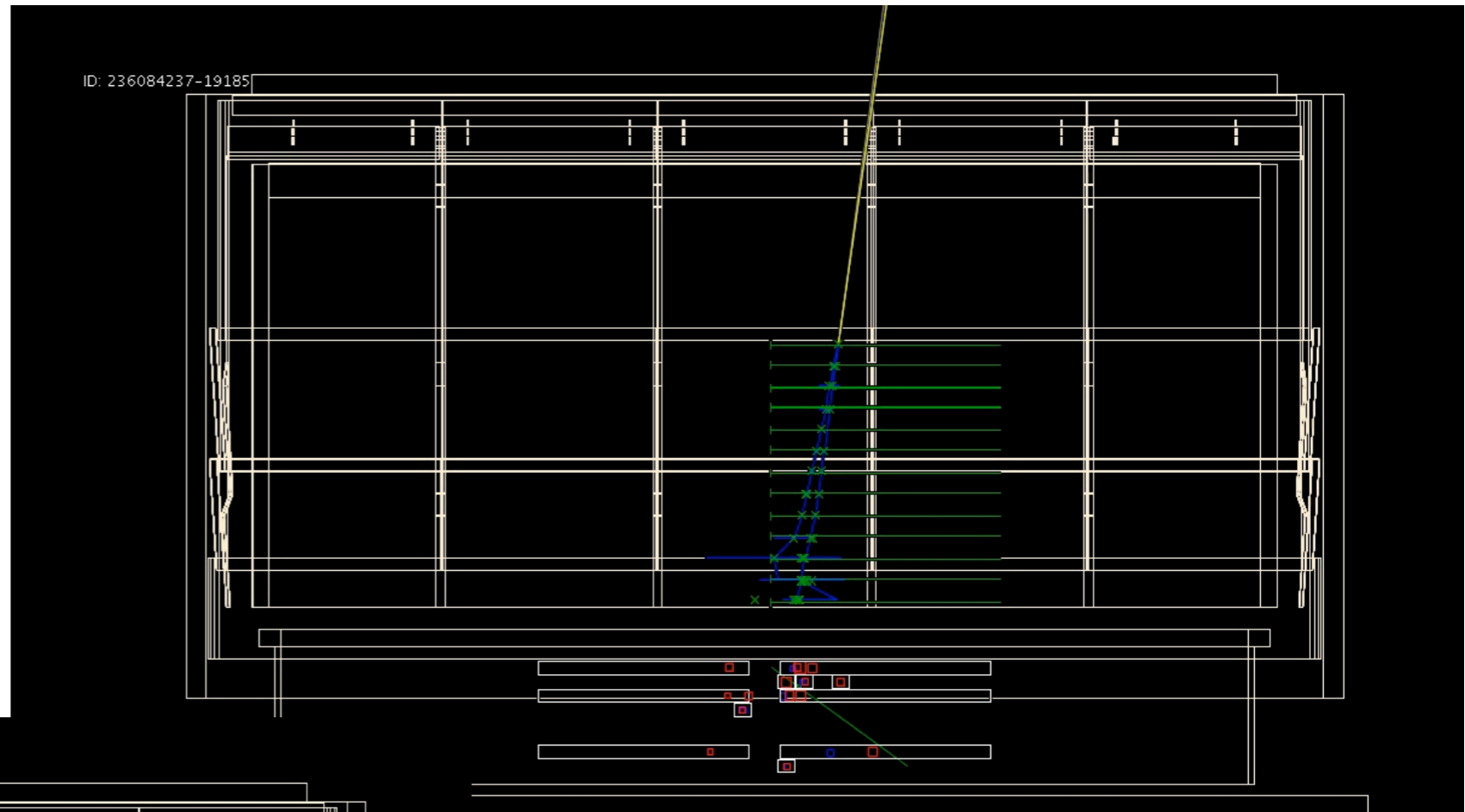


PSF HWHM

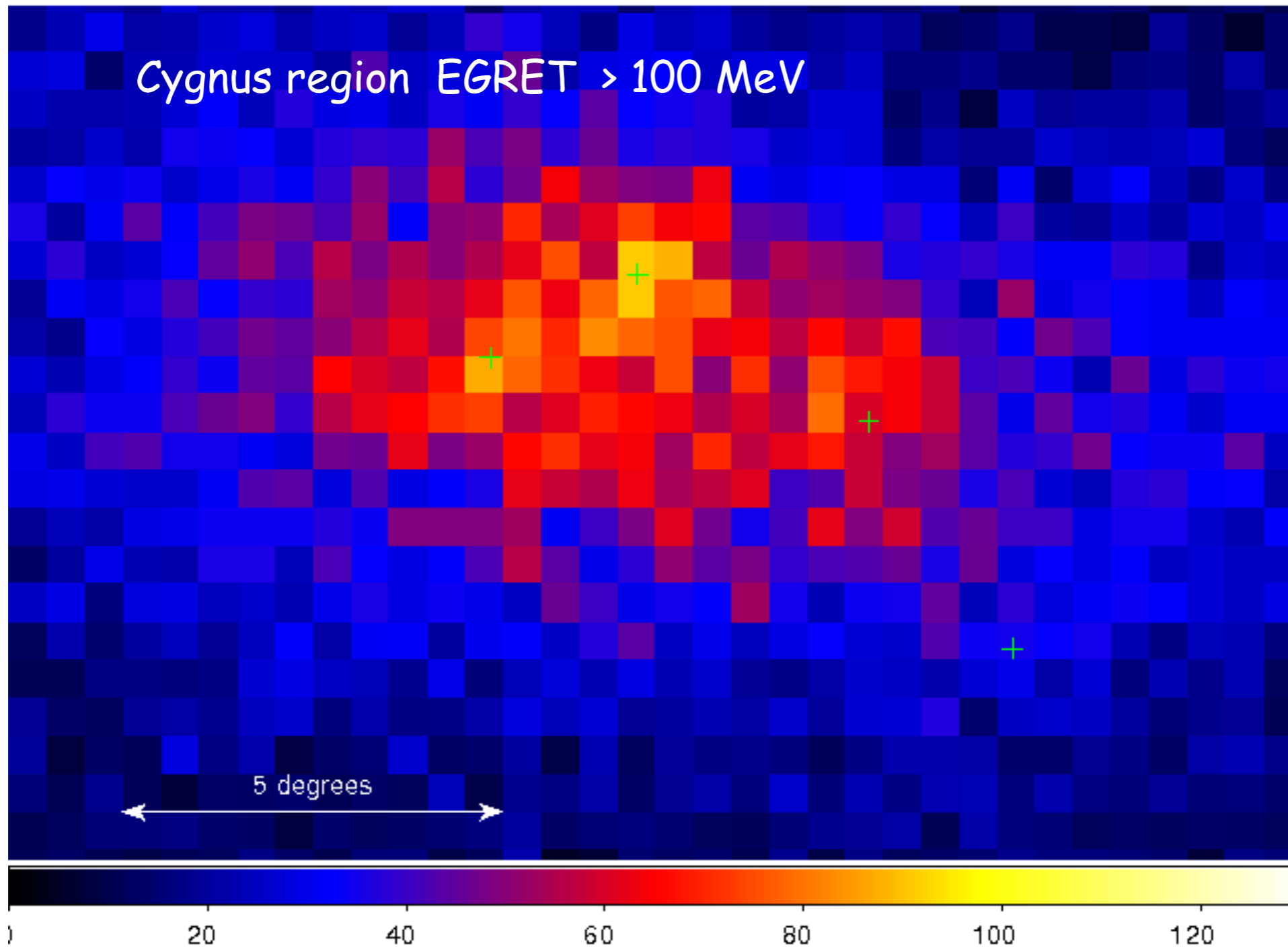
- for E^{-2} source
- 0.1-1 GeV band: 0.6°
- 1-100 GeV: 0.05°



2.4 sr (20% sky)

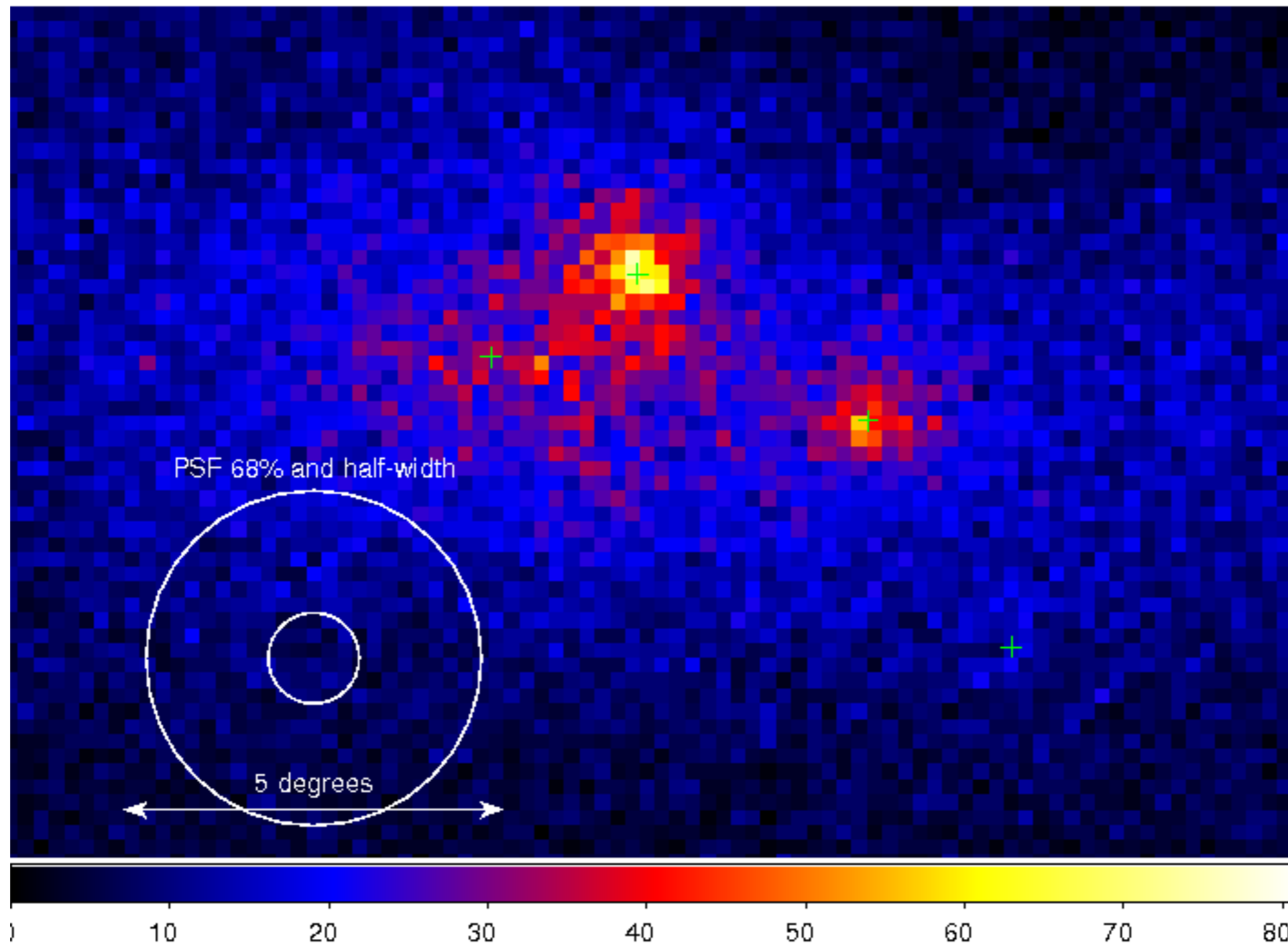


with old EGRET eyes

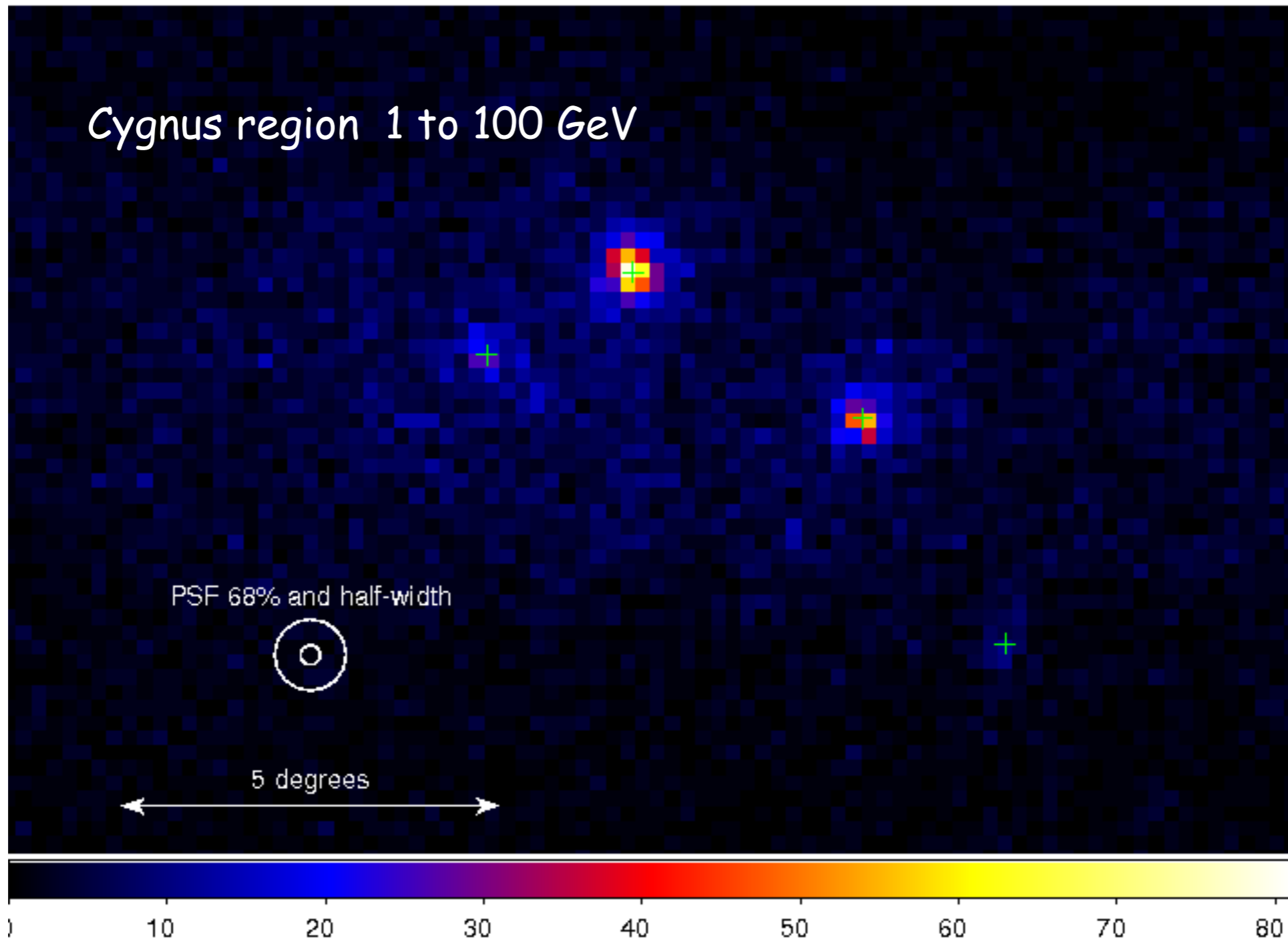


sharper Fermi eyes


-  Cygnus region: 0.1-1 GeV, 3 months

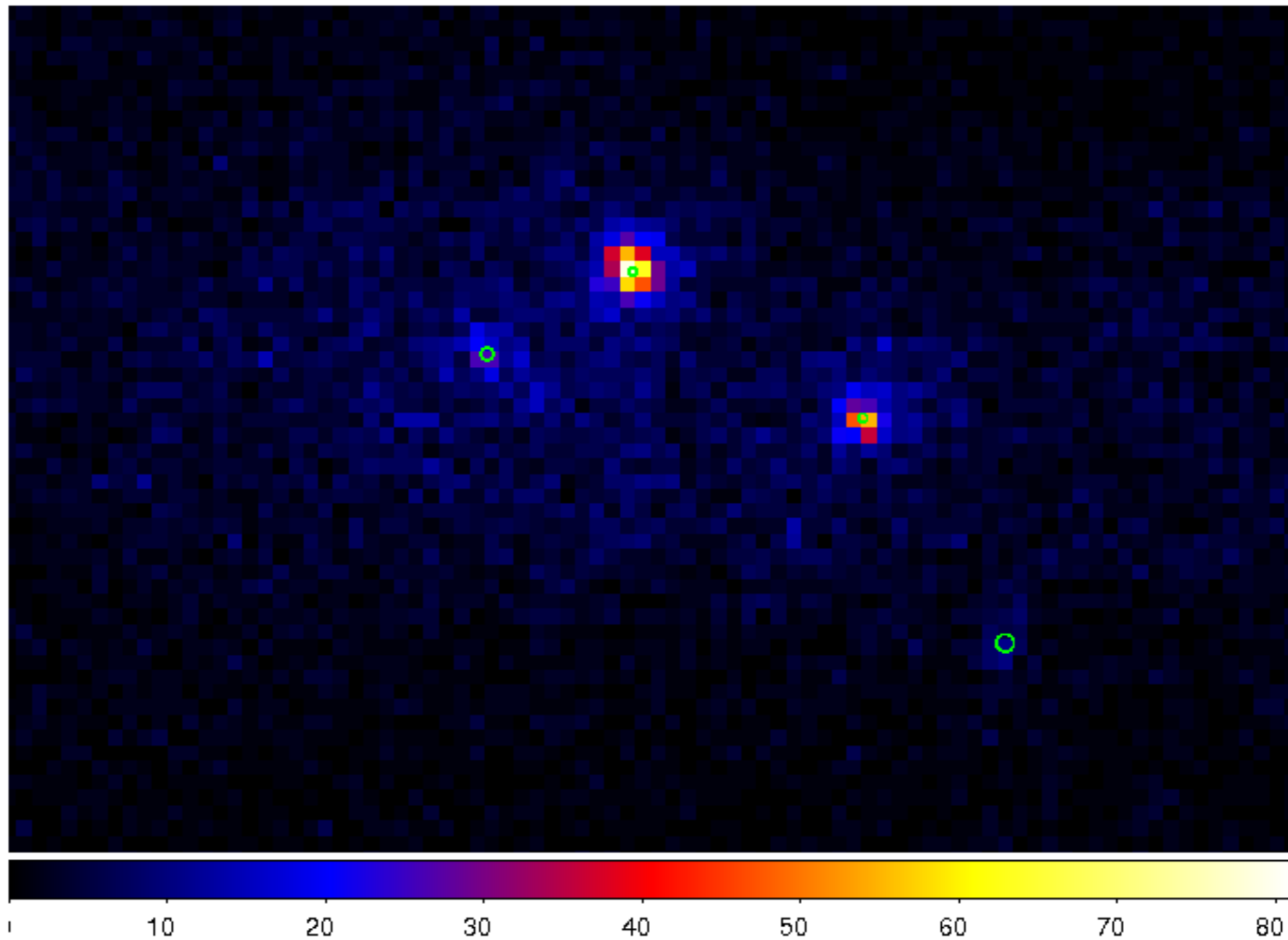


energy-dependent eyes



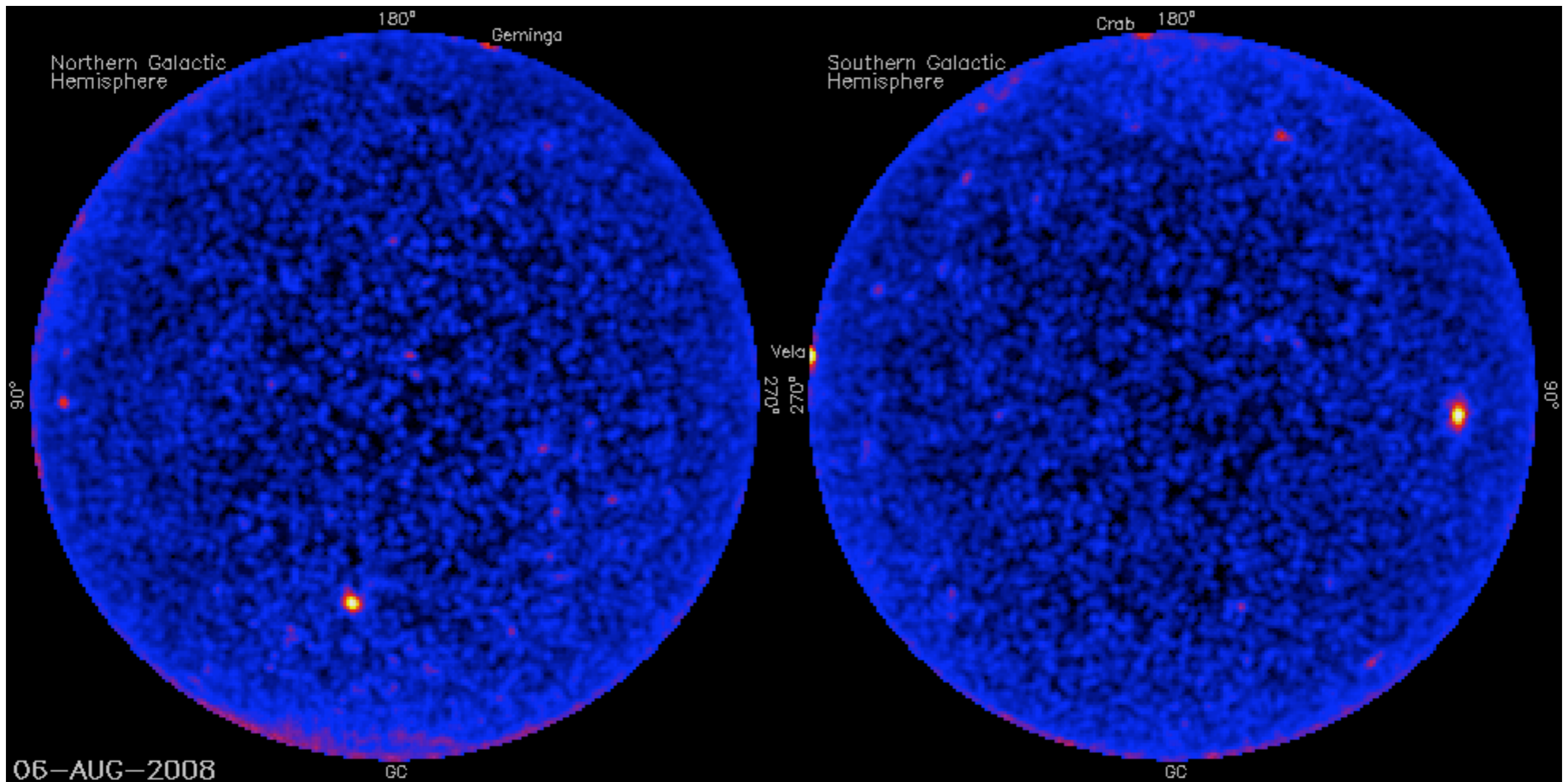
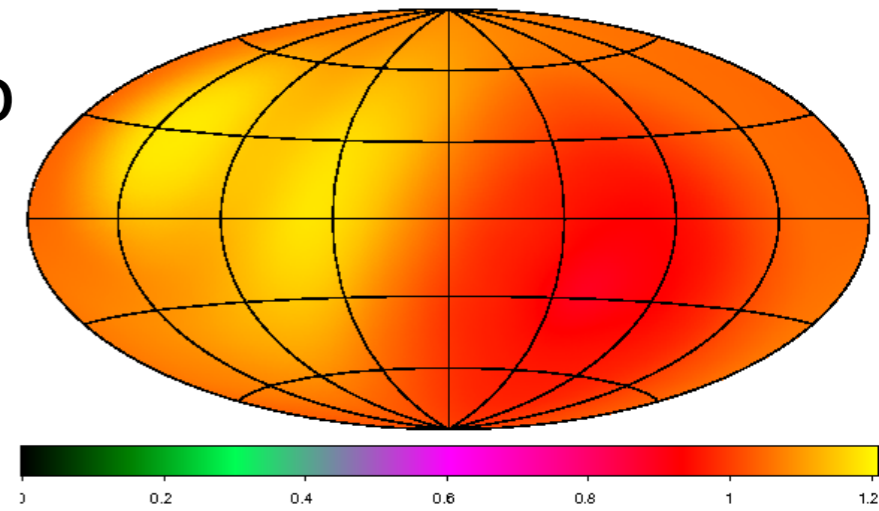
better localization

-  OFGL sources, 95% error circles



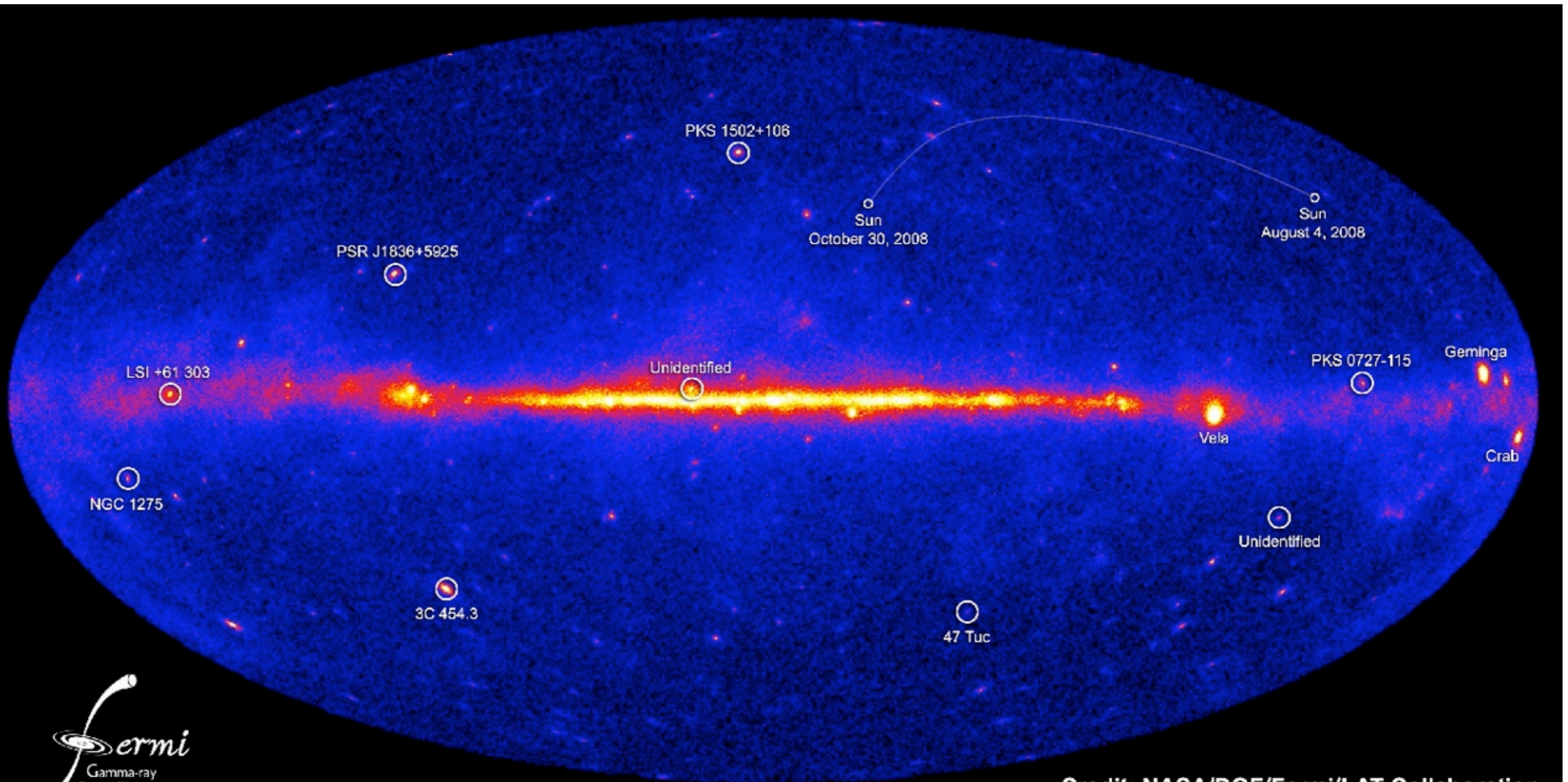
twinkling sky

- what sensitivity and smooth exposure can do
< 30% exposure variations (SAA)
- whole sky every 3 hours
- variability: minutes, hours, days, months



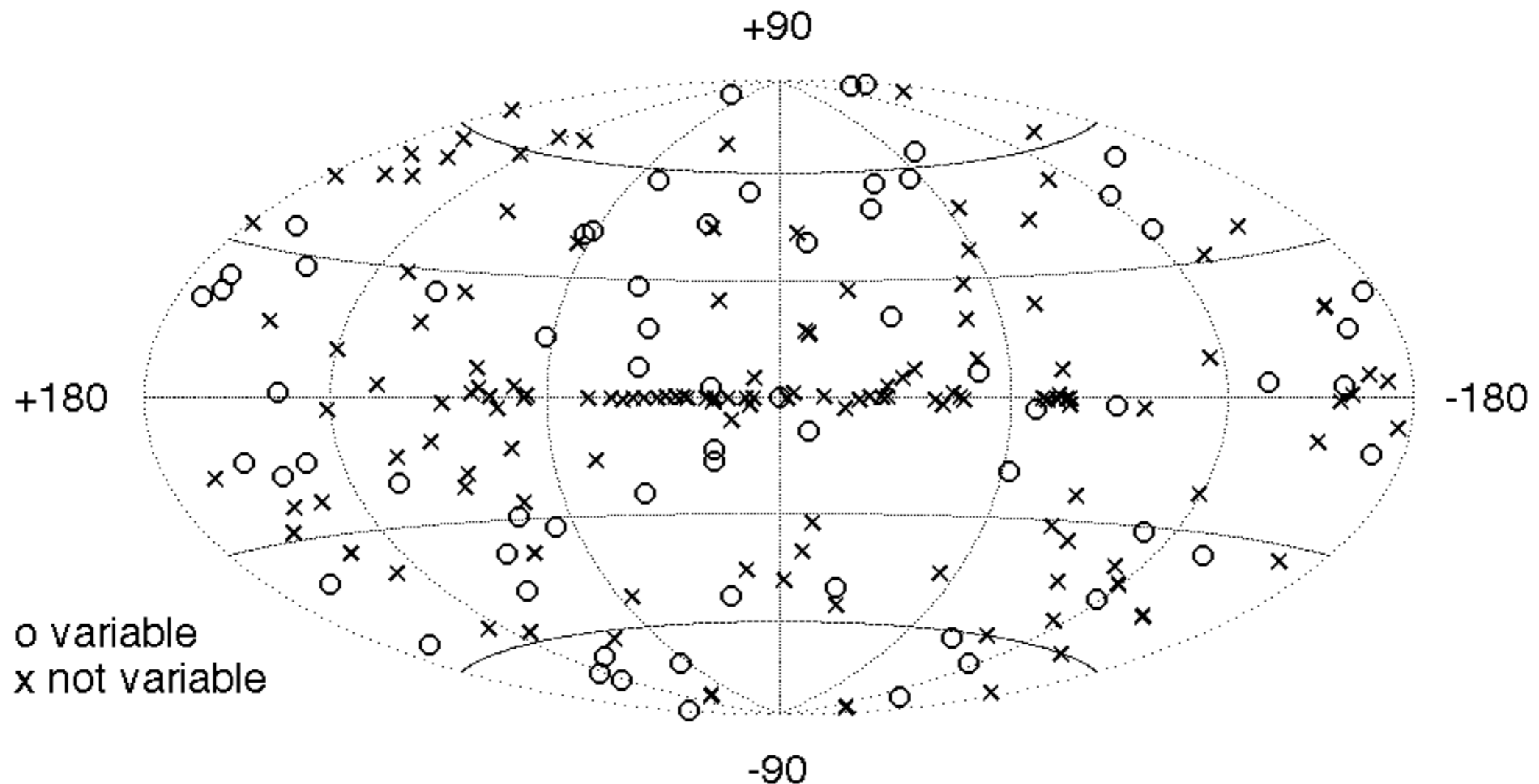
source detection

- wavelet detection
- max-likelihood: TS evaluation, spectrum characterization
- interstellar emission model needs improvement



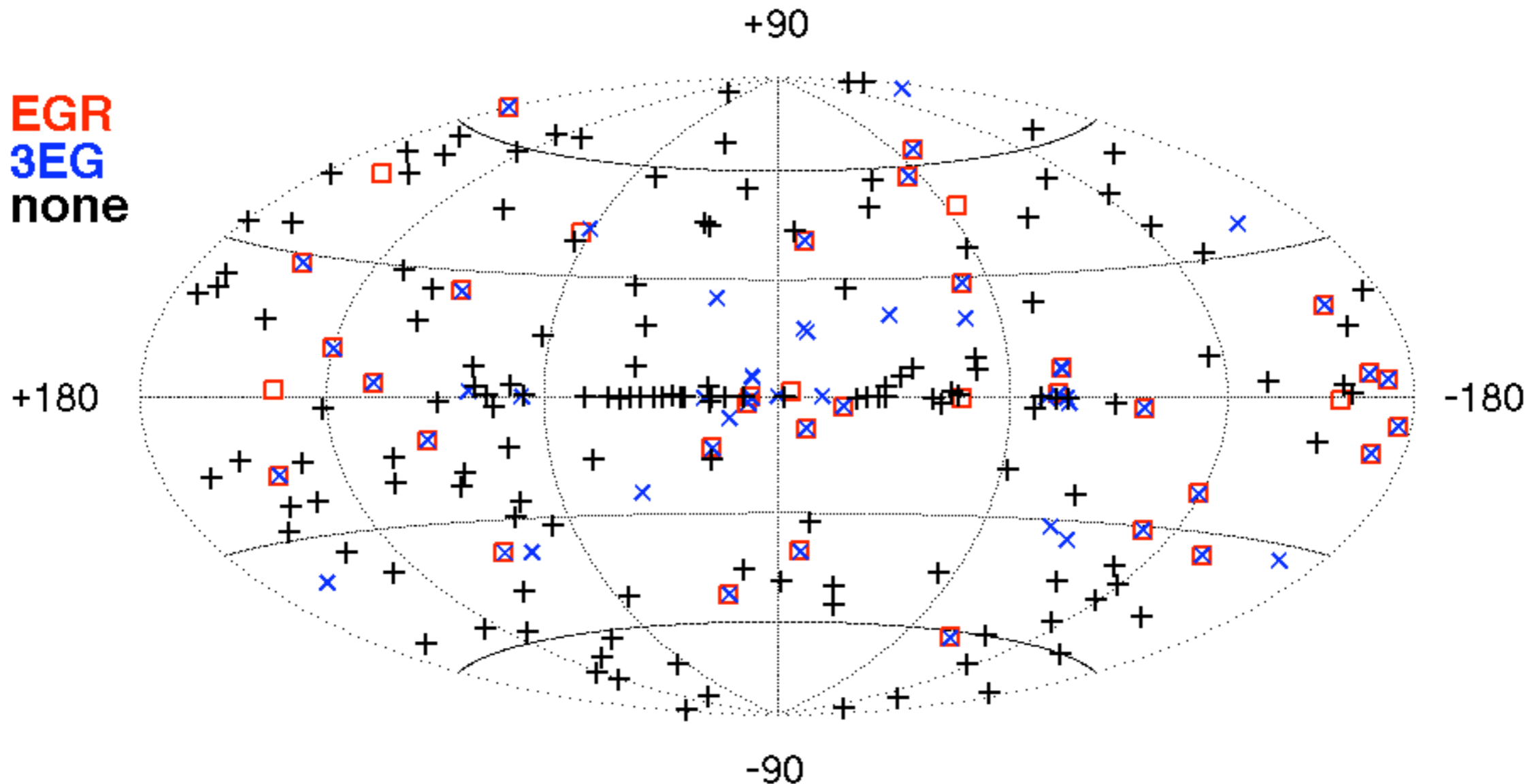
205 bright sources

- significance $> 10 \sigma$ (point-sources, not flux limited)
- compared to 31 3EG sources $> 10 \sigma$ over 9 years
- 1/3 sources at $|b| < 10^\circ$ (inner Galaxy), 2/3 off the plane
- \sim weekly flux measurements and χ^2 test ($\Delta F/F_{\text{pulsar}} \leq 3\%$)
- 1/3 variable sources, mostly off the plane ($P_{\text{chance}} < 1\%$)



Fermi versus EGRET

- 40% LAT sources off the plane with no EGRET counterpart = variable
- better LAT PSF \Rightarrow less confusion with ISM and neighbours in the plane



205 bright sources

- LAT PSF \Rightarrow localization $> 2.4'$ and $6'-20'$ near threshold
- \Rightarrow multi- λ studies

identified:

- 15 radio-X PSR
- 14 radio-quiet PSR
- 1 HMXB
- + 3 BZB + 3 BZQ
- Sun & Moon

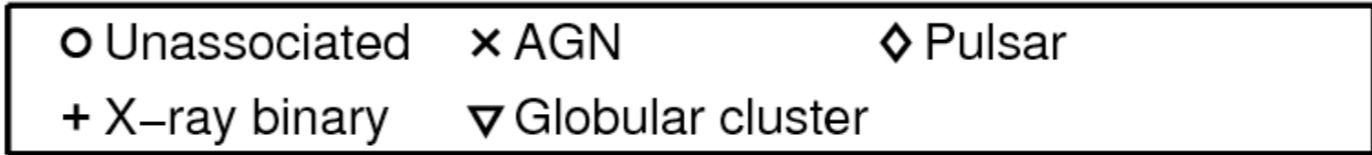
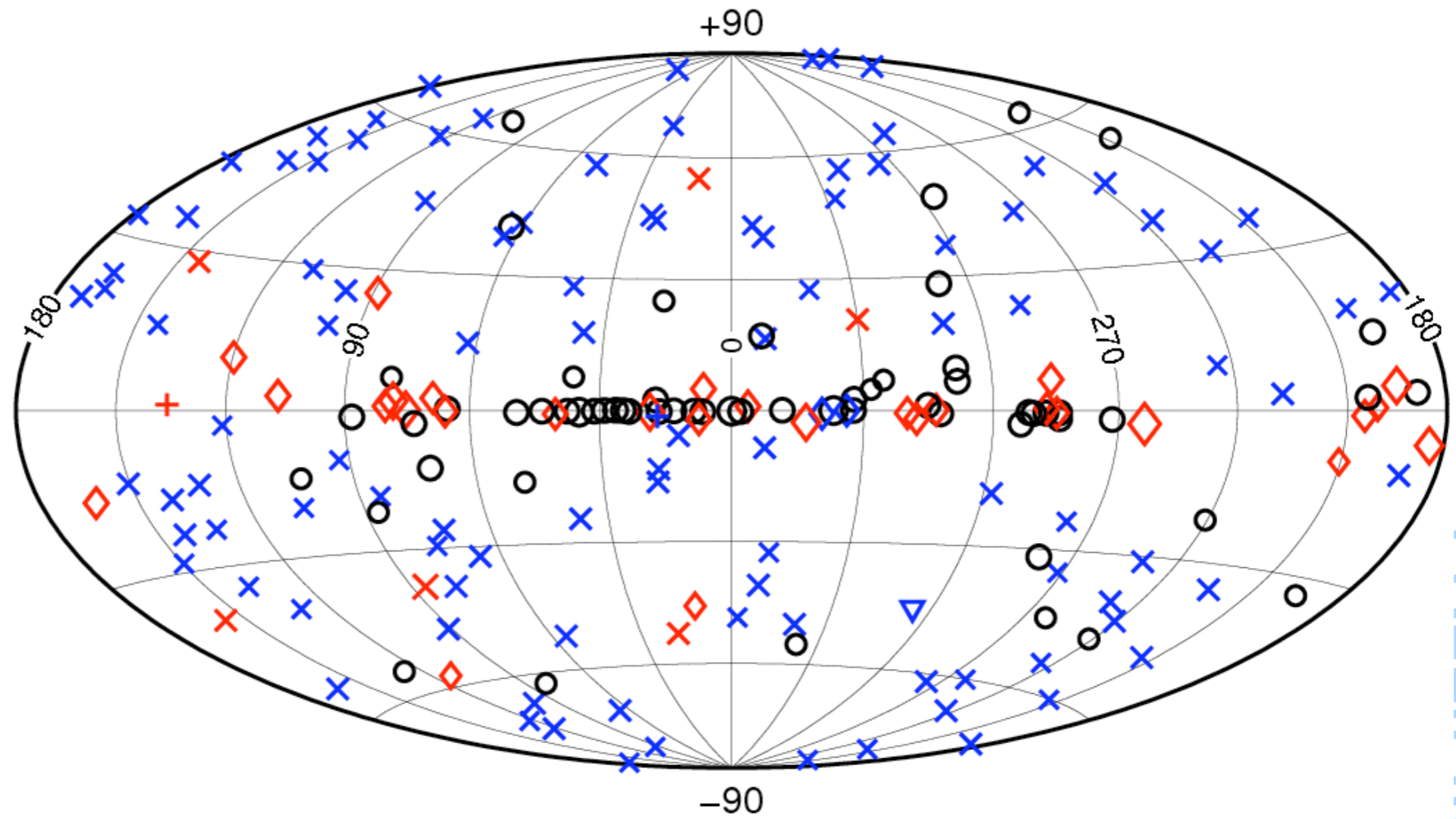
associated:

- 1 hmx
- 43 bzb + 59 bzbq
- 11 bzu
- Cen A + NGC1275
- LMC
- 47 Tuc

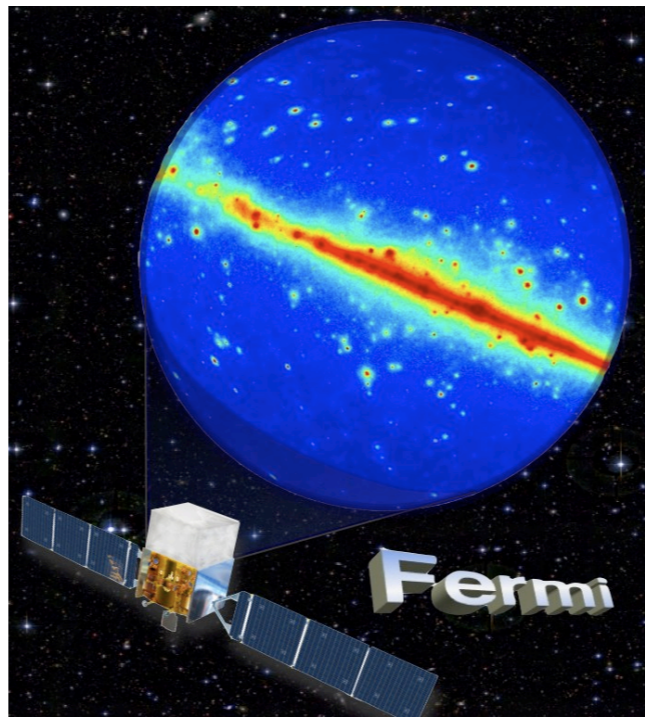
unidentified:

38

with weak associations for
11 SNR, 4 radio psr, 2 pwn



PRELIMINARY



active galactic nuclei

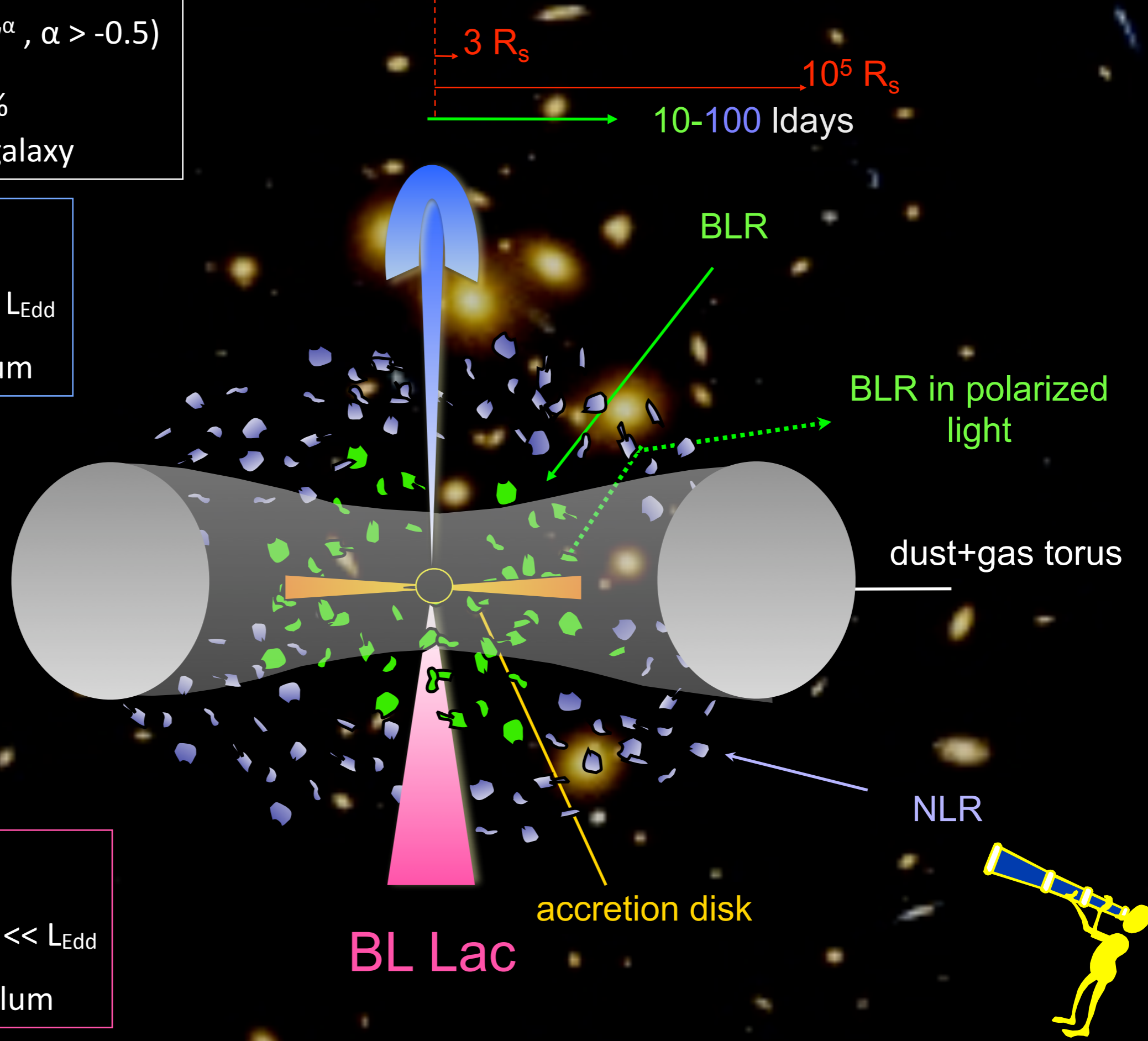


$L_{\text{bol}} = 10^{38-41}$ W radio-loud
 $(f_{\text{core}} \gg f_{\text{extended}}, S_v \propto v^\alpha, \alpha > -0.5)$
 high dL/dt , polar $> 3\%$
 often giant elliptical galaxy

smaller M_{BH}
 larger L_{acc} and $L_{\text{jet}}, L \leq L_{\text{Edd}}$
 bright lines+superlum

larger M_{BH}
 smaller L_{acc} and $L_{\text{jet}}, L \ll L_{\text{Edd}}$
 weak lines +superlum

FSRQ, OVV, HPQ



FR II
 FR I

BL Lac

NLR

dust+gas torus

BLR

$3 R_s$

$10^5 R_s$

10-100 Idays

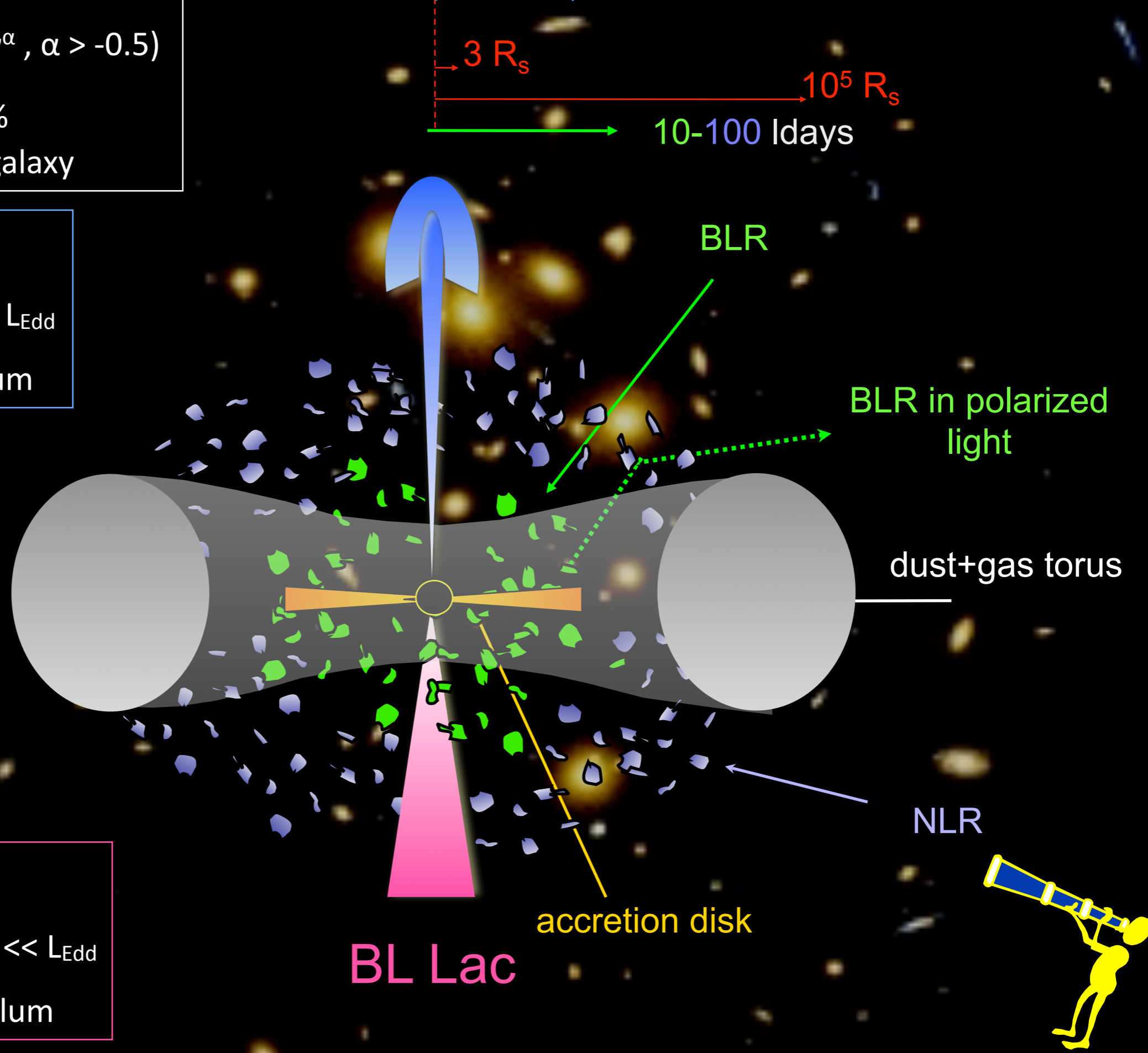
accretion disk

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FR II
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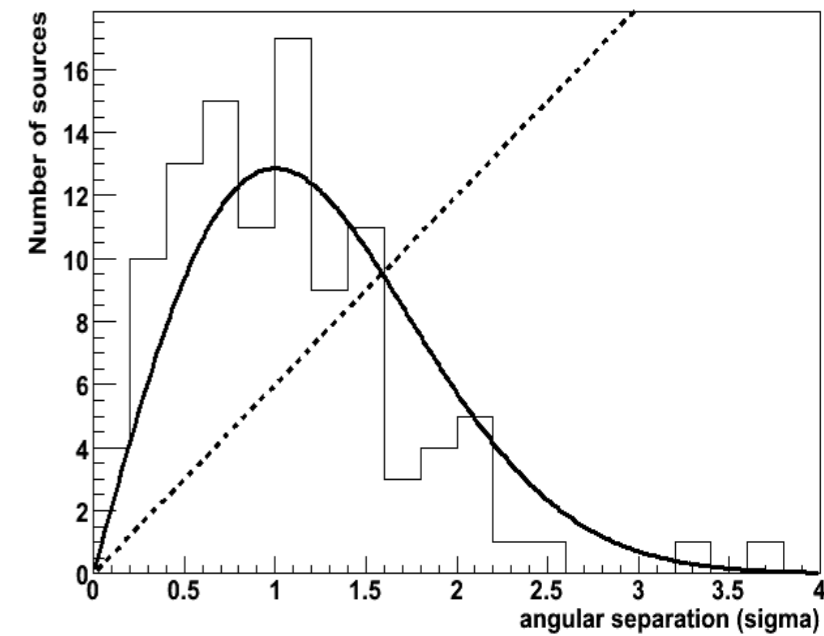
dust+gas torus

BLR

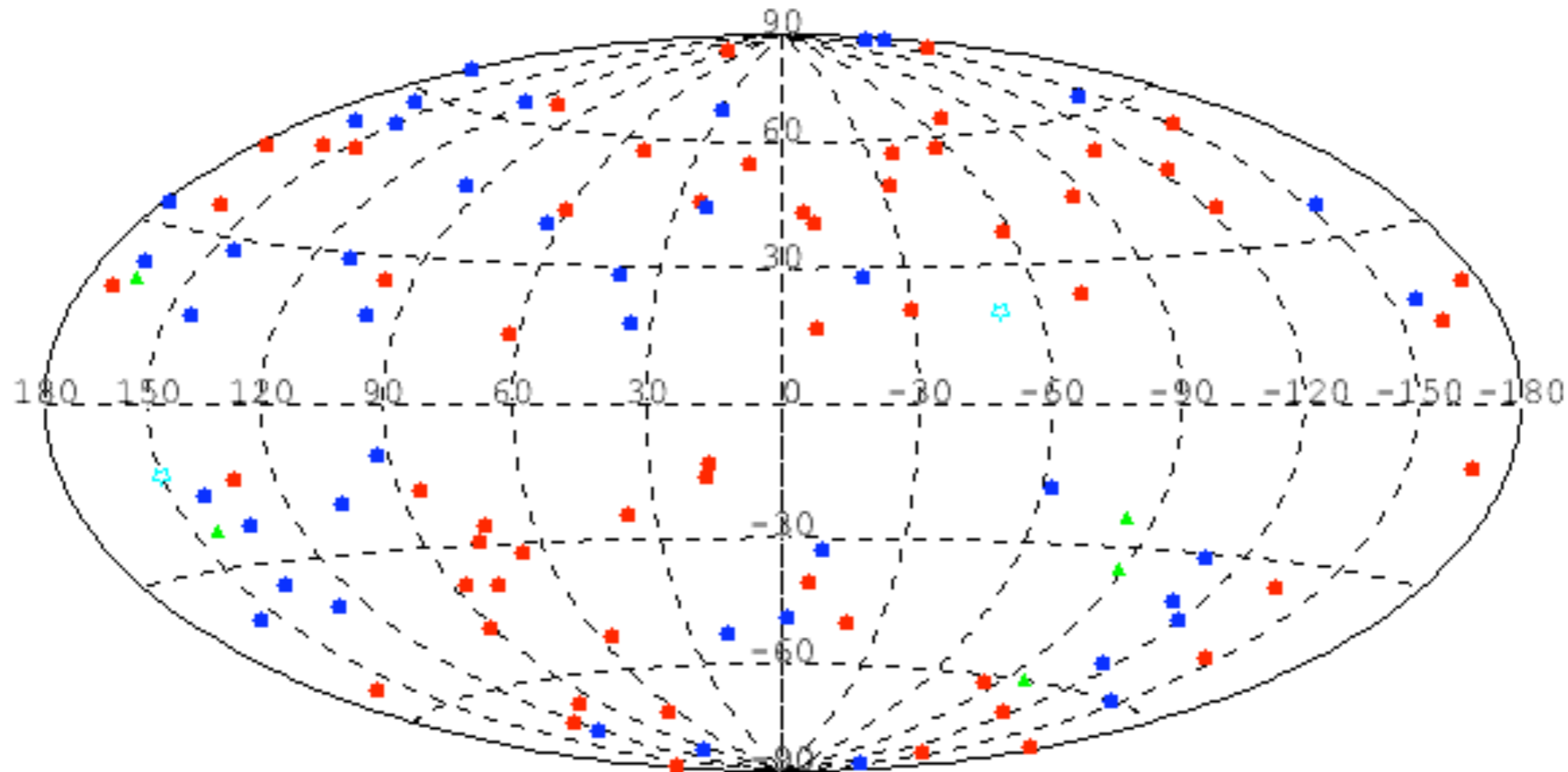
BLR in polarized light

Fermi AGN at $|b| > 10^\circ$

- 106 high-confidence ($> 90\%$) associations
- 57 FSRQ, 42 Bl Lac, 5 uncertain
 - 40% Bl Lac (23% for EGRET)
 - 7 HBL (only 3+1 for EGRET)
- 2 radiogalaxies: Cen A, NGC1275
- 33/116 LAT sources at $|b| > 10^\circ$ seen by EGRET



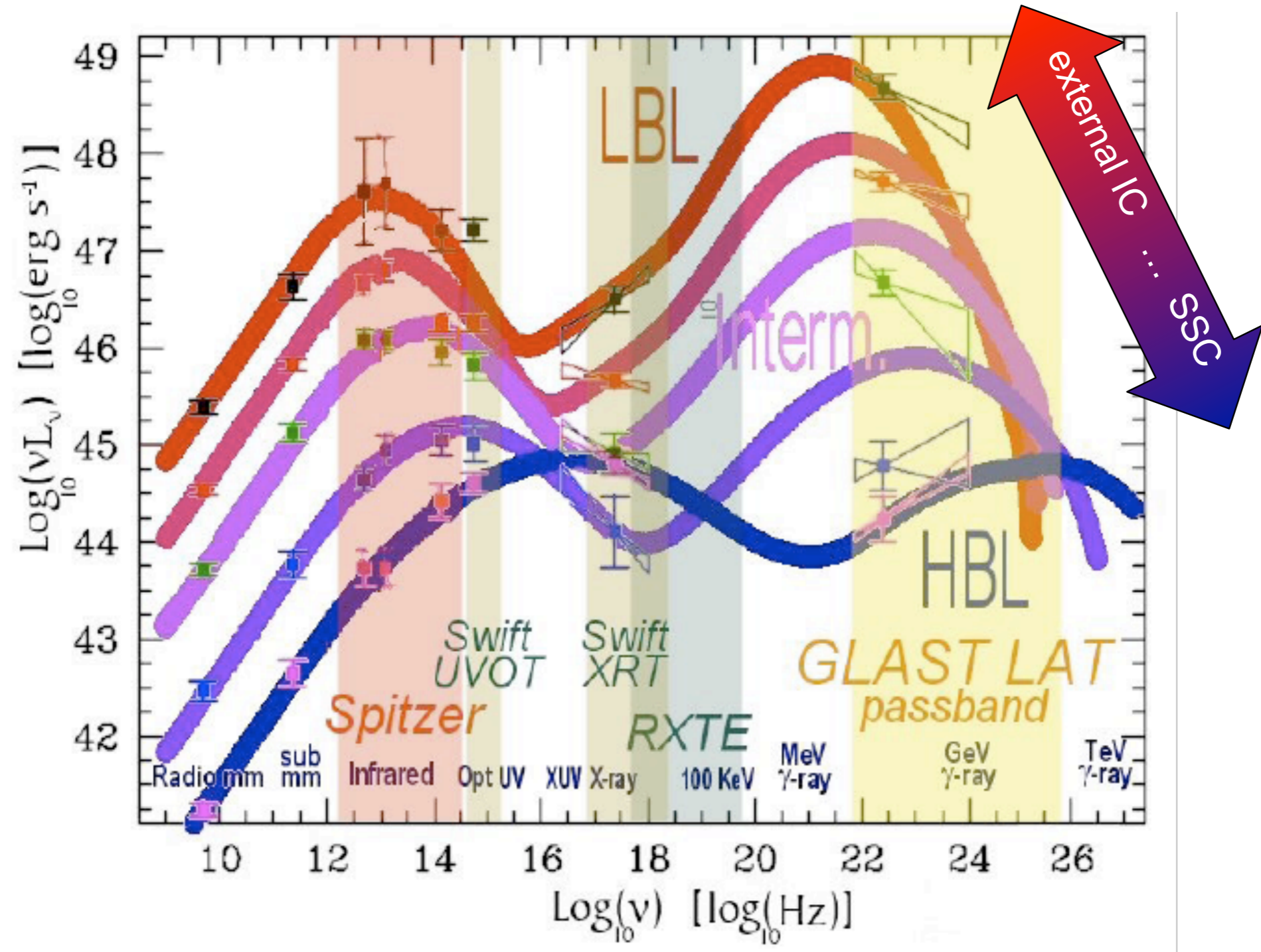
$\theta_{95} \sim 0.14^\circ$ (EGRET 0.62°)



PRELIMINARY

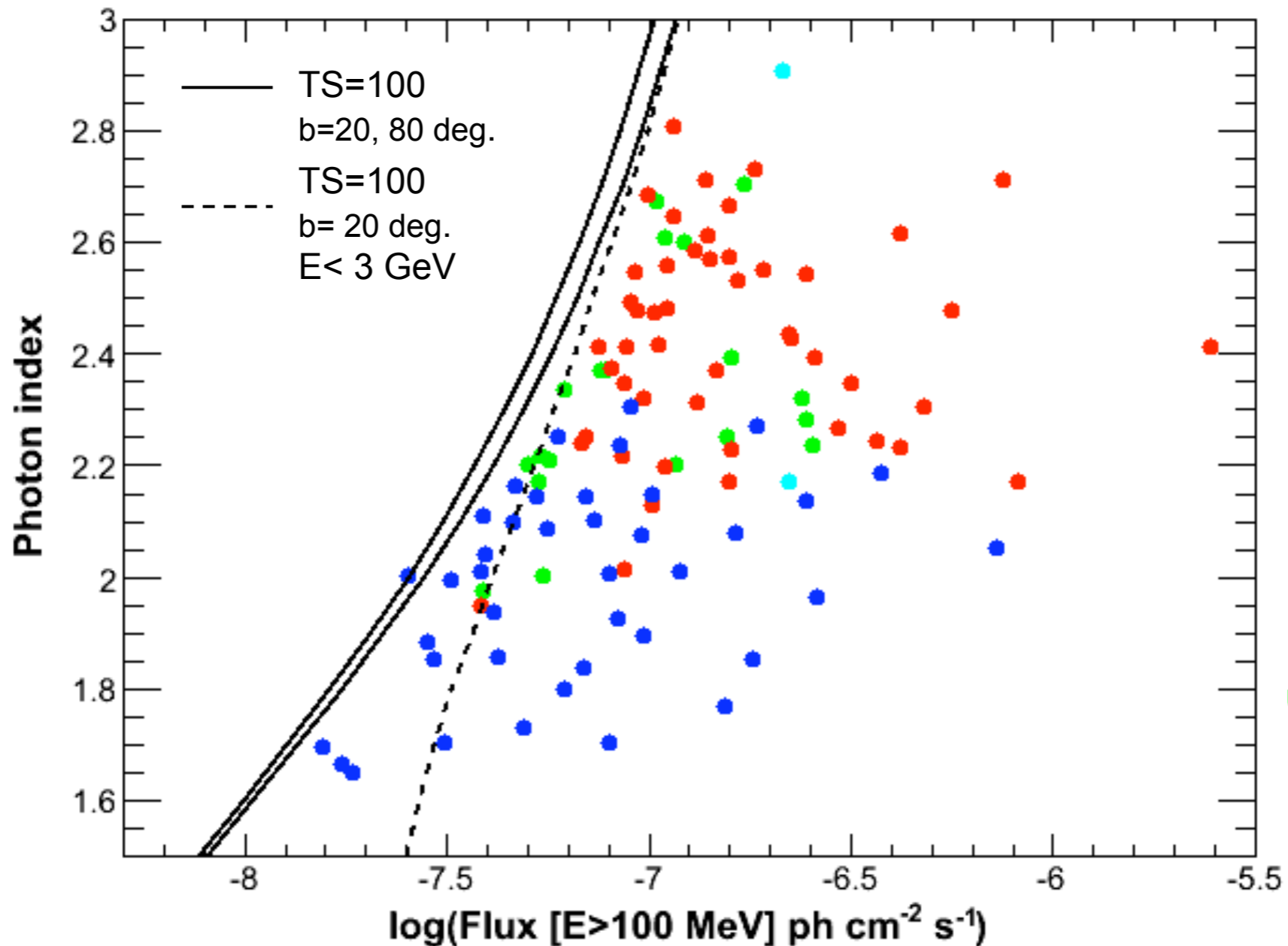
SED with blazar type

blazar sequence



Fermi AGN

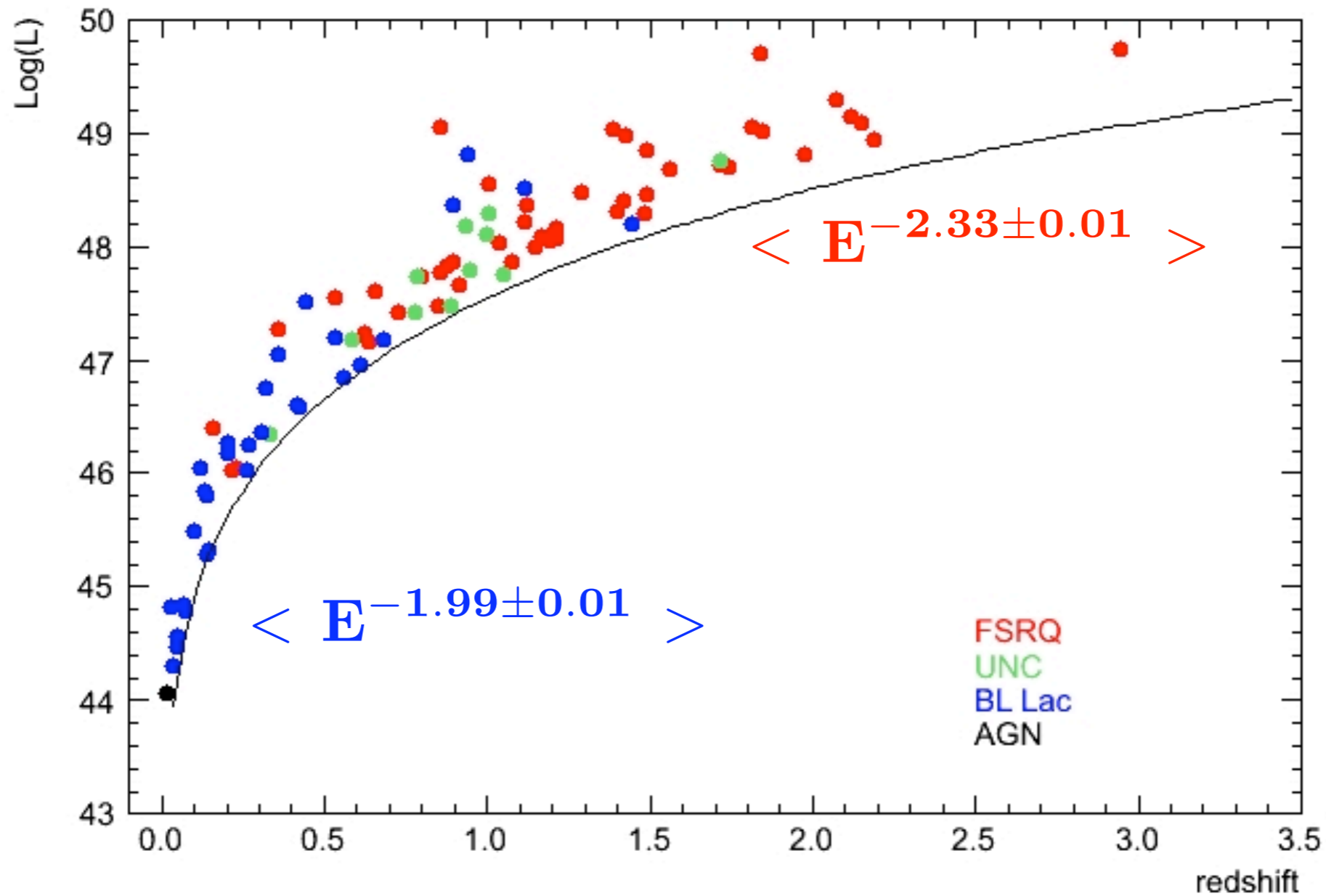
- flux and hardness
- ⇒ many more soon
- trend for fainter, harder BL Lacs



PRELIMINARY

red and blue blazars

- more powerful, softer FSRQ

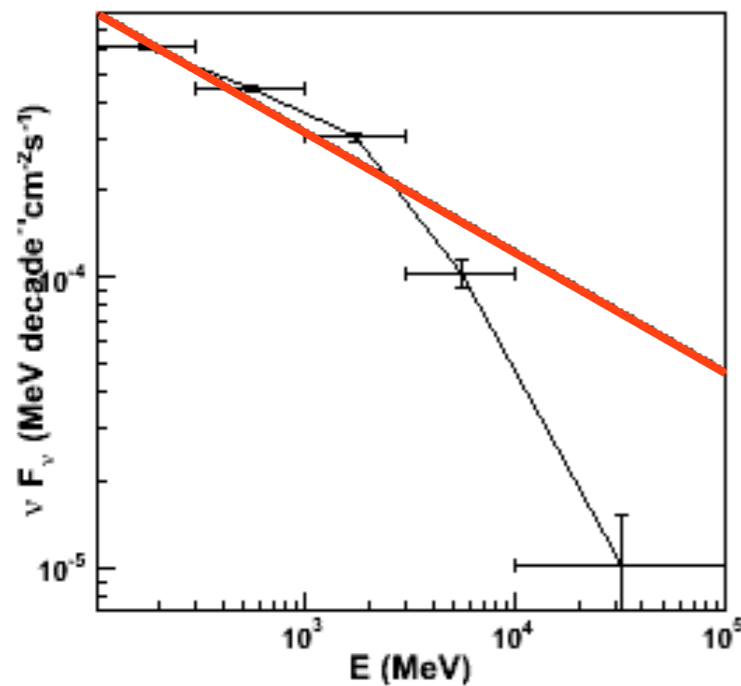


PRELIMINARY

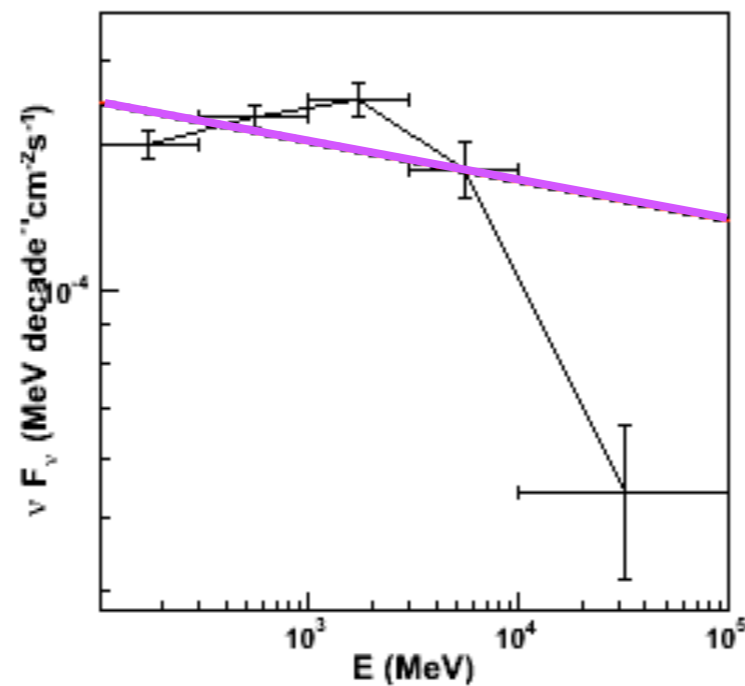
spectral curvatures

- IC curvature showing up for bright sources

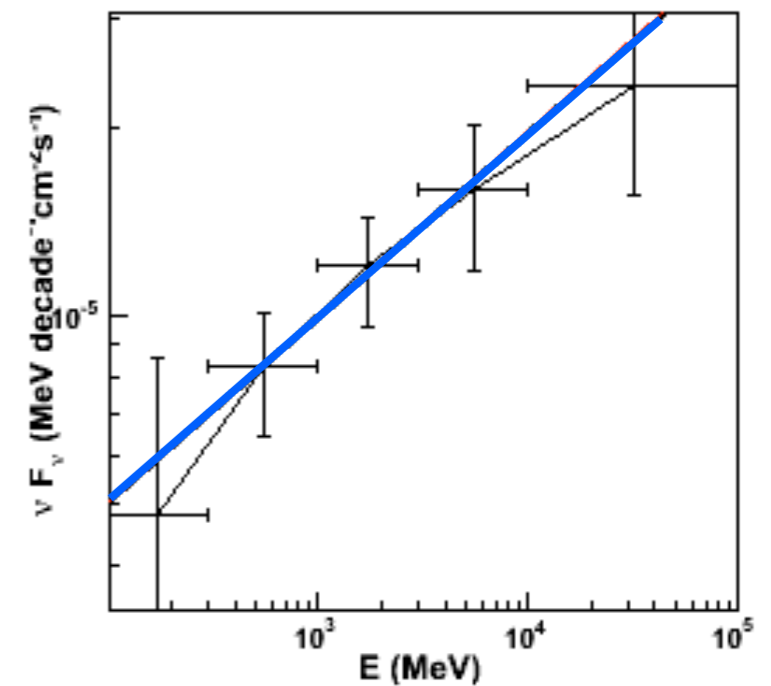
3C454.3 (FSRQ)



AO 0235+165 (interm. BL)







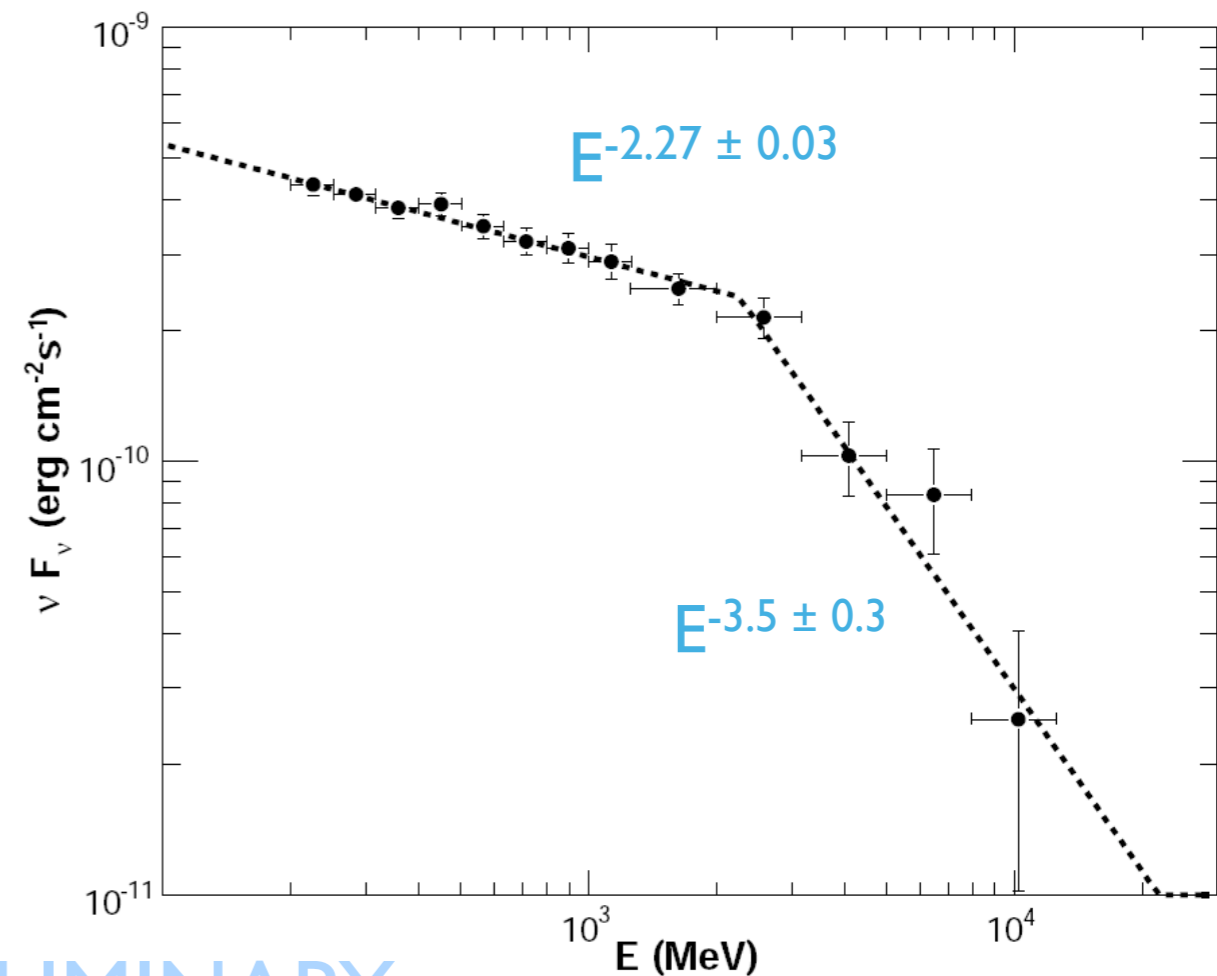
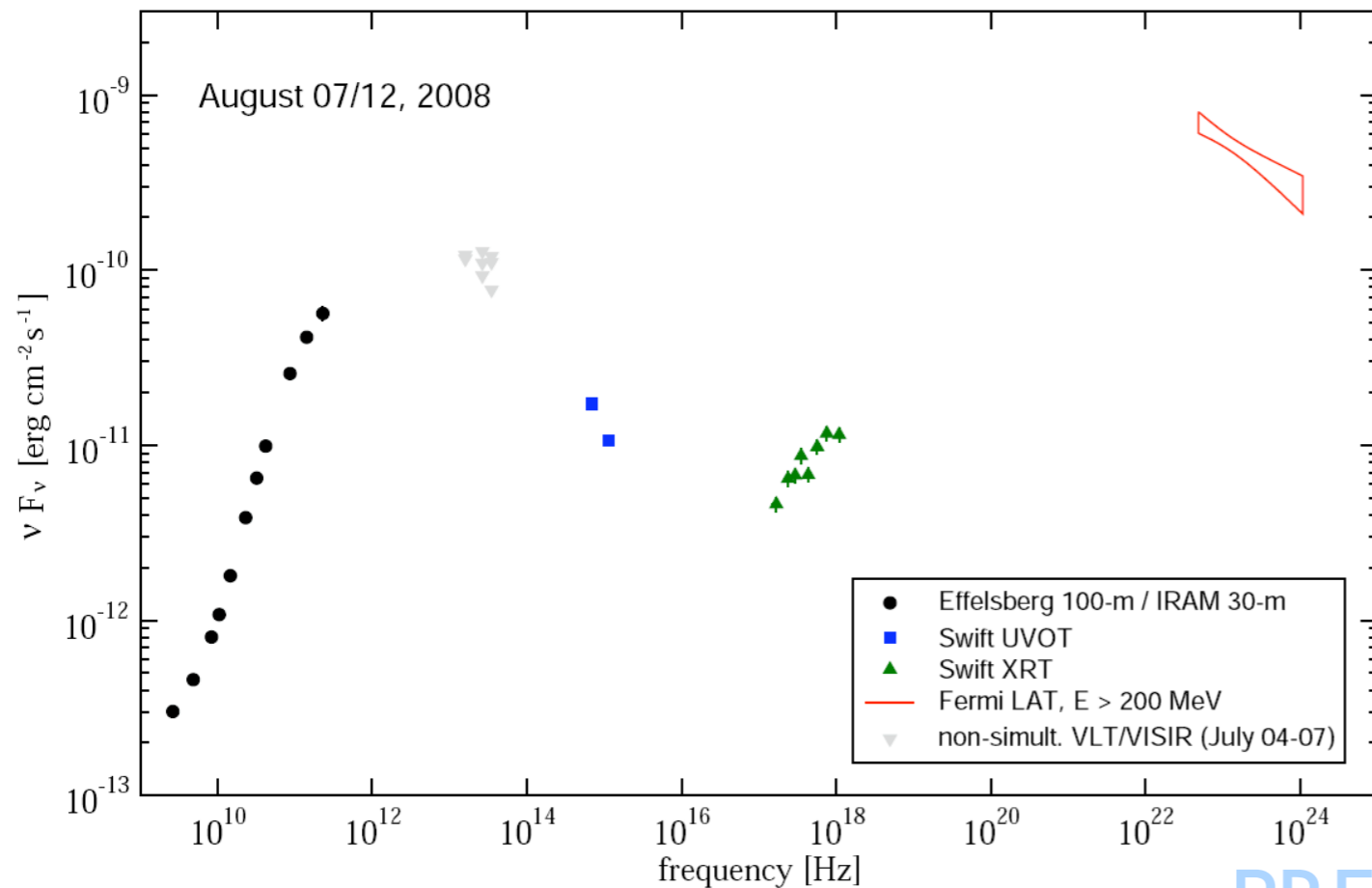
Mkn501 (HBL)



PRELIMINARY

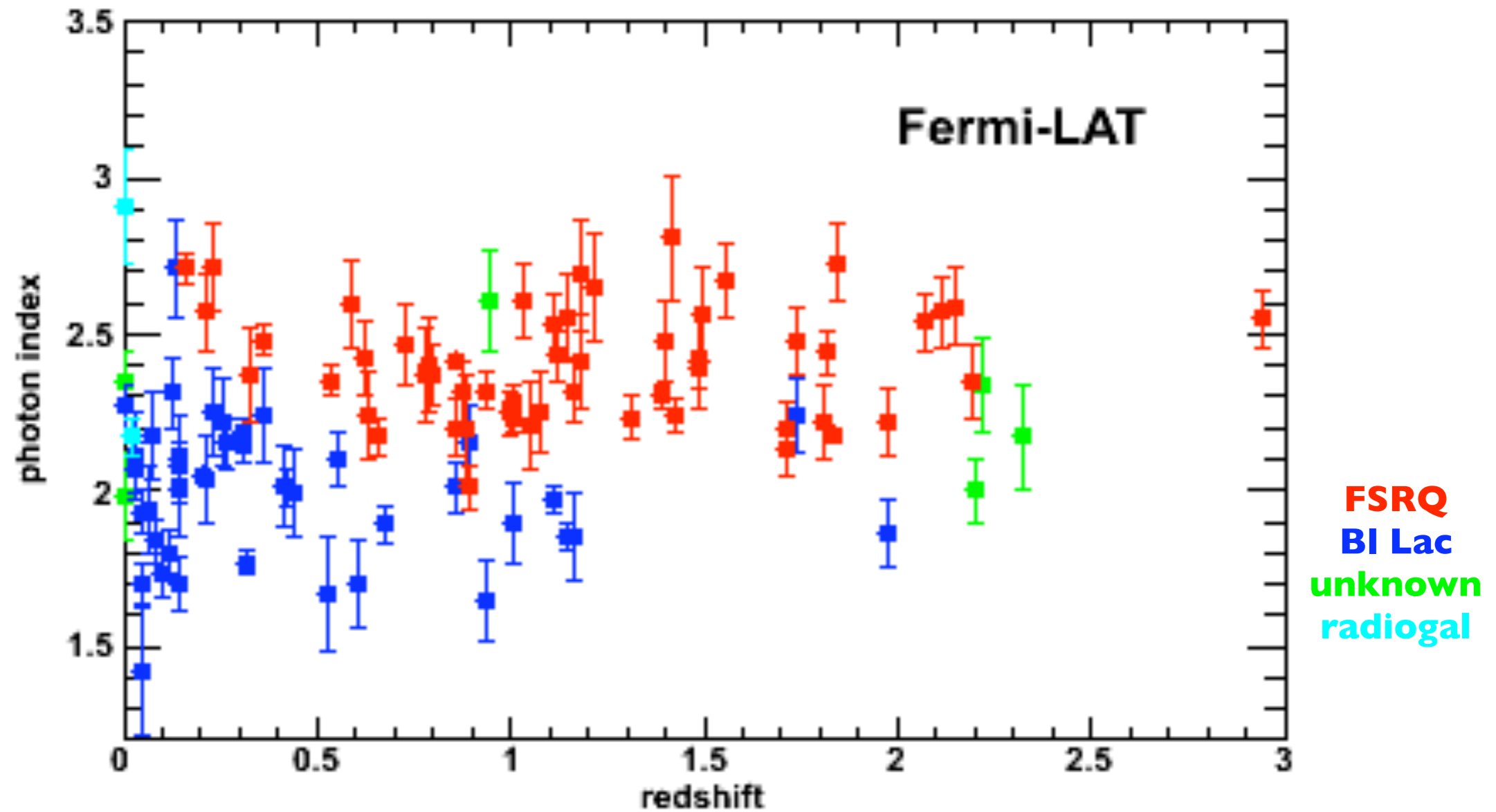
3C454.3

-  spectral break at $E = 2.4 \pm 0.3$ GeV
 -  not a cooling break ($\Delta\alpha > 0.5$)
 -  $\gamma + \gamma_{\text{disc}}$ or $\gamma_{\text{corona}} \rightarrow e^{\pm}$ unlikely (very close to BH and no cascading in X rays detected)
-  intrinsic electron break?



PRELIMINARY

blazars with redshift



PRELIMINARY

blazar evolution?



logN-logS slope:

- all: 2.50 ± 0.12 (euclidian)
- **FSRQ: 2.55 ± 0.12**
- **Bl Lac: 2.32 ± 0.15**

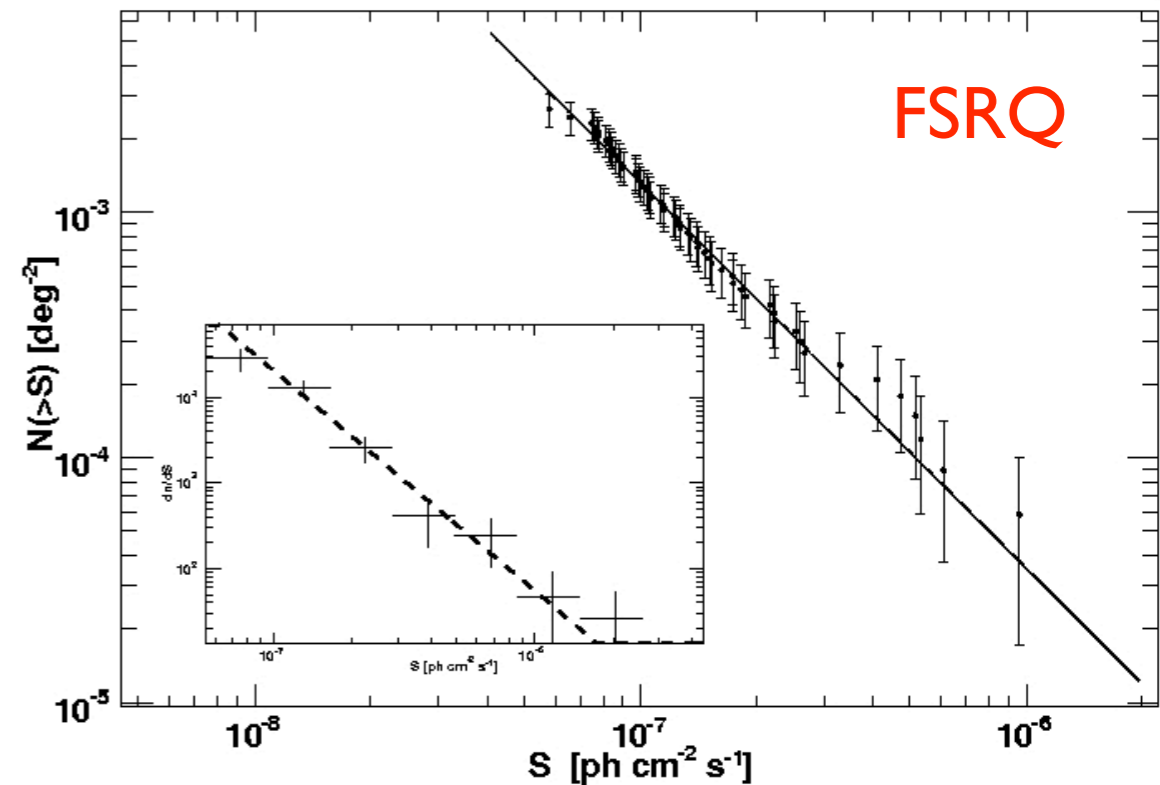


V/V_{\max} :

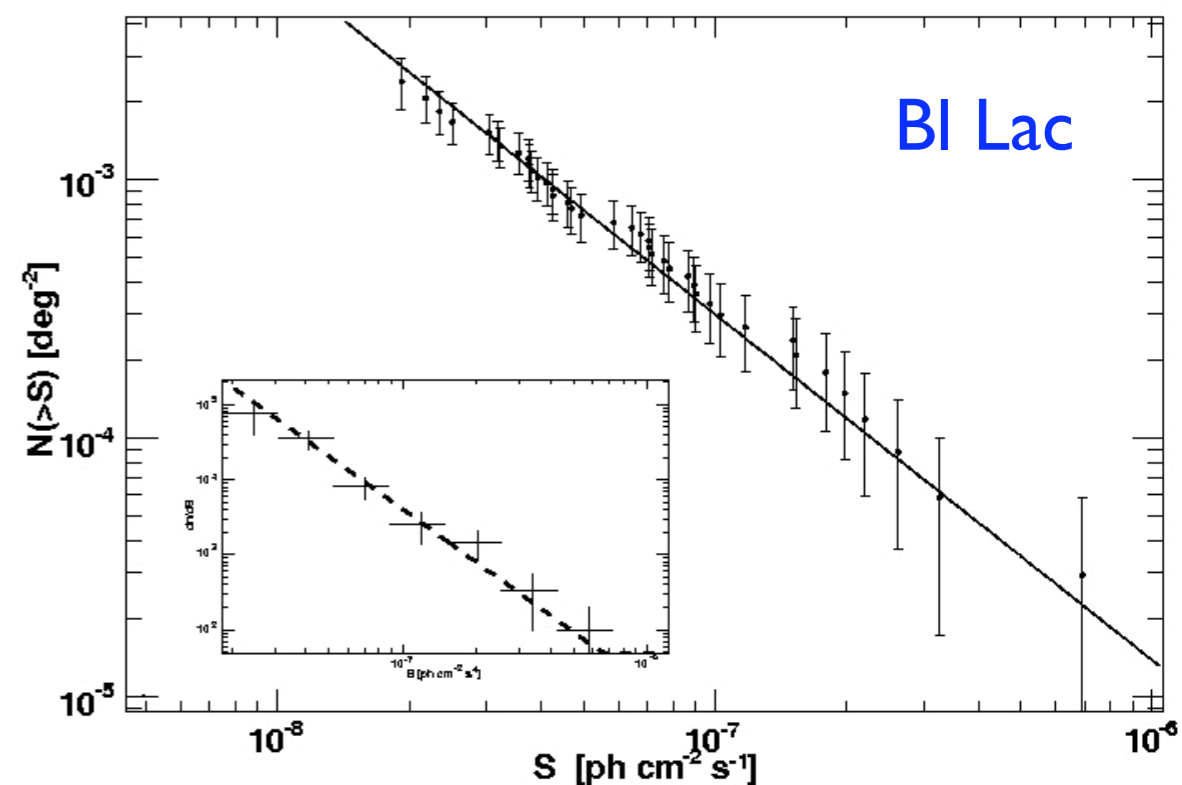
- $V_{\text{comoving where source}} / V_{\text{maximum available for its detection}}$

0.5 for uniform,
non evolving distribution
in euclidian space

- all: 0.512 ± 0.031
- **FSRQ: 0.645 ± 0.043 (more in past?)**
- **Bl Lac: 0.473 ± 0.046 (no evolution)**



PRELIMINARY



FSRQ variability

- PKS1502+106 ($z = 1.84$)

- rapid variability

- multi- λ campaign

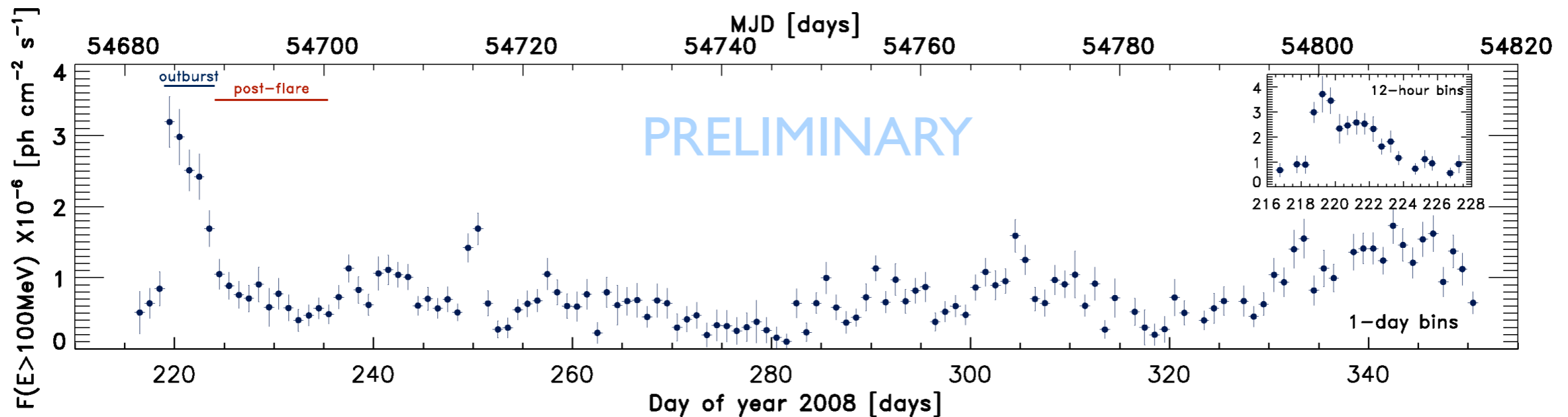
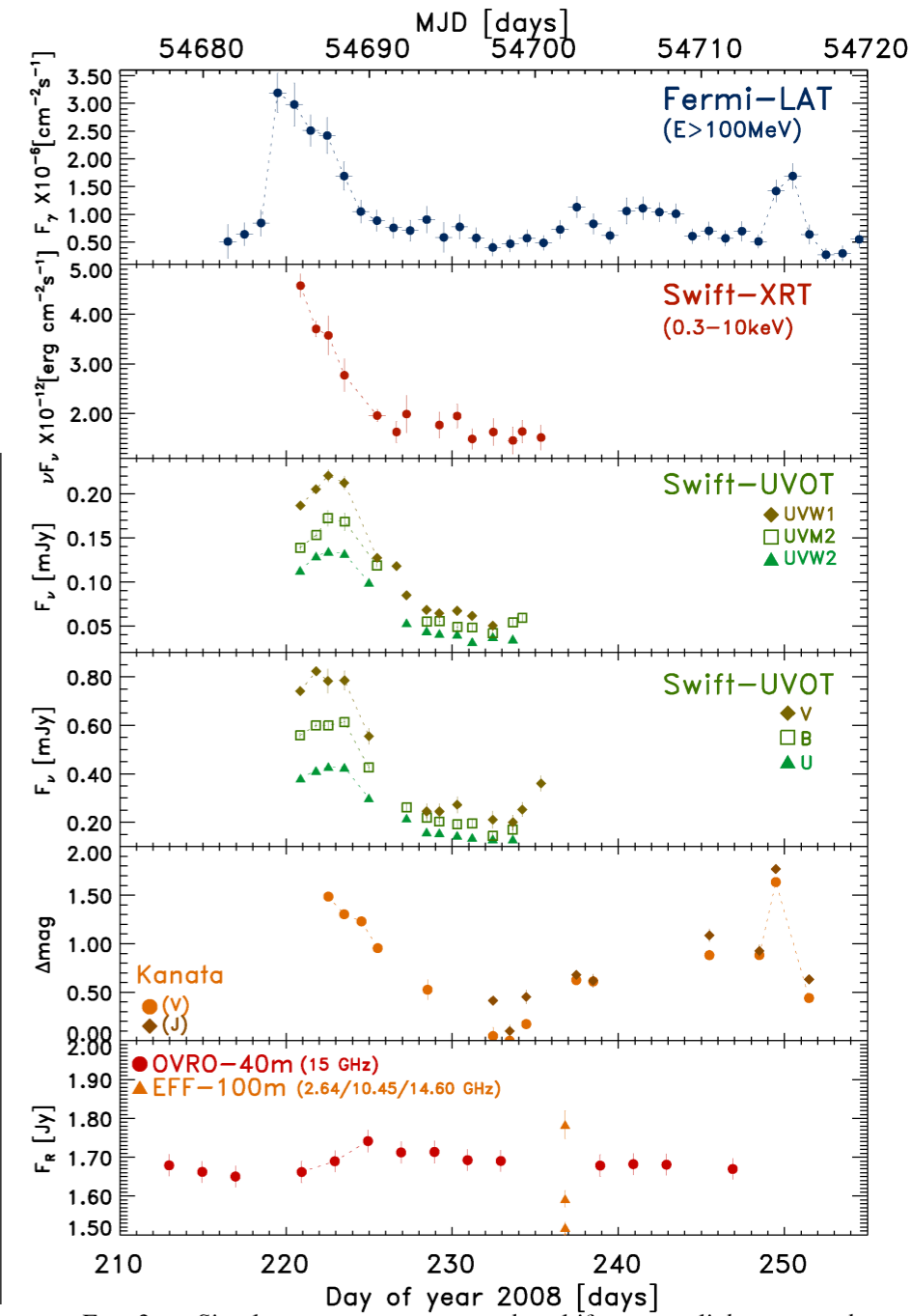
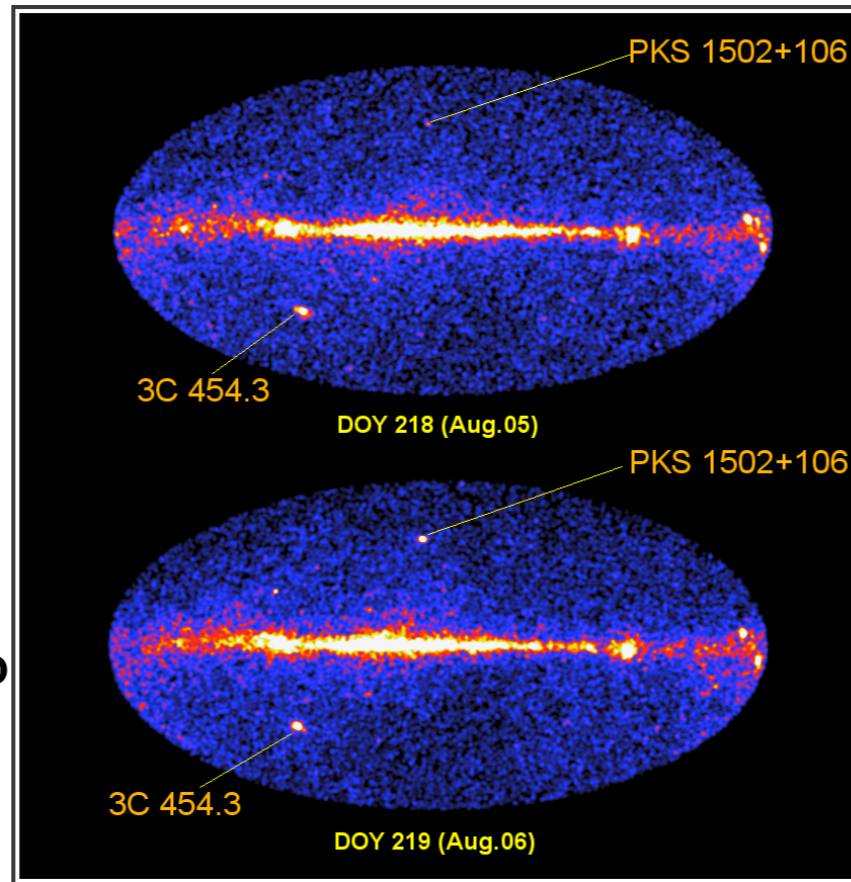
- γ -X: correlated

- no time lag

- UV-opt: 4-day lag

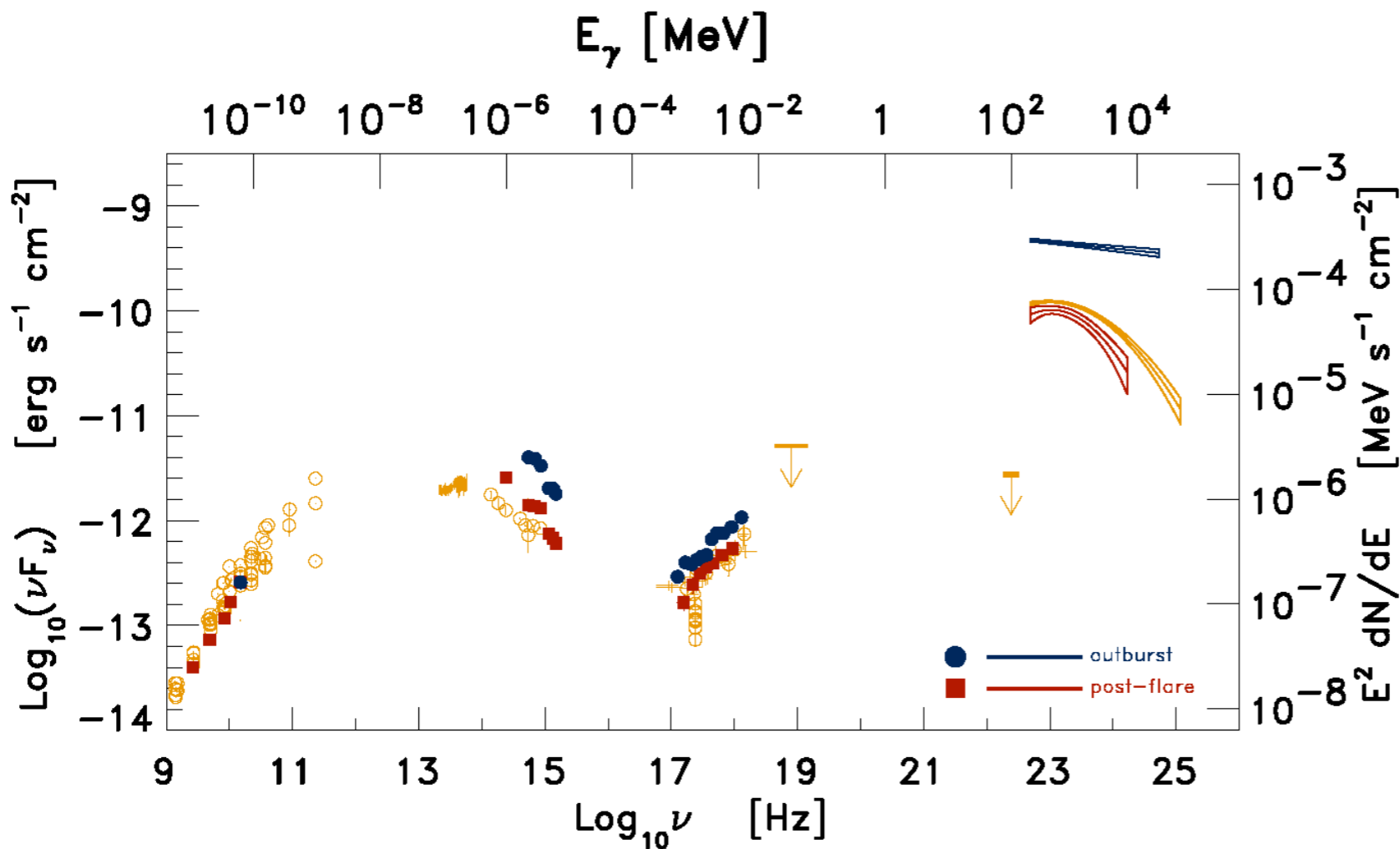
- mm: 1 month lag?

- radio: 3 month lag?

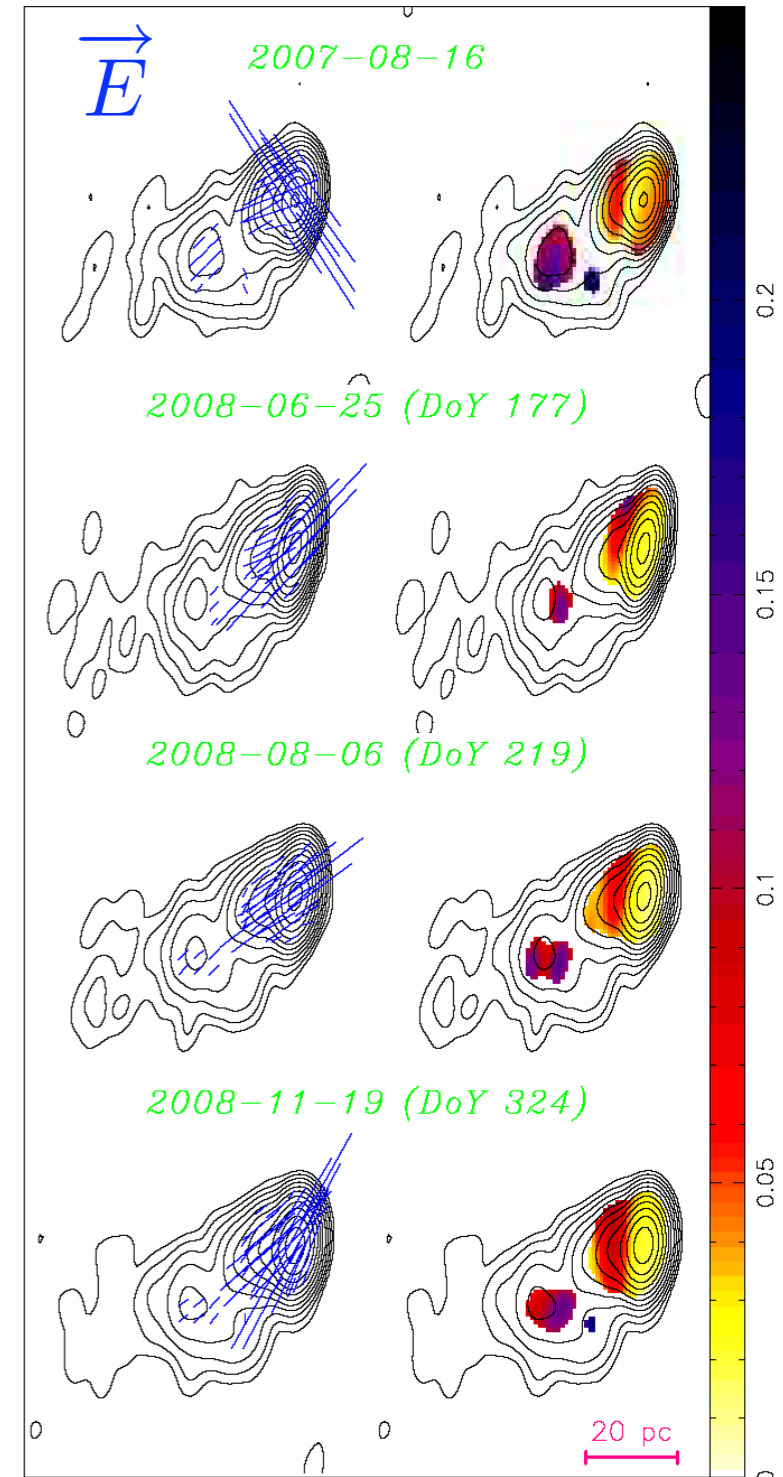


PKS 1502+106

- short flare, γ and X co-spatial, $E_{\text{rest frame}} \leq 140 \text{ GeV}$, $\tau_{\gamma\gamma} \propto \delta^{-5} L/\Delta t \Rightarrow \delta \dots$
- after ejection of VLBI core knot
- and E-field ordering
- ExC (disc, BLR) emission or SSC...

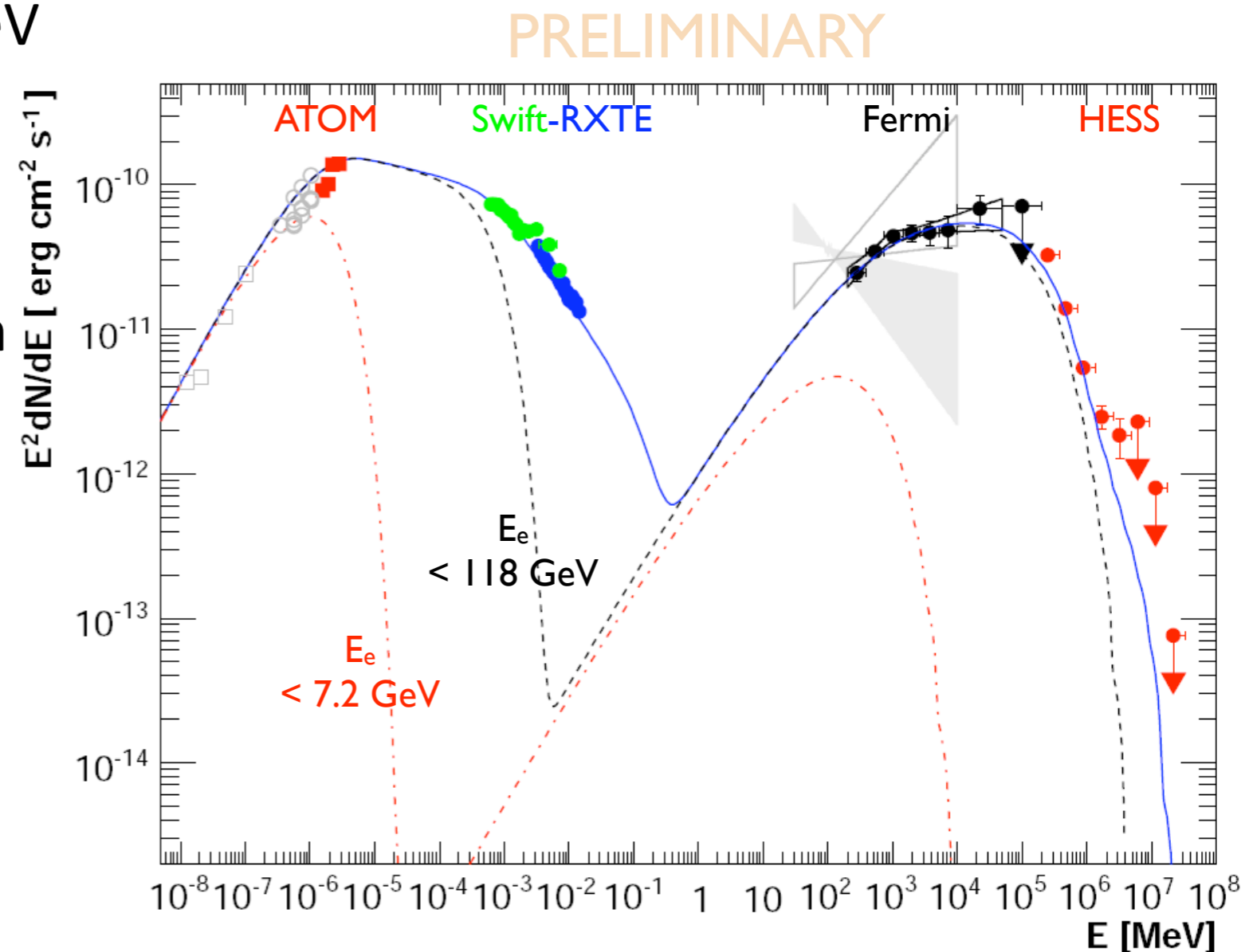


PRELIMINARY



Bl Lac variability

- PKS2155-304 ($z = 0.12$) in a low state
 - 12-day multi- λ campaign
- SSC single zone, 3 power-law electron spectrum
 - $E_e(X) > 120$ GeV
 - $10 < E_e(\text{GeV-TeV}) < 120$ GeV
 - TeV is K-N dominated
- \Rightarrow X- γ time correlation
 - none expected, none seen
 - unlike in flare state
- opt-TeV time correlation
 - none expected, but seen
 - \Rightarrow not SSC optical seeds
- \Rightarrow muti-zone model



$L_{\text{bol}} = 10^{36-38} \text{ W}$
radio-quiet or weak
spiral galaxy

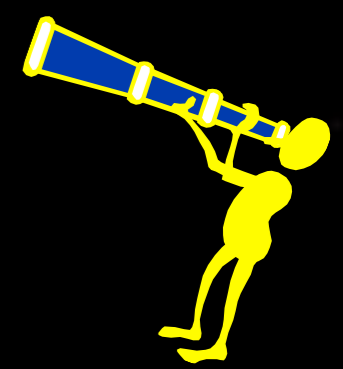
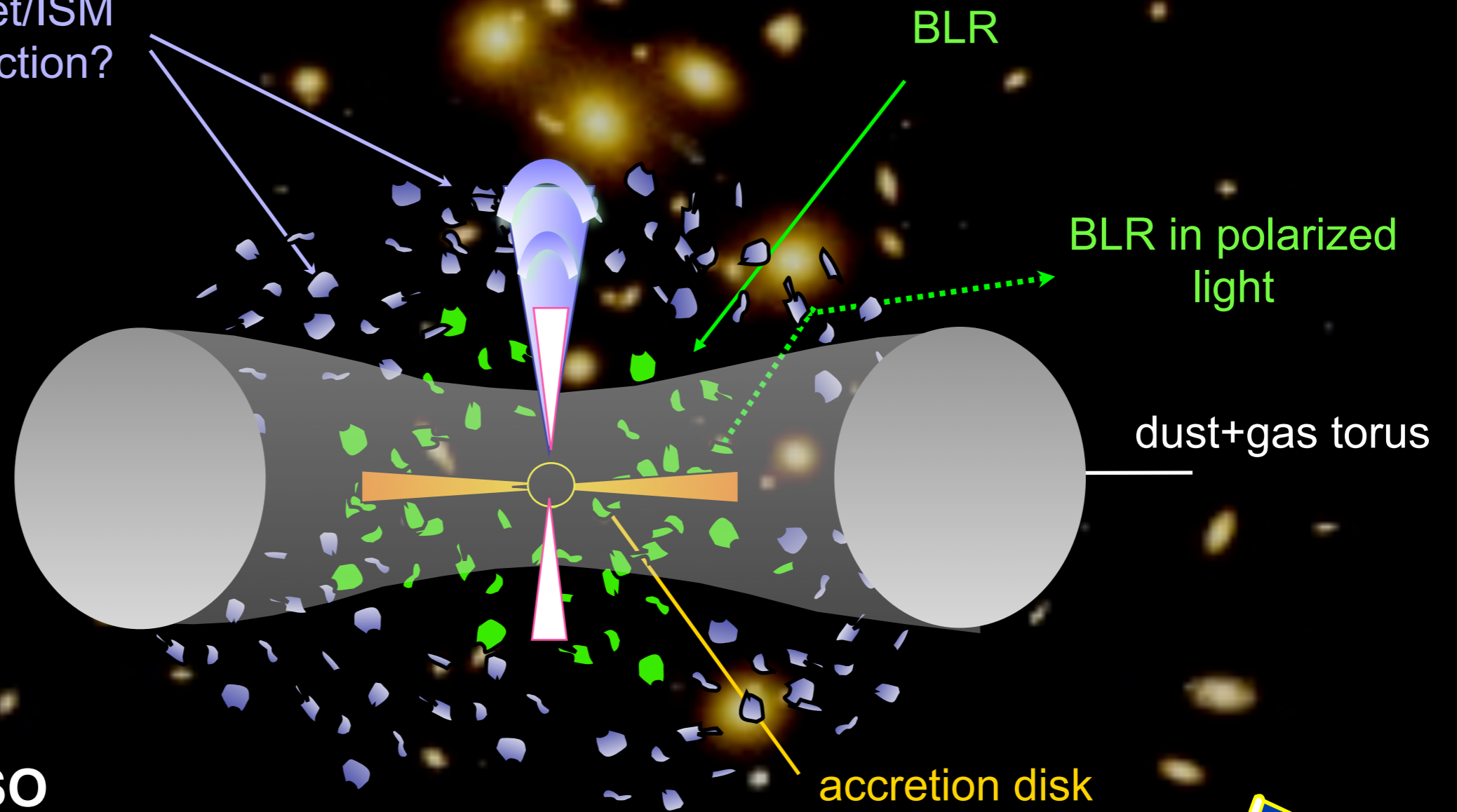


NLR clouds?
or jet/ISM
interaction?

Seyfert II

QSO
BLRG
NLRG

Seyfert I



$L_{\text{bol}} = 10^{36-38} \text{ W}$
radio-quiet or weak
spiral galaxy

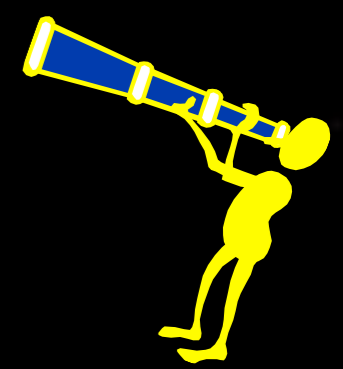
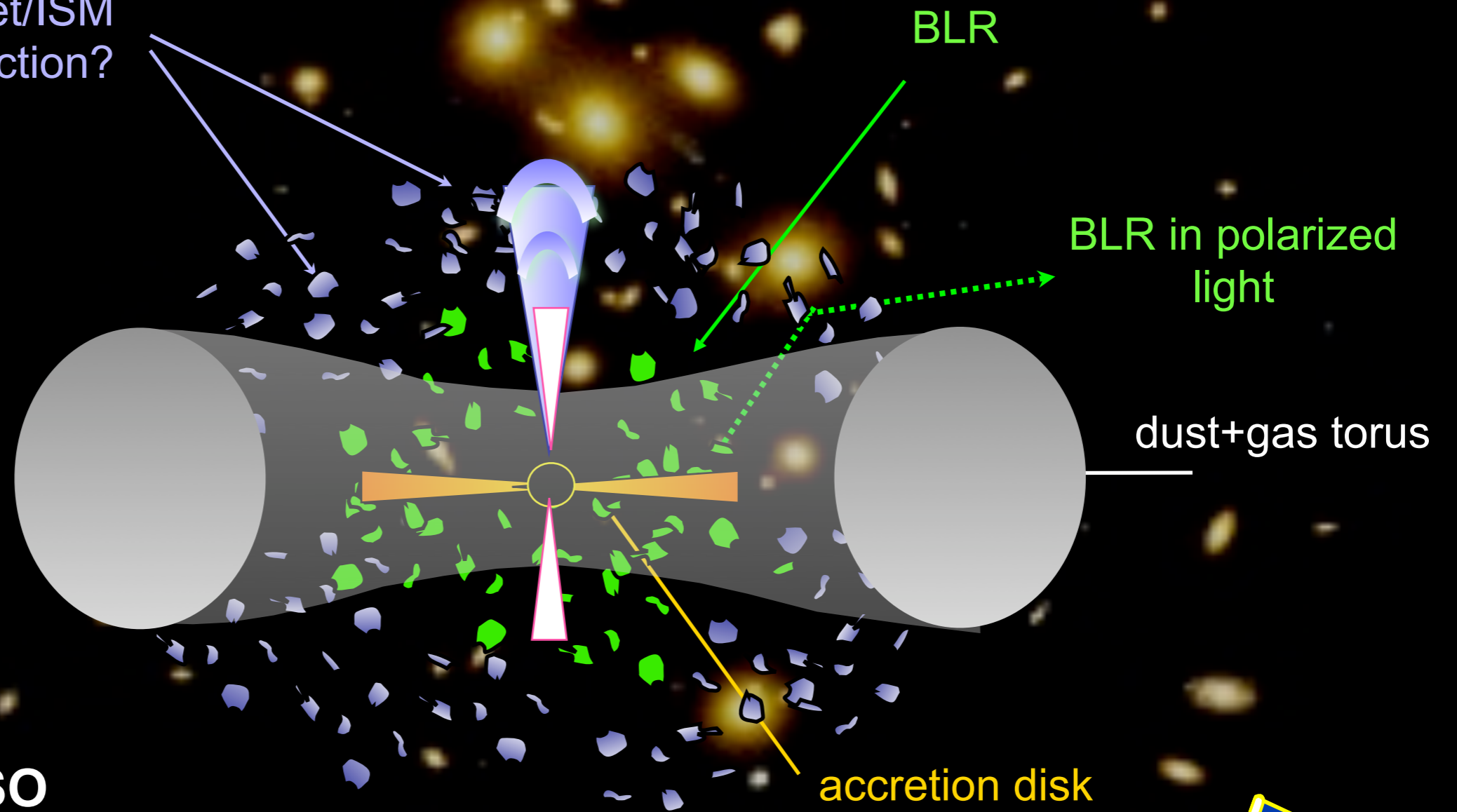


NLR clouds?
or jet/ISM
interaction?

Seyfert II

QSO
BLRG
NLRG

Seyfert I



radio-loud Seyfert in γ rays!

PMN J0948+0022 (Sey1 lines + radio-loud variable core, $z = 0.58$)

- $\delta > 2.5$ and $\theta < 22^\circ$

SED similar to FSRQ

- confirms jet presence
- $\Gamma = 10$, $\delta = 18$
- exC on BLR dominates
- low-power FSRQ

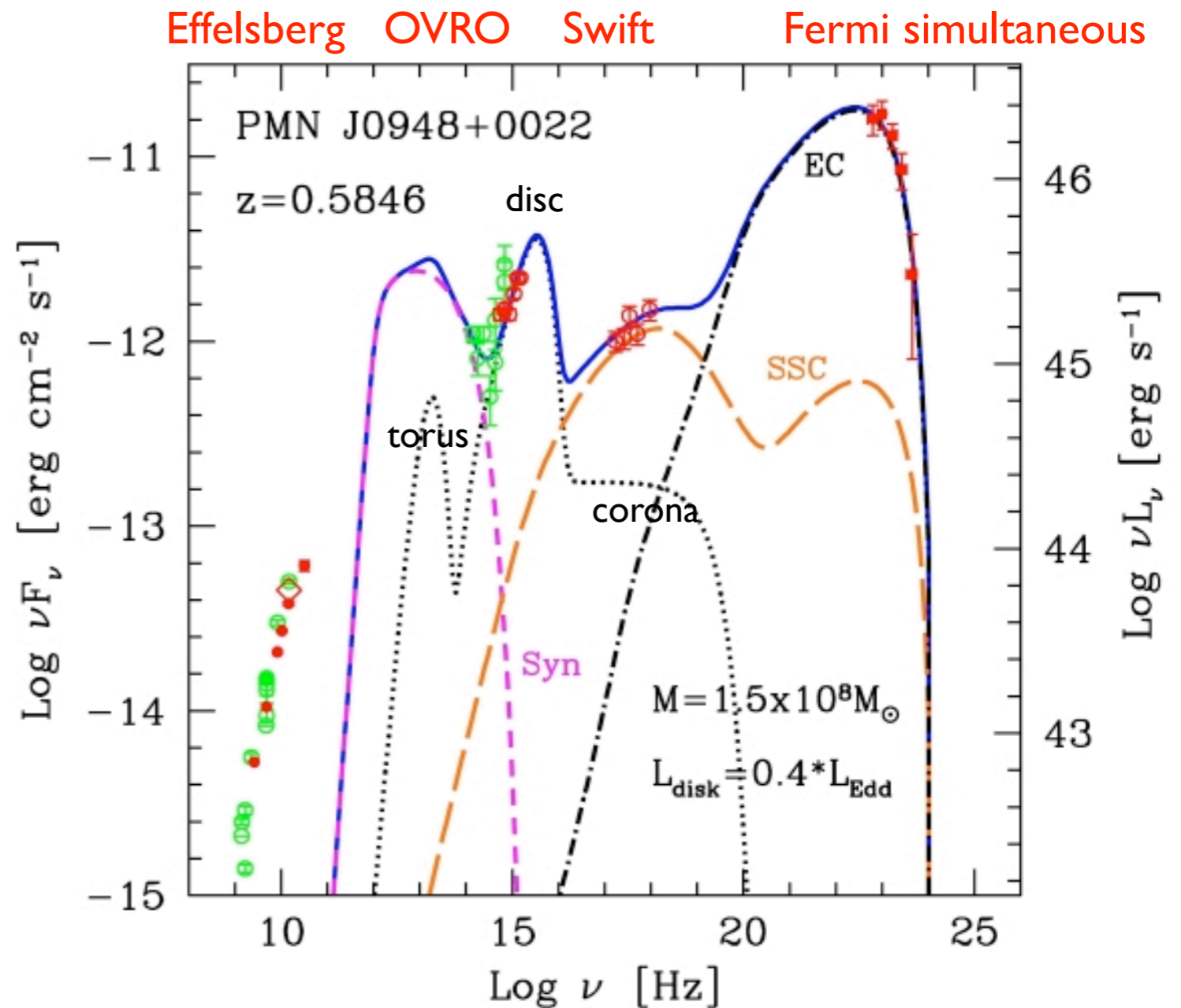
low-mass black hole

- \Rightarrow low power

high $L/L_{\text{Edd}} = 0.4$

- \Rightarrow active jet

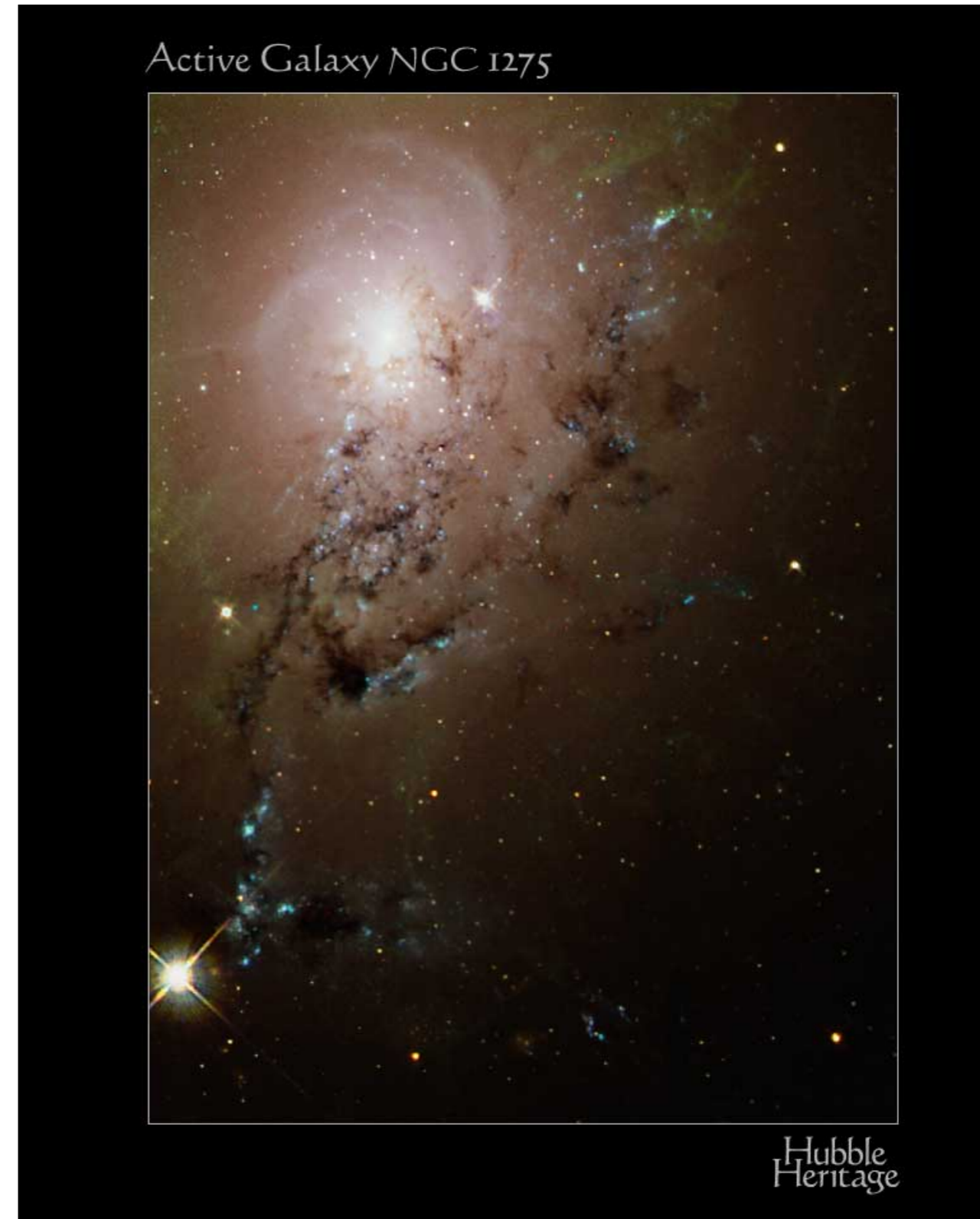
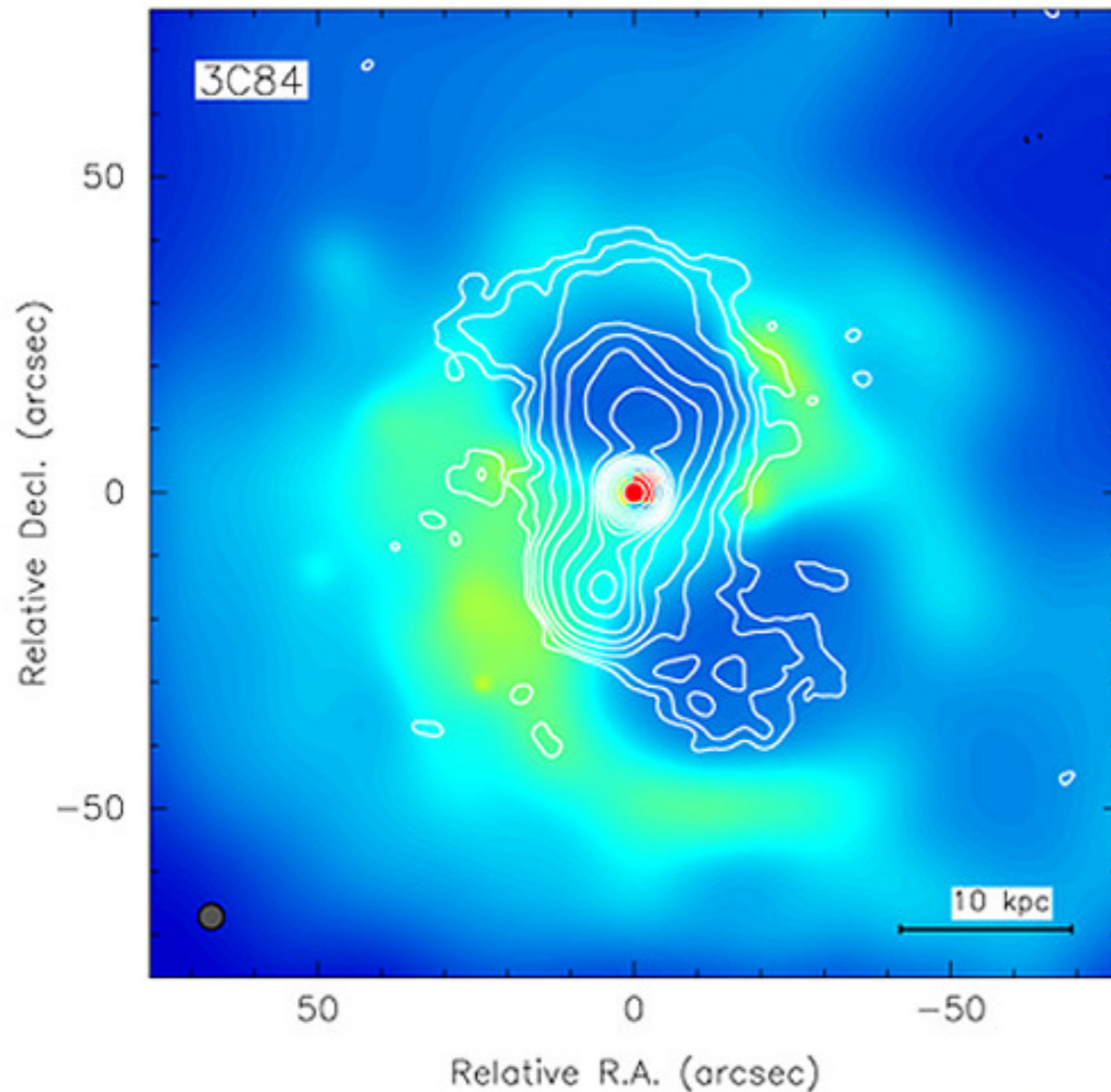
any other?



PRELIMINARY

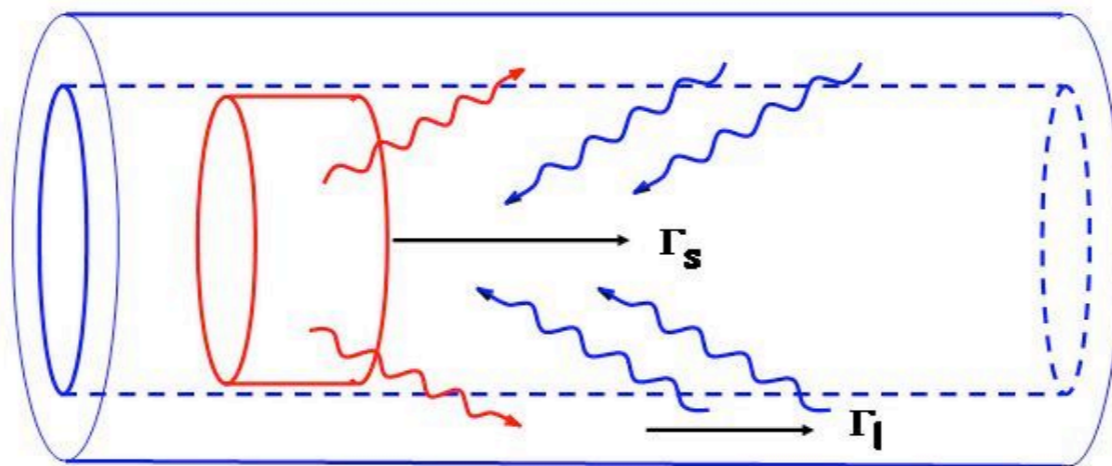
NGC 1275

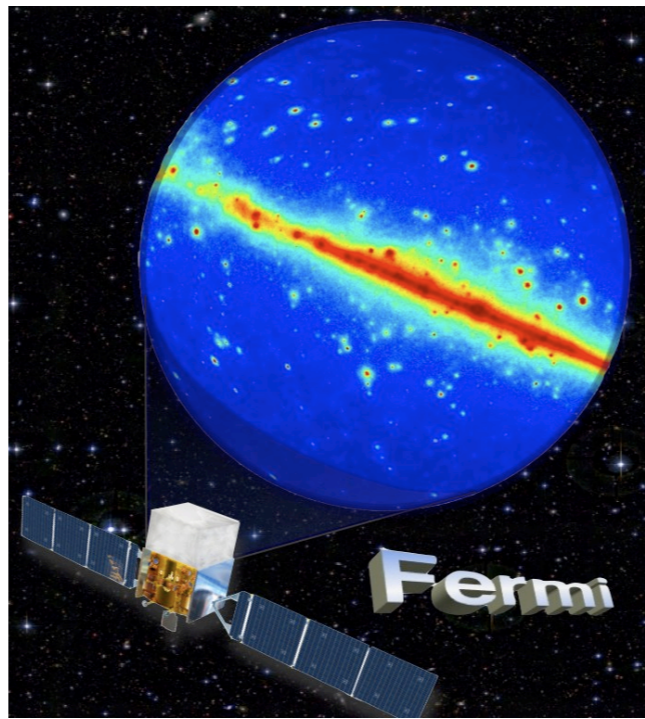
- nearby radiogalaxy (alias Perseus A or 3C84) in the Perseus cluster
- with blazar-like radio core
- piercing jets



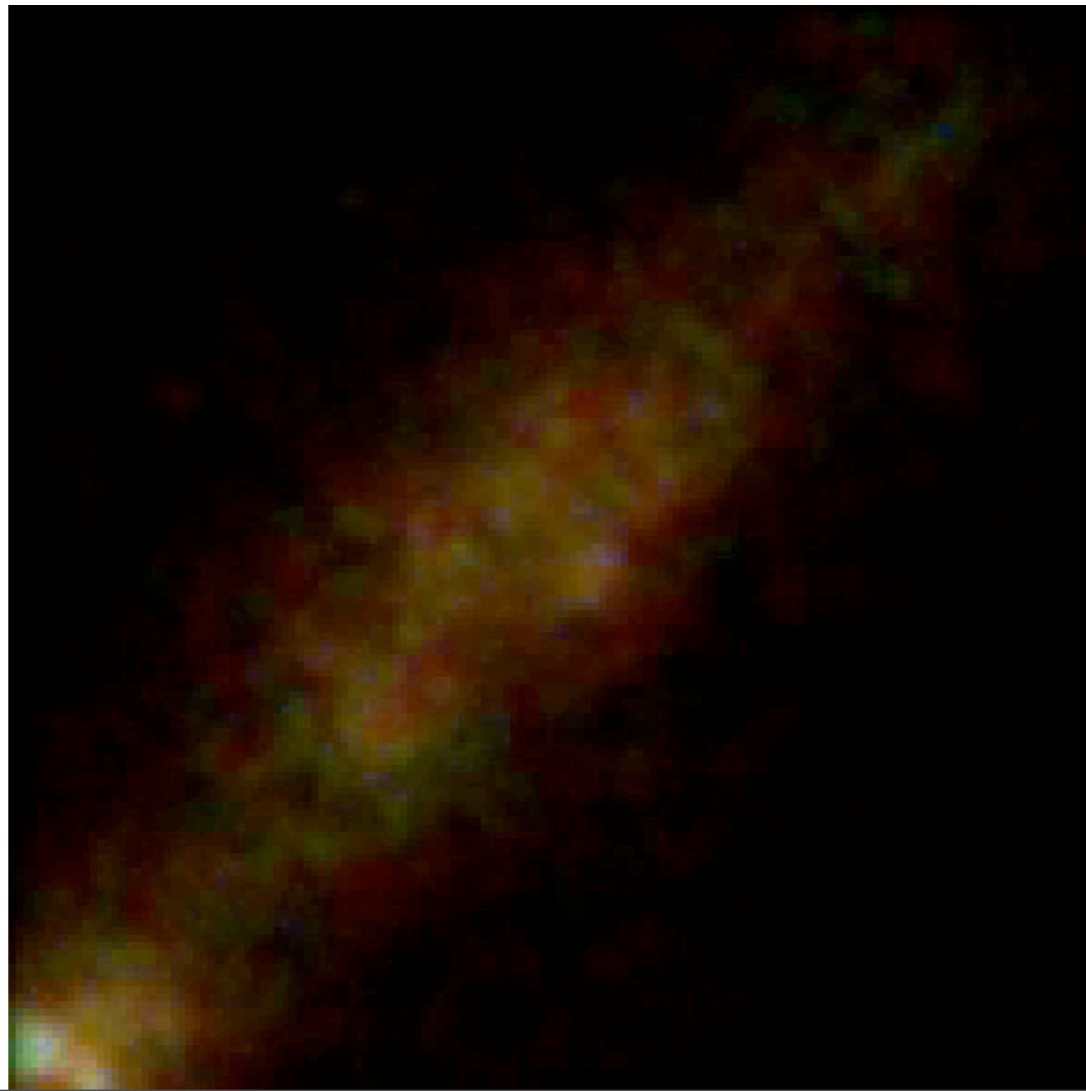
NGC 1275

- detected by LAT
- stable over 4 months, but variable between COS-B, EGRET, and LAT
 - γ -ray source = AGN, not the Perseus cluster or dark matter
- γ rays at large angle from slow+fast beams or decelerating jet
 - Ghisellini '05 and Georganopoulos & Kazanas '03
 - enhanced IC emission from the interaction of the two zones

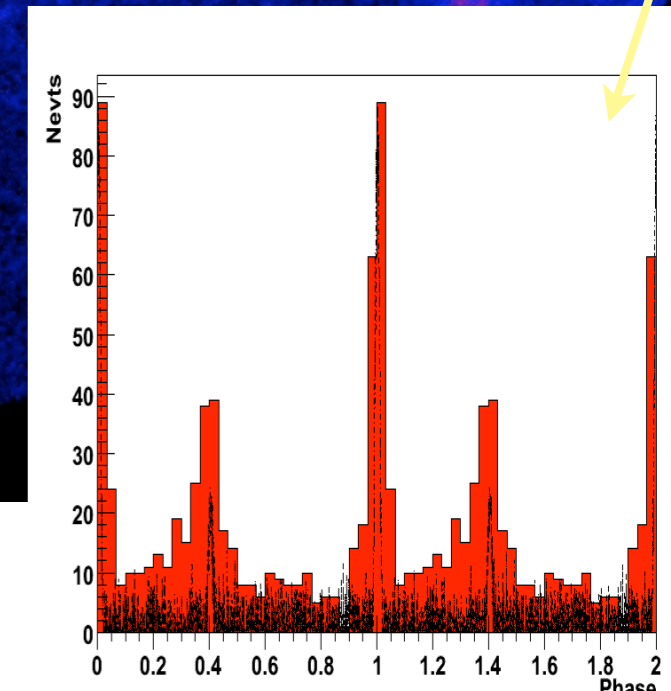
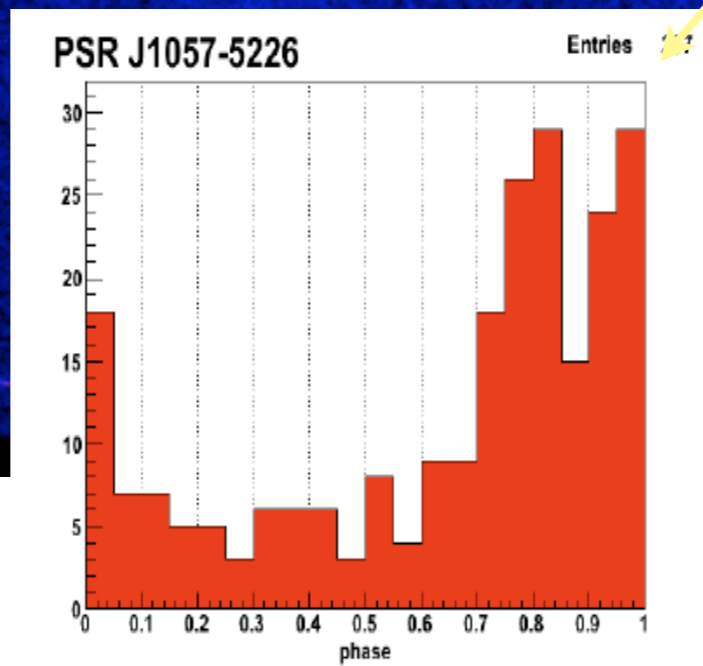
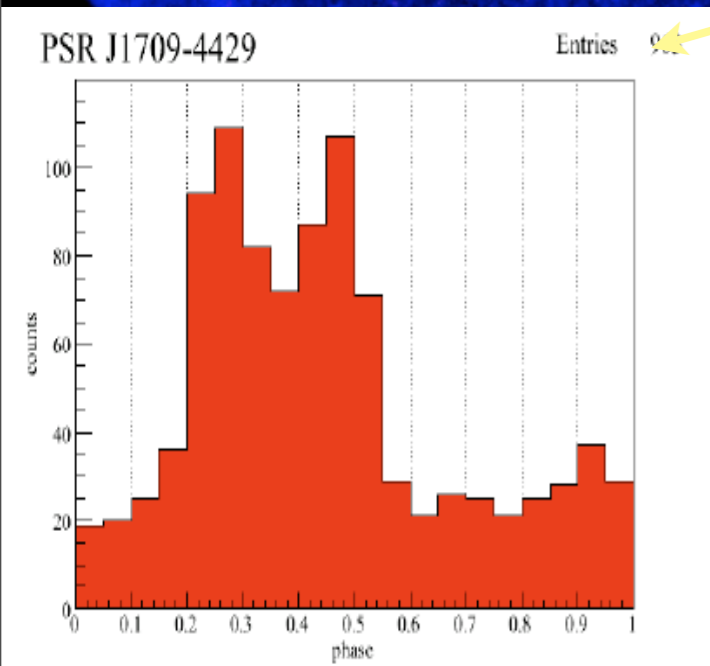
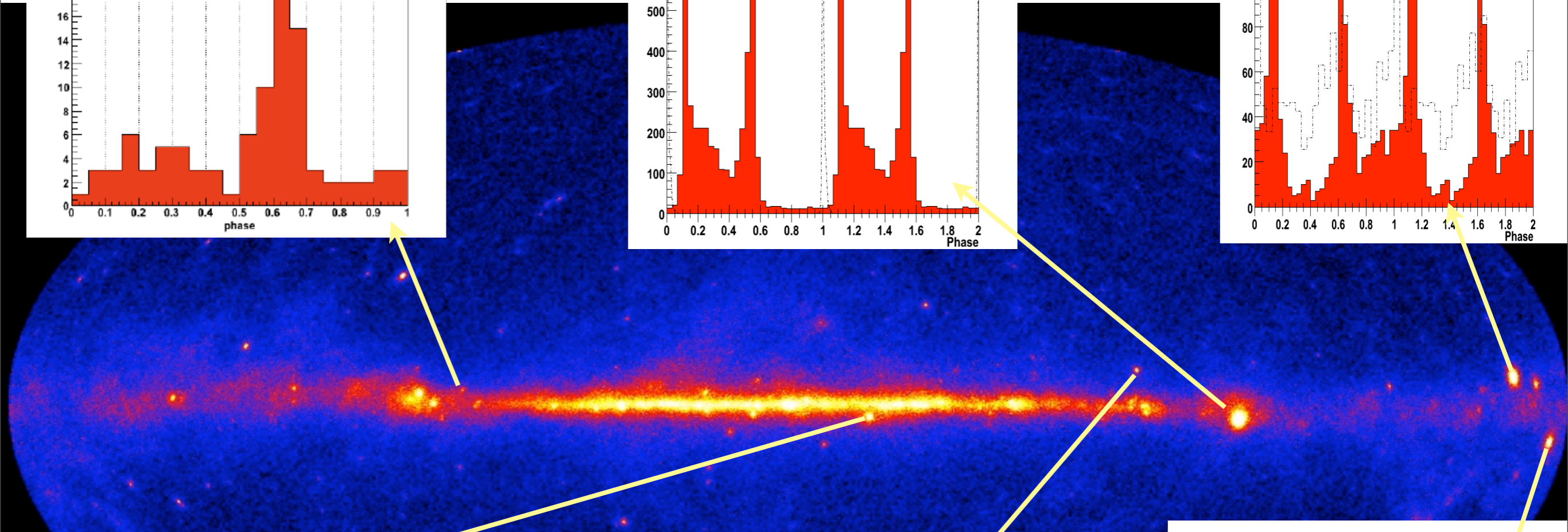
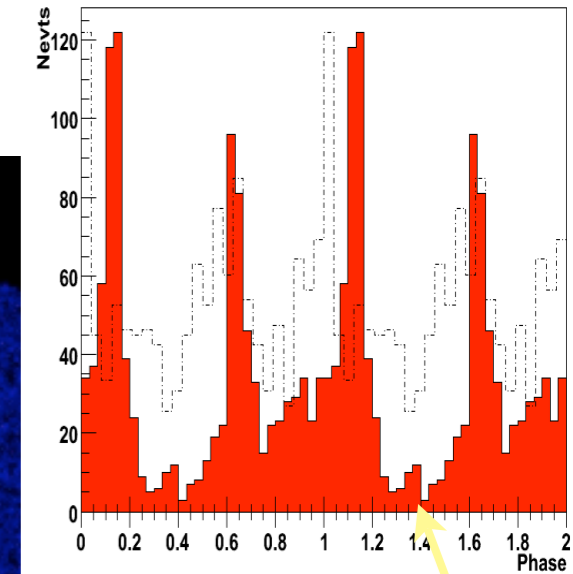
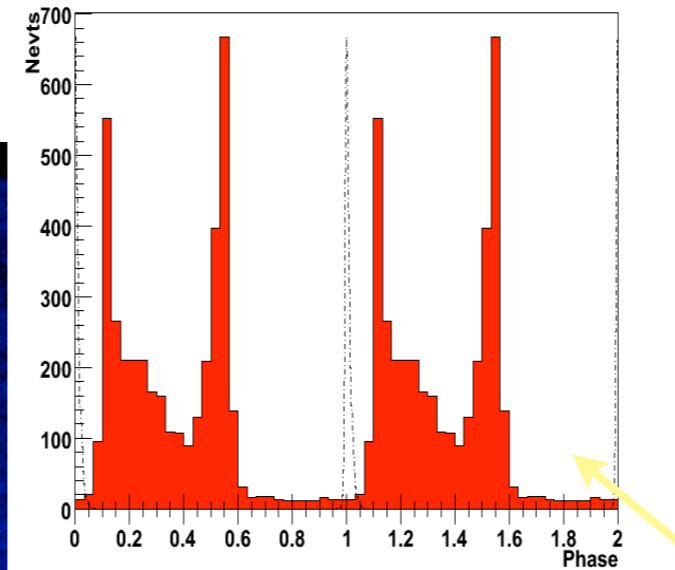
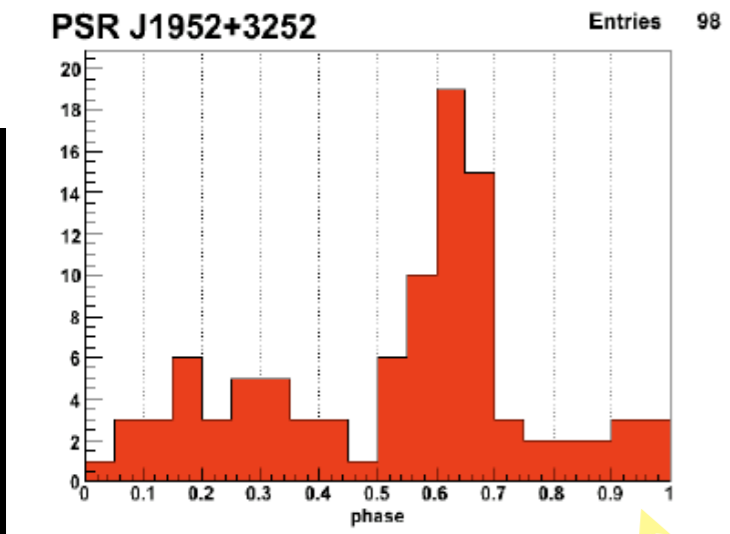




pulsars

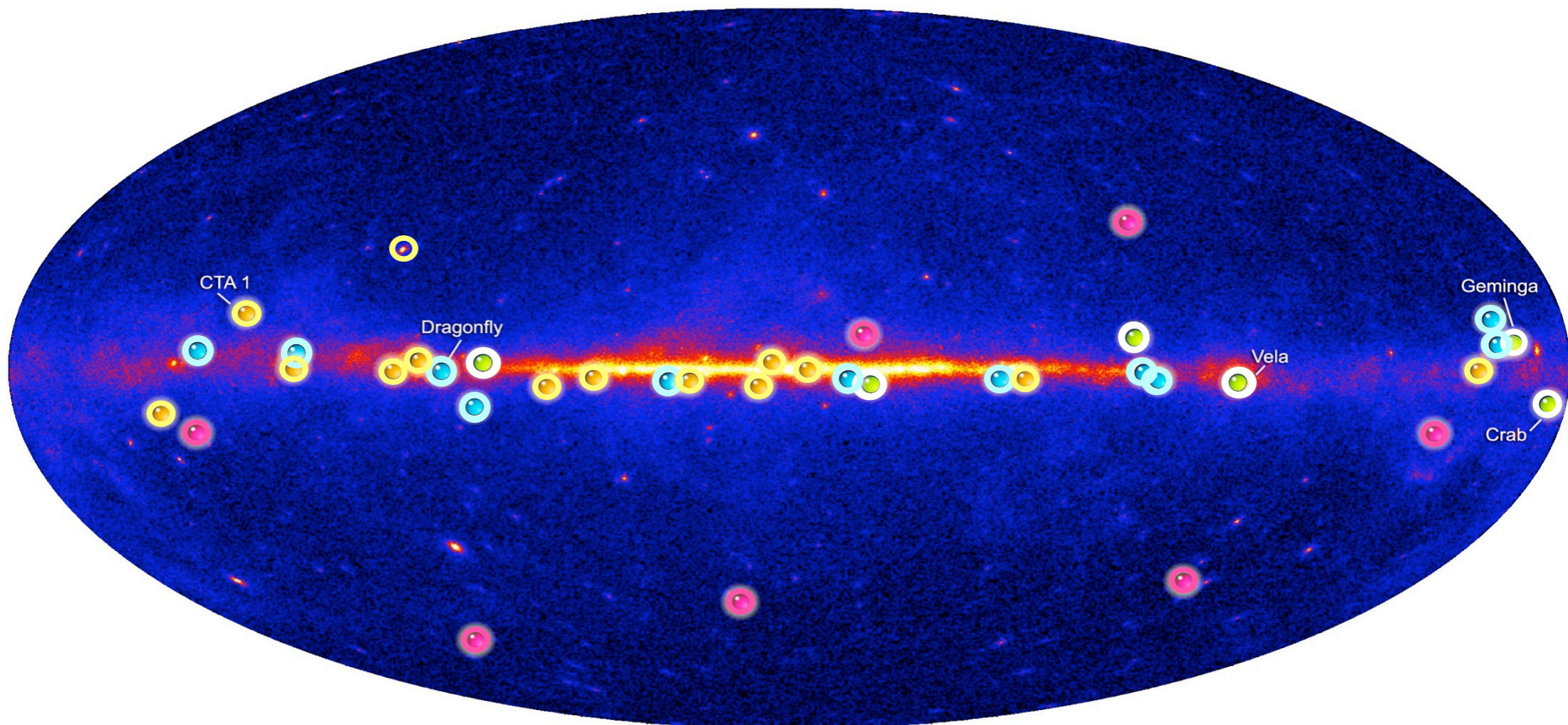


EGRET pulsars in a few days



the pulsing sky

- pulsars: > 25 radio-loud (≥ 7 ms psr), > 14 radio-quiet
- identified pulsars = 40% of the bright sources at low latitude

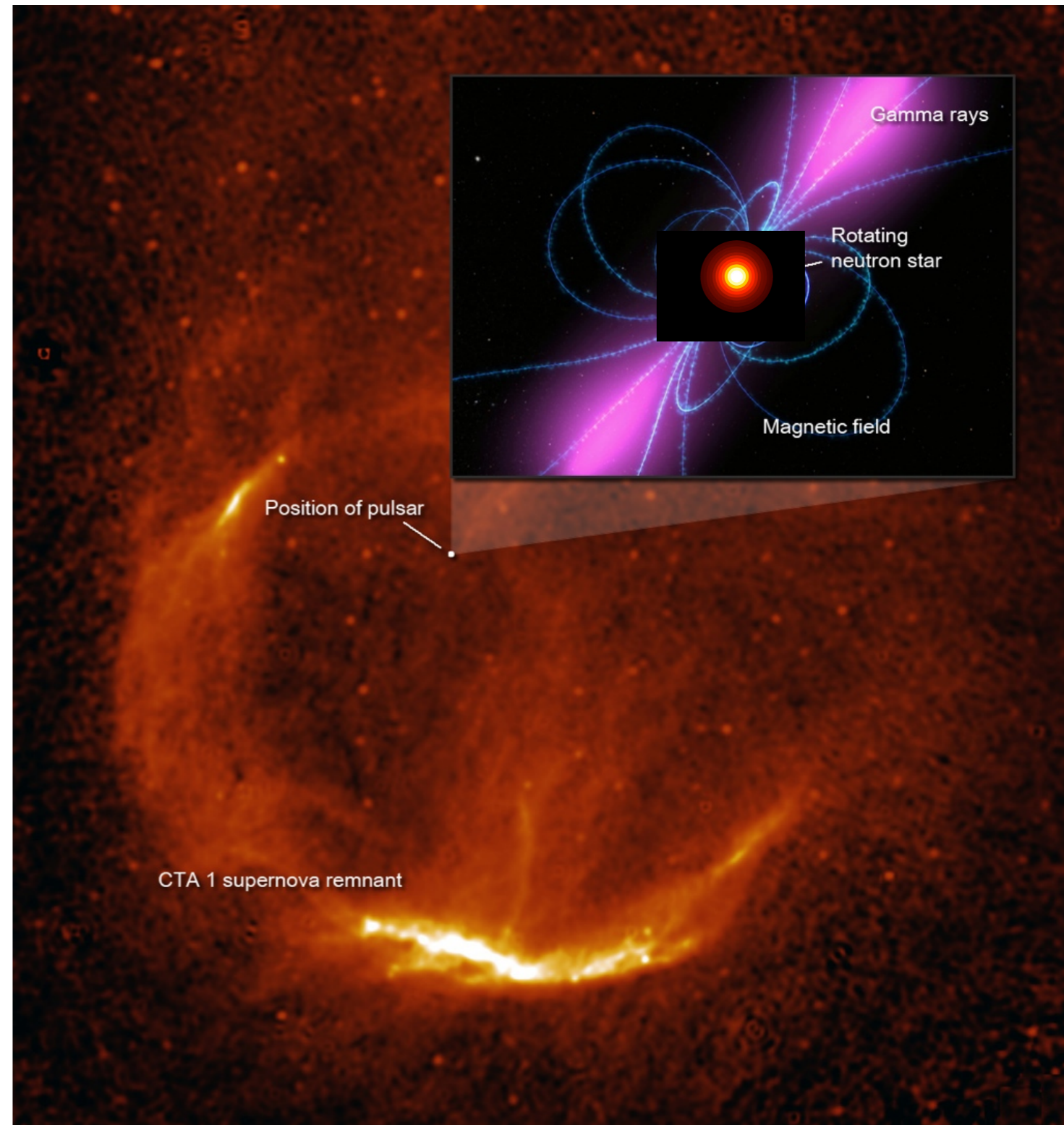
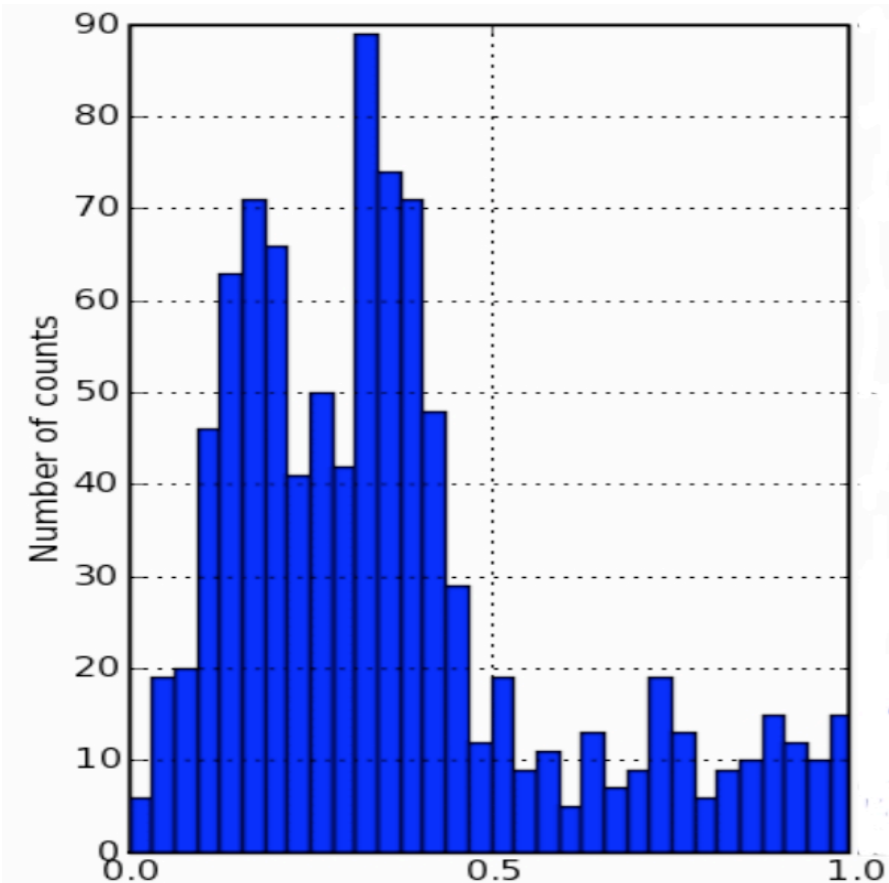


Fermi Pulsar Detections

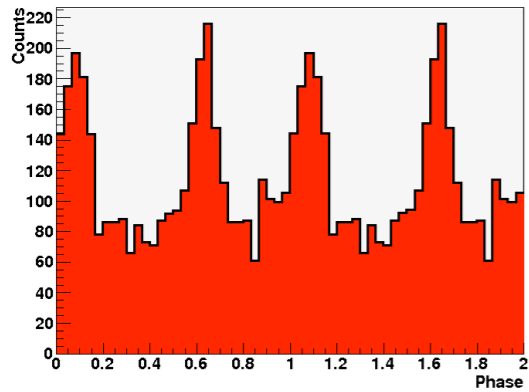
- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

blind search: CTA I

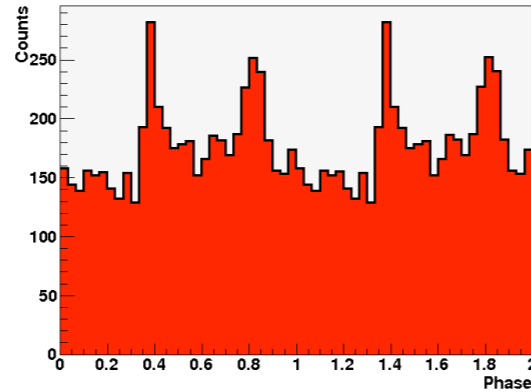
- $P = 316.86$ ms
- close peaks $\Delta\phi \sim 0.2$, as in PSR B1706-44
- age ≈ 10 kyr consistent with SNR and X-ray PWN



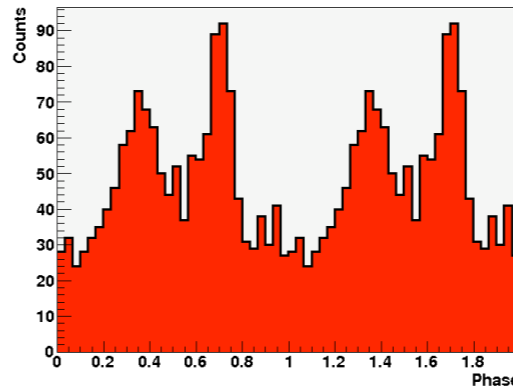
identified sources



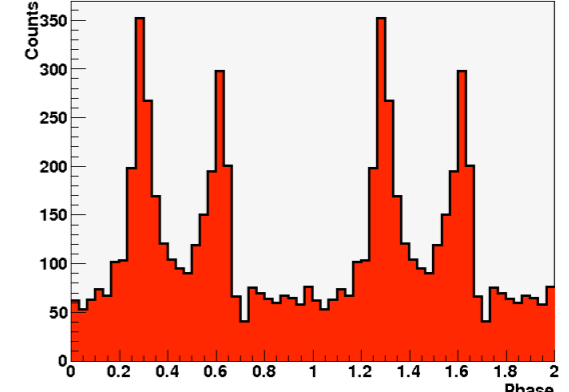
3EG J1826-1302 (Eel)



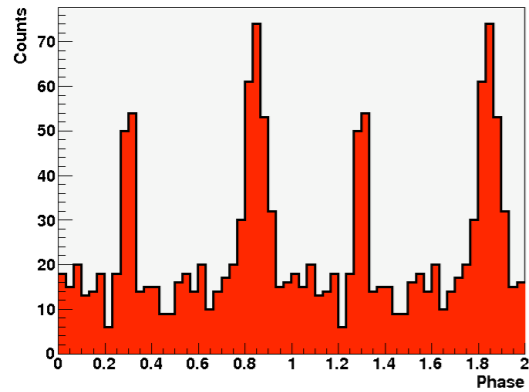
3EG J1420-6038 (Rabbit)



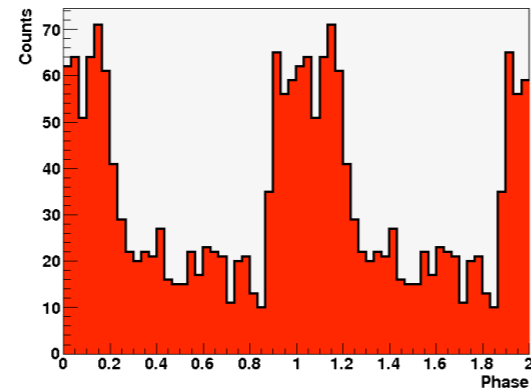
3EG J1734-3232



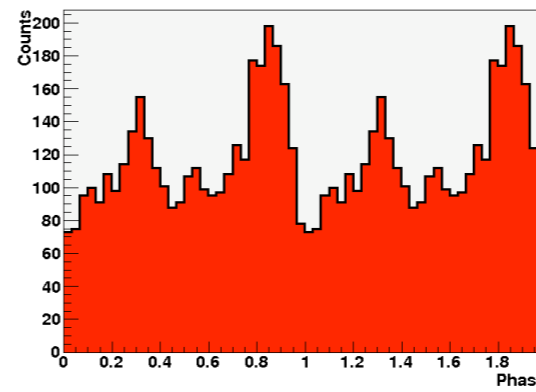
3EG J1809.5 (Taz)



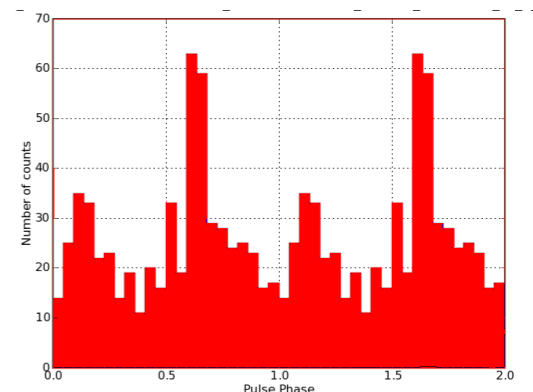
3EG J0631+0642



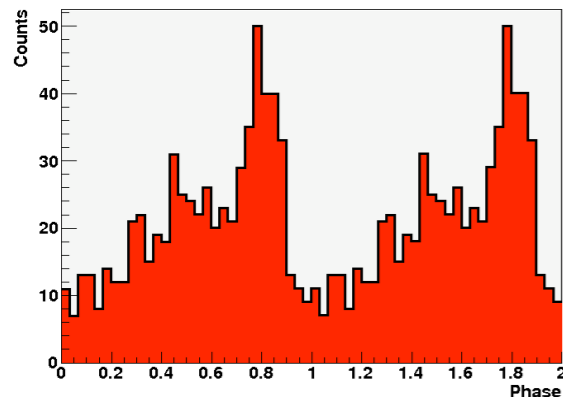
3EG J1741-2050



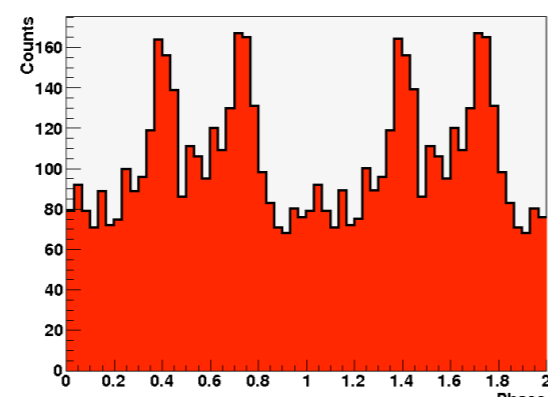
3EG J2020 γ Cyg



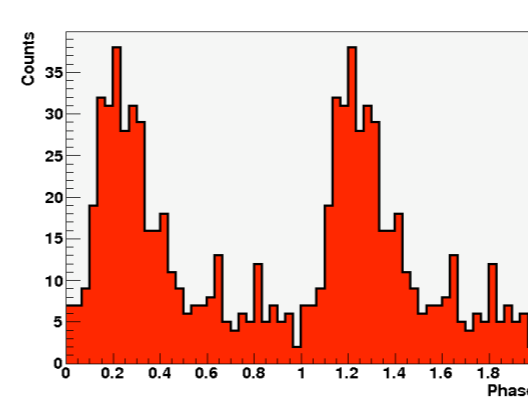
3EG J2033+4118



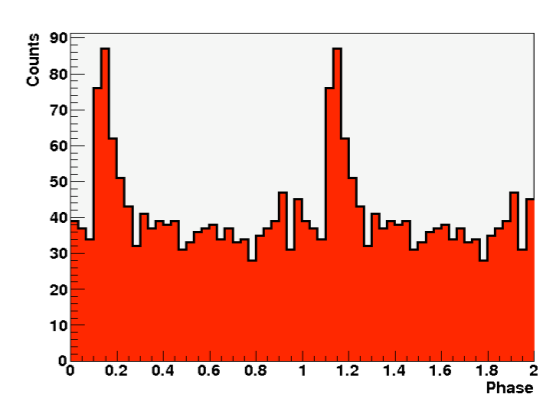
3EG J1958+2909



MGRO J1908+06



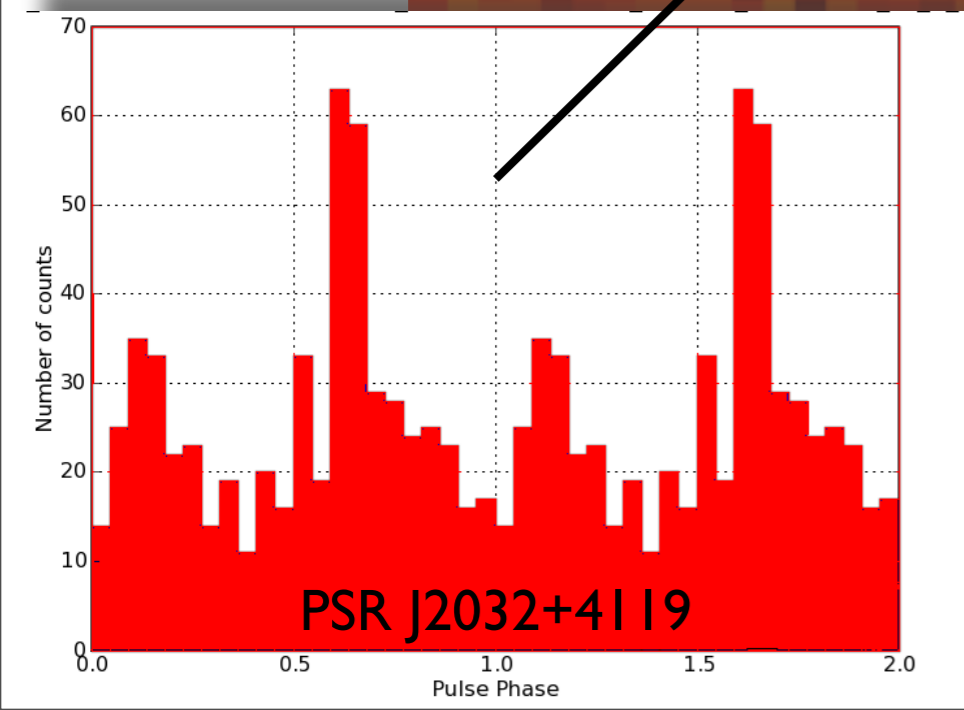
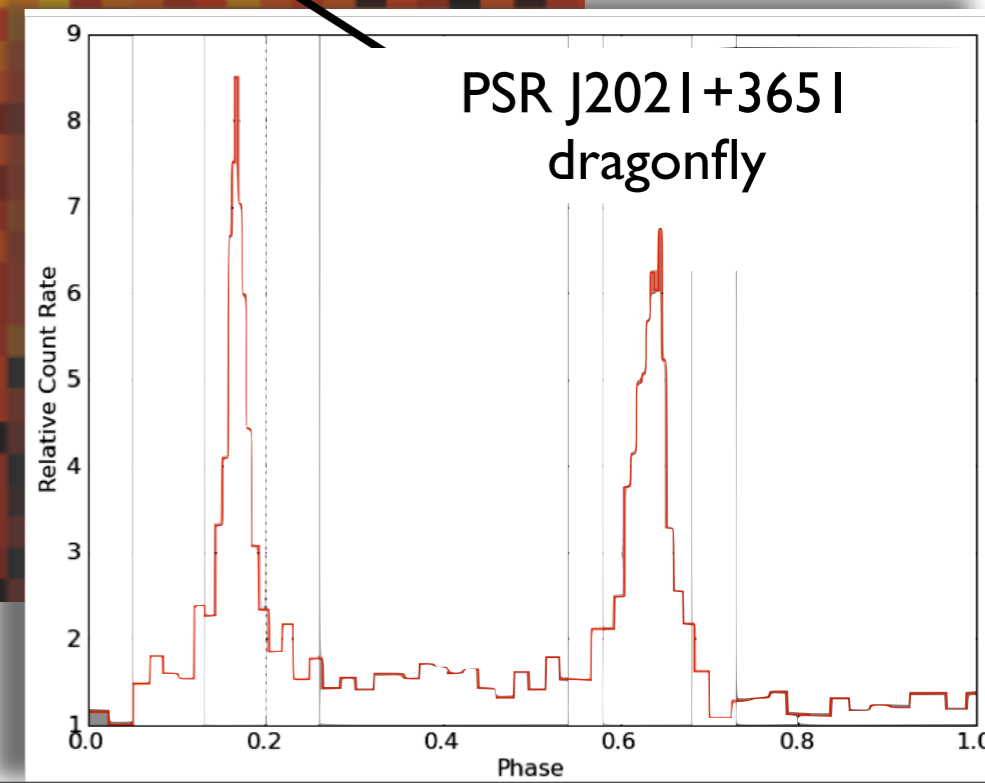
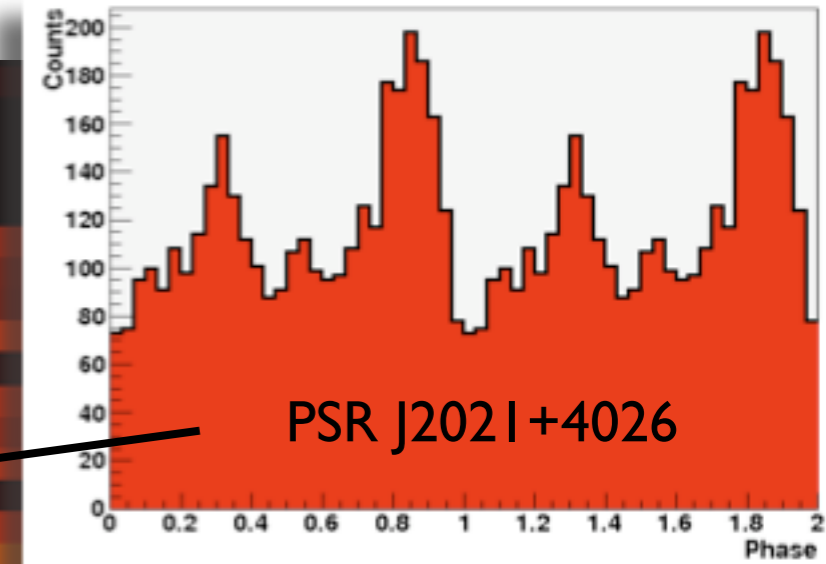
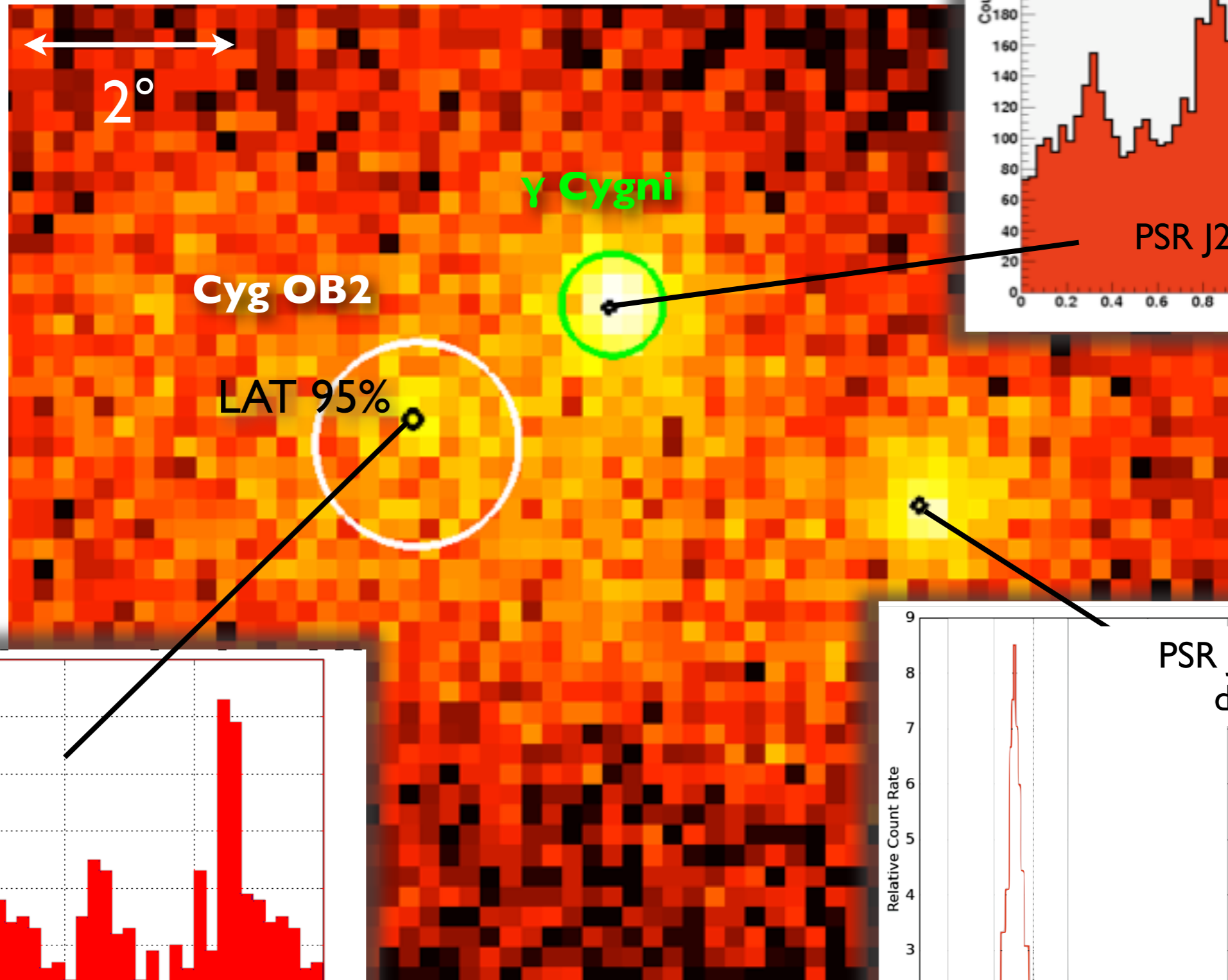
new Fermi J0357+32



new Fermi J2238+58

PRELIMINARY

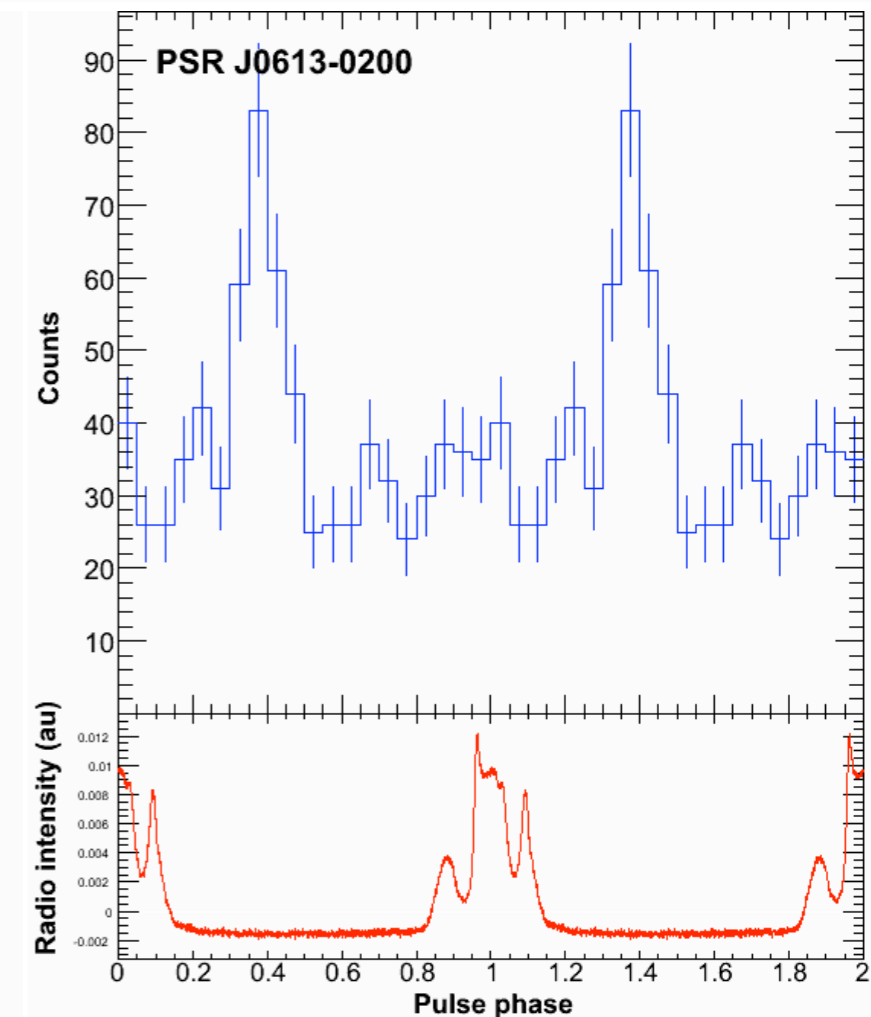
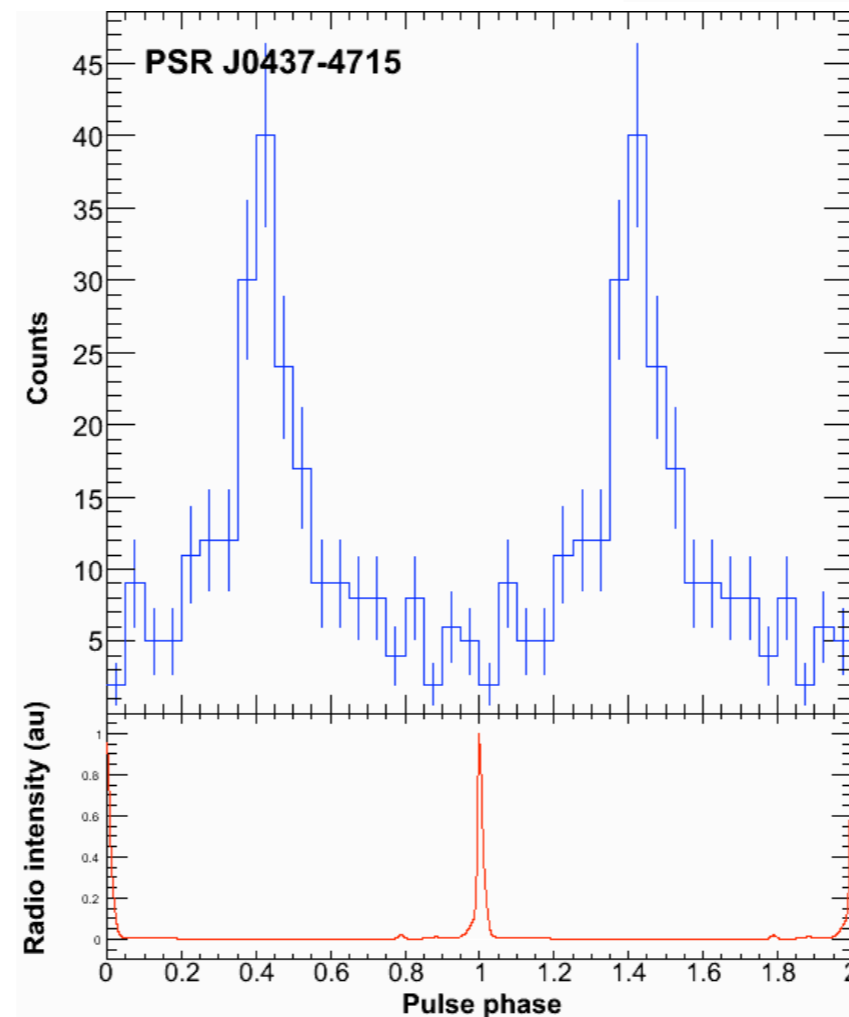
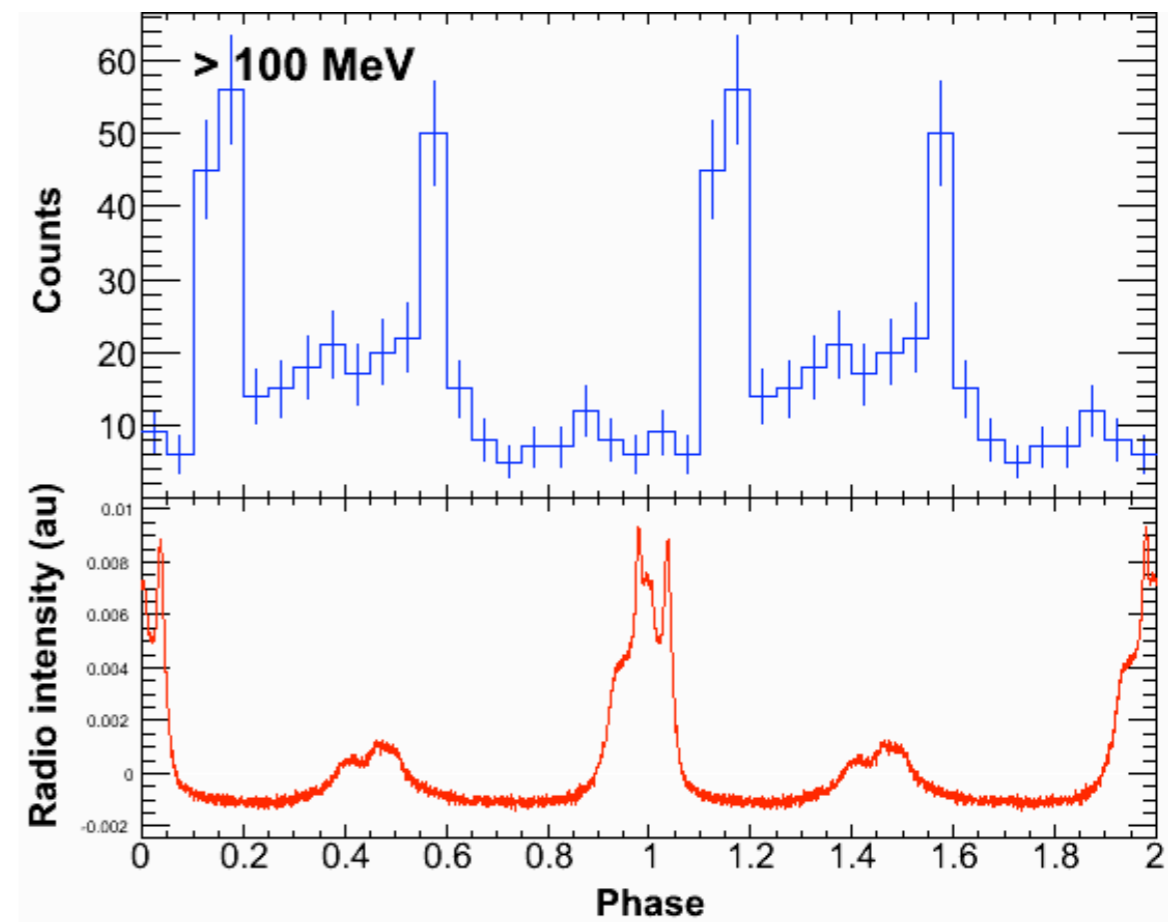
Cygnus region



3 month survey
 $E > 450$ MeV




ms pulsars

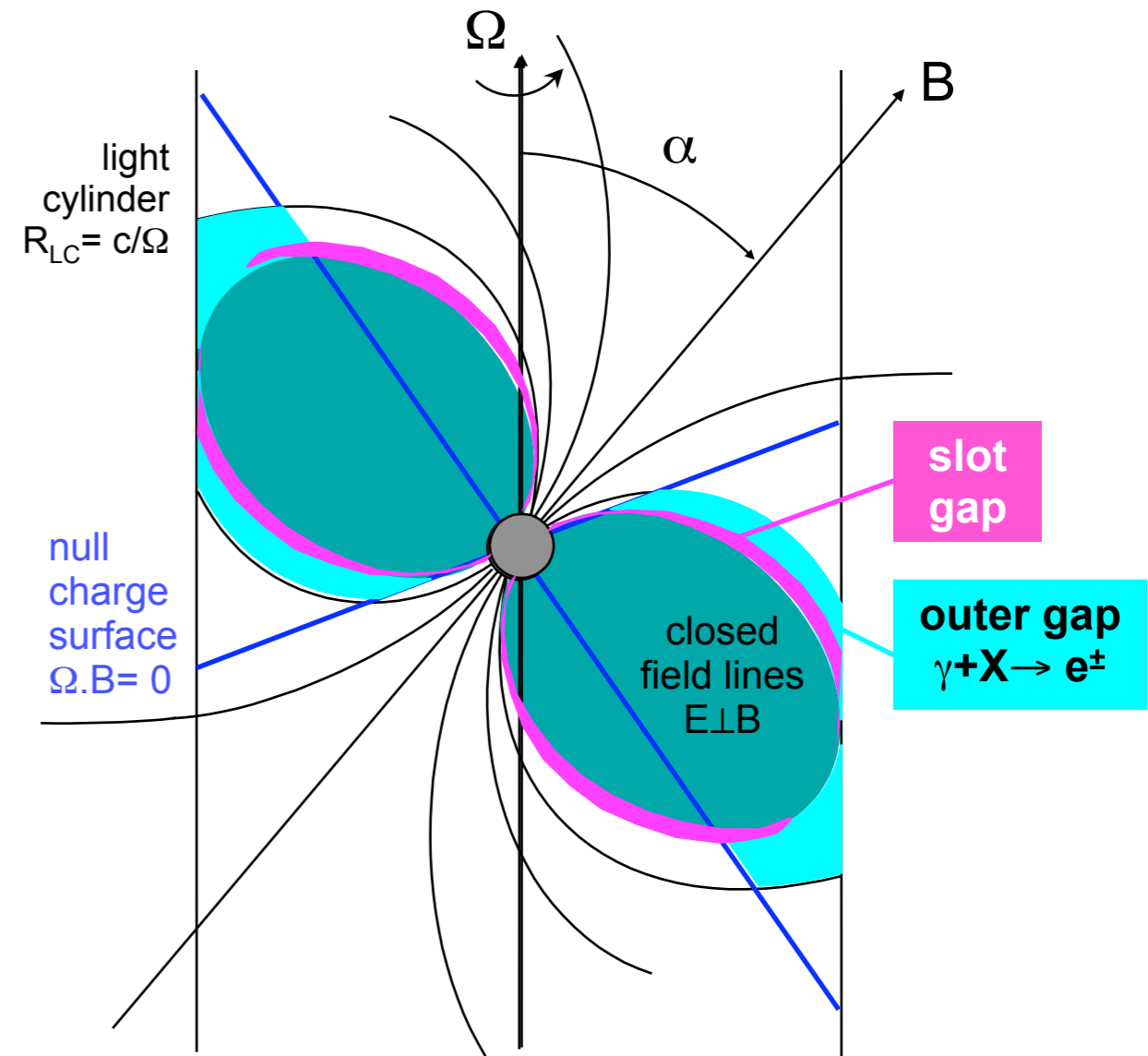
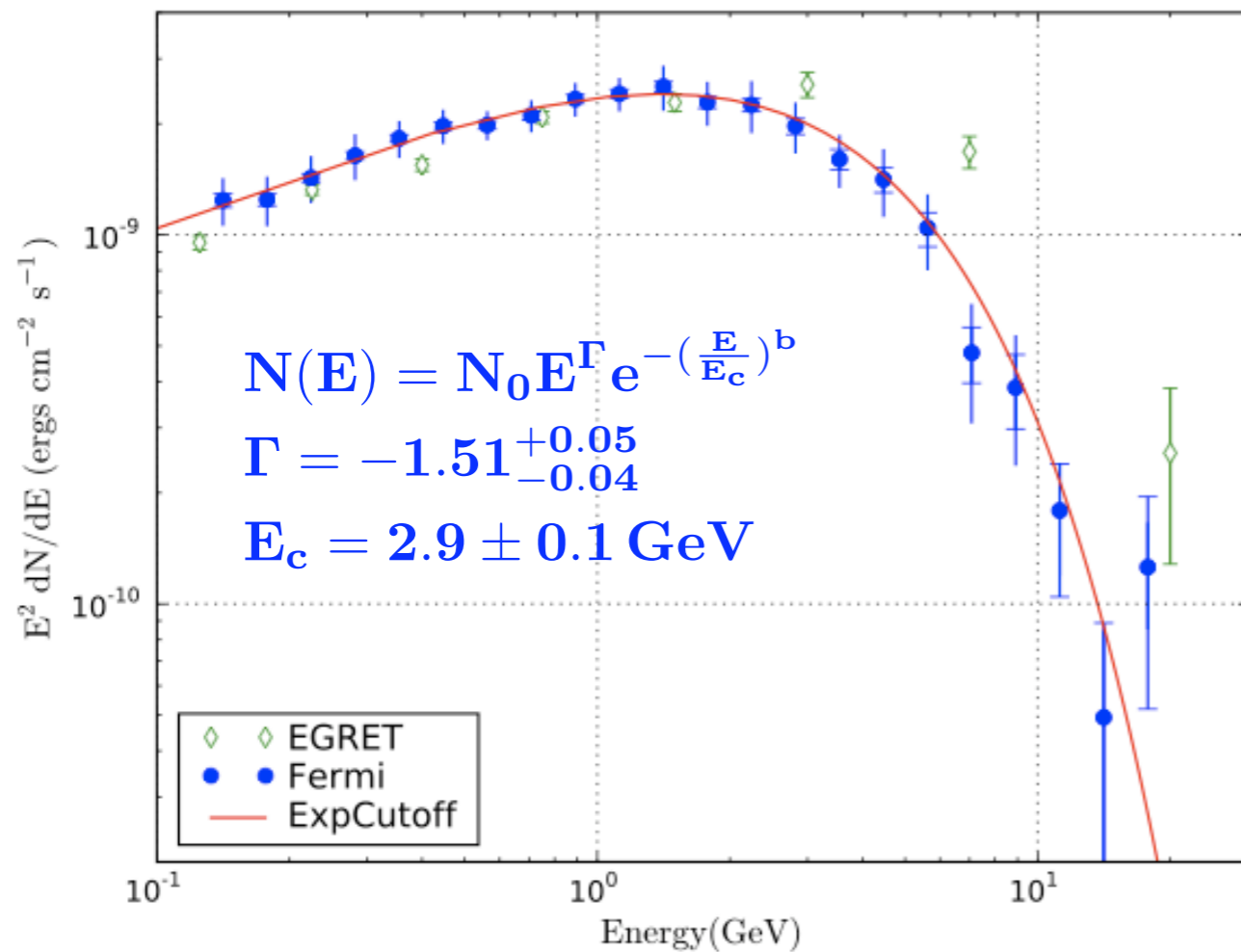
- many nearby ms pulsars detected
 - \Rightarrow large beaming fraction
 - J0218+4232 at 3.2 kpc confirmed
 - 6 with $D < 500$ pc, large \dot{E}/D^2
 - a variety of shapes



PRELIMINARY

accelerator sites

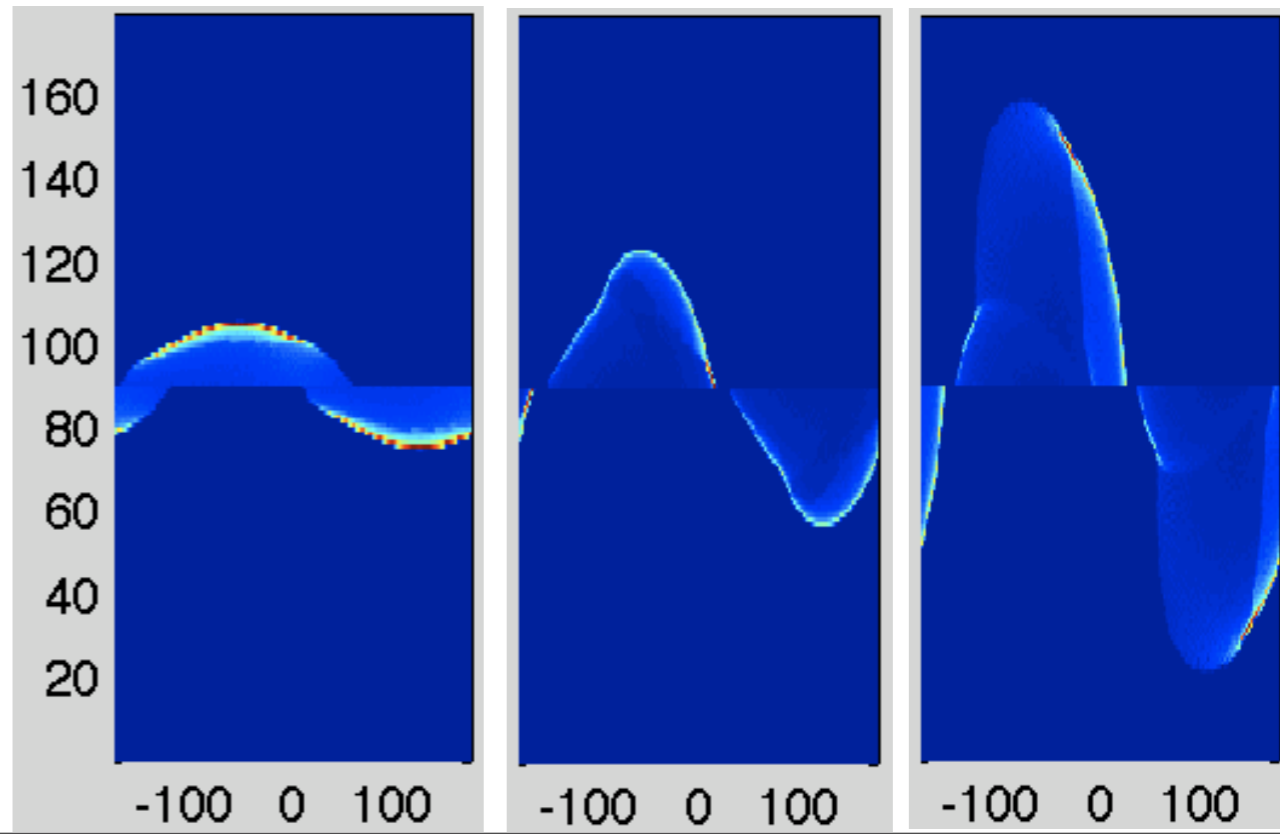
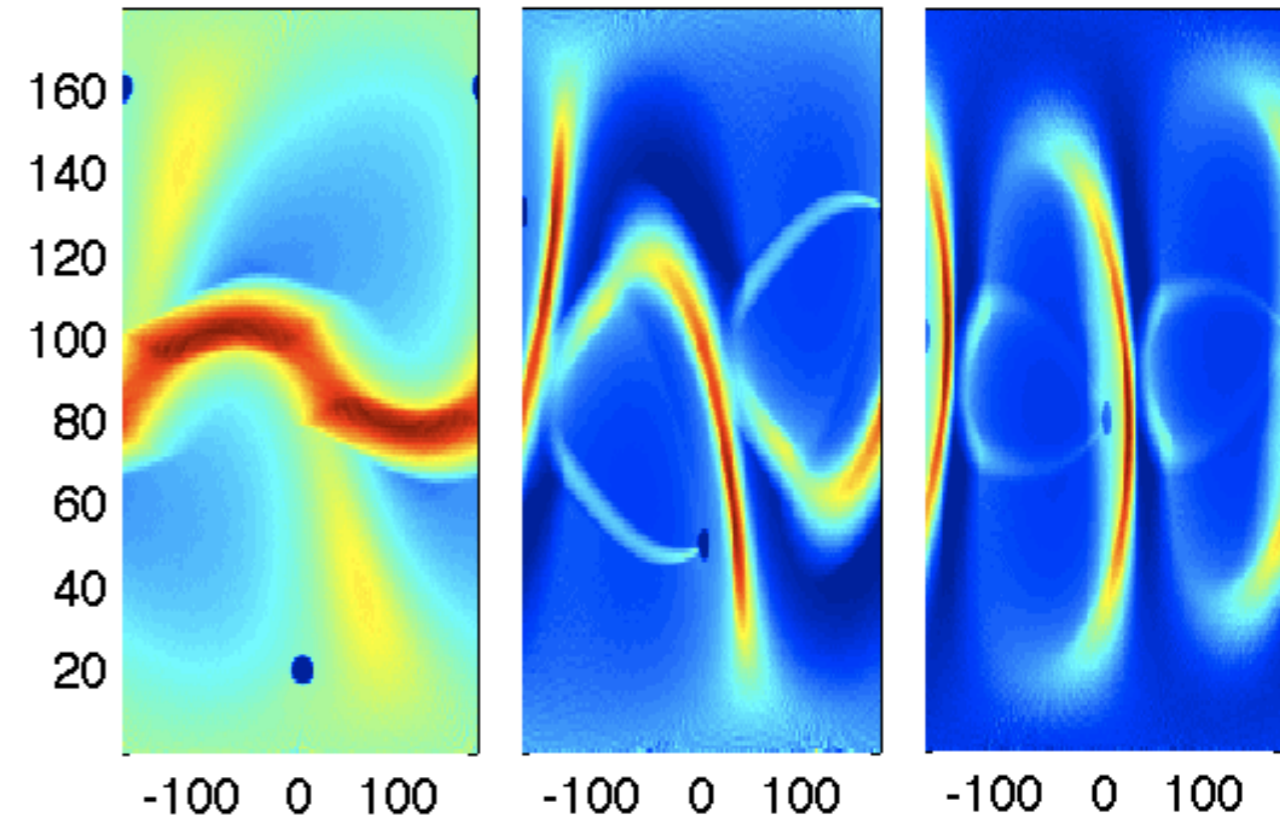
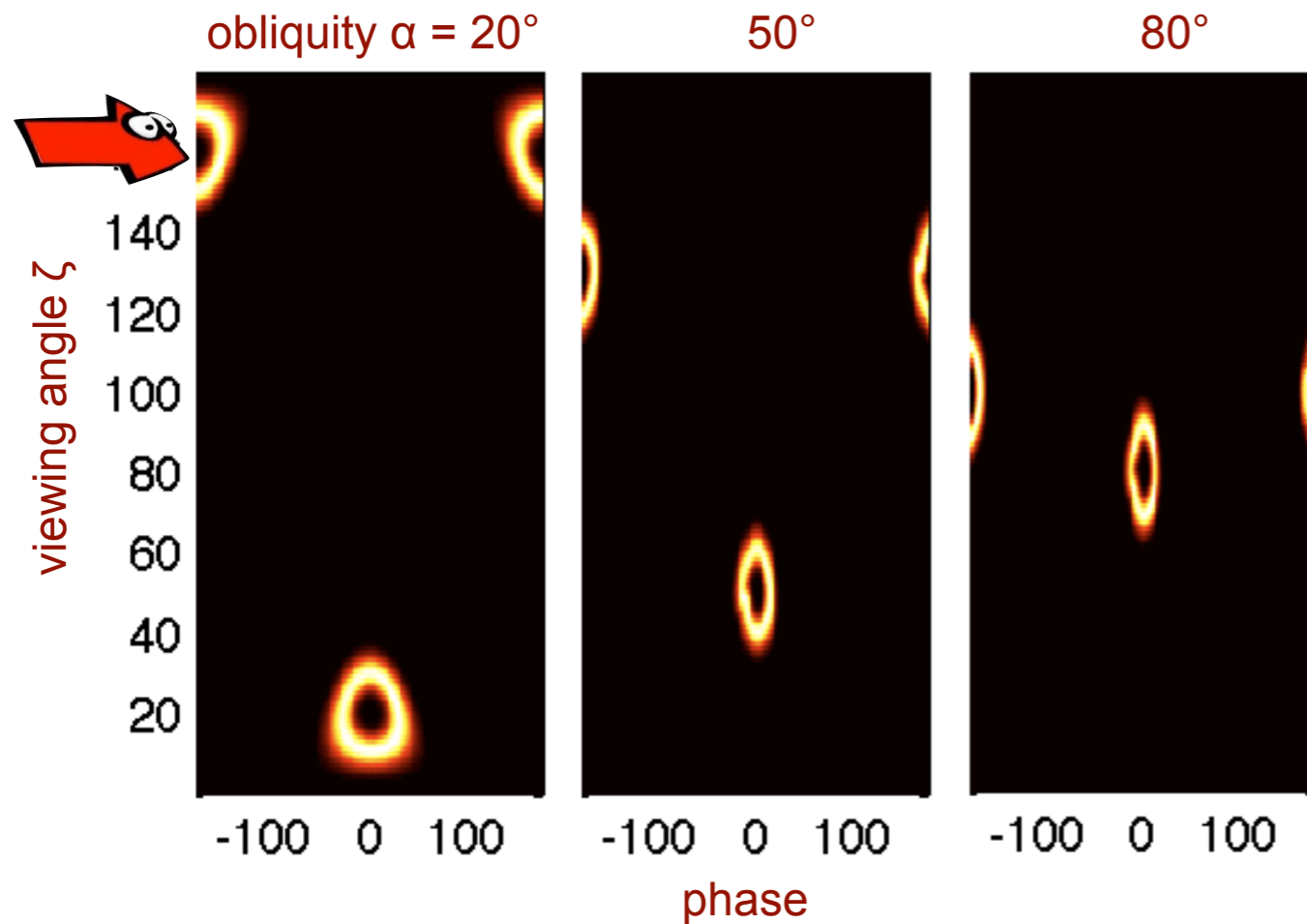
-  Vela: simple exponential cut-off ($b = 1$, $b = 2$ rejected at 16.5σ)
 -  \Rightarrow no evidence for $\gamma + B \rightarrow e^\pm$
 -  \Rightarrow medium- to high-altitude accelerator gap



geometry & radiation pattern

different “antenna” patterns

- slot gap
- radio cone



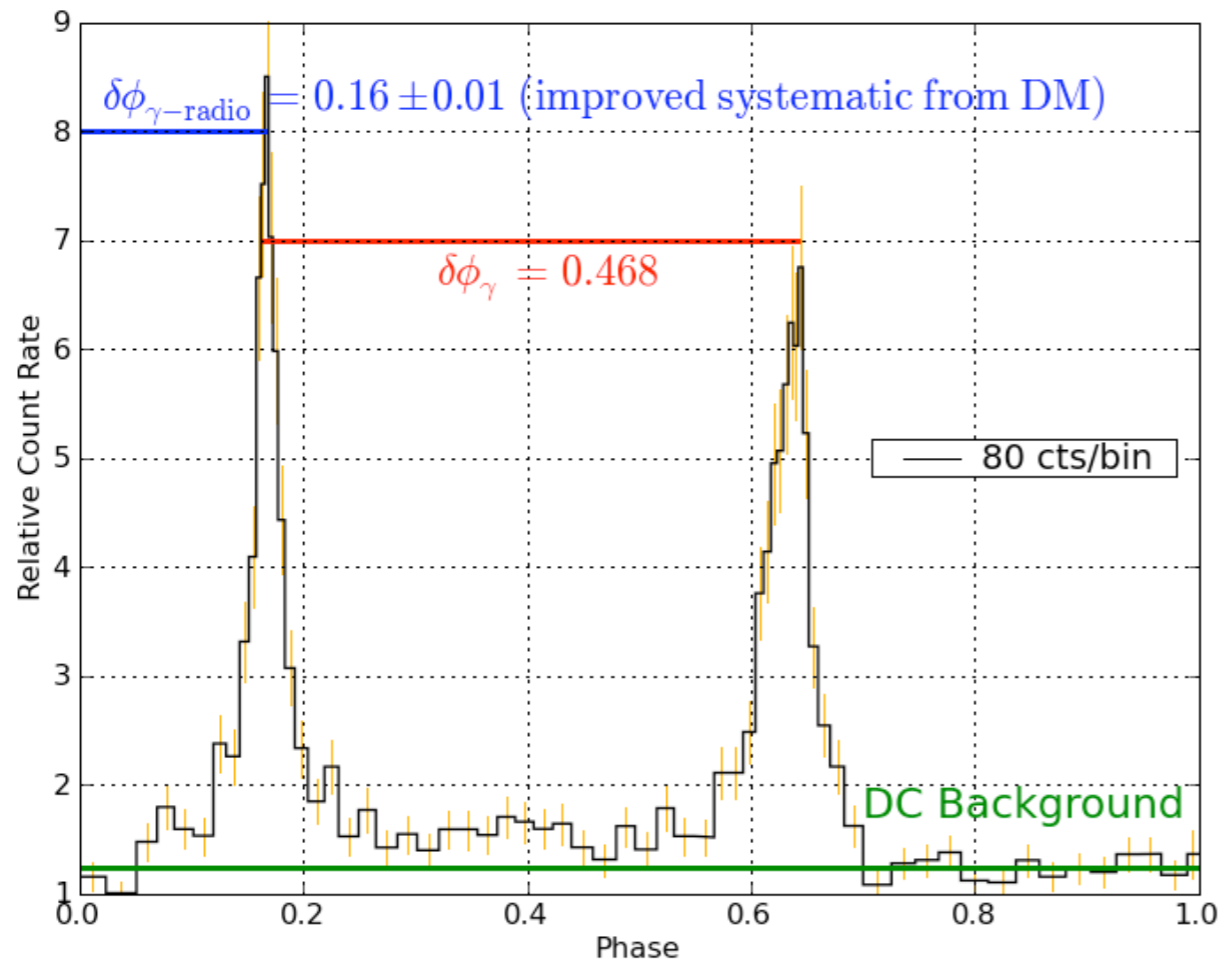
- outer gap
- impact on true $L_\gamma/\dot{E}_{\text{psr}}$ efficiency

sharp caustic peaks

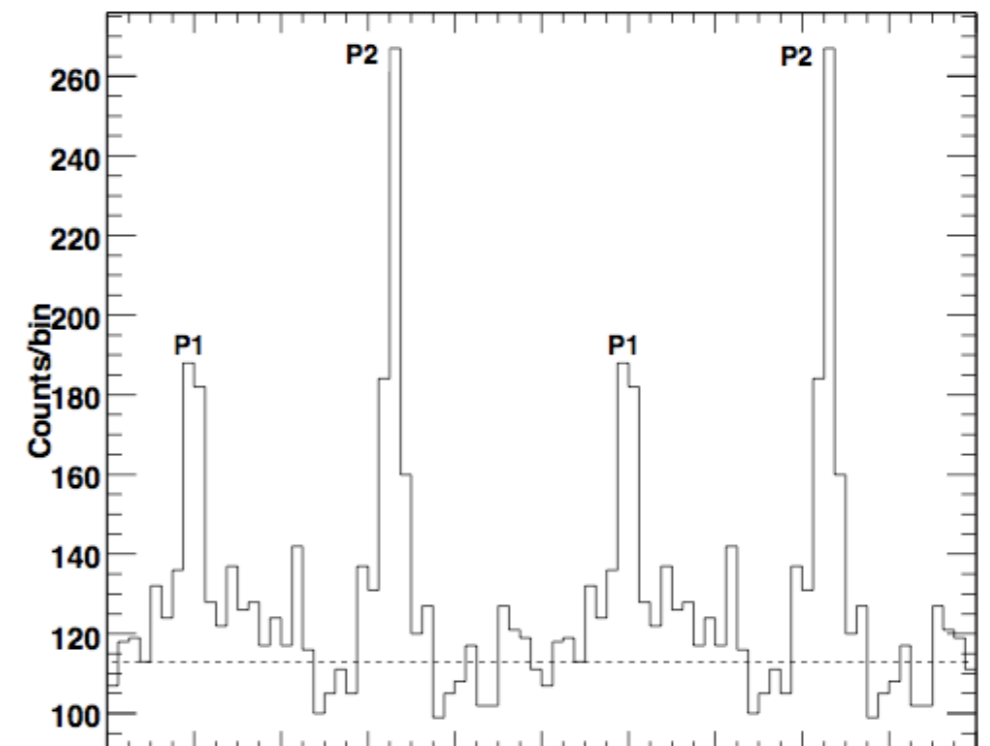
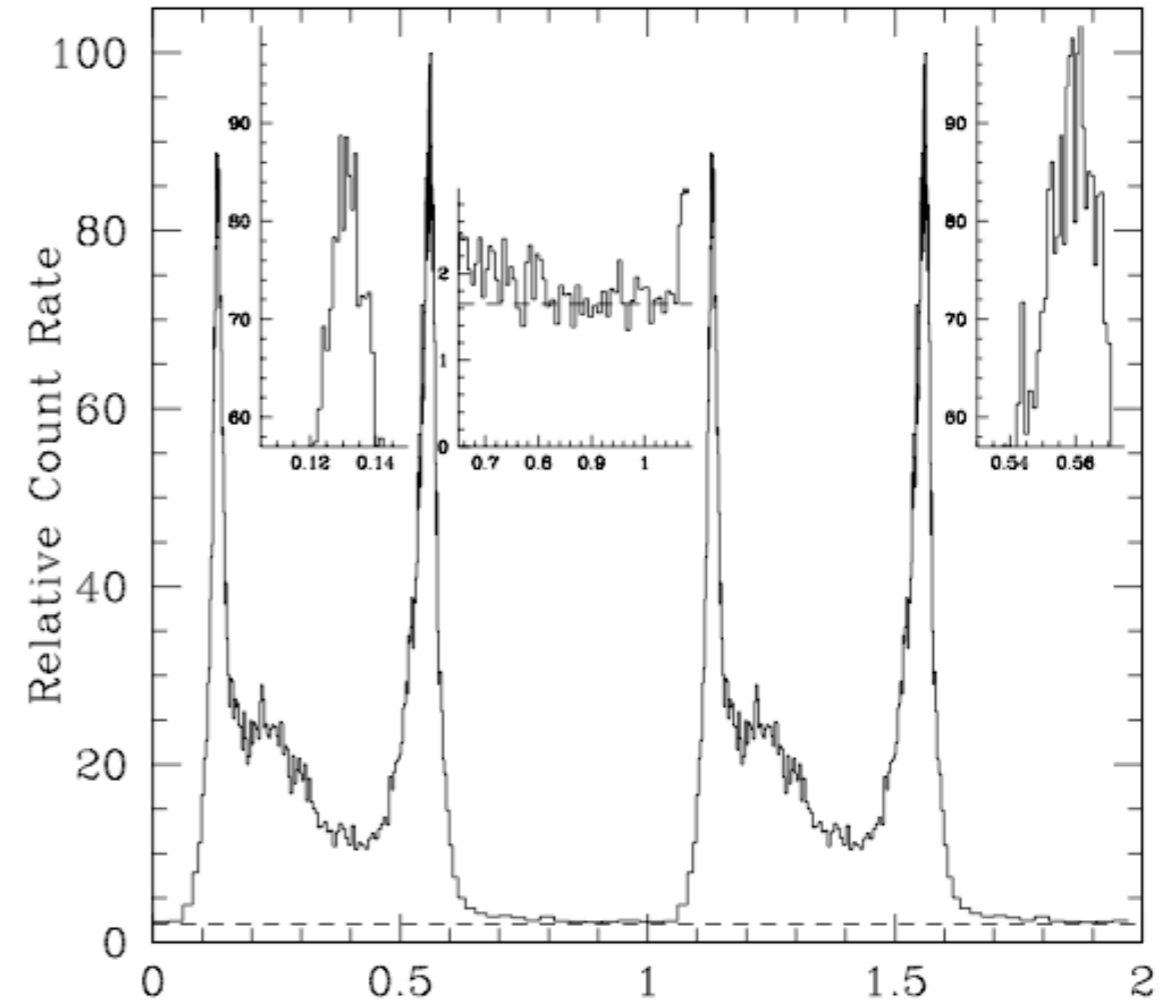


ex:

- Vela (< 0.3 ms):
- Dragonfly:

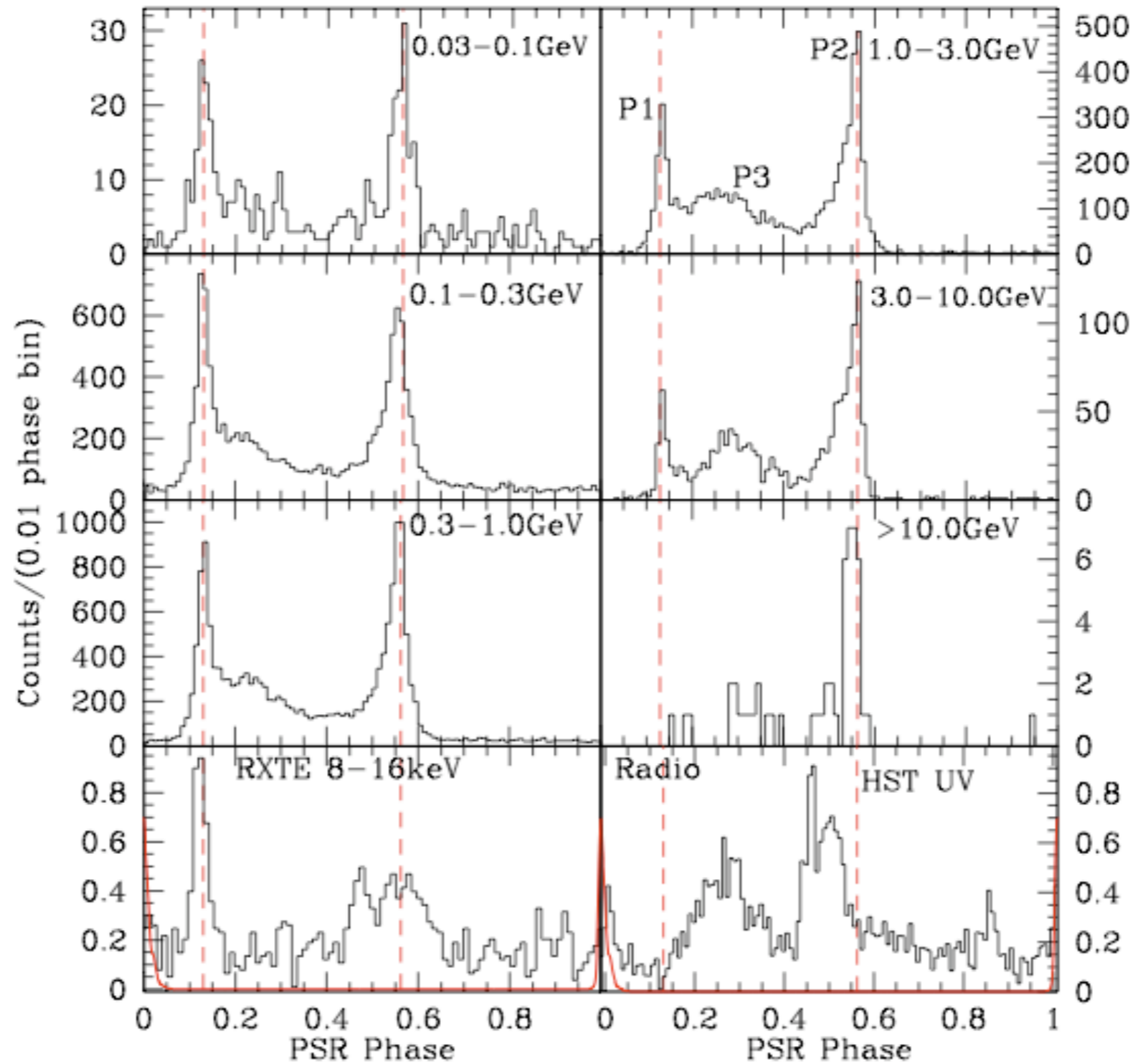


- PSR J1028-5819:



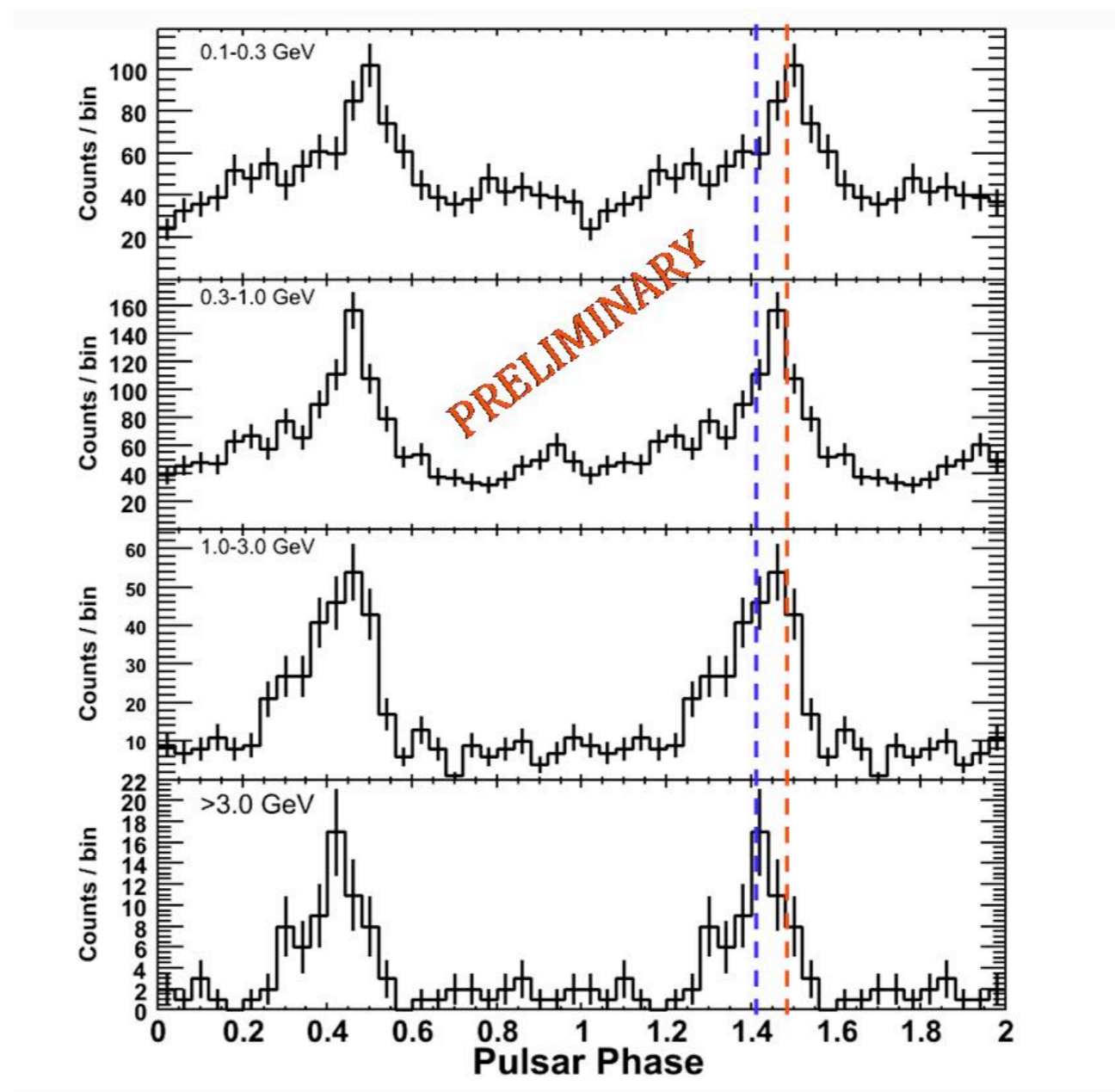
multi- λ sub-structures

 ex: Vela



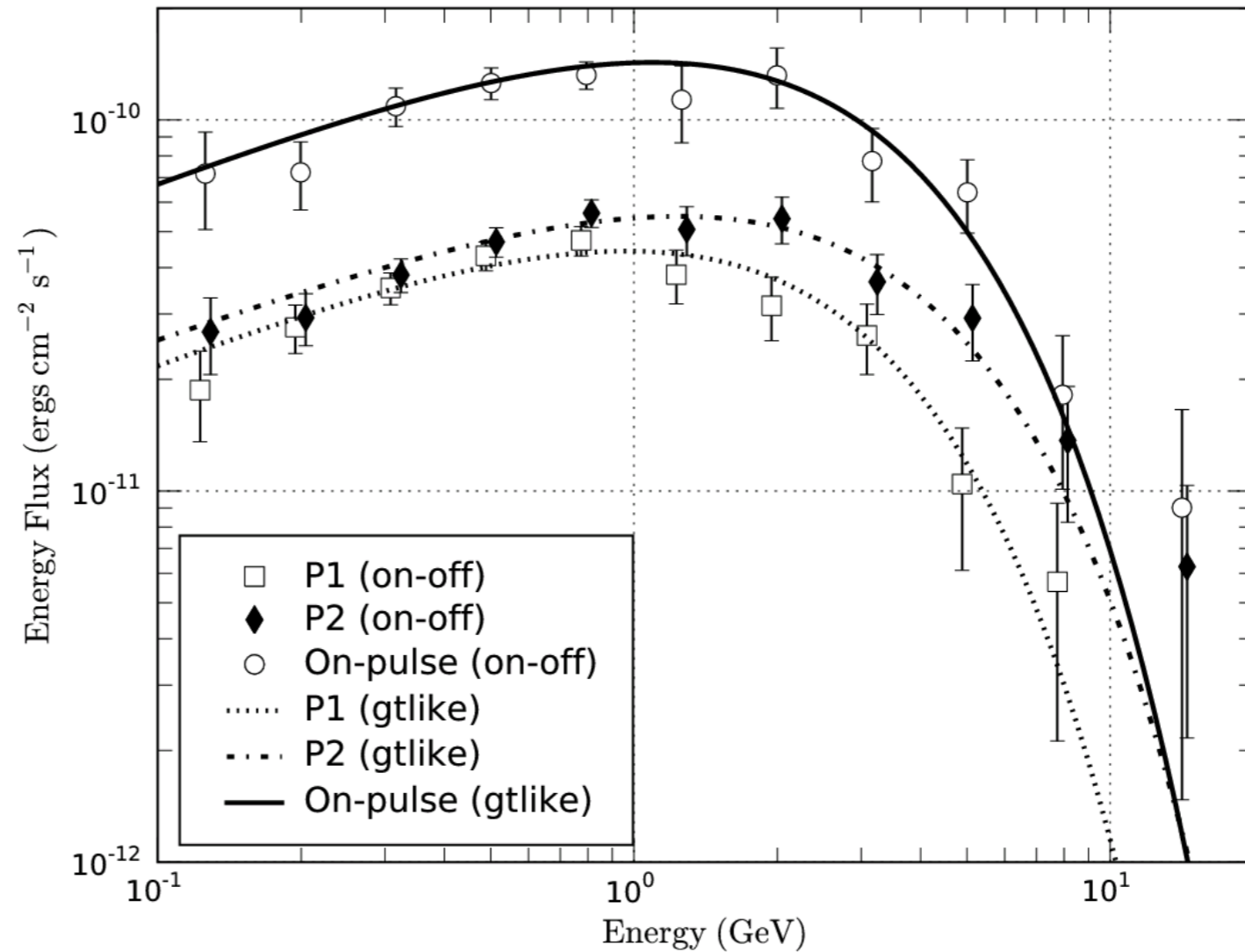
phase separation and shifts

- a variety of $\Delta\phi(\gamma \text{ peaks})$ and $\Delta\phi(\text{radio-}\gamma)$
 - with age, luminosity...
 - ex: J2229+6114



phase-resolved spectroscopy

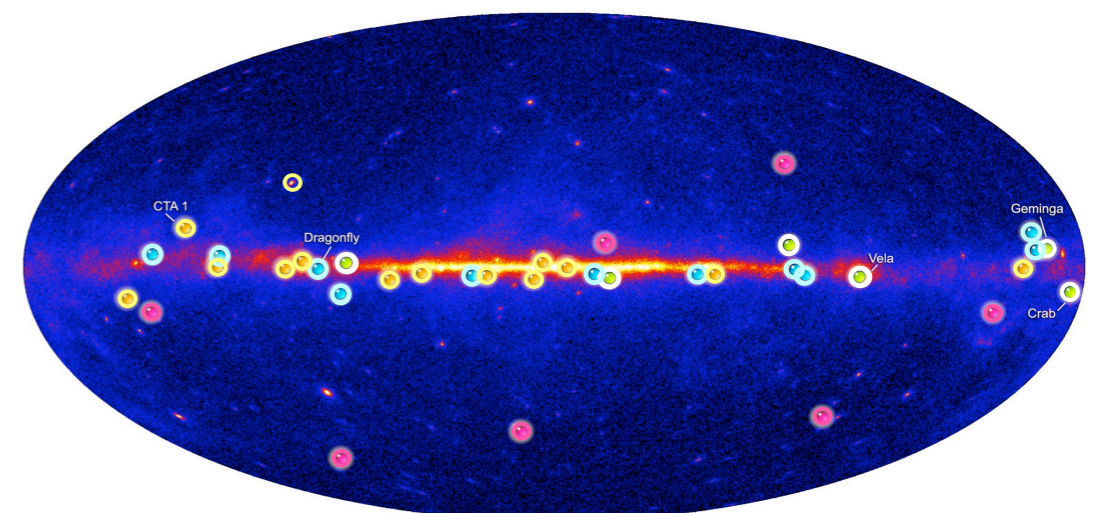
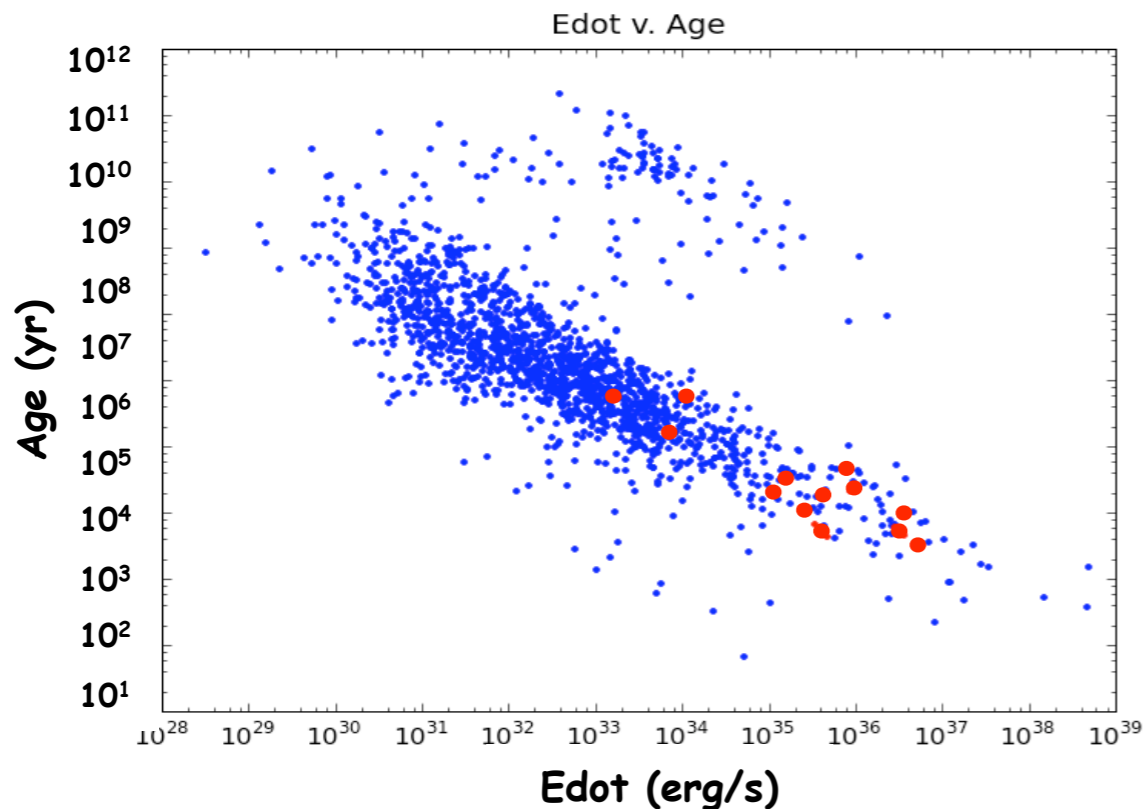
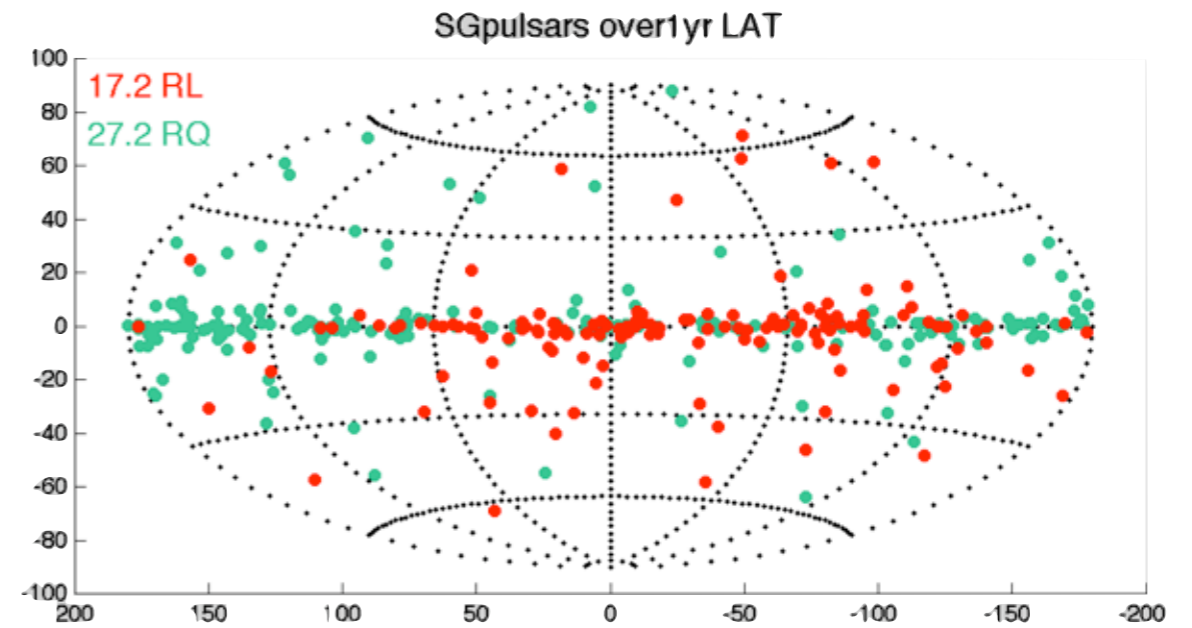
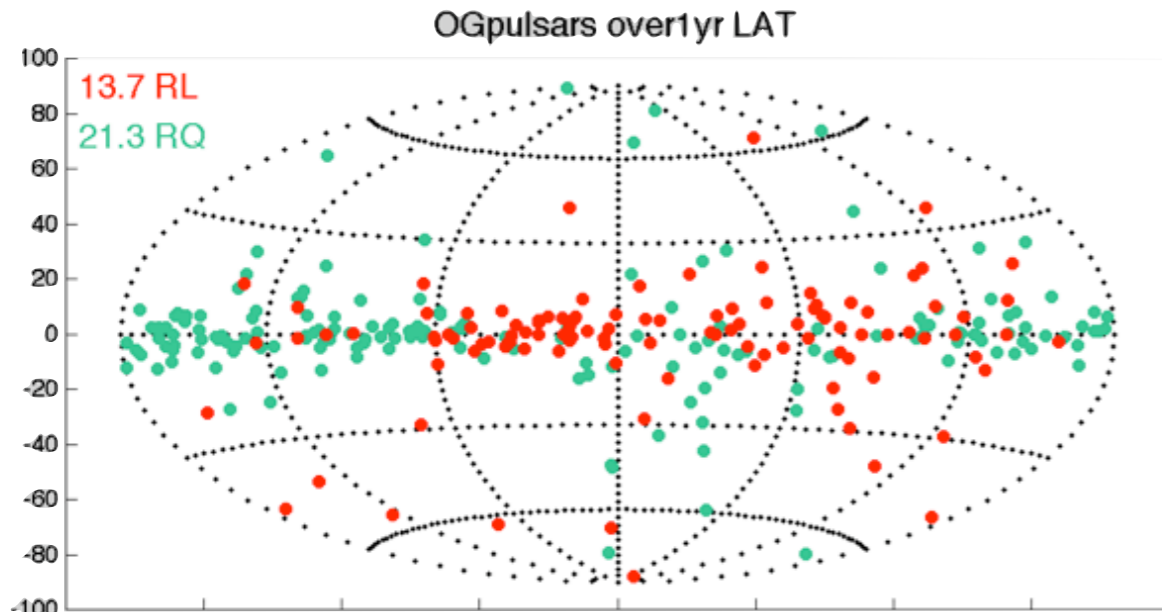
- on its way...
- ex: dragonfly



PRELIMINARY

population studies

- simulations of 10^6 pulsars for polar, slot, outer gap
- confrontation to observations

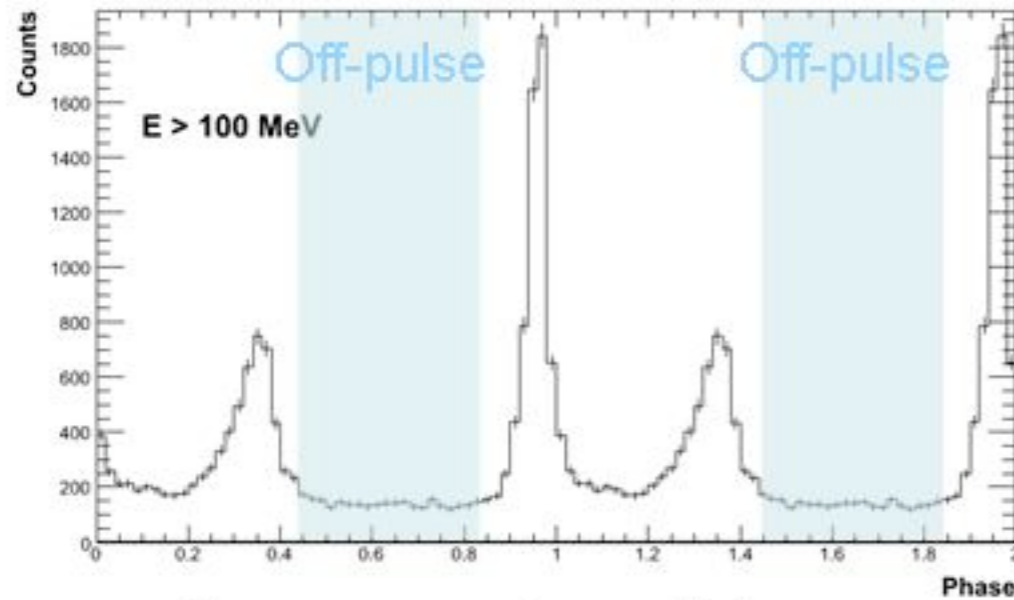


Fermi Pulsar Detections

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

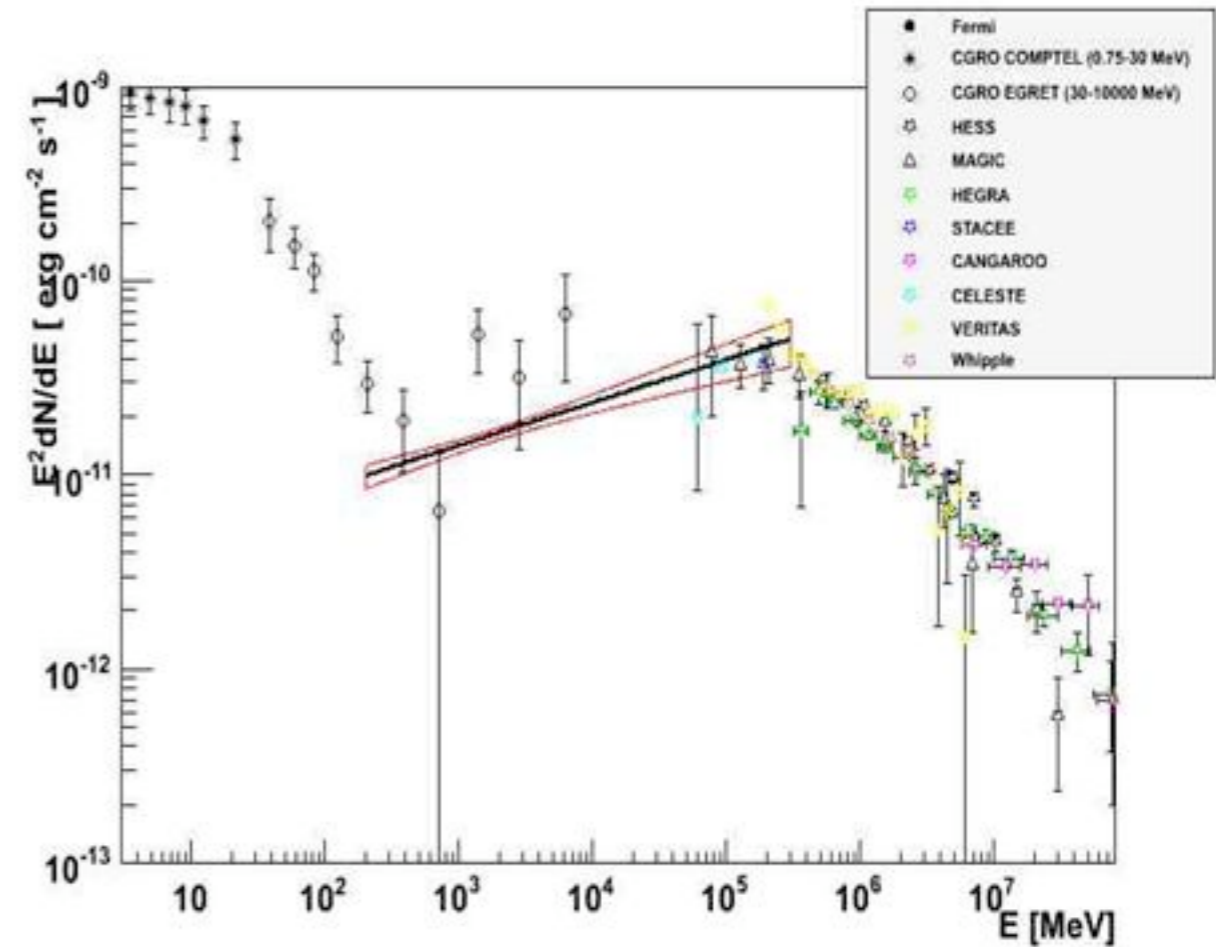
pulsar wind nebulae

Crab



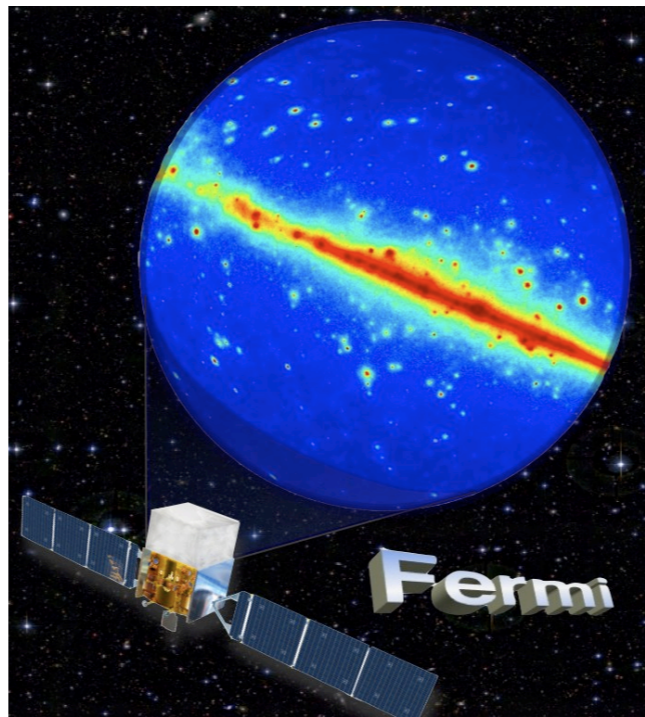
Gamma-ray phase histogram
above 100 MeV (50 bins)

PRELIMINARY



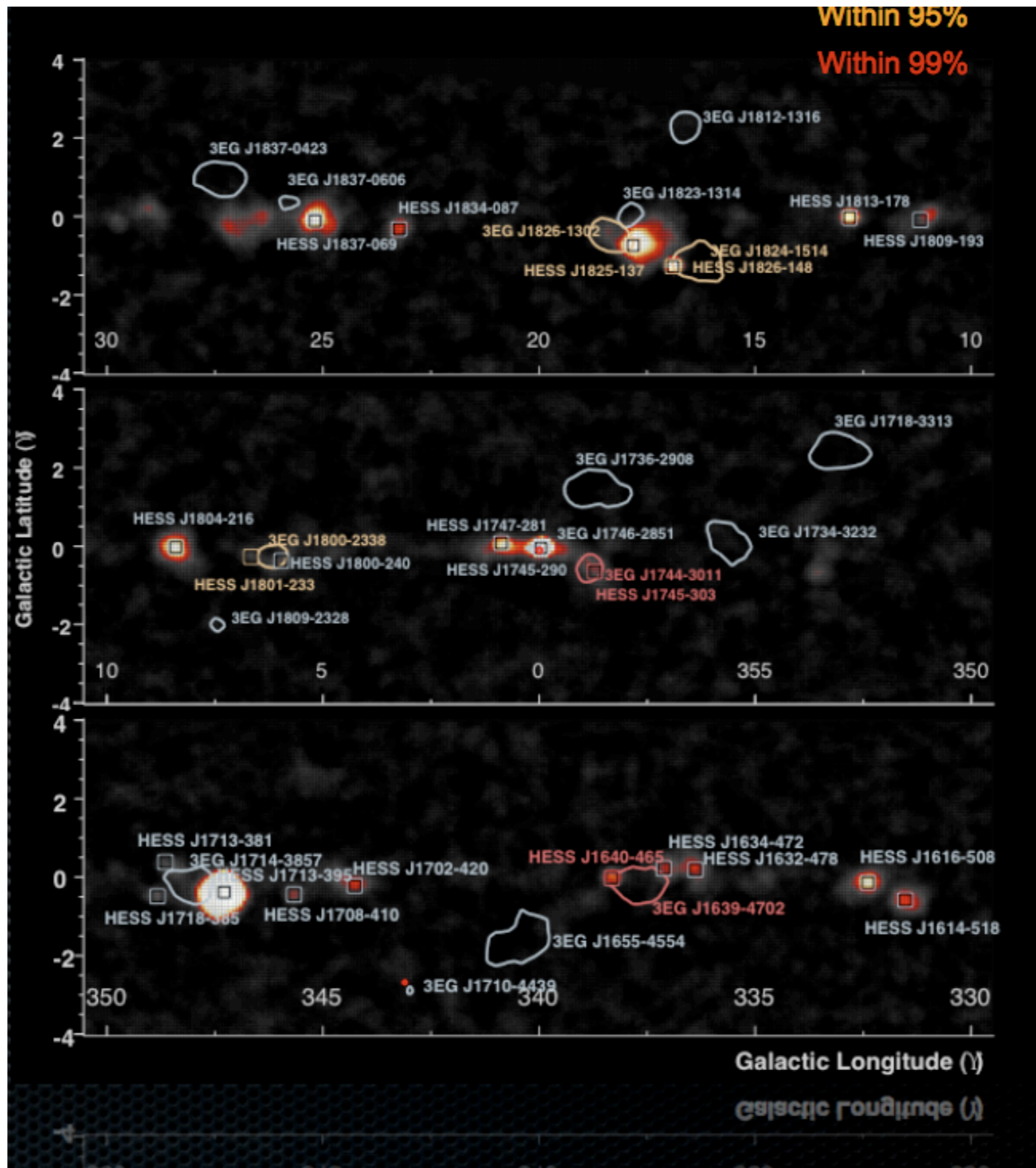
Spectral energy distribution of
the Crab Nebula

- on-going search for extended emission around pulsars
- also toward IC 443, W44, W28...

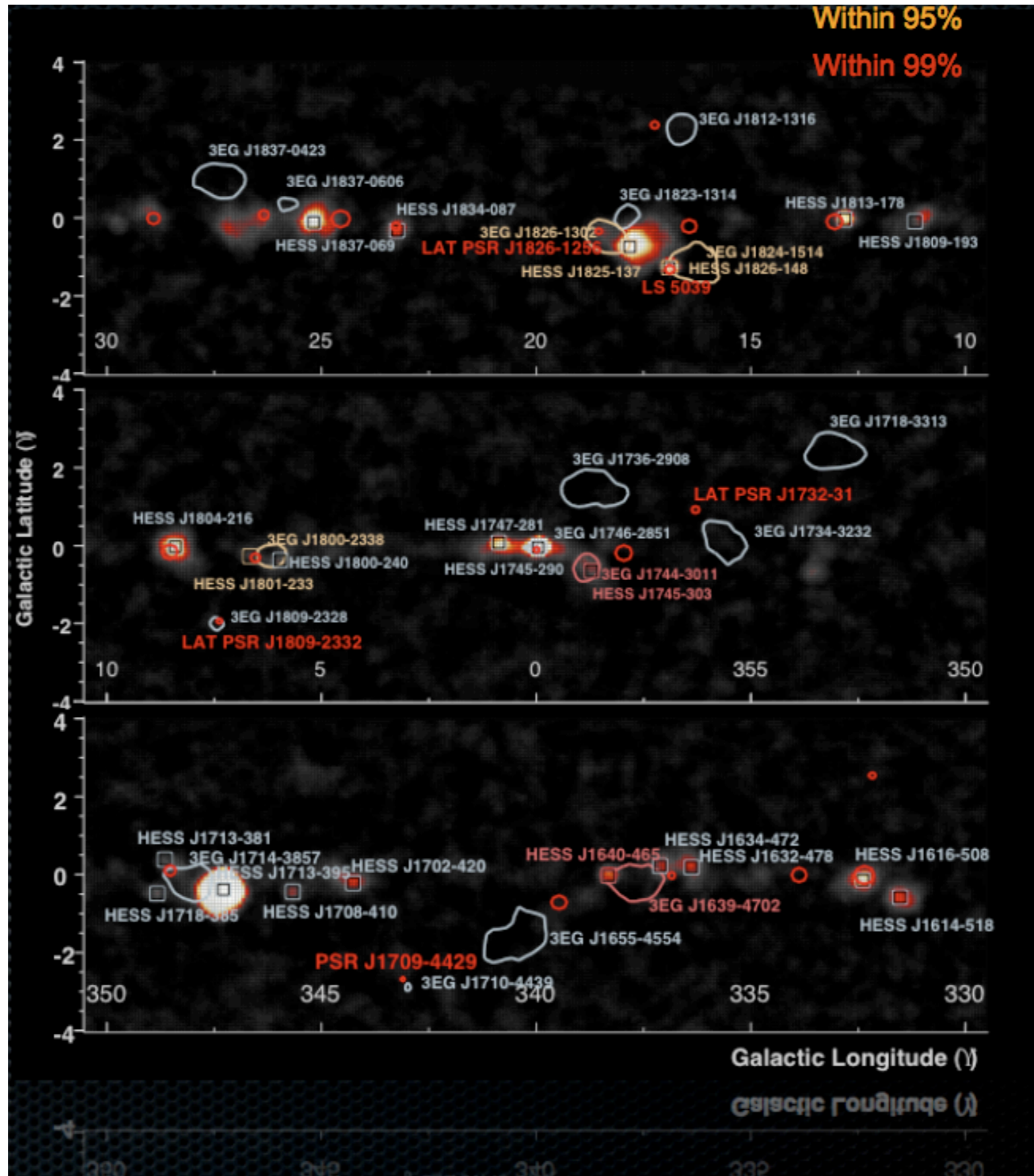


other Galactic sources

inner Galaxy

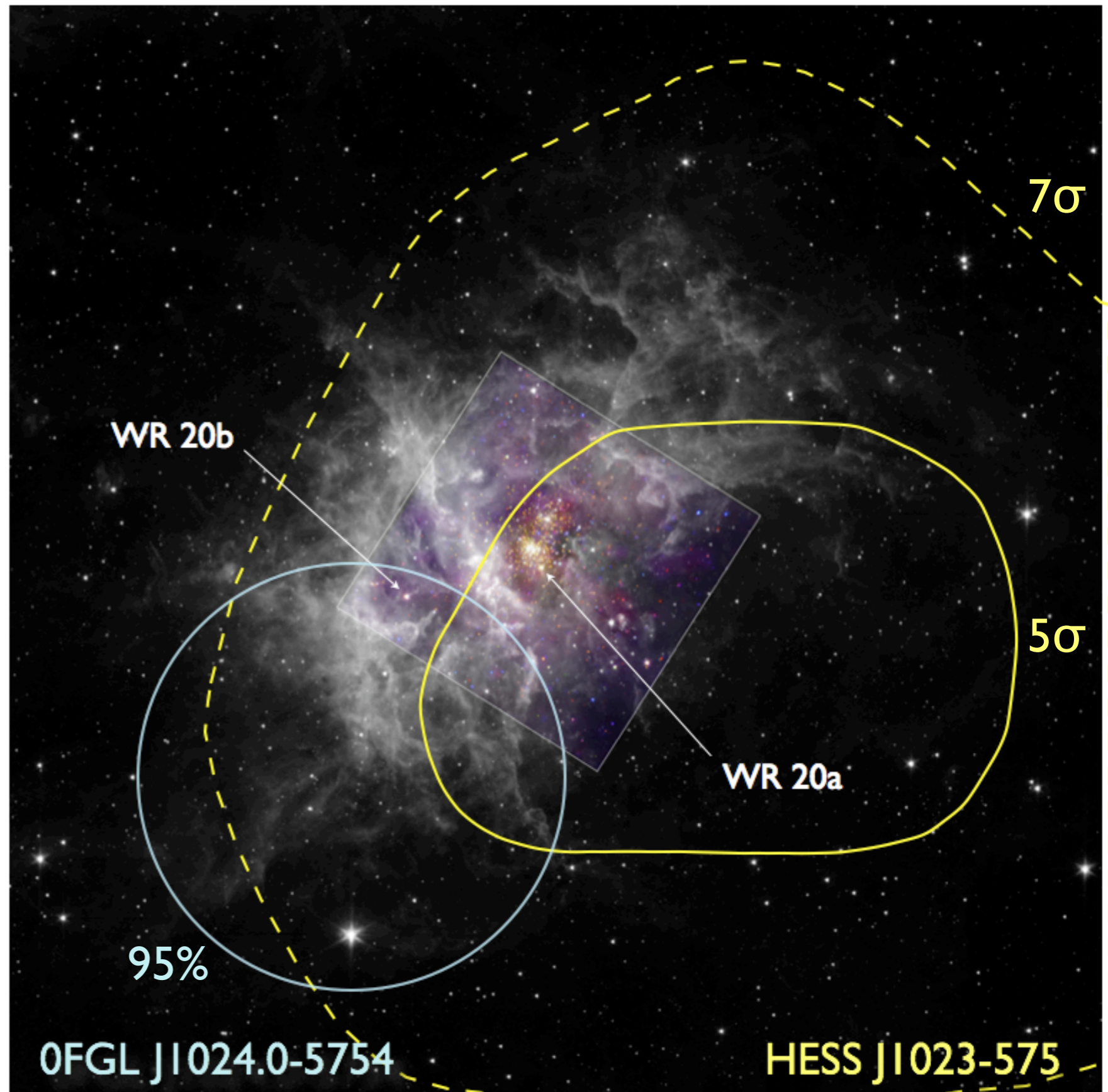


inner Galaxy



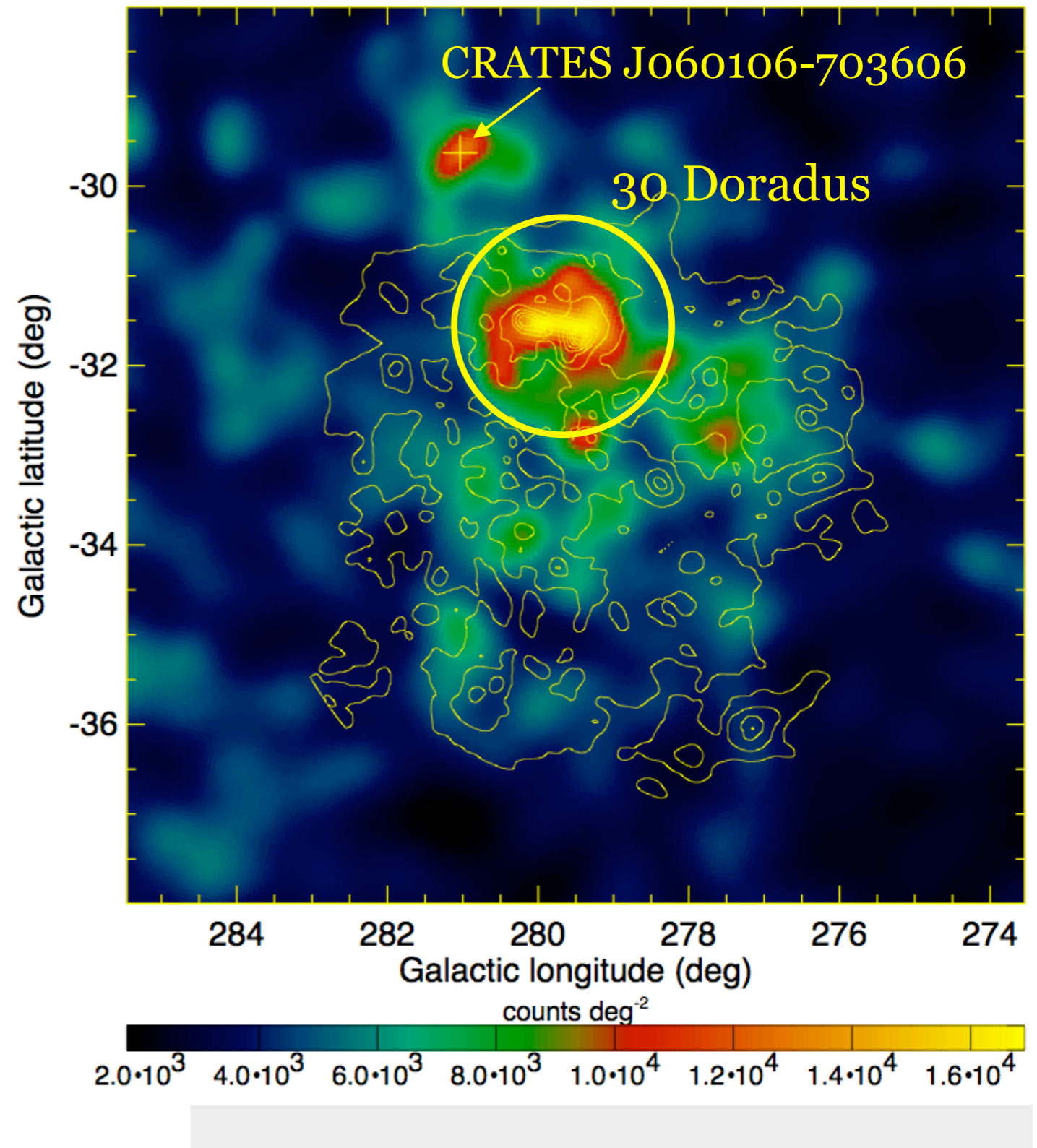
massive stars

- unidentified source in Westerlund 2
- other WR coincidences toward crowded and confused Gal. center and Carina regions
- WR 140 & WR 147 not bright sources



LMC and 30 Doradus

- extended source + hot spot on 30 Doradus
- extension correlated with HI



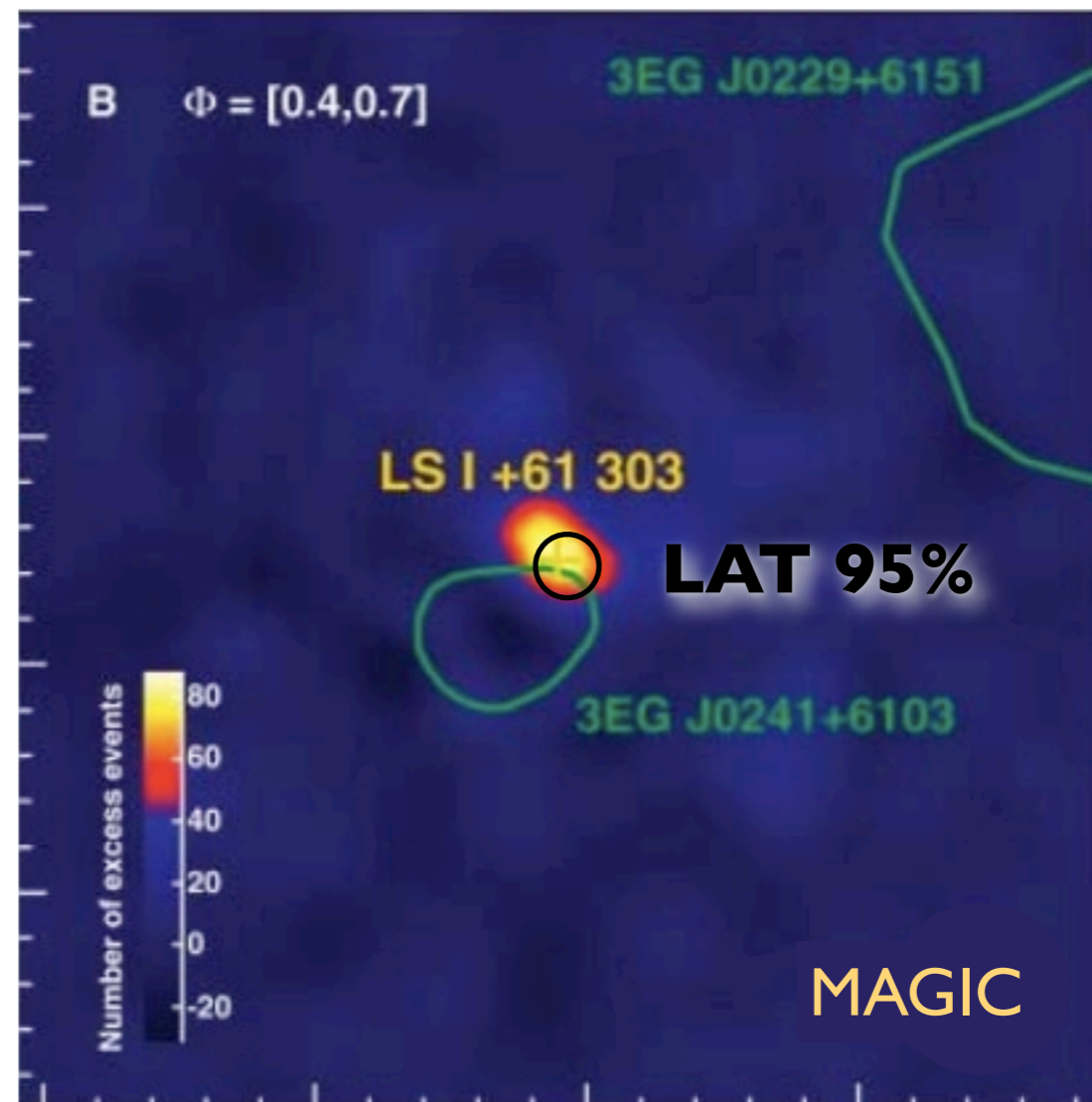
γ -ray binaries

systematic orbital modulation searches for many binaries

LSI +61°303 source

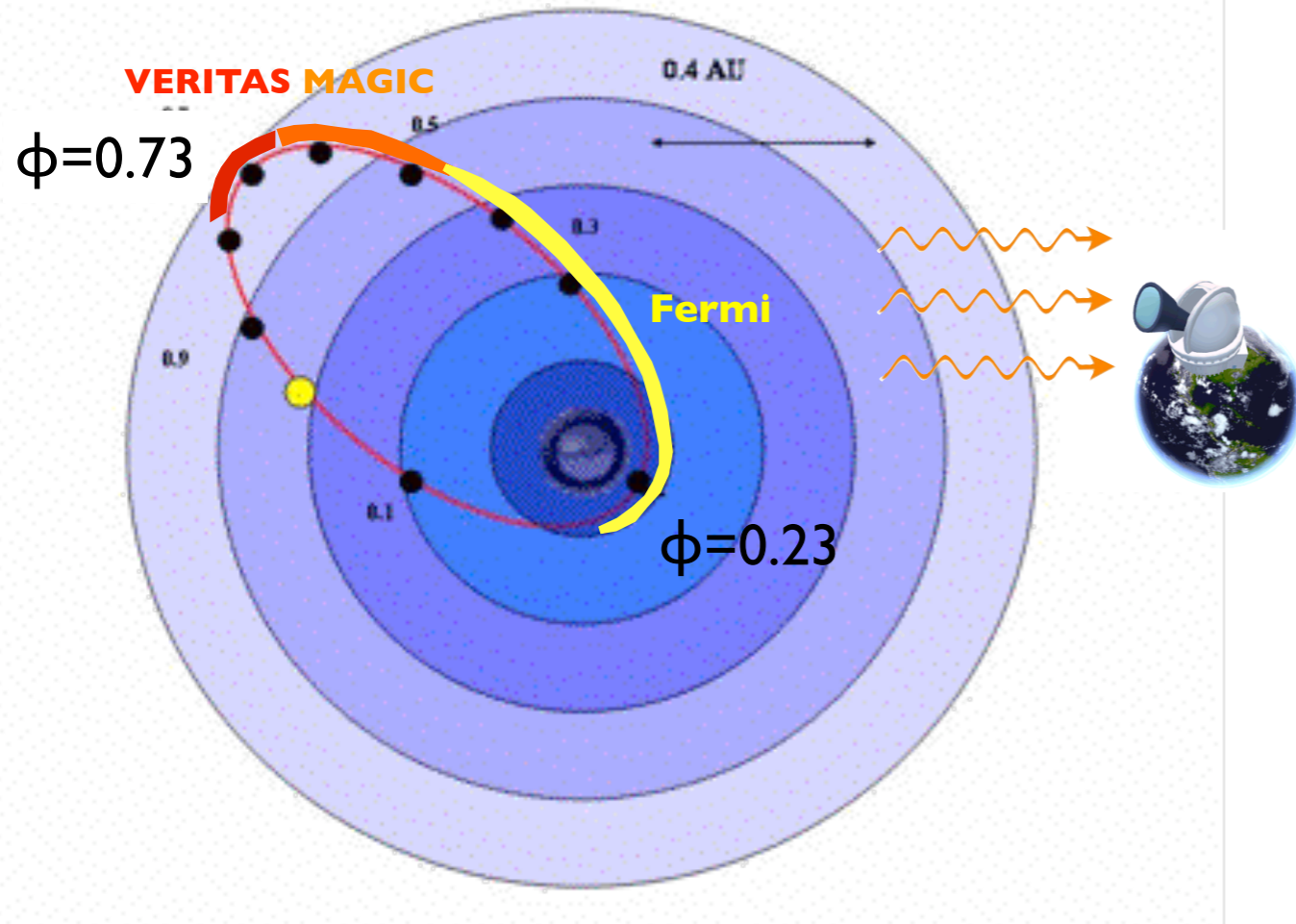
modulated \Rightarrow identified

LS 5039 under study

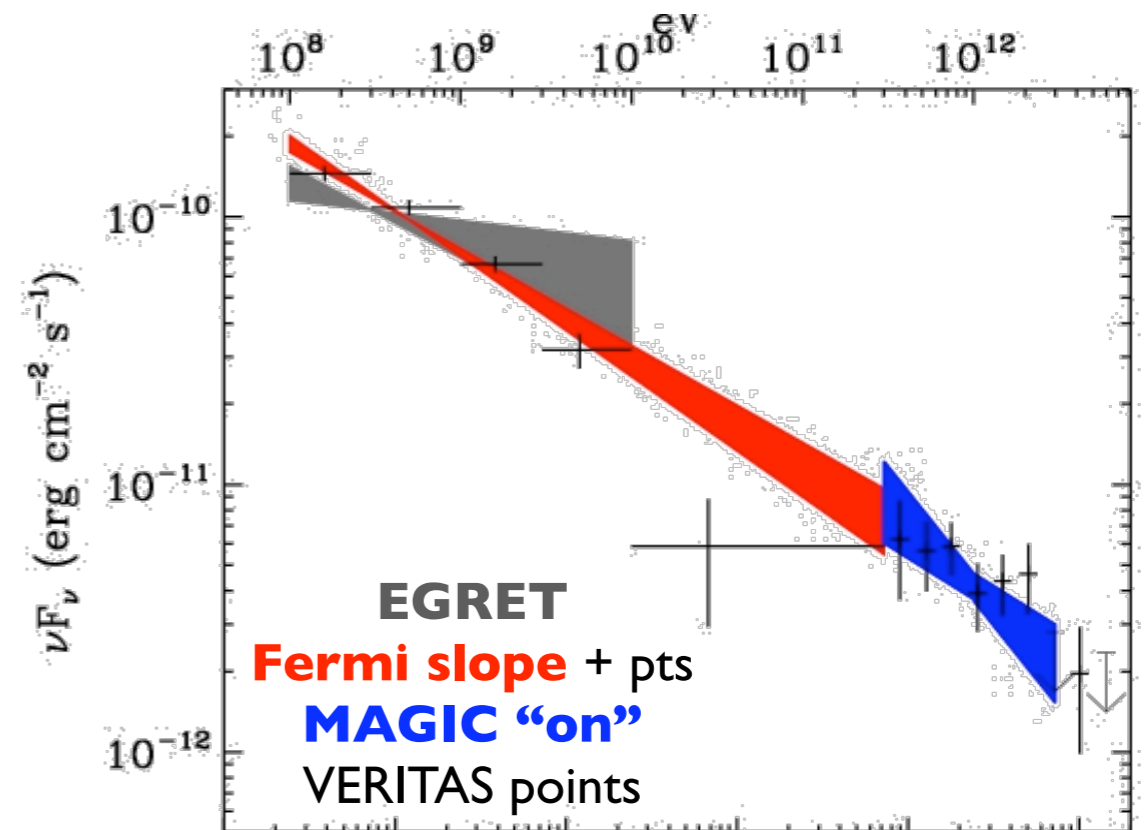
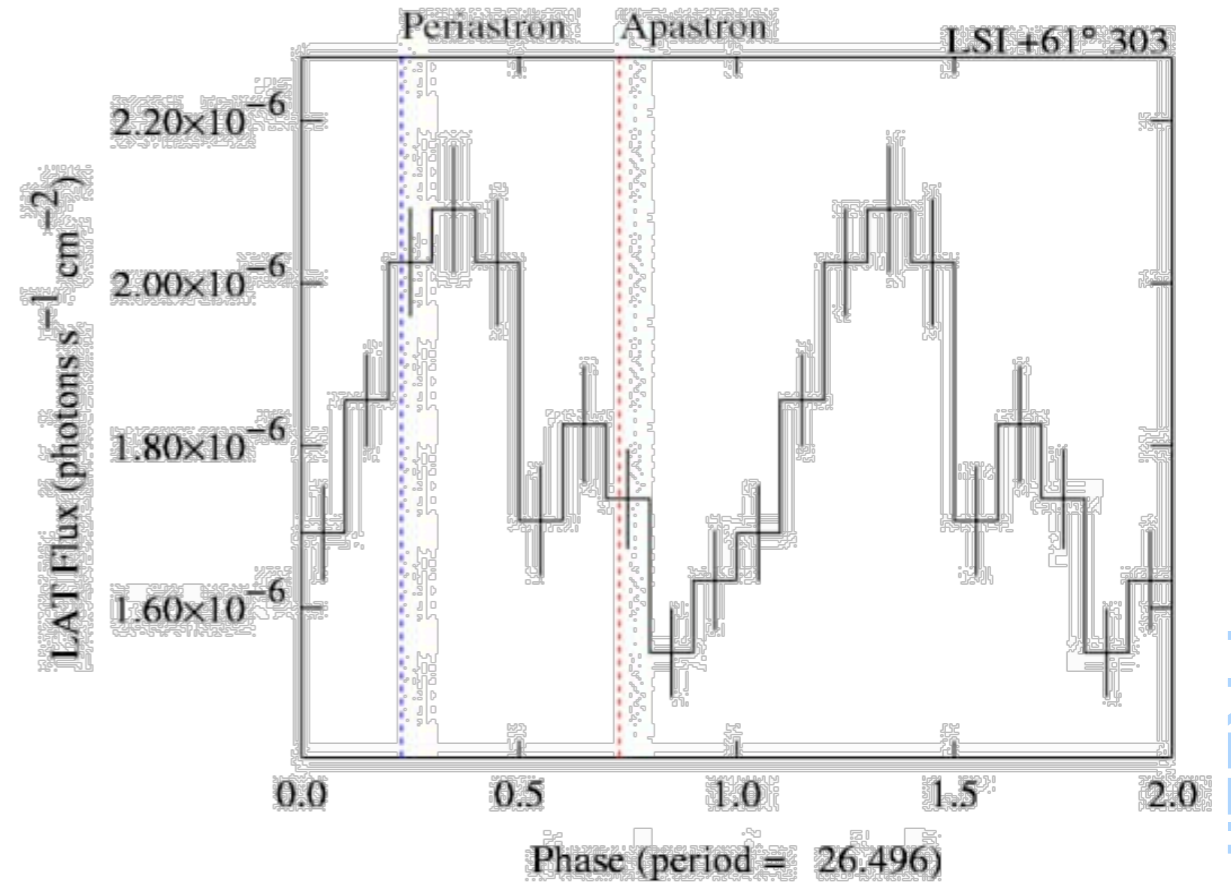


LSI +61°303

26.5 day modulation



average spectrum $\approx E^{-2.41 \pm 0.03 \pm 0.17}$
non simultaneous spectra

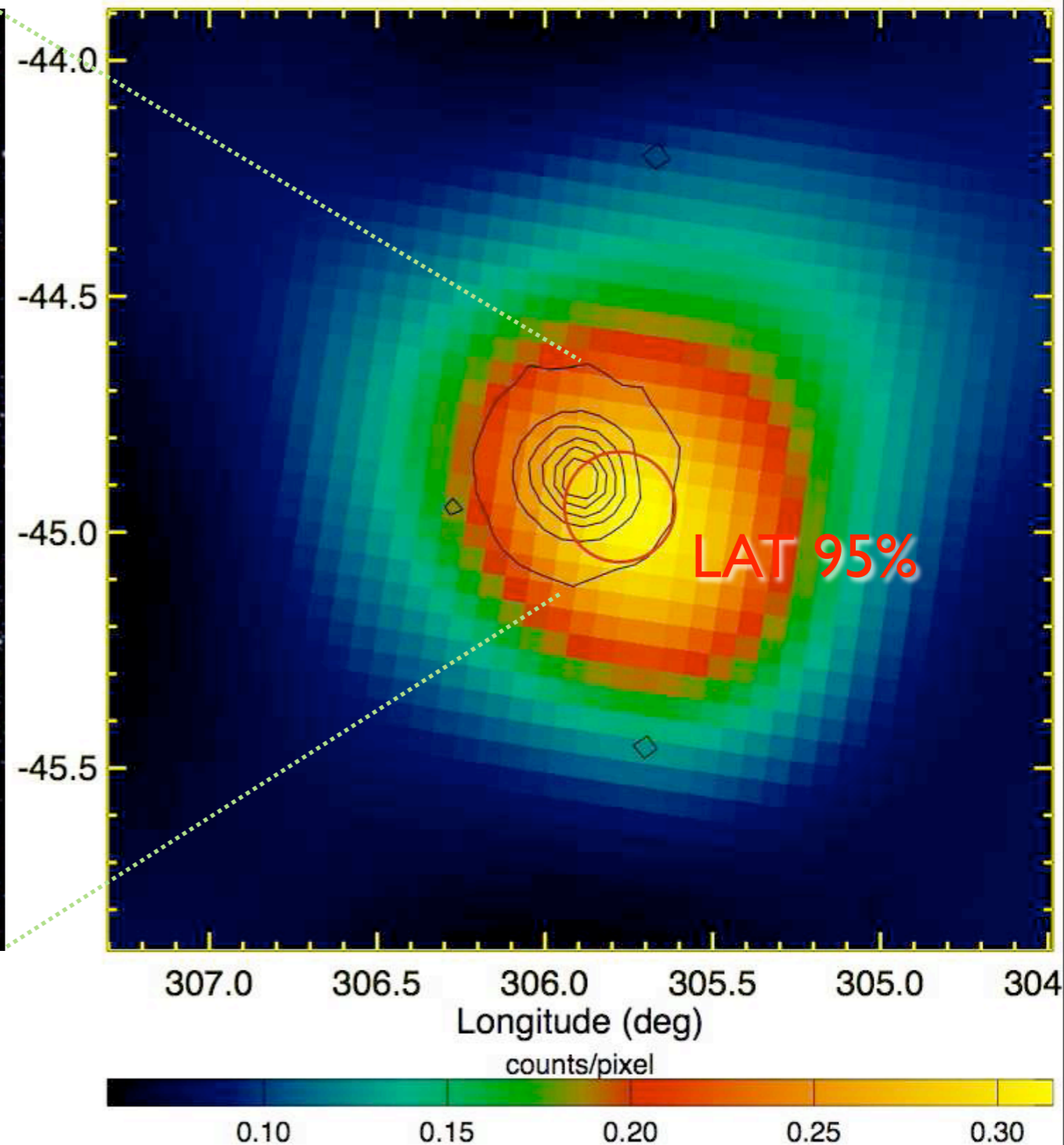



PRELIMINARY

47 Tuc

 ms pulsars? binaries?

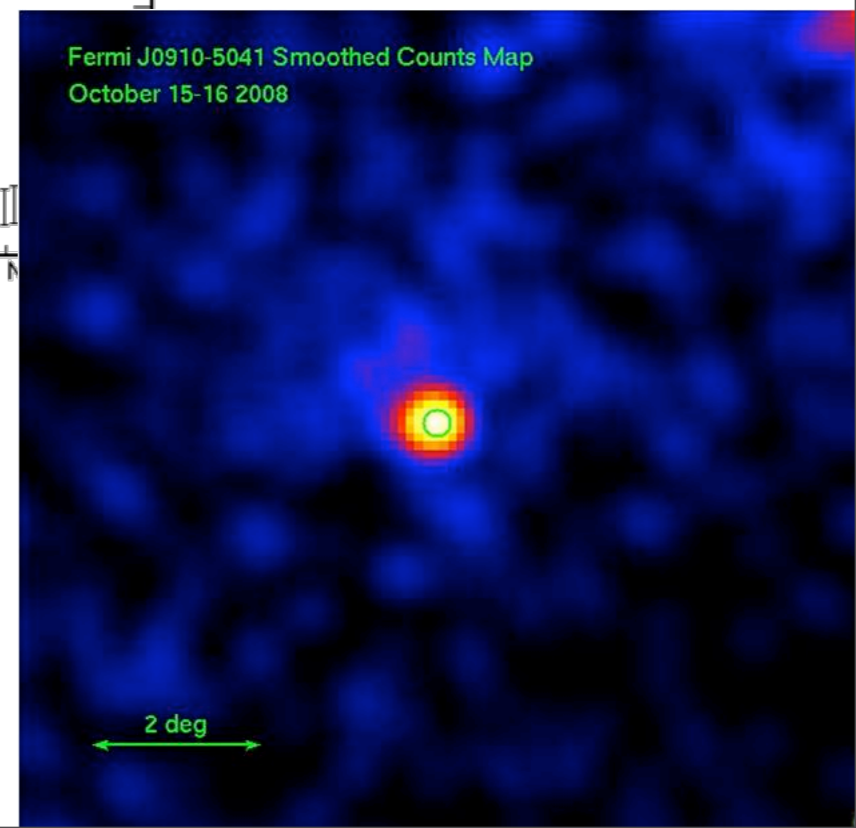
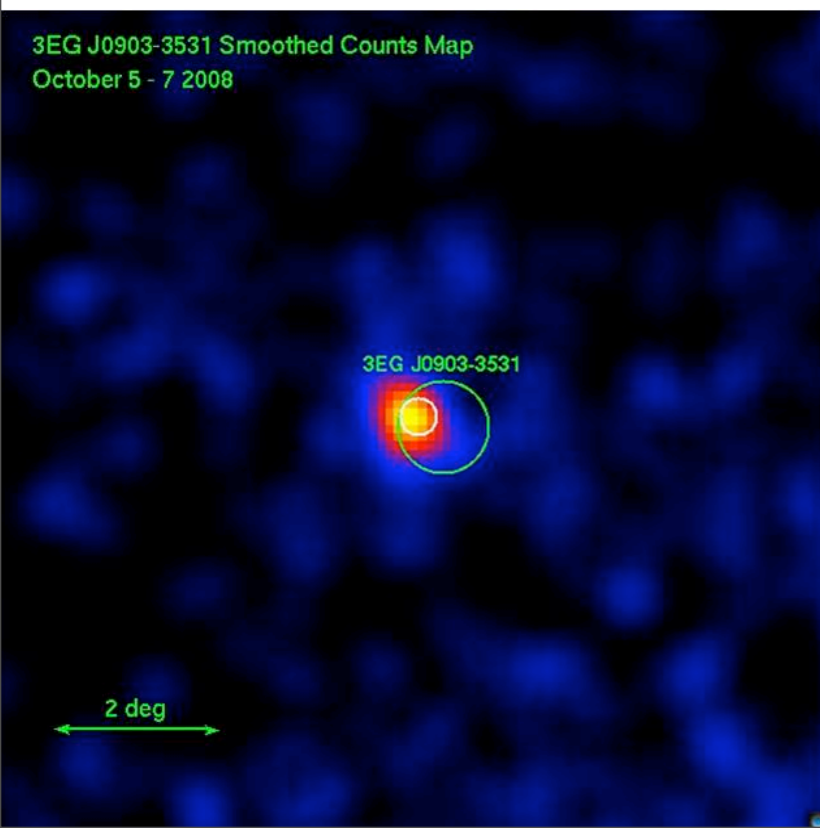
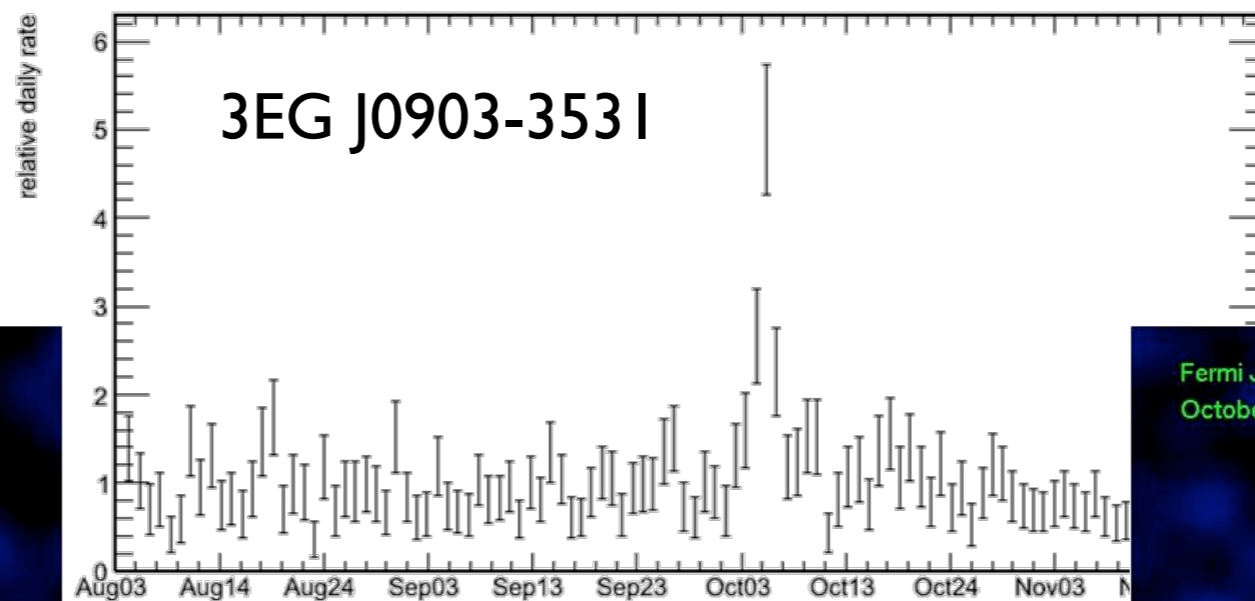
PRELIMINARY

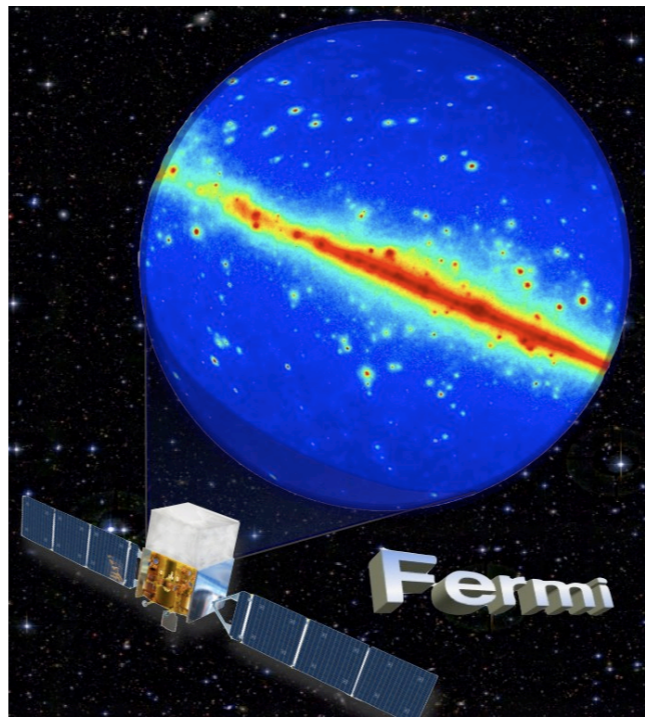


 ok with 23 ms pulsars and 10% efficiency

fast transients


- bright & fast transients
 - released by ATels
 - http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/
 - 2 bright transients detected at low latitude (ATels 1771 & 1788)
- Swift, Chandra, and VLA follow-up observations in place

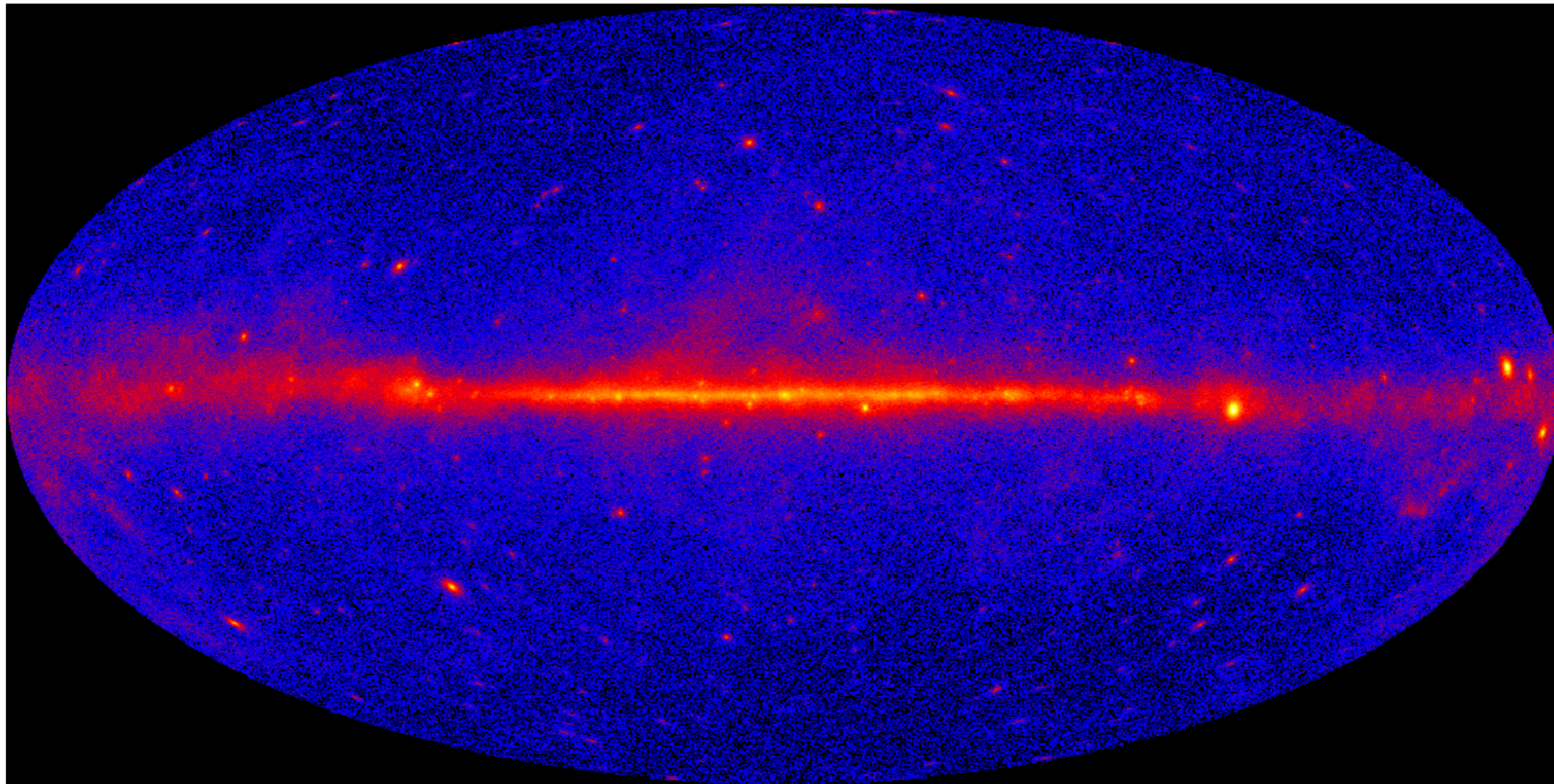
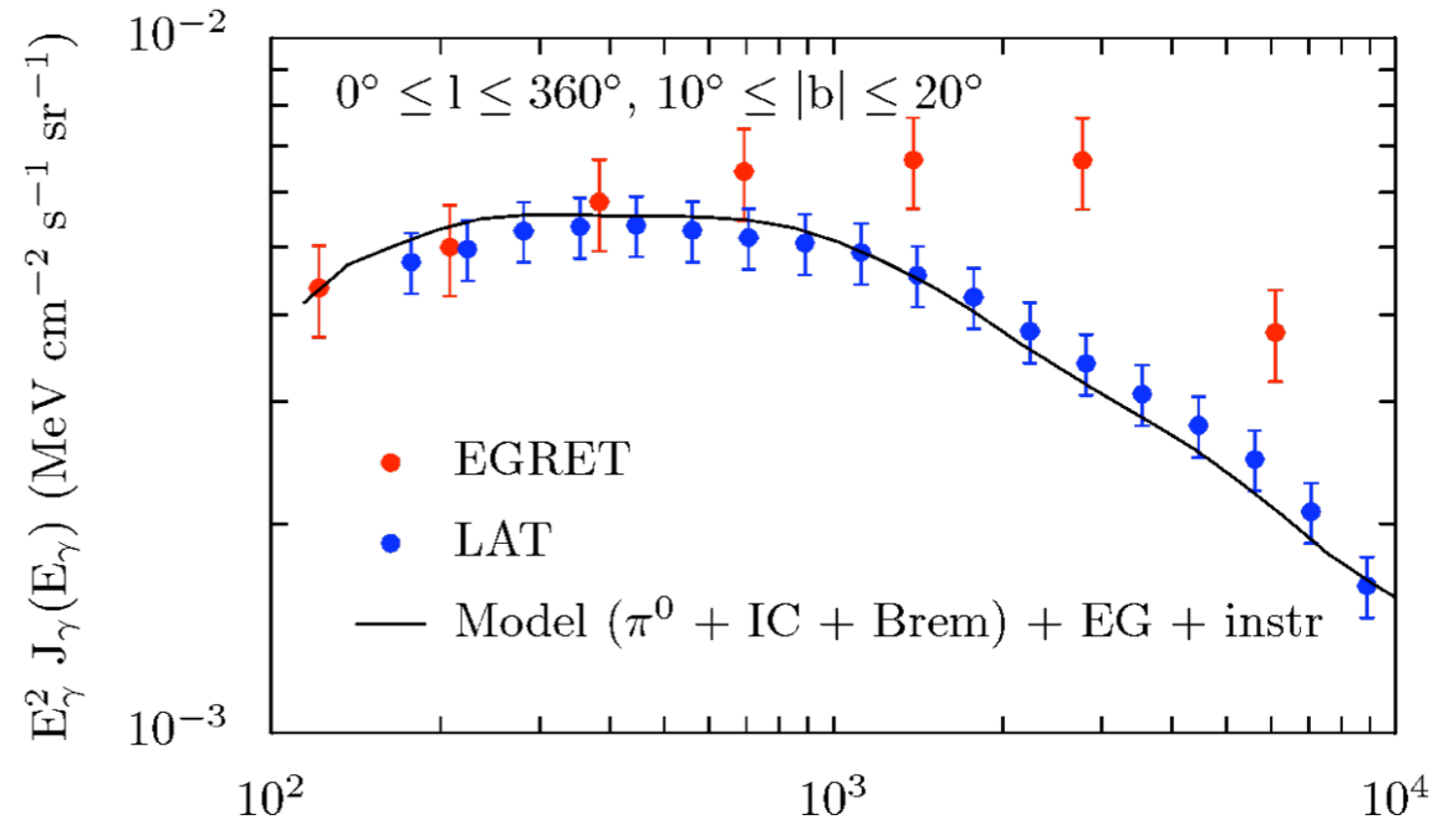




**the stable GeV sky:
the Milky Way**

interstellar emission

-  80% of LAT photons
-  no GeV excess



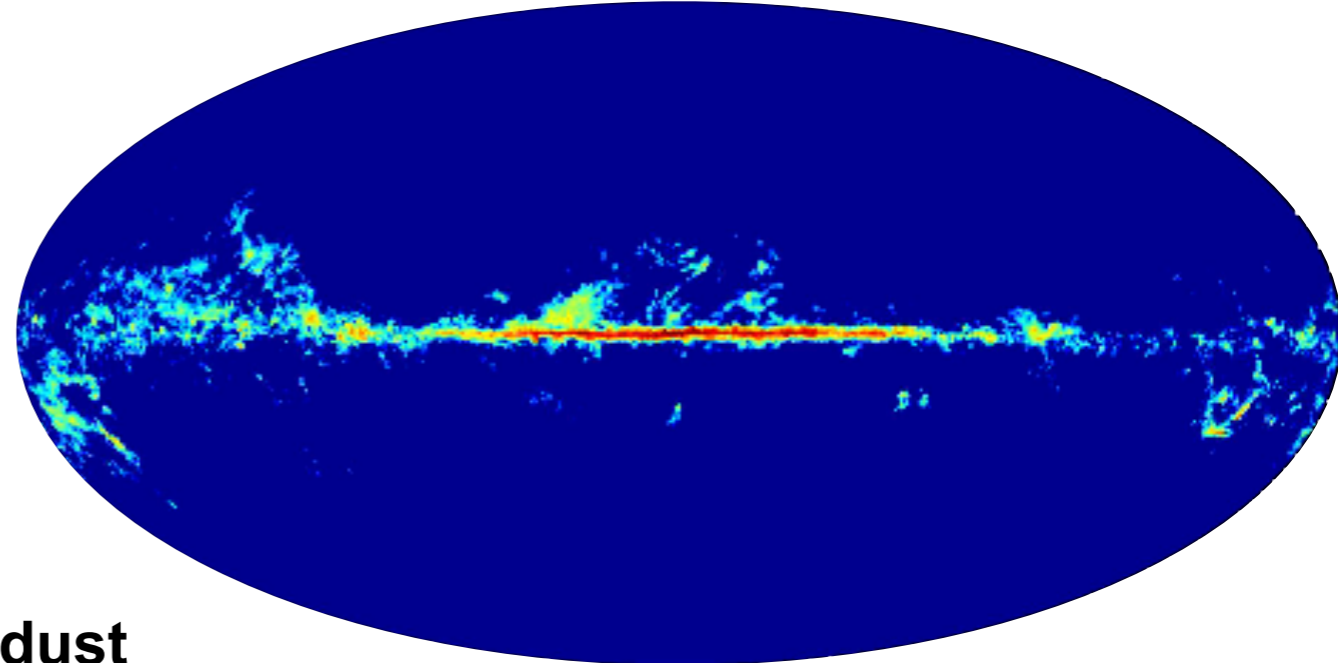
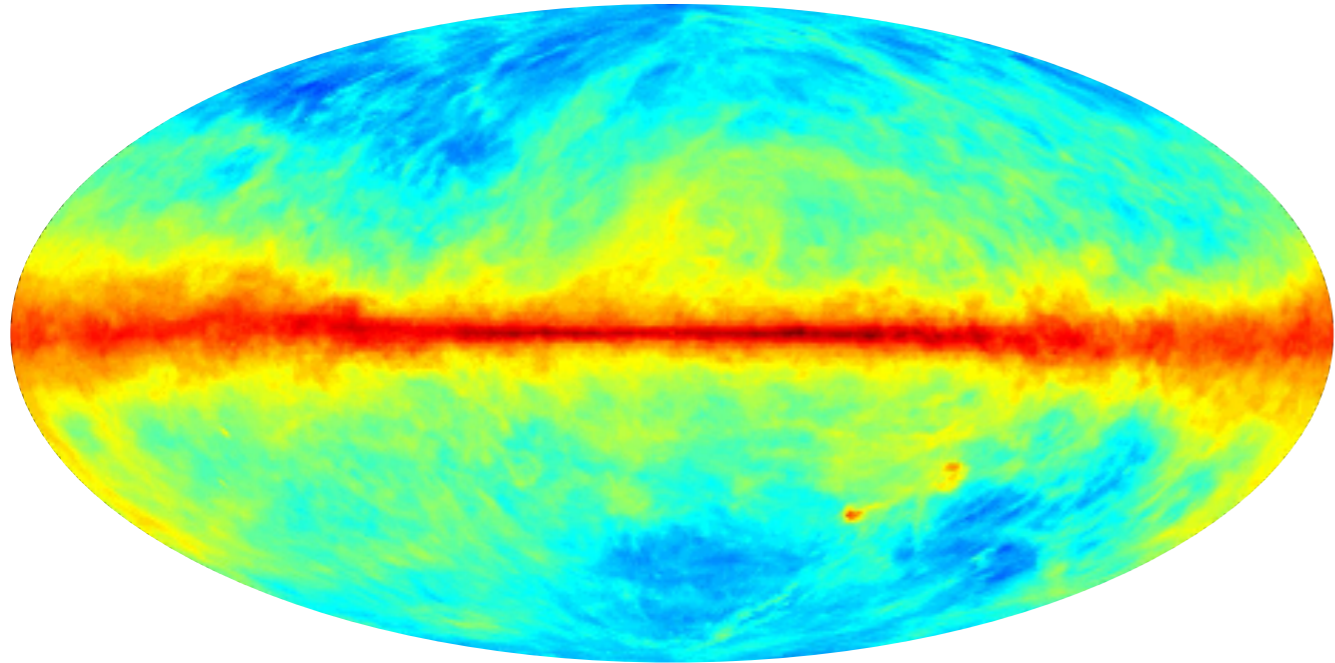
interstellar medium

gas

HI (LAB) Kalberla '05

HII <<

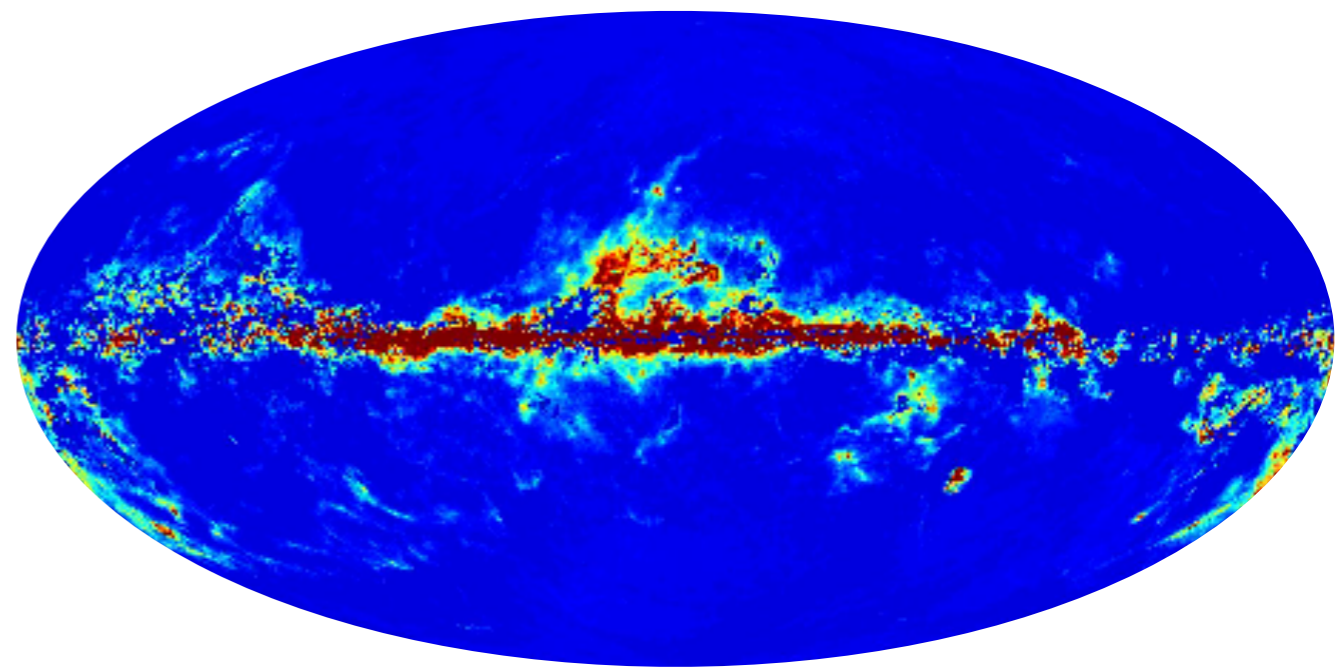
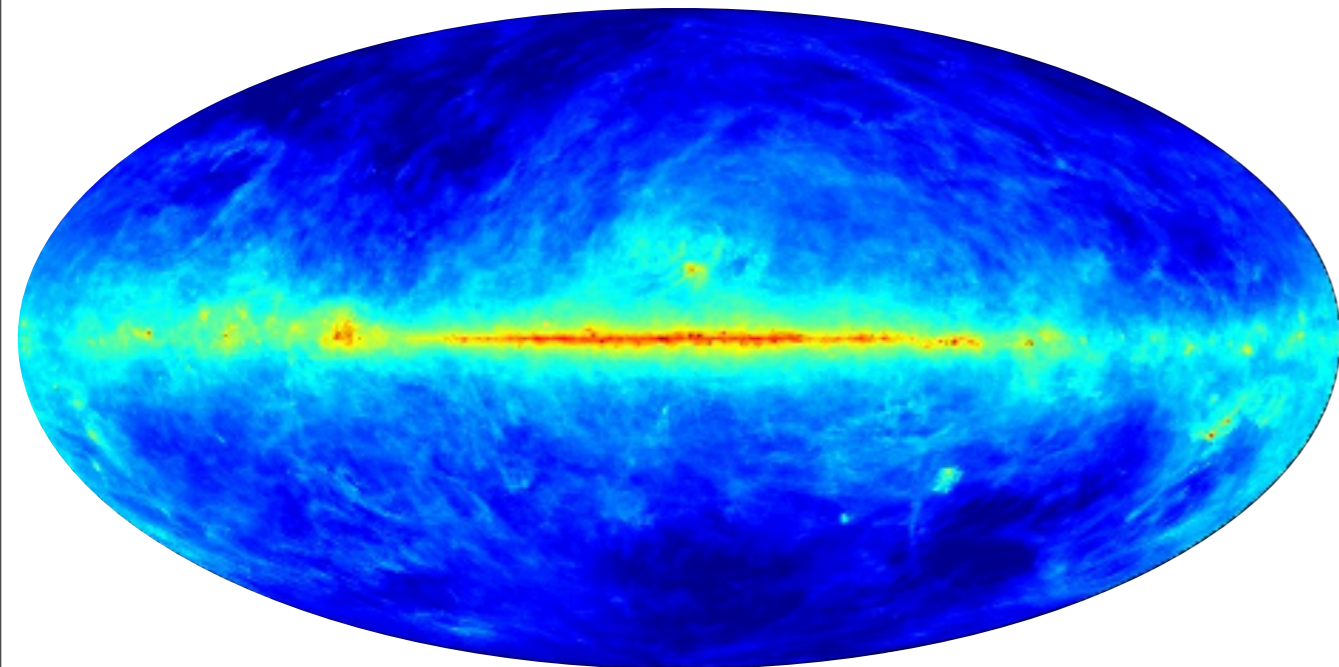
CO (CfA) Dame '01



dust

I(100 μm) IRAS Schlegel '98

dark gas Grenier '05



IR emission $\rightarrow N_{\text{dust}}$: temperature correction

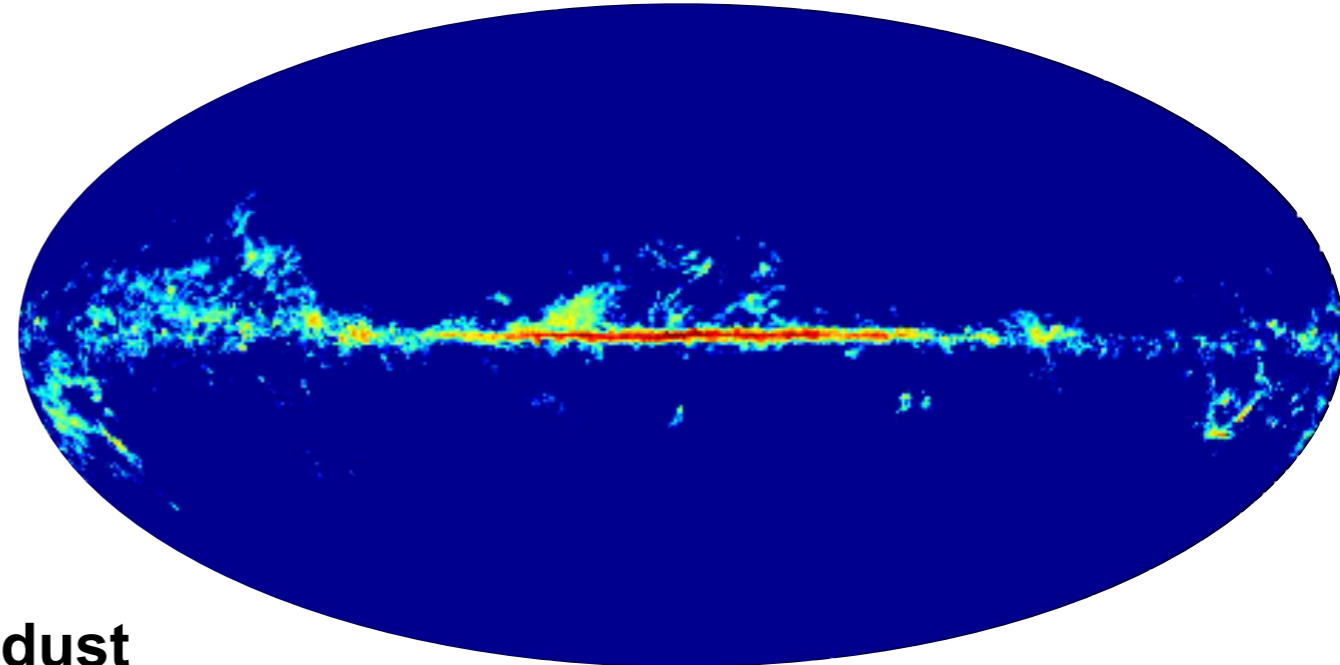
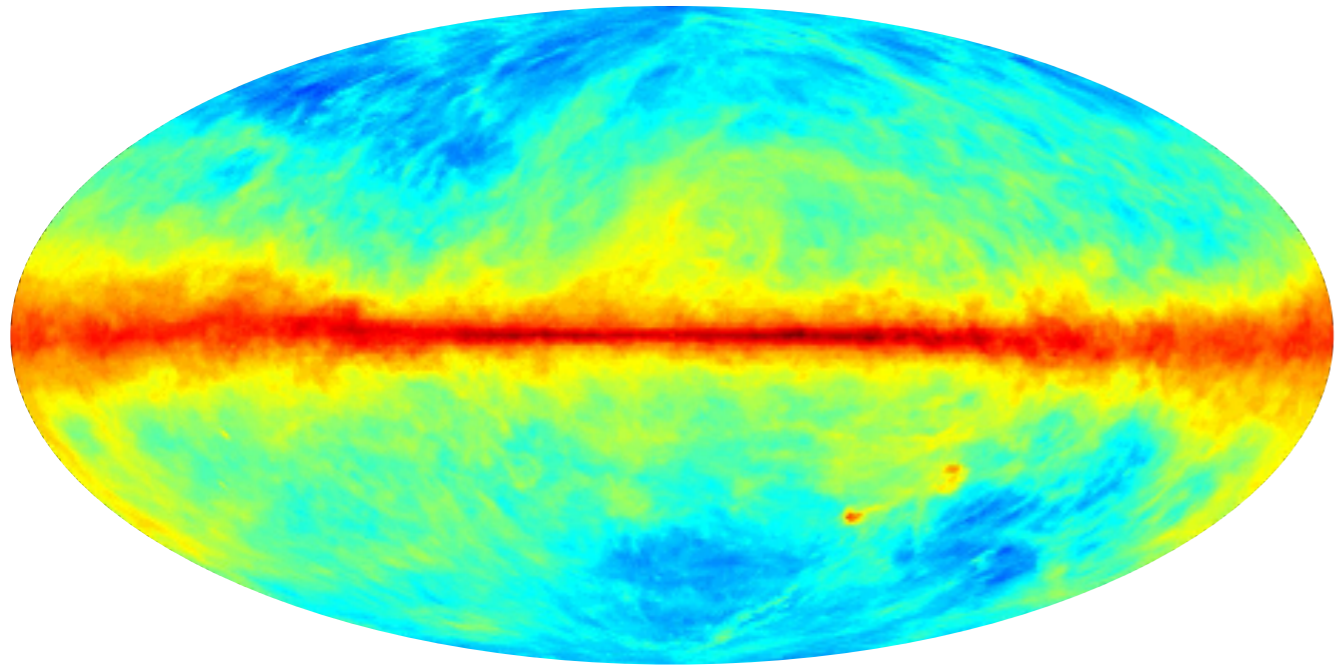
interstellar medium

gas

HI (LAB) Kalberla '05

HII <<

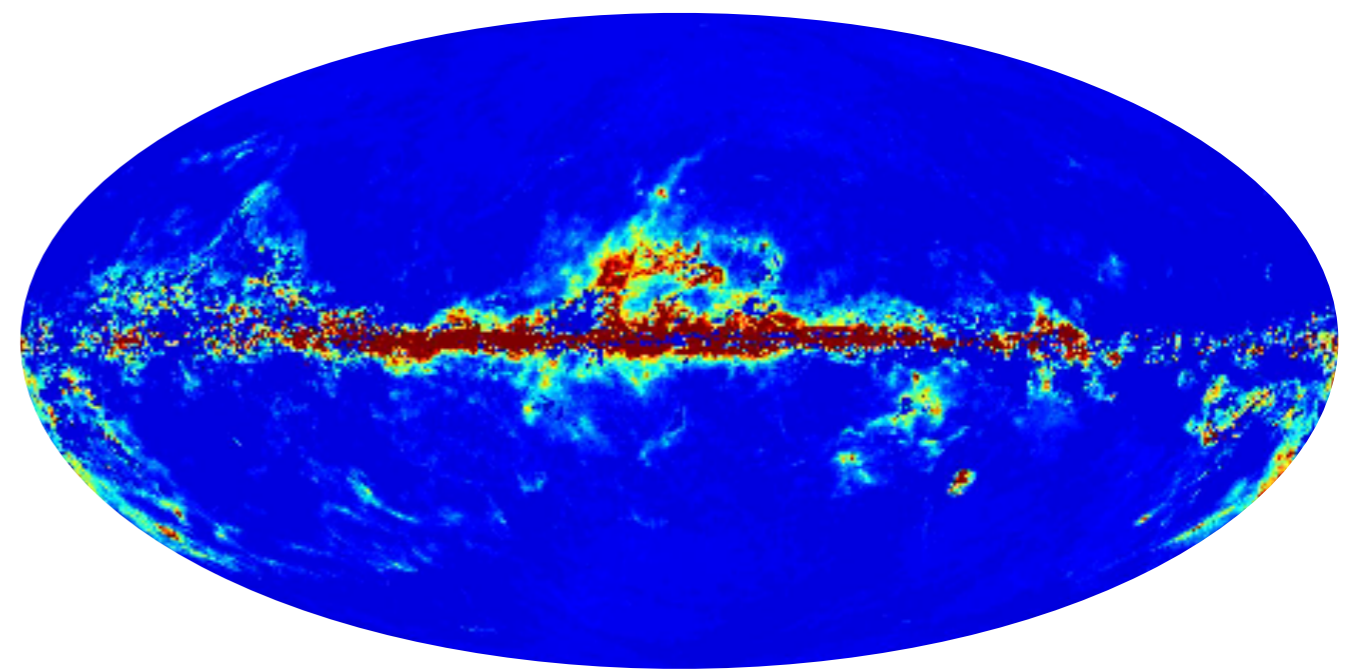
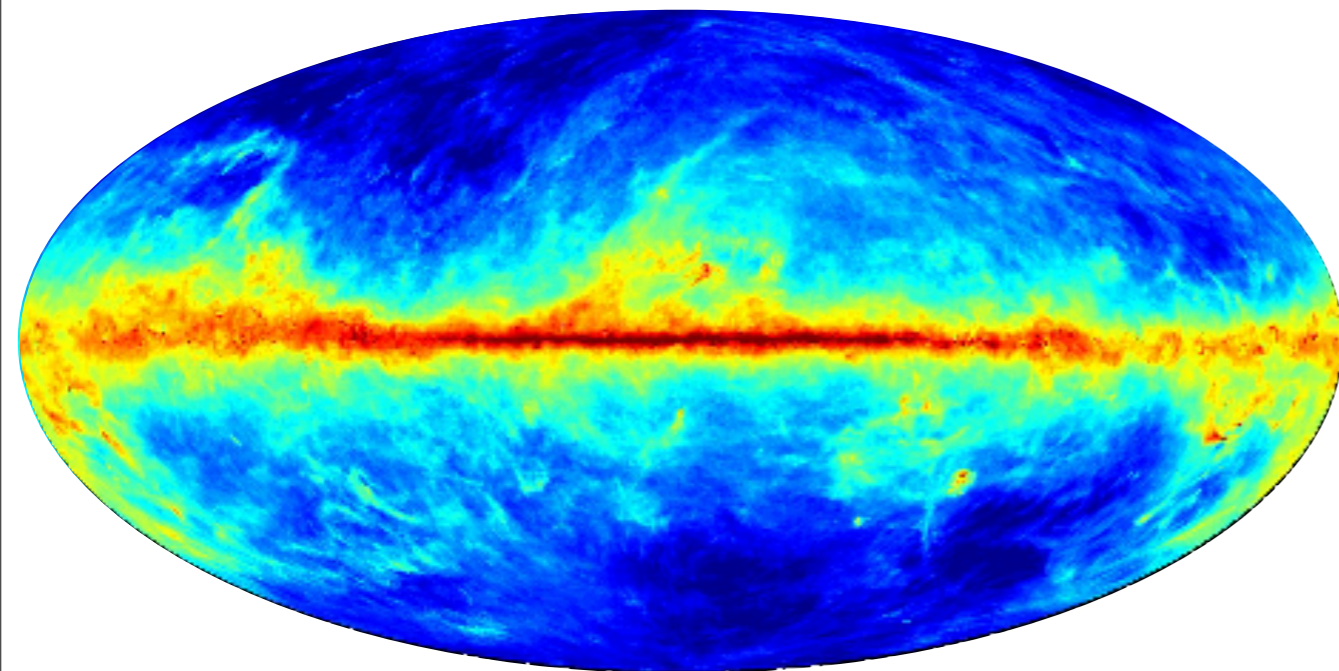
CO (CfA) Dame '01



dust

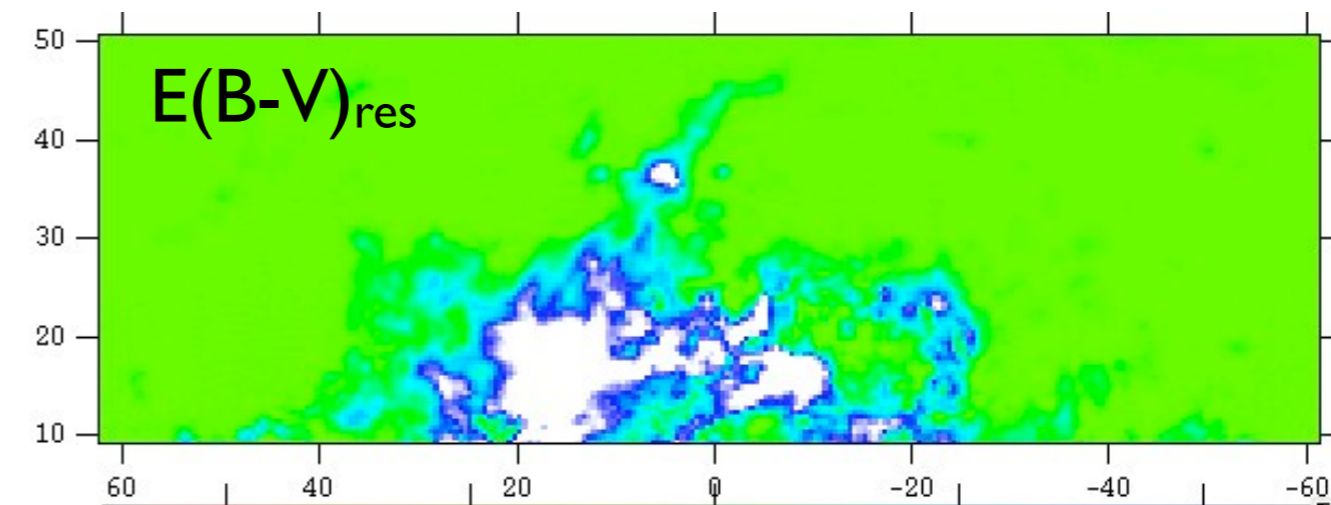
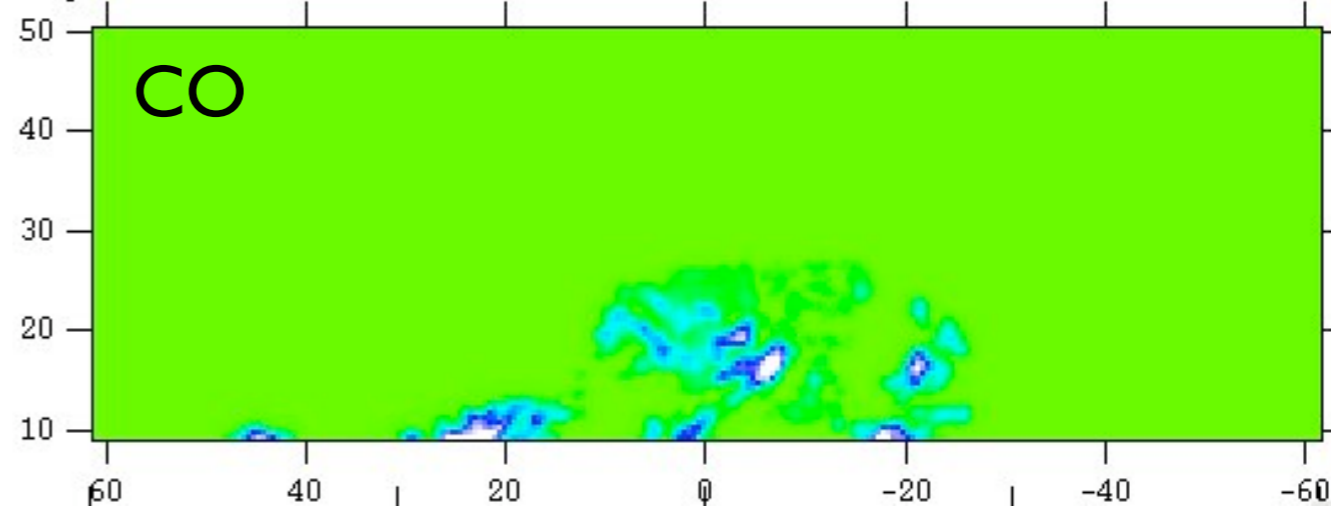
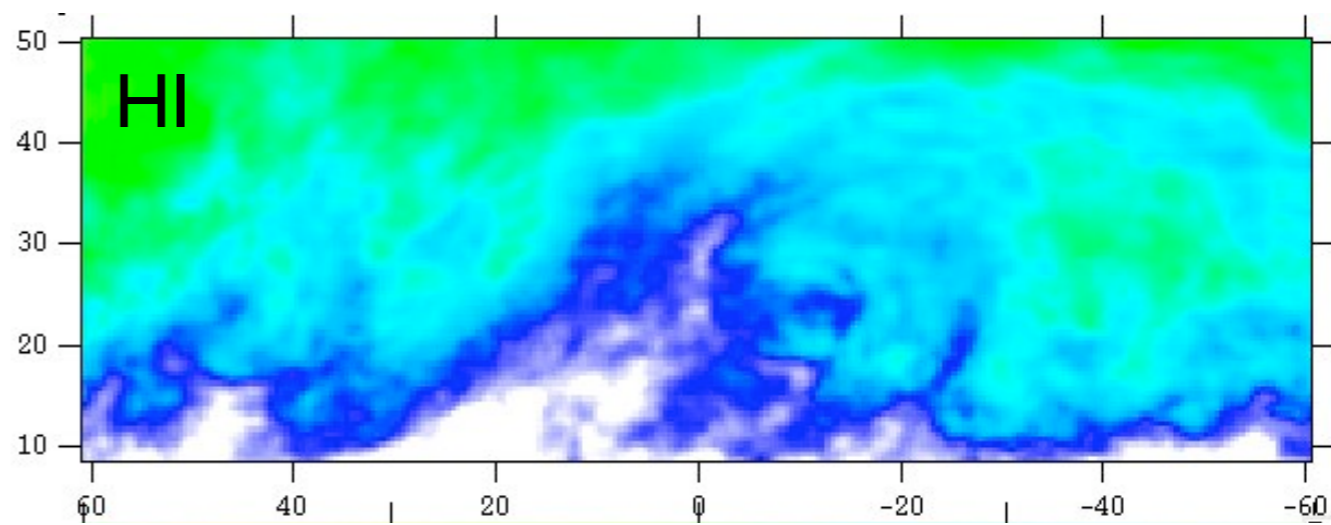
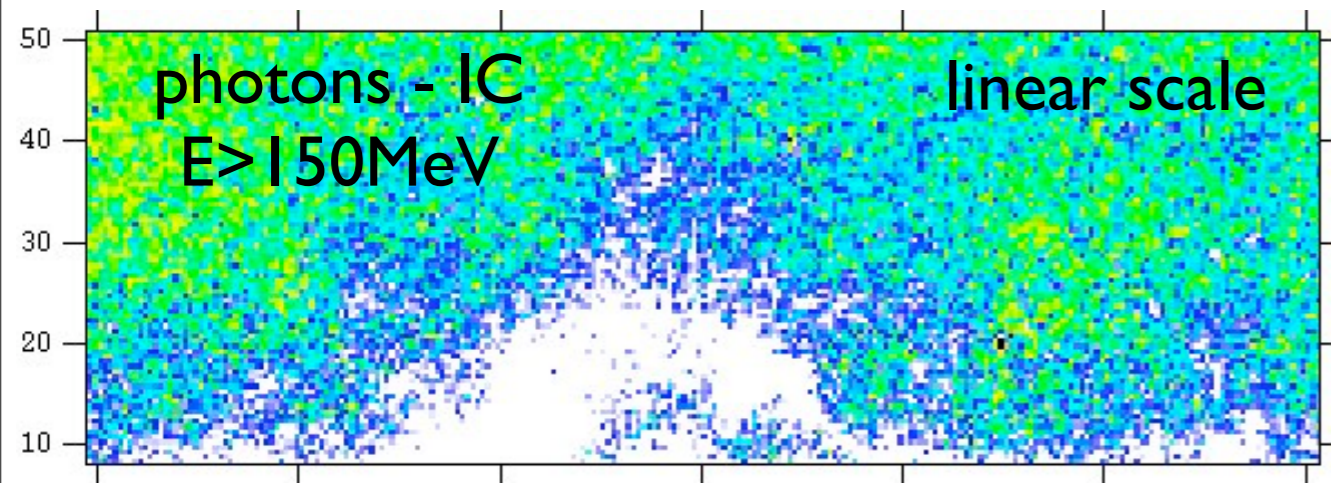
E(B-V) Schlegel '98

dark gas Grenier '05

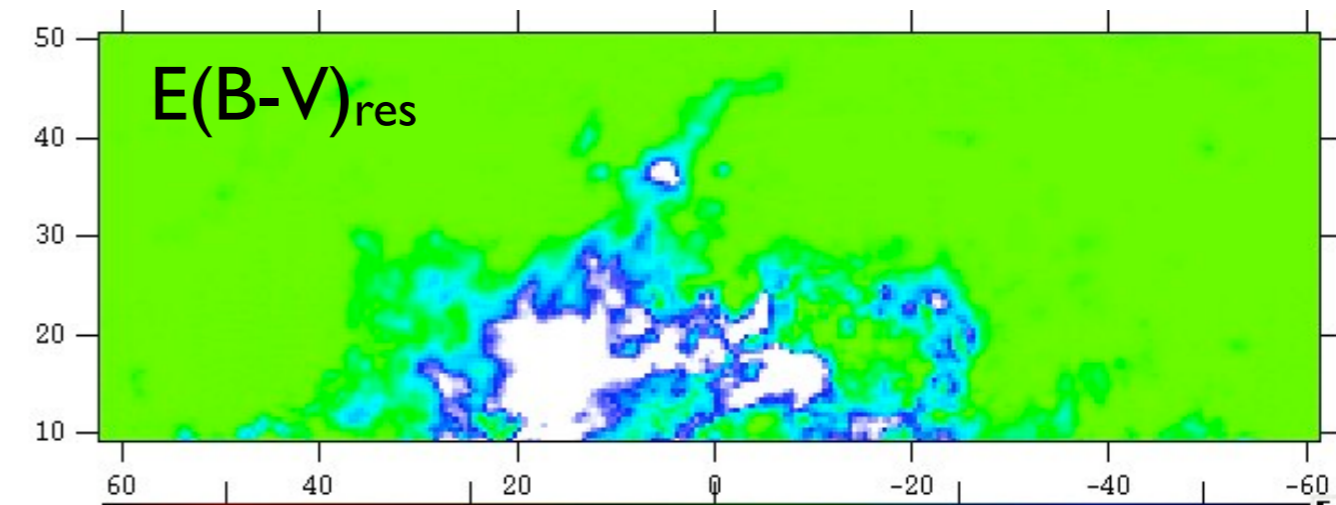
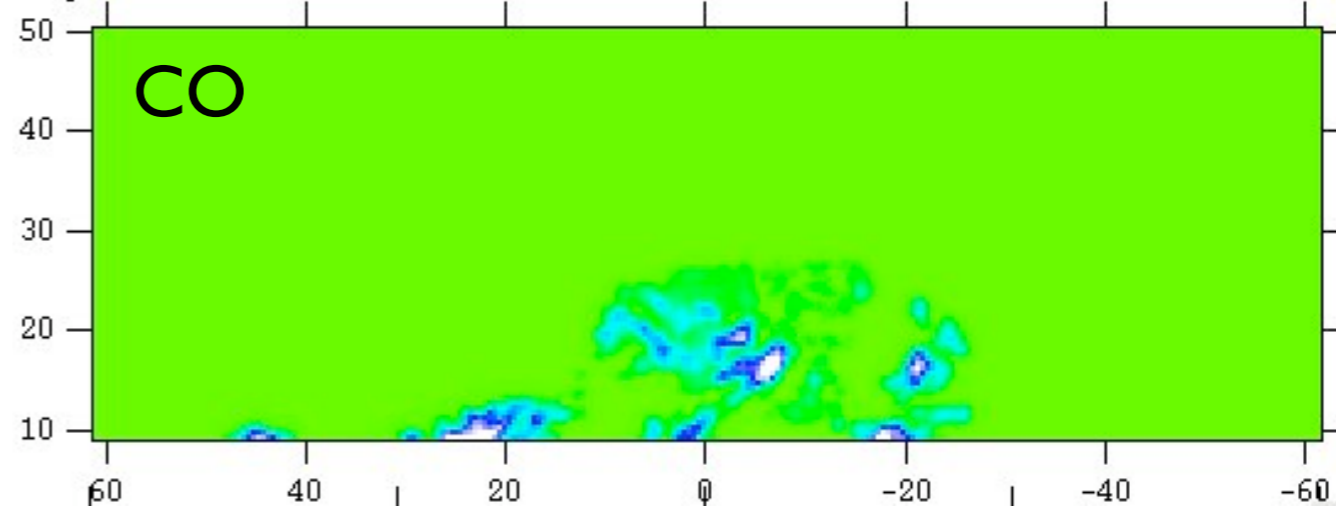
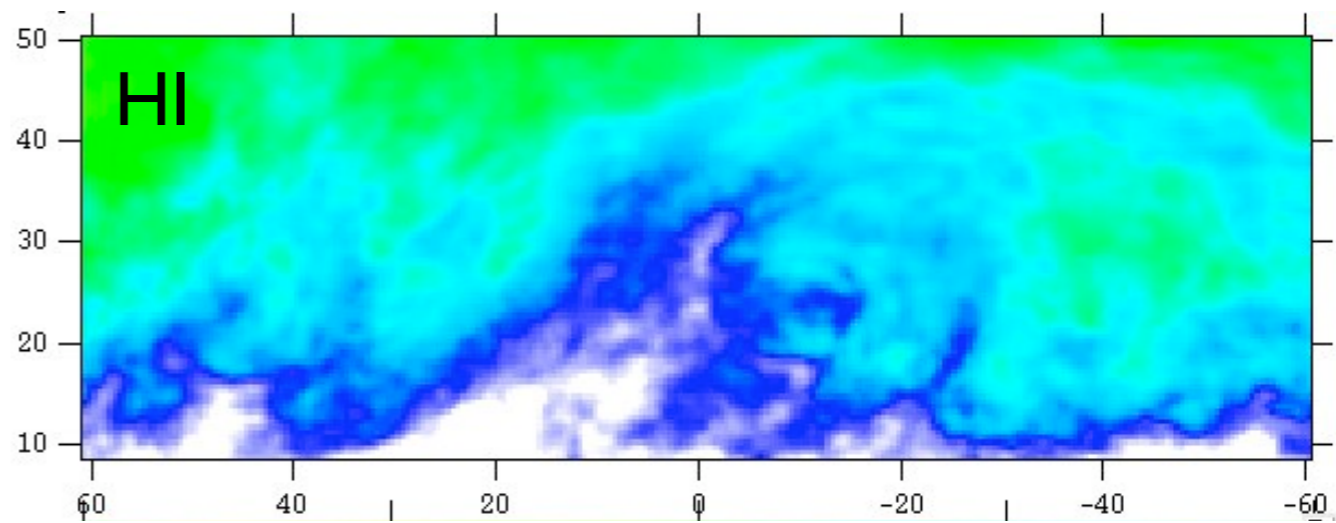
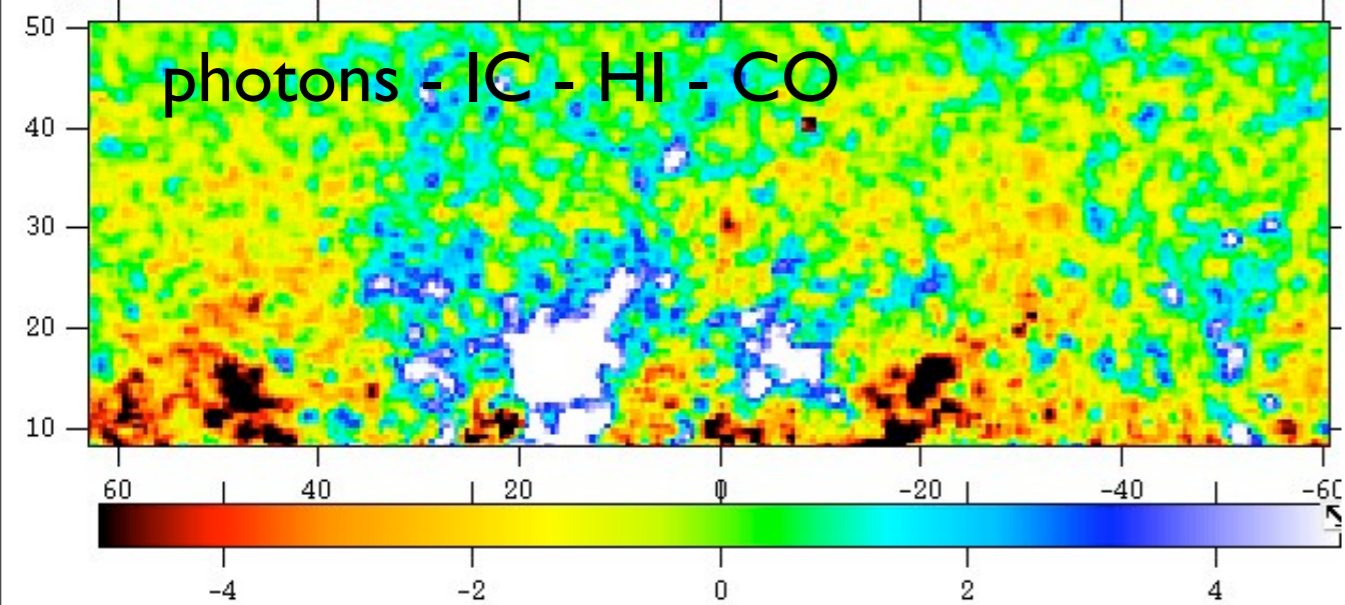
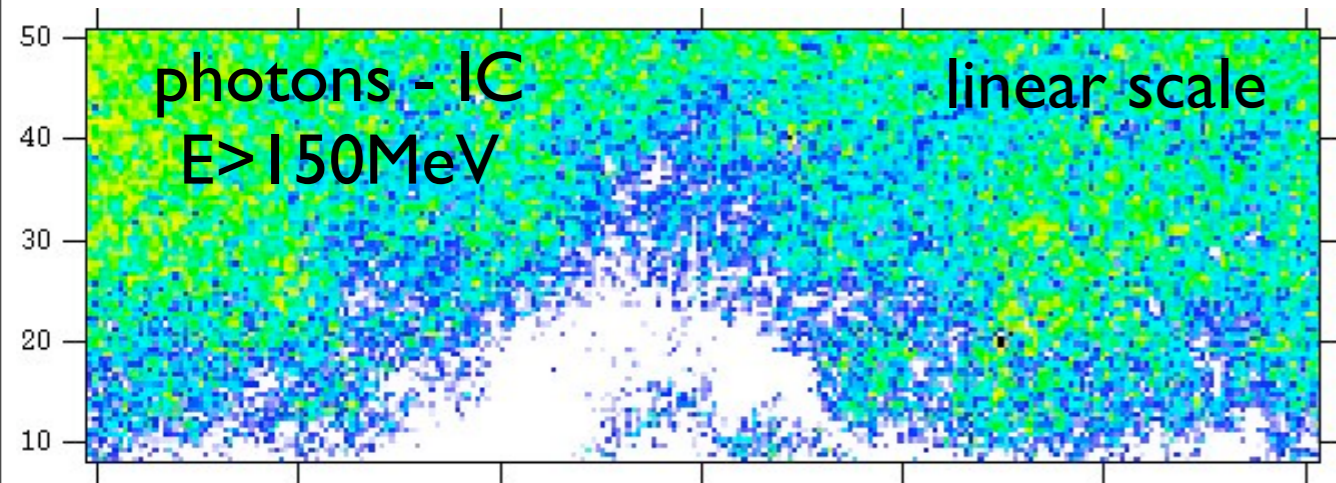


IR emission $\rightarrow N_{\text{dust}}$: temperature correction

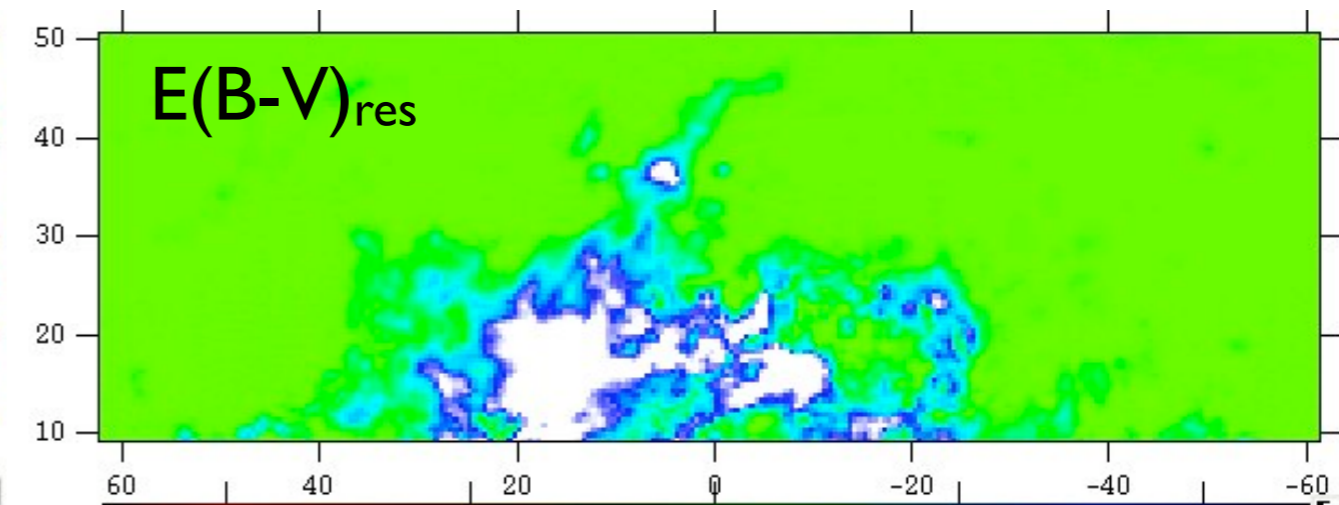
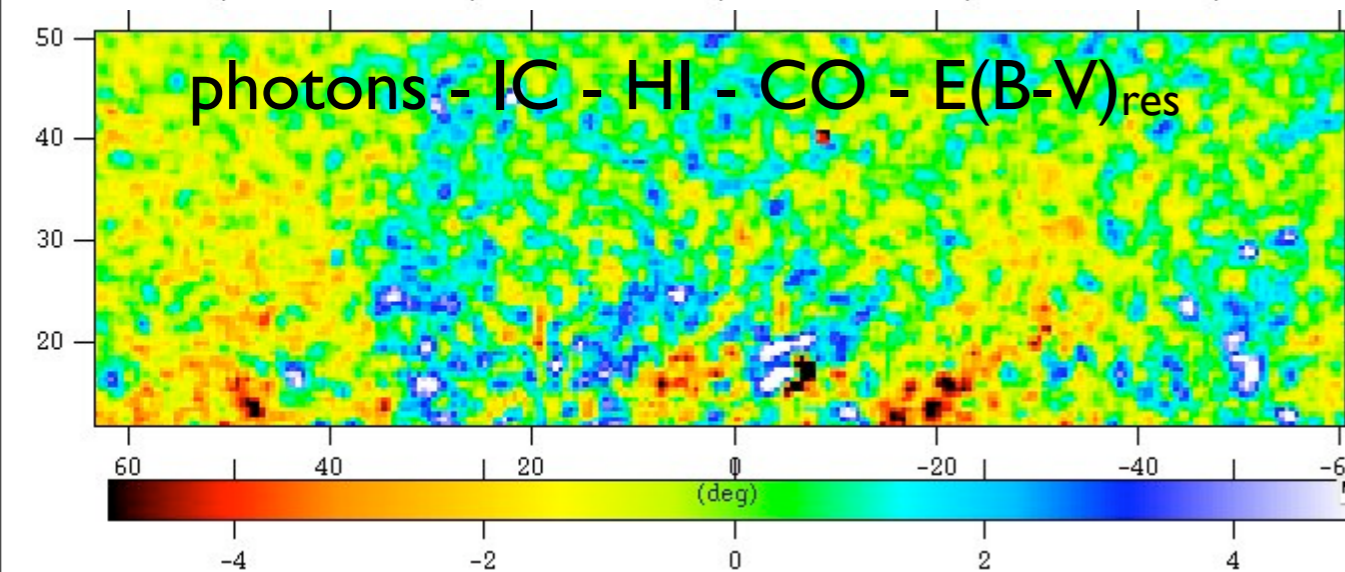
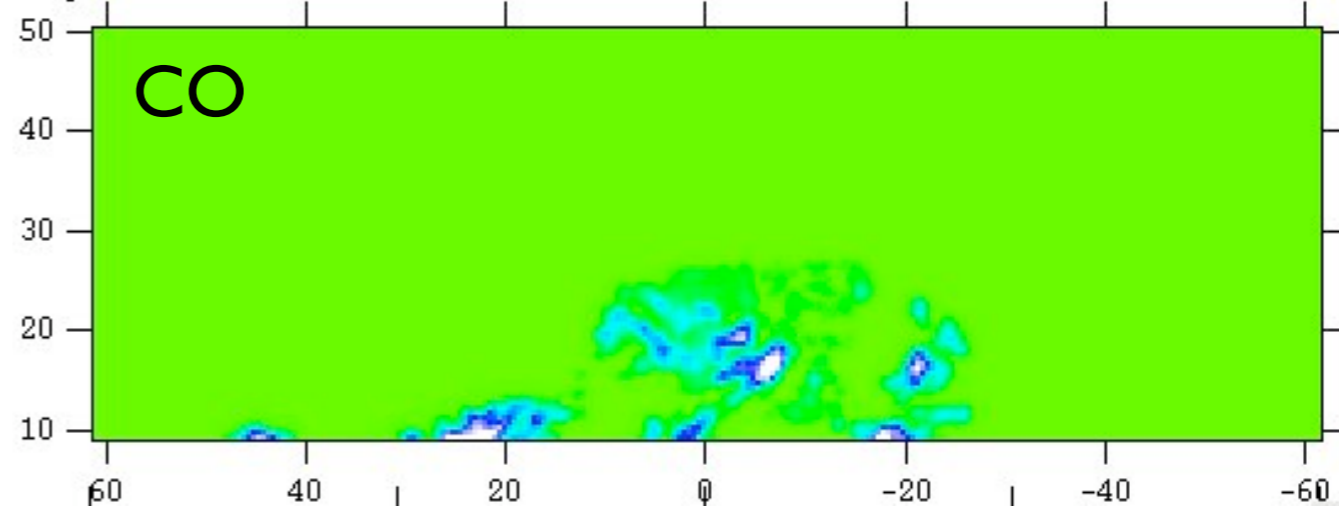
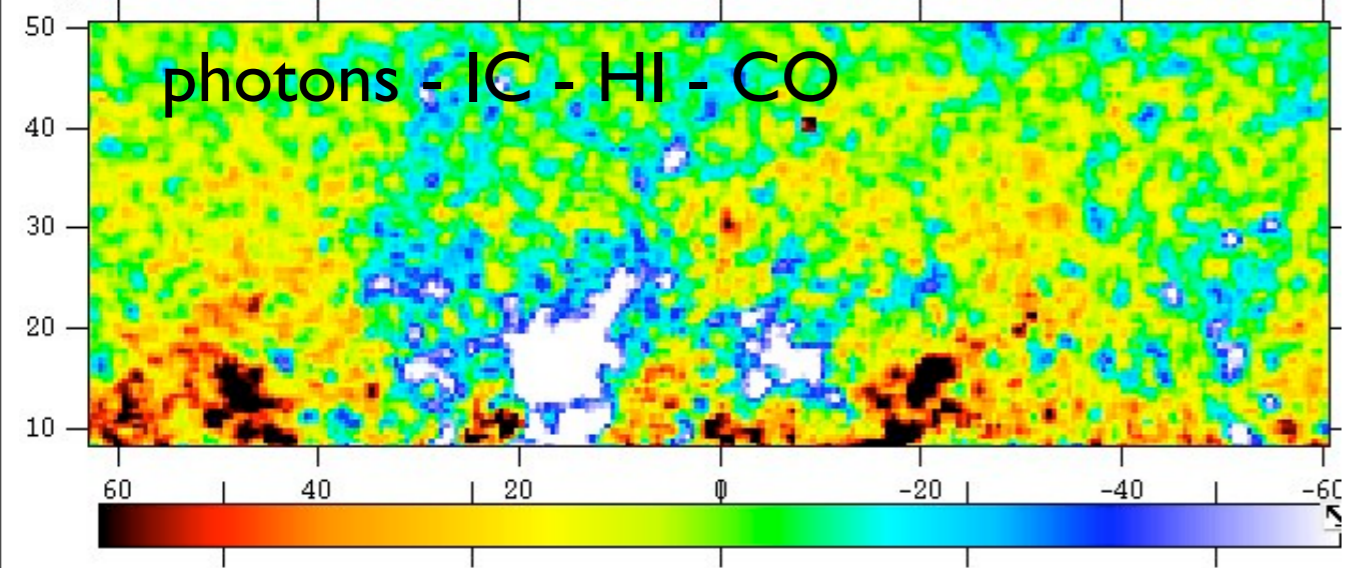
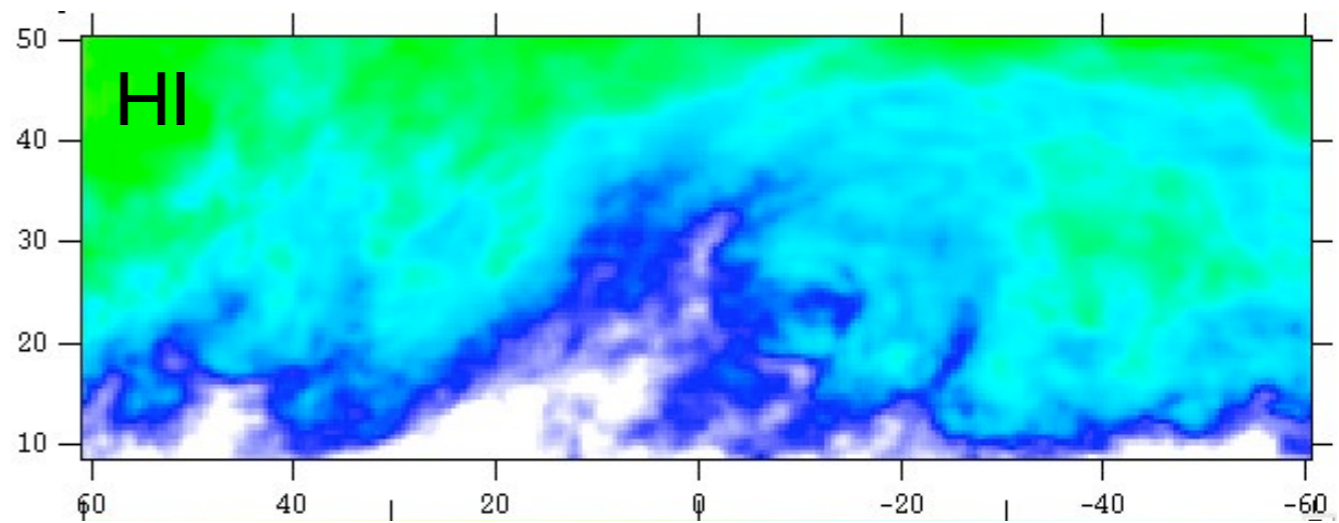
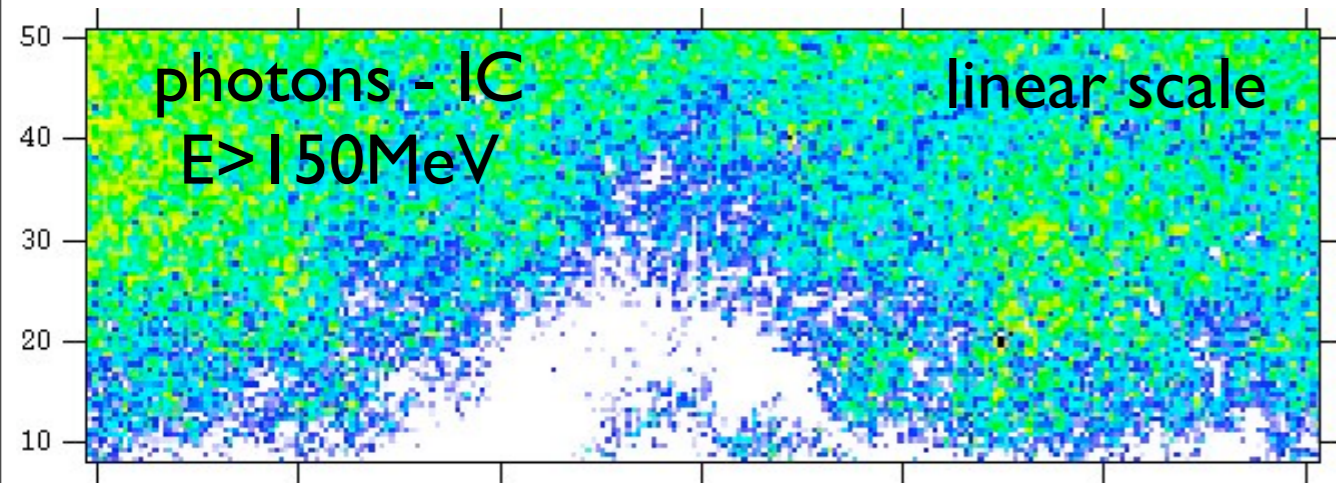
dark gas



dark gas



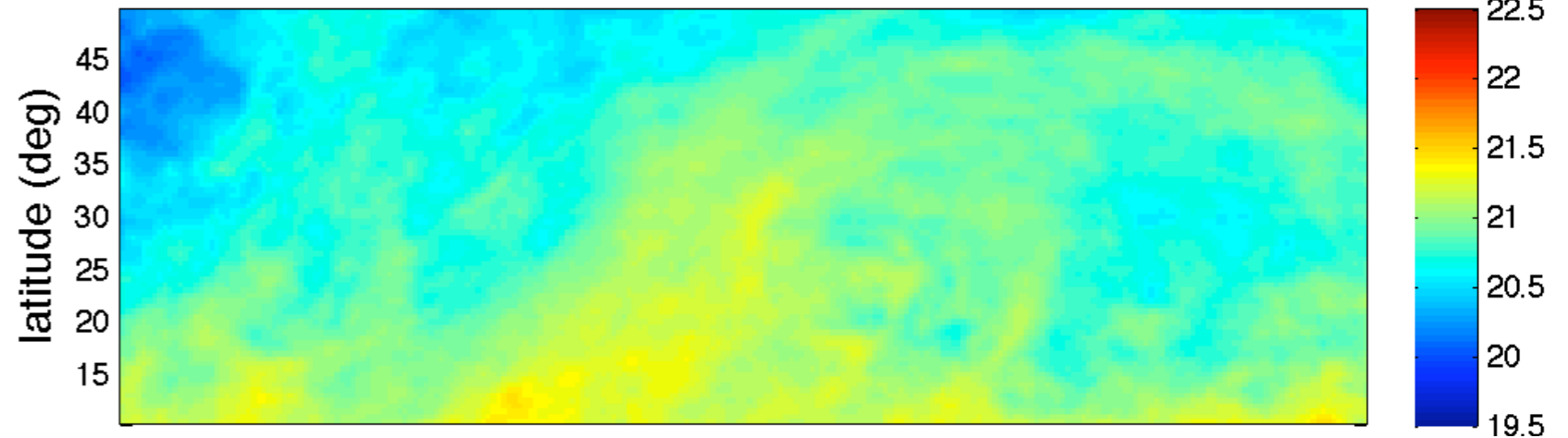
dark gas



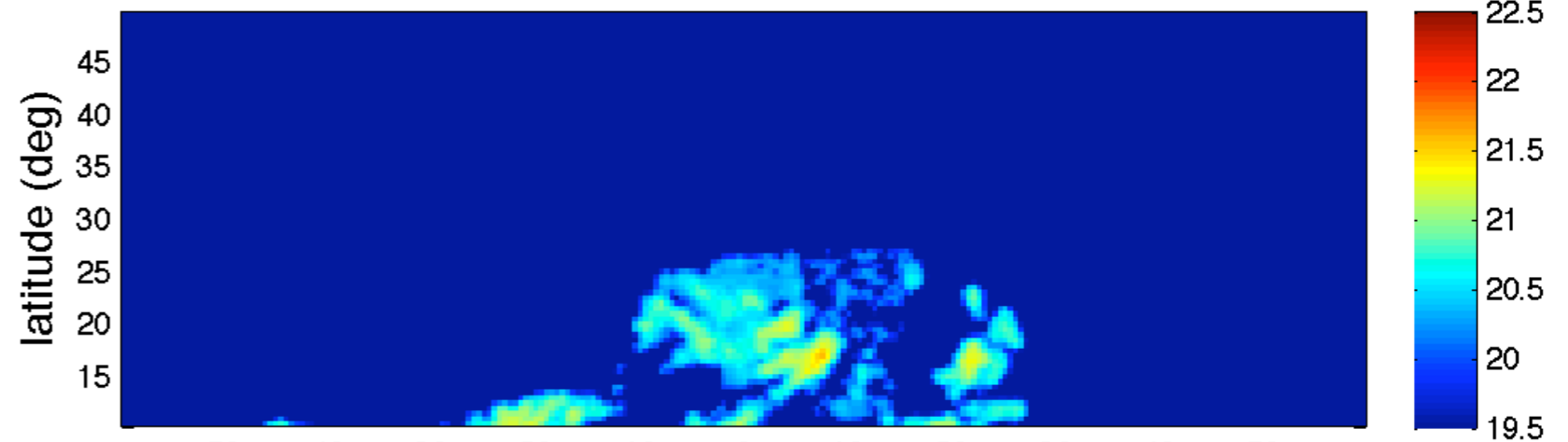
dark gas

- comparable $N(H)$ column-densities in the 3 phases
- problems with linear combination of ISM tracers in the Galactic plane...

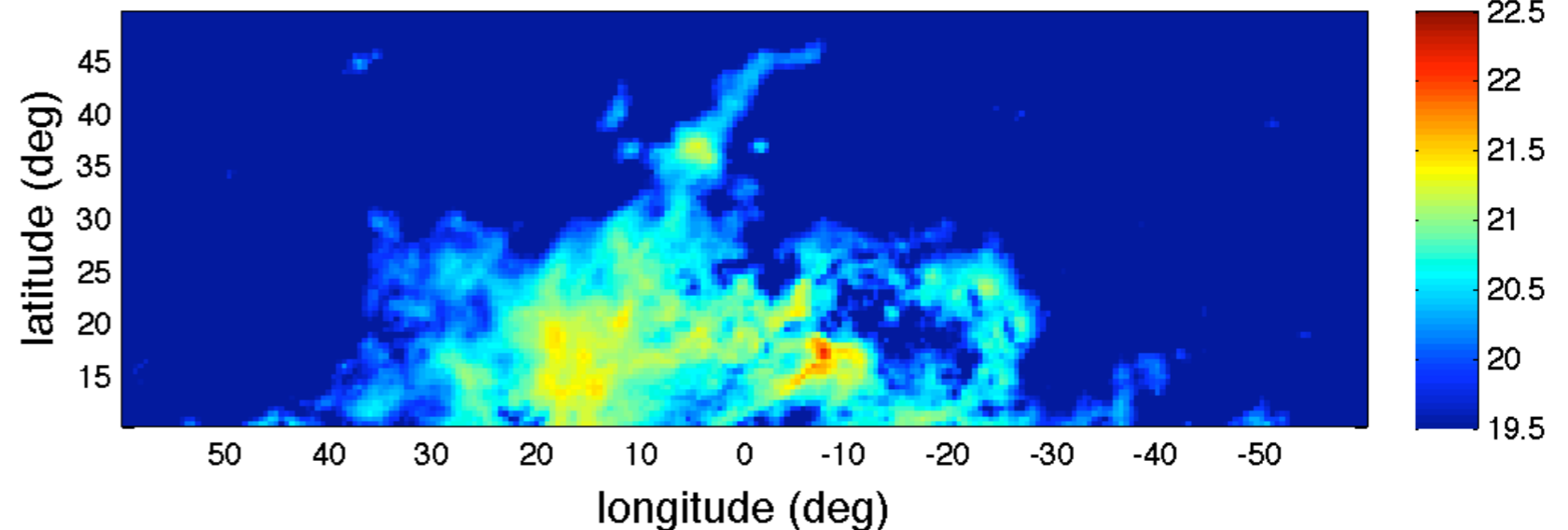
$\log(N(H))$ in the HI phase ($H \text{ cm}^{-2}$)



$\log(N(H))$ in the CO phase ($H \text{ cm}^{-2}$)



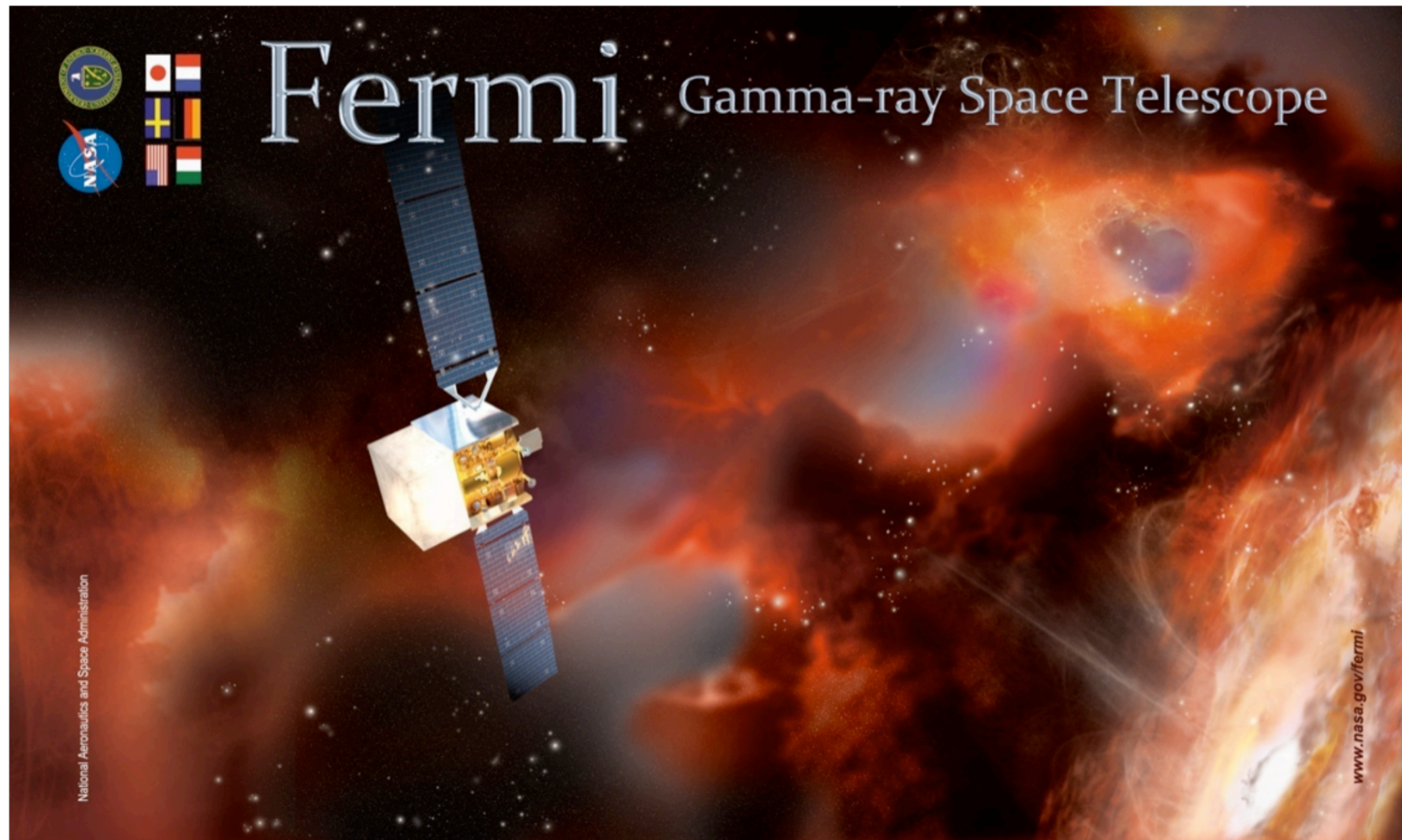
$\log(N(H))$ in the dark-gas phase ($H \text{ cm}^{-2}$)





more tomorrow

- 🌐 Fermi Science Support Center (<http://fermi.gsfc.nasa.gov/ssc/>)



W28

 HII W28A2

