

# Astronomía de rayos gamma: fuentes extragalácticas

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# Fuentes extragalácticas

1. Tipos de fuentes
2. Galaxias normales y starburst
3. Núcleos activos de galaxias
4. Hoyos negros, acreción y jets
5. Radiogalaxias
6. Blazares
7. Absorción de pares por luz extragaláctica
8. Destellos de rayos gamma

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COS-B (1975 - 1982)

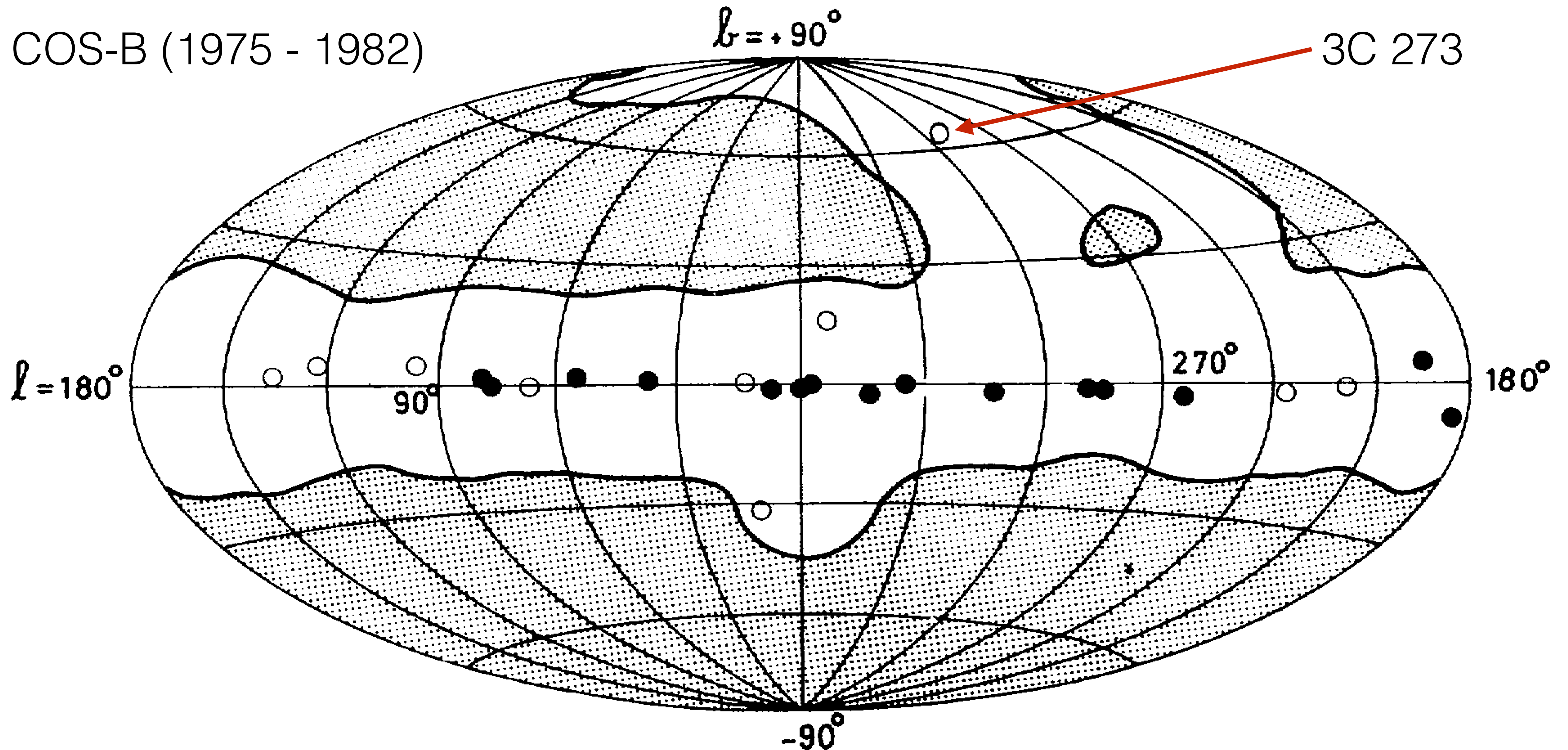
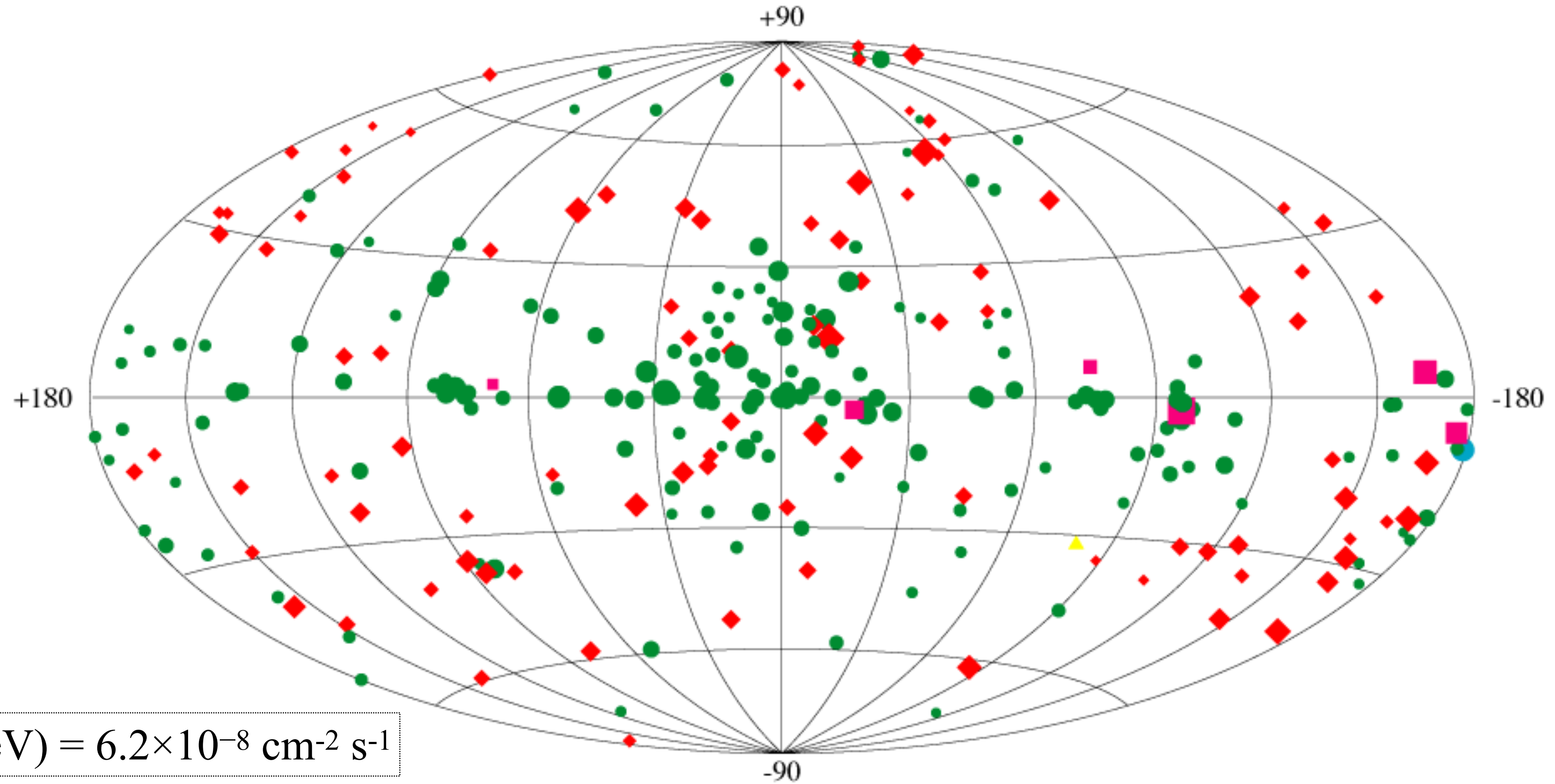


FIG. 1.—Region of the sky searched for gamma-ray sources (*unshaded*) and sources detected above 100 MeV by spatial analysis. The filled circles denote sources with measured fluxes  $\geq 1.3 \times 10^{-6}$  photons  $\text{cm}^{-2} \text{s}^{-1}$ . Open circles denote sources below this threshold.

# Third EGRET Catalog

$E > 100 \text{ MeV}$

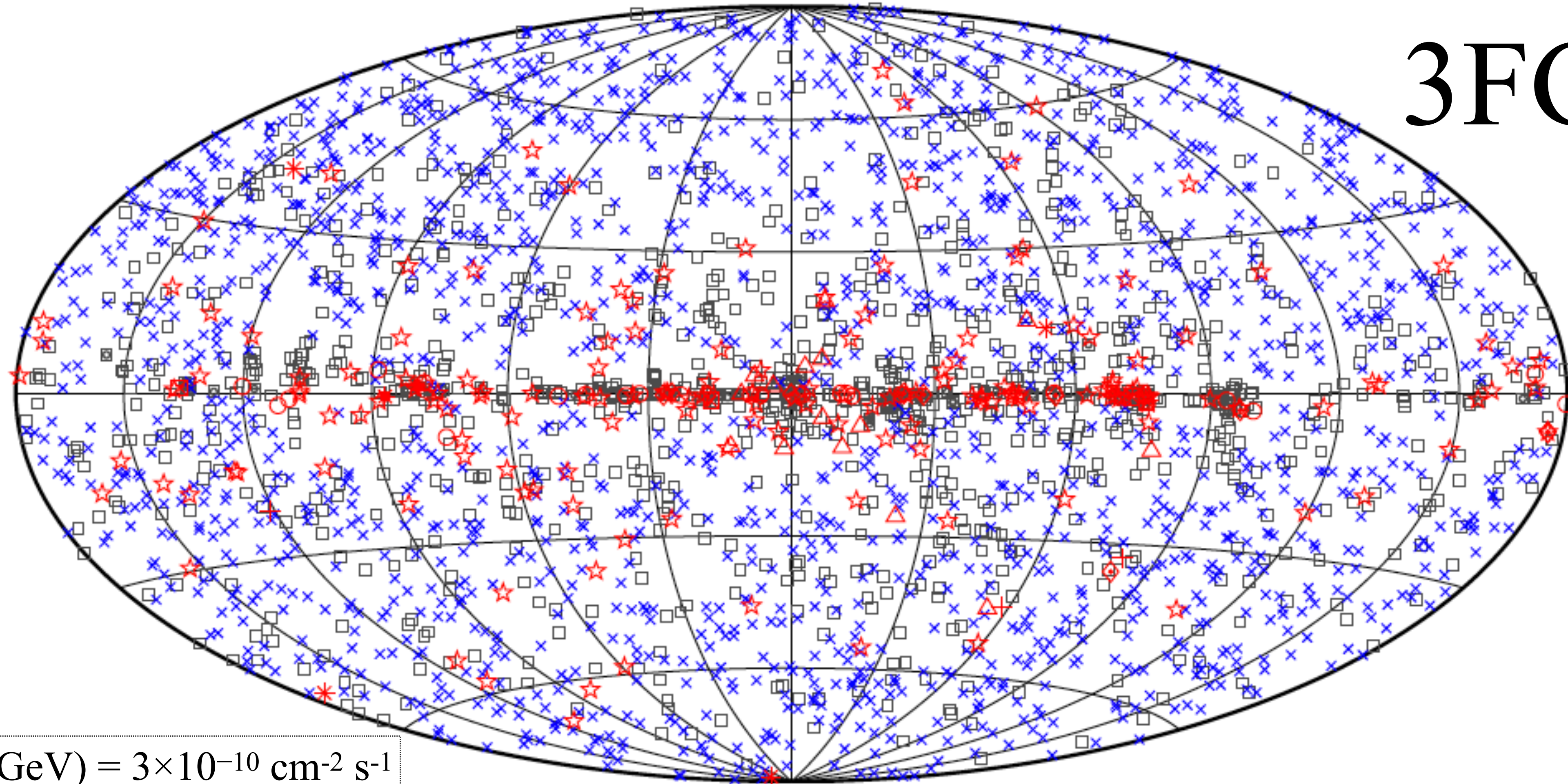


$$F_{\min}(E > 100 \text{ MeV}) = 6.2 \times 10^{-8} \text{ cm}^{-2} \text{ s}^{-1}$$

- ◆ Active Galactic Nuclei
- Unidentified EGRET Sources
- Pulsars
- ▲ LMC
- Solar FLare

Hartman et al. (1999)

# 3FGL



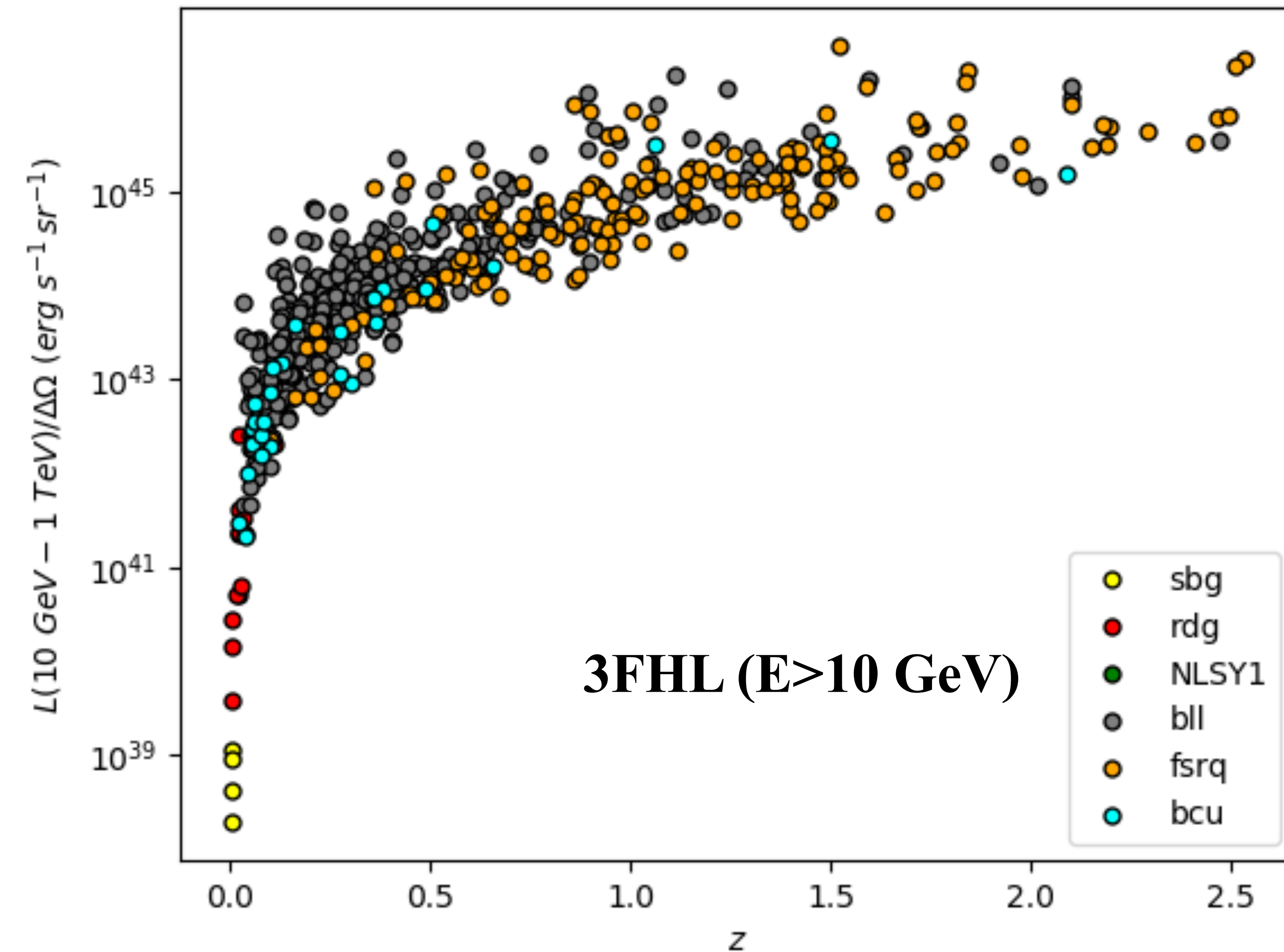
$$F_{\min}(0.1 - 100 \text{ GeV}) = 3 \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$$

- |                       |  |        |
|-----------------------|--|--------|
| □ No association      | ▣ Possible association with SNR or PWN | × AGN  |
| ☆ Pulsar              | △ Globular cluster                     | ◇ PWN  |
| ⊠ Binary              | + Galaxy                               | ○ SNR  |
| ★ Star-forming region |  | ✱ Nova |

## LAT 4FGL extragalactic sources (4FGL-DR3)

Description	Identified		Associated (high/low confidence)			Total
	Category	Count	Category	High Confidence	Low Confidence	
Blazar candidate of uncertain type	BCU	1	bcu	1493	0	<b>1493</b>
BL Lac type of blazar	BLL	22	bll	1434	0	<b>1456</b>
Flat spectrum radio quasar	FSRQ	44	fsrq	750	0	<b>794</b>
Non-blazar active galaxy	AGN	1	agn	8	174	<b>183</b>
Radiogalaxy	RDG	6	rdg	39	0	<b>45</b>
Starburst galaxy	SBG	0	sbg	8	4	<b>12</b>
Seyfert galaxy	SEY	0	sey	2	8	<b>10</b>
Narrow-line Seyfert 1	NLSY1	4	nlsy1	4	0	<b>8</b>
Normal galaxy	GAL	2	gal	4	0	<b>6</b>
Compact steep spectrum radio source	CSS	0	css	5	0	<b>5</b>
Steep spectrum radio quasar	SSRQ	0	ssrq	2	0	<b>2</b>
Galaxy cluster	CLUST	0	clust	0	1	<b>1</b>
<b>Total</b>						<b>4015</b>

Fermi-LAT AGN with redshift



Del catálogo 3FHL de fuentes Fermi-LAT detectadas por encima de 10 GeV.

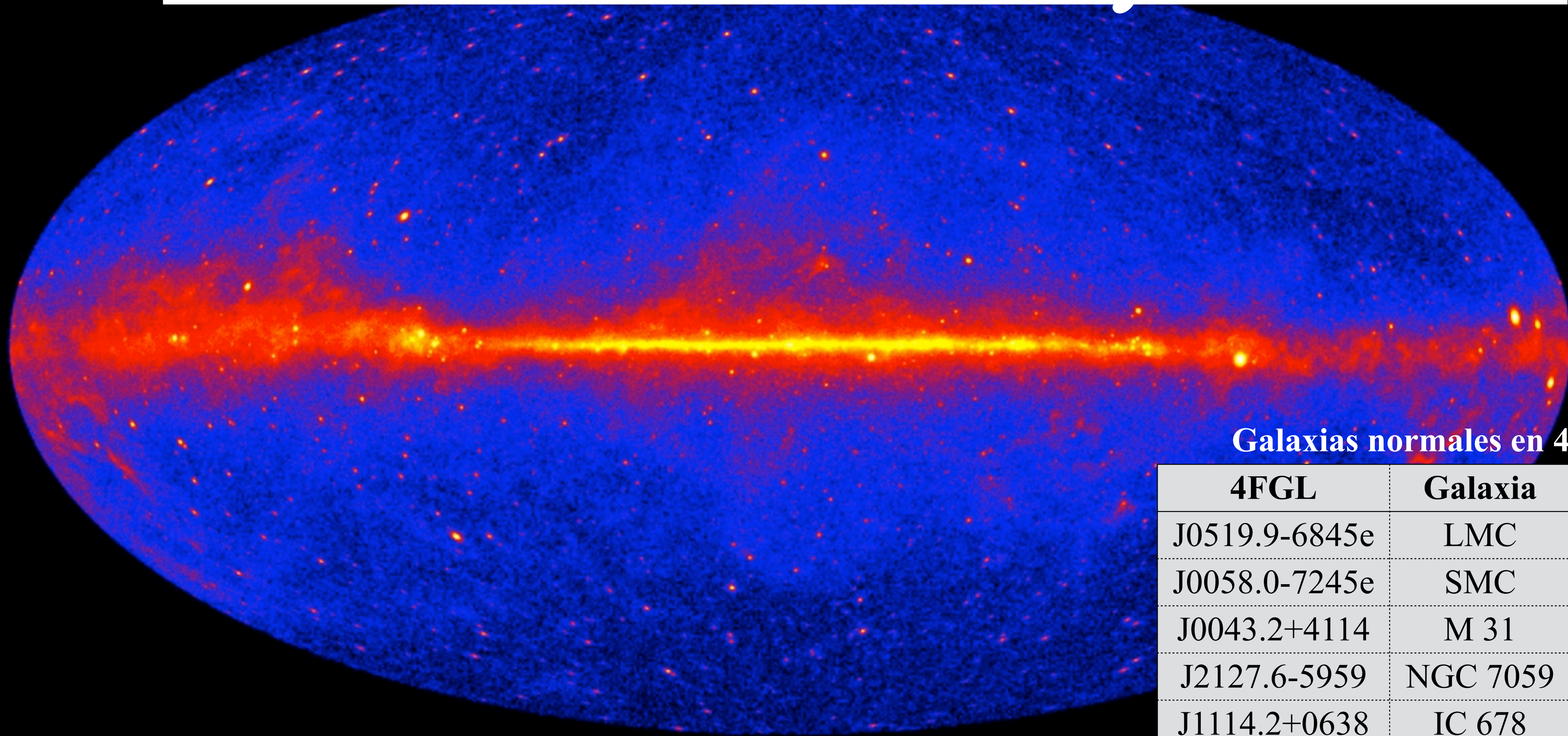
3FHL contiene 1556 objetos, de los cuales 1231 son AGNs, principalmente BL Lacs (735), BCU (290) y FSRQ (172).

# Fuentes extragalácticas de rayos $\gamma$

Galaxias normales	Galaxias starburst	Seyferts	Radio galaxias	BL Lac	Flat Spectrum Radio Quasars FSRQ
MW LMC SMC M31 + M33	M82, NGC 253 NGC 4945 (Sb? Sy 2?)	PMN J0948+0022, PKS 1502+036, PKS 2004-447, NGC 6951	M87, Cen A, NGC1275, NGC1218, NGC 6251	Dominante en Fermi-LAT & fuentes TeV	Dominantes en EGRET, 3C 454.3
Rayos cósmicos por formación estelar $\Rightarrow$ rayos cósmicos & medio interestelar	Mayor formación estelar que en galaxias normales. Sin variabilidad. AGN débil?	Narrow line Sy1 Sy 2 LINER Seyferts radio quiet?	Variables. Aceleración de partículas en jets. AGN desalineado.	Espectro $\gamma$ duro. Altamente variables. Aceleración en jets relativistas.	Altamente variables. Aceleración en jets relativistas.

Formación estelar  $\rightarrow$  AGN & jet  $\rightarrow$

# 2. Galaxias normales y starburst



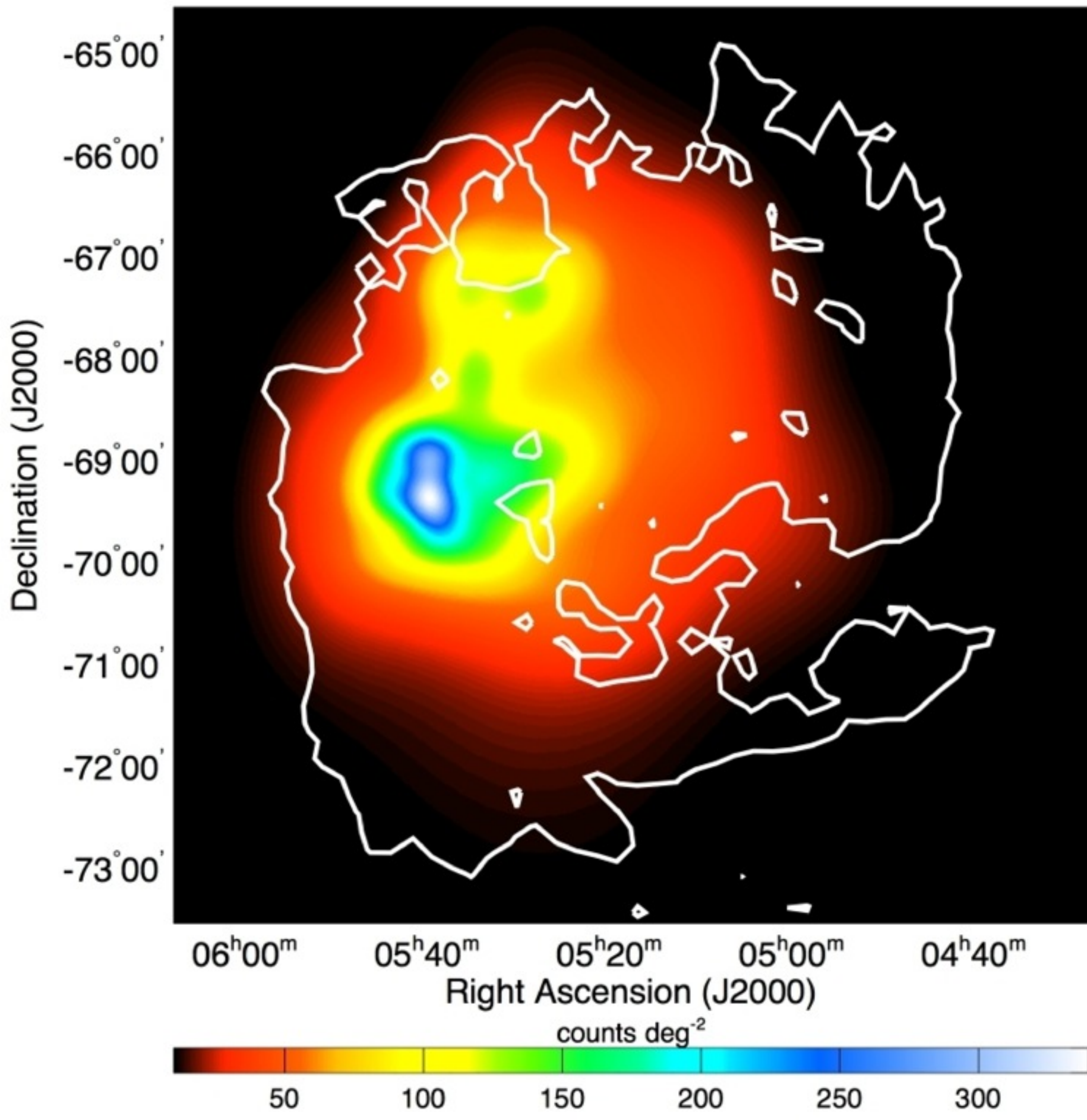
**Galaxias normales en 4FGL-DR3**

4FGL	Galaxia	Signif	TeV
J0519.9-6845e	LMC	48.54	N
J0058.0-7245e	SMC	34.19	N
J0043.2+4114	M 31	8.84	N
J2127.6-5959	NGC 7059	5.82	N
J1114.2+0638	IC 678	4.62	N
J1357.3+3730	NGC 5380	3.28	N

# Galaxias normales

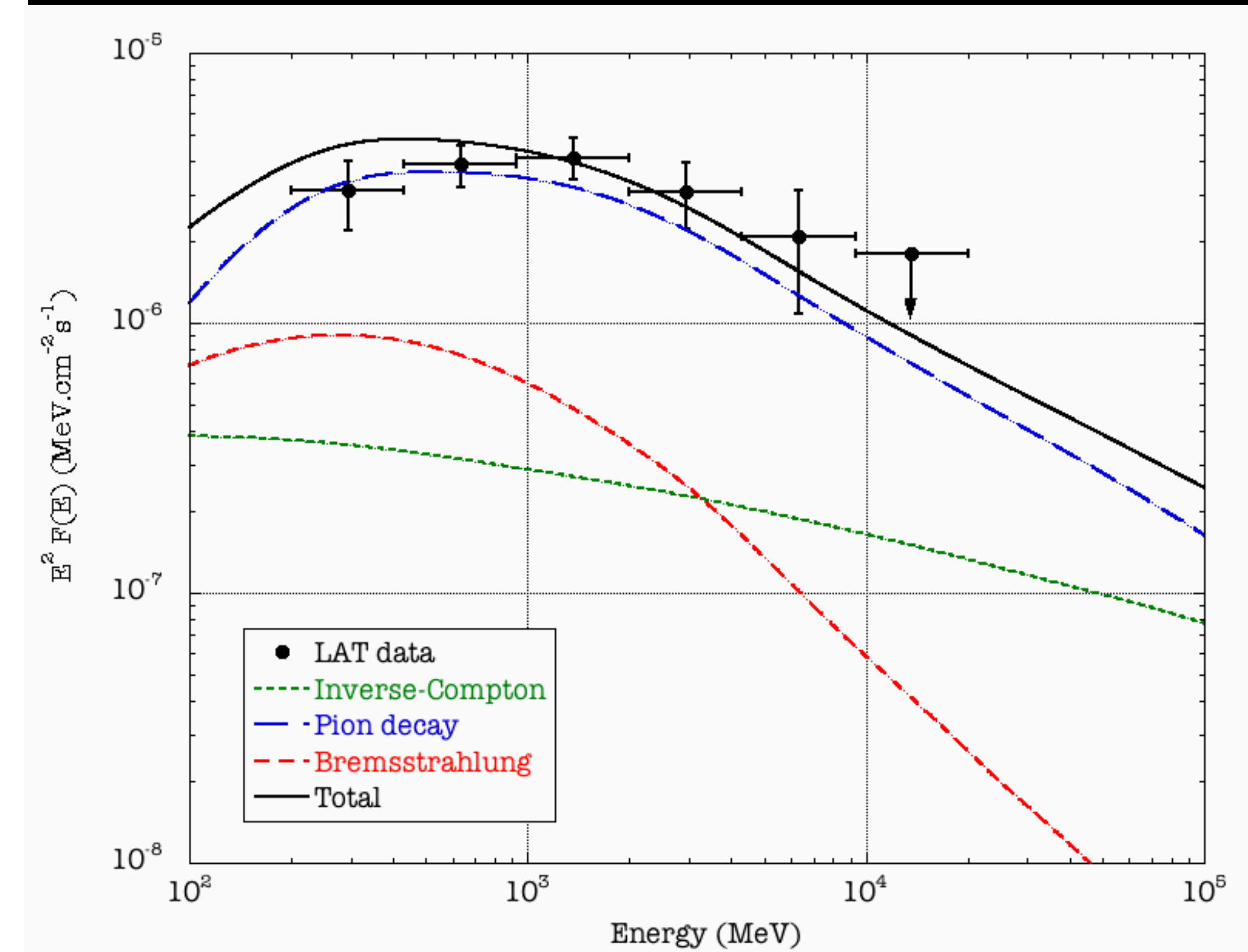
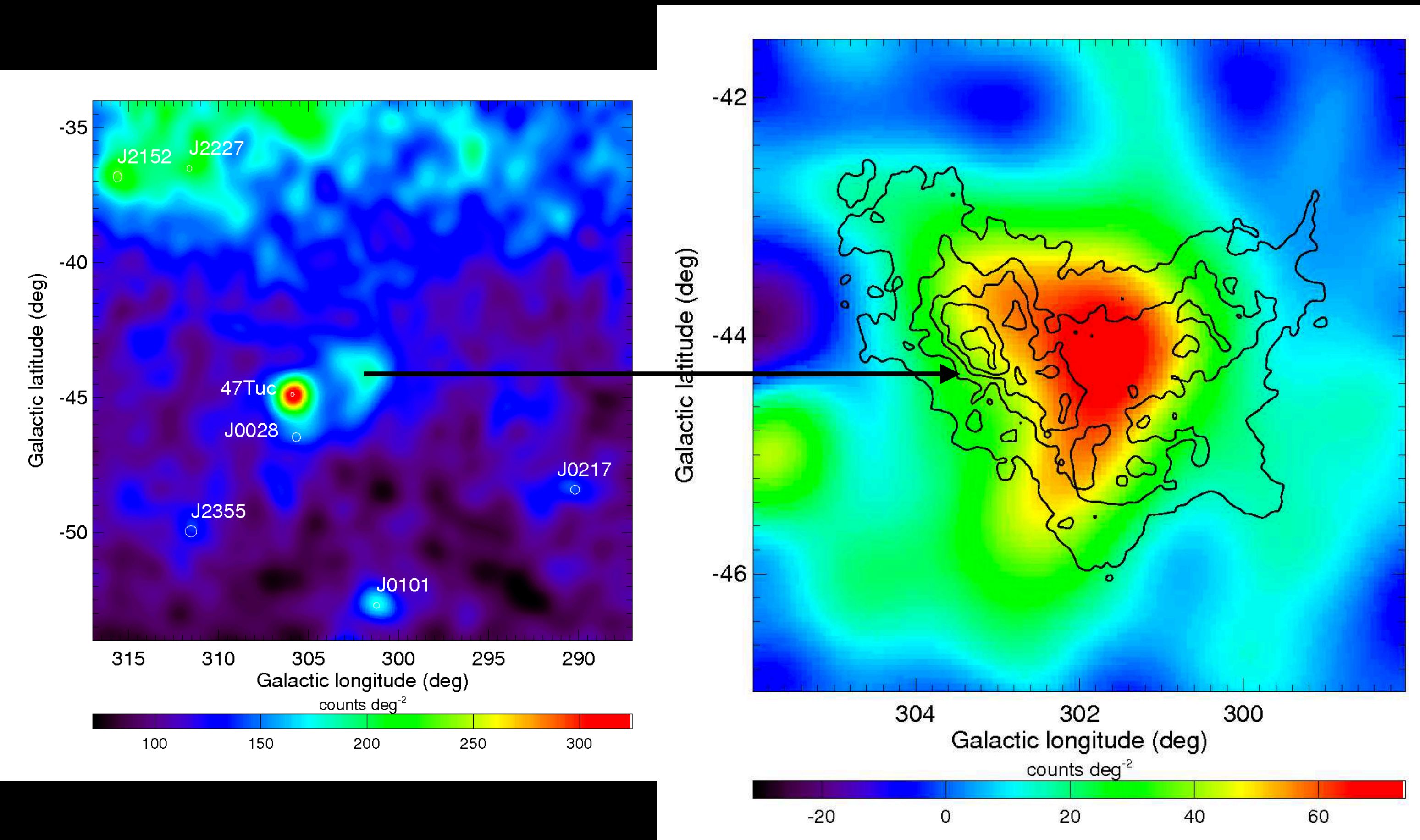
## La Nube Mayor de Magallanes (LMC)

- Galaxia cercana resuelta.
- Identificación de 30 Doradus, PSR J0540-6919, N 157B (PWN), N 132D (SNR) y una fuente no asociada.
- Consistente con  $u(\text{cr}) = 1/3 \text{ MW}$ .



Ackermann et al. (2016)

# Galaxias normales - SMC



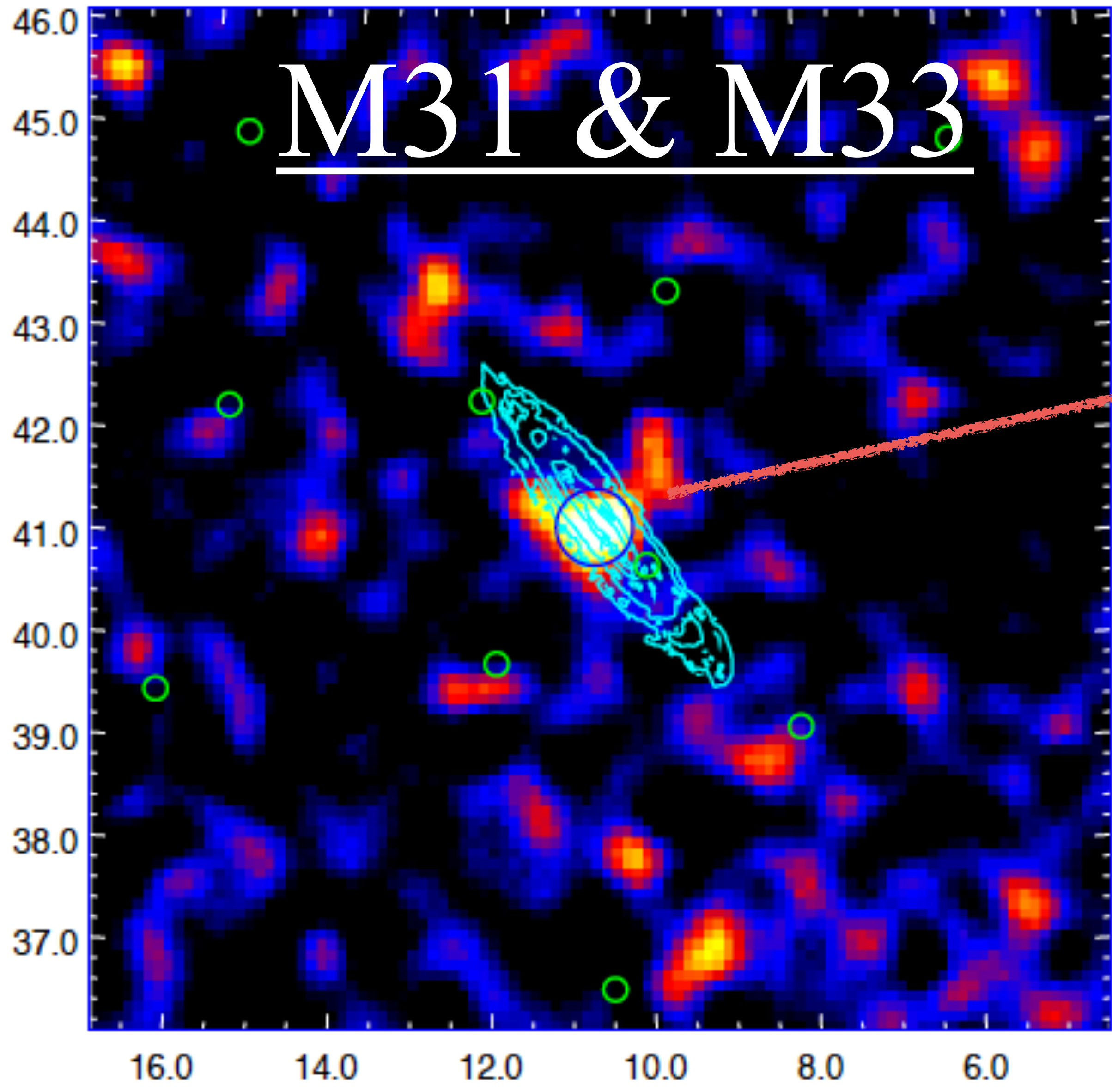
## Small Magellanic Cloud

SFR  $\sim 1/40$  MW  $\sim 0.1$  SN / siglo

Abdo et al (2010)

# M31 & M33

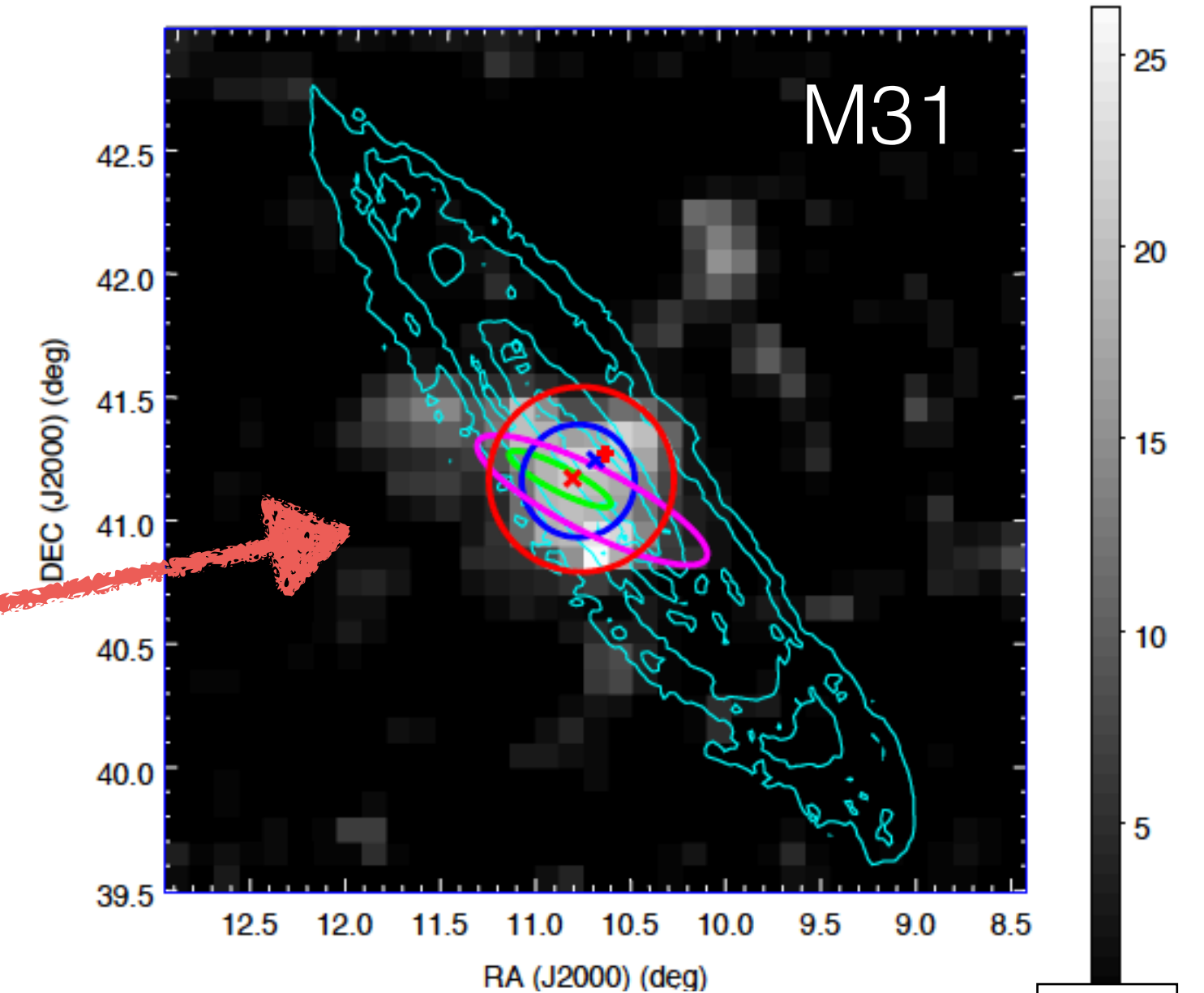
DEC (J2000) (deg)



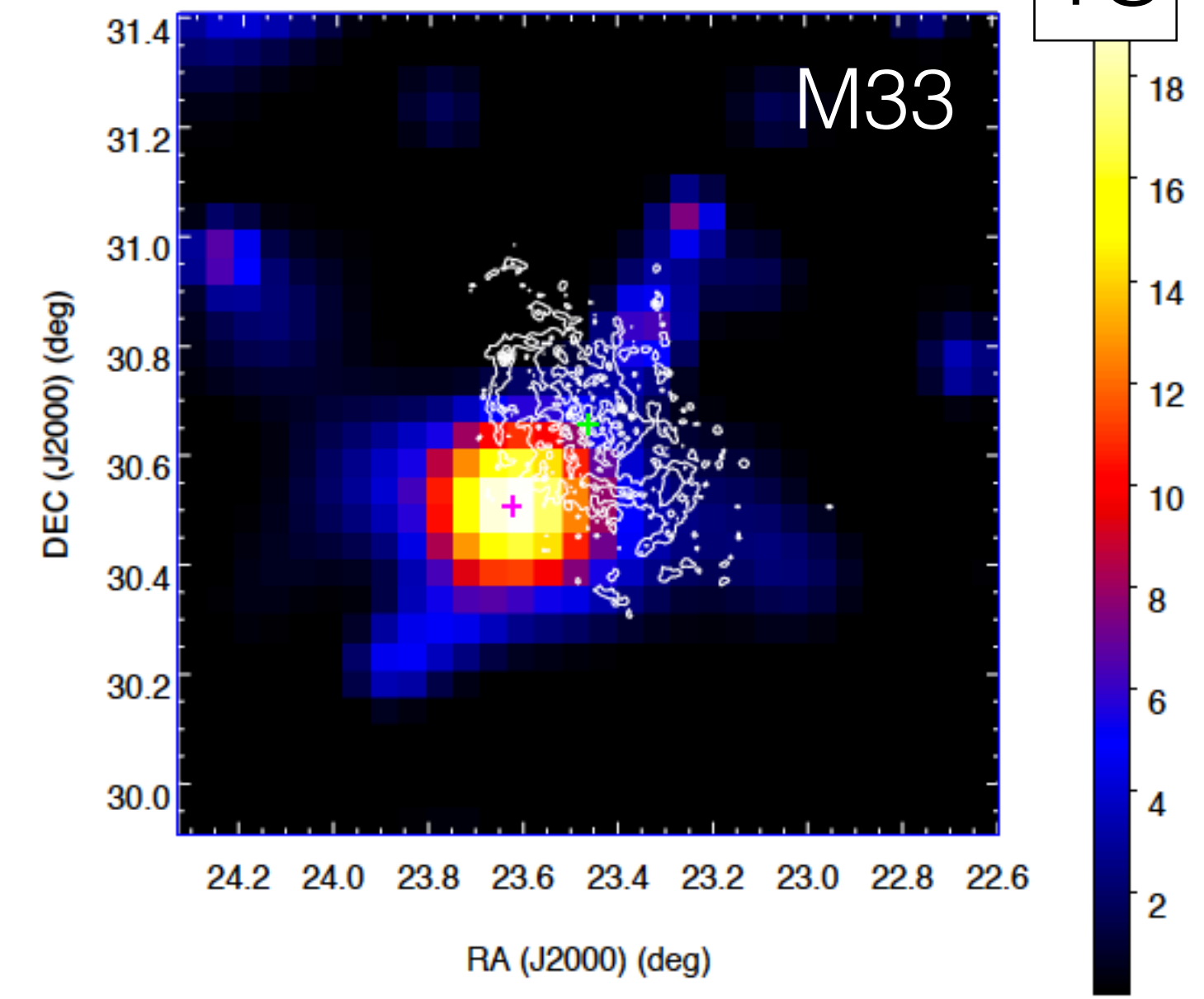
Ackermann et al. (2017)

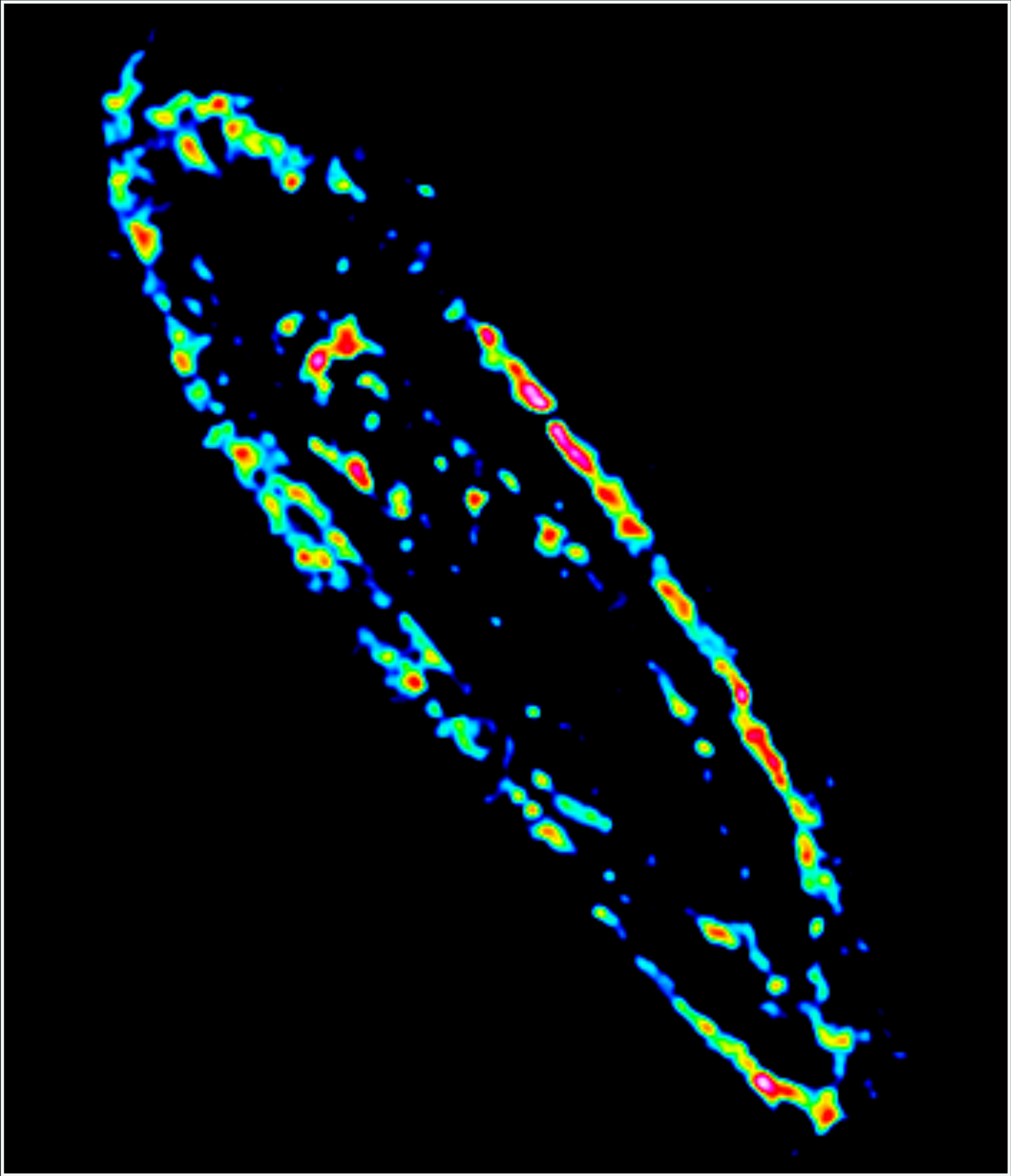
RA (J2000) (deg)

counts/pixel



TS





M31 en CO

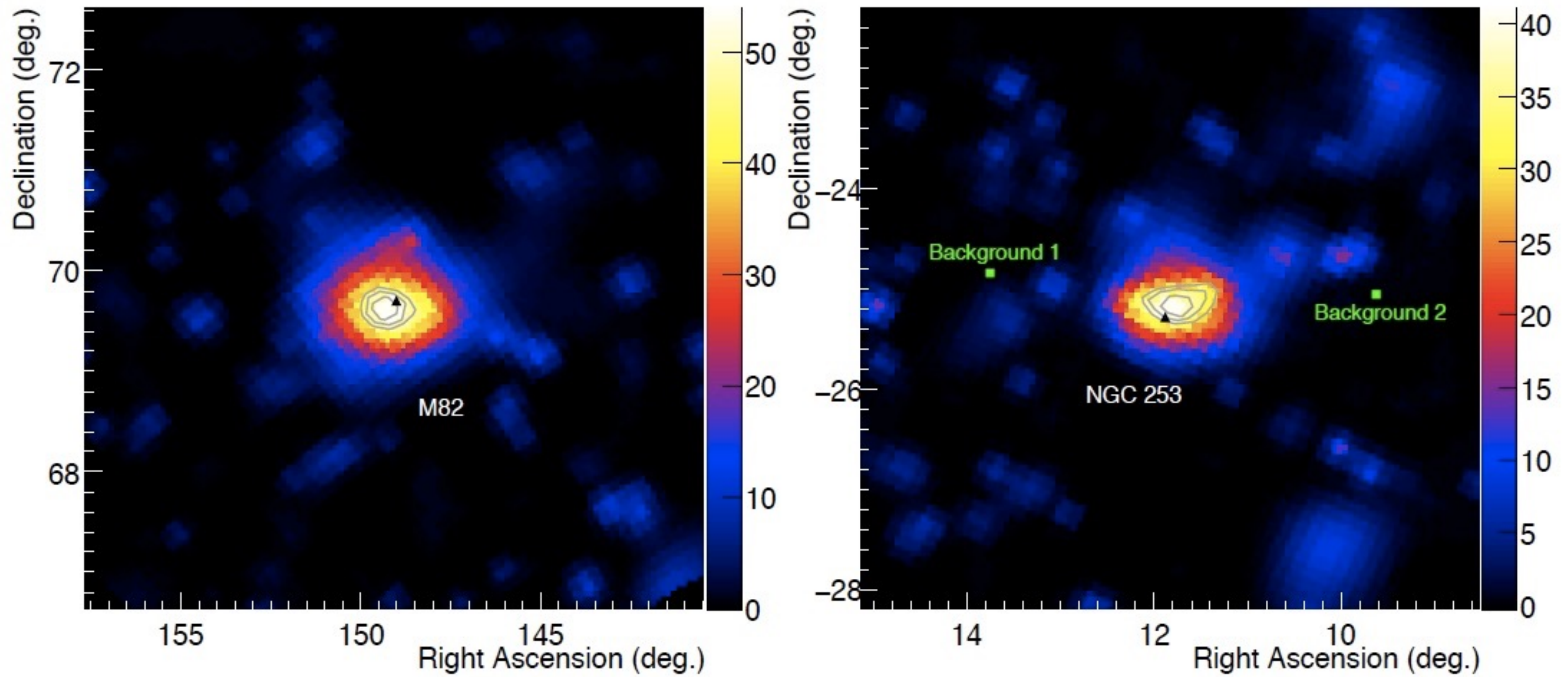
# Galaxias normales

- LMC mapeada con alta S/N: emisión extendida, dominada por 30 Doradus, junto con tres fuentes puntales brillantes. Densidad RC  $\sim$  30% de Vía Láctea
- SMC: densidad RC  $\sim$  15% de Vía Láctea, con posible contribución de pulsares.
- M31: fuente extendida; emisión dominada por la parte interna de la galaxia (no el anillo de gas molecular).
  - M33 por debajo del umbral de detección ( $5\sigma$ ).
- También 4FGL-DR3: IC 678, NGC 5380, NGC 7059.

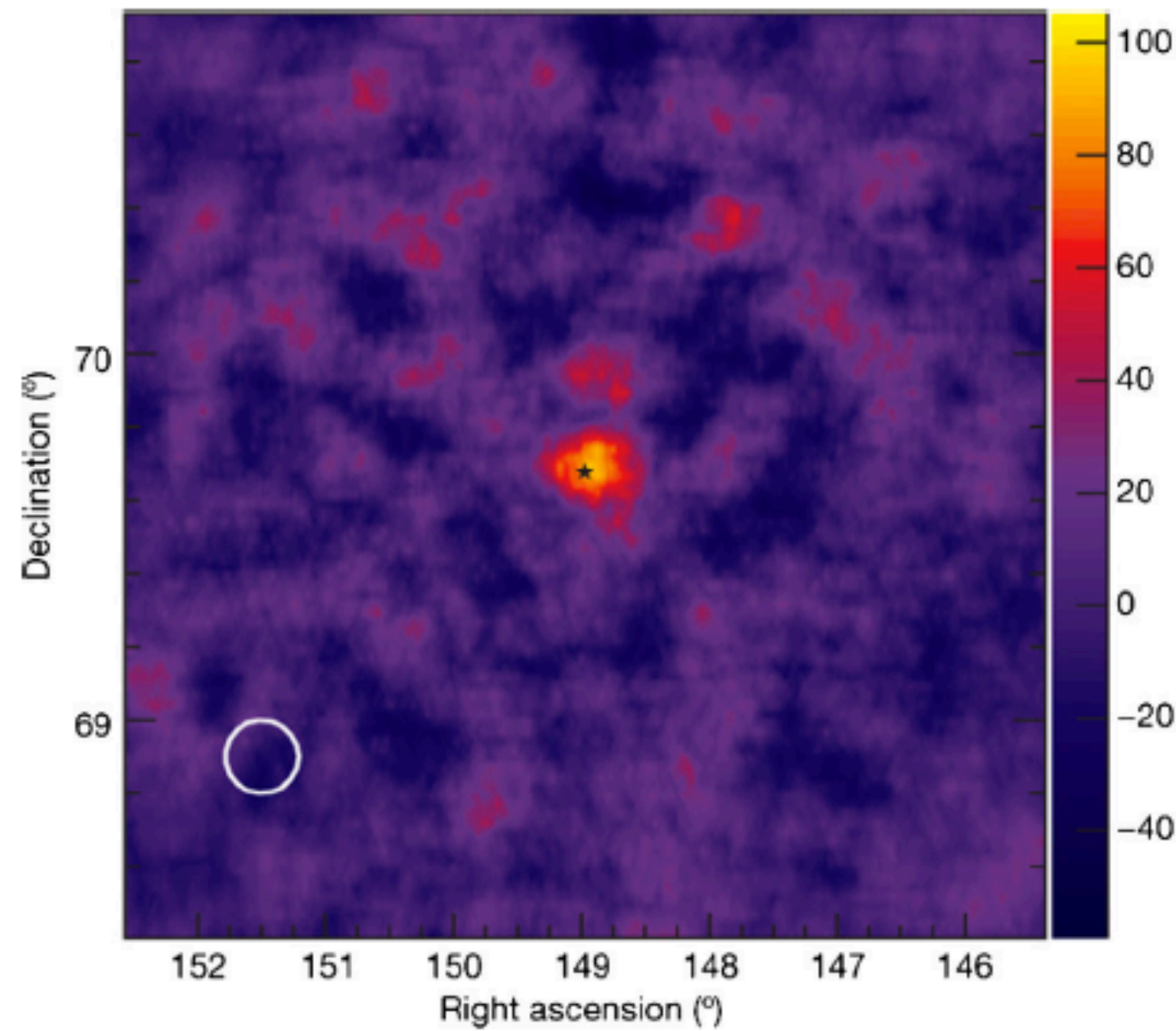
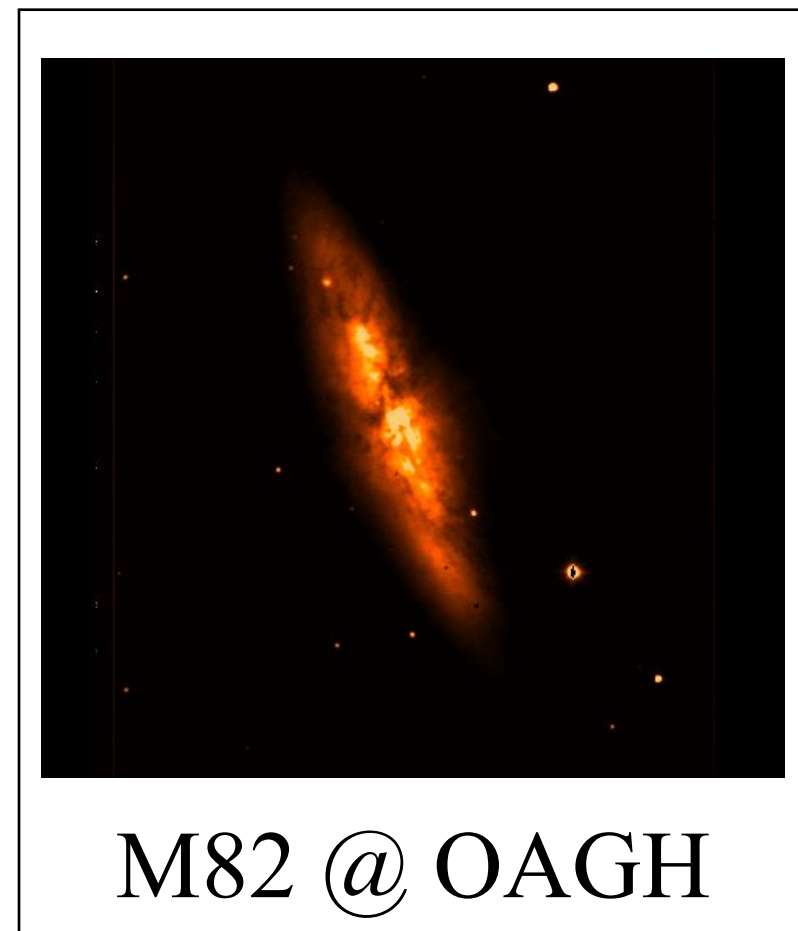
# Galaxias starburst en 4FGL-DR3

Nombre	Tipo	Galaxia	Signif	TeV
4FGL J0955.7+6940	sbg	M 82	36.95	P
4FGL J0047.5-2517	sbg	NGC 253	27.12	P
4FGL J1305.4-4928	sbg	NGC 4945	22.97	N
4FGL J0242.6-0000	sbg	NGC 1068	18.37	N
4FGL J0618.1+7819	sbg	NGC 2146	7.19	N
4FGL J1128.2+5831	sbg	Arp 299	5.86	N
4FGL J1051.6+3253	sbg	NGC 3424	5.28	N
4FGL J1534.7+2331	sbg	Arp 220	5.74	N
4FGL J0737.4+6535	sbg-lc	WISEA J073707.21+653623.0	6.66	N
4FGL J1308.9-5730	sbg-lc	WISEA J130831.60-572649.2	6.92	N
4FGL J1438.0+0219	sbg-lc	WISEA J143747.60+021733.5	5.86	N
4FGL J1651.1-5848	sbg-lc	WISEA J165121.14-590011.5	8.84	N

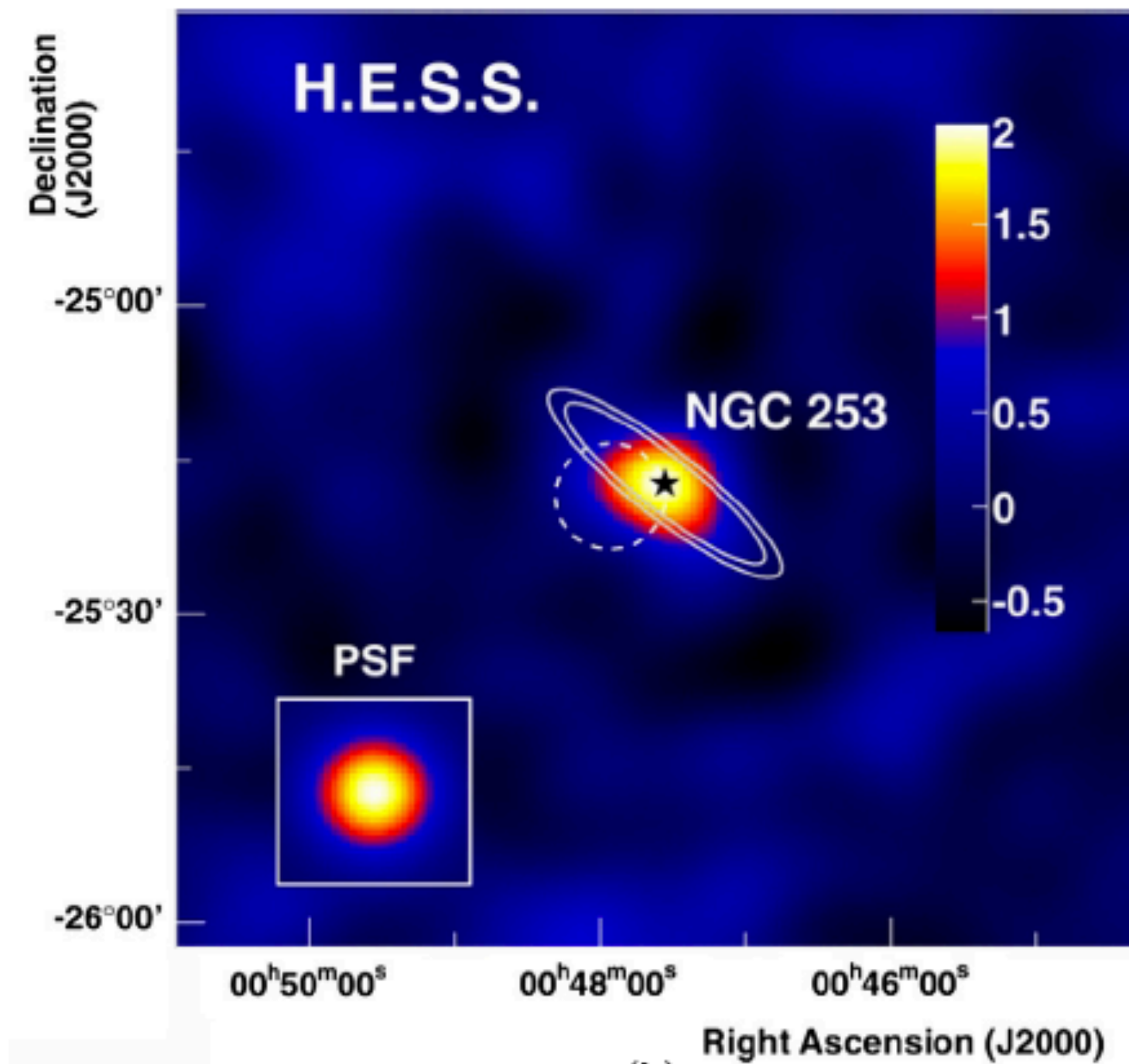
# M82 & NGC 253



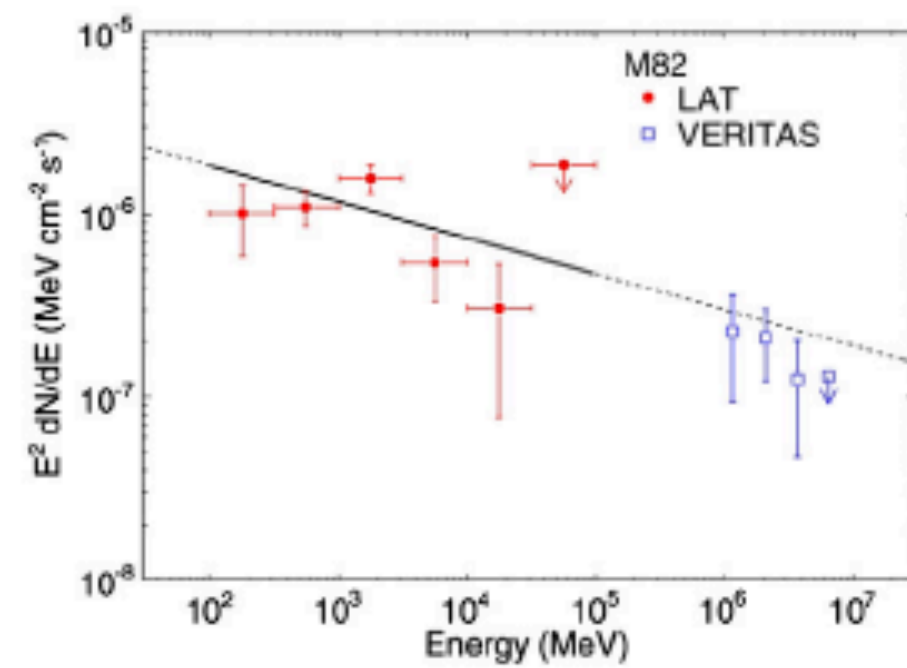
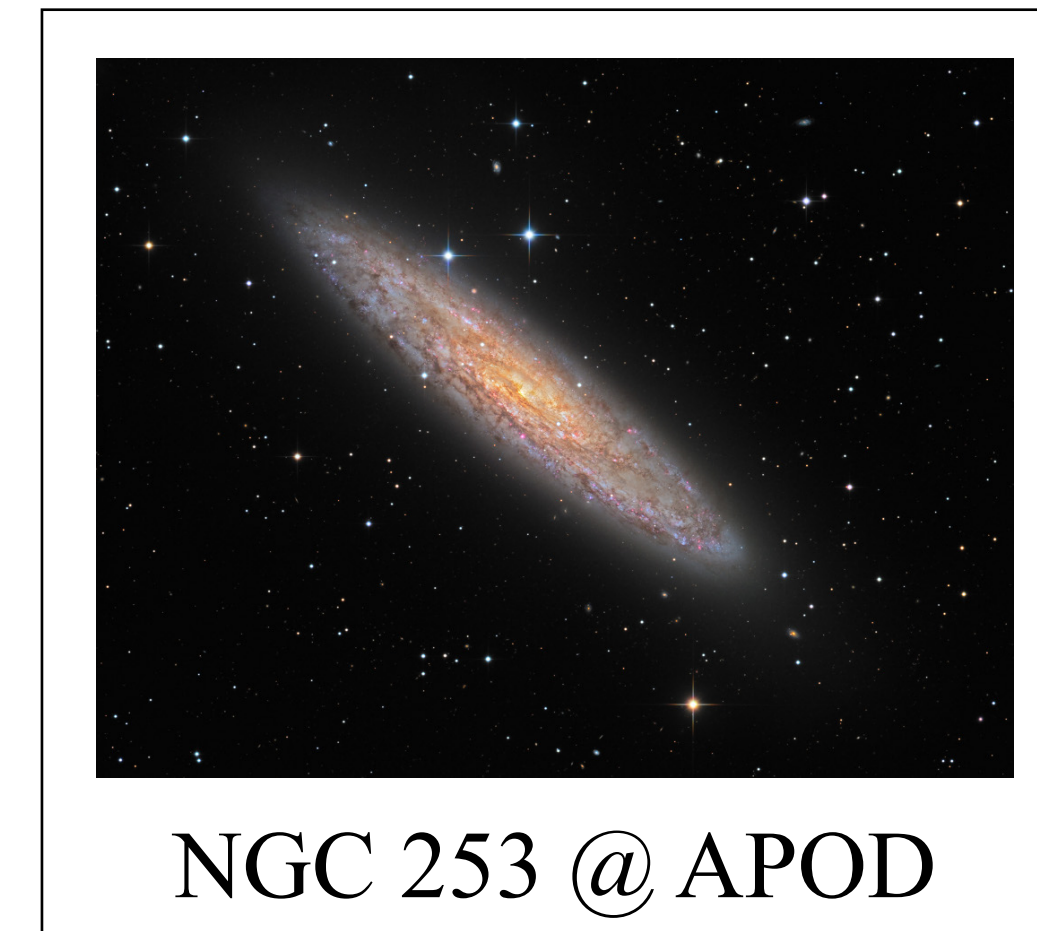
Fermi-LAT (Abdo et al. 2010)



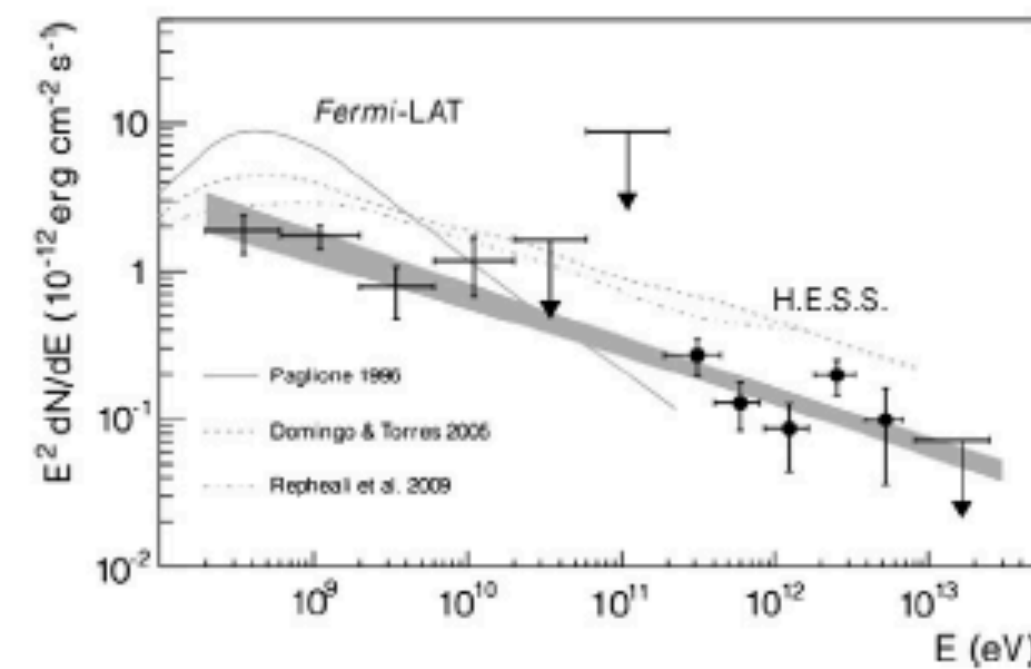
(a)



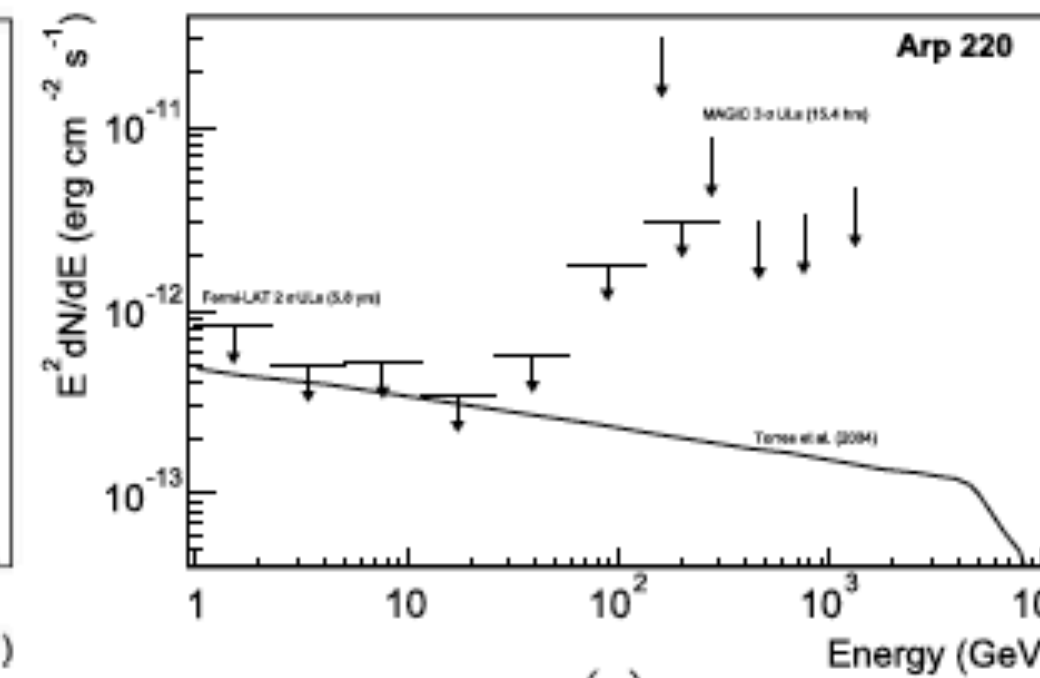
(b)



(c)



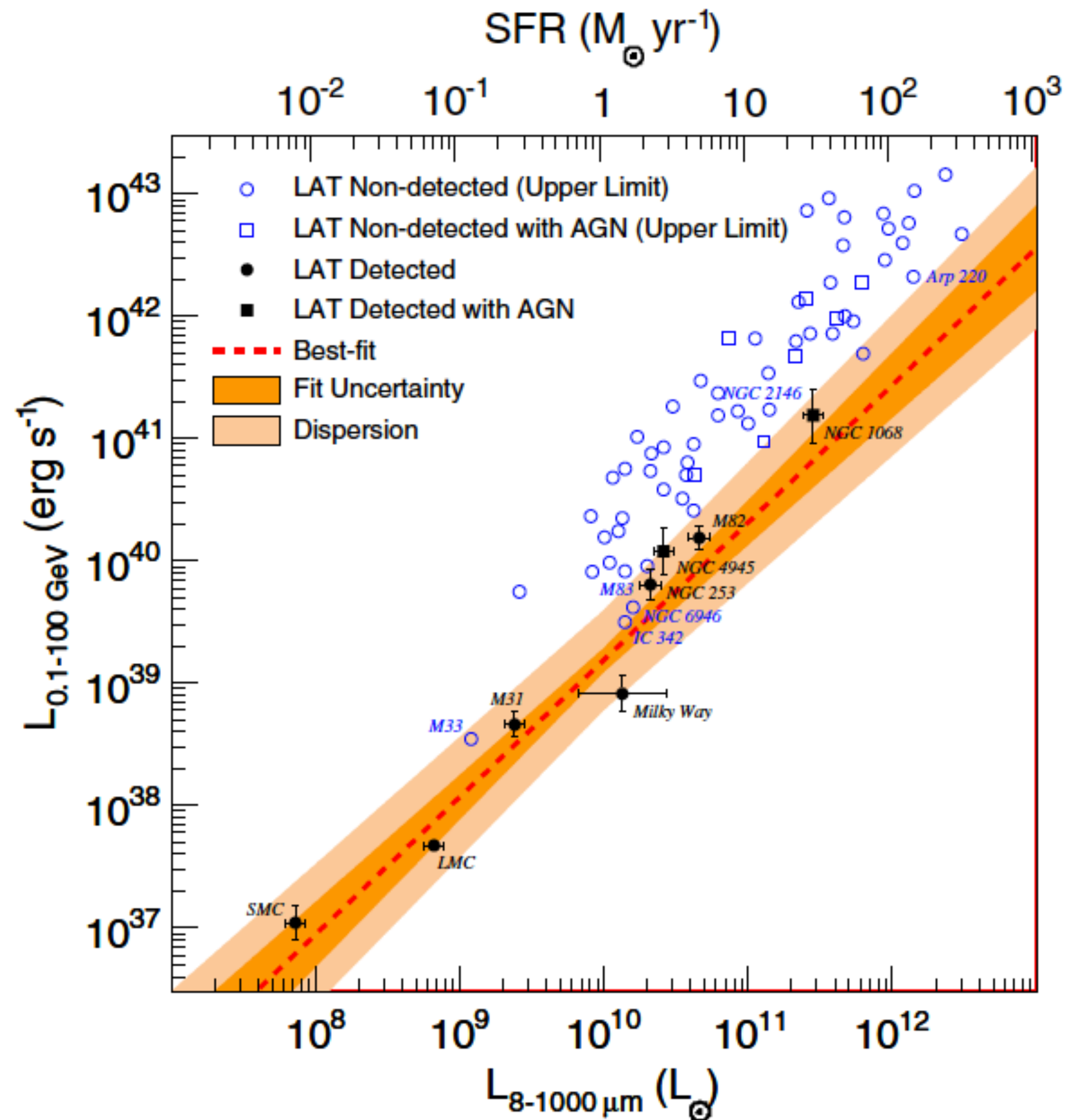
(d)



(e)

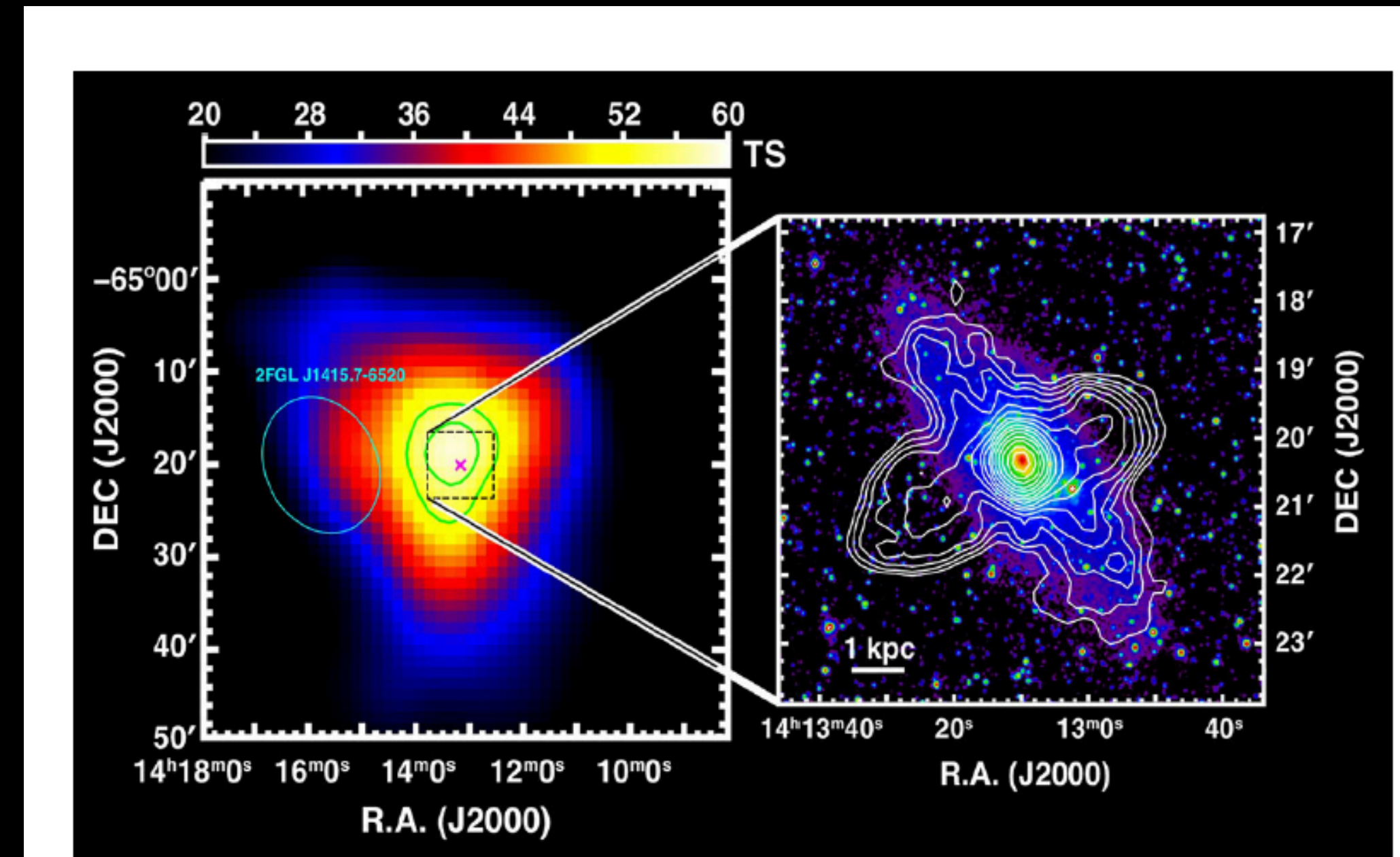
Fig. 1. Sky maps of M82 (a, [20]) and NGC253 (b, [23]), and their combined GeV and TeV  $\gamma$ -ray spectra (c, [22]; d, [23]). e) Arp220:  $\gamma$ -ray flux upper limits from 5.8 years of Fermi-LAT data along with the MAGIC data and model predictions (full line, [24]). Note the conversion of energy flux into SI units is  $1 \text{ W}\cdot\text{m}^{-2} = 10^3 \text{ erg}\cdot\text{cm}^{-2}\cdot\text{s}^{-1} = 6.24 \times 10^8 \text{ MeV}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$ .

**Fig. 20** Gamma-ray luminosity (0.1–100 GeV) versus total IR luminosity (8–1000  $\mu\text{m}$ ) for normal and starburst galaxies (Ackermann et al. 2012d). Galaxies significantly detected by the LAT are indicated with *filled symbols*, whereas galaxies with  $\gamma$ -ray flux upper limits (95 % confidence level) are marked with *open symbols*. Galaxies hosting *Swift-BAT* AGN are shown with *square markers*. IR luminosity uncertainties for the non-detected galaxies are omitted for clarity, but are typically  $\sim 0.06$  dex. The *upper abscissa* indicates SFR estimated from the IR luminosity



# Galaxias Seyfert en 4FGL-DR3

Objeto	Tipo	Galaxia	sig
4FGL J0948.9+0022	NLSY1	PMN J0948+0022	62.92
4FGL J0850.0+5108	NLSY1	SBS 0846+513	53.64
4FGL J1505.0+0326	NLSY1	PKS 1502+036	34.24
4FGL J2007.9-4432	nlsy1	PKS 2004-447	31.68
4FGL J0324.8+3412	nlsy1	1H 0323+342	22.08
4FGL J1644.9+2620	NLSY1	MG2 J164443+2618	13.52
4FGL J1443.1+4728	nlsy1	B3 1441+476	11.00
4FGL J1413.1-6519	sey	Circinus galaxy	9.52
4FGL J1305.3+5118	nlsy1	IERS B1303+515	5.03
4FGL J2118.8-0723c	sey	TXS 2116-077	4.61
4FGL J0112.5-0651	sey-lc	WISEA J011252.37-064057.1	4.49
4FGL J0153.3-1845	sey-lc	WISEA J015316.45-184328.2	4.35
4FGL J0859.8+0053	sey-lc	WISEA J085956.49+005244.1	2.61
4FGL J1015.1-6353	sey-lc	WISEA J101433.06-635155.0	8.30
4FGL J1603.6-0451	sey-lc	WISEA J160325.44-044907.7	6.56
4FGL J1737.1-2901	sey-lc	WISEA J173737.21-290825.4	5.63
4FGL J1821.6+6636	sey-lc	WISEA J182223.43+663751.2	9.25
4FGL J2210.4-0930	sey-lc	WISEA J221031.71-093158.5	4.65



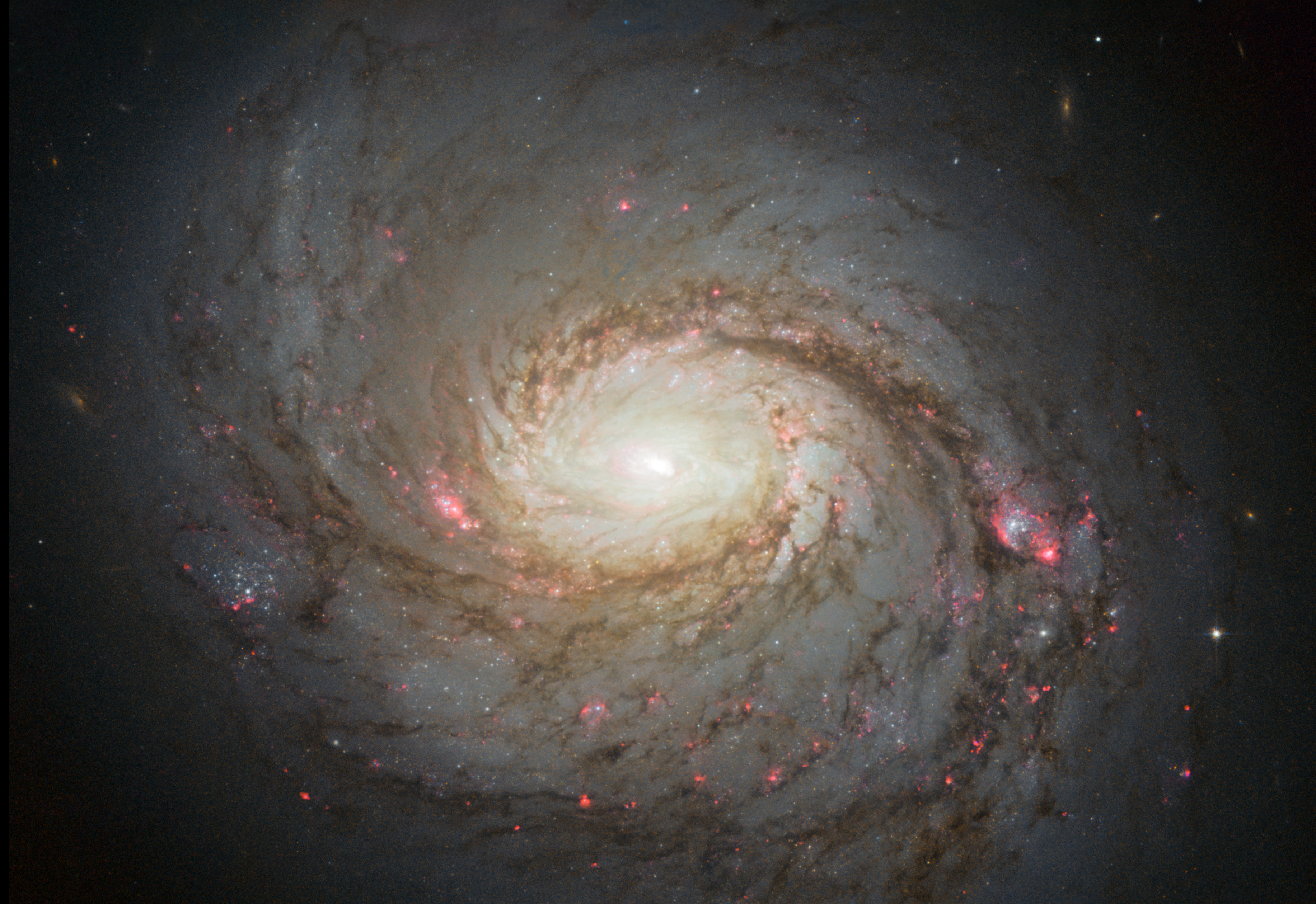
19 Left test statistic (significance) map for the  $\gamma$ -ray excess centered on the Circinus galaxy. The cyan ellipse and black circle indicate the *Fermi* positional uncertainty at 68 and 95 % level of confidence, respectively. The black square marks the position of the Circinus galaxy core, while the cyan ellipse corresponds to the positional uncertainty region of the nearby *Fermi* source 2FGL J1415.7-6520. The black square corresponds to the position of the galaxy core. The right panel, which shows the Australia Telescope Compact Array (ATCA) 1.4 GHz radio contours superposed with the 2MASS H-band color image (Jarrett et al. 2003) (outtie et al. 1998).

Circinus LAT  
Hayashida et al. (2013)

Ninguna detectada en TeV.

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NGC 1068 (M 77) [apod.nasa.gov](http://apod.nasa.gov)

De la muestra de seis galaxias espirales de Seyfert (1943)

# NOTA PRELIMINAR SOBRE GALAXIAS AZULES CON LINEAS DE EMISION \*

*Guillermo Haro*

Mediante el uso de la técnica fotográfica desarrollada en el Observatorio de Tonantzintla para el estudio de estrellas de tipo T Tauri con fuerte radiación ultravioleta,<sup>1</sup> hemos investigado algunas regiones lejanas al ecuador galáctico —particularmente cerca de los polos galácticos— con el fin de descubrir nuevas estrellas enanas blancas u objetos muy azules o ultravioletas semejantes a los descubiertos por Humason y Zwicky<sup>2</sup> en la región del polo norte galáctico. Tres exposiciones, ligeramente desplazadas la una de la otra, fueron sucesivamente hechas en cada placa (Eastman 103aD), bajo filtros que aislan regiones espectrales en el amarillo, el azul y el ultravioleta, respectivamente. La duración de las tres exposiciones se escogió de tal modo que una estrella no enrojecida y de tipo espectral A0, produjera imágenes aproximadamente de la misma densidad a través de cada uno de los filtros empleados. En la práctica, y tomando como referencia las estrellas A0-A5 contenidas en las áreas cubiertas, se encontró que en la mayoría de nuestras placas una estrella normal de tipo espectral A mostraba, sistemáticamente, la imagen amarilla con una densidad aproximadamente igual a la imagen azul, siendo las imágenes azul y amarilla ligeramente más brillantes que la imagen ultravioleta.

El mismo material fotográfico obtenido para el descubrimiento de estrellas azules, (los resultados preliminares a este respecto se publicarán por separado en un futuro próximo) sirvió para la identificación de un buen número de galaxias que muestran intensa radiación ultravioleta. En algunas de estas galaxias la relación de densidades en sus tres imágenes es comparable a la relación de densidades en las tres imágenes de estrellas de extremo color violeta, tales como ciertas enanas blancas o el núcleo de nebulosas planetarias.



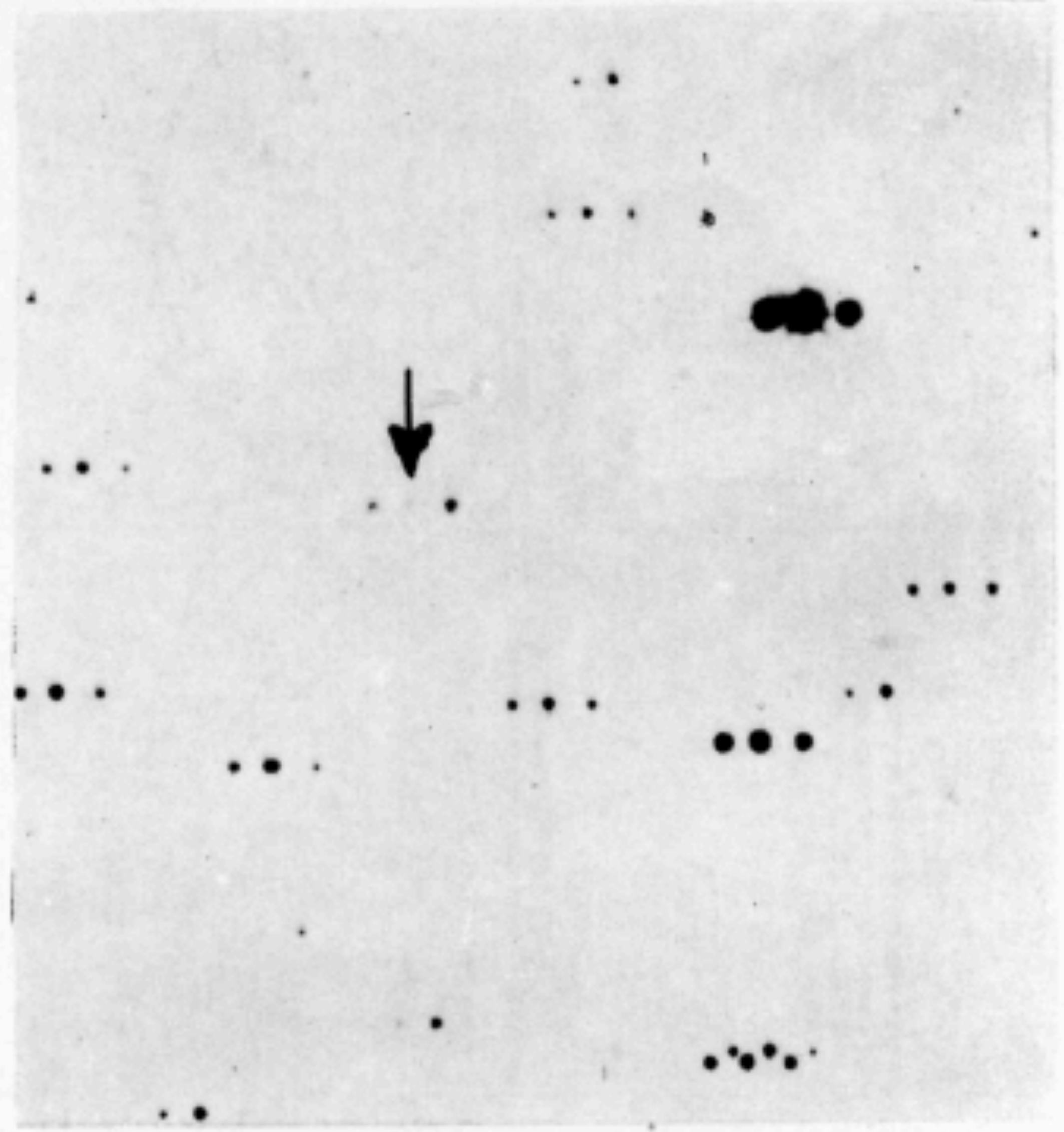
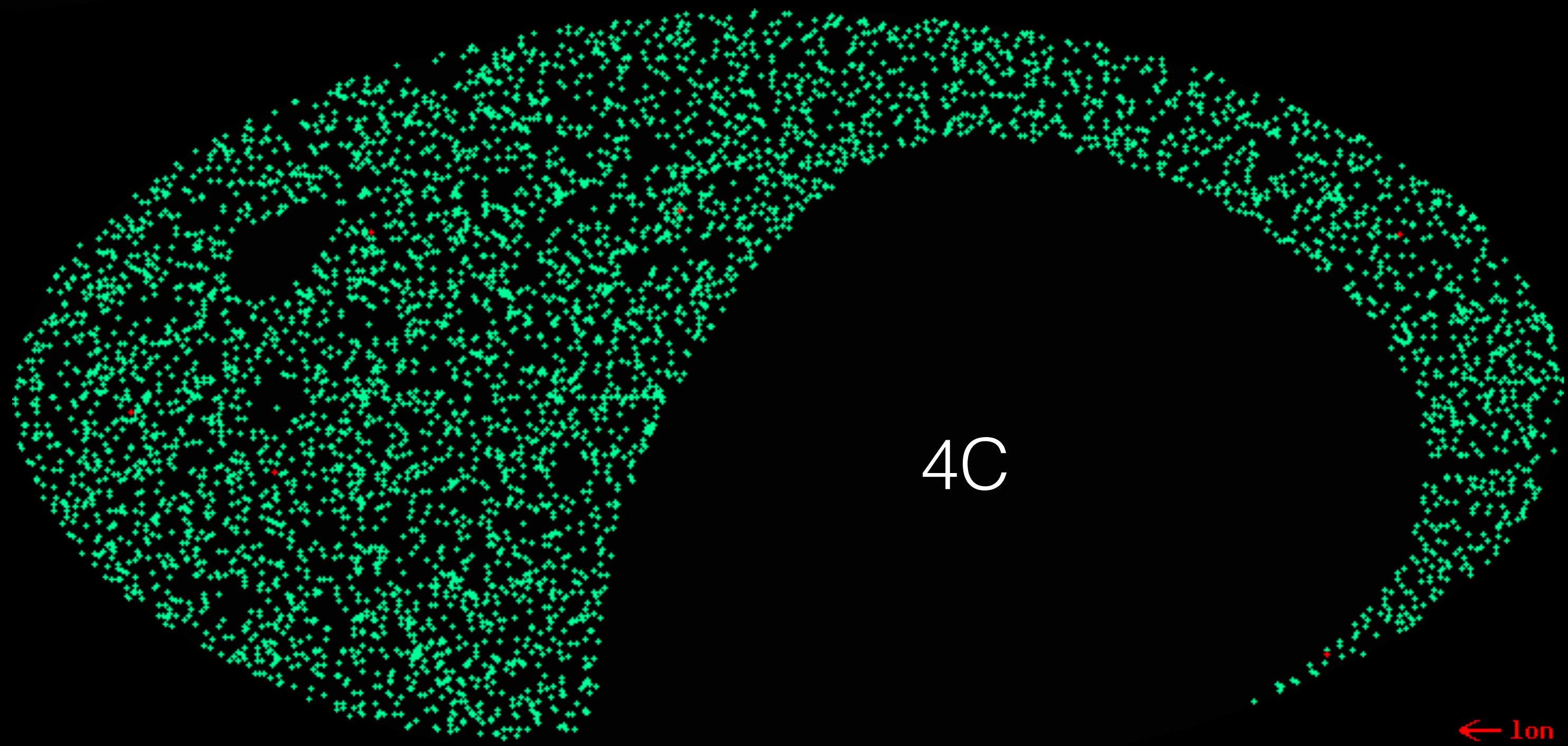
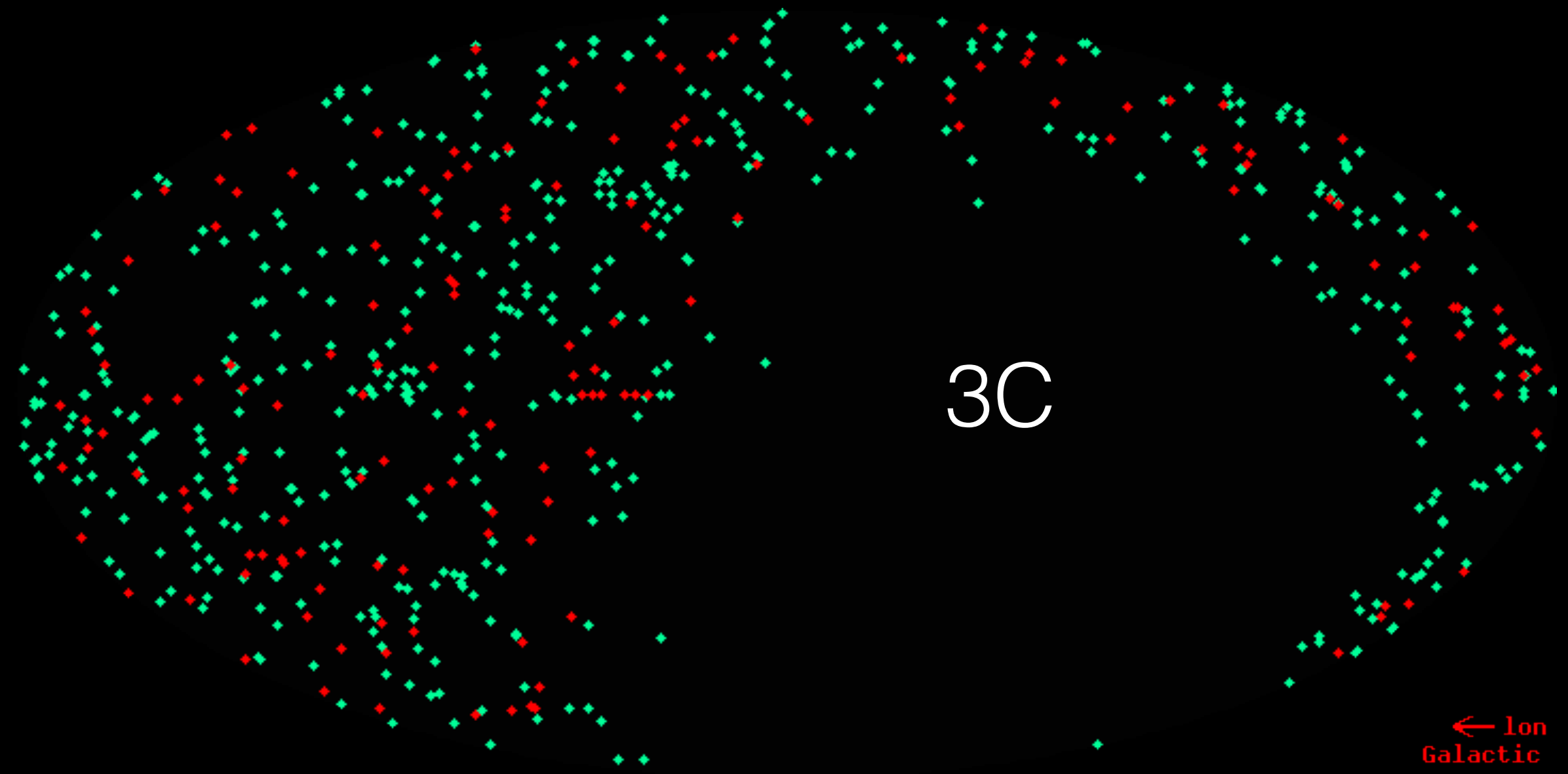


Figura 1. En estas fotografías en tres colores las galaxias señaladas con los números 1, 2, 3, son NGC 3991, 3994 y 3995, respectivamente. Cada una aparece (de derecha a izquierda) en luz ultravioleta, amarilla y azul. A la derecha del grabado se indican con una flecha las tres imágenes de la galaxia N° 4 de la Tabla 1.

**Cambridge MRAO - 4C array  
(wikipedia)**





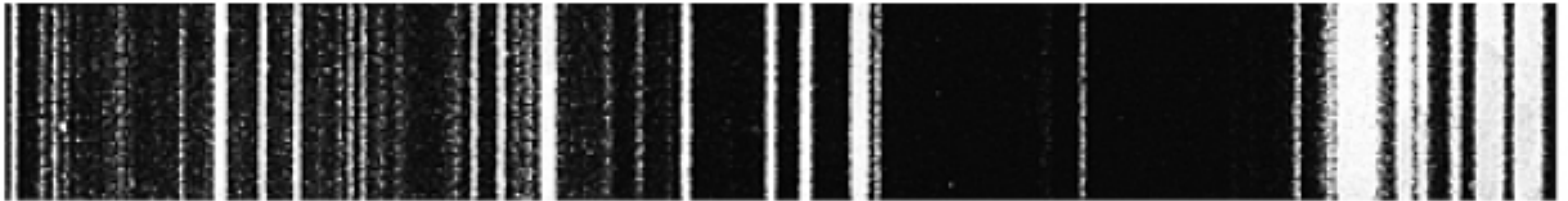
*3C 273*

3C 273

H $\delta$  H $\gamma$  H $\beta$



comparison spectrum



388.9 nm

H $\delta$

H $\gamma$

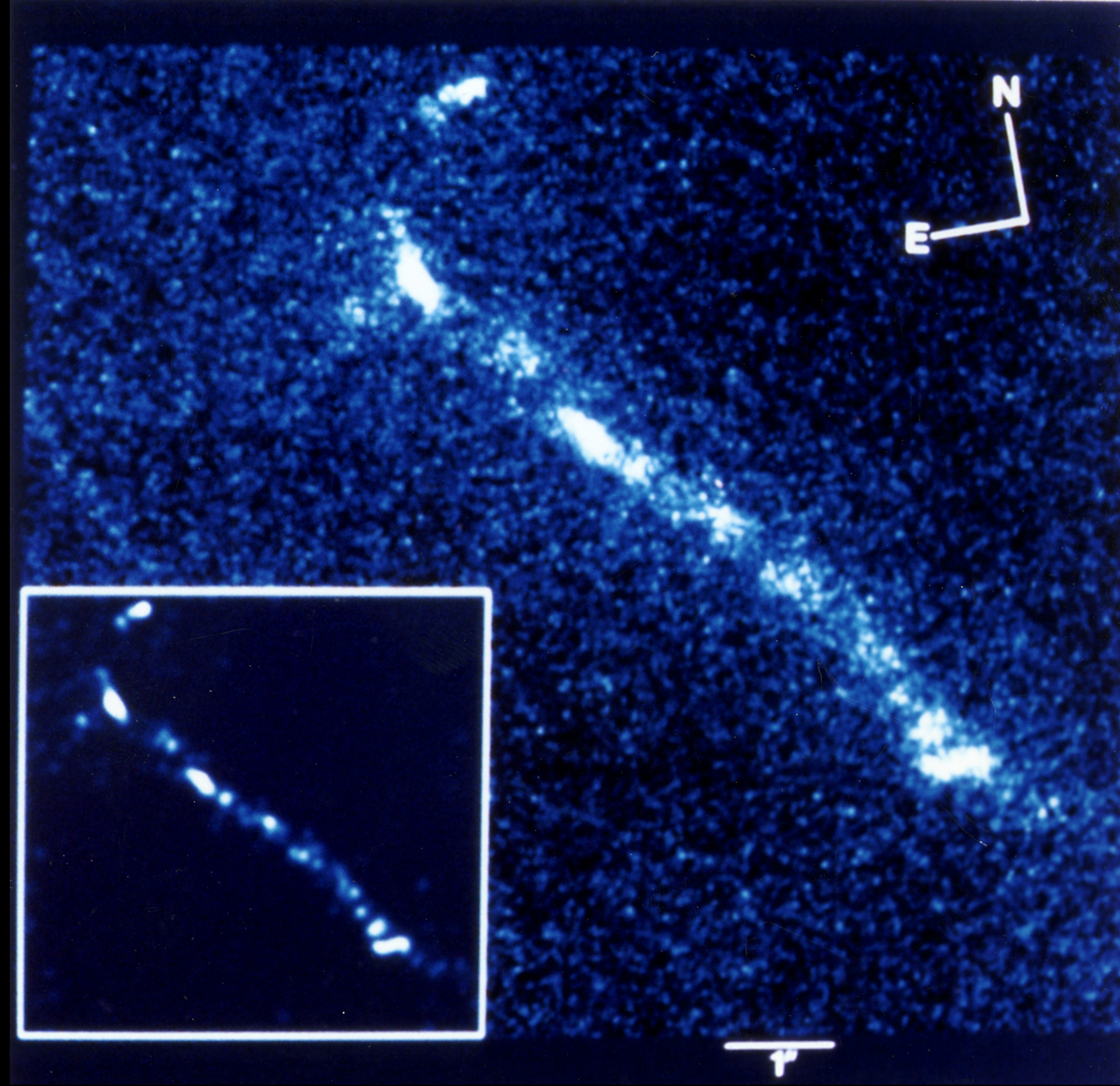
H $\beta$

501.6 nm

Schmidt & Oke (1963)  
 $z = 0.158$

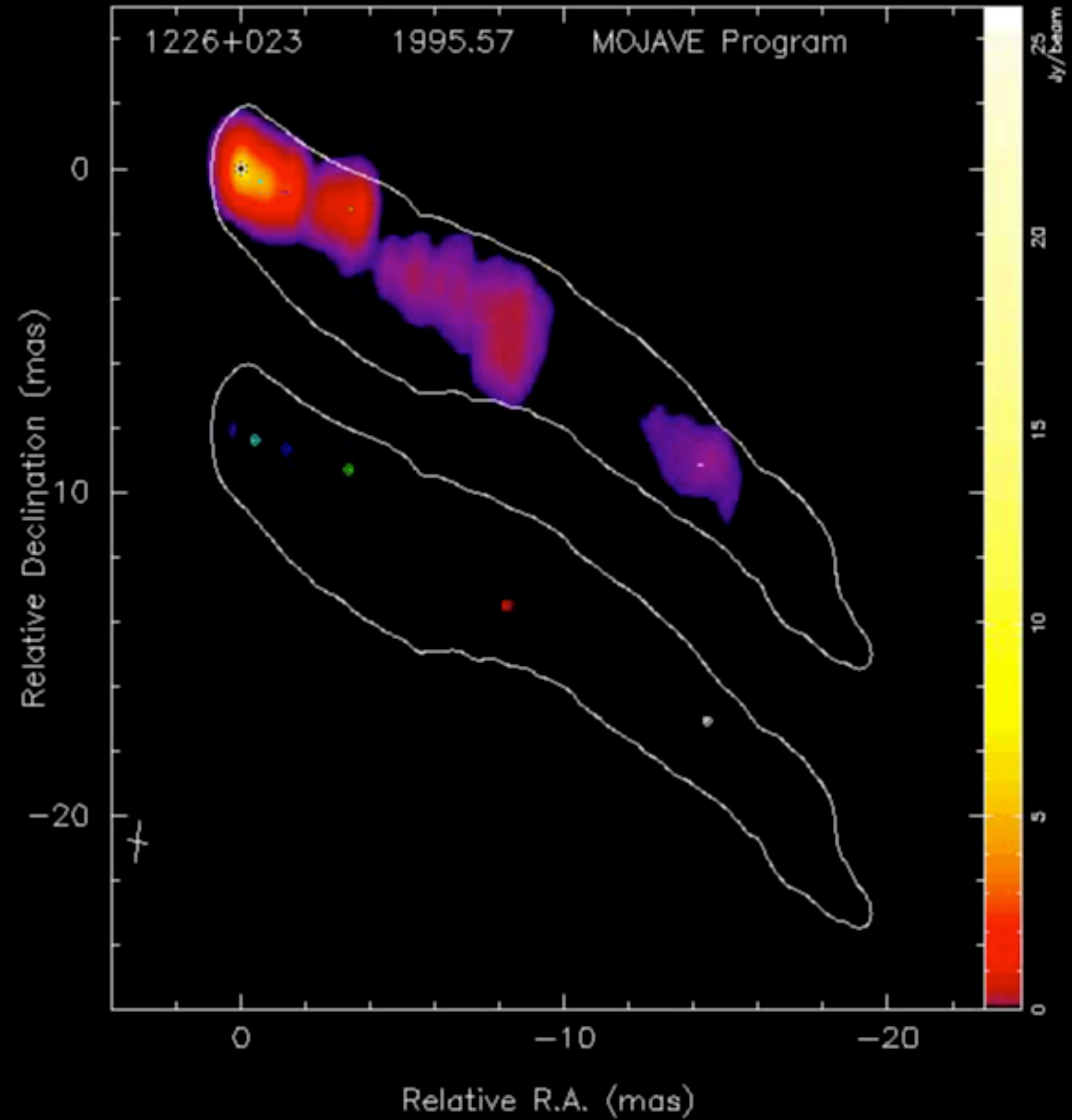


603.0 nm



HST snaps optical jet of quasar 3c 273

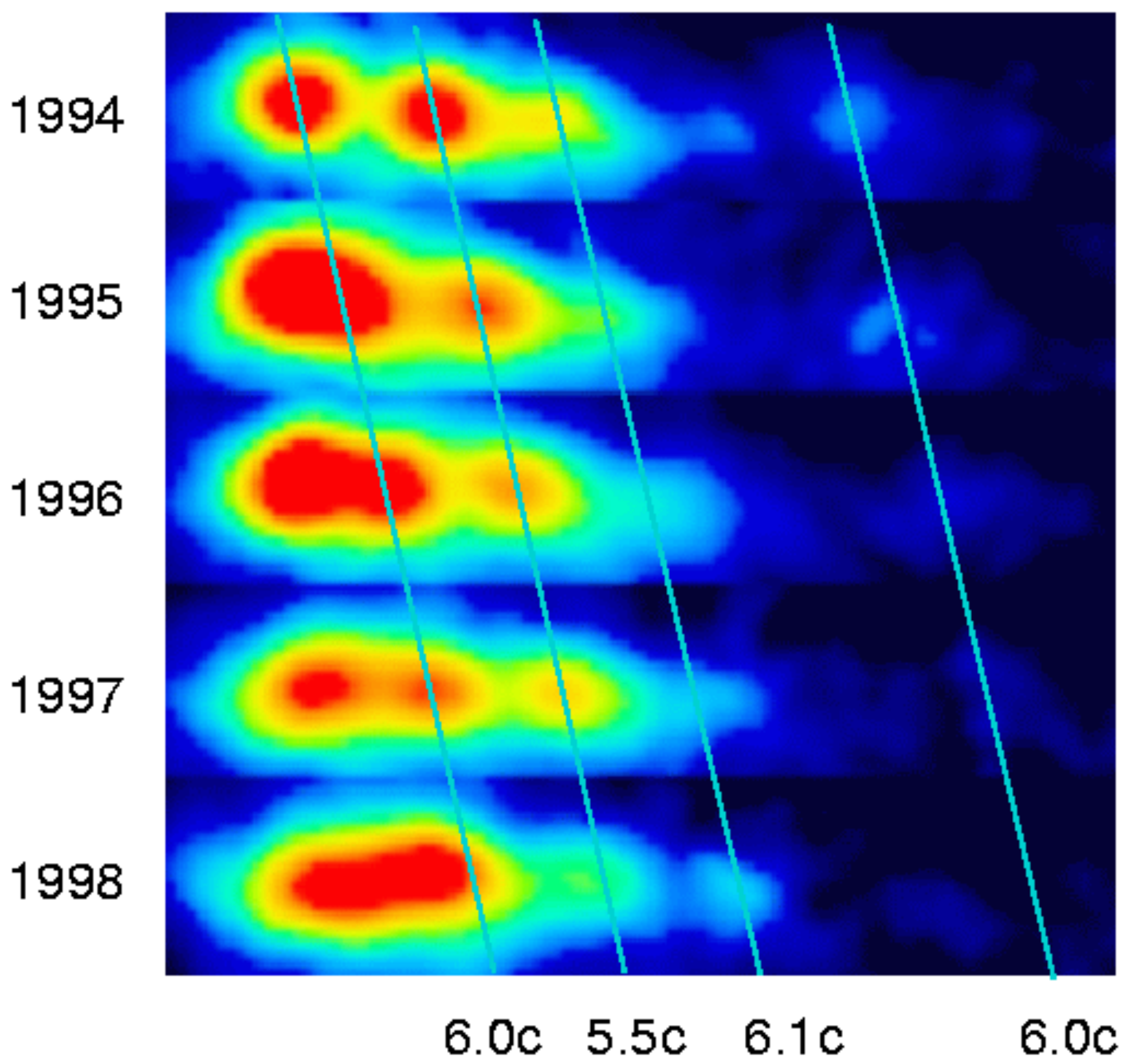
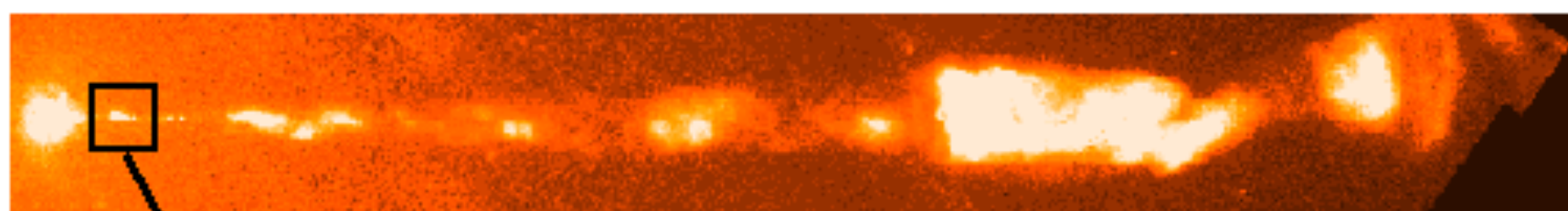
R.C. Thomson, IoA, Cambridge, UK;C.D. Mackay, IoA, Cambridge, UK;A.E. Wright, ATNF, Parkes, Australia



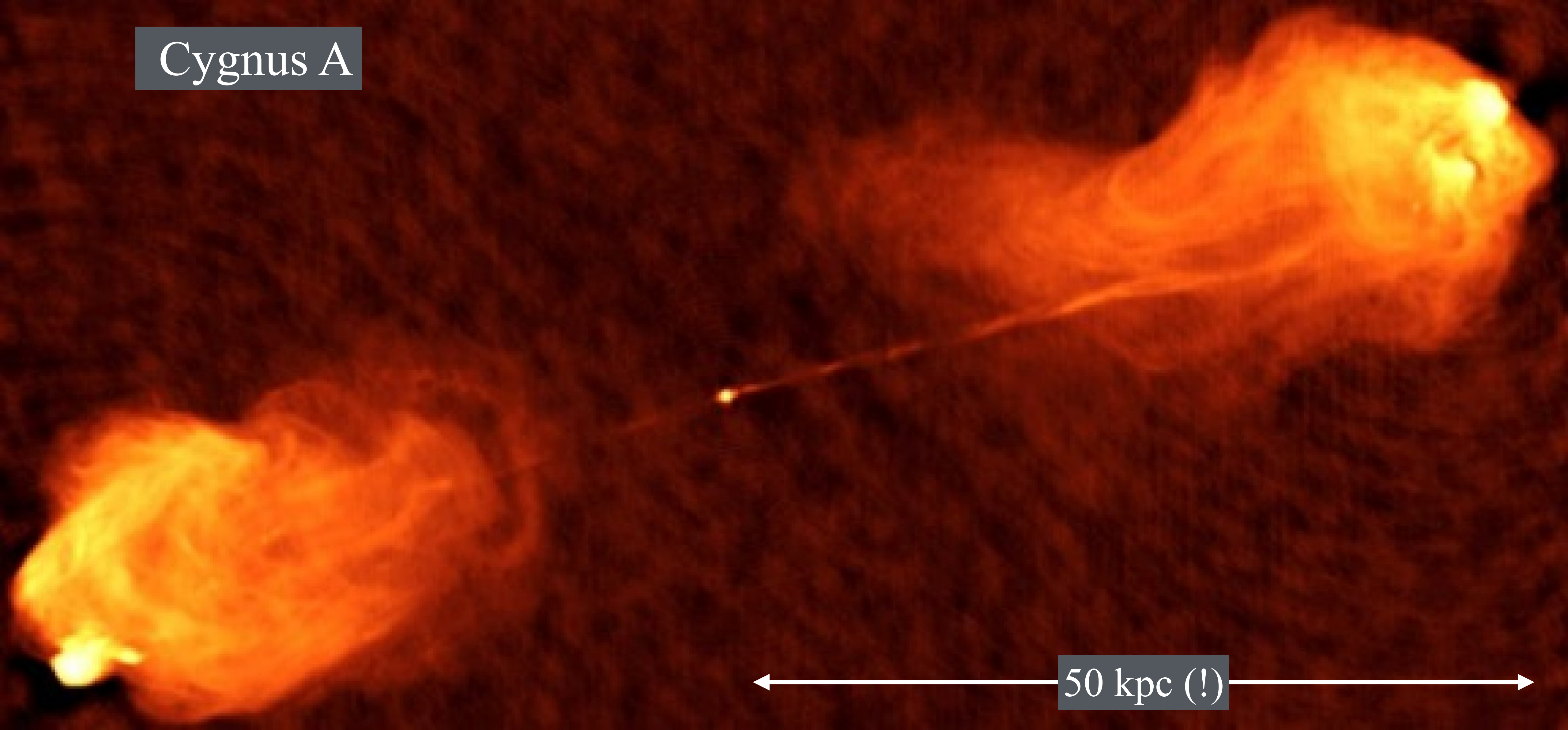
# M87 por HST



## Superluminal Motion in the M87 Jet



# Cygnus A



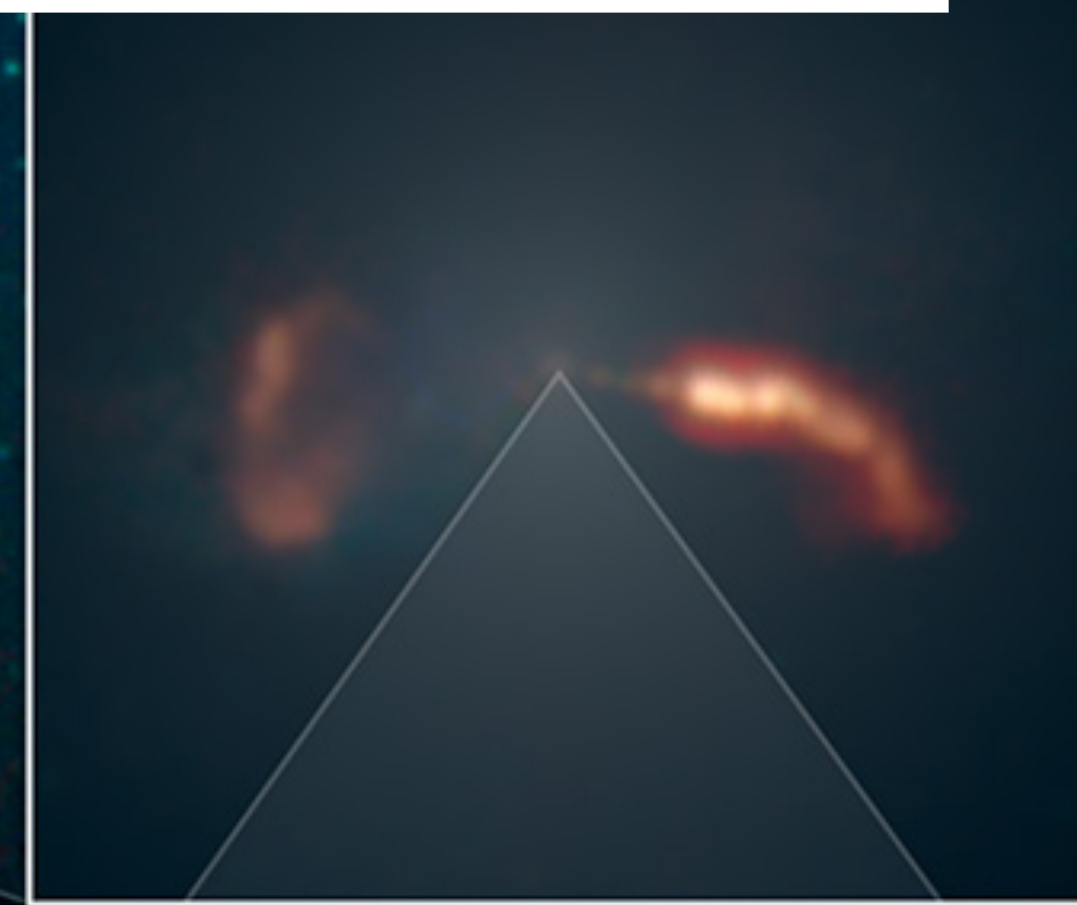
50 kpc (!)

# Cuasares y galaxias activas

- **Cuasares:** descubiertos como objetos de apariencia estelar con intensa emisión en radio.
- **QSOs (Quasi-Stellar Objects):** objetos extragalácticos con propiedades similares a los cuasares, con o sin emisión en radio.
- **Galaxias Seyfert:** galaxias identificadas por Seyfert (1943) por tener un núcleo muy brillante y exceso de emisión azul (Haro 1956, Markarian 1967).
- **Radio galaxias:** galaxias con intensa emisión de radio; mayormente elípticas.
- **Objetos BL Lac:** fuentes de radio cuasi-estelares, sin líneas en el óptico; algunos identificados como núcleos de galaxias elípticas. Muestran emisión de rayos X.

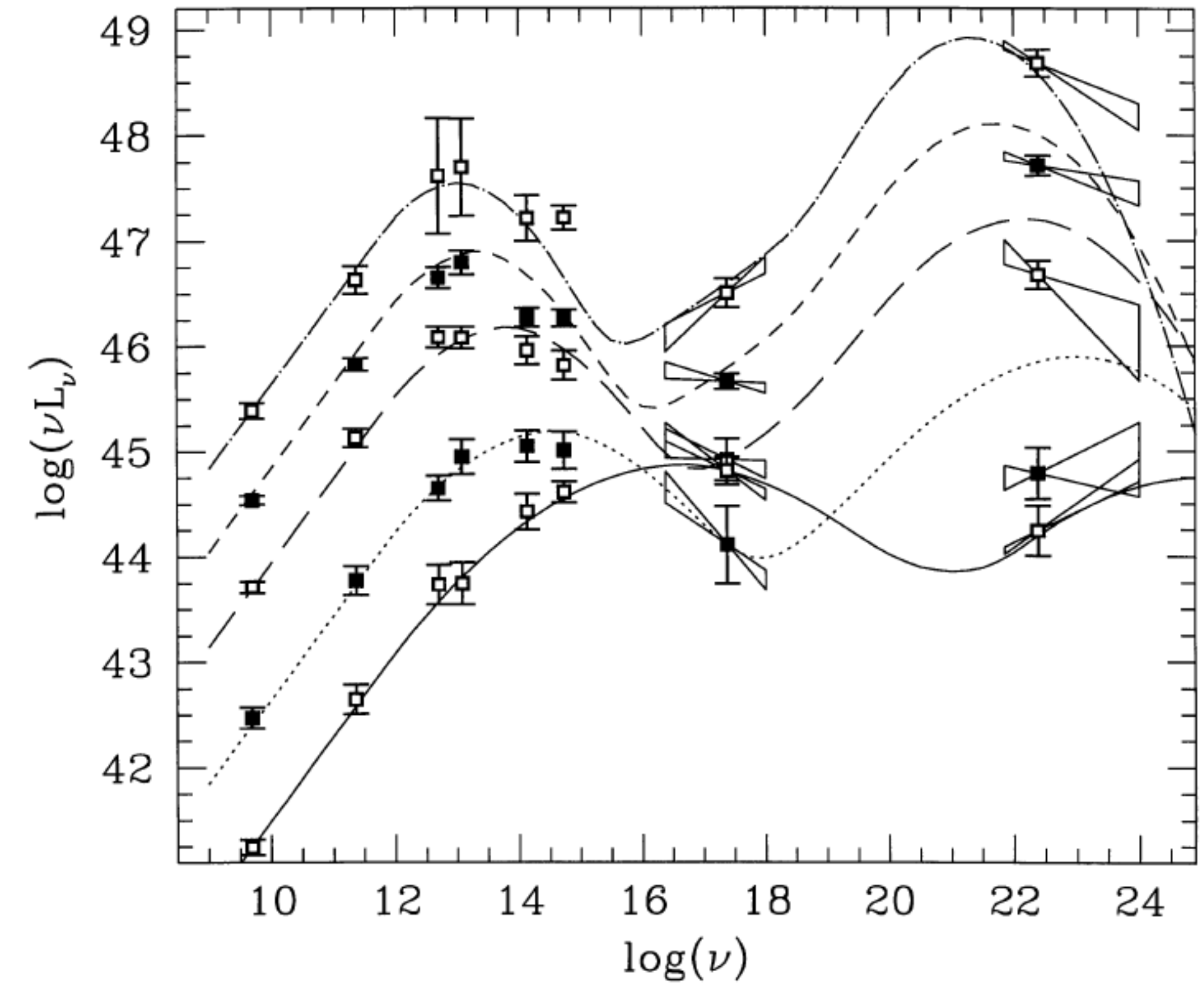
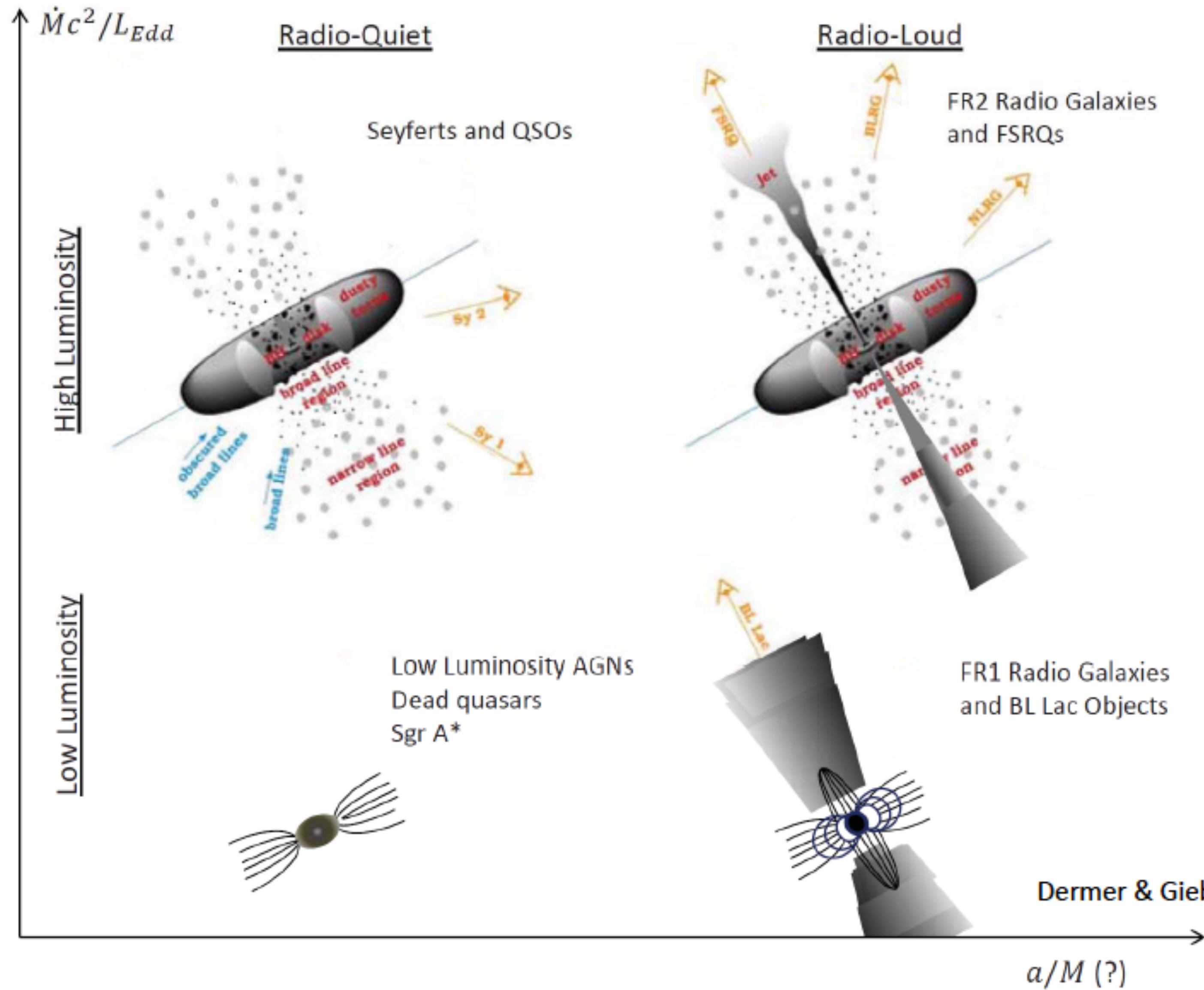
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$$M87 - M_{bh} = 6.5 \times 10^9 M_{\odot}$$

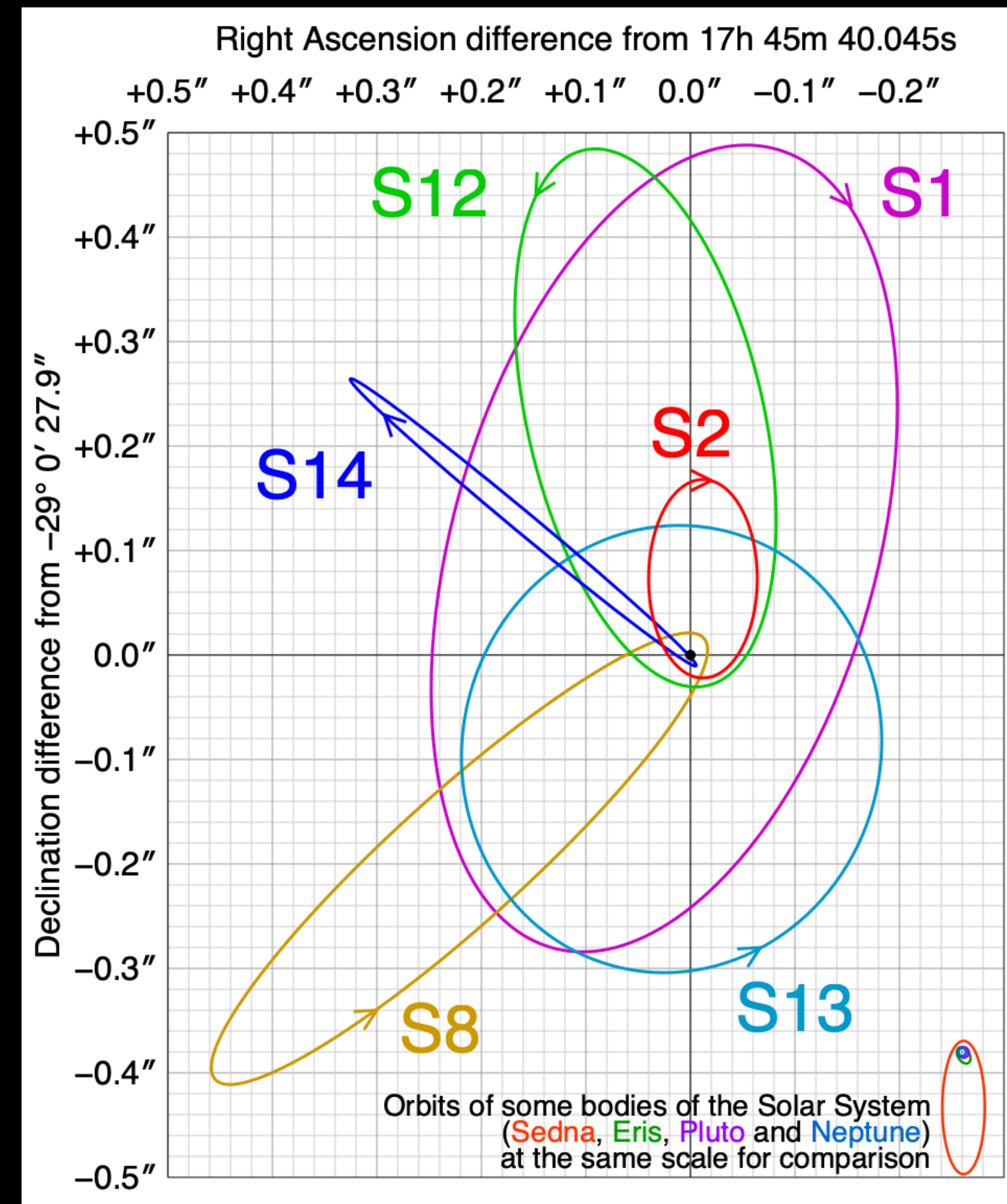
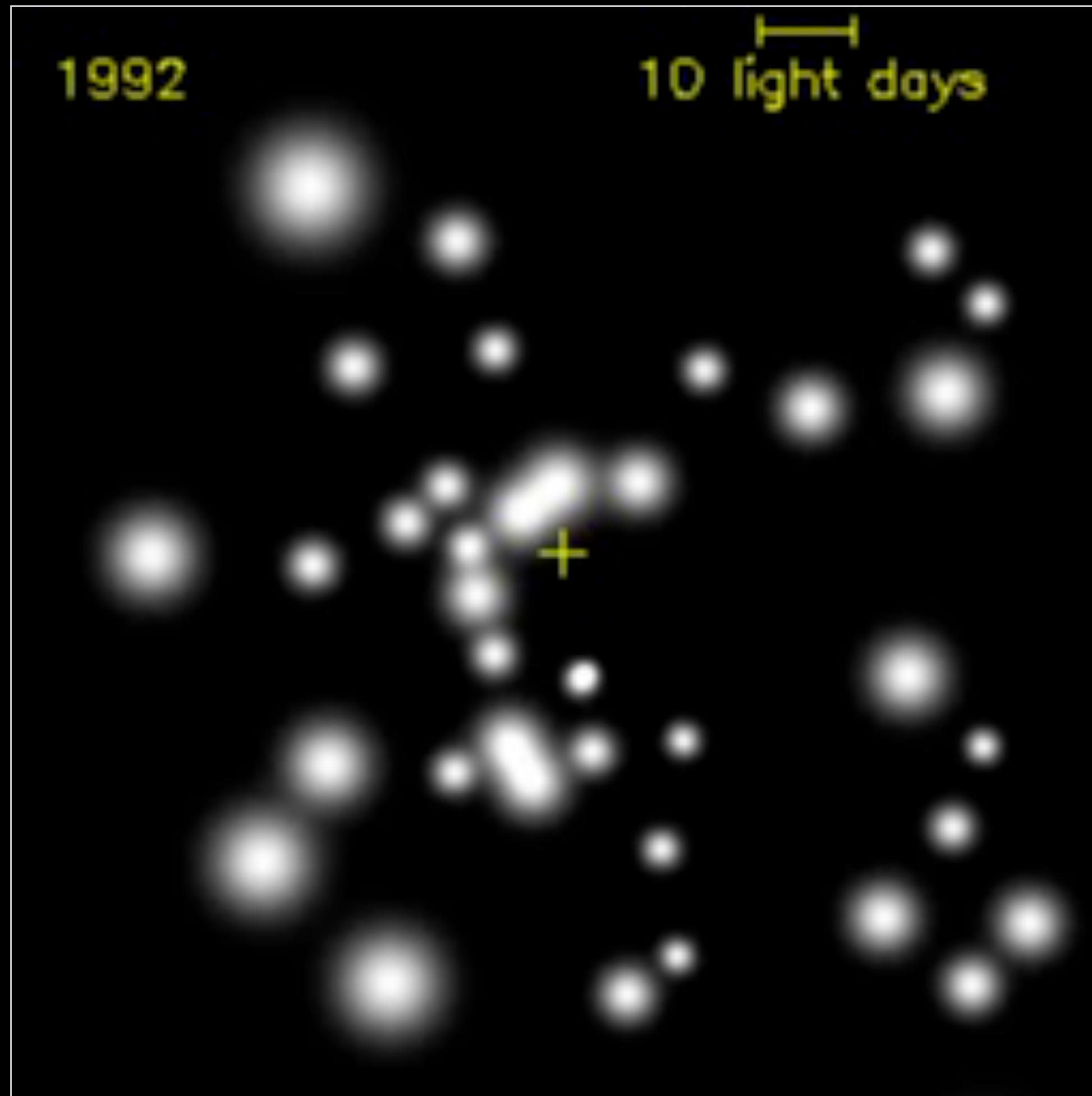
# Classes of AGN and Unification



**Figure 12.** Average SEDs for the ‘total blazar sample’ binned according to radio luminosity irrespective of the original classification. The overlaid curves are analytic approximations obtained according to the one-parameter-family definition described in the text.

Fossati et al. (1998)

# Hoyo negro Galáctico



# ¿La naturaleza de los AGNs?

Pista: emisión sincrotrón en radio  $\Rightarrow$  electrones relativistas en campos magnéticos (Shlovsky 1952)

¿Colisiones de nubes de gas durante colisiones entre galaxias?

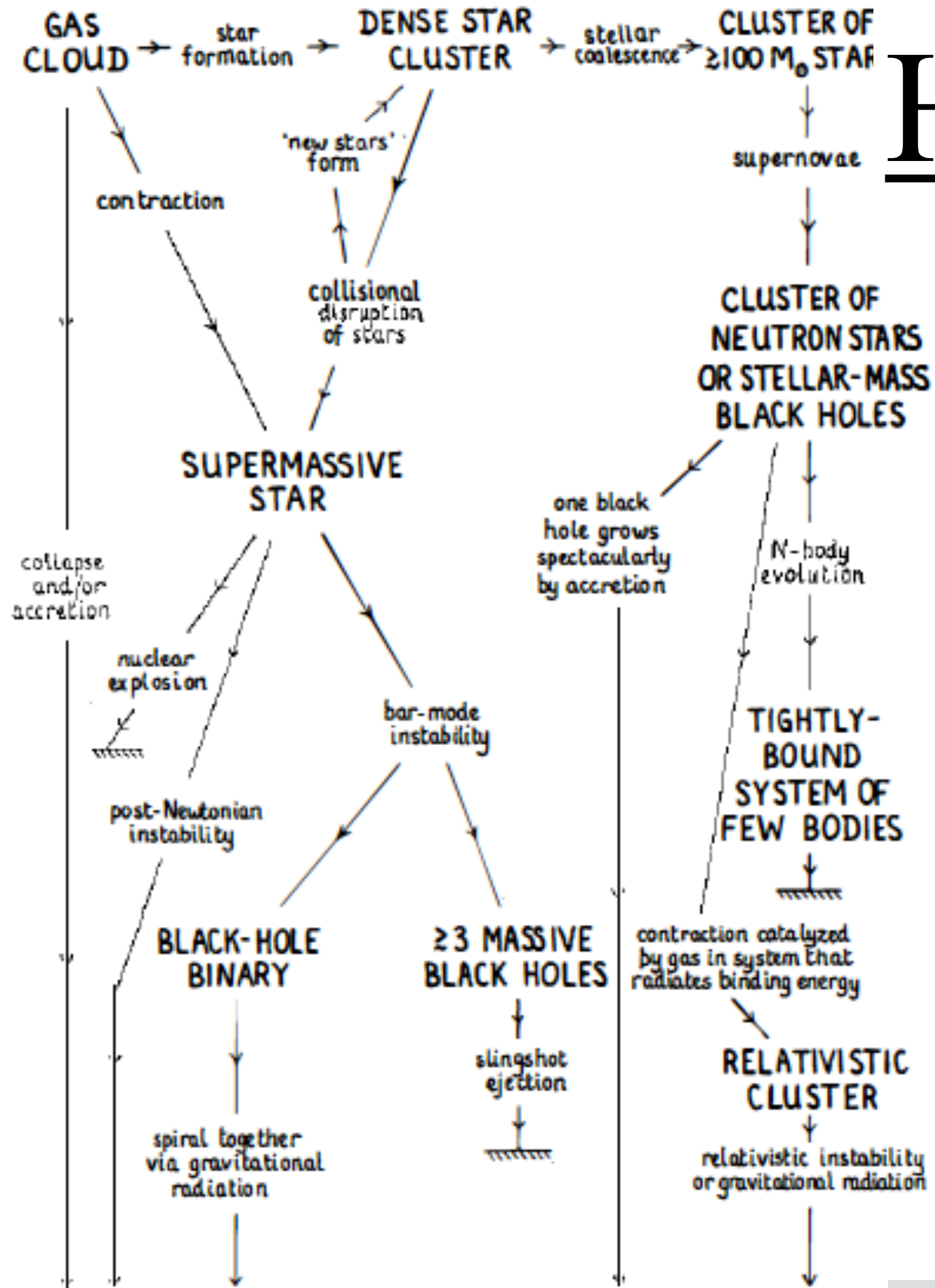
¿Supernovas en cadena (Burbidge 1970s)?

¿Brotos de formación estelar - Starbursts (Terlevich & Melnick 1985)?

¿Aniquilación de materia y antimateria?

¿Explosiones en objetos “estelares” supermasivos (Hoyle & Fowler 1962)?

¿Acreción en objetos supermasivos (Hoyle & Fowler 1963, Salpeter 1964)?



# Hoyos negros supermasivos

- Fuente de energía ✓
- Variabilidad ✓
- Jets ✓
- Emisión de radio, rayos X, rayos  $\gamma$  ✓
- ¿Formación de un SMBH?

Rees (1984)

## massive black hole

Figure 1 Schematic diagram [reproduced from Rees (106)] showing possible routes for runaway evolution in active galactic nuclei.

## Acreci3n en hoyos negros

- ▶ Para un hoyo negro (un review cl3sico es Rees (1984)),

$$r_s = 2GM/c^2 \Rightarrow \begin{cases} L = \eta \dot{M} c^2, & \eta = 1/2, \\ r_s/c = 10^4 s (M/10^9 M_\odot). \end{cases}$$

- ▶ Un l3mite te3rico a la acreci3n es la luminosidad de Eddington; en simetr3a esf3rica,

$$L_E = \frac{4\pi GMm_p c}{\sigma_T} \simeq 1.3 \times 10^{47} \text{ erg/s } M_9.$$

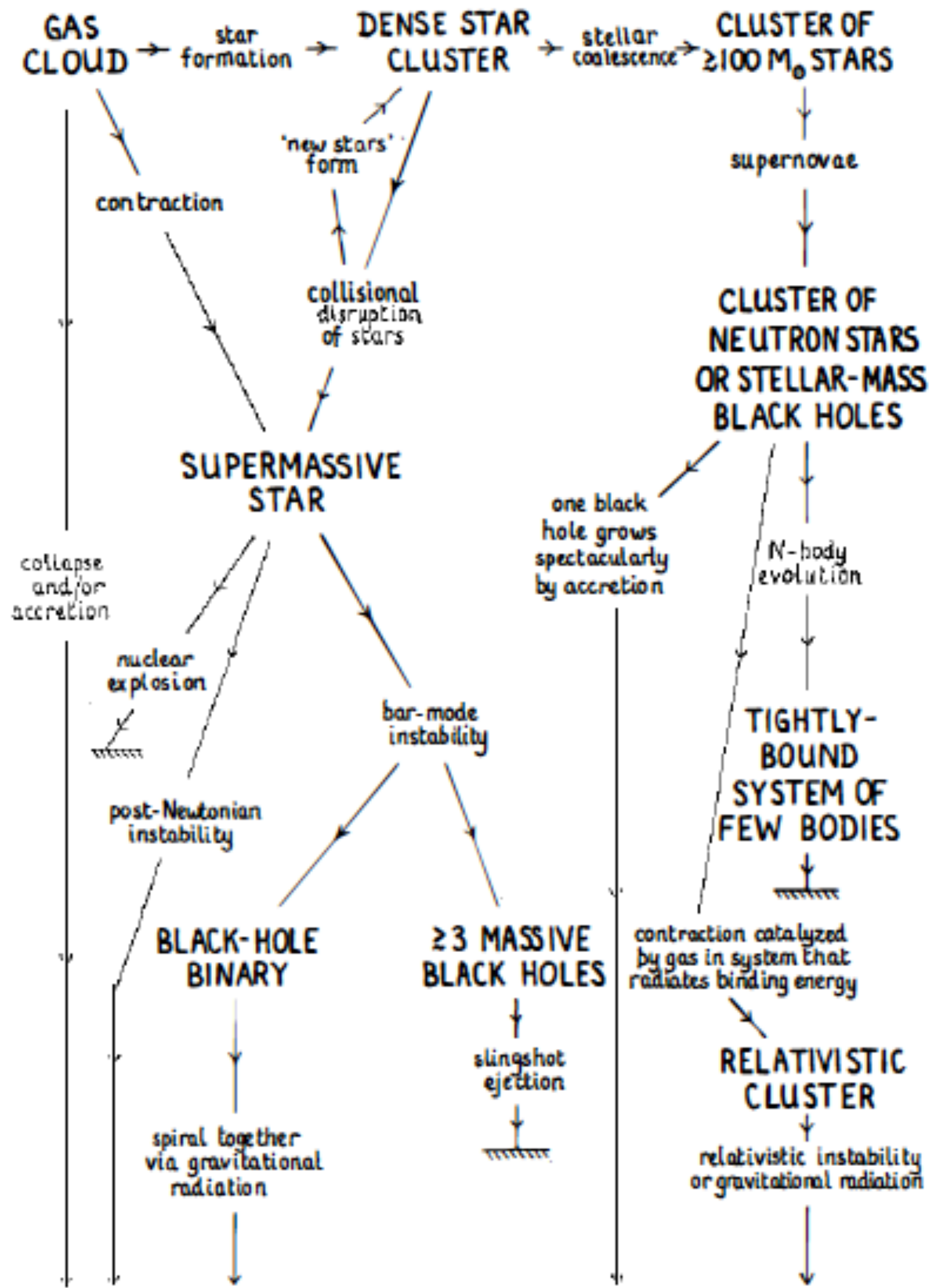
- ▶ Tasa de acreci3n cr3tica, para un hoyo negro ( $R = 2GM/c^2$ ),

$$\dot{M}_c = 4.4 M_\odot/\text{yr } M_9,$$

- ▶ y el tiempo caracter3stico,

$$t_E = Mc^2/L_E = \frac{\sigma_T c}{4\pi Gm_p} \simeq 4 \times 10^8 \text{ yr.}$$

La presencia de momento angular da lugar a discos de acreci3n.



# massive black hole

Figure 1 Schematic diagram [reproduced from Rees (106)] showing possible routes for runaway evolution in active galactic nuclei.

## exponential growth of black holes

quasar lifetime  $t_Q$       mass of initial black hole seed  $M_{seed}$

$$M_{BH}(t_Q) = M_{seed} \cdot \exp\left(\frac{t_Q}{t_S}\right)$$

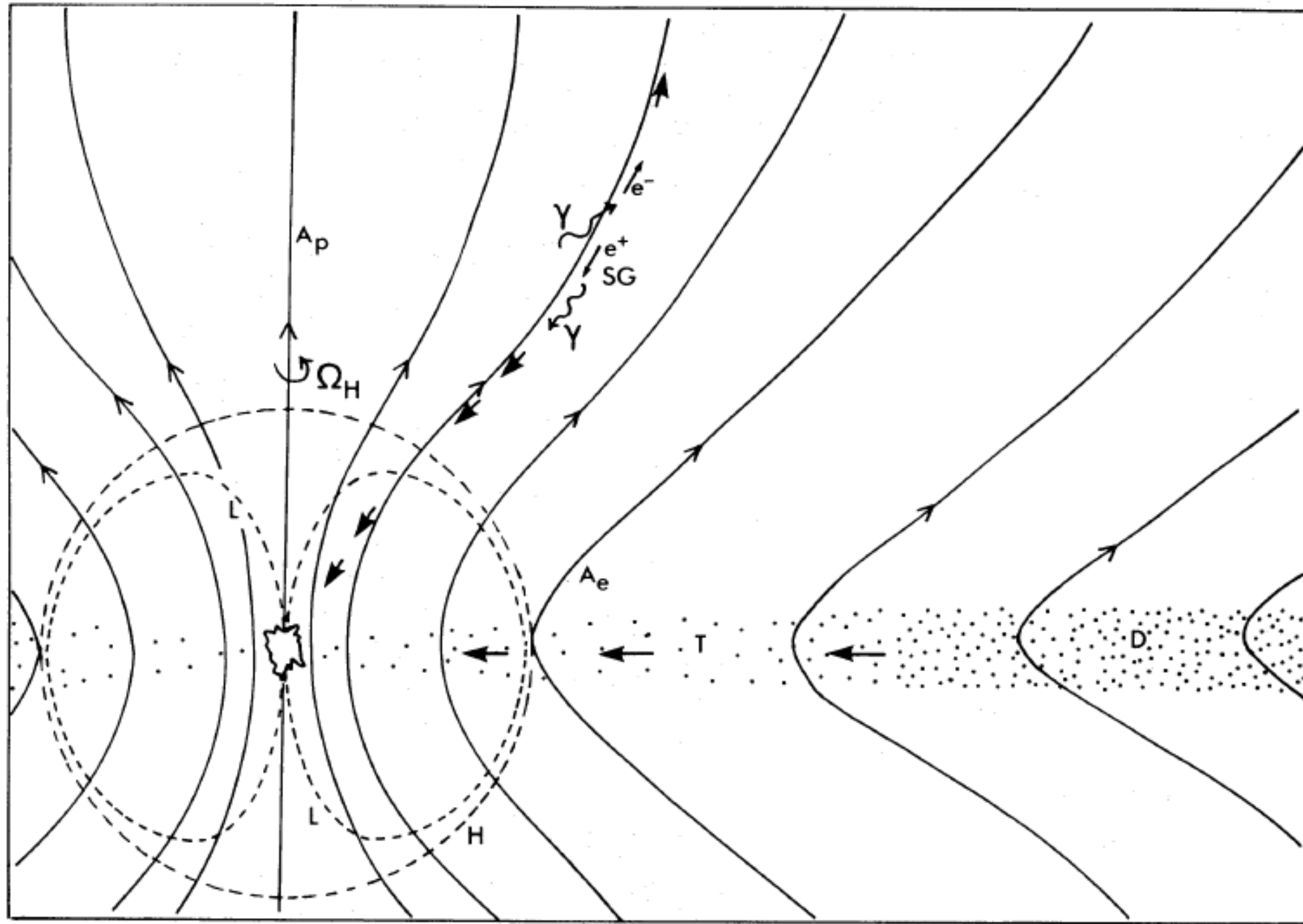
Salpeter "e-folding" time:

$$t_S = 4.5 \times 10^7 \left(\frac{\epsilon}{0.1}\right) \left(\frac{L}{L_{Edd}}\right) \text{ yr}$$

bolometric luminosity  $L$

radiative efficiency of the accretion  $\epsilon$

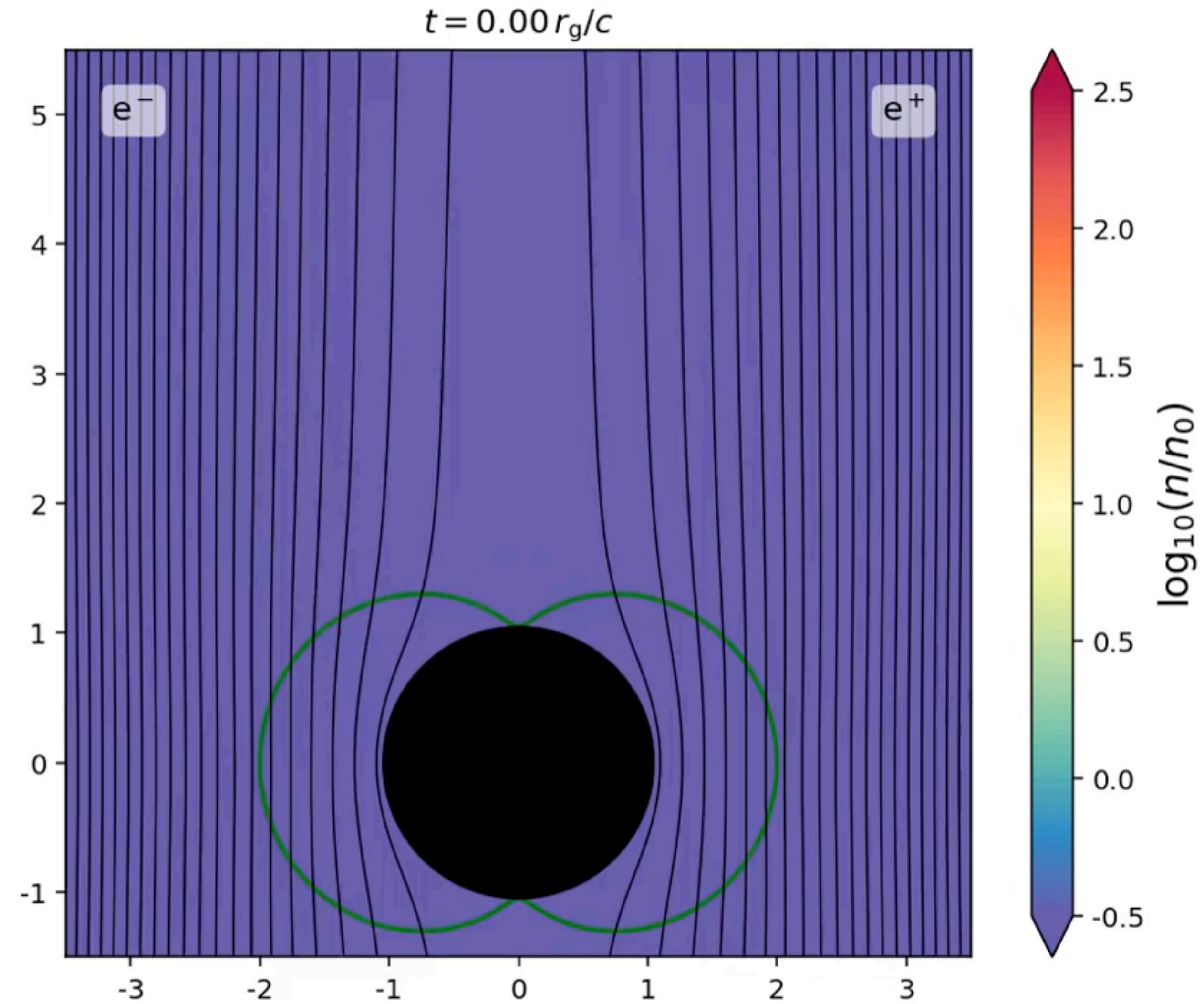
Re-Iniciar Audio    Iniciar Video    Participantes 171    Chatear    Compartir pantalla    Grabar    Reacciones    Salir



**Figure 1.** Schematic cross-section of black hole and magnetosphere, using  $r$  and  $\theta$  coordinates in normal way. (Due to axial and time symmetry the diagram is independent of the azimuthal and time coordinates that are being held constant; these can be the Kerr coordinates  $v$  and  $\bar{\phi}$ , or for  $r > r_+$  the Boyer–Lindquist coordinates  $t$  and  $\phi$ .) The poloidal field has been chosen so that  $\Omega_H \cdot \mathbf{B} > 0$ . H is the event horizon  $r = r_+$ . The poloidal field surfaces (i.e. surfaces of constant  $A_\phi$ ) are shown as solid lines, with the polar and equatorial surfaces  $A_\phi = A_p$  and  $A_\phi = A_e$  specifically labelled. A current  $I$  is flowing from the magnetosphere into the hole and back out of it in the direction of the field lines.

Blandford & Znajek (1977)

Downloaded from https://academic.oup.com/mnras/article-abstract/179/1/433/1088888



# Fuentes extragalácticas

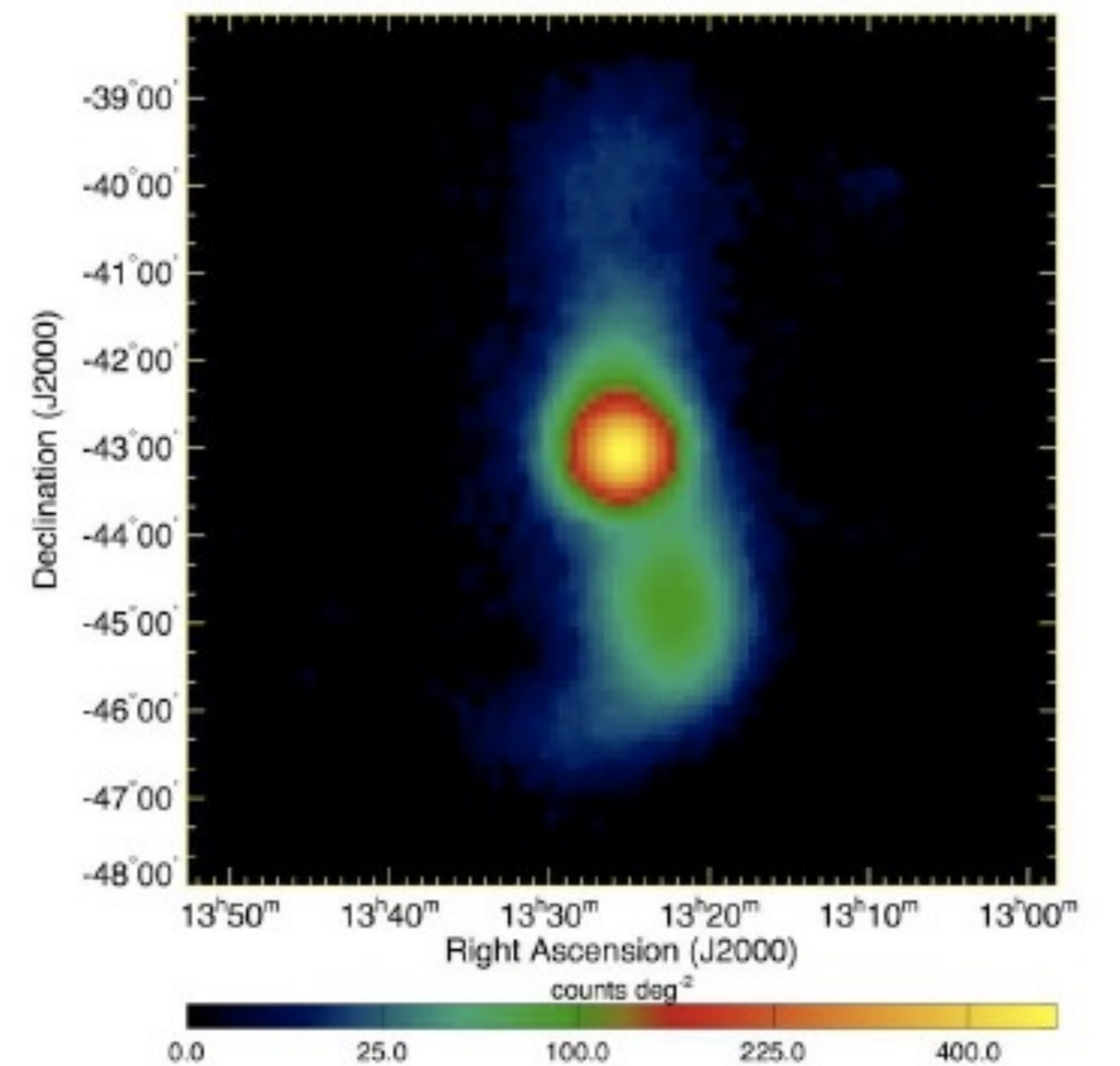
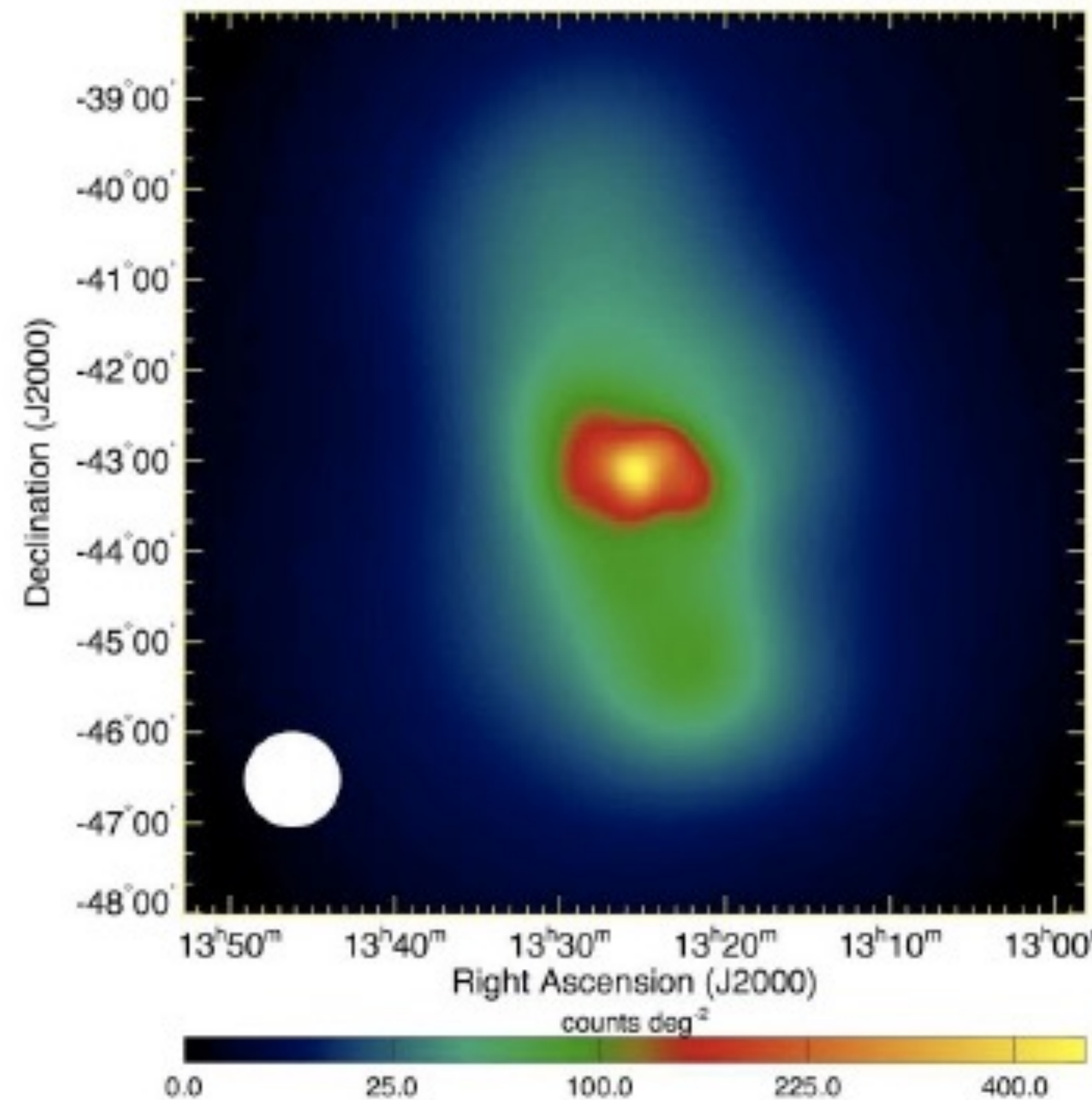
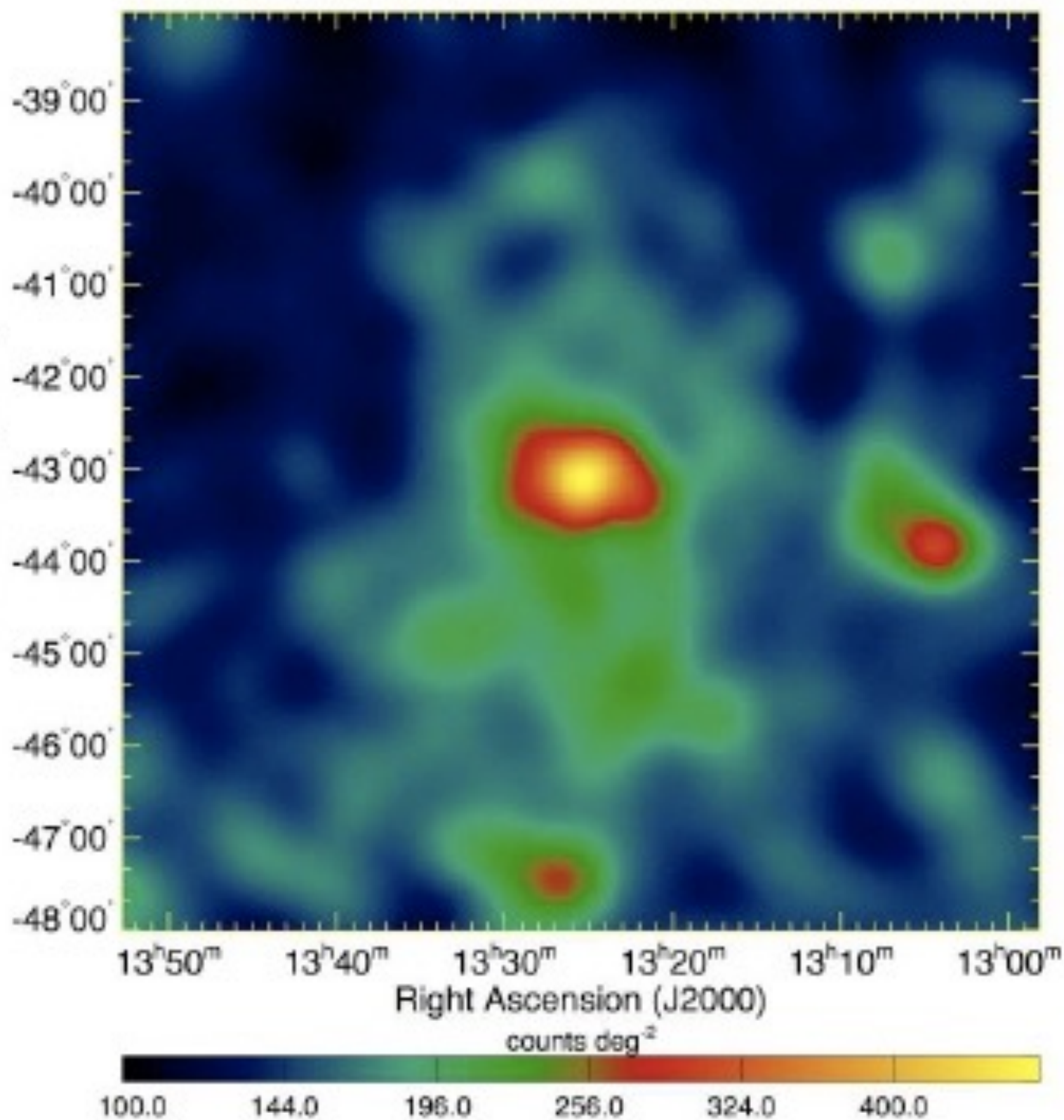
1. Tipos de fuentes
2. Galaxias normales y starburst
3. Núcleos activos de galaxias
4. Hoyos negros, acreción y jets
- 5. Radiogalaxias**
6. Blazares
7. Absorción de pares por luz extragaláctica
8. Destellos de rayos gamma

## Radiogalaxias en 4FGL-DR3

Objeto	Tipo	Galaxia	Sign	3FHL	TeV
4FGL J1325.5-4300	RDG	Cen A	73.54	Y	P
4FGL J1324.0-4330e	RDG	Cen A Lobes	35.11	?	?
4FGL J0319.8+4130	RDG	NGC 1275	45.49	Y	P
4FGL J1230.8+1223	rdg	M 87	43.41	Y	P
4FGL J0627.0-3529	rdg	PKS 0625-35	39.42	Y	P
4FGL J1144.9+1937	rdg	3C 264	13.33	Y	P
4FGL J0316.8+4120	RDG	IC 310	9.26	Y	P
4FGL J1630.6+8234	rdg	NGC 6251	41.47	Y	N
4FGL J0308.4+0407	rdg	NGC 1218	24.77	Y	N
4FGL J0433.0+0522	RDG	3C 120	24.60		N
4FGL J1346.3-6026	rdg	Cen B	23.59	Y	N
4FGL J0931.9+6737	rdg	NGC 2892	21.33	Y	N
4FGL J0322.6-3712e	RDG	Fornax A	18.40	Y	N
4FGL J1306.7-2148	rdg	PKS 1304-215	14.38		N
4FGL J0418.2+3807	rdg	3C 111	13.14		N
4FGL J2329.7-2118	rdg	PKS 2327-215	12.42		N
4FGL J1149.0+5924	rdg	NGC 3894	10.84		N
4FGL J0057.7+3023	rdg	NGC 315	10.70		N
4FGL J0519.6-4544	rdg	Pictor A	10.58		N
4FGL J0153.4+7114	rdg	TXS 0149+710	10.15	Y	N
4FGL J1516.5+0015	rdg	PKS 1514+00	9.91		N
4FGL J0334.3+3920	rdg	4C +39.12	9.90	Y	N
4FGL J0038.7-0204	rdg	3C 17	9.48		N

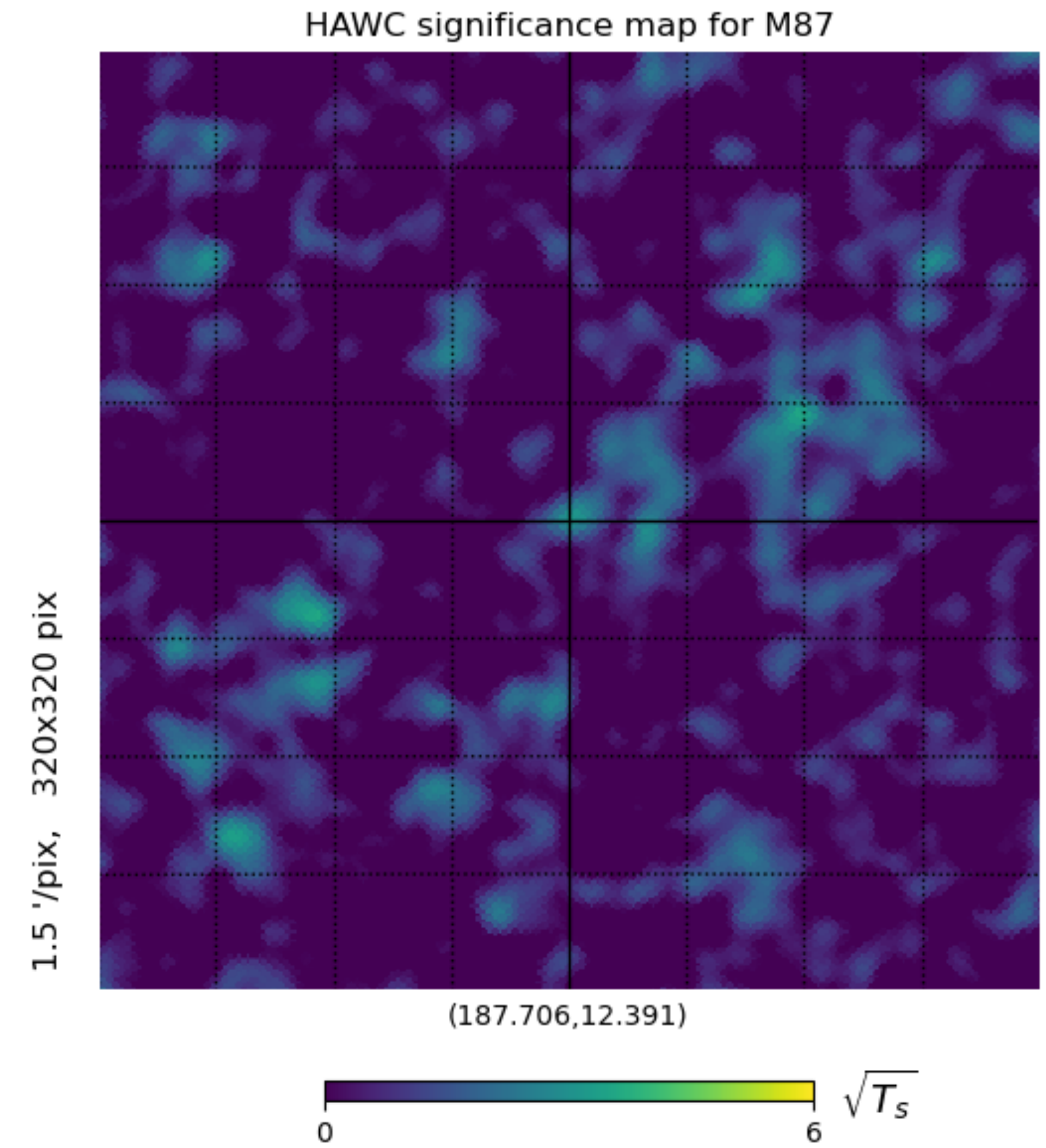
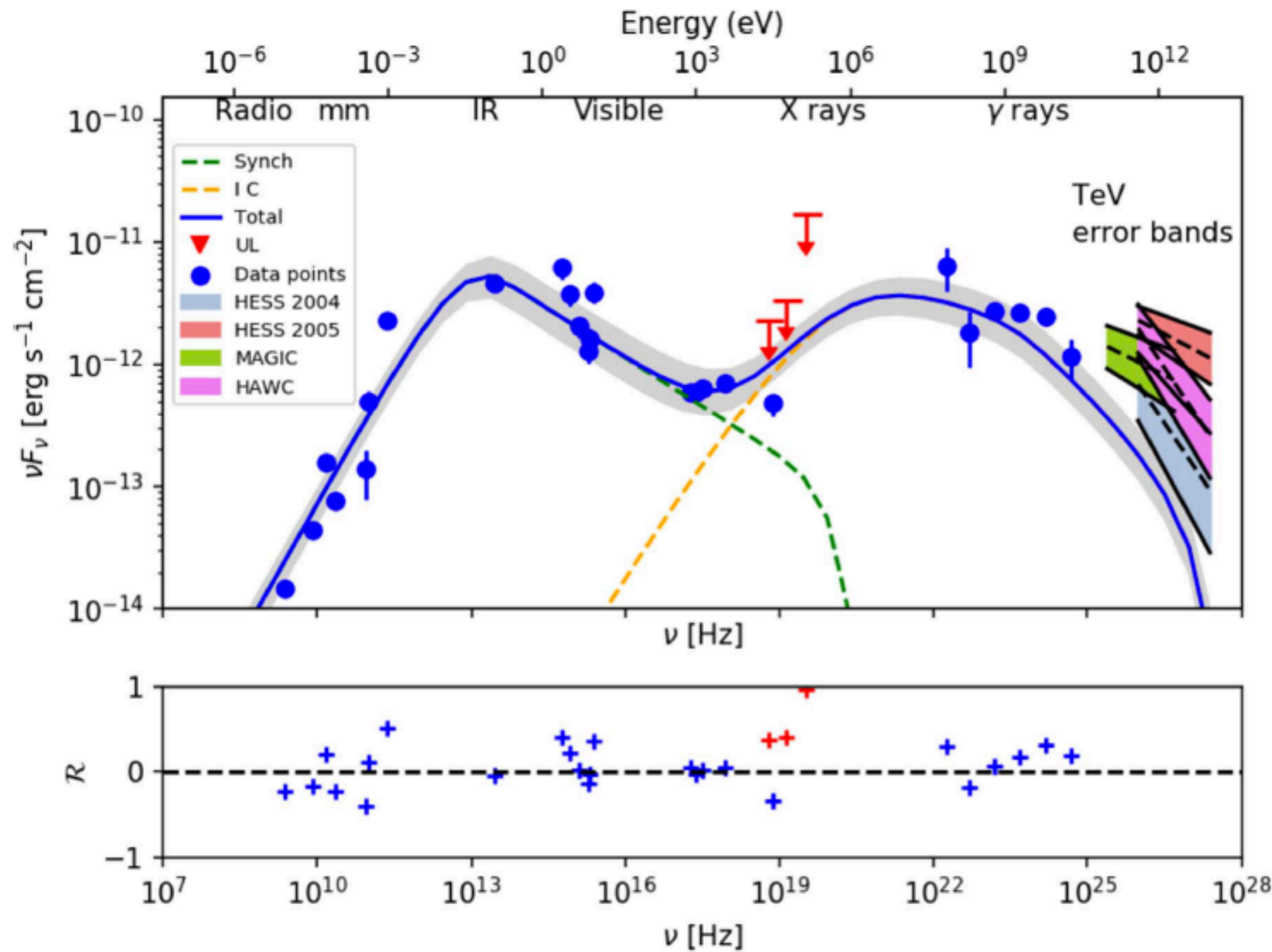
Objeto	Tipo	Galaxia	Sign	3FHL	TeV
4FGL J0009.7-3217	rdg	IC 1531	9.07		N
4FGL J1443.1+5201	rdg	3C 303	9.04		N
4FGL J2302.8-1841	rdg	PKS 2300-18	8.88		N
4FGL J2326.9-0201	rdg	PKS 2324-02	8.46		N
4FGL J1306.3+1113	rdg	TXS 1303+114	7.73		N
4FGL J2341.8-2917	rdg	PKS 2338-295	7.46		N
4FGL J1219.6+0550	rdg	NGC 4261	7.40		N
4FGL J0708.9+4839	rdg	NGC 2329	7.39		N
4FGL J1449.5+2746	rdg	B2 1447+27	6.93	Y	N
4FGL J2156.0-6942	rdg	PKS 2153-69	6.89		N
4FGL J0958.3-2656	rdg	NGC 3078	6.81		N
4FGL J1724.2-6501	rdg	NGC 6328	6.53		N
4FGL J2227.9-3031	rdg	PKS 2225-308	6.31		N
4FGL J0237.7+0206	rdg	PKS 0235+017	5.86		N
4FGL J0758.7+3746	rdg	NGC 2484	5.55		N
4FGL J1843.4-4835	rdg	PKS 1839-48	5.42	Y	N
4FGL J1236.9-7232	rdg	PKS 1234-723	5.96		N
4FGL J1518.6+0614	rdg	TXS 1516+064	5.65		N
4FGL J1530.3+2709	rdg	LEDA 55267	4.81		N
4FGL J0312.9+4119	rdg	B3 0309+411B	4.60		N
4FGL J1521.1+0421	rdg	PKS B1518+045	4.41		N
4FGL J1116.6+2915	rdg	B2 1113+29	3.90		N

# Centaurus A



Fermi-LAT @  $E > 200$  MeV - núcleo & lóbulos  
(Abdo et al. 2010)

WMAP @ 22 GHz

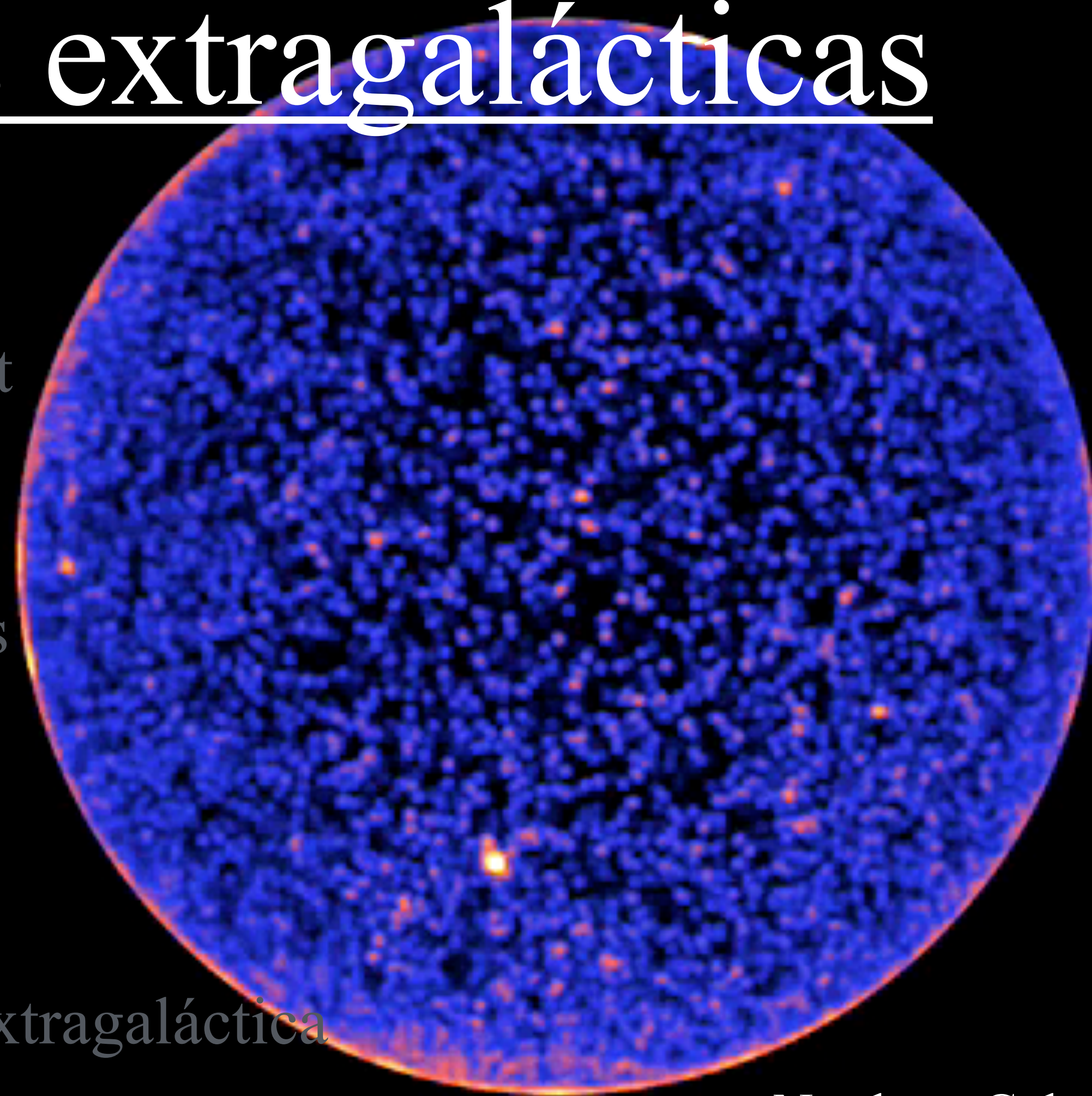


**Figure 1.** SED of M87 with the best fit SSC model. Blue points correspond to measured fluxes taken from Morabito et al. (1986, 1988), Junor & Biretta (1995), Lee et al. (2008), Lonsdale et al. (1998), Doeleman et al. (2012), Biretta et al. (1991), Perlman et al. (2001), Sparks et al. (1996), Marshall et al. (2002), Wong et al. (2017), Abdo et al. (2009), and the 4FGL catalog (Abdollahi et al. 2020). The model of the synchrotron component is the orange dashed curve and the model of the inverse Compton component is the green dashed curve. Swift/BAT upper limits obtained by Abdo et al. (2009) are shown by red triangles. The gray region corresponds to the  $1\sigma$  error of the best fit model parameters. For comparison, TeV error bands from 2004 H.E.S.S. (blue) (Aharonian et al. 2006), 2005 H.E.S.S. (red) (Aharonian et al. 2006), MAGIC (green) (Aleksić et al. 2012), and HAWC (violet) (Albert et al. 2021) are shown. Residuals of the best fit model, which  $\mathcal{R} = \log(F_{\nu,obs}/F_{\nu,mod})$  where  $F_{\nu,obs}$  and  $F_{\nu,mod}$  are the observed and predicted fluxes respectively, are shown in the bottom panel.

M 87 con HAWC - Alfaro et al. (2022)

# Fuentes extragalácticas

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4. Hoyos negros, acreción y jets
5. Radiogalaxias
6. Blazares
7. Absorción de pares por luz extragaláctica
8. Destellos de rayos gamma

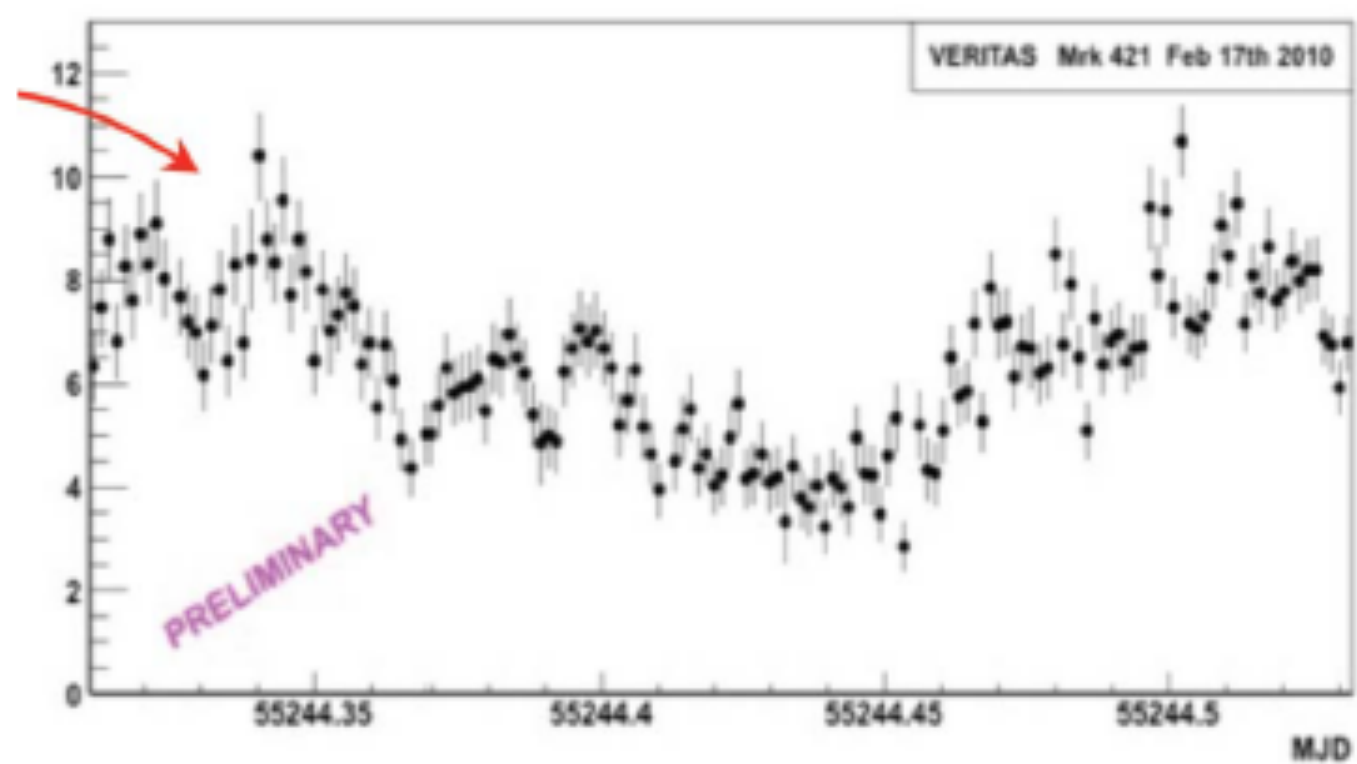
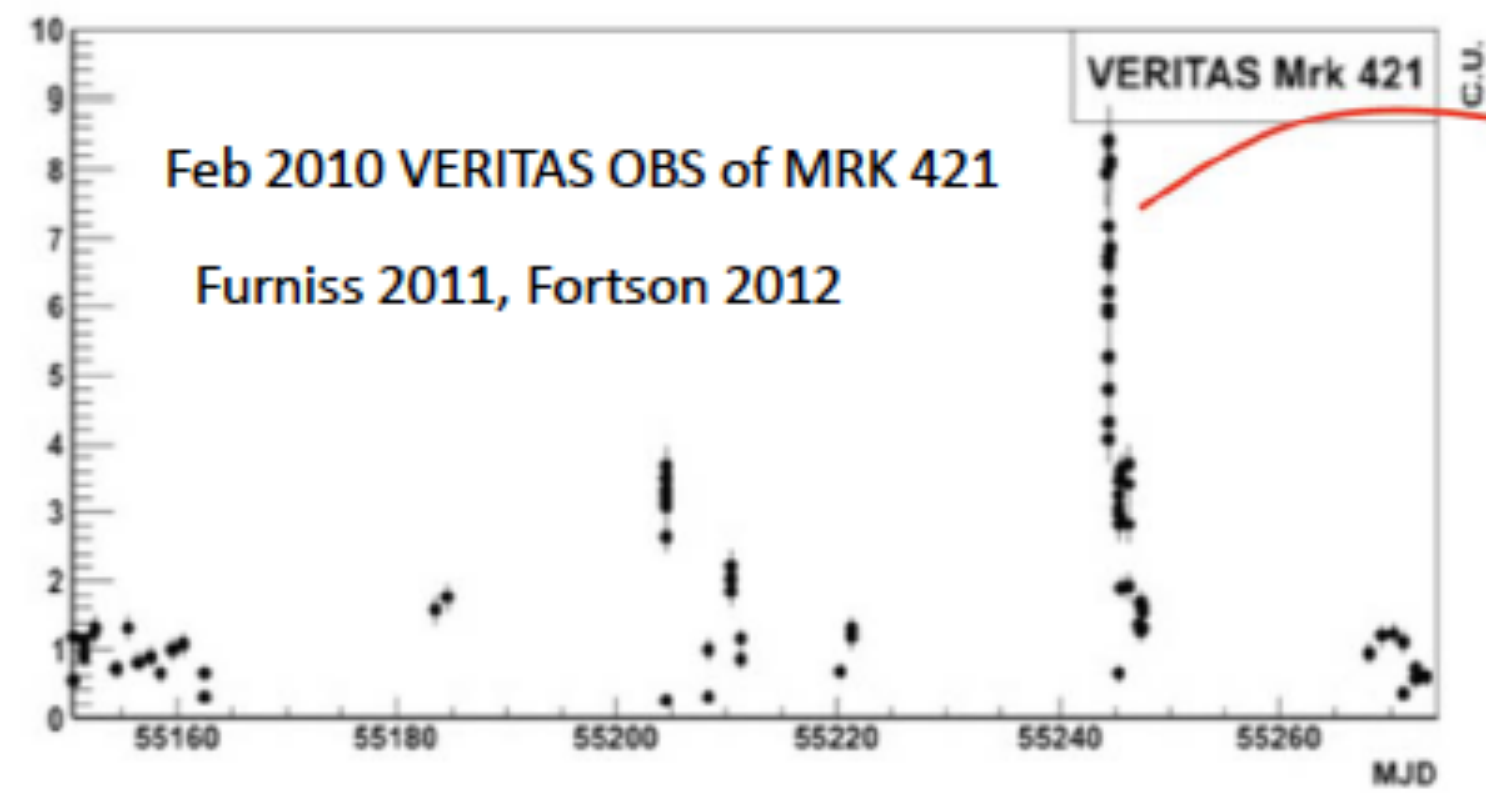
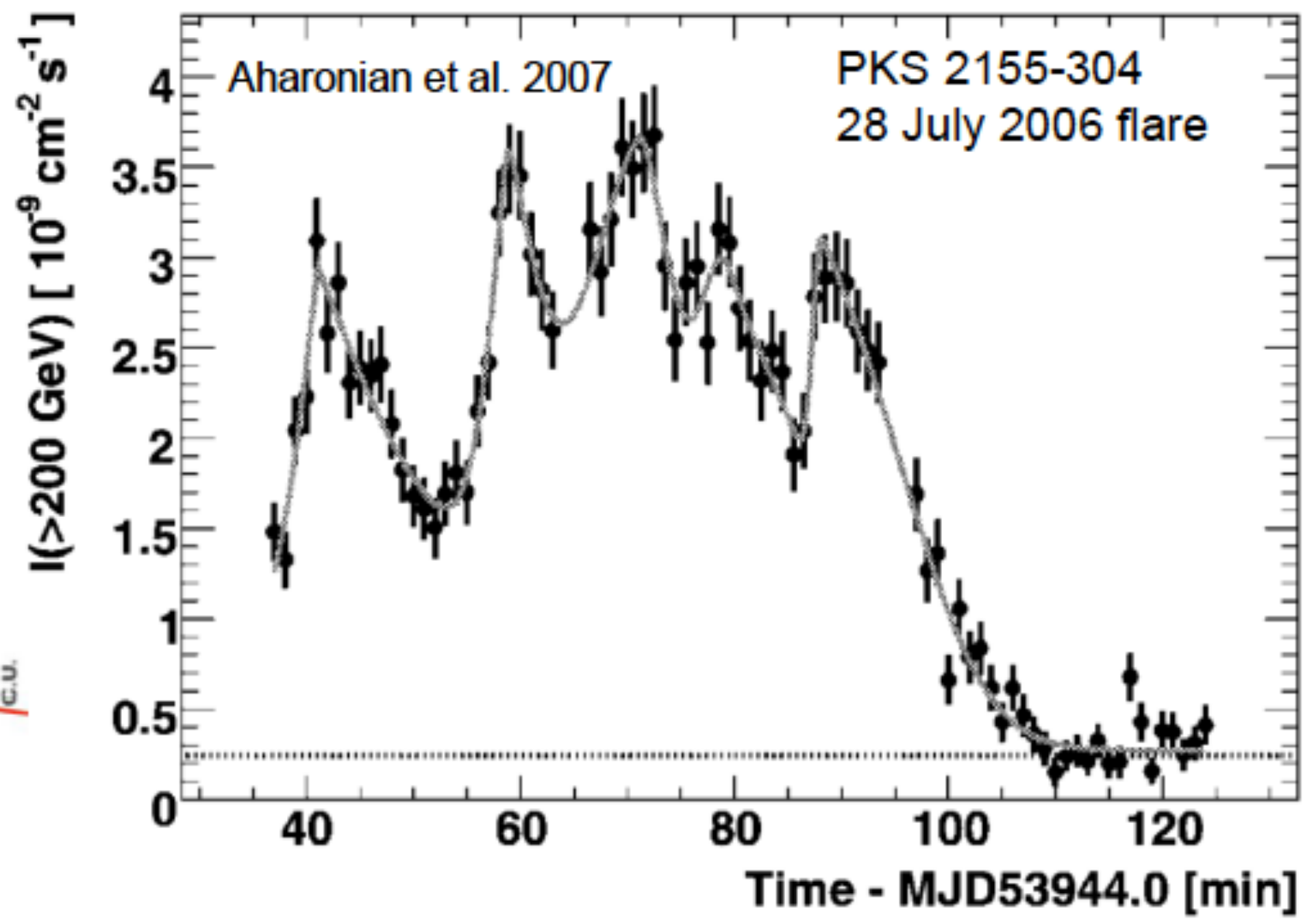


Northern Galactic hemisphere  
11 month sequence by Fermi-LAT

# Strongly Variable Class of BL Lac Objects

## Strongly variable class

- Mrk 421,  $z = 0.03$
- Mrk 501,  $z = 0.033$
- PKS 2155-305,  $z = 0.116$
- $t_{\text{var}} < R_S/c, L > L_{\text{EDD}}$
- Extreme sources

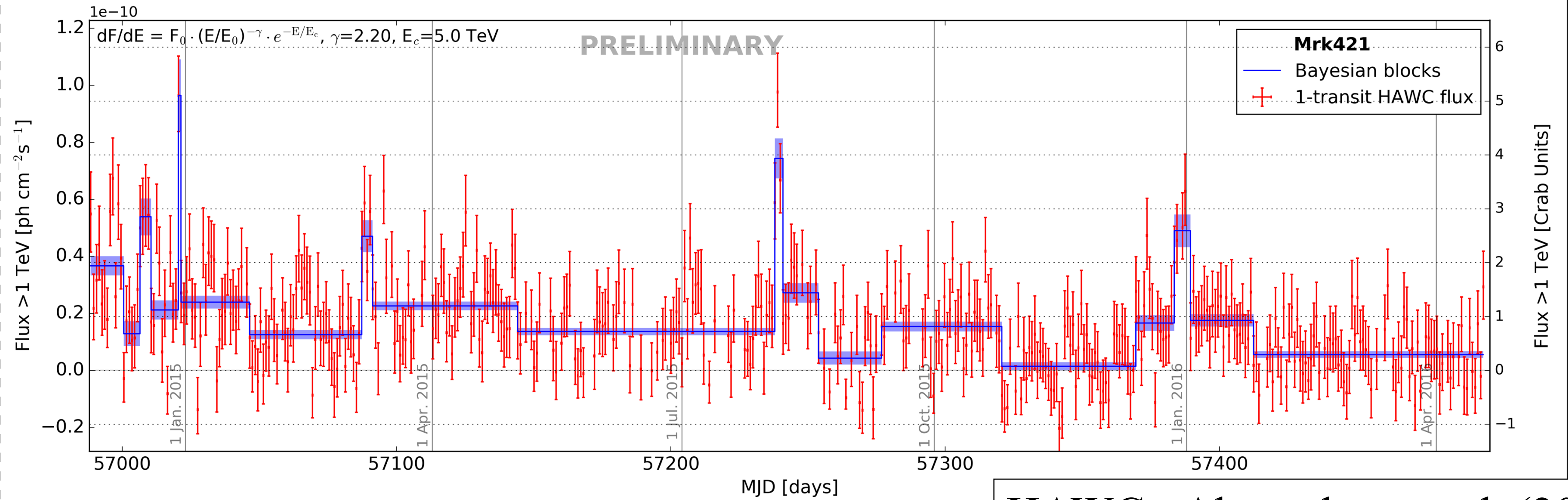
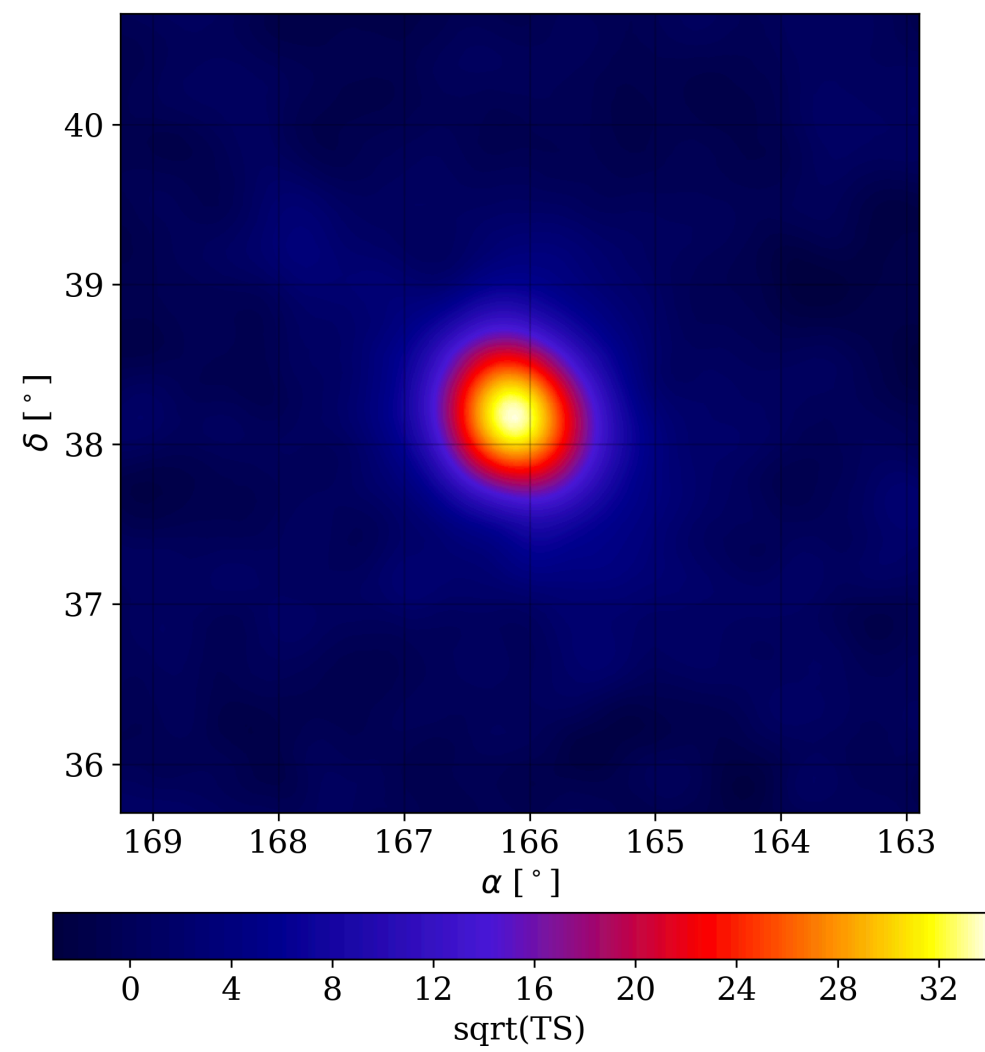


$$R_S/c = 10^4 M_9 \text{ s}$$

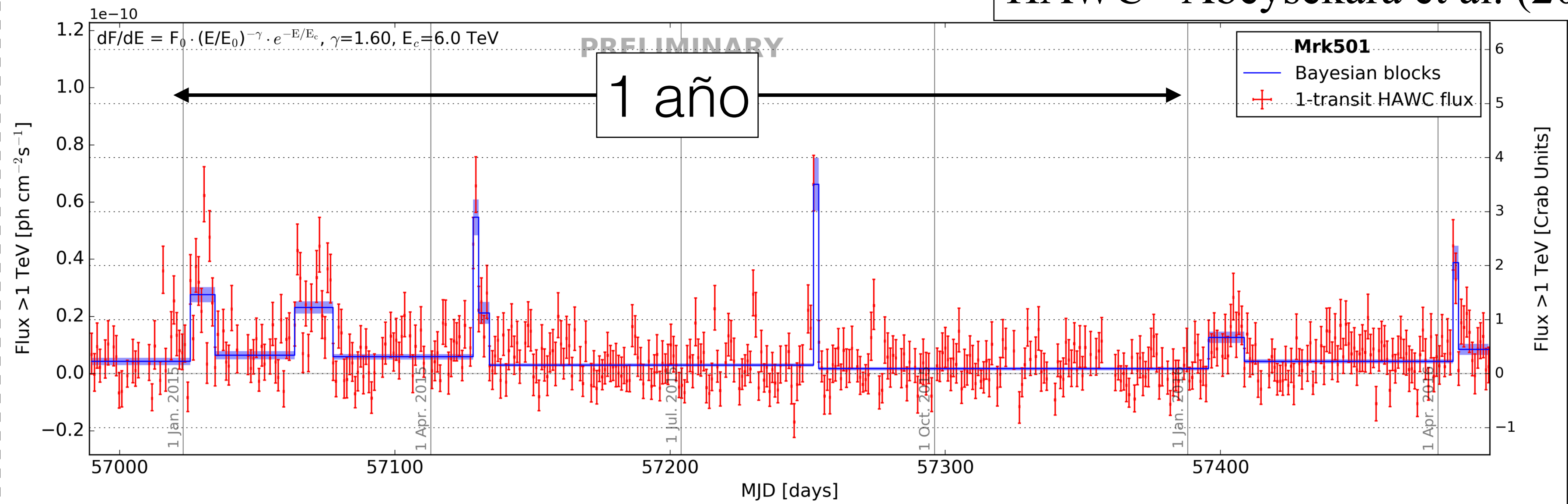
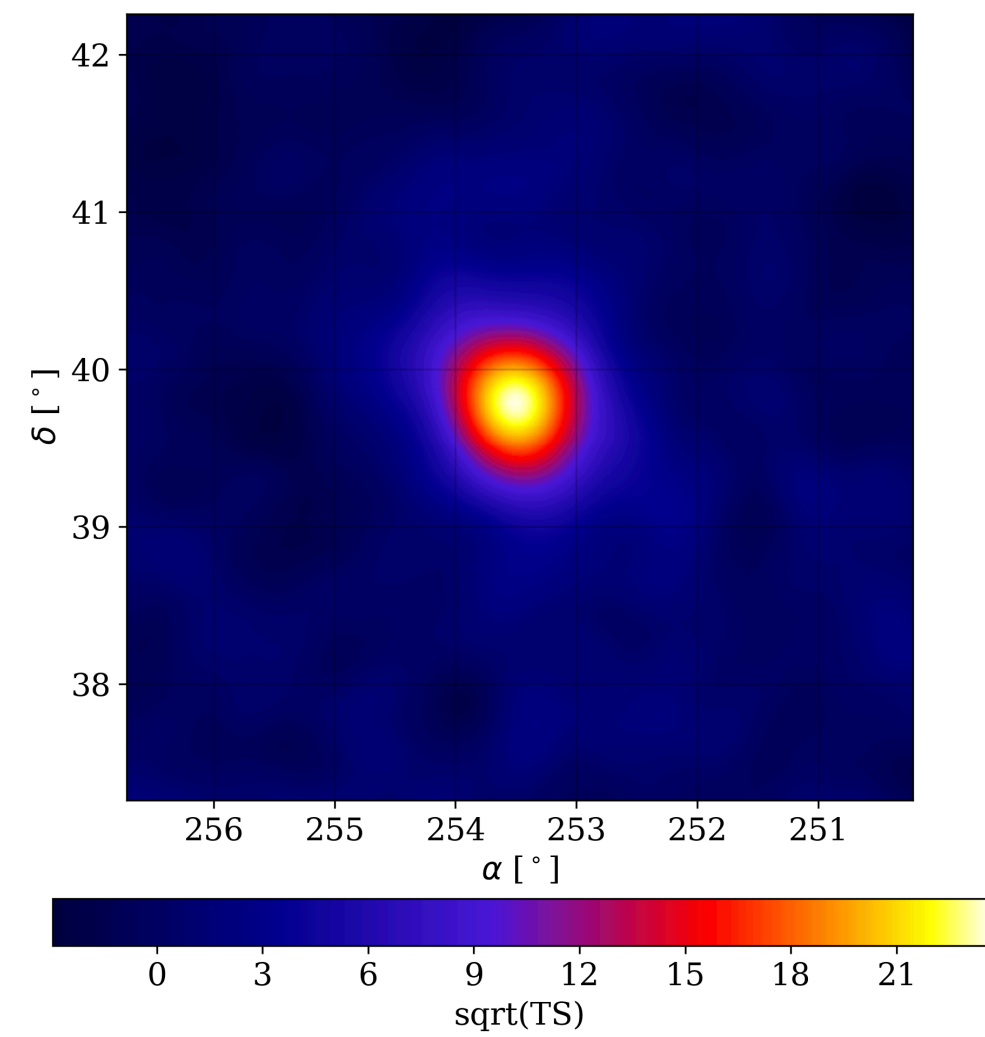
$$t_{\text{var}} \sim 5 \text{ min} = 300 \text{ s}$$

$$\Rightarrow (?) M \ll 10^8 M_0$$

# Seguimiento de Mrk 421 y Mrk 501 con HAWC

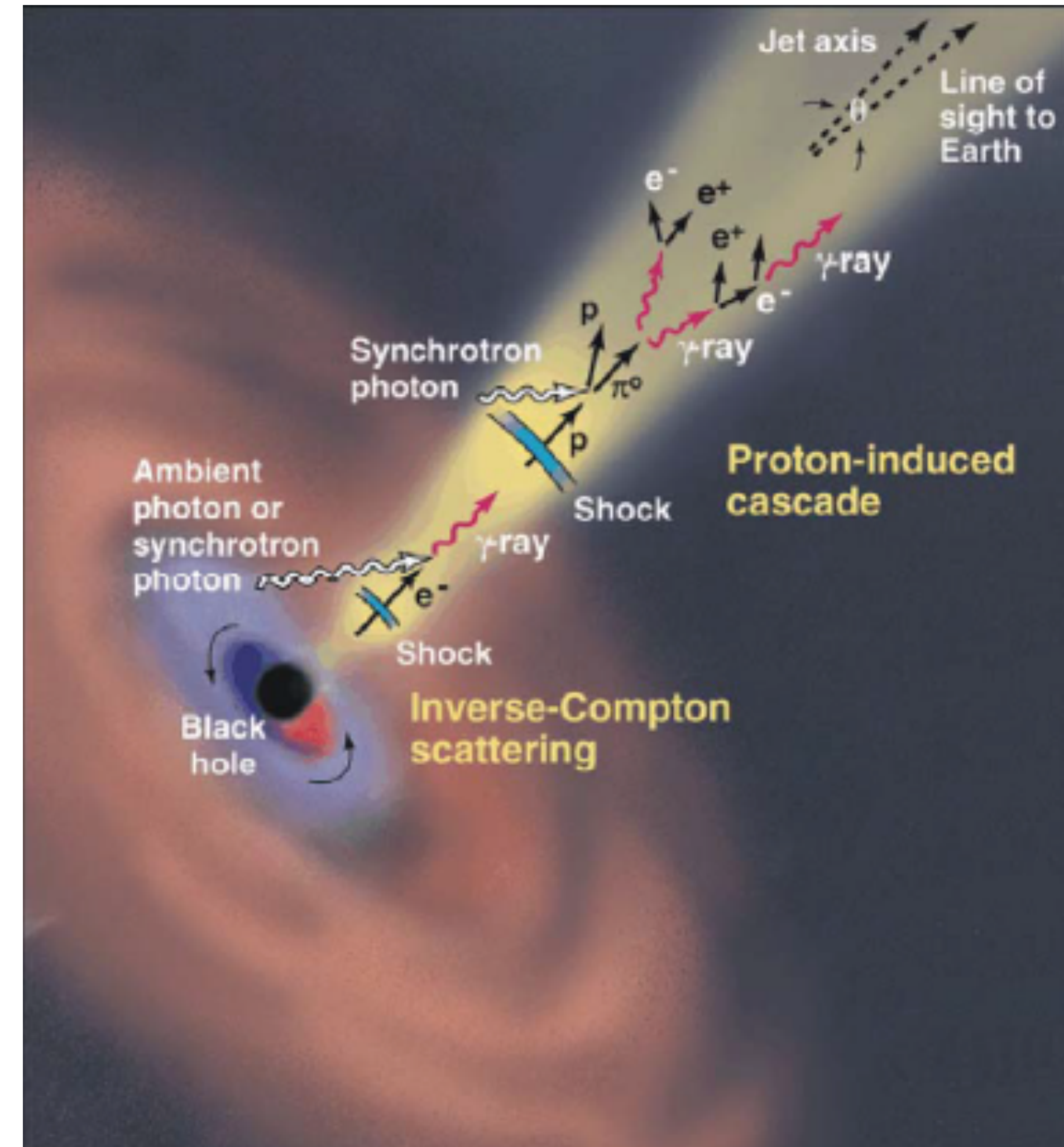


HAWC - Abeysekara et al. (2017)



# Blazares

- Aceleración de partículas en jets con  $\Gamma \gtrsim 1-10$ 
  - jet por extracción de energía rotacional del BH (Blandford - Znajek 1977).
  - choques dentro del jet  $\Rightarrow$  aceleración de partículas.
- Modelos leptónicos:
  - sincrotrón: radio a óptico, o más (LSP, ISP, HSP);
  - Compton inverso, versión SSC o con radiación externa; por ejemplo disco de acreción o CMB.
- Modelos hadrónicos:
  - sincrotrón por e primarios y secundarios;
  - emisión gamma por  $\pi^0 \Rightarrow$  neutrinos.

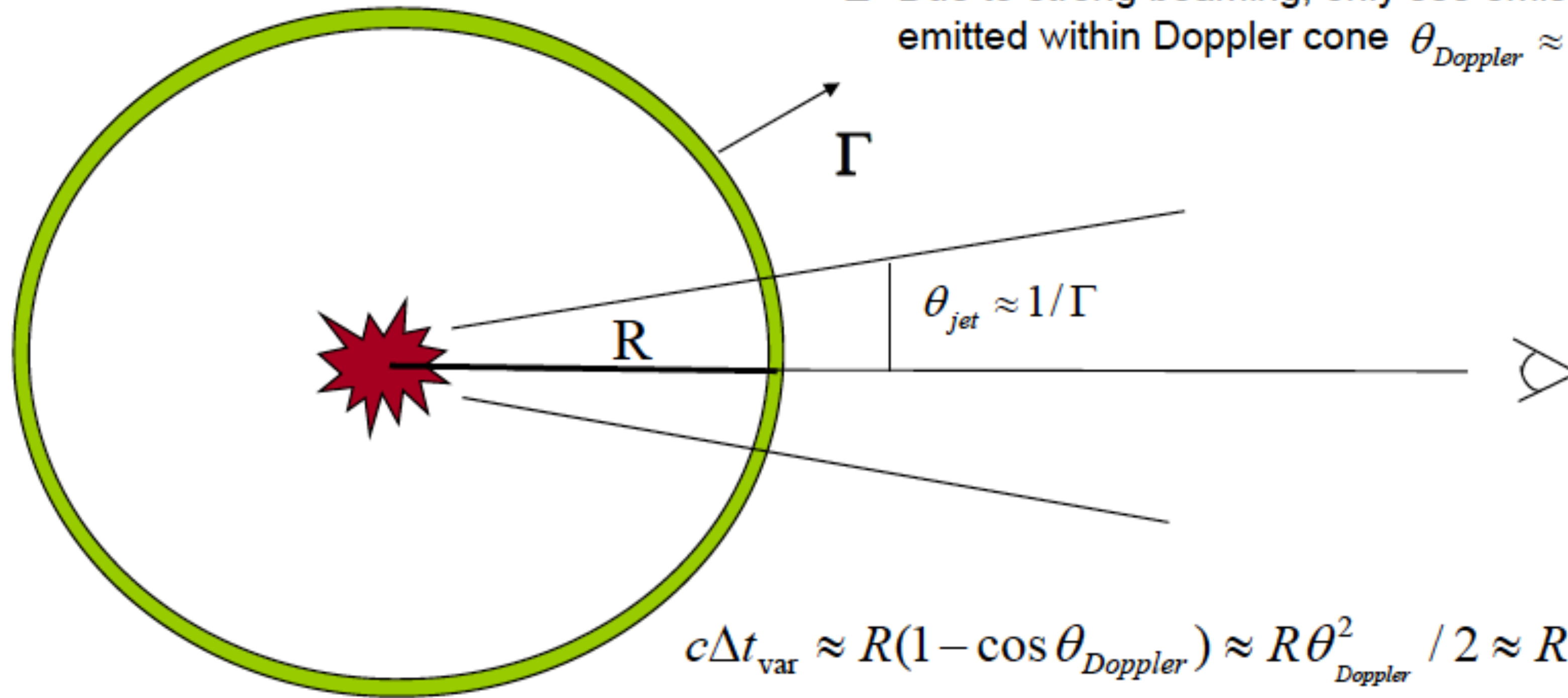


# Solution: Bulk Relativistic Motion

Causality relation for stationary sources:

$$R < c\Delta t_{\text{var}}$$

- Suppose relativistic spherical shell briefly illuminated, e.g., by shell collisions
- Due to strong beaming, only see emission emitted within Doppler cone  $\theta_{\text{Doppler}} \approx 1/\Gamma$

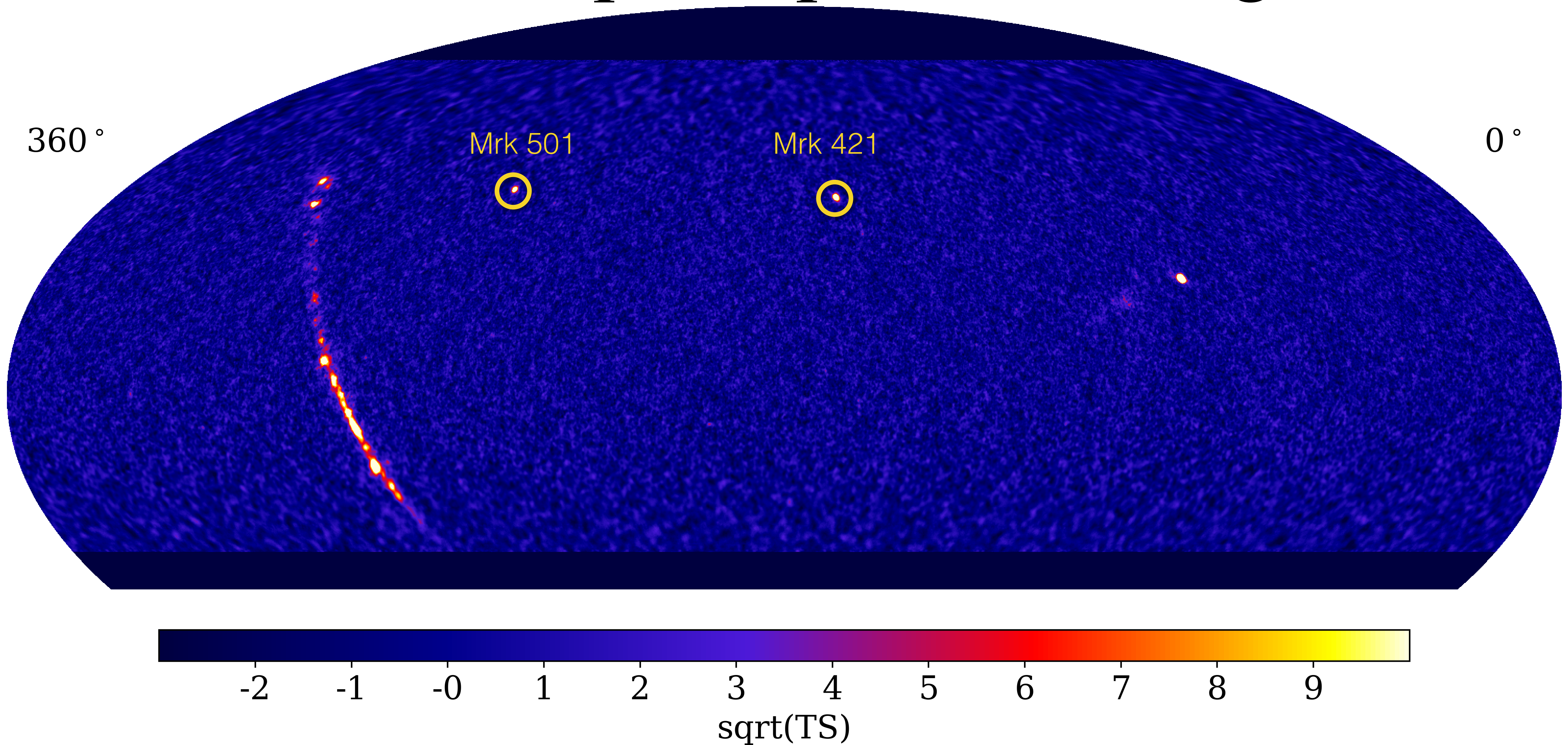


$$c\Delta t_{\text{var}} \approx R(1 - \cos \theta_{\text{Doppler}}) \approx R\theta_{\text{Doppler}}^2 / 2 \approx R / 2\Gamma^2$$

$$\Rightarrow R < 2\Gamma^2 c\Delta t_{\text{var}}$$

Emission size  $\sim \Gamma^2$  larger than values inferred for stationary region

# 7. Absorción de pares por luz extragaláctica



## Absorci3n EBL - producci3n de pares

- La producci3n de pares por dos fotones,

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

sigue la conservaci3n de energ3a y momento ( $\hbar = 1, mc = 1$ ),

$$\begin{pmatrix} \omega_0 + \omega_1 \\ \omega_0 \hat{k}_0 + \omega_1 \hat{k}_1 \end{pmatrix} = \begin{pmatrix} \gamma_0 + \gamma_1 \\ \gamma_0 \vec{\beta}_0 + \gamma_1 \vec{\beta}_1 \end{pmatrix}.$$

- El invariante es

$$s = -p_\alpha p^\alpha = 2\omega_0\omega_1 (1 - \hat{k}_0 \cdot \hat{k}_1) = 2 + 2\gamma_0\gamma_1 (1 - \vec{\beta}_0 \cdot \vec{\beta}_1) = 4\gamma^2 = 4/(1 - \beta^2),$$

siendo  $\beta$  la velocidad del par en el CM.

- La secci3n eficaz,

$$\sigma = \frac{\pi}{2} r_e^2 (1 - \beta^2) \left\{ (3 - \beta^4) \ln \left( \frac{1 + \beta}{1 - \beta} \right) - 2\beta (2 - \beta^2) \right\},$$

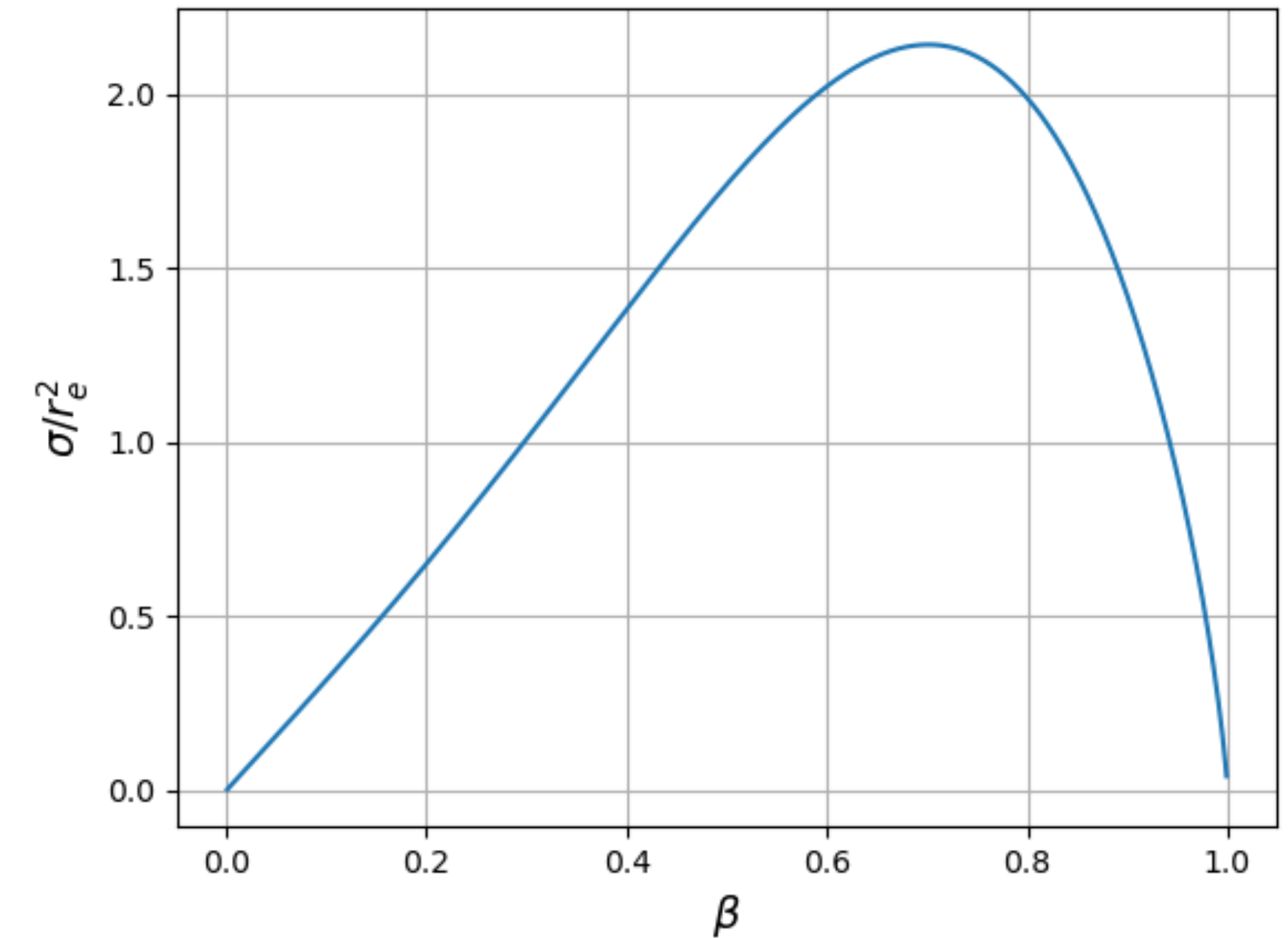
con  $s = 4\gamma^2 = 4/(1 - \beta^2)$ , siendo  $\beta$  la velocidad del par en el CM.

# Absorci3n EBL

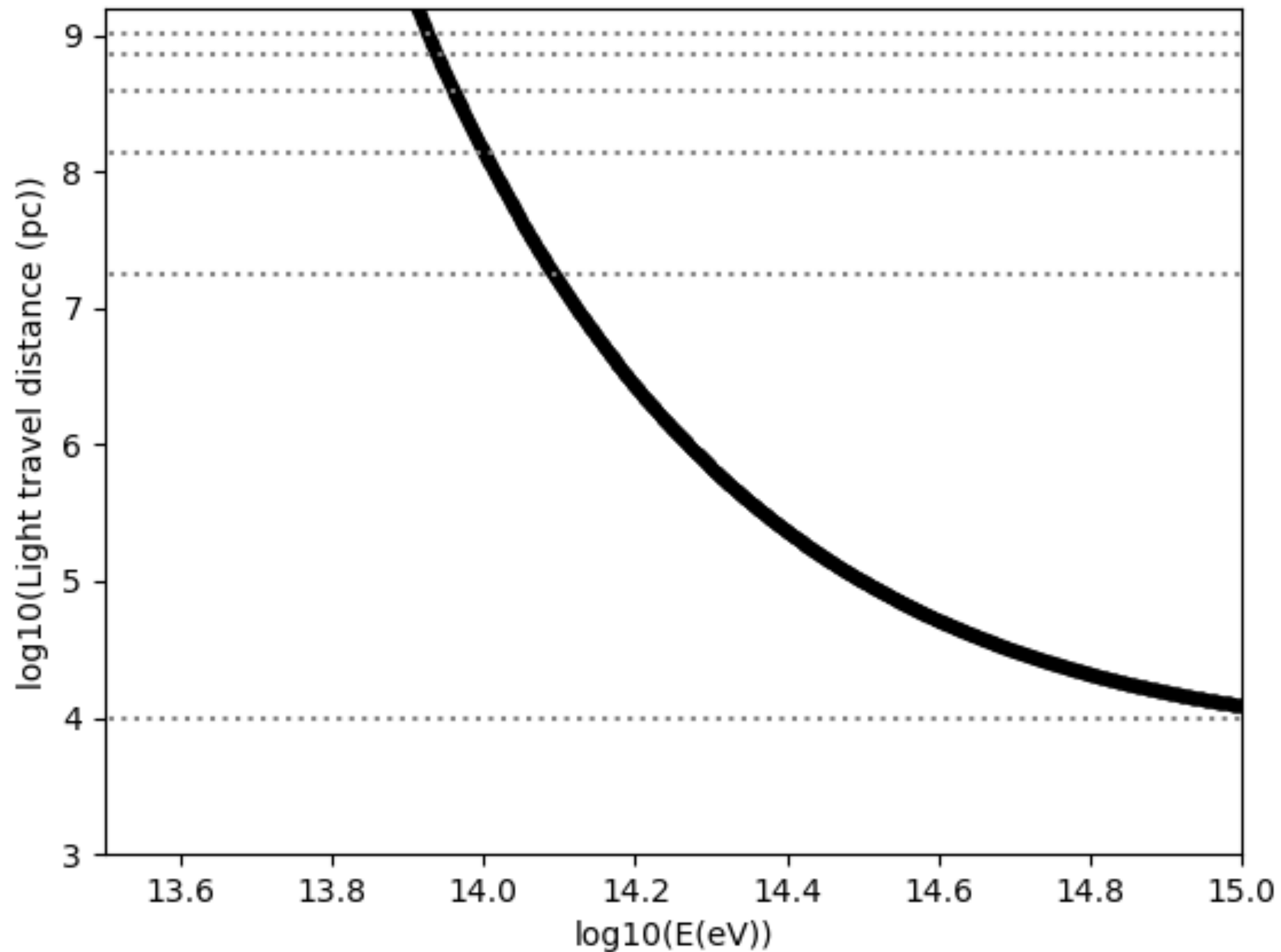
- ▶ El m3ximo de  $\sigma$  corresponde a  $\beta \simeq 0.7 \Rightarrow \gamma \simeq 2$ ,  
 $\Rightarrow E_\gamma h\nu(1 - \cos \theta) \simeq 4 (mc^2)^2 \simeq 1 \text{ eV TeV}$ .
- ▶ Se calcula la opacidad sobre la l3nea de visi3n,

$$\tau(E_\gamma, z) = \int_0^z \int_0^\infty \int_{\mu_{min}}^2 \sigma(\omega) n_\nu(z') \frac{\mu}{2} d\mu d\nu \left( \frac{d\ell}{dz'} \right) dz',$$

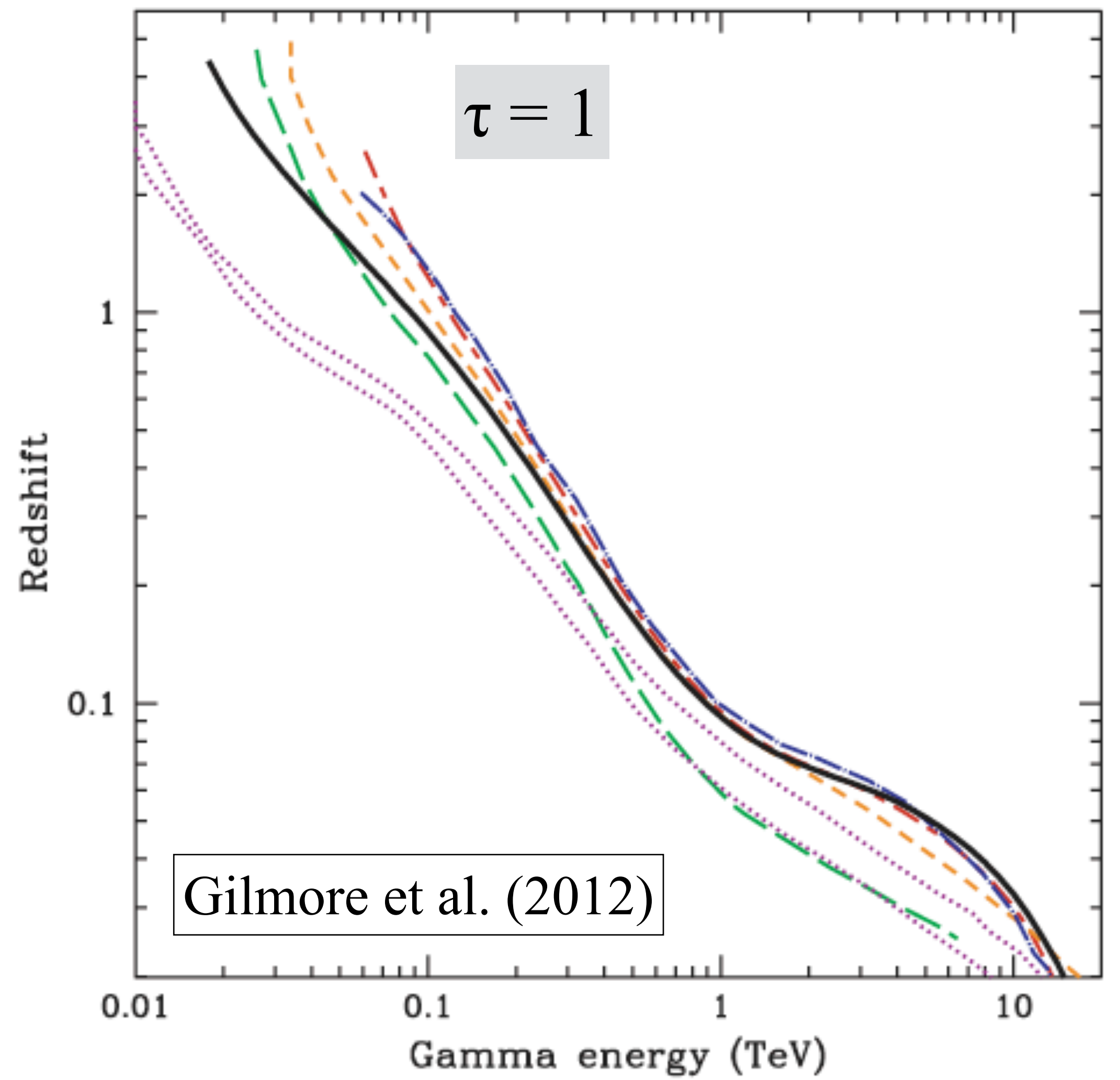
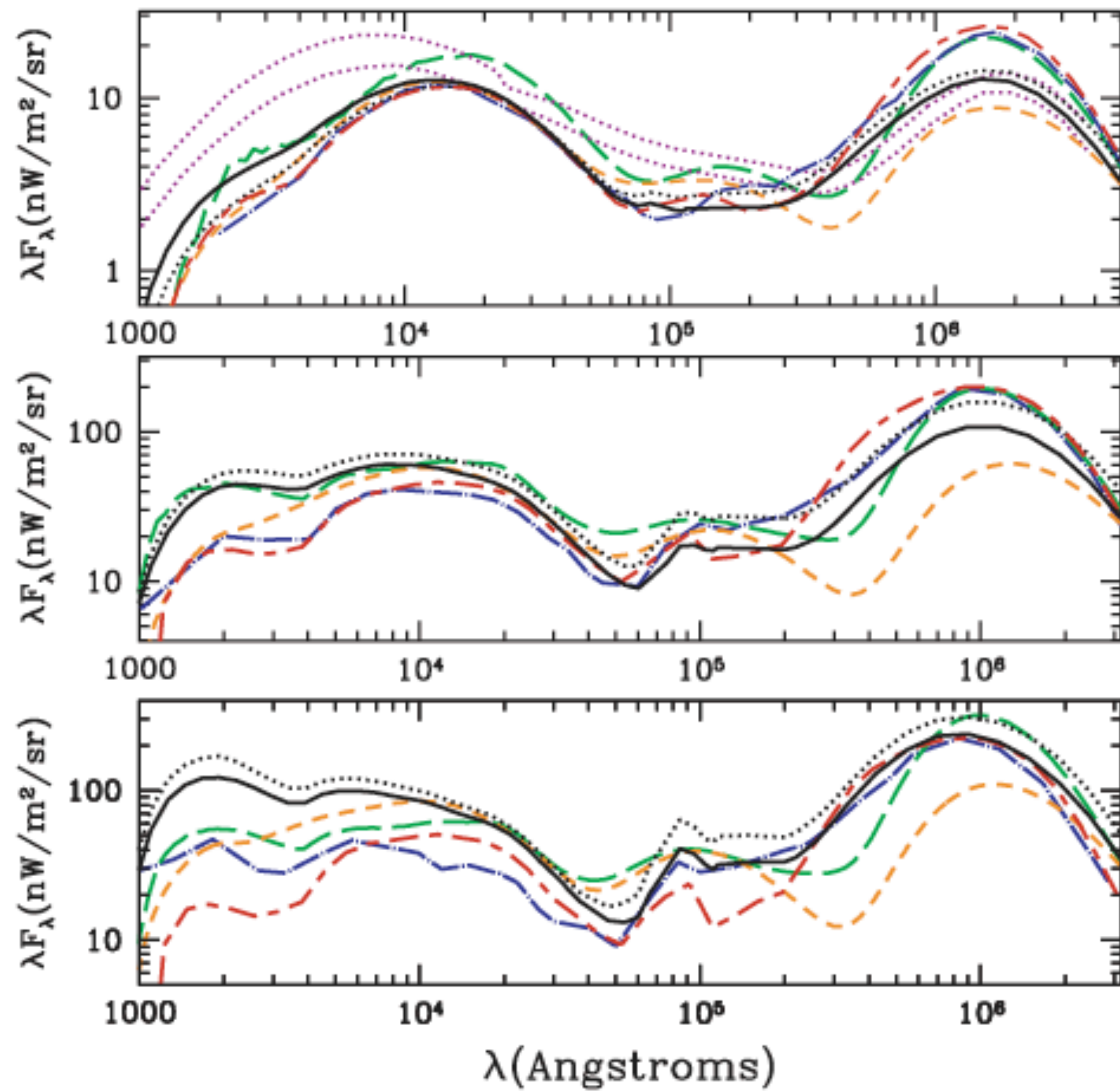
con  $\omega = \sqrt{Eh\nu \mu/2}$ ,  $\mu = 1 - \cos \theta \geq \mu_{min} = m^2 c^4 / E_\gamma h\nu(1 + z')^2$ , y un modelo de distancias cosmol3gicas,  $d\ell/dz = c/H(z)(1 + z)$ .



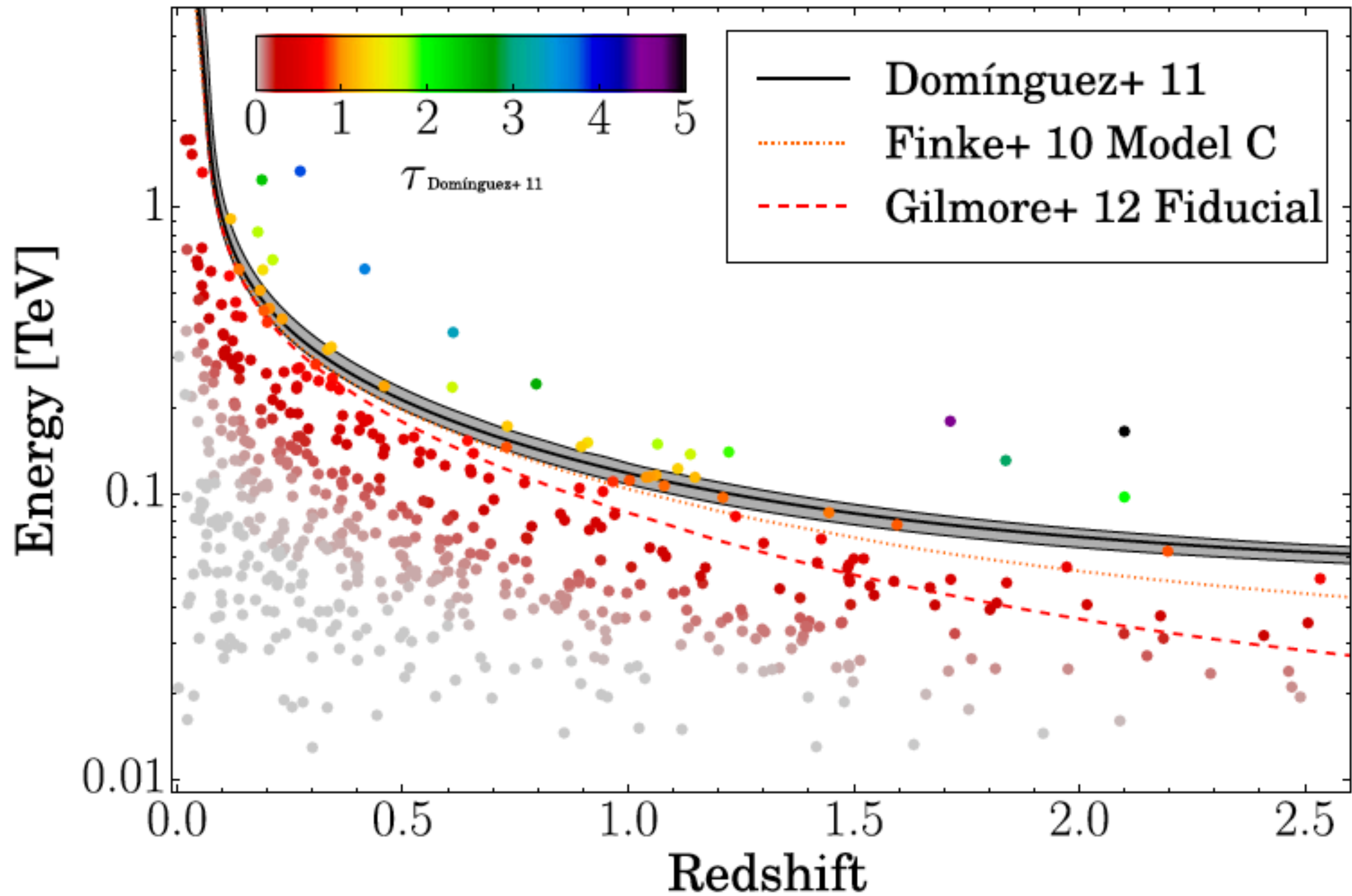
CMB travel distance (tau=1)



Gould & Schreder (1966)  
calcularon la opacidad  
 $\gamma\gamma \rightarrow e^-e^+$   
para el CMB ( $h\nu \sim 10^{-3}$  eV)

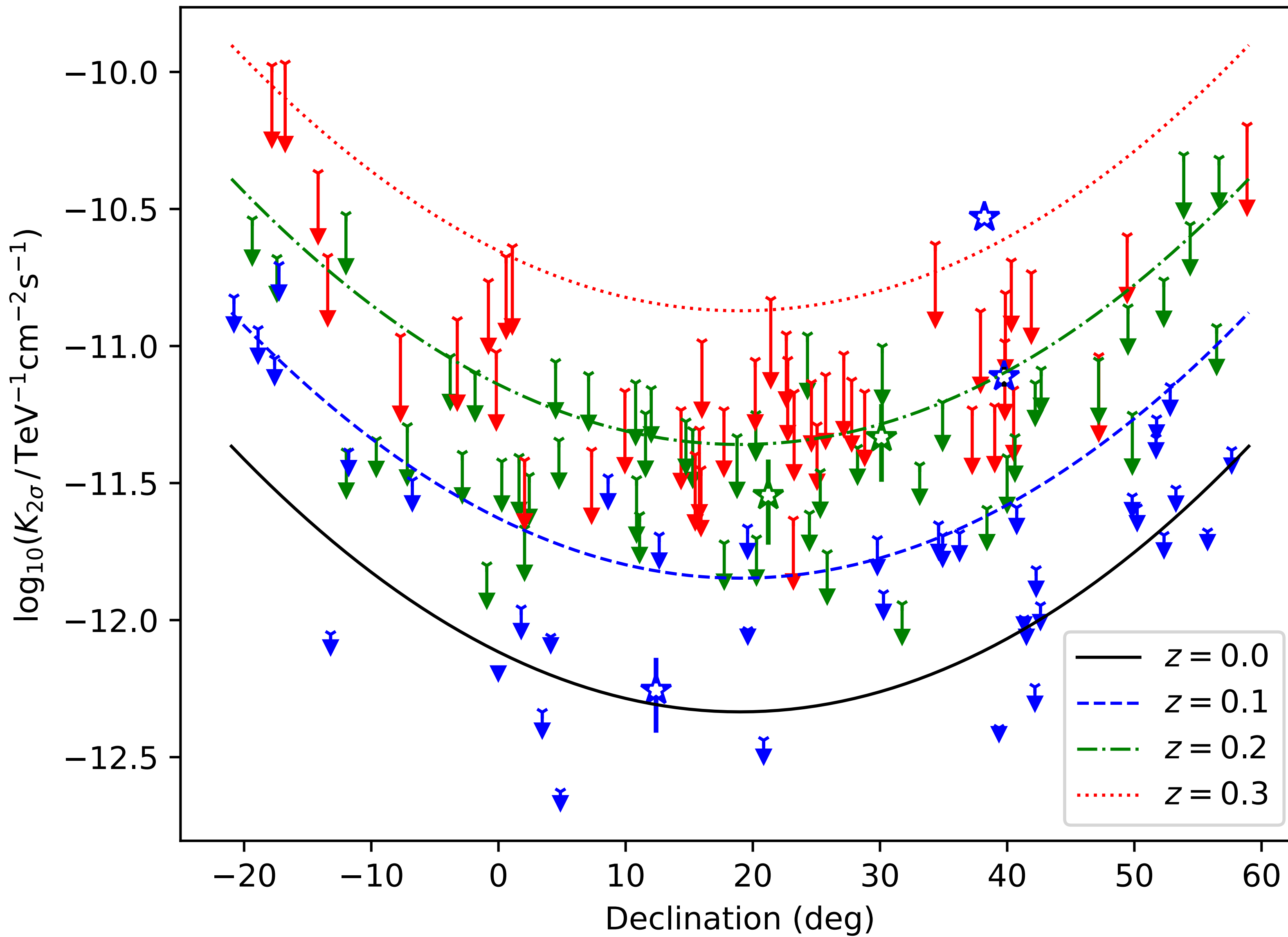


**Figure 11.** Left: our EBL predictions compared with several recent models from the literature. Solid and dotted black lines show the proper flux density from our *WMAP5* and  $\Lambda$ CDM models in the local universe and at  $z = 1$  and  $2$ . Other lines are from Franceschini et al. (2008) (dashed–dotted blue), the best-fitting model of (Kneiske et al. 2004) (long-dashed green), D11 (long-short dashed red) and model ‘C’ from Finke et al. (2010) (dashed orange). The baseline and fast evolution models of Stecker et al. (2006) are the low and high dotted violet points in the  $z = 0$  panel. Right: a comparison of the  $\tau_{\gamma\gamma} = 1$  attenuation edges for several models. Line types are as in the opposite panel. In this instance, the lower set of dotted points denotes the fast evolution model of Stecker et al. (2006), while the upper are the baseline model.



3FHL ( $E > 10$  GeV)  
Ajello et al. (2017)

Energy photons vs. redshift for 3FHL-associated blazars, color-coded by the optical depth,  $\tau$ , calculated from the model presented by Domínguez et al. (2011a). The solid black line shows the  $\gamma$ -ray horizon (energy for which  $\tau = 1$  as a function of redshift) from the Domínguez et al. (2011a), Finke et al. (2010), and Gilmore et al. (2012) models, respectively. Several of the highest-energy LAT photons from these blazars are shown around and beyond  $\tau = 1$ .



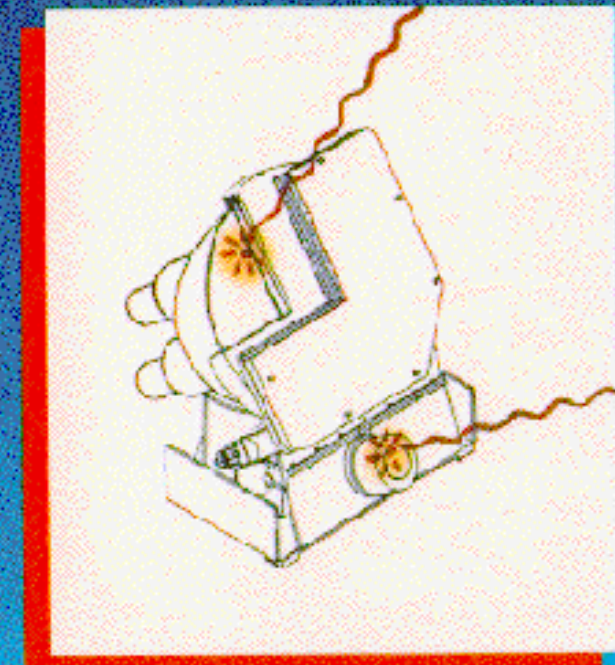
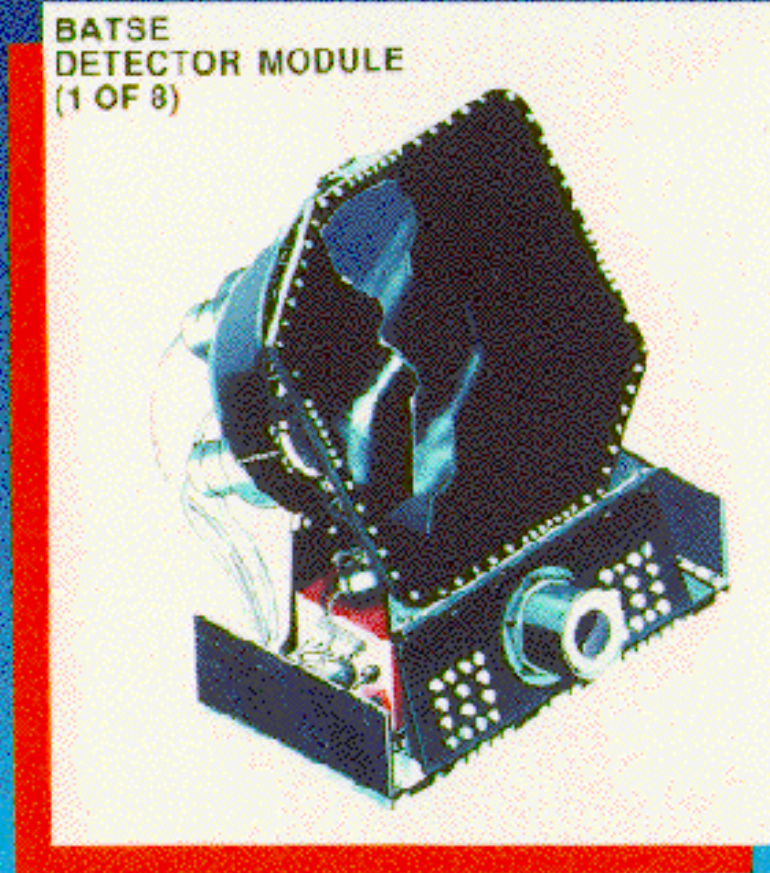
Mrk 421, Mrk 501  
 M 87,  
 VER J0521+211,  
 1ES 1215+303.

# Fuentes extragalácticas

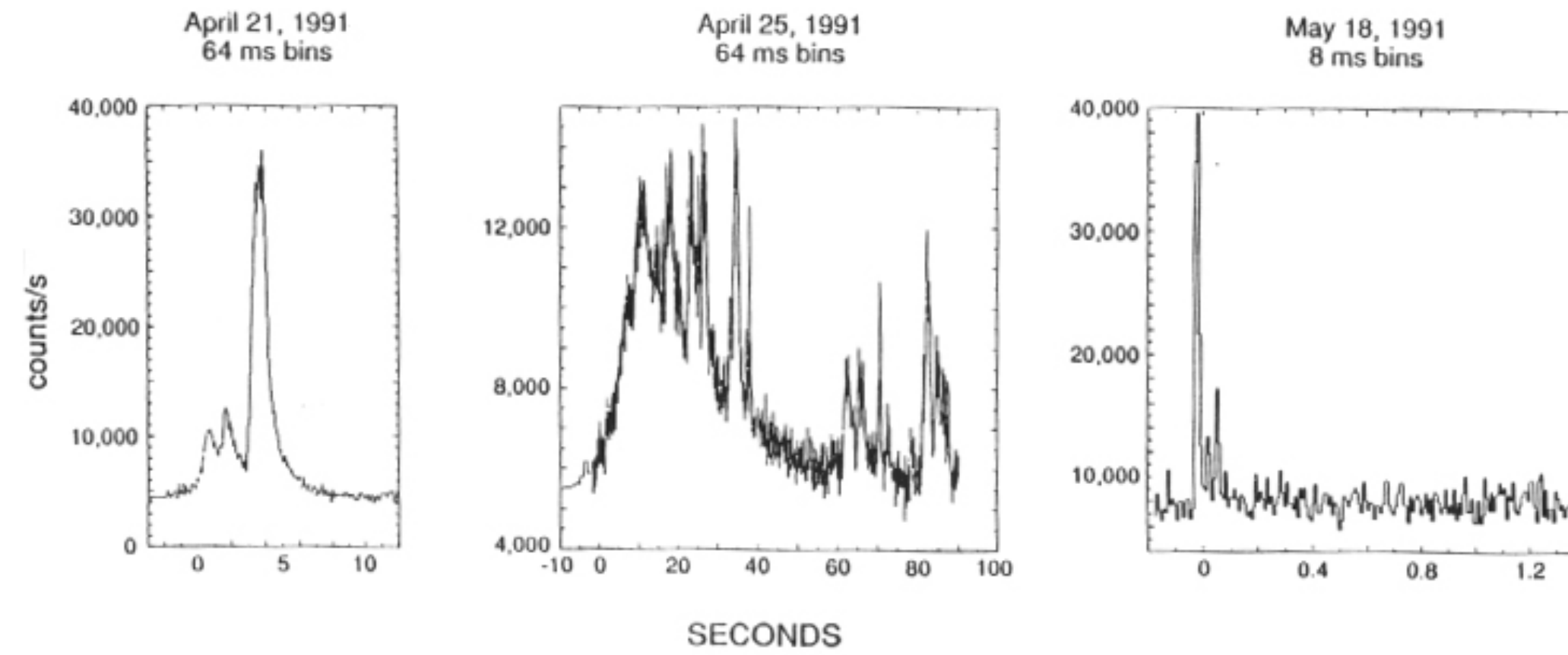
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GRB 080916C

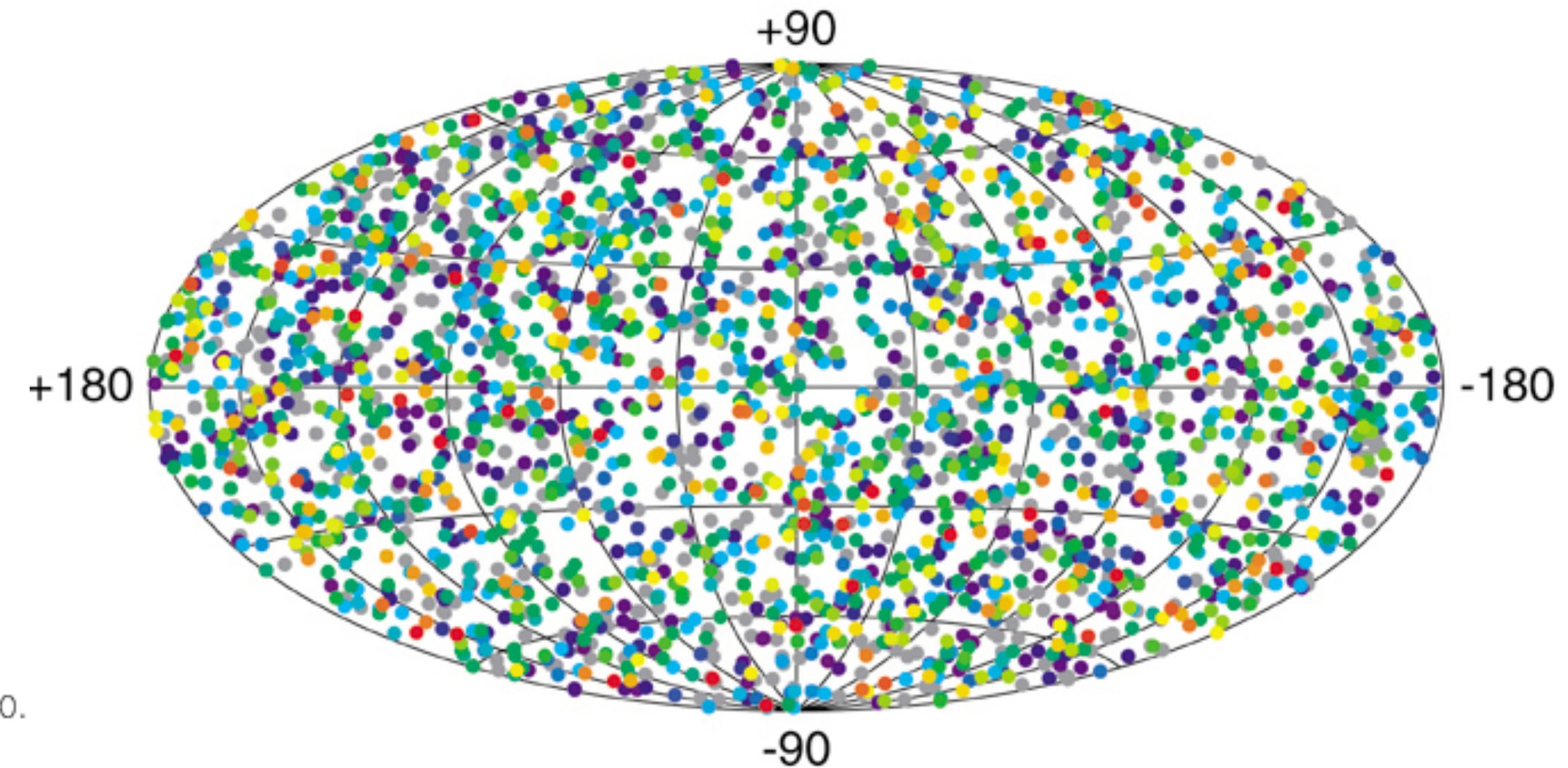
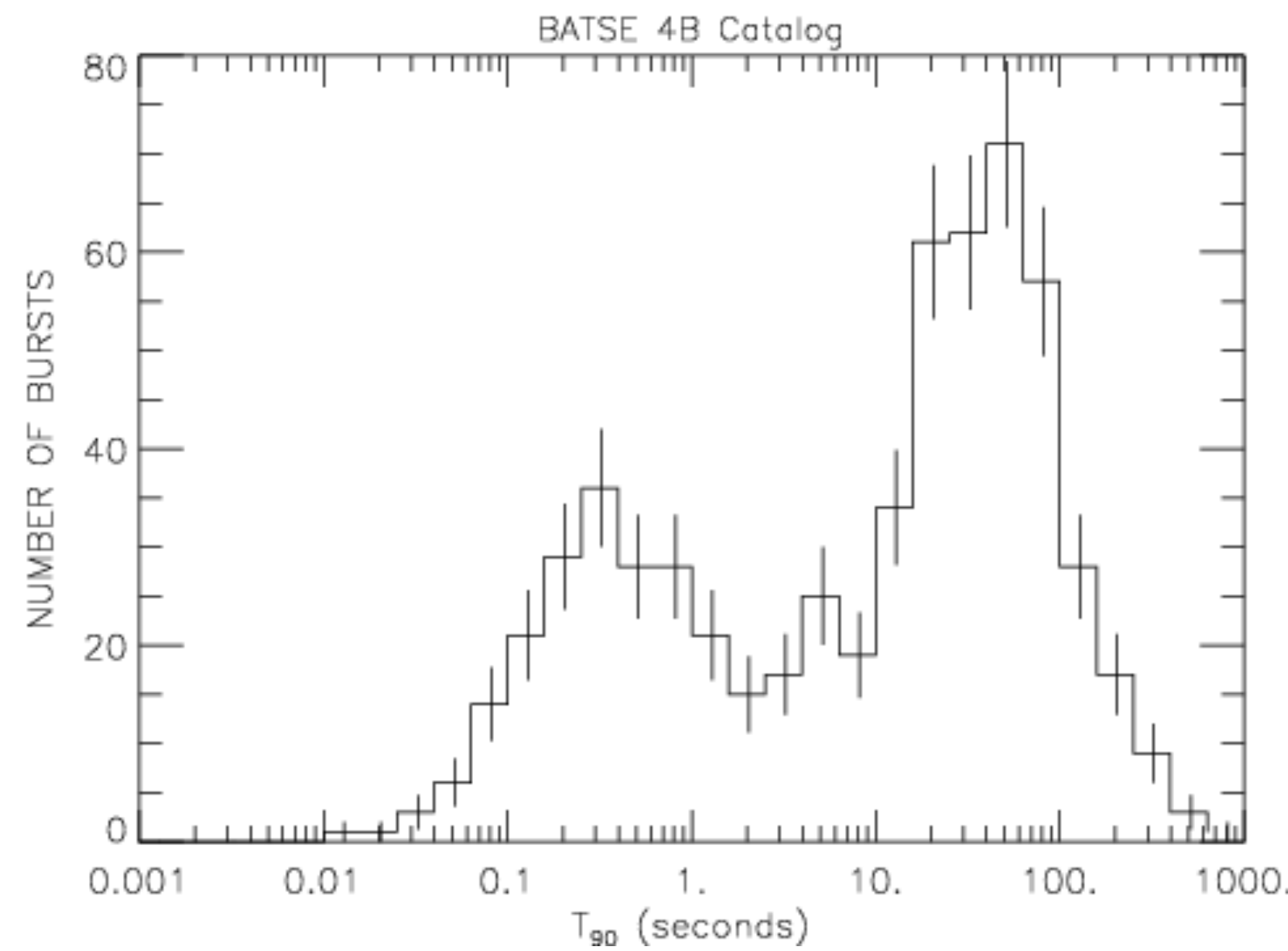
# Burst and Transient Source Experiment (BATSE)



## BATSE—GRO 3 Types of Gamma-Ray Bursts 50-300 keV

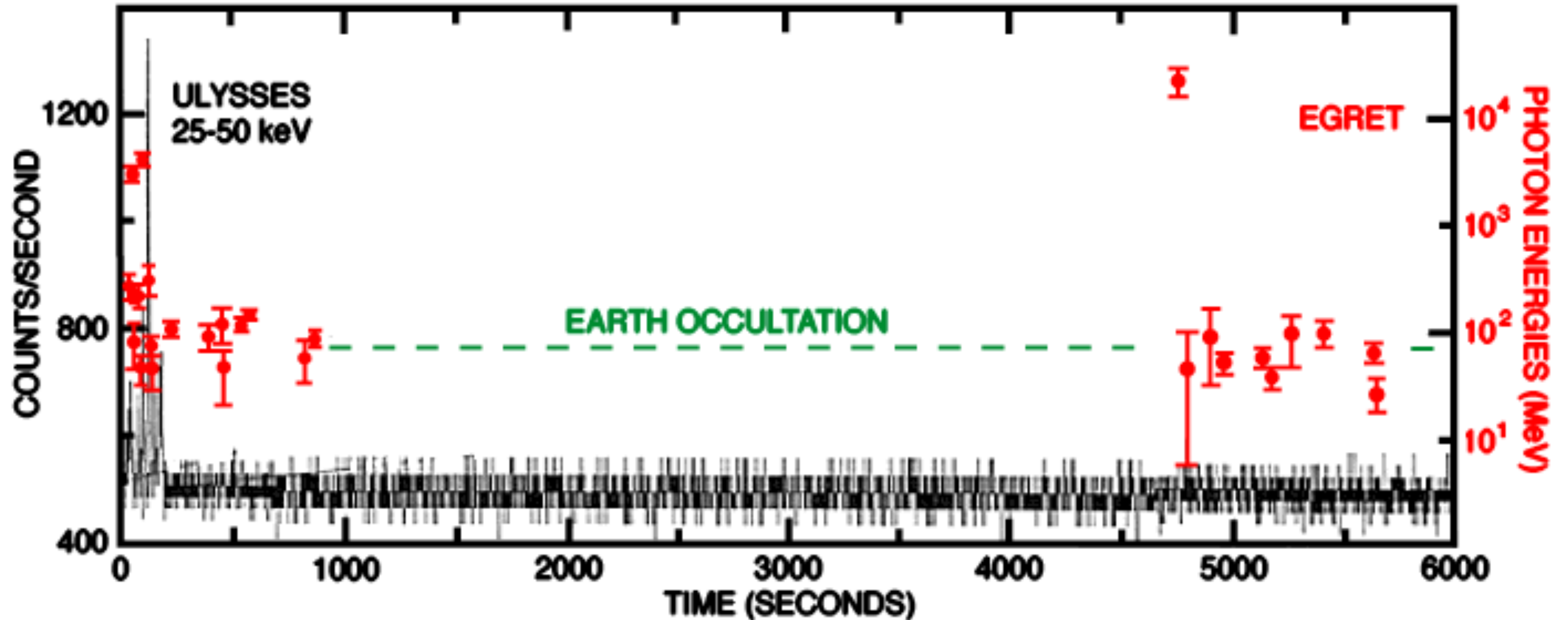


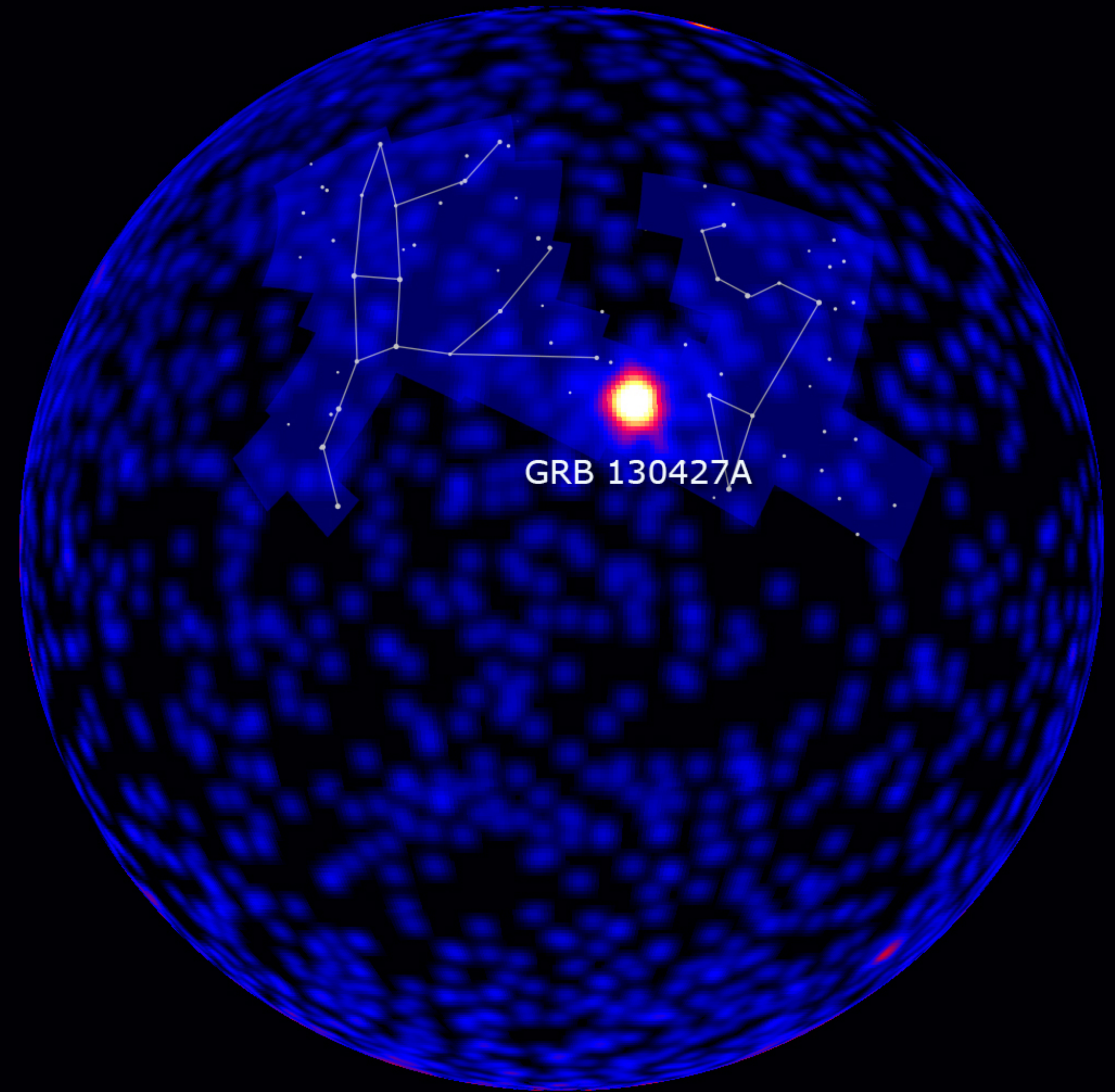
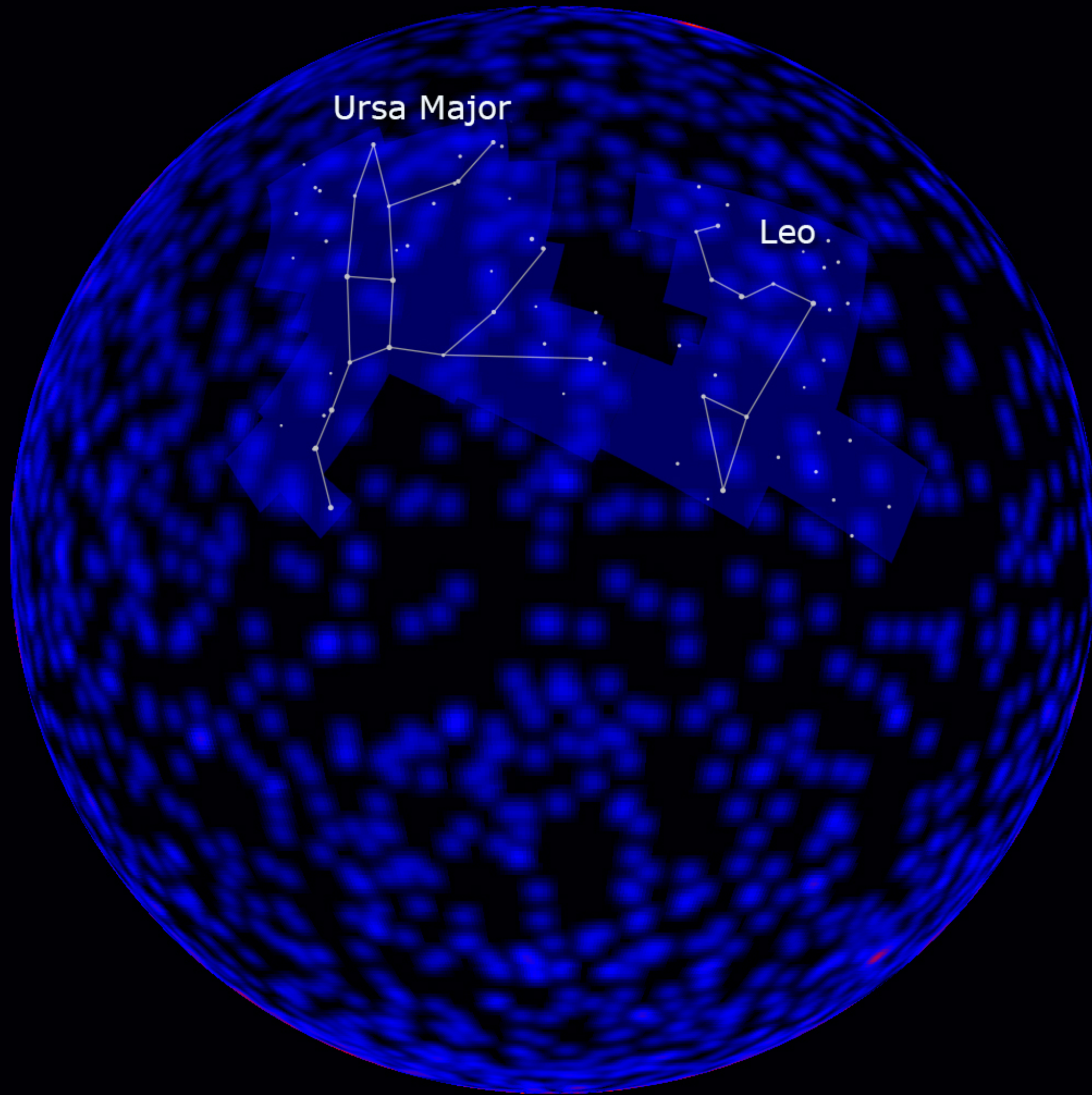
## 2704 BATSE Gamma-Ray Bursts



# GRB 940217

FEBRUARY 17, 1994 BURST





Before and after Fermi LAT views of GRB 130427A, centered on the north galactic pole

# Los crepúsculos

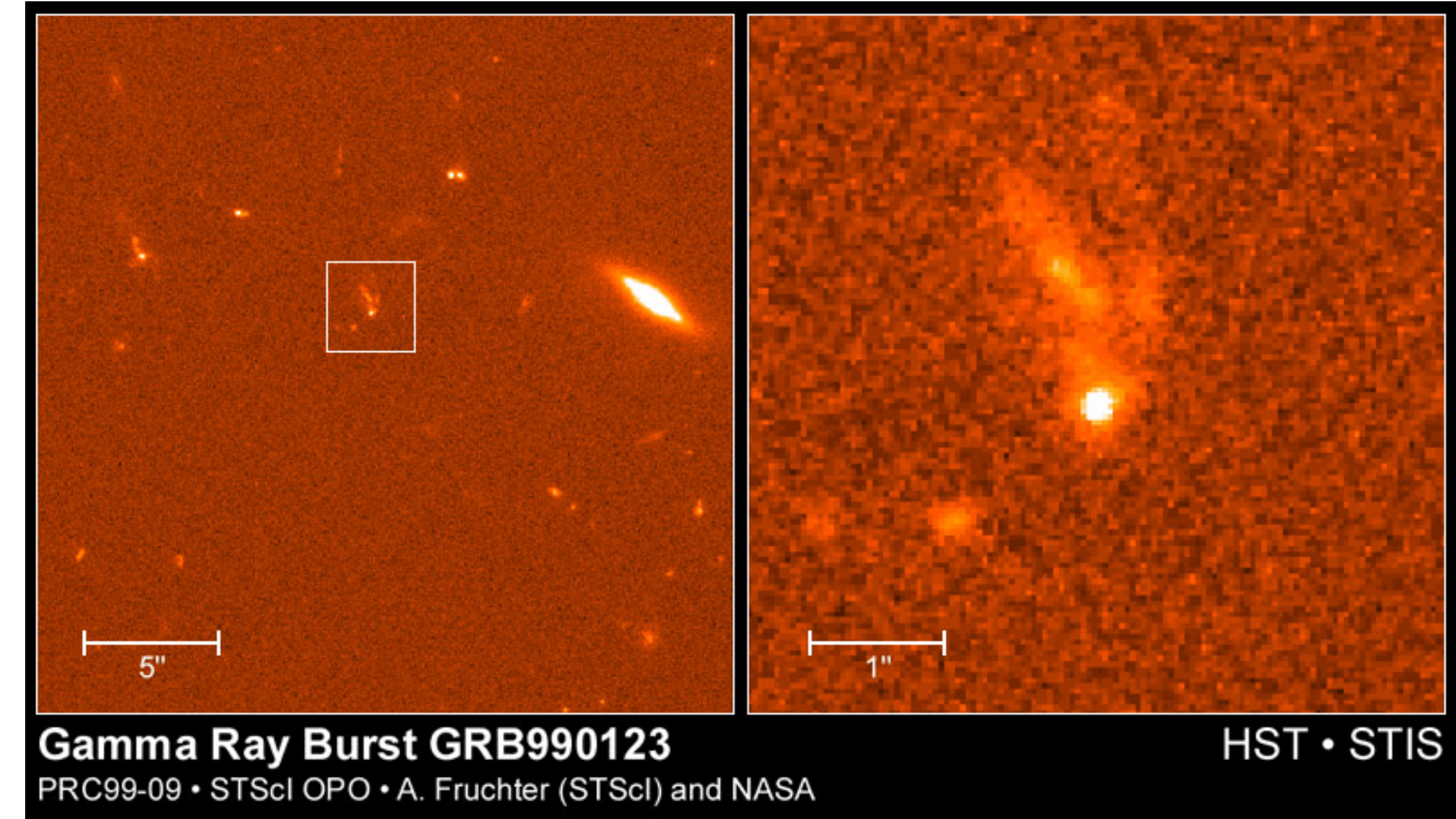
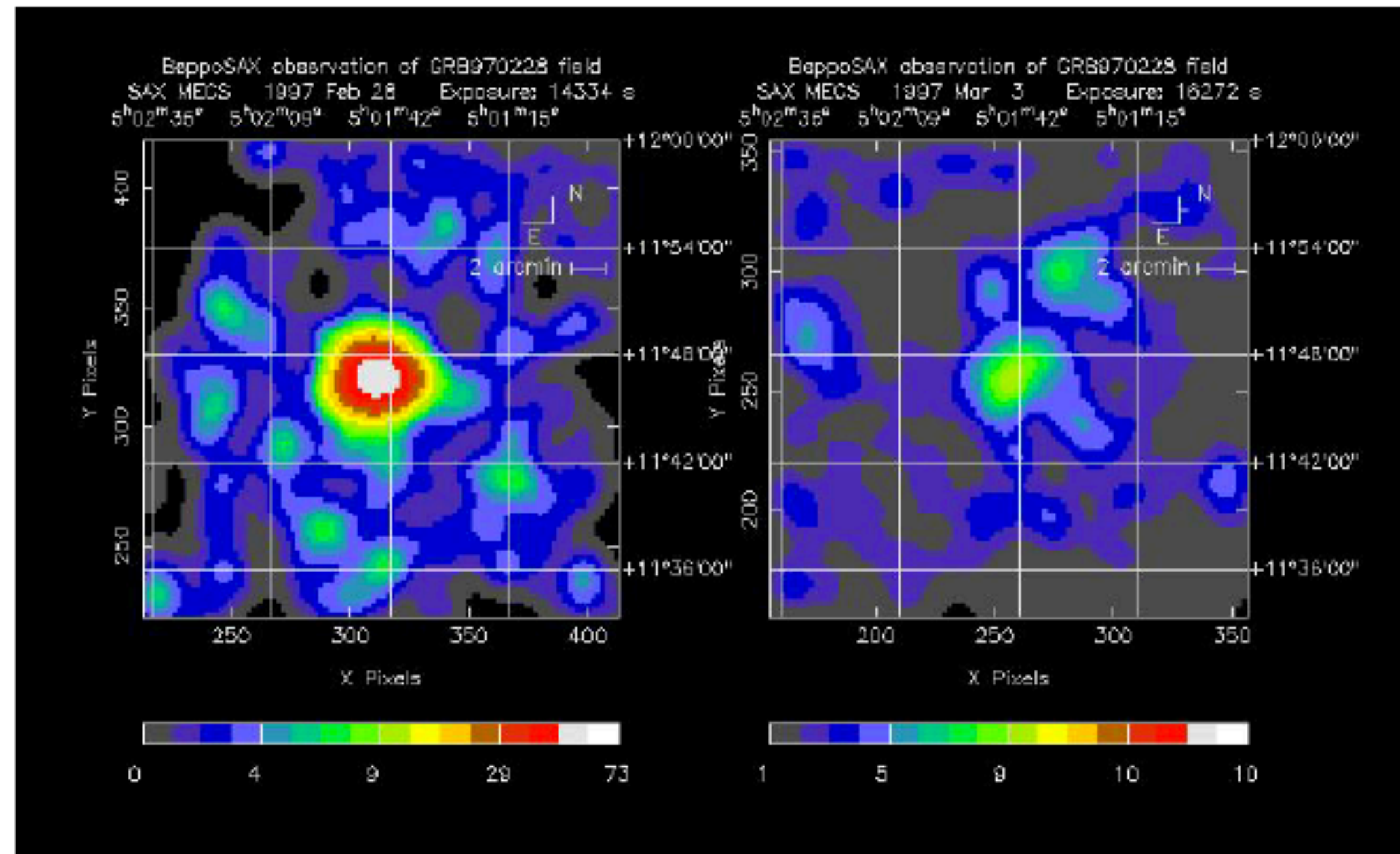


Figure 1.7: Localization of GRB 970228 observed by BeppoSAX. The left image is the X-ray emission in the  $\gamma$ -ray instrument error box taken  $\sim 8$  hours after trigger while the right image is taken  $\sim 3$  days after trigger. A fainting source was clearly detected at the GRB location which is the first detection of an X-ray afterglow. Through the subsequent measurement of the host galaxy redshift, this was the first conclusive evidence of the extragalactic nature of long GRBs.

“Afterglows”



GRB 080319B

Naked eye

$m = 5.3$

$z = 0.937$

[https://www.pi.fuw.edu.pl/results/highlights/grb080319b\\_normal/](https://www.pi.fuw.edu.pl/results/highlights/grb080319b_normal/)

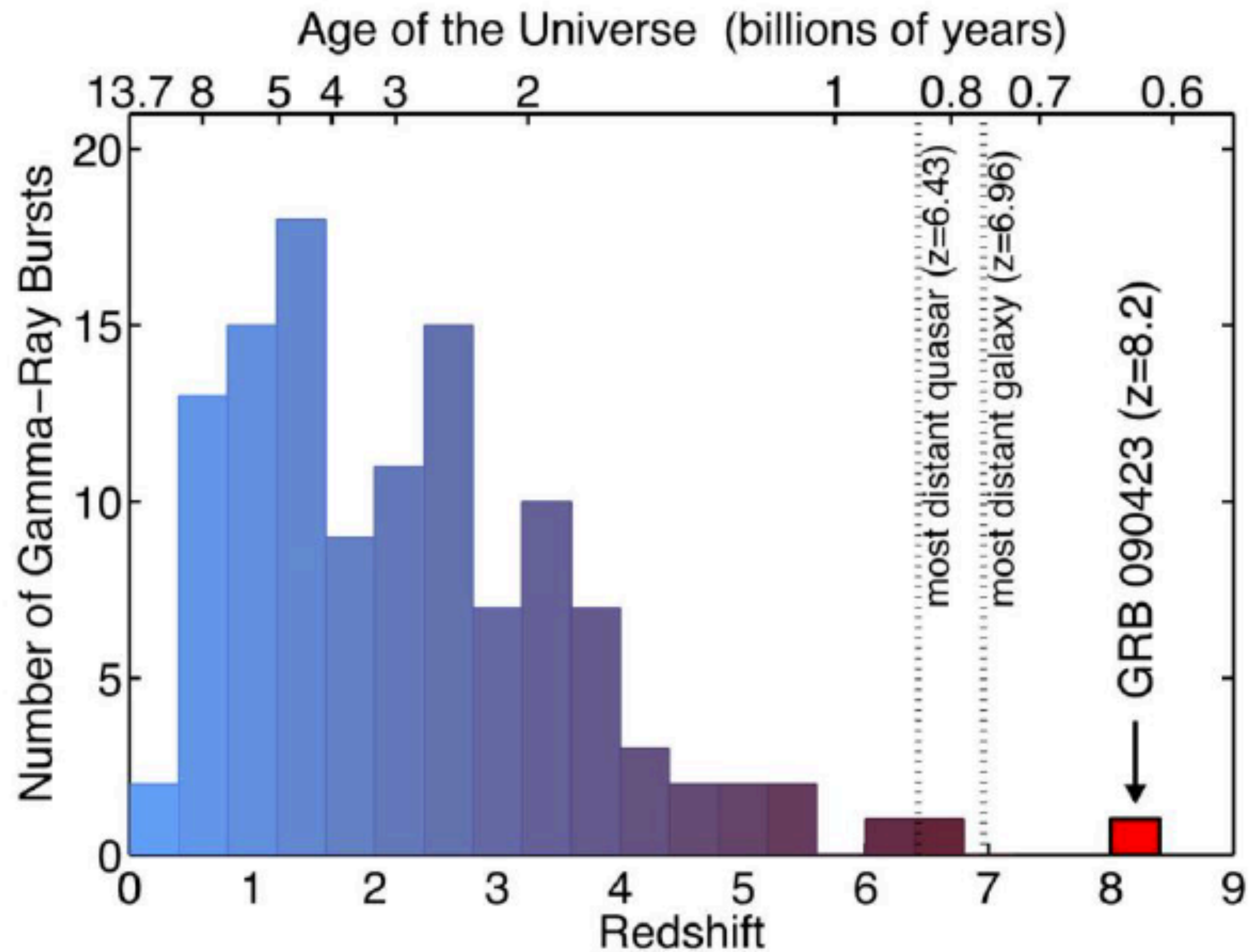
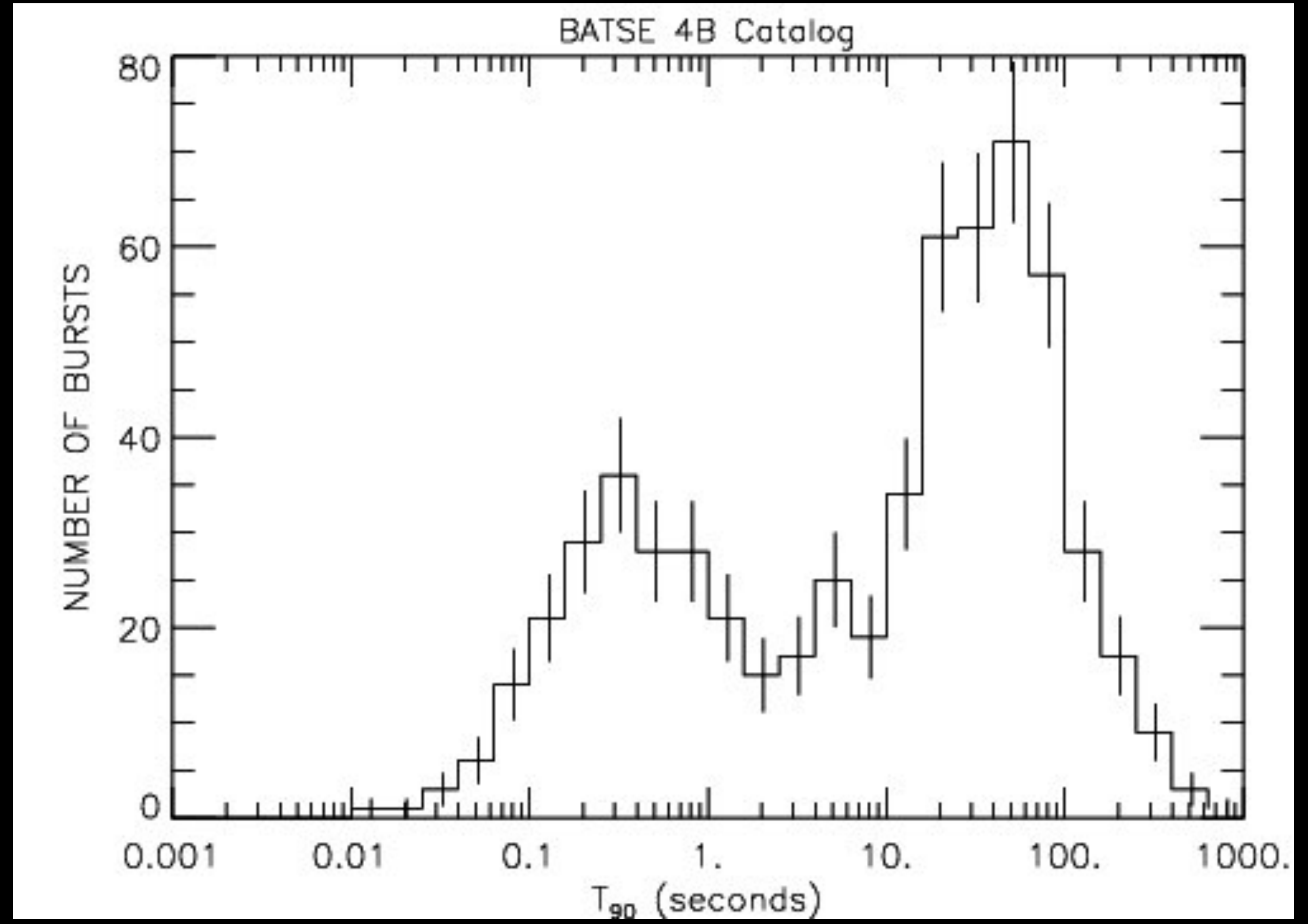
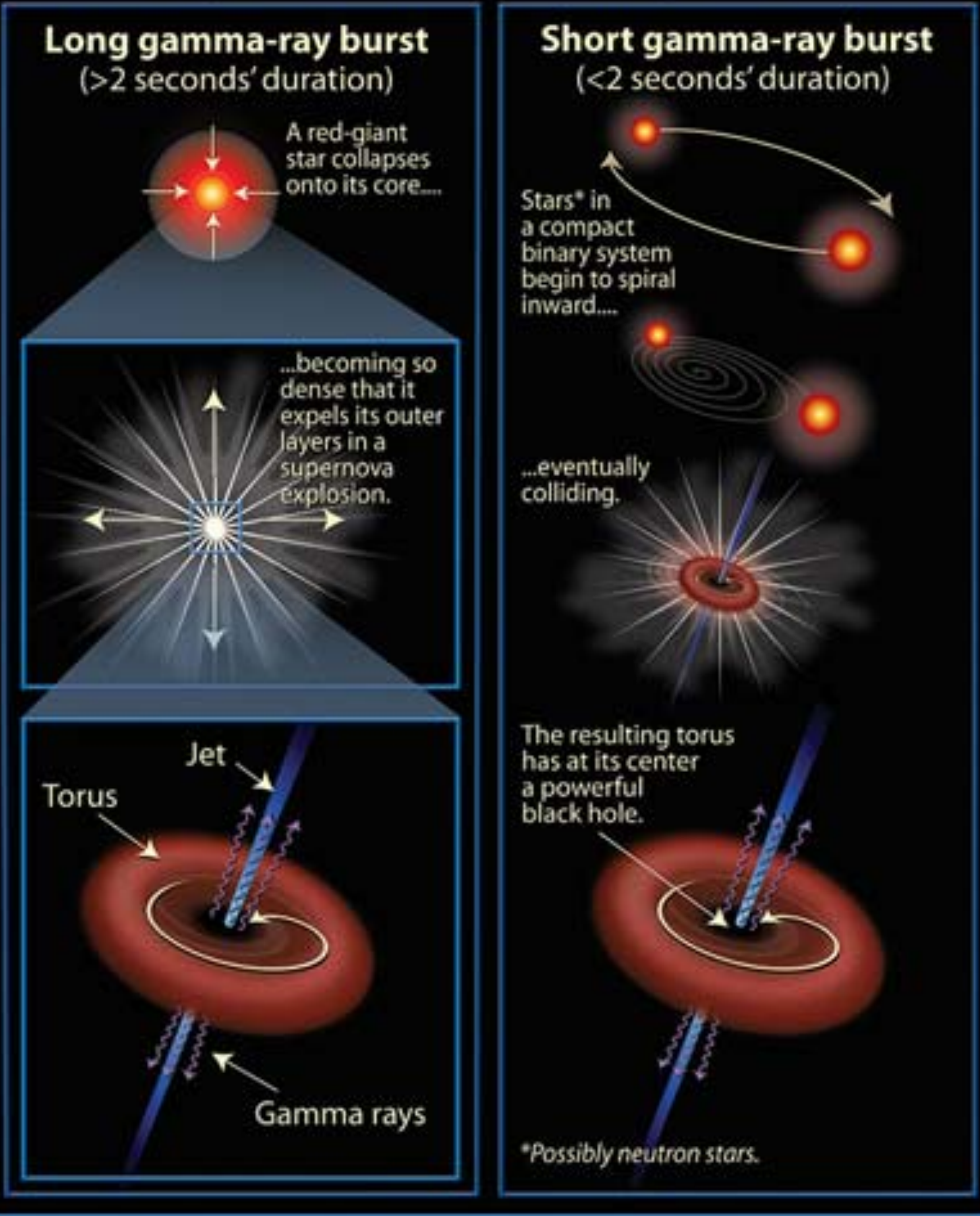
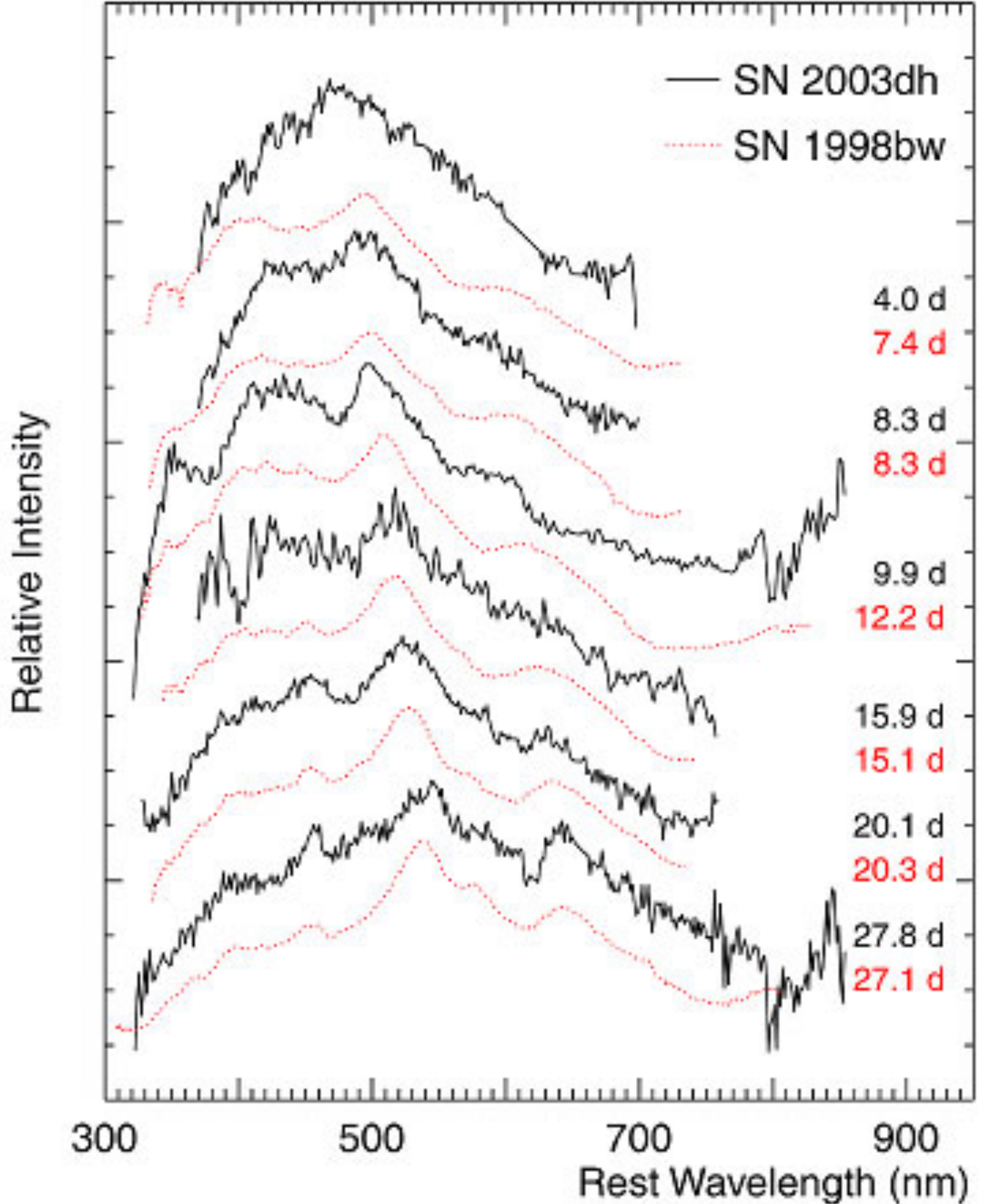


Figure 1.10: Redshift distributions of GRBs detected up to the 23<sup>rd</sup> of April 2009, when the highest redshift GRBs was discovered at  $z = 8.2$ . Credit: Edo Berger (Harvard/CfA)

# Gamma-Ray Bursts (GRBs): The Long and Short of It





Visual Spectra of Hypernova in GRB 030329  
 (VLT + FORS)

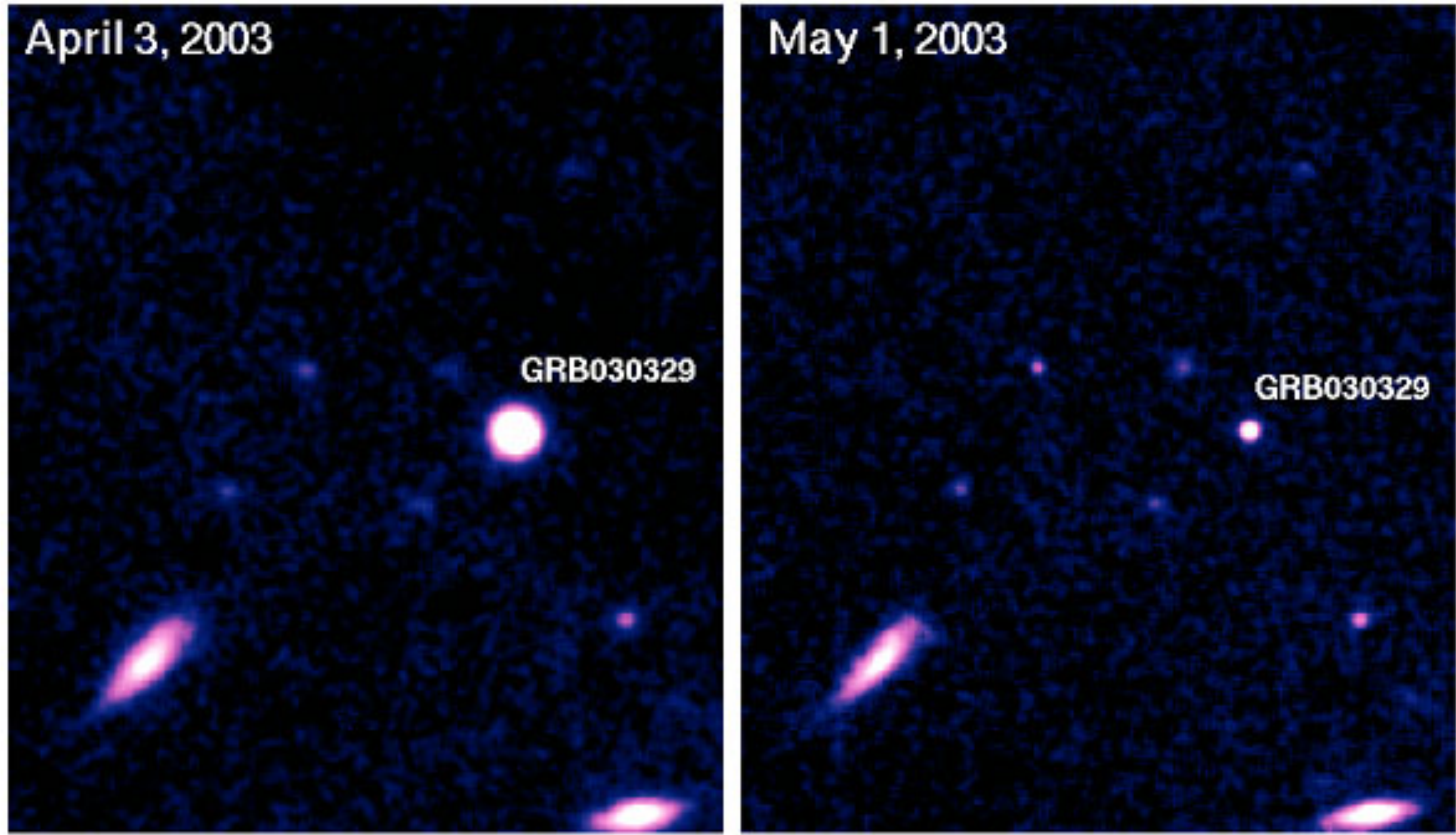


Image of Afterglow of GRB 030329  
 (VLT + FORS)

ESO PR Photo 17a/03 (18 June 2003)

©European Southern Observatory

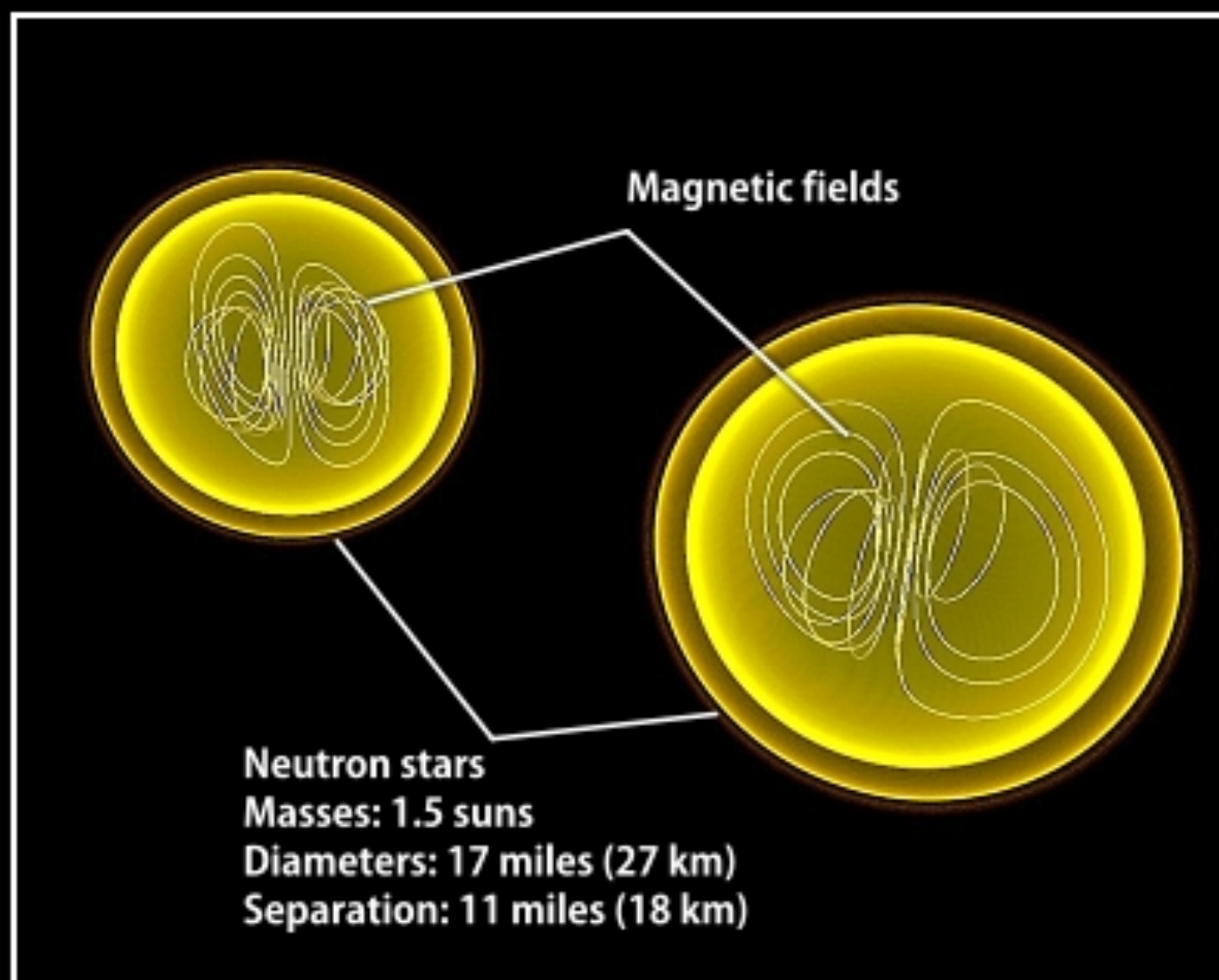


ESO PR Photo 17b/03 (18 June 2003)

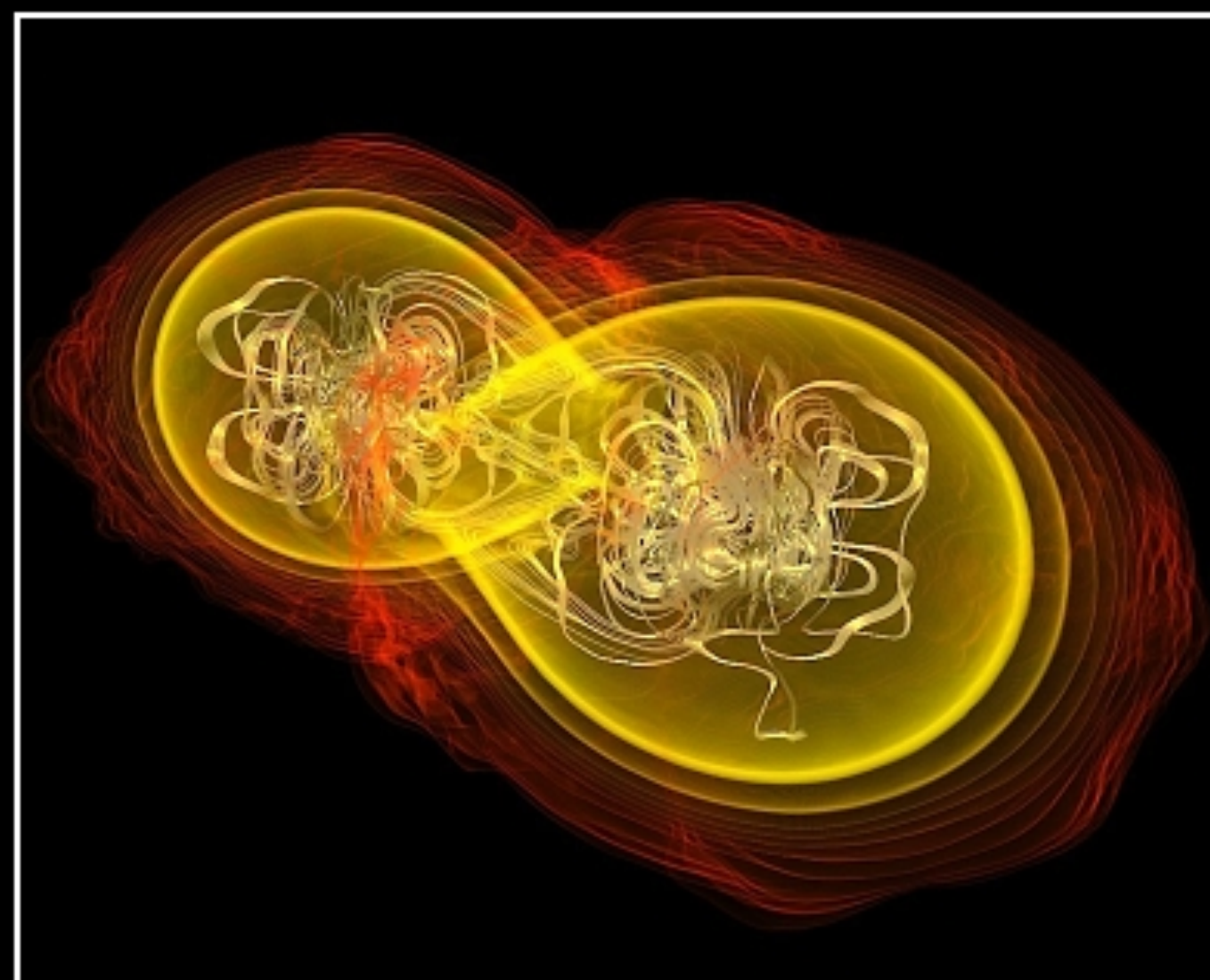
©European Southern Observatory



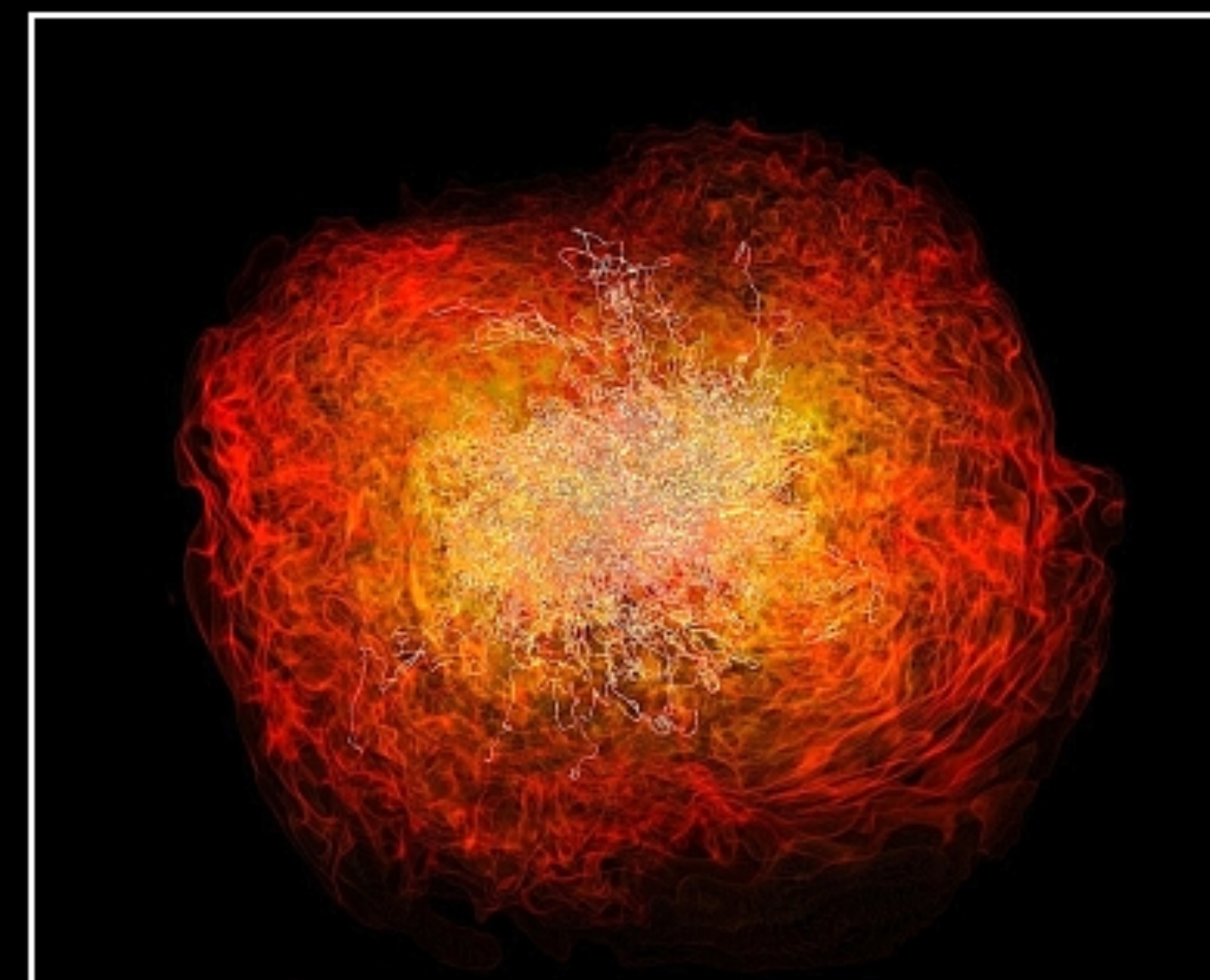
# Crashing neutron stars can make gamma-ray burst jets



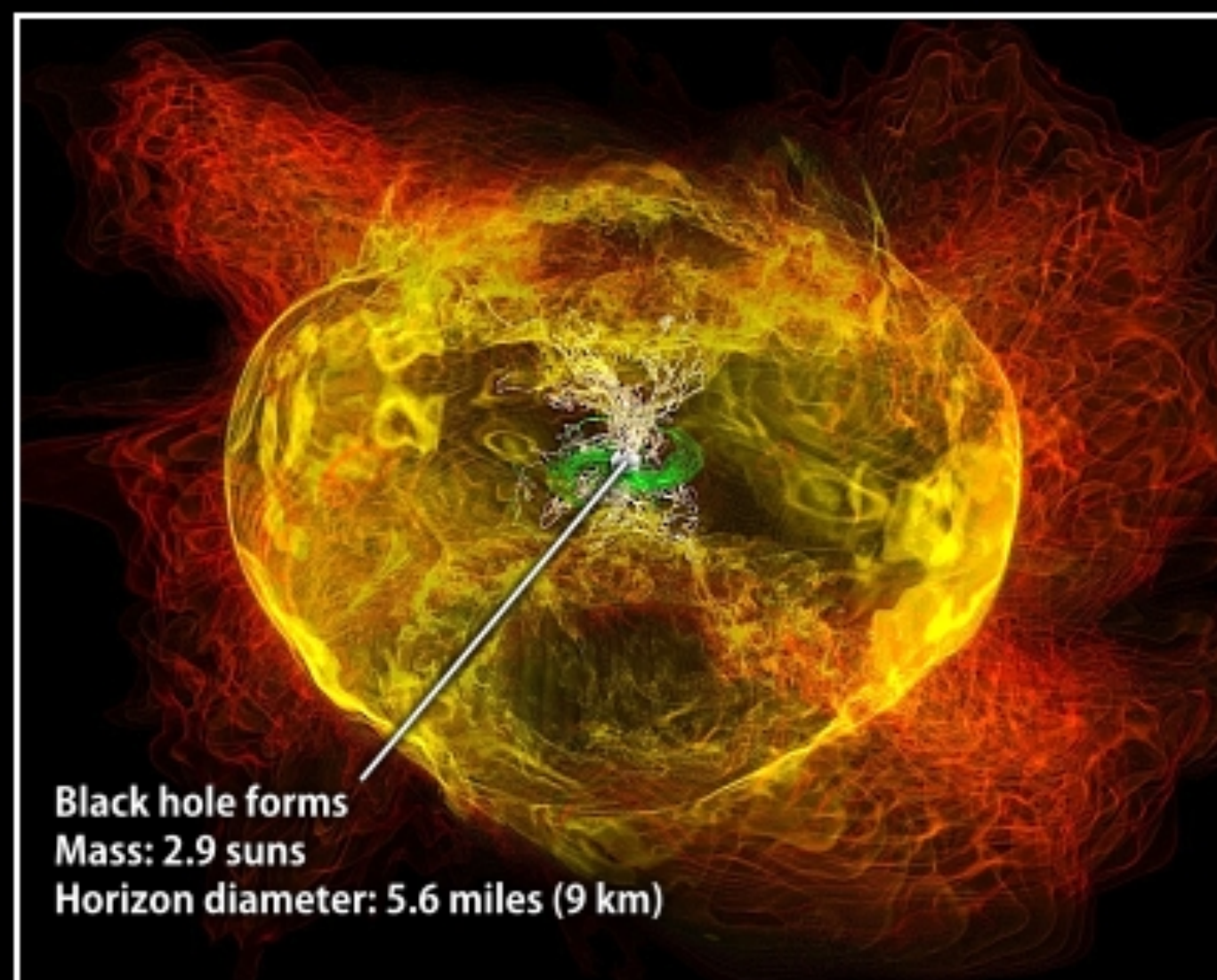
Simulation begins



7.4 milliseconds



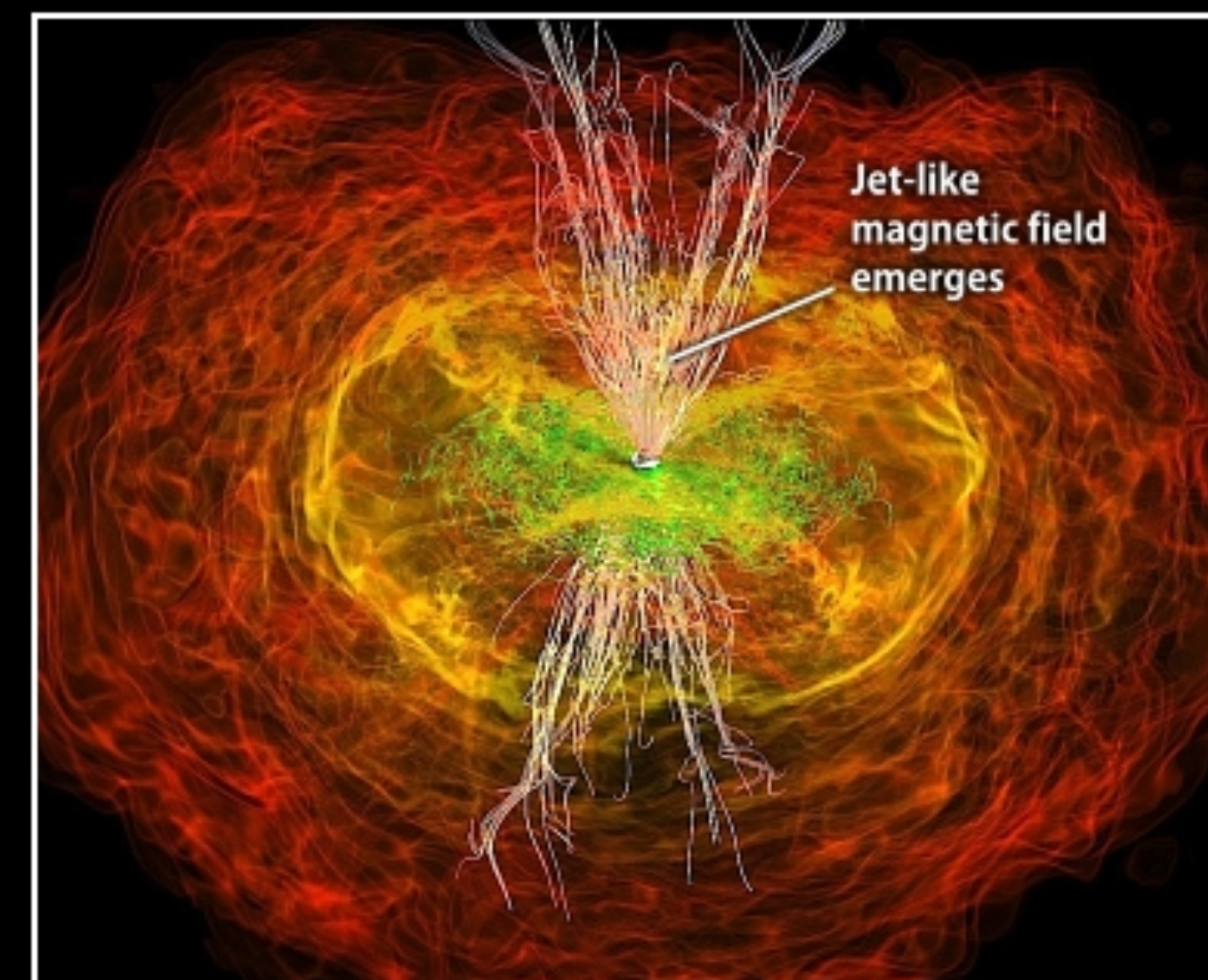
13.8 milliseconds



15.3 milliseconds



21.2 milliseconds



26.5 milliseconds

