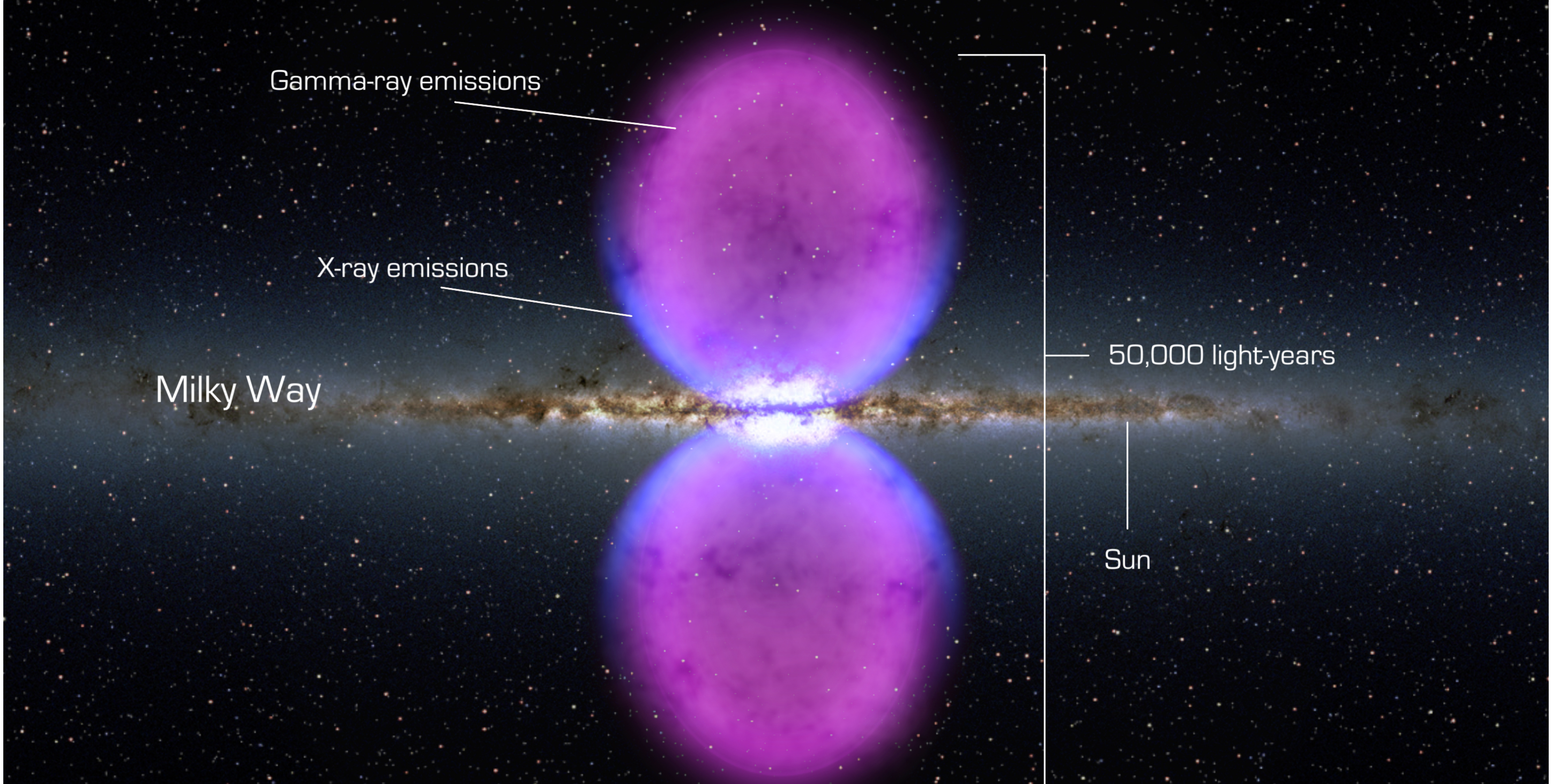
Stochastic nature of feedback processes in galaxies

Joss Bland-Hawthorn (U. Sydney)



Astro-ph/1309.5455 – posted at 10am today

The Astrophysical Journal, 776:1 (15pp), 2013 ???
doi:10.1088/0004-637X/776/1/1

FOSSIL IMPRINT OF A POWERFUL FLARE AT THE GALACTIC CENTER ALONG THE MAGELLANIC STREAM

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Question: Sgr A★ is 10^8 below Eddington today. When was it last a full blown Seyfert?

Outline:

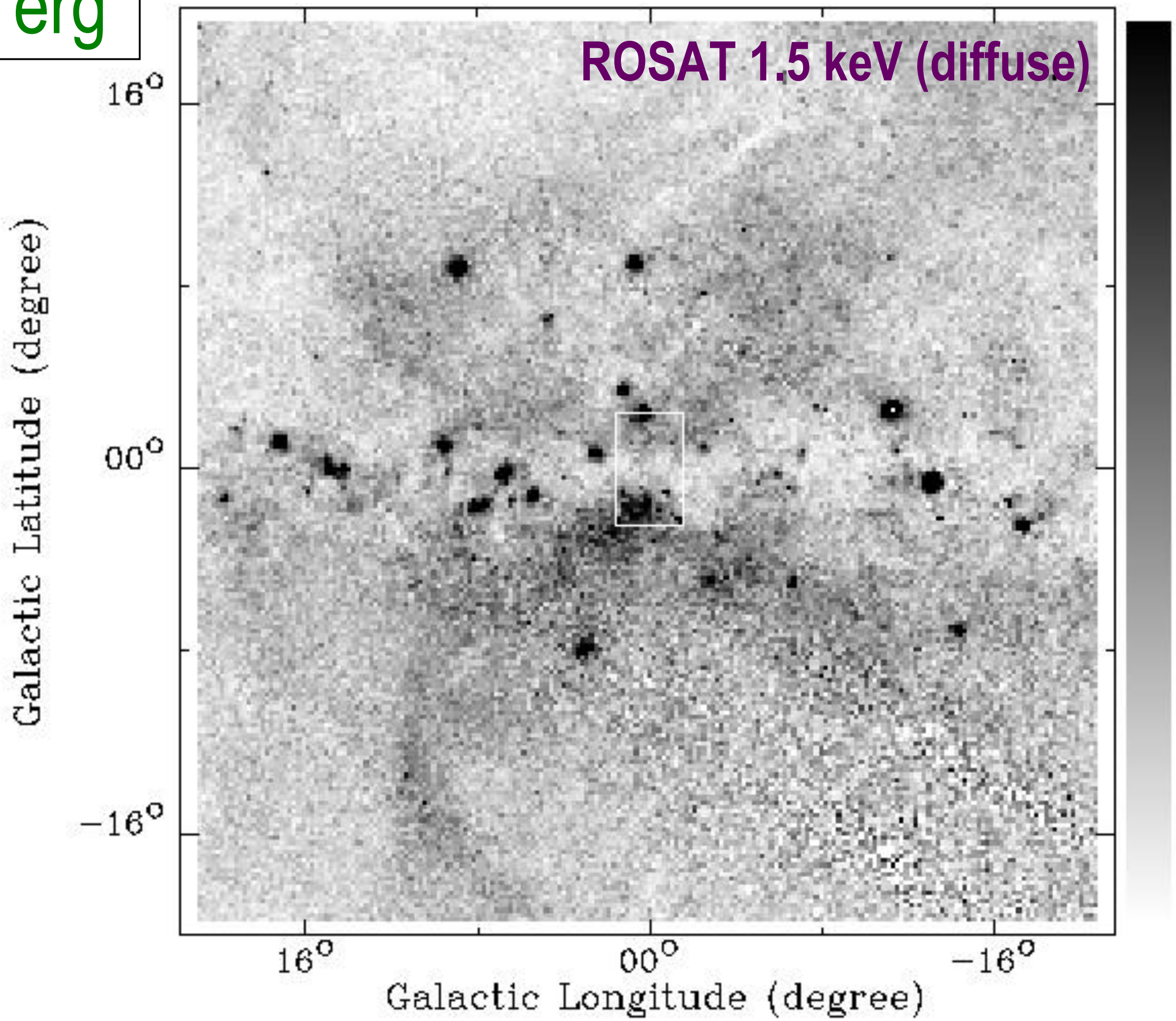
Energetic feedback (2003-13): starburst or AGN?
Fermi bubbles mystery solved (2011-13)
Magellanic Stream mystery solved (1996-2013)
New insight on AGN feedback (2011-13)
Better prescription for galaxy models

The Galaxy's bipolar wind seen on 10 kpc scales…

AGN or starburst driven?

JBH & Cohen (2003)

Estimated energy ~ 10^{55} erg



Two key observations argue for a Galactic Centre outflow:

1. GC bipolar structure not seen in soft X-rays (JBH & Cohen 2003)

2. hard X-ray bipolar structure never seen in OB blow-outs

(McClure-Griffiths+ 2005)

Giant Gamma-Ray Bubbles at the Galactic Centre

Su+ 2010

5

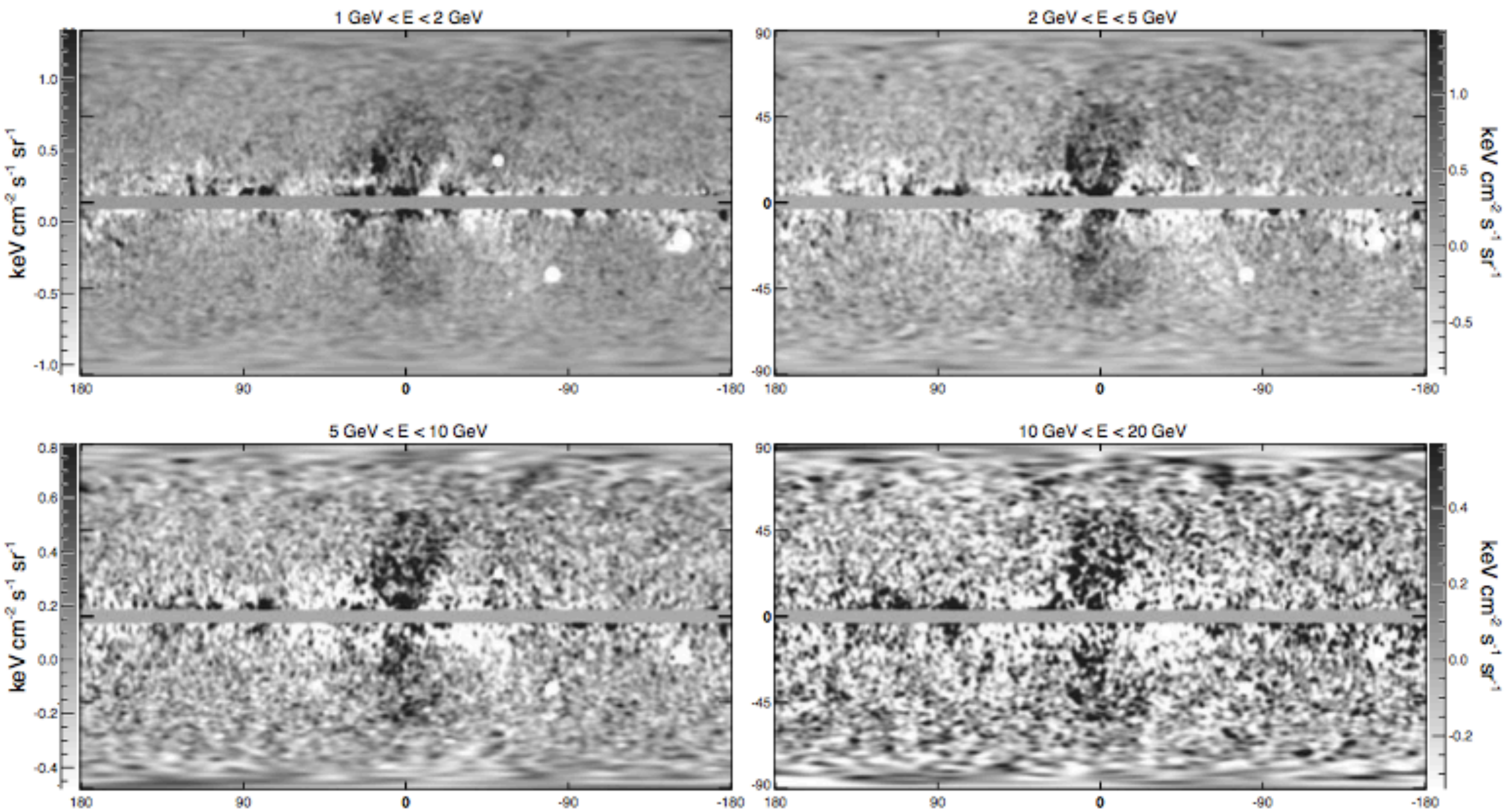
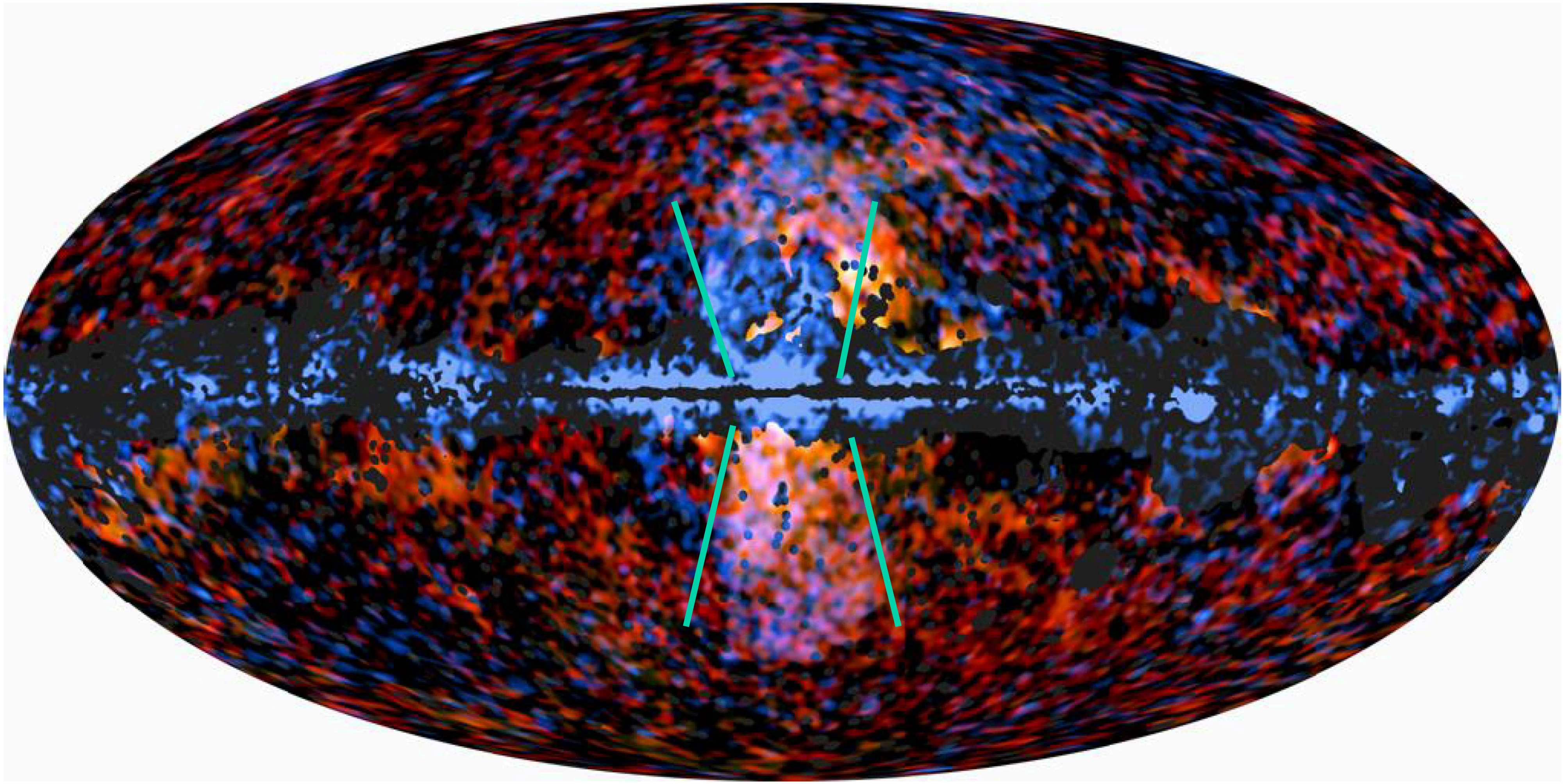


FIG. 2.— All-sky residual maps after subtracting the *Fermi* diffuse Galactic model from the LAT 1.6 year maps in 4 energy bins (see §3.1.1). Two bubble structures extending to $b \pm 50°$ appear above and below the GC, symmetric about the Galactic plane.

Radio counterpart

30 & 44 GHz (red and yellow) vs gamma-rays (blue)



(Planck collaboration, 2012)

Guo & Mathews 2012

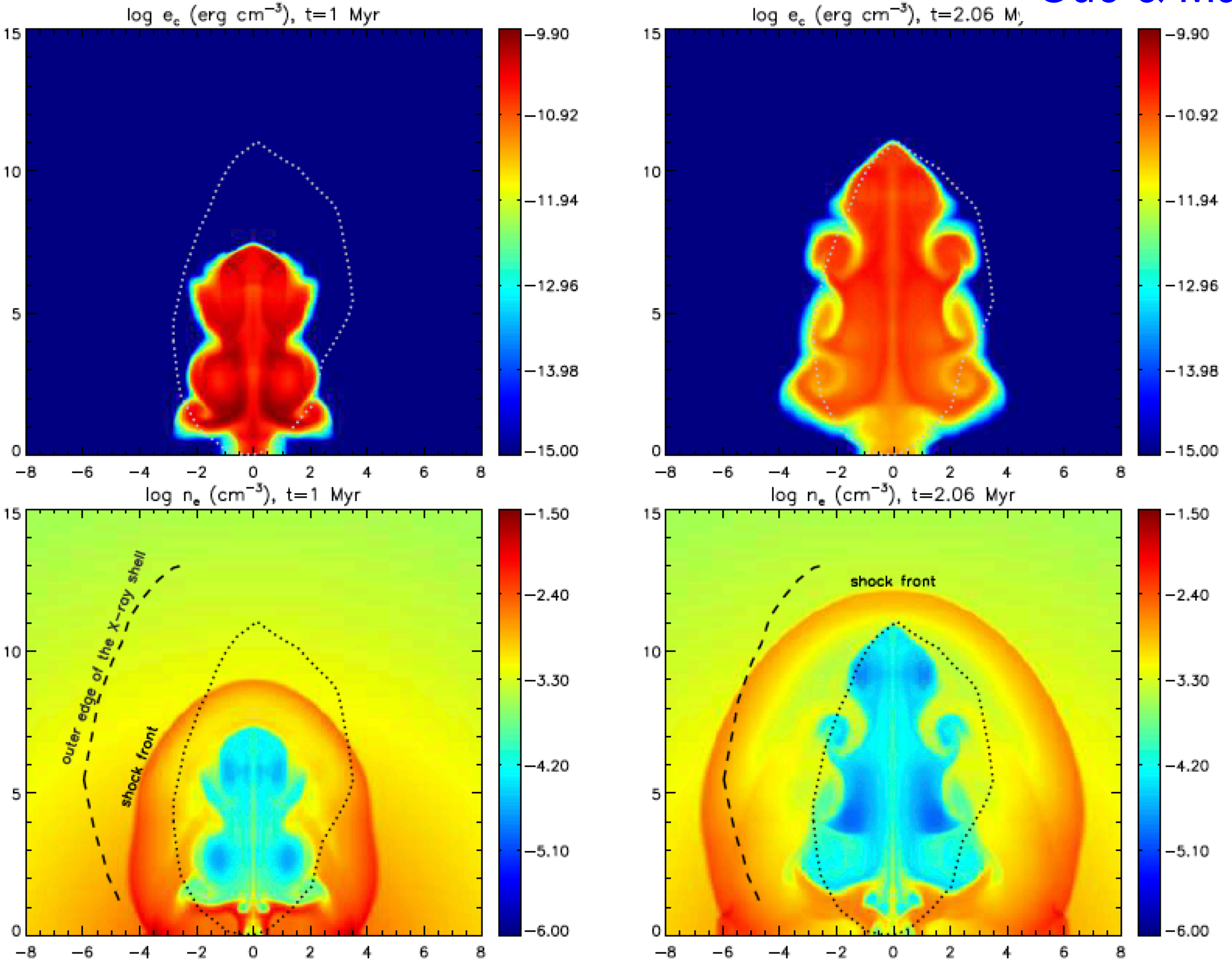


FIG. 2.— Central slices (16 × 15 kpc) of CR energy density (top panels) and thermal electron number density (bottom panels) in logarithmic scale in run A1 at $t = 1$ Myr (left panels), and $t = t_{\rm Fermi} = 2.06$ Myr (right panels). Horizontal and vertical axes refer to R and z respectively, labeled in kpc. The dotted region in each panel approximately encloses the observed north *Fermi* bubble. The propagation of the AGN jet, active for only $t_{\rm jet} = 0.3$ Myr, produces a CR bubble at $t = 2.06$ Myr approximately matching the observed *Fermi* bubble. The dashed lines in bottom panels trace the outer edge of the *ROSAT* X-ray shell feature in the northeastern direction (which is most prominent), and is roughly spatially coincident with the jet-induced shock at $t = 2.06$ Myr.

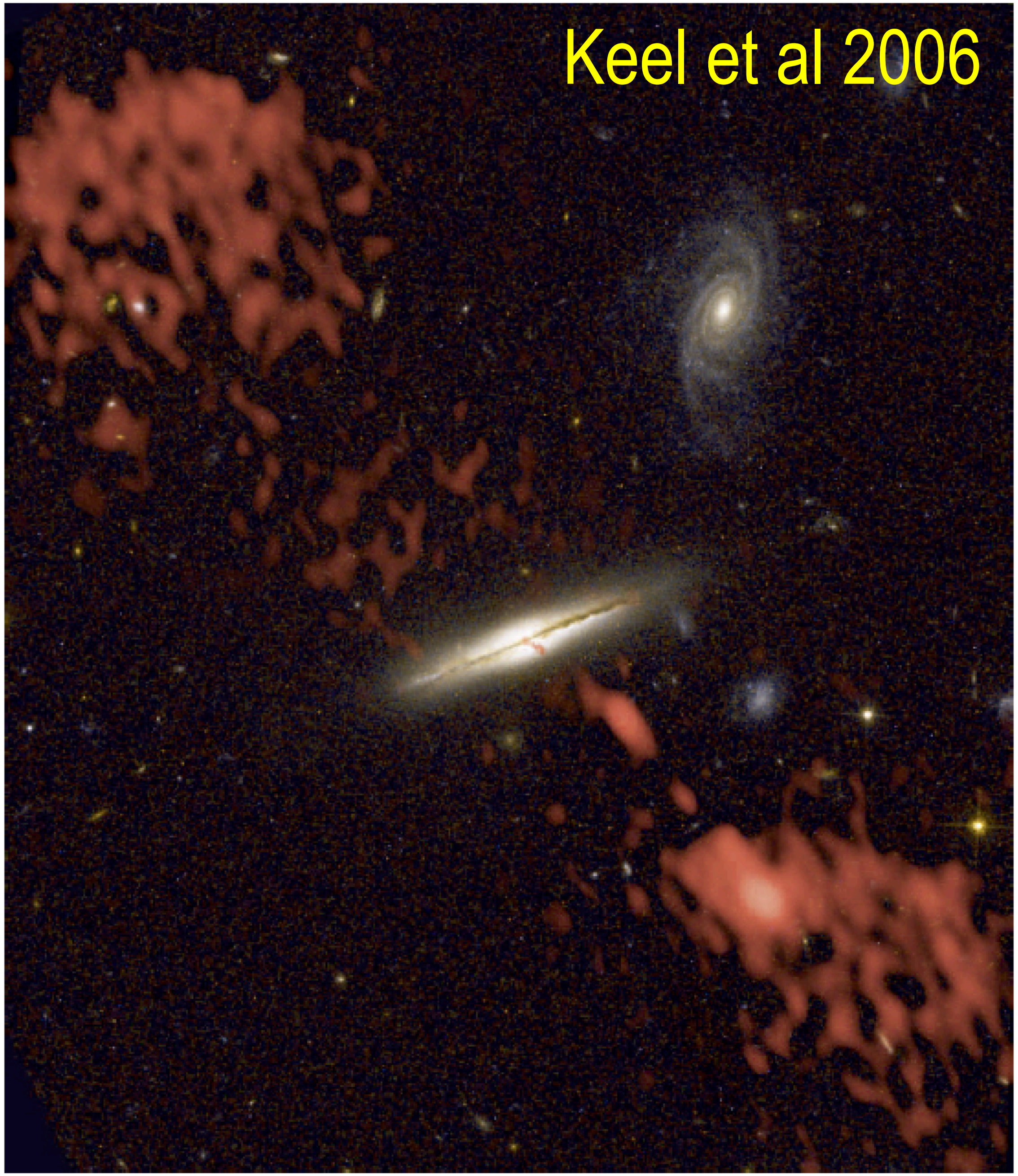


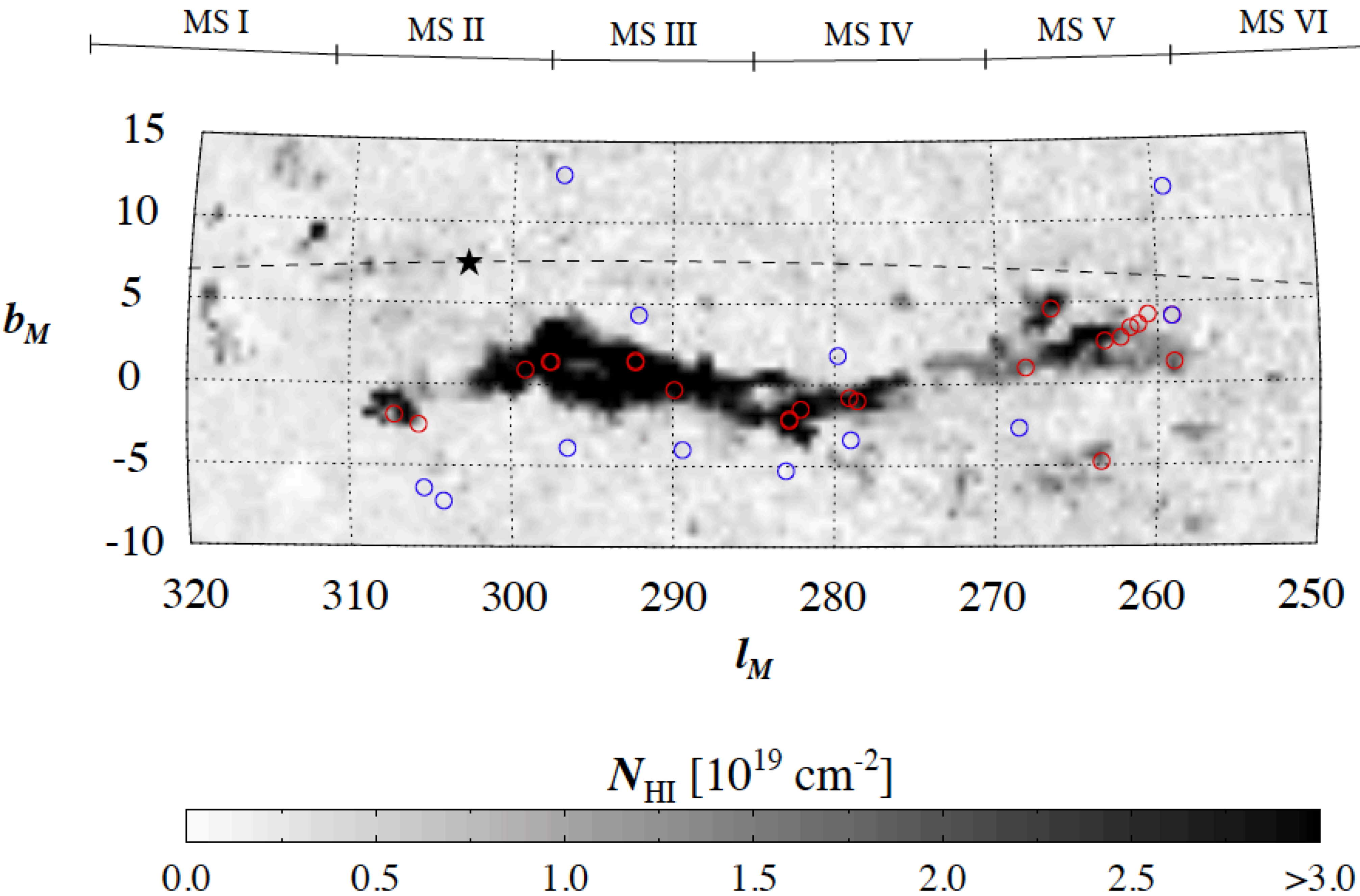
Fig. 1.—Radio galaxy 0313−192 and its environment in a color composite produced from the ACS images in F555W and F814W. The red overlay shows the VLA 20 cm structure, encompassing a wide field of 82″ × 96″ to show most of the radio source. Multiple arrays have been combined to retain higher resolution in the kiloparsec-scale jet. This image is available as STScI-PRC03-04. North is about 20° counterclockwise from the top. The less inclined spiral has a substantially different redshift and, while likely part of Abell 428, does not form a bound interacting system with 0313−192.

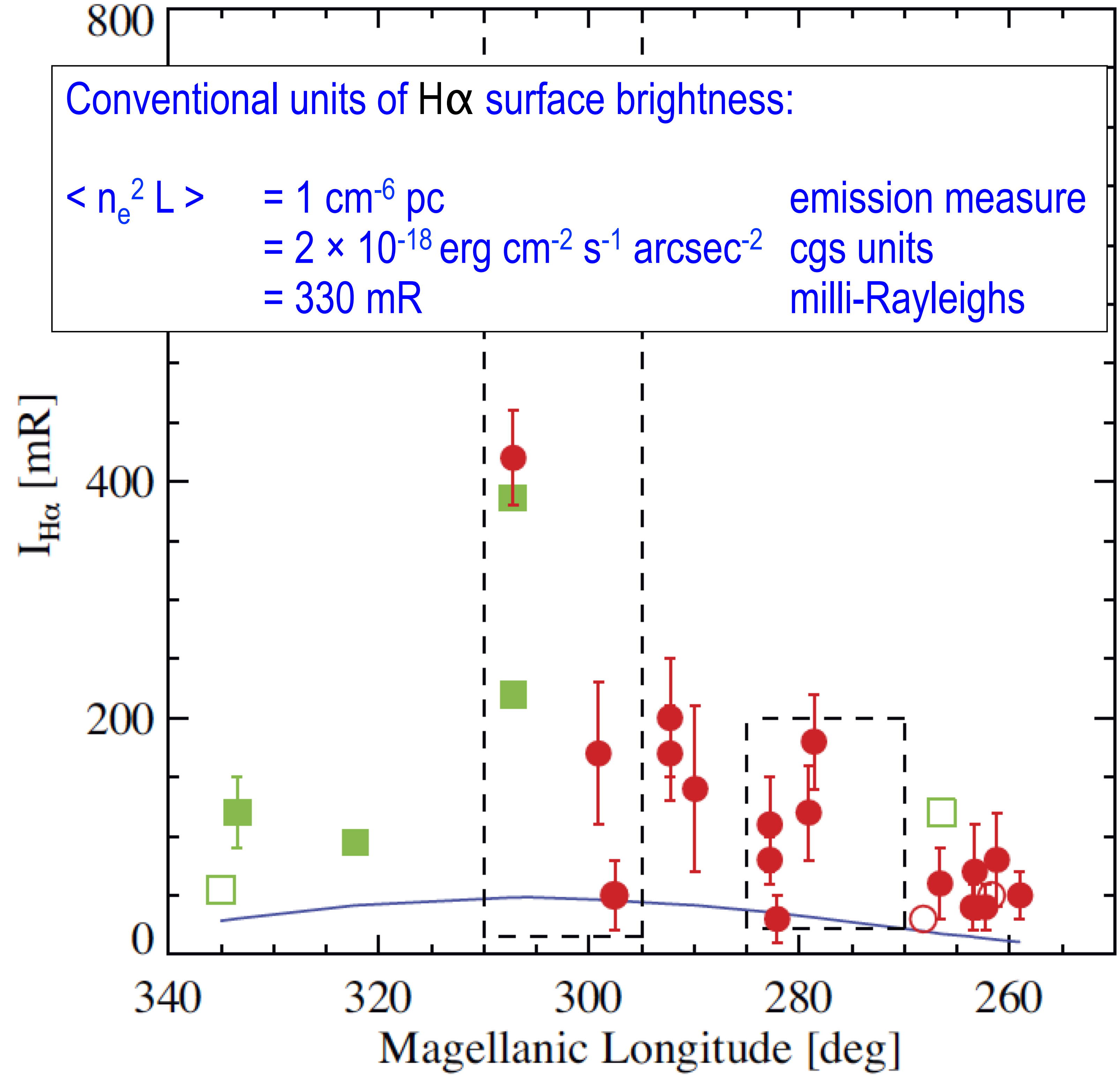
30 or more nearby Seyfert examples:

0313-192
NGC 1068
NGC 2992
NGC 3079
NGC 3801
NGC 5506
NGC 6764
Circinus
Markarian 6
M51
…

The mystery of the Magellanic Stream’s ionization

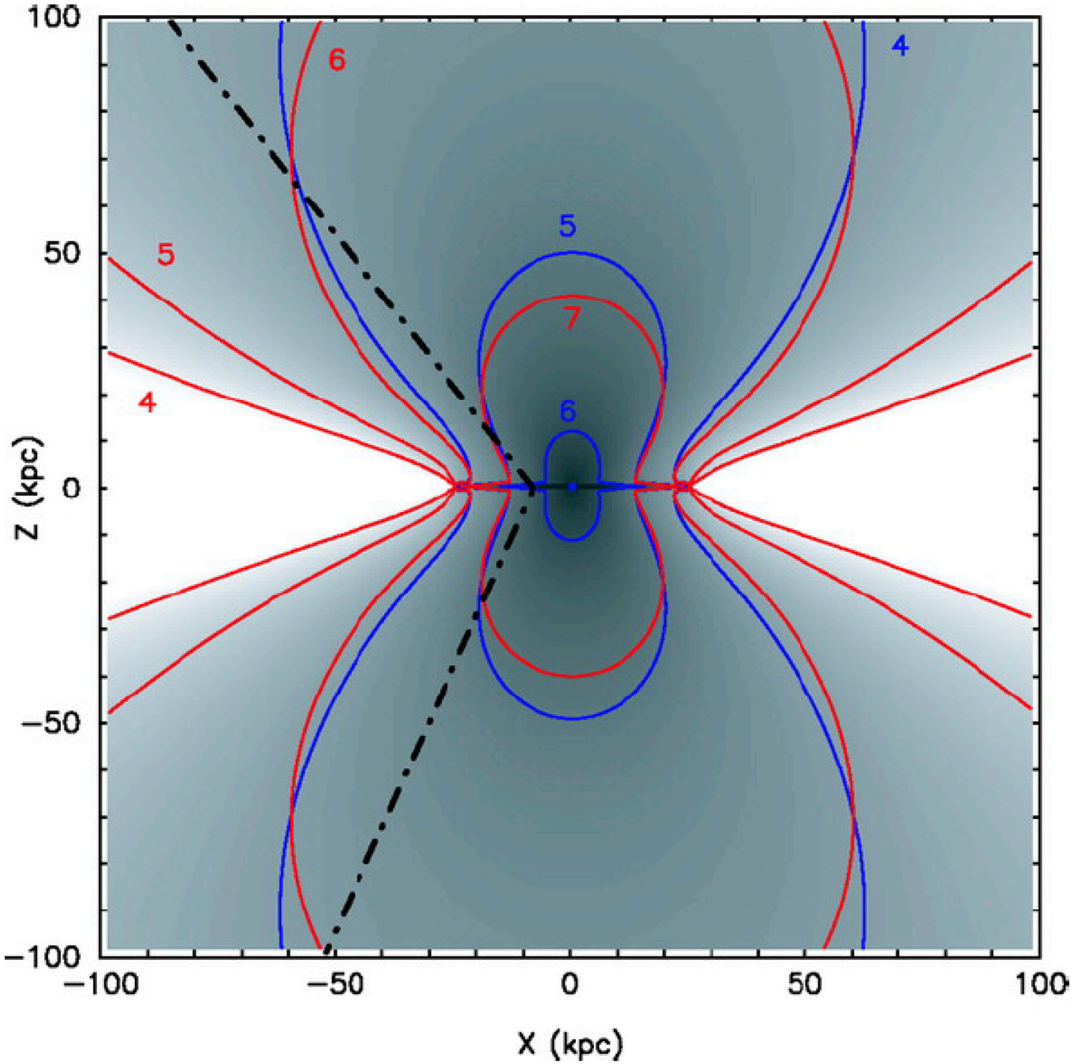
The Magellanic HI Stream





Conventional units of Hα surface brightness:
< n_e^2 L > = 1 cm^{-6} pc emission measure
= 2 × 10^{-18} erg cm^{-2} s^{-1} $arcsec^{-2}$ cgs units
= 330 mR milli-Rayleighs
$I_{H\alpha}$ [mR]
800
400
200
0
340
320
300
280
260
Magellanic Longitude [deg]

JBH & Maloney (1999, 2002)



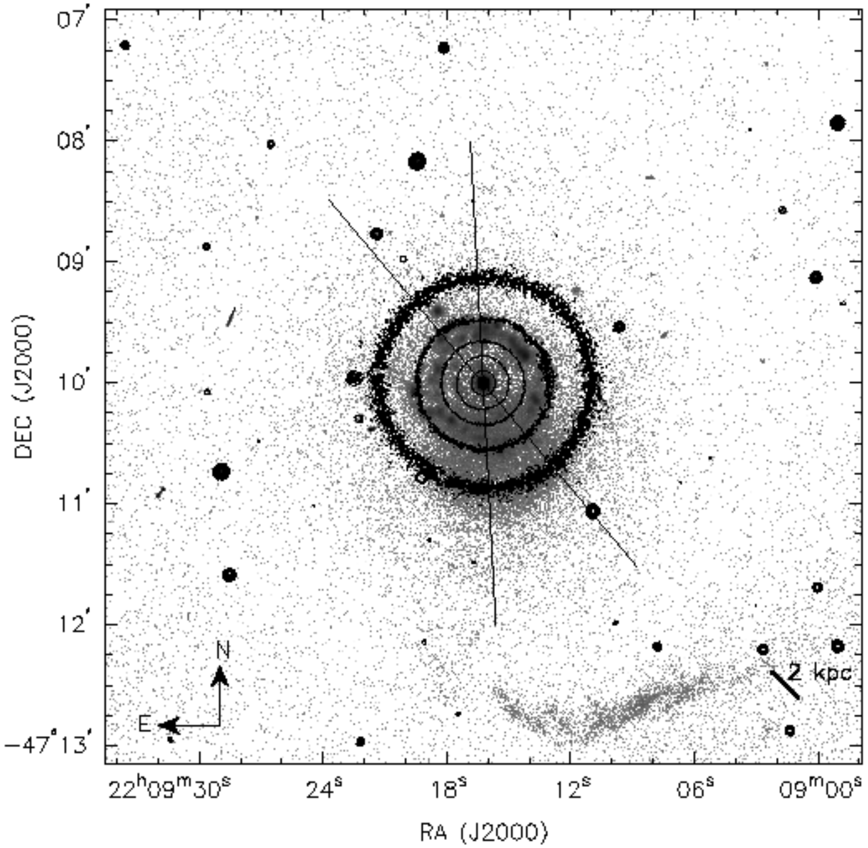
E > 13.6 eV
E < 13.6 eV

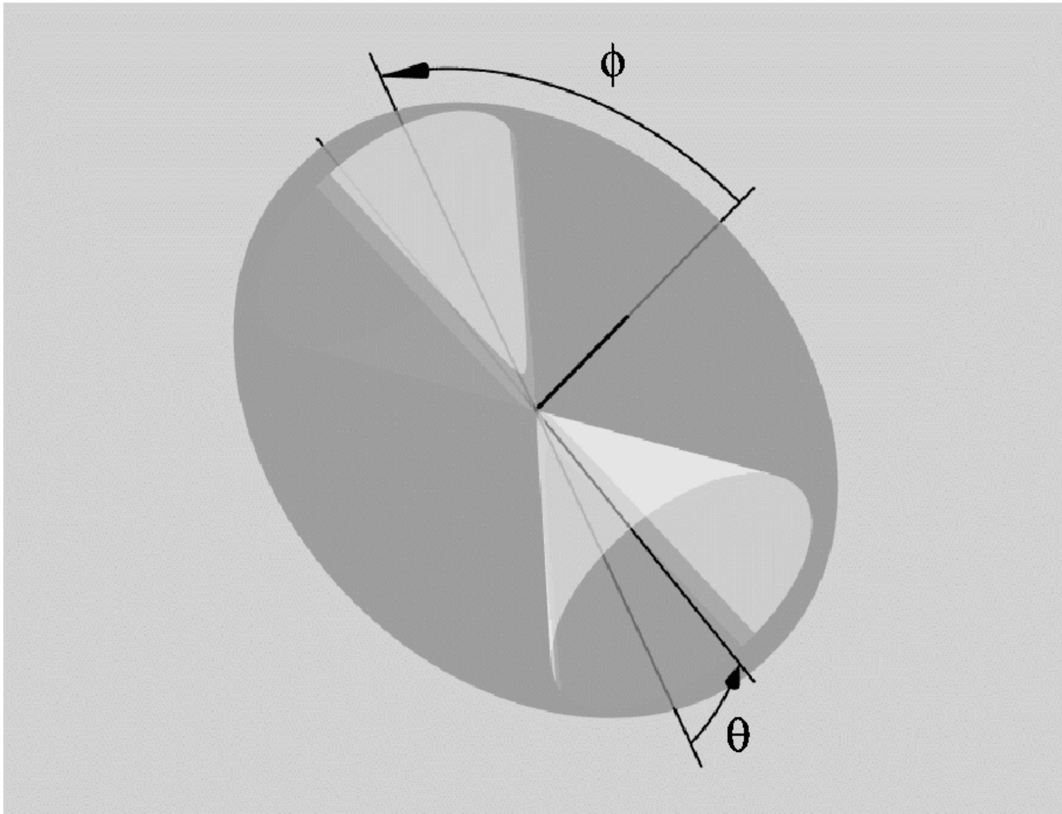
$$\mu_\star(\mathrm{H}\alpha) = 21\zeta \left(\frac{f_{\star,\mathrm{esc}}}{0.06}\right)\left(\frac{D}{55\ \mathrm{kpc}}\right)^{-2}\ \mathrm{mR}$$

Factor ~ 2 for poorly known UV sources

UV escape fraction

Seyfert NGC 7213 ionizes gas stream at r ~ 30 kpc

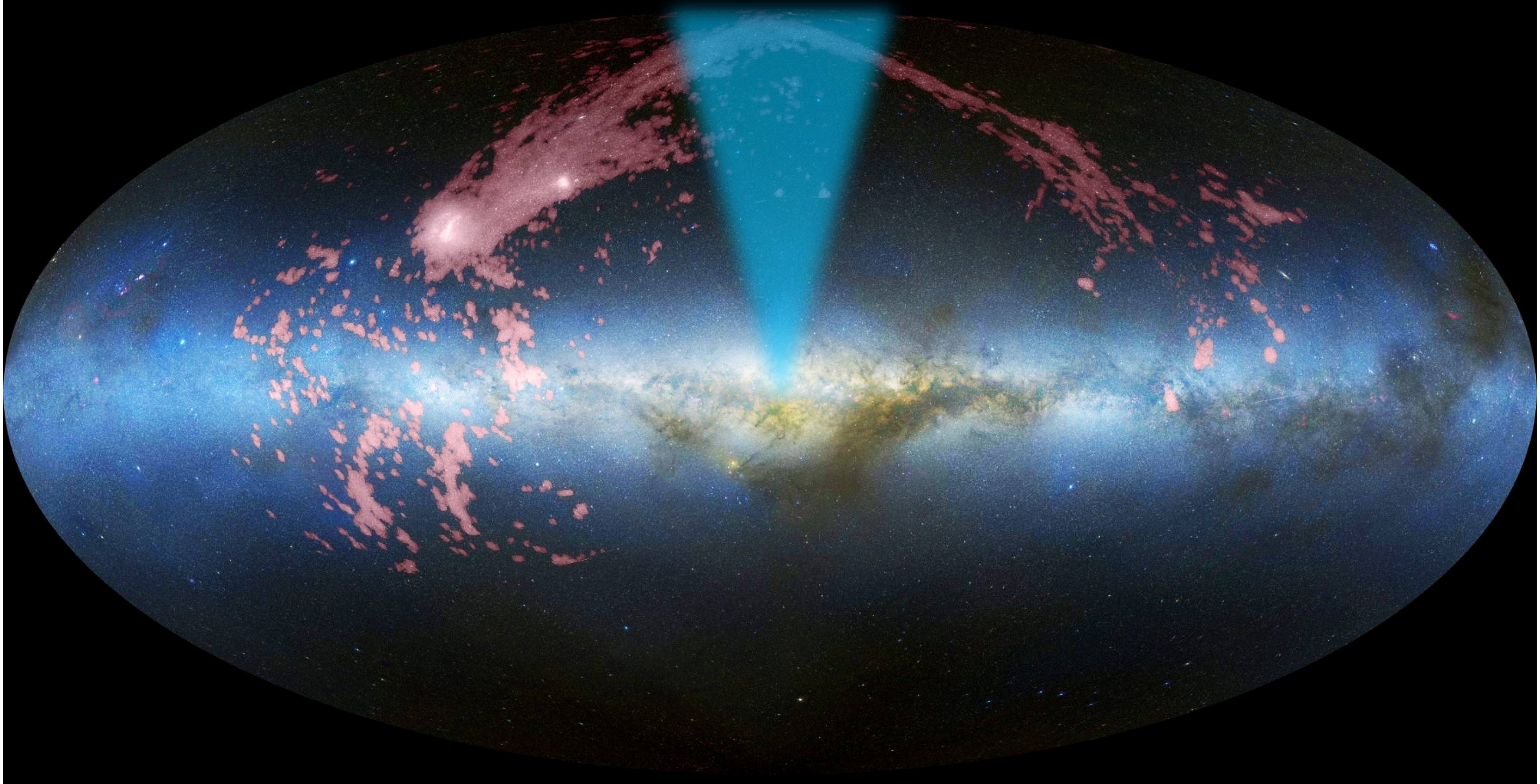




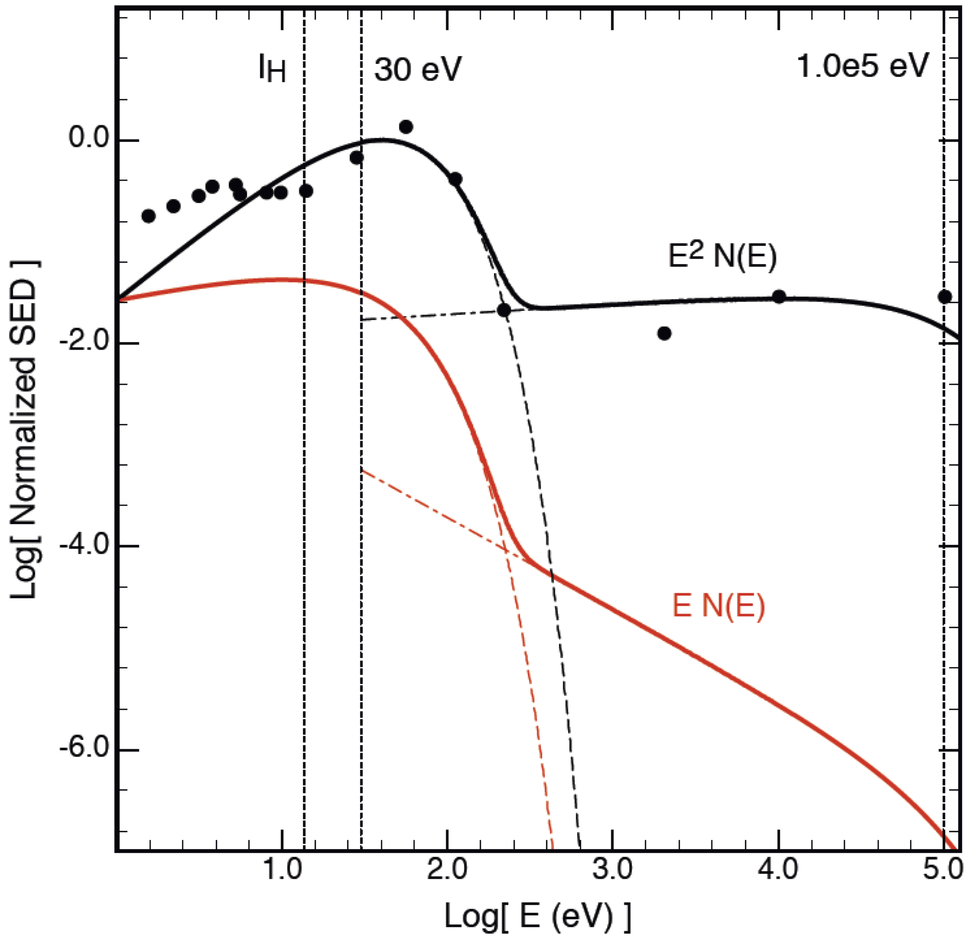
Galaxy Zoo has discovered dramatic ionization cones on scales ~ 10 kpc

New: Kreimeyer & Veilleux (2013) see ionization cone out to r ~ 90 kpc

The Stream's ionization powered by Seyfert activity?



AGN model



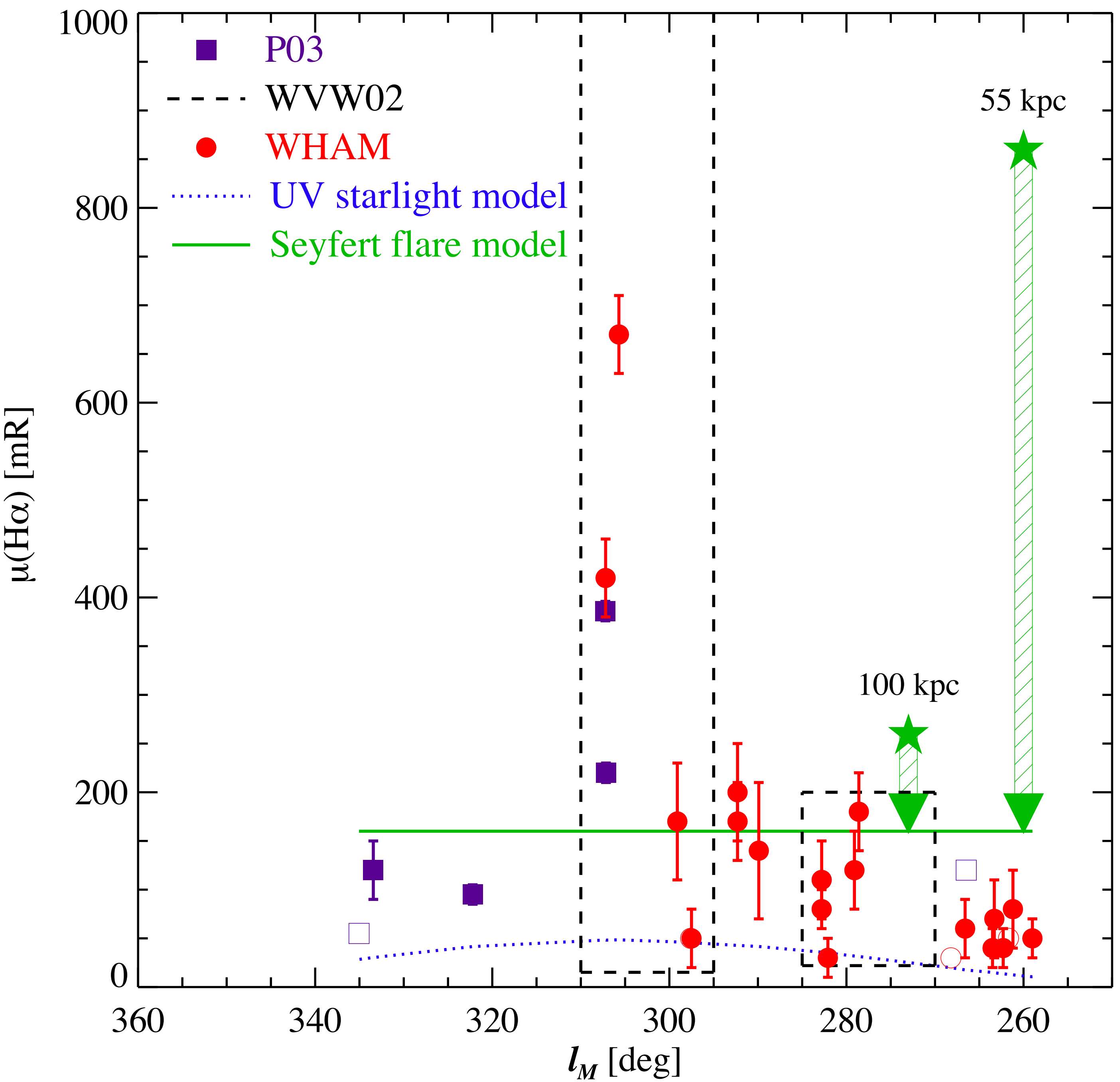
Eddington luminosity fraction

Peak brightness

$$\mu_\bullet(\mathrm{H}\alpha) = 825\, b \left(\frac{f_E}{0.1}\right)\left(\frac{f_{\bullet,\mathrm{esc}}}{1.0}\right)\left(\frac{D}{55\ \mathrm{kpc}}\right)^{-2}\ \mathrm{mR}$$

Beam factor

UV escape fraction

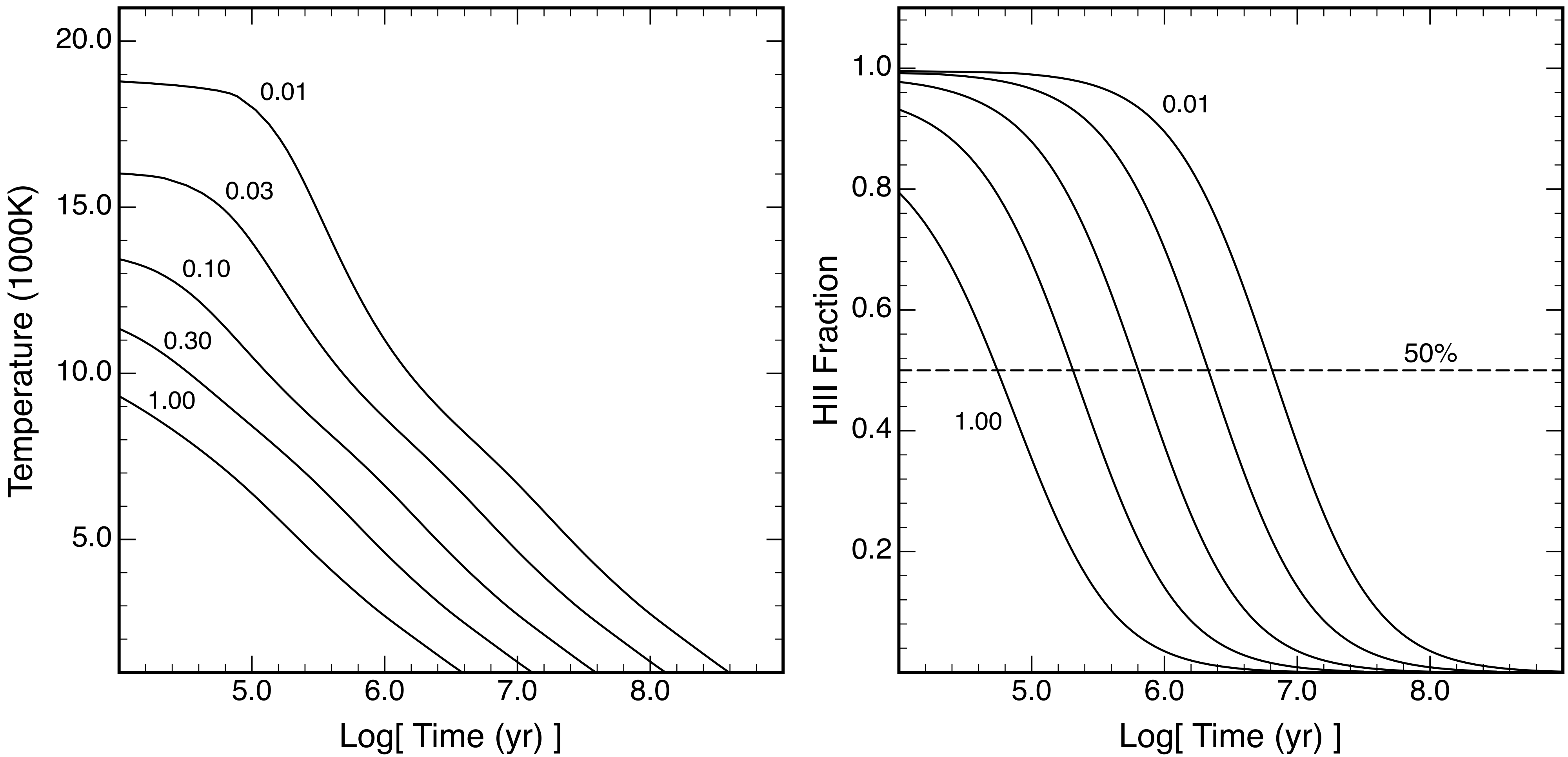


P03
WVW02
WHAM
UV starlight model
Seyfert flare model
55 kpc
100 kpc
μ(Hα) [mR]
l_M [deg]
0
200
400
600
800
1000
360
340
320
300
280
260

$f_E = 0.1$

Photoionizing flash followed by fading recombination emission

Recombination is faster than cooling



Time-dependent ionization using new MIV code

Timescales

Consider a Seyfert flare that took place at t = T_o for a burst time T_B

We must consider other timescales:

Double-crossing time T_C ~ $2x10^5$ $(D/55\ \mathrm{kpc})$ yr
Photoionization time T_P ~ $4x10^3\ \varphi_6$ yr
Recombination time T_R ~ $8x10^4\ /n_H$ yr

TABLE 1

MAPPINGS IV TIME-DEPENDENT IONISATION CALCULATIONS[a]

(a) 55 kpc

$n_H(\text{cm}^{-3})$	$d_m(\text{pc})$	$\mathcal{E}_m(\text{cgs})$	$\mathcal{E}_m(\text{mR})$	$T_R(\text{yr})$	$T_o(\text{yr})$
1.0	9	4.8e-18	844	1.3e5	4.9e5
0.3	**63**	**4.8e-18**	**848**	**4.3e5**	**7.9e5**
0.1	**404**	**4.8e-18**	**849**	**1.4e6**	**1.8e6**
0.08	**1423**	**4.8e-18**	**852**	**2.5e6**	**2.9e6**
0.03	3461	4.9e-18	858	4.7e6	5.1e6

(b) 100 kpc

$n_H(\text{cm}^{-3})$	$d_m(\text{pc})$	$\mathcal{E}_m(\text{cgs})$	$\mathcal{E}_m(\text{mR})$	$T_R(\text{yr})$	$T_o(\text{yr})$
1.0	4	1.4e-18	251	3.0e4	7.5e5
0.3	**31**	**1.5e-18**	**258**	**1.0e5**	**8.2e5**
0.1	**178**	**1.5e-18**	**258**	**3.2e5**	**1.0e6**
0.03	**1345**	**1.5e-18**	**257**	**1.2e6**	**1.9e6**
0.01	9230	1.5e-18	259	4.2e6	4.9e6

Best estimate is Seyfert flash at T_o ~ 1-3 Myr ago

Final slide of Guo & Mathews (2013 Kavli talk)

Summary: The Fermi Bubbles

- The Fermi bubbles can be created with a recent AGN jet activity about 1 – 3 Myr ago, which lasted for ~ 0.1 – 0.5 Myr.
- The estimated energy of the event is ~ 10^{55} – 10^{57} ergs, depending on the gas densities in the Galactic halo.
- The jet activity produces a strong shock, which heats and compresses the hot halo gas, potentially explaining the ROSAT X-ray features
- Many physical processes play important roles in this event, including magnetic draping, shear viscosity, cosmic-ray diffusion

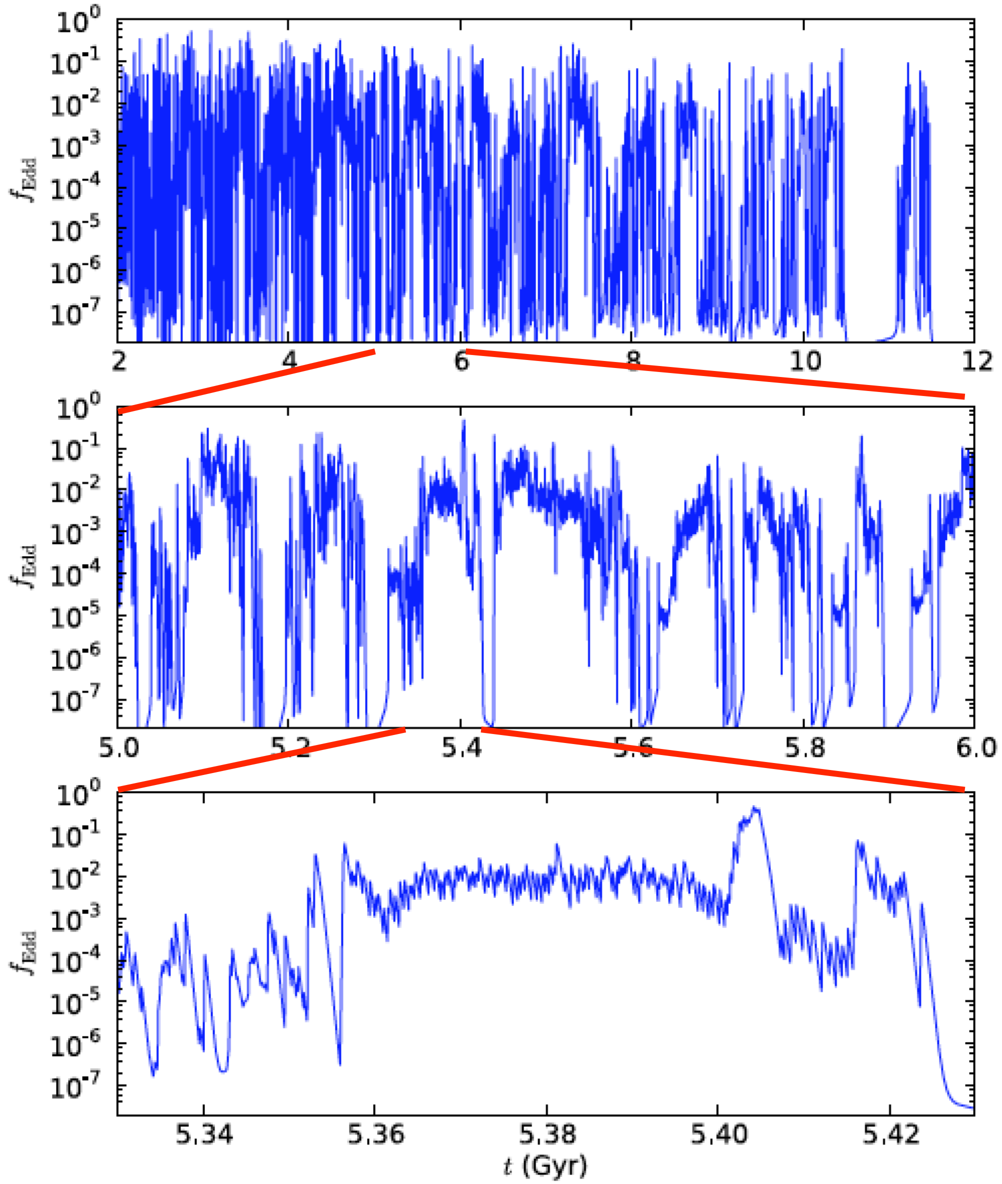


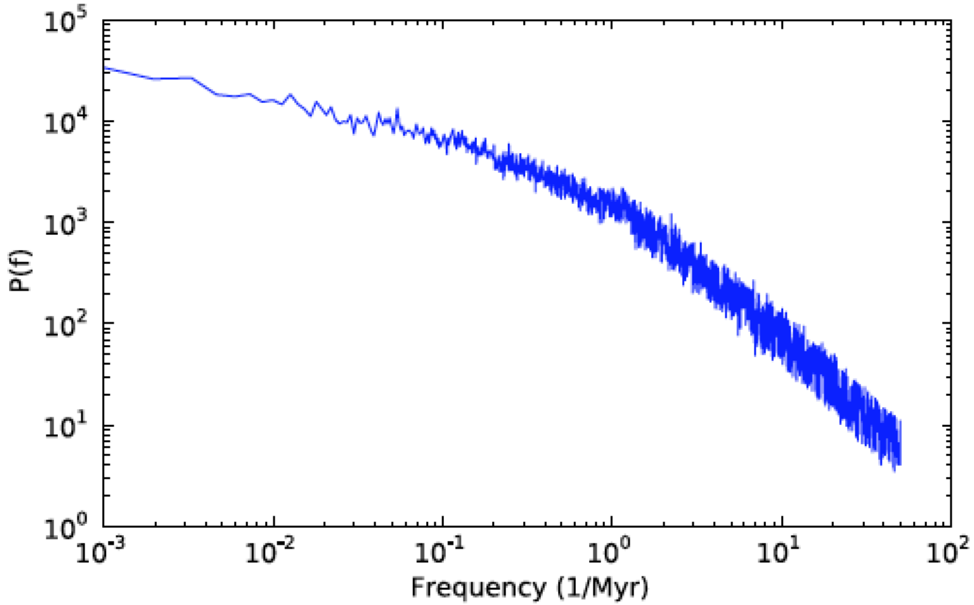
Figure 6. Eddington ratio as a function of time, for three different time intervals in the A2 simulation.

Novak, Ostriker & Ciotti (2011, 2012):

SMBH growth and accretion within CDM.

Complex activity on all temporal scales.

50 dB variation in 1 Myr largest seen in these simulations…



Final thoughts

Nuclear activity allows galaxies to be observed to z~7. The Galactic Centre provides us with a front-row seat.

The imprint of full-blown Seyfert activity is visible across the Stream.

Excellent match to the Fermi bubbles model: **alignment – energetics – timescale**.

SMBH feedback can be very strong but difficult to detect beyond the LG.

Hard to explain 80 dB variation in 2 Myr without MHD (Balbus).

We can expect great advances in GC research in the near future.