Relativistic kinematics, GRBs and COSMIC RAYs

COMMERCIALS

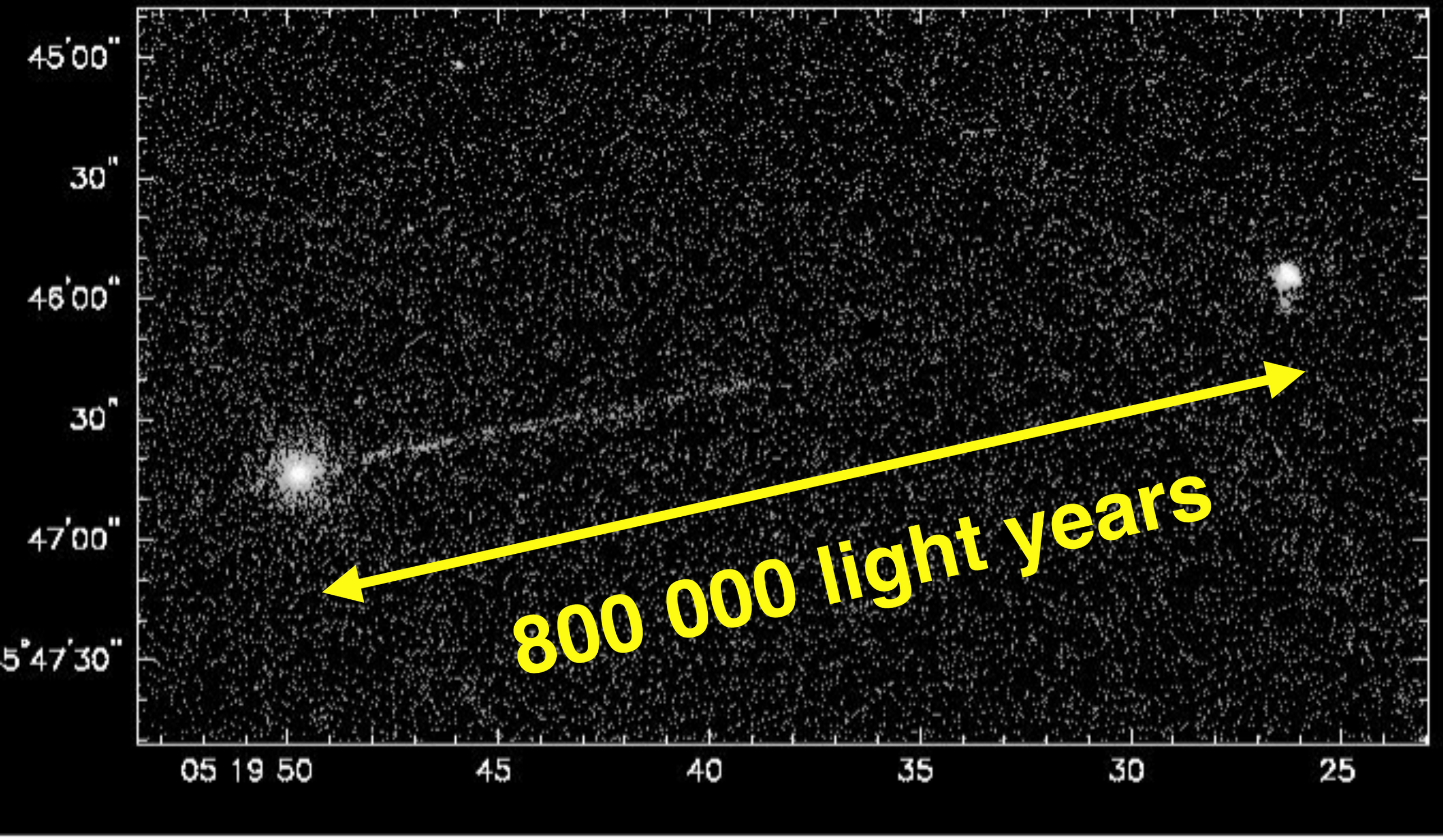
THIS TALK

WILL START IN

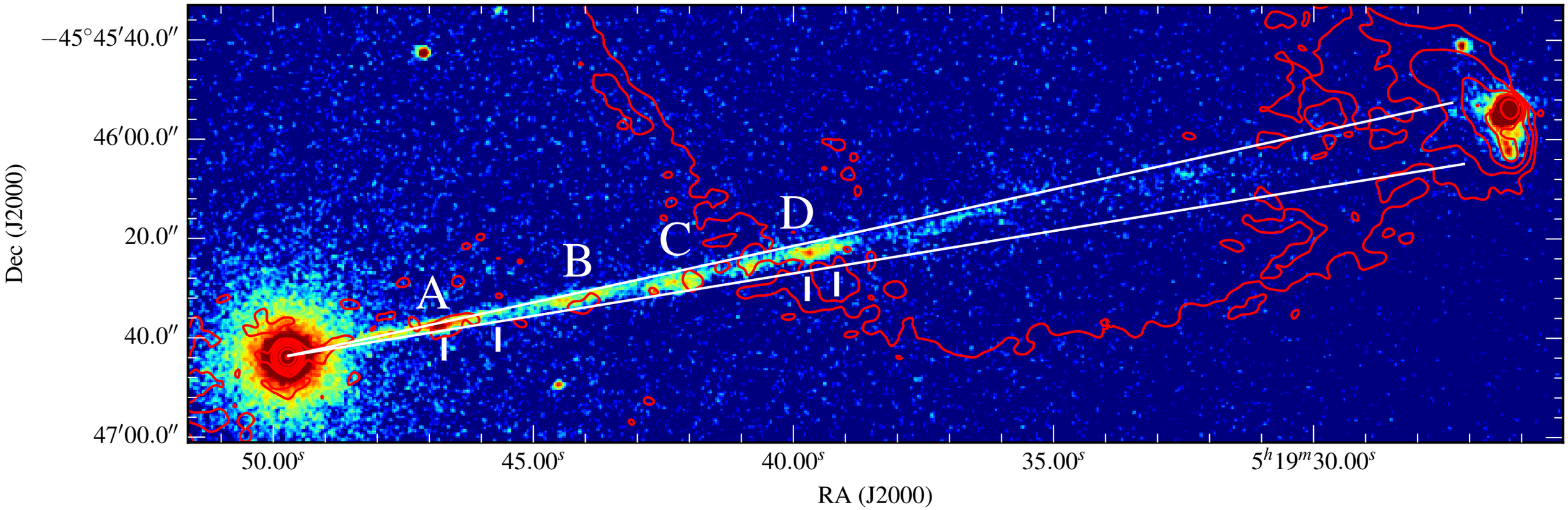
...

SEVEN

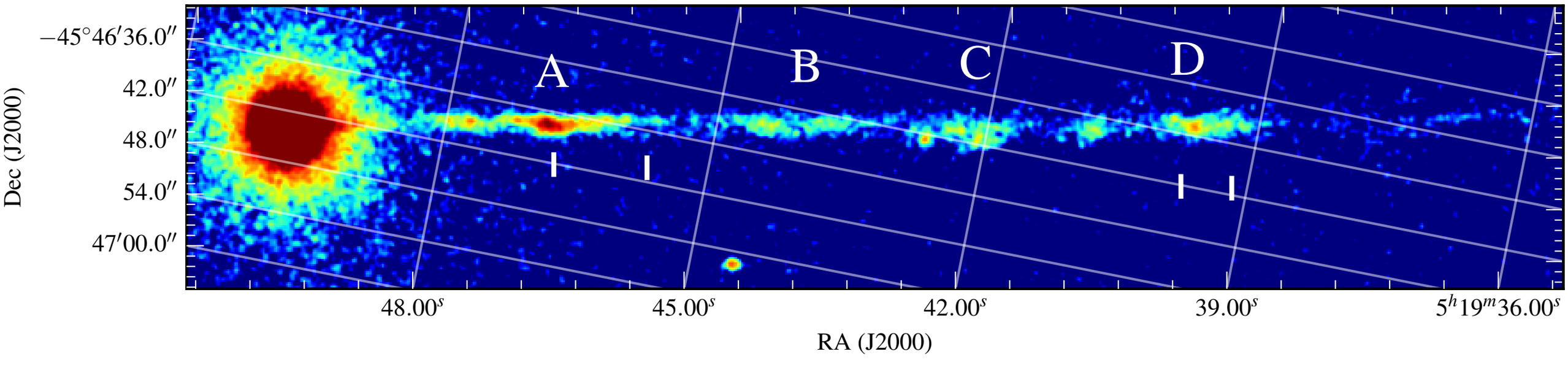
TRANSPARENCIES

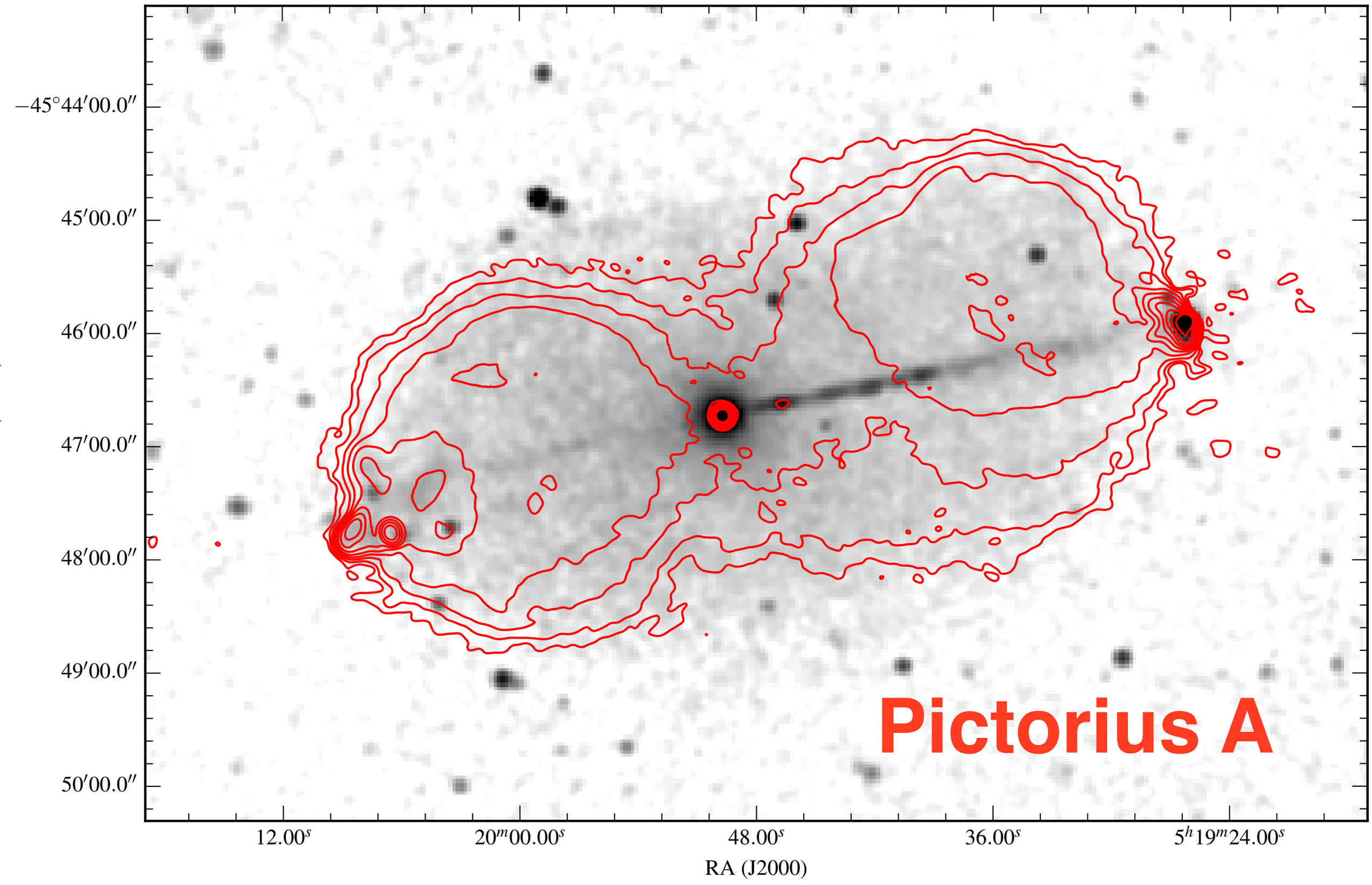


Pictor A quasar



M. J. Hardcastle et al. arXiv:1510.08392v1





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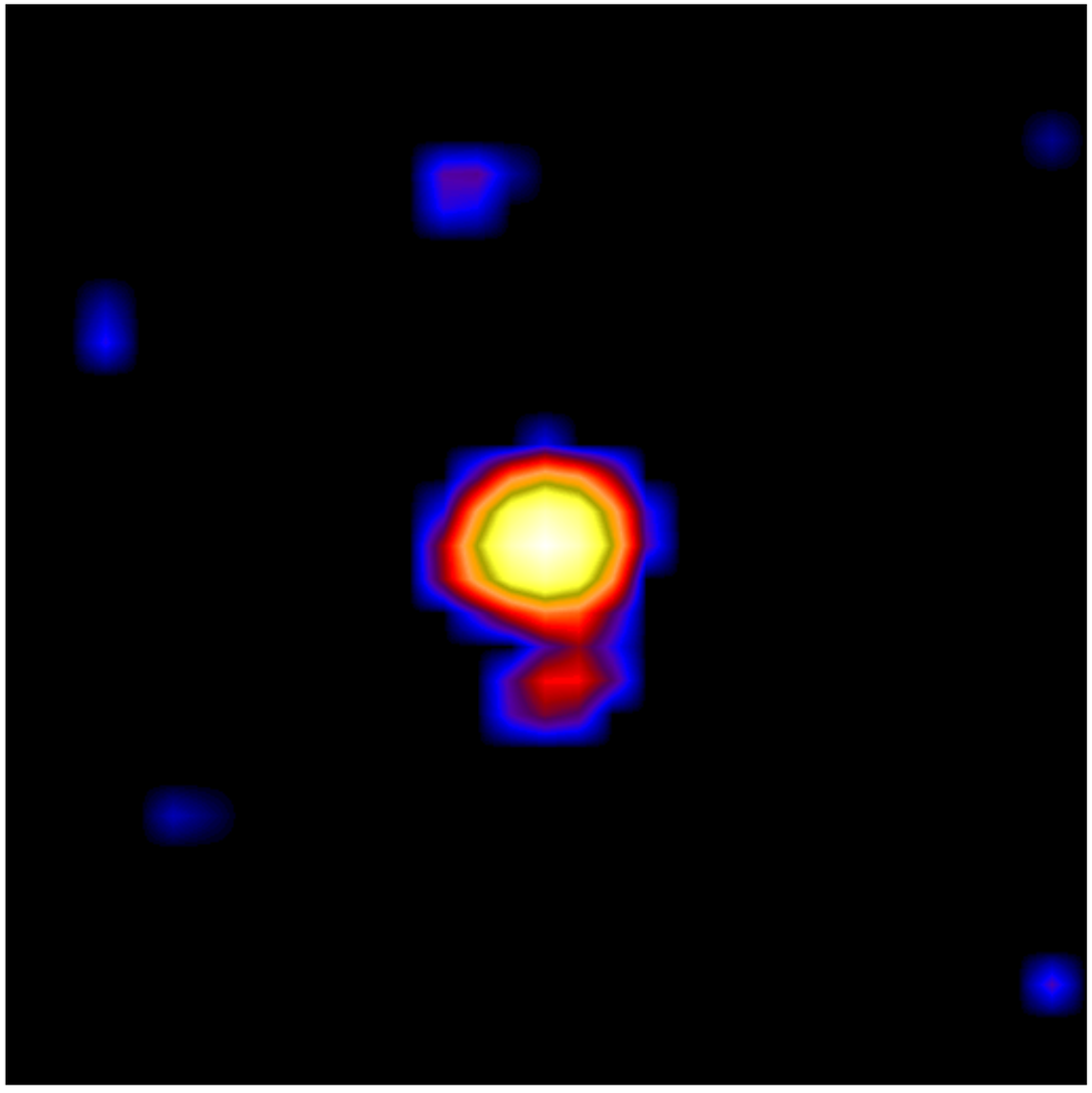
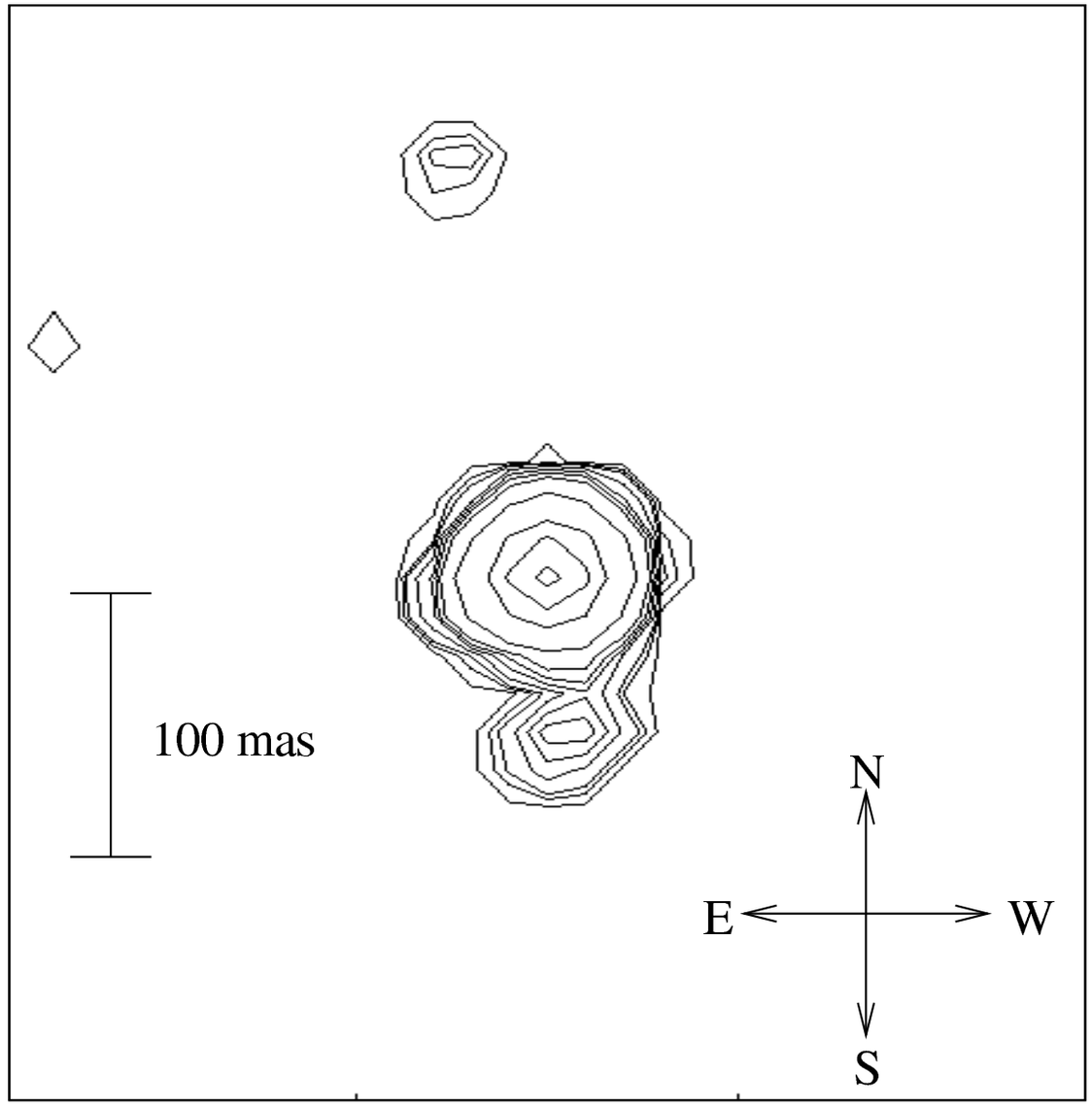
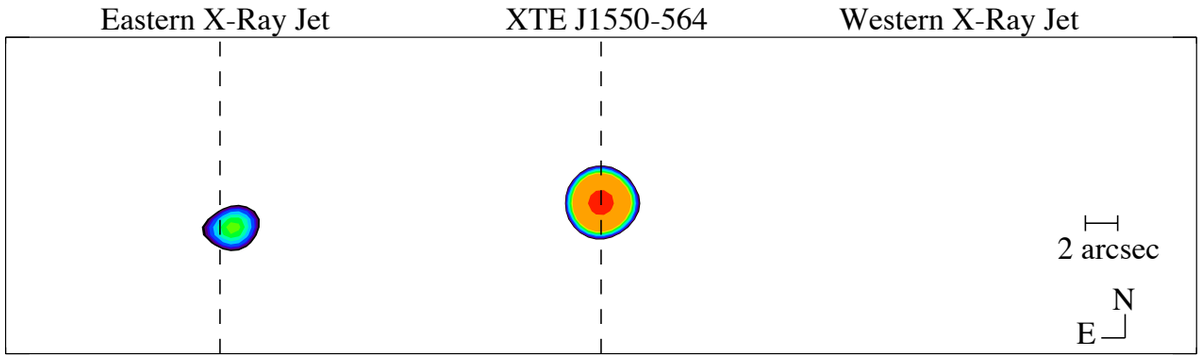
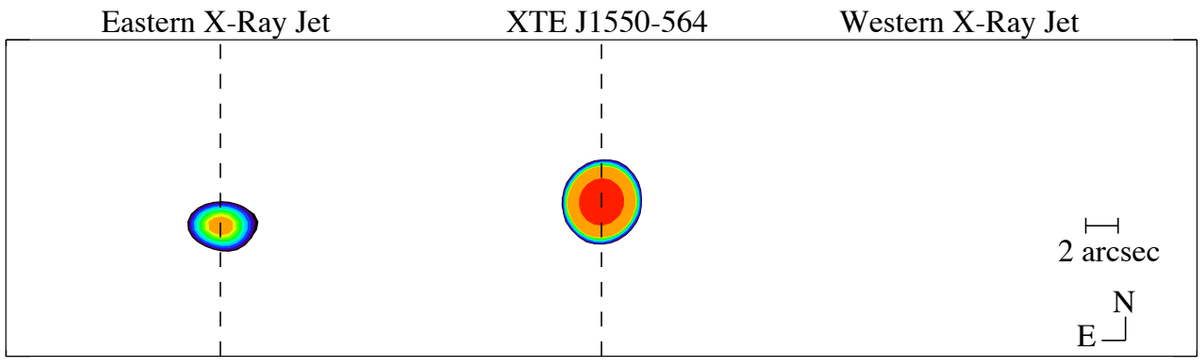




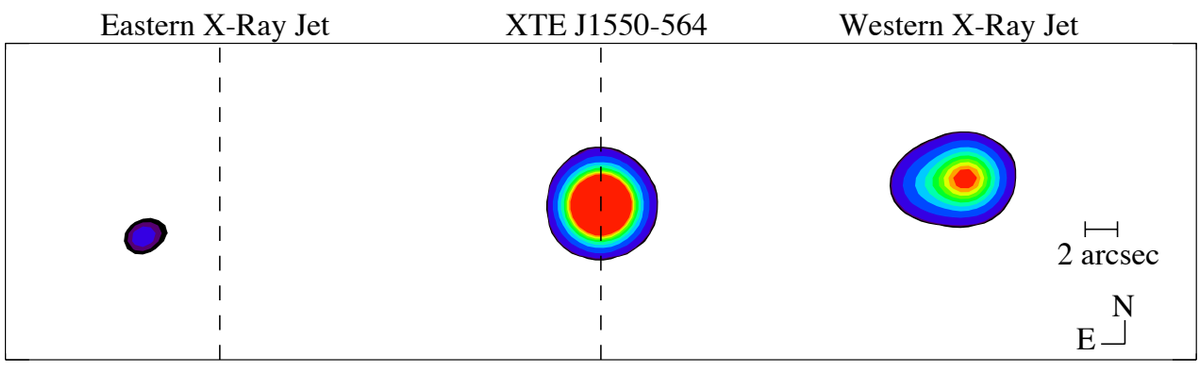
SN 1987A



2000 August 21



2000 September 11



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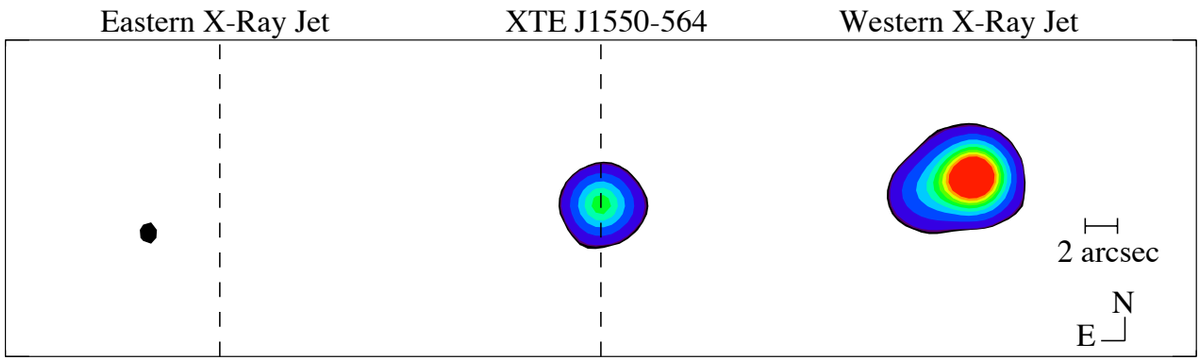
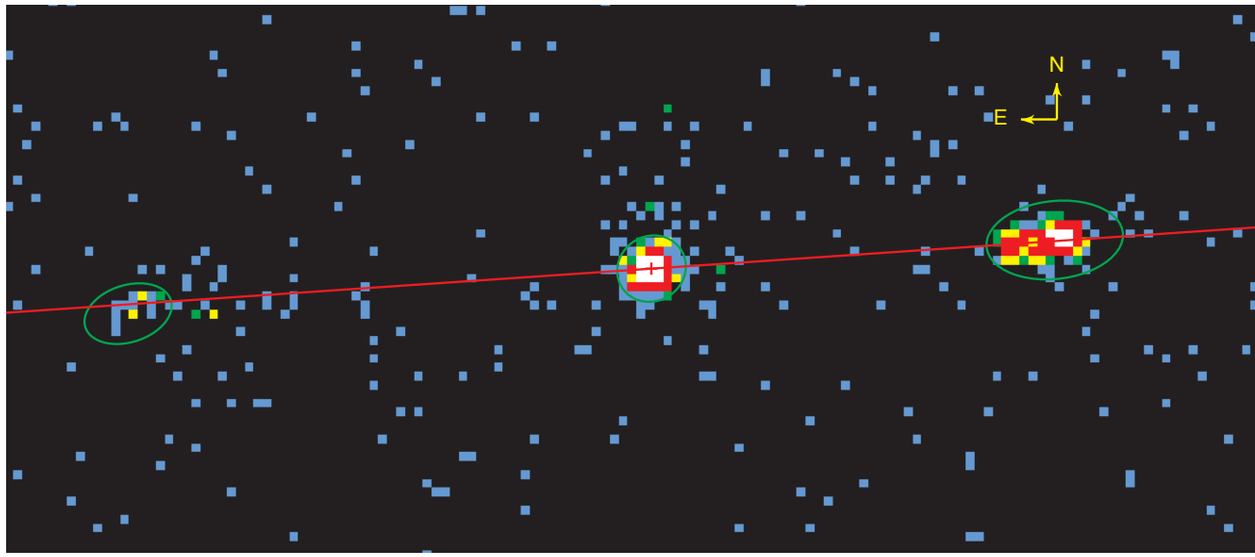
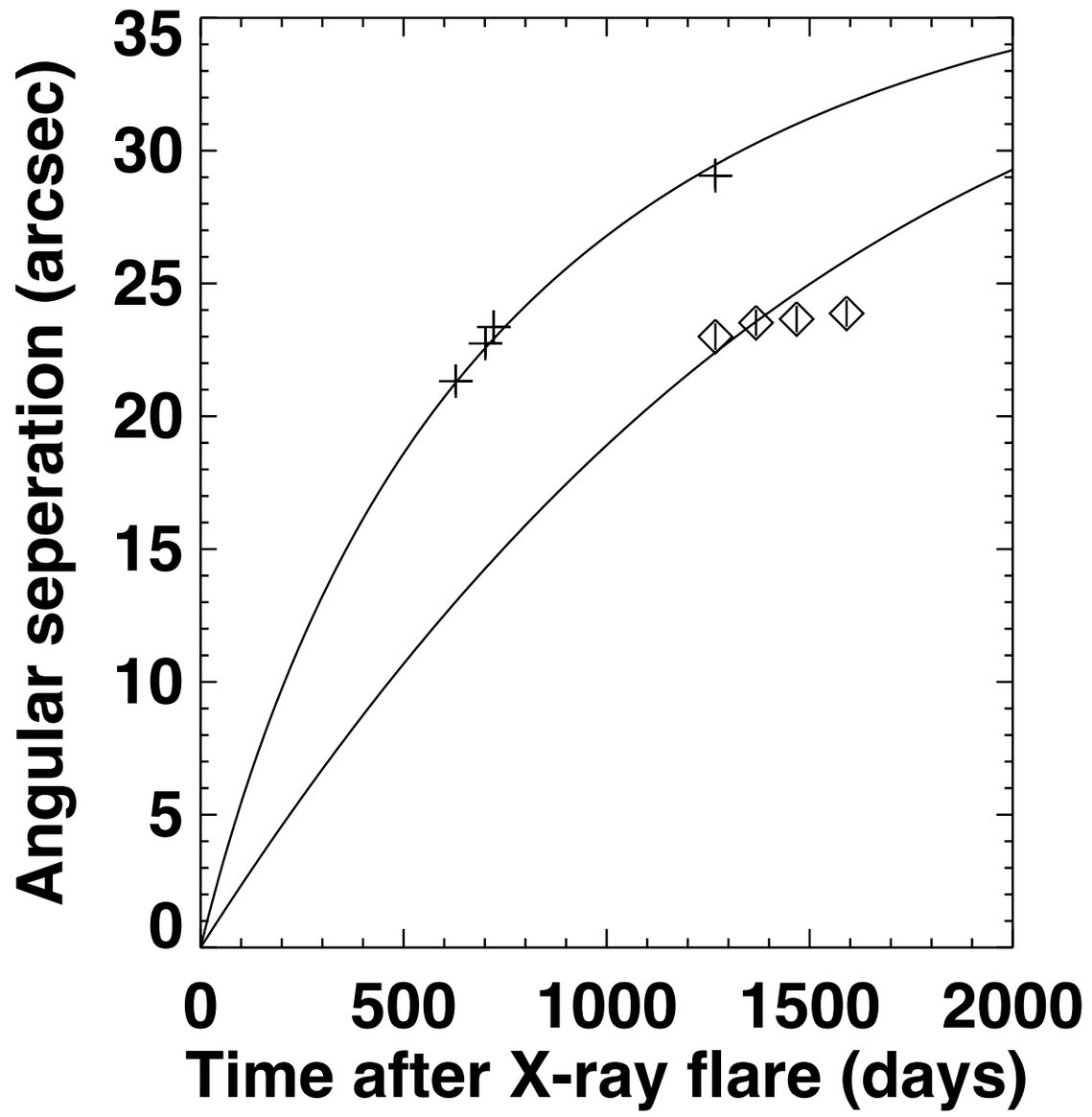


2002 June 19



XTE J1550-564



End of Commercials

SKIP VIDEO

The "standard model" of Cosmic Rays

Implementation: a Computer Program

Background to "New Physics"

All as in SM of P.Phys. & LHC ***BUT***

The CR-model inputs are unbelievable

It must be modified every time
the data become more precise

It NEVER made a correct prediction

CORRECT CR PREDICTION HAPPENED ONLY ONCE!!

$$E_{\rm CR} > E_{\rm conf}(Z)$$

CRs must be extragalactic

$$R_{\rm L} \sim 0.65\,{\rm kpc}\ \frac{5\,\mu G}{B}\ \frac{p(E)}{E_{\rm conf}(Z)}$$

$$E_{\rm conf}(Z) \sim Z\,(3\times 10^9)\,{\rm GeV}$$

$$E_{\rm ankle} \sim 3\times 10^9\,{\rm GeV}$$

G. Cocconi (1956) **P. Morrison (1957)**

Auger 2017

$E_{\rm CR} > 8 \times 10^9\,{\rm GeV}$

$E_{\rm ankle} \sim 3 \times 10^9\,{\rm GeV}$

Galactic Center

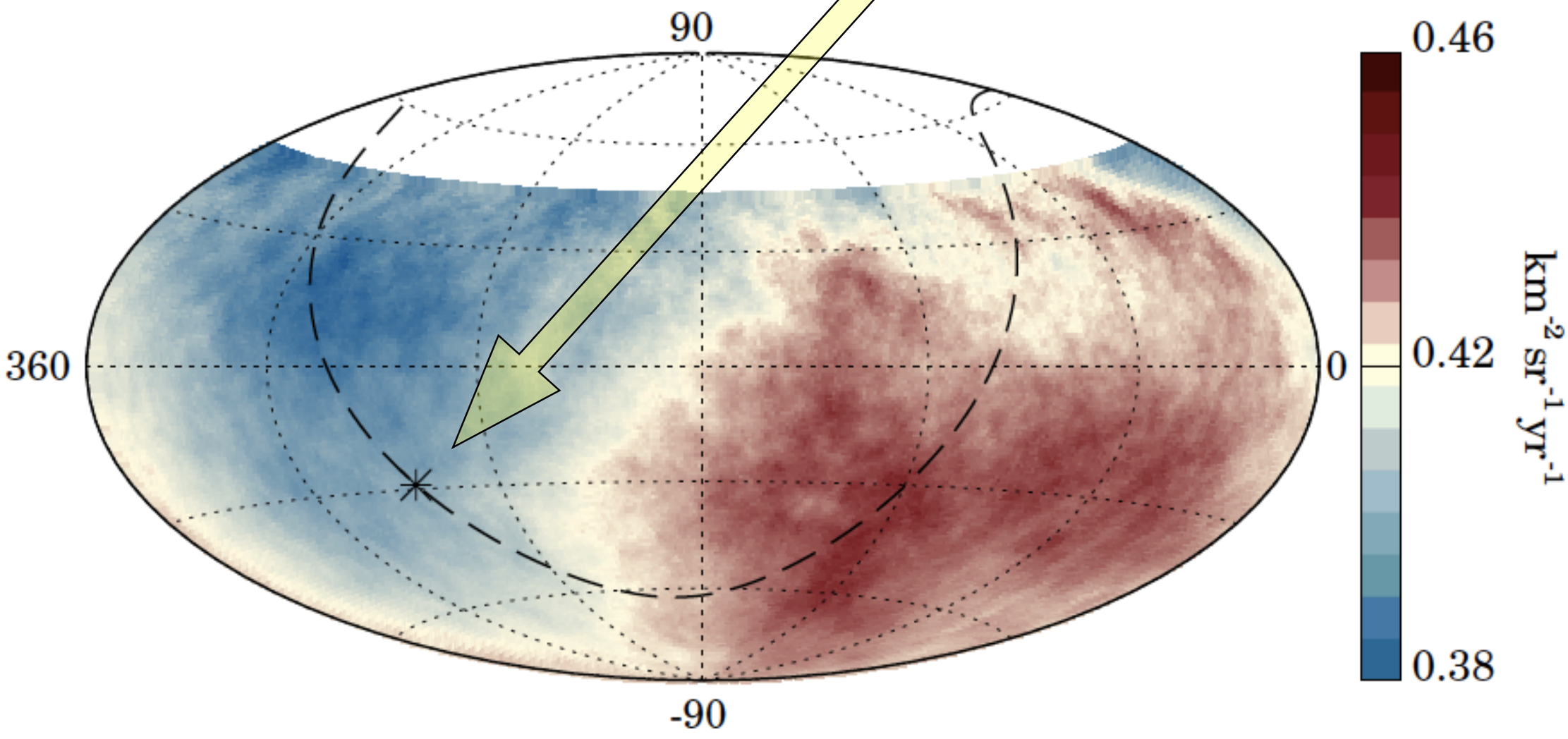
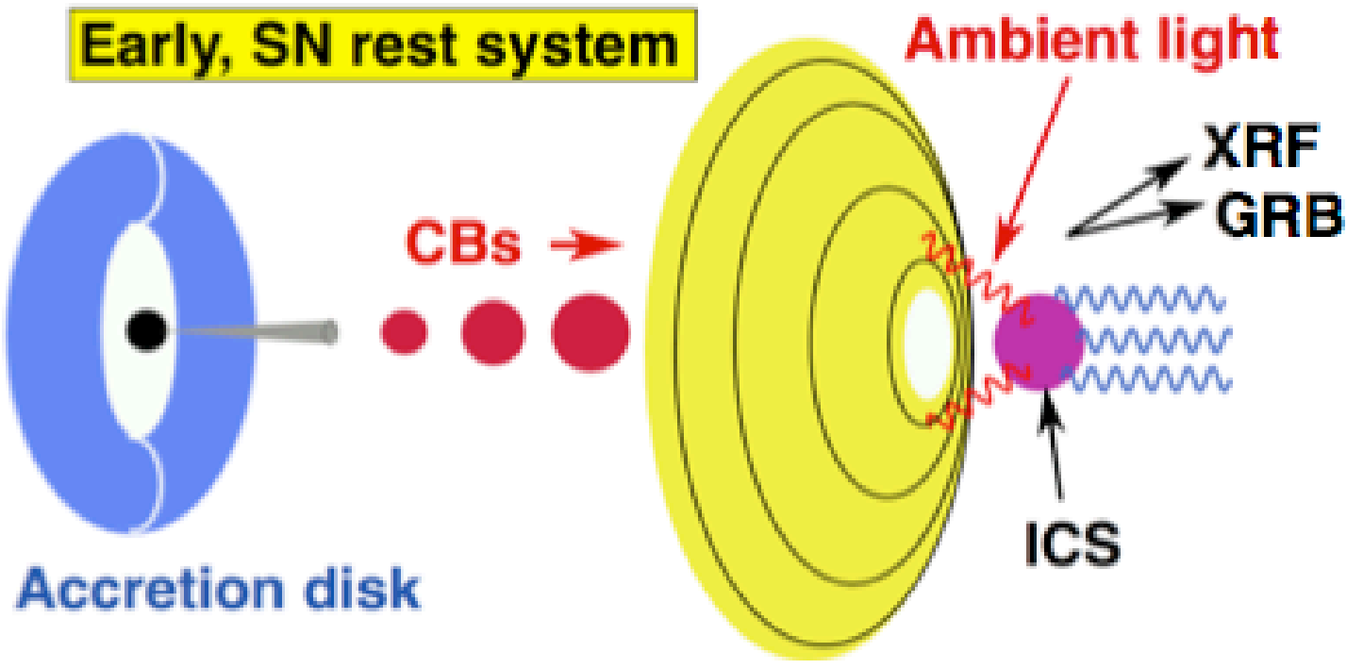


Figure 2: **Map showing the fluxes of particles in equatorial coordinates.** Sky map in equatorial coordinates, using a Hammer projection, showing the cosmic-ray flux above 8 EeV smoothed with a 45° top-hat function. The Galactic center is marked with an asterisk and the Galactic plane is shown by a dashed line.



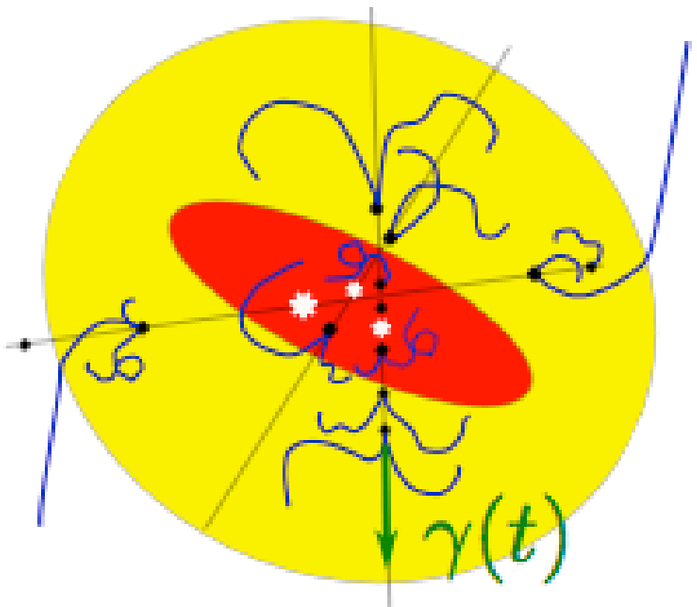
GRBs and XRFs are emitted by core-collapse SNe (Type Ia)

CBs scatter ions & electrons —> CRs

HOW ??

CBs decelerate as they travel in galaxy & halo

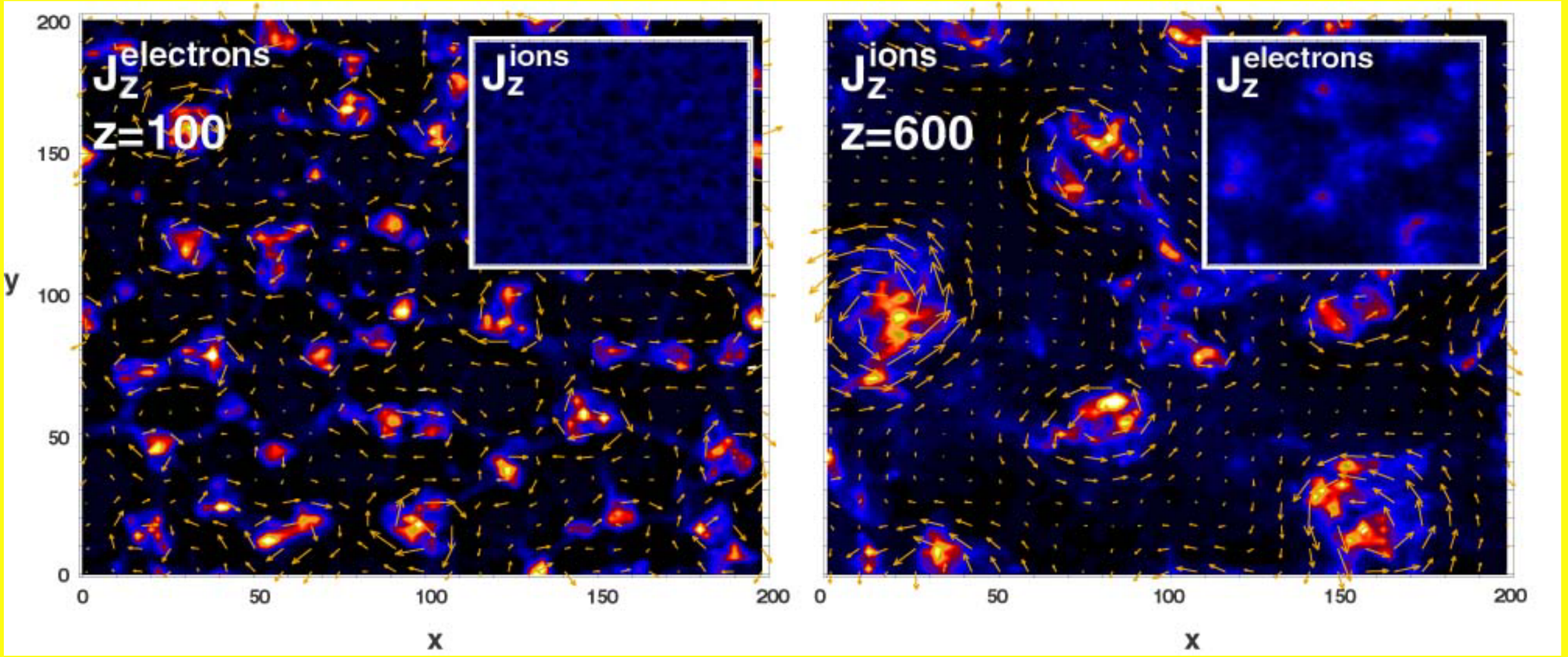
Late, SN rest-system



$$\rho_E(\mathrm{CR}) = \frac{4\,\pi}{c}\int E\frac{dF}{dE}dE \sim 0.5\,\mathrm{eV/cm^3}$$

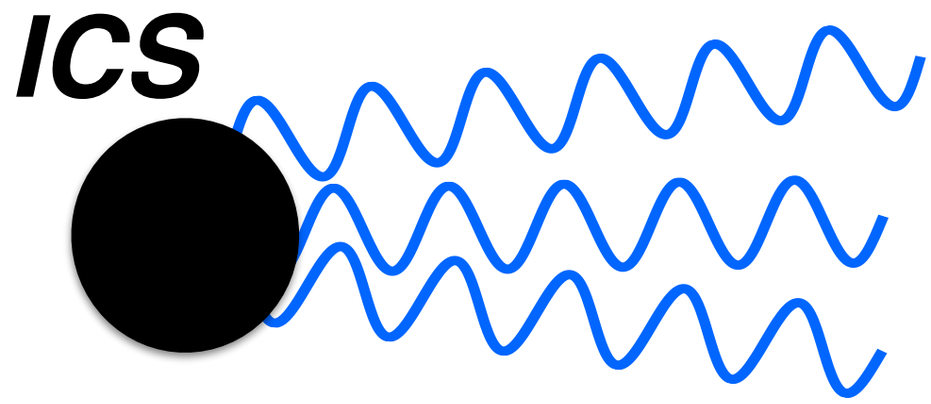
$$B^2/(8\,\pi) \simeq \rho_E(\mathrm{CR}) \quad \text{for } B \sim 5\,\mu\mathrm{G}$$

Equipartition

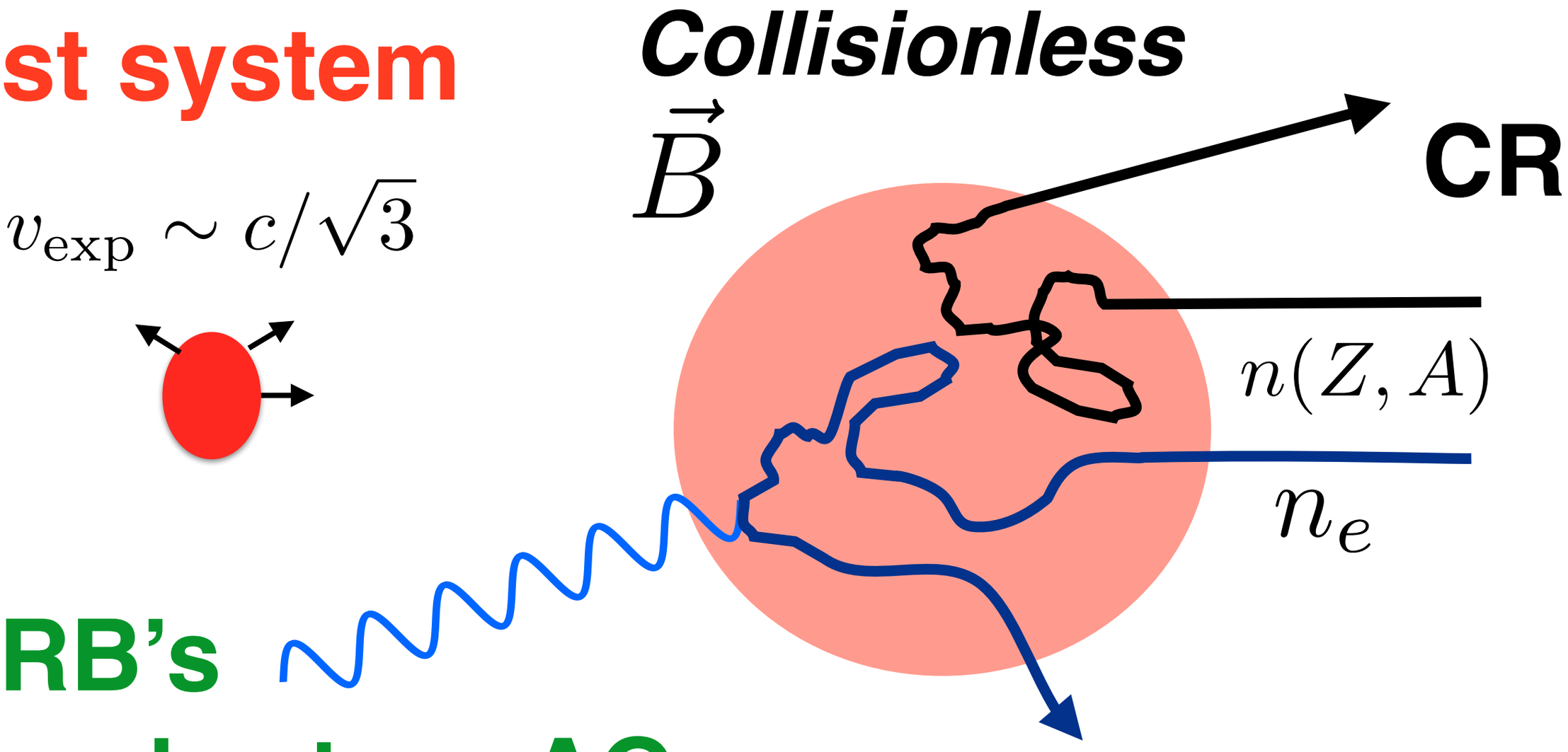


CB in motion in a galaxy

CB in its rest system



GRB ionizes ISM



GRB's synchrotron AG

CR electron

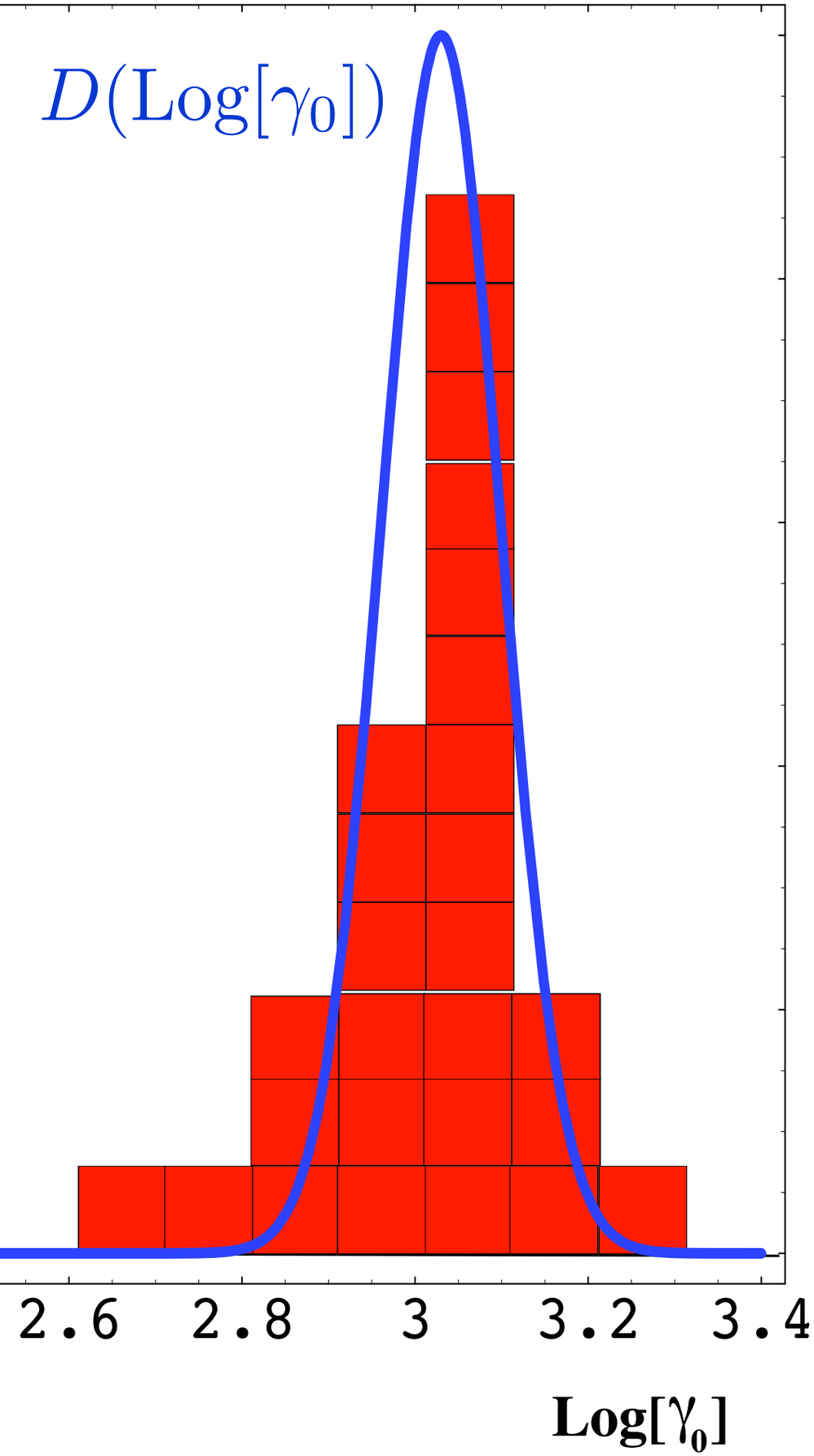
CB Theory of Cosmic Rays

- **Flux Normalixation**
- **Spectral Features**
  (knees, ankle, endpoint)
- **Spectral Slopes**
- **"Chemical" Abundances**
  (and their E-evolution)
- **Confinement volume, time**

All Predicted

ONE Mechanism
at ALL energies

ONE Parameter for CR nuclei (not used today)
Relative proton flux norm above/below its knee
ONE Parameter (freely chosen today)
(primary electron flux normalization)



TODAY'S PRIOR:

From the CB-model of GRBs and XRFs

$$D(\gamma_0)$$

OTHER PRIORS:

- **SN Rate / Galaxy $\propto$ Luminosity**

  1 / 50 y *(in our Galaxy now)*

CR flux normalization within a factor 2 to 3

- **Star-Formation Rate [z]**

  $\propto$ SN Rate $\propto$ CR Flux

Extragalactic CRs, uncertainty?

- **Galaxy's Magnetic fields**

  → *CR confinement & escape*

$$\tau_{\rm conf} \sim 2 \times 10^7 \, {\rm y} \, [Z/p]^{-\beta_{\rm conf}}$$

$$\beta_{\rm conf} \sim 0.6 \pm 0.1$$

$$dF/dE \sim E^{-\beta_{\rm conf}} \, dF[{\rm source}]/dE$$

- **CR interacts on background photons (Photodissoc & GZK)**

Magnitude & shape of UHECR. Error?

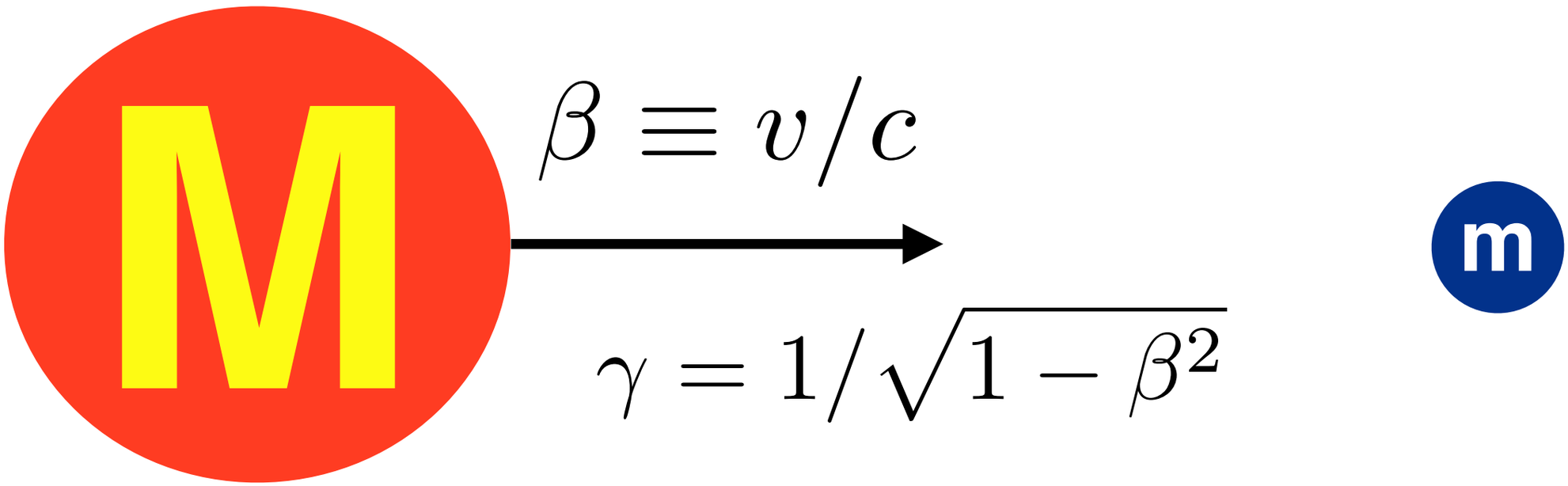
- $n(Z,A)$ **measused in superbubbles** $\mathcal{O}[10\%]$ error

To look at our old

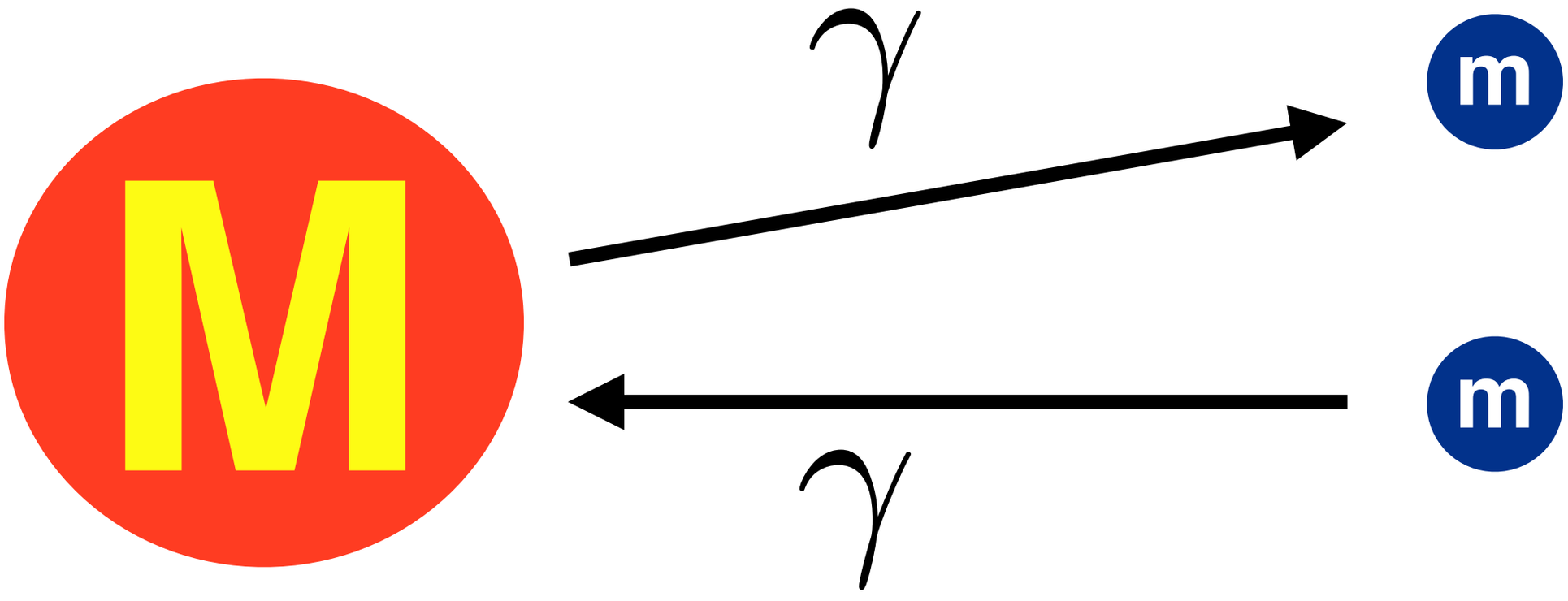
POSTDICTIONS

on ABUNDANCES

of CR nuclei



GO to the CB's REST SYSTEM



BOOST BACK TO MOVING CB's SYSTEM

$$E_m[\max] = 2\,m\,\gamma^2$$

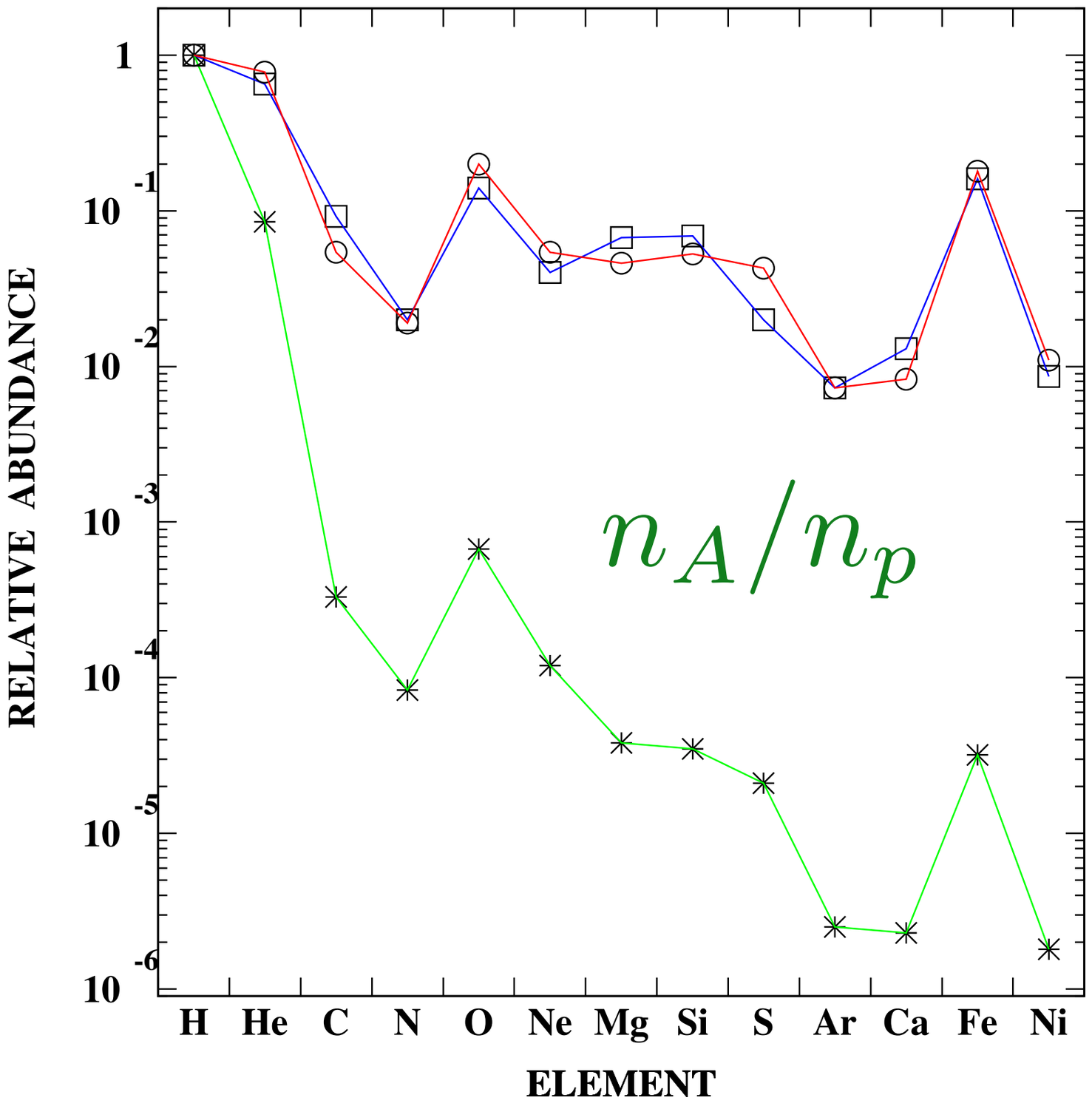
$$\frac{dF}{d\gamma_{\rm CR}} \propto \gamma_{\rm CR}^{-\beta_s}$$

$$\beta_s = \frac{13}{6} \sim 2.17$$

$$\beta_{\rm th} = \beta_s + \beta_{\rm conf}$$

$$\simeq 2.77$$

$$E_A \propto A\,\gamma$$



$$\frac{dF}{dE_A} \propto n_A\, A^{\beta_{\rm th}-1}\, E_A^{-\beta_{th}}$$

$$\text{fixed E} \rightarrow n_A\, A^{1.77}$$

(a)

Larmor Cutoffs ~ Z

Lorentz Knees ~ A

p

He

CNO

Fe

SOURCE

$\log_{10}[E^3\, dF/dE]]$ (Not normalized)

$\log_{10}[E]$ GeV

(b)

p

He

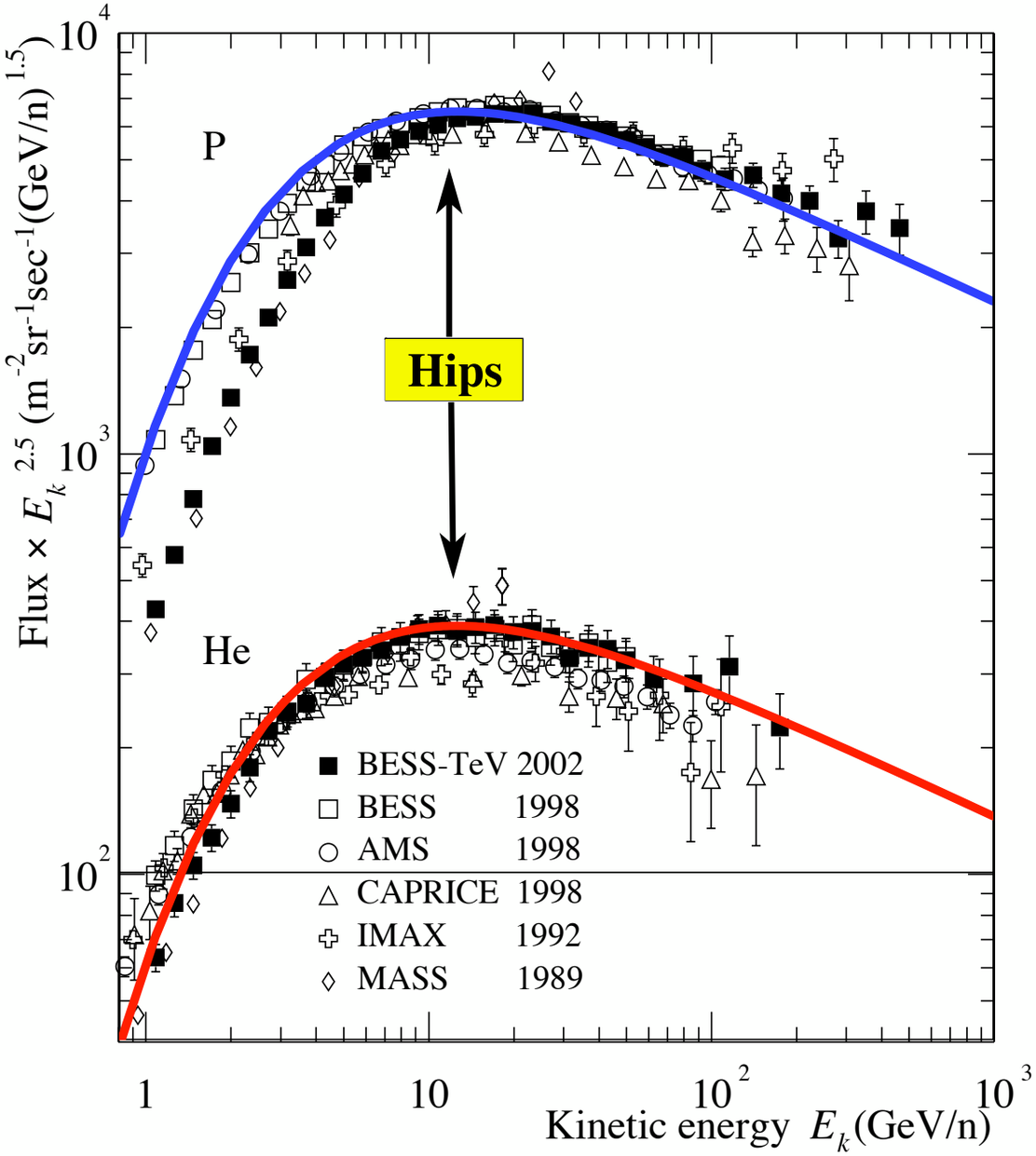
CNO

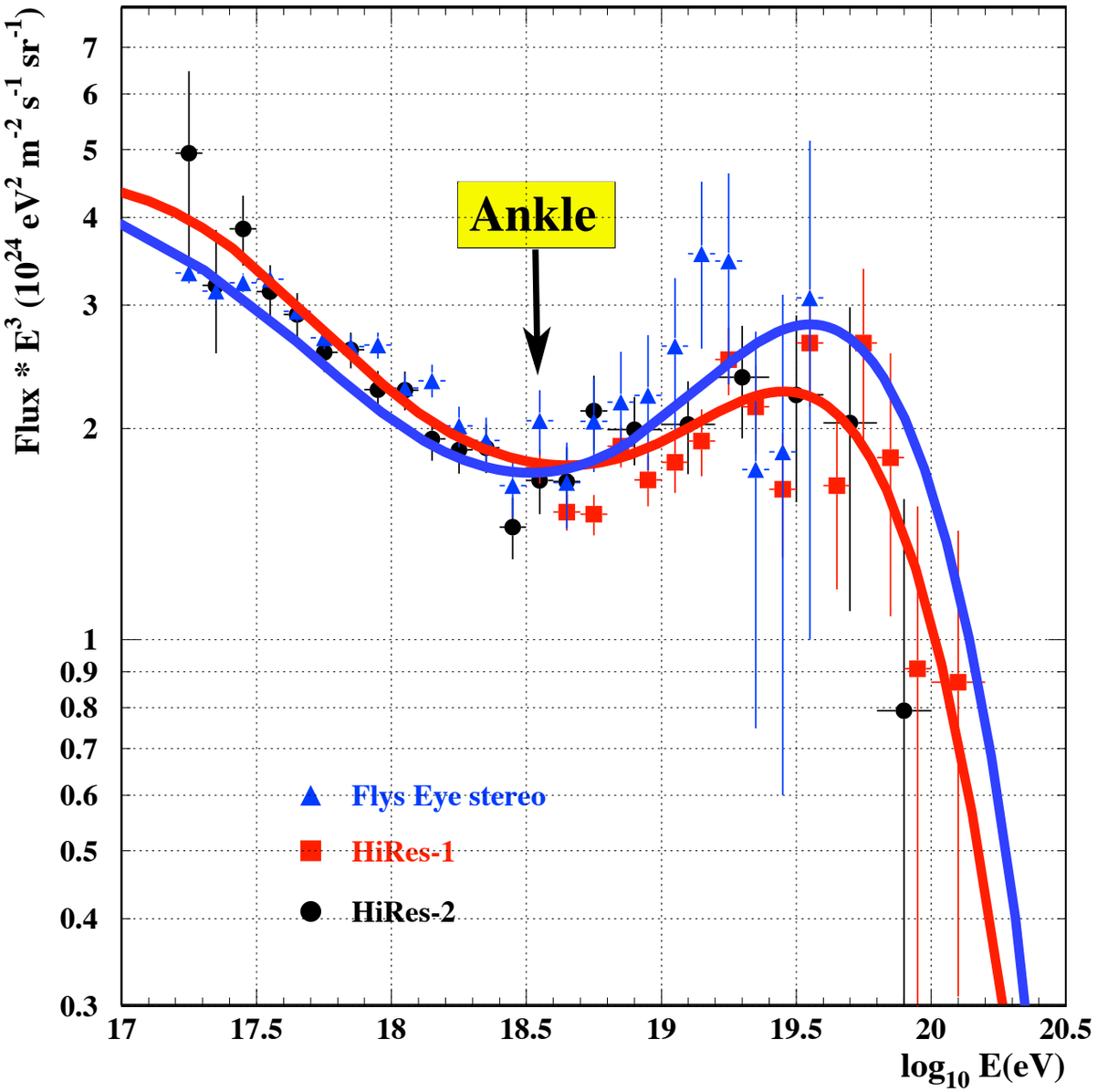
Fe

ON EARTH

$\log_{10}[E^3\, dF/dE]\ ]$ $(\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}^2)$

$\log_{10}[E]$ GeV





Red <—> Blue

Within uncertainties in priors

MY conclusion

> decade ago

The CHALLENGE of CR PRODUCTION

ONLY POST-DICTIONS

has been met

faced

OVERCOME

... almost ...

?

to MY entire

satisfaction

But ...

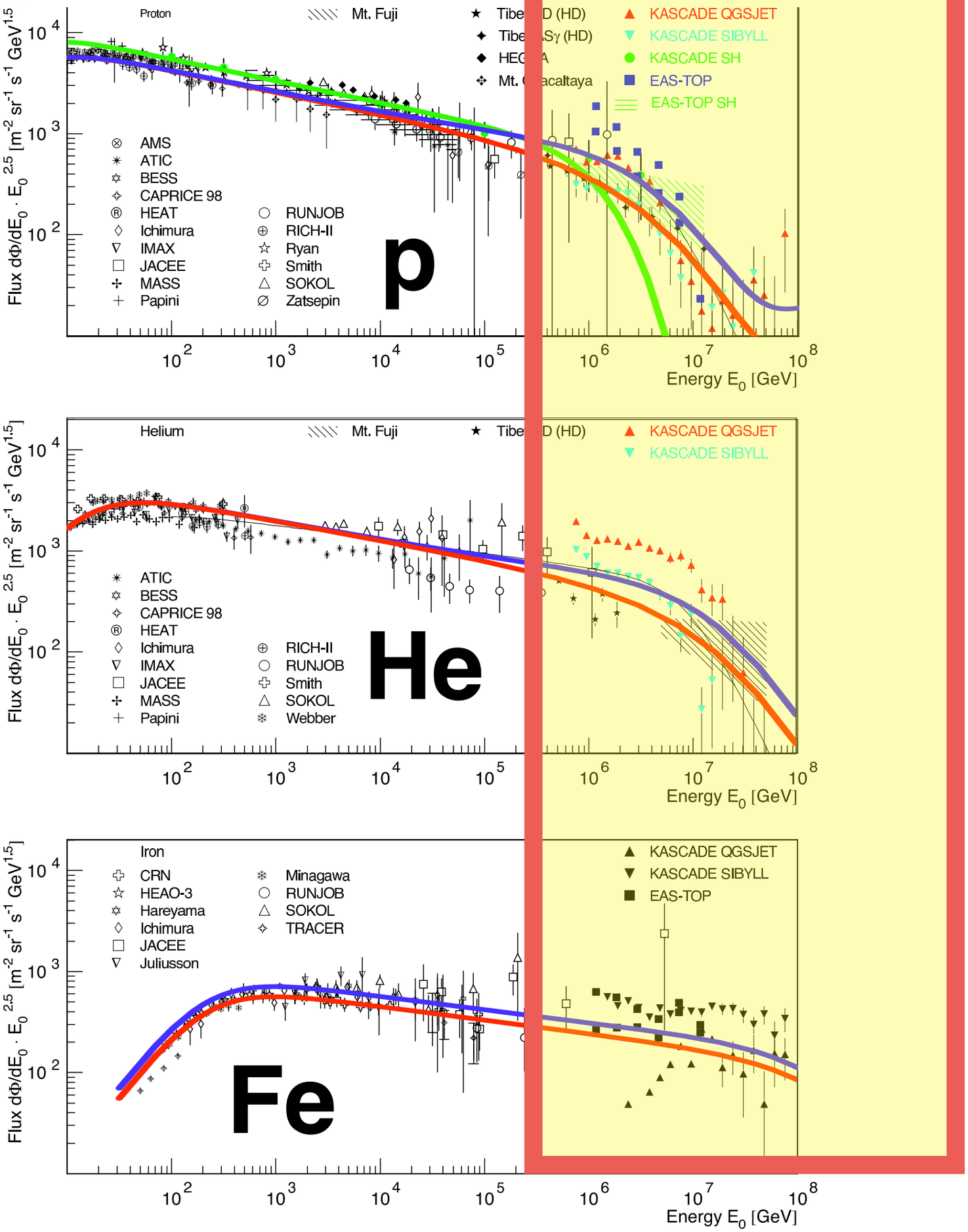
There are NEW DATA

> 10 years
- old data

$\mathrm{Log}[E^{2.5}\,F(E)]$

$\mathrm{Log}[E]$

$1 < E < 10^8 \mathrm{GeV}$



p
Knee

He
Knee
?

Fe
Knee
????

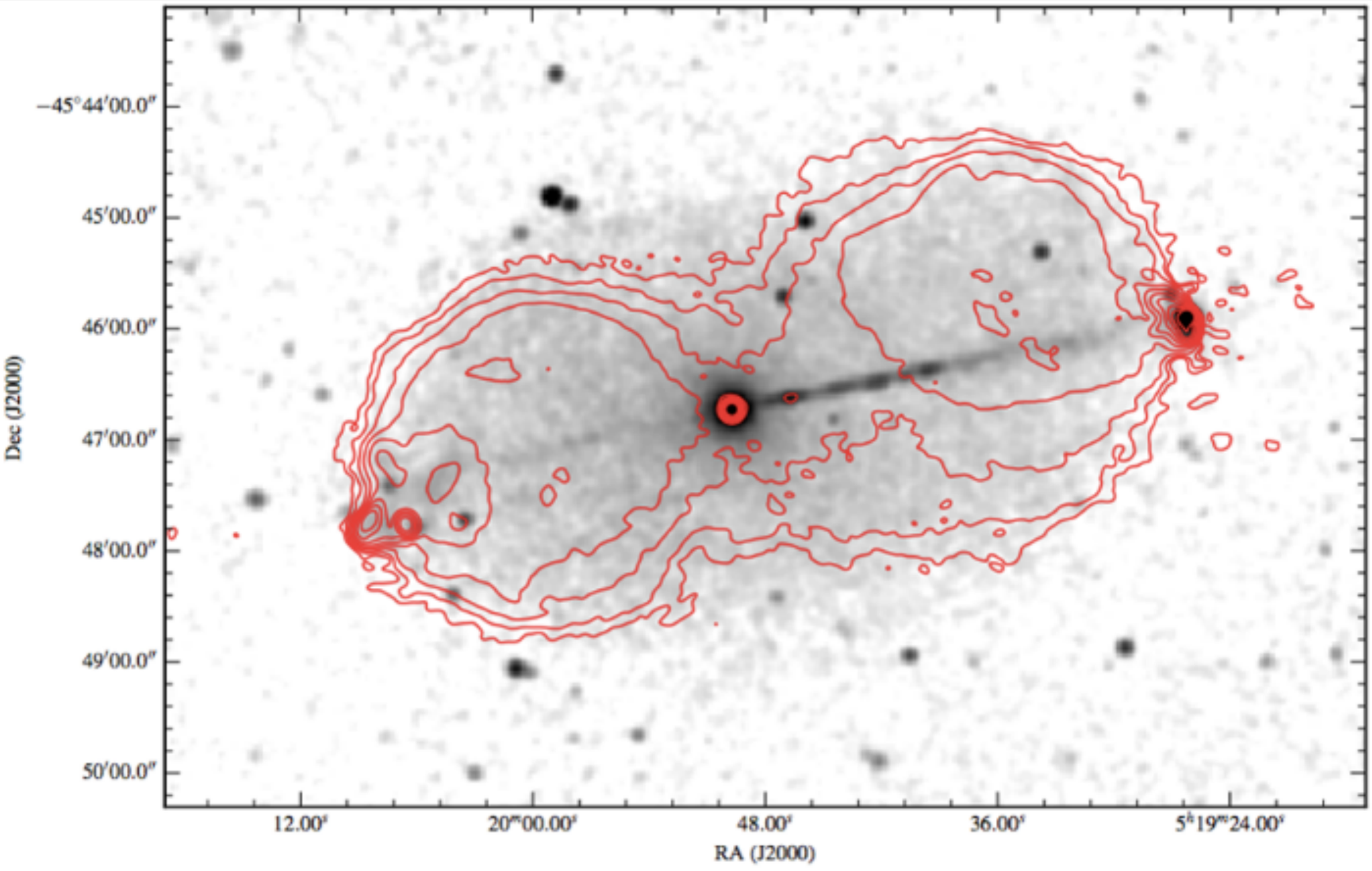
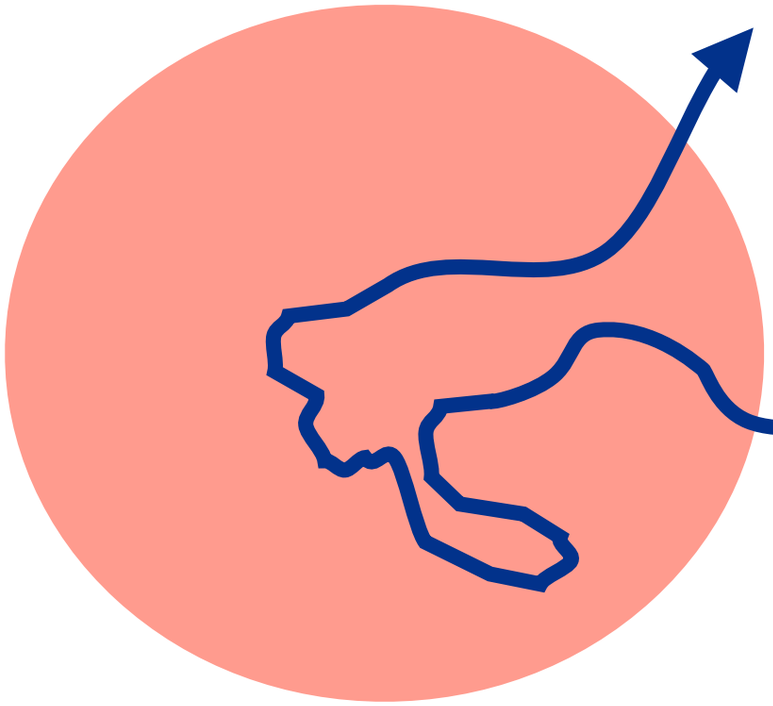


Figure 1. X-ray emission from Pictor A and its field. The greyscale shows an exposure-corrected image made from all the data in the 0.5-5.0 keV passband, smoothed with a Gaussian with a FWHM of 4.6 arcsec and with a logarithmic transfer function to highlight fainter structures. Superposed are contours of our ATCA 5.5-GHz image tapered to a resolution of 5 arcsec: contour levels are at $0.6 \times (1, 2, 4 \ldots)$ mJy beam^{-1}.

The X-ray (B&W) and radio (red contours) emissions from the [+]

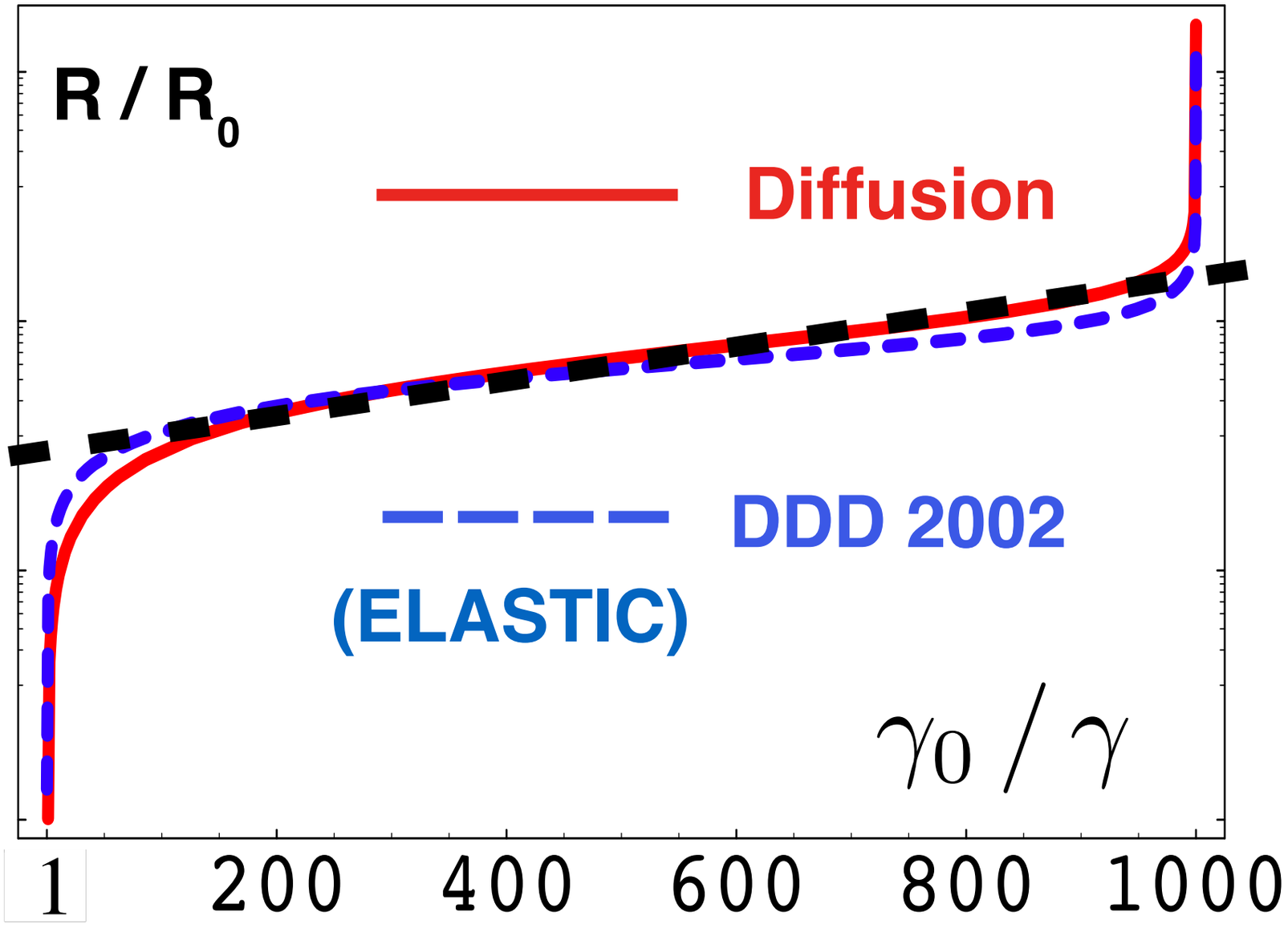
Oozing out by diffusion



$$M_{\rm CB} \approx M_0 \frac{\gamma_0}{\beta\,\gamma}$$

$$R_{\rm CB} \approx R_0 \left[\frac{\gamma_0}{\beta\,\gamma}\right]^{2/3}$$

$R_0 \sim 10^{14}\,{\rm cm}$



It is almost Baron Munchausen !!!!

$$M_{\rm CR} \ll E_{\rm CR}$$

$$10^6\, M_{\rm CR} < n_A \left(\frac{A}{Z}\right)^c \int_1^{\gamma_0} \frac{d\gamma}{\gamma^{7/3}}\, G[\gamma,\gamma_{\rm CR}]$$

$$2\,\gamma_0^2 = (2\,\text{to}\,4)\,10^6$$

$$\frac{dF_{\rm elast}}{d\gamma_{\rm CR}} \propto {}_A\beta_{\rm CR} \left(\frac{A}{Z}\right)^c \int_1^{\gamma_0} \frac{d\gamma}{(\beta\,\gamma)^{7/3}}\, \frac{G[\gamma,\gamma_{\rm CR}]}{(\gamma-1)^c}$$

$$G[\gamma,\gamma_{\rm CR}] \equiv \int_{\rm Max(\gamma,B)}^{\rm Min(\gamma_0,T)} \frac{\beta_{\rm co}\, d\gamma_{\rm co}}{(\beta_{\rm co}\,\gamma_{\rm co})^{4-c}}$$

$$\frac{dF_{\rm elast}}{d\gamma_{\rm CR}} \propto$$

$$G[\gamma,\gamma_{\rm CR}] \equiv \int_{\rm Max[\gamma,\gamma_{\rm CR}/(2\,\gamma)]}^{\rm Min[\gamma_0,2\,\gamma\,\gamma_{\rm CR}]} \frac{d\gamma_{\rm co}}{\gamma_{\rm co}^4}$$

$$\sim \gamma_{CR}^{-\beta_s}$$

$$\gamma_{CR} < 2\gamma_0^2$$

$$\beta_s = \frac{13}{6} \approx 2.17$$

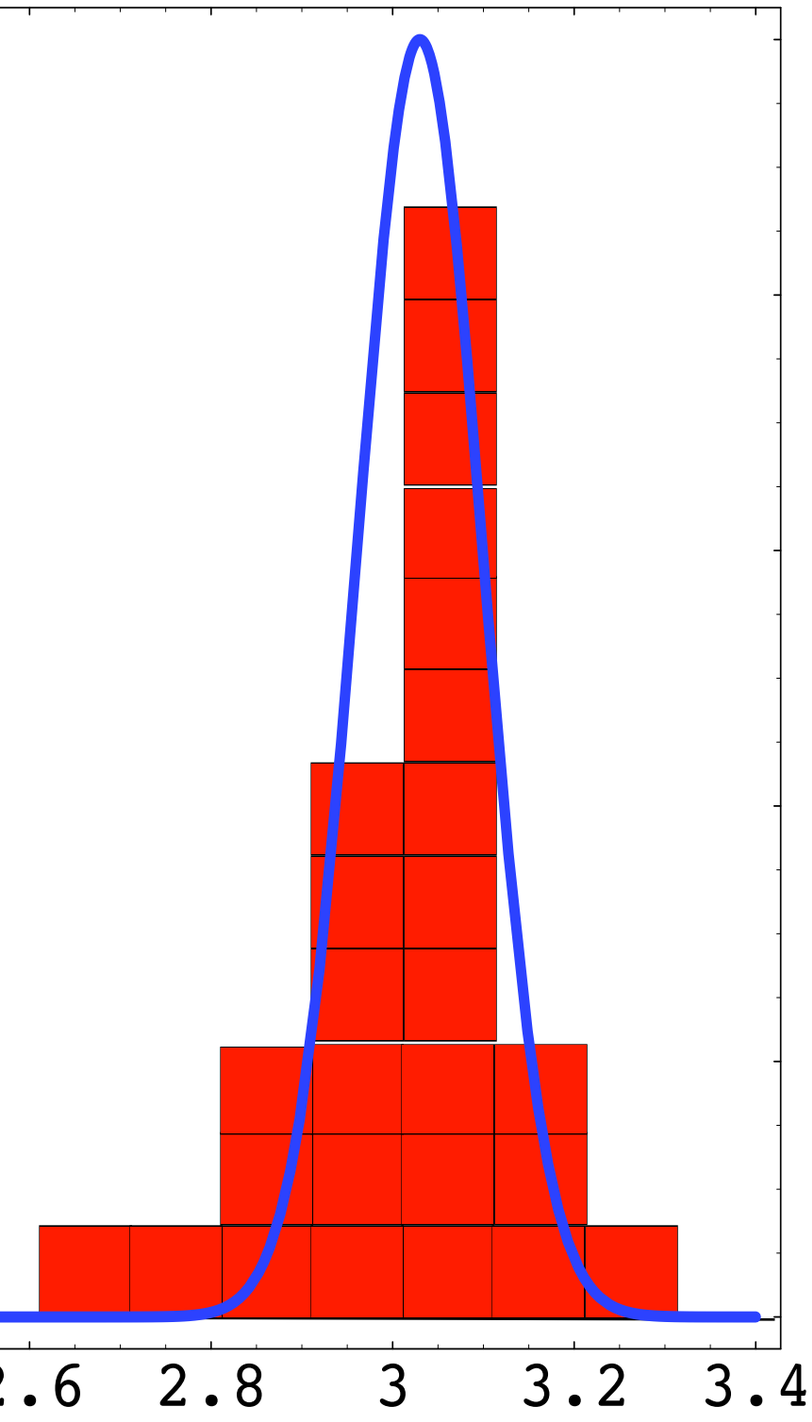
$$f_p = E_p^{-\beta_p}\,\Theta[2\,\gamma_0^2\,m_p - E]$$

$$F_p = E_p^{-\beta_p}\int_{E_p/(2\,m_p)}^{\infty} d\gamma_0^2\; D(\gamma_0^2)$$

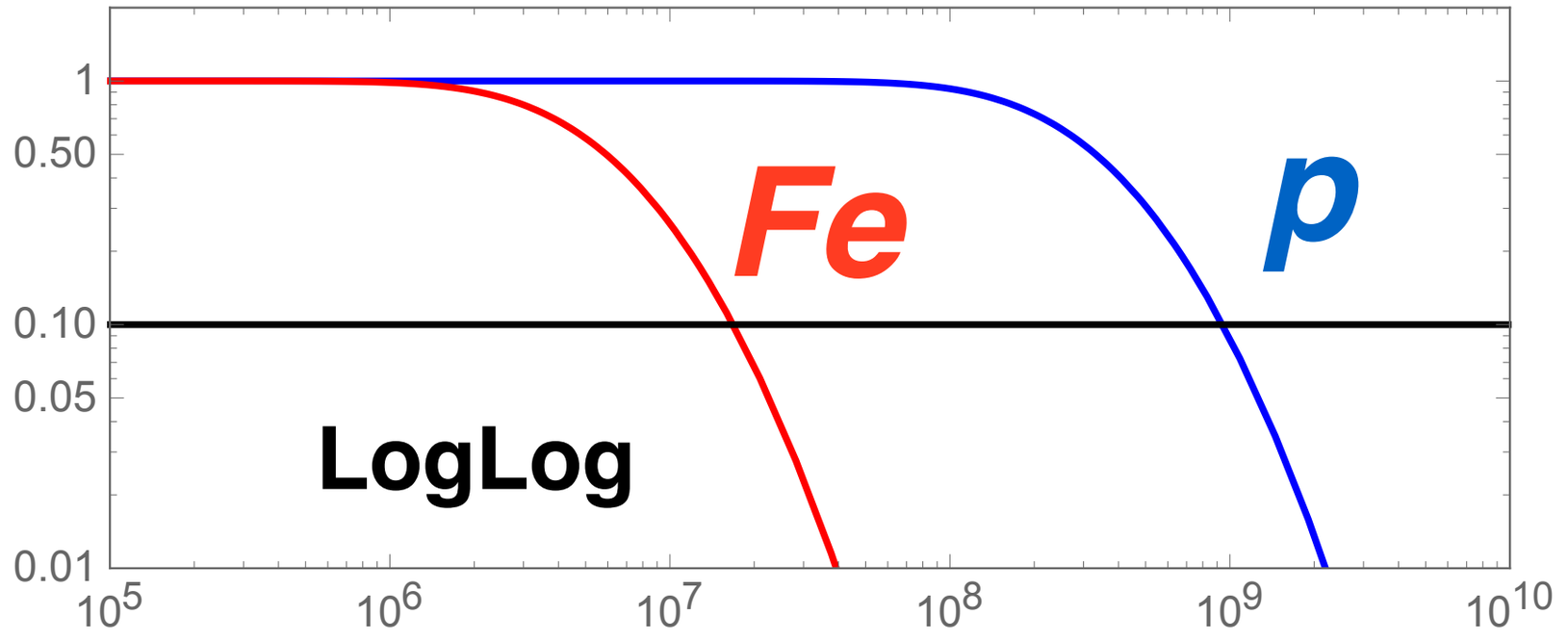
$$F_A = E_A^{-\beta_A}\,\mathrm{Knee}(A, E_A)$$

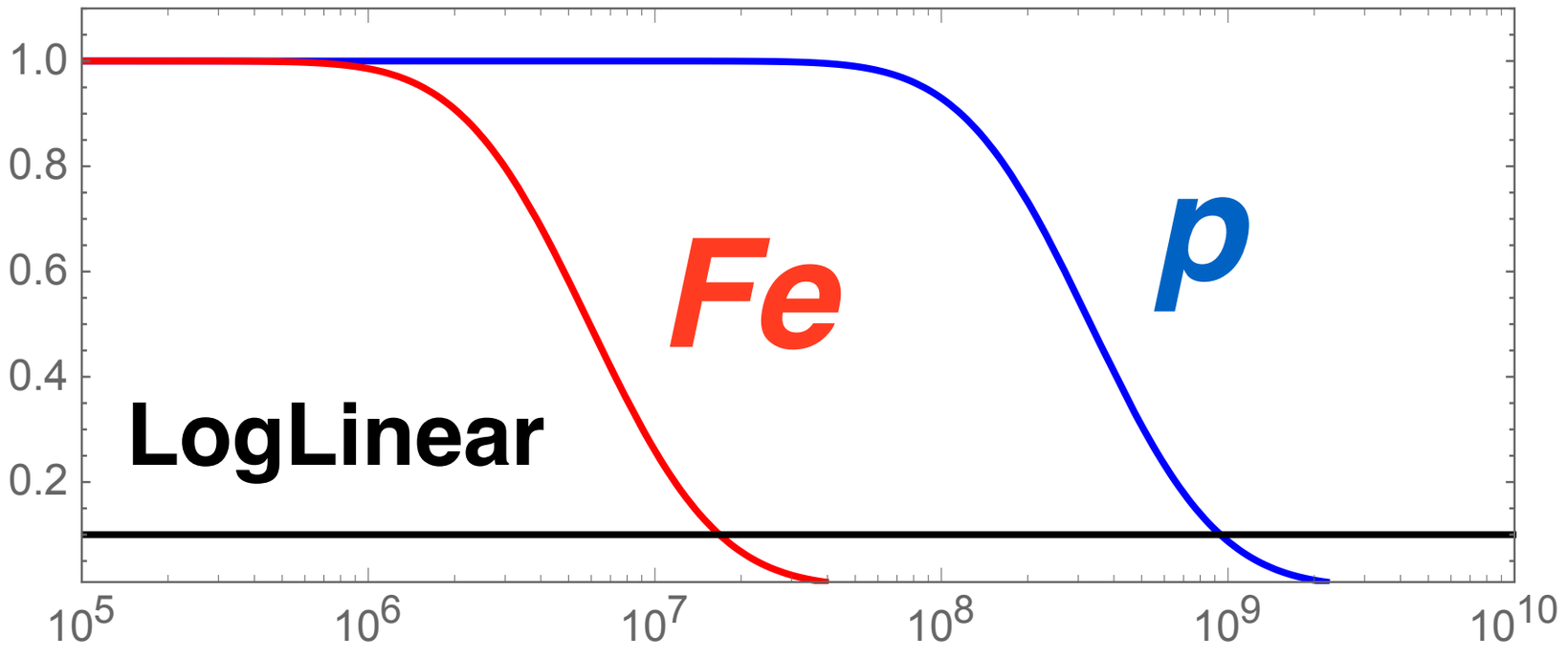
$$\mathrm{Knee}(A) = \int_{E_A/(2\,A\,m_p)}^{\infty} d\gamma_0^2\; D(\gamma_0^2)$$

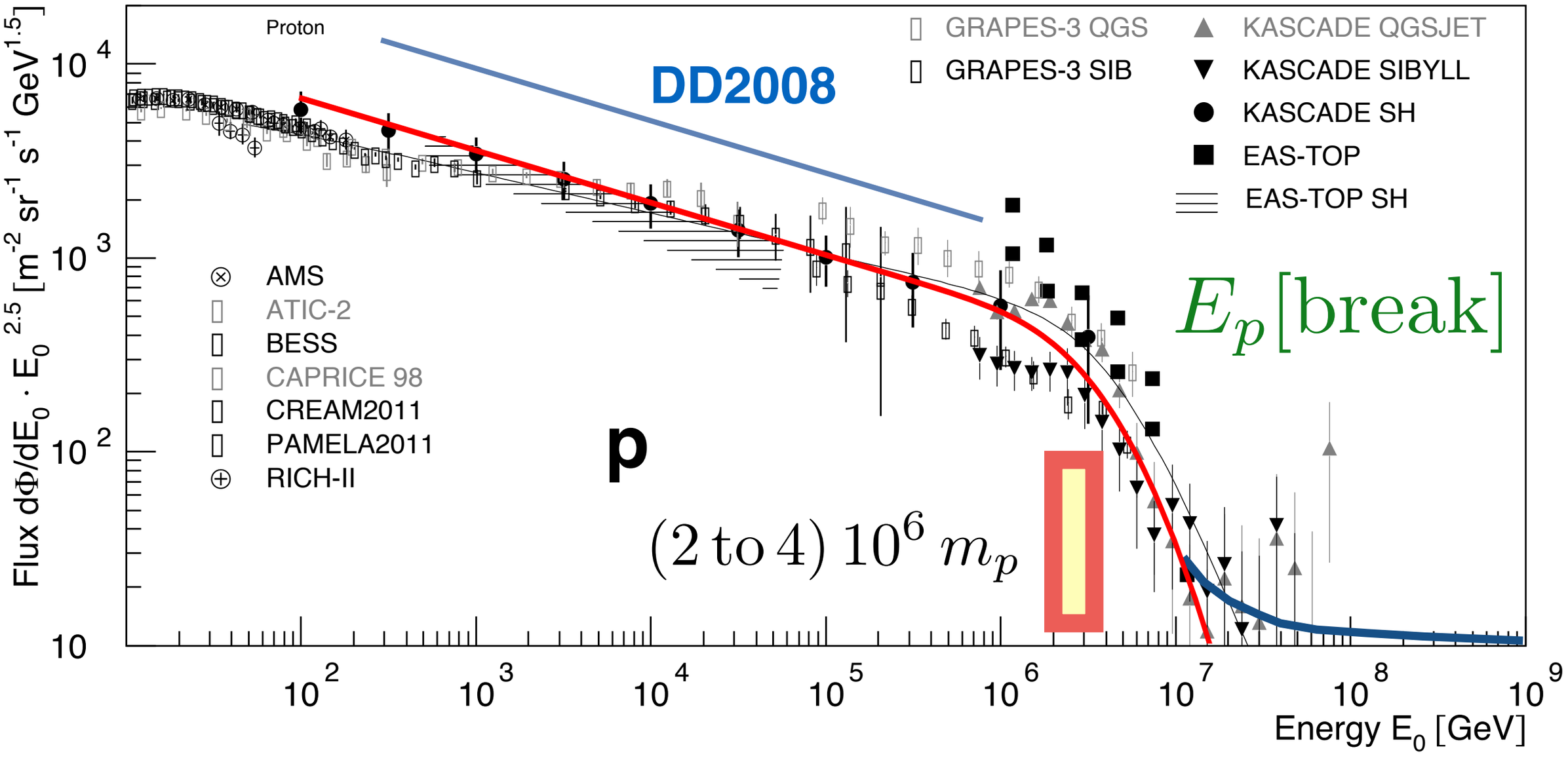
$$\mathrm{Knee}(A) = \int_{E_A/(2\,A\,m_p)}^{\infty} d\gamma_0^2\; D(\gamma_0^2)$$



$D(\gamma_0)$

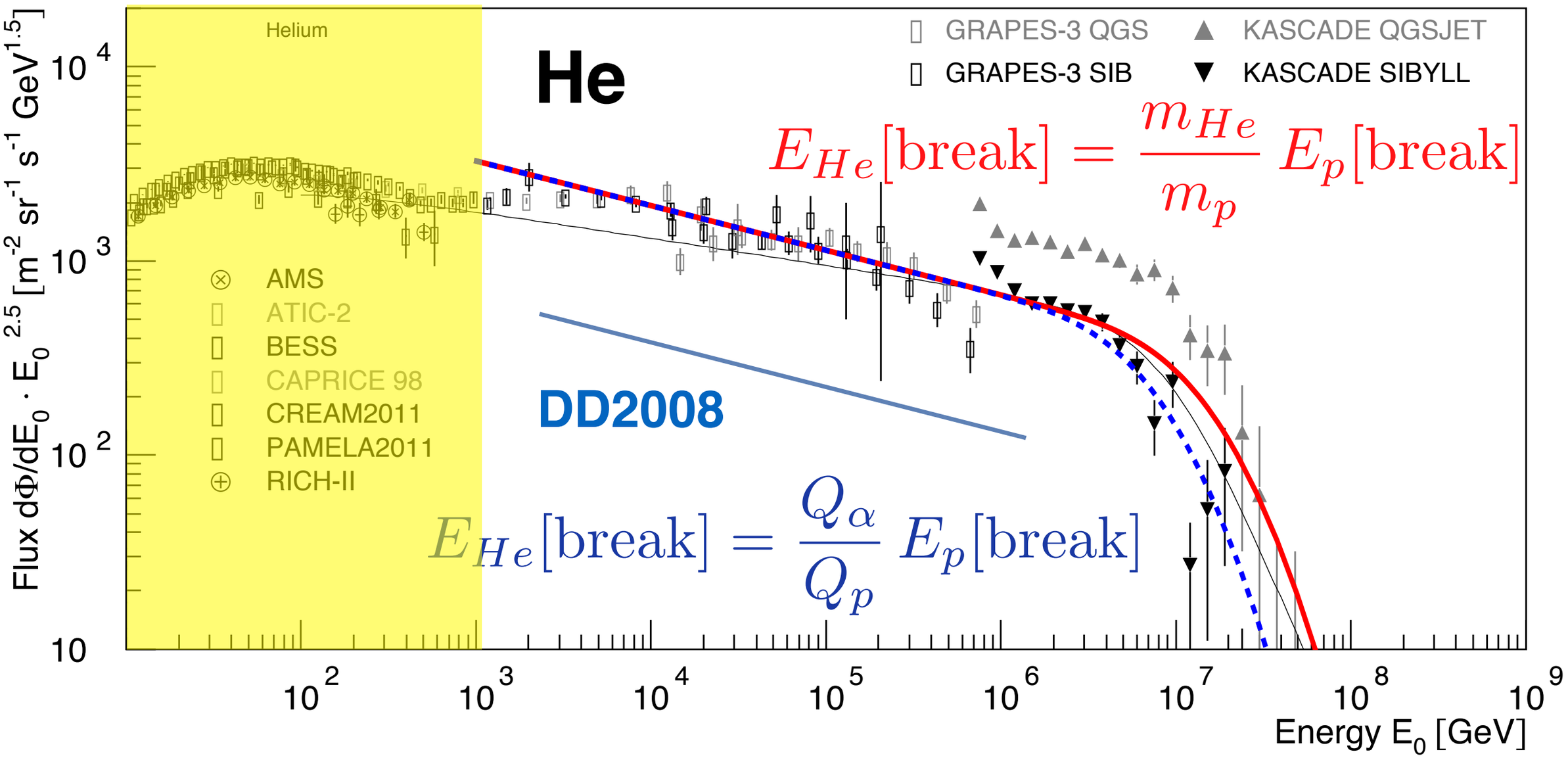






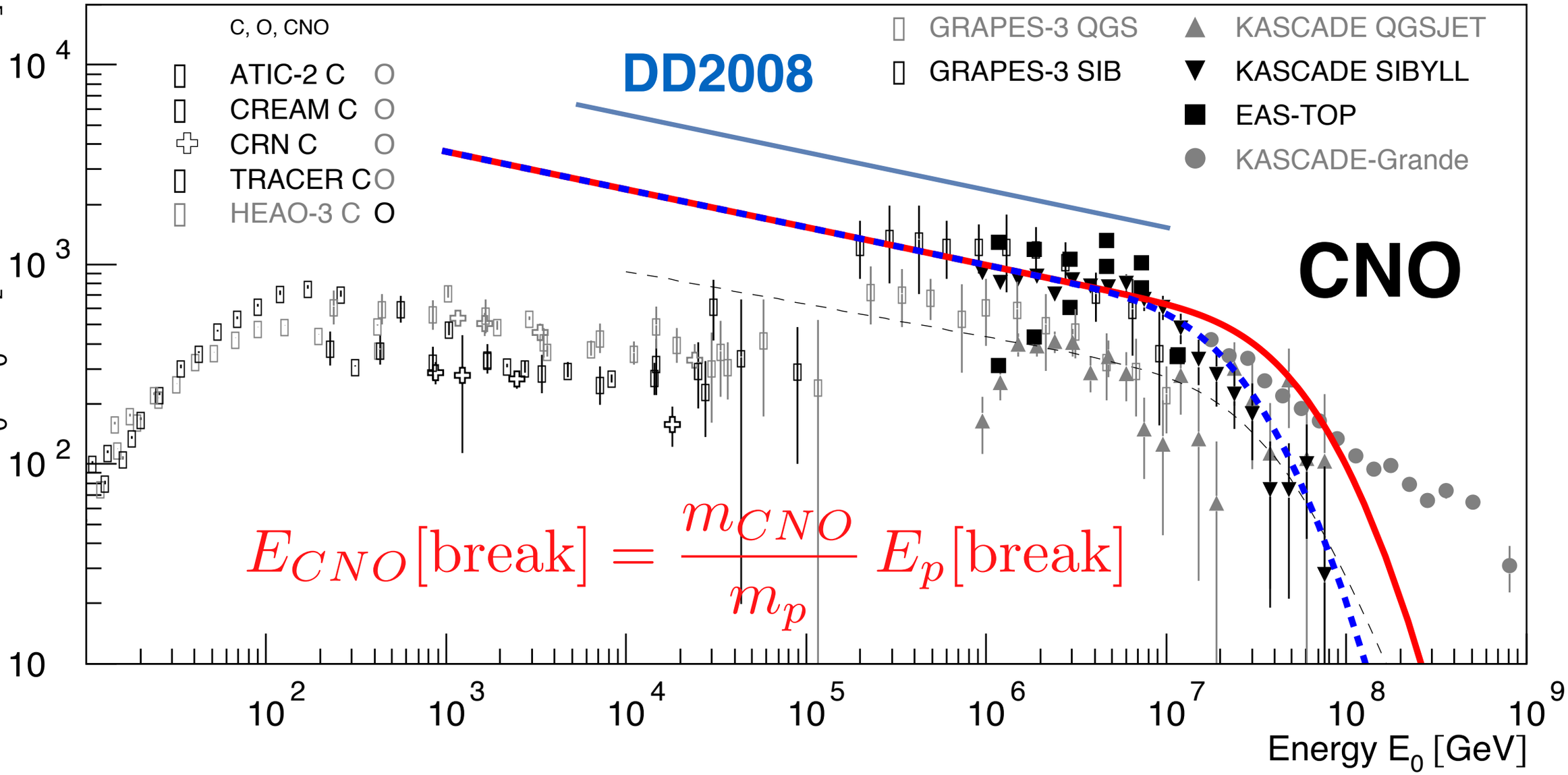
$$f_p = E_p^{-\beta_p}\,\Theta[2\,\gamma_0^2\,m_p - E]$$

$$F_p = E_p^{-\beta_p} \int_{E_p/(2\,m_p)}^{\infty} d\gamma_0^2\; D(\gamma_0^2)$$

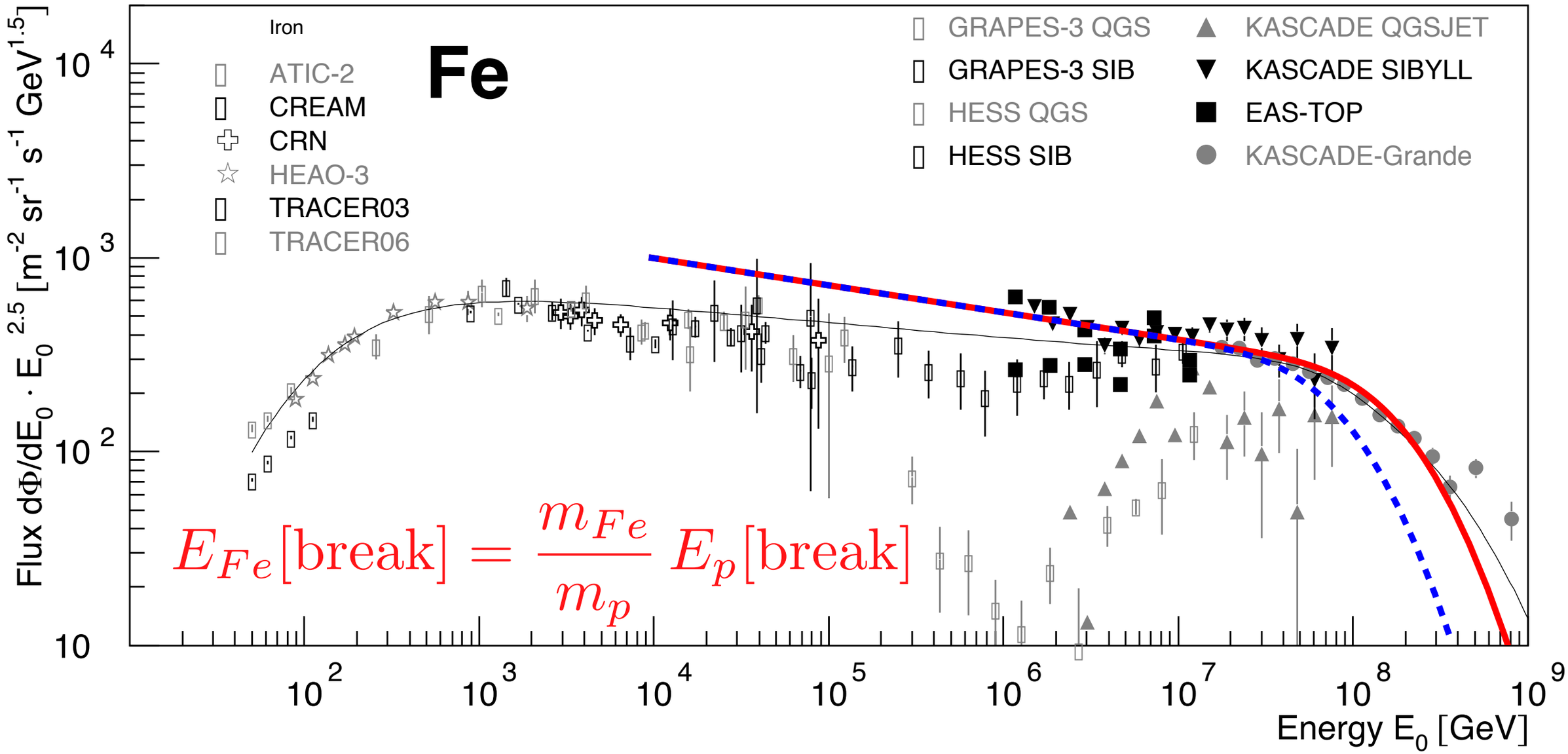


$$f_{He} = E_{He}^{-\beta_{He}}\,\Theta[2\,\gamma_0^2\,m_{He} - E]$$

$$F_{\mathrm{He}} = E_{\mathrm{He}}^{-\beta_{\mathrm{He}}} \int_{E_{\mathrm{He}}/(2\,m_{\mathrm{He}})}^{\infty} d\gamma_0^2\; D(\gamma_0^2)$$


C, O, CNO
ATIC-2 C O
CREAM C O
CRN C O
TRACER C O
HEAO-3 C O
GRAPES-3 QGS
GRAPES-3 SIB
KASCADE QGSJET
KASCADE SIBYLL
EAS-TOP
KASCADE-Grande
DD2008
CNO
$E_{CNO}[\mathrm{break}] = \frac{m_{CNO}}{m_p} E_p[\mathrm{break}]$
Flux $d\Phi/dE_0 \cdot E_0^{2.5}$ [m^{-2} sr^{-1} s^{-1} $GeV^{1.5}$]
Energy E_0 [GeV]

?



A(Fe) ~ 56 Z(Fe) = 26

KASCADE-Grande …. “Best knee”:
Used to refine the γ_0 distribution

The strong test of these trivial kinematic knees would be the electron flux

Now measured to higher energy and much better precision

$$m_e/m_p = 5.46 \times 10^{-4}$$

$$-Q_e/Q_p = 1$$

$$\beta_e = \beta_p + 1$$

WARNING:
In the CB model de normalization of the ELECTRON FLUX
is NOT (yet) predictable

BUT its shape IS

CB model —> Primary electron flux

But, highest-energy measurements

$$e^+ + e^- \; flux$$

Need secondary

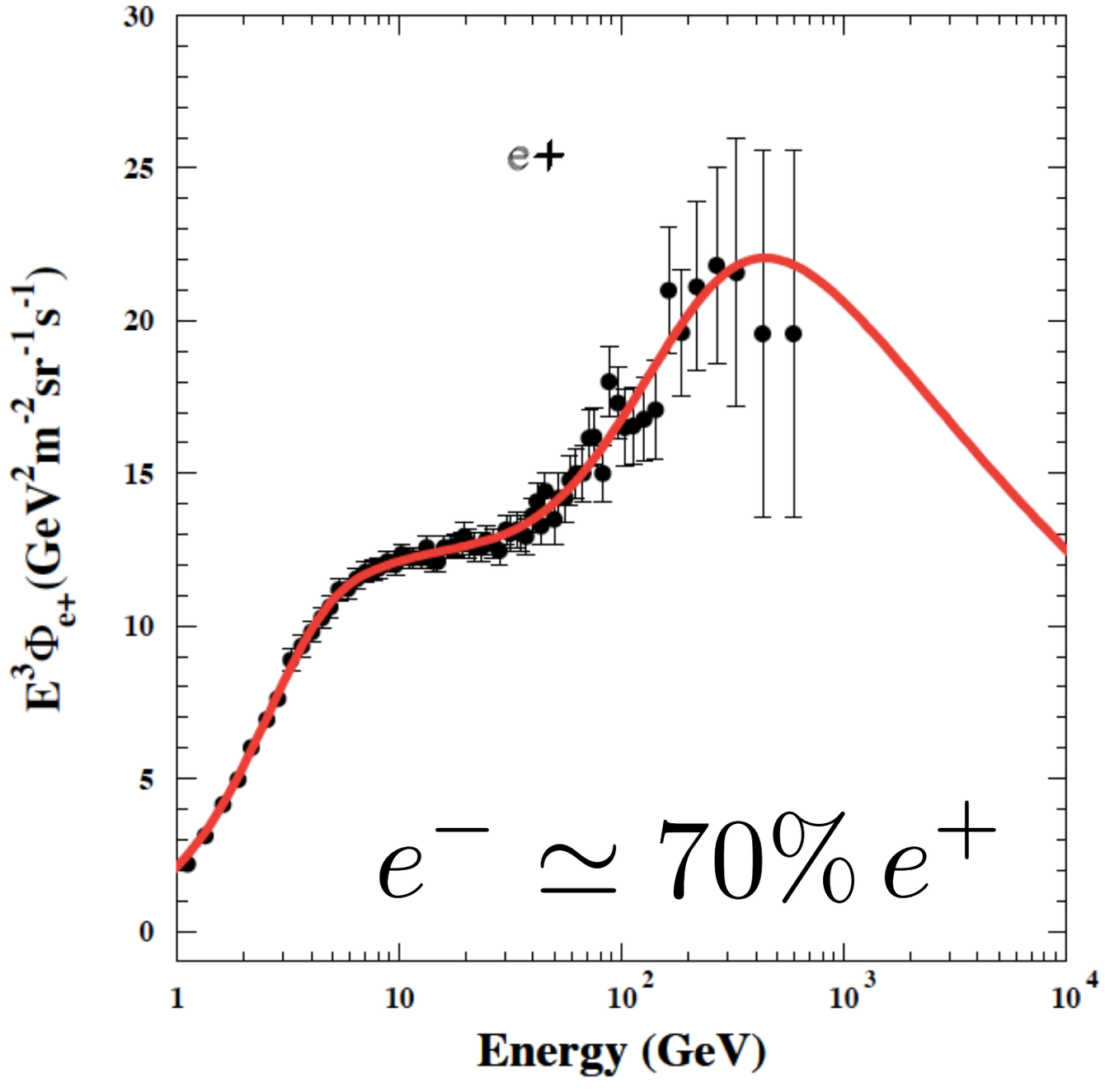
$$e^+ + e^- \; flux$$

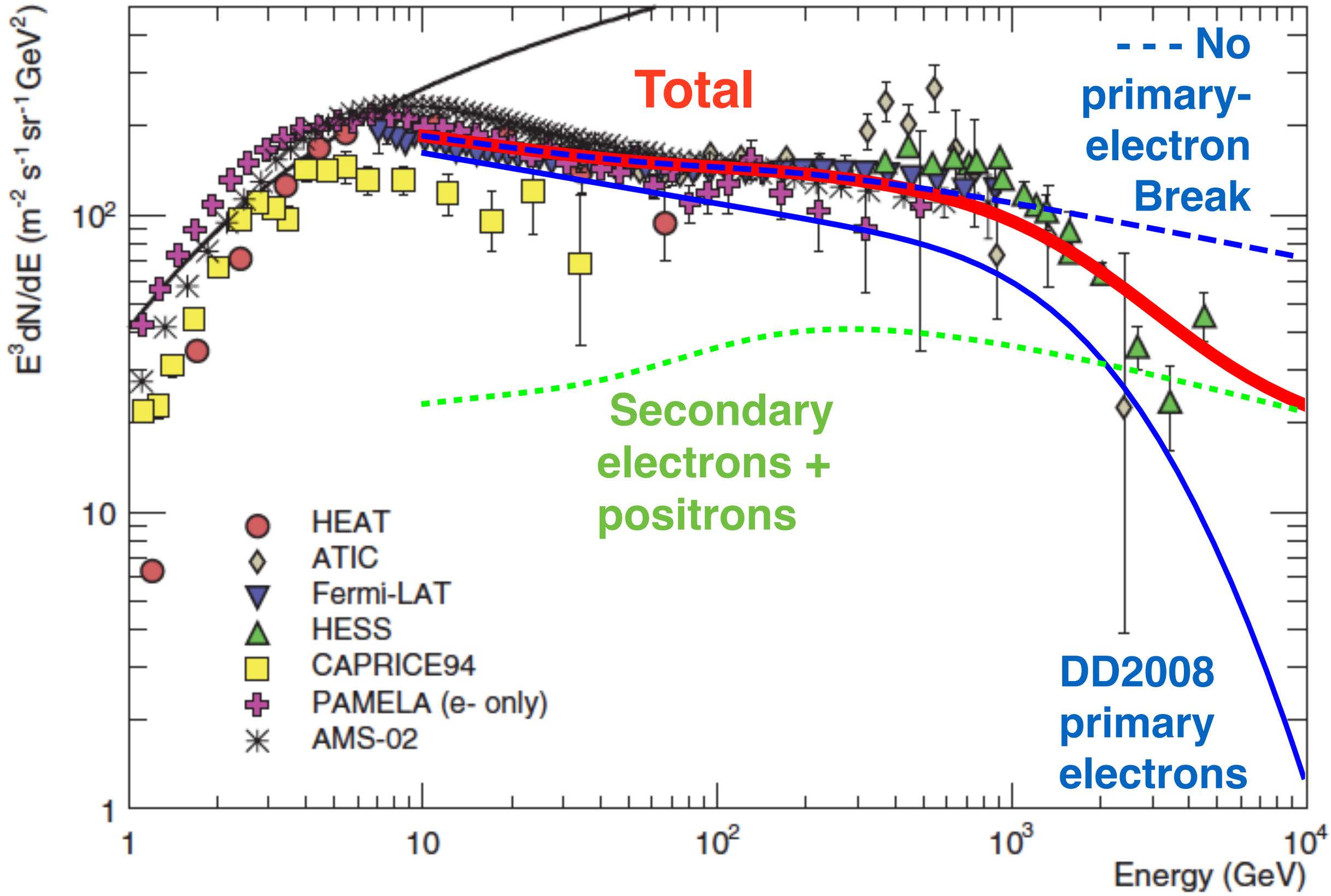
Dado&Dar

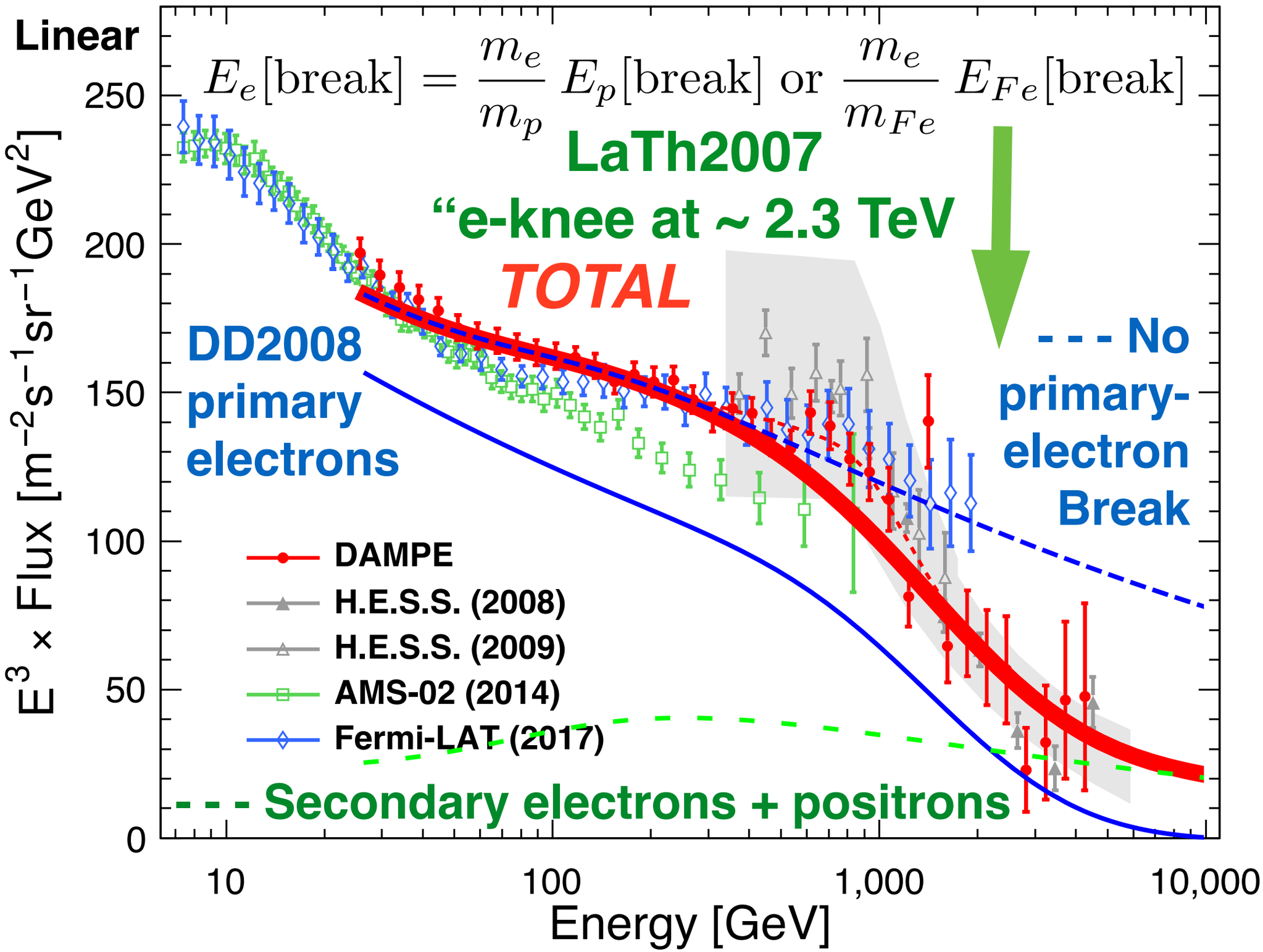
CR + ISM —>

$$\pi^{\pm},\, K^{\pm,0}$$

$$\rightarrow \mu^{\pm} \rightarrow e^{\pm}$$




$E^3 dN/dE$ (m^{-2} s^{-1} sr^{-1} GeV^2)
10^2
10
1
1
10
10^2
10^3
10^4
Energy (GeV)
Total
- - - No primary-electron Break
Secondary electrons + positrons
DD2008 primary electrons
HEAT
ATIC
Fermi-LAT
HESS
CAPRICE94
PAMELA (e- only)
AMS-02



$$\frac{\mathbf{m[Fe]}}{\mathbf{m[e]}} \sim 10^5$$

$$F_e = E_e^{-\beta_e} \int_{E_e/(2\,m_e)}^{\infty} d\gamma_0^2 \; D(\gamma_0^2)$$

AMS ?

Eddington:

Never trust an experiment

until it has been confirmed

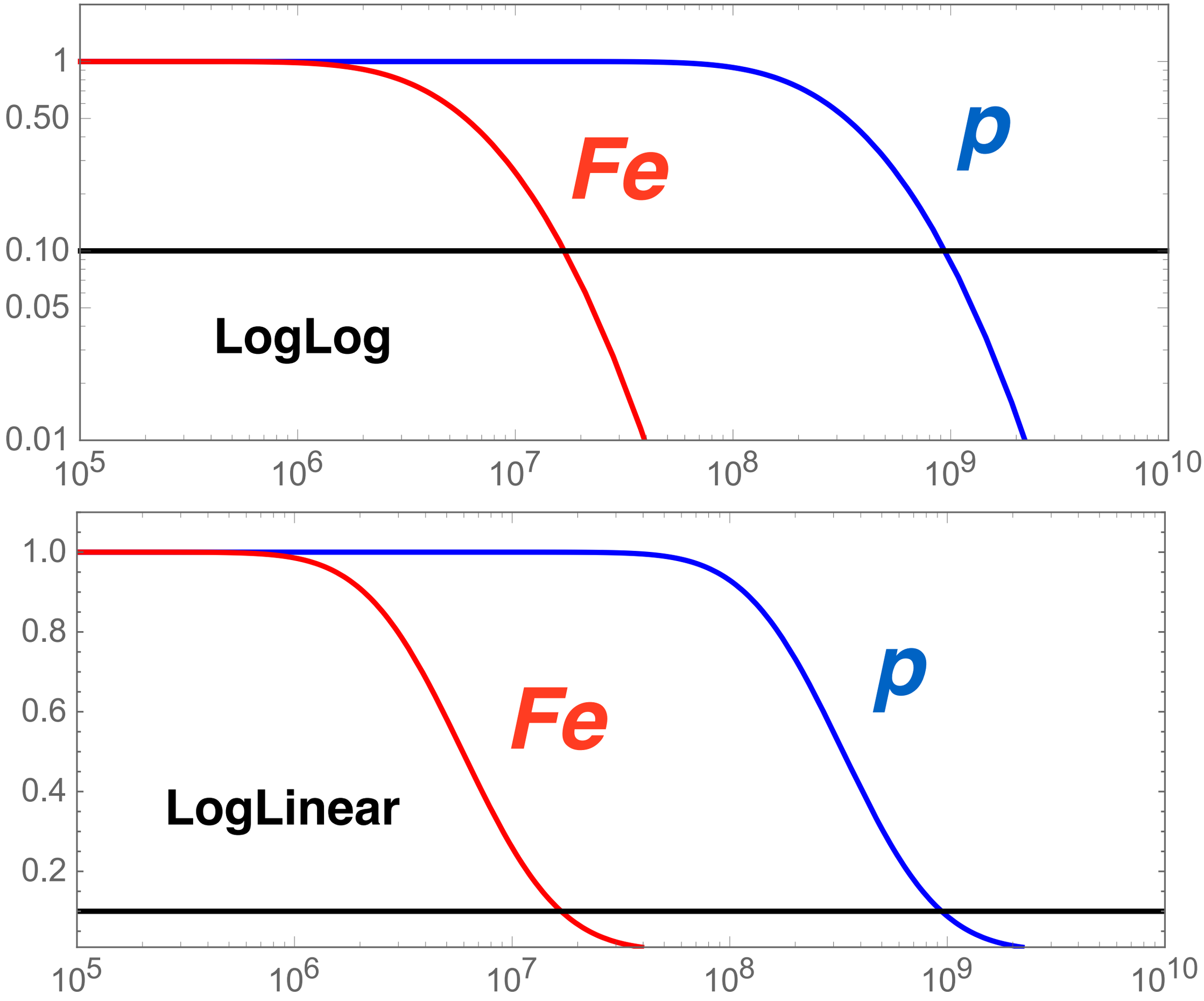
by THEORY

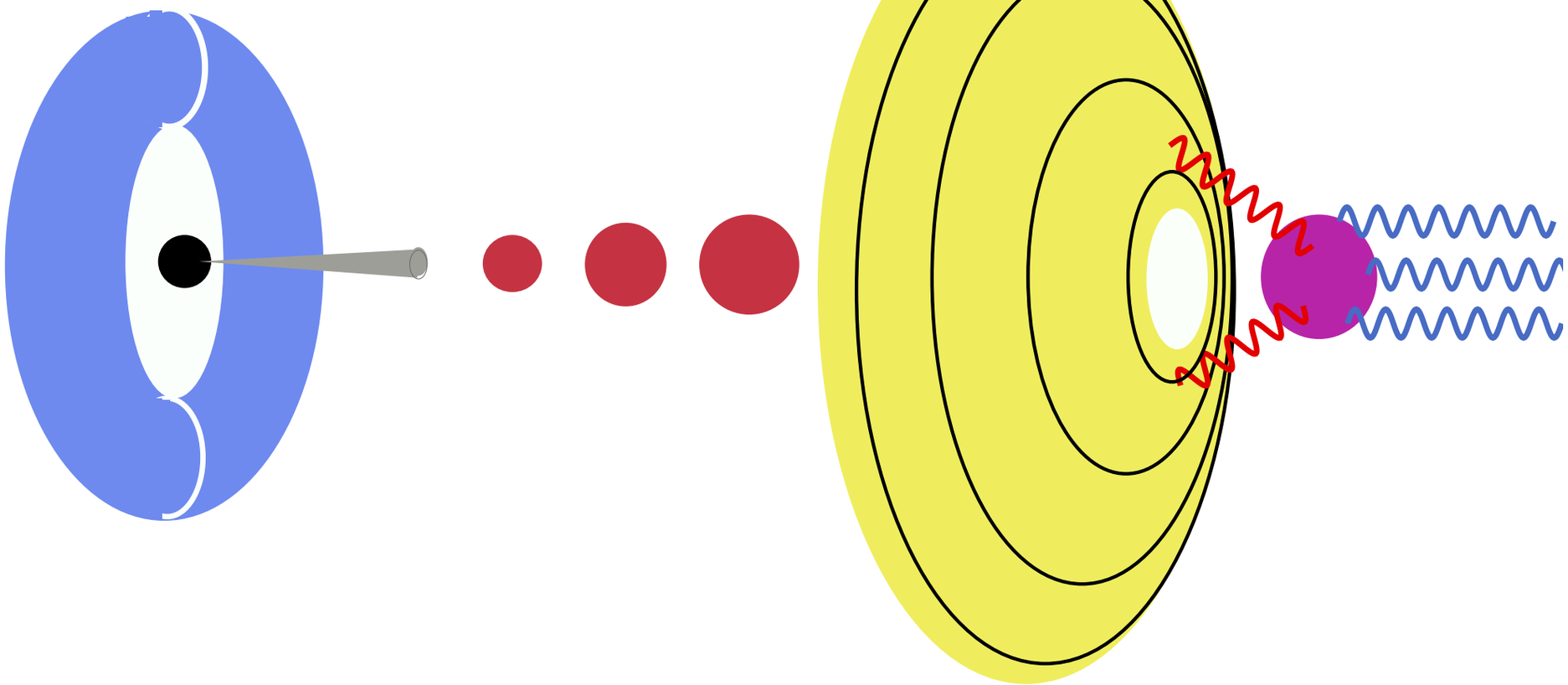
NEWS: CannonBalls, initially moving with

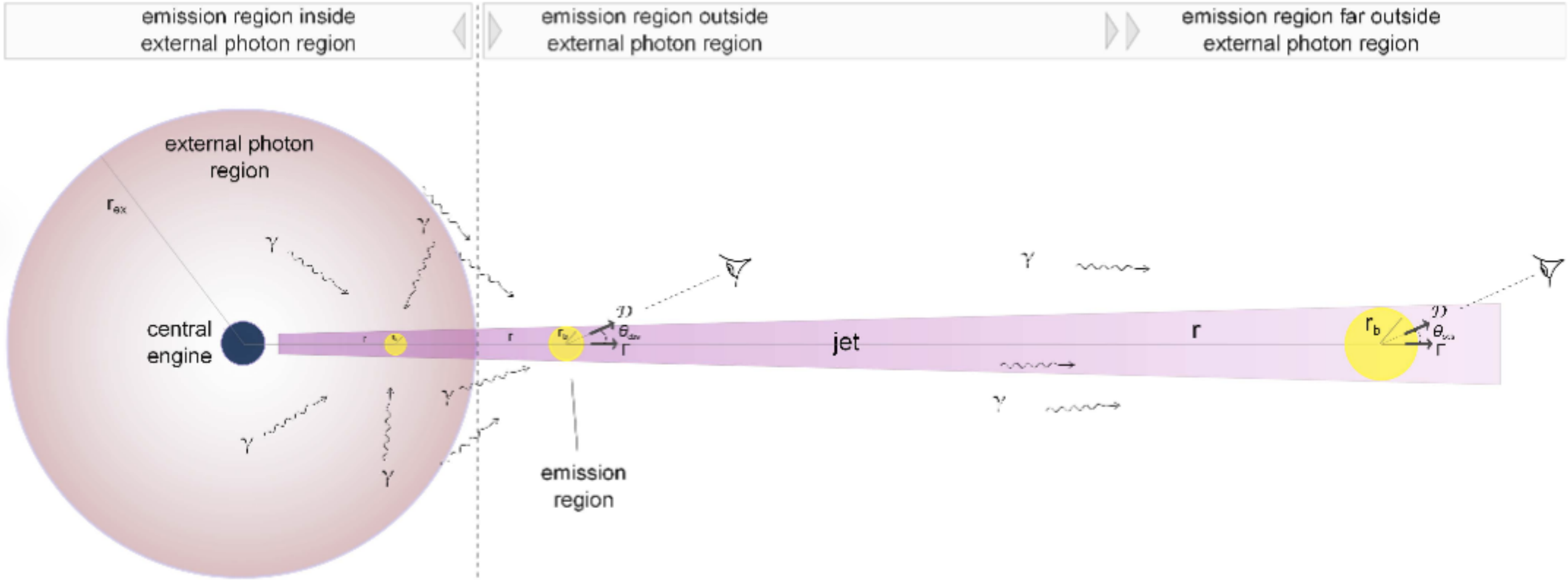
$$\gamma_0 = \mathcal{O}(10^3)$$

and kicking the ISM as they move, trivially predict the CR KNEES

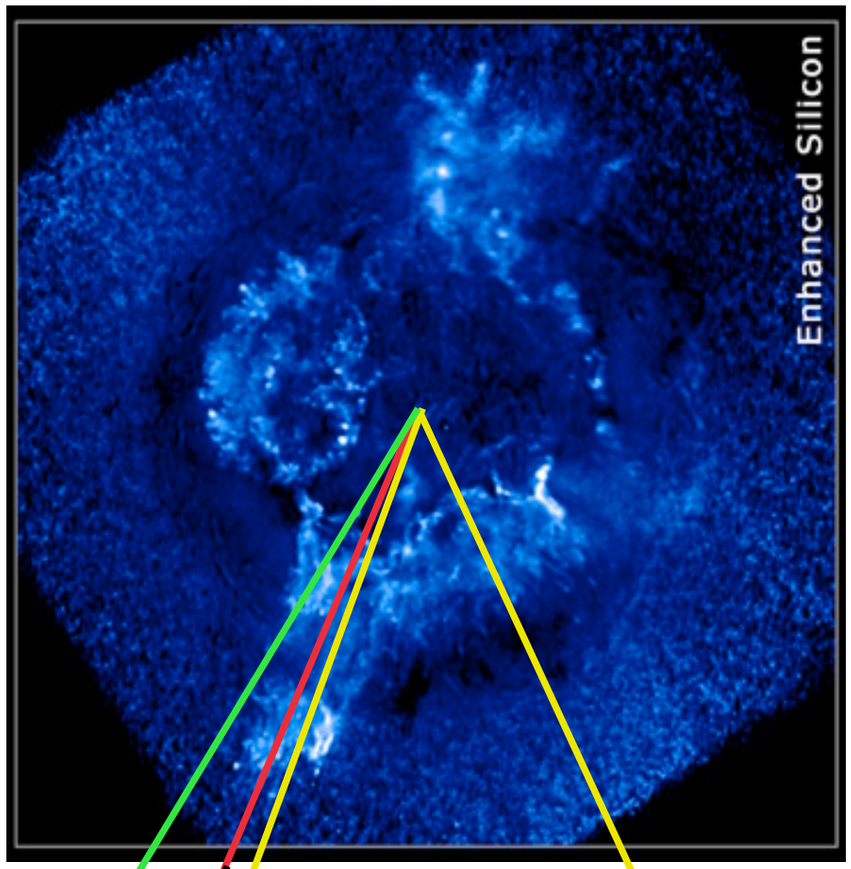
STOP


1
0.50
0.10
0.05
0.01
LogLog
Fe
p
10^5
10^6
10^7
10^8
10^9
10^{10}
1.0
0.8
0.6
0.4
0.2
LogLinear
Fe
p
10^5
10^6
10^7
10^8
10^9
10^{10}




emission region inside
external photon region
emission region outside
external photon region
emission region far outside
external photon region
external photon
region
r_{ex}
central
engine
jet
r
r_b
emission
region

A core-collapse SN



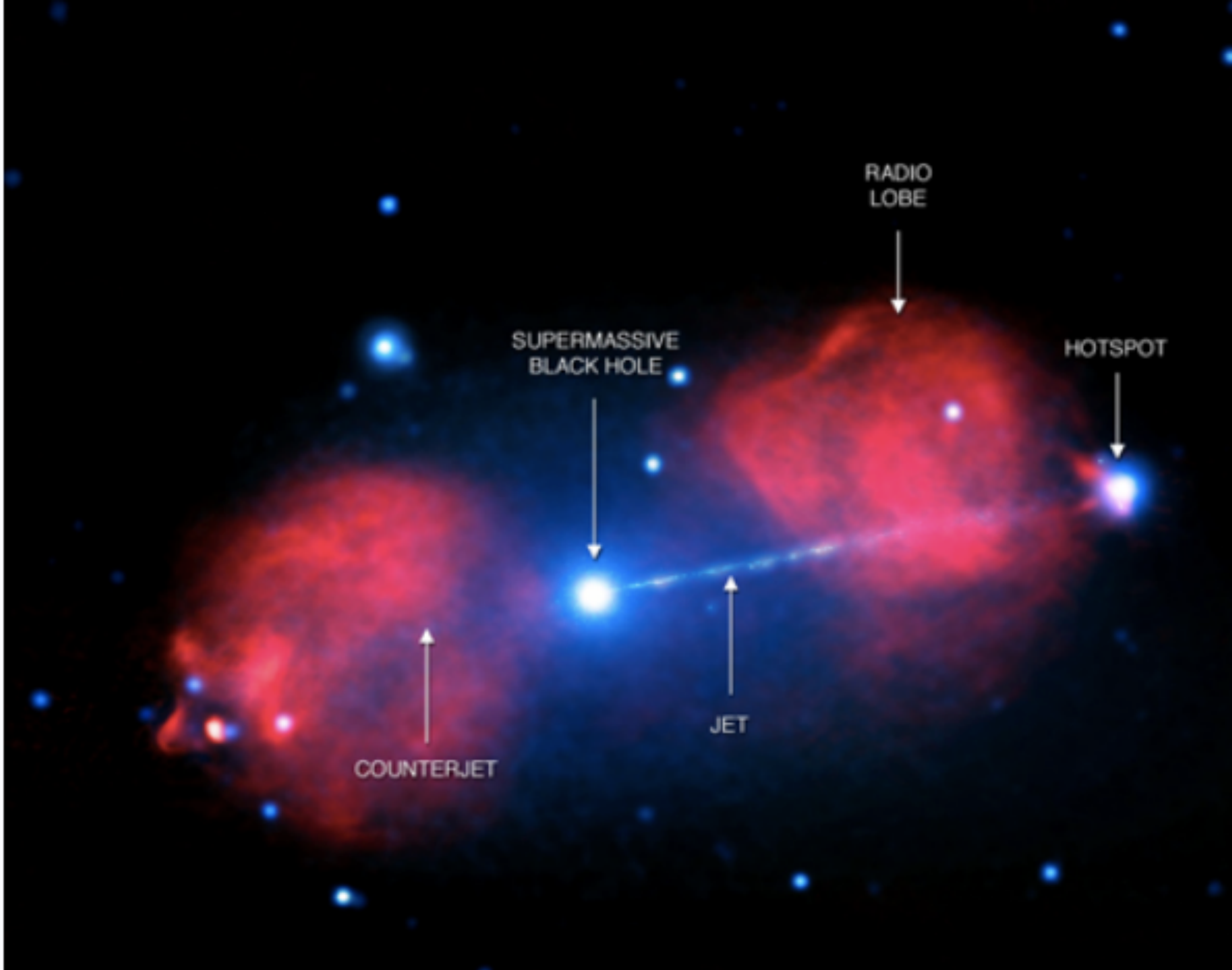
XRF
Smallish θ

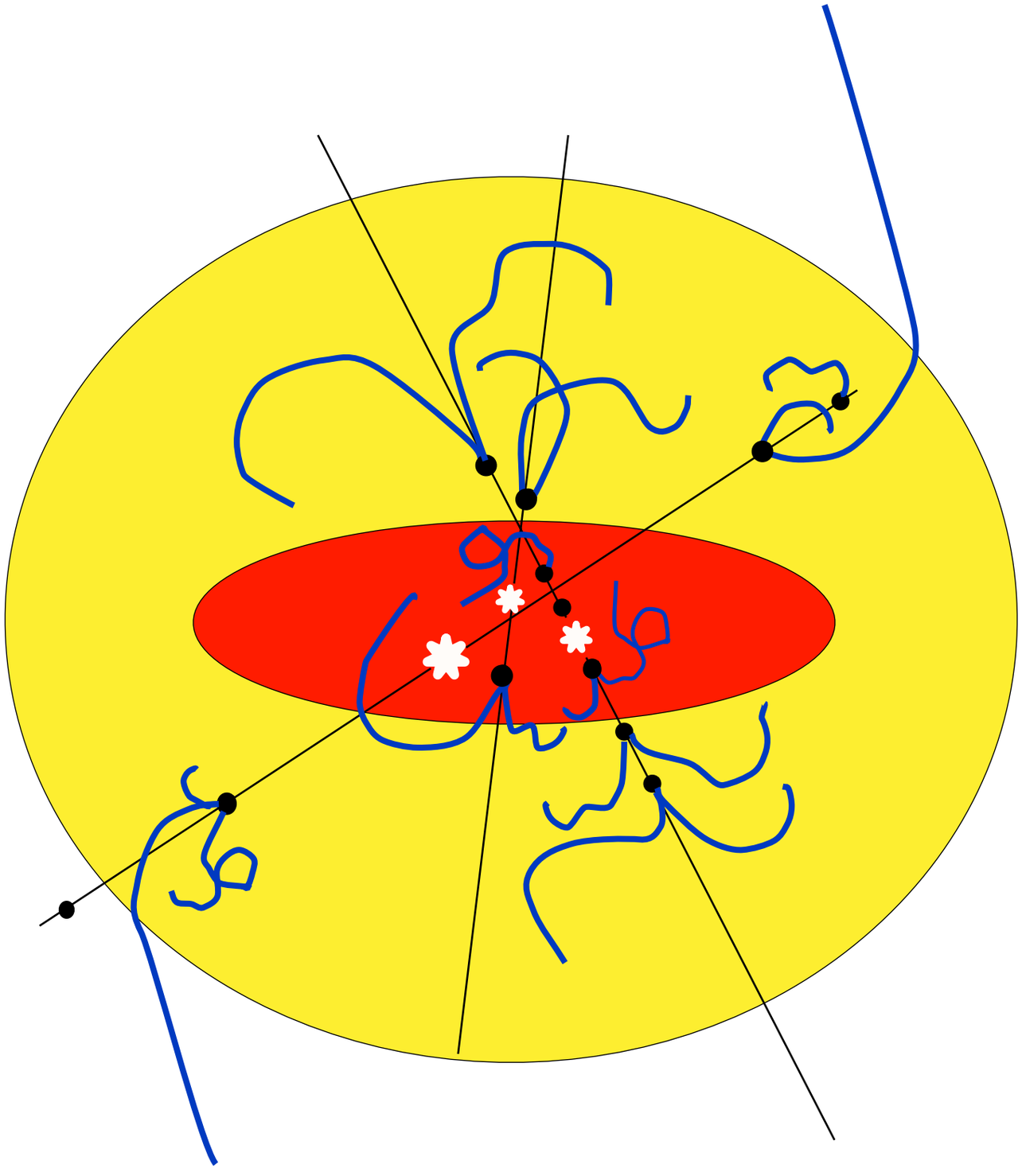
Axis of CBs

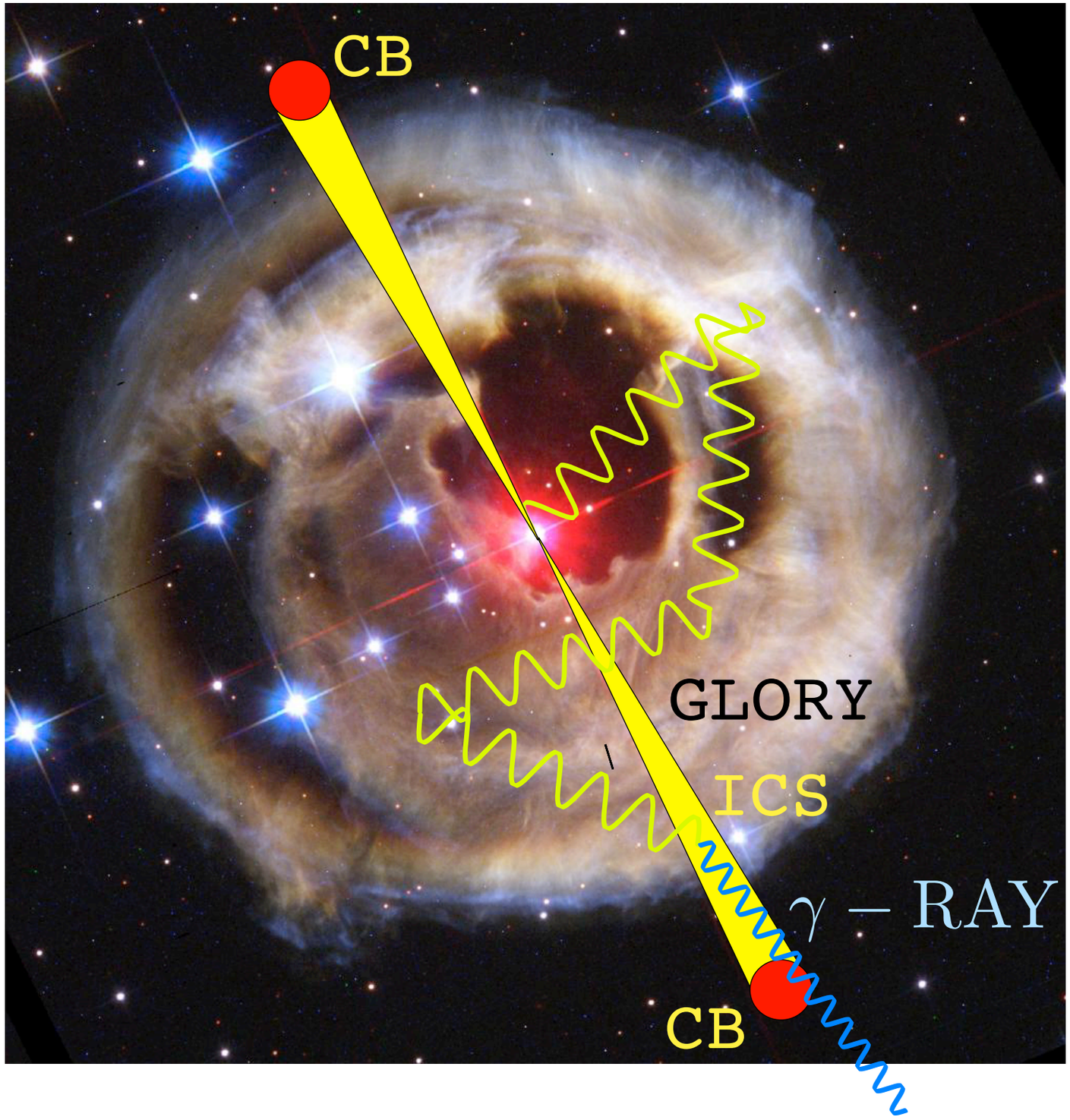
Very Small θ

Observer sees an ordinary Supernova not a GRB

Observer sees a GRB and fast SN ejecta Calls it a "Hypernova"


RADIO
LOBE
SUPERMASSIVE
BLACK HOLE
HOTSPOT
JET
COUNTERJET




CB
GLORY
ICS
γ – RAY
CB

At E > E (conf.)

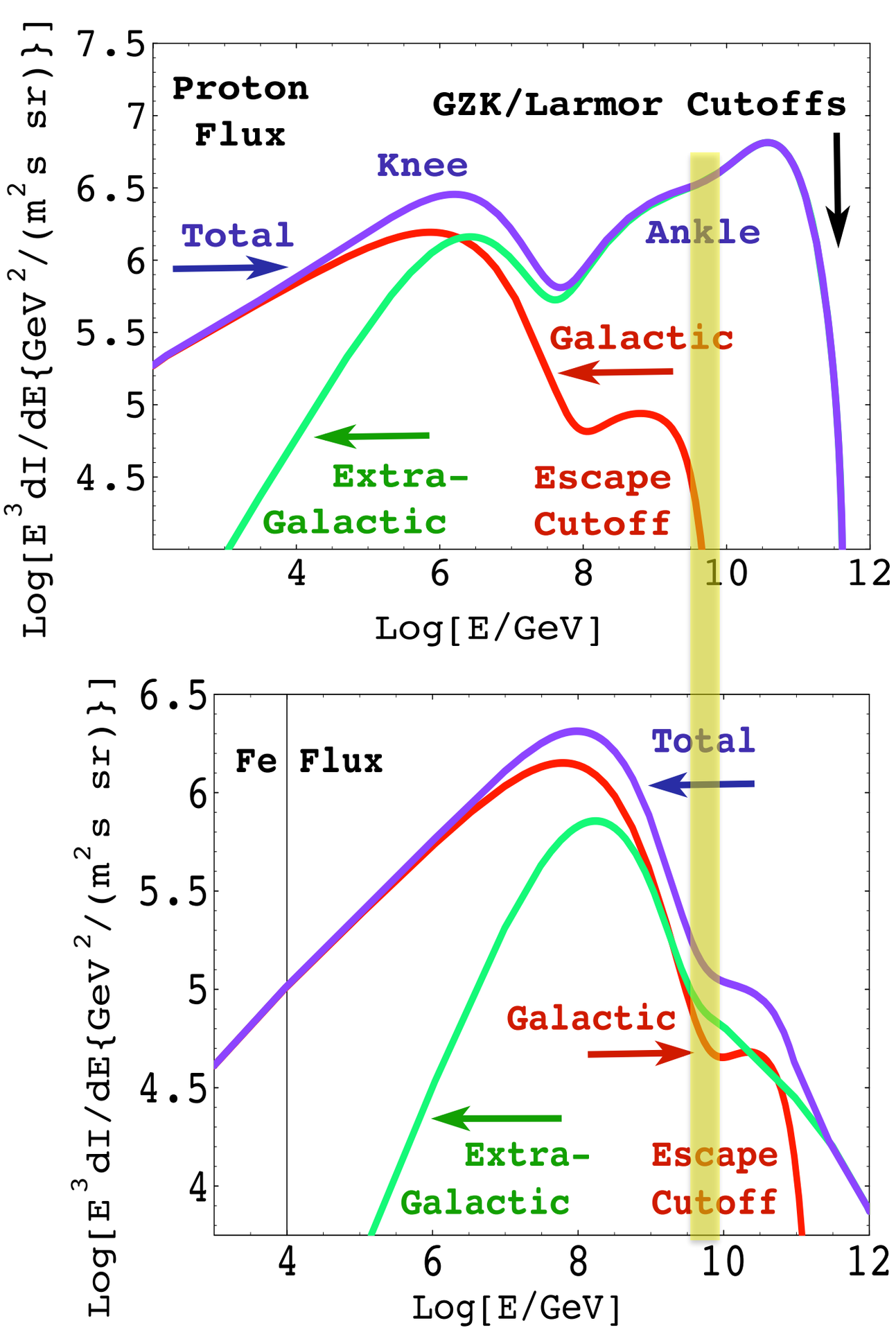
CRs must be extragalactic

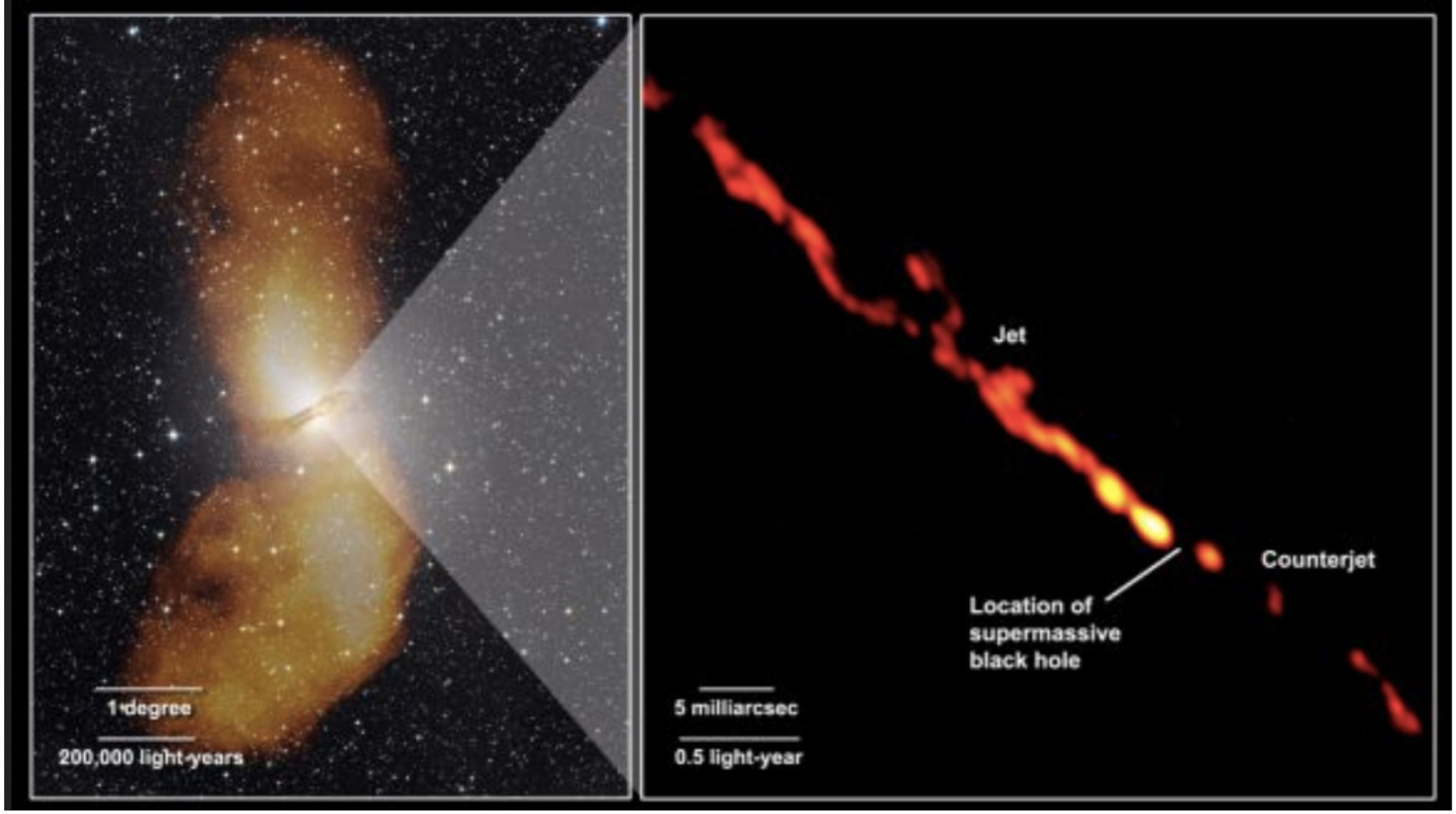
$$R_{\rm L} \sim 0.65\,{\rm kpc} \times \frac{5\,\mu G}{B}\,\frac{p(E)}{E_{\rm ankle}(Z)}$$

$$E_{\rm ankle}(Z) \sim Z\,(3\times 10^9)\,{\rm GeV}$$

Cocconi (1956)

Morrison (1957)




1 degree
200,000 light-years
Jet
Counterjet
Location of
supermassive
black hole
5 milliarcsec
0.5 light-year