Veniamin Berezinsky and the physics of Galactic cosmic ray sources

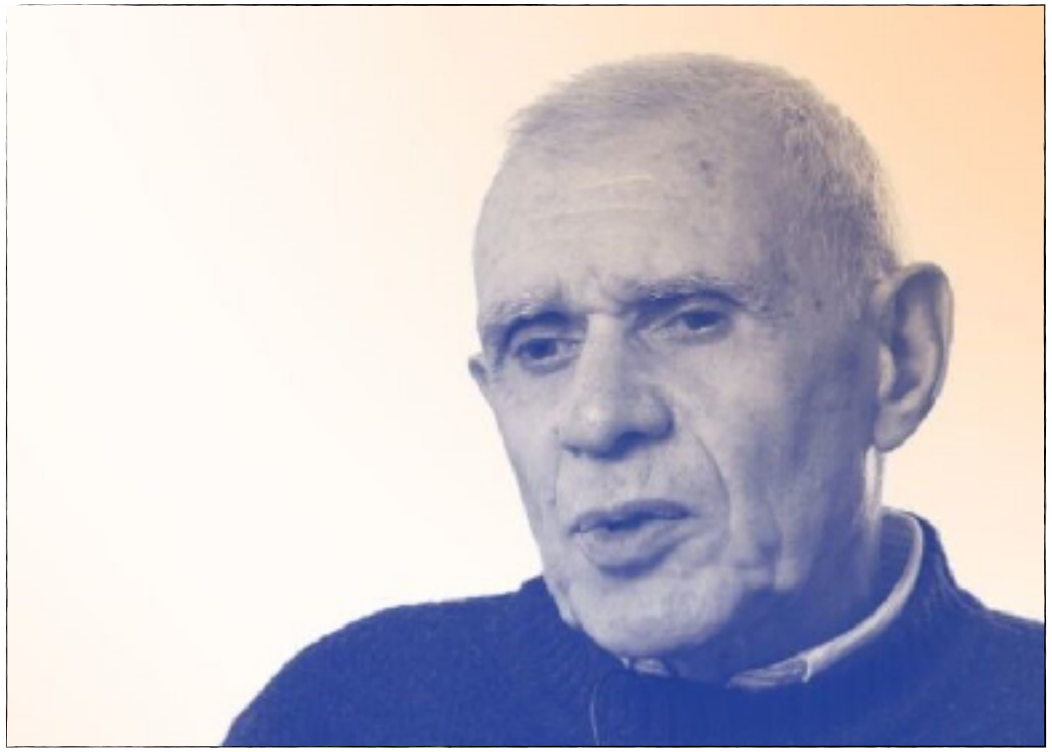
Stefano Gabici
APC, Paris

Academic family tree

Dmitri
Vladimirovich
Skobeltsyn

Georgy
Timofeyevich
Zatsepin

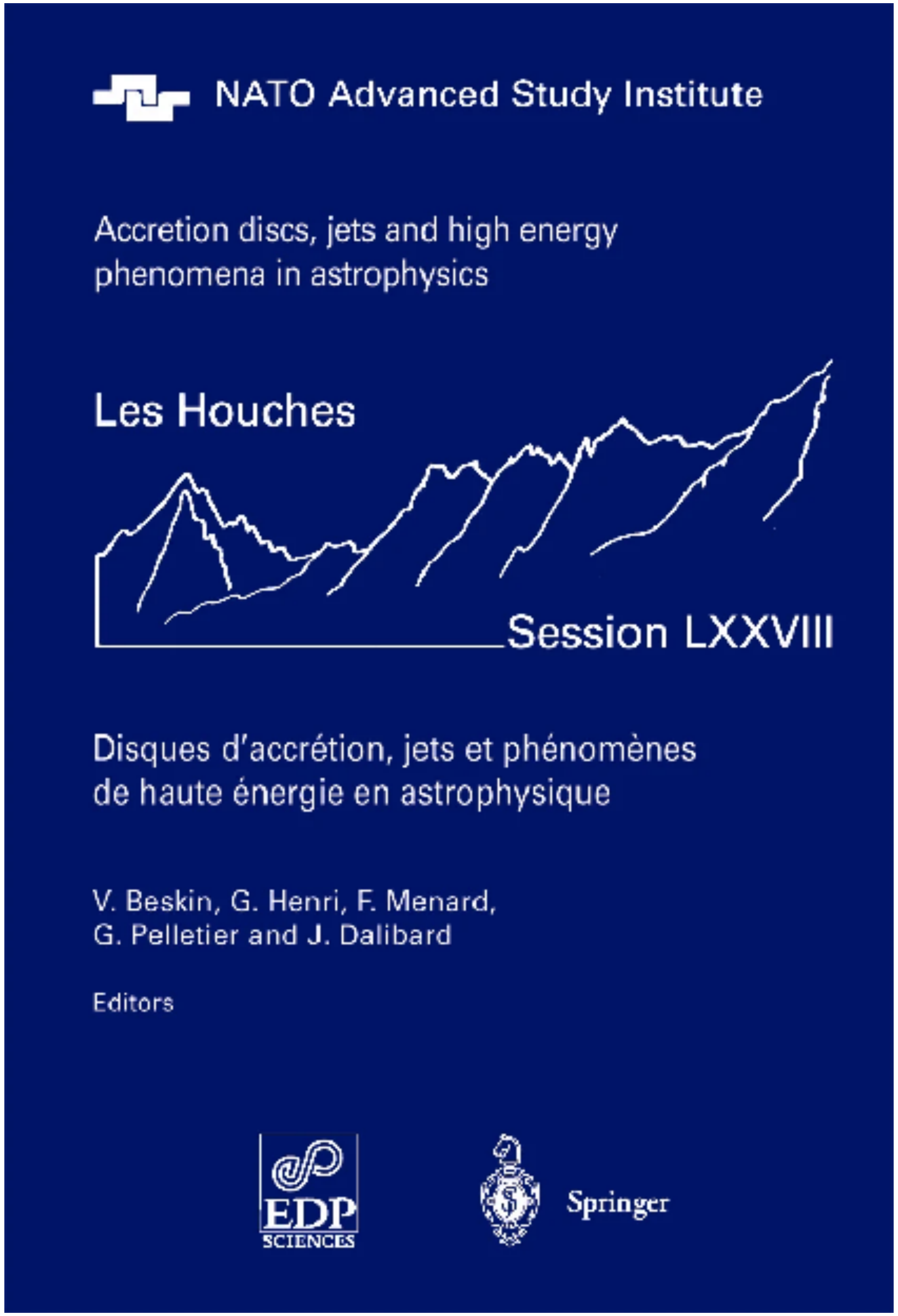
Veniamin
Sergeevich
Berezinsky



Pasquale
Blasi

me

Meeting Berezinsky…



NATO Advanced Study Institute

Accretion discs, jets and high energy
phenomena in astrophysics

Les Houches

Session LXXVIII

Disques d'accrétion, jets et phénomènes
de haute énergie en astrophysique

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Editors

EDP SCIENCES

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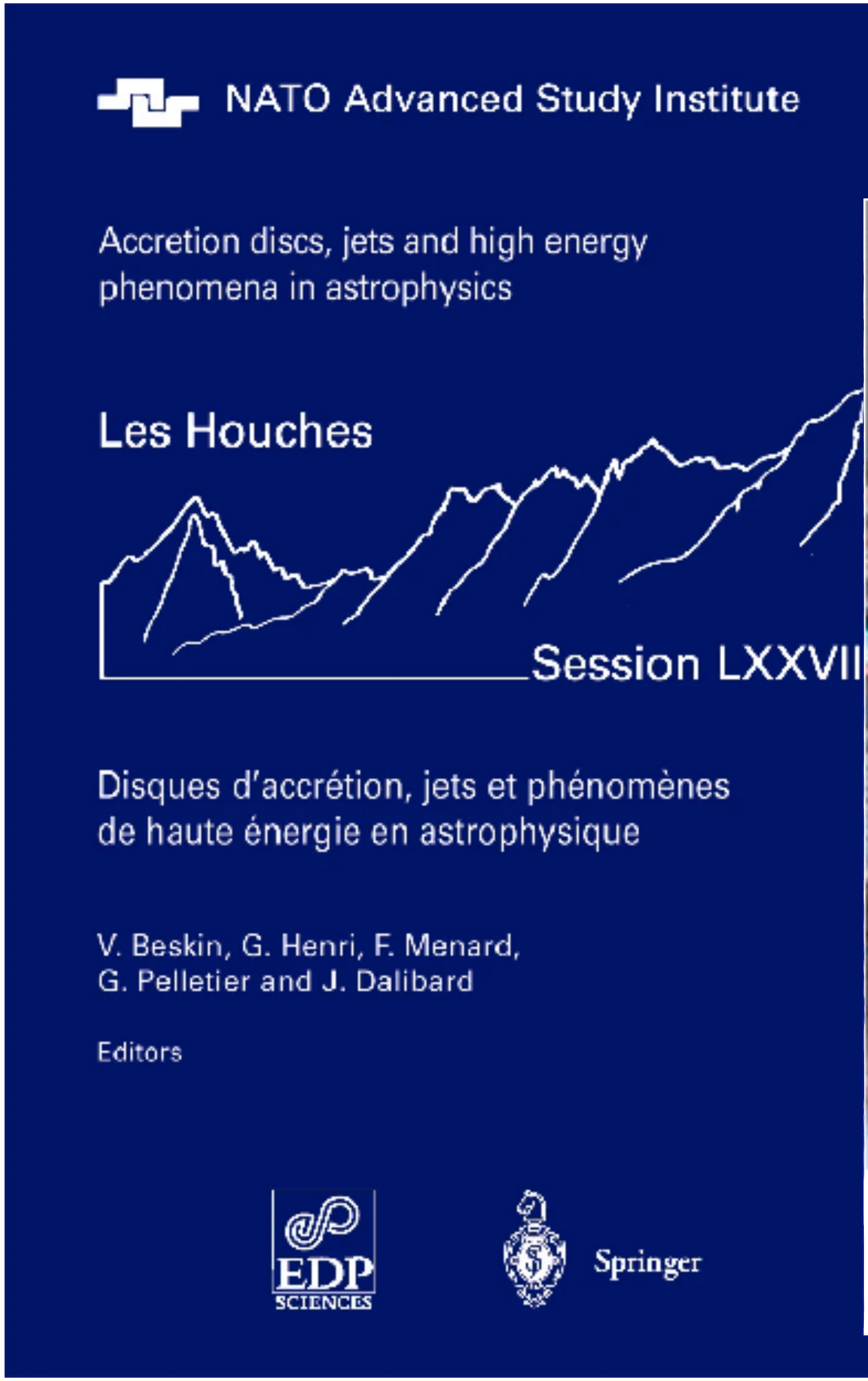

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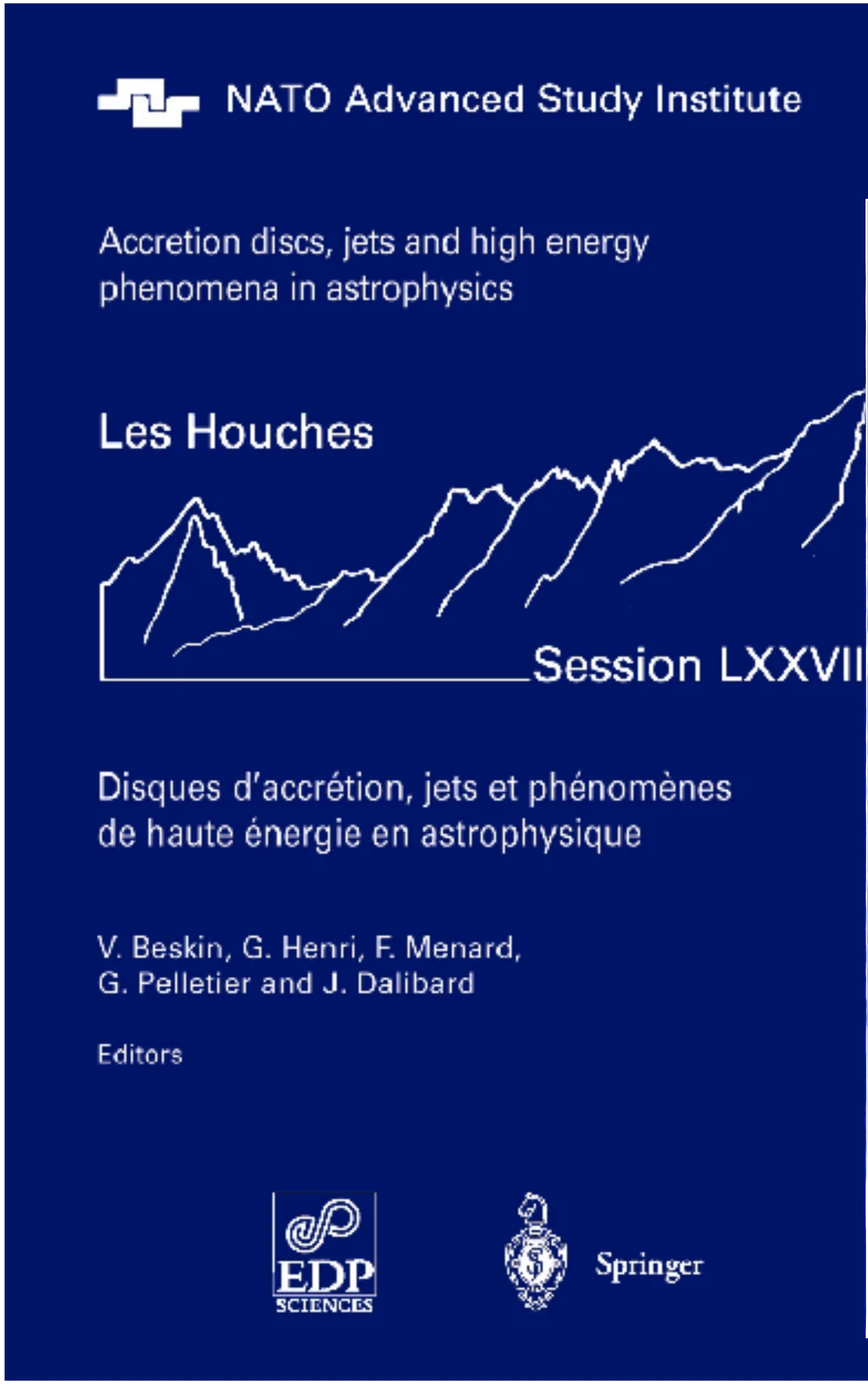

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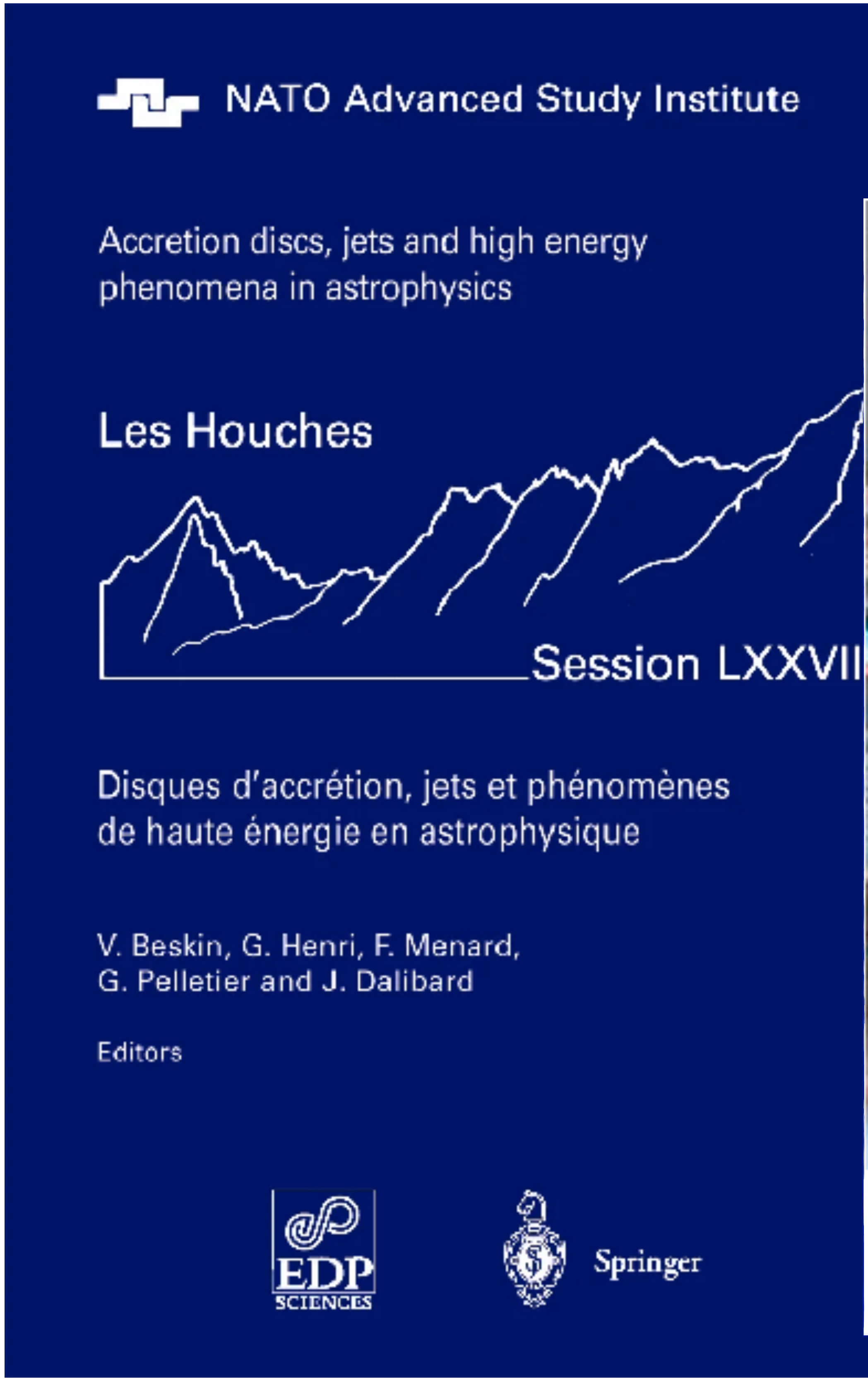

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FAKE

COURSE 5

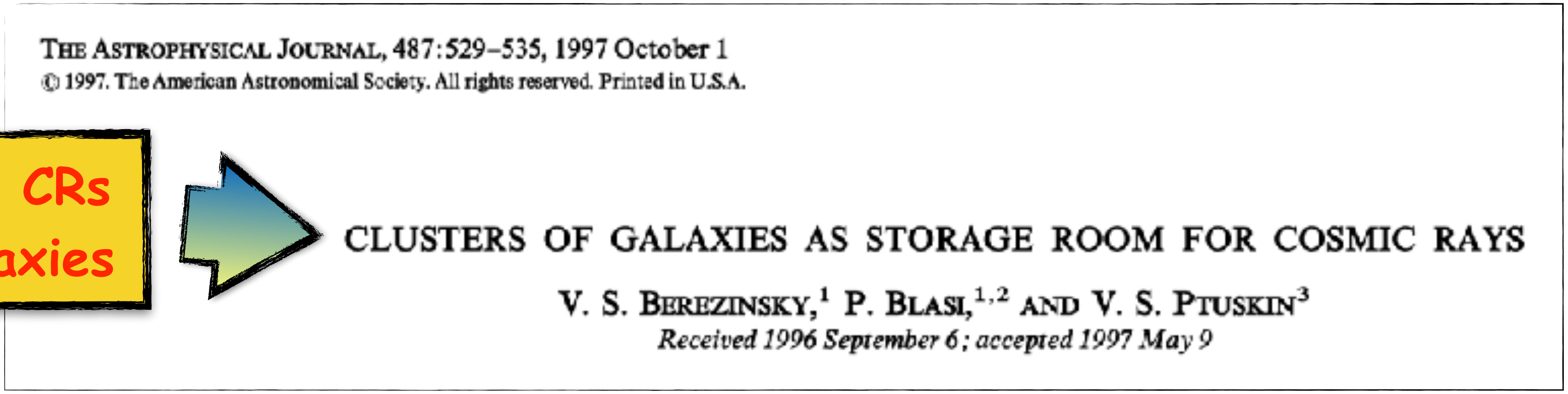
ULTRA HIGH ENERGY COSMIC RAYS

V. BEREZINSKY

INFN,
Laboratori Nazionali del Gran Sasso,
67010 Assergi (AQ),
Italy

…over the years (legendary papers)

during my PhD on CRs
in clusters of galaxies



THE ASTROPHYSICAL JOURNAL, 487:529–535, 1997 October 1

CLUSTERS OF GALAXIES AS STORAGE ROOM FOR COSMIC RAYS

V. S. BEREZINSKY,[1] P. BLASI,[1,2] AND V. S. PTUSKIN[3]

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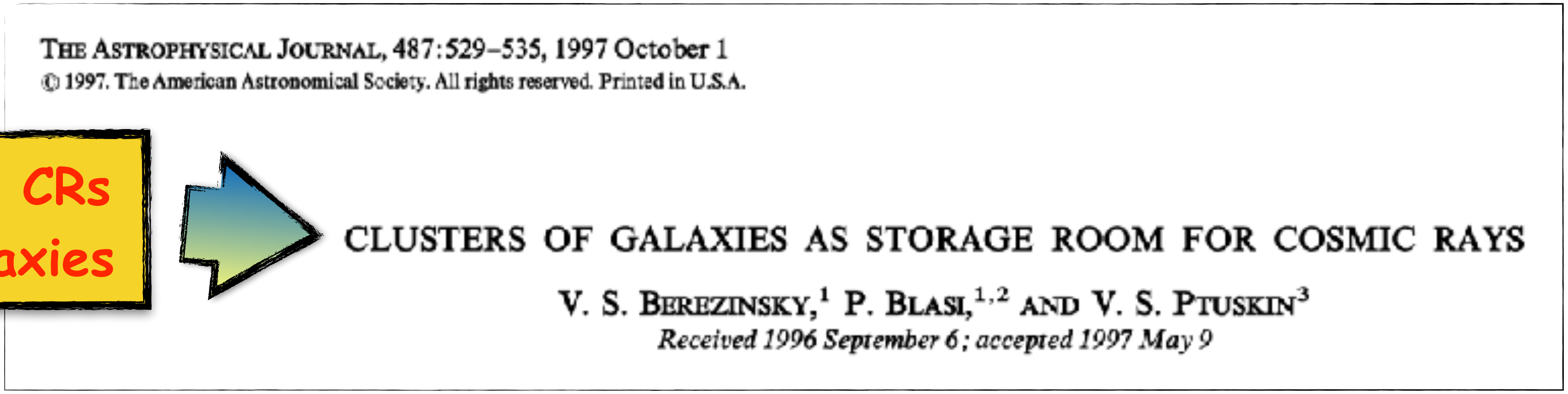

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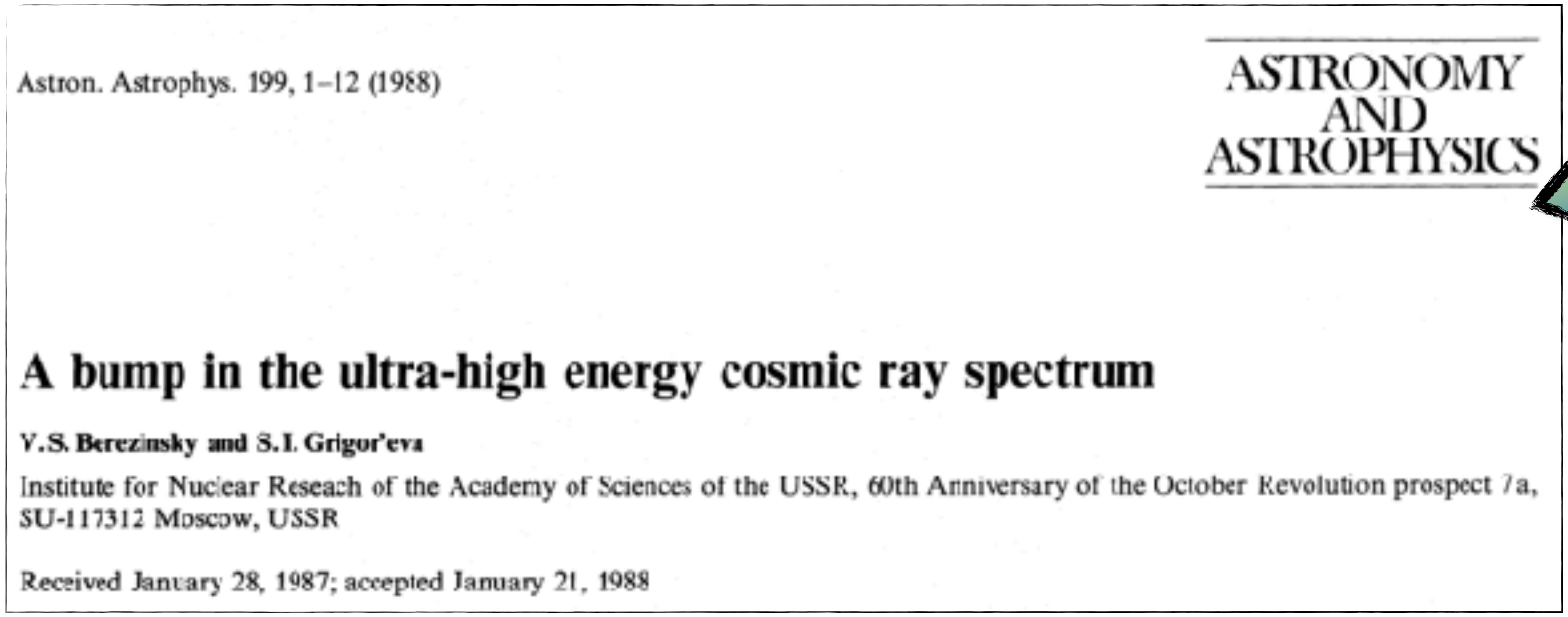

Astron. Astrophys. 199, 1–12 (1988)

ASTRONOMY
AND
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A bump in the ultra-high energy cosmic ray spectrum

V.S. Berezinsky and S.I. Grigor'eva

Institute for Nuclear Reseach of the Academy of Sciences of the USSR, 60th Anniversary of the October Revolution prospect 7a, SU-117312 Moscow, USSR

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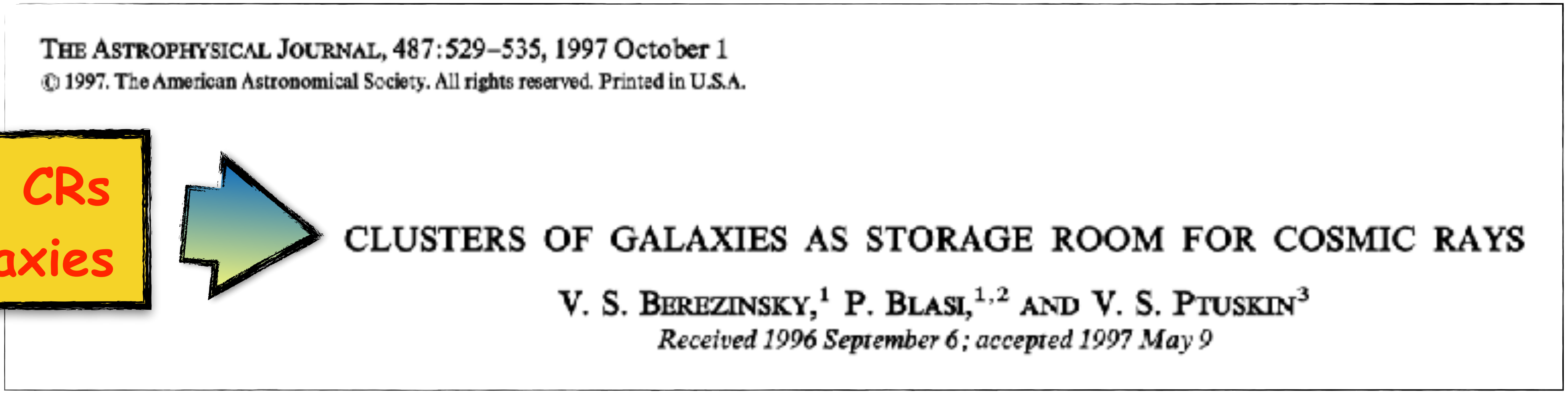
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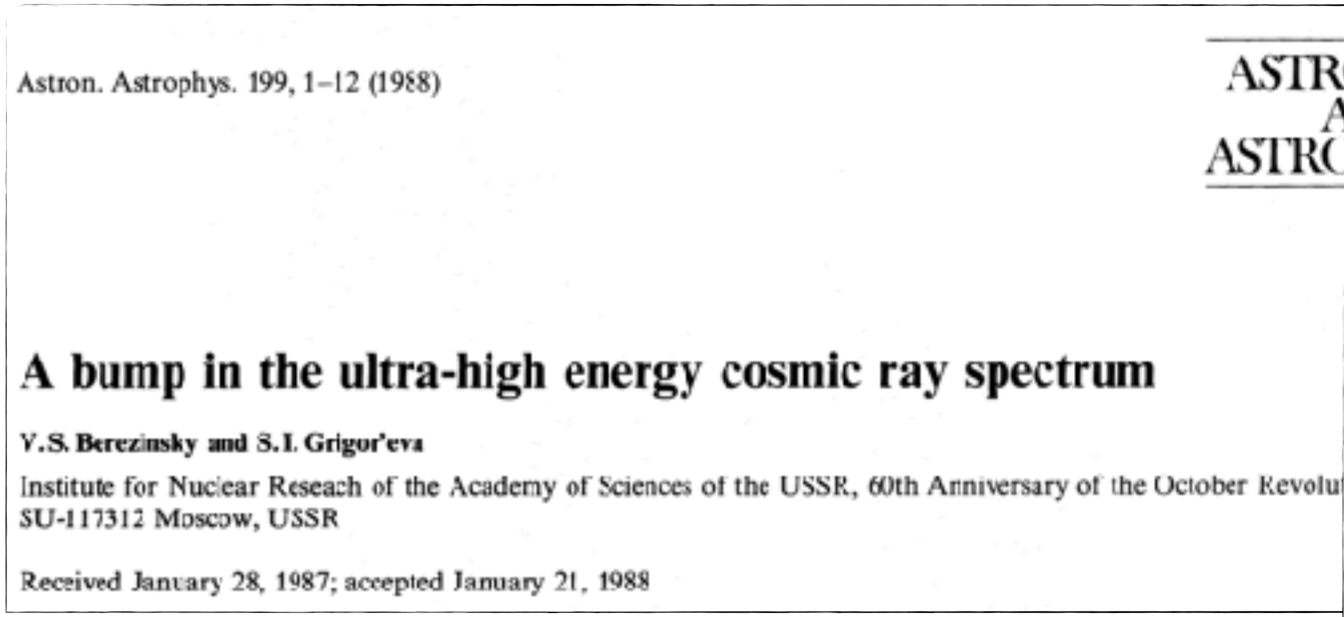
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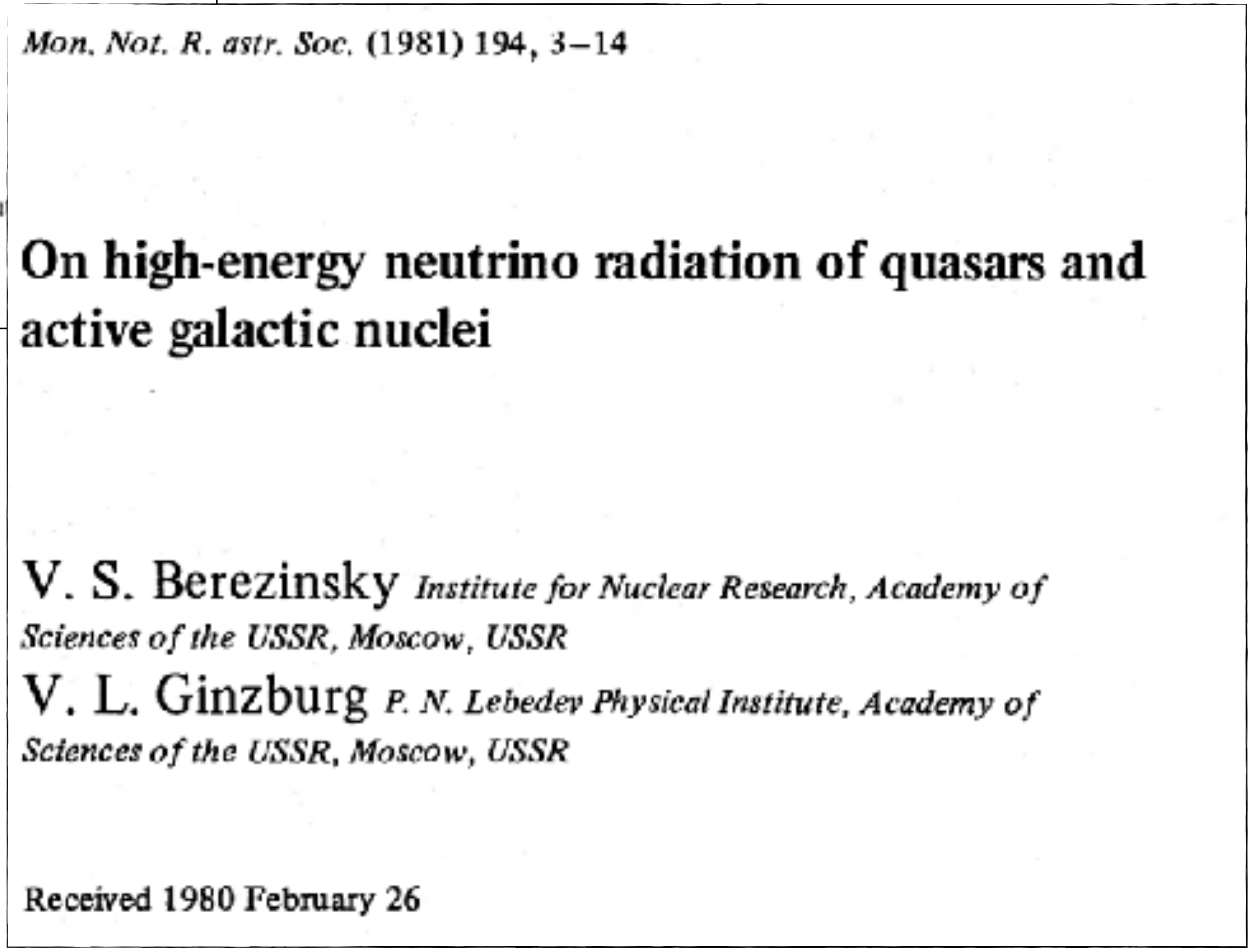
Mon. Not. R. astr. Soc. (1981) 194, 3–14

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V. L. Ginzburg *P. N. Lebedev Physical Institute, Academy of Sciences of the USSR, Moscow, USSR*

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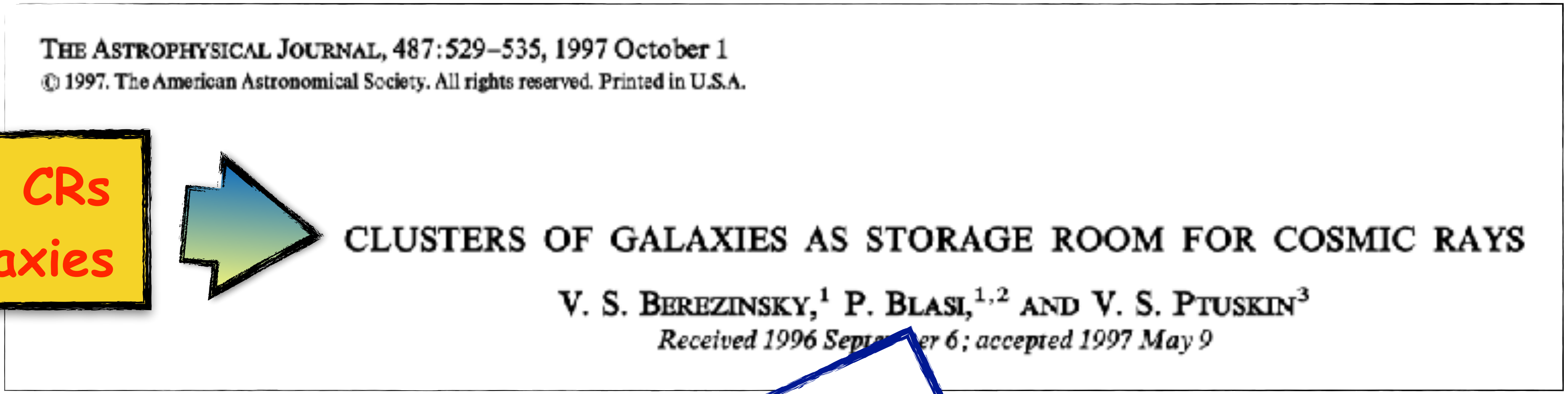

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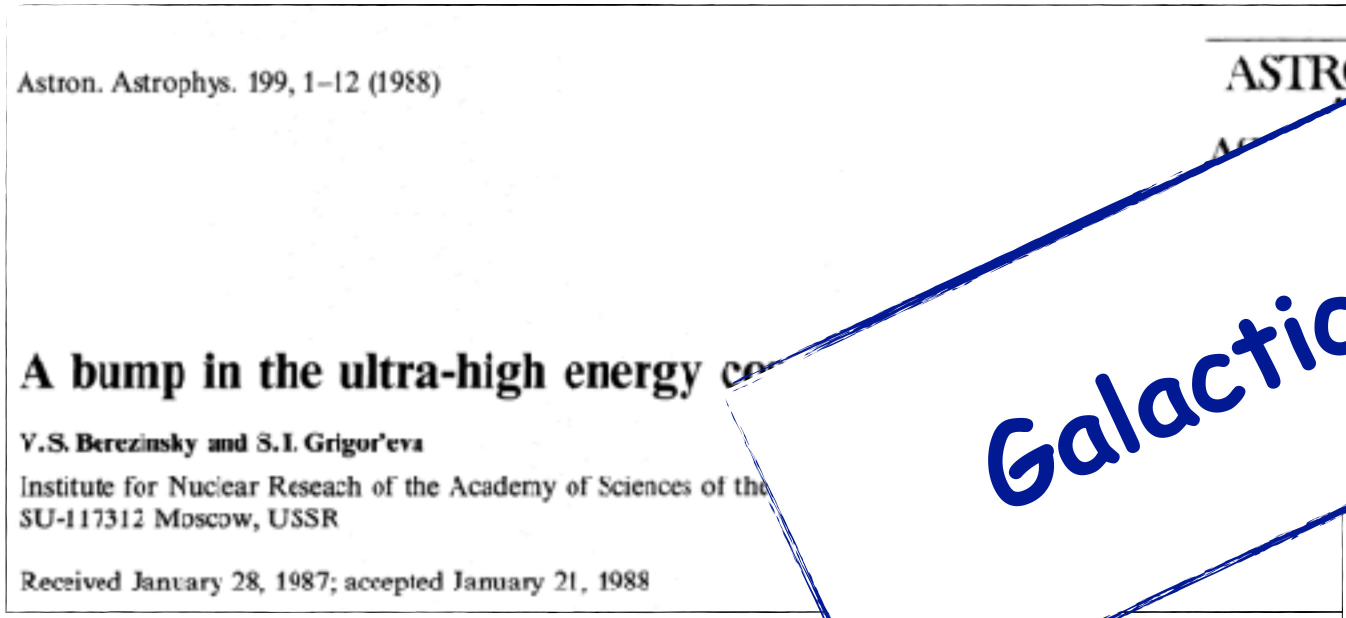

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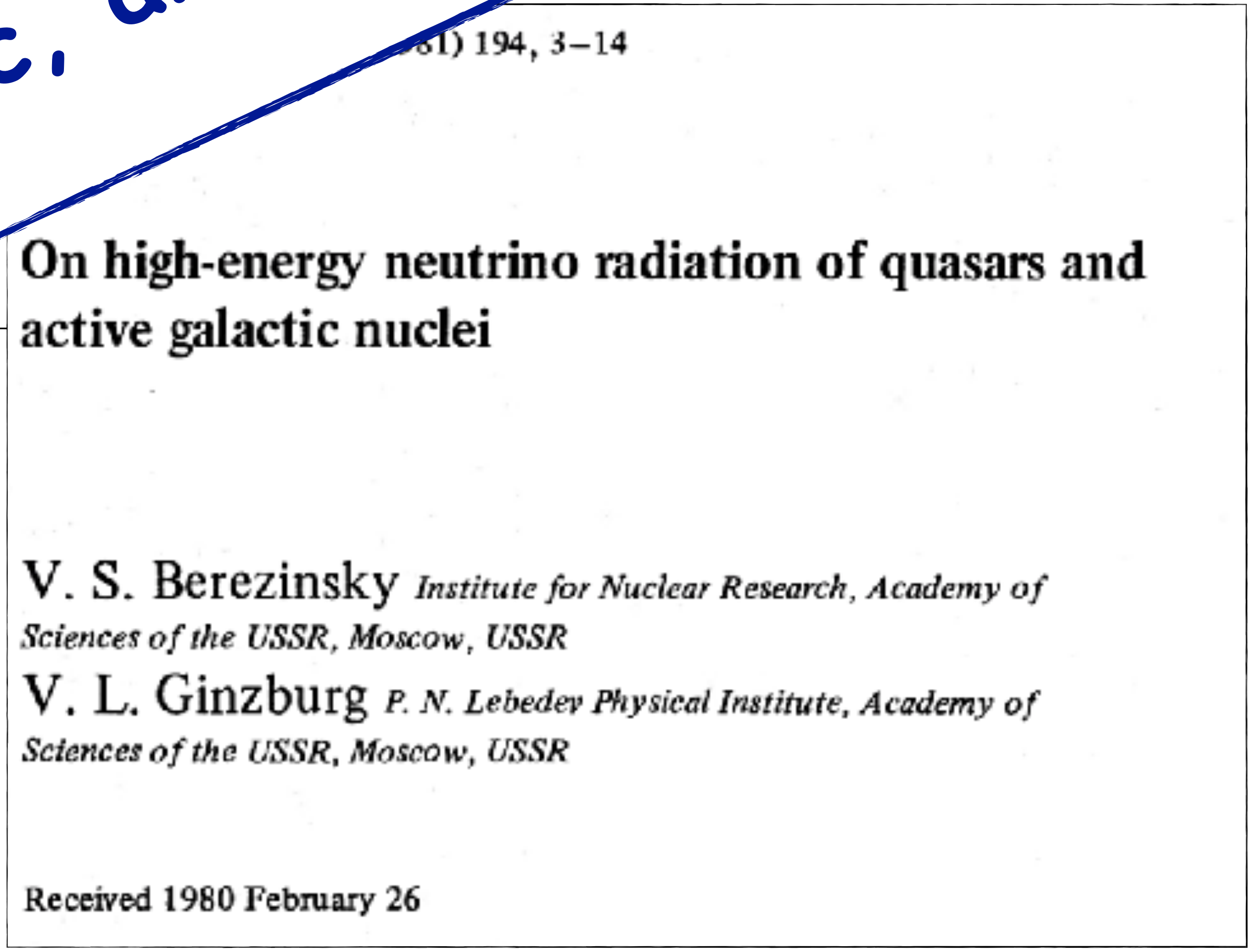

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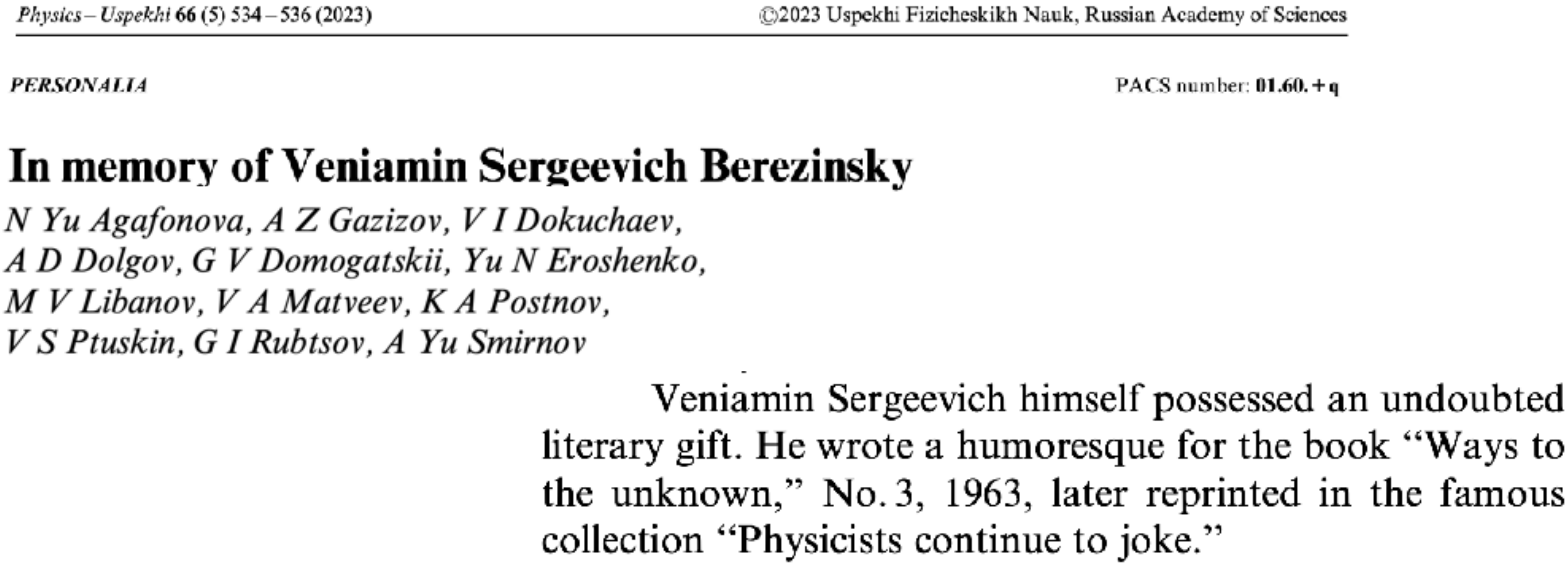

Physics – Uspekhi **66** (5) 534 – 536 (2023)

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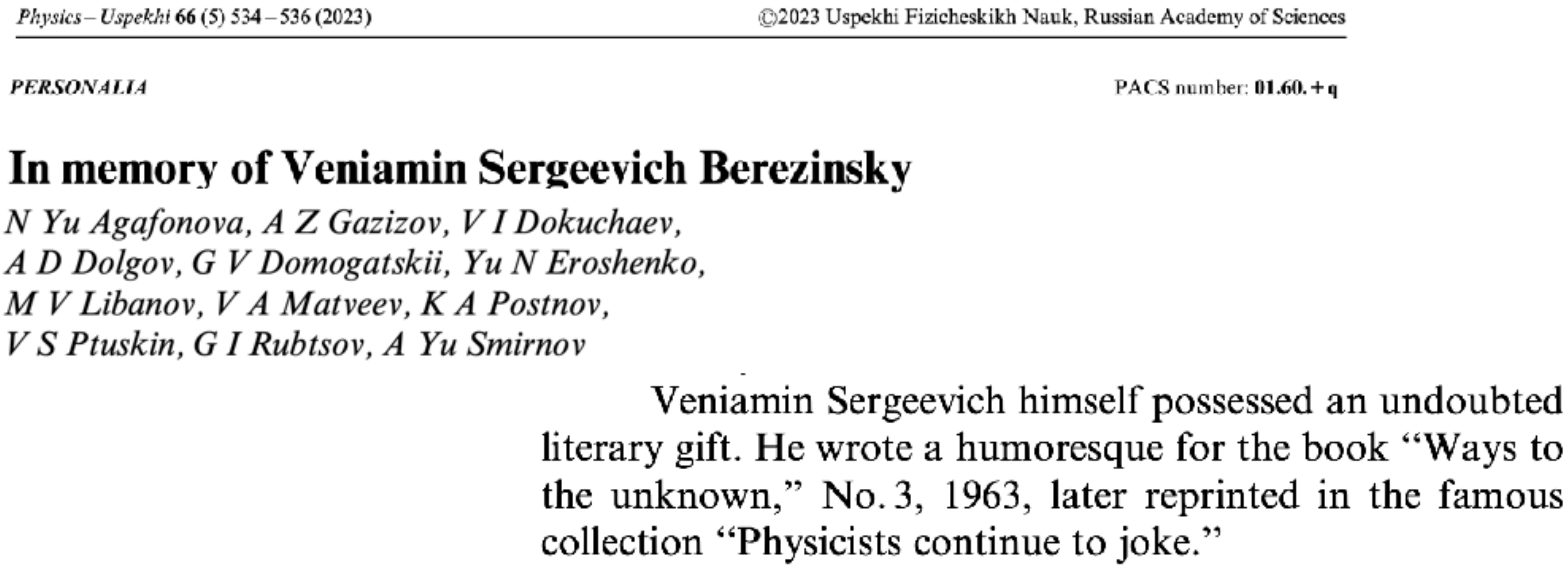

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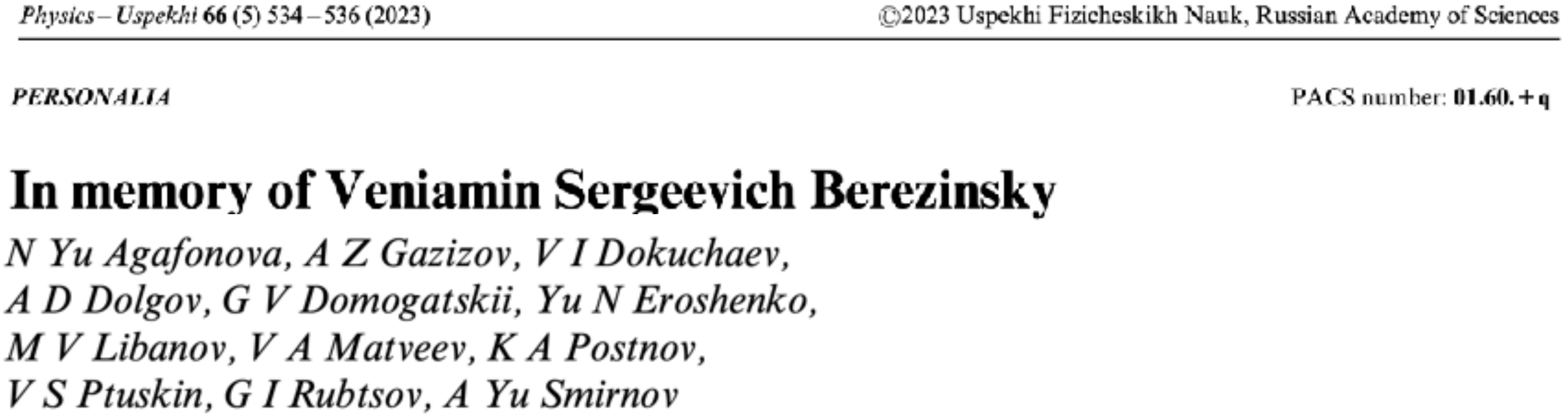
And everyone knows they can explain any result.

And much more…



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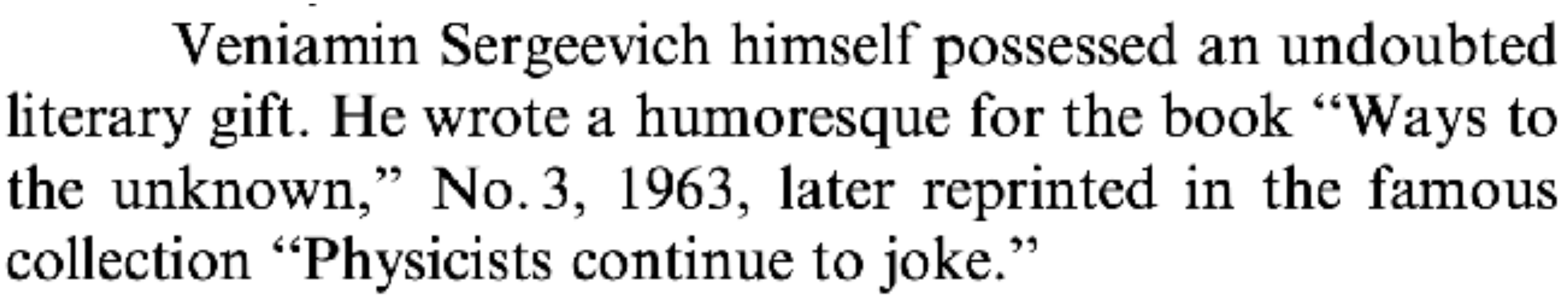

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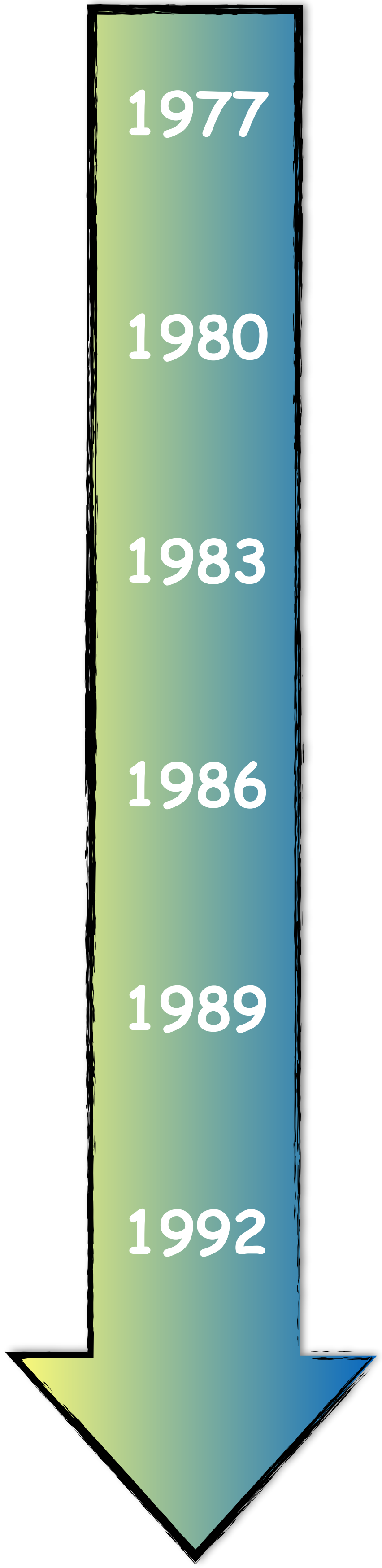
The story is told about Yakov Frenkel: supposedly, in the 30s at the Ioffe Institute, an experimentalist caught him in the corridor and showed him an experimental curve. After thinking for a minute, Frenkel gave an explanation of the curve. However, it turned out that the plot was upside down. The curve was put in its place and, after thinking a little more, Frenkel explained this curve as well.

The “Galactic” Berezinsky



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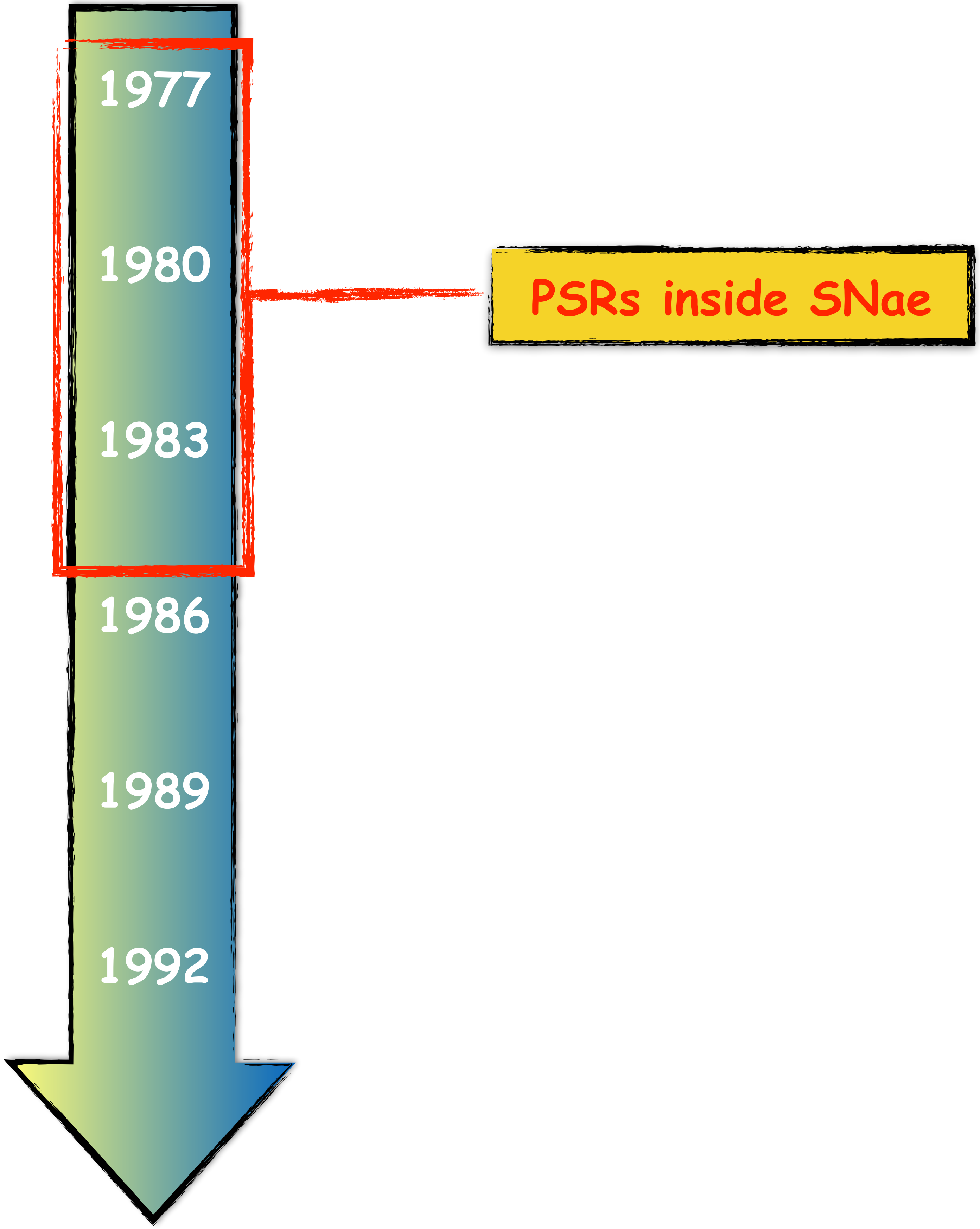

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PSRs inside SNae

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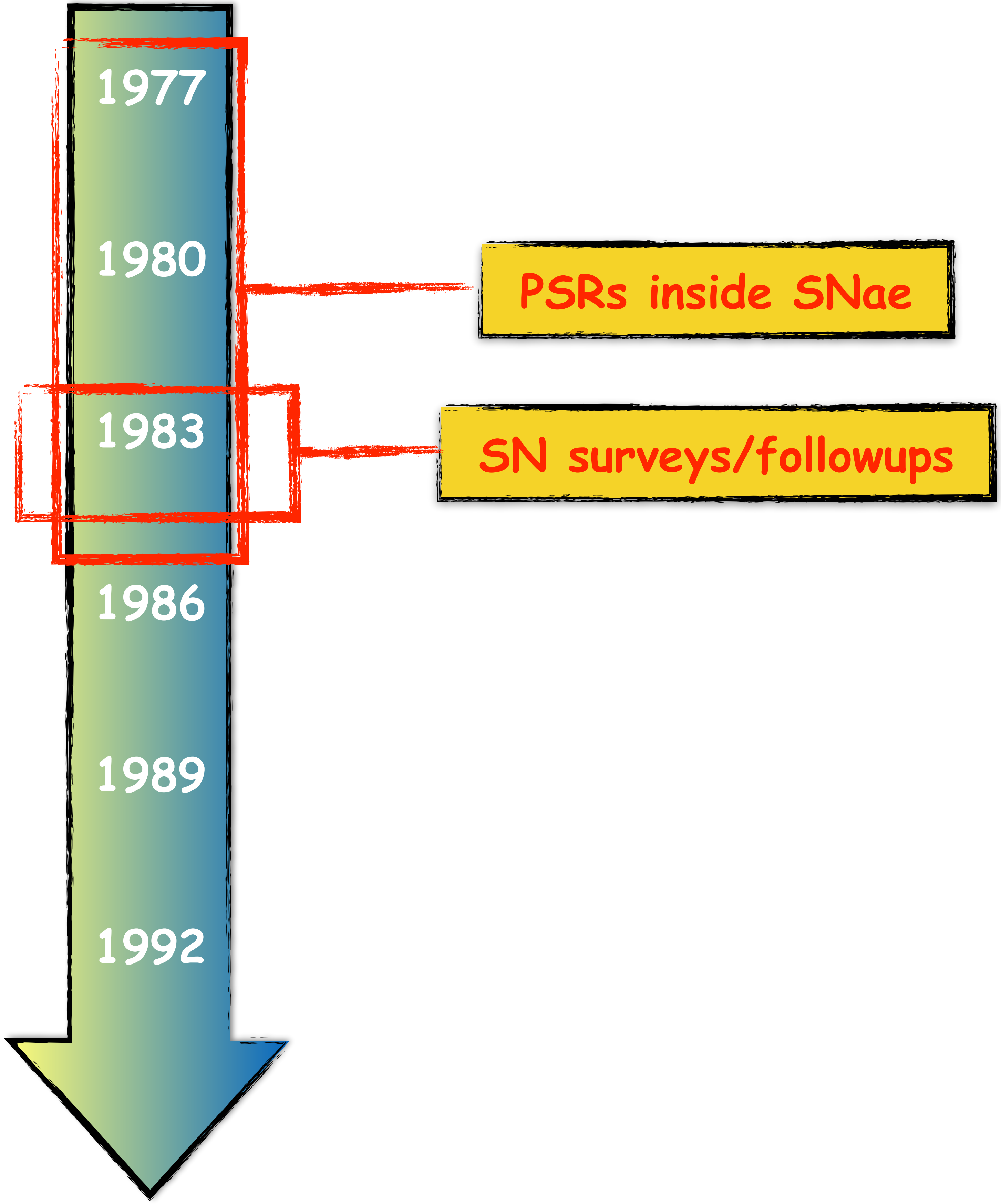

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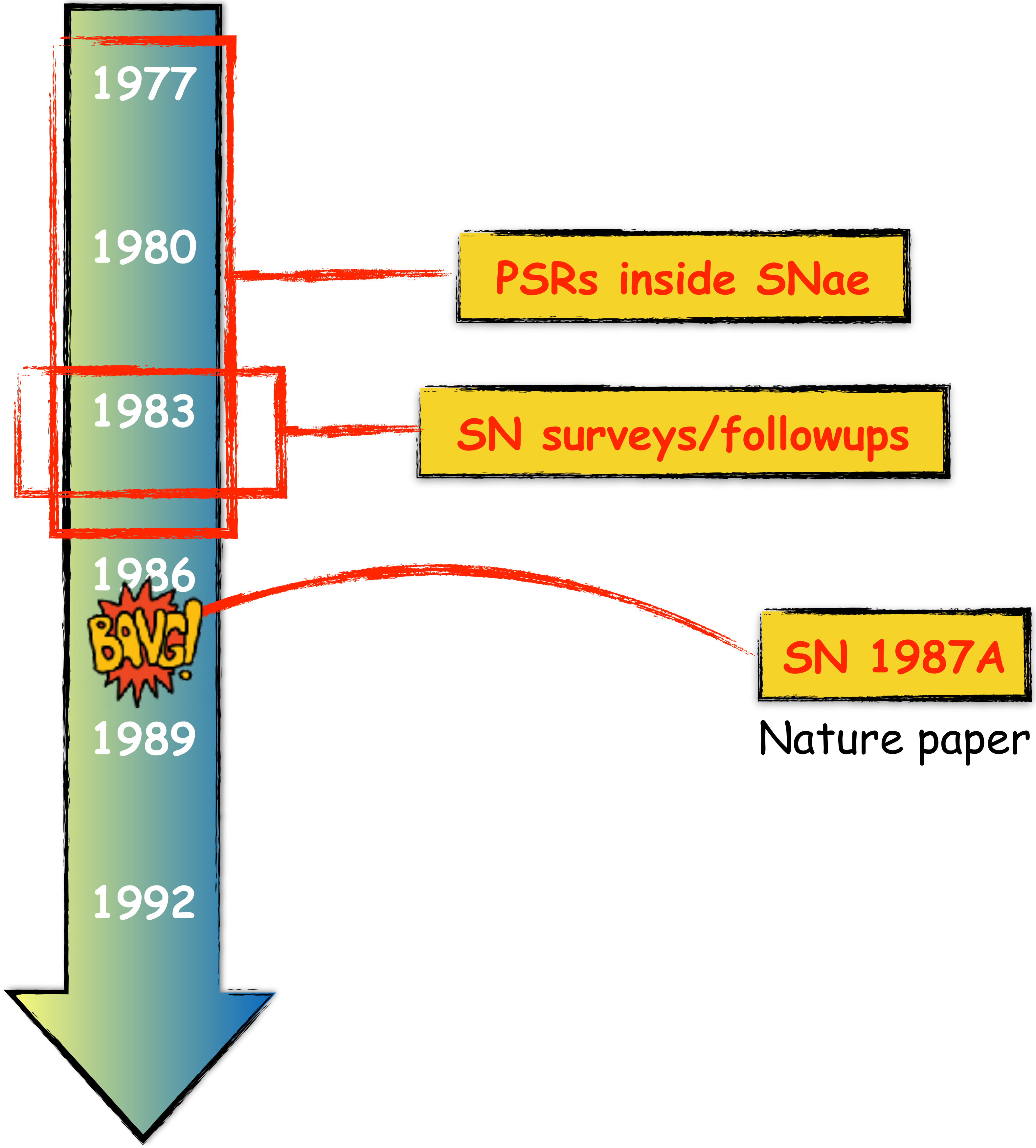

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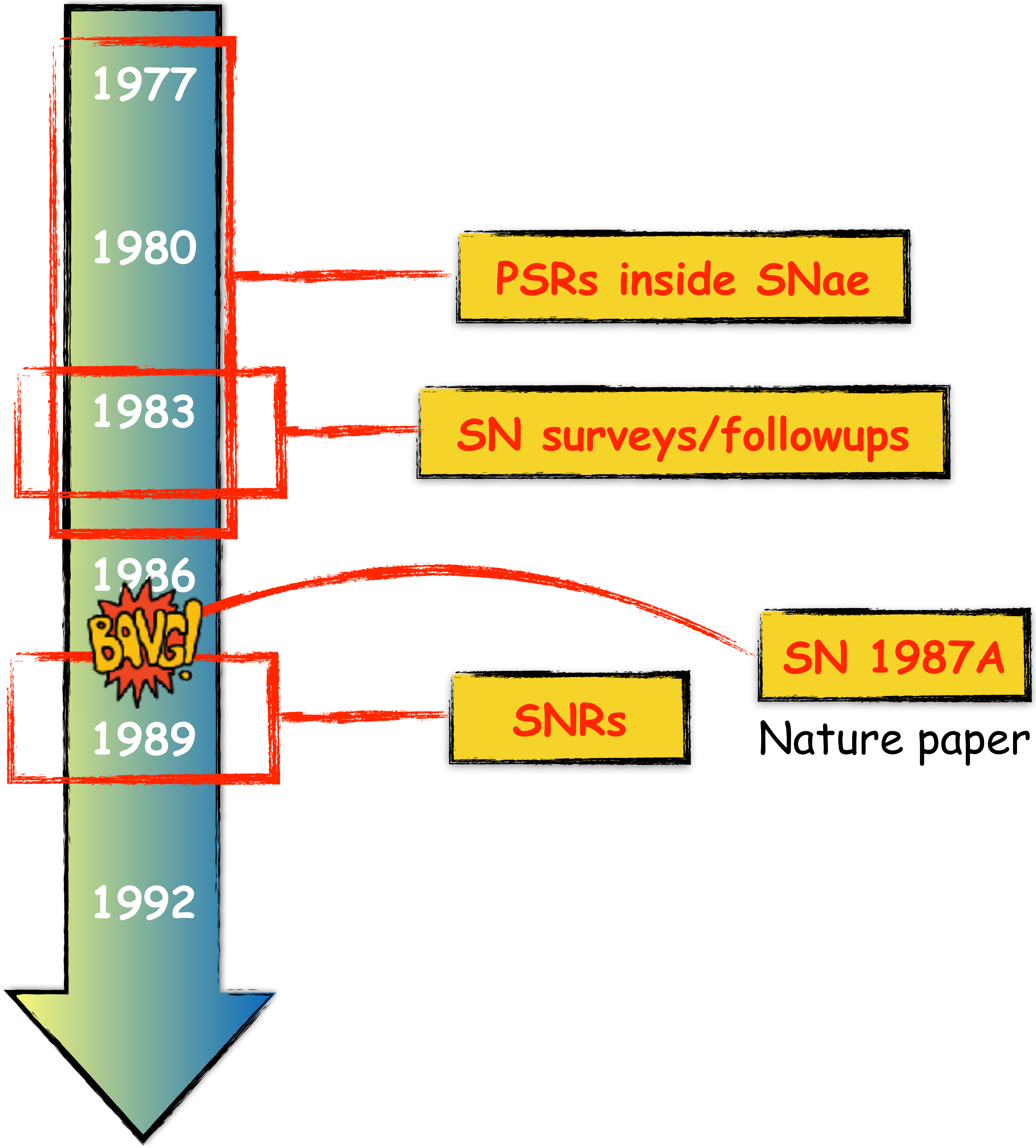

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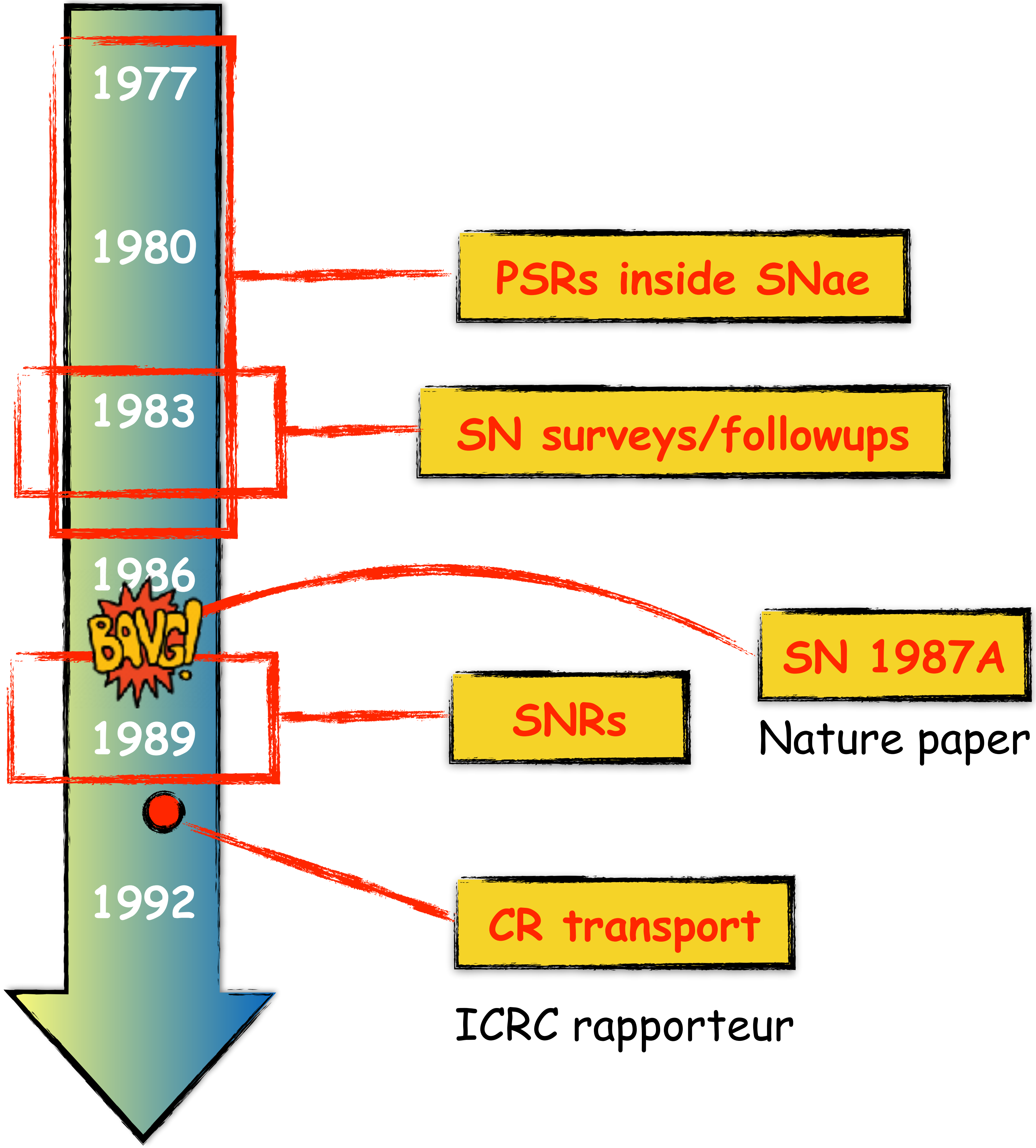

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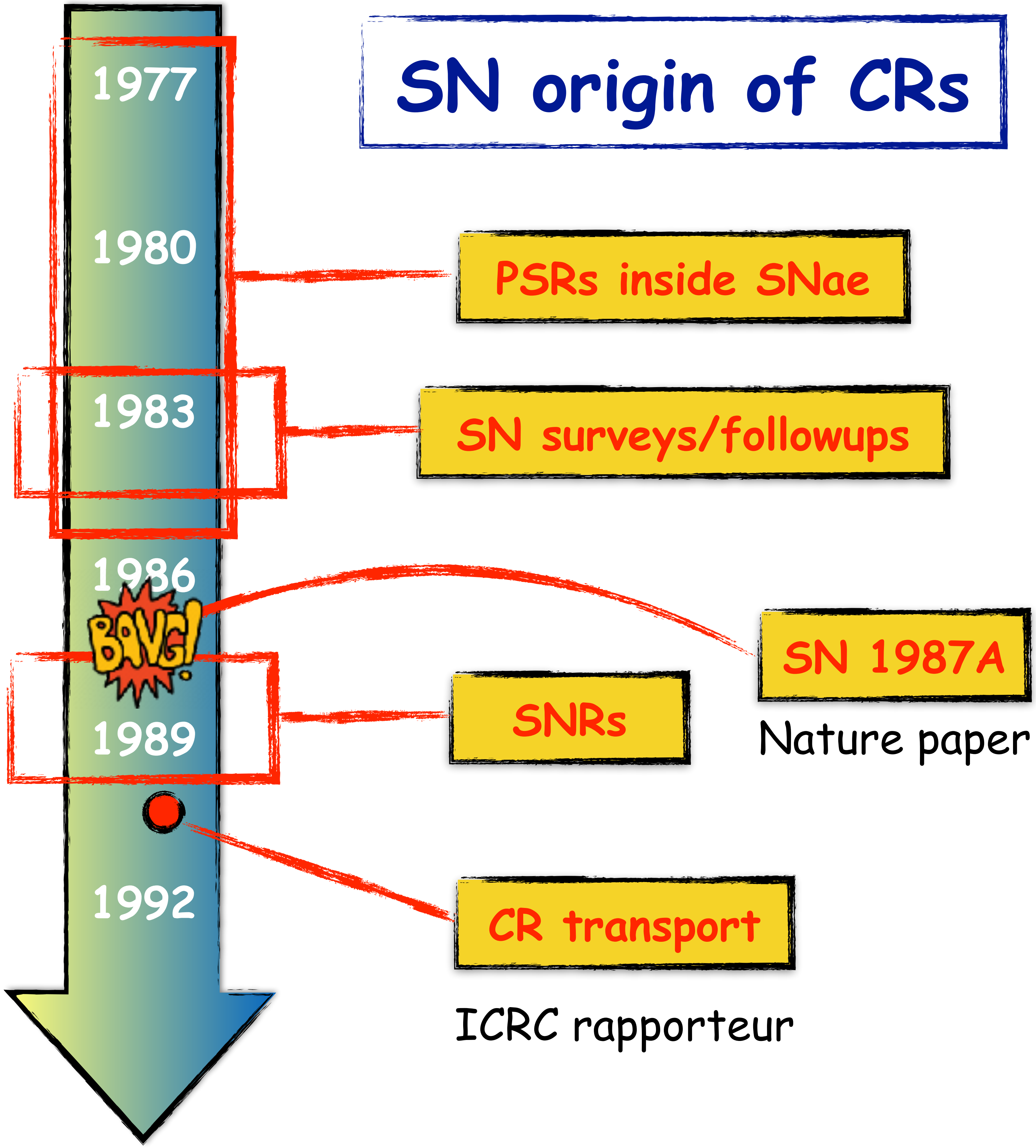

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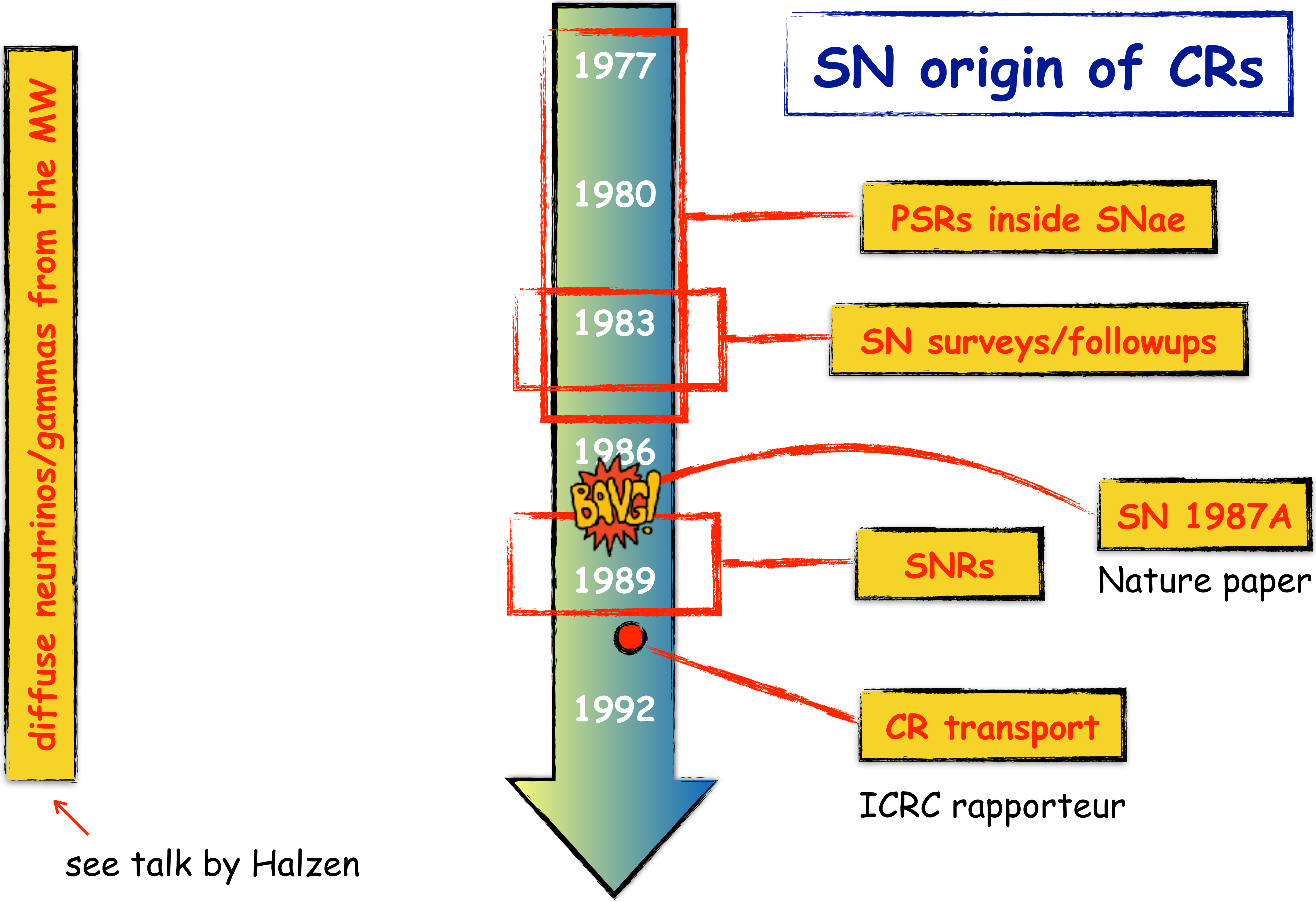

SN origin of CRs

diffuse neutrinos/gammas from the MW

see talk by Halzen

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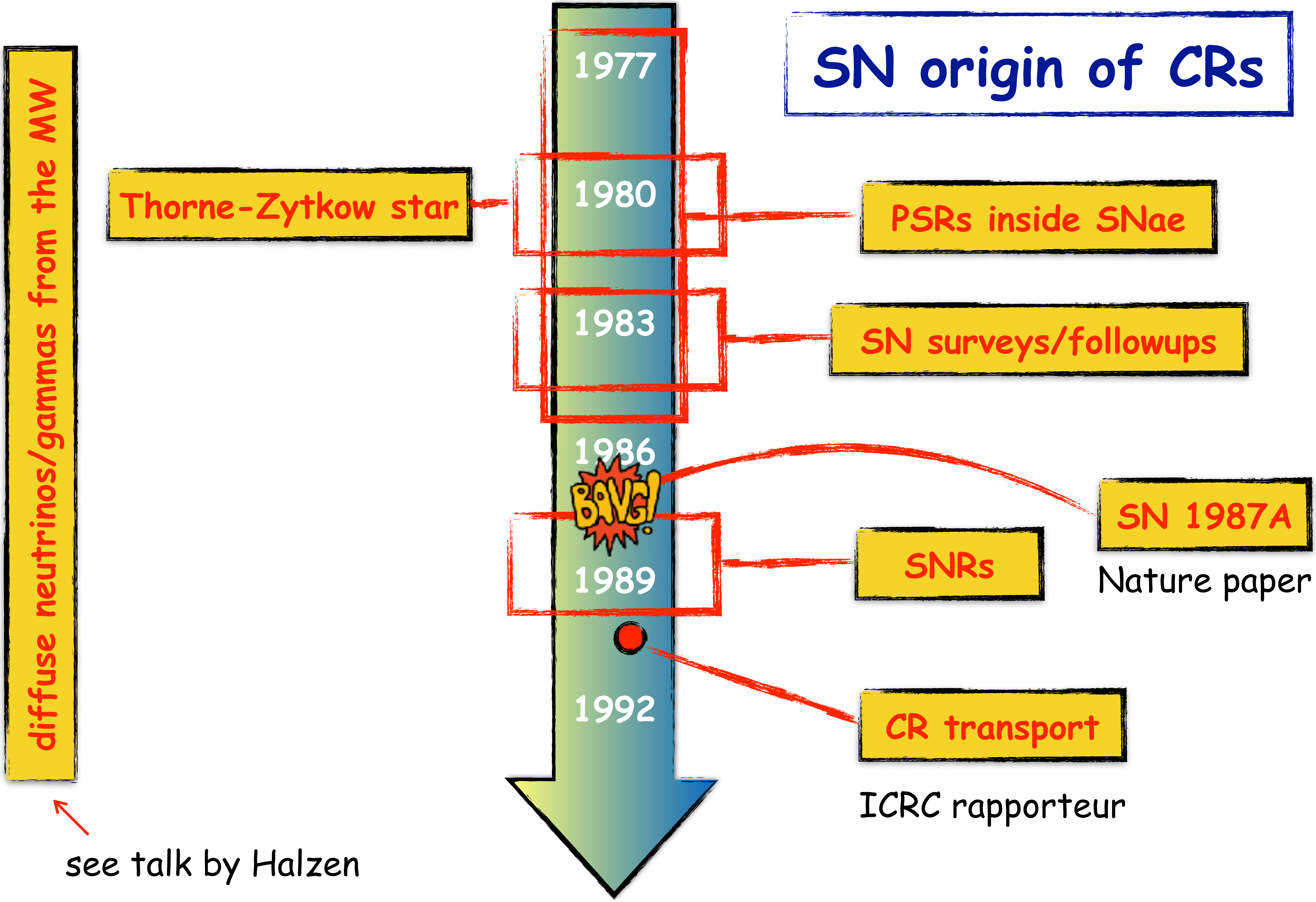

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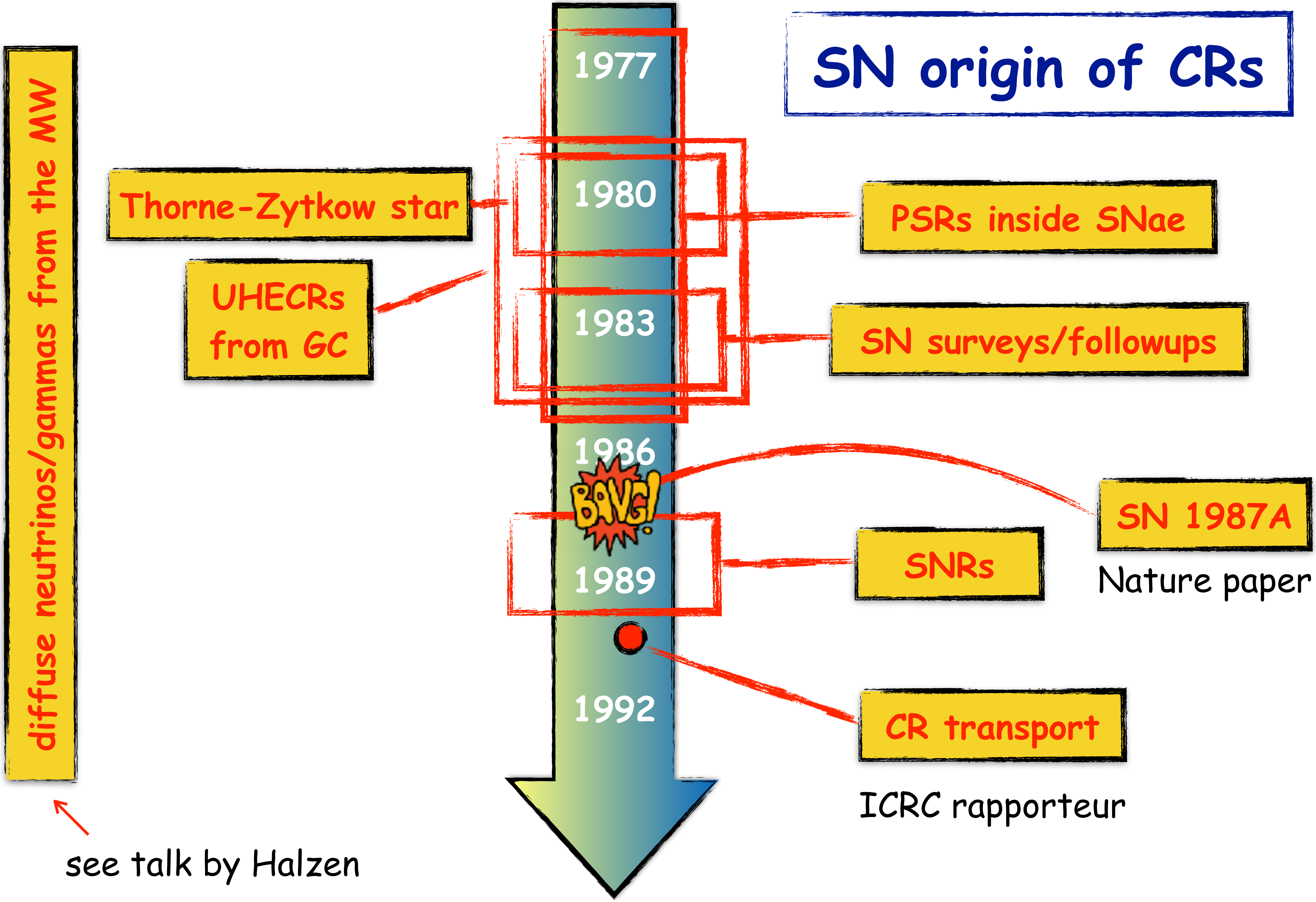

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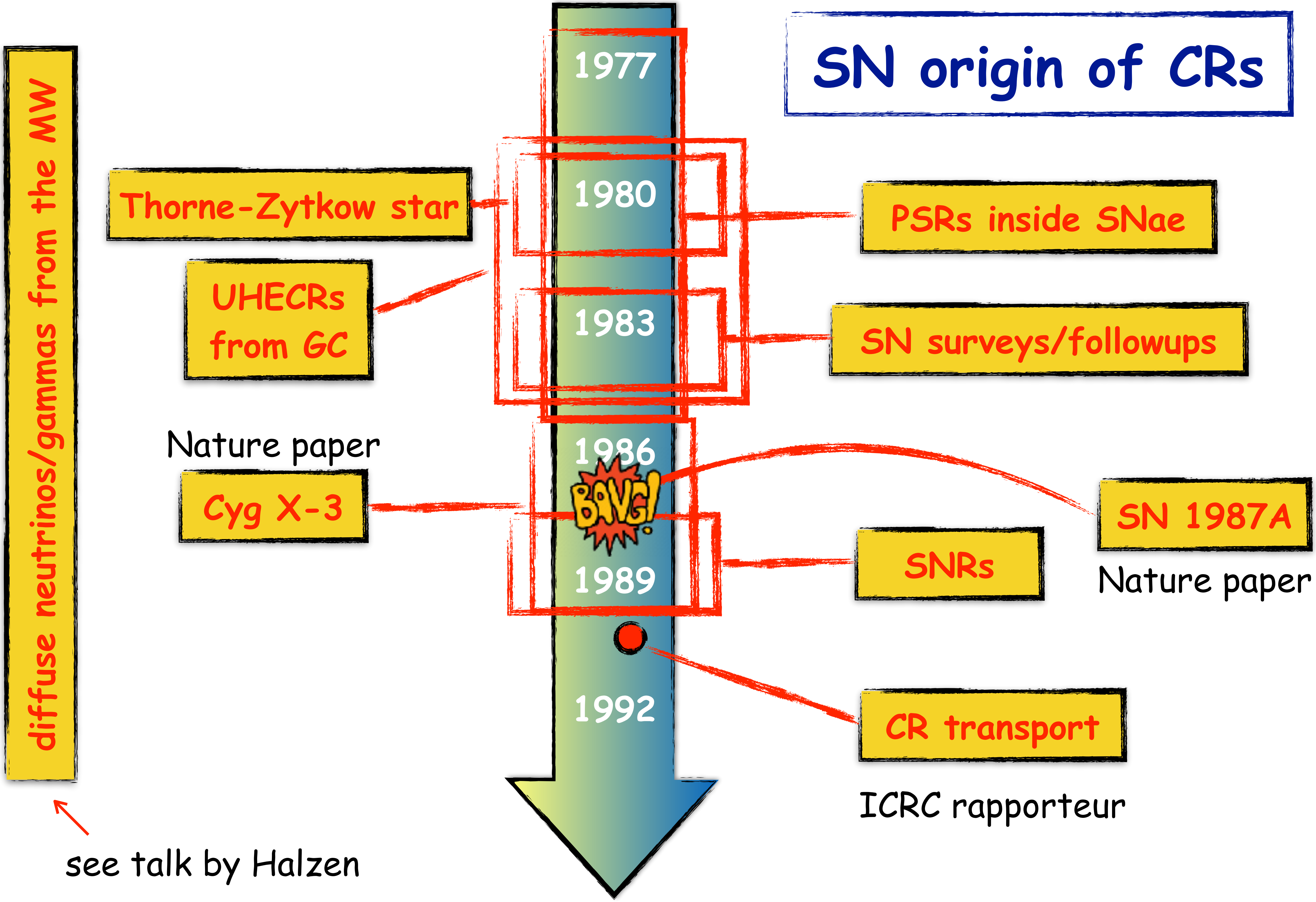

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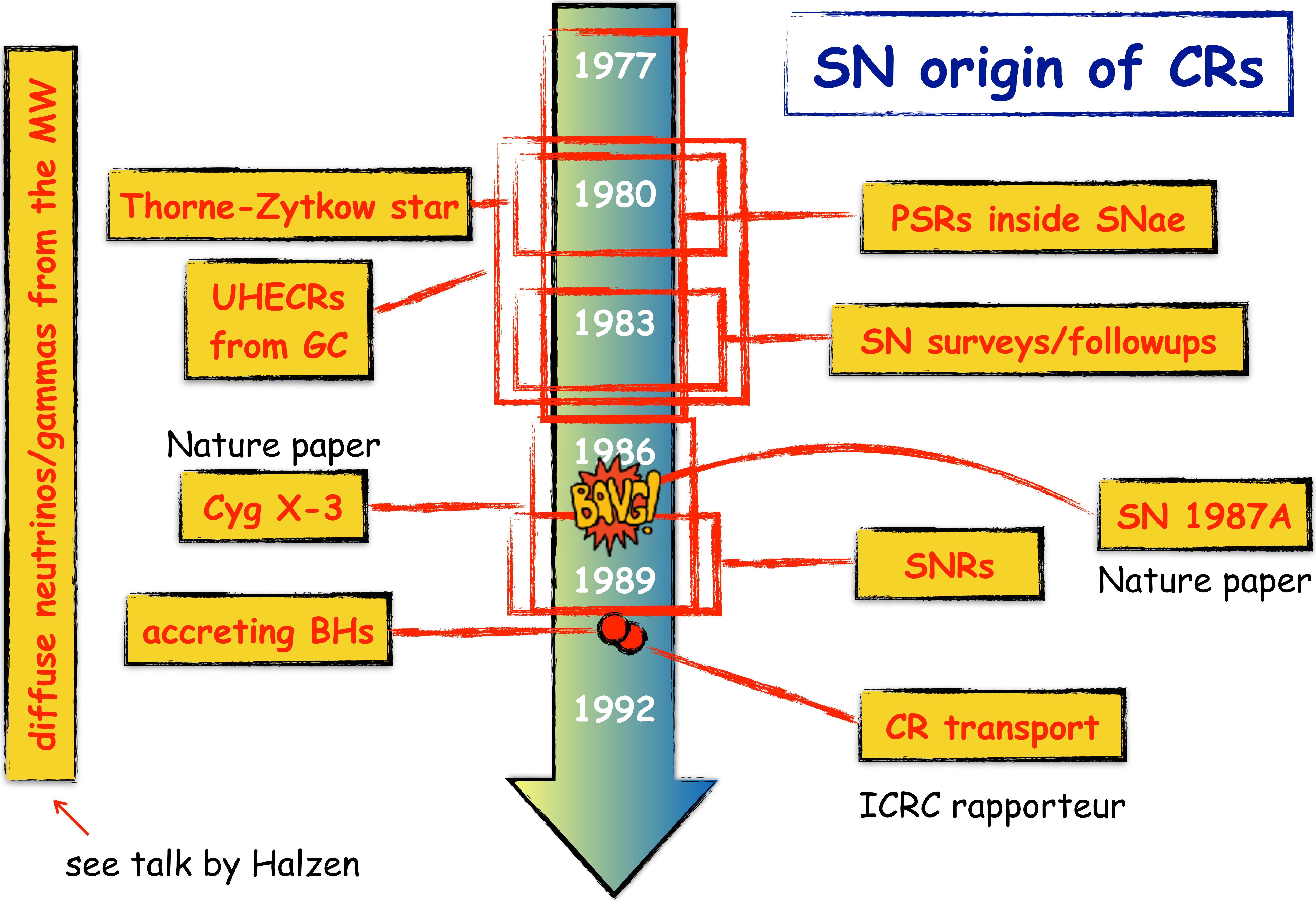

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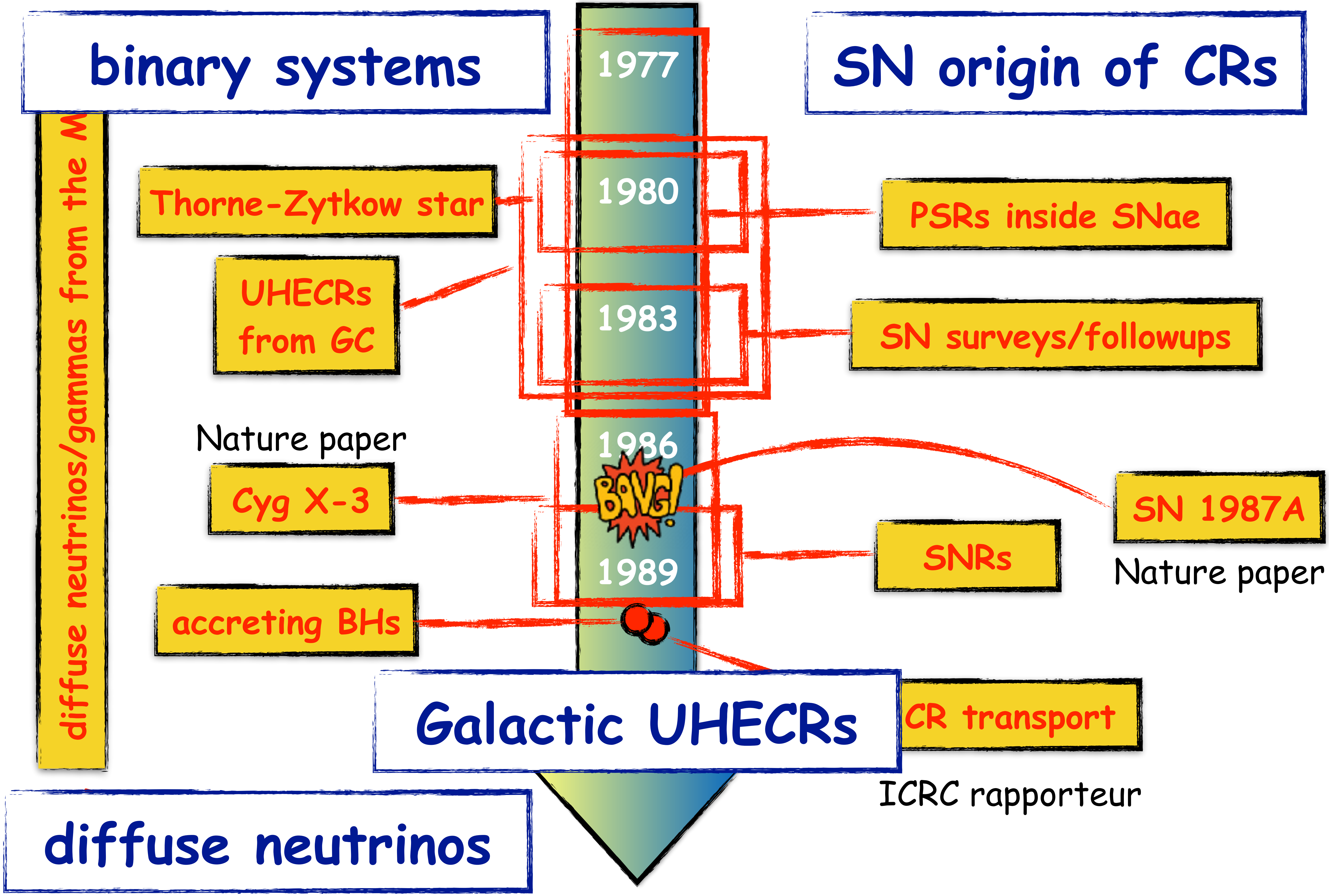

binary systems

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diffuse neutrinos

Supernovae and the origin of Galactic cosmic rays

The origin of Galactic cosmic rays

The three pillars of "orthodoxy"

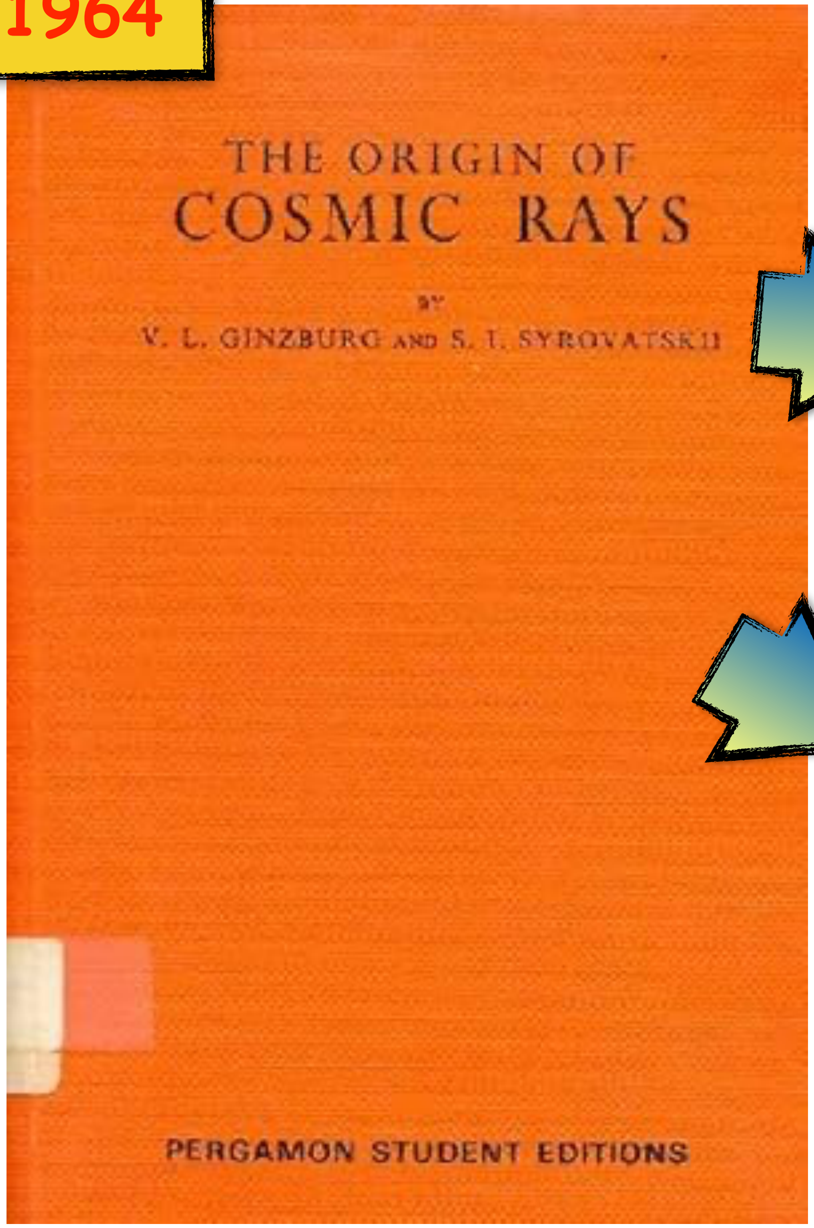
(1) The bulk of the energy of CRs originates from **supernova explosions** in the Galactic disk

(2) Cosmic rays are **diffusively confined** within an **extended and magnetised Galactic halo**

(3) Cosmic rays are accelerated out of the (**dusty**) interstellar medium through **diffusive shock acceleration** in supernova remnants

The origin of Galactic cosmic rays

1964



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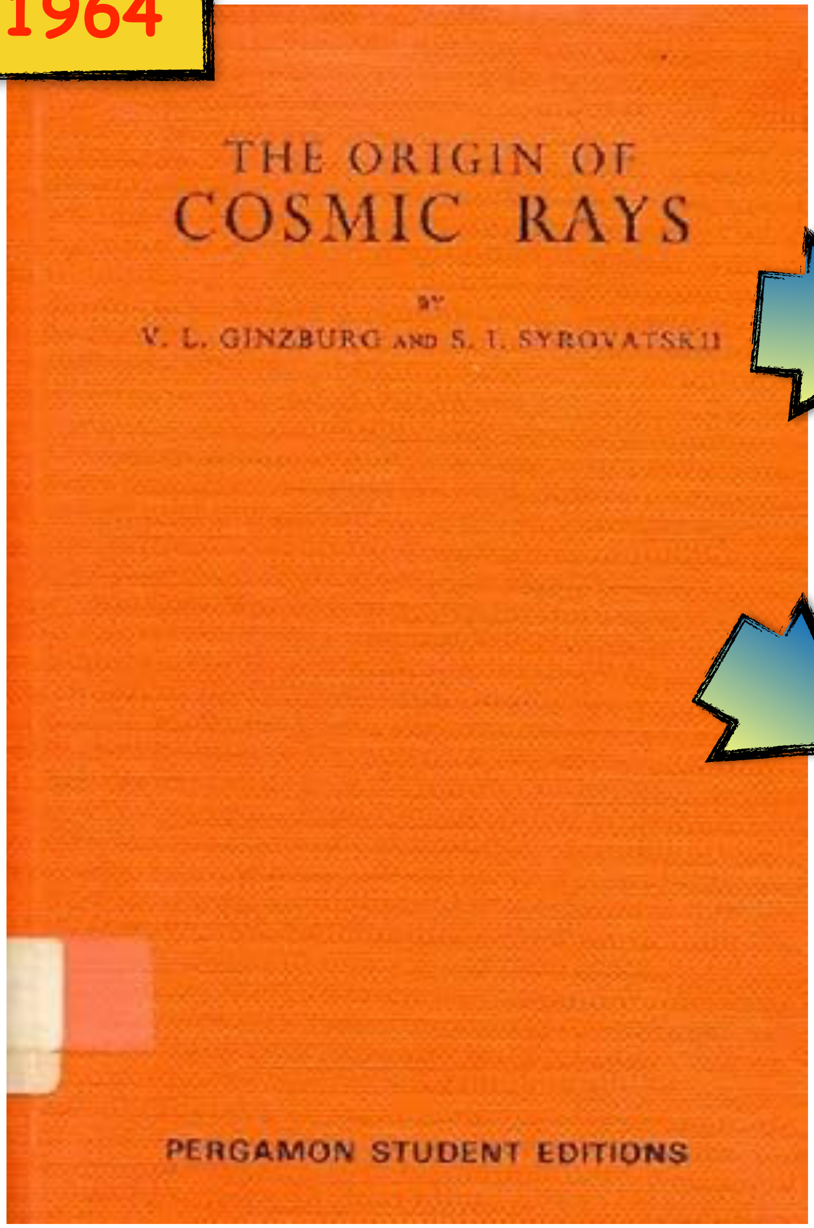

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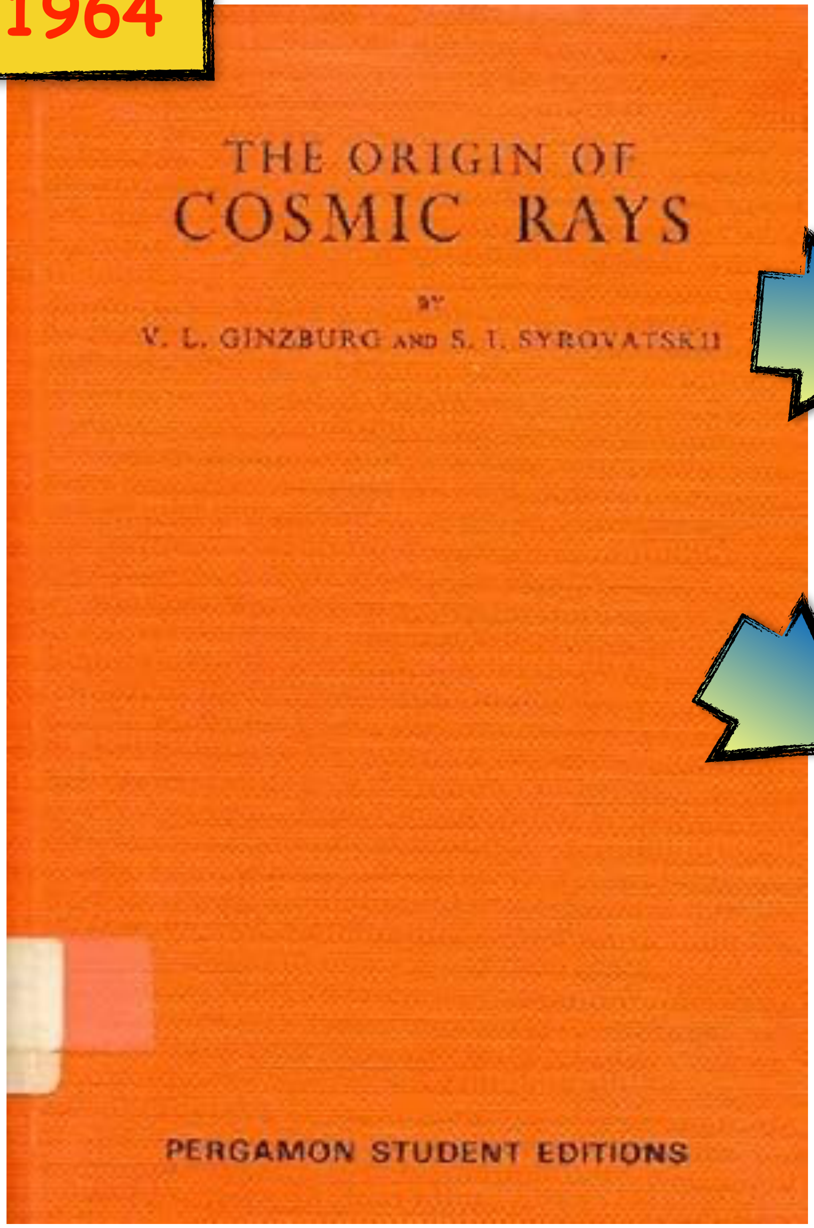
BOBALSKy 77/78

The origin of Galactic cosmic rays



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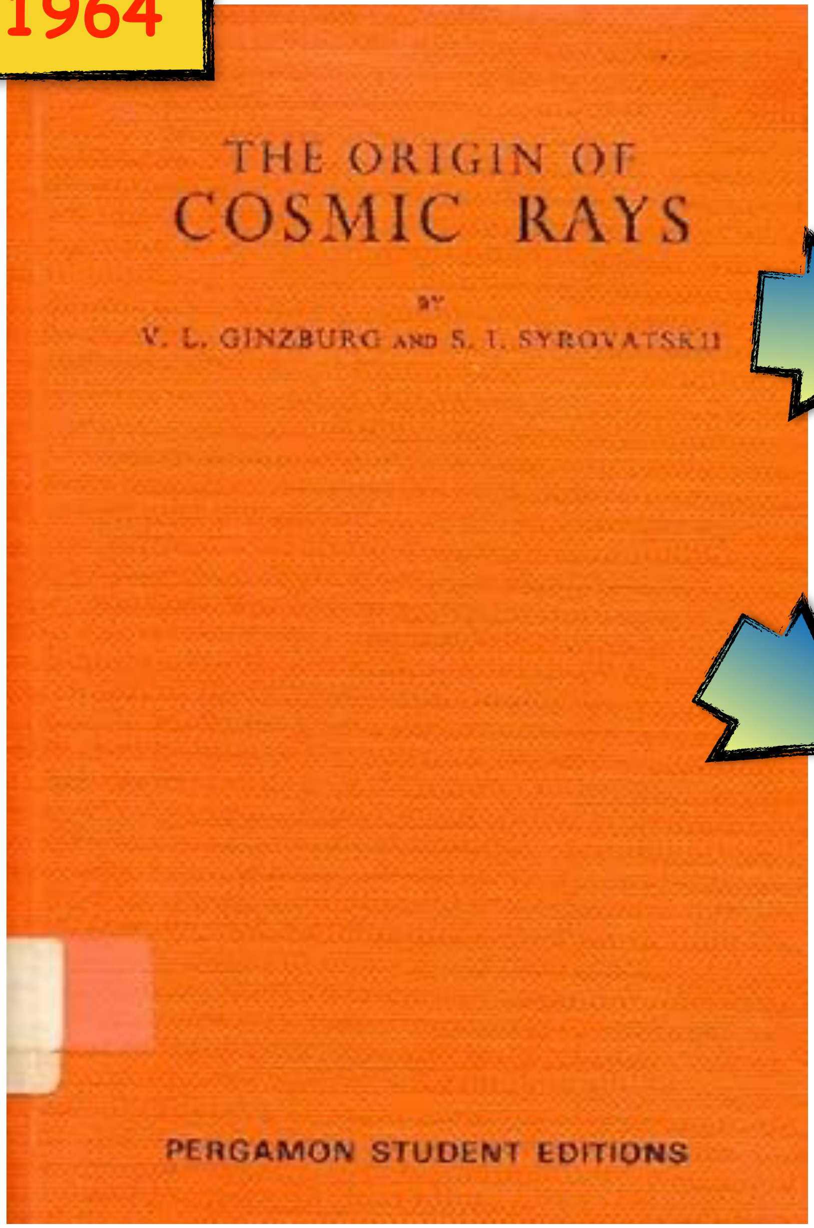

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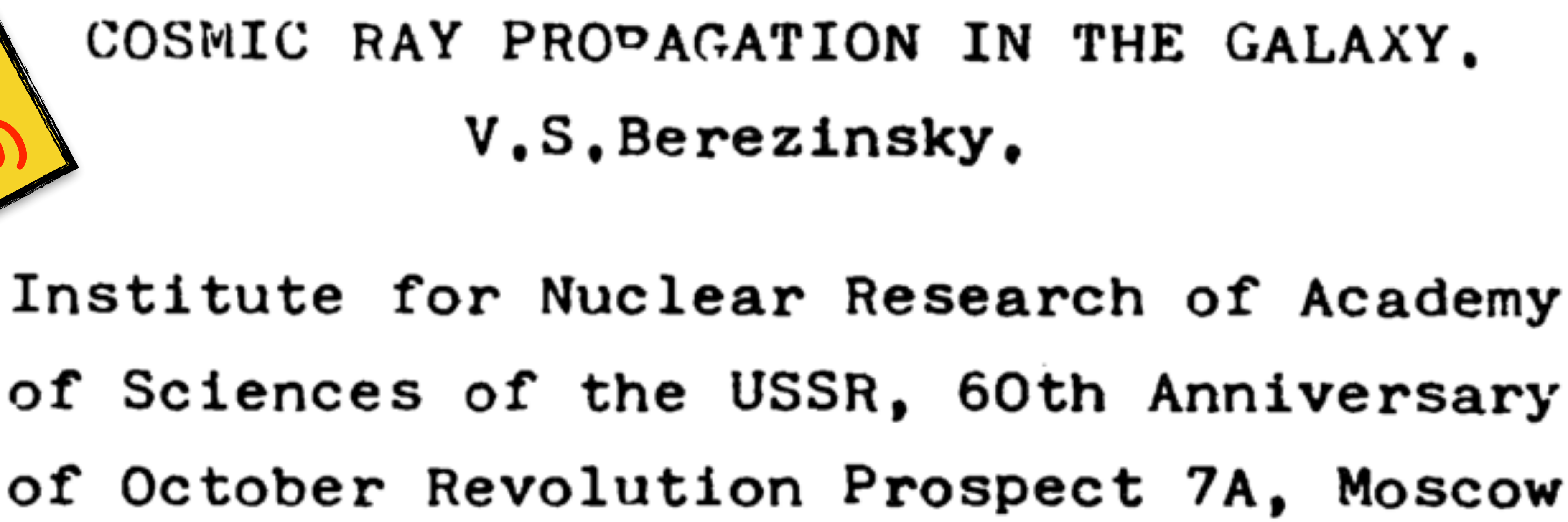
if you do not want to explain the acceleration mechanism you can ignore this

77/78 Epstein 80, Cesarsky&Biebring 81 … Meyer, Drury, Ellison 97

Cosmic ray transport in the Galaxy

rapporteur talk
21st ICRC
(Adelaide, 1990)



COSMIC RAY PROPAGATION IN THE GALAXY.

V.S.Berezinsky.

Institute for Nuclear Research of Academy
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Cosmic ray transport in the Galaxy

rapporteur talk
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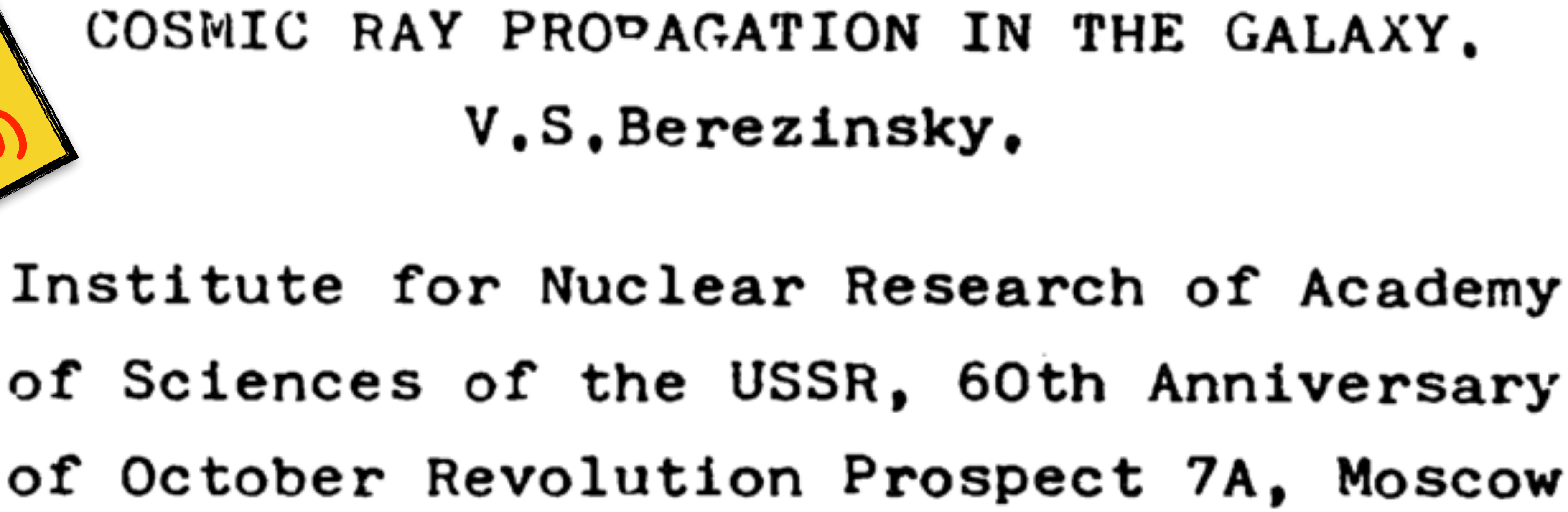

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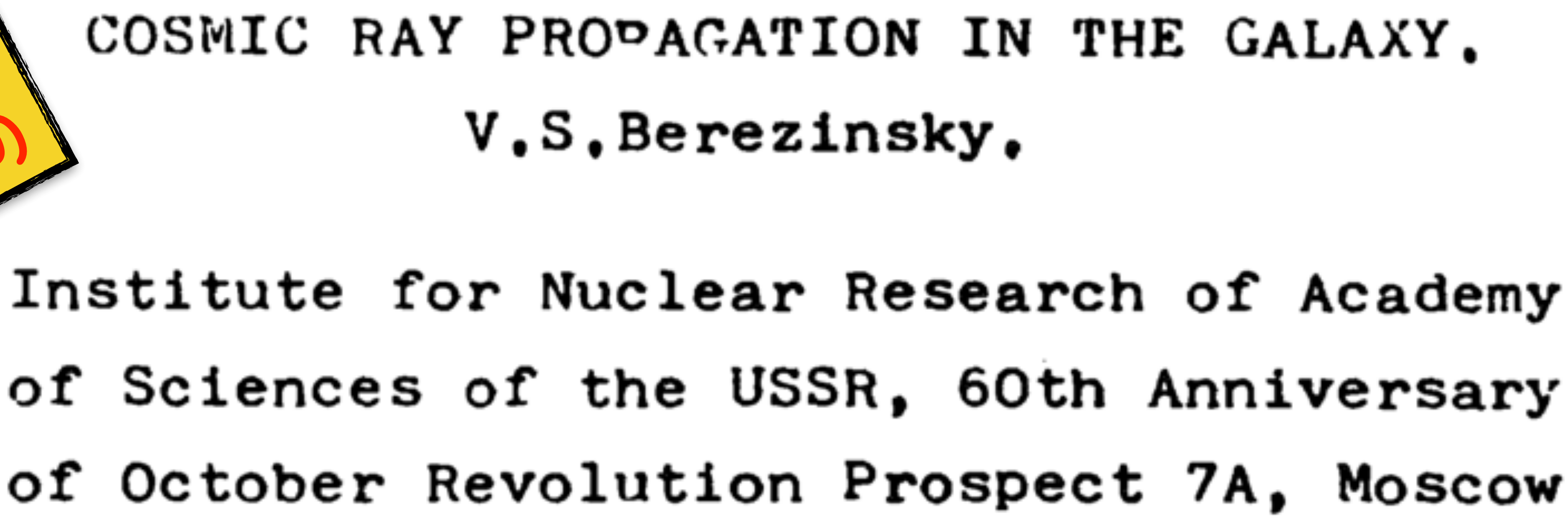

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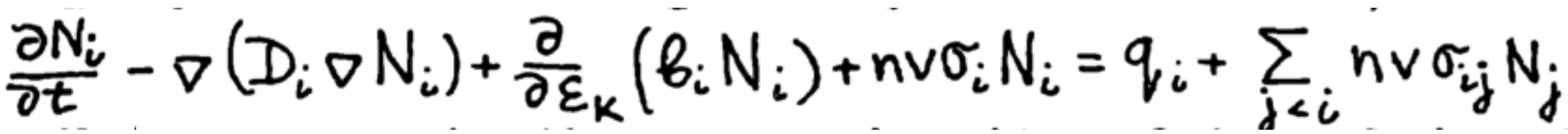

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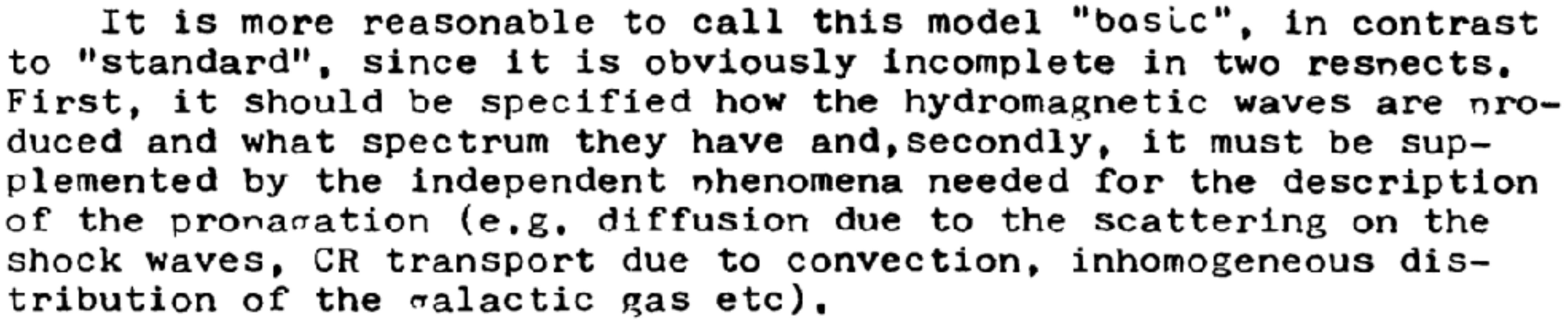

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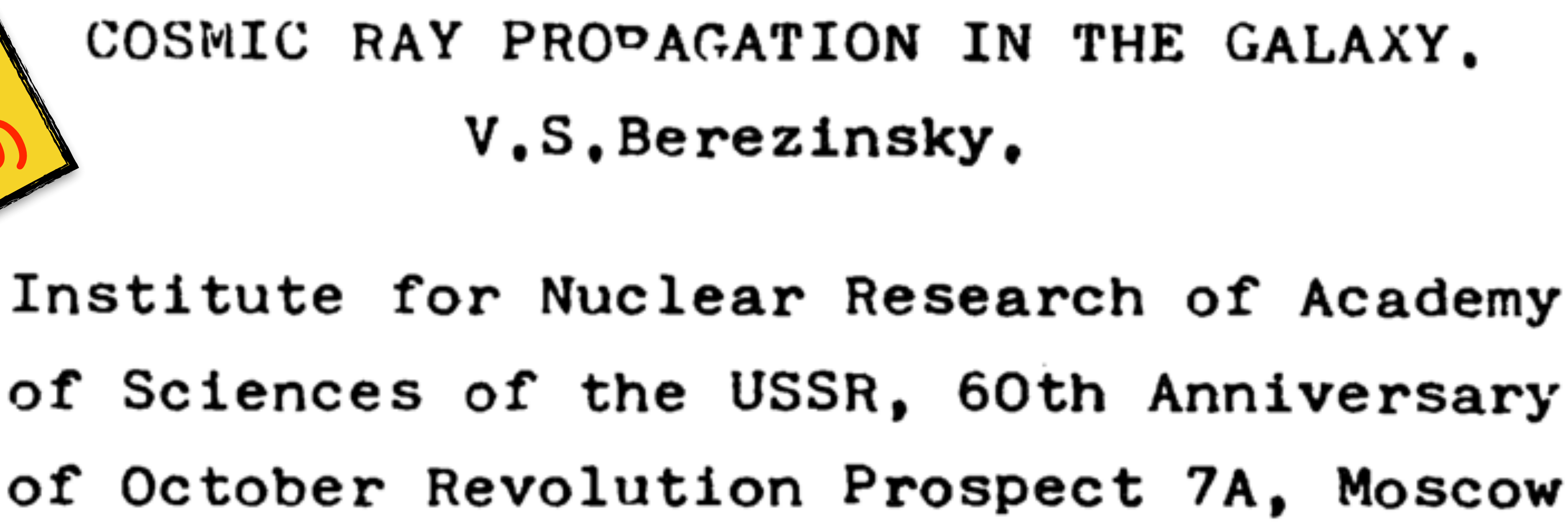

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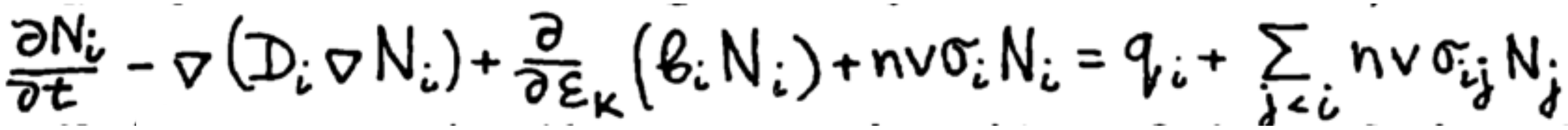

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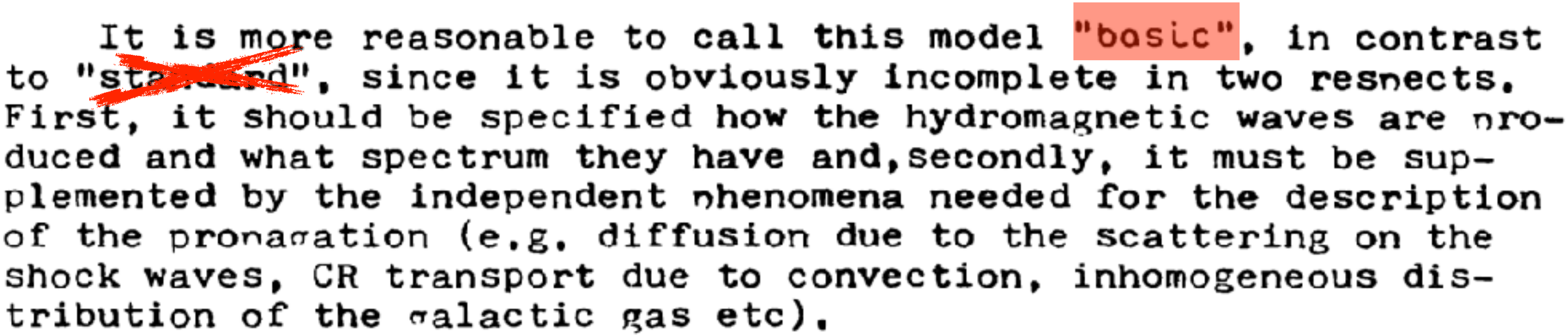

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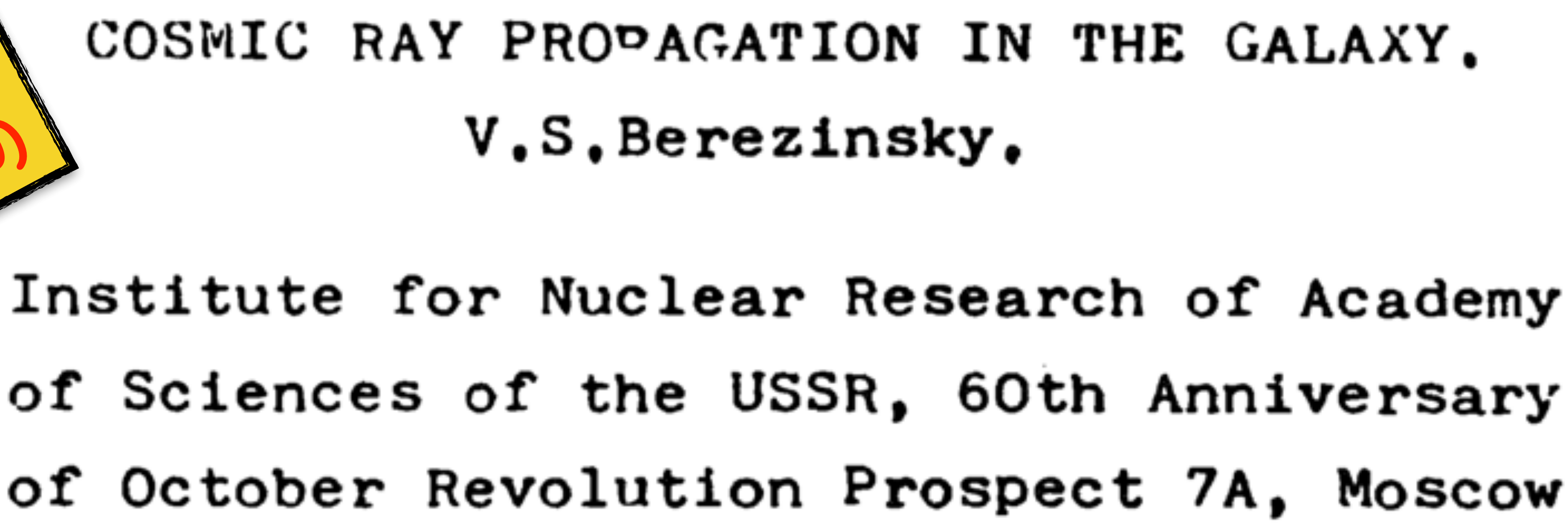

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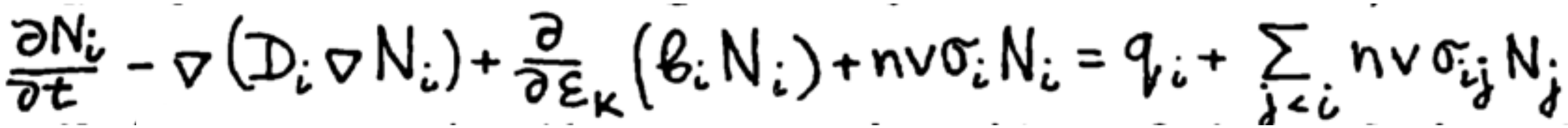

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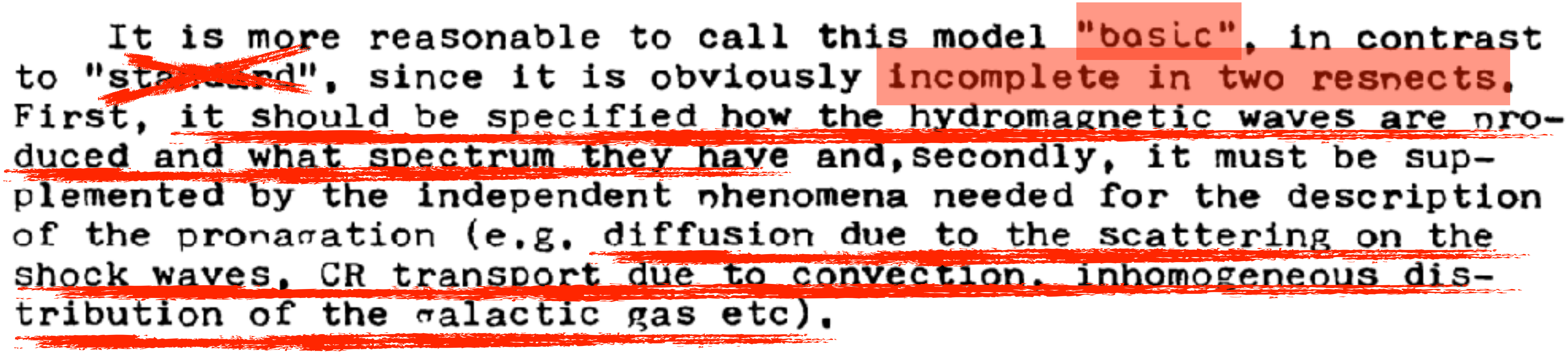

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VSB & Prilutsky 1977, 1978

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link SN/PSR/SNR —> PSR rotational energy —> magnetic dipole radiation energy —> energetic particles*

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PSR must be extremely powerful to explain Galactic CRs

- newborn rapidly rotating PSR can accelerate to 10^{20} eV
  - compensate adiabatic losses in the expanding SN shell

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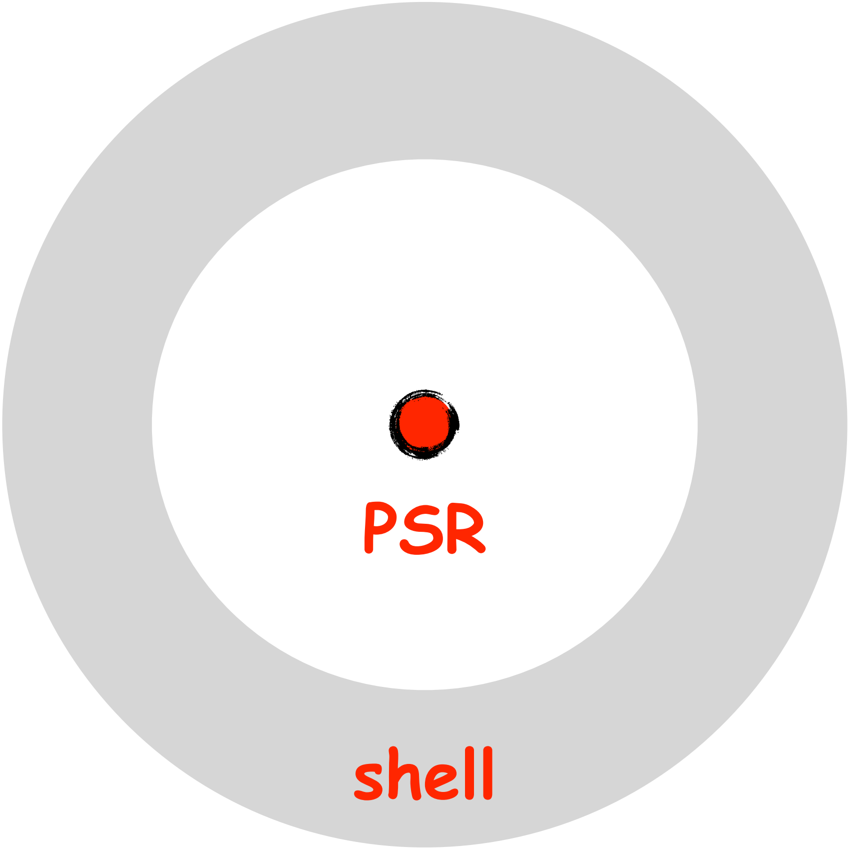

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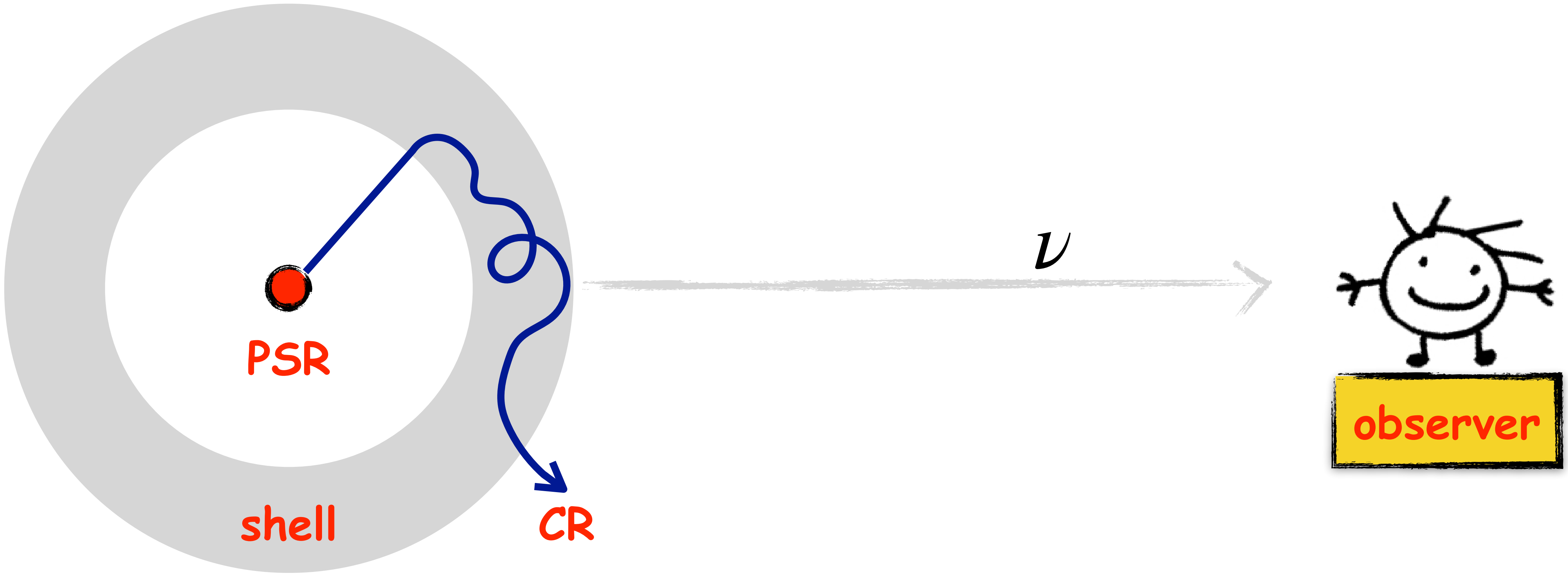

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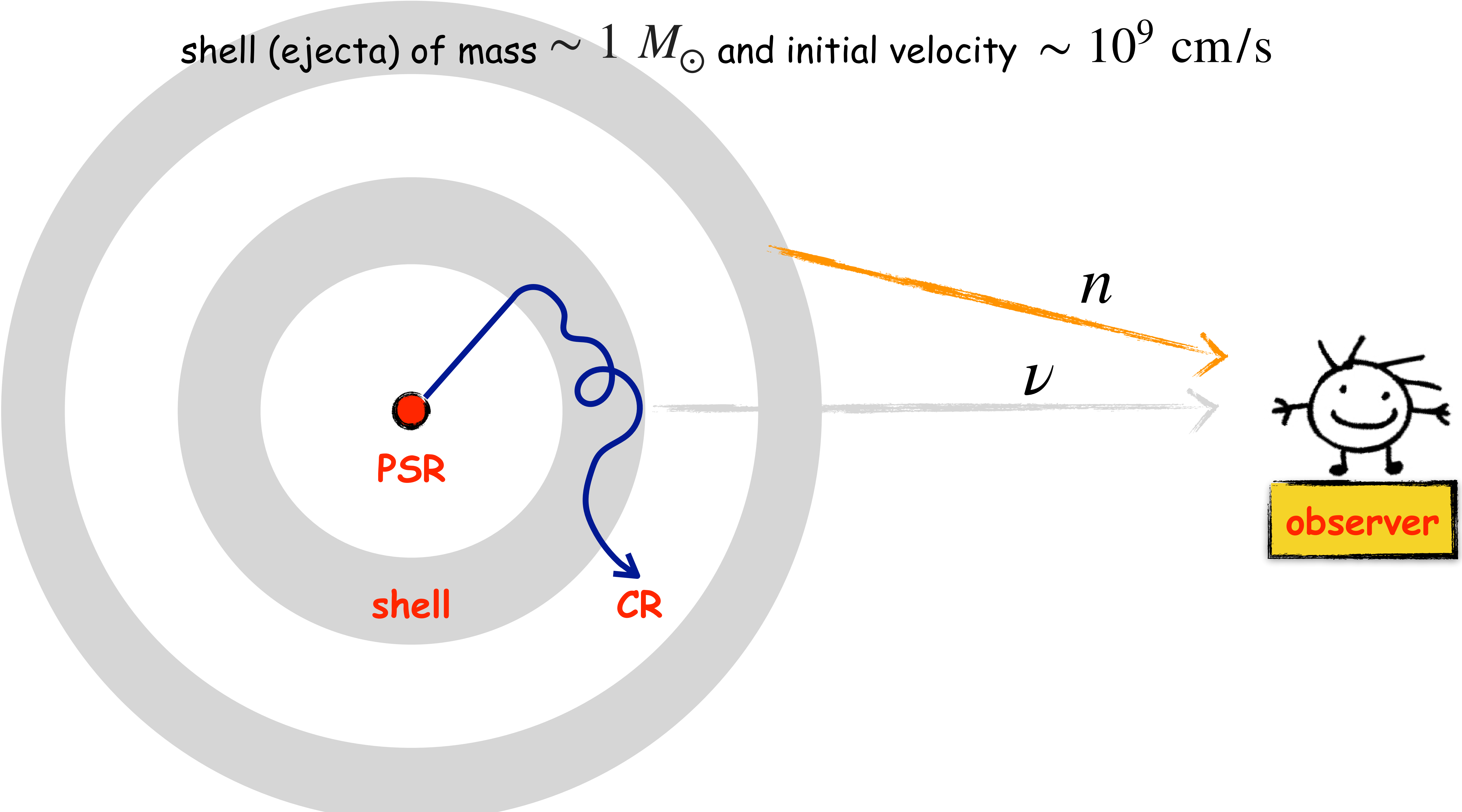

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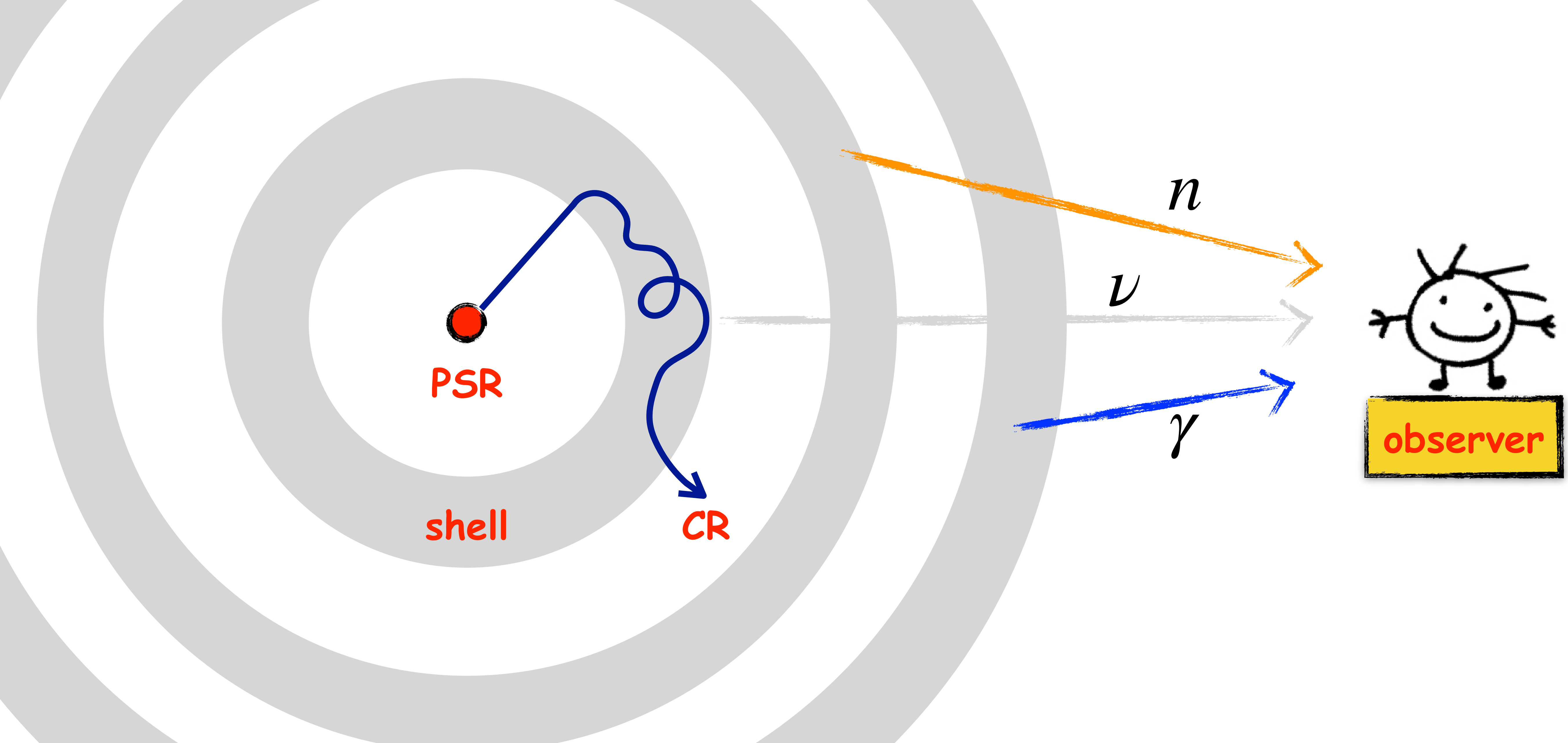

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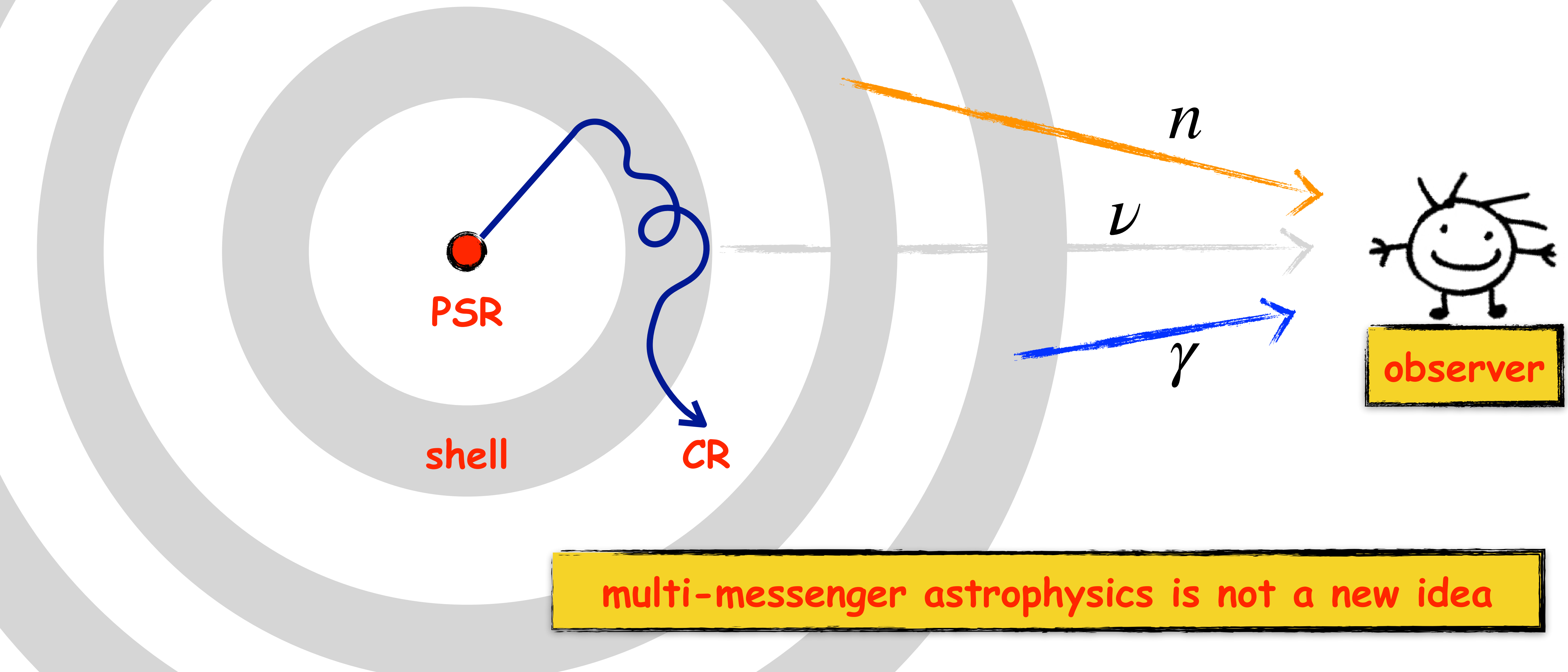

multi-messenger astrophysics is not a new idea

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neutrino emission

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γ-ray emission

consider also pair production in soft ambient radiation

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VSB & Prilutsky 1977, 1978

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            - escape due to p —> n conversion could also help

SN surveys/follow ups

VSB, Ginzburg & Prilutskii 1983, 1984

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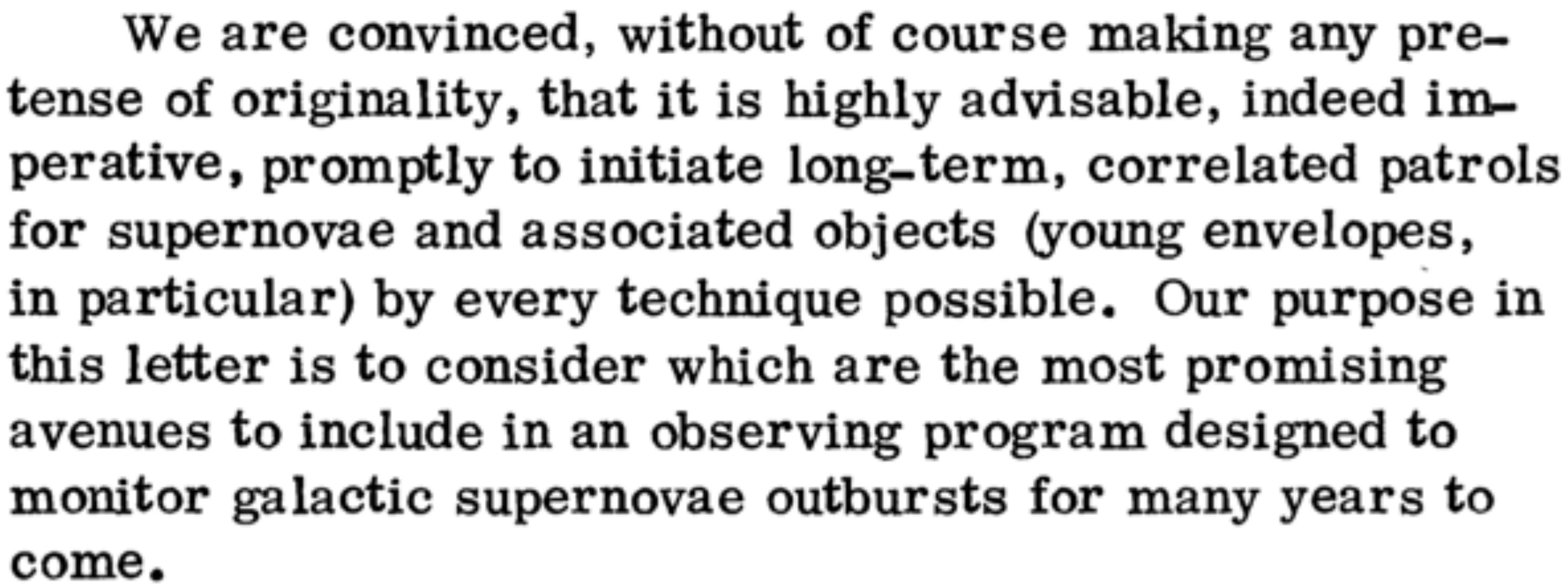

We are convinced, without of course making any pretense of originality, that it is highly advisable, indeed imperative, promptly to initiate long-term, correlated patrols for supernovae and associated objects (young envelopes, in particular) by every technique possible. Our purpose in this letter is to consider which are the most promising avenues to include in an observing program designed to monitor galactic supernovae outbursts for many years to come.

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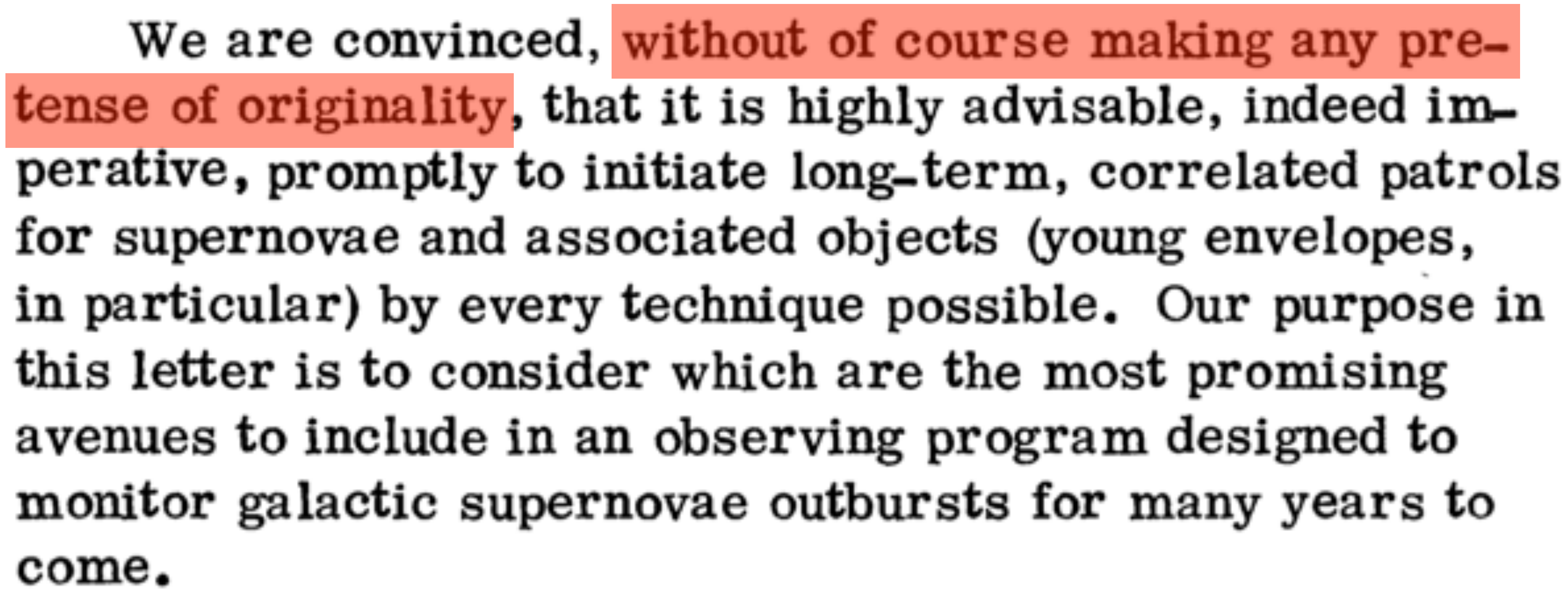

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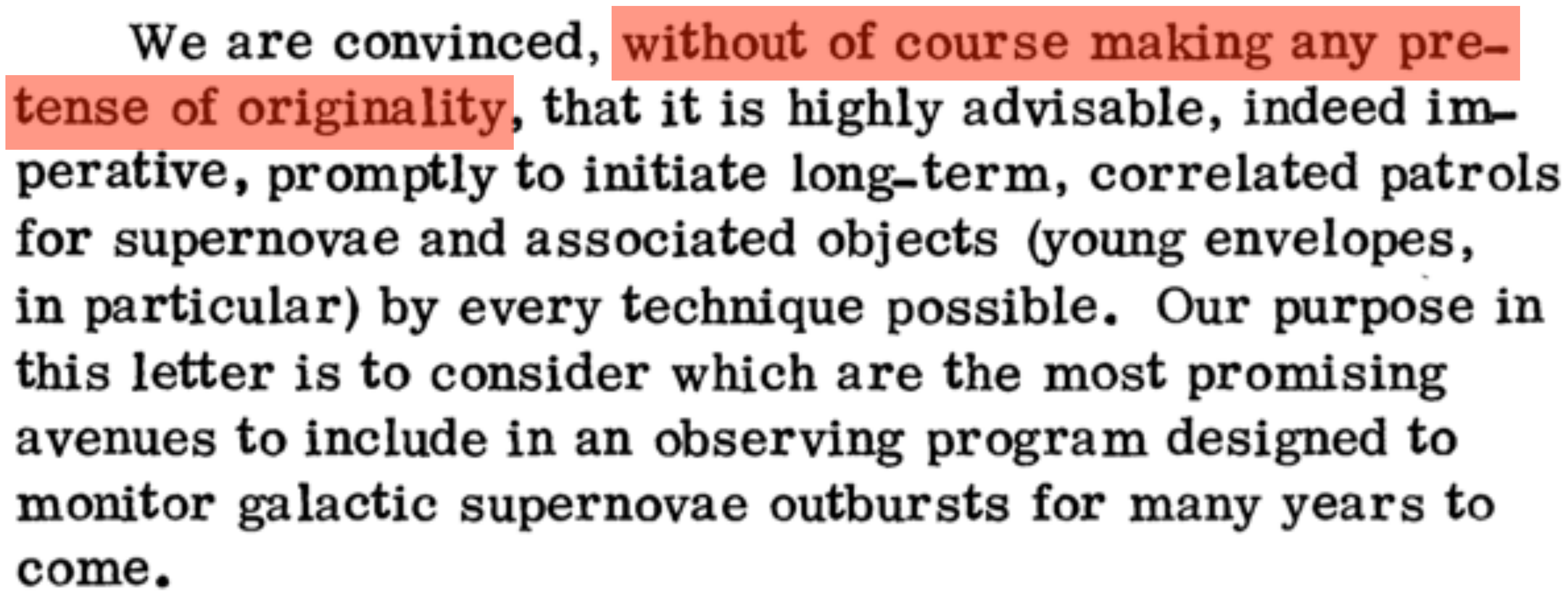

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- Neutrinos in the MeV domain —> SN1987A !
- Gravitational waves (w. "current" detectors, but how anisotropic is the explosion?)
- Infrared radiation (less attenuated by dust)
- Radio emission from SN shells
- Gamma rays beyond 100 MeV (see previous slide)
- Neutrinos beyond 100 GeV (to break the hadronic/leptonic degeneracy)
- UHE ($>10^{18}$ eV) neutrons (can reach us from Gal centre without decaying)

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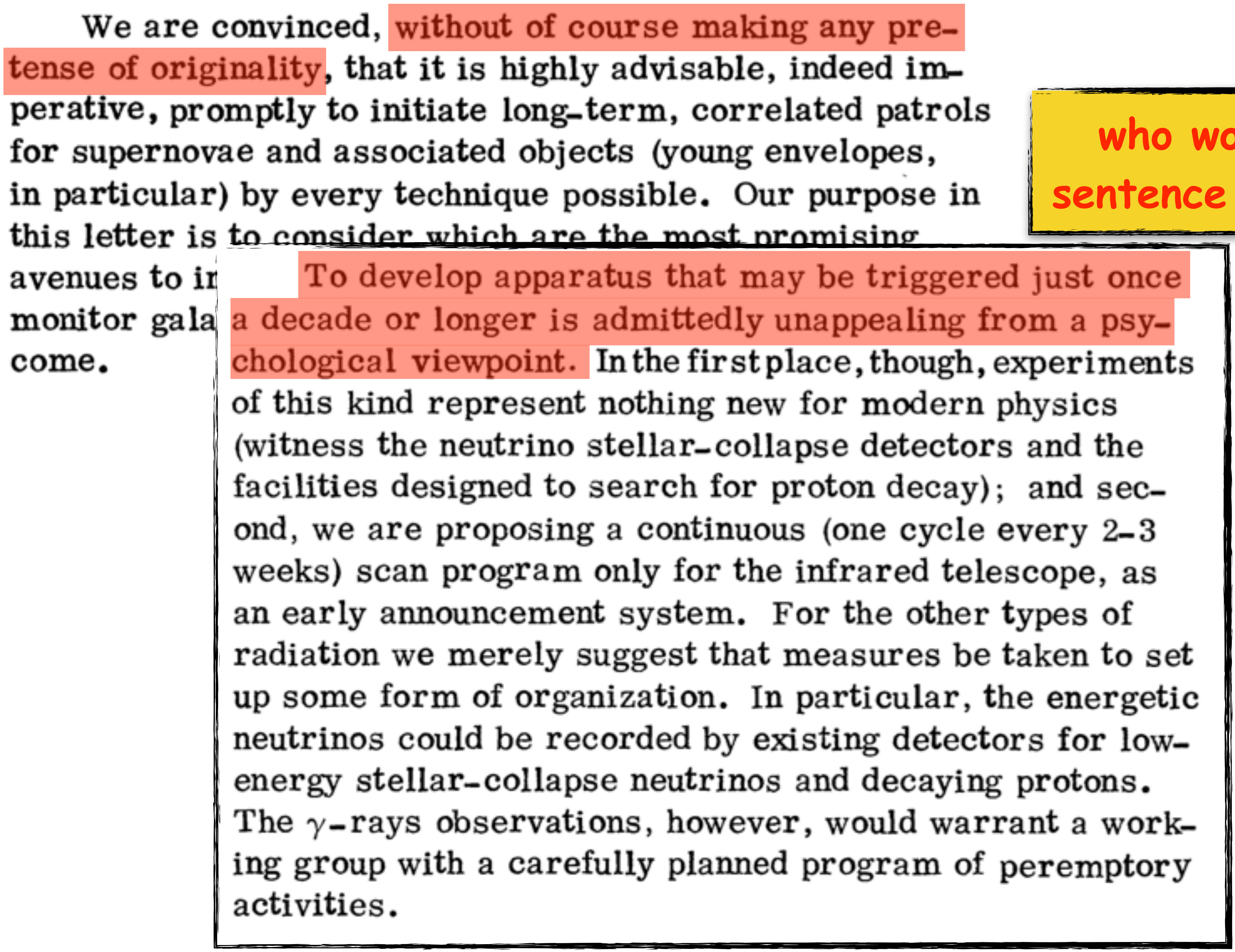

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To develop apparatus that may be triggered just once a decade or longer is admittedly unappealing from a psychological viewpoint. In the first place, though, experiments of this kind represent nothing new for modern physics (witness the neutrino stellar-collapse detectors and the facilities designed to search for proton decay); and second, we are proposing a continuous (one cycle every 2-3 weeks) scan program only for the infrared telescope, as an early announcement system. For the other types of radiation we merely suggest that measures be taken to set up some form of organization. In particular, the energetic neutrinos could be recorded by existing detectors for low-energy stellar-collapse neutrinos and decaying protons. The γ-rays observations, however, would warrant a working group with a carefully planned program of peremptory activities.

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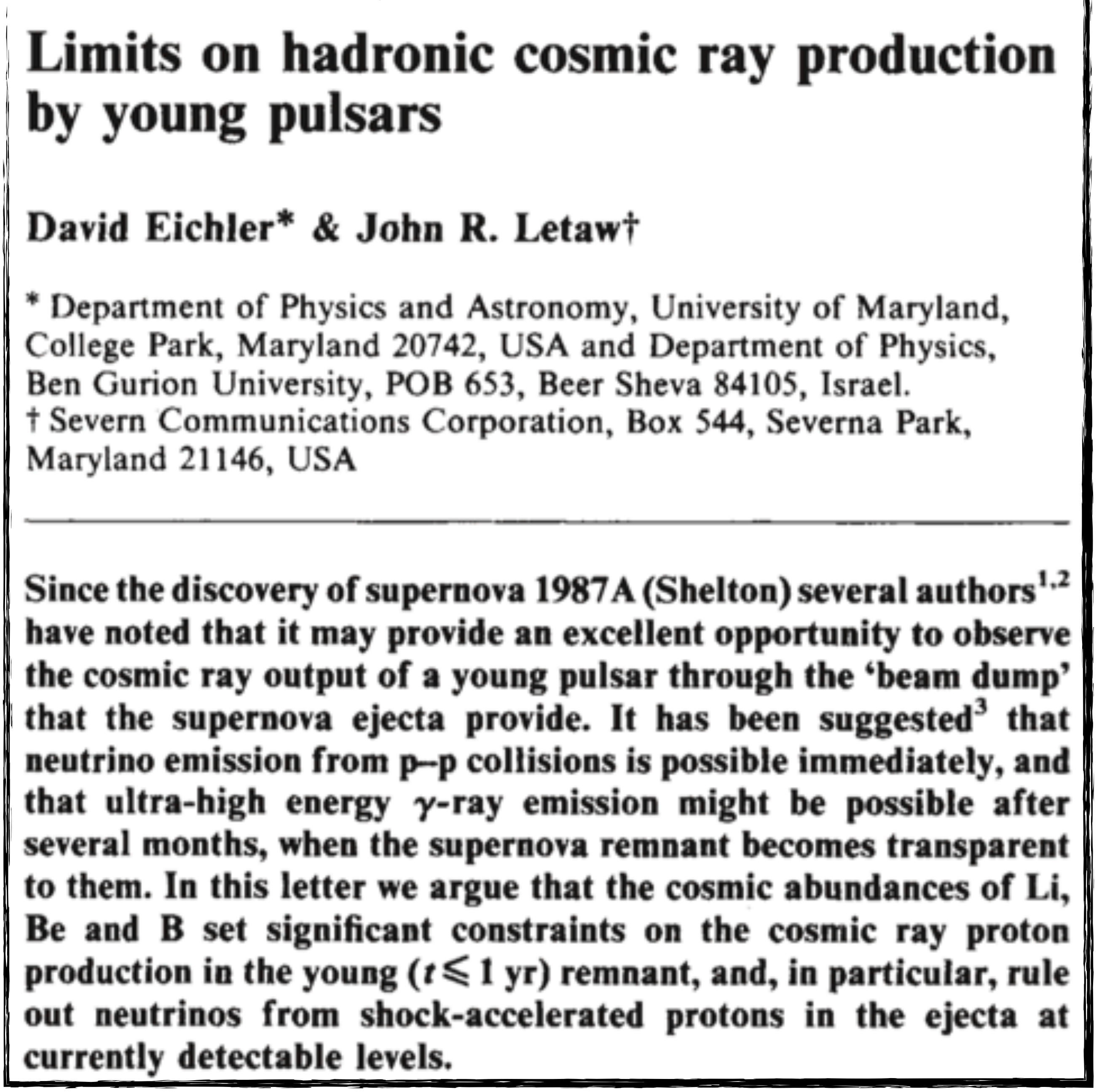
February 23rd 1987



Limits on hadronic cosmic ray production by young pulsars

David Eichler* & John R. Letaw†

* Department of Physics and Astronomy, University of Maryland,
College Park, Maryland 20742, USA and Department of Physics,
Ben Gurion University, POB 653, Beer Sheva 84105, Israel.
† Severn Communications Corporation, Box 544, Severna Park,
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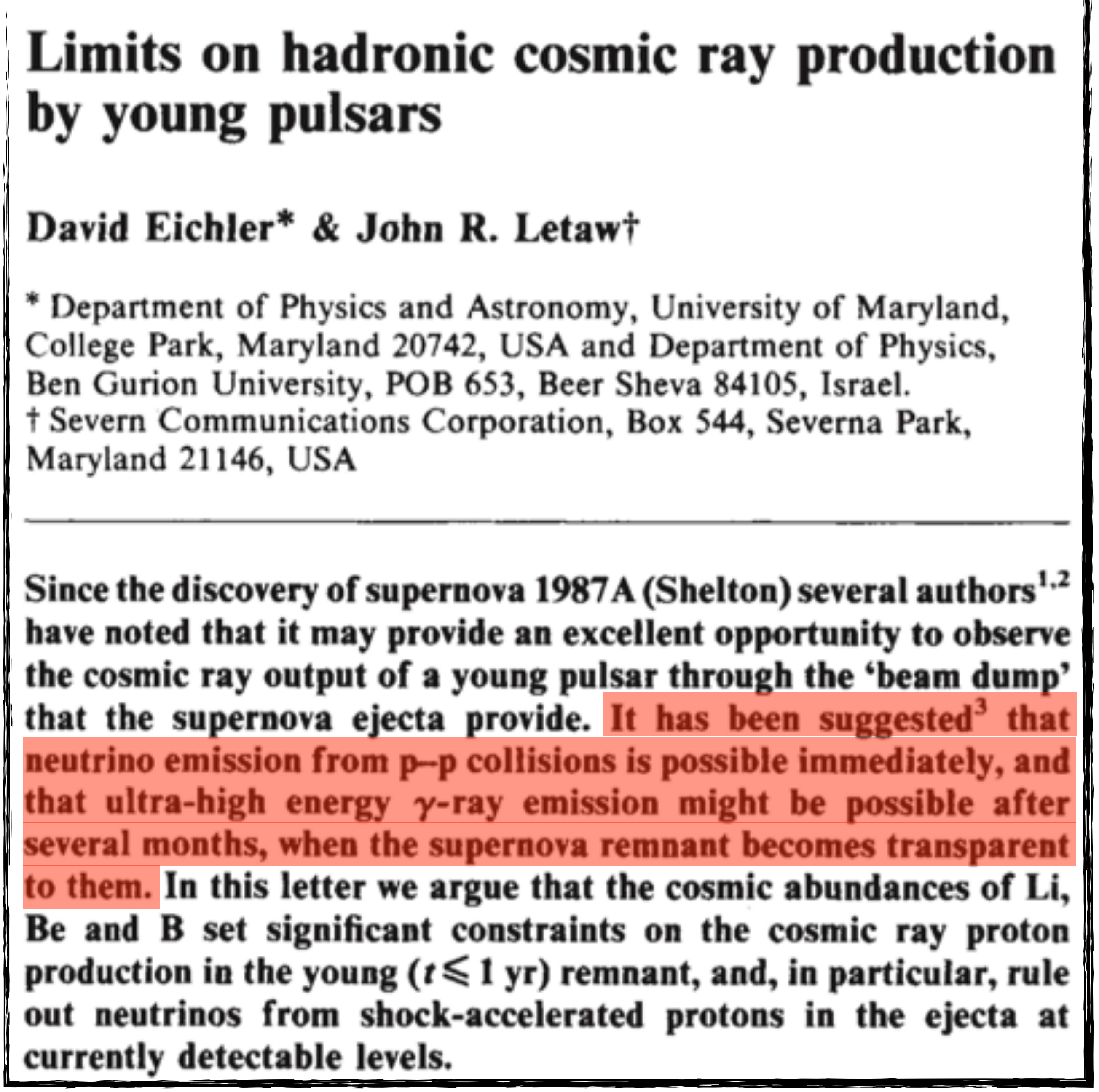
Since the discovery of supernova 1987A (Shelton) several authors[1,2] have noted that it may provide an excellent opportunity to observe the cosmic ray output of a young pulsar through the 'beam dump' that the supernova ejecta provide. It has been suggested[3] that neutrino emission from p–p collisions is possible immediately, and that ultra-high energy γ-ray emission might be possible after several months, when the supernova remnant becomes transparent to them. In this letter we argue that the cosmic abundances of Li, Be and B set significant constraints on the cosmic ray proton production in the young ($t \leqslant 1$ yr) remnant, and, in particular, rule out neutrinos from shock-accelerated protons in the ejecta at currently detectable levels.

august



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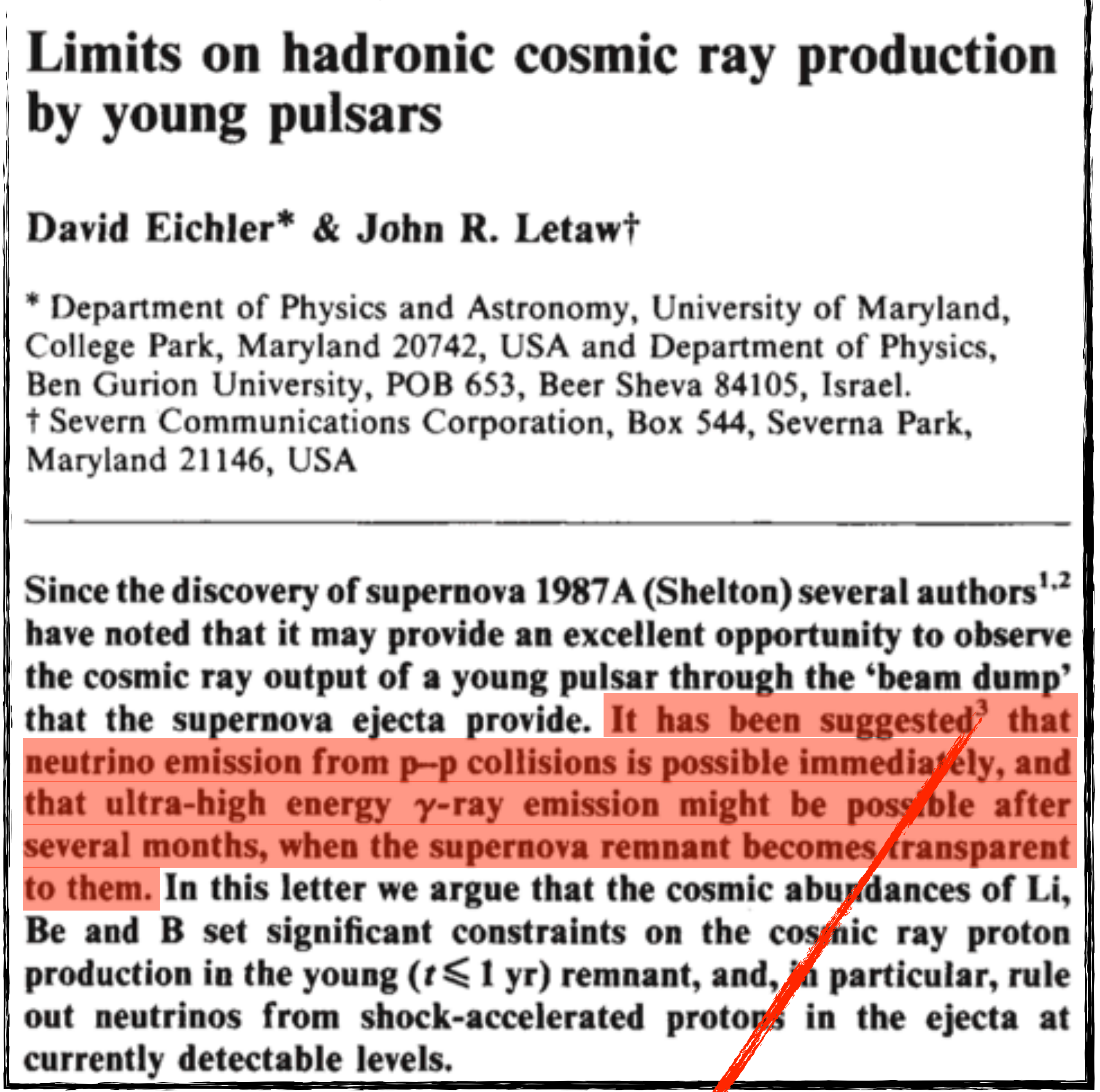

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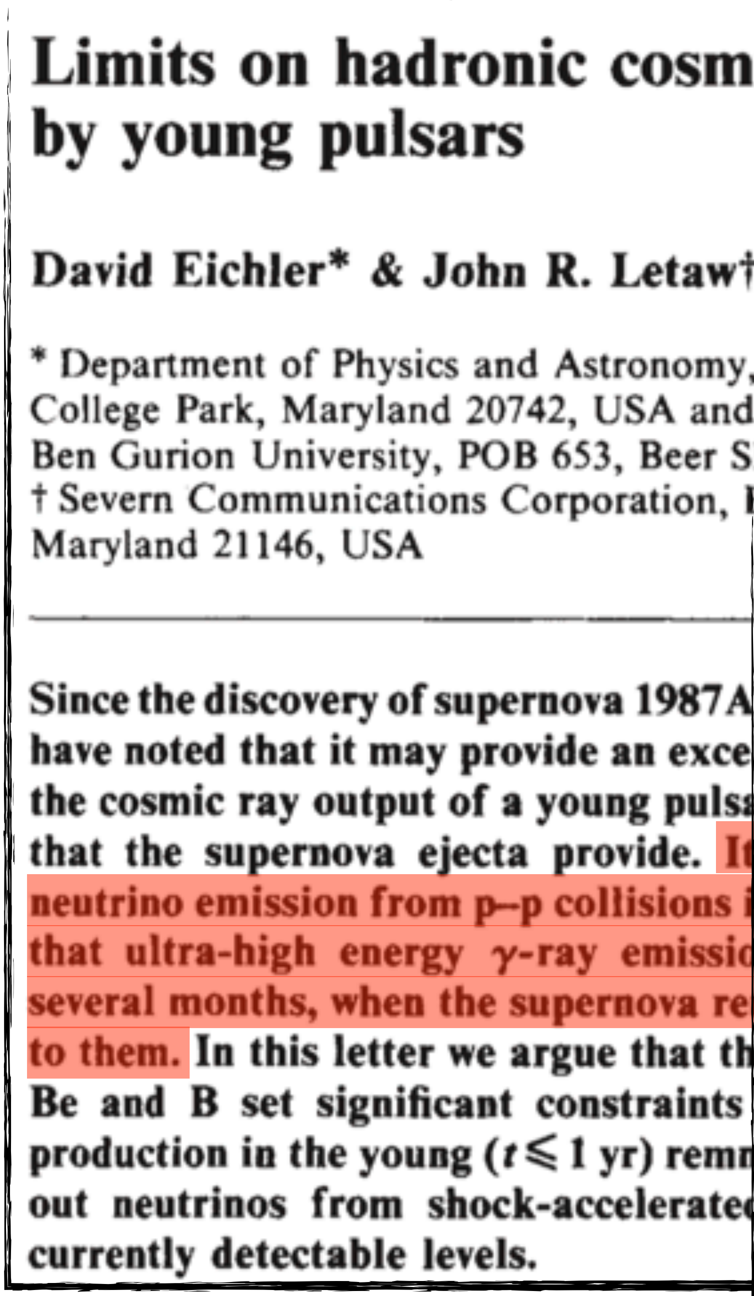

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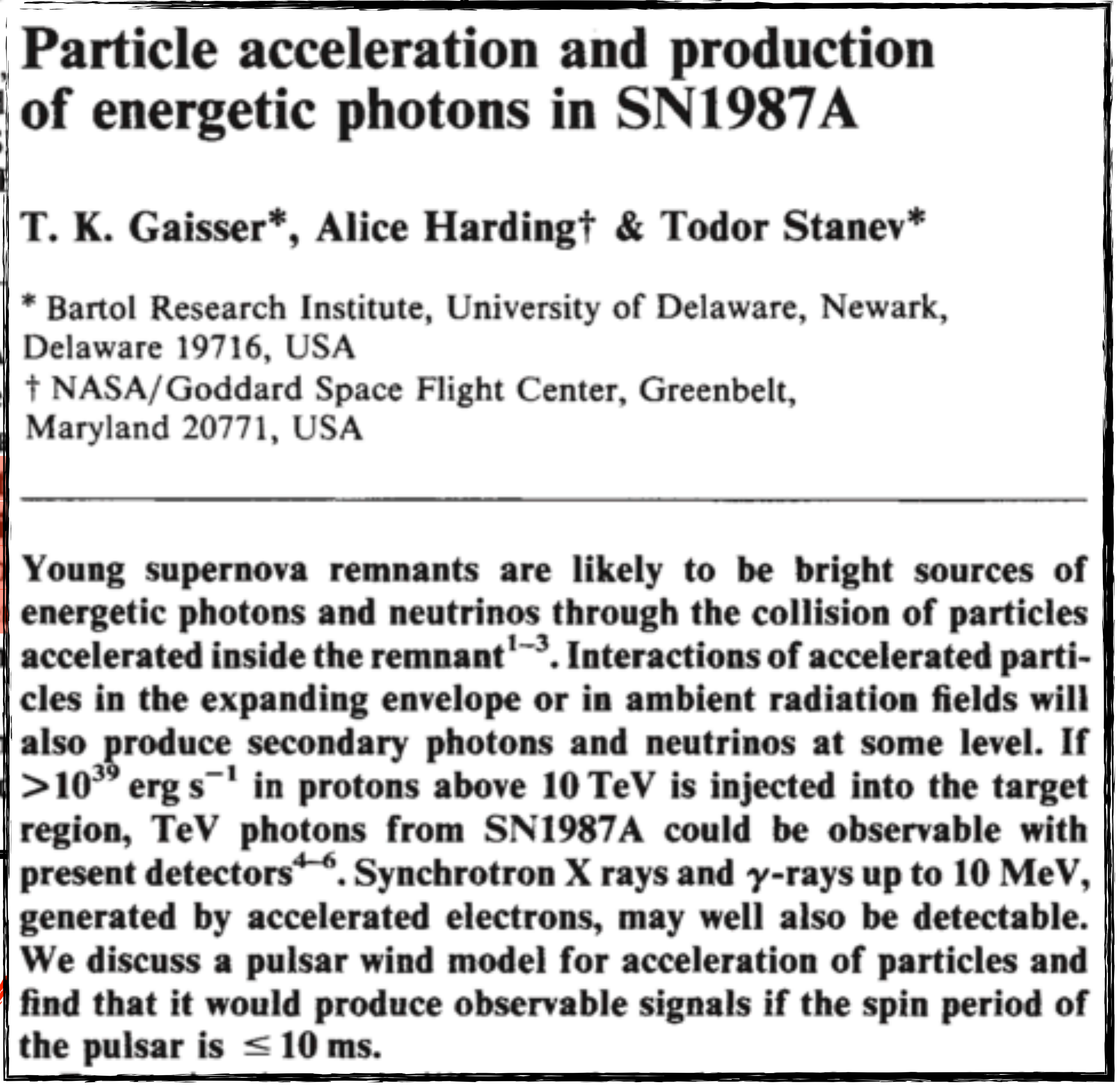

Particle acceleration and production of energetic photons in SN1987A

T. K. Gaisser*, Alice Harding† & Todor Stanev*

* Bartol Research Institute, University of Delaware, Newark,
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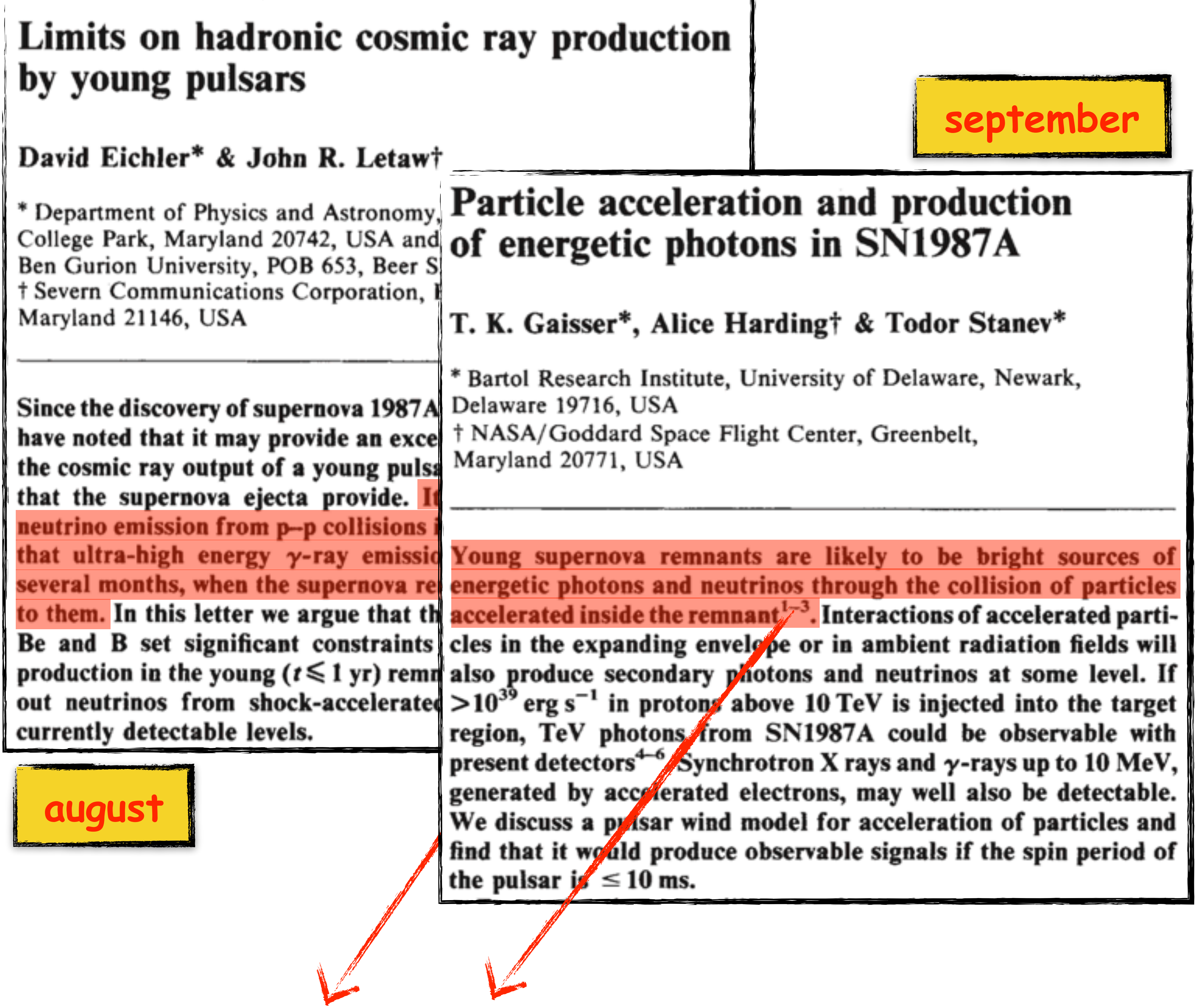
Young supernova remnants are likely to be bright sources of energetic photons and neutrinos through the collision of particles accelerated inside the remnant[1–3]. Interactions of accelerated particles in the expanding envelope or in ambient radiation fields will also produce secondary photons and neutrinos at some level. If $>10^{39}$ erg s^{-1} in protons above 10 TeV is injected into the target region, TeV photons from SN1987A could be observable with present detectors[4–6]. Synchrotron X rays and γ-rays up to 10 MeV, generated by accelerated electrons, may well also be detectable. We discuss a pulsar wind model for acceleration of particles and find that it would produce observable signals if the spin period of the pulsar is ≤ 10 ms.

VSB & Prilutsky 1978



Limits on hadronic cosmic ray production by young pulsars

David Eichler* & John R. Letaw†

* Department of Physics and Astronomy,
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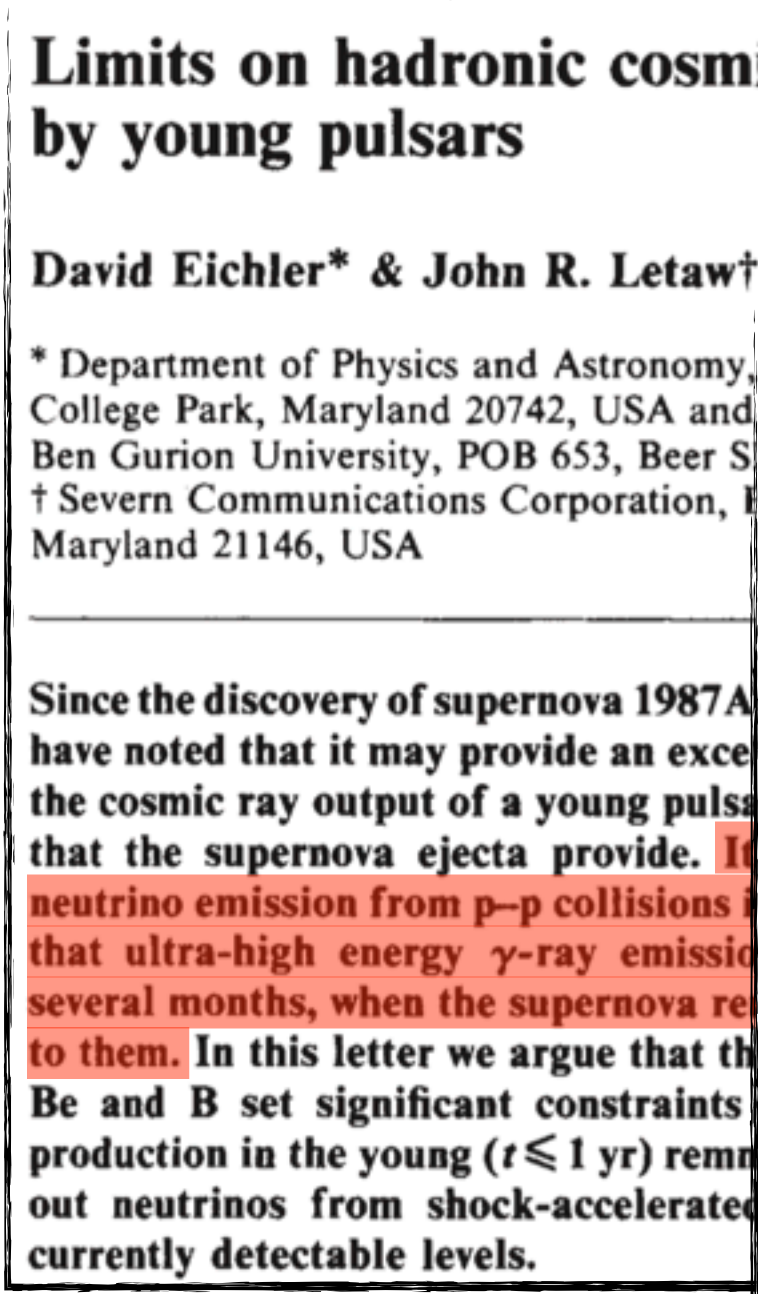

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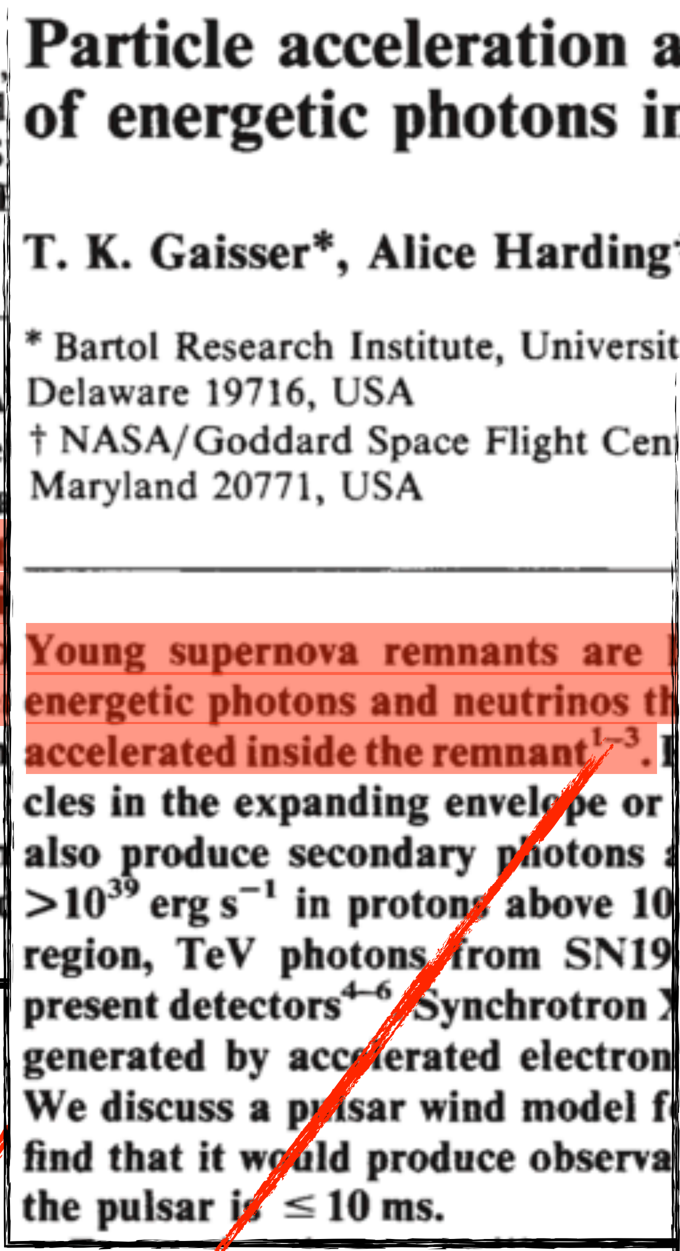

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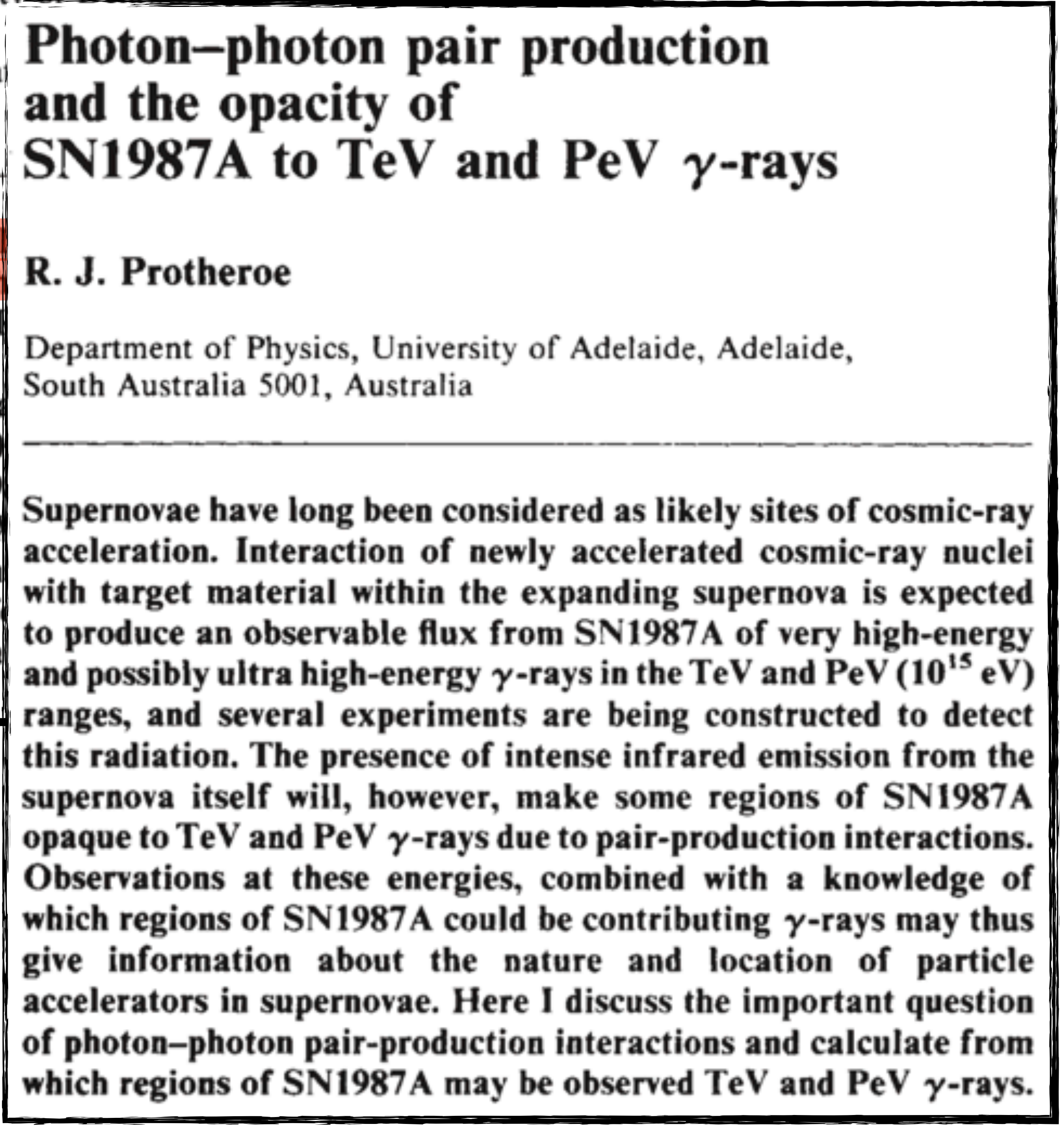


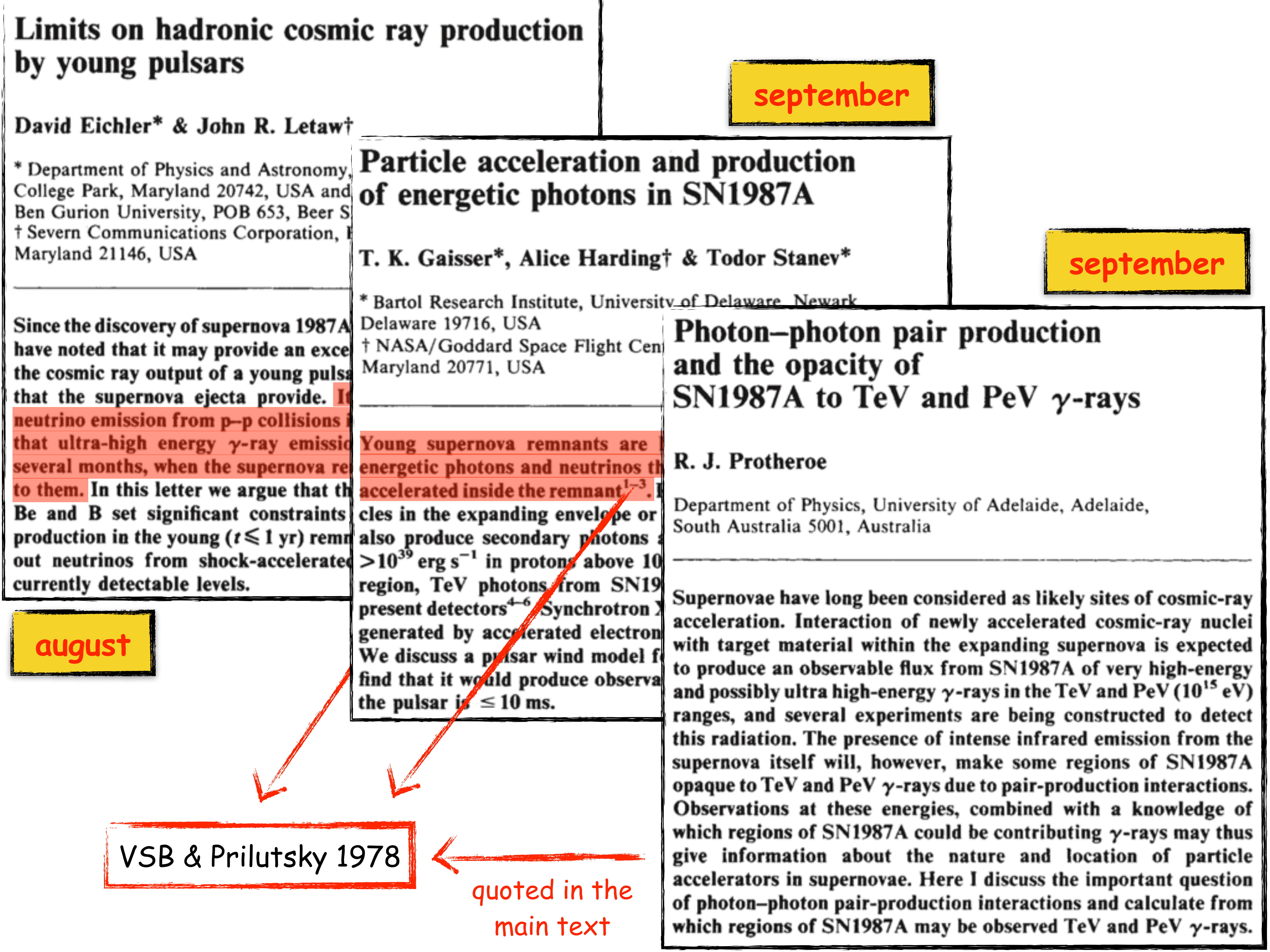
Photon–photon pair production and the opacity of SN1987A to TeV and PeV γ-rays

R. J. Protheroe

Department of Physics, University of Adelaide, Adelaide,
South Australia 5001, Australia

Supernovae have long been considered as likely sites of cosmic-ray acceleration. Interaction of newly accelerated cosmic-ray nuclei with target material within the expanding supernova is expected to produce an observable flux from SN1987A of very high-energy and possibly ultra high-energy γ-rays in the TeV and PeV (10^{15} eV) ranges, and several experiments are being constructed to detect this radiation. The presence of intense infrared emission from the supernova itself will, however, make some regions of SN1987A opaque to TeV and PeV γ-rays due to pair-production interactions. Observations at these energies, combined with a knowledge of which regions of SN1987A could be contributing γ-rays may thus give information about the nature and location of particle accelerators in supernovae. Here I discuss the important question of photon–photon pair-production interactions and calculate from which regions of SN1987A may be observed TeV and PeV γ-rays.

VSB & Prilutsky 1978



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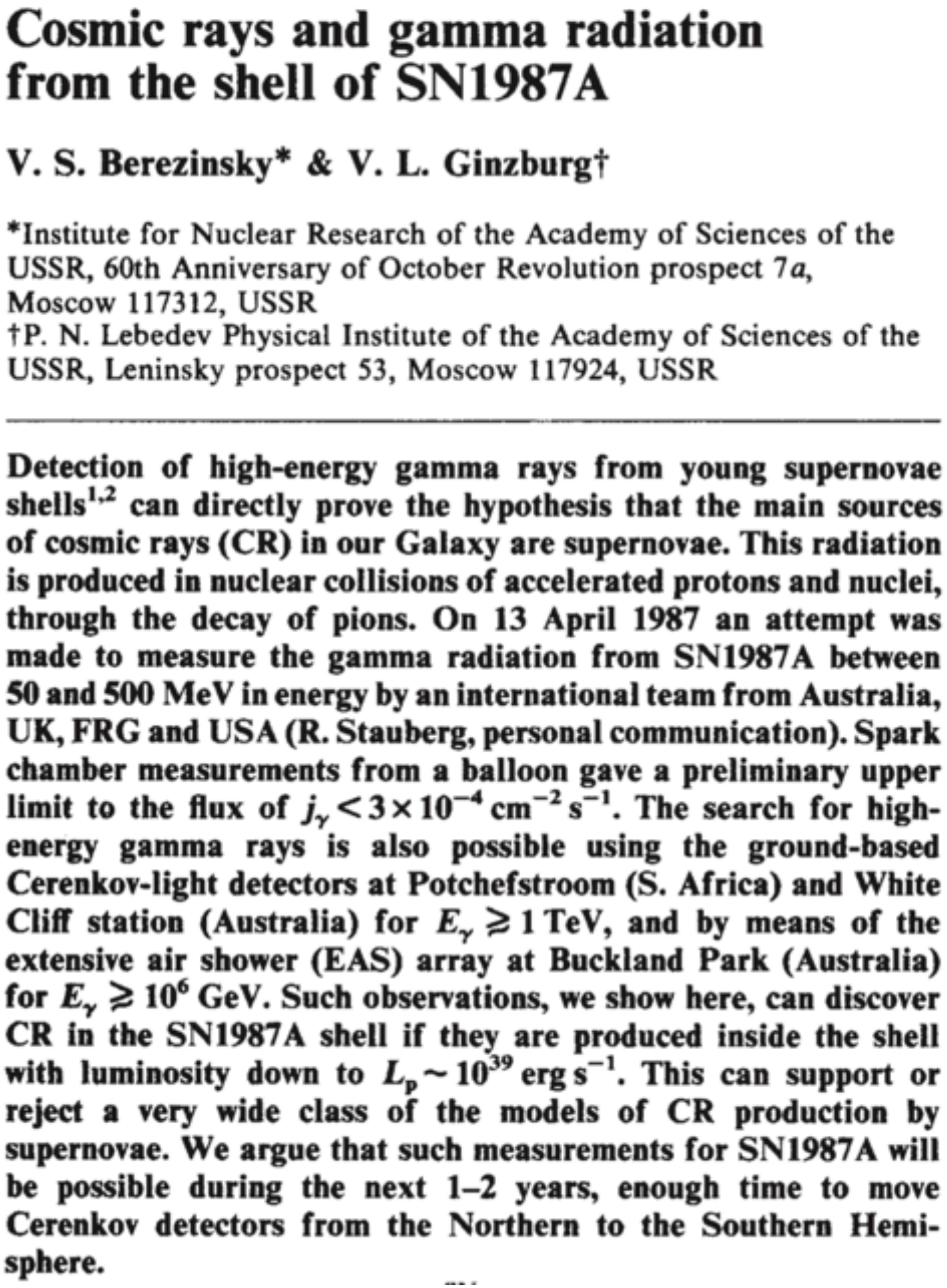
VSB & Prilutsky 1978

quoted in the main text

SN 1987A

october



Cosmic rays and gamma radiation from the shell of SN1987A

V. S. Berezinsky* & V. L. Ginzburg†

*Institute for Nuclear Research of the Academy of Sciences of the
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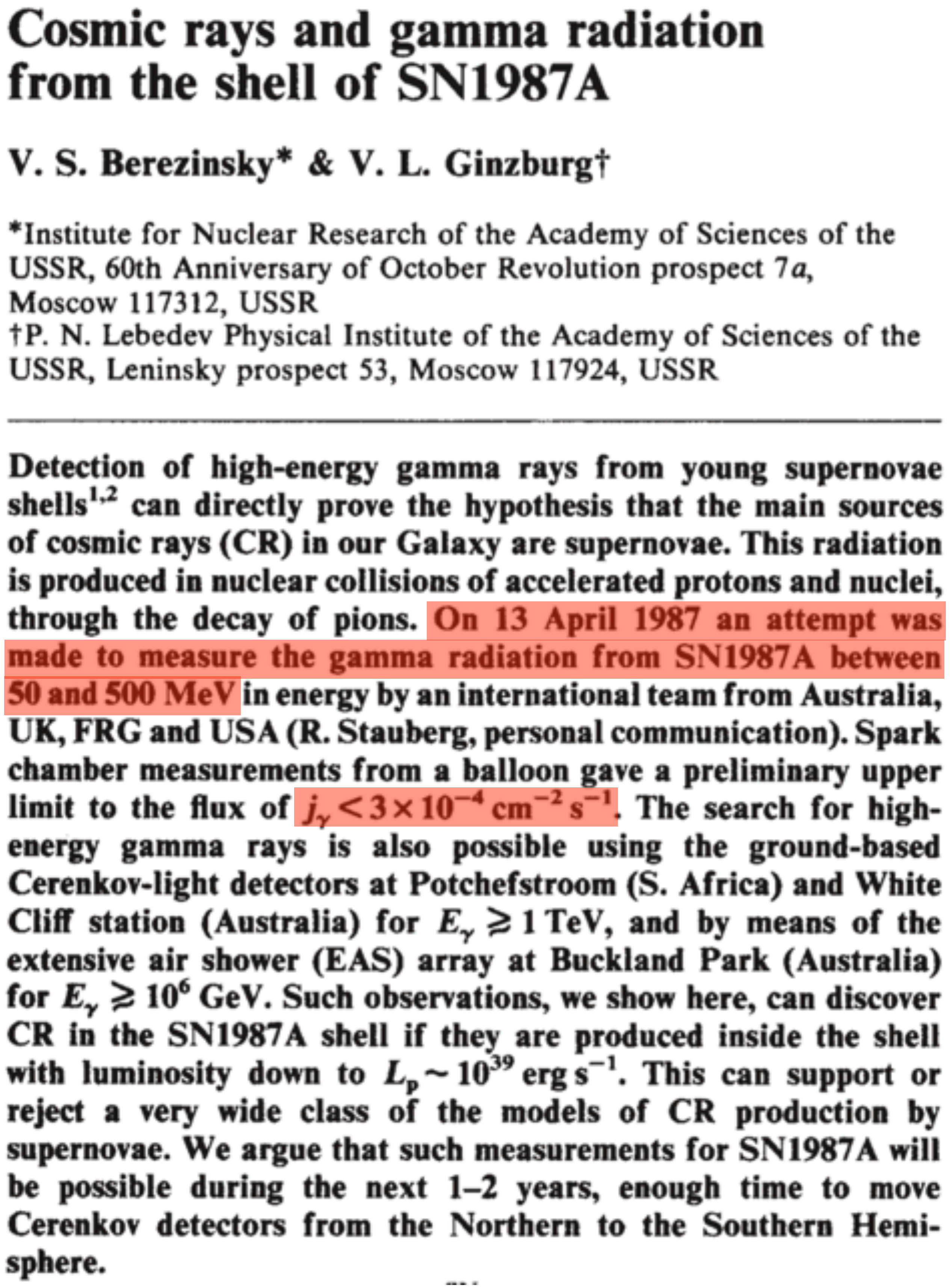
Detection of high-energy gamma rays from young supernovae shells[1,2] can directly prove the hypothesis that the main sources of cosmic rays (CR) in our Galaxy are supernovae. This radiation is produced in nuclear collisions of accelerated protons and nuclei, through the decay of pions. On 13 April 1987 an attempt was made to measure the gamma radiation from SN1987A between 50 and 500 MeV in energy by an international team from Australia, UK, FRG and USA (R. Stauberg, personal communication). Spark chamber measurements from a balloon gave a preliminary upper limit to the flux of $j_\gamma < 3\times10^{-4}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The search for high-energy gamma rays is also possible using the ground-based Cerenkov-light detectors at Potchefstroom (S. Africa) and White Cliff station (Australia) for $E_\gamma \gtrsim 1\ \mathrm{TeV}$, and by means of the extensive air shower (EAS) array at Buckland Park (Australia) for $E_\gamma \gtrsim 10^6\ \mathrm{GeV}$. Such observations, we show here, can discover CR in the SN1987A shell if they are produced inside the shell with luminosity down to $L_p \sim 10^{39}\ \mathrm{erg\,s}^{-1}$. This can support or reject a very wide class of the models of CR production by supernovae. We argue that such measurements for SN1987A will be possible during the next 1–2 years, enough time to move Cerenkov detectors from the Northern to the Southern Hemisphere.

SN 1987A

october



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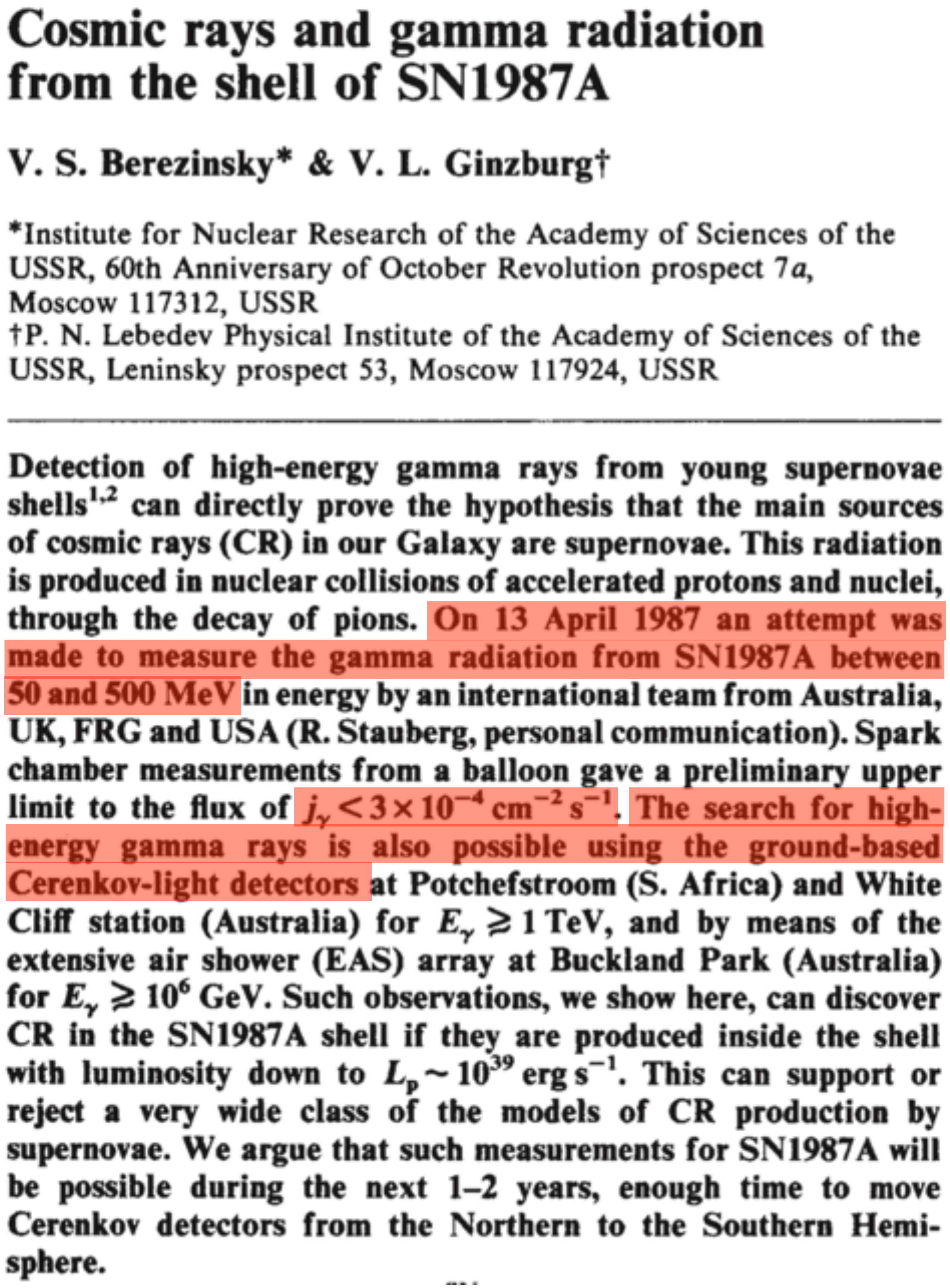

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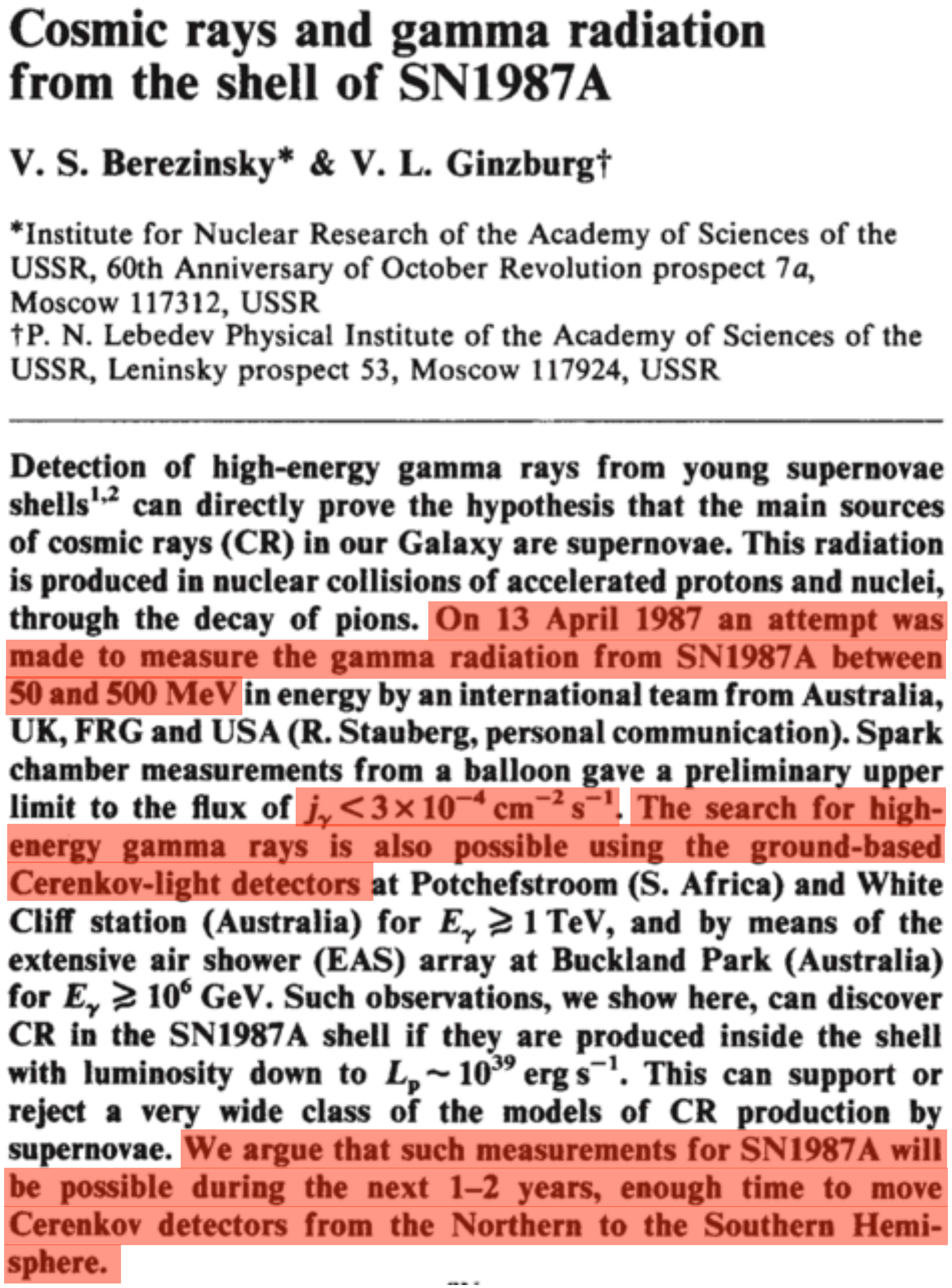

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SN 1987A

VSB & Ginzburg, Nature, 1987

CR input per SN —>

$$W_p^{SN} \approx \frac{c W_p M_g}{\nu_{SN} \Lambda} \approx 10^{50}\ \mathrm{erg}$$

VSB & Ginzburg 1987; VSB, Castagnoli & Navarra 1988

SN 1987A

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SN rate

CR grammage

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CR power

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CR energy density   gas mass in the disk

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time

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SN rate

CR grammage

model —>

adiabatic losses

10^{50} erg

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CR power

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SN rate

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model —>

adiabatic losses

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<— hypothesis

γ-ray limits constrain this —>

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SN 1987A

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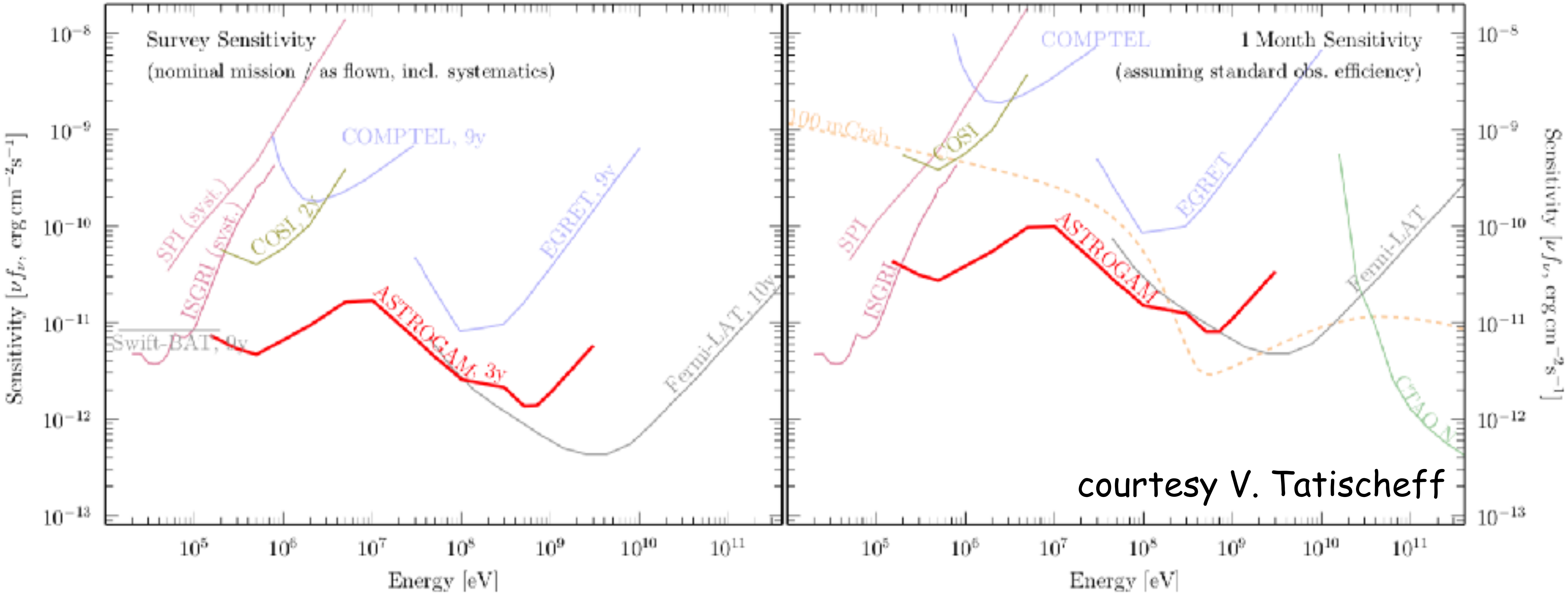

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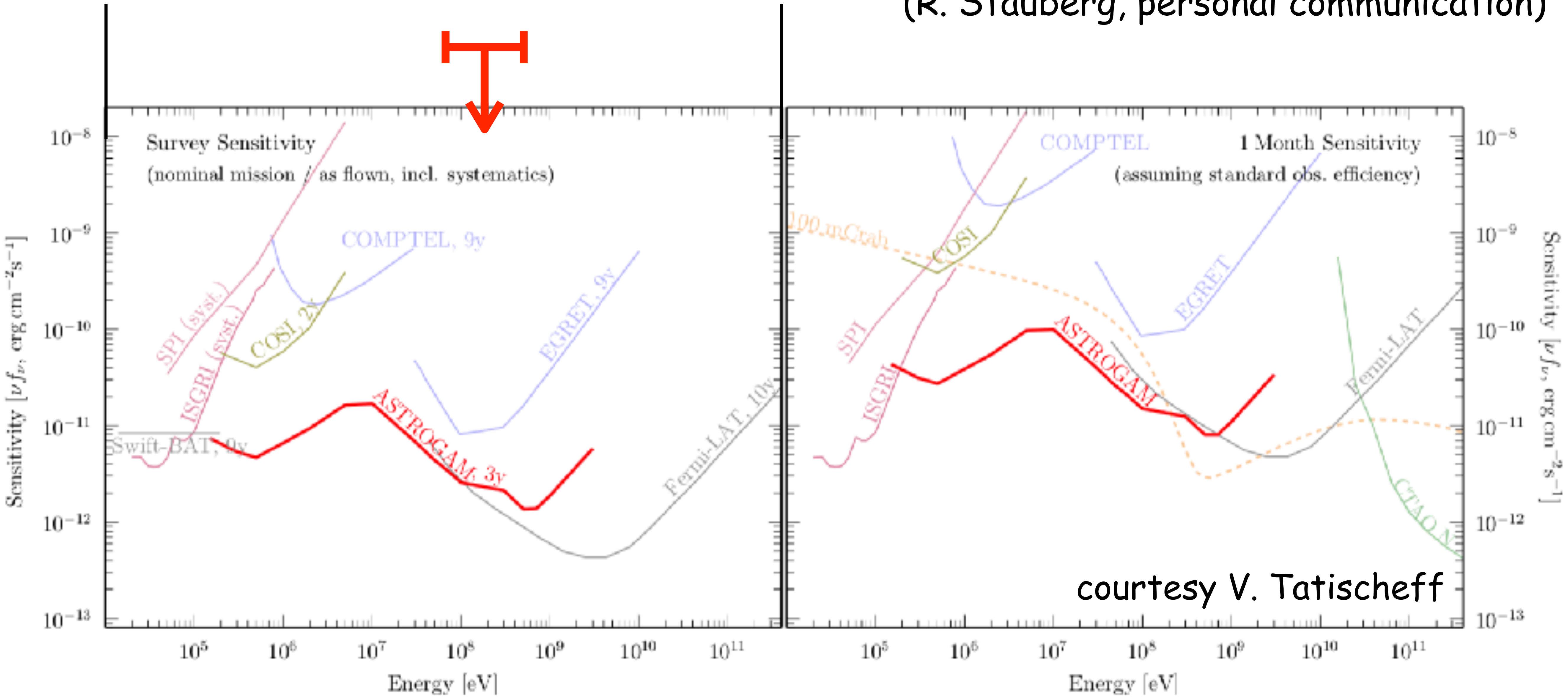

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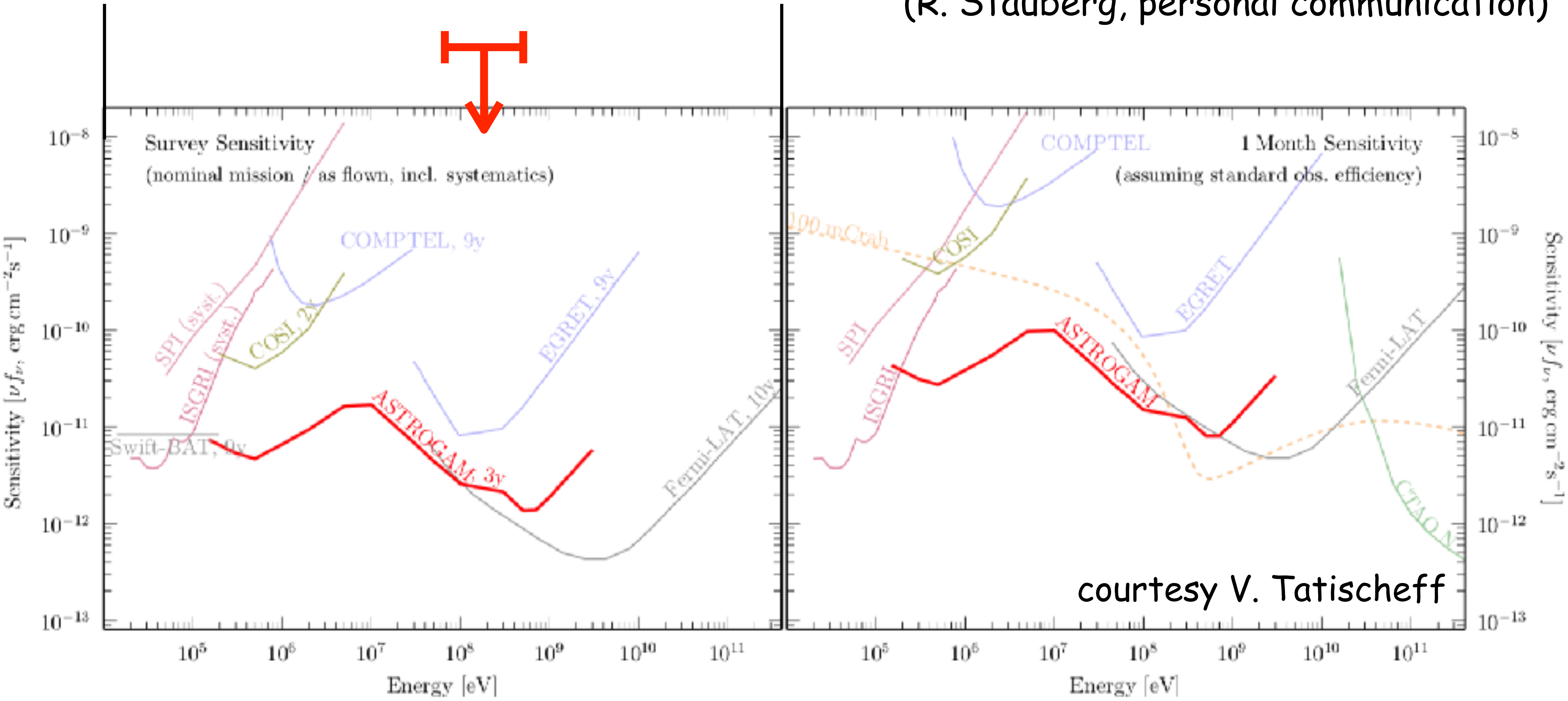

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limit on CR luminosity —>

$$L_p < 5 \times 10^{41} \text{ erg/s}$$

SN 1987A

VSB & Ginzburg, Nature, 1987

TeV emission emitted later (opacity) and could be see by "current" instruments if

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SN 1987A

VSB & Ginzburg, Nature, 1987

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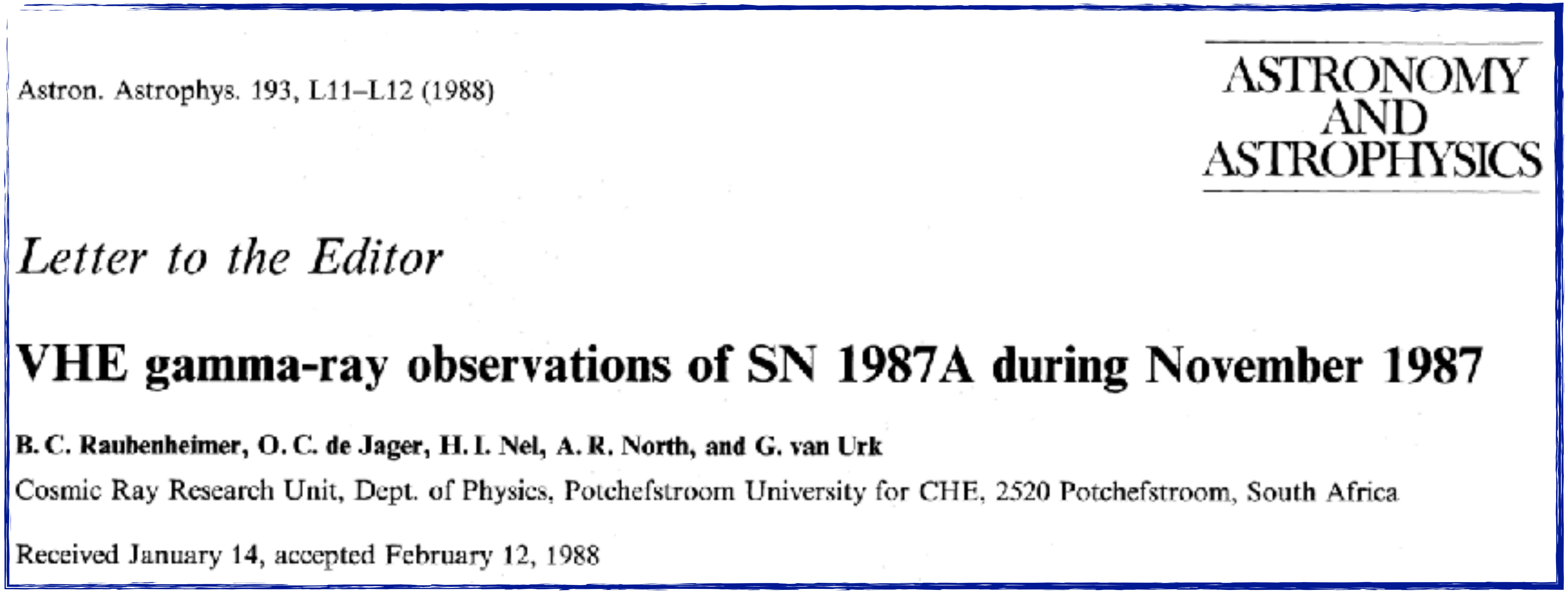
MK I, Potchefstroom



Astron. Astrophys. 193, L11–L12 (1988)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

VHE gamma-ray observations of SN 1987A during November 1987

B. C. Rauhenheimer, O. C. de Jager, H. I. Nel, A. R. North, and G. van Urk

Cosmic Ray Research Unit, Dept. of Physics, Potchefstroom University for CHE, 2520 Potchefstroom, South Africa

Received January 14, accepted February 12, 1988

SN 1987A

VSB & Ginzburg, Nature, 1987

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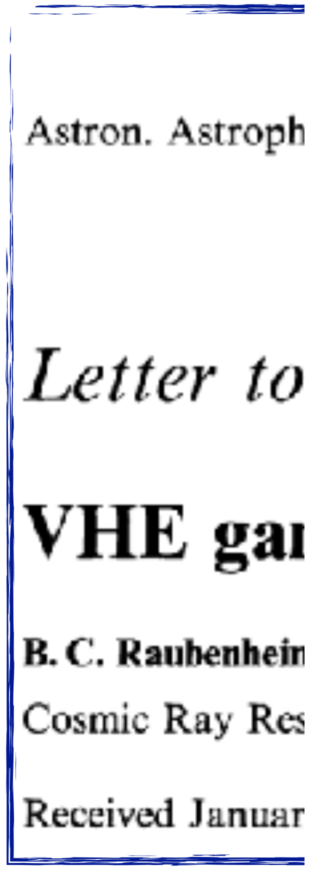

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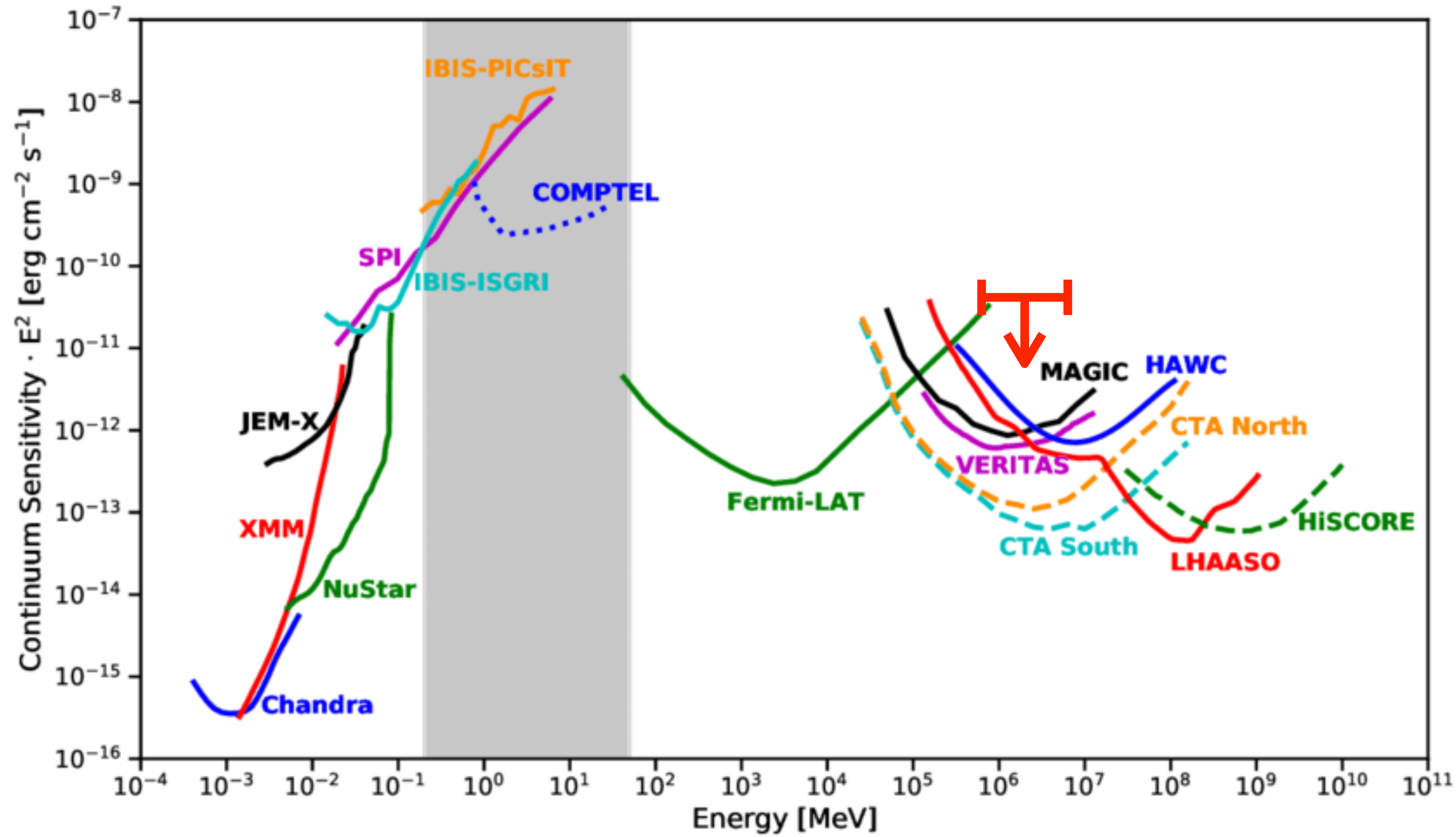
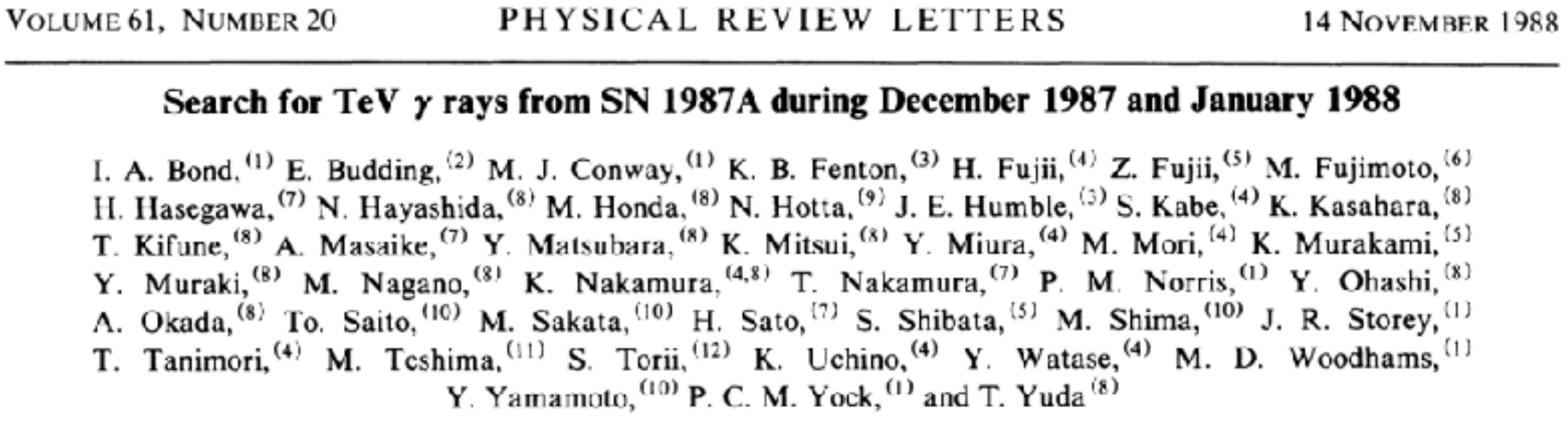


Gamma-ray flare from SN 1987A



VOLUME 61, NUMBER 20 PHYSICAL REVIEW LETTERS 14 NOVEMBER 1988

Search for TeV γ rays from SN 1987A during December 1987 and January 1988

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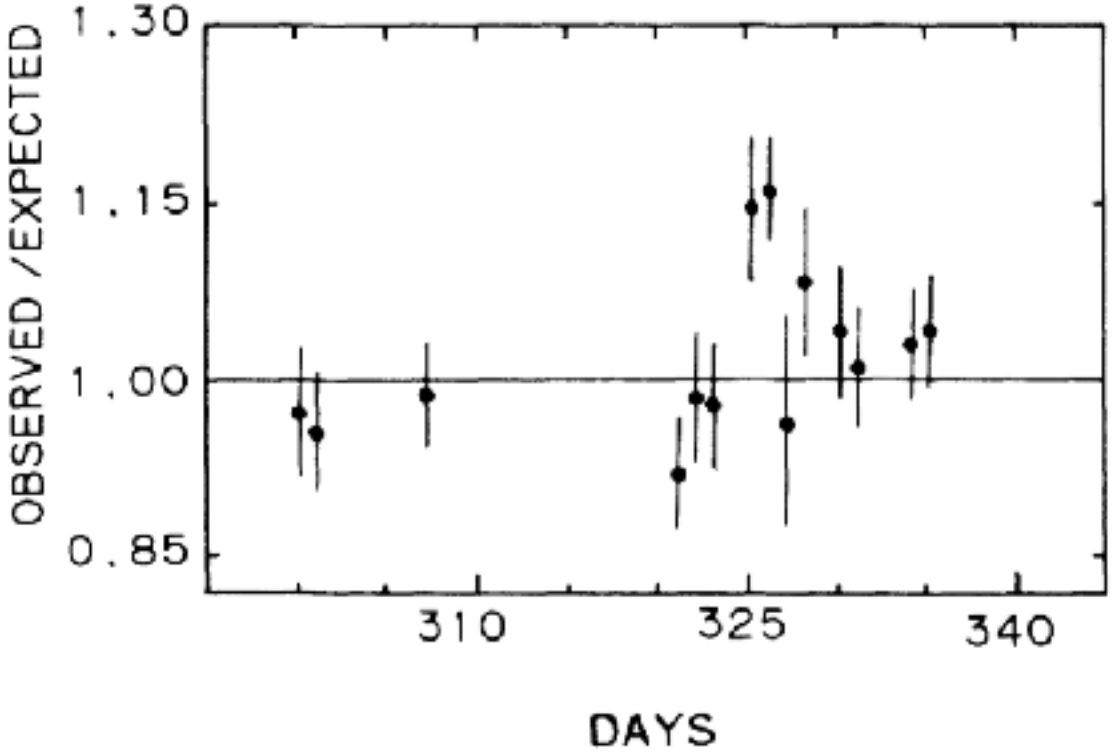
(The JANZOS Collaboration)



VSB & Stanev, 1989

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(The JANZOS Collaboration)

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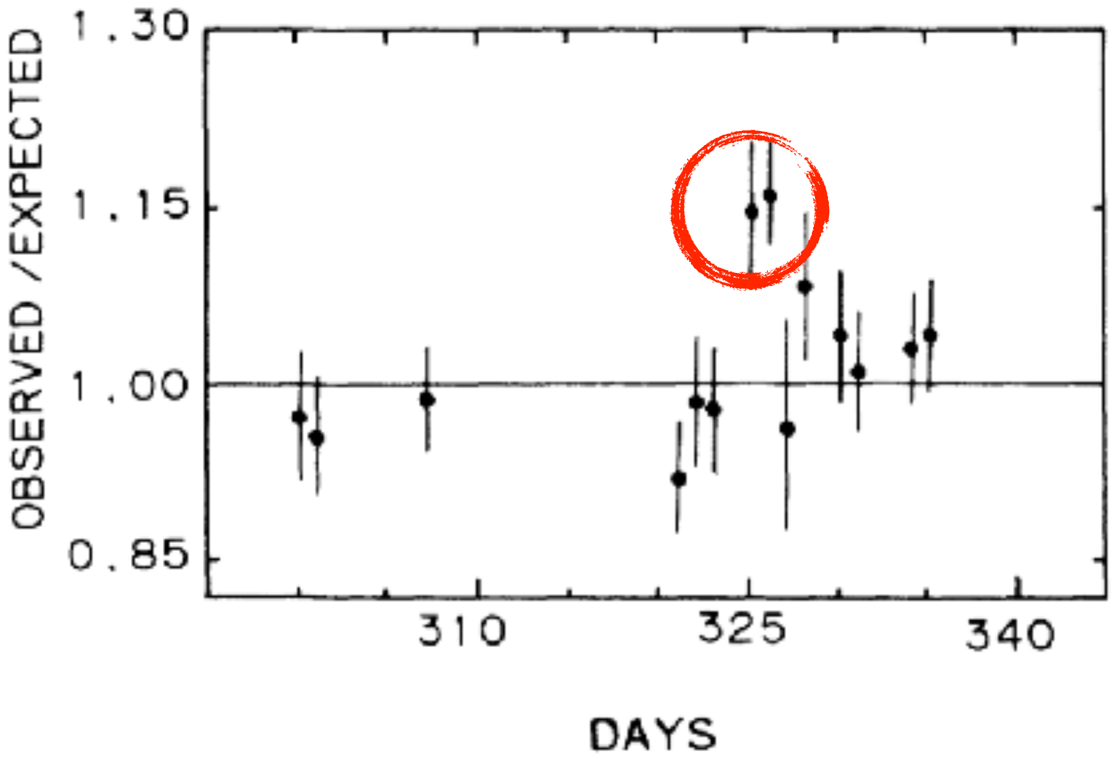

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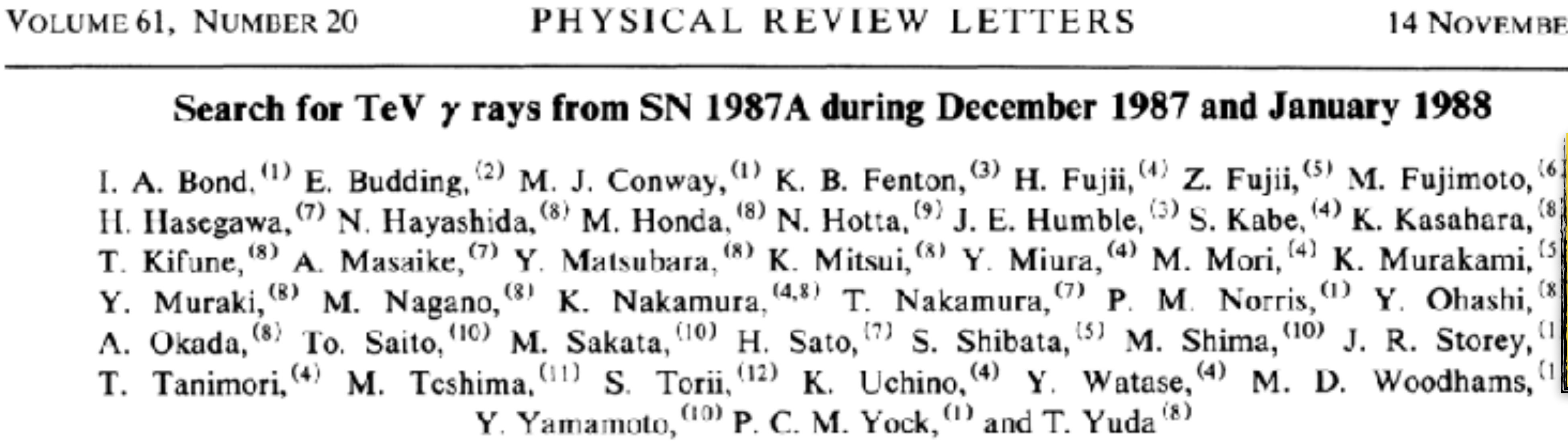

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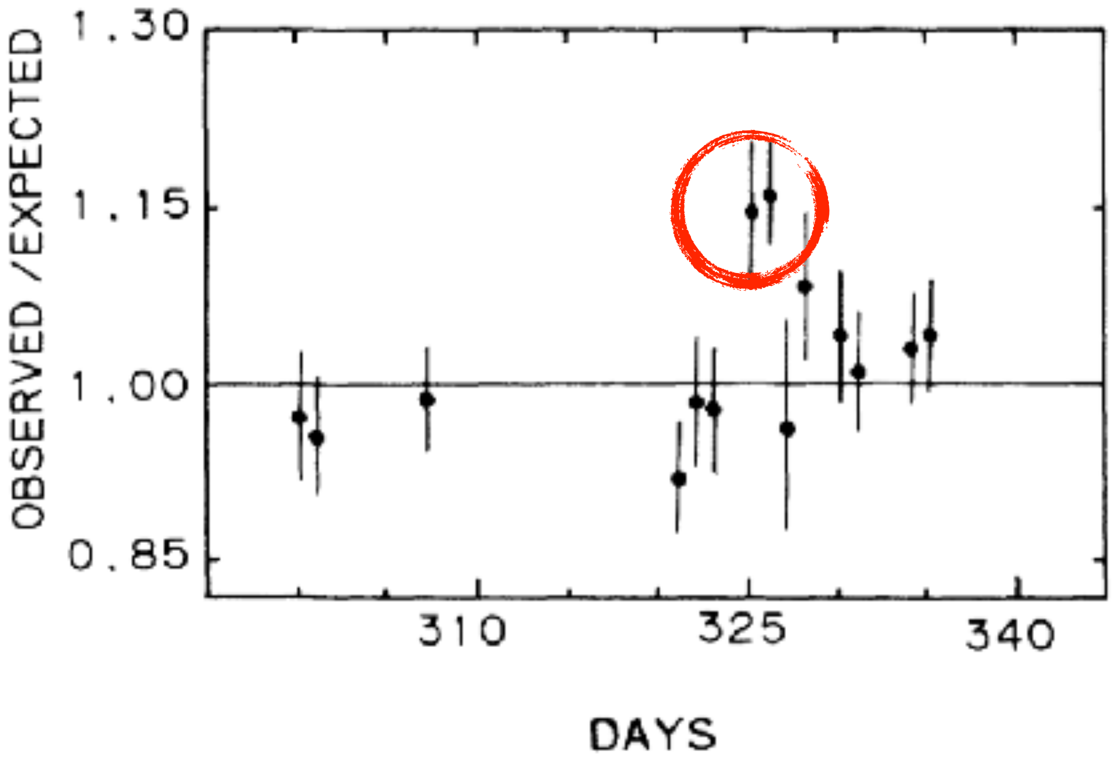

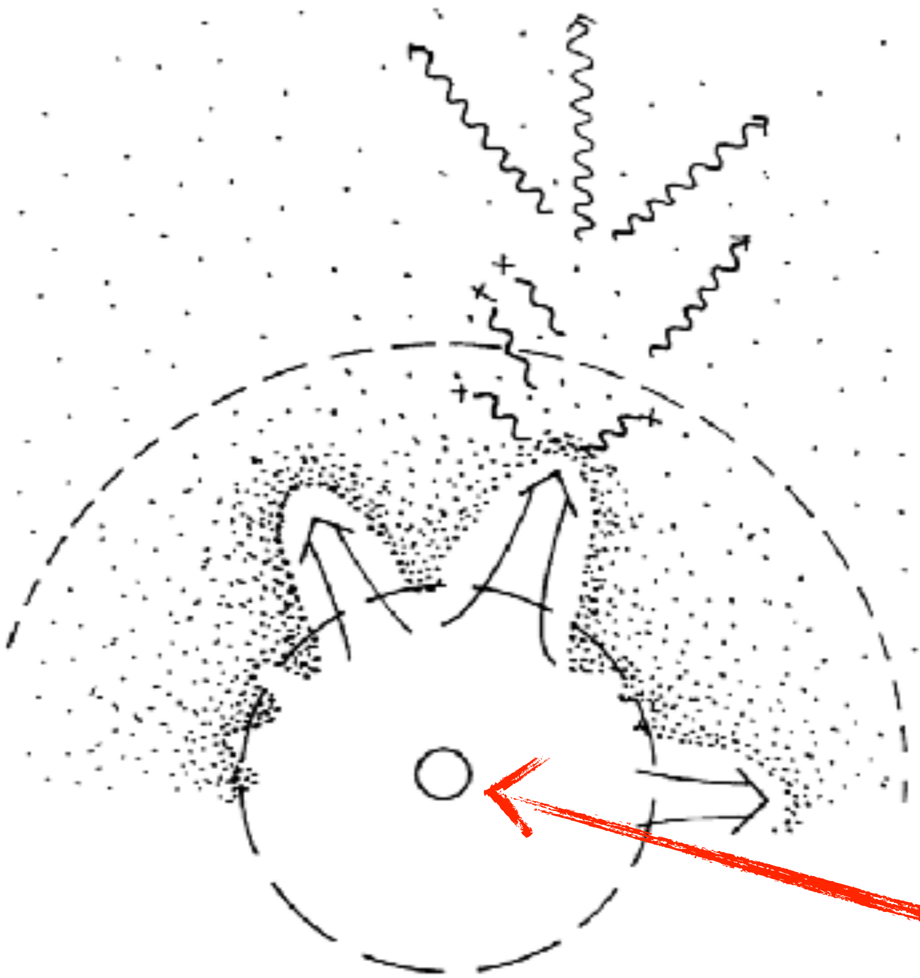

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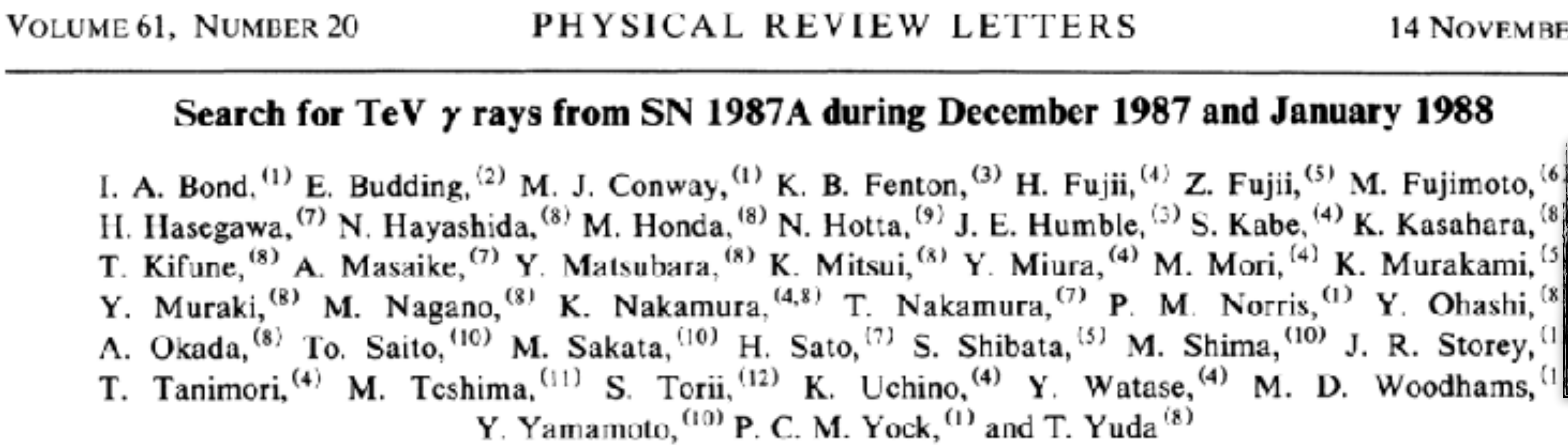

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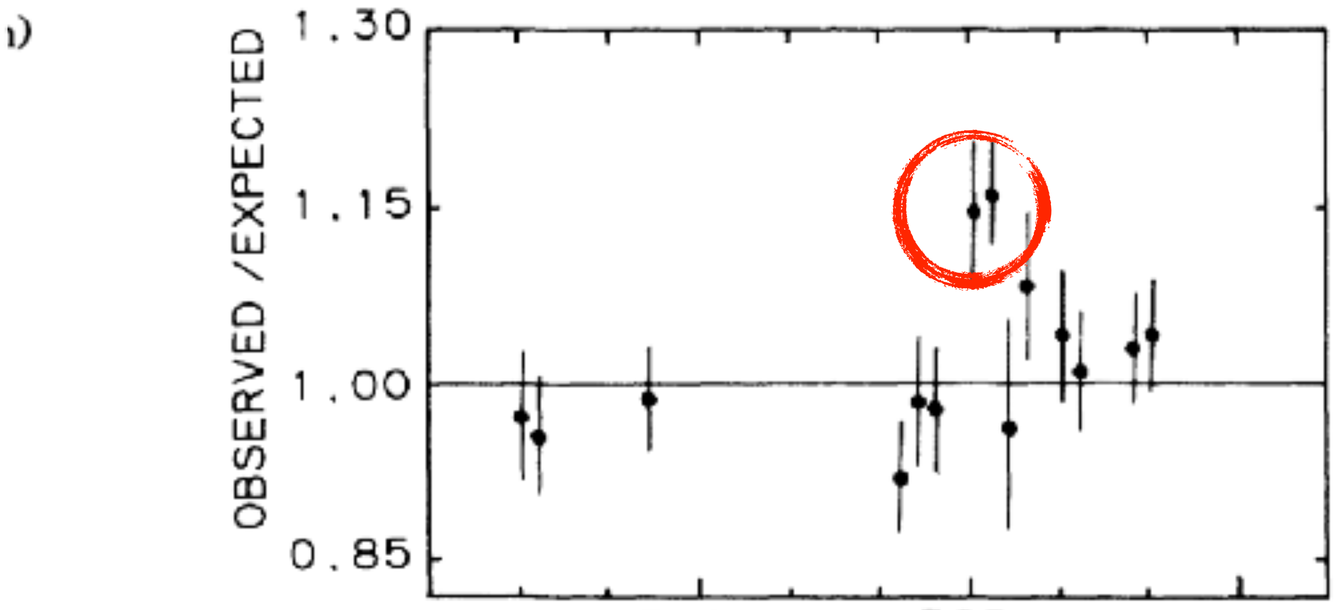

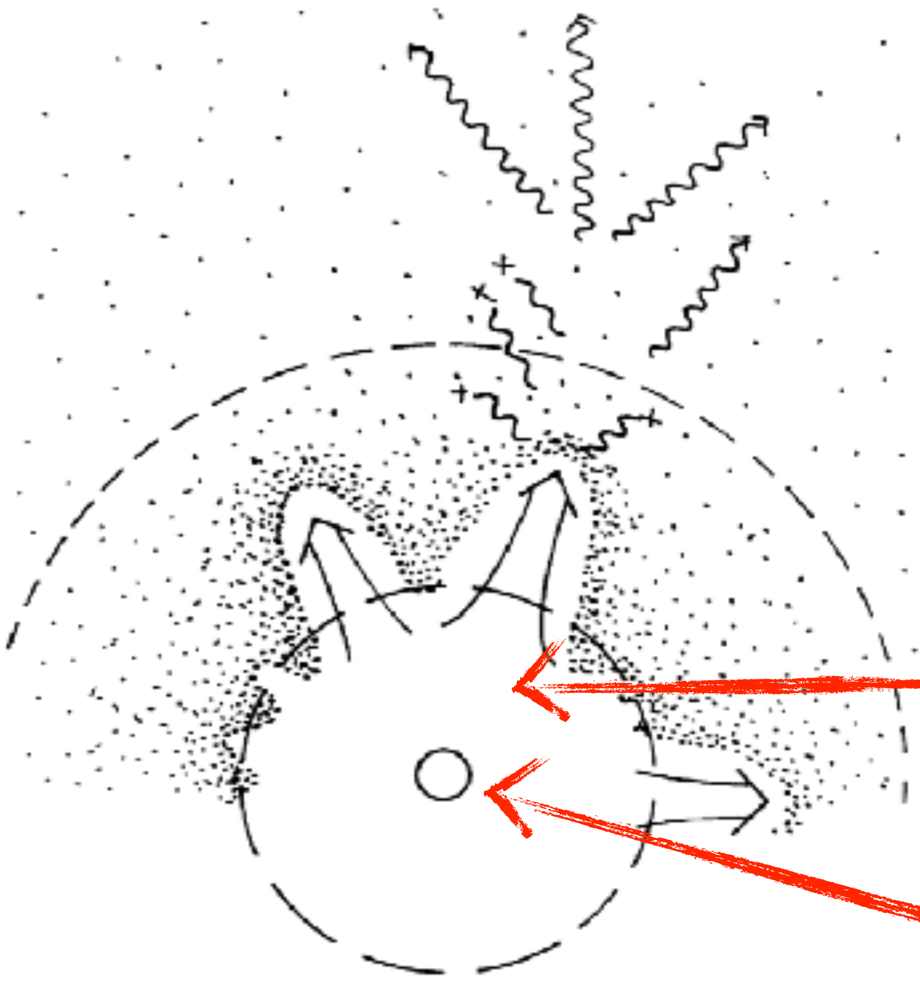

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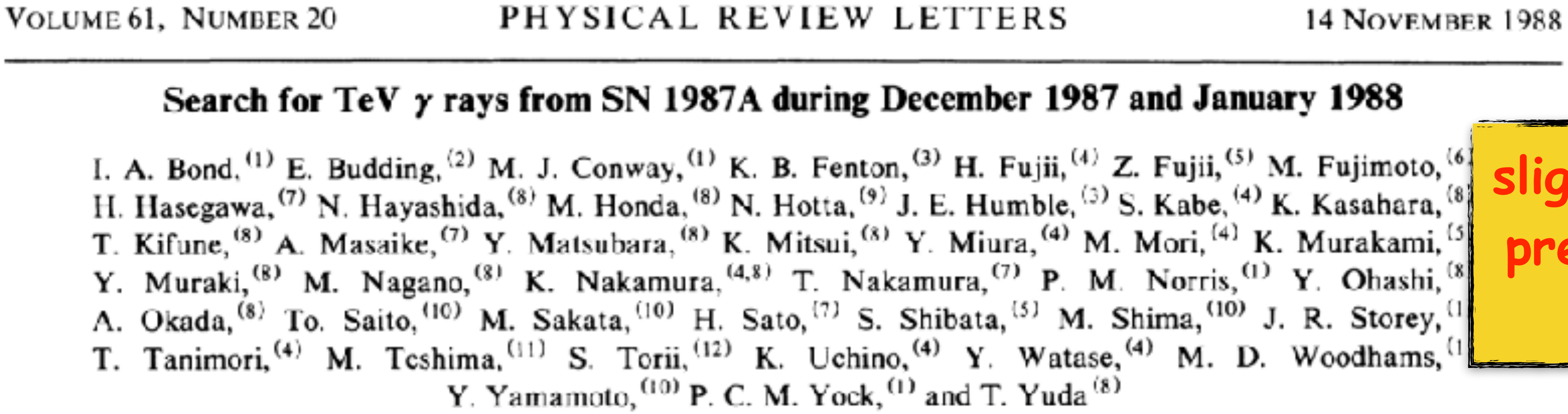

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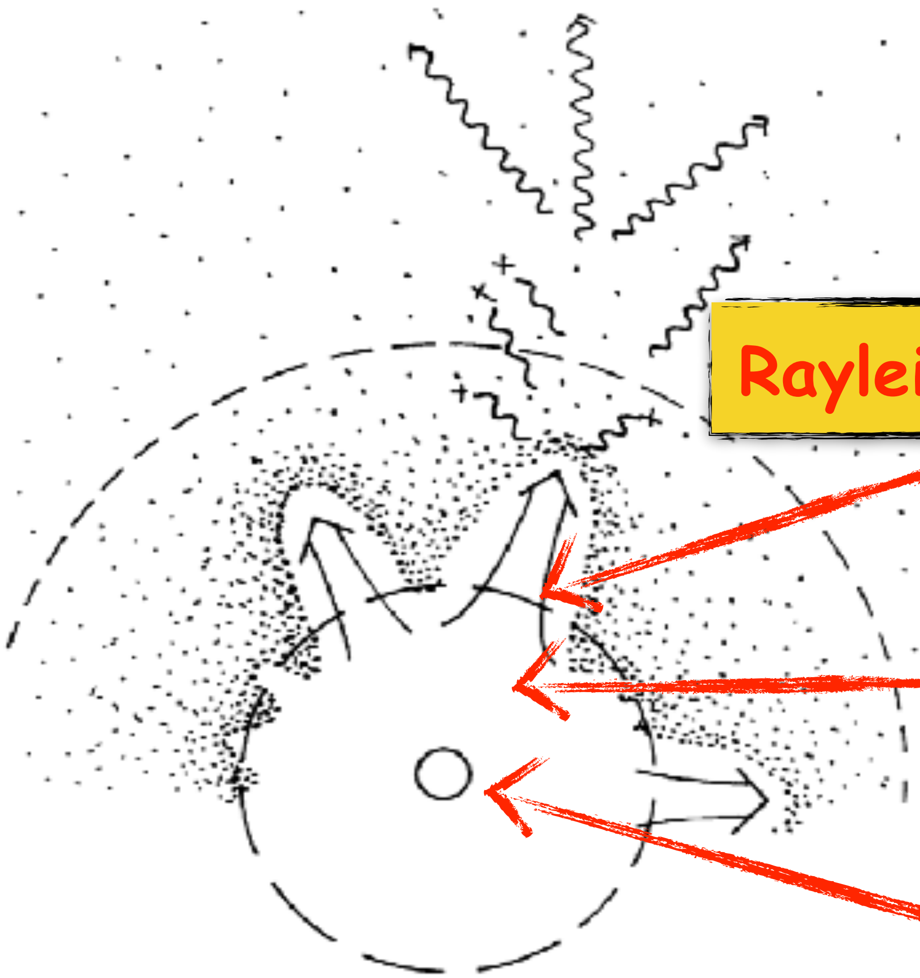

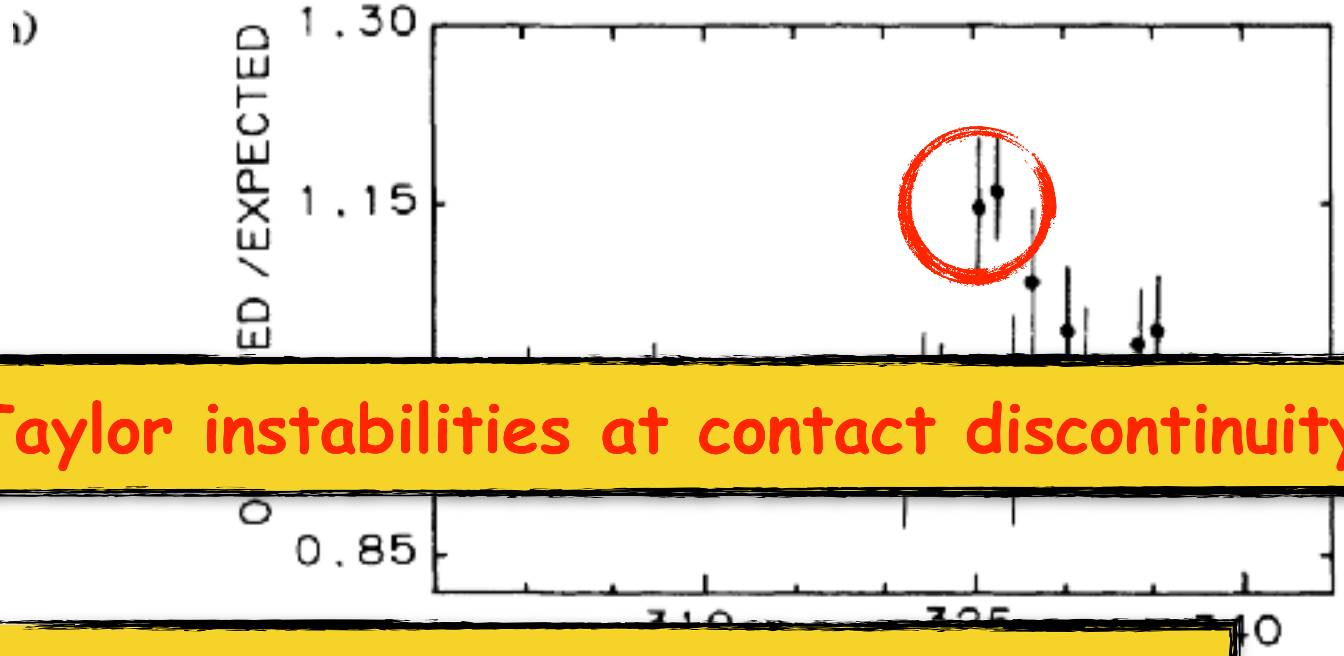

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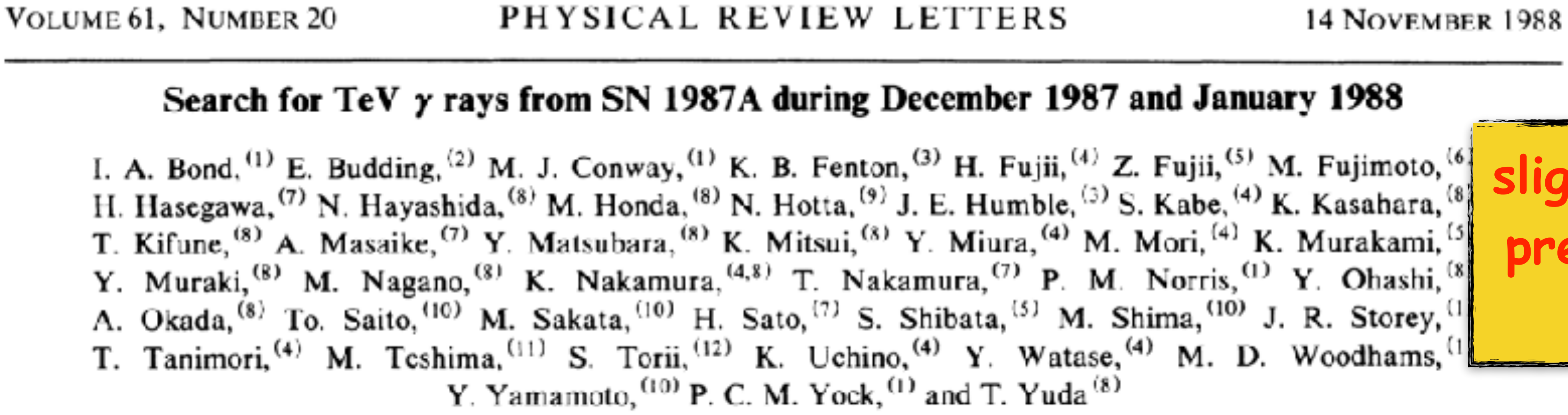

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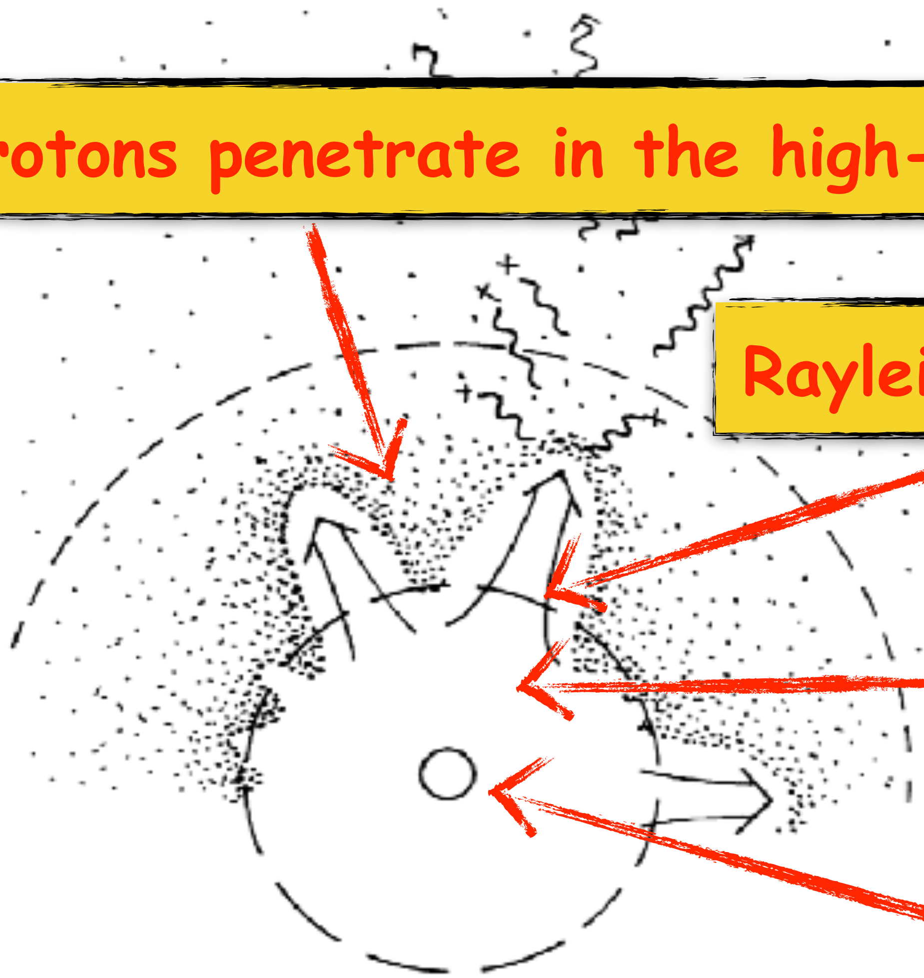

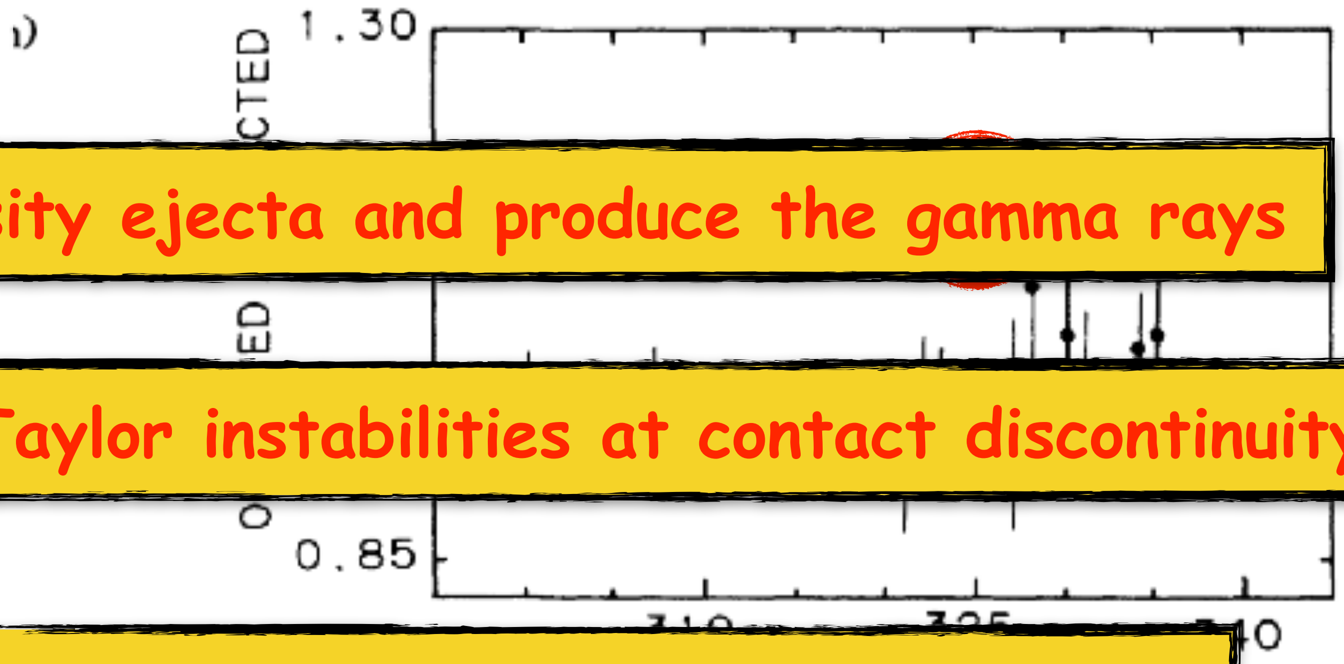

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VSB & Stanev, 1989

Gamma ray emission from young SNRs

VSB & Ptuskin, 1988, 1989a, 1989b

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acceleration takes place to larger distances from the explosion site
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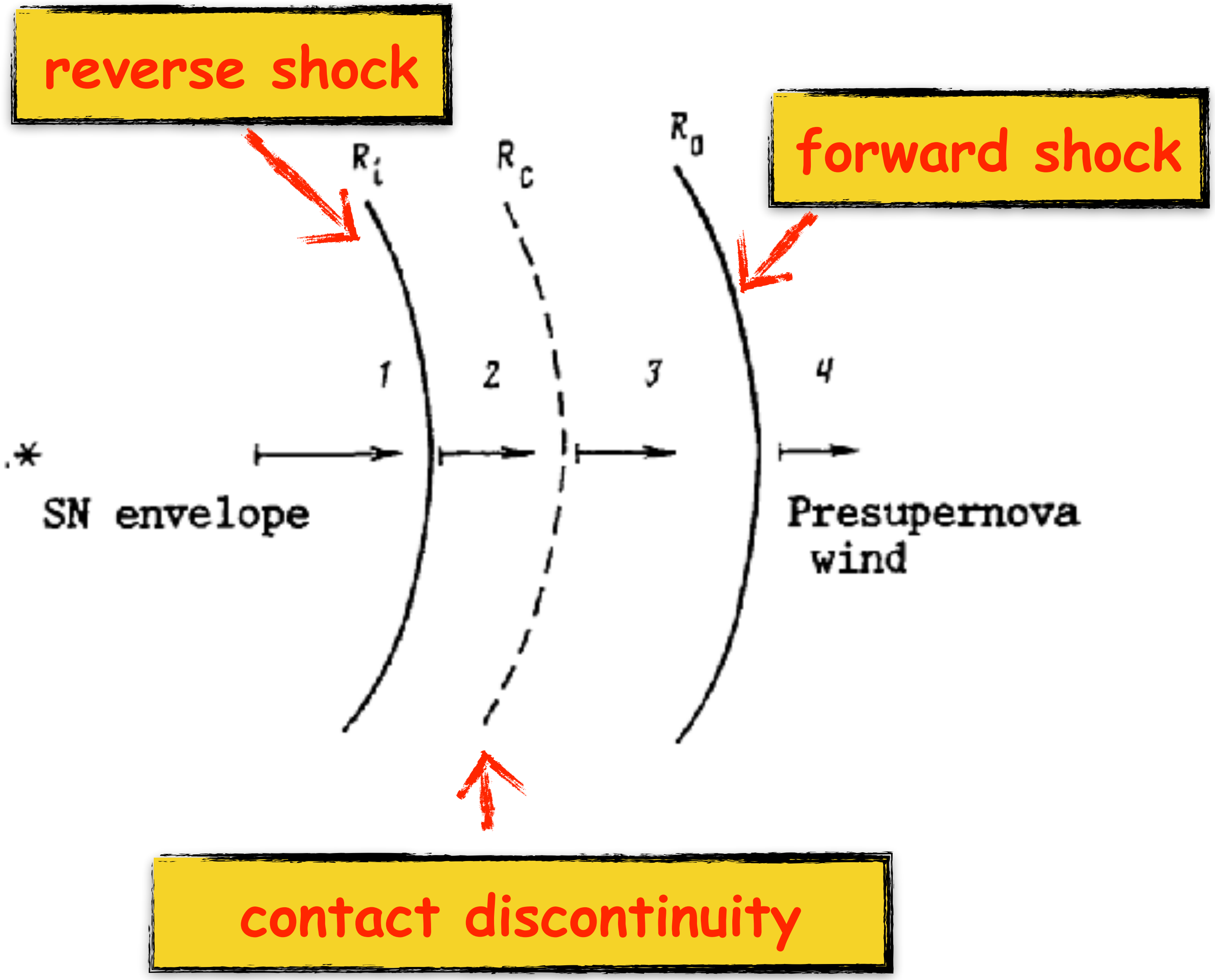

reverse shock

forward shock

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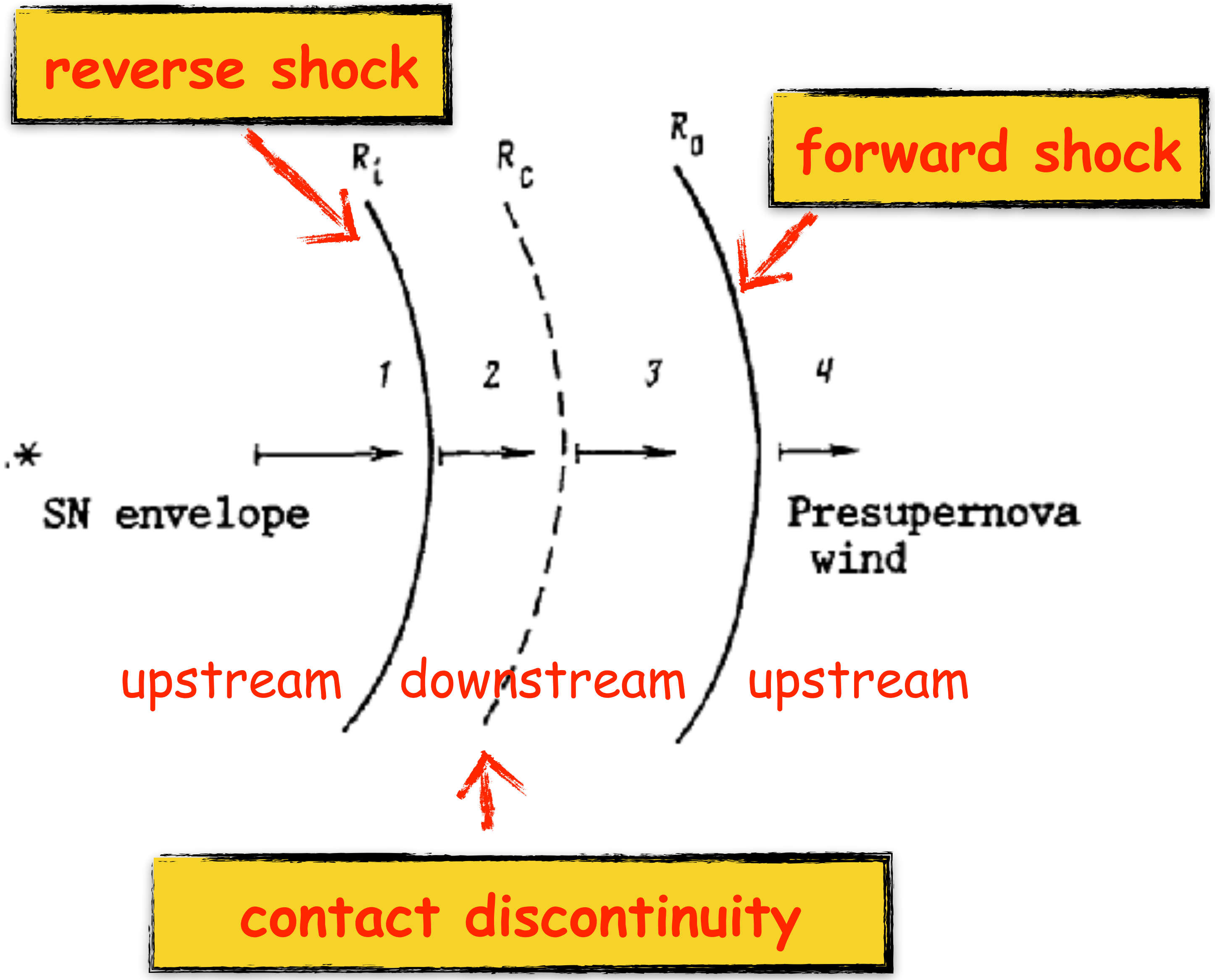

reverse shock

forward shock

upstream

downstream

upstream

contact discontinuity

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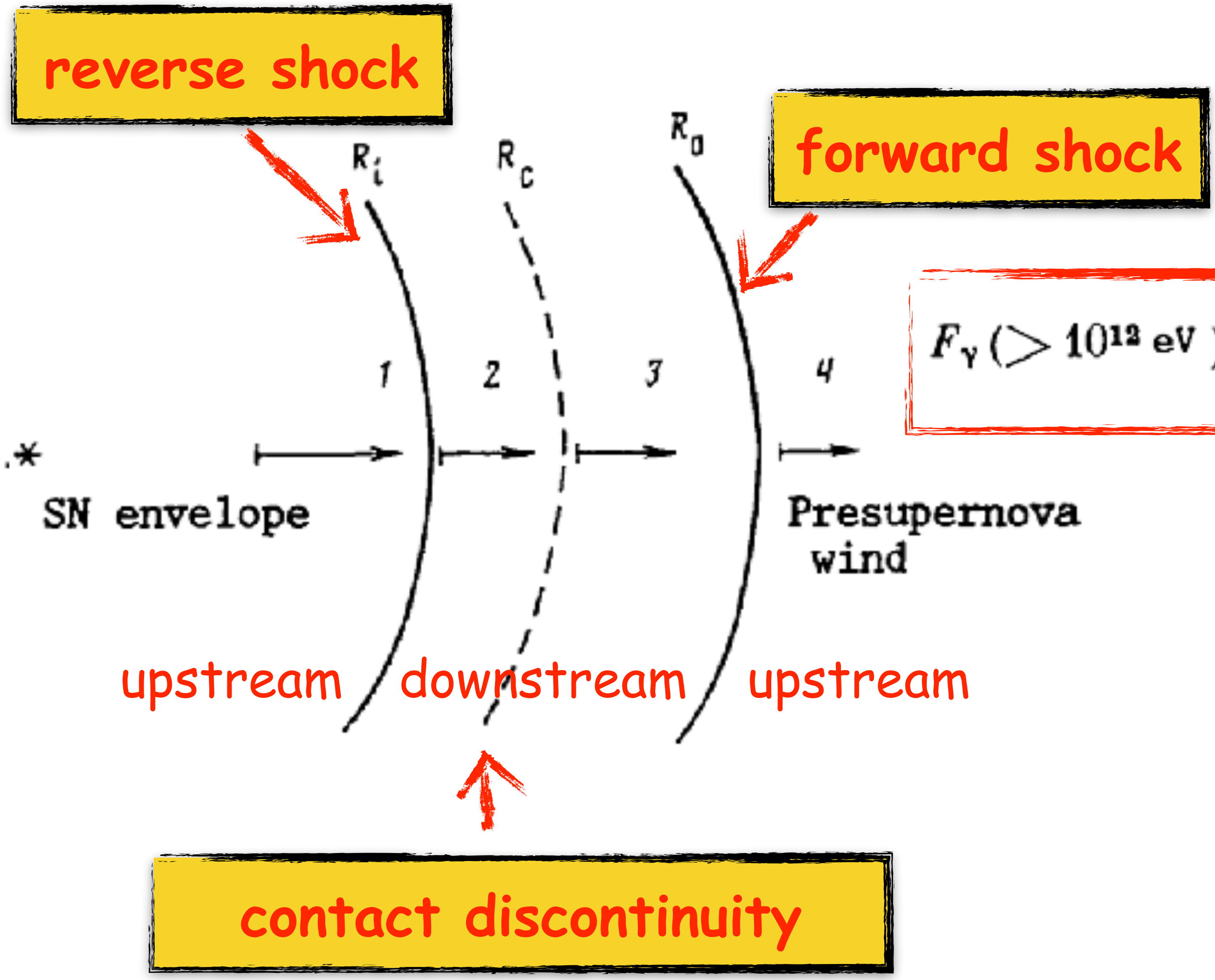

reverse shock

forward shock

upstream

downstream

upstream

contact discontinuity

adiabatic losses

$$F_\gamma(>10^{12}\ \mathrm{eV}) \approx 8.4\cdot10^{-9}\left(\frac{10\,\mathrm{kpc}}{d}\right)^2\left(\frac{t}{10^7}\right)^{-1.1}\mathrm{cm}^{-2}\cdot\mathrm{sec}^{-1}.$$

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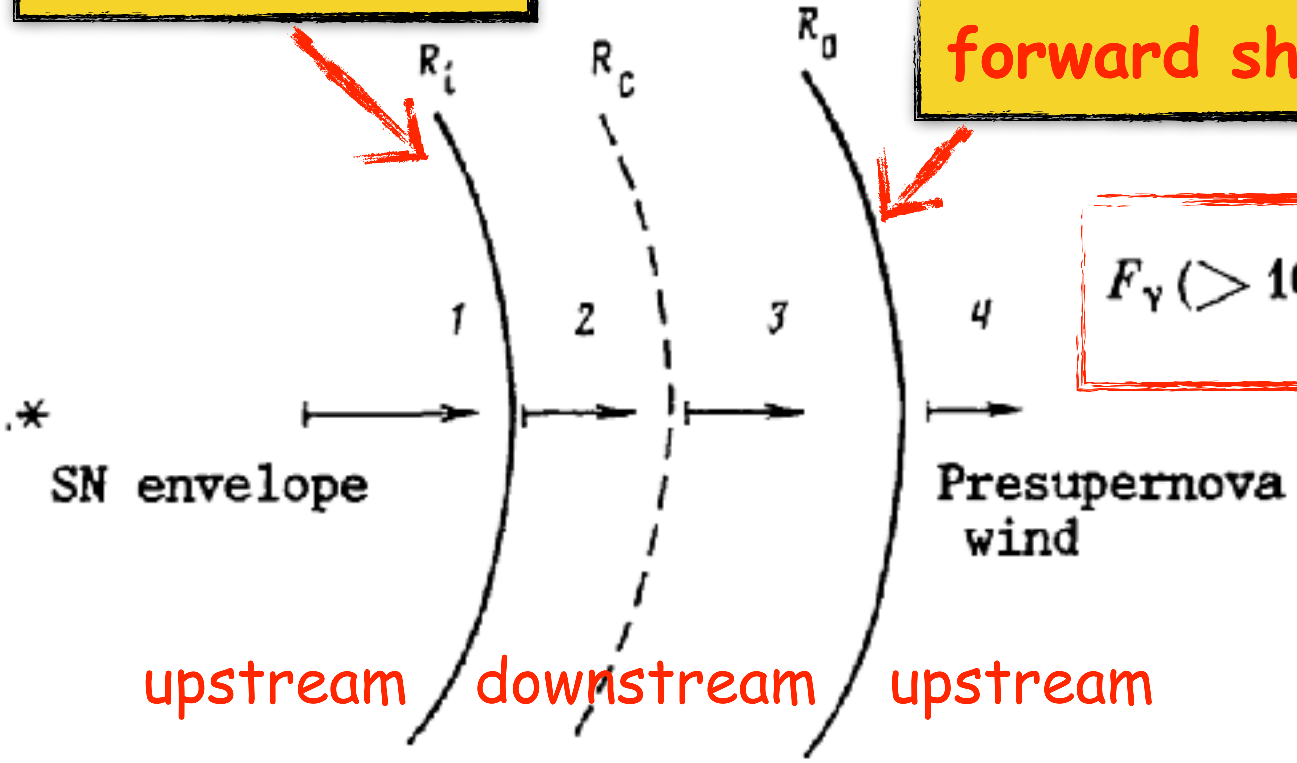

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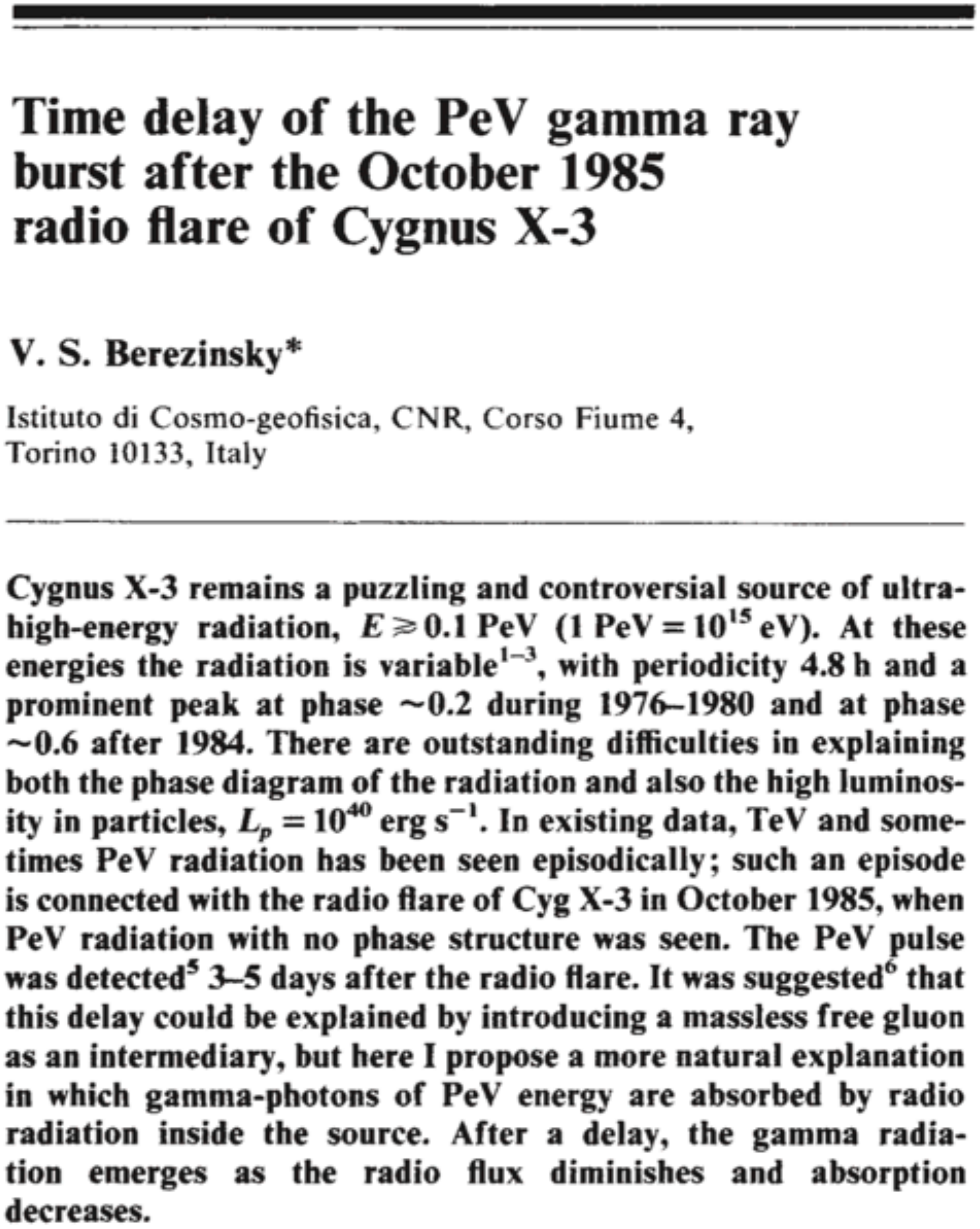
beginning of a long story who let
to the development of
sophisticated non-linear models...

Cygnus X-3

Cygnus X-3

VSB, 1988 (Nature)



Time delay of the PeV gamma ray burst after the October 1985 radio flare of Cygnus X-3

V. S. Berezinsky*

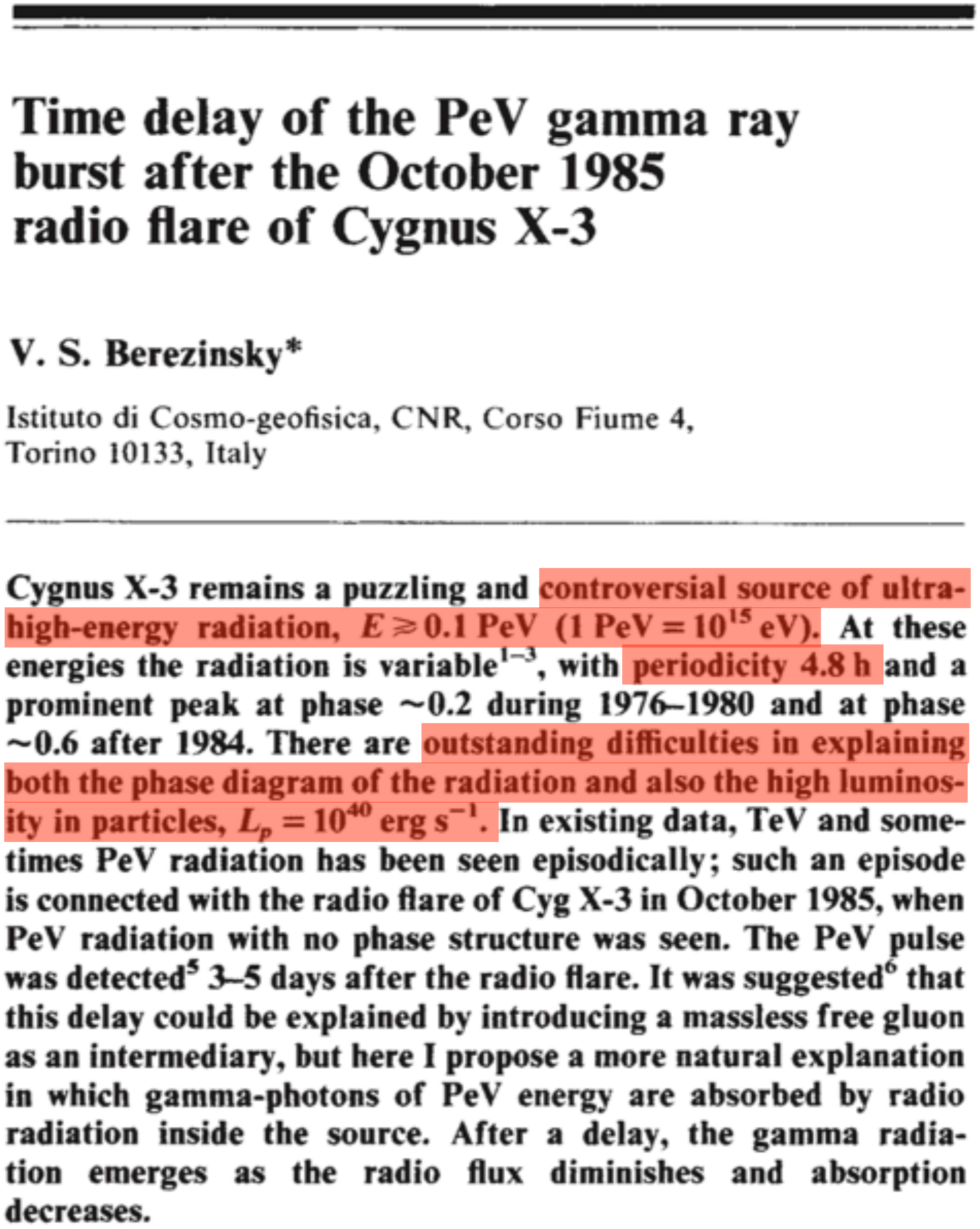
Istituto di Cosmo-geofisica, CNR, Corso Fiume 4,
Torino 10133, Italy

Cygnus X-3 remains a puzzling and controversial source of ultra-high-energy radiation, $E \geqslant 0.1$ PeV (1 PeV $= 10^{15}$ eV). At these energies the radiation is variable[1–3], with periodicity 4.8 h and a prominent peak at phase ~0.2 during 1976–1980 and at phase ~0.6 after 1984. There are outstanding difficulties in explaining both the phase diagram of the radiation and also the high luminosity in particles, $L_p = 10^{40}$ erg s^{-1}. In existing data, TeV and sometimes PeV radiation has been seen episodically; such an episode is connected with the radio flare of Cyg X-3 in October 1985, when PeV radiation with no phase structure was seen. The PeV pulse was detected[5] 3–5 days after the radio flare. It was suggested[6] that this delay could be explained by introducing a massless free gluon as an intermediary, but here I propose a more natural explanation in which gamma-photons of PeV energy are absorbed by radio radiation inside the source. After a delay, the gamma radiation emerges as the radio flux diminishes and absorption decreases.

also VSB 1985, VSB, Castagnoli & Galeotti 1986

Cygnus X-3

VSB, 1988 (Nature)



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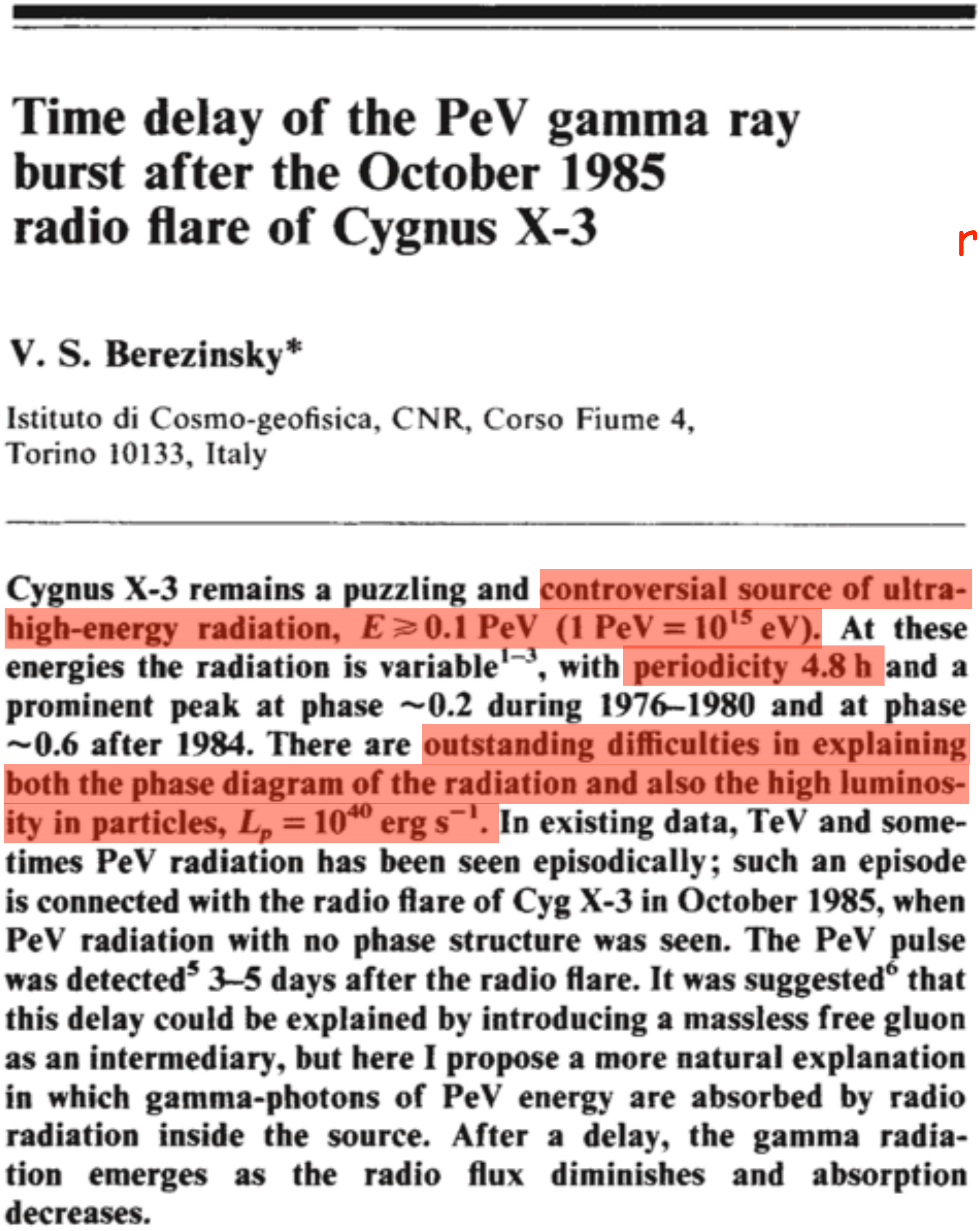

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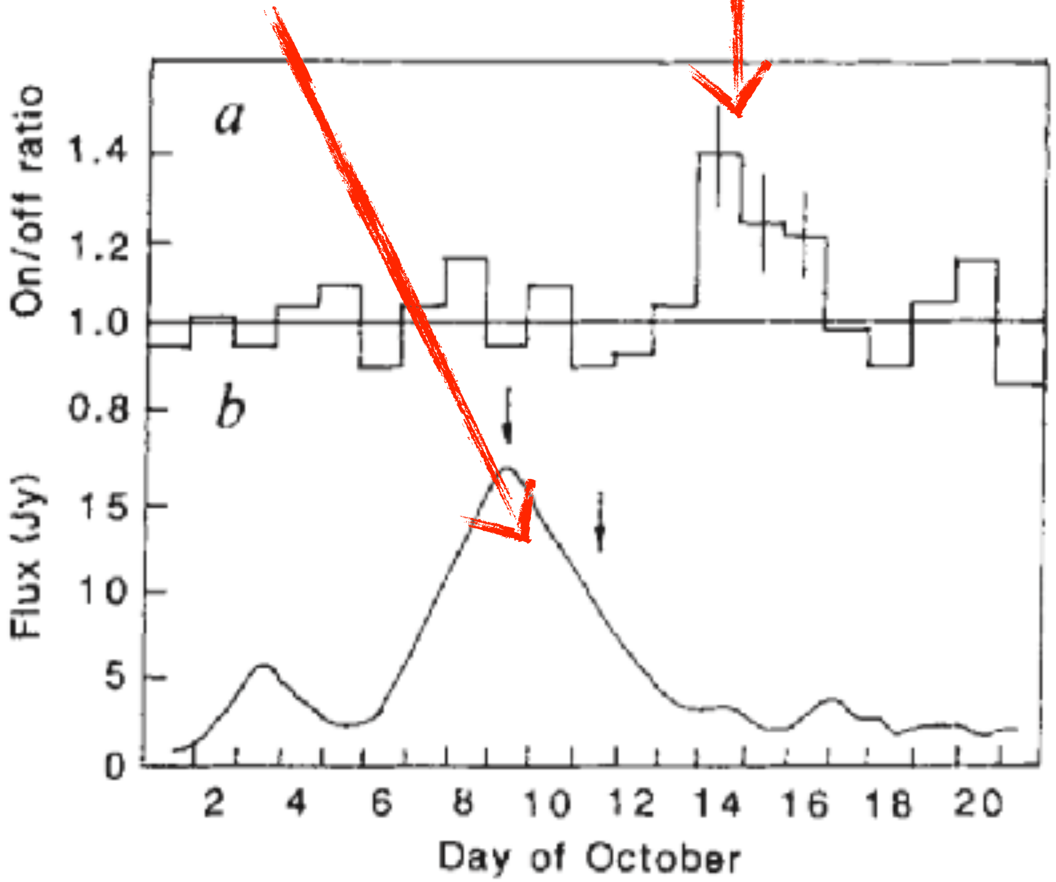
PeV radiation emerges

radio emission diminishes



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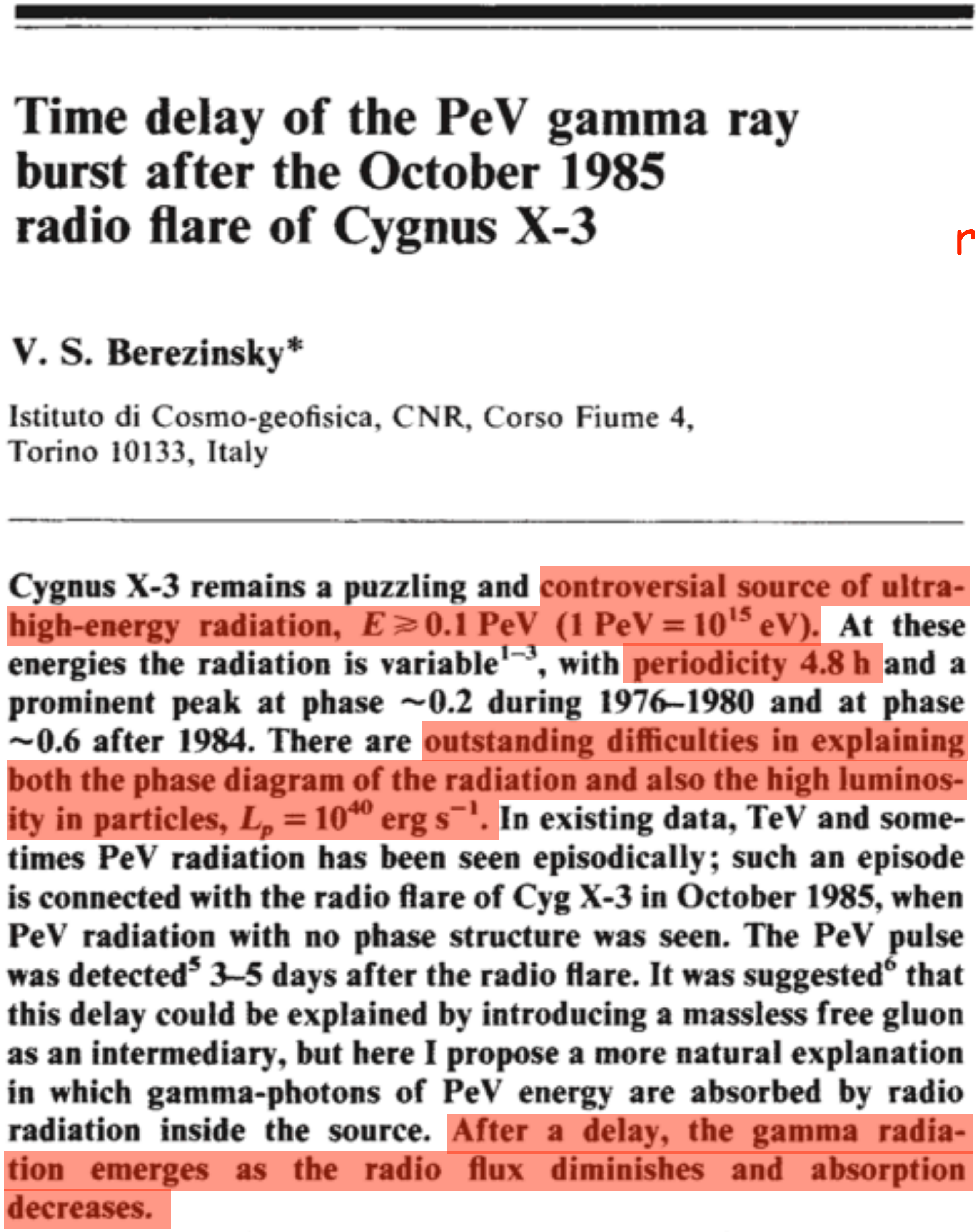

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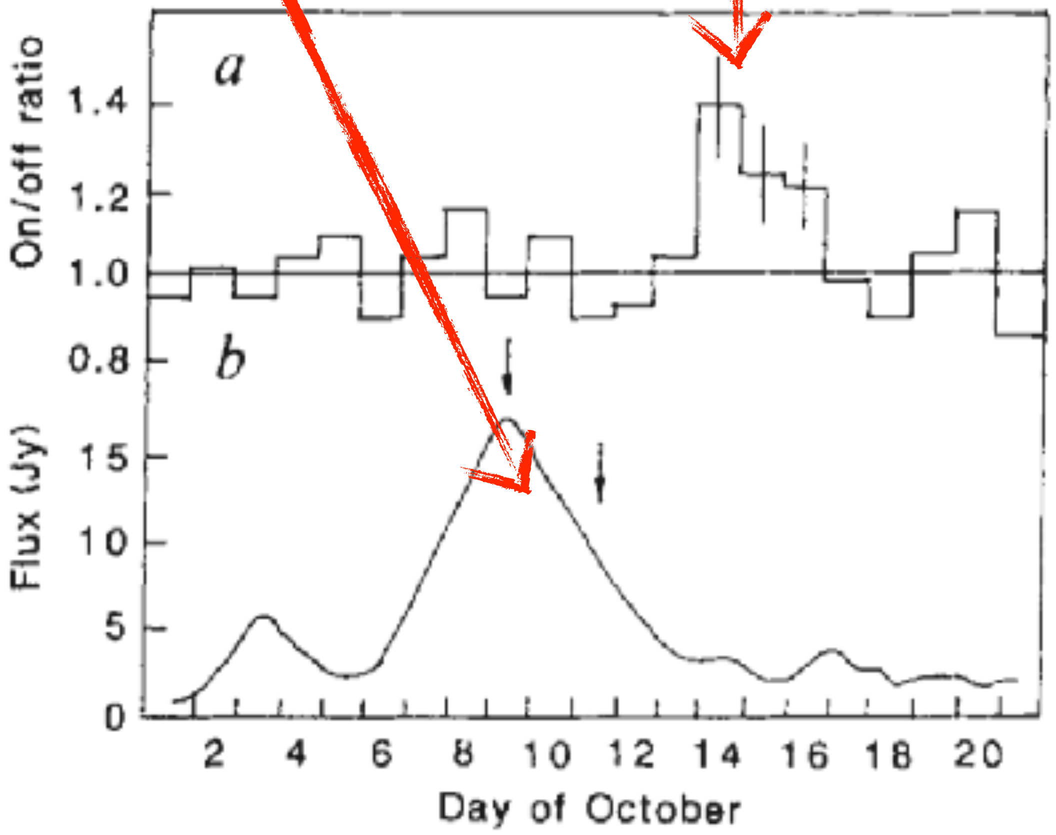
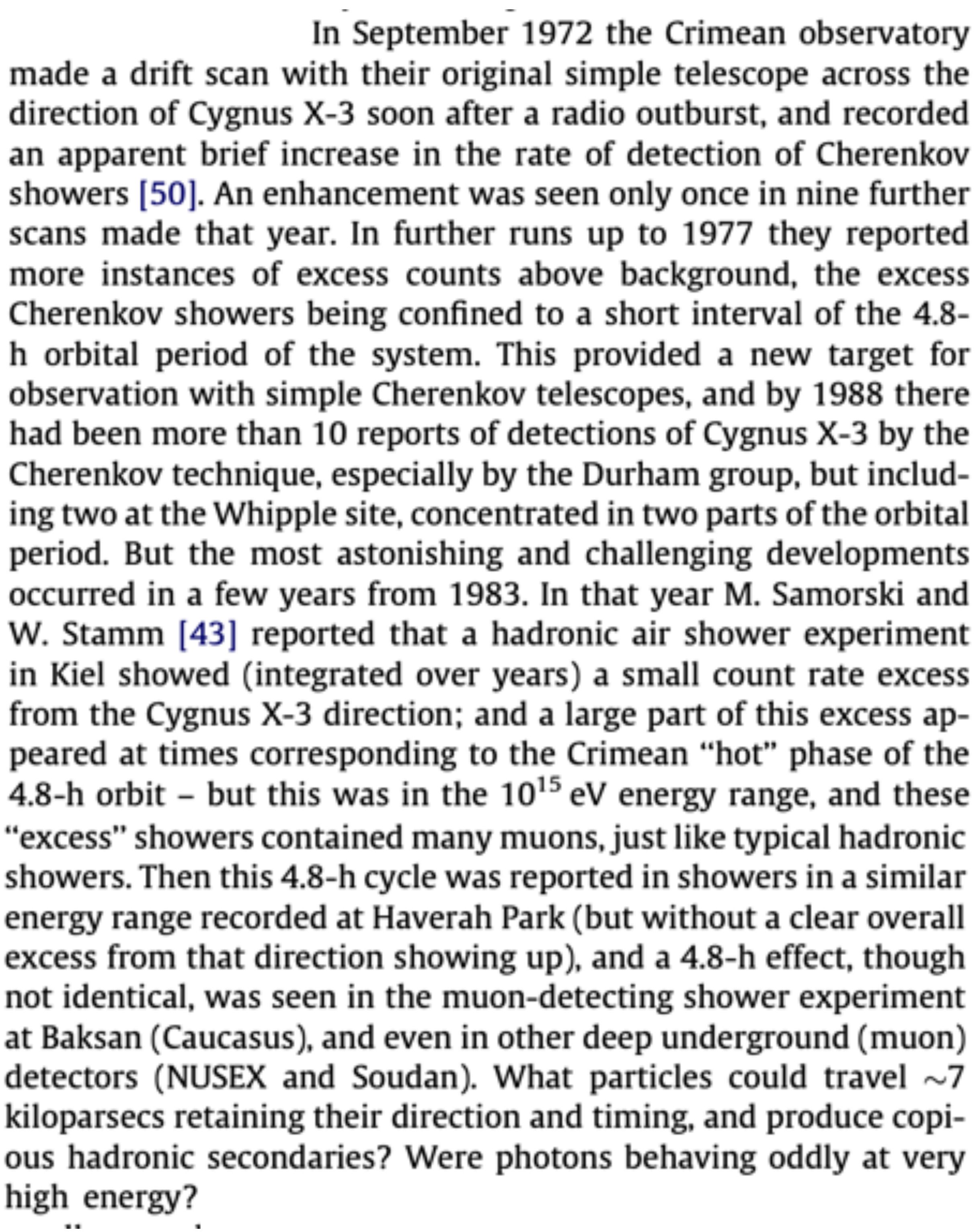


absorption of PeV gammas inside the source

also VSB 1985, VSB, Castagnoli & Galeotti 1986

Cygnus X-3

A. M. Hillas, "Evolution of ground-based gamma-ray astronomy from the early days to the Cherenkov Telescope Arrays" (2013)



In September 1972 the Crimean observatory made a drift scan with their original simple telescope across the direction of Cygnus X-3 soon after a radio outburst, and recorded an apparent brief increase in the rate of detection of Cherenkov showers [50]. An enhancement was seen only once in nine further scans made that year. In further runs up to 1977 they reported more instances of excess counts above background, the excess Cherenkov showers being confined to a short interval of the 4.8-h orbital period of the system. This provided a new target for observation with simple Cherenkov telescopes, and by 1988 there had been more than 10 reports of detections of Cygnus X-3 by the Cherenkov technique, especially by the Durham group, but including two at the Whipple site, concentrated in two parts of the orbital period. But the most astonishing and challenging developments occurred in a few years from 1983. In that year M. Samorski and W. Stamm [43] reported that a hadronic air shower experiment in Kiel showed (integrated over years) a small count rate excess from the Cygnus X-3 direction; and a large part of this excess appeared at times corresponding to the Crimean "hot" phase of the 4.8-h orbit – but this was in the 10^{15} eV energy range, and these "excess" showers contained many muons, just like typical hadronic showers. Then this 4.8-h cycle was reported in showers in a similar energy range recorded at Haverah Park (but without a clear overall excess from that direction showing up), and a 4.8-h effect, though not identical, was seen in the muon-detecting shower experiment at Baksan (Caucasus), and even in other deep underground (muon) detectors (NUSEX and Soudan). What particles could travel ~7 kiloparsecs retaining their direction and timing, and produce copious hadronic secondaries? Were photons behaving oddly at very high energy?

Cygnus X-3

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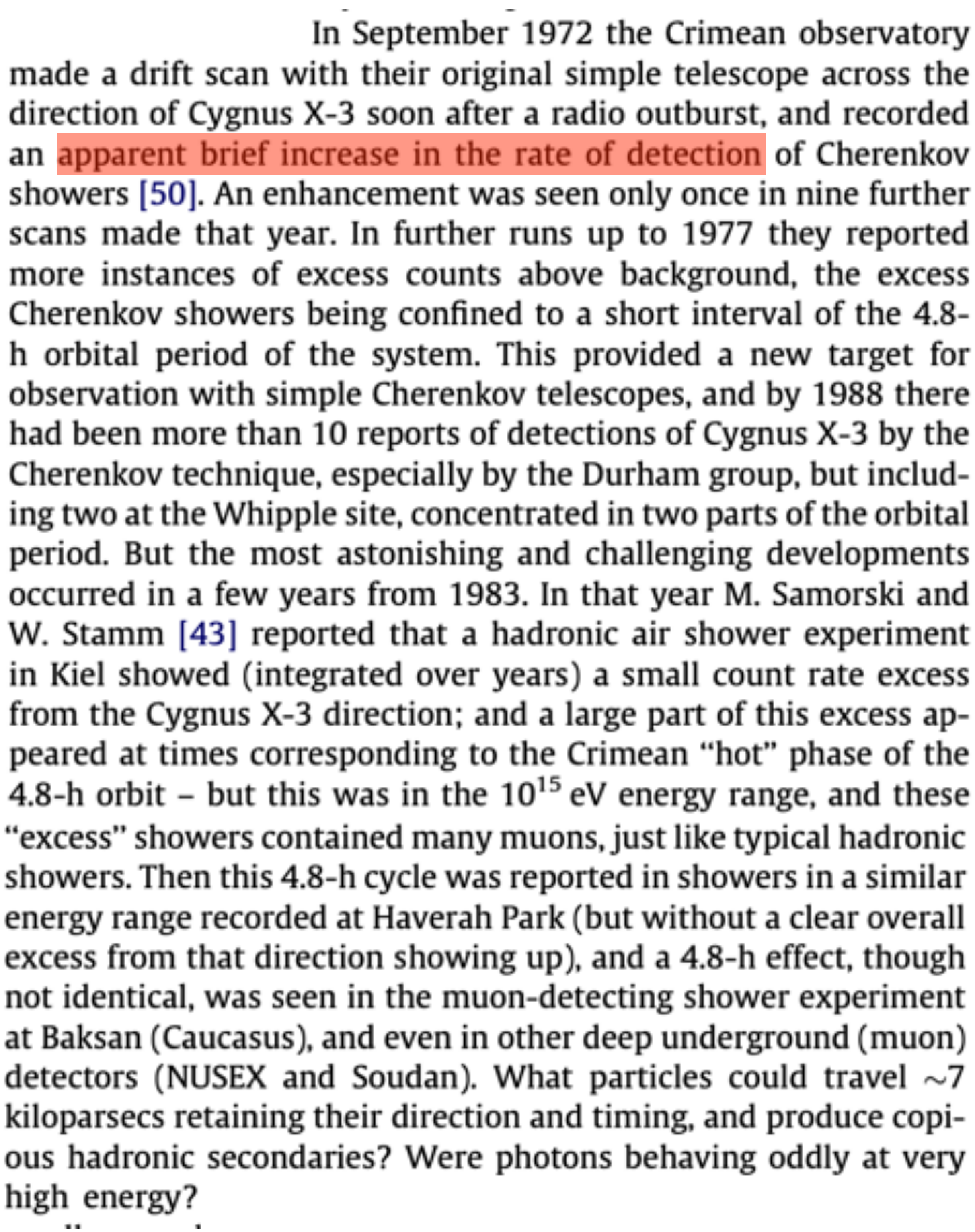

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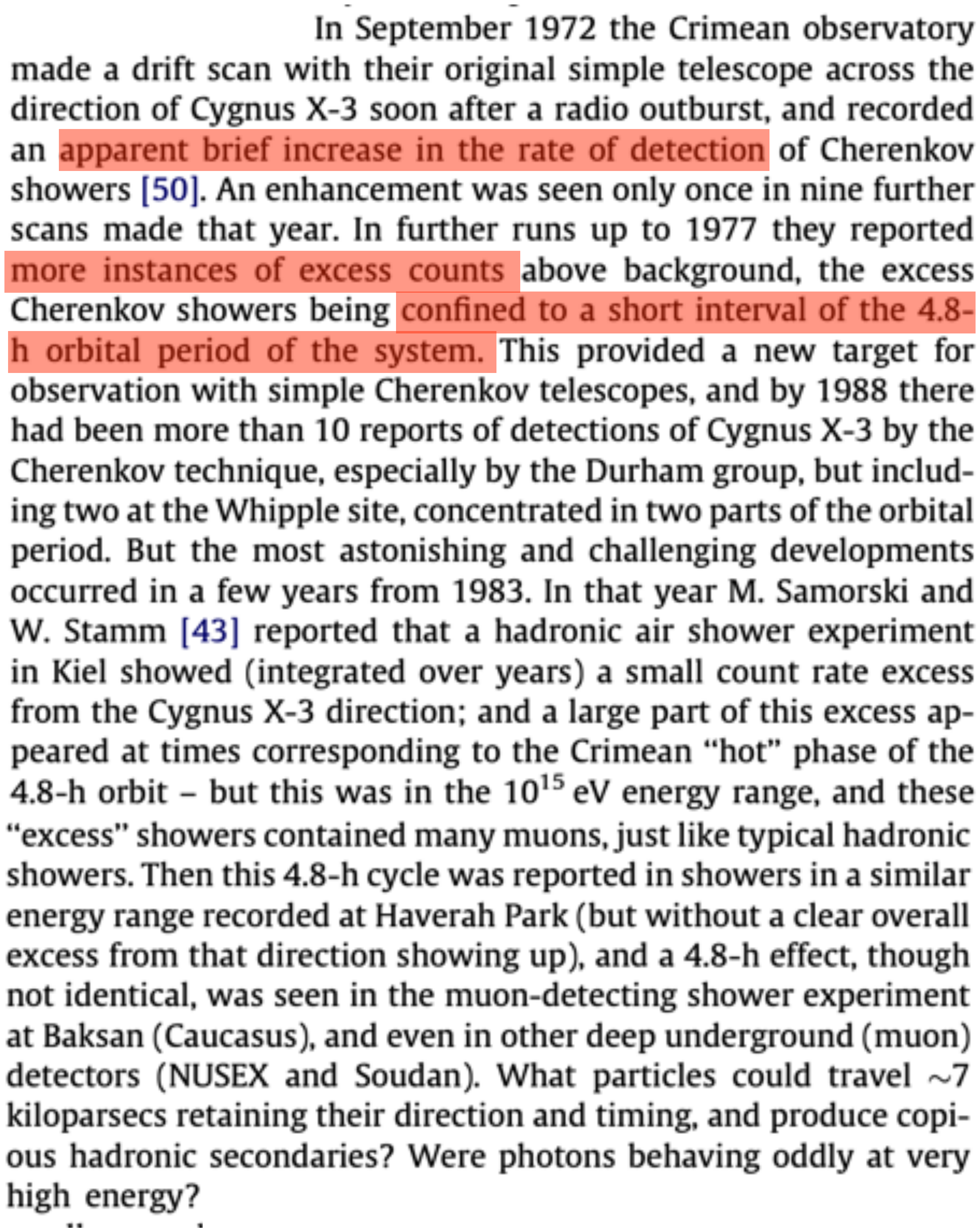

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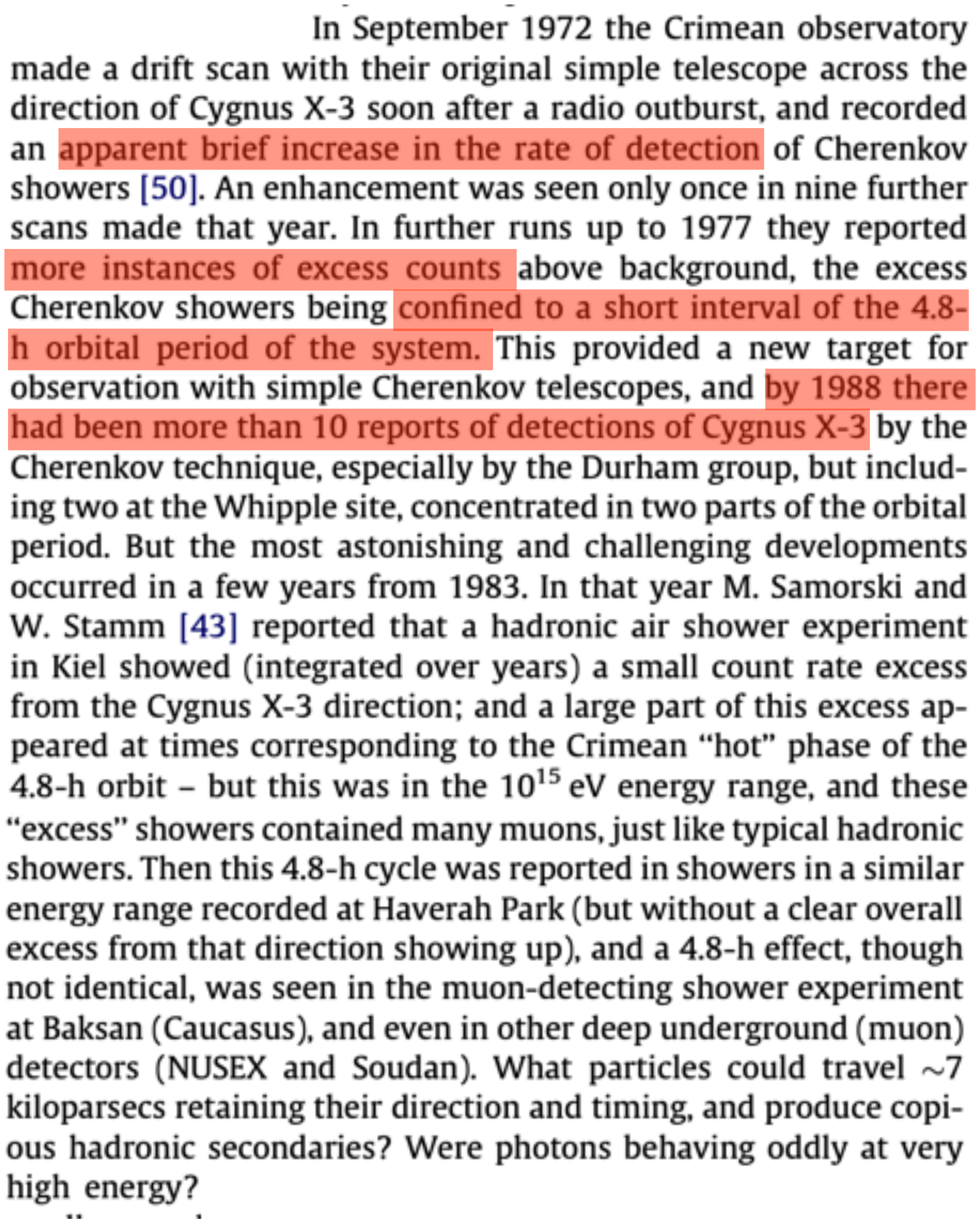

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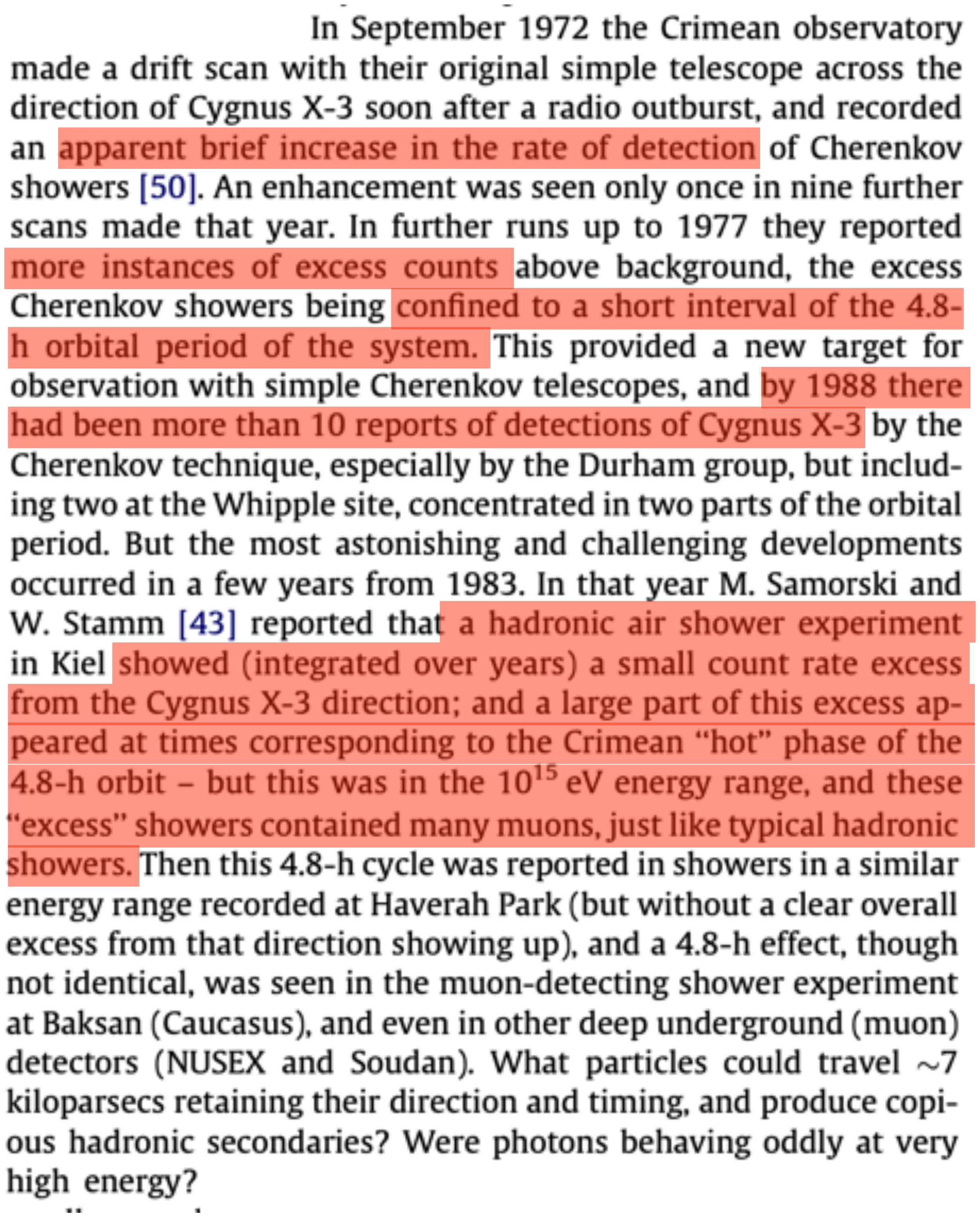

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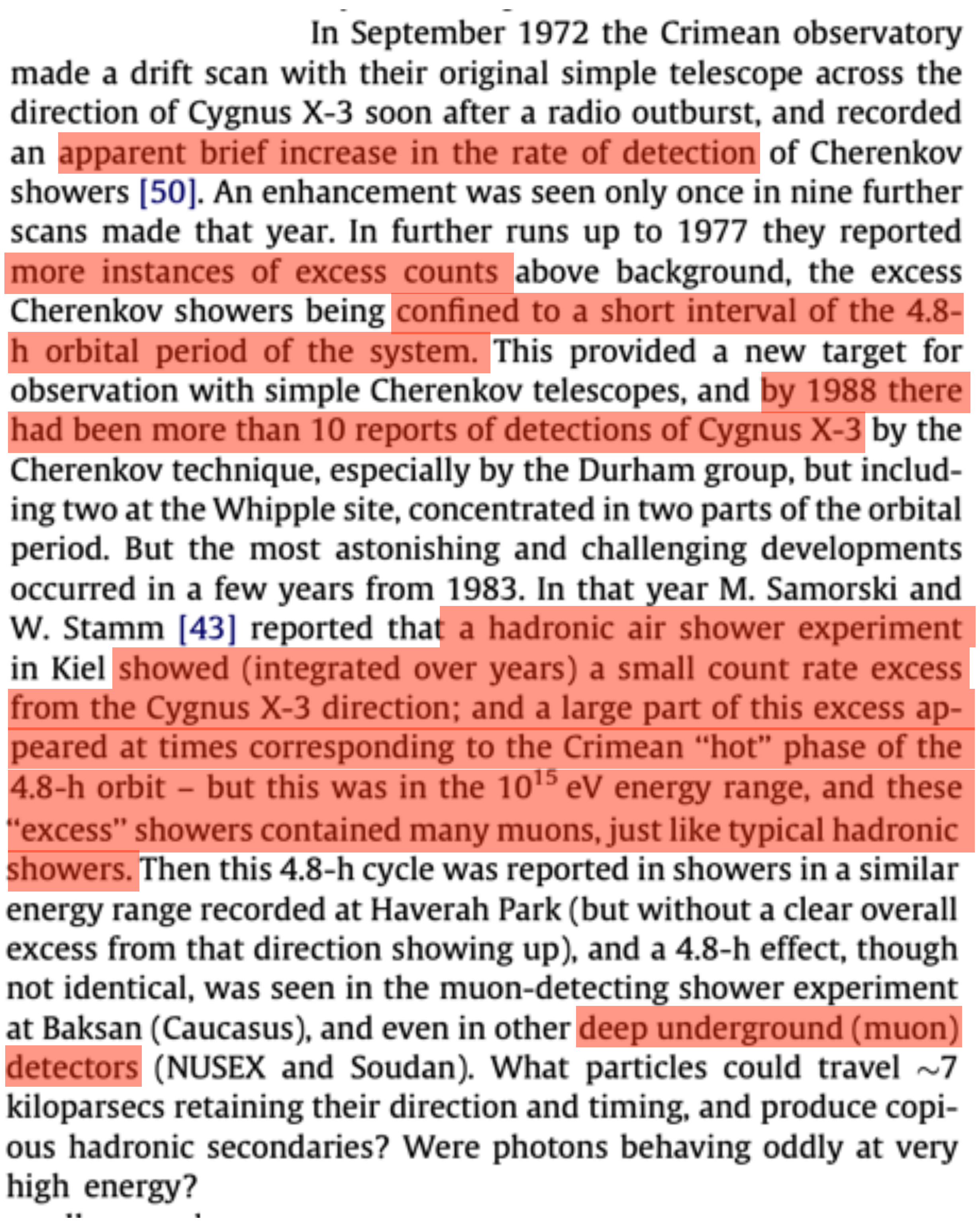

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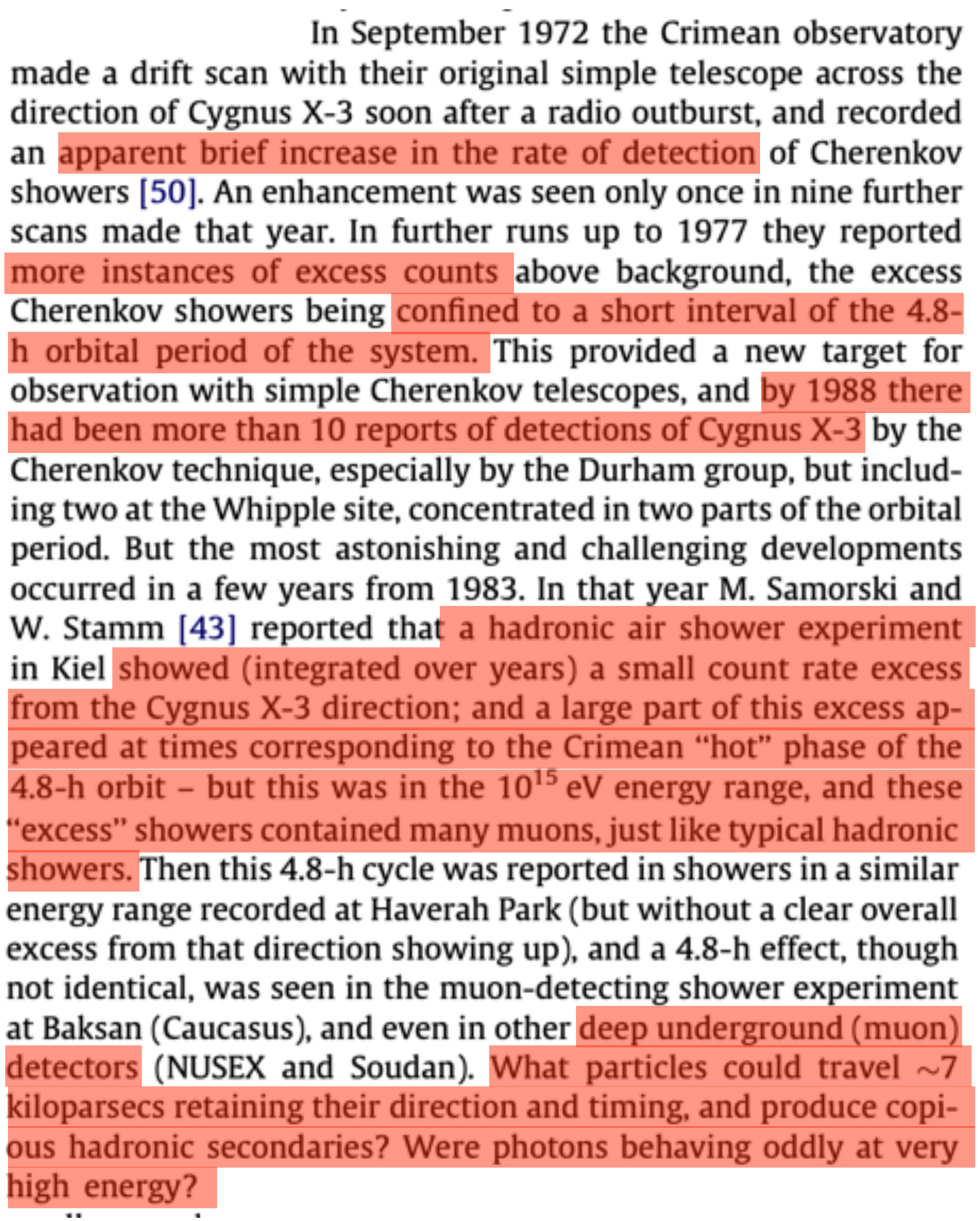

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VSB, Ellis, Ioffe 1986

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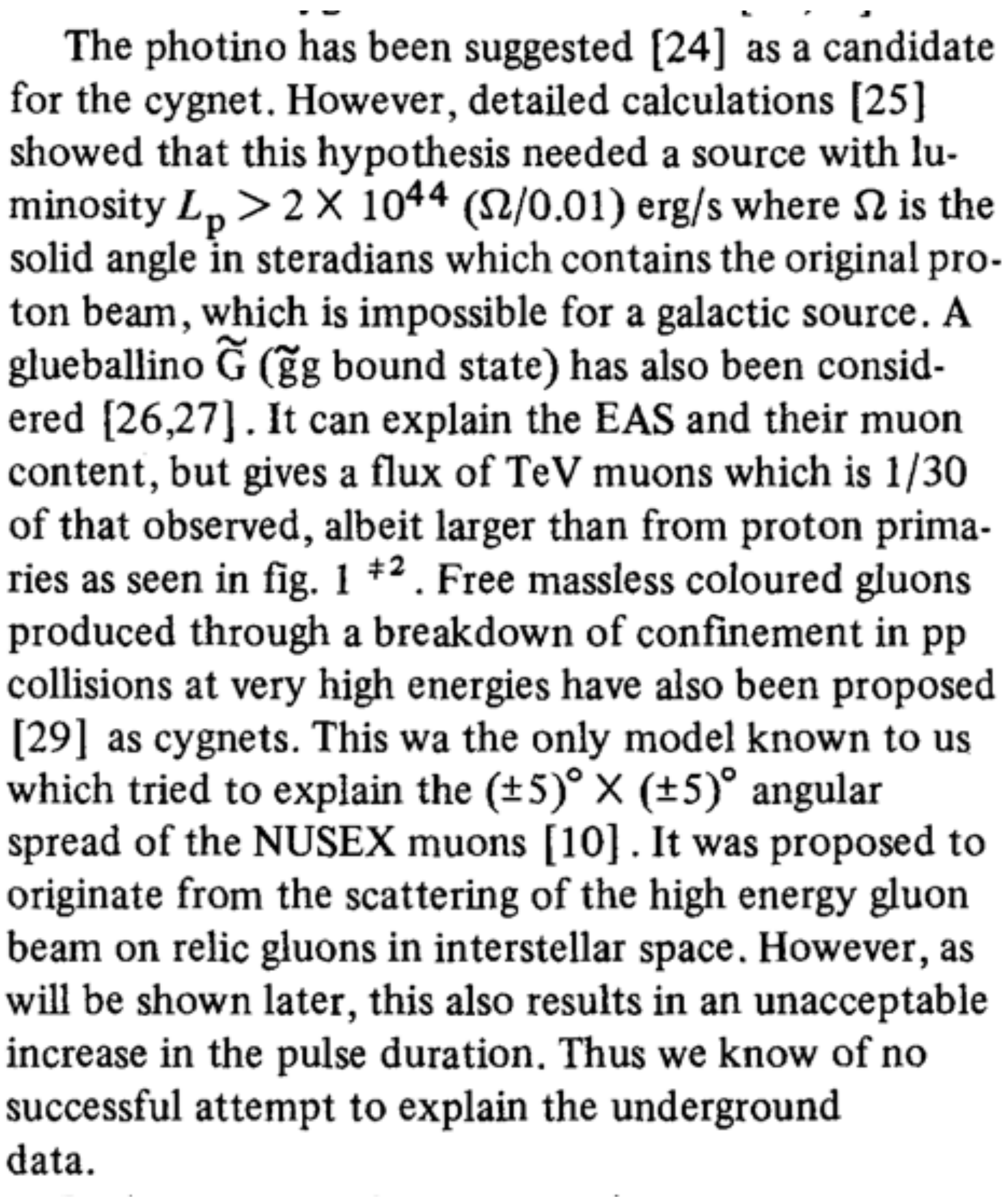

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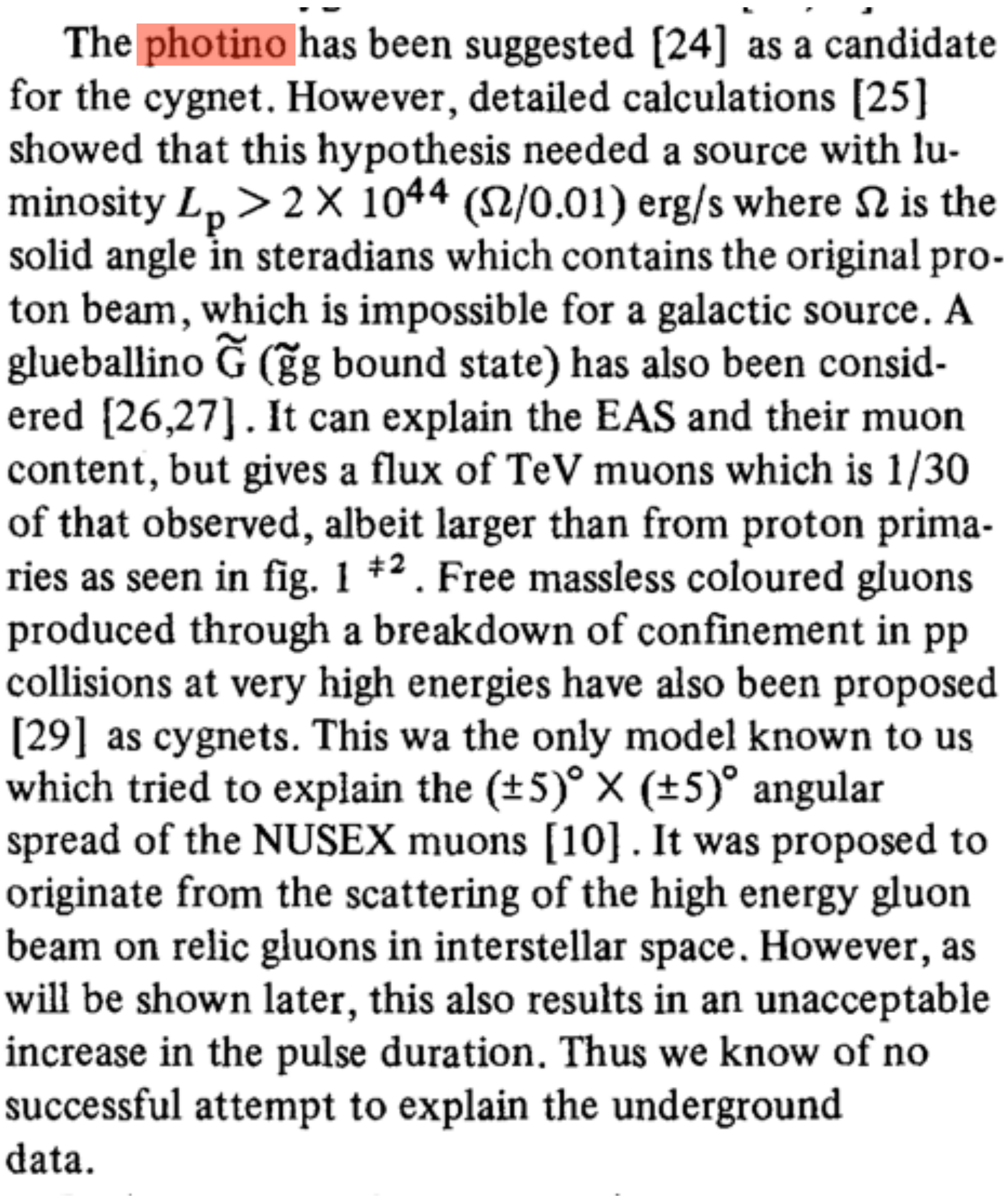

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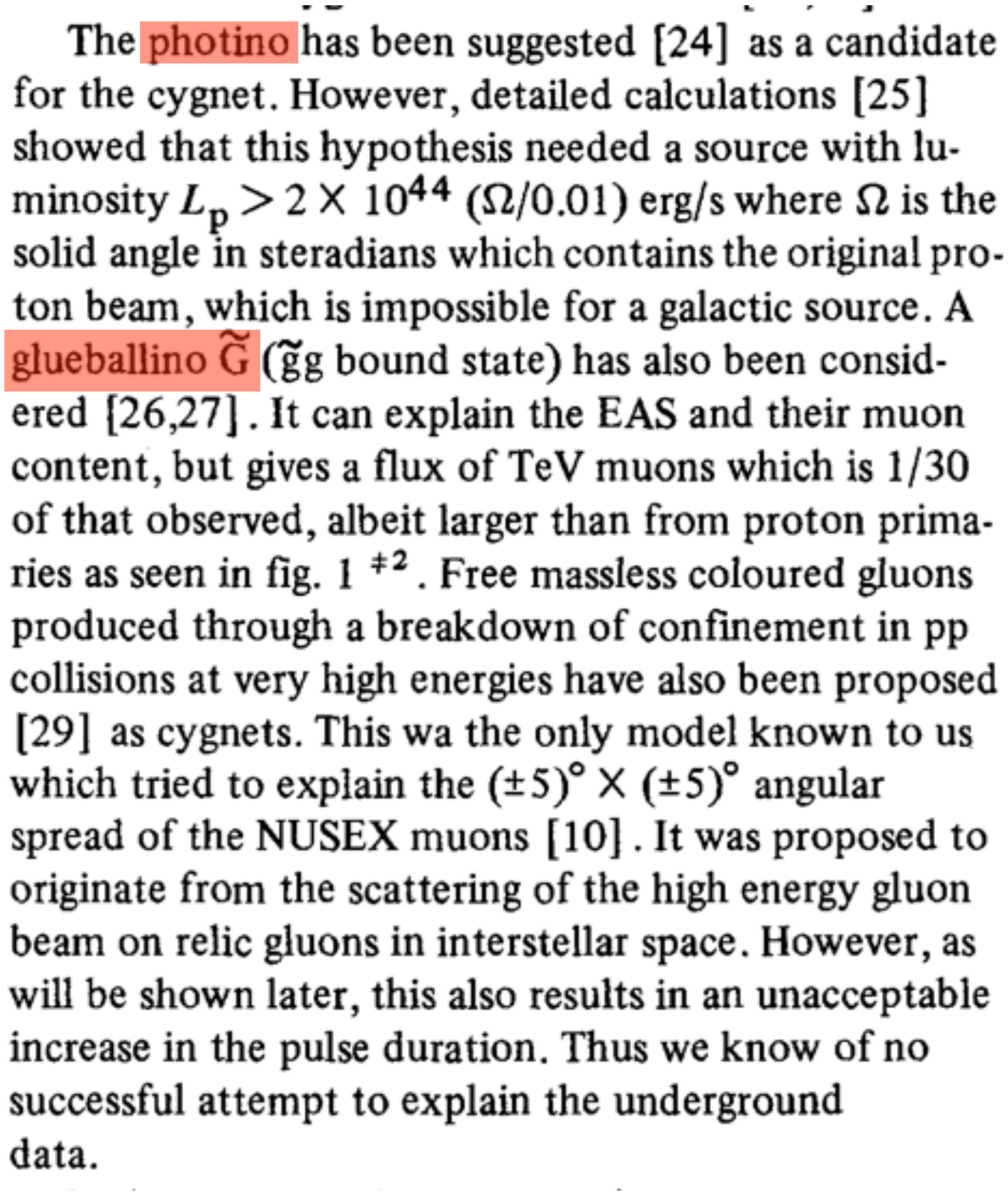

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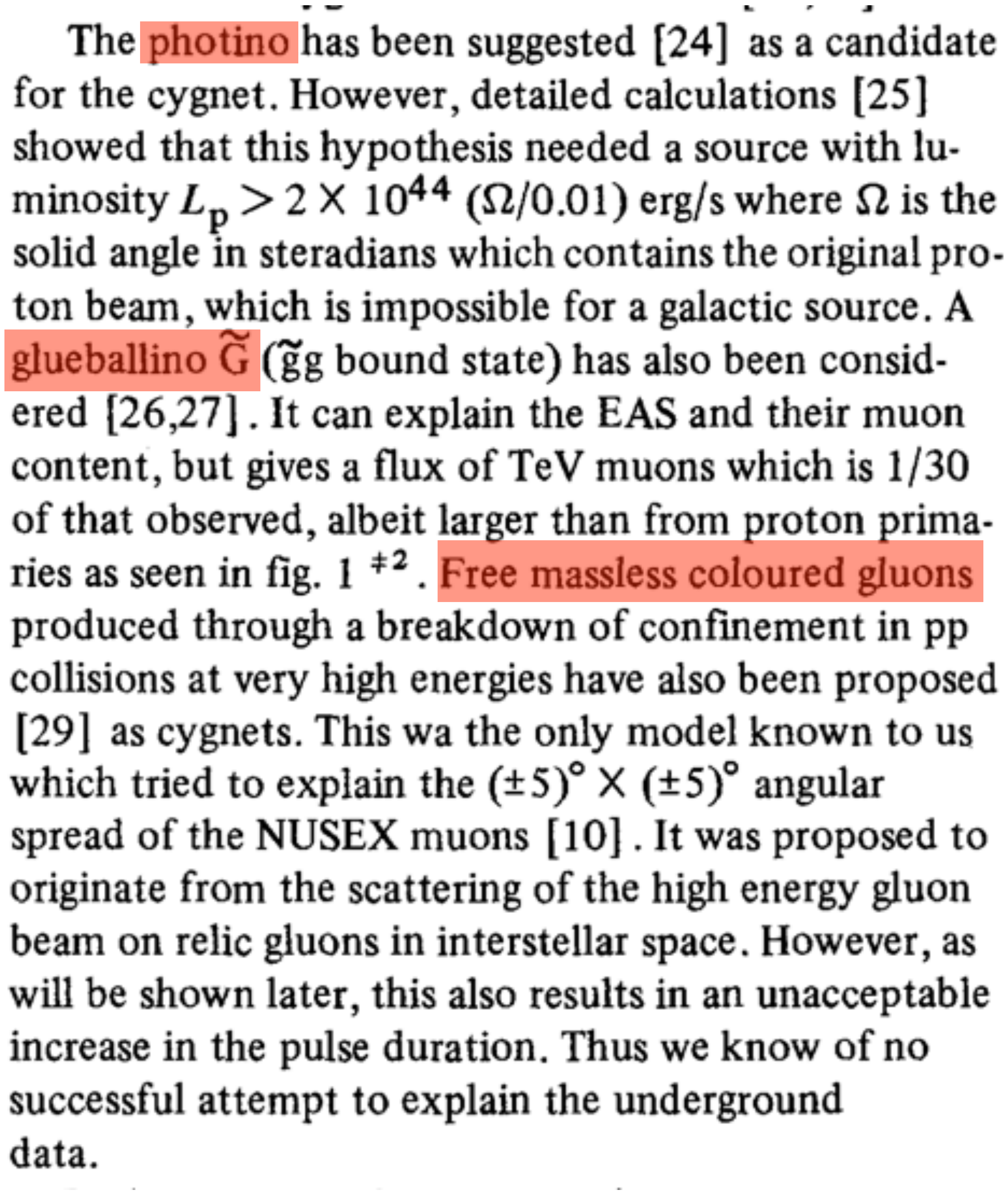

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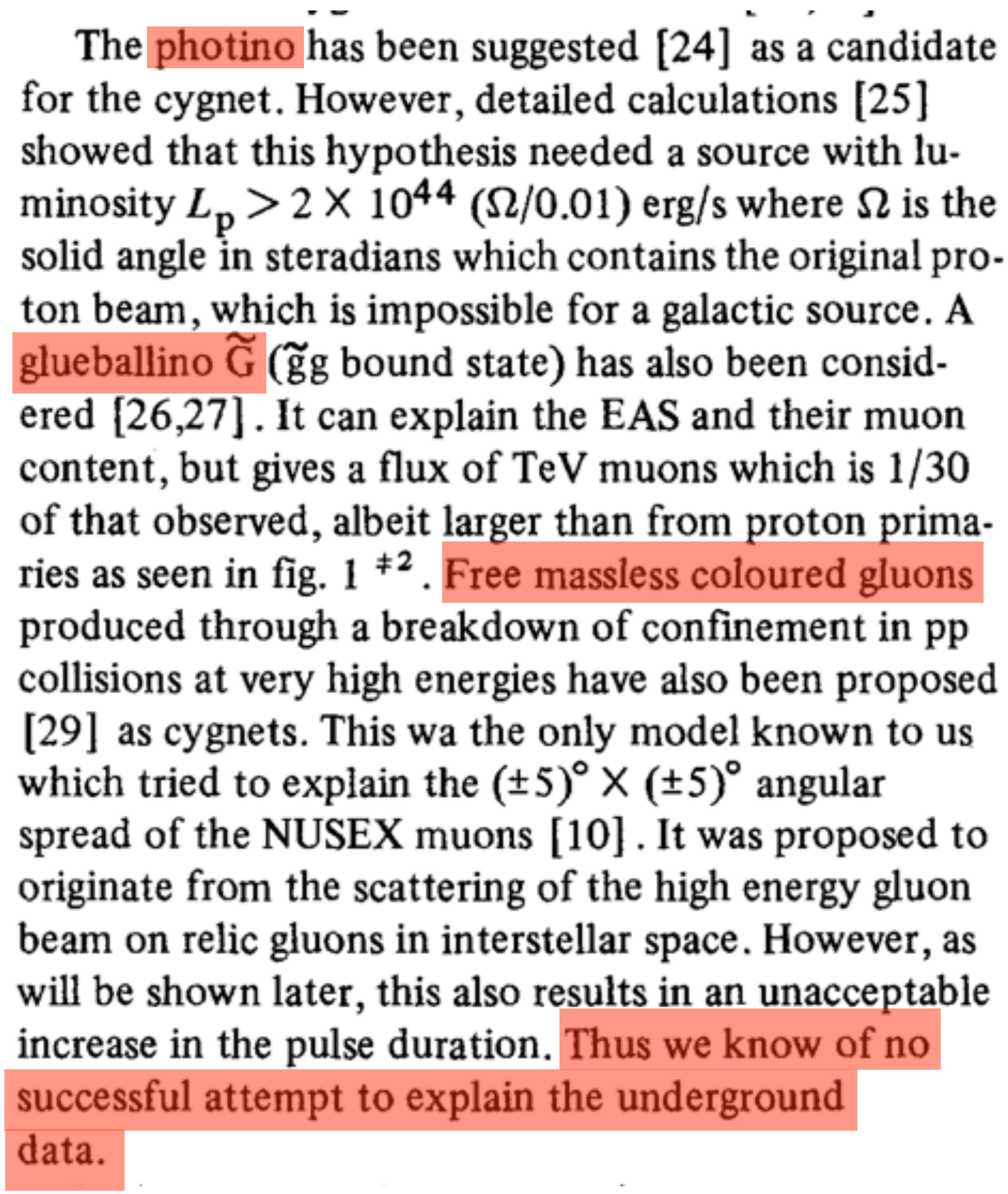

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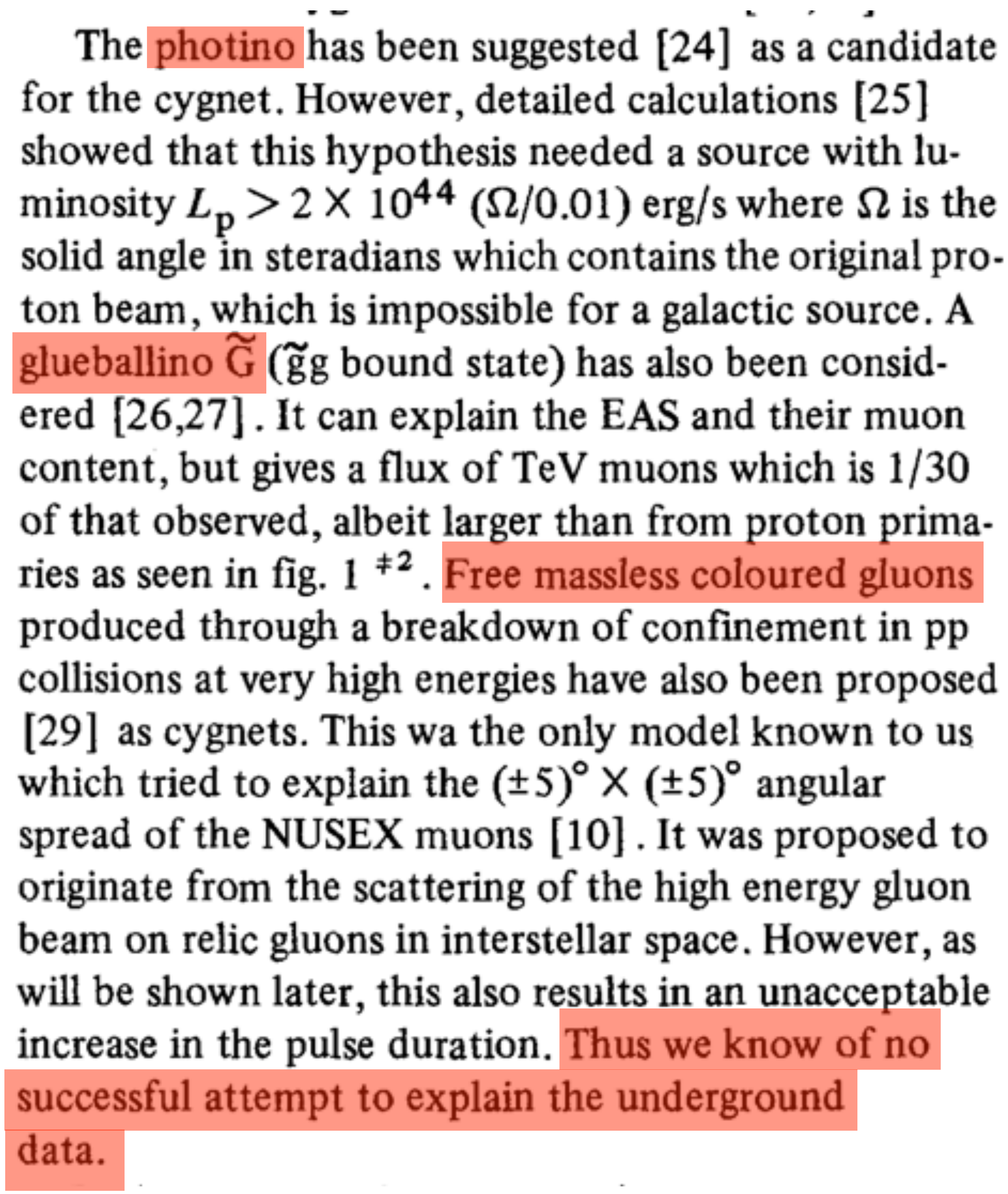

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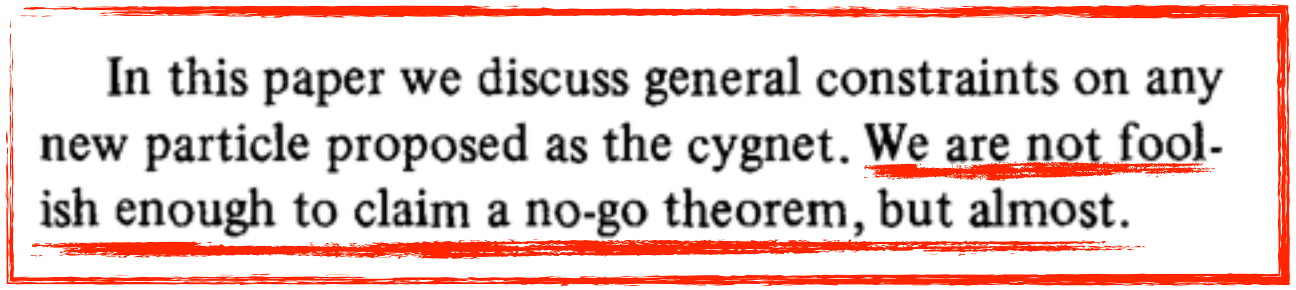

In this paper we discuss general constraints on any new particle proposed as the cygnet. We are not foolish enough to claim a no-go theorem, but almost.

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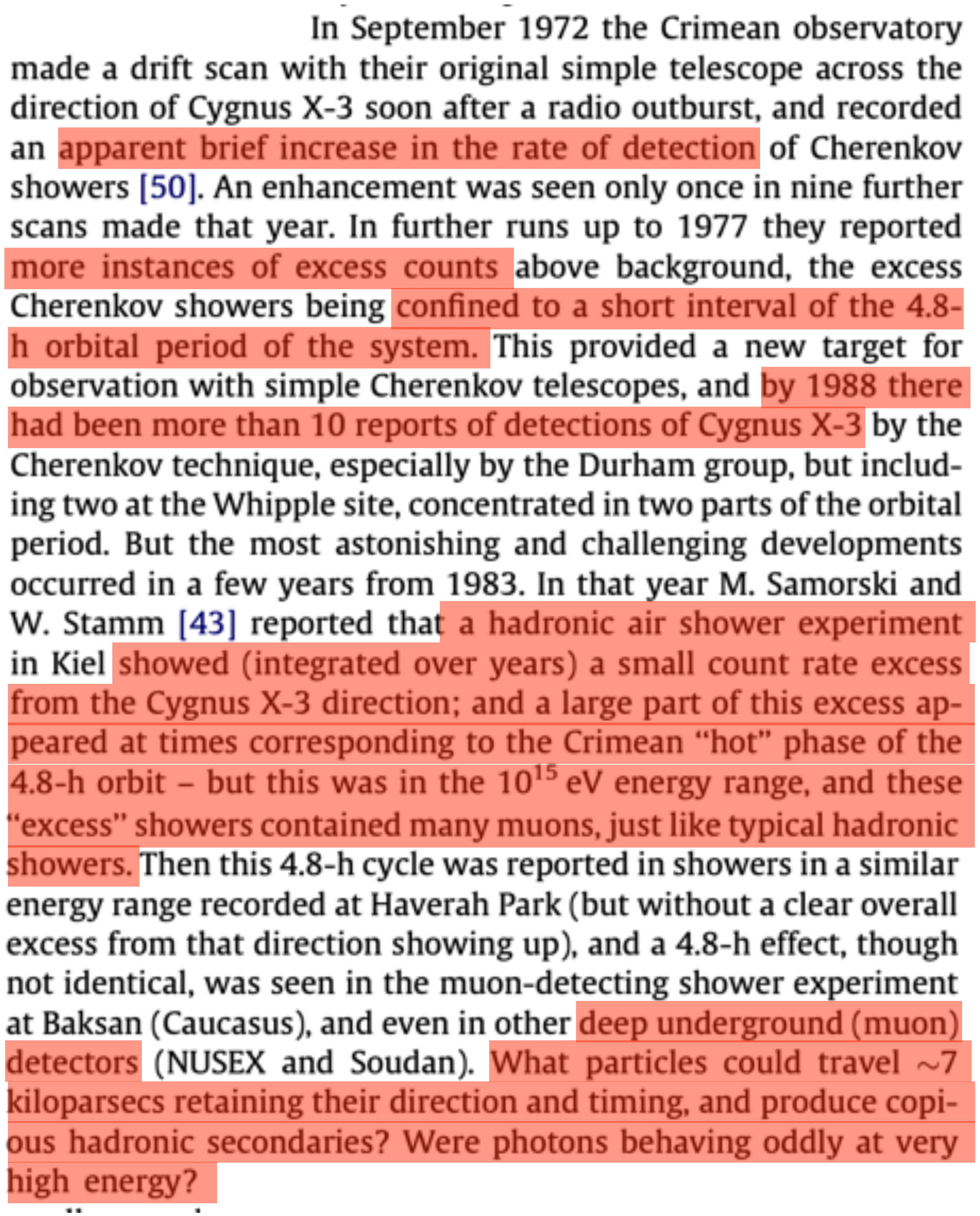

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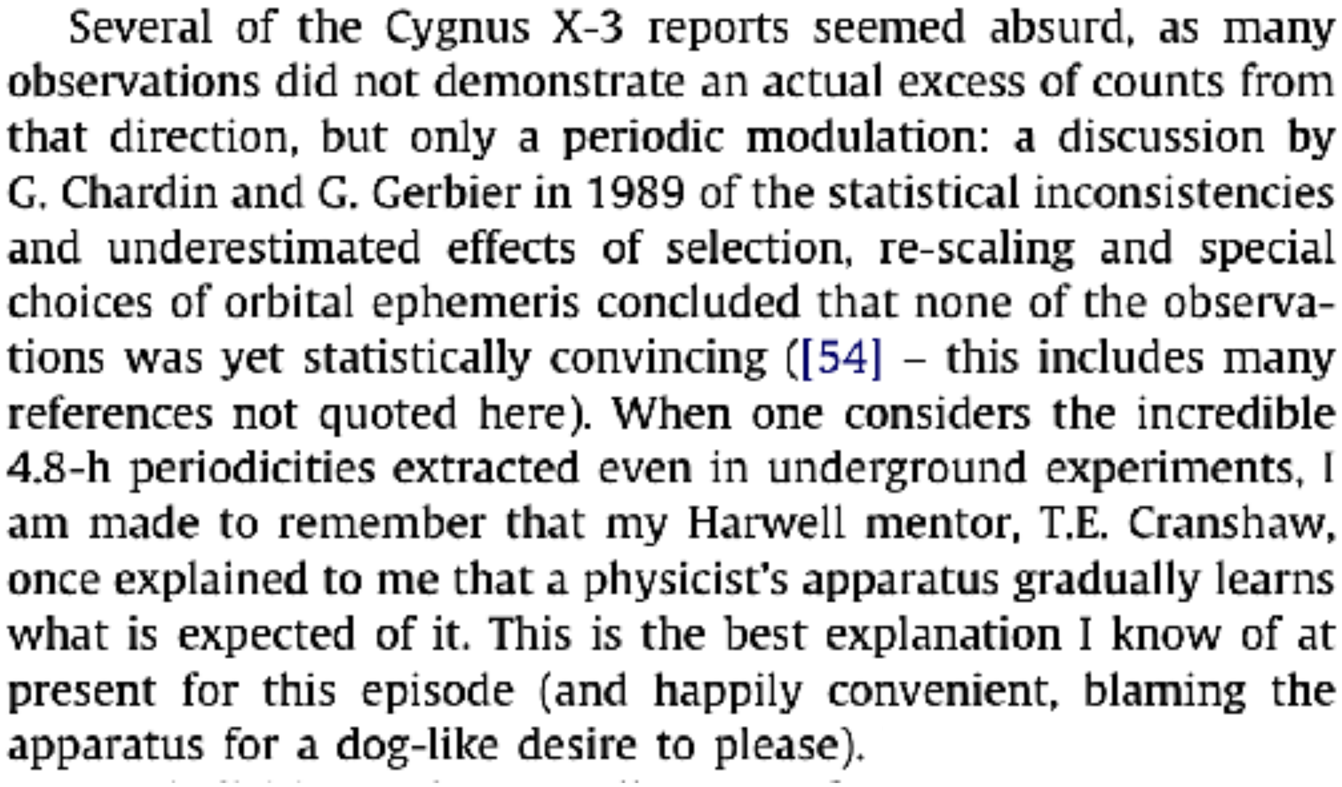

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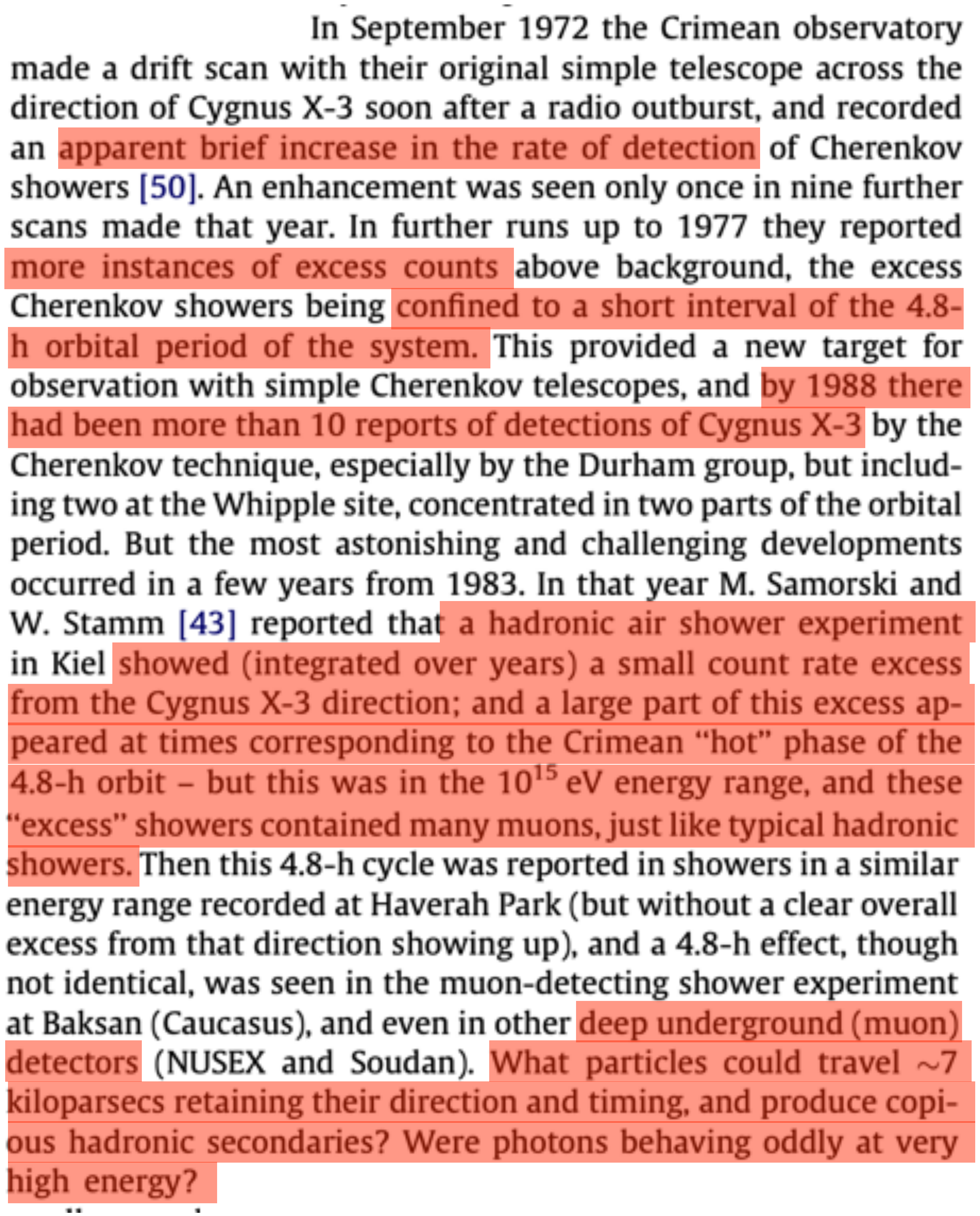

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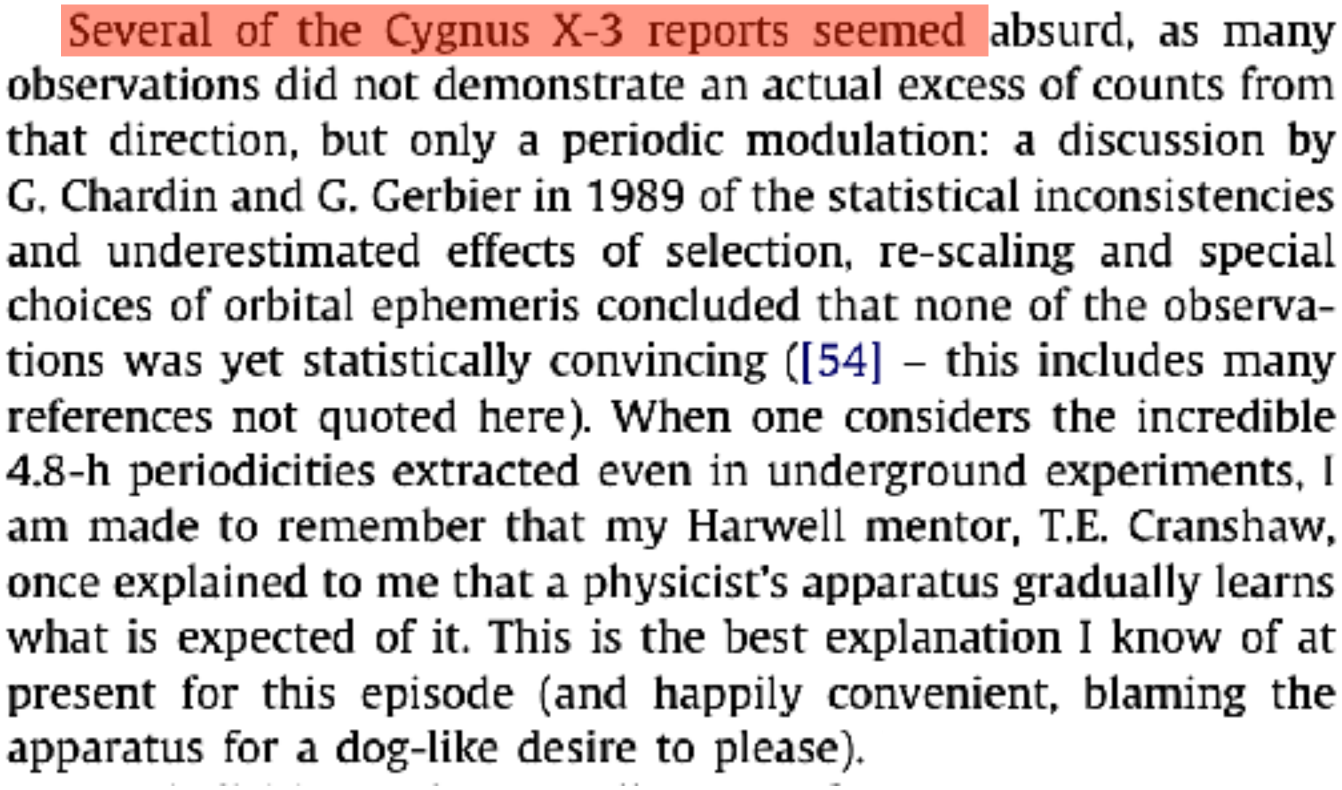

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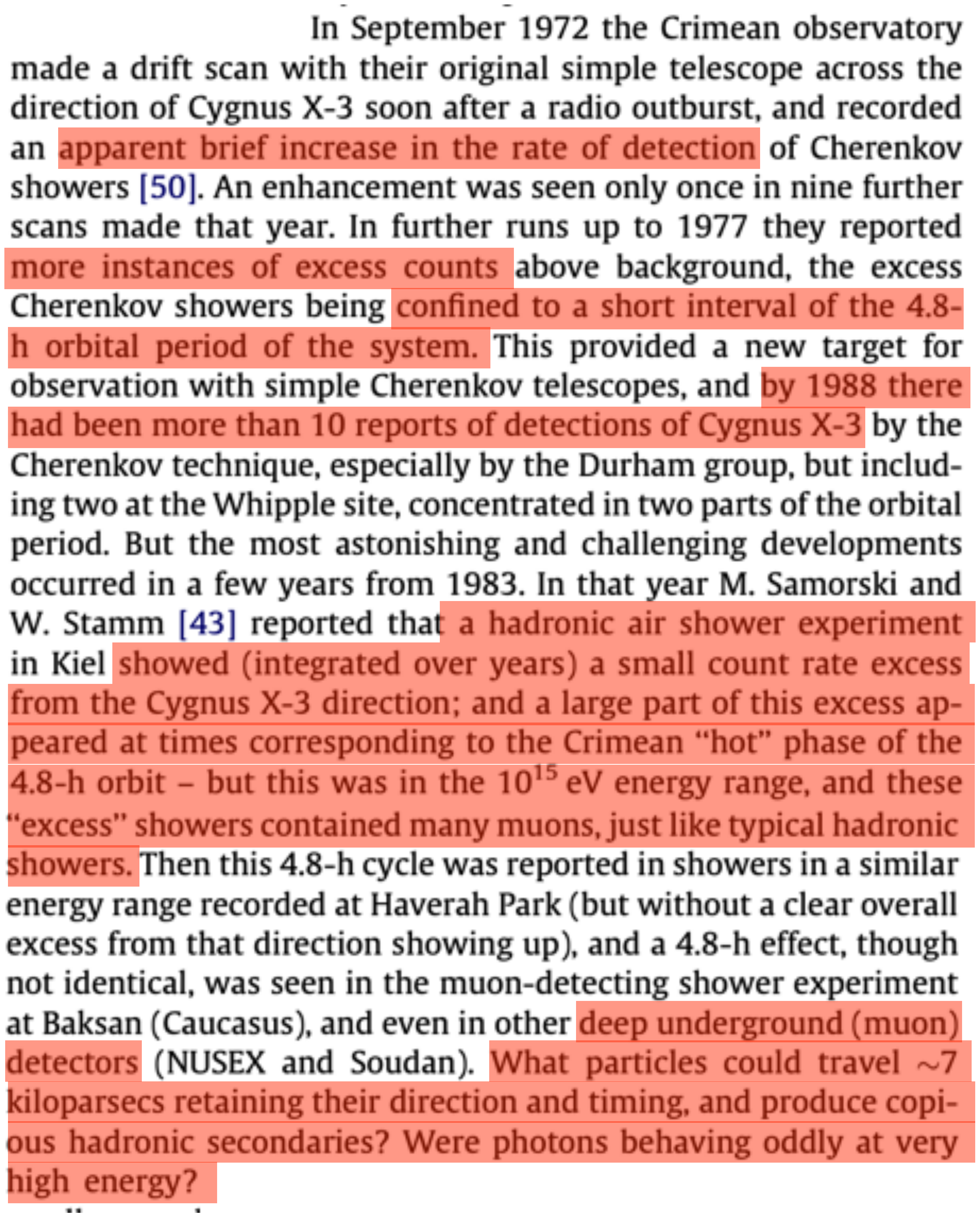

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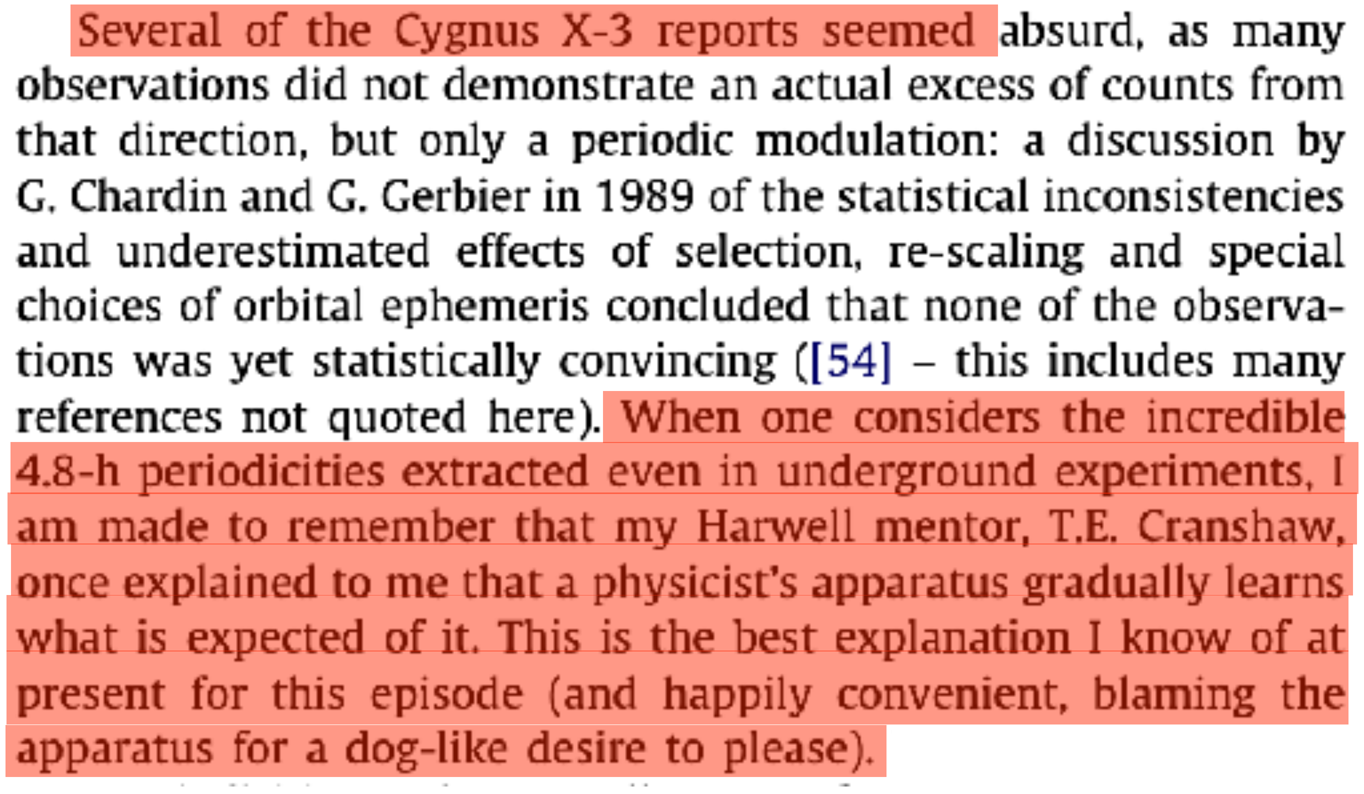
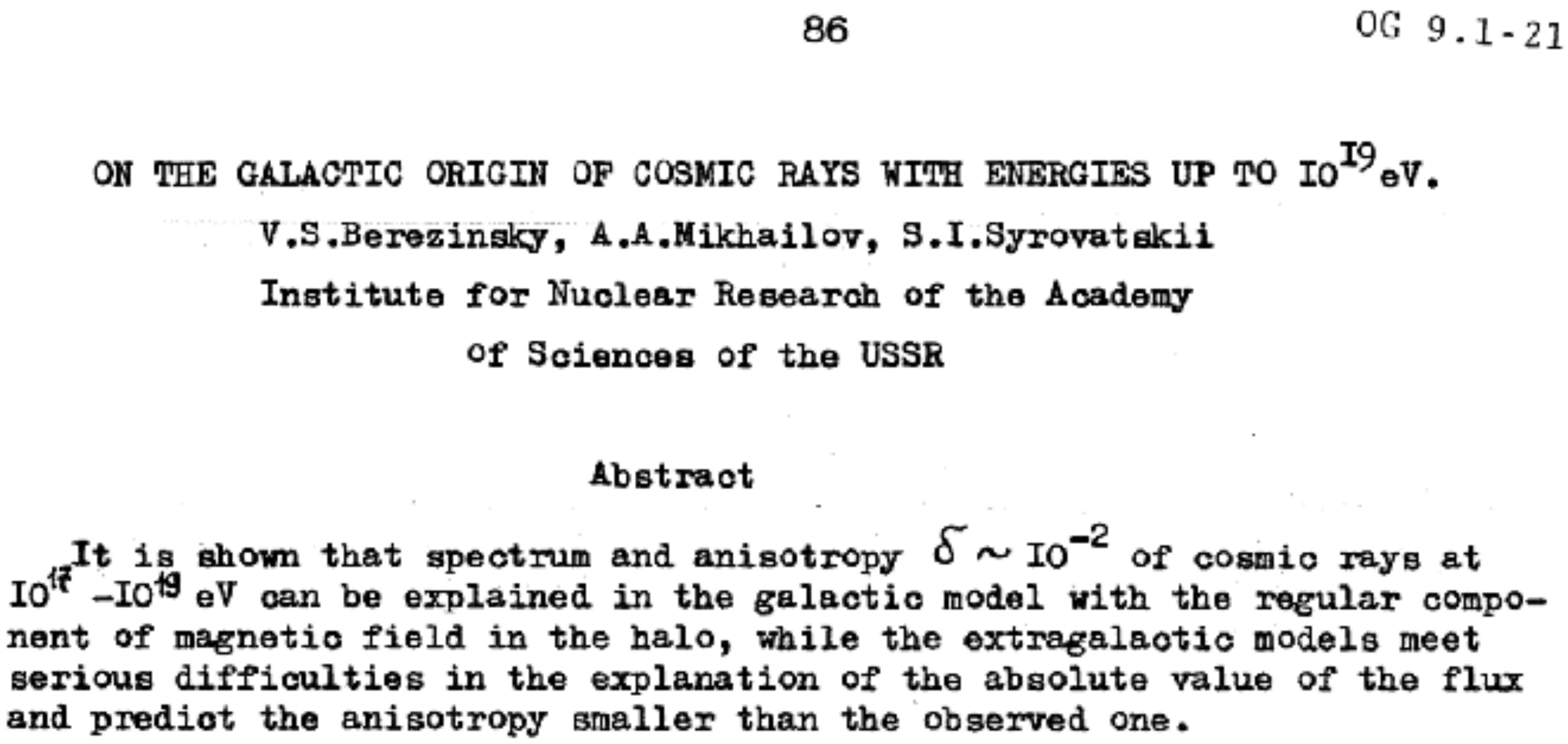


Several of the Cygnus X-3 reports seemed absurd, as many observations did not demonstrate an actual excess of counts from that direction, but only a periodic modulation: a discussion by G. Chardin and G. Gerbier in 1989 of the statistical inconsistencies and underestimated effects of selection, re-scaling and special choices of orbital ephemeris concluded that none of the observations was yet statistically convincing ([54] – this includes many references not quoted here). When one considers the incredible 4.8-h periodicities extracted even in underground experiments, I am made to remember that my Harwell mentor, T.E. Cranshaw, once explained to me that a physicist's apparatus gradually learns what is expected of it. This is the best explanation I know of at present for this episode (and happily convenient, blaming the apparatus for a dog-like desire to please).

More stuff

UHECRs from the Galactic centre?

VSB, Mikhailov & Syrovatskii 1979; VSB & Mikhailov 1984



86 OG 9.1-21

ON THE GALACTIC ORIGIN OF COSMIC RAYS WITH ENERGIES UP TO 10^{19} eV.

V.S.Berezinsky, A.A.Mikhailov, S.I.Syrovatskii
Institute for Nuclear Research of the Academy
of Sciences of the USSR

Abstract

It is shown that spectrum and anisotropy $\delta \sim 10^{-2}$ of cosmic rays at $10^{17}-10^{19}$ eV can be explained in the galactic model with the regular component of magnetic field in the halo, while the extragalactic models meet serious difficulties in the explanation of the absolute value of the flux and predict the anisotropy smaller than the observed one.

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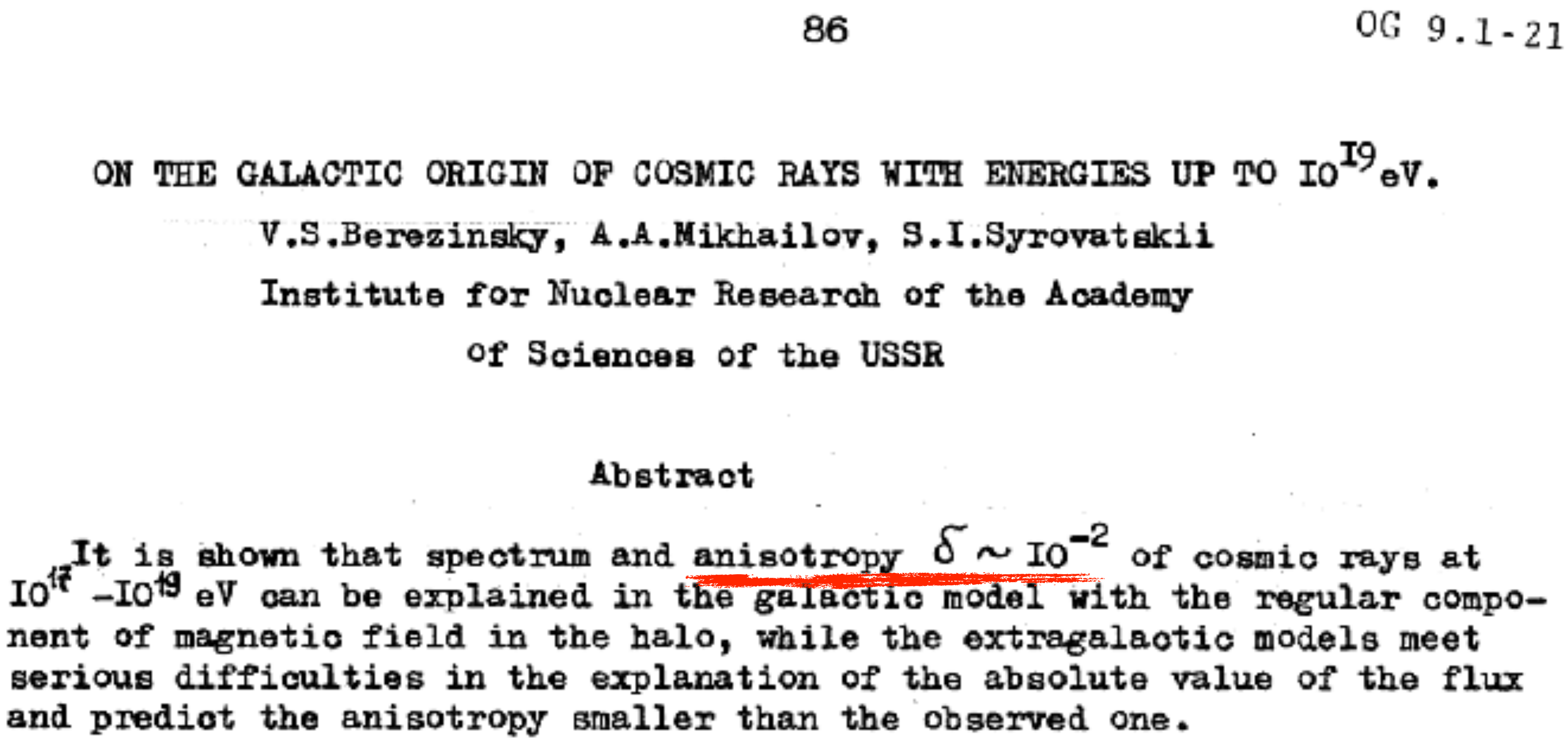

ON THE GALACTIC ORIGIN OF COSMIC RAYS WITH ENERGIES UP TO IO^{19} eV.

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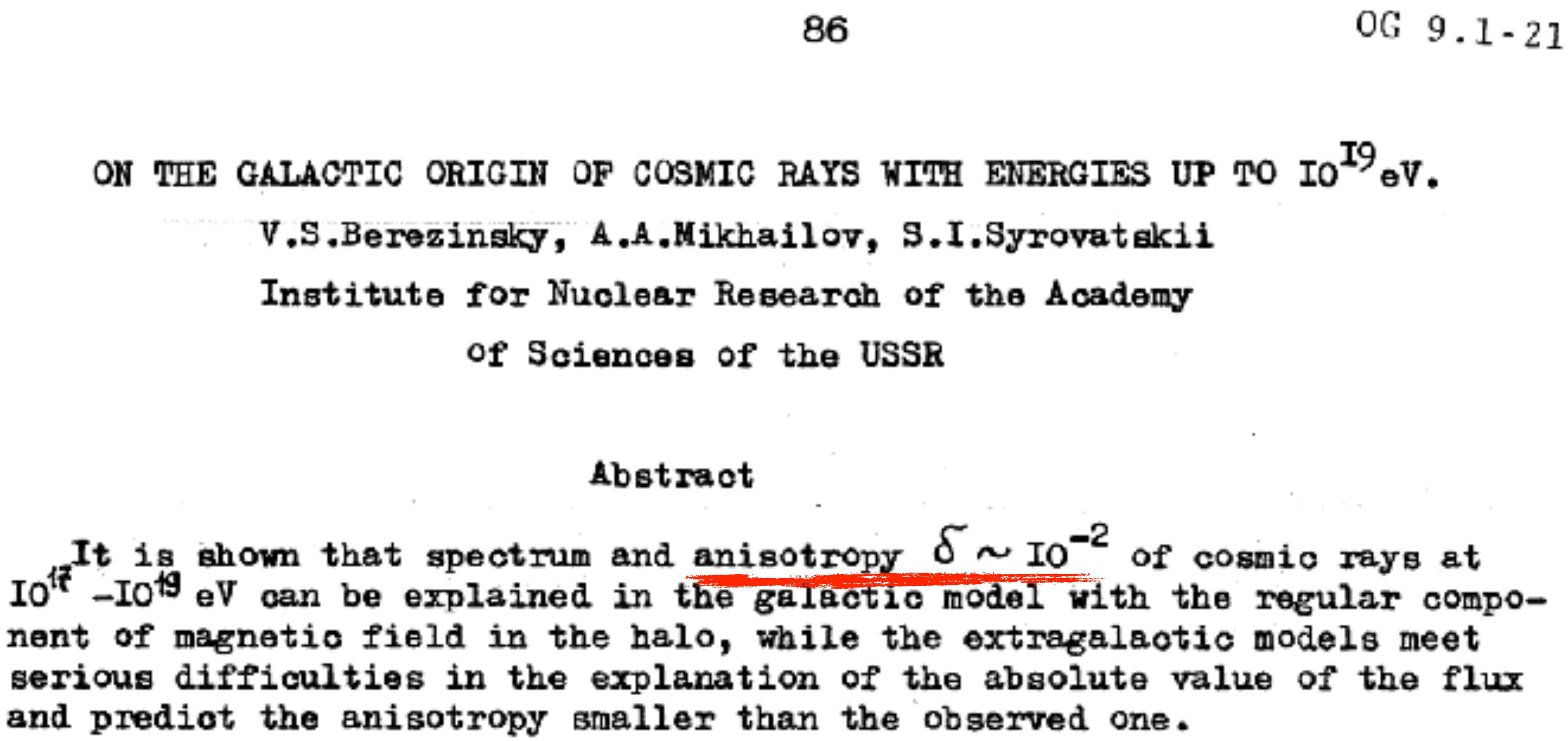
It is shown that spectrum and anisotropy $\delta \sim \mathrm{IO}^{-2}$ of cosmic rays at IO^{17} $-\mathrm{IO}^{19}$ eV can be explained in the galactic model with the regular component of magnetic field in the halo, while the extragalactic models meet serious difficulties in the explanation of the absolute value of the flux and predict the anisotropy smaller than the observed one.

UHECRs from the Galactic centre?

VSB, Mikhailov & Syrovatskii 1979; VSB & Mikhailov 1984



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ON THE GALACTIC ORIGIN OF COSMIC RAYS WITH ENERGIES UP TO IO^{I9}eV.

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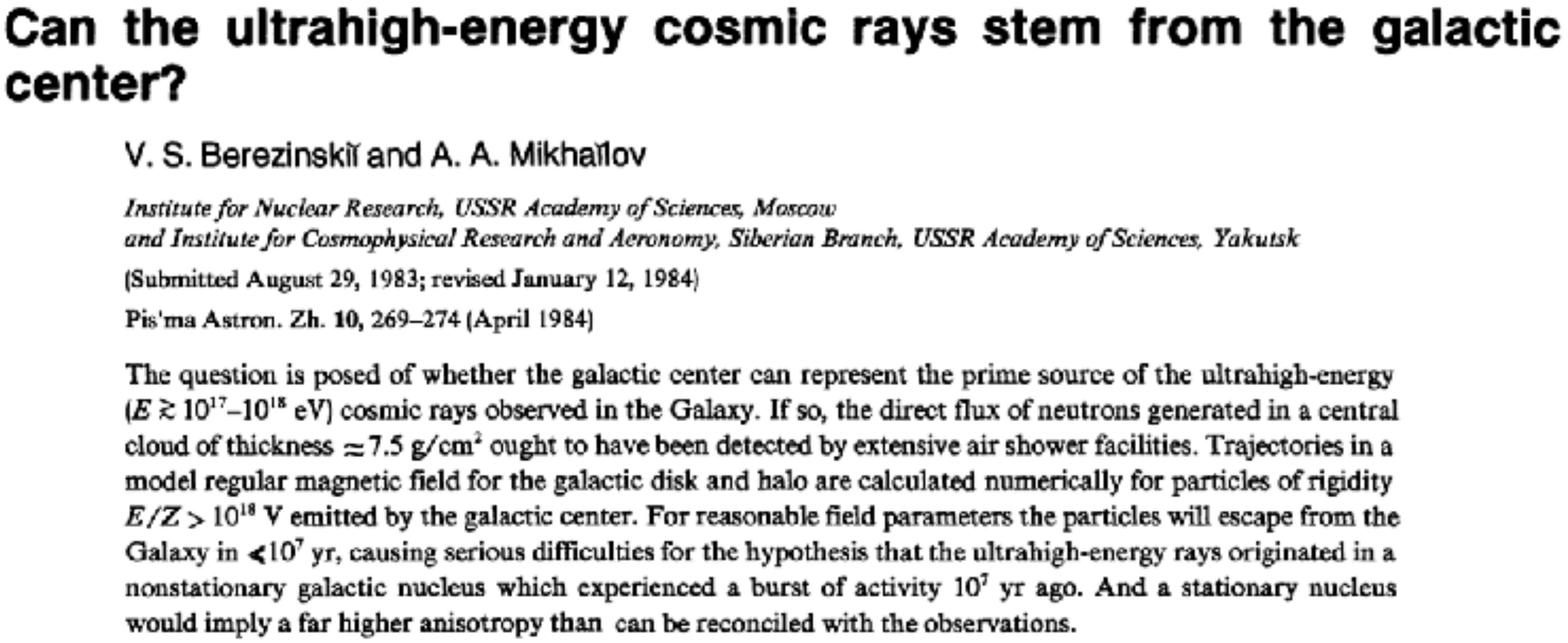

Can the ultrahigh-energy cosmic rays stem from the galactic center?

V. S. Berezinskiĭ and A. A. Mikhaĭlov

Institute for Nuclear Research, USSR Academy of Sciences, Moscow
and Institute for Cosmophysical Research and Aeronomy, Siberian Branch, USSR Academy of Sciences, Yakutsk

(Submitted August 29, 1983; revised January 12, 1984)
Pis'ma Astron. Zh. **10**, 269–274 (April 1984)

The question is posed of whether the galactic center can represent the prime source of the ultrahigh-energy ($E \gtrsim 10^{17}$–10^{18} eV) cosmic rays observed in the Galaxy. If so, the direct flux of neutrons generated in a central cloud of thickness $\simeq 7.5$ g/cm^2 ought to have been detected by extensive air shower facilities. Trajectories in a model regular magnetic field for the galactic disk and halo are calculated numerically for particles of rigidity $E/Z > 10^{18}$ V emitted by the galactic center. For reasonable field parameters the particles will escape from the Galaxy in $< 10^7$ yr, causing serious difficulties for the hypothesis that the ultrahigh-energy rays originated in a nonstationary galactic nucleus which experienced a burst of activity 10^7 yr ago. And a stationary nucleus would imply a far higher anisotropy than can be reconciled with the observations.

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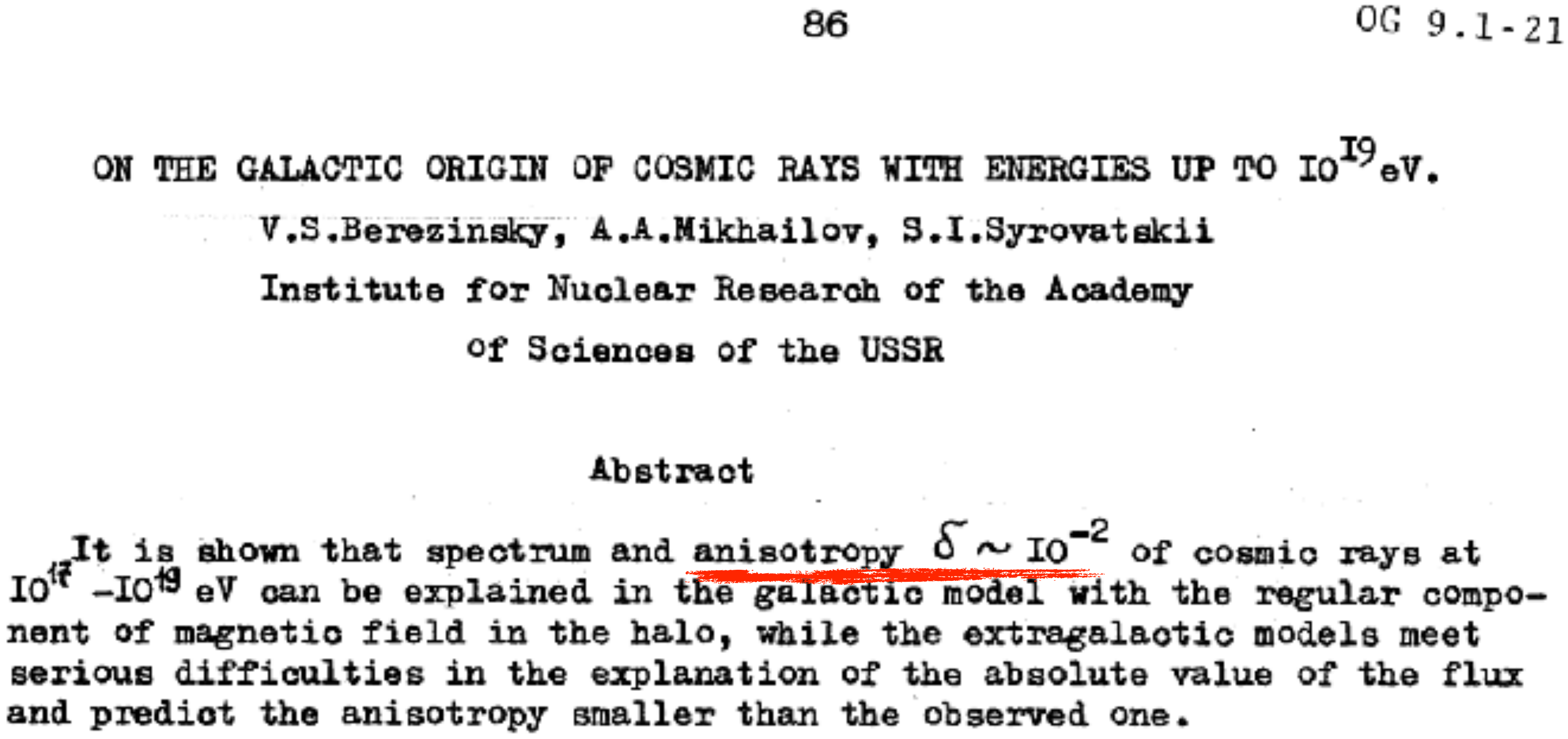

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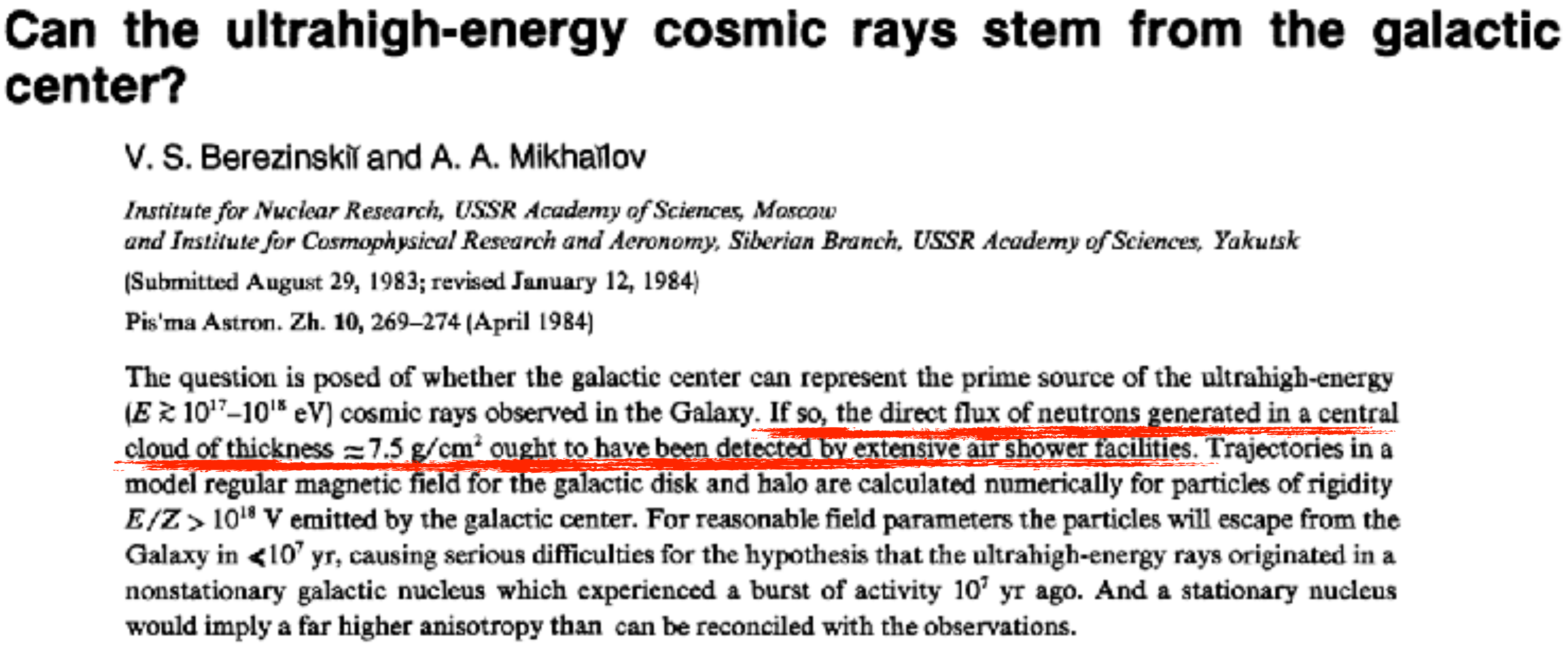

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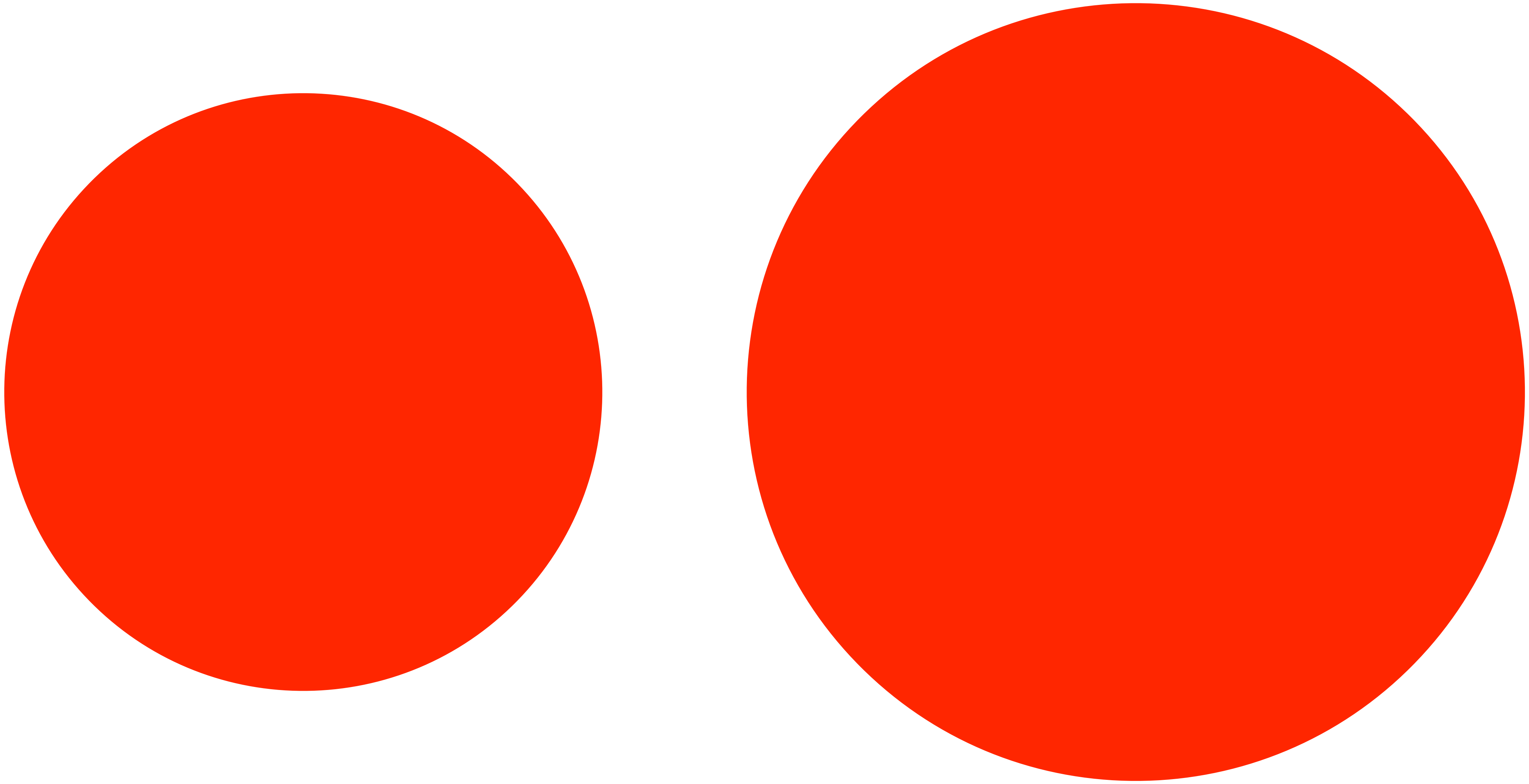
Neutrinos from Thorne-Zytkow stars

VSB & Prilutsky 1981



binary system

Neutrinos from Thorne-Zytkow stars

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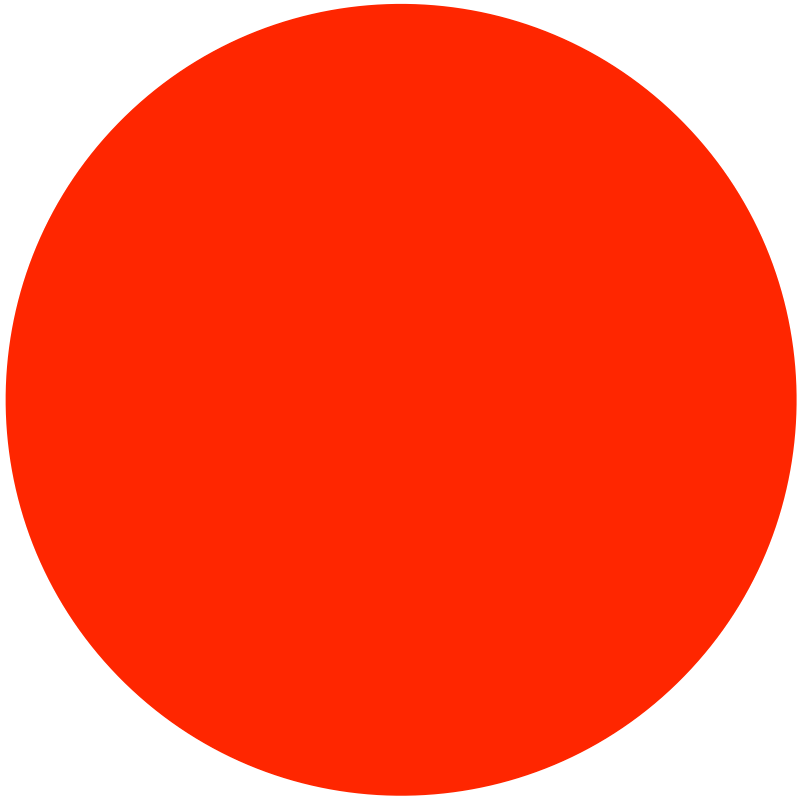

supernova

binary system

Neutrinos from Thorne-Zytkow stars

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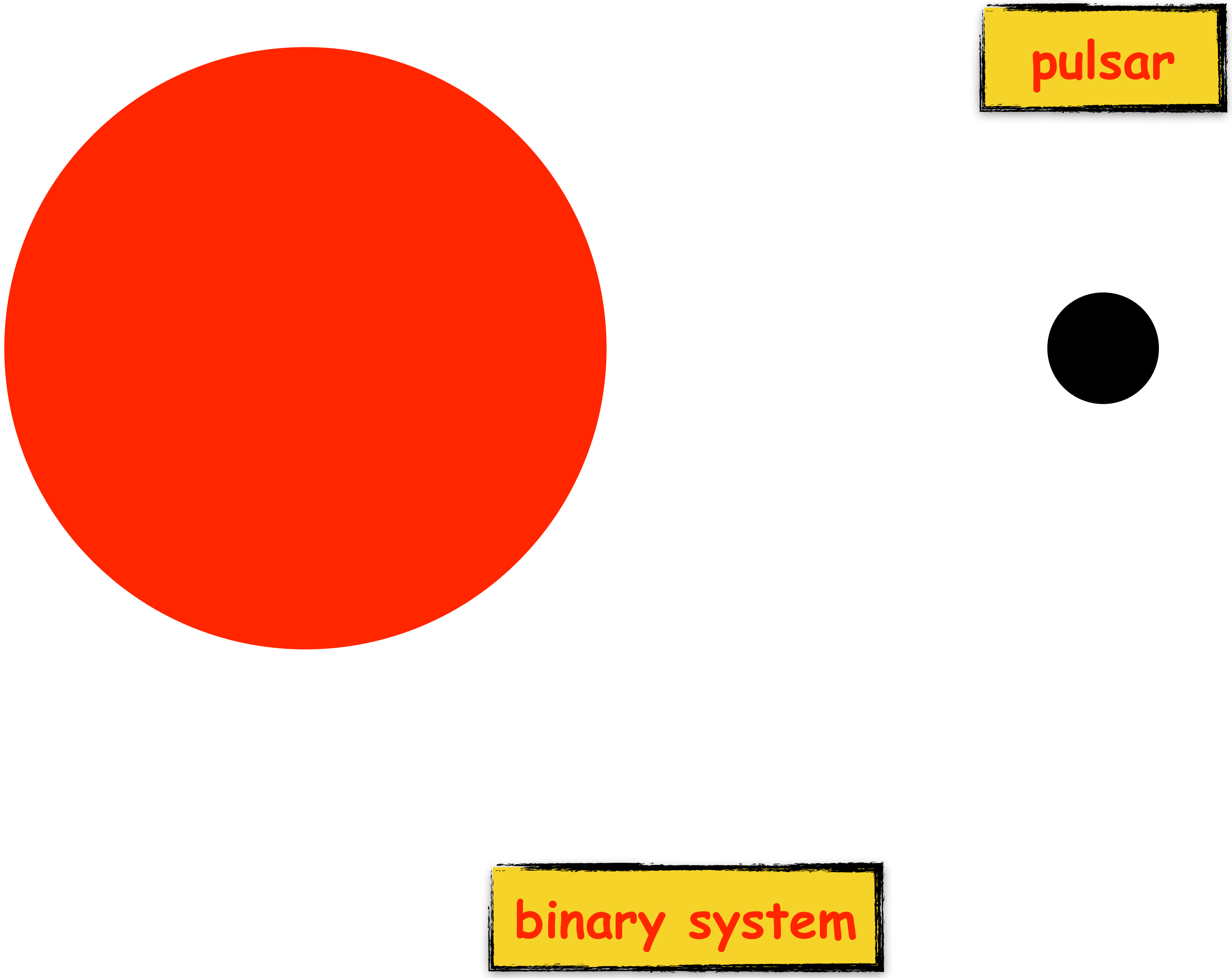
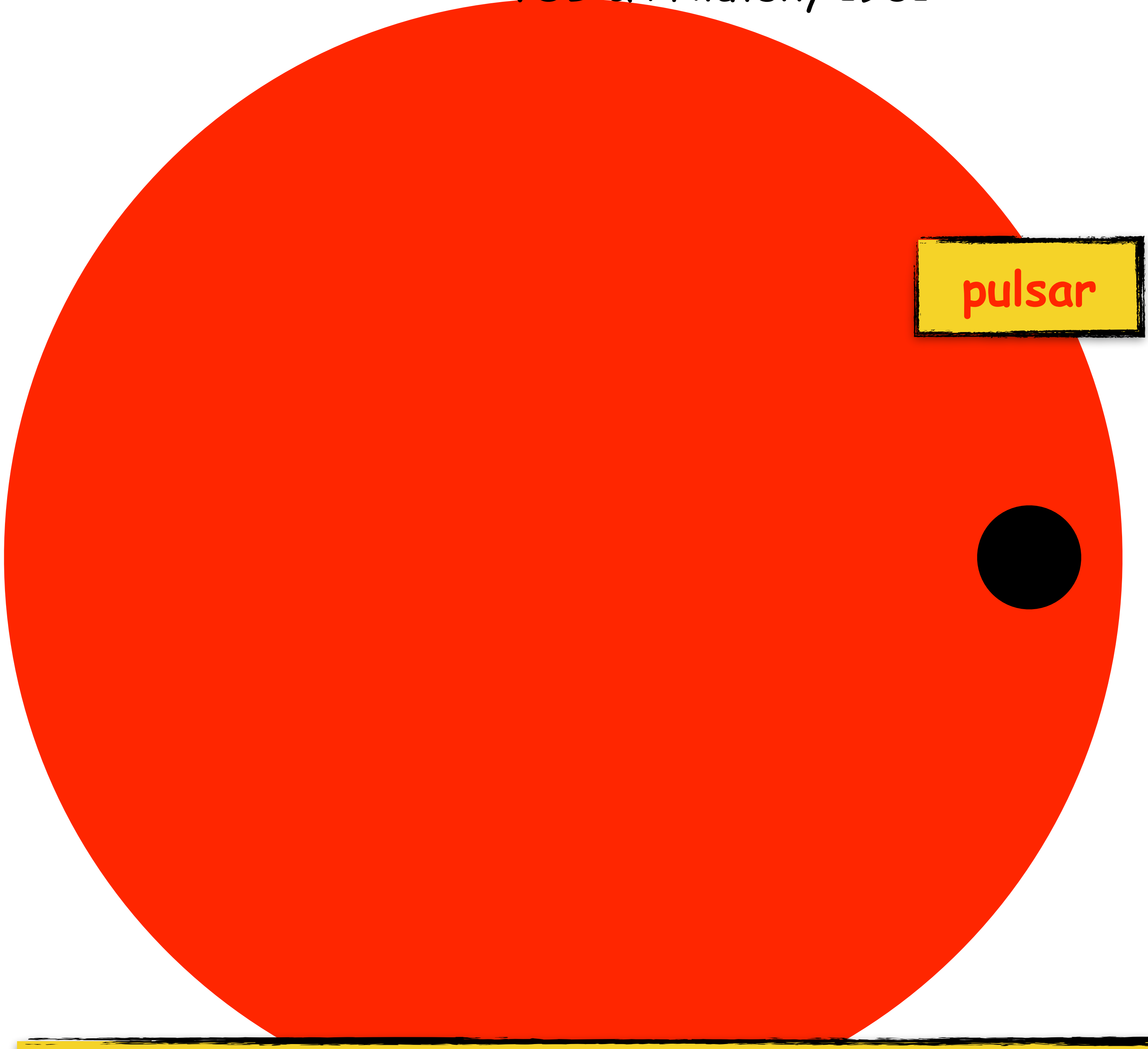


pulsar

binary system

Neutrinos from Thorne-Zytkow stars

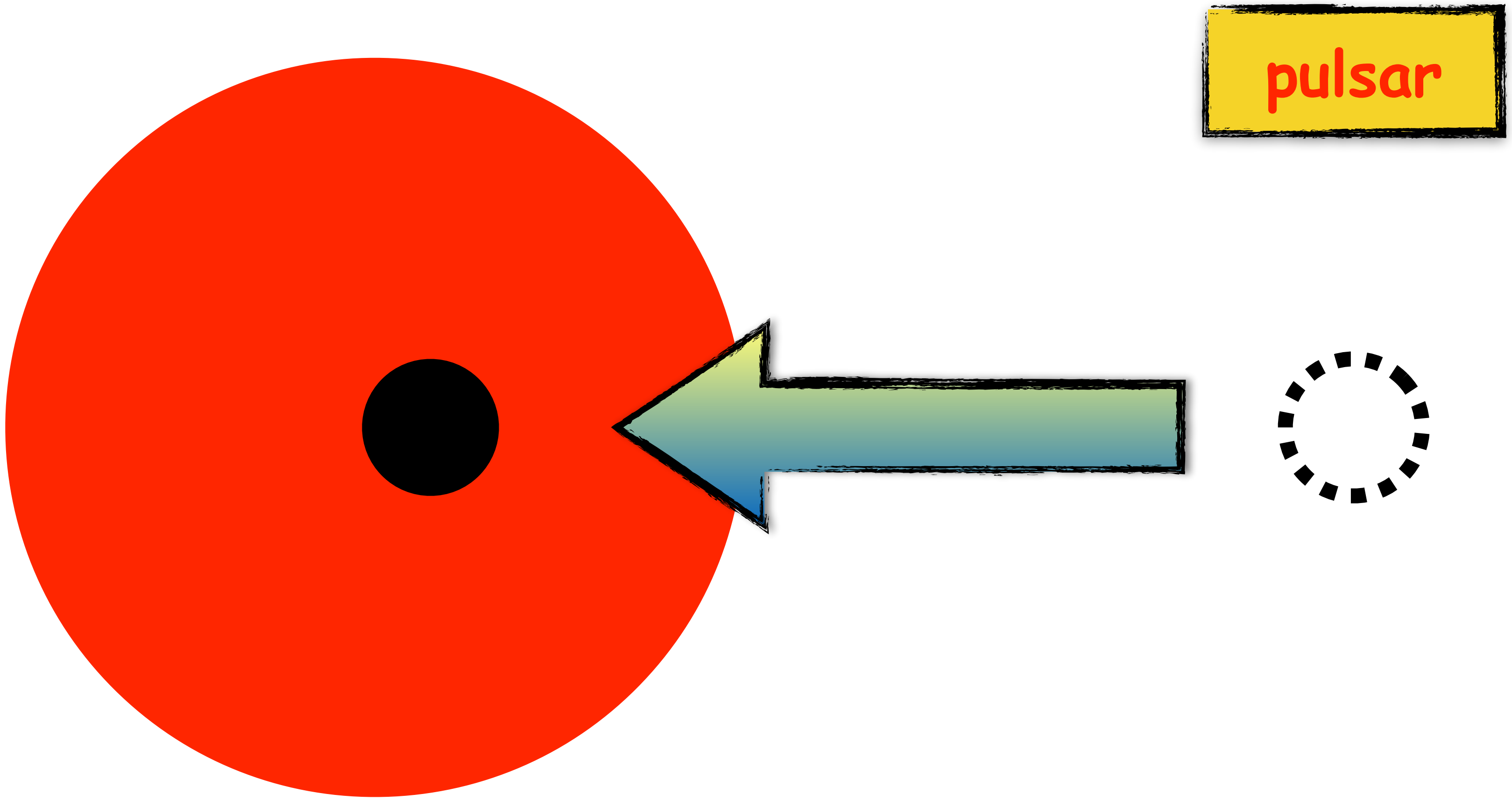
VSB & Prilutsky 1981



the red supergiant expands and swallows the PSR

Neutrinos from Thorne-Zytkow stars

VSB & Prilutsky 1981

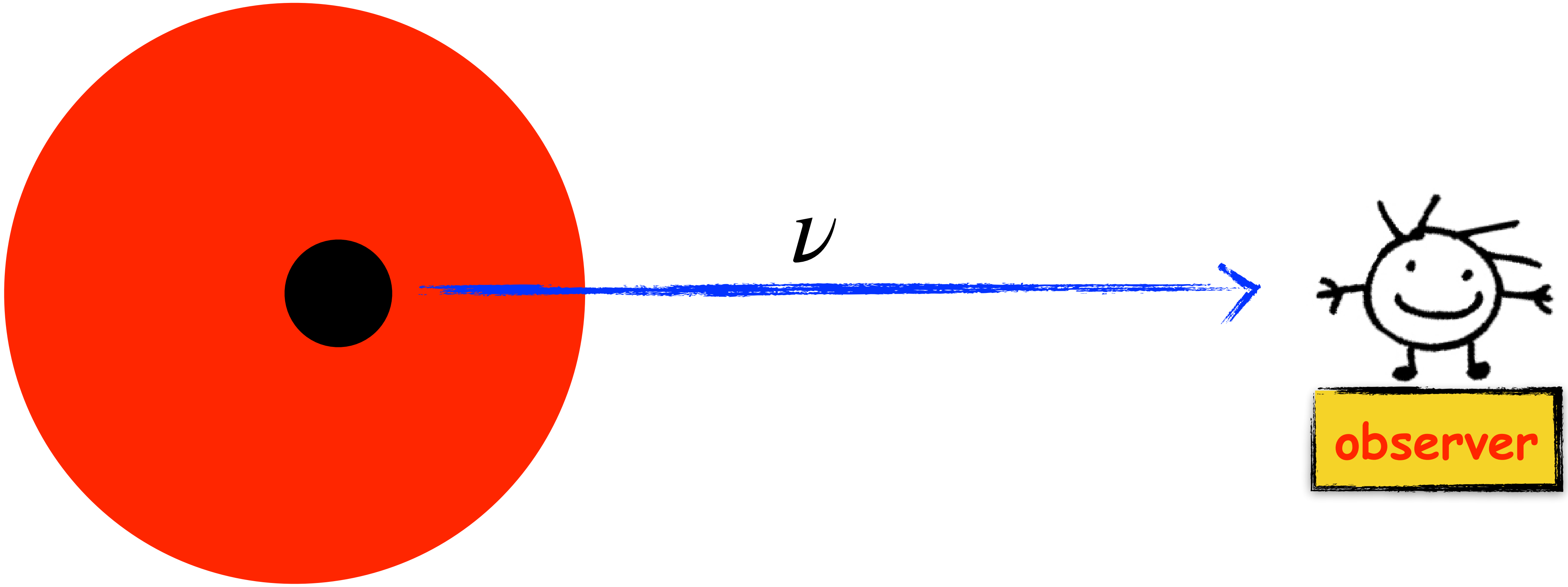


pulsar

or the PSR is kicked into its companion

Neutrinos from Thorne-Zytkow stars

VSB & Prilutsky 1981



all radiation is thermalised (column density 10^5 g/cm^2), only neutrinos escape!

Neutrinos from Thorne-Zytkow stars

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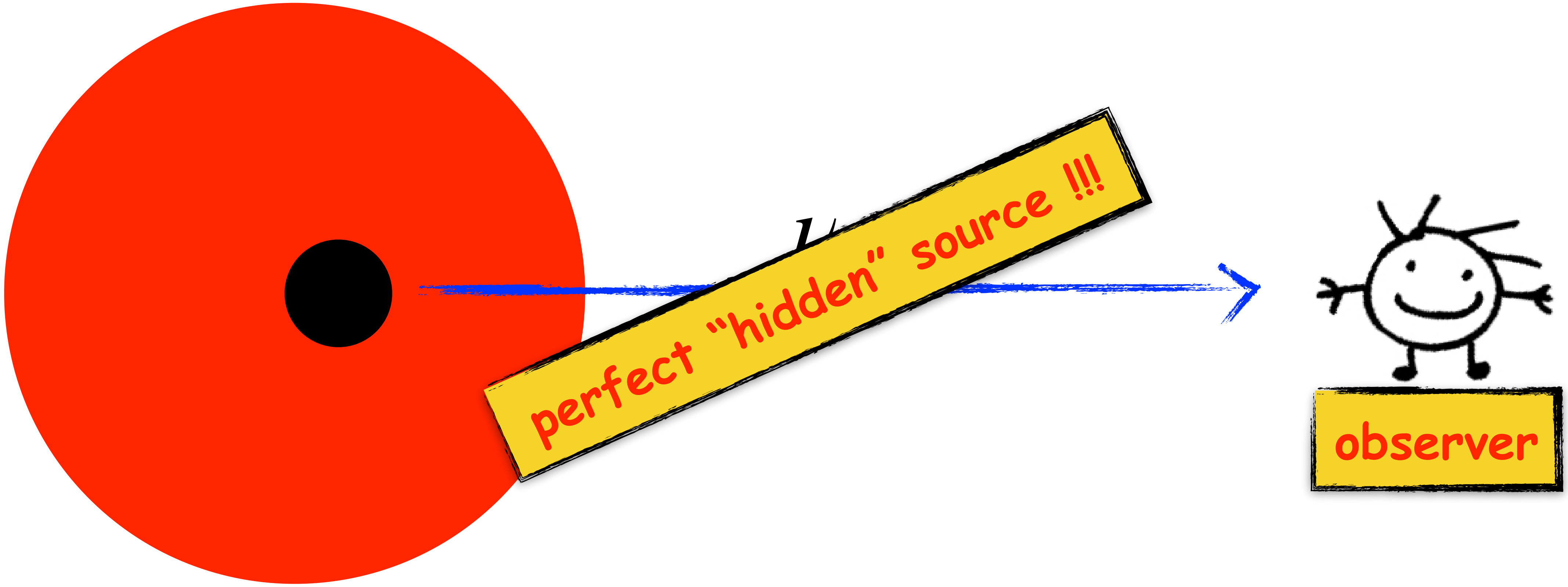
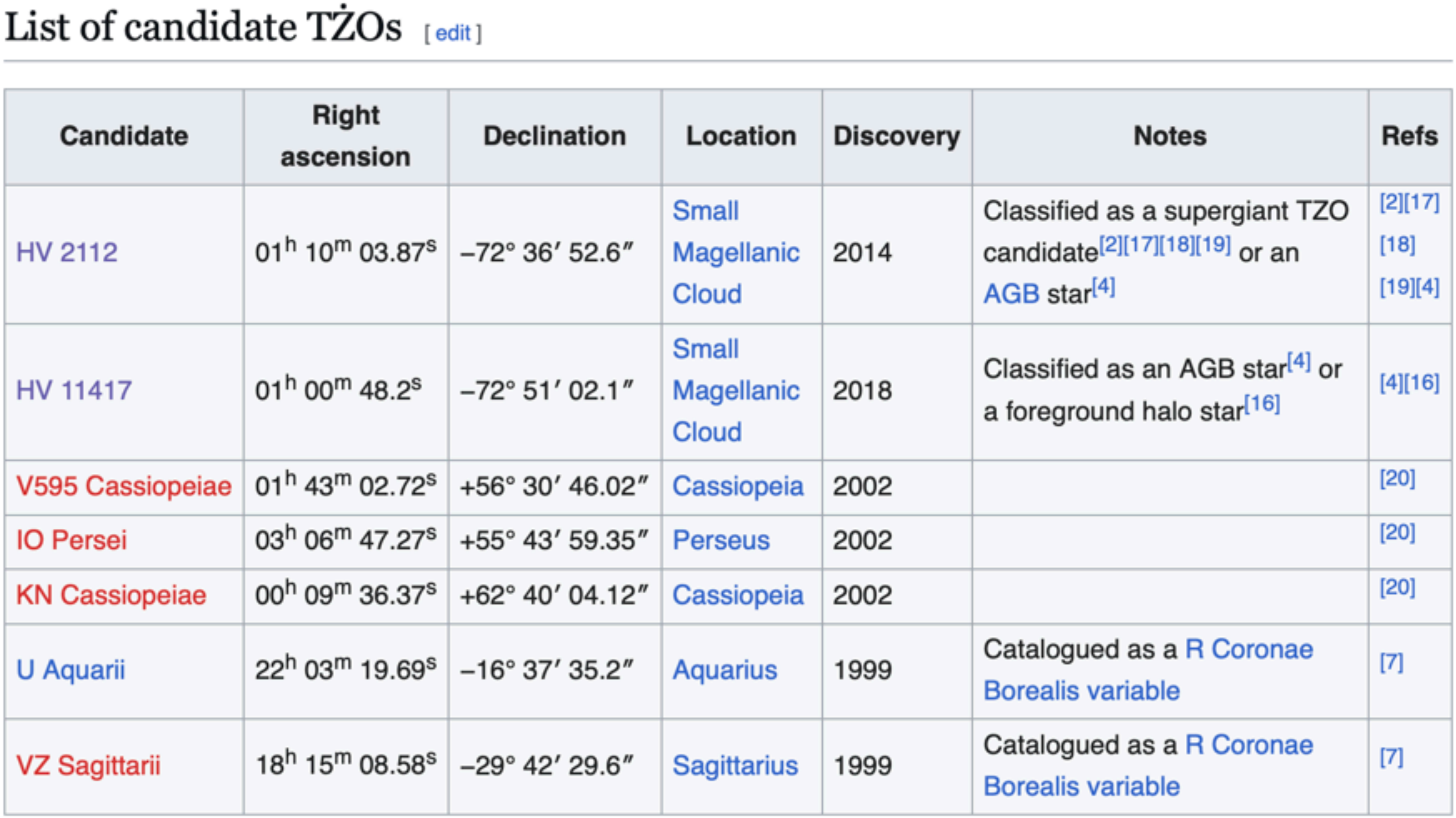


perfect "hidden" source !!!

observer

all radiation is thermalised (column density 10^5 g/cm^2), only neutrinos escape!

Thorne-Zytkow star candidates



List of candidate TŻOs [edit]

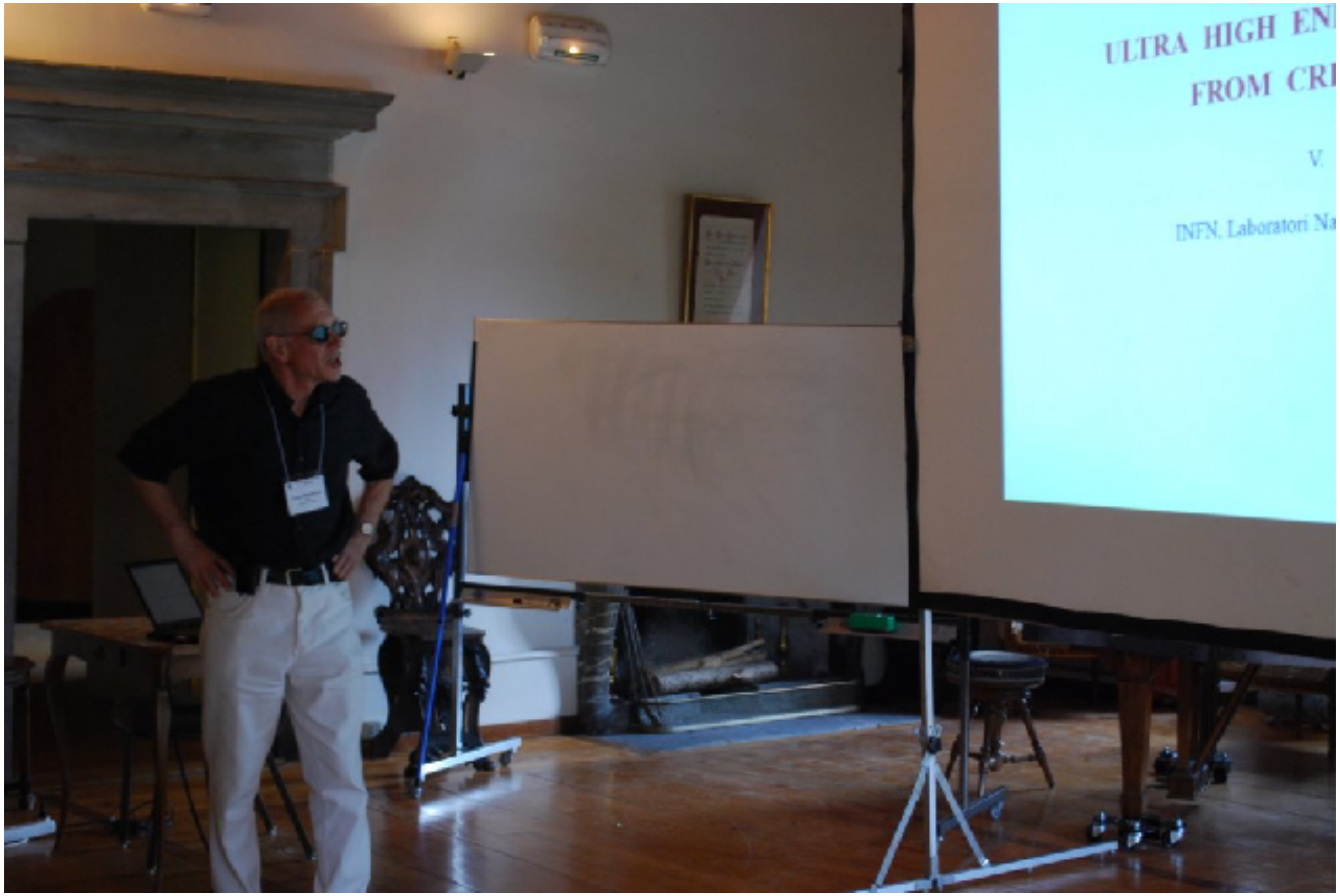
Candidate	Right ascension	Declination	Location	Discovery	Notes	Refs
HV 2112	01^h 10^m 03.87^s	−72° 36′ 52.6″	Small Magellanic Cloud	2014	Classified as a supergiant TZO candidate[2][17][18][19] or an AGB star[4]	[2][17][18][19][4]
HV 11417	01^h 00^m 48.2^s	−72° 51′ 02.1″	Small Magellanic Cloud	2018	Classified as an AGB star[4] or a foreground halo star[16]	[4][16]
V595 Cassiopeiae	01^h 43^m 02.72^s	+56° 30′ 46.02″	Cassiopeia	2002		[20]
IO Persei	03^h 06^m 47.27^s	+55° 43′ 59.35″	Perseus	2002		[20]
KN Cassiopeiae	00^h 09^m 36.37^s	+62° 40′ 04.12″	Cassiopeia	2002		[20]
U Aquarii	22^h 03^m 19.69^s	−16° 37′ 35.2″	Aquarius	1999	Catalogued as a R Coronae Borealis variable	[7]
VZ Sagittarii	18^h 15^m 08.58^s	−29° 42′ 29.6″	Sagittarius	1999	Catalogued as a R Coronae Borealis variable	[7]

What I learned preparing this talk

“Call yourself a theorist, and doing nothing becomes intense thinking about a topic”

- the breadth of VSB’s scientific interests was even broader than I thought !!!
- the history that led from Baade & Zwisky 1934 to the first detection of SNRs in gamma-rays (2003) was much longer than I knew !!!
- multi-messenger astronomy is old stuff
- (in some sense, what said above is a bit embarrassing but, on the other hand, that proves that I am still young !)
- “the theorist plays no role in physics” —> our field is definitely data-driven, truly original and innovating theoretical predictions are very rare (but think about, e.g., hidden neutrino sources!)
- “…and everyone knows they can explain any result” —> not always true! (think about Cygnets…)

Acknowledgments



Even though I never talked to him (and I now regret that), I have always considered VSB as a sort of a “guide” or “teacher”, from my very first day as a graduate student (clusters of galaxies are storage rooms for cosmic rays!) to very recent days (if I had known better VSB’s papers, the detection in neutrinos ONLY from NGC 1068 would have been much less of a surprise…). Thanks!