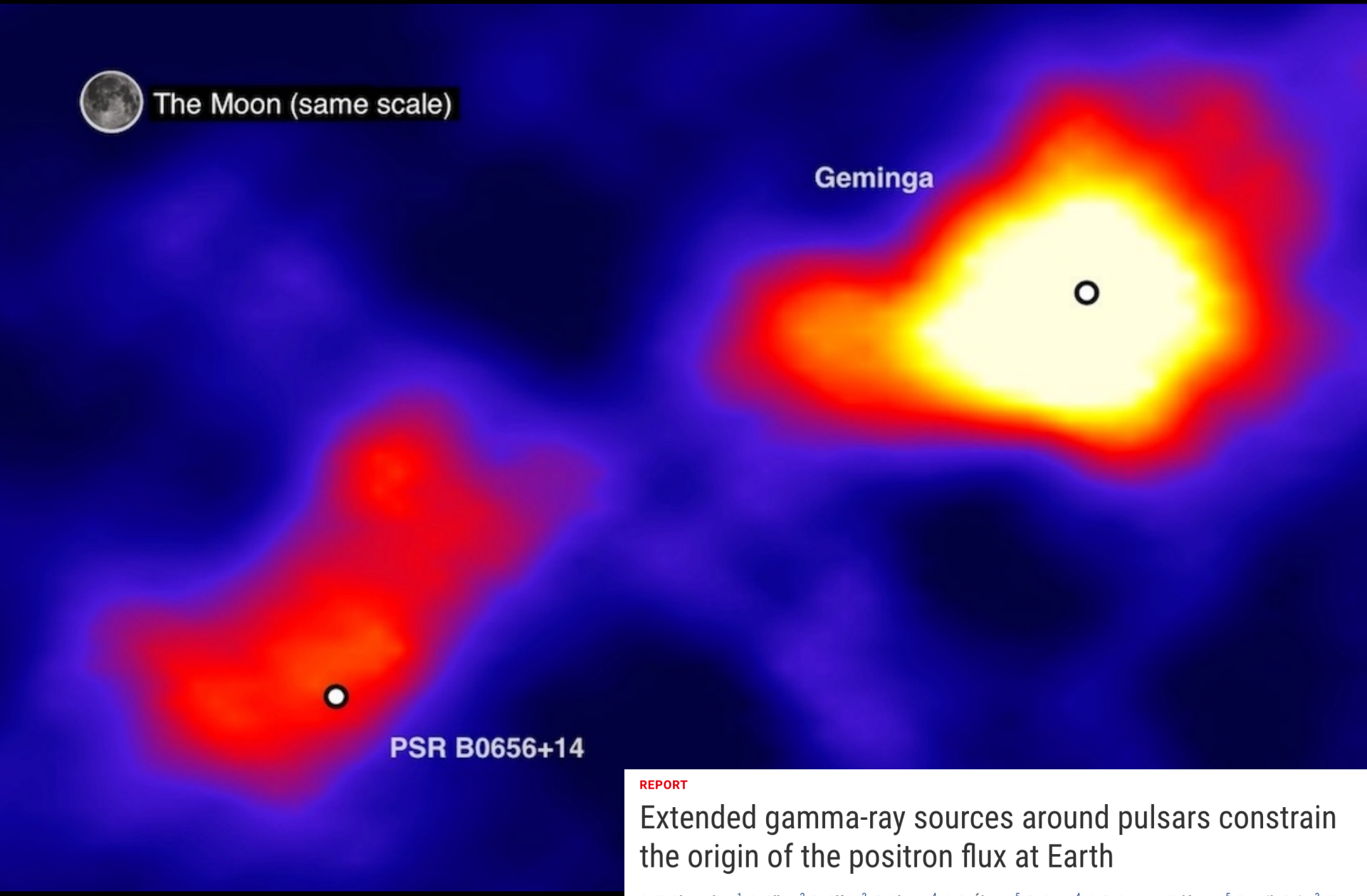
Gamma-ray Halos around Pulsars
Introduction to the Workshop

1st December 2020

Jim Hinton – Max Planck Institute for Nuclear Physics

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK



REPORT

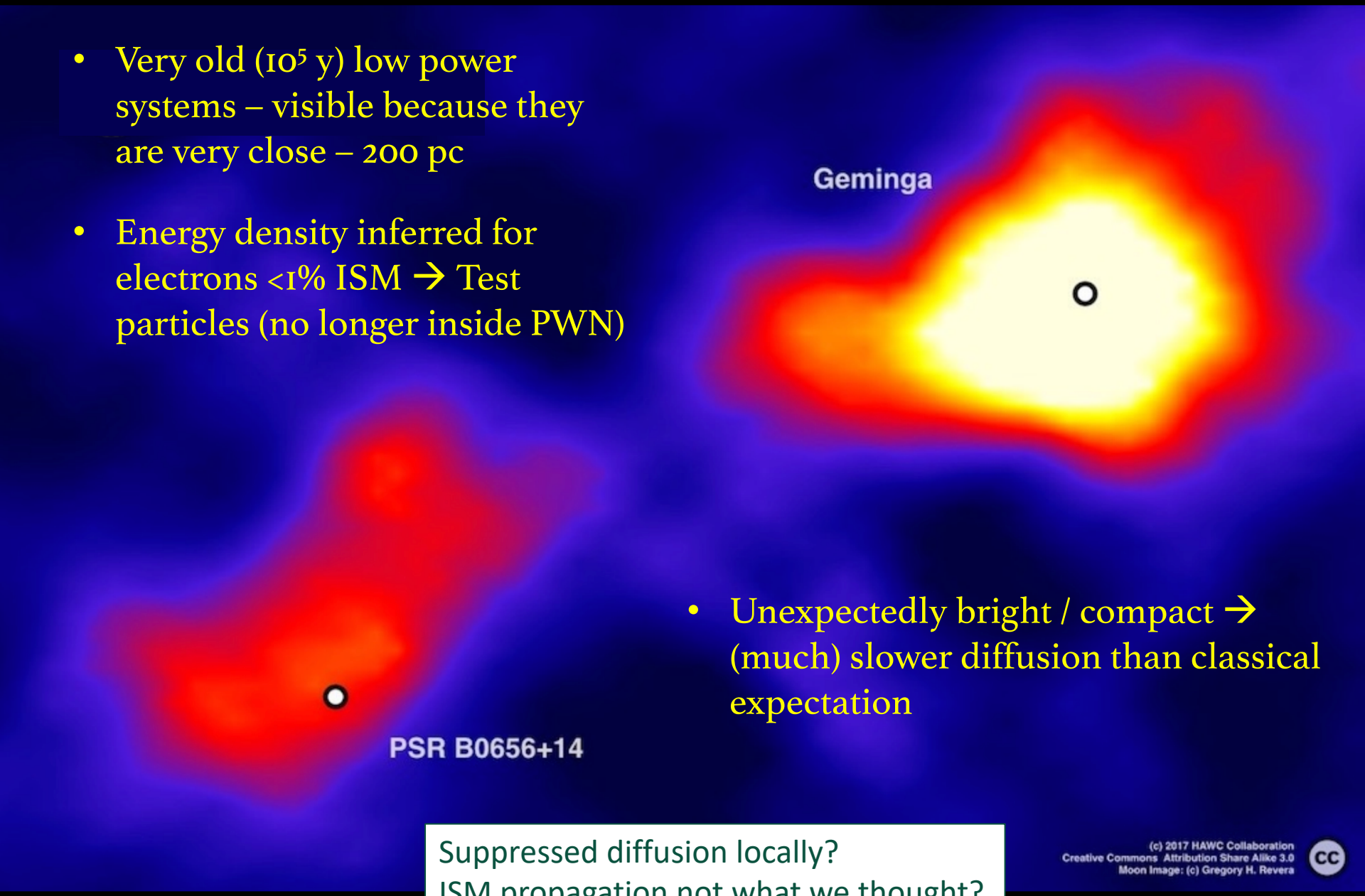
Extended gamma-ray sources around pulsars constrain the origin of the positron flux at Earth

A. U. Abeysekara[1], A. Albert[2], R. Alfaro[3], C. Alvarez[4], J. D. Álvarez[5], R. Arceo[4], J. C. Arteaga-Velázquez[5], D. Avila Rojas[3], H…

+ See all authors and affiliations

Science 17 Nov 2017:
Vol. 358, Issue 6365, pp. 911-914
DOI: 10.1126/science.aan4880

- Very old (10^5 y) low power systems – visible because they are very close – 200 pc
- Energy density inferred for electrons <1% ISM → Test particles (no longer inside PWN)



- Unexpectedly bright / compact → (much) slower diffusion than classical expectation

Suppressed diffusion locally?
ISM propagation not what we thought?

13 2019ApJ...875..149L 2019/04 cited: 7
Constraining the Magnetic Field in the TeV Halo of Geminga with X-Ray Observations
Liu, Ruo-Yu; Ge, Chong; Sun, Xiao-Na *and 1 more*

14 2018MNRAS.480.5419B 2018/11 cited: 8
Escape of high-energy particles from bow-shock pulsar wind nebulae
Bucciantini, N.

15 2018PhRvD..98f3017E 2018/09 cited: 25
Self-generated cosmic-ray confinement in TeV halos: Implications for TeV γ -ray emission and the positron excess
Evoli, Carmelo; Linden, Tim; Morlino, Giovanni

16 2018PDU....21...40H 2018/09 cited: 14
TeV gamma rays from Galactic Center pulsars
Hooper, Dan; Cholis, Ilias; Linden, Tim

17 2018PhRvD..98d3005H 2018/08 cited: 11
Millisecond pulsars, TeV halos, and implications for the Galactic Center gamma-ray excess
Hooper, Dan; Linden, Tim

18 2018PhRvL.120l1101L 2018/03 cited: 9
Pulsar TeV Halos Explain the Diffuse TeV Excess Observed by Milagro
Linden, Tim; Buckman, Benjamin J.

19 2018APS..APRS17002L 2018
Rise of the Leptons: Pulsar Emission Dominates the TeV Gamma-Ray Sky
Linden, Tim

20 2018APS..APRD07002R 2018
Highlights from the HAWC Observatory
Rivière, Colas

21 2017PhRvD..96j3016L 2017/11 cited: 26
Using HAWC to discover invisible pulsars
Linden, Tim; Auchettl, Katie; Bramante, Joseph *and 5 more*

22 1994ApJ...423L...5A 1994/03 cited: 200
Very High Energy Gamma Rays from Active Galactic Nuclei: Cascading on the Cosmic Background Radiation Fields and the Formation of Pair Halos
Aharonian, F. A.; Coppi, P. S.; Voelk, H. J.

2020ApJ...904...85C 2020/12
The TeV Gamma-Ray Luminosity of the Milky Way and the Contribution of H.E.S.S. Unresolved Sources to Very High Energy Diffuse Emission
Cataldo, M.; Pagliaroli, G.; Vecchiotti, V. *and 1 more*

2020A&A...640A..76P 2020/08 cited: 1
Energy dependent morphology of the pulsar wind nebula HESS J1825-137 with Fermi-LAT
Principe, G.; Mitchell, A. M. W.; Caroff, S. *and 3 more*

2020arXiv200604106C 2020/06
The TeV gamma-ray luminosity of the Milky-Way and the contribution of H.E.S.S. unresolved sources to VHE diffuse emission
Cataldo, Maddalena; Pagliaroli, Giulia; Vecchiotti, Vittoria *and 1 more*

2020arXiv200514079B 2020/05
3D Relativistic MHD Simulations of Pulsar Bow Shock Nebulae
Bucciantini, N.; Olmi, B.; Del Zanna, L.

2020A&A...636A.113G 2020/04 cited: 9
Halo fraction in TeV-bright pulsar wind nebulae
Giacinti, G.; Mitchell, A. M. W.; López-Coto, R. *and 3 more*

2020ApJ...889...12Z 2020/01
Discovery of a Spatially Extended GeV Source in the Vicinity of the TeV Halo Candidate 2HWC J1912+099: a TeV Halo or Supernova Remnant?
Zhang, Hai-Ming; Xi, Shao-Qiang; Liu, Ruo-Yu *and 3 more*

2019PhRvL.123v1103L 2019/11 cited: 5
Understanding the Multiwavelength Observation of Geminga's Tev Halo: The Role of Anisotropic Diffusion of Particles
Liu, Ruo-Yu; Yan, Huirong; Zhang, Heshou

2019MNRAS.488.4074F 2019/09 cited: 7
Possible origin of the slow-diffusion region around Geminga
Fang, Kun; Bi, Xiao-Jun; Yin, Peng-Fei

2019PhRvD.100d3016S 2019/08 cited: 10
TeV halos are everywhere: Prospects for new discoveries
Sudoh, Takahiro; Linden, Tim; Beacom, John F.

2019ICRC...36..797S 2019/07
A Systematic Search for TeV Halos associated with known pulsars
Smith, A.

2019ICRC...36...68F 2019/07
Unveiling the Origin of Cosmic-ray Leptons in Light of the Recent HAWC TeV-halo Observations
Fornieri, O.; Gaggero, D.; Grasso, D.

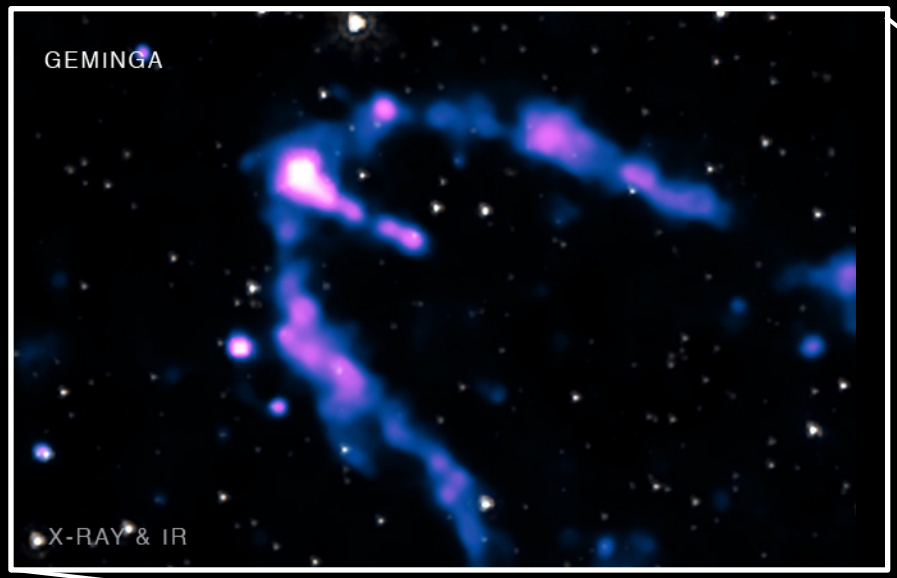
2019BAAS...51c.311F 2019/05 cited: 2
Pulsars in a Bubble? Following Electron Diffusion in the Galaxy with TeV Gamma Rays
Fleischhack, Henrike; Albert, A.; Alvarez, C. *and 33 more*

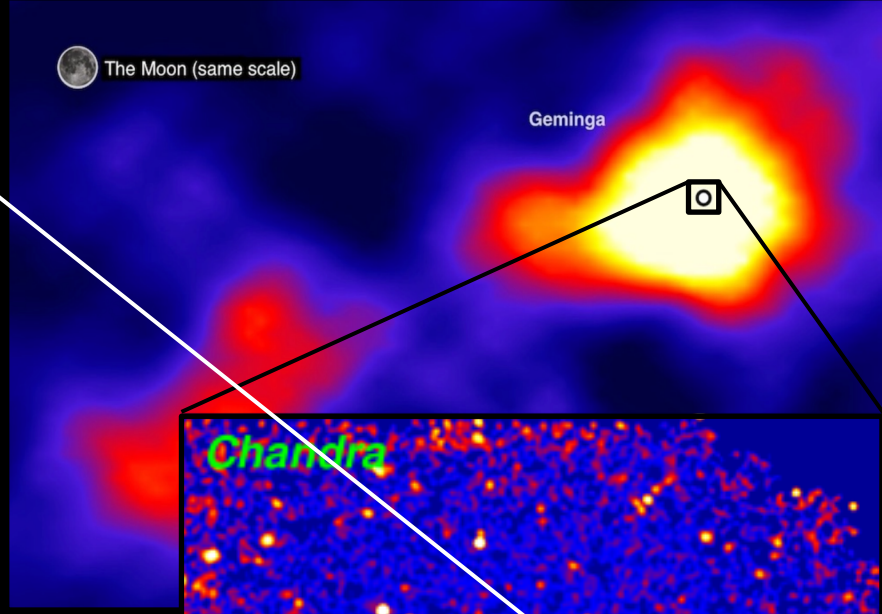
Why have a workshop?

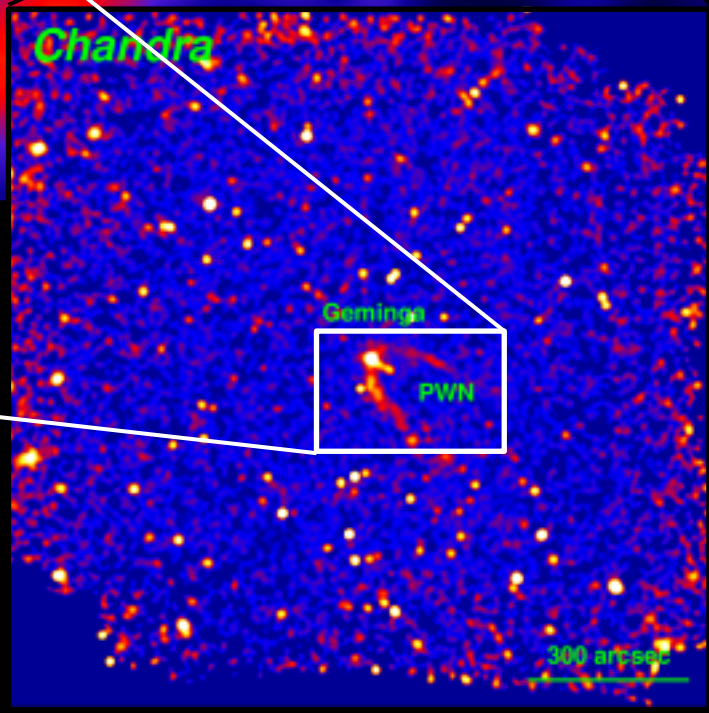
- Growing interest in 'Halos' and significant potential for important astrophysical results
- Confusion (or perhaps Controversy!) on the definition
  - Discussions here towards a common understanding
- A broad spectrum of expertise is needed to (even begin to) understand the full system from pulsar → halo
  - Bring people together with deep knowledge of the different aspects

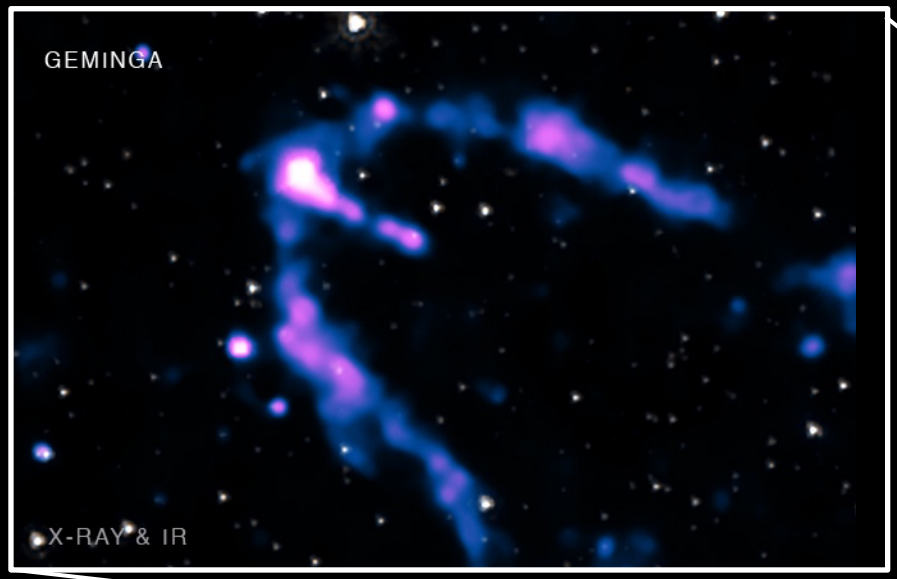
Four brief introductory points – **scales, evolution, propagation, observational status**

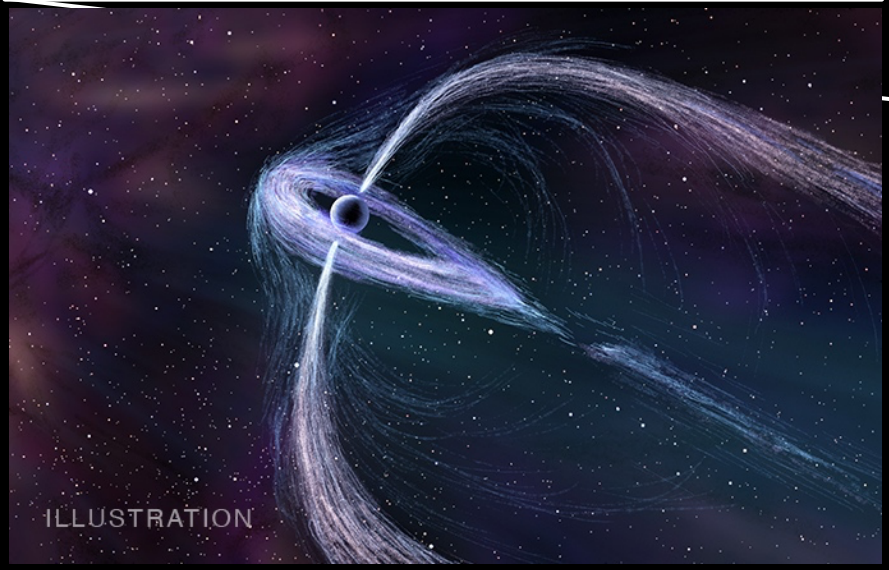
Credit: X-ray: NASA/CXC/PSU/B.Posselt et al

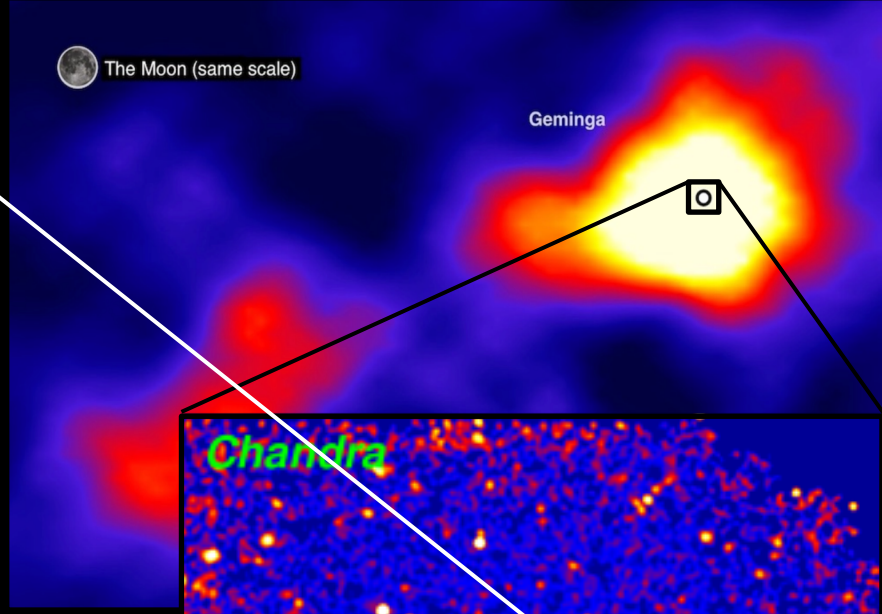












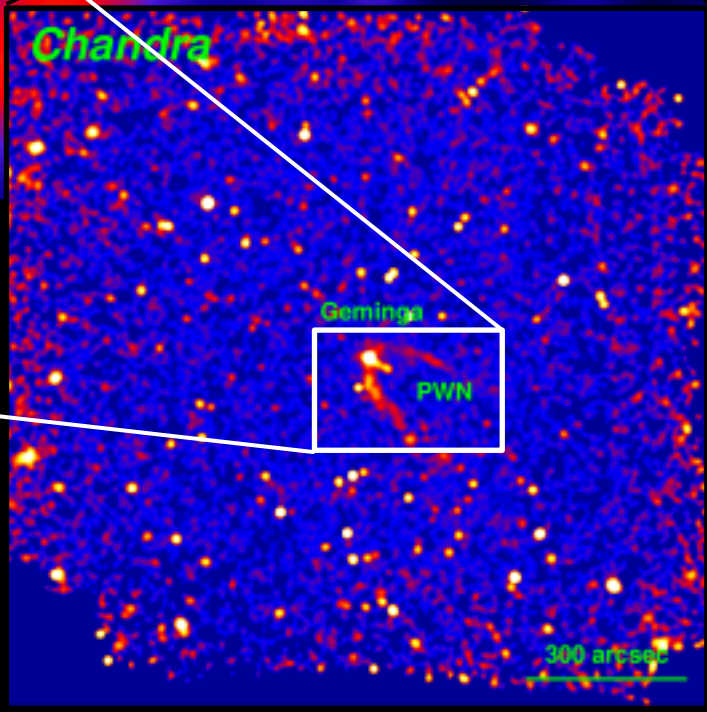
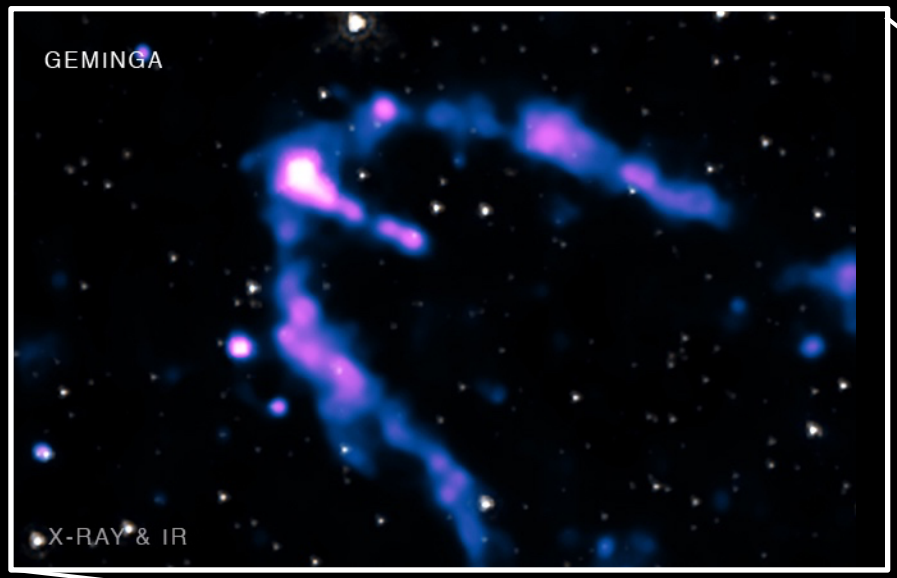
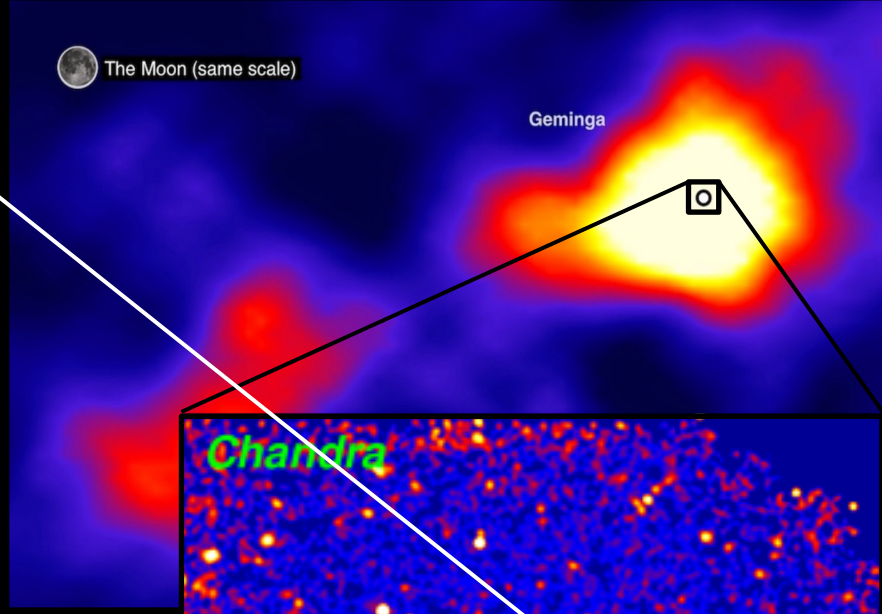
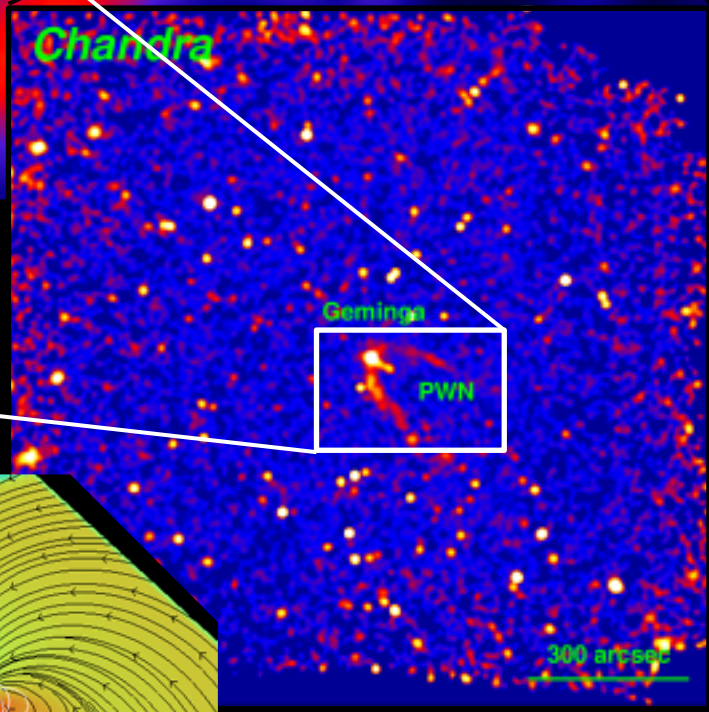
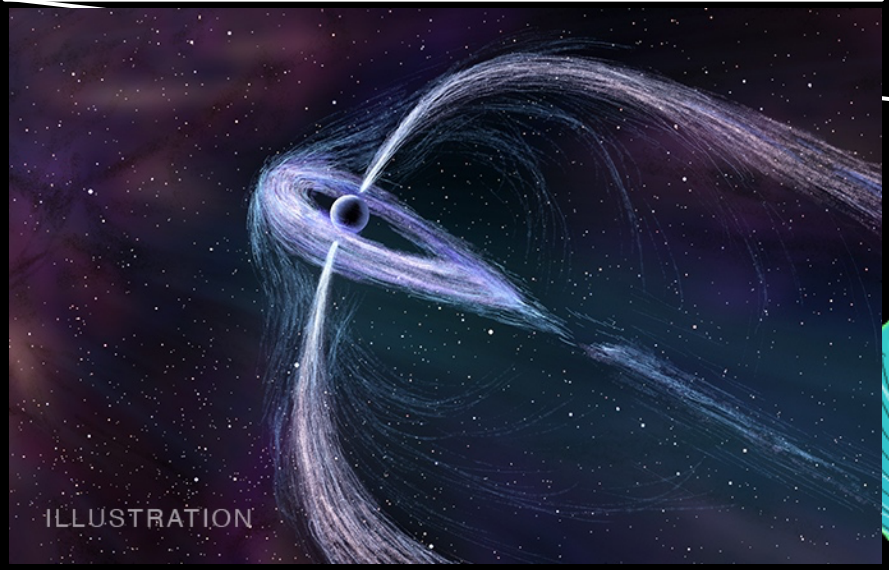


Illustration: Nahks TrEhnl

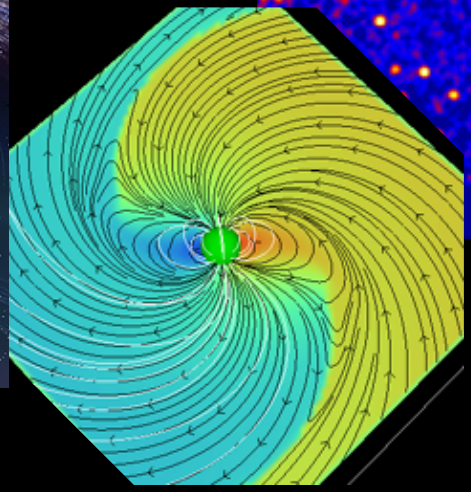

GEMINGA
X-RAY & IR

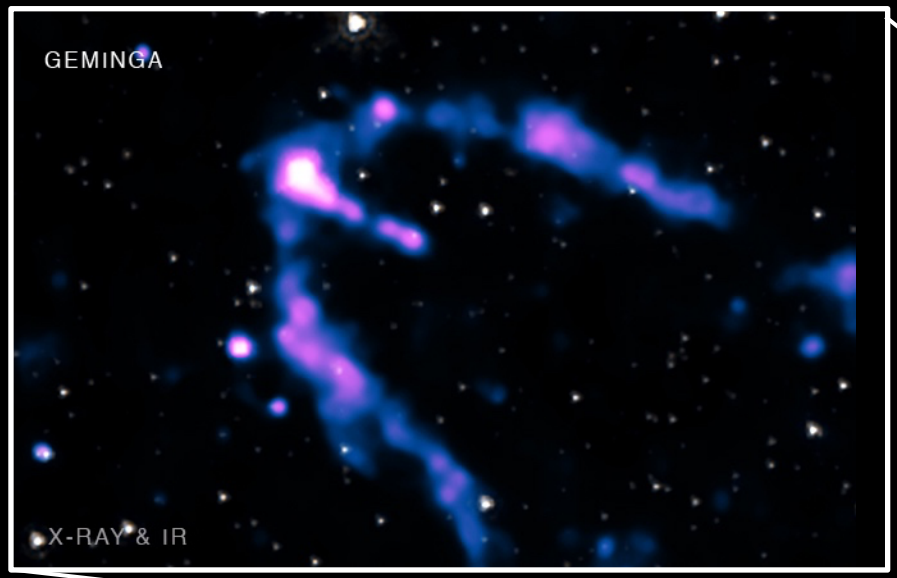

The Moon (same scale)
Geminga

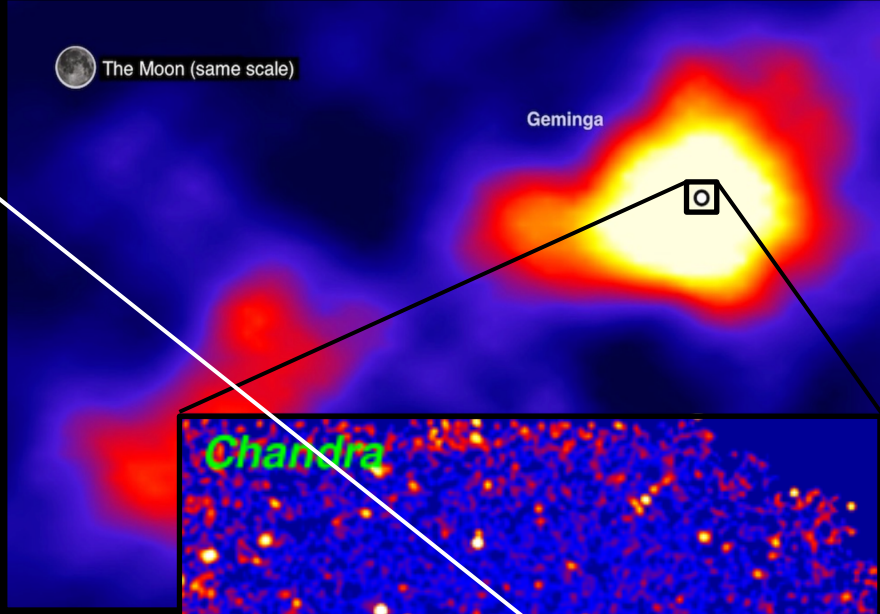

Chandra
Geminga
PWN
300 arcsec

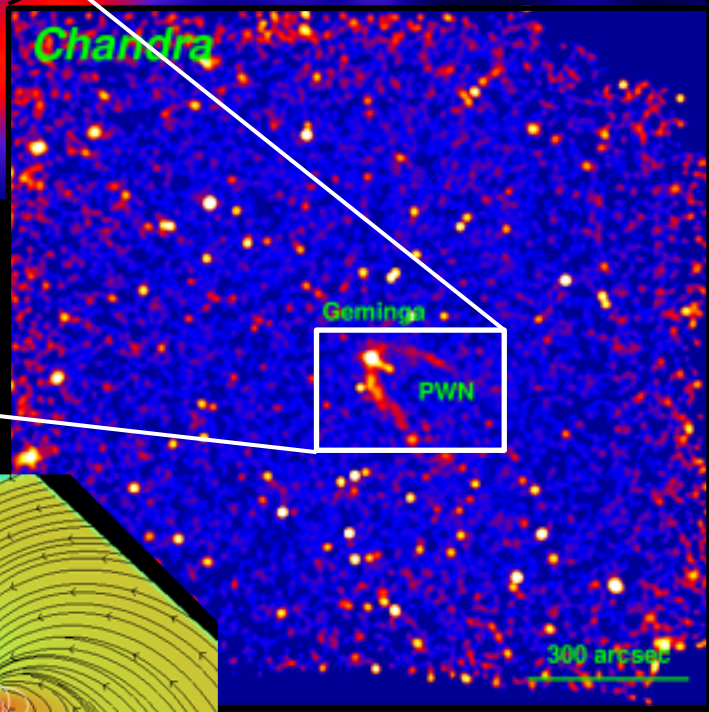


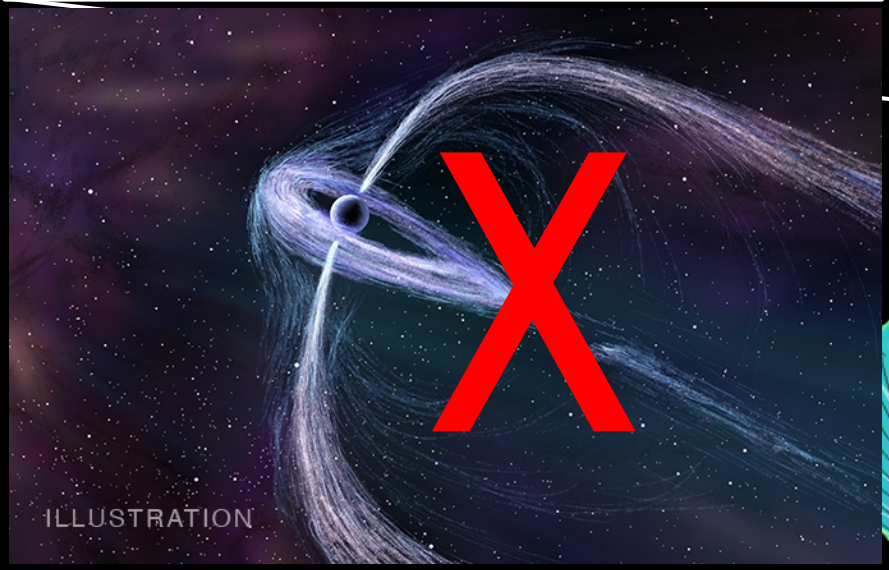
ILLUSTRATION

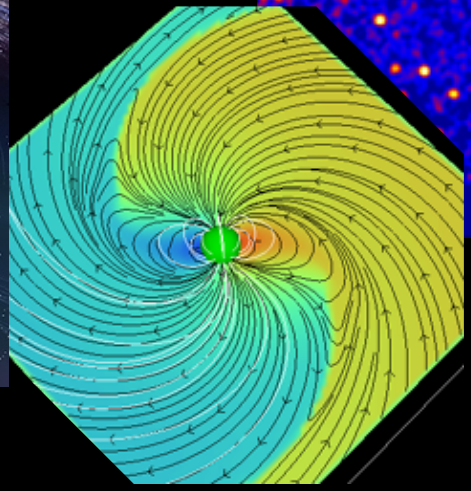


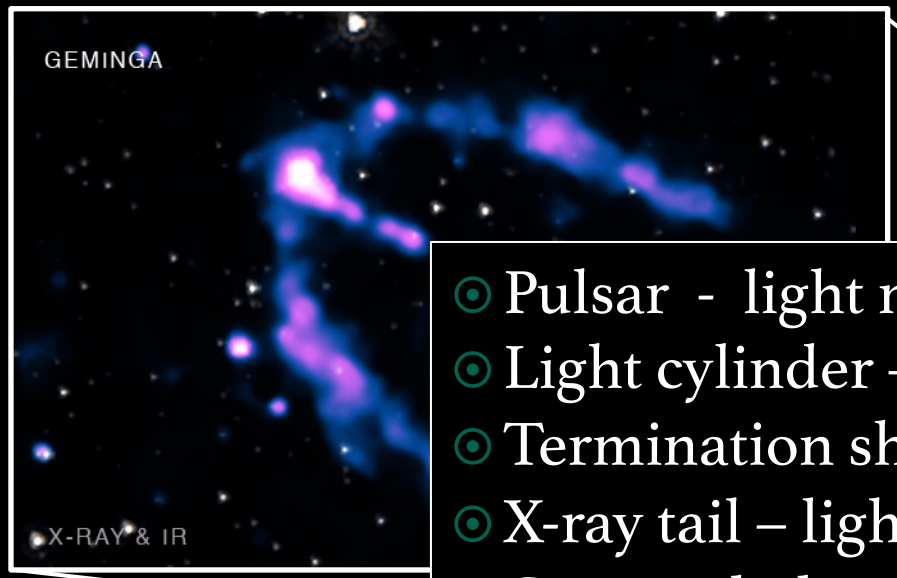

GEMINGA
X-RAY & IR

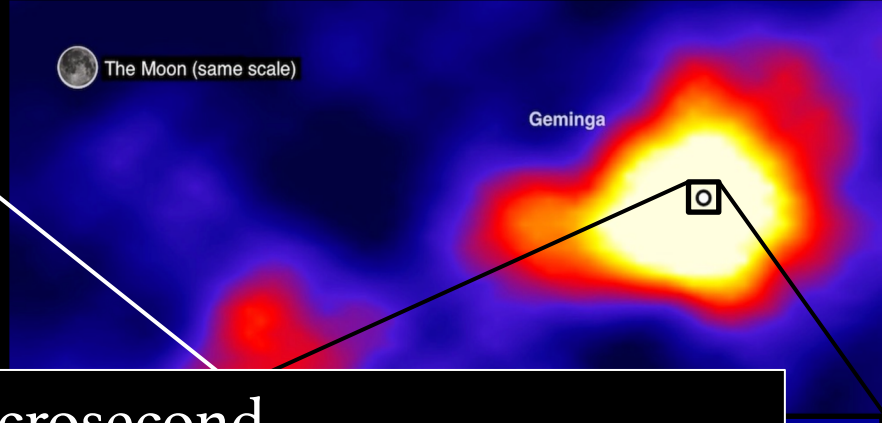

The Moon (same scale)
Geminga


Chandra
Geminga
PWN
300 arcsec

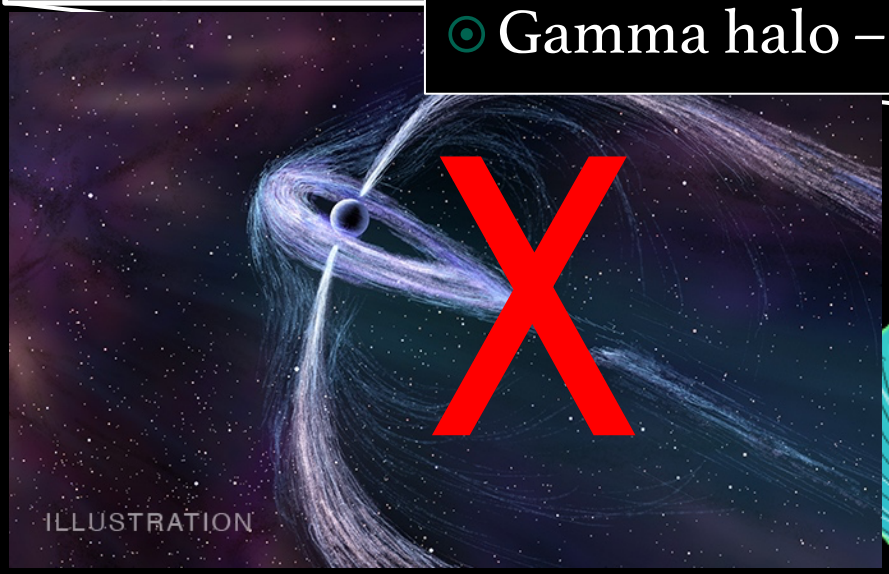

X
ILLUSTRATION

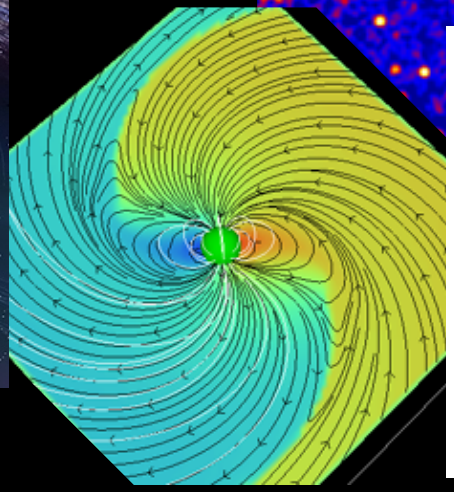


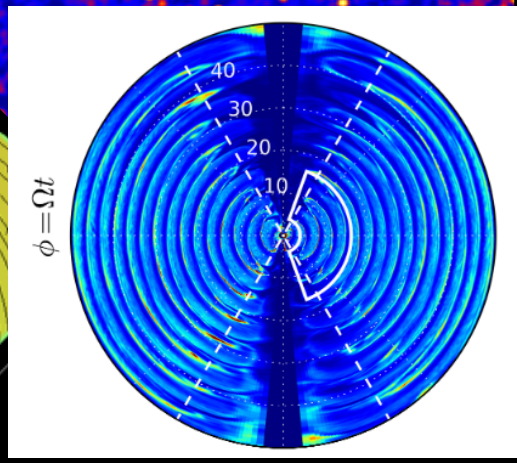


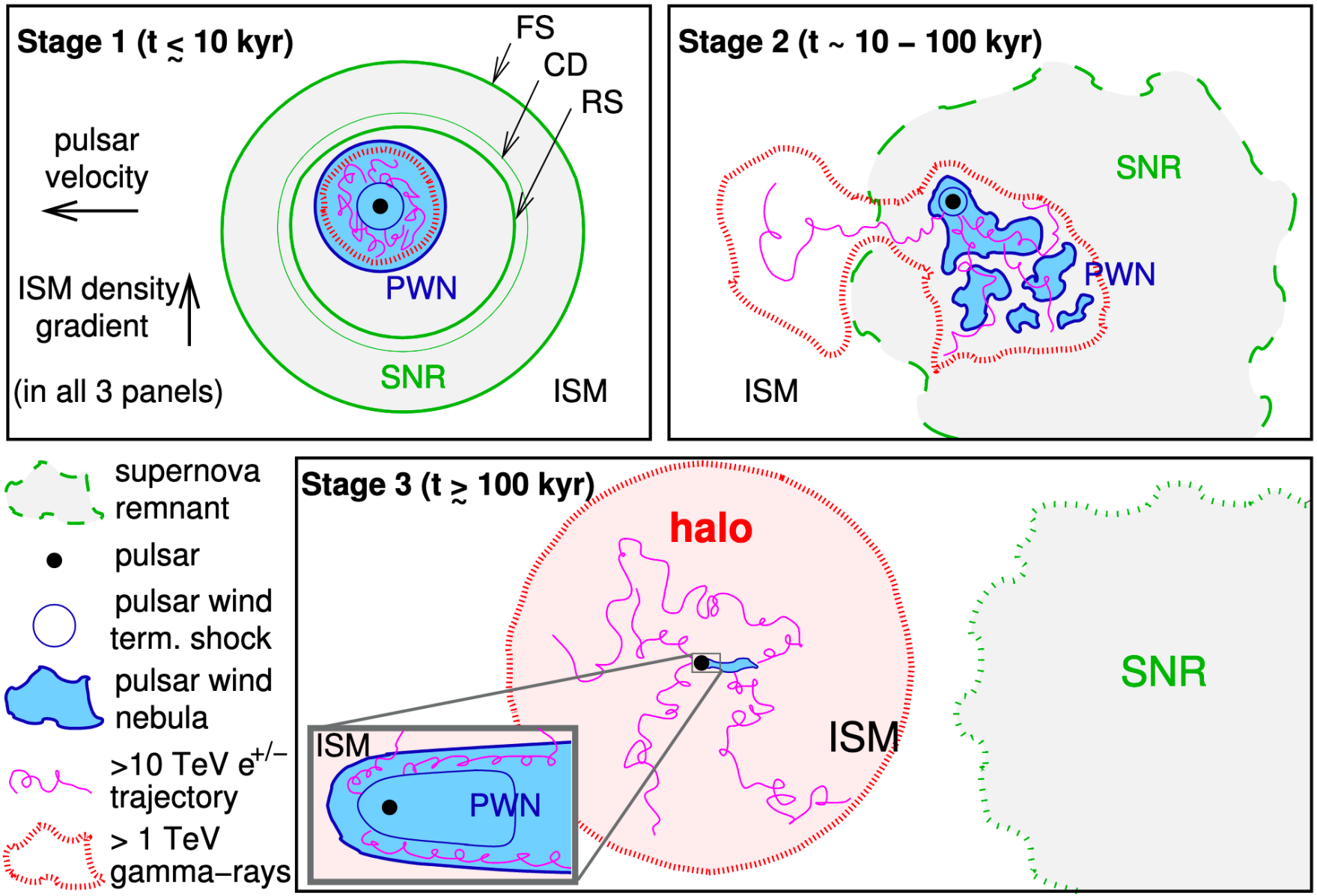


- Pulsar - light microsecond
- Light cylinder – light millisecond
- Termination shock (stand off) – light month
- X-ray tail – light year
- Gamma halo – light century



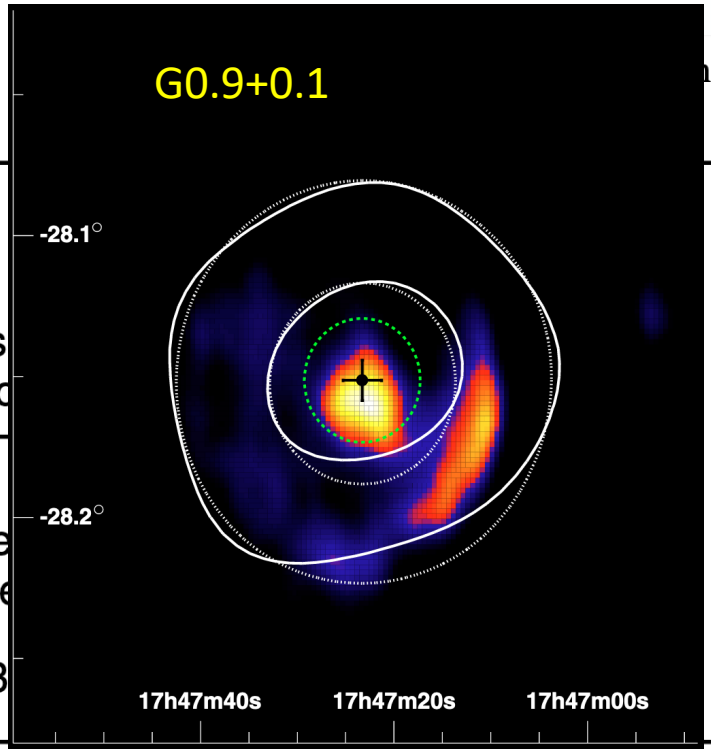





Stage 1 (t ≲ 10 kyr)
FS
CD
RS
pulsar velocity
ISM density gradient
(in all 3 panels)
PWN
SNR
ISM
Stage 2 (t ~ 10 – 100 kyr)
SNR
PWN
ISM
supernova remnant
pulsar
pulsar wind term. shock
pulsar wind nebula
>10 TeV e+/− trajectory
> 1 TeV gamma–rays
Stage 3 (t ≳ 100 kyr)
halo
ISM
PWN
ISM
SNR

A&A 636,

in TeV-bright pulsar wind nebulae

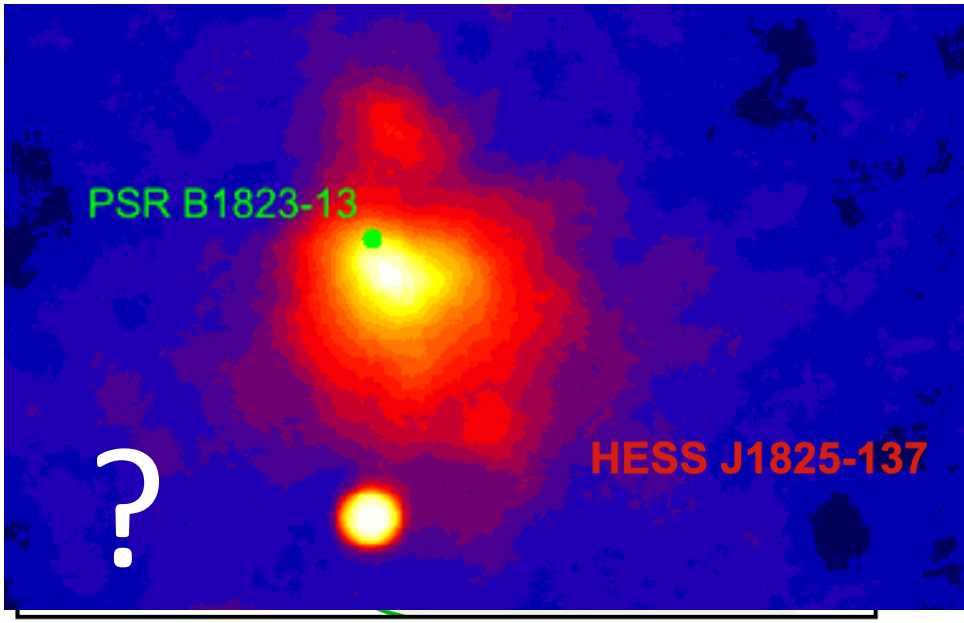


Stage

puls
veloc

ISM de
gradie

(in all 3



supernova remnant

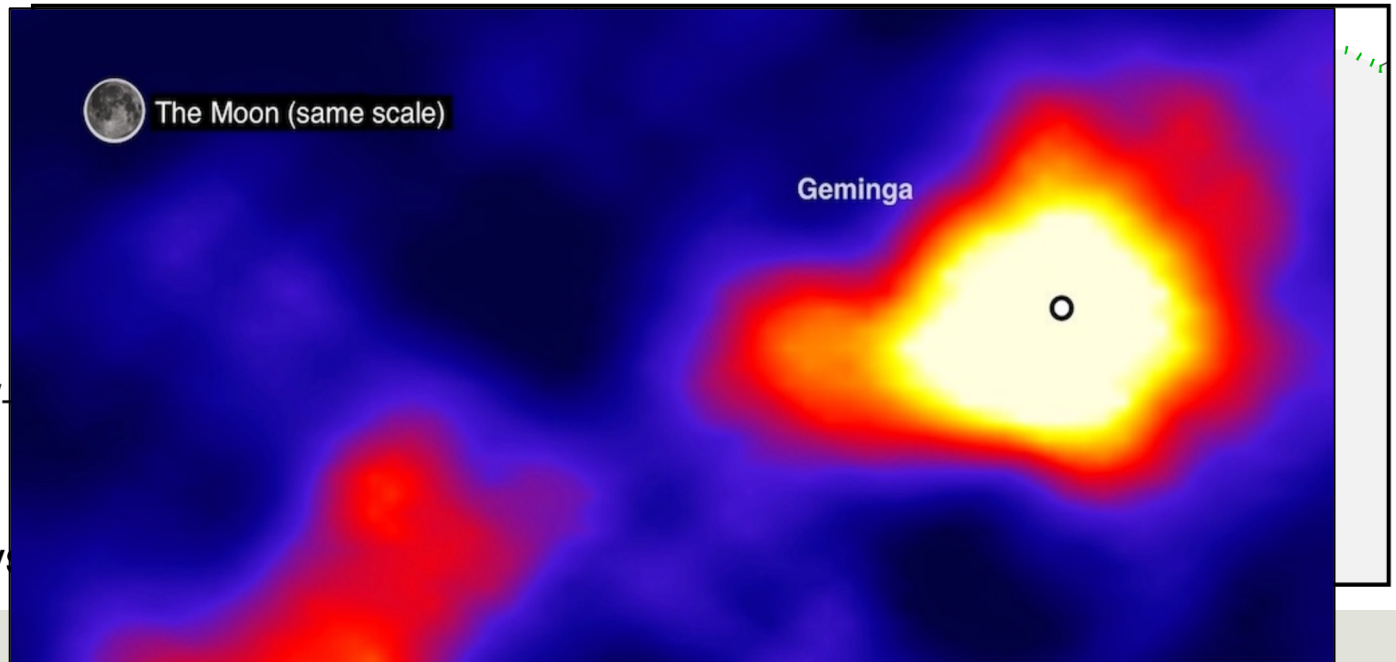
pulsar

pulsar wind term. shock

pulsar wind nebula

>10 TeV $e^{+/-}$ trajectory

> 1 TeV gamma–ray

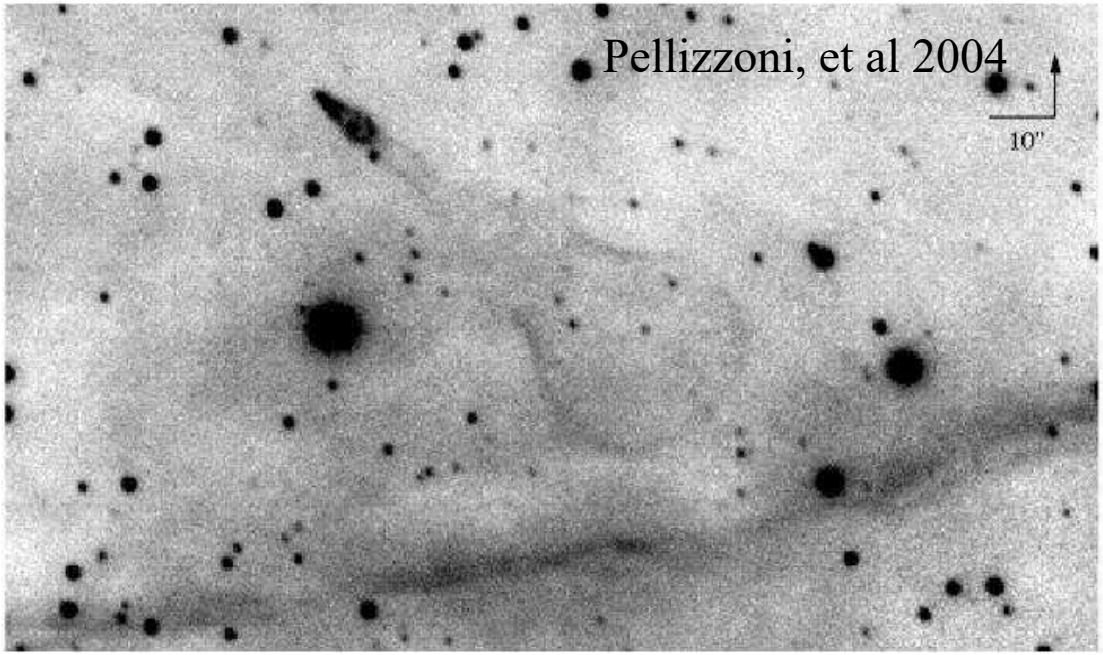


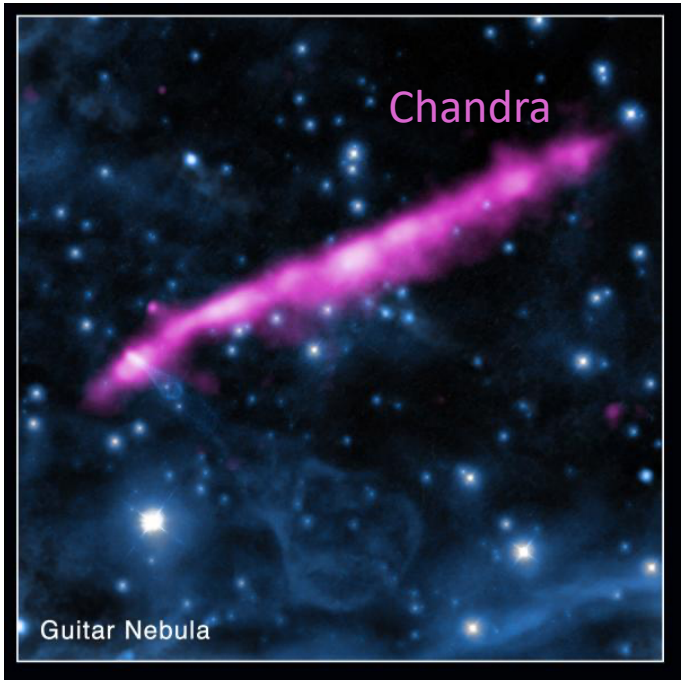
How to get a diffusion coeff?

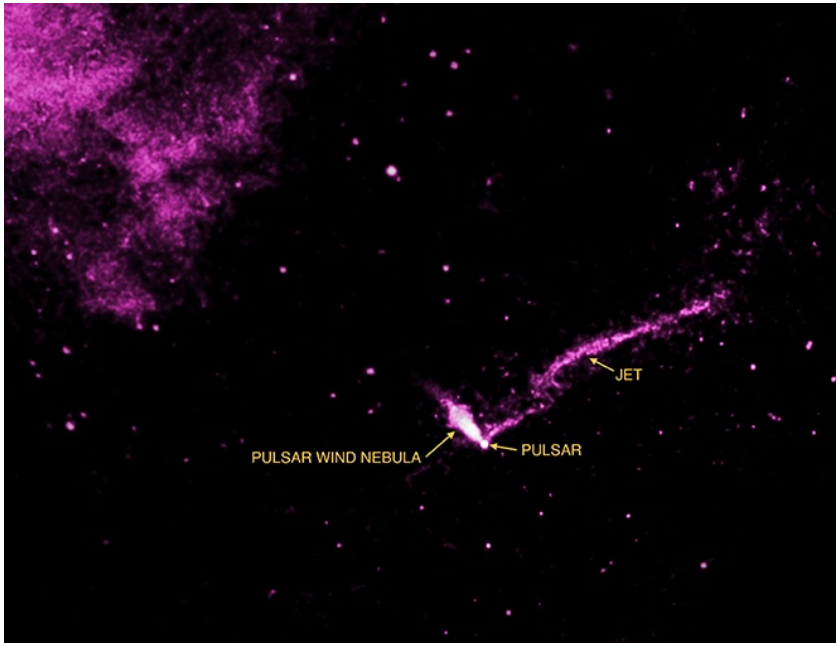
- Burst-like injection, no cooling, uniform target → easy!
  - Blob – if you know the **age** width gives you D
- Continuous injection
  - Feature associated with **cooling** limit of propagation – characteristic 'cooling radius'
    - Changes with electron energy, ambiguities in terms of measured energy in particular for instruments with poor energy resolution
  - Or: Feature associated with limited **age** of the sources
  - BUT
    - Cooling rate poorly constrained (IC losses, synch losses)
    - Injection history poorly constrained, pulsar and PWN evolution…
- Old source, no cooling
  - Steady state, 1/r profile, no info from shape → BUT
    - **Luminosity provides constraint** on D → available injected power

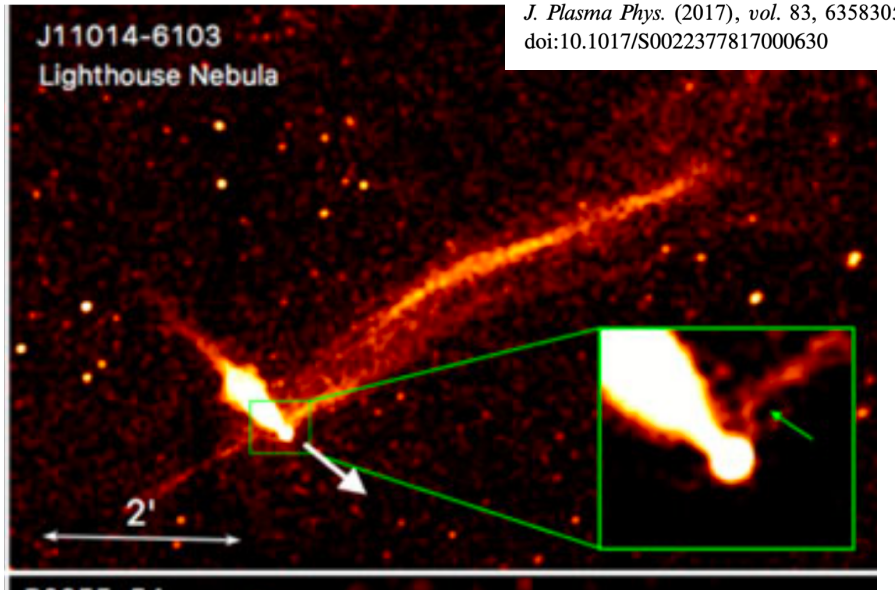
BUT → all assumes isotropic diffusion on all relevant scales…

Also projection effects complicate the picture



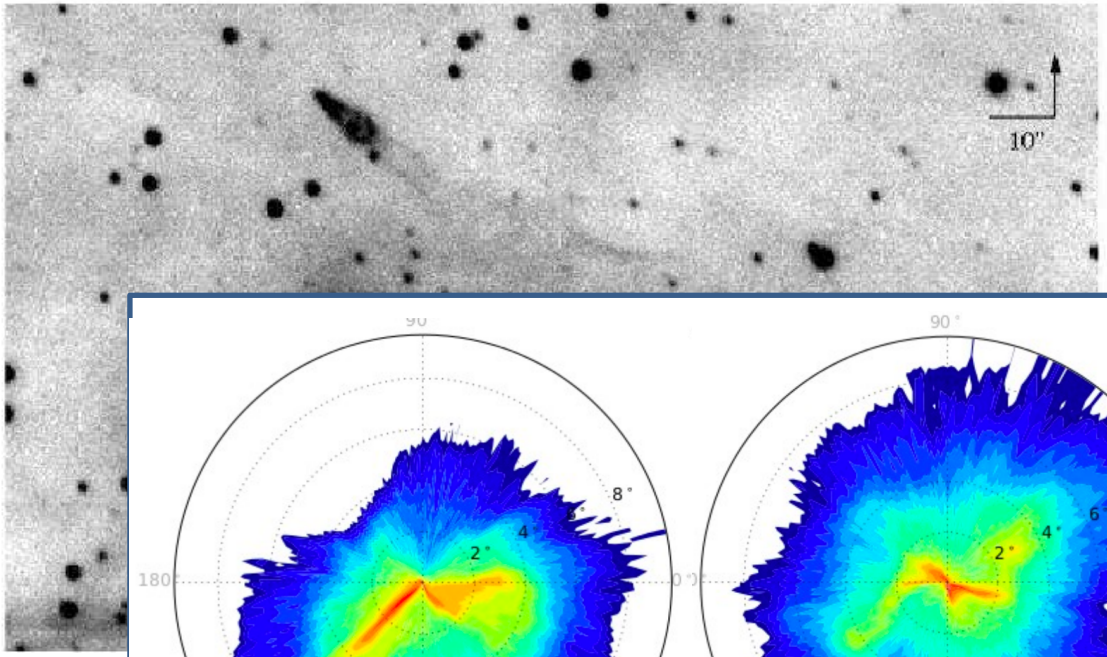


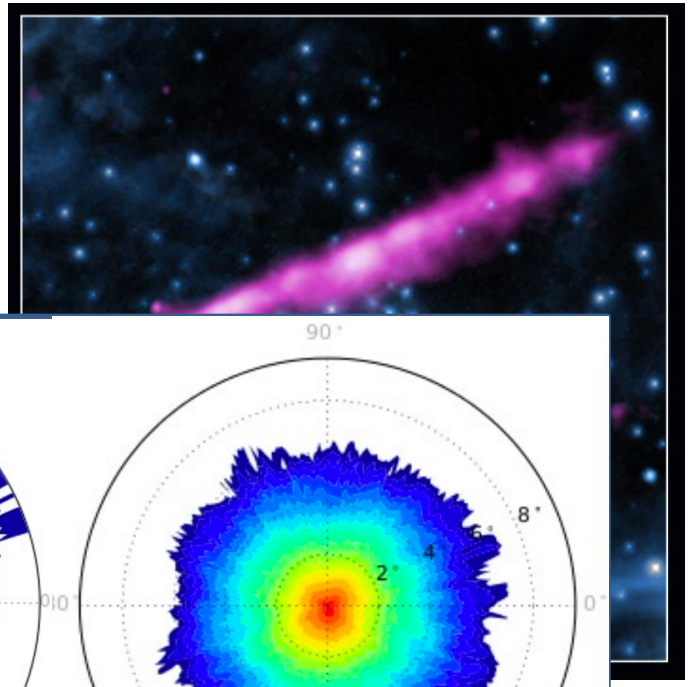


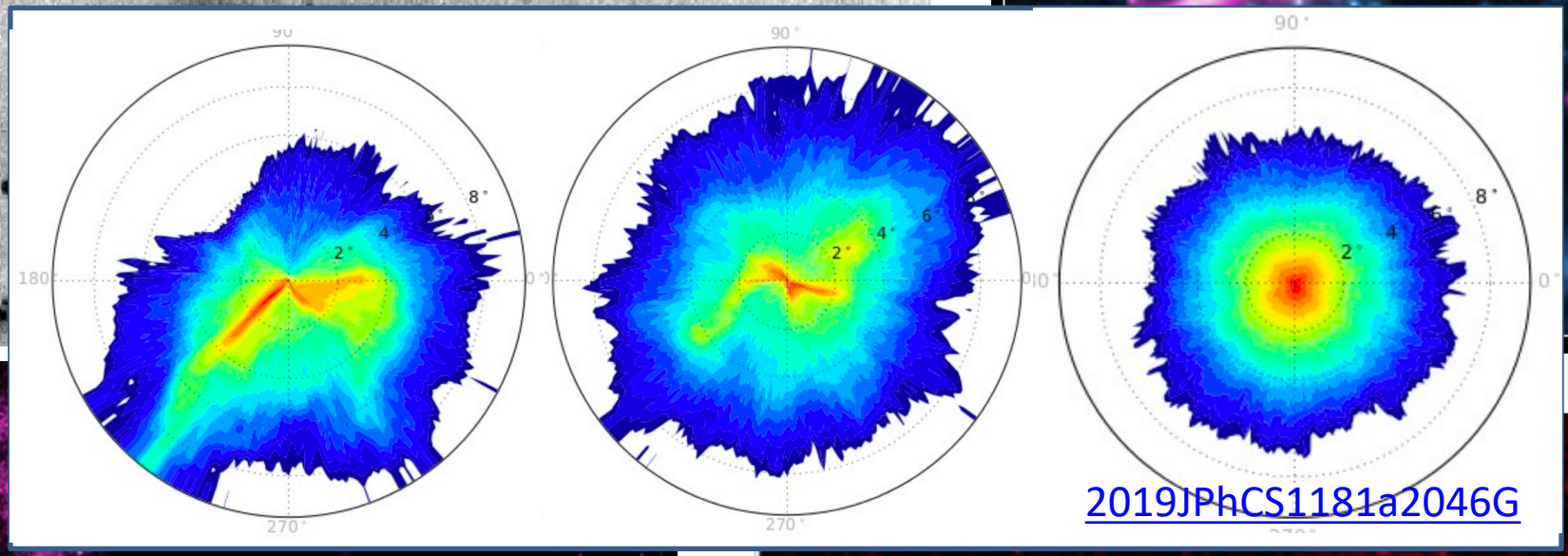


J. Plasma Phys. (2017), *vol.* 83, 635830501
doi:10.1017/S0022377817000630

NASA / CXC / ISDC / L. Pavan et al.







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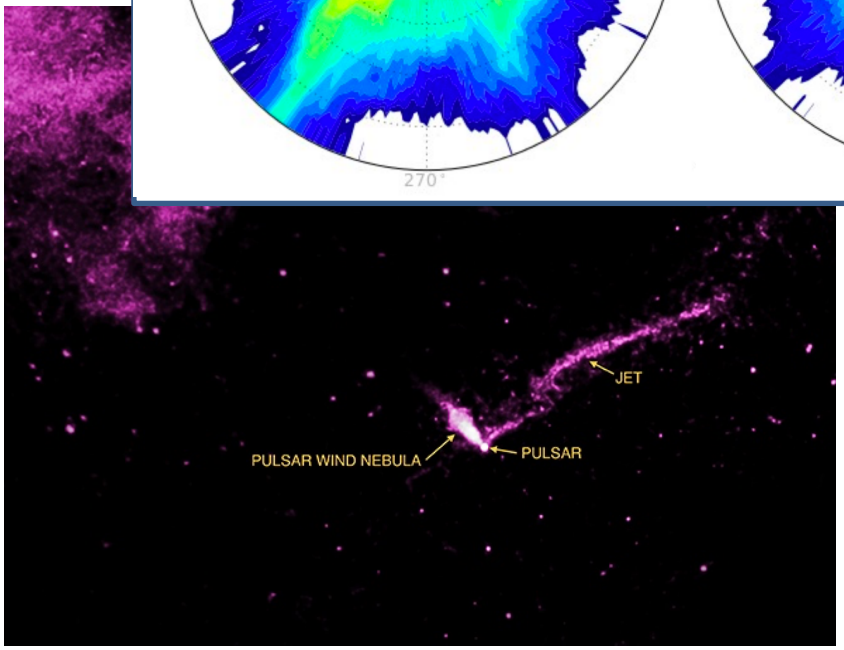

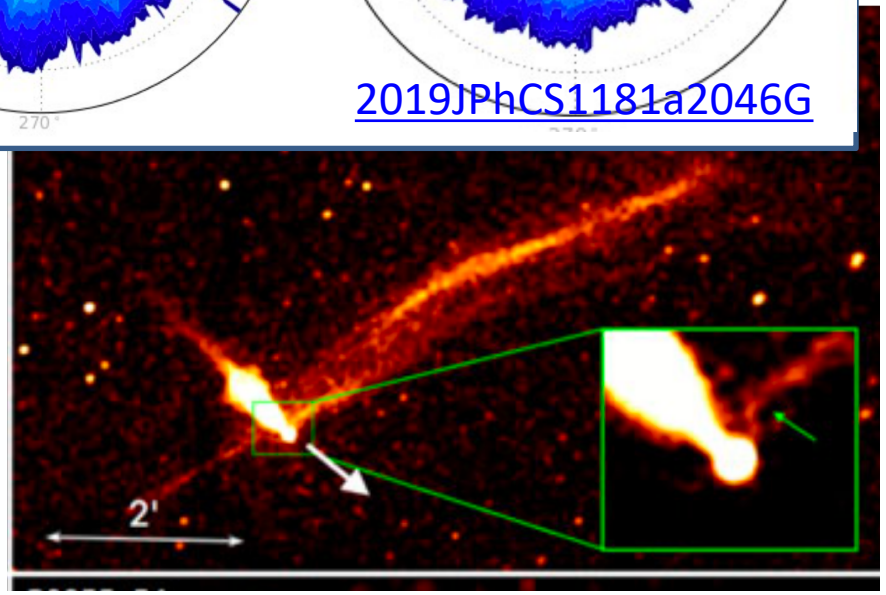

Observational Status