Evolution of the Composite Supernova Remnant G327.1-1.1

Collaborators:

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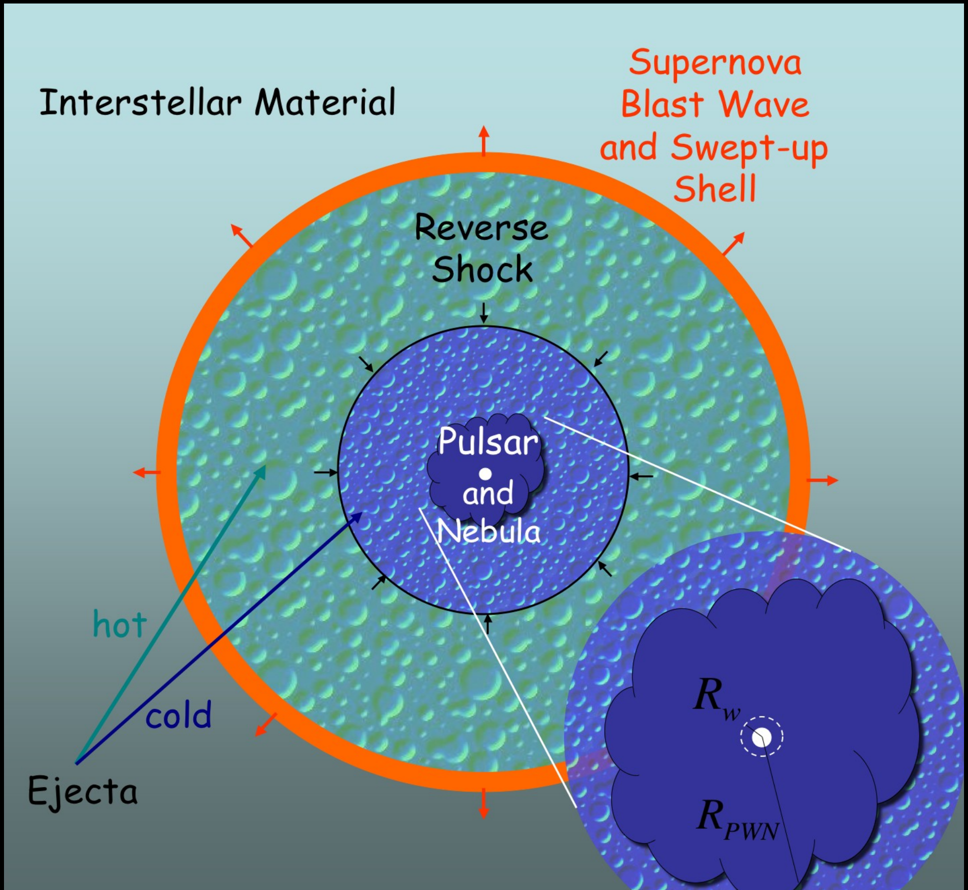
Evolution of Composite Supernova Remnants

- Early Evolution: PWN drives a shock into the inner SN ejecta

- Late Evolution: PWN interacts with the SN reverse shock, usually asymmetrically

  (Blondin et al. 2001, van der Swaluw et al. 2004)

  - Pulsar motion
  - Non-uniform ISM



Gaensler & Slane 2006

Evolution of Composite Supernova Remnants

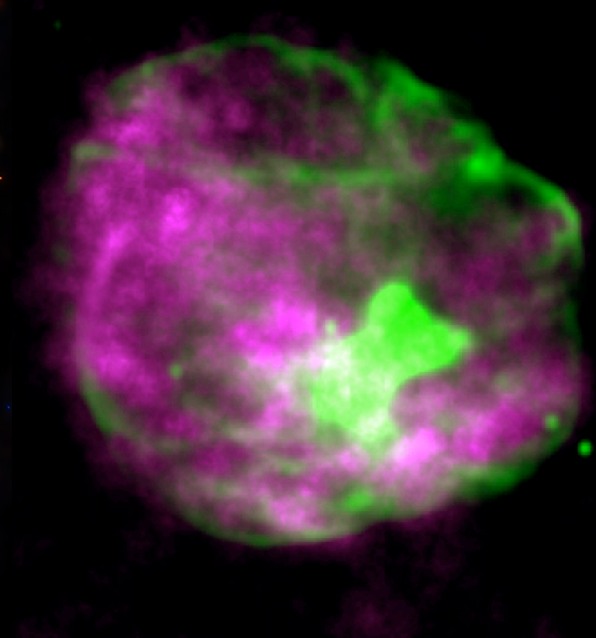
Age: < 1000 yr ~ 1200 yr ~ 16500 yr

R ~ 3.6 pc

SNR G21.5-0.9
(Matheson & Safi-Harb 2010)

R ~ 8 pc

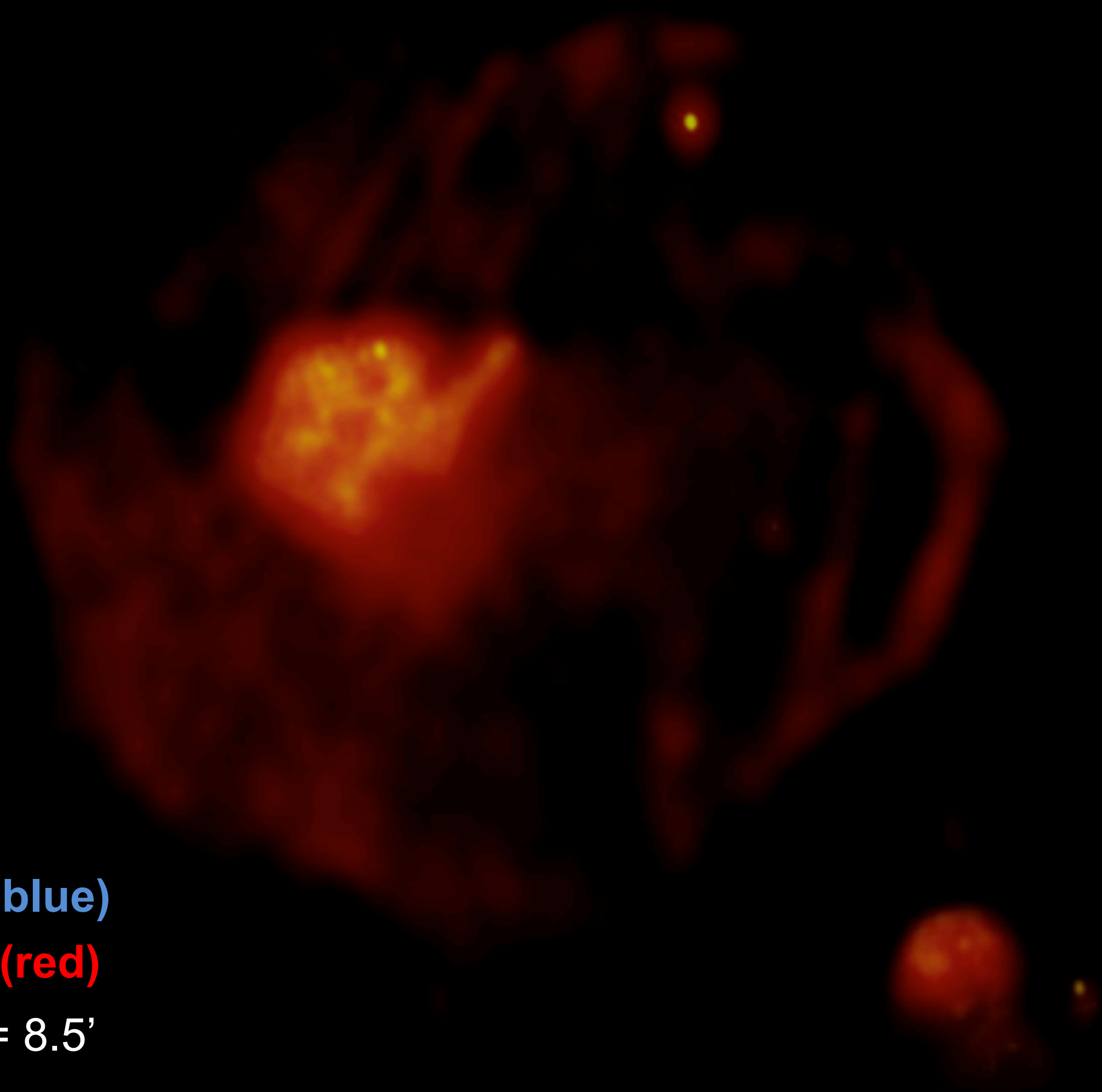
SNR MSH 11-62
(Slane et al. 2012)



R ~ 20 pc

SNR MSH 15-56
(Temim et al. 2013)

SNR G327.1-1.1: Crushed PWN in an evolved SNR



Sedov

(d = 9 kpc)

R = 22 pc

n_0 = 0.12 cm^{-3}

Age = 17k yr

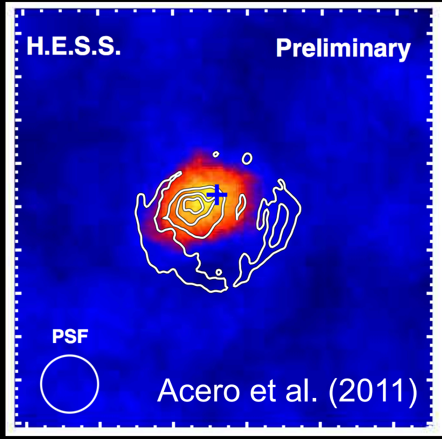
T = 0.3 keV

v_s = 500 km/s

N_H = 2 x 10^{22} cm^{-2}

v_{PSR} = 400 km/s

Also a γ-ray source



X-ray (blue)

Radio (red)

R_{SNR} = 8.5'

Temim et al. 2009

SNR G327.1-1.1: Crushed PWN in an evolved SNR

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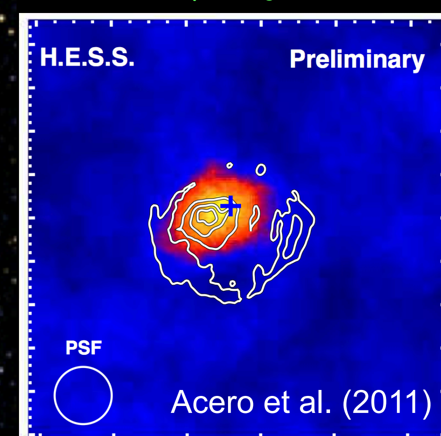
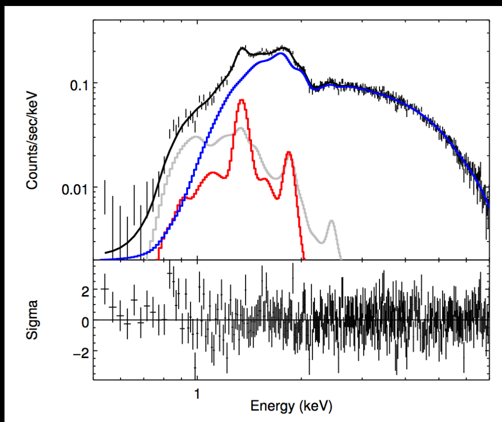
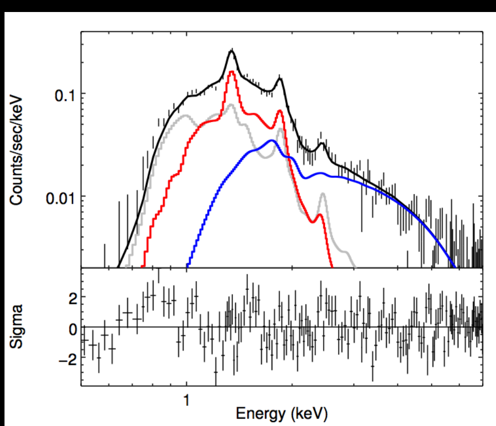


Chandra 350 ks observation

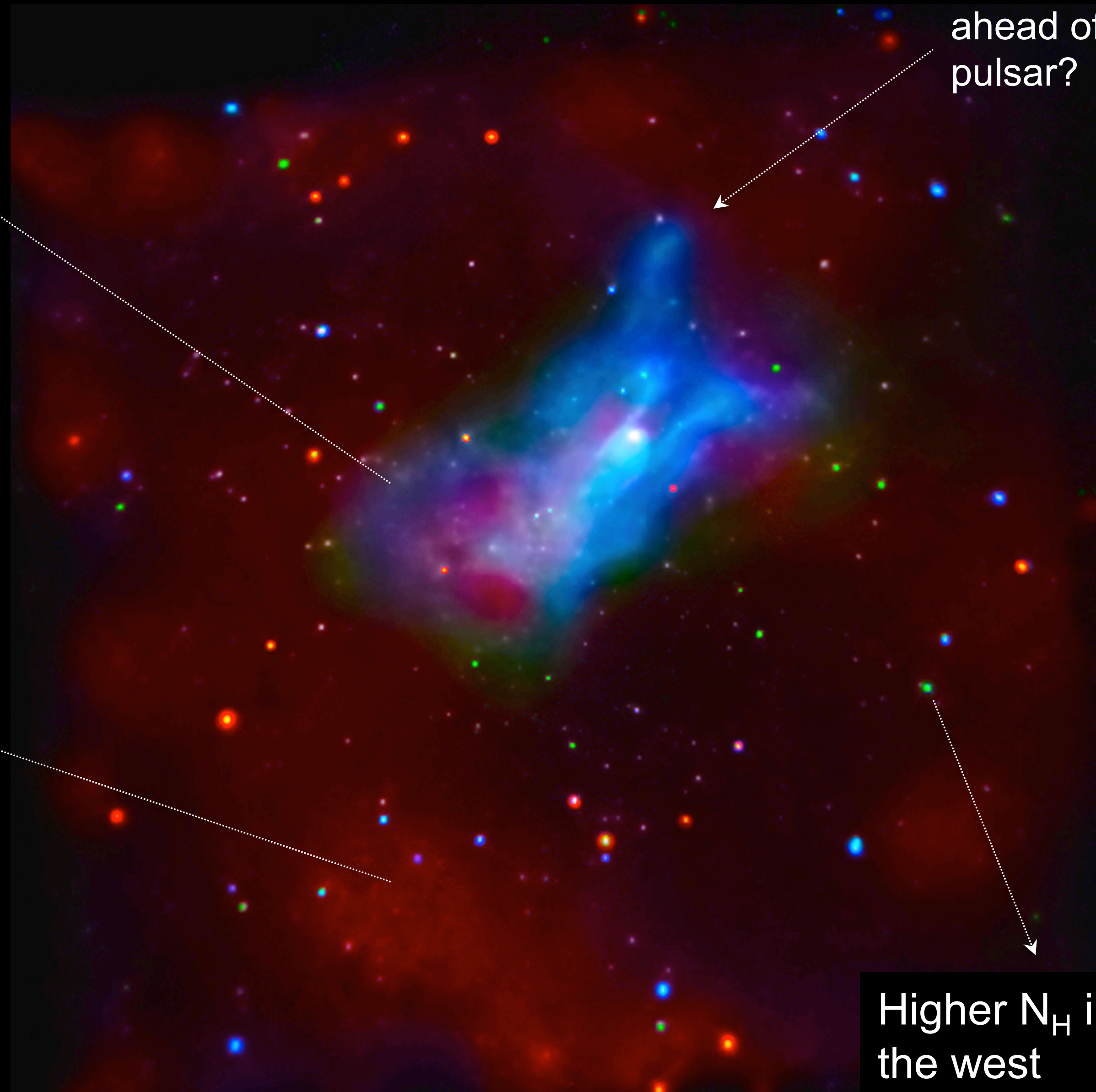
X-ray emission from relic PWN, mixed-in ejecta



Thermal X-ray emission from SNR shell, T= 0.3 keV



Outflow ahead of the pulsar?



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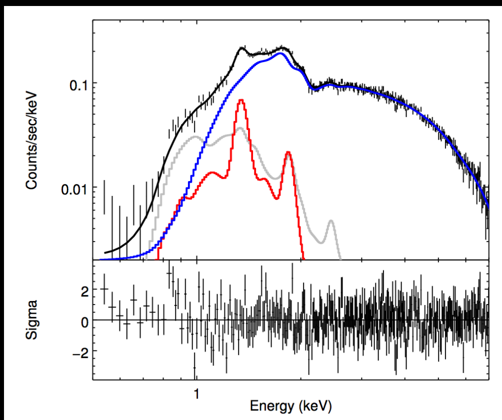

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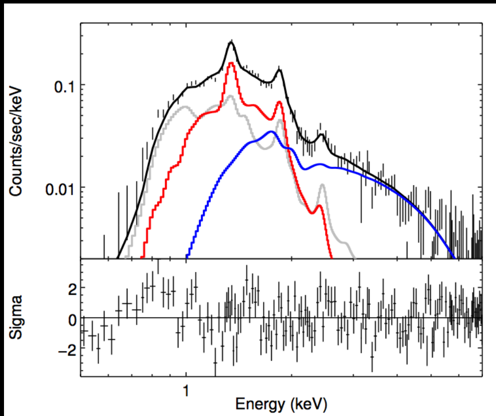

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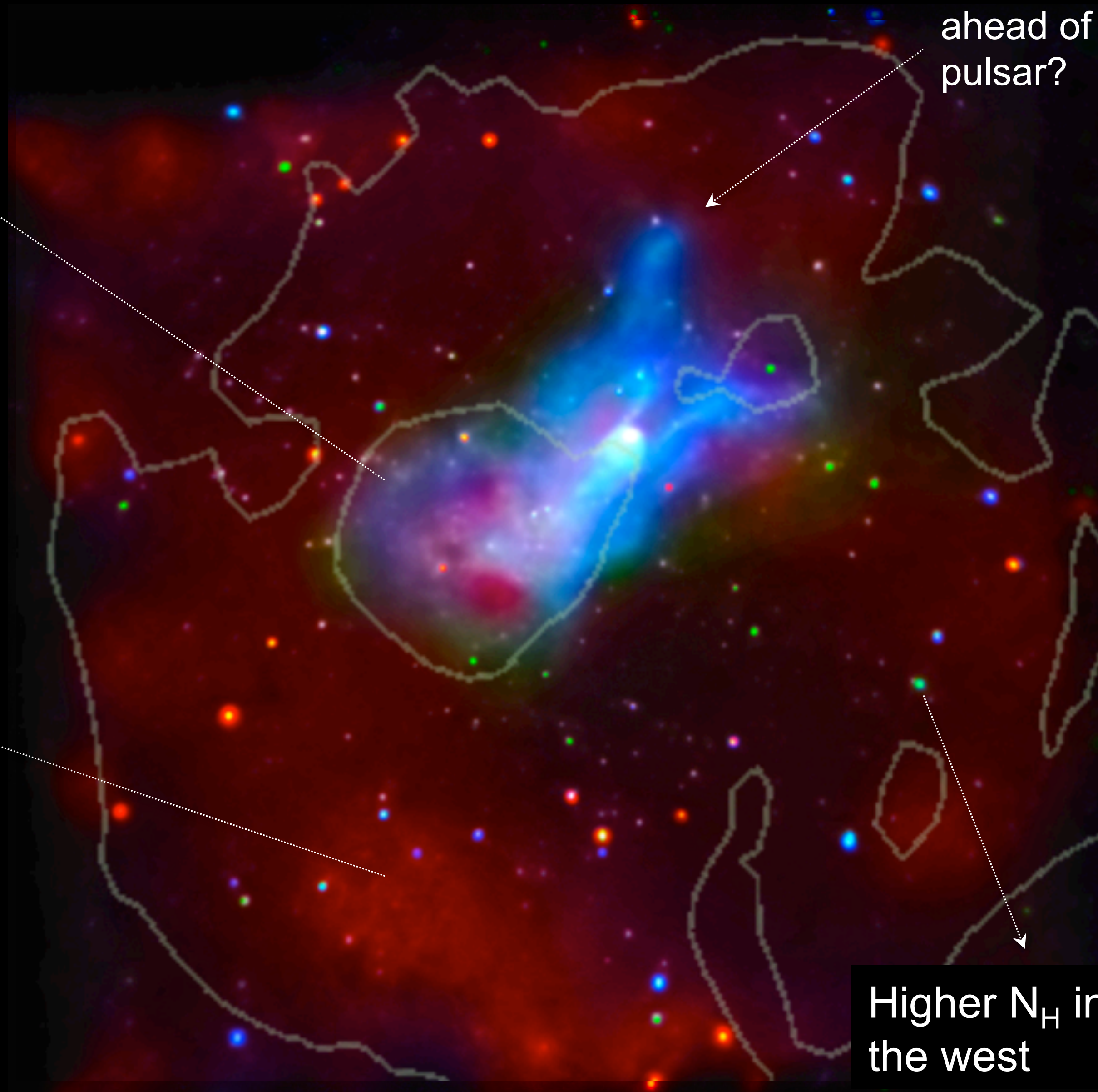


Higher N_H in the west

HD Model of a PWN Expanding Inside a Supernova Remnant

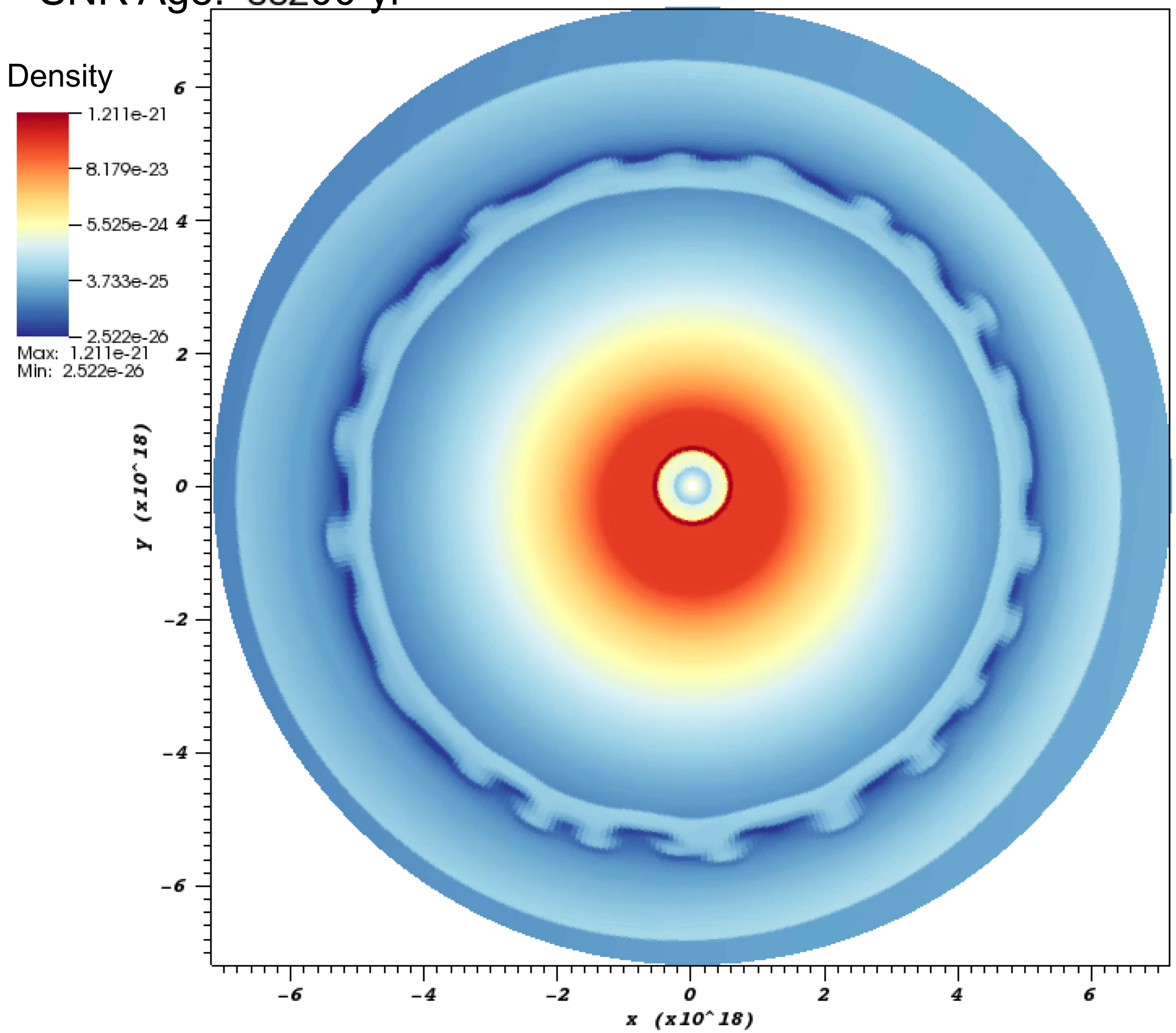
Parameter	Description	Value
SNR Properties:		
D (kpc)*	SNR distance	9.0
R_{SNR} (pc)*	SNR radius	22
v_s (km/s)*	Shock velocity	500
t (yr)*	SNR age	17400
n_0 (cm^{-3})	Average ambient density	0.12
E_{51} (10^{51} erg)	Explosion energy	0.5
M_{ej} ($M_\odot$)	SN ejecta mass	4.5
PWN Properties:		
R_{PWN} (pc)*	PWN radius	5.0
v_p (km/s)	Pulsar velocity	400 (north)
$L_{X(2-10)}$ (erg/s)	PWN X-ray luminosity	7.2×10^{34}
$\dot{E}_0$ (erg/s)	Initial spin-down luminosity	2.8×10^{38}
n	Pulsar braking index	3.0
τ_0 (yr)	Spin-down timescale	2000
B (μG)	PWN magnetic field	11
Density Gradient:		
x	Density contrast of 12.5	1.08
H (pc)	Characteristic length scale	5.2
Orientation		East/West

Time dependent pulsar spin-down power driving the PWN:

$$\dot{E} = \dot{E}_0 \left(1 + \frac{t}{\tau}\right)^{-\frac{n+1}{n-1}}$$

Parameters in blue adjusted to produce the desired PWN morphology and SNR/PWN dimensions at the estimated SNR age of ~ 17,000 yr.

SNR Age: 00200 yr



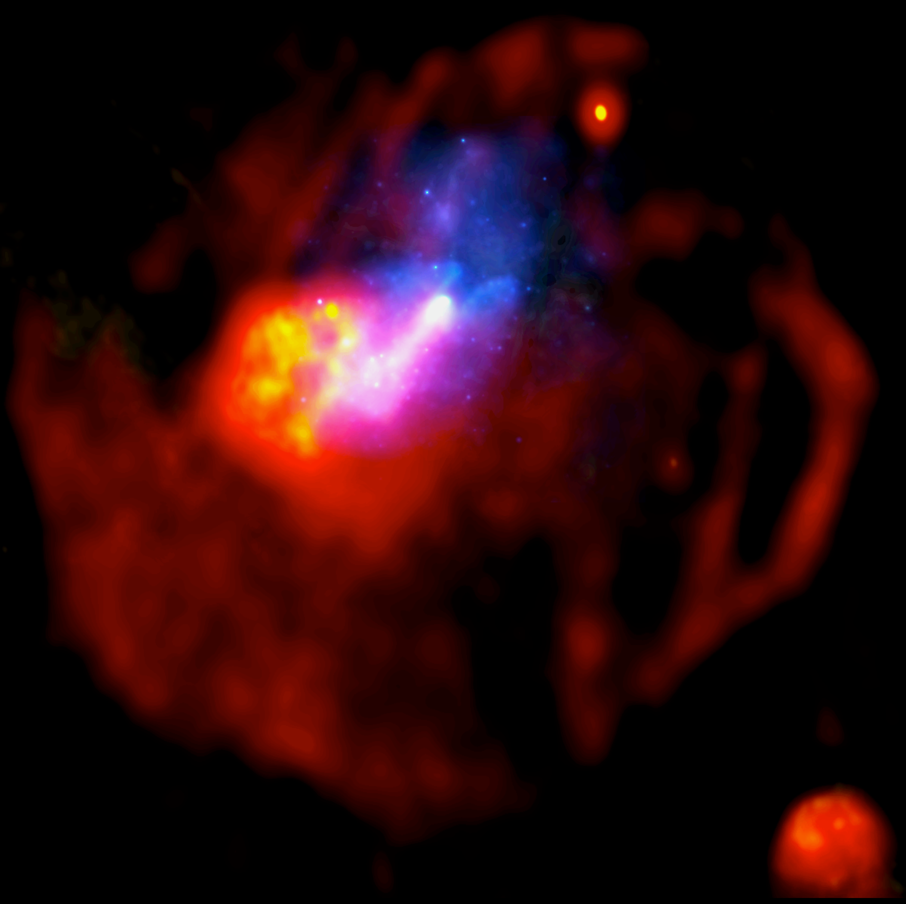
Pulsar velocity 400 km/s

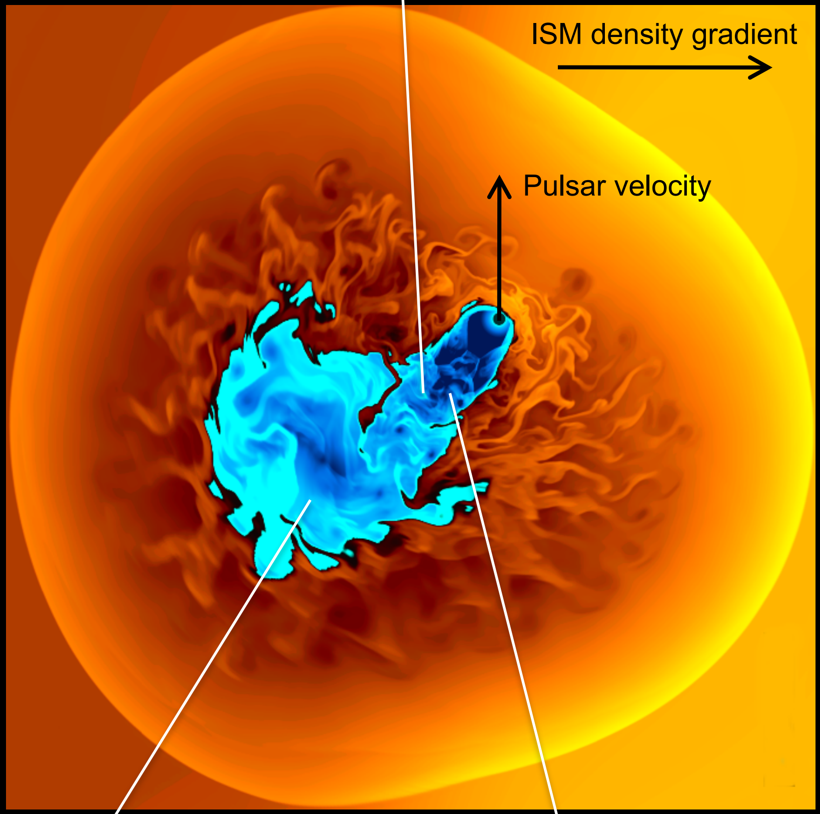
ISM density gradient

Modified VH-1 (Blondin et al. 2001)

Morphology Comparison

Trail thickness → pulsar's spin down luminosity

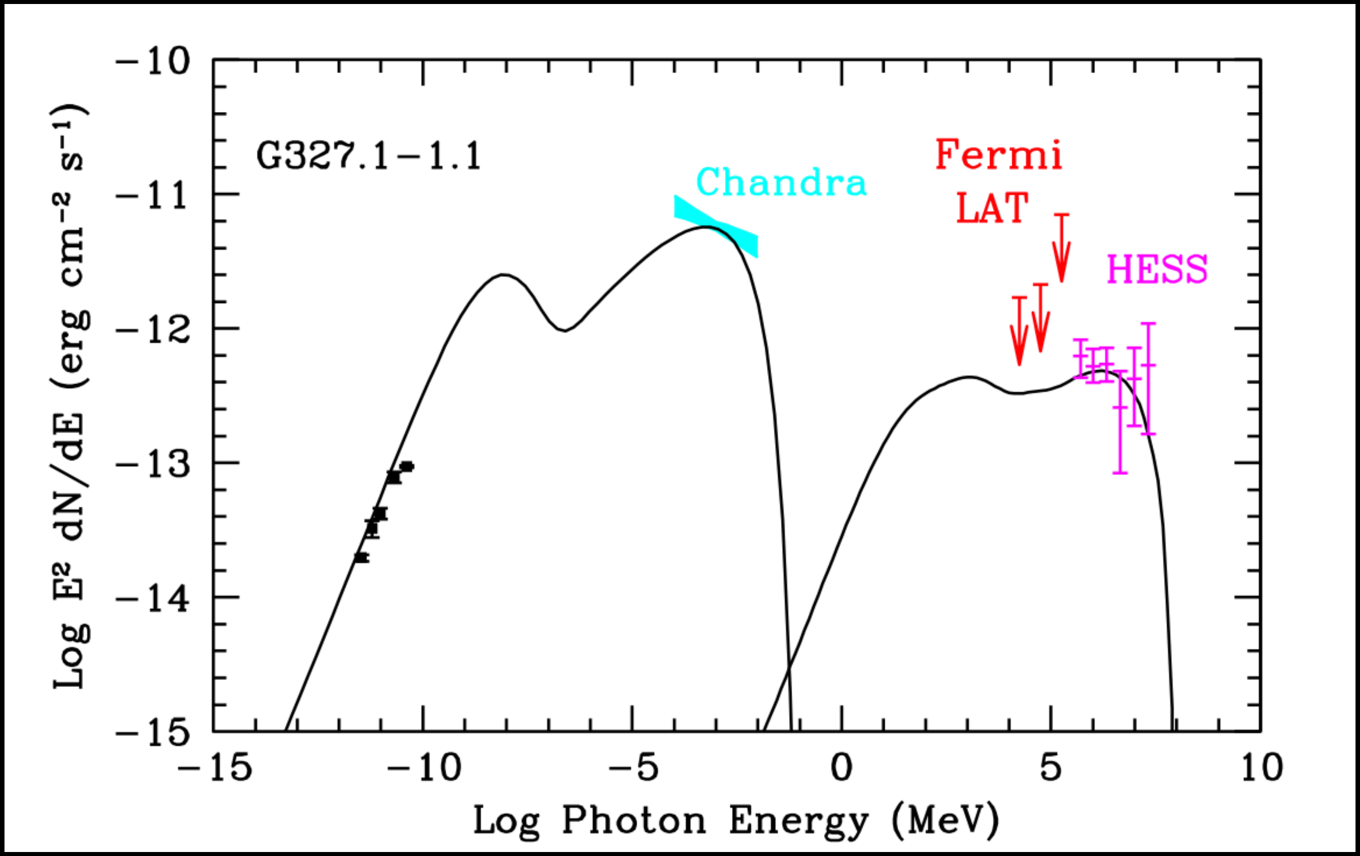




Displacement of "relic" PWN → orientation of density gradient

Orientation of trail → combination of gradient and pulsar motion direction

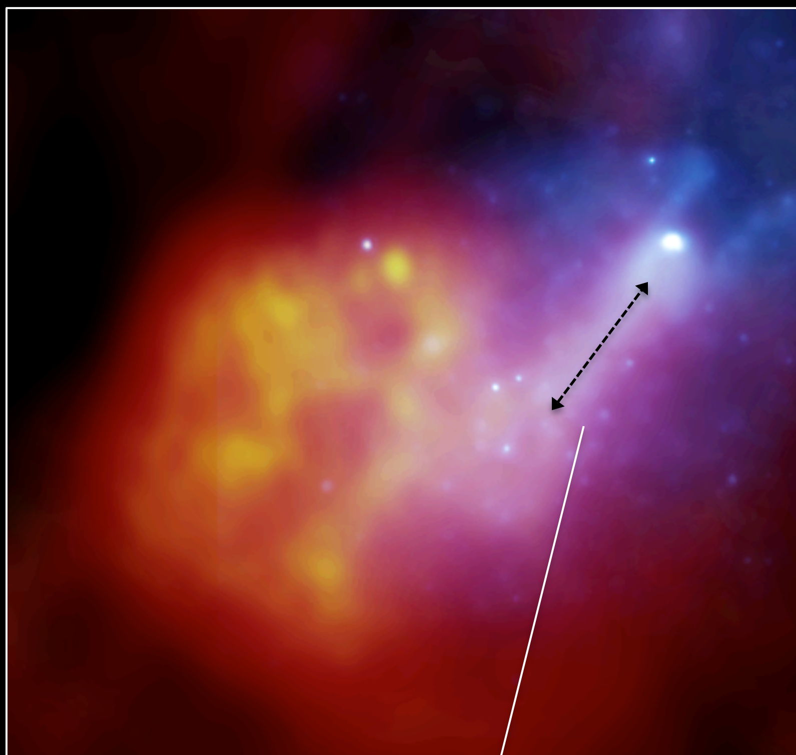
Broadband Spectrum of the PWN at 17,000 yrs

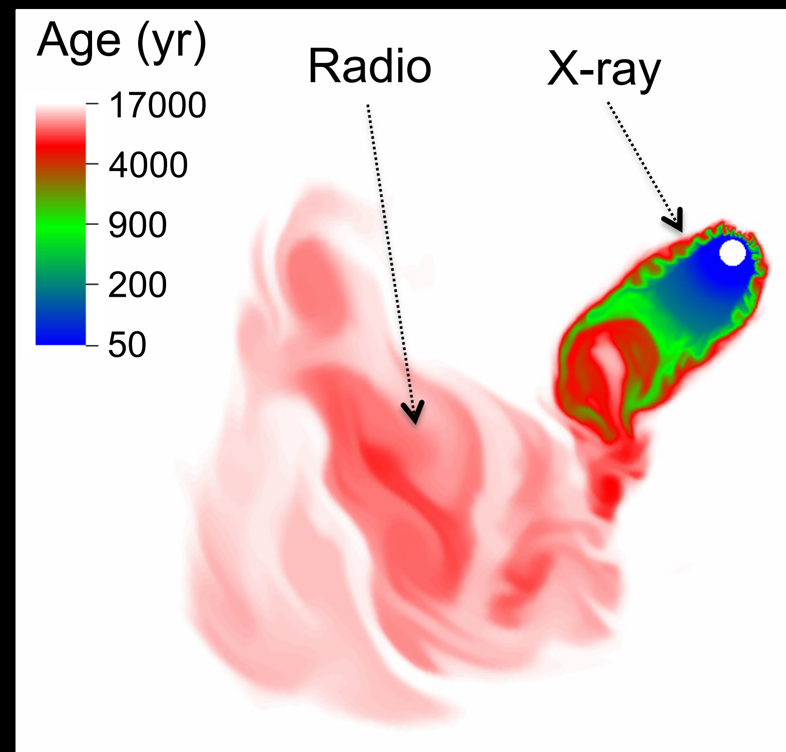


- Model for radiative evolution of the PWN - Gelfand et al. (2009)
- Input parameters from observational constraints and HD model

→ B = 11 μG and an electron energy break at 300 GeV

Age of particles injected by the pulsar at SNR age of 17,000 yr





Photon index in the trail steepens from 1.76 to 2.28:

$\Delta\Gamma = 0.52 \pm 0.17$

Synchrotron lifetime ~ 1700 yr

→ Expect spectral steepening of 0.5 over a synchrotron lifetime

Conclusions

• Observed properties of SNR G327.1-1.1 explained by an SNR expanding in a density gradient with orientation perpendicular to the pulsar's motion → can also reproduce the spectral properties of the PWN

• The simulations give insight into the structure and evolution of composite SNRs and clues on what physical parameters determine the morphology of the systems → information about ambient ISM, SN ejecta, pulsar properties

See poster by Chris Kolb for more details on the HD model!

T. Temim, P. Slane, C. Kolb, J. Blondin, J.P. Hughes, & N. Bucciantini, ApJ, 2015, soon on arXiv!