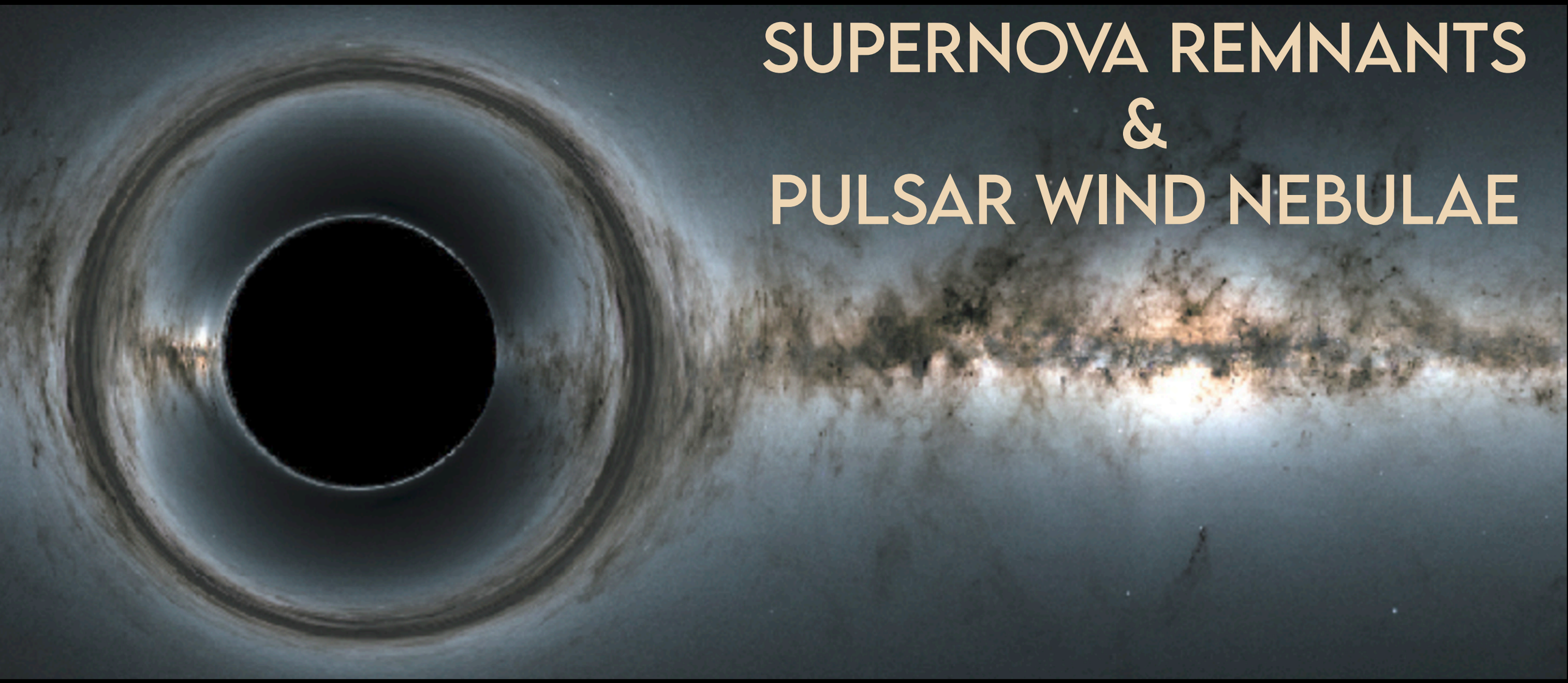


SUPERNOVA REMNANTS & PULSAR WIND NEBULAE

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

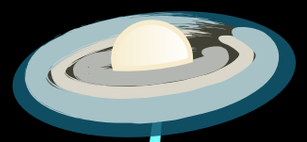
BARBARA OLMI

OAPA-OAA

GIORNATE INAF DEL RSN4: ASTROFISICA RELATIVISTICA E PARTICELLE

22-24/11/2022
NAPOLI OACN

LIFE AND DEATH OF MASSIVE STARS



PROTOSTAR

MAIN SEQUENCE
MASSIVE STAR

RED SUPERGIANT

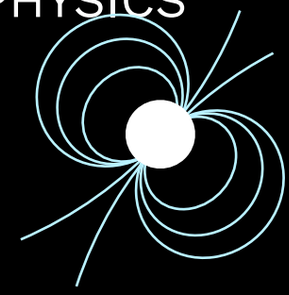
SUPERNOVA

REMNANT + CO

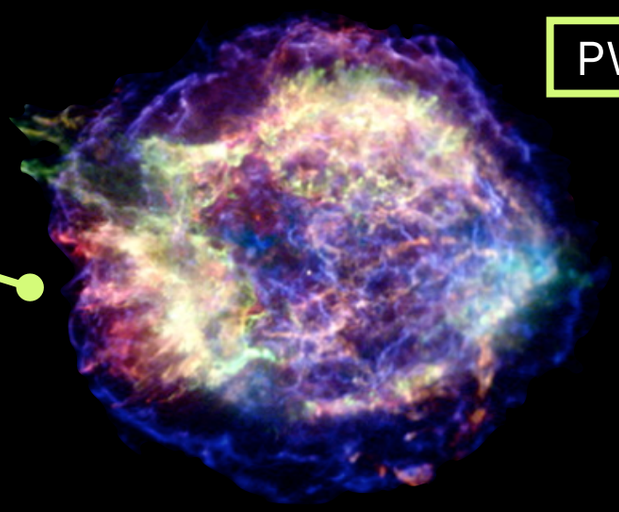
REMNANT + PWN

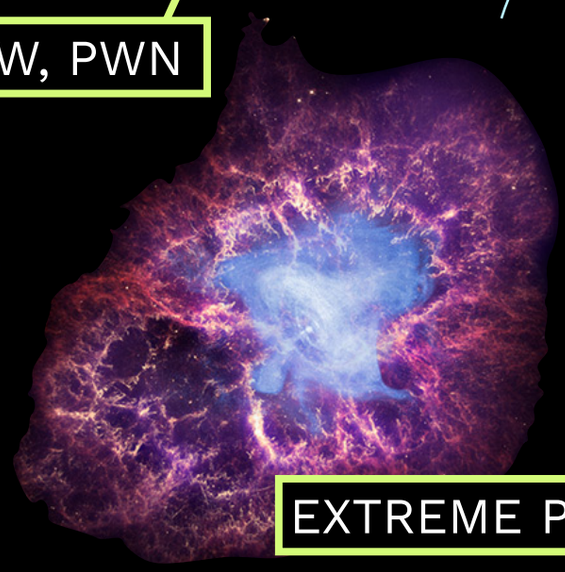
LIFE AND DEATH OF MASSIVE STARS

PULSAR PHYSICS

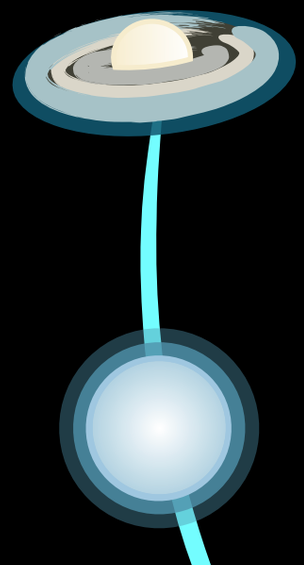


PW, PWN





EXTREME PHYSICS



COMPACT OBJECT

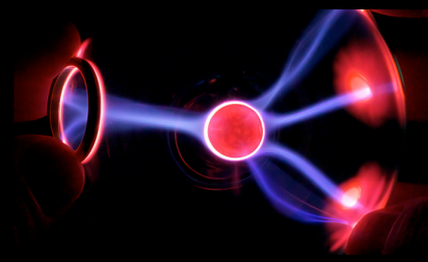
CHEMICAL COMPOSITION

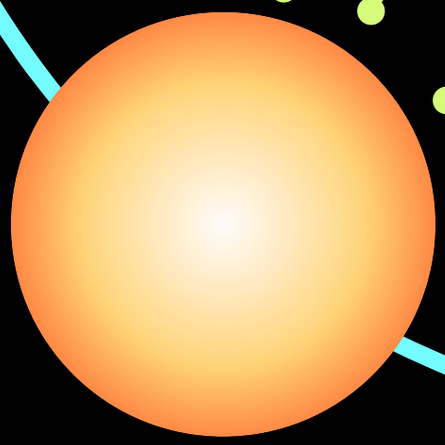
EJECTA ANISOTROPIES

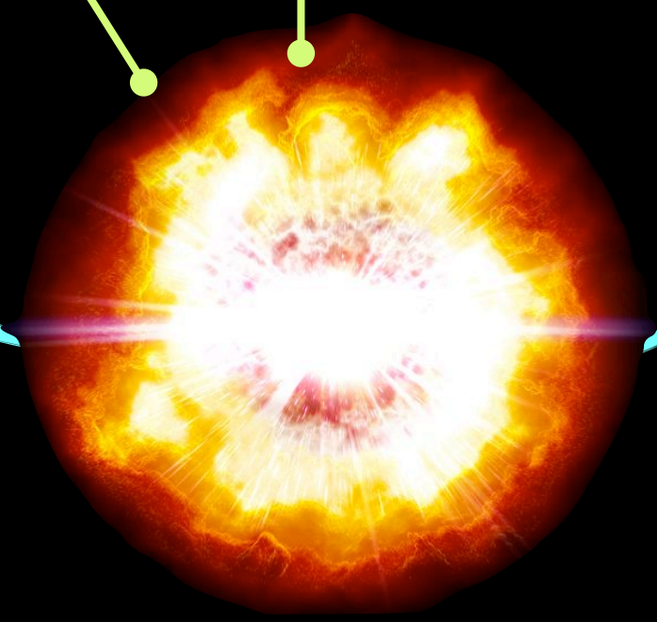
ASIMMETRIES

PARTICLE ACCELERATION

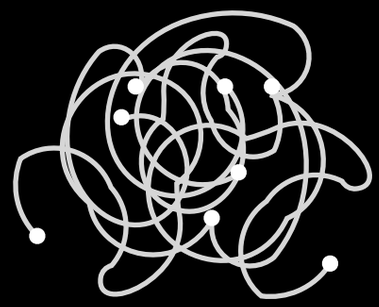
PLASMA PHYSICS







CR PHYSICS



MASSIVE STARS, SN EXPLOSIONS AND SNRS

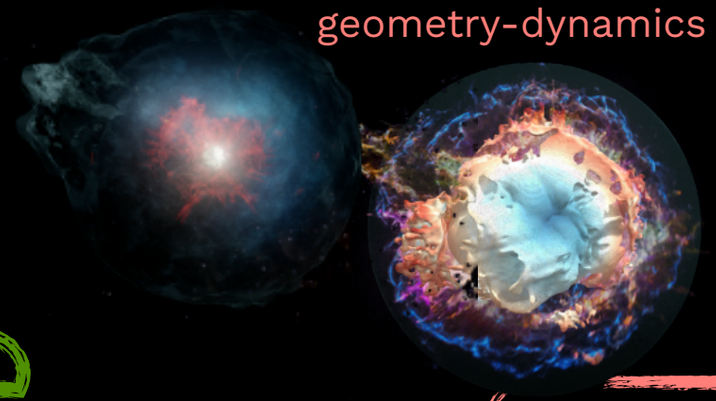
THE STATE OF THE ART MODELS ARE @ INAF

STELLAR EVOLUTION CODE

@INAF OAR, IAPS

3D SN MODELS

@INAF OAPa



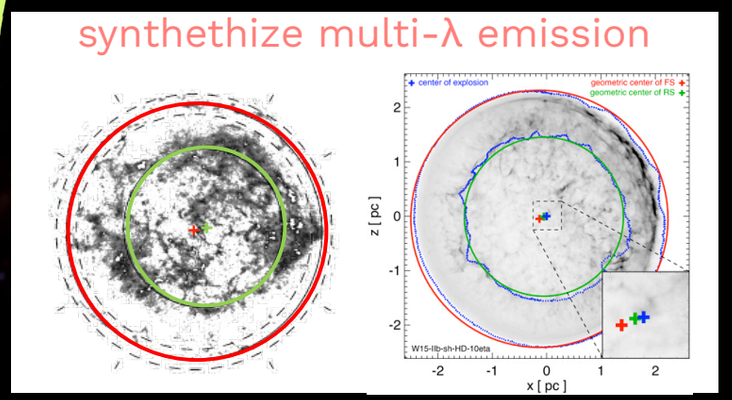
geometry-dynamics

3D SNR MODELS

@INAF OAPa

COMPARE WITH DATA

@INAF OAPa (X-ray)
@INAF OAC, OACT (radio)



structure of progenitor
ambient inhomogeneities
CSM

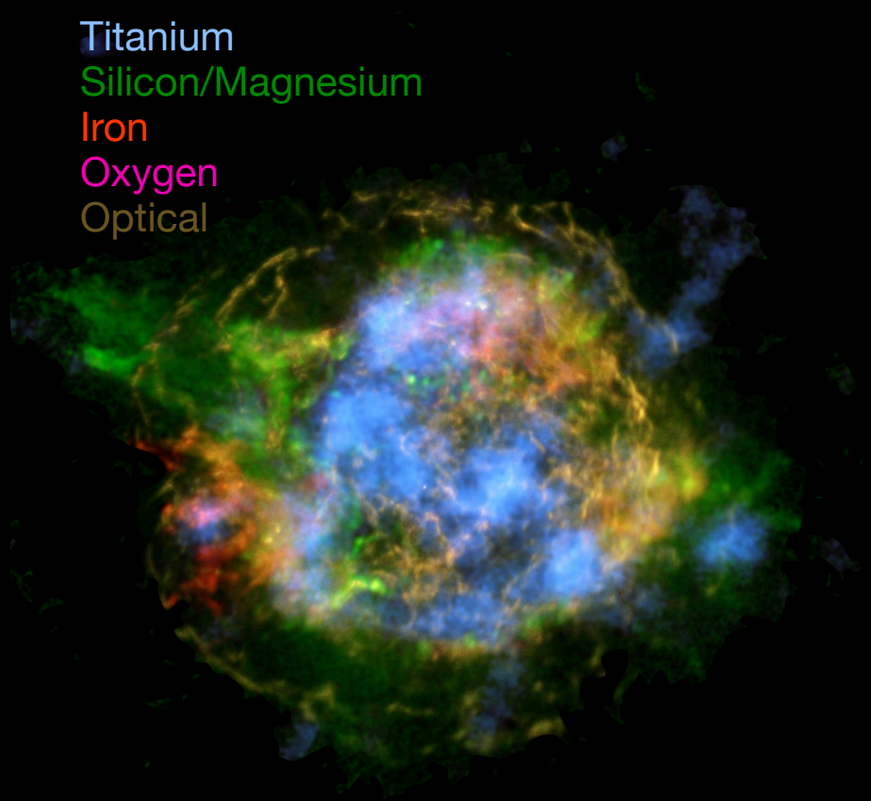
INPUT

FEEDBACK

[Orlando S. et al., 2012-2015-2019-2021, Ono et al. 2020]

LINKING THE SNR TO THE PARENT SN AND TO THE PROGENITOR STAR

RECENT RESULTS



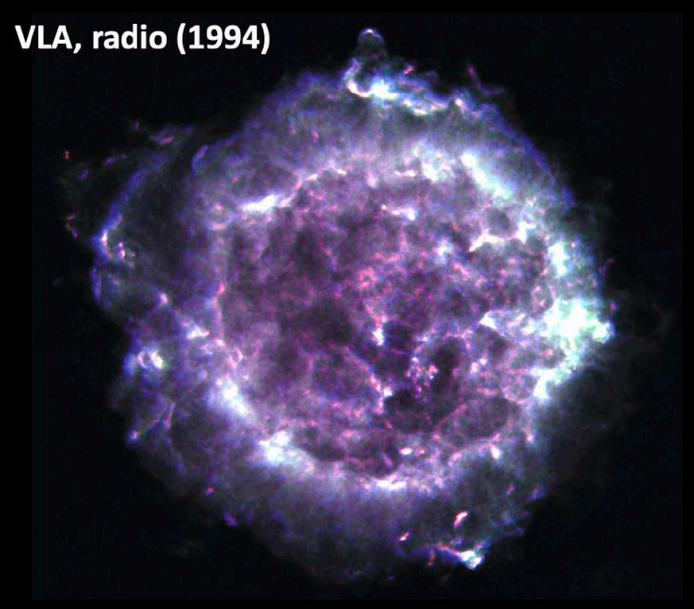
Bulk asymmetries in Cas A are intrinsic to explosion and can be explained through a neutrino driven SN

Interaction with asymmetric circumstellar shell (likely originated by a massive eruption from the progenitor 10^4-10^5 yr before collapse)

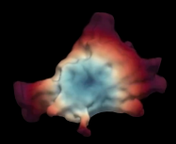
Large scale asymmetries modify chemical stratification in the ejecta

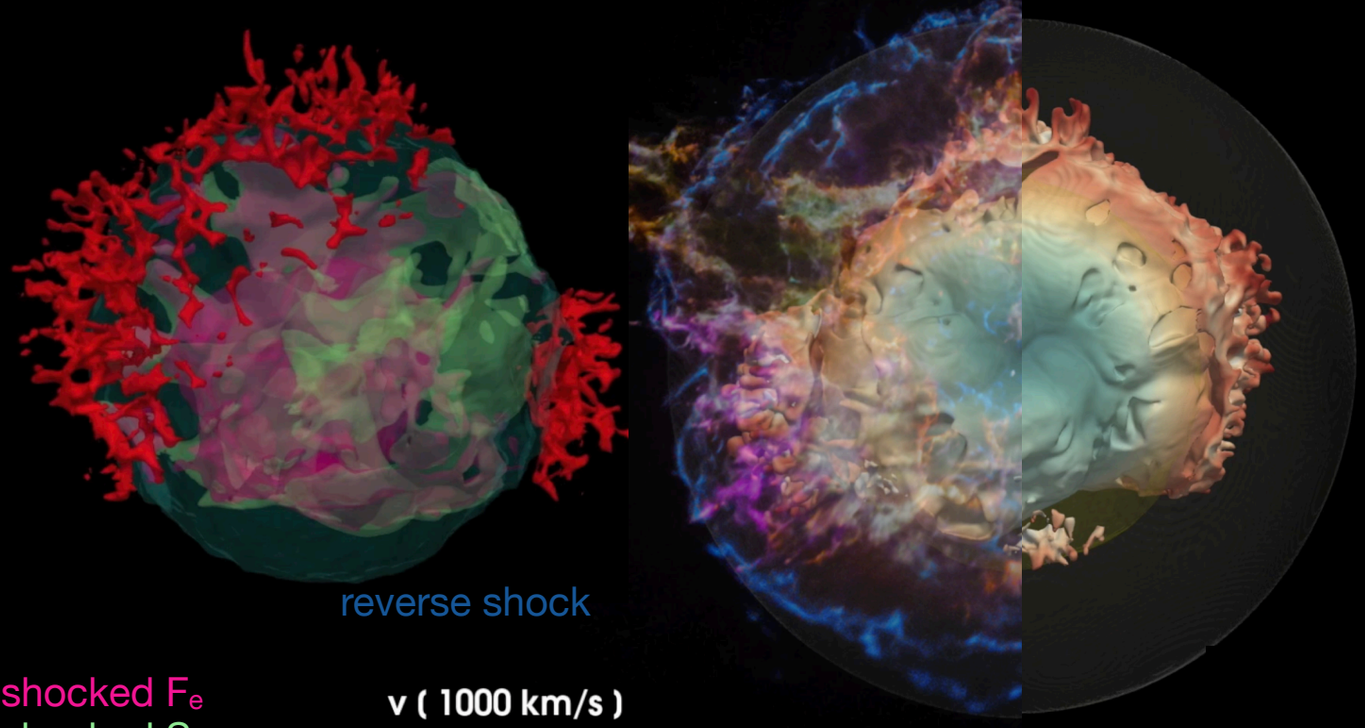
Age~400 yr

CAS A



20 h after SN event



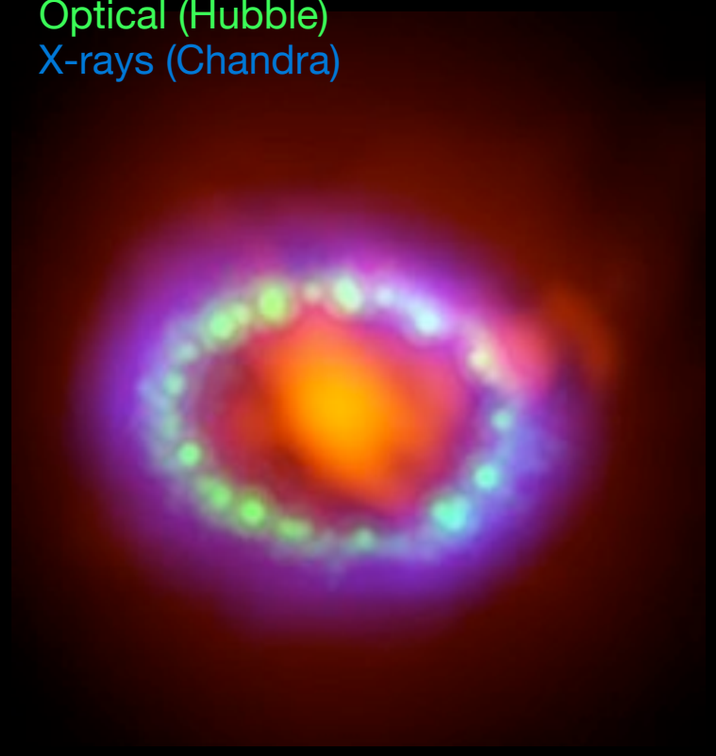


[Orlando S. et al., 2016, 2021, Wongwathanarat 2017]

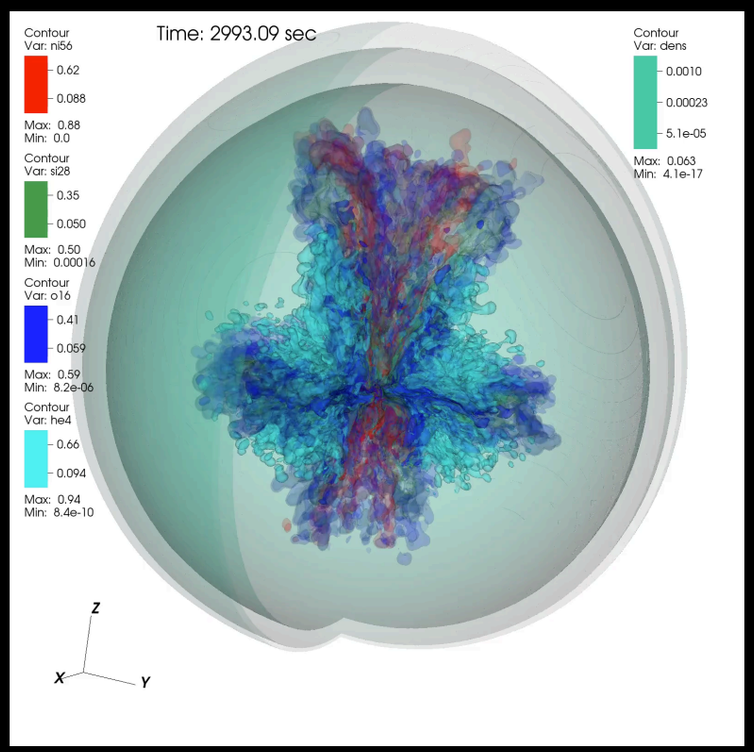
LINKING THE SNR TO THE PARENT SN AND TO THE PROGENITOR STAR

RECENT RESULTS

Radio (ALMA)
Optical (Hubble)
X-rays (Chandra)



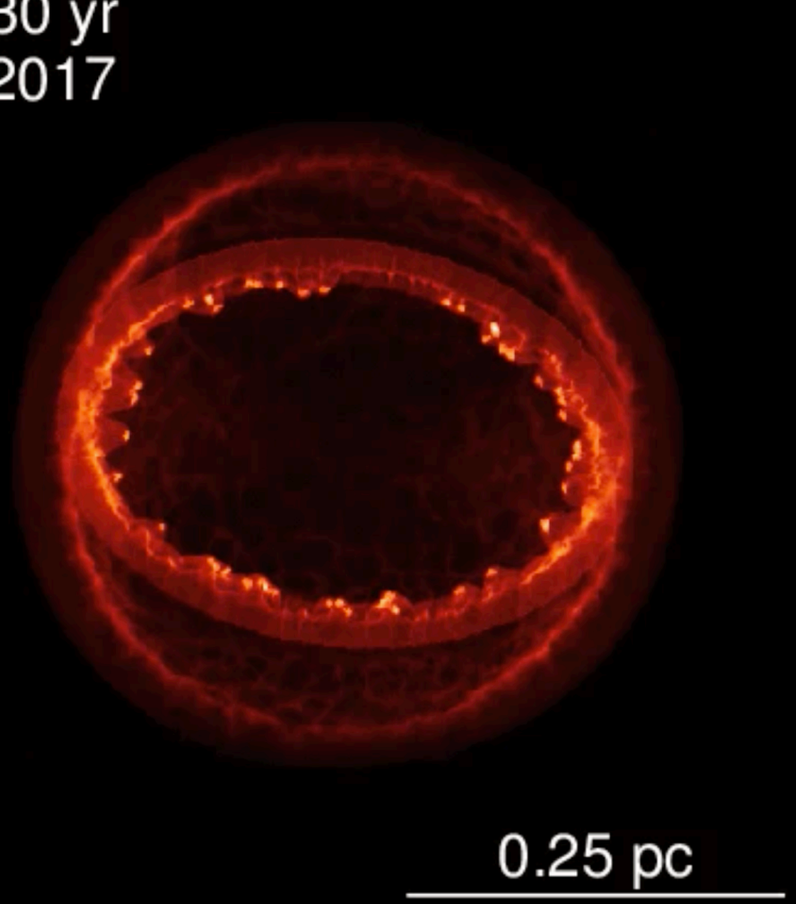
SN 1987A



Prove the nature of the progenitor: SN 1987A was originated by the merger of two massive stars

Observed anisotropies explained as due to large-scale asymmetries in the explosion and to the interaction with the inhomogeneous and dense CSM

Inferred the dependence of the post-shock temperature on the particle mass in collisionless shocks

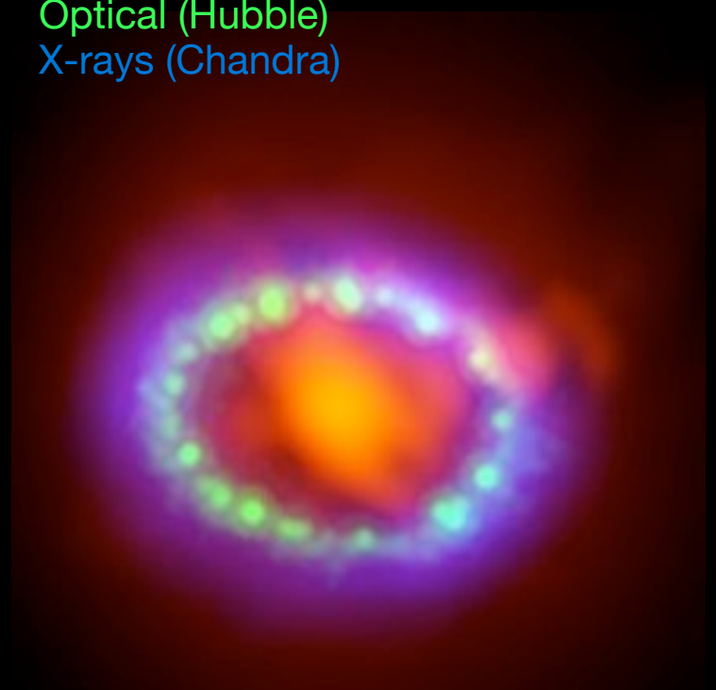


[Orlando S. et al., 2020, Ono et al. 2020, Miceli et al 2019]

LINKING THE SNR TO THE PARENT SN AND TO THE PROGENITOR STAR

RECENT RESULTS

Radio (ALMA)
Optical (Hubble)
X-rays (Chandra)

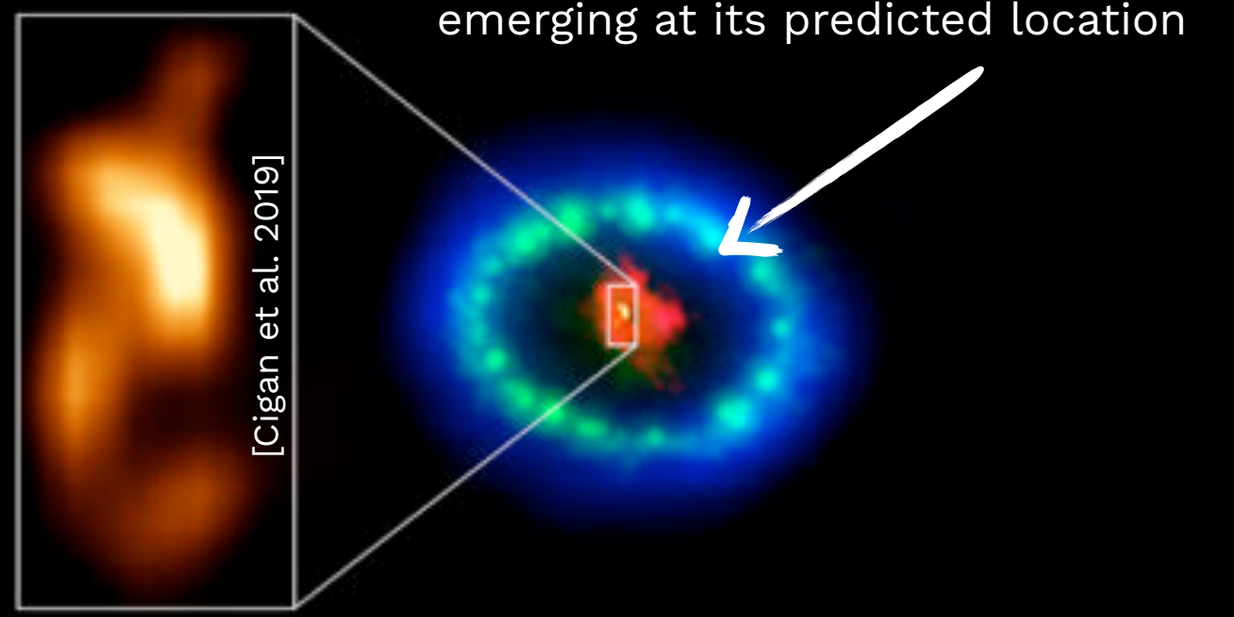


SN 1987A

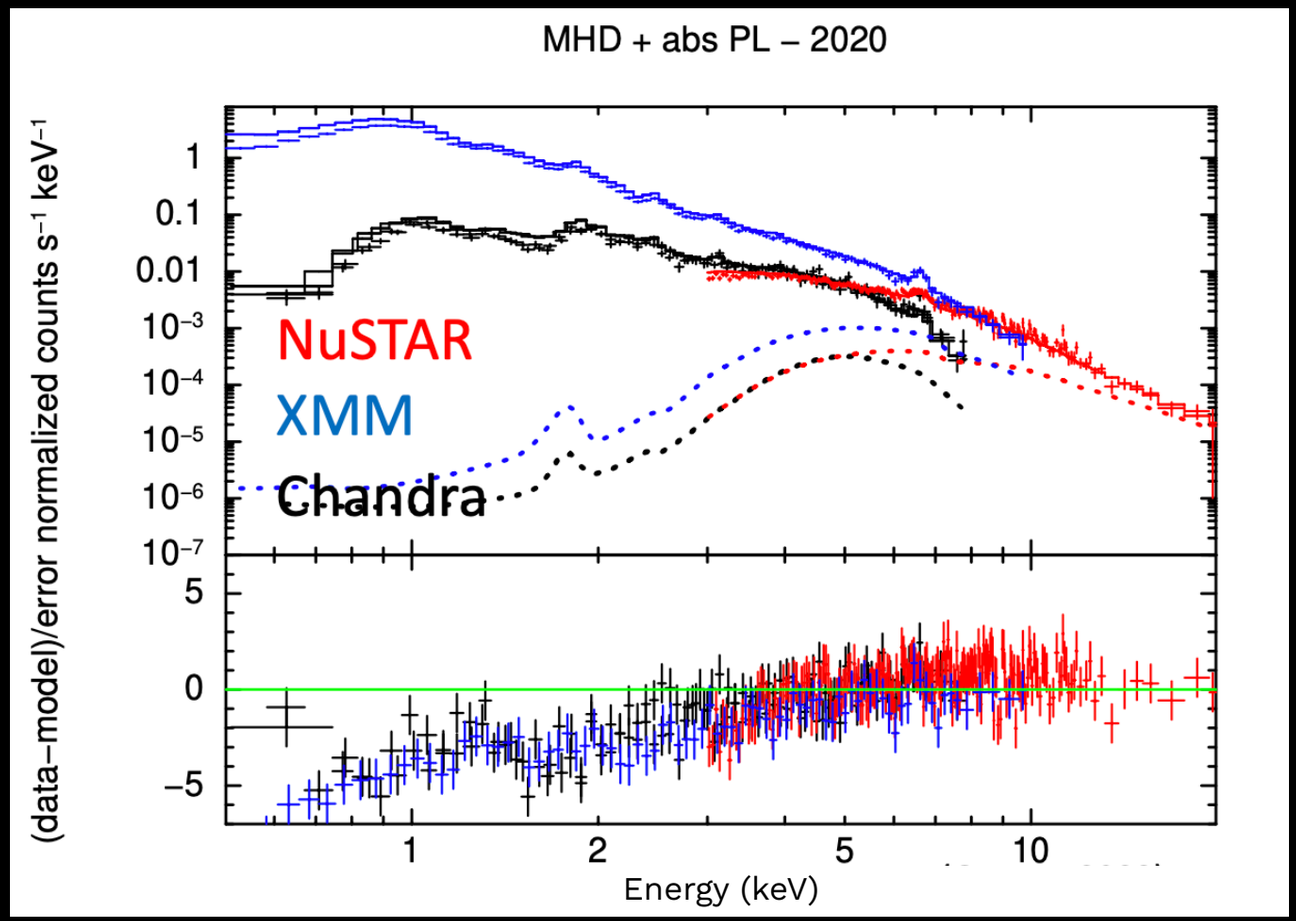
Possible detection of a newborn PWN

Multi-epoch absorption and thermal emission based on the MHD ejecta

[Orlando S. et al., 2020, Greco E. et al. 2021-22]



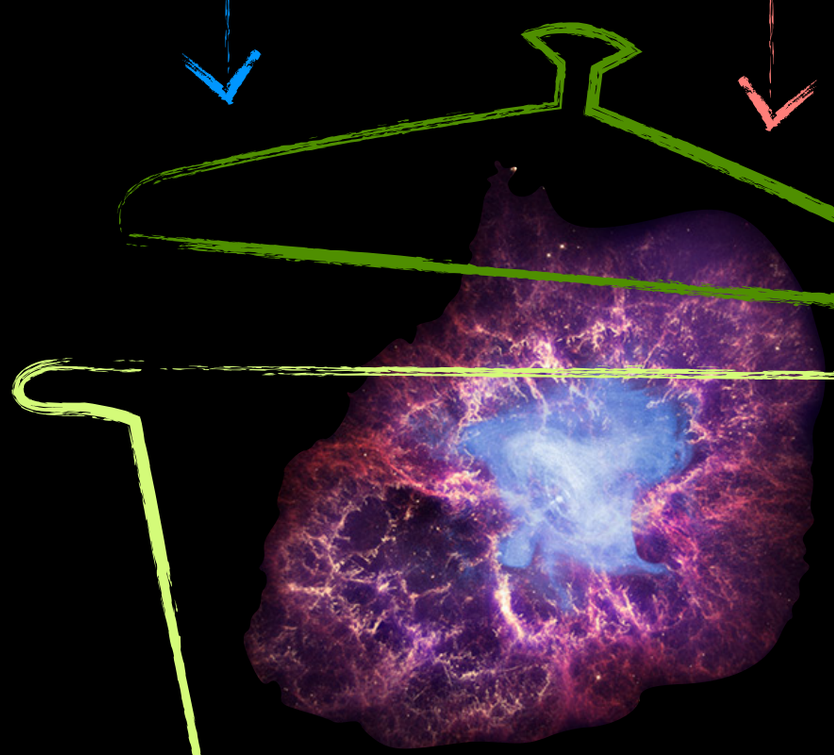
No CO detected but a radio blob is emerging at its predicted location



PULSAR WIND NEBULAE

THE STATE OF THE ART MODELS ARE @ INAF

THEORETICAL MODELS OF PW

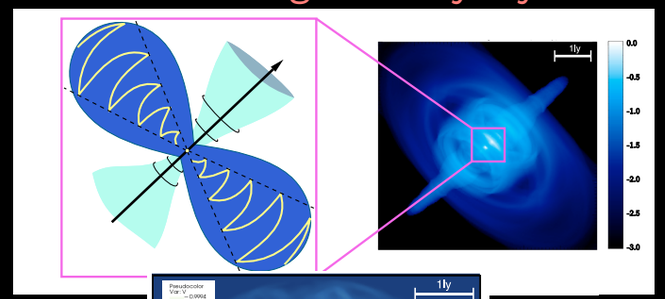


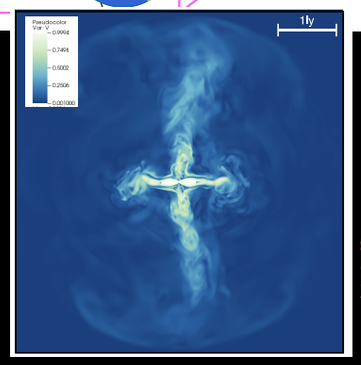
3D R-MHD MODELS
@INAF OAA

magnetization
anisotropy

INPUT

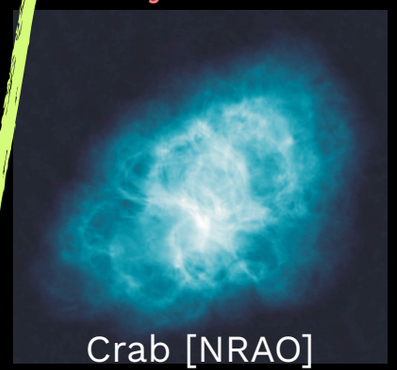
geometry-dynamics





COMPARE WITH DATA

synthethize multi-λ emission



Crab [NRAO]

synth

FEEDBACK

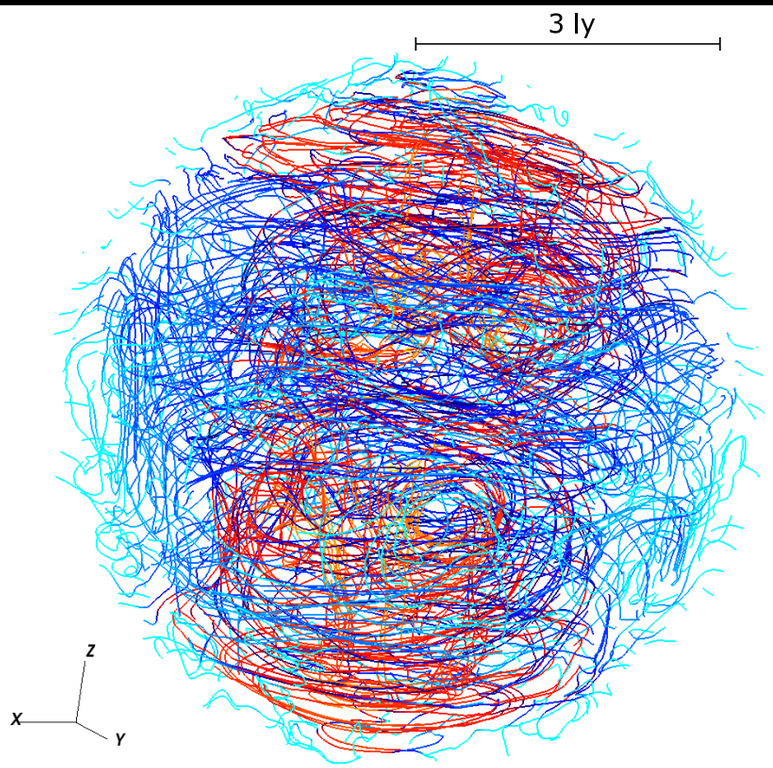
[Del Zanna et al. 2006, Olmi et al. 2016]

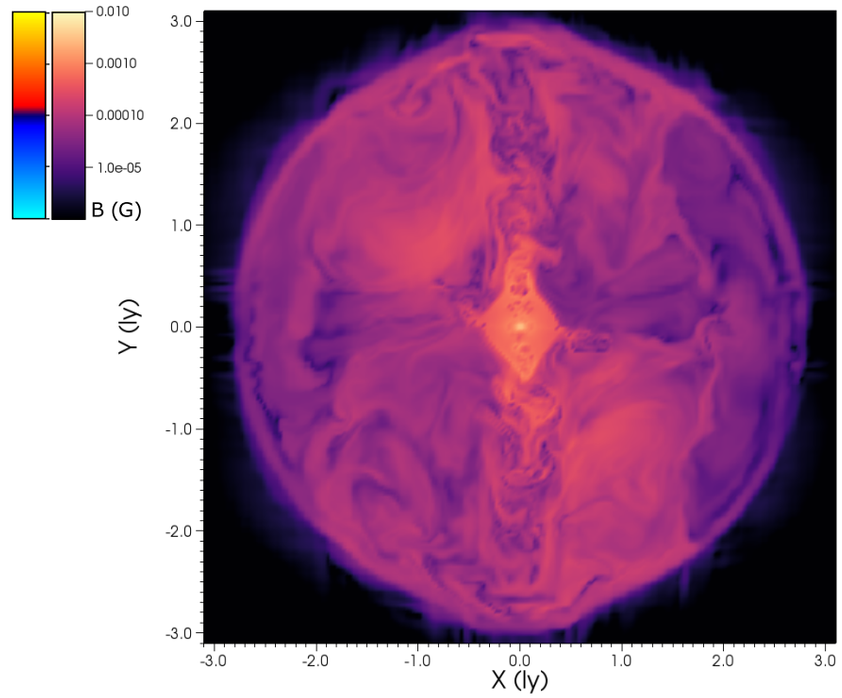
YOUNG PULSAR WIND NEBULAE

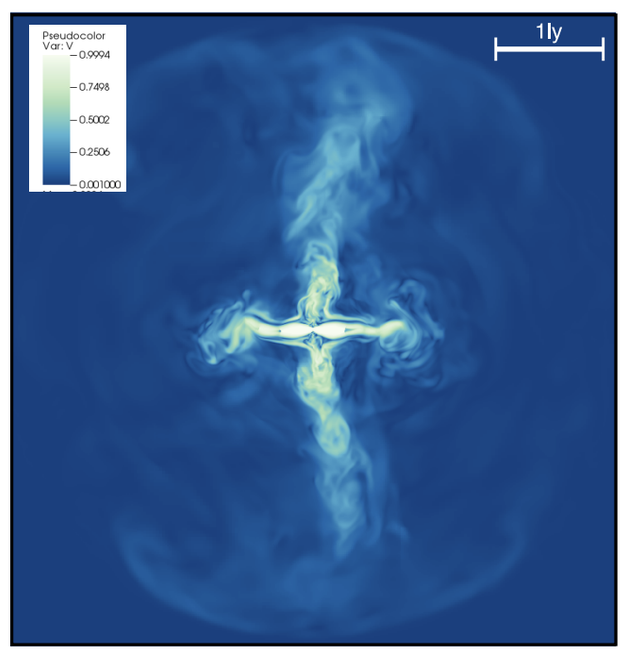
RECENT RESULTS

Magnetization > 1 available if 3D

[Olmi et al. 2016 + Olmi et al in prep.]







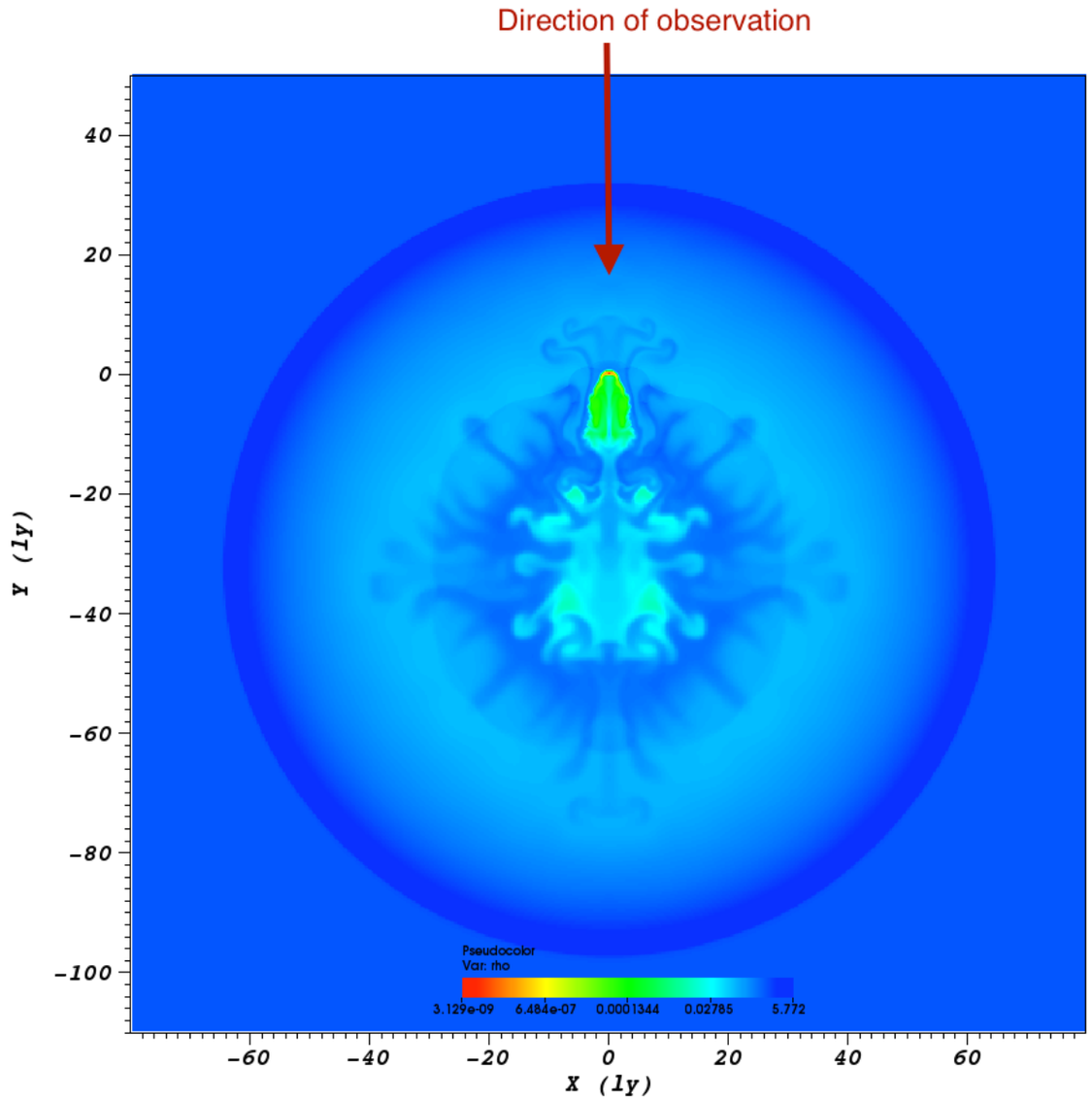
Complex structure of the magnetic field + formation of poloidal component + huge dissipation

kinking jets

EVOLUTION OF PULSAR WIND NEBULAE

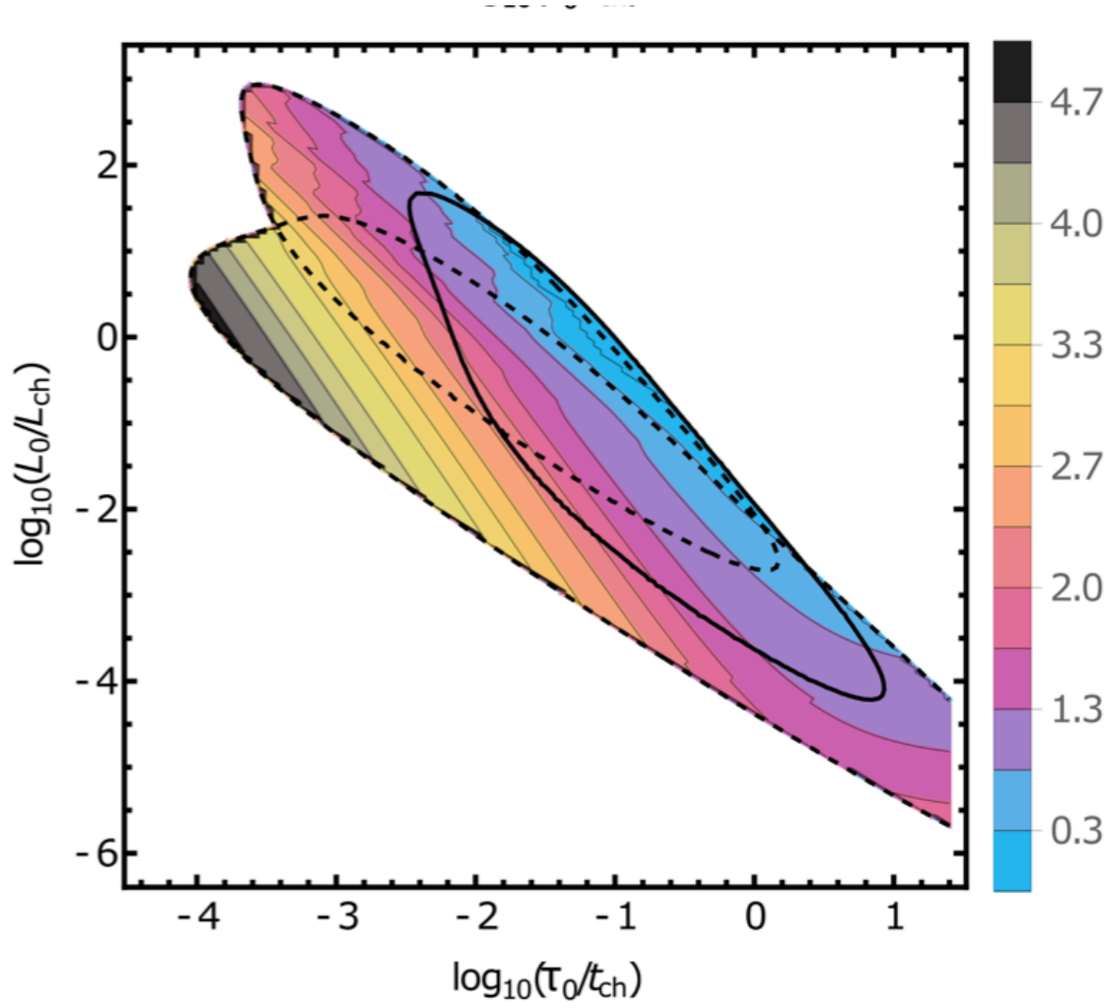
RECENT RESULTS

Long term evolution of the PWN - interaction with SNR



[Olmi Torres 2020]

Middle aged PWN, interaction with the SNR and reverberation phase and PWN compression



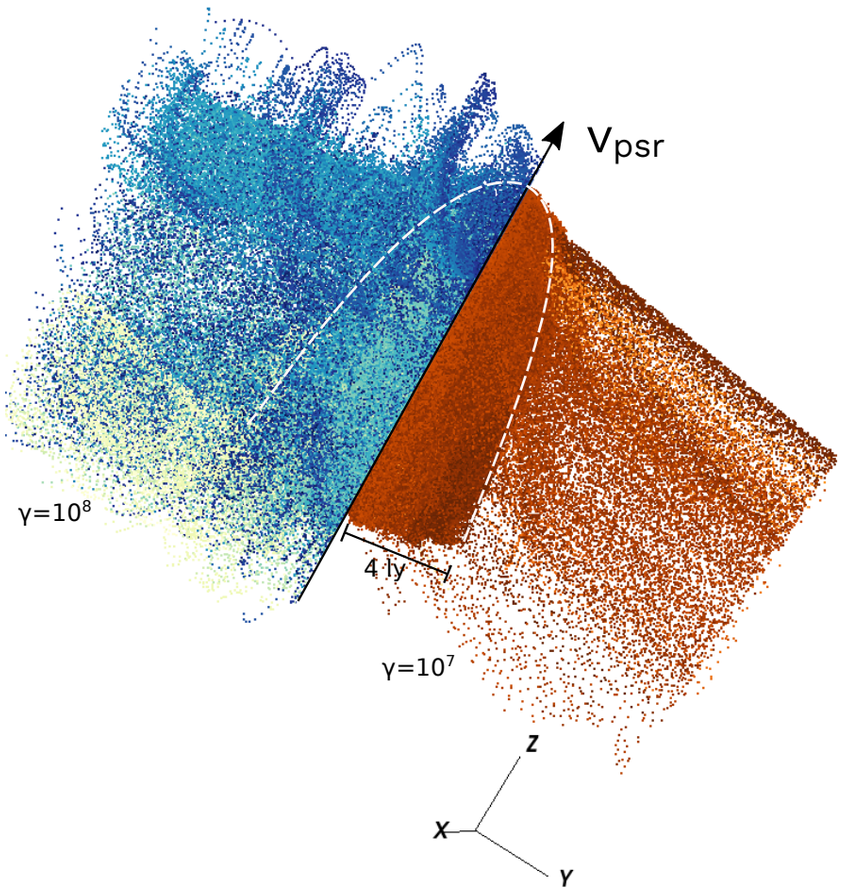
[Bandiera + 2020, 2021, 2022 in press]

EVOLVED PULSAR WIND NEBULAE

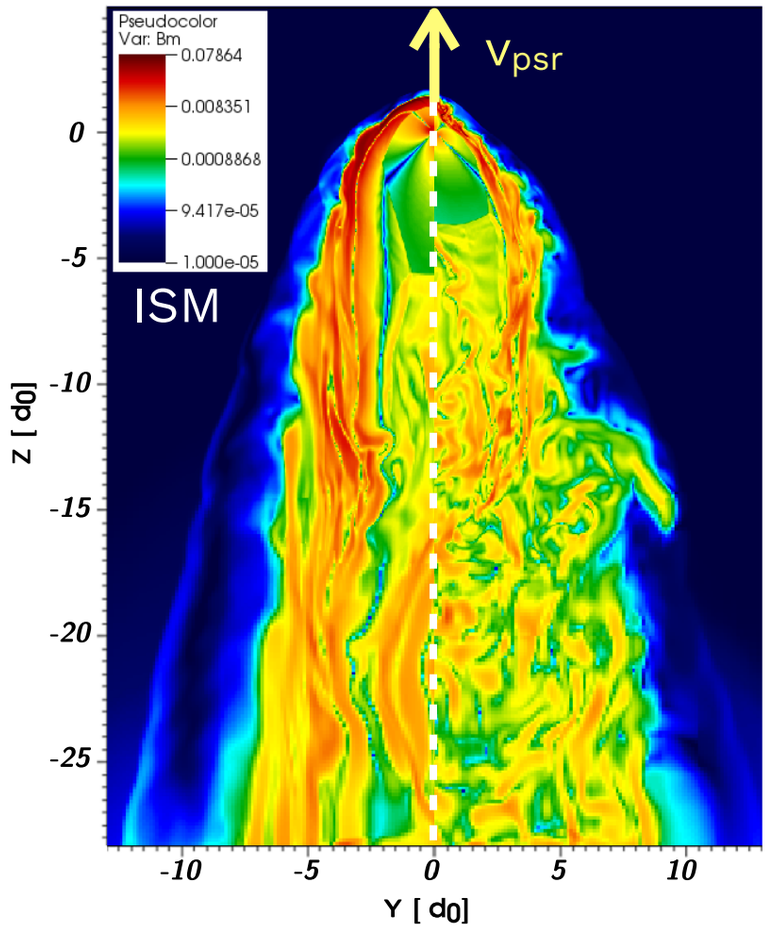
RECENT RESULTS

Structure, evolution, level of anisotropy, magnetization and turbulence in evolved bow shock nebulae

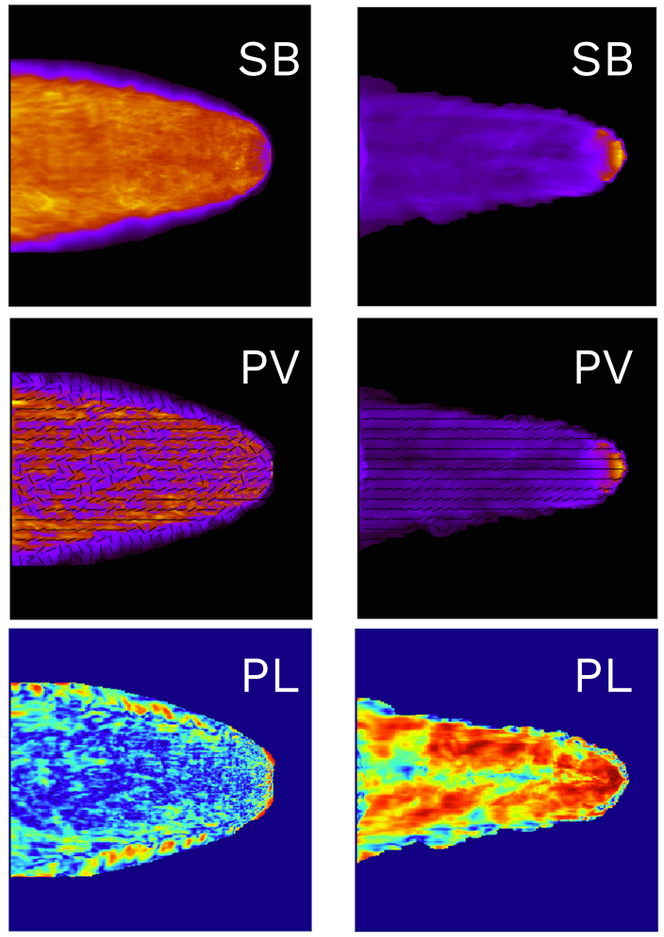
Relevance of turbulence in observed properties (surface brightness-SB, polarization vector/level-PV/PL)



[Olmi & Bucciantini 2019c]



[Olmi & Bucciantini 2019a,b]



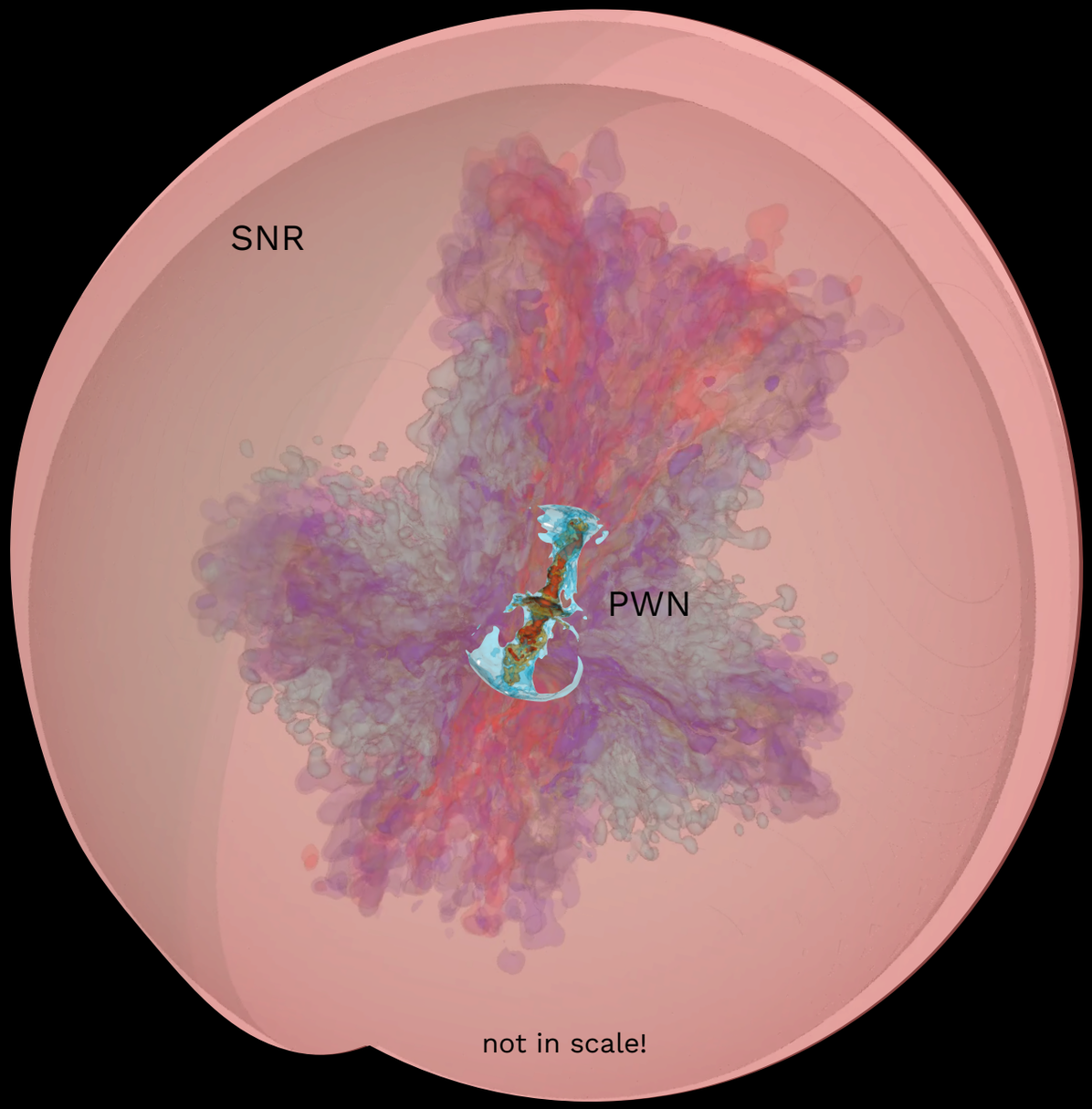
high anisotropy
low magnetization

low anisotropy
high magnetization

Interaction with ISM magnetic field
Particle massively escape from bow shocks (with charge separation) above threshold energy (≳10 TeV).
Diffuse or directional escape depends on energy of escaping particles (the higher the more diffuse)

BIG QUESTIONS AND FUTURE WORK

#1 - EVOLUTION OF PWN INSIDE REALISTIC SNR

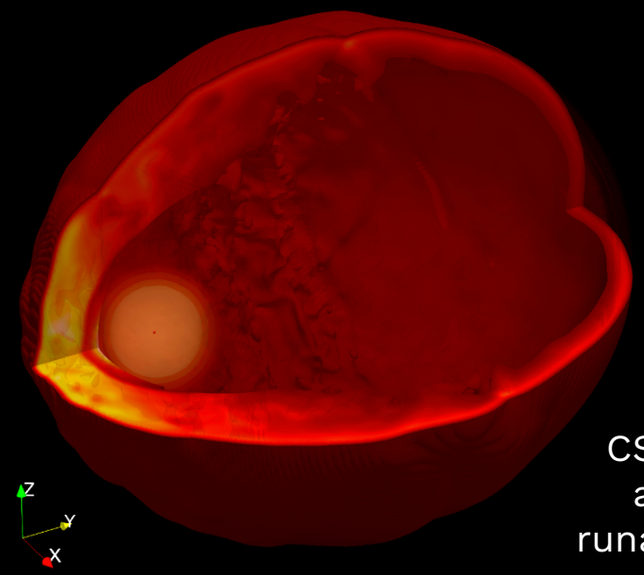


Connect the state of the art models for SN+SNR and PWN evolution
—> first example in the literature

Olmi, Orlando +

BIG QUESTIONS AND FUTURE WORK

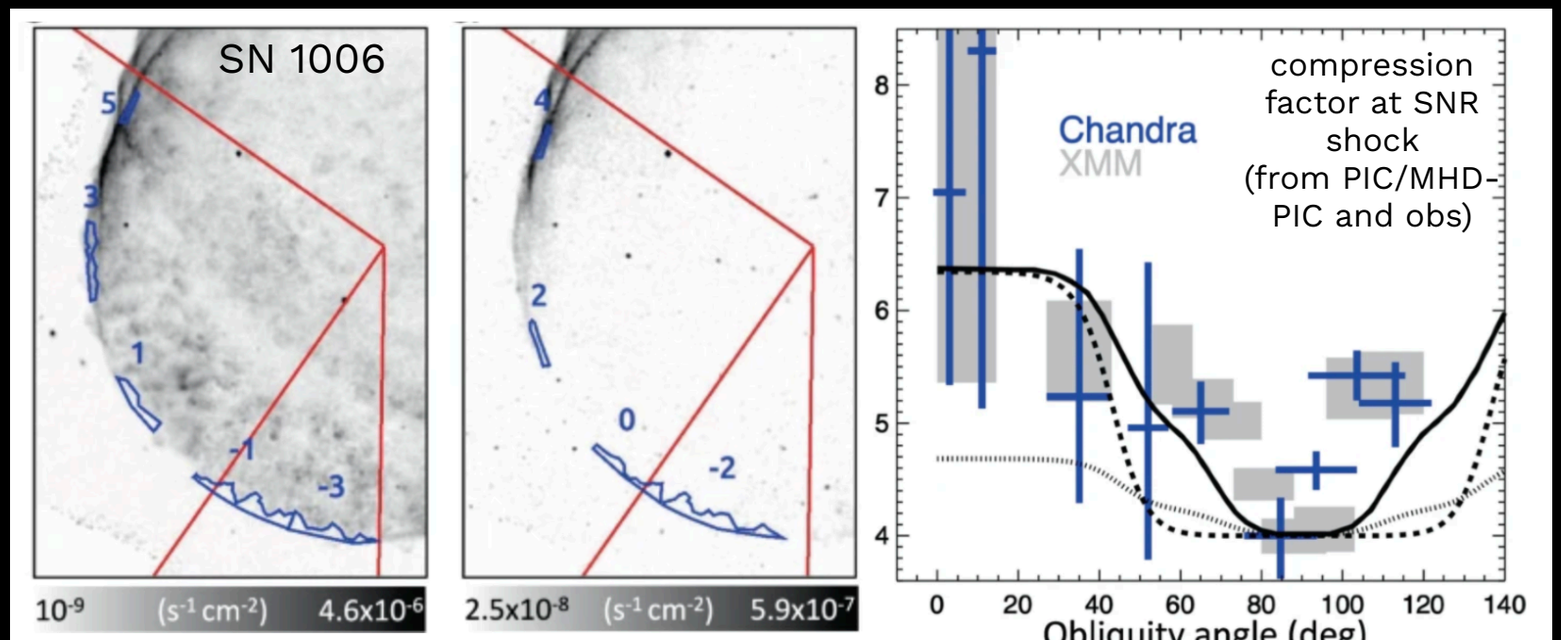
#2- CONNECTING THE SNR WITH THE MASS LOSS HISTORY OF THE PROGENITOR



CSM shell around runaway RSG

Tighter connection with stellar evolution models, dynamic of SNR connected with the properties of the ambient medium (e.g. CAS A).

#3- EVOLUTION OF THE SNR INCLUDING THE CR FEEDBACK



Giuffrida, Miceli ++ Nature 2022

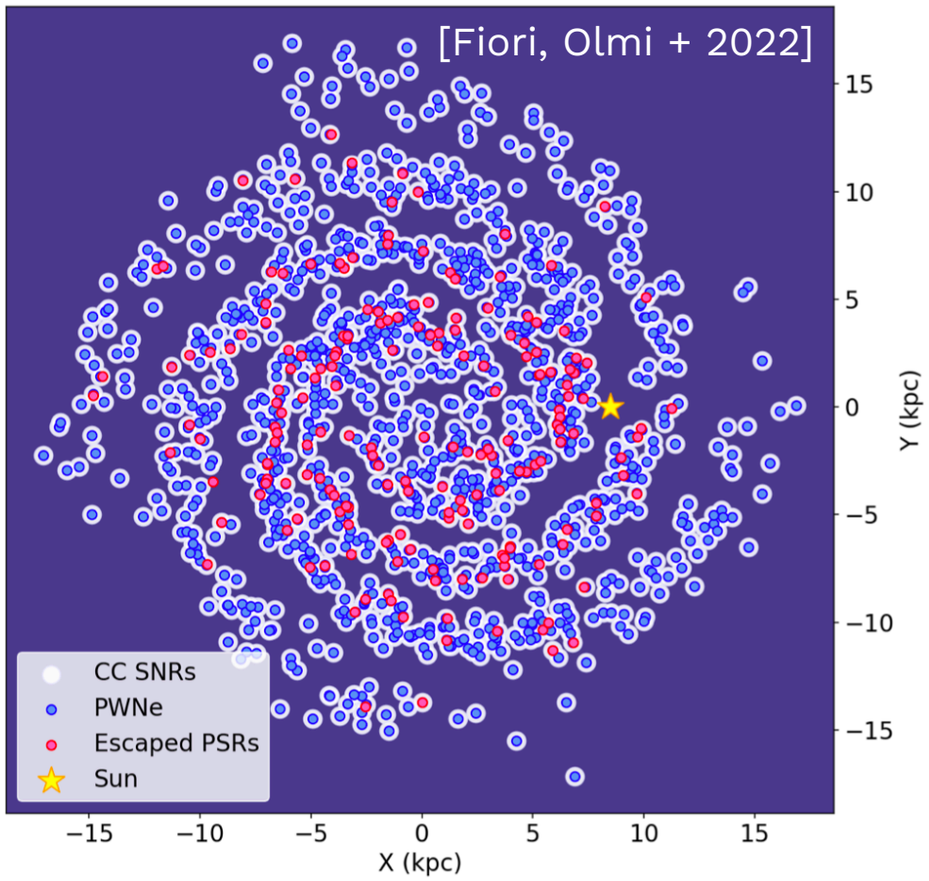
Using recipes from state of the art PIC/MHD-PIC codes for the CR feedback —> allow for direct comparison with observations and then feedback on SNR and CR physics (especially relevant for CC SN and Ia SN, e.g. SN 1006)

BIG QUESTIONS AND FUTURE WORK

#4 - PULSARS & PWNe AT GAMMA-RAYS

PWNe will be the most numerous Galactic gamma-ray sources

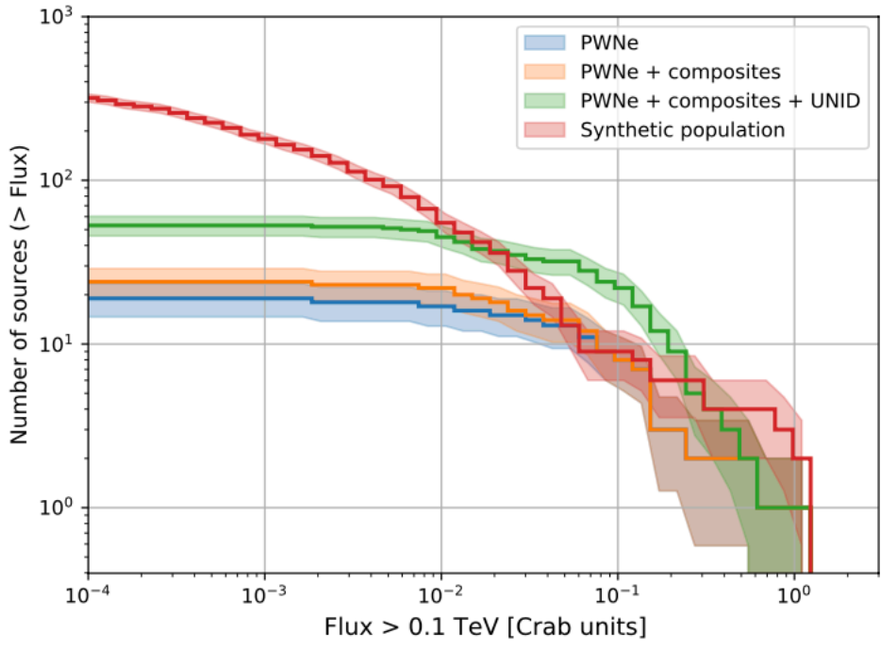
Distribution in the Galaxy



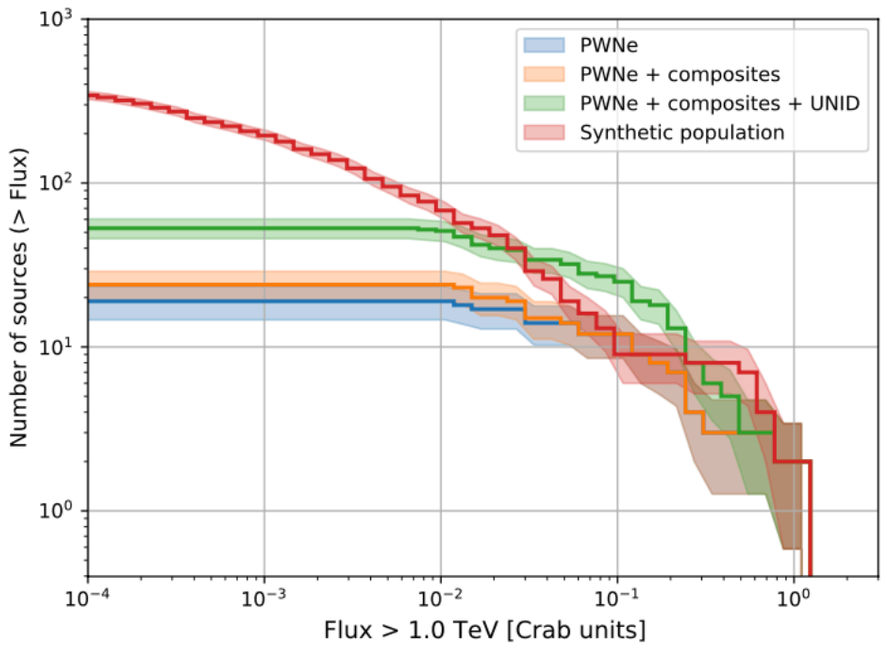
PWN in the Galaxy modeled with numerical simulations + radiative code

PWN ARE PRIMARY TARGETS FOR CTA AND ASTRI MA

Contribution at gamma-rays



F>0.1 TeV

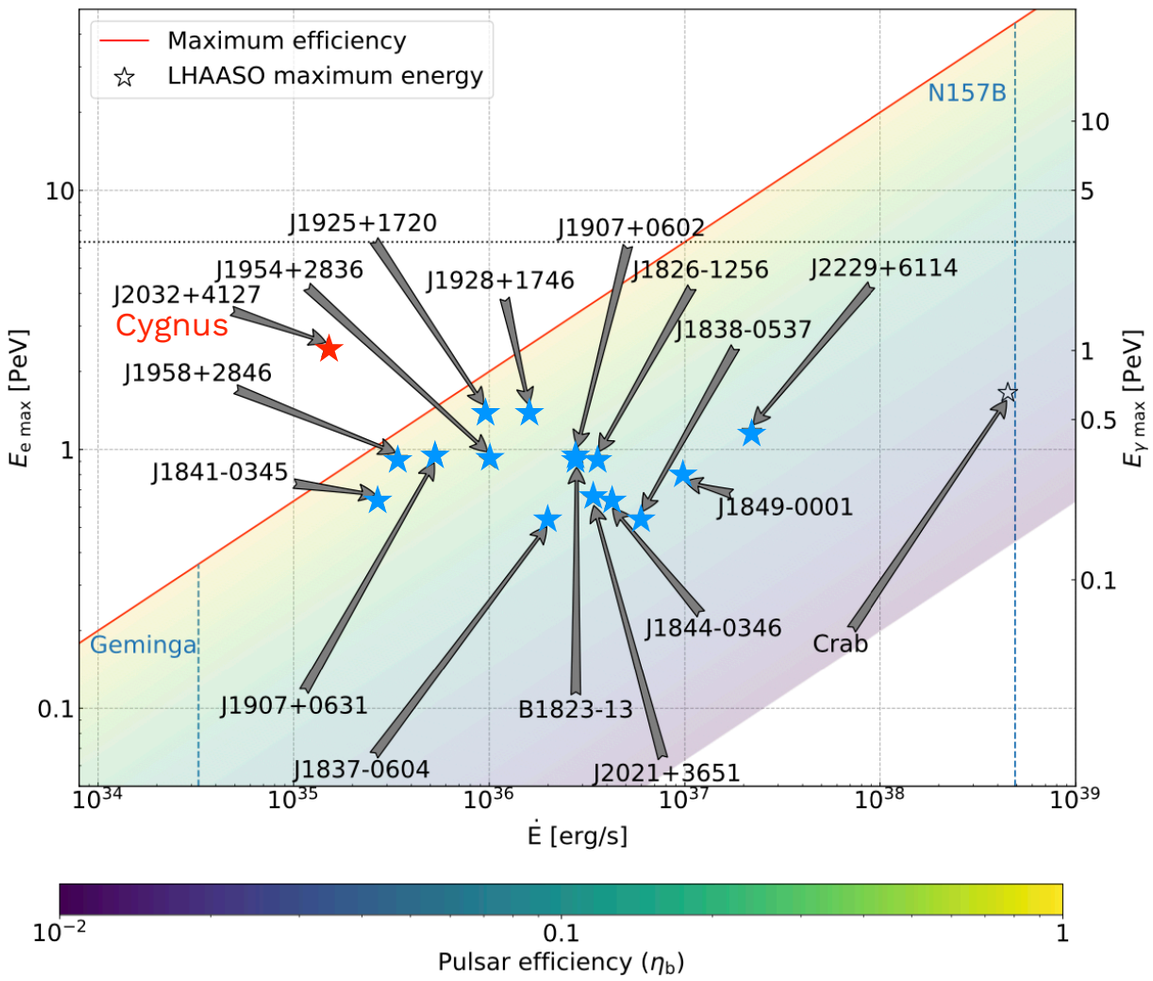


F>1 TeV

BIG QUESTIONS AND FUTURE WORK

#4 - PULSARS & PWNe AT GAMMA-RAYS —> PEVATRONS

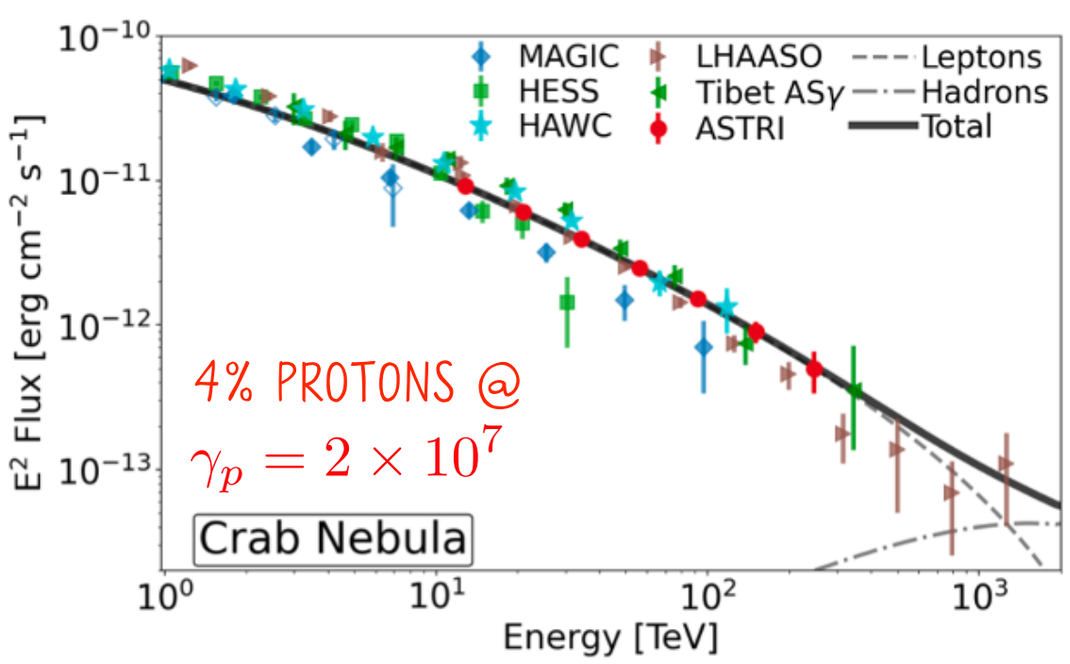
LHAASO PeVatrons all (except one) compatible with pulsars:



[De Ona Whilhelmi, Lopez-Coto, Amato, Aharonian 2022]

Role of pulsars and PWNe as extreme accelerators.

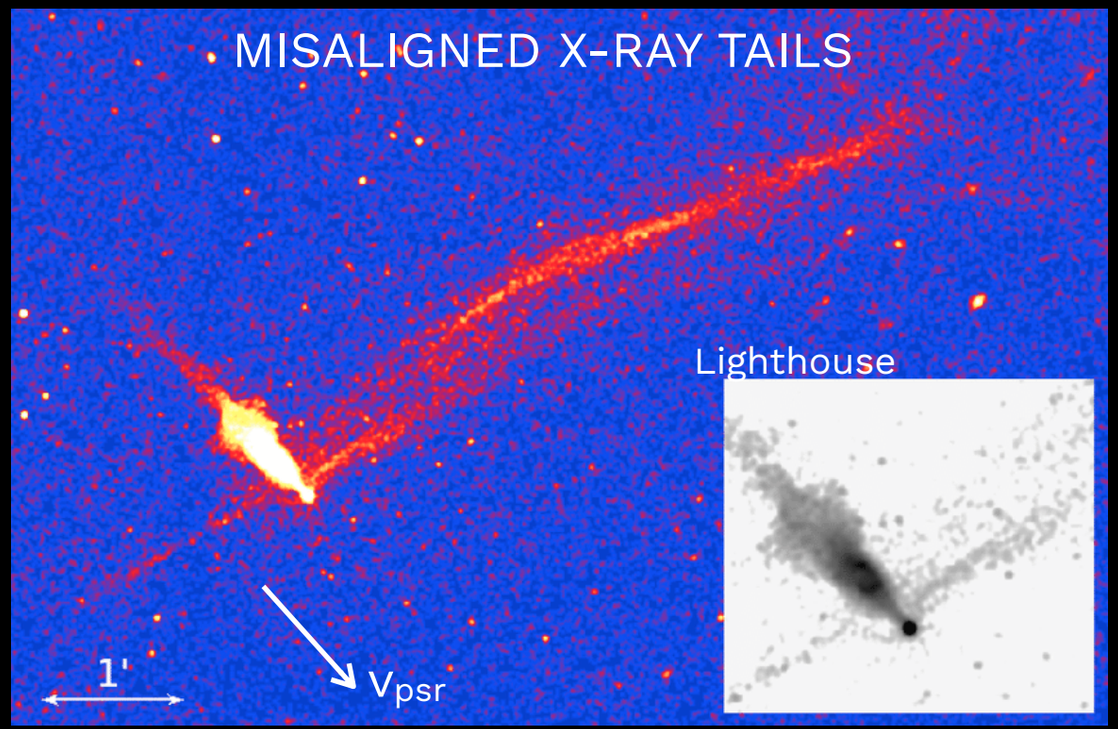
Also hadronic accelerators?



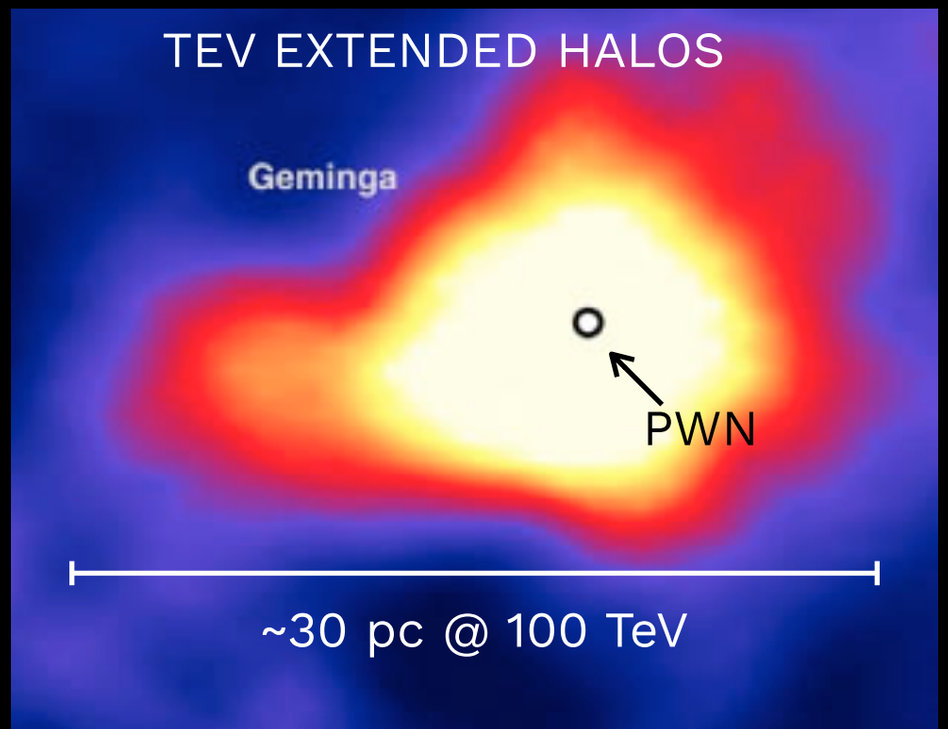
[Vercellone et al. 2022 - Astri coll.]

BIG QUESTIONS AND FUTURE WORK

#5 - FORMATION OF DIFFERENT STRUCTURES OUTSIDE PWN: TRANSPORT/DIFFUSION



VS

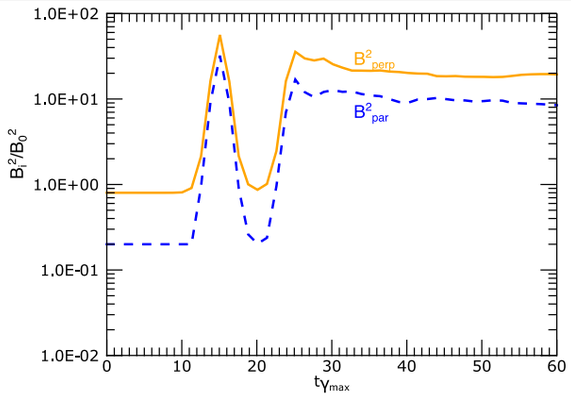


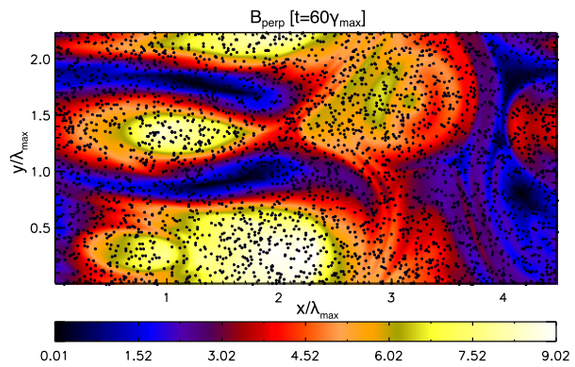
#5.1 - PARTICLE ACCELERATION AND TRANSPORT

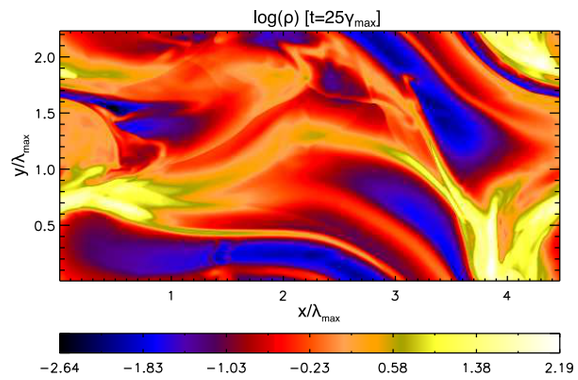
PIC/HYBRID SIMULATIONS

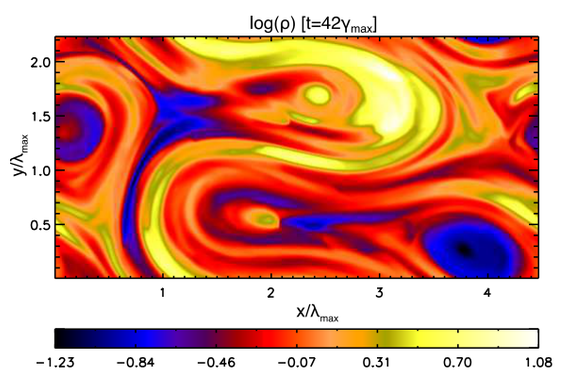
generation of instabilities

acceleration in PWNe and the nature of Crab flares









PROGRAMMI PRIMARI - STRUTTURE COINVOLTE

Inviluppo FTE 40

PI Amato E.

CRACHEN

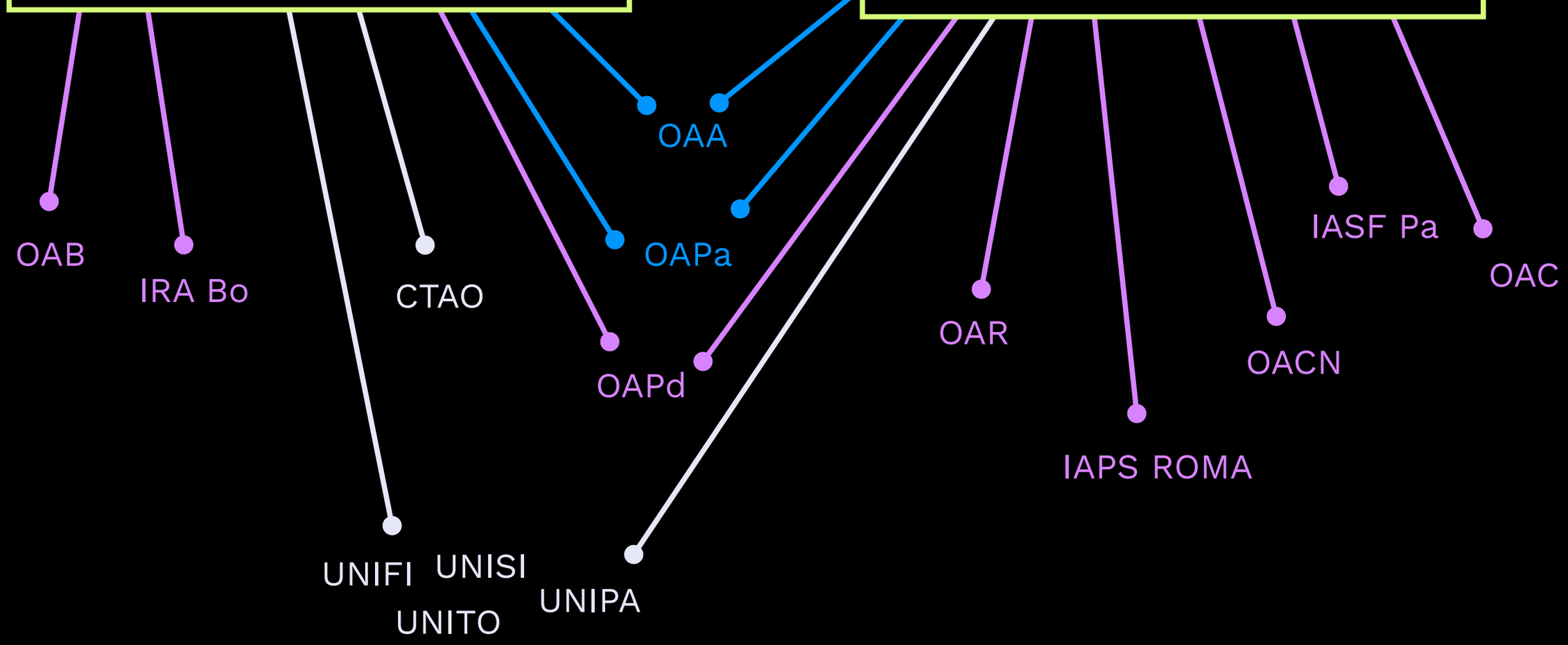
Cosmic ray accelerators unveiled by high energy astrophysical observations

Inviluppo FTE 24

PI Orlando S.

PAMSUR

The path from massive stars to supernovae and supernova remnants: driving mass, energy and cosmic rays in the Galaxy



MAIN CONTRIBUTORS

SECONDARY CONTRIBUTORS

OTHER INSTITUTIONS

PROGRAMMI PRIMARI - FACILITIES/OTHERS

Inviluppo FTE 40

PI Amato E.

CRACHEN

Cosmic ray accelerators unveiled by high energy astrophysical observations

Inviluppo FTE 24

PI Orlando S.

PAMSUR

The path from massive stars to supernovae and supernova remnants: driving mass, energy and cosmic rays in the Galaxy

RSN1

RSN2

CR physics

ASTRI

MAGIC

CTA

HPC facilities/programs (CINECA, INAF, PRACE)

ESO

SKA

NuSTAR

FERMI

MeerKAT

ASKAP

XMM-NEWTON

LT

GTC

ALMA

NOT

TNG

JWST

CHANDRA

RSN SECONDARIO

ESPERIMENTO/OSSERVATORIO

OTHER FACILITIES

SCHEDE CONNESSE/PROGETTI

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CRACHEN
Cosmic ray accelerators unveiled by high energy astrophysical observations

PI Morlino G.

SCARFACE
Star clusters as cosmic ray factories

PI Vittorini V.

CRAB
Crab Nebula and pevatrons

NFTE 1.4

PI Cardillo M.

PEACE
Probing extreme acceleration in cosmic environment

NFTE 0

PI Bucciantini N.

PWNnumpol
Numrical studies of PWNe in the light of

NFTE 1.8

Inviluppo FTE 24

PI Orlando S.

PAMSUR
The path from massive stars to supernovae and supernova remnants: driving mass, energy and cosmic rays in the Galaxy

PI Miceli M.

SNR
Multi-wavelengths observations of supernova remnants

NFTE 3

PI Pellizzoni A.

SDI/SNR
Single-Dish Radio Imaging of Supernova Remnants: Investigating High-Energy Particles Properties

NFTE 4

SCHEDE CONNESSE/FUNDS

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CRACHEN

Cosmic ray accelerators unveiled by high energy astrophysical observations

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PI Morlino G.

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Star clusters as cosmic ray factories

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THEORY GRANT

MINI GRANT

PI Miceli M.

SNR

Multi-wavelengths observations of supernova remnants

MINI GRANT

PI Loru S.

SDI/SNR

Multi-wavelengths observations of supernova remnants

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~~LARGE PROGRAM~~

~~THEORY GRANT~~

MINI GRANT €

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~~THEORY GRANT~~

~~PI Cardillo M.~~

~~PEACE~~

~~Probing extreme acceleration in cosmic environment~~

MINI GRANT €

PI Loru S.

SDI/SNR

Multi-wavelengths observations of supernova remnants

MINI GRANT €

PI Bucciantini N.

PWNnumpol

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TIME EVOLUTION OF FUNDS

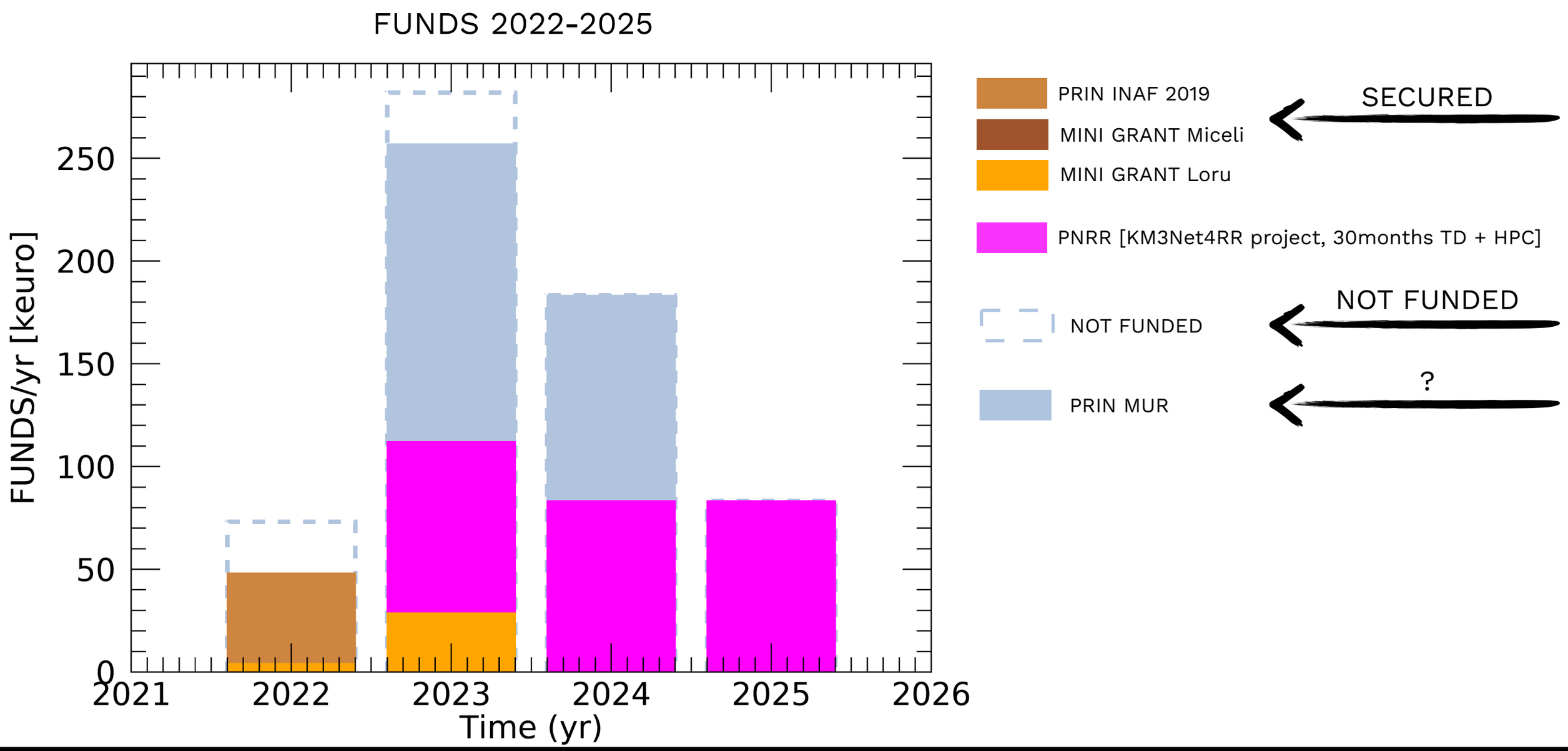
SUPERNOVA REMNANTS PROJECTS

SNR — PI Miceli M.
Multi-wavelengths observations of supernova remnants

SDI/SNR — PI Loru S.
Multi-wavelengths observations of supernova remnants

\+

PAMSUR — PI Orlando S.
The path from massive stars to supernovae and supernova remnants: driving mass, energy and cosmic rays in the Galaxy



TIME EVOLUTION OF FUNDS

SNR/PWN/CR PROJECTS

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Cosmic ray acelerators unveiled by high energy astrophysical observations

+

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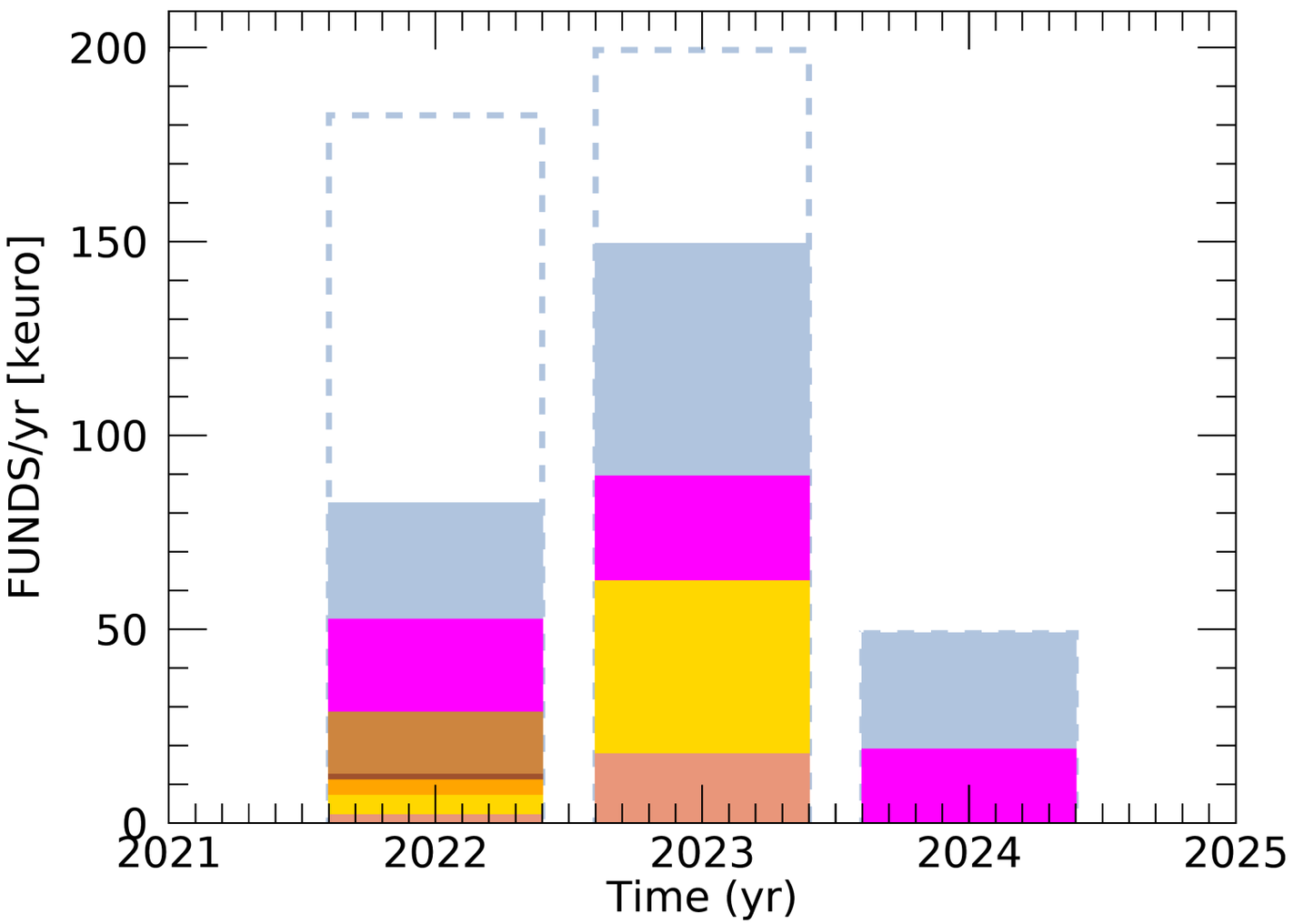
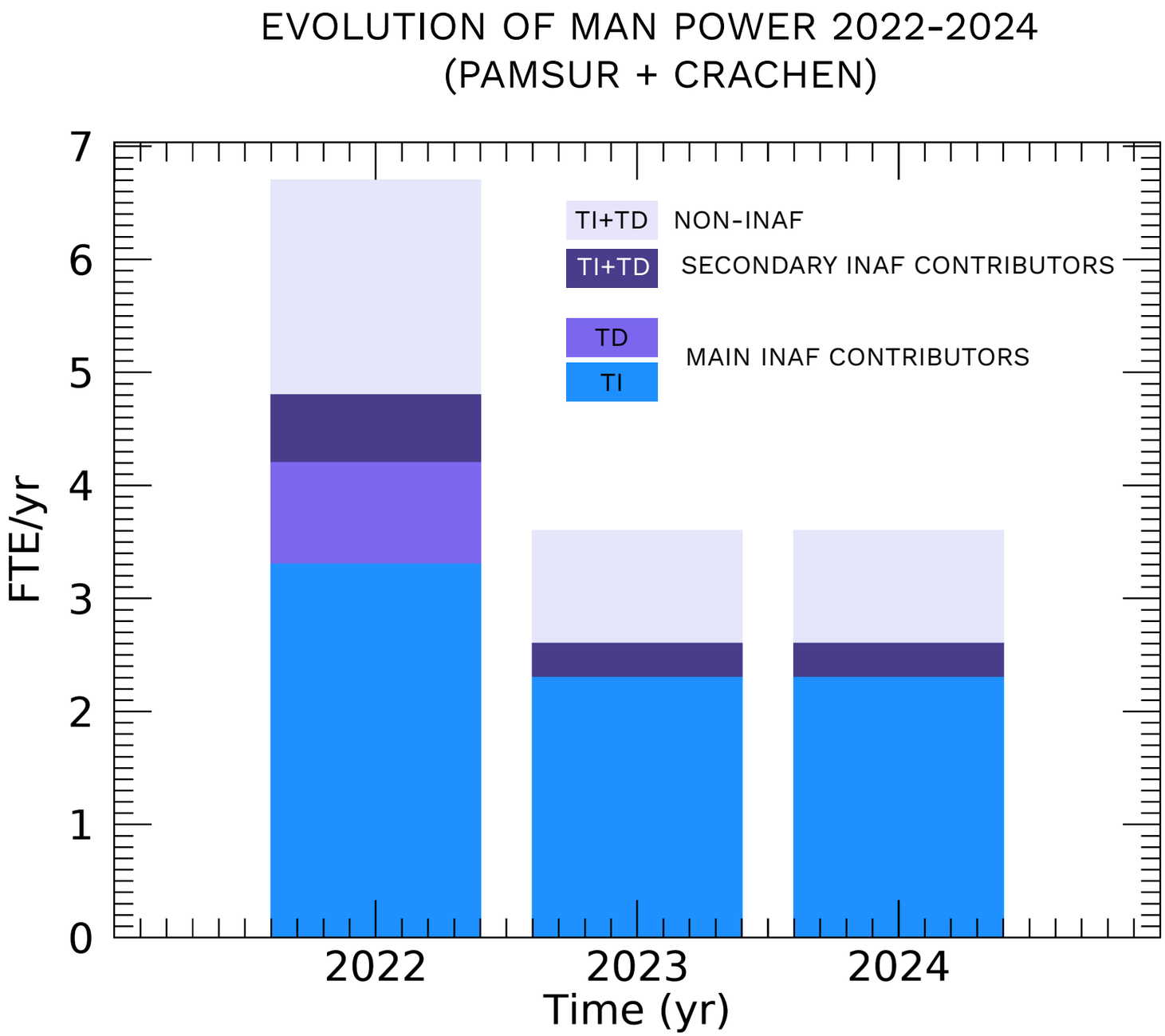


CRITICALITIES



MAN POWER

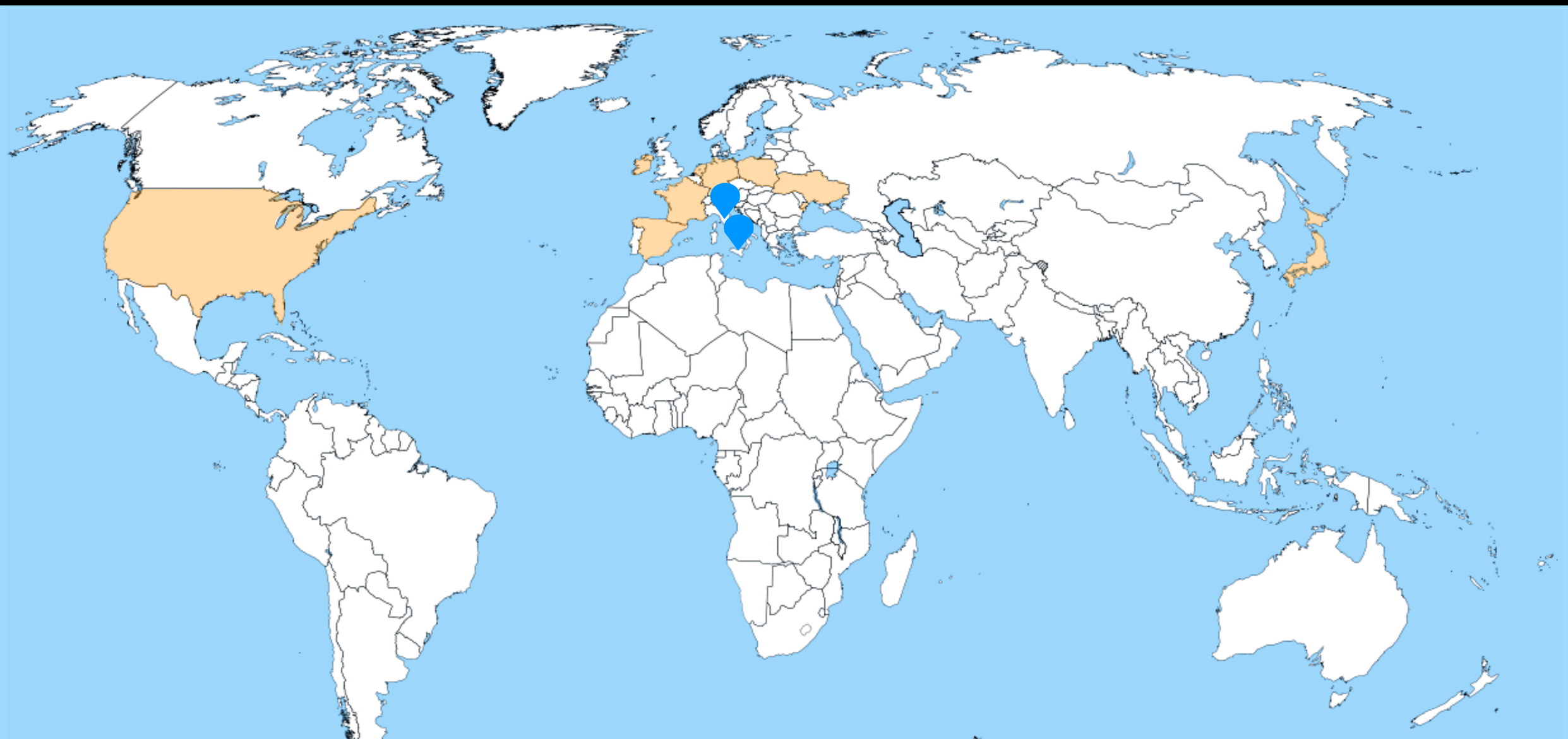
A clear planning for research resources is fundamental to maintain alive the projects + in the view of next future instruments (XRISM - CTA - ASTRI MA - SKA)

MISSIONS/INSTRUMENTS

✔ gamma-rays (CTA, ASTRI MA)

? X-rays facilities (Athena, eXTP)

COLLABORATIONS



DESY Berlin (Germany)
Purdue University (USA)
Penn State University (USA)
Universidad de Valencia (Spain)
University of Amsterdam (Netherland)
Lviv Astronomical Observatory (Ukraine)
Dublin Institute for Advanced Studies (Ireland)
Astroparticle and Cosmology Laboratory, Paris (France)
Harvard-Smithsonian Center for Astrophysics (USA)
ICREA, Institute of Space Science Barcelona (Spain)
RIKEN, the astrophysical Big Bang Laboratory (Japan)

University of Chicago (USA)
Institute of Nuclear Physics Krakow (Poland)
Max Plank Institute for Astrophysics (Germany)
Cherenkov Telescope Array Observatory (CTAO)
Ecole Polytechnique, Université Paris-Saclay (France)
Università di Torino
Università degli Studi di Firenze
La Sapienza
Università di Palermo
Istituto Nazionale di Fisica Nucleare (INFN)
Gran Sasso Science Institute (GSSI)

PUBLICATIONS, DISSEMINATION, SERVICES (2016-2022)

SCIENTIFIC PRODUCTION

~200 refereed papers,
~30 conference proceedings

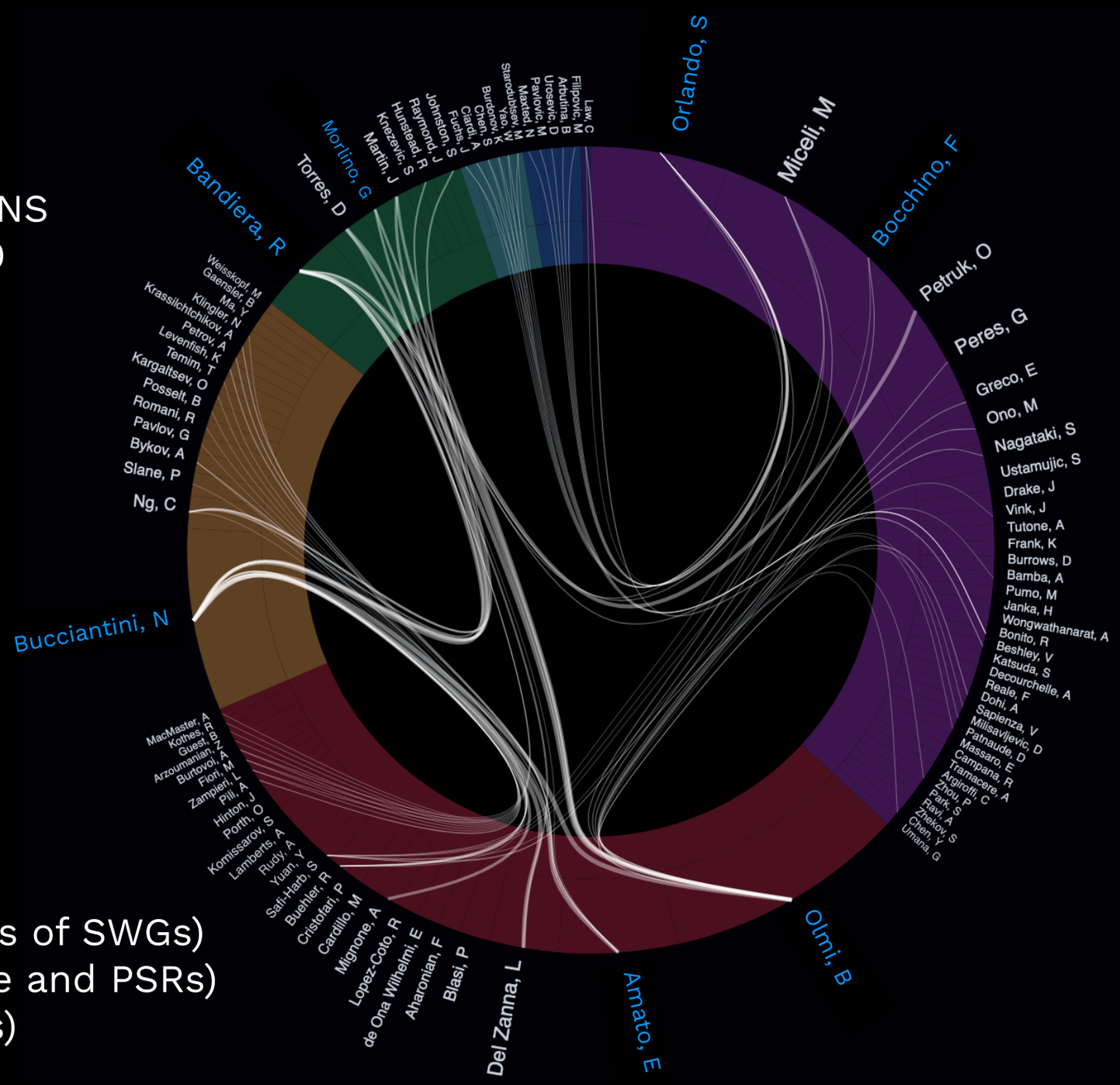
CITATIONS
~4700

INTERNATIONAL CONFERENCES

>100 talks at international conferences
(~70 invited)

OUTREACH

participation in local and national initiatives, development of innovative outreach programs with 3D visualization



MOST RELEVANT SERVICES

CTA (Amato, Morlino, Olmi as coordinators of SWGs)
IXPE (Bucciantini as TWG leader for PWNe and PSRs)
HPC (Orlando as PI of key PRACE projects)
~30 participation to SOC

MEMBERSHIPS

ASTRI, CTA, MAGIC, ATHENA, IXPE, LEM ++ collaborations