Particle accelerators in the LMC

Focus on recent Fermi+HESS gamma-ray observations
Prospects for the detection of SN87A with CTA

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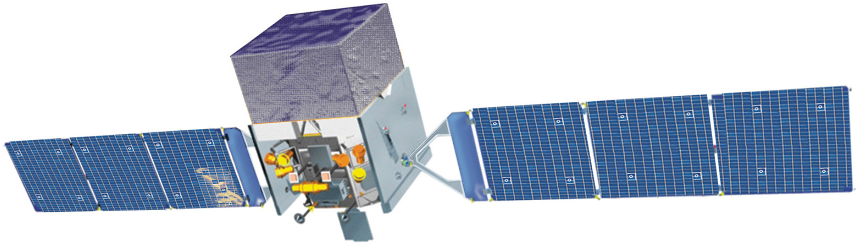
Recent advances in gamma-ray observations of the LMC

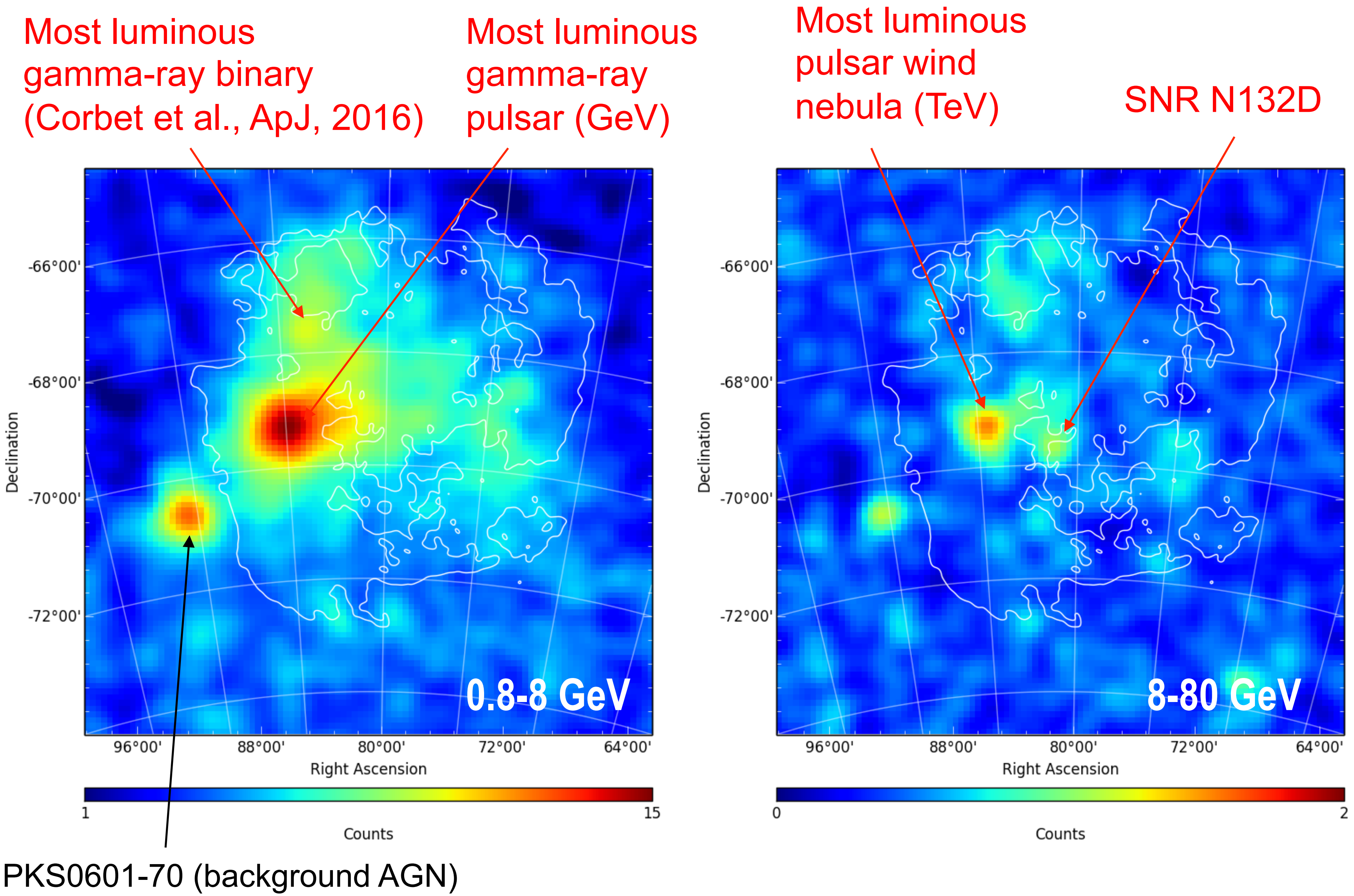
- Unprecedented sensitivity level in gamma-ray observations of the LMC
- 200h exposure with H.E.S.S (~100GeV-100TeV)
- 7 years allsky survey with Fermi P7REP (~100MeV-100GeV)

The exceptionally powerful TeV gamma-ray emitters in the LMC
H.E.S.S. collab., Jan 2015, Science, 347, 6220
(Lead: Nukri Komin)

Deep view of the LMC with 6 years of Fermi-LAT observations
Fermi collab., Jan 2016, A&A, 586, A71
(Lead: Pierrick Martin)

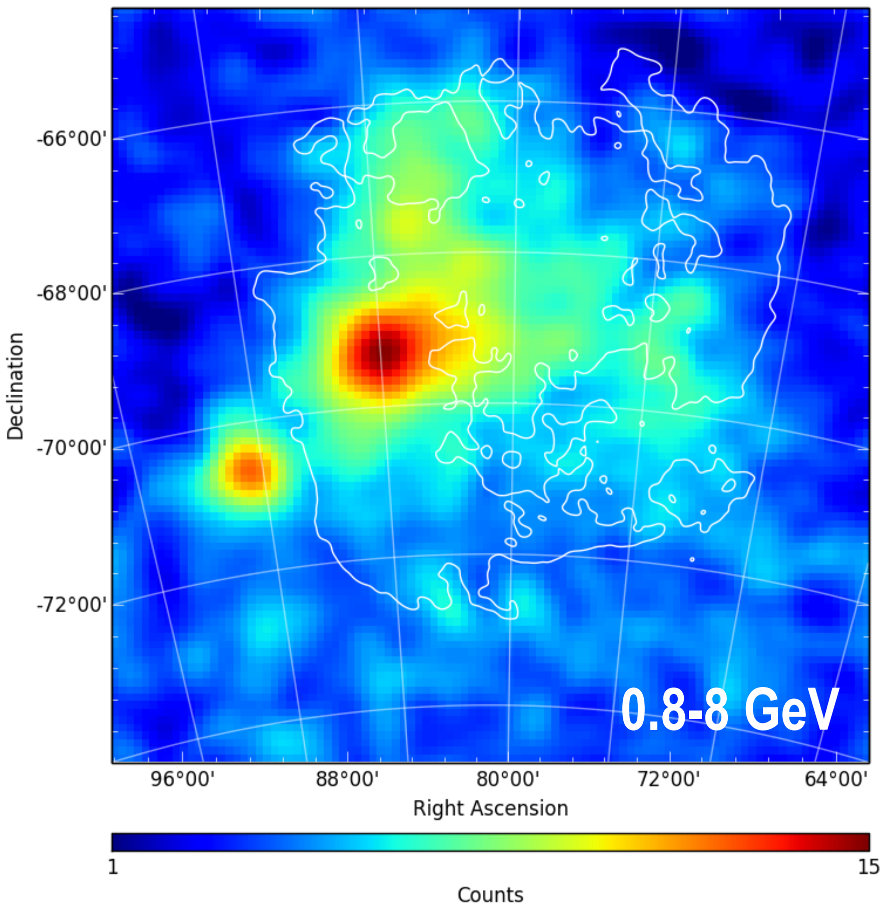


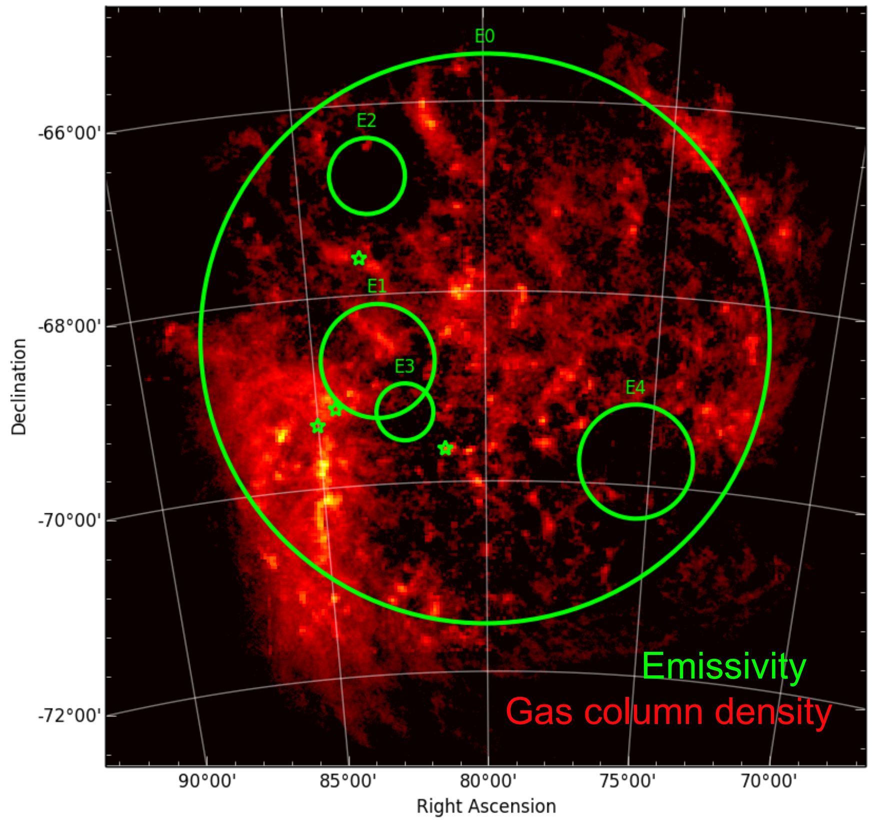
Recent advances in gamma-ray observations of the LMC



Recent advances in gamma-ray observations of the LMC

Puzzling diffuse/extended emission suggesting accumulation of cosmic rays in cavities and/or away from active star-formation sites

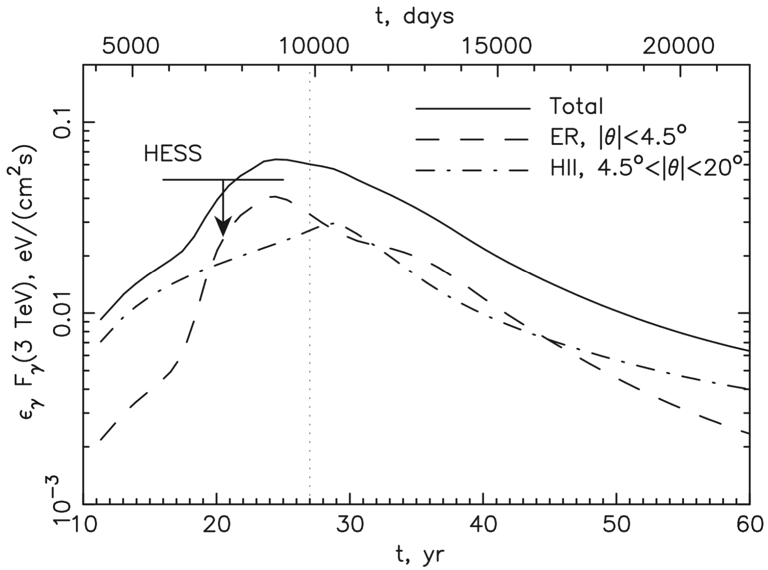




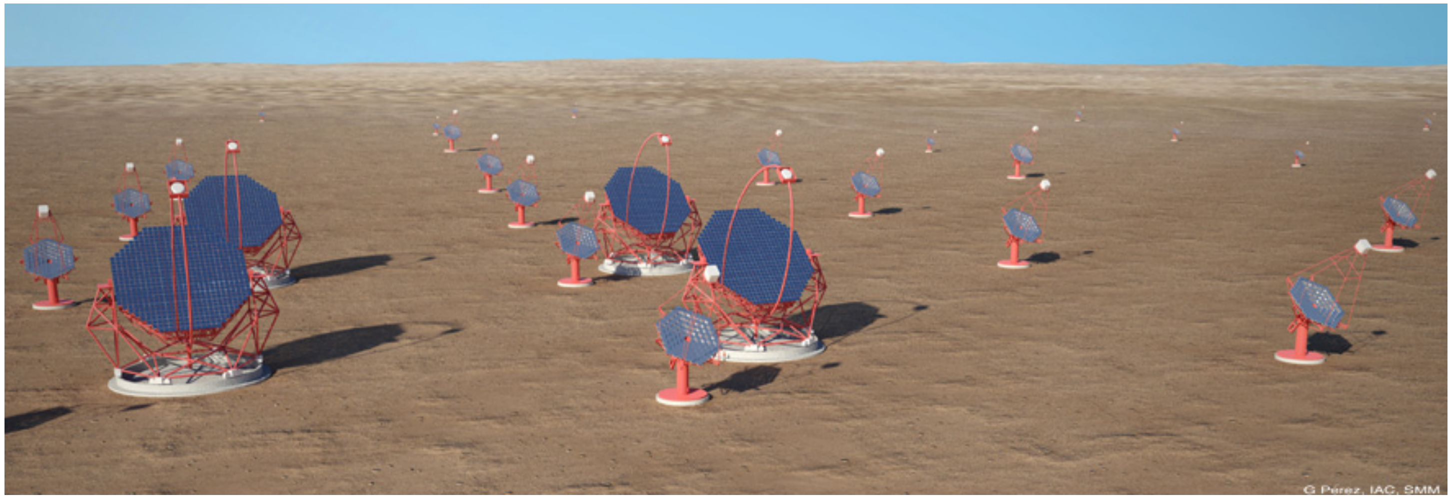
LMC now offering a complete view of CR lifecycle, from acceleration in a variety of astrophysical setups to galactic-scale old populations

…but SN1987A still not detected in gamma-rays !

- TeV upper limits are now constraining and forced revision of models
- Berezhko et al. (2011,2015)



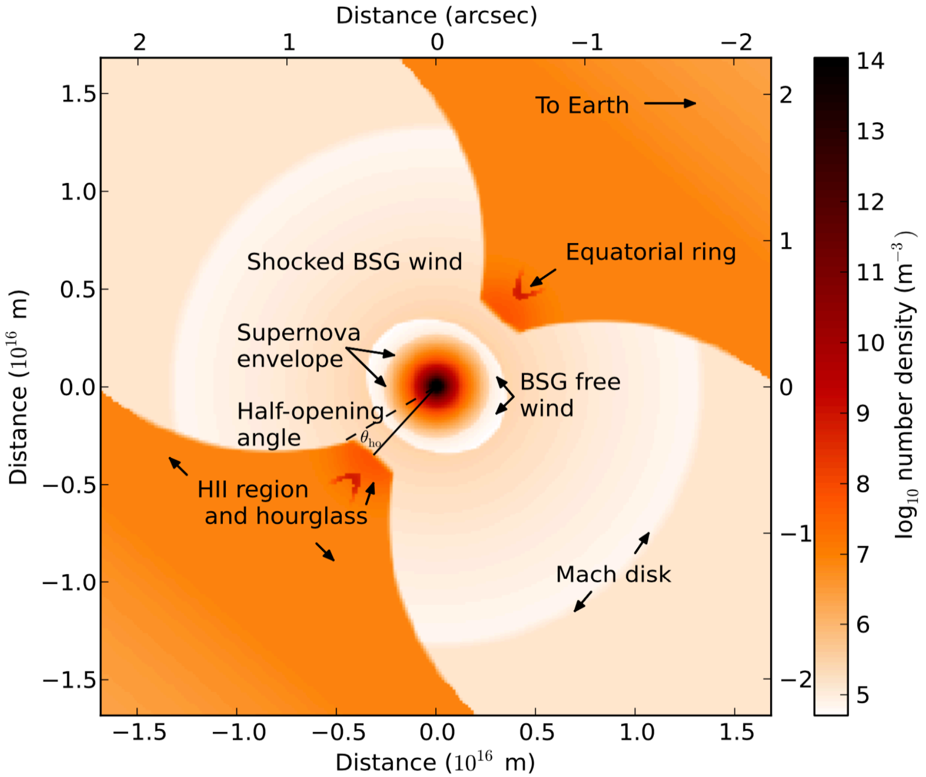
Evaluate the prospects for studying SN87A with the Cherenkov Telescope Array (CTA)
(work in progress…)



Model

- **Circumstellar medium** (CSM):
  - Inspired from Potter et al. (2014)
  - Free BSG wind
  - Shocked BSG wind with n~1 cm^{-3}
  - HII region with n~100 cm^{-3} and half-opening angle 15°
  - Equatorial ring/clumps of n~10^3-10^4 cm^{-3} and half-opening angle 4°

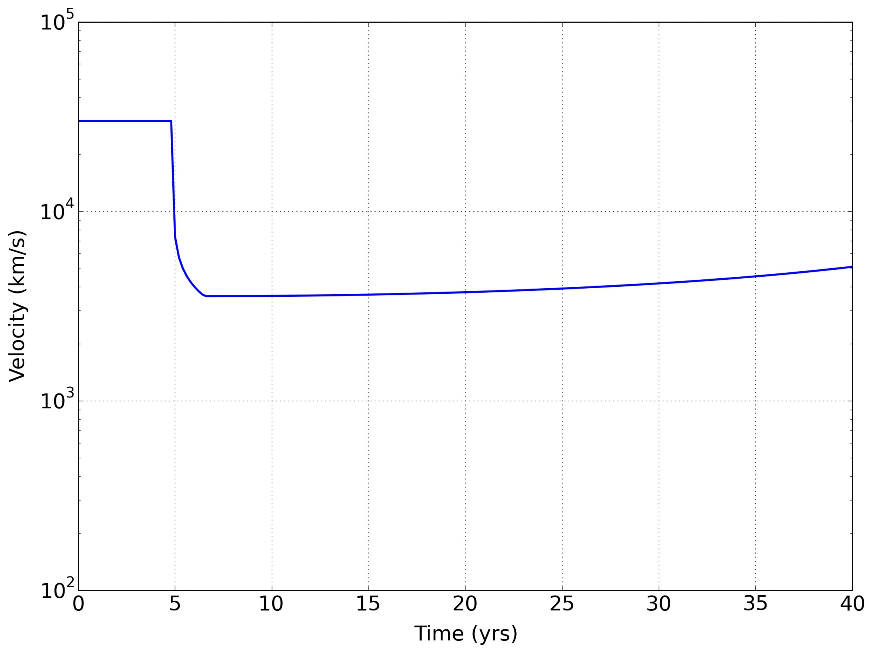
Strongly inhomogeneous CSM expected to host forward, reflected, and transmitted shocks (Zhekov et al. 2009,2010)

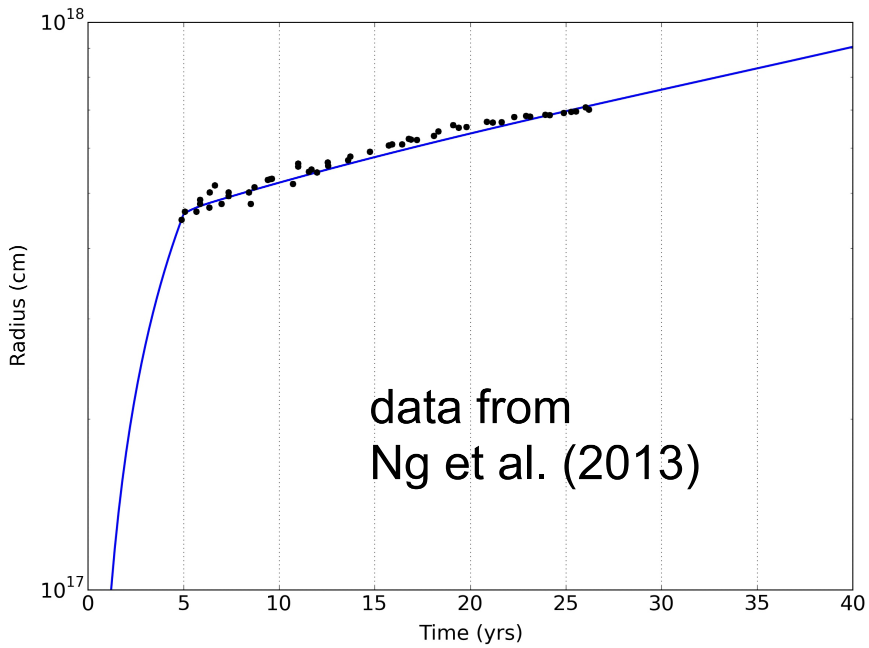


Model

- CSM: Potter et al. (2014)
- **Shock dynamics**:
  - Shock driven by downstream overpressure
  - Velocity evolves such that $\rho_0 V_S^2$ is constant
  - Starts with $\rho_0 V_S^2 = (1\ \mathrm{cm}^{-3}) \times (30000\ \mathrm{km/s})^2$ in BSG shocked wind

Forward shock dynamics in HII region

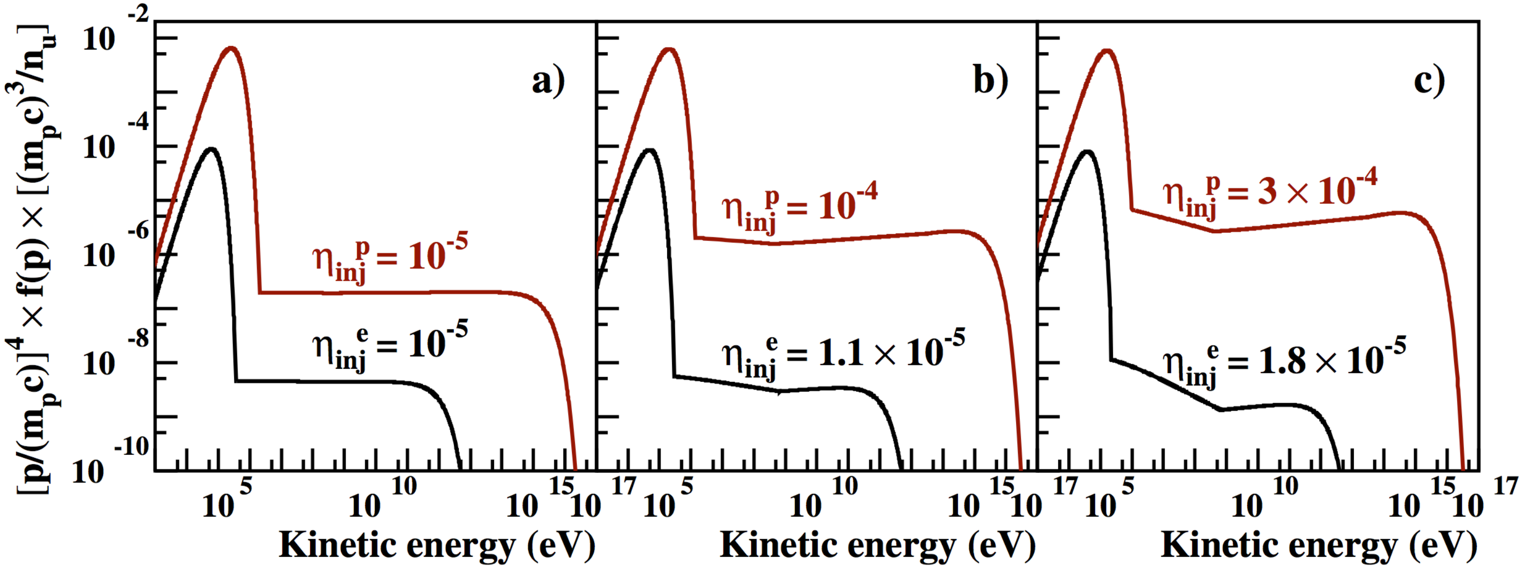




Model

- CSM: Potter et al. (2014)
- Shock dynamics: $\rho_0 V_S^2$ is constant
- **Particle acceleration**:
  - Non-linear DSA module from Tatischeff (2009)
  - Yields shock structure and particle distributions
  - Assumes B field amplification by resonant streaming instability
  - Main input parameters: ρ_0, V_S, injection fraction, e/p ratio
  - Particles accumulate in thin region downstream and cool/radiate

Effect of threshold for suprathermal particle injection



Now features Alfven drift effect that limits concavity

Model

- CSM: Potter et al. (2014)
- Shock dynamics: $\rho_0 V_S^2$ is constant
- Particle acceleration: Non-linear DSA + Alfven drift
- **Radiation**:
  - Synchrotron
  - Inverse Compton, Bremsstrahlung, hadronic interactions (π^0 decay)
  - No absorption

  - <u>Caveat:</u> at any given time, all accelerated particles experience the same conditions downstream (but these conditions vary with time)

Model

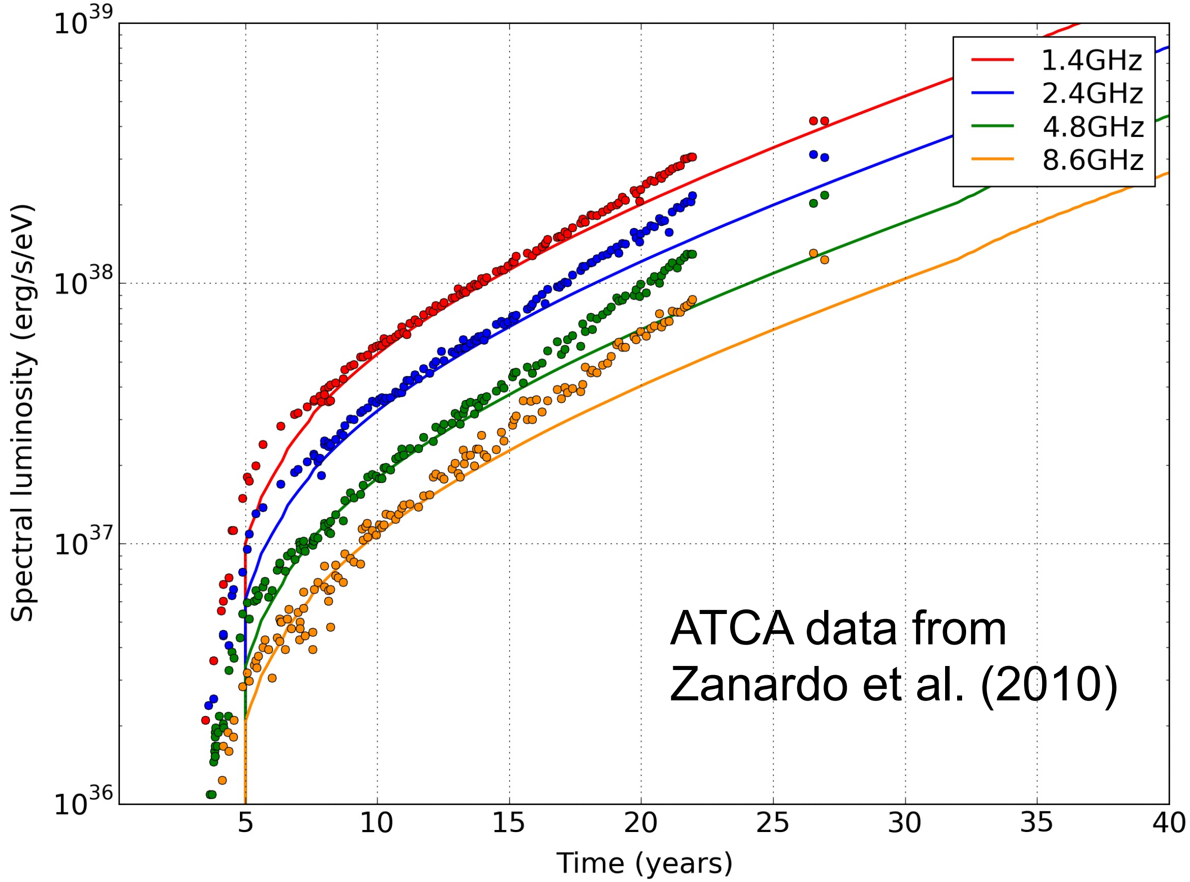
- CSM: Potter et al. (2014)
- Shock dynamics: $\rho_0 V_S^2$ is constant
- Particle acceleration: Non-linear DSA + Alfven drift
- Radiation: synchrotron and gamma-rays

- Free parameters
  - Modest tuning of the CSM description from Potter et al. (2014)
  - Proton injection fraction
  - Electron-to-proton ratio **fixed to 1%**

1- Start by modelling the observed radio synchrotron emission
2- Examine the implications on gamma-ray emission

Radio emission: forward shock in HII region

- Shock moving at ~3600 km/s in n=120 cm^{-3}, swept-up ~0.06$M_{\odot}$ at 30y
- Injection fractions $5x10^{-2}$ for protons, $5x10^{-4}$ for electrons
- Modified shock with subshock / total compression ratios 3.2 / 4.7
- Downstream magnetic field 10mG

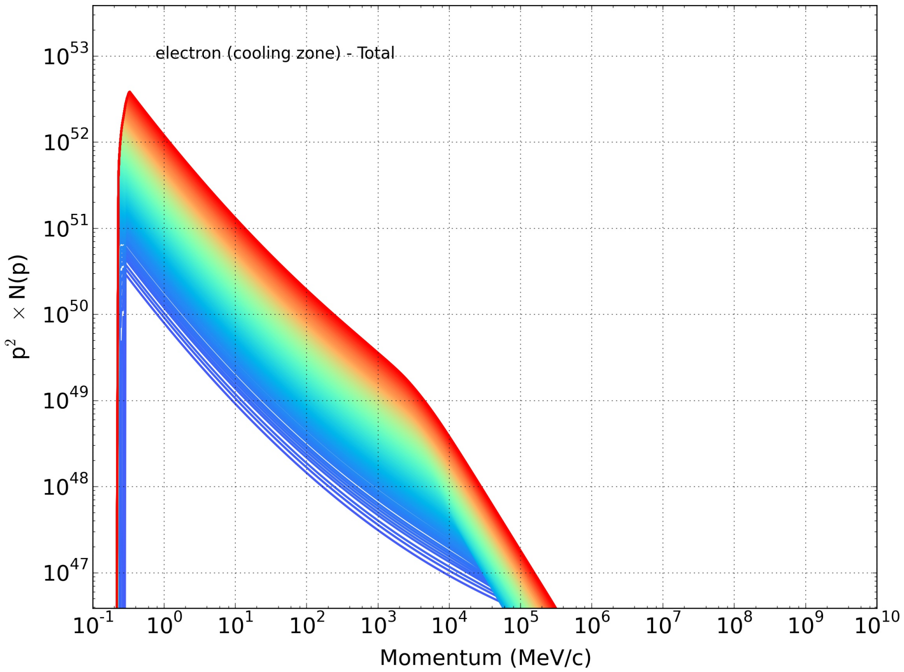


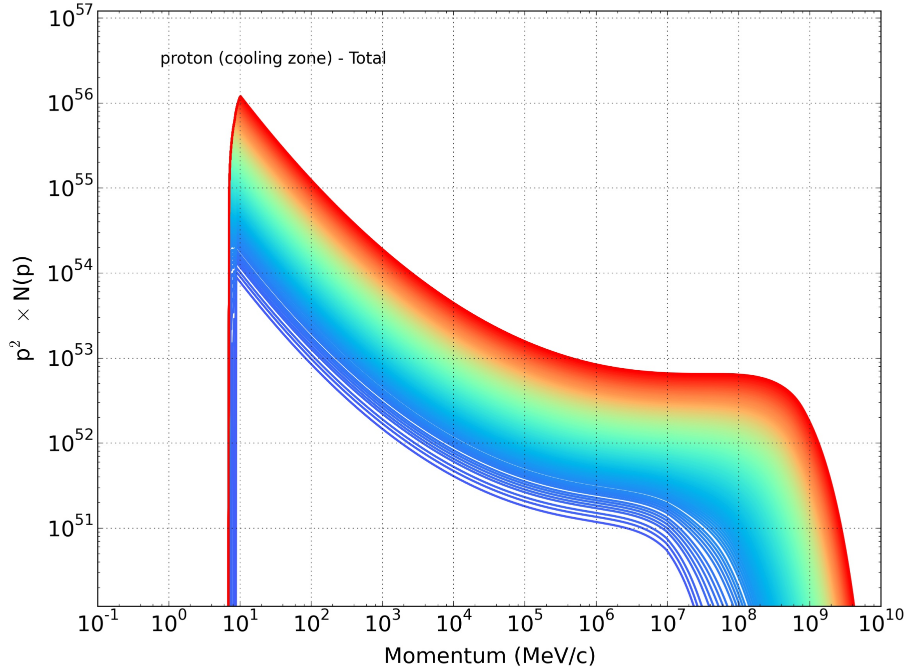
Deviation at ~15y
- observed flux rise
- radio index hardening

We investigated the contribution of reflected shocks propagating back into shocked HII region material after blast wave encounters the equatorial ring

Particle distributions behind forward shock in HII region

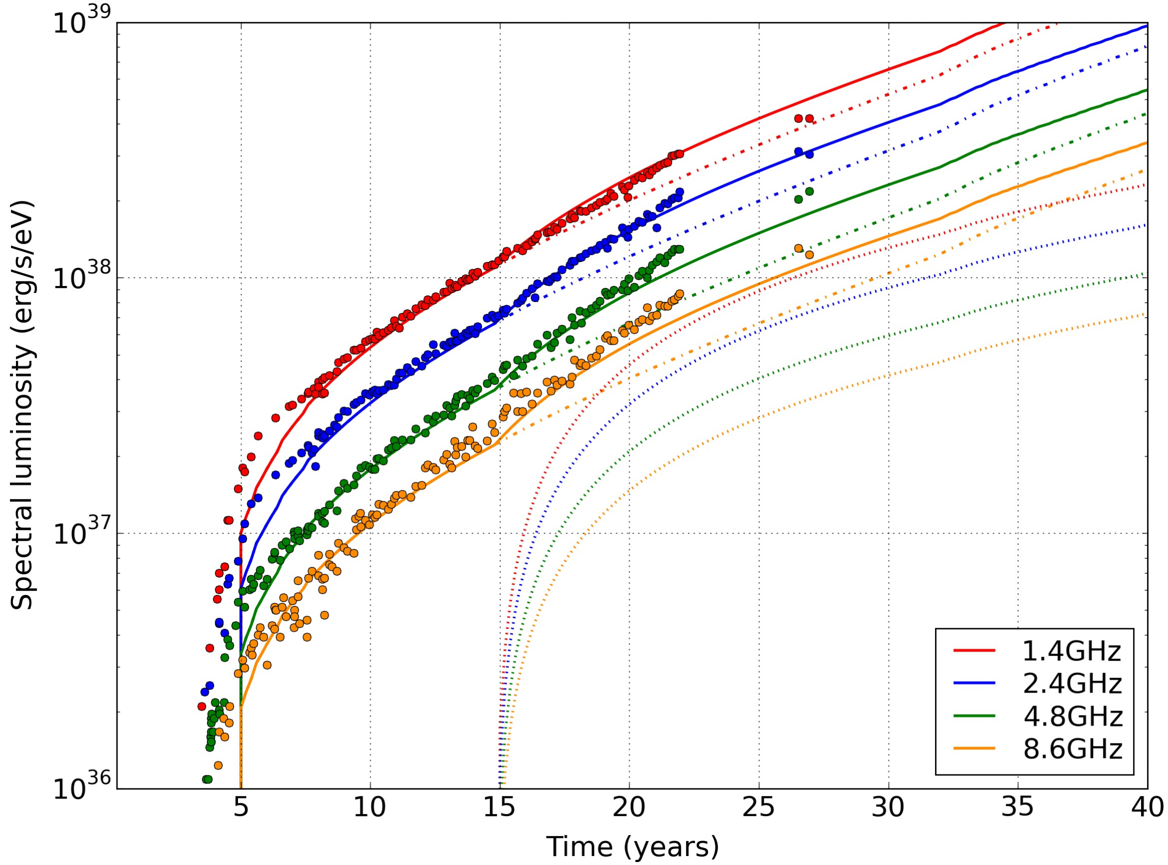
- Protons
  - Reaching up to >100 TeV
  - Flat spectrum above 100GeV (effect of Alfven drift)
- Electrons
  - Sub-GeV particles radiating at 1-10 GHz
  - Strong synchrotron losses: break at few GeV
  - Synchrotron SED peaking at THz, faint in X-rays (NuSTAR ?)





Radio emission: forward shock + reflected shock in HII region

- Reflected shock moving backwards at ~1800 km/s in n=540 cm^{-3}
  … swept-up ~0.01$M_\odot$ at 30y
- Injection fractions ~100 times lower than forward shock
- Caveat: no reacceleration of previously shock-accelerated particles

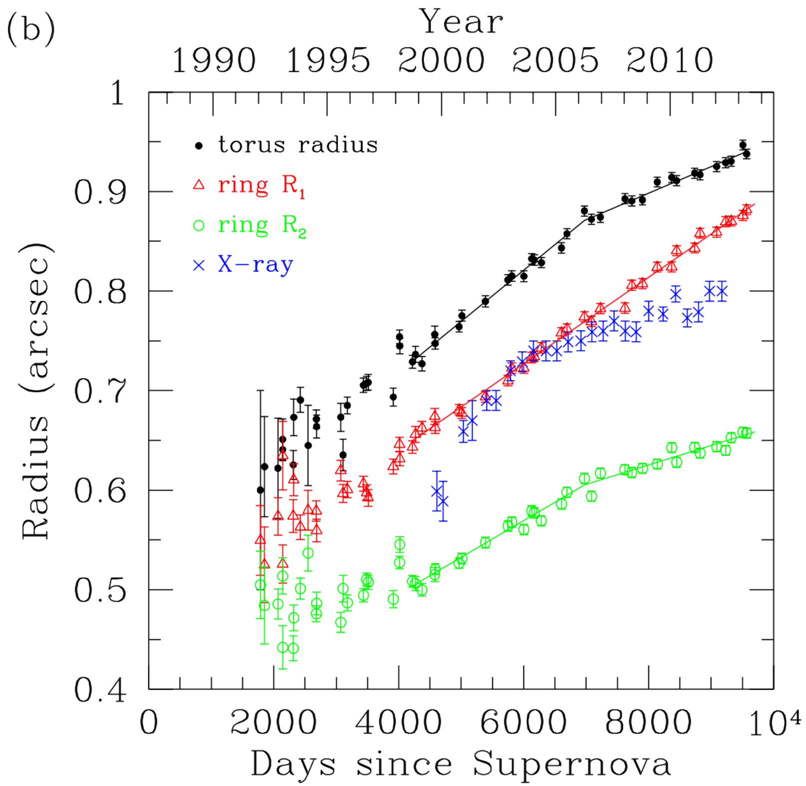


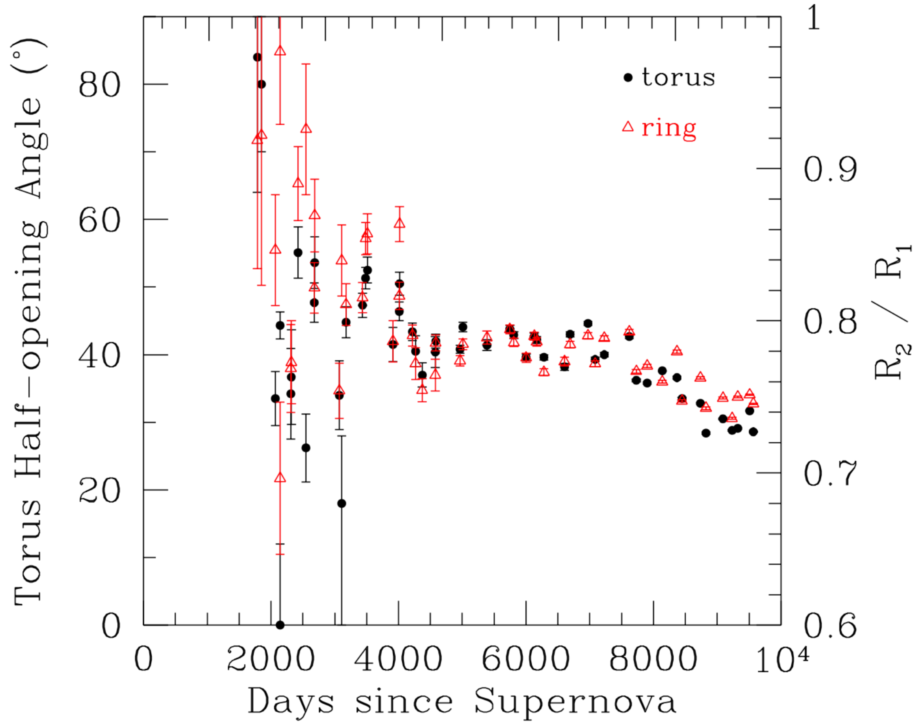
Reproduces the trend beyond 15y within 10%

Hard to get the same trend by tuning injection parameters without also fine-tuning CSM and shock dynamics (in this model)

Radio emission: forward shock + reflected shock in HII region

- Also accounts qualitatively for evolution of radio ring (Ng et al. 2013)
  - break in expansion rate
  - flattening of the morphology
- …because it adds radio-emitting material from inside the ring

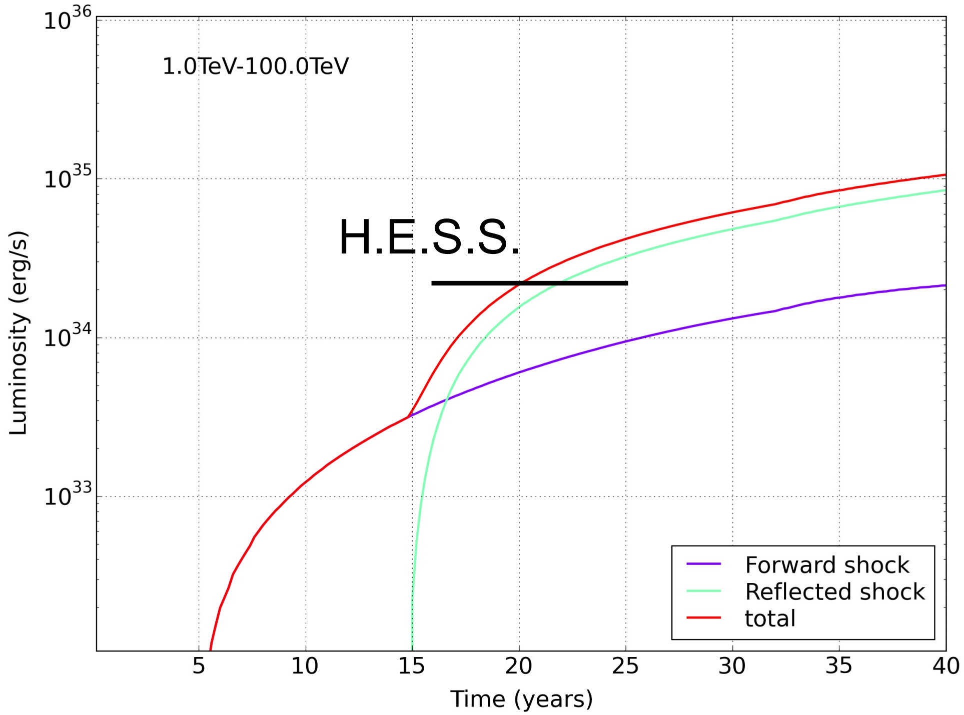


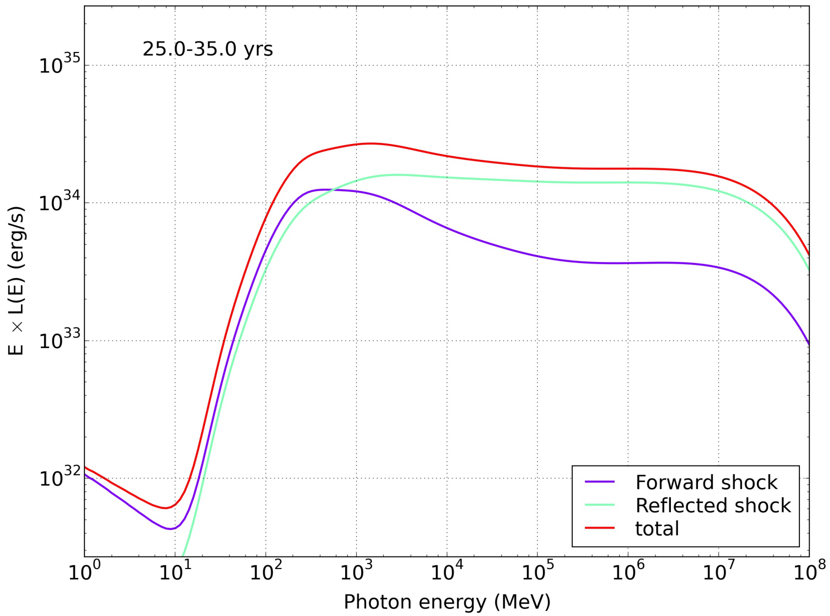


Implications at the other end of the spectrum

- Predicted TeV flux nearly consistent with recent H.E.S.S. upper limit
- Trend over next 10y depends on:
  - Density structure of smooth HII region over r= $7x10^{17}$ - 10^{18} cm
  - Evolution of reflected shock in inner HII region

Good prospects for CTA with its 10x increased sensitivity
… but first detection might be achieved by H.E.S.S. II

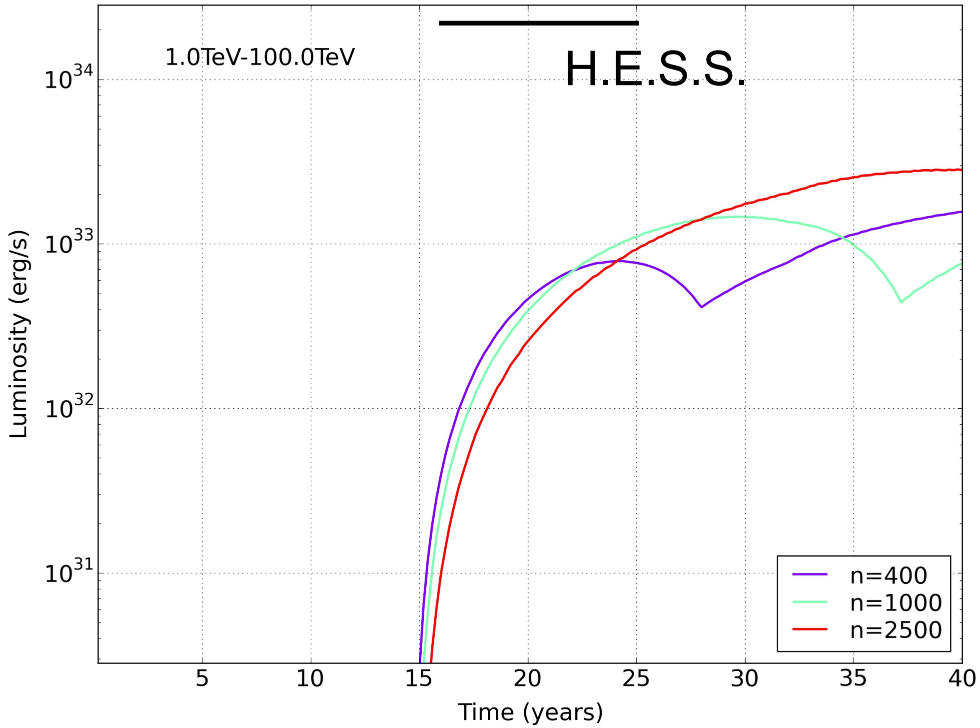


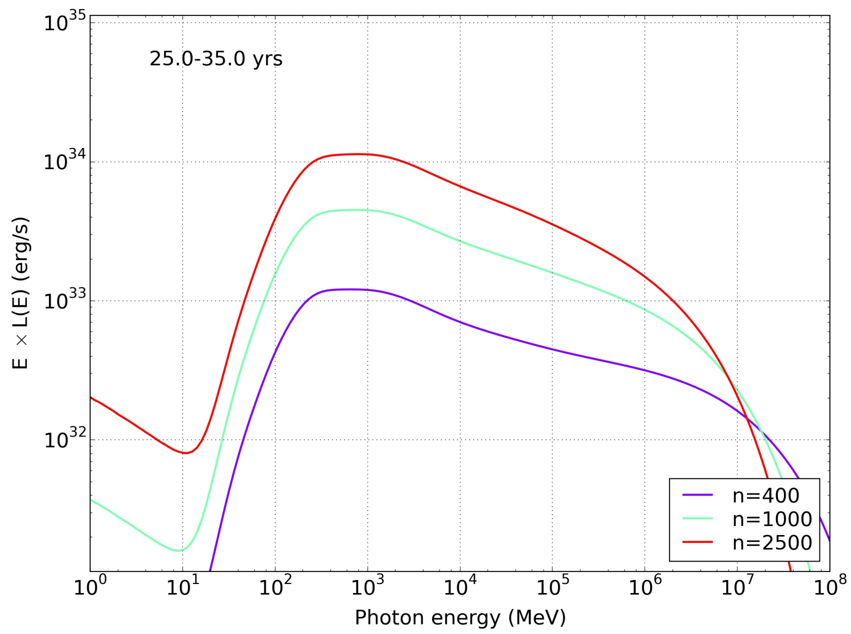


Implications at the other end of the spectrum

- Additional contribution from transmitted shocks in ring clumps ?
- Shock velocities ~2000,1000,800 km/s in n=400,1000,2500 cm^{-3}
- Swept-up masses ~0.01,0.02,0.03 $M_\odot$ at 30y
- Assuming same injection as in HII region

Negligible contribution from transmitted shocks (also in radio)





Conclusions

- Scenario for non-thermal particle acceleration and radio emission
  - Dominated by forward shock in HII region since year 5
  - Contribution by 10-30% from reflected shocks from year 15
  - High injection at forward shock, much lower at reflected shock
    - ➔ Needs to be clarified/understood

- Associated gamma-ray emission
  - Pion decay from >100TeV protons
  - Rising luminosity
  - Dominated by reflected shock contribution
    - ➔ Expected to be within reach now (H.E.S.S., CTA)

The next decade may be when SN987A is detected in high-energy gamma-rays. If not, we should learn something on particle acceleration and/or injection and on SN87A itself