



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)



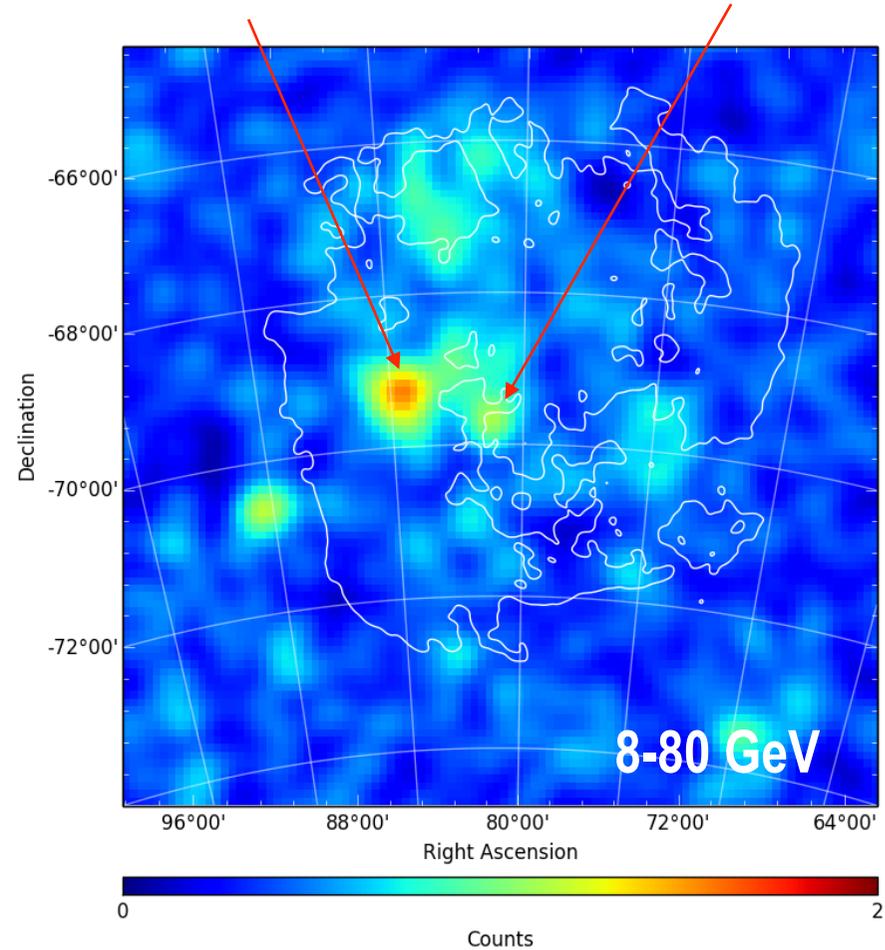
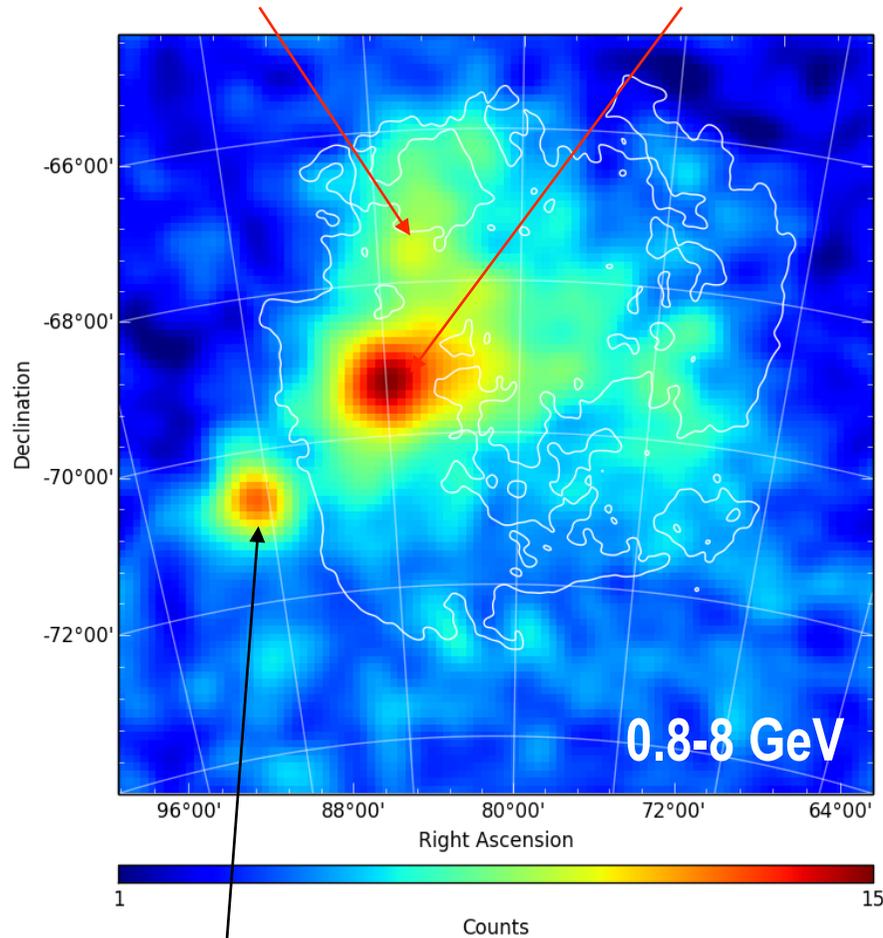
Recent advances in gamma-ray observations of the LMC

Most luminous
gamma-ray binary
(Corbet et al., ApJ, 2016)

Most luminous
gamma-ray
pulsar (GeV)

Most luminous
pulsar wind
nebula (TeV)

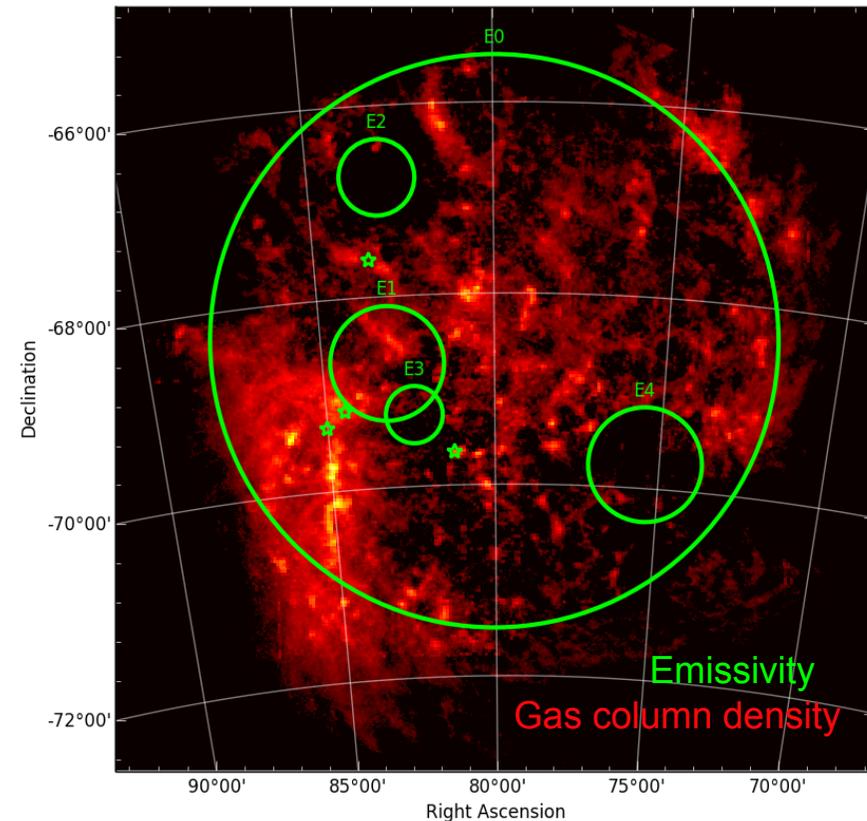
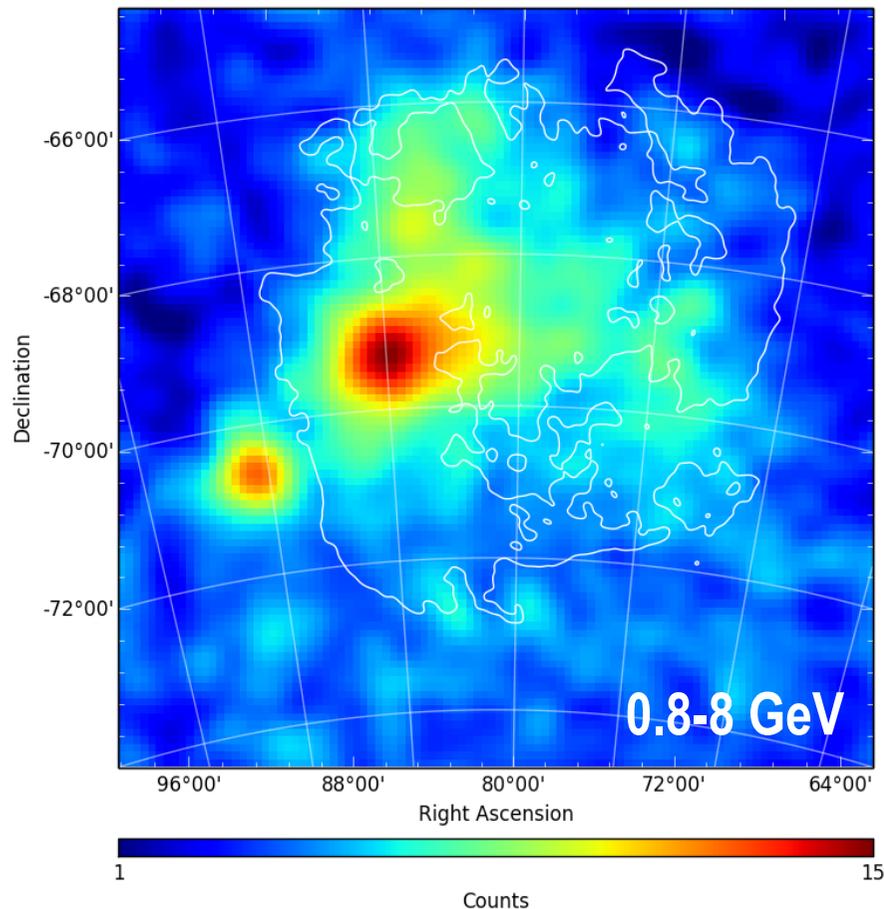
SNR N132D



PKS0601-70 (background AGN)

Recent advances in gamma-ray observations of the LMC

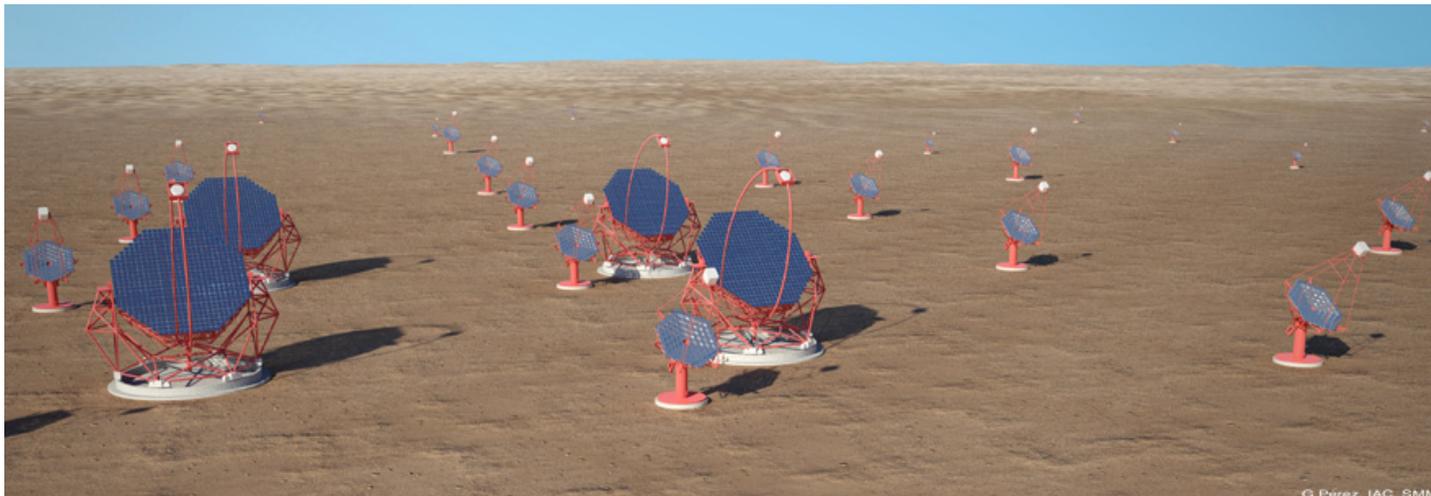
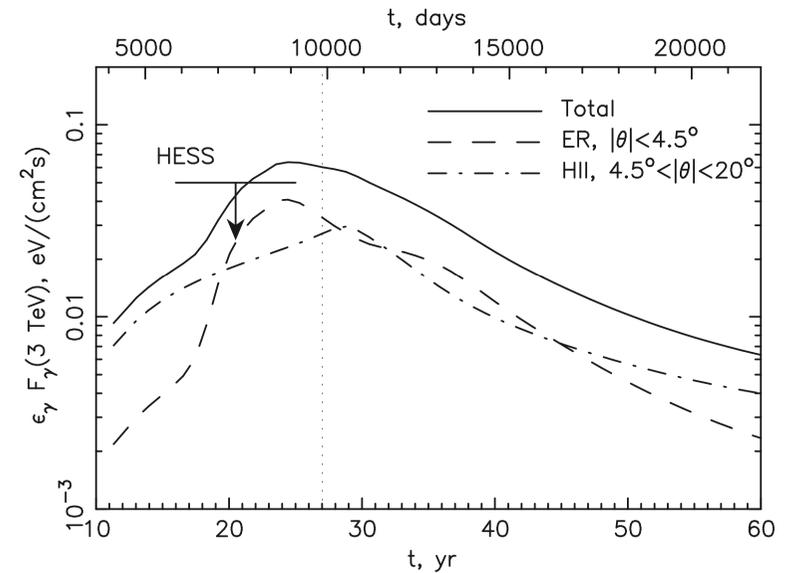
Puzzling diffuse/extended emission suggesting accumulation of cosmic rays in cavities and/or away from active star-formation sites



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 !

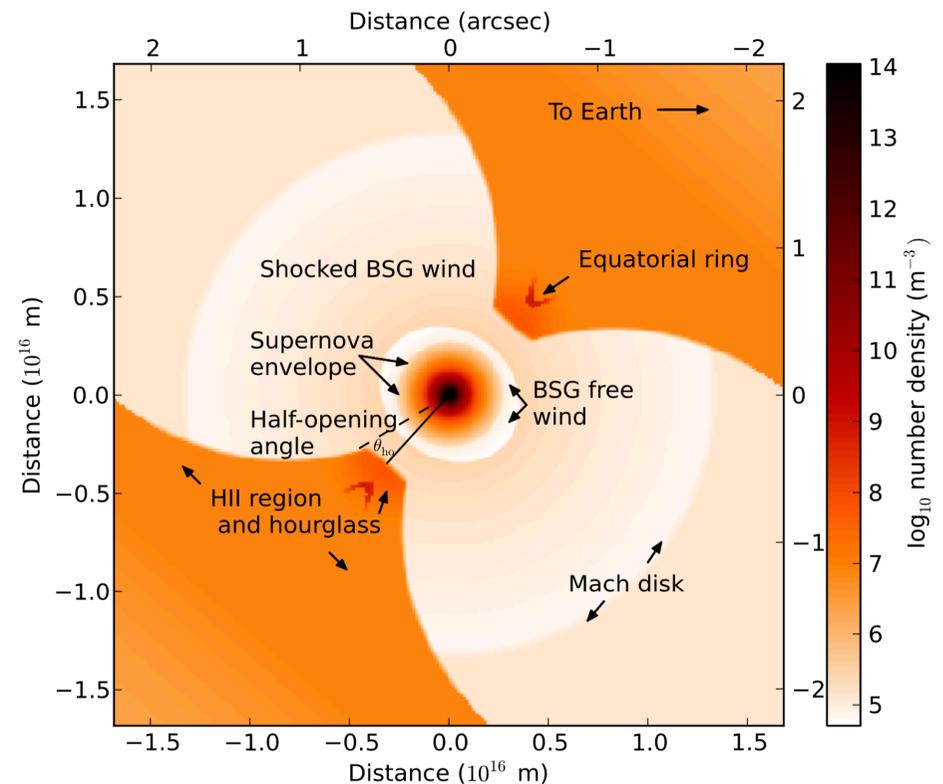
- TeV upper limits are now constraining and forced revision of models
- Berezhko et al. (2011,2015)
- We developed a new model for particle acceleration and non-thermal emission in SN87A to evaluate the prospects for future observations with CTA . Work in progress...



Model

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

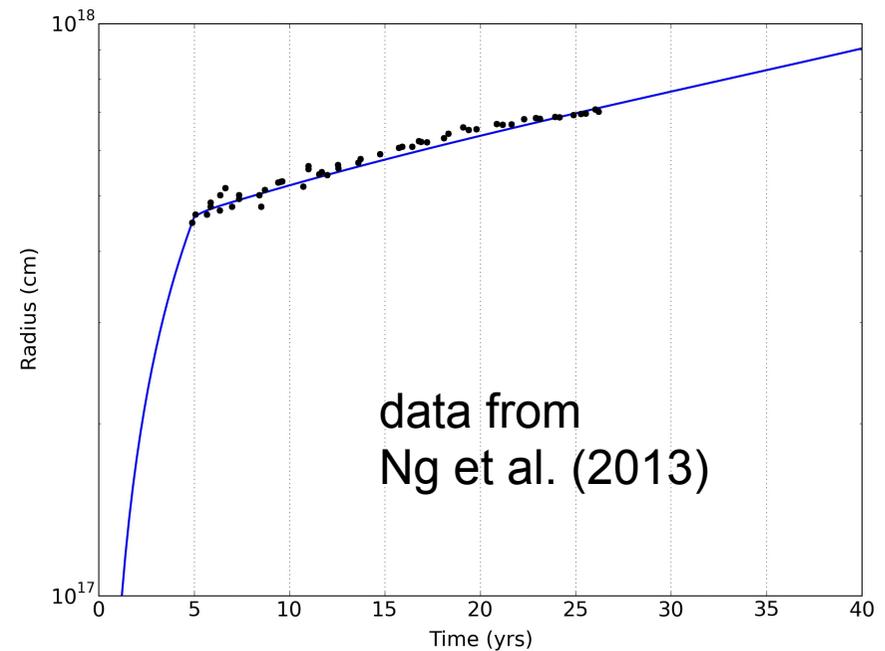
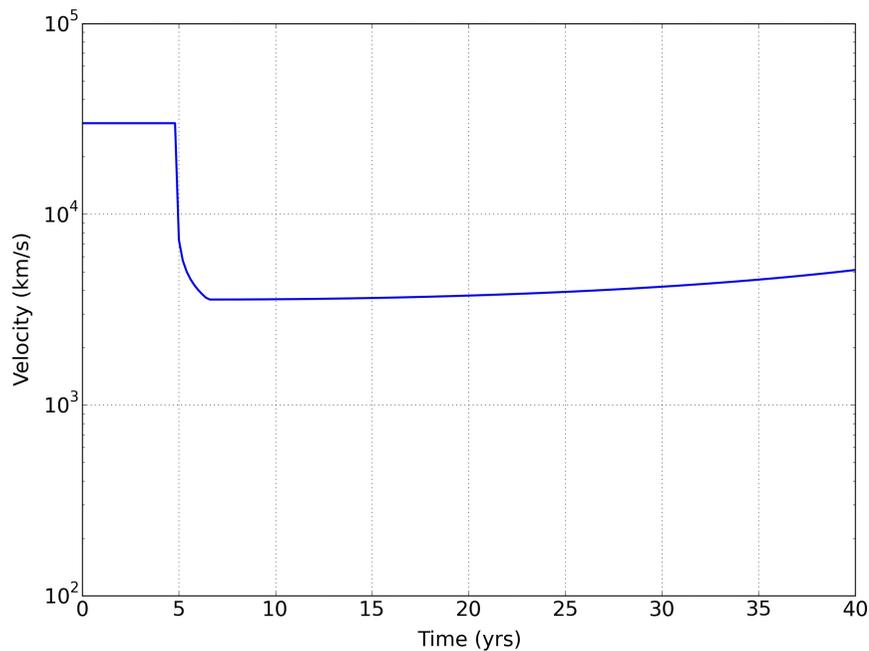
Strongly inhomogeneous CSM
expected to host forward,
reverse, reflected, and
transmitted shocks
(Zhekov et al. 2009,2010)



Model

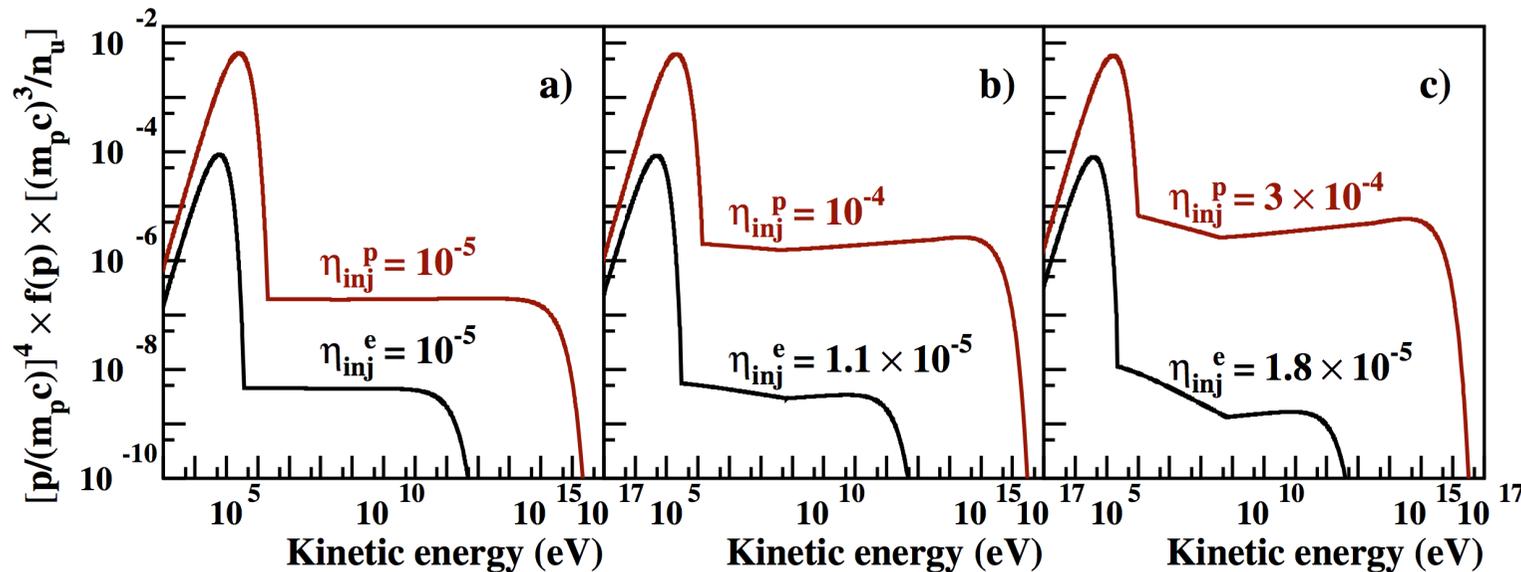
- CSM: Potter et al. (2014)
- **Shock dynamics:**
 - Shock driven by downstream overpressure
 - Velocity evolves such that $\rho_0 V_S^2$ is constant
 - Starts with $\rho_0 V_S^2 = (1 \text{ cm}^{-3}) \times (30000 \text{ km/s})^2$ in BSG shocked wind

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
 - Main input parameters: ρ_0 , V_S , injection fraction, e/p ratio
 - Particles accumulate in thin region downstream and cool/radiate



Now features
Alfven drift
effect that
limits
concavity

Effect of threshold for suprathermal particle injection

Model

- CSM: Potter et al. (2014)
- Shock dynamics: $\rho_0 V_S^2$ is constant
- Particle acceleration: Non-linear DSA + Alfvén drift
- **Radiation:**
 - Synchrotron
 - Inverse Compton, Bremsstrahlung, hadronic interactions (π^0 decay)
 - No absorption
 - Caveat: at any given time, all accelerated particles experience the same conditions downstream (but these conditions vary with time)

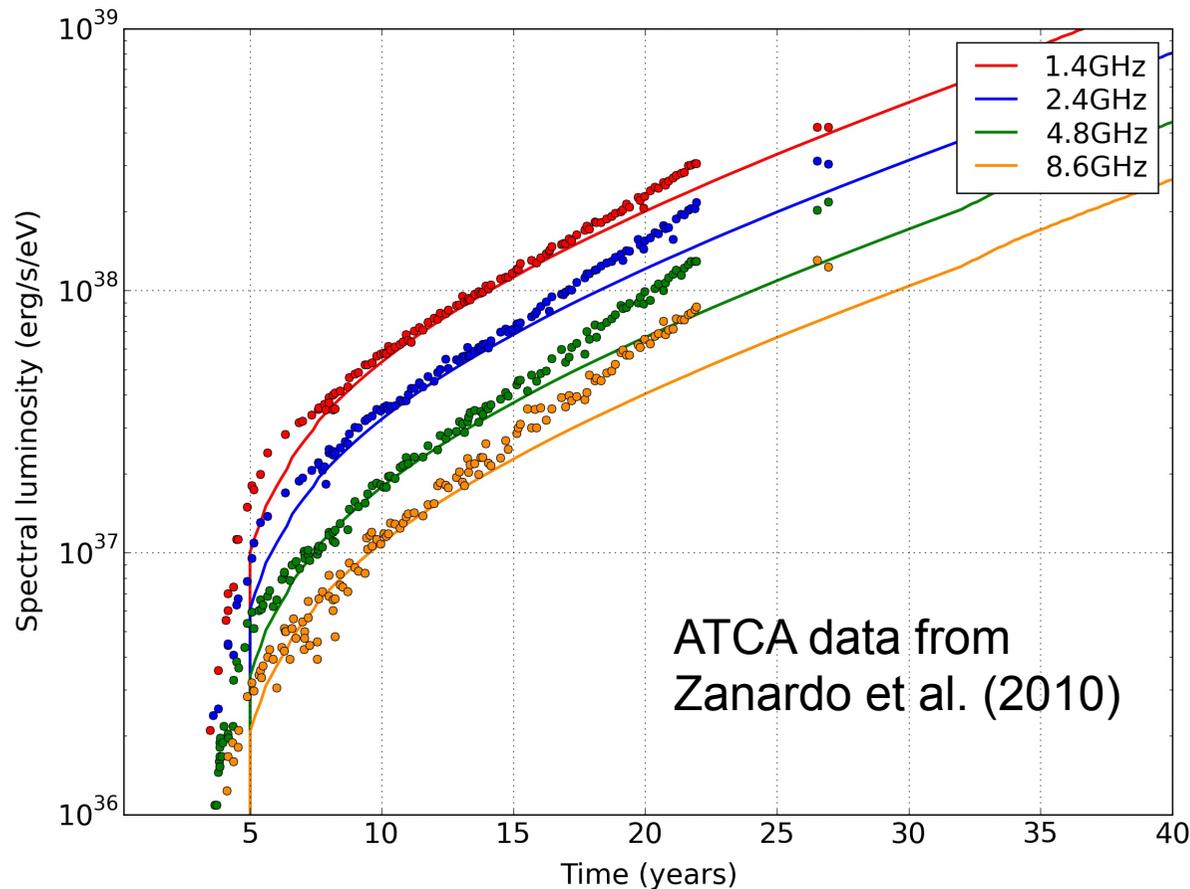
We start by modelling the observed radio synchrotron emission

This will fix some uncertain parameters (injection)

We then 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 $\sim 0.06M_{\odot}$ at 30y
- Injection fractions 5×10^{-2} for p^+ , 5×10^{-4} for e^-
- Modified shock with subshock / total compression ratios 3.2 / 4.7
- Downstream magnetic field 10mG

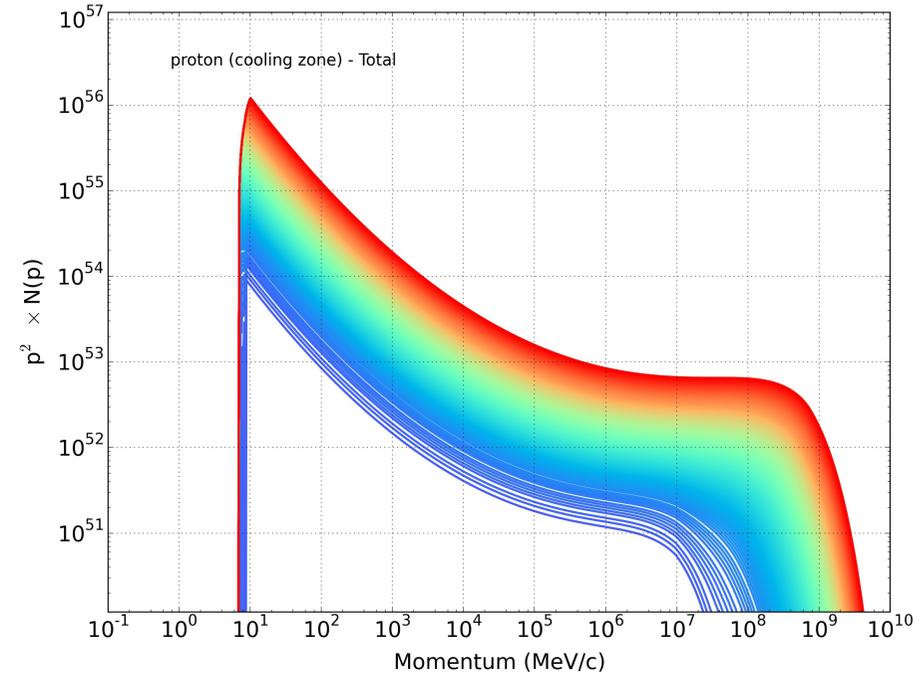
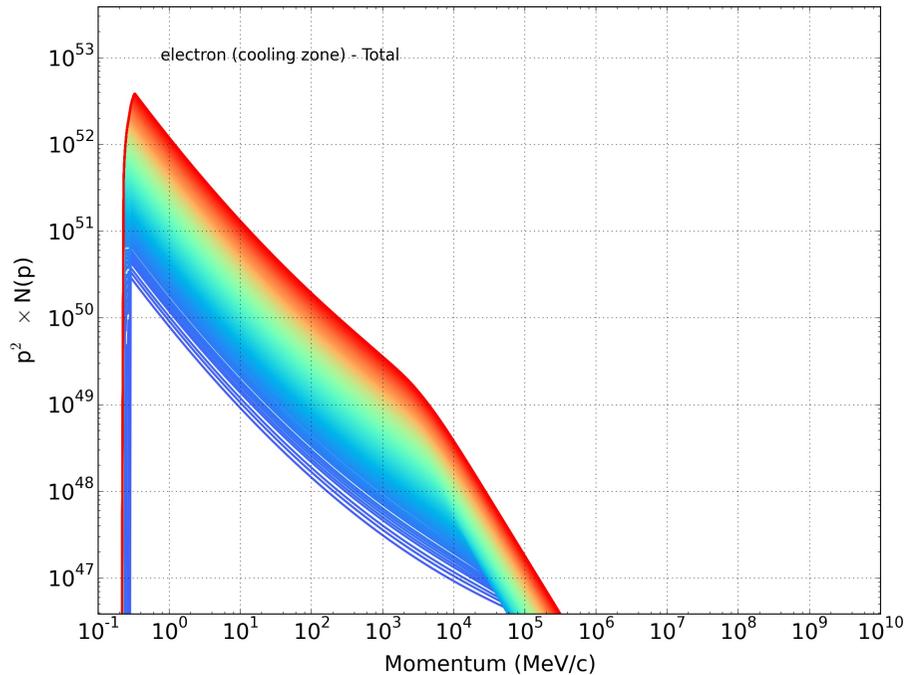


Deviation at ~ 15 y
- observed flux rise
- radio index hardening

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

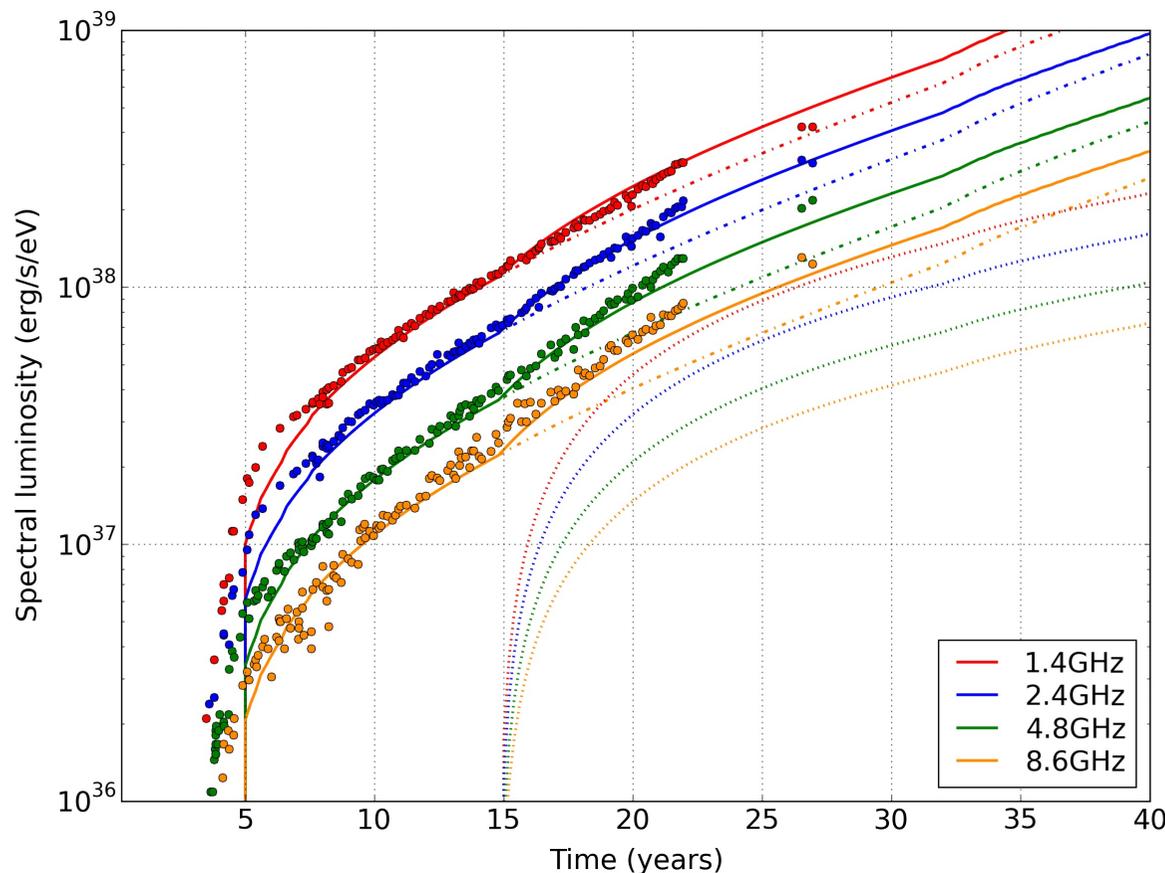
Particle distributions behind forward shock in HII region

- Protons
 - Reaching up to >100 TeV
 - Flat spectrum above 100GeV (effect of Alfvén 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



Radio emission: forward shock + reflected shock in HII region

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



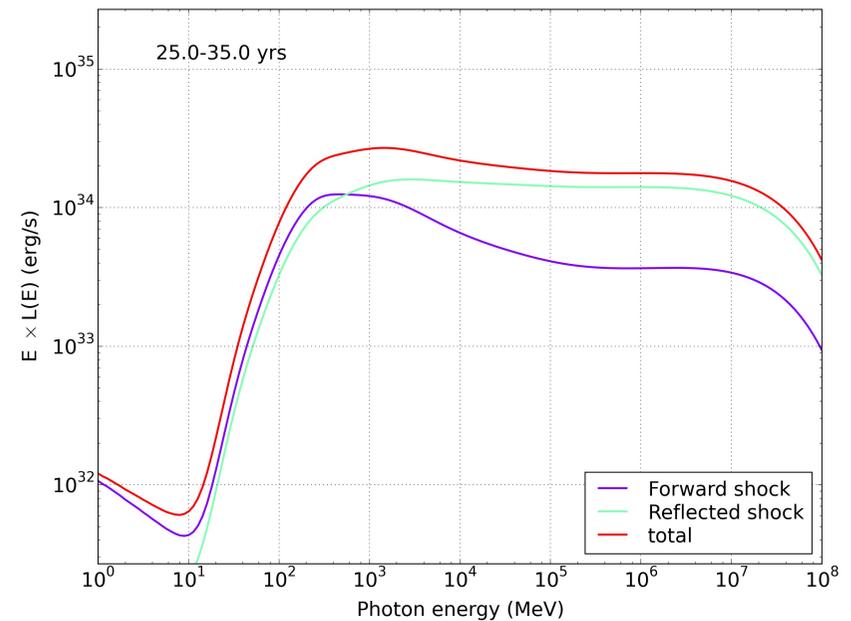
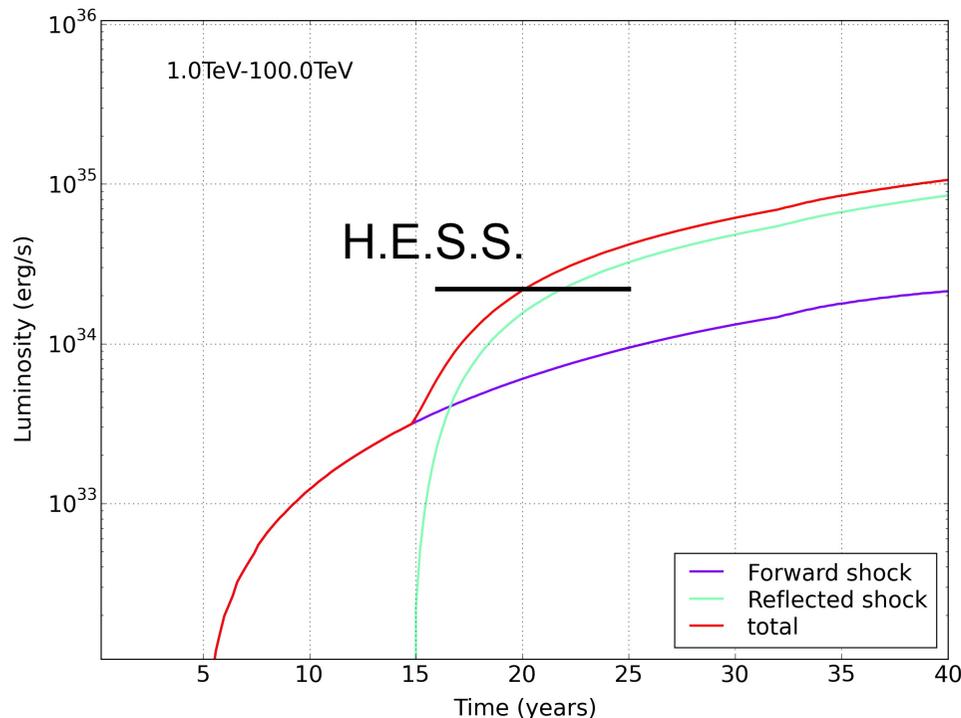
Reproduces the trend beyond 15y within 10%

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

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 $r= 7 \times 10^{17} - 10^{18}$ cm
 - Evolution of reflected shock in inner HII region

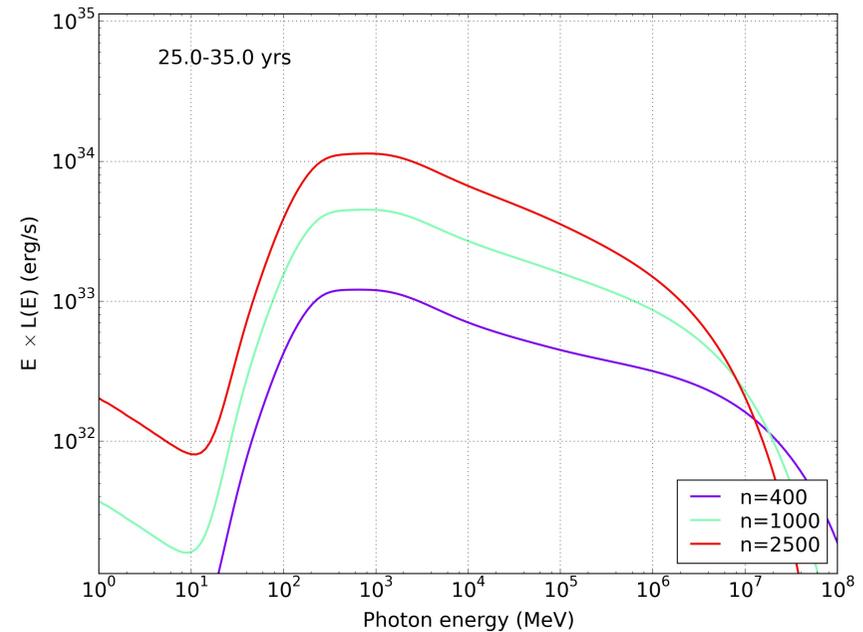
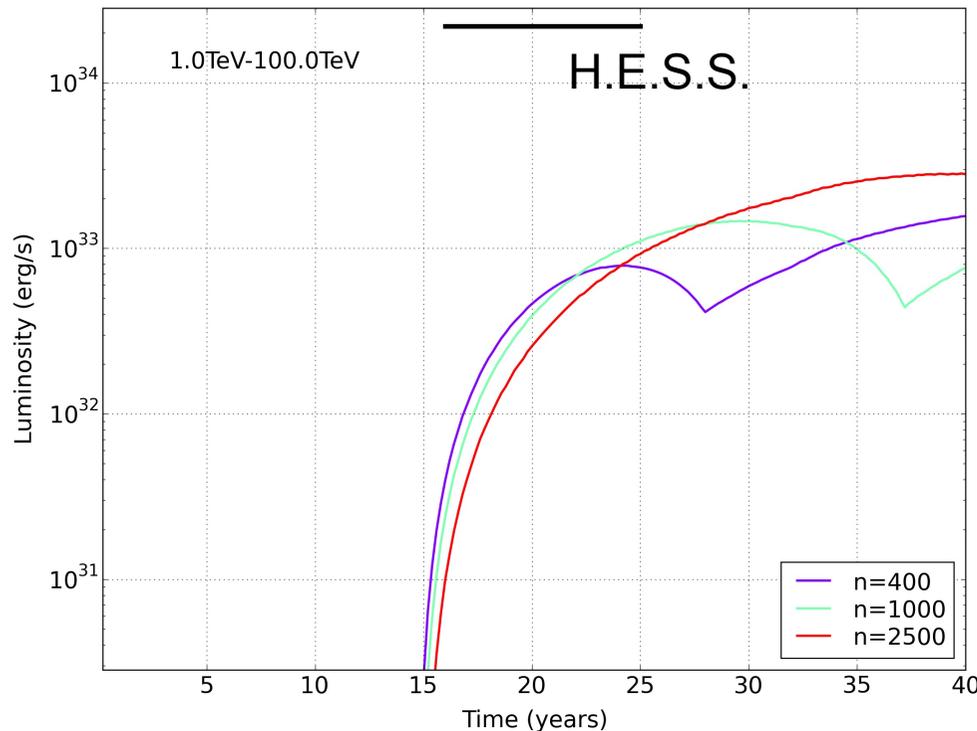
Good prospects for CTA with its 10x increased sensitivity
... but first detection might be achieved by H.E.S.S. II



Implications at the other end of the spectrum

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

Negligible contribution from transmitted shocks



Conclusions

- TBW