Studying 30 Doradus in LMC with the CTA

(excerpt from submitted consortium paper)

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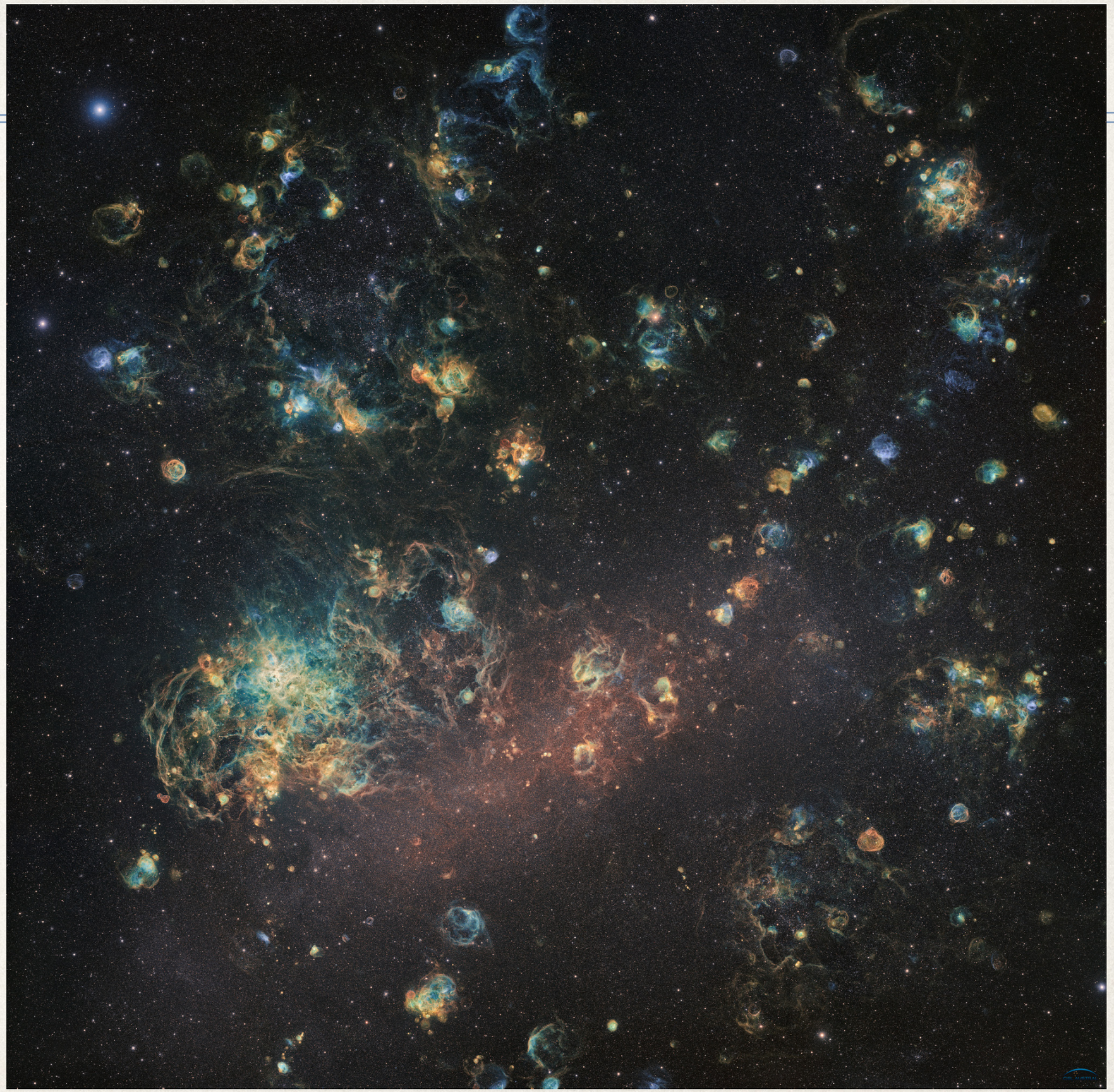
Context

- Deep survey of the LMC KSP
  - satellite dwarf galaxy at 50kpc distance
  - disk-like galaxy seen with low inclination (i~20-30°)
  - 340h+150h exposure over ~7° patch of sky
  - (southern hemisphere target)

- Interest and limitations
  - major star-forming regions (esp. 30 Doradus or N11)
  - reduced line of sight confusion w.r.t. Galaxy
  - … but distant: need powerful sources for detectable fluxes
  - … and sources large enough for morphology studies
    (3 arcmin PSF ~ 44 pc in LMC)

Context



Credit: Team Ciel Autral
Ha,SII,OIII
APOD link
Image size 6°

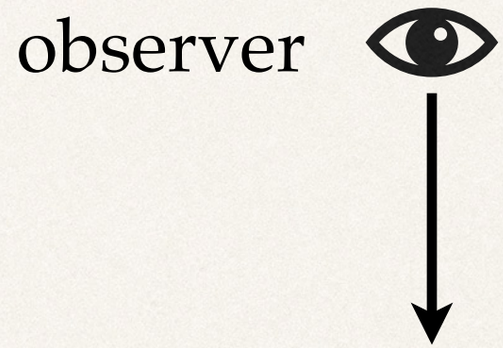
Modeling star-forming regions

- Main assumptions
  - Point-like continuous CR injection (no specific mechanism)
  - CR injection spectrum PL with index 2.25 and cutoff at 1PeV
  - Hadronic emission only
  - Diffusion-loss transport (no advection, no reacceleration,…)
  - Homogeneous losses in average galactic gas density
  - Two-zone diffusion (typically suppressed within r<100pc and ISM-like beyond)

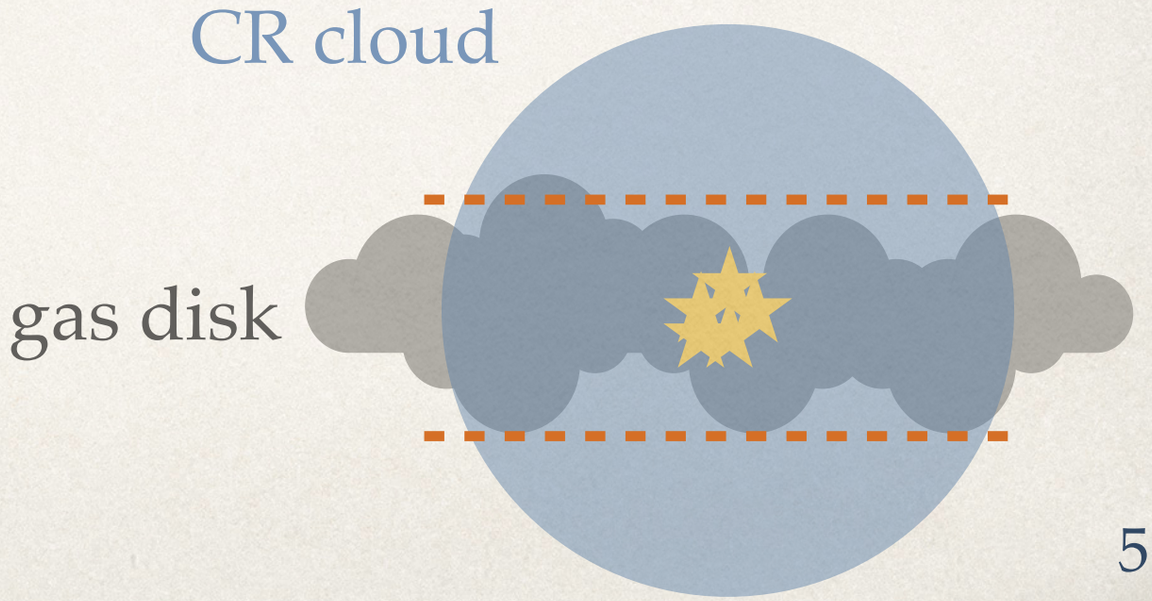
- Main questions addressed
  - Can we detect emission from SFRs/30 Doradus ?
  - For which set of injection luminosity and diffusion properties ?
  - Can we identify it as such and distinguish among scenarios ?
  - (leave aside question of specific acceleration process)

Modeling star-forming regions

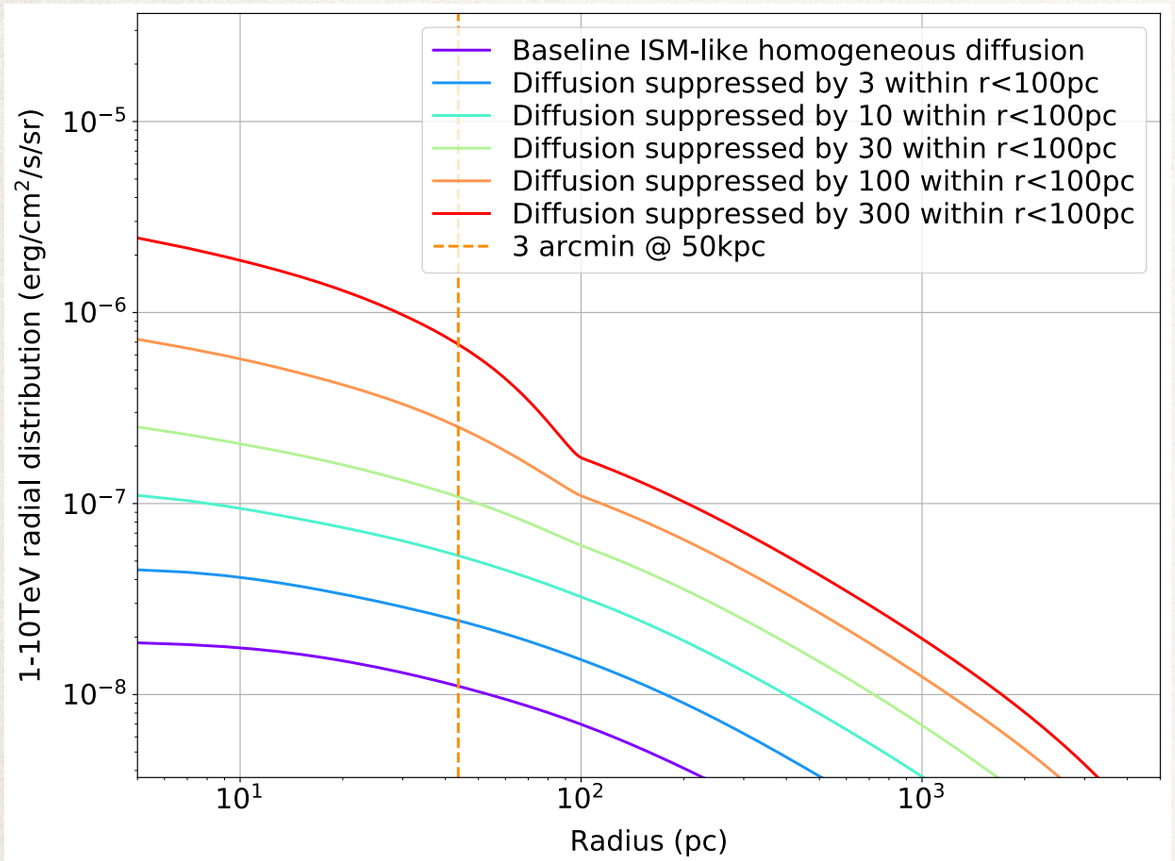
- Model calculation recipe
  - Compute two-zone diffusion kernel
    for specific choice of diffusion coefficients
  - Integrate kernel along line of sight
    over gas disk thickness
  - Compute pion decay intensity distribution
    for average gas density
  - Correct intensity distribution
    for actual gas density around target SFR



NB: Injection lasting for 5Myr
but results little sensitive to that parameter
at very high energies



Case of 30 Doradus



Top:

Effect of confinement on intensity profiles

Injection arbitrarily set at 10^{40} erg/s

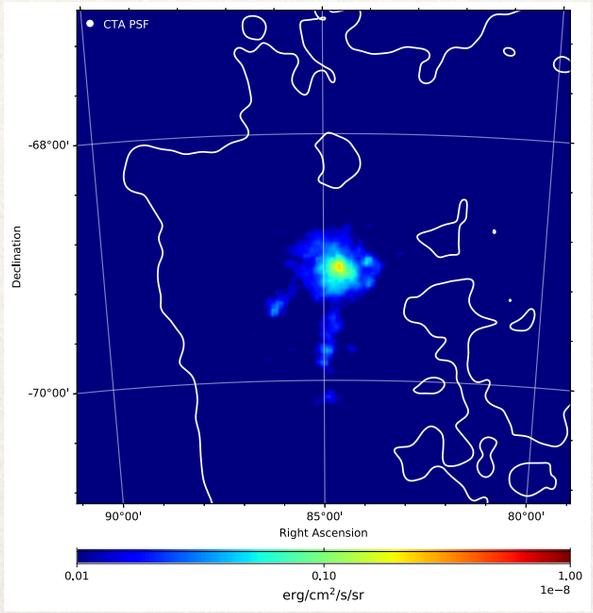
Bottom:

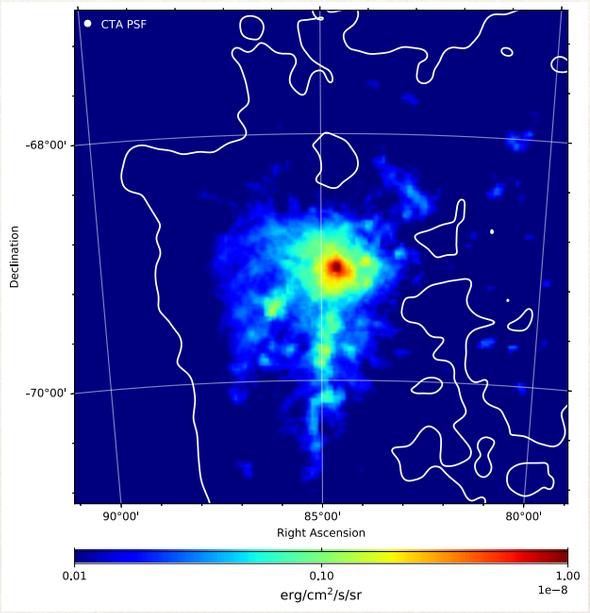
Intensity maps at 1TeV

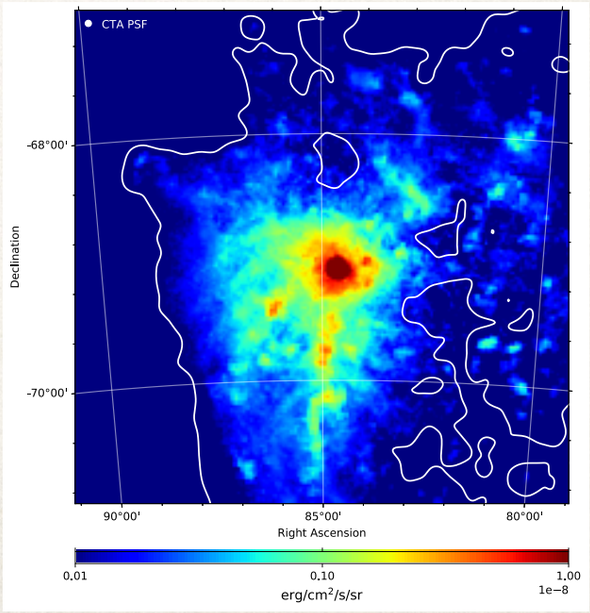
After actual gas distribution correction

30 Doradus SFR only

Diffusion suppression by 3,30,300







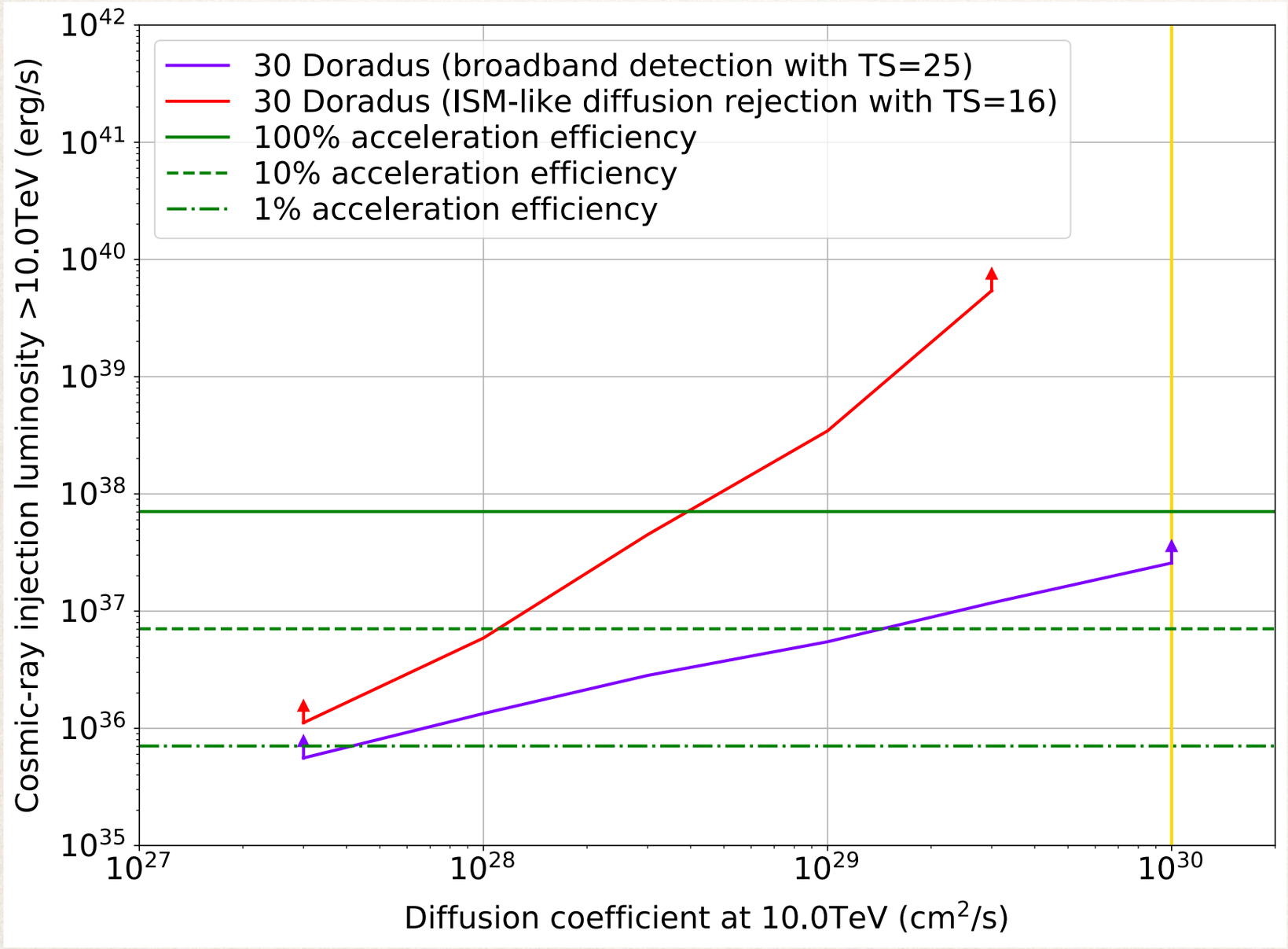
Observation simulation/analysis

- Analysis setup
  - 340h exposure spread over LMC
  - IRF prod5-v0.1/South_z40_50h
  - Energy range 0.1-100TeV
  - gammalib/ctools
  - 3D maximum likelihood analysis with stacked data
  - source model: SFR+instrumental background only !
  - using Asimov data sets to derive sensitivities

Optimistic analysis conditions:
No source confusion (no other sources than the SFR)
3D maximum likelihood with true models

Observation simulation/analysis

- Constraints on 30 Doradus main properties



No diffusion suppression

simple detection:

>40% injection efficiency

Diffusion suppression by 100

simple detection:

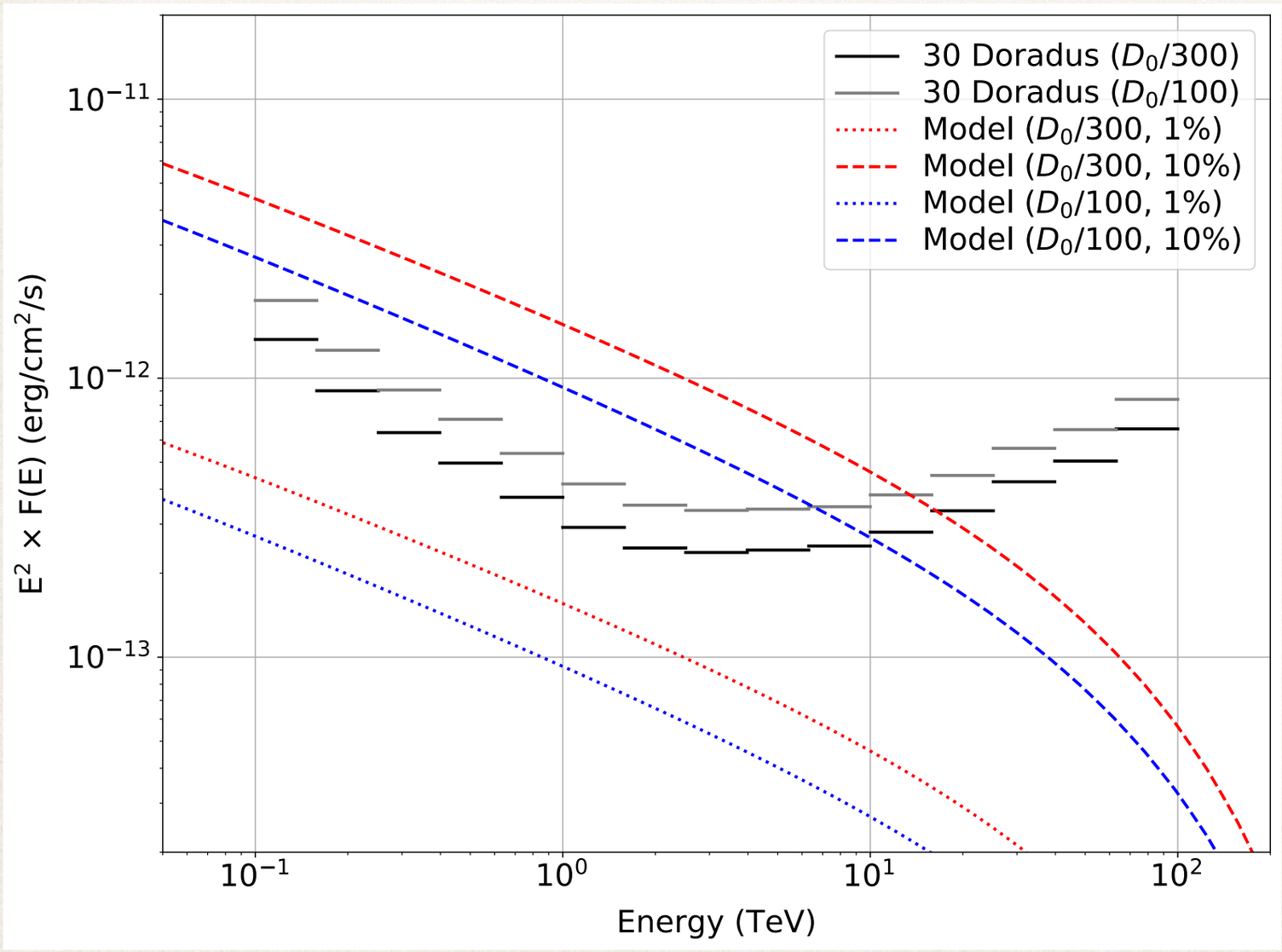
>2% injection efficiency

rejection of ISM-like diffusion:

>8% injection efficiency

Observation simulation/analysis

- Survey sensitivity to emission from 30 Doradus SFR
  - Reference case: homogeneous ISM-like diffusion



Sensitivity curves including energy-dependent morphology TS=25 in each bin

Models with diffusion suppression by factor 100 or 300 and two efficiencies: 1 or 10% of 10^{39} erg/s

Detections up to ~10TeV Too short to constrain PeVatron nature of SFRs

Conclusion

- 30 Doradus detectability in LMC
  - Injection of ~1-10% of 10^{39} erg/s mechanical for simple detection
  - Diffusion suppression by ~10-100 or more w.r.t. large-scale average
  - Stronger requirements for constraints on transport process
  - Survey not sensitive enough for constraints on PeVatron nature
  - Not addressed
    - Source confusion (other sources in the SFR)
    - Disentangling from large-scale interstellar emission
    - Realistic data analysis (sources and methods)

For a critical perspective on what can be done on SFRs, see
Multiple emission components in the Cygnus cocoon detected from Fermi-LAT observations
https://arxiv.org/abs/2301.04504