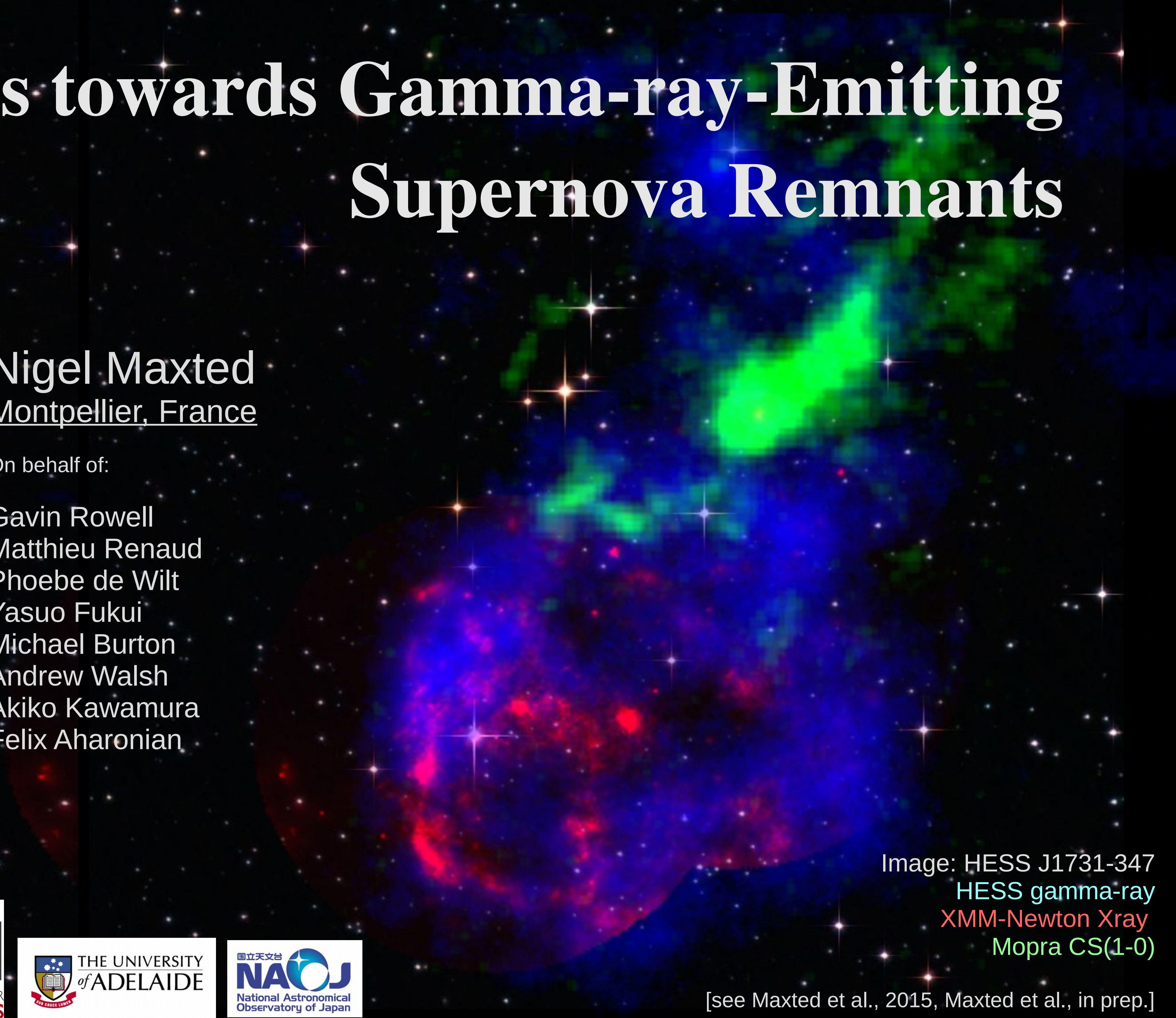
Gas towards Gamma-ray-Emitting Supernova Remnants



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Montpellier, France

On behalf of:

Gavin Rowell
Matthieu Renaud
Phoebe de Wilt
Yasuo Fukui
Michael Burton
Andrew Walsh
Akiko Kawamura
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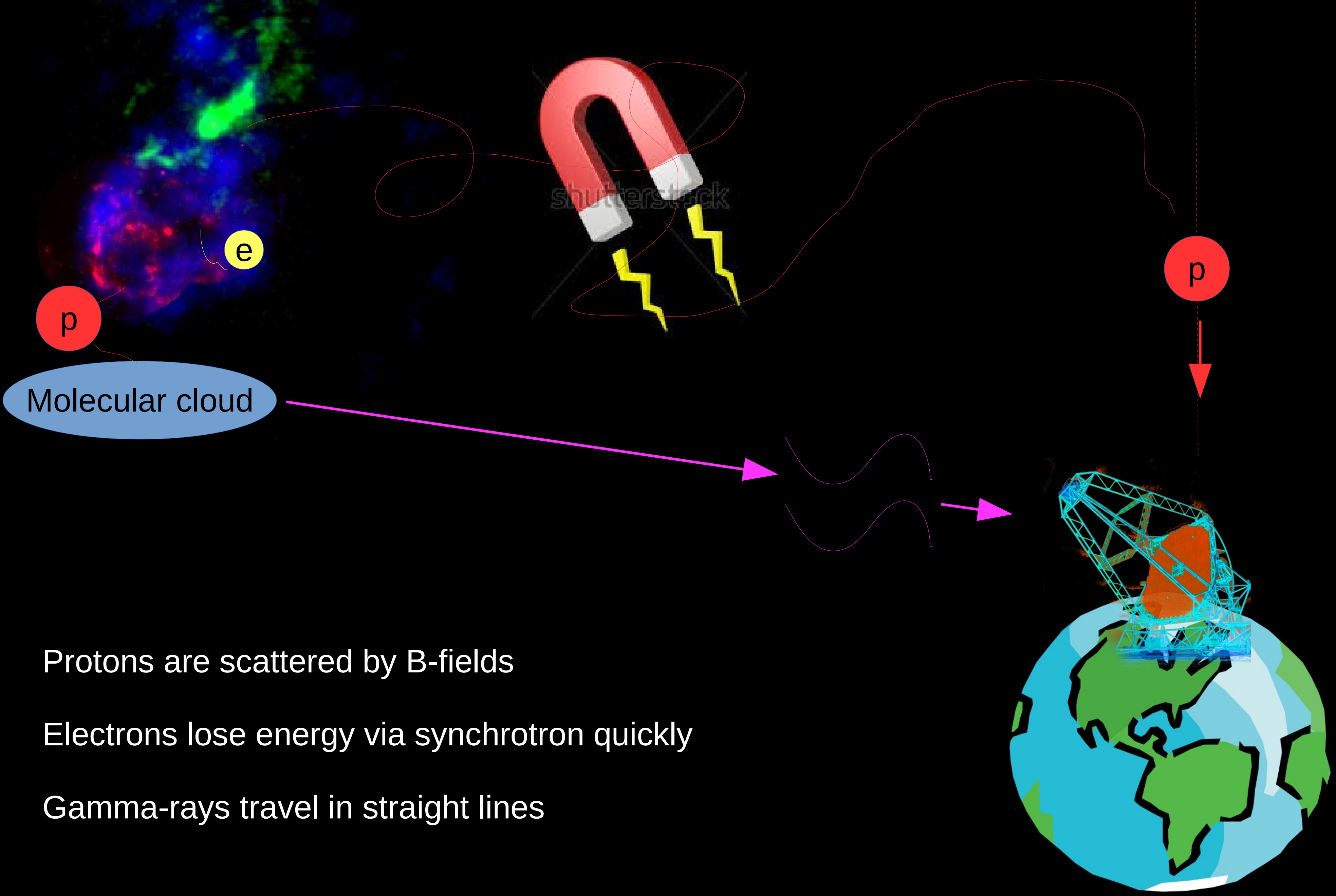
Curtin University
THE UNIVERSITY OF NEW SOUTH WALES
NAGOYA UNIVERSITY 名古屋大学
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG
LABORATOIRE UNIVERS & PARTICULES MONTPELLIER
THE UNIVERSITY of ADELAIDE
国立天文台 NAOJ National Astronomical Observatory of Japan

Image: HESS J1731-347
HESS gamma-ray
XMM-Newton Xray
Mopra CS(1-0)

[see Maxted et al., 2015, Maxted et al., in prep.]

Cosmic ray origin



Molecular cloud

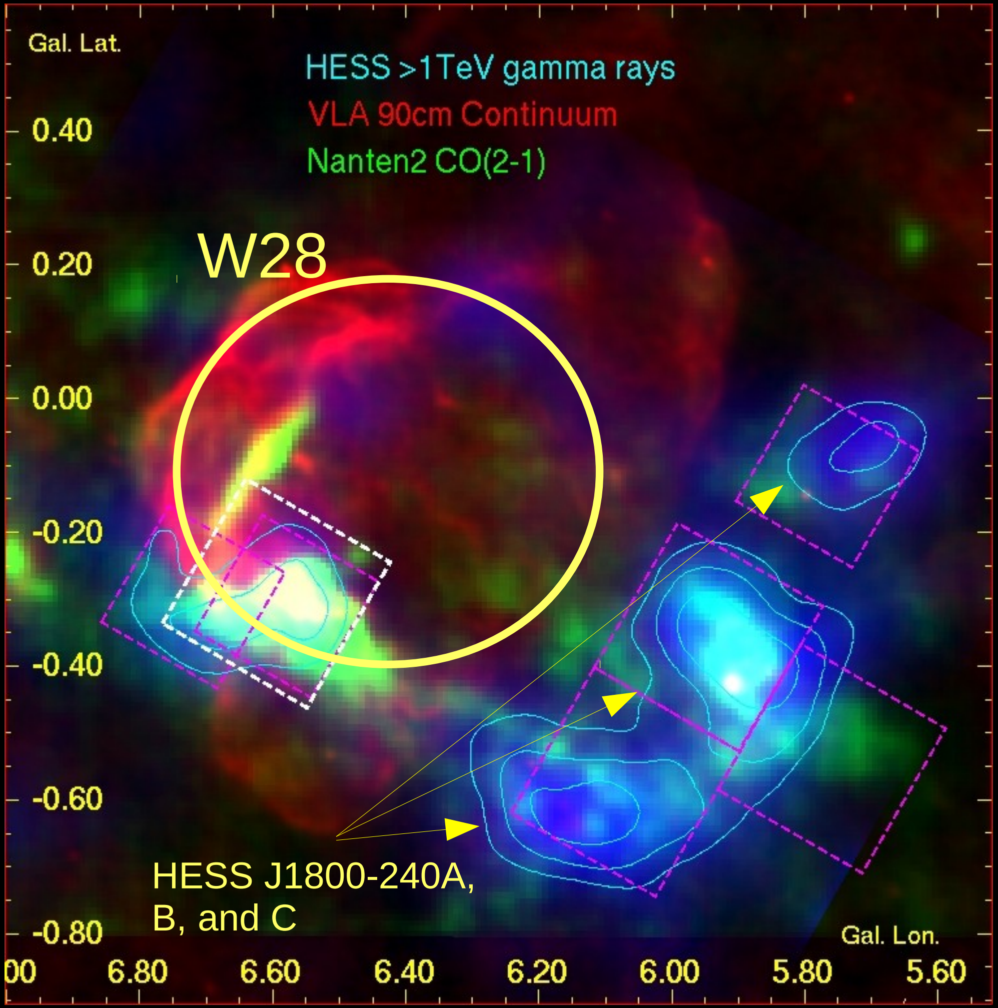
Protons are scattered by B-fields

Electrons lose energy via synchrotron quickly

Gamma-rays travel in straight lines

Gamma-ray emitting Supernova Remnants

W28

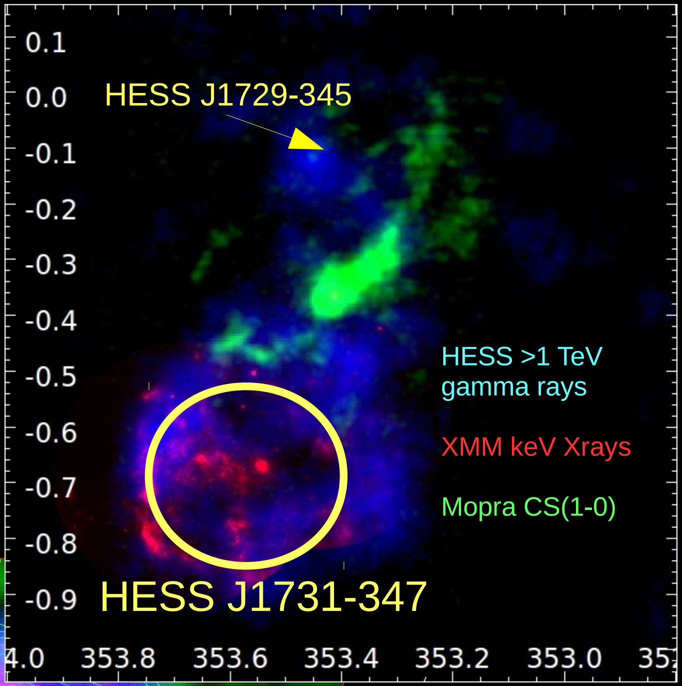


Dubner etl al. 2000, Brogan et al. 2006, Fukui 2008,

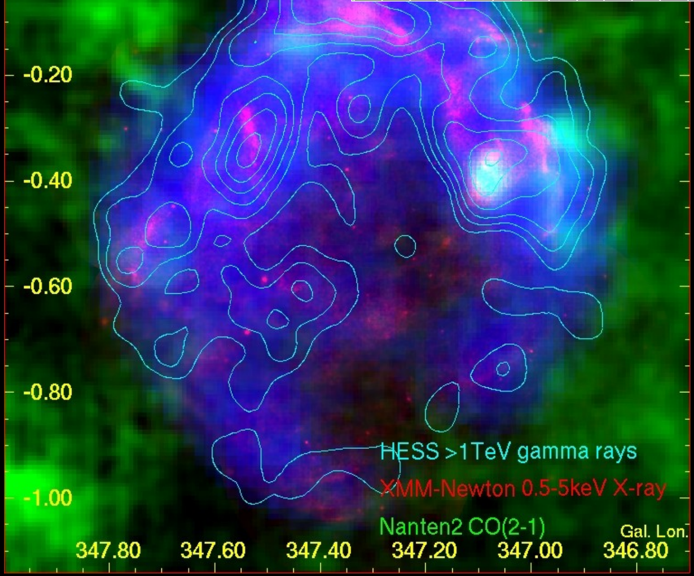
Abdo et al 2010, Nakamura et al. 2014
Nicholas et al 2011, Nicholas et al 2012
Maxted et al *Submitted(2015)*

HESS J1731-347

Abramowski et al 2011
Bamba et al 2012
Maxted et al 2015
Maxted et al *in prep*



RX J1713.7-3946

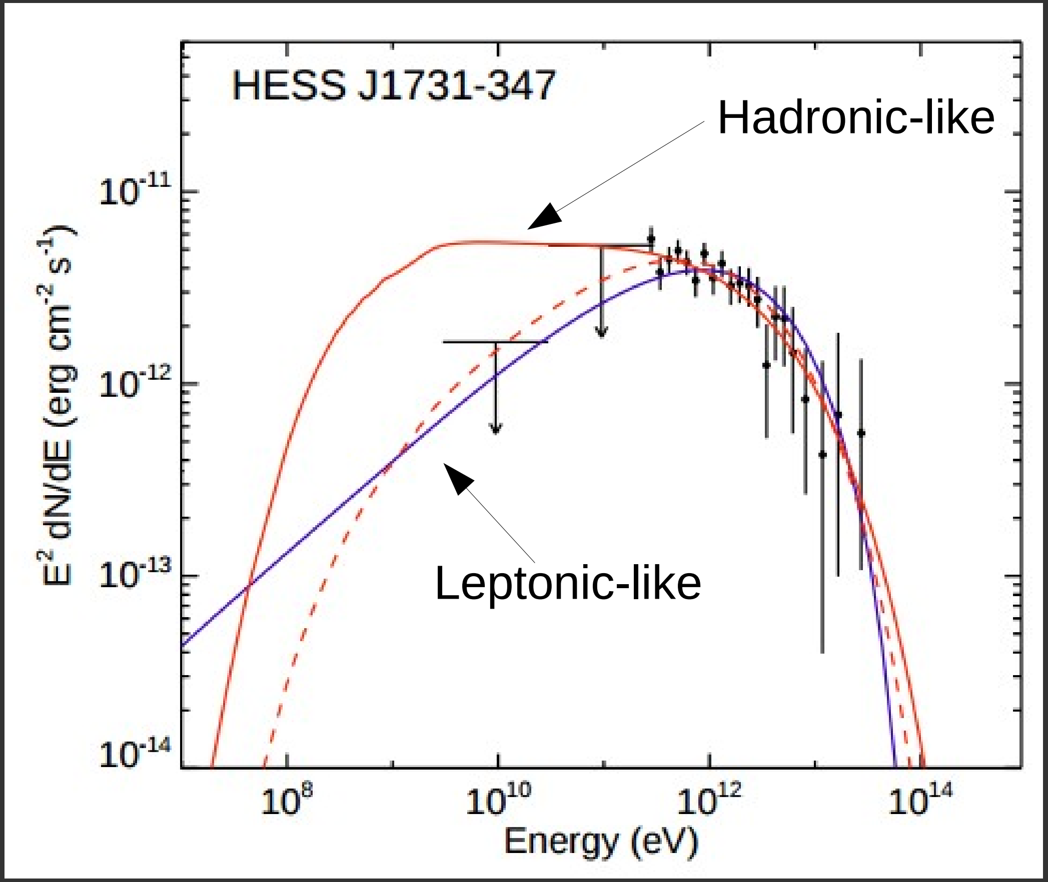


Aharonian et al 2006/07
Acero et al 2009
Fukui et al 2003
Moriguchi et al 2005
Maxted et al 2012
Maxted et al 2013

Young (~10^3 yr) SNRs

Young SNRs, such as RX J1713.7-3946 and HESS J1731-347 have spectra which suggest leptonic gamma-ray emission (e.g. Acero et al 2015).

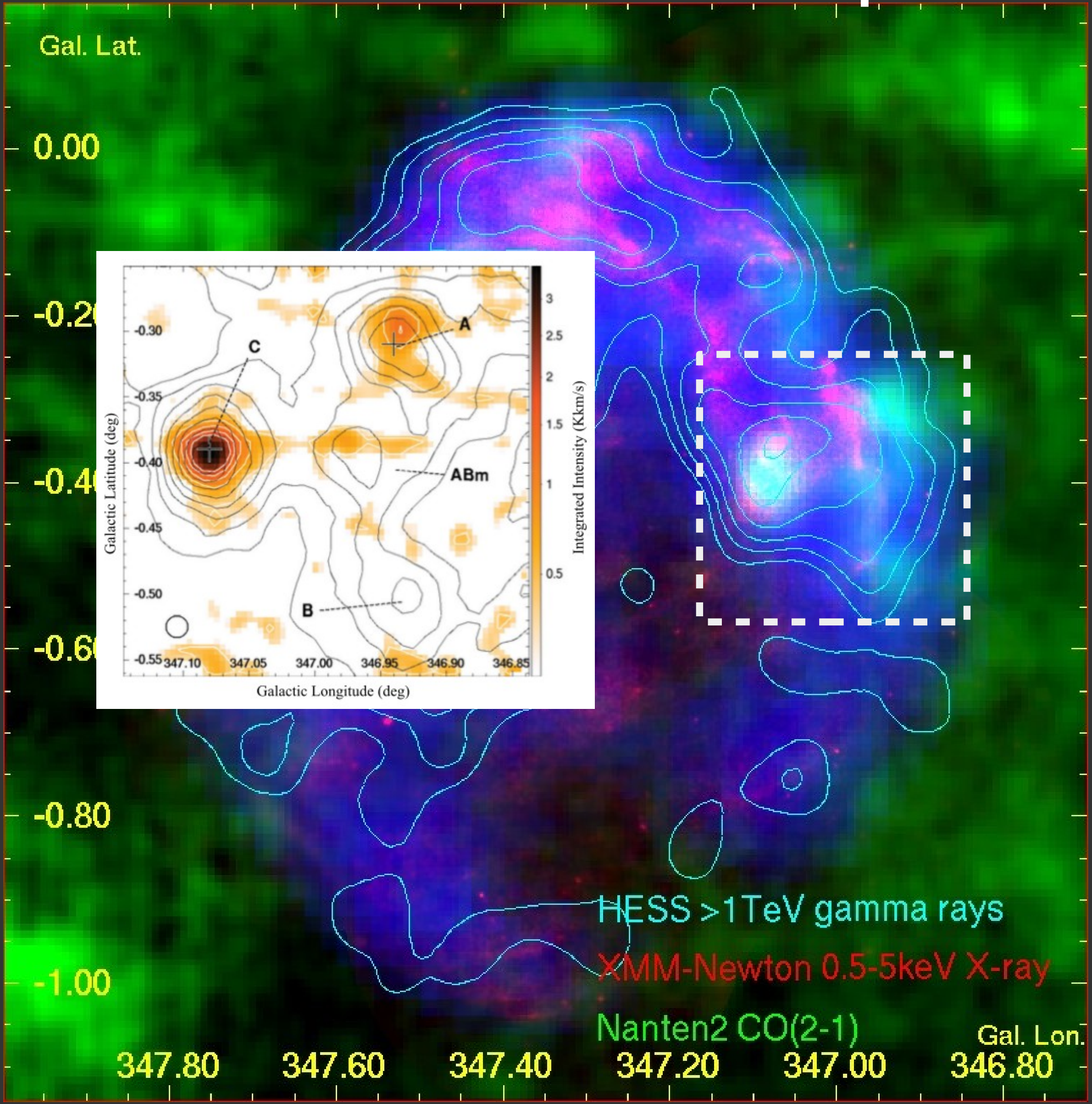
But some argue that the existence of dense clumps might lead the a lack of a distinct 'pion bump' in gamma-ray spectra (e.g. Gabici & Aharonian 2014/2015).

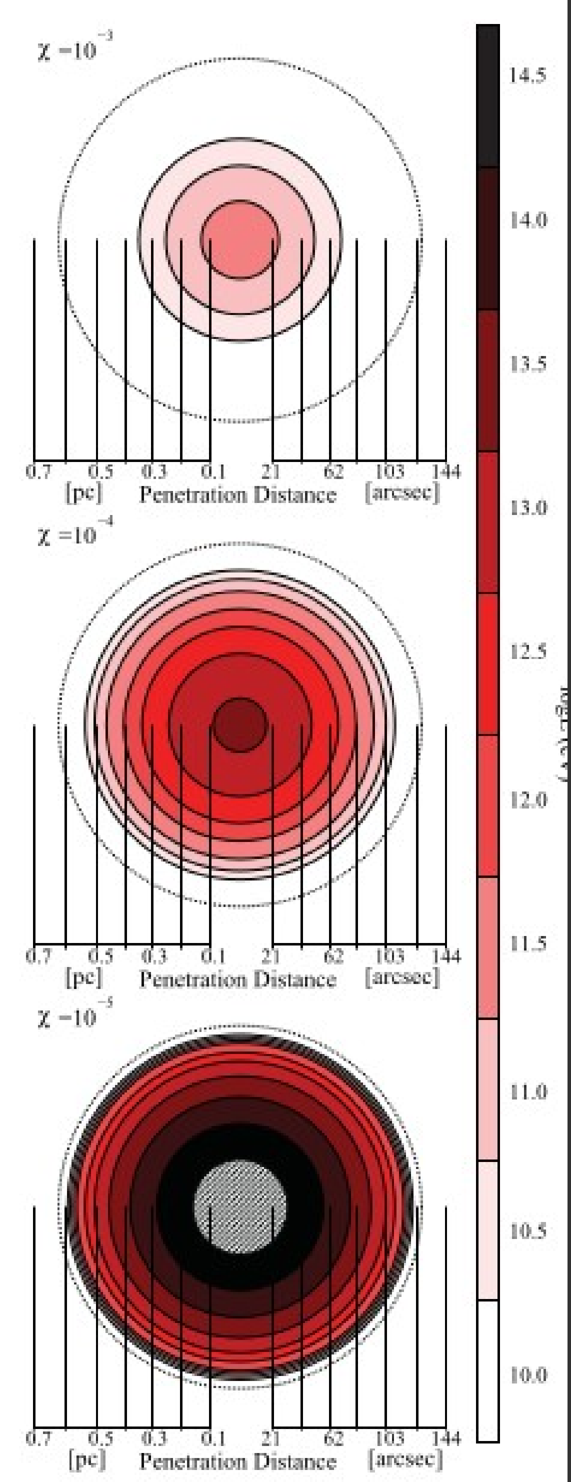


Acero et al 2015

RX J1713.7-3946

Diffusion into clumps?

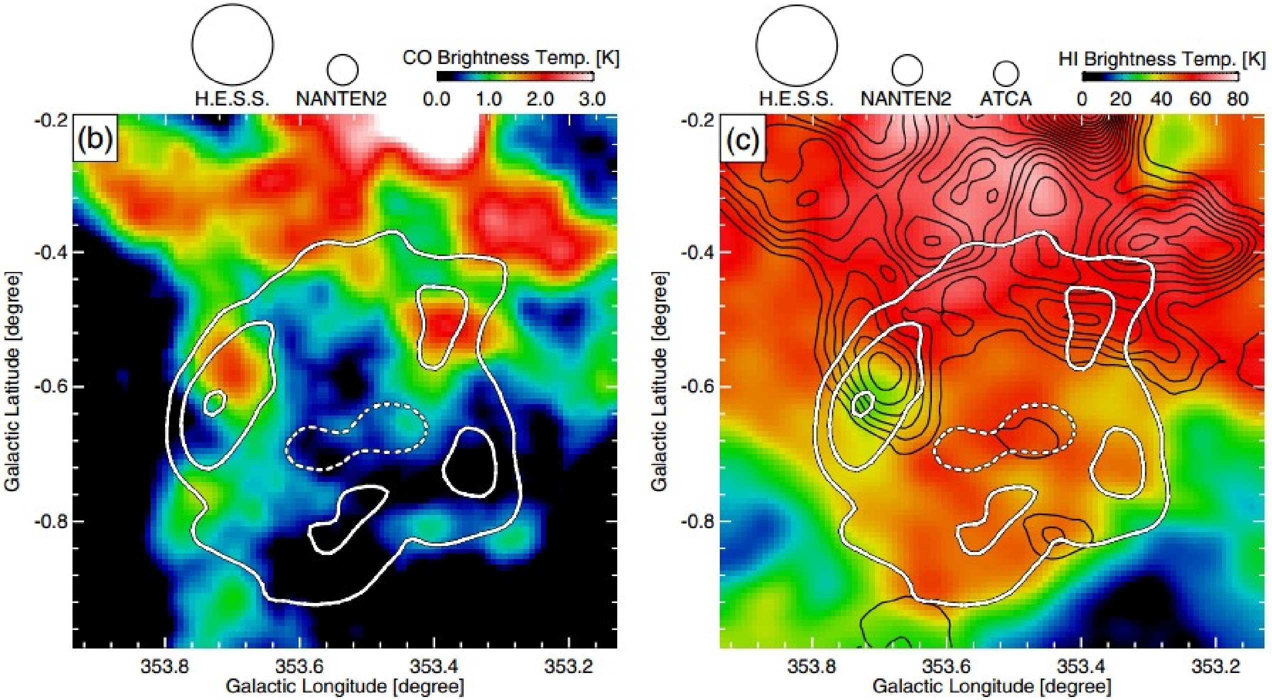




Maxted et al 2012

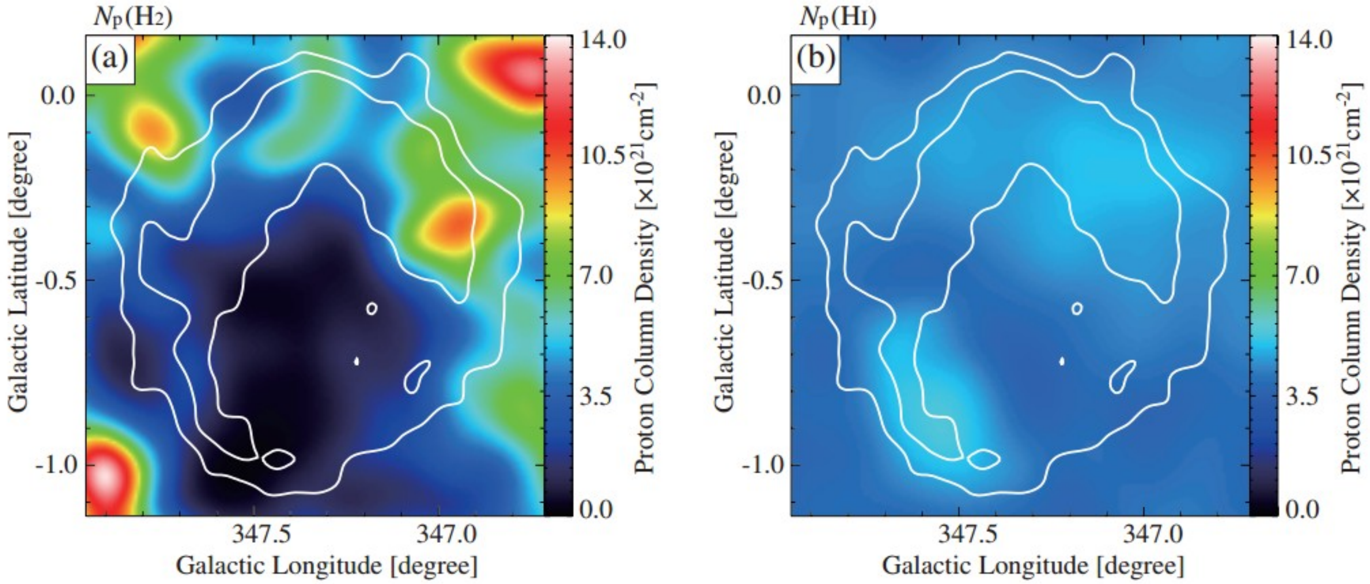
HESS J1731-347 & RXJ1713.7-3946

CO and HI



HESS J1731-347

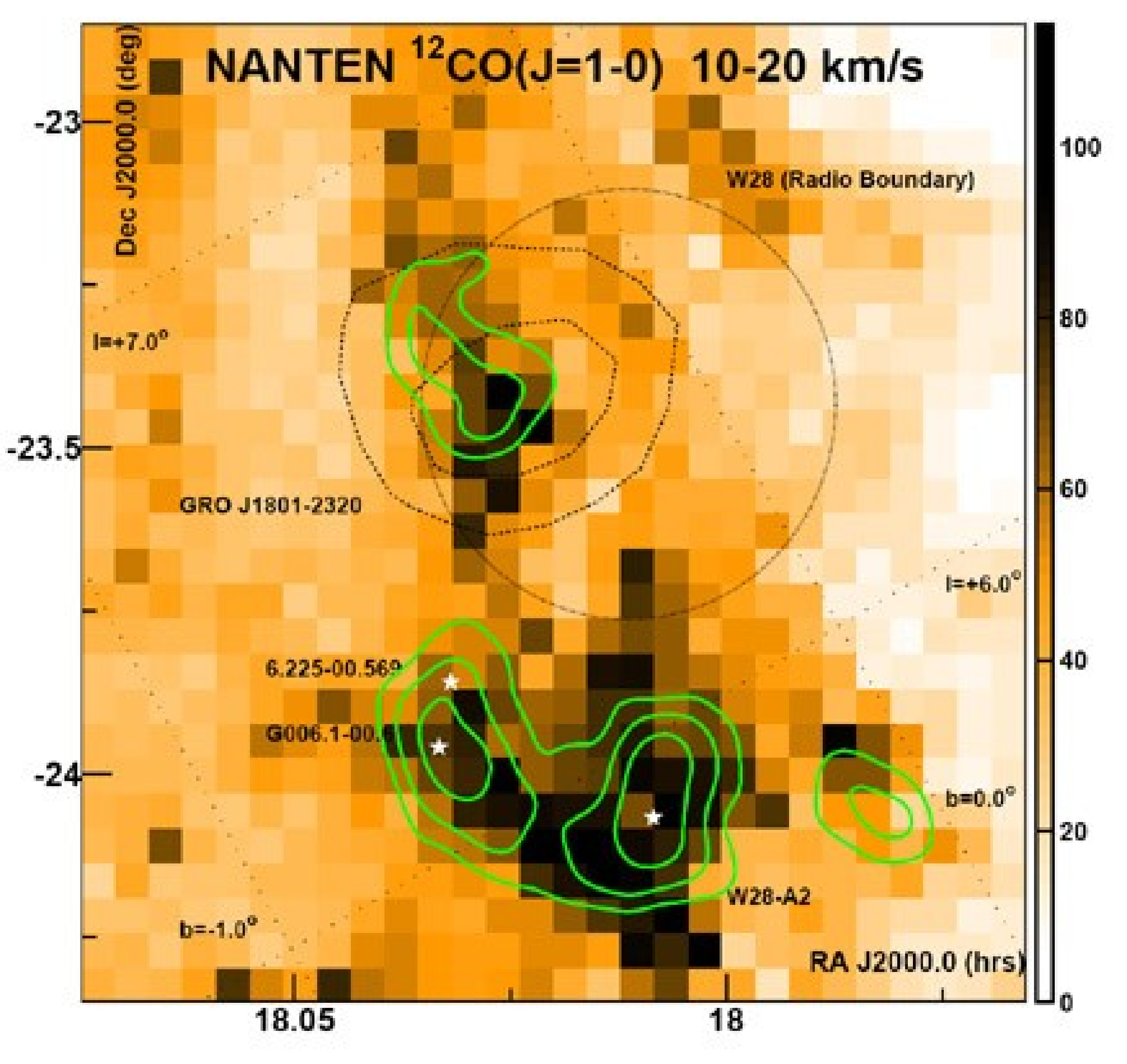
Fukuda et al 2014



RXJ1713.7-3946

Fukui et al 2012

W28 Gamma-ray emission (and CO)



Fukui et al 2008

Good correlation between CO(1-0) emission and gamma-rays.

Suggestive of high energy protons (cosmic rays) interacting with gas.

Great evidence that W28 is a source of Cosmic rays!

Mopra surveys of W28


Mopra,
Warrumbungles, Australia

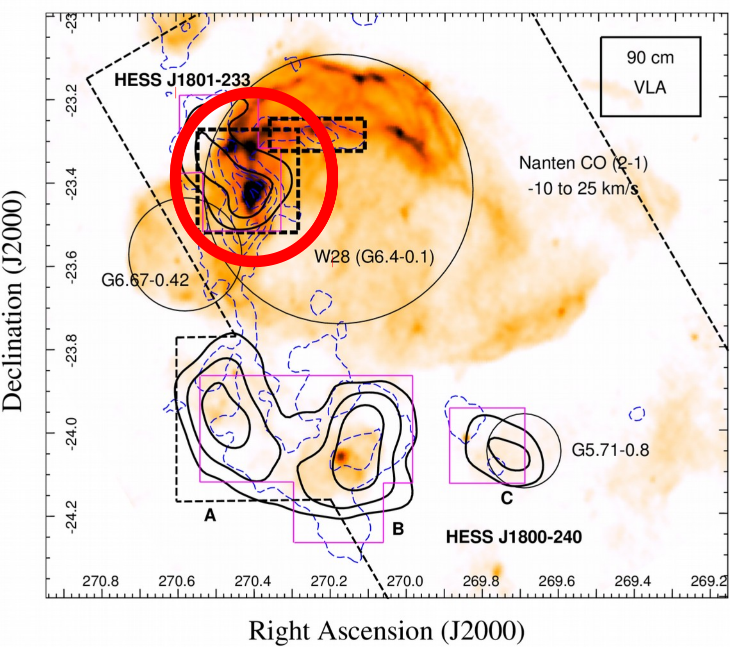
Mopra 7 mm survey of the northern cloud W28 interaction region.

Targeted transitions include:
- CS(1-0)
- 13CS(1-0)
- CH3OH
- C34(1-0)
- SiO(1-0)
- HC3N

7mm

~1' angular resolution
~0.2 km/s velocity resolution

Nicholas et al., 2012



A new Mopra 12mm survey of the northern cloud W28 interaction region.

Transitions targeted:
- NH3(1,1)
- NH3(3,3)
- NH3(6,6)
- NH3(2,2)
- NH3(4,4)
- NH3(9,9)

12mm

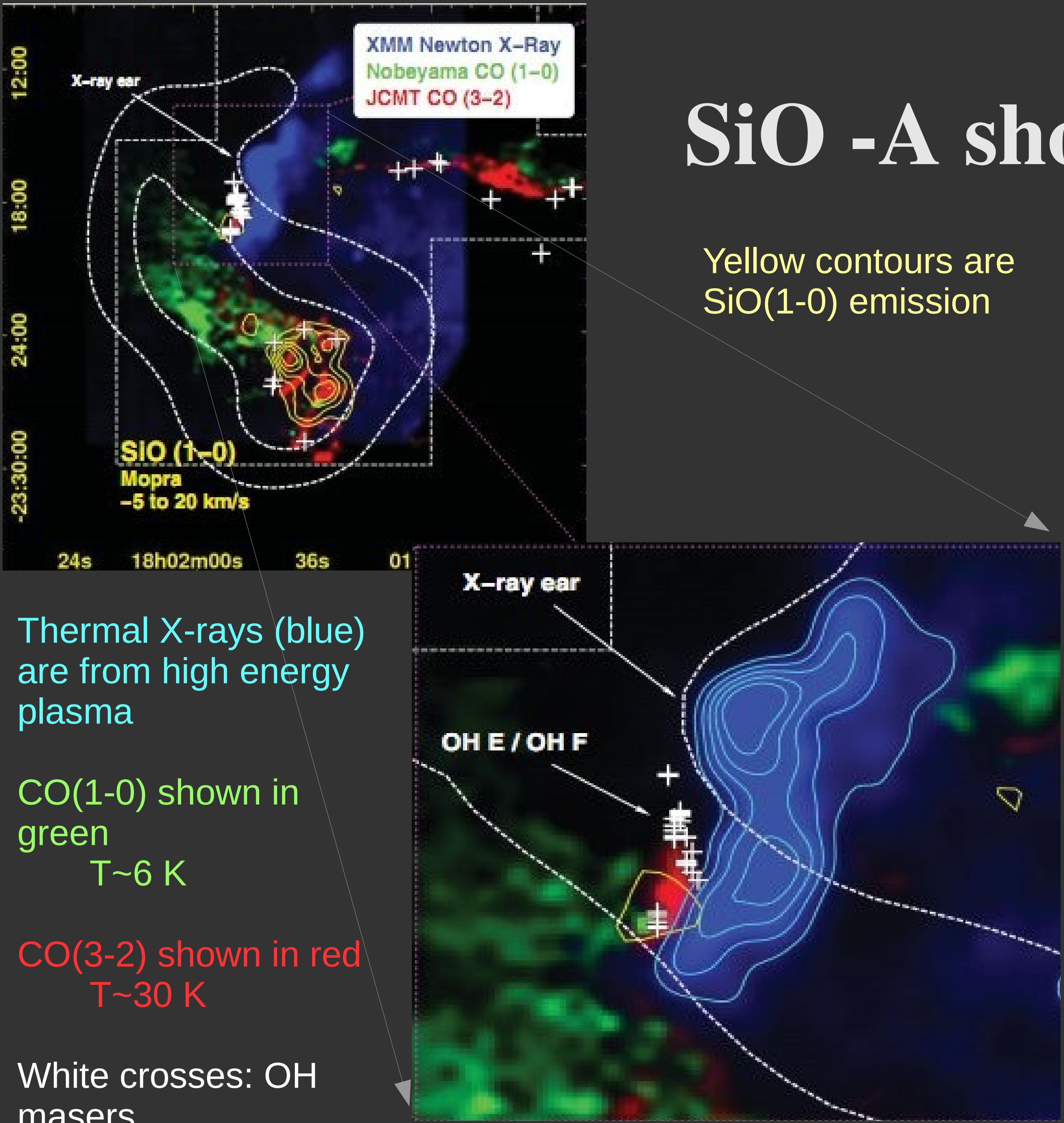
~2' angular resolution
~0.4 km/s velocity resolution

Maxted et al., submitted (2015)

SiO -A shock tracer

7mm

Yellow contours are SiO(1-0) emission

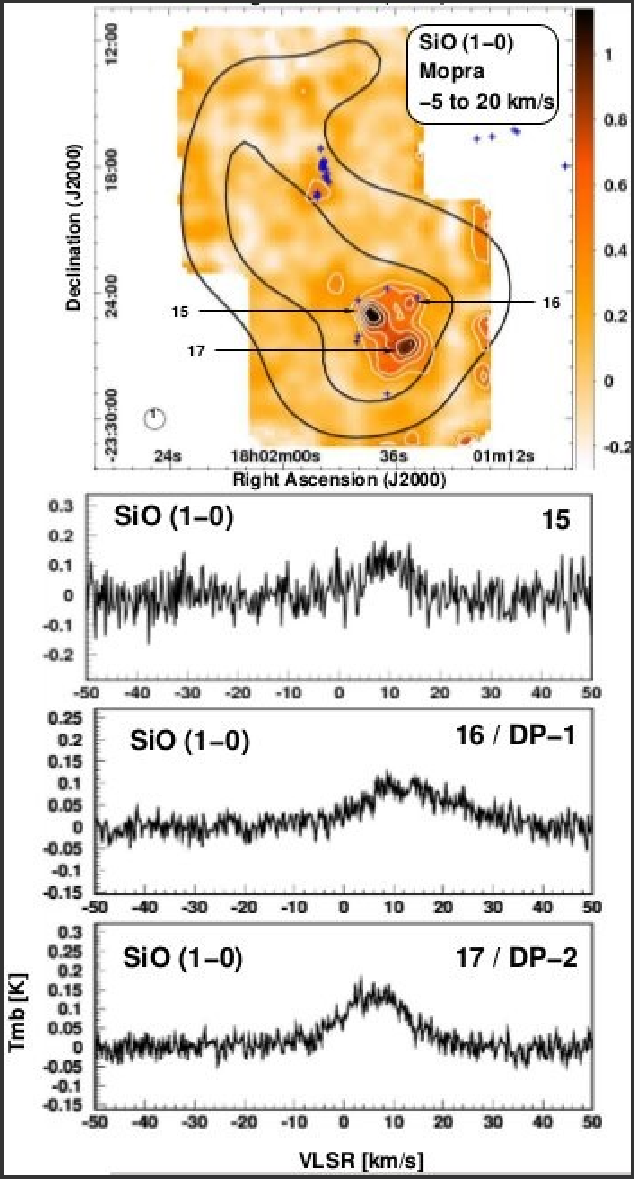


Thermal X-rays (blue) are from high energy plasma

CO(1-0) shown in green
T~6 K

CO(3-2) shown in red
T~30 K

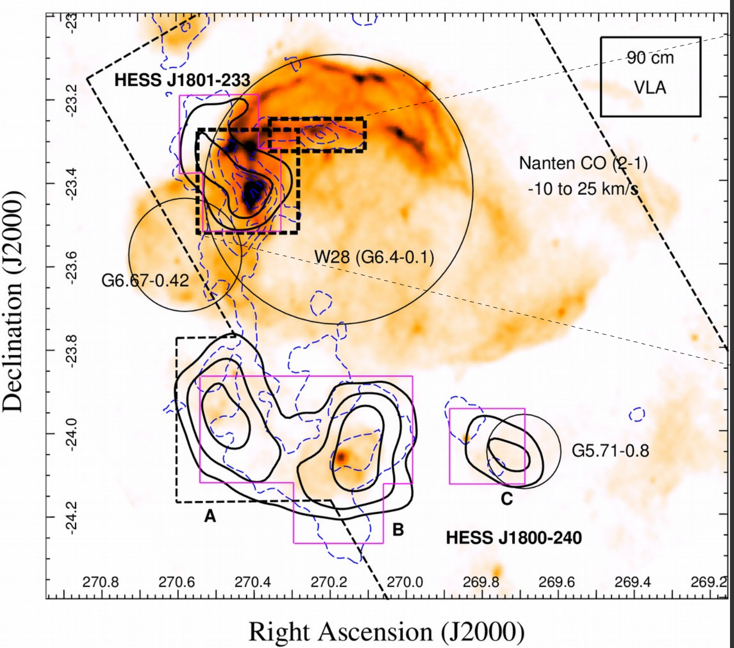
White crosses: OH masers

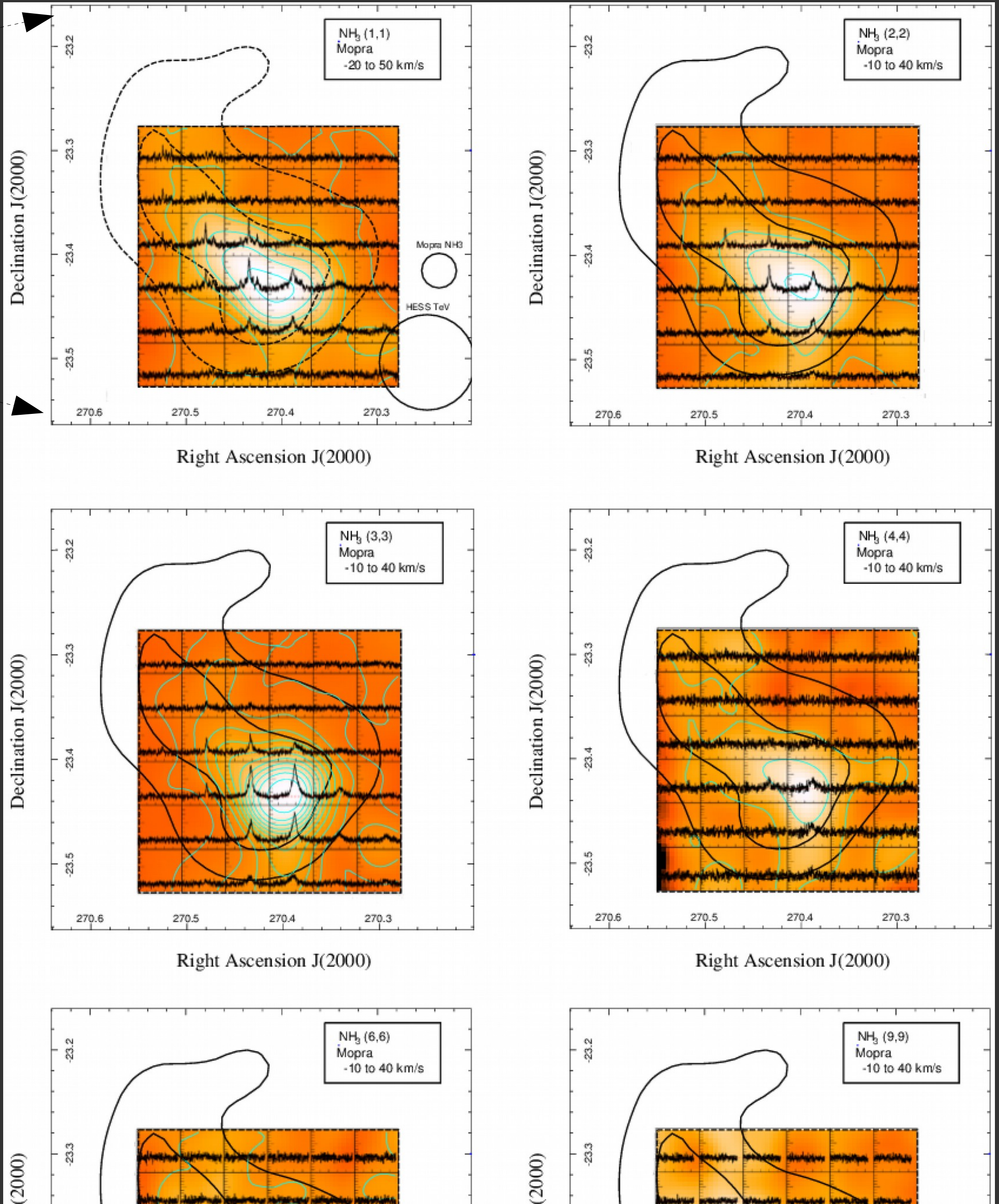


Nicholas et al 2012

W28 NH3 study

12mm



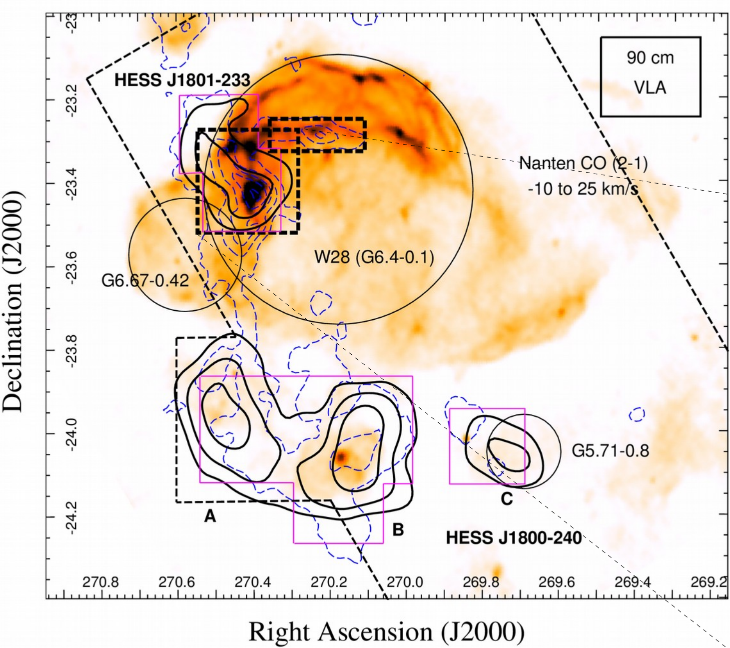


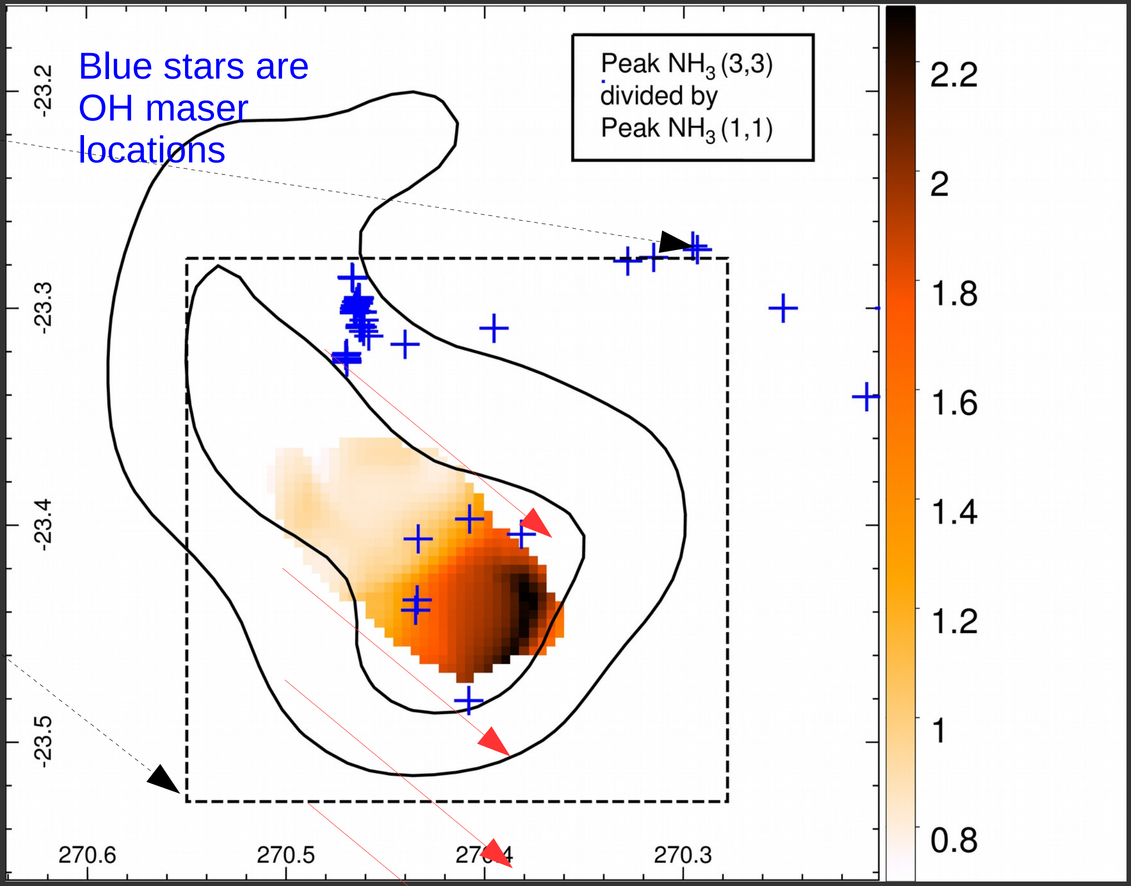
Unprecedented spectral detail

Maxted et al., submitted (2015)

W28 NH3 study

12mm





Blue stars are OH maser locations

Transition Energies

NH3(1,1) : 22.7 K
NH3(3,3) : 123 K

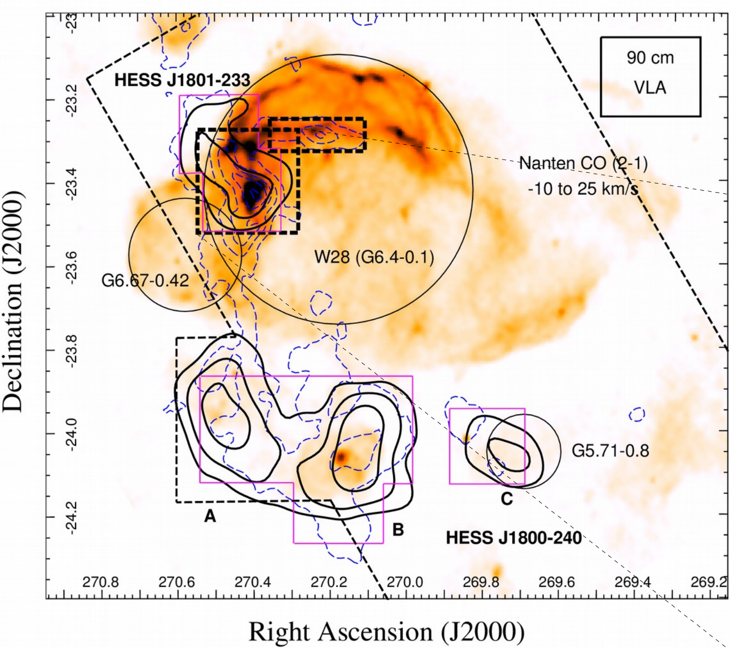
Increasing NH3(3,3) / NH3(1,1) ratio

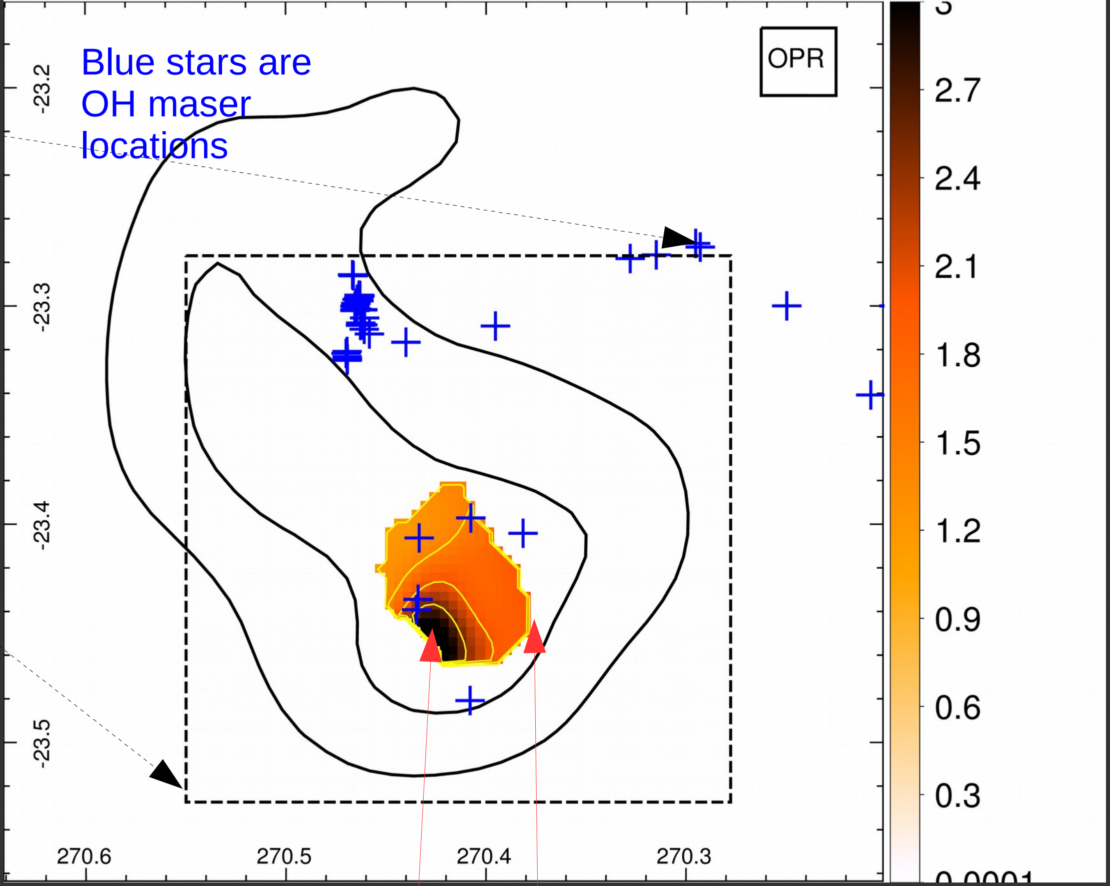
W28 shock

Maxted et al., submitted (2015)

W28 NH3 study

12mm

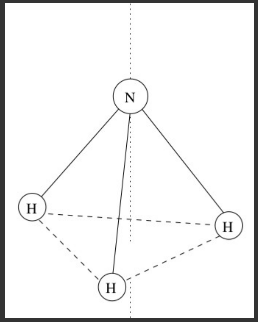




Blue stars are OH maser locations

Ortho-para-NH3 ratio can be calculated in the region exhibiting NH3(3,3), (4,4) and (6,6) emission lines

Variation of ortho/para ratio: ~1.5 – 3



Maxted et al., submitted (2015)

o-NH3 p-NH3 ratio

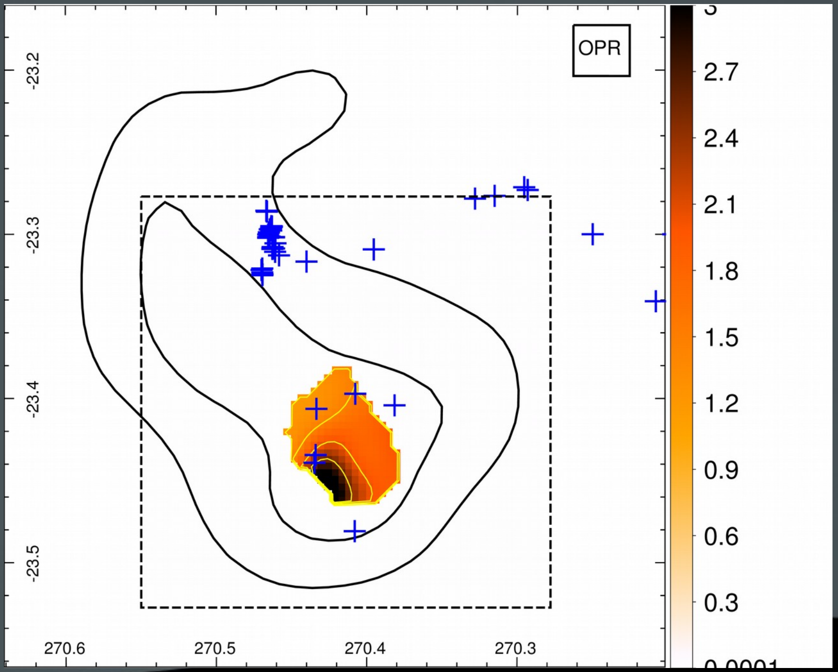
12mm

*OPR ~ 1 : suggestive of gas-phase NH3 formation (Faure et al. 2013),

*OPR > 1 : suggestive that NH3 is released from dust grains (Umemoto et al. 1999)

In W28, OPR ~1.5-3, suggesting that NH3 molecules are being released from dust grains. Is the W28 shock responsible?

If so, this technique is yet another method of tying a SNR to a gas cloud.

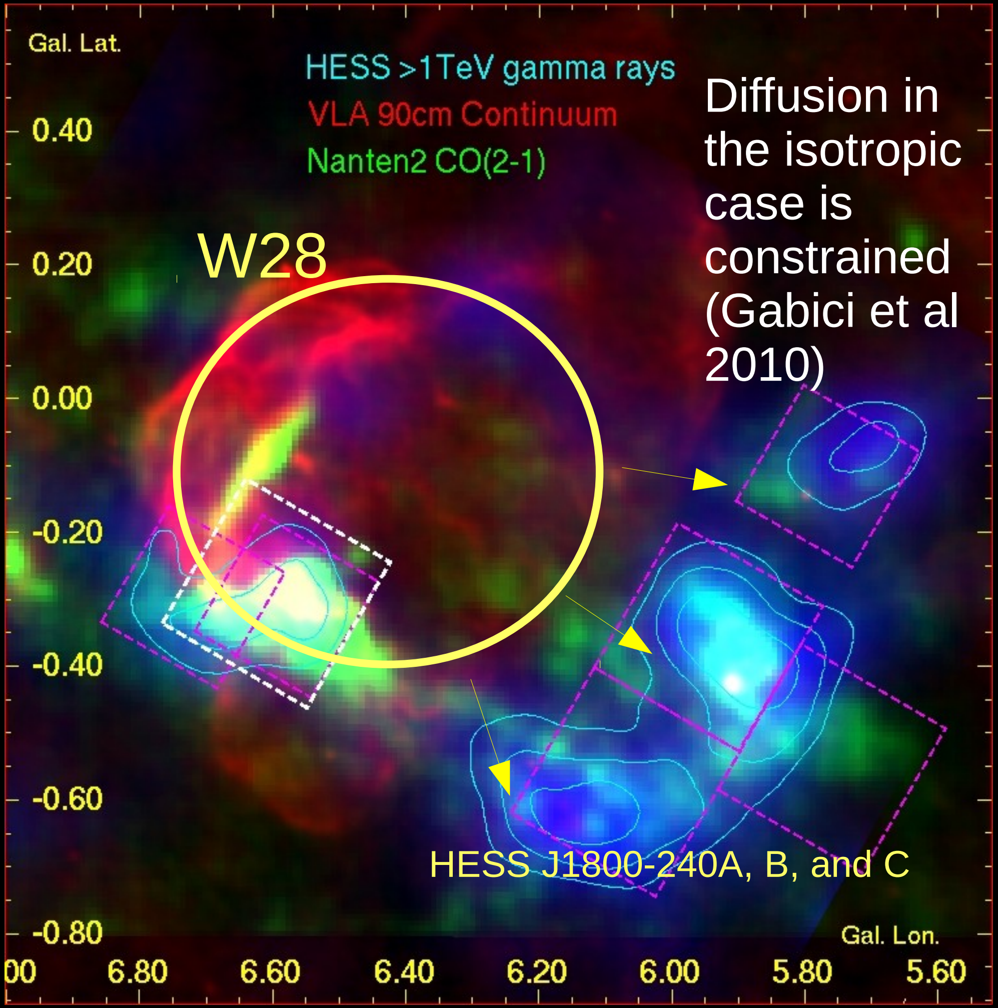


Maxted et al., submitted *(2015)*

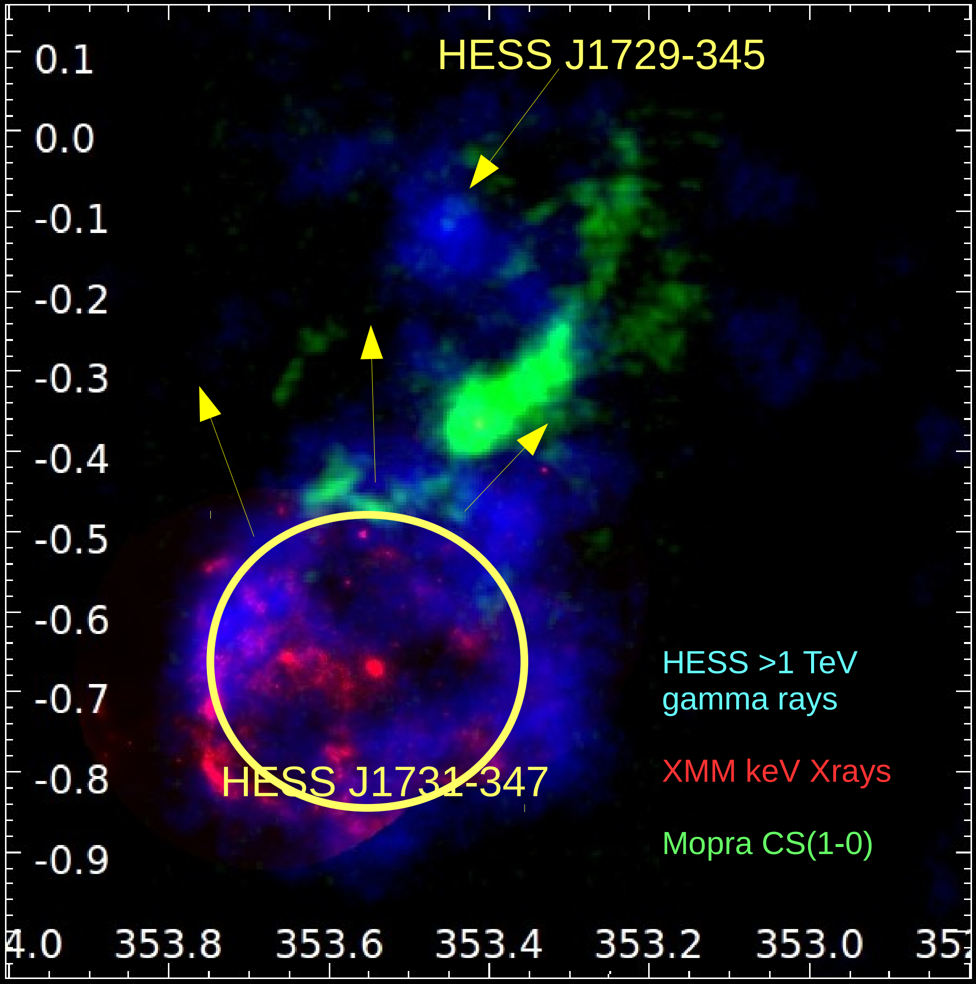
Suppressed Diffusion away from CR sources

W28

HESS J1731-347



Diffusion in the isotropic case is constrained (Gabici et al 2010)



Dubner etl al. 2000, Brogan et al. 2006, Fukui 2008,
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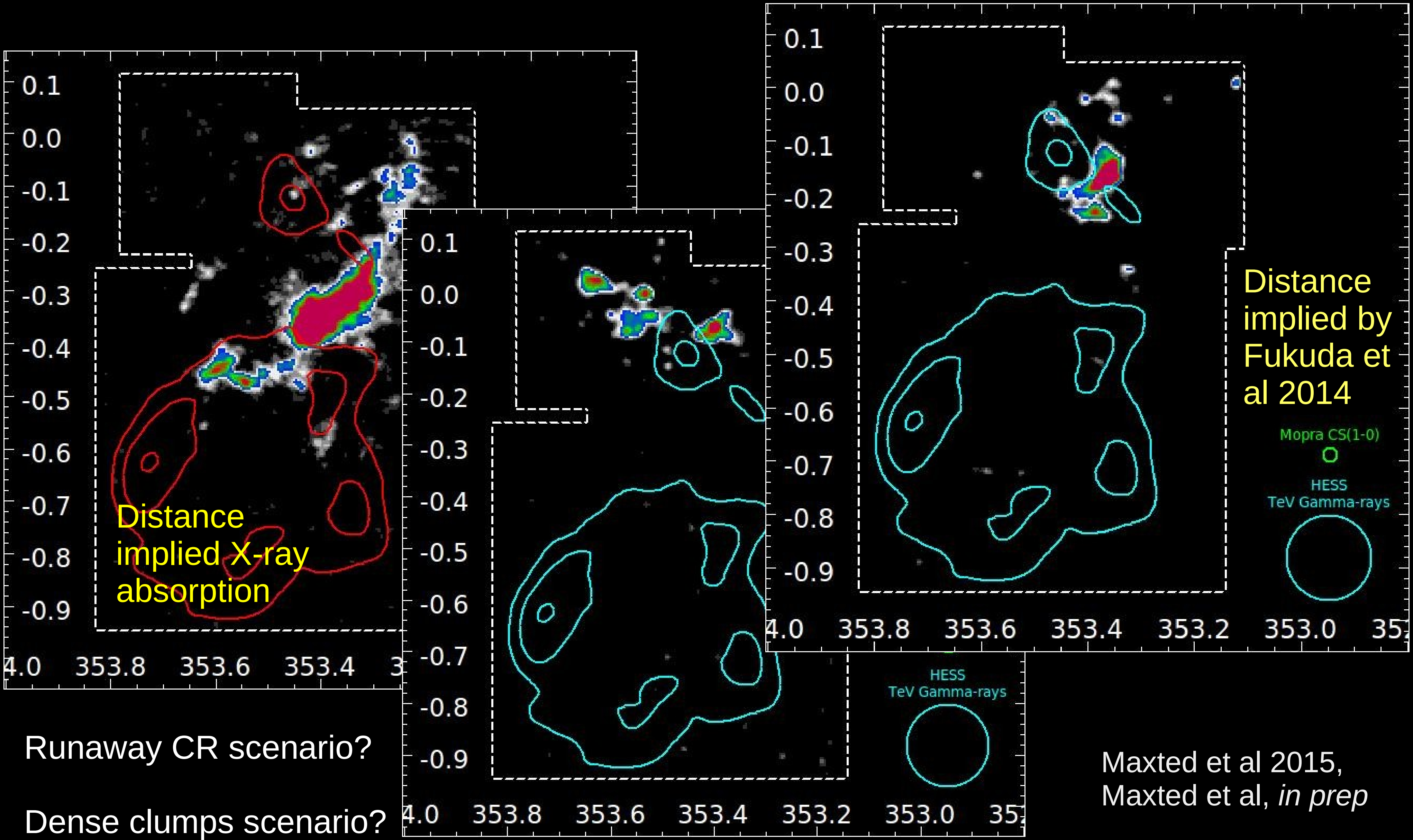
Nicholas et al 2011, Nicholas et al 2012
Maxted et al *Submitted(2015)*

Abramowski et al 2011
Bamba et al 2012
Maxted et al 2015
Maxted et al *in prep*

HESS J1731-347 CS(1-0) emission



Distance implied X-ray absorption

Distance implied by Fukuda et al 2014

Runaway CR scenario?

Dense clumps scenario?
-not molecular clumps?

Maxted et al 2015,
Maxted et al, *in prep*

Thank you

Back-up Slides

CO vs SiO

- CO
- Low electric dipole moment
- Critical density for emission $\sim 1.10^{3}$ cm^{-3}
- High abundance everywhere except cold, starless cores.
- Good general H_2 tracer

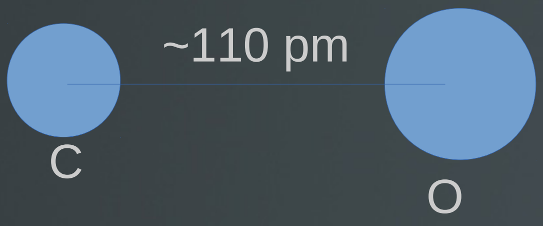
- SiO
- High electric dipole moment
- Critical density for emission $\sim 6.10^{4}$ cm^{-3}
- Si and SiO released from dust grains in energetic environments
- Si is manufactured into SiO at high (~100K) temperatures
- Good shock-tracer

CO vs SiO

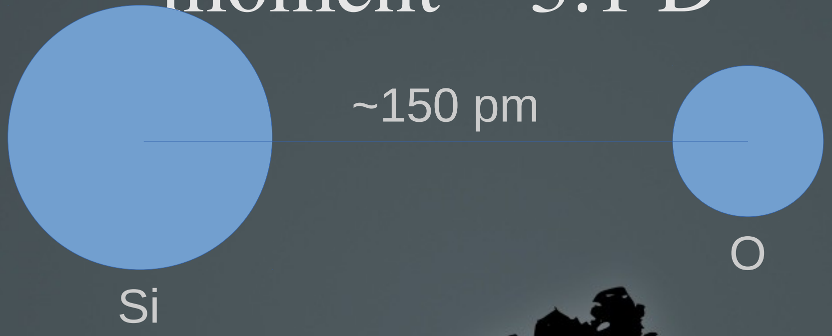
Since the shared electrons 'spend more time' with the atom with the highest electronegativity, there is a charge difference between atoms, hence a molecular dipole moment, $\mu=\delta d$ (half the charge difference * distance between bonds)

Ie, ionic species ----> highest dipole moment,
Molecular Nitrogen, N2-----> Zero dipole moment

- CO
- Electric dipole moment ~ 0.12 D



- SiO
- Electric dipole moment ~ 3.1 D



What effect does this difference in dipole moment have?

Cold, quiescent (star-less?) core

- CO freeze-out

  (eg. L1544, L1498, L1517B)

  (Caselli et al., 1999, Tafalla et al., 2002 ,2004)

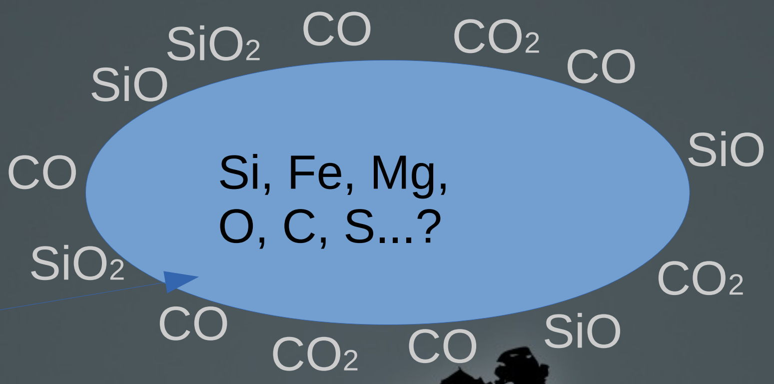
- Usually just a drop by a factor of few though..

- Total SiO freeze-out

  (eg. TMC-1, L1551, L34N, B335)

  (Ziurys, 1989)

- Remember that SiO is heavier...



Grain composition not well constrained...
contains:
Fayalite (Fe_2SiO_4)
Fosterite (Mg_2SiO_4)
Olivine ($MgFeSiO_4$)
(Schilke et al., 1997)

Slightly warmer gas (say... 20-40 K)

- CO abundant in gas-phase.
- Prominent CO(1-0,2-1) emission ($T\sim5.5,16.6$ K, respectively)

- SiO not very abundant in gas-phase, still heavily depleted.

Hot Core (~100K)

- Higher-J CO transitions
- Increased (~10^{-8}-10^{-7}) SiO abundance observed in star-formation regions (~90K) Orion and NGC 7538 (Ziurys, 1989)
- Consistent with Si-release from grains and endothermic reactions:

  Si + O2 ⩾ SiO + ~

  Si + OH ⩾ SiO + ~

  with energy barrier of 111K (Langer & Glassgold, 1990)

Shocked Core

- SiO released from grain-surface or Si released.
- Dust-dust and dust-gas collisions may release Si from grains (Gusdorf et al., 2008a/b, May et al., 2000)
- Dust-gas collisions may release whole SiO molecules from the outer mantle of dust grains (Schilke et al., 1997)
- Dust grains destroyed by X-ray emission (Martin-Pintado et al.,1999)

OH masers

- Shocks drive dissociation of H_2O molecules into OH
- And collisionally excite OH
- Seen towards SNRs: w28, IC443, CTB37A, W51, Sag A east, + more..

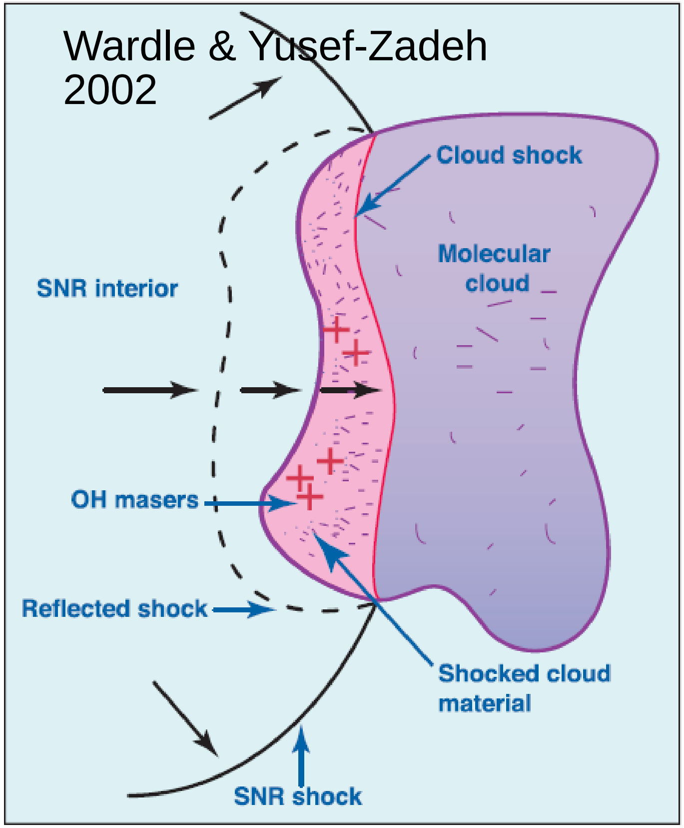
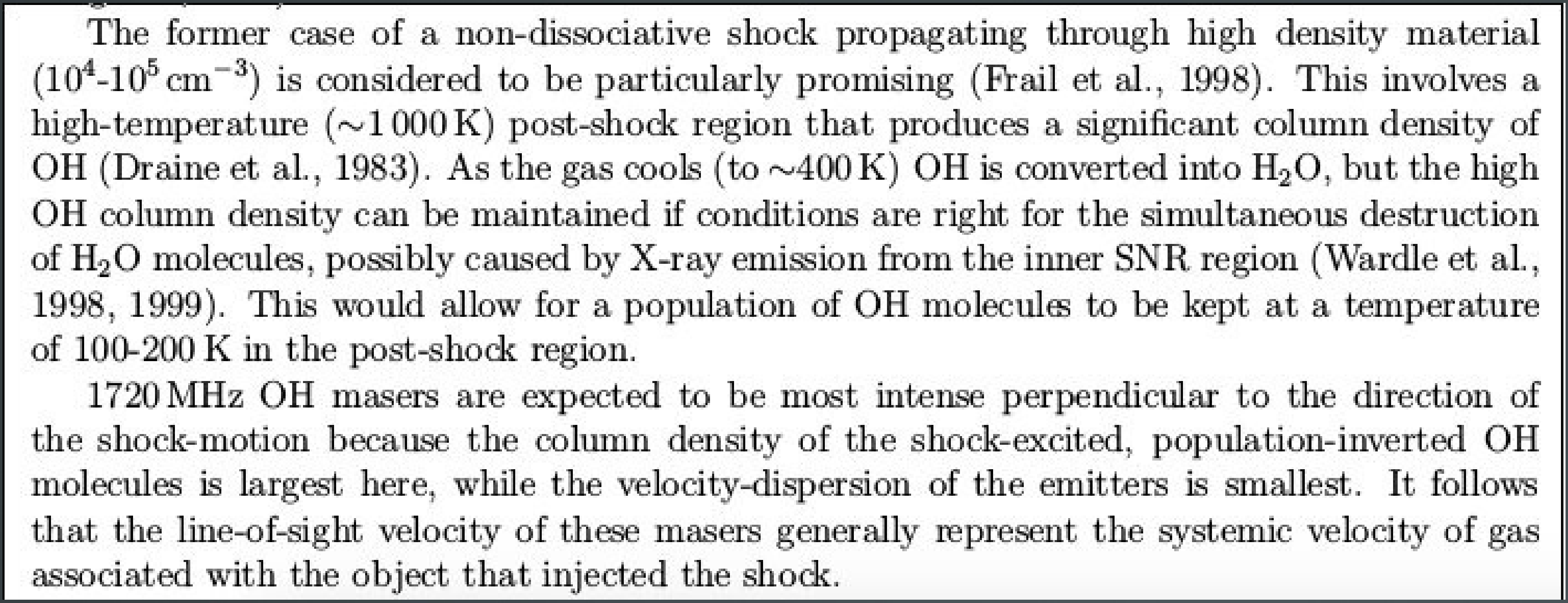

Wardle & Yusef-Zadeh 2002

Fig. 1. Schematic of an expanding supernova remnant (SNR) interacting with an adjacent molecular cloud. Black arrows indicate velocity.

OH

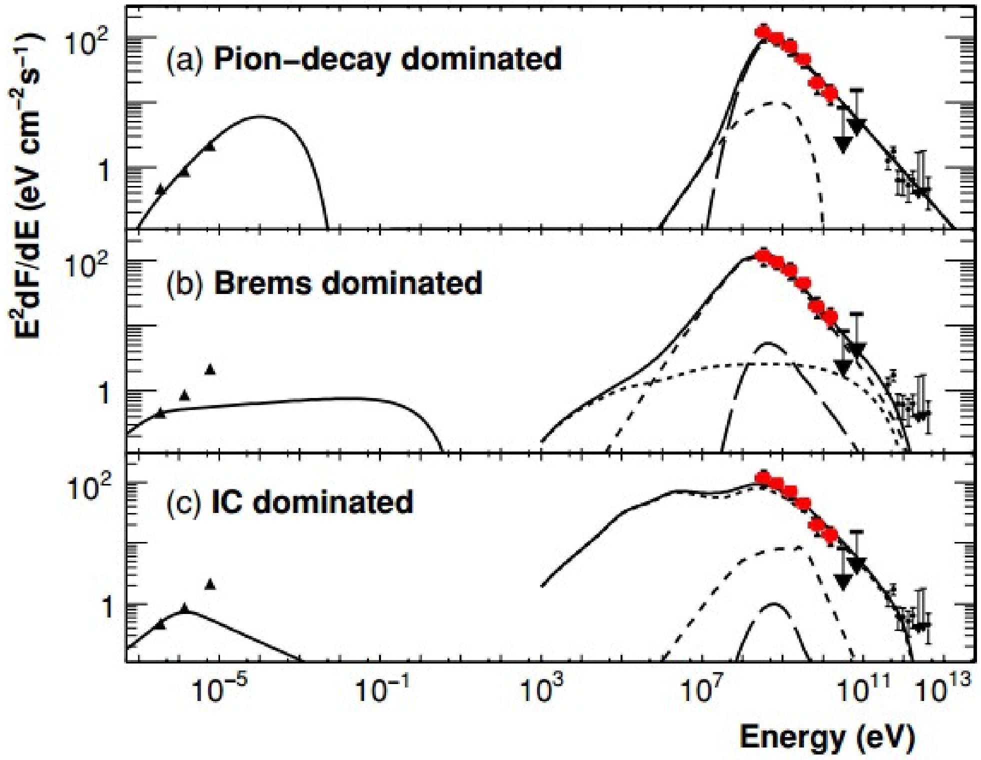


The former case of a non-dissociative shock propagating through high density material (10^4-$10^5\,\mathrm{cm}^{-3}$) is considered to be particularly promising (Frail et al., 1998). This involves a high-temperature (~1 000 K) post-shock region that produces a significant column density of OH (Draine et al., 1983). As the gas cools (to ~400 K) OH is converted into H_2O, but the high OH column density can be maintained if conditions are right for the simultaneous destruction of H_2O molecules, possibly caused by X-ray emission from the inner SNR region (Wardle et al., 1998, 1999). This would allow for a population of OH molecules to be kept at a temperature of 100-200 K in the post-shock region.

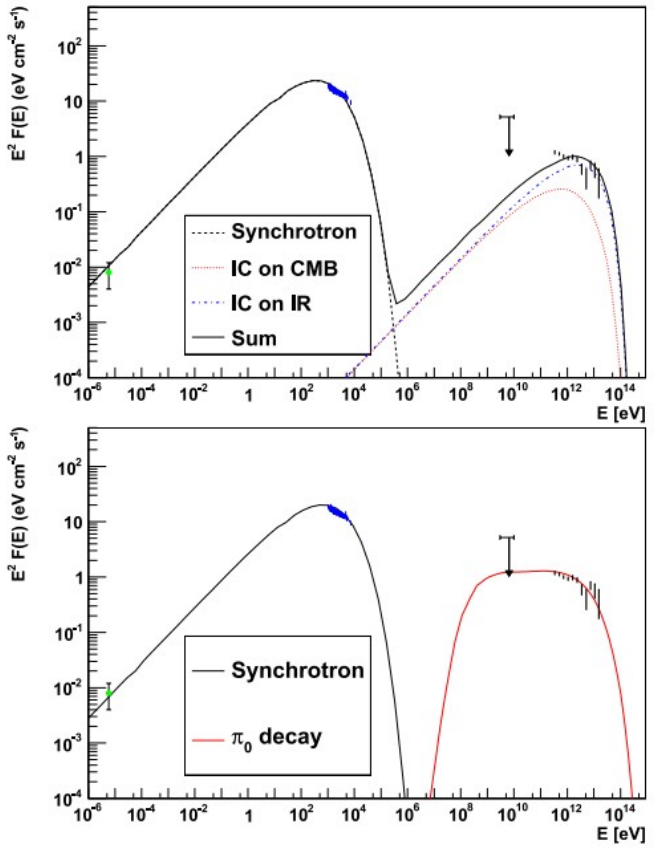
1720 MHz OH masers are expected to be most intense perpendicular to the direction of the shock-motion because the column density of the shock-excited, population-inverted OH molecules is largest here, while the velocity-dispersion of the emitters is smallest. It follows that the line-of-sight velocity of these masers generally represent the systemic velocity of gas associated with the object that injected the shock.

Maxted et al 2013

The W28 (north) & HESS J1731-347 Spectra



Abdo et al (Fermi collab.), 2010



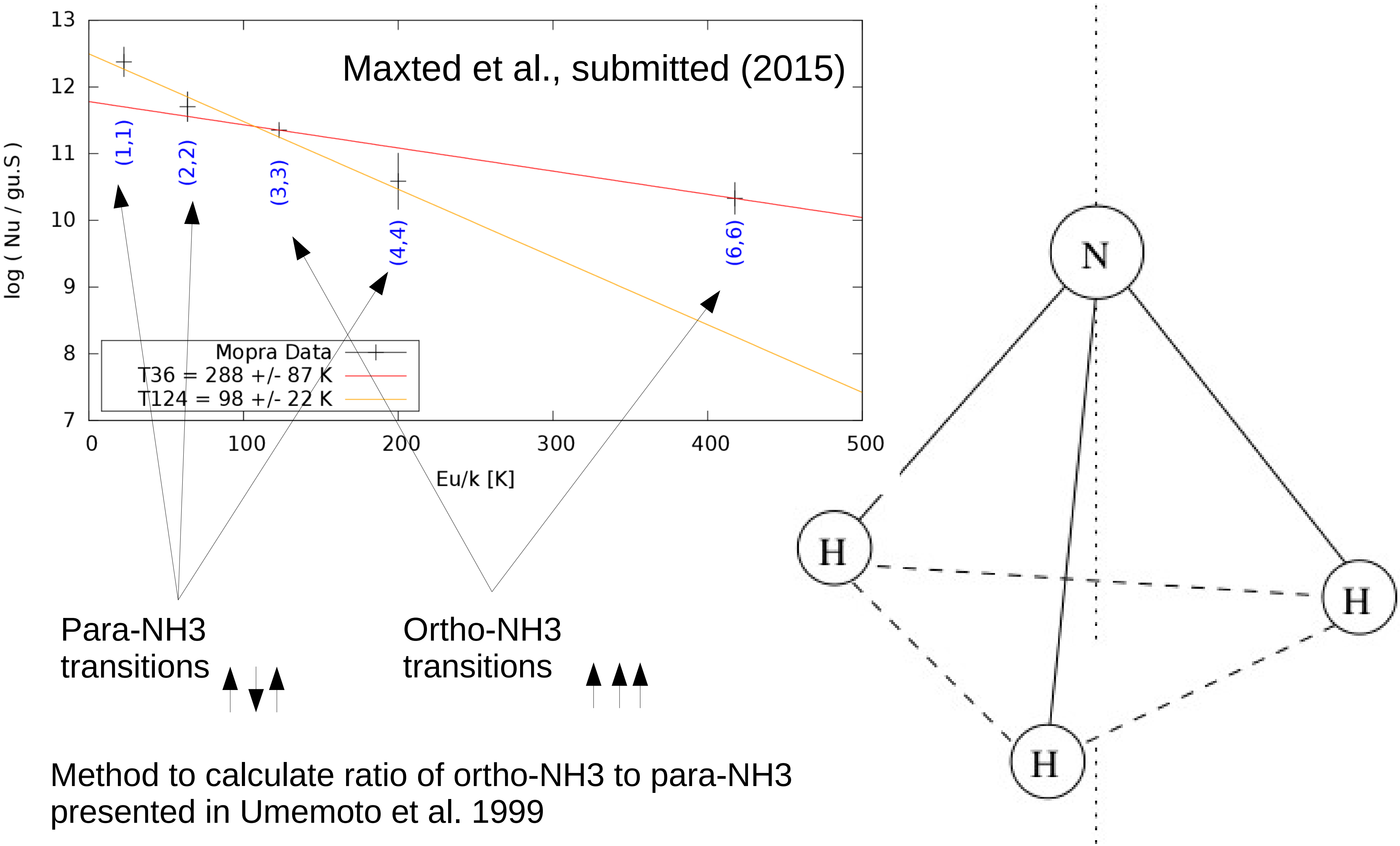
Abramowski et al (HESS collab.), 2011

Difficult to distinguish gamma-ray mechanism in some older remnants.

Other old remnants exhibit hadronic interactions (e.g. Ackermann et al 2011)

Difficult to distinguish gamma-ray mechanism in some newer remnants, but a leptonic mechanism is often favoured

A new NH3 survey of W28

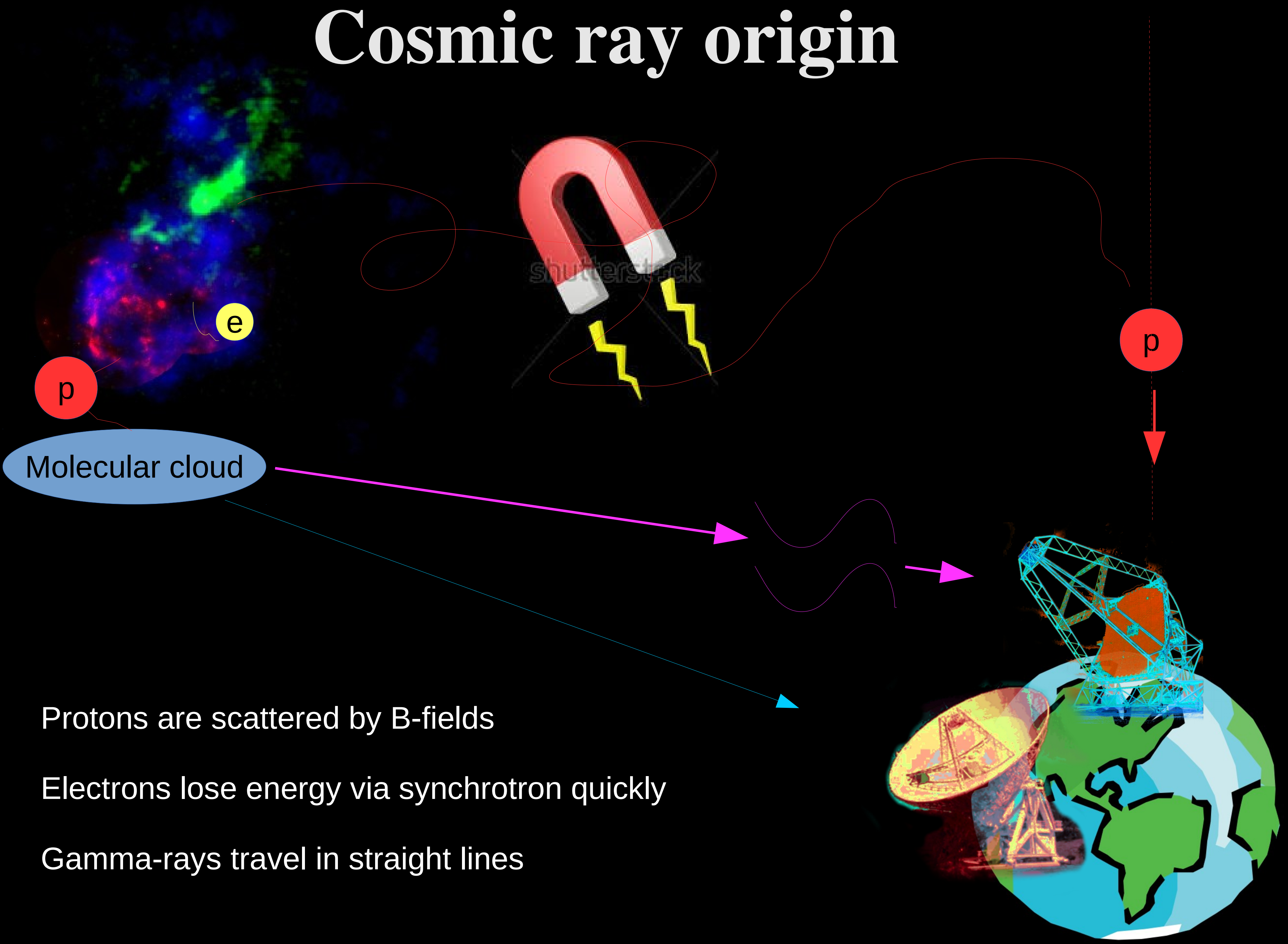

Maxted et al., submitted (2015)

Para-NH3
transitions

Ortho-NH3
transitions

Method to calculate ratio of ortho-NH3 to para-NH3 presented in Umemoto et al. 1999

Cosmic ray origin



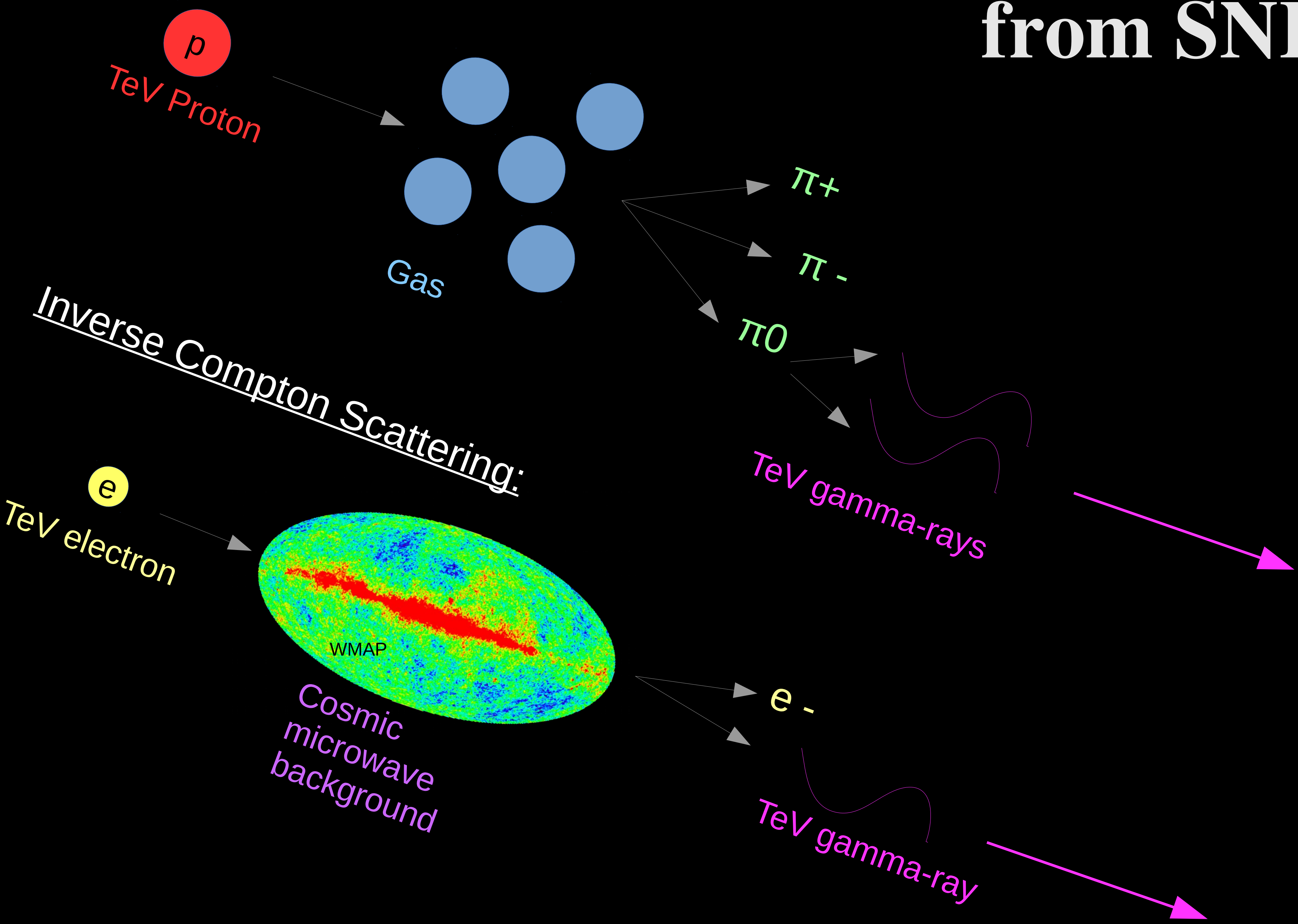
Molecular cloud

Protons are scattered by B-fields

Electrons lose energy via synchrotron quickly

Gamma-rays travel in straight lines

Gamma-ray emission from SNRS



p-p interaction:

p

TeV Proton

Gas

π+

π -

π0

TeV gamma-rays

Inverse Compton Scattering:

e

TeV electron

WMAP

Cosmic microwave background

e -

TeV gamma-ray