Title: Li/Be/B: theory and observations

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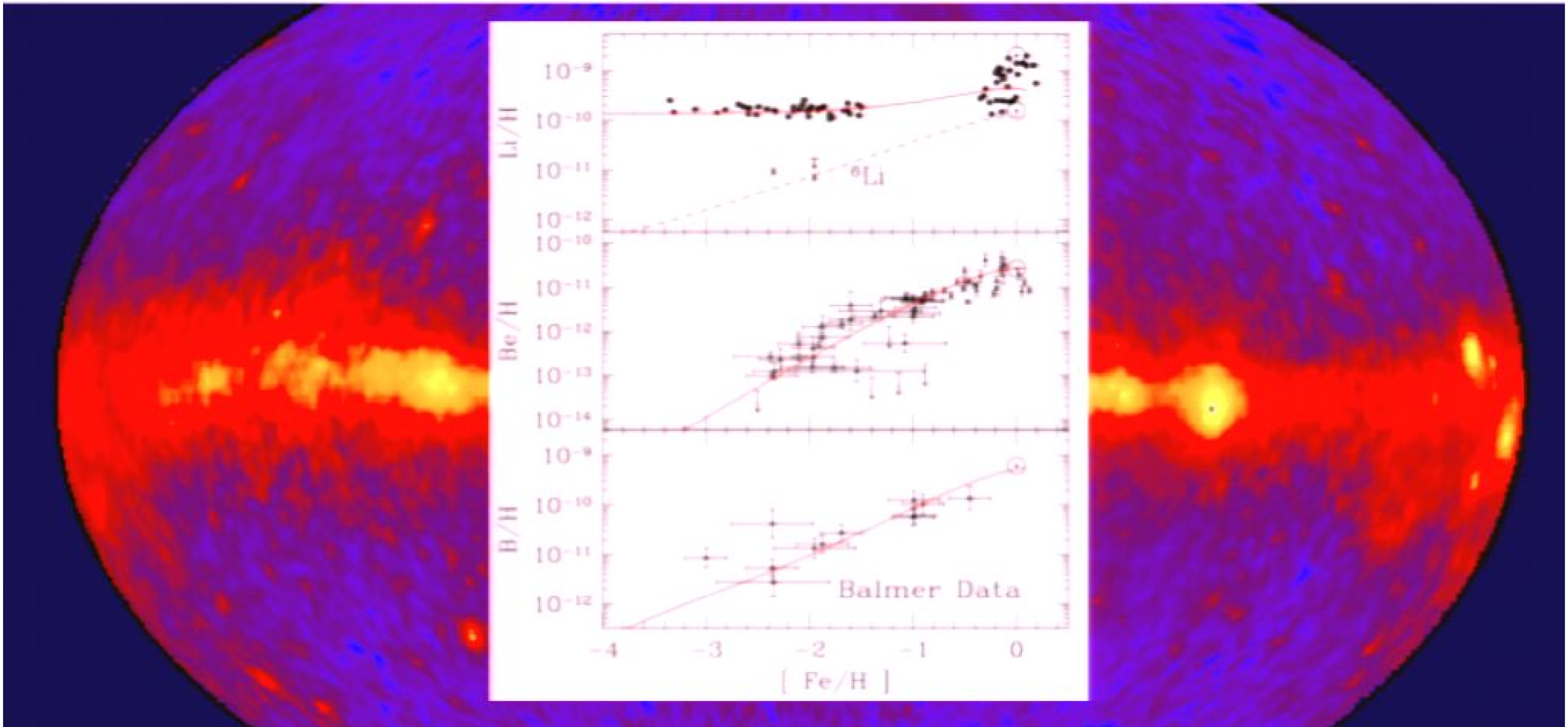
Abstract:

Pregalactic ^{6}LiBeB Nucleosynthesis:
Cosmic Rays vs Dark Matter Decays



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Tijana Prodanovic	U. Novi Sad
Vassilis Spanos	
Keith Olive, Evan Skillman	U. Minnesota
Elisabeth Vangioni, Michel Casse	IAP
John Ellis	CERN

Pregalactic ^{6}LiBeB Nucleosynthesis: Cosmic Rays vs Dark Matter Decays

★ **^{6}LiBeB Observed**

A pre-Galactic component?

★ **Guaranteed LiBeB Production**

Galactic Cosmic Rays

★ **Pre-Galactic ^{6}LiBeB Production**

Cosmological Cosmic Rays

Decaying Dark Matter

^{6}LiBeB Observed

LiBeB Fossil Hunting in Galactic Halo Stars

- **^{6}LiBeB: rare orphans of nucleosynthesis**
  - why? stars destroy LiBeB at a mere T~2-4 MK
  - encode unique info on nonstellar energetic processes
- **Detectable** in atmospheres of primitive stars (Pop II "halo"/spheroid)
  - but must be hot: thin convection zone T_{eff} ~ 6000 K
- Observables: LiBeB, H, metals (Fe,O) in each halo star records abundance at star's birth
- Want: record of LiBeB evolution, e.g., vs time/redshift

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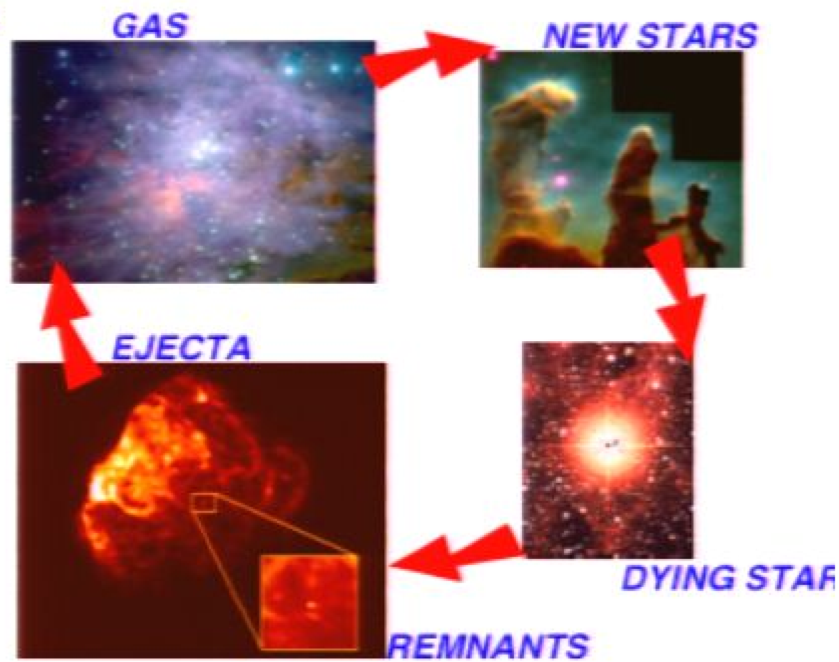
- Strategy:

  use metals as measure of Galactic evolution:

  star form = metal increase with time

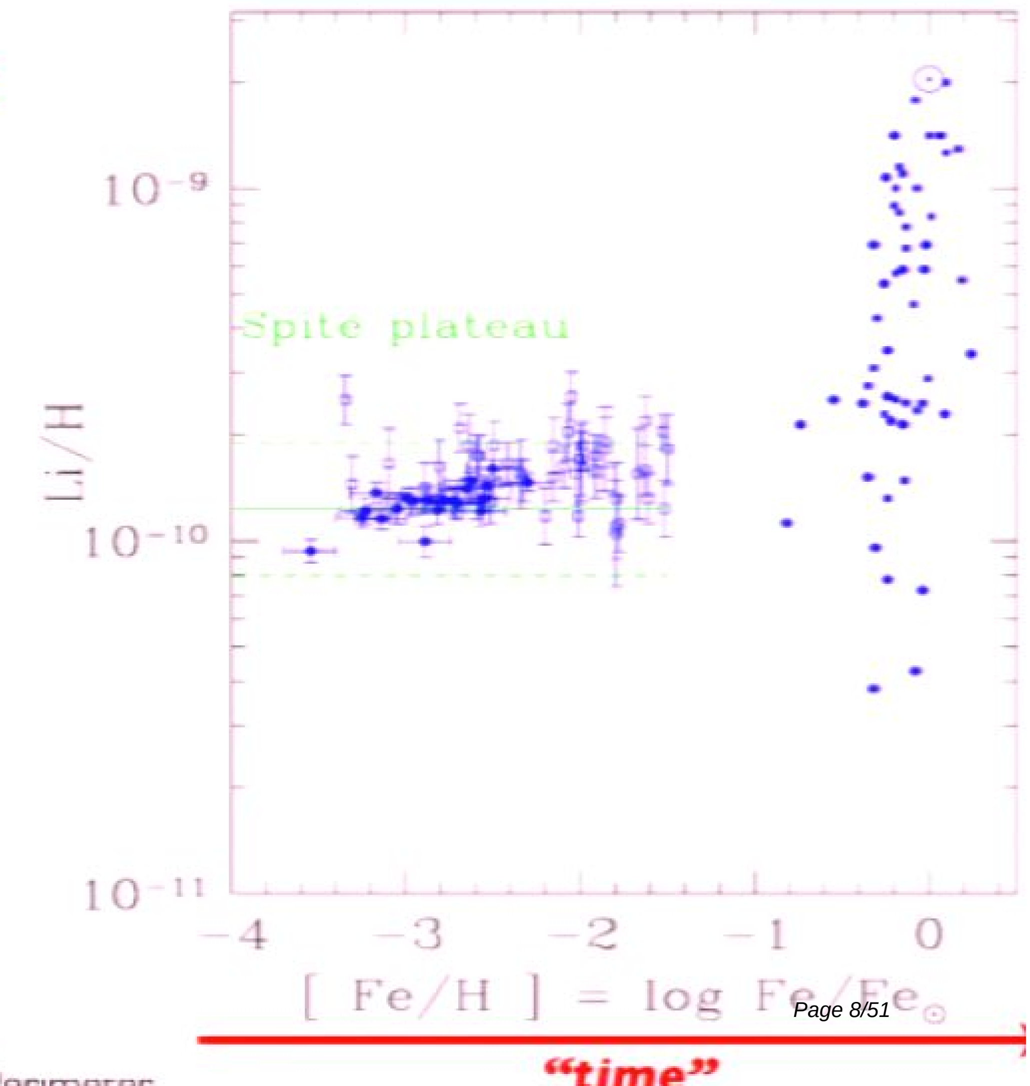
  LiBeB vs Fe trend ⇨ measures evolution



Primordial Lithium Observed

Li vs Fe well-studied at low and high metallicity

At high Fe ⇨ late times: Li rise



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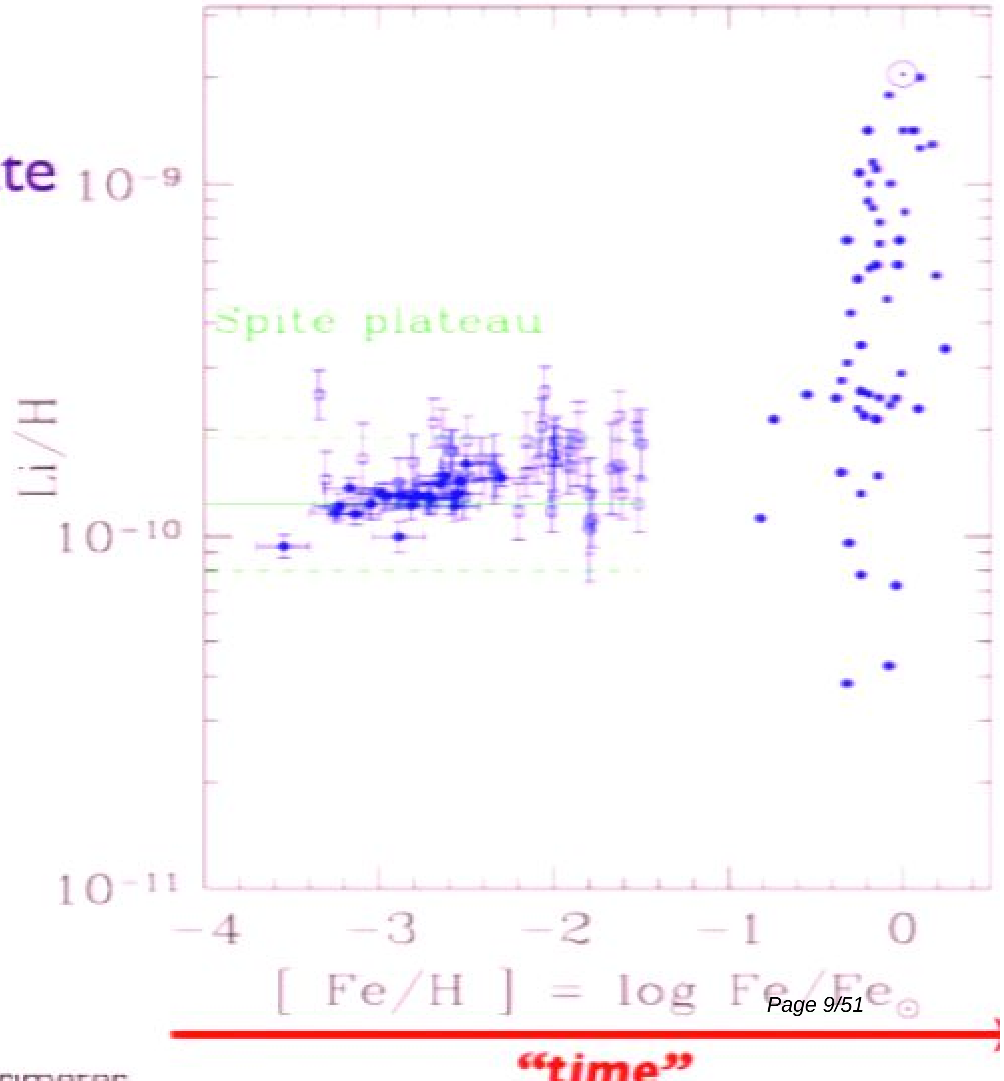

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- const. abundance at early epochs
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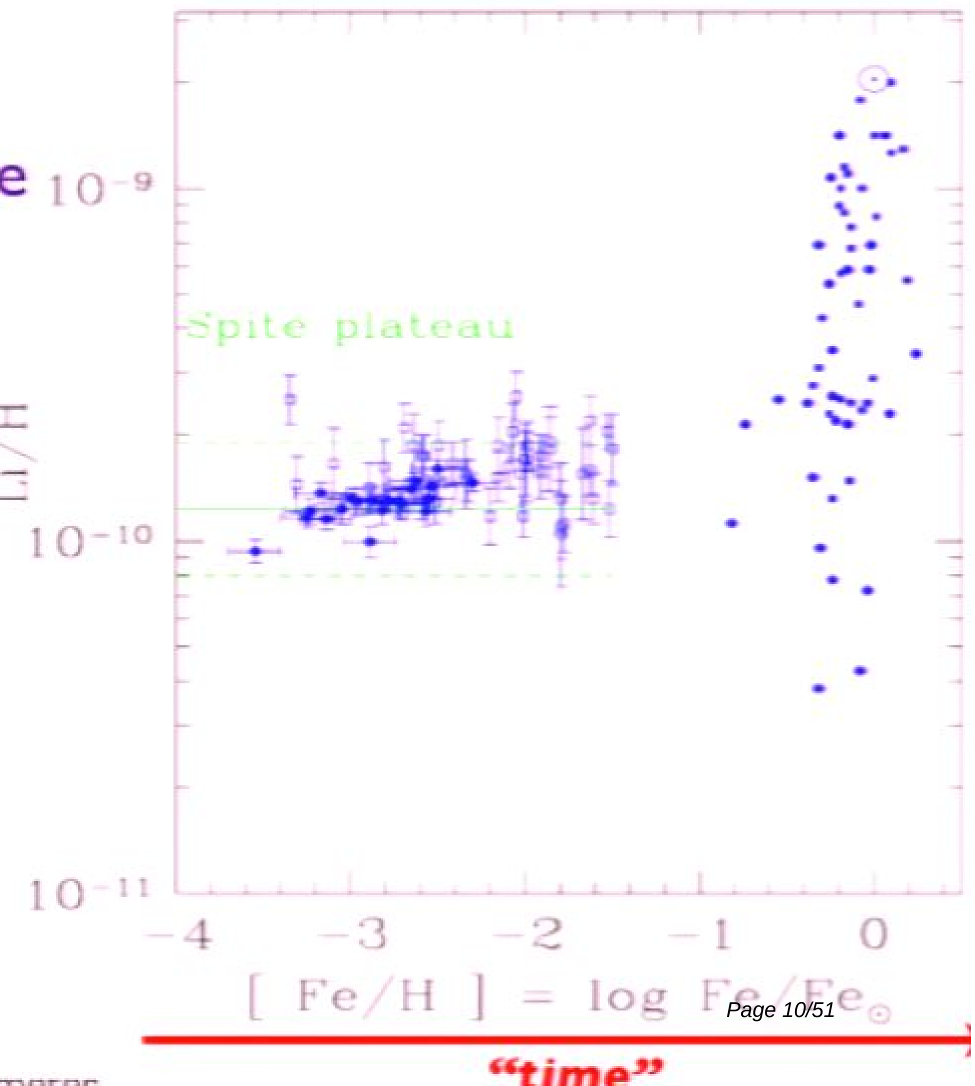

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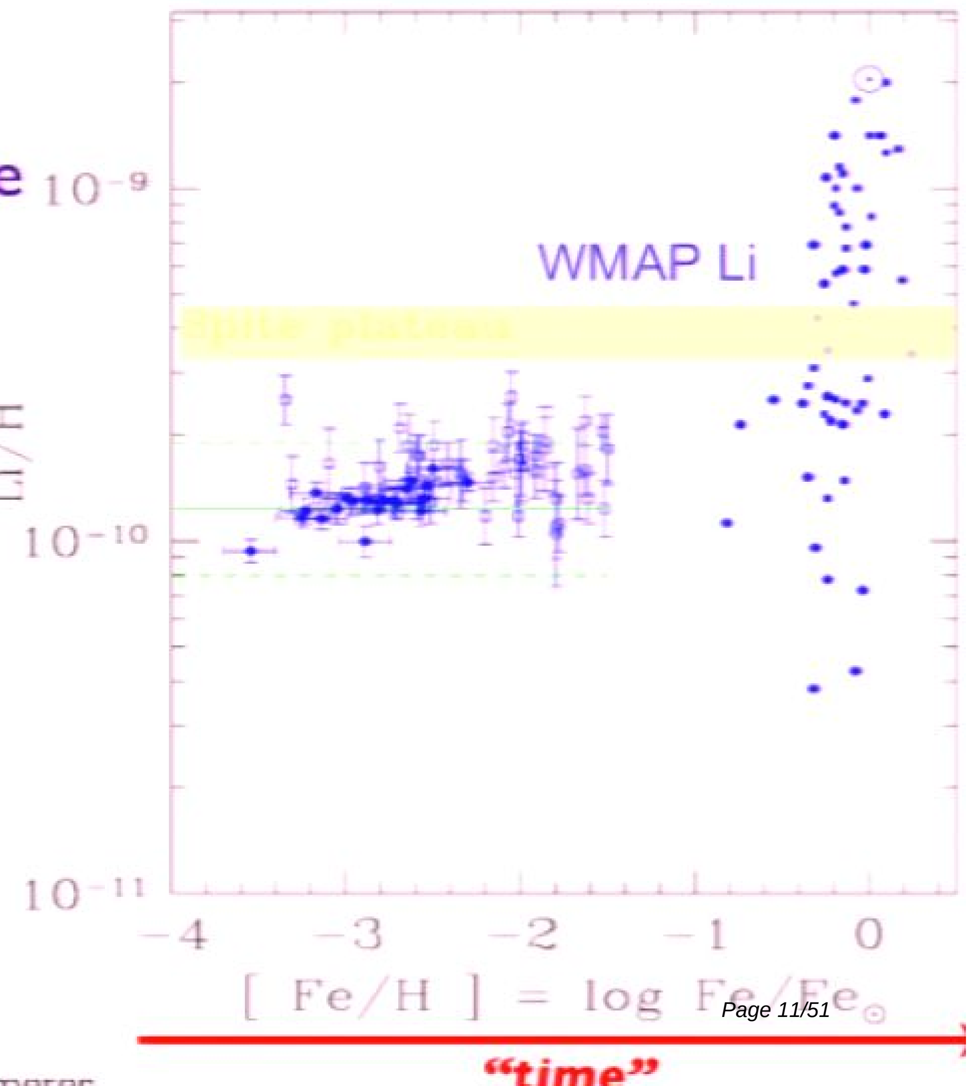
- $Li_{WMAP}/Li_{obs} \sim 3$



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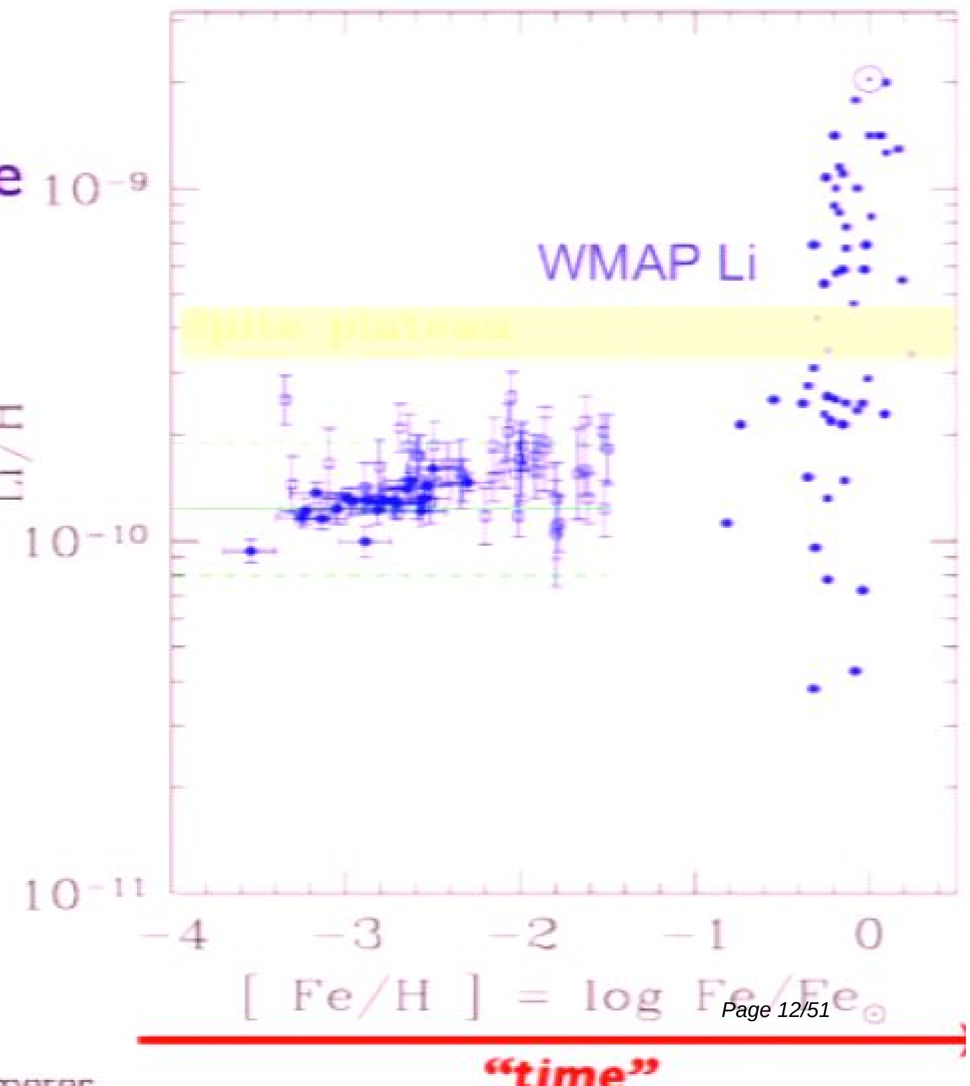

BBN@Perimeter

Lithium Systematic Uncertainties

Observational Systematics

Measure: Li I neutral absorption line(s)

Infer: Li/H

T_{eff} critical: mostly ionized Li II

But: Needed error in T scale ~500 K: large!

Astrophysical Systematics

stellar depletion over $\sim 10^{10}$ yr

if Li burned: correct Li_p ***upward***!

High S/N Data

Ryan, Norris, & Beers 1999; Asplund et al 2006

1. Li plateau "razor-thin" -- depletion negligible/fine tuned
2. small but real ***rise*** in Li vs Fe ⟹ Li vs t

   corrects Li_p ***downward***!

   evidence for early Galactic Li production: need to identify mechanism!

Beryllium and Boron Observed

Observables

- ★ Be: line observable from ground
- ★ B line from space only: fewer points

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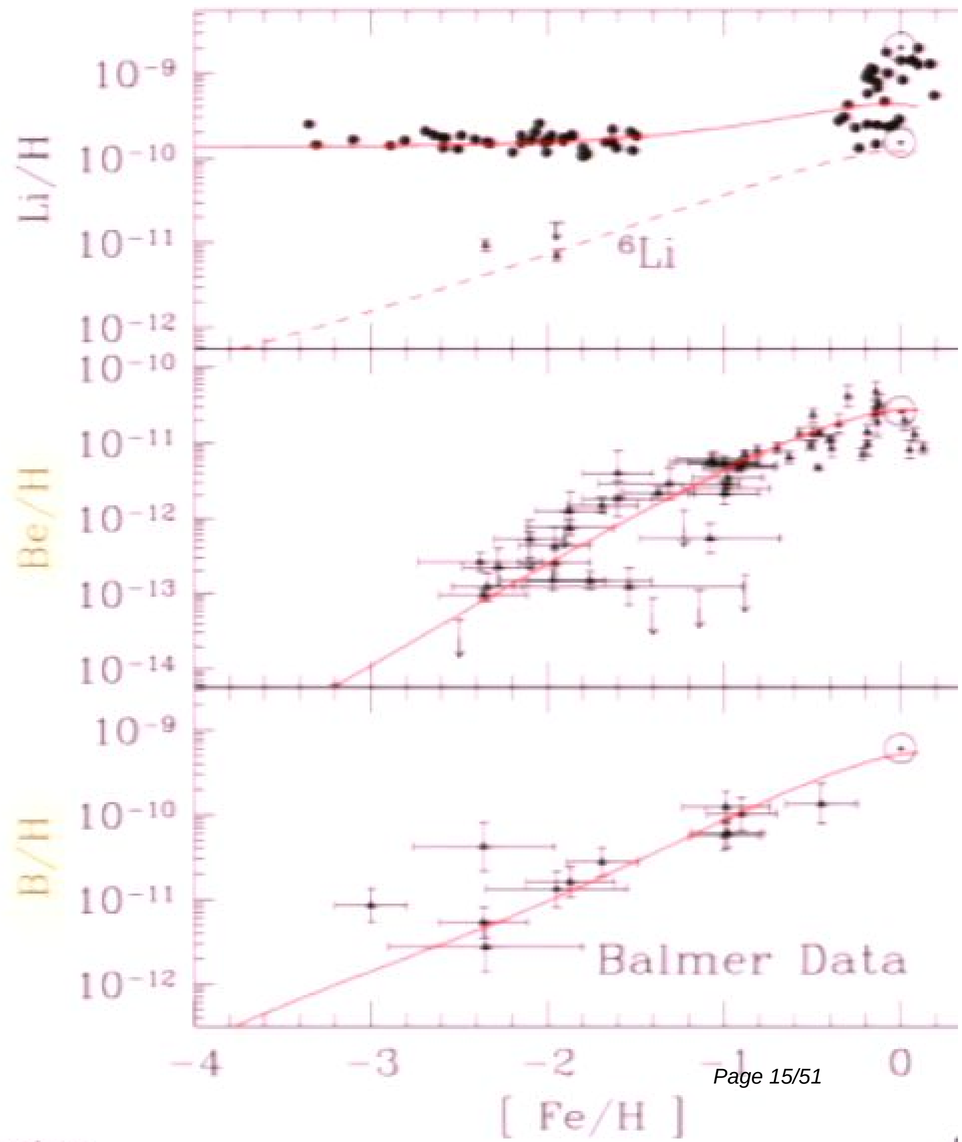

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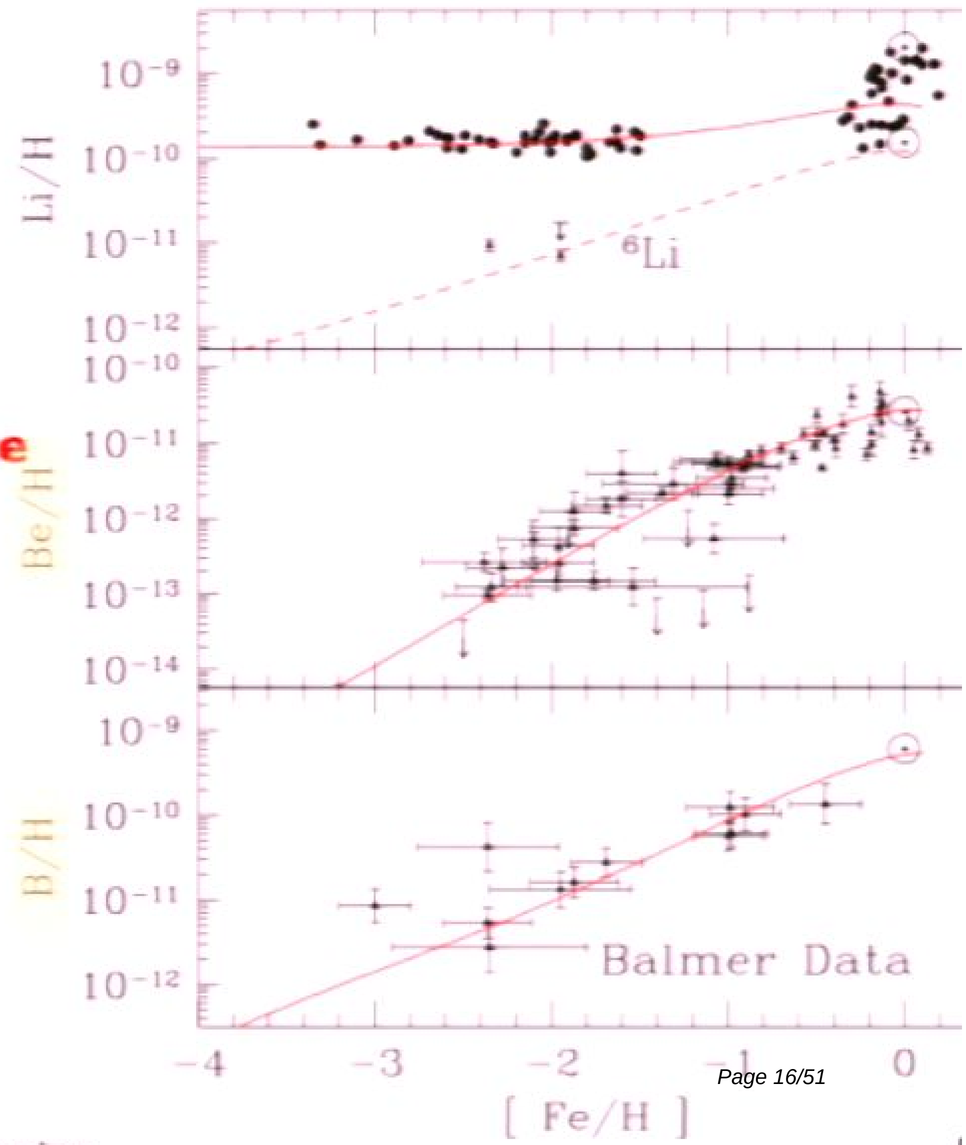

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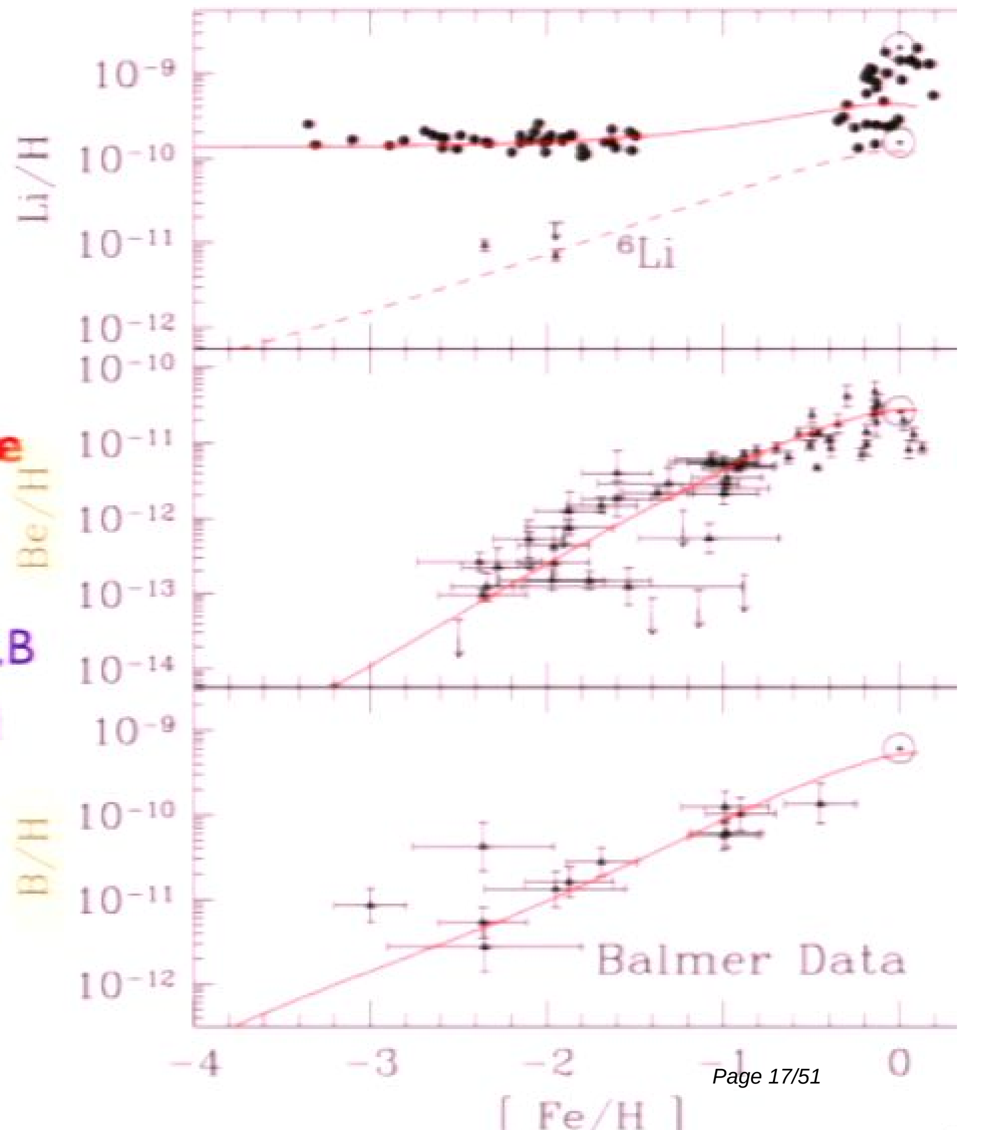
✓ no clear evidence for plateaus

- ➡ no clear observed evidence for primordial Be,B
- ➡ upper limits on primordial: ~ lowest observed abundance

lack of plateau consistent with SBBN

Be,B << observable levels



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Good News

^{6}Li/^{7}Li ratio observable

isotope shift $\lambda(^6\mathrm{Li}) < \lambda(^7\mathrm{Li})$

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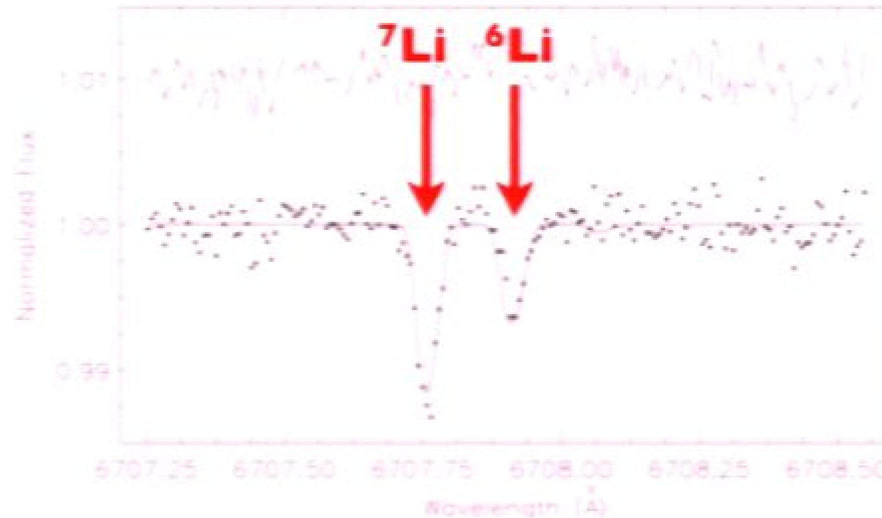

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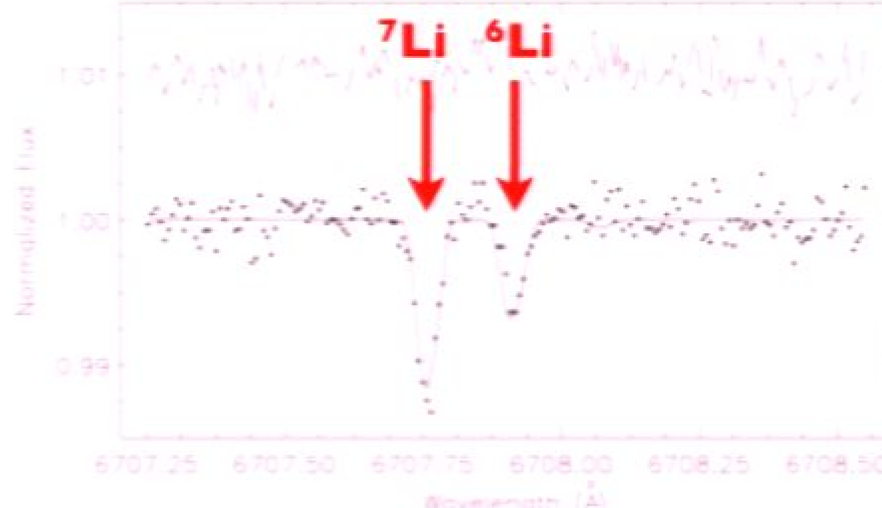
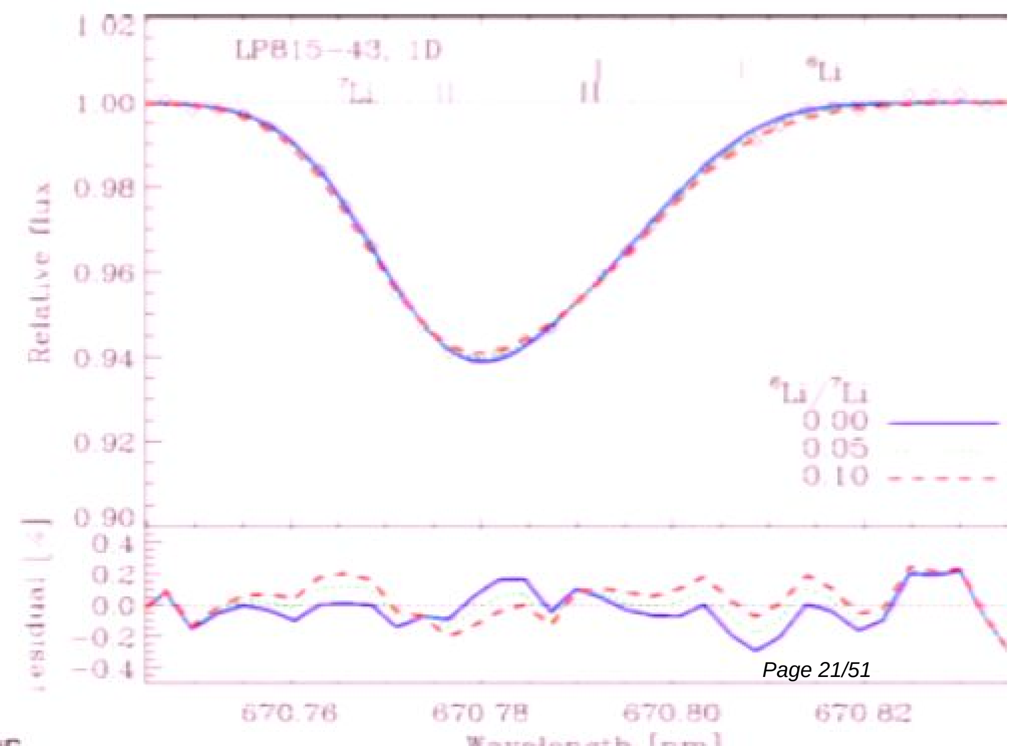


Bad News

in halo star atms: $\delta\lambda_{\mathrm{thermal}} > \delta\lambda_{\mathrm{isotope}}$

isotopes blended into one line



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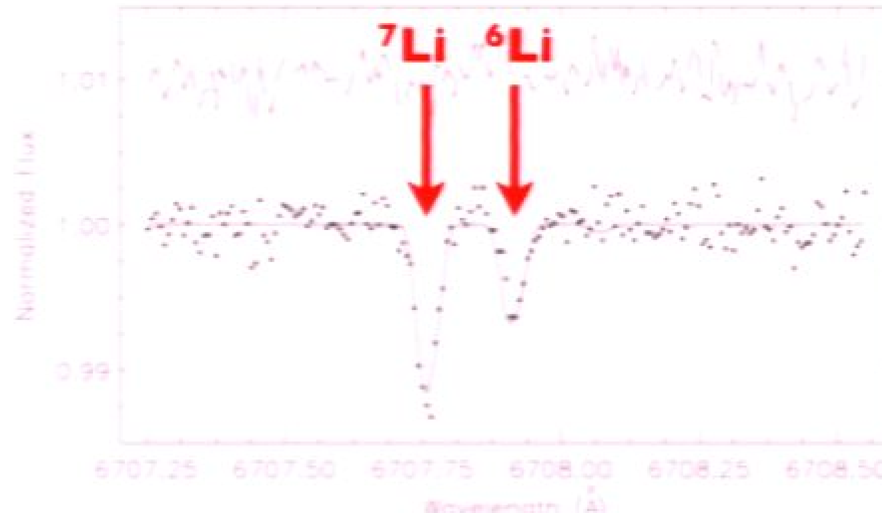

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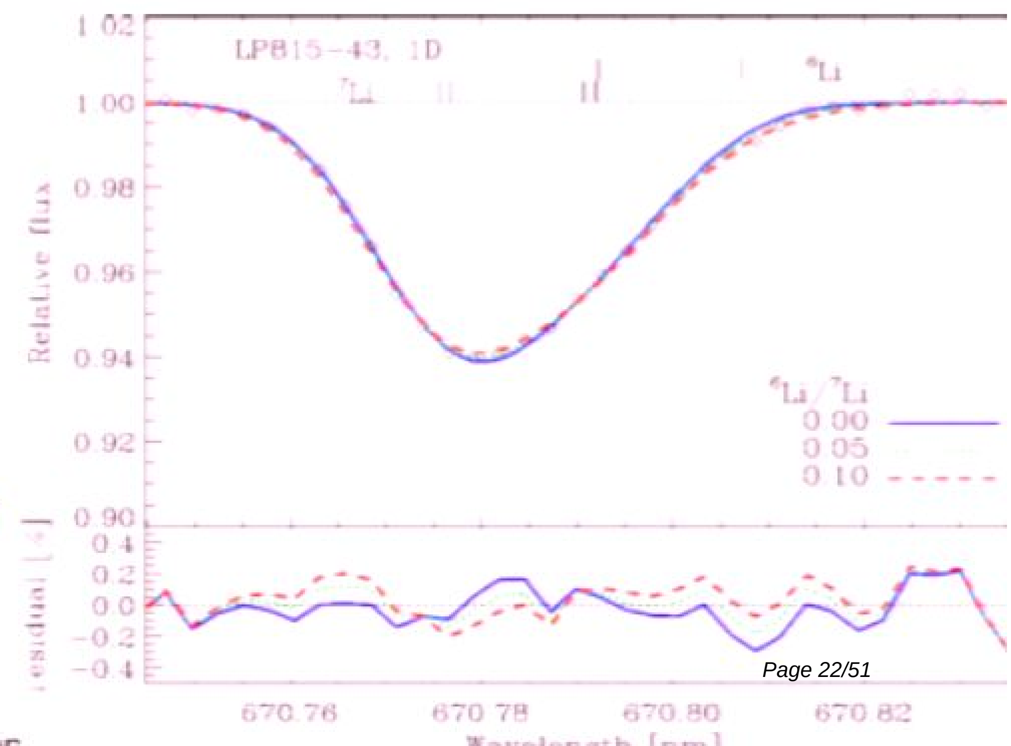
Strategy

measure line profile *very* accurately

Smith Lambert Nissen; Asplund et al

lineshape encodes isotopic ratio



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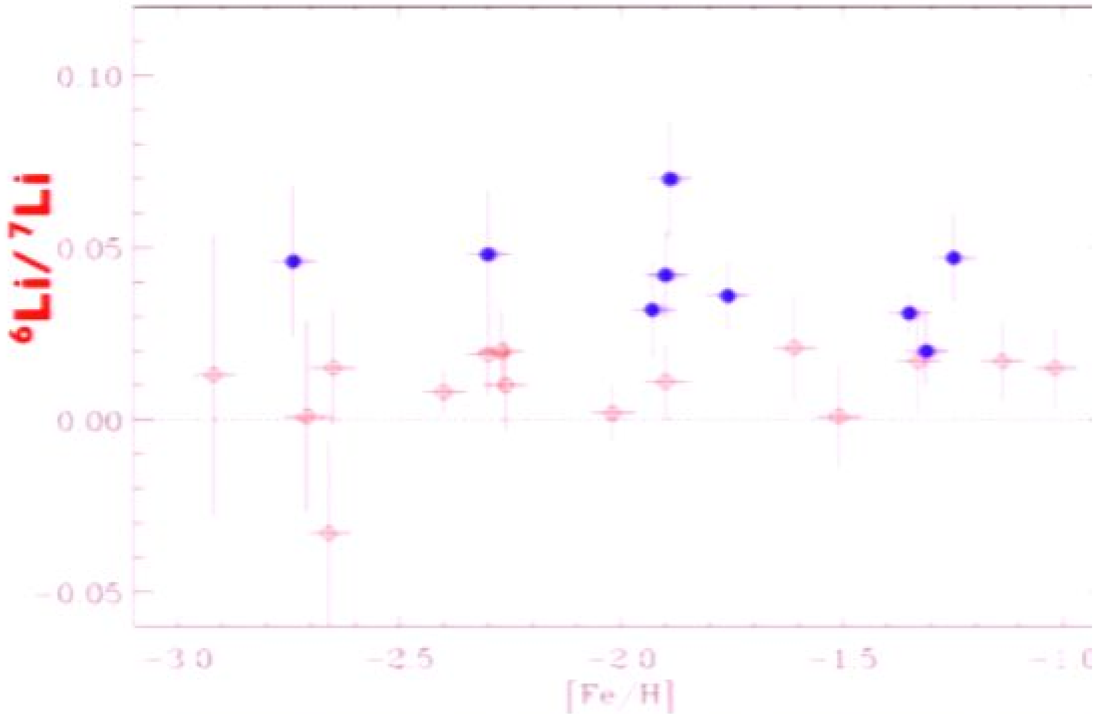
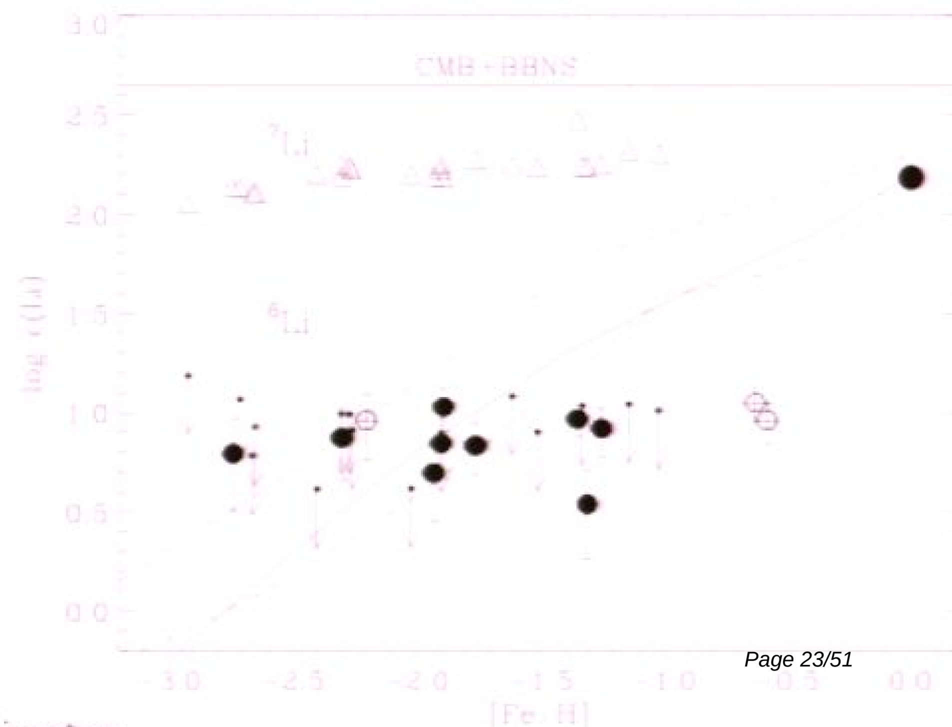
- $^6\mathrm{Li} \ll {}^7\mathrm{Li}$ as expected in SBBN
- similar ratios in all detections

Li elemental plateau

⟹ plateaus in each isotope

primordial 6Li?





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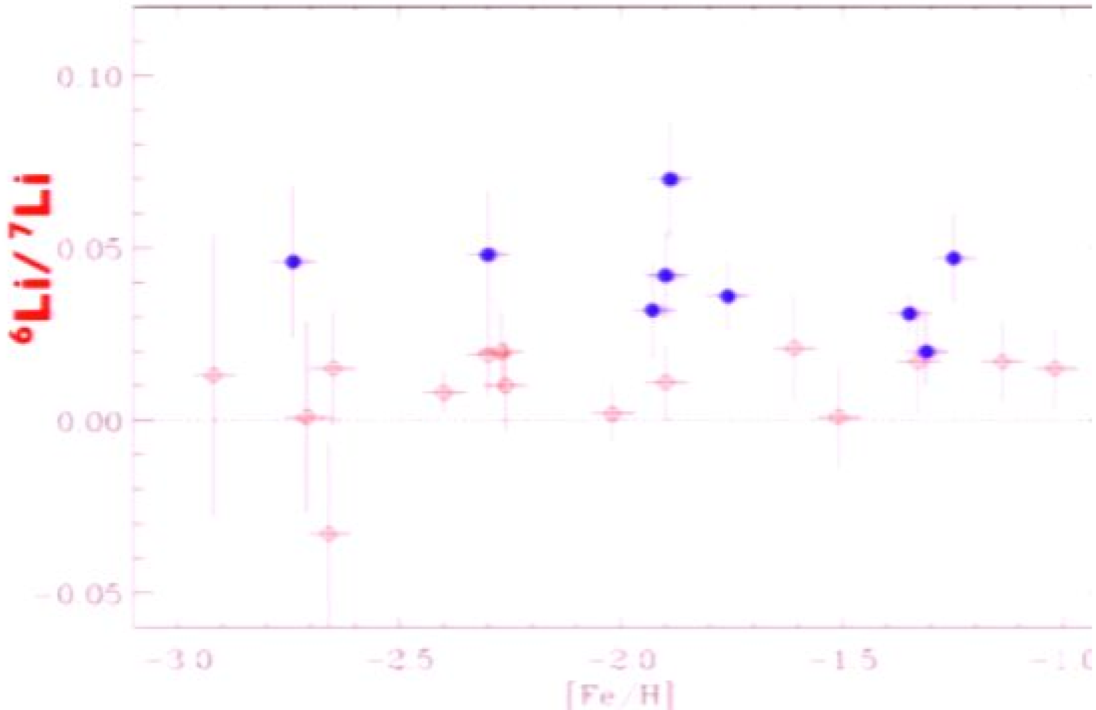

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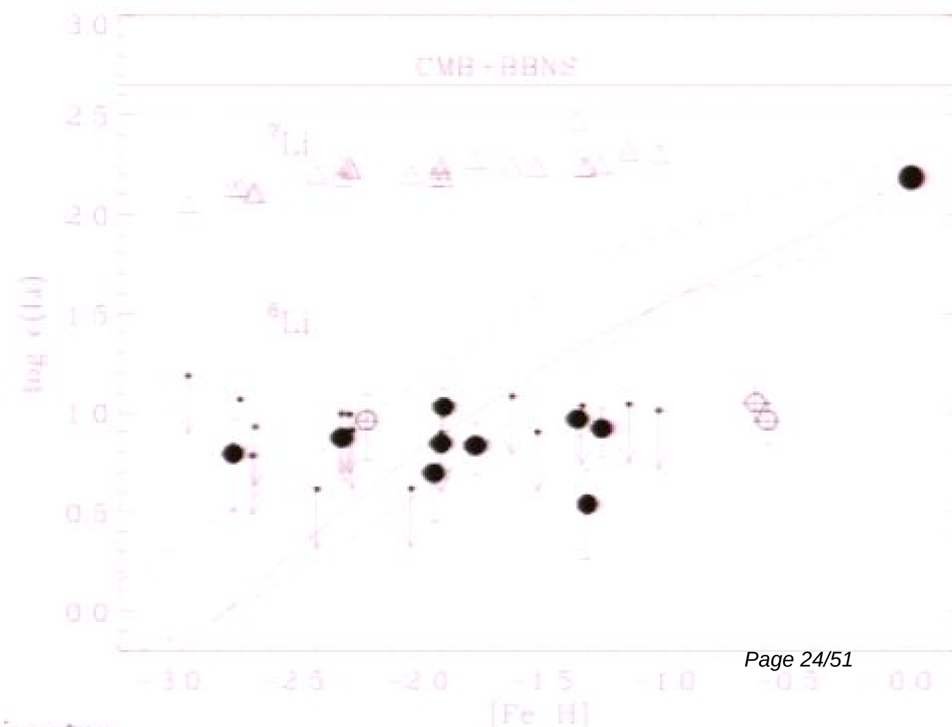

Cayrel et al 2007

convective motion of photosphere

➡Doppler redshifts in lines

➡upwelling gas hotter, brighter

➡asymmetry: boosts "red" signal more

mimics 6Li!?

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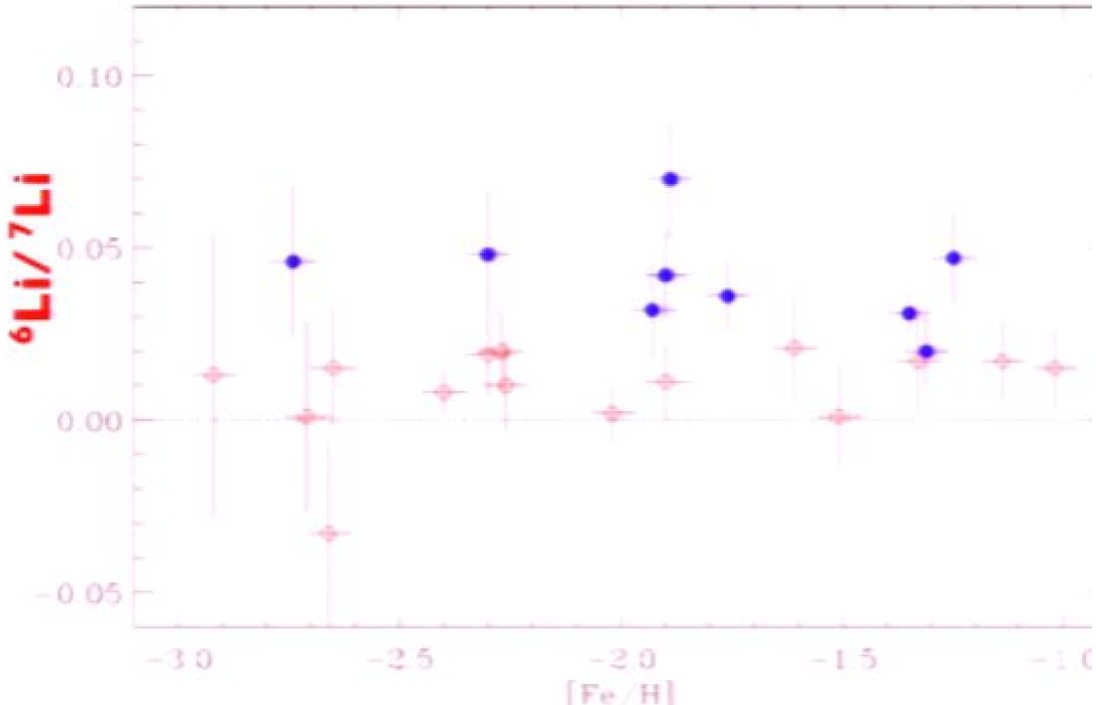

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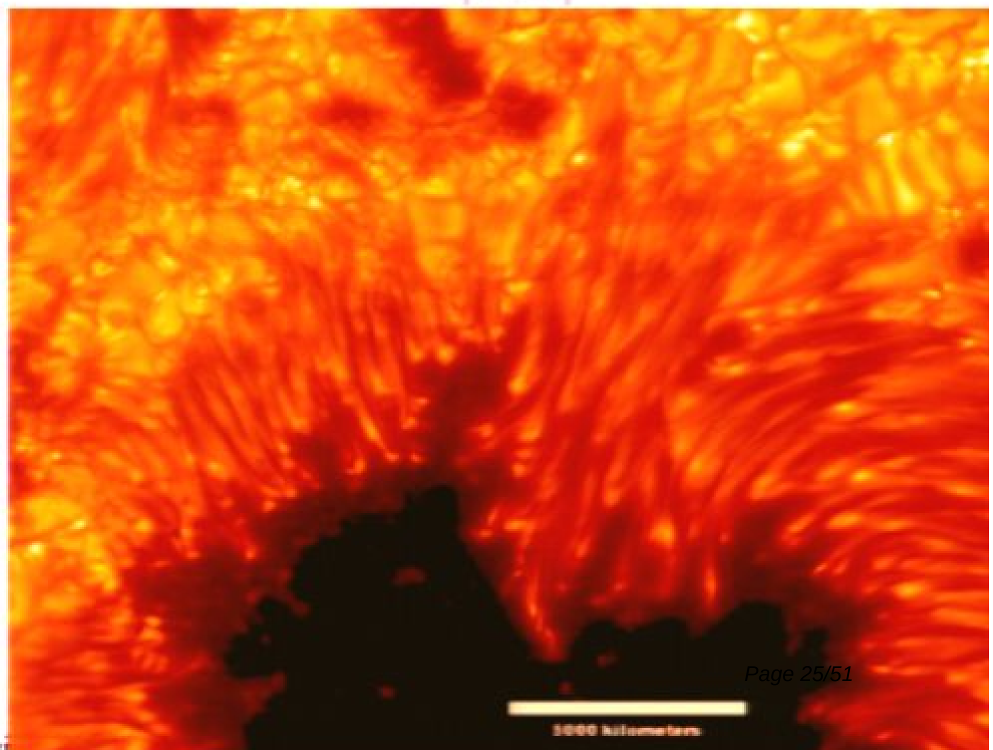

Guaranteed ^{6}LiBeB Sources

Cosmic-Ray Nucleosynthesis

Reeves, Fowler, Hoyle; Meneguzzi, Audouze,, Reeves, Walker, Mathews Viola

Cosmic Rays interact with ISM

Interstellar gas: beam dump

- Observe in gamma-ray sky

$$p_{\rm cr} + p_{\rm gas} \rightarrow pp\pi^0$$

$$\pi^0 \rightarrow \gamma\gamma$$

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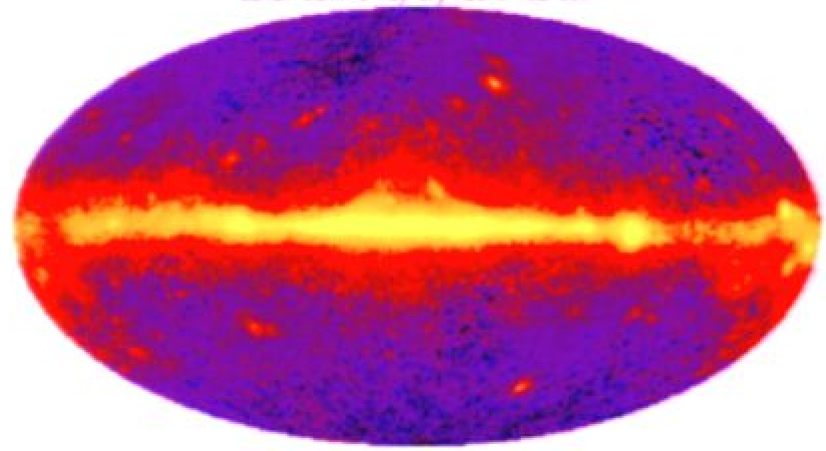
EGRET Gamma Ray Sky Above 100 MeV



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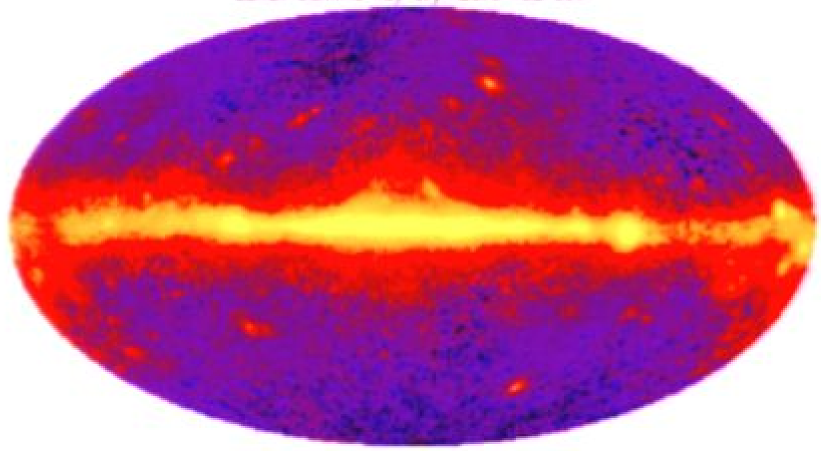

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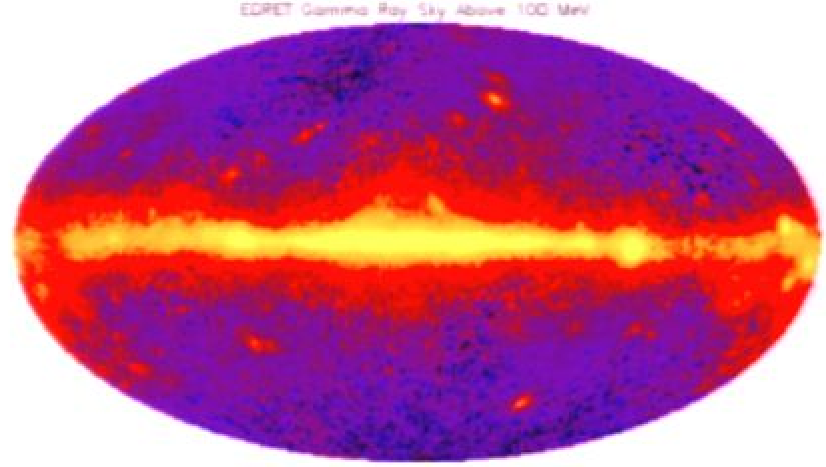

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BBN@Perimeter

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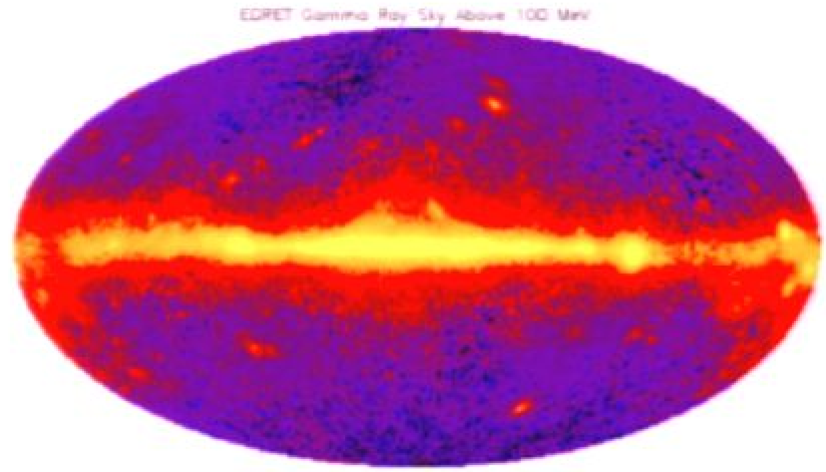

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Fusion: $\alpha + \alpha$ ^{6}Li and ^{7}Li *only*

Galactic Cosmic Ray Archaeology

LiBeB as Cosmic Ray Dosimeters

- Solar LiBeB: cumulative irradiation at Sun birth

  Galactic cosmic rays are ***only*** conventional ^{6}Li, ^{9}Be, ^{10}B source

  neutrino spallation (nu process) in supernovae also makes ^{7}Li, ^{11}B

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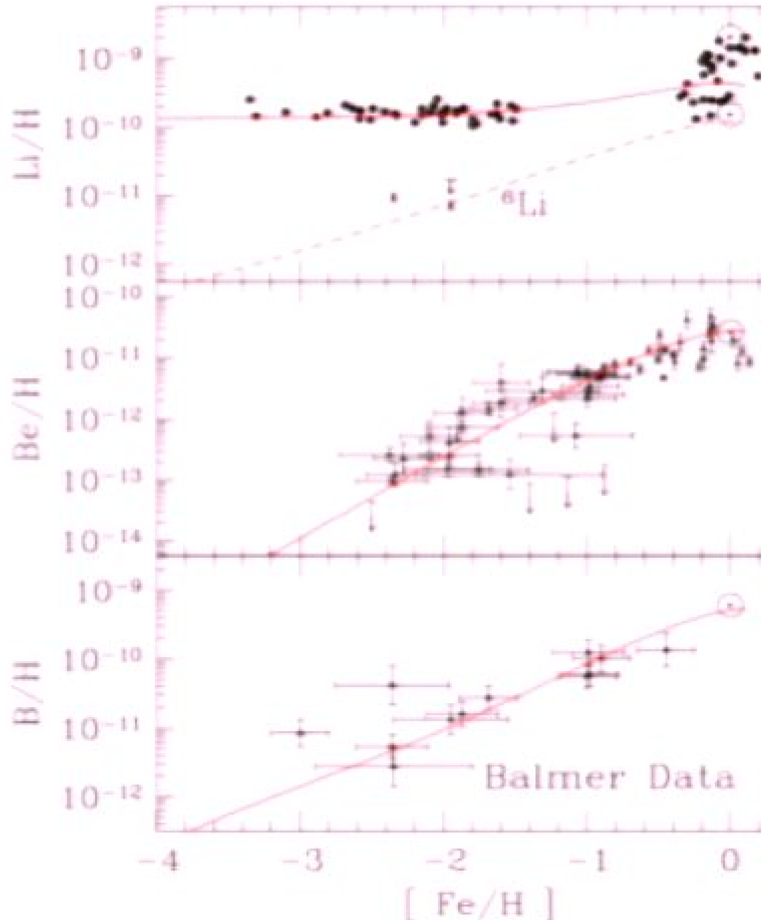
  Cosmic rays present in early Galaxy!

  LiBeB ⇒ cosmic ray origin, history

  can build successful models of cosmic-ray and chemical evolution



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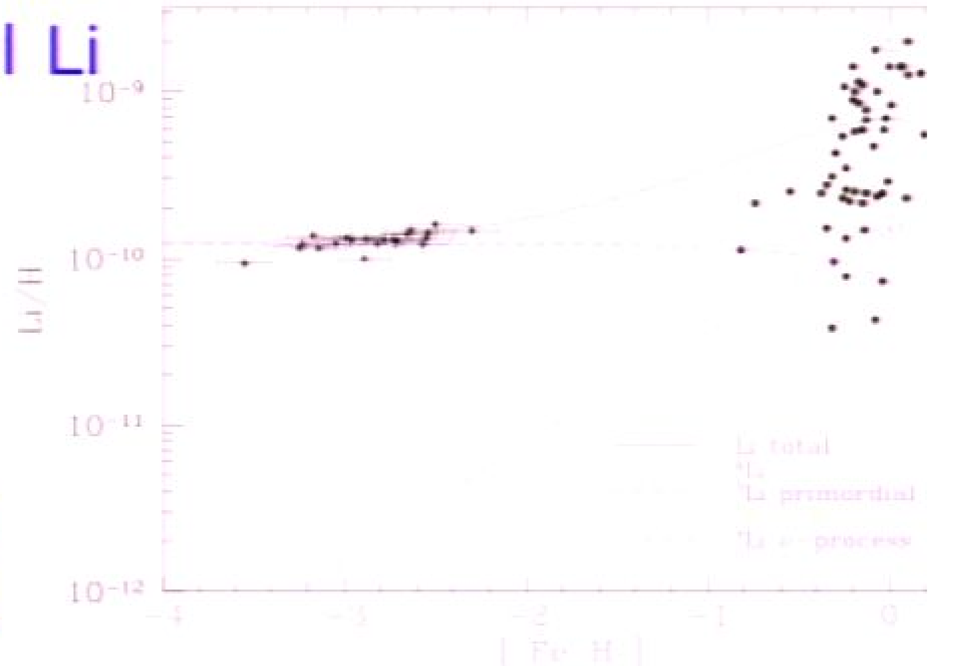

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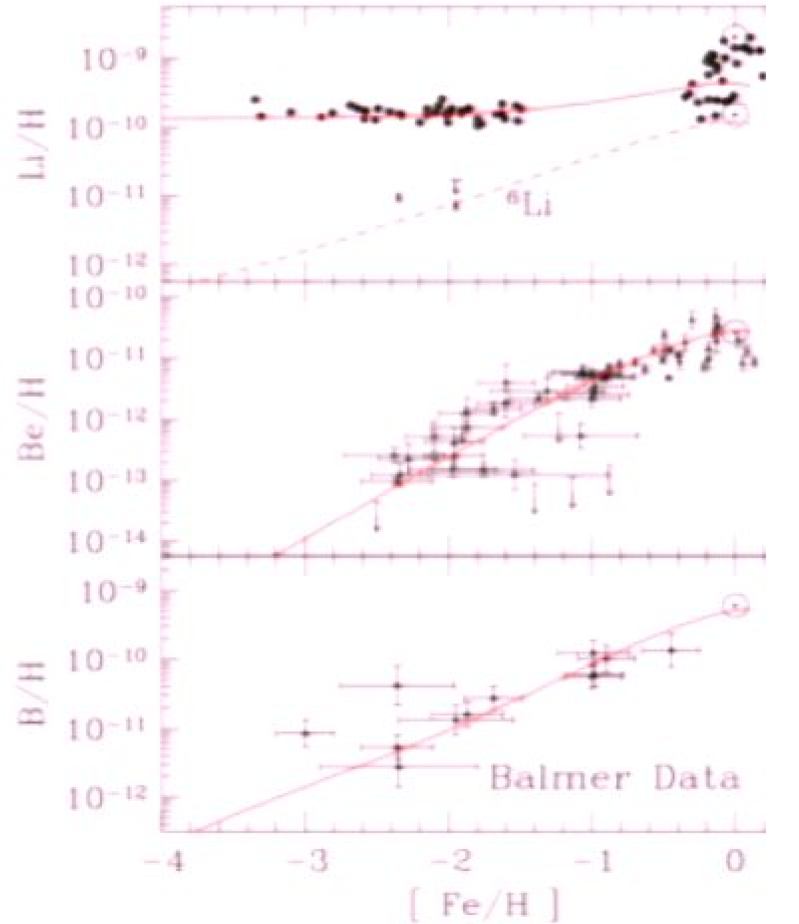

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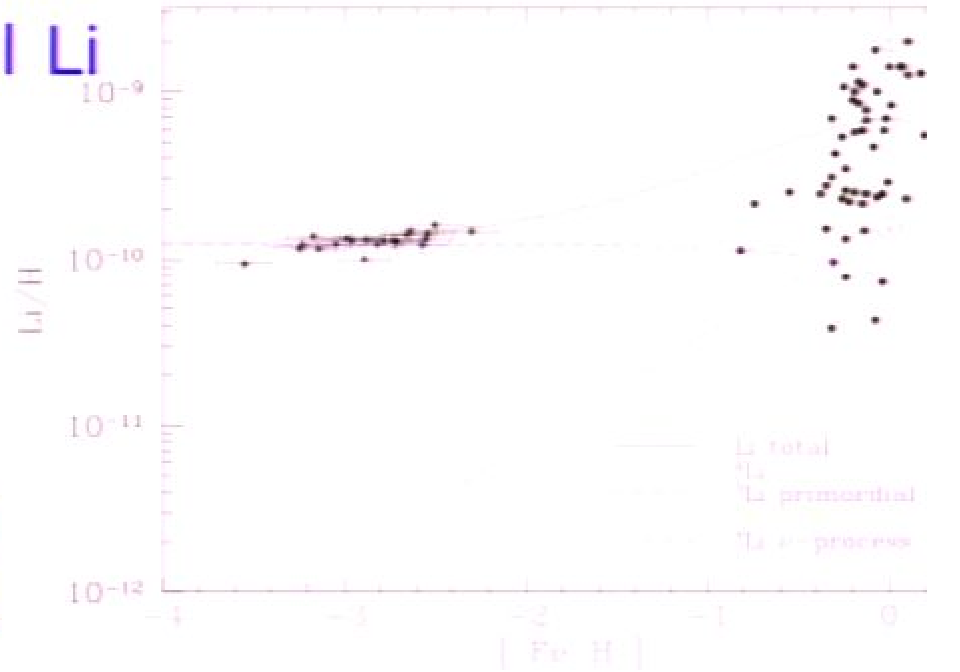

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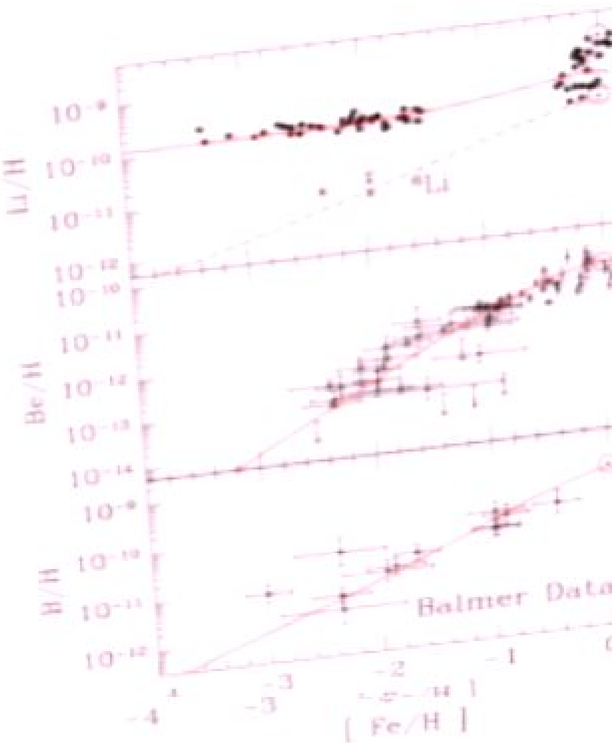

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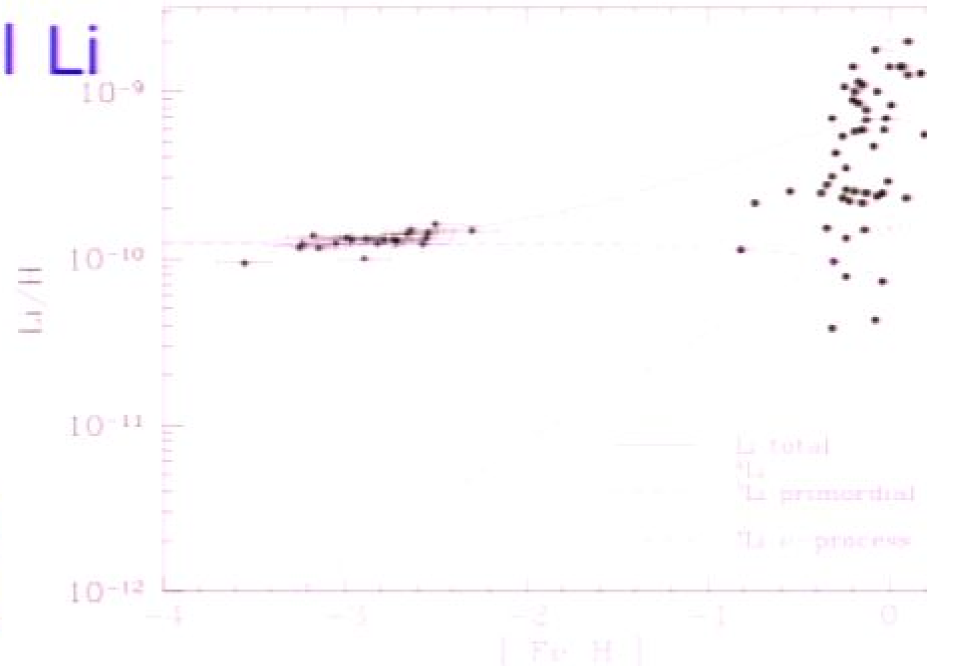

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Pre-Galactic ^{6}LiBeB Production

Baryon Response to Structure Formation: Shocks

DM potentials drive bayron flows
If *flow speed > sound speed*: **shocks**

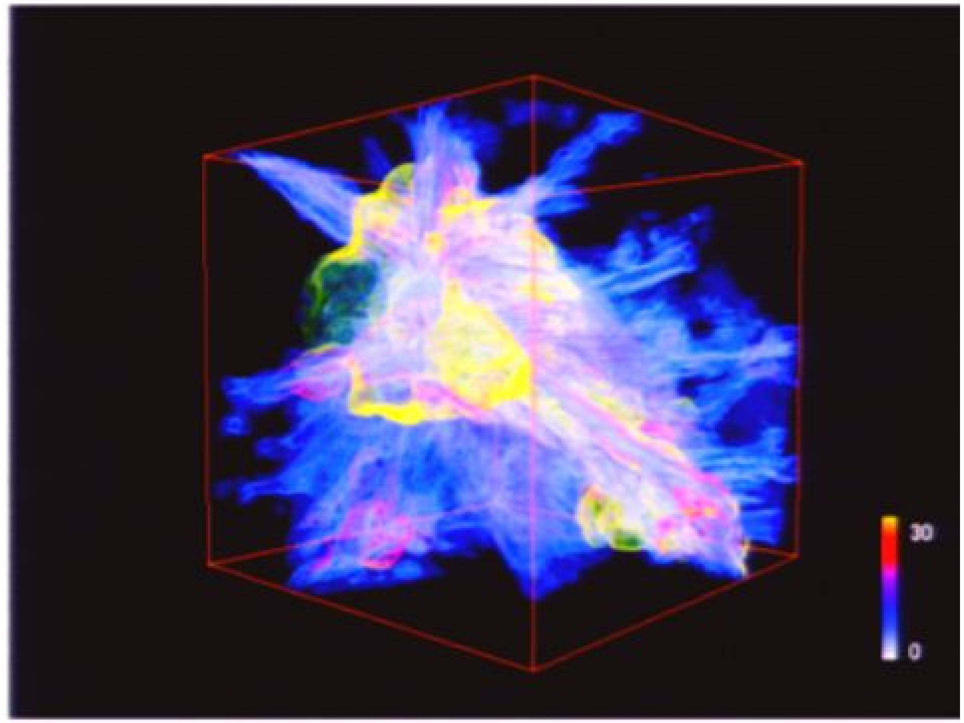
Simulations: Miniati, Jones, Ryu, Kang

- Structure formation shocks ubiquitous
- enclose cosmic web
- complex geometry
- range of Mach numbers

Analytic Approach: Nath & Silk; Blasi & Gabici; Furlanetto & Loeb; Pavlidou & BDF

Classify by *physical origin*

- Gravitational attraction
  - accretion
  - mergers
- Void expansion
  - filaments



Ryu et al 2003
Shock surfaces, Mach colors
$(25\ h^{-1}\ \mathrm{Mpc})^3$ simulation

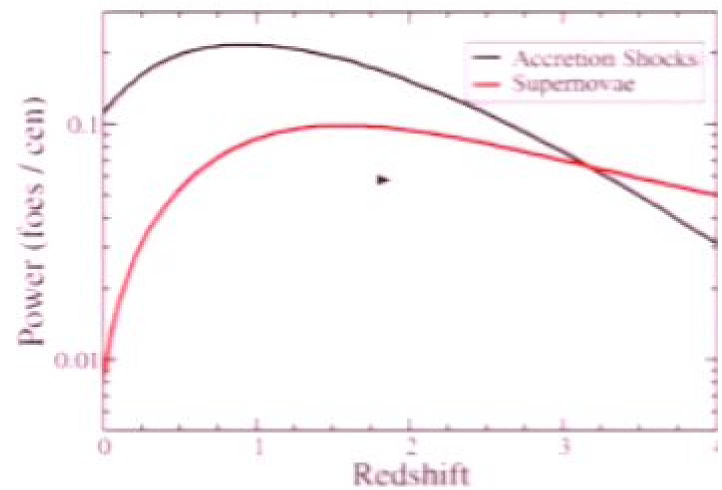
BBN@Perimeter

Shock Power for Acceleration of ***Cosmological Cosmic Rays***

Cosmic accretion shocks:

- ✓ High Mach
- ✓ Long-lived
- ✓ Large power

Ideal sites for particle acceleration!



Structure Formation Cosmic Rays

- An inevitable fact of baryonic life?
- Acceleration begins before galaxy birth?
- Already seen in clusters? Fusco-Femiano et al 99

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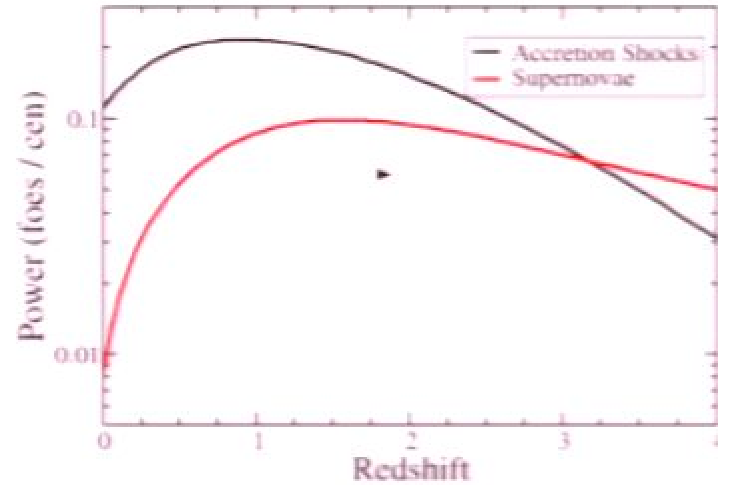

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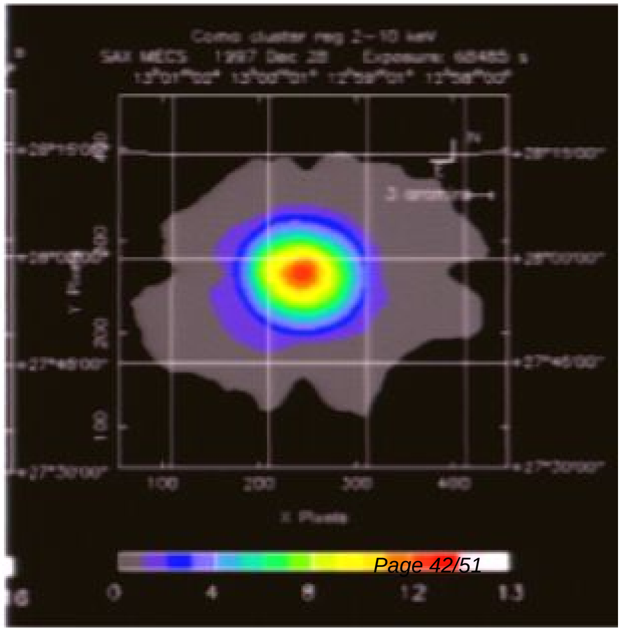
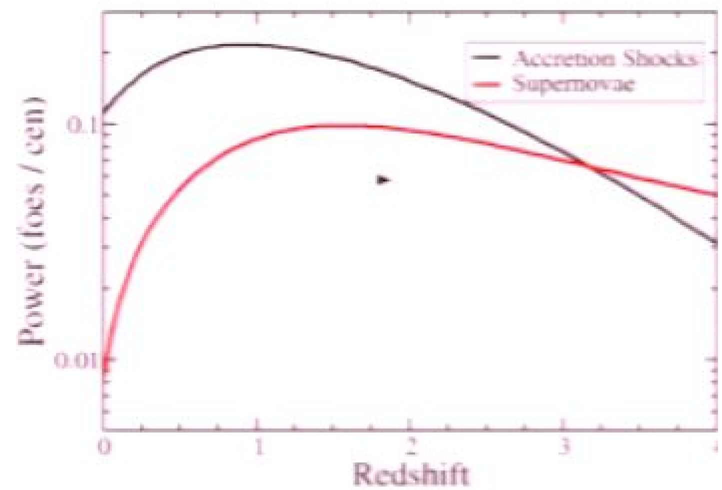


Shock Power for Acceleration of ***Cosmological Cosmic Rays***

Cosmic accretion shocks:

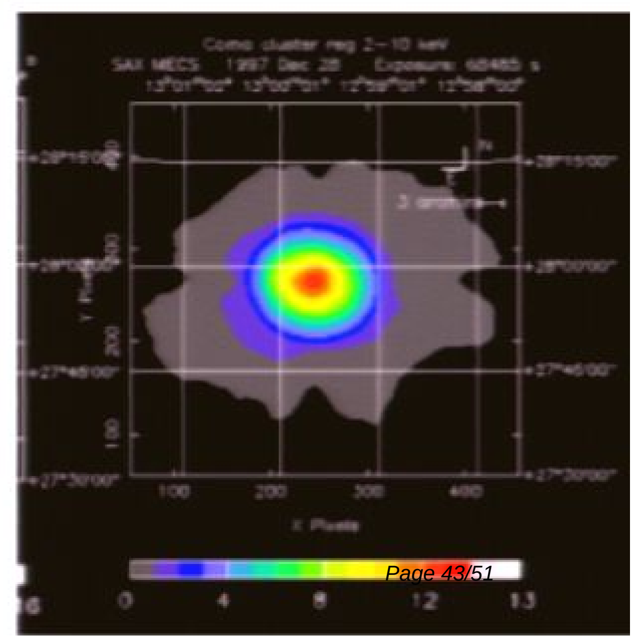
- ✓ High Mach
- ✓ Long-lived
- ✓ Large power

Ideal sites for particle acceleration!



Structure Formation Cosmic Rays

- An inevitable fact of baryonic life?
- Acceleration begins before galaxy birth?
- Already seen in clusters? Fusco-Femiano et al 99



Structure Formation CR Nuke

Primordial beam, targets:

- ✓ produce ^{6}Li and ^{7}Li *only*,
- ✓ no Be & B
- ✓ no correlation with metals

Plateau candidate!

But how disentangle primordial Li?

Paleolithography:
Probing Cosmic-Ray Pre-History

Prodanovic & BDF

Lithium fusion synthesis $\alpha\alpha \to {}^6\mathrm{Li} + \cdots$

inevitably prodcues hadronic gammas $pp \to \pi^0 \to \gamma\gamma$

Observables

★ gammas: measure mean CR fluence across universe

★ lithium abundance: measures local CR fluence

$$\frac{\mathrm{Li}}{\gamma} \sim \frac{\int \Phi_{\mathrm{CR}}(\mathrm{local})\ dt}{\int \Phi_{\mathrm{CR}}(\gamma\mathrm{path})\ dt}$$

★ *ratio* well-determined: fixed by cross sections

Complementary: use one to probe the other

Cosmic gamma-ray background constrains

pre-Galactic Li made by CRs from structures, Pop III stars Rollinde

but current gamma data cannot robustly exclude large $\mathrm{Li}_{\mathrm{pre\text{-}gal}}$

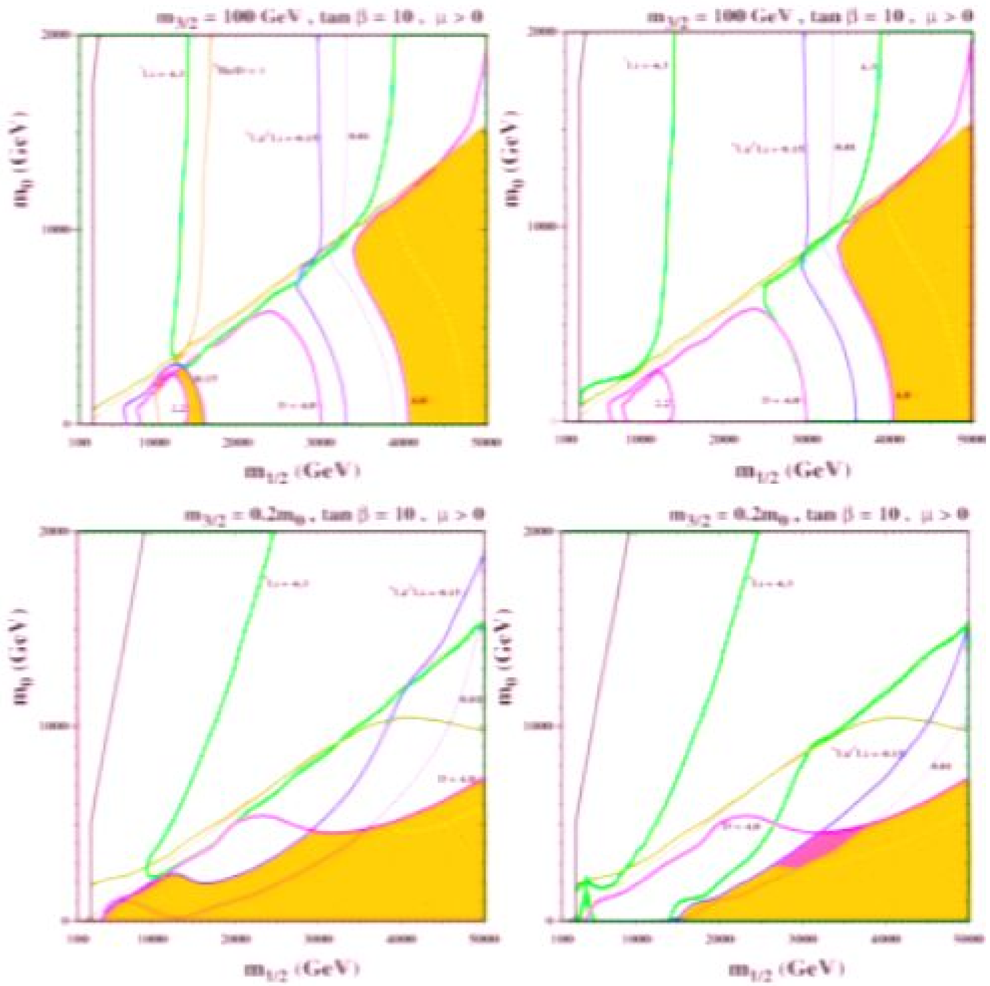
Could Lithium Be SUSY-licious?

If

- ✓ the world is supersymmetric
- ✓ and nonbaryonic dark matter is the lightest SUSY particle

Then

- In Early U: SUSY cascade
- next-to-lightest particle can be long-lived
- hadronic decays can erode ^{7}Li, and make ^{6}Li Jedamzik, Pospelov, Cyburt etal,Khori,Kusakabe; see also ~all other talks this meeing!



A SUSY solution to lithium problems?

In any case: illustrates tight links among nucleo-cosmo-astro-particle physics

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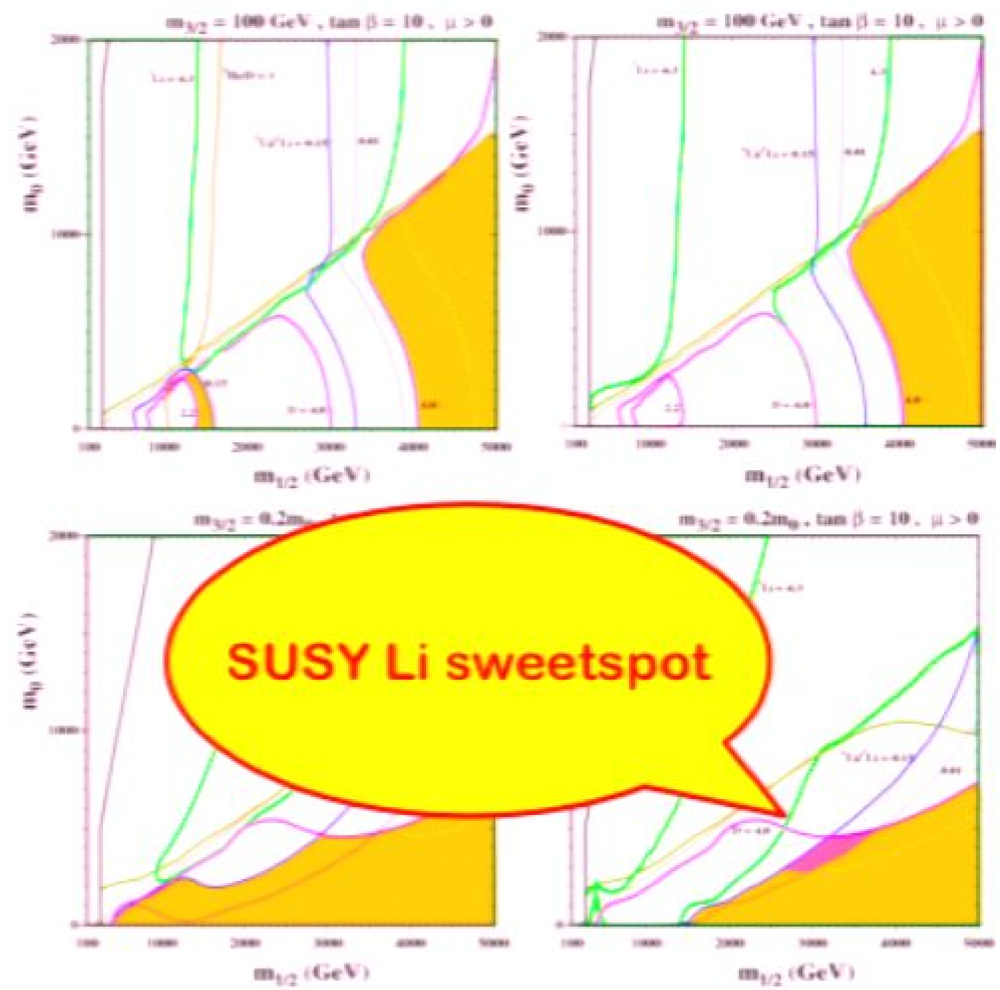

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Future Experiments/Observations

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  - gamma rays 20 MeV - 0.3 TeV
  - better angular, spectral resolution: clarify diffuse gamma background
  - launch June 5, 2008 = *Thursday*!

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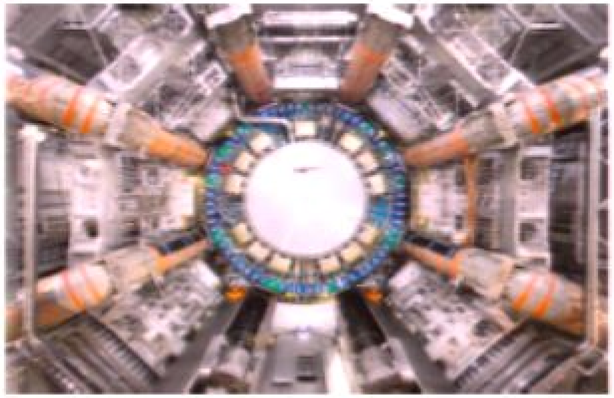

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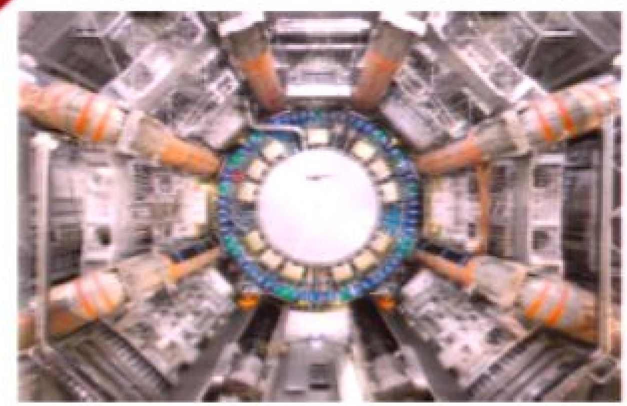
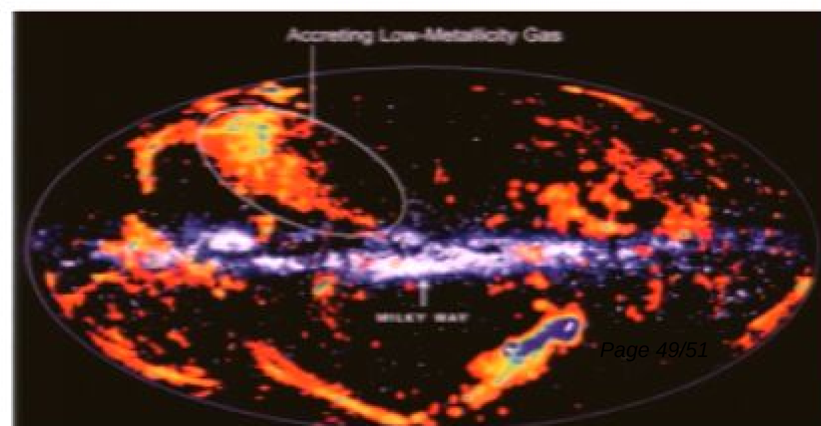
- **Lithium Observations**
  - systematics dominated: new approaches needed
  - high-velocity clouds: infalling low-metal gas: pre-Galactic? possible unblended isotope sensitivity? Prodanovic & BDF





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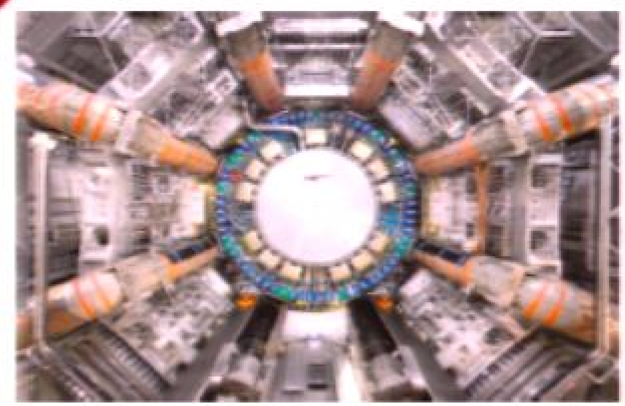

Pregalactic ^{6}LiBeB Nucleosynthesis: Cosmic Rays vs Dark Matter Decays

★ **^{6}LiBeB Observed**

A pre-Galactic component?

★ **Guaranteed LiBeB Production**

Galactic Cosmic Rays

★ **Pre-Galactic ^{6}LiBeB Production**

Cosmological Cosmic Rays

Decaying Dark Matter