

# Nuclear-Astrophysics Studies with $^{60}\text{Fe}$ : Future Instrumentation & Prospects

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# $^{60}\text{Fe}$ : Why is it Interesting?

$2.0 \cdot 10^6 \text{y}$      $^{60}\text{Fe} \rightarrow ^{60}\text{Co}^* \rightarrow ^{60}\text{Ni}^*$     59, 1173, 1332

Co55 17.53 h 7/2- EC	Co56 77.27 d 4+ EC	Co57 271.79 d 7/2- EC	Co58 70.82 d 2+ EC *	Co59 7/2- 100	Co60 5.2714 y 5+ *	Co61 1.650 h 7/2- *	Co62 1.50 m 2+ *	Co63 27.4 s (7/2)- *
Fe54 0+ 5.8	Fe55 2.73 y 3/2- EC	Fe56 0+ 91.72	Fe57 2+ 2.2	Fe58 0+ 0.28	Fe59 44.503 c 3/2- *	<b>Fe60</b> 1.5E+6 y 5+ *	Fe61 5.98 m 3/2-, 5/2- *	Fe62 68 s 0+ *
Mn53 3.74E+6 y 7/2- EC	Mn54 312.3 d 3+ EC, $\beta^-$	Mn55 5/2- 100	Mn56 2.5785 h 3+ $\beta^-$	Mn57 85.4 s 5/2- $\beta^-$	Mn58 3.0 s 0+ *	Mn59 4.6 s 3/2-, 5/2- *	Mn60 51 s 0+ *	Mn61 0.71 s (5/2)- *

★  $^{60}\text{Fe}$  is Produced through Successive Neutron Captures

☞ n Capture Astrophysics...(->s-Process...)

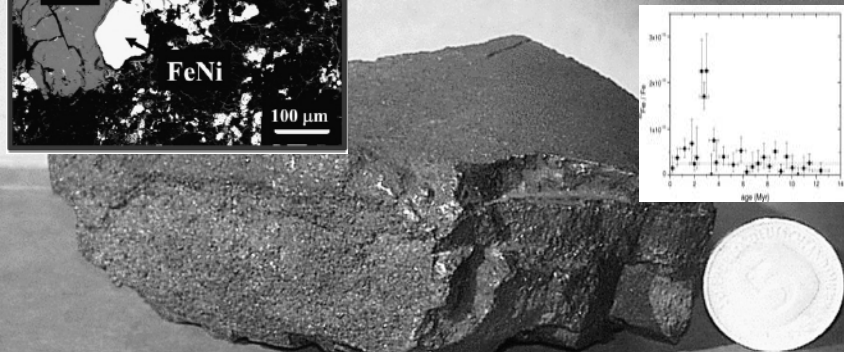
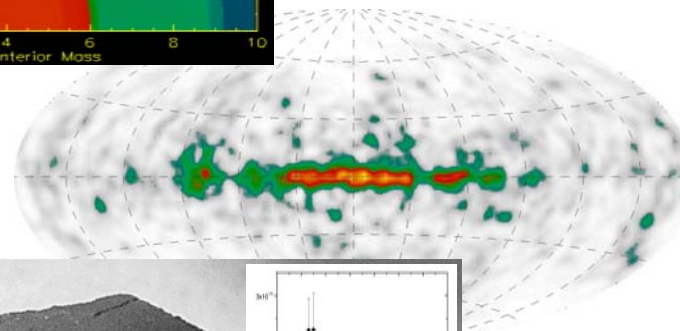
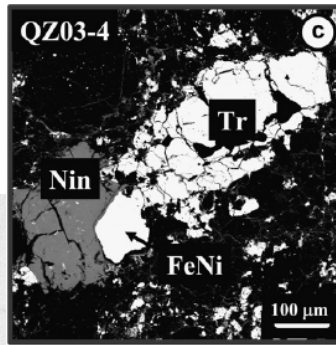
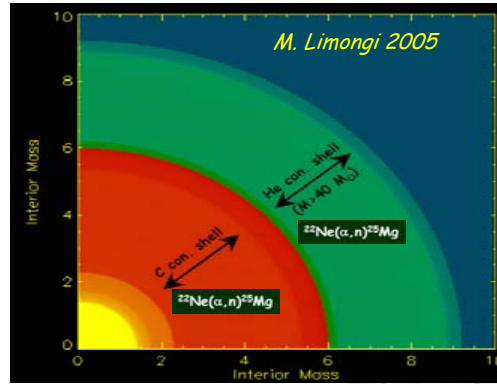
★ Massive Stars are Likely Sources of  $^{60}\text{Fe}$

☞ ... the MAIN Agents of Cosmic Evolution

★  $^{60}\text{Fe}$  has been Detected in

- ☞ a Pacific-Ocean Crust
- ☞ Solar-System Meteorites
- ☞ the Interstellar Medium

☞ Radioactive Dating of Different Astrophysical Events!



Knie et al., 2004



★ What are the  
Key Measurements of Interest?

★ What are the  
Chances to Make These Happen?

# Meteoritic-Inclusion Measurements

## ★ Secondary-Ion Mass Spectroscopy

👉 nano-SIMS

- » 50 nm resolution in probe
- » several laboratories (Mainz, St.Louis, ...)

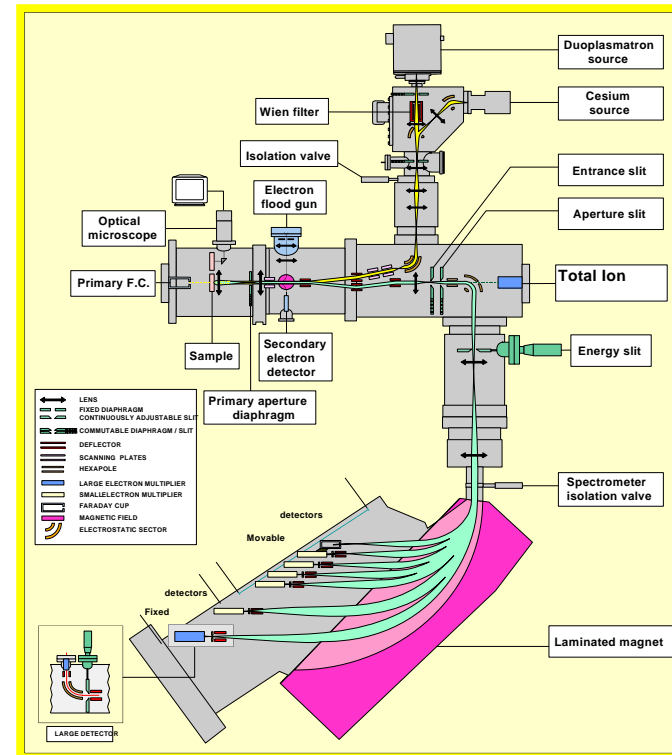
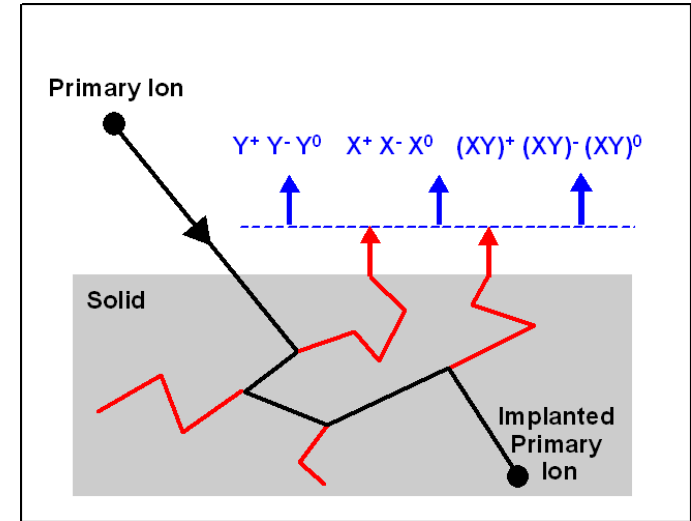
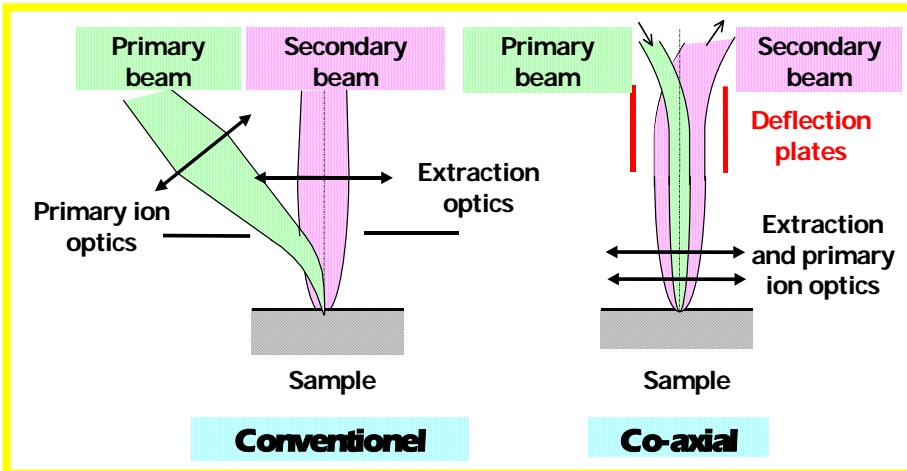
👉 ToF-SIMS

- » multiple isotopes simultaneously
- » e.g. Uni Münster

## ★ Resonant Ion Mass Spectroscopy

👉 RIMS

- » selective laser ablation and excitation of specific isotopes
- » for trace isotopes
- » CHARISMA (Argonne/Chicago)



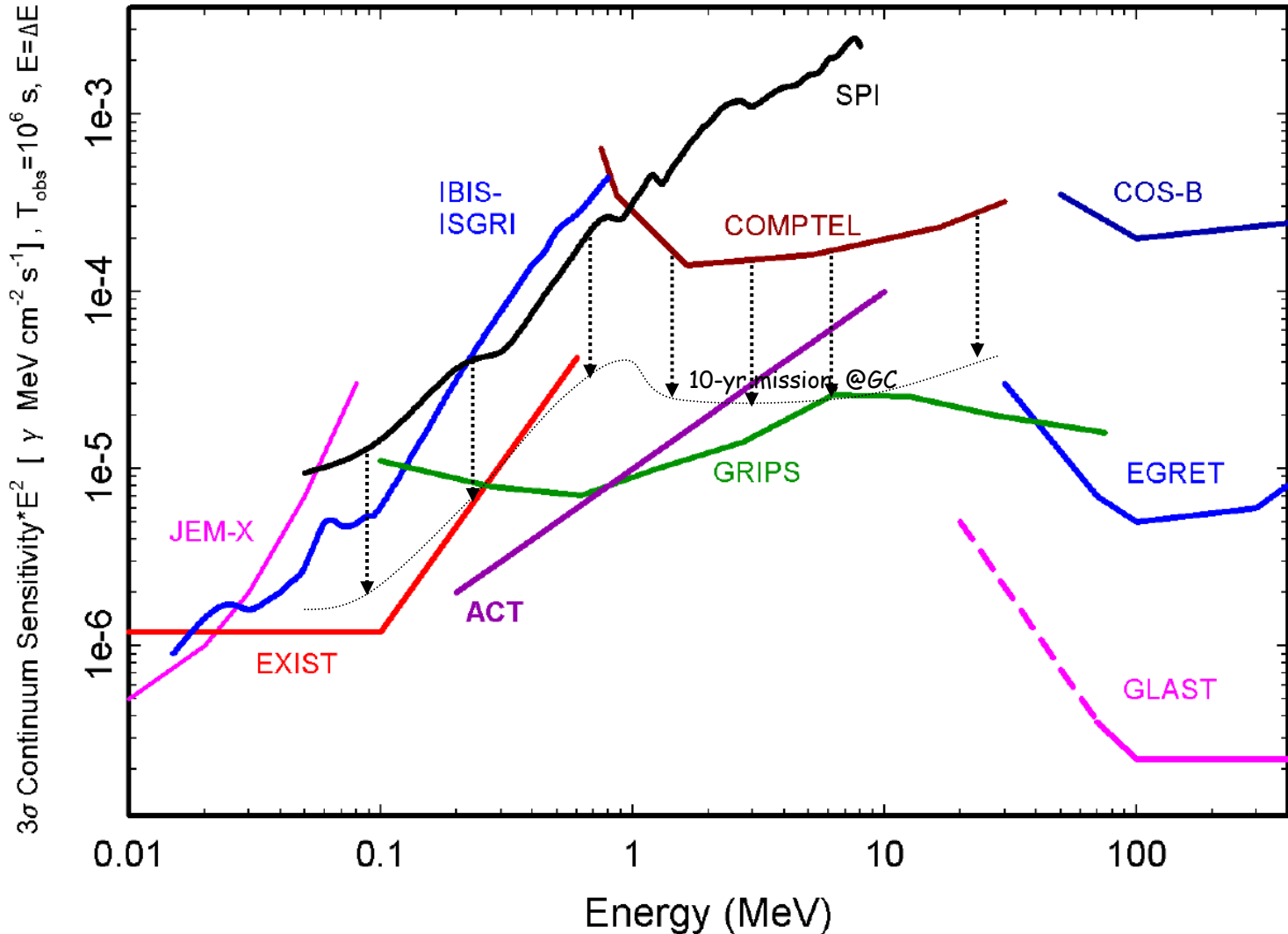
courtesy U. Ott



# Instrumental Sensitivities around Nuclear Energies

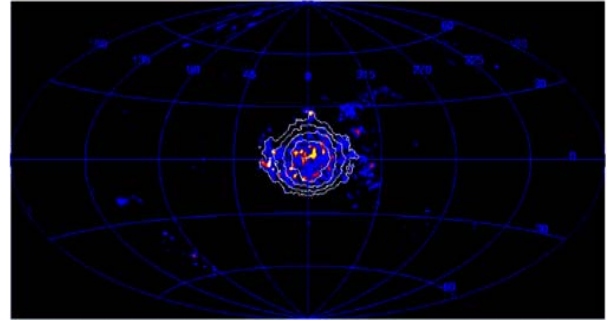
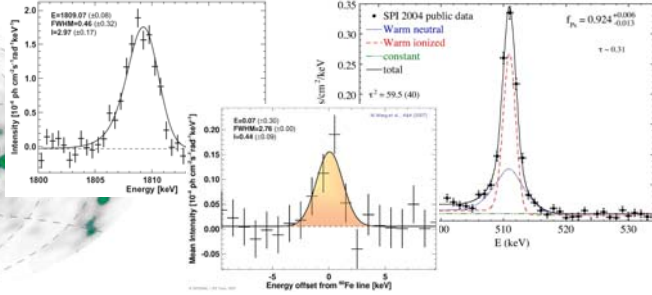
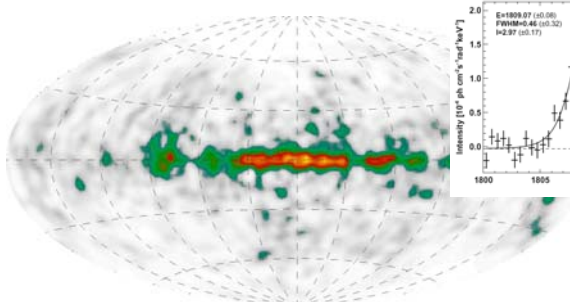
next steps: advances by factor ~3...10

Continue with INTEGRAL until Next Mission is in Place



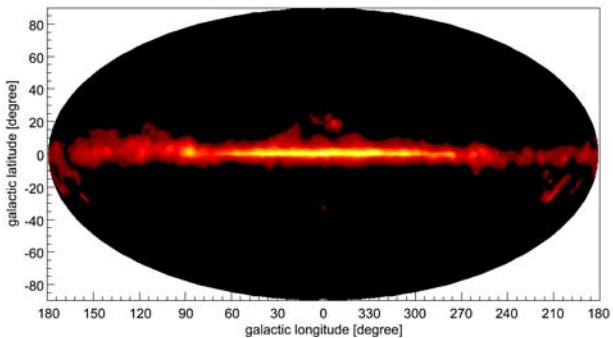
# GRIPS: From All-Sky to Specific-Source Studies

★ Current Gamma-Ray Line Surveys Can Only See Brightest Emission:

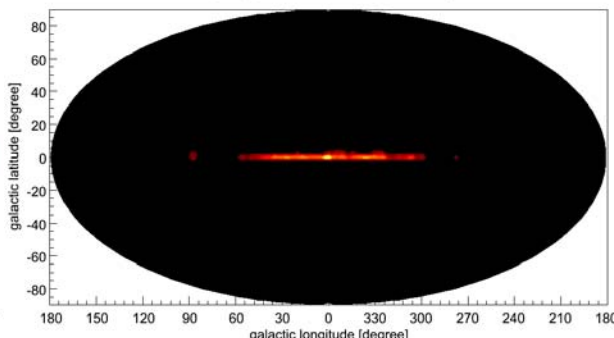


★ GRIPS Will Provide Localized Results:

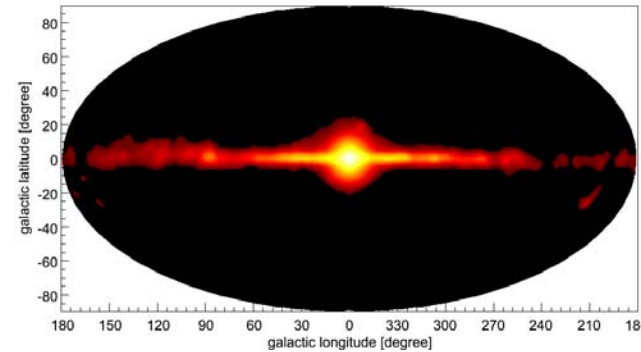
All-sky image in the <sup>26</sup>Al line after five years



All-sky image in the <sup>60</sup>Fe lines after five years



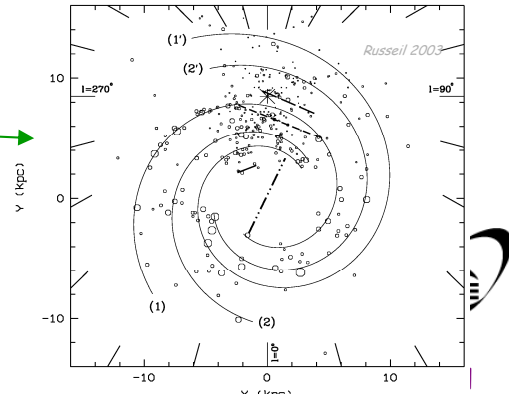
All-sky image in the 511 keV annihilation line after five years



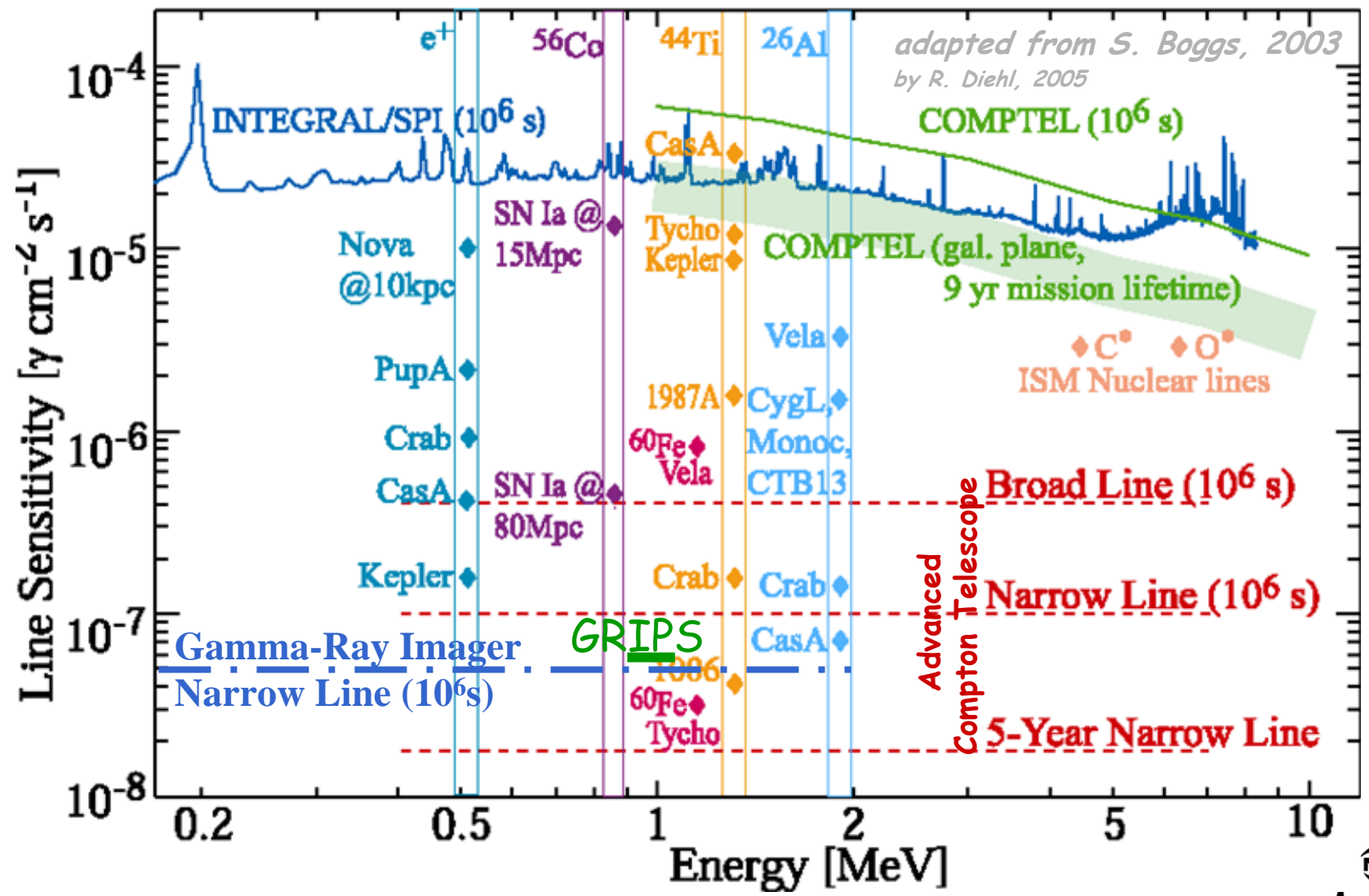
☞ <sup>26</sup>Al to <sup>60</sup>Fe to Positron Yields per Massive-Star Group

☞ We Know ~ 500 Star-Forming Complexes; Gamma-Rays will also see Embedded SFR's

★ From All-Sky to Many Specific Sources  
→ Study the Conditions for Pop I Star Evolution



# Future Goals for $\gamma$ -Ray Line Astronomy <sup>$\gamma$</sup>



# Key Science Issues

## ★ What is the $^{60}\text{Fe}$ Production from Nucleosynthesis Sources

- ☞ Massive-Star Structure
  - » Convection Zones, Shell-Burning Zone Temperatures
- ☞ Supernova Explosive Nuclear Re-Processings
  - » Neutrino Processes
- ☞ Nuclear Reaction Networks
  - » Neutron Capture and Beta Decay Rates

## ★ What is the Massive-Star Activity in the Solar Vicinity?

- ☞ Nearby Massive-Star Group Histories
  - » Sco-Cen Subgroups
- ☞ Nearby ISM Morphologies
  - » Solar Bubble Origins, Molecular-Cloud Lifetimes

## ★ What is the Galaxy's Current Nucleosynthesis Activity?

- ☞ Where are the Active Massive-Star Groups?
  - » Cygnus Region, Nearby Groups; Steady-State or Non-Equilibrium on My Time Scale
- ☞ Is  $^{60}\text{Fe}$  from Massive-Stars Only? What about  $^{26}\text{Al}$ ?
  - » WR Phase Releases of Nucleosynthesis Products

## ★ How did the Early Solar System Evolve?

- ☞ Normal or Late-Injection  $^{60}\text{Fe}$  Content?
  - » Nearby SN, Triggered Formation of Solar System
- ☞ Disk Phase, Solid-Body- and Chondrule Formation Times
  - » Homogeneity of Solar System Disk, Formation of Planetesimals