^{44}Ti Emission from Cassiopeia A

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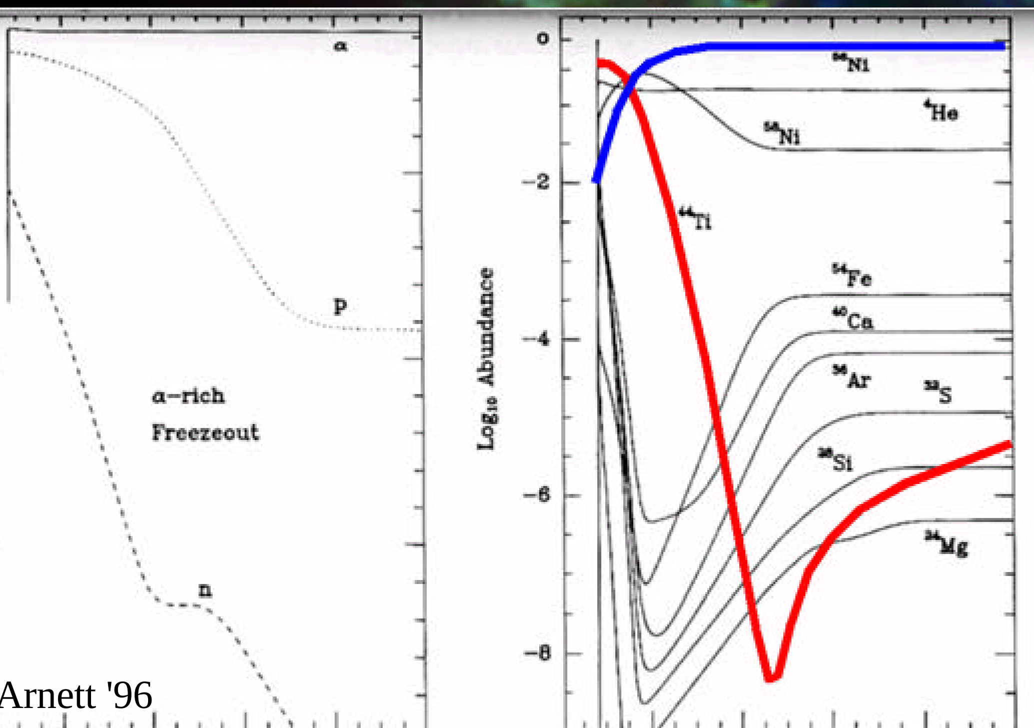
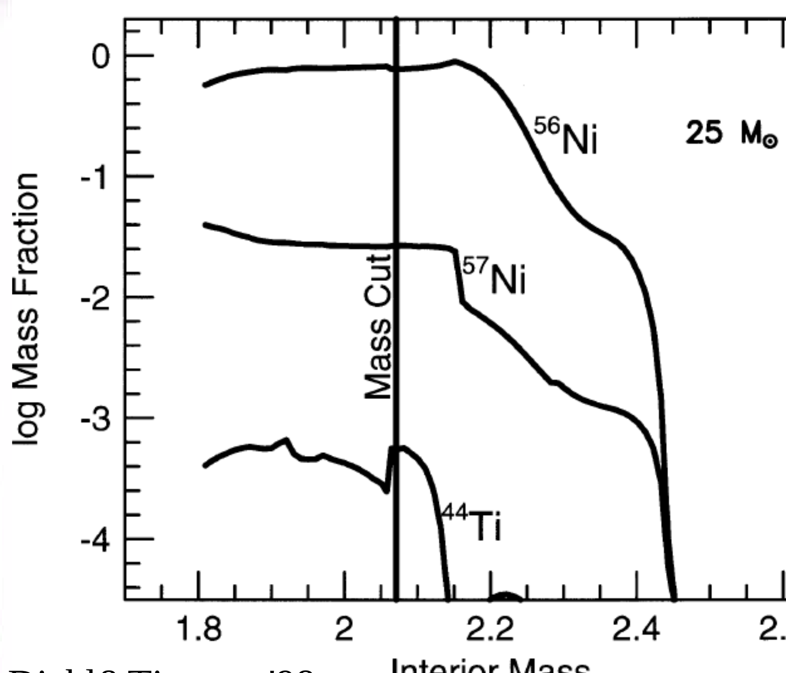
Supernova remnants & Importance of

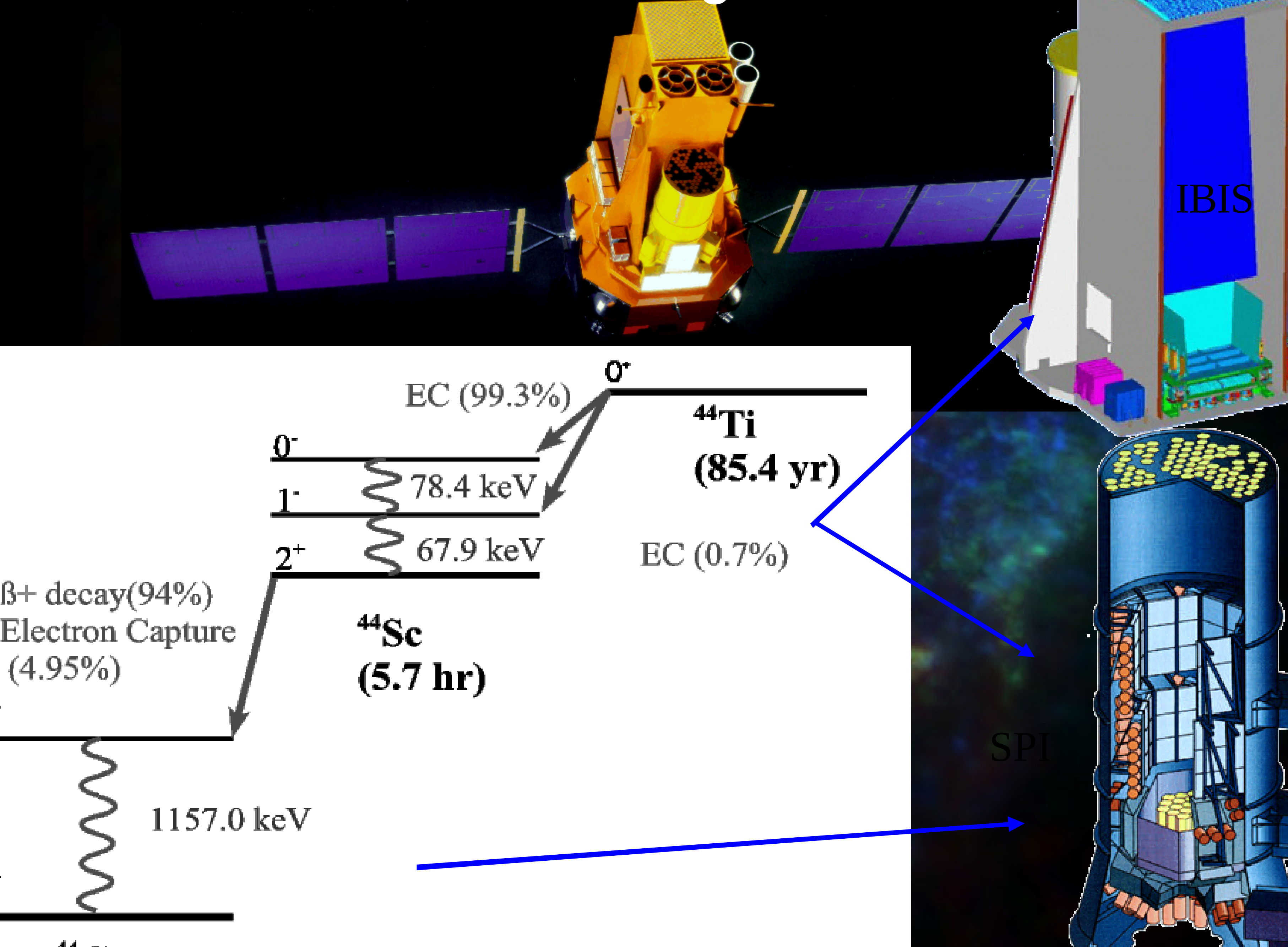
Decay time ~85 yr: present in young remnants
Less abundant than ^{56}Ni (~0.07 vs 10^{-5}-10^{-4} $M_?$)
Alpha rich freeze out product
(excess of alpha particles during rapid expansion)
Amount sensitive to SN mass cut/energy/asymmetries



Arnett '96



Ti & Integral



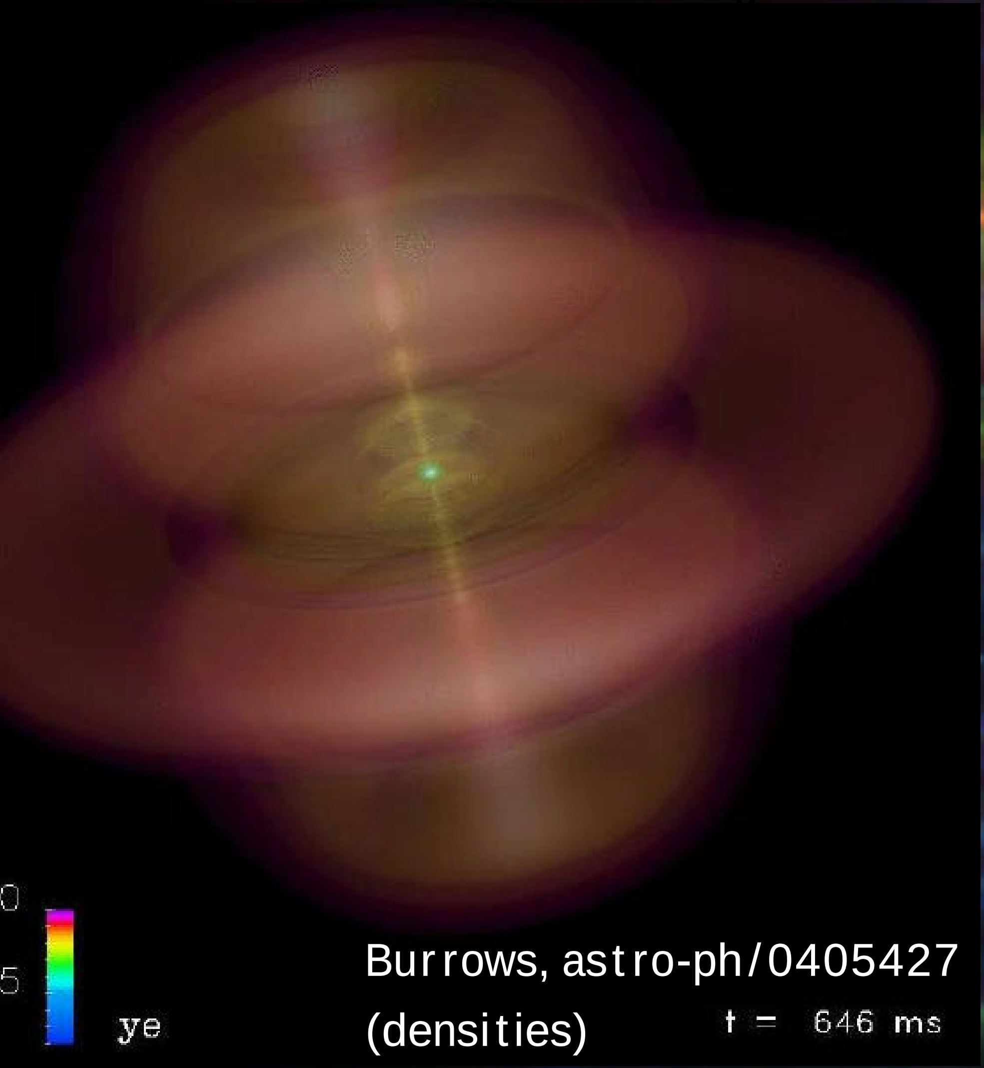
IBIS
SPI
0+
EC (99.3%)
0-
1-
2+
78.4 keV
67.9 keV
44Ti
(85.4 yr)
EC (0.7%)
ß+ decay(94%)
Electron Capture
(4.95%)
44Sc
(5.7 hr)
1157.0 keV

als of Integral observations of ^{44}Ti

Use ^{44}Ti as a tracer for young supernova remnants
- **-> M. Renaud (search)**
- **-> A. von Kienlin (Vela Jr.)**

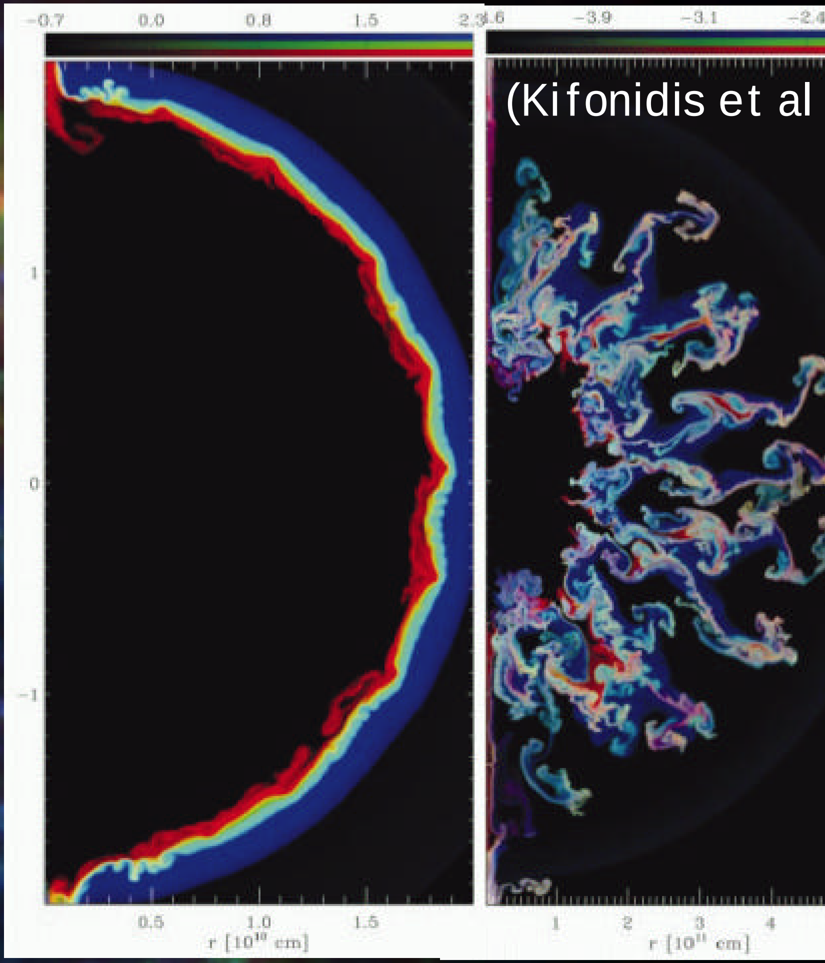
Test supernova explosion theories
- **-> This talk**
- **-> M. Renaud (how much ^{44}Ti do Type Ia SNe (e.g. Tycho) produce?)**

Cassiopeia A: the most certain source of ^{44}Ti



Burrows, astro-ph/0405427
(densities)

MHD: formation of jets?



Evolution of fast fingers, containing ^{56}Ni
(can escape in Type Ib/c SNe)

^{44}Ti Emission from Cassiopeia A

Cassiopeia A

Youngest known galactic supernova remnant (~320 yr)

Brightest radio source in sky (2500 Jy @ 1 Ghz)

Distance: 3.4 kpc (Reed et al. 1995)

Size of ~5‘ -> 5 pc (<v> ~ 8000 km/s)

High blast wave velocity: 5200 km/s

(Vink et al. '98,DeLaney & Rudnick'03)

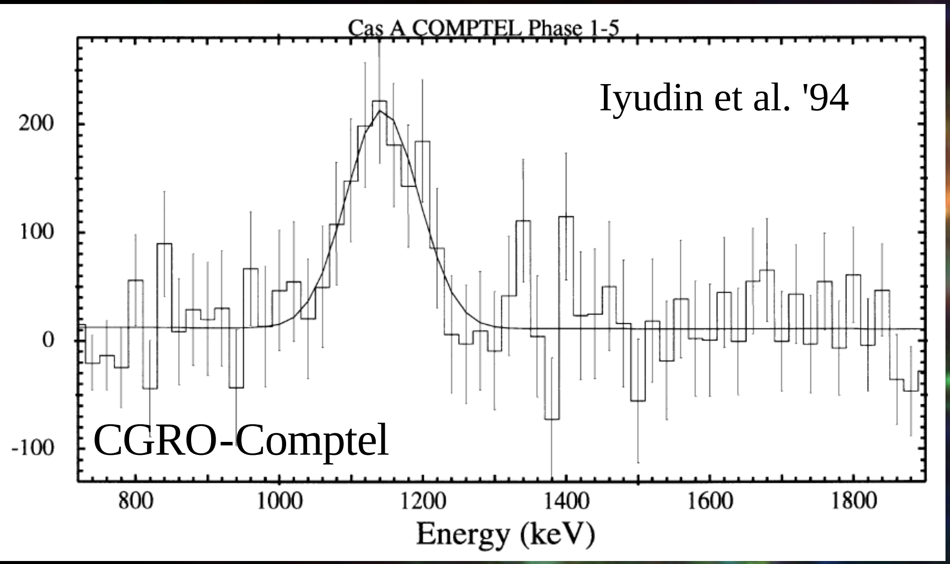
Oxygen rich, no hydrogen ejecta (optical emission)

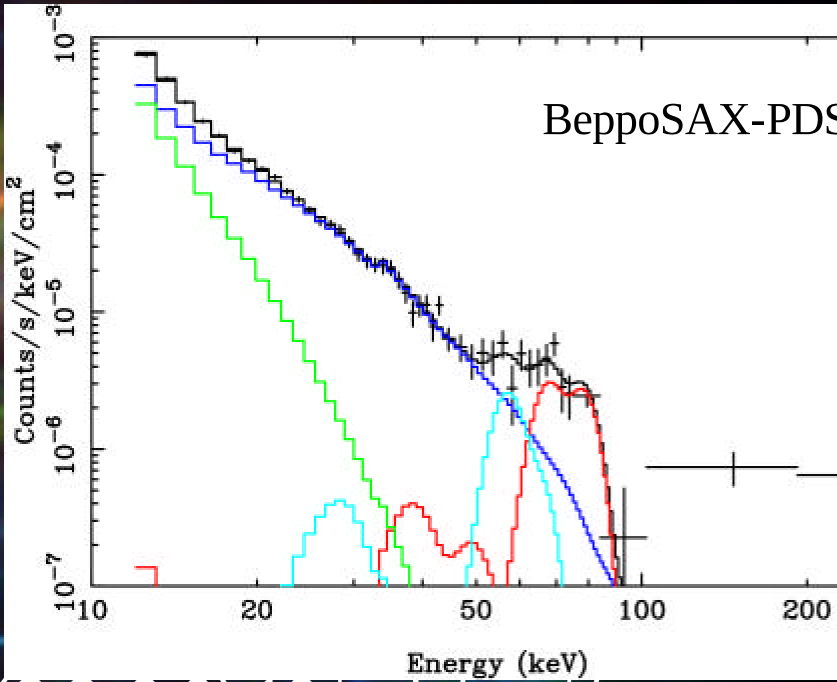
-> SN Type Ib?, Massive Star? (probably ~18 – 25 Msun

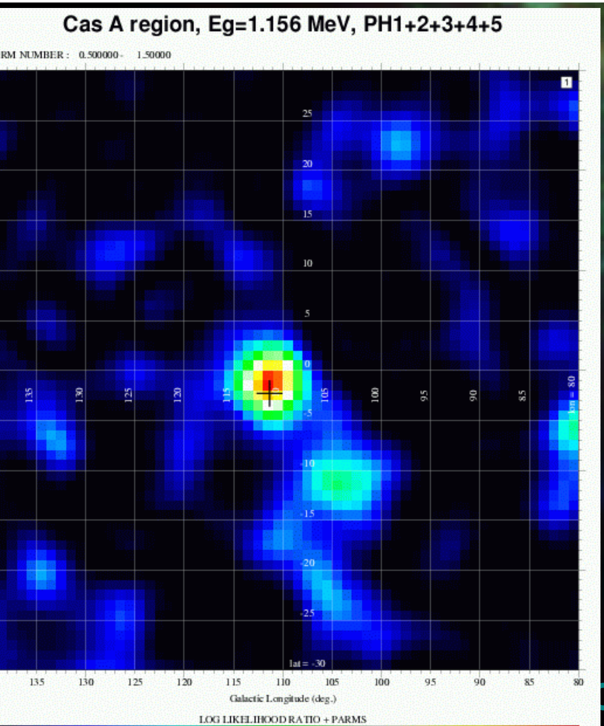
X-ray emission dominated by ejecta

Chandra discovery of probable neutron star (Tananbaum 199

Detection of Ti emission from Cas A







Comptel: F= (3.3±0.6) 10^{-5} ph/cm^2/s

(Iyudin '97)

BeppoSAX using Power law continuum:

Power law: F=(2.2±0.3) x 10^{-5} ph/cm^2/s

Other models: F=(3.2±0.3) x 10^{-5} ph/cm^2/s

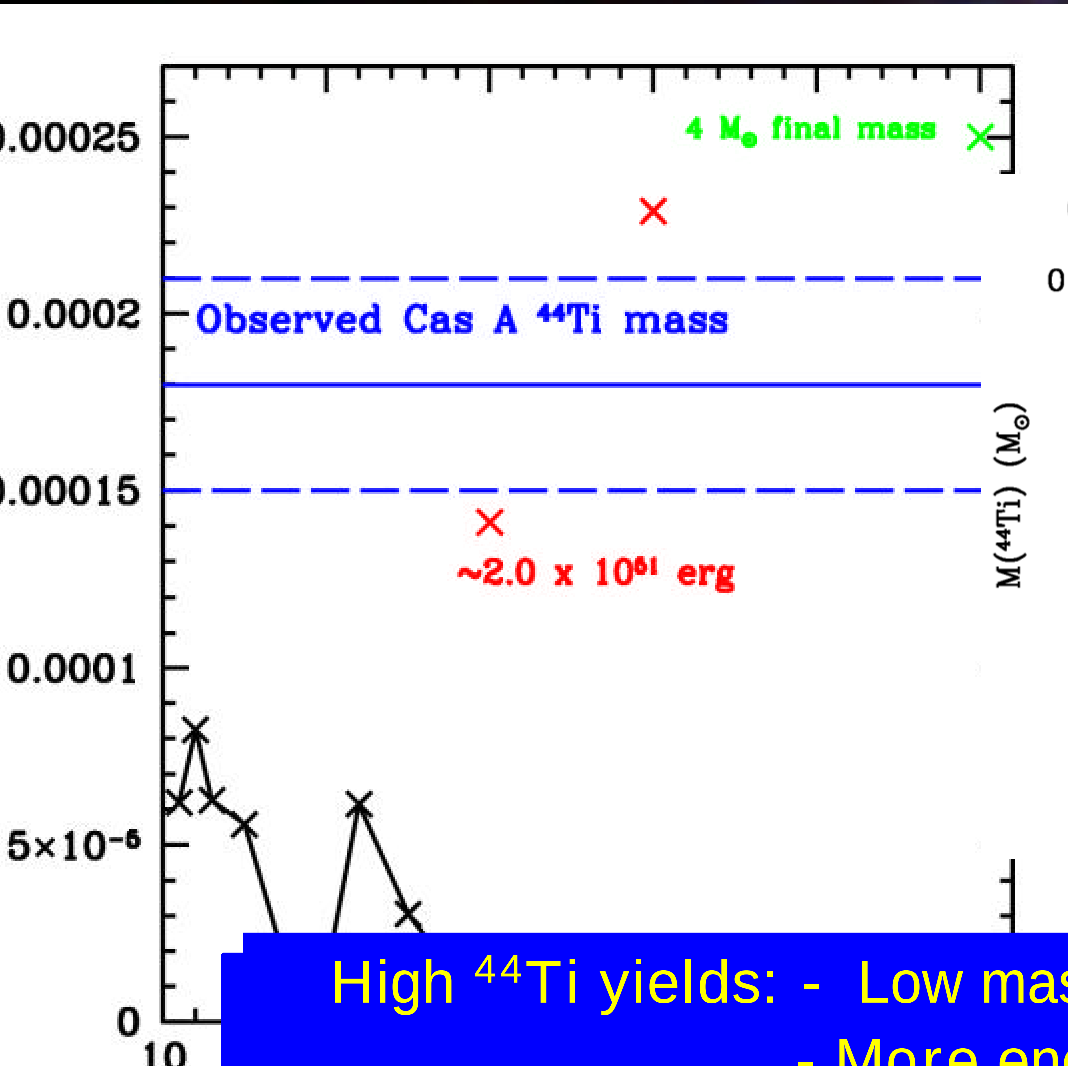
(Vink et al. '01/Vink & Laming '03)

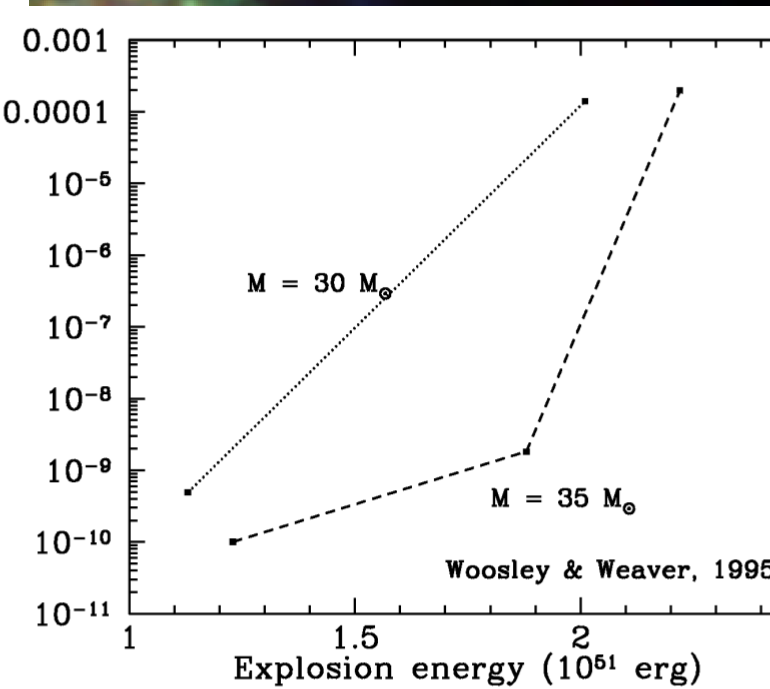
Implied ^{44}Ti yield:

M = (1.8±0.2) x10^{-4} $M_?$

(combining COMPTEL & BeppoSAX)

Nuclear decay and expected yields of

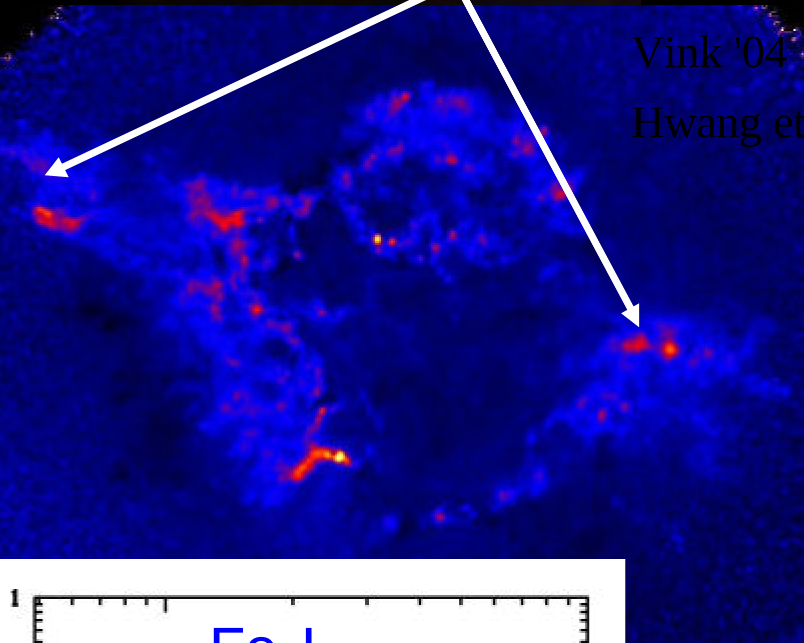


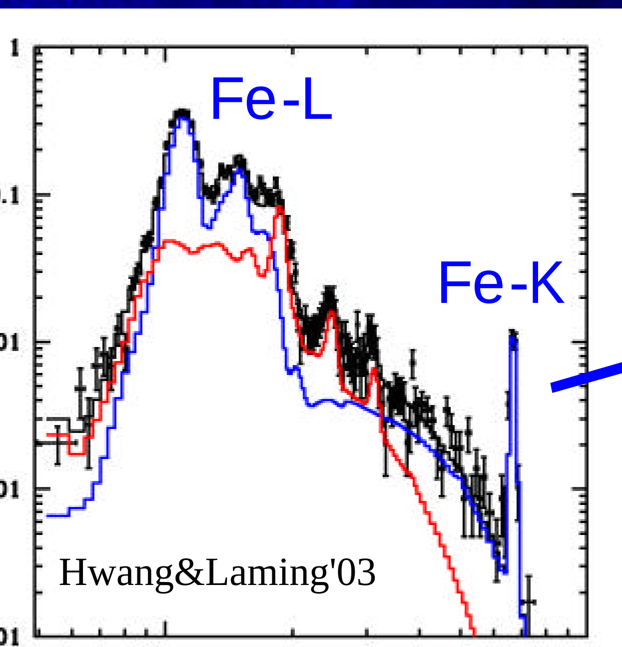


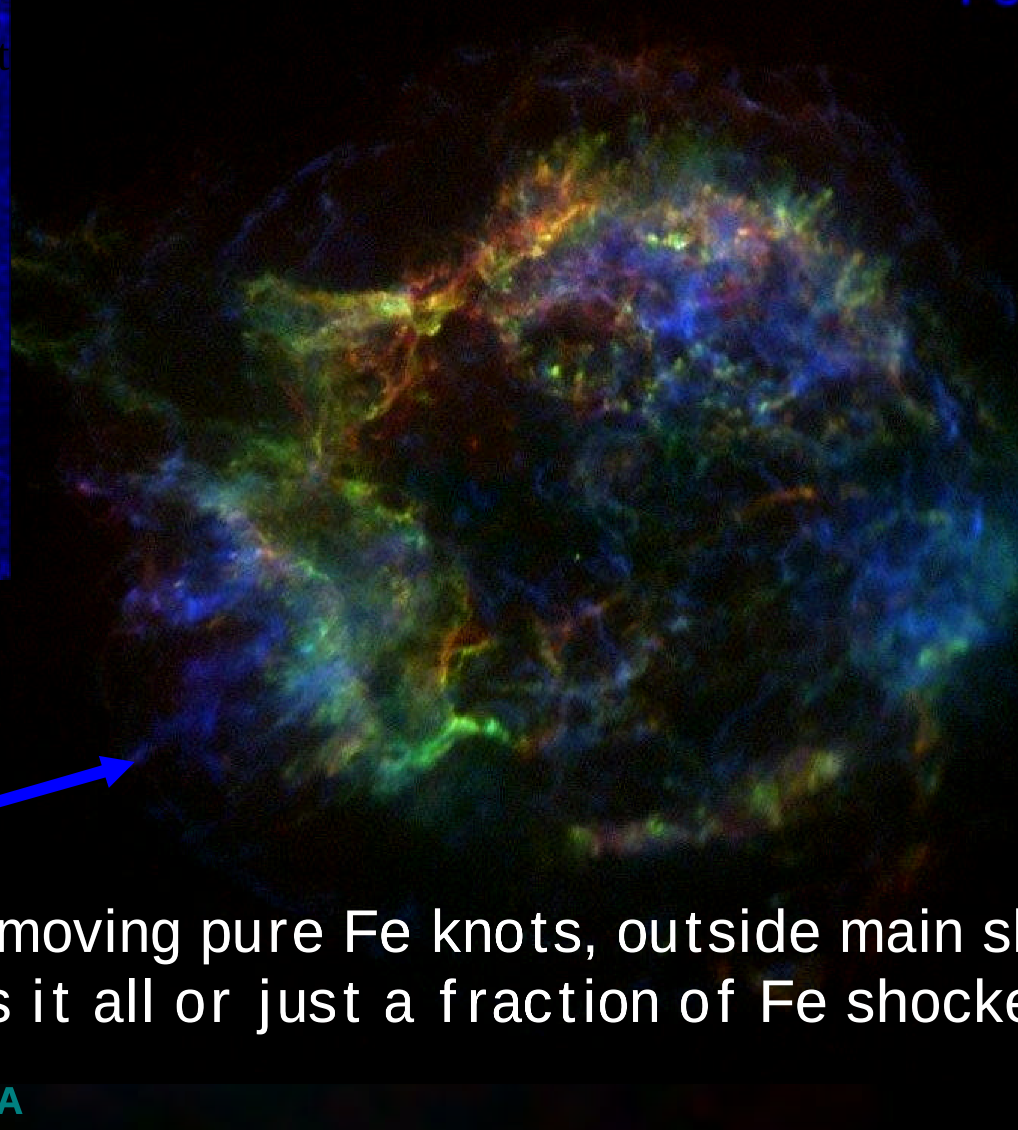
High ^{44}Ti yields:
- Low mass stars,
- More energetic explosion,
- Asymmetric explosion,
- Low mass cut

vidence for Asymmetric Explosion Cas A

Jet-like structures







Fast moving pure Fe knots, outside main sh
but is it all or just a fraction of Fe shocke

Primary Goals of the Integral observations

Obtain a more accurate ^{44}Ti line flux

IBIS: - measure 68 keV & 78 keV line flux

- constrain continuum beyond 90 keV (steepening?)
  - -> gives better line flux measurements &
  - -> interesting in itself!

SPI: - detect the 1157 keV & 78 keV line

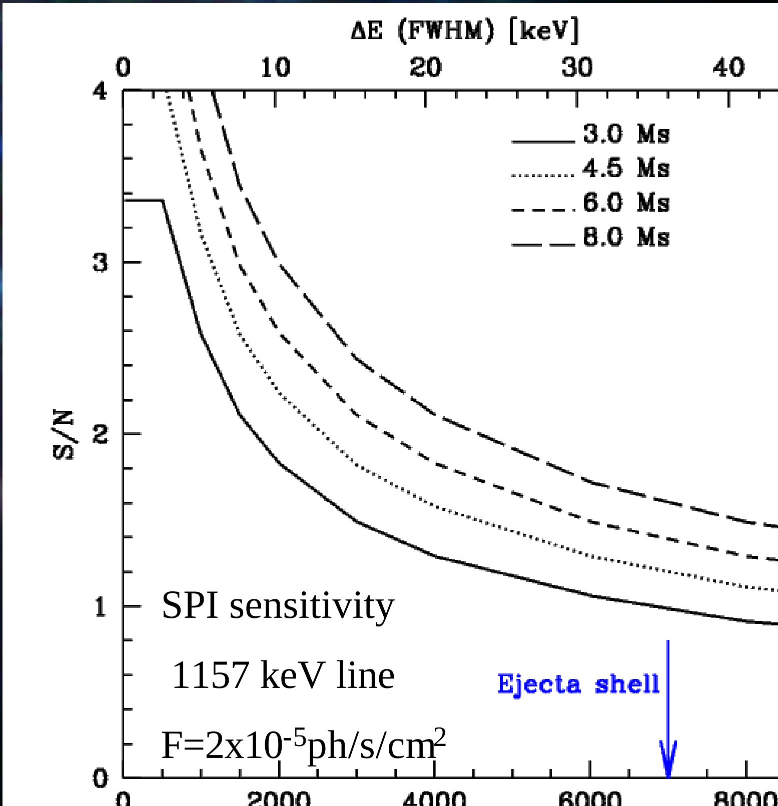
- detect or constrain velocity broadening
- detection not possible if ? V > 2500 km/s (FWHM)
- conventional model ? V < 2000 km/s (FWHM)

(connection with fast moving Fe seen in X-rays?)

velocities to expect?

- Current shock velocity: ~5000 km/s (Average ~7800 km
- Current Si ejecta shell velocity: ~3200 km/s
- Pure iron knots: <v> < 7800 km/s, but probably <5000 km
- Big (and important!) question: Where is ^{44}Ti, mixed in shell or still inside reverse shock radius?

A non detection by SPI can also be important, provided we know the total ^{44}Ti flux:
→ importance IBIS & continuum model/detection up to ~ 120 keV



Two possible emission mechanisms:

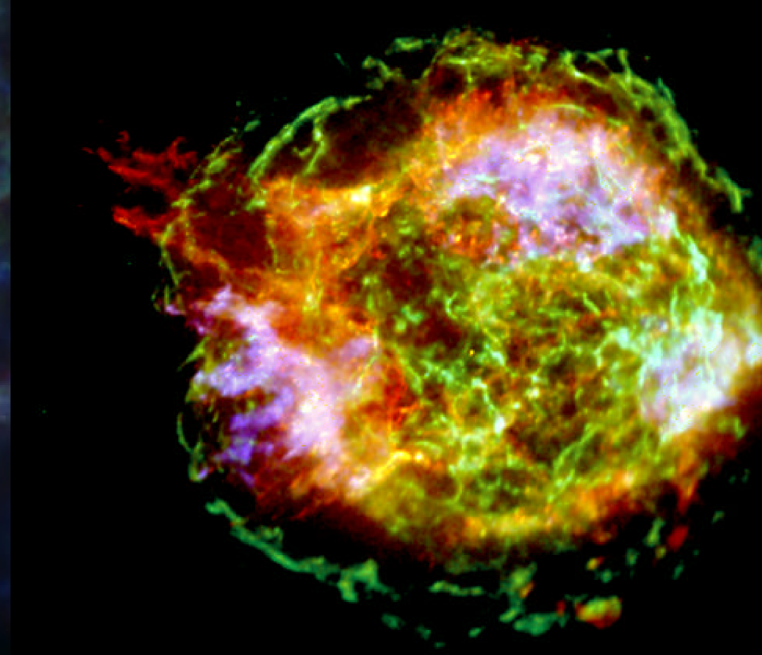
- synchrotron emission -> 10- 100 TeV electrons
- bremsstrahlung -> 10 – 1000 keV electrons

Bremsstrahlung, several causes:

1) electrons accelerated by plasma waves inside Cas A should steepen at high energies (Laming '01)
2) low energy part of electron cosmic ray spectrum
   i.e. injection spectrum ->
   will give injection efficiency!
   (Asvarov et al. '90)

Synchrotron emission:

losses -> always steepens!



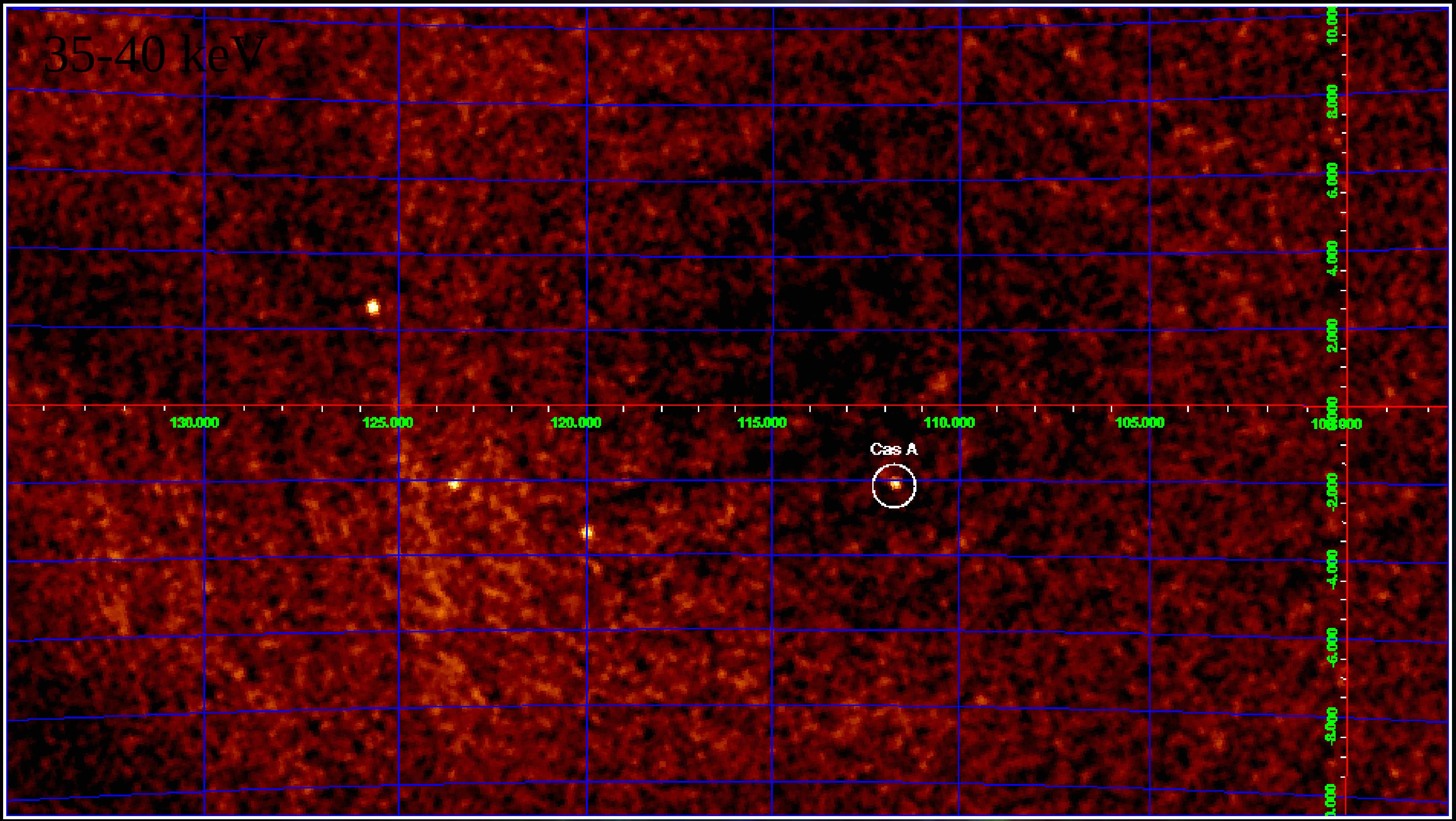
EGRAL Observations Cas A
Amalgamated with Tycho)

- Cycle 1 completed in March 2004: 1.5 Ms
- Cycle 2 just completed: 1.5 Ms (last obs. rev 269)
- Cycle 3: 2.5 Ms approved

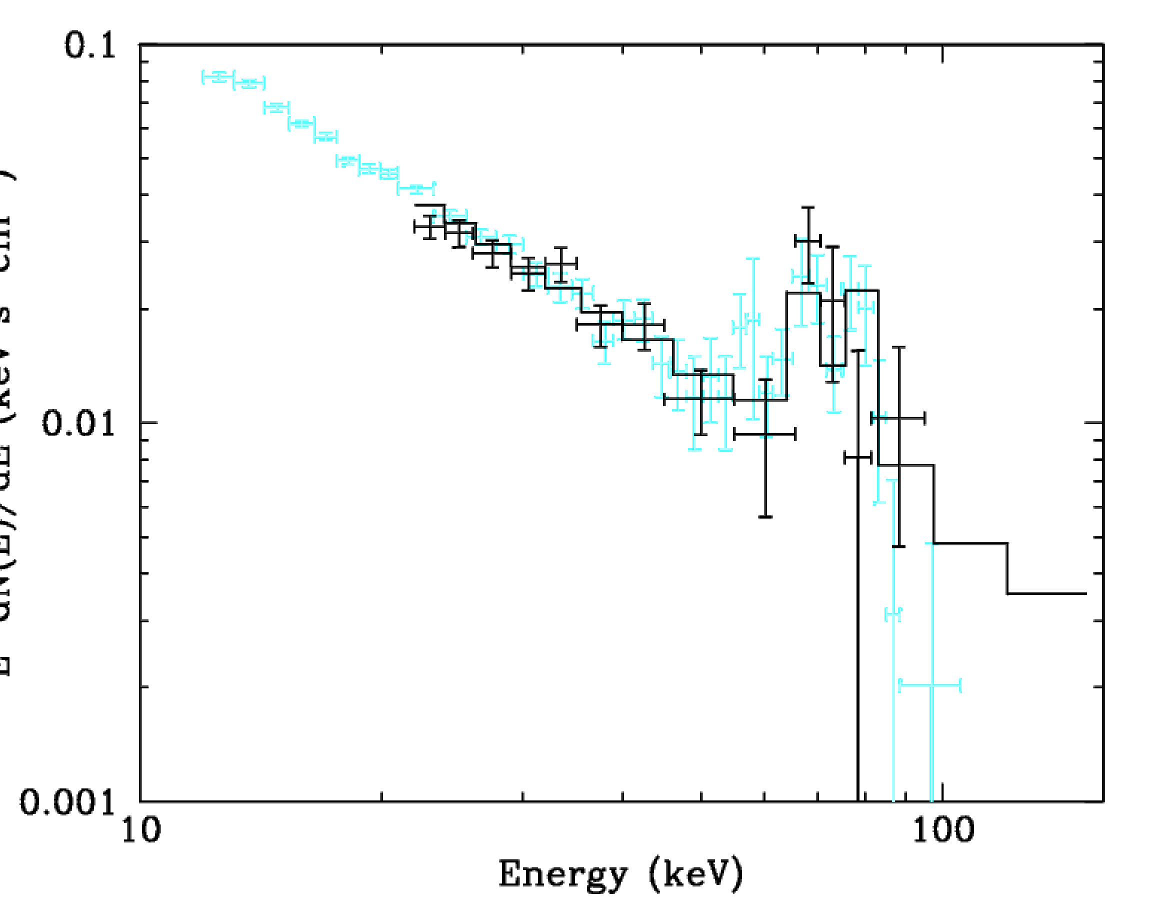
Analyzed so far: 1.7 Ms (rev. 142-162) of validated data

Other results based on these observations:

see Matthieu Renaud, Peter den Hartog, & Lucien Kuiper



- Cas A detected up to ~72 keV
- Several other sources detected (see Peter den Hartog's tal
- In hindsight: no sources contaminate BeppoSAX detection!



NB
Spectrum directly calib
on Crab spectrum

67.9 keV line detected at 3.1s level F= (2.3±0.8)x10^{-5} ph/s/cm^2

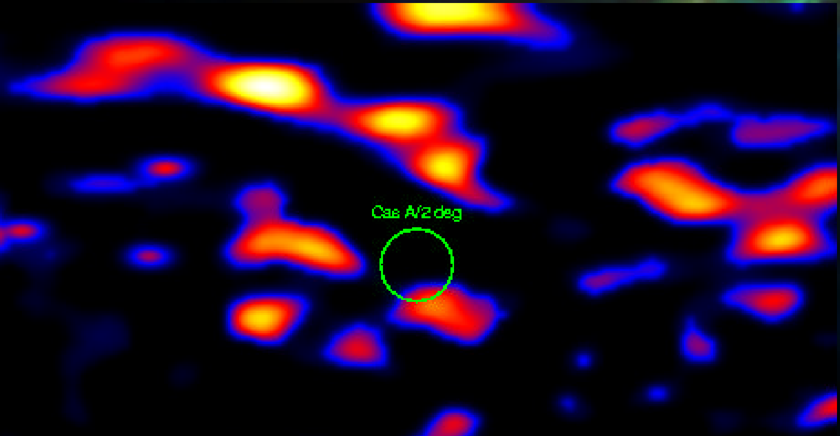
78.4keV line 3s upper limit (power law cont): < 2.3x10^{-5} ph/s/cm^2

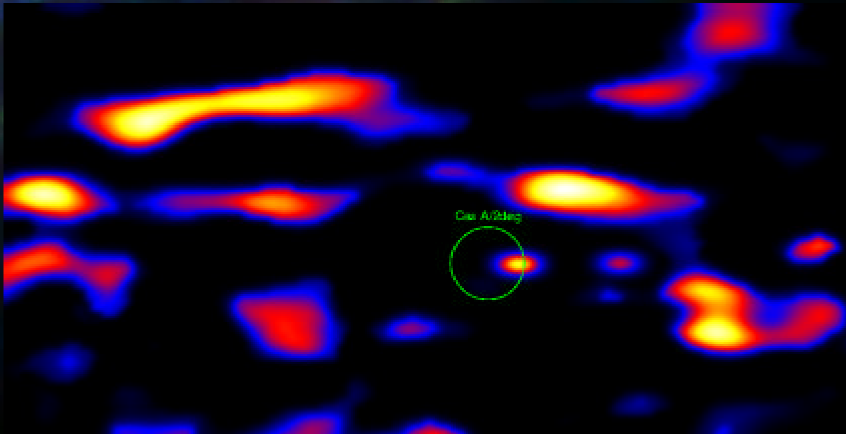
Joined IBIS/BeppoSAX-PDS result (pow. law): F= (1.7±0.3)x10^{-5} ph/s/c

3s upper limit (with pow. Law): < 2.7x10^{-5} ph/s/cm^2

With synchrotron model (srcut): F = (2.2±0.3)x10^{-5} ph/s/cm^2

- Data until rev 162, after cleaning: 1.5 Ms
- No detection yet, upper limits depend on energy band width
- Significance images behave nicely (spurious sources = ~3s)
- Upper limits close to expected flux!!
- Narrow line flux 3s upper limit (? E=4keV): 3.1×10^{-5} ph/s/cm^2
- Narrow line flux 2s upper limit (? E=4keV): 1.7×10^{-5} ph/s/cm^2
- Broad line flux (? E=30keV, 7800 km/s) 2s upper limit: 1.9×10^{-5} ph/s/cr
- Marginal source within 2 degr. error circle: 1.7s Flux = 1.8×10^{-5} ph/s/c
- We may be getting close:
  - next few month statistics will double
  - more refined background models will be tested





mmary and Conclusions

- ^{44}Ti an important tracer for the core collapse process
- 1.7 Ms of INTEGRAL data analyzed, more will follow soon
  complete cycles 1+2)
- IBIS: 67.8 keV detected by IBIS-ISGRI at 3.1s level
  - Flux 3s upper limit lower than Comptel flux
  - Joined fit of 67.8 & 78.4 keV line in agreement with BeppoSAX data
  - Uncertainty about continuum shape (& nature) remains:
    detection > 90 keV needed
- SPI: No detection yet, but results so far look promising
  - Narrow line 3s upper limit comparable to Comptel detection
    > indication that line is broadened
  - Weak signal 1.8s picked up in broad band (? E=30keV, 7779 km/s)
  - 2s Upper limit in broad band: 1.9×10^{-5} ph/s/cm^2,
    comparable to IBIS/BeppoSAX flux!!