Young, thin, & on the move: HETG Observations of SNRs

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Overview

- SNR Science
- SNRs with Gratings
- Three SNR-HETG examples:
  - E0102, Cas A, SN1987A
- For the Future

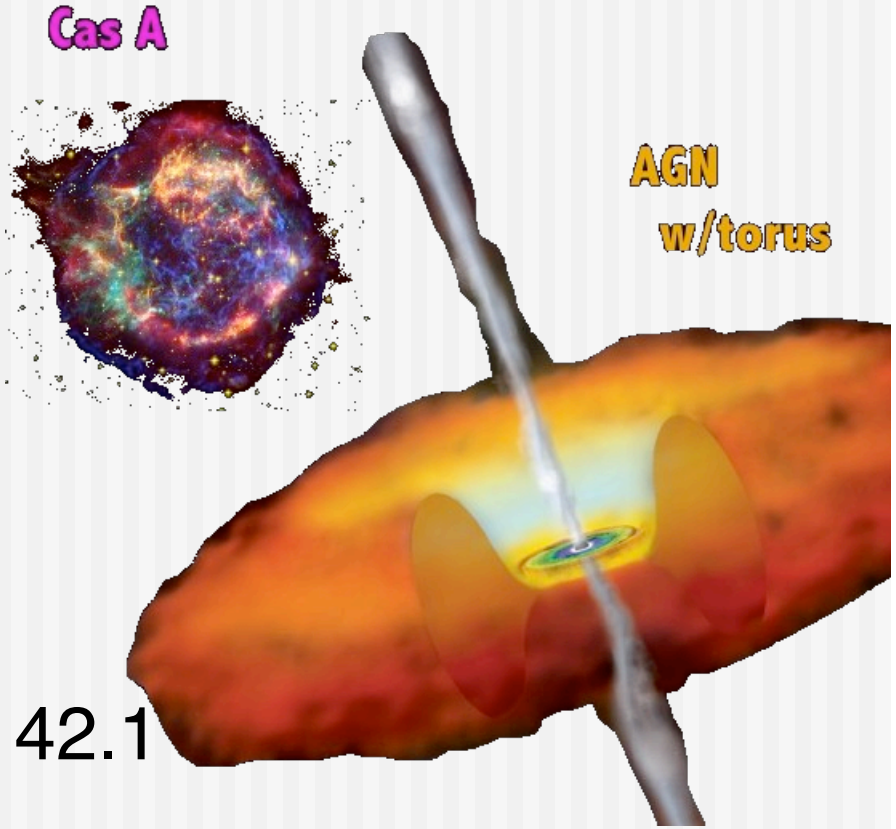
SNR Science

- Progenitor and CSM
- SN Explosion - Core collapse & Type Ia
  - Mechanism, asymmetry, jets, mixing
  - Compact object formation
  - Nucleosynthesis
  - GRB connection
- ISM enrichment: dust, hot plasma, CRs

For fun...

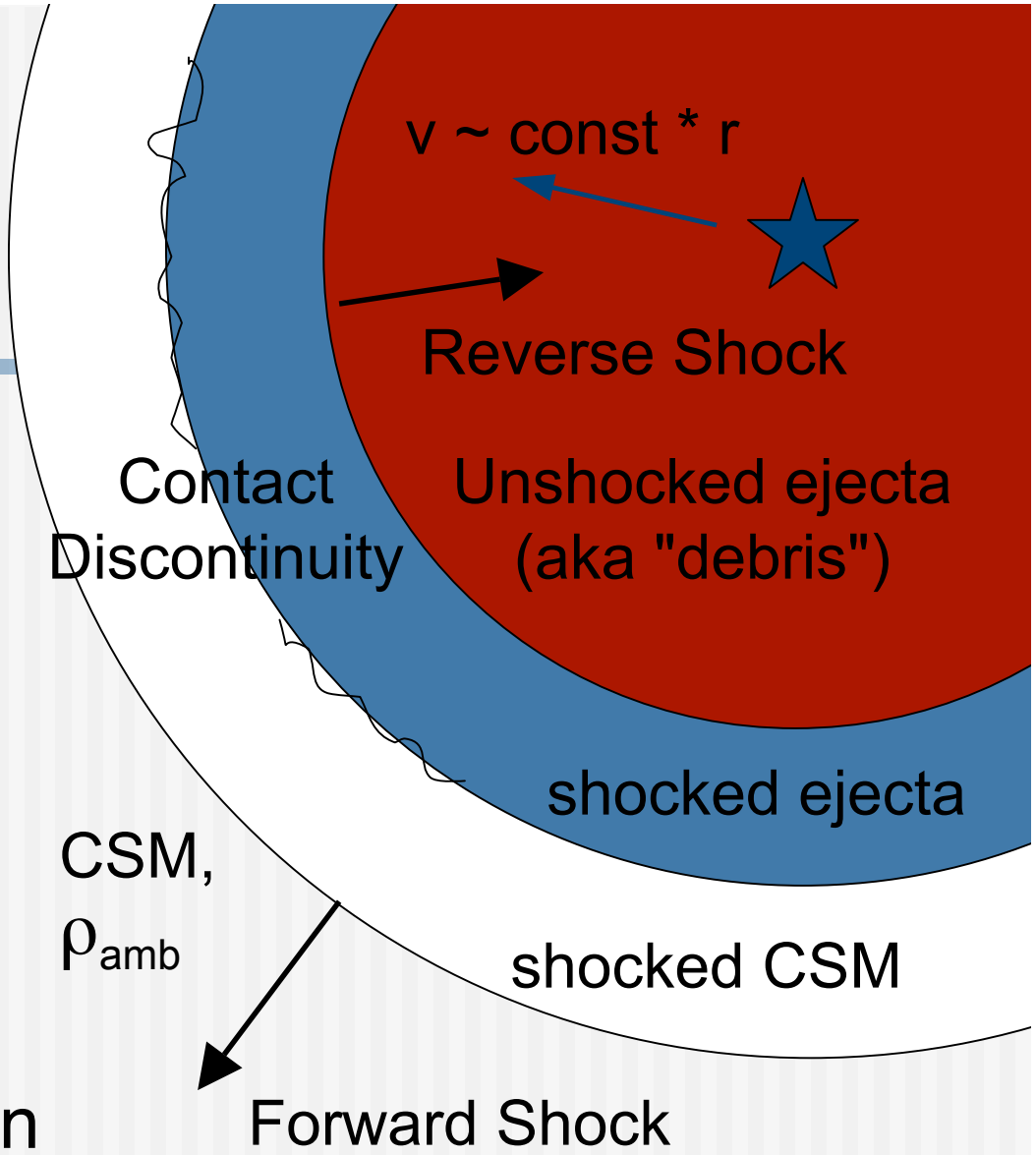
SNRs and AGN

- Size - similar:
  - few parsecs scale
- Mass:
  - SNR: 10's M_{solar}
  - torus: ~ 10^5 M_{solar}
- $L_{X\text{-}ray}$ [log10(erg/s)]
  - SNR ~ 37.5, AGN ~ 42.1



SNR cartoon

- Sedov self- similar solution
- Reality adds:
  - R-T/mixing at CD
  - Non-uniform CSM
  - Asymmetric ejecta
  - Particle acceleration



SNR Plasma

- Collision-less shocks: FS, RS, reflected
  - V forward shock: 3k - 40k km/s
  - V_{ejecta}@RS ~ r_{RS}/age
    SN1987A=7800; CasA=4800; E0102=2800 [km/s]
- NEI evolution, cooling
  - Electron & ion heating at shocks

SNR Plasma, cont.

- Shock-cloud interactions
  - Non-uniform CSM
  - Thermal conduction effects
- Particle acceleration & Cosmic rays
  - Efficiency and effect on hydrodynamics

SNR Plasma Emission

- Emission across wide λ-range
- Thermal
  - shocked ejecta; shocked CSM; dust
- Non-thermal
  - Synchrotron, T_e max, magnetic fields
  - non-thermal brems., inverse Compton
- Photoionized (unshocked, precursor)

SNRs with Gratings

- High(er) spectral resolution than CCDs
  - Line separation
    - From nearby lines: He-like triplets
    - From continuum: low-E lines: O VIII, Fe-L, Ne
  - Doppler velocities can be measured

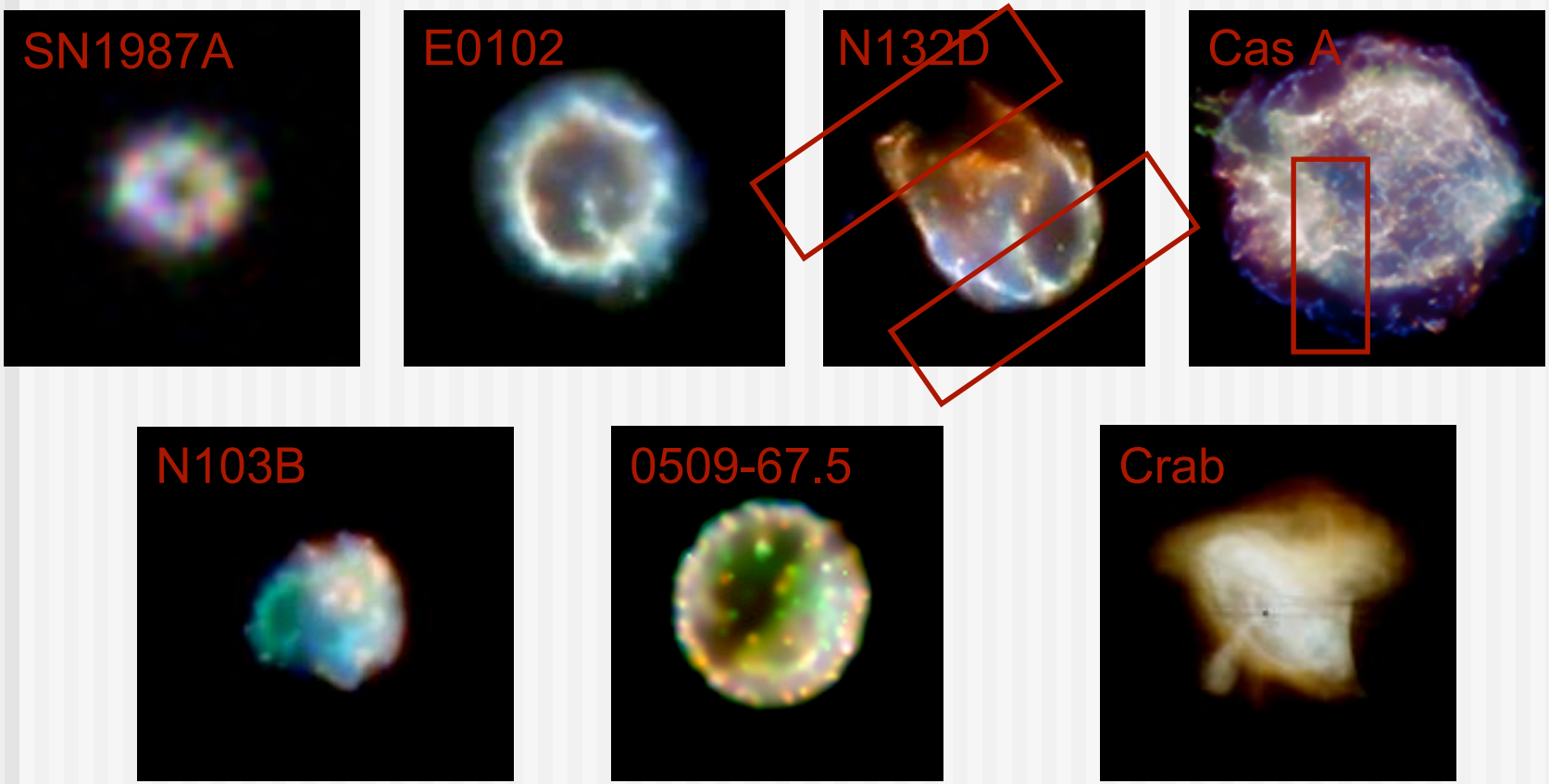
- Extended and/or multiple source
  - More complex analysis
  - Focus on *line emission*

SNRs observed w/HETG

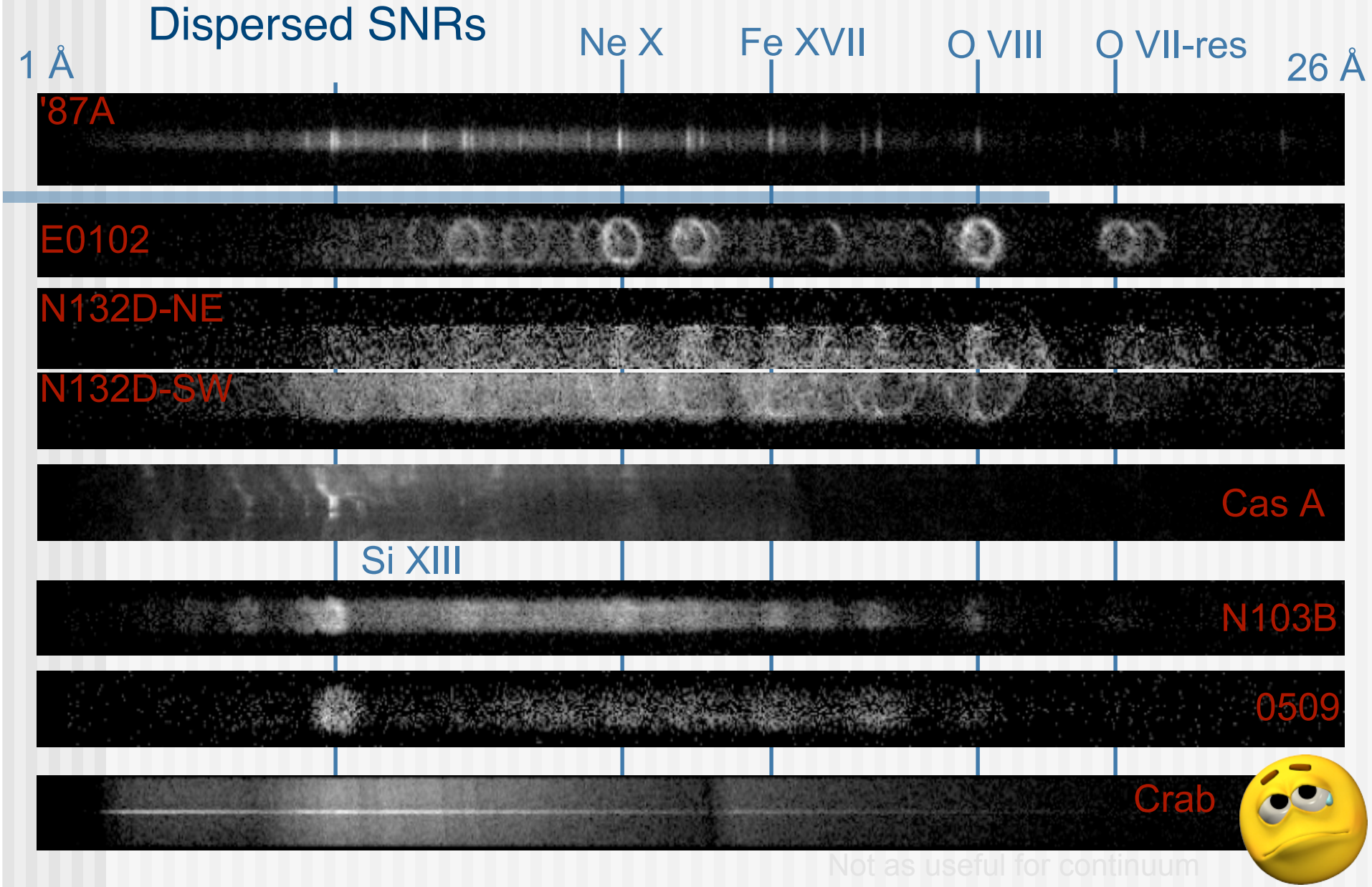
SNR		*Age (yr) [Date]*	n_e *	$\lvert v_{bulk} \rvert$ *
SN 1987A	cc	20 [1987]	~ 800	150--500
E0102	cc	~ 1000	~ 1	~ 2000
N132D	cc	~ 2500 -- 3400		
Cas A	cc	~ 337 [~1670]	~ 100	~ 4000
N103B	Ia	~ 860		
0509-67.5	Ia	~ 400 [~1600]		
(Crab)	cc	953 [1054]		

* Values are for the bright X-ray emitting plasma.

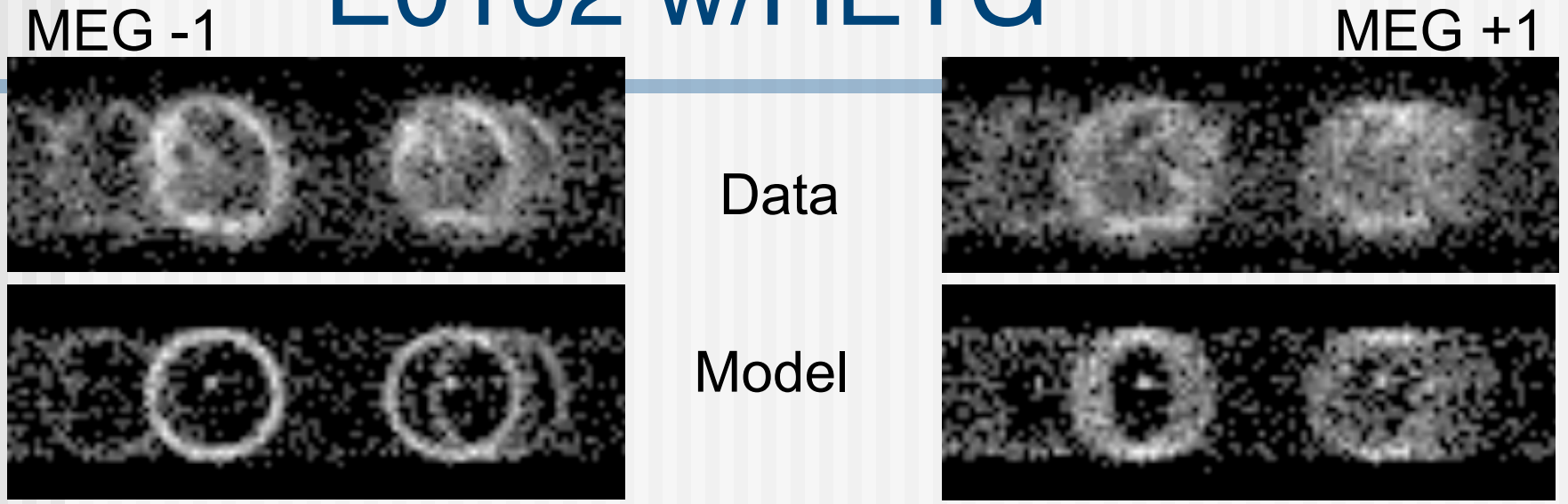
SNRs w/HETG: images



Dispersed SNRs



E0102 w/HETG



Distortions between the + and - orders of the Ne lines are qualitatively reproduced with a cylinderical geometry for the ring emission.

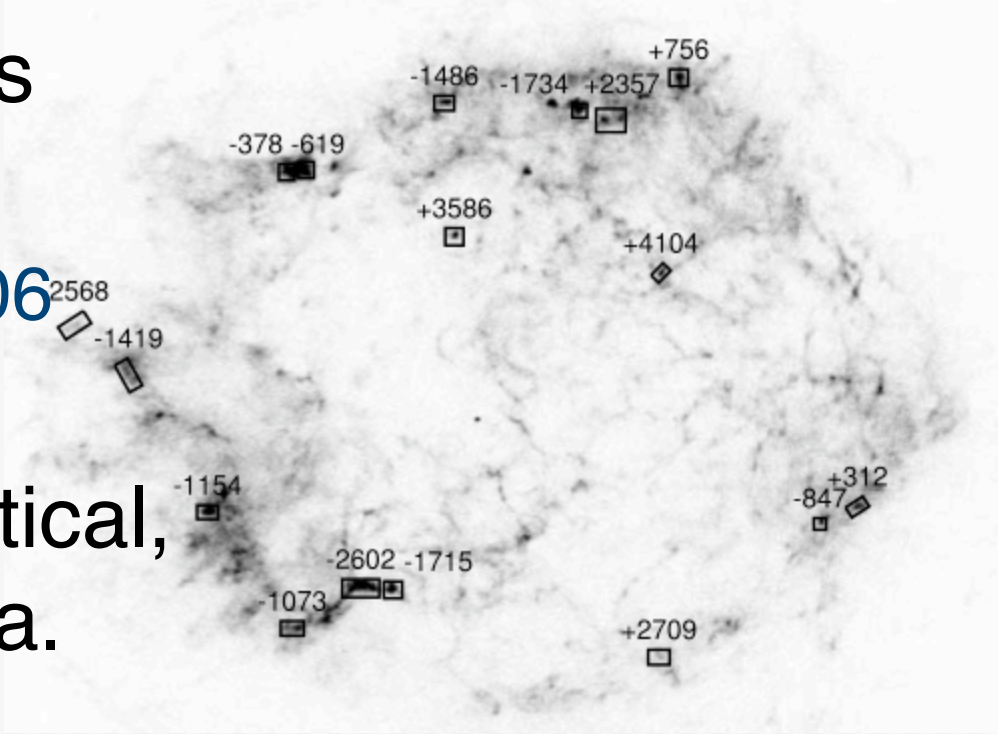
Dewey 2002; Flanagan et al. 2004.

Model geometry

Cas A w/HETG

- Doppler velocities
  - → 3D spatial info

  Lazendic et al. 2006



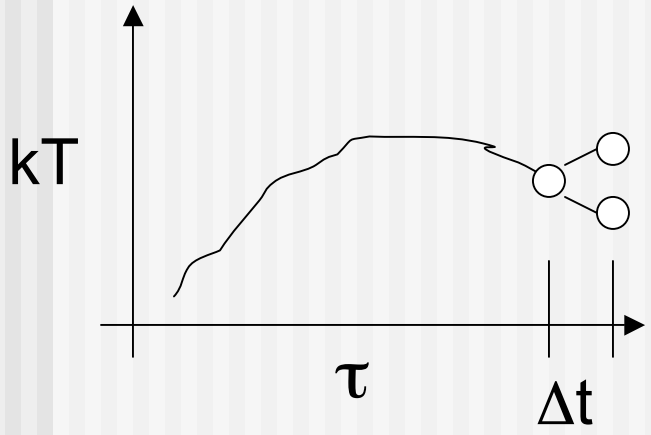
- Combine with optical, IR, and radio data.

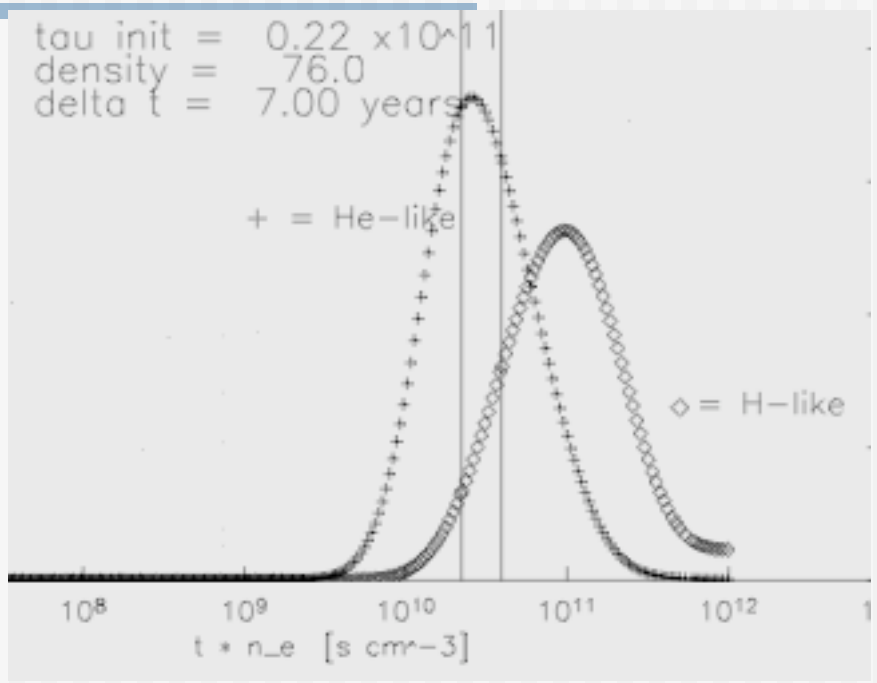
  DeLaney 2007

Cas A w/HETG, cont.

- Line ratios
  - → NEI parameters

    Δ params / Δt :

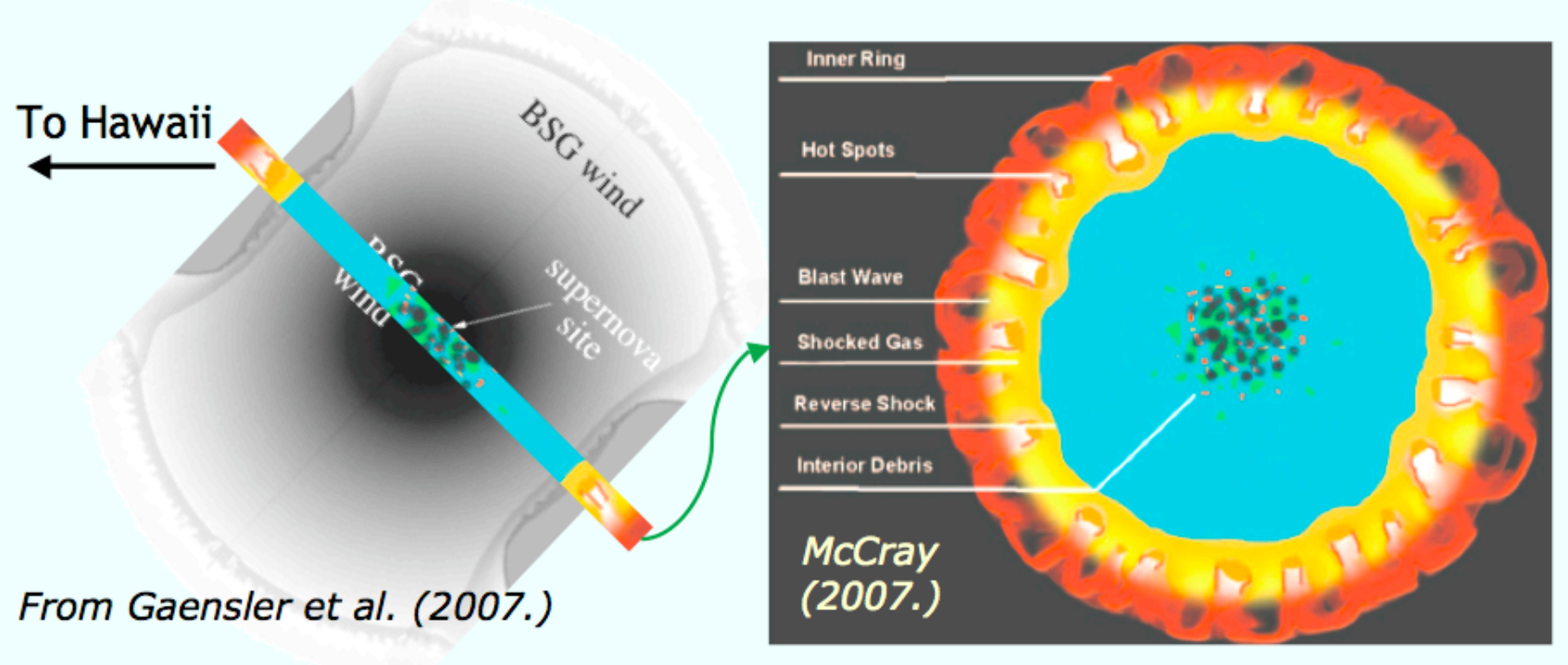


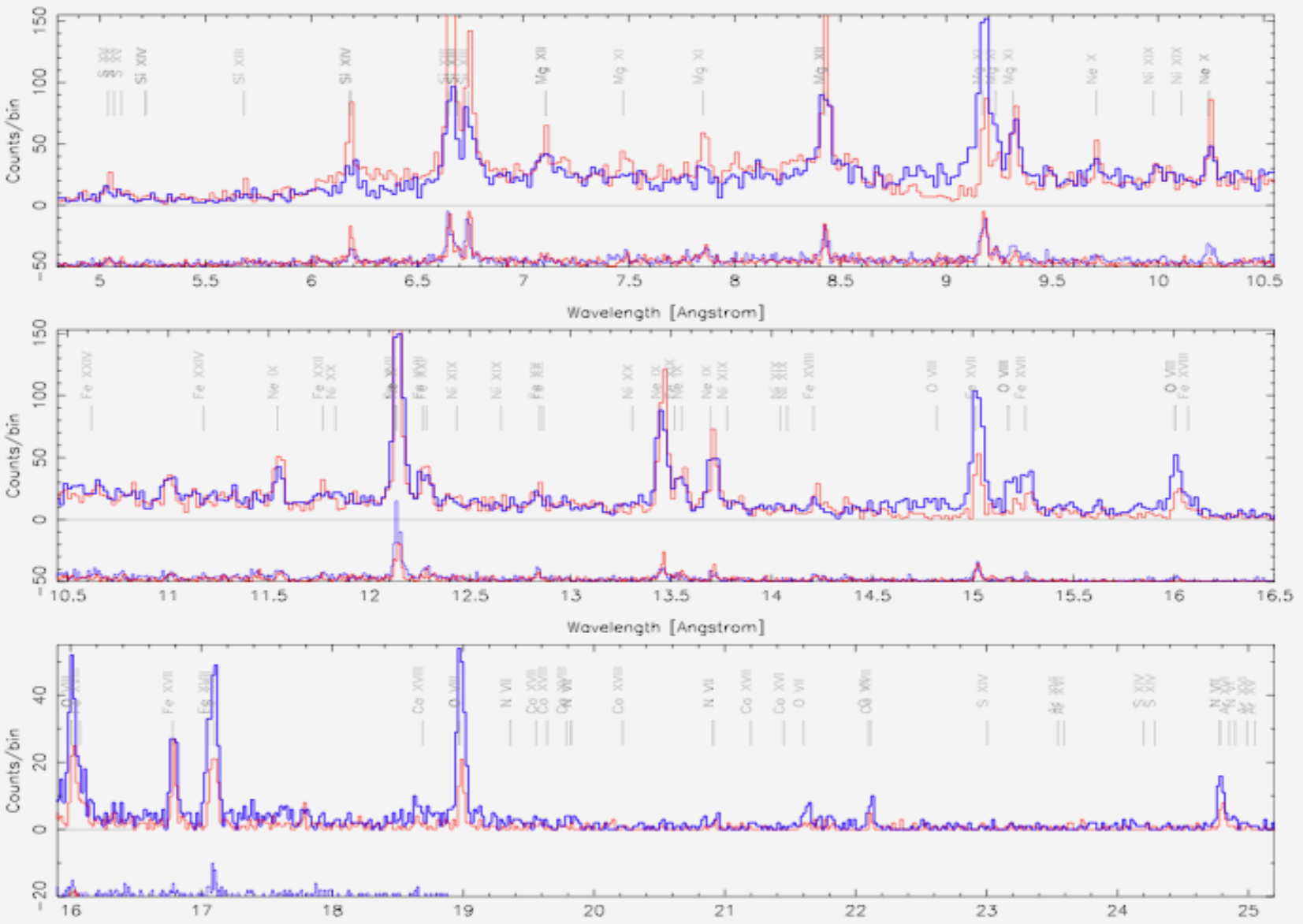


Change in plasma parameters over many years baseline can constrain models.

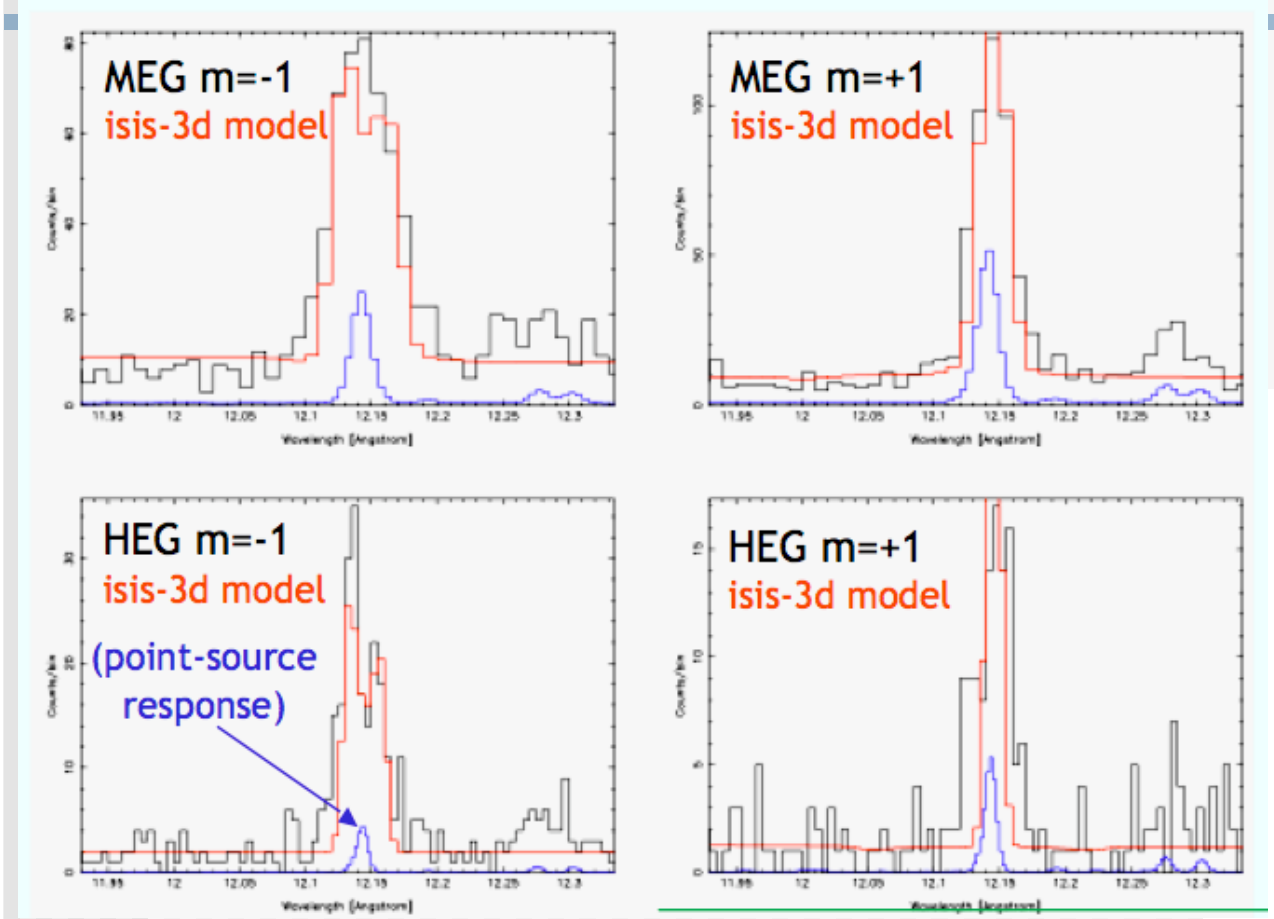
SN 1987A w/HETG

- The blast wave is hitting a dense equatorial ring, tilted 45 degrees to our line of sight

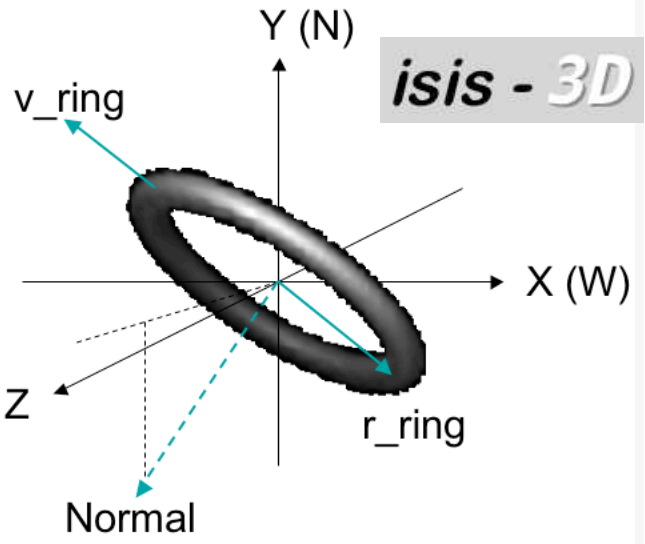



Counts/bin
Wavelength [Angstrom]
Counts/bin
Wavelength [Angstrom]
Counts/bin

SN 1987A w/HETG, cont.

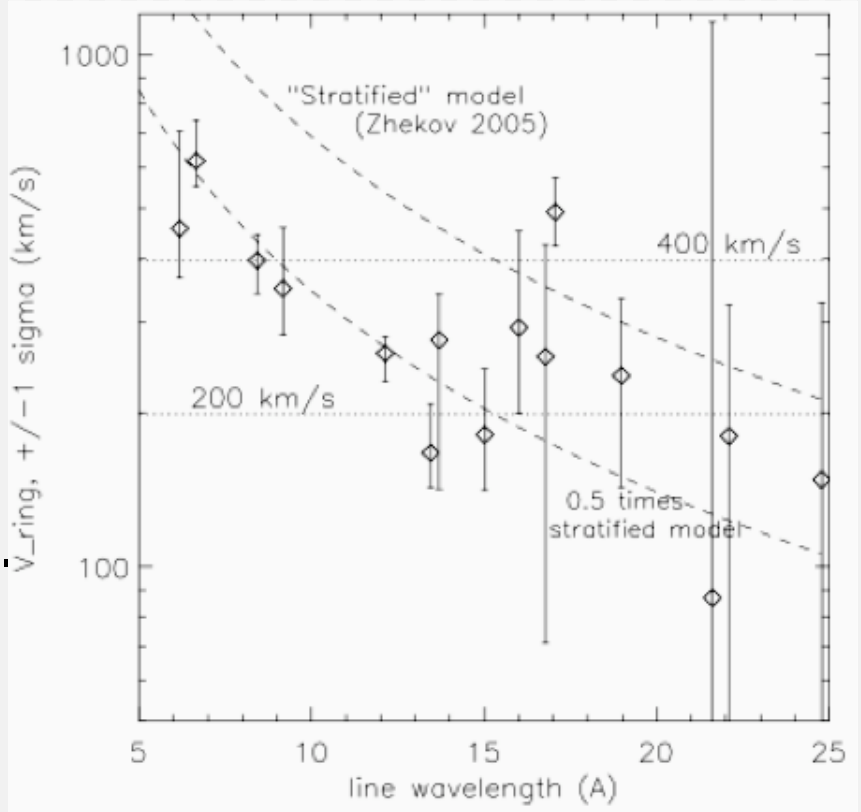


A 3D model is used to fit the HETG line shapes; a key free parameter is V_{ring} .



SN 1987A w/HETG, cont.

- V_{ring} varies with λ.
- Seen in LETG/ACIS data (McCray PI.)
- Zhekov et al. 2005
- Range of shock (and hence bulk) velocities.
- Higher ionization with faster velocities.



For the future

- Can get information from HETG-SNR observations, so …
- Further HETG observations…
  - O-rich SNR
- Future X-ray instruments for SNR
  - Long slit spectrometer

Oxygen-rich SNRs

In SMC/LMC:

- **SN 1987A** (LMC) ?O-rich?
- **N132D** (LMC)
- **SNR 0540-69.3** (LMC)
- **E0102**.2-7219 (SMC)
- SNR 0103-72.6 (SMC)
- IKT6, SNR 0049-73.6 (SMC)

Galactic & extra-Galactic:

- **Cas A**
- Pup A
- **G292+1.8**

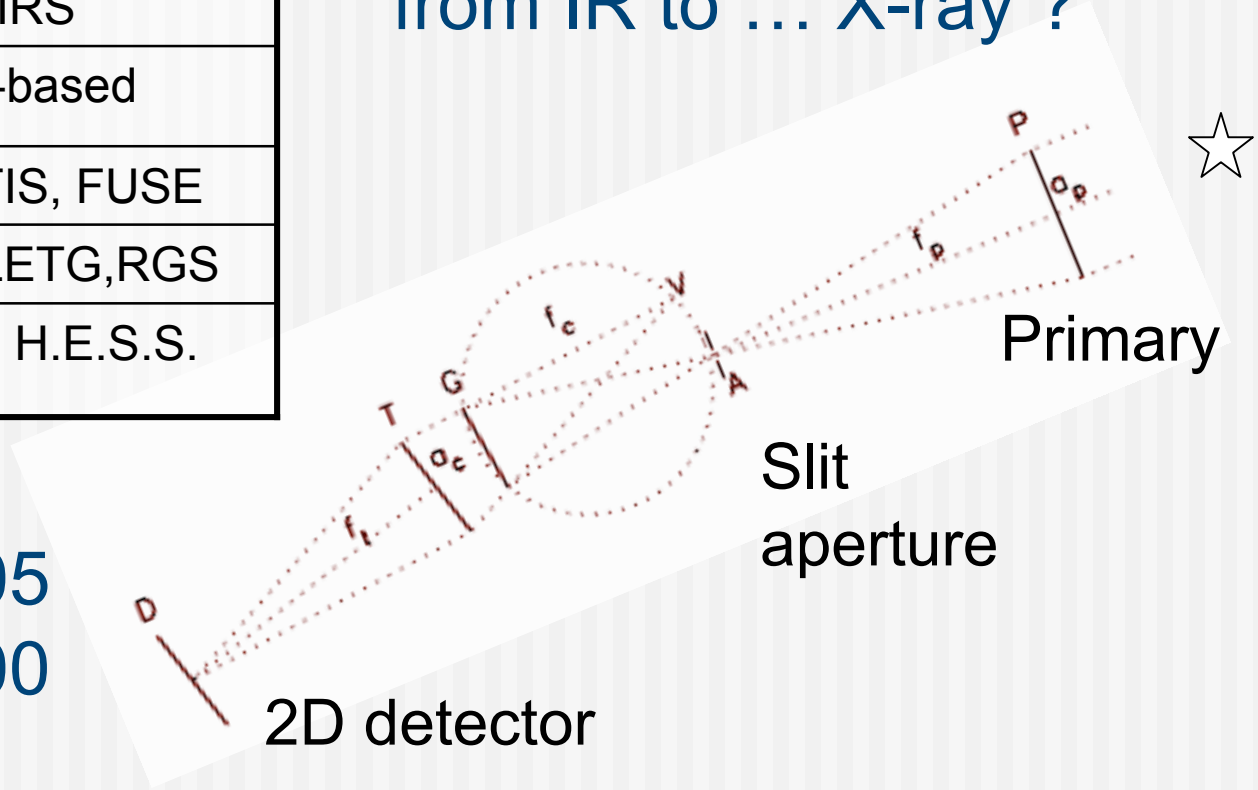
- SNR in NGC 4449
- SN 1957D in M83

Underline = Grating observed
Bold = Deep ACIS data taken

Multi-λ & High Resolution

Radio	VLA
IR	Spitzer-IRS
NIR, Opt.	Ground-based
UV, EUV	HST-STIS, FUSE
X-ray	HETG,LETG,RGS
γ-ray - TeV	GLAST, H.E.S.S.

Long-slit instruments from IR to … X-ray ?



Willingale 2005
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Thanks to

Claude Canizares and MKI collegues

Hydra project:
http://space.mit.edu/hydra

Dick McCray and '87A collaborators

See the program of the Aspen '87A workshop:
http://astrophysics.gsfc.nasa.gov/conferences/supernova1987a/

Kelly Korreck and many SNR enthusiasts

See the Endpoints and Interactions workshop:
http://www.cfa.harvard.edu/~kkorreck/snrconf.htm