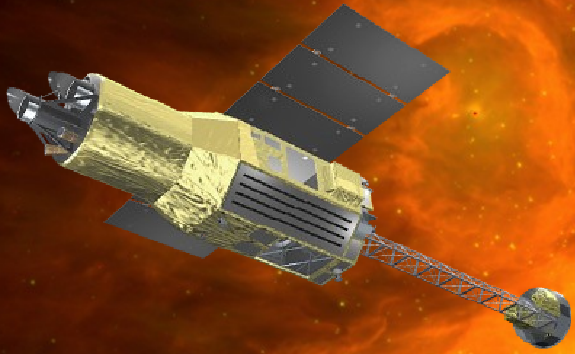


Accretion and outflows with ASTRO-H, ATHENA, and SPICA

Marc Audard

(University of Geneva)

FACULTÉ DES SCIENCES

Département d'astronomie

UNIVERSITÉ DE GENÈVE

The XMM-Newton/Chandra/Suzaku era

- Densities in a handful of young stars evidence of accretion
- Detection of Fe Kα at 6.4 keV: information on source size, height, mechanism (but very limited!)
- Detection of jets and shocks in HH objects
- X-ray light curves of episodic accretion events in multi-wavelength campaigns and some CCD spectra of FUors/EXors
- Magnetically confined wind shocks in some Herbig stars
- Diffuse X-ray emission in star forming regions

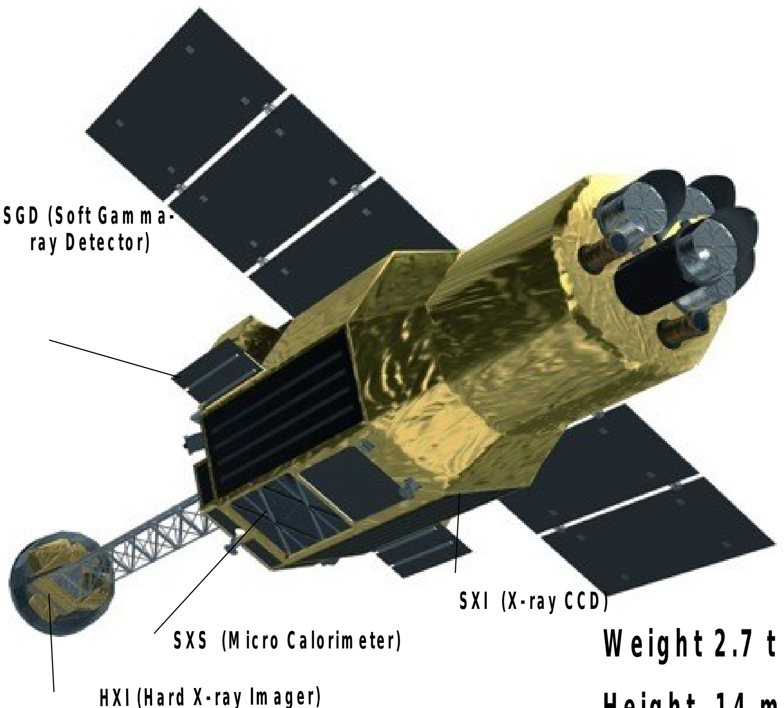
- Abundance studies (FIP and inverse FIP effect)
- Average density & opacity measurements
- Density variations during flares (rare! Low S/N)
- Eclipse & Doppler mapping of corona (limited by spectral resolution & resolution)
- Colliding wind binaries, WR stars, massive O stars
- Etc, etc…

ASTRO-H in a nutshell

(Takahashi et al., 2012, SPIE, 8443, 1)

ASTRO-H is an international X-ray observatory, which is the 6th in the series of the X-ray observatories from Japan. More than 200 scientists from Japan/US/Europe/Canada.

- **Launch vehicle: JAXA H-IIA rocket**
- **Orbit Altitude: 550km**
- **Orbit Inclination: ~31 degrees**
- **Launch: 2016**



Weight 2.7 t

Height 14 m

International Cooperations

Micro Calorimeter Array/ADR Two soft X-ray Telescopes Eight Science Advisors Pipeline Analysis
SRON & U. of Geneva Filter Wheel/MXS for SXS CEA/DSM/IRFU Contribution to BGO Shield/ASIC test ESA Three Science Advisors Contribution to mission instruments (SXS/HXI/SGD/HXT) User support in Europe
CSA Metrology System

58 institutions (Japan 33)
266 scientists & leading engineers (Japan 152)

courtesy M. Guainazzi

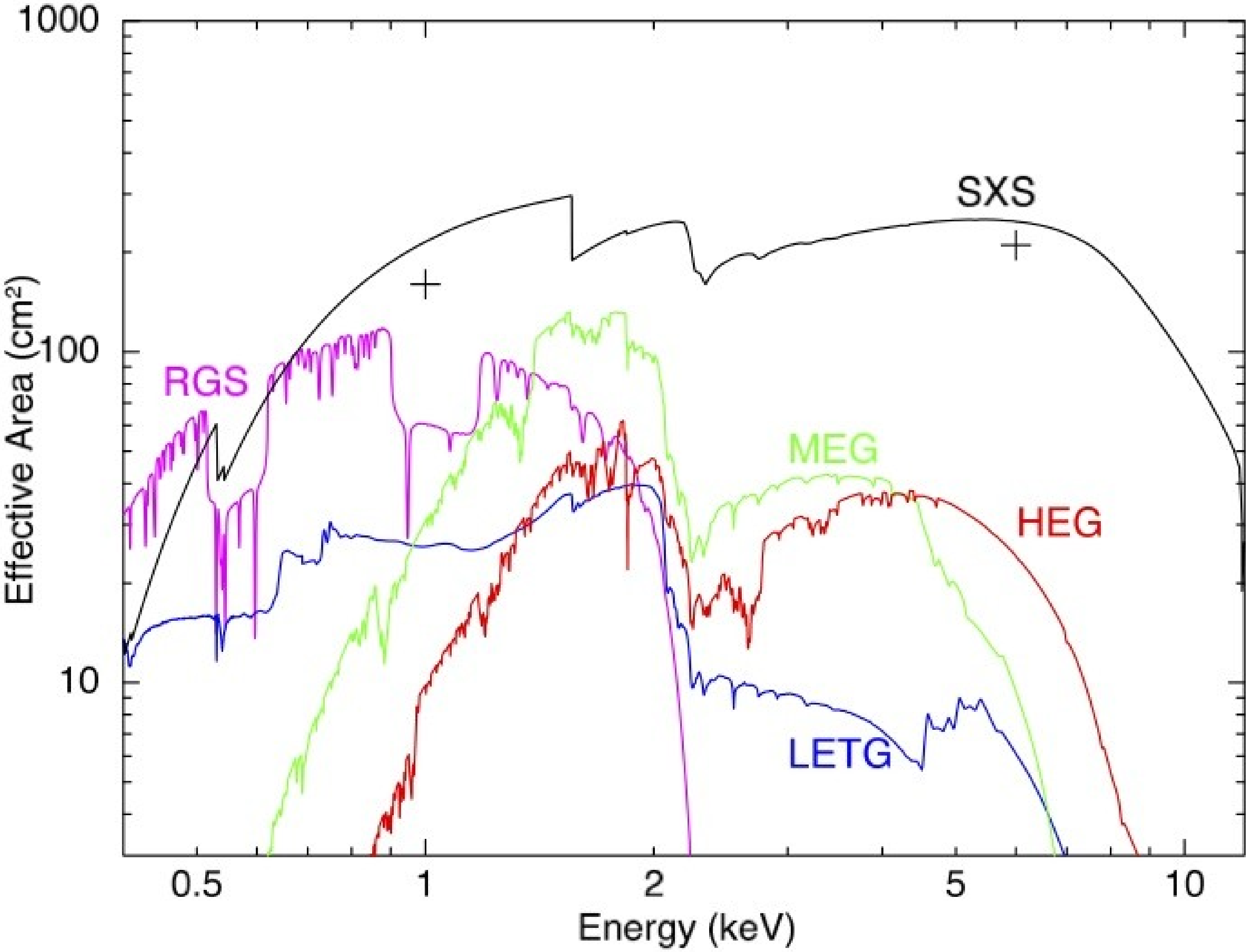
(Takahashi, 2013, MmSAI, 84, 776

TABLE 2. Key parameters of the ASTRO-H payload

Parameter	Hard X-ray Imager (HXI)	Soft X-ray Spectrometer (SXS)	Soft X-ray Imager (SXI)	Soft γ-ray Detector (SGD)
Detector technology	Si/CdTe cross-strips	micro calorimeter	X-ray CCD	Si/CdTe Compton Camera
Focal length	12 m	5.6 m	5.6 m	–
Effective area	300 cm^2@30 keV	210 cm^2@6 keV 160 cm^2 @ 1 keV	360 cm^2@6 keV	>20 cm^2@100 keV Compton Mode
Energy range	5 –80 keV	0.3 – 12 keV	0.5 – 12 keV	40 – 600 keV
Energy resolution (FWHM)	2 keV (@60 keV)	< 7 eV	150 eV (@6 keV)	4 keV (@40 keV)
Angular resolution	<1.7 arcmin	<1.3 arcmin	<1.3 arcmin	–
Effective Field of View	$\sim 9 \times 9$ $arcmin^2$	$\sim 3 \times 3$ $arcmin^2$	$\sim 35 \times 35$ $arcmin^2$	0.6×0.6 deg^2 (< 150 keV)
Time resolution	several 10 μs	several 10 μs	4 sec	several 10 μs
Operating temperature	−20°C	50 mK	−120°C	−20°C

High-resolution spectroscopy **Imaging up to 80 keV** **Wide band, high sensitivity**

courtesy M. Guainazzi


1000
100
10
Effective Area (cm²)
SXS
RGS
MEG
HEG
LETG
0.5
1
2
5
10
Energy (keV)

ASTRO-H timeline

- Launch by the end of JFY 2015
- Similar operational approach as Suzaku, incl. data rights and access for European astronomers (≈8%)

Time Allocation (TBC)

Phase 0 : 3 Months : Satellite/Instruments Check out
Phase 1 : 6 Months : SWG 100 % (PV Phase, including Calibration)
Phase 2 : 12 Months : SWG Carry Over 15 %, GO 75 %, Observatory 10 %
Phase 3 : Rest of the mission : Key Project 15 % (TBD) , GO 75 %, Observatory 10 %

- Call will be released some time after launch

ASTRO-H user support for the European community

Science Operations Centre (SOC) at ESAC

- Handling of European Announcement of Opportunities, proposal technical evaluation, OTAC support
- Liaison with JAXA for the implementation of European proposals and cross-calibration observations
- Storage and dissemination of data
- Support to calibration and operations at JAXA

Science Support Centre (ESSC) at UNIGE

- Promotion in Europe (w/SOC)
- Expert knowledge on ASTRO-H instruments for European users
- Review user's documentation
- Training activities for European astronomers
- Contribute to the validation of calibration and data analysis software

ESAC, Spain

Current personnel:
Matteo Guainazzi (@JAXA)
Peter Kretschmar
Celia Sanchez

Project Scientist: David Lumb (ESA-ESTEC)

astroh.unige.ch

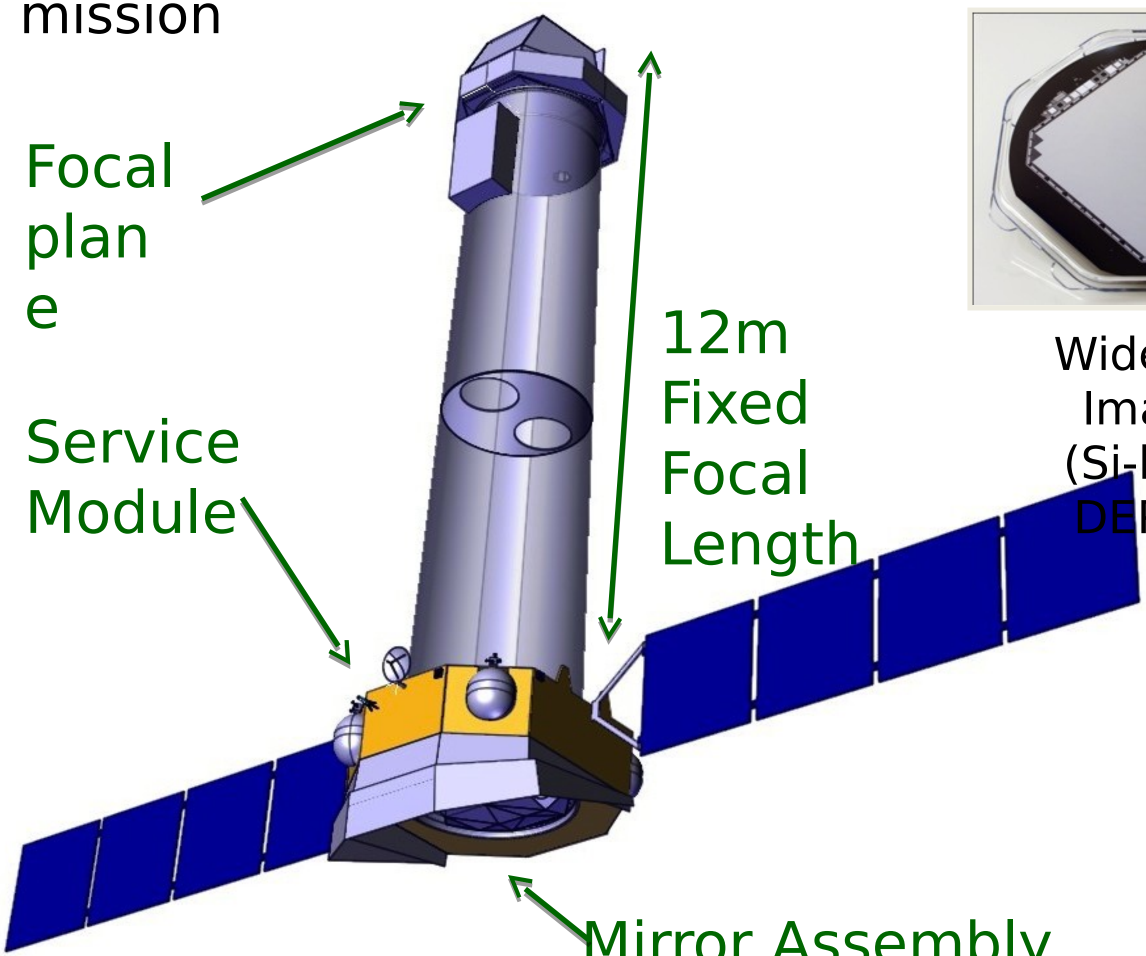
Écogia, Versoix, Switzerland

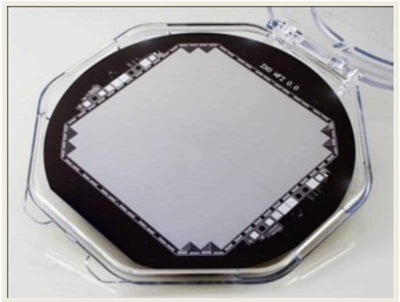
Current personnel:
Marc Audard
Carlo Ferrigno
Stephane Paltani

Athena

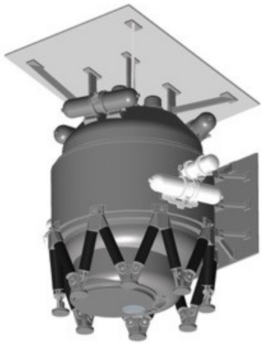
Launch goal: 2028 (L2)

Ariane V launch to L2, 5yr nominal mission





Wide Field Imager (Si-based DEPFET)



ESA Silicon Pore Optics
5” (3”) resolution

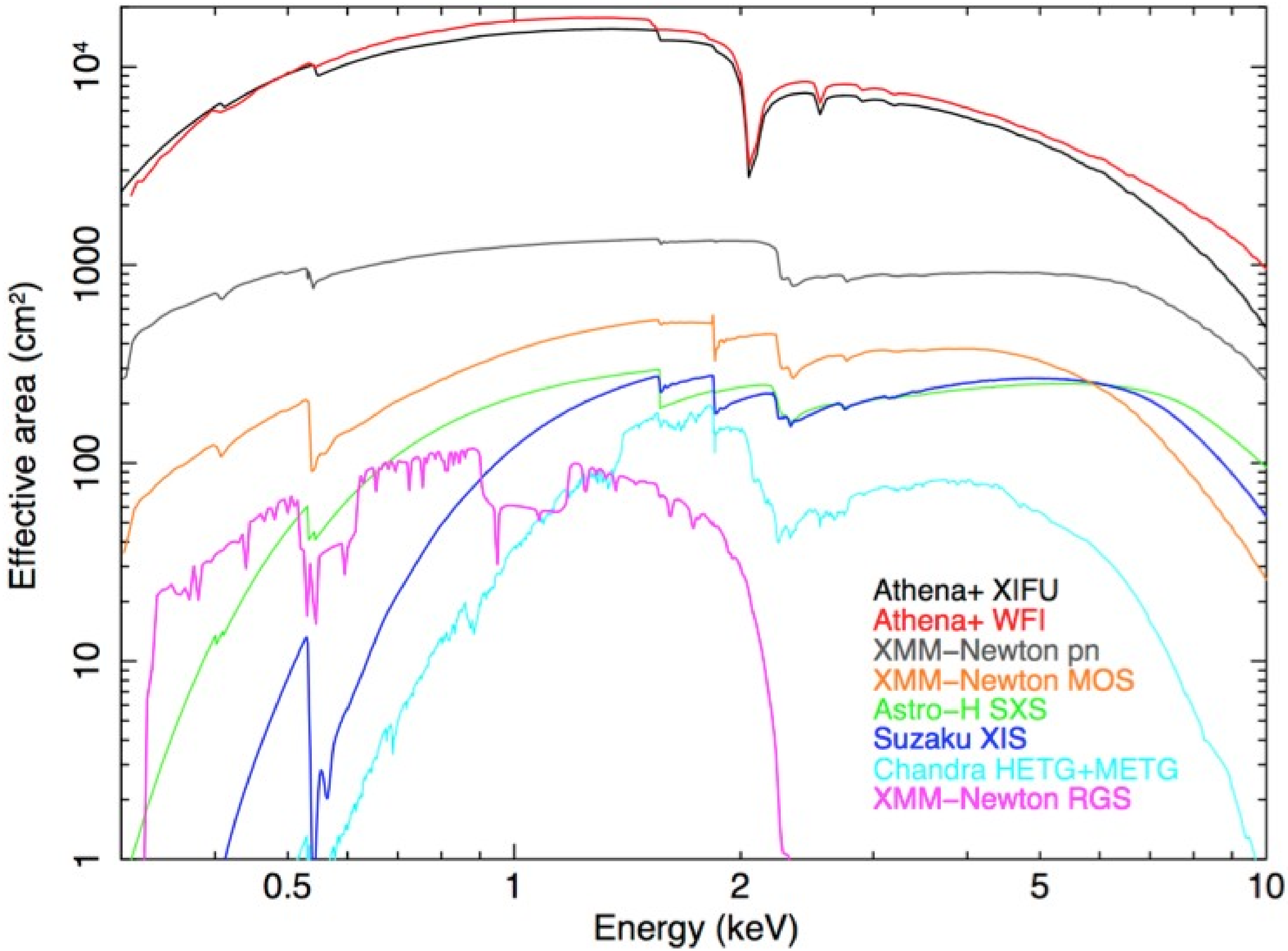
courtesy Athena Coordination group

Science Requirements

	Requirement	Driver
Effective Area	2 m2@ 1 keV (goal 2.5m2) 0.25m2 @ 6 keV (goal 0.3m2)	Hot Baryons Black hole evolution Accretion Physics
Angular Resolution	5” (goal of 3”)	Black Hole Evolution Hot Baryons
Fields of view	WFI: 40’ diameter (goal 50’) X-IFU: 5’ x 5’ (goal 7’ x 7’)	Hot Baryons Black Hole Evolution
Spectral resolution	150 eV @ 6 keV (WFI) 2.5 eV (X-IFU) goal 1.5 eV	Black Hole Evolution Hot Baryons
Count rate capability	>1 Crab (WFI); 1mCrab (X-IFU; goal 10 mCrab)	Accretion Physics
Timing resolution	10 μs (X-IFU)	Accretion Physics

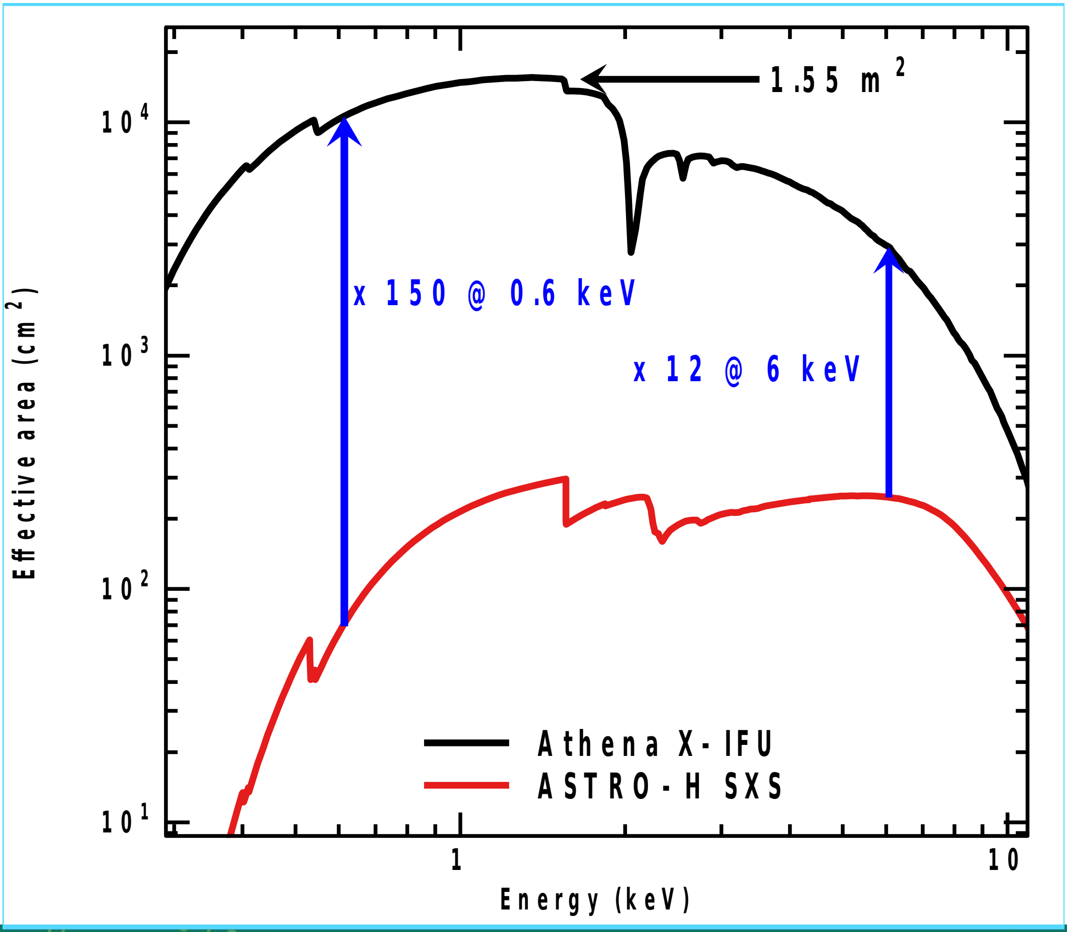
courtesy Athena Coordination group

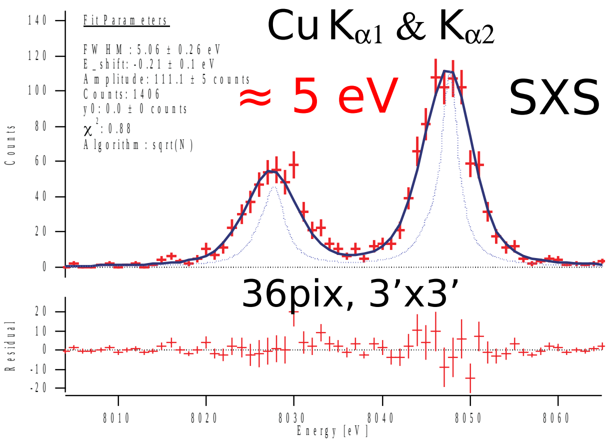
FAC
Dépa
TÉ
VE

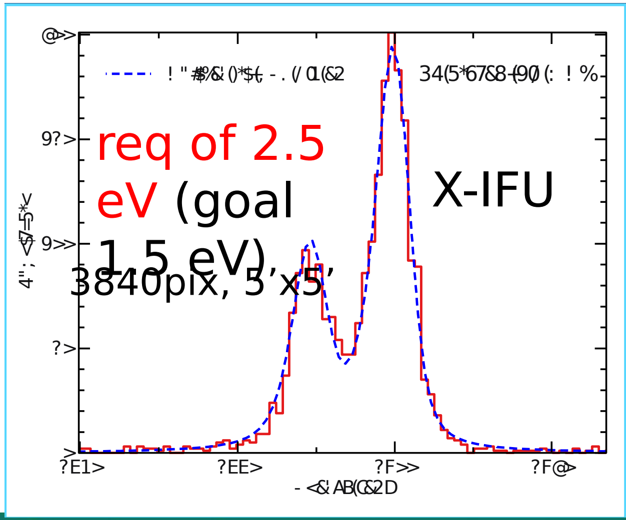


Effective area (cm²)
Energy (keV)
Athena+ XIFU
Athena+ WFI
XMM–Newton pn
XMM–Newton MOS
Astro–H SXS
Suzaku XIS
Chandra HETG+METG
XMM–Newton RGS

ASTRO-H SXS vs Athena X-IFU



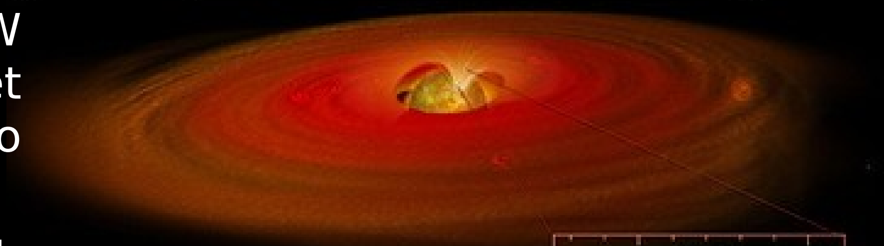




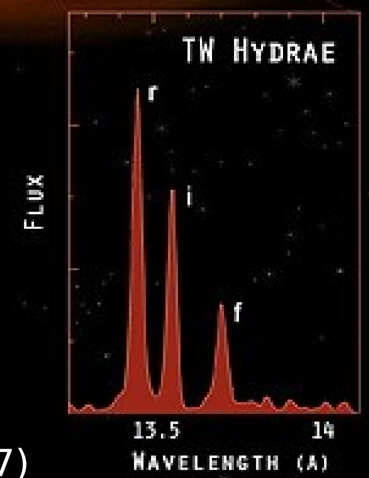
High densities in accreting stars

- High i/f ratio in He-like triplets of TW Hya indicate ne≈1013 cm-3 (Kastner et al. 2002; Stelzer & Schmitt 2004). Also Fe XVII (Ness & Schmitt 2005)
- Plasma T≈3 MK consistent with adiabatic shocks from gas in free fall (v≈150-300 km s-1)
- High densities in accreting young stars (Schmitt et al. 2005; Robrade & Schmitt 2006; Günther et al. 2006; Argiroffi et al. 2007), but not all (Telleschi et al. 2007; Güdel et al. 2007, Argiroffi et al. 2011; etc)

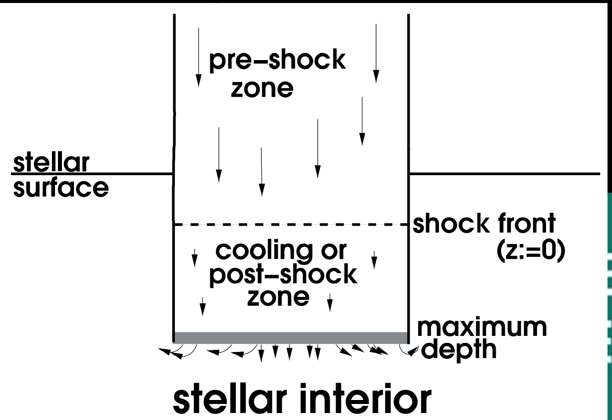
- *Very limited sample, with poor signal-to-noise ratio in grating spectra*



$$T_s = \frac{3\mu m_{\rm H} v_s^2}{16k}$$



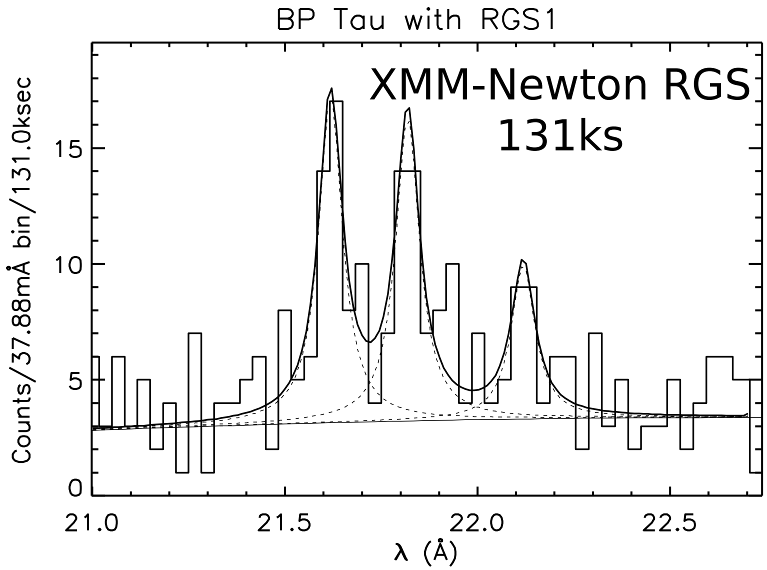
Günther et al. (2007)

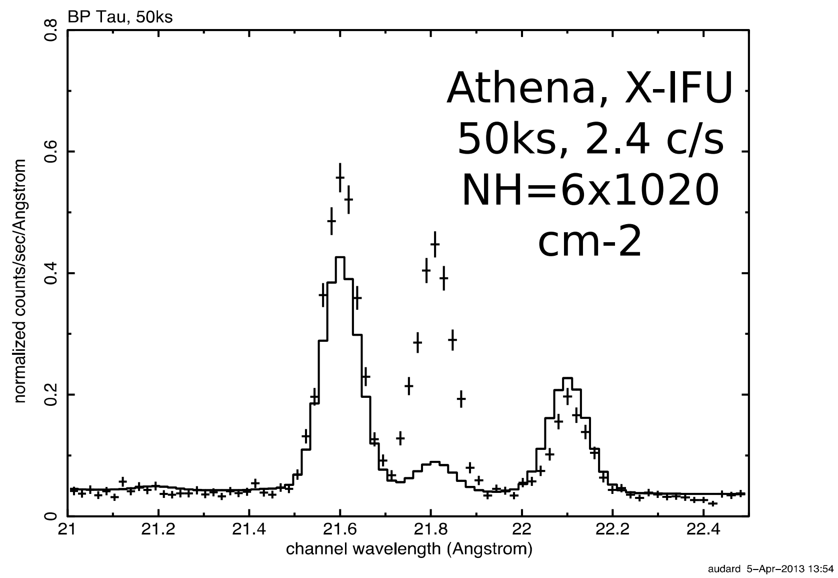


From present challenges to future observations

- Many grating spectra of magnetically active stars (esp. young pre-main sequence stars) suffer from low signal-to-noise ratios
- It will be possible to obtain densities in many sources within 500 pc relatively quickly (<50 ks, e.g., Taurus, Chamaeleon, Orion, etc)
- Caveat of NH for young stars (1020-1022 cm-2)

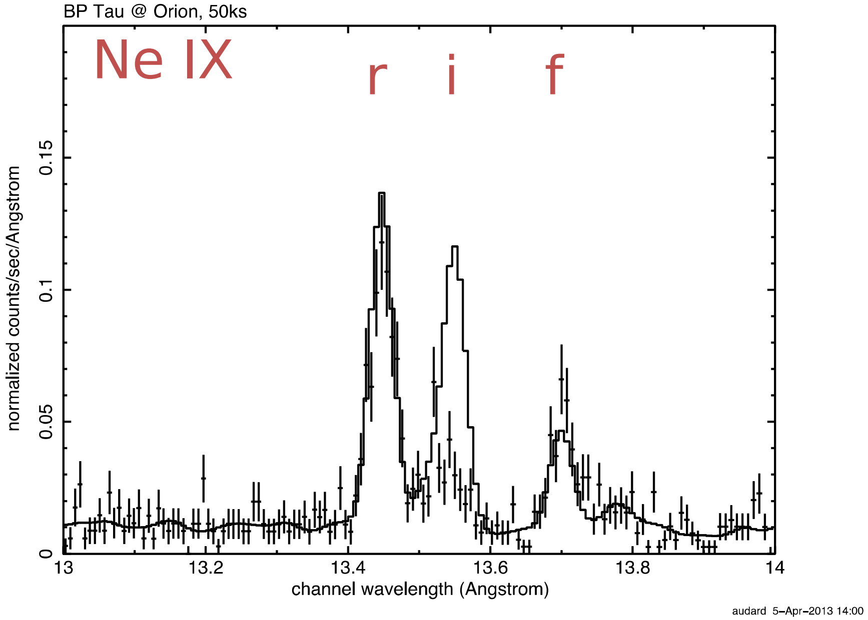
Schmitt et al. (2005)

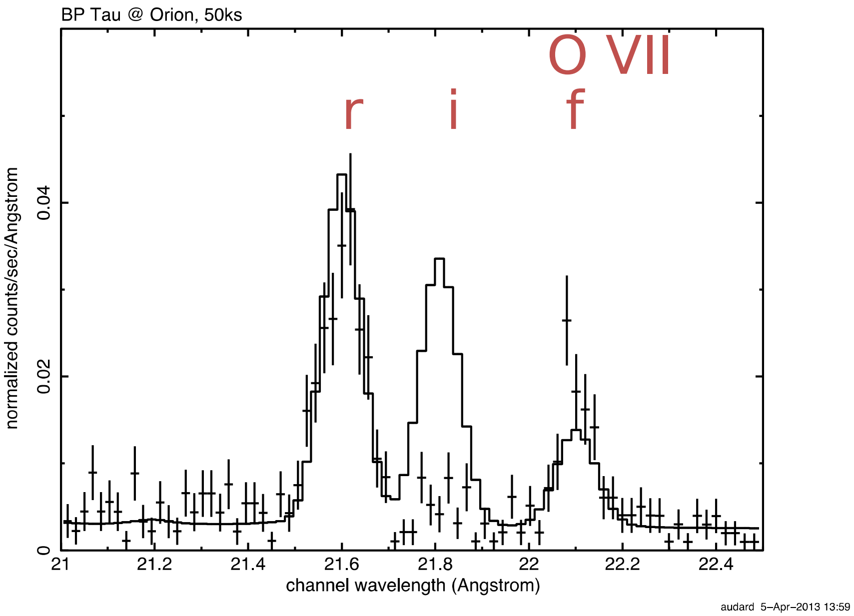




- Potential of Athena to observe several “nearby” (≤500pc) star forming regions also with Athena X-IFU to obtain densities
- Importance to determine the contribution of accreting plasma
- Access to Ne IX (but blends with Fe). Access to OVII will depend on column density (OK for NH<5x1021 cm-2 AV<3 at 500pc).

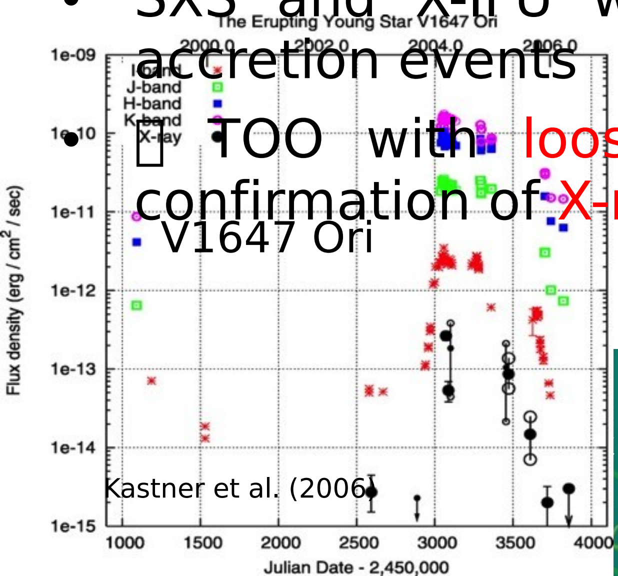
Orion distance (500pc), Athena X-IFU (50 ks), 0.22 c/s





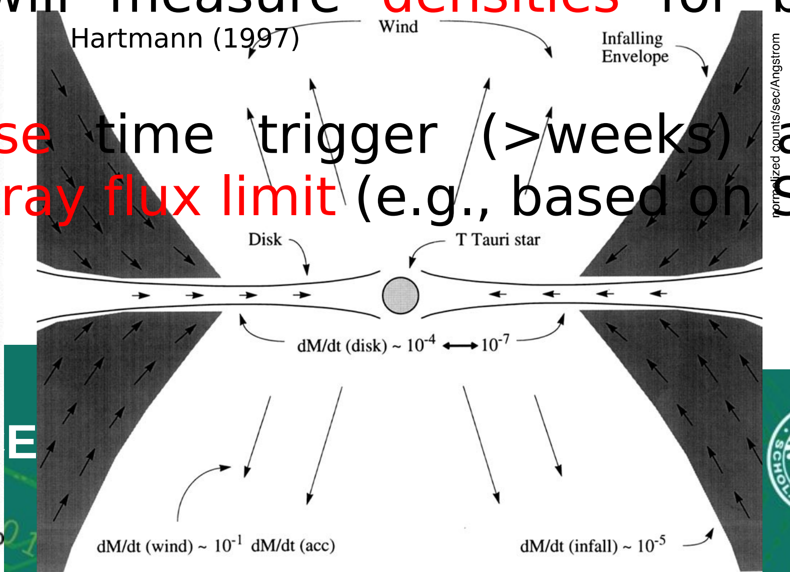
TOO observation of an erupting young star

- Young accreting star can undergo episodic accretion during which massive loads of circumstellar matter falls onto the star
- Previous observations showed a correlation between the optical-IR and the X-ray fluxes → interaction between magnetosphere and accretion
- But previous observations have failed to measure electron densities which can provide measurements of the infalling mass
- SXS and X-IFU will measure densities for bright episodic accretion events
- → TOO with loose time trigger (>weeks) and based on confirmation of X-ray flux limit (e.g., based on Swift TOO)

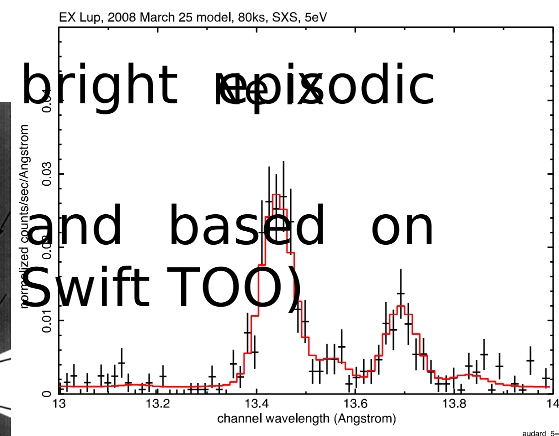


V1647 Ori

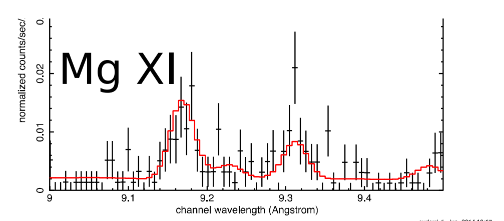
Kastner et al. (2006)



Hartmann (1997)

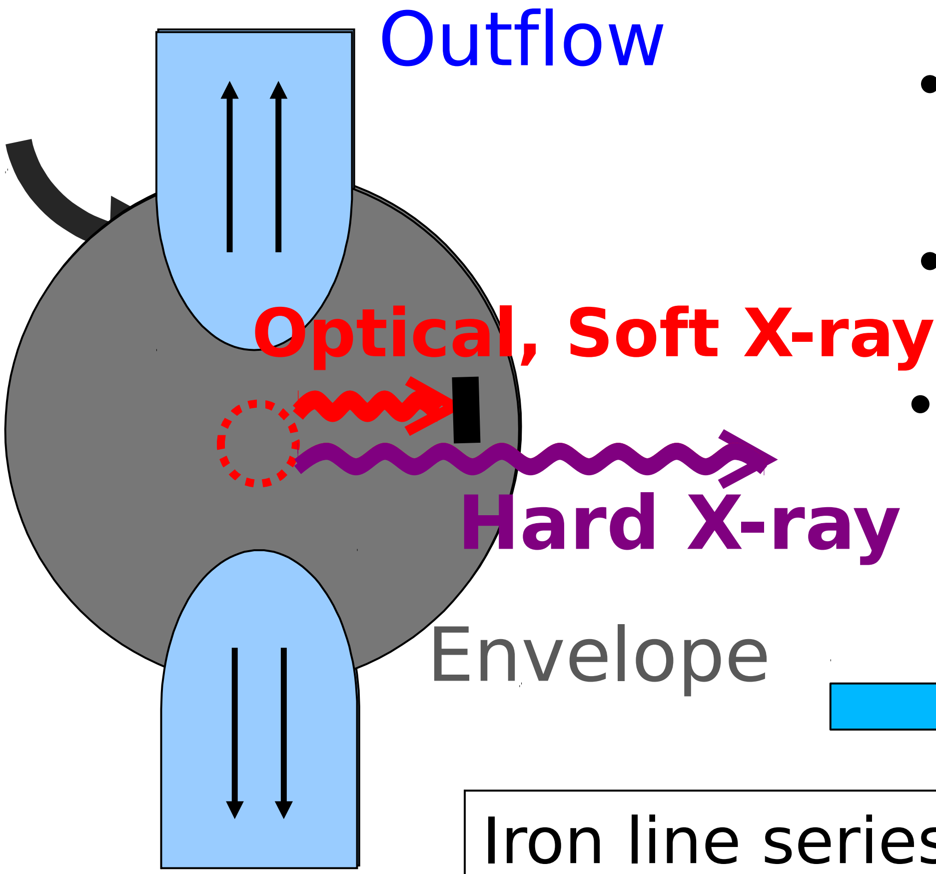


Ne IX



Mg XI

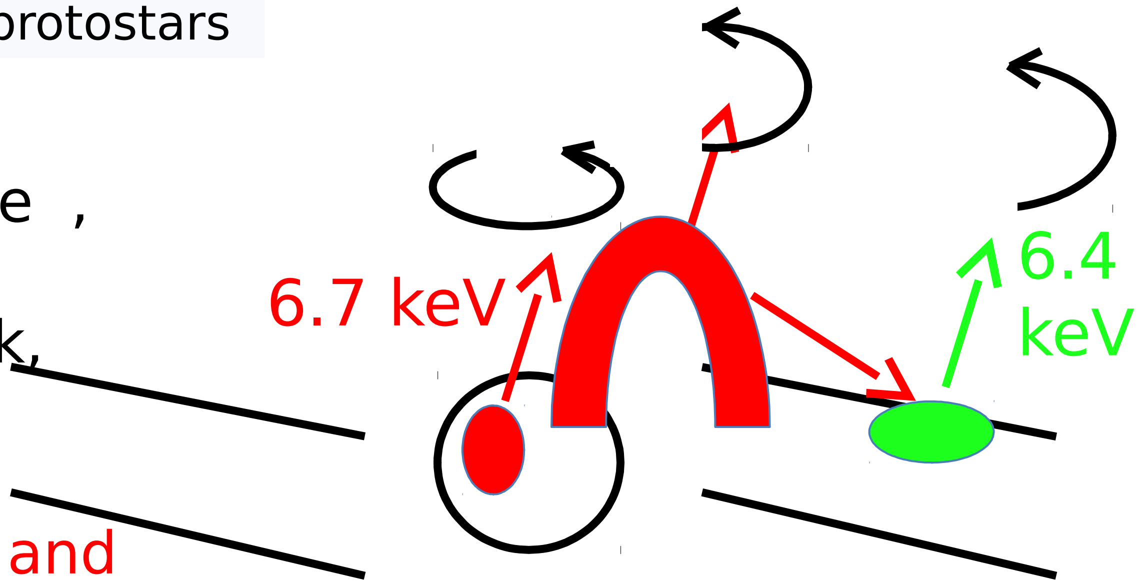
Protostar



- the accreting phase of stars
- surrounded by dense dust envelope
- only > 2 keV X-ray emission gives view on core and the formation process

Iron line series at 7 keV is an unique probe of the dynamics and structures of protostar (core)!!!

From 6.7 keV line
  Pcore, vcore Rcore ,
From 6.4 keV line
  Pdisk, vdisk rdisk, Mcore



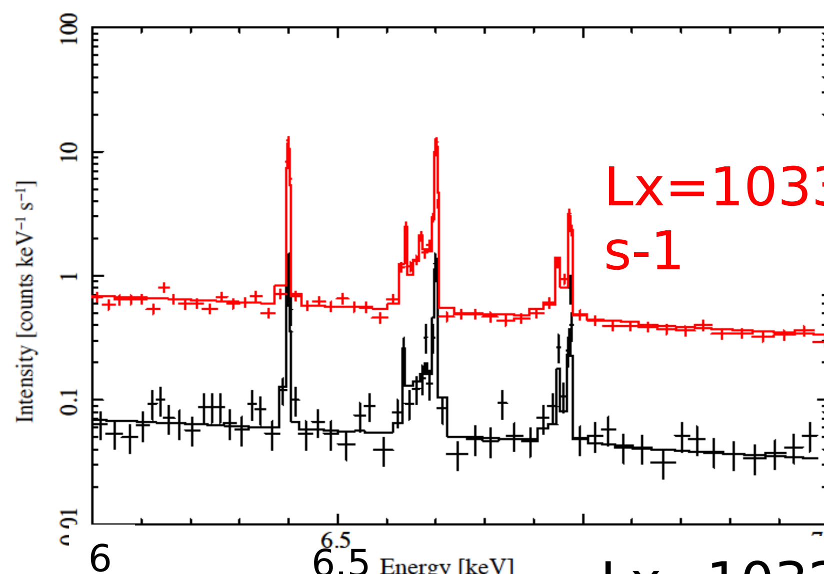
quite brand-new and unique science which can be only done with Astro-H/SXS

A few hints are obtained for protostellar rotation (Pcore~1 day) at near-break-up speed

Tsuboi+2000, Montmerle+2000, Hamaguchi+2012

vcore = a factor x 100 km s-1 is expected

can be resolved with Lx >1032erg s-1 and exposure time of t > 10 ks



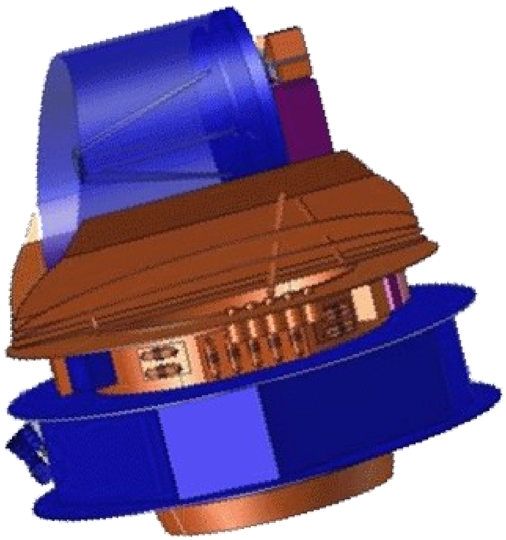
Lx=1033 erg s-1

Lx=1032 erg s-1

10 ks exposure time is assumed

courtesy Y. Tsuboi

SPICA

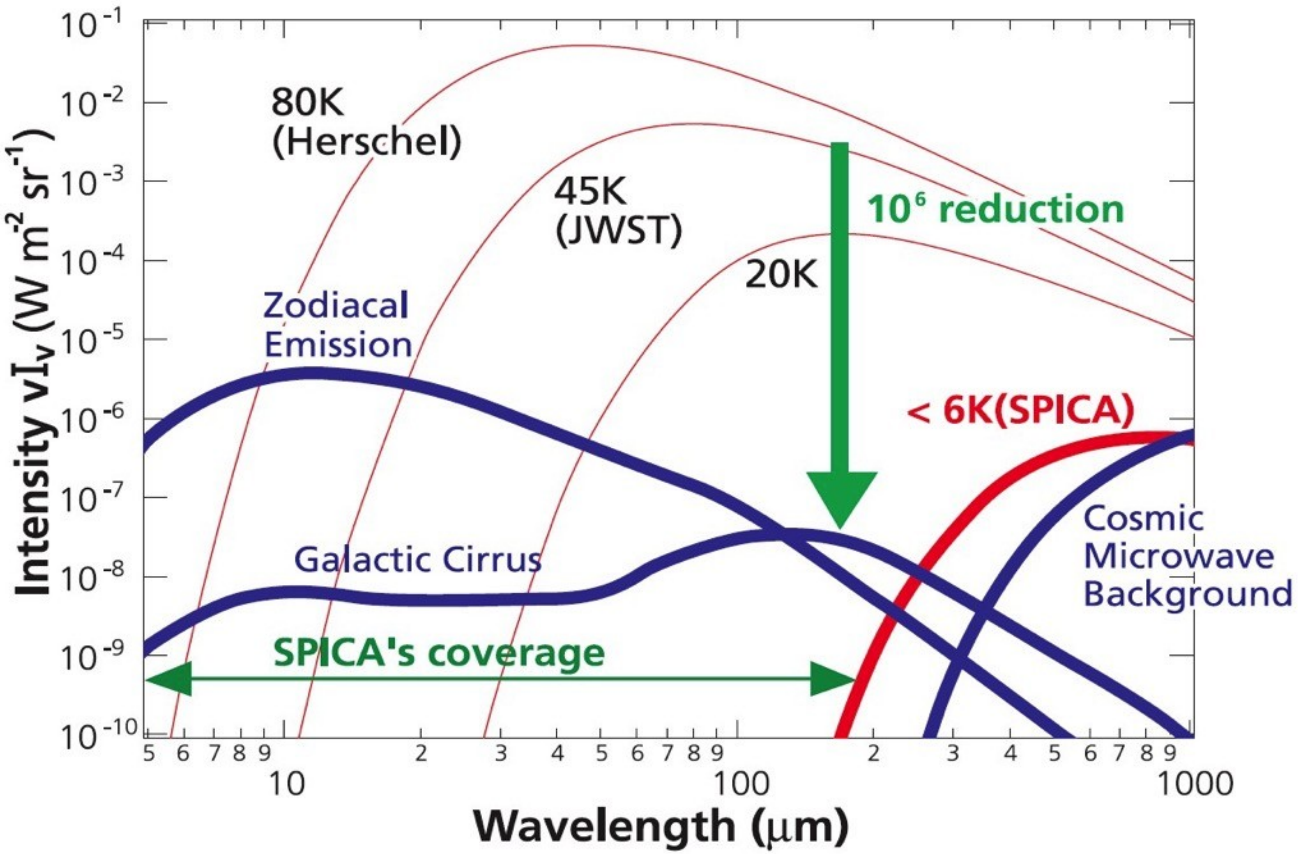


Send your email to B.Sibthorpe@sron.nl to register as a supporter

- SPICA originally a MOO for ESA participation in large JAXA mission, since 2007
- New plan due to budgetary issues: ESA proposed CDF study for cold IR mission within ESA/M + JAXA/M context
- European-Japanese project competing for ESA M5 slot, launch in late 2020's
- Japan MDR (Oct '15) supports SPICA
- Telescope of ø=2.5m, T=8K
- Two instruments
  - SMI (12-36 µm) SAFARI (34-210 µm)

A cool telescope

old plot that needs revision!!



SMI: SPICA Mid-infrared Instrument

hree spectroscopic channels: PI: Kaneda (JAXA, JP)

SMI-LRS

Multi-long-slit prism + Si:Sb w/ slit viewer
17 – 36 µm, R = 50 – 120, slit:10' long, 4 slits;
5σ-1hr ≈ 6-23 10-20 W m-2, 20-140 µJy

SMI-MRS

Grating + Si:Sb w/ beam-steering mirror
18 – 36 µm, R = 1200 – 2300, slit: 1' long;
5σ-1hr ≈ 3-40 10-20 W m-2, 2-4 mJy

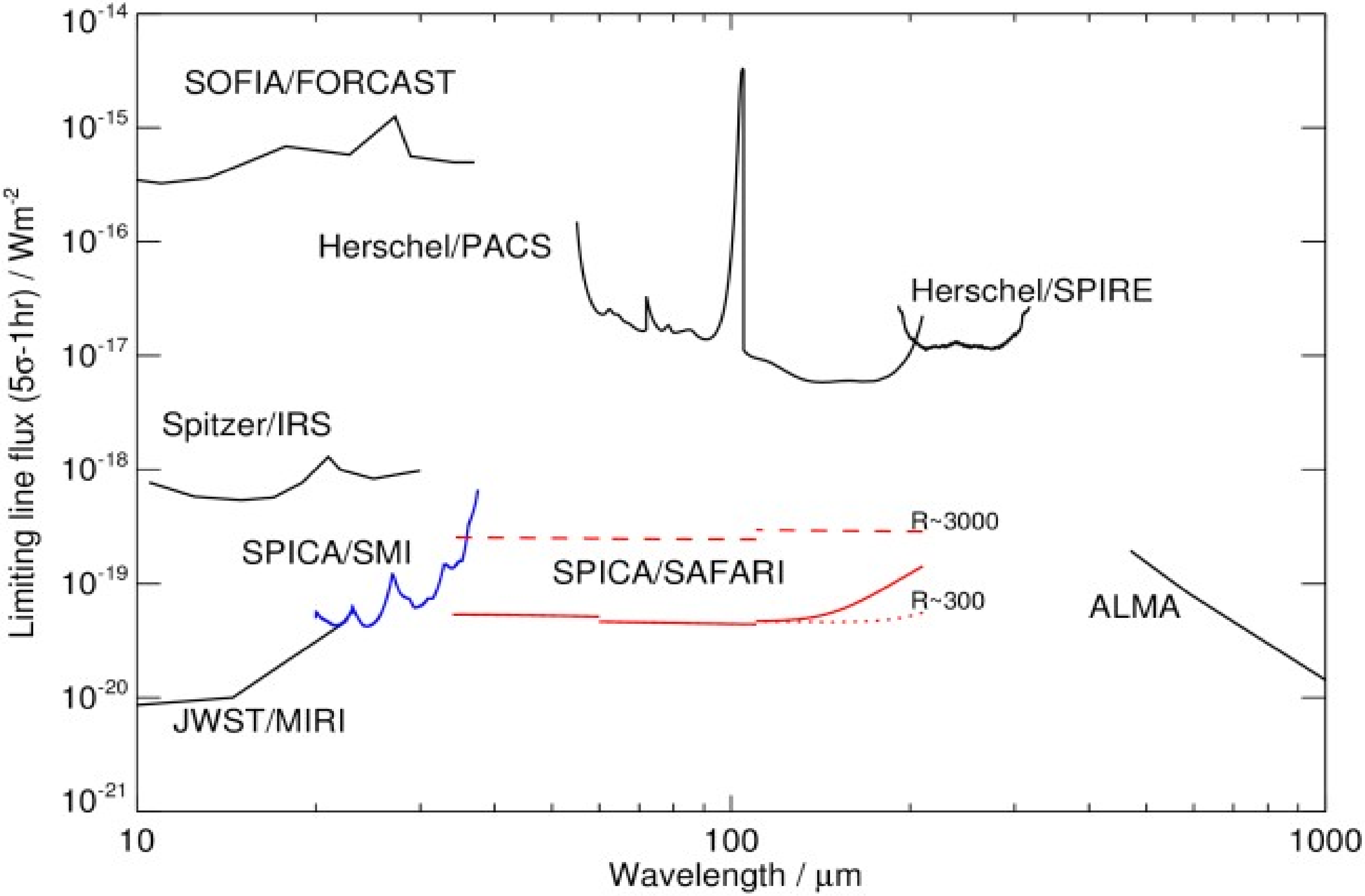
SMI-HRS

Immersion grating + Si:As
12 – 18 µm, R = 25,000, slit: 4" long;
5σ-1hr ≈ 1.5-3 10-20 W m-2, 2-4.2 mJy

SAFARI: SPICA Far-infrared Instrument

PI: Roelfsema (SRON, NL)

- New design: grating instrument
- 3 bands covering 34-210 µm
- 3 pixels simultaneous on-sky
- Grating R=300: 5σ-1hr: ≈5 10-20 W m-2, ≈0.5 mJy
- Fabry-Perot R=3000: 5σ-1hr ≈ 2.5 10-19 W m-2, ≈30 mJy
- Mapping spectroscopy possible
- Photometry by degrading spectroscopic data
- Better handling of bright sources (up to 10-50 Jy, depending on the band and background)


SOFIA/FORCAST
Herschel/PACS
Herschel/SPIRE
Spitzer/IRS
SPICA/SMI
SPICA/SAFARI
R~3000
R~300
ALMA
JWST/MIRI
Limiting line flux (5σ-1hr) / Wm^{-2}
Wavelength / μm
10
100
1000
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}

SPICA Main Science Goals

- Galaxy formation and evolution over cosmic time

  (co-coordinators: Luigi Spinoglio, Lee Armus)

- Lifecycle of gas and dust within the Milky Way and the local Universe

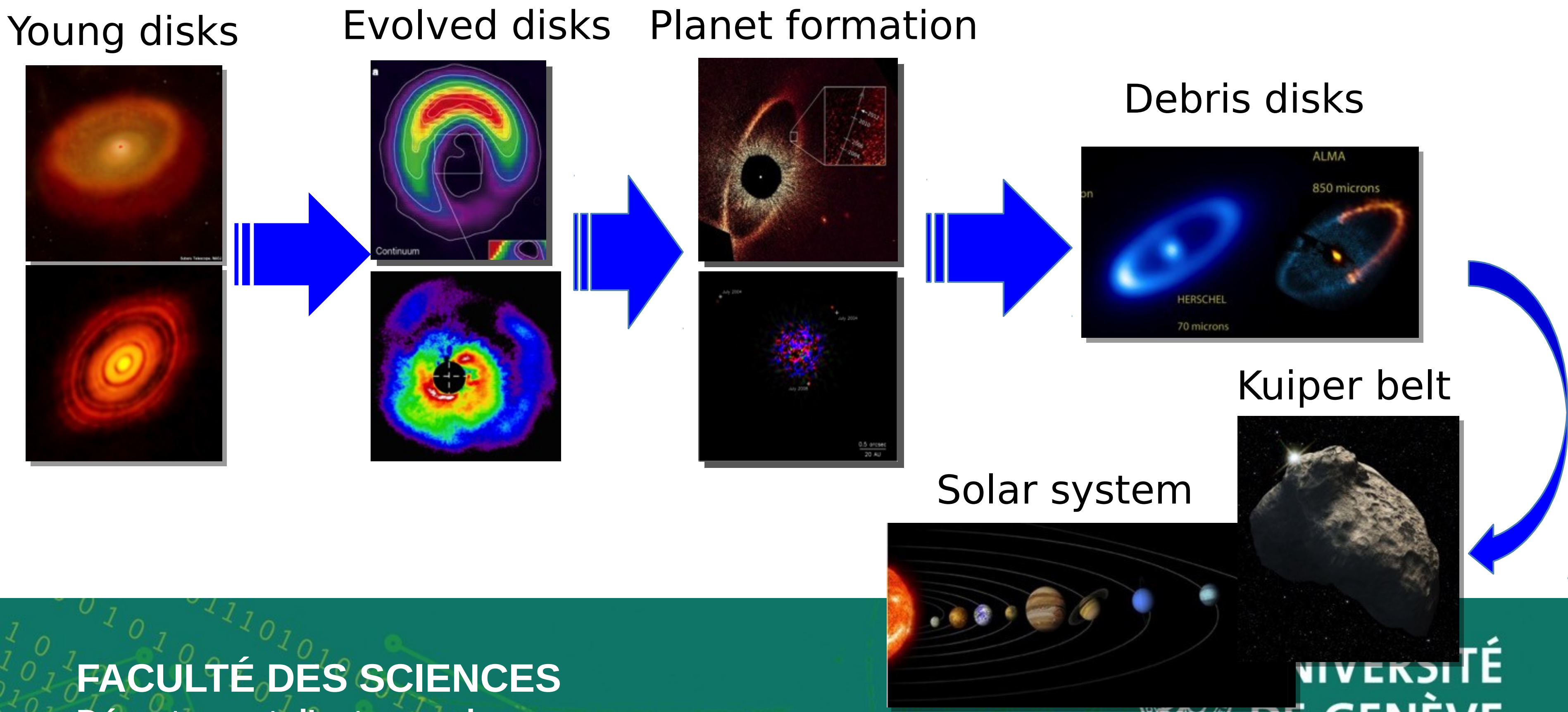
  (co-coordinators: Floris van der Tak, Suzanne Madden)

- Tracing gas, ice, and dust evolution in (proto)planetary systems

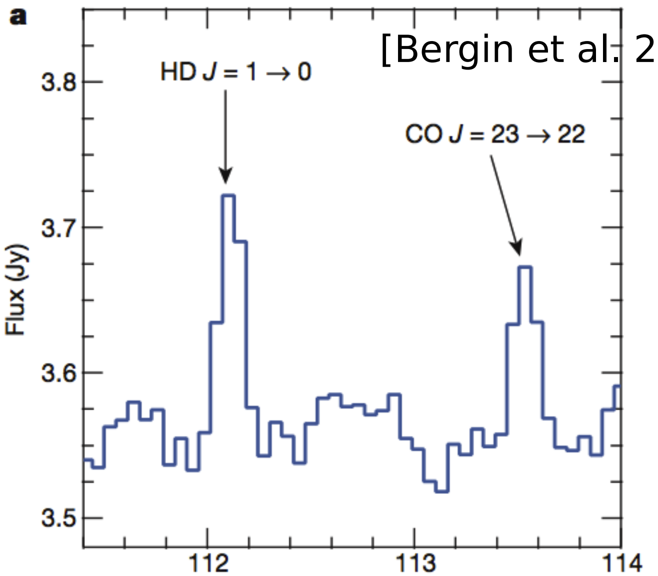
  (co-coordinators: Inga Kamp, Marc Audard)

Tracing the gas, ice and dust evolution in (proto)planetary systems

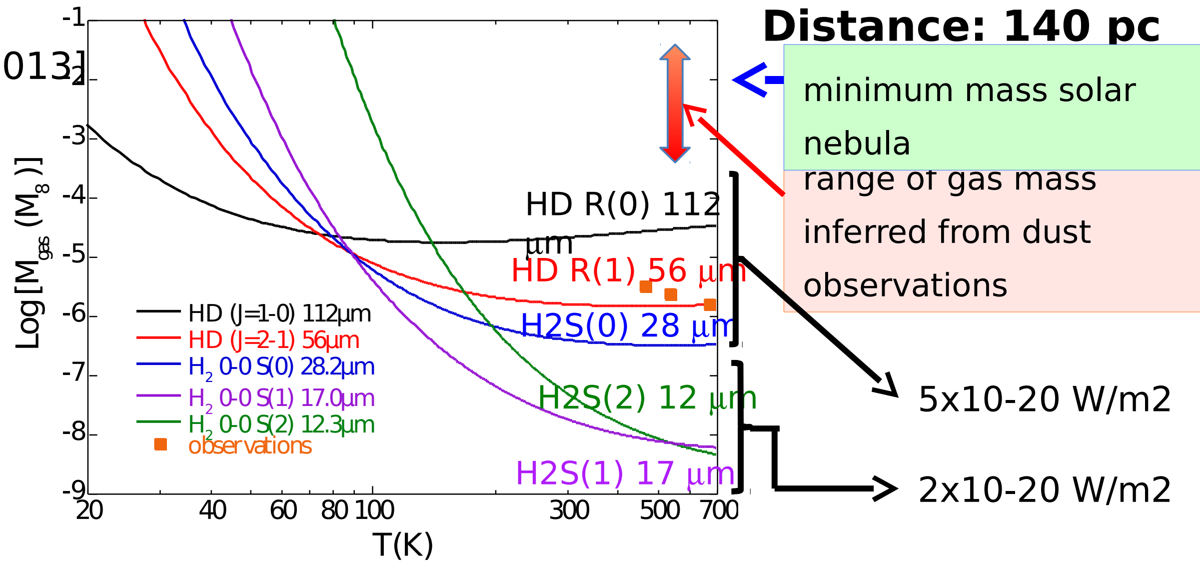
SPICA's mid- to far-IR spectroscopy will provide crucial information on the evolution of gas, the thermal and chemical history of building dust and ice blocks of planets, and relate nearby Kuiper belt objects to distant debris disks.



Disk Gas Mass Evolution (HD)



[Bergin et al. 2013]



HD lines optically thin

HD abundance unaffected by chemistry and dust

Science goals SMI/SAFARI:

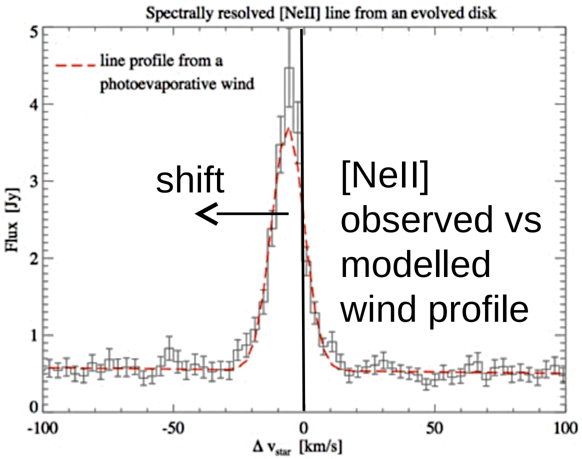
- direct disk gas mass evolution through HD

→ Robust disk mass probe of cool H2

Uniqueness: several lines of HD probing a wide range of Tgas

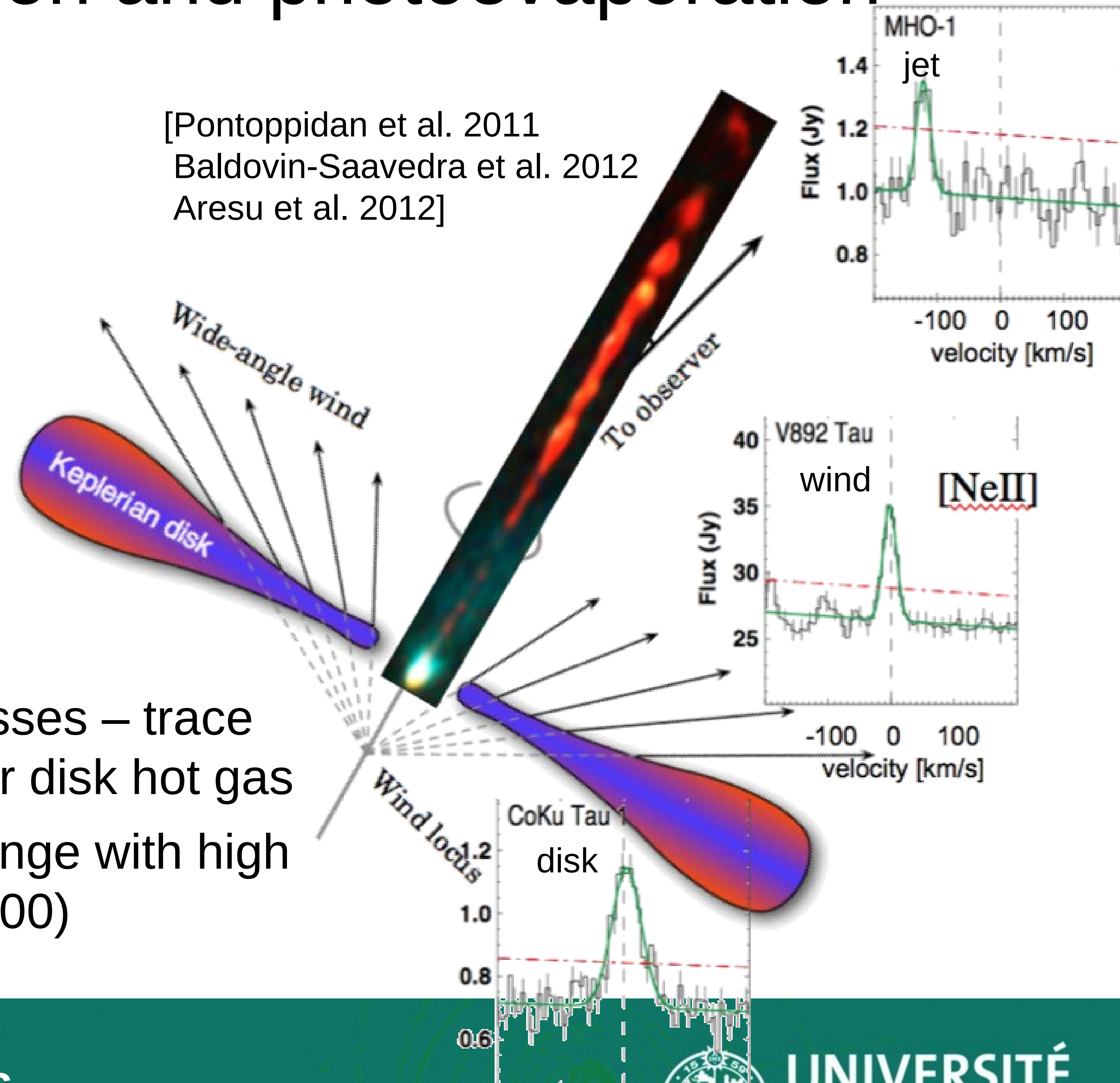
HD J=1-0 @112µm (Tex=128.5K) and J=2-1 @56 µm (Tex=384.6K)
NB: higher excitation lines in SMI range (at high R)

Gas dissipation and photoevaporation



[Pascucci et al. 2012]

[Pontoppidan et al. 2011
Baldovin-Saavedra et al. 2012
Aresu et al. 2012]



Science goals SMI:

- gas disk dispersal processes – trace directly launching of inner disk hot gas

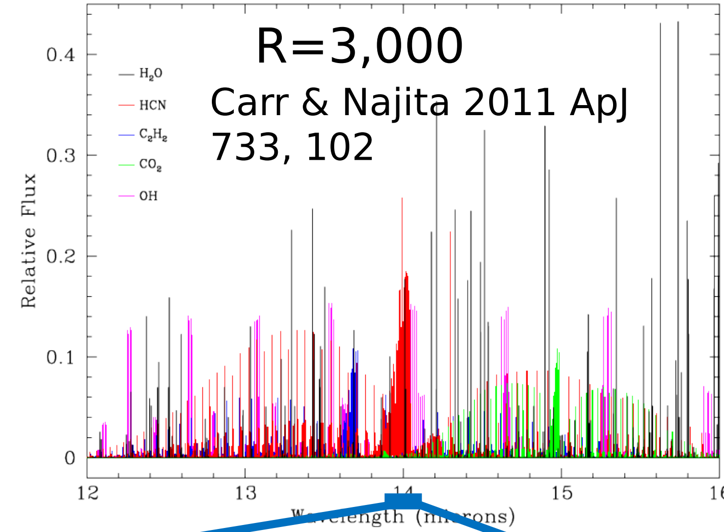
Uniqueness: 12-18 μm range with high spectral resolution (R~25000)

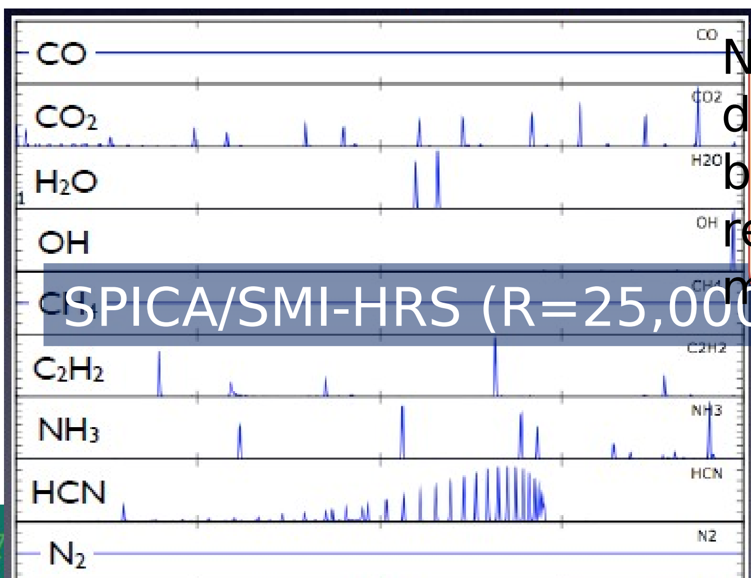
Courtesy I. Kamp

Chemistry in protoplanetary disks

- Spectral range of 12–18 μm contains numerous emission bands of major C-bearing molecules, HCN, C2H2, and CO2, as well as lines of H2O and OH.

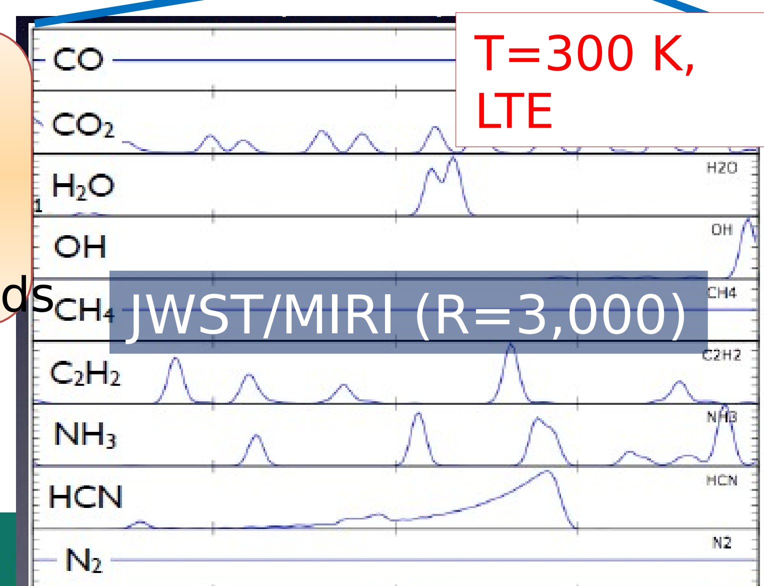
Velocity-resolved H2O, OH, HCN, CO2, C2H2 lines
→ C/O ratio distribution at <~1–2 AU in disks





13.9 14.0 14.1
Wavelength (μm)

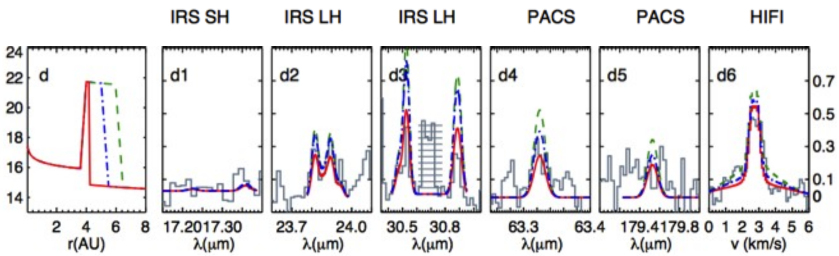
Not only de-blending, but also resolving molecular bands



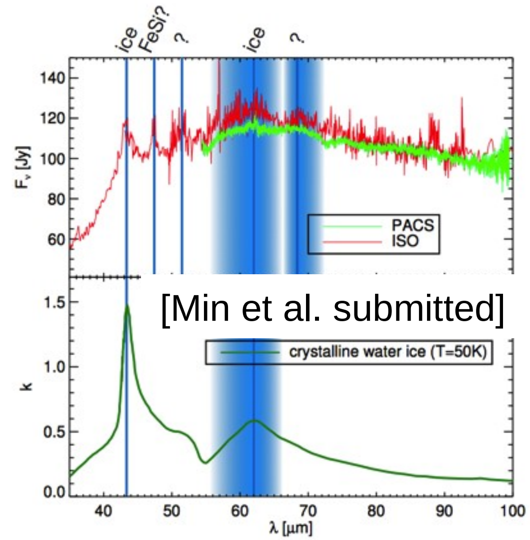
13.9 14.0 14.1
Wavelength (μm)

Courtesy by T. Onaka

The Water Trail

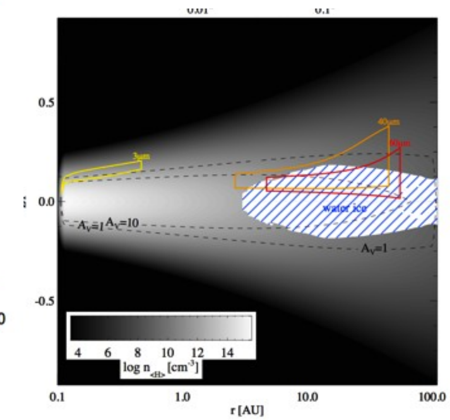


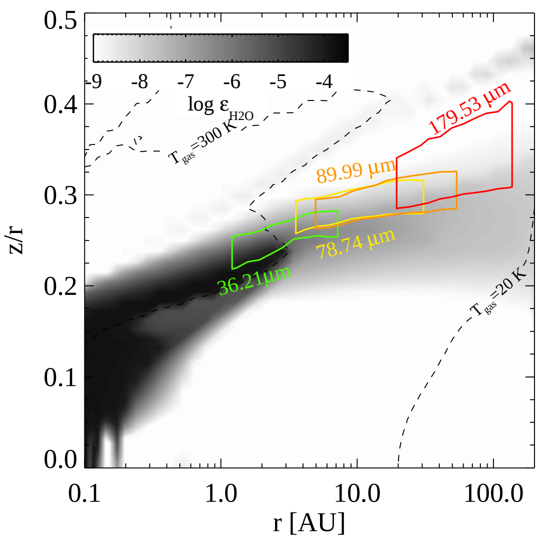
[Zhang et al. 2013]



[Min et al. submitted]

thermal emission from water ice in a standard T Tauri disk





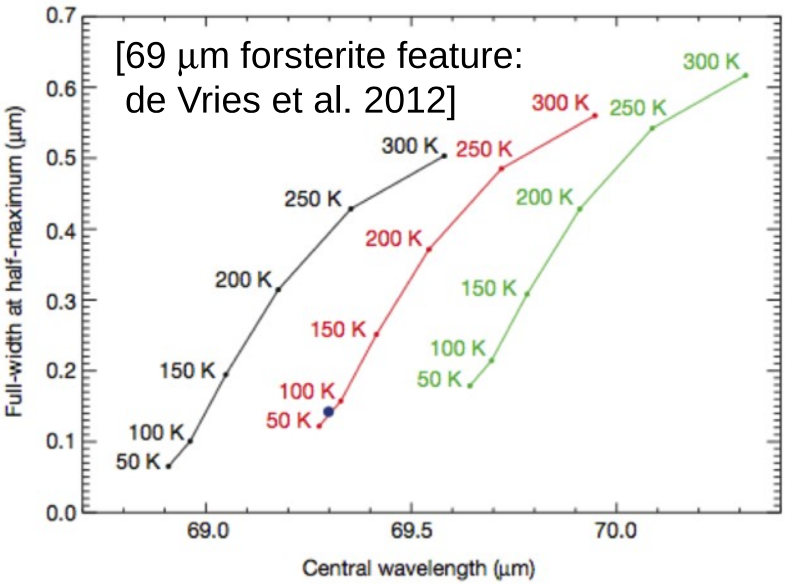
[FT Tau disk model: Garufi et al. 2014]

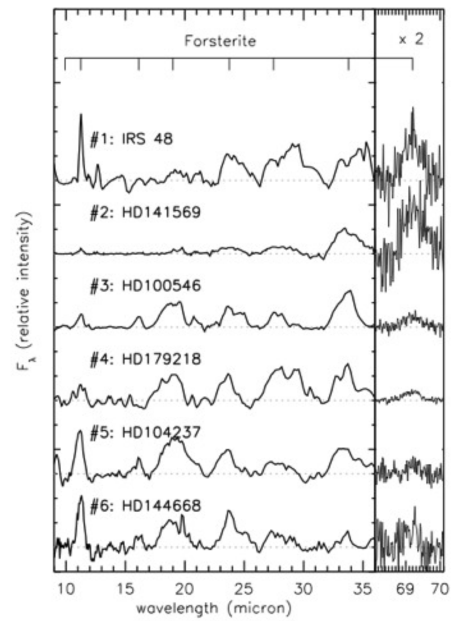
Science goals SMI/SAFARI:

- trace the snow line with line fluxes (drop-out method)
- study the thermal history of ices during disk evolution

Uniqueness: ice features, broad λ coverage

Mineralogy of Planet Forming Disks



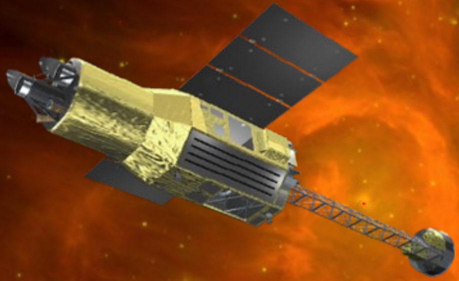


[10, 20 and 69 µm features:
Maaskant et al. 2015]

Science goals SAFARI(/SMI – DD?):

- determine evolution of composition and lattice structure of grains

Uniqueness: features beyond 30 µm (e.g. forsterite, calcite, dolomite, pyroxene)



Conclusions

- X-rays will contribute further in the study of accretion (and jets) with ASTRO-H and Athena
- Plasma electron densities will be routinely measured at least up to distances of Orion
- In the post-JWST era, SPICA will fill the gap in the mid and far-infrared at unprecedented sensitivities, studying