Report from

High Throughput UV/EUV Spectroscopy sub-WG

Toshifumi Shimizu (ISAS/JAXA)

high throughput UV/EUV spectroscopy sub-WG

High throughput UV/EUV spectrograph

- Instrument for quantitative investigations on the physics of dynamics with UV/EUV **spectroscopy** -

Objective:

Quantitatively observe **energy flows at dynamic times scale over the entire atmosphere** from chromosphere to hot corona **with high resolution**, high throughput spectroscopy in UV-EUV and understand physics of dynamics and heating.

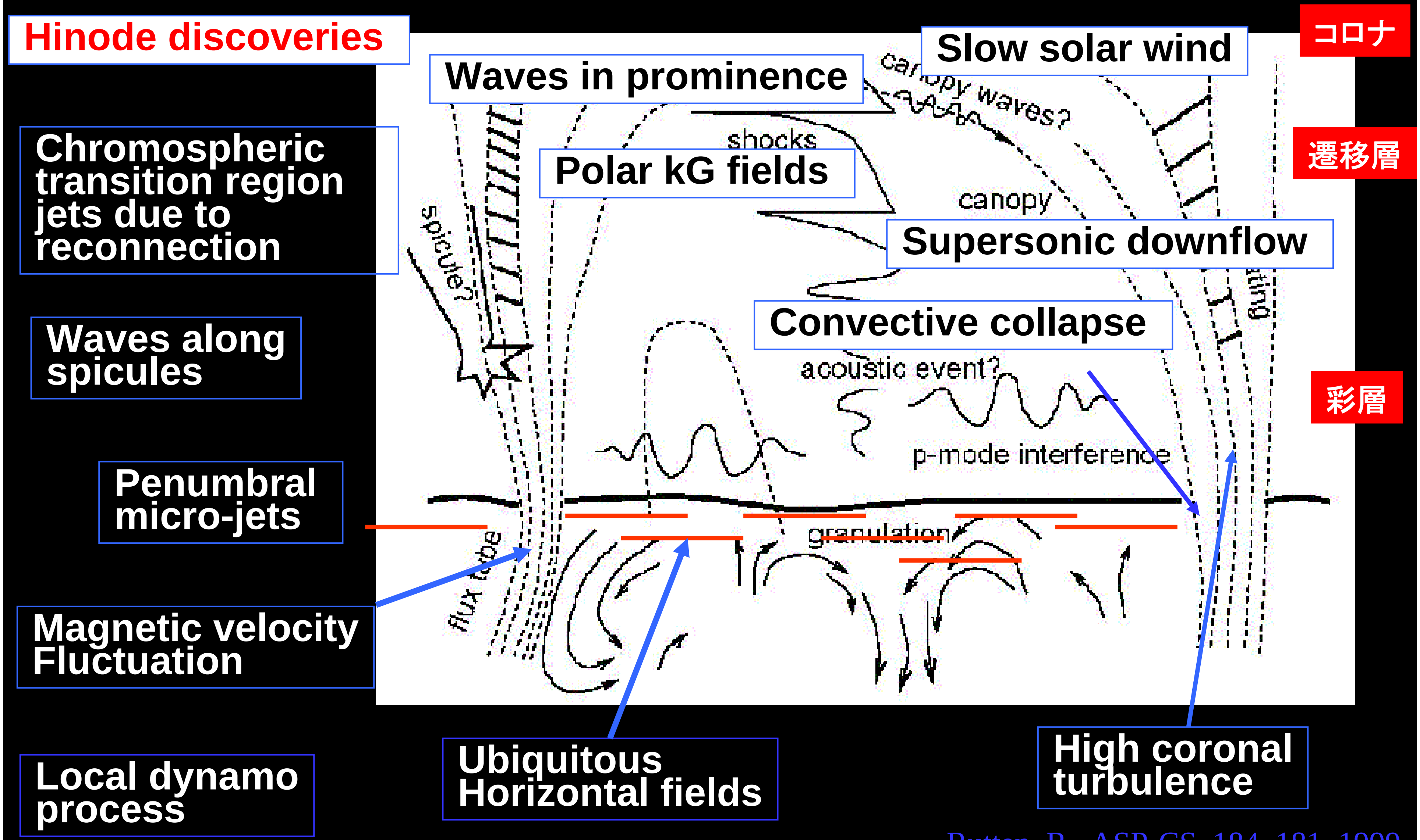
Study Activities:

• International high-throughput UV/EUV spectroscopy sub-WG working for science & feasibility investigation of the instrument.

Luca Teriaca (MPS)
Udo Schuehle (MPS) - instrument expert
Louise Harra (MSSL)
George Doschek (NRL, co-chair for this sub WG)
Clarence Korendyke (NRL) - instrument expert
Joe Davila (NASA/GSFC)
Ted Tarbell (LMSAL)
Hiroaki Isobe (Kyoto University)
Shinsuke Imada (ISAS/JAXA)
Tetsuya Watanabe (NAOJ)
Hirohisa Hara (NAOJ)
Toshifumi Shimizu (ISAS/JAXA, Chair for this sub WG)

Quantitative understanding of highly dynamic atmosphere

waves, turbulence, magnetic reconnection



Rutten, R., ASP-CS, 184, 181, 1999

High throughput UV/EUV spectrograph

- Instrument for quantitative investigations on the physics of dynamics with UV/EUV **spectroscopy** -

- B案衛星に搭載を想定した大型の分光器
  - 目指す装置方向性
  - サイエンスケース
- A案衛星に載せる小型化分光器

B案衛星
High throughput UV/EUV spectrograph

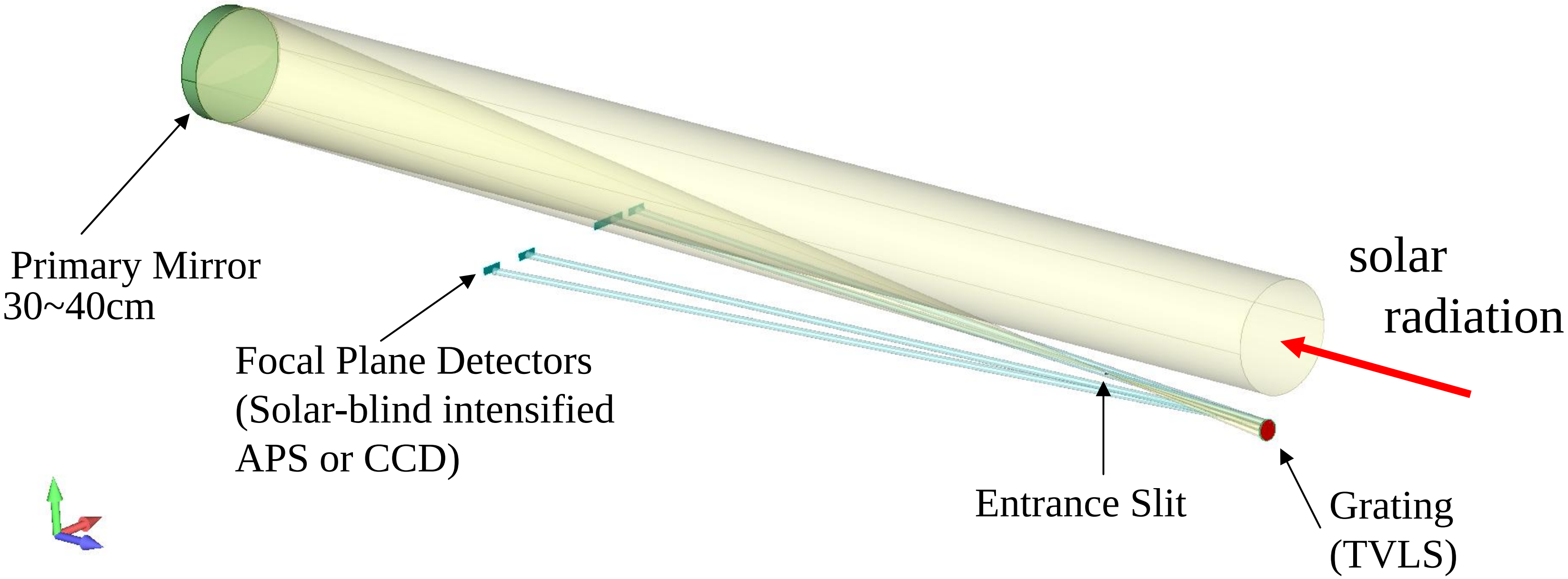
- 将来の分光望遠鏡の方向性（装置に求める性能）

1. ***高い時間分解能(頻度)*** ダイナミックな活動の物理的診断。既存の分光望遠鏡に比べ1桁以上高いスループット。
2. ***広い温度範囲をくまなくカバー*** 彩層(1万度)から高温コロナ・フレア(1000万度)のプラズマを同時診断。多温度プラズマから成る構造を理解
3. ***高い解像度*** ひのでSOTが分解した彩層磁場構造（スピキュール等）の上空への結びつきを確実に特定。0.5秒角以下 (0.2-0.3”目標)。
4. ***可能な限り広い視野*** 高解像度の視野は~5x5分角以下に制限されるが、低解像度では広い視野をカバー。宇宙天気とのリンク。
5. ***低散乱光での観測*** 低いEM領域の診断を可能に。磁気リコネクション領域、オフリム上空(太陽風加速, 衝撃波)など。
6. ***他望遠鏡との協調*** 他の搭載望遠鏡からの観測データと確実な比較研究を可能に。コアラインメント。

High throughput UV/EUV spectrograph

Performance much improved from previous instruments

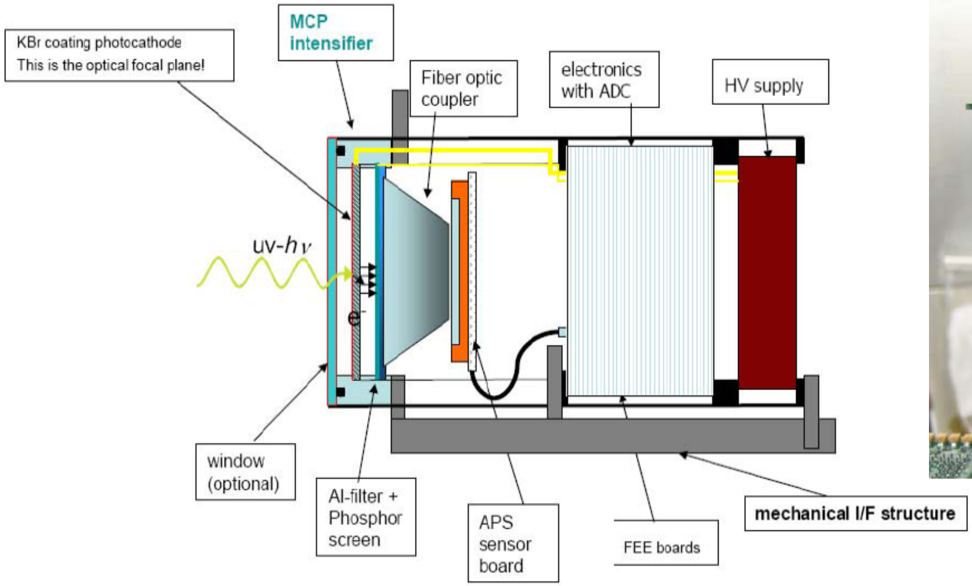
大型分光望遠鏡の雛形概念図



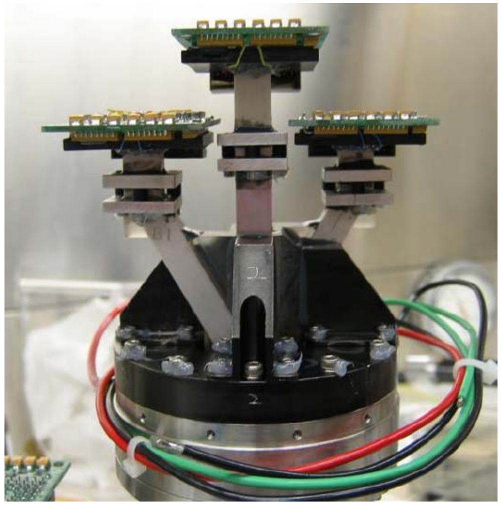
- By removing metal filters with solar-blind intensified detector, having minimum numbers of optics and ~30cm aperture, we expect >10 improvement in effective area from EIS and SUMER.

High throughput UV/EUV spectrograph

Performance much improved from previous instruments

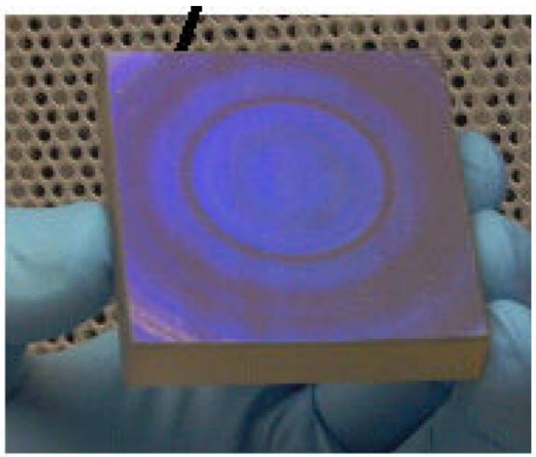


ロケット実験EUNIS用センサ部（例）



TVLS (Toroidal Varied Line-Space) グレーティングにより、光学拡大率を持つことが可能に。サブ秒角の解像度の実現が可能に。

UV光に感度をもつマイクロチャンネルプレート(MCP)を使用。太陽可視・赤外光に感度をなくす設計で、金属プレフィルタ(の厚み・枚数)を削除する。センサはCCDかAPS（高速読み出しに利点）が候補。

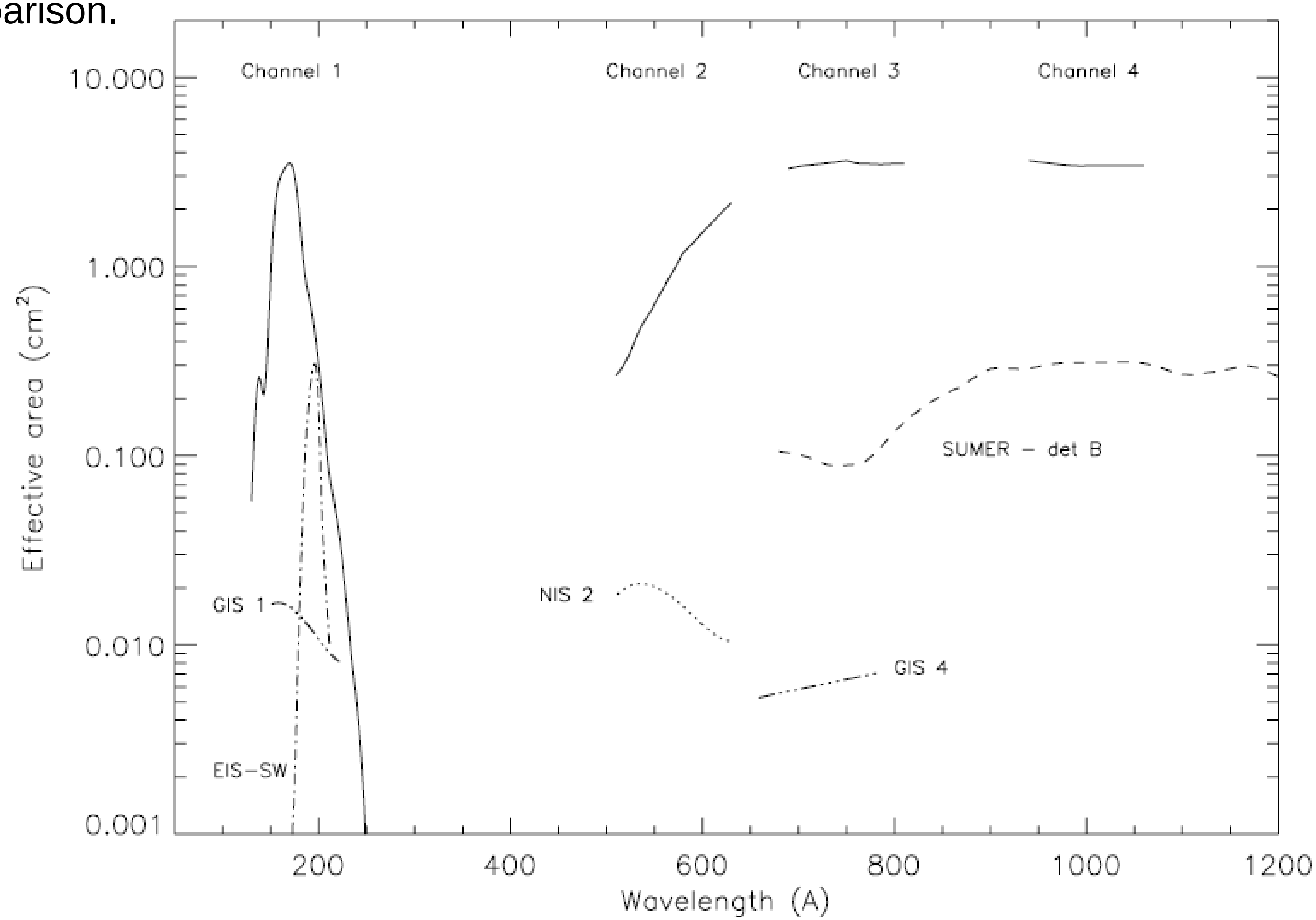


High throughput UV/EUV spectrograph

Performance much improved from previous instruments

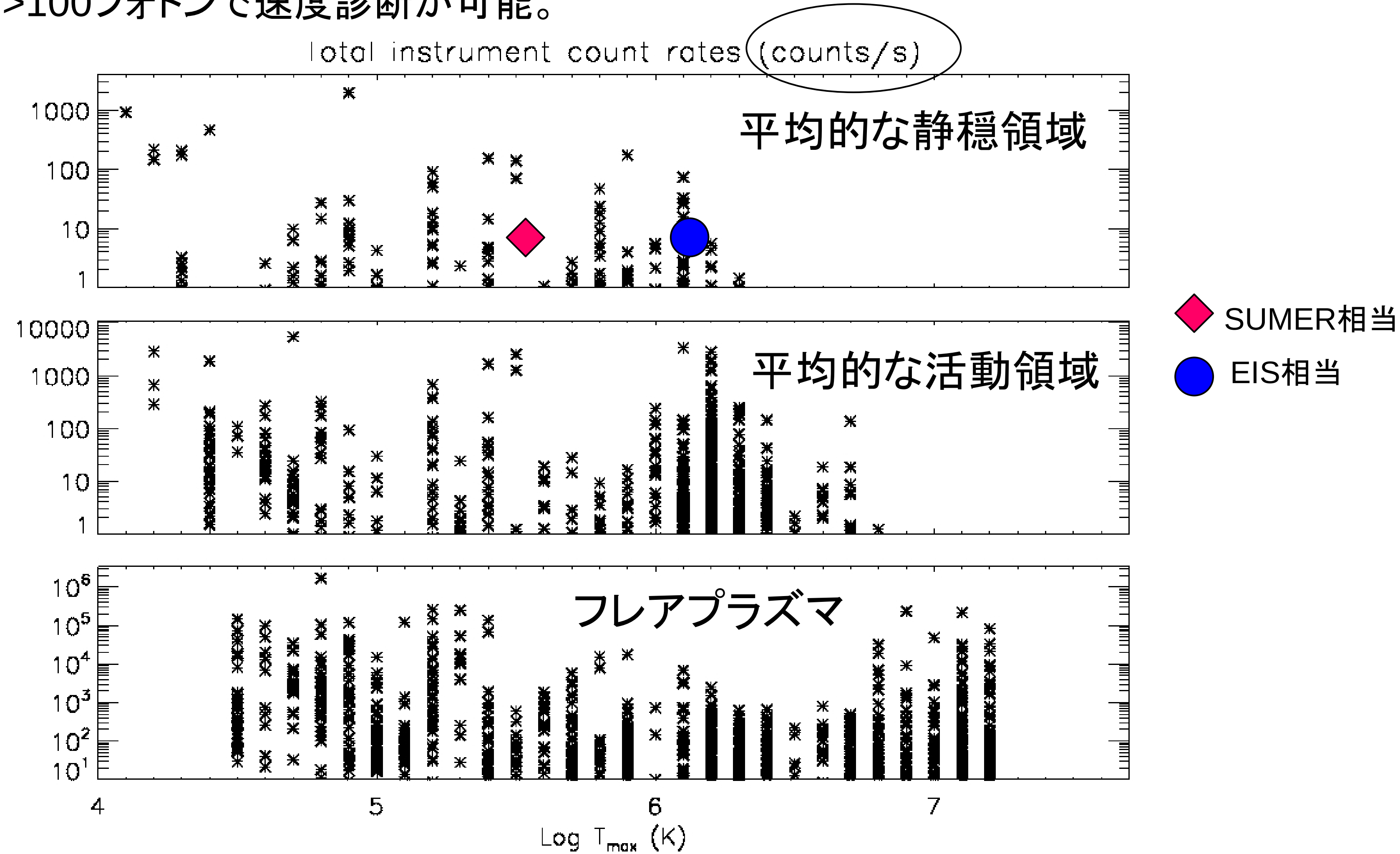
Effective area of the strawman instrument (solid lines).

Previous comparable effective areas for EIS, CDS and SUMER are plotted for comparison.



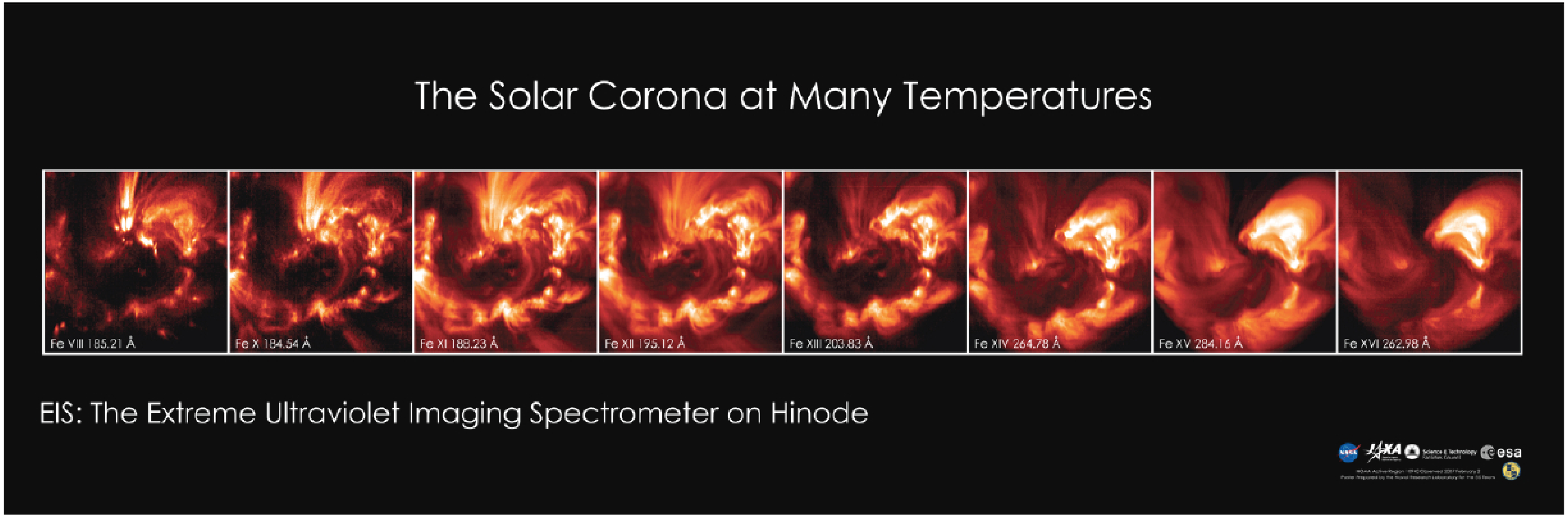
UVラインのフォトン数(輝線形成温度の関数で)

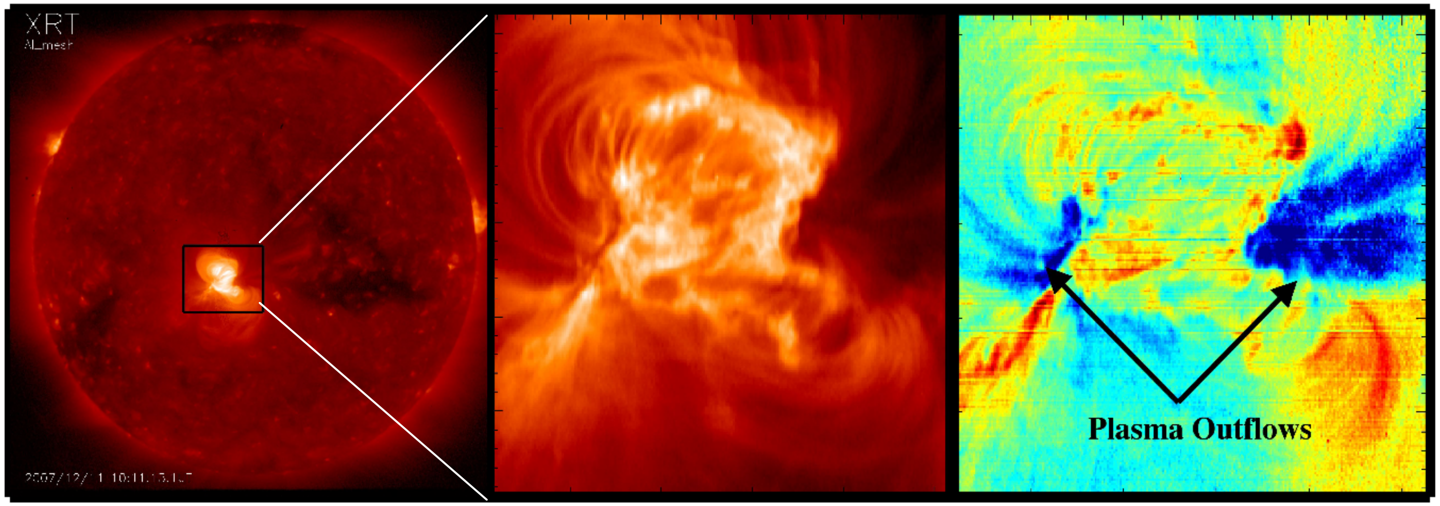
各点が雛形の観測波長内の各ラインで期待されるフォトン数。空間サンプリング0.33"にて。>100フォトンで速度診断が可能。



- Temporal resolution can be more improved with observing **bright lines**, which are formed in wide temperature range in 10^4-10^7 K.

既存の装置 Hinode/EIS





EIS intensity and velocity maps to show plasma outflows from the edges of the active region, June 27, 2009, Credit Deb Baker

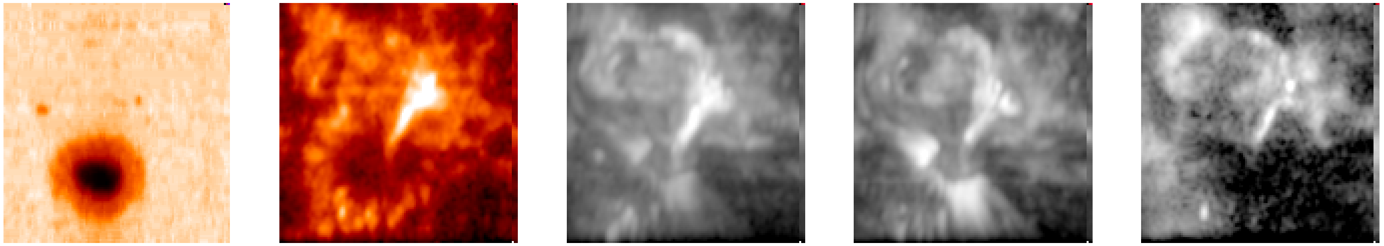
既存の装置 Hinode/EIS: Insufficient performance

- EIS is a very good instrument, but ….
- Need long exposure for the quiet Sun observations. ~100 s required.
- It is also true for some topic of active region observations
  - ~ 1hr scan duration for 4x4 $arcmin^2$ for line width measurements
- Low spectral resolution for line profile analysis
- Weak TR lines in the EIS wavelength band
- We now know that there are unresolved structures.

VUV spectrograph SUMER on SOHO

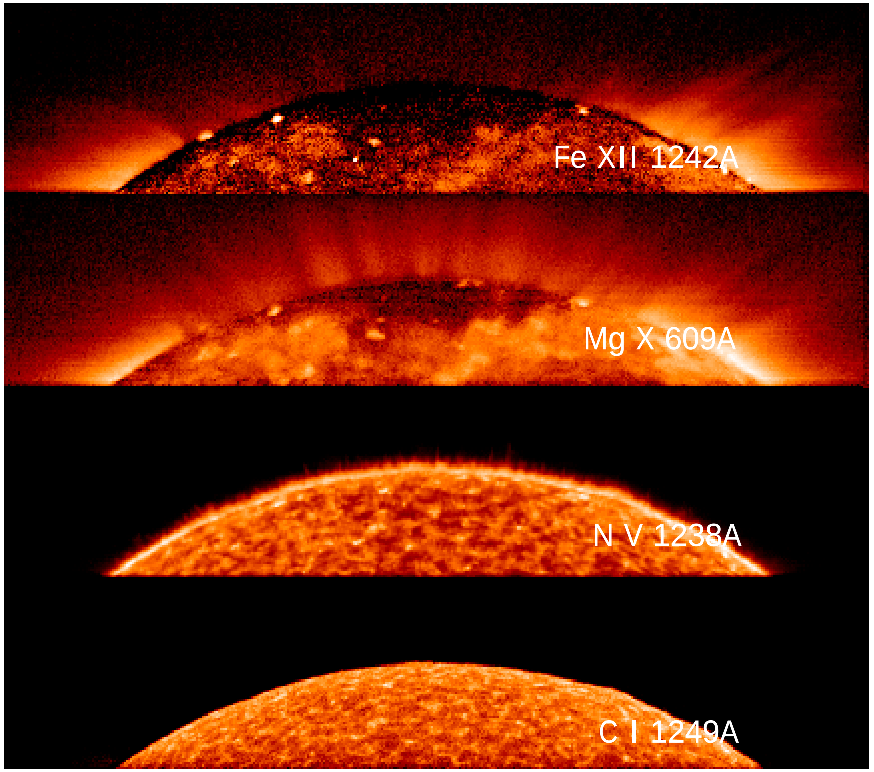
Spectral coverage from 800 to1600A, where spectral lines from TR is rich.

raster scan of sunspot:



vis 6330A | cont. ~1250A | N V 1238A | O V 629A | Fe XII 1242A

raster scan of polar region:



EISで弱い遷移層の診断を可能とする輝線があるが、時間分解能・空間分解能が不十分。

既存の装置 Hinode/EIS: Insufficient performance

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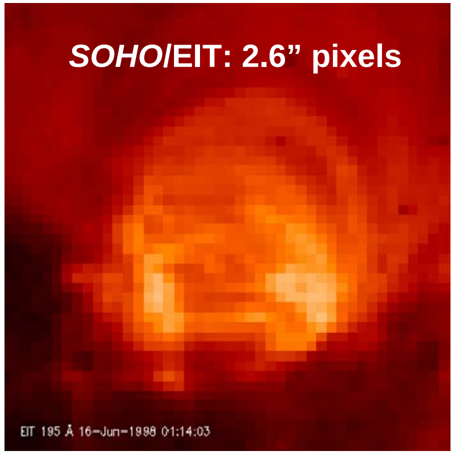
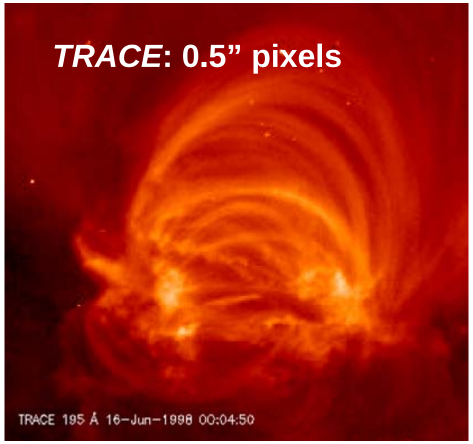
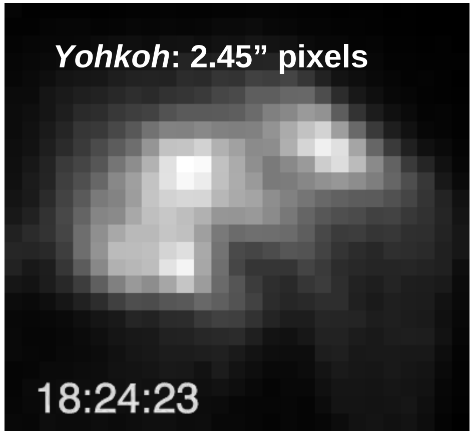
Unveiling the Microphysics of the Solar Corona

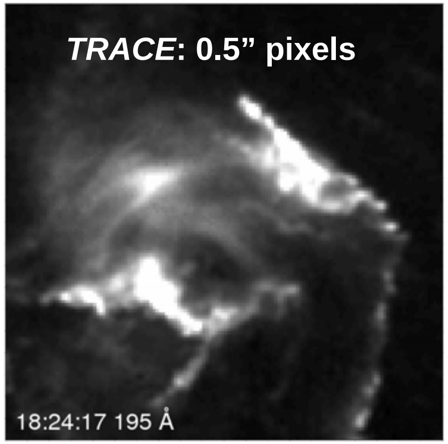
- •Particle acceleration
- •Magnetic reconnection
- •Ion-cyclotron wave heating
- •Turbulent cascades
- •Non-Maxwellian distributions

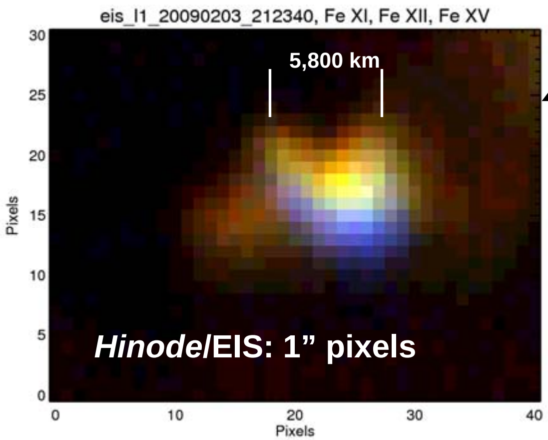
Seeing the microphysics requires high spatial and spectral resolution coupled observations from the photosphere into the corona











Elementary heating event in a polar coronal hole. This event is clearly unresolved at ~EIS/ TRACE spatial resolution.

Plan B Solar-C: 0.1” – 0.3” spatial resolution will provide an exact match from the photosphere into the corona, thus allowing resolution of elementary heating events and traceability of footpoint mechanical energy into the coronal magnetic field and into consequent plasma heating.

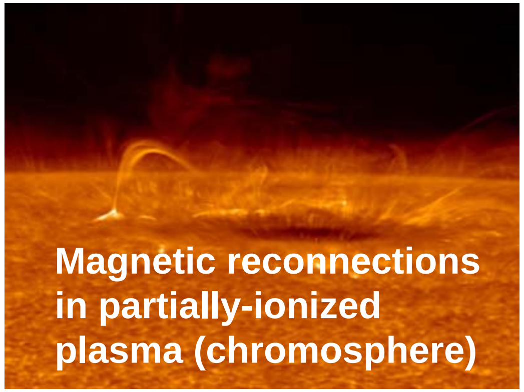
Science Goals

- **Trace energy flow at natural dynamic solar time scales over a large dynamic range from the photosphere into the corona through small spatial-scale elementary solar structures and determine the resulting large-scale structures (Understand the physics of the beta = 1 region)**
- **Understand physical processes such as magnetic dissipation and reconnection in astrophysical plasmas, under a wide variety of physical conditions. (Measure the magnetic field in the chromosphere; make accurate extrapolations of the coronal field)**
- **Understand and spatially resolve elementary atmospheric structures over each temperature domain of the atmosphere and determine how they are created and evolve**
- **Understand how small-scale physical processes initiate large scale dynamic phenomena creating space weather**
- **Understand how physical processes alter coronal properties such as variations in its composition (put in for supporting in situ measurements)**
- **Particle acceleration???**

新しいサイエンスの窓への期待

- 磁気エネルギ開放過程(磁気リコネクション)の真髄に迫る
- 彩層~遷移層~コロナの磁気カップリング
  – コロナ加熱: エネルギー・物質輸送
  – 磁気大気の素構造　彩層磁場
- オフリム観測: 太陽風加速、衝撃波面
- 宇宙天気研究への展開
  – 大きな構造・現象(CME, フレア, 太陽風)とミクロな物理過程

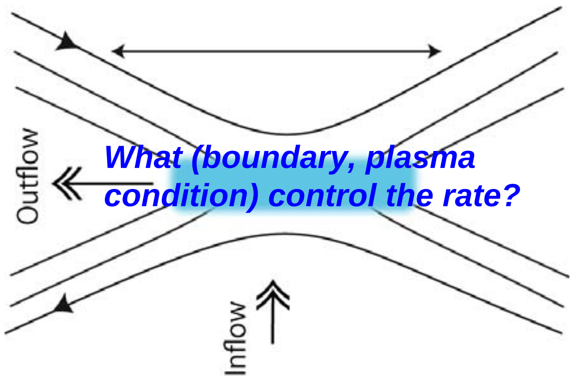
磁気エネルギ開放過程(磁気リコネクション)の真髄に迫る (→ 今田講演)



For understanding astrophysical plasma

Exploring physics of magnetic dissipation (reconnection)

Why the dissipation is so fast?



It is a key point to make direct measurements of plasma in the area close to diffusion region.

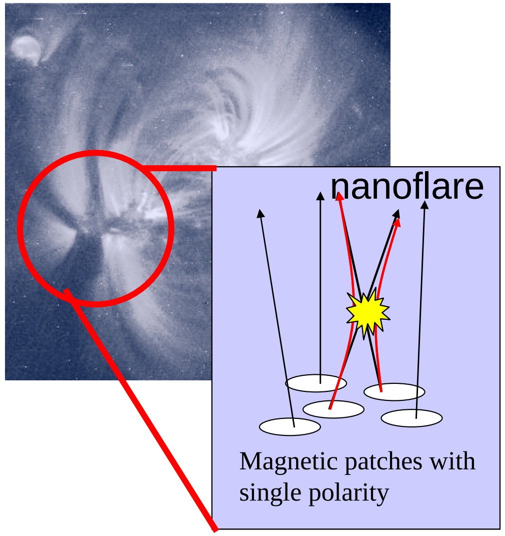
For understanding nature of dynamics in the solar plasma, flares, and CMEs.

It is a key point to make high cadence measurements for dynamics.

It is a key point to investigate simultaneously the broad temperature range.

Heating problem (Corona, Chromosphere)

Fundamental structures of energy flows in dynamic time scales?



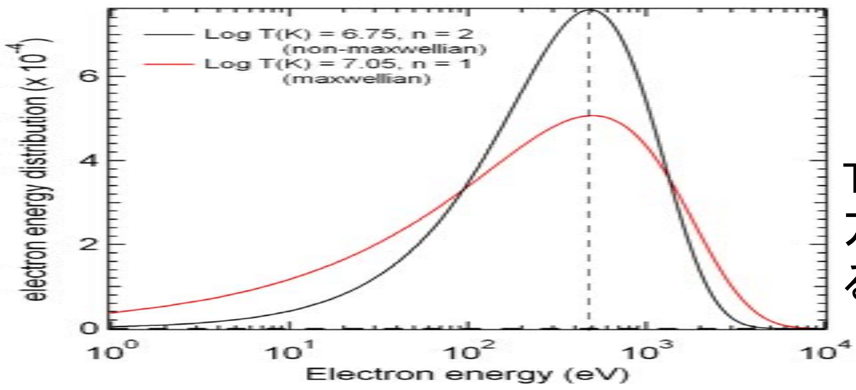
Their connection to magnetic fields in the chromosphere/ photosphere?

20 Jan 2010

時間・空間分解能の向上で、

1) 磁気リコネクションによって一時的に生成される非平衡プラズマの状態
2) 電子速度の非マクスウェル分布の情報
3) イオン温度分布 (Imada et al 2008)

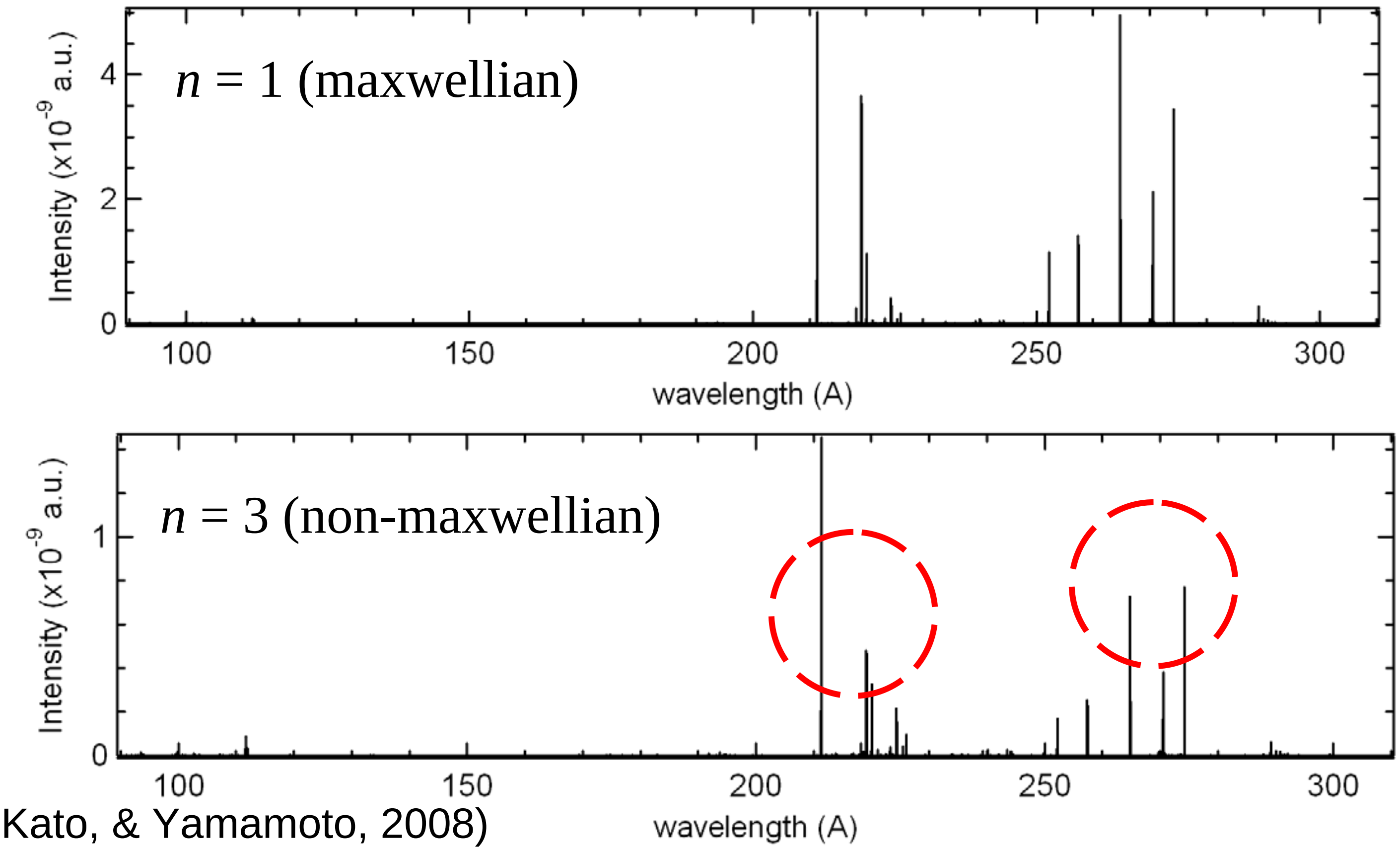
などを探ることができる。



Te~650eV(750万度)に対応する電子温度分布

Line Spectra on **Fe XIV**

$\log T_e$(K)=6.3, $N_e=10^{11}$cm^{-3}, $T_p=T_e$, $N_p=0.83N_e$

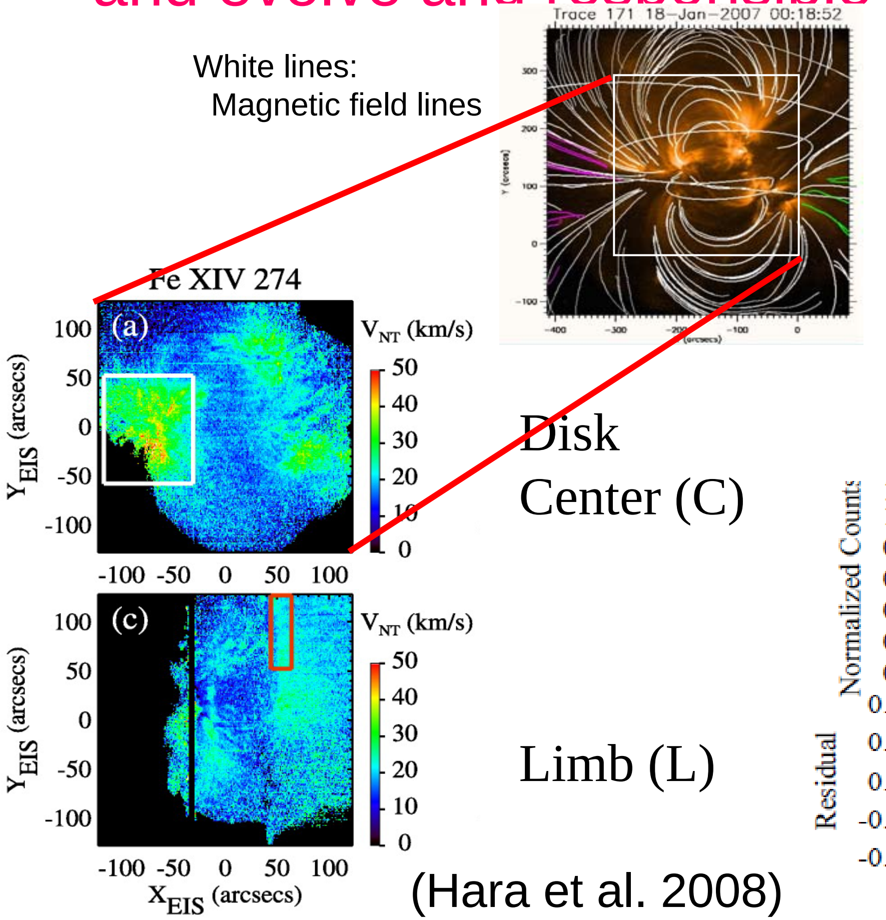


(Watanabe, Kato, & Yamamoto, 2008)

彩層~遷移層~コロナの磁気カップリング
Understanding elementary atmospheric structures

- Understand and spatially resolve elementary magnetic atmospheric structures over each temperature domain of the atmosphere and determine how they are dynamically created and evolve and responsible for heating and dynamics.

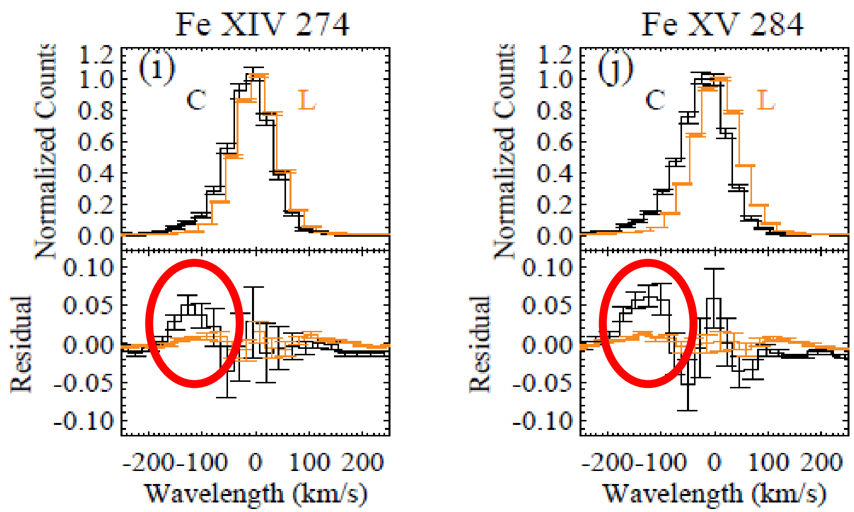
White lines:
Magnetic field lines



(Hara et al. 2008)

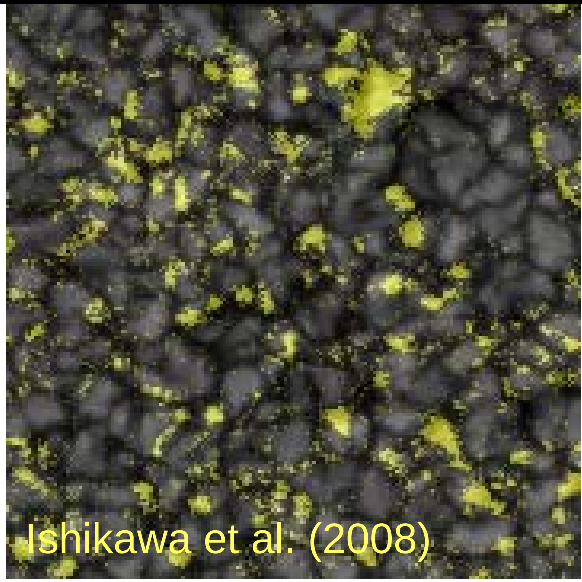
In the corona

- A signature caused by highly blueshifted component (>100km/s) was discovered with EIS observations, which may be a signature of nanoflares at the base of coronal loops

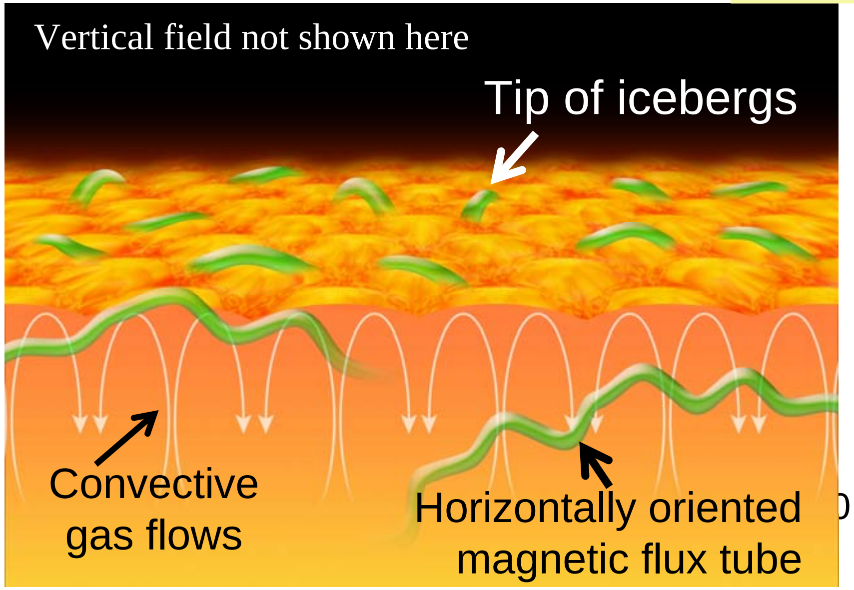


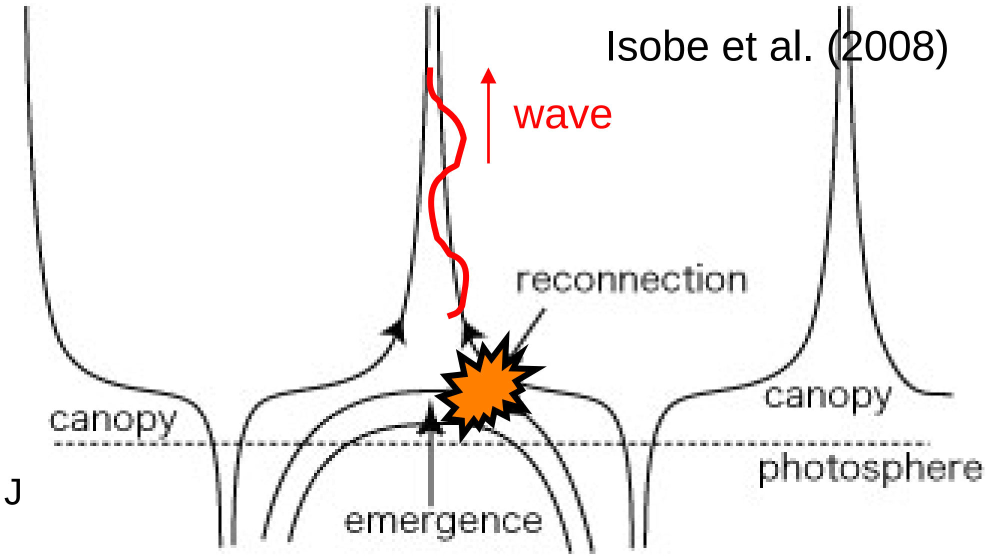
Important roles of weak magnetic fields in chromosphere

Horizontal fields (yellow) overlapped on granule image



- Hinode revealed that small-scale horizontal fields exist ubiquitously and behave dynamically in the photosphere (Lites et. al. 2007, Ishikawa et al. 2008)
- Horizontal magnetic fields may play important roles in forming the magnetic structures in the chromosphere.
- *They may produce* ***nanoflares (magentic reconnections)*** *and* ***resultant MHD waves****, which are important in understanding heating and dynamics of the atmosphere.*

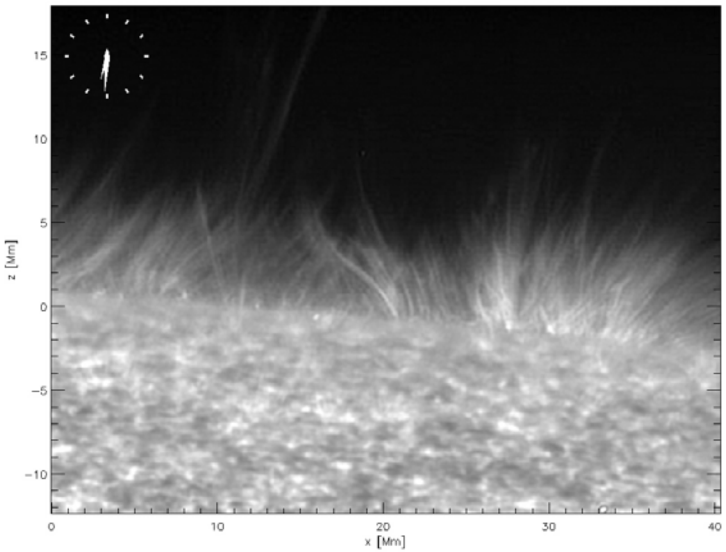


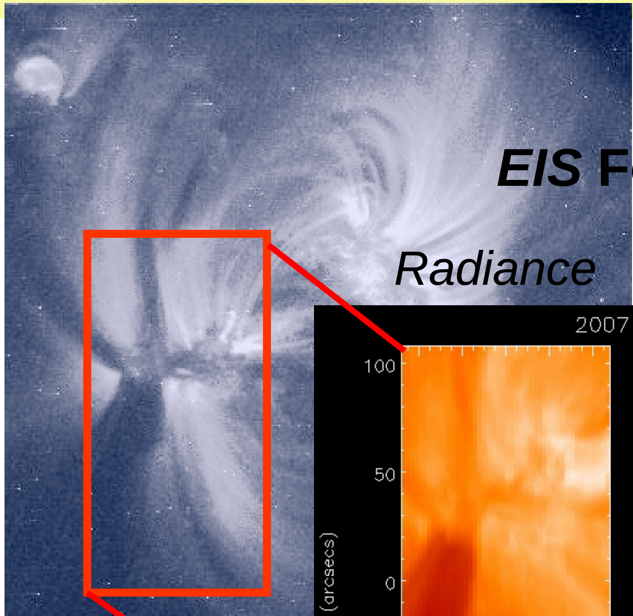


彩層~遷移層~コロナの磁気カップリング
Trace energy and mass flows at dynamic time scales

- Quantitatively understand energy and mass flows at dynamic time scales over a large dynamic range from the photosphere into the corona through small spatial-scale elementary solar structures.

Magnetic dynamic structure
In the chromosphere by SOT



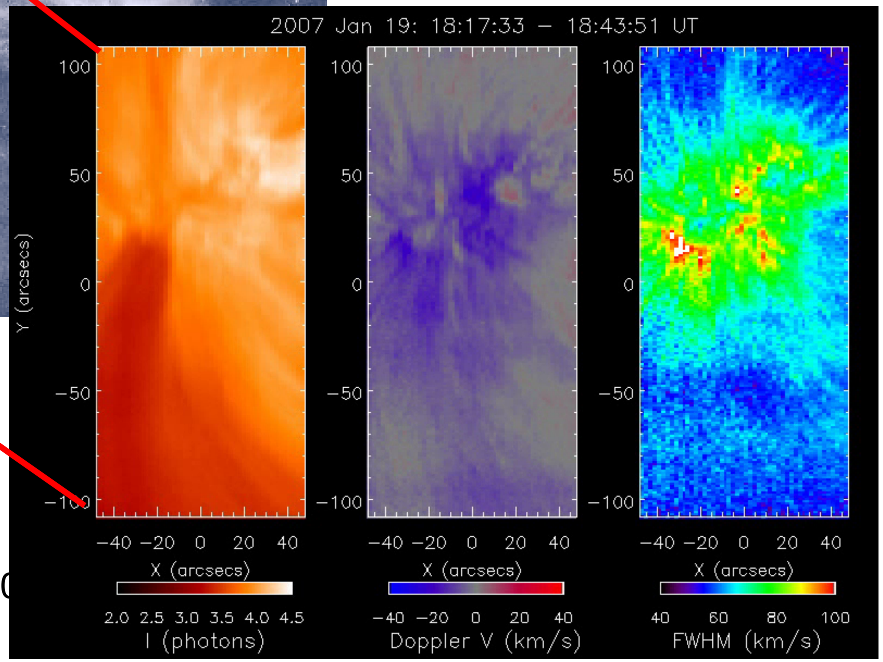


TRACE 171

20 Jan 201

***EIS* Fe XII 195 (~1.4MK)**

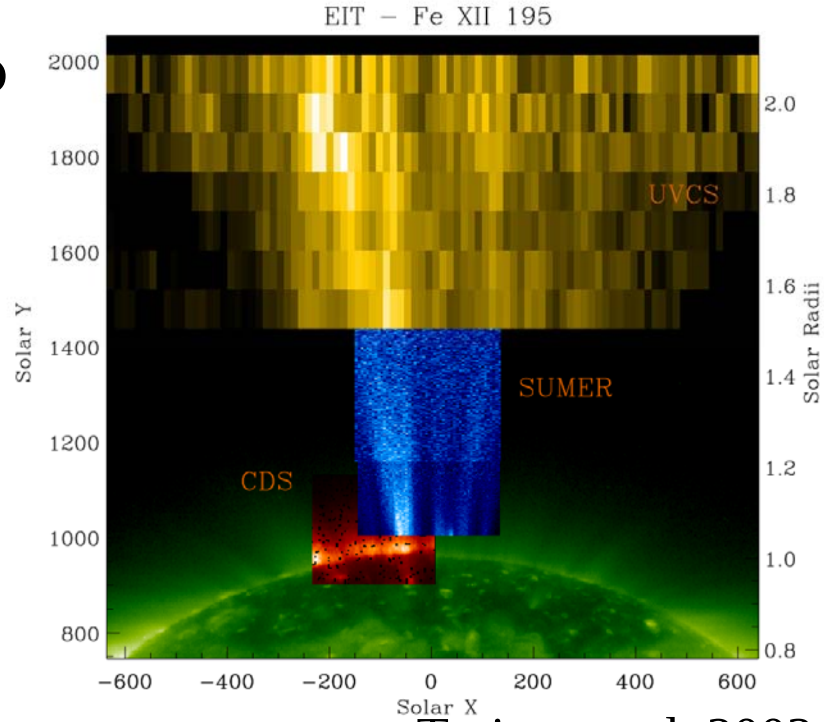
Radiance *Doppler* *FWHM*



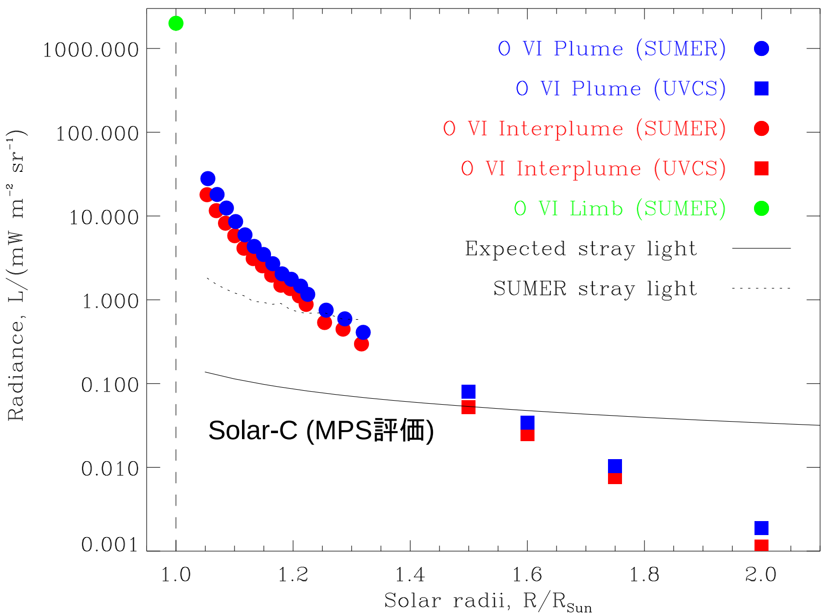
両者を観測から如何に結びつけるか
→ 空間・時間分解能・温度カバー

オフリム観測(1)
Sources of the solar fast wind

- 極域：**高速太陽風加速**における plumes, interplumesの役割は？
- VUV (>1000A)スペクトル観測による診断方法
  - Doppler shift
  - Doppler dimming



Teriaca et al. 2003

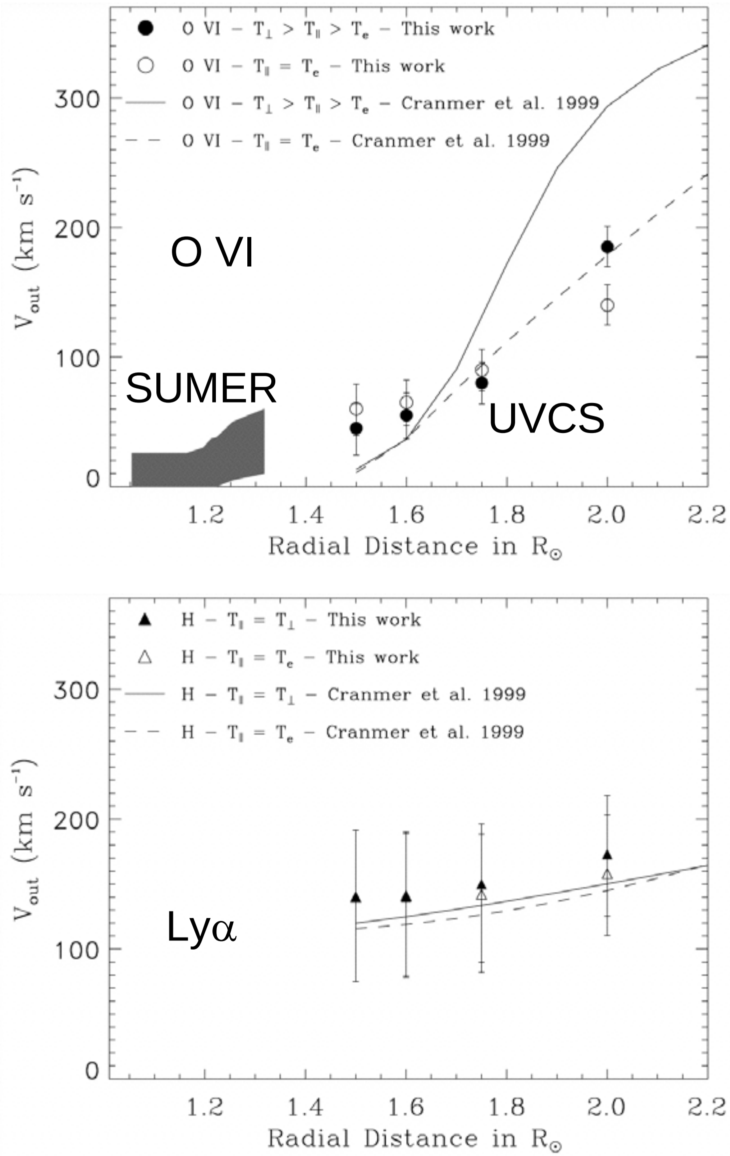


- <u>We need a very good control of the stray-light (micro-roughness ~2 Å rms).</u>

Doppler Dimming

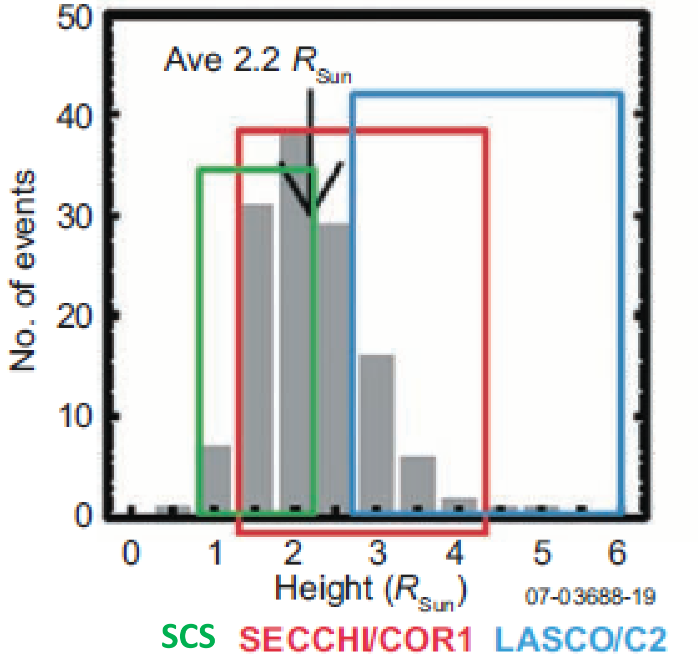
- Allows to determine **the radial component of the plasma outflow velocity** from the analysis of off-limb spectra.
- Line emission mechanisms
  - Electron impact excitation (collisional component).
  - Resonant absorption of disk radiation (radiative component).
  - Example, Ratio of O VI 1032A and O VI 1037A, Lyα
    - 比は、主にNeとアウトフロー速度の関数
- 結果、4者4様
- S/Nの不足, 太陽大気ダイナミックスとの関係 → High throughput

Teriaca et al. 2003



オフリム観測(2) Shocks/Energetic Particles?

- **Type II radio events are generated by coronal shocks**
- **Most are below 3 Rsun**
- **Shocks passing through FOV visible as narrow high temperature events**



Gopalswamy

宇宙天気現象への展開

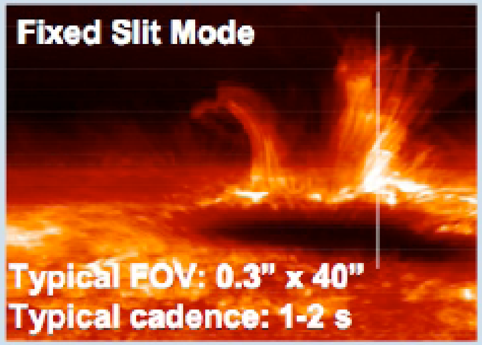
- How microphysics are linked to resulting large-scale structures (such as corona and solar winds) and dynamics (such as flares and CME)?

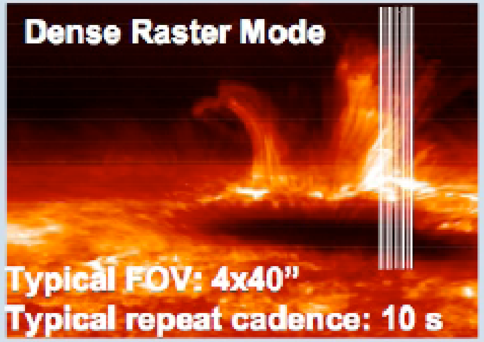
Major jumps from IRIS?

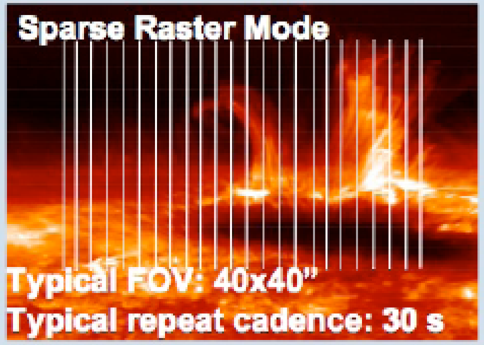
- IRIS (Interface Region Imaging Spectrograph) is approved for launch in 2012.
  - IRIS diagnoses spectral lines in 120-280nm with 0.3” and 1-5s cadence to discover how an outer stellar atmosphere is energized.
  - The spectral lines observed with IRIS are suitable to explore the interface between upper chromosphere and lower transition region.
- Still major jumps from IRIS, because the S-C plan-B can provide unique observations which have never been realized:

  (IRIS-Hinodeデータを見る必要はあるが、現時点で)
  - Quantitative measurements of magnetic fields in the chromosphere
  - EUV/UV spectral lines used in Solar-C spectrograph will seamlessly cover from chromospheric temperature through the coronal temperature with 0.1-0.5” and 1-5 s cadence.
  - Energy spectral (thermal and non-thermal) diagnostics in 10^6-10^7 K plasma for flares and active region dynamics.

IRIS spectra and slit-jaw imaging covers the photosphere, chromosphere, transition region and corona - 4,500 to 10,000,000 K







Ion Spectrum	λ	Δλ	Log T	Estimated Count Rate (counts/s/line/spatial pixel)			Detector
	Å	mÅ	K	Quiet Sun	Active Region	Flare	
UV Spectra (effective area of 2.8 cm^2 for far-UV, 0.3 cm^2 for Mg passband, continuum is 1 Å) †: Count rates for Mg II wing, h and k are in counts/s/spectral pixel/spatial pixel							
Si I (3P) Cont	1335	12.5	3.7	40	80	---	1
Mg II wing	2820	25	3.7-3.9	2100†	7500†	7500†	3
O I	1356	12.5	3.8	50	100	250	1
Mg II h	2803	25	4.0	870†	3400†	13000†	3
Mg II k	2796	25	4.0	1100†	4500†	10000†	3
C II	1335	12.5	4.3	540	1970	22000	1
C II	1336	12.5	4.3	500	1780	20000	1
Si IV	1403	12.5	4.8	400	1000	1e6	2
Si IV	1394	12.5	4.8	640	2200	3e6	2
O IV	1401	12.5	5.2	65	116	2e5	2
O IV	1400	12.5	5.2	25	60	1e5	2
Fe XII	1349	12.5	6.2	30	50	500	1
Fe XXI	1354	12.5	7.0	10	40	4e4	1
UV Slit-Jaw Images				**Estimated Count Rate (counts/s/pixel)**			
Effective area 0.005 cm^2 with 5 Å FWHM filter for Mg II; 0.7 cm^2 with 40 Å FWHM for far-UV.							
Mg II wing	2816		3.7-3.9	1500	3500	3500	4
Mg II k	2796		4.0	750	3500	8500	4
C II	1335		4.3	400	1300	13000	4
Si IV	1400		4.8	300	1200	2e5	4

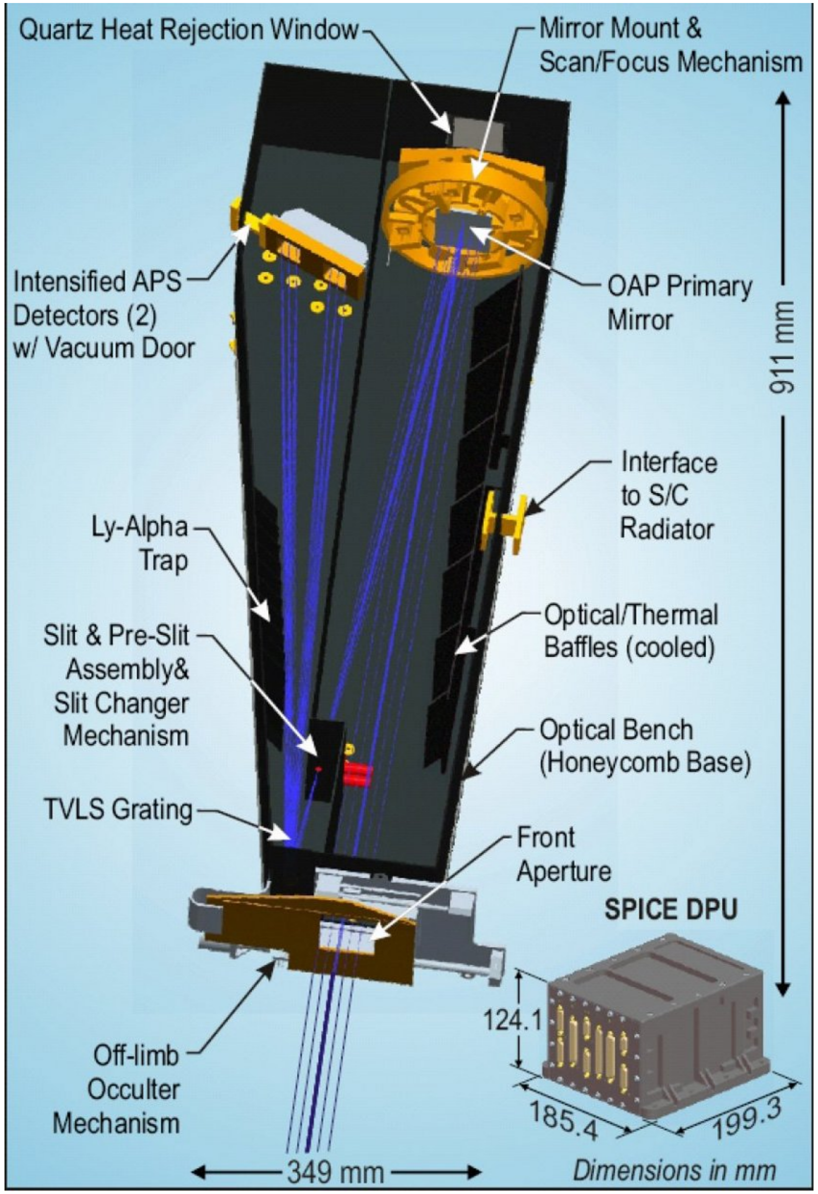
A案衛星
High throughput UV/EUV spectrograph

- A案衛星に載せる小型分光器
- ESA/NASA Solar Orbiter（SO）の搭載機器の一つとして選ばれたSPICE (Spectral Imaging of the Coronal Environment, PI: D.Hassler)とほとんど同じものを想定。
- B案衛星搭載の大型分光器を長さ1m規模に小型がしたもの

SPICE on Solar Orbiter

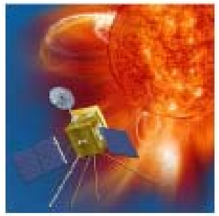
- 駆動機構付きオフセット主鏡、スリット、TVLSグレーティング、intensified APS
- 主鏡の開口径 5cm x 5cm
- FOV 16-17 arcmin (1Kx1K), spatial 1” @0.3AU
- 観測波長帯 2バンド:
  702-792 A
  972-1050A (2nd order 486-525A)
  - 強輝線: C III 977 (logT=4.8),
    O VI 1032 (logT=5.5)
    Ne VIII 770 (logT=5.8)
    Si XII 521 (logT=6.3)

  他にも多数の輝線あり
- 速度サンプリング 23 km/s/pixel@1000A ~EIS長波長バンド程度と同等
- 熱環境が大きく変動するため、焦点調節機構をもつ
- 遮光板 (off-limb occulter) for オフリム観測 (>3.0Rsの観測)



http://solarorbiter3.oato.inaf.it/Presentazioni/so3_2805_hassler_talk.pdf

SPICE Science Objectives



- **1) Where do fast and slow solar wind streams originate?**
  - Map both fast & slow solar wind streams to their solar origins by matching compositional signatures.
- **2) How do fast and slow solar wind streams originate?**
  - Discriminate physical processes that inject material into solar wind streams by observing dynamic and thermal signatures (jets, shocks, waves) at the source regions.
- **3) How is the extended solar wind accelerated?**
  - Discriminate between solar wind acceleration models by measuring line broadening versus height of minor ions with different charge/mass ratios from the solar limb to beyond the sonic point (~2 Rs).
- **4) What are the source regions (seed populations) of energetic particles?**
  - Remotely image supra-thermal ions (broad spectral wings) thought to be the seed populations of energetic particle events as they are accelerated and depleted.
- **5) How is the structure of ICMEs related to their origin?**
  - Quantitatively characterizing flux ropes and current sheets in their pre-eruptive and erupting state.
  - Search for partial reconnections in post-CME current sheets
- **6) How and when do shocks form near the Sun?**
  - Image the turbulent broadening associated with shock formation.

A案衛星の利点は？

- UVスペクトル観測の観点からも、極を見る観測は、極域コロナホール(高速太陽風の源のダイナミックス)の理解のための観測を可能とする。極を見るミッションは科学的に重要。
- しかし、A案衛星は、Solar orbiterに対して大きなジャンプの期待は小さい。また、下記の利点から失うものがある。
  - その場観測との連携の不足
  - 太陽自転速度と同期しない観測 (SOは太陽自転と同期した観測を行う)
  - 約1/3の解像度
- 一方で、衛星リソースから、A案の利点がある可能性
  - SO 100Kbps観測 数日~10日/orbitと期間が限定。SPICEは16Kbps程度。→ データ量、連続観測の点でA案に利点
- A案スペクトル観測は、Solar Orbiterの実現如何に依存 (世界で２つ作るのは…)

High Throughput UV/EUV Spectrograph

- sWGの一致した意見として、2010年代後半に早急に、大型分光装置を実現させたい。
- 鍵となる性能として。
  - 高スループット、高時間・空間分解能化。EIS+SUMERに対して1桁以上の向上可能
  - 彩層からコロナ・フレアまで強輝線で抜けのないカバー。観測波長(詳細選択は未)としてはEIS+SUMER合体版。
  - 技術的には、現時点では実現可能な範囲。
- IRIS(2012)からのジャンプは、多少なやみのたね。
- A案への小型分光装置は、Solar Orbiterの実現如何に依存。