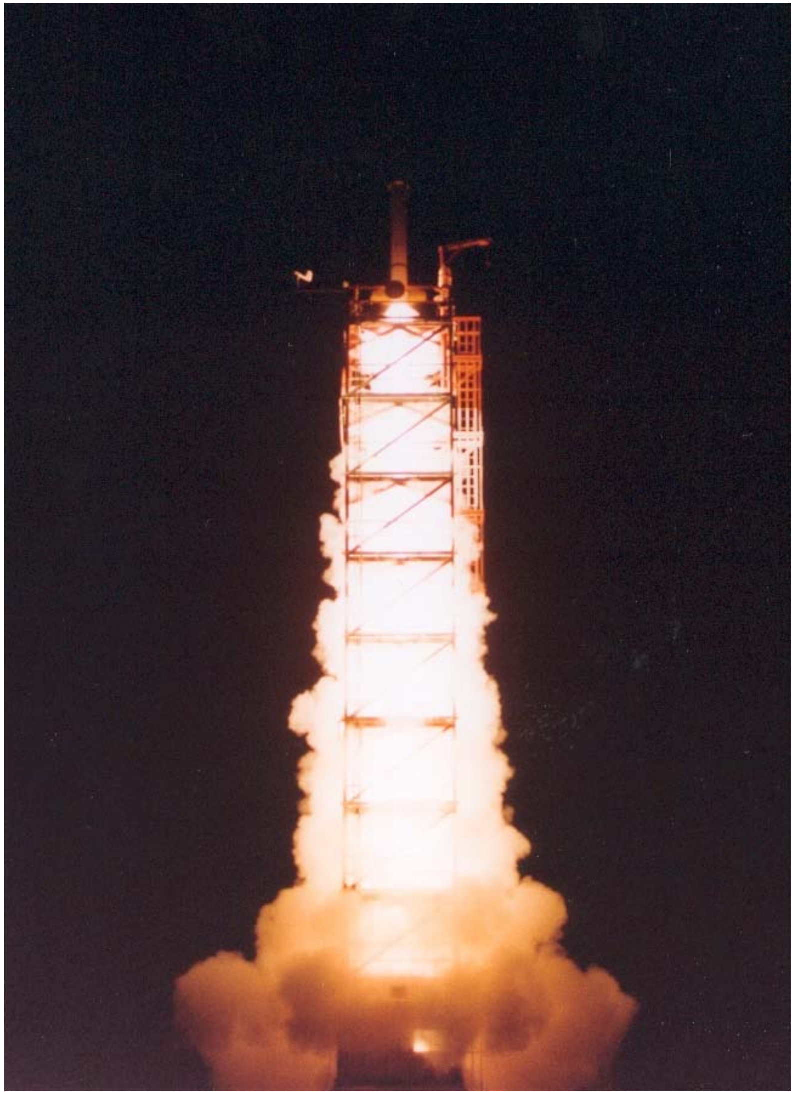
CIBER

The Cosmic Infrared Background ExpeRiment



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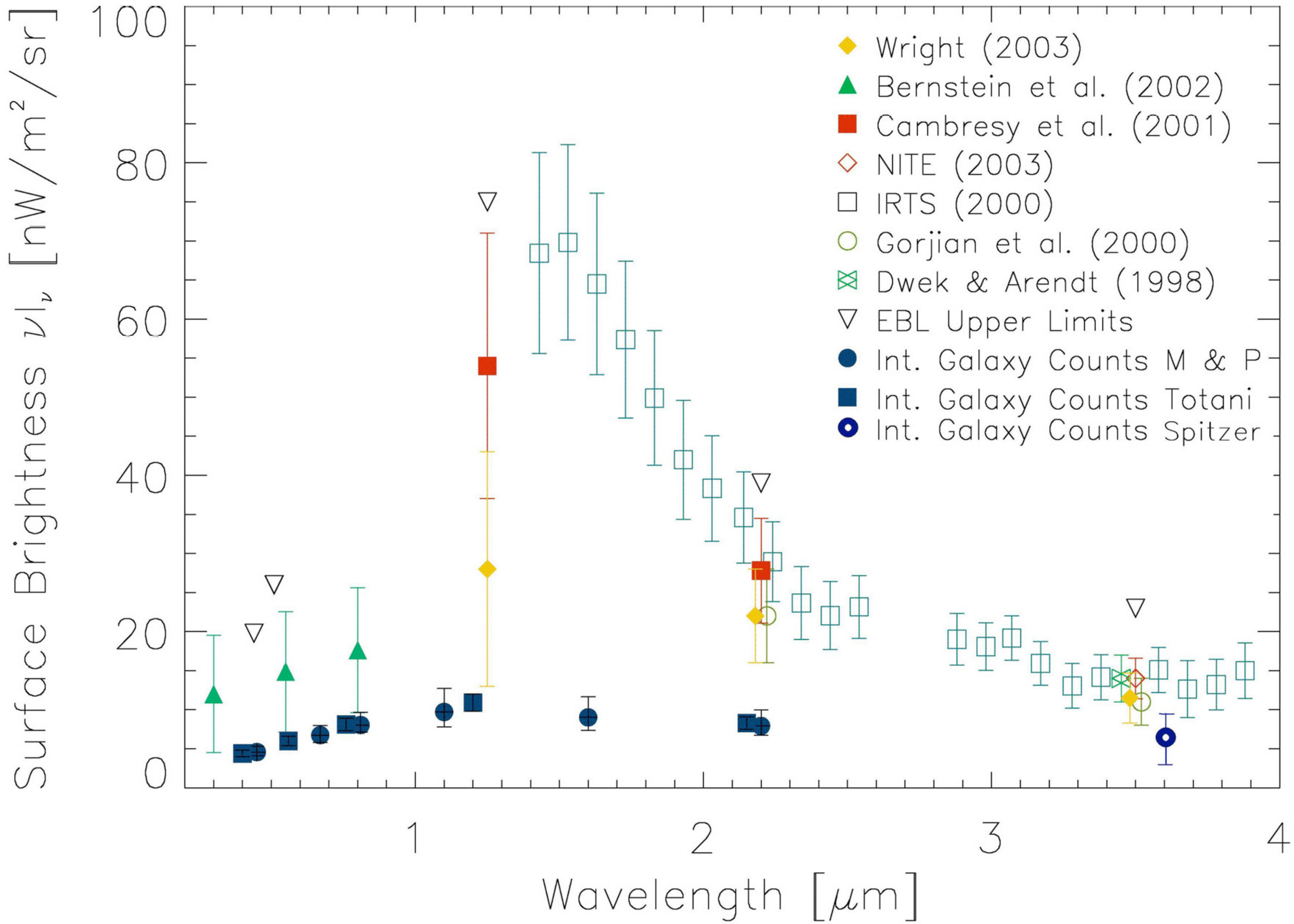
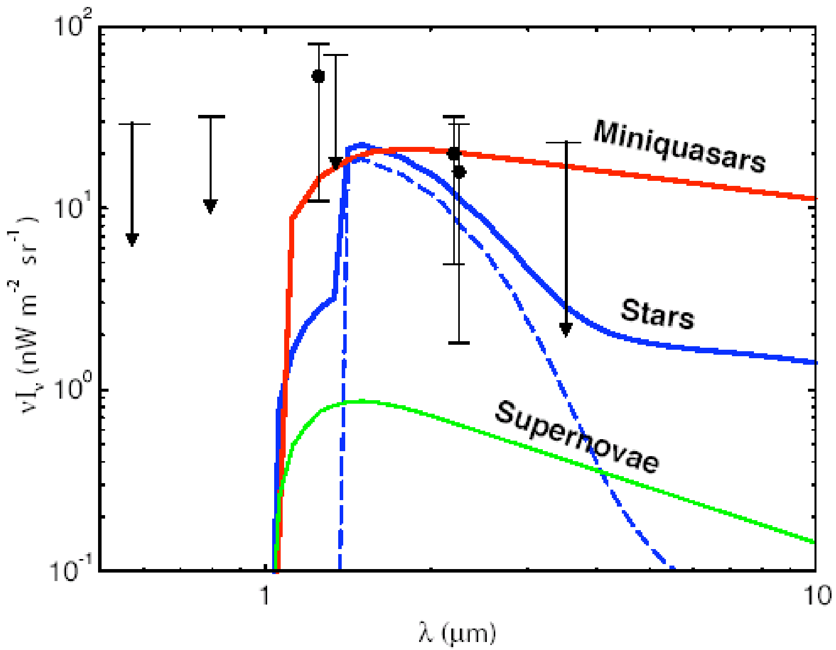
Is the Infrared Background Trying to Tell Us Something?



Could Exotic Sources Produce the IRB Excess?

Yes!



Santos *et al*. 2002
Salvaterra & Ferrara 2003
Magliocchetti *et al*. 2003
Cooray & Yoshida 2004

…but there are difficulties

Do not need large IRB to explain WMAP

for τ_e = 0.17 +/- 0.04

-need $n_\gamma = 2\ C_{IGM}\ (\tau_e / 0.17)$ [γ/baryon]

-IRB excess: $n_\gamma = f_{esc}\ (1+z)\ u_J / 0.7\ E_a\ n_b = 4000\ f_{esc}$

Population III Stars

-Must convert 5-10 % of Baryons into Pop III stars

- High star formation fraction in collapsed structures
- Many recombinations to suppress Ly continuum

-Hard to avoid metal overproduction

- Stars between 140 – 260 solar masses give
  - PISN, eject half the star's mass in metals

Mini-Quasars

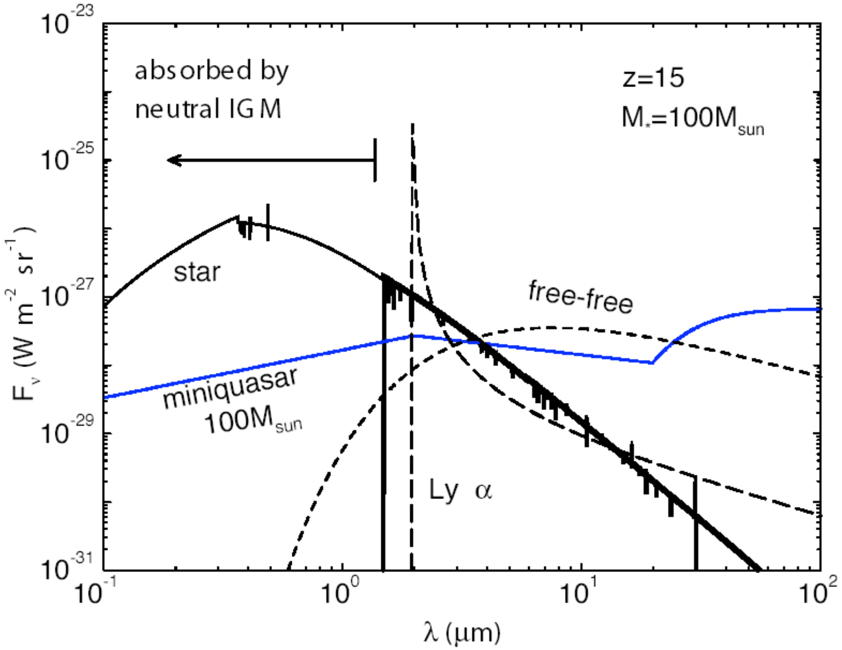
-Need 1/5000th the formation rate of Pop III stars, but

- Overproduce SXB unless very X-ray quiet
- Exceed current estimated black hole densities

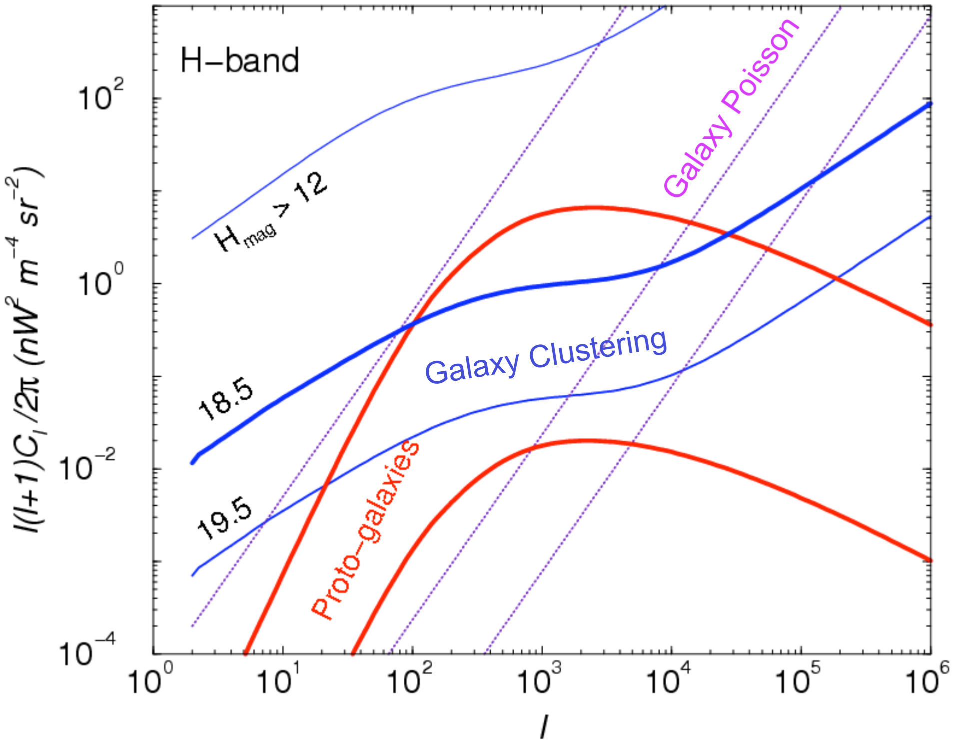
Madau & Silk 2004

Generic Predictions for First-Light Galaxies

Strong Lyman Spectral Break



Distinctive Clustering Properties



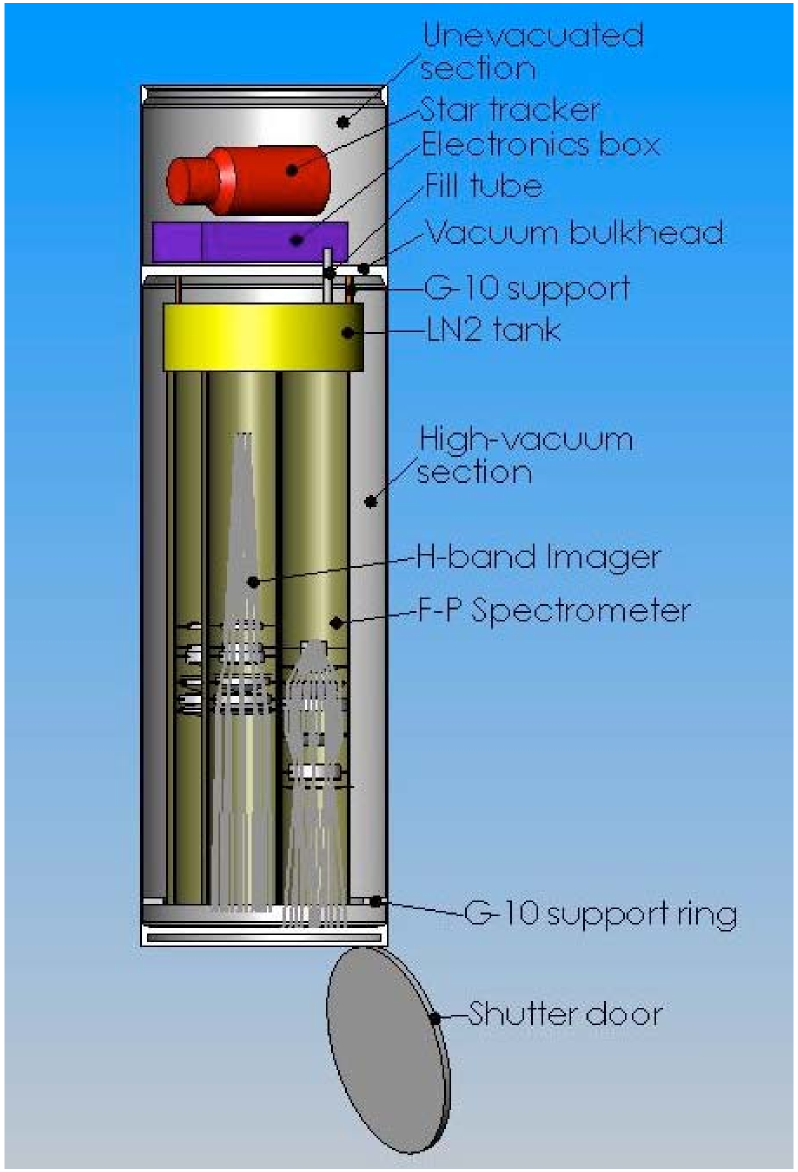
Optimistic: $\nu I_\nu(H) = 25$ nW m^{-2} sr^{-1}
highly biased formation

Pessimistic: $\nu I_\nu(H) = 3$ nW m^{-2} sr^{-1}
moderately biased formation

First-light star formation ends at z = 8-9

Cooray *et al*. 2004

CIBER Science Goals



Dual Wide-Field Imagers

λ= 0.8 μm & 1.6 μm — λ/Δλ = 2

7" pixels — 2° x 2° FOV

- Measure power spectrum from 7" to 2 degrees
- Test power spectrum & isotropy of IRTS fluctuations
- Combine with ASTRO-F and Spitzer fields to probe spatial fluctuations 100x fainter than IRTS

Low-Resolution Spectrometer

λ = 0.8 – 2.0 μm — λ/Δλ ~ 20

60" pixels — 4° x 4° FOV

- Search for Ly cutoff feature in 0.8 – 1.2 μm region
- Combine with Fabry-Perot spectrometer for new absolute measurement of IRB

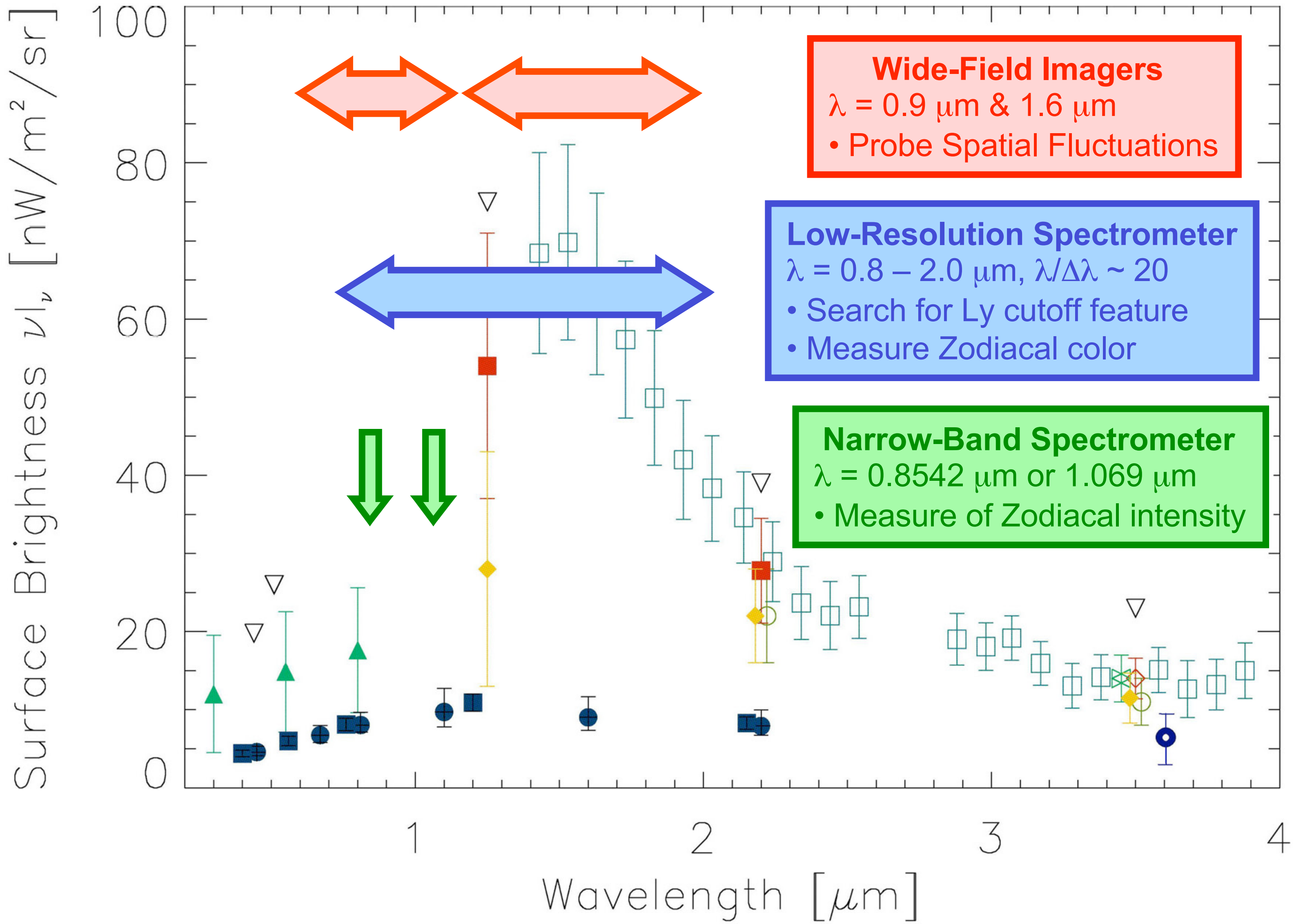
Narrow-Band Spectrometer

λ= 0.8542 μm or 1.069 μm — λ/Δλ = 1000

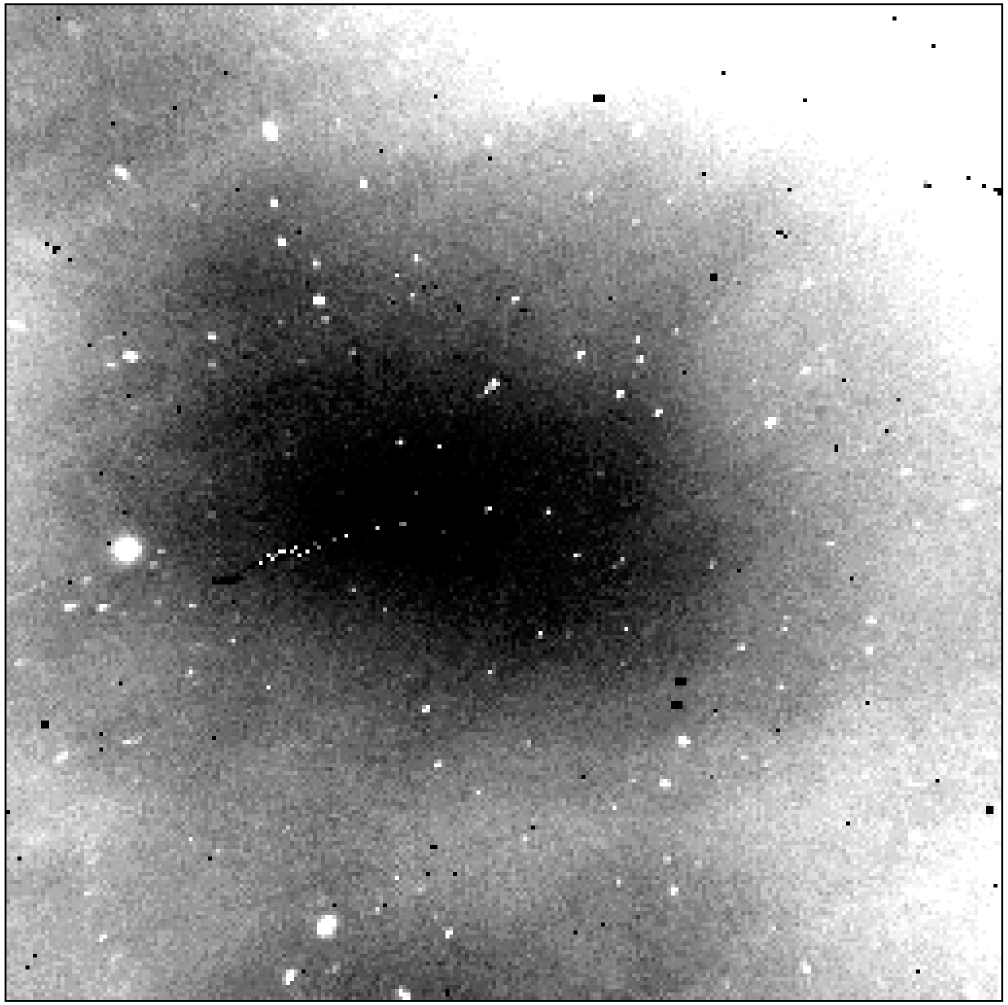
120" pixels — 8° x 8° FOV

- Use Fraunhofer lines to measure absolute Zodiacal intensity
- Systematic test of DIRBE/Kelsall Zodiacal model

CIBER: Probing the First-Light IR Background



The Case for Space



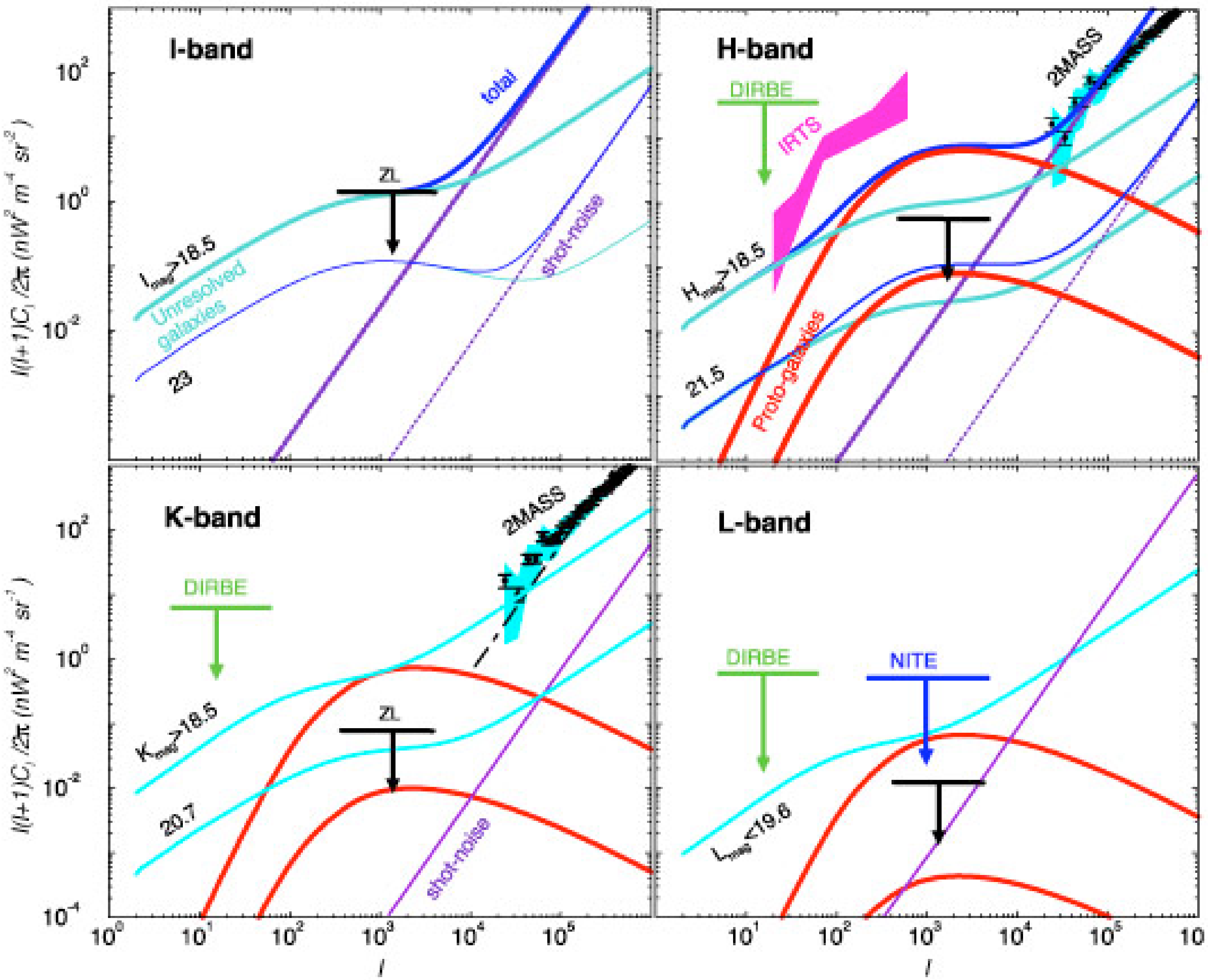
H-band 9º x 9º image over 45 minutes from Kitt Peak

Wide-field airglow experiment: http://pegasus.phast.umass.edu/2mass/teaminfo/airglow.html

Airglow Emission

- Atmosphere is **500 – 2500** times brighter than the astrophysical sky at 1-2 μm
- Airglow fluctuations in a **1-degree** patch are **10^6** times brighter than CIBER's sensitivity in 50 s
- Brightest airglow layer at an altitude of **100 km**… can't even use a balloon

Background Fluctuation Measurements to Date

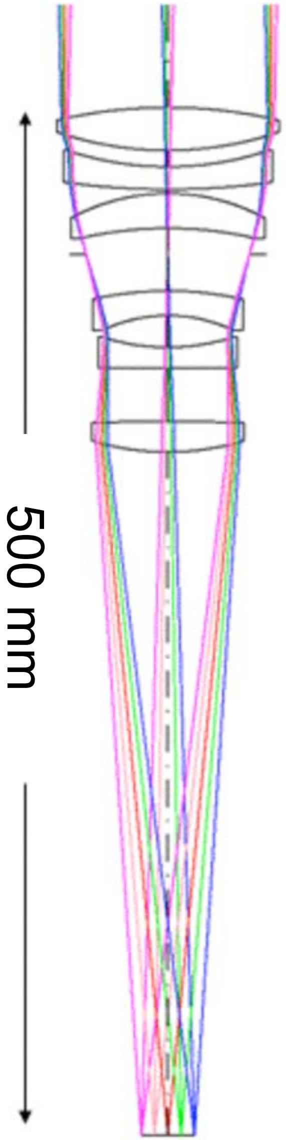


Wide-Field Imager Specifications

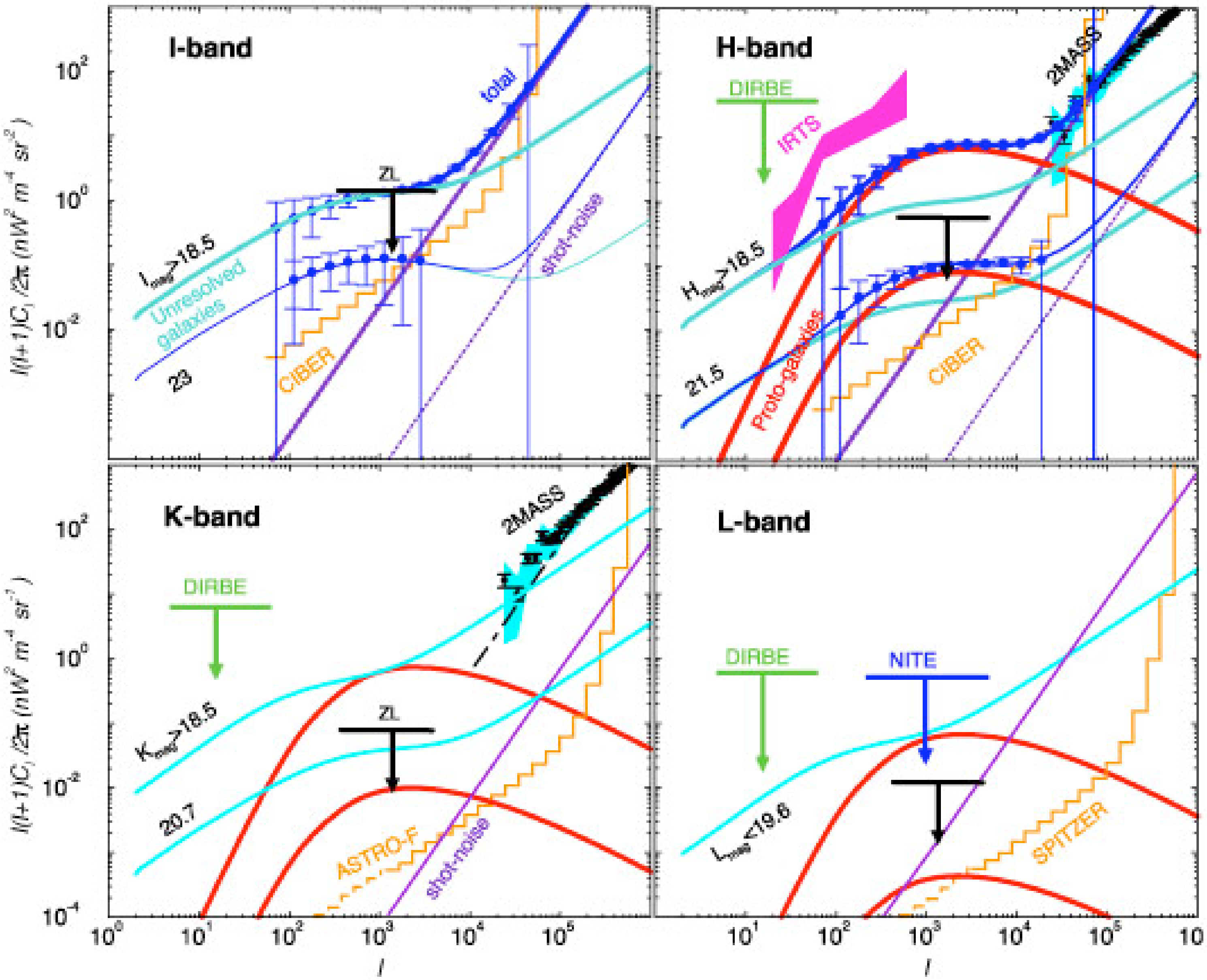
Imager Sensitivity in a 50 s Observation

Aperture	10		cm
Pixel size	7		arcsec
FOV	2.0 x 2.0		degrees
Array	1024 x 1024		HAWAII*
Dark current	< 0.3		e-/s
Read noise (CDS)	15		e-
Wavelength	0.95 (I)*	1.6 (H)	μm
$\lambda/\Delta\lambda$	0.5	0.5	
Photo current	10	9	e-/s
$\nu I\nu$ (sky)	800	390	nW m^{-2} sr^{-1}
$\delta\nu I\nu$ (per pixel)	44	22	nW m^{-2} sr^{-1}
$\delta F\nu$	18.5 (3σ)	17.8 (3σ)	mag
CIBER galaxy cut	I < 18.5 800 0.3 %	H < 17.8 2000 0.8 %	mag cut #/sq degree pixel loss
Deep galaxy cut	I < 23 60,000 25 %	H < 21.5 60,000 25 %	mag cut #/sq degree pixel loss

***Note: we will use a JDEM 1024 x 1024 InGaAs array, now under test, if the performance is acceptable.**

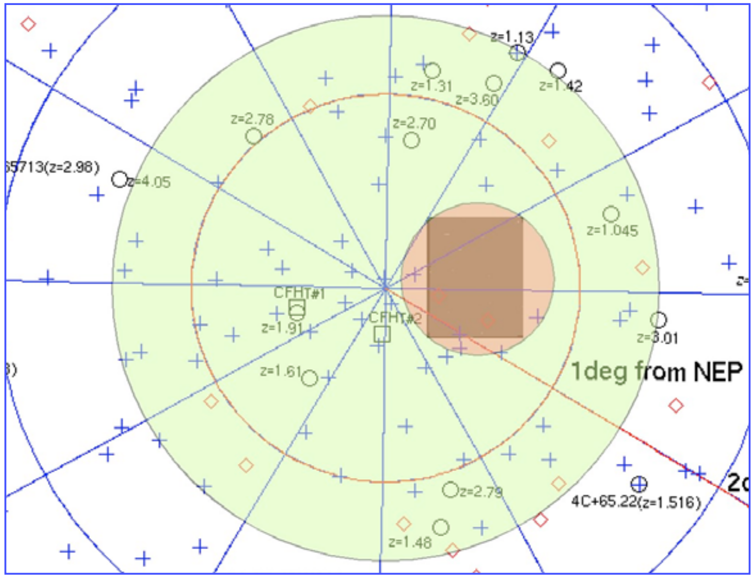


Future Background Fluctuation Measurements



Co-Observations with ASTRO-F & Spitzer

Field	Galactic Lat (b)	Ecliptic Lat (β)	t (s)	Coverage
SWIRE ELIAS-N1	45	73	50 + 50	**Spitzer** 9 sq deg L=19.0 r = 23.8 i = 23.0 z = 21.7 (5σ)
North Ecliptic Pole	30	90	50 + 50	**ASTRO-F** 6 sq deg SUBARU B, V, R, I, K, L
IRAC GTO Bootes	68	46	50 + 50	**Spitzer** 10 sq deg L=19.1 K=19.5 - 20.5 H=19.6 J=20 - 22 I=25.5 (5σ)
elat 10	70	10	15	N/A
elat 30	90	30	15	N/A



ASTRO-F NEP Field (6 sq deg)

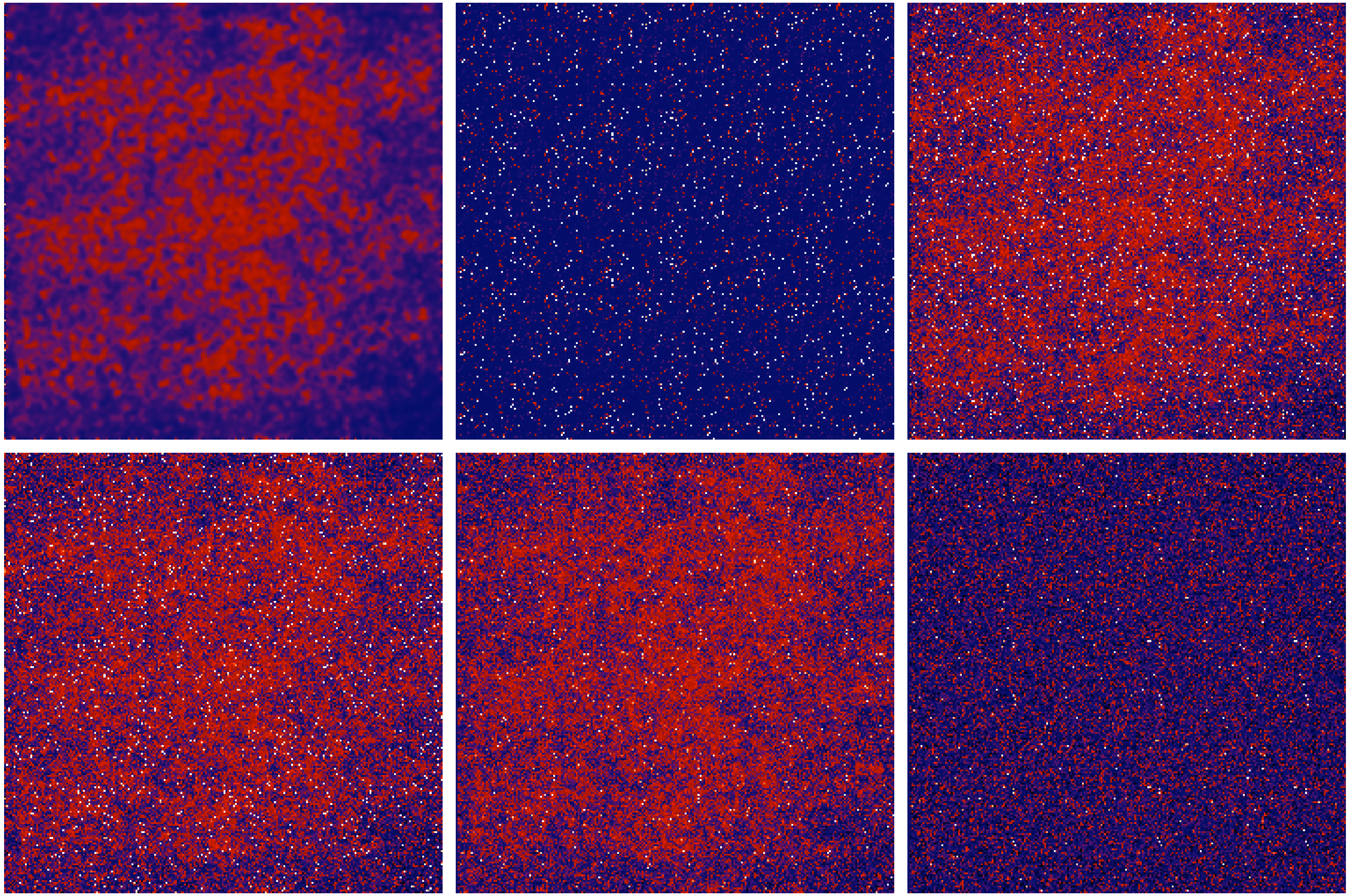
Spitzer Bootes Field (10 sq deg)

Simulated Images

First-Light Fluctuations (Optimistic Model)

Local Galaxies to H = 24

Flucts + Galaxies + Noise

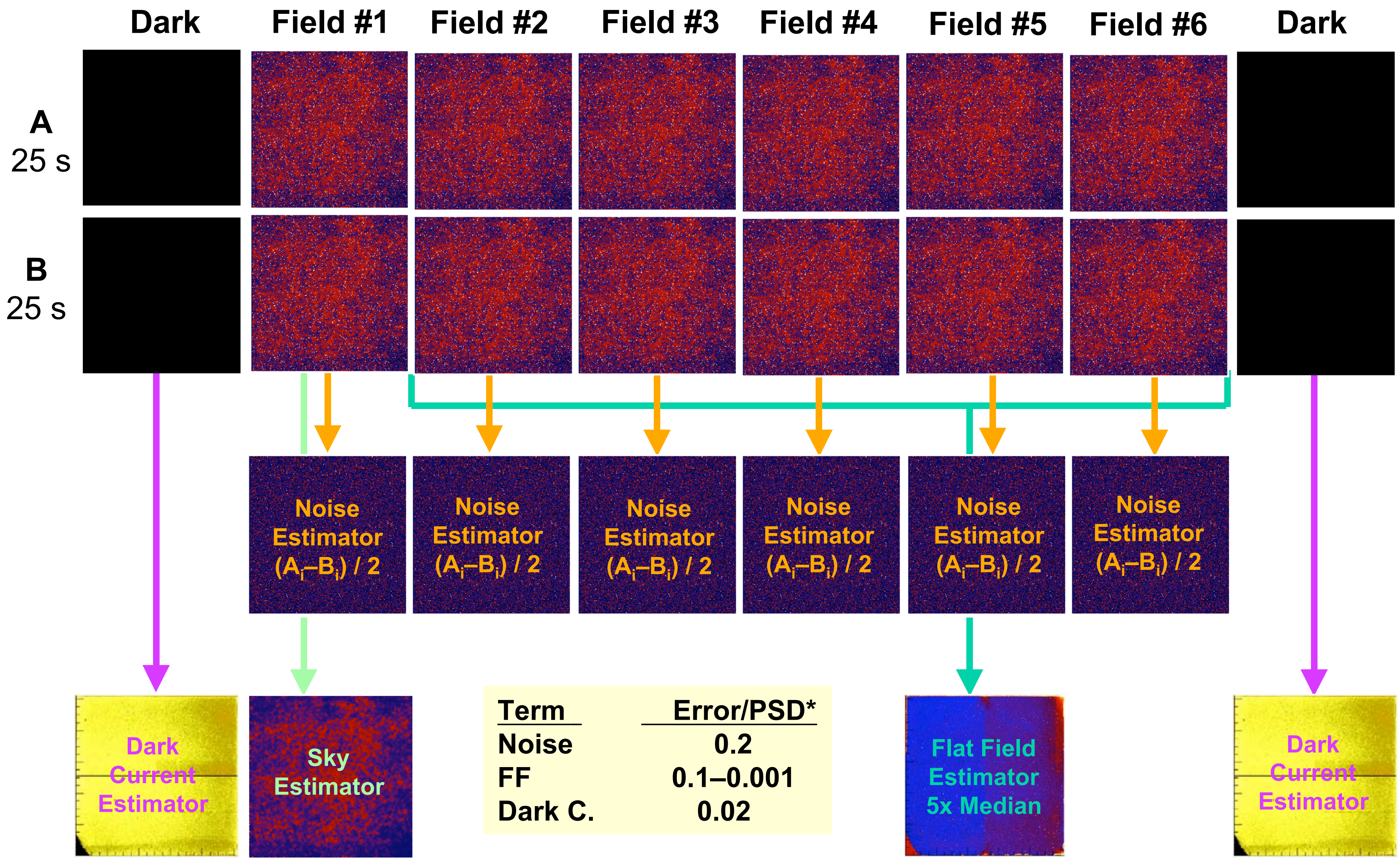


Flucts + Galaxies + Noise
Galaxies cut to H < 18

Flucts + Galaxies + Noise
Galaxies cut to H < 21

Flucts + Galaxies + Noise
(Pessimistic Model)
Galaxies cut to H < 21

Observing Strategy and Control of Errors

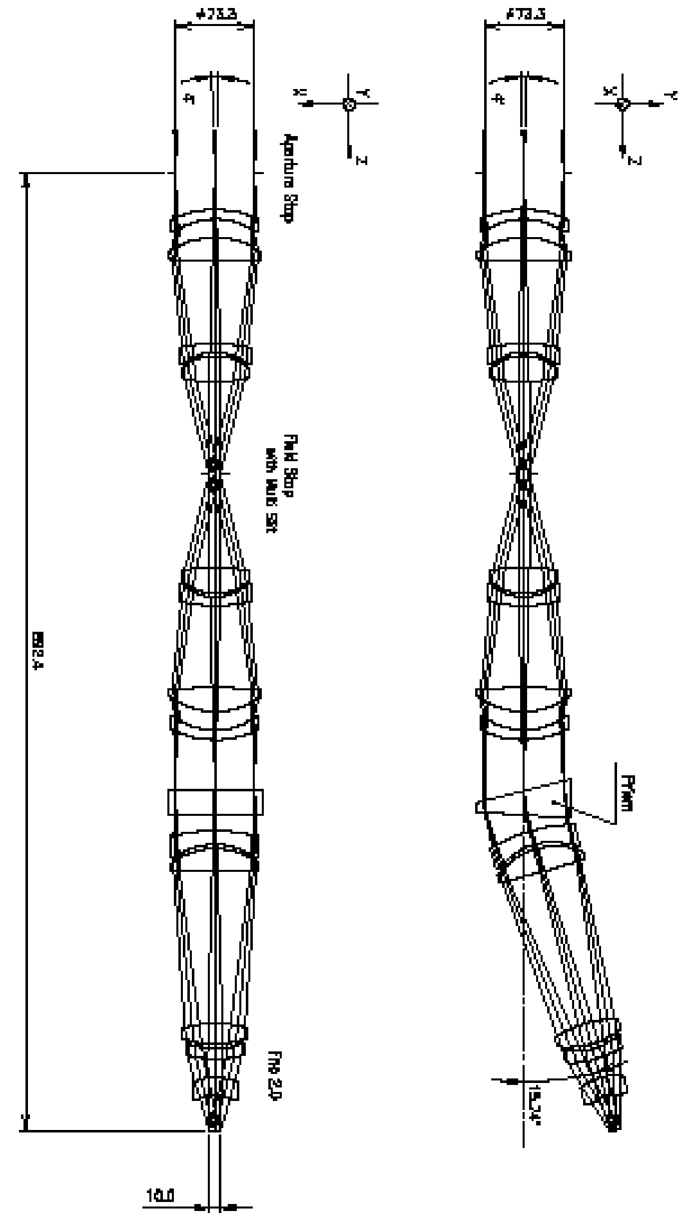


Term	Error/PSD*
Noise	0.2
FF	0.1–0.001
Dark C.	0.02

*Effect on final power spectrum based on knowledge of error term, PSD from statistical noise in sky frame

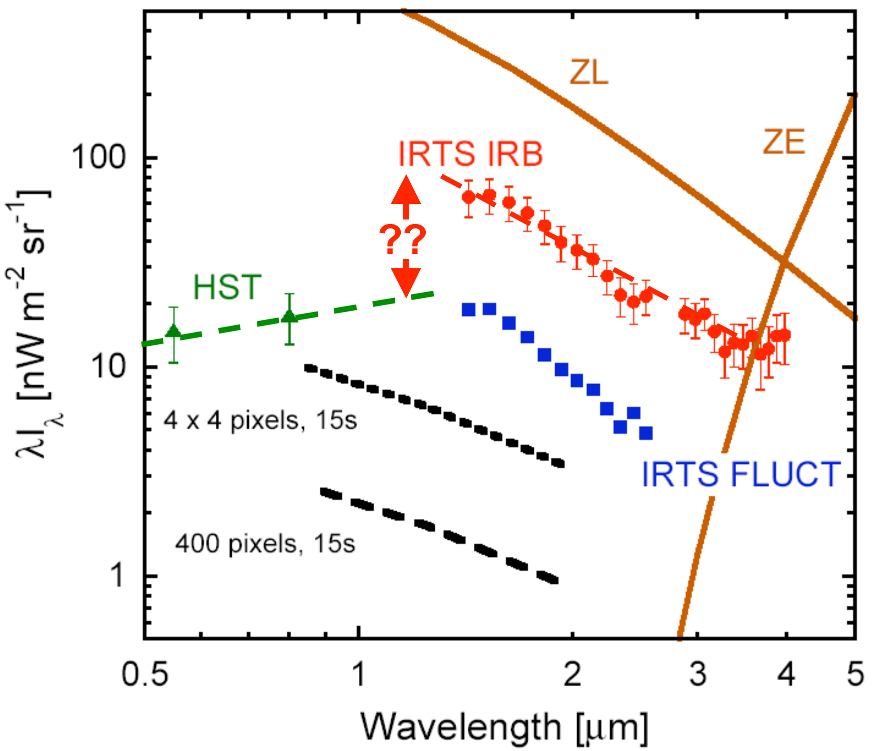
Absolute Low-Resolution Spectrometer

Optics	13 lenses & 1 prism Linear dispersion Multiple slits	
Aperture	ϕ73.3	mm
Focal ratio	F/2	
FOV	4 x 4	degrees
Pixel size	1 x 1	arcmin
Slit size	1 x 256	arcmin
Wavelength range	0.8 – 2.0	μm
Spectral resolution	$\lambda/\Delta\lambda$ = 21 - 23	
Optical efficiency	0.8	
Focal plane array	256 x 256	HgCdTe
Operating temperature	77	K
Array quantum efficiency	0.5	
Dark current	< 0.1	e-/s
Readout noise (CDS)	< 30	e-
Photo current (at NEP)	10 ~ 20	e-/s
Photon noise (τ = 15 s)	12 ~ 17	e-
Limiting mag (15 s, 3σ)	J = 15.0	

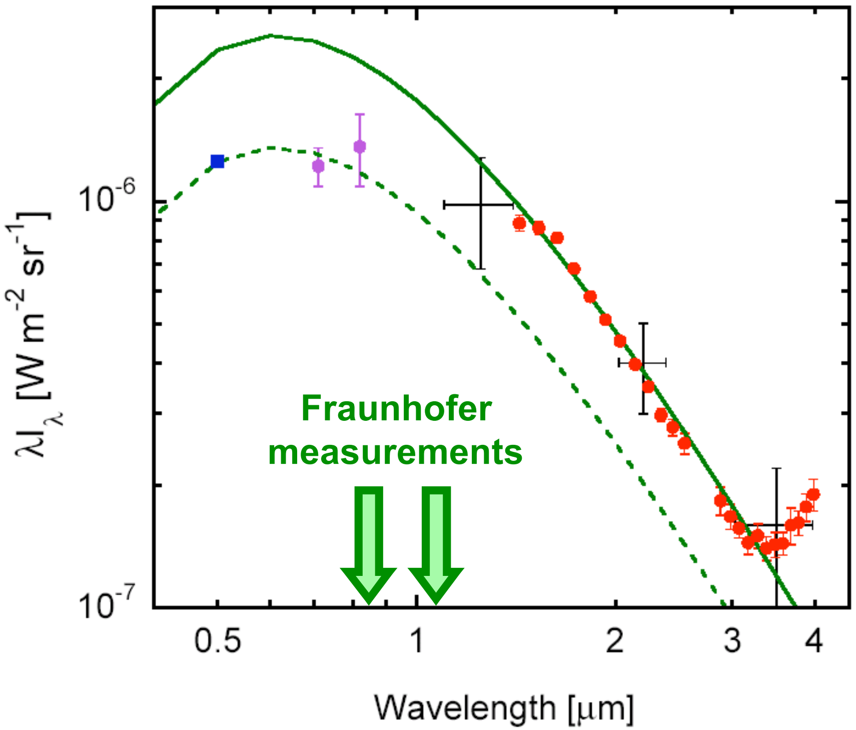


Low-Resolution Spectrometer Science

Spectrometer Sensitivity



Spectrum of Zodiacal Foreground



Is the gap between IRTS/DIRBE and HST real?

CIBER would see it easily, *without any* Zodiacal subtraction

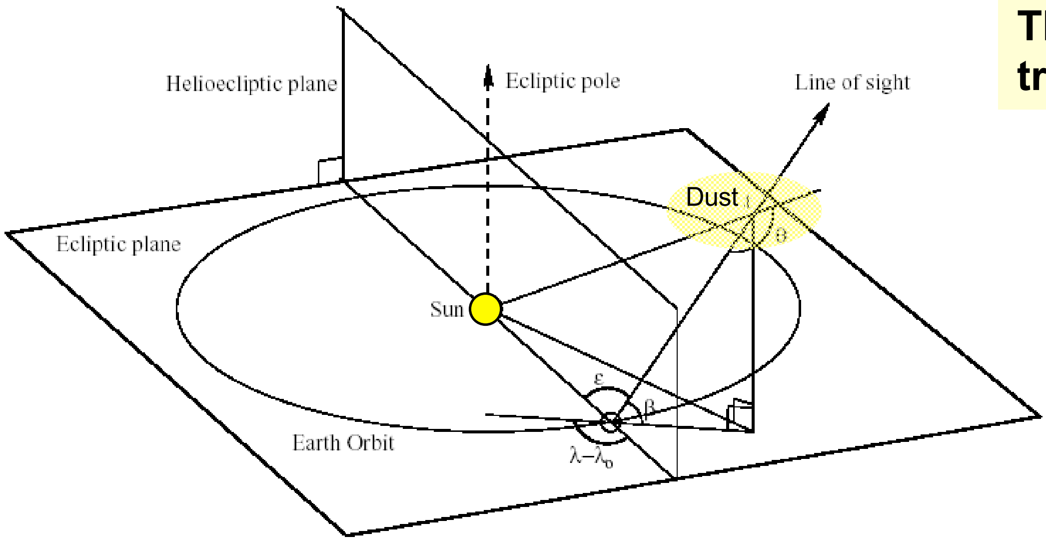
Precisely measure Zodiacal color, link with narrow-band spectrometer

Low-resolution spectrometer sensitivity is 1-2 nW m^{-2} sr^{-1}

NB Spectrometer Zodiacal zero point is 3 nW m^{-2} sr^{-1} at 0.85 μm

Controversy at J-band is ~30 nW m^{-2} sr^{-1}

Using Fraunhofer Lines to Trace Zodiacal Intensity



<u>Zodiacal Light is just scattered sunlight</u>

Features in the solar spectrum are mimiced in Zodiacal light

The solar spectrum gives a precise tracer of the absolute Zodiacal intensity

<u>But reality is messy</u>

Atmospheric scattering, emission, and extinction

- **- scattered ZL**
- **- scattered starlight**
- **- airglow**
- **- etc**

Calibration on diffuse sources

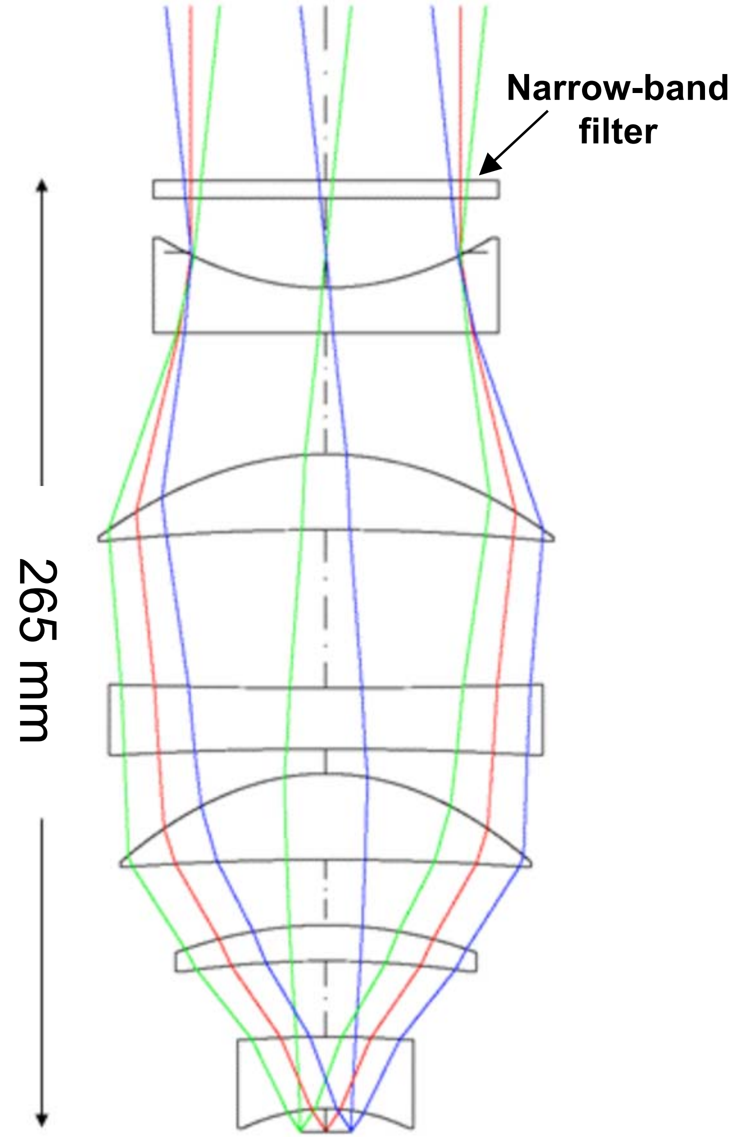
For details see: Dube *et al*. 1979
Bernstein *et al*. 2002
Matilla 2003

Narrow-Band Spectrometer Specifications

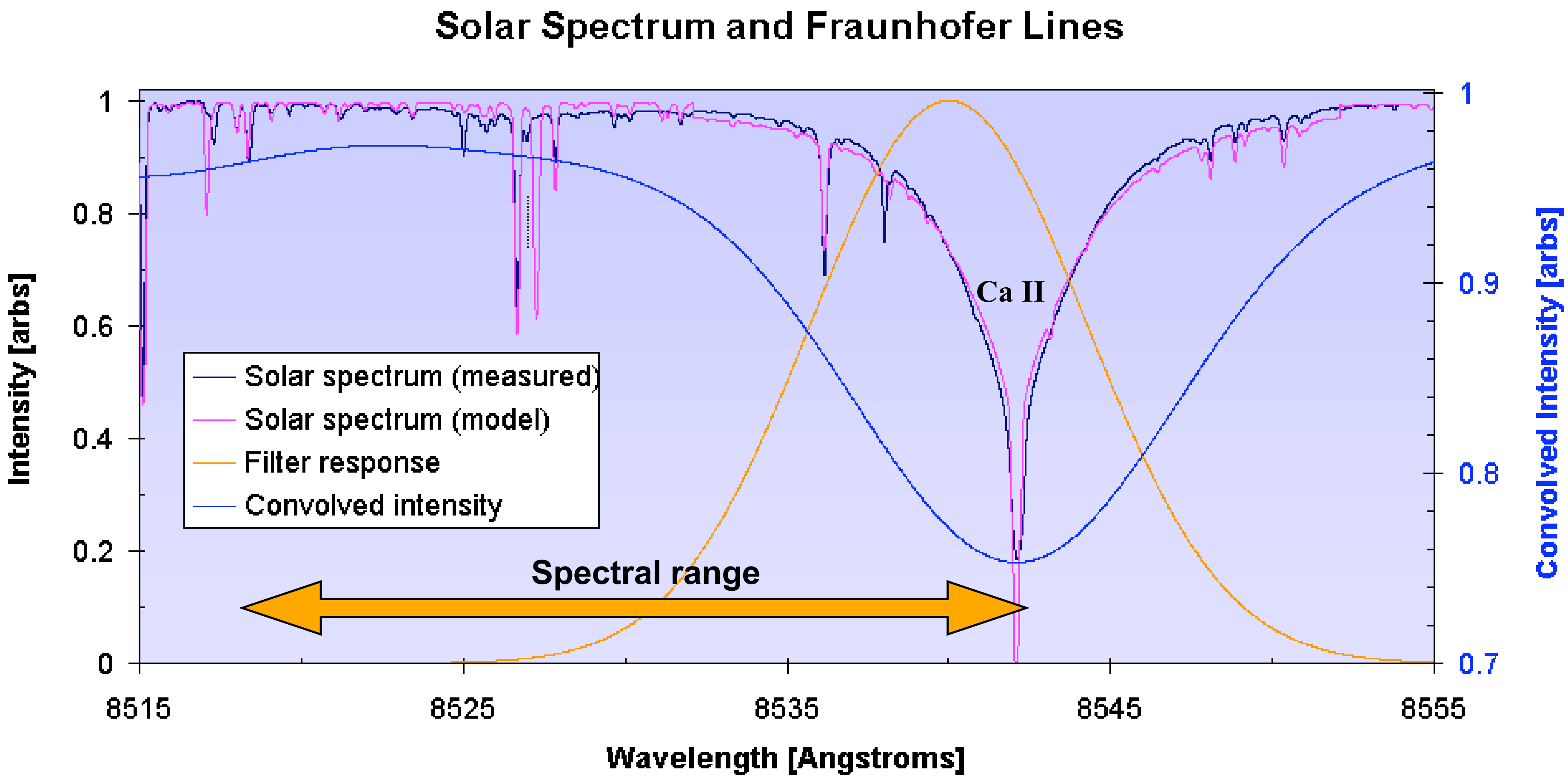
Spectrometer Sensitivity in a 50 s Observation

Aperture	7.5		cm
Resolution	1000		
Pixel size	2		arcmin
FOV	8.5 x 8.5		degrees
F/#	0.9		
Filter efficiency	0.7		
Optics efficiency	0.9		
Array QE	0.65		
Array	256 x 256		PICNIC
Dark current	< 0.1		e-/s
Read noise (CDS)	20		e-
Array samples	250		per reset
Wavelength	0.8542	1.069	μm
$\nu I \nu$ (sky at NEP)	550	450	nW m^{-2} sr^{-1}
Line strength	2.7	0.7	Angstroms
Photo current	1.5	1.5	e-/s
$\delta \nu I \nu$ (per pixel)	55	60	nW m^{-2} sr^{-1}
Contrast	25	6	%
S/N zodi	170	40	100 x 100 pix
$\Delta \nu I \nu$ (zodiacal zero point)	3	12	nW m^{-2} sr^{-1} 100 x 100 pix

- **Eliminates the atmosphere**
- **Small telescope is absolutely calibrated**
- **Highly accurate relative calibration to LRS**



Instrument Response to 8542 Å Ca II Line



Conclusions

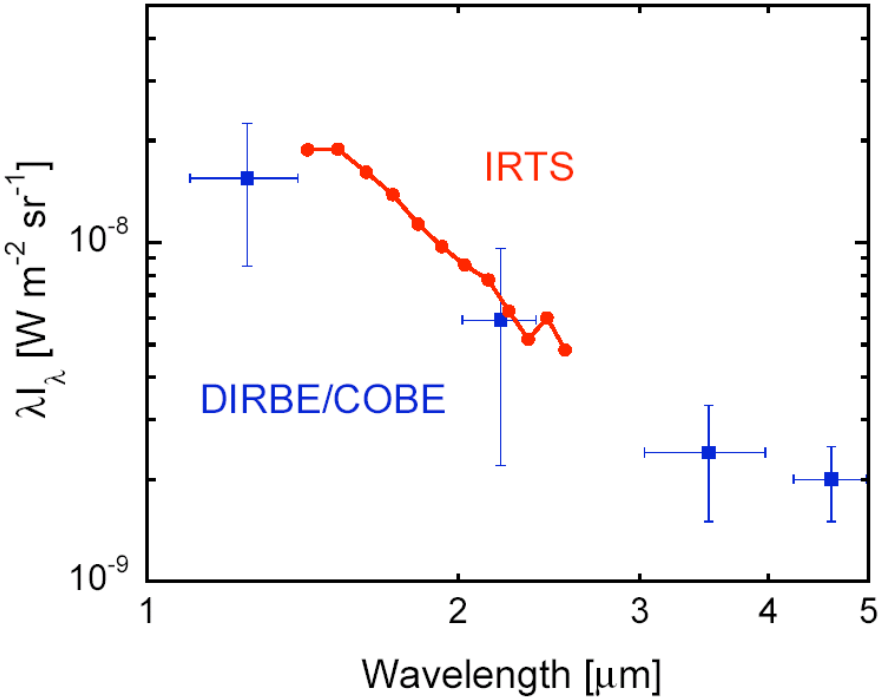
Infrared background is cosmologically important

Current measurements are wanting

- fluctuations
  limited in l range,
  poor coverage on medium scales,
  no cohesive wavelength coverage
- no absolute spectroscopy from 0.8 – 1.4 μm
- uncertainty in Zodiacal light subtraction

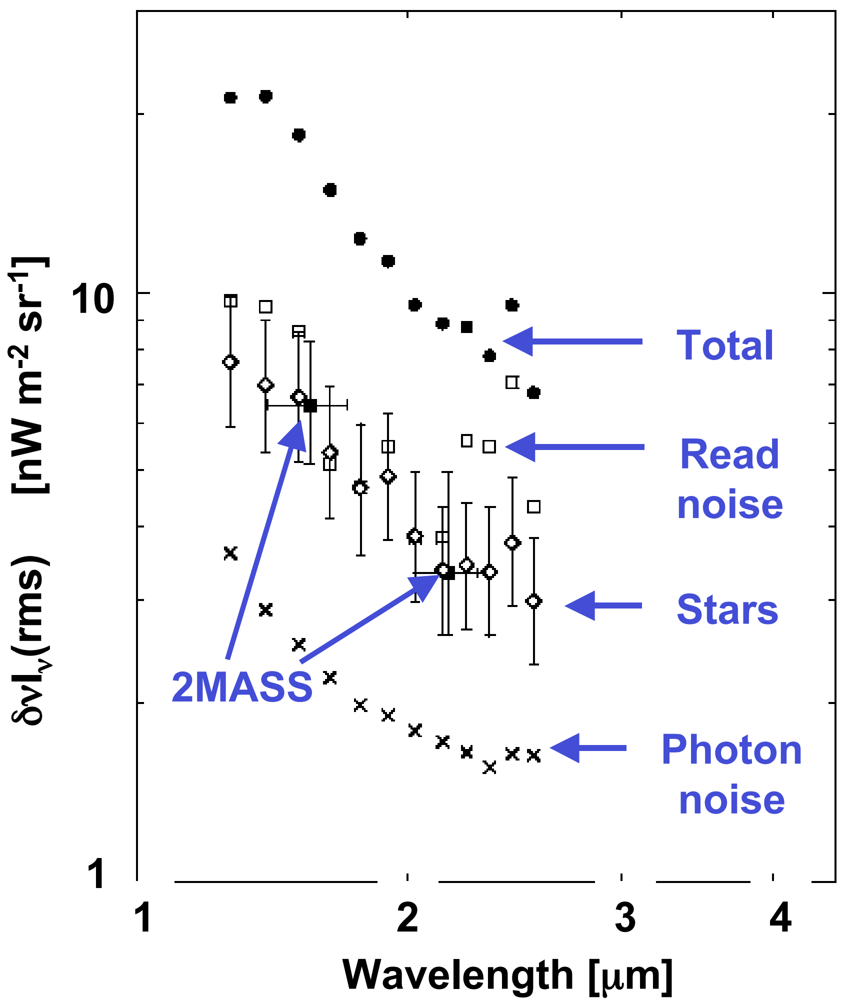
CIBER will answer these questions!

IRTS Background Fluctuations

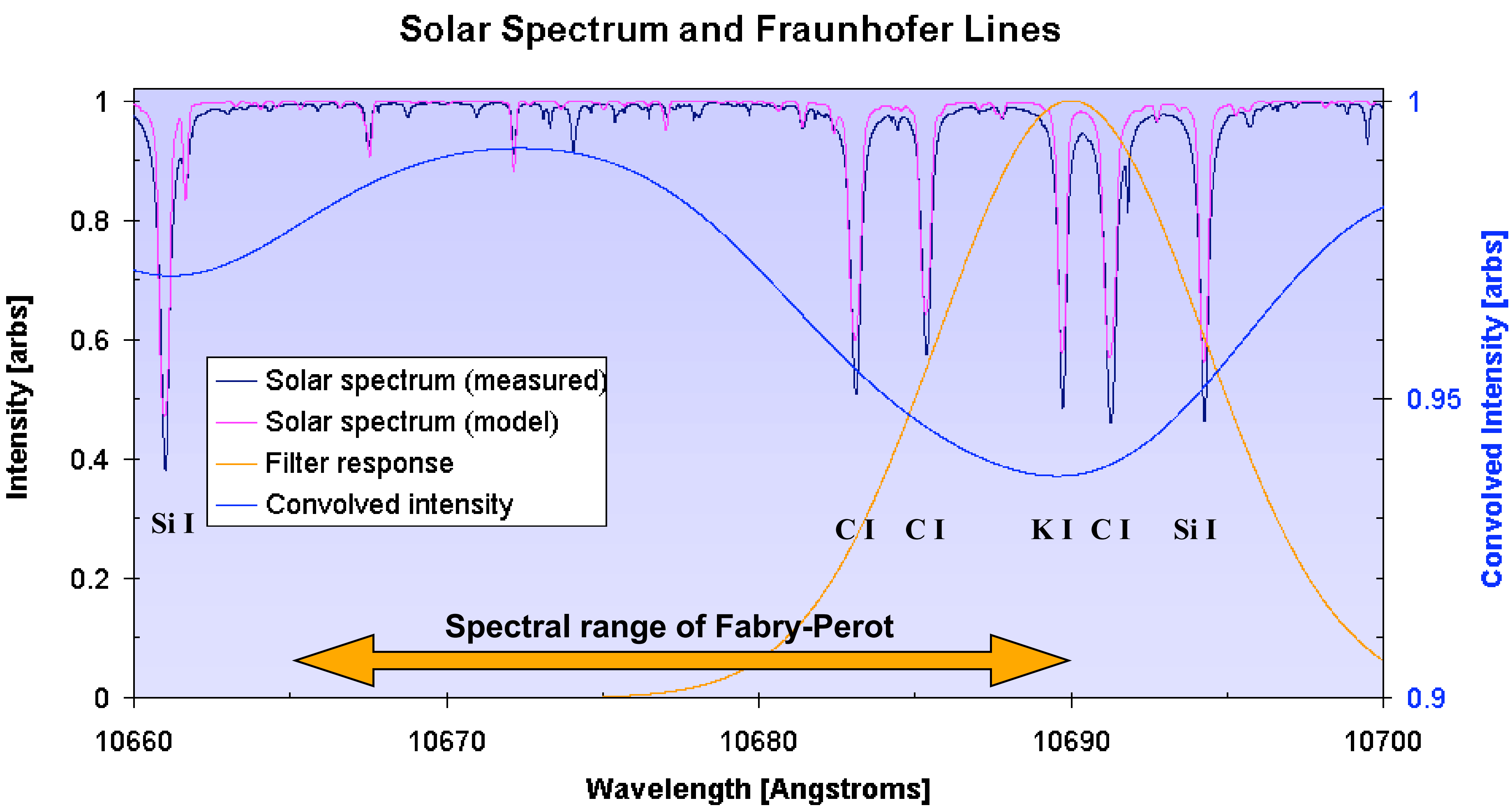


IRTS Fluctuations

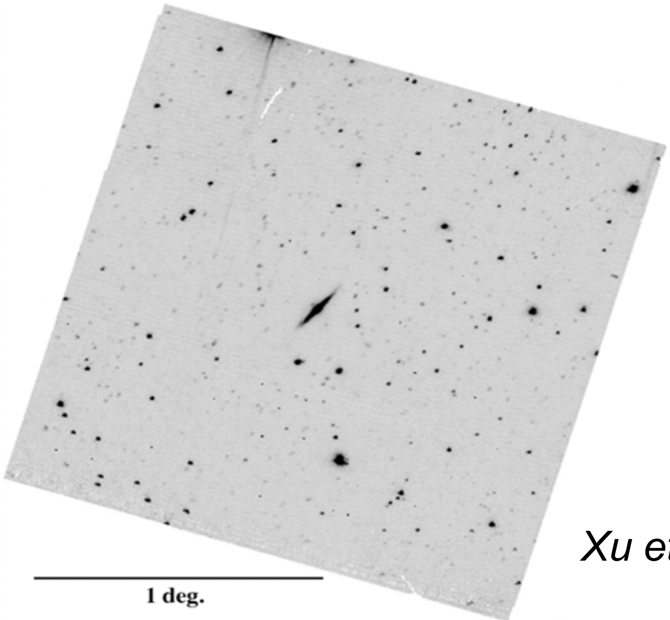
- **20 % of the IRTS residual IRB!**
- **Similar spectrum to residual IRB**
- **Isotropic (approximately)**
- **Source confusion accounted**



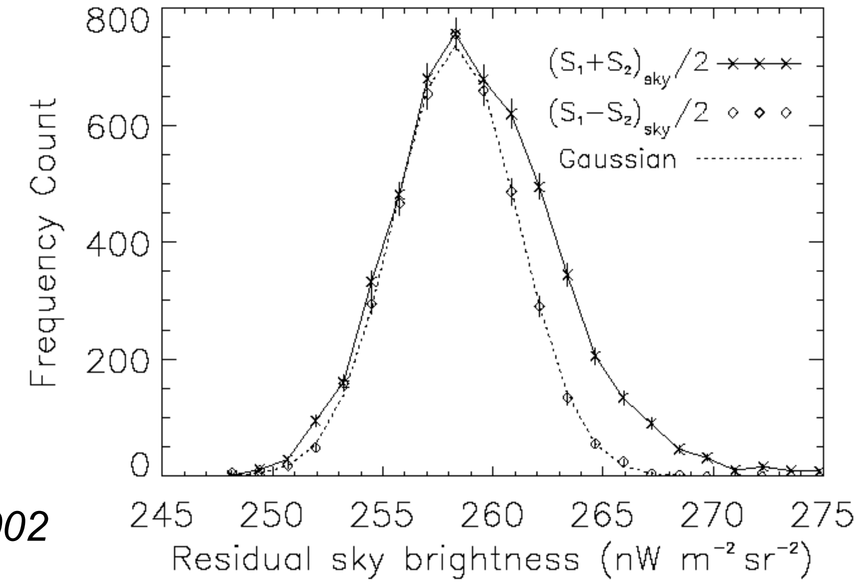
Fabry-Perot Response to 1.069 μm Lines

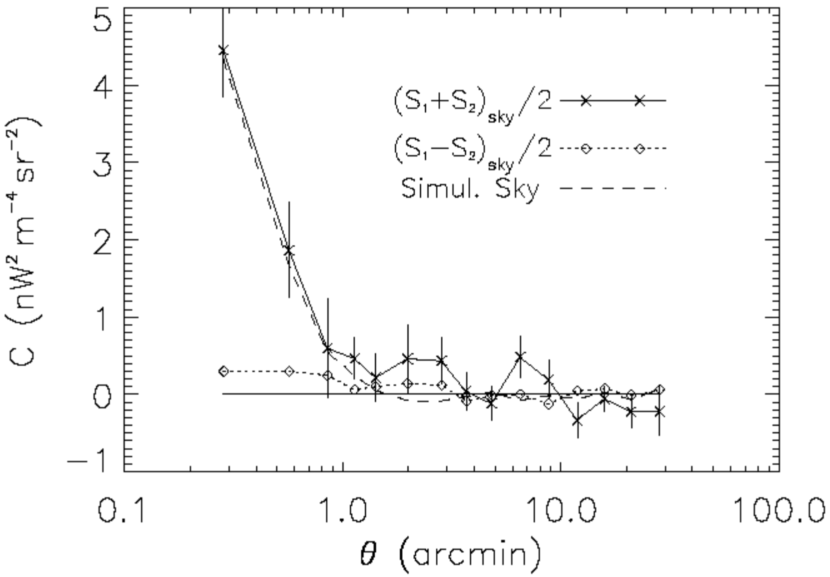


Background Fluctuations with NITE at λ = 4 μm



Xu et al. 2002



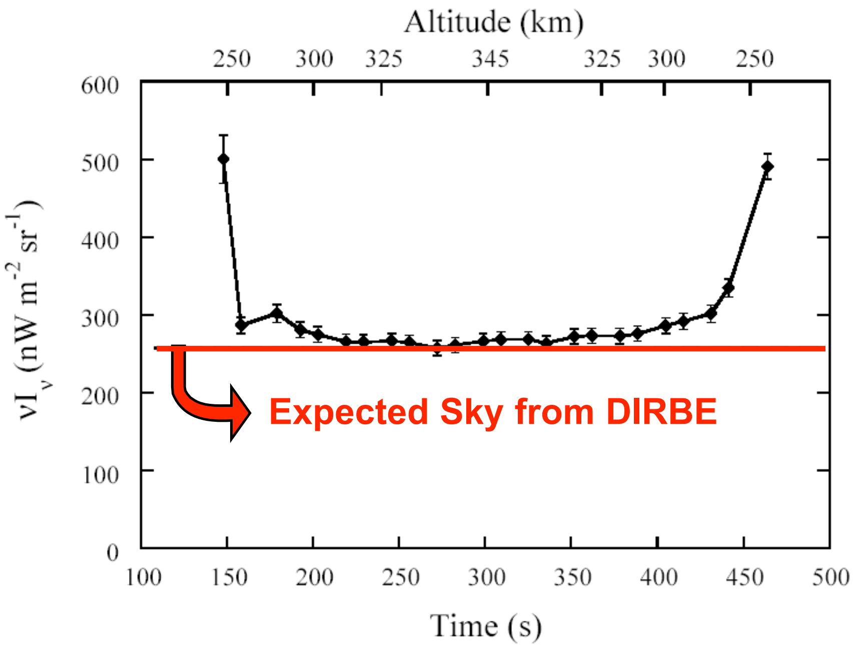


Detection of Sky Fluctuations

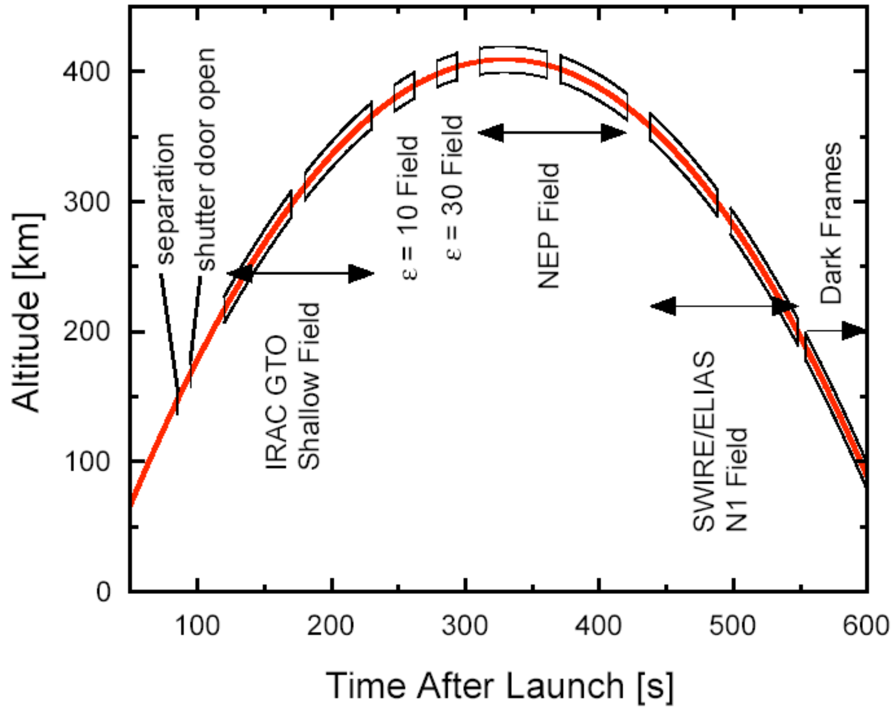
- Separate instrument, flat-field, and sky terms
- Sky fluctuations are S/N = 1 per pixel, but clearly seen in statistical ensemble
- Consistent with rapidly rising galaxy counts (as expected)
- No evidence of non-Poissonian fluctuations

Issues with Sounding Rockets

Total Intensity from NITE at 4 μm



CIBER Trajectory and Observations



Attribute		Comment
+ Apogee = 400 km	+ Pointing = 3”	+ TM Rate = 26 Mbps

- Limited observing time………………. **Sensitivity not a problem for CIBER**
- Systematic error control……………. **Mitigated by observing strategy**

Imagers – study anisotropies, “spatial chop”

Spectrometers – narrow band, “spectral chop”