SUNSET –
the SUperNovae SEarch Telescope

Idea: Provide quasi-diffraction limited resolution with high point source sensitivity over half a square degree on the sky

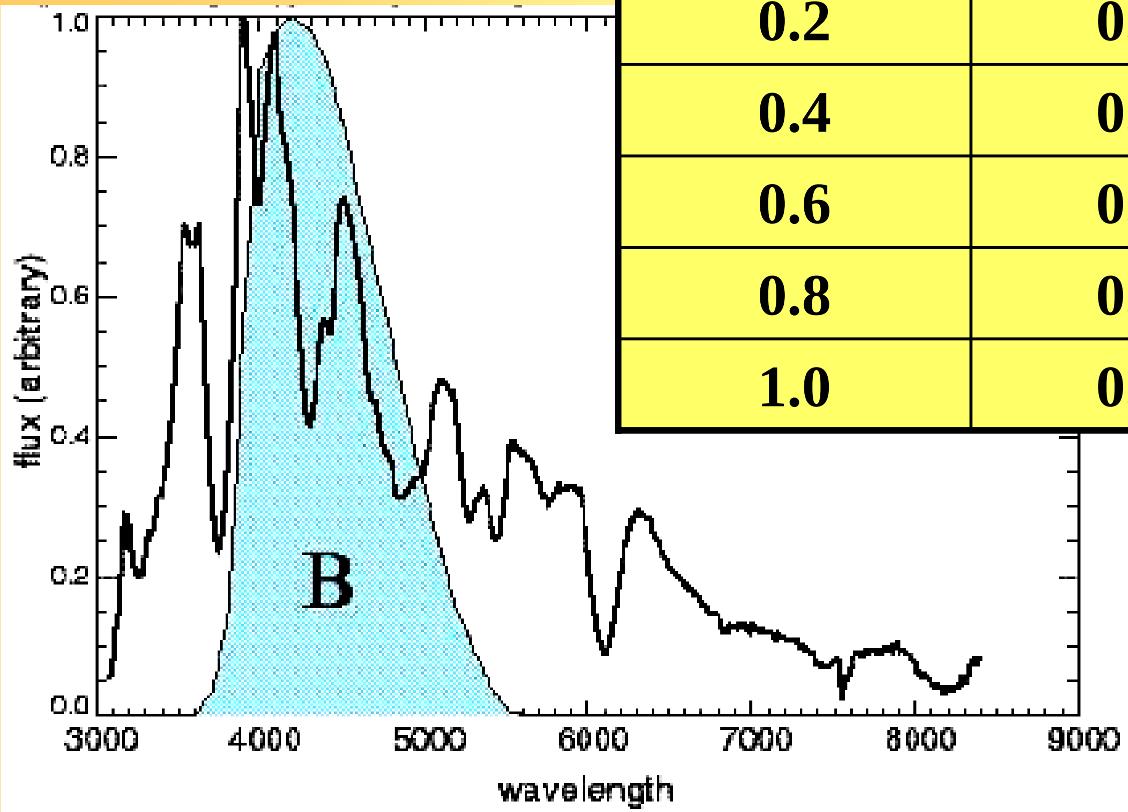
→ Ideal to detect e.g., supernovae in large area surveys.

No such ground-based telescope or technical solution exists yet!

Scientific Motivation

Would enable a wealth of complementary scientific projects:

- **Time resolved (~50Hz) imaging surveys of transient phenomena**
- **Searches for moving targets (asteroids, …)**
- **Targets that require high resolution (small gravitational lenses, …)**
- **Supernova searches (less than 100 SNe evaluated so far!)**



Redshift	Peak [μm]	Peak [mag]	ΣSNe/fov*/yr
0.2	0.53	20.6	0.36
0.4	0.62	22.3	1.62
0.6	0.70	23.4	3.81
0.8	0.79	24.2	6.73
1.0	0.88	24.8	10.1

based on data from SNAP website

30 min / fields
10 fields / night
50 fields / year
} **500 SNe/yr***

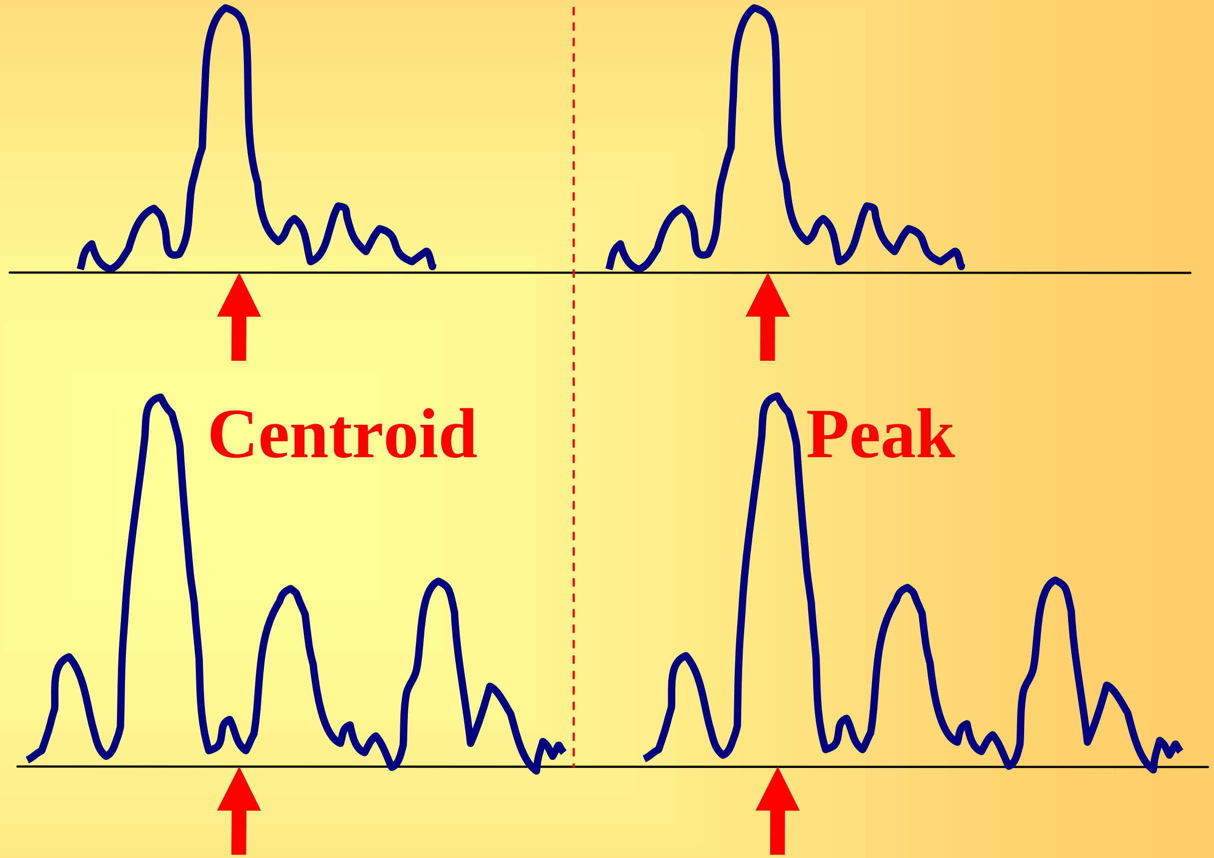
* **for a 0.35×0.35 deg² FOV (see below)**

Speckles and Tip-Tilt

- Speckles contain diffraction limited information of the source
- 87% of the power lies in the tip-tilt term alone (Noll 1976)

Small telescope: **D ~ r_0**
"just one speckle"

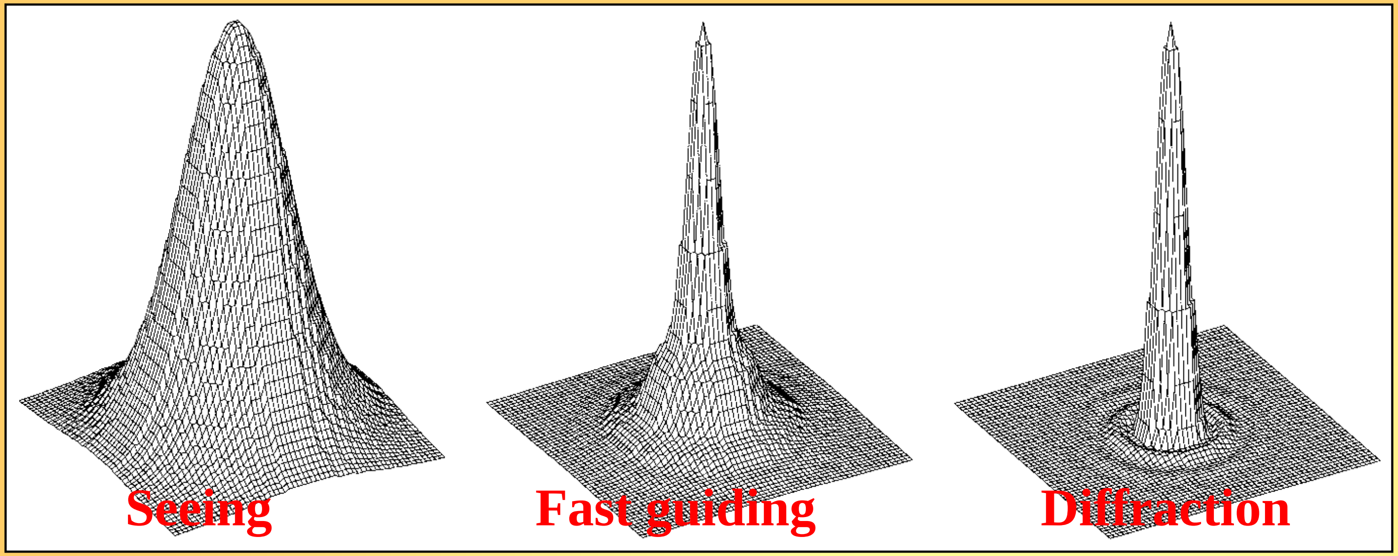
Large telescope: **D >> r_0**
"many speckles"



- **Centroid tracking** requires: quad-cell detector *(only possible option here!)*
- **Peak tracking** requires: Nyquist sampled tracking of speckle pattern

If $D/r_0 = 4$ → $(2\times4)^2$ pixels are needed, (64 vs. 4) → guide star 16 × brighter!

Tip-Tilt Improvement for $D/r_0 < 10$

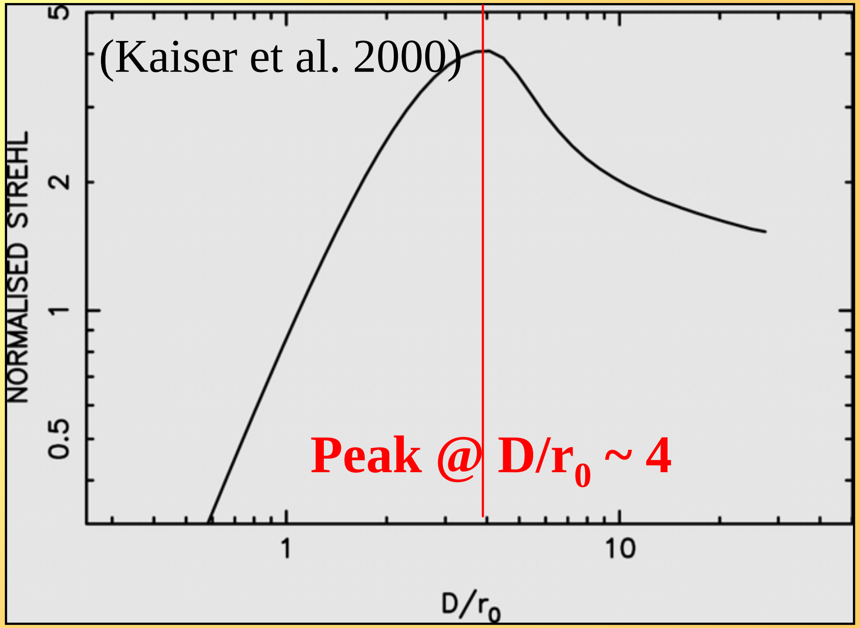


Assumptions: λ=0.8μm, D=1.6m, r_0=40cm (Kaiser et al. 2000)

SR comparison (point sources) (Christou 1991):

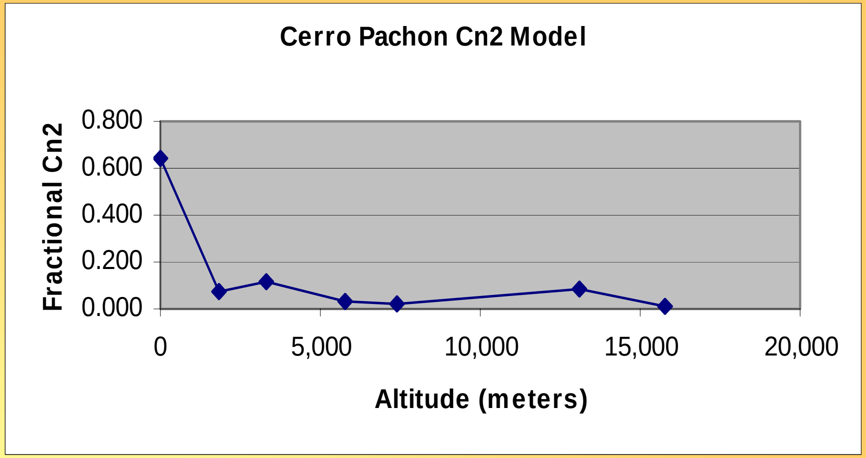
D / r_0	Centroid	Seeing	SR Gain
3.45	0.32	0.07	4.6
4.22	0.21	0.05	4.2
5.43	0.11	0.03	3.7

Gain = relative "amplification" of point sources



Gain ~ 4 means: same S/N as from a seeing limited telescope <u>4 × bigger</u> in diameter since S/N $\propto$ D/source (BLIP)

Turbulence, Telescope and Pixel Size



Atmospheric model of Cerro Pachon (Gemini-S):

- $r_0 \sim \lambda^{6/5} (\cos\zeta)^{3/5}$
- $\theta' = \theta_0 [\lambda_0 / \lambda']^{-0.2}$

Good seeing ~ 0.4″ @ V	V (0.55μm)	R (0.64 μm)	I (0.79 μm)
r_0 @ zenith	0.25m	0.30m	0.39m
r_0 @ 30º	0.23m	0.28m	0.36m
r_0 @ 60º	0.16m	0.20m	0.26m

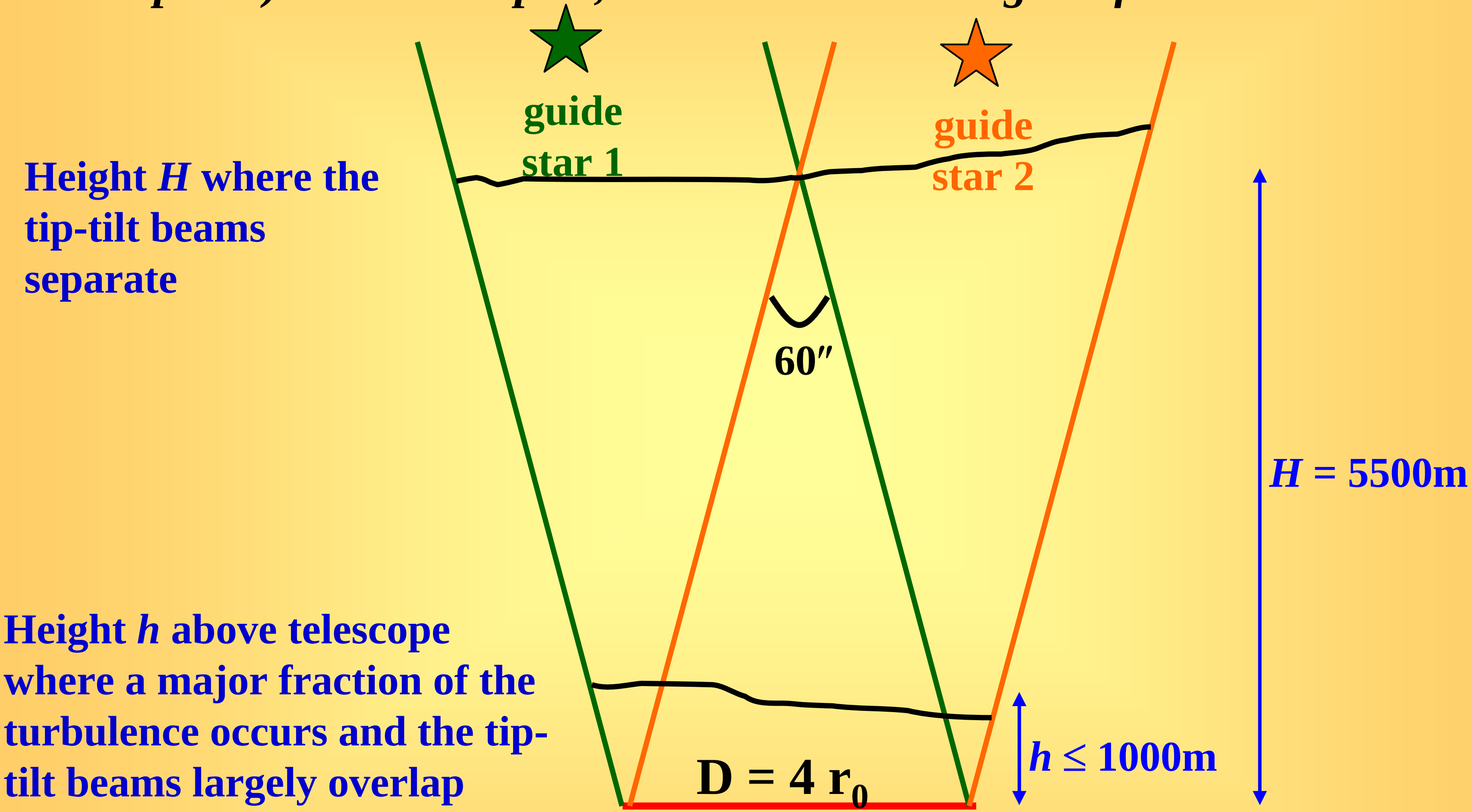
➔ best to image at long λ

Mean r_0 ~ 0.35m @ I-band → telescope diameter ~ $4r_0$ = 1.4 m

➔ A small 1.4m telescope could provide the same S/N to point sources than a 6m telescope but over a much wider field-of-view!

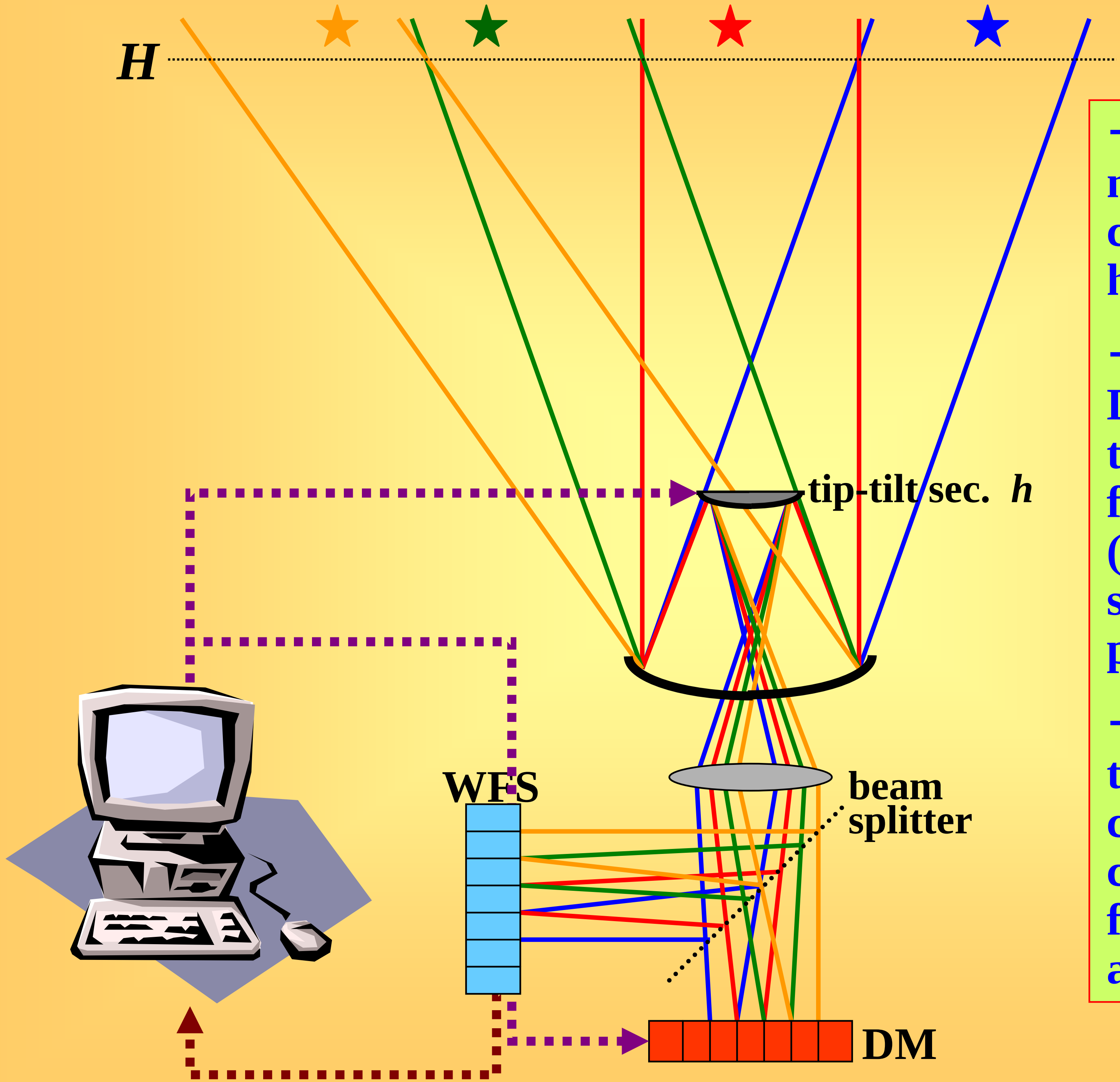
The Basic Idea I: "The simplest case of MCAO"

Consider two different tip-tilt "beams" (i.e. columns of tip-tilt corrected atmosphere) about 60″ apart; each one containing a reference star.



Now "assemble" a large FOV from many adjacent tip-tilt beams. The tilt-isoplanatic patch (here 60″ across) replaces the turbulence cell (r_0) in conventional AO "thinking". For correction use a system similar to a conventional AO system.

The Basic Idea II



→ The deformable mirror (DM) must be conjugated to the height *H*

→ Each element of the DM now corrects only tip-tilt but over the full telescope aperture (rather than over a small fraction of the pupil).

→ In addition, a tip-tilt secondary mirror conjugated to height *h* can take out a large fraction of the tilt that applies to all beams.

Why not do "it" in the Focal Plane?

1. **Read short frames and "shift-and-add" → read noise**
2. **OTAs → charge transfer noise, cosmetic imperfections (flat fielding), limited to specific FPA arrays, …**
3. **New generation of IR arrays → too expensive (~25M$)**

Our proposed approach allows a much more general use of the focal plane:

-Visitor instruments
-Spectroscopy
-Narrowband filters
-FPA configuration not coupled to scales of turbulence
-IR detectors (non-CCD)
-Quickly respond to new FPA devices → better performance
-Cheaper FPA detectors

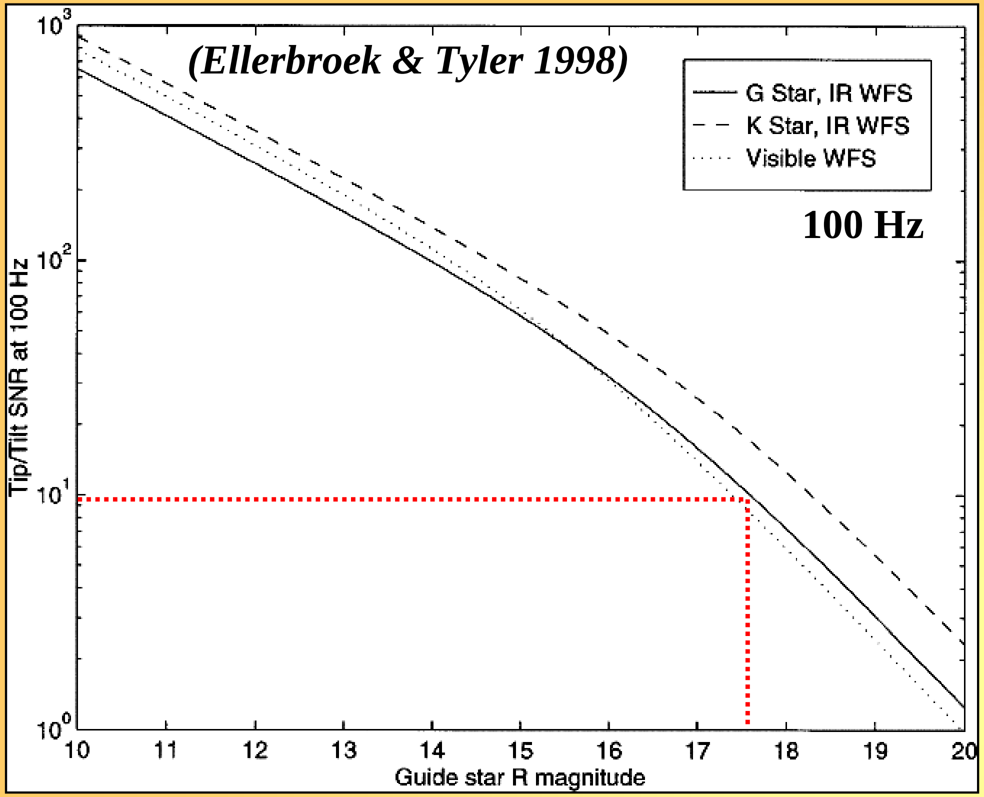
Implications for DMs and WFSs

Working assumption: corrected field of view ~ 0.35 × 0.35 deg^2

- ❑ needs ≥ 21 × 21 control elements to cover the entire field
- ❑ that's about 500 deformable mirror elements (commercially available)
- ❑ each element requires a maximum stroke of 15 – 20μm (not yet possible with commercial continuous face sheet devices)
- ❑ are segmented MEMS DMs a good alternative?

- ❑ WFS chip needs only 21 × 21 "quad cells", BUT: location of tip-tilt reference stars not a priori known and variable from field to field
- ❑ WFS chip needs to cover entire FOV, not just the center of each "beam"
- ❑ using a 0.25″ /pixel scale for centroiding one would need a 5k × 5k CCD
- ❑ low read noise WFS chips are ≤ 512×512 pixels and ~50–100Hz
- ❑ → more sophisticated methods needed:
  - a fish eye lens sampled with a large lenslet array
  - a micro-mirror array to steer the selected star onto subaperture
  - using multiple reference stars, some of which fall onto pixel boundaries

Reference Stars: Magnitudes, Densities, Errors



At 100 Hz one can achieve sufficient S/N with sources as faint as 17.7 mag

→ one star brighter than 17.7^m per arcmin^2 needed

Allen's (1973) average over whole sky:

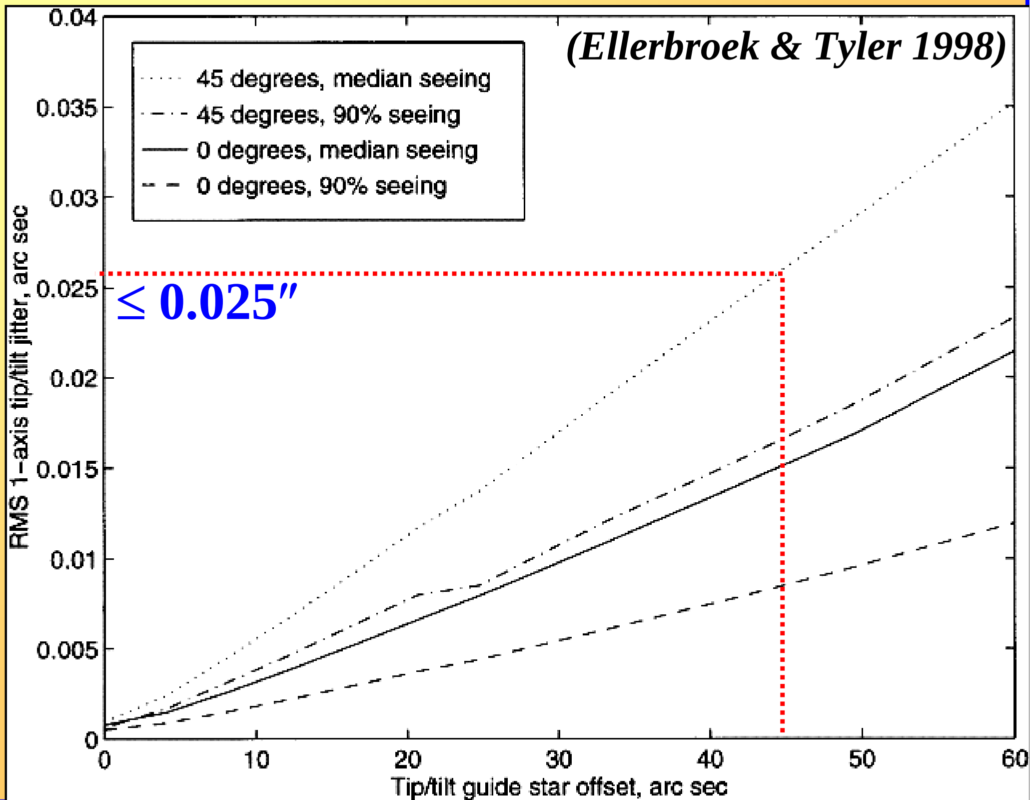
V-band: ~2500 / deg^2

I-band: ~5500 / deg^2

Required: ~3600 / deg^2

→ Works not always but in most cases

Guide star offset errors

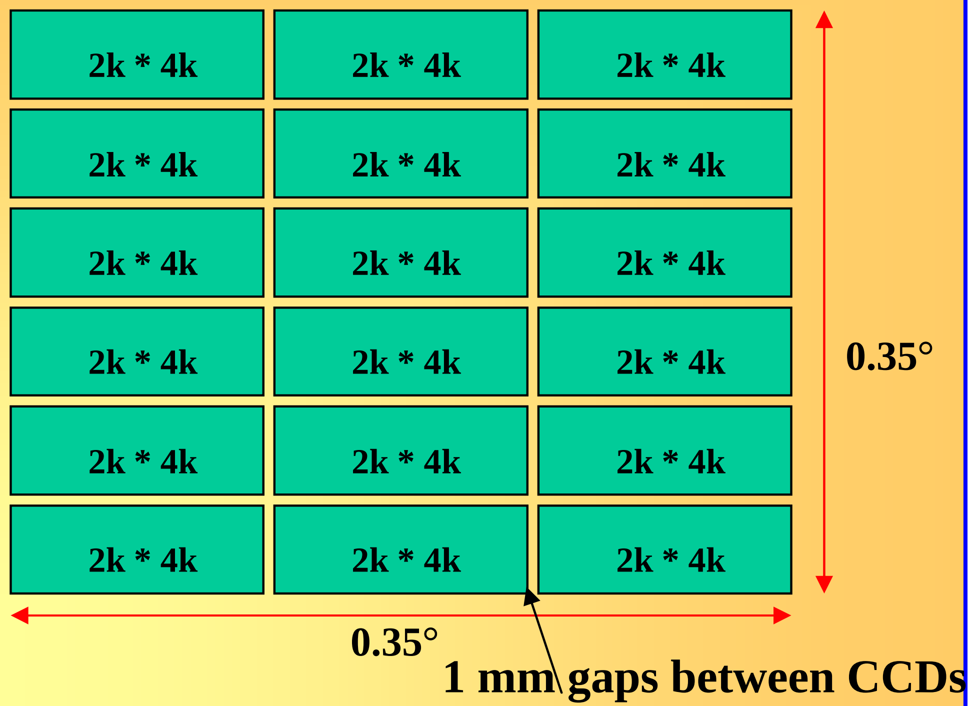


Focal Plane and Science Camera

1.4m telescope @ I-band: θ_{PSF} ~ 0.15″

➔ 0.1″/pixel scale (compromise)

➔ 12k × 12k detector array needed



I-band sensitive CCDs with optimized AR coating and "deep depletion" → Marconi CCD44-82: ***2048 × 4096 pixels, 15µm, BIP***

To cover 0.35 × 0.35 deg^2 18 CCDs ($75,000) are needed ➔ total ~ 1.35 M$

<u>Wavelength advantages:</u> short λ (0.5µm) vs. long λ (0.9 µm)

<u>WFS</u>	**<u>SciCam</u>**
cheaper commercial CCDs	cheaper commercial CCDs
higher DQE	lower sky background
no "sharing" of γs with SciCam	larger r_0 → larger D → smaller θ_{min}
larger sky coverage (SC)	larger r_0 → larger D → better S/N
lower bandwidth → better S/N & SC	objects at higher redshift

Basic Observing Procedure

1. Point anywhere on the sky within 45^{o} from zenith
2. Take a deep WFS exposure
3. Select suitable guide stars on WFS chip (compromise between S/N and sky coverage)
4. Locate quad-cells around each guide star used for tracking
5. Start algorithm that uses:
   1. all guide stars to control tip-tilt secondary
   2. individual guide stars to control the DM
6. Close tip-tilt loops (i.) and (ii.)
7. Start science exposures
8. Go to next *n* fields starting at item 1.
9. Reobserve same fields after *X* hours (nights)

automated (steps 2–6)

possibly automated (steps 7–8)

Open Issues

1. DM technology: continuous face sheets vs. segmented MEMS DMs
2. WFS optics non-trivial
3. Large (1k × 1k), fast (≥ 100Hz) and low readnoise (≤ 5e$^-$) WFS chips
4. Operating wavelengths of WFS and SciCam
5. Complicated control algorithm to:
   - locate suitable reference stars
   - combine info from adjacent beams
   - reject bleeding from bright stars in FOV
6. Guide star density may not always be sufficient
7. Variable seeing leads to variable PSF shape and sensitivity

Cost Estimate:

For a 0.35 × 0.35 deg^2 system: $7.5M

Telescope and enclosure	no cost, but …
Secondary mirror modifications	$0.3M
Science Camera CCDs	$1.4M
Science Camera – other	$0.8M
Wavefront sensor chip(s)	$1.0M
WFS camera optics	$1.5M
Deformable mirror	$0.3M
Design study, modeling	$0.4M
Software development	$1.5M
Computer hardware	$0.3M

Summary

- **This telescope would enable diffraction limited searches for point sources with high sensitivity (6m class) over a large FOV, currently impossible from the ground with any other instrument.**
- **For “only a couple of bucks” this telescope could complement vastly more expensive space missions**
- **The concept is expandable:**
    - **One unique instrument with 0.5° × 0.5° FOV for ≤ $10M**
    - **Downsized technology demonstrator for a fraction of the price**
    - **A “network” of such telescopes, operated by Universities**