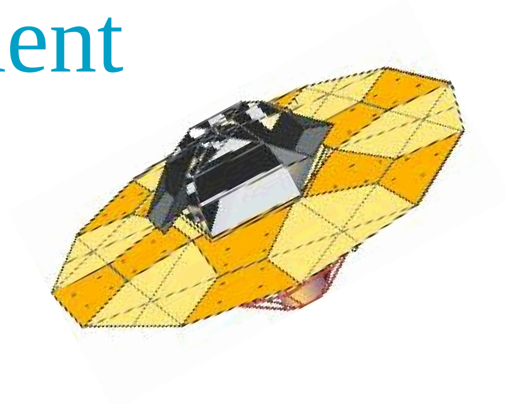
GAIA RVS: Design of the Instrument



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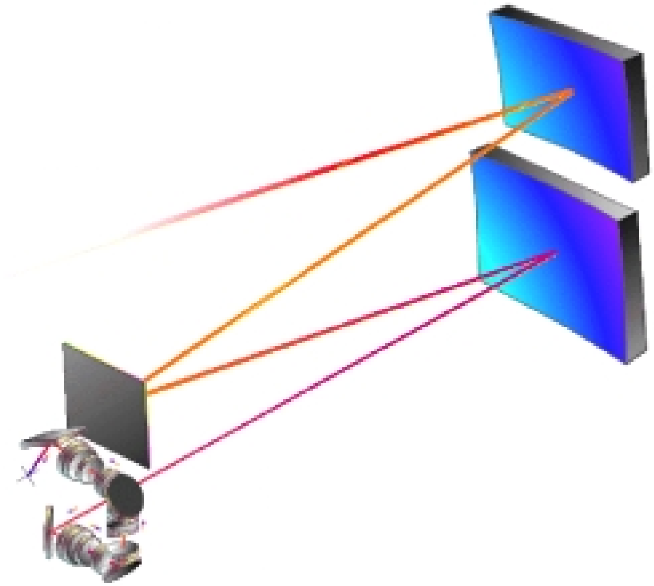
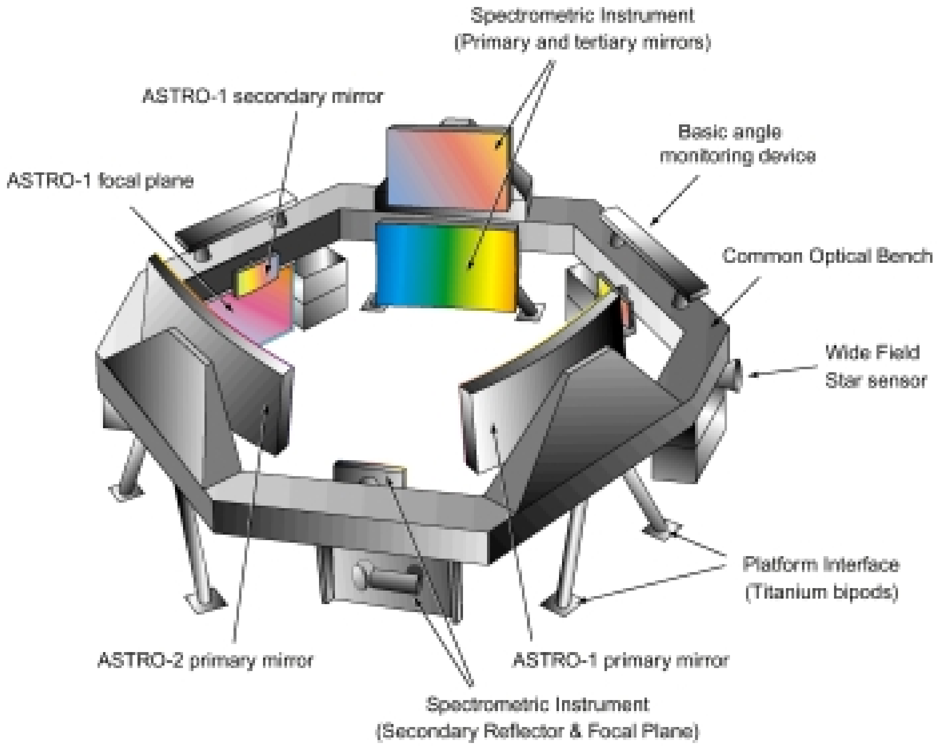
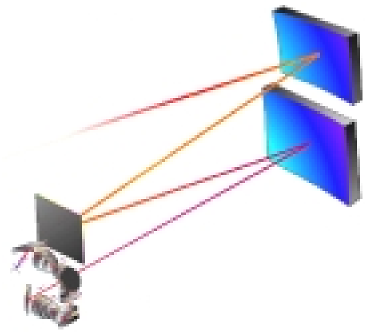
Structure of the Talk

1. Deficiencies with the existing design
2. Making improvements
    a) scan direction
    b) crowding
    c) background suppression
    d) sensitivity
3. Other issues
    a) windows
    b) telemetry and compression
4. Summary





Deficiencies with the existing design



The RVS is a powerful and well thought out instrument, but the current design has some disadvantages:

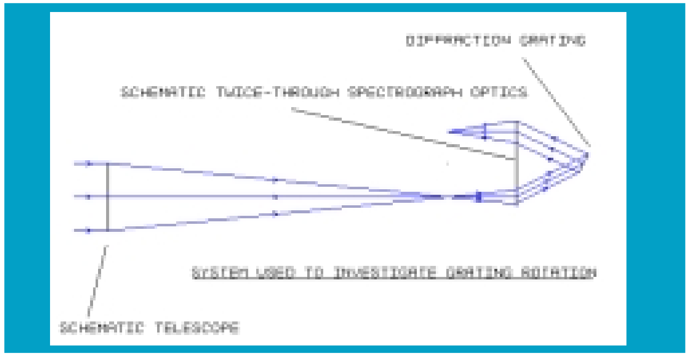
- the focal plane needs to be rotated to deal with the changing scan direction (serious);
- crowding will be a problem (needs careful consideration, windows?);
- there is no prescription for the suppression of the background, and the truncation of spectra to the required spectral range (difficult);
- it is not well matched in sensitivity to the Astro instruments – in fact most of the astrometric catalog will not have a corresponding RVS entry.

It also is potentially compromised by being packaged together with the medium-band photometry, and in turn imposes constraints on the MBP.

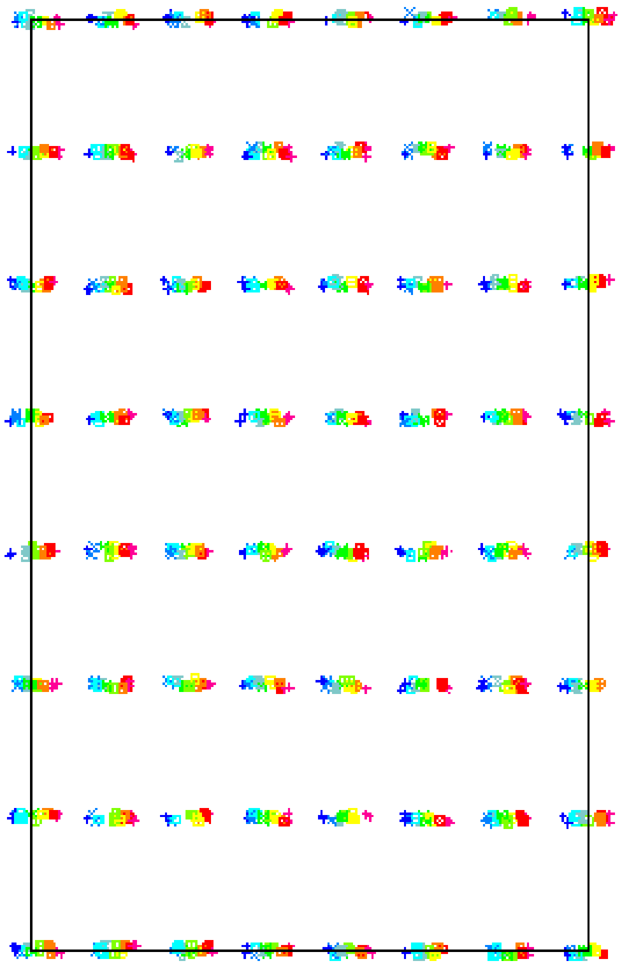
Making improvements: (a) scan direction changes

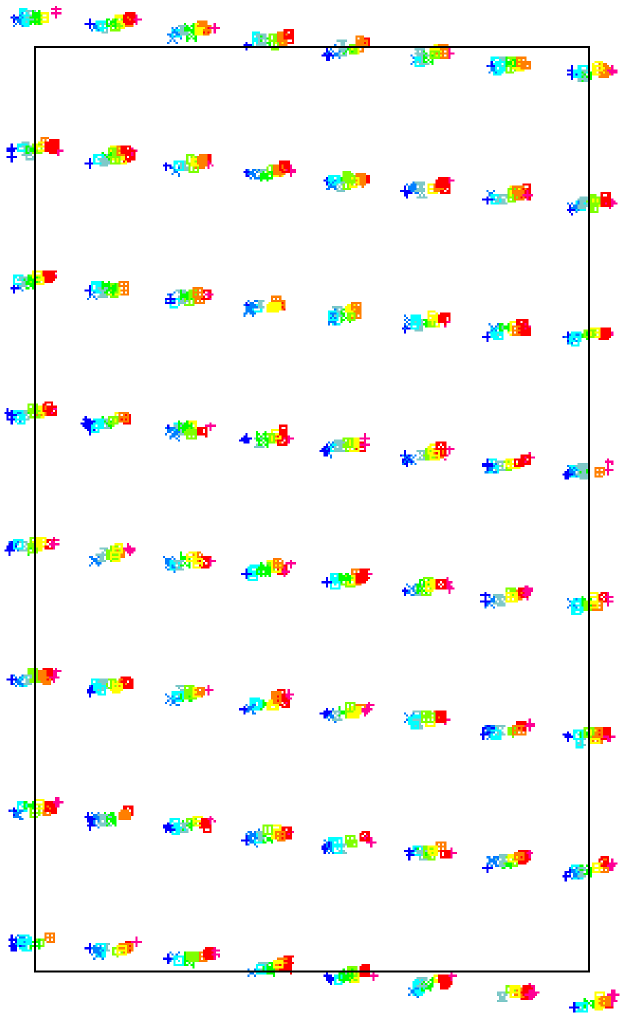
- Any movement of the focal plane requires a flexible electrical harness and thermal connection, in addition to actuators and launch clamps.
- There are serious implications for
  - wavelength scale stability and calibration
  - reliability and lifetime
- Recommendation: move grism instead. In current optical design, if grism is rotated in its own plane, the field of view on the sky can be slightly changed and there will be components of rotation. More complex effects are available if the grating is also tilted:
  - advantage is that harness/thermal link problems are eliminated
  - also that the flexible mass is significantly reduced
  - demonstration...

Making improvements:
(a) scan direction changes (ctd)



- field shear
- dispersion rotated in opposite direction
- anamorphic mag of grating

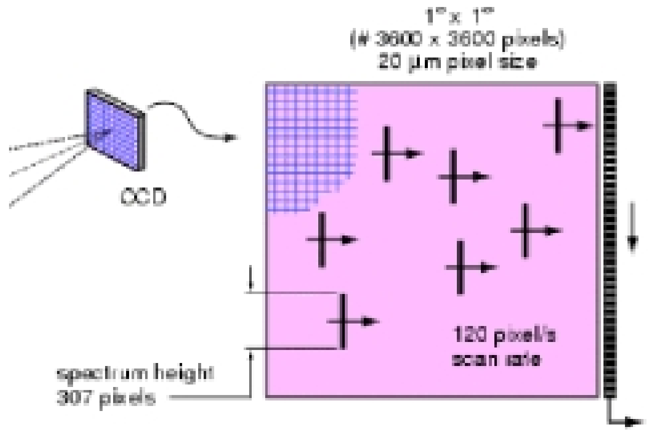




0.5°x0.5° field of view
grating rotated by 10°
axis to be defined (not orthogonal to grating)
(~0.1° rotn required)

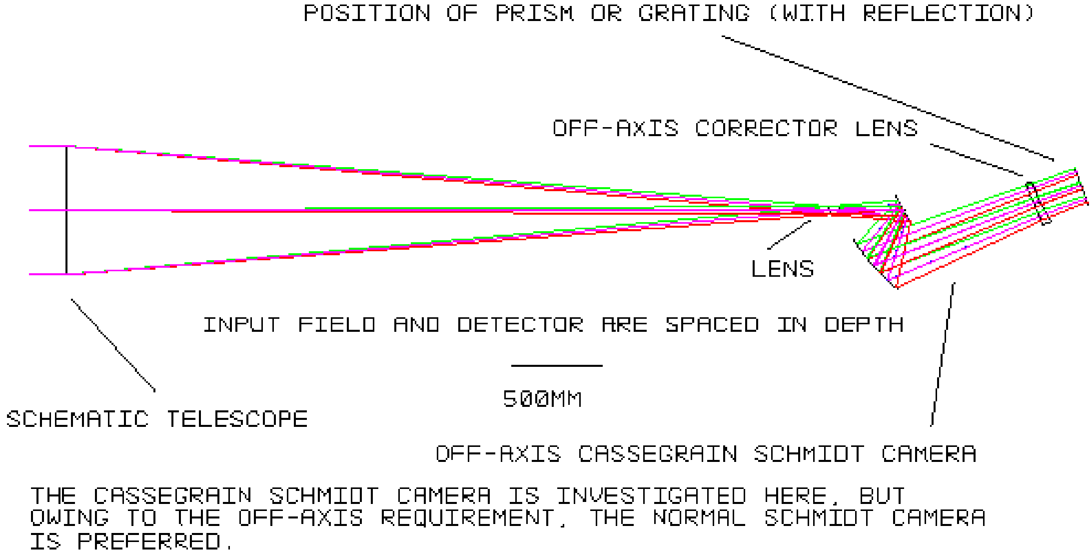
Making improvements: (a) scan direction changes (ctd)

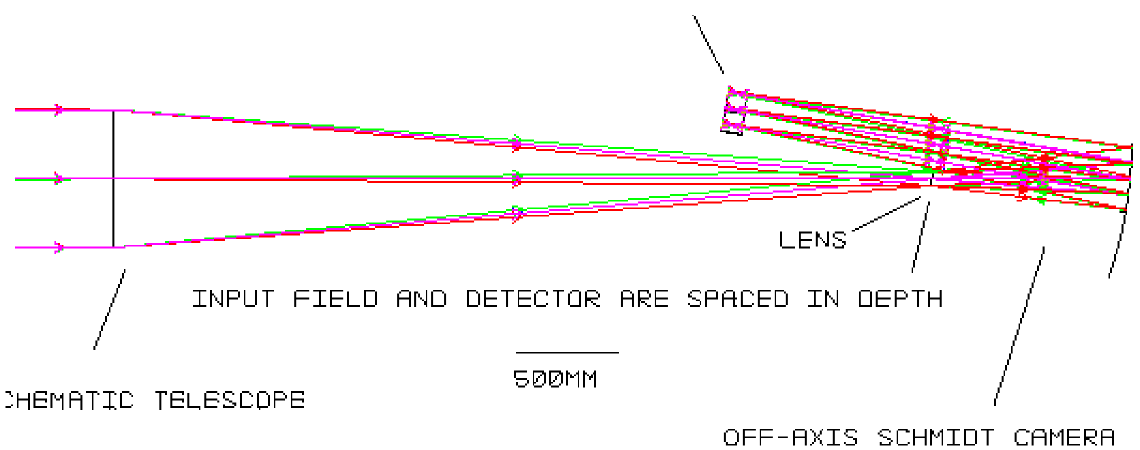
- Recommendation: change dispersion direction to lie in the scan direction. Smearing now takes place in the spatial direction =>
  - varying signal-to-noise ratio, but this is probably more satisfactory than varying resolution;
  - optical design needs to be optimised to minimise the amount of variation in dispersion as a function of position on the focal plane, at least in the scan direction – off-axis double-pass Schmidt designs (next viewgraphs).



- Recommendation: practically eliminate blurring by using a larger number of CCDs in the focal plane – for example, use the Astro focal plane. Several advantages BUT: problems of readout noise – see later.

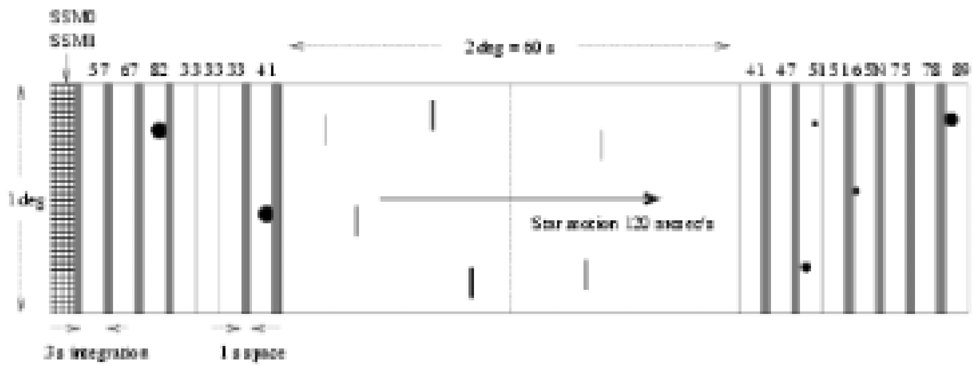
Double-pass Schmidt schematics





Making improvements: (b) Crowding

- Current RVS focal plane has 20µm 1 arcsec pixels
  => crowding is a serious issue,
  especially for RVS with extended spectra

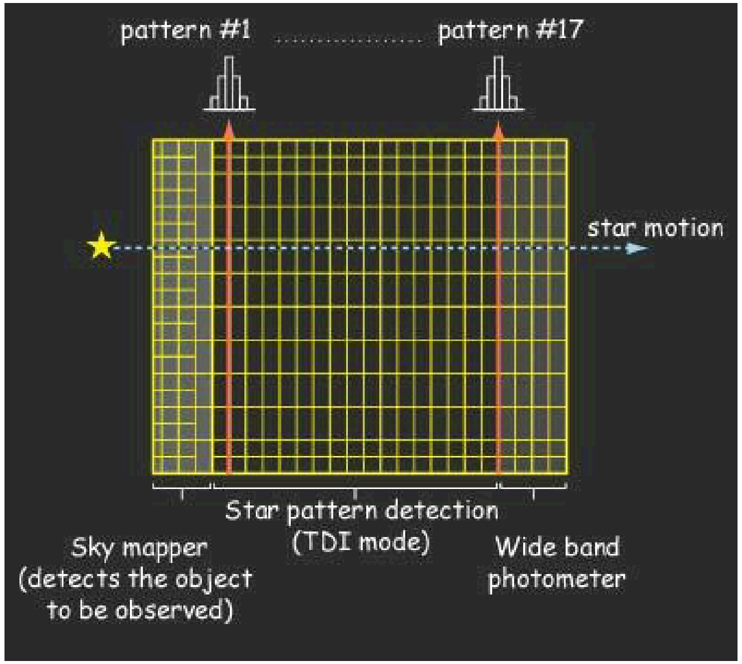


- RVS design strongly driven by
  need to keep readout noise to a minimum
  => minimum number of readouts per scan.
- Recommendation: consider use of L3CCD technology developed by MAT, to essentially eliminate readout noise. But:
  - radiation tolerance?
  - $\sqrt{N}$ noise increases to $\sqrt{(2N)}$
  - technology heritage.

Requires investigation:
sufficient time available

Making improvements: (b) Crowding (ctd)

- If L3CCD technology is available, the option to make ASTRO and SPECTRO focal planes the same can be considered:
  - advantages from system point of view to have same telescope, focal planes (qualification, calibration, costs)
  - advantages to RVS for crowding 0.1 arcsec instead of 0.5 arcsec pixels
  - advantages to RVS for spectral/spatial smearing, because readout node is reached before significant smearing has occurred (as in ASTRO)
  - disadvantages from point of view of medium band photometry



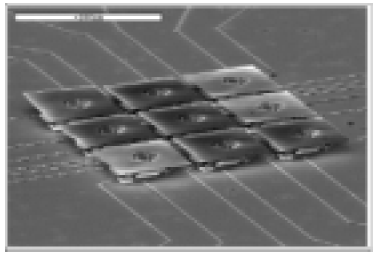
- Recommendation: system level tradeoff to be carried out.

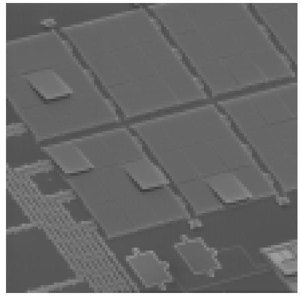
Making improvements: (c) suppression of background

- Currently slit-less spectrograph design does not envisage any means
  - for truncating spectral range to that required
  - at the same time significantly reducing the background
- These measures are essential.
- Standard approach would be to use narrow-band filters, BUT
  - steep cut-offs,
  - sufficient mid-band throughput and
  - radiation performance

  all difficult to achieve
- Other possible approaches include
  - pre-monochromator, perhaps incorporated into the telescope (initial indications are that this would be difficult for large FOV)
  - spatial filtering with MEMS-based micro-mirror/slit mechanisms.

Making improvements:
(c) suppression of background (ctd)





- MEMS devices have significant drawbacks
  - filter still required to truncate spectrum
  - high technology risk (devices developed for NGST are cryogenic)
  - no credible European supplier (significant funds to NASA)
  - need to be continuously driven to follow scan
    => lifetime requirements much more stringent than NGST
  - micro-slits not applicable for GAIA because of magnetic actuator bar, but these might be the technology selected for NGST
  - losses in active area, and photometric stability
    => implications for radial velocities in TDI mode?
  - pixel sizes, format and mirror throw highly constraining of the RVS
  - single large arrays not available on NGST/GAIA timescale
    => unfilled focal planes in a chequerboard mosaic.
- MEMS devices are not *central* to GAIA design.

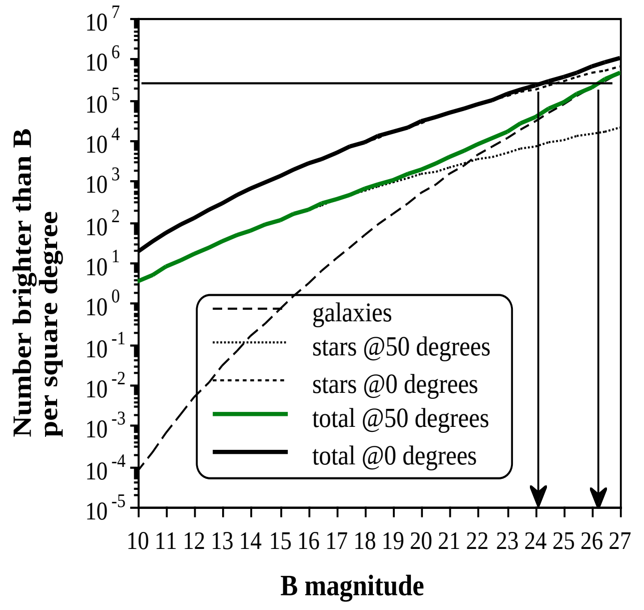
Making improvements: (d) increasing sensitivity

- In order that most ASTRO sources will also have RVS counterparts, need to ensure maximum sensitivity for RVS. Recommendation:
  - reduce number of optical surfaces (*c.f.* off-axis Schmidt design)
  - use gold or silver coatings for reflective surfaces
    => implications for medium band photometry
  - use optimised anti-reflection coatings for transmissive optics
  - use prism or prisms to replace grating
    (higher efficiency, less scattered light)
  - push for 2°x1° FOV instead of 1°x1° FOV
  - ensure CCD is optimised for 8490–8740Å band ("red" CCD)
- Maximum sensitivity also means reducing background (*c.f.* earlier)
  - optimised filters
  - maximum resolution (small pixel sizes, ASTRO-type focal plane).
  - minimise readout noise (L3CCDs?)

Other Issues: (a) windowing

- The placing of windows in the RVS instrument will be difficult in even moderately crowded fields (Galactic Plane but even at 50°)
- Situation gets worse if we manage to increase sensitivity of RVS.
- Algorithm must be robust and repeatable: selection effects need to be carefully evaluated.

300x3 arcsec => 14000 individual spectra/sq deg
but at B=18 => 800 and 10000 sources



- Recommendation: Extensive simulation will be required to identify issues and find optimal solutions.
- Note that better pixel scale will help considerably (ASTRO-type focal plane).

Other Issues: (b) telemetry and compression

- RVS is responsible for a significant fraction of the total GAIA telemetry budget because of the larger windows required for spectroscopy.
- The sensitivity limit is different in the cases of
  - radial velocity
  - astrophysically useful spectra
- Radial velocities can be extracted from information with much lower S/N ratio than those required for astrophysics,
- Faint sources dominate => use up even more of telemetry budget
- Recommendation: Use 2 different criteria for sensitivity limits
  - for RV only spectra use lossy compression schemes (factors >20) (investigation required into possible systematic effects from lossy compression)
  - brighter spectra (V~17) use lossless compression (factor 2.8).
- Recommendation: Bin spatially on board to reduce bandwidth?

Summary recommendations for RVS

- Rotate grating instead of focal plane
- Place dispersion direction in scan direction
- Investigate L3CCDs
- Investigate ASTRO-type focal plane (crowding, scan blurring)
- Maximise throughput
- Investigate background suppres-sion and spectral truncation (no MEMS)
- Simulate window selection and placement
- Lossless (V<17) and lossy (V>17) compression schemes